→ "FROM GIOTTO TO ROSETTA"
50TH ESLAB SYMPOSIUM

14-18 March 2016

Leiden, The Netherlands

Organising Committee

M. A'Hearn
N. Altobelli
M. Barthelemy
H. Balsiger
S. Besse
J-P. Bibring
C. Bingham
D. Bockelee-Morvan
B. Buratti
C. Engrand
M. Fulchignoni
M. Fulle
B. Geiger
B. Grieger
E. Grün
H.U. Keller
J. Knollenberg
C. Könders
M. Küppers
L. LeRoy
A. Levasseur-Regourd
R. Lorente
K. Mandt
P. Martin
S. McKenna-Lawlor
R. Moissl
C. Munoz
M. Riemens
G. Schwehm
C. Snodgrass
C. Stephen
M. Taylor
C. Vallat
P. Weissman
I. Wright
J. Zarnecki

Abstract Book

50th ESLAB Symposium: “From Giotto to Rosetta”

14 – 18 March 2016

Leiden, The Netherlands

Table of Contents

Programme

MONDAY, 14 March		TUESDAY, 15 March		WEDNESDAY, 16 March		THURSDAY, 17 March		FRIDAY, 18 March	
08:00	Registration and COFFEE	08:00	Registration and COFFEE	08:00	Registration and COFFEE	08:00	Registration and COFFEE	08:00	Registration
09:45	Introduction	08:40	Coma composition and physical properties (dust, refractories, volatiles, plasma)	08:40	Coma composition and physical properties	08:40	Process of cometary activity and nucleus-inner coma interaction	08:40	Nucleus surface and interior
10:00	Keynote Talk 1	10:30	COFFEE	09:40	Process of cometary activity and nucleus-inner coma interaction	10:40	COFFEE	10:00	New and un-resolved questions in cometary science and how to resolve them.
10:40	Keynote Talk 2	11:00	Coma composition and physical properties	10:30	COFFEE	11:10	Nucleus surface and interior	10:20	COFFEE
11:20	Keynote Talk 3	13:00	LUNCH	11:00	Process of cometary activity and nucleus-inner coma interaction	13:00	LUNCH	10:50	New and un-resolved questions in cometary science and how to resolve them.
12:00	Cometary origins and evolution of the solar system	14:00	Coma composition and physical properties	13:10	LUNCH	14:00	Nucleus surface and interior	12:10	END OF MEETING
13:00	LUNCH	16:00	Posters and refreshments	14:00	SWT	16:00	COFFEE		
14:00	Cometary origins and evolution of the solar system	18:00	END DAY 2	18:00	END DAY 3	16:30	Nucleus surface and interior		
16:10	COFFEE			18:30	Departure Conference Dinner	18:00	END DAY 4		
16:40	Coma composition and physical properties (dust, refractories, volatiles, plasma)								
18:15	Ice Breaker								
19:15	END DAY 1								

Posters will be displayed all week.

Monday 14 March 2016

08:00	**Registration and Welcome Coffee**
09:45	**Introduction** *Arvind Parmar* *ESA/ESTEC (The Netherlands)*
10:00	**Opening Session**
10:00	"From 1P to 67P" *Roger-Maurice Bonnet* *ISSI (Switzerland)*
10:40	"Cometary Science from the Halley Armada to Rosetta" *Michael F. A'Hearn et al.* *University of Maryland (United States)*
11:20	"How and why to get a lander on a comet" *Jean-Pierre Bibring et al.* *IAS (France)*
12:00	**Session 1: Cometary origins and evolution of the solar system**
12:00	"The chemistry trail from clouds to disks and comets" *Ewine van Dishoeck et al.* *Leiden Observatory (The Netherlands)*
12:30	"Comets as Tracers for the Formation and Volatile Acquisition of the Planets and Satellites" *Kathleen Mandt et al.* *Southwest Research Institute (United States)*
13:00	**Lunch Break**
14:00	"Origin(s) of inner planet atmospheres and terrestrial oceans in the light of the Rosetta results" *Bernard Marty et al.* *(France)*
14:30	"The Comet-Kuiper Belt Connection" *Harold Weaver et al.* *JHU Applied Physics Laboratory (United States)*
15:00	"Cometary origins after Rosetta and implications for solar system formation" *Björn Davidsson et al.* *Uppsala University (Sweden)*
15:30	"Sulfur Isotopic Ratios in the Coma of 7P/Churyumov-Gerasimenko" *Ursina Calmonte et al.* *Physikalisches Institut, University of Bern (Switzerland)*

15:50	“The tale of a cometary dust particle of comet 67P/Churyumov-Gerasimenko" *Martin Hilchenbach et al.* *Max Planck Institute for Solar System Research (Germany)*
16:10	**Coffee Break**
16:40	**Session 2: Coma composition and physical properties (dust, refractories, volatiles, plasma)**
16:40	“In situ mass spectrometry from Giotto to Rosetta" *Kathrin Altwegg et al.* *Physikalisches Institut (Switzerland)*
17:10	“Mass-loading, pile-up, and mirror-mode waves at comet 67P/Churyumov-Gerasimenko" *Martin Volwerk et al.* *Austrian Academy of Sciences (Austria)*
17:30	“The Global State of the Plasma Environment at 67P/CG at Perihelion - Comparing RPC Observations and Simulations" *Christoph Koenders et al.* *TU Braunschweig (Germany)*
17:50	"Properties of the Diamagnetic Cavity at Comet 67P/Churyumov-Gerasimenko" *Charlotte Goetz et al.* *Technische Universität Braunschweig (Germany)*
18:15	**ICE BREAKER –celebrating the 50th ESLAB**
19:15	**END DAY 1**

Tuesday 15 March 2016

08:00	**Registration and Welcome Coffee**
08:40	**Session 2: Coma composition and physical properties (dust, refractories, volatiles, plasma)**
08:40	“Coma composition in comets from remote sensing" *Bockelee-Morvan Dominique et al.* *LESIA, Observatoire de Paris (France)*
09:10	“ROSINA/DFMS and IES observations at 67P/Churyumov-Gerasimenko: Ion composition in the heterogeneous coma" *Stephen A. Fuselier et al.* *Southwest Research Institute (United States)*
09:30	“Molecular Oxygen in 1P/Halley and 67P/Churyumov-Gerasimenko" *Martin Rubin et al.* *Physikalisches Institut, University of Bern (Switzerland)*
09:50	“Halogens at Comet 67P/Churyumov-Gerasimenko Observed by ROSINA-DFMS and COSIMA" *Frederik Dhooghe et al.* *Belgian Institute for Space Aeronomy (Belgium)*
10:10	“The heliocentric variation of the outgassing rate and molecular abundances in the coma of 67P as seen by MIRO" *Nicolas Biver et al.* *LESIA (France)*
10:30	**COFFEE BREAK**
11:00	“Coma Isotopic composition" *Jehin Emmanuel et al.* *Liege University (Belgium)*
11:30	“The size distribution of dust emitted from 67P/Churyumov-Gerasimenko and comparison to other comets" *Jessica Agarwal et al.* *Max Planck Institute for Solar System Research (Germany)*
12:00	“Study of 67P/CG coma dust/gas evolution as derived from VIRTIS observations" *Giovanna Rinaldi et al.* *IAPS-INAF (Italy)*
12:20	“Distributed sources in comets: from Giotto to Rosetta" *Herve Cottin et al.* *LISA, UPEC (France)*
12:40	“Measuring the distribution and excitation of cometary volatiles using ALMA" *Martin Cordiner et al.* *NASA Goddard Space Flight Center (United States)*

13:00	**LUNCH**
14:00	“Diversity of Organic Matter in Comets: The Case of 81P/Wild 2" *Bradley De Gregorio et al.* *U.S. Naval Research Laboratory (United States)*
14:30	“Organics from ROSINA measurements at 67P/Churyumov-Gerasimenko" *Léna Le Roy et al.* *Center for Space and Habitability (Switzerland)*
15:00	"Comet Encounters of the Serendipitous Kind: The Ulysses Comet Tail Crossings" *Geraint Jones et al.* *UCL Mullard Space Science Laboratory (United Kingdom)*
15:20	“Typology of cometary particles collected by COSIMA before and after perihelion" *Yves Langevin et al.* *Institut d’Astrophysique Spatiale (France)*
15:40	“TOF-SIMS analysis and characterization of the solid organic matter in the dust particles of 67P/Churyumov-Gerasimenko with the COSIMA instrument." *Nicolas Fray et al.* *LISA, UMR CNRS 7583, UPEC, UPD (France)*
16:00	**Posters and refreshments**
18:00	**END DAY 2**

Wednesday 16 March 2016

08:00	**Registration and Welcome Coffee**
08:40	**Session 2: Coma composition and physical properties (dust, refractories, volatiles, plasma)**
08:40	“The morphological diversity of micron-sized cometary dust detected with MIDAS" *Thurid Mannel et al.* *Space Research Institute of the Austrian Academy of Sciences (Austria)*
09:00	“Variations in cometary dust compositions from Giotto to Rosetta, clues to their formation mechanisms" *Cecile Engrand et al.* *CSNSM CNRS/IN2P3-Univ. Paris Sud, University Paris Saclay (France)*
09:20	“Coma dust environment observed by GIADA during the Perihelion of 67P/Churyumov-Gerasimenko." *Vincenzo Della Corte et al.* *IAPS-INAF (Italy)*
09:40	**Session 3: Process of cometary activity and nucleus-inner coma interaction**
09:40	“How in-situ observations changed our understanding of cometary activity" *Jean-Baptiste Vincent et al.* *MPS (Germany)*
10:10	"Investigation into the disparate origin of CO2 and H2O outgassing for comet 67/P" *Uwe Fink et al.* *University of Arizona (United States)*
10:30	**COFFEE BREAK**
11:00	“How theory is being shaped by in-situ cometary observations" *Wing-Huen Ip et al.* *Institute of Astronomy, National Central University (Taiwan)*
11:30	“Our closest encounter with a dynamically new Oort Cloud comet: the activity and evolution of comet Siding Spring." *Dennis Bodewits et al.* *U. Maryland in College Park (United States)*

11:50 “The Nature and Frequency of the Gas Outbursts in comet 67P/Churyumov-Gerasimenko observed by the Alice Far-ultraviolet Spectrograph on Rosetta"
Paul D. Feldman et al.
Johns Hopkins University (United States)

12:10 “Comet 67P Inner Coma Structure and Evolution with Rosetta/MIRO Observations and Models"
Seungwon Lee et al.
Jet Propulsion Laboratory/California Institute of Technology (United States)

12:30 “Evolution of the Surface Activity Distribution and the Resulting Coma of Comet 67P/Churyumov-Gerasimenko Pre- and Post-Equinox observed by ROSINA and VIRTIS"
Nicolas Fougere et al.
University of Michigan (United States)

12:50 "Two-Point observations of low-frequency waves by ROMAP and RPC-MAG during the FSS"
Philip Heinisch et al.
TU Braunschweig (Germany)

13:10 LUNCH

14:00 ***Rosetta Science Working Team Meeting, ALL WELCOME !!!***

18:30 Bus Departure from hotel for Conference Dinner

Thursday 17 March 2016

08:00	**Registration and Welcome Coffee**
08:40	**Session 3: Process of cometary activity and nucleus-inner coma interaction**
08:40	“Modeling Cometary Activity" *Tamas Gombosi et al.* *University of Michigan (United States)*
09:10	“Advances in combining cometary plasma and dust science" *Xu Wang et al.* *University of Colorado at Boulder (United States)*
09:40	“Dust and Spacecraft Charging Effects" *Mihaly Horanyi et al.* *University of Colorado (United States)*
10:00	“Modeling 67P/CG’s Dust Environment" *Maximilian Sommer et al.* *University of Stuttgart, Institute of Space Systems (Germany)*
10:20	“Ground based support of the Rosetta mission" *Colin Snodgrass et al.* *The Open University (United Kingdom)*
10:40	**COFFEE BREAK**
11:10	**Session 4: Nucleus surface and interior**
11:10	“The Development of Cometary Landscapes" *Nicolas Thomas* *University of Bern (Switzerland)*
11:40	“Relevance of KOSI Experiments for Rosetta" *Eberhard Grün* *IDS (Germany)*
12:00	“Fractures on comets: New insights from Rosetta" *Mohamed Ramy El-Maarry et al.* *Physikalisches Institut (Switzerland)*
12:20	“Composition and temporal variations of the 67P/Churyumov-Gerasimenko nucleus observed by the OSIRIS instrument onboard Rosetta" *Sonia Fornasier et al.* *LESIA-Obs. de Paris/Univ Paris Diderot (France)*
12:40	“MIRO Observations of subsurface temperatures of the nucleus of 67P/Churyumov-Gerasimenko" *F. Peter Schloerb et al.* *University of Massachusetts (United States)*

13:00 **LUNCH**

14:00 “Dirty Snowball – Icy Dirtball – Rosetta"
Horst Uwe Keller et al.
Universität Braunschweig (Germany)

14:30 Modeling of the evolution of cometary surface and subsurface"
Aurelie Guilbert-Lepoutre et al.
CNRS - UTINAM (France)

15:00 "Evolution of the UV Surface Properties of Comet 67P/C-G as Observed with Rosetta Alice"
Lori M. Feaga et al.
University of Maryland (United States)

15:20 “The presence of clathrates and their implications on the composition of comet 67P"
Adrienn Luspay-Kuti et al.
Southwest Research Institute (United States)

15:40 “Understanding the surface of comet 67P as seen in post-landing ROLIS images"
Stefan Schroeder et al.
DLR (Germany)

16:00 **COFFEE**

16:30 “Advances in laboratory studies of cometary ice analogues"
Diana Laufer et al.
Tel Aviv University (Israel)

17:00 “In-situ Properties of Comet 67P/Churyumov-Gerasimenko measured with SESAME"
Klaus Seidensticker et al.
DLR (Germany)

17:20 “The interpretation of decaying mass spectra from COSAC and Ptolemy on the surface of 67/P Churyumov Gerasimenko"
Fred Goesmann et al.
Max Planck Institute for Solar System Research (Germany)

17:40 “New perspectives on the surface chemistry of 67P from Ptolemy data"
Ian Wright et al.
Open University (United Kingdom)

18:00 **END DAY 4**

Friday 18 March 2016

08:00	**Registration**
08:40	**Session 4: Nucleus surface and interior**
08:40	“Refractory and semi-volatile organics at the surface of 67P/Churyumov-Gerasimenko" *Eric Quirico et al.* *IPAG (France)*
09:00	“Infrared detection of exposed water ice on 67P/CG surface" *Gianrico Filacchione et al.* *INAF-IAPS (Italy)*
09:20	"Results from radio tracking the Rosetta spacecraft: gravity, internal structure, nucleus composition, outgassing activity and nucleus mass loss during perihelion" *Matthias Hahn et al.* *Rheinisches Institut für Umweltforschung an der Universität zu Köln (Germany)*
09:40	“Looking at Comet 67P sub-surface in the vicinity of Abydos" *Valerie Ciarletti et al.* *UVSQ (UPSay) ; UPMC (Sorbonne Univ.) ; CNRS/INSU; LATMOS-IPSL (France)*
10:00	**Session 5: New and un-resolved questions in cometary science and how to resolve them.**
10:00	“Mystery of cometary circular polarization: new clues from studying plasma environment in comet 67P/Churyumov-Gerasimenko" *Ludmilla Kolokolova et al.* *University of Maryland (United States)*
10:20	**COFFEE BREAK**
10:50	How Stardust may inform Rosetta, and vice versa" *Andrew Westphal* *UC Berkeley (United States)*
11:20	"COMETS, WHAT NEXT?" *Marcello Fulchignoni et al.* *Lesia, Observatore de Paris (France)*
11:40	“Unexpected and significant findings in 67P: the IDS view" *Marco Fulle et al.* *INAF Trieste (Italy)*
12:10	**END OF MEETING**

Poster Sessions

P01 "Laboratory Investigations on Cometary Analogues in Support of the Interpretation of Multi-instrumental Rosetta Data."
Antoine Pommerol et al.
University of Bern (Switzerland)

P02 "The Distribution of Geometric Albedos of Jupiter-Family Comets From SEPPCoN and Visible-Wavelength Photometry"
Y. R. Fernandez et al.
University of Central Florida (United States)

P03 "Thermophysical history of the nucleus of the comet 67P/CG"
Michelangelo Formisano et al.
INAF-IAPS (Italy)

P04 "Extended Comparative Photometric Study of Comet 67P/Churyumov-Gerasimenko as seen by VIRTIS-H and VIRTIS-M Onboard Rosetta"
Baptiste Rousseau et al.
LESIA - Observatoire de Paris (France)

P05 "Thermo-physical Properties and Heat Transport Mechanisms of Comet 67P/CG from VIRTIS Data"
Cedric Leyrat et al.
LESIA - Observatoire de Paris (France)

P06 "First Landing(s) on a Comet - Lessons Learned"
Jens Biele et al.
DLR (Germany)

P07 "A Comparative Analysis of Opposition Effect on Comet 67P/Churyumov-Gerasimenko using Rosetta-OSIRIS Images"
Nafiseh Masoumzadeh et al.
Max-Planck-Institut für Sonnensystemforschung (Germany)

P08 "67P/CG Nucleus Layered Structure: Formation Vs Evolutionary Processes. Clues from VIRTIS Data."
Fabrizio Capaccioni et al.
IAPS – INAF (I)

P09 "The interior of 67P/Churyumov-Gerasimenko from observation and modeling"
Maria Teresa Capria et al.
INAF/IAPS (Italy)

P10 "Induction signatures at 67P/CG"
D. Constantinescu et al.
Institute for Space Sciences (Romania)

P11 "What CONSERT measurements tell us about the interior of the 67/C-G comet ?"
Wlodek Kofman et al.
Univ. Grenoble Alpes, IPAG, F-38000 Grenoble, France; CNRS, IPAG, F- 38000 Grenoble, France (France)

P12 "Mineralogical implications of CONSERT permittivity characterization of 67P."
Herique Alain et al.
IPAG - UGA/CNRS (France)

P13 "Photometric behavior of 67P spectral parameters"
Andrea Longobardo et al.
IAPS-INAF (Italy)

P14 "Surface thermal emission model assuming a sub-pixel distribution of temperatures: application to VIRTIS-M observations of 67P/Churyumov-Gerasimenko"
Andrea Raponi et al.
IAPS - INAF (Italy)

P15 "Comparative study of icy patches on comet nuclei using multispectral imaging data"
Nilda Oklay et al.
Max Planck Institute for Solar System Research (Germany)

P16 "Cosmic ray interaction with cometary nuclei"
Romain Maggiolo et al.
BISA (Belgium)

P17 "Comet 67P/CG – gravity, material strength and surface forming processes"
Stubbe F. Hviid et al.
DLR (Germany)

P18 "Seasonal variation of water ice abundance on 67P/CG surface"
Mauro Ciarniello et al.
IAPS-INAF (Italy)

P19 "ESA's Cometary Spacecrafts Giotto and Rosetta with 30 Years in between - Radio and Microwave Remote Sensing Technology and Efficient Inversion of Data"
Peter Edenhofer
Ruhr-University of Bochum (Germany)

P20 "Philae attitude and trajectory reconstruction"
Philip Heinisch et al.
TU-Braunschweig (Germany)

P21 "Dust Impact Monitor (SESAME-DIM) Measurements at Comet 67P/Churyumov-Gerasimenko"
Harald Krüger et al.
Max-Planck-Institut für Sonnensystemforschung (Germany)

P22 “The Las Cumbres Observatory Global Telescope Network for Cometary Science”
Tim Lister et al.
Las Cumbres Observatory (United States)

P23 “The interaction between surface morphology and inner neutral gas coma of Comet 67P/ Churyumov-Gerasimenko”
Ying Liao et al.
University of Bern (Switzerland)

P24 “Observations and Analysis of A Curved Jet in the Coma of Comet 67P/Churyumov-Gerasimenko”
Zhong-Yi Lin et al.
Institute of Astronomy, NCU (Taiwan)

P25 "Evolution of the dust particles size distribution and flux from comet 67P around perihelion measured by the COSIMA instrument on-board Rosetta"
Sihane Merouane et al.
Max-Planck Institute for Solar System Research (Germany)

P26 "Activity-Driven Changes in Cometary Rotation"
Rosita Kokotanekova et al.
MPI for Solar System Research (Germany)

P27 "RPC observation of the development and evolution of plasma interaction boundaries at 67P/Churyumov-Gerasimenko"
Kathleen Mandt et al.
Southwest Research Institute (United States)

P28 “Sub-surface porosity and water ice content along an 800-meter track of the MIRO footprint in the Imhotep region of 67P/Churyumov-Gerasimenko”
Paul von Allmen et al.
Jet Propulsion Laboratory (United States)

P29 "Pre- and Post-equinox ROSINA COPS production rates compared with pre-equinox MIRO, VIRTIS and ground based measurements"
Kenneth Hansen et al.
University of Michigan (United States)

P30 "Cometary plasma science from Giotto to Rosetta"
Andrew Coates
UCL-MSSL (United Kingdom)

P31 "Millimeter and Submillimeter Observations of Comet 67P's Nucleus, Gas, and Dust with the Rosetta/MIRO Instrument"
Mark Hofstadter et al.
JPL/Caltech (United States)

P32 “Thermophysical Modeling of the Nucleus of Comet 29P/Schwassmann-Wachmann 1 Using Spin-State Constraints Derived from Outburst Observations”
Charles Schambeau et al.
University of Central Florida (United States)

P33 “What can we learn about the ice composition on 67P from in-situ measurements with ROSINA-DFMS”
Andre Bieler et al.
University of Michigan (United States)

P34 "The Making Of "Closest Encounter", a movie made from images acquired by the Halley Multicolor Camera aboard the Giotto probe"
Björn Grieger et al.
Aurora Technology B.V. for ESA - European Space Agency (Spain)

P35 "Activity and composition of comet 67P/Churyumov-Gerasimenko from high resolution infrared spectroscopy with the VIRTIS-H instrument onboard Rosetta"
Dominique Bockelee-Morvan et al.
LESIA, Observatoire de Paris (France)

P36 "A long term study of Centaur 174P/Echeclus"
Philippe Rousselot et al.
Institut UTINAM / OSU THETA (France)

P37 "Dust Release from Cometary Surfaces"
Eberhard Grün et al.
IDS (Germany)

P38 "Cometary activity investigated by laboratory experiments"
Bastian Gundlach et al.
Technische Universität Braunschweig (Germany)

P39 "A comparison between VEGA 1, 2 and Giotto flybys of comet 1P/Halley"
Martin Volwerk et al.
Austrian Academy of Sciences (Austria)

P40 “Long-term characterization of the coma of comet 67P/Churyumov-Gerasimenko from the ground”
Matthew Knight et al.
University of Maryland (United States)

P41 “Evolution of the plasma environment of comet 67P from spacecraft potential measurements by the Rosetta Langmuir probe instrument”
Elias Odelstad et al.
Swedish Institute of Space Physics (Sweden)

P42 “Observations of stormy solar wind interacting with comet 67P/C-G”
Niklas J.T. Edberg et al.
Swedish Institute of Space Physics, Uppsala (Sweden)

P43 “Post-perihelion spectroscopic observations of comet 67P/Churyumov-Gerasimenko with the Liverpool Telescope”
Miguel de Val-Borro et al.
Princeton University (United States)

P44 “The Oxygen Isotopic Ratio in Cometary Dust with Rostetta/COSIMA”
John Paquette et al.
Max Planck Institute for Solar System Research (Germany)

P45 “Survey for Ortho-to-Para Abundance Ratios (OPRs) of Ammonia in 20 Comets”
Hideyo Kawakita et al.
Koyama Astronomical Observatory of Kyoto Sangyo University (Japan)

P46 “Survey for nitrogen isotopic ratio of NH2 in comets: Implication for 15N-fractionation in cometary ammonia”
Yoshiharu Shinnaka et al.
National Astronomical Observatory of Japan (Japan)

P47 "Herschel observations of the Rosetta target 67P/Churyumov-Gerasimenko"
Laurence O'Rourke et al.
ESA/ESAC (Spain)

P48 "Forbush effects detected at comet 67/P Churyumov-Gerasimenko with the Rosetta Radiation Environment Monitor (SREM)"
Olivier Witasse et al.
European Space Agency (The Netherlands)

P49 "Is the sublimation of icy grains detectable with the OSIRIS cameras onboard Rosetta?"
Adeline Gicquel et al.
MPS (Germany)

P50 "Short time-scale variations in the ion environment around 67P"
Hans Nilsson et al.
Swedish Institute of Space Physics (Sweden)

P51 "Detection of NH4+ of cometary origin at comet 67P near perihelion"
Arnaud Beth et al.
Imperial College London (United Kingdom)

P52 "Photochemistry of forbidden oxygen lines in the coma of 67P/Churyumov-Gerasimenko"
Gaël Cessateur et al.
BIRA-IASB (Belgium)

P53 "Neutral-neutral reactions in cometary comae"
Steven Charnley et al.
NASA Goddard Space Flight Center (United States)

P54 "Spectroscopic and photometric monitoring of comet C/2013 US10 (Catalina)"
Cyrielle Opitom et al.
University of Liège (Belgium)

P55 "Alkali Metals in Cometary Particles – what is the Chemical Context?"
Oliver J. Stenzel et al.
Max-Planck-Institut für Sonnensystemforschung (Germany)

P56 "Two-point observations of low-frequency waves at 67P/Churyumov-Gerasimenko during descent of PHILAE: Comparison of RPCMAG and ROMAP"
Ingo Richter et al.
TU-Braunschweig (Germany)

P57 "Dust tail analysis from a new application of the Finson-Probstein technique"
O. D. Price et al.
Mullard Space Science Laboratory, University College London (United Kingdom)

P58 "Photometry of dust grains of comet 67P, using OSIRIS images"
Gabriele Cremonese et al.
INAF-Astronomical Observatory of Padova (Italy)

P59 "Spacecraft Dynamics during the Halley Encounter: The Giotto Radio-Science Experiment (GRE)"
Michael Bird et al.
Uni-Bonn (Germany)

P60 "A hot and active place: The ionosphere of comet 67P"
Anders Eriksson et al.
Swedish Institute of Space Physics (Sweden)

P61 "Broadband monitoring of coma radicals at high spectral resolving power with a multi-order spatial heterodyne spectrometer."
Walter Harris et al.
University of Arizona (United States)

P62 "An Overview of Cometary Science with WISE/NEOWISE"
Emily Kramer et al.
Jet Propulsion Laboratory (United States)

P63 "The Complex Rotation State of Comet 103P/Hartley 2"
Tony Farnham et al.
University of Maryland (United States)

P64 "Cometary dust at the nm scale from the MIDAS atomic force microscope"
Mark Bentley et al.
Space Research Institute, Austrian Academy of Sciences (Austria)

P65 "Grain structure of cometary dust at the nanometre scale: new insights from MIDAS"
Roland Schmied et al.
Space Research Institute (Austria)

P66 "Aspherical dust dynamics and coma dust analysis of 67P/Churyumov- Gerasimenko based on the in situ observations of the GIADA instrument."
Stavro L. Ivanovski et al.
IAPS - INAF (Italy)

P67 "Is the dust in the jets different from that in the diffuse coma"
Gian Paolo Tozzi et al.
INAF - Osservatorio Astrofisico di Arcetri (Italy)

P68 "First spectrally complete survey of cometary water emission at near IR wavelengths (0.9-2.5 µm): C/2014 Q2 Lovejoy with TNG/GIANO spectrograph."
Sara Faggi et al.
Osservatorio Astrofisico di Arcetri (Italy)

P69 "Four-fluid MHD Simulations of the Plasma and Neutral Gas Environment of Comet 67P/CG Near Perihelion"
Tamas I. Gombosi et al.
University of Michigan (United States)

P70 "Far-ultraviolet Spectroscopy of Recent Comets with the Cosmic Origins Spectrograph on the Hubble Space Telescope"
Paul D. Feldman et al.
Johns Hopkins University (United States)

P71 "Evolution of the major cometary volatiles around comet 67P/Churyumov-Gerasimenko as seen by ROSINA-RTOF from 3.1 to 1.6 AU."
Sébastien Gasc et al.
University of Bern, Physikalisches Institut (Switzerland)

P72 "In Situ Space Gas Dynamic Measurements by the ROSINA Comet Pressure Sensor COPS Onboard Rosetta Spacecraft"
Chia-Yu Tzou et al.
Physikalisches Institut, University of Bern (Switzerland)

P73 "Characterizing Cometary Electrons with Kappa Distributions"
Thomas Broiles et al.
Southwest Research Institute (United States)

P74 "Ionisation source of the plasma environment around comet 67P"
Marina Galand et al.
Imperial College London (United Kingdom)

P75 "Properties of dust particles in comets from polarimetric observations of 67P"
Edith Hadamcik et al.
Univ. P. & M. Curie, LATMOS (France)

P76 "67P/Churyumov-Gerasimenko Coma dust environment at 2 AU measured by GIADA"
Vincenzo Della Corte et al.
IAPS-INAF (Italy)

P77 "Volatile species in the inner coma of 67P/Churyumov-Gerasimenko observed with VIRTIS on board Rosetta"
Alessandra Migliorini et al.
IAPS-INAF (Italy)

P78 "The abundance of complex organic molecules in comets from molecular surveys at submm/mm wavelengths."
Nicolas Biver et al.
LESIA, Observatoire de Paris (France)

P79 "Evolution and structure of a comet magnetosphere - Rosetta observations"
Hans Nilsson et al.
Swedish Institute of Space Physics (Kiruna)

P80 "Origin(s) of the microscopic structures at the Philae landing site and possible implications on the formation and evolution of the nucleus"
Francois Poulet et al.
Institut d'Astrophysique Spatiale (France)

P81 "The fate of molecular oxygen: from the protosolar nebula to comets"
Olivier Mousis et al.
Laboratoire d'Astrophysique de Marseille, Aix-Marseille Université (France)

P82 "Assessing the primordial character of comet 67P/Churyumov-Gerasimenko"
Hermann Boehnhardt et al.
MPI for Solar System research (Germany)

P83 "High spectral resolution of Doppler shifted emission from comet 9P/Tempel 1 following the Deep Impact encounter: Evidence for large scale internal energy release producing a high velocity jet from the impact site."
Jason Corliss et al.
University of Arizona (USA)

P84 "Thirty Years of Detecting Primary Volatiles in Comets"
MIchael J Mumma
NASA Goddard Space Flight Center (USA)

P85 "The Distribution of Extended Source Species in Comets: the Case of H2CO"
Stefanie Milam et al.
NASA Goddard Space Flight Center (USA)

P86 "Sulfur from protostars to comets"
Maria N. Drozdovskaya
Leiden Observatory (The Netherlands)

P87 “Exploring 67P through art”
Ekaterina Smirnova
ekaterina-sminova.com (United States)

P88 “Ground-based Observing Campaigns of Comets From 1P/Halley to 67P/Churyumov-Gerasimenko”
Padma A. Yanamandra-Fisher et al.
Space Science Institute (United States)

P89 “The new Planetary Science Archive: a tool for exploration and discovery of scientific dataset of ESA planetary missions”
Sebastien Besse et al.
ESAC (Spain)

P90 "Adding value to 67P/Churyumov-Gerasimenko data archives with Virtual Observatory protocols"
Stéphane Erard et al.
LESIA / Observatoire de Paris (France)

P91 "No bit left behind: PDS cometary archive from Giotto to Rosetta"
Ludmilla Kolokolova et al.
University of Maryland (United States)

P92 General comet traits and comparison of their dynamical history – towards understanding long-term evolutionary processes on comets?"
Mathieu Choukroun et al.
Jet Propulsion Laboratory (United States)

P93 "Main Belt Comets: the next frontier"
Colin Snodgrass
The Open University (United Kingdom)

Abstracts

Oral Presentations

From 1P to 67P

Roger-Maurice Bonnet

ISSI (Switzerland)

When Giotto revealed the nucleus of Halley's comet in the night of 13March 1986, European scientists were already dreaming of landing on another comet nucleus and bringing samples of its soil down to Earth. Indeed a "Mission to Primordial Bodies including Return Pristine Material" was introduced as one of four Cornerstones in the Horizon 2000 program formulated in 1984 and eventually approved by the ESA council at ministerial level 5 months before the launch of Giotto. Certainly, the lessons learnt from Giotto have proven useful to making what would become Rosetta in 1993, a better mission. Both Giotto and Rosetta made history. Both were confronted to adversity: one had to fight against a schedule imposed by astronomical and orbital constraints, the other against a fixed budget. The TRLs of both missions' payloads, not much above 2, would not authorize these missions to start given present space management policies. Scientific and political vision, risk acceptance and luck have characterized the creation of two missions, which eventually confirmed European leadership in the exploration of the small bodies of the Solar System.

****

Cometary Science from the Halley Armada to Rosetta

Michael F. A'Hearn et al.

University of Maryland (United States)

At the time of the Halley Armada, the existence of the Kuiper belt had been predicted but not observed. Since then we have observed mulitple, well-defined dynamical groups among the TNOs and have constraints on which groups can be the source of short-period comets. At the time of the Halley Armada, our knowledge of the composition of cometary volatiles had several great breakthroughs but now our knowledge has expanded many-fold. The Halley Armada provided the first direct images of a cometary nucleus, but we have now observed a half dozen cometary nuclei at even higher spatial resolution and we see a surprising diversity. In this time we have gone from fast flybys to sub-surface probing and to an orbiter that studies the seasonal evolution. I will trace these and other aspects of the increased knowledge of comets and the evolution of our understanding of the role of comets in understanding the solar system.

****

How and why to get a Lander on a Comet

Jean-Pierre Bibring et al.

IAS (France)

In response to the Rosetta AO for investigations, two "Surface Science Packages" were selected, which merged into Philae. Philae has been developed by an integrated engineering and scientific team, supported by a consortium of European institutes and agencies from Germany, France, Italy, Hungary, Austria, Finland, Great Britain and Ireland. The task was to build both a lander, as an autonomous vehicle capable of soft landing and operating at the surface of a comet, at 3 AU from the Sun, and 10 selected PI investigations, for an in-depth characterization of the surface and subsurface composition and properties, at a micro- and macro-scale. We shall present the design and the processes that finally led to the successful Philae landing on November 12, 2014, as well as the scientific goals targeted, in the context of the planetary space exploration programs. We shall then discuss the major outcomes of Philae investigations, in the frame of the global Rosetta mission.

****

The Chemistry Trail from Clouds to Disks and Comets

Ewine van Dishoeck et al.

Leiden Observatory (The Netherlands)

As clouds collapse to form new stars and planetary systems, the physical conditions change by orders of magnitude. This talk will review the main chemical characteristics of star- and planet-forming regions and their evolution from cloud cores to disks. The Atacama Large Millimeter Array (ALMA) can zoom in on collapsing clouds as well as the comet-forming zones of disks around solar-mass young stars for the first time. A very rich chemistry is found in the protostellar stage, including the detection of organic molecules such as sugars and amine-containing species (key molecules for building life). These molecules are mostly formed as ices on the surfaces of interstellar grains and recent progress in laboratory and modeling studies of gas-grain chemistry will be highlighted. Chemical studies of disks are still in their infancy and have so far revealed mostly simple species. Much of the oxygen and carbon budget may be locked up early in large icy bodies. The connection with our own early Solar System will be made by comparing protostellar abundances with recent results from the Rosetta mission to comet 67 P/C-G and other comets.

****

Comets as Tracers for the Formation and Volatile Acquisition of the Planets and Satellites

Kathleen Mandt et al.

Southwest Research Institute (United States)

Comets play a dual role in understanding formation and evolution of the solar system. Comets formed early and their composition is thought to serve as a record of conditions during the formation of planets and moons. Once they formed, their orbits were perturbed allowing them to travel into the inner solar system and impact the planets contributing to the volatile inventory of atmospheres. We will review how knowledge of comet composition prior to Rosetta contributed to understanding the formation processes of planets and moons. We also discuss how comets contributed to the volatile inventories of the giant and terrestrial planets. Finally, we will discuss implications of recent Rosetta results for understanding the

****

Origin(s) of Inner Planet Atmospheres and Terrestrial Oceans in the Light of the Rosetta Results

Bernard Marty et al.

CRPG-CNRS, Université de Lorraine (France)

Recent measurements of the volatile composition of the coma of Comet 67P/Churyumov-Gerasimenko (hereafter 67P) allow constraints to be set on the origin of volatile elements (water, carbon, nitrogen, noble gases) in inner planets' atmospheres. Analyses by the ROSINA mass spectrometry system onboard the Rosetta spacecraft indicate that 67P ice has a D/H ratio three times that of the ocean value (Altwegg et al., 2015) and contains significant amounts of N2, CO, CO2, and importantly, argon (Balsiger et al., 2015). Here we establish a model composition of cometary composition based on literature data and the ROSINA measurements. From mass balance calculations, and provided that 67P is representative of the cometary ice reservoir, we conclude that the contribution of cometary volatiles to the Earth's inventory was minor for water (≤ 1%), carbon (≤ 1%), and nitrogen species (a few % at most). However, cometary contributions to the terrestrial atmosphere may have been significant for the noble gases. They could have taken place towards the end of the main building stages of the Earth, after the Moon-forming impact and during either a late veneer episode or, more probably, the Terrestrial Late Heavy Bombardment around 4.0-3.8 billion years (Ga) ago. Contributions from the outer solar system via cometary bodies could account for the dichotomy of the noble gas isotope compositions, in particular xenon, between the mantle and the atmosphere. A mass balance based on 36Ar and organics suggests that the amount of prebiotic material delivered by comets could have been quite considerable – equivalent to the present-day mass of the biosphere. On Mars, several of the isotopic signatures of surface volatiles (notably the high D/H ratios) are clearly indicative of atmospheric escape processes. Nevertheless, we suggest that cometary contributions after the major atmospheric escape events, e.g., during a Martian Late Heavy Bombardment towards the end of the Noachian era, could account for the Martian elemental C/N/36Ar ratios, solar-like krypton isotope composition and high 15N/14N ratios. Taken together, these observations are consistent with the volatiles of Earth and Mars being trapped initially from the nebular gas and local accreting material, then progressively added to by contributions from wet bodies from increasing heliocentric distances. Overall, no unified scenario can account for all of the characteristics of the inner planet atmospheres. Advances in this domain will require precise analysis of the elemental and isotopic compositions of comets and therefore await a cometary sample return mission.

****

The Comet-Kuiper Belt Connection

Harold Weaver et al.

JHU Applied Physics Laboratory (United States)

Models of the Solar System's formation and evolution developed over the past two decades have highlighted the critical role played by the extensive radial migration of the Giant Planets. The gravitational stirring that resulted produced several dynamical families within the Kuiper Belt, including the scattered disk population that is likely the source of the Centaurs, the short period comets, the Trojan populations of the Giant Planets, and possibly even some of the objects in the asteroid Main Belt, including Ceres and some of the Main Belt Comets (MBCs). This gravitational stirring also resulted in extensive mixing of material across large heliocentric distances, thereby complicating efforts to use the compositions of the small bodies to determine their place of origin. Nevertheless, it is still worthwhile to compare the various populations of small bodies in the Solar

System for clues that might further elucidate the processes that shaped the architecture of our planetary system. Here we first review the dynamical arguments that identify the source region(s) of the short period comets, and then we explore what is known about the physical properties (sizes, shapes, rotational states), albedos, and compositions of the Kuiper Belt Objects (KBOs), Centaurs, Trojans, and MBCs and how they compare to what we have learned so far about comets.

****

Cometary Origins after Rosetta and Implications for Solar System Formation

Björn Davidsson et al.

Uppsala University (Sweden)

The comets we observe today enter the inner Solar System from remote reservoirs beyond the planets known as the Oort Cloud, the Scattered Disk, and the Edgeworth-Kuiper Belt. These reservoirs most likely formed about 4 Gyr ago when comets and other TNOs were relocated from the primordial disk (stretching from 15-30 AU from the Sun), as the giant planets migrated from their birth zone at 5-15 AU to their current orbits. The primordial disk itself was an old remnant of the Solar Nebula, in which the comet nuclei formed. Our scientific interest in comet nuclei stems from the notion that their elemental, isotopic, chemical, and mineralogical composition reflects that of the Solar Nebula, and that their physical structure might reveal how macroscopic bodies form out of microscopic dust in protoplanetary disks. Thus, they provide unique opportunities for us to learn how the Solar System formed and how it evolved to its current state. The ESA Rosetta mission to comet 67P/Churyumov-Gerasimenko is the most ambitious spacecraft mission to a comet nucleus in human history. A wealth of information has been collected from the orbiter and from the lander Philae. This data will be discussed in the context of contemporary comet formation theories.

****

Sulfur Isotopic Ratios in the Coma of 7P/Churyumov-Gerasimenko

Ursina Calmonte et al.

Physikalisches Institut, University of Bern (Switzerland)

In October 2014 the ROSINA instrument on board the European Space Agency's spacecraft Rosetta measured the isotopologues of H2S, OCS, SO2, S2, and CS2 in the coma of the Jupiter-family comet 67P/Churyumov-Gerasimenko. ROSINA consists of a pressure sensor and two complementary mass spectrometers. Here we report the isotope fractionation of 34S in H2S, OCS, SO2, S2, and CS2. In addition for the first time the ratio of 32S/33S could be determined for cometary volatiles. The obtained results will be discussed in context with the values for 32S/34S which have been reported so far in comets 1P/Halley, C/1995 O1 Hale-Bopp, and 17P/Holmes. Furthermore, a short summary will be given on the sulfur isotope fractionation in the Solar System.

****

The Tale of a Cometary Dust Particle of Comet 67P/Churyumov-Gerasimenko

Martin Hilchenbach et al.

Max Planck Institute for Solar System Research (Germany)

COSIMA, the COmetary Secondary Ion Mass Analyzer instrument, onboard the ESA mission Rosetta to comet 67P/Churyumov-Gerasimenko collected and analyzed dust particles in the inner coma of comet 67P since August 2014. The morphology and composition of a cometary dust particle as derived from microscopic images and hundreds of secondary ion mass spectra will be presented in view of the evolution of the solar system .

****

In Situ Mass Spectrometry from Giotto to Rosetta

Kathrin Altwegg et al.

Physikalisches Institut (Switzerland)

The Giotto spacecraft was the first mission performing in situ measurements with different mass spectrometers in a cometary coma. While it set out to measure for the first time water in a comet and to understand the comet-solar wind interaction, the rich abundance of heavier molecules in the mass spectra of the neutral mass spectrometer NMS, the ion mass spectrometer IMS-HIS, the PICCA sensor and the dust mass spectrometer PIA was what triggered the interest in comets as pristine reservoirs of material older than our solar system. While many more molecules were found by remote sensing telescopes in many more comets since, the Rosetta mission again sets a new standard in composition measurements in a cometary coma, doubling to date the number of detected parent molecules.

****

Mass-loading, Pile-up, and Mirror-mode Waves at Comet 67P/Churyumov-Gerasimenko

Martin Volwerk et al.

Austrian Academy of Sciences (Austria)

The data from all RPC instruments and from the ROSINA COPS instrument are used to study the interaction of the solar wind with the outgassing cometary nucleus of 67P/CG. During 6 and 7 June 2015, the interaction was first dominated by an increase in the solar wind dynamic pressure. This pressure compressed the draped magnetic field around the comet, and the increase in solar wind electrons enhanced the ionization of the outflow gas through collisional ionization. The new ions are picked up by the solar wind magnetic field, and create a ring distribution which is unstable for mirror mode wave generation. Two different kinds of mirror modes are observed: one of small size generated by locally ionized water and one of large size generated by ionization and pick-up farther away from the comet.

****

The Global State of the Plasma Environment at 67P/CG at Perihelion - Comparing RPC Observations and Simulations

Christoph Koenders et al.

TU Braunschweig (Germany)

The Rosetta Mission reveals a unique possibility to monitor the plasma environment of comet 67P/Churyumov-Gerasimenko. However, based on the restricted spacecraft trajectory, the ability to scan the entire plasma environment is quite limited, and , therefore, gaining a full picture of the global state of the interaction considering only measurements is difficult. We solve this problem by using 3D plasma simulations, which describe the many processes in the cometary environment. In this study we compare the results of hybrid plasma simulations with various observations obtained by the instruments of the Rosetta Plasma Consortium (RPC). While we see agreements between simulations and observations in the close vicinity of the diamagnetic cavity, observations reveal unexpected structures at larger distances. We will discuss this difference to identify the important processes in the cometary plasma environment.

****

Properties of the Diamagnetic Cavity at Comet 67P/Churyumov-Gerasimenko

Charlotte Goetz et al.

Technische Universität Braunschweig (Germany)

After the detection of a diamagnetic cavity at comet 1P/Halley, it was predicted that the cavity at the weaker comet 67P/Churyumov-Gerasimenko would only extend a few tens of kilometers. However in July 2015, the signatures of a cavity were detected at distances of up to 330 km kilometers. Up until November 2015 a total of 480 intervals when Rosetta was situated in the diamagnetic cavity have been detected. This opens up the possibility of a statistical analysis of the diamagnetic cavity properties. With the help of a Minimum Variance Analysis the boundary normal may be estimated and used to determine a general structure of the diamagnetic cavity, revealing that the cavity is by no means describable by a simple paraboloid model. The large number of data points is also used to estimate a boundary velocity and verify the existence of Kelvin-Helmholtz instabilities at the cavity boundary.

****

Coma Composition in Comets from Remote Sensing

Dominique Bockelee-Morvan et al.

LESIA, Observatoire de Paris (France)

The composition of cometary ices provides clues to the chemistry and conditions prevailing in the early solar system. Since the detection of HCN at millimeter wavelengths in comet C/1973 E1 (Kohoutek), almost 30 molecules have been identified in cometary atmospheres from remote sensing observations from ground or from space platforms. Thanks to progresses in instrumentation and the availability of large telescopes, complex organic molecules have been identified. Measurements will be reviewed and the observed chemical diversity among comets will be presented. The relative abundances will be compared to values measured in star-forming regions to discuss the possible formation routes of cometary molecules.

****

ROSINA/DFMS and IES Observations at 67P/Churyumov-Gerasimenko: Ion Composition in the Heterogeneous Coma

Stephen A. Fuselier et al.

Southwest Research Institute (United States)

The Rosetta spacecraft encountered comet 67P in August 2014 and escorted it to perihelion. Late in this escort phase, the Ion and Electron Sensor (IES) observed distinct regions of cold (10’s of eV) and hotter (100’s of eV) ions in the coma between 100 and 300 km from the nucleus. These observations suggest a boundary similar to the ion pileup boundary observed during the Giotto encounter with comet Halley. The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) observed distinct increases in the H_3O^+/H_2O^+ ratio in the cold ion regions of the coma of comet 67P. ROSINA also observed distinct changes in the H3O+/H2O+ ratio with longitude of the sub-spacecraft location. These changes are discussed in terms of ion-neutral chemistry in the heterogeneous coma of comet 67P.

****

Molecular Oxygen in 1P/Halley and 67P/Churyumov-Gerasimenko

Martin Rubin et al.

Physikalisches Institut, University of Bern (Switzerland)

The ROSINA mass spectrometer on board of ESA's Rosetta spacecraft detected abundant molecular oxygen in the coma of Jupiter-family comet 67P/Churyumov-Gerasimenko (67P). The observed density is remarkably well correlated with water (O2/H2O = 3.80±0.85%), suggesting - rather unexpected - that primordial O2 was already incorporated during the comet's formation. Recently, we re-analyzed data collected by Giotto's Neutral Mass Spectrometer (NMS) during the flyby at Oort cloud comet 1P/Halley in 1986. Despite NMS' limited mass resolution, it was possible to derive a comparable relative amount of O2/H2O = 3.7±1.7%. In summary we have two comets that, despite different dynamic histories and origins, have similar relative amounts of molecular oxygen indicating that O2 is rather common in comets.

****

Halogens at Comet 67P/Churyumov-Gerasimenko Observed by ROSINA-DFMS and COSIMA

Frederik Dhooghe et al.

Belgian Institute for Space Aeronomy (Belgium)

The halogens HF, HCl and HBr have been measured in the coma of comet 67P/Churyumov-Gerasimenko using the Double Focussing Mass Spectrometer (DFMS) of the ROSINA instrument on board of the Rosetta spacecraft. Fluorine has also been detected on cometary dust particles collected by COSIMA, the COmetary Secondary Ion Mass Analyzer instrument. This contribution will focus on the abundance, variability and isotopic ratios of the halogens in the coma and the abundance of F in dust particles. These results may provide insights on the halogen chemistry in the early Solar System since comets may have retained information about the physical and chemical conditions of the protoplanetary disk from which it was formed.

****

The Heliocentric Variation of the Outgassing Rate and Molecular Abundances in the Coma of 67P as seen by MIRO

Nicolas Biver et al.

LESIA (France)

Since July 2014, the MIRO instrument on board the Rosetta spacecraft has been regularly mapping the emission of 8 molecular lines around 560 GHz of H2O and its isotopes, CO, NH3 and CH3OH in the inner coma of comet 67P/Churyumov-Gerasimenko (pointing within 20km from the nucleus). We have used those observations to estimate the mean outgassing rates as a function of time in 2014-2016 and heliocentric distance (Rh=4-1.2 AU). The peak outgassing rate of water (~10**28 molec./s), based on maps of $H_2^{18}O$ was reached slightly after perihelion. We also measured the evolution of the abundances relative to water of CO, CH_3OH and NH_3. The abundances of CH_3OH and CO were found to be higher around perihelion time when most of the outgassing was coming from the illuminated southern pole.

****

Coma Isotopic Composition

Jehin Emmanuel et al.

Liege University (Belgium)

Having retained and preserved pristine material from the Solar Nebula at the moment of their accretion, comets contain unique clues to the history and evolution of the Solar System. Important diagnostics of how and where cometary materials formed are contained in isotopic ratios, since isotopic fractionation is very sensitive to chemical and physical conditions. We will present the measurements of the isotopic ratios of the light elements (D/H, 12C/13C, 16O/18O, 14N/15N, 32S/34S, …) in cometary comae from an historical point of view, present the latest results and discuss their implications. Over the last 30 years many different techniques have been used, from remote observing to in situ measurements and targeting an increasing number of species in various types of comets. Still measurements are not always in agreement and their interpretation remains difficult.

****

The Size Distribution of Dust Emitted from 67P/Churyumov-Gerasimenko and Comparison to other Comets

Jessica Agarwal et al.

Max Planck Institute for Solar System Research (Germany)

The dust size distribution describes the relative abundance of particles of different sizes in a given ensemble of dust particles, such as the dust ejected from a comet. It reveals, e.g., which particles dominate the optical scattering cross-section of the dust when observed from Earth, and which particles carry the bulk of mass carried into the interplanetary dust environment by the comet. The size distribution also provides clues to the conditions under which the refractory material was stored in the comet, and to the processes releasing the dust from the surface. It potentially also preserves information on the primordial material of which the comet has formed. On board Rosetta, many instruments contribute to measuring the dust size distribution, both in situ and from remote sensing. The instruments are sensitive to different size ranges and measure different physical quantities from which eventually the particle sizes are derived. This talk will give an overview of the results obtained so far by the individual instruments and attempt to provide a synopsis of these results. We will investigate if a common picture emerges from the measurements of the individual instruments and identify open questions. We will compare the results obtained with Rosetta to pre-arrival models of the dust size distribution derived from ground-based data, and to the dust size distributions of those comets visited by earlier spacecraft missions. We will, finally, discuss the implications of the measured size distribution for our understanding of the origin of comet 67P and its contribution to the zodiacal dust cloud.

****

Study of 67P/CG Coma Dust/ Gas Evolution as Derived from VIRTIS Observations

Giovanna Rinaldi et al.

IAPS-INAF (Italy)

We report an investigation of the dust dynamical and spectral compared to H2O and CO2 outgassing in the coma of 67P/Churyumov-Gerasimenko obtained by the VIRTIS-M imaging spectrometer on the Rosetta mission. Three dust characteristics were observed: (1) Reflectance of the dust and its spectral slope in the visible and infrared regions; (2) Morphological correlations between dust and gas and for observed jets; and (3) Radial profiles of the dust which can be compared with model calculations. We find that in the inner coma the spectral reflectivity of the coma from 0.4 to 5.0 um displays a red slope but does not show significant absorption features. The spatial distribution of the dust is strongly correlated with H2O emission and is quite different from that of CO2 emission, indicating that H2O plays a key role in 67/P dust activity. The radial profile of the radiance in the coma follows 1/ρ distributions at distances more than 4 km from the surface, but is steeper at smaller distances. This behaviour is as expected from model calculations in which the dust accelerates as it flows outwards.

****

Distributed Sources in Comets: from Giotto to Rosetta

Herve Cottin et al.

LISA, UPEC (France)

Observations of comet Halley lead to the conclusion that some volatile species had a distributed source, i.e. they were produced in the atmosphere of the comet from grains and not from the nucleus itself. Formaldehyde is a clear example for such a process, and it shows similar behavior also in comets Levy, Austin, Hyakutake, Hale-Bopp, and recently in comets Lemmon and ISON. Thermal degradation of polyoxymethylene (POM) has been evoked to account for those observations. In this presentation, the feasibility of distributed sources measurements with Rosetta will be discussed, not only for H2CO after a tentative detection of POM with PTOLEMY, and a search for this polymer with COSIMA, but also in the inner coma with ROSINA for other volatile species sublimating from grains.

****

Sub-mm and FIR Interferometry of Small Solar System Bodies

Martin Cordiner et al.

NASA Goddard Space Flight Center (United States)

Cometary nuclei preserve some of the most pristine material in the Solar System. Studies of their compositions therefore provide unique and powerful information on the physical and chemical properties of the Solar Nebula and protosolar disk, including the inventory of simple and complex organic molecules. However, significant gaps remain in our understanding of cometary compositions, limited in part by uncertainties regarding the physical and chemical structure of the coma, which hinder our ability to infer accurate nuclear abundances. Here, we summarise results from our work to exploit the unprecedented resolution and sensitivity of the Atacama Large Millimeter/submillimeter Array (ALMA) to provide new information on the temperature and distribution of molecular material in cometary comae. Maps of several coma gases will be presented, providing a new level of detail on size scales from a few hundred to a few thousand km in typical, moderately bright comets. This presentation will focus in particular on our latest ALMA maps of methanol (CH3OH) in the inner coma of comet C/2012 K1 (PanSTARRS).

Detection of 12-14 emission lines from CH3OH has permitted the derivation of the first spatially-resolved rotational temperature maps for this molecule, for the innermost 5000 km of the coma. These data indicate significant variations in the coma temperature over spatial scales ~500 km. The observed variations in molecular excitation are interpreted primarily as a result of variations in the coma kinetic temperature due to adiabatic cooling and photolytic coma heating.

****

Diversity of Organic Matter in Comets: The Case of 81P/Wild 2

Bradley De Gregorio et al.

U.S. Naval Research Laboratory (United States)

Carbonaceous matter is a major component of comets. However, it is difficult to reliably characterize macromolecular CHON material, due to limitations of spacecraft instrumentation, terrestrial contamination, or alteration during sampling. In this talk I will discuss the variety of organic chemistries observed in cometary CHON matter returned by the NASA Stardust mission to 81P/Wild 2, ranging from polymer-like material to graphitic material and diamond. During the preliminary examination phase, several extreme chemistries (N-rich, O-rich, etc.) were observed, suggesting comets are a unique reservoir for carbonaceous phases among planetary bodies. D and N-15 isotopic anomalies were also observed, indicating a likely interstellar origin. However, further characterization by transmission electron microscopy (TEM) has shown that these extreme N-rich and O-rich organics are contaminants, and the majority of the Wild 2 carbonaceous samples have isotopic compositions consistent with a solar system origin. Some of the Wild 2 organics show signatures of aliphatic carbon, but except for one example, all of these samples show some amount of interaction with aerogel during capture or epoxy during sample preparation. It is unclear if the high aliphatic signatures are due to chemical fractionation or alteration during capture. Fourteen verified samples of unaltered cometary CHON matter look similar to that found in chondrites and IDPs, albeit still with a wider range of functional chemistry. These contain two examples of poorly graphitized carbon, whose presence in Wild 2 was implied by Raman observations but dismissed as capture heating. Nanoglobule morphologies have also been observed in at least three captured grains. There are two outstanding questions that arise from these results. First, compared with primitive carbonaceous chondrites and IDPs, the abundance of presolar/interstellar organic matter appears much too low in Wild 2. While the nature of hypervelocity capture into silica aerogel creates a sampling bias against all carbonaceous matter relative to silicates, it cannot explain the apparent overabundance of isotopically “solar” CHON material. This may be a clue regarding the homogeneity of particle transport in the early Solar Nebula. Secondly, it is unclear how much of the macromolecular CHON matter formed in situ on the comet. Recent observation of polyoxymethylene (POM) hydrocarbons near the surface of 67P/Churyumov-Gerasimenko by Rosetta’s Philae lander suggests that reactions between formaldehyde polymers could generate macromolecular CHO matter, or CHON matter if incorporating the abundant N-bearing organics also observed on the surface by the COSAC instrument. Formaldehyde polymers have been shown to form globular morphologies when exposed to liquid water. However, organic nanoglobules in Wild 2 contain abundant aromatic carbon bonding, inconsistent with an origin from POM-like precursors.

****

Organics from ROSINA Measurements at 67P/Churyumov-Gerasimenko

Léna Le Roy et al.

Center for Space and Habitability (Switzerland)

As comets are thought to be the most primitive bodies in the Solar System, their composition can give us insights into the conditions and the processes that occurred during the formation of our Solar System. Since August 2014, the Double Focusing Mass Spectrometer (DFMS), part of the ROSINA experiment onboard the Rosetta spacecraft, monitors continuously the coma composition of comet 67P/Churyumov-Gerasimenko. In this presentation we will give an overview of the organic compounds that have so far been detected with ROSINA/DFMS and compare the abundances to remote observations of hot cores.

****

Spatial and Temporal Heterogeneities in the Gas Distribution of 103P/Hartley2 : How is it different from 67P/C-G ?

WITHDRAWN

Sebastien Besse et al.

ESA-ESAC (Spain)

During its close flyby of the hyperactive comet 103P/Hartley 2, Deep Impact acquired an extensive data set that provided an opportunity to study the spatial and temporal distribution and absolute abundance changes in gas emission (A'Hearn et al., 2011). The HRI-IR spectrometer was used to monitor the coma from 1.05--4.85 microns throughout the encounter. Spatially-resolved infrared scans were acquired every 2 hours over the 18 hours prior to closest approach and several times per day for 10 days before and after closest approach. Water vapor at 2.7 microns, carbon dioxide at 4.3 microns, and bulk organics at 3.4 microns were the dominant emission bands detected in these spectra and their distribution was found to be highly asymmetric and variable. Variability of the sources for carbon dioxide and water are indicative of the distinct composition of the nucleus, as well as the various mechanisms that feed the coma with these species. Carbon dioxide production is found to be associated with the small lobe, even when this small lobe is on the night side and bulk organics are found to be highly correlated to carbon dioxide. Water production is much more complex and linked to various sublimation sources such as the waist of the nucleus, icy grains in the coma (Protopapa et al., 2014), and possibly recondensed ices on the surface the nucleus. The periodicity of the water and carbon dioxide and the variability of the amplitudes are also clues to understanding the complex rotation of the nucleus and the enrichment of the coma in water with respect to carbon dioxide. Water seems to be slightly correlated with the roll angle of the comet whereas carbon dioxide is not. In this paper, we present the latest analysis of the coma of comet 103P/Hartley 2, and we highlight this analysis with the latest results obtained by the Rosetta mission on comet 67P/C-G. Analyses from various instruments (e.g., VIRTIS, ROSINA, etc.) have shown that the bulk composition of 67P varies with sub-solar region. 103P and 67P are clearly indicative of the heterogeneous composition of the nucleus, which has important implications for the formation of cometary nuclei.

****

Comet Encounters of the Serendipitous Kind: The Ulysses Comet Tail Crossings

Geraint Jones et al.

UCL Mullard Space Science Laboratory (United Kingdom)

Giotto and Rosetta are not the only ESA spacecraft to encounter comets. Launched in 1990, the ESA/NASA Ulysses spacecraft's mission was to explore the solar wind and other components of the heliosphere over a wide range of solar latitudes. This highly successful mission ended in 2009. During its operational phase, Ulysses unexpectedly encountered the ion or plasma tails of three active comets: C/1996 B2 (Hyakutake) (Jones et al. 2000; Gloeckler et al. 2000), C/1999 T1 (McNaught-Hartley) (Gloeckler et al. 2004), and C/2006 P1 (McNaught) (Neugebauer et al. 2007). During each encounter, clear signatures were observed in the solar wind density and composition, reflecting the charge-exchange of solar wind particles with cometary neutral species, and the addition of cometary pickup ions to the solar wind flow. Magnetic field signatures indicated the draping of heliospheric magnetic field lines at the comets. The distances at which the encounters occurred were all impressive: the Hyakutake encounter implied an ion tail length of at least 3.8 astronomical units, or 550 million km (Jones et al. 2000). Two separate sections of Comet McNaught-Hartley's tail were encountered inside the interplanetary counterpart of a coronal mass ejection (ICME), suggesting that the tail had been disrupted by the ICME itself. Finally, the crossing of Comet McNaught's tail, which was one of the brightest comets visible for decades, involved an encounter period that persisted for several days. An overview will be given of these three encounters, outlining what has been learnt regarding comet-solar wind interactions as a result of these tail crossings. Other candidate comet-related events observed by Ulysses's suite of instruments will also be described.

****

Typology of Cometary Particles Collected by COSIMA before and after Perihelion

Yves Langevin et al.

Institut d'Astrophysique Spatiale (France)

The COSIMA mass spectrometer collects cometary particles on targets 1 cm x 1 cm in area. The cometary particles are detected by taking images before and after exposure with a microscope, COSISCOPE, with a resolution of 14 µm / pixel. Since rendez-vous, COSISCOPE has detected close to 20,000 particles or fragments of particles. The typology of particles collected from August 2014 to April 2015 has been presented in Langevin et al. (Icarus, in press). After an excursion in the tail in October 2015, ROSETTA has been getting closer to the nucleus (120 km in late November), and many new particles have been collected. This contribution will present the evolution of the typology of particles before and after perihelion (August 13, 2015) in relationship with the evolution of cometary activity.

****

TOF-SIMS Analysis and Characterization of the Solid Organic Matter in the Dust Particles of 67P/Churyumov-Gerasimenko with the COSIMA Instrument.

Nicolas Fray et al.

LISA, UMR CNRS 7583, UPEC, UPD (France)

Cometary particles are partly made of solid complex organic matter. The presence of this organic component was demonstrated in 1P/Halley by in-situ mass spectrometry analysis in 1986. Since that time, this solid organic matter has not been adequately characterized. The COSIMA instrument, which is a Time Of Flight – Secondary Ion Mass Spectrometer, analyses the composition of the dust particles of 67P/C.-G. since September 2014. We will present the preliminary characterization of the solid organic matter in the dust particles of 67P/C.-G., as measured by COSIMA. We will focus on the N/C elemental ratio and we will compare the solid organic matter present in 67P/C.-G. with the one of 1P/Halley, as well as with that of chondritic meteorites, Stardust samples, chondritic porous IDPs and UCAMMs.

****

The Morphological Diversity of Micron-sized Cometary Dust Detected with MIDAS

Thurid Mannel et al.

Space Research Institute of the Austrian Academy of Sciences (Austria)

The Rosetta mission is revolutionising our understanding of comets through its detailed investigation of comet 67P. The characterisation of almost pristine cometary dust particles is carried out by the dedicated experiments COSIMA [Kissel et al. 2007], GIADA [Colangeli et al. 2007], and MIDAS [Riedler et al. 2007] as well as other instruments. Whilst COSIMA and GIADA focus on dust particles larger than 10 micrometres, MIDAS extends the investigation to the smallest scale. MIDAS (Micro-Imaging Dust Analysis System) is a novel Atomic Force Microscope (AFM) capable of imaging the surface of dust particles in 3D with a resolution down to nanometres. This opens for the first time the possibility to explore the morphology of the smallest cometary dust particles. Here we present the MIDAS dust collections to date and describe the key particle properties. MIDAS has imaged dozens of cometary dust particles that can be divided into different categories according to their morphology, size, collection time or other distinctive features. These categories will be introduced and discussed. For example, large dust particles are typically rather flat agglomerates of non-spherical grains, several tens of micrometres in size. Their fragile structure can change during the MIDAS scanning process and produce many fragments. The fragments reflect the aggregate structure of the large particles on a smaller scale and tend to disaggregate further. The smallest detected particles are about one micrometer diameter, which is the size range of the sub-structures of the large particles and fragments. This aggregate nature appears to extend to the smallest scale, suggesting a hierarchical structure of the dust. For a comprehensive understanding of cometary dust morphology the properties of micrometre sized particles detected with MIDAS are compared to the larger dust detected by other instruments on board Rosetta. The porous aggregates found by GIADA [Della Corte et al. 2015, Fulle et al. 2015] and the flat rubble piles imaged by COSIMA [Schulz et al. 2015] are reminiscent of the largest porous aggregates detected with MIDAS. Furthermore, the appearance of the dust resembles unprocessed interplanetary dust particles (IDPs), thus introducing the possibility to compare almost pristine and cometary dust with IDPs at the micrometre scale.

****

Variations in Cometary Dust Compositions from Giotto to Rosetta, Clues to their Formation Mechanisms

Cecile Engrand et al.

CSNSM CNRS/IN2P3-Univ. Paris Sud, University Paris Saclay (France)

Cometary dust compositions have been measured by in situ and remote sensing instruments in the last decades, each analysis adding pieces to the puzzle of how and where comets formed. Giotto analyses of comet 1P/Halley dust particles have shown the presence of CHON and mixed particles. Astronomical observations showed that olivine and pyroxene are present in comets. Laboratory analyses of comet 81P/Wild 2 samples brought back by Stardust suggested the existence of a continuum between asteroids and comets. Some interplanetary dust particles and micrometeorites collected at the Earth surface could also have a cometary origin and constitute well preserved comet samples to be analyzed in the laboratory. We will present the implications of these results for the formation of comet dust particles.

****

Coma Dust Environment Observed by GIADA during the Perihelion of 67P/Churyumov-Gerasimenko.

Vincenzo Della Corte et al.

IAPS-INAF (Italy)

GIADA (Grain Impact Analyzer and Dust Accumulator) is an in-situ instrument onboard Rosetta monitoring the dust environment of comet 67P/Churyumov-Gerasimenko. GIADA is composed of 3 sub-systems: 1) the Grain Detection System, based on particle detection through light scattering; 2) the Impact Sensor, giving momentum measurement; 3) the Micro-Balances System, constituted of 5 quartz crystal microbalances, giving cumulative deposited dust. The combination of the measurements performed by these 3 subsystems provides: the number, the mass, the momentum and the speed distribution of dust particles emitted from the comet nucleus. We will present the coma dust environment as observed by GIADA during the perihelion phase of the Rosetta space mission. Despite the large distance from the nucleus, more than 200 km, GIADA was able to detect temporal and spatial variation of dust density distribution. Specific high dust spatial density sectors of the coma have been identified and their evolution during the perihelion phase was studied. Acknowledgements. GIADA was built by a consortium led by the Univ. Napoli “Parthenope” & INAF- Oss. Astr. Capodimonte, IT, in collaboration with the Inst. de Astrofisica de Andalucia, ES, Selex-ES s.p.a. and SENER. GIADA is presently managed & operated by Ist. di Astrofisica e Planetologia Spaziali-INAF, IT. GIADA was funded and managed by the Agenzia Spaziale Italiana, IT, with a support of the Spanish Ministry of Education and Science MEC, ES. GIADA was developped from a PI proposal supported by the University of Kent; sci. & tech. contribution given by CISAS, IT, Lab. d'Astr. Spat., FR, and Institutions from UK, IT, FR, DE and USA. We thank the RSGS/ESAC, RMOC/ESOC & Rosetta Project/ESTEC for their outstanding work. Science support provided by NASA through the US Rosetta Project managed by JPL/California Institute of Technology. GIADA calibrated data will be available through the ESA’s PSA web site.

****

How In-situ Observations changed our Understanding of Cometary Activity

Jean-Baptiste Vincent et al.

MPS (Germany)

Cometary activity is the result of the sublimation of volatile material, and resulting acceleration of refractory elements, leading to a gas and dust coma around the nucleus. In-situ observations have shown that this description is not sufficient. Volatiles are scarce on the surface of cometary nuclei, and the activity patterns are far more complex than initially thought. Gas and dust arise from the nucleus as collimated streams, which may or not be related to local inhomogeneities in morphology and/or composition. Giotto observed these features for the first time 30 years ago but their formation mechanism remains to be explained. I will present how the Rosetta observations can bring a solution to this problem, with important consequences for the models of formation and evolution of cometary nuclei.

Comparison between the Physical Modelling Techniques Involved in the Analysis of the P/Halley and 67P Coma Observations

WITHDRAWN

Jean-François Crifo et al.

CNRS/LATMOS (France)

The VEGA/Giotto missions to P/Halley, on one hand, and the Rosetta mission to 67P, on the other hand, occurred in differring contexts regarding the understanding of cometary activity. Furthermore, the level of activity of the two comets and their nuclear rotational state differed considerably. Finally, the regions of the coma sampled in-situ, and the observational capabilities of the spacecraft instruments differed significantly. Despite these differences, we show that the physical modelling approach needed to interpret the coma observations and to infer from them nuclear properties are not qualitatively different. On the other hand, the very high resolution mapping of the nucleus of 67P, and its non-stellar nucleus shape, create a great challenge for the numerical codes. In addition, we suggest that the results from the physical modeling of the 67P coma will depend upon the answers given to two rarely raised questions: 1./ what, precisely (i.e., with e.g. spatial and temporal resolutions given) are the scientific goals of this modelling, as far are the coma itself or the nucleus are considered? 2./ under which conditions are these goals achievable? We try to answer these questions in a very preliminary and provisory manner.

****

Investigation into the Disparate Origin of CO2 and H2O Outgassing for Comet 67/P

Uwe Fink et al.

University of Arizona (United States)

We present an investigation of the emission intensity of CO2 and H2O in the coma of 67P/ Churyumov-Gerasimenko obtained by the VIRTIS-M imaging spectrometer on the Rosetta mission. We analyze 4 data cubes from Feb28, 2015 and 7 data cubes from April 27. For both data sets the spacecraft was at a sufficiently large distance from the comet to allow images of the whole comet and the surrounding coma.

We find that unlike water which is quite well behaved and outgasses rather uniformly from the illuminated portions of the comet, CO2 outgasses only in specific regions or spots. Furthermore for the data on April 27 the CO2 evolves almost exclusively from the southern hemisphere, a region of the comet that has not received solar illumination since the comet's last perihelion passage. Because CO2 and H2O have such disparate origins, deriving mixing ratios from local column density measurements cannot provide a meaningful measurement of the CO2/H2O ratio in the coma of the comet. We obtain total production rates of H2O and CO2 by integrating the band intensity in an annulus surrounding the nucleus and obtain pro-forma CO2/H2O mixing ratios of ~7.5% and ~3% for Feb28 and April 27 respectively. Because of the highly variable nature of the CO2 evolution we do not believe that these numbers are diagnostic of the comets bulk CO2/H2O composition. We believe that our investigation provides an explanation for the large observed variations reported in the literature for the CO2/H2O production rate ratios. Our measurements indicate that this ratio depends on the comet's geometry, illumination and past orbital history. Our annulus measurement for the total water production for Feb.28 at 2.21AU from the sun is 1.4x1026 molecules /s while for April 25 at 1.76 Au it is about a factor of 2.5 higher. We find that about 80% of the H2O resides in the illuminated portion of our annulus and about 20% of the production diffuses to the night side. We also make an attempt to obtain the fraction of the H2O production coming from the highly active neck of the comet versus the rest of the illuminated surface from the pole-on view of Feb.28 and find that about 60% of the H2O derives from the neck. A rough estimate of the surface outgassing for April 27 yields about 3x1019 molecules/s m2. Spatial radial profiles of H2O on April 27 extending from 1.78 to 6.47 km from the nucleus center on the illuminated side of the comet show that the water and continuum follow the predictions of the DSMC model quite well, with the gas accelerating as it expands into the coma. Our dayside radial profile allows us to make an empirical determination of the expansion velocity of water. On the night side the spatial profile of water follows 1/ρ. The CO2 profiles do not exhibit any acceleration into the coma but are closely matched by a 1/ρ profile.

****

How Theory is being Shaped by In-situ Cometary Observations

Wing-Huen Ip et al.

Institute of Astronomy, National Central University (Taiwan)

Understanding of the grand design of the cometary complex and the long term interaction (i.e., space weathering effect) with the interplanetary and interstellar matters since solar system formation depend critically on in-situ measurements by spacecraft. We will describe how the pre-Giotto model of the cometary ionosphere has been modified to explain the diamagnetic cavity detected at comet Halley and the complex behavior now revealed by the Rosetta measurements. If combined with the ROSINA and the OSIRIS observations, an interesting scenario concerning the corpuscular radiation of the planetesimals in the primitive solar system might emerge.

****

Our Closest Encounter with a Dynamically New Oort Cloud Comet: the Activity and Evolution of Comet Siding Spring.

Dennis Bodewits et al.

U. Maryland in College Park (United States)

Dynamically new comets enter the inner solar system for the first time since they were ejected to the Oort cloud 4.6 billion years ago. Heating of cometary nuclei alters their physical properties as any putative irradiation mantle formed in the Oort cloud is removed and ices near the surface sublime. By comparing the activity behavior of dynamically new comets to more evolved comets it may be possible to disentangle evolutionary effects from primordial signatures. Comet C/2013 A1 (Siding Spring) is a dynamically new comet that passed within 140,000 km of Mars on Oct 19, 2014. The close encounter made the comet the target of a world-wide campaign including many ground based and space-borne facilities, and allowed for the first time ever to directly image the nucleus of a dynamically new comet. In our contribution, we will present a review on what was learned from Siding Spring's apparition, and connect the orbital trends of its activity levels with our current knowledge of its nucleus.

****

The Nature and Frequency of the Gas Outbursts in comet 67P/Churyumov-Gerasimenko Observed by the Alice Far-ultraviolet Spectrograph on Rosetta

Paul D. Feldman et al.

Johns Hopkins University (United States)

Alice is a far-ultraviolet imaging spectrograph onboard Rosetta that, amongst multiple objectives, is designed to observe emissions from various atomic and molecular species from within the coma of comet 67P/Churyumov-Gerasimenko. The initial observations, made following orbit insertion in August 2014, showed emissions of atomic hydrogen and oxygen spatially localized close to the nucleus and attributed to photoelectron impact dissociation of H2O vapor. Weaker emissions from atomic carbon were subsequently detected and also attributed to electron impact dissociation, of CO2, the relative H I and C I line intensities reflecting the variation of CO2 to H2O column abundance along the line-of-sight through the coma (Feldman et al., A&A 583, A8, 2015). Beginning at about the time of the equinox in mid-May 2015, principally in June and July, Alice observed a number of outbursts above the sunward limb characterized by sudden increases in the atomic emissions, particularly the semi-forbidden OI λ1356 multiplet, over a period of 10-30 minutes, without a corresponding enhancement in long wavelength solar reflected light characteristic of dust production. The large increase in the brightness ratio OI λ1356/OI λ1304 suggests CO2 or O2, or both, as sources of the additional gas. The variation in the brightness ratio OI λ1356/CI λ1657 also indicates that it cannot be CO2 alone, nor can the effects be due to an increase in photoelectron flux. These outbursts do not correlate with any of the visible images of outbursts taken with either OSIRIS or the navigation camera. Following equinox the nature of the Alice spectrum changed considerably. CO Fourth Positive band emission was observed continuously, asymmetrically about the nucleus, much brighter towards the Sun, and varying with pointing but otherwise fairly constant in time. However, CO does not appear to be driving any of the observed outbursts. The Alice team acknowledges continuing support from NASA's Jet Propulsion Laboratory through contract 1336850 to the Southwest Research Institute.

****

Comet 67P Inner Coma Structure and Evolution with Rosetta/MIRO Observations and Models

Seungwon Lee et al.

Jet Propulsion Laboratory/California Institute of Technology (United States)

The Microwave Instrument on the Rosetta Orbiter (MIRO), operating at frequencies near 190 GHz and 562 GHz, has been observing Comet 67P since May 2014. Water was first detected in the coma in May 2014. Thermal emission from the nucleus was detected several months later. As Comet 67P approached perihelion in its orbit around the Sun in August 2015, MIRO observed the increase in temperature of the nucleus and the development of a complex, and rich coma structure. The coma structure evolves with a heliocentric-distance dependent solar illumination condition and with a seasonal change from the northern summer to the southern summer around the equinox in May 2015. In order to study nucleus-coma interactions and coma structure and evolution, MIRO has used scan patterns, which cover the nucleus, limb, and inner coma region in detail. We will present the MIRO spectral line measurements from October 2014 to December 2015. We have analyzed the line measurements with a non local-thermal-equilibrium molecular radiative transfer model and an optimal estimation method in order to retrieve nucleus and coma parameters such as outgassing rate, column density, expansion velocity, and gas kinetic temperature. We have modeled the inner coma structure with hydrodynamics models and collision-free models and compared the model results with the observed structure in order to infer the outgassing source distribution on the nucleus. Along with the line analysis retrieval and the coma model results, we will discuss the implication of the results on nucleus-coma interactions, coma structure, outgassing source distribution, and their temporal evolutions.

****

Evolution of the Surface Activity Distribution and the Resulting Coma of Comet 67P/Churyumov-Gerasimenko Pre- and Post-Equinox Observed by ROSINA and VIRTIS

Nicolas Fougere et al.

University of Michigan (United States)

The Rosetta spacecraft has been orbiting Comet 67P/Churyumov-Gerasimenko (67P) for an extended period of time spanning a large range of heliocentric distances. As the comet continues its journey around the Sun, the illumination pattern of the nucleus critically changes from a pre-equinox geometry where some parts of the southern hemisphere are constantly in shadows, to a configuration post-equinox where the southern latitudes are directly under sunlight. The surface activity distribution is directly impacted by these changes in solar energy inputs received by the different regions of the nucleus. We describe the surface activity distribution of H2O, CO2, and CO using a spherical harmonic expansion with constants determined by a least squares method constrained by ROSINA-DFMS data both pre- and post-equinox. These surface activity distributions are coupled with the local illumination to describe the inner boundary conditions of a 3D Direct Simulation Monte-Carlo (DSMC) method to model the coma of 67P. Then, we use the simulation outputs to compare the coma model with ROSINA and VIRTIS measurements. The model presents a good agreement with the data from these instruments showing our understanding of the physics of the coma of comet 67P.

****

Two-Point Observations of Low-frequency Waves by ROMAP and RPC-MAG during the FSS

Philip Heinisch et al.

TU Braunschweig (Germany)

During PHILAE's First Science Sequence (FSS) the onboard ROMAP magnetometer and the RPC-MAG magnetometer of the orbiter were operating simultaneously for about 14h. These measurements provided the unique possibility to analyze the spatial and temporal evolution of waves in the magnetic field of the comet boundary region. An initial analysis revealed, that neither the amplitude nor the direction of these waves depend on the day-night cycle at the landing site, but rather on the outgassing of the nucleus. Based on a minimum-variance analysis two different types of waves could be identified. These mostly compressible waves have a propagation direction from the comet tail to the front with a velocity between 2km/s and 10km/s.

****

Modeling Cometary Activity

Tamas Gombosi et al.

University of Michigan (United States)

Cometary activity is driven by the sublimation of frozen volatiles. This talk will briefly review the evolution of models from the early days of comet research through the improvements coming from the activities associated with the Halley Armada to the giant leap forward due to the wealth of data provided by the Rosetta mission. Particular attention will be devoted to sublimation models, inner coma dusty gas dynamics and the interaction of the coma with the solar wind.

****

Advances in Combining Cometary Plasma and Dust Science

Xu Wang et al.

University of Colorado at Boulder (United States)

When comets are far from the Sun, outgassing from the cometary bodies is less active. In this scenario, the surfaces of comets will be directly exposed to solar wind plasma and ultraviolet (UV) radiation. Dust particles on these surfaces can become charged, and may be consequently released due to electrostatic forces. Recently, the COSIMA instrument onboard Rosetta spacecraft has collected dust particles coming off Comet 67P /Churyumov–Gerasimenko when the comet's activity was relatively low. Electrostatic mechanism may play a role in dust release from the comet surface in addition to the outgassing process. Electrostatic dust transport has been a long-standing problem that is thought to be related to many observed phenomena on the surfaces of other airless bodies, including the lunar horizon glow, the dust ponds on asteroid Eros, and the spokes in Saturn's rings. Previous laboratory experiments have demonstrated that dust indeed was released from surfaces exposed to plasma. However, the exact electrostatic release mechanisms remained a mystery. Current charging models, including the "shared charge model" and the charge fluctuation theory, cannot explain the results from either laboratory experiments or in-situ observations. We present new laboratory dust experiments with a new "patched charge model". In addition to the observations of dust transport and lofting in plasma conditions, dust was moved and lofted in UV illumination for the first time, providing a direct laboratory evidence for dust release from airless bodies, including distant comets from the Sun. Based on the experimental results, we proposed the "patched charge model" that has two requirements: photo- or secondary electrons and the formation of a micro-cavity in-between neighboring dust particles. Photo- or secondary electrons emitted from dust particles can be absorbed inside the micro-cavity and collected on the surface patches of neighboring dust particles. The calculations showed that this negative charge is much larger than the charge on the surface patches exposed to plasma or UV illumination. The repulsive (Coulomb) forces between these charged dust particles were a dominant force to release them from the surface, rather than the previously considered sheath electric field force. The cohesive force, surface morphology, and shape of dust particles are all the factors to determine the dust charging and release process. The application of our new "patched charge model" to the Rosetta observations will be discussed.

****

Dust and Spacecraft Charging Effects

Mihaly Horanyi et al.

University of Colorado (United States)

Objects exposed to solar wind plasma and UV radiation charge to a typical electrostatic surface potential on the order of +5V with respect to 0 at infinity. In the vicinity of outgassing cometary nucleus near the Sun, the produced neutrals become ionized by UV radiation and become an additional source of plasma. The increased plasma density might be sufficiently large to change the sign of the spacecraft surface potential to negative values. These effects could complicate to analysis and interpretation of plasma and dust measurements, especially if the neutral gas production becomes highly variable, due to jets and/or outbursts of gas from the nucleus, for example. This talk will describe the charging currents, the characteristics of the plasma sheath surrounding a spacecraft, and its consequences. Similar approach is taken to describe the charging of small dust particles. Their charging time, contrary to a spacecraft, can be very long as it is inversely proportional to their size. Hence, depending on the plasma environment and its characteristic variability, small and large particles can intermittently have opposite signs of their charge. In that case both rapid coagulation and disruption can take place, efficiently altering the initial size distribution of the particles. These effects are examined as functions of both the heliocentric distance, that sets the production rate of the neutrals and their lifetime, as well as the distance from the nucleus itself. The possible changes of the expected collection efficiency and sensitivity of in situ dust measurements will be also described.

****

Modeling 67P/CG's Dust Environment

Maximilian Sommer et al.

University of Stuttgart, Institute of Space Systems (Germany)

Comet 67P/CG has a bilobate nucleus of 10^13 kg mass and density of 533 kg/m3 (Paetzold et al., 2015). Images of the nucleus of 67P/CG show highly irregular dust emission. After release from the cometary surface, dust is accelerated by the expanding gas flow. In an initial background model we assume that the gas flow is insulation driven and we calculate the forces on micron to centimeter sized dust grains in the vicinity of the nucleus. The dust trajectories are carried forward to interplanetary space by taking into account solar gravity and radiation pressure. The resulting dust densities are compared with images from Rosetta and from the ground.

****

Ground Based Support of the Rosetta mission

Colin Snodgrass et al.

The Open University (United Kingdom)

The ground-based observation campaign that supports the Rosetta mission provides large scale context by studying the comet on thousand to million km scales. Nearly all major observatories world-wide are participating at some level, with over a hundred nights of observing time dedicated to the campaign. Regular monitoring of the comet follows its evolution through the start of activity in 2014, perihelion passage in 2015, and will continue until the end of the visibility window just before end of mission in 2016. Results from a number of individual groups and facilities are presented elsewhere in this meeting. I will present an overview of the campaign, the evolution of various 'total activity' metrics throughout the mission, and a selection of images showing the changing morphology of the large-scale comet.

****

The Development of Cometary Landscapes

Nicolas Thomas

University of Bern (Switzerland)

The Giotto HMC observations of comet 1P/Halley gave hints of nucleus surface structural diversity. Imaging from Rosetta has taken this a huge step forward by showing that the surface morphology of comet 67P/Churyumov-Gerasimenko is diverse at all scales. A comparison of, for example, Ash, Anubis, and Khepry illustrates significant regional (km-scale) differences in surface structure. Local morphological differences in complex regions such as Imhotep and Seth and the evidence of chemically inhomogeneous outgassing point to further diversity on intermediate (decametre to hectometre) scales while the highest resolution data show significant structure at the metre scale. Perhaps one of the most fundamental questions is whether this diversity is the result of original inhomogeneity or the consequence of evolution. The answer to this question will have significant implications for current solar system formation models. Observations of 67P can be selected to support both hypotheses, particularly because surface processes are more complex than were generally considered prior to Rosetta. The effects of multi-scale variable topography (including collapse), surface dust transport (with its multiple implications), self-shadowing and self-heating, fracturing, and localized intense mass loss form a web of possibilities to explain surface structural and chemical heterogeneity. This is compounded by a remaining lack of understanding of the nature of "activity" including the mechanism for non-volatile mass loss. Hence, the key question - Can the observations be reconciled with homogeneity or are there tests that allow us to state that the nucleus formed as a heterogeneous object? - is by no means trivial. In this presentation, we will look at the diversity as revealed by, principally, OSIRIS, and discuss some of the mechanisms involved (including reviewing some prescient past work). The consequences for the "homogeneity debate" will be discussed.

****

Relevance of KOSI Experiments for Rosetta

Eberhard Grün

IDS (Germany)

A total of 11 comet simulation experiments KOSI were conducted from 1987 to 1993 at the large space simulation chamber of the DLR Institute for Space Simulation in Cologne. The objective of the KOSI experiments was to study in detail processes which occur near the surface of ice-dust mixtures under irradiation by light. The processes include heat transport into the sample, chemical fractionation of sample material, and gas and dust emission. Various porous ices (H2O und CO2), minerals and carbonaceous materials were irradiated with light of up to 1.4 solar constants. Significant results were the characterization of the energy balance, the modification of mechanical properties, the fractionation of the porous sample, release and emission of gas, ice, and dust particles. Experimental studies influenced the development of some Philae instruments. Theoretical models describing the processes during the simulation experiments helped with the development of comet models. The relevance of KOSI results for Rosetta findings is reviewed.

****

Fractures on Comets: New Insights from Rosetta

Mohamed Ramy El-Maarry et al.

Physikalisches Institut (Switzerland)

The ability of the Rosetta spacecraft to orbit around comet 67P at very close distances coupled with the mission's long duration has provided unprecedented views of the morphology of cometary nuclei and offers remarkable new insights into their evolution with time. Fractures were never observed on comets prior to Rosetta. However, images from the OSIRIS camera have shown that fractures are wide-spread on the surface of comet 67, particularly associated with consolidated materials. Moreover, fractures have been observed in various settings and topologies suggesting a number of different formation mechanisms. We will give an overview of these observations as well as an update on current efforts to understand their formation and their implications to surface composition and evolution.

****

Composition and Temporal Variations of the 67P/Churyumov-Gerasimenko Nucleus Observed by the OSIRIS Instrument Onboard Rosetta

Sonia Fornasier et al.

LESIA-Obs. de Paris/Univ Paris Diderot (France)

We present the results on spectrophotometry of the 67P nucleus derived from the OSIRIS instrument from the first Rosetta bound orbits through the comet’s perihelion passage and beyond. Globally, the nucleus shows a red spectral behavior and it has spectrophotometric properties similar to those of bare cometary nuclei, of primitive D-type asteroids such us Jupiter Trojans, and of the moderately red Transneptunians. No clear absorption bands have been identified in the 250-1000 nm wavelength range, except for a potential absorption centered at 290 nm, possibly due to SO2 ice. Three groups of regions have been identified on the basis of the spectral slope, and they are distributed everywhere on the nucleus, with no evident distinction between the two lobes of the comet. The comet’s southern hemisphere shows a lack of spectrally red regions associated to the absence of wide spread smooth or dust covered terrains. Several local, bright and spectrally blue patches have been identified on the nucleus and attributed to exposed water ice on the surface. In particular we observed big (> 1500 m2) bright ice rich areas in the southern hemisphere which completely sublimated in a few weeks. We see evidence of diurnal and seasonal color variations associated with sublimation and recondensation processes of volatiles.

****

MIRO Observations of Subsurface Temperatures of the Nucleus of 67P/Churyumov-Gerasimenko

F. Peter Schloerb et al.

University of Massachusetts (United States)

Observations of the nucleus of 67P/Churyumov-Gerasimenko in the millimeter-wave continuum have been obtained by the Microwave Instrument for the Rosetta Orbiter (MIRO). Measurements have been carried out at wavelengths of 0.5 mm and 1.6 mm covering the entire surface of the nucleus over a range of heliocentric distance between 3.62 and 1.25 AU. In this analysis, the data are fit to simple models of the nucleus thermal emission in order to characterize its global behavior and make quantitative estimates of important physical parameters, including thermal inertia and the millimeter-wave absorption properties of the nucleus at the MIRO wavelengths. MIRO brightness temperatures of the irregular surface of 67P/C-G are strongly affected by the local solar illumination conditions, and there is a strong latitudinal dependence of the mean brightness temperature as a result of the seasonal orientation of the comet's rotation axis with respect to the Sun. The MIRO emission exhibits strong diurnal variations, which indicate that it arises from within the thermally varying layer in the upper centimeters of the surface.

The data over most of the nucleus are quantitatively consistent with very low thermal inertia values, between 10-30 J K^{-1} m^{-2} $s^{-1/2}$. The 0.5 mm emission arises from 1 cm beneath the surface and the 1.6 mm emission from a depth of 4 cm. However, even though a single set of thermal parameters does a good job of describing the millimeter-wave emission over much of the nucleus, there are anomalous millimeter-wave features which correlate well with topographic features on the nucleus. These anomalous features may indicate regions with different thermal properties, or they may indicate that a more sophisticated modeling treatment of the surface insolation, including effects of shadowing or self heating by infrared radiation from other parts of the nucleus, is required in order to match the observations. The MIRO brightness temperatures are also affected by the sublimation of ice at or beneath the surface and provide a valuable constraint on distribution of the water production from the nucleus.

****

Dirty Snowball – Icy Dirtball – Rosetta

Horst Uwe Keller et al.

Universität Braunschweig (Germany)

A keyword has been sufficient to describe early cometary nucleus models and observations by flyby missions. This has dramatically changed during the Rosetta rendezvous with comet 67P/Churyumov-Gerasimenko. The topography and morphology of 67P are surprisingly diverse in various parts reminiscent of surface forms observed at earlier flybys on different comets. The northern hemisphere is rough on a large scale covered with many steep pits and alcoves seen similarly on the nucleus of comet Wild 2. The equatorial and southern landforms show consolidated rough terrain and smooth plains probably covered by loose material. Appearances that on earth would be called mountains and deserts. These very diverse erosional forms have been created by cometary activity. This diversity seems to defy all (simple) models describing the loss of dusty material due to sublimating ice(s). How are the volatiles (ices) and the refractory material organized inside the nucleus to achieve the observed low density that requires high porosity? What do we know about the physical and chemical heterogeneity of the nucleus? Its bilobate shape and the strong seasonal effects due to the obliquity of its rotation axis cover up any primordial inhomogeneity of 67P.

****

Modeling of the Evolution of Cometary Surface and Subsurface

Aurelie Guilbert-Lepoutre et al.

CNRS - UTINAM (France)

Modeling the evolution of comet nuclei is aimed at providing constraints on physical processes and internal properties inaccessible to observations, so to perform as detailed a study as possible of what may be the most best preserved material in the solar system. This field made a tremendous step forward after the detailed observations of comet 1P/Halley by Giotto, and the KOSI experiments performed around the same time. However, questions as to whether and to what extent comets may be pristine, and how to decipher the clues they hold on the formation of the solar system are still open. Increasingly sophisticated models of the evolution of comet nuclei have allowed to build an elaborate picture of what these objects may be. With time, they have been able to reproduce the activity pattern of most comets, which is quite remarkable considering the complexity of mechanisms involved, the uncertainties on thermo-physical parameters, and the few direct evidence we gathered on the nature of cometary material. They highlighted effects we may expect from cometary activity, such as the layering of the internal composition, the non-even erosion and dust mantle formation, modifications of the nucleus size and shape for example. In this context, the detailed study of 67P/Churyumov-Gerasimenko by Rosetta has revealed that the processes shaping the surface and subsurface of comets may be even more complex than we had previously envisioned. In this presentation, we review the processes that we think may be responsible for the thermo-physical evolution of comet nuclei and their subsurface in particular, their expected outcome, and what the features observed by Rosetta may tell us on processes which have affected and are still affecting 67P.

****

Evolution of the UV Surface Properties of Comet 67P/C-G as Observed with Rosetta Alice

Lori M. Feaga et al.

University of Maryland (United States)

Alice, NASA's light weight and low power far-ultraviolet (FUV) imaging spectrograph onboard ESA's comet rendezvous mission Rosetta (Stern et al. 2007), has continually monitored the surface of comet 67P/Churyumov-Gerasimenko (C-G) from 3.7 AU through perihelion at 1.24 AU and back out to its current heliocentric distance. With a spectral range from 700-2050 Å, Alice was designed foremost to study C-G's gaseous coma, but a secondary objective has been to observe the cometary nucleus to better establish its general spectral properties and albedo, search for UV absorption features due to the presence of refractories and ices, and determine the magnitude of the dramatic drop in reflectance from the NUV down to the FUV. Upon arrival during summer in the comet's northern hemisphere in 2014, initial characteristics and properties of the surface were derived with Alice data, resulting in a dark, homogeneous, and blue sloped surface in the FUV with an average geometric albedo of ~5% at 1475 Å (Feaga et al. 2015). To date, Alice has acquired multiple global data sets of G-G that we will use to quantify changes in the spectral behavior over the course of the comet's orbit and change of seasons. With comet C-G having a distinct bi-lobed shape and strong seasonal effects, it is of interest to determine when and where surface changes occur as a result of surface sublimation and fresh material being unearthed. This analysis will add to the study of the extent of C-G's chemical heterogeneity and evolutionary behavior. We will highlight any spectral absorption features and variability in the spectral slope that is detected and discuss their implications in the context of contemporaneous in situ and remote sensing measurements from other Rosetta instruments, including the change in color of the nucleus recently measured by OSIRIS and water ice patches detected on the surface by VIRTIS.

****

The Presence of Clathrates and their Implications on the Composition of Comet 67P

Adrienn Luspay-Kuti et al.

Southwest Research Institute (United States)

Pre-perihelion ROSINA/DFMS measurements revealed a strongly heterogeneous coma. The concentrations of major and various minor volatile species were found to depend on the latitude and longitude of the nadir point of the spacecraft. Minor species correlated with either H2O or CO2 better, but CH4 showed a different, unexplained pattern. Using a simple thermodynamic approach, we show that the observed CH4 outgassing over the southern mid-latitudes is consistent with CH4 clathrate decomposition in the nucleus of 67P. Our results further suggest that C2H6 is also present as clathrate. We propose that the nucleus of 67P is a mixture of crystalline H2O ice, various clathrate species, and pure condensates likely formed in the protosolar nebula.

****

Understanding the Surface of Comet 67P as seen in Post-landing ROLIS Images

Stefan Schroeder et al.

DLR (Germany)

At Abydos, Philae's final landing site, the ROLIS camera imaged the surface of 67P/Churyumov-Gerasimenko from its vantage point on the instrument platform at the highest resolution ever obtained for a cometary surface (~0.5 mm per pixel). Due to the strong tilt of the lander, ROLIS peered towards the local horizon instead of straight down onto the surface. Having landed at night, the surroundings of Philae were completely dark with the coma beyond the horizon faintly illuminated. Still, ROLIS could image the surface using an illumination device with LEDs in four different colors: red, green, blue, and near-IR. Due to the highly non-nominal landing conditions the interpretation of the images is challenging. A 3D reconstruction of the scene demonstrates that the surface was meters away, instead of the few decimeters expected. As a consequence, the illumination was very weak and stray light off parts of the lander played a significant role. The surface has a unique morphology that defies easy interpretation. Color variations appear to be minor and individual grains are not distinguished. However, there are significant brightness variations in a bi-modal regime. To uncover the basic photometric principles that govern the appearance of the comet surface we recently imaged various artificial surfaces with a ROLIS camera spare. The experimental results and the similarities with structures seen in the lower resolution CIVA images hint at the physical properties of the surface, and we speculate on a possible relation with activity at the landing site.

****

Advances in Laboratory Studies of Cometary Ice Analogues

Diana Laufer et al.

Tel Aviv University (Israel)

Diana Laufer, Akiva Bar-Nun and Adi Ninio Greenberg Department of Geosciences, Tel Aviv University, Tel Aviv, Israel   Comets are pristine objects and they have preserved the original material of the solar nebula which formed the Solar System. Over the past 30 years our knowledge and understanding of cometary nuclei expended due to in-situ observations and measurements. The ongoing Rosetta mission around the comet 67P/Churyumov-Gerasimenko continues to surprise us with new discoveries such as the detection of Ar, N2 and O2, for the first time and a high D/H ratio, which changes our understanding on water and volatiles delivery to the early Earth and other planets. Our experimental study on comet analogues at low temperature and pressure can explain and predict the observations. We will presents the new findings as compared to ROSSETA's observations. Our experimental studies on gas-laden amorphous ice provided data on cometary ices conditions of formation, gas content and nucleus physical properties such as density, mechanical strength and thermal conductivity as well as the comet activity due to its thermal evolution during the solar heating process in the inner Solar System.   Acknowledgments This research was supported by the Israeli Space Agency. We thank the members of Cometary Lab at Tel Aviv University Dr. Gila Notesco, Dr. Igal Pat-El and Dr. Roni Jacovi.

****

In-situ Properties of Comet 67P/Churyumov-Gerasimenko measured with SESAME

Klaus Seidensticker et al.

DLR (Germany)

The SESAME experiment (Surface Electric Sounding and Acoustic Monitoring Experiment) is part of the lander Philae of the ESA Rosetta mission that landed on the nucleus of comet 67P/Churyumov-Gerasimenko on 12 November 2014. SESAME is a suite of the three instruments CASSE, DIM and PP that use different measurement techniques in order to determine physical properties of the surface and the activity of 67P. SESAME was operated successfully during the descent until the end of the First Science Sequence (FSS). The Comet Acoustic Surface Sounding Experiment (CASSE) can record and generate acoustic vibrations with two kinds of sensors in the range from 50 Hz to 10 kHz. It was operated during the descent and measured completely Philae's first touchdown at Agilkia at 15:34:04 UTC with three triaxial accelerometers mounted in Philae's feet. These data, which are influenced by the properties of Philae's landing gear and by the complex surface layer at Agilkia with a regolith ranging from dust to boulders, describe the sequence of Philae's surface contacts. At the final landing site Abydos, CASSE recorded many signals generated by the hammering of the Philae experiment MUPUS-Pen, in order to determine sound velocities of the cometary surface layer and related elastic properties. Finally, CASSE conducted sounding measurements from foot to foot. The Dust Impact Monitor (DIM) used three piezoelectric sensor plates orthogonally mounted on a cube to detect impacts of sub-millimeter and millimeter-sized ice and dust particles that are emitted from the cometary surface. DIM measurements during the 7 h descent to the cometary surface were hampered by the fact that none of the sensor plates pointed to the cometary surface. Nevertheless, one millimeter-sized particle was detected at an altitude of 2.4 km. Comparison with laboratory data showed that the particle properties are compatible with a porous grain having a bulk density of approximately 250 kg m**-3. At Abydos, DIM recorded no particle impacts, which may be due either to low cometary activity at this place or shading by obstacles close to Philae or both. The SESAME Permittivity Probe (PP) is a combined quadrupole permittivity detector and plasma wave sensor. The unplanned landing in Abydos required many modifications to the FSS operation plan. Thus, PP could study the surface layer with only a three-electrode configuration reducing the resolution significantly. Nevertheless, PP's data constrain the relative permittivity of the surface material to about 2.5 at a surface temperature of about -160 °C for the position of Philae's foot –Y, which was in permanent shadow. This result suggests that the first meters of the surface of Abydos are more compact and/or richer in dust than its interior as probed by the orbiter/lander experiment CONSERT. Additionally, PP detected weak plasma wave activities at Abydos two hours after local sunset. By combining data from different FSS operation periods, we were able to determine temperature profiles of the CASSE sensors in each Philae foot over 9.2 h of a 12.4 h comet day. With proper modeling, these data could give the surface temperature variation at Abydos during FSS.

****

The Interpretation of Decaying Mass Spectra from COSAC and Ptolemy on the Surface of 67/P Churyumov Gerasimenko

Fred Goesmann et al.

Max Planck Institute for Solar System Research (Germany)

The COSAC instrument on Philae was operational during the first science sequence after landing on the nucleus of 67/P in November 2014. While it was unfortunately not possible to retrieve a soil sample, seven mass spectra of the gas that entered the mass spectrometer were acquired. The first mass spectrum contained the strongest signals of organic material and the results were published in SCIENCE, 31 July 2015, Vol. 349, No. 6247, DOI: 10.1126/science.aab0689. During the following six mass spectra the signals decreased and almost vanished completely. A similar set of mass spectra was acquired by the Ptolemy instrument. The decay rates of the peaks belonging to different masses were not identical over time. The ratio of the exponents obtained in an exponential fit for the count rate decay is factor of at least five between slowest and fastest decaying species. There are at least three categories. One set decays similar to the total ion count in the mass spectra, one set decays faster, and another set decays at a slower rate. Here we describe the chemical interpretation of the evolving mass spectra.

****

New Perspectives on the Surface Chemistry of 67P from Ptolemy Data

Ian Wright et al.

Open University (United Kingdom)

We have previously published results from the Ptolemy investigations of the surface of 67P. These were, respectively, from the “scratch ‘n’ sniff” obtained during the first bounce at Agilkia, and the long-term sniffing measurements made at Abydos [1, 2]. Here we will discuss results obtained by one of the final experiments carried out by Philae as the primary battery power declined to levels where the lander was ultimately put to sleep. During this “last gasp” we analysed those materials that were contained in a specialised, adsorbent-filled oven included on the carousel of SD2 (see, for instance, [3]). The CASE oven (Cometary Atmosphere Sampling Experiment) had been exposed to the cometary environment for a total of about 4 weeks (i.e. the interval since it had been degassed for the last time prior to separation of Philae from Rosetta). So, what was analysed would have been a combination of volatiles trapped on the adsorbate, along with any particulates that had been serendipitously deposited into the oven during the somewhat bumpy landing. At first glance there are some remarkable similarities with results from the first bounce, as well as some remarkable differences. It would seem that an understanding of the results in toto is likely to have the potential to refine our understanding of what was sampled at the surface of the comet.
[1] I.P.Wright, S.Sheridan, S.J.Barber, G.H.Morgan, D.J.Andrews and A.D.Morse (2015). CHO-bearing organic compounds at the surface of 67P/Churyumov-Gerasimenko revealed by Ptolemy. Science, 349 (6247). DOI: 10.1126/science.aab0673 [2] A.Morse, O.Mousis, S.Sheridan, G.Morgan, D.Andrews, S.Barber and I.Wright (2015). Low CO/CO2 ratios of comet 67P measured at the Abydos landing site by the Ptolemy mass spectrometer. Astron. Astrophys., 583, A42. DOI: 10.1051/0004-6361/201526624 [3] A.Ercoli-Finzi, F.Bernalli-Zazzaera, C.Dainese, P.G.Malnani, E.Re, P.Bologna, S.Espinasse and A.Olivier. SD2 - How to sample a comet. Space Science Reviews (2007) 128: 281–299 DOI: 10.1007/s11214-006-9134-6

****

Refractory and Semi-volatile Organics at the Surface of 67P/Churyumov-Gerasimenko

Eric Quirico et al.

IPAG (France)

The VIRTIS instrument onboard the Rosetta spacecraft has provided new insights into the nature of the surface of comet 67P/Churyumov-Gerasimenko: (1) The low albedo of comet 67P/CG is accounted for by a dark refractory polyaromatic carbonaceous component mixed up with opaque minerals. (2) A semi-volatile organic component, consisting of a complex mix of low weight molecular species not volatilized at T~220 K, is likely a major carrier of a broad band centered at 3.2 µm. (3) Photolytic/thermal residues, produced in the laboratory from interstellar ice analogs, appear as potential interesting spectral analogs. (4) No hydrated minerals were identified and our data support the lack of generic links with the CI, CR and CM primitive chondrites. (5) The comparison between fresh and aged terrains revealed no effect of solar wind irradiation on the 3.2 µm band.

****

Infrared Detection of Exposed Water Ice on 67P/CG Surface

Gianrico Filacchione et al.

INAF-IAPS (Italy)

Infrared detection of exposed water ice on 67P/CG surface G. Filacchione, M. C. De Sanctis, F. Capaccioni, A. Raponi, A. Barucci, S. Fornasier, M. Ciarniello, F. Tosi, S. Erard, D. Bockelee-Morvan, C. Leyrat, A. Migliorini, E. Palomba, A. Longobardo, M. T. Capria, G. Arnold, E. Quirico, D. Kappel, J. Crovisier, M. Blecka After the identification of two water ice patches in the Imhotep region by means of VIRTIS-M (Filacchione et al., Nature, in press), we report about the detection of further deposits observed in the Khepry and Anhur regions. These water ice-rich areas have been identified by using the 2.0 µm absorption feature as a proxy. Differently from the red slope and low albedo characterizing the nucleus surface at visible wavelengths, a neutral slope and higher albedo is observed on these patches. We report about the spectral properties and temporal stability of these features during the period between August 2014 to early May 2015 when the 67P/CG heliocentric distance was decreasing from 3.62 to 1.71 AU.

****

Results from Radio Tracking the Rosetta Spacecraft: Gravity, Internal Structure, Nucleus Composition, Outgassing Activity and Nucleus Mass Loss during Perihelion

Matthias Hahn et al.

Rheinisches Institut für Umweltforschung an der Universität zu Köln (Germany)

The nucleus mass and its gravity field up to degree and order two was sensed by the Radio Science Experiment RSI during the first months of the Rosetta prime mission phase at 67P/Churyumov-Gerasimenko. These results helped to constrain the parameters of the internal structure of the nucleus. Conclusions on the density, porosity, homogeneity and dust-to-ice mass ratio are made by comparing measured results with theoretical models. When the comets activity started to increase with decreasing heliocentric distance, the outgassing pressure became the dominant force acting on the spacecraft. An analysis of the tracking data regarding the gas drag acting on the spacecraft shall be presented. Outgassing models used in the orbit determination show the long-term evolution of activity parameters like the total gas production rate. When the activity reached its maximum near the perihelion in August 2015, the nucleus lost a significant amount of material by releasing gas and dust. The total mass loss may be determined by a comparison of the measured nucleus mass from August 2015 and a repeated precise mass determination by RSI at the end of mission in

August/September 2016. Preliminary estimates based on the pre-perihelion activity suggest that the total mass loss of the nucleus may be much larger than the statistical 3-sigma uncertainty of the nucleus mass determination.

****

Looking at Comet 67P Sub-surface in the Vicinity of Abydos

Valeri Ciarletti et al.

UVSQ(UPSay) ; UPMC (Sorbonne Univ.) ; CNRS/INSU; LATMOS-IPSL (France)

While amazing surface features of comet 67P have been observed and revealed since the beginning of the Rosetta mission by a number of cameras onboard Rosetta's main spacecraft (OSIRIS and NAVCAM) and Philae lander (CIVA and ROLIS), information below the surface has also been collected by the CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) experiment that can help constrain the nucleus formation and evolution. CONSERT is a bistatic radar with receivers and transmitters on-board both Rosetta's main spacecraft and Philae lander. It has been successfully operating during the descent and First Science Sequence (FSS) right after Philae's final landing at Abydos. The nucleus in the vicinity of Abydos has been actually sounded by CONSERT's electromagnetic waves at 90 MHz with a spatial resolution around 10m (over lengths ranging from approximately 200 to 800 m and maximum depths of about one hundred of meters). The data collected provide information about the permittivity values inside the sounded volume and allows us to retrieve some constraints about the internal structures of the nucleus inside the sounded volume. In this paper, we specifically focus on local variations in the nucleus subsurface permittivity simulated over spatial scales ranging from tens to hundreds of meters. A number of propagation simulations corresponding to the CONSERT operations have been performed for a variety of subsurface permittivity models. The effect of local vertical and horizontal variations of the permittivity values around the landing site as well as comparison with CONSERT's experimental data collected in the same configurations will be presented and discussed. Possible interpretations of the results will be presented as well as potential consequences for the nucleus structure in connection with observations made available by other instruments.

****

Mystery of Cometary Circular Polarization: New Clues from Studying Plasma Environment in Comet 67P/Churyumov-Gerasimenko

Ludmilla Kolokolova et al.

University of Maryland (United States)

Light is called circularly polarized if the plane of electromagnetic wave rotates with the frequency of the light. Circular polarization is called positive if the plane rotates clockwise from the point of view of the observer or negative if the rotation is counterclockwise. Circular polarization can result from scattering of light on media characterized by some mirror asymmetry (van de Hulst, 1957). Circular polarization produced by scattering of sunlight on cometary dust was first time reliably observed in comet 1P/Halley (Dollfus and Suchail, 1987). It was highly variable over the coma and showed temporal variations; the values ranged from -0.25% to +0.35%. Since that time circular polarization has been observed in 11 comets. The absolute values of circular polarization varied from 0.01% to 0.8%. Circular polarization of both signs was observed, although negative circular polarization dominated. Recent observations of several comets using SCORPIO-2 focal reducer at the 6-m BTA telescope of the Special Astrophysical Observatory (Russia) allowed producing maps of circular polarization in the comet continuum filter at 684 nm and red wide-band filter. To find out the mechanism responsible for formation of circular polarization in comets, a cause of mirror asymmetry in the cometary environment should be investigated. Among the mechanisms which may provide a mirror asymmetry of cometary environment, the following considered were considered: light scattering by particles of a specific mirror-asymmetric shape (Guirado et al. 2007), multiple scattering in asymmetric coma (Guirado et al. 2010), light scattering by particles containing homochiral organic molecules (Nagdimunov et al. 2013). However, all of these approaches failed: domination of particles with shape characterized by one type of mirror asymmetry (only left- or only right-handed) was found to be unrealistic; multiple scattering in comets is insufficient to provide any measurable value of circular polarization; amount of homochiral organics is also estimated to be too small to affect polarization of the light scattered by the cometary dust. One more opportunity to form mirror asymmetry in cometary coma is to align cometary dust particles in some direction. The most plausible reason of such an alignment could be the solar magnetic field. However, in-situ data for comet Halley, indicated that the solar magnetic field could not penetrate deep into the coma, limited by the diamagnetic cavity, and, thus, could not be responsible for the circular polarization observed closer than ~1000 km from the nucleus. Advanced theoretical studies of interaction of the solar magnetic field with cometary ions led to reconsidering the diamagnetic cavity boundary - it is defined by the cometary ionopause, at which a balance is achieved between the magnetic pressure in the magnetic pile up region and the ion-neutral friction force. The nucleocentric distance where this balance is achieved depends on the comet characteristics, increasing with the increase of the gas production rate, and local solar wind conditions, approximatively given by the comet location, specifically, its heliocentric distance. We calculated the size of diamagnetic cavity for the conditions of our polarimetric observations. We found that it could be as small as dozens (comets 73P, 8P, 290P) or hundreds (comets Q4 NEAT, K1 PanSTARRS, Tago-Sato-Kosaka) kilometers. Thus, non-zero circular polarization close to the nucleus can be explained by the interaction of the dust particles with the solar magnetic field. Study of the plasma environment of comet 67P/ Churyumov-Gersimenko showed that the shape of the diamagnetic cavity is quite complex, defined by instability and inhomogeneity of the comet activity as well as the Kelvin-Helmholtz instability. If the cometary circular polarization is produced by the alignment of dust particles in the solar magnetic field, then the distribution of the circular polarization in the coma can be very complex. Polarimetric observations with a high spatial resolution, which allow detailed mapping of the cometary circular polarization, may provide not only additional information about cometary dust, but can be useful to study cometary plasma environment.

References

Dollfus, A., and Suchail, J.-L. (1987) Polarimetry of grains in the coma of P/Halley I. Observations, Astron. Astrophys., 187, 669-688.

Guirado, D., Moreno, F., and Muñoz, O. (2010). Circular polarization of light scattered by a non-central region of a comet. Electromagnetic and Light Scattering XII, Proceedings of the 12th conference held in Helsinki, June 28 - July 2, 2010. Helsinki: Helsinki University Print, 66-69.

Guirado, D., Hovenier, J. W., and Moreno, F. (2007). Circular polarization of light scattered by asymmetrical particles. Journal of Quantitative Spectroscopy and Radiative Transfer, 106(1), 63-73.

Koenders, C., Glassmeier, K. H., Richter, I., (2015). Dynamical features and spatial structures of the plasma interaction region of 67P/Churyumov–Gerasimenko and the solar wind, Plan.Sp.Sci., 105, 101-116.

Nagdimunov, L., Kolokolova, L., and Sparks, W. (2013). Polarimetric technique to study (pre) biological organics in cosmic dust and planetary aerosols. Earth, Planets and Space, 65(10), 1167-1173.

Van de Hulst, H.C. (1957) Light scattering by small particles. Dover Publications Inc., New York, 470p.

****

How Stardust may Inform Rosetta, and Vice Versa

Andrew Westphal

UC Berkeley (United States)

I will present highlights of laboratory analyses of samples of comet Wild 2, returned by the Stardust mission almost exactly a decade ago, and will summarize outstanding unsolved problems in planetary science that can be addressed by continuing analyses of Stardust samples. I will explore the ways in which laboratory analyses of cometary rocks from Wild 2 and in Chondritic Porous Interplanetary Dust Particles (CP-IDPs), and in situ observations of C-G, complement and inform each other. In particular, the need for consistency in the interpretation of all three sets of data raises new questions about the origin and history of comets and their components. Specifically, the metal content of Wild 2 and CP-IDPs, and the unambiguous presence of microchondrules and micro-CAIs in Wild 2, must be consistent with recently-reported Rosetta observations of C-G internal structure and the implications that these observations have for cometary assembly and conditions in the outer nebula.

****

Comets, what next?

Marcello Fulchignoni et al.

LESIA, Observatoire de Paris (France)

The six comets approached up to now by space missions learned us several lessons on their basic physical and chemical properties. These information together with those by the wide database obtained from ground based observations provided us with several pieces of a puzzle, which still need to be completed. Some of intriguing unknowns on a comet concern i) the nucleus internal structure: what is the ratio between refractory materials and ices? How the different types of ices are mixed together? Are they the "glue" used to build and to maintain the nucleus? ii) the composition of the so called "complex organic matter" covering most of the nucleus surface: is it a remnant of the interior degassing or it is formed because of it? what is it relationship with the species found in the coma? iii) the processes governing the evolution of a nucleus from its birth to its death: the relaxation of the upper layer of the nucleus is responsible of the lack of craters? The answer to these and more other questions can be obtained by a new mission to a comet which will perform a complete and detailed radar tomography of the nucleus, will deliver a lander which provide a complete set of measures on the bulk surface properties and, from far more significant, will collect a sample and returns it to the Earth.

****

Unexpected and Significant Findings in 67P: the IDS View

Marco Fulle et al.

INAF Trieste (Italy)

After its first year and a half of close observations, Rosetta can provide a preliminary coherent description of a Jupiter Family comet, which confirms the diversity of these objects. In particular, 67P appears composed of very pristine material, as suggested by the abundance of volatiles gases, the D/H ratio, the abundant molecular oxygen, and the gentle accretion of the two nucleus lobes. However, the observation of mineral aggregates, the high dust-to-gas ratio, and the hardness of the nucleus surface suggests recent processing in the inner Solar System. We discuss the most important and unexpected discoveries regarding the nucleus, the released gas, the ejected dust and how gas and dust leave the nucleus, the so-called cometary activity. These unexpected discoveries are relevant to not only the comet itself, but also to the unforeseen interaction between the comet and the orbiting spacecraft.

****

Posters

Laboratory Investigations on Cometary Analogues in Support of the Interpretation of Multi-instrumental Rosetta Data.

Antoine Pommerol et al.

University of Bern (Switzerland)

The Giotto flyby of comet Halley triggered ambitious experimental programs in Europe to study various aspects of its nature and activity the results of which have been instrumental in defining objectives and methods for Rosetta. In preparation for the scientific exploitation of data obtained at comet 67P, we have undertaken new experiments with diverse analogue recipes prepared from water ice, organics and minerals. Initially focused on the microstructure and spectro-photometry of the samples, our interests now extend as well to the dielectric and thermo-mechanical properties of the samples, through implementation of these techniques at our facility in Bern and collaboration with other groups in Europe. We will present some of the most interesting results obtained so far.

****

The Distribution of Geometric Albedos of Jupiter-Family Comets From SEPPCoN and Visible-Wavelength Photometry

Y. R. Fernandez et al.

University of Central Florida (United States)

We present a preliminary estimate of the distribution of geometric albedos among the Jupiter-family comet (JFC) population. This is the first time it has been possible to measure a statistically-significant number of cometary albedos. While an assumption of ~4% is common and consistent with the heretofore limited number of known albedos, the true average albedo and albedo spread have not been well constrained. By knowing a statistically-significant number of albedos, and thus the distribution of albedo values across the comet population, we can investigate overarching science questions about the evolution of cometary surfaces. Our current work makes use of and builds on the results of the Survey of Ensemble Physical Properties of Cometary Nuclei (SEPPCoN), in which we obtained new and independent estimates of the radii of 89 JFCs [1,2]. By using the thus-known radius and photometry of a bare nucleus, we can constrain its geometric albedo. We will present our preliminary albedo estimates for over 50 JFC nuclei, and we will discuss the implications of the results in the context of other cometary properties. These JFCs were all observed in R-band, and were all observed at relatively large heliocentric distances (usually >4 AU from the Sun) where the comets appeared inactive, thus minimizing coma contamination. We acknowledge the support of NASA grant NNX09AB44G, of National Science Foundation grant AST-0808004, and of the Astrophysical Research Consortium/Apache Point Observatory for this work. References: [1] Y. R. Fernandez et al., 2013, Icarus 226, 1138. [2] M. S. Kelley et al., 2013, Icarus 225, 475.

Thermophysical History of the Nucleus of the Comet 67P/CG

Michelangelo Formisano et al.

INAF-IAPS (Italy)

Comet 67P/CG has a dynamical (and consequently thermophysical) history quite complex, since it experienced several encounters with Jupiter that have significantly changed its orbital parameters, as reveled by a recent paper of Maquet. L 2015 (A&A 2015). By using a numerical thermophysical code ("Rome Model") (De Sanctis et al. 2009 Icarus 207, De Sanctis et al. 2010, AJ 140), we have tried to depict the past evolution of the comet, which have made the comet as we currently know thanks to the ROSETTA ESA mission. In particular, we study how the change in orbital parameters has influenced the internal structure and shape, that could result in stratification and inhomogeneity of the body.

****

Extended Comparative Photometric Study of Comet 67P/Churyumov-Gerasimenko as seen by VIRTIS-H and VIRTIS-M Onboard Rosetta

Batiste Rousseau et al.

LESIA - Observatoire de Paris (France)

Since 6 August 2014, VIRTIS allows us to study comet 67P/Churyumov-Gerasimenko with two different channels: VIRTIS-M and VIRTIS-H. The first one is a mapper working from 0.25 to 5.1µm and which covers a large field of view. The second one is a point spectrometer covering 1.9 to 5.0µm but with a higher spectroscopic resolution. Both have already study comet 67P/CG under many different illumination conditions and observation geometries (e.g. between 20 to 110° phase angle). It allows us to perform a photometric study and to potentially follow the change of the physical properties of the nucleus. In order to do that and to compare these results with previous study made by Ciarniello et al. we work on the dataset of VIRTIS-H and VIRTIS-M available since August 2014 to April 2015. Because of the infrared part of VIRTIS-M is off (due to cryocooler failure) since April 2015, VIRTIS-H is the only instrument to look the nucleus in the infrared range. We will then study the data covering the end of the year 2015 with this instrument. Comet 67P/CG is very dark so it is possible to hypothesize that there is no multiple scattering through particles on the surface. Secondly, we will investigate phase angle greater than 20° which permits to neglect opposition effect (OE). From these two assumptions we will use a Lommel-Seeliger model in order to describe the reflectance data. Based on Hapke reflectance theory we also add a term related to the macroscopic roughness in the model. The available data are calibrated in radiance (W/m2/sr/µm). In order to use them according to the model previously described, we convert every pixel in reflectance which allows to remove the solar distance effect. Then we compute the product $w * p(g)$ and we choose to filter data where incidence and emergence angle are greater than 60° in order to remove extreme values of their cosine. These angles are computed from the center of each pixels, based on the shape model 5 of Osiris. The number of pixels is greater than 90.000 in the case of VIRTIS-H and greater than 2.000.000 in the case of VIRTIS-M giving us in both cases a sufficient statistical sample of data. From these solid bases we will study the behavior of the single scattering albedo and the asymmetry parameter (determining the behavior of the phase function) through the wavelengh, until 3.5µm because the thermal range follows another modelling. We repeat this analysis through the time and according different areas on the nucleus (e.g. Northerm hemisphere or Southern hemisphere) in order to compare coherent dataset and to see potential evolution of the surface.

****

Thermo-physical Properties and Heat Transport Mechanisms of Comet 67P/CG from VIRTIS Data

Cedric Leyrat et al.

LESIA-Observatoire de Paris (FRANCE)

Orbital eccentricity, high spin axis inclinations, surface low albedo together with complex shapes and low thermal inertias are the main causes of the very intense thermal variations experienced on the surface and the sub-surface of many comets. Using the huge dataset of the

Visible InfraRed Thermal Imaging Spectrometer (VIRTIS) onboard the Rosetta spacecraft, we were able to measure the surface's temperatures of the comet 67P/C-G over a long period of time. The diurnal variations were monitored at different local times, allowing us to derive the thermal inertia of the terrain, providing clues of the surface's porosities and thermal properties. This study was extended to the seasonal variations. Indeed, the rotation axis of the nucleus is highly inclined, such that the Southern summer is characterized by large but brief thermal variations close to perihelion, while the Northern hemisphere is continuously illuminated by the Sun near aphelion. Combining seasonal data analysis and thermal modeling, we aim to infer how heat penetrates the sub-surface, and how ice abundance, porosity, compaction, and sublimation processes of volatiles are affected by the temporal variations of the temperatures. This helps to understand basic mechanisms of heat transport in a cometary nucleus.

****

First Landing(s) on a Comet - Lessons Learned

Jens Biele et al.

DLR (Germany)

The Philae lander, part of the Rosetta mission to investigate comet 67P/Churyumov-Gerasimenko, was delivered to the cometary surface in November 2014. Here we report the lessons learned of this endeavour - from design, building, test, in-flight operations, on-comet operational planning and landing. We give an update to the precise circumstances of the multiple landings of Philae, based on engineering data in conjunction with operational instrument data and simulations. These data also provide information on the mechanical properties of the comet surface. The lessons learned by the landings of Philae also allow an improved preparation for future in-situ or sampling missions to cometary surfaces. Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI with additional contributions from Hungary, UK, Finland, Ireland and Austria.

****

A Comparative Analysis of Opposition Effect on Comet 67P/Churyumov-Gerasimenko using Rosetta-OSIRIS Images

Nafiseh Masoumzadeh et al.

Max-Planck-Institut für Sonnensystemforschung (Germany)

We aim to explore the behavior and the physical mechanism behind the opposition effect as an important tool in optical remote sensing on the nucleus of comet 67P/Churyumov-Gerasimenko (67P). The opposition effect (OE) is defined as a sharp spike in the brightness of airless bodies when the angle between incident ray and the detector (phase angle, α) reaches to zero. The OE is characterized by two parameters coming from the photometric phase curve of the body: amplitude (also called enhancement factor, ζ) and the angular width estimated as the Half-Width at Half-Maximum, HWHM, respectively. The effect has been observed in various planetary surfaces (Belskaya & Shevchenko 2000; Rosenbush et al. 2002; Shevchenko et al. 2008; Déau et al. 2009) and planetary regolith analogs in the laboratory (Shkuratov et al. 2002; Psarev et al. 2007; Déau et al. 2013; Jost et al. 2016). We extract the global and local brightness from the surface of 67P with respect to the phase angle (phase curve) using OSIRIS images acquired in August 2014 and in February 2015. Two phase curves are combined to study the opposition surge morphology and constrain the physical structure and properties of 67P. The global phase curve is constructed from images

including the entire shape of 67P in a wide phase angle range in August 2014. The local phase curve is built from close flyby images taken in February 2015 from Imhotep-Ash regions, where the spacecraft shadow is appeared. The shape and the modeled parameters of opposition surge are further compared with other bodies in the solar system as well as existing laboratory studies. We found that the morphological parameters of opposition surge have a non-monotonic variation with wavelength. This suggests there is no coherent back scattering but only shadow hiding that forms the phase curve at small phase angles. The results from comparative analysis positions 67P as an object among dark bodies such as low-albedo asteroids, leading site of Iapetus, Martian satellites and the dark lunar feature of Mare Imbrium. The similarity between the surface phase function of 67P and carbon soot at extremely small phase angles is identified, introducing the regolith in the boundary of Imhotep-Ash regions of 67P as very dark and fluffy layer of small particles.

****

67P/CG Nucleus Layered Structure: Formation Vs Evolutionary Processes. Clues from VIRTIS Data.

Fabrizio Capaccioni et al.

IAPS - INAF (Italy)

Recent results published by the VIRTIS team (Filacchione et al, Nature, 2015) have shown that the stratigraphy observed on 67P/CG could represent the surface expression of the processes occurring in the uppermost layers of the cometary nucleus: sublimation of volatile molecules, vapour diffusion in ice-rich layers followed by recondensation, heat released by amorphous-crystalline phase transition, surface erosion with removal of dust and water ice, etc. All these processes concur to modify the structure of the nucleus leading to densification, to changes in thermal conductivity, porosity, ice to dust ratio. Laboratory measurements (Stöffler et al.,1991; Benhkoff et al, 1995) as well as models of the heat transport through the interior (Cossacki et al, 1999) indicate that the above processes can profoundly alter the thermal and mechanical behaviour over depths of several meters. The VIRTIS results will be discussed in the light of the proposed (Massironi et al, Nature, 2015) mechanism of formation of the nucleus through primordial stratified accretion in early forming planetesimals.

****

The Interior of 67P/Churyumov-Gerasimenko from Observation and Modeling

Maria Teresa Capria et al.

INAF/IAPS (Italy)

Even if Rosetta gave us un unprecedented amount of information on the comet 67P/Churyumov-Gerasimenko, the interior of comet nuclei remains largely unprobed and unknown. Fundamental questions on internal structure (does the porosity drastically change? Are there voids? rDoes it havea layered structure?), composition (is the interior mostly homogeneous, or there are strong compositional differences? Is there any amorphous ice?), remain unanswered. There are, anyway, many clues from the results of the instruments onboard Rosetta on the physical structure, composition and temperature of the interior, below the layers on which the processes shaping the comet are taking place.With the help of modeling, we review what we know and which answers could be given to the questions above.

****

Induction Signatures at 67P/CG

D. Constantinescu et al.

Institute for Space Sciences (Romania)

The Philae landing on the nucleus of Churiomov-Gerasimenko (67P/CG) opens up the opportunity to derive the electrical properties of the comet nucleus by taking advantage of simultaneous measurements done by Philae on the surface and by Rosetta away from the nucleus. This allows the separation of the induced part of the electromagnetic field, which carries information about the electrical conductivity distribution inside the cometary nucleus. Using the transfer function and the phase difference between the magnetic field at the nucleus surface and the magnetic field measured on orbit, we give a lower bound estimate for the mean electrical conductivity of the Churiumov-Gerasimenko nucleus.

****

What CONSERT Measurements tell us about the Interior of the 67/C-G Comet ?

Wlodek Kofman et al.

Univ. Grenoble Alpes; CNRS, IPAG (France)

The structure of the nucleus is one of major unknown in the cometary science. The scientific objectives of the Comet Nucleus Sounding Experiment by Radiowave Transmission (CONSERT) aboard ESA spacecraft Rosetta are to perform an interior characterization of comet 67P/Churyumov-Gerasimenko nucleus. This is done by means of a bi-static sounding between the lander Philae launched on the comet's surface and the obiter Rosetta. During the first night after Philae landing CONSERT operated during 9 hours and have made the measurements through the small lobe (head) of the 67P/ C-G. We will describe measurements that explored the interior of the comet, discuss results and their interpretation in term of the internal structure. The analyses and interpretation have been done using the form of the received signals and then 2D and 3D modelling of the signal that propagated through the comet. This led us to conclusions that the comet is homogenous on the scale of the ten of wavelengths and perhaps slowly variable with the dielectric constant decreasing into interior of the comet. The measured value 1.27 +- 0.05 of the average dielectric constant permit us to interpret the composition of the materials in terms of porosity, dust to ice ratio and possible materials (Kofman et al, Science 2015, Ciarletti et al, A&A, 2015). In this presentation we will discuss all these results.

****

Mineralogical Implications of CONSERT Permittivity Characterization of 67P.

Herique Alain et al.

IPAG - UGA/CNRS (France)

On 12 November 2014, after the descent and rebounds of the lander Philae, COmet Nucleus Sounding Experiment by Radio Transmission (CONSERT) restarted operating at 18h56 UTC and continued until 04h06 UTC, providing the first investigation of the internal structure of the nucleus of a comet. The analysis of the signal that propagated throughout the upper part of "head" of 67P allows us to estimate an average permittivity of approximately 1.27 (Kofman et al., 2015). This average permittivity induces constraints on the permittivity of the dust components versus volume fraction of dust and ices. We analyze constraints on dust permittivity using mixing formulas and ice composition models. Additional comparisons to laboratory measurements will allow us to discuss the implication on composition and mineralogy of the 67P dust particules.

****

Photometric Behavior of 67P Spectral Parameters

Andrea Longobardo et al.

IAPS-INAF (Italy)

The photometric behavior of spectral parameters describing the 67P/CG surface is analyzed by means of a statistical analysis of the VIRTIS-M dataset. We considered the reflectance at seven different wavelengths, as well as center and depth of the 3.2 μm band and visible and infrared spectral slope. The behavior of these parameters as a function of incidence, emission and phase angles has been studied for the four regions of the comet (head, neck, bottom and body) and for different local times. Phase function is found to be constant on the whole comet surface, but seems to be flatter with respect to other comets. 3.2 μm band depth increases at increasing emission angles, but this behavior is not observed in the “nocturnal” Local Solar Time, probably due to the influence of water ice.

****

Surface Thermal Emission Model Assuming a Sub-pixel Distribution of Temperatures: Application to VIRTIS-M Observations of 67P/Churyumov-Gerasimenko

Andrea Raponi et al.

IAPS - INAF (Italy)

The thermal emission in the infrared range is usually treated assuming an isothermal surface within the field of view of an instrument pixel (IFOV). However, for atmosphereless bodies, thermalisation occurs at scales typically smaller than the IFOV. In this work the thermal emission is modeled as a contribution of many non-resolved facets having a distribution of their orientations that can be described by different functions, and each one presenting its own temperature. Goal of the model is the definition of the roughness, the net power absorbed by the body, and the distribution of temperatures within the IFOV. This approach is essential to derive the appropriate input to any physical model of the nucleus interior. Here we apply this model to VIRTIS-M observations of 67P/CG nucleus.

****

Comparative Study of Icy Patches on Comet Nuclei using Multispectral Imaging Data

Nilda Oklay et al.

Max Planck Institute for Solar System Research (Germany)

Cometary missions Deep Impact, EPOXI and Rosetta investigated the nuclei of comets 9P, 103P and 67P respectively. Bright patches (BPs) were observed on the surfaces of each of these three comets. With high spatial resolution data on 67P, three types of BPs were detected on comet surfaces: Clustered (CBPs), isolated (IBPs) and bright boulders. In the visible spectral range, CBPs display bluer spectral slopes than the average surface while IBPs have flat spectra. Spectroscopic observations of CBPs revealed the existence of water ice. CBPs on comet 67P have similar visible spectra to the BPs on comets 9P and 103P. The comparison of the spectral properties of the BPs observed on comet surfaces using various spectral analysis techniques will be presented together with the images investigated.

****

Cosmic Ray Interaction with Cometary Nuclei

Romain Maggiolo et al.

BISA (Belgium)

Comets are believed to contain the most pristine material of our solar system. After their formation they are constantly bombarded by cosmic rays which can alter their nucleus, for instance by modifying its surface albedo, the structure of its ices, or its isotopic and chemical composition. Estimating the total dose received by comets is of foremost importance to quantify the impact of cosmic rays on cometary material. We model the energy deposition of cosmic rays as a function of depth over the lifetime of comets. Several scenarios are tested depending on the location of comets and on the cosmic ray flux variation over time. While the bulk of the cosmic rays penetrate only the surface layers of comets, galactic cosmic rays can deposit a significant amount of energy down to several meters. The implications of this energy deposition on the evolution of cometary material and on the interpretation of cometary observations are also discussed.

****

Comet 67P/CG – Gravity, Material Strength and Surface Forming Processes

Stubbe F. Hviid et al.

DLR (Germany)

In the middle of 2014 the OSIRIS camera on Rosetta delivered the first resolved image of comet 67P/Churyumov–Gerasimenko. The Images showed a rough surface with apparent fractures, layering, terraces, landslides and mass wasting. Many of the features seem hauntingly familiar from other bodies in spite of the gravity field being 5 orders of magnitude smaller than that of the Earth. The surface forming processes of the comet seems to be controlled by gravity and not by inter grain Van Der Waals forces. This paper will discuss what we have learned about the material properties of the comet and how this relates to cometary activity and surface forming processes.

****

Seasonal Variation of Water Ice Abundance on 67P/CG Surface

Mauro Ciarniello et al.

IAPS-INAF (Italy)

The VIRTIS-M instrument onboard the Rosetta spacecraft observed a diurnal variation of water ice abundance in the Hapi region of the comet 67P/CG (De Sanctis et al., 2015). Conjointly, an increase of the average water ice content is observed across the whole surface, while the comet approaches the Sun, from August 2014 up to May 2015. This is indicated by an increase of surface albedo and of the water ice absorption feature in the 3 µm region as well as by the reduction of the spectral slope across the VIS-NIR range. We studied the evolution of the abundance of water ice at the surface by means of spectral modelling of VIRTIS-M measurements, and this is compared to the water vapour production rate as measured by Miro and Rosina.

****

ESA's Cometary Spacecrafts Giotto and Rosetta with 30 Years in between - Radio and Microwave Remote Sensing Technology and Efficient Inversion of Data

Peter Edenhofer

Ruhr-University of Bochum (Germany)

The paper is devoted to the concept of taking remote sensing measurements in the radio and microwave range of frequencies to determine the physical shape and material of deep space objects such as comets by specifically optimized mathematical methods of inversion. The paper discusses the development and progress of typical features of passive and active remote sensing technology ground-based and space-borne as well and the efficient stochastic numerical inversion of data measured to compromise highly spatial and temporal resolution versus numerical stability and error robustness. Passive remote sensing is presented based on radiometric tracking (such as range, range rate) and microwave radiometry (emission) whereas the assessment of active remote sensing is concerned with radar reflection and transmission, respectively. In addition to ESA missions Giotto and Rosetta the specific science returns are outlined including NASA missions Deep Impact and Stardust.

****

Philae Attitude and Trajectory Reconstruction

Philip Heinisch et al.

TU-Braunschweig (Germany)

Since Rosetta's lander Philae touched down on the surface of comet 67P/Churyumov-Gerasimenko on November 12, 2014, many different methods have been used together to reconstruct Philae's flightpath and attitude between separation, the two touchdowns, the collision and the final landing at "Abydos". In addition to OSIRIS, ROLIS and CIVA images, CONSERT ranging results and solar array and RF-Link housekeeping data, one of the major sources for timing and attitude information were two point magnetic field observations by the magnetometers ROMAP and RPC-MAG aboard Philae and Rosetta. Now more than one year after touchdown all of these individual results were combined to show what exactly happened to Philae.

****

Dust Impact Monitor (SESAME-DIM) Measurements at Comet 67P/Churyumov-Gerasimenko

Harald Krüger et al.

Max-Planck-Institut für Sonnensystemforschung (Germany)

Additional co-authors: 6) Alberto Flandes, Instituto de Geofisica, Universidad Nacional Autonoma de Mexico, Mexico; 7) Attila Hirn, MTA Centre for Energy Research, Budapest, Hungary; 8) Masanori Kobayashi, Chiba Institute of Technology, Chiba, Japan; 9) Alexander Loose, Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany; 10) Attila Peter, MTA Centre for Energy Research, Budapest, Hungary; 11) Morris Podolak, Tel Aviv University, Tel Aviv, Israel
Abstract: The Philae lander carries the Dust Impact Monitor (DIM) on board, which is part of the Surface Electric Sounding and Acoustic Monitoring Experiment (SESAME). DIM employs piezoelectric PZT sensors to detect impacts by sub-millimeter and millimeter-sized ice and dust particles that are emitted from the nucleus and transported into the cometary coma. The sensor measures dynamical data like flux and the directionality of the impacting particles. Mass and speed of the grains can be constrained for assumed density and the elastic modulus of the grains. DIM was operated during Philae's descent to its nominal landing site Agilkia and detected one particle impact at an altitude of approximately 2.4 km from the nucleus surface. This is the closest ever dust detection at a cometary nucleus by a dedicated in-situ dust detector. Laboratory calibration experiments performed with compact and porous cometary analogue materials showed that the detected particle had a low bulk density of approximately 250 kg m^−3, and a radius of about 1 mm. The measured parameters can be understood in the context of a simple gas flow model. At Philae's final landing site, Abydos, DIM detected no dust

impact which may be due to low cometary activity in the vicinity of Philae, or due to shading by obstacles close to Philae, or both.

****

The Las Cumbres Observatory Global Telescope Network for Cometary Science

Tim Lister et al.

Las Cumbres Observatory (United States)

Las Cumbres Observatory Global Telescope Network (LCOGT) has deployed a homogeneous telescope network of nine 1-meter telescopes to four locations in the northern and southern hemispheres, with a planned network size of twelve 1-meter telescopes at 6 locations. This 1-meter network is in addition to the two 2-meter Faulkes Telescopes that have been operating since 2005. This network is very versatile and is designed to respond rapidly to target of opportunity events and also to perform long term monitoring of slowly changing astronomical phenomena. The global coverage of the network and the apertures of telescope available make LCOGT ideal for follow-up and characterization of a variety of Solar System objects e.g. comets, Near-Earth Objects (NEOs), asteroids and Kuiper Belt Objects and also for the discovery of new objects. LCOGT has completed the first phase of the deployment with the installation and commissioning of the nine 1-meter telescopes at McDonald Observatory (Texas), Cerro Tololo (Chile), SAAO (South Africa) and Siding Spring Observatory (Australia). The telescope network has been fully operational since 2014 May, and observations are being executed remotely and robotically. Future expansion to sites in the Canary Islands and Tibet are planned for 2016-2017. I will describe the Solar System science research that is being carried out using the LCOGT Network with highlights from the long-term monitoring of the Rosetta spacecraft target comet 67P and comet C/2013 A1 (Siding Spring) and support for Hubble Space Telescope observations of 252P (LINEAR).

****

The Interaction between Surface Morphology and Inner Neutral Gas Coma of Comet 67P/ Churyumov-Gerasimenko

Ying Liao et al.

University of Bern (Switzerland)

Since the rendezvous of comet 67P/Churyumov-Gerasimenko and ESA's spacecraft Rosetta in mid-2014, numerous images taken by OSIRIS imaging system reveal the complexity of the comet's morphology and drive on the relevant research. Many studies indicate that the cometary activities play a role in the surface morphology and its evolution, yet the effects of morphology upon the gas flow field is not well understood. We aim to investigate the possible correlations between the surface morphology and the innermost neutral gas coma of comet 67P based on numerical simulations. In this work, we present the simulation results and conclude on the sensitivity of solutions to certain inputs.

****

Observations and Analysis of A Curved Jet in the Coma of Comet 67P/Churyumov-Gerasimenko

Zhong-Yi Lin et al.

Institute of Astronomy, NCU (Taiwan)

Aims. Analysis of the physical properties and dynamical origin of a curved jet of comet

67P/Churyumov-Gerasimenko that was observed repeatedly in several nucleus rotations starting on May 30, 2015. Methods. Simulation of the motion of dust grains ejected from the nucleus surface under the influence of the gravity and viscous drag effect of the expanding gas flow from the rotating nucleus. Results. The formation of the curved jet is a combination of the size of the dust particles (~0.1-1 mm) and the location of the source region near the nucleus equator, hence enhancing the spiral feature of the collimated dust stream after being accelerated to a terminal speed of the order of m s^{-1} .

****

Evolution of the Dust Particles Size Distribution and Flux from Comet 67P around Perihelion Measured by the COSIMA Instrument on-board Rosetta

Sihane Merouane et al.

Max-Planck Institute for Solar System Research (Germany)

The COSIMA instrument collects dust particles ejected from the nucleus of 67P/C-G and analyses their composition by Secondary Ion Mass Spectrometry. The particles are collected on metallic plates with a high sticking efficiency and are detected with the internal camera of the instrument, the COSISOPE, which has a resolution of 14 microns x 14 microns. Since August 2014, more than 20,000 cometary particles and particle fragments have been detected on the COSIMA plates, with a variety of morphologies and sizes. We will describe how the flux of dust and the size distribution of the particles have evolved along the comet journey around the Sun, from 3.5 AU to perihelion. In particular, we will compare the particles properties before and after perihelion passage.

****

Activity-Driven Changes in Cometary Rotation

Rosita Kokotanekova et al.

MPI for Solar System Research (Germany)

A sample of six well-studied comets exhibits detectable spin changes on orbital timescales. The changes are mostly caused by the net torque due to surface outgassing. It is not known, however, which are the dominant parameters controlling the spin rate changes and to what extent they influence the long-term evolution of comet populations. To increase the number of studied rotation changes, we combine newly-acquired and archival data of comets re-observed after their previous period determinations. The new targets have: 1) well-characterized spins, 2) similar sizes, 3) various shapes and 4) different levels of activity. We use the increased sample to establish the connection between the measured spin changes and the sizes, shapes and activity levels of the nuclei. The study is complemented by comparison of the observed comets with comet 67P/Churyumov–Gerasimenko. We analyze previously unpublished rotational lightcurves of comet 67P/Churyumov–Gerasimenko in the period 2011-2013. These data cover the period between the last perihelion passage in 2009 and the Rosetta rendezvous in 2014, and allow a better understanding of the spin changes at low activity levels of the comet.

****

RPC Observation of the Development and Evolution of Plasma Interaction Boundaries at 67P/Churyumov-Gerasimenko

Kathleen Mandt et al.

Southwest Research Institute (United States)

One of the primary objectives of the Rosetta Plasma Consortium, a suite of five plasma instruments on board the Rosetta spacecraft, is to observe the formation and evolution of plasma interaction regions at the comet 67P/Churyumov-Gerasimenko. Observations made between April and October 2015 show that solar wind-cometary plasma interaction boundaries and regions formed around mid-April 2015. At least two regions were observed between April and October, separated by a boundary: an inner region characterized by low energy ions, and an outer region where ions are accelerated to energies above 100 eV. Up until early May, a weak signal at solar wind energies appeared intermittently when Rosetta was within the outer region. Since early May, the only time a solar wind signal has been observed was during the excursion, well outside the boundary and just prior to the impact of a CME at CG. We find that this boundary is most likely the ion pileup boundary that was observed at Halley by Giotto, and we determine that the location of the boundary along the Sun-comet line varies linearly with the production rate, although its location is also influenced by variability in the solar wind dynamic pressure.

****

Sub-surface Porosity and Water Ice Content along an 800-meter Track of the MIRO Footprint in the Imhotep Region of 67P/Churyumov-Gerasimenko

Paul von Allmen et al.

Jet Propulsion Laboratory (United States)

In late October 2014, the Rosetta spacecraft orbited around 67P/Churyumov-Gerasimenko at a distance less than 10 km, the closest orbit in the mission so far. During this close approach, the Microwave Instrument on the Rosetta Orbiter (MIRO) observed an 800-meter long swath in the Imhotep region on October 27, 2014. Continuum and spectroscopic data were obtained. These data provided the highest spatial resolution obtained to date with the MIRO instrument. The footprint diameter of MIRO on the surface of the nucleus was about 20 meters in the sub-millimeter band at λ=0.5 mm, and 60 meters in the millimeter band at λ=1.6 mm. The swath transitions from a relatively flat area of the Imhotep region to a topographically more diverse area, still making the data relatively easy to analyze. We used a thermal model of the nucleus, including water ice sublimation, coupled with a simulation of the gas dynamics in the coma to analyze the continuum and spectroscopic data collectively. The H216O spectral absorption spectrum at 560 GHz was the primary coma molecular line used in the analysis. The sub-surface material of the nucleus is described in terms of its porosity, grain size and water ice content, in addition to assumptions for the dust bulk density and grain packing geometry. We used the optimal estimation algorithm to fit the material parameters for the best agreement between the observations and the simulation results. We will present the material parameters determined from our analysis.

****

Pre- and Post-equinox ROSINA COPS Production Rates compared with Pre-equinox MIRO, VIRTIS and Ground Based Measurements

Kenneth Hansen et al.

University of Michigan (United States)

We have used results from the AMPS DSMC model to create an empirical model of the near comet coma (<400 km) of comet 67P for both the pre-equinox and the post-equinox/post-perihelion time periods. The empirical model characterizes the neutral coma in a comet centered, sun fixed reference frame as a function of heliocentric distance, radial distance from the comet, local time and declination. This empirical model has been used to determine the production rate of 67P based on ROSINA/COPS measurements for the period of the entire Rosetta mission (August 2014 – January 2015). We will present details of our empirical model as well as the production rate calculated from the ROSINA/COPS data. In addition, for the pre-equinox period, we will compare the production rate determined from ROSINA data with production rates determined from measurements made by both the MIRO and the VIRTIS instruments aboard Rosetta. The pre-equinox production rates determined by the three different instruments, using both in situ and line-of-sight measurements together with different processing techniques, show a very good correlation. Details of the production rate comparison will be presented. Finally, we will present a ground-based measurement of dust production that correlates well with some details of the production rate curves.

****

Cometary Plasma Science from Giotto to Rosetta

Andrew Coates

UCL-MSSL (United Kingdom)

As a comet approaches the Sun, the nucleus warms and increasingly large numbers of neutral particles are produced with decreasing comet-sun distance. These particles become ionised and interact with the solar wind. The ions are picked up, are initially accelerated along the electric field and the particles then spiral around the magnetic field. They scatter in pitch angle and energy. With increasing gas production rate, the interaction starts with these kinetic pickup effects and the interaction further develops and a bow shock and contact surface forms. Comets thus provide a fascinating plasma laboratory for exploring the interaction of the solar wind with neutral particles. The Giotto spacecraft visited not only comet Halley (visited also by Vega and Suisei) but also the weaker comet Grigg-Skjellerup, providing a fascinating contrast with the intermediate comet Giacobini-Zinner visited by ICE in 1985. More recently, DS1 visited another comet and the Rosetta spacecraft has made spectacular measurements during its approach to and on the outbound leg. Here, we will revies these remarkable measurements form Giotto to Rosetta..

****

Millimeter and Submillimeter Observations of Comet 67P's Nucleus, Gas, and Dust with the Rosetta/MIRO Instrument

Mark Hofstadter et al.

JPL/Caltech (United States)

The Microwave Instrument for the Rosetta Orbiter (MIRO), currently flying alongside Comet 67P/C-G, studies the comet's nucleus, gases in the coma, and dust in the coma. It has broadband continuum receivers working at wavelengths of 0.5 and 1.6 mm which are used to study the nucleus sub-surface at depths from about 1 mm to 10 cm, as well as to study large dust particles (radius > ~1mm) in the coma. The 0.5 mm (560 GHz) receiver includes a 4096-channel spectrometer to study the abundance, velocity, and spatial distribution of H2_16O, H2_17O, H2_18O, CH3OH, NH3, and CO in the coma. This presentation has two parts. The first provides a high-level review of cometary processes being studied by our team, while the second focuses on the distribution of large (~1 mm and up) dust particles in the coma. In particular, we discuss mechanisms that could explain the radial distribution of particles observed within 20 km of the nucleus.

****

Thermophysical Modeling of the Nucleus of Comet 29P/Schwassmann-Wachmann 1 Using Spin-State Constraints Derived from Outburst Observations

Charles Schambeau et al.

University of Central Florida (United States)

The enigmatic Comet 29P/Schwassmann-Wachmann 1 (SW1) has been of interest since its discovery almost 100 years ago. A nearly circular orbit around 6 AU, continuous activity outside of the water sublimation line, and frequent outbursts in activity make SW1 a useful observational target for a better understanding of distant cometary activity drivers. Since sublimation of water ice is likely not the primary driver of activity, is the sublimation of supervolatiles and/or the release of gasses trapped in amorphous water ice the driver? Furthermore, why does the comet have frequent major changes in activity despite receiving a nearly constant insolation? These unresolved questions reflect our lack of understanding of the fundamental nature of cometary activity. We are working to replicate SW1's complex activity patterns observed in an expansive set of imaging observations (~25 years of SW1 observations) with the synergy of a well-developed 3D Monte Carlo coma model for the determination of SW1's nuclear spin state [1,2,3], a quasi-3D thermophysical/chemical nucleus model for simulating activity levels [4,5], and the incorporation of recent Rosetta mission results. This level of detailed thermophysical analysis of an individual comet is usually reserved for spacecraft-flyby targets. Using the most common type of ground-based remote-sensing observations of a comet (dust imaging) to infer physical and dynamical properties of its nucleus, we are undertaking a detailed thermophysical analysis of an unvisited comet nucleus. We present analysis of two sets of observations of SW1 while in outburst. The first set is from the Kitt Peak 2.1-m telescope taken on UT 2008 September 25.5, 26.5, 27.5, 28.5, and 29.5 and shows SW1 with an expanding asymmetrical shell of material with a sky-plane projected expansion velocity of 0.11 ± 0.02 km/s. Additionally, four linear, radial features are present and are contained within the expanding shell of material. The morphological features were modeled [6], resulting in the following: The outburst source was an active region covering ~6% of the nucleus's surface area and centered slightly below the sub-Earth point. Constraints on the rotation period (P) to outburst duration (Δt) ratio were found for a set of four possible spin-pole orientations (symmetry in the outburst coma did not allow independent constraints on the spin-pole direction). Overall, coma modeling suggested that either $P/\Delta t > 10$, the spin-pole orientation was along the sub-Earth direction, or both. To place an independent constraint on the outburst duration, radial surface-brightness profiles of the observations were compared with profiles from synthetic comet models. An upper-limit of $\Delta t \leq 1.5$ days was derived for the outburst of SW1. The second set of observations is from the Hubble Space Telescope WFPC2 instrument, which serendipitously caught SW1 while in outburst on UT 1996 March 11.3 and 12.1. The 0.046-arcsec/pixel scale (~180 km/pixel at the distance of SW1) of the PC detector gives an order-of-magnitude improvement in spatial resolution over our ground-based observations. Preliminary analysis of the Hubble observations has constrained the outburst time to ~15 hours prior to the first observation and a dust outflow velocity ~0.1 km/s, in agreement with a previous analysis [7]. Morphology of the observations shows an asymmetric coma with two curved jets on the northeast and southeast sides. We present results from the application of our 3D Monte Carlo coma model to both Hubble observations in order to constrain SW1's nucleus spin state. These spin state results are incorporated into the aforementioned thermal model to accurately replicate the insolation distribution due to rotational and orbital variations. A progenitor nucleus is thermally evolved in SW1's current orbit using different plausible nucleus interior compositional and layering schemes [4, 8]. The models are constrained by comparing the synthetic dust-mass loss rate and its variability with what has been observed through optical imaging of the comet at various epochs in its orbit. We present preliminary thermal modeling of a homogeneous progenitor nucleus that evolves into a body showing internal material layering, the generation of CO and CO2 ice pockets, and the production of outbursts, thus bringing us closer to explaining the behavior of this intriguing comet. [1] Samarasinha, N. and Larson, S.: 2014, Icarus, 239, 168-185. [2] Samarasinha, N. H., et al.: 2004, Comets II, 281-299. [3] Schleicher, D. G. and Farnhasm, T. L.: 2004, Comets II, 449-469. [4] Prialnik, et al. 2004, Comets II, 359-387. [5] Sarid, G.: 2009, PhD thesis, Tel Aviv Univ. [6] Samarasinha, N. H.: 2000, The Astrophysical Journal, 529:L107-L110. [7] Feldman, P. D., et al.: 1996, DPS Meeting Abstracts #28, 1084. [8] Meech, K. J. and Svoren, J.: 2004, Comets II, 317-335. We thank the NASA Outer Planets Research Program (NNX12AK50G), the Space Telescope Science Institute (AR14294), and the Center for Lunar and Asteroid Surface Science (CLASS, NNA14AB05A) for support of this work.

****

What can we Learn about the Ice Composition on 67P from In-situ Measurements with ROSINA-DFMS

Andre Bieler et al.

University of Michigan (United States)

The Double Focusing Mass Spectrometer ROSINA-DFMS has been analyzing the composition of the coma of 67P ever since the Rosetta spacecraft arrived at 67P/Churyumov-Gerasimenko (67P) in August 2014. We constrain our 3D computational model with ROSINA observations and compute total production rates for various species of 67P. The evolution of these production rates between 3.5 AU to perihelion at 1.3 AU and past can tell us about properties of the ice on the nucleus and the corresponding release mechanisms. Here we present the numerical methods to compute production rates from in-situ DFMS measurements and time series of several major volatiles over the course of the Rosetta mission and implications thereof for the conditions on the nucleus and its formation.

****

The Making Of "Closest Encounter", a Movie made from Images Acquired by the Halley Multicolor Camera Aboard the Giotto Probe

Björn Grieger et al.

Aurora Technology B.V. for ESA - European Space Agency (Spain)

In March 1986, the Giotto probe passed Halley's Comet at a distance of 596 km. During the encounter, the Halley Multicolour Camera (HMC) acquired 2043 images. Shortly after the encounter, a movie was created from the HMC data, however, the quality and resolution of the movie lagged significantly behind the original images. On the occasion of the 25th anniversary of the flyby in 2011, based on 111 full frame, full resolution, clear filter HMC images, we have created a remake of the flyby movie which fully preserves the original quality of the data. We describe the geometry of the flyby, the format of HMC image data and meta data, and the steps applied to merge the images into a movie.

****

Activity and Composition of Comet 67P/Churyumov-Gerasimenko from High Resolution Infrared Spectroscopy with the VIRTIS-H Instrument Onboard Rosetta

Dominique Bockelee-Morvan et al.

LESIA, Observatoire de Paris (France)

The high spectral resolution channel of the VIRTIS instrument onboard Rosetta covers the 2-5 micron region where gas phase molecules can be detected through their vibrational bands emissions. Water and carbon dioxide were detected starting from 3 AU from the Sun, allowing to study the evolution of their outgassing and of their source regions on the nucleus surface. Raster maps extending up to 25 km in radius were obtained near perihelion. Thanks to the high spectral resolution, 13CO2 and hot-bands of both H2O and CO2 were detected, allowing a better estimation of opacity effects which were significant for the main bands near perihelion. Several lines were detected in the 3-3.5 micron range, attributed to organics and hydrocarbons, with the P, Q, R branches of CH4 being clearly identified. An overview of the VIRTIS-H coma observations and results will be presented.

****

A Long Term Study of Centaur 174P/Echeclus

Philippe Rousselot et al.

Institut UTINAM / OSU THETA (France)

Centaur 174P/Echeclus presented a surprising cometary outburst in December 2005, that led to a change in its overall visual magnitude from about 21 to 14. At that time (60558) 2000 EC 98 was located at 13.07 au to the Sun and was subsequently renamed with a cometary designation. Another secondary outburst happened in 2011. This target was at its perihelion (5.82 au) on April 22, 2015. We present new observational data obtained during the 2011 outburst and in July 2013, April, 2014, August, 2014 and June, 2015. We also found archive observational data obtained on December 22, 2005. All these data, as well as the one already published, will be used to present a long term study of Echeclus, with a quantitative analysis of its level of activity and lightcurve change.

****

Dust Release from Cometary Surfaces

Eberhard Grün et al.

IDS (Germany)

Dust particles are embedded in cometary ices. When the ices sublimate dust particles are set free and are carried by the released gases. This is the canonical view of dust release from cometary surfaces. However, this process can be much more complicated. In simulation experiments it was observed that dust particles accumulate in a porous fluffy dust mantle which insulates the ice from the solar radiation and, hence, quenches eventually any further sublimation. Touching dust particles are held together by cohesive forces that are generally much stronger than cometary gravity or gas drag. In these cases bonds may crack open by processes described by fracture mechanics. Microscopic weaknesses (flaws) can open under macroscopic forces. Such processes may be responsible both for microscopic and macroscopic outbursts of cometary activity. Recent lab experiments indicate that even electrostatic disruption may play an important role in the release of dust particles from a cometary surface. We will discuss the observational evidence for these different processes.

****

Cometary Activity Investigated by Laboratory Experiments

Bastian Gundlach et al.

Technische Universität Braunschweig (Germany)

At the Technische Universität Braunschweig, laboratory experiments were carried out to better understand different aspects of the origin of cometary activity, namely: - How effective is the energy transport through the porous, non-volatile surface layer towards the volatile constituents? - Is the covering dust layer influencing the sublimation process and how effective is the gas diffusion through the porous material? - Is it possible to lift particles from the surface by outgassing of the volatiles? - Can we understand the formation of comets by studying their surface properties? During this conference, we present our studies and we discuss how laboratory experiments can help to better understand the activity of comets.

****

A Comparison between VEGA 1, 2 and Giotto Flybys of Comet 1P/Halley

Martin Volwerk et al.

Austrian Academy of Sciences (Austria)

Three flybys of comet Halley by VEGA 1, 2 and Giotto are investigated with respect to the occurrence of mirror mode waves in the cometosheath and field line draping. The time interval covered by these flybys is approximately 8 days, which is also the approximate length of an orbit or flyby of Rosetta around comet 67P/CG. Thus any significant changes observed around Halley are changes that might occur for Rosetta during one pass of 67P/CG. The occurrence of mirror mode waves in the cometosheath is strongly influenced by the dynamical pressure of the solar wind and the outgassing rate of the comet. Field line draping happens in the magnetic pile-up region. Changes in nested draping regions can occur within a few days, possibly influenced by changes in the outgassing rate of the comet.

****

Long-term Characterization of the Coma of Comet 67P/Churyumov-Gerasimenko from the Ground

Matthew Knight et al.

University of Maryland (United States)

Over the past two years, Rosetta has been studying the coma of comet 67P/Churyumov-Gerasimenko to distances <1000 km. During this time, we have monitored 67P regularly at scales larger than 1000 km, which the spacecraft cannot measure. Our observations were taken primarily with Gemini North and South, with supplementary observations when the comet was brightest acquired at Las Cumbres Observatory and Lowell Observatory. Observations will continue into 2016 and have included optical and near-IR imaging plus near-IR spectroscopy. We will present ongoing results of this campaign, including the overall activity level as a function of time, the appearance and evolution of structures (e.g., jets) in the coma, and spectral analysis of the inner coma. These findings will be compared with previous ground-based studies to look for trends from one apparition to the next, and with in-situ results to provide a multi-scale view of the comet’s activity.

****

Evolution of the Plasma Environment of Comet 67P from Spacecraft Potential Measurements by the Rosetta Langmuir Probe Instrument

Elias Odelstad et al.

Swedish Institute of Space Physics (Sweden)

We present and compare two techniques for obtaining the electrostatic potential of the Rosetta spacecraft from two very different instruments, and use the results for mapping the comet plasma environment and for tracking its evolution with time. The low collision rate keeps the electron temperature high (~5 eV), resulting in a negative spacecraft potential whose magnitude depends on the electron density. This potential is more negative in the summer hemisphere, particularly over sunlit parts of the neck region on the nucleus, consistent with neutral gas measurements by Rosetta Orbiter Spectrometer for Ion and Neutral Analysis Cometary Pressure Sensor. Assuming constant electron temperature, the spacecraft potential traces the electron density. This increases as the comet approaches the Sun, most clearly in the southern hemisphere by a factor possibly as high as 20–44 between September 2014 and January 2015. The northern hemisphere plasma density increase stays around a factor of around or below 8–12, consistent with seasonal insolation change.

****

Observations of Stormy Solar Wind Interacting with Comet 67P/C-G

Niklas J.T. Edberg et al.

Swedish Institute of Space Physics, Uppsala (Sweden)

We present observations from the Rosetta Plasma Consortium of the effects of stormy solar wind on comet 67P/Churyumov-Gerasimenko. 4 corotating interaction regions (CIRs) are traced from Earth (using ACE) to Mars (using Mars Express and MAVEN) and to comet 67P (using Rosetta) from October to December 2014. When the comet was 3.1-2.7 AU from the Sun and the neutral outgassing rate ~1025-1026 s-1 the CIRs significantly influence the cometary plasma environment down to cometocentric distances of 10-30 km, where Rosetta is located. The ionospheric low-energy plasma density increases significantly, by more than a factor of 2 in the first two events, and to a lesser extent in the last two events. The spacecraft potential drops to values below -20V upon impact. The increased density is probably caused by compression of the cometary plasma environment, increased particle impact ionisation, and possibly charge exchange processes and acceleration of mass loaded plasma back to the comet ionosphere through electric fields. During all events, the fluxes of suprathermal (~10-100 eV) electrons increase significantly, suggesting that the heating mechanism of these electrons is strongly coupled to the solar wind energy input. At impact the magnetic field strength in the coma increases by a factor of ~2-5 as more interplanetary magnetic field piles up around of the comet. Furthermore, we also present later observations when the comet was closer to the sun (1.4 AU) and a coronal mass ejection (CME) impacted on the comet. The impact occurred during the inbound leg of an excursion interval when Rosetta was moving from 1500 km to ~400 km. The CME impact poses similar disturbances as the CIRs and compresses the plasma environment as well as causes the plasma density and magnetic field pileup to increase.

****

Post-perihelion Spectroscopic Observations of Comet 67P/Churyumov-Gerasimenko with the Liverpool Telescope

Miguel de Val-Borro et al.

Princeton University (United States)

We present spectroscopic observations with the robotic 2-m Liverpool Telescope at the Roque de los Muchachos observatory for monitoring the activity of comet 67P/Churyumov-Gerasimenko during its latest post-perihelion apparition. The LOTUS and SPRAT instruments were used to obtain low resolution near-UV and optical spectroscopy in the wavelength ranges from 3200 Å to 6400 Å and 4000 Å to 8000 Å, respectively, since September 2015 with a few days cadence. The CN emission at 3880 Å is clearly detected in the LOTUS observations, as well as several weak bands of the carbon-chain molecules C2 (4738, 5165 and 5635 Å) and C3 (4050 Å). We followed the evolution of the gas production rates computed with a Haser spherical model for daughter species as an indicator of comet activity, and compared with the dust production from the reflected continuum brightness in the SPRAT spectroscopy data to derive dust-to-gas ratios.

****

The Oxygen Isotopic Ratio in Cometary Dust with Rostetta/COSIMA

John Paquette et al.

Max Planck Institute for Solar System Research (Germany)

COSIMA is an instrument onboard the Rosetta orbiter that captures and images dust from comet 67P/Churyumov-Gerasimenko and measures the dust composition using Time of Flight Secondary Ion Mass Spectrometry (ToF-SIMS). In this work, the oxygen isotopic ratio (18O/16O) will be measured for several grains. The oxygen isotopic ratio may shed light on cometary formation and the possible incorporation into comets of material from the inner solar system.

****

Survey for Ortho-to-Para Abundance Ratios (OPRs) of Ammonia in 20 Comets

Hideyo Kawakita et al.

Koyama Astronomical Observatory of Kyoto Sangyo University (Japan)

The ortho-to-para abundance ratio (OPR) of cometary molecules is considered to be one of the primordial characteristics of cometary ices. We present OPRs of ammonia in twenty comets based on optical high-resolution spectroscopic observations of NH2 which is a dominant photodissociation product of ammonia in cometary coma. Those spectra were taken by mainly the UVES mounted on the VLT in Chile and also taken by the HDS mounted on the Subaru telescope in Hawaii. The estimated OPRs of ammonia in comets clustered between 1.1 and 1.2 (cf., the high-temperature equilibrium value of ammonia is 1.0). This range corresponds to a nuclear spin temperature of ~30K. We discuss about the real meaning of OPR of cometary ammonia based on our survey. This work was supported by JSPS, 15J10864 (Y. Shinnaka).

****

Survey for Nitrogen Isotopic Ratio of NH2 in Comets: Implication for 15N-fractionation in Cometary Ammonia

Yoshiharu Shinnaka et al.

National Astronomical Observatory of Japan (Japan)

Isotopic ratios are diagnostic for the physico-chemical condition of the molecular formation. In comets, 14N/15N ratios have been well observed from Nitriles (e.g., Manfroid et al. 2009; Bockelée-Morvan et al. 2008). Those ratios are enriched in 15N compared to the Sun by a factor of ~3 and have small diversity. However, there are only a few reports on 14N/15N ratios in NH3 (Rousselot et al. 2014, 2015; Shinnaka et al. 2014), although NH3 is one of the most abundant N-bearing volatiles in comets. We estimate the 14N/15N ratios in NH3 for more than ten comets individually from high-resolution spectra of NH2 taken with the UVES/VLT and HDS/Subaru. We discuss about the the origin of cometary materials.

****

Herschel Observations of the Rosetta target 67P/Churyumov-Gerasimenko

Laurence O'Rourke et al.

ESA/ESAC (Spain)

Introduction:

In June 2010, the Herschel Space Observatory observed comet 67P/Churyumov-Gerasimenko with the PACS Instrument when the comet was at a heliocentric distance of 4.1 AU. This comet is the prime target for the Rosetta spacecraft due to arrive to orbit it in mid-2014 [1]. Observations performed on 67P/Churyumov-Gerasimenko : A 2 hour cross scan PACS observation was executed observing the comet 67P/Churyumov-Gerasimenko. The comet was detected only at 70um with a significant extended emission in the processed data set. A follow-up “shadow” DDT observation in December 2010 of the area where the comet was locat-ed in the June timeframe took place to address the orig-inal slow moving nature of the comet at the time of the June observation. An empty background confirmed that what was observed by Herschel in June 2010 was in-deed due to 67P.

Summary of data processing :

Data processing was performed on all observation sets using the most recent HIPE software [2]. Special processing was performed to correct for pointing errors as well as to address the extended features visible in the observed comet images. The derived fluxes were aperture and colour corrected to obtain monochromatic flux densities at the PACS reference wavelengths.

Data Analysis – 67P :

Our data analysis focuses on the expected dust emission around the comet nucleus at this distance which could have produced the flux obtained.We conclude that the extended emission offset from the anti-velocity vector is the neckline of the comet linked to dust emitted about 100 days before perihelion (180 deg away in true anomaly = Nov.2008). We present our modeling results which confirm the neckline. We also provide an explanation for the ex-tended emission observed perpendicular to the nucleus position as well as the size & distribution of the dust particles that need to exist at that distance to explain both the neckline & its presence.

Conclusions:

The benefits of Herschel in the study of comets will be highlighted. The results of observa-tions of 67P are presented and reviewed with associated conclusions reached on the dust observed in its wake and dust production rates required to generate such dust. We compare our results to those of other pub-lished articles and look at the synergies possible in the merging of data from a multi-wavelength data set. References: [1] Schwehm, G. H. (2003), BAAS, 35, 1001 [2] Ott, S. (2009), Proceedings of the Astro-nomical Data Analysis Software and Systems XIX Con-ference, 434, 139-142

****

Forbush Effects Detected at Comet 67/P Churyumov-Gerasimenko with the Rosetta Radiation Environment Monitor (SREM)

Olivier Witasse et al.

European Space Agency (The Netherlands)

A Forbush effect is a transient decrease followed by a gradual recovery in the observed galactic cosmic ray intensity, and can be caused by the passage of a coronal mass ejection (Cane, 2000). We report here the detection of such an event at comet 67/P, with data acquired by the SREM radiation monitor aboard the Rosetta spacecraft. The event, recorded on 22 October 2014, is associated with a large coronal mass ejection (CME) launched on 14 October 2014, with a velocity of around 900 km/s. The CME also hit Mars, on 17 October 2014, leading to a Forbush effect of a similar magnitude. SREM (Standard Radiation Environment Monitor) measures high energy electrons and protons with three detectors and fifteen detector counters with different energy threshold levels and range. The range for electrons is ~ 0.75-6 MeV and ~ 12-300 MeV for protons. We discuss here: - the propagation of the CME from the Sun to Rosetta, and we show comparison with dedicated ENLIL runs; - the characteristics of the Forbush decrease that can be linked to CME parameters; - a preliminary lists of Forbush decreases detected at comet 67P; - the usefulness of indentification of Forbush decreases in the study of solar wind interaction with the comet 67/P, as they provide a clear and reliable signature of CMEs; Rosetta plasma data are also shown in this context; - the usefulness of radiation monitor data in general in the context of planetary space weather.

****

Is the Sublimation of Icy Grains Detectable with the OSIRIS Cameras Onboard Rosetta?

Adeline Gicquel et al.

MPS (Germany)

Before the Rosetta mission, the composition of cometary nuclei (mainly ices and silicates dust) was known primarily from the observations of their coma. The structure of cometary coma are often expressed in terms of a uniform, spherically-symmetric outflow that interprets volatile species as either parent species, sublimated directly from the nucleus, or daughter species, produced in the coma. However, processes like chemical, temporal evolution and sublimation of icy grains occur in the coma and don't always reflect the primary composition of the nucleus. Also, observations of some extended sources in the coma remain a mystery. In situ spacecraft observations of several comets have allowed their nuclei to be imaged and the gas and dust properties of their coma to be studied in great detail. Sublimation of icy grains has been detected in the ejecta of the comet 9P/Tempel 1 after the impact with the Deep Impact spacecraft and in the coma of comet 103P/Hartley 2 during the Deep Impact eXtended Investigation (DIXI). Also, photometric analysis of dust grain with two different filters of the OSIRIS Narrow Angle Camera (NAC) suggested the presence of hydrated minerals in the coma of comet 67P/Churyumov-Gerasimenko. Our work addresses whether the sublimation of icy grains ejected by 67P/Churyumov-Gerasimenko could be detected by Rosetta's OSIRIS cameras.

****

Short Time-scale Variations in the Ion Environment around 67P

Hans Nilsson et al.

Swedish Institute of Space Physics (Sweden)

The ion environment around the 67P/Churyumov-Gerasimenko is highly varying. To be able to study this a new measurement mode was implemented for the Ion Composition Analyzer (ICA), which is part of the Rosetta Plasma Consortium (RPC). In this mode RPC-ICA observes ions in a plane (2D) with a resolution of 1 s or 4 s. We present measurements made with this mode and discuss how the short time-scale variations depend on, for example, spacecraft potential, distance to the comet and magnetic field direction.

****

Detection of NH4+ of Cometary Origin at Comet 67P near Perihelion

Arnaud Beth et al.

Imperial College London (United Kingdom)

On 13th of August 2015, comet 67P/Churyumov-Gerasimenko made its closest approach to the Sun at 1.24 AU. Around this period, from early summer to early fall, the ESA's Rosetta spacecraft, with the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) onboard, scanned both hemispheres, recording high neutral gas densities and outgassing rates that increased by one order of magnitude compared with earlier observations. This impacts the chemical balance between the ions inside the coma, including the relative abundance of protonated ammonia NH4+ with respect to water ions. We will present the first results about the detection of NH4+ around perihelion by the ROSINA Double Focusing Mass Spectrometer (DFMS). We will discuss its origin and will assess consistency with ionospheric modelling applied to comet 67P, with different outgassing rates and composition as applied to comet 67P.

****

Photochemistry of Forbidden Oxygen Lines in the Coma of 67P/Churyumov-Gerasimenko

Gaël Cessateur et al.

BIRA-IASB (Belgium)

The green (557.7 nm) and red-doublet (630, 636.4 nm) emission lines have previously been observed at several comets. This contribution will present a coupled chemistry-emission model for atomic oxygen green and red-doublet emission for comet 67P. The recent discovery of O2 in significant abundance relative to water within the coma of 67P has been taken into consideration for the first time in such models. Our simulations, solving the continuity equation with transport, show that not taking O2 into account leads to an underestimation of the CO2 abundance within 67P. Since there is no compelling reason for O2 not being a common cometary volatile, CO2 production rates derived for other comets will most likely have to be revised.

****

Neutral-neutral Reactions in Cometary Comae

Steven Charnley et al.

NASA Goddard Space Flight Center (United States)

Reactions between positive ions, electrons and neutral molecules play a fundamental role in chemistry of cometary comae [1]. The

importance of (slower) neutral-neutral processes, on the other hand, remains relatively unexplored [2, 3, 4]. Rosetta measurements allow the possible detection of many simple and complex neutral molecules as a function of cometocentric and heliocentric distances [5]. We have therefore re-evaluated coma synthesis pathways to various organic molecules [2] in the light of new reaction data [6], and to the molecular oxygen detected by Rosina [7].
[1] Rodgers, S.D., Charnley S.B., Boice, D.C. & Huebner, W.F. (2004) In COMETS II, Eds. Festou, M., Keller, H.U. & Weaver, H.A., University of Arizona Press, 505-522 [2] Rodgers, S.D. & Charnley, S.B. (2001) MNRAS, 320, L61 [3] Glinski, R.J. et al. (2004) ApJ, 608, 601 [4] Rodgers, S.D. & Charnley, S.B. (2005) MNRAS, 356, 1542 [5] Le Roy, L. et al. (2015) A&A, 583, A1 [6] Barone, V. et al. (2015) MNRAS, 453, L31 [7] Bieler, A. et al. (2015) Nature, 526, 678 This work was supported by NASA's Planetary Atmospheres and Planetary Astronomy Programs.

****

Spectroscopic and Photometric Monitoring of Comet C/2013 US10 (Catalina)

Cyrielle Opitom et al.

University of Liège (Belgium)

Comet C/2013 US10 (Catalina) is a dynamically new comet that reached perihelion on November 15, 2015 at 0.82 au from the Sun. We observed the comet during several months in 2015 with the 0,6-m TRAPPIST robotic telescope at La Silla observatory. The telescope is equipped with a set of narrow-band cometary filters designed by the NASA for the Hale-Bopp observing campaign. From the images of comet Catalina in these filters, we derived OH, NH, CN, C3, and C2 production rates using a Haser model, as well as the Afρ parameter as a proxy for the dust production. Simultaneously, we obtained low-resolution spectra with the FORS 2 instrument at the VLT on 4 epochs between May and September 2015. We first discuss the consistency of both data sets by comparing simultaneous observations. We then discuss the slow evolution of comet Catalina gas and dust activity between 3.5 and 1.4 au pre-perihelion and study its coma composition and morphology.

****

Alkali Metals in Cometary Particles – what is the Chemical Context?

Oliver J. Stenzel et al.

Max-Planck-Institut für Sonnensystemforschung (Germany)

The Rosetta mission is one of the few endeavors to visit a comet and to sample its coma. The COSIMA instrument on board Rosetta catches the dust and analyses it with its time of flight secondary ion mass spectrometer (SIMS). Grains from 67P contain elements like sodium and others (Schulz et al., 2015). In this work we try to get an idea on the context in which the alkali metals Li, Na and K, as far as we can detect them, are present in the cometary particles. Correlation based methods are used to find associated elements and compounds.

****

Two-point Observations of Low-frequency Waves at 67P/Churyumov-Gerasimenko during Descent of PHILAE: Comparison of RPCMAG and ROMAP

Ingo Richter et al.

TU-Braunschweig (Germany)

Authors: I. Richter, H.-U.Auster, G. Berghofer, C.Carr, E. Cupido, K.-H. Fornacon, C.Goetz, P. Heinisch, C. Koenders, B. Stoll, B.T. Tsurutani, C.Vallat, M.Volwerk, K.-H. Glassmeier The European Space Agency's spacecraft ROSETTA has reached its final destination, the comet 67P/Churyumov-Gerasimenko. Whilst orbiting in the close vicinity of the comet the ROSETTA magnetometers have detected a new type of ultra-low frequency waves possibly generated by a cross-field current instability due to freshly ionized cometary water group particles. During separation, descent and landing of the lander PHILAE on comet CG, we used the unique opportunity to perform combined measurements with both instruments RPCMAG & ROMAP and revealed new details about the spatial distribution of wave properties along the connection line of the ROSETTA orbiter and the lander PHILAE.In this work we concentrate purely on the analysis of the descent and landing phase. A correlation analysis and the spatial distribution of the observed amplitudes, frequencies, phases and wavelengths will be presented. Additionally the calculated dispersion relation of the detected waves will be discussed.

****

Dust Tail Analysis from a New Application of the Finson-Probstein Technique

O. D. Price et al.

Mullard Space Science Laboratory, University College London (United Kingdom)

We present results from a new application of Finson & Probstein's (1968) model of cometary dust tails. The dominant forces of radiation pressure and gravity acting on dust both follow inverse square laws, so the structure of the tail can be explained by adjusting the Keplerian orbits of ejected material. Each particle is parameterised by its ratio of radiation pressure to gravity - beta, and its time of ejection from the nucleus. A dust map is extracted directly from dust tail images, displayed in the beta and emission time parameter space. We use this technique to track the development of features in the tail of C/2006 P1 (McNaught), using data from the SOHO LASCO coronagraph and the STEREO SECCHI heliospheric imagers, with a focus on other potential non-gravitational influences on dust.

****

Photometry of Dust Grains of Comet 67P, using OSIRIS Images

Gabriele Cremonese et al.

INAF-Astronomical Observatory of Padova (Italy)

Multiple pairs of high-resolution images have been used to derive the photometric properties of dust grains. A semi-automatic program developed for the photometric analysis of grain tracks was successfully applied to a first set of images acquired on September 2014. This study leads to two color measurements for 70 grains. In the subsequent months OSIRIS obtained a huge amount of data, among which several sets of images of the dust coma, obtained with 4 filters covering the spectral range from 443 to 849 nm. In this work, we describe the results on the first set of images obtained at large heliocentric distances, and the preliminary results on images obtained at later times during the mission, including the analysis of the light curves visible in some tracks.

****

Spacecraft Dynamics during the Halley Encounter: The Giotto Radio-Science Experiment (GRE)

Michael Bird et al.

Uni-Bonn (Germany)

The Giotto spacecraft survived its encounter with comet Halley on 14 March 1986, but did not emerge unscathed. The downlink to Earth was lost for about 20 s exactly when the spacecraft crossed through the subsolar coma. After encounter it was determined that impacting cometary dust had decelerated Giotto by 23 cm/s, tilted its attitude by 1 deg, and increased its spin period by 12 ms. The available data indicated that one particularly severe impact about 8 s before closest approach was responsible for the onset of large-amplitude spacecraft nutation. The largest single particle to strike the spacecraft probably had a mass between 100 and 200 mg. Simulations of the downlink signal level yield best agreement with observations for a wobble angle of 0.4 deg and a High Gain Antenna (HGA) off-pointing angle of approximately 1.0 deg.

****

A Hot and Active Place: the Ionosphere of Comet 67P

Anders Eriksson et al.

Swedish Institute of Space Physics (Sweden)

Since the arrival of Rosetta at comet 67P in August 2014, the plasma environment around the nucleus has been dominated by plasma of cometary origin, as witnessed from the start by a strong modulation by the rotation of the nucleus on the plasma density from the Langmuir probe (LAP) and Mutual impedance probe (MIP) instruments. Coma densities have mainly been too low to efficiently cool the electrons emitted by ionization of neutrals, keeping the electron temperature well into the eV range and driving the spacecraft to a potential often below -10 V. Exceptions to this include observations of a diamagnetic cavity extending out to Rosetta distance around perihelion, where electron temperatures below 0.1 eV are found. While events in the solar wind cause some of the variations detected, the expanding cometary plasma is also unstable in itself, generating much more structuring and dynamics than can be found in the neutral gas.

****

Broadband Monitoring of Coma Radicals at High Spectral Resolving Power with a Multi-order Spatial Heterodyne Spectrometer.

Walter Harris et al.

University of Arizona (United States)

We describe the first results from broadband, high-resolving power measurement of coma radicals using a multi-order spatial heterodyne spectrometer (SHS) at the McMath-Pierce Solar Telescope on Kitt Peak. SHS instruments are wide field interferometric remote sensing devices that operate by using a diffraction grating to divide incoming light into two beams that interfere to produce a pattern of linear fringes from which spectral information is obtained with a Fourier Transform. Compared with other high-resolving techniques, SHS instruments pair a large intrinsic field of view with high spectral resolution, which makes them well suited to the study of faint extended emission line features in comet comae. The multi-order SHS is an improved design that utilizes a coarse-ruled high order grating that overlaps multiple bandpasses at the output. This design allows the simultaneous sampling of coma radicals over a large wide wavelength range (300-1000 nm) at a velocity resolution <10 km/sec using a compact instrument that requires neither moving parts nor a large telescope. We report here on the relative production rates of multiple species, the performance of the instrument, and its potential for use at small telescopes or on resource-limited remote probes at wavelengths from the ultraviolet through near infrared.

****

An Overview of Cometary Science with WISE/NEOWISE

Emily Kramer et al.

Jet Propulsion Laboratory (United States)

Since the launch of the Wide-Field Infrared Survey Explorer (WISE) mission in 2009, the NEOWISE augmentation to the mission has provided the largest survey of comets in the infrared [1]. During the fully cryogenic prime mission, 163 comets were detected in four infrared wavelength bands (3.4, 4.6, 12, and 22 um), and over 80 comets have been detected (as of Dec. 2015) in the two-band (3.4 and 4.6 um) restarted mission. Twenty-two comets were discovered during the prime mission, and four have been discovered to date with the restarted mission. The detected comets represent a substantial fraction of the known Jupiter-Family comet (JFC) population, and many of the recently discovered long period comets (LPCs), allowing characterization to be done across a wide range of objects. The non-targeted nature of the survey allows for population-wide characterization to be done with fewer biases than with a targeted survey. We present here some highlights of cometary science with NEOWISE, showcasing how these data have been and will be used to enhance our understanding of these pristine bodies. The data can be used to constrain nucleus diameter and albedo, the active fraction of a comet's surface, the CO + CO_2 gas production rate, Afρ and εfρ (quantity of emitted dust), the color temperature of the dust, and dust tail particle sizes and ages. By analyzing data from the four-band prime mission, focusing on the objects discovered during the course of the mission, we have found a possible relation between CO + CO_2 gas production rate and the amount of dust produced, and a possible size difference between JFC and LPC nuclei [2]. Dust tail modeling of the 12 and 22 um data suggest that most comets emit large dust grains close to perihelion, and that the dust emitted by JPCs and LPCs is surprisingly similar [3]. Modeling of data from both the prime and restarted mission is ongoing. NEOWISE completed the 2nd year of data collection in its restarted mission in December 2015, and is continuing to collect a wealth of data. Data from prime and 1st year of restart are now available online on IRSA website [4], with data from the 2nd year expected to be released in March 2016. This unique data set will be a valuable resource for the analysis of comets in the infrared for years to come. References: [1] Mainzer, A. et al., 2014, ApJ, 792:1; [2] Bauer et al. 2015, ApJ, 814:2; [3] Kramer 2014, PhD Thesis, Univ. of Central FL; [4] Cutri, R. et al., 2015, http://wise2.ipac.caltech.edu/docs/release/neowise/expsup/ Acknowledgments: This publication makes use of data products from (1) WISE, which is a joint project of UCLA and JPL/Caltech, funded by NASA; and (2) NEOWISE, which is a project of JPL/Caltech, funded by the Planetary Science Division of NASA. EK and SS gratefully acknowledge support from the NASA Postdoctoral Program.

****

The Complex Rotation State of Comet 103P/Hartley 2

Tony Farnham et al.

University of Maryland (United States)

On November 4, 2010, the Deep Impact (DI) spacecraft made its closest approach to comet 103P/Hartley 2, passing only 694 km from the nucleus. During the approach, encounter and departure, hundreds of thousands of images were obtained with the Medium Resolution Instrument (MRI), High Resolution Instrument (HRI), and the HRI infrared spectrograph. The many discoveries revealed in these observations included a nucleus that has concentrated collimated jets driven by CO_2 emission (A'Hearn et al, 2011), large variability in the production of H2O and CO2 (Besse et al. 2016), and ice patches on the surface (Sunshine et al. 2011). In order to interpret the observations of these phenomena it is necessary to understand the orientation of the nucleus with time, so that its thermal history can be derived and properly modeled. Approach observations of the continuum coma produced a lightcurve that shows the nucleus is in a state of non-principal axis rotation that evolves with time, suggesting that the comet's high activity levels play an important role in the nucleus dynamics. Unfortunately, this excited rotation complicates the task of finding the orientation of the nucleus as a function of time. An analyses of Hartley 2's lightcurve by Belton et al. (2013) described the comet's rotation state, with two periodicities (primary of 18 h, secondary of 28 or 55 h) that change with time. Although the solution they presented describes the periodicities observed around closest approach, it is not sufficient to reproduce the morphology observed at times more than a few days away. We are performing an analysis of the coma morphology over the entire encounter, to derive a comprehensive solution for the nucleus' rotation. Structures in the coma are produced by material flowing from the active jets on the surface. The DI images capture snapshots of these structures and we can use Monte Carlo routines to model them, extracting information about the intensity of the jet activity and the motions of the outflowing dust (Farnham 2009). Using the known orientation at close approach as a bounding case, we are stepping backward and forward in time to determine the orientation of the nucleus throughout the DI encounter. We will present an update on the status and conclusions of this analysis.

A'Hearn, M.F., et al. (2011) Science 332, 1396-1400 Belton M.J.S., et al (2013) Icarus 222, 595-609. Besse, S., et al. (2016) This meeting. Farnham, T.L., (2009) Planetary and Space Science 57, 1192-1217. Sunshine, J.M., et al., (2011) EPSC-DPS Abs. 6, #1345.

****

Cometary Dust at the Nm Scale from the MIDAS Atomic Force Microscope

Mark Bentley et al.

Space Research Institute, Austrian Academy of Sciences (Austria)

The Micro-Imaging Dust Analysis System (MIDAS) on-board Rosetta is a unique tool for understanding the nature of the cometary dust at the smallest scales. The instrument consists of a dust collection and handling system and the first space-borne atomic force microscope (AFM). MIDAS maps the 3D morphology of individual particles by rastering a sharp tip across their surface. Additional modes allow the magnetic and elastic properties to be constrained. Dust has been collected sporadically in a series of exposures totalling more than 160 days since arrival at 67P. Some dozens of dust particles have been collected and imaged during this time, ranging in size from hundreds of nanometres to tens of microns, and have been scanned with a resolution down to 80 nm. Once collected, a particle can be re-imaged many times in different modes, although some particles are seen to be either modified or indeed broken apart by these scans, putting constraints on their tensile strengths. A major surprise has been the collection of rather larger particles, with sizes of tens of micrometres or greater. These present both technical challenges for instrument operations but also interesting opportunities to compare dust particle properties with other instruments on-board Rosetta (in particular COSIMA and GIADA) which also study particles in this size range. Equally surprising has been the lack of rather small particles; to date no clear sign of particles smaller than about 500 nm has been detected. An overview of the instrument will be presented and the key properties of dust particles thus far collected will be summarised, along with their implications for cometary processes. Finally, expectations for the remaining mission will be given.

****

Grain Structure of Cometary Dust at the Nanometre Scale: New Insights from MIDAS

Roland Schmied et al.

Space Research Institute (Austria)

Investigation of Solar System formation has led to models which are dependent on the dynamics of small dust grains and their interactions in the protoplanetary nebula. Dust aggregation leads to the formation of planets and comets, where the latter have since only undergone minimal alteration. Due to the sensitivity of the models to the microscopic properties of the dust grains, a direct measurement of these properties is critical. To date the structure of cometary dust has been investigated by Stardust after collection in aerogel and by interplanetary dust collected in the stratosphere. Both suffer morphological modifications, due to the collection process, or are of unknown provenance. Therefore a primary objective of ESA's Rosetta mission is the investigation of cometary dust in its most pristine state. Complementary instruments including OSIRIS, GIADA, COSIMA and MIDAS are observing dust particles and grains in the range of a few metres down to approximately 100 nanometres. MIDAS is the first atomic force microscope in space and thus it is uniquely placed to investigate shape, texture and microstructure of cometary dust with nanometre resolution. Here we present a collection of unprecedented 3D images of cometary dust particles comprising loosely connected dust grains with sizes down to a few tens of nanometres. These grains represent the smallest and most pristine material of cometary origin imaged so far. Due to the 3D character of an atomic force microscope the determination of their shape is possible, revealing a non-spherical, irregular structure down to the smallest sizes. Furthermore, a comparison to IDP and Stardust particles shows, despite their modification, very similar morphology and grain sizes. This ground truth measurement revealing the aggregate nature of irregular grains at the sub-micron scale can provide inputs to models of dust aggregation in the presolar nebula. Furthermore the interpretation of remote observations is essentially supported by the determination of size, shape and roughness of the smallest cometary dust grains.

****

Aspherical Dust Dynamics and Coma Dust Analysis of 67P/Churyumov- Gerasimenko based on the In Situ Observations of the GIADA Instrument.

Stavro L. Ivanovski et al.

IAPS - INAF (Italy)

The Rosetta mission has provided unique measurements in the close vicinity of comet 67P/Churyumov-Gerasimenko (67P/CG). Among the closest ever to the comet nucleus in-situ measurements are also those of the dust dynamics performed by the Grain Impact Analyzer and Dust Accumulator (GIADA). We performed numerical simulations of aspherical dust dynamics aimed at interpreting both the GIADA data and any dust data dealing with rotating particles in a cometary coma (e.g. OSIRIS data). The translational and rotational motion of homogeneous, isothermal ellipsoidal dust particles is studied under the influence of gravity, aerodynamic force, torque and radiation pressure. Particularly, we discuss the coma dust environment observed by GIADA during and after the 67P/CG Perihelion.

****

Is the Dust in the Jets Different from that in the Diffuse Coma

Gian Paolo Tozzi et al.

INAF - Osservatorio Astrofisico di Arcetri (Italy)

Determination of the radiance profile of the dust as a function of the distance from the nucleus within jets or within the diffuse coma is essential to study the dust dynamics and physical properties. It can suggest whether a particular component sublimes, fragments, is accelerated, or is in a constant outflow. To perform this analysis, we have considered observations of the 67P/C-G coma performed by the VIRTIS-M spectrometer onboard Rosetta during the pre e post perihelion "era", from April to September 2015, when the spacecraft was at about 150-400 km from the nucleus, in order to cover the greatest part of the coma. We have chosen observations within the diffuse coma and others within strong jets originating from different part of the nucleus. We will describe the results obtained in both cases showing the evolution of the grains as they recede from the nucleus.

****

First Spectrally Complete Survey of Cometary Water Emission at Near IR Wavelengths (0.9-2.5 µm): C/2014 Q2 Lovejoy with TNG/GIANO Spectrograph.

Sara Faggi et al.

Osservatorio Astrofisico di Arcetri (Italy)

Comets are the most pristine bodies of Solar System and water is the most abundant constituent of cometary ice – its production rate is used to quantify cometary activity and the measurements of ortho-para ratio can clarify the nature and meaning of the spin temperature in the cosmic context. Last February 2015, we acquired the first comprehensive high resolution spectral survey of comet C/2014 Q2 Lovejoy in the 0.9-2.5 µm range, by observing with GIANO - the near-IR spectrograph on TNG (the Italian Telescopio Nazionale Galileo in La Palma, Canary Islands, ES). We detected emissions of radical CN, water (H2O), and many undefined emission features. We quantified the water production rate by comparing the calibrated line fluxes with the NASA Goddard full non resonance fluorescence cascade model for H2O. The production rate of ortho and para water provide an estimation of ortho to para ratio consistent with statistical equilibrium (3.0), but the confidence limits are not small enough to enable a critical test of the nuclear spin temperature in this comet. Until now, high-resolution spectroscopy in the infrared (2.7 - 5µm) has been a powerful tool to quantify molecular abundances in cometary comae. Today the expansion to the near-IR region (0.9-2.5 µm) will extend this capability to new band systems. Our observations open a new pathway for cometary science in the near-infrared spectral range (0.9-2.5 µm) and establish the feasibility of astrobiology-related scientific investigations with future high resolution IR spectrographs on 30-m class telescopes, e.g., the HIRES spectrograph on the E-ELT telescope.

****

Four-fluid MHD Simulations of the Plasma and Neutral Gas Environment of Comet 67P/CG Near Perihelion

Tamas I. Gombosi et al.

University of Michigan (United States)

The neutral and plasma environment is critical in understanding the interaction of comet 67P/Churyumov-Gerasimenko (CG), the target of the Rosetta mission, and the solar wind. To serve this need we developed a 3-D four fluid model, which is based on BATS-R-US within the SWMF (Space Weather Modeling Framework) that solves the governing multi-fluid MHD equations for the plasma and the Euler equations for the neutral gas fluid. These equations describe the behavior and interactions of the cometary heavy ions, the solar wind protons, the electrons, and the neutrals. The model incorporates different mass loading processes, including photo and electron impact ionization, charge exchange, dissociative ion-electron recombination, and collisional interactions between different fluids. We simulate the near nucleus plasma and neutral gas environment near perihelion with a realistic shape model of CG and compare our simulation results with Rosetta observations.

****

Far-ultraviolet Spectroscopy of Recent Comets with the Cosmic Origins Spectrograph on the Hubble Space Telescope

Paul D. Feldman et al.

Johns Hopkins University (United States)

Since its launch in 1990, the Hubble Space Telescope (HST) has served as a platform with unique capabilities for remote observations of comets. Successive generations of imagers and spectrographs have seen large advances in sensitivity and spectral resolution enabling observations of the diverse properties of a representative number of comets during the past 25 years. To date, four comets have been observed in the far-ultraviolet by the Cosmic Origins Spectrograph (COS), the last spectrograph to be installed in HST, in 2009: 103P/Hartley 2, C/2009 P1 (Garradd), C/2012 S1 (ISON), and C/2014 Q2 (Lovejoy). COS has unprecedented sensitivity, albeit no spatial resolution, and the principal objective was to determine the relative CO abundance from measurements of the CO Fourth Positive system in the spectral range of 1400 to 1700 Å. In the two brightest comets, nineteen bands of this system were clearly identified. The water production rate was derived from nearly simultaneous observations of the OH (0,0) band at 3085 Å by the Space Telescope Imaging Spectrograph (STIS). The derived CO/H2O production rate ratio ranged from ~0.3% for Hartley 2 (Weaver et al., ApJ 734:L5, 2011) to ~20% for Garradd. In addition, strong partially resolved emission features due to multiplets of S I, centered at 1429 Å and 1479 Å, and of C I at 1561 Å and 1657 Å, were observed in all four comets. Weak emission from several lines of the H2 Lyman band system, excited by solar Lyman-α and Lyman-β pumped fluorescence, were detected in comet Lovejoy. This work is based on observations made with the NASA/ESA Hubble Space Telescope, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. Support was provided by NASA through grants from the Space Telescope Science Institute.

****

Evolution of the Major Cometary Volatiles around Comet 67P/Churyumov-Gerasimenko as seen by ROSINA-RTOF from 3.1 to 1.6 AU.

Sébastien Gasc et al.

University of Bern, Physikalisches Institut (Switzerland)

Aboard the ESA Rosetta spacecraft orbiting comet 67P/Churyumov-Gerasimenko since autumn 2014, the Reflectron-type Time-Of-Flight mass spectrometer has been monitoring in situ the evolution of the main cometary volatiles with high time resolution. We present in this work the long-term evolution of H2O, CO2, and CO, and the time variations of the measured CO2/H2O ratios from August 2014 to spring 2015, thus investigating the strong heterogeneity and the substantial diurnal and seasonal variations of the coma of the comet.

****

In Situ Space Gas Dynamic Measurements by the ROSINA Comet Pressure Sensor COPS Onboard Rosetta Spacecraft

Chia-Yu Tzou et al.

Physikalisches Institut, University of Bern (Switzerland)

The ROSINA instrument onboard of the European Space Agency's Rosetta spacecraft consists of two mass spectrometers and a pressure sensor to determine the total density of the volatiles, their composition, and the gas bulk velocities in the coma of comet 67P/Churyumov-Gerasimenko (67P). The Comet Pressure Sensor (COPS) of ROSINA includes a "nude gauge", which measures the total neutral density in the coma, and a "ram gauge", which measures the dynamic pressure of the cometary gas flux. With the two gauges COPS is capable to derive the gas dynamics at the location of the spacecraft. We will present ROSINA COPS observations of the gas dynamics of comet 67P's coma from the first observations in early August 2014 to spring 2015.

****

The Plasma Interaction of Comet 67P/Churyumov-Gerasimenko With The Solar Wind

WITHDRAWN

Karl-Heinz Glassmeier et al.

TU Braunschweig (Germany)

During the past 20 months the sensors of the Rosetta Plasma Consortium have been able to provide numerous new and exciting measurements of the plasma interaction processes of the active nucleus of 67P/Churyumov-Gerasimenko and the solar wind. Details of the pick-up process and subsequent acceleration of charged particles of cometary origin, the deflection of the solar wind, new wave generation processes, indications of bow shock dynamics, magnetic cavity formation, the impact of CMEs on the inner most coma and further cometary plasma processes could be studied and provide most important new information on the development of the interaction region. Based on these new measurements the Rosetta Plasma Consortium suite of sensors has been able to fully reach its science goals within the Rosetta project. A review of up-to-date results and comparision with comparable measurements at other comets is presented.

****

Characterizing Cometary Electrons with Kappa Distributions

Thomas Broiles et al.

Southwest Research Institute (United States)

Comet 67P/Churyumov-Gerasimenko (67P) is a Jupiter class comet that orbits the Sun between 1.3 and 5 AU. The Rosetta spacecraft has travelled with 67P since Aug. 6, 2014, and has been an unprecedented opportunity to study cometary plasma. Cometary electrons are particularly important to chemistry and plasma dynamics within the coma. Previous studies have considered the importance of electrons in cometary physics, however none have considered the importance of electrons residing out of thermal equilibrium. Particle systems out of thermal equilibrium can be characterized with the kappa distributions or combinations thereof.

In this work, we show that the electrons at 67P are better described by kappa distributions, and consider the implications of this to cometary chemistry and plasma physics.

****

Ionisation Source of the Plasma Environment around Comet 67P

Marina Galand et al.

Imperial College London (United Kingdom)

Despite low outgassing rates (<5x10^(26) s^(-1)) at large heliocentric distances (>2.5 AU), the plasma close to the Rosetta target comet C-G/67P (<30 km) is primarily of cometary origin. The main focus of this study is to identify the prime source for this plasma. For that purpose we use an ionospheric model to organize a multi-instrumental dataset, which includes: (1) Rosetta Plasma Consortium (RPC) measurements from the Langmuir Probe (LAP), Mutual Impedance Probe (MIP), Ion and Electron Sensor (IES), Fluxgate Magnetometer (MAG), and Ion Composition Analyser (ICA) and (2) total neutral number density from the Cometary Pressure Sensor (COPS), part of the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA). At such large distances from the Sun, the outgassing rate is low enough to have the ionization rate balanced by transport. While the model provides ionospheric densities, which often agree well with observations from LAP and MIP, we identify periods when it departs from measurements and discuss possible reasons for the discrepancies. For all instances in which the model output is compared with measured data, we identify the prime source of ionization and assess the relative contribution of extreme ultraviolet solar radiation and suprathermal electron impact ionization.

****

Properties of Dust Particles in Comets from Polarimetric Observations of 67P

Edith Hadamcik et al.

Univ. P. & M. Curie, LATMOS (France)

Cometary activity changes considerably when comets approach the Sun. Jets can be observed in polarization maps, allowing interpretations in terms of properties of the dust particles. We summarize polarimetric observations of 67P/Churyumov-Gerasimenko during its 2008-09 apparition, between solar distances of 1.26 au and 1.45 au (before and after perihelion). We present observations from Hubble Space Telescope at 2.56 au and 1.64 au, before and after perihelion, respectively, and photometric observations from Himalayan Chandra telescope (India). Interpretation of such observations will be discussed, taking into account Rosetta results on dust particles. We will also compare 67P polarimetric properties with those of other JFC comets (47P, 81P, 22P), and of 1P/Halley and Oort cloud comets at similar solar distances. *On behalf of the HST Comet Polarimetry Team.

****

67P/Churyumov-Gerasimenko Coma Dust Environment at 2 AU Measured by GIADA

Vincenzo Della Corte et al.

IAPS-INAF (Italy)

GIADA (Grain Impact Analyzer and Dust Accumulator) is an in-situ instrument onboard Rosetta devoted to measure physical and dynamical properties of the dust particles emitted by comet 67P/Churyumov-Gerasimenko nucleus. The 3 measurement sub-systems constituting GIADA provide for each dust particle: the mass, the momentum and the speed. During the period February 2015 to March 2015 Rosetta performed several flybys with different close approach distances, different coordinates of the sub-spacecraft point at the closest approach, and different observing geometry (phase angle), allowing GIADA to characterize the dust environment within the 67P/C-G coma. The close distances from the surface reached by the spacecraft during the flybys allowed linking compact particle dust emission to confined regions on the nucleus. Acknowledgements. GIADA was built by a consortium led by the Univ. Napoli “Parthenope” & INAF- Oss. Astr. Capodimonte, IT, in collaboration with the Inst. de Astrofisica de Andalucia, ES, Selex-ES s.p.a. and SENER. GIADA is presently managed & operated by Ist. di Astrofisica e Planetologia Spaziali-INAF, IT. GIADA was funded and managed by the Agenzia Spaziale Italiana, IT, with a support of the Spanish Ministry of Education and Science MEC, ES. GIADA was developed from a PI proposal supported by the University of Kent; sci. & tech. contribution given by CISAS, IT, Lab. d'Astr. Spat., FR, and Institutions from UK, IT, FR, DE and USA. We thank the RSGS/ESAC, RMOC/ESOC & Rosetta Project/ESTEC for their outstanding work. Science support provided by NASA through the US Rosetta Project managed by JPL/California Institute of Technology. GIADA calibrated data will be available through the ESA’s PSA web site.

****

Volatile Species in the Inner Coma of 67P/Churyumov-Gerasimenko Observed with VIRTIS on Board Rosetta

Alessandra Migliorini et al.

IAPS-INAF (Italy)

Volatile species in the inner coma of 67P/Churyumov-Gerasimenko observed with VIRTIS on board Rosetta Migliorini A., Piccioni G., Capaccioni F., Filacchione G., Bockelée-Morvan D., Erard S., Leyrat C., Combi M., Fougere N., Crovisier J., De Sanctis M.C., Schmitt B., Tozzi G.P., Rinaldi G.,Capria M.T., and the VIRTIS-Team The study of 67P/CG inner coma environment, including the H2O and CO2, is one of the primary scientific goals of the VIRTIS/Rosetta spectrometer. Vibrational emission lines of H2O and CO2 at 2.67 and 4.27 µm, respectively, are identified by VIRTIS-M imaging channel and mapped from the surface up to about 10 km altitude. April 2015 data show how the gas distribution in the inner coma is linked with active areas on the nucleus: the maximum H2O emission is mainly concentrated above Aten-Babi and Seth-Hapi regions, while CO2 is more uniformly distributed in the southern latitude regions. Further data acquired during the escort phase of the mission will be analysed to have a general picture of evolution of H2O with heliocentric distance. Our study confirms the asymmetric distribution of carbon dioxide and water at northern latitudes, and improves our knowledge about the spatial and temporal distribution of the gases in the lower coma.

****

The Abundance of Complex Organic Molecules in Comets from Molecular Surveys at Submm/mm Wavelengths

Nicolas Biver et al.

LESIA, Observatoire de Paris (France)

Since 1997, beginning with the great comet Hale-Bopp, submm/mm radio techniques have proven to be very efficient in detecting a large number of parent molecules in cometary comae. The abundances relative to water of complex organic molecules (COMs) such as ethylene glycol were measured for the first time in a comet. Current mm detectors, especially at the IRAM telescopes, are over 20 times more efficient for spectroscopic surveys. The recent apparitions of several bright comets (e.g., C/2012 F6, C/2013 R1, C/2014 Q2) have enabled the detection of all molecules previously observed in comet Hale-Bopp, as well as new COMs such as ethanol and glycolaldehyde. More sensitive upper limits on the abundance relative to water of other COMs were also obtained and will be presented.

****

Evolution and Structure of a Comet Magnetosphere - Rosetta Observations

Hans Nilsson et al.

Swedish Institute of Space Physics (Sweden)

Rosetta has followed comet 67P from low activity at more than 3 AU heliocentric distance to high activity at perihelion and then out again. We study the evolution of the dynamic ion environment using the RPC-ICA ion spectrometer. In mid to late April the solar wind started to disappear from the observation region. This was associated with the solar wind deflection reaching 90°, indicating that the solar wind free region formed due to severe mass loading and associated solar wind deflection. Accelerated water ions, moving mainly in the anti-sunward direction kept being observed. We report how the accelerated water ion environment changed as Rosetta was located relatively deeper into comet magnetosphere as comet activity increased. Shortly after perihelion, Rosetta made an excursion to 1500 km cometocentric distance, the only data providing a spatial context to the comet magnetosphere plasma environment observations. We discuss the data from the excursion and what we learn about the scale size of the comet magnetosphere as well as the energy transfer from the solar wind to the comet environment inside the comet magnetosphere.

****

Origin(s) of the Microscopic Structures at the Philae Landing Site and possible Implications on the Formation and Evolution of the Nucleus

François Poulet et al.

Institut d'Astrophysique Spatiale (France)

The CIVA cameras onboard PHILAE provided unique in situ images of the surface of a comet at a microscopic scale (Bibring et al., Science, 2015). The CIVA panorama at the landing site on the 67P comet reveals a rough, irregular and inhomogeneous terrains dominated by fractures and agglomerates of consolidated materials. While the composition of these materials is unknown, they provide unique structures to constrain the conditions prevailing at the surface of a comet and also possibly to its formation. A quantitative analysis of one ubiquitous microscopic structure (grains that look like pebbles) will be presented. Two spatial scale systems of the landscape are used to characterize their dimension. The first one is based on the antenna and legs visible on the image. However, given the complex and irregular landscape including cliffs and overhangs , a second reference and likely more accurate system is provided by a synthetic reconstruction of the OSIRIS-based topography of Abydos in 3D from a method called "multiresolution photoclinometry by deformation" (Capanna et al., Visual Computer & DPS, 2015). The pebble size distribution are reasonably well fitted by power-laws having different cumulative indexes. The pebble sizes and their distributions will be compared to the properties of various 67P materials such as grains at the touchdown site (Mottola et al., Science, 2015), boulders surrounding the landing site (Lucchetti et al., A&A, 2016), >7m sized boulders globally distributed on the comet (Pajola et al., A&A, 2015), grains collected by the COSIMA experiment onboard Rosetta (Langevin et al., JGR, 2016) as well as population of grains remotely observed in the coma (Bauer et al. ApJ, 2012; Rotundi et al. Science, 2015). The nature of the pebbles will be then discussed in

relation to modern and past processes that could explain their formation. As recent structures, they could be the result of current erosive processes that affect the comet (fracturing microscopic process, sublimation processes, non-escape and redeposition of particles previously emitted from other regions of the comet). Given the consolidated nature of the pebble agglomerates, a formation in an inhomogeneous granular media is however preferred. An intriguing possibility is that these particles may be left over relics of the formation process, as there are several lines of evidence (especially lack of thermal and aqueous alteration processing as expected if it would be the collisional relics of larger bodies) that the nucleus could be primordial (Davidsson et al., DPS, 2015), and not a collisional rubble piles of a large body (Morbidelli and Rickman A&A, 2015). This view is also supported by numerical simulations in which small icy bodies in the outer-Solar System formed from collapsing clouds of small pebbles (e.g., see Johansen et al., 2015 for a review). Under this assumption, we then compare the observed properties of the pebbles with the outputs of several numerical simulations performed by various authors to provide constraints on the formation location of 67P.

****

The Fate of Molecular Oxygen: from the Protosolar Nebula to Comets

Olivier Mousis et al.

Laboratoire d'Astrophysique de Marseille, Aix-Marseille Université (France)

The recent detection of large amounts of molecular oxygen by the Rosetta/ROSINA instrument in comet 67P/Churyumov-Gerasimenko poses the question of its origin. Because the measured mole fraction of molecular oxygen is 1-10% relative to water in the coma, this implies that a major process and/or a significant part of the cometary material is participating in the trapping. Here we explore the different scenarios (trapping, condensation, etc) that can potentially lead to the incorporation of this molecule in the building blocks of comets at their formation epoch in the protosolar nebula. We also discuss the different ice structures that could match the strong correlation between the molecular oxygen and water production rates. This allows us to propose some constraints on the mechanisms that favored the presence of molecular oxygen into 67P/Churyumov-Gerasimenko.

****

Assessing the Primordial Character of Comet 67P/Churyumov-Gerasimenko

Hermann Boehnhardt et al.

MPI for Solar System research (Germany)

Comets are considered to be primordial. Rosetta is therefore a mission which investigates a remnant of the early solar system formation phase which may carry information characterizing the conditions in the early solar system. The primordial character of the Rosetta target comet 67P/Churyumov-Gerasimenko (67P) is assessed by evaluating answers to three questions: Which observable parameters provide information on the primordialof 67P? Which primordial environment and conditions do the individual parameters describe and/or constrain? Is there a pathway for 67P through the formation and early evolution history that is indicated by the available set of parameters with primordial relevance? In our meeting contribution we report on how we intend to approach the answers to the questions above.

****

High Spectral Resolution of Doppler Shifted Emission from Comet 9P/Tempel 1 following the Deep Impact Encounter: Evidence for Large Scale Internal Energy Release Producing a High Velocity Jet from the Impact Site

Jason Corliss et al.

University of Arizona (United States)

At 5:52 UTC on July 4, 2005 a 372 kg mass collided with comet 9P/Tempel 1 as part of the Deep Impact encounter. The relative velocity of the impactor was 10.3 km/sec, with a total energy input of ~20 GJ. We report here on narrow bandpass, high spectral resolution measurements targeting the metastable [O1D] emission line obtained over the 48-hour period after the impact event using a wide-field spatial heterodyne spectrometer at the McMath-Pierce Solar Telescope on Kitt Peak. Observations on July 4th show evidence for an emission feature that is partially blended with the Telluric [O1D] line that appears approximately 1 hour after the impact. Follow up measurements on July 5th and 6th show robust, spectrally resolved detections of comet emission. In each case the observed line is Doppler shifted from the geocentric rest velocity of Temple 1. The extent of the shift varies with time reaching a maximum of -13.4 km/sec on July 5th and follows a pattern of velocity changes roughly consistent with the nucleus rotation rate. In this presentation we describe the measurements, their calibration, and various potential source mechanisms for the emission. We conclude that the most likely source of the observed feature is a collimated, high velocity jet composed of atomic oxygen and water group ions emanating from the nucleus and producing [O1D] emission from a combination of collisional stimulation and recombination. Based on this, a kinetic energy calculation assuming one [O1D] photon per oxygen atom implies the need for at least 2 to 3 orders of magnitude more energy than was delivered by the impact. We discuss the implications of this for internal nucleus structure.

****

Thirty Years of Detecting Primary Volatiles in Comets

MIchael J. Mumma

NASA Goddard Space Flight Center (United States)

Cometary water (H2O) was first detected in December 1985 using infrared spectroscopy from NASA's Kuiper Airborne Observatory, and again in March 1986 with the KAO and (in situ) via infrared spectra from Vega 2 and in mass spectra from Giotto. The KAO detections punctuated and validated a long effort (since 1972) to develop the concepts and methodology for infrared vibrational sensing of cometary parent volatiles, and marked the onset of 30 years of continuing advances that now permit simultaneous measurement of many primary volatiles using ground-based astronomical facilities. With more than 20 comets now studied in detail, the infrared database has permitted an emerging cometary taxonomy based on primary volatile composition. Together with similar advances in rotational spectroscopy in 1985 and beyond, the combination has revolutionized our understanding of these primitive bodies from the early planetary system (Mumma and Charnley ARAA 2011). How did this happen? The KAO detection confirmed a strategy first identified in 1972, and under development since then. The eureka moment came when I realized that the cometary atmosphere was both very cold and also collisionally impoverished, suggesting that radiative decay from solar-pumped excited vibrational states would compete favorably against collisional quenching, thereby permitting intense ro-vibrational emission from populations characterized by low rotational temperatures. Non-thermal effects would characterize the molecular excitation and emission processes, and the optimum wavelength domain for detections would depend on the specifics of the process and the molecule in question. Development of quantitative predictions for

emission intensities and optimal search regions was critical. I immediately embarked on intense consideration of the physics involved, and presented first results at an international conference in 1981 (Mumma-NASA-CP2223-1982). Hal Weaver joined me as a post-doctoral fellow that year, and we submitted our greatly expanded version of this idea for publication on 8 March and it was accepted on 28 June 1983 (Weaver and Mumma ApJ1984). Our models targeted fluorescence equilibrium in which the detailed ro-vibrational populations are controlled by fluorescent pumping and decay in both vibrational and rotational emissions and so have very low rotational temperatures. Unknown to us, Crovisier and Encrenaz were developing the concept in parallel, but they emphasized LTE rotational populations at 300K so then-available molecular databases could be used for simulations; their paper was submitted on 12 March and accepted on 26 April 1983 (Crovisier and Encrenaz A&A1983). These two papers form the basis for the now-widely accepted observational approach of solar-pumped infrared fluorescence, for detection of primary volatiles in comets. Many subsequent papers established the methodology for vibrational band systems of molecules having up to 8 atoms (C2H6). This work drove the search strategies that led to KAO detection of water (v3 band, 2.7µm) in comet 1P/Halley, C/1987 P1 (Wilson), and 23P/Brorsen-Metcalf (in 1989) (Mumma+Science1986, Weaver+Nature1986, Larson+ApJL1986). However, the attempted detections of methane in comets Halley and Wilson did not succeed (Larson+ApJ1989). The wide optical bandwidth of the FTS presented large stochastic noise to the detection system, limiting the sensitivity and dictating the need for a different instrumental approach. Cryogenic grating spectrometers with array-based detectors provided the solution. We also needed a new method for detecting cometary water from ground-based observatories. The problem can be stated succinctly: how can we make Earth's atmospheric water disappear, so as not to absorb the water lines emitted by an extraterrestrial water source? The successful strategy seems obvious once explained – and so it is – but it was not so obvious before the strategy was conceived, and then demonstrated! The solution is to search for hot-band and combination band emission lines that are pumped from the ground vibrational state but that terminate on a ro-vibrational level lying far above the ground state (E/k >>300 K), where atmospheric populations are negligible. After 1992, ground-based capabilities expanded rapidly. CSHELL at IRTF enabled a major breakthrough by coupling high resolving power and a 256x256 array detector. With CSHELL, my team detected an emission line of the (111-100) H2O hot-band (near 2µm) in C/1991 T2 (Shoemaker-Levy), and CSHELL's upgrade with a 256x256 InSb detector array in 1995 permitted detection of H2O in comet 6P/d'Arrest. These were the first definite detections of cometary water from ground-based observatories (Mumma+BAAS1995). We now use H2O emissions from 20 different hot- and combination-bands ranging from 1.4–5µm wavelength. The 1995 upgrade also permitted detection of water and 8 trace gases in C/1996 B2 (Hyakutake) and later comets, while the 1999 commissioning of the first cross-dispersed echelle spectrometer (1Kx1K InSb array; NIRSPEC at Keck-2) revolutionized the field again. The imminent commissioning of iSHELL (RP ~90,000; 2Kx2K HgCdTe array detector) at IRTF will do so once more. I will present aspects of the emerging taxonomy for comets based on composition, and compare them with insights obtained from Rosetta, Deep Impact/EPOXi, and Giotto.

****

The Distribution of Extended Source Species in Comets: the Case of H2CO

Stefanie Milam et al.

NASA Goddard Space Flight Center (United States)

The composition of comet nuclei is determined primarily from the remote detection of material found in their atmospheres (Mumma & Charnley 2011). These detections are then deconvolved by a simple Haser model that interprets species as either “parent”, having direct sublimation from the nucleus, or “daughter”, typically associated as a photoproduct of a parent species (Haser 1957). This simple model has been manipulated to account for comet chemistry beyond photodissociation and other physical properties, such as hydrodynamics, to help interpret remote observations (Rodgers et al. 2004). However, not all species can be explained by these models. The distributions of some molecules extend beyond direct sublimation, at least in part, and have no known parent for this additional contribution (Cottin & Fray 2008). The Rosetta mission has confirmed the presence of nonvolatile organic macromolecular materials on the surface, which are likely the source of some of the extended species (Capaccioni et al. 2015). Since the first radio detection of H2CO toward Comet Halley, it has been proposed that this molecule arises generally from a source 103-104 km from the nucleus (Snyder et al. 1989). The extended source of H2CO was predicted and observed to have a scalelength approximately 1.2 times the photodissociative scalelength of H2CO at 1 AU for Comet Halley, roughly 104 km from the nucleus (Meier et al. 1993). This is now confirmed in a number of bright comets where H2CO was mapped at millimeter wavelengths (e.g. Biver et al. 1999; Milam et al. 2006; Bockelée-Morvan et al., 2000), verifying the source scalelength to be ~7000 km at 1 AU and does not fit with any known parent. Using the unique sensitivity and high spatial resolution of ALMA, we observed H2CO emission from the innermost regions of several cometary comae and have verified the extended source of H2CO. Scale lengths ~300-2000 km were derived at heliocentric distances 0.5-1.5 AU (Cordiner et al. 2014), although ALMA is not sensitive to extended emission on larger scales. To date only a limited number of objects have been imaged in H2CO, thus a rigid identification of the parent source is still not highly constrained. The most compelling source is the H2CO polymer, polyoxymethylene (POM), due to the strong correlation with laboratory results on the thermal degradation of POM with the long term evolution studies in Hale-Bopp (Biver et al. 1997; Fray et al. 2006). We will present full details of recent H2CO observations with a few case studies from ALMA observations and compare those to results obtained from spacecraft.

References: Biver, N. et al. 1997, Science, 275, 1915 Biver, N. et al. 1999, AJ, 118, 1850 Bockelee-Morvan, D. & Crovisier, J. 2000, A&A, 353, 110 Capaccioni, F. et al. 2015, Science, 347, aaa0628-1 Cordiner, M. et al. 2014, ApJ, 792, L2 Cottin, H. & Fray, N. 2008, SpSciRev, 138, 179 Fray, N. et al. 2006, Icarus, 184, 239 Haser, L. 1957, Bulletin de l’académie royale de Belgique 43, 740 Meier, R., Eberhardt, P., Krankowsky, D., & Hodges, R.R. 1993, A&A, 277, 677 Milam S.N., et al., 2006, ApJ, 649, 1169 Mumma, M. & Charnley, S. 2011, ARAA, 49, 471 Rodgers S.D. et al. 2004, in COMETS II, eds. M. Festou, et al., Univ. Arizona Press, p. 505 Snyder, L. E, et al. 1989, AJ, 97, 246

****

Sulfur from Protostars to Comets

Maria N. Drozdovskaya

Leiden Observatory (The Netherlands)

Sulfur is one of the top ten most abundant elements in the interstellar medium, however; its budget remains puzzling. Diffuse clouds contain [S]tot =1.5×10−5, while in dense cores only [S]tot ~10−8 (relative to H2) has been accounted for. Sulfur chemistry has remained poorly constrained and the missing S-reservoir in dense cores has not been uncovered. Suggestions have been made that sulfur is partially concealed in refractories, which would prove it to be a unique tracer of both the volatile and rocky content of cometary and protoplanetary materials. In this work, sulfurbearing molecules in the large ALMA survey of the protostar IRAS16293-2422, that has been carried out in the framework of the “Protostellar Interferometric Line Survey (PILS)” program (Jørgensen et al. in prep.), have been identified and isotopic ratios derived. The obtained results are compared with the latest sulfur isotopic ratios derived for 67P/Churyumov-Gerasimenko with the ROSINA instrument (Calmonte et al. in prep.). The two data sets represent some of the best data to date on a protosolar analogue and the building blocks of our Solar System, allowing us to relate the extrasolar and Solar System sulfur budgets. Such comparative work will subsequently be used to guide physicochemical models in implementing sulfur chemistry into the chemical networks, thus shedding light on the missing sulfur problem and the degree of processing between protosolar and cometary contents.

****

Exploring 67P through Art

Ekaterina Smirnova

ekaterina-sminova.com (United States)

It is not a secret that art often inspires science and vice versa. I am an artist, who is deeply inspired by science. For over a year, since the landing of the robotic probe Philae on the comet I have been working on an art project called 67P. Having a goal of discovering our place in the universe, I chose ESA’s Rosetta mission as a successful example of such discovery. Basing my art projects on science I try to share scientific research with my viewers, hoping to inspire them to appreciate science. By building an interest in this impressive mission I hope to stimulate the public to think deeper about the importance of cosmic research and therefore, perhaps, spark a desire to participate in the exploration of space. Exploratory science, such as cometary science, is a creative pursuit. However, by focussing on the logic, the details, the numbers it might happen that the overall beauty, the wonder of what’s in front of us is overlooked. The problems that we attack so diligently always have another side: the grace of the object explored. From the point of view of an artist, who is focusing on visual and aesthetic aspects of 67P, I would be negligent if my art ignored the "science". To me representing the beauty and research are equally important. Just as my art is informed by the science, I believe that science can also benefit from art. During my presentation at the symposium I would like to expand the dialogue to include art and aesthetics. I invite the participants to take a short break from data and equations and enjoy the undefinable charm of the comet through the lens of art and create inspirational reciprocity in between two spheres, creative and scientific. New ideas often originate when two vocabularies are smashed together. By merging art and science, we should be able to create something beyond the mechanical and towards the meaningful. Via this path we perhaps will be able to get a new way of exploring the topic of cometary science. For my project inspired by the 67P mission I focus on the water found on the comet. In my art studio I re-create water that is close in composition to the water on the comet, by enriching it with D2O With this water I paint large scale paintings, based on the photographs by Rosetta. D2O does not effect my paint in any way, but it does provide another way to entice the audience to blend between the art and science. When displaying my works, I share the process of electrolysis which I use for concentrating the level of D2O for the water I paint with and explain its significance. From my experience, the audience is always interested in both sides of the project, the scientific and the creative. And in my opinion, both of the aspects are meant to go along together. I believe that science should be accessible to everyone and this will help to grow a successful generation. So I urge for artists to be invited to become a part of scientific research, which will not only lead to the growth of public interest in the science via arts, but will help both spheres to benefit from one other. Displaying (posters): For the duration of the

Symposium I would like to display some of the paintings and sculptures of the project 67P, which will be accompanied by the music, remixed from the sound of the evaporating from the comet 67P water and a video, demonstrating the creative process of painting 67P. If requested, I can prepare a slide show-demonstration/talk or poster on the subject. To see artwork, please visit: http://www.ekaterina-smirnova.com/eslab-proposal.

****

Ground-based Observing Campaigns of Comets From 1P/Halley to 67P/Churyumov-Gerasimenko

Padma A. Yanamandra-Fisher et al.

Space Science Institute (United States)

The observations and interpretations of comets through the ages have undergone many changes due to the advancement of available technology, observers and cultural moirés. With the advent of telescopes, and remote exploration of the solar system via spacecraft, it became necessary to re-visit legacy data and identify the knowledge gaps in cometary science. The archetype for comets, 1P/Halley, was the target of a well-defined observation campaign by the scientists, ground-based professional observers and the inclusion of the amateur community – a first of its kind! The global observing campaign was based on the identified gaps in knowledge and how to address these questions. The main goals of the campaign were to characterize the comet, coma, tail and morphology; coordinate the professional observer community; data collection and its archival from the campaign and sharing of the data with the both the participating scientists and the public. While scientific analyses continues on the data collected and archived, several important aspects of the campaign determined the standards for ensuing comet observing campaigns. Now, 50 years later, the ESA/Rosetta mission identified the need for a dedicated ground-based observing campaign (including both professional and amateur observers) for observations of its final target, 67P/Churyumov-Gerasimenko (CG). Incorporating the best practices identified during IHW, new requirements and guidelines were developed to include changes in resources and technologies that have occurred over the past 50 years. Some of the issues include the increased number of amateurs, introduction of robotic telescope networks; the development of data repositories for planetary missions (e.g., NASA/PDS and ESA/PSA); improved data reduction models. We will compare and contrast various comet observing campaigns to identify how the science goals of the campaigns were met and what issues need to be changed/improved to provide synergy between mission, professional and amateur observing communities.

****

The New Planetary Science Archive: a Tool for Exploration and Discovery of Scientific Dataset of ESA Planetary Missions

Sebastien Besse et al.

ESA/ESAC (Spain)

The Planetary Science Archive (PSA) is European Space Agency's (ESA) repository of science data from all planetary exploration missions, including the Giotto and Rosetta missions. The PSA is providing access to scientific datasets through various interfaces (e.g. FTP browser, Map based, Advanced search interface, and Machine interface) at this address: http://archives.esac.esa.int/psa. All datasets are scientifically peer-reviewed by independent scientists, and are compliant with the Planetary Data System (PDS) standard, which is the default standard used in planetary science. The PSA is currently implementing a number of very important and significant changes, both for its web-based interface to the scientific community and the public, and for its database structure. The new PSA will be up-to-date with the PDS3 standard, and the new PDS4 standard being used for ESA's upcom- ing ExoMars and BepiColombo missions. The new PSA will maintain the various interfaces and services it had in the past, and will include significant improvements in particular through a Geographical In- formation System (GIS) based search. The new PSA is expected to be made available to the public by mid- 2016. It will support the Rosetta and Giotto scientific and auxiliary datasets and will enhance the scientific output of these cometary missions.

****

Adding Value to 67P/Churyumov-Gerasimenko Data Archives with Virtual Observatory Protocols

Stéphane Erard et al.

LESIA / Observatoire de Paris (France)

Several "use cases" are studied to optimize the ease of access of archival observations of 67P, both from the Rosetta mission and from the ground-based support observations. The Rosetta archive at PSA will soon be accessible using a Virtual Observatory (VO) protocol defined in the Europlanet programme. This will allow the user to search data based on observational or physical parameters (e.g., viewing angles or coordinates / distances). These new capabilities will not only favour the use of instrument datasets, but it will also make comparisons between data acquired by various instruments much easier, e.g. images and spectra. Navcam images could usefully be made available in such a way, provided they are described properly. The ground-based support programme can also take advantage of this type of access protocol. This only requires a catalogue of observations providing the list of search parameters, and a data server supporting the protocol in use. In a first step, this catalogue may only point to the original raw data distributed by the observatories (e.g. ESO archive), but the catalogue could also describe the selected amateur observations that will be included in the ground-based archive. In the long run it will be more useful to collect calibrated or reduced data products and make them available to the community – typically after publication. Similarly, derived Rosetta data product such as maps, time series, light curves, etc, can be made accessible via this type of system. A user interface allowing such searches is already available at http://vespa.obspm.fr. It will provide access to all sorts of Planetary Science data, including past comet observations. These currently include infrared spectroscopy from IKS/Vega-1, and observations of 53 comets from the Nançay radio telescope.

****

No Bit left behind: PDS Cometary Archive from Giotto to Rosetta

Ludmilla Kolokolova et al.

University of Maryland (United States)

The history of cometary data archiving began 30 years ago with the publication of the CD-ROM collection of data resulting from the International Halley Watch (IHW) campaign and associated space missions to comet Halley: Giotto, Vega 1 and 2, Sakigake and Suisei. Archiving these data was one of the first tasks undertaken by the Small Bodies Node of NASA's then recently-established Planetary Data System (PDS). This was done after converting the IHW archive into PDS format and carrying out an international peer review of those data. The PDS is NASA's permanent archive for all planetary data obtained by its spacecraft missions to solar system bodies, and has grown to include ground-based and laboratory data to support mission planning and the analysis of the resulting data. The PDS is structured as a distributed archive, with data germane to various disciplines (atmospheric sciences, geosciences, small bodies, etc.) hosted by and with specialists having vested interest in collecting, maintaining, and using the data – the PDS Nodes. The Small Bodies Node (SBN) is the PDS home for observations of small solar system bodies – comets, asteroids, dwarf planets, interplanetary dust, meteorites, and so on. The SBN itself has two specialist subgroups – the Comet group located at the University of Maryland and led by Mike A'Hearn, and the Asteroid/Dust group located at the Planetary Sciences Institute in Tucson, AZ, headed by Eric Palmer. Since bringing the IHW data into its archives nearly 25 years ago, SBN has archived, or is archiving, the data resulting from every deep-space mission to a small body. The Comet group now hosts and maintains data from: the International Cometary Explorer to comet 21P/Giacobini-Zinner ; the Giotto Extended Mission to comet 26P/Grigg-Skjellerup; the Deep Space 1 observations of comet 19P/Borrelly; the Deep Impact mission to comet 9P/Tempel 1 and its extended mission (EPOXI) to comet 103P/Hartley 2 (the EPOXI mission also included remote observations of comets C/Garradd (2009 P1) and C/ISON (2012 S1)); the Stardust Mission to comet 81P/Wild 2, and its extended mission, Stardust NexT, to comet 9P/Tempel 1 and recent balloon mission BOPPS. Currently, the SBN Comet group is focused on the Rosetta mission to comet 67P/Churyumov-Gerasimenko (1969 R1). To date there are over 300 Rosetta datasets (672GB) hosted by the SBN. The SBN Comet group also archives cometary observations mined from the data collections of non-planetary missions like the Ultraviolet Explorer (IUE), the Solar and Heliophysics Observatory (SOHO), and the Solar Terrestrial Relations Observatory (STEREO). In addition to the IHW collection, the SBN cometary holdings include ground-based data ranging from images and spectra, through reference data sets of reported results and characteristics compiled from the literature, to laboratory spectra of various ice and mineral samples. The overall SBN holdings currently stand at 885 individual data collections (comprising over 4TB of data) reviewed and archived over its lifetime. In addition, SBN holds copies of 63 collections from failed missions or partially successful data rescue attempts (so called "safed" data, ~200GB); and has 471 collections (~ 1TB) in active development. The archived (and safed) data are freely available for downloading through the SBN website <pdssbn.astro.umd.edu>. Each collection contains both the data and the documentation to explain and describe the data, including calibration procedures, processing history, caveats for interpretation and use, and so on. The PDS has developed an interface for searching across the holdings of all nodes simultaneously. Like other nodes, SBN has developed interfaces for searching within specific, large data collections. Both PDS and SBN have developed tools for visualizing and manipulating various types of data within the archives. The PSI division of SBN has also developed the Online Archiving Facility (OLAF) to facilitate the creation of well-formed archive submissions for the most common ground-based and mission data formats. Both groups within the SBN are working on extending our archive holdings, specifically by including more high-level mission data products (shape models, gravity models, and such), more ground-based observations, and more reference data resulting from laboratory experiments. We encourage you to submit your data to the SBN to make it accessible to your colleagues and to ensure that it remains useful and available to future generations of researchers.

****

General Comet Traits and Comparison of their Dynamical History – Towards Understanding Long-term Evolutionary Processes on Comets?

Mathieu Choukroun et al.

Jet Propulsion Laboratory (United States)

Six comets have been visited by spacecrafts to date (1P/Halley, 19P/Borelly, 81P/Wild 2, 9P/Tempel 1, 103P/Hartley 2, and 67P/Churyumov-Gerasimenko). Very diverse nucleus morphologies are observed, within a single comet and between them: pits, layered regions, scarps; some of which appear correlated with primary locations of geologic activity. In this review presentation, we highlight general morphological traits, as well as their evolution. We also compare outgassing rates, composition, and their evolution with time. We then investigate the dynamical history of these objects, as it is presently known. These joint comparison of comet properties will be used to identify processes (whether morphological or compositional) that control the long-term evolution of comets over the course of their history.

****

Main Belt Comets: the next frontier

Colin Snodgrass

The Open University (United Kingdom)

The so called 'Main Belt Comets' (MBCs) are a relatively recently identified population. These are bodies that have asteroid-like orbits, within the outer main belt, but show comet-like appearance. While various causes of mass loss from asteroids (such as collisions) can produce short lived debris, only comet-like activity (sublimation of ices) can explain the repeated tails at each perihelion of at least four of the observed population. The survival of ice over the age of the solar system in the asteroid belt was unexpected - it must be buried under the surfaces of MBCs and have been exposed relatively recently to produce the observed activity. The MBCs therefore represent an interesting population to test the amount of water in the asteroid belt (and therefore constrain planet formation models), and also the most obvious route to allow us to sample the water there. As Rosetta results indicate that Earth's water does not match the D/H seen in Jupiter family comets (or, at least, in 67P), water-rich asteroids should also be considered as a likely source of our oceans. There is therefore an increasing astrobiological interest in studying MBCs, beyond the obvious cometary science goals of investigating active bodies from very different source locations.

I will present a summary of our current knowledge of MBCs, and outline future steps to progress in this field, including the detection, sampling and characterisation of water in the asteroid belt.