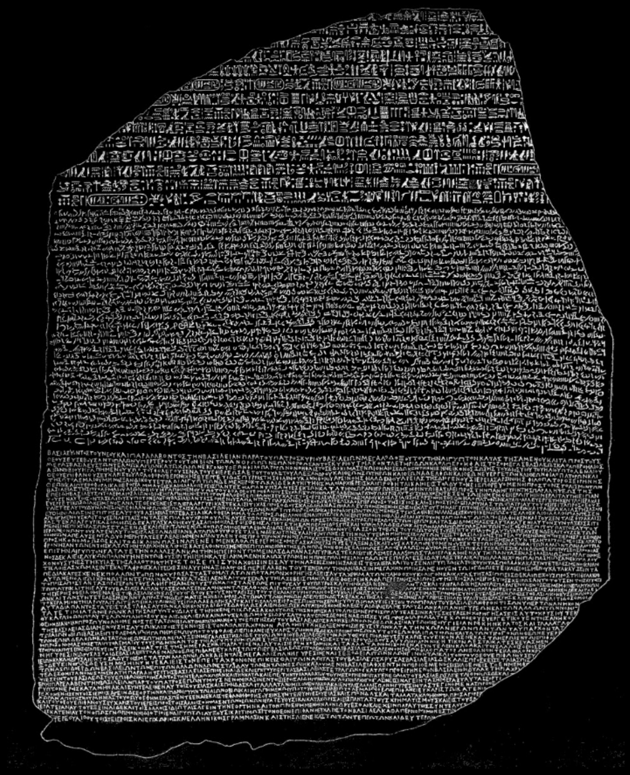
Deciphering the Rosetta stone

The ultimate goal of Rosetta:

Decipher the origin of the solar system, the Earth and life by studying a comet

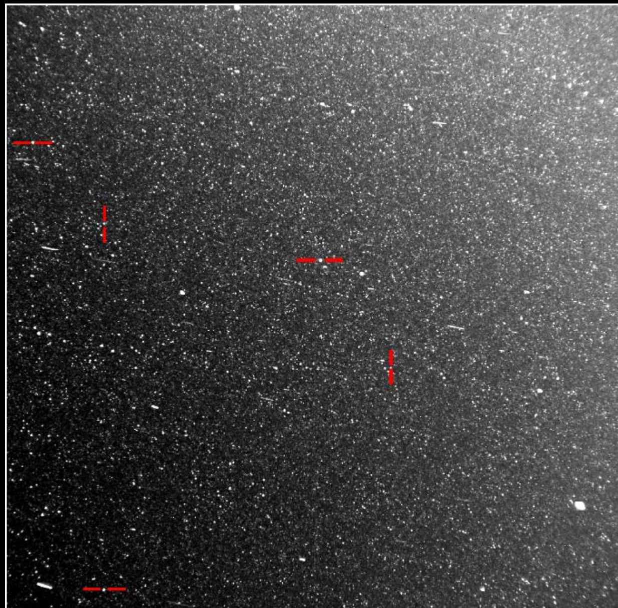


Payload

• OSIRIS	Camera	28 kg
• ROSINA	Gas-Mass spectrometer	35 kg
• COSIMA	Dust-Mass spectrometer	20 kg
• GIADA	Dust flux analyzer	4.5 kg
• MIDAS	Dust microscope	5.5 kg
• VIRTIS	Infrared-Spectrometer	23 kg
• MIRO	Microwave-Experiment	16.2 kg
• ALICE	Ultraviolet-Spectrometer	2.2 kg
• RPC	Plasma instruments	5.7 kg
• RSI	Radio Experiment	0.0 kg
• CONSERT	Comet Nucleus Sounder	2.0 kg
• LANDER Philae	with 9 experiments	100 kg

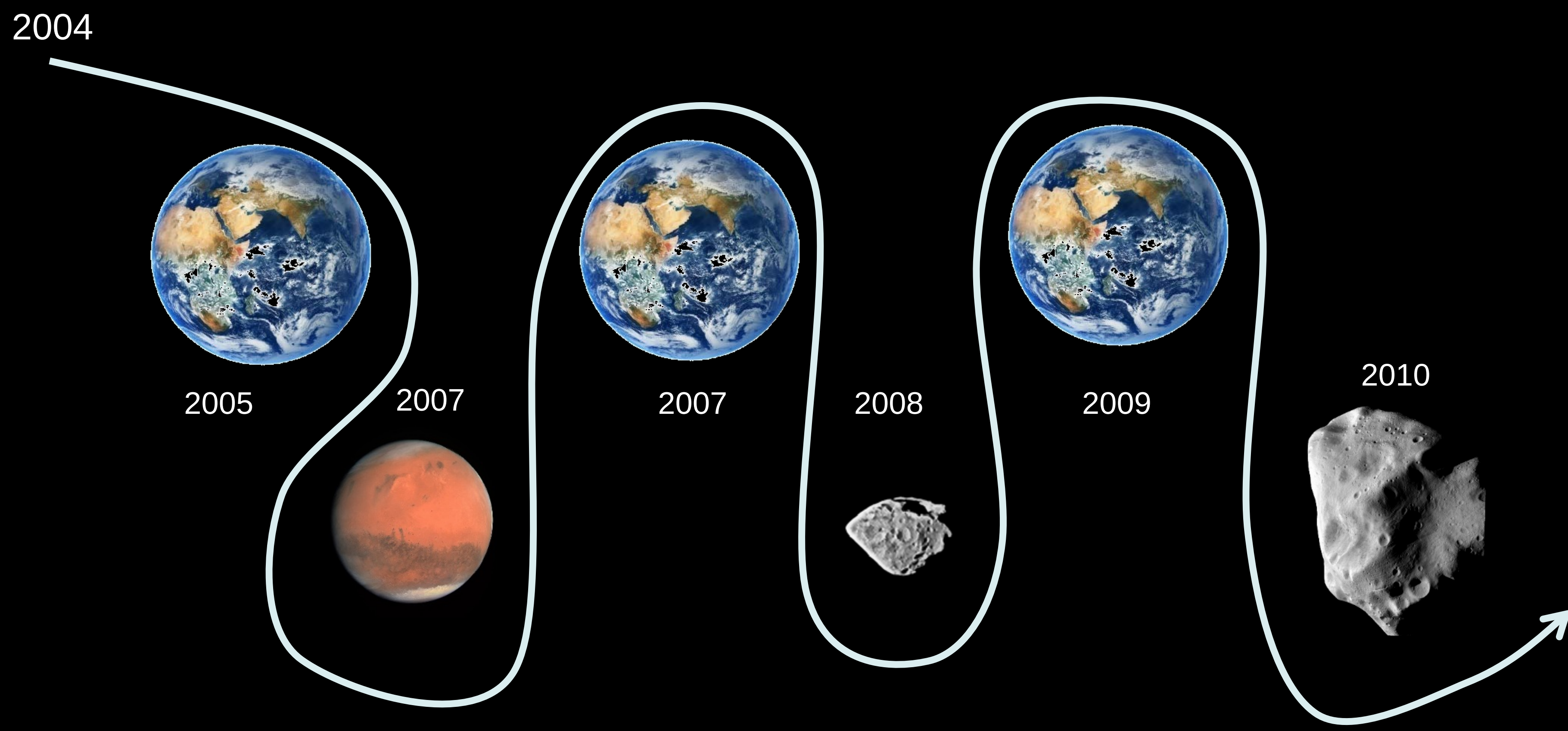
Rosetta: the third cornerstone of Horizon 2000

- The closest ever encounter with a comet
- The first mission to put a lander on a comet
- The first mission to accompany a comet from 4 au through perihelion out to 4 au
- The biggest challenge so far for Flight Dynamics

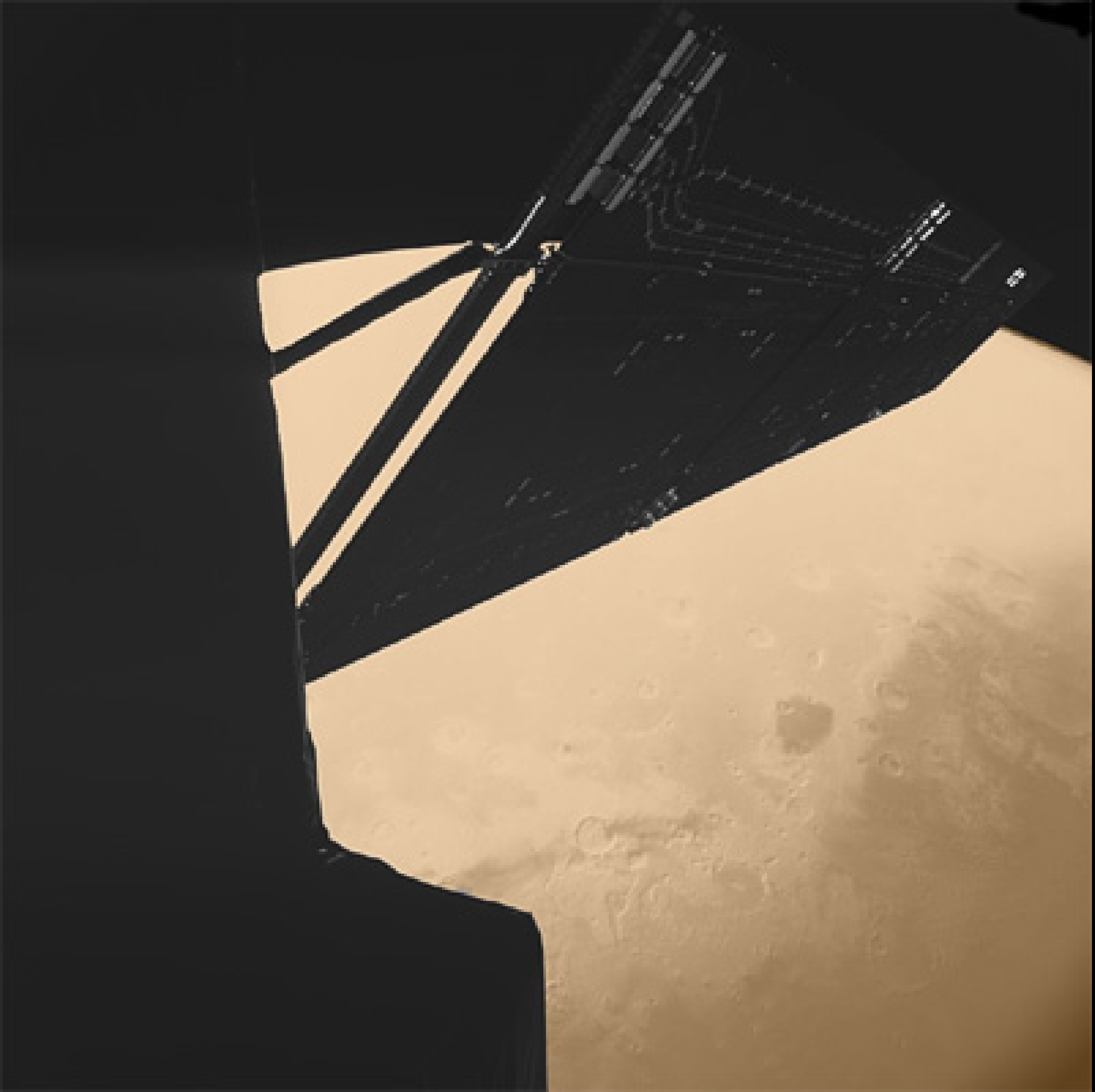


13. January 2003,
Comet Wirtanen

2. March 2004
Comet Chury

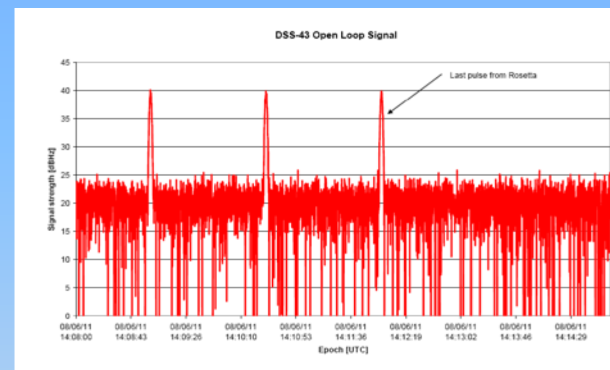

2004
2005
2007
2007
2008
2009
2010

The first Selfie:
25. 2. 2007



IPhone: July 2007

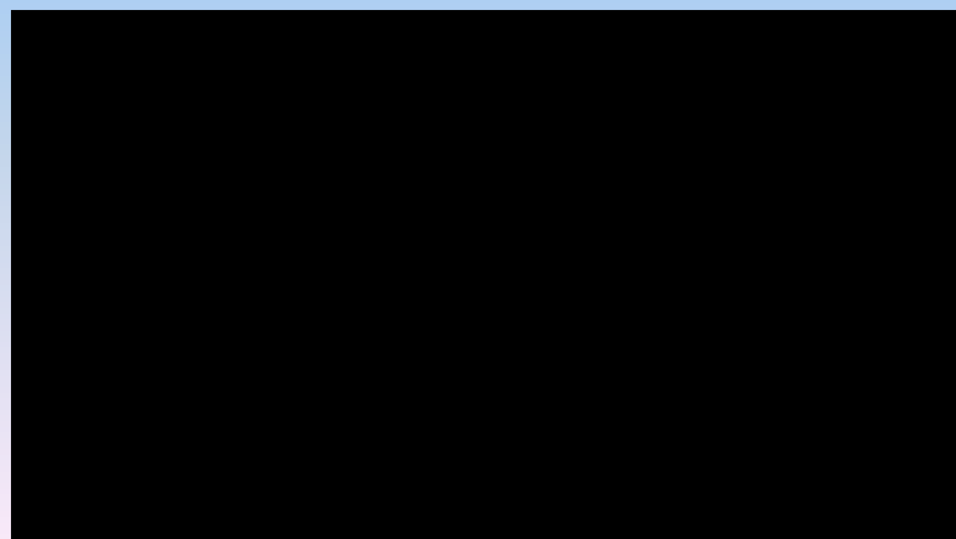
In June 2011 Rosetta was put into hibernation



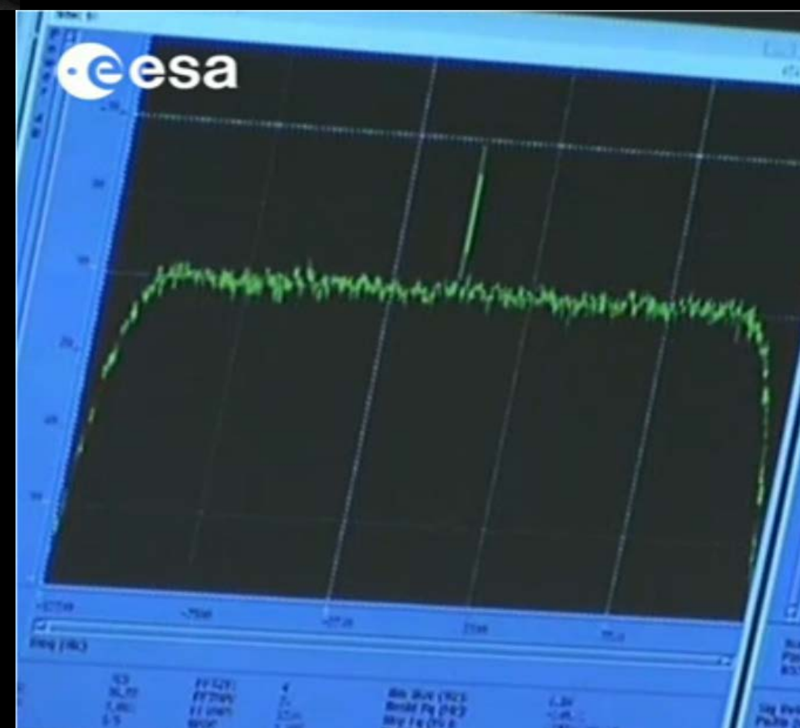
And on January 20,2014

….

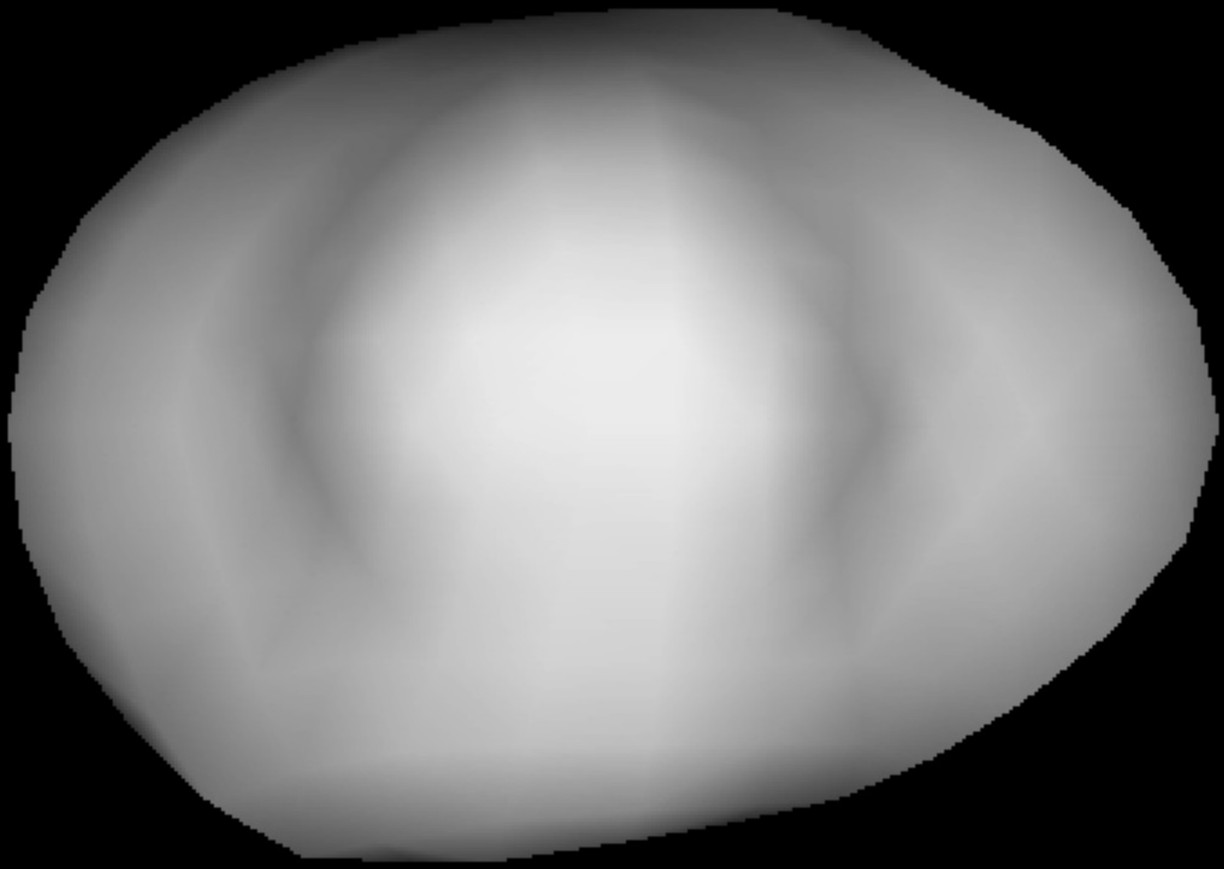
Rosetta woke up



19:19 CET



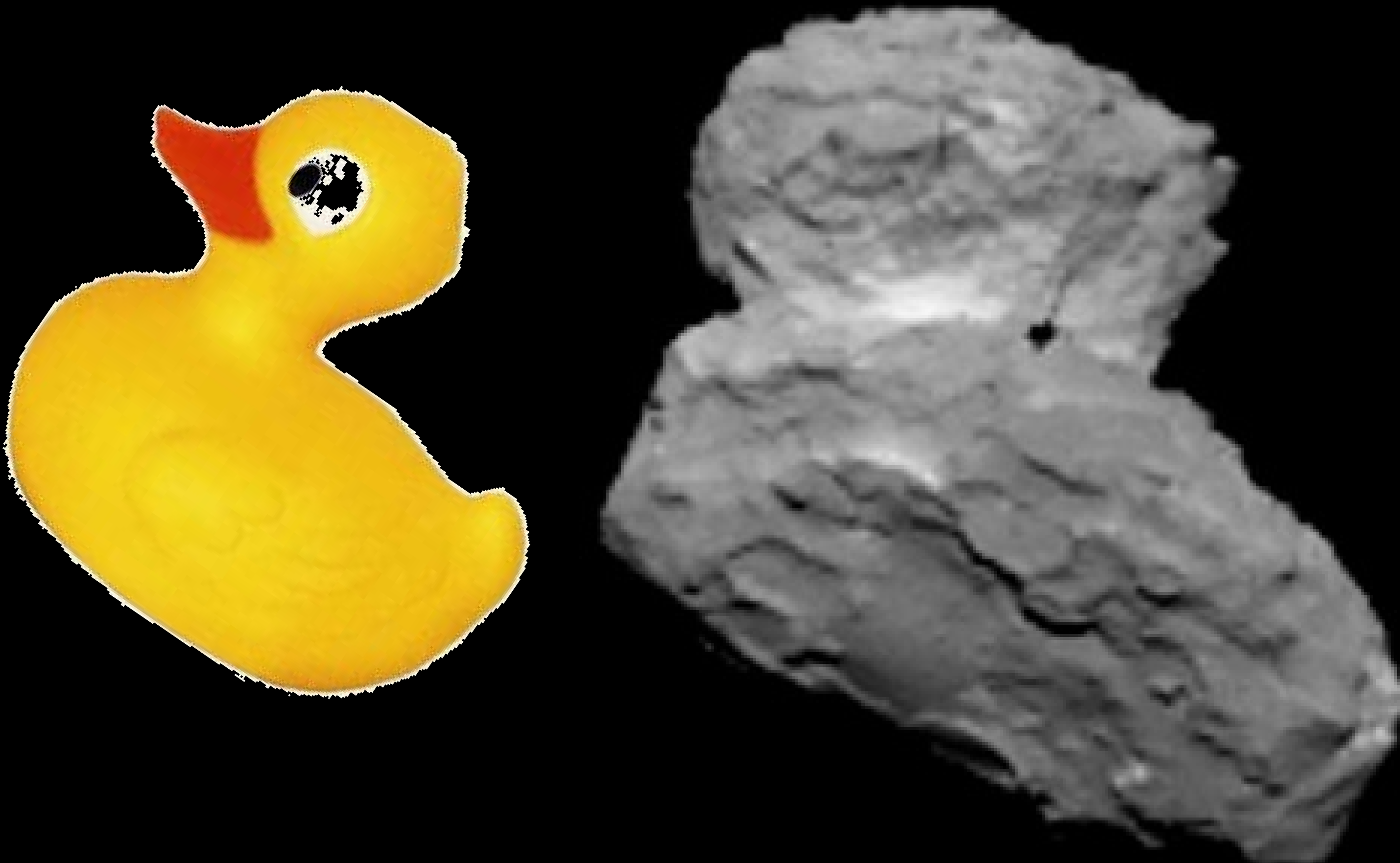
67P / Churyumov-Gerasimenko



Model

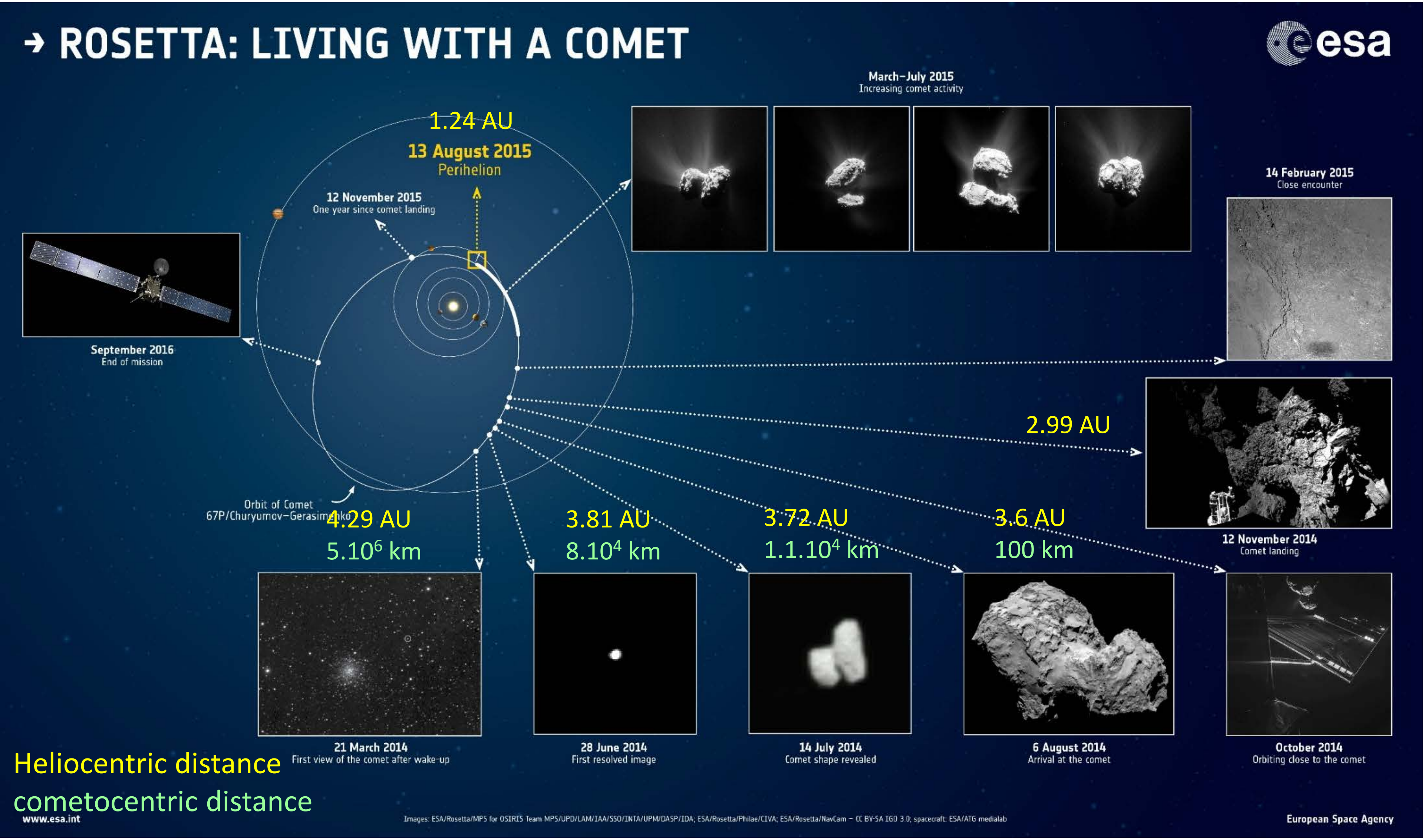
....

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO /INTA/UPM/DASP/IDA



Chury – the rubber duck

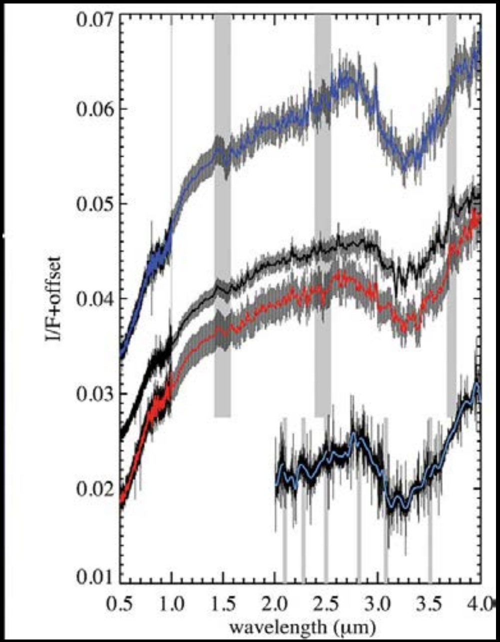
The Rosetta mission



Date: 06 August 2014
Satellite: Rosetta
Depicts: Comet 67P/Churyumov-Gerasimenko

Portrait of 67P

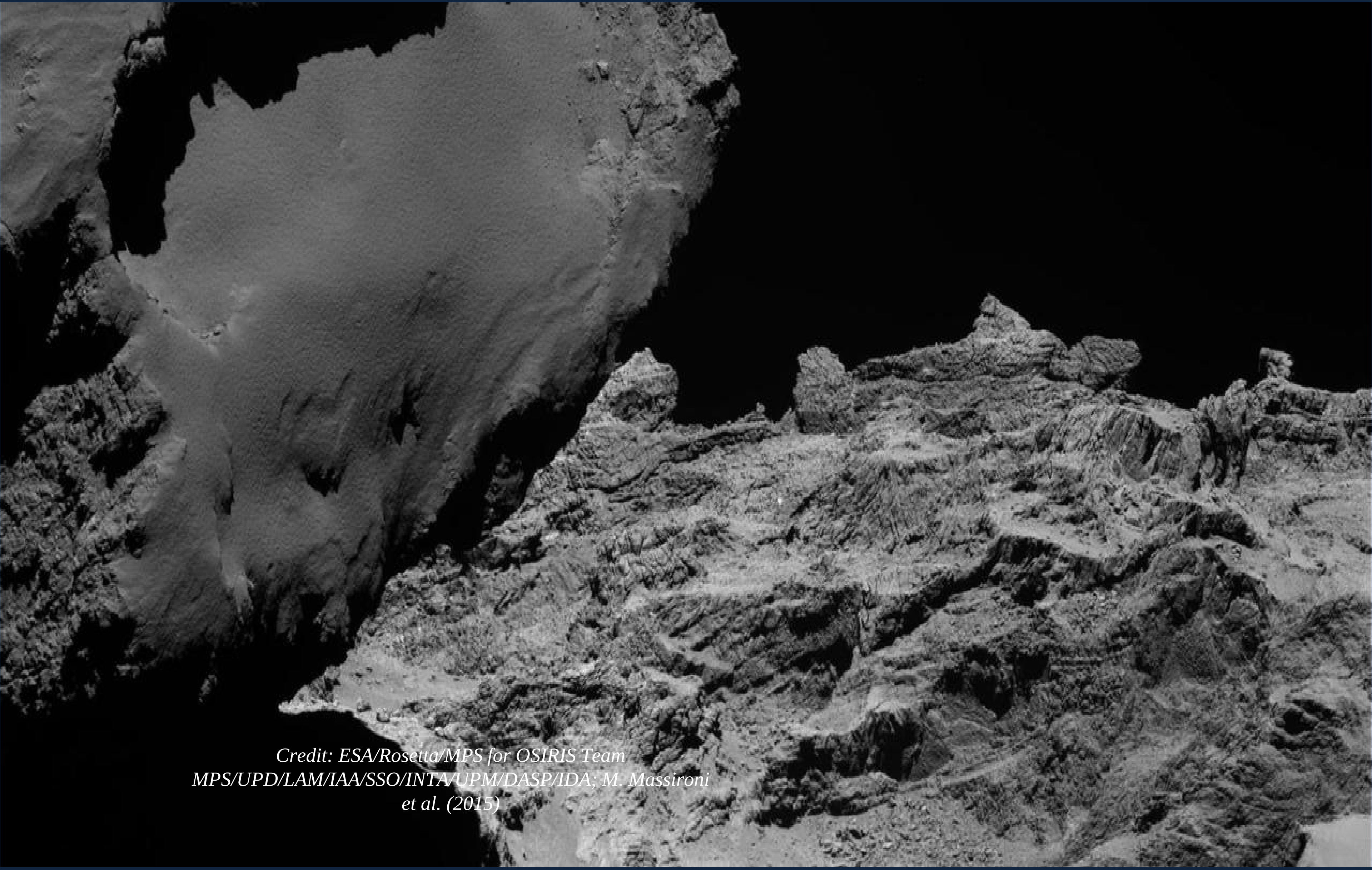
Longest dimension 4.1km
Rotation period 12.4 (12.0)h
Orbital period: 6.5 y
Perihelion distance 1.25AU
Rotation axis tilt: 68°
Density 0.5 g/cm^3
Porosity: 75%, homogeneous
Low reflectance (5%)



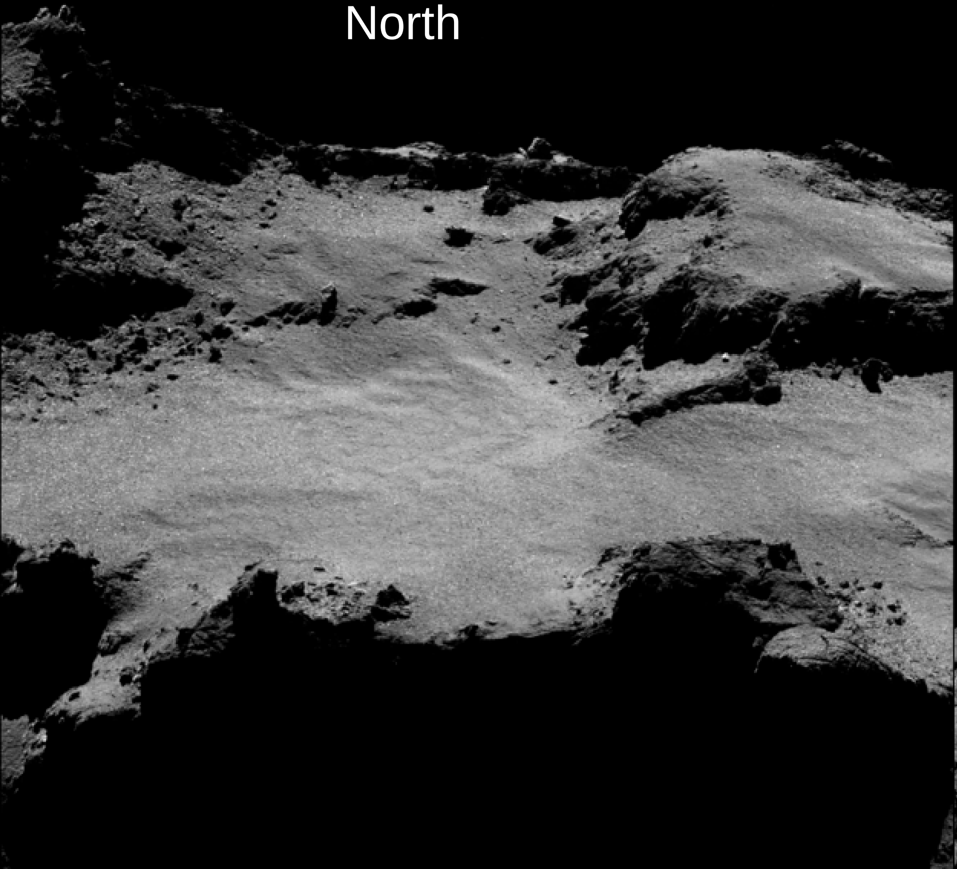
F. Capaccioni et al. Science 2015;347:aaa0628

2 for 1

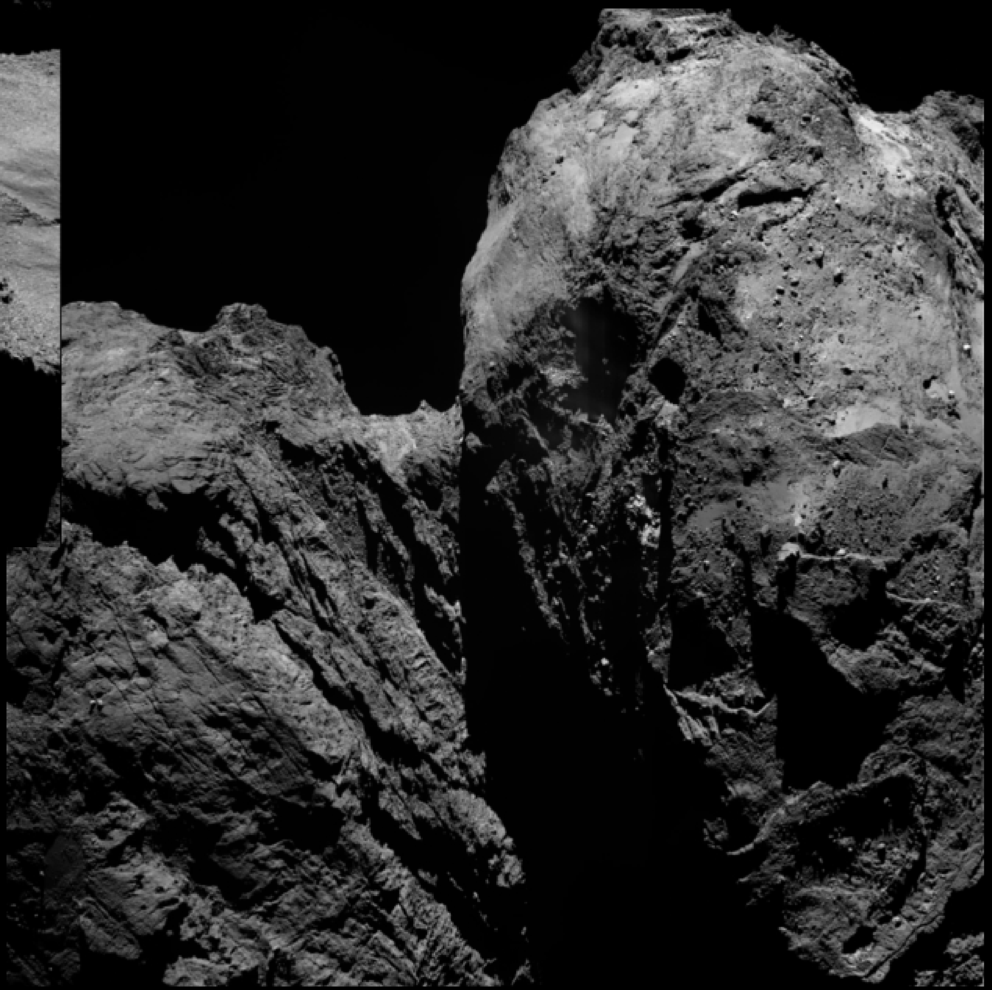
C-G is made out of two pieces which gently collided.



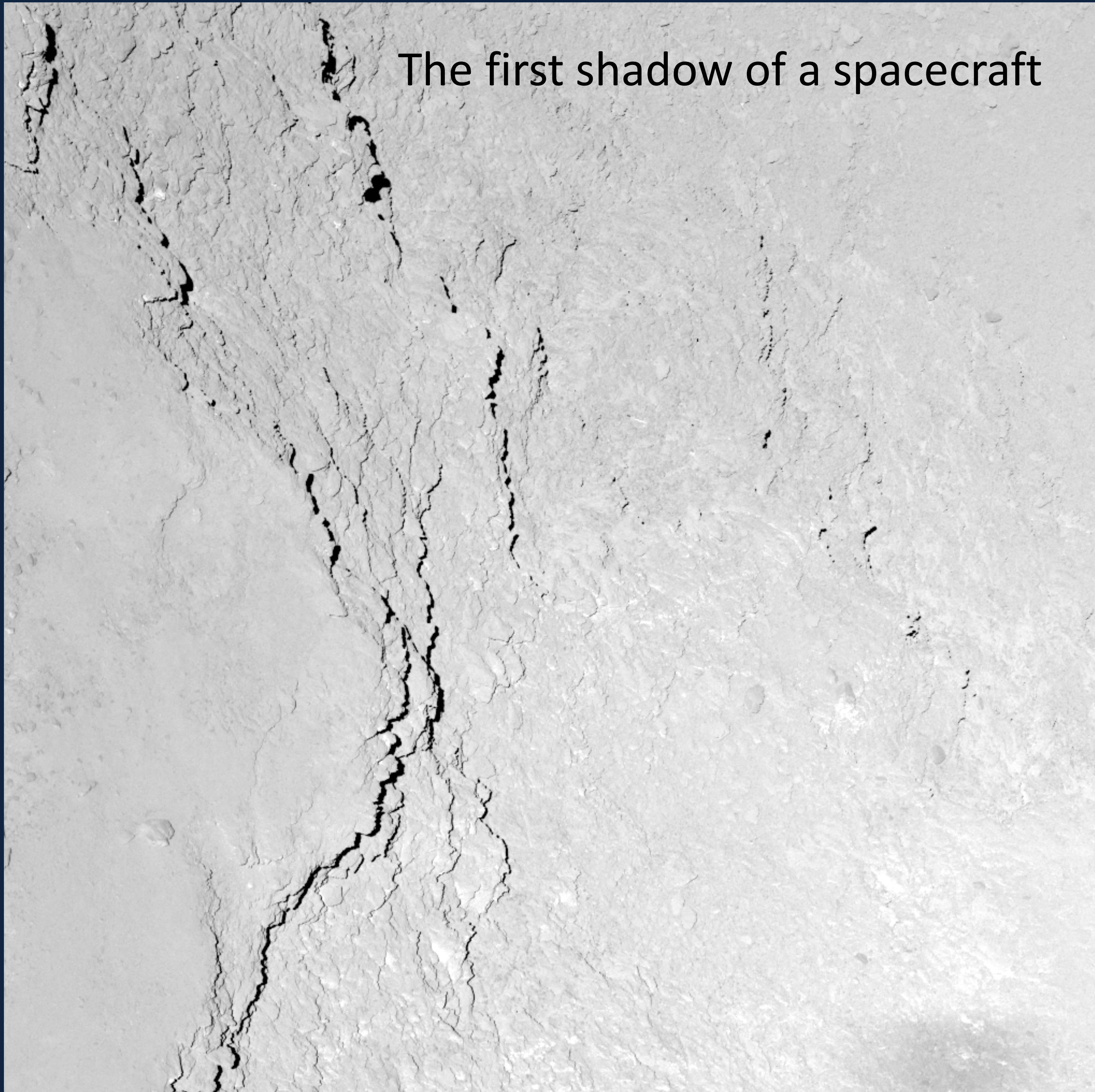
North



South



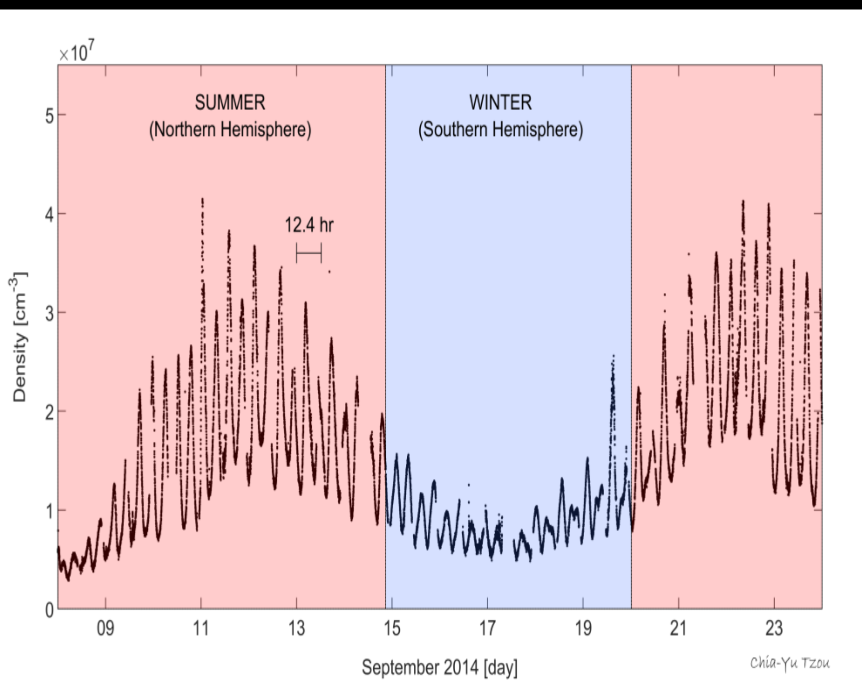
Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

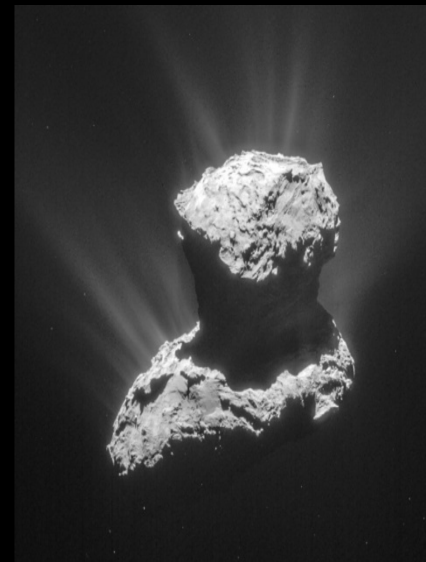


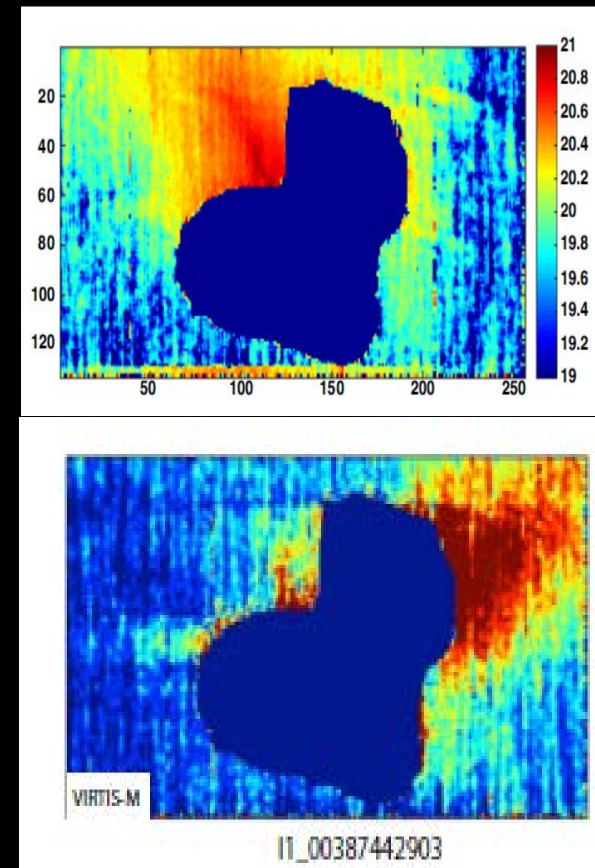
Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO /INTA/UPM/DASP/IDA

A close look at 67P's neutral heterogeneous coma

Total density (ROSINA-COPS)

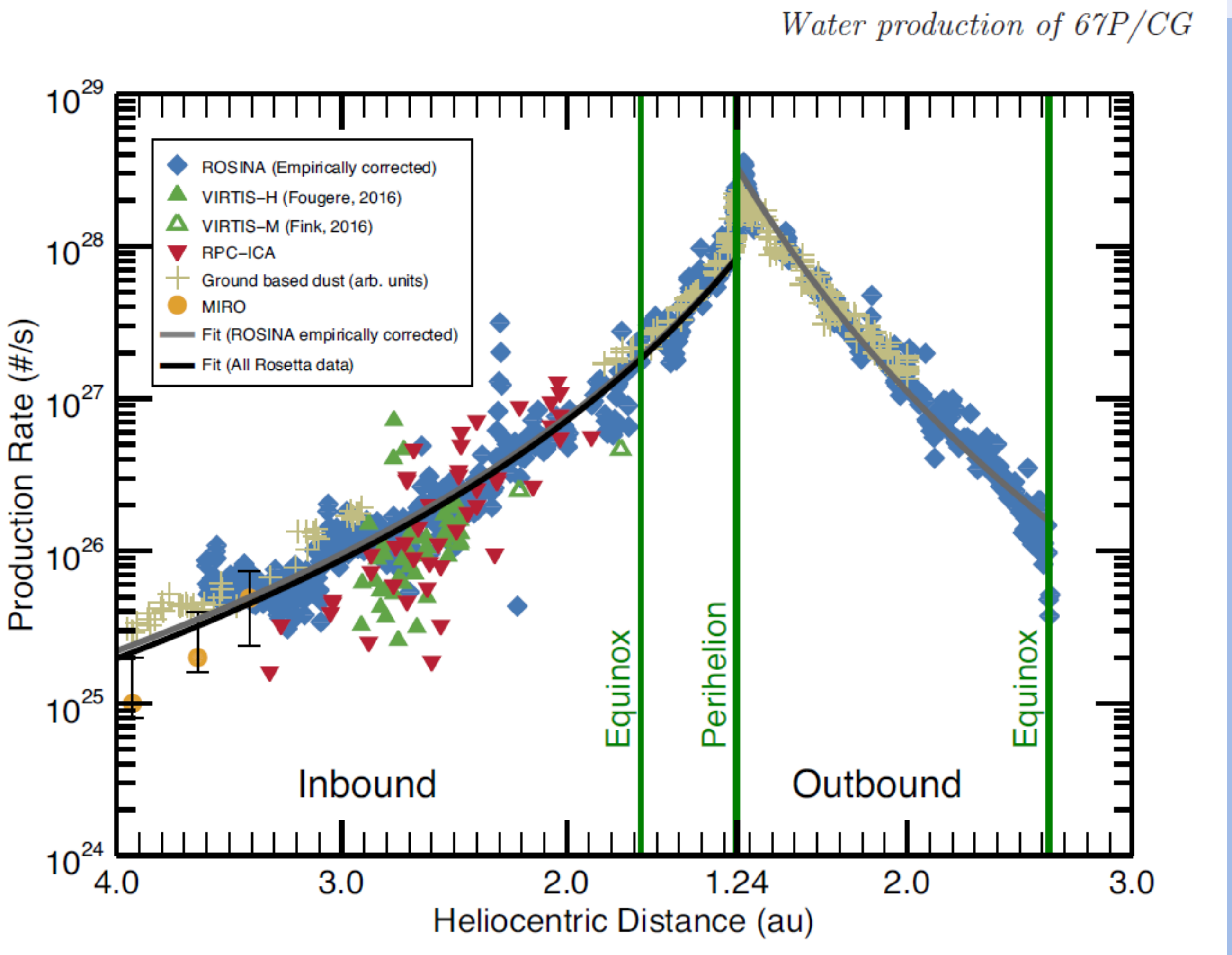






Neutral water (top) and CO_2 outgassing measured by VIRTIS (Fougère et al., 2016, data from Migliorini et al., 2016)

Total outgassing rate



Hansen et al., 2016, MNRAS

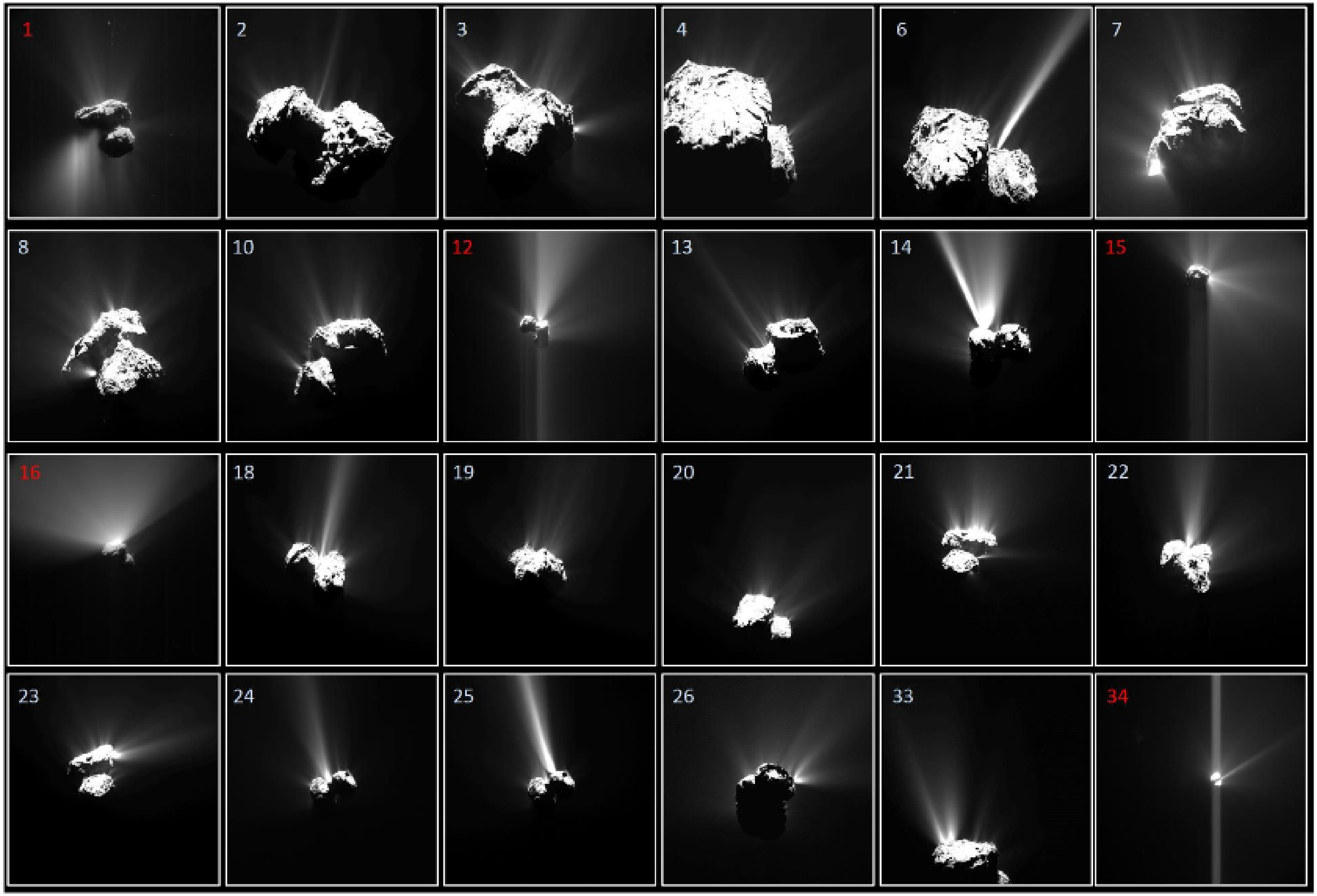
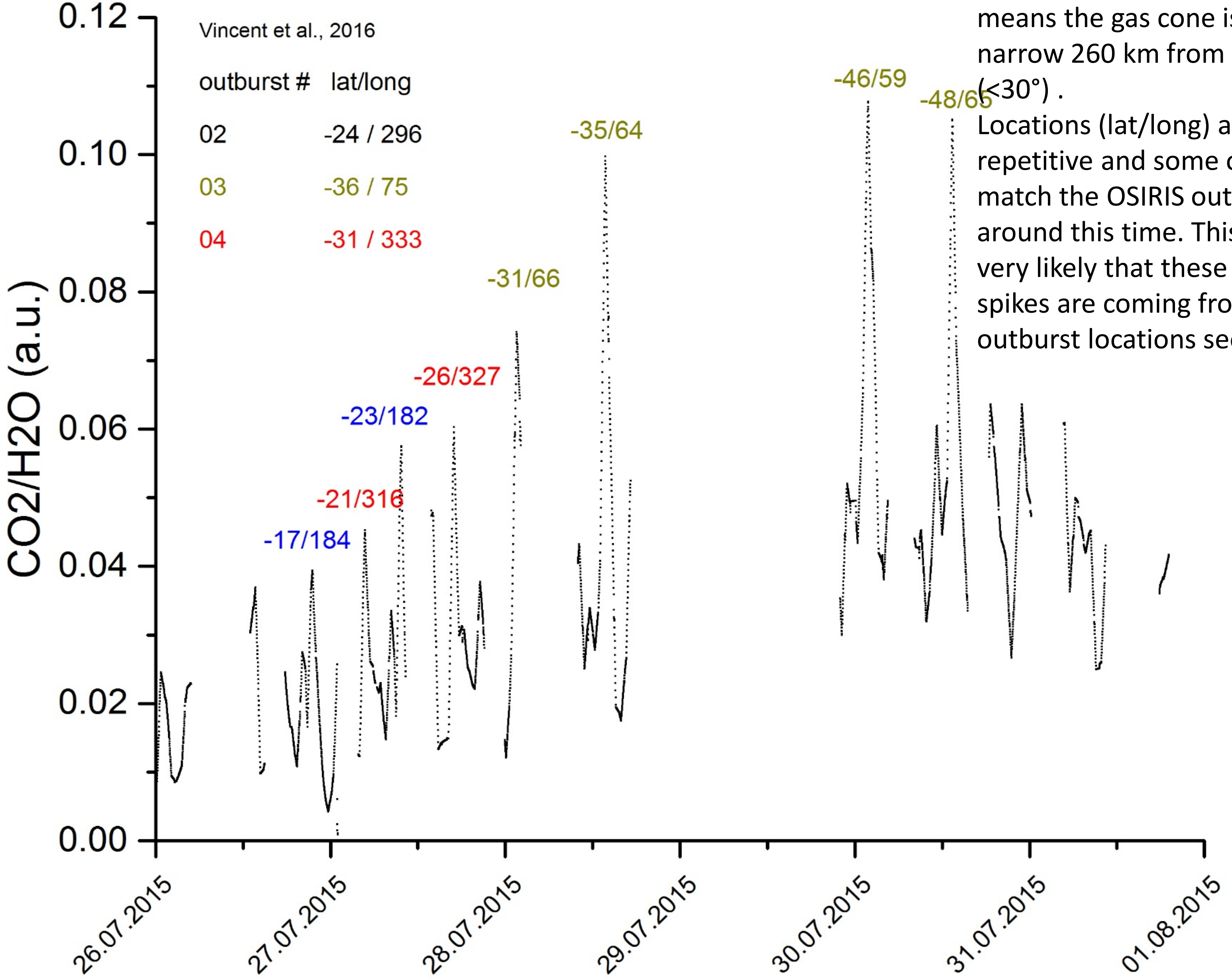


Figure 3. Mosaic of the brightest OSIRIS NAC (white) and NavCam (red) outbursts detected by Rosetta from July to September 2015. Observation details are give in 1. See Acknowledgments for detailed credit lines of the images.

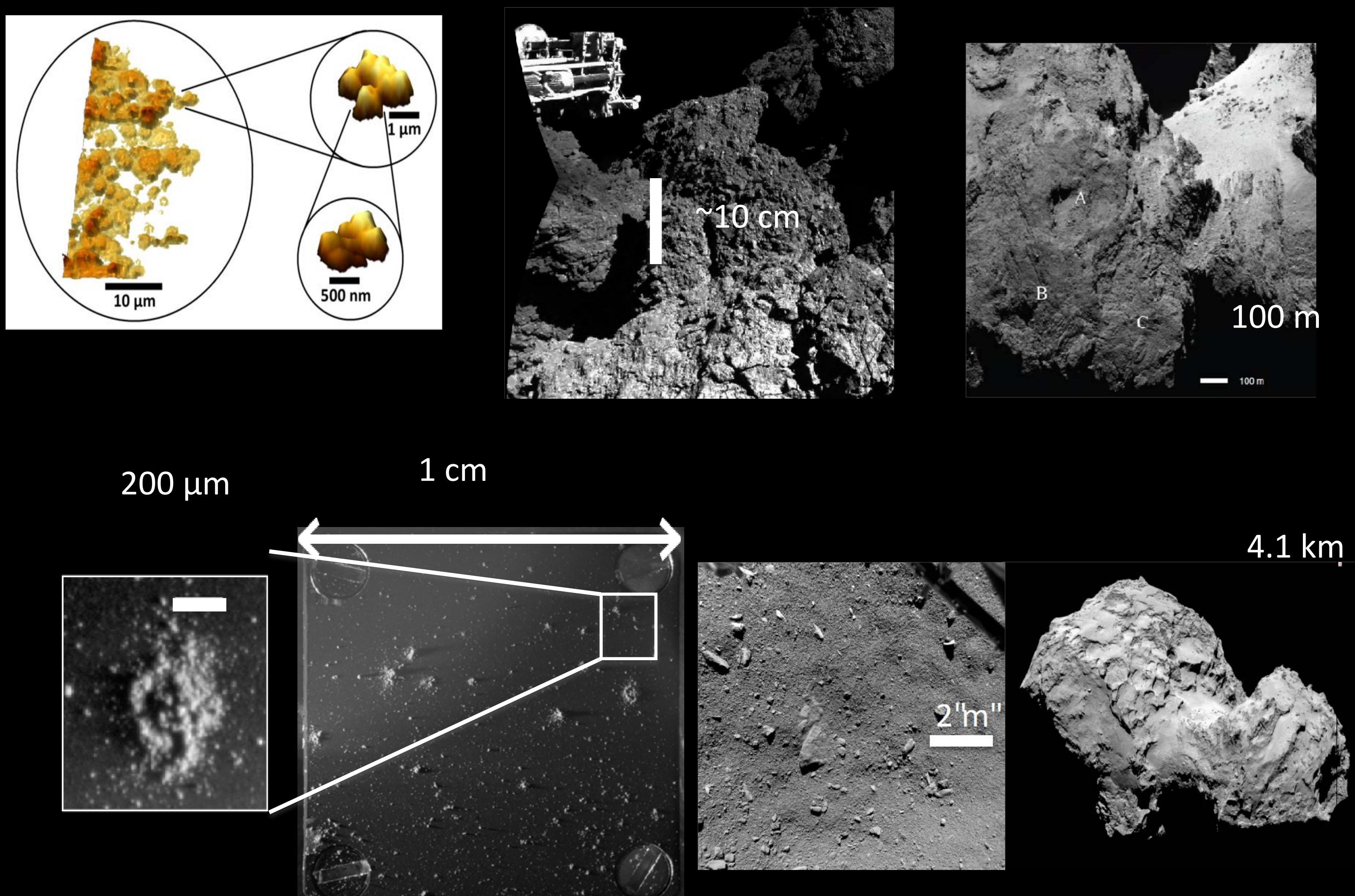
J.-B. Vincent et al.; Summer fireworks on comet 67P, *MNRAS* 462, 2016



High CO_2/H_2O ratios during short spikes, much more pronounced after July 20. This means the gas cone is still narrow 260 km from nucleus (<30°) .

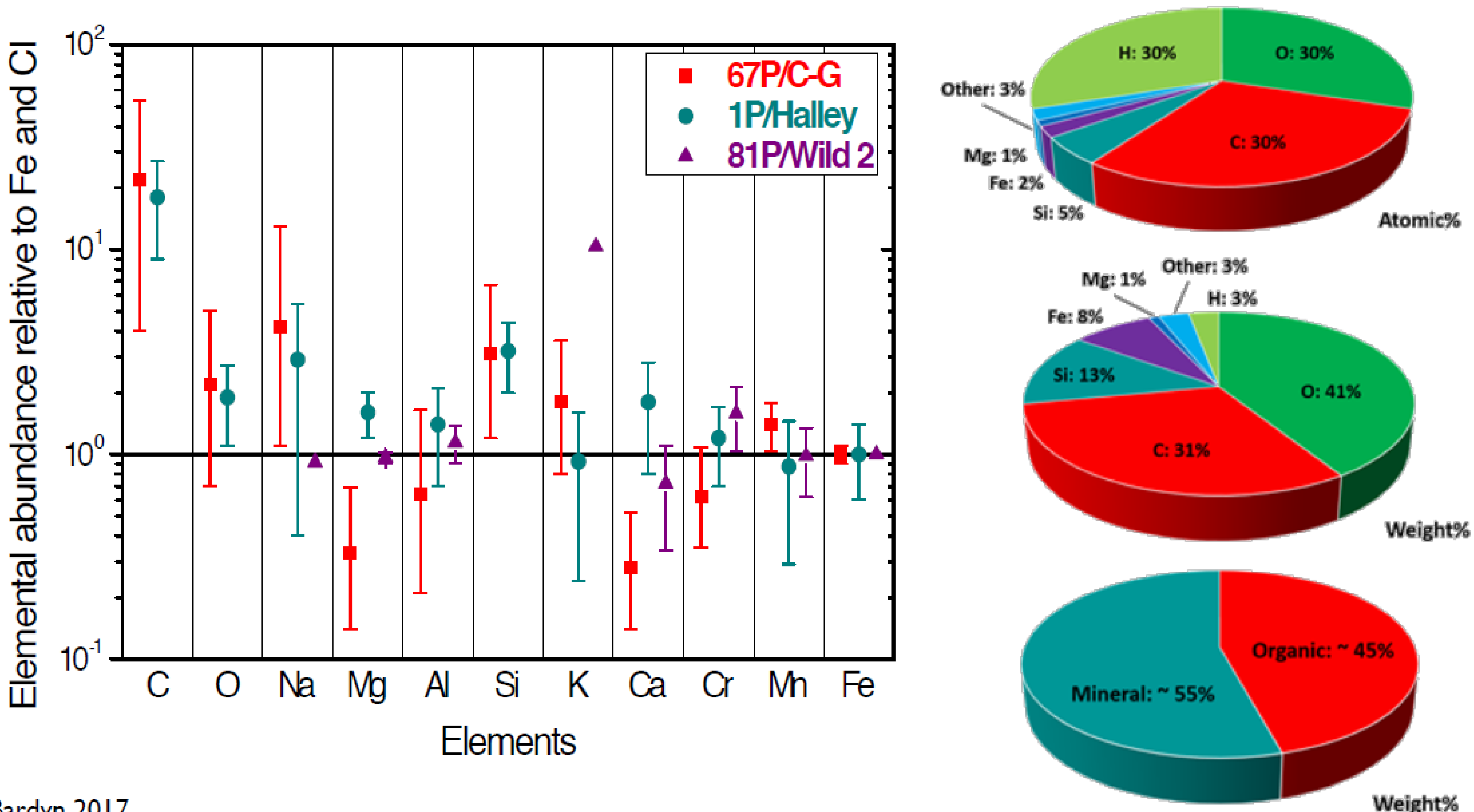
Locations (lat/long) are repetitive and some of them match the OSIRIS outbursts seen around this time. This makes it very likely that these CO_2 gas spikes are coming from the outburst locations seen by Osiris

ESA/ROSETTA/MIDAS ESA/ROSETTA/COSIMA ESA/ROSETTA/PHILAE/CIVA ESA/ROSETTA/PHILAE/ROLIS ESA/ROSETTA/OSIRIS



Davidsson et al., 2016 Mottola et al., 2015 Bibring et al., 2015 Langevin et al., 2016 Bentley et al., 2016 **Mannel et al., 2016** Fulle et al., 2016

Elemental abundances in "dry" 67P particles

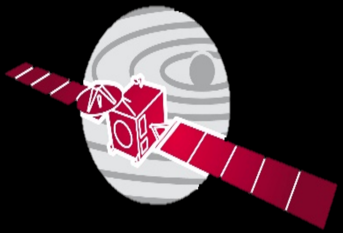


Bardyn 2017

Interstellar medium

Giant Molecular Cloud

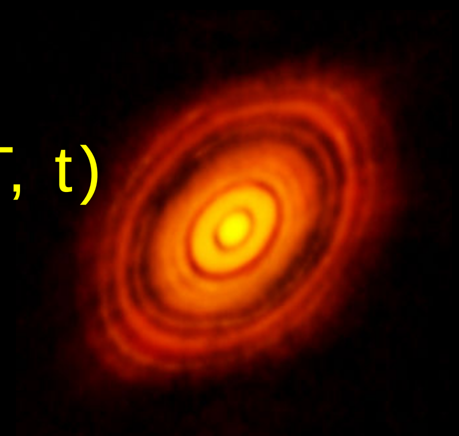
Star forming region



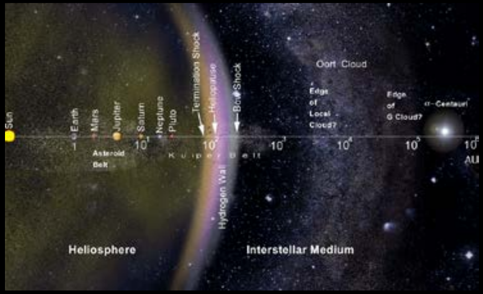
Protoplanetary nebula

Evolution of the material

- Starting conditions
- Chemistry
- Physical conditions (d, T, t)



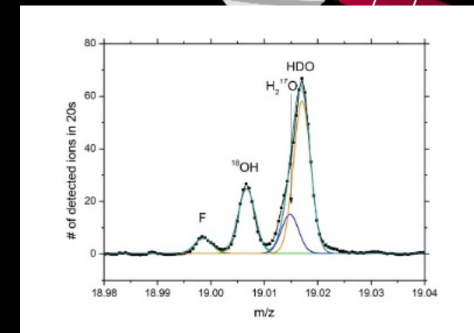
Evolution of life

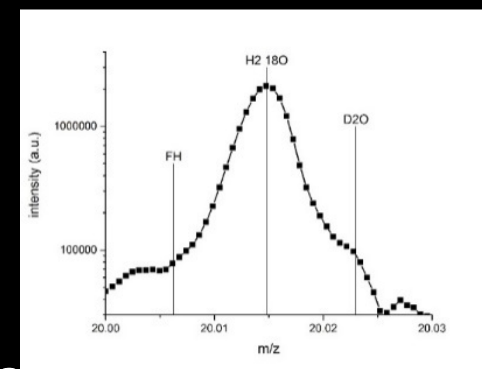


Solar system

Deuterated species

Comet 67 P/C-G	**Molecular clouds**
D/H ~5.3 10^{-4} in H_2O	D/H ~ 8 10^{-4} – 10^{-2} in H_2O
D_2O / HDO ~1 %	1.2 %





- Water is inherited from the presolar cloud
- The big variability of D/H in comets points to the fact that they were formed over a large region, that the comet families (Oort cloud, Kuiper belt, etc.) were not formed separately, but just have a dynamically different history
- The Earth did not get the bulk of its water from comets

Silicon isotopes (Rubin et al., A&A, 2017)

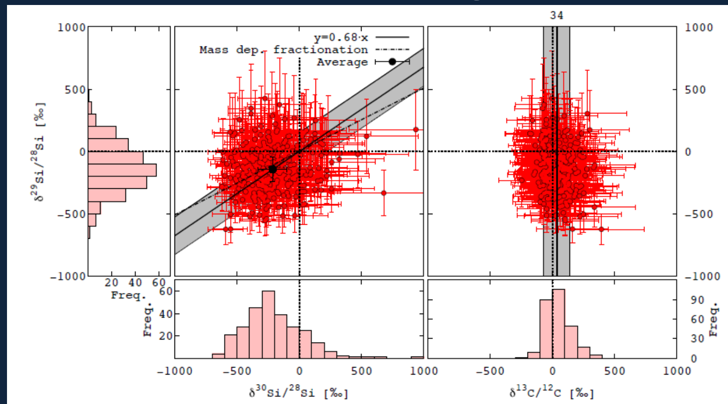
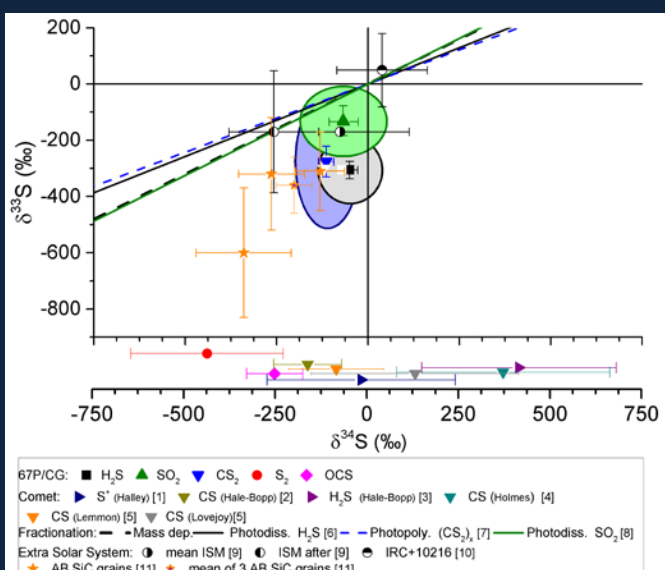


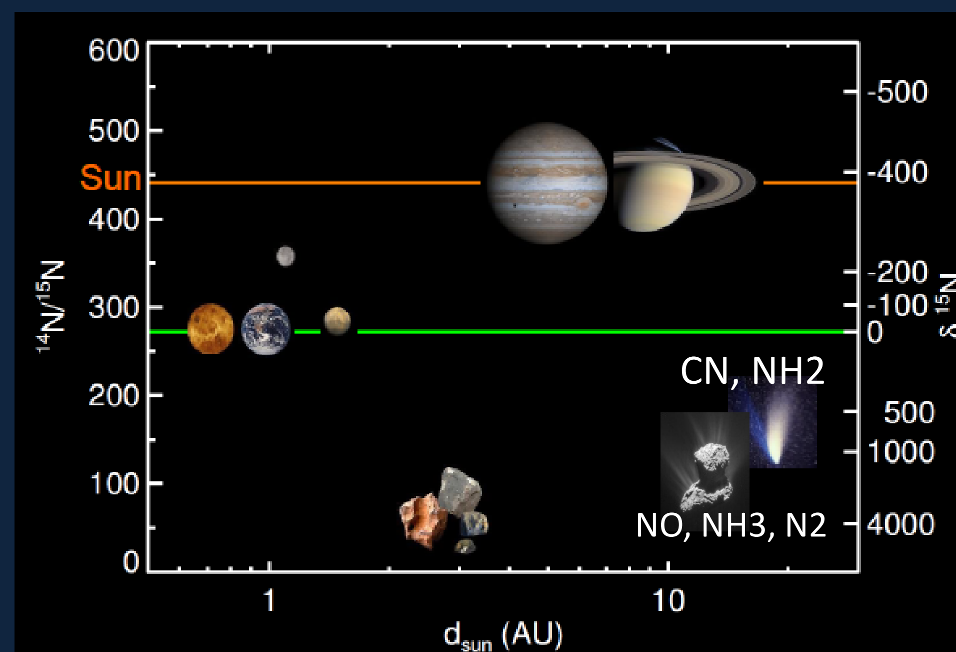
Fig. 4. Measured isotopic ratios of Si plotted in δ-notation depicting deviations in permil (‰). Left: individual $\delta^{29}Si/^{28}Si$ versus $\delta^{30}Si/^{28}Si$ ratios (red points) and average (black point). Also shown are the expected line from mass dependent fractionation (black dash dotted line) and a line through the origin and average (black solid line) with error (grey area, see text). Right: The red points show individual $\delta^{29}Si/^{28}Si$ versus $\delta^{13}C/^{12}C$ in carbon monoxide and the black solid line the average $\delta^{13}C/^{12}C=34$ with error (grey area, see text). The black dashed lines indicate the corresponding solar values in both plates from McSween & Huss (2010). Below and on the left side are the individual measurements binned.

Sulphur isotopes

Calmonte et al., 2017



Nitrogen isotopes

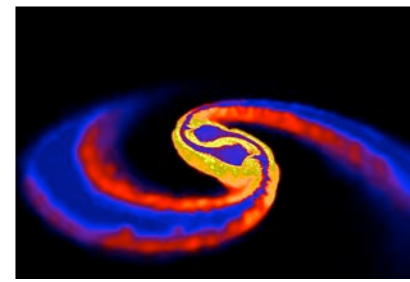


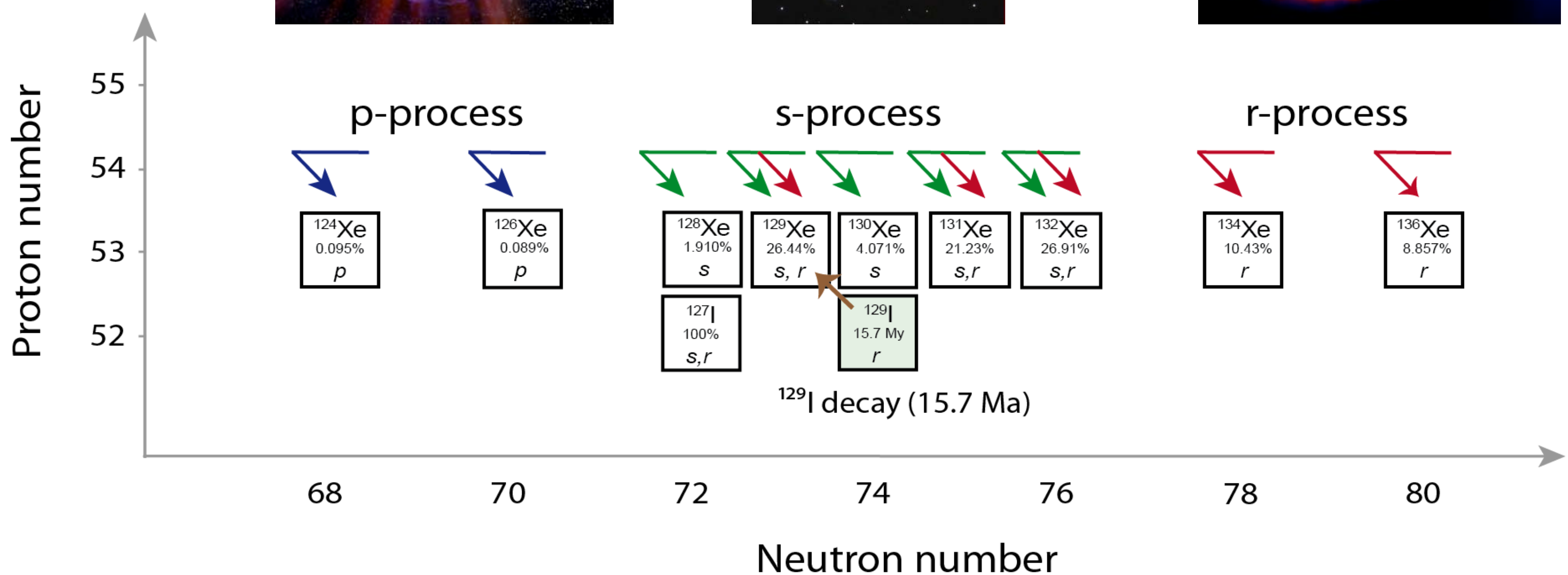
Xenon: 9 isotopes, different star formation processes

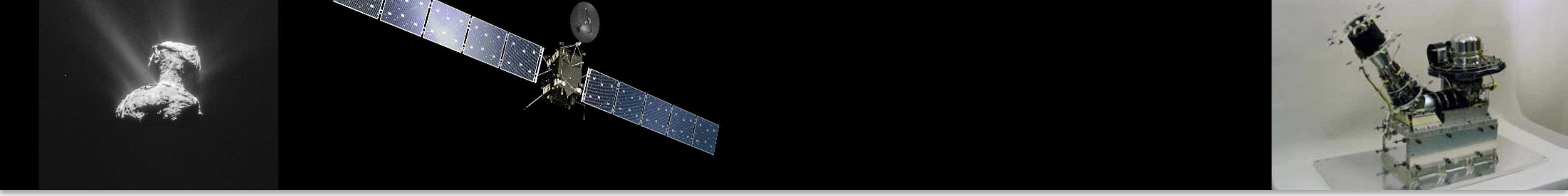
Supernovae

AGB stars

Neutron star mergers

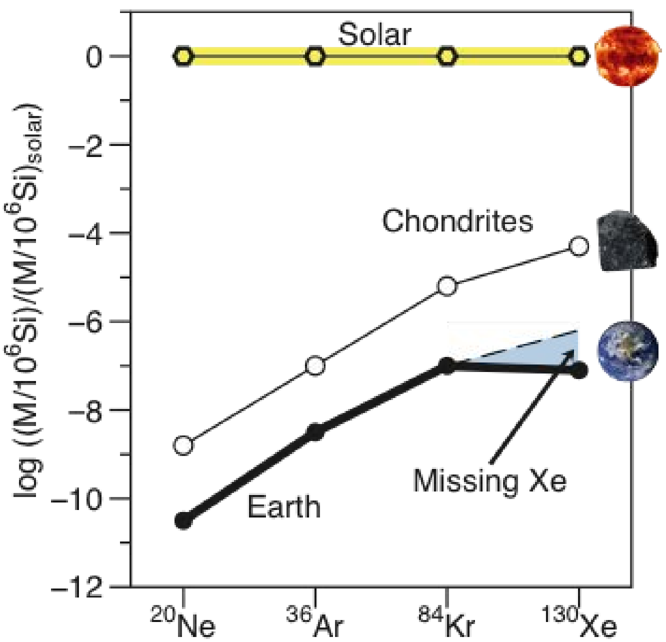


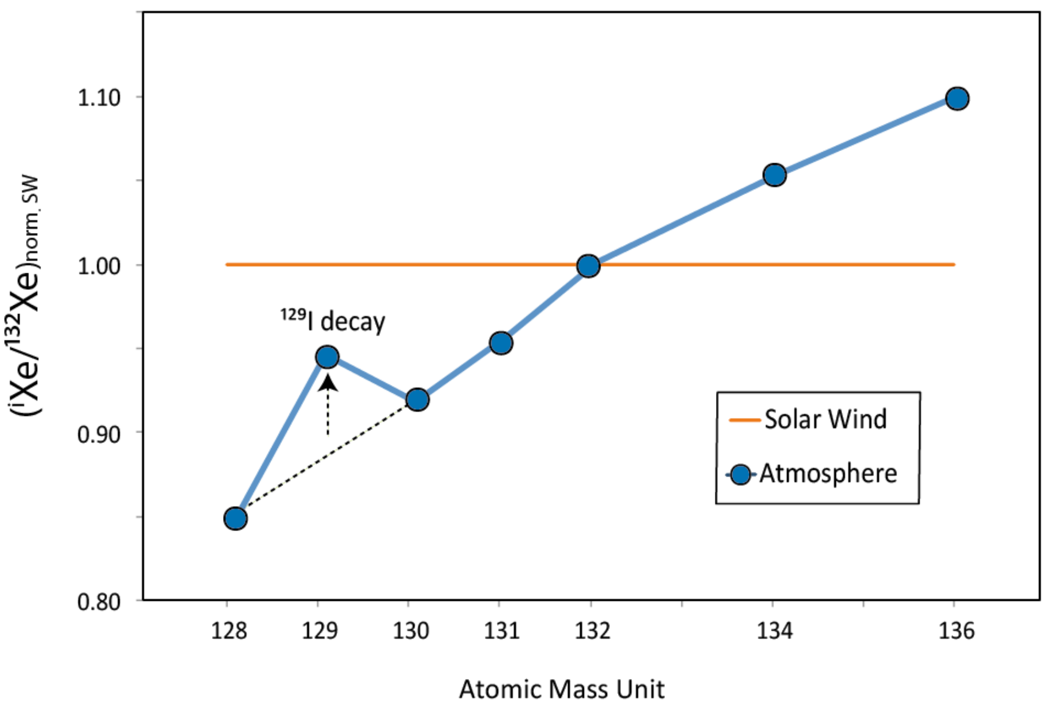


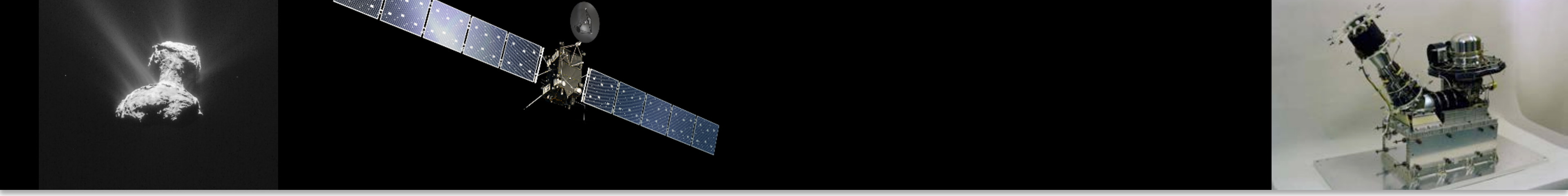


The Xenon paradox

- Xe in Earth's atmosphere elementally depleted relative to lighter noble gases (eg Kr)
- Heavy Xe isotopes enriched relative to the light ones (3.5 %/u) relative to solar wind Xe (representing the protosolar nebula) or to meteoritic Xe





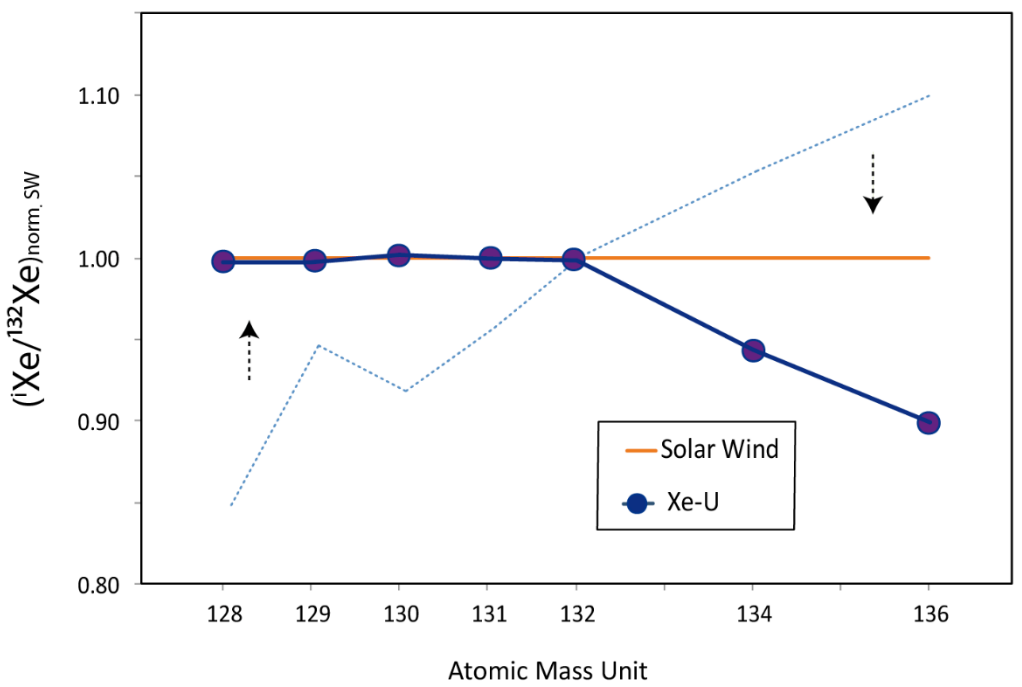


U-Xe : the elusive progenitor of atmospheric xenon

After correction for isotope (mass-dependent) fractionation and for contribution of radioactivity through time, atmospheric xenon does not match solar wind Xe (nor meteoritic Xe)

Requires a non-solar composition, labelled U-Xe by Pepin and Phinney (1978)

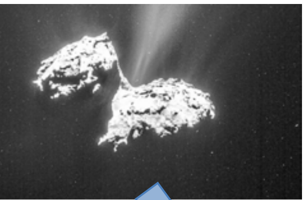
- U-Xe is near-solar for $^{124-130}Xe$, but depleted in heavy isotopes eg ^{134}Xe and ^{136}Xe
- U-Xe has never been identified in solar system material (from the inner solar system, eg meteorites)

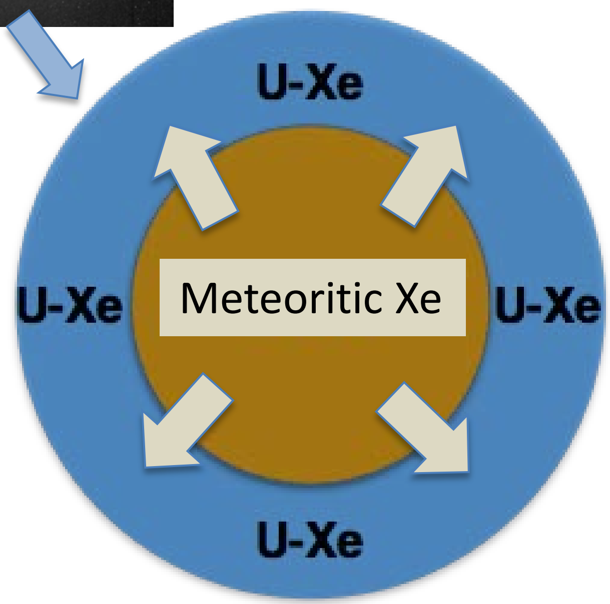


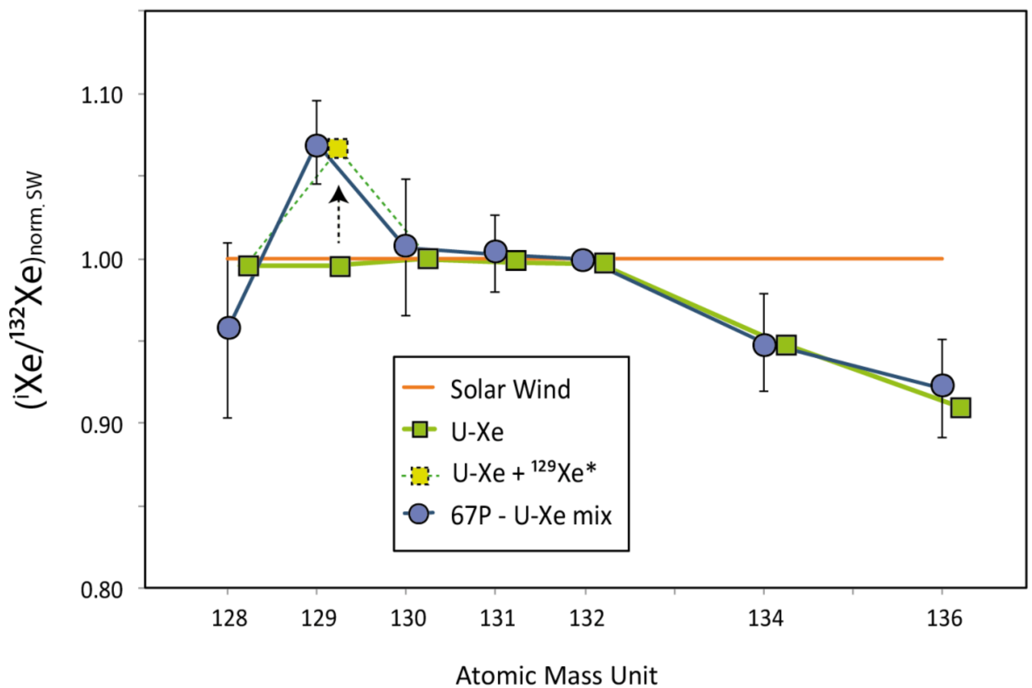
Pepin and Phinney (1978)

Rosina's double focusing mass spectrometer (DFMS) on board of the Rosetta spacecraft

Comets as a source of U-Xe in the Earth's atmosphere





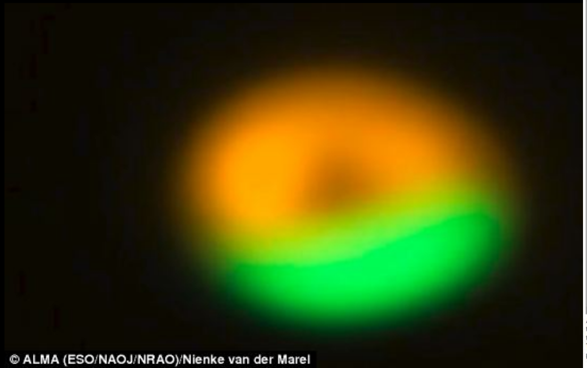


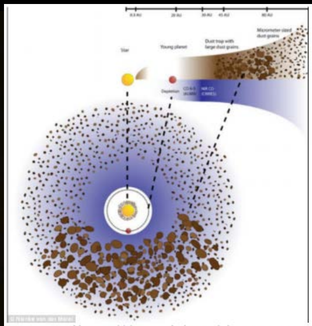
Terrestrial atmosphere contains 22±5 % cometary xenon

Several indications for a non-homogeneized protoplanetary disk

- Xenon isotopic ratios are non solar
- Silicon isotopic ratios are non-solar
- Nitrogen isotopic ratios are non-solar
- Sulfur isotopic ratios differ among molecules, but the bulk is non-solar.
- Very high (D_2O/HDO) vs. (HDO/H_2O) ratio of 17, compatible with direct heritage of water ice from presolar disk
- Presence of very volatile S_2 requires presolar ice
- Good correlation of O_2 with H_2O requires presolar ice

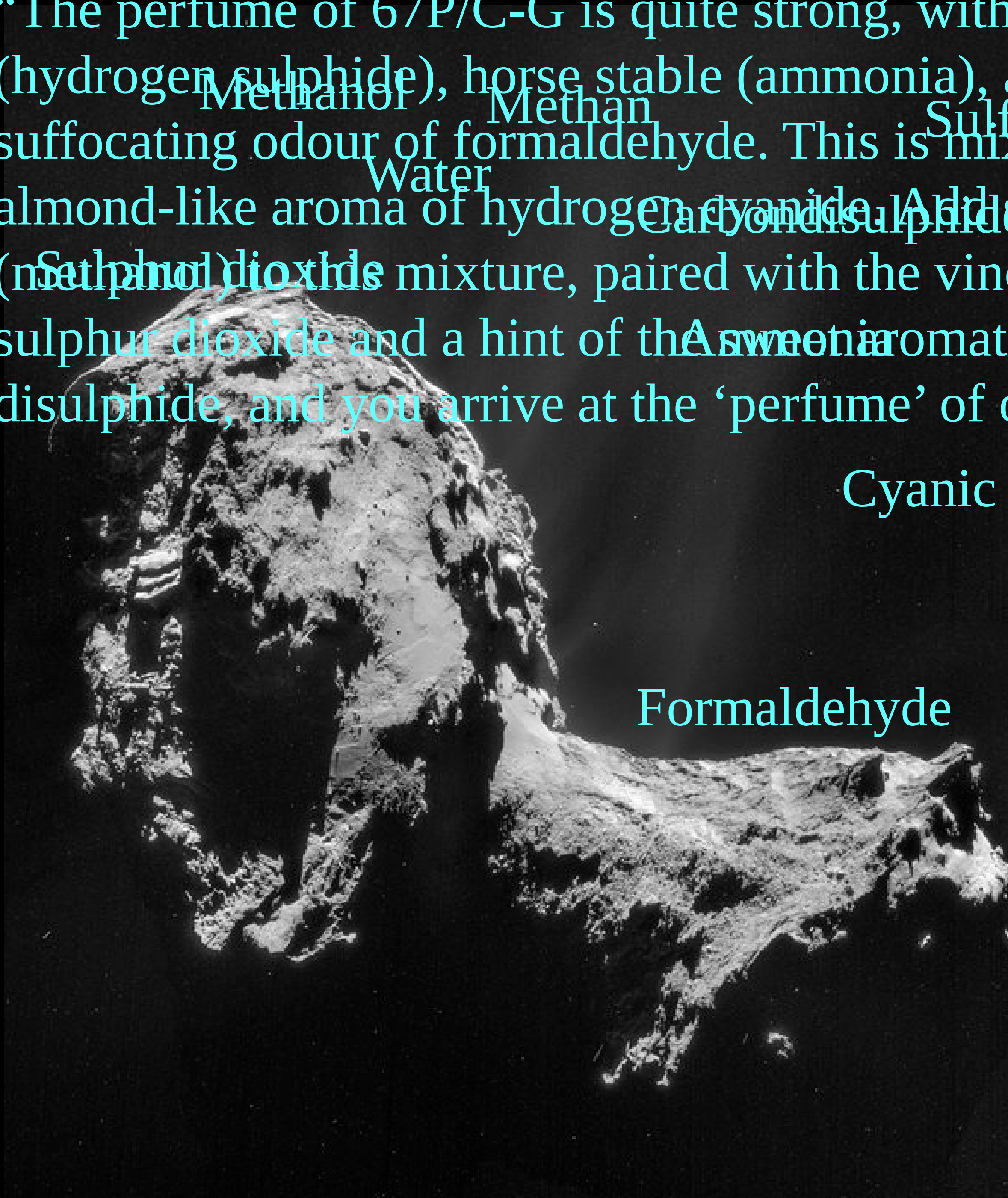
Mixing in the protosolar / protoplanetary nebula was inefficient at the location of comet formation or C-G is an alien





Artist's impression of the proposed disk structure of Oph IRS 48. The brown spots represent the large and small grains. The larger grains detected by ALMA are concentrated in the dust trap at the bottom of the image. The blue represents the distribution of carbon monoxide gas. The gap in is shown with the proposed planetary body that is sweeping the area clear and providing the conditions necessary to form the dust trap

“The perfume of 67P/C-G is quite strong, with the odour of rotten eggs (hydrogen sulphide), horse stable (ammonia), and the pungent, suffocating odour of formaldehyde. This is mixed with the faint, bitter, almond-like aroma of hydrogen cyanide. Add some whiff of alcohol (methanol) to this mixture, paired with the vinegar-like aroma of sulphur dioxide and a hint of the sweet aromatic scent of carbon disulphide, and you arrive at the ‘perfume’ of our comet.”



Le Nouvelliste

DIMANCHE 8° / 17° LUNDI 3° / 16°

VALAIS SUISSE SPORTS ECONOMIE MONDE SOCIÉTÉ

Société › Loisirs et culture

23.10.2014, 14:11 - Loisirs et culture

Actualisé le 23.10.14, 15:25

La comète Tchourioumov-Guérassimenko pue, selon le "nez" de la sonde Rosetta

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Astronomie

Komet «Chury» riecht nach Pferdestall und faulen Eiern

Publiziert: 23.10.2014

Drucken · E-M

BERN - BE - Der Komet «Chury» riecht offenbar ziemlich streng, wie neuste Daten der Berner Messgeräte auf der Kometensonde «Rosetta» nahelegen: Er dünstet Noten von Pferdestall, faulen Eiern, Formaldehyd und Bittermandel

schweizerbauer.ch

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WETTER POLITIK & WIRTSCHAFT MARKT & PREISE TIERE PFLANZEN LANDTECHNIK GALERIEN VERMISCHTES

ALLERLEI BAUERNKALENDER BEKANNTSCHAFTEN BAUER, LEDIG, SUCHT AGROPREISE SCHWEIZER LAND UND LEBEN

Quelle: schweizerbauer.ch - sda

Weltall

Komet riecht nach Pferdestall

MEISTGELESEN NEUES OFT KOMMENTIERT

Bauer, ledig, sucht... jeden Donnerstag um 20:15 Uhr auf 3+

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Quel "profumo" di cometa "annusato" dalla sonda Rosetta

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Rotten eggs, horse pee, alcohol and bitter almonds: Astronomers reveal what the comet Rosetta is set to land on smells like

→ THE COMETARY ZOO: GASES DETECTED BY ROSETTA

esa

THE LONG CARBON CHAINS
Methane
Ethane
Propane
Butane
Pentane
Hexane
Heptane

THE AROMATIC RING COMPOUNDS
Benzene
Toluene
Xylene
Benzoic acid
Naphtalene

THE KING OF THE ZOO
Glycine (amino acid)

THE "MANURE SMELL" MOLECULES
Ammonia
Methylamine
Ethylamine

THE "POISONOUS" MOLECULES
Acetylene
Hydrogen cyanide
Acetonitrile
Formaldehyde

THE ALCOHOLS
Methanol
Ethanol
Propanol
Butanol
Pentanol

THE VOLATILES
Nitrogen
Oxygen
Hydrogen peroxide
Carbon monoxide
Carbon dioxide

THE "SMELLY" MOLECULES
Hydrogensulphide
Carbonylsulphide
Sulphur monoxide
Sulphur dioxide
Carbon disulphide

THE "SMELLY AND COLOURFUL"
Sulphur
Disulphur
Trisulphur
Tetrasulphur
Methanethiole
Ethanethiol
Thioformaldehyde

THE TREASURES WITH A HARD CRUST
Sodium
Potassium
Silicon
Magnesium

THE "SALTY" BEASTS
Hydrogen fluoride
Hydrogen chloride
Hydrogen bromide
Phosphorus
Chloromethane

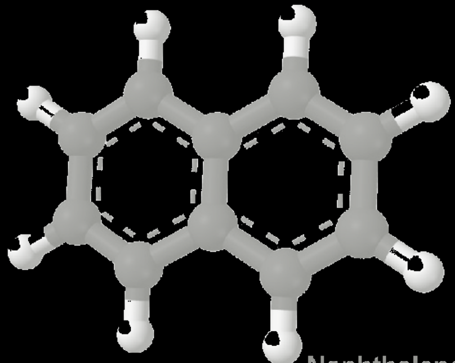
THE BEAUTIFUL AND SOLITARY
Argon
Krypton
Xenon

THE "EXOTIC" MOLECULES
Formic acid
Acetic acid
Acetaldehyde
Ethylenglycol
Propylenglycol
Butanamide

THE MOLECULE IN DISGUISE
Cyanogen

Credits: Based on data from ROSINA

Hydrocarbons in comets

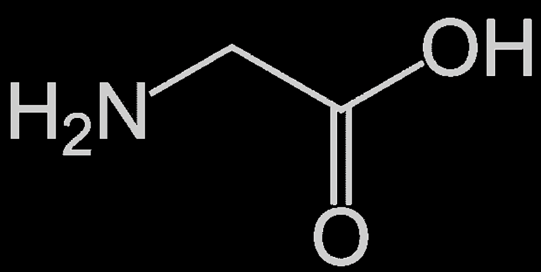


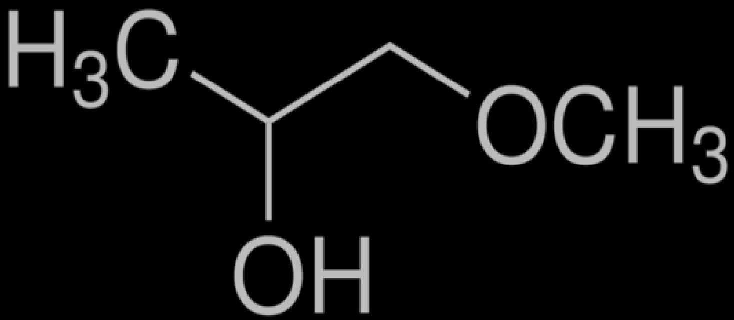
Naphthalene

- Long carbon chains seen in the volatile part (ROSINA)
- Macromolecules (C-H) seen in the dust (COSIMA)
- Carbon signature seen on the surface (VIRTIS)
- Polyaromatic hydrocarbons detected in the volatile coma (benzene, naphthalene,..) (ROSINA)

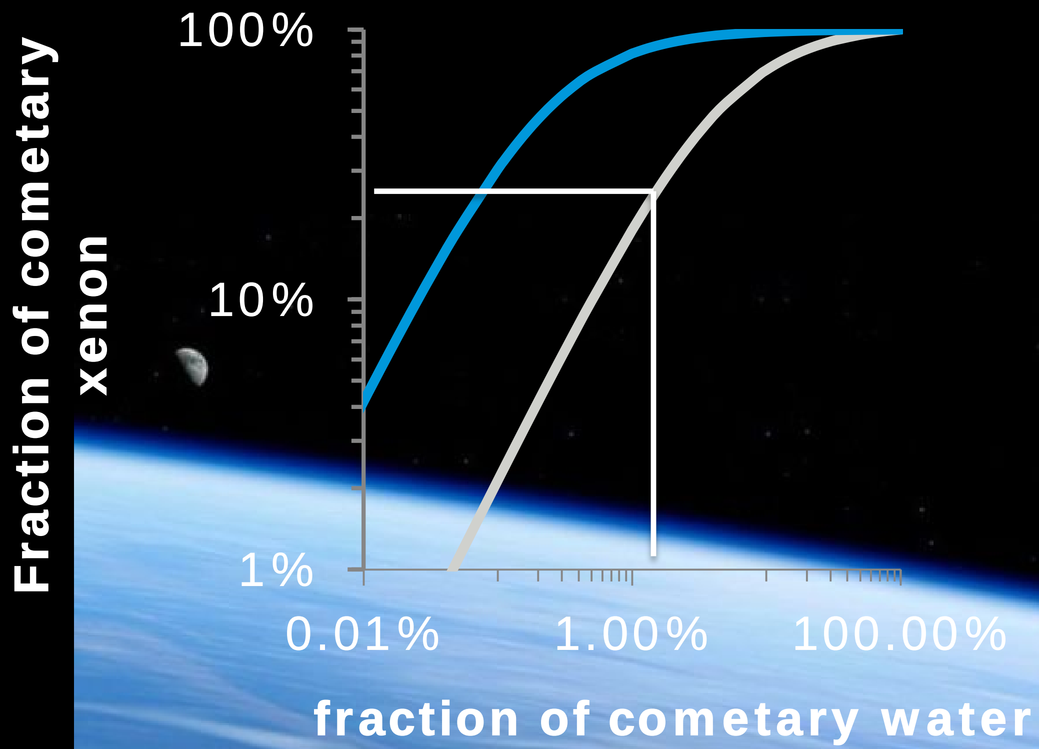
Complex organics

- seen by ROSINA in the coma and by COSAC & Ptolemy on ground
- More complex than anticipated, up to mass >140 Da, > 10 C's
- Large amount and diversity
- Prebiotic molecules including glycine (amino acid)

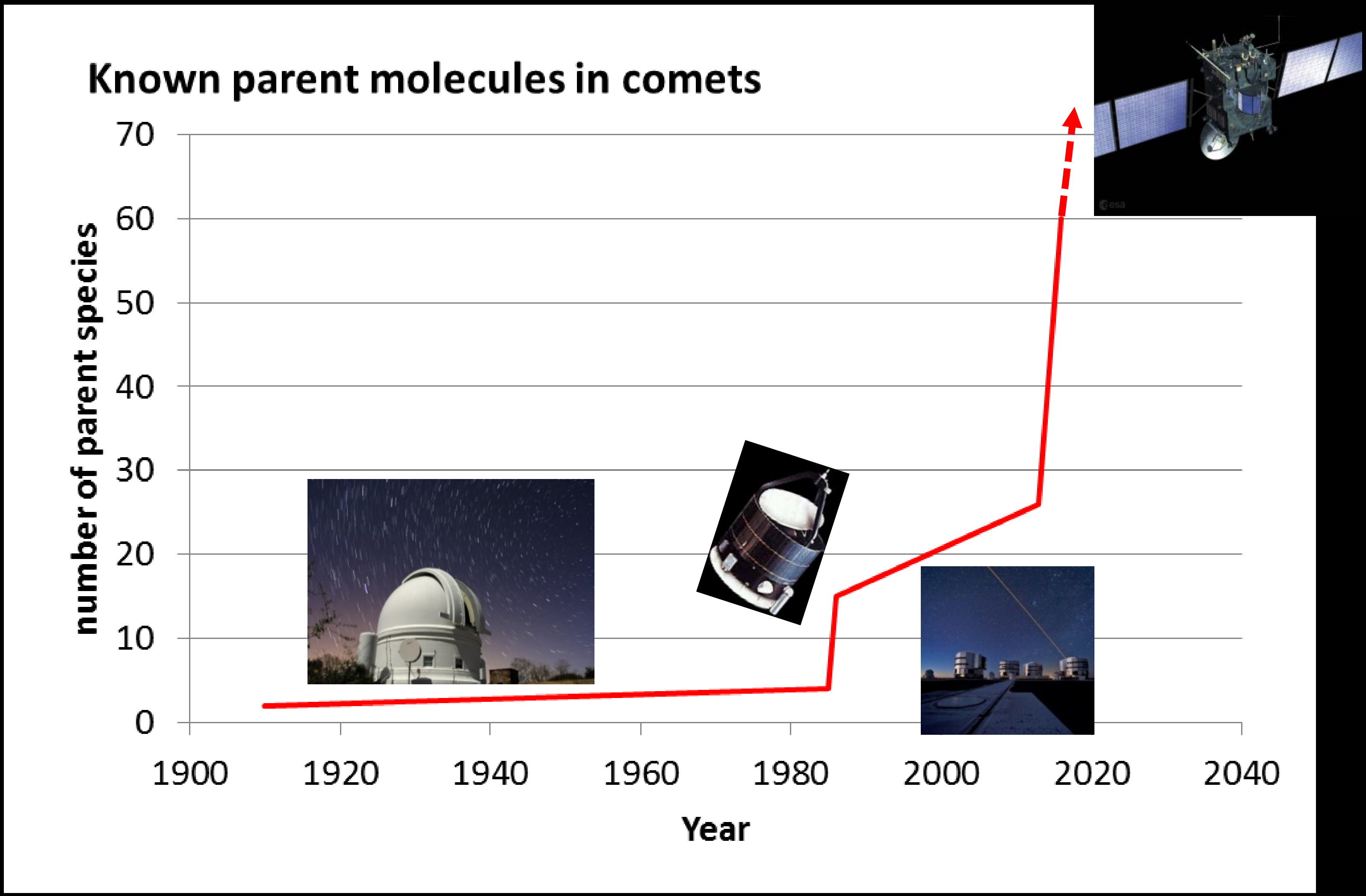




Did comets deliver material to the Earth and if so, how much?



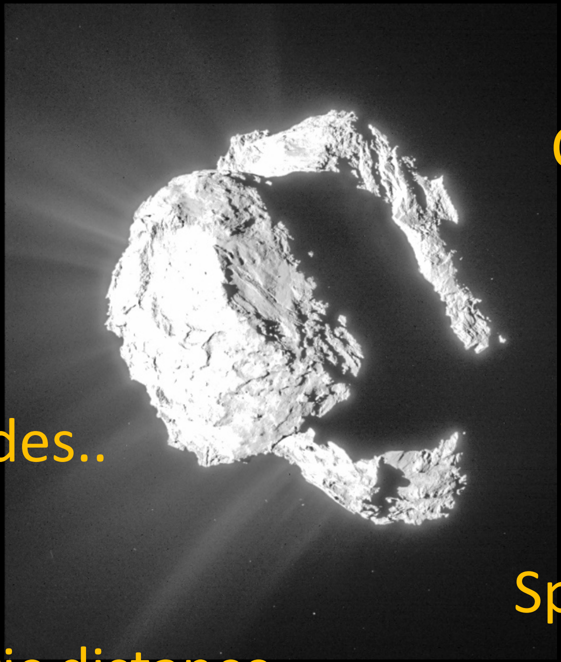
Mass Earth	10^{24} kg
Surface water	10^{21} kg
Delivered by comets	10^{19} kg
Organics delivered by comets (volatile and semivolatile)	10^{17} kg
Organics from refractories	$>10^{18}$ kg


Known parent molecules in comets
number of parent species
0
10
20
30
40
50
60
70
1900
1920
1940
1960
1980
2000
2020
2040
Year

Rosetta results contribute to the understanding of how comets work

Understanding solar wind-comet interaction

Illumination driven activity



Coma heterogeneity

Extended sources (dust – ice)

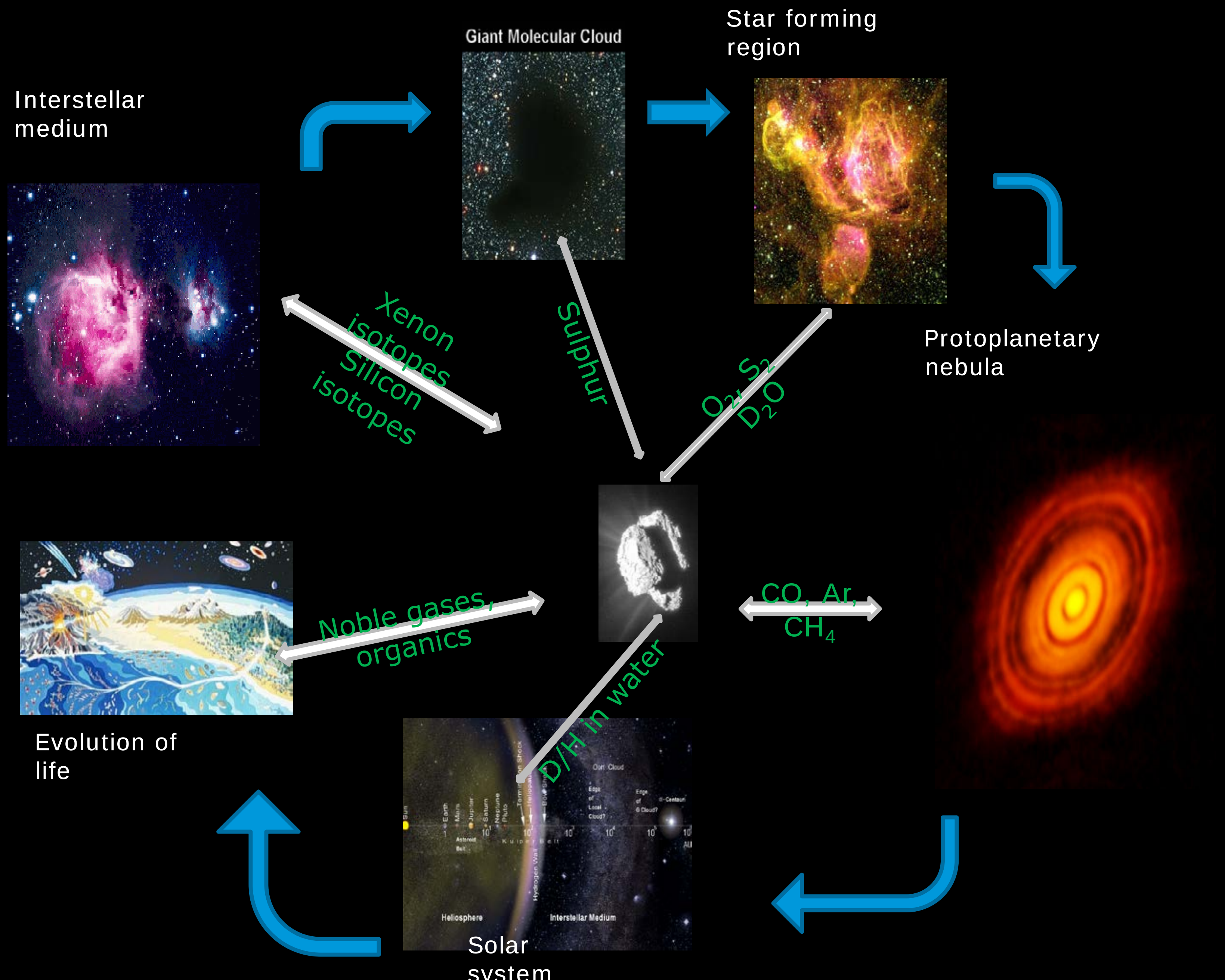
Outbursts from landslides..

Sputtering by solar wind

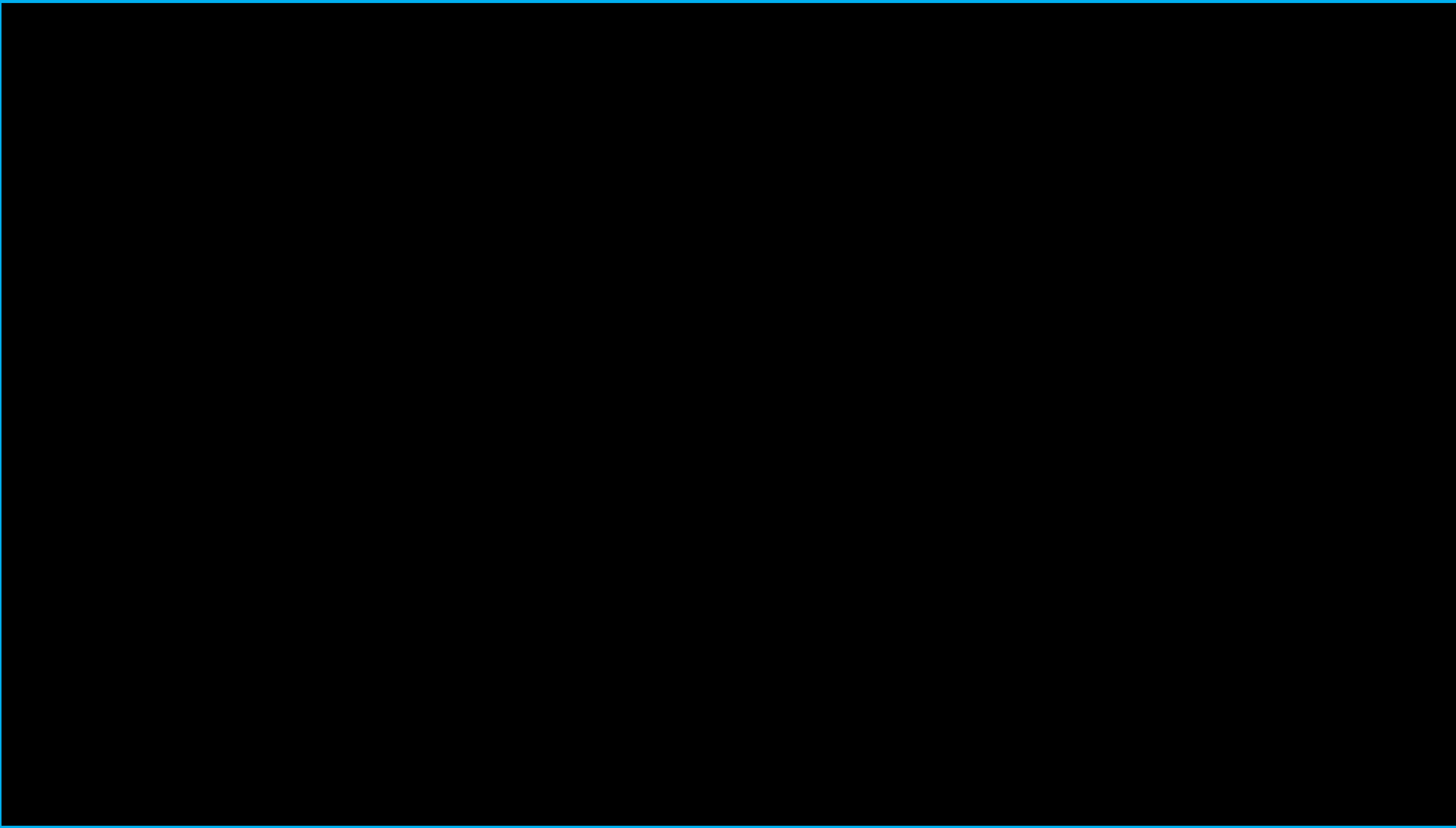
Activity rel. to heliocentric distance

Outbursts driven by very volatiles

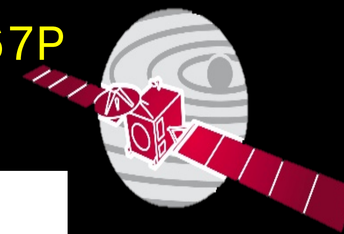
…and how the solar system formed

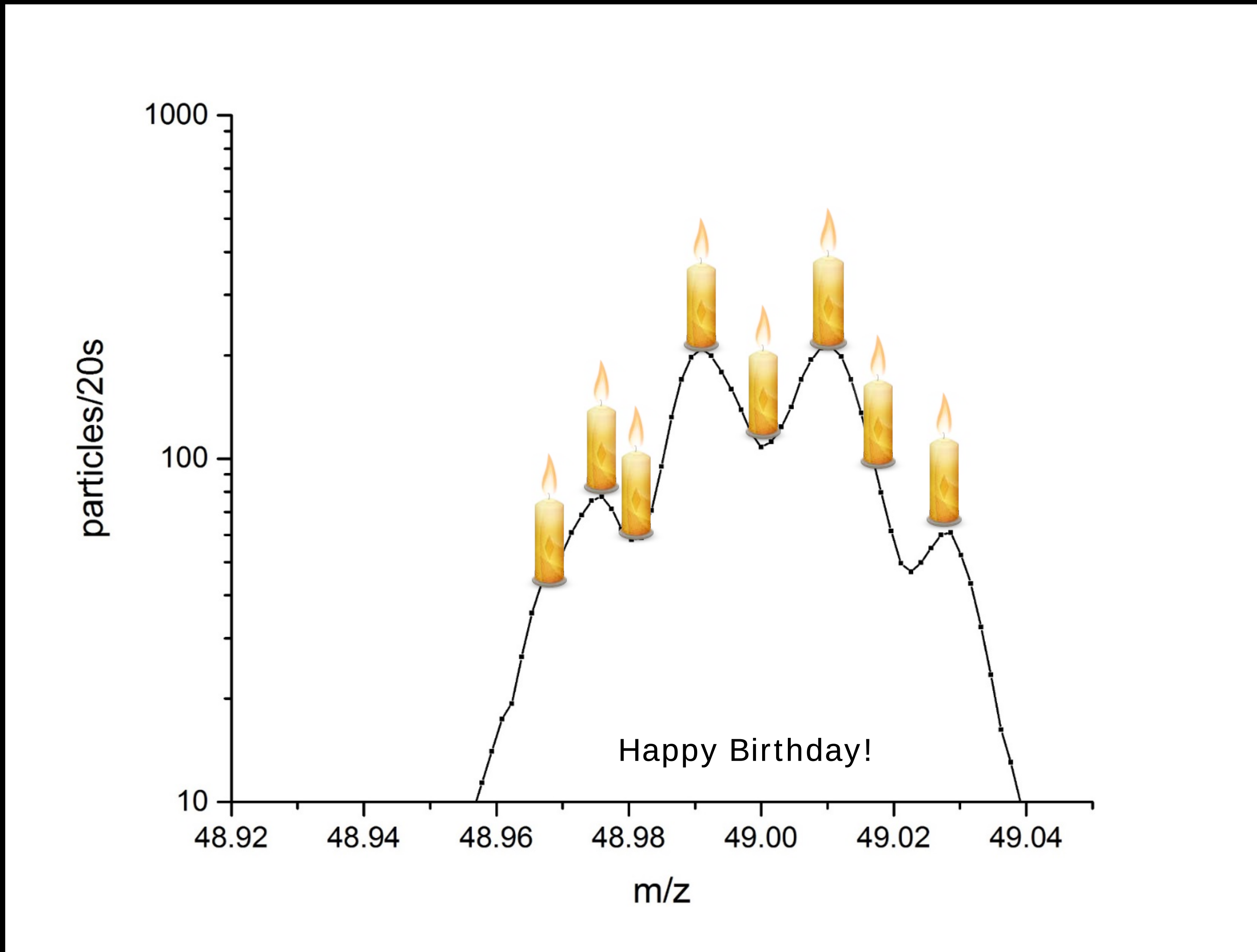


Even the most beautiful story has an end…



Mass spectrum, ROSINA/DFMS, Sep 5, 2016, 2 km above 67P
Dedicated to Roger Bonnet





A very dynamical coma seen in the plasma

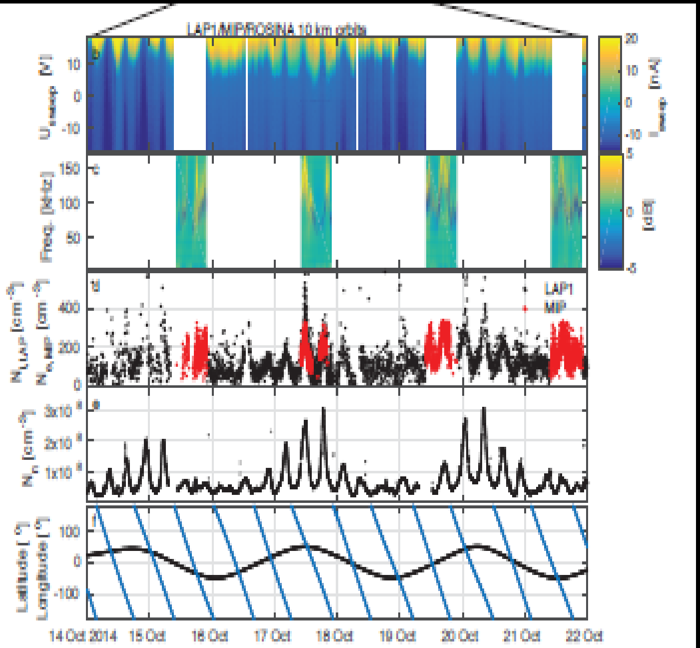
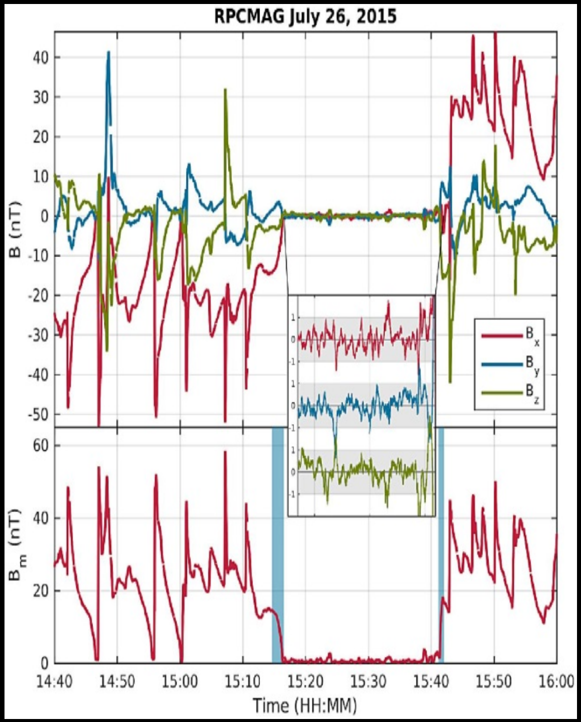


Figure 1. Time series of Rosetta RPC-LAP/MIP data from the bound orbits at 10 km distance. The individual panels show (a) the cometocentric distance of Rosetta, with the inset showing the trajectory of Rosetta around the comet in CSO coordinates with time color-coded along the track, (b) sweep data from LAP1 where the bias voltage is shown swept from -18V to +18 V and the collected current is color-coded, (c) active spectrogram from MIP (d) derived ion density from the LAP1 sweeps (black) and electron density measured by MIP (red), (e) ROSINA/COPS neutral density and (f) latitude (black) and longitude (blue).

Comparison of plasma and neutral gas (Edberg et al., 2015)



Diamagnetic cavity
C. Goetz et al., 2016

Plasma waves: the singing comet
Richter et al., 2016

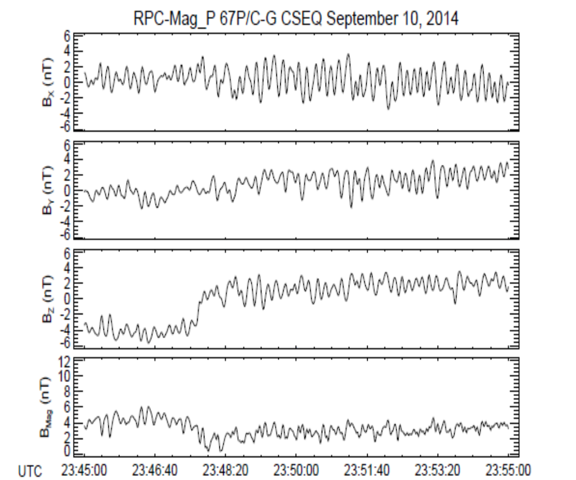
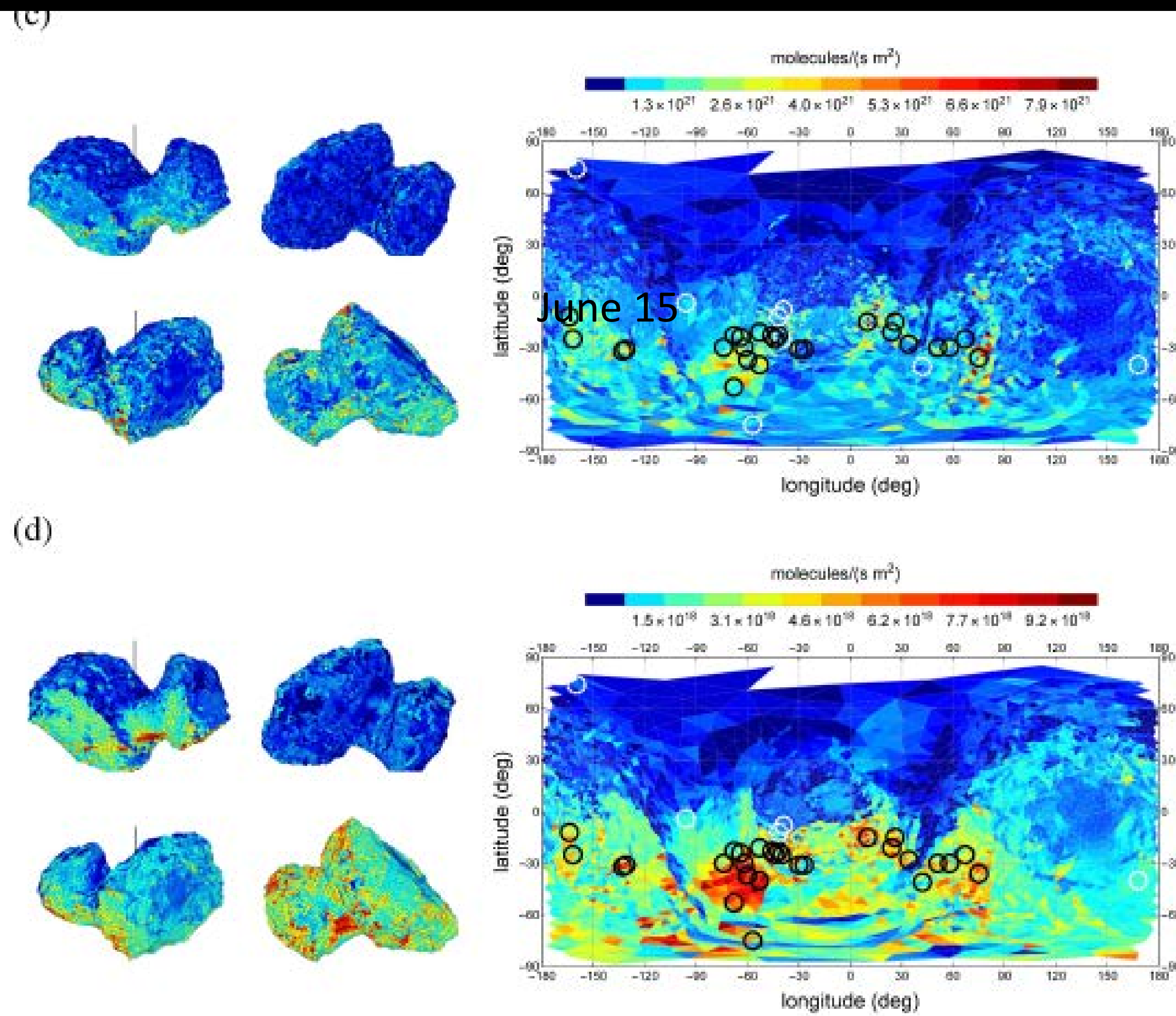


Figure 1. Example of magnetic field observations made onboard the Rosetta spacecraft on 10 September 2014, 23:45–23:55 UTC. The position vector of the spacecraft in the comet-centered solar equatorial (CSEQ; for details see text) coordinate system was (3.9, −20.6, 20.4) km.

September 2015 and May 2016, 29 out of 34 reported dust outburst locations are close to active gas emitters, while in April 2015 only 8 and in June 2015 15 locations match.



Sept 15

May 16

Kramer et al., MNRAS 2017