Estrategia para el desarrollo de instrumentación científica compacta para exploración planetaria *in-situ*

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Instituto Nacional de Técnica Aeroespacial

CONTENTS

1.- The need for miniaturization:

Synergy between Planetary Exploration & Small Satellites

2.- Roadmap concept

3.- Starting from the basic buildng blocks

4.- Gaining In-Orbit Experience

5.- And finally, going to Mars

1 – The need for miniaturization: synergy between Planetary Exploration & Small Satellites

Planetary Exploration missions impose some special conditions to any Space H/W to be put on-board:

- Low power available
- Low mass and volume
- High performance desired

Technology Development programs with a Non-Specific-Mission approach have existed for long both in NASA and ESA, to boost Planetary Exploration capabilities.

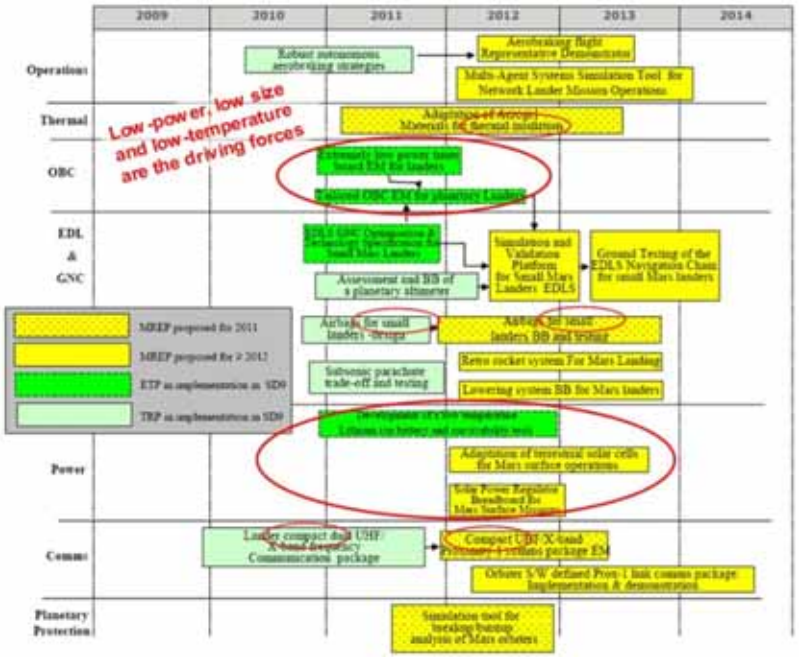
At a reduced scale, we started a similar program working on:

1. A bottom-up approach, from components to systems
2. Technology developments at instrument/unit level, that we test within our Small Satellites Program, which also demand low-power, low-mass, high-performance.

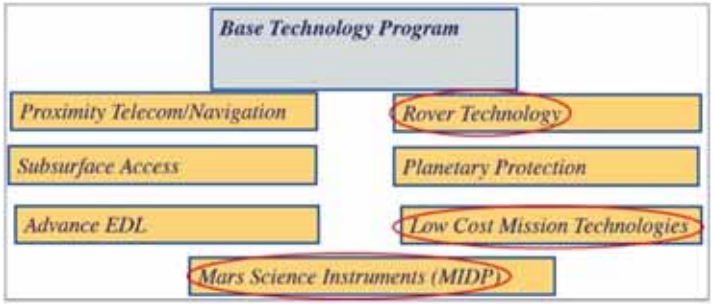
Sci. Instr., Observatories & Sensors Roadmap (NASA, by 2010):

Mission	Technology	Metric	State of Art	Need	Start	TRL6
Discovery 13/14, New Frontiers 4, EJSM	Large arrays: Vis & IR	Pixel count	1 k x 1k format	>2k x 2k format	2011	2015
	Spectral-tunable IR	Narrow-band/ range	1 µm/ few µm	0.1 µm / 1-15 µm	2015	2018
	Spectral-tune Sub-mm	Tunability @ x GHz	60 @600 GHz	>150 GHz @1200	2015	2018
	γ-ray, neutron detec-tors	Energy resolution, Directionality	1%, 10 deg	0.1%, 1 deg	2015	2018
	Polarization	s/p, switching speed	50%, ~1 Hz	>90%, >50 Hz	2013	2018
	Photon Counting	Λ, array size	Some λ's:	UV/vis InGaAs	2010	2018
	Rad hard Detector	TID, no SEU/SEL	Heavy shielding	<100 mils shield	2010	2020
Dis 13/14, NF 4, EJSM	Rad Hard Electronics	TID tolerance	0.1-1 Mrad	3 Mrad	2010	2020
	Low Noise Electronics	Noise level (%)	<1%	<0.01%	2011	2020
	Extreme Environment Electronics	Operating temperature	-55C to 125C	-180C to125C	2011	2020

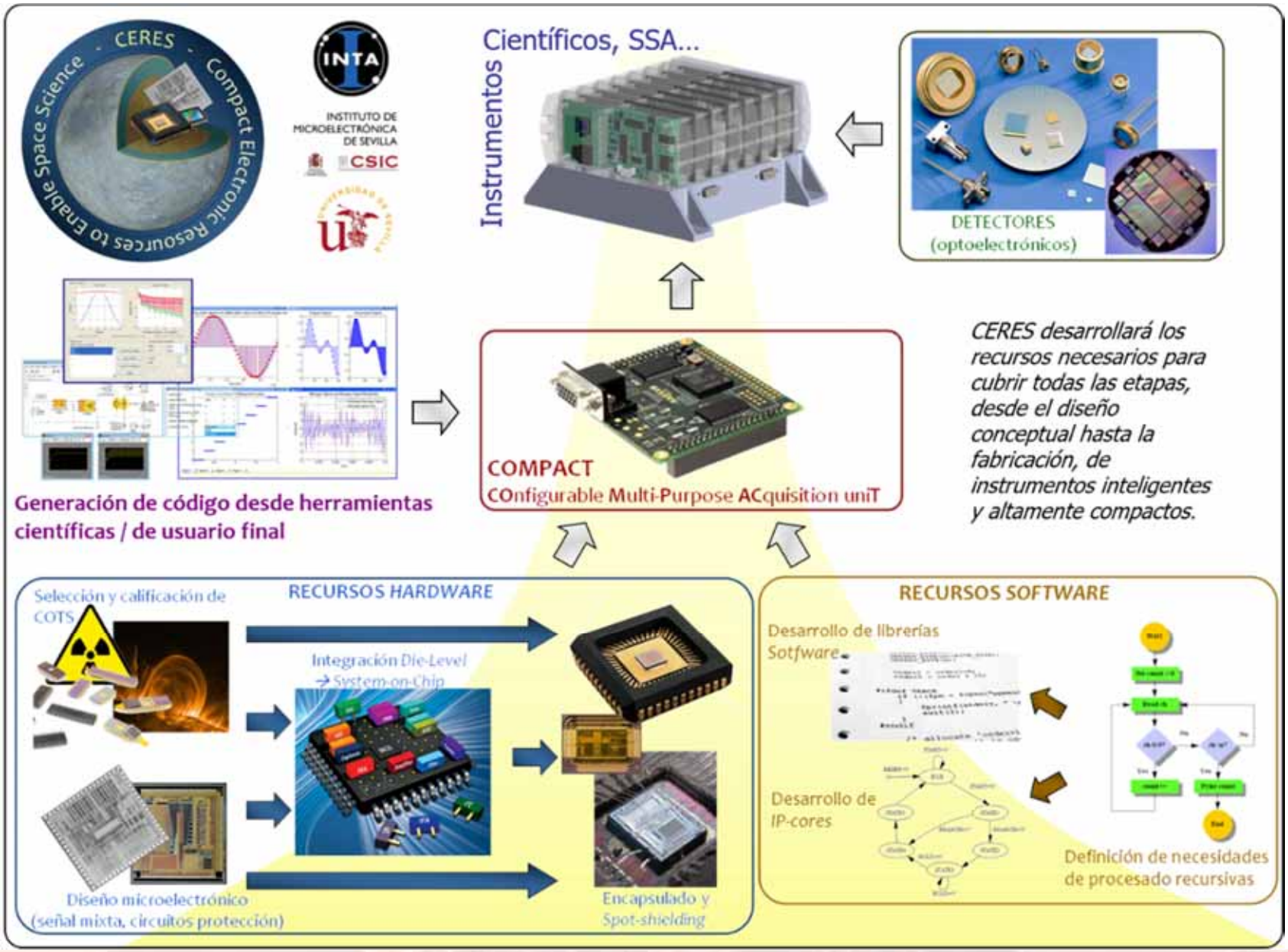
Robotic Exploration Technology Plan (ESA, by 2010):



Mars Technology Program (NASA, by 2010):

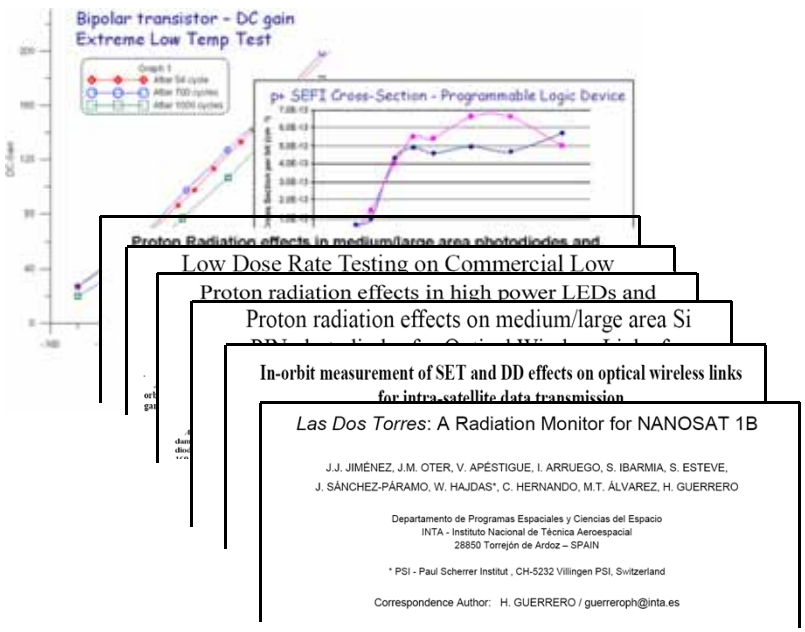


2 – Roadmap approach



3 – Starting from the basic buildng blocks: EEE parts, OE, MEMS

- Analysis & selection
- Intensive testing
- Qualification and Screening for COTS

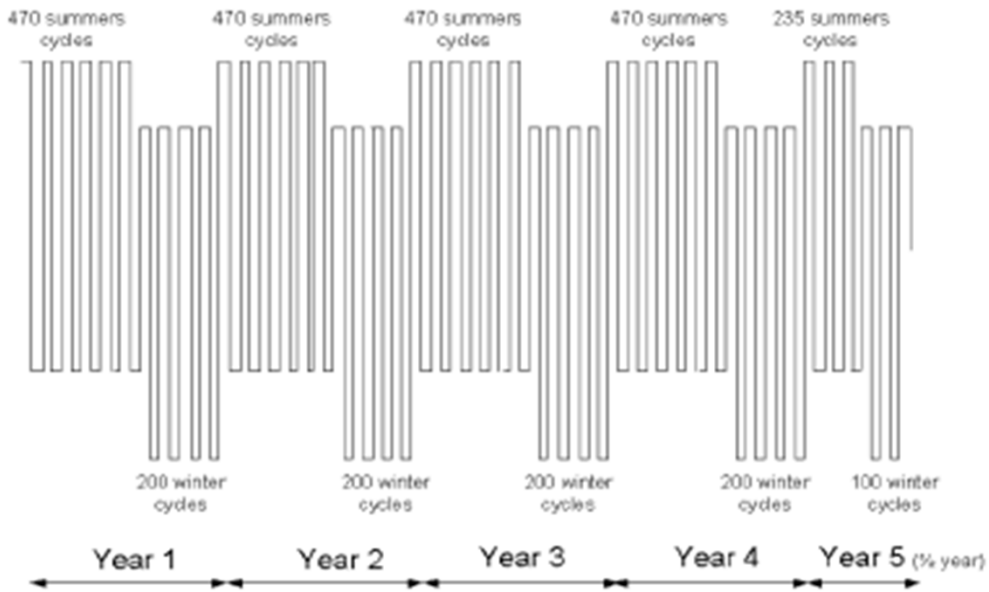


	Kind of Part	Number of different P/Ns	TID	SEE	Extreme Temp.	In-Orbit
Space grade	A/D Converter	1	N/A	N/A	X	X
	D/A Converter	1	N/A	N/A	X	X
	Analog MUX/Switch	3	N/A	N/A	X	X
	FPGA	1	N/A	N/A	X	X
	Voltage Reg./Ref.	3	N/A	N/A	X	X
	Comparator	1	N/A	N/A	X	X
	SRAM	1	N/A	N/A	X	X
COTS	A/D Converter	1	X		X	
	D/A Converter	1	X		X	
	Instrum. Amplif.	4	X		X	X
	FPAA	1	X	X		
	CPLD	2	X	X		X
	Microcontroller	2	X	X	X	X
	Operational Amp.	8	X	X (2)	X	X (3)
	Voltage Reg./Ref.	3	X		X	X (2)
Sensors	Temperature	6	X		X	
	Magnetic	5	X			
	Accelerometer	1	X		X	
	TID	4	X			
Optoelectr.	Emitters (UV/VIS/NIR)	28	X	X	X (3)	X (4)
	Photodetectors	23	X	X	X (3)	X (3)
	Microspectrometer	1	X		X	
	CMOS, linear array	1	X		X	
	CMOS, image	1	X	X		X

TOTAL: 103

3 – Starting from the basic buildng blocks: EEE parts, OE, MEMS

- And PQV – Package Qualification and Verification, including:
  - Components
  - Different soldering techniques
  - Materials: PCBs, structural, optical, etc.
  - Coatings, adhesives, paintings, surface finishes



3 – Starting from the basic buildng blocks: EEE parts, OE, MEMS

E.g. PQV for Radiation and Dust Sensor on Mars 2020 Rover

20 UUT BOARDS

2 RDS SUBASSEMBLIES

18 EGSE BOARDS

MORE THAN 170 DOCUMENTS

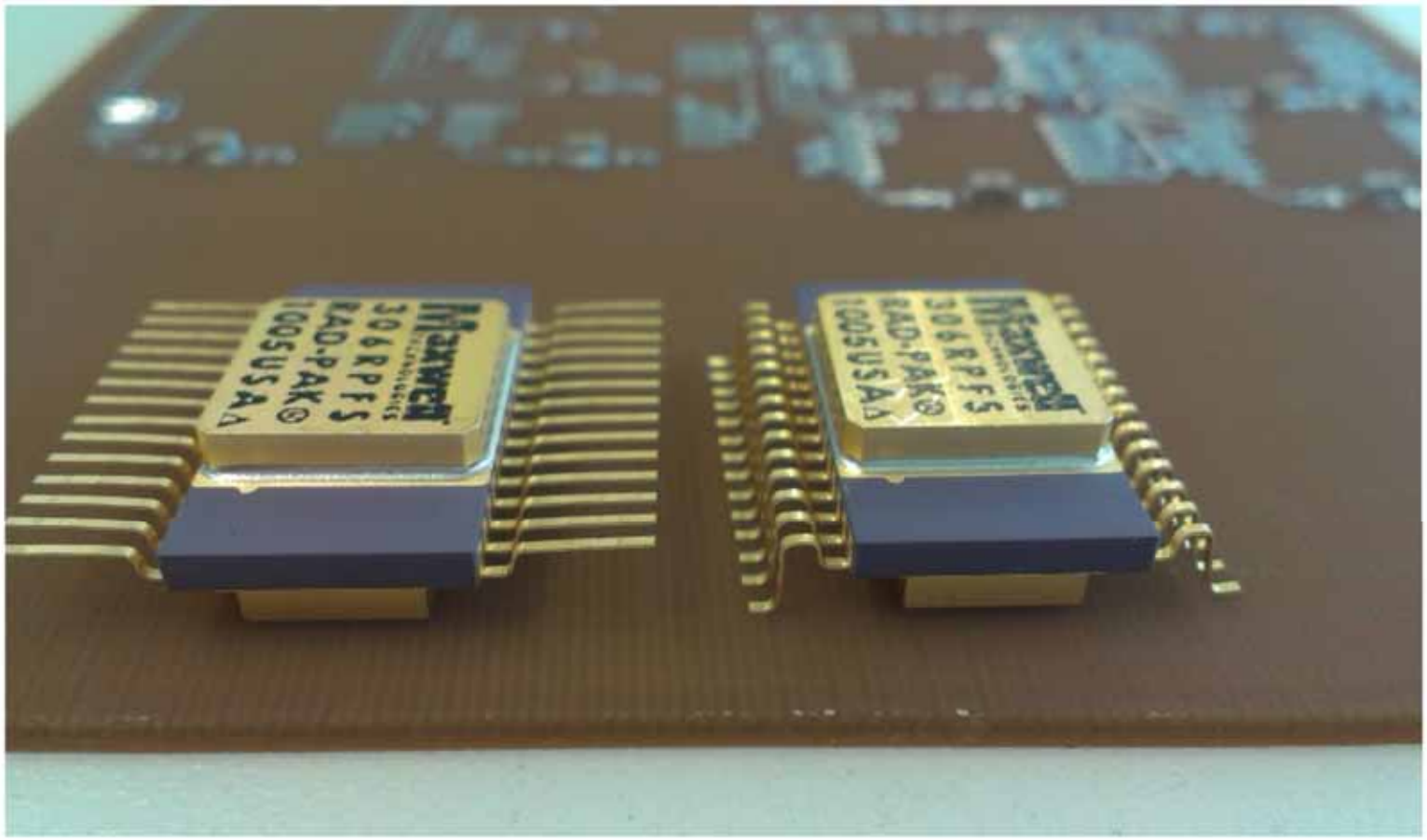
7 PEOPLE HAVE WORKED INTENSIVELY

300k€ ESTIMATED COST

Tested Technology	NUMBER OF ITEMS
Paint	2 Types
Glue	3 Types
Silicones	2 Types
PCB material	2 Types
Coating	1 Type

EEE Parts Tested	NUMBER OF ITEMS
Photodiodes (stand alone)	6 Large size 6 Small size
Opto-mechanical sets	6 Large size 9 Small size
Cristal Oscillator	3 FMI 3 QTech
Operational Amplifier	3 National 3 Analog Dev.
ADC	3 Maxwell 3 Texas Instr.
SERIAL DRIVERS	6 Intersil 3 Texas Instr.
FPGA	3 Actel
RAM MEMORY	3 Atmel
DAC	3 Texas Instr.
PASIVES	TONS
MULTIPLEXER	3 Intersil 3 Maxwell

PQV in images



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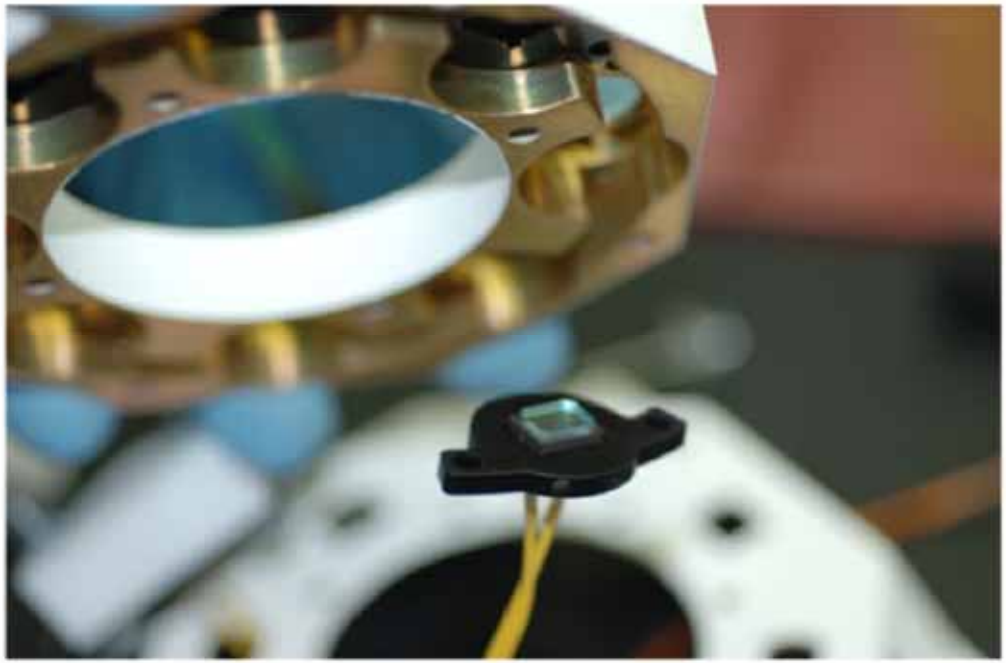

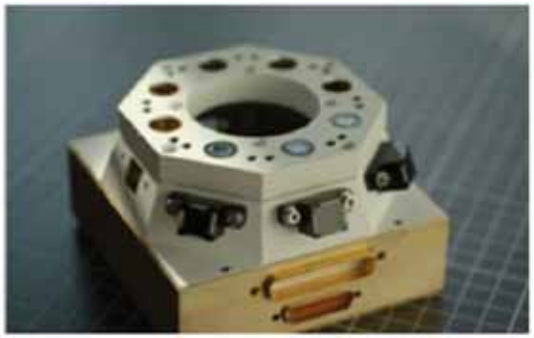

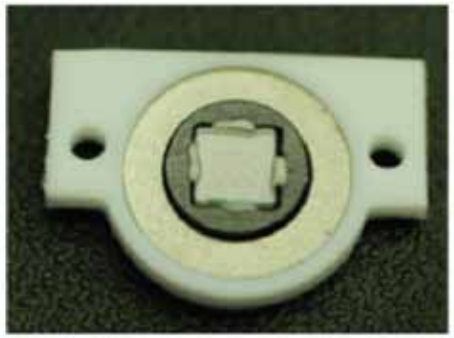

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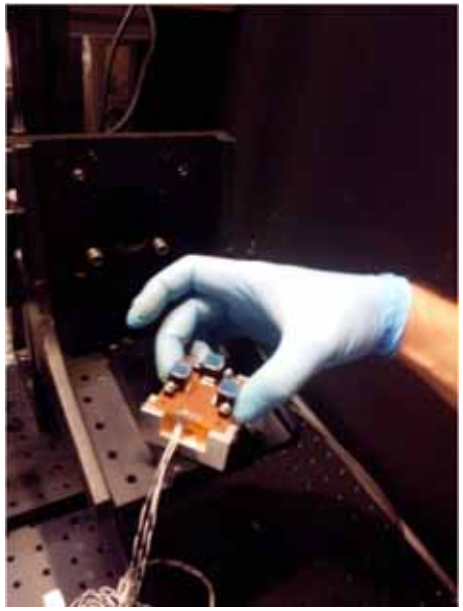

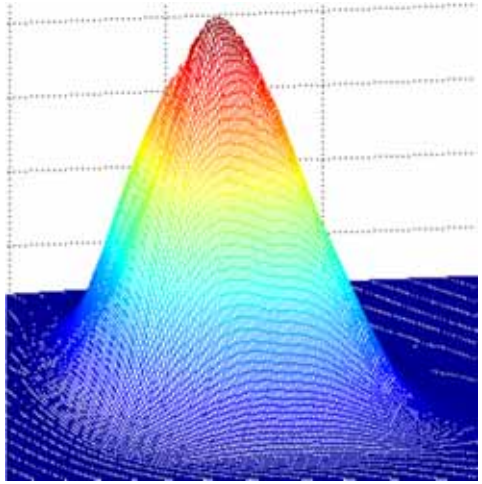

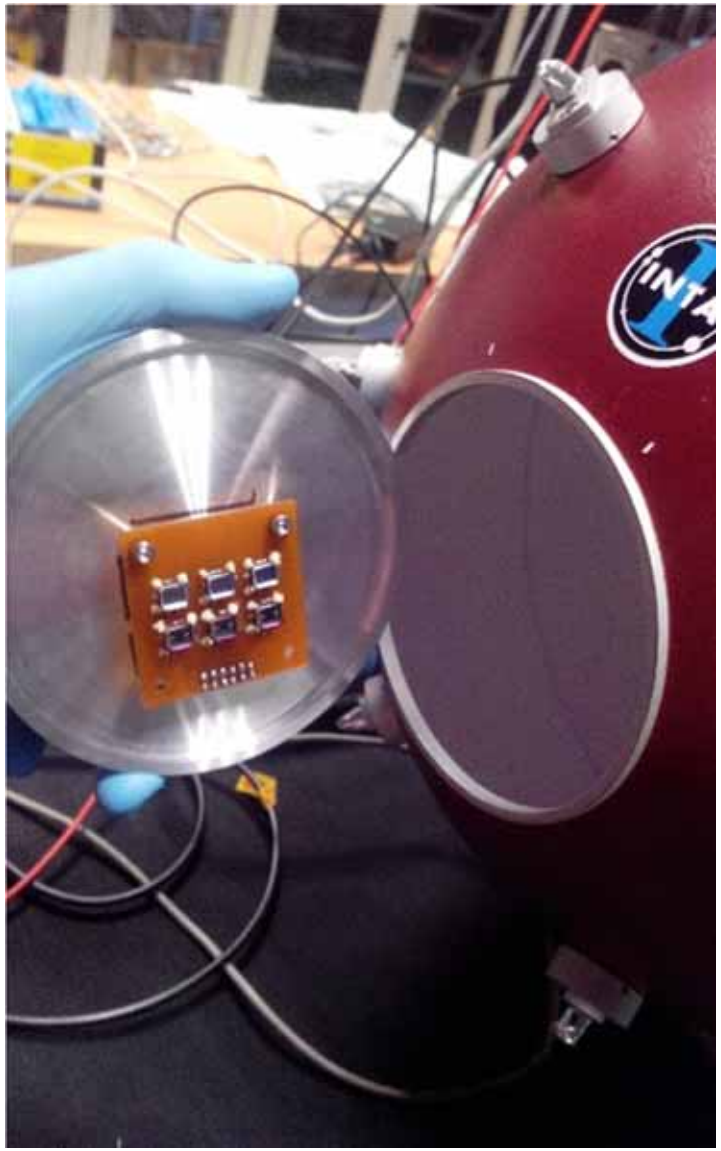

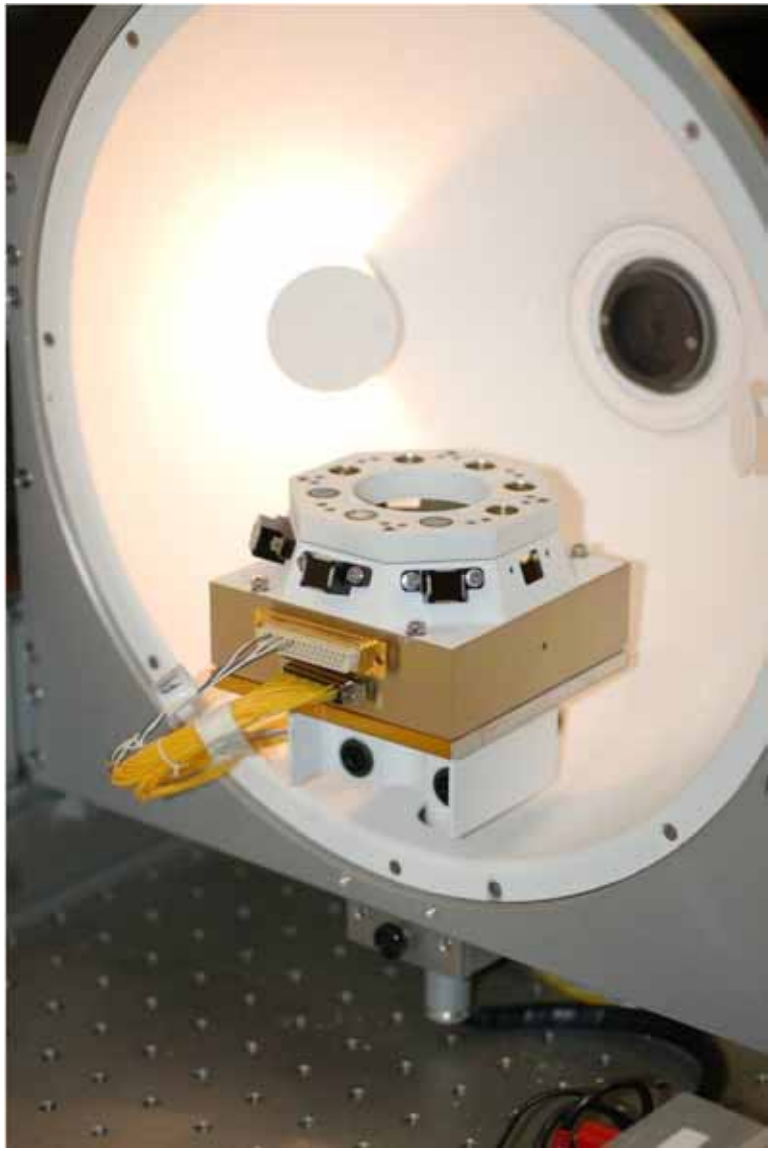

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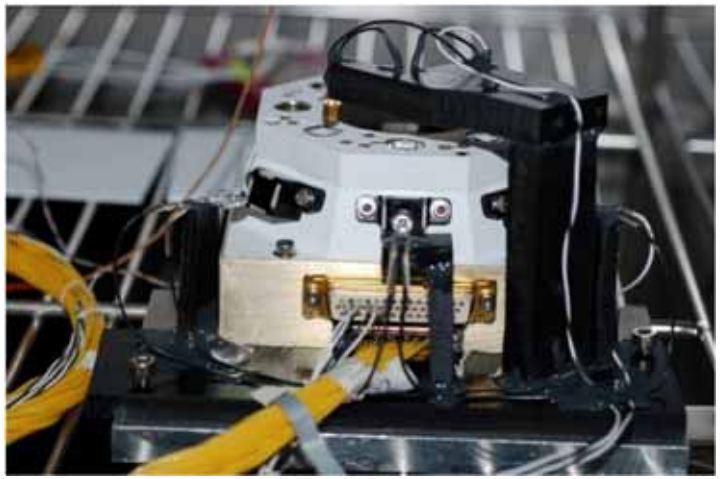


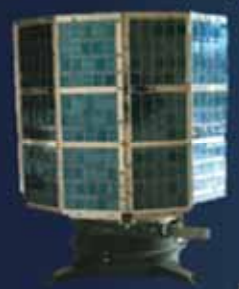
PQV in images

Access to Space through Small Platforms

Space Programs and Flight Segment

Minisatellites Microsatellites Nanosatellites

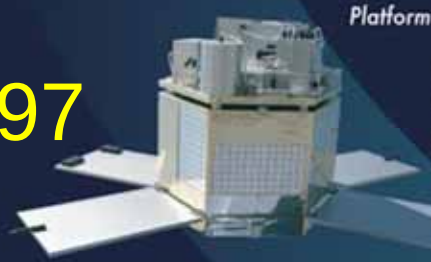
INTASAT (1974) . 25 Kg. 1974



Payload: Ionospheric Beacon
Subsystems: Developed by INTA and national Industries
Launch: Delta Rocket (Vanderberg, USA). Sep. 74 with ITOS-G
AIT: Assembled, qualified and tested at INTA facilities

MINISAT-01 (1997) - 190 Kg.

1997



Platform: developed by INTA and national industries

Payload : Three Instruments:
LEGRI (INTA-UV-RAL) Gamma ray instrument
EURD (INTA-UCB) UV Spectrograph
CPLM (INTA-UPM) Microgravity experiment

Assembly of Rocket/Satellite at INTA facilities.

MINISAT 01 re-entered atmosphere after 5 year of successful operation

NANOSAT 01 (2004) - 18 Kg.

2004

Mission: Store and Forward Communications
Experiments: Micro-nanotechnologies magnetic and solar sensors
Platform: developed at INTA. Electronics modular design
Batteries: Ion-Li From AEA technologies (UK)
Solar Panels: GaAs/Ge form Galileo Avionica (Italy)
Launch: Ariane 5/ASAP, 18 sep. 04
Life time: 3 years nominal. 5 years feasible.
Developed, integrated and tested at INTA facilities

NANOSAT 1B

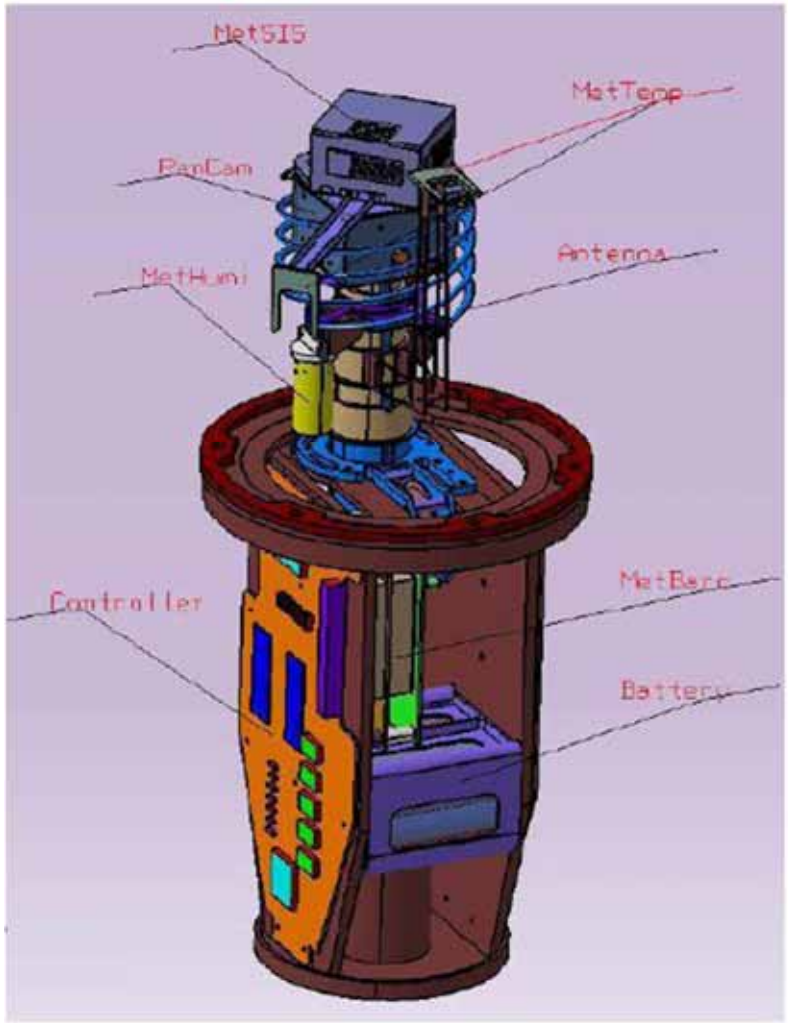
2009

Technical support to National Space Programs (HISPASAT, HISDESAT, SEOSAT, etc)

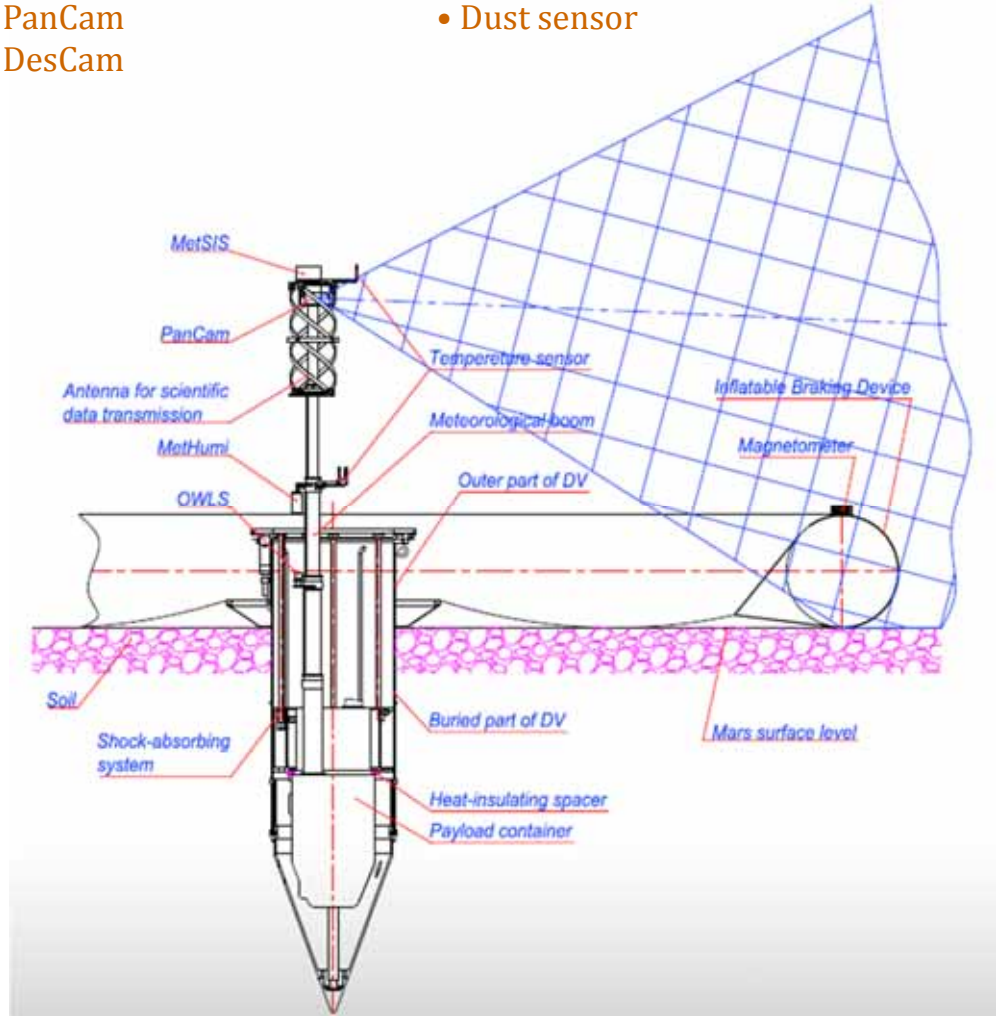
From the developments in our Small Platforms...
... to the exploration of Solar System
In-Orbit experience, Payloads Engineering Area
OPTOS
NANOSAT 1B
NANOSAT-1B (2009)
• Radiation Monitor
• Payload Computer
• AMR sensor
• Magneto-Impedance sensor
• RadFET dosimetry
1U – CUBESATs – 3U
OPTOS (2013)
• Distributed Computer Concept
• Wireless On-Board Comms.
•CMOS Active Pixel Sensor
• GMR sensor
• AMR sensor
• Sun detector
Xatcobeo (2012)
& Humesat (2013)
• On board processor
The Two Towers – SEOSAT/INGENIO (2015):
• Space Weather Monitor
• Autonomous Instrument
• Payload Computer
• 5 Radiation Sensing Technologies
FOTON M3
FOTON-M3 (2007)
• 1 Wireless On board Computer
• 2 Wireless µRTUs
• 2 Optical transceivers
... INCREASING PERFORMANCE AND MINIATURIZATION...
MetNet (2020 ?)
• Magnetometer
• Spectrometer
• Optical Wireless
• Dust Sensor
• Mixed-Signal ASICs
METNET
FROM FIRST IN-ORBITSTEPS...
...TOWARDS MARS AND SOLAR SYSTEM
INTA
NANOSAT-01 (2004)
• AMR sensor
• Faraday effect magnetometer
• Porous Si solar sensor
• 2 Optical Wireless experiments
NANOSAT 01
Under Development:
• Exomars 2016 Lander, ESA
(DREAMS-SIS radiometer)
• Exomars 2018 Lander, Roskosmos/ESA
(SIS'18, DS'18, MAG, MicroMED)
• Mars2020, NASA
(Radiation & Dust Sensor in MEDA meteo station)
In-Orbit experience in Miniature Space Instruments
Scientific Payloads

5 – And finally, going to Mars → (A) MetNet

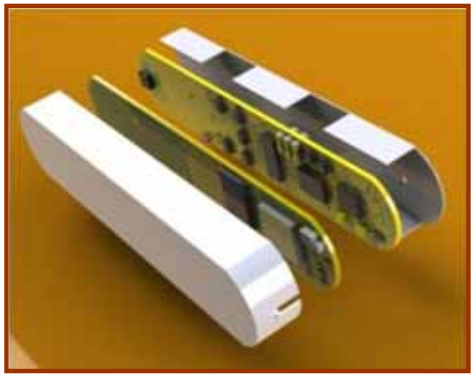
5 – And finally, going to Mars → (A) MetNet

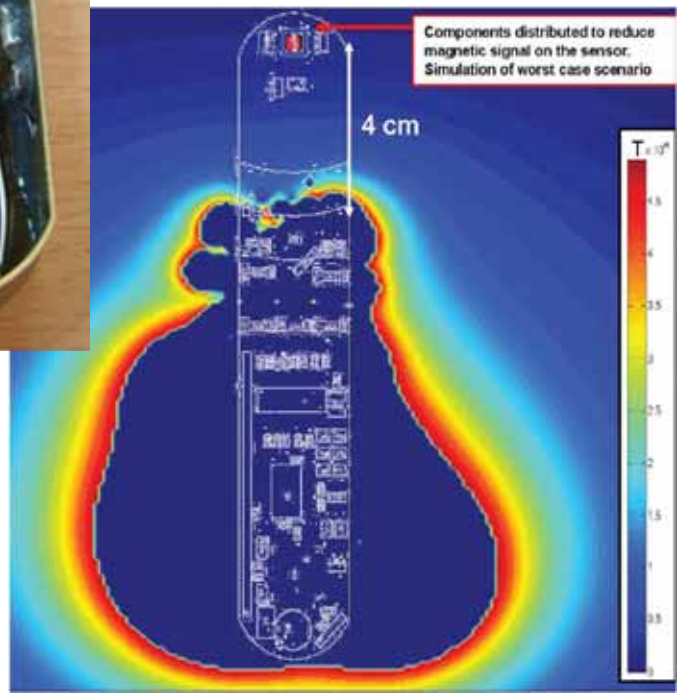


- Air temperature sensors
- Pressure
- Humidity
- PanCam
- DesCam
- Tri-axial accelerometer
- Megnetometer
- Photometer
- Dust sensor

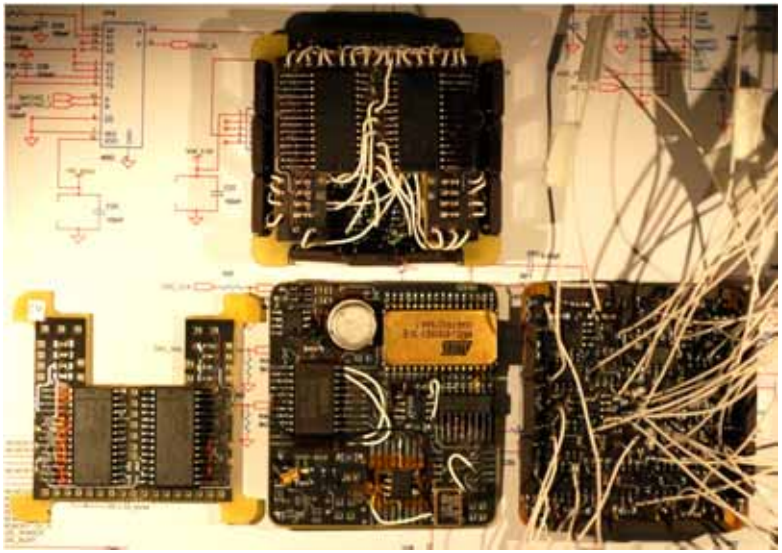


5 – And finally, going to Mars → (A) MetNet

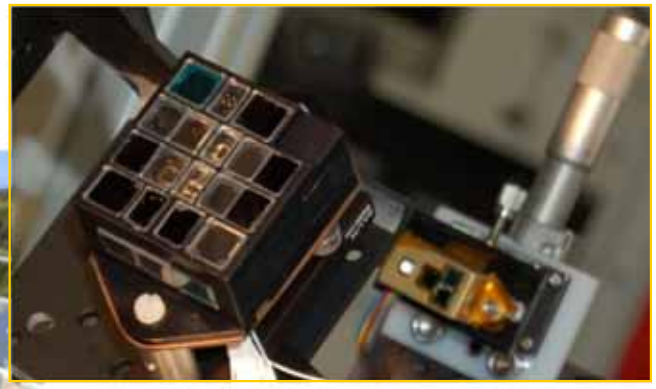




70 g
400 mW



114 g
500 mW

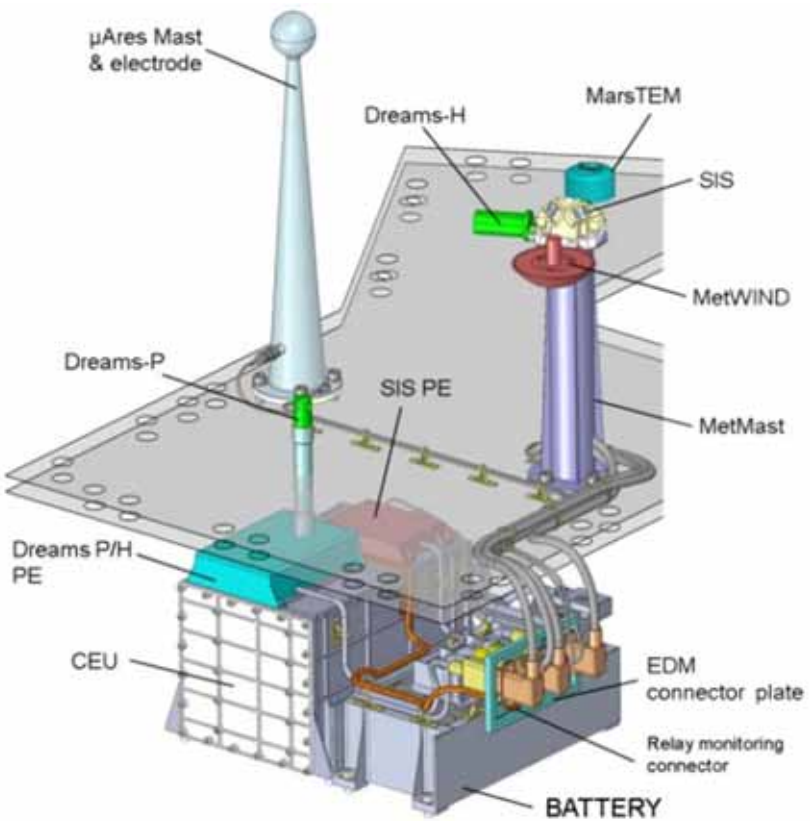


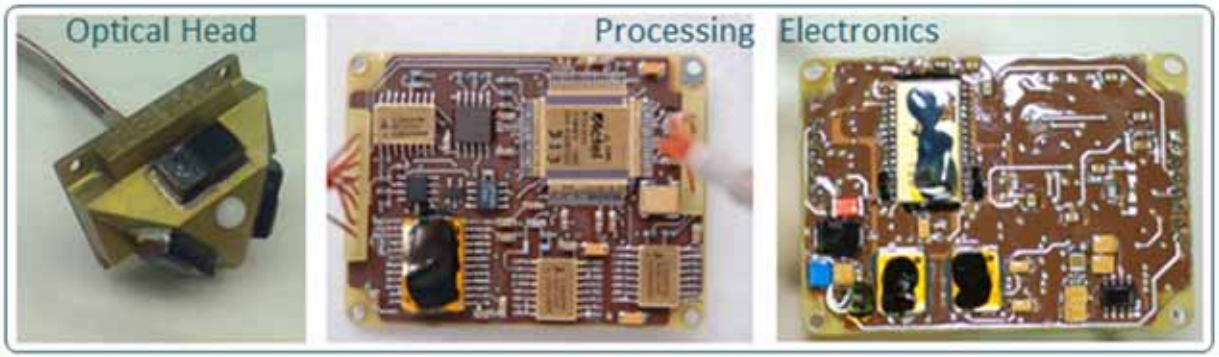
+ 2 ASICs

CENTRO NACIONAL DE MICROELECTRÓNICA · IMSE · UNIVERSIDAD DE SEVILLA

5 – And finally, going to Mars → (B) ExoMars'16 EDM

DREAMS:
Dust characterization, Risk assessment and Environment Analyzer on the Martian Surface





DREAMS (ExoMars 2016 EDM) Solar Irradiance Sensor – DREAMS SIS	
Sensing elements	Si-photodiodes + interference filters + density filters + FoV shaping elements
Power supply	5 V
Current consumption	<58 mA
Data I/F	Serial, RS-422
Mass	25 g Optical Head (OH) + 52 g Processing Electronics (PE)
Dimensions	OH: 42x33.7x22.5 mm; PE: 80x50x13.5 mm
Operating Temperature	-120 to +125 °C
Optical Bands (nm)	Total:[220-1200], UV:[315-400], NIR:[700-1100]
Range / Resolution (W/m^2)	Total: 1050 / 10^{-3}, UV: 110 / 10^{-4}, NIR: 390 / $3.7x10^{-4}$
Additional Sensors	Temperature (PT-1000, x2: OH and PE), Dark-current for Dispacement Damage estimation.
Operation and others	Fully digital. RadHard FPGA used. Allows autonomous operation under configurable parameters: channels to acquire, sampling period, etc. 128 kB internal RadTol memory.

5 – And finally, going to Mars → (B) ExoMars'16 EDM

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DREAMS-SIS: The Solar Irradiance Sensor on-board the ExoMars 2016 lander

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Abstract

The Solar Irradiance Sensor (SIS) was part of the DREAMS (Dust characterization, Risk assessment, and Environment Analyzer on the Martian Surface) payload package on board the ExoMars 2016 Entry and Descent Module (EDM), "Schiaparelli". DREAMS was a meteorological station aimed at the measurement of several atmospheric parameters, as well as the presence of electric fields, during the surface operations of EDM. DREAMS-SIS is a highly miniaturized lightweight sensor designed for small meteorological stations, capable of estimating the aerosol optical depth (AOD) several times per sol, as well as performing a direct measurement of the global (direct plus scattered) irradiance on the Martian surface in the spectral range between 200 and 1100 nm. AOD is estimated from the irradiance measurements at two different spectral bands – Ultraviolet (UV) and near infrared (NIR) – which also enables color index (CI) analysis for the detection of clouds. Despite the failure in the landing of Schiaparelli, DREAMS-SIS is a valuable precursor for new developments being carried-on at present. The concept and design of DREAMS-SIS are here presented and its operating principles, supported by preliminary results from a short validation test, are described. Lessons learnt and future work towards a new generation of Sun irradiance sensors is also outlined.
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Keywords: Solar Irradiance Sensor; Martian atmosphere; Optical depth; Color index; ExoMars; Mars 2020

1. Introduction

DREAMS-SIS is a radiometer that was part of the DREAMS meteorological station on board the ill-fated ExoMars 2016 EDM "Schiaparelli" (Esposito et al., 2014). DREAMS goal was to increase our understanding of the Martian environment through the measurement of different parameters such as pressure, temperature, humidity, wind speed and direction, and solar irradiance on surface, as well as novel measurements of the electric field on Mars atmosphere.

The two main goals of DREAMS-SIS were to provide high time resolution estimations of the aerosol optical

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Measurement of dust optical depth using the solar irradiance sensor (SIS) onboard the ExoMars 2016 EDM

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ABSTRACT

The solar irradiance sensor (SIS) was included in the DREAMS package onboard the ExoMars 2016 Entry Descent and Landing Demonstrator Module, and has been selected in the METEO meteorological station onboard the ExoMars 2020 Lander. This instrument is designed to measure at different time intervals the scattered flux or the sum of direct flux and scattered flux in UVA (315–400 nm) and NIR (700–1100 nm) bands. For SIS16, these measurements are performed by a total of 3 sensors per band placed at the faces of a truncated tetrahedron with face inclination angles of 60°. The principal goal of SIS16 design is to perform measurements of the dust opacity in UVA and NIR wavelengths ranges, crucial parameters in the understanding of the Martian dust cycle. The retrieval procedure is based on the use of radiative transfer simulations to reproduce SIS observations acquired during daytime as a function of dust opacity. Based on different sensitivity analysis, the retrieval procedure also requires to include as free parameters (1) the dust effective radius; (2) the dust effective variance; and (3) the imaginary part of the refractive index of dust particles in UVA band. We found that the imaginary part of the refractive index of dust particles does not have a big impact on NIR signal, and hence we can kept constant this parameter in the retrieval of dust opacity at this channel.

In addition to dust opacity measurements, this instrument is also capable to detect and characterize clouds by looking at the time variation of the color index (CI), defined as the ratio between the observations in NIR and UVA channels, during daytime or twilight. By simulating CI signals with a radiative transfer model, the cloud opacity and cloud altitude (only during twilight) can be retrieved. Here the different retrieval procedures that are used to analyze SIS measurements, as well as the results obtained in different sensitivity analysis, are presented and discussed.

1. Introduction

On Mars, dust particles play a key role in the structure and dynamics of the atmosphere (Gierasch and Goody, 1972). Dust particles, absorbing and scattering the solar radiation, influence directly into the heating rates of the surface and atmosphere, and hence on the Martian atmospheric circulation at various scales (e.g. Madeleine et al., 2011; Medvedev et al., 2011). In addition, in the absence of massive condensed water and precipitation, dust lifted from the surface of Mars is the unique condensation nuclei available at the atmosphere. However, depending on characteristics such as the particle size distribution, airborne Martian dust can provide positive or negative radiative feedbacks into dynamical processes. This identification of the role played by Martian dust in the circulation of the atmosphere has resulted in big efforts to estimate the concentration and physical properties of dust at different key locations and time periods. Physical properties and concentrations of dust at different wavelengths have been retrieved from land observations (e.g. Pollack et al., 1979; Colburn et al., 1989; Smith and Lemmon, 1999; Pollack et al., 1995; Tomasko et al., 1999; Markiewicz et al., 1999; Lemmon et al., 2015), as well as from space borne observations (e.g. Toon et al., 1977; Korablev et al., 1993; Wolff and Clancy, 2003; Montmessin et al., 2006; Fedorova et al., 2014). Such properties are for instance the refractive index, the size distribution or the shape of dust particles.

Models have allowed to understand with more clarity the processes involved in the Martian dust cycle. This has been possible thanks to the great progress that has been made in modeling the different non-linear feedback mechanisms involved in the Martian dust cycle with lifting

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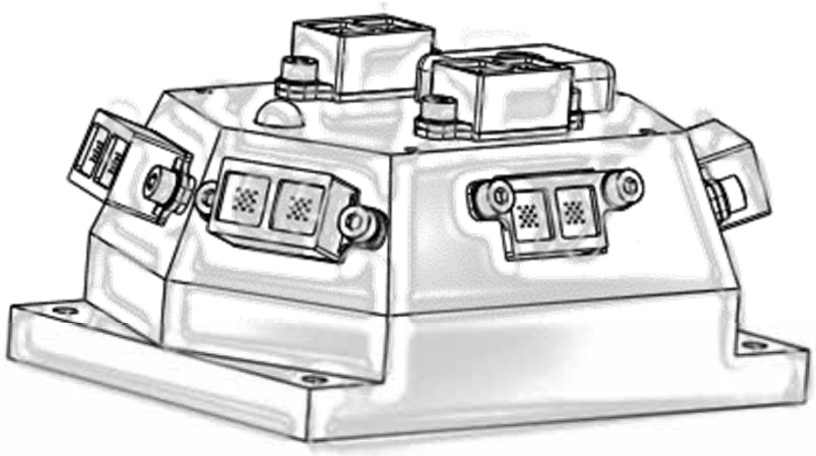
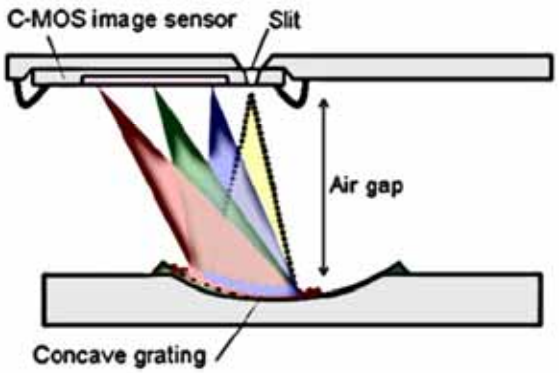
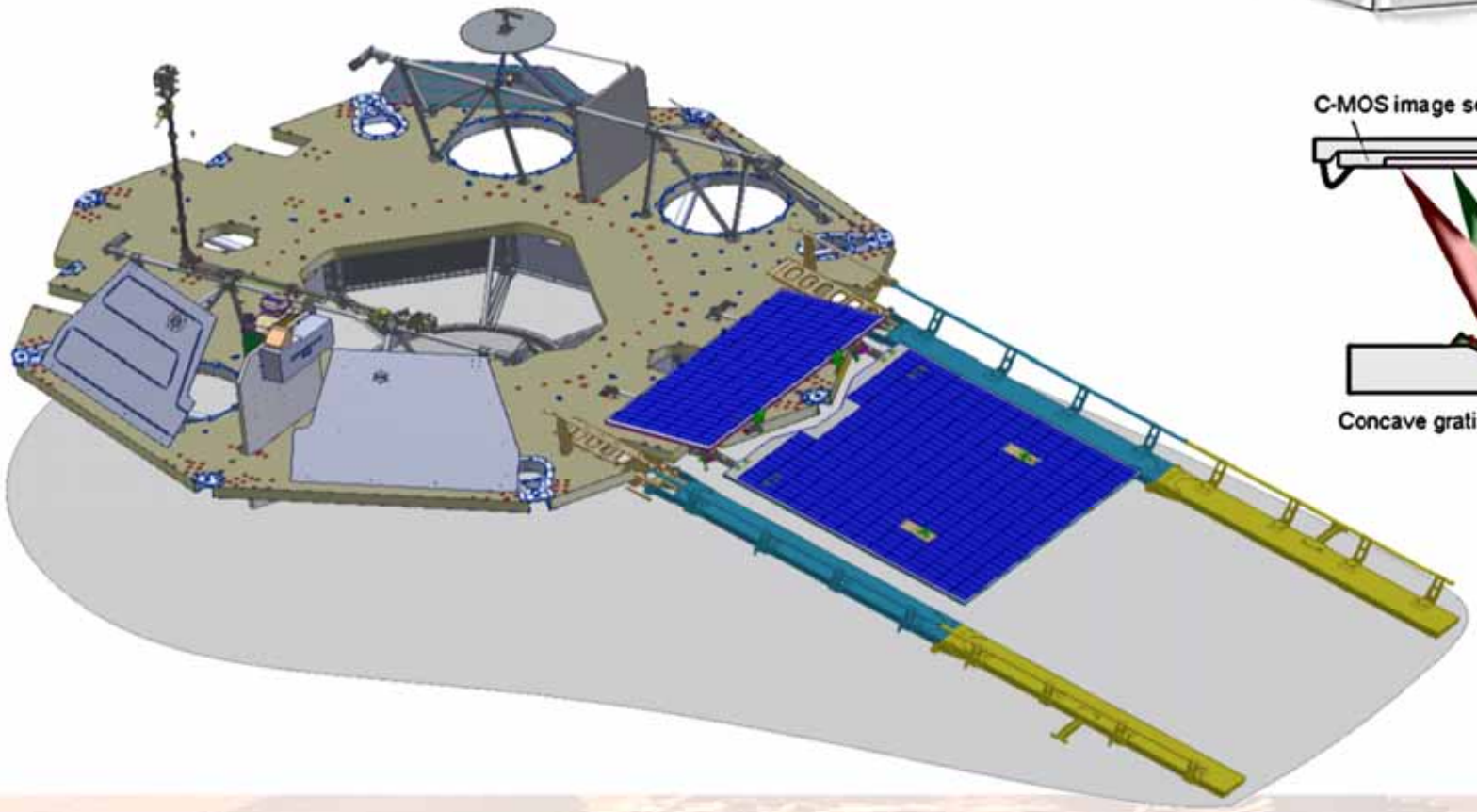
5 – And finally, going to Mars → (C) SIS'20 on ExoMars'20 Lander

SIS'20

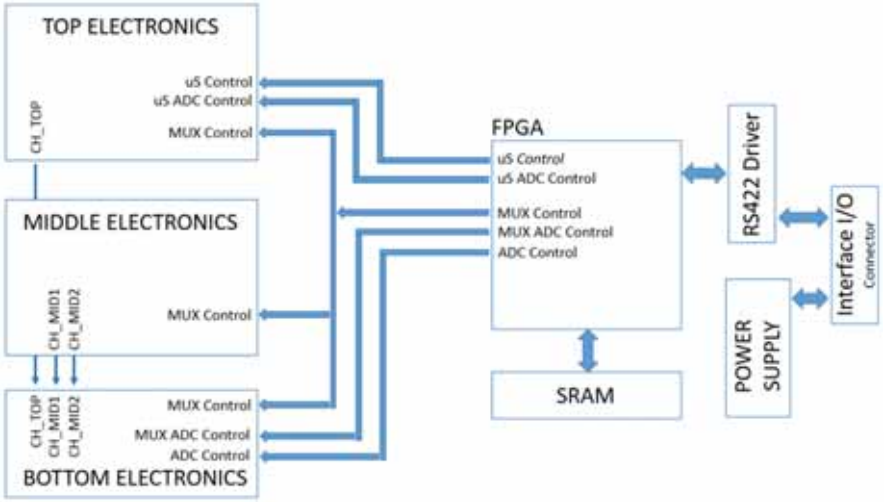
- Part of METEO – ExoMars 2020 Lander
- 180 g, 600 mW
- 6 lateral faces: UV + NIR on each (20 deg. Elevation, +/-5 deg. FoV)
- TOP: UV, NIR, 255 nm, 295 nm, "panchromatic"
- Incorporates Microspectrometer: 340- 780 nm, 5g



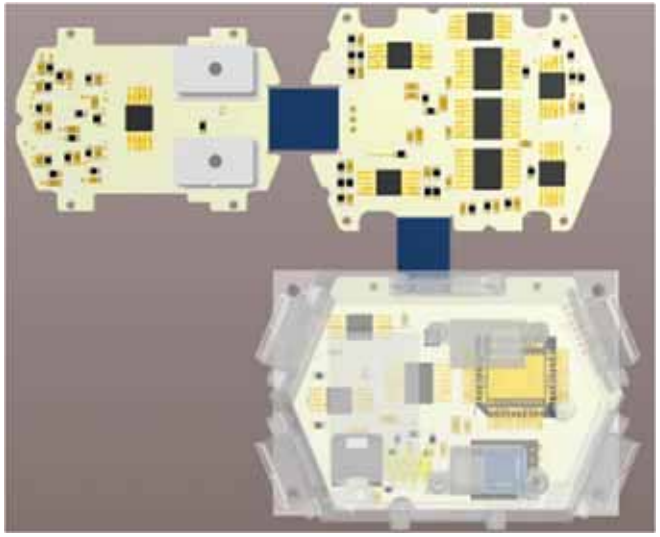


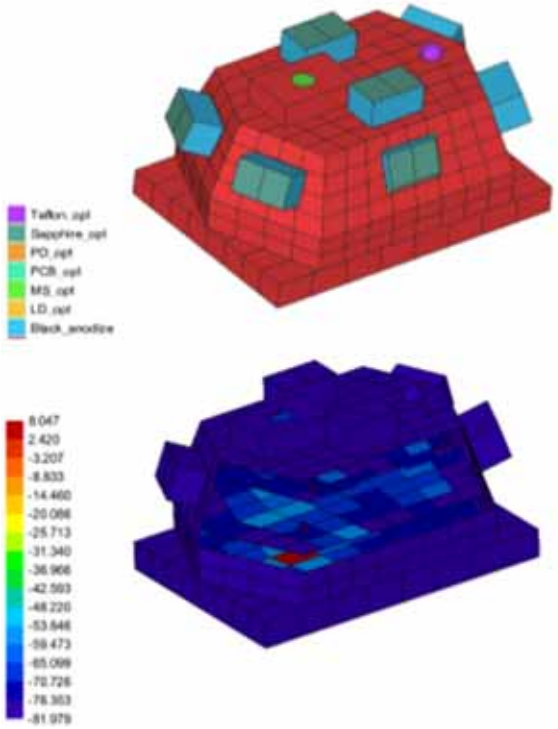


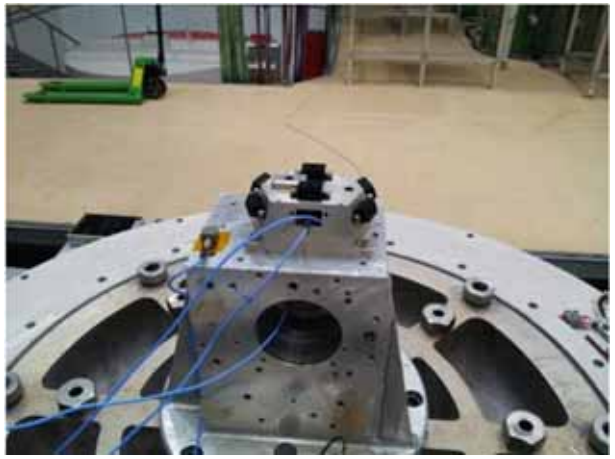
5 – And finally, going to Mars → (C) SIS'20 on ExoMars'20 Lander



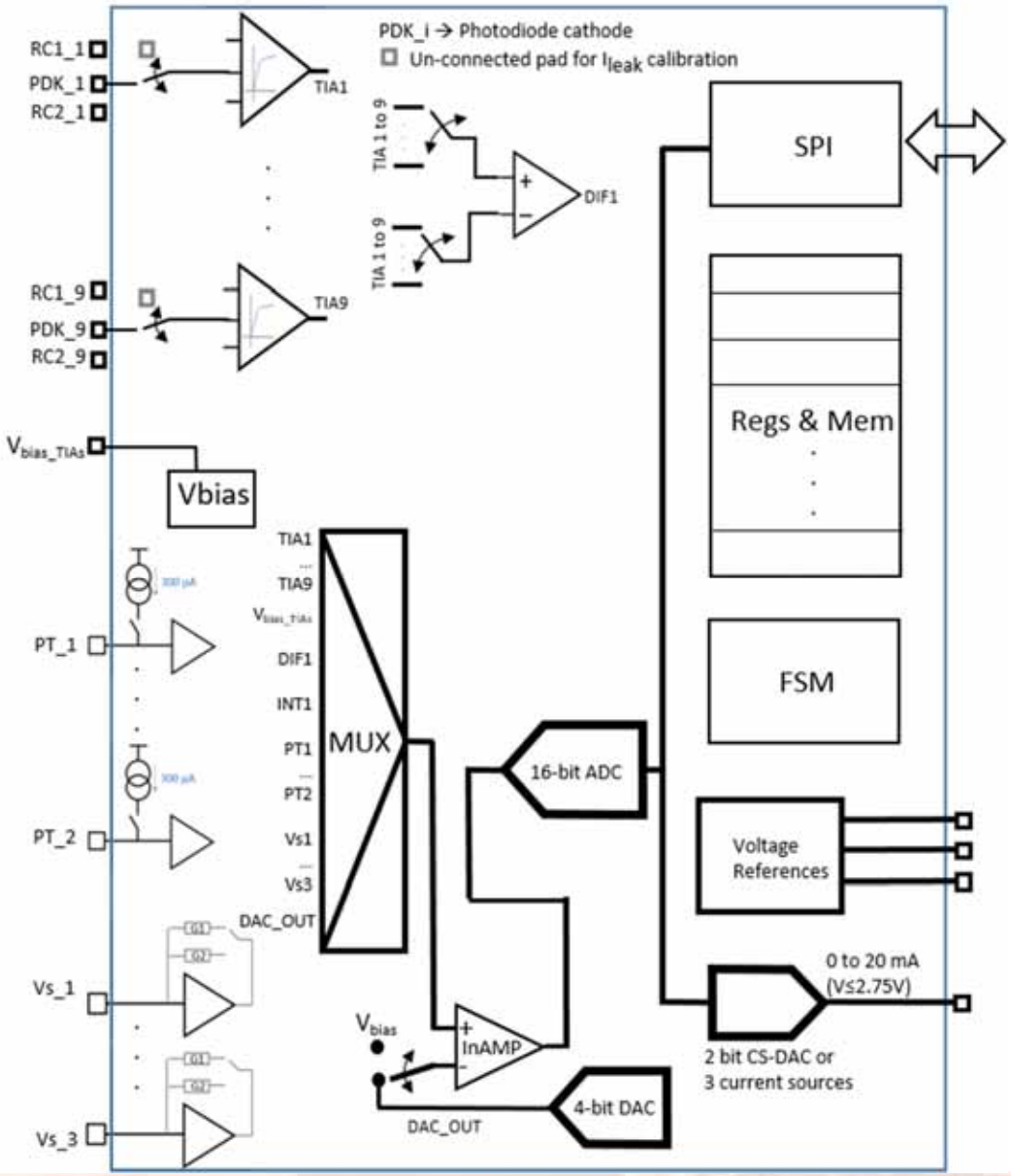
- Ultra-compact design, fully digital
- 17 discrete detectors (several wavelengths, FoVs, pointing)
- 2 microspectrometers
- Accelerometer for attitude determination





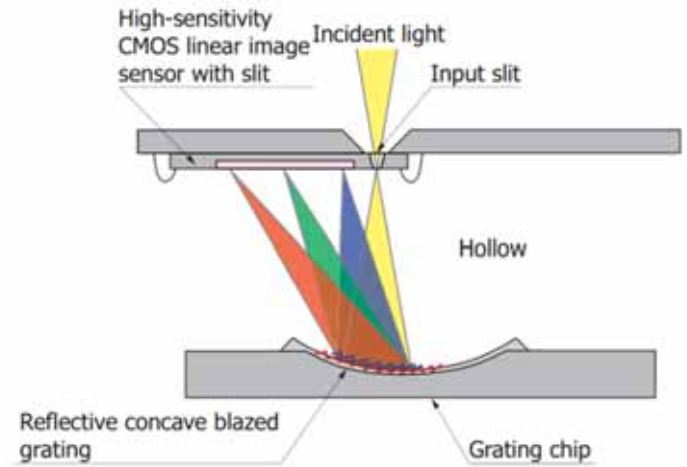


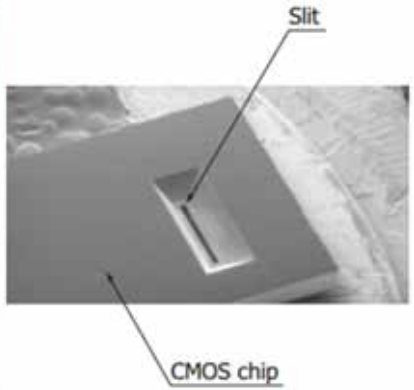
5 – And finally, going to Mars → (C) SIS'20 on ExoMars'20 Lander



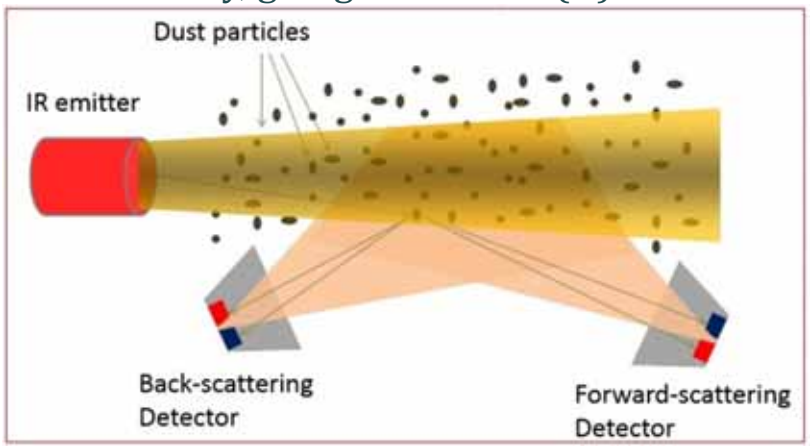
Miniaturization efforts:

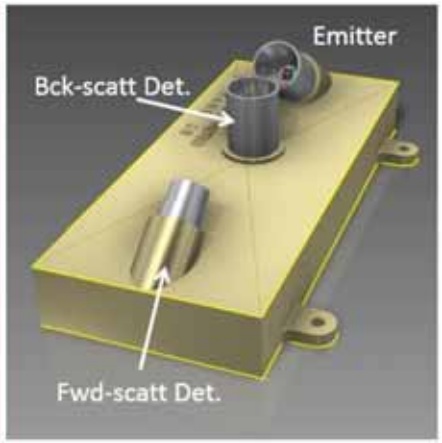
- ASIC: Front-End + A/D for photodetectors, 3-axis accelerometer, Thermal sensors, etc.
- Qualification of compact mid-resolution (10 nm) spectrometer





5 – And finally, going to Mars → (D) DS'20 on ExoMars'20 Lander





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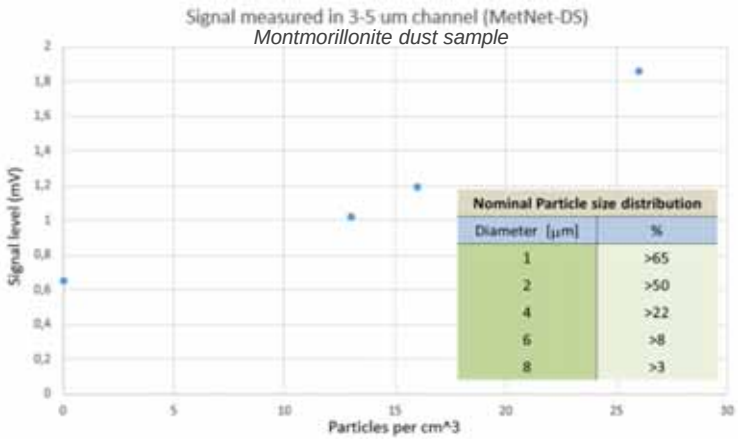
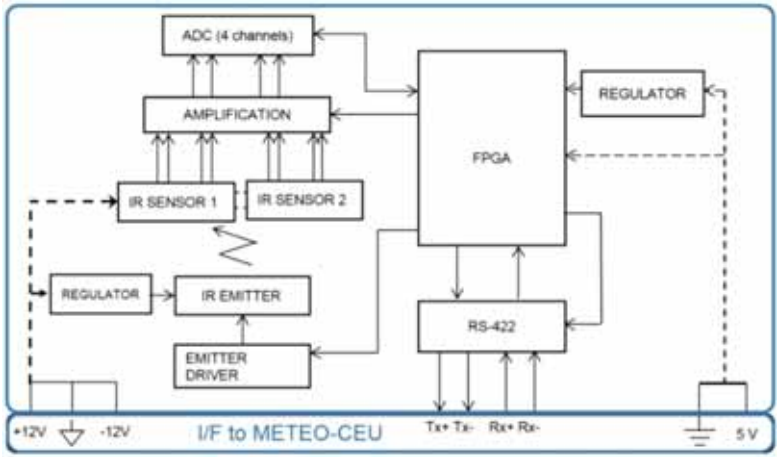
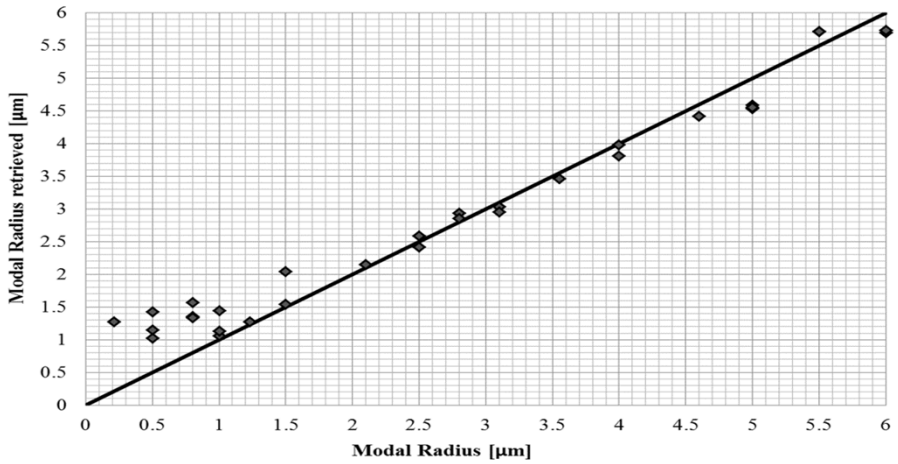
Instrument	European Contribution
METEO	- Humidity sensor - Pressure sensor - Optical depth sensor - Solar irradiance sensor - Magnetometer - Dust sensor

Universidad Carlos III de Madrid

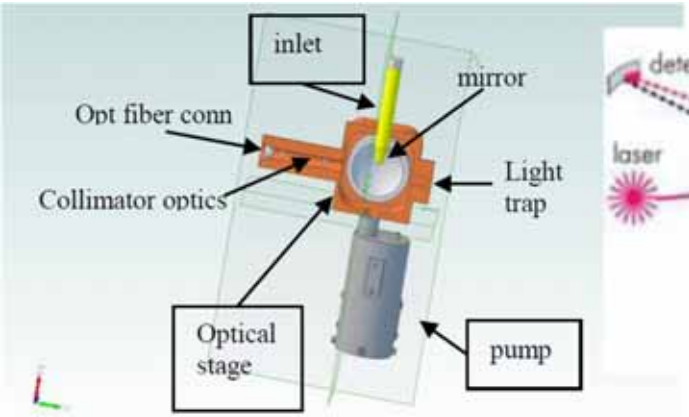
	Accomodation	Mass (g)	Volume (mm)	Power (W)	Active time per sol (minutes)	Energy per Sol (W·h)	Data per Sol (kBytes)
DS	Facing open atmosphere. Emitter and detectors vertical to avoid/reduce dust deposition	101	110x67x36.8	Warm-Up: 0.36@5V Avg. while measuring: 0.6@5V ±12V<<1mA	Day: 264 Night: 144	Day: 2.59 Night: 1.35	13.2

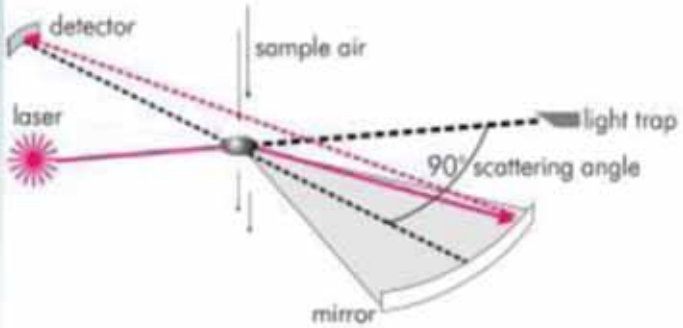


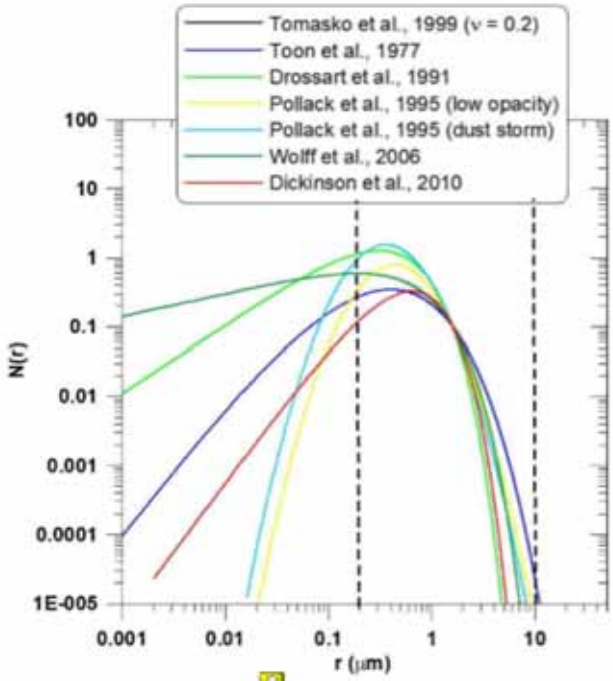




5 – And finally, going to Mars → (E) MicroMED on ExoMars'20 Lander

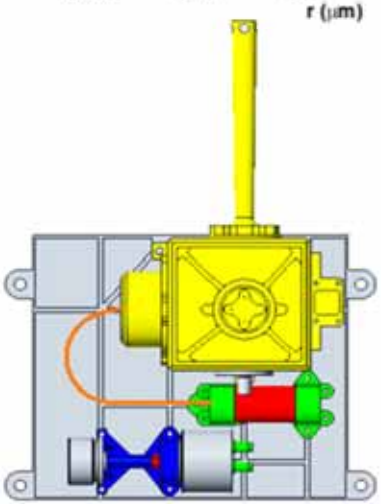






MEDUSA
(TRL=5.3 at PDR 2009)

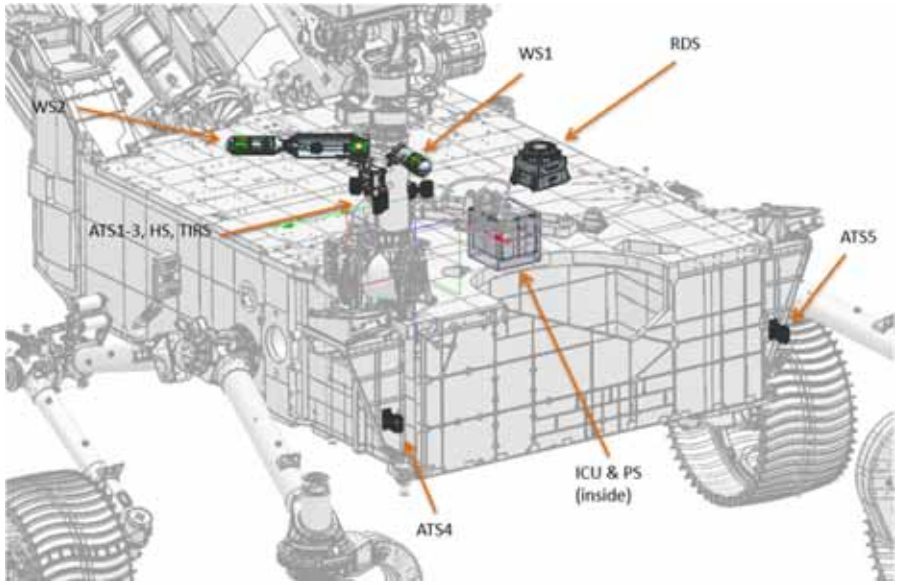
MICROMED
Laboratory B/B 4<TRL<5

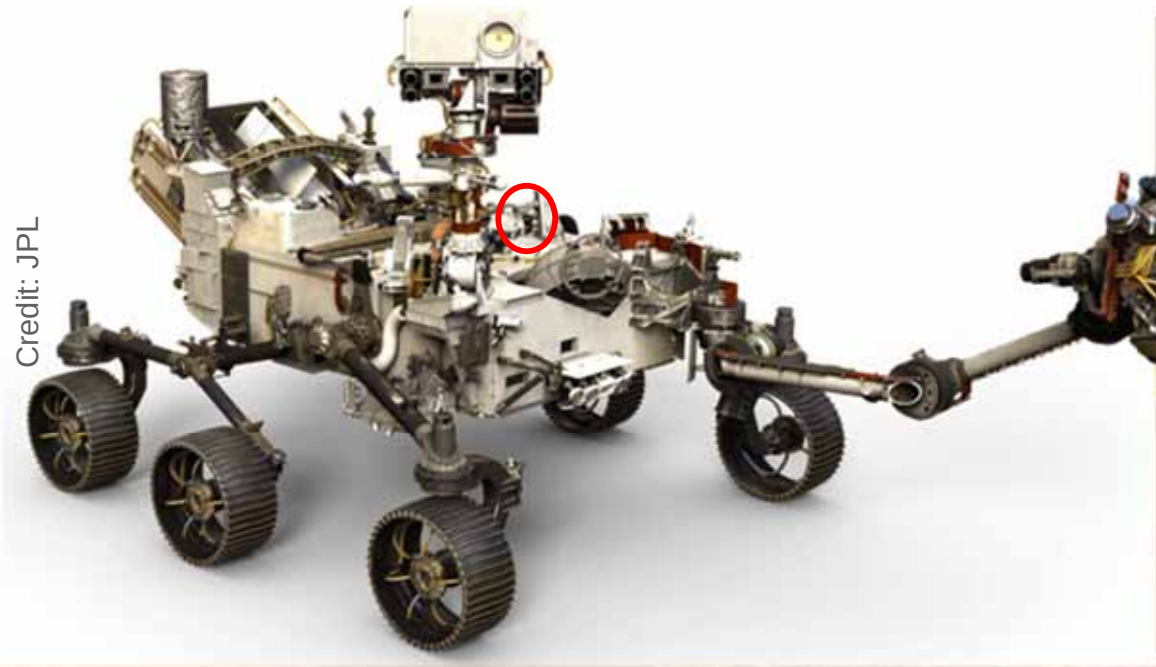


MICROMED
ExoMars 2020

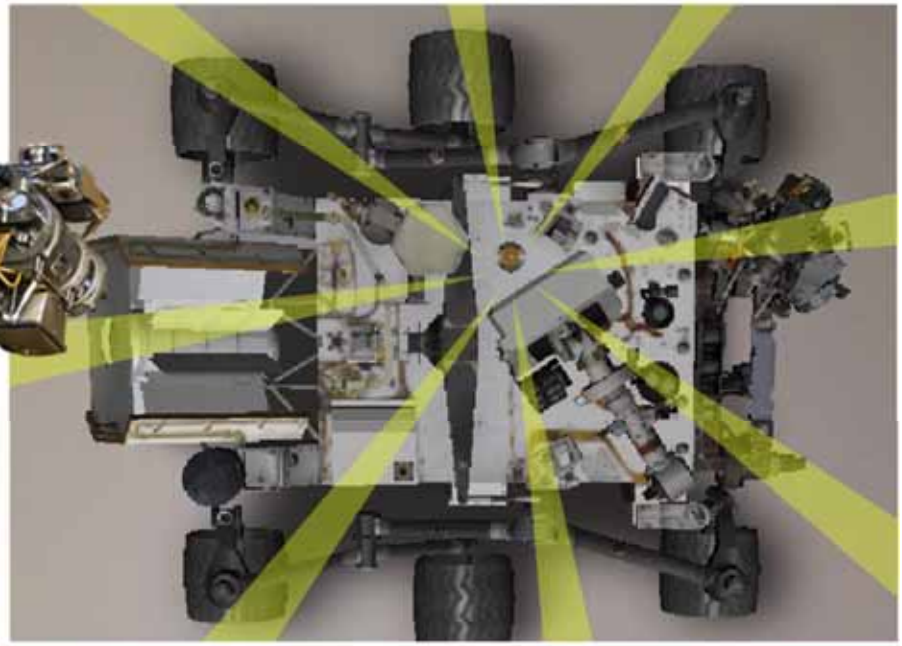
5 – And finally, going to Mars → (F) MEDA-RDS on Mars 2020 Rover

- MEDA: Mars Environmental Dynamic Analyzer
- On board Mars 2020 Rover (NASA/JPL)
- Main actors: INTA, CAB, CRISA, UPC, AVS
- Heritage from: REMS, DREAMS, MetNet
- 2 Wind Sensors, 3 Thermal, TIR, Pressure, Humidity
- + **RDS**: Radiation & Dust Sensor (SIS)
- + ICU



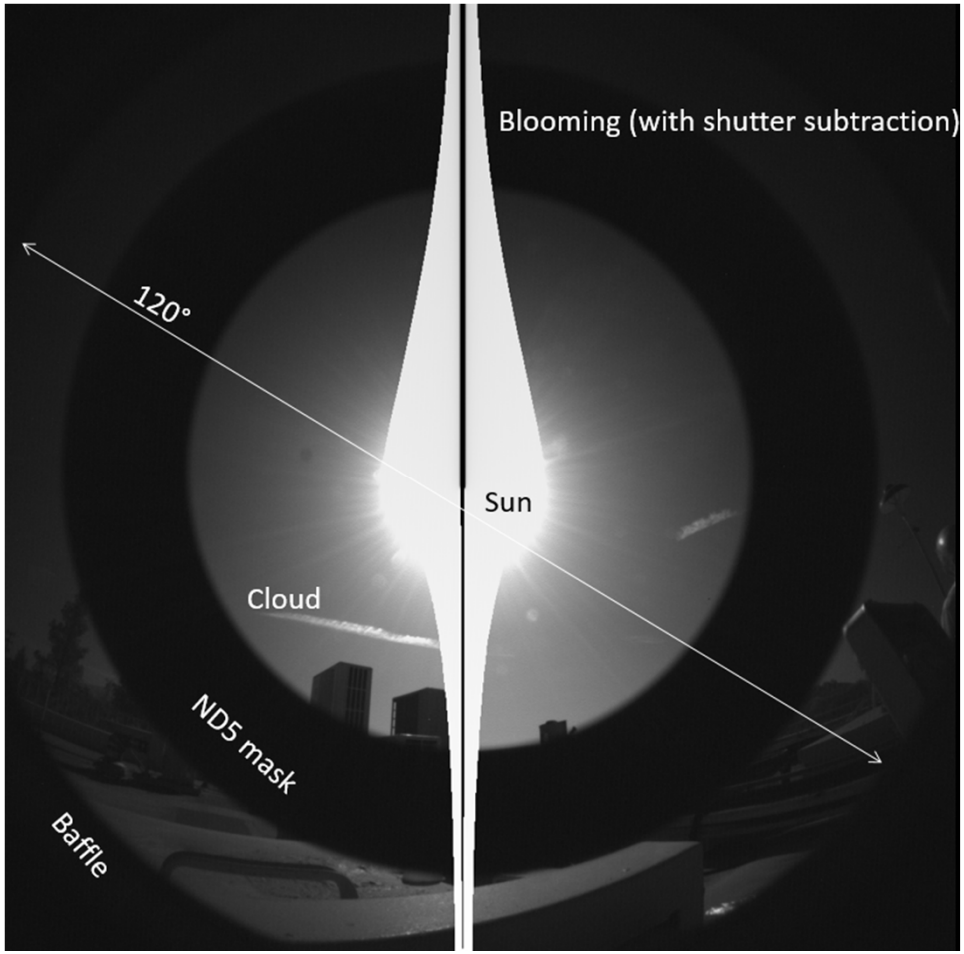


Credit: JPL

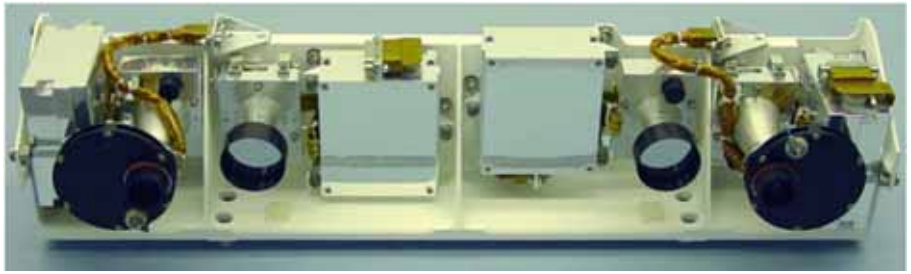


5 – And finally, going to Mars → (F) MEDA-RDS on Mars 2020 Rover

- SkyCam: 7 pictures by sol, at 5:30am, 6am, 6:30am, 7am, 5:30pm, 6pm, 6:30pm.
- Picture acquisition is 60 seconds (TBC).
- CCD: 0.25 W
- E-unit: 2.44 W
- **Total power for SkyCam: 2.69 W**



- Heritage from previous rovers engineering cameras



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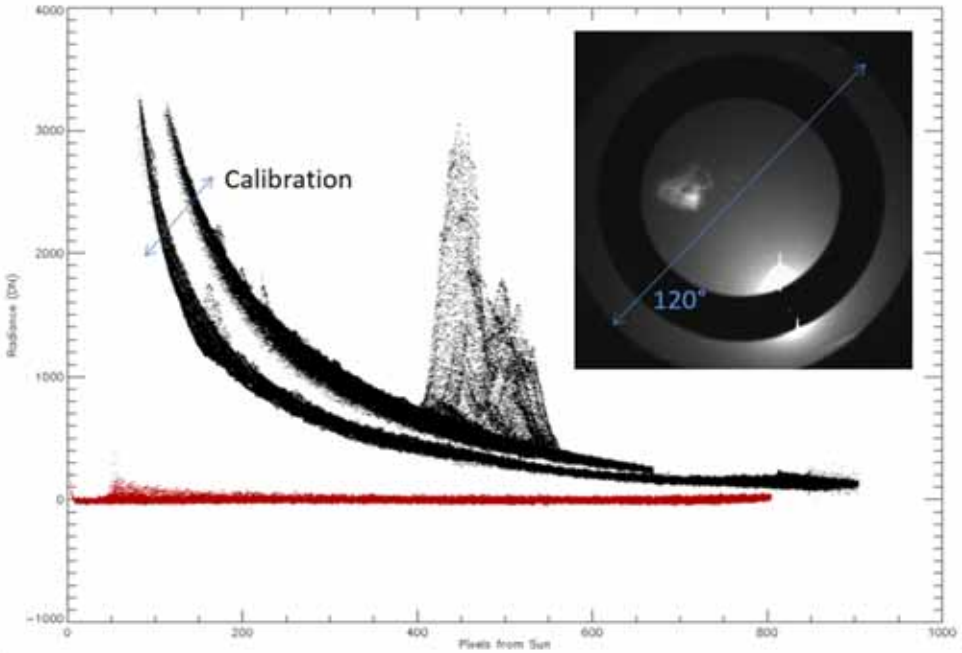
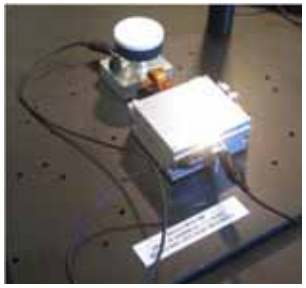
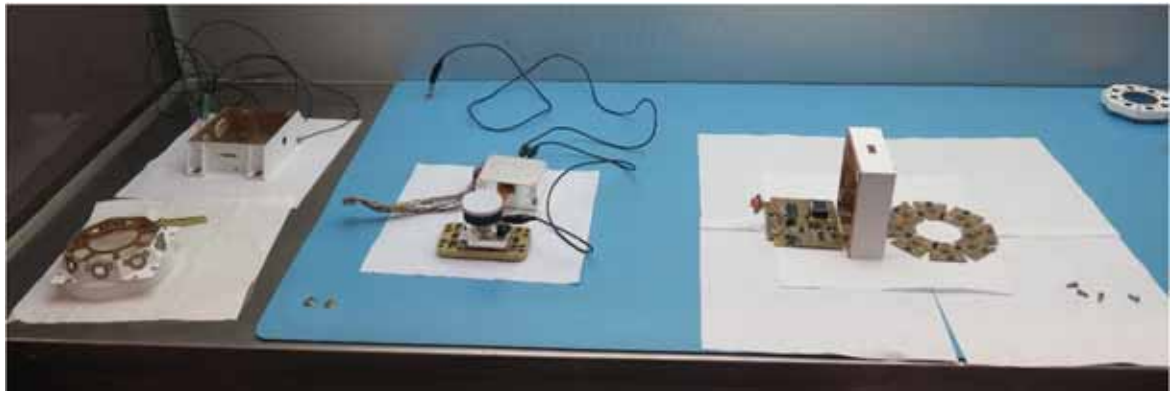
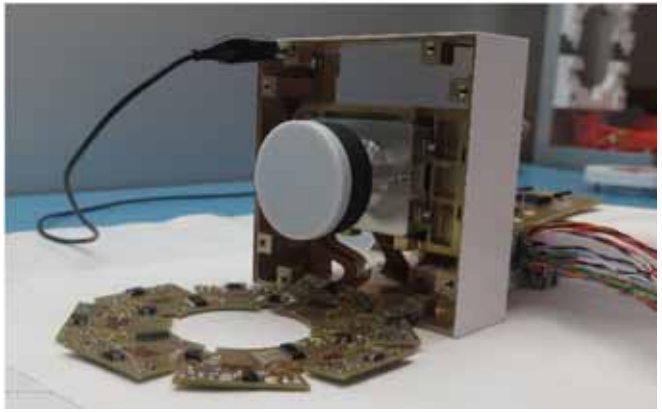
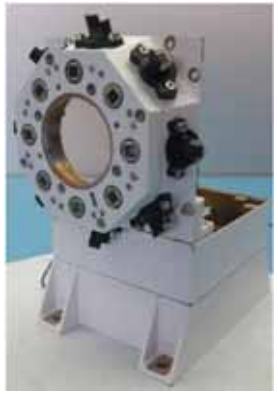


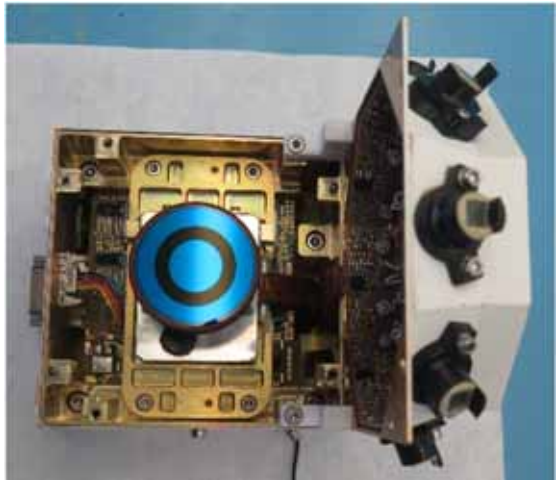
5 – And finally, going to Mars → (F) MEDA-RDS on Mars 2020 Rover

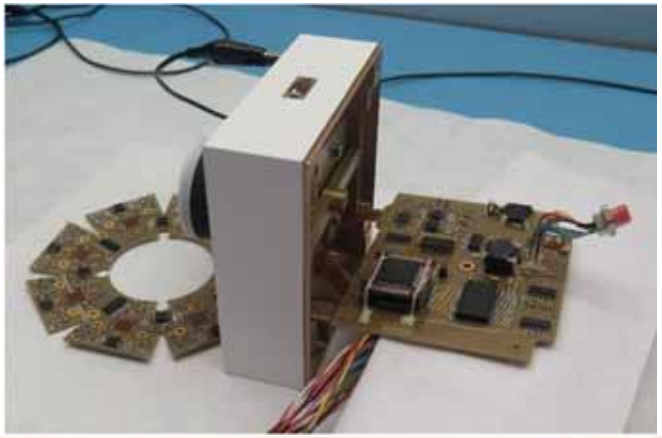


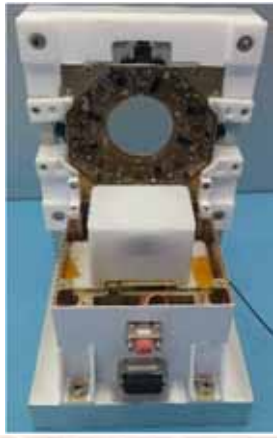


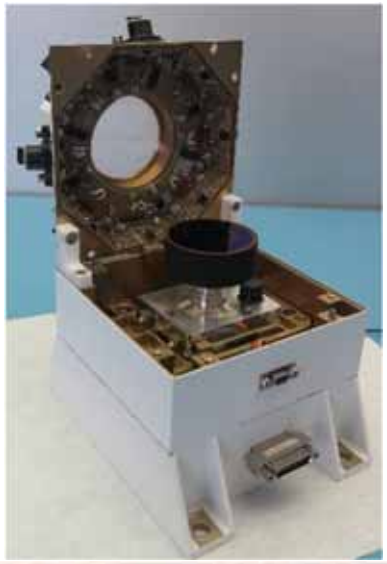


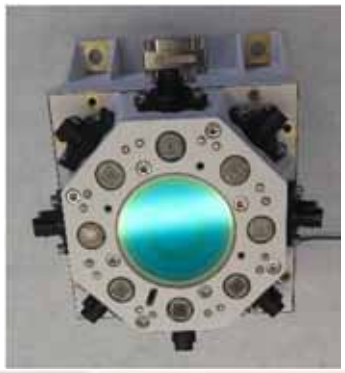






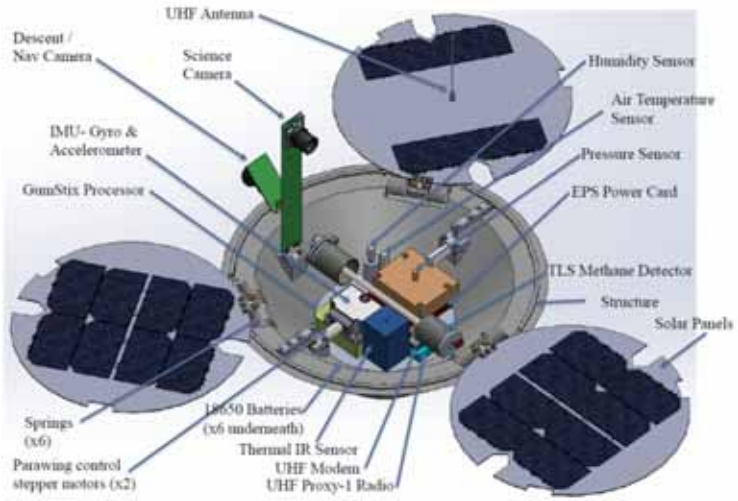


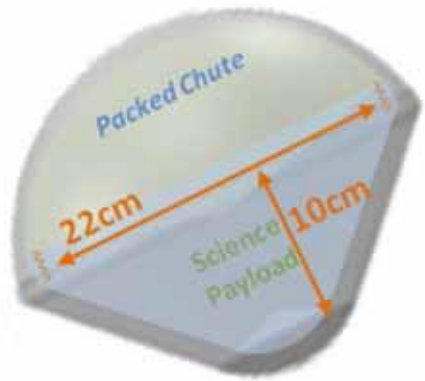


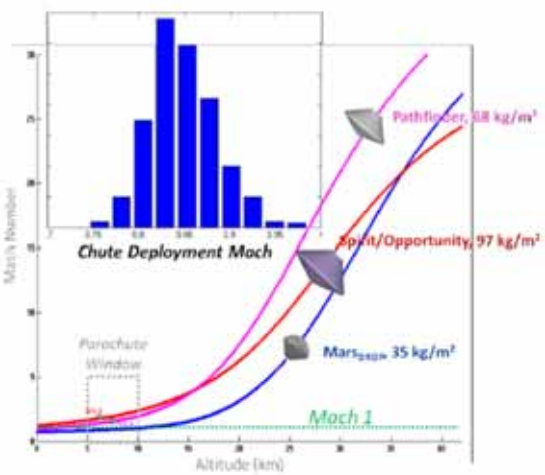


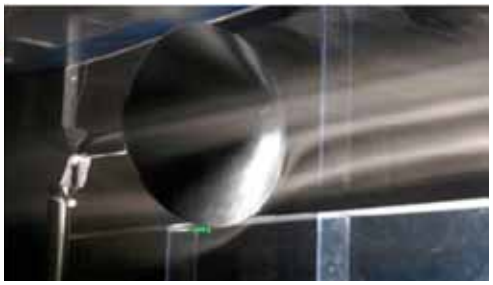
6 – The future? MarsDrop initiative

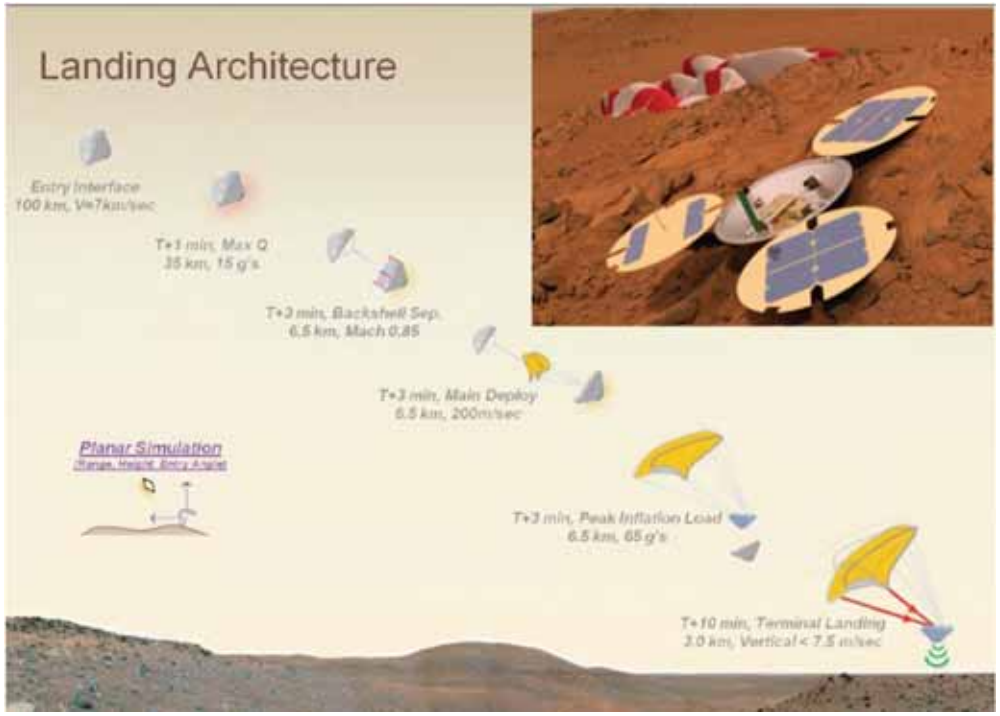
- Entry mass limited by the need to provide a subsonic parachute deployment: *3-4 kg probe entry mass*
- *Accommodates a ~1 kg science payload*

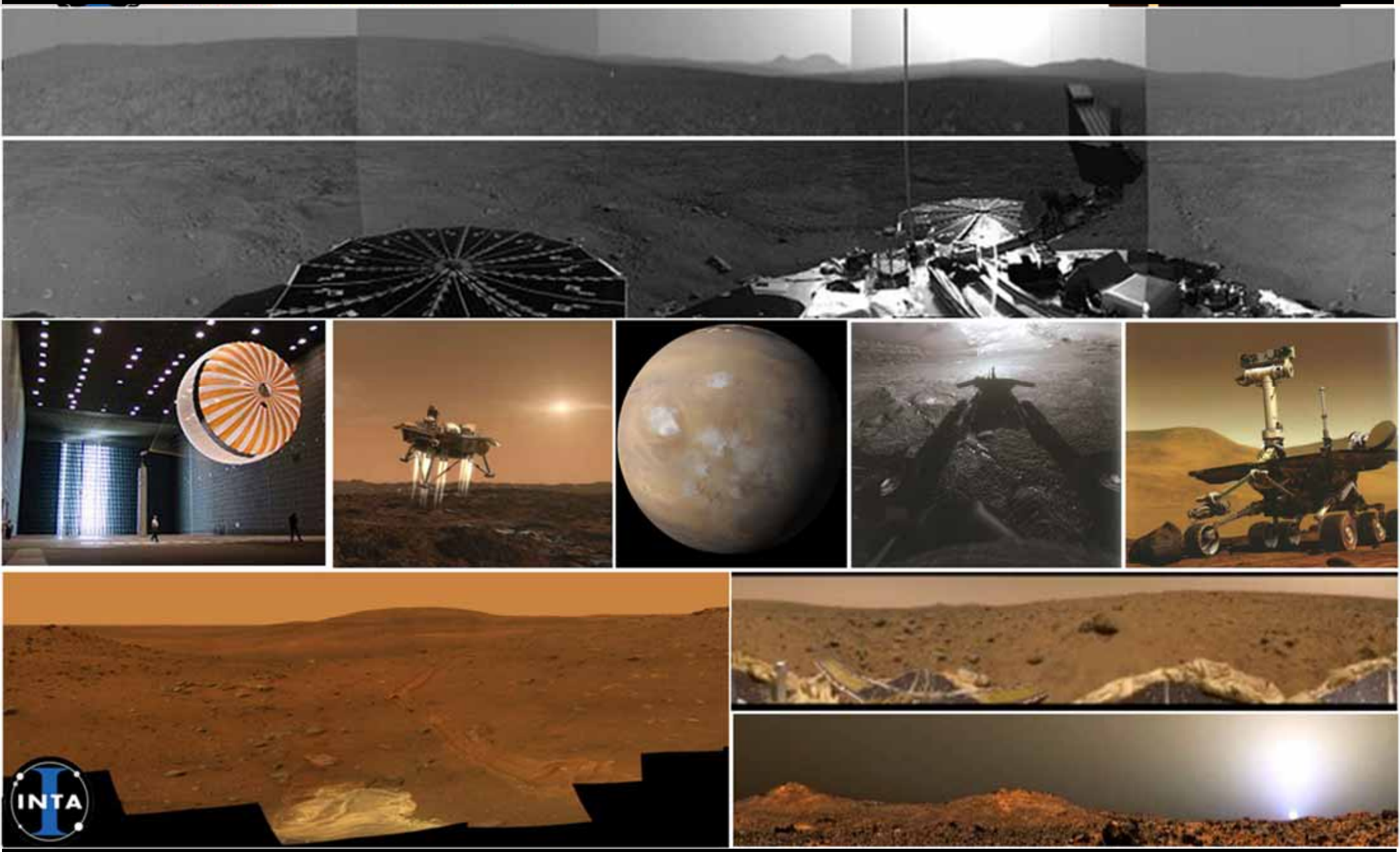












Thank you!!