INTA's Family of Compact Sun Irradiance Sensors for the Martian Surface

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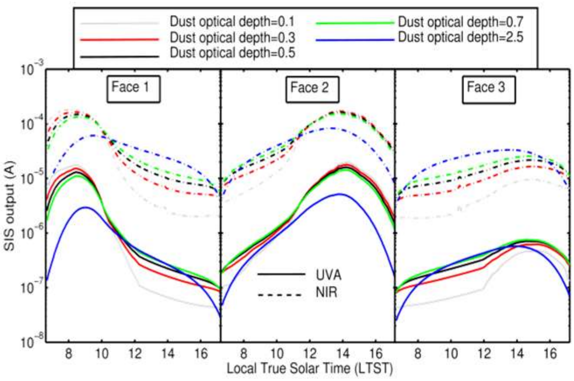
General science goals of SIS

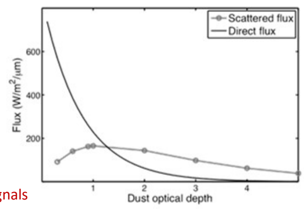
1.- Dust Optical Depth & Angstrom parameter: direct vs diffuse ratio observations



reff = 1.4 μm
veff = 0.3
n = 1.5
K(UVA) = 0.015
K(NIR) = 0.001

Simulations from DREAMS (Schiaparelli)

- Ratio scattered-direct flux and shape of the SIS signal strongly depend on DOD
- Best fit between simulation (RTM) and real signal provides the DOD



Wide-FoV detectors to ensure Sun enters into FoV at some time.
2 different spectral bands → Angstrom parameter and CI
About dust deposition:

- AOD retrieval procedure based on relative signals.
- Certain estimation of the dust deposition rate can be done based on abosulte signals

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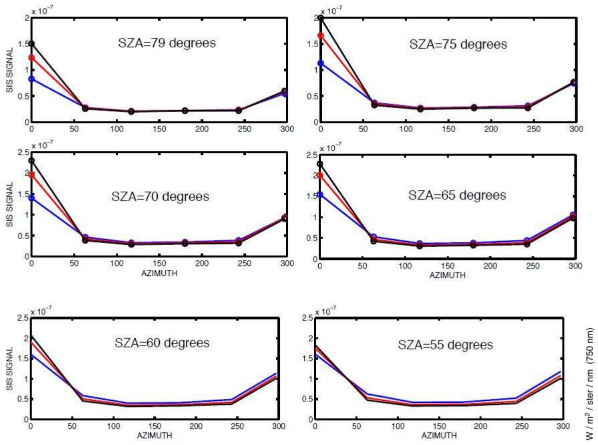
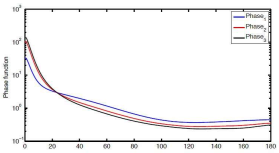
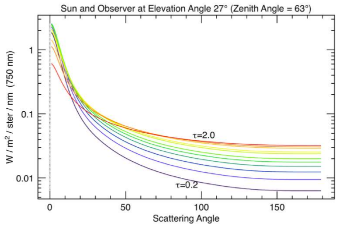
General science goals of SIS

2.- Scattering Phase Function: adjust AZ observations (lateral detectors) to model predicitons (@several SZA)





- At least 12 lateral sensors (one NIR and one UV) each 60° of azimuth
- FoV = ± 5°
- Inclination = 20 °



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General science goals of SIS

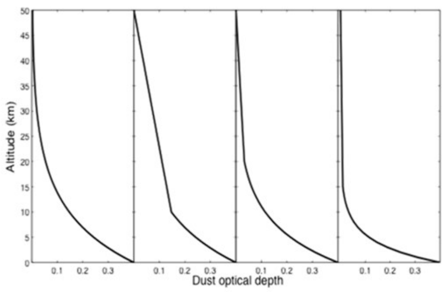
3.- Vertical column: very low elevation (SZA: 85… 95) observations adjust to model predictions (for a total colum OD previously estimated)

Two steps process:

1. During the day: the average daily AOD is be estimated (typical vertical aerosol profile), since for SZAs lower than 80°, the vertical distribution of dust has a low impact on the simulated SIS signal.
2. SZA: 85 – 95: different aerosols profiles are used to simulate the SIS'20 measurements, in order to check out which of them provide the best fit with the measurements (AOD constrained by value obtained during the day)

Zenith-pointed detectors, with FoV > +/-30 deg.

- Duration of twilights is relatively short → good temporal resolution is needed
- Solar radiation is weak during the twilight → the sensibility must be high
- Dynamic range has to allow: direct Sun w/o saturation and scattered light until SZA = 96 → High dynamic range



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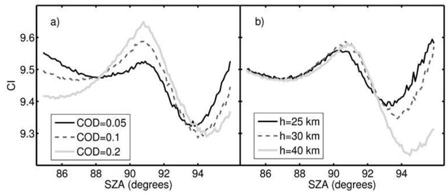
General science goals of SIS

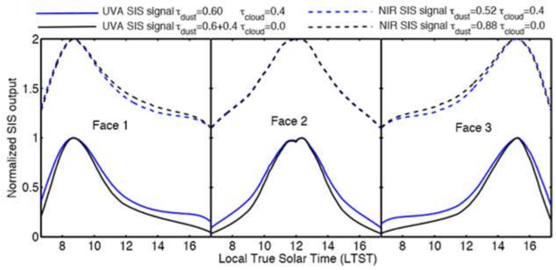
4.- Clouds: color index → altitud and COD, main parameters affecting signal (with known AOD by 1)



CI evolution at twilight:

- Cloud detection
- COD
- Altitude

- 2 different spectral ranges
- Great FoV and/or great gain
- Sensor pointing to zenith
- High dynamic range and sensitivity needed
- High temporal resolution measurements needed



Cloud detection also posible during daytime

(Simulations from DREAMS-SIS)

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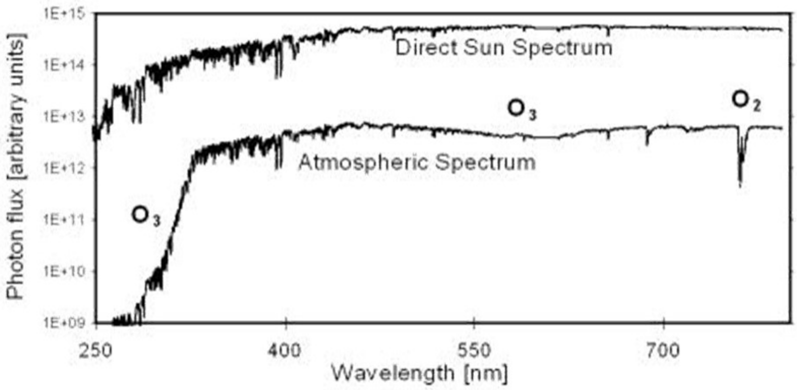
General science goals of SIS

5.- Ozone variation estimations: relative 255 vs. 295 nm observations

- Differential measurements between the 2 detectors
- Zenith Pointing
- FoV TBD (Simulations work on-going)
- High dynamic range needed

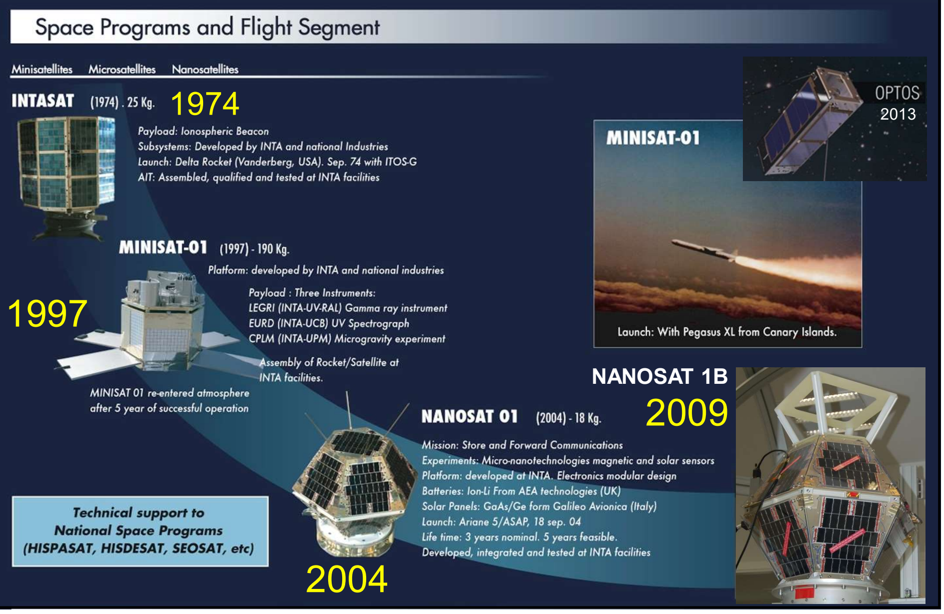


Now let's go to the technical matters

This is the story of a family... A "saga"!

And every saga has an origin…

Access to Space through Small Platforms



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Then came MetNet…

… and that was our introduction into the Martian "arena"

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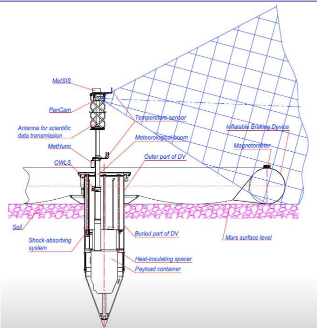
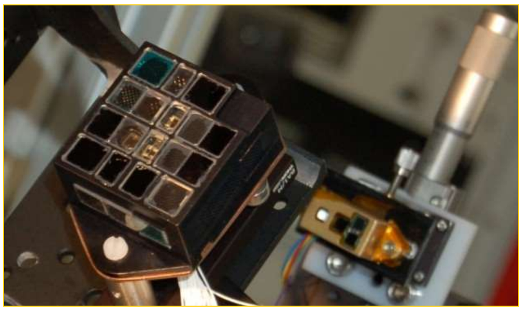
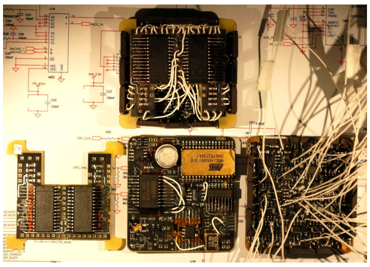
The father: MetSIS

MetSIS on MetNet Precursor:

- 32 sensing channels
- 11 spectral bands
- Compact, unique box (114 g)
- OWLS data link







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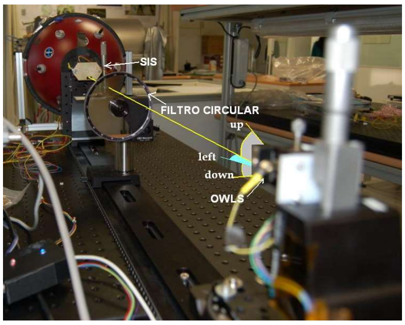
The father: MetSIS

MetSIS Datasheet



Characteristics		Conditions	Min	Typ	Max	Unit
Power Supply						
Supply Voltage	SIS & OWLS		4,5	5	5,5	V
Supply Current	SIS & OWLS → 5V T=25ºC	@5V; 25ºC	-	102	105	mA
	SIS → @5V T=25ºC		-	80	82	mA
	OWLS → @5V T=25ºC		-	22	25	mA
Temperature						
Operating (SIS & OWLS)			-55		70	ºC
Storage (SIS & OWLS)			-130		125	ºC

Optical Sensing Characteristics @ 25°C; Samples Averaged: 1024

Band Name	Spectral Response Range (nm)	Responsivitty XENON Lamp [mV/W]	Responsivity Error (%)	Noise [µV]
Hartey Band*	200-310	-	-	-
UV MRO*	245-290	-	-	-
UVB*	280-315	-	-	-
Huggins Band	300-345	140.59	8.04%	-
UVA	315-400	47.32	2.85%	42
Dust Optical Depth	440	1176.23	1.71%	14
	600	963.85	1.55%	15
Visible	400-700	8.09	1.59%	37
Infrared	700-1100	8.48	1.68%	13
H_2O	930-950	192.69	1.26%	33
Total Irradiance	230-1200	4.10	1.38%	27

** Channels under calibration*

	Conditions	Min	Typ	Max	Unit
Dark Signal Channel Sensitivity	@ -70ºC		1.02	-	mV
	@ -2ºC		32.2	-	mV
	@ 24ºC		52.7	3.86	mV
	@ 57ºC		3260	-	mV
Angle Sensor					
Peak Sensitivity		-	960	-	nm
Nº Elements		-	4	-	Elements
	@ 500 W/m²	-	±50	-	°
	@ 500 W/m²	-	2	5	°
			[-90, 70]		ºC
			0.9696		$ºC_{SIS}/ºC_{True}$
	@ 35ºC		0.081		ºC
	SIS		119.0		g
	SIS		48 x 45 x 26.65		mm
	OWLS		11.3		g
	OWLS		41 x 15 x 14		mm

Environmental qualification

Bioburden	• Bioburden reduction temperature 125°C / 6 h
Vibration	• Low sweep-sine: A sweep from 5Hz to 2000 Hz at 2 Oct/ min, and 0.5 g for each axis • Sine test: A sweep from 5Hz to 200 Hz at 2 Oct/ min, and 1.5 g for each axis • Random test
Thermal Vacuum Cycling	• -55°C…+70°C • 6 cycles • Dwell time in hot and cold at least 2 h • Stabilization criterion for temperature Δ T / dt ≤ 1°C/h
Thermal Cycling	• -90°C …+70°C • 6 cycles • Planned 2 hours of dwell time in hot and cold, as well as a rate of change of 5 ºC/min
X-Y-Z Axis Shock Survival	• Half sine shock of 500g and 15 ms

Radiation Hardening

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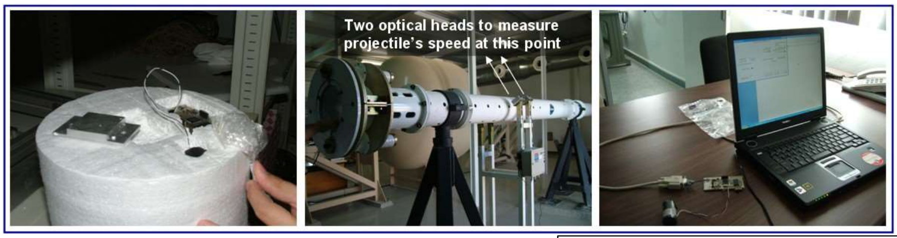
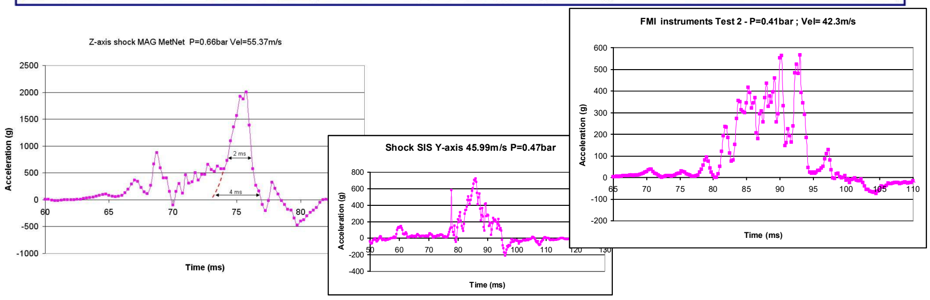
Special test facilities were been developed for shock tests within MetNet Precursor Project





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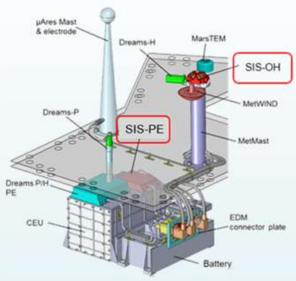
Our sweetheart: small but powerfull!!

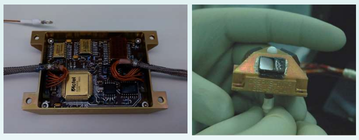
DREAMS on ExoMars 2016 and DREAMS-SIS



DREAMS (*Dust Risk Assesment and Environment Analyzer on the Martian Surface*): a suite of sensors for the characterization of the Martian basic state meteorology and of the atmospheric electric properties at the landing site of the Entry, descent and landing Demonstration Module (EDM) of the ExoMars mission.
On board the ill-fated Lander Schiaparelli, ExoMars 2016.

SIS-OH mounted on DREAMS Mast

SIS-PE (left) and SIS-OH (right)



DREAMS **Solar Irradiance Sensor (SIS)** main goals/capabilities:

- Measurement of irradiance in the UV (315-400 nm), IR (700-1100 nm) and "panchromatic" (200-1100 nm) bands.
- Estimation of Optical Thickness and its variation within a Sol.
- Color Index analysis (IR vs. UV)
- Includes an accelerometer for Lander attitude determination, once landed.
- Includes a sensor for the estimation of radiation received during the trip to Mars

It is composed of 2 units: Optical Head (SIS-OH) and Processing Electronics (SIS-PE).

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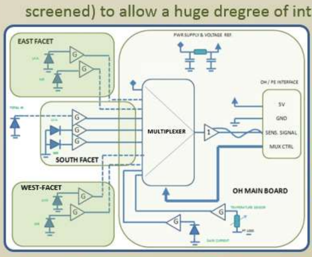
DREAMS-SIS construction

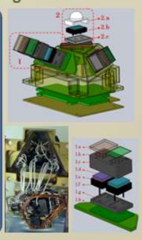
SIS–OH

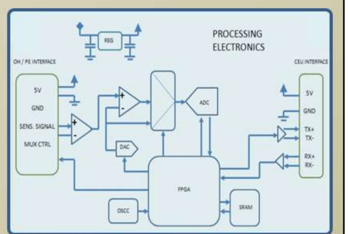
- Tetrahedral shape. 3 faces ("East, South, West") 120º apart from each other (AZ), looking at 60º SZA. Panchromatic, hemispheric-FoV channel on top with a dome-shaped diffuser.
- Combination of Si-photodiodes, interference filters, FoV-shaping masks and density filters.
- Intensive use of COTS amplifiers (qualified and screened) to allow a huge dregree of integration.

SIS–PE

- 16 bit ADC + 6 bit DAC for sub-ranging acquisition.
- 22 bit resolution. Noise = 2xLSB.
- Anti-fuse FPGA, 128k RAM, RS-422 I/F.
- Allows programmable autonomous operation.
- Additional House-Keeping signals.







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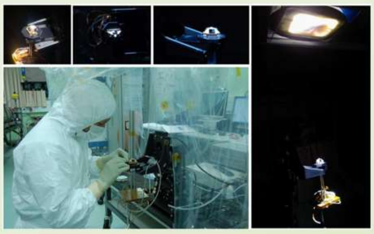
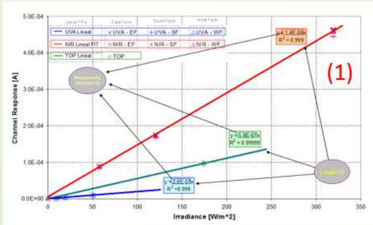
Calibration

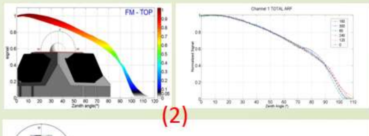
CALIBRATION STEPS

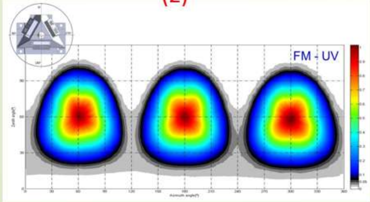
(1) Normal incidence Responsivity, at ambient temperature, variable-power AM0 spectrum.
(2) Angular Responsivity Function, with constant power, constant temperature.
(3) Thermal Responsivity Function, with constant power, 3 fixed incidence angles.

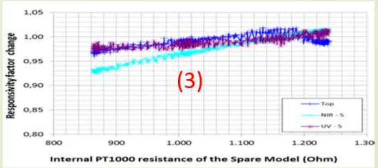
Plus several measurements with reference Martian spectrums (at SPASOLAB, INTA).











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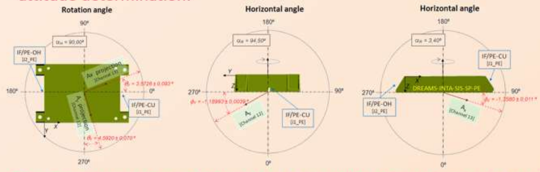
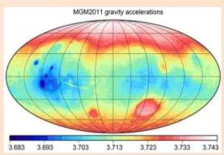
Attitude and Sun position determination

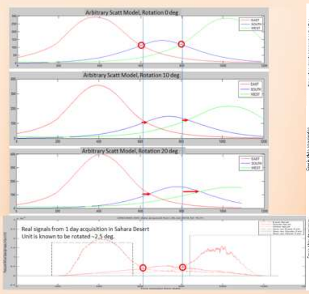
A 3-axis COTS accelerometer was qualified, screened and integrated into SIS-PE to facilitate Lander attitude determination:

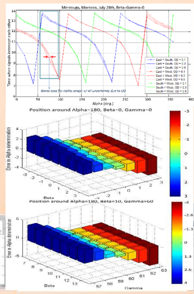




Only 2-axis are read due to limitation in available House-Keeping channels:

- *Gravity uncertainty of 0.1 m/s² would only be equivalent to 0.25 degrees tilt error.*
- *14 ºC change generates same signal change as 1 degree tilt, in the worst case → Temperature of SIS-PE is sensed.*



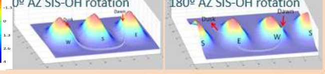


Relative Sun position determination through analysis of:

- Time of Sol when Sun is symmetrically positioned w.r.t. 2 different faces (works even with variable dust conditions).
- Time when signals change variation sense (independent of Optical Thickness, if steady dust conditions).

IR FoV relative to Sun for 0º AZ SIS-OH rotation

IR FoV relative to Sun for 180º AZ SIS-OH rotation



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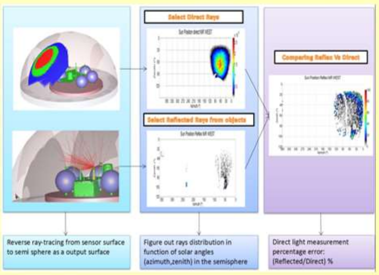
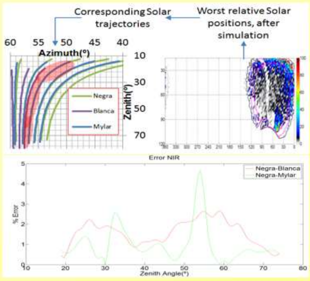
Integration on the Lander

Minor interferences of some EDM elements in SIS Field-of-View (FoV) were found:

- Ray-tracing simulations to evaluate worst case interferences.
- Real measurements done in a 1:1 mock-up with representative elements of EDM.
- Different finishes for the fuel tanks compared (black as reference, diffusing white, aluminum Mylar, golden MLI).
- Different relative trajectories of Sun emulated by rotating the mock-up in both AZ and SZA.
- Cases emulated: those for which simulations indicate highest levels of interference.



- Worst Sun relative positions identified.
- Maximum interference level bounded and found acceptable.



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Parameter	Value	Observations
Dimensions	OH: 42 x 33.75 x 22.5 mm³ PE: 80 x 50 x 13.5 mm³	Complete envelop, including fixation points, in both cases.
Mass	OH: 25 g PE: 53 g	
Power consumption	OH: 11 mA @ 5V PE: 51 mA @ 5V	Constant current consumption.
Temperature	Operational: -120 / +60 °C Storage: -120 / + 80ºC	Upper value limited only by nominal (datasheet) information for the photodetectors. No extended temperature range was tested (long duration one, apart from DHMR) as it was not needed.
DHMR compatibility	YES	DHMR = Dry Heat Microbiology reduction
Spectral bands	NIR: 700 – 1100 nm UV: 315 – 400 nm Top: 200 – 1100 nm	NIR x 3 side detectors UV x 3 side detectors
Side detectors (NIR, UV) pointing and FoV	Pointing: Rel. elevation: 30 deg. Rel. azimuths: 60, 180, 300 deg. FoV: ~ 25 deg @ 50%	See Figure
Top detector pointing and FoV	Pointing: to zenith FoV: ~hemispheric	See Figure
Effective (free-of-noise) resolution	20-21 bits	
Operational modes	1.- "MANUAL" 2.- "AUTOMATIC"	1.- An Instrument Control Unit commands each single measurement. 2.- SIS operates autonomously according to a configurable sampling period, and stores data in internal memory (128 kB) until it is requested.
Design lifetime	> 1 Earth year	
Interface	RS-422 serial port, 57.6 kbps.	Proprietary, character-oriented, protocol
Data volume	100 Bytes data packet	Each measurement
Calibration uncertainties	Thermal: NIR: irrelevant UV: up to 2% (worst-case) (a) ARF: (b) <1% around ARF=1 <5% around ARF=0.5 Absolute responsivity @ normal incidence: (c) NIR: 1% UV: 0.5%	(a) Due to technical problem during calibration process. Refer to (Jiménez, J.J., et al., 2016). (b) Due to pointing uncertainty within angular dependence calibration set-up. (c) Due to reference-cell uncertainty.
Associated products	Raw data: 16 sensing channels. 6 data Bytes per channel (a) Pre-processed data: photocurrents, resistor values (thermal sensors), voltages (internal references and accelerometer). Calibrated data: normal-incidence-equivalent irradiance, temperature, inclination. Derived products: AOD (UV and NIR), Displacement Damage.	(a) Includes the standard deviation value of the averaged samples for each channel, to provide an estimation of the raw signal noise.

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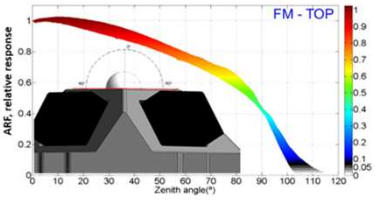
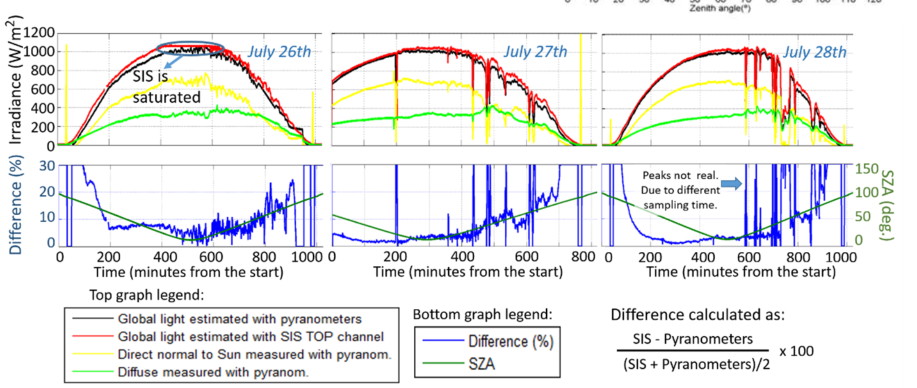
Sahara campaign with DREAMS-SIS

- Absolute irradiance estimation with TOP detector.
- Comparison with 2 pyranometers (shadowed + unshadowed)





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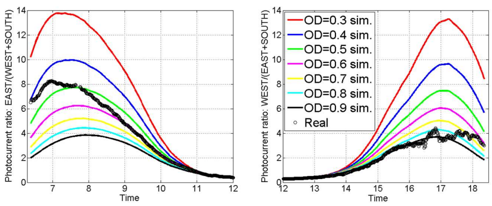
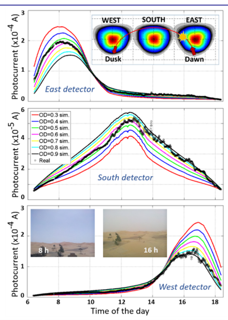
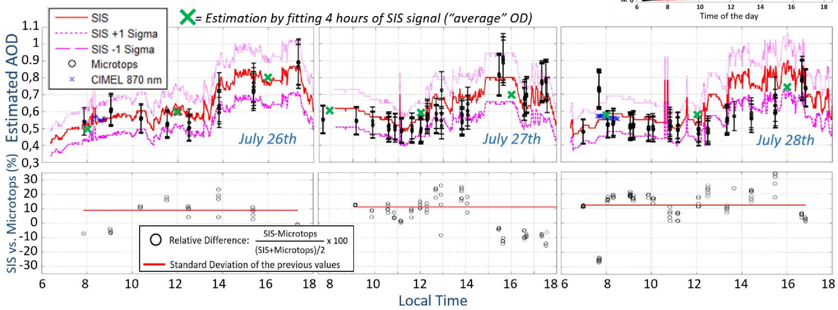
Sahara campaign with DREAMS-SIS

- Different AOD estimation methods. Comparison with Microtops & CIMEL







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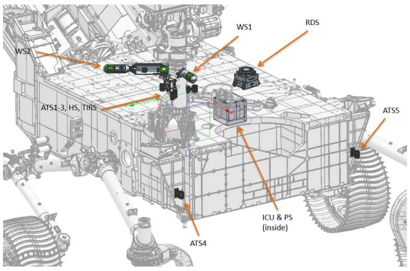
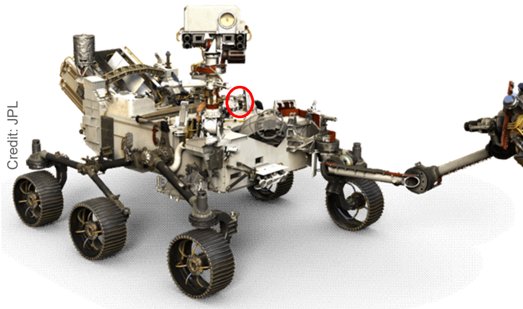
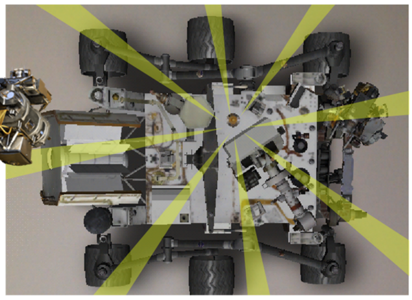
The big brother… *or maybe the "spoiled-child"!*
MEDA-RDS: Radiation & Dust Sensor

- 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

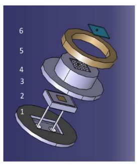




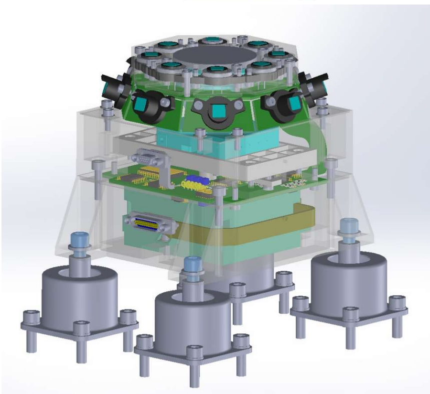


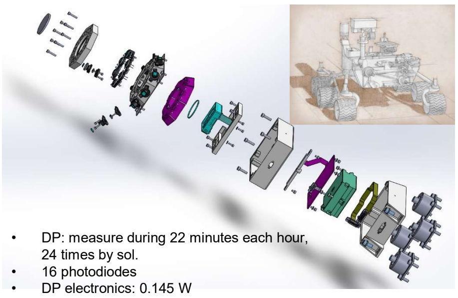
INTA's family of compact Sun Irradiance Sensors for the Martian surface

The big brother: MEDA-RDS



1. Radiation Shield
2. Photodiodes
3. Interference filters encapsulated with the photodiode
4. FoV Aluminum Mask
5. Magnet
6. Glasses to avoid Dust





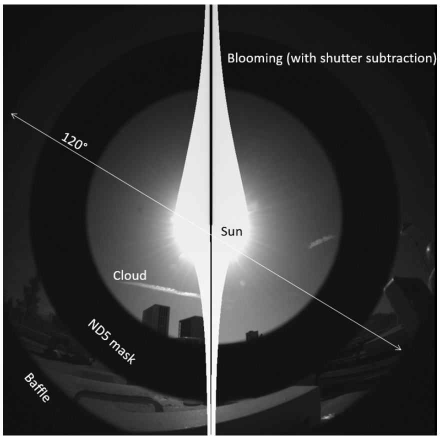
- DP: measure during 22 minutes each hour, 24 times by sol.
- 16 photodiodes
- DP electronics: 0.145 W
- DP processing board: 0.352 W
- **Total power for DP: 0.537 W**

TOP Channel	Center Wavelength (nm)	Bandwidth (nm)
1	255	± 5
2	295	± 5
3	250-400	
4	450	± 40
5	650	± 25
6	750	± 10
7	190-1100	
8	950	± 50

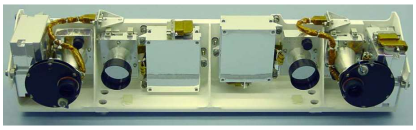
INTA's family of compact Sun Irradiance Sensors for the Martian surface

The big brother: MEDA-RDS

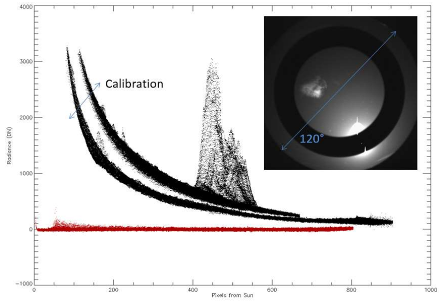
- SkyCam: 7 pictures by sol, at 5:30am, 6am, 6:30am, 7am, 5:30pm, 6pm, 6:30pm.
- Picture acquisition is 60 seconds (TBC).
- CCD: 0.25 W
- E-unit: 2.44 W
- **Total power for SkyCam: 2.69 W**



- Heritage from previous rovers engineering cameras



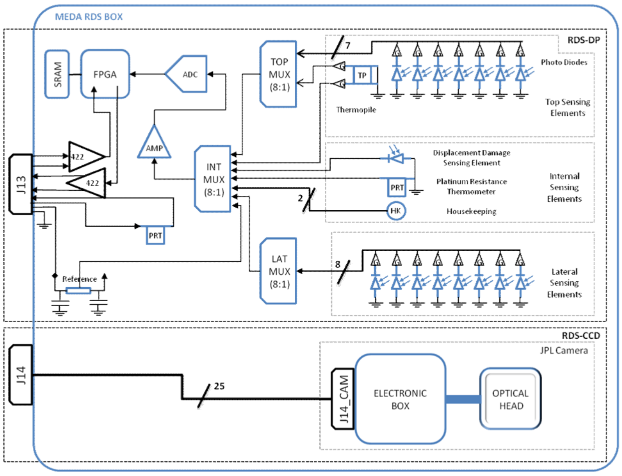
Credit: JPL

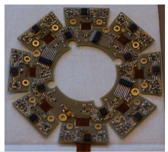


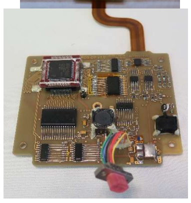
INTA's family of compact Sun Irradiance Sensors for the Martian surface

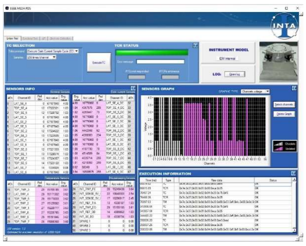
The big brother: MEDA-RDS

Electronic design





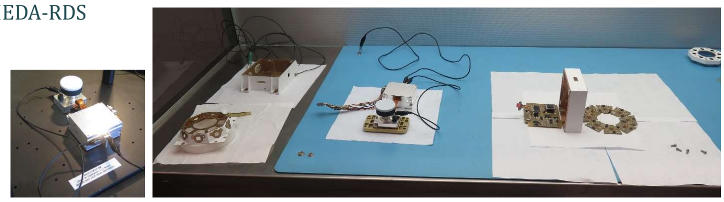


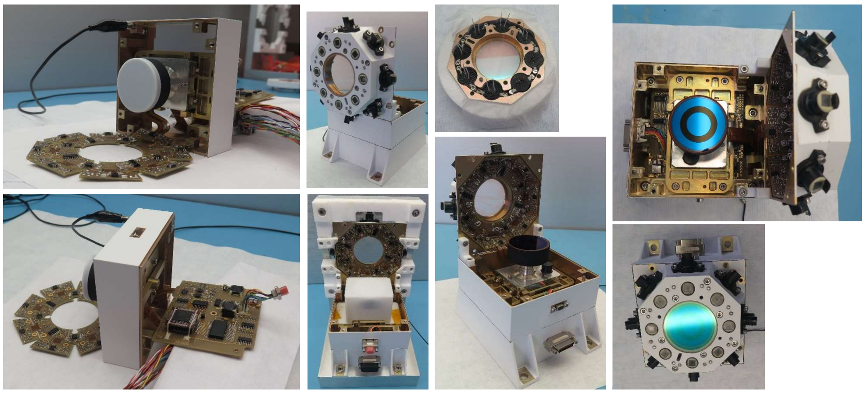


INTA's family of compact Sun Irradiance Sensors for the Martian surface

The big brother: MEDA-RDS

EM integration

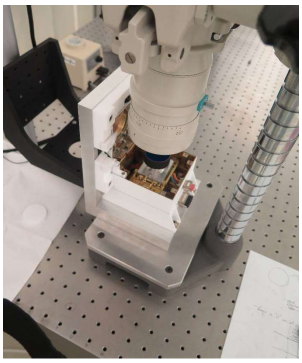


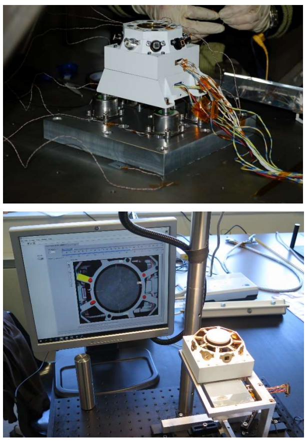


INTA's family of compact Sun Irradiance Sensors for the Martian surface

The big brother... *or maybe the "spoiled-child"!*
MEDA-RDS: Radiation & Dust Sensor

- Skycam allignment
- Vibration test (STM)
- Shock test (STM)



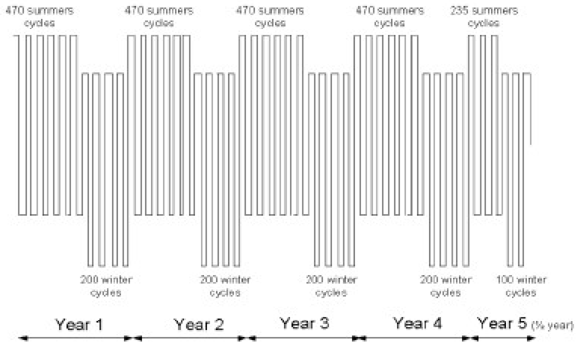


INTA's family of compact Sun Irradiance Sensors for the Martian surface

Why did I say "spoiled child" ?

It is requiring the most of our attention and care!

Package Qualification and Verification (PQV): a real pain in the…



INTA's family of compact Sun Irradiance Sensors for the Martian surface

PQV numbers

20 UUT BOARDS

2 RDS SUBASSEMBLIES

18 EGSE BOARDS

MORE THAN 170 DOCUMENTS

7 PEOPLE HAVE WORKED INTENSIVELY

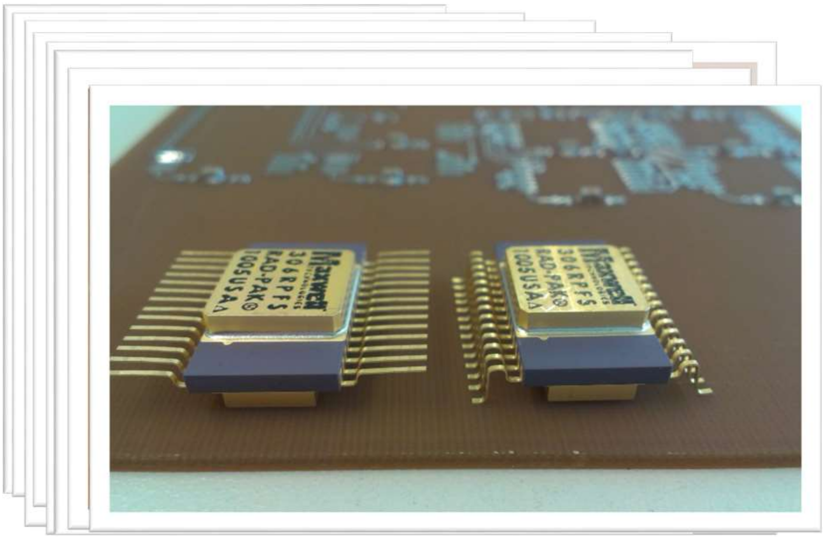
300k€ ESTIMATED COST

Technology Tested	NUMBER OF ITEMS
Paint	1 Type
Glue	3 Types
Silicones	2 Types
PCBs	1 Type
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

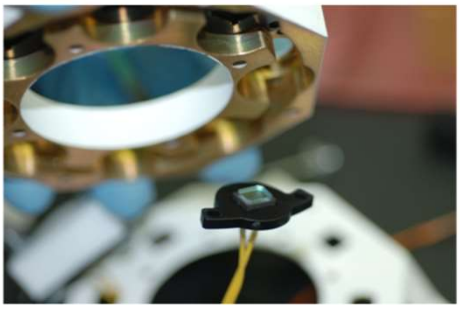
INTA's family of compact Sun Irradiance Sensors for the Martian surface

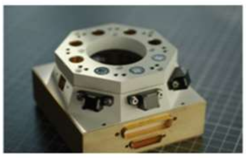
PQV in images

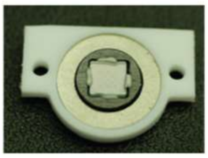


INTA's family of compact Sun Irradiance Sensors for the Martian surface

PQV in images

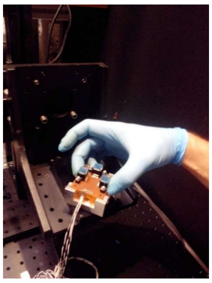


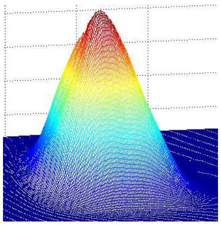


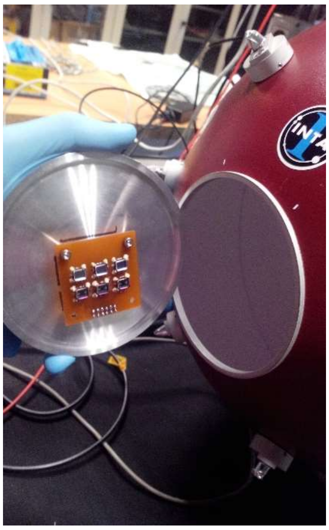


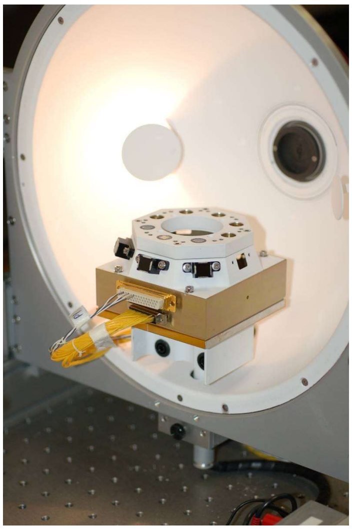
INTA's family of compact Sun Irradiance
Sensors for the Martian surface

PQV in images



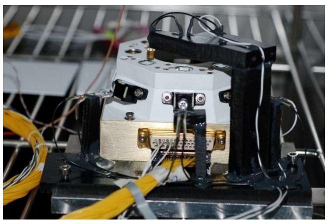






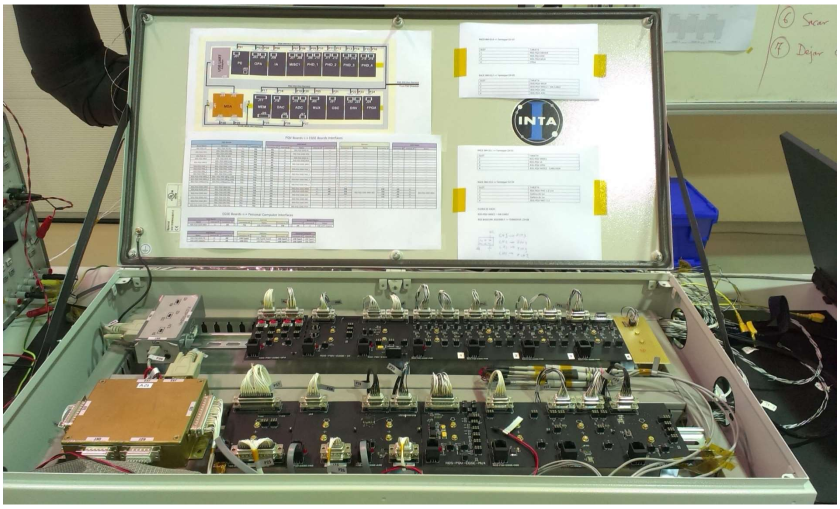
INTA's family of compact Sun Irradiance
Sensors for the Martian surface

PQV in images



INTA's family of compact Sun Irradiance Sensors for the Martian surface

PQV in images



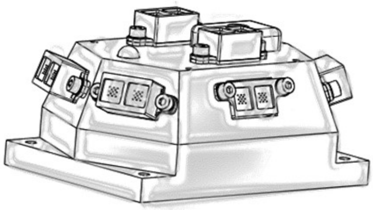
INTA's family of compact Sun Irradiance Sensors for the Martian surface

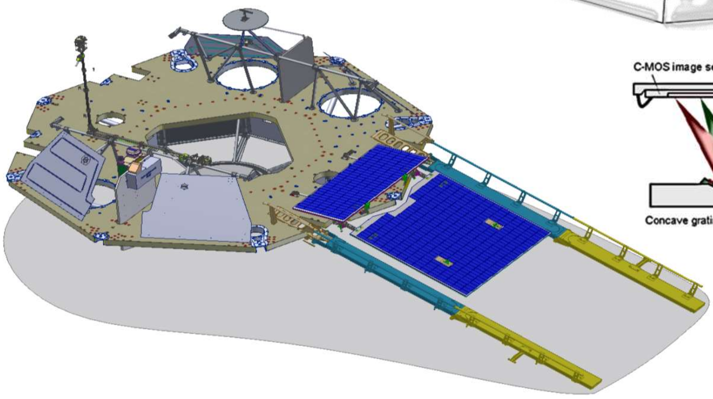
PQV in images

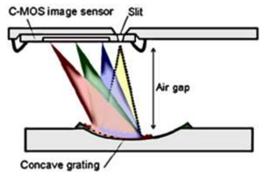
INTA's family of compact Sun Irradiance Sensors for the Martian surface

SIS'20: virtue is in the happy medium

- Part of METEO – ExoMars 2020 Lander
- Mid-term between DREAMS-SIS and MEDA-RDS: 180 g, 600 W
- 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



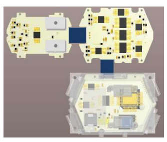


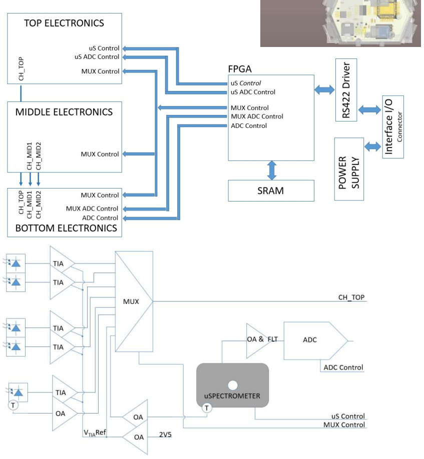


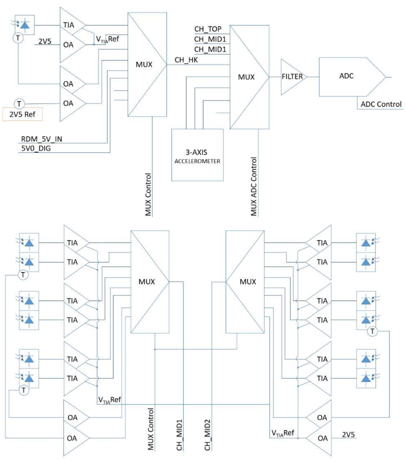
INTA's family of compact Sun Irradiance Sensors for the Martian surface

SIS'20: virtue is in the happy medium

- Electronics design in an advanced stage
- FPGA design building blocks 90% (design and validation)
- Functional EGSE 60%



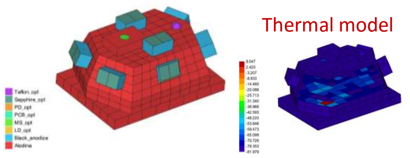


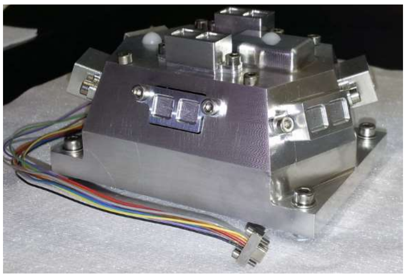


INTA's family of compact Sun Irradiance Sensors for the Martian surface

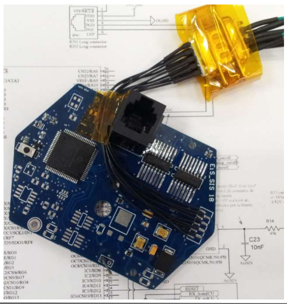
SIS'20: virtue is in the happy medium

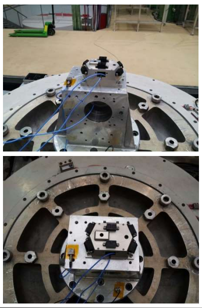
Thermal model



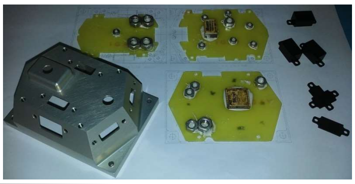


Electrical Interface Simulator





Structural & Thermal Models



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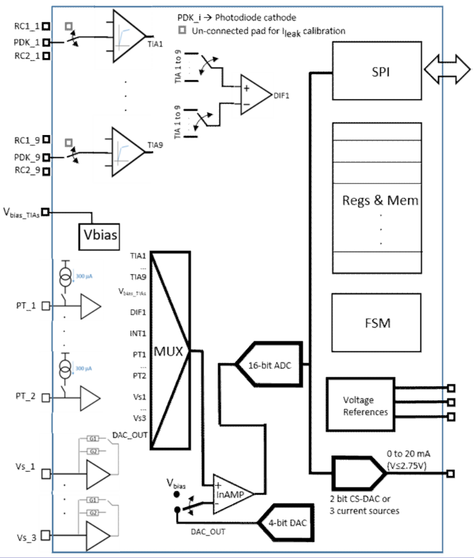
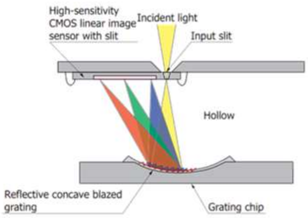
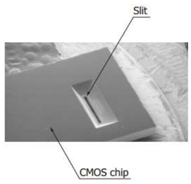
SIS'20: virtue is in the happy medium



Miniaturization efforts:

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

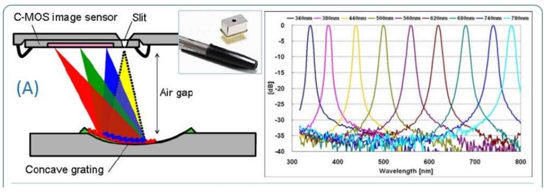


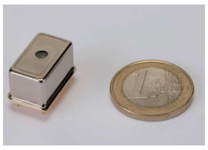


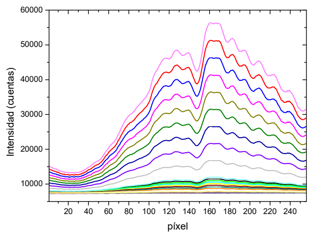
INTA's family of compact Sun Irradiance Sensors for the Martian surface

SIS'20: virtue is in the happy medium

CMOS detector, 340 to 780 nm, ~10 nm resolution, 256 pixels





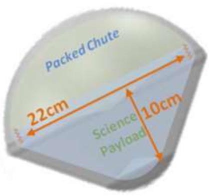


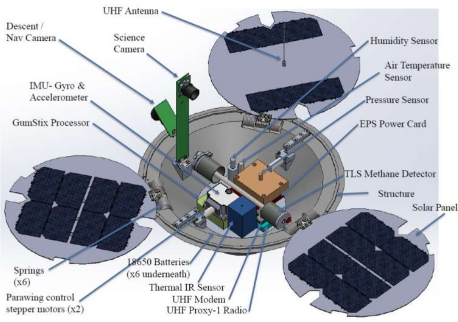
Successfully passed test at this moment:
- Vacuum
- Operation down to -135ºC
- Thermal Cycling > 1000 cycles
- Vibration and Shock (as per DREAMS reqs.)
- Optical characterization.

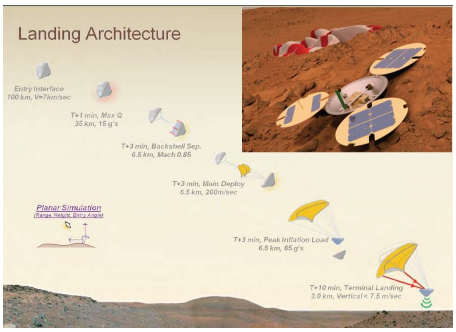
INTA's family of compact Sun Irradiance Sensors for the Martian surface

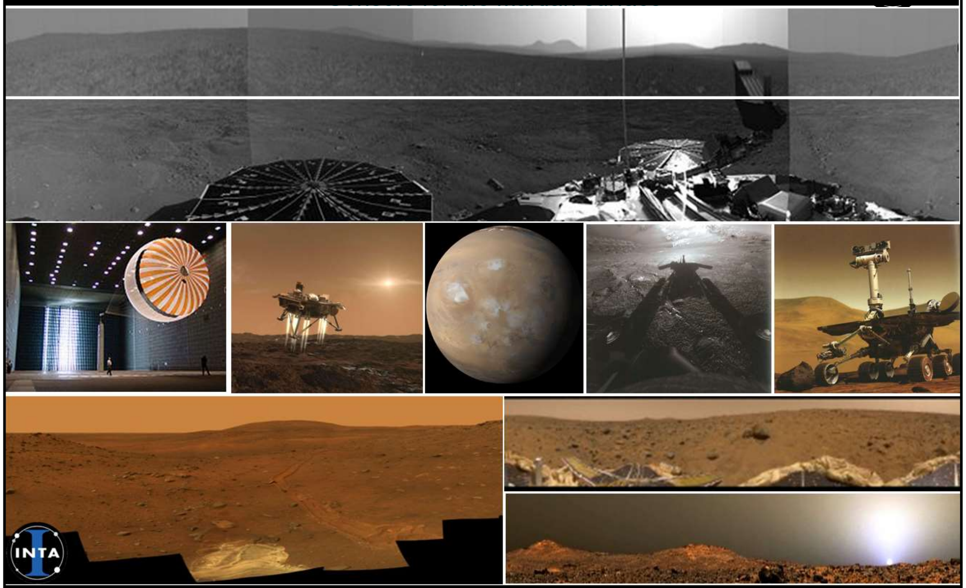
A "new" potential misión concept: MarsDrop

- 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!!