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.
   - 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 absolute signals

2. 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
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General science goals of SIS

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

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

3.- Vertical column: very low elevation (SZA: 85…95) observations adjust to model predictions (for a total column 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 → altitude 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
- High dynamic range and sensitivity needed
- High temporal resolution measurements needed

Cloud detection also possible during daytime
(Simulations from DREAMS-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...

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**Access to Space through Small Platforms**

<table>
<thead>
<tr>
<th>Mission</th>
<th>Microsat</th>
<th>Nanosat</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTASAT</strong></td>
<td>(1974) 12 kg</td>
<td></td>
<td>1974</td>
</tr>
<tr>
<td></td>
<td><em>Payload</em>: Atmospheric Sensors, infrared and imager industries</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Launch</em>: Tendra 1 (Germany)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **MINISAT-01** | (1997) 18 kg | | 1997 |
| | *Payload*: **Optos**: Microsatellite optical imaging experiment |
| | *Launch*: Pegasus R, Vandenberg AFB |

| **NANOSAT 1B** | (2004) 10 kg | | 2004 |
| | *Mission*: 5-year operational satellite |
| | *Payload*: **HISPASAT** | **HISDESAT** | | **SEOSAT**, etc. |
| | *Technical Support*: National Space Programs |
| | *Launch*: Typhoon, 18-mg, 3.5 kg |

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Then came MetNet…

… and that was our introduction into the Martian “arena”
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The father: MetSIS

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

Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Max.</th>
<th>50%</th>
<th>90%</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Supply</td>
<td>DC 3.0 - 3.6V</td>
<td>2.55</td>
<td>3.64</td>
<td>3.05</td>
<td>3.63</td>
<td>V</td>
</tr>
<tr>
<td>Current Limits</td>
<td>DC 3.0 - 3.6V</td>
<td>250</td>
<td>60</td>
<td>300</td>
<td>60</td>
<td>mA</td>
</tr>
<tr>
<td>Temperature</td>
<td>0°C - 60°C</td>
<td>0°C</td>
<td>60°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>METAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Environmental qualification

- Shock Y-axis 45.99 m/s, P=0.47 bar
- Vibration ±20 m/s², P=0.47 bar
- Thermal Shock
  - 50°C (10 minutes)
  - 150°C (10 minutes)
  - ±50°C, 5 cycles
- Humidity: 95% RH, 10 cycles

Environmental testing
- 100% humidity, 10 cycles
- ±50°C, 5 cycles
- ±20 m/s², 10 cycles
- 95% RH, 10 cycles

Two optical heads to measure projectile's speed at this point

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Our sweetheart: small but powerful!!

DREAMS on ExoMars 2016 and DREAMS-SIS

DREAMS (Dust Risk Assessment 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.


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).

**SIS-OH mounted on DREAMS Mast**

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

DREAMS-SIS construction

**SIS-OH**

- Tetrahedral shape. 3 faces ("East, South, West") 120° apart from each other (AZ) looking at 60° 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 degree 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

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).

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.
  - ±4°C change generates some signal change as 2 degree tilt. In the worst case, temperature of SIS-PE is sensed.

Relative Sun position determination through analysis of:
- Time of Sols 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).
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Minor interferences of some EDM elements in 515 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 Myl)
- 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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**Table: Performance Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>230 x 110 x 50 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>250 g</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1.5 W (5% PF, 18 VDC)</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-40°C to +50°C</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.001 W/m²</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>18 VDC</td>
</tr>
<tr>
<td>Interface</td>
<td>RS-232, USB</td>
</tr>
</tbody>
</table>

**Integration on the Lander**
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Sahara campaign with DREAMS-SIS

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

Difference calculated as:
\[
\text{Difference} = \frac{(\text{SIS} - \text{Pyranometers})}{\text{SIS} + \text{Pyranometers}} \times 100
\]

Different AOD estimation methods. Comparison with Microtops & CIMEL

- Estimation by fitting 4 hours of SIS signal ("average" O3D)
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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

The big brother: MEDA-RDS

- 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

<table>
<thead>
<tr>
<th>Channel</th>
<th>Center Wavelength (nm)</th>
<th>Bandwidth (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>255 ± 5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>266 ± 5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>260-400</td>
<td>± 10</td>
</tr>
<tr>
<td>4</td>
<td>450 ± 40</td>
<td>± 10</td>
</tr>
<tr>
<td>5</td>
<td>650 ± 25</td>
<td>± 10</td>
</tr>
<tr>
<td>6</td>
<td>750 ± 10</td>
<td>± 10</td>
</tr>
<tr>
<td>7</td>
<td>196-1100</td>
<td>± 10</td>
</tr>
<tr>
<td>8</td>
<td>950 ± 50</td>
<td>± 10</td>
</tr>
</tbody>
</table>
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

Electronic design
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The big brother: MEDA-RDS

The big brother... or maybe the "spoiled-child"!

MEDA-RDS: Radiation & Dust Sensor

- Skycam alignment
- Vibration test (STM)
- Shock test (STM)
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...

<table>
<thead>
<tr>
<th>Technology Tested</th>
<th>NUMBER OF ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paint</td>
<td>1 Type</td>
</tr>
<tr>
<td>Glue</td>
<td>3 Types</td>
</tr>
<tr>
<td>Silicones</td>
<td>2 Types</td>
</tr>
<tr>
<td>PCBs</td>
<td>1 Type</td>
</tr>
<tr>
<td>Coating</td>
<td>1 Type</td>
</tr>
</tbody>
</table>

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 numbers

20 UUT BOARDS
2 RDS SUBASSEMBLIES
18 EGSE BOARDS
MORE THAN 170 DOCUMENTS
7 PEOPLE HAVE WORKED INTENSIVELY
300k€ ESTIMATED COST
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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

Yes, we did it!!
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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

- Electronics design in an advanced stage
- FPGA design building blocks 90% (design and validation)
- Functional EGSE 60%
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SIS’20: virtue is in the happy medium

Structural & Thermal Models

Electrical Interface Simulator

Miniaturization efforts:
- ASIC: Front-End + A/D for photodetectors, 3-axis accelerometer, Thermal sensors, etc.
- Qualification of compact mid-resolution (10 nm) spectrometer
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 -135°C
- Thermal Cycling > 1000 cycles
- Vibration and Shock (as per DREAMS reqs.)
- Optical characterization.

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!!