An Introduction to the MTG-IRS Mission

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Summary

1. Products and Performance
2. Design Overview
3. L1 Data Organisation
Part 1

1. Products and Performance
2. Design Overview
3. L1 Data Organisation
Meteosat Third Generation (MTG)

- The MTG Space Segment consists of two different types of satellites, both 3-axis stabilised, for a total of **six satellites:**
  - **Four Imaging Satellites (MTG-I)**
  - **Two Sounding Satellites (MTG-S)**
- In full operational capability, 3 satellites will be operated at the same time (2 MTG-I, 1 MTG-S)
- First launches:
  - MTG-I1: 2018
  - MTG-S1: 2020
  - MTG-I2: 2023
- The IRS flies on board MTG-S
The Infrared Sounder

- Scope of the MTG-IRS mission is providing the user community with high spatial and temporal resolution information on the vertical distribution of humidity and temperature, as well as on their horizontal distribution.

- Humidity and temperature profiles will be generated on the vertical hybrid-sigma coordinates of the ECMWF forecast system (91 levels).

- The requested horizontal resolution is **4 km at nadir**.

- The data rate must be such that the entire Earth Disc is covered in one hour.
These products are the result of a sequence of processing steps, that produce different data levels (L0, L1, L2 ...)

The vertical profiles of temperature and humidity are L2 data, that can be obtained by manipulating spectral radiance data with high spectral resolution.

This means that the IRS has to provide a set of spectra (at Level 1), along the entire Earth disc.

The L2 algorithms will convert these spectra into vertical profiles, by exploiting the physical laws that govern radiation transfer.
The Level 1 Data

- The IRS produces 3D data; two dimensions, the horizontal ones (latitude and longitude) are the same for both L1 and L2 data; the difference is in the third dimension, which represents:
  - a spectrum at Level 1
  - a vertical profile at Level 2

- This also means that an IR spectrum must be generated for every spatial element of the Earth disc

- A single spectrum is also named a spectral sounding; so the L1 products of the IRS are a collection of IR spectral soundings

In conclusion:
- The IRS L1 data are a 3D set with two spatial and one spectral dimension
- This means that the IRS must be an imaging spectrometer
Spatial Coverage & Repeat Cycle

- The Earth disc is split in **4 Local Area Coverage (LAC) Zones**
- Numbered from South to North
- Hence LAC1 is South Africa and **LAC4 is Europe** (strange shape needed to cover Canary Islands)
- 1 LAC covered in **15min** (so the entire Earth can be theoretically covered every hour)
- But LAC4 is revisited every **30min**
Spectral Performances

- The spectral range and resolution are dictated by the needs on vertical resolution at L2, resulting in a spectrum that entirely lies in the IR region, between 680cm-1 and 2250cm-1 (4.44μm to 14.7μm), more exactly:

  - split in two non contiguous bands:
    - 680cm-1 to 1210cm-1 (LWIR band)
    - 1600cm-1 to 2250cm-1 (MWIR band)

  - with a spectral resolution of 0.625cm-1
Part 2

1. Products and Performance

2. Design Overview

3. L1 Data Organisation
The IRS collects the **radiation** emitted by the Earth and produces as output a **set of spectra**

*How does it work?*

**Earth Radiance**

IRS

*L1b data (measured spectral radiance)*
Fourier Transform Spectrometry

The IRS is a: 

**Fourier Transform Spectrometer (FTS)**

That means:

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That means:

1. The Earth radiation is focused on a focal plane
2. Where it is directly detected in the time domain
3. The signal is handled by an analogue chain and eventually digitised
4. A Fourier Transform (FFT) is carried out to get the spectrum
Problem:

Light is an e.m. wave, but not a radio wave!
Even in the IR the frequency is too high (up to 67 THz, that is 0.015 ps wave period) for being followed by any man made detector (not to mention energy issues)

Definitely not a working design!
Classical solution:

Scale down the frequency by interferometry and generate interferograms

*Michelson interferometer* is introduced in the optical path
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*Michelson interferometer* is introduced in the optical path

*This is the core of IRS*
The processing load is **too high** for being handled by the on-board processing alone.
Space vs. Ground Processing

The processing load is **too high** for being handled by the on-board processing alone.

It must be split between **Space Segment (SS)** and **Ground Segment (GS)**.
Working in the IR has disadvantages:

The **detector must be cooled** (actually at 60K)

and the **nearby optics as well** (a bit less cold)
Infrared Technology: Radiometric Calibration

However, despite cooling:
A residual thermal offset background adds up to the signal; it must be removed

Two deep space views are then exploited (not shown here)

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A residual thermal offset background adds up to the signal; it must be removed.

Two deep space views are then exploited (not shown here)

An internal **Blackbody** must be introduced
and everything must be **calibrated** (on ground)

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**Earth Radiance**

**L1b data**

**IRS SS**

**ON-BOARD ELECTRONICS**

- **Blackbody**
- **Interferometer**
- **On-board Processing**
- **Analogue Electronics**
- **Cooled Focusing Optics**
- **Cooled Detection Assembly**

**IRS GS**

- **Calibration**
- **FFT**
The IRS has to be an **imaging** spectrometer.

Hence it must have a spatial discrimination capability.

This is achieved using **two matrix detectors:**

- one for LWIR
- one for MWIR
IR detectors able to ensure the desired resolution of 4km over the entire Earth (3200x3200 pixels) are not available. A **scan mirror** must be introduced and a step-&-stare scanning method must be followed.

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**Earth Radiance**

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**IRS GS**

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**L1b data**

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**IRS SS**

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**OPTICS**

- Blackbody
- Interferometer
- On-board Focusing Optics
- Cooled Matrix Detectors

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**ON-BOARD ELECTRONICS**

- On-board Processing
- Analogue Electronics
- Cooled Electronics

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**Calibration**

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**FFT**
Optical and radiometric quality ask for a rather large pupil (280 mm)

An interferometer matching this pupil would be large and heavy

A good alternative is reducing the beam size via an afocal telescope
A similar problem exists for the cooled optics.

Cooling requires a lot of energy, directly proportional to the size of the cooled element.

Again an afocal telescope solves the problem, with the same method.
Straylight Issues

As in most optical instruments, the Sun disturbance must be neutralised. As a minimum, a **baffle** needs to be introduced.
With the addition of the last element the (very) simplified IRS End-to-End Functional Chain is complete.

A lot of elements and processing steps have not been mentioned (e.g. INR and spectral calibration), but the basic structure is essentially this one.
The IRS Working Principle in a Nutshell

- In summary:
- The instrument works in **step-&-stare** mode, with the Earth disc covered through a sequence of contiguous square sub-images (**dwell**s)
- With the current design, each dwell is taken in 10s and covers about **640 x 640 km2** (at nadir) with 160 x 160 spatial samples
- Within a single dwell, a set of **interferograms**, one per detection element, is produced
- A **spectral sounding** is the result of the Fourier transformation of an interferogram from a single detection element
A Sketch of the IRS Design

IRS design: Kayser-Threde (Munich)

Optics:
- Baffle
- Scan Mirror
- Front Telescope
- Interferometer
- Back Telescope
- Cooled Focusing Optics
- Cooled Matrix Detectors

Source:
MTG-KT-IR-DD-0004
"IRS Design and Technical Description", Kayser-Threde
A Slightly More Detailed Sketch

Interferometer design: Thales-Alenia Space (Cannes)
Size, Mass and Power

• Envelope: 1.4 x 1.6 x 2.2 m³

• Mass: 400 kg

• Power consumption: 650 W

The IRS mock-up at Kayser-Threde
Part 3

1. IRS Products and Performance
2. IRS Design Overview
3. L1 Data Organisation
A Summary of the IRS L1 Data

- Earth disc split in LACs and dwells
- Each LAC contains about 80 dwells
- Each dwell covers 160 x 160 samples with 4 km resolution (at nadir), that is 640 x 640 km², for a time of 10s
- The data are taken in two bands:
  - LWIR, 680 cm⁻¹ to 1210 cm⁻¹
  - MWIR, 1600 cm⁻¹ to 2250 cm⁻¹
- Two high resolution images are also generated (one per band), with 1.33 km resolution, 480 x 480 samples
Use of L1 Data

- The main scope of the L1 data is to act as inputs for further processing, aimed at the generation of the geophysical (L2) data.

- The L2 data will then be **disseminated** to all users in real time.

- The L1 data (about **2000 spectral samples per sounding**) will be:
  - **archived** (at EUM)
  - but **also disseminated**

- So the users will receive (in addition to the L2 data) the L1 data.

- But the disseminated data are a **lossy compressed version** of the archived data (**300 principal components per sounding**).
Data Amount

- 160 x 160 soundings, times 2000 spectral samples per sounding, makes 51.2 million samples per dwell, that is (roughly):
  - 100 Mbytes per dwell
  - 8 Gbytes per LAC
  - more than 4 Pbytes (4 million Gbytes) during the MTG system lifetime

- 100 Mbytes per dwell (i.e. every 10s) means a net data flux (to the archive) of 10 Mbytes/s (or 32 Gbytes per hour)

- The disseminated data will be “only” 15% of the above, that is:
  - users will get 1.2 Gbytes per LAC
  - with a data rate of 1.5 Mbytes/s

- This large amount of data has to be suitably packed in what is called a dataset
Dataset Organisation

- An L1 dataset is a **collection of dwells**
- A single dwell can been seen as a **data cube**, with two spatial dimensions and a spectral dimension
- There are two possible ways for organising this data cube, either:
  - as a vector of monochromatic images, that is a sequence of slices
  - or as a **matrix of spectra**
- The current approach is the second one, the most suitable for the intended use of the data (as spectra, not images)
Dataset Format

- L1 datasets will be in **netCDF-4** format (for all MTG instruments)
- This format allows to organise the data in groups, and this feature can be fruitfully used to reflect the structure described up to now
- A common structure for all MTG instruments and products is used
- The **science data** (spectra and images) are part of the **data group**
Thank you for your attention!