# Spectral and Radiometric characteristics of MTG-IRS

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# Outlines

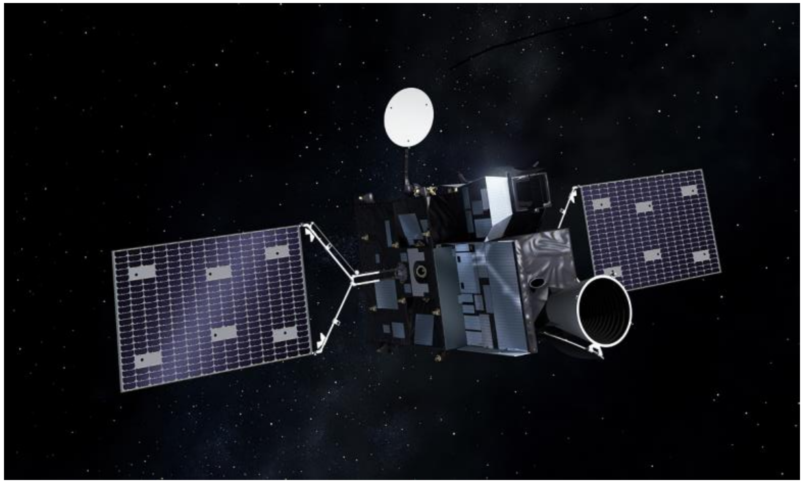
1) Overview of IRS mission, instrument and spatial coverage
2) Overall L1 processing for MTG-IRS
3) IASI as a proxy to explain IRS particularities
4) IRS Spectral Response Function (SRF) and impact for the users community:
   a) Current status
   b) Apodisation
   c) Variablility of the Radiometric response
5) PC compression
6) Conclusion

# 1) IRS mission

- ✓ The IRS mission performance requirements have been established by EUMETSAT and ESA, after users consultation, and are applicable to the level 1 data
- ✓ The requirements concern all spectra covering the entire Earth disk, as seen from the geostationary orbit, when radiometrically and spectrally calibrated and geolocated
- ✓ IRS instrument is developed by OHB as a subcontractor of Thales Alenia Space under the MTG space segment contract to ESA. Whilst EUMETSAT is responsible for the overall MTG system and ground segment procurement

# 1) IRS mission

The main performances can be summarized as follows:

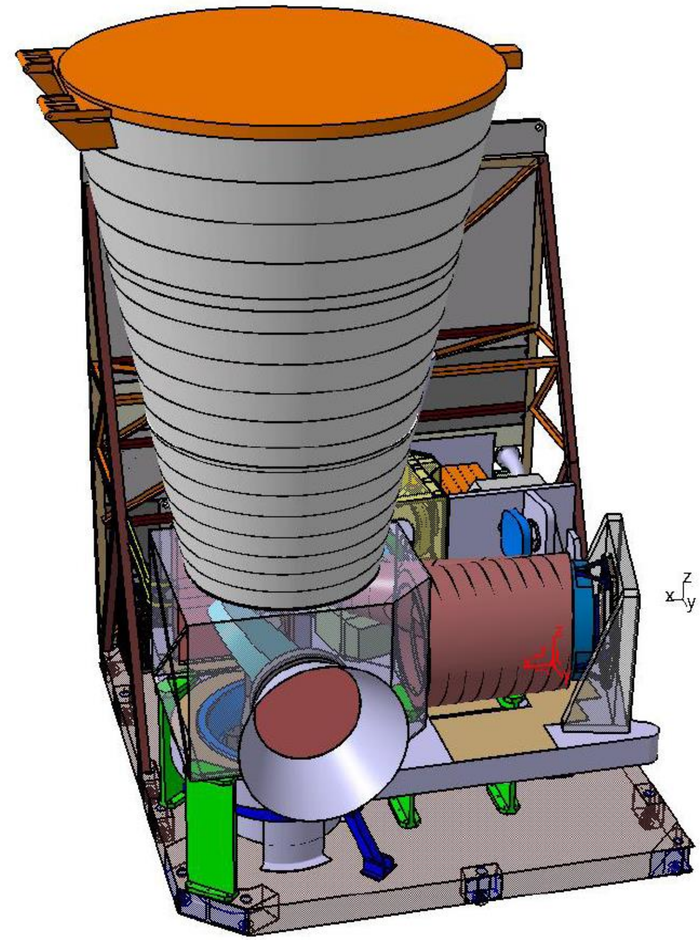


*in courtesy of ESA*

- Spatial resolution : 4km at Sub-Satellite Point
- Spectral resolution / sampling : 0.754 $cm^{-1}$ / 0.625 $cm^{-1}$
- Radiometric stability and noise : around 0.1-0.2K
- Spectral accuracy : 0.1K equivalent noise
- Repeat cycle : 30 min Europe
  6h repeat cycle for the Whole Earth

# 1) IRS instrument

- ✓ Imaging Fourier Transform Spectrometer, based on a Michelson interferometer
- ✓ 2 spectral bands: LWIR (700 to 1210 cm-1) and MWIR (1600 to 2175 cm-1)
- ✓ CCM mechanism similar to IASI
- ✓ 3 laser beams allowing monitoring the CCM speed variations as well as apex vector offset and slope
- ✓ Maximum OPD: 0.848 cm
- ✓ Detector: 160x160 pixels (a “dwell”) measured in 10 sec, with a pixel size of 4 km.





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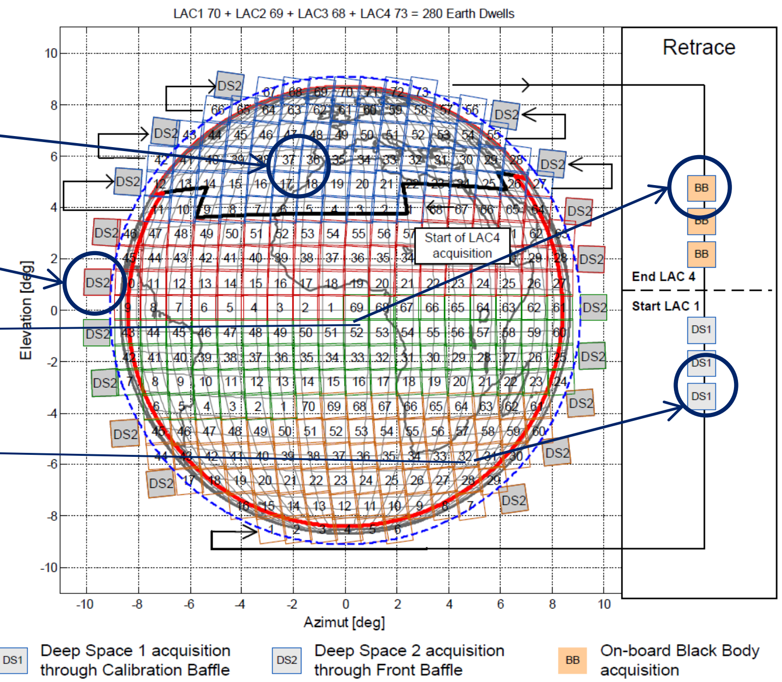
# 1) IRS measurements

✓ L0 data (interferograms, images and auxiliary data) from the instrument, collected and packed by the L0 pre-processor

✓ Each dataset represents a dwell (split into 2 bands)

✓ 4 different kinds of measurements within an L0 dataset, one Earth View and three radiometric Calibration Views:

- Earth View (EV): actual Earth scene
- Deep Space 2 (DS2): a deep space observation at the beginning of a row
- Blackbody (BB): direct observation of the internal blackbody (every 15 min)
- Deep Space 1 (DS1): a deep space observation through the BB path (every 15 min)



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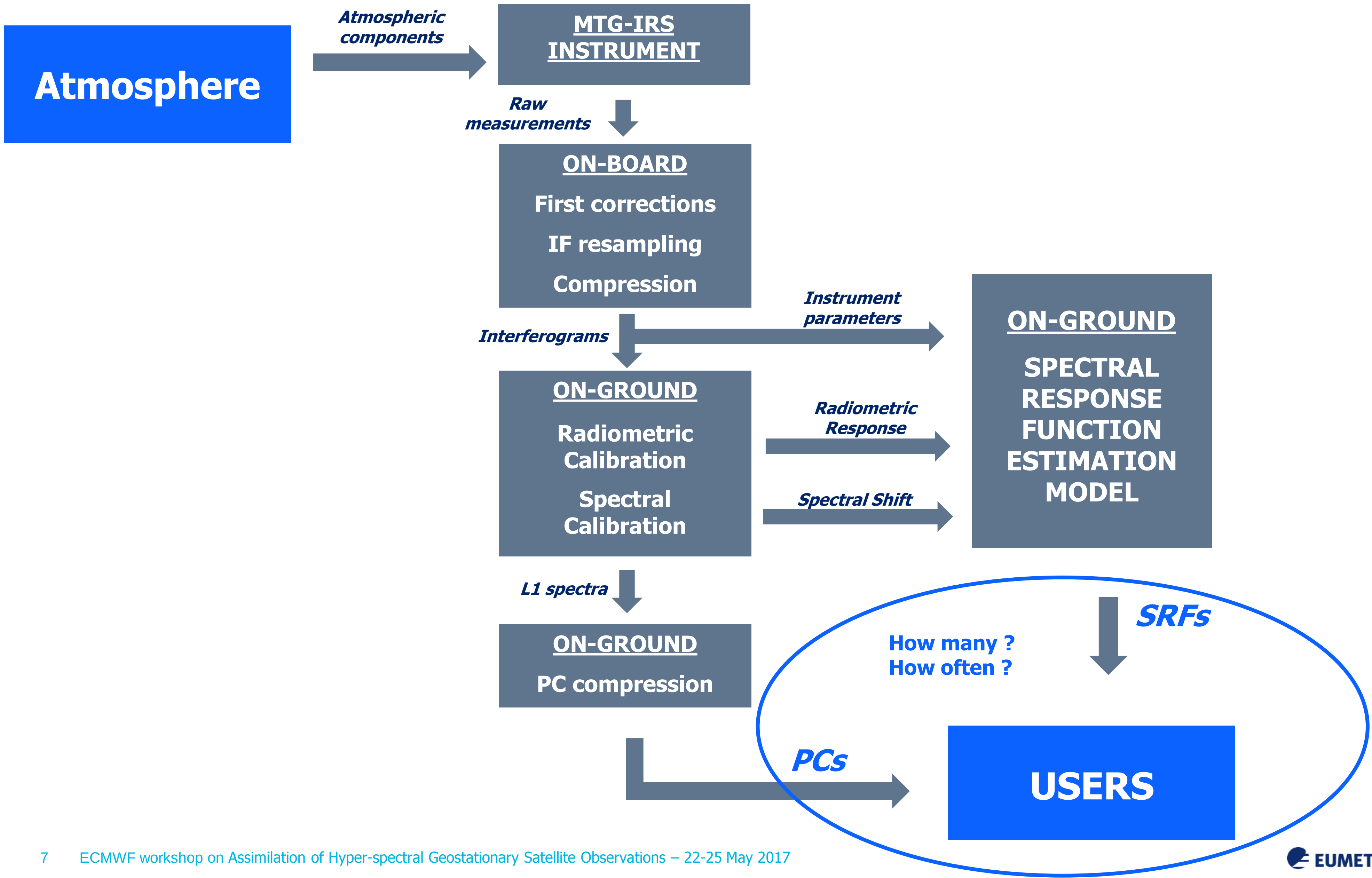
# 2) Quick overview of the IRS data processing



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# 3) MTG-IRS situation compared to IASI

## Main characteristics which are not transparent to the users:

1) Size of the interferogram (maximum Optical Path Difference)
   - ✓ **2 cm** for IASI → Spectral resolution of **0.5 $cm^{-1}$** (after apodisation)
   - ✓ **0.8 cm** for IRS → Spectral resolution of **0.754 $cm^{-1}$** (after apodisation)

2) Pixel size:
   - ✓ **12 km** for IASI → Spectral Response Function is **apodised by design**
   - ✓ **4 km** for IRS → Spectral Response function is close to the **cardinal sine**

3) Size of the detector array
   - ✓ **2x2** pixels for IASI → Spatial coverage of **50x50 $km^2$**
     → **Small** variation of the radiometric response
   - ✓ **160x160** pixels for IRS → Spatial coverage of **640x640 $km^2$**
     → **Large** variation of the radiometric response



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# 3) MTG-IRS situation compared to IASI

## ✓ Dwell of 160x160 pixels (IRS) ➔ 2x2 pixel (IASI)

| Wn (in $m^{-1}$) | 70000 | 121000 | 159000 | 225000 |
|---|---|---|---|---|
| IRS centre | 0.0053 | 0.0091 | 0.0119 | 0.0169 |
| IRS corner | 88.34 | 152.7 | 200.0 | 284.0 |
| IASI | 9.24 | 15.84 | 21.12 | 29.70 |

Factor 10

-> Corner pixel is much further, the spectral shift is **10 times larger**

## ✓ Pixel size of 4km (IRS) ➔ 12 km (IASI)

| FWHM (in $m^{-1}$) | 70000 | 121000 | 159000 | 225000 |
|---|---|---|---|---|
| IRS centre | 72.87 | 72.87 | 72.87 | 72.87 |
| IRS corner | 72.874 | 72.883 | 72.893 | 72.917 |
| IASI | 30.64 | 31.63 | 32.94 | 36.70 |

Increase of

➔ 0.04%

➔ 19.8 %

➔ Instrument Line shape **varies less** for IRS and is closer to the cardinal sine

➔ It means that the Radiometric Response has **more impact** on the Spectral Response Function

# 4) IRS Spectral Response Function

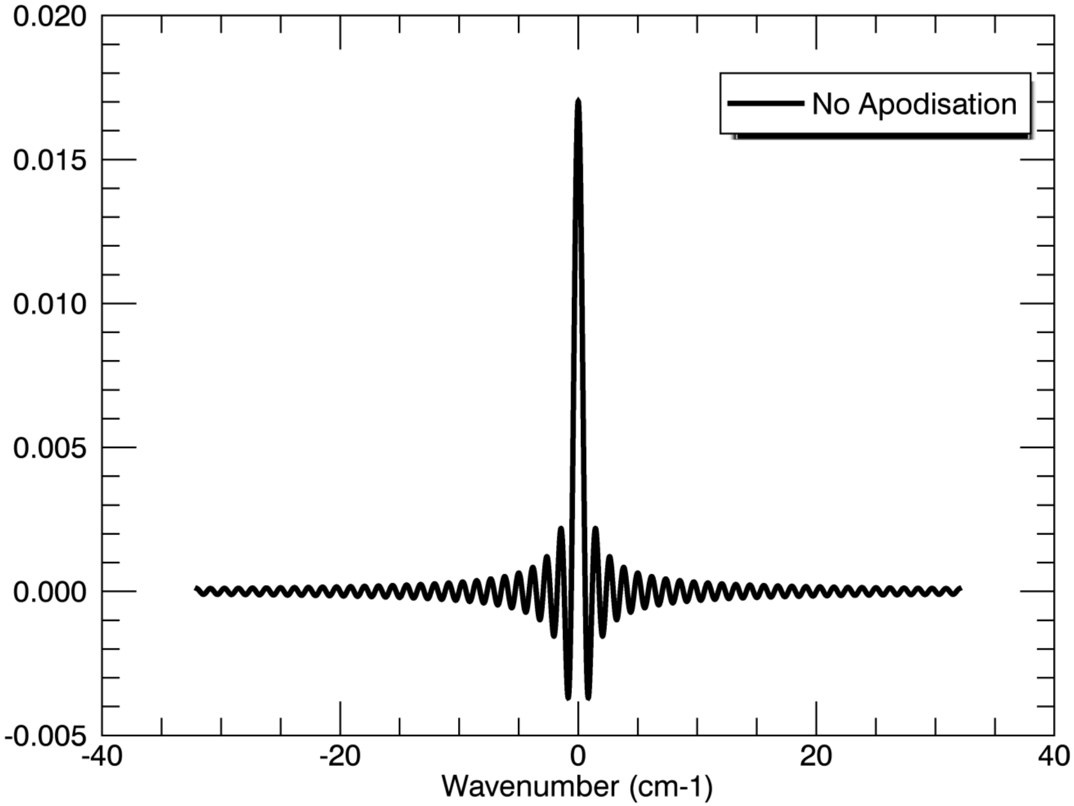
- ✓ Status of the SRF for MTG-IRS
- ✓ Improvement with the apodisation
- ✓ Potential improvements regarding the dependency over the detector array, spectrally and in time with the uniformisation
  - ✓ Presentation of the methodology
  - ✓ Validation of each main contributors of the estimated SRF
  - ✓ Impact on the noise correlation
  - ✓ Impact for the user community

# 4-a) IRS Spectral Response Function (SRF)

The SRF is a combination of two main terms:

- ✓ The Radiometric Response **R** (next slide)
- ✓ the Instrument Line Shape **ILS**

$$SRF_{\nu_0}(\nu) = Re\left[\frac{R(\nu)}{R(\nu_0)} \times ILS_{\nu}(\nu_0)\right]$$




→In the case of IRS, the ILS is close to a cardinal sine

(simulation coming from the IRS performance tool, called IRASS)



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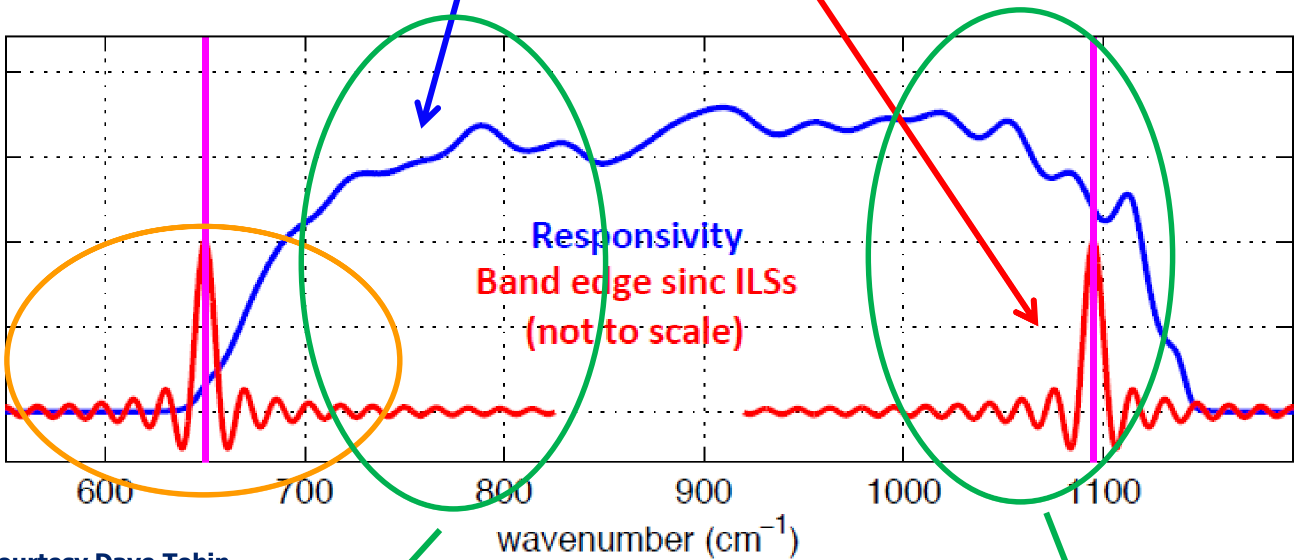
# 4-a) Radiometric Response in the SRF estimation

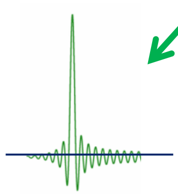
$$SRF_{\nu_0}(\nu) = Re\left[\frac{R(\nu)}{R(\nu_0)} \times ILS_{\nu}(\nu_0)\right]$$

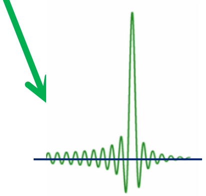
Radiometric Response

~ Cardinal Sine




Courtesy Dave Tobin





**Missing information in the band edge is a problem**

**SRF more spectrally dependent**

**Radiometric Response is pixel dependent (25600 pixels for a dwell)**



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# 4-a) Situation for the users regarding the SRF

$$SRF_{\nu_0}(\nu) = Re\left[\frac{R(\nu)}{R(\nu_0)} \times ILS_{\nu}(\nu_0)\right]$$

The Spectral Responsivity is:

- ✓ Pixel dependant → 25600 SRF
- ✓ Spectral dependant → 1800 SRF
- ✓ Instrument dependant → Regular update: every year? Month? Day?

**Current situation of today:**

→ To reduce that number in grouping spatially – no information on reduction

→ Since the spectral variation is small, we can reduce to 5 functions per band

→ No information

→ **Update of ~~1800~~ 10 x 25600 SRF, every year, month or day**

# 4-b) IRS Instrument Line Shape

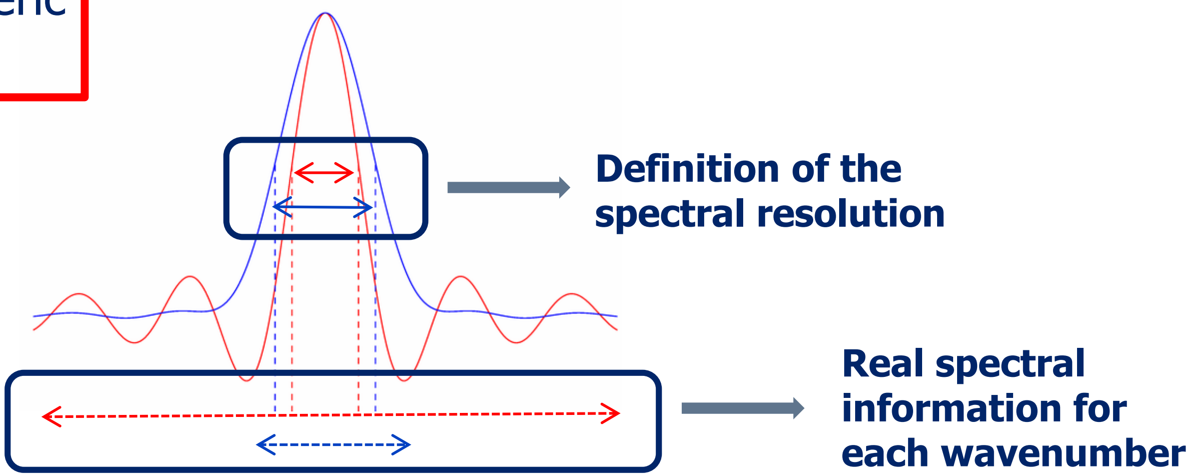
It is possible to improve the situation regarding the ILS with an apodisation (which respects the mission requirement)

**Measured ILS:**

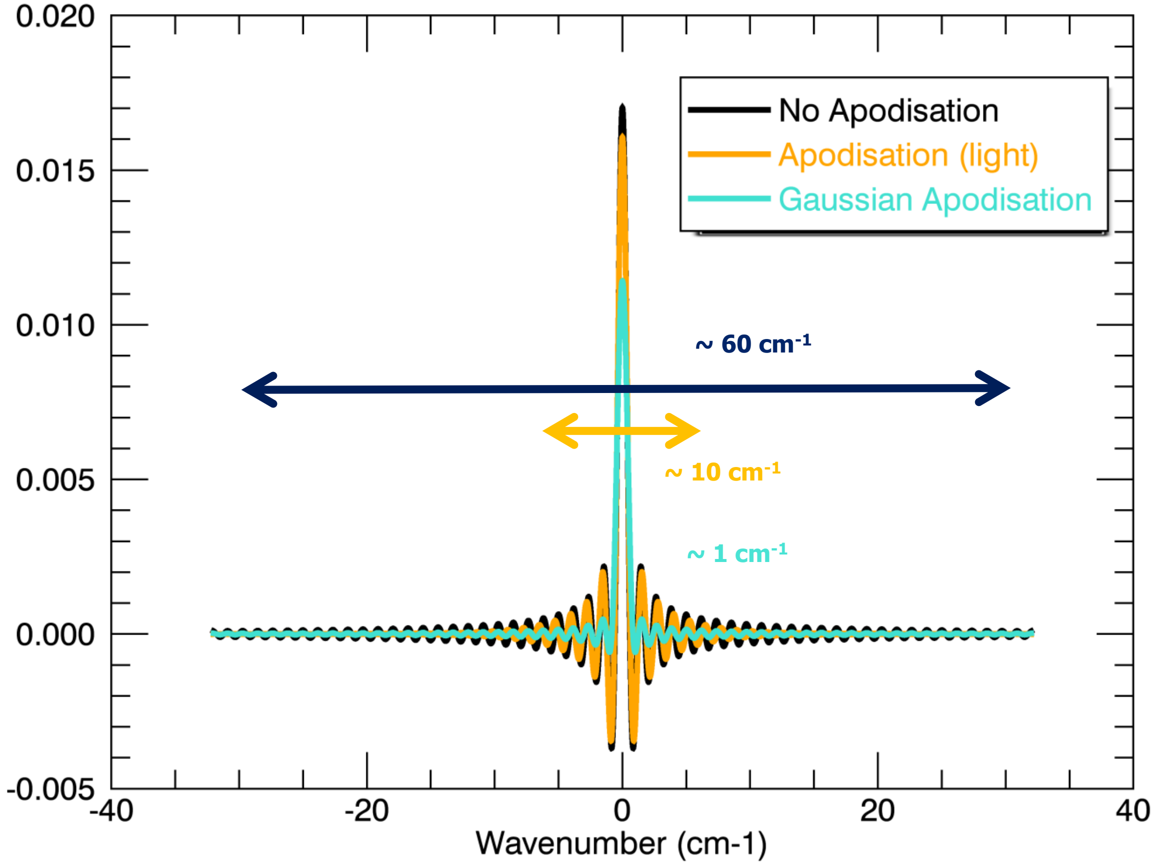
- ✓ It respects the spectral resolution of 0.754 $cm^{-1}$ (mission requirement)
- ✓ Defined on a larger spectral area, each wavenumber represents the information coming from a spectra covering (at least) 60 $cm^{-1}$ → kind of "polluted" by different atmospheric component (spectral cross-talk)

**Gaussian apodisation (IASI type)**

- ✓ It degrades the spectral resolution by 0.1 $cm^{-1}$ (TBC)
- ✓ Each wavenumber are independent in terms of integrated information (no spectral cross-talk)



# 4-b) Possible apodisations

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1) Light apodisation (gate slightly apodised) which:
- ✓ respect the spectral resolution of 0.754 $cm^{-1}$
- ✓ reduce the spectral cross-talk
- ✓ Does not remove the first lobes

2) Apodisation type Gaussian would:
- ✓ remove the spectral cross-talk
- ✓ degrade the spectral resolution by 0.1 $cm^{-1}$ (at first estimation)

# 4-c) Principle of the uniformisation

**Objectives:** To uniformise the Spectral Response Function across the detector array, in the spectral range and in time ⟷ To remove the SRF from the measurements.

**Measured spectrum:**

$$S_{mes} = (S.R) \otimes ILS$$

S: Infinite spectrum
R: is the Radiometric response
ILS: Instrument Line Shape
(including the apodisation function)

**Methodology:**

$$I_{1B}(x) = FT\left[S_{mes}(v)\right]$$

$$S_{1C}(v) = FT^{-1}\left[\frac{I_{1B}(x)}{SAF_{1B\_est}(v,x)}\right]$$

SRF

with $SAF_{1B\_est}(v,x) = FT\left[\underbrace{ILS_{1B\_est}(v_0\text{-}v).R(v).}_{SRF}\right]$



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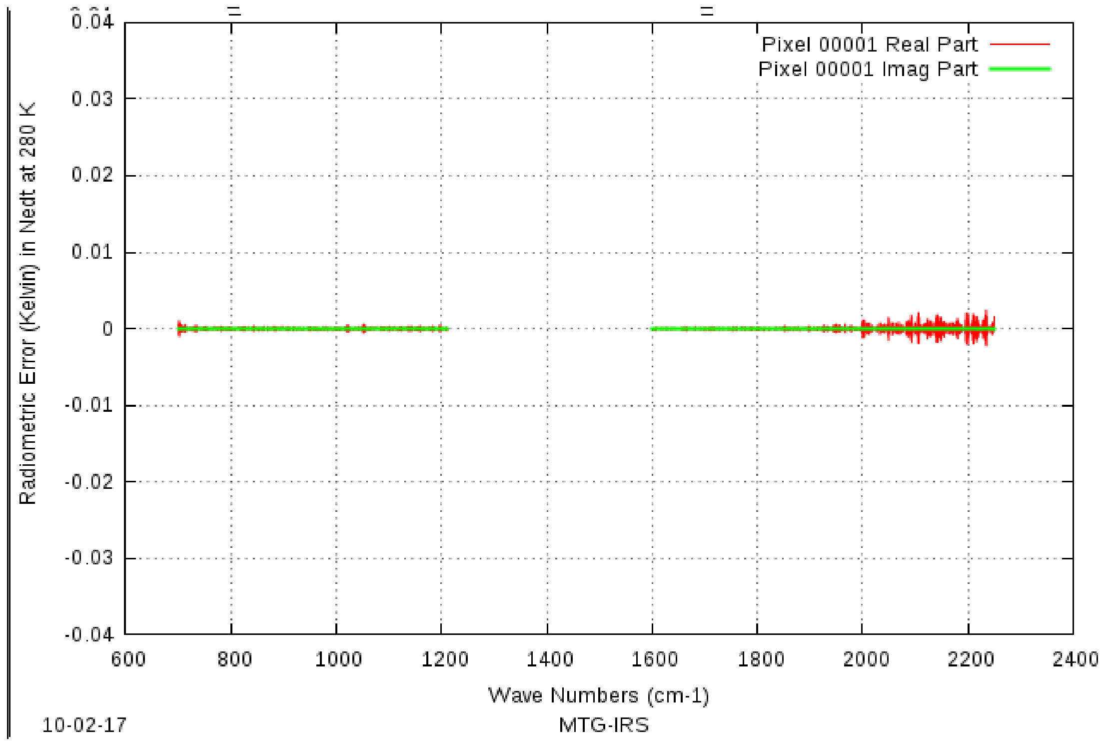
# 4-c) Uniformisation - ILS

## Difference between Corner and Center pixels

**No Uniformisation**

**With Uniformisation**



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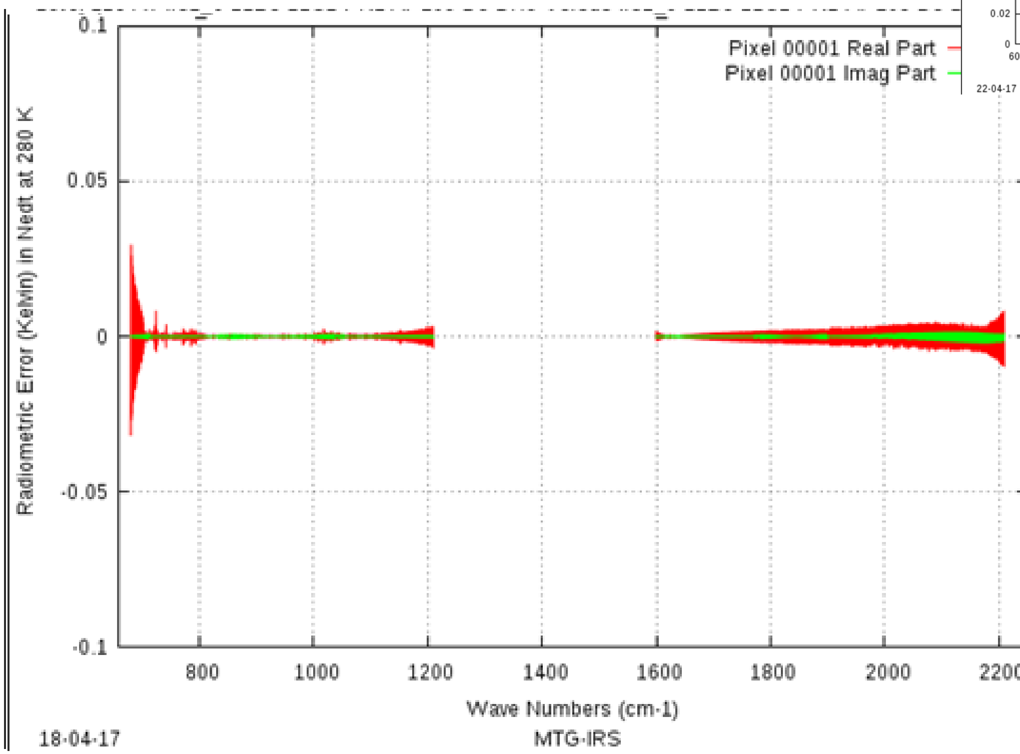
# 4-c) Uniformisation – Radiometric Response

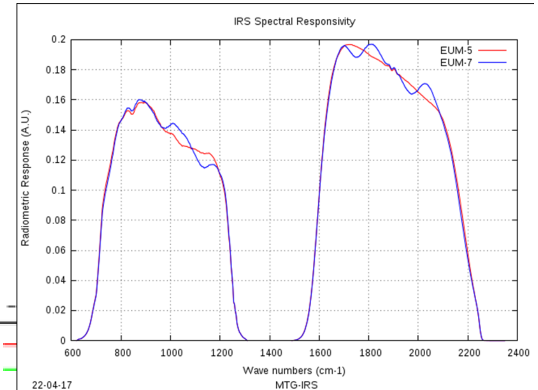
## Effect on different Radiometric Response

***Extreme Case***

**No Uniformisation**

**With Uniformisation**

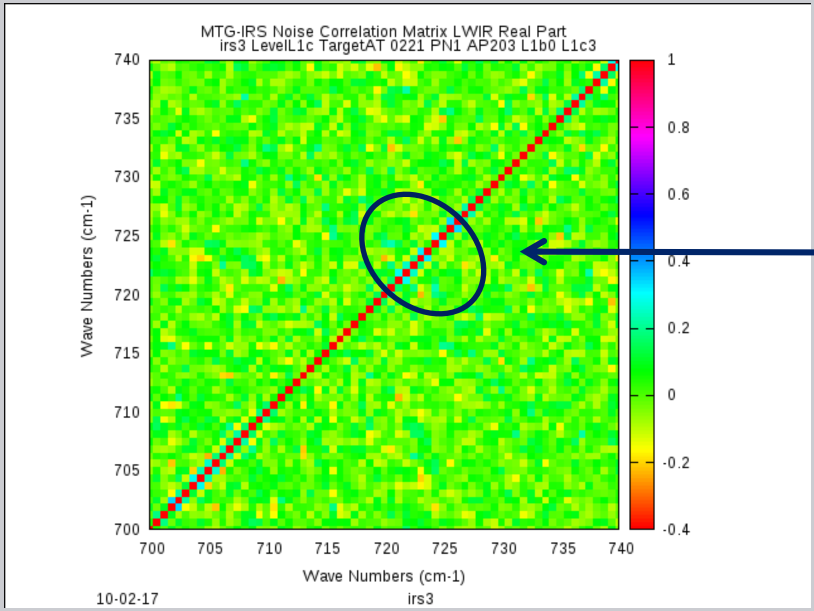


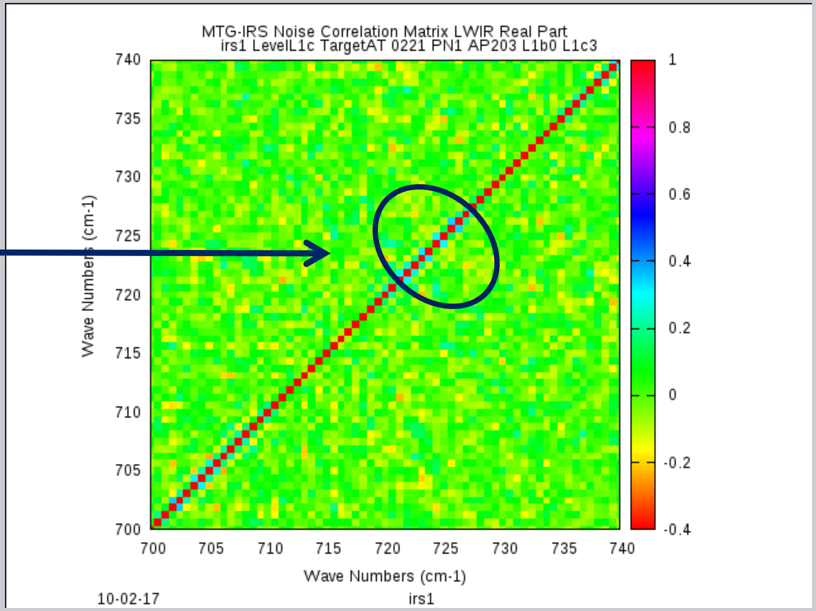



# 4-c) Impact on the noise correlation

Effect of the **uniformisation** on the noise correlation

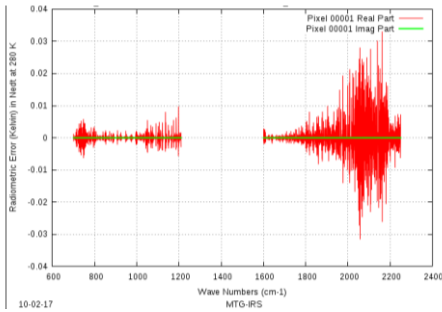
| Without shape removal | With shape removal |
|---|---|




Uniformisation = No impact on the noise correlation

# 4-c) Situation for the users regarding the SRF

<table>
<tr><th></th><th>Simulated error to be corrected</th><th>Residual error after uniformisation</th></tr>
<tr><td>ILS (corner-center pixel)</td><td>


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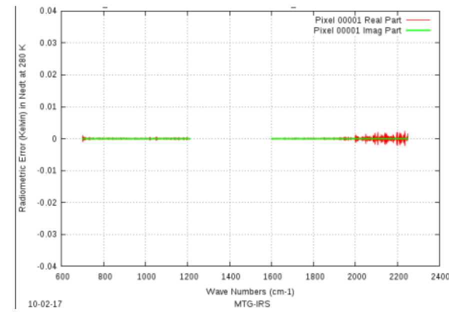
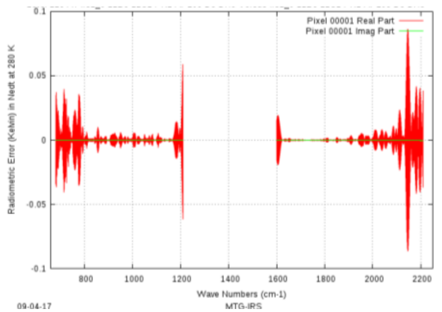
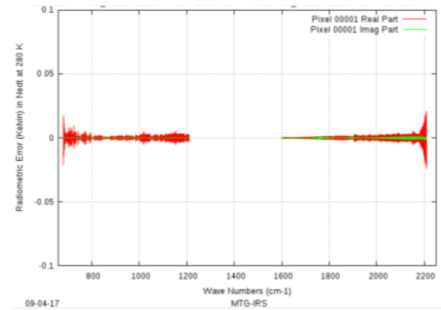


</td></tr>
<tr><td>Radiometric response (EUM5-Flat)</td><td>


</td><td>
+


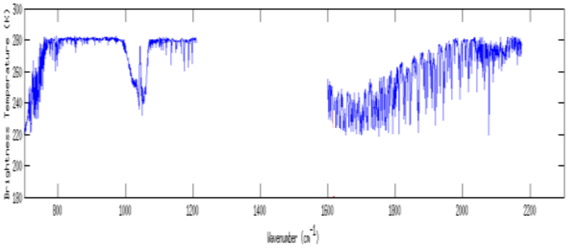
</td></tr>
<tr><td>➡</td><td>
= noise for 1 pixel by 25600 pixels<br>
= 256000 SRF to be updated regularly


</td><td>
= = <u>Negligeable noise</u> for all pixels, and no evolution in time

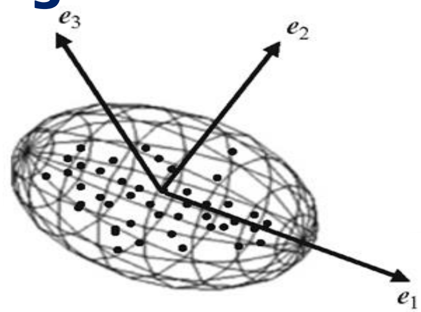
</td></tr>
</table>

# 5) PC compression

**IRS L1b spectrum**



**eigenvectors**




**PCS** — **Atmospheric signal**
*+ noise*

**Residuals** — **Noise**

# Local

# Global

*... as with IASI*
*[MTG-SRD] DIS-14050*

**???**
**Raised at extraordinary IRS-MAG Feb'16**

# 5) PC compression

| | Global | Local |
|---|---|---|
| **Data Producer** | Eigenvectors (EV) monitored and maintained off-line | Extra on-line computations: EV-decomposition for each dwell |
| **User** | Static EV basis | New EV basis / dwell |
| | (PCS + quality indicators)/pix | (PCS + quality indicators)/pix + EV/dwell |
| | Less noise in leading PCs<br>Weak signal distinguished from noise | More noise in leading PCs<br>Less noise/signal separation |
| | New features not retained in PCS<br>➔ EV basis update may be required | All local "strong enough" signals retained in leading scores |

**Experience from IASI operational (Global)**

- ✓ **Last update in 2011**, included rare AC signatures (peat fires, Russia, Summer 2010)
- ✓ **Thermodynamic signal** preserved:
  - + In-house inspections
  - + "IASI PC compression – **Searching for signal in the residuals**", T. Hultberg *ECMWF/EUMETSAT NWP-SAF Workshop on efficient representation of hyperspectral infrared satellite observations*
  - + Assimilation experiments at ECMWF using **operational static IASI eigenvector** basis

# Conclusion

✓ **SRF**

✓ Improvements regarding the size of the ILS has been chosen with the use of a light apodisation ⟷ Spectral cross-talk of the ILS covers ~10 $cm^{-1}$ and the light apodisation does not reduce the first lobes.

→ Constrain for the users regarding the RTM ? And Retrievals ?

✓ No stronger apodisation could be chosen because of the mission requirement on the spectral resolution of 0.754 $cm^{-1}$.

→ Constrain for the users regarding the retrievals ?

✓ The uniformisation is currently not in the baseline of the IRS level 1 processing ⟷ Thousands SRF need to be taken into account in the Radiative Transfer Models at first place + regular updates.

→ Constrain for the users regarding the RTM ?

✓ **PCs**

✓ Global approach (IASI type): No EV update, less noise → capture all signals even the weak ones below the signal noise. New singular signal could be missed.

✓ Regional approach: EV disseminated at each dwell, more noise and different for each dwell, good to see singular signal but not the weak ones.

→ What is the preferred solution for the users ?

# Thank you for your attention !

**Current baseline**

**LAC**

| | |
|---|---|
| every 30 min | 4 |
| every 4h00 min<br>5 times every 30 min | 3 |
| every 4h30 min<br>4 times every 30 min | 2 |
| every 5h00 min<br>3 times every 30 min | 1 |

**Earth Views only**