The FORUM Mission Calibration Concept | Metrology for Climate Action 26-20 September 2022

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FORUM Mission

The main science objective of the FORUM mission is the evaluation of the role of the far-infrared in shaping the current climate and thus reducing uncertainty in predictions of future climate change.

Key to these objectives is the capability to provide a highly accurate global dataset of FIR radiances (0.1 K at 3σ), traceable to SI in orbit, to validate present-day climate in climate models and to validate Numerical Weather Prediction models.Previous satellites have not provided the spectral detail necessary to test the understanding of key physical processes in the energetically significant far-infrared. FORUM will provide these observations for the first time. Such measurements are key for understanding exactly how Earth currently cools to space, and, critically, how it responds to both natural and anthropogenic change.

FORUM Spacecraft

Programme: ESA Earth Explorer (EE9)

Measurements: Earth's top-of-atmosphere **emission spectrum in the 100 to 1600 cm^{-1}** spectral region

Orbit: 830 km SSO. Loose Formation with MetOp-SG A1

Launcher: VEGA C (dual passenger)

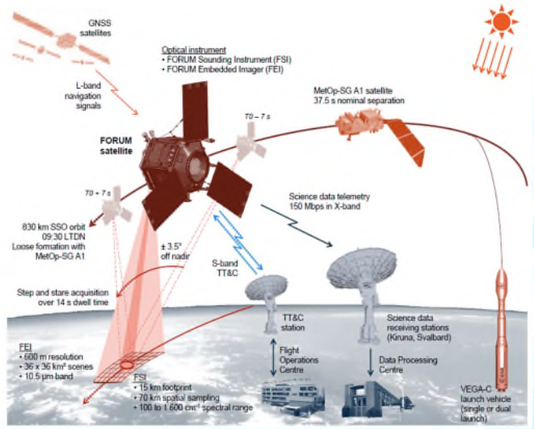
Platform: S5p-like mechanical platform with AstroBus-NG avionics

Instrument: Fourier Transform Spectrometer and Thermal Imager

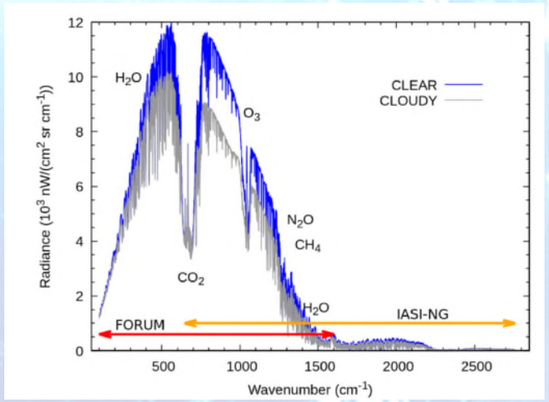
Mass: 883 kg

Power: 639 W

Lifetime: 6 years



FORUM Mission Architecture



FORUM Spectral Range

FORUM Instrument

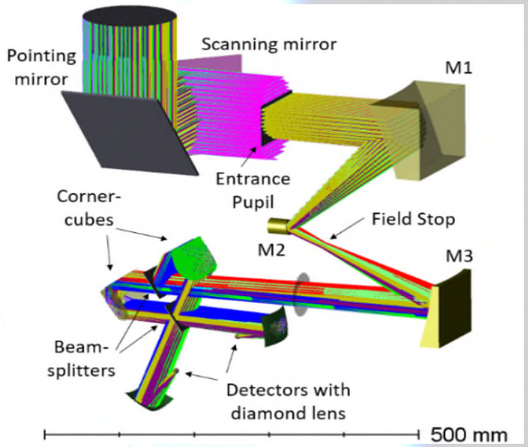
The FORUM payload consists of two instruments. The FORUM Sounding Instrument (FSI) and the FORUM Embedded Imager (FEI).

The FSI is the primary instrument based on a Fourier Transform Spectrometer that scans the Earth atmosphere in the step-and-stare mode with the following characteristics:

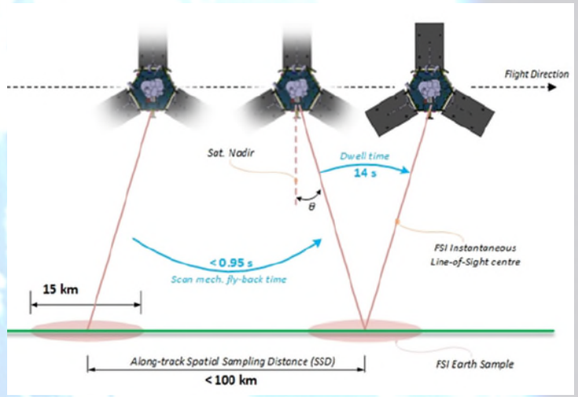
- Ground sampling: 15 km diameter
- Ground sampling distance: 100 km
- Sample geolocation knowledge: 1 km
- Sample staring time: 14 s

The FSI has demanding performance requirements:

- Measured scene temperatures: 180 K - 310 K
- Absolute radiometric accuracy: 0.1 K - 1.0 K
- Spectral coverage: 100 - 1600 cm-1
- Spectral resolution: 0.5 cm-1
- Spectral accuracy:: 1 ppm
- NESR (Noise-Equivalent Spectral Radiance): from 0.4 mW/(m2 sr cm-1) depending on spectral range



Optical Layout of the FSI



FSI Scanning Geometry

Calibration Concept

The demanding performance requirements necessitate a complex calibration approach both on-ground and in-flight. The on-ground FORUM calibration is based on thorough characterisation of the sub-systems and the assembled instrument during test. In-flight geometric, spectral and radiometric calibration is performed.

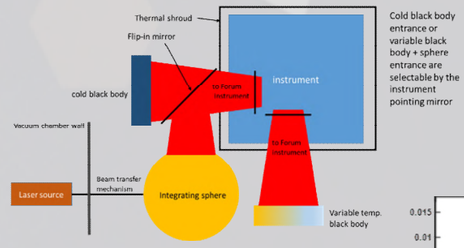
On-ground calibration and characterisation

The testing will be done in ambient and vacuum conditions addressing:

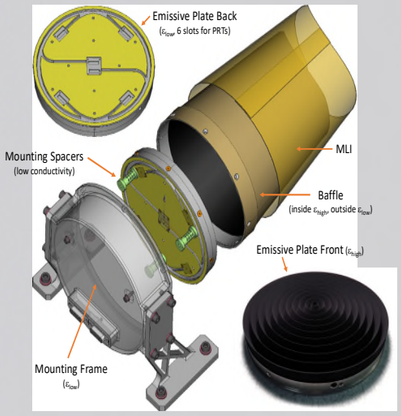
- **Geometric Performance (ambient test)** - Instrument Line of Sight (LOS), FSI Integrated Energy and Energy Distribution Function, FEI Modulation Transfer Function, In-field and out-of-field Straylight Characteristics
- **Spectral Performance (vacuum test)** - (Spectral Resolution, Spectral Accuracy, ISRF FWHM, ISRF Shape Error)
- **Radiometric Performance (vacuum test)** - Instrument NESR and NEdT, Radiometric accuracy, Dynamic Range, Response linearity
- **Thermal (vacuum test)** - Short and medium term stability/repeatability, Temperature sensitivity of radiometric, spectral and spatial performance.

Thermal Vacuum Chamber testing is the most representative as it can simulate vacuum and thermal environment. A special ground support equipment (GSE) will be developed for the purpose. The complete FOV and pupil will be illuminated with two precision blackbodies for the radiometric calibration and characterisation.

One blackbody is at liquid Nitrogen temperature and simulates cold space. The other is adjustable in temperature and simulates scene radiances. In addition, a smaller cold blackbody for the interferometer second input port is required. The blackbodies will have high emissivity (order of 0.999), high temperature measurement accuracy, and be traceable to reference calibration standards. This will ensure reliable and justified verification of radiometric performances as well as additional verification of the on-board calibration blackbody and in-flight calibration concept.



Sketch of vacuum configurations



Blackbody Configuration

In-flight calibration and characterisation

Geometrical calibration

The pointing performance comprises pointing accuracy, stability knowledge and co-registration.

The driver for pointing accuracy is the FSI to FEI co-registration. The bias error from ground to orbit transition is calibrated by scanning the full Moon on the eclipse side of the orbit.

For absolute LOS determination, the Moon signal will be correlated with the platform orientation and the pointing mirror and scan mirror position at that instance in time.

The FEI will record the same moon transitions simultaneously and with high resolution (about 25 pixels across the moon diameter). This will allow precise determination of the image CoG and thus co-registration with the FSI.

Spectral calibration

Spectral calibration is based on the approach implemented in MTG-IRS developed by Micos. A special apodization is applied to remove the blackbody component of the Earth radiance and limit the ISRF sidelobes to reveal atmospheric invariants when observing the North Atlantic.

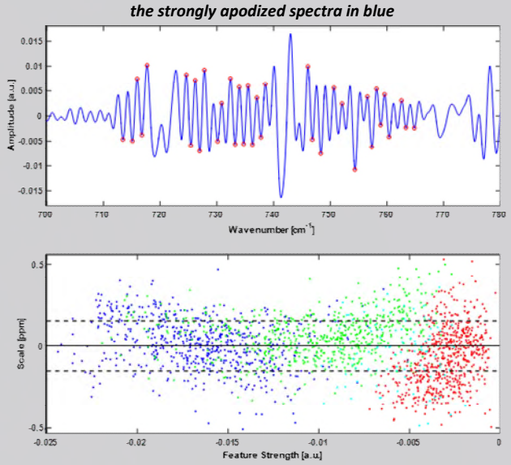
For a single pixel centered on the FOV, a single scale factor is required. The chosen invariant is the one of CO_2 absorption in the upper atmosphere in the band of 720 to 780 cm^{-1}. Other sources of errors are the noise and spatial non-uniformity, highly reduced by averaging acquired spectra in the area of interest over one month. Using the imager information, highly non-uniform cases will be discarded. This long averaging time is possible because only slowly varying effects are impacting the spectral accuracy: the dominant source will be the drift of the laser wavelength (5 ppm at EoL) and with much lower impact, the optical axis angle drift (reference and science beams). Orbital changes will be low and included in the budget but not monitored or corrected. The acquired spectra is modified to match the FORUM resolution.

Radiometric calibration

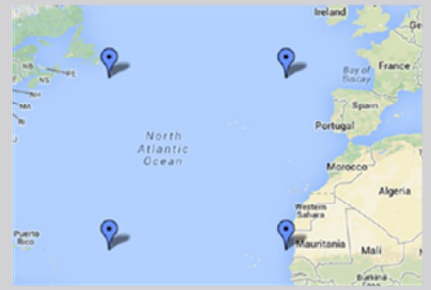
Radiometric calibration includes the complete optical chain, full aperture and FOV. The calibrations are performed after 12 science acquisitions and consist of 3 Blackbody and 3 Cold Space observations, resulting in 27 radiometric events per orbit. 389 radiometric events will occur per day. Several orbits can be used in exclusive radiometric mode to collect the necessary number of reference spectra.

The internal blackbody of FORUM is the key component to perform the radiometric calibration. It is used in conjunction with deep-space views (equivalent to a zero-radiance blackbody). The blackbody shall provide a uniform and known radiance with a very high level of accuracy. Therefore, high effective emissivity and accurate emitting surface temperature knowledge is needed. A free-floating blackbody has been chosen because the full instrument is fully thermally regulated.

Selected spectral features in red on the strongly apodized spectra in blue



Invariant deviation for 600 representative Nadir spectra (no-clouds in blue, 1km opaque cloud in greed, 4km opaque cloud in red)



Spectral Calibration Area: 18 to 54 deg West and 18 to 45 deg North.