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and

The FORUM Science Team and Mission Advisory Group

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Tropical & Arctic Top-of-Atmosphere Emission Spectra

![Graph showing emission spectra for different temperatures and gases.]

- Far-Infrared
- Mid-Infrared

Radiance (mW/m²/sr/cm⁻¹)

Wavenumber (cm⁻¹)

300 K, 280 K, 260 K, 240 K, 220 K

Gases:
- CO₂
- H₂O
- O₃

Regions:
- Tropics
- Arctic

“Window” regions in the spectrum.
• FORUM is a new space flight mission announced 9/2019 by the European Space Agency as its 9th Explorer Mission

• FORUM directly measures the previously unobserved far-infrared wavelengths longer than 15.5 μm (650 cm⁻¹)

• FORUM mission consists of a Fourier Transform Spectrometer (FTS) for measuring the infrared spectrum and an imager for scene identification

• FORUM will fly in approximate formation with one of the METOP satellites and will have close synergy with IASI

• Launch is ~ 2025/26
FORUM Background

• FORUM is the culmination of a 20-year international quest to achieve direct measurement of the far-IR from space

• Multiple teams developed ground, aircraft, and balloon-borne instruments to demonstrate science need and technology for measuring the far-IR

• These include:
  • Tropospheric Airborne FTS (TAFTS) – Imperial College, UK
  • Radiation Explorer in the Far-InfraRed (REFIR) – Italy
  • Far-Infrared Spectroscopy of the Troposphere (FIRST) – NASA
  • Atmospheric Emitted Radiation Interferometer (AERI Extended) – U. Wisconsin

• A number of aircraft flights, balloon flights, and ground campaigns since late 1990’s

• In addition, spectroscopy of the far-IR, the water vapor continuum, has been and continues as a forefront of scientific inquiry
Measured Top-of-Atmosphere IR Spectrum

Mlynczak et al., GRL, 2006

Ft. Sumner, NM

T surface = 320 K (116 F)
T air = 308 K (95 F)
FORUM Mission Advisory Group (MAG)

- Helen Brindley – Imperial College, London
- Stefan Buhler – University of Hamburg
- Dorothee Coppens – EUMETSAT
- Adrien Deschamps – CNES
- Steven DeWitte - RMIB
- Bianca Maria Dinelli – ISAC-CNR
- Laurent Labonnote – University of Lille
- Quentin Libois – Meteo France
- Marty Mlynczak – NASA Langley Research Center
- Luca Palchetti – CNR National Institute of Optics
- Marco Ridolfi – University of Bologna
- Martin Riese – Forschungszentrum Jülich
- Roger Saunders – UK Met Office
Why is the Far-IR so special?

Over the observed range of Earth’s surface temperature and atmosphere, the peak energetic emission is in the far-infrared!
Why is the Far-Infrared so special?

Consistent with the TOA spectra, the Global OLR is dominated by the Far-IR

Fraction of OLR in the Far-IR

Collins and Mlynczak, 2001
Why is the Far-Infrared so special? – Greenhouse Effect

Contribution to atmospheric trapping:

Absorption in the far-infrared contributes ~50% to the total clear-sky Greenhouse Effect, $G_v$.
Importance of the Far-IR: Infrared Radiative Cooling Rate

Impact throughout the atmosphere:

Dominant contribution to clear-sky atmospheric radiative cooling also located within the far-infrared: key driver of atmospheric dynamics
FORUM: A true explorer

Research Objective

• to evaluate the role of the far-infrared in shaping the current climate and thus reduce uncertainty in predictions of future climate change

by

• building a highly accurate global dataset of far-infrared radiances for validation of the present-day state as captured by Earth system models
• using these measurements to understand and constrain the processes that control far-infrared radiative transfer and hence the Earth’s Greenhouse Effect
• updating the parametrisations of these processes for implementation in radiative transfer codes, and ultimately in Earth system models
• characterising critical feedback mechanisms

Additional benefit for ice cloud, surface emissivity and water vapour retrievals
Mission Concept: Footprint and Spatial Sampling

Nadir-looking observations

**Spectrometer footprint**
- single circular pixel $\varnothing = 15$ km

**Along-track sampling step**
**Goal** = 70 km, **Threshold** = 100 km

**Thermal imager footprint**
- 60x60 pixels, 36x36 km$^2$
- resolution = 0.6 km

**Lifetime** = at least 4 years to resolve seasonal & inter-annual variability

Flight in **loose formation with MetOp-SG-A1**
LEO, SSO at 9:30 LTDN – average altitude = 830 km to exploit synergy with IASI-NG
Radiometric accuracy is the difference between the true value and the measurement in absence of random errors.

**High accuracy is required at 3σ**
- to provide benchmark spectral observations against which climate models and future observations can be compared, which is the overarching goal of FORUM.
- to derive FIR surface emissivity with accuracy better than 0.01.
- to observe the effects of small perturbations in UTLS due to ENSO, QBO, etc. on zonal, monthly means.

**Goal** = 0.1 K in 300-1100 cm\(^{-1}\), 0.2 K in 200-300 cm\(^{-1}\) and 1100-1300 cm\(^{-1}\)
**Threshold** = 0.25 K in 200-1300 cm\(^{-1}\)
FORUM Summary

• FORUM is the 9th ESA Explorer Mission

• Selection announced 9/24/19 after a 1.5 year Phase A competition

• Instrument specifics pending ESA selection of Industry Partner/Vendor
  • ESA competes the flight instrument build separately from the science team
  • Two Industry teams competing – selection at end of 2020
  • FORUM’s Mission Advisory Group provided input on science and measurement requirements

• FORUM opens a new window on our understanding of the climate system

• Strong synergy with CERES
  • FORUM and CERES will have SNO’s in polar regions

• Launch NET 2025/26
Backup Slides
The missing link: Far-Infrared Spectra

- Broadband integrated radiation (ERBE, CERES, GERB, ScaRAB) since 1975
- Mid-IR spectra (5-15 um; AIRS, IASI, CrIS) continuous since 2002
- No science quality far-IR spectra from space (Nimbus-III and Nimbus-IV < 10 months)
- No observations < 400 cm$^{-1}$
- FORUM fills the critical gap!!
Goal = 0.4 mW/(m² sr cm⁻¹) in 200-800 cm⁻¹, 1 mW/(m² sr cm⁻¹) elsewhere
Threshold = 0.6 mW/(m² sr cm⁻¹) in 200-800 cm⁻¹, 2 mW/(m² sr cm⁻¹) elsewhere
The Greenhouse Effect: Sensitivity to water vapor in Far-IR

Signatures of changes in atmospheric water vapour:

A small increase in water vapour can induce a change in trapping equivalent to doubling CO₂.

Significant fraction in far infrared, especially if the perturbation occurs in the colder upper-troposphere.
Why the Far-Infrared?
FORUM Mission Objectives

Primary

- Measure the spectral distribution of the Earth’s OLR encompassing, for the first time, the far-ir
- Evaluate the underlying spectroscopy and cloud models currently employed in the far-ir
- Tie the observed radiative signatures directly to variability in, in particular, water vapour, greenhouse gases, cloud and surface properties
- Provide a stringent evaluation of key radiative processes/feedback mechanisms as currently represented in climate models

Additional

- Retrieval of FIR surface emissivity in appropriate conditions (clear-sky, dry conditions)
- Assessment of additional benefit of FIR spectral observations compared to state-of-the-art hyperspectral mid-infrared radiances for water vapour retrieval
- Detection of optically thin and sub-visual ice-cloud
- Retrieval of ice-cloud optical depth, cloud top height and particle size
Far-Infrared: Sensitivity to upper troposphere H$_2$O

Signatures of changes in atmospheric water vapour:

A small increase in water vapour can induce a change in trapping equivalent to doubling CO$_2$.

Significant fraction in far infrared, especially if the perturbation occurs in the colder upper-troposphere