The Radiation Explorer in the Far InfraRed prototype: technical overview and measurement performance

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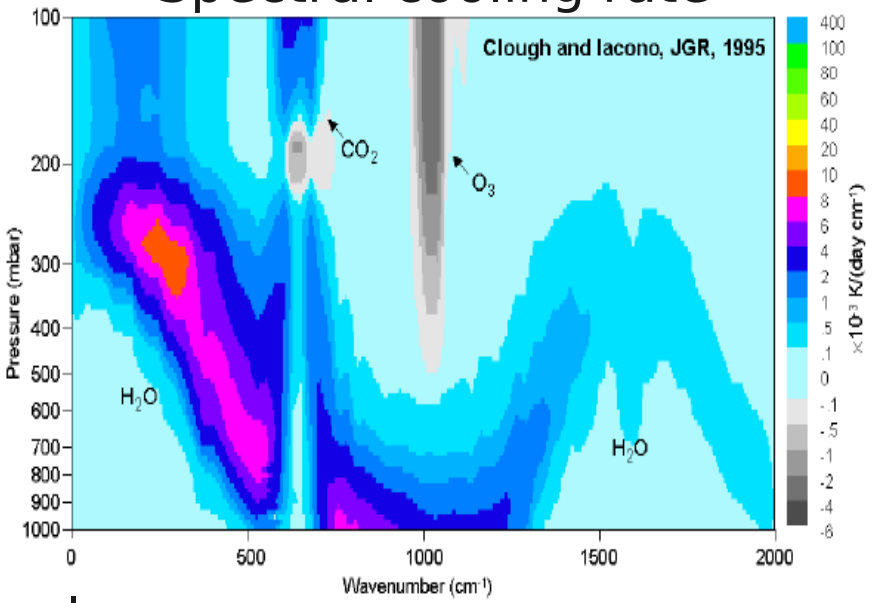
Importance of the FIR spectral region

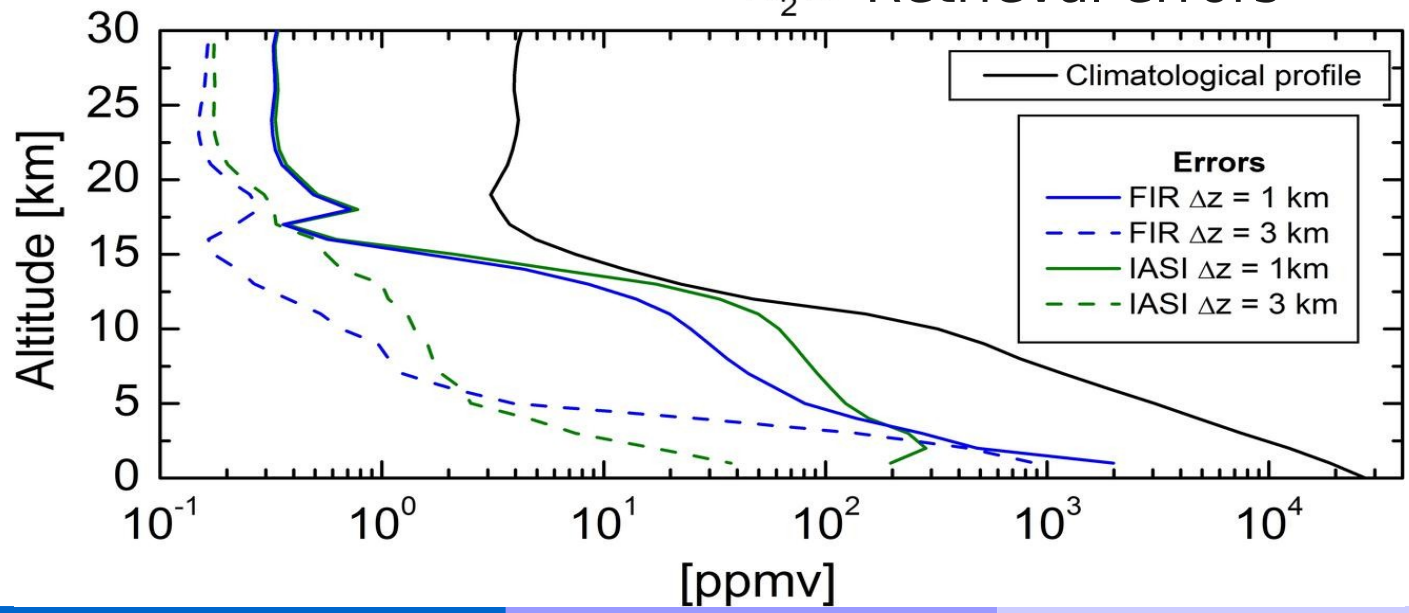
Water vapour and cirrus

- The FIR region can provide unique information on WV and cirrus clouds radiative effects with sensitivity to microphysics
- The FIR is strongly sensitive to mid-upper level tropospheric humidity that produces a peak in the cooling rate of the atmosphere

Spectral cooling rate



H_2O Retrieval errors



FORUM/EFTWVAC
ESA proposals

Historical overview
The REFIR project

Radiation Explorer in the Far InfraRed

Spectral characterization of the emitted radiance in the 100-1100 cm^{-1} range

- REFIR feasibility space mission, EU 1997-2000
- REFIR feasibility for Small Scientific Missions, ASI 1998-2001
- BB pre-development, ESA 2001-2003
  - ADGB-Dip. Fisica, Univ. Bologna, Italy PI Rolando Rizzi
  - Selex-Galileo, Campi Bisenzio, Italy
  - Blackett Laboratory, Dep. Physics, ICSTM, London, UK
  - CNRS-SNCMP, Toulouse, France
  - Space Science Dep., CCRLC-RAL, Chilton, UK
  - DIFA, Univ.Basilicata, Potenza, Italy
  - Dip. Fisica, Univ. La Sapienza, Roma, Italy

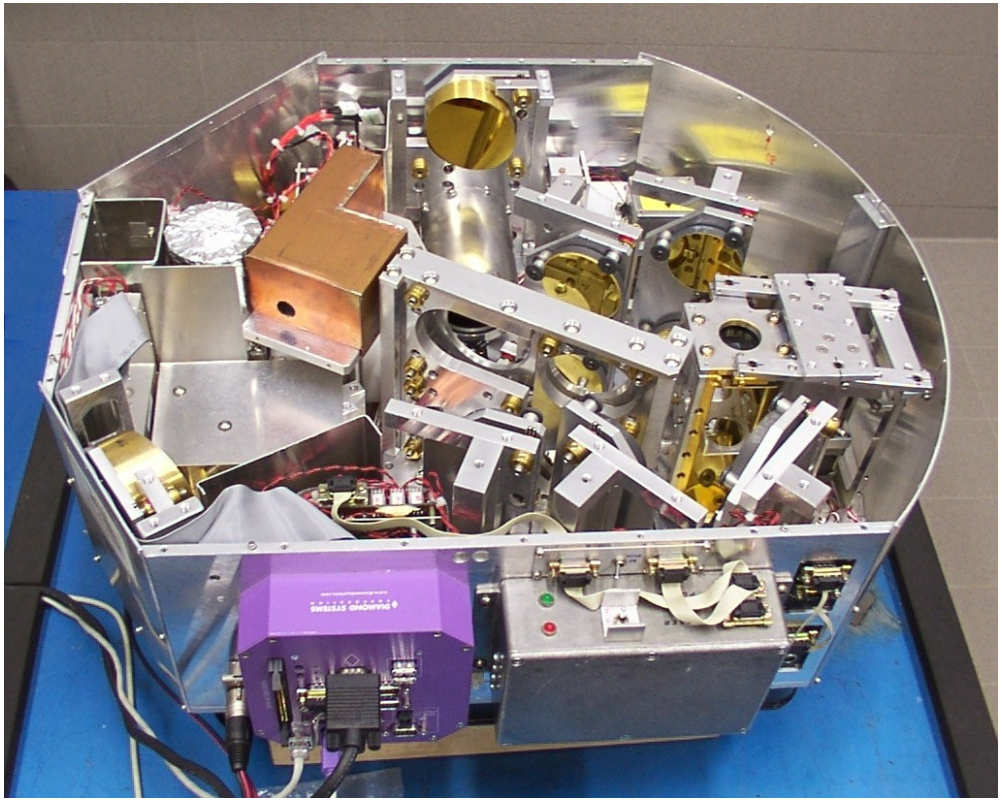
- REFIR-BB laboratory applications, UniBas, IFAC 2000-2001
- REFIR-PAD ground-based and stratospheric balloon, IFAC 2003-present
  - IFAC-CNR, Firenze, Italy
  - DIFA, Univ. Basilicata, Potenza, Italy
  - IMAA-CNR, Potenza, Italy
  - ADGB-Dip. Fisica, Univ. Bologna, Italy

- Recent proposals for space missions:
  - FORUM
  - EFTWVAC

The REFIR-PAD prototype

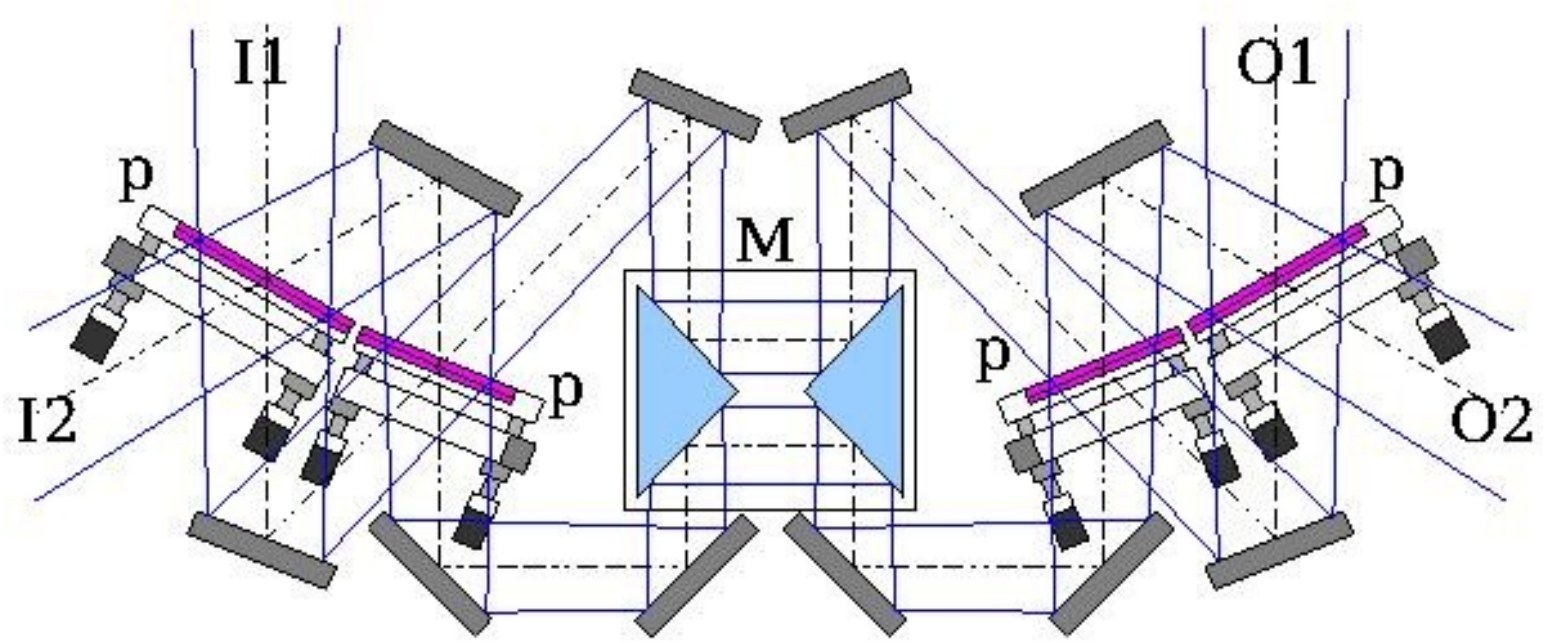
Radiation Explorer in the Far-InfraRed – Prototype for Applications and Development

- Developed in 2003-2004
- Fourier Transform Spectrometer
- Broadband Ge on PET beam splitters and DLATGS pyroelectric room-temperature detectors
  - Spectral coverage = 100-1400 cm^{-1},
  - Resolution 0.25 cm^{-1} max. double-sided
  - NESR in the range 0.8-2.5 $mW/(m^2\ sr\ cm^{-1})$ with 30 s. acquisition time
- Small Payload: 62 cm dia., 55 kg weight, 50 W avg power



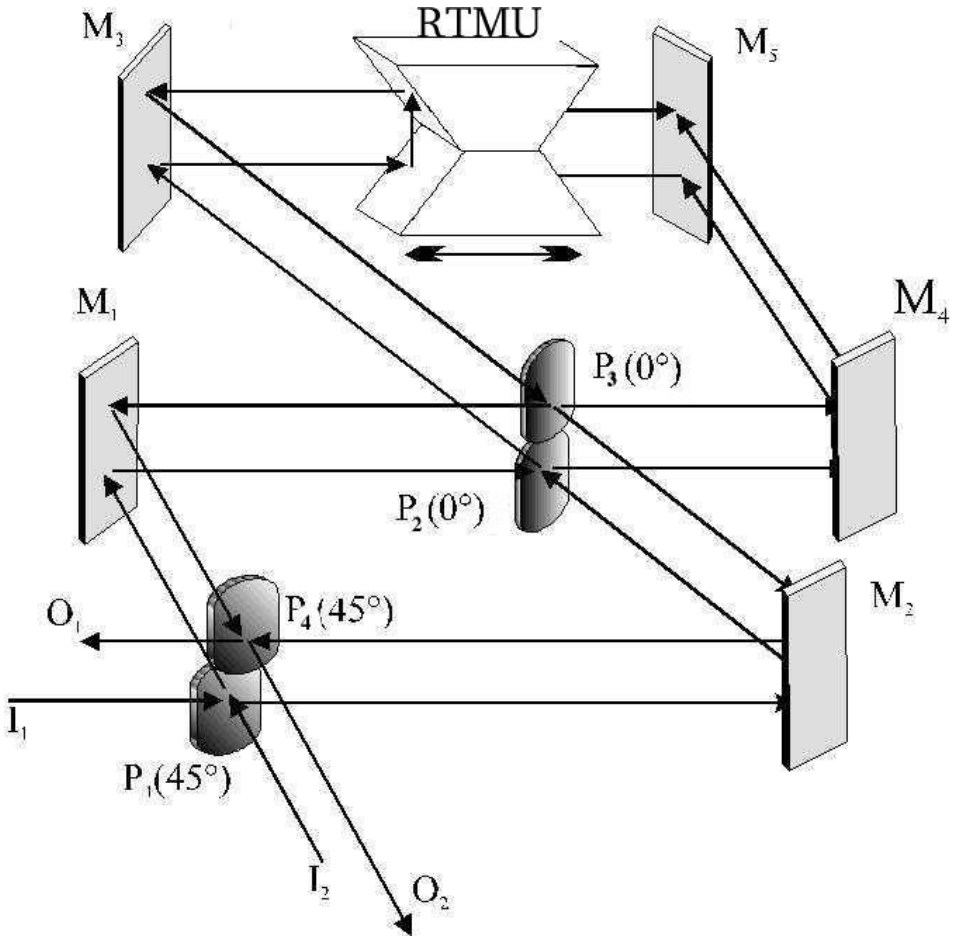
Optical configuration of interferometer

- 2 input / 2 output ports
- Martin-Puplett (polariser BSs) or Mach-Zehnder (amplitude BSs) interferometer
- Tilt and lateral shift compensation of moving mirrors
- 4x folding OPD



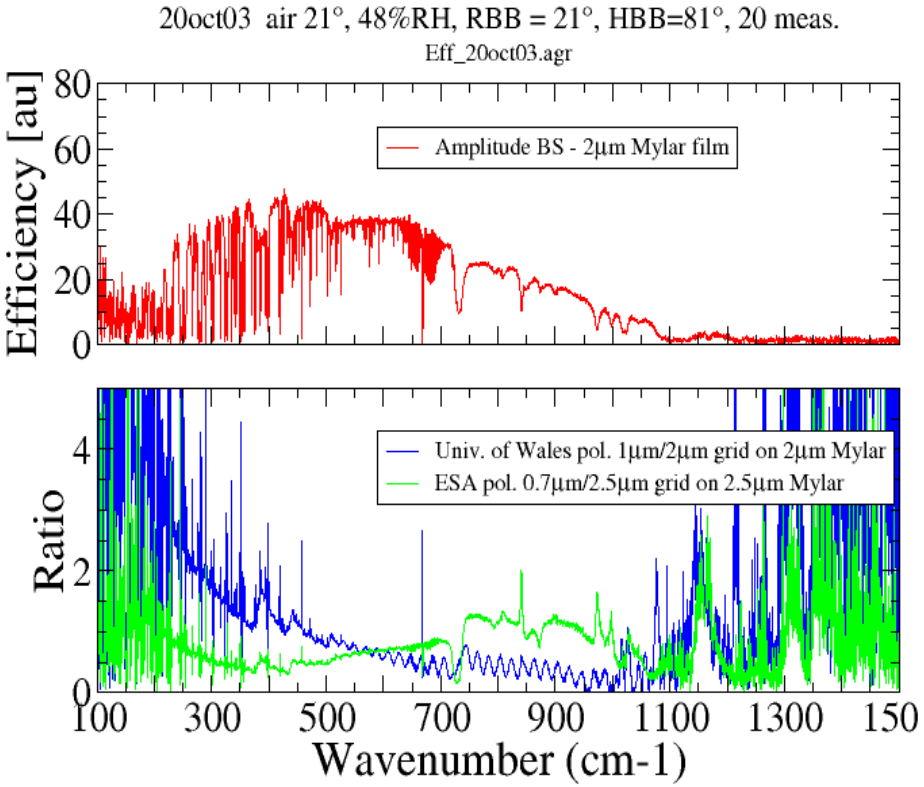
Two levels interferometer

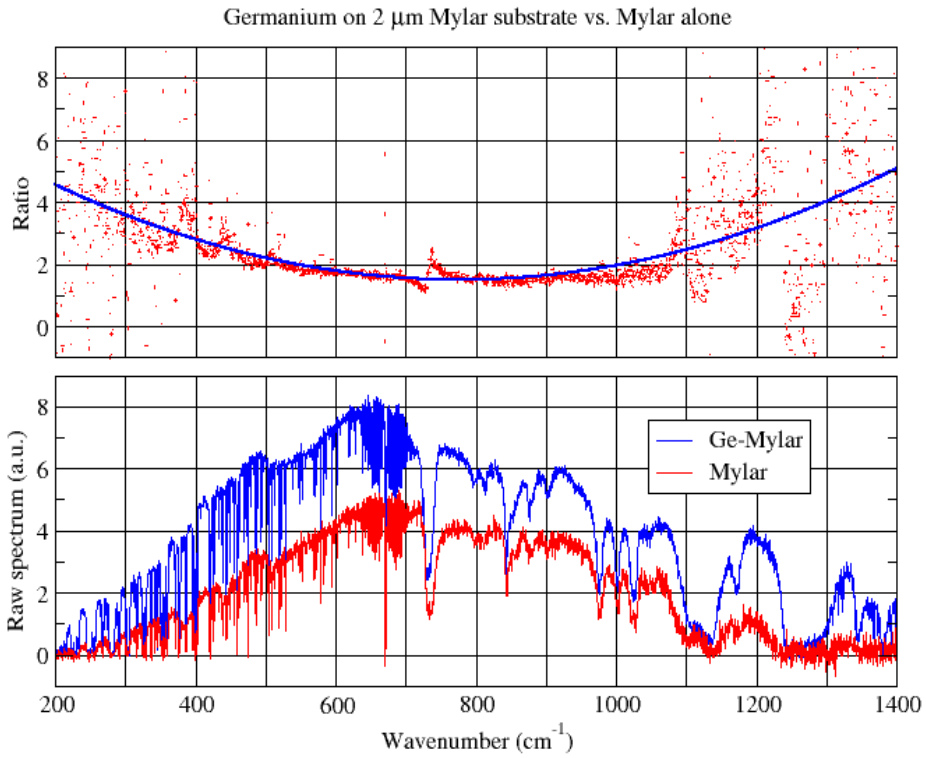
- Folding around the moving mirror to obtain two levels containing input ports (lower level) and output ports (upper level)
- Horizontal tilt compensation



Broadband Beam Splitters

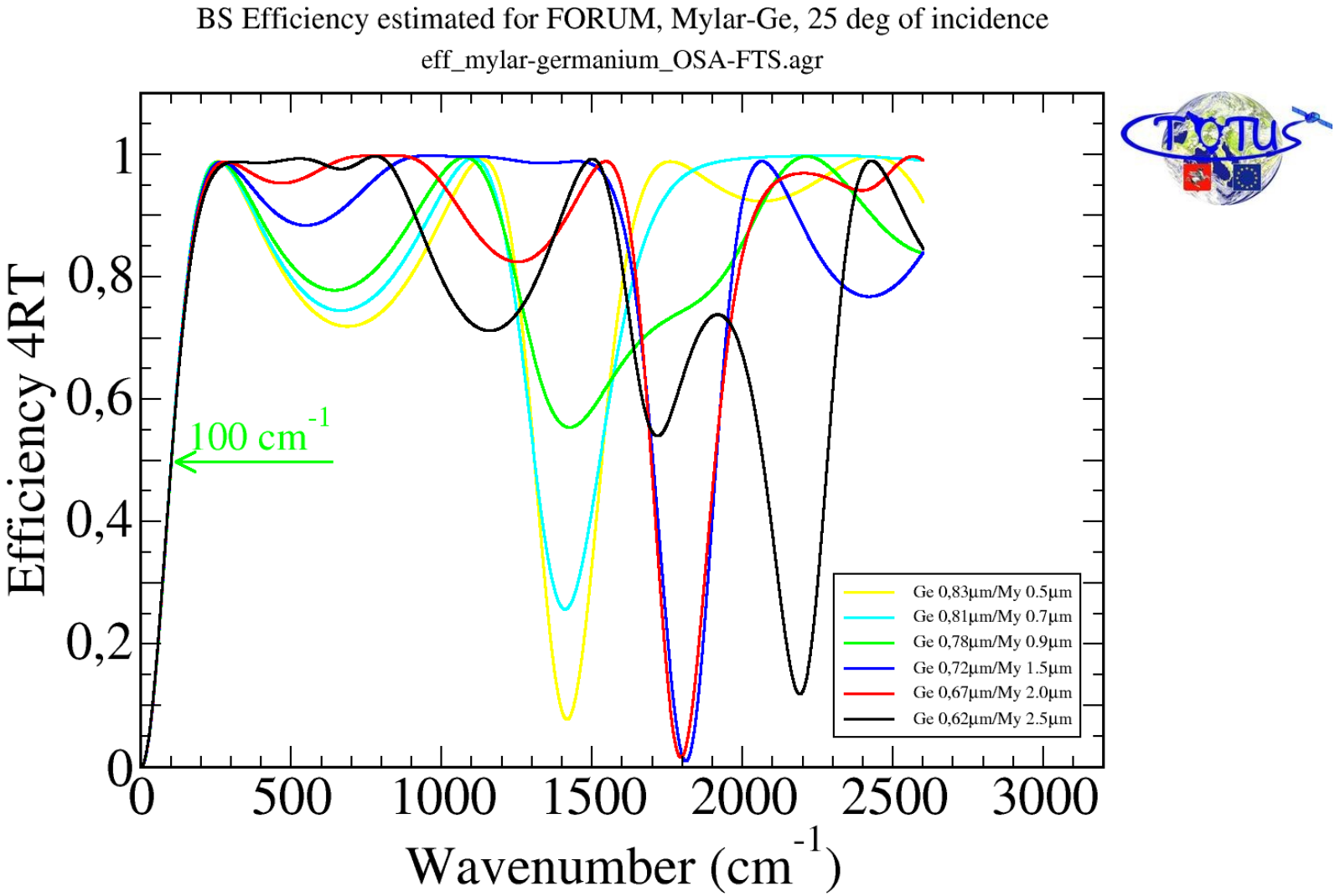
- Photolithographic wires on PET
- Single PET/PP layer
- Ge-PET/PP bilayer



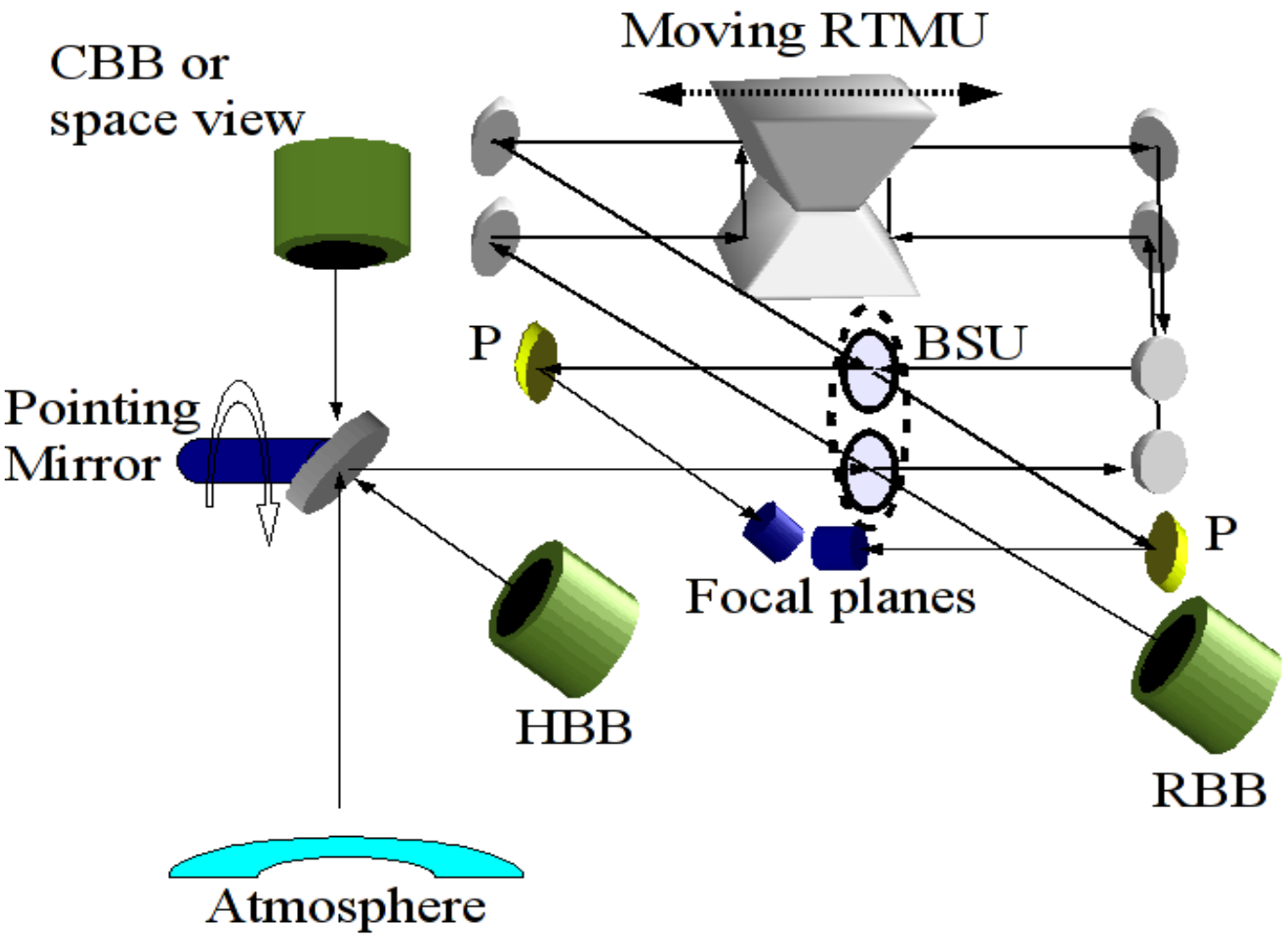


Wideband beam-splitters design

- Bilayer structures

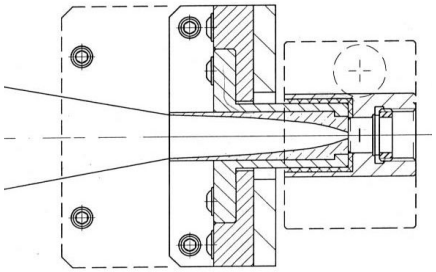


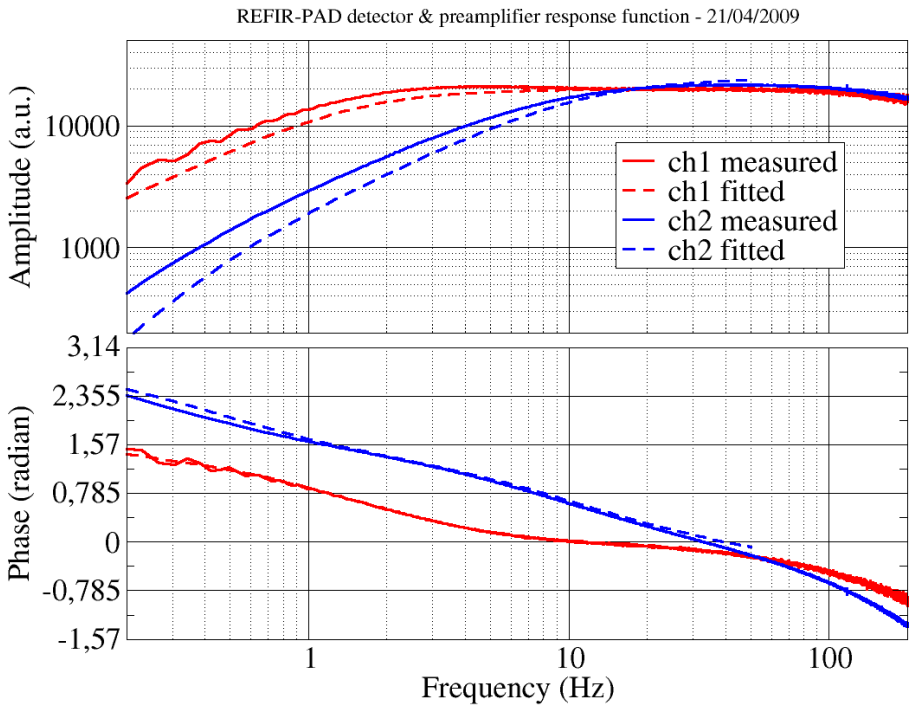
REFIR-PAD FTS optical layout



Interferogram Sampling

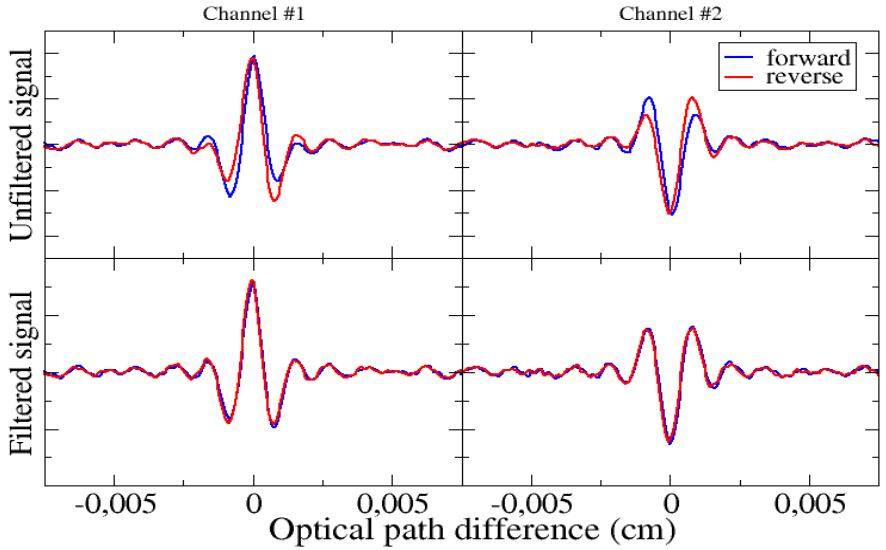
DLATGS pyroelectrics
Winston cones





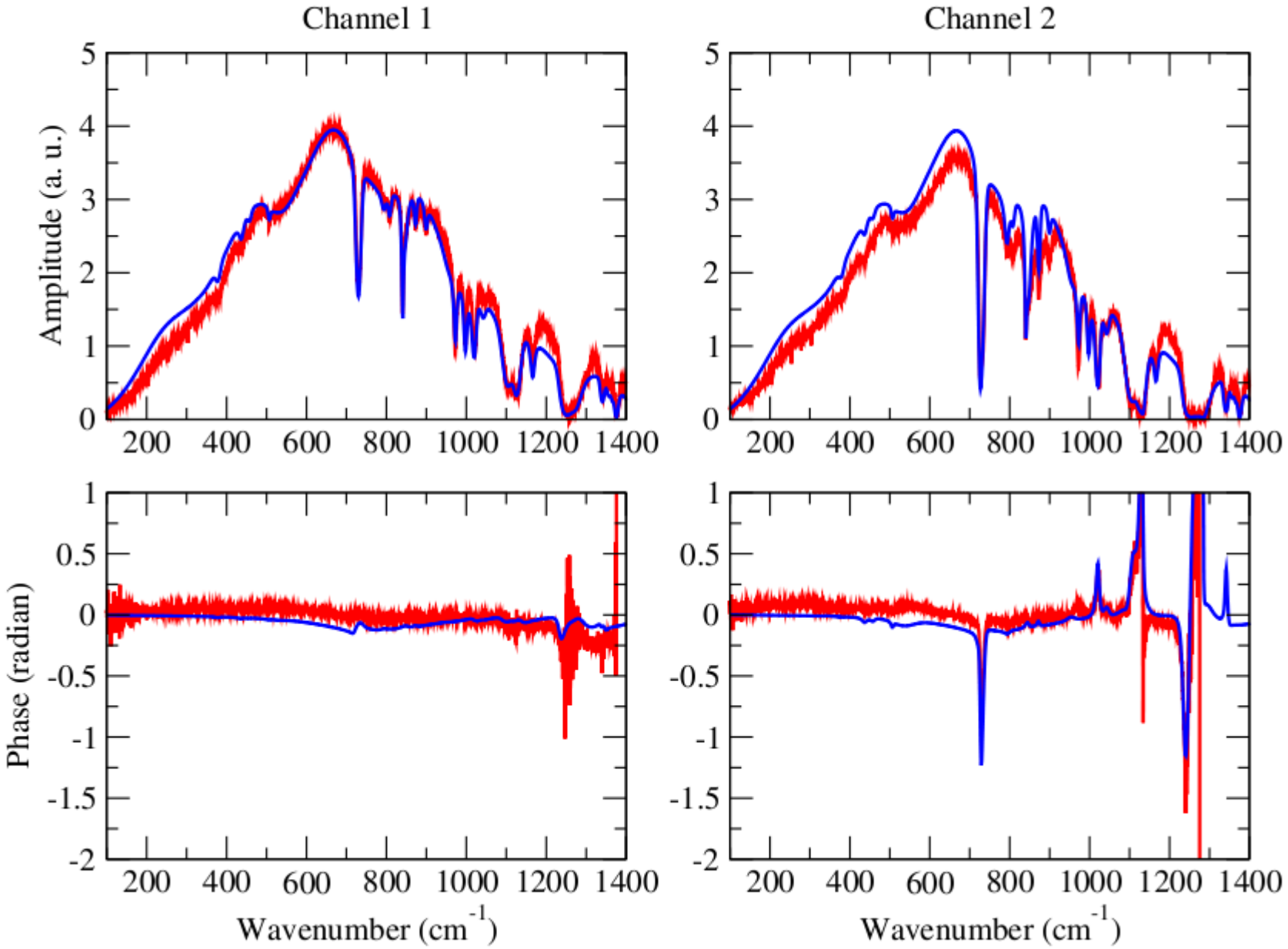
Equal Time Sampling

Filtering and Resampling

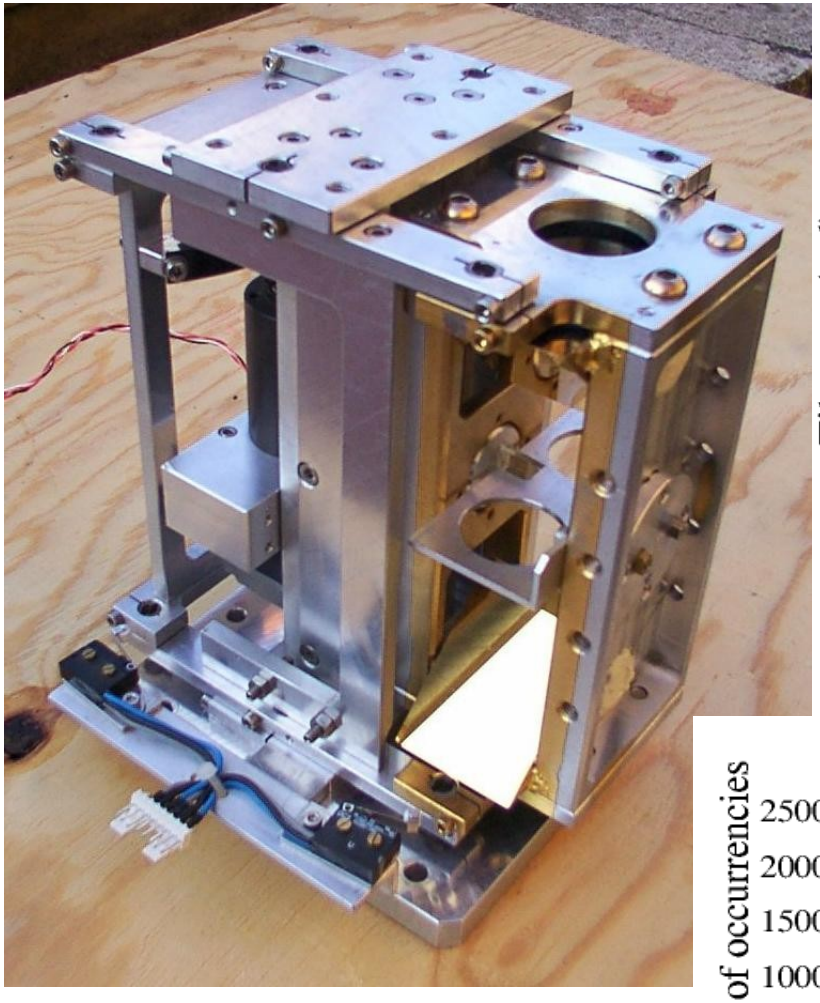


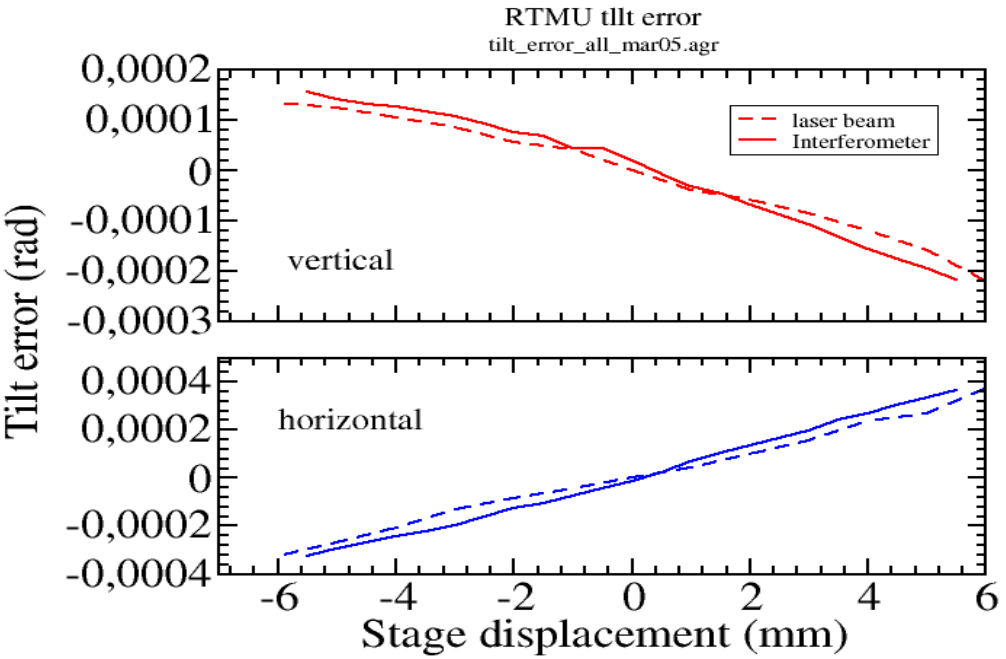
Uncalibrated Spectra

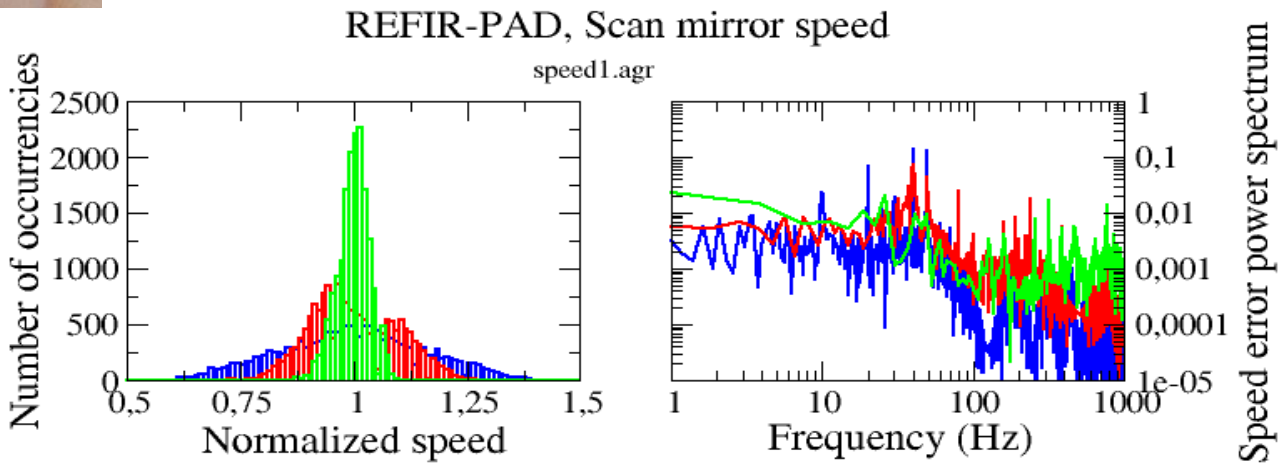
Hot blackbody source (T_M=347 K) T_R=302 K, T_{BS}=302 K



Scanning mirror performances







Radiometric calibration

- Uncalibrated complex spectrum S(σ) given by:

$$S(\sigma) = F1(\sigma)\,L(\sigma) - F2(\sigma)\,L_{RBB}(\sigma)$$

- Calibration with 2 views of reference sources: HBB,CBB. With L_{RBB} is constant we have:

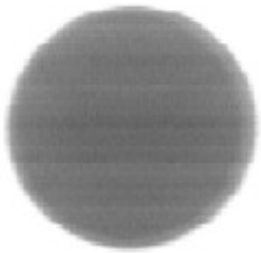
$$L(\sigma) = \mathbb{R}\left\{ \frac{S(\sigma) - S_{CBB}(\sigma)}{S_{HBB}(\sigma) - S_{CBB}(\sigma)} \cdot \left(L_{HBB}(\sigma) - L_{CBB}(\sigma)\right) + L_{CBB}(\sigma) \right\}$$

- The used optical layout allows the best way to have access to all the sources and with minimum phase errors

Black-body calibration sources

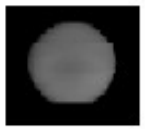
- RBB for reference input
- HBB/CBB for calibration
- Cylinder + cone cavity
- Xylan© coated surface
- Emissivity estim. ~ 0.99
- PT100 temperature meas.
- $\Delta T < 0.3$ K

Thermal images

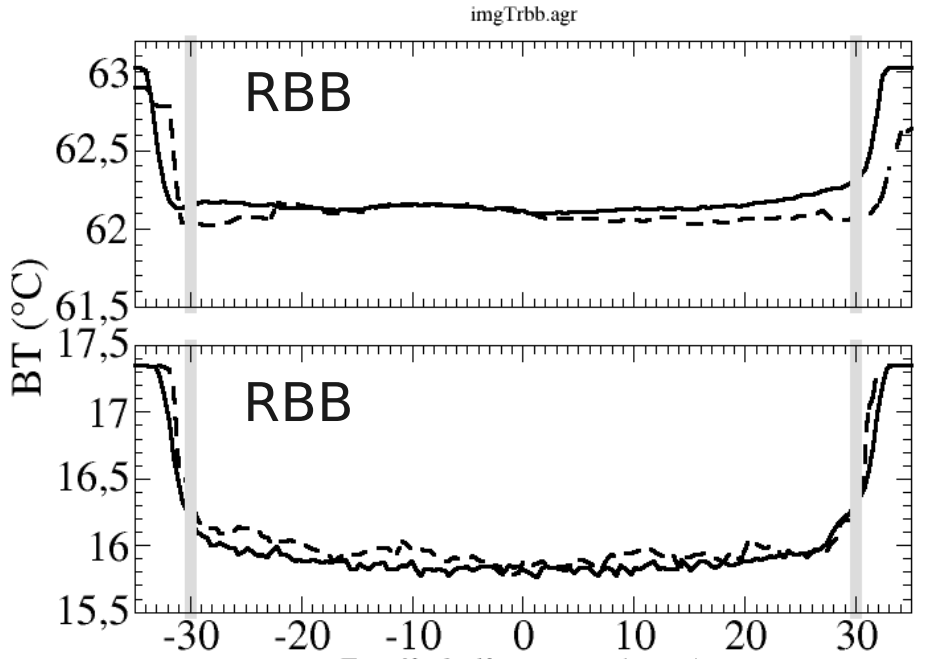


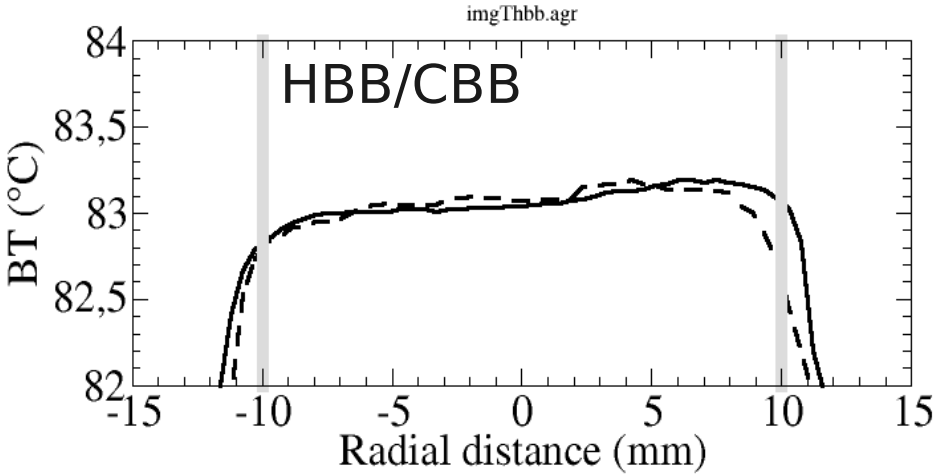
RBB cooled

RBB heated



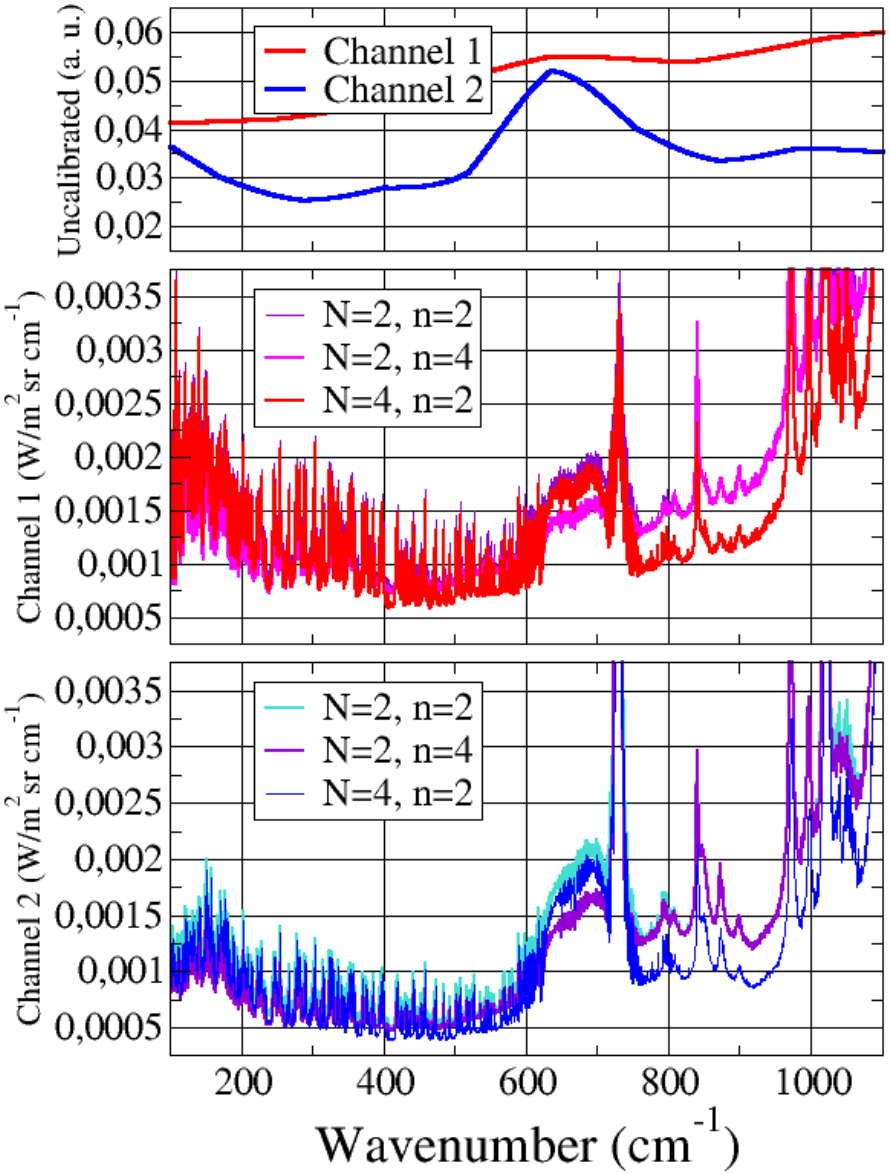
HBB/CBB heated





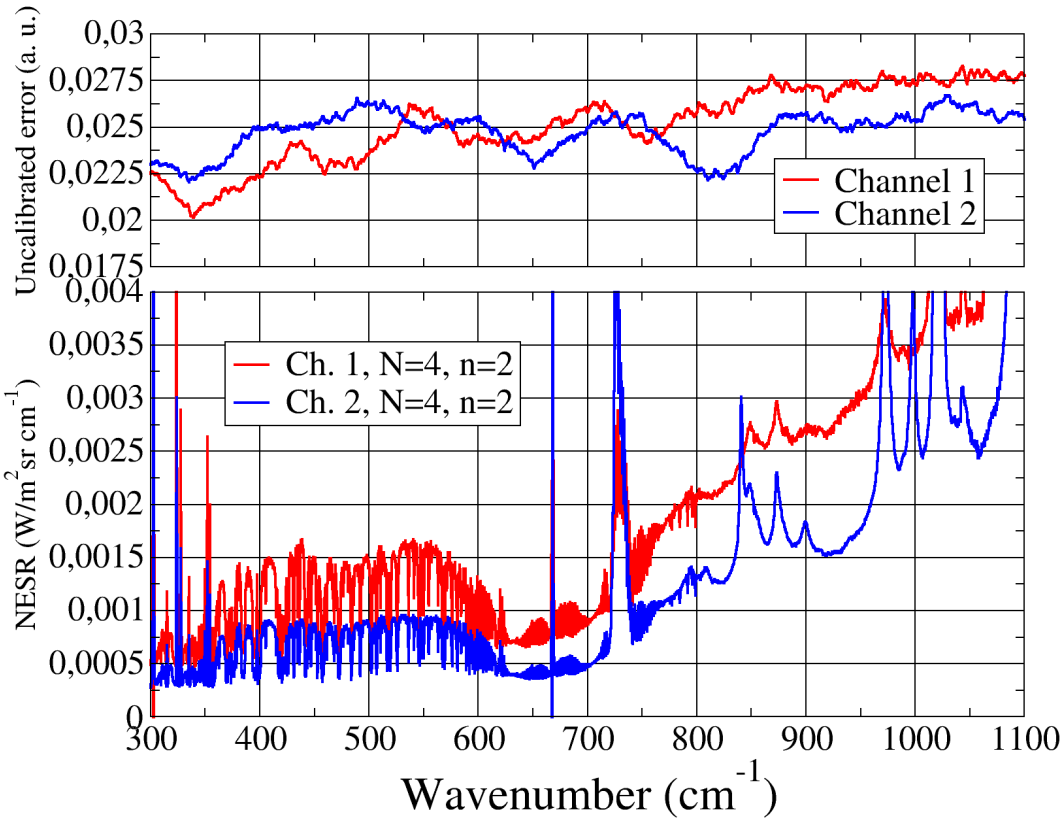
NERS

Nadir looking



$$NESR = \sqrt{\frac{1}{N} + \frac{2}{n}\left(\frac{S}{S_h - S_c}\right)^2}\,\frac{\Delta S}{F1}$$

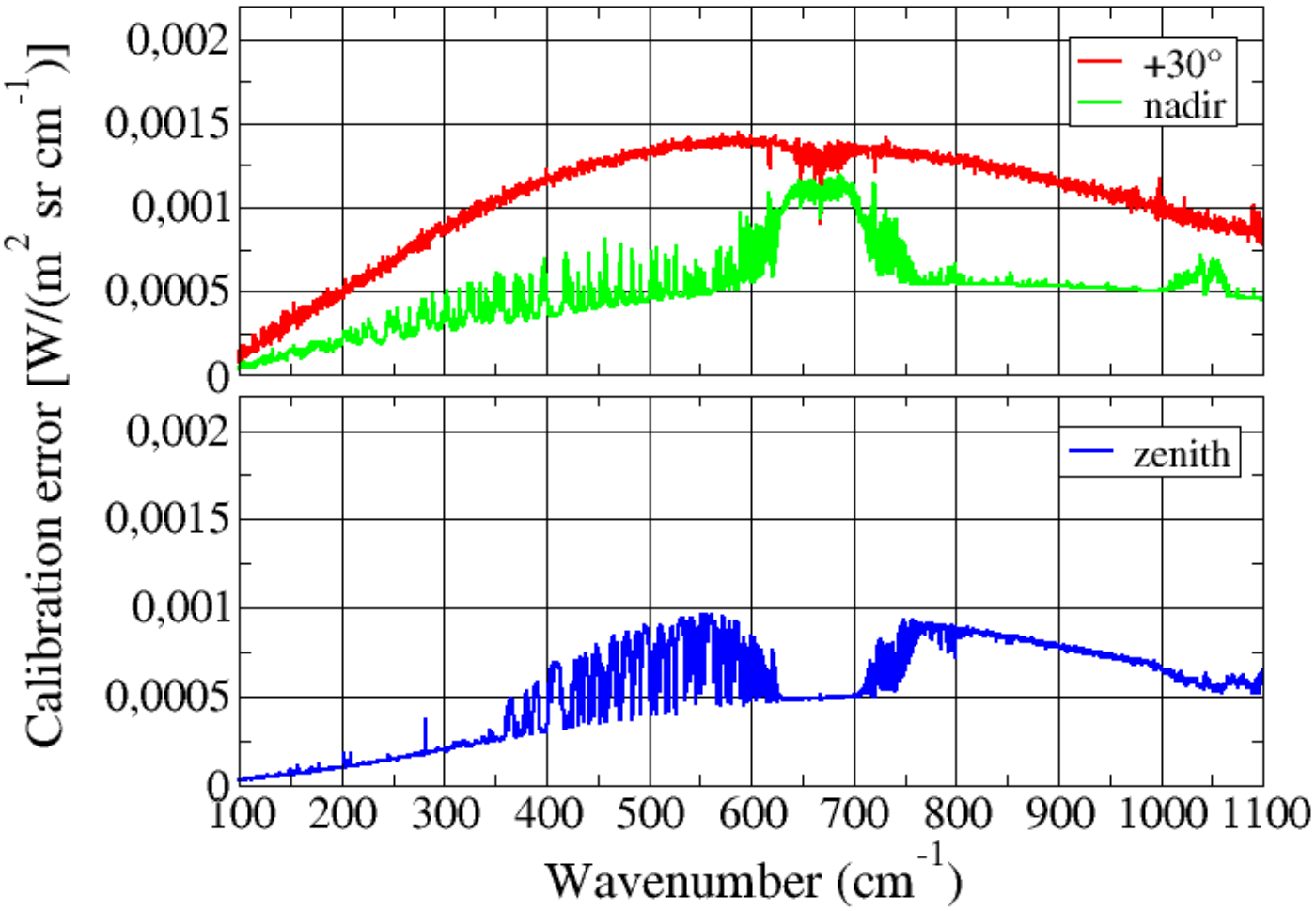
Zenith looking



Calibration Error

$$\Delta L = \sqrt{\Delta B_r^2 + \left(\frac{S}{S_h - S_c}\right)^2 (\Delta B_h^2 + \Delta B_c^2)}$$

Estimate with ΔT_{BB} = 0.3 K



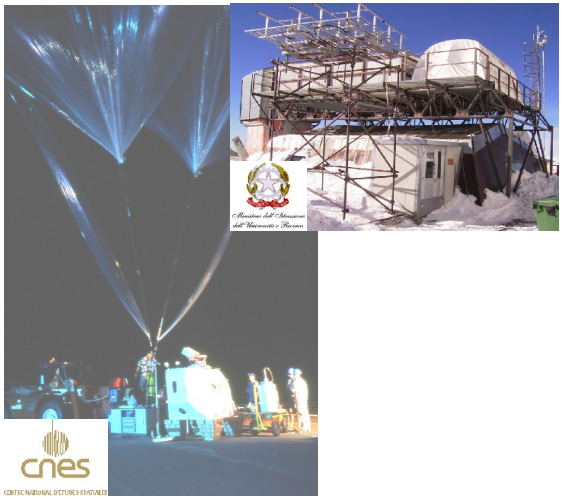
The REFIR-PAD Experiment

Balloon-borne and Ground-based Campaigns

TABLE 1. Data available from the measurement campaigns of REFIR-PAD

	Date	Time (UTC)	Meas. time (min)	Spectral band (cm^{-1})	Resol. (cm^{-1})
Teresina, Brazil *	30 June 2005	8:05–15:48	6.4	100–1100	0.475
Monte Morello, Italy †	6 February 2006	16:26–17:58	5.1	350–850	0.5
Monte Gomito, Italy **	13 March 2006	16:20–9:30 (+1 d)	6.1/9.9	350–1100	0.5
Testa Grigia, Italy ‡	4 March 2007	19:20–23:39	5.1	240–1400	0.5
	5 March 2007	17:54–0:43 (+1 d)			
	9 March 2007	7:25–13:53			
	11 March 2007	16:22–2:06 (+1 d)			
	12 March 2007	8:44–15:45			
	12 March 2007	17:55–23:02			
	13 March 2007	9:15–14:03			
	13 March 2007	18:21–8:04 (+1 d)			
Breuil-Cervinia, Italy§	15 March 2007	15:14–23:09	5.1	350–1400	0.5
Pagosa Springs, USA¶	22 April 2009	17:15–19:58	5.1	350–1400	0.5
	23 April 2009	22:24–23:21			
	24 April 2009	11:30–17:58			
	25 April 2009	12:33–18:23			
	27 April 2009	12:34–18:05			
	28 April 2009	14:09–17:59			
	29 April 2009	19:04–23:29			
Cerro Toco, Chile‖	from 21 August 2009 - - - 37 days - - - to 24 October 2009	-	5.1	100–1500	0.5

* OLR from balloon at 34 km, 5.078° S, 42.874° W
† DLR from ground at 610 m a.s.l., 43.844° N, 11.246° E
** DLR from ground at 1892 m a.s.l., 44.128° N, 10.644° E
‡ DLR from ground at 3480 m a.s.l., 45.933° N, 7.7° E
§ DLR from ground at 1990 m a.s.l., 45.933° N, 7.6° E
¶ DLR from ground at 2329 m a.s.l., 37.28° N, 107.08° W
‖ DLR from ground at 5340 m a.s.l., 23° S, 68° E



Università degli Studi della Basilicata — Dipartimento di Ingegneria e Fisica dell'Ambiente

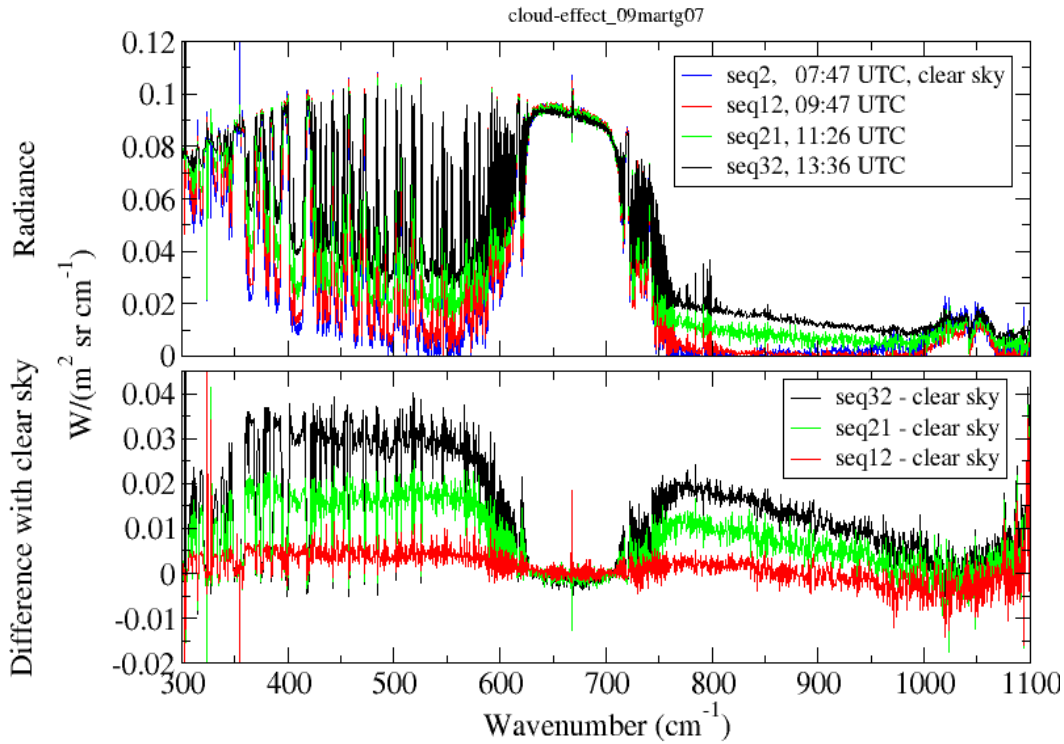
IFAC

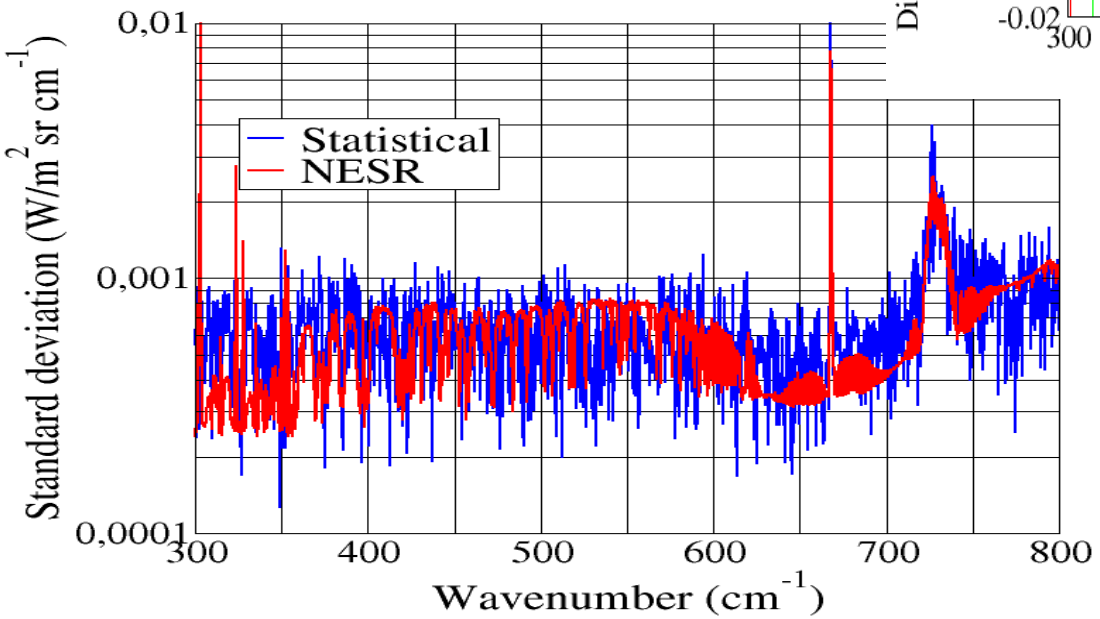
ADGB Atmospheric Dynamics Group Bologna

imaa istituto di metodologie per l'analisi ambientale

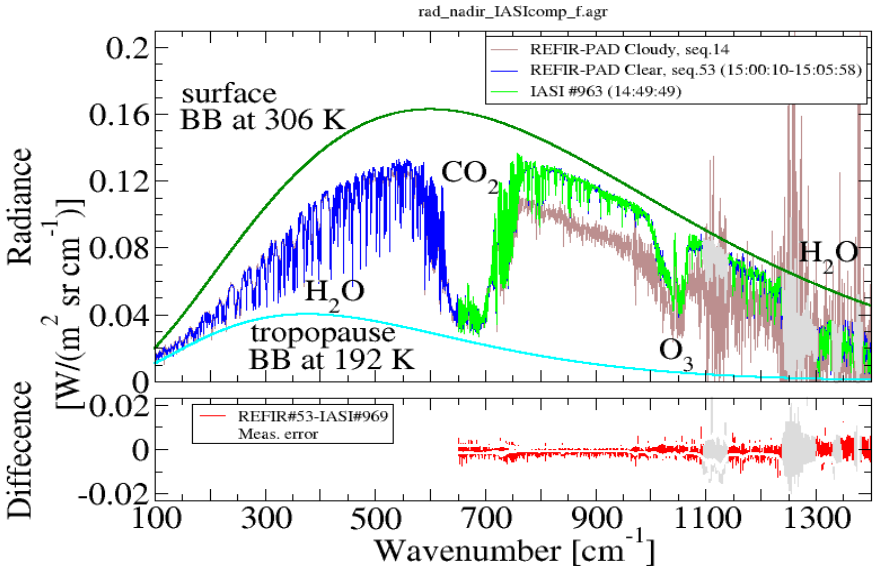
Atmospheric measurements and STD

Cerro Toco 2009
From clear sky to cirrus cover

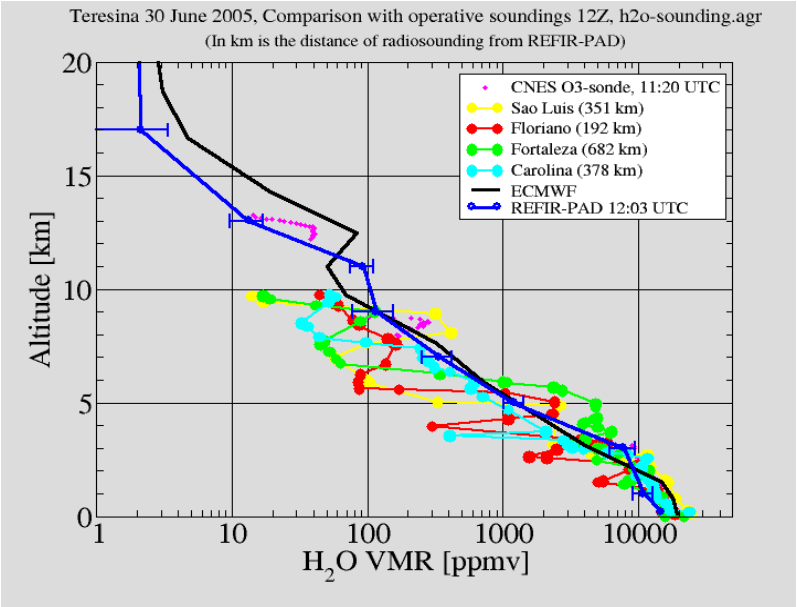




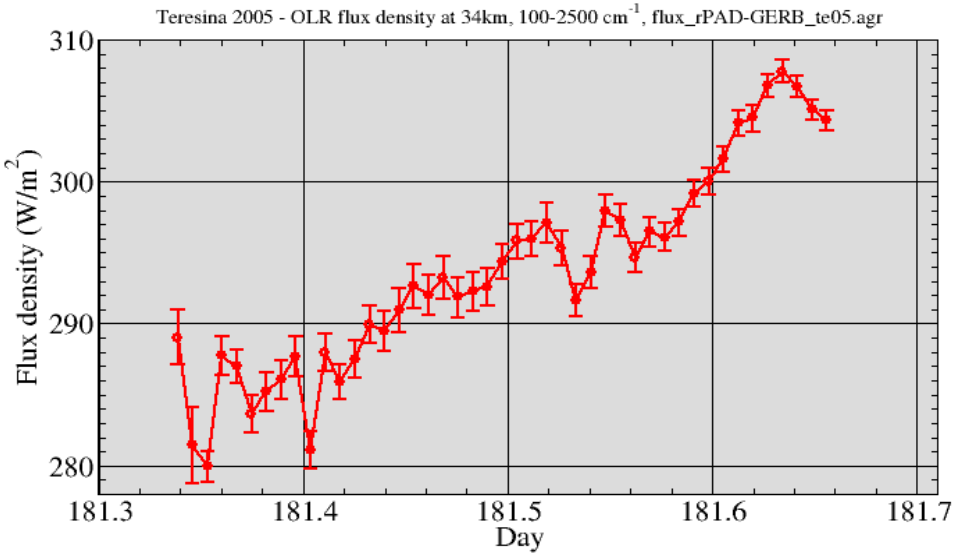
Products



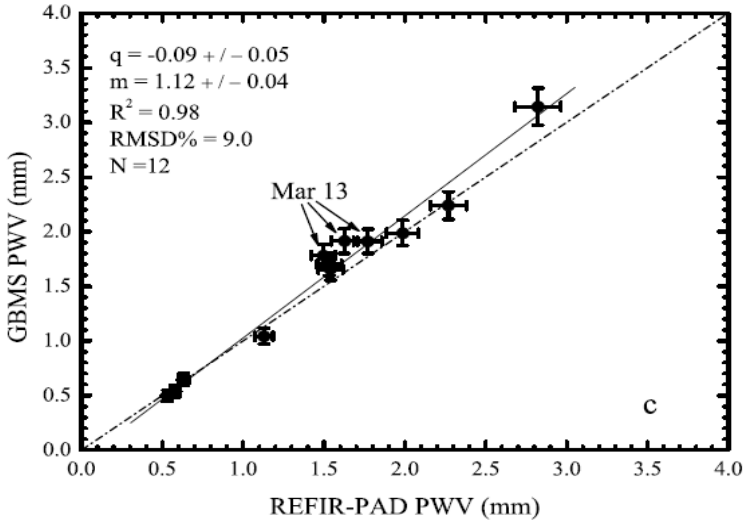
OLR accuracy = 0.3K



VMR_{H2O} error = 22-35% from 0 to 17 km



TOA irradiance Error = 1.3 W/m²

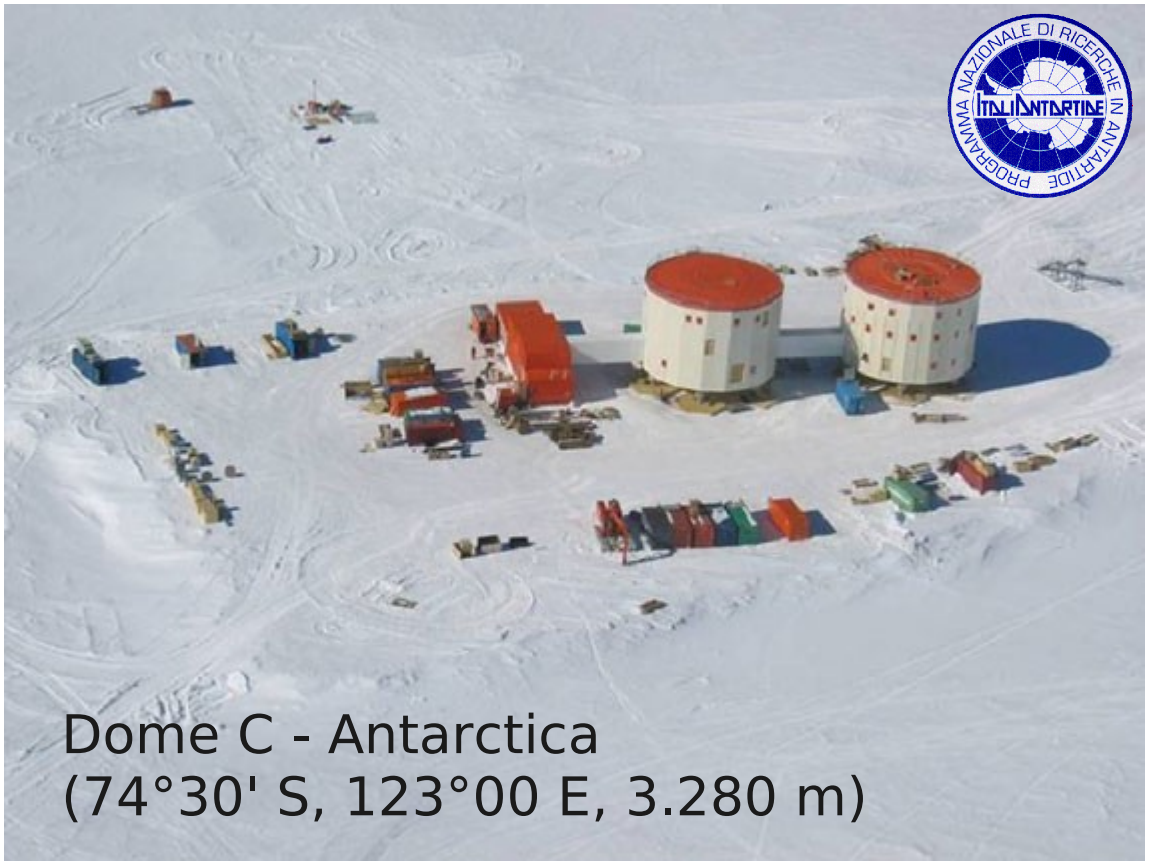


Retrieval of PWV, error = 5%

FIR ground-based measurement opportunity
2011-2013

- Deployment of REFIR-PAD at the Italian-French station of Concordia on the Antarctic plateau (Dome-C) on Dec. 2011

PNRA-Programma Nazionale di Ricerche in Antartide



Dome C - Antarctica
(74°30' S, 123°00 E, 3.280 m)

PRANA project

- Scientific Objective
  - Study of the radiative properties of WV and clouds in the FIR spectral region
- Available instruments
  - REFIR-PAD
  - Backscatter LIDAR
  - Radiosoundings

FORUM and EFTWVAC

Main mission objectives

- Study of the forcing/feedback effect on the climate system of the atmospheric water, in the form of both vapour and clouds, by measuring from space on a global scale for the first time the spectrally-resolved emission of the Earth in a broad spectral range that includes the FIR region.
  - Far Infrared Outgoing Radiation Understanding Monitoring
    - Polar satellite

Far-infrared-Outgoing-Radiation Understanding and Monitoring

forum

  - Emission Fingerprints of Tropical Water Vapour and Clouds
    - ISS

EFTWVAC

Space mission opportunities

FORUM - 2010-11

ESA – Earth Explorer Opportunity Mission EE8 results

- FORUM was in a short list of 4 but it was not financed. ESAC recognises “the very high scientific interest in a radiation mission, measuring the far infra-red spectrum for the first time and examining important dependencies on cirrus cloud properties”.
- ESAC committee recommended that ESA initiate a study, to better identify the benefits of a FORUM-type mission (wavelength coverage, radiometric performance, etc.). This is under investigation.

EFTWVAC - 2011-12

ESA – AO for ISS Experiments relevant to study of Global Climate Change

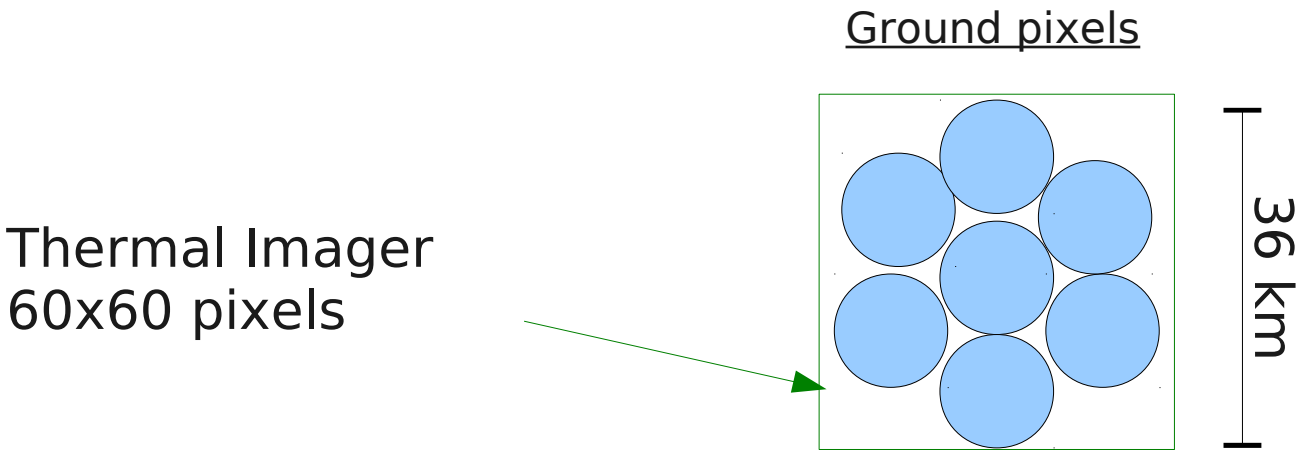
- A national support for the deployment on the ISS is also under investigation.

Specific objectives
Instrument requirements

- Spectrally resolved observation of the OLR for the attribution of the changes of total Earth irradiance to the underlying climatic parameters (H_2O, CH_4, O_3, etc.)
  - Spectral range = 100-1600 cm^{-1}
  - Radiometric accuracy = 0.1 K
  - Observing mode = nadir
- Determination of the atmospheric state (improved WV profiles in the upper troposphere) and assessment of its relationship with the LW spectral radiance and irradiance.
  - OPD = ± 2.5 cm (0.2 cm^{-1} resolution)
  - NESR = 0.2 mW/m^2-sr-cm^{-1}
  - Max resolving power, Rmax = 2500
- Improved cloud characterisation using the new information present in the FIR, and assessment of the LW contribution of clouds to the ERB.
  - Ground pixel = 12 km
  - Thermal imager (10.5-12.5 μm) for identifying pixel contamination

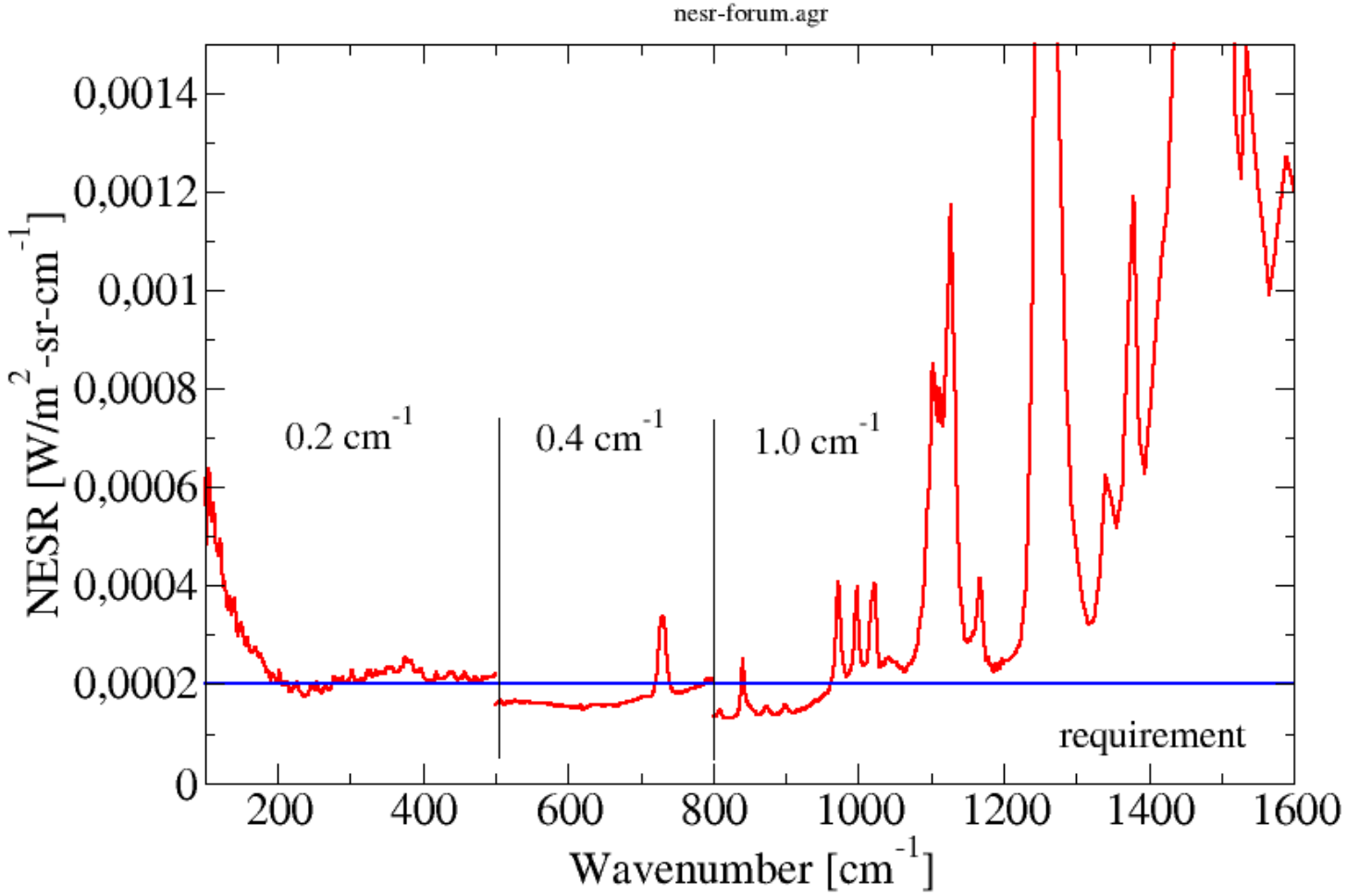
Imaging capability

- Resolution requirements
  - 0.2 cm^{-1} (H_2O retrieval) in 100-500 cm^{-1} → Rmax = 2500
  - 0.4 cm^{-1} (T retrieval) in 500-800 cm^{-1} → Rmax = 2000
  - 1 cm^{-1} (fingerprints) in 800-1600 cm^{-1} → Rmax = 1600
- Aperture limit on Rmax for a FOV = 7 pixels (optical throughput of single pixel = 0.01 cm^2 sr)
  - Limit on Rmax-central = 17000
  - Limit on Rmax-off axis = 2100

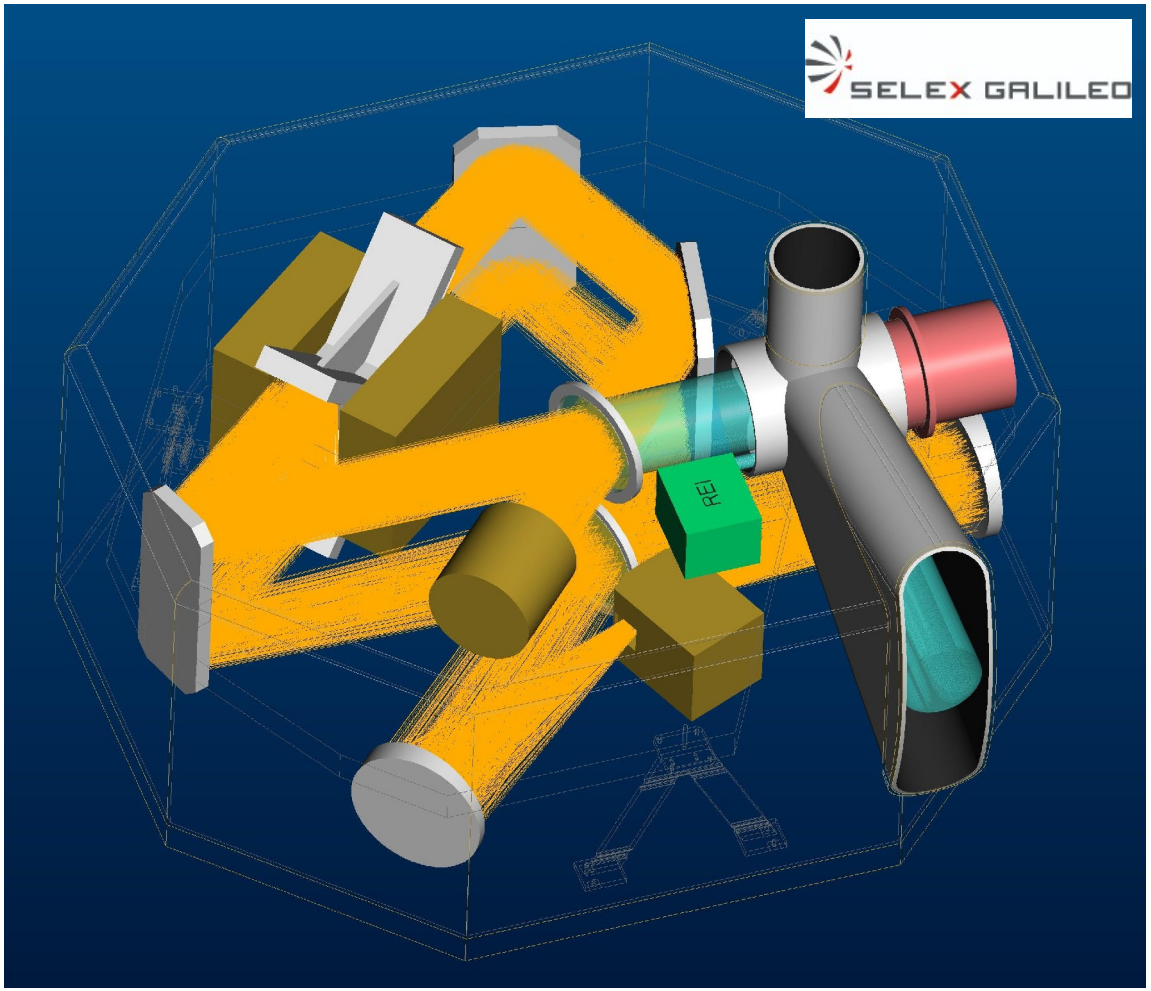


Performances
Expected radiometric precision

- NESR requirement (blue curve) compared to the estimation performed for the FIR FTS of FORUM/EFTWVAC based on REFIR-PAD performances



FTS optomechanical design



1 m

- FTS specifications
  - 14 uncooled pyroelectrics (D* ≈10^9 cm√Hz/W)
  - Sampling rate = 1.25 kHz
  - Acquisition time = 32 s
  - Weight = 70 kg
  - Power = 40 W
  - T_{BB} abs. cal. = 50 mK
- EI = Embedded Imager

Acknowledgements and References

- **Acknowledgements**

· Financial support for ESA proposal provided by the project POR-CREO-FESR-2007-2013, CTOTUS of the Italian Regione Toscana.

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