

The Far-infrared-Outgoing-Radiation Understanding and Monitoring (FORUM) explorer

Luca Palchetti



Italian National Research Council
Institute for Applied Physics
"Nello Carrara" - Florence (Italy)

L.Palchetti@ifac.cnr.it

Contribution to the
CLARREO Science Definition Team meeting
17-19 May 2011

FORUM proposing Team

FORUM explorer mission proposed for the ESA call for the Earth Explorer opportunity missions EE8

The proposing Team

Istituto di Fisica Applicata “Nello Carrara” - CNR, Italy (IFAC)	Luca Palchetti , Giovanni Bianchini, Bruno Carli, Ugo Cortesi, Samuele Del Bianco
Imperial College, United Kingdom (IC)	Helen Brindley , Richard Bantges, Claudio Belotti, John E. Harries, Jacqui Russell
SELEX Galileo, Italy (SG)	Demetrio Labate , Marco Cavallini, Enrico Suetta
Clough Radiation Associates, LLC, USA (CRA)	Shepard A. Clough , Vivienne H. Payne (AER Inc.)
Dipartimento di Fisica, Università di Bologna, Italy (DFBO)	Marco Ridolfi , Tiziano Maestri
Environmental Systems Science Centre, University of Reading, United Kingdom (ESSC)	Richard Allan
Laboratoire de Physique Moléculaire pour l'Atmosphère et l'Astrophysique – CNRS, France (LPMAA)	Claude Camy-Peyret
Dipartimento di Fisica, Università di Roma “La Sapienza”, Italy (DFRM)	Alfonso Sutura , Isabella Bordi, Pietro Sofi
Meteorologisches Institut, University of Hamburg, Germany (MI)	Klaus Fraedrich , Hartmut Borth, Thomas Frisius, Joachim Pelkowski
Centro de Astrobiología – CSIC/INTA, Spain (CAB)	F. Javier Martin-Torres

Scientific Rationale

Motivation

ESA Living Planet Program

The document “The Changing Earth” (ESA, SP-1304, 2006) states: “... the major missing observation is that of spectrally resolved measurements at moderate resolution of both long-wave and short-wave fluxes. ..”

FORUM rationale

- Improve WV profile characterisation with respect to the upper troposphere to obtain a better understanding of WV forcing/feedback (Solomon et al. 2010, IPCC 2007)
- Improve knowledge of the radiative effects of cirrus clouds depending on height, thickness and microphysics to develop a full characterisation of cloud feedbacks (IPCC, 2007)

Scientific Rationale

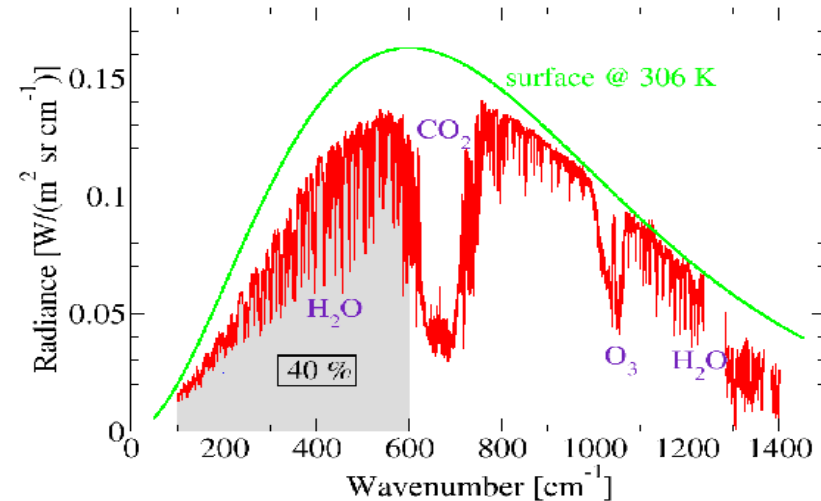
Far-infrared

Improve the knowledge of the Far Infrared (FIR) spectral region never observed from space

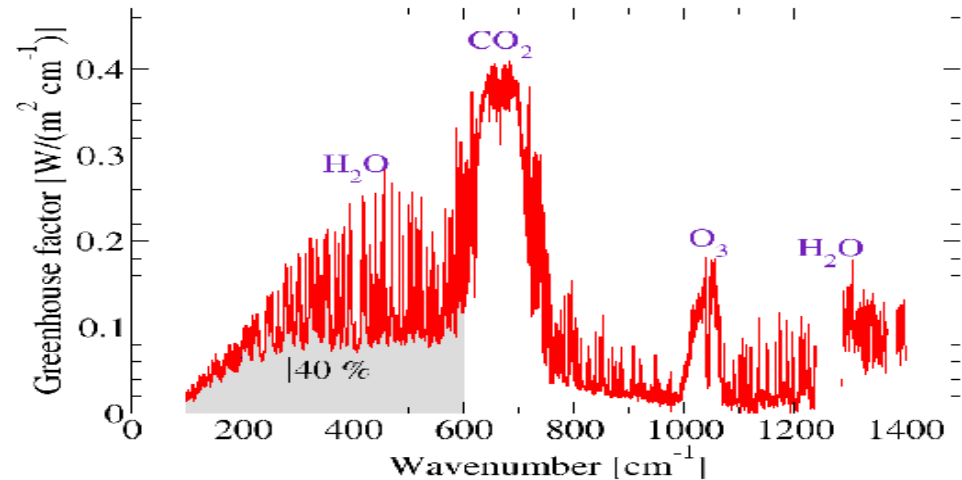
In the FIR we have

- the pure rotational water vapour band
- More than 40 % of the OLR and of the Greenhouse factor

Spettro di radianza in onda lunga: REFIR-PAD, Teresina; Brasile, 30 giugno 2005
nadir_s55-57-14e1r_te05_lpale_3_en.agr



Effetto serra: REFIR-PAD, Teresina; Brasile, 30 giugno 2005
GF_s55-57-14e1r_te05_lpale_en.agr

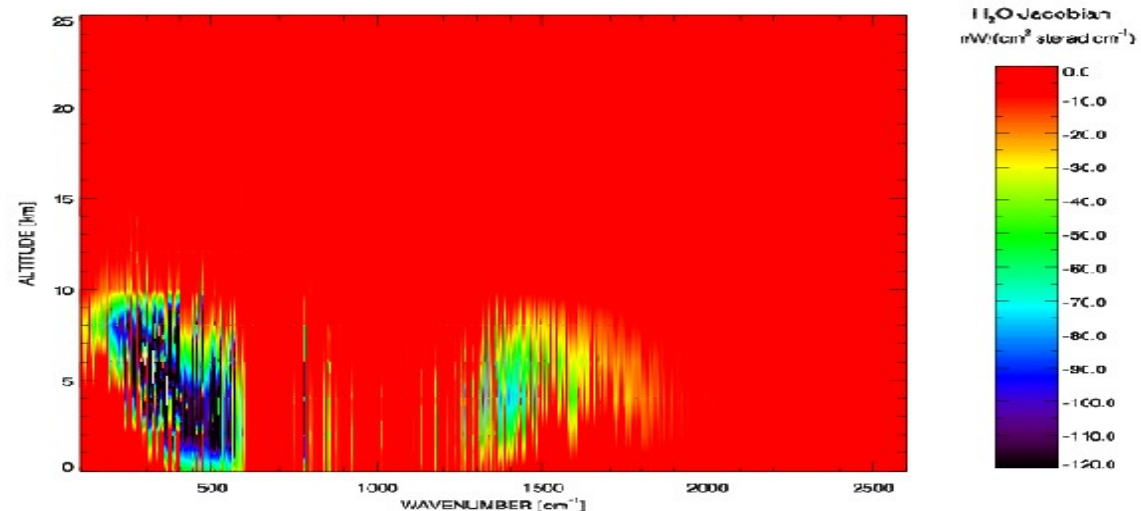
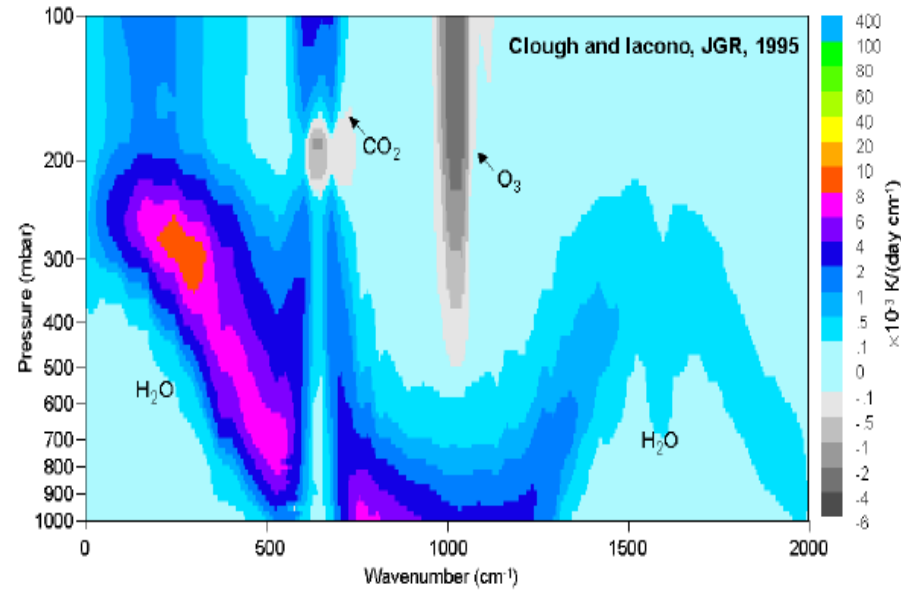


Scientific Rationale

Water vapour

FIR sensitivity to WV

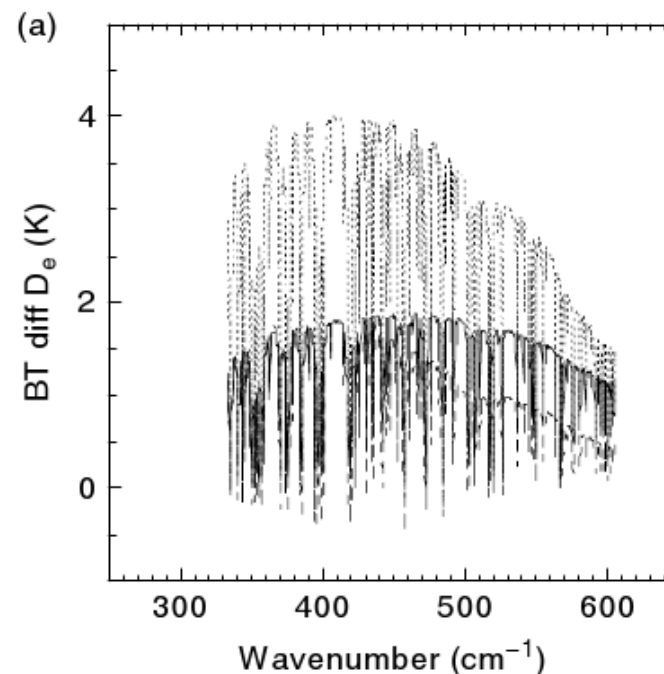
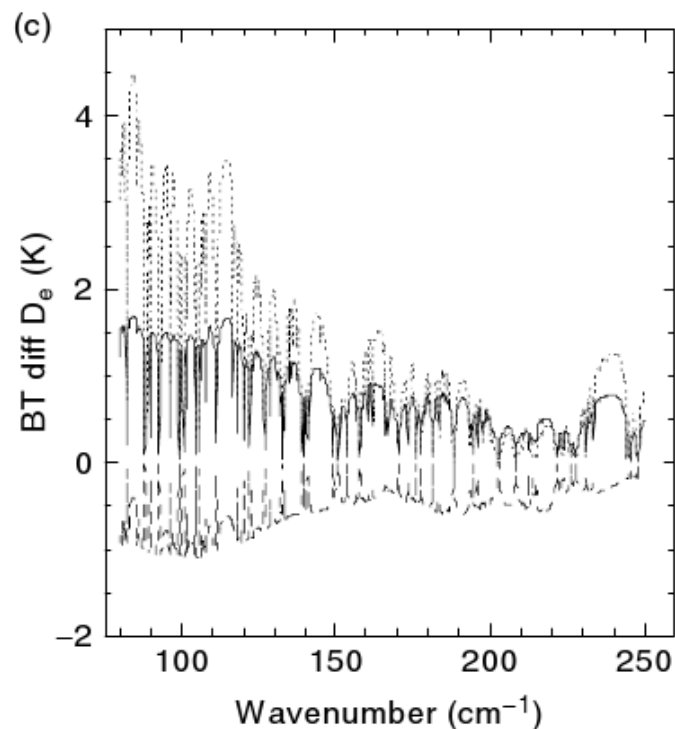
The FIR is strongly sensitive to mid-upper level tropospheric humidity that produces a peak in the cooling rate of the atmosphere and Jacobians



Scientific Background of REFIR-PAD

Cirrus clouds

FIR sensitivity to cirrus clouds



From A.J.Baran, Q. J. R. Meteorol. Soc., 133, 627, pp. 1425-1437, 2007

The FIR region can provide unique information on cirrus clouds radiative effects with sensitivity to microphysics

Main Mission Objective

- 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.
 - F → Far Infrared
 - O → Outgoing
 - R → Radiation
 - U → Understanding
 - M → Monitoring



Specific Mission Objectives

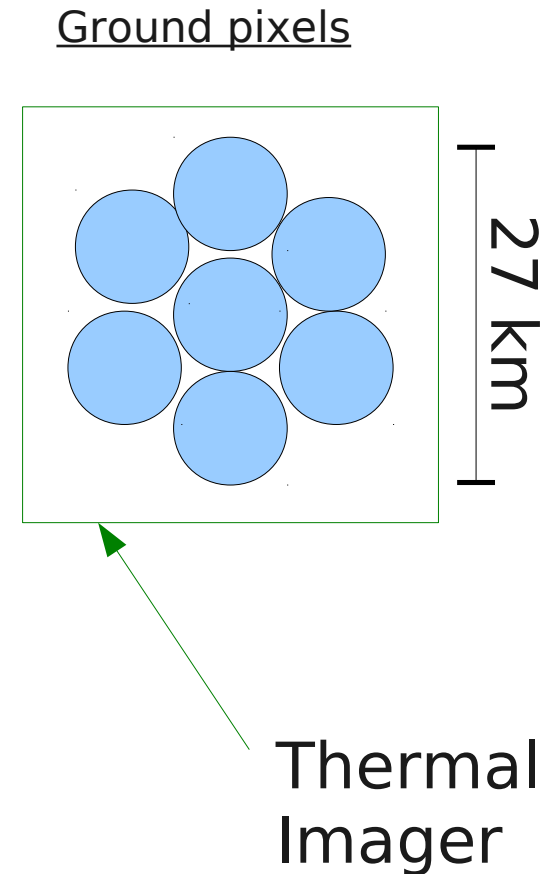
- **Understanding** the water vapour and cirrus clouds FIR contribution to the Earth radiative exchange
 - Water vapour spectroscopy and continuum absorption in the FIR
 - Ice cloud radiative properties
 - Upper troposphere water vapour and ice clouds
- **Monitoring** of the fingerprints of climate variables
 - Spectral irradiance determination from the associated retrieval of the atmospheric state
 - Measurement of the water vapour distribution with improved accuracy in the upper troposphere
 - Cirrus-cloud properties (optical depths, altitude and cloud parameters)
 - Measurement of changes and trends in the greenhouse contribution of other gases (CO_2 , CH_4 , O_3 , etc) and of the surface properties
- **Studying** of climate processes by combining the information available from other missions with the new information provided by spectrally resolved FIR measurements.
 - Water feedback processes (vapour and cirrus)

Primary Objectives

- 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.)
- Determination of the atmospheric state, improving in particular the water vapour profile in the upper troposphere, and assessment of its relationship with the spectral radiance for an accurate determination of the LW radiance and irradiance.
- Improved cloud characterisation using the new information present in the FIR, and assessment of the LW contribution of clouds to the ERB.

Measurement and Sampling Requirements

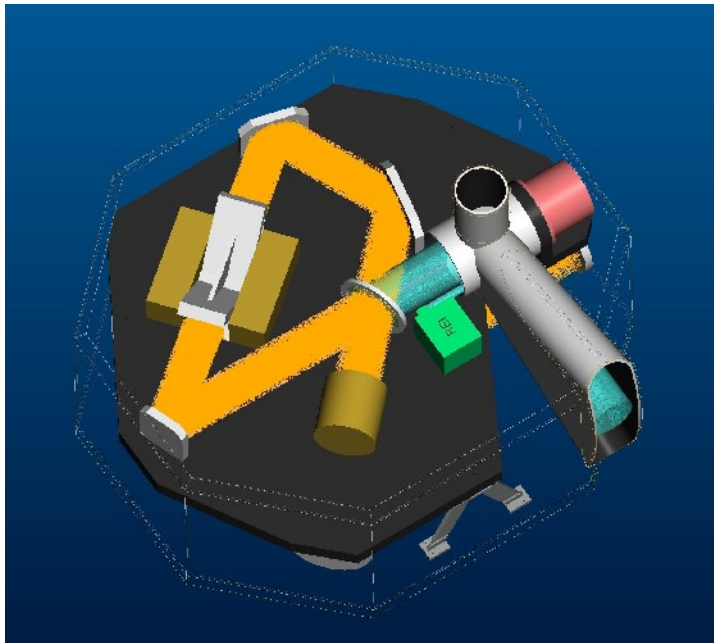
- Along-track sampling = 250 km
- Observing mode = nadir
- FIR spectrometer
 - FOV = 7 pixels
 - ground pixel = 9 km
 - Spectral range = 100-1600 cm^{-1}
 - Max resolving power = 2500, OPD = ± 2.5 cm
 - NESR = 0.2 $\text{mW/m}^2\text{-sr-cm}^{-1}$
 - Radiometric accuracy = 0.1 K
- Thermal imager for identifying pixel contamination
 - Spectral range = 10.5-12.5 μm



Satellite key requirements

		Requirement	
Mission	Lifetime [years]	3	
Orbit	Type	LEO, SSO	
	LTDN [hh:mm]	9:30	
	Altitude [km]	600	
Payload	Free views	Nadir, Cold Space	
	Volume l x w x h	IOU: 1180 mm x 1050 mm x 450 mm IEU: 240 mm x 200 mm x 80 mm	
	Mass: net / + 20% margin	IOI = 70 kg / 84 kg IEU = 6 kg / 7.2 kg Total = 76 kg / 91.2 kg	
	Power (including margin)	< 40 W	
	Duty Cycle	Nominal 100% Including calibration	
	Output Data Rate	545 Kbps	
	Orbit Data Volume [worst case]	384 Mbyte	
	Attitude		3-axis Nadir Pointed
			APE: 0.3 pixel (TBC)
Ground I/F	TT&C	S-band	
	P/L data downlink	X-band	
	Data Rate P/L data	< 155 Mbps	

FORUM measurement concept

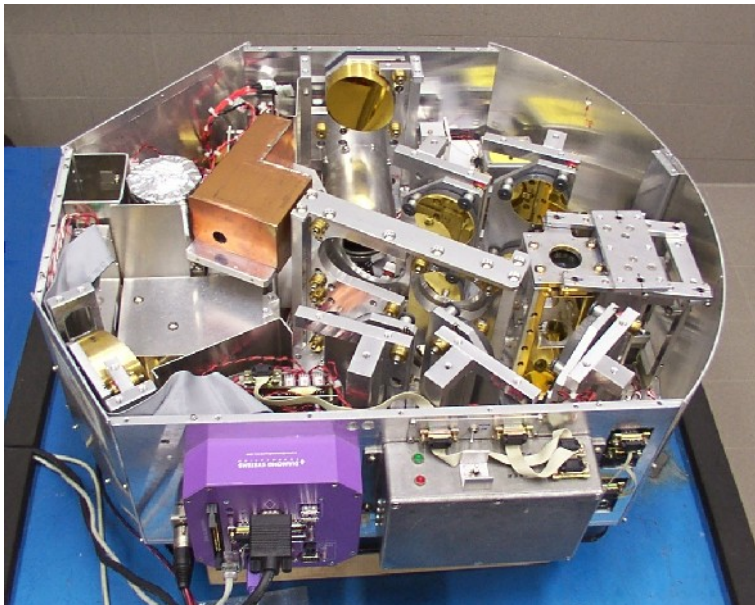
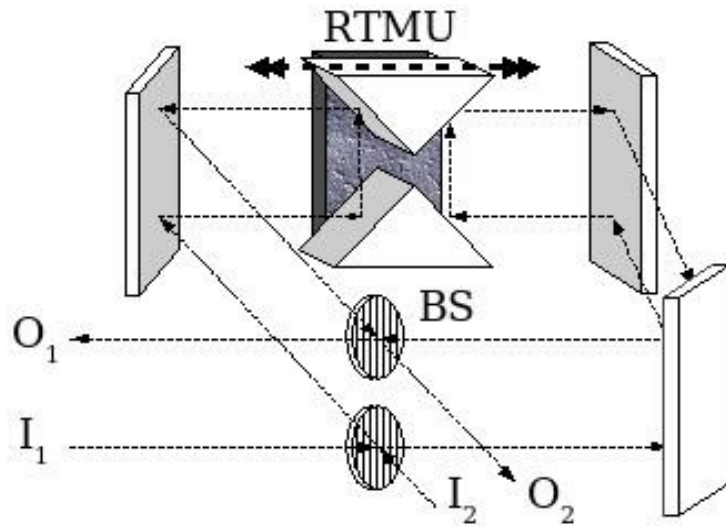


- **FIR-FTS**
- Mach-Zehender interferometer with amplitude beamsplitters
- 2 input / 2 output ports
- Pyroelectric room-temperature detectors
- Full compensation of moving mirror
- High calibration accuracy
- Small payload - low power

- **Thermal imager** sharing the same front end optics of the FIR-FTS

Heritage

The REFIR-PAD interferometer, 2003-04

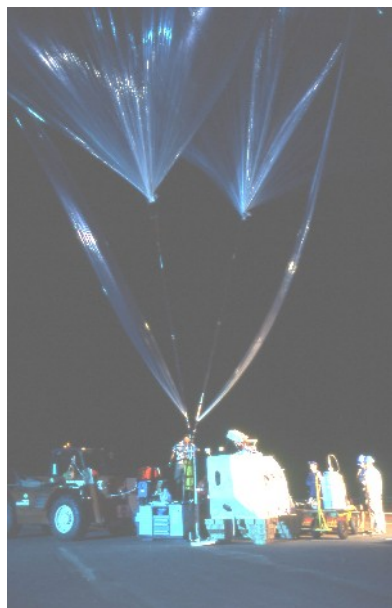


- Fourier Transform Spectrometer
- Mach-Zehender interf.: Ge on PET beamsplitters and DLATGS pyroelectric room-temperature detectors
 - Spectral coverage = 100-1400 cm^{-1} ,
 - Resolution 0.25 cm^{-1} max. double-sided
 - NESR in the range 0.8-2.5 $\text{mW}/(\text{m}^2 \text{sr cm}^{-1})$ with 30 s.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

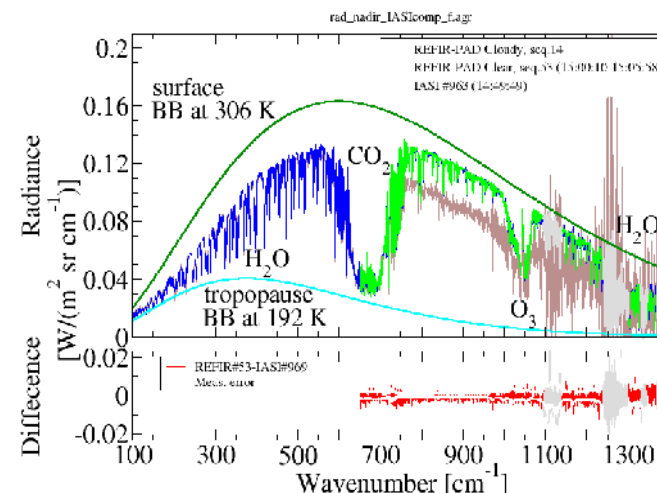
Carli B., et al., App.Opt. 38, 18, pp. 3945-3950, 1999

Heritage

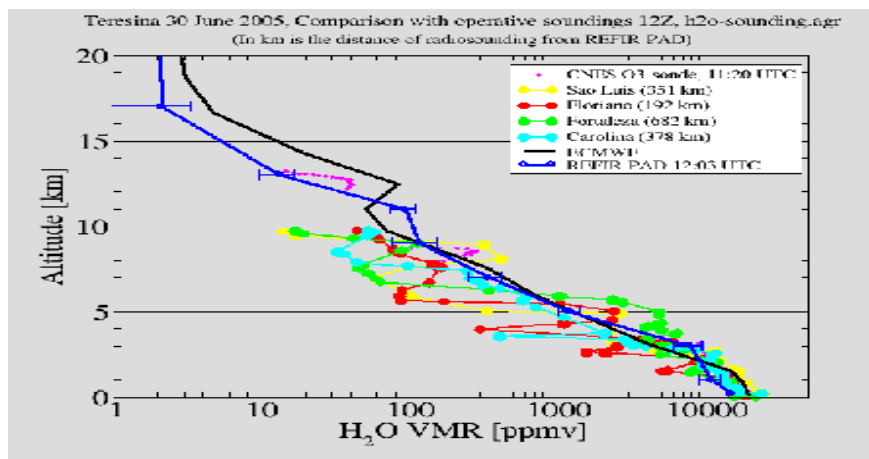
REFIR-PAD measurements from balloon



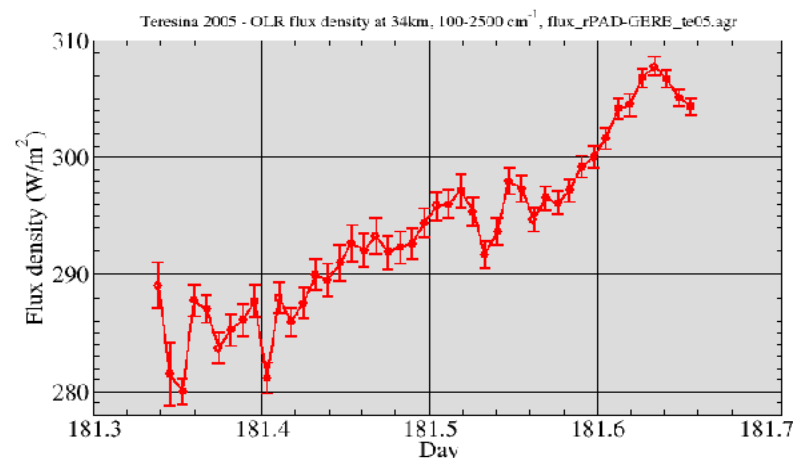
Stratospheric balloon experiment with IASI-balloon, Teresina, Brazil, 30/05/2005, IFAC-CNR, LPMAA-CNRS, CNES



OLR accuracy = $\pm 0.1\text{K}$



$\text{VMR}_{\text{H}_2\text{O}}$ error = 22-35% from 0 to 17 km



TOA irradiance

Error = 1.3 W/m^2

Palchetti L., et al, Atmos. Chem. Phys., 6, 5025-5030, 2006

Heritage

REFIR-PAD measurements from ground

ECOWAR Campaign (PRIN program, Italy, 2007)

<https://www.difa.unibas.it/jFM/dlf/Progetti/cobra/index.htm>

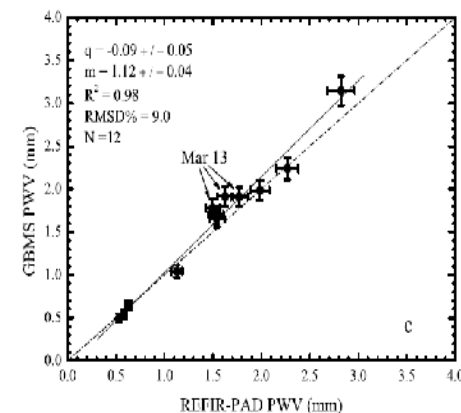


Testa Grigia, Italy, 3500 m. a.s.l.

Spectral characterisation of the DLR

- WV spectroscopy
- WV Continuum
- Cirrus FIR properties

see poster n. 5



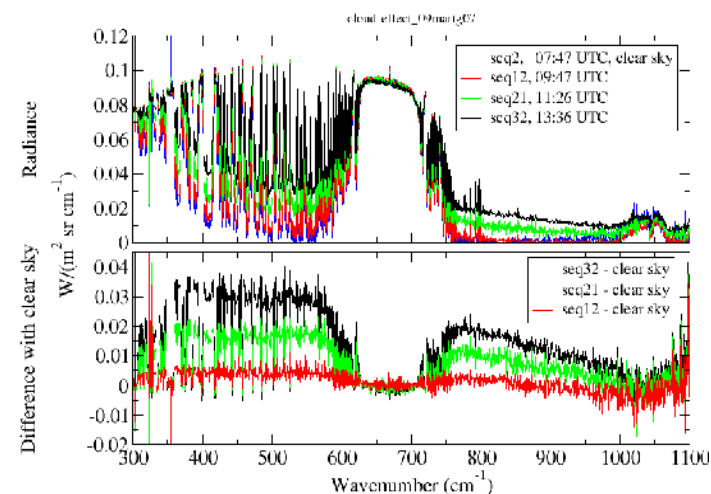
Retrieval of PWV,
error = 5%

RHUBC-II Campaign (ARM program, US, 2009)

<http://campaign.arm.gov/rhubcII/>



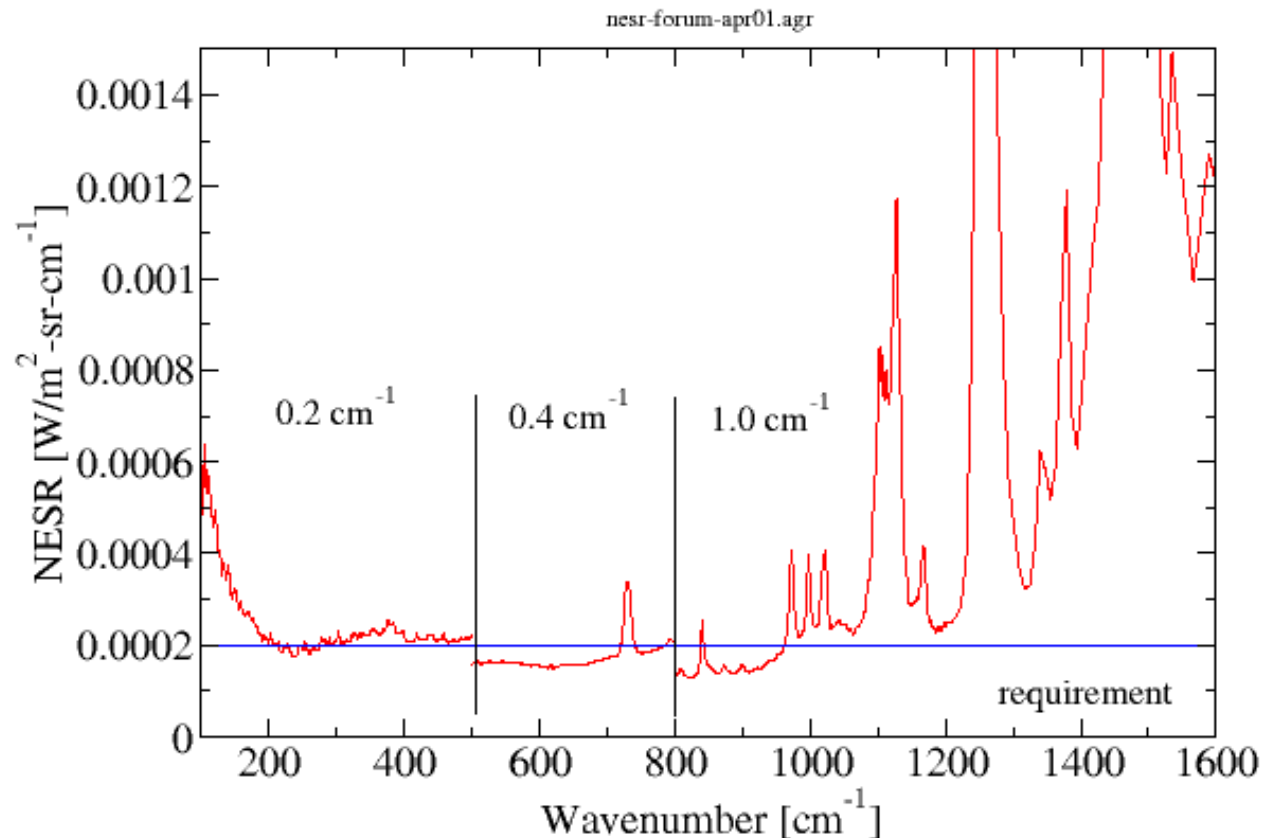
Cerro Toco, Chile, 5380 m. a.s.l.



FORUM performances

Expected radiometric precision

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

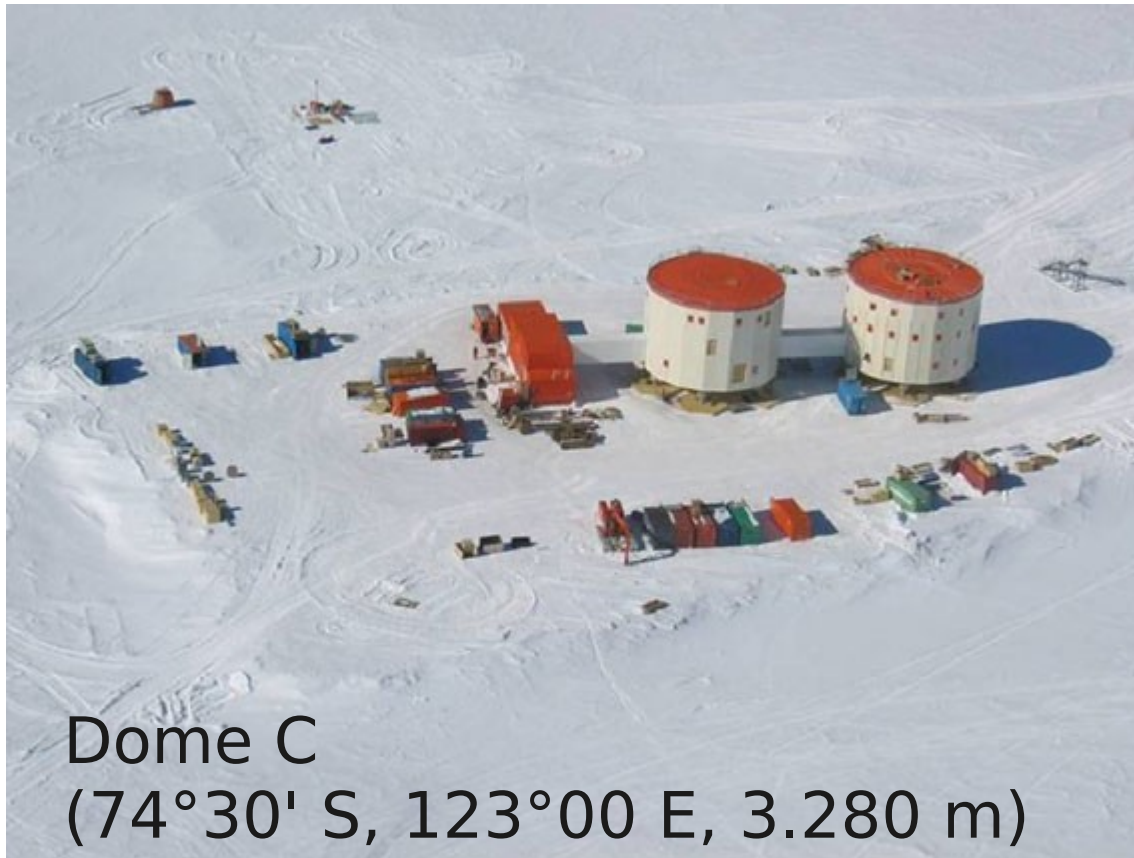


Current status and new opportunities

- 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 dependences on cirrus cloud properties”.
- ESA – opportunity
 - 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.
- ASI opportunity
 - A national support for the deployment on the ISS with descoped scientific objectives is also under investigation.

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



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

International Scenario and Synergy with FirEX

With the missing implementation of both CLARREO and FORUM, the following scientific objectives are shelved:

- spectrally-resolved modelling of the ERB, including the FIR
 - improvement of the characterisation of the UTLS WV
 - FIR characterisation of cirrus clouds contribution to the ERB
- Possible synergy with FirEX
 - Similar scientific objectives
 - Quite similar FTS instruments in the case of the FirEX descoped option.
 - The deployment on the ISS platform fits well with our plans to exploit national assets for this platform.

Possible merging is to be discussed in view of new opportunities



Many thanks to Helen for the talk and to the CLARREO Scientific Team for having given me the opportunity to present the FORUM project

Luca

References

- B.Carli, A.Barbis, J.E.Harries, L.Palchetti, Design of an efficient broad band far infrared FT spectrometer, Applied Optics Vol. 38, No. 18, pp. 3945-3950, 20 June 1999.
- L.Palchetti, A.Barbis, J.E.Harries, D.Lastrucci, Design and mathematical modelling of the space-borne far-infrared Fourier transform spectrometer for REFIR experiment, Infrared Physics & Technology Vol. 40, pp. 367-377, 1999.
- Rizzi R., Palchetti L., Carli B., Bonsignori R., Harries J.H., Leotin J., Peskett S., Serio C., Sutura A., Feasibility study of the space-borne Radiation Explorer in the Far InfraRed (REFIR), Proceedings SPIE 4485, Edr. A.M.Larar and M.G.Mlynczak, San Diego, USA, pp. 202-209, 2001.
- Bianchini G., Palchetti L., and Carli B. A wide-band nadir-sounding spectroradiometer for the characterization of the Earth's outgoing long-wave radiation, Proceeding SPIE vol. 6361, p. 63610A, 2006.
- G.Bianchini, F. Castagnoli, M. Pellegrini, and L.Palchetti, Frictionless mirror drive for intermediate resolution infrared Fourier transform spectroscopy, Infr. Phys. Tech. 48/3, pp. 217-222, Aug 2006
- L.Palchetti, G.Bianchini, F.Castagnoli, Design and characterisation of black-body sources for infrared wide-band Fourier transform spectroscopy, Infrar. Phys. & Tech. 51, pp. 207-215, 2008.
- Bianchini G. and Palchetti L., REFIR-PAD level 1 data analysis and performance characterization, Atmos. Chem. Phys. 8, pp. 3817-3826, 2008.
- Harries J., B. Carli, R. Rizzi, C. Serio, M. Mlynczak, L. Palchetti, T. Maestri, H. Brindley, and G. Masiello, The Far Infrared Earth, Reviews of Geophysics, 46, RG4004, 2008.
- Bianchini G., Carli B., Palchetti L., Vectorial combination of signals in Fourier transform spectroscopy, Infr. Phys. & Tech 52(1), 19-21, 2009.
- L.Palchetti, G.Bianchini, B.Carli, and C.Serio, Ground-based and balloon-borne characterization of the far infrared atmospheric emission spectrum, AIP Conf. Proc. 1100, pp. 147-150, IRS 2008), 2009.