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Atmosphere monitoring in the mm/sub-mm spectral band with the CASPER spectrometer at Concordia Station (Antarctica)

SAPIENZA
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Outline

Concordia Station @ Dome C (Antarctica) is an excellent site for sub&mm sky observations.
Atmospheric performance monitoring will support future installations, (see the incoming QUBIC experiment [Buzi et al. SIF Communication]).

Two requirements:

- ✓ Low opacity (*i.e.* low pwv content)
- ✓ High stability (*i.e.* low pwv fluctuations)

Two strategies:

- ✓ A semi-empirical approach to perform analysis of atmospheric transmission and emission at Dome C with radiosoundings data
- ✓ A spectrometer to explore the 90÷450 GHz (3÷15 cm^{-1}) spectral region: CASPER

Semi-empirical approach: data + code

Old data: 469 radiosounding measurements taken routinely at Dome C at 12:00 UTC from May 2005 to Jan 2007

Routine Meteorological Observations (RMO) Research Project (http://www.climantartide.it)

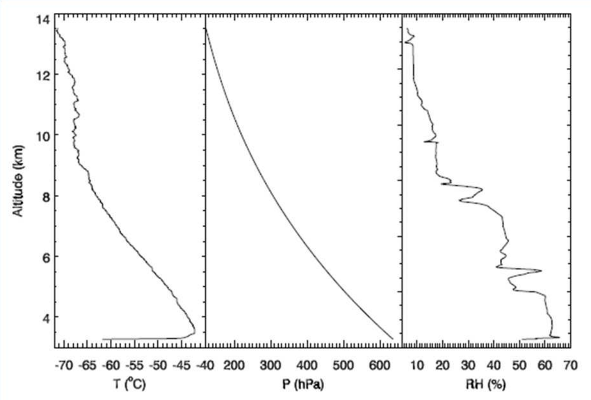


Figure 1. Vertical profiles of air temperature, pressure and relative humidity obtained from the June 22nd 2006 radiosounding data.

Millimetre and submillimetre atmospheric performance at Dome C combining radiosoundings and ATM synthetic spectra

S. De Gregori,[1★] M. De Petris,[1] B. Decina,[1] L. Lamagna,[1] J. R. Pardo,[2] B. Petkov,[3] C. Tomasi[3] and L. Valenziano[4]

Mon. Not. R. Astron. Soc. **425,** 222–230 (2012)

Data Correction (Tomasi et al. 2006)

(i) the not correct calibration of the Barocap sensors;

(ii) the effects caused by solar and infrared radiation heating, heat conduction and ventilation on the Thermocap sensors;

(iii) lag errors, ground-check errors and dry biases of the Humicap sensors due to basic calibration model, chemical contamination, temperature dependence and sensor aging, corrected according to Wang et al. (2002).

ATM

Atmospheric Transmission at Microwaves

Opacity

100 GHz – 2 THz

Selected 7 observational bands

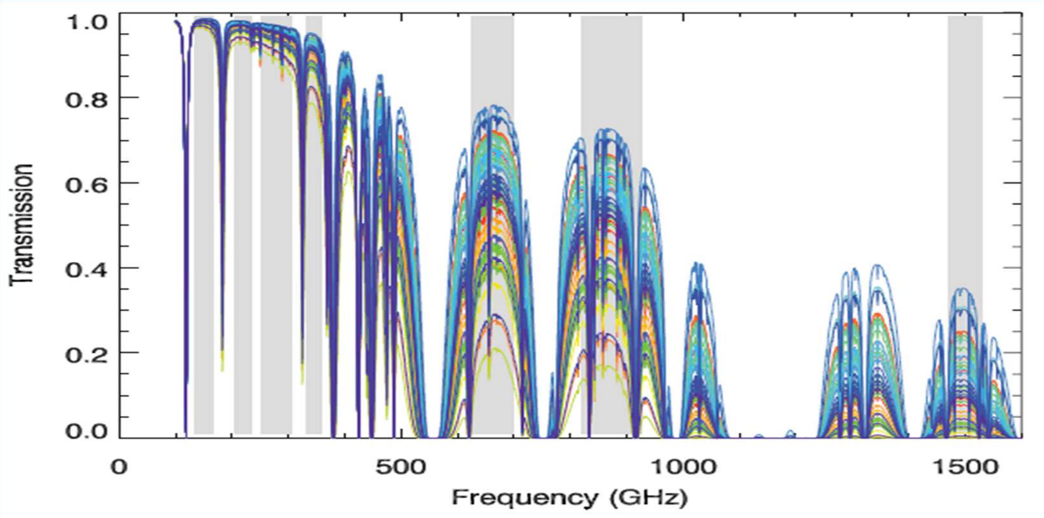
Table 1. Characteristic spectral bands assumed in this work.

	ν_0 (GHz)	λ_0 (μm)	FWHM (per cent)	References
	150	2000	22	1, 2, 3, 4
LF	220	1400	13	1, 2, 3
	270	1100	18	1, 2, 3
	350	860	8	1, 2, 5, 6
	660	450	11	5, 6
HF	870	350	13	5
	1500	200	5	7

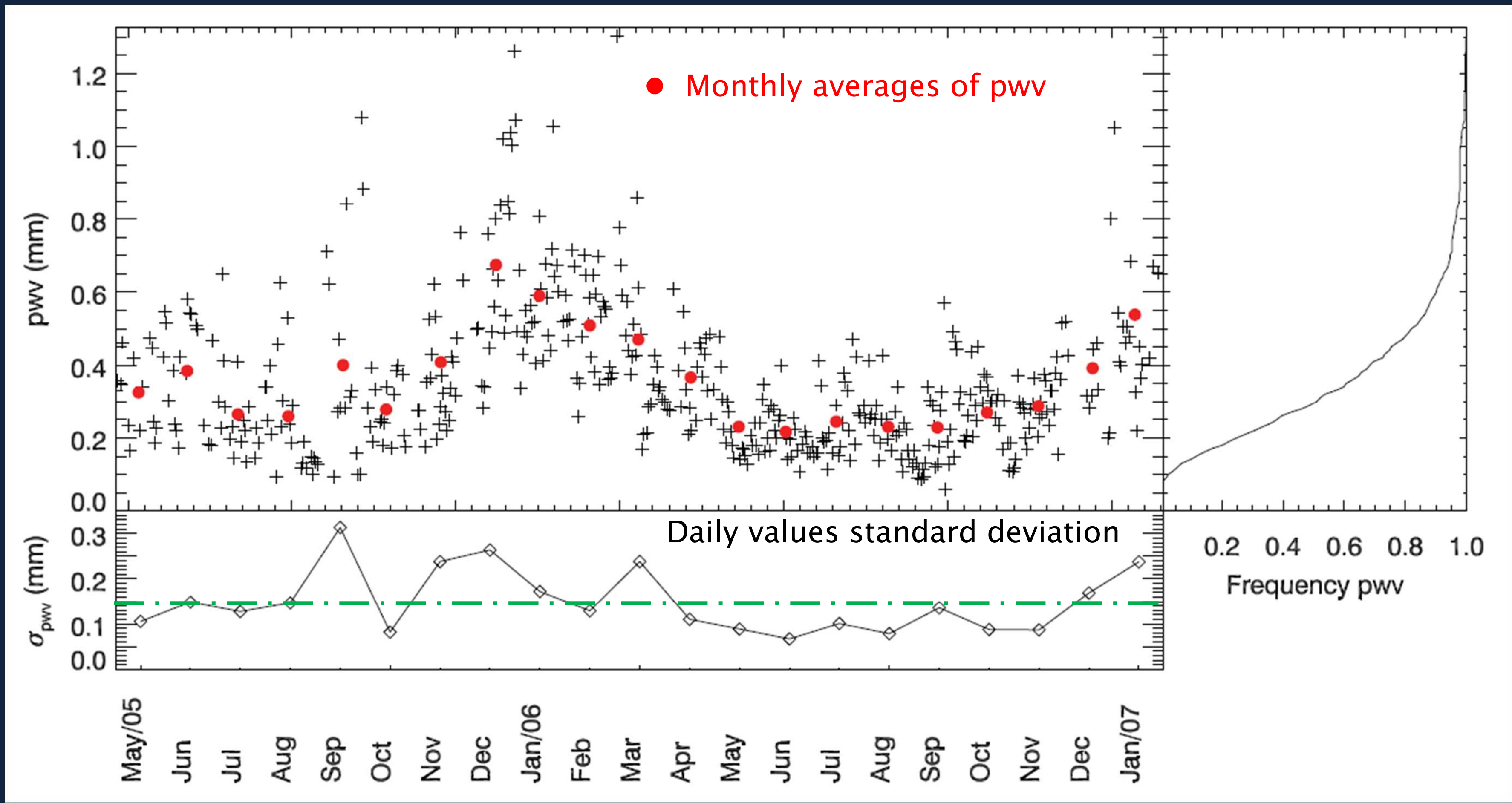
Note. References: 1 – SPT, Schaffer et al. (2011); 2 – MITO, De Petris et al. (2002); 3 – ACT, Swetz et al. (2011); 4 – BRAIN, Battistelli et al. (2012); 5 – SCUBA, Holland et al. (1999); 6 – SCUBA-2, Dempsey et al. (2010); 7 – THUMPER, Ward-Thompson et al. (2005).

Daily transmission spectra

$T = e^{-\tau}$



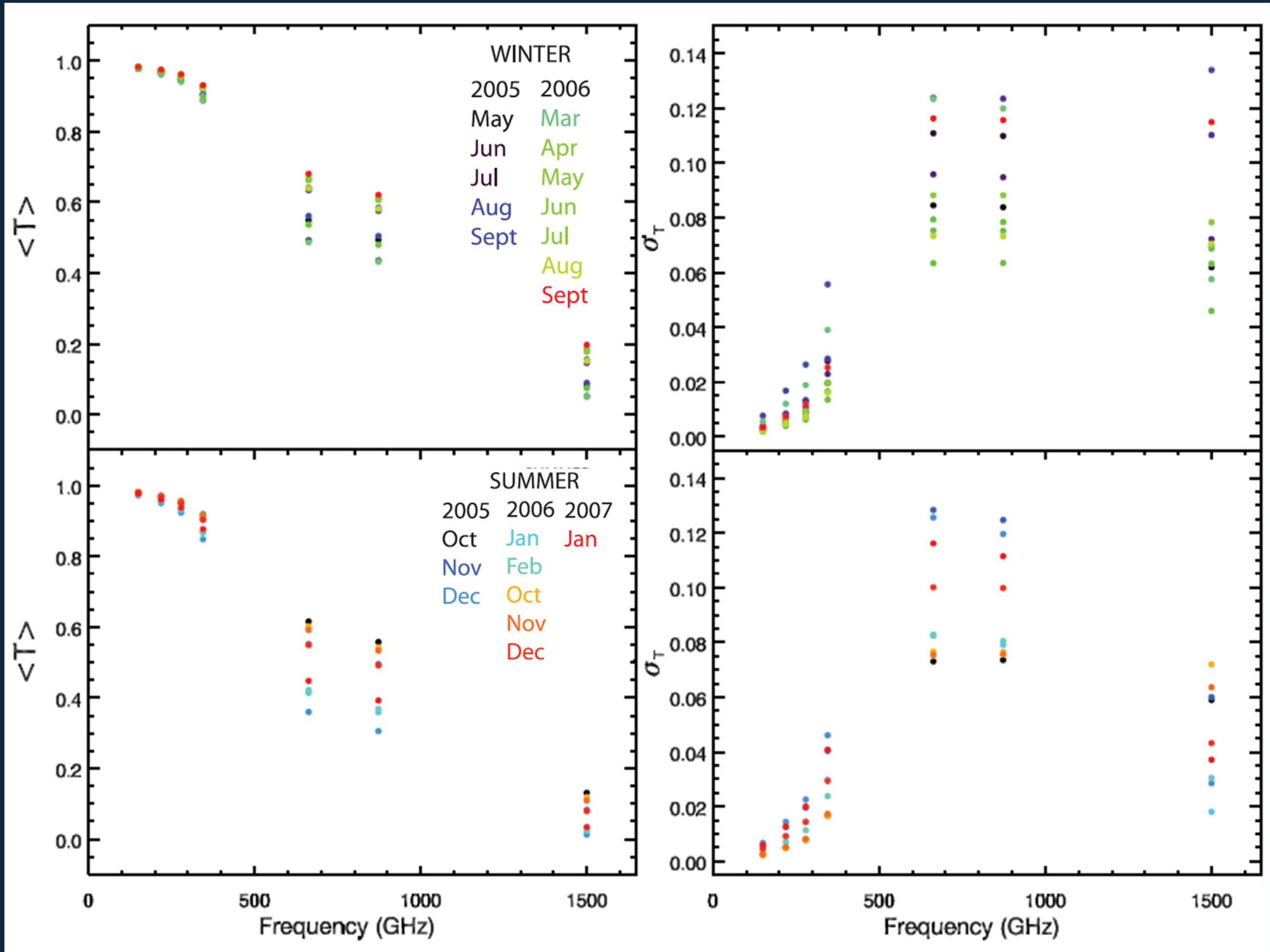
pwv values



Daily values of pwv estimated from the 12:00 UTC radiosounding measurements performed at Dome C over the period from 2005 May to 2007 January.
PWV seasonal variation with values lower than 0.3 mm and a mean dispersion of about 150 μm (on daily data)

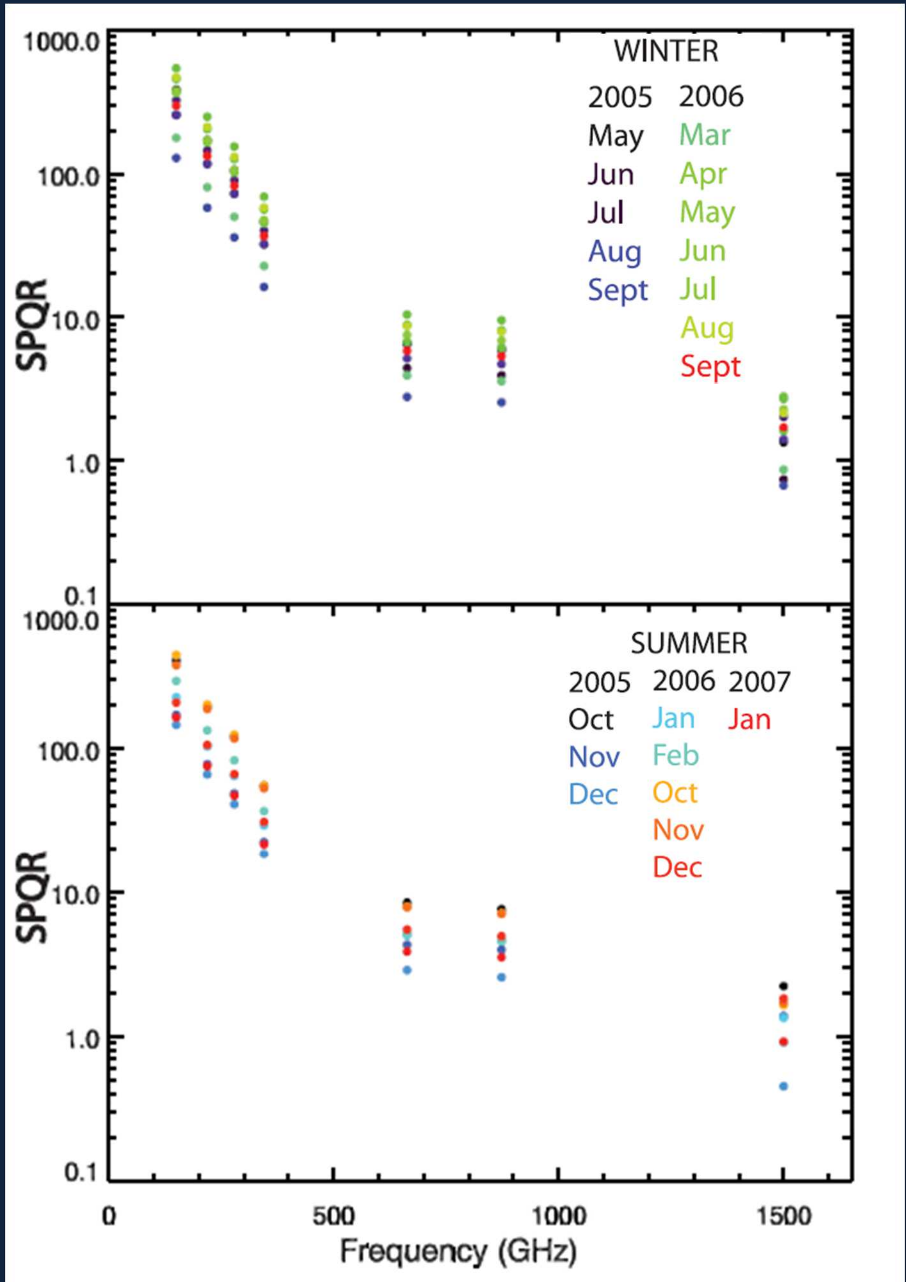
In-band Transmission fluctuations

Monthly average values of transmission



Monthly transmission fluctuations

Site quality



To quantify the real capability of the observational site we need to study the atmospheric performance, mainly stability and high transmission.

A new specific quality indicator:
the Site Photometric Quality Ratio
for each band

$$\mathrm{SPQR} = \frac{\langle T \rangle}{\sigma_T}$$

monthly averaged transmission

monthly transmission fluctuations

Table 4. Seasonal averages of the SPQR.

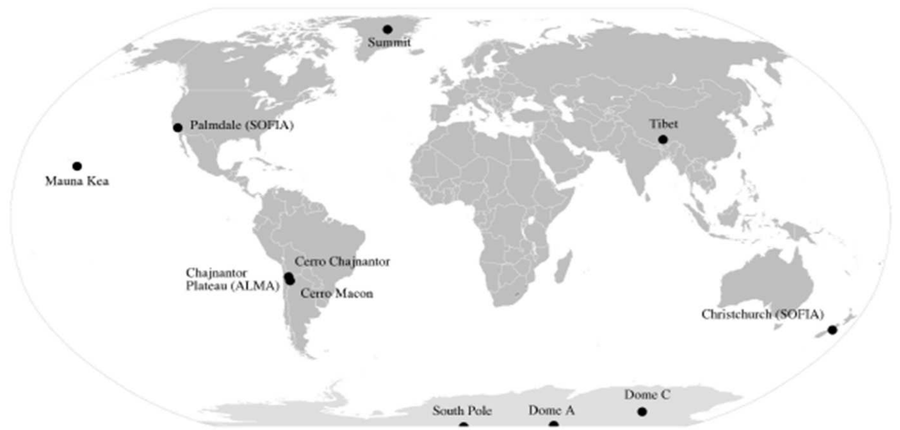
	ν_0 (GHz)	Summer	Winter
LF	150	272	335
	220	127	152
	270	79	94
	350	36	42
HF	660	6	7
	870	5	6
	1500	1	2

It is difficult to identify a desired SPQR threshold but this proxy could represent a useful tool to compare band performance or …sites

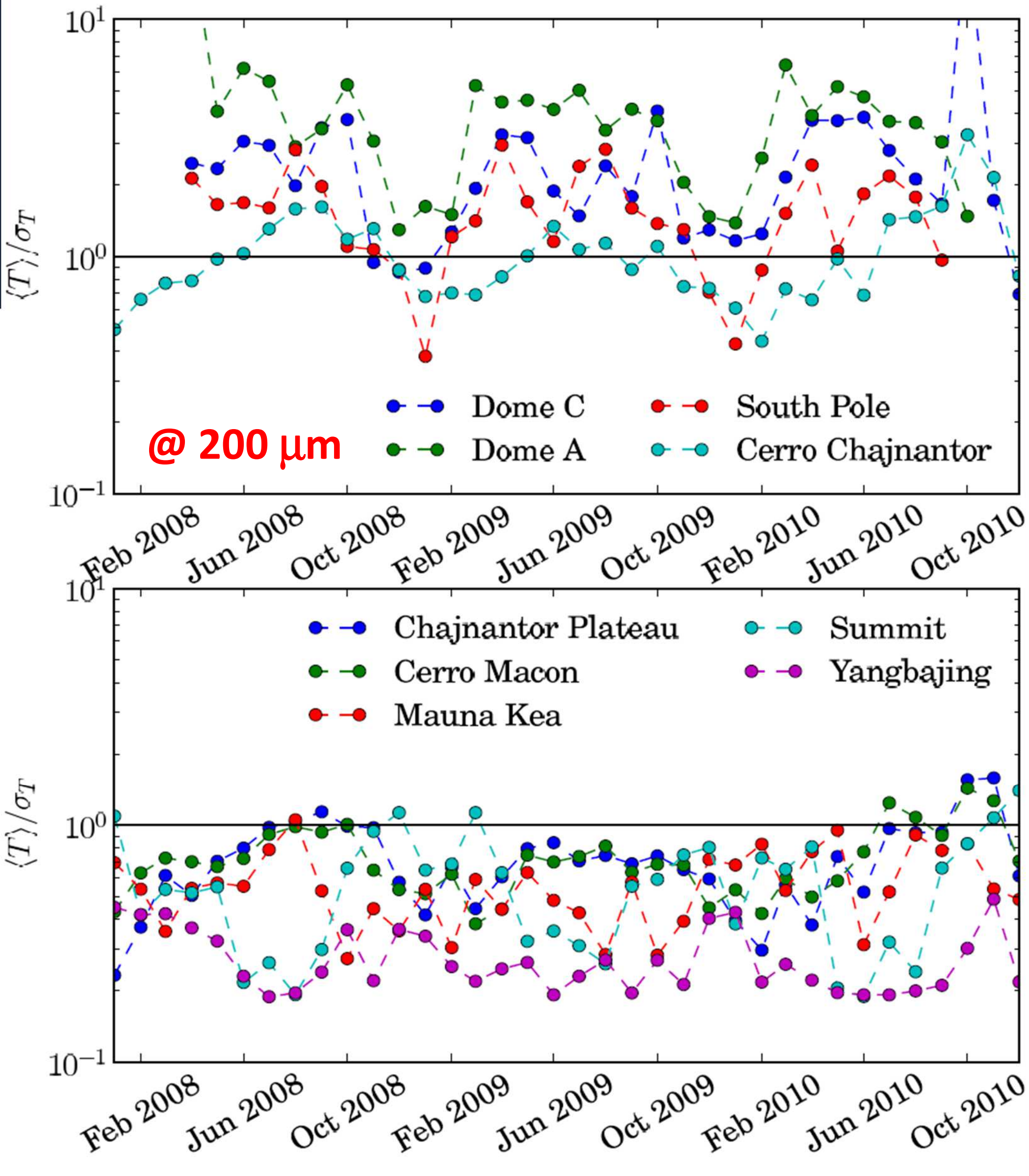
Comparisons of atmo performance @200μm

Fixed the band, SPQR has been used as indicator to quantify and compare the best sub/mm worldwide observational sites.

The comparison of 7 sites at 200 μm in 2008-2010 period (Tremblin+12)



Site	Latitude	Longitude	Alt. [m]	Tel.
Dome C	75°06′s	123°23′e	3233	IRAIT
Dome A	80°22′s	77°21′e	4083	
South pole	90°s	0°e	2800	SPT
Cerro Chajnantor	22°59′s	67°45′w	5612	(CCAT)
Cerro Macon	24°31′s	67°21′w	5032	
Chaj. Plateau	23°00′s	67°45′w	5100	ALMA
Mauna Kea	19°45′n	155°27′w	4207	JCMT
Summit (Greenland)	72°35′n	38°25′w	3210	
Yangbajing (Tibet)	30°05′n	90°33′e	4300	KOSMA
Palmdale	34°37′n	118°05′w	12000	SOFIA
Christchurch	43°31′s	172°38′e	12000	SOFIA

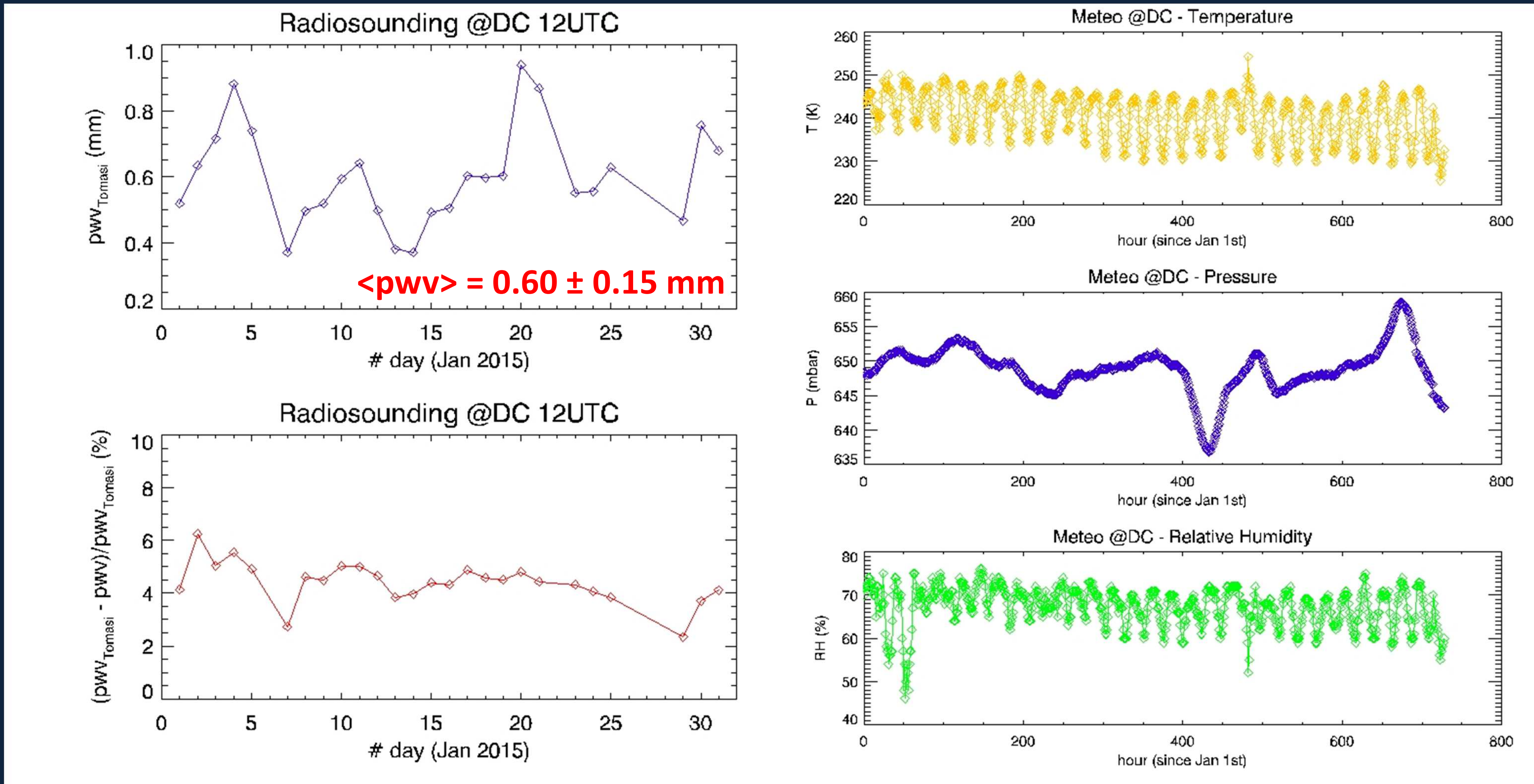


Antarctic sites (+CC) SPQR>1

Arctic + Temperate sites SPQR<1

Tremblin et al. A&A (2012)

pwv fluctuations DC Jan 2015



credits B. Petkov

www.climantartide.it

Daily values of pwv estimated by the 12:00 UTC radiosounding measurements performed at Dome C over the period from January 1st to 31st 2015 and corrected with Tomasi et al. procedure.

Atmospheric wide spectral coverage

Radiosounding data: 1/day – a code to infer atmo in the sub-mm/mm range

Direct and frequent measurements of atmospheric transmission in a wide spectral range can provide a perfect knowledge of atmospheric influence on astronomical observations.

If the opacity measurements are done in a narrow (a few MHz) spectral coverage, it is impossible to distinguish between clear sky opacity, hydrometeors contributions and systematic errors.

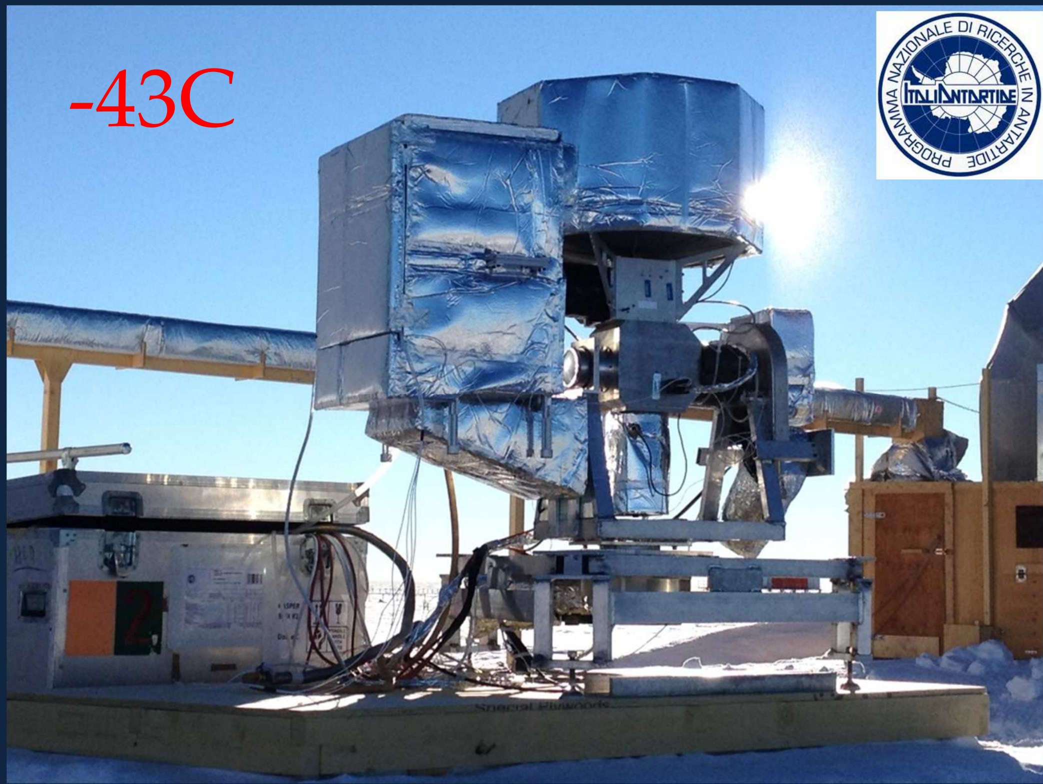
A wide frequency coverage (several hundreds of GHz) is necessary to make sure we are in clear sky conditions and no instrumental offset is affecting our measurement and our analysis. In this way it is also possible to determine the dry and the wet continuum terms [Pardo, Serabyn, & Cernicharo 2001]

A mm/submm spectrometer: CASPER

A large spectral sampling can be achieved at the price of a bit complex instrument. The possibility to monitor the atmosphere towards different positions in the sky, also avoids bias due to a spatial model assuming the multi layers approximation.

CASPER, a dedicated spectrometer that already operated at Testa Grigia station (3500m asl, Alps, Italy) [Decina , MDP et al. +10; MDP et al., +13] , has been adapted to work at severe ambient conditions and installed at Concordia Station in Antarctica in December 2014 to observe during January 2015.

Testa Grigia station
Alps 3500 m a.s.l.



Concordia station
Antarctica 3200 m a.s.l.

A mm/submm spectrometer: CASPER

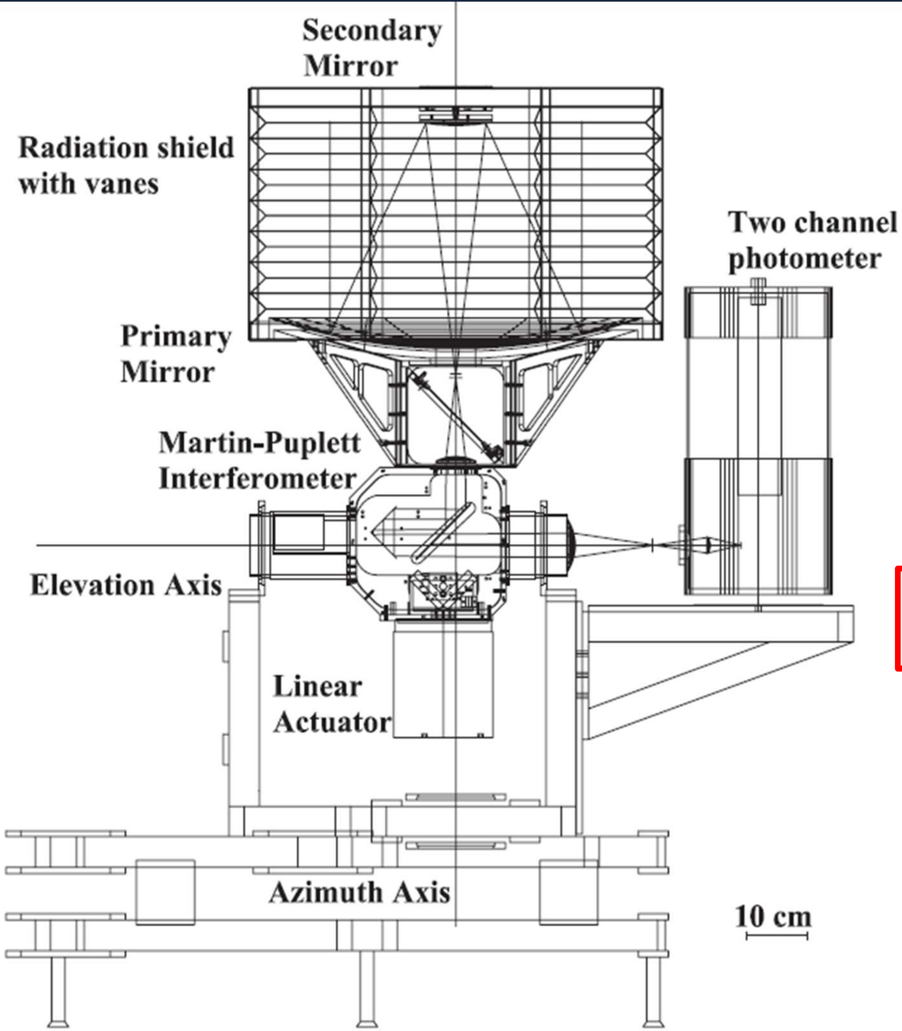
Dec 2014 - Jan 2015

First installation in Antarctica at Italian-French base, Concordia Station

(75° 05′ 59.25″ S - 123° 19′ 55.33″ E, 3220 m a.s.l.) ,close to the Astronomy Laboratory

CASPER – the instrument

62-cm reflective telescope + Martin-Puplett Interferometer + 0.3K detectors + altaz mount

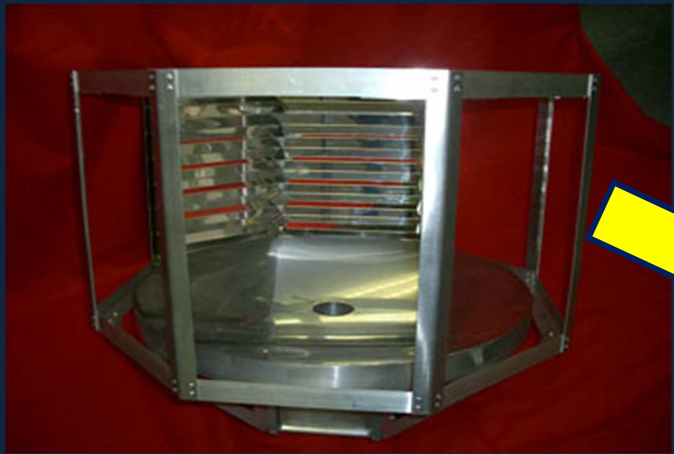


Telescope	f/3.5 Pressman–Camichel
Telescope effective focal length	1621 mm
Primary mirror diameter	620 mm
Primary mirror conic constant	0
Primary mirror curvature radius	978.4 mm
Secondary mirror diameter	120 m
Secondary mirror conic constant	8.86
Secondary mirror curvature radius	354.9 mm
Entrance pupil diameter	460 mm
Field of view (FWHM)	26 arcmin
$A\Omega$	0.05 cm^2 sr
Interferometer	Martin–Puplett
Spectral range	Channel 1: 90–360 GHz Channel 2: 90–450 GHz
Mechanical path difference	30 mm
Spectral resolution	5 GHz
Detectors	Two composite NTD bolometers @ 0.3 K
Calibrator	Eccosorb AN72
Mount	Altazimuthal
Star tracker field of view	1 arcmin
CCD field of view	(14.4 × 13.6) arcmin

CASPER – the instrument

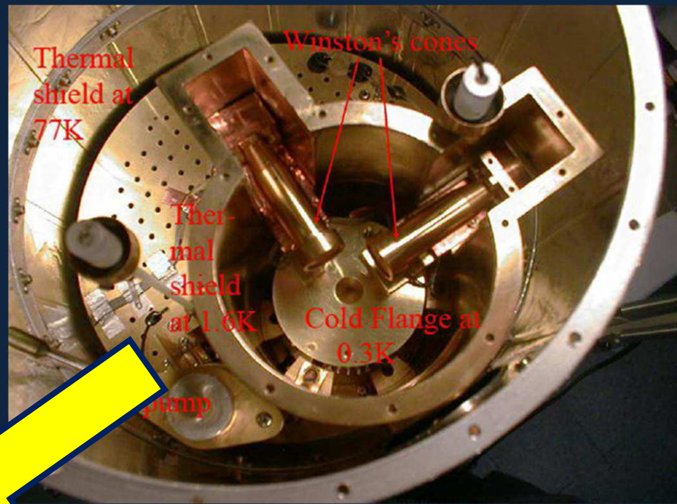
62-cm reflective telescope

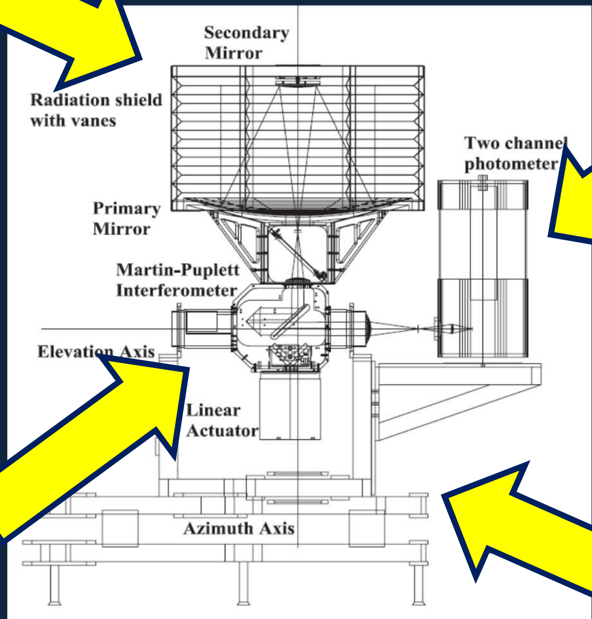
f/3.5 Pressman-Camichel config. / telescope shield with vanes / subreflector support in styrodur



Wet cryostat with 300 mK detectors

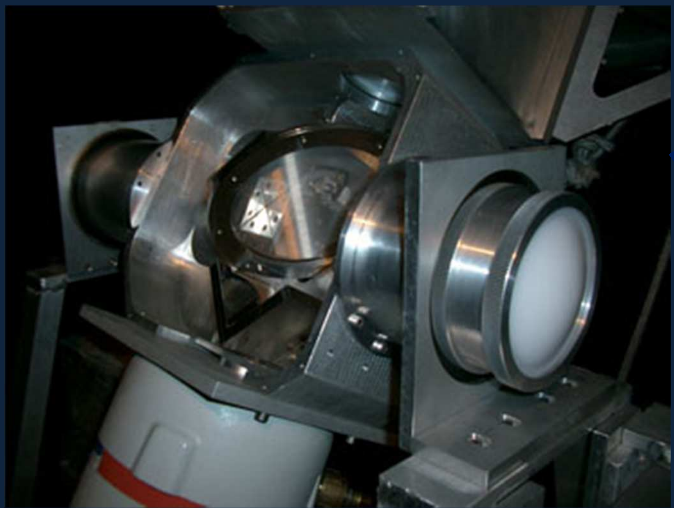
liquid nitrogen and helium tanks and a He3 fridge to cool down to 290 mK two Ge-bolometers





Martin-Puplett Interferometer

3 different kinds of phase modulations

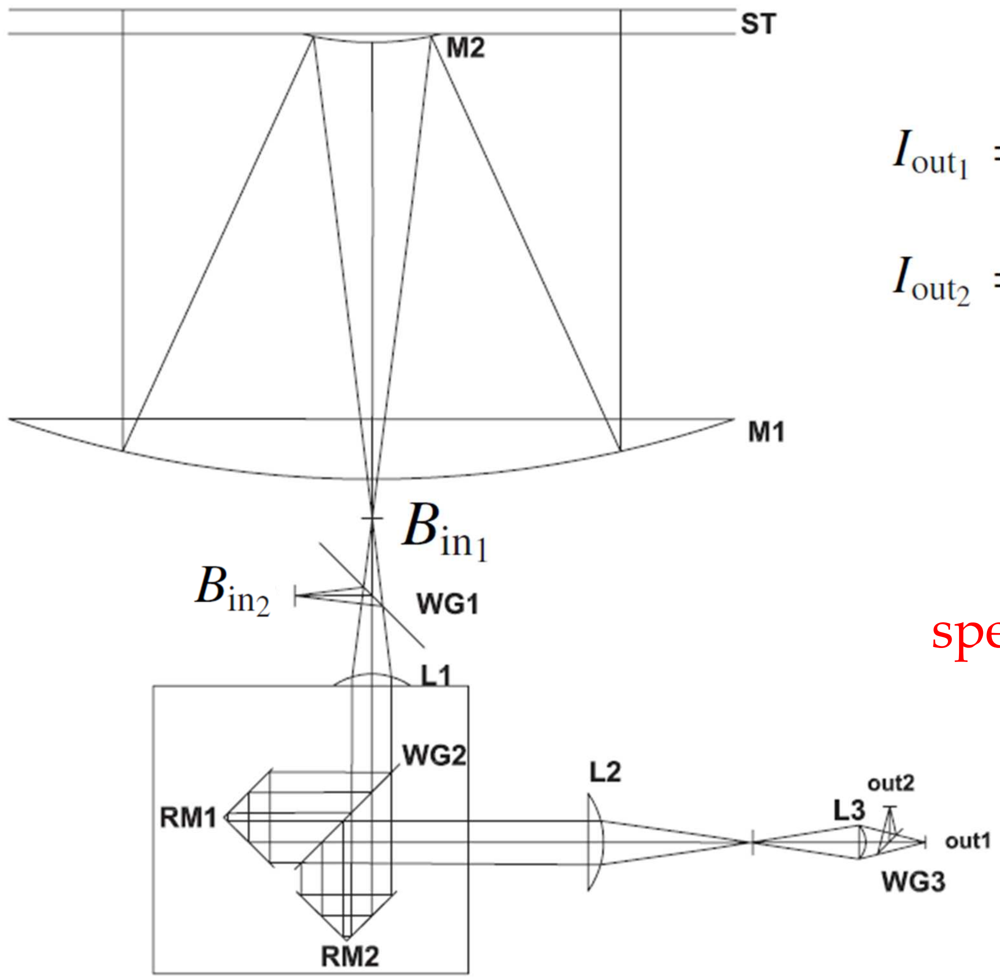


Altazimuthal mount

with a CCD camera as star-tracker

CASPER – the optics

f/3.5 Pressman-Camichel telescope 62-cm in dia + MPI : abs calibration procedure 1/2



$$I_{\text{out}_1} = \Delta^{+} + \Delta^{-}\cos\delta,$$
$$I_{\text{out}_2} = \Delta^{+} - \Delta^{-}\cos\delta.$$

interferograms

where

$$\Delta^{+} = B_{in_1} + B_{in_2}$$
$$\Delta^{-} = B_{in_1} - B_{in_2}$$

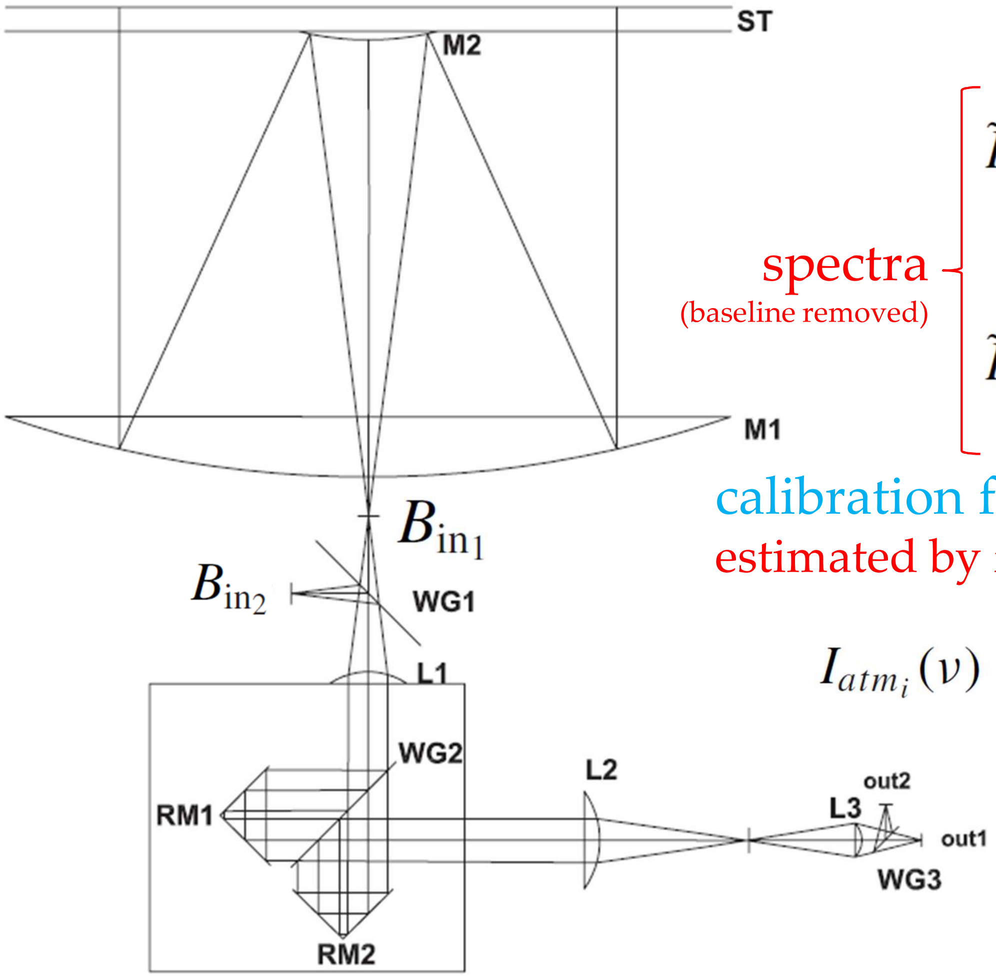
specific brightness of ..

$$B_{\text{in}_1}(\nu) = \epsilon_{\text{atm}}(\nu) BB(T_{\text{atm}}, \nu) + \epsilon_{\text{tele}}(\nu) BB(T_{\text{tele}}, \nu),$$

$$B_{\text{in}_2}(\nu) = BB(T_{\text{ref}}, \nu),$$

CASPER – the optics

f/3.5 Pressman-Camichel telescope 62-cm in dia + MPI : abs calibration procedure 2/2



spectra (baseline removed)

$$\begin{aligned}\tilde{I}_{out_1}(\nu) &= R_1(\nu)\varepsilon_1(\nu)A\Omega(\nu)\left[B_{in_1}(\nu) - B_{in_2}(\nu)\right] \\ &= F_1(\nu)\left[B_{in_1}(\nu) - B_{in_2}(\nu)\right],\end{aligned}$$

$$\begin{aligned}\tilde{I}_{out_2}(\nu) &= R_2(\nu)\varepsilon_2(\nu)A\Omega(\nu)\left[B_{in_2}(\nu) - B_{in_1}(\nu)\right] \\ &= F_2(\nu)\left[B_{in_2}(\nu) - B_{in_1}(\nu)\right].\end{aligned}$$

calibration functions

estimated by filling in_1 with a well-modeled source (77K BB)

$$I_{atm_i}(\nu) = \frac{I_{out_i}(\nu)}{F_i(\nu)} + BB(T_{ref}, \nu) - \epsilon_{tele}(\nu)BB(T_{tele}, \nu)$$

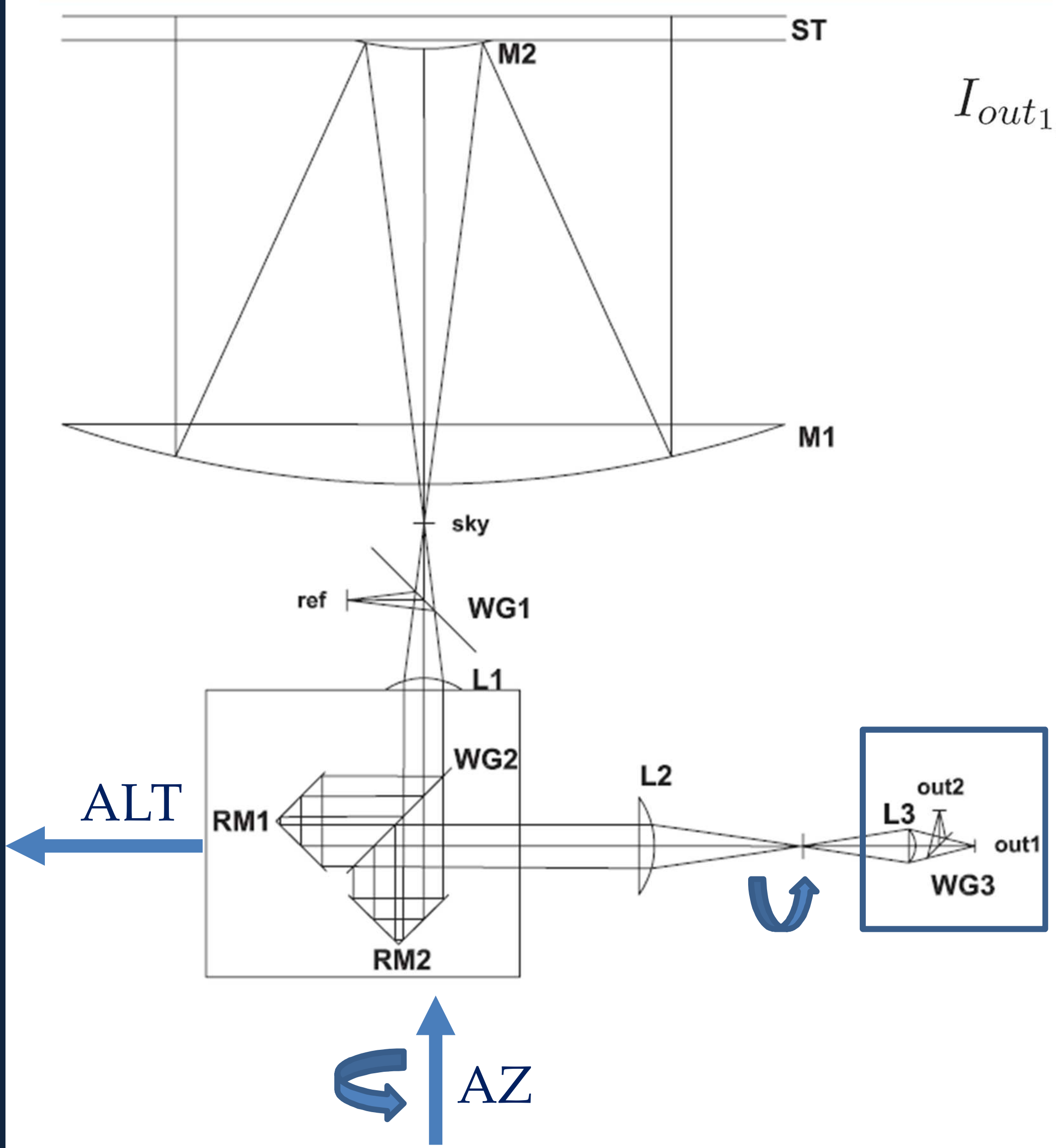
2 identical inputs = *Null* interferogram

To put a constraint on the minimum detectable contribution on the PWV content:
discriminate spectra with ΔPWV = 0.01 mm at least for PWV<1 mm

CASPER – the optics

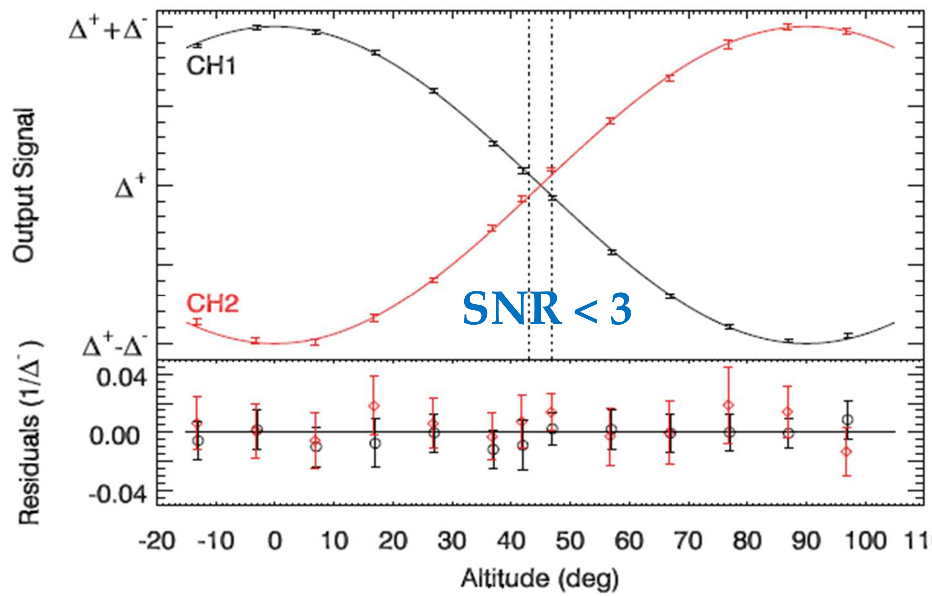
MPI efficiency *versus* telescope altitude

Fixed detector ⇨ dependence of ZPD output signals with altitude angle, α



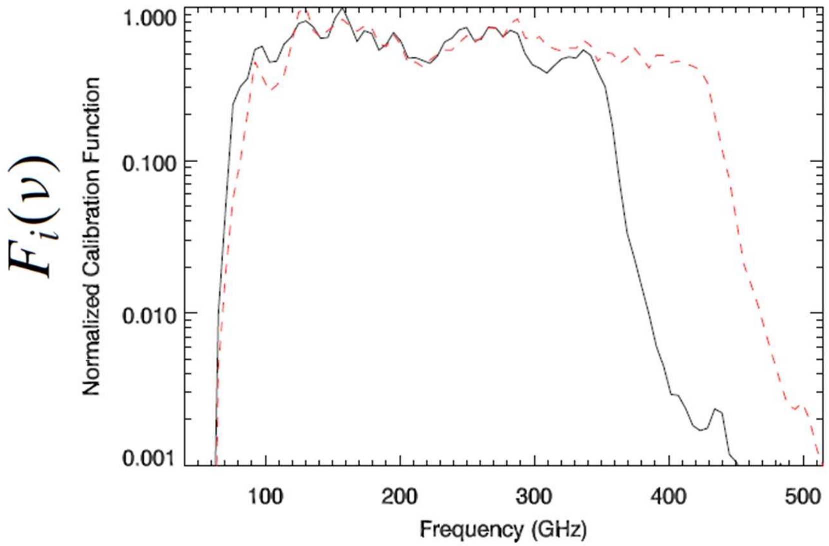
$$I_{out_{1,2}} = \Delta^{+} \pm \Delta^{-} cos2\alpha$$

$$\Delta^{+} = B_{in_1} + B_{in_2}$$
$$\Delta^{-} = B_{in_1} - B_{in_2}$$

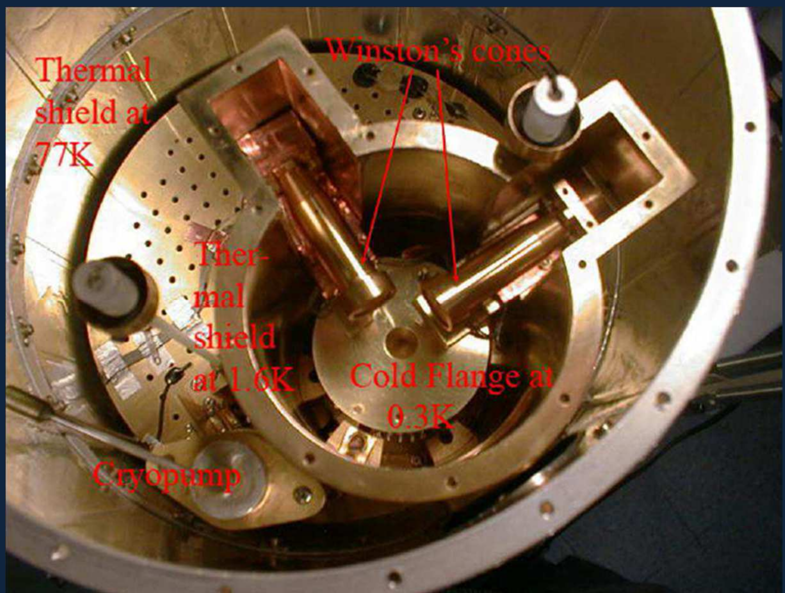


Blind region around alt= 45 deg

CASPER – cold detectors & bands



Type	Cut (GHz)	Temperature (K)
Quartz window	Off (>3000)	300
ARC quartz + black polyethylene	Off (>1200)	77
Yoshinaga	Off (>1650)	1.6
Mesh	Off (>450)	1.6
Yoshinaga	Off (>1500)	0.3
Mesh channel 1	Off (>360)	0.3
Mesh channel 2	Off (>450)	0.3
Winston cones	On (<90)	0.3



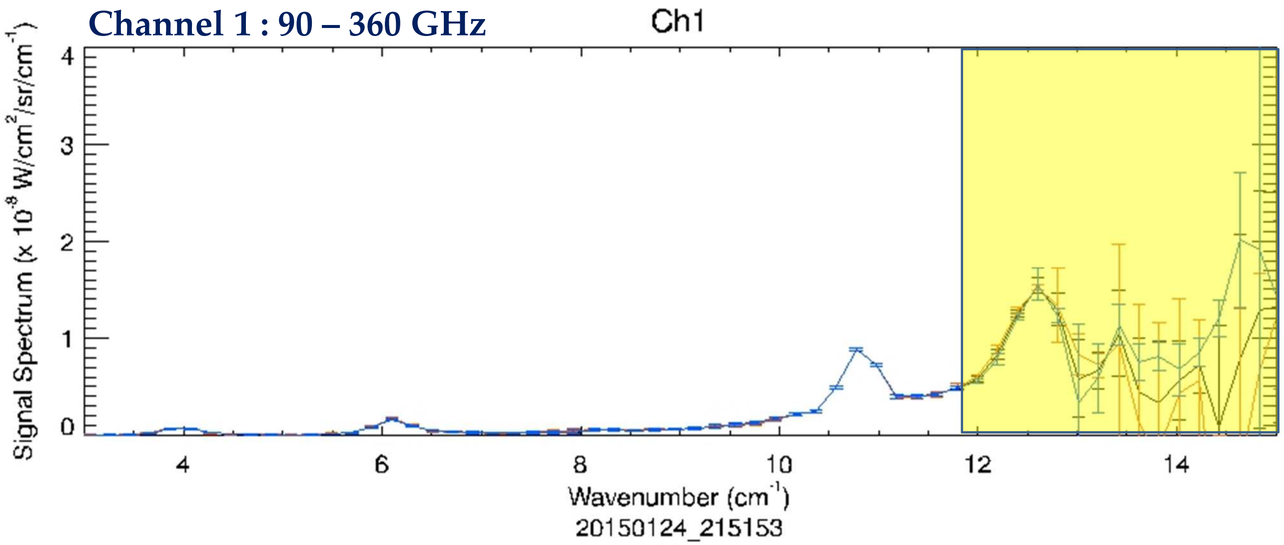
Channel 1 : 90 – 360 GHz
Channel 2 : 90 – 450 GHz
(to explore high-frequency atmospheric emission, more sensitive to PWV fluctuations)

2 Ge-bolometers with NEP ~ 10^{-15} W $Hz^{1/2}$ cooled down to 290 mK by a wet cryostat (Infrared Labs, HDL-8)

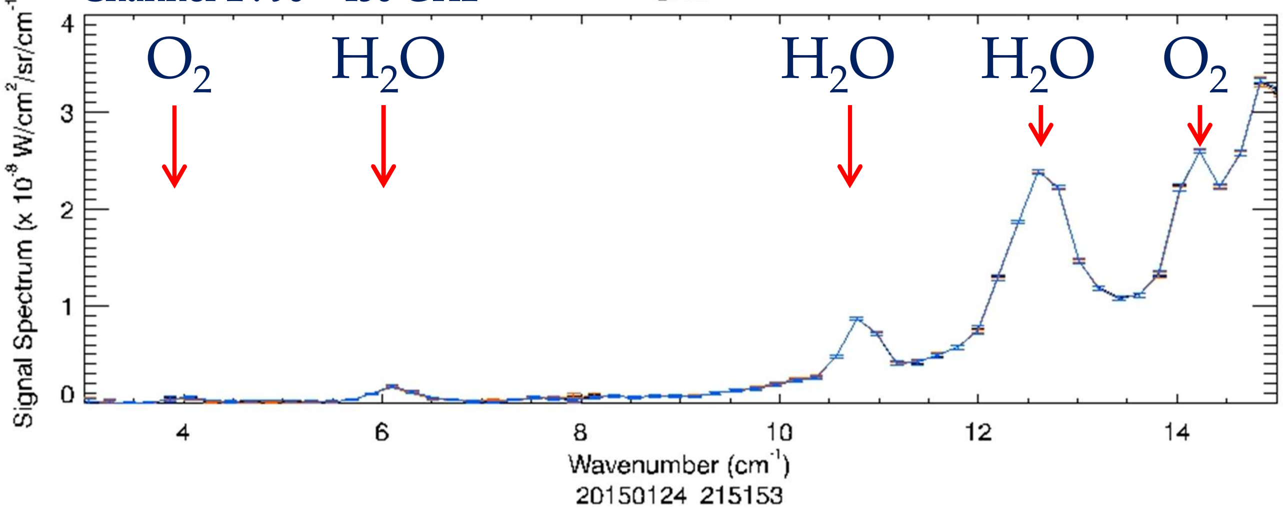
CASPER – 2 bands spectra

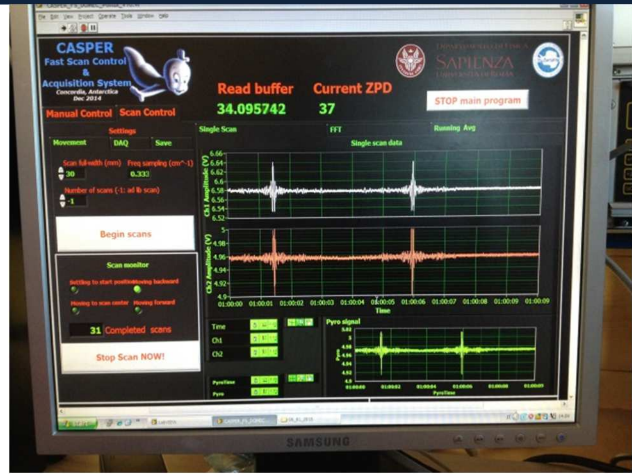
Atmospheric spectra and correlation between common range signals (Jan 24th 2015 DC)

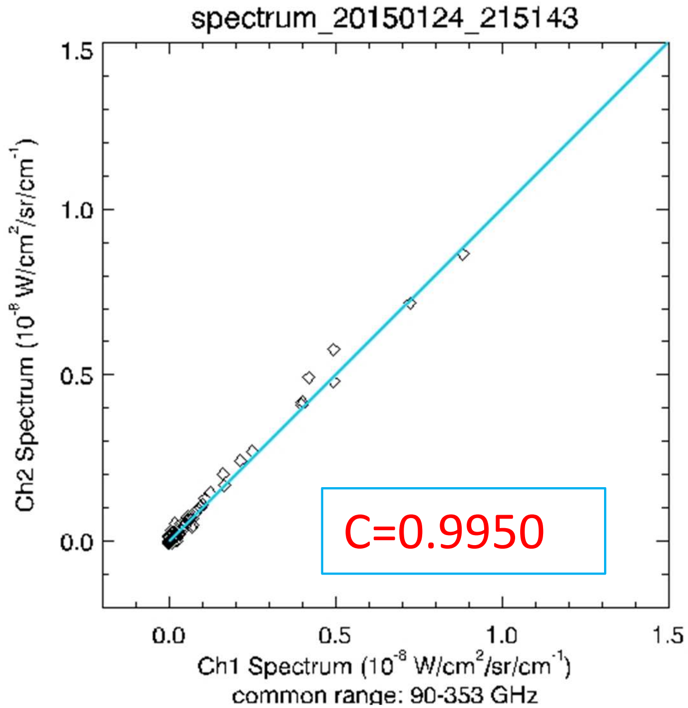
Channel 1 : 90 – 360 GHz



Channel 2 : 90 – 450 GHz

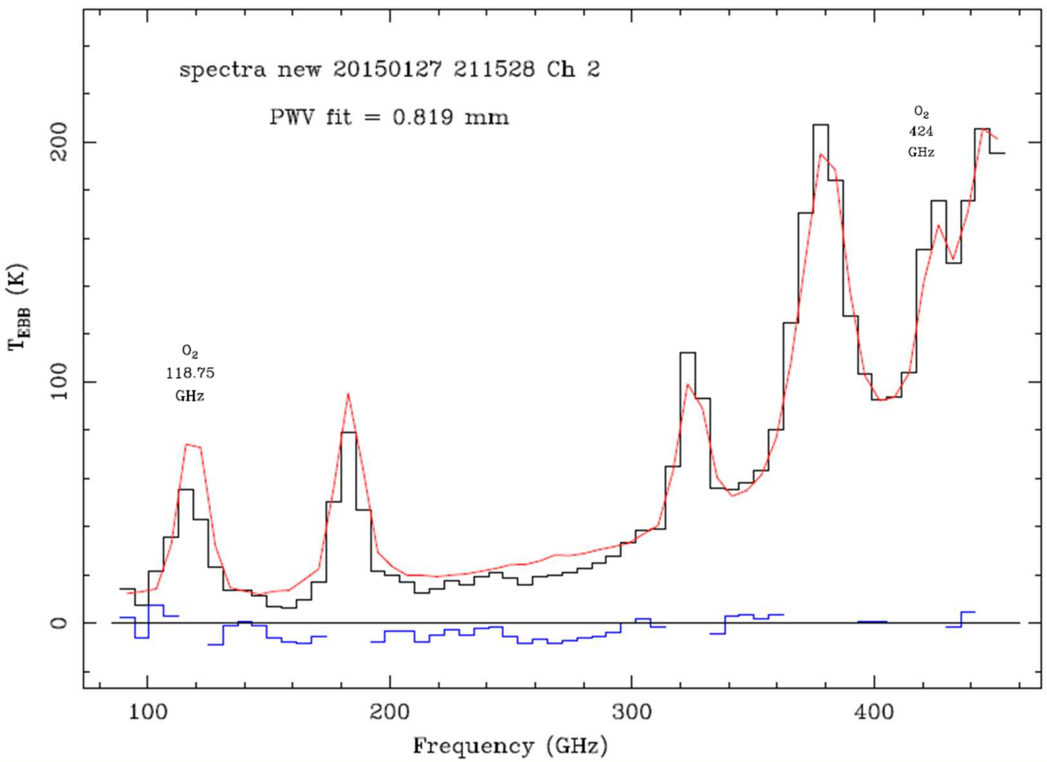


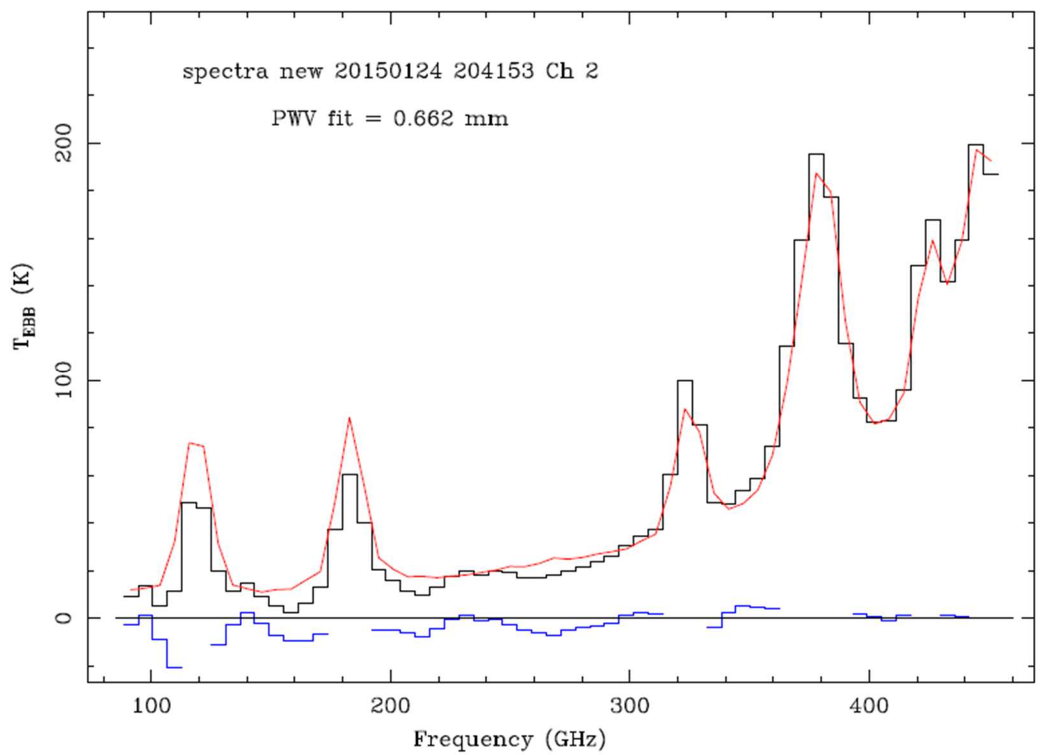




CASPER – pwv

Fit with ATM code to infer pwv content for two spectra, as an example





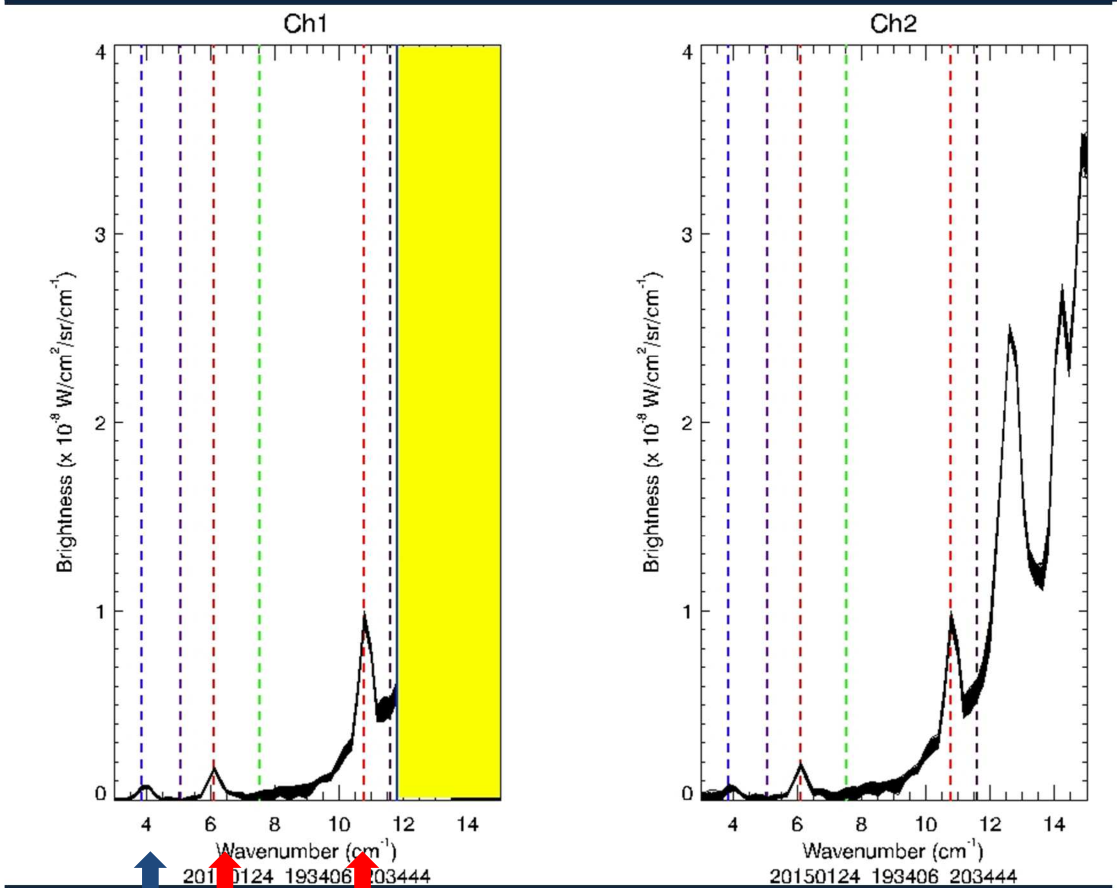
fits J.R. Pardo

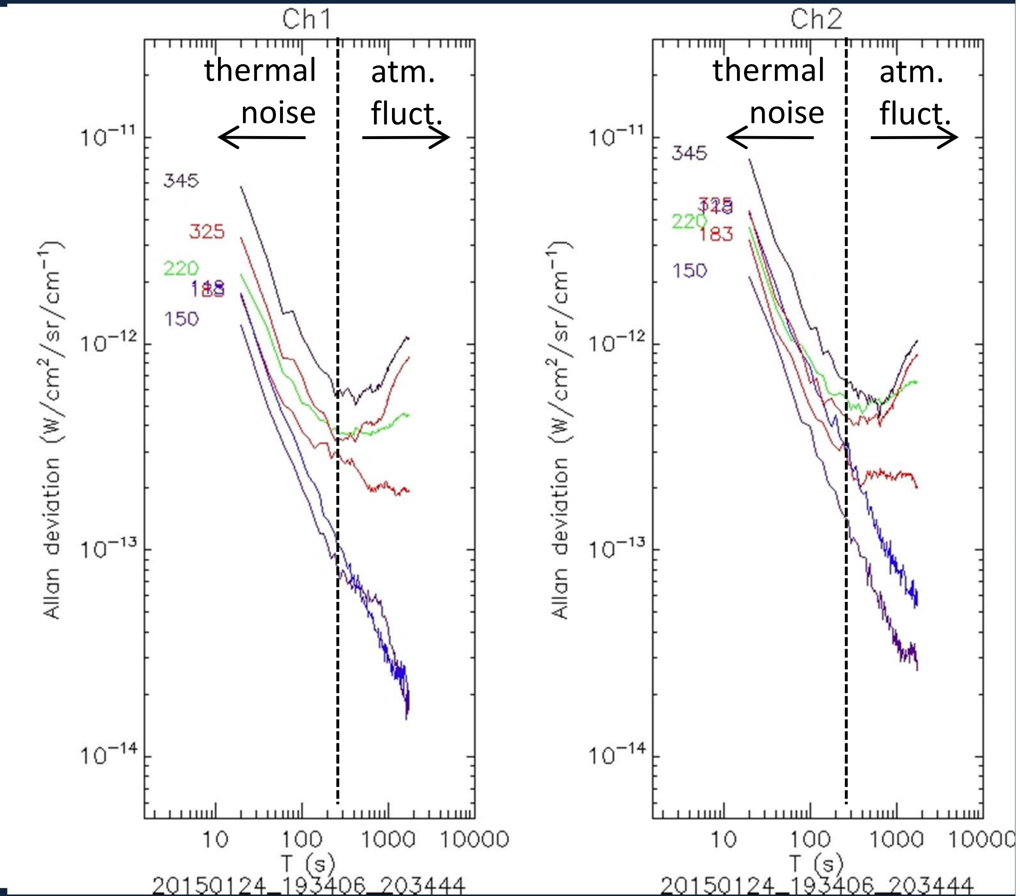
input 1 = SKY ; input 2 = BB_ref
T_BB_ref = 240.670 K
T_amb = 233.450 K
P_amb = 650.700 mbar
UR = 61.0000 %
Elevation: 90 deg
Procedure: Fast Scan
Clear sky: YES

input 1 = SKY ; input 2 = BB_ref
T_BB_ref = 243.150 K
T_amb = 233.350 K
P_amb = 647.700 mbar
UR = 64.0000 %
Elevation: 90 deg
Procedure: Fast Scan
Clear sky: YES

CASPER – atmosphere stability

Allan Variance estimated at 6 fiducial frequencies: in-band & out-band





O_2 118 GHz H_2O 183 GHz H_2O 325 GHz

180 atmospheric zenithal spectra recorded at DC (Jan 24th, 2015)

Maximum timescale ~200-300 s
to average multiple spectra
or
to achieve constant emission

Conclusions

- Installation and first observations (mm-spectra) with CASPER (wet cryostat version) at Dome C

- Preliminary results: pwv from zenith observations and atmosphere stability

- On-going analysis:

  - Complete the zenith obs and skydips to compare the opacities at mm/sub-mm bands and the pwv values with other *in-situ* observational approches;

  - Observations with polarization modulation.

Acknoledgements

- PNRA and IPEV for logistic support
- W. Jones and *SPIDER team* for providing us LHe4 from McMurdo
- COCHISE team for instrumental support on-site
- On-site meteo data and information were obtained from IPEV/PNRA Project "Routine Meteorological Observation at Station Concordia - www.climantartide.it.

Thank you for your attention!