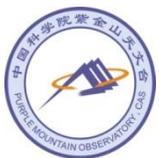


# THz/FIR Atmospheric Transmission Measured at Dome A

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Sheng-Cai Shi & Dome-A-FTS Team

Purple Mountain Observatory, CAS, CHINA  
Key Lab of Radio Astronomy, CAS, CHINA

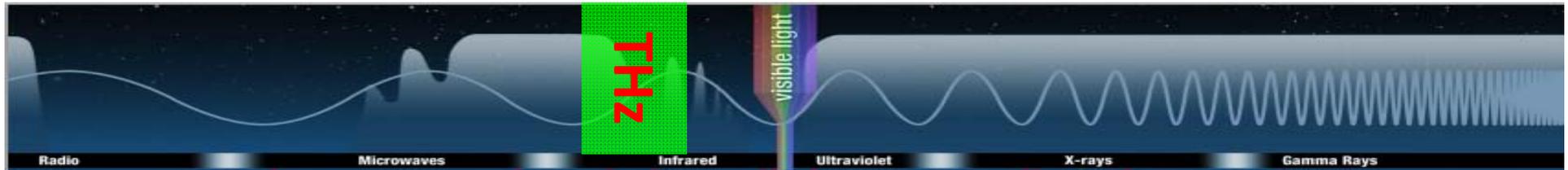


# Outline

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- Introduction
- Dome A Fourier transform spectrometer
- THz/FIR atmospheric transmission measured at Dome A
- Antarctic Observatory at Chinese Kunlun Station & DATE5 Telescope
- Summary

# Uniqueness of THz/FIR Astronomy



Observation at THz/FIR band -- probing cold universe: colder (in formation), earlier, dust-obscured objects, more spectral-line probes

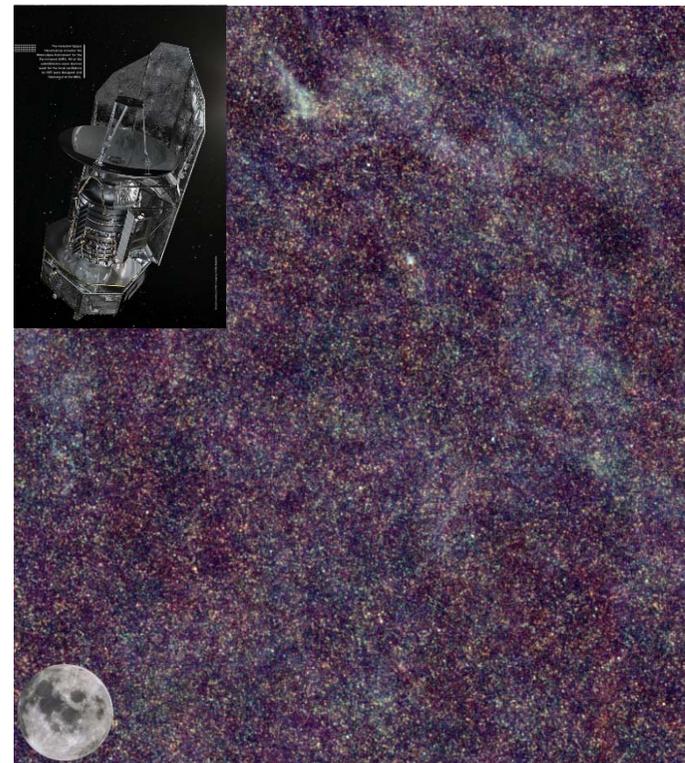
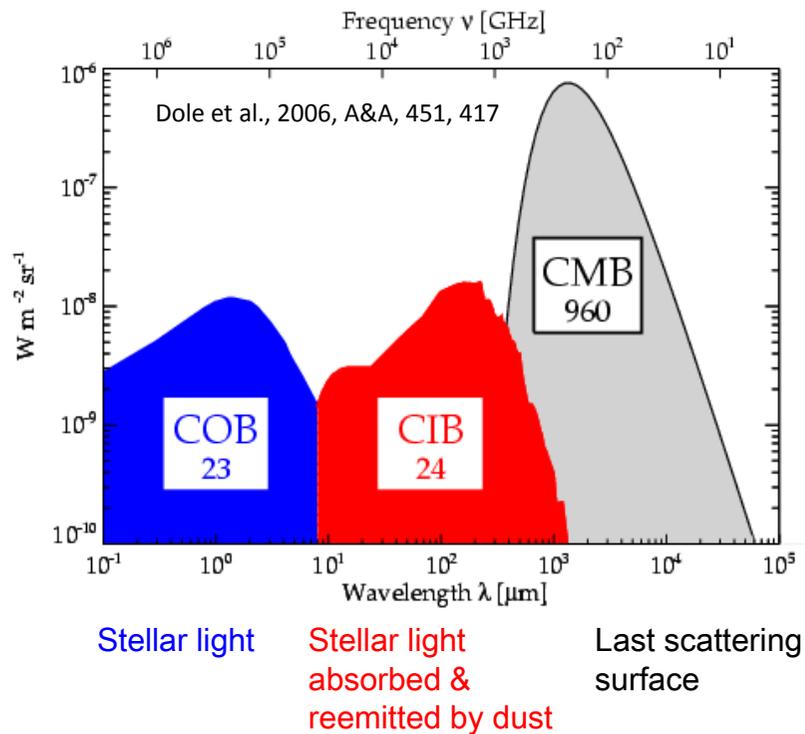
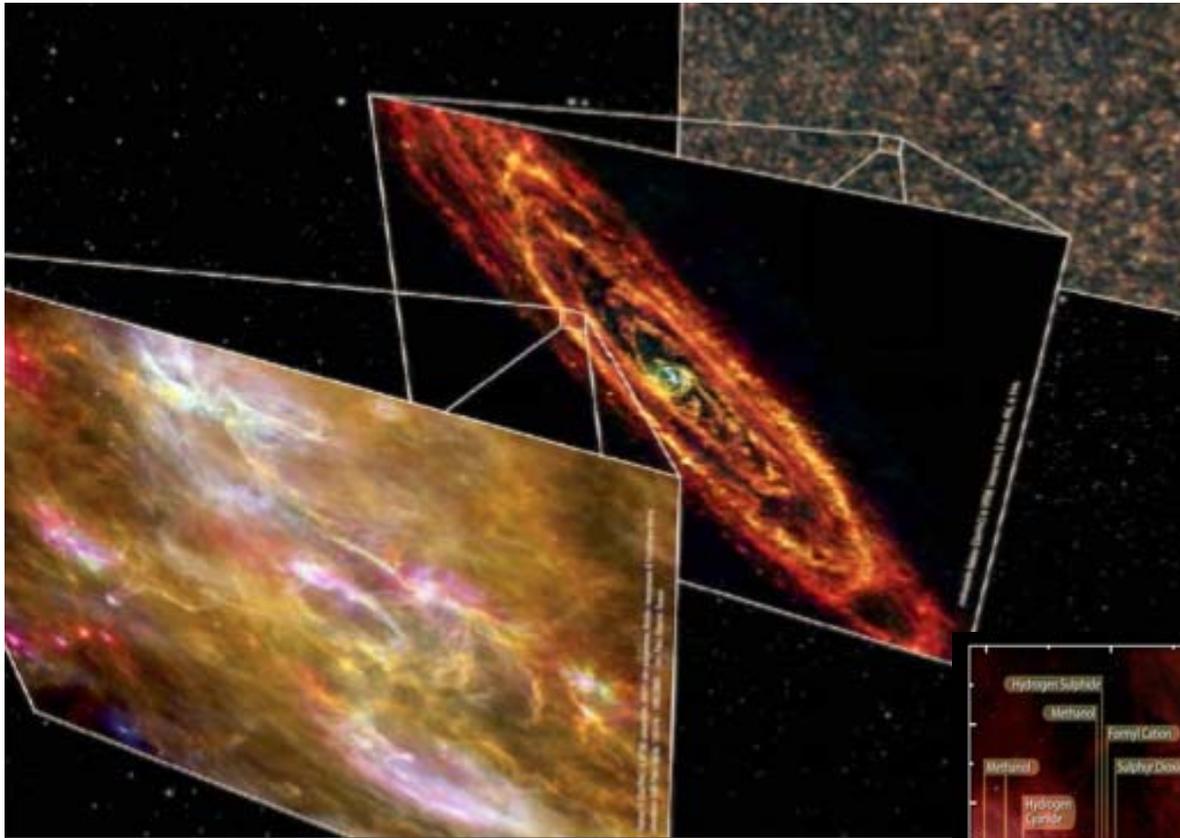
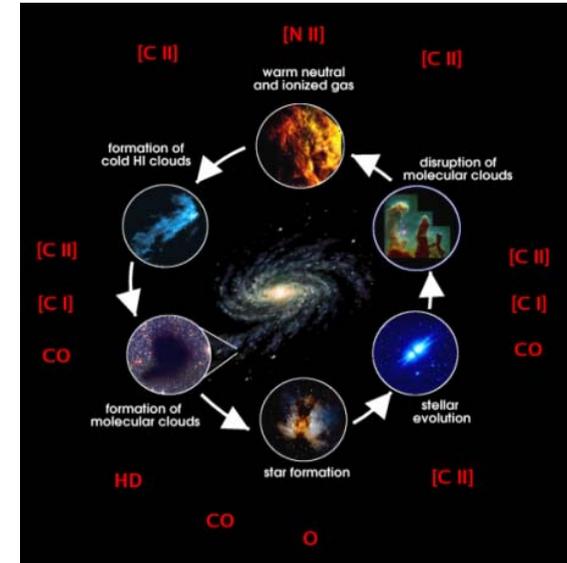


Image credit: Dole/ivison/ESA

# Higher Resolution & More “Fingerprints”

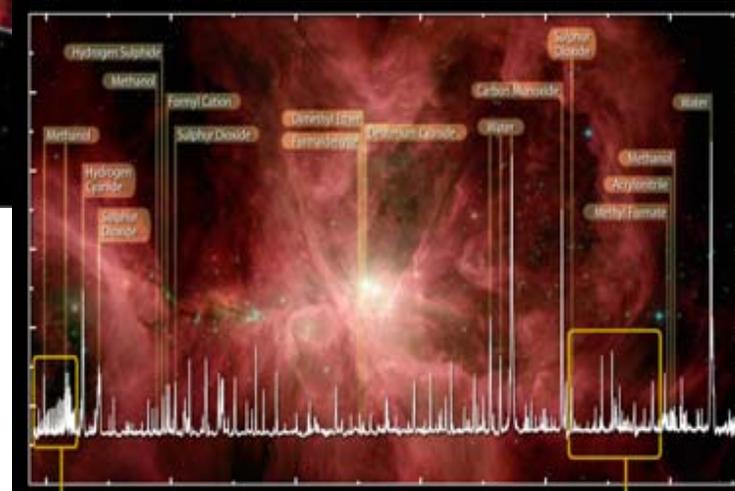


Higher resolution at THz/FIR

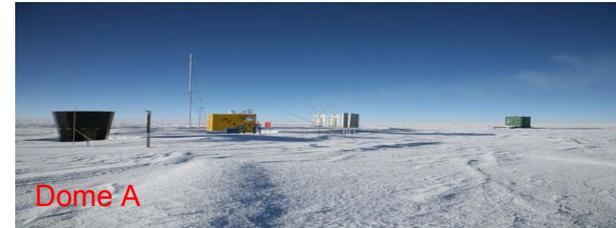
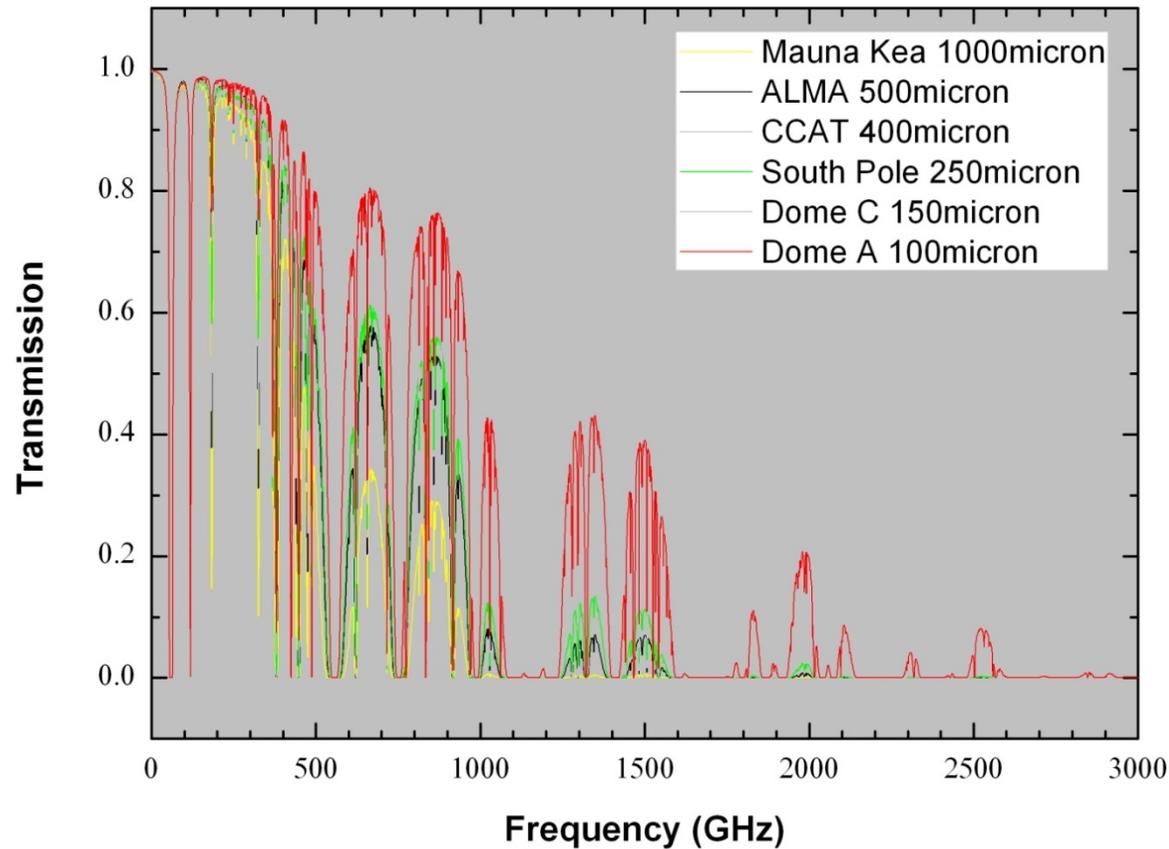


Ecology of ISM

THz “forest” in Orion observed by Herschel/HIFI

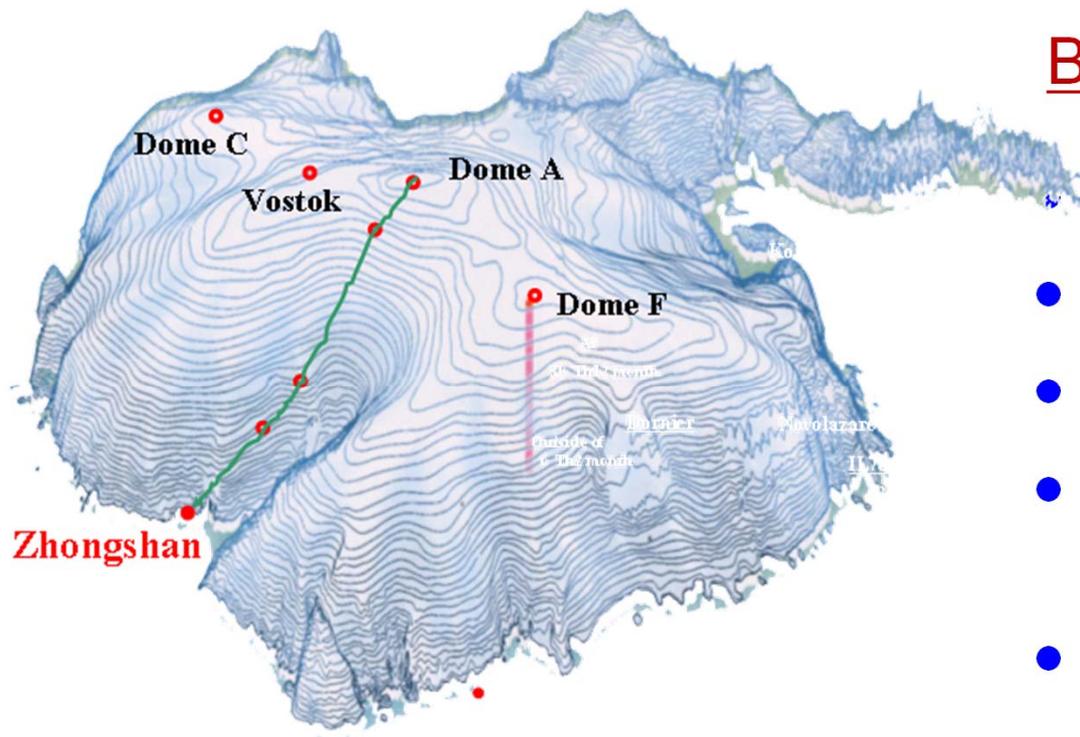


# Sites for THz/FIR Observatory?



# Where is Dome A in Antarctic?

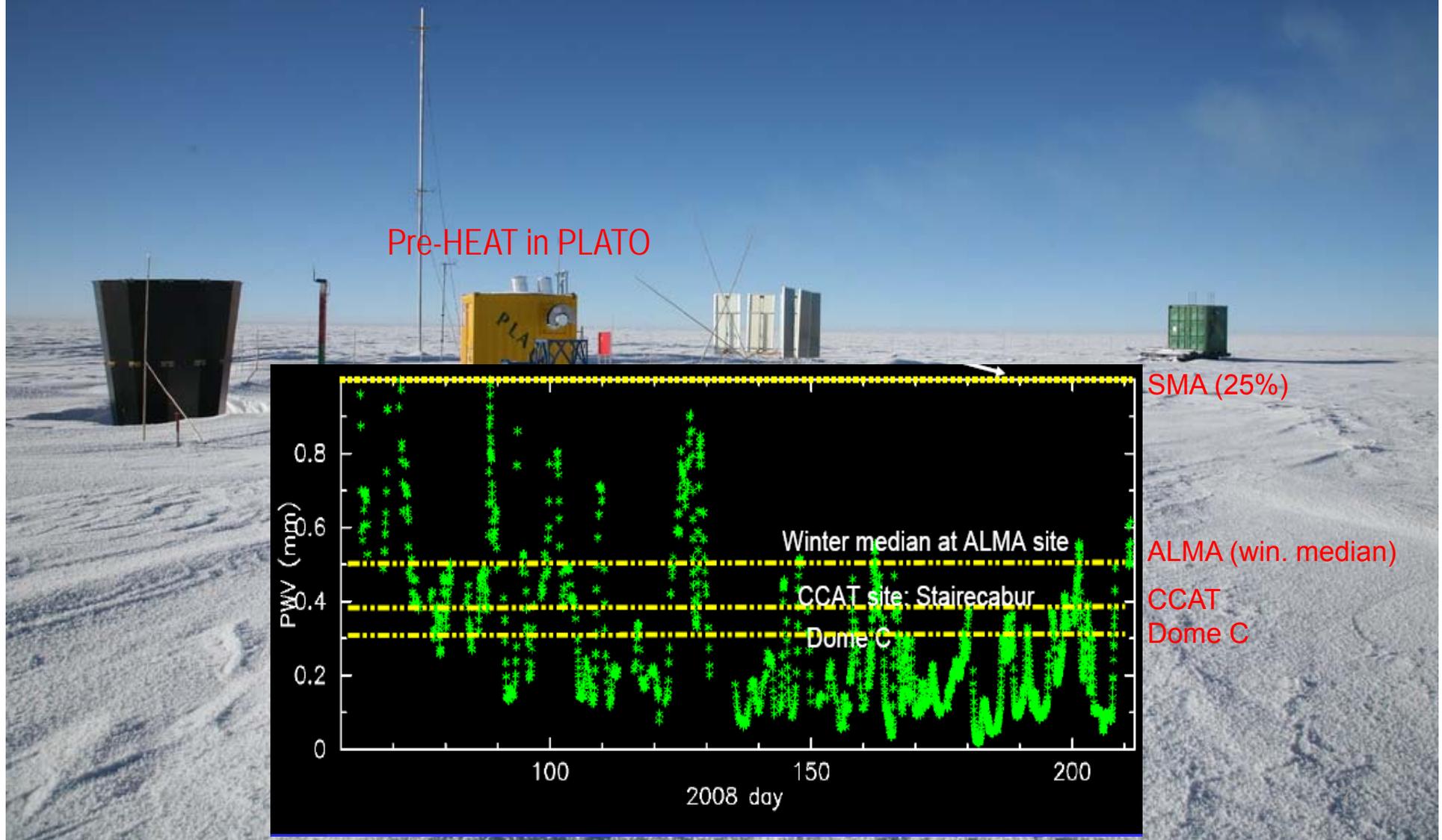
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## Basic facts about Dome A

- Altitude: 4093m (60km×10km)
- Lowest temp: -83°C
- A plateau of small fluctuation
- 1300km from China's Zhongshan station
- Extremely good THz/IR windows

# Radiometric Measurement by Pre-HEAT at 661GHz at Dome A



# Why Deploy an FTS to Dome A?

	Band	Method	Temp Calibration	$\tau$ Range	Systematic error	Other Freq
Radio-meter	single freq	tipping with $z$ , $P_{IF}(z) \rightarrow \tau_0$	not	good with small $\tau_0$	large	modeling
FTS	large	$T_{sky}(\nu)$ at fixed $z \rightarrow \tau_z(\nu)$	yes	reliable for $\tau \sim 5$	small	measuring

**Note:** Other methods (satellites, Nigel spectrometer) have limited accuracy at low PWV.

## Dome A FTS

- ✓ Systematic measurement of the atmospheric emission at Dome A in a large bandwidth (0.75~15THz)
- ✓ With broad spectral coverage, better water vapor continuum modeling (not well tested at low temperatures)

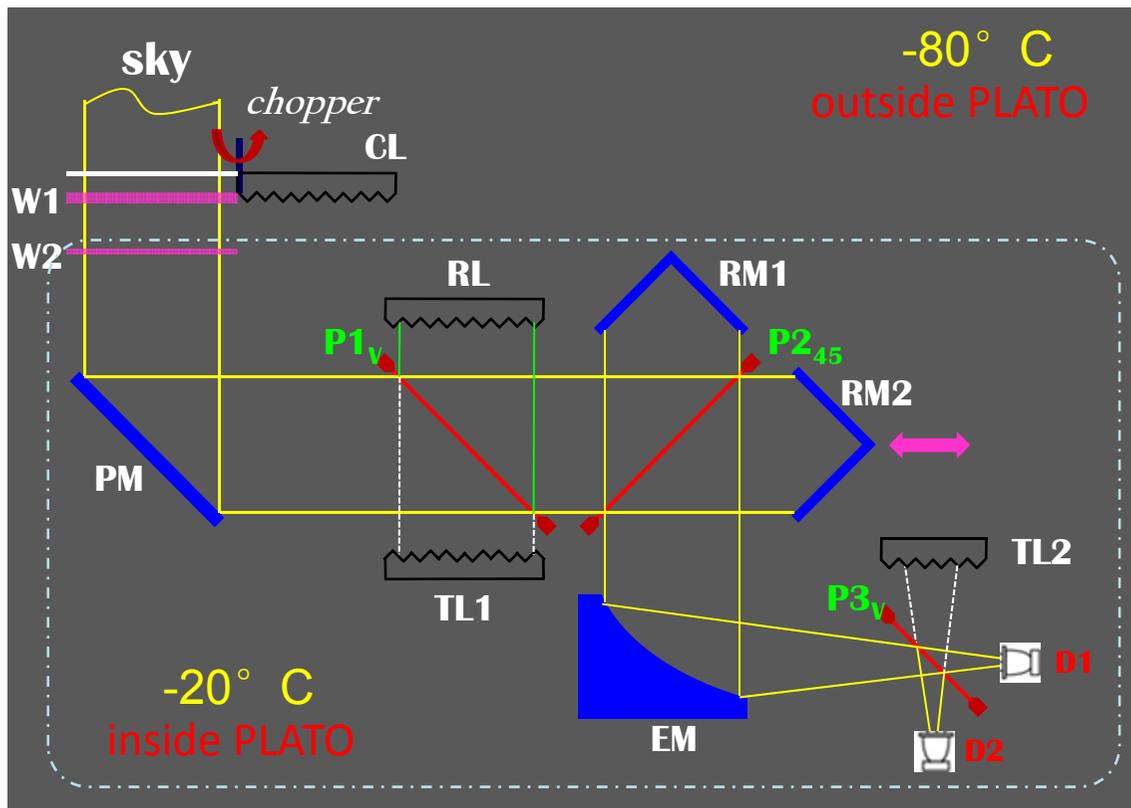
# Technical Challenges & Specs

## Technical Challenges

- ✓ unattended operation
- ✓ long duration (>1yr)
- ✓ largest bandwidth to cover FIR windows
- ✓ LNe not available → *no low-temp calibration*
- ✓ cryogenically cooled detectors cannot be used → *limited sensitivity*

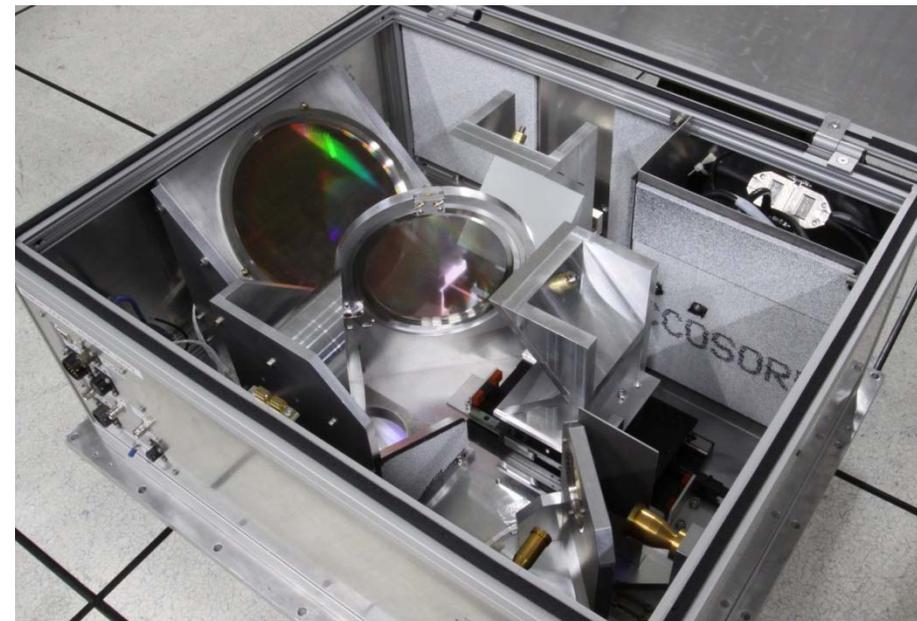
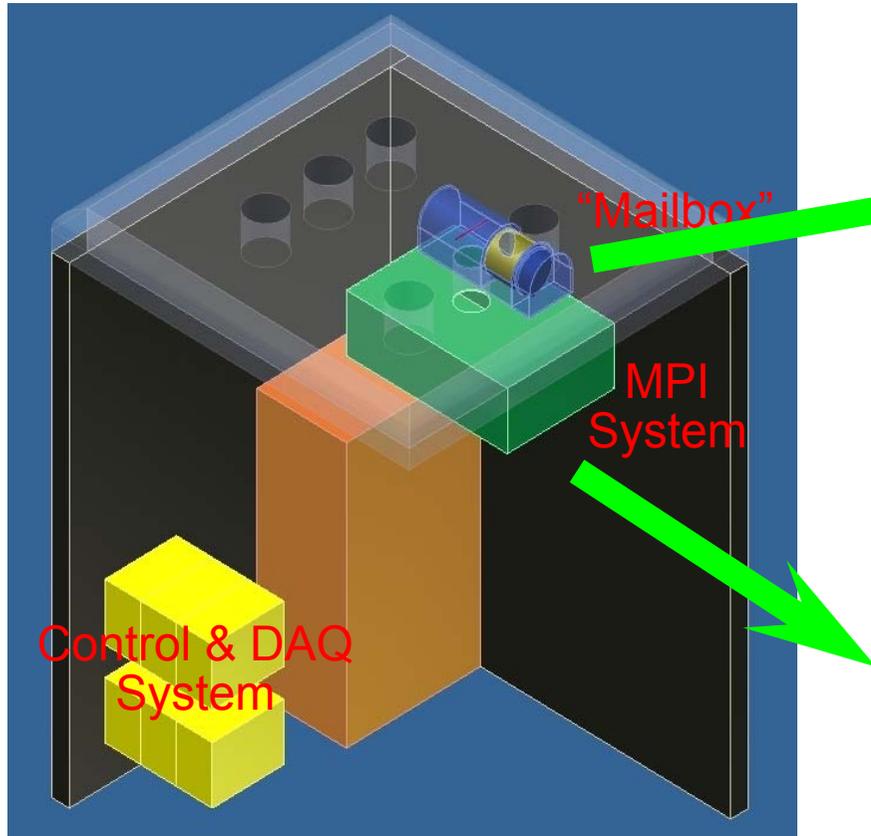
Mode	rapid scan
Freq. range	0.75-15THz (0.75-3.6THz & 0.75-15THz)
Freq. resolution	10GHz (13.8GHz)
Beam aperture	75mm
DLATGS NEP	$\sim 5 \times 10^{-10} \text{W/Hz}^{0.5}$
Time/Spectrum	~10mins
MPI volume	0.7mx0.7mx0.3m
Power	<200W

# Design of Dome A FTS



- two passive loads with CL at  $-80^{\circ}\text{C}$  and RL at  $-20^{\circ}\text{C}$  for calibration
- two orthogonal output polarizations with different LPFs (lo & high bands), with better sensitivity at low band with larger throughput and keeping the dynamic range manageable
- RT DLATGS detectors adopted

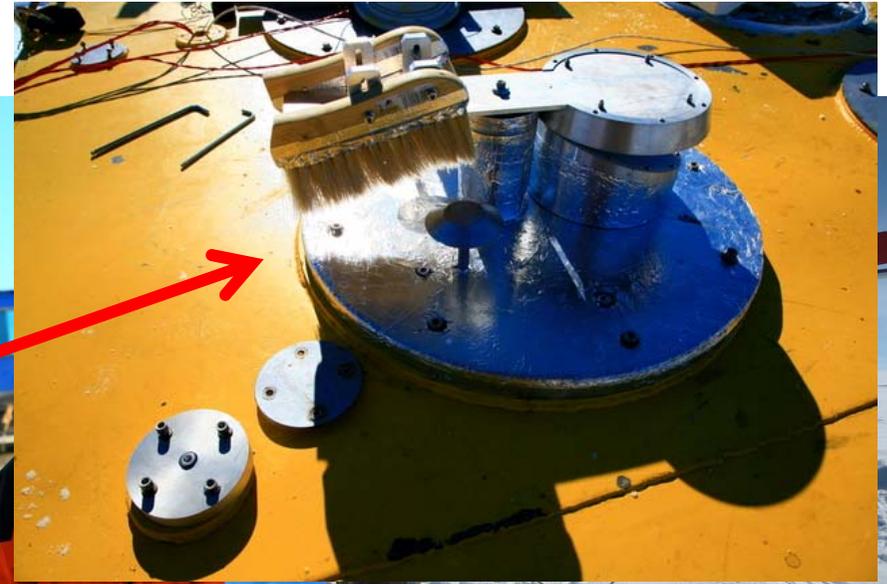
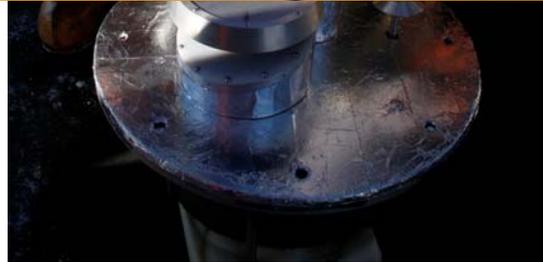
# Joint Development of Dome A FTS



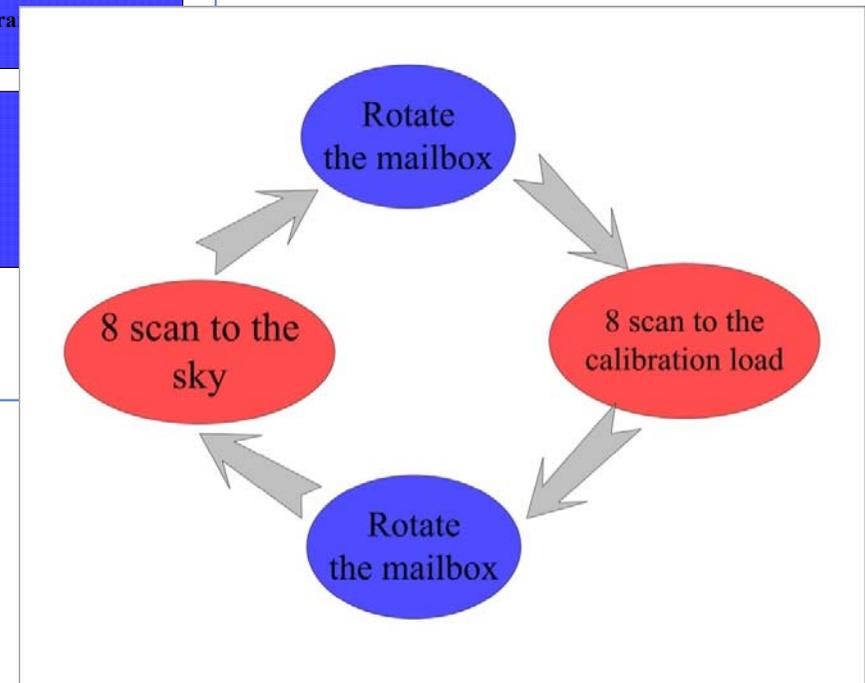
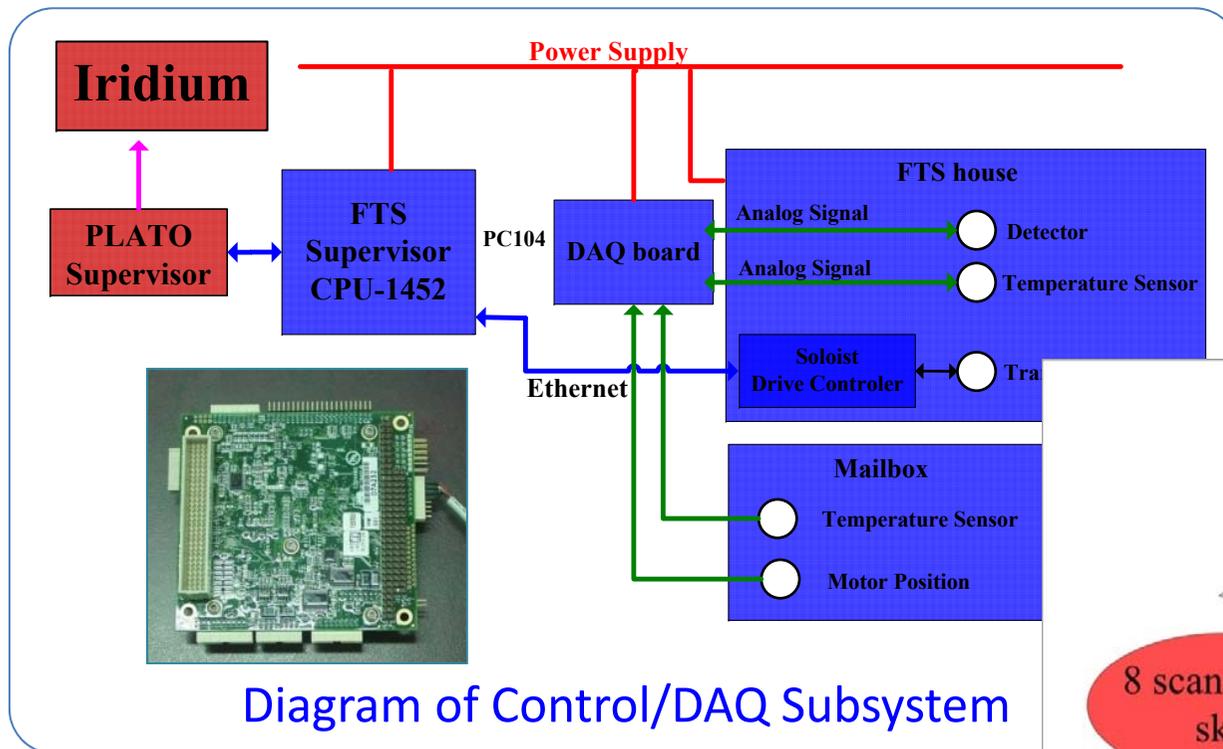
MPI fabricated by BlueSky  
DLATGS detectors provided by QMC

# Deployment of Dome A FTS

- Brush: count-balance & cleaning snow



# Control & Data Acquisition

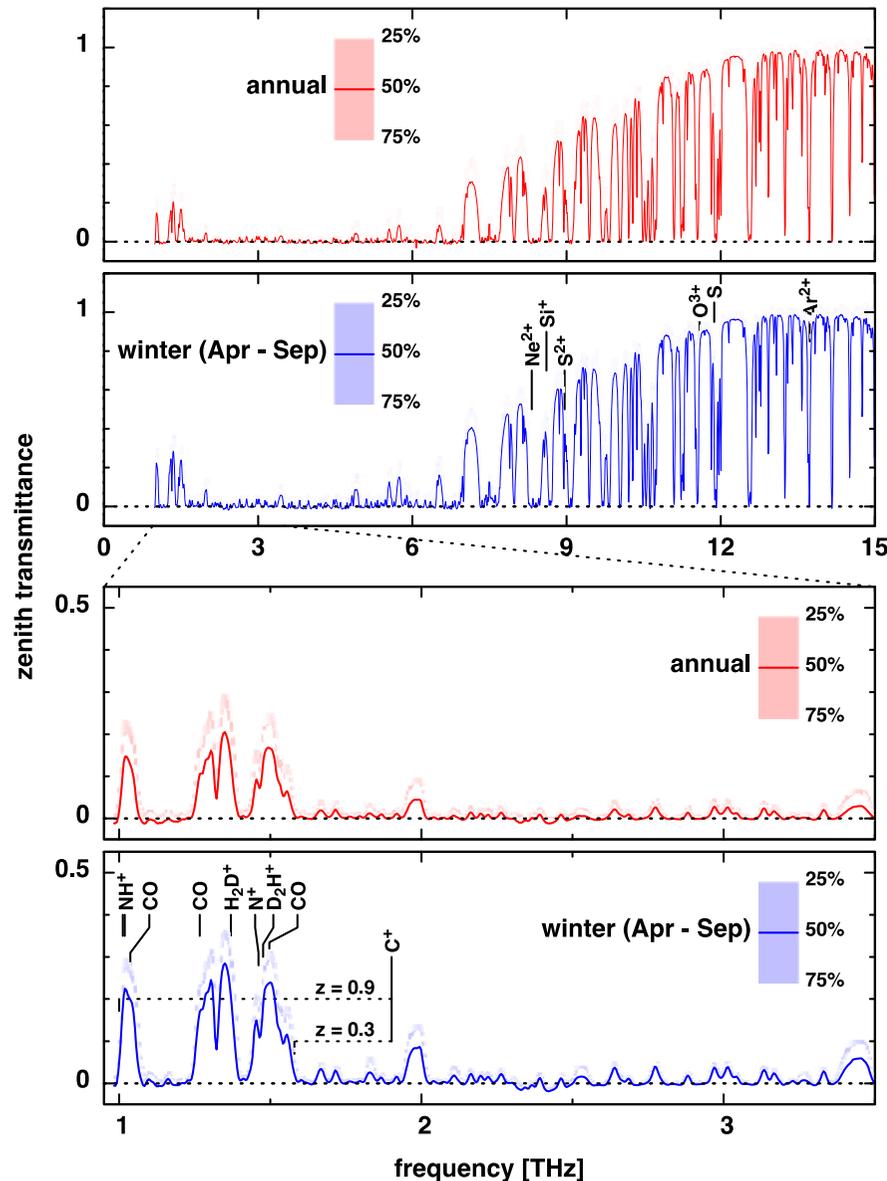


# Remote Operation of Dome A FTS

FTS status	
Jan 18-26 2010	Instrument installation at Dome A
Jan 27-Feb 28 2010	Testing measurement
Mar 1, 2010- Aug 3, 2011 (513days)	Normal operation at Dome A, including 8 days for maintenance. <b>Producing good data in 470days, about ~92%.</b>
Aug 4-	Stop working

```
1622043 200 -rw-r--r-- 1 root root 200323 Mar 21 03:56 ./Mar/21/2010Mar21_034728.igm
1622044 200 -rw-r--r-- 1 root root 200323 Mar 21 04:05 ./Mar/21/2010Mar21_035634.igm
1622045 200 -rw-r--r-- 1 root root 200323 Mar 21 04:14 ./Mar/21/2010Mar21_040539.igm
1622046 200 -rw-r--r-- 1 root root 200323 Mar 21 04:23 ./Mar/21/2010Mar21_041444.igm
```

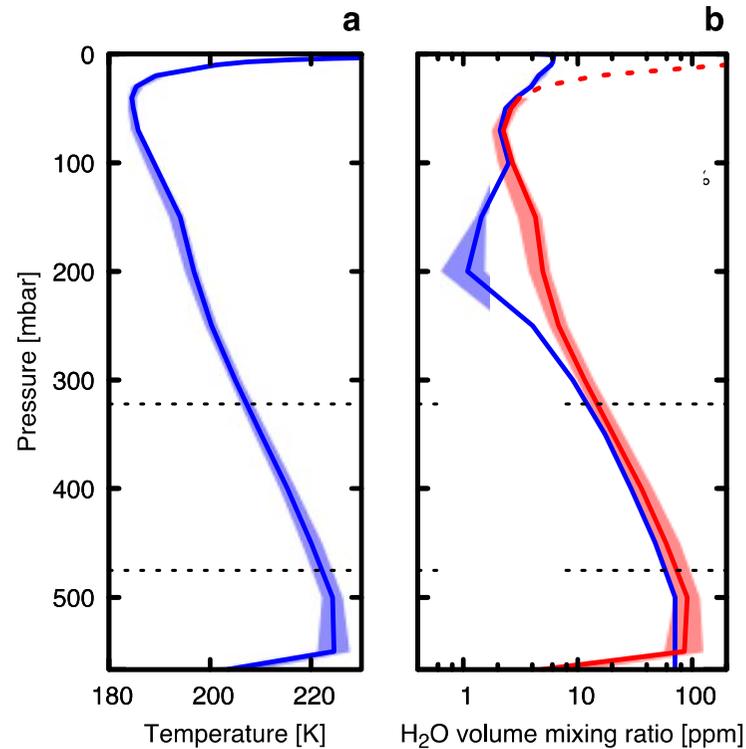
# Transmittance Computation & Statistics



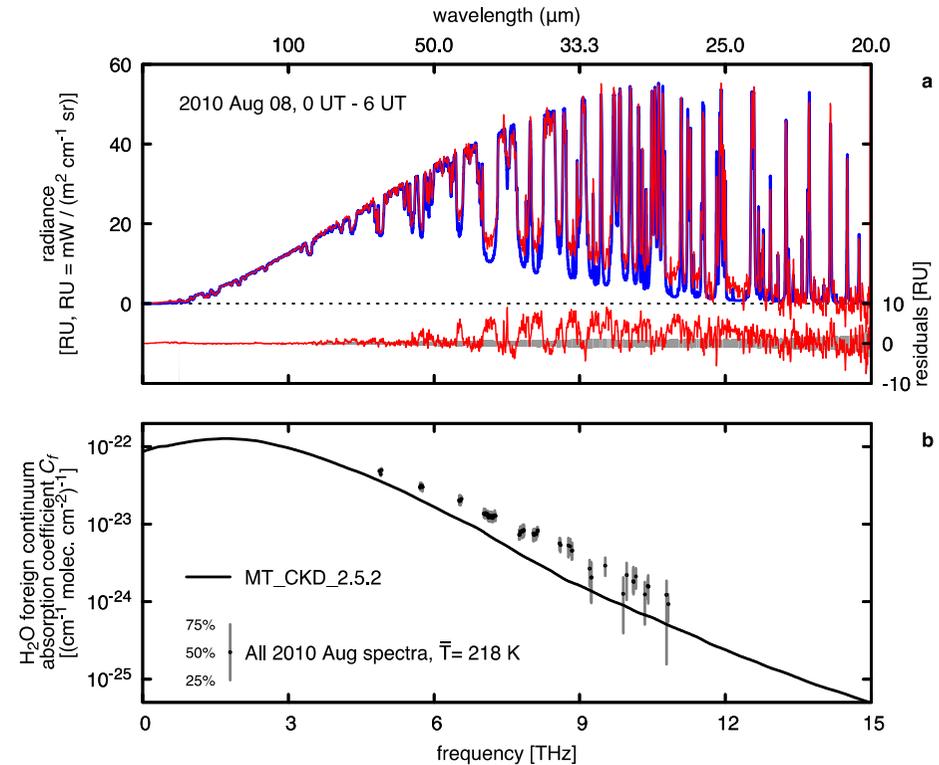
- ✓ A de-biasing procedure used to correct for uneven sampling over the calendar year
- ✓ Adopting isothermal radiative transfer approximation
- ✓ Deriving  $T_{atm}$  using the opaque channels forming the Planck baseline
- ✓ Absorption loss of HDPE window well calibrated
- ✓ Adopting complex-domain calibration method

*arXiv:1609.06015, 2016*

# Continuum Adjustment Statistics



Atmospheric profiles over Dome A, Antarctica during the August 2010 study period. Median vertical profiles of temperature (a) and H<sub>2</sub>O volume mixing ratio (b) during August 2010, derived from the NASA MERRA reanalysis



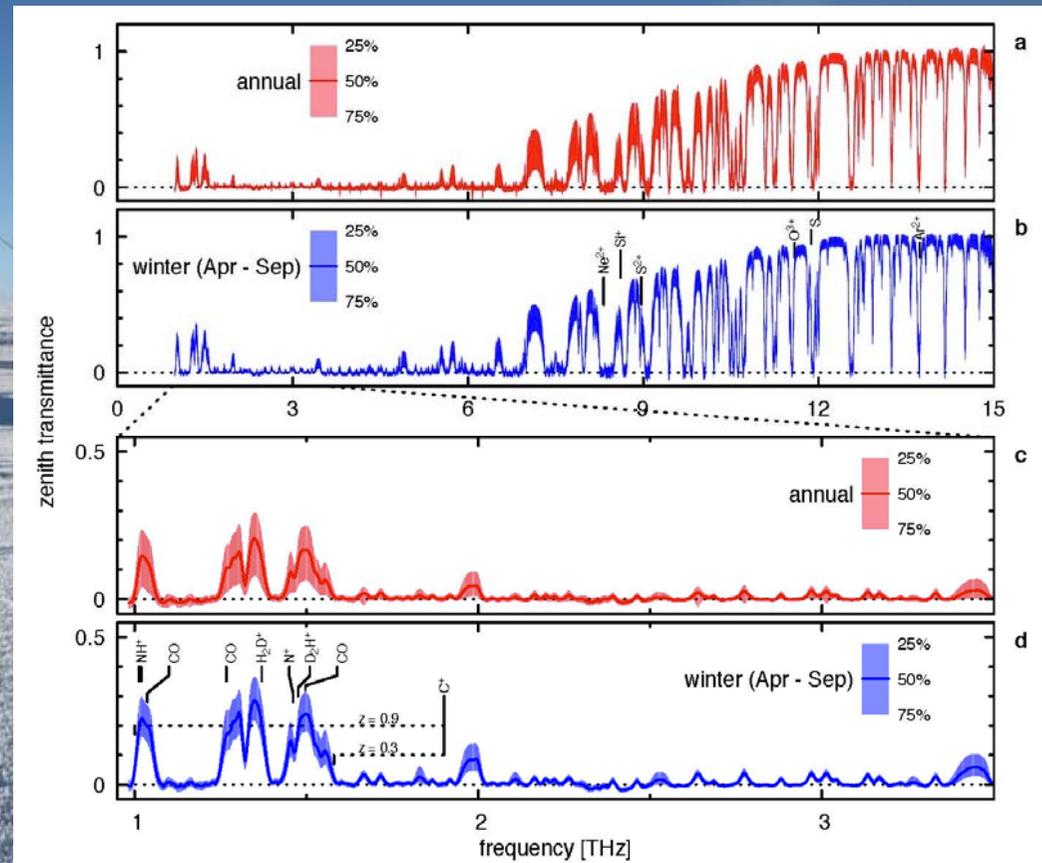
H<sub>2</sub>O foreign continuum correction derived from spectral residuals

# Terahertz and far-infrared windows opened at Dome a in Antarctica

Sheng-Cai SHI et al., Nature Astronomy 1, 0001 (2016)



Unmanned Dome A FTS deployed to Dome A



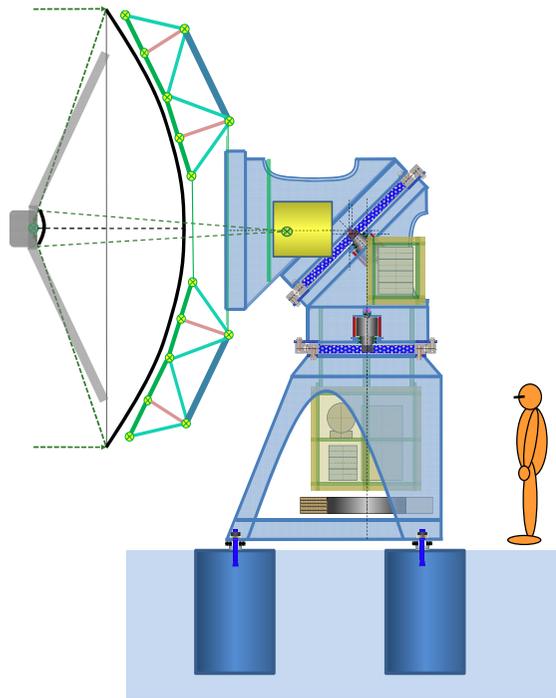
Measured THz/FIR transmission at Dome A in Antarctic

# Antarctic Observatory at Chinese Kunlun Station & DATE5



Antenna	Cassegrain
Diameter	5m, with rms accuracy $<10\mu\text{m}$
Band	450/350/200 $\mu\text{m}$
Receiver	1x4 SIS & 1x4 HEB mixer
IF BW	4GHz x 4 beams x 2 bands
FOV	5'x5' ( 200 $\mu\text{m}$ )
Pointing	$\leq 2''$

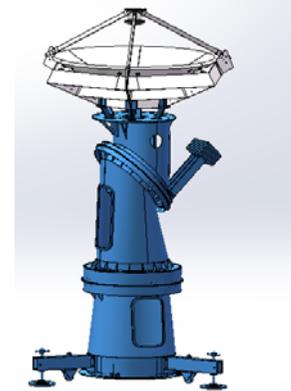
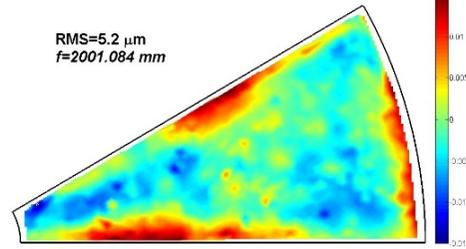
# Development for DATE5 Telescope



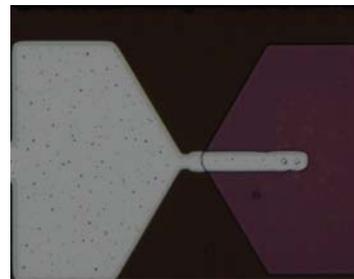
preliminary design of DATE5



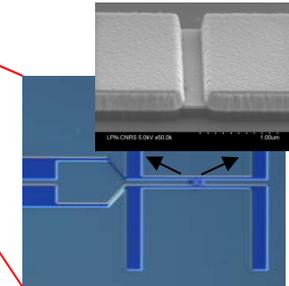
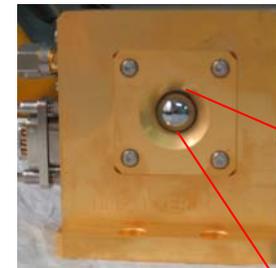
CFRP (1100×600mm)



1.2m scale model



0.85THz SIS mixer

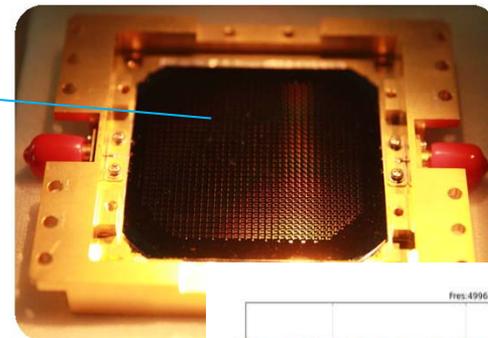
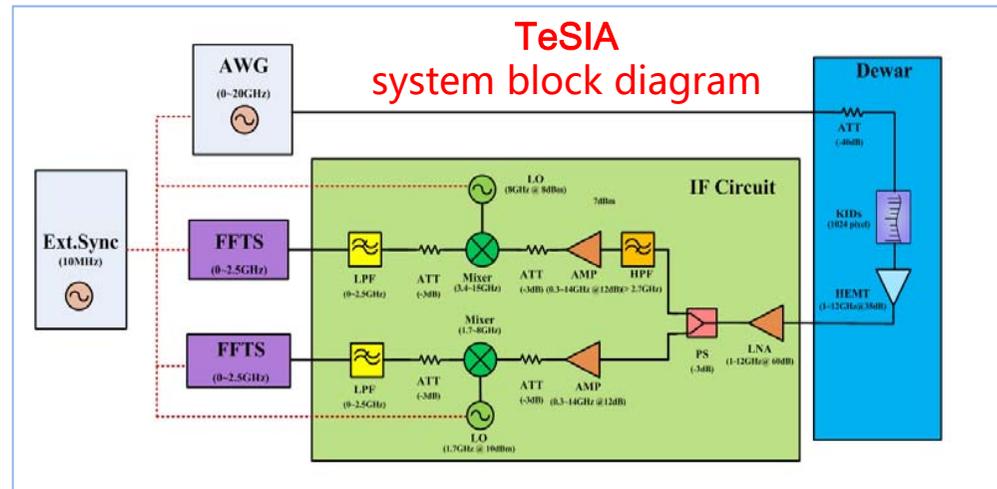
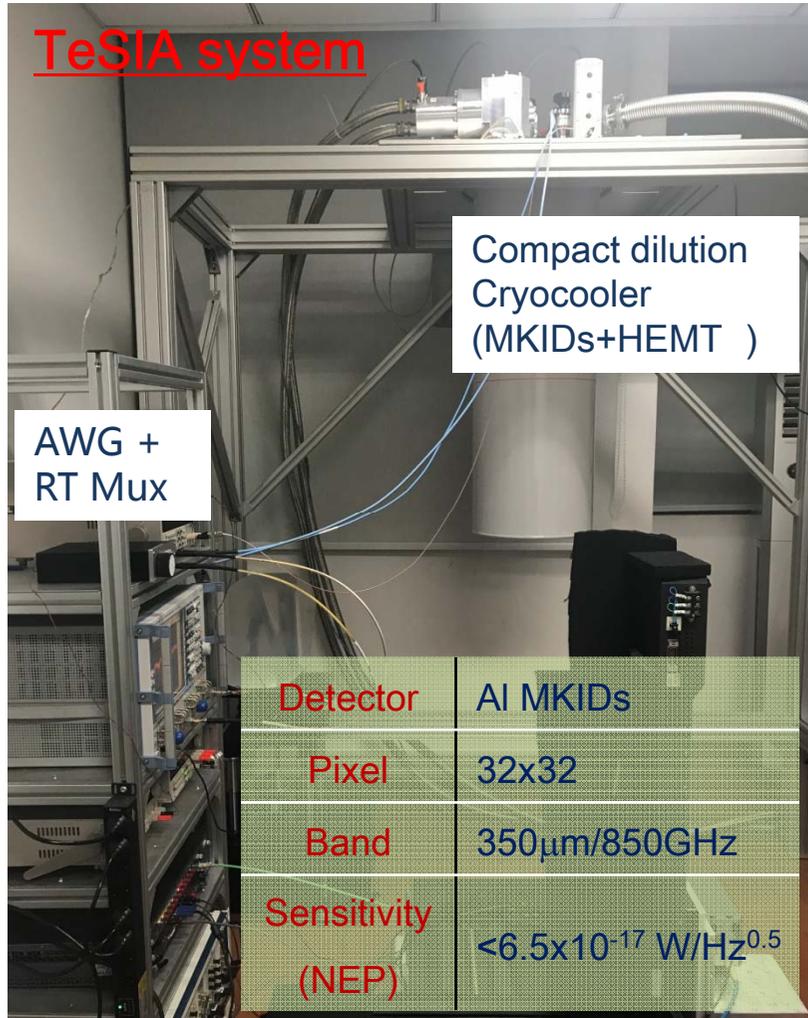


1.4THz superconducting HEB mixer



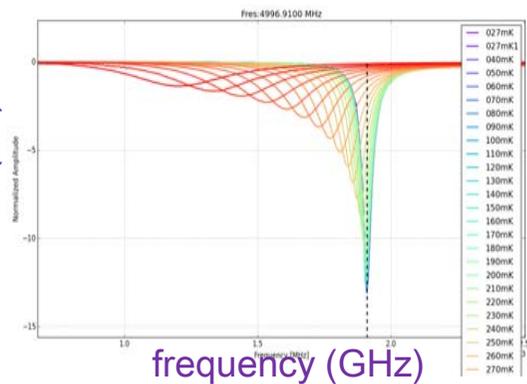
FFTS spectrometer  
(BW=5GHz,  $\Delta f=76kHz$ )

# THz Superconducting Imaging Array



32x32 MKIDs & measured S21 response w.r.t. temperature

S21 (dB)



# Summary

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- An ultra-wideband (0.75-15THz) FTS -- Dome A FTS -- has been deployed to Dome A in Antarctic to remotely measure atmospheric transmission for 2010-2012
- Measurement results from Dome A expose atmospheric windows having significant transmission throughout the THz/FIR band
- It has been found that current spectral models significantly underestimate the H<sub>2</sub>O continuum absorption
- China is planning to build an observatory at Dome A in Antarctic, with the DATE5 telescope dedicated to observations in the THz/FIR regime
- Sensitive superconducting SIS and HEB mixers have been developed for DATE5, with the HEB mixer recording the best performance at 1.3THz

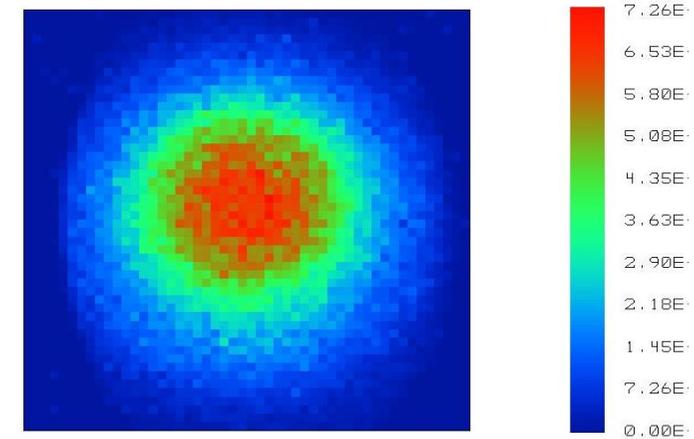
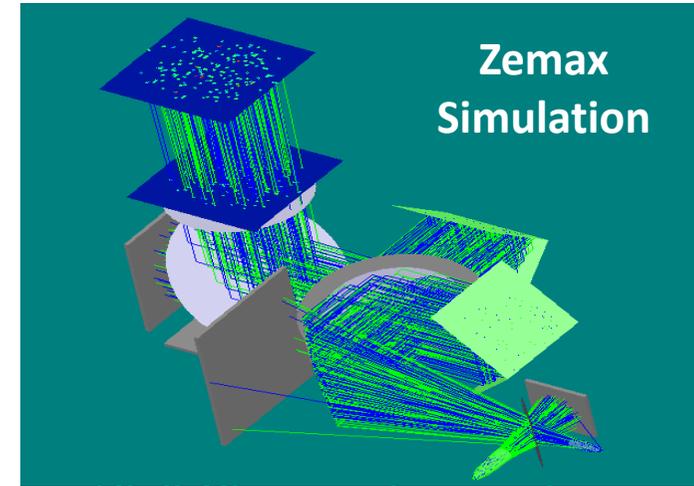
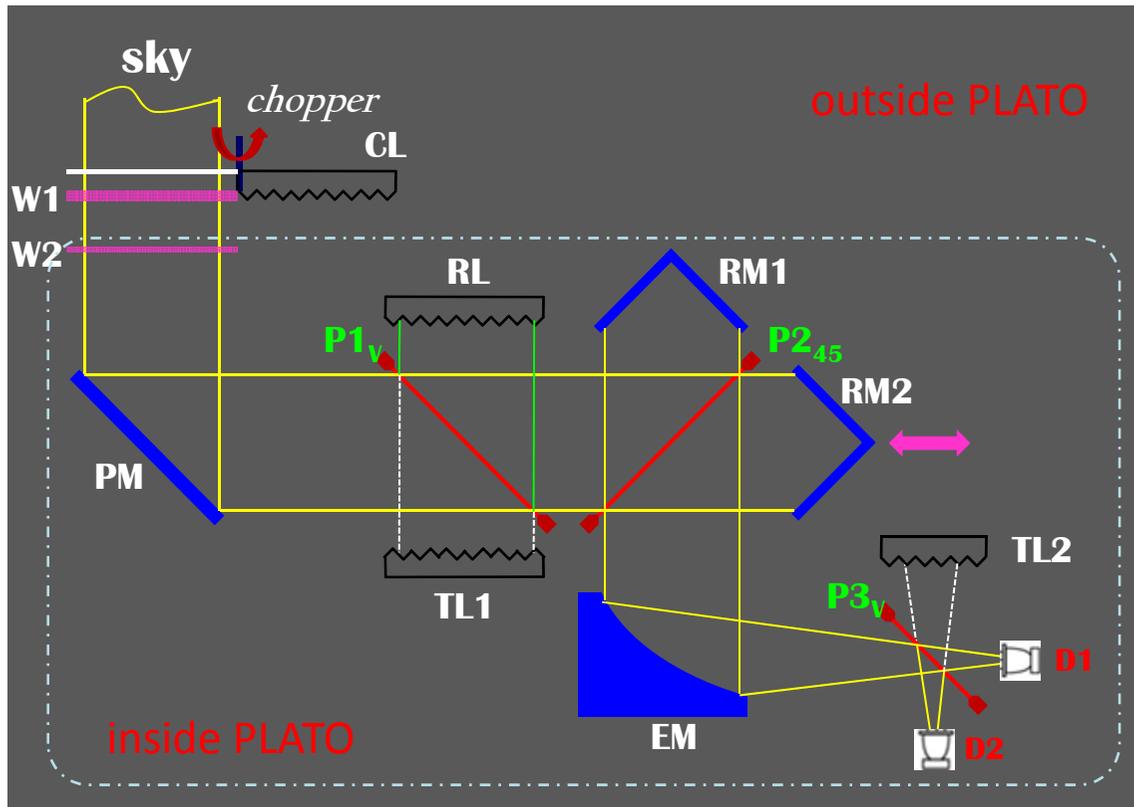
# Acknowledgment



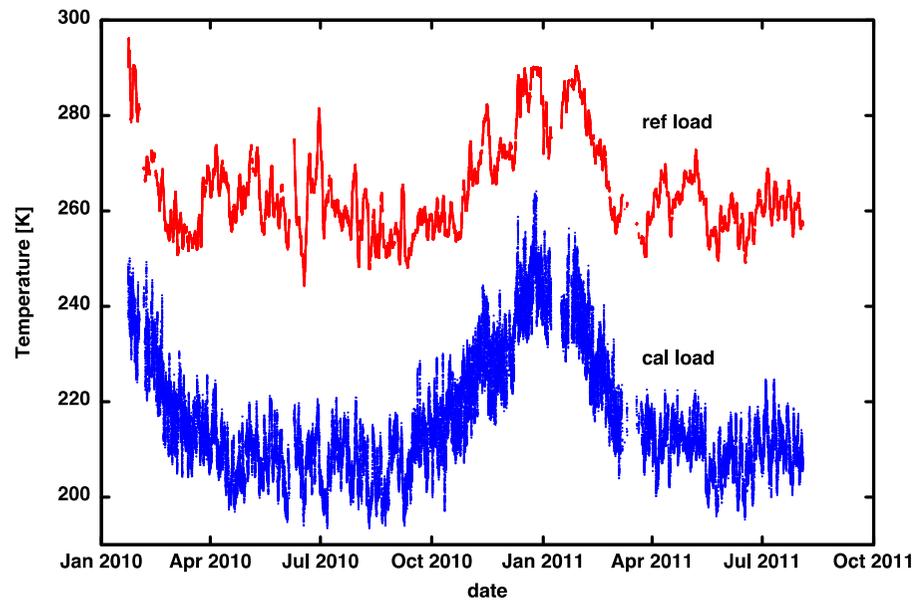
- CAS Special Funding for Astronomical Instruments
- CCAA, Polar Institute (China) & PLATO Team for the deployment & operation of the instrument
- Blue Sky (Canada) and QMC (UK) for good cooperation in developing the instrument
- Team for CAS's Int. Collaboration Partnership Program



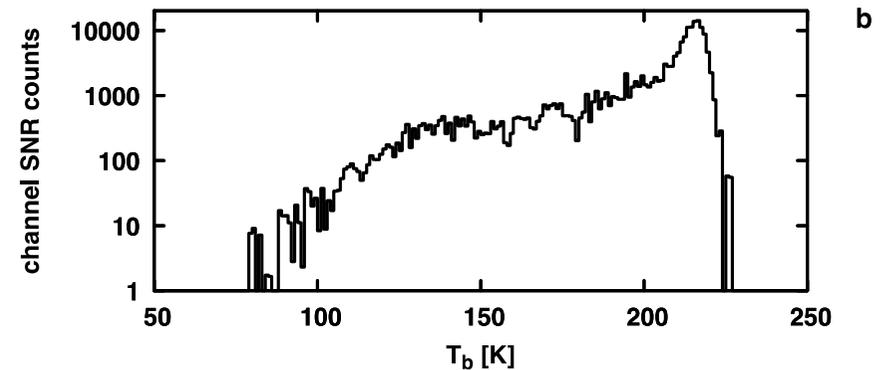
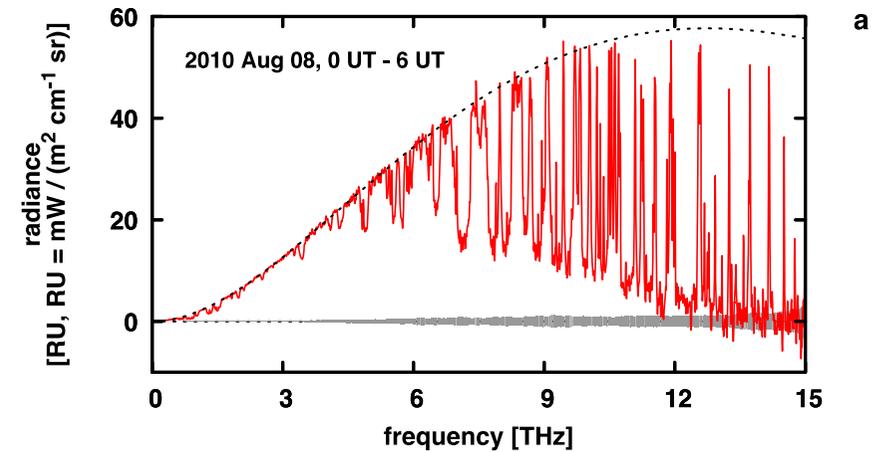
# Design of Dome A FTS



# Transmittance Computation & Statistics

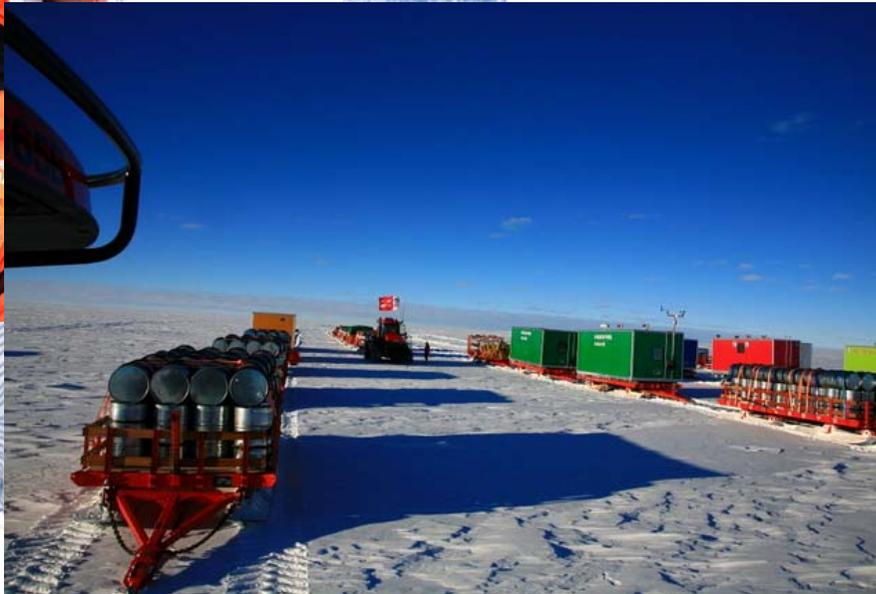
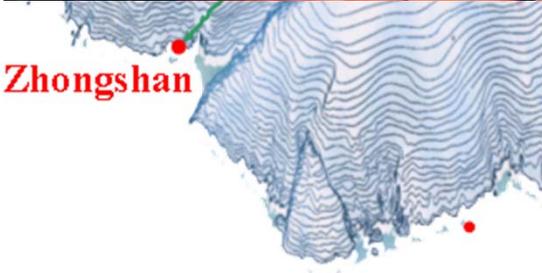


Calibration load temperatures



Example of Planck baseline determination for isothermal transmittance estimates

# Where is Dome A in Antarctic?



## Basic facts about Dome A

60km (60km×10km)

-83°C

small fluctuation

