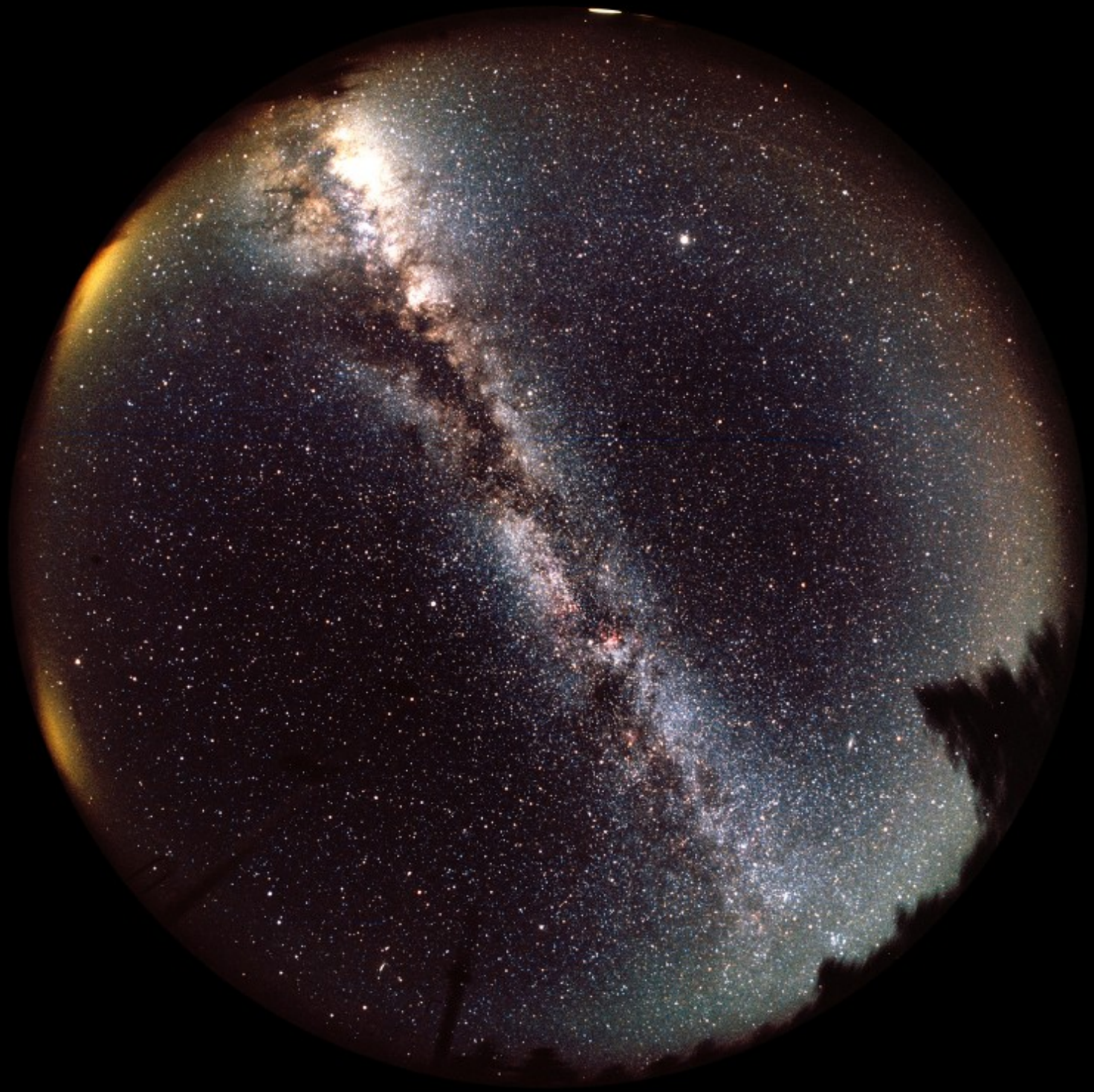
High Elevation Antarctic Terahertz (HEAT) telescopes for the High Plateau

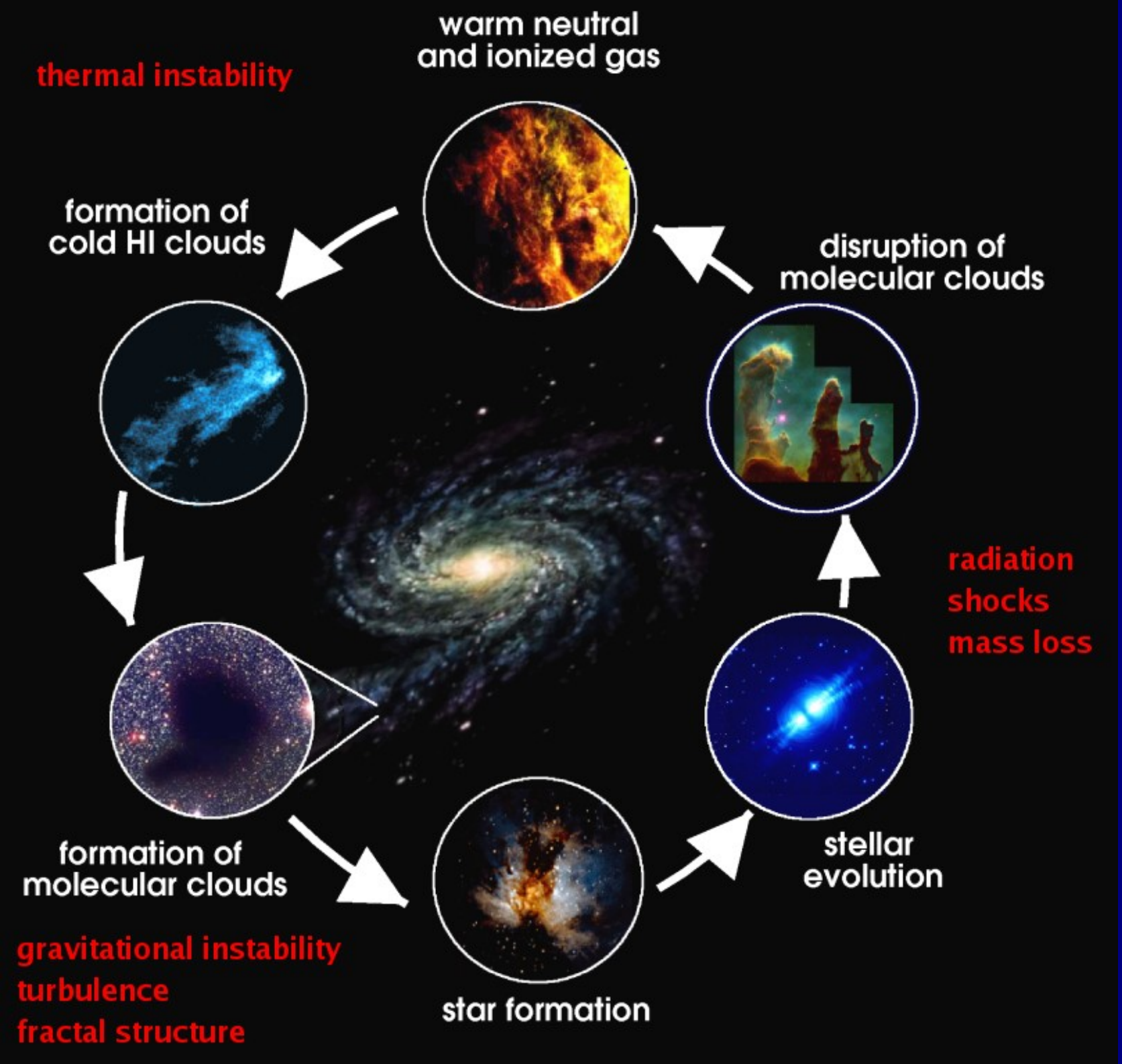
Craig Kulesa (Univ of Arizona)
On behalf of the entire HEAT team

Image: John Storey



We live in a Galaxy comprised of stars, dust, gas, planets, and people.

Where did it all come from?



The Life Cycle of matter in the Galaxy

or

'Galactic Ecology'

Long Standing Questions

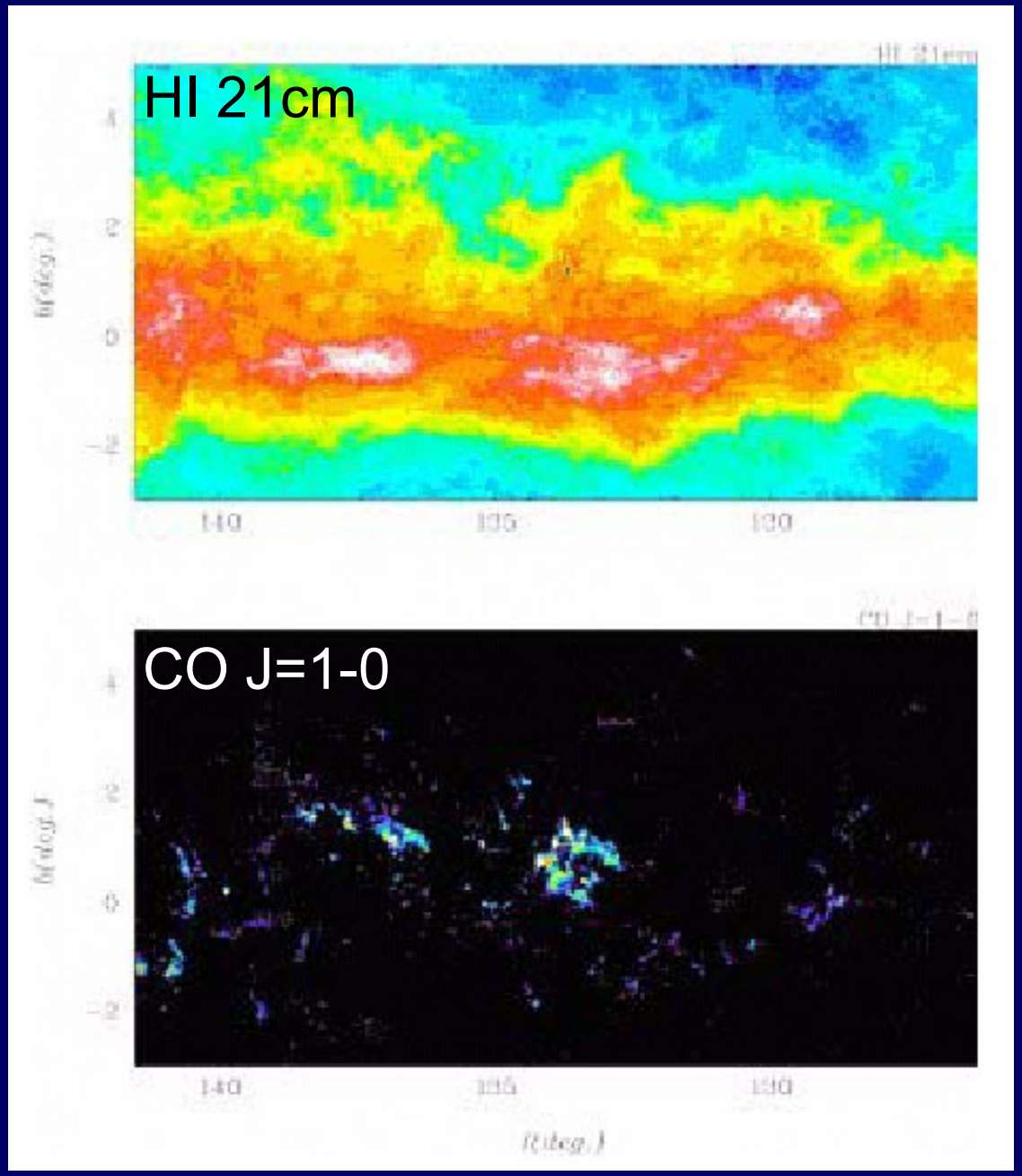
- How and where are interstellar clouds made, and how long do they live?
- Under what conditions do clouds form stars?
- How do stars return enriched material back to the Galaxy?
- How do these processes sculpt the evolution of galaxies?

Our understanding of the cold ISM is incomplete

- HI provides a measure column density, but provides little insight into which ISM component it comes from

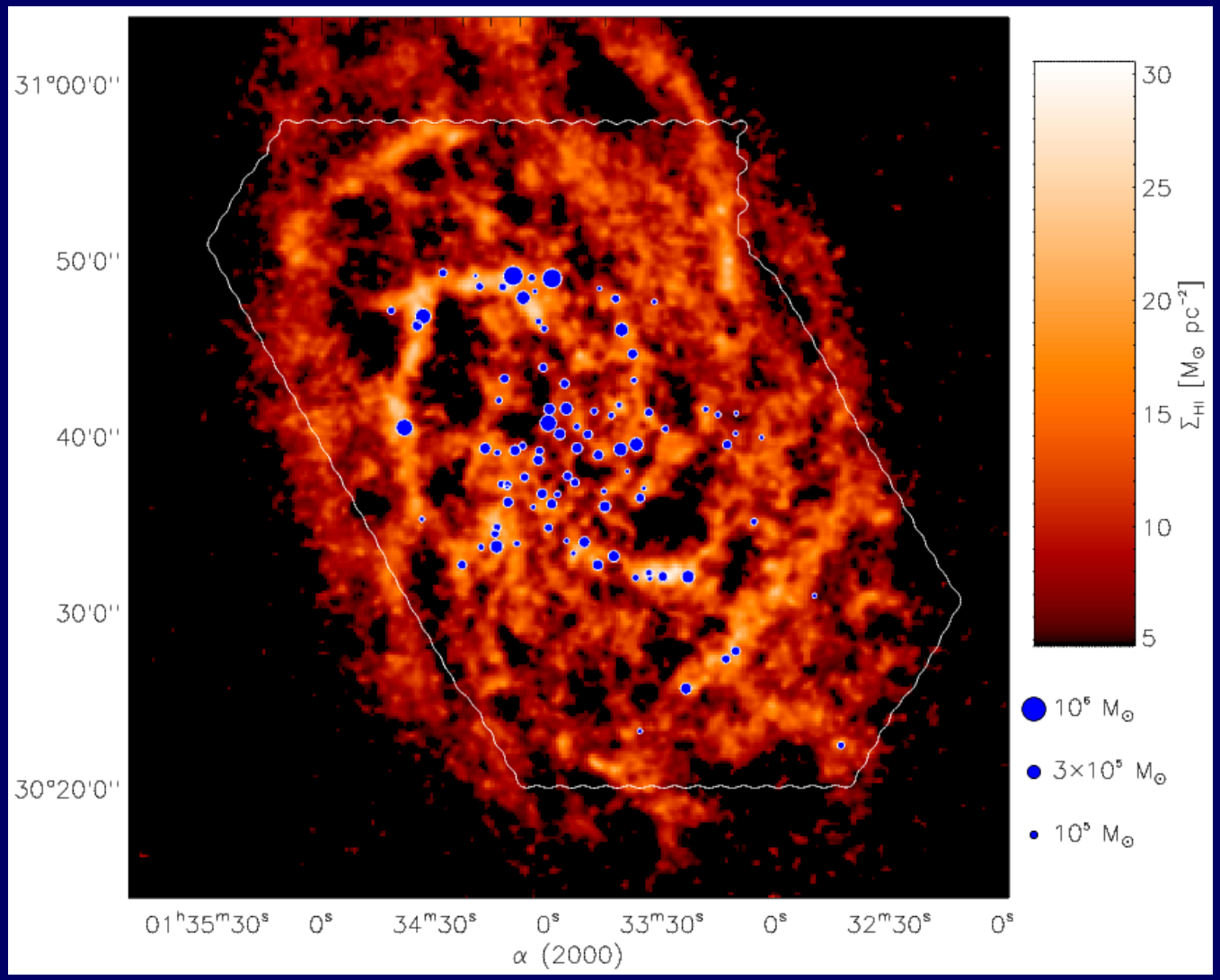
- CO only probes already-formed molecular clouds

So how can we see cloud formation?



Example: Formation of GMC's

HI and CO in M33 (Engargiola et al. 2004)



1) gravitational instabilities within diffuse atomic gas

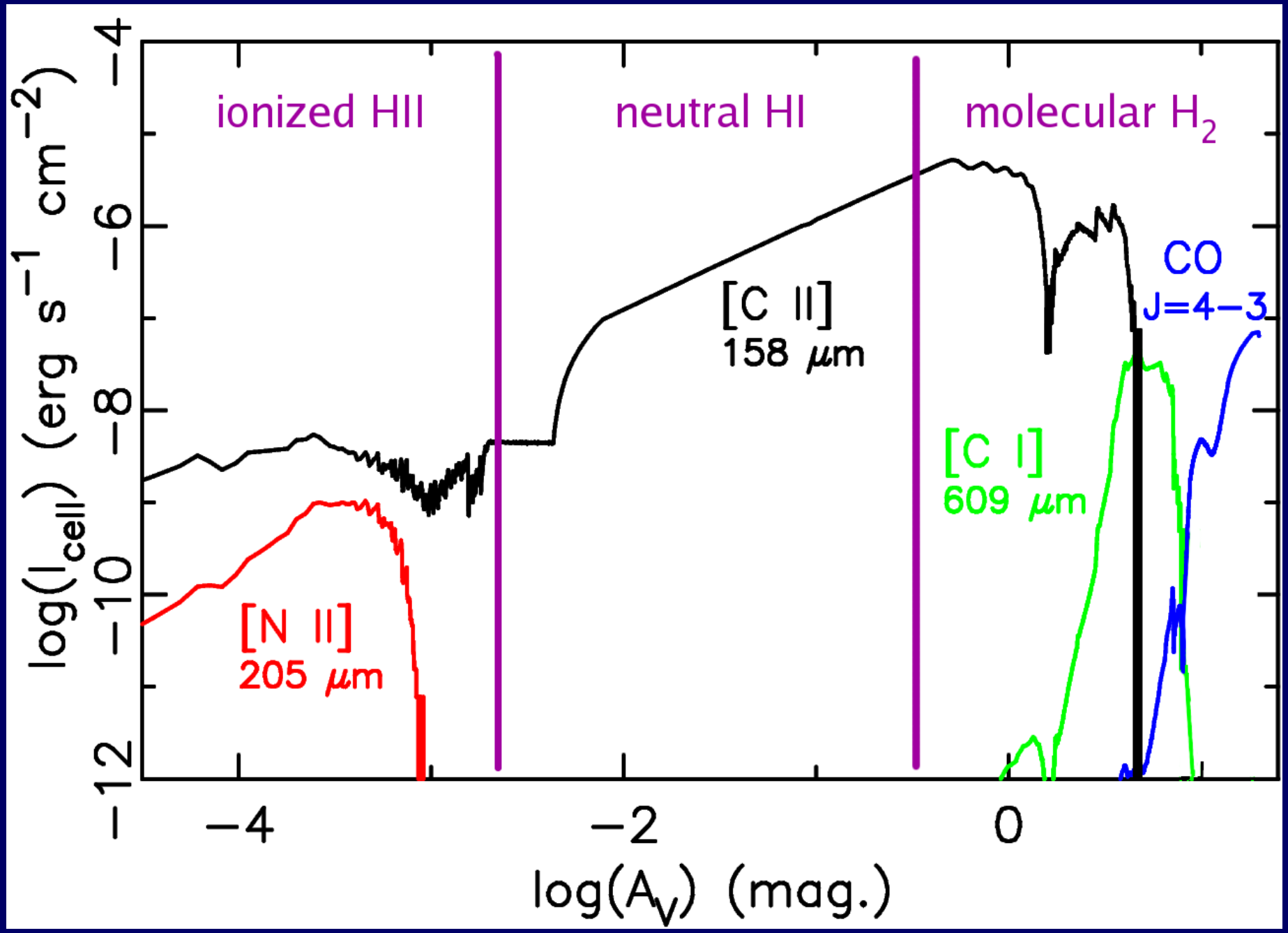
2) collisional agglomeration of small, long-lived molecular clouds

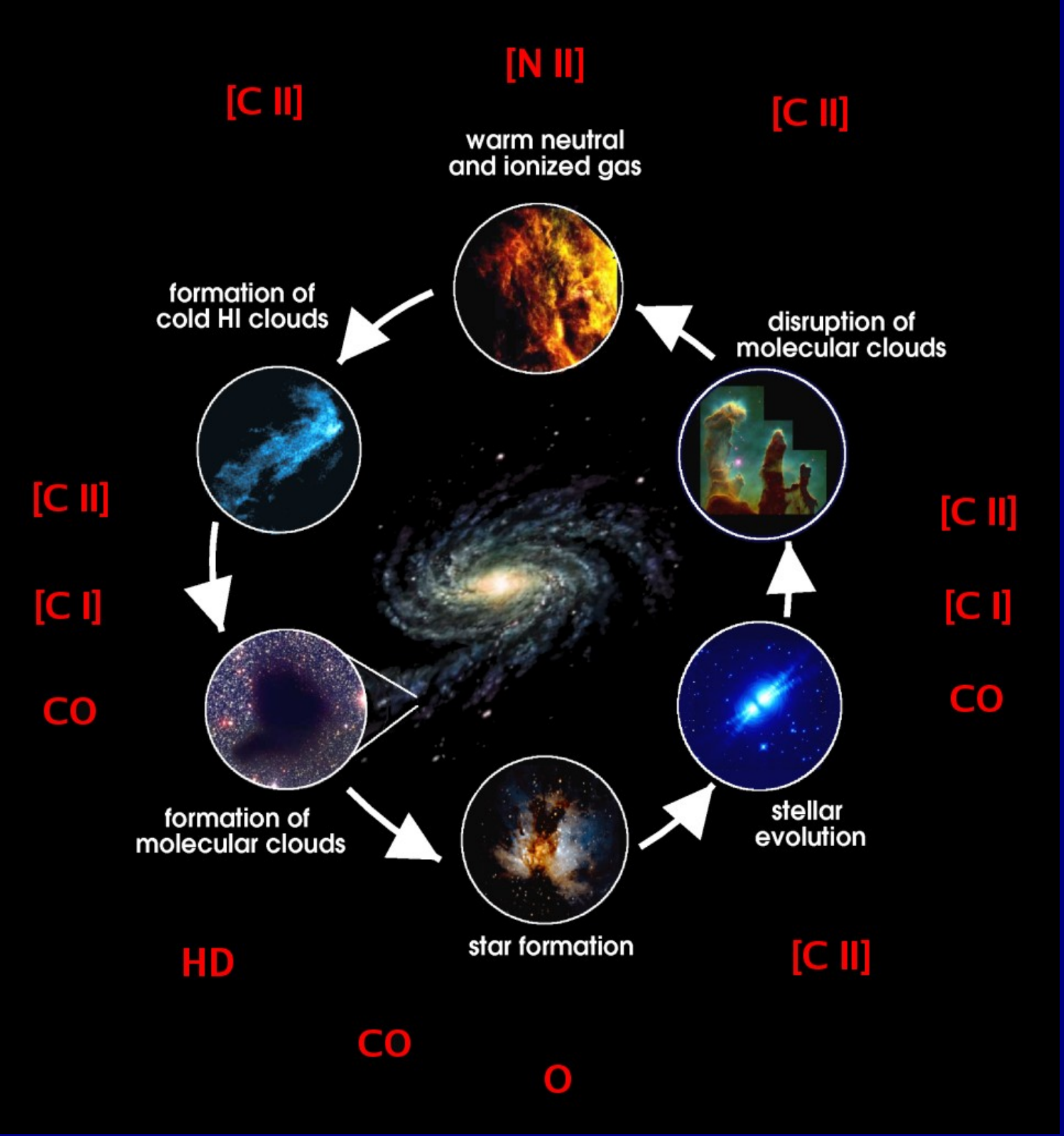
3) accumulation of material within high pressure environments such as OB-generated shells

4) compression in randomly converging parts of a turbulent medium

A statistical survey can distinguish between these mechanisms!

[CII] emission can show us “hidden” molecular gas not probed by CO





The best diagnostics of this cycle are in the far-infrared

Carbon at 370, 609 um

CO from 200-400 um

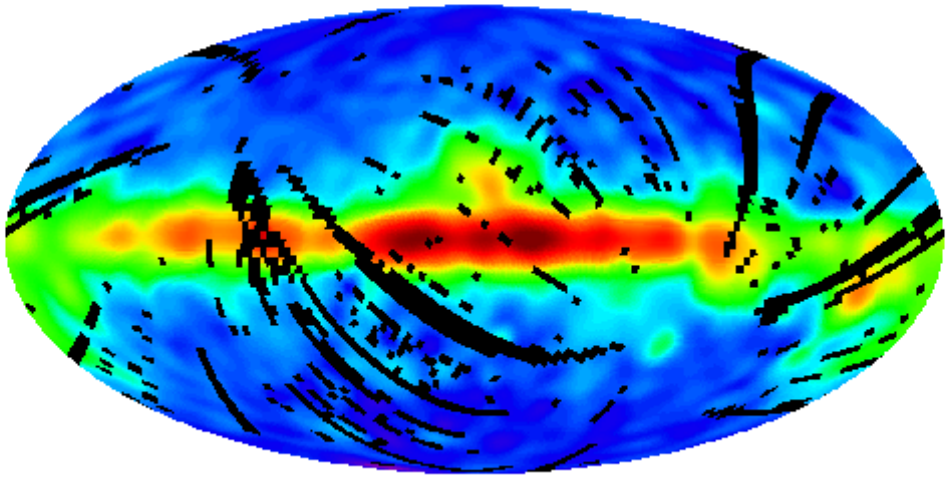
C^+ at 158 um

N^+ at 122, 205 um

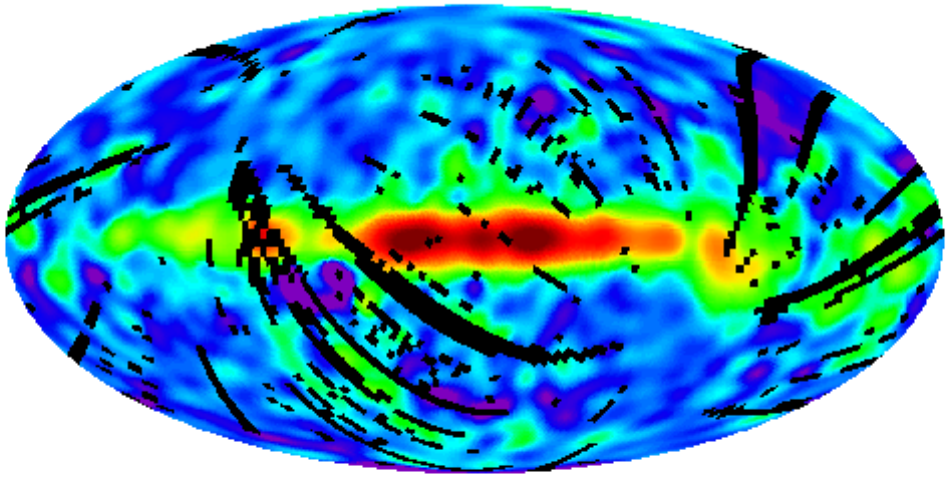
Oxygen at 63, 146 um

HD at 112 um

COBE FIRAS 158 μm C^+ Line Intensity



COBE FIRAS 205 μm N^+ Line Intensity



The only large scale maps of the Galaxy in C, C^+ and N^+ come from COBE, with degree-scale angular resolution and no velocity information.

Even a 0.5-meter telescope with a heterodyne spectrometer would improve both the angular & spectral resolution by more than 10^3!

What is needed:

- large scale mapping survey of the Milky Way, of order 100 square degrees

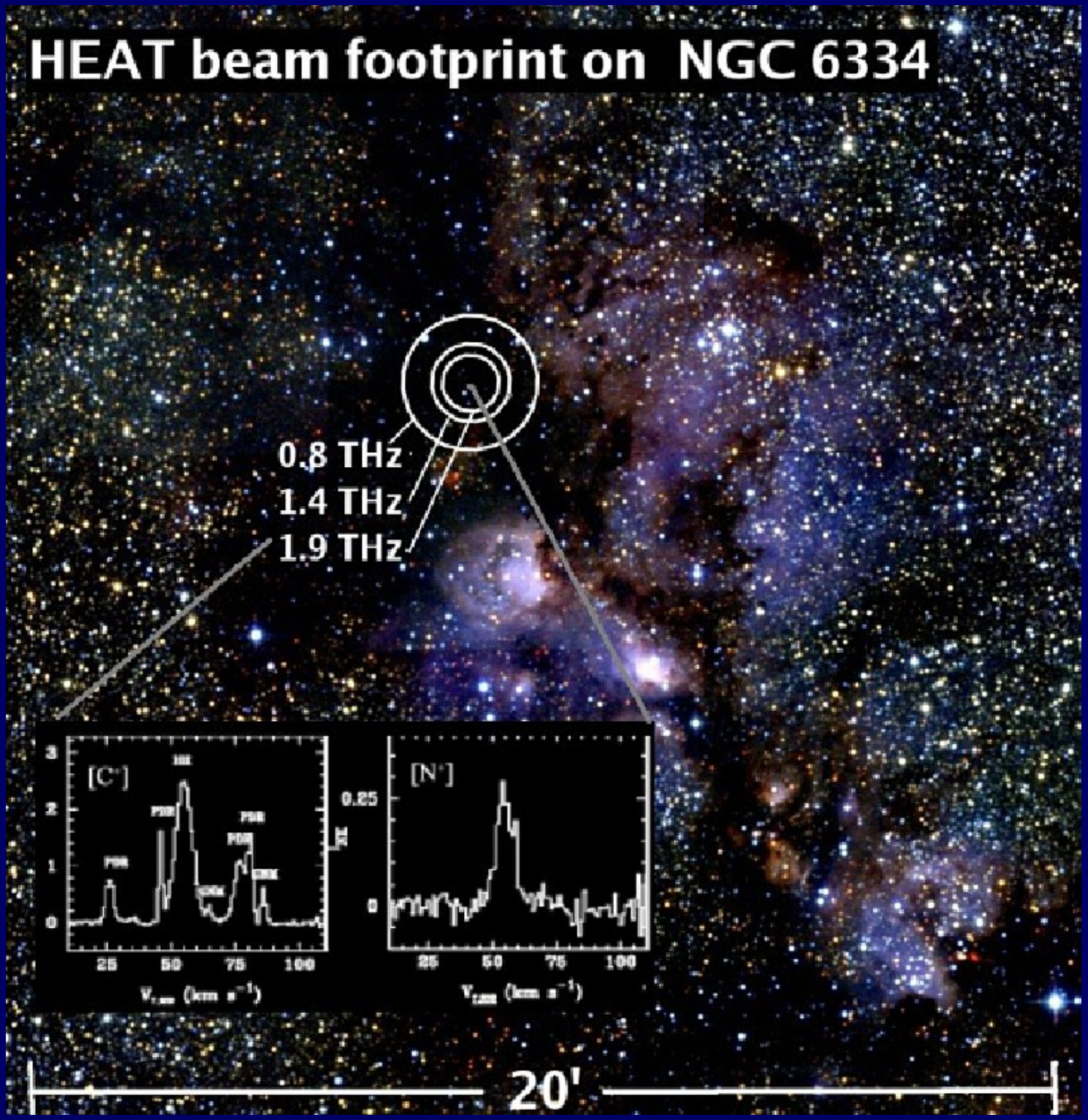
- with high spectral resolution of ~1 km/s

- with sufficient angular resolution to resolve clouds across the Galaxy (~1 arcminute)

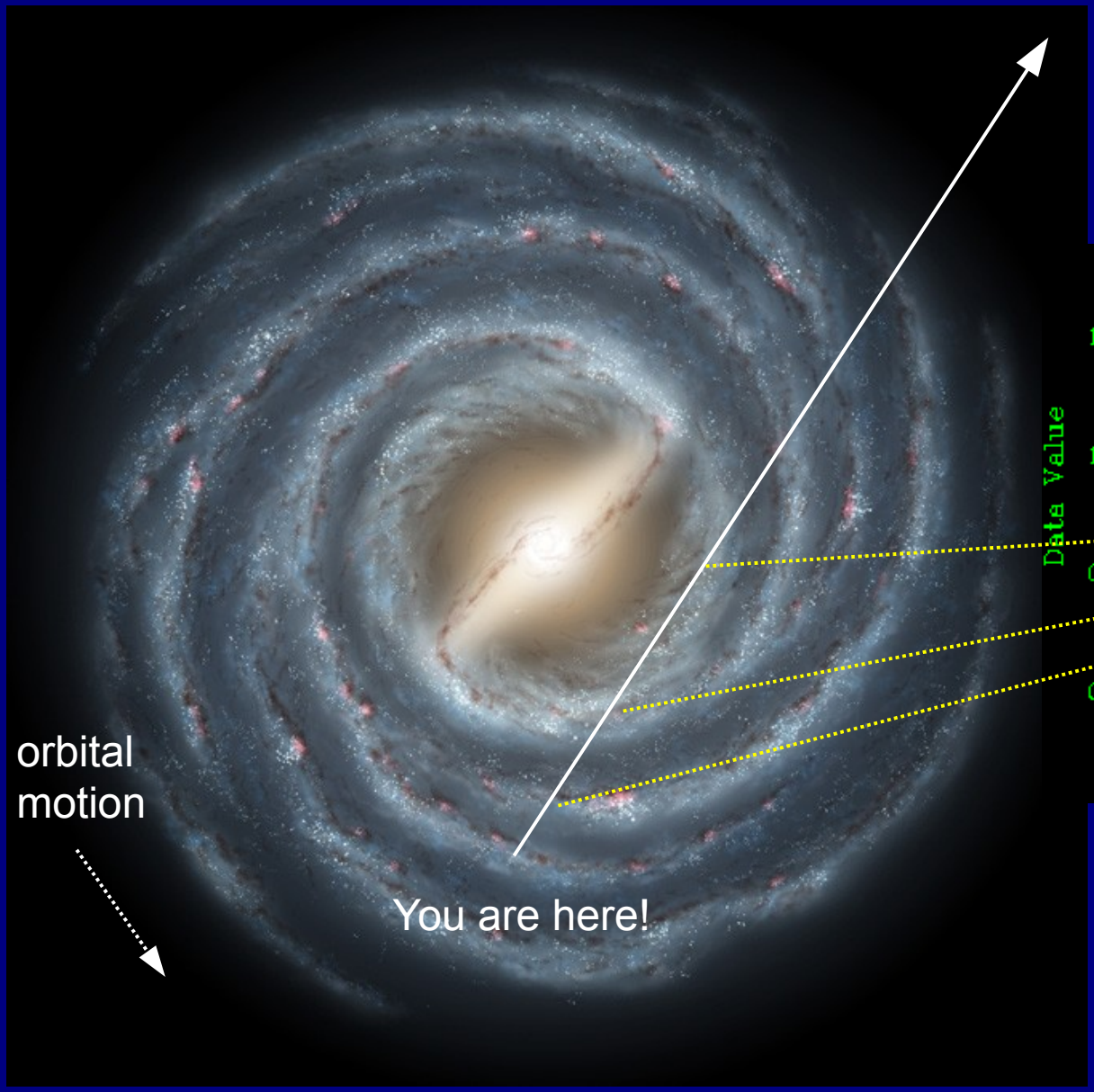
- at THz frequencies to probe pivotal carbon, nitrogen, oxygen fine structure & molecular lines

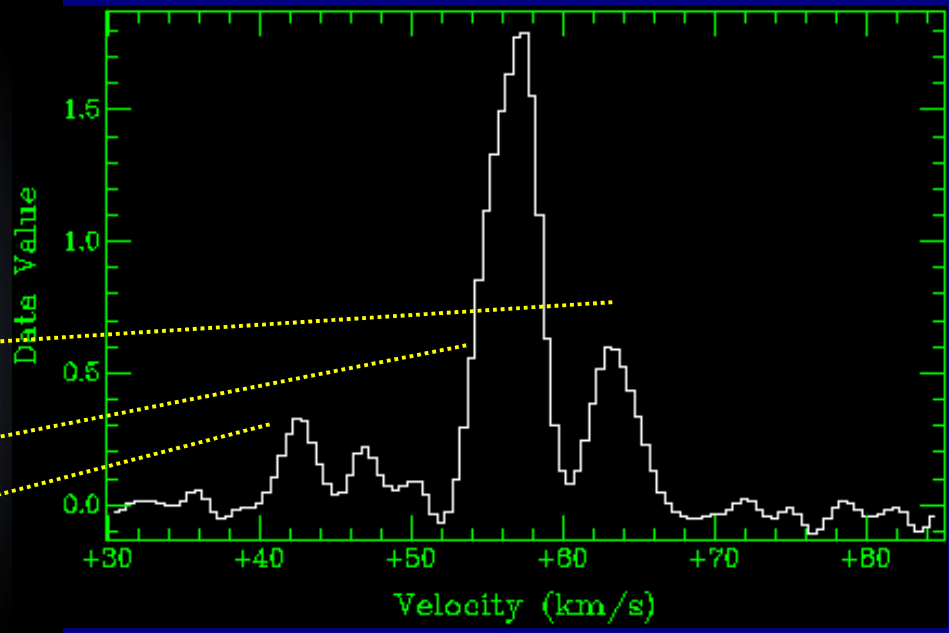
8/24 um portion of Galactic Plane from Spitzer MIPSGAL/GLIMPSE programs

Every pixel in the map represents a high resolution spectrum.

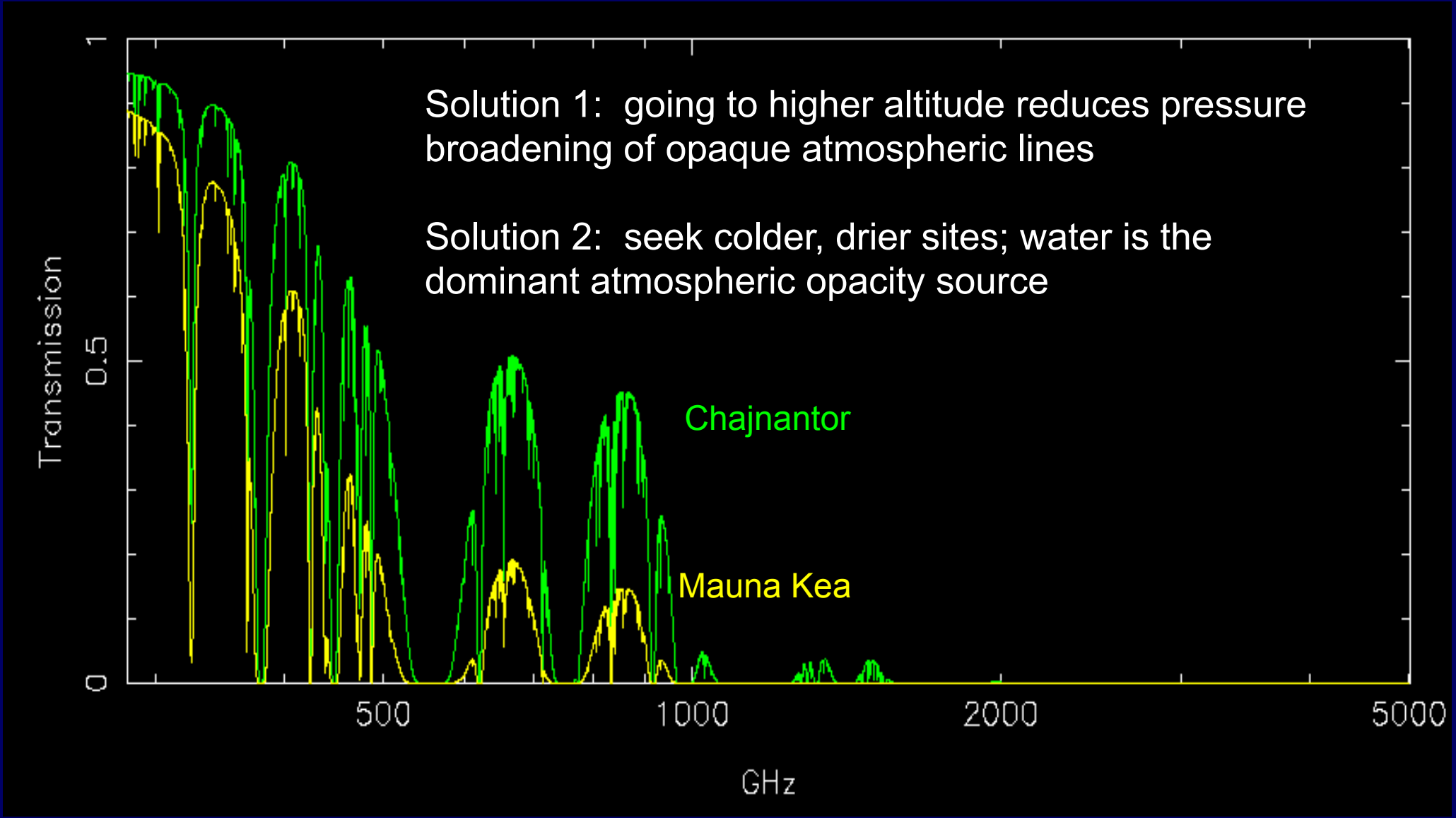


High resolution (heterodyne) spectroscopy turns a 2D map of the sky into a 3D map of the Galaxy...

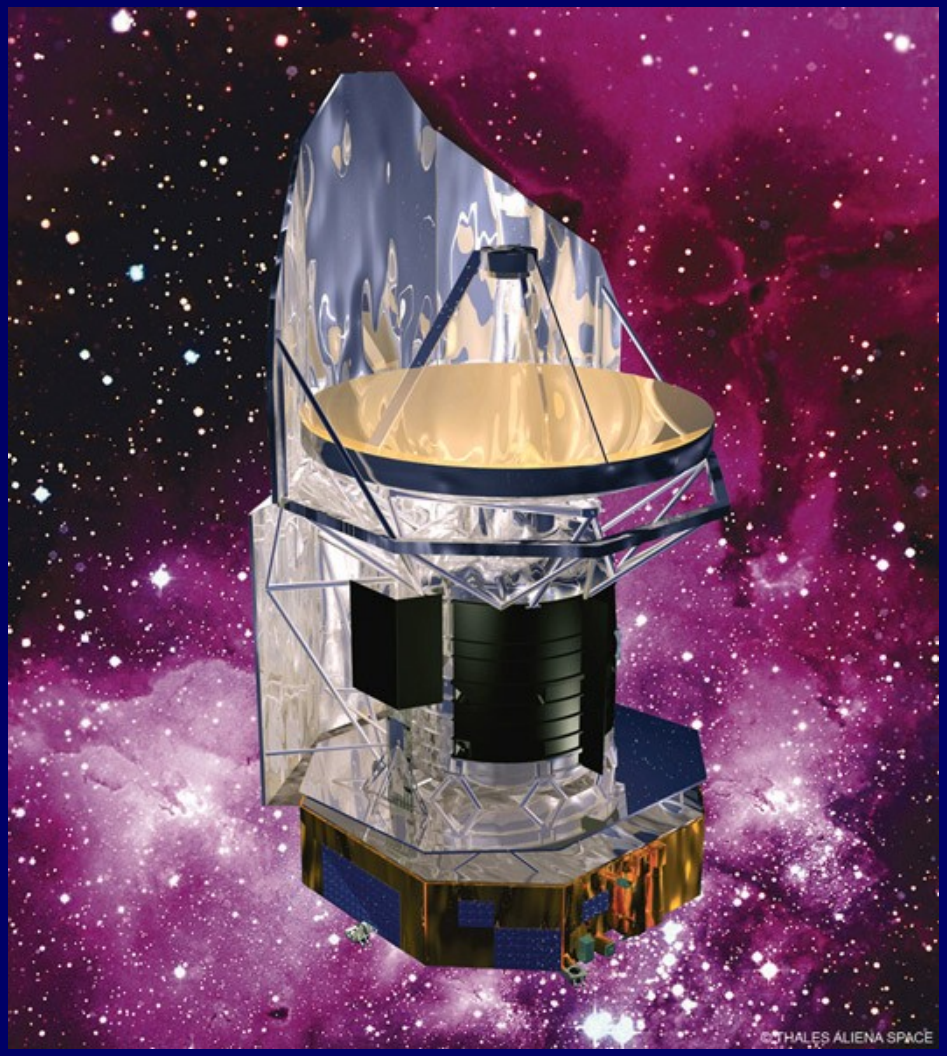




Sadly, far-infrared atmospheric transmission is typically poor from the ground, even from the best mid-latitude sites



Of course, there's Herschel...



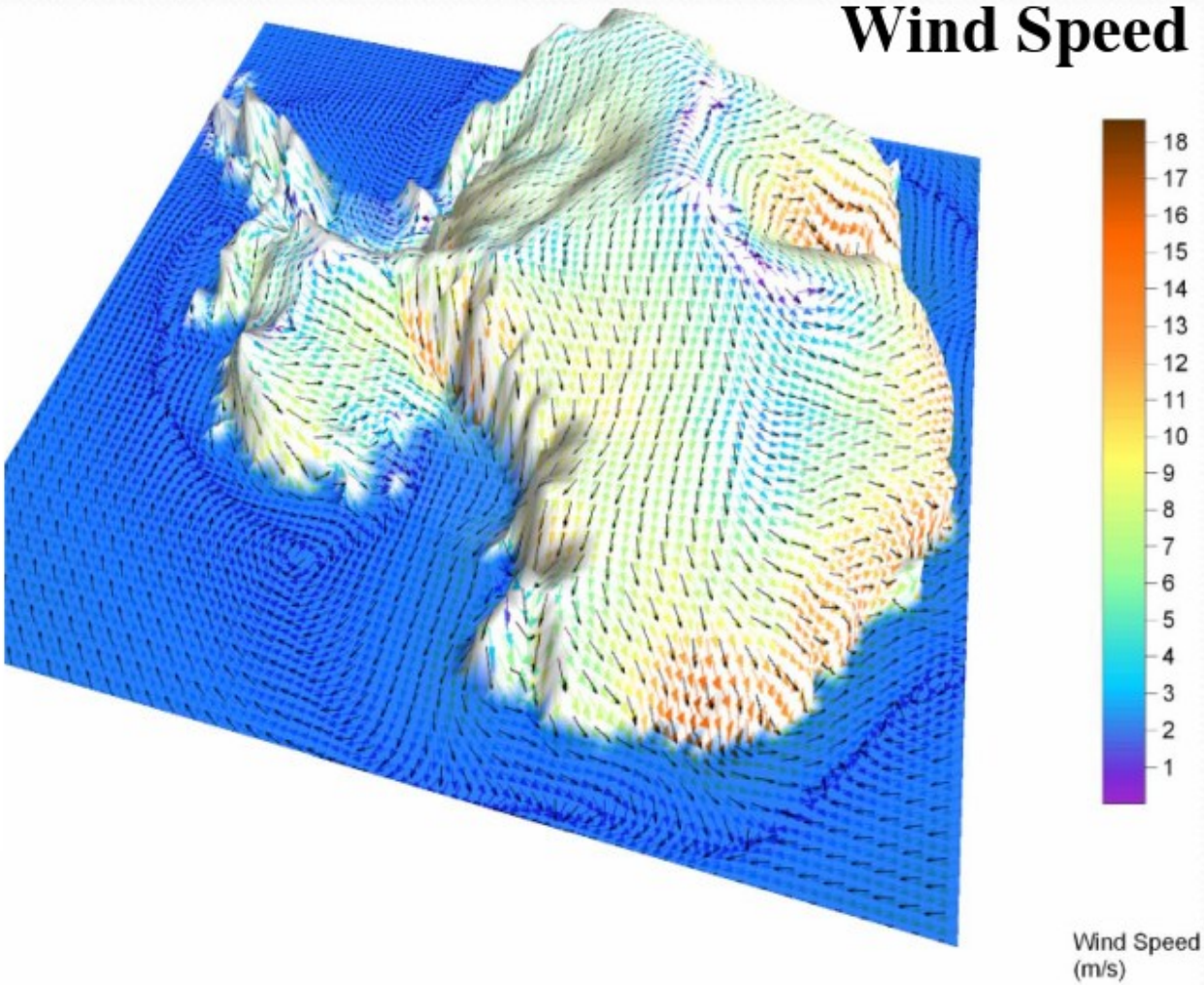
Unprecedented capabiities for targeted observations, but ....

- Limited lifetime
- General purpose observatory
- Slow mapping speed
- Did I mention the limited lifetime?

The Antarctic Plateau

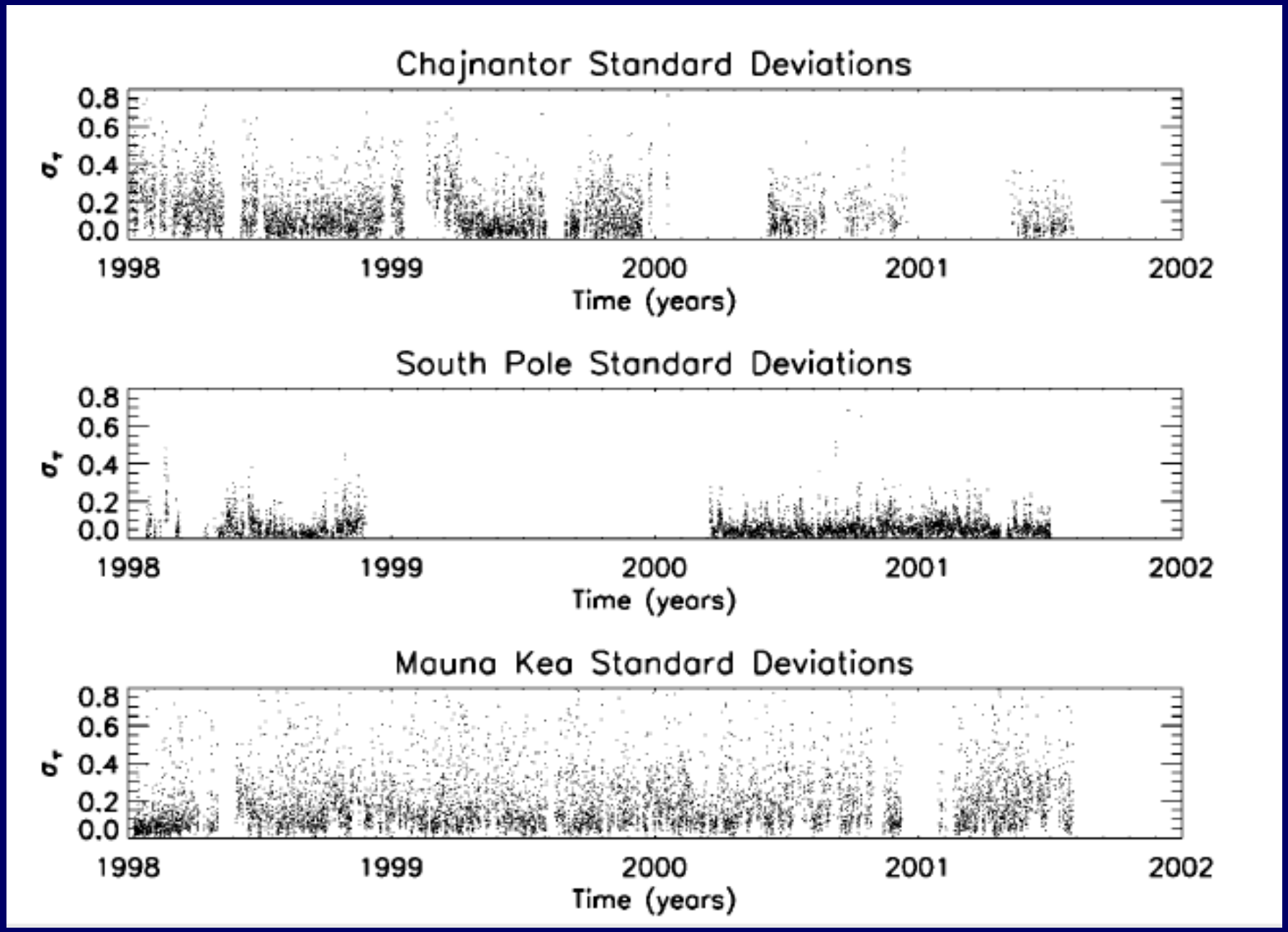
Site conditions enabling unique science:

- **Calm:** wide field high resolution seeing limited imaging
- **Cold and dry:** high sensitivity in thermal infrared
- **High latitude:** long time series observations possible



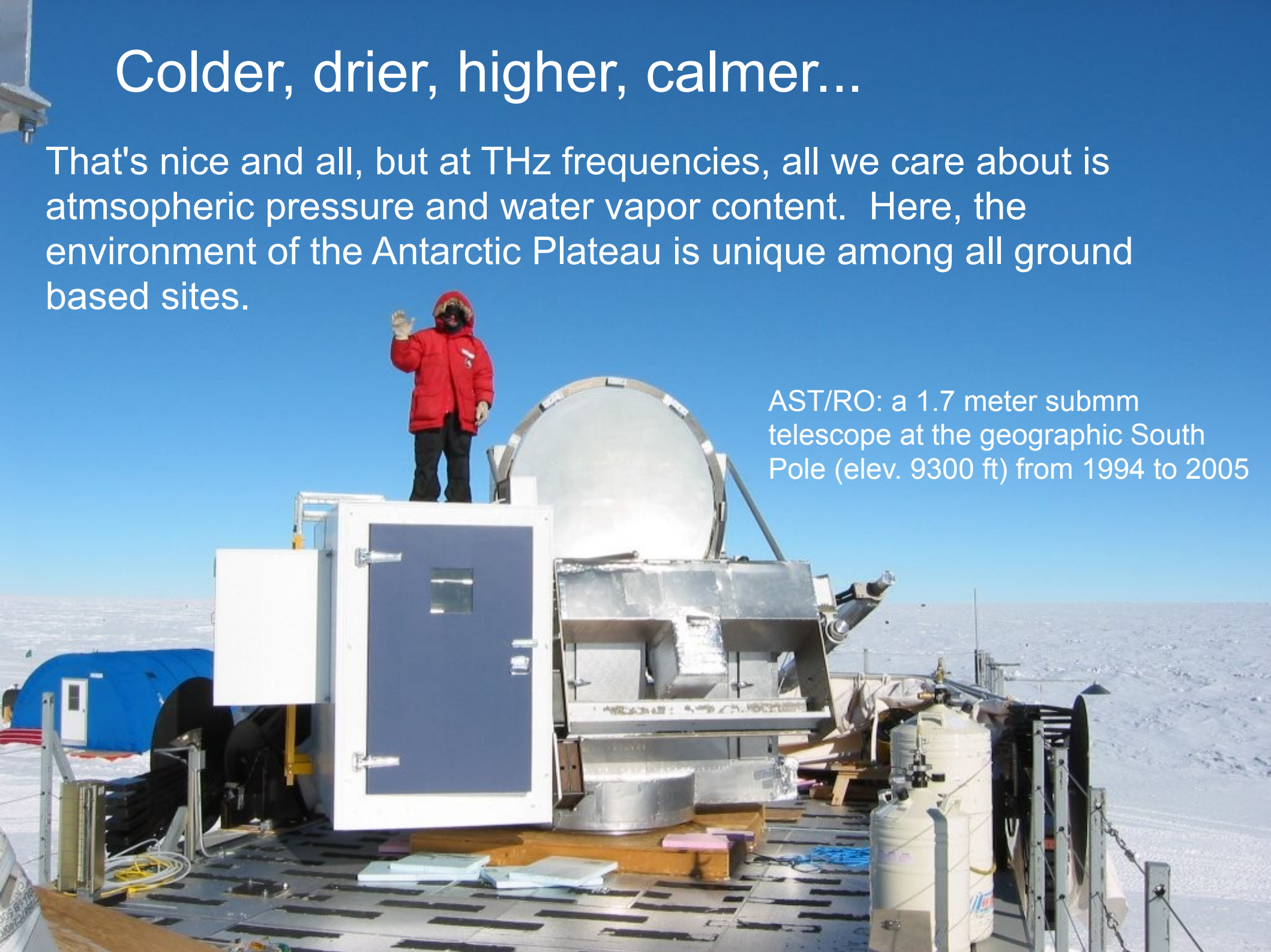
A. Monaghan, Byrd Polar Research Center

Environmental stability translates into exceptional submillimeter and terahertz stability. 100X less sky noise!



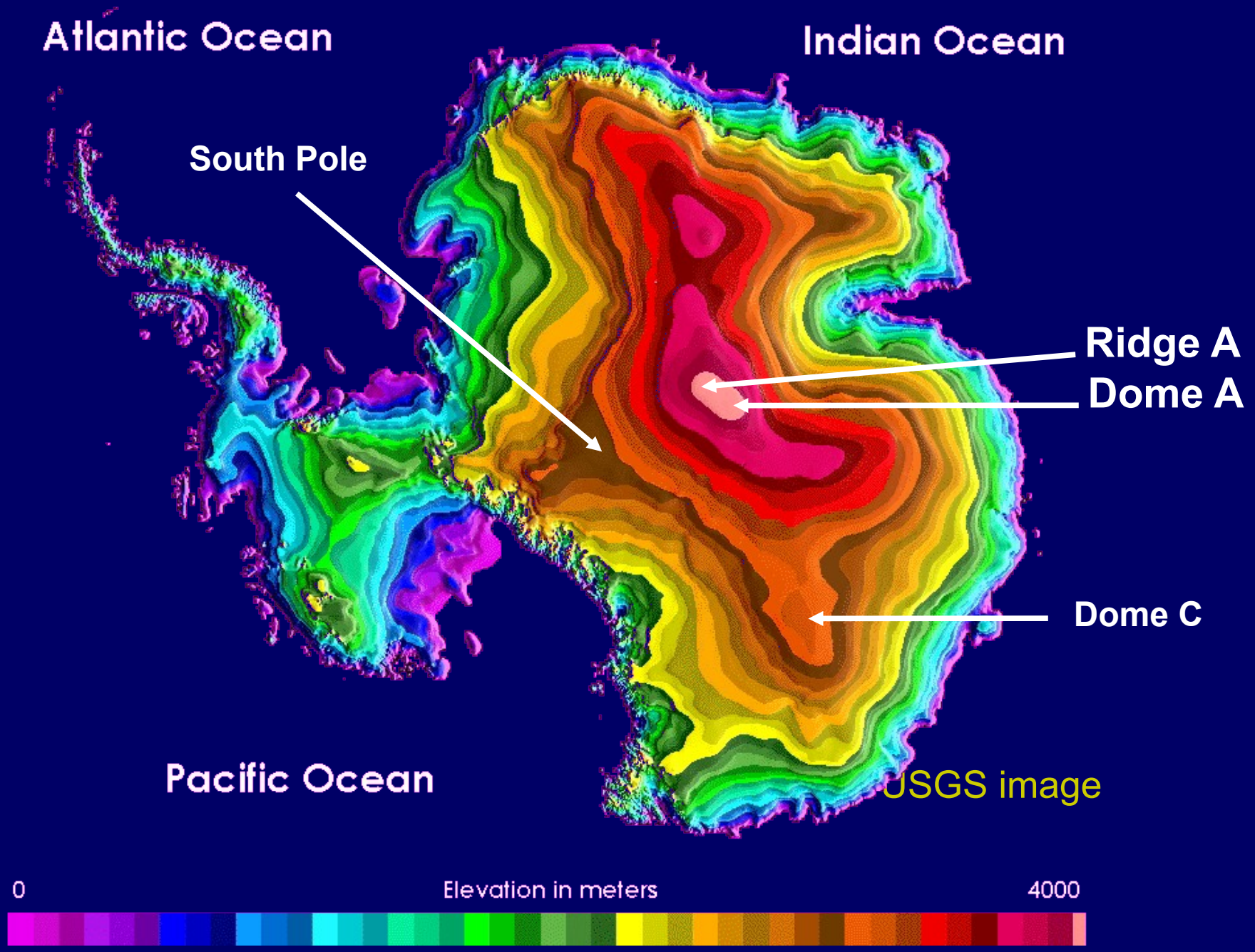
Colder, drier, higher, calmer...

That's nice and all, but at THz frequencies, all we care about is atmsopheric pressure and water vapor content. Here, the environment of the Antarctic Plateau is unique among all ground based sites.



AST/RO: a 1.7 meter submm telescope at the geographic South Pole (elev. 9300 ft) from 1994 to 2005

Contour map of Antarctica



Getting there...

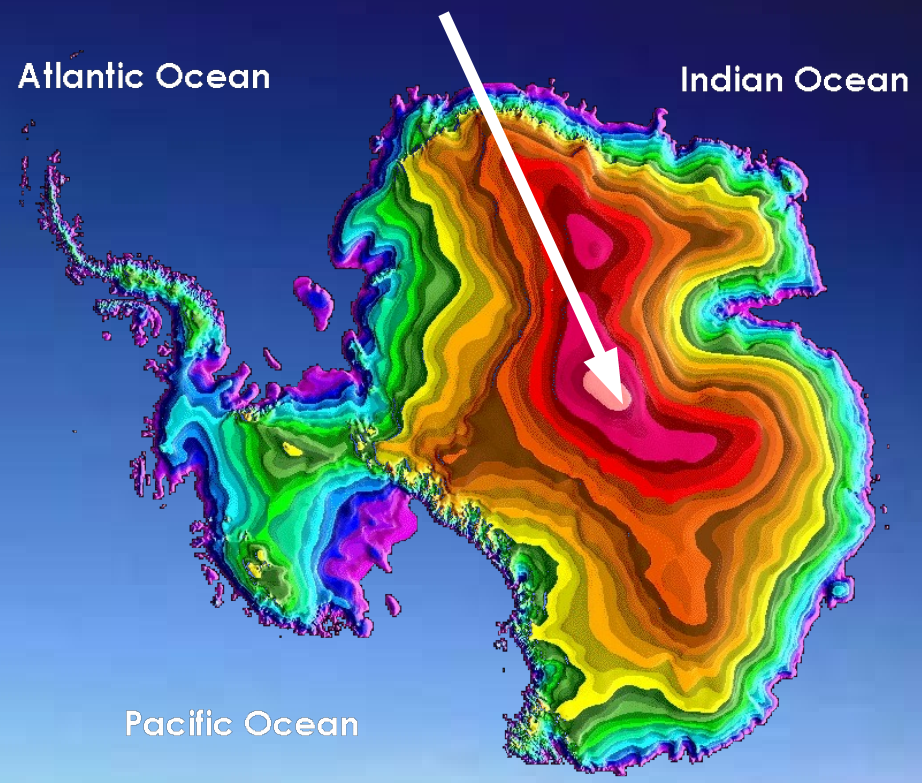
... hitching a lift *might* work ...

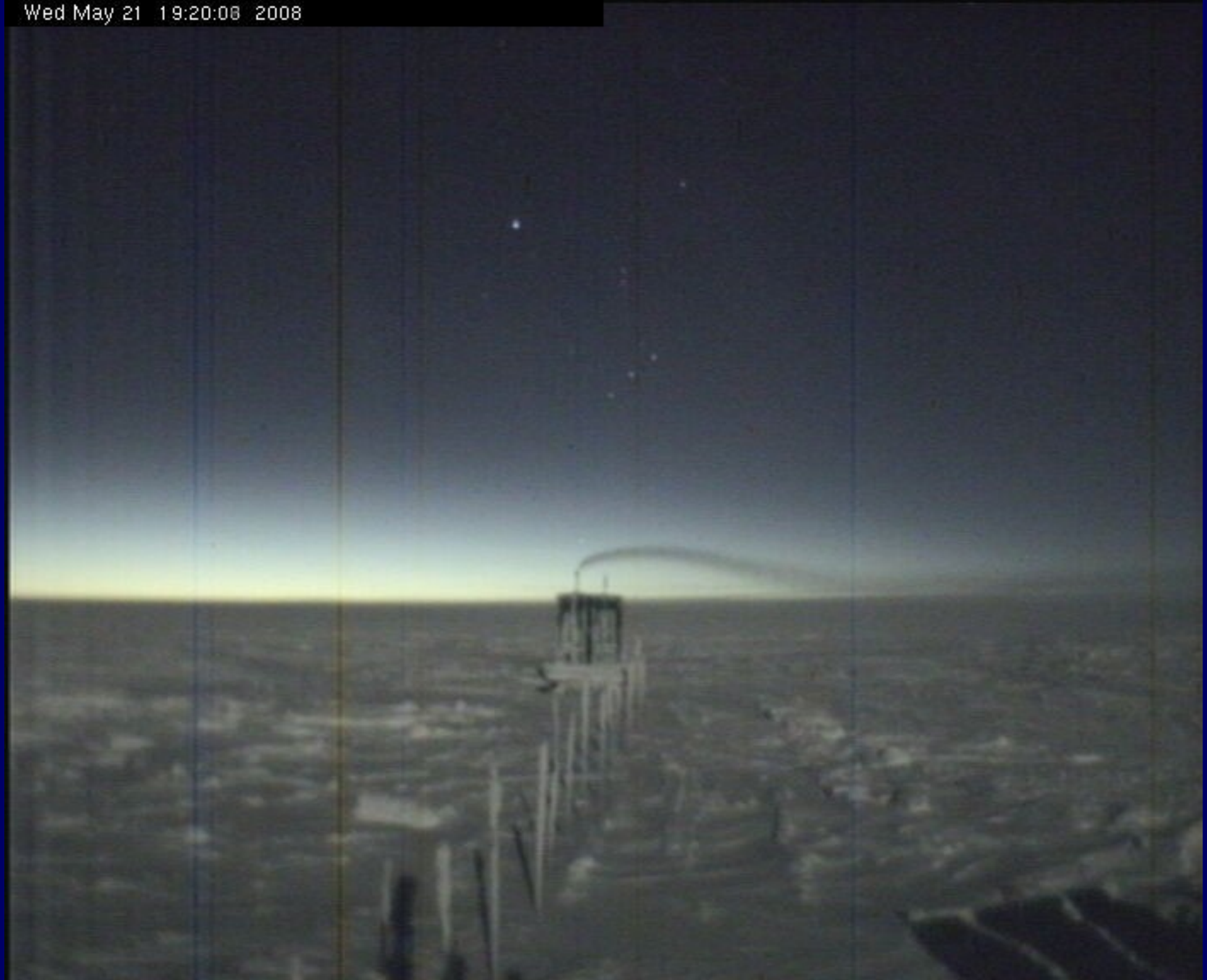
International Far-IR astronomy from Dome A, Antarctica

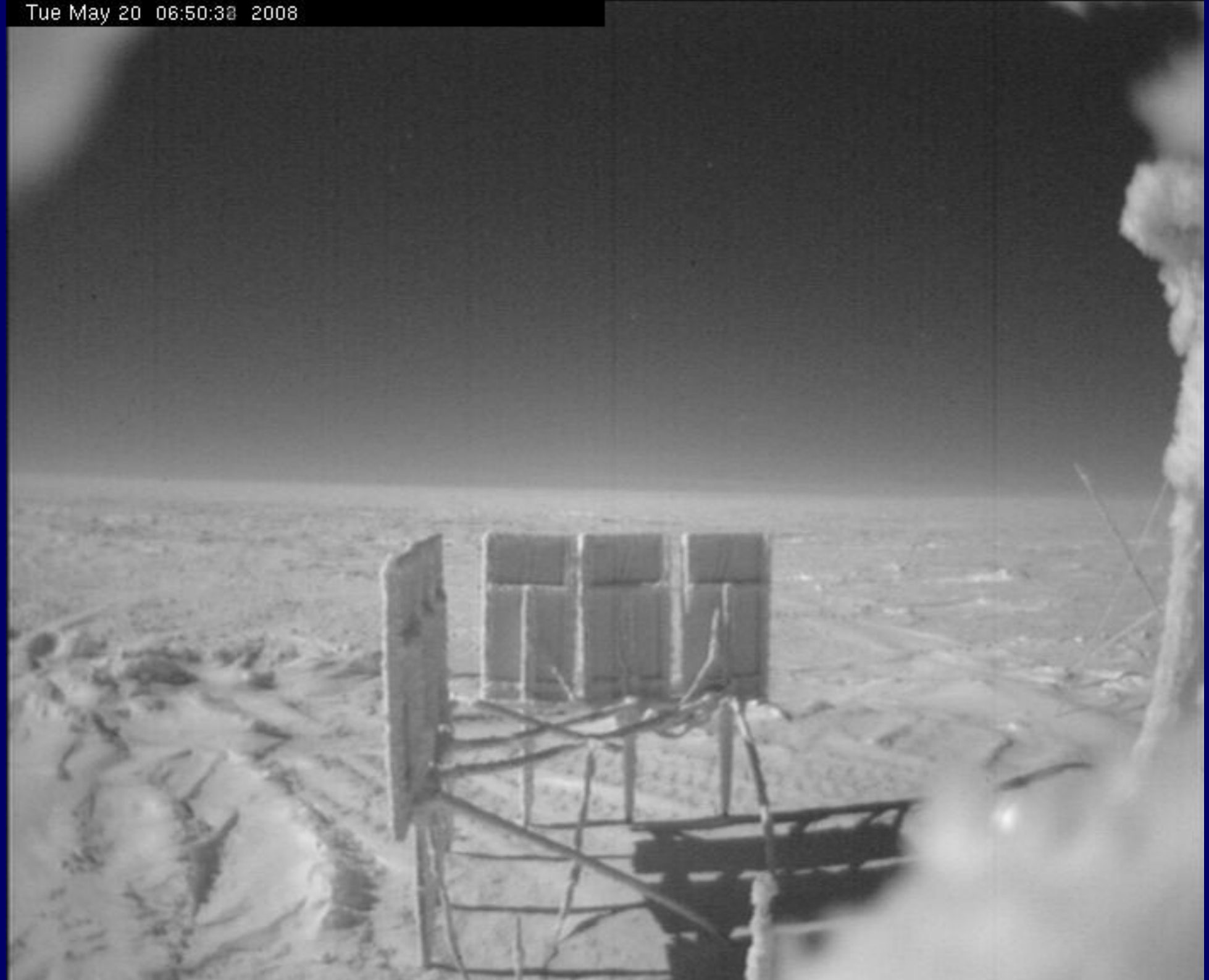
PLATO: the **Plat**eau **O**bservatory, designed at UNSW and deployed by Chinese traverse (PANDA IPY program) for site testing & astronomy on the high plateau.

Pre-HEAT was PLATO's first submillimeter instrument, a 20 cm telescope with heterodyne spectrometer. Operated autonomously through 2008.

A Chinese-built Fourier Transform Spectrometer **(FTS)** was installed onto PLATO in 2010 to perform wide-band THz site testing.




Wed May 21 19:20:08 2008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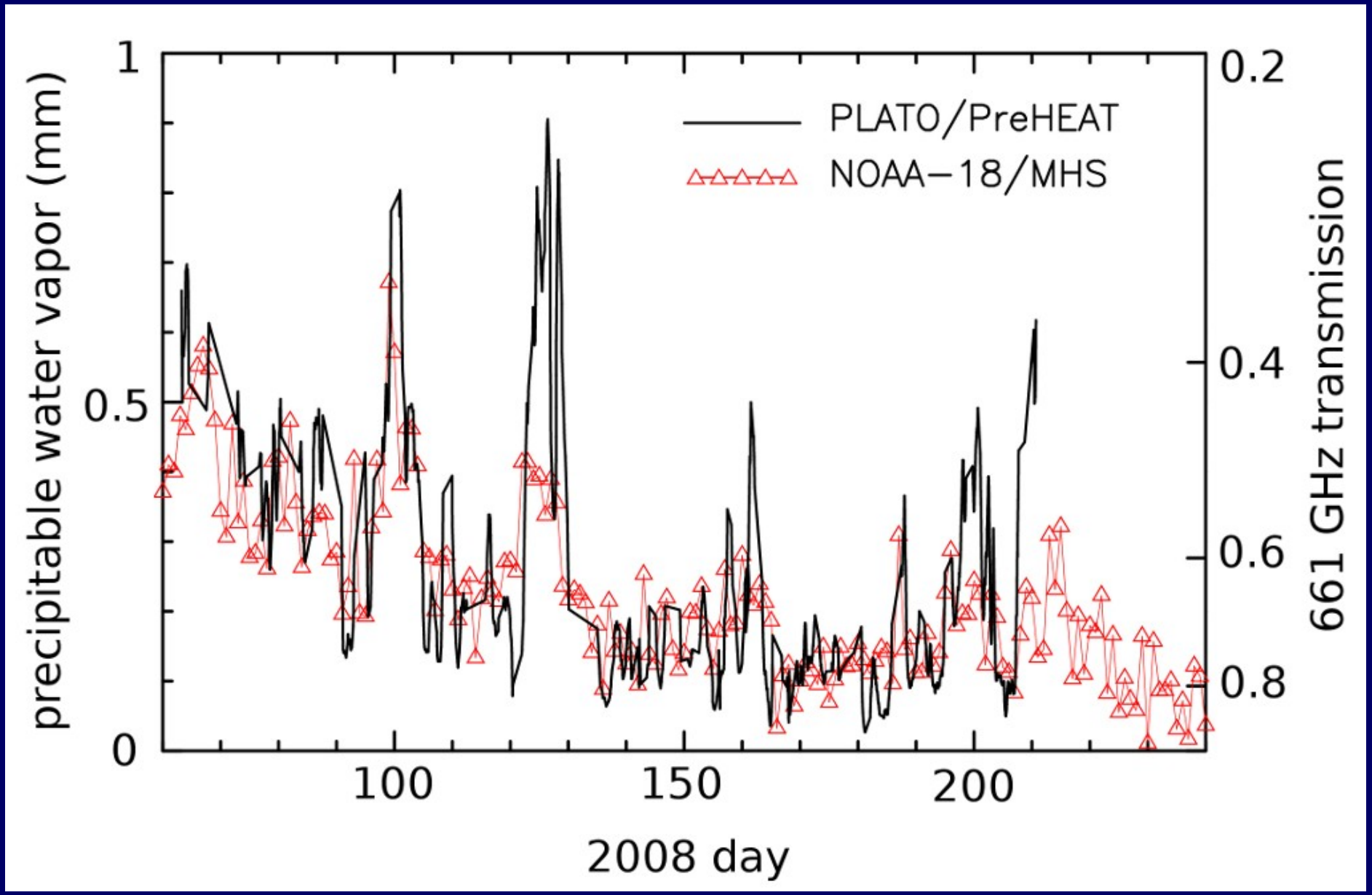
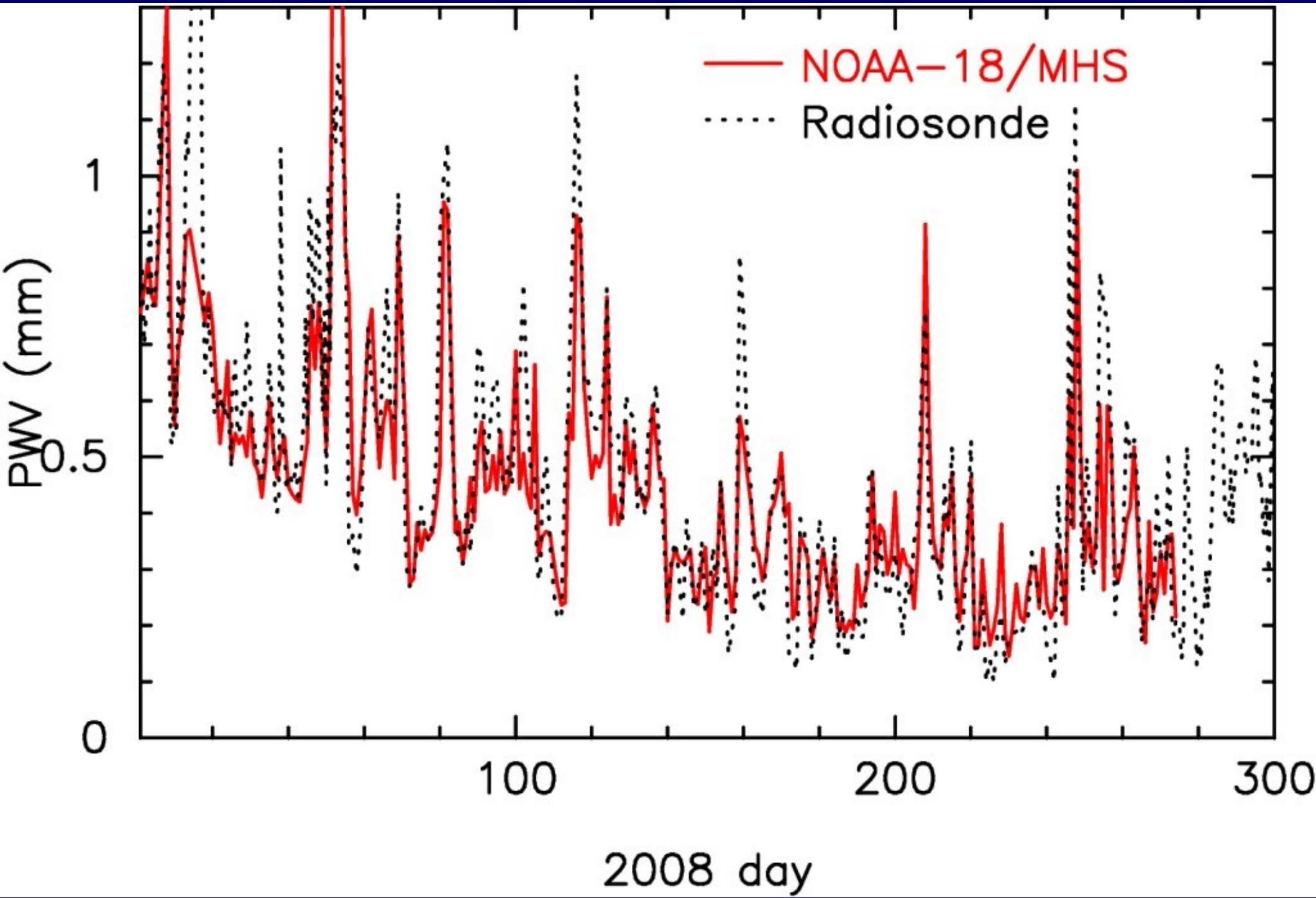
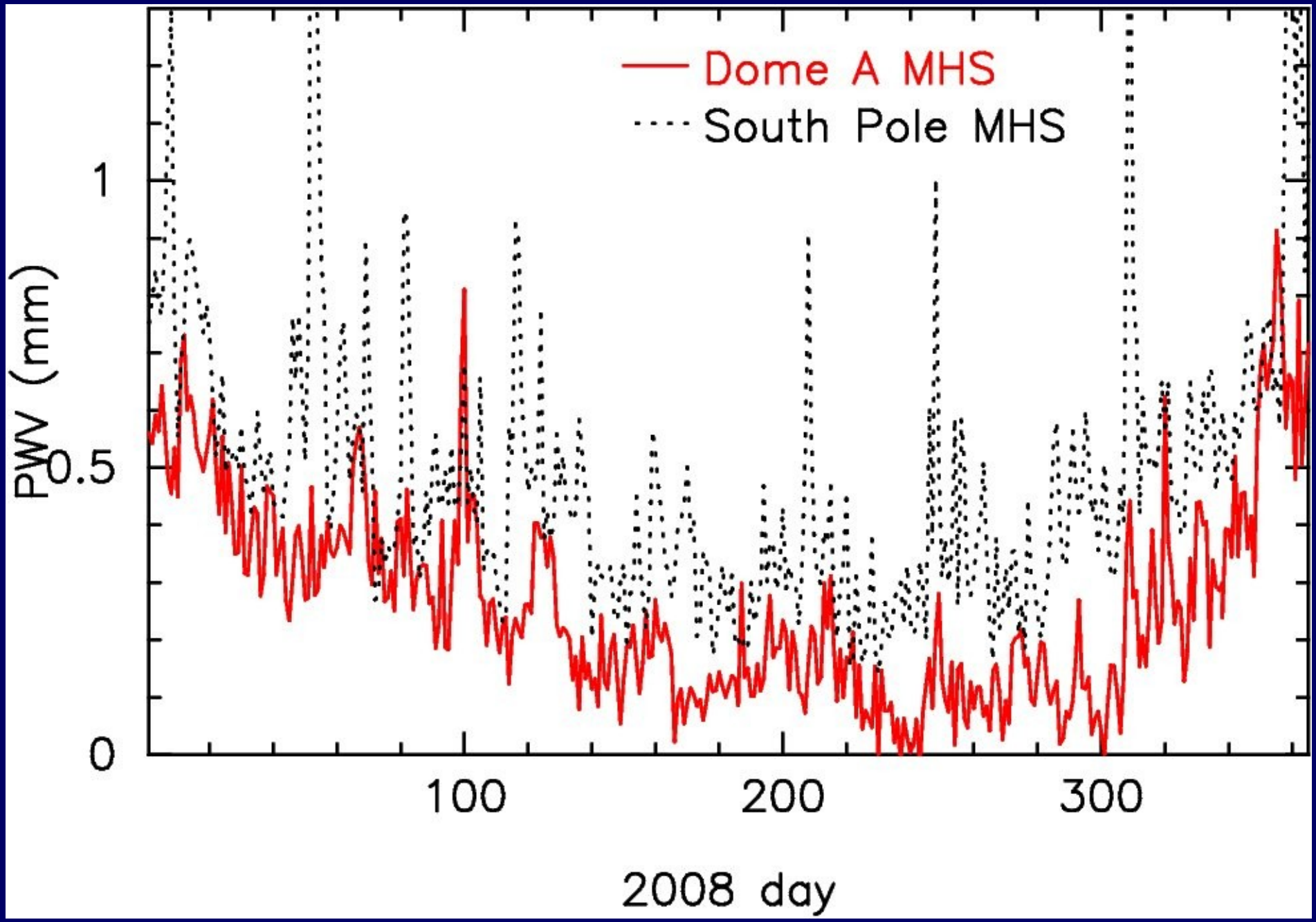
Combined NOAA satellite soundings and Pre-HEAT data show very low precipitable water vapor and high THz atmospheric transmission




NOAA−18/MHS
Radiosonde
PWV (mm)
0
0.5
1
100
200
300
2008 day

A more transparent and stable atmosphere than South Pole!



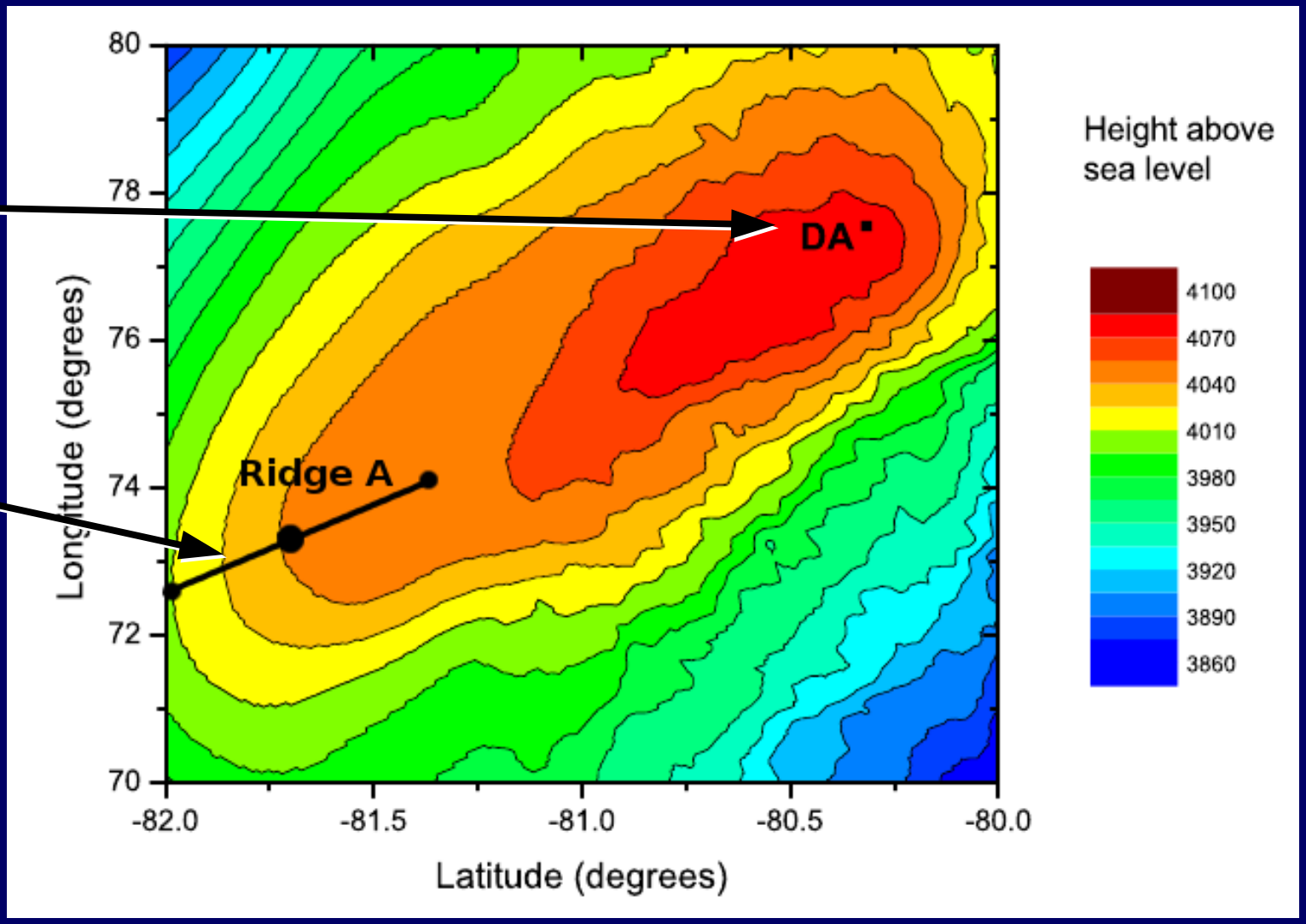
Ridge A, even better than Dome A (!)

Calibrated satellite microwave soundings suggest that the water vapor minimum lies 150 km inland of Dome A.

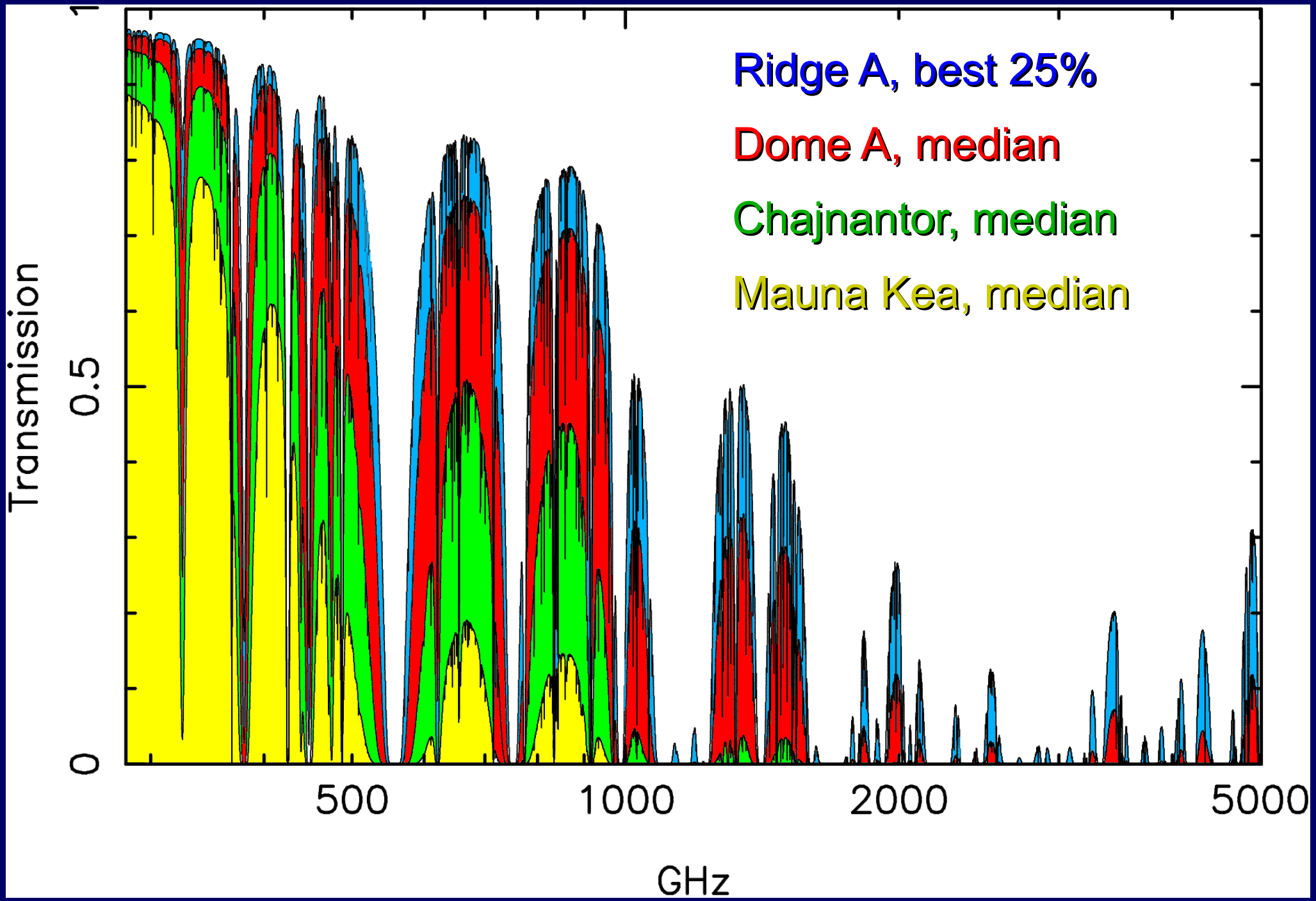
Best 10% PWV
75 um

Best 10% PWV
50 um

(That's 2-3X more THz time!)

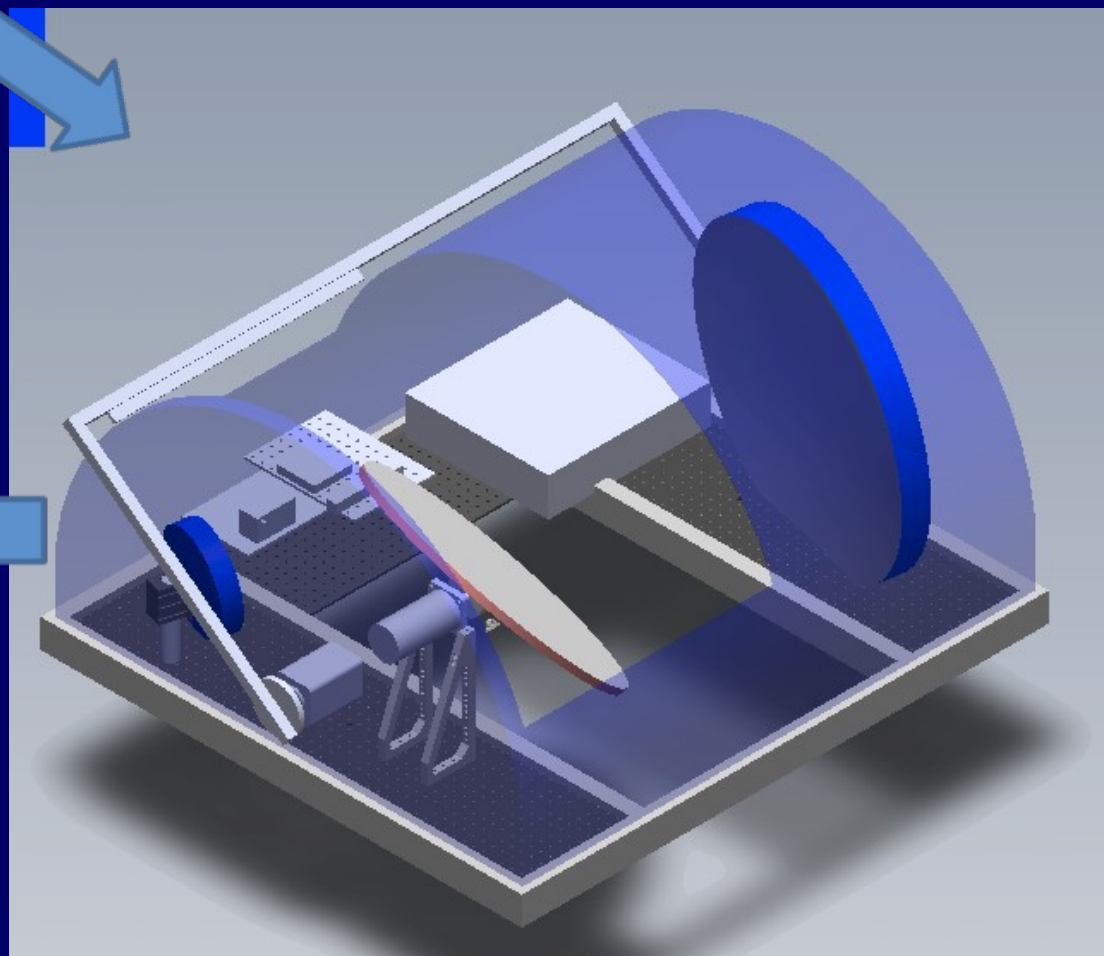


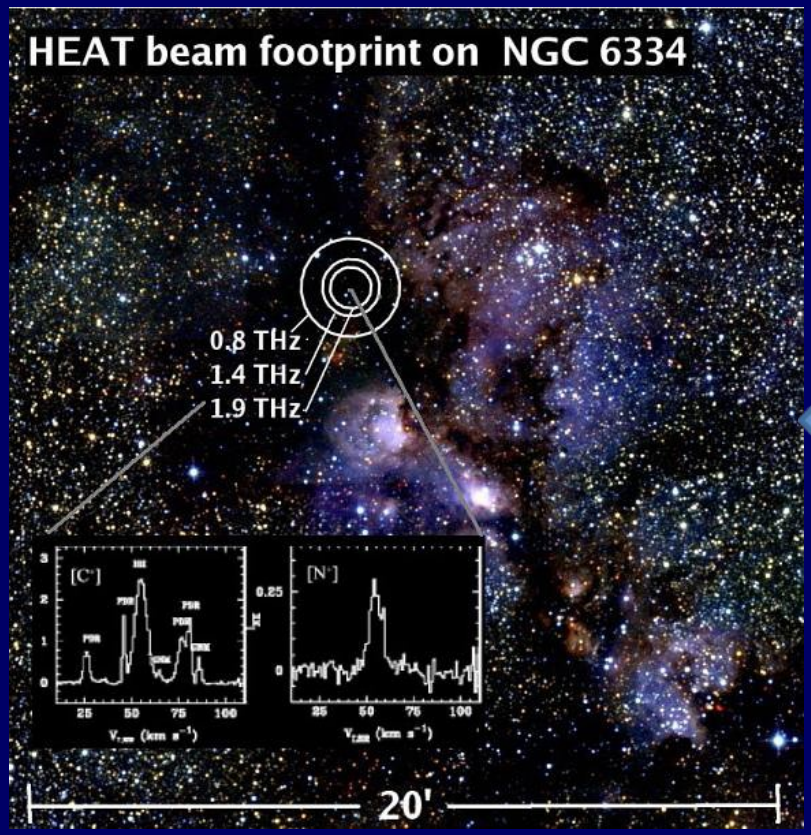
New atmospheric 'windows' open over the High Plateau



From PreHEAT to HEAT...

Primary 0.6 m
Surface 5 um rms
Pointing 30 arc sec
Power <200 W



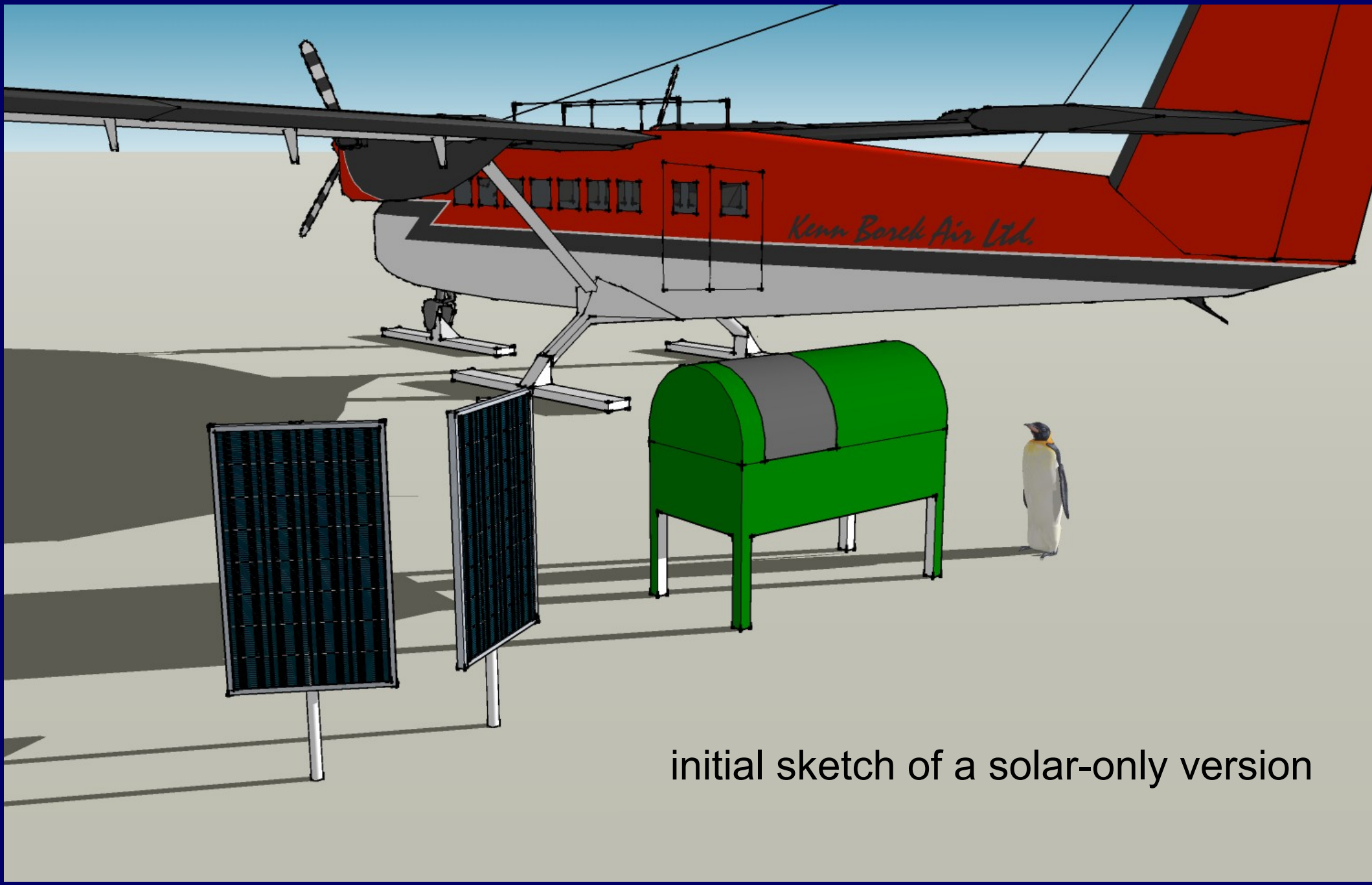


Requirements

- Off axis telescope with **0.6 meter aperture** & at least one moving axis for pointing
- The ideal site is **Ridge A**, 150 km inland from the Chinese station at Dome A. ~82S, 74E, elevation 4050m, mean winds ~2 m/s, minimum winter temperatures -80C
- Year-round operations; **June – October most valuable**
- **Heterodyne receivers & spectrometers** operating at an RF frequency starting at 800 GHz... to 2 THz
  - Preferably cryogenic
  - Even more preferably cooled to 4K.
- DC power requirements
  - with detectors at 80K: < 200W
- A fully sampled map of the Galactic Plane requires ~1GB per line of transmitted data

Operations Sketch

- Build two 0.6m HEAT telescopes and receiver systems to be field-swapped annually.
- Rapid-prototype the first telescope and **test at South Pole** Station at 800 GHz (350 um) over 2011 season
- Deploy the 2nd HEAT telescope via Twin Otter from South Pole to **Ridge A in January 2012** using a light-weighted **PLATO** unit from **UNSW** for all observatory support, just as is currently being done at Dome A and Dome F.
- HEAT/PLATO-R will operate for a year at a time between “servicing missions”.
- for a 3-year science survey mission, performed in concert with the Stratospheric Terahertz Observatory (STO), a partnering balloon borne experiment



initial sketch of a solar-only version

PLATO-F

“Lightweight”and simplified PLATO using 5 Hatz diesel engine, solar and LiFePO4 batteries

Now in operation at Dome F

Basis for Ridge A model for HEAT deployment 2011-12.

PLATO Dome A Robotic Observatory

Mission Time 812 Days 13 Hours 48 Mins 31 Sec

Navigation
Home
Science
Contacts

Live updates
Week
Month
Year
Sun and Moon
Webcams

PLATO Module
Instrument
Engine

Instruments
CSTAR
DASLE
FTS
Gattini
HRCAM
Nigel
PreHEAT
Snodar

Publications
Papers

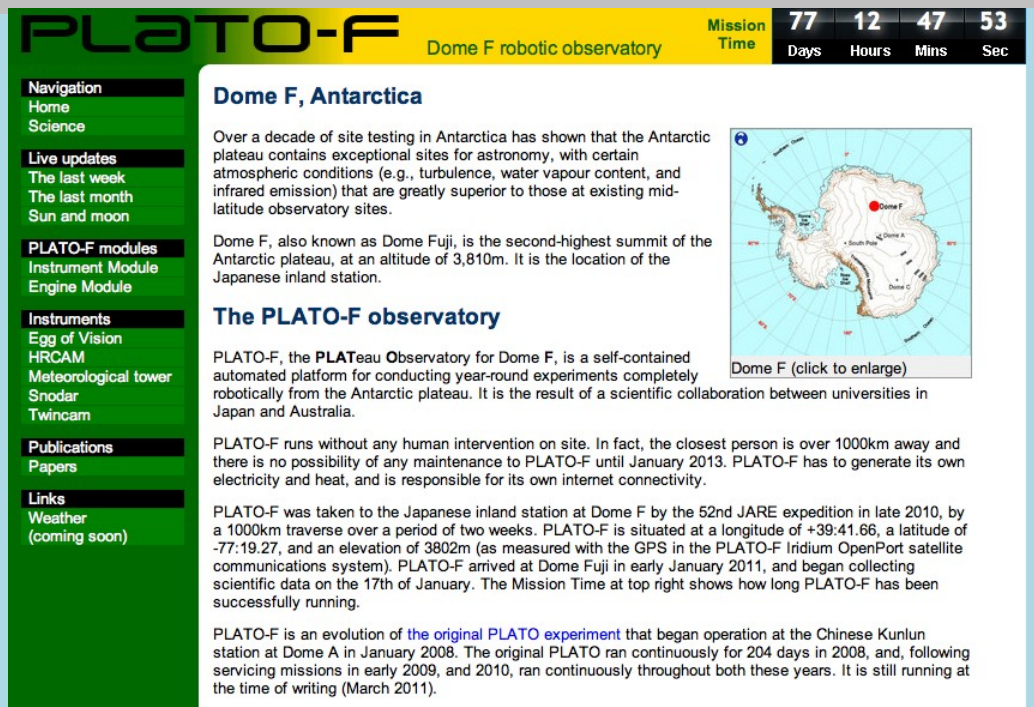
Links
Images
Weather (AAD)
Chinese translation

Dome A, Antarctica

Over a decade of site testing in Antarctica has shown that both South Pole and Dome C are exceptional sites for astronomy, with certain atmospheric conditions greatly superior to those at existing mid-latitude sites. The highest point on the Antarctic plateau, Dome A, is expected to experience even colder atmospheric temperatures, lower wind speeds, and a turbulent boundary layer that is confined even closer to the ground.

As part of the PANDA and Astropoles programs of the International Polar Year (IPY), an agreement was signed between the the National Astronomical Observatories of the Chinese Academy of Sciences (NAOC), the Polar Research Institute of China (PRIC), and the University of New South Wales (UNSW) to develop and deploy an autonomous observatory called PLATO to Dome A. The PANDA traverse successfully delivered PLATO to Dome A in January 2008. A large international team has contributed to PLATO and its instruments, with Iridium satellite communication being provided by the U.S. Antarctic Program (USAP).

Dome A (click to enlarge)



PLATO-F Dome F robotic observatory

Mission Time 77 Days 12 Hours 47 Mins 53 Sec

Navigation
Home
Science

Live updates
The last week
The last month
Sun and moon

PLATO-F modules
Instrument Module
Engine Module

Instruments
Egg of Vision
HRCAM
Meteorological tower
Snodar
Twincam

Publications
Papers

Links
Weather
(coming soon)

Dome F, Antarctica

Over a decade of site testing in Antarctica has shown that the Antarctic plateau contains exceptional sites for astronomy, with certain atmospheric conditions (e.g., turbulence, water vapour content, and infrared emission) that are greatly superior to those at existing mid-latitude observatory sites.

Dome F, also known as Dome Fuji, is the second-highest summit of the Antarctic plateau, at an altitude of 3,810m. It is the location of the Japanese inland station.

Dome F (click to enlarge)

The PLATO-F observatory

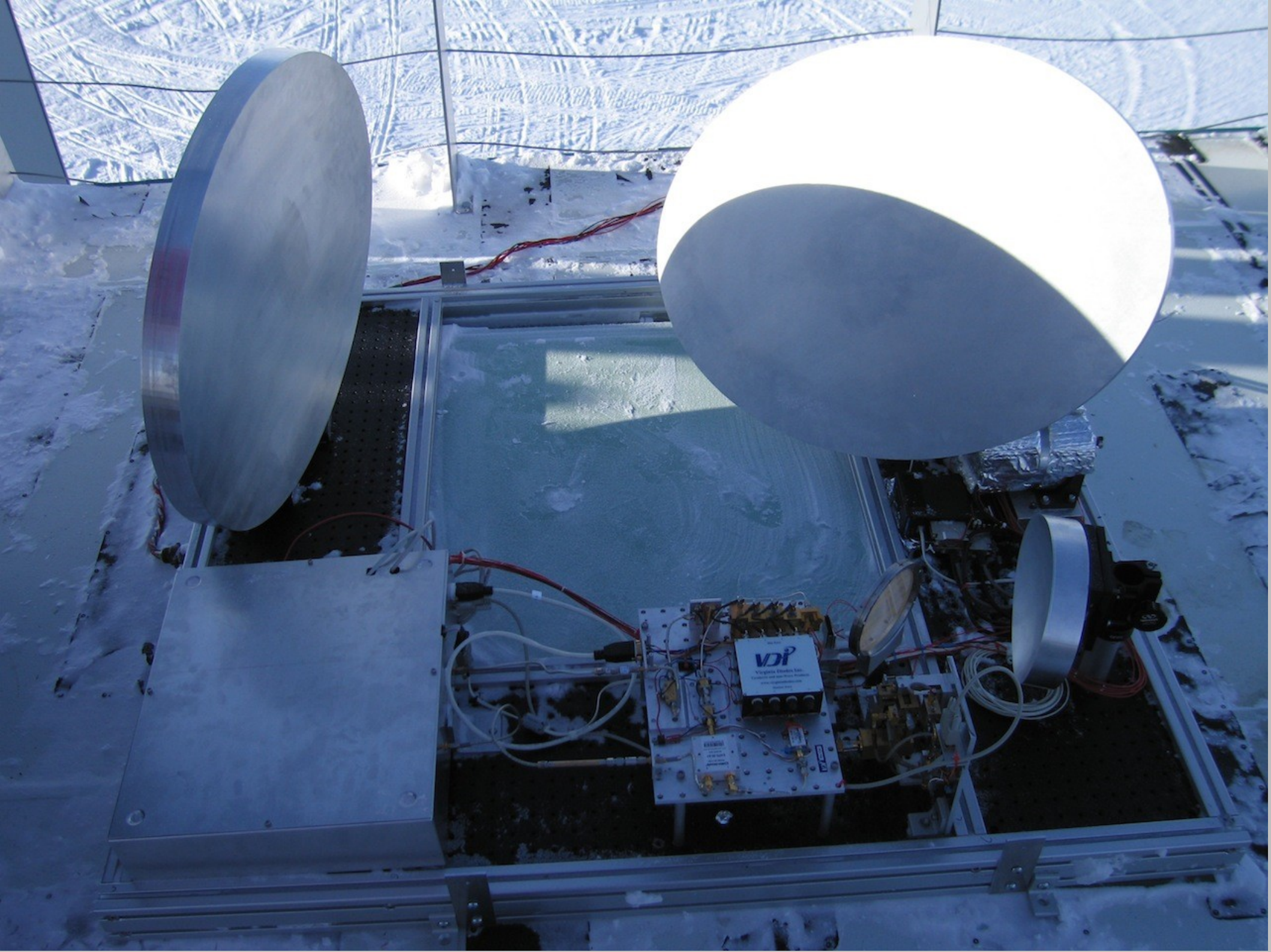
PLATO-F, the **PLAT**eau **O**bservatory for Dome **F**, is a self-contained automated platform for conducting year-round experiments completely robotically from the Antarctic plateau. It is the result of a scientific collaboration between universities in Japan and Australia.

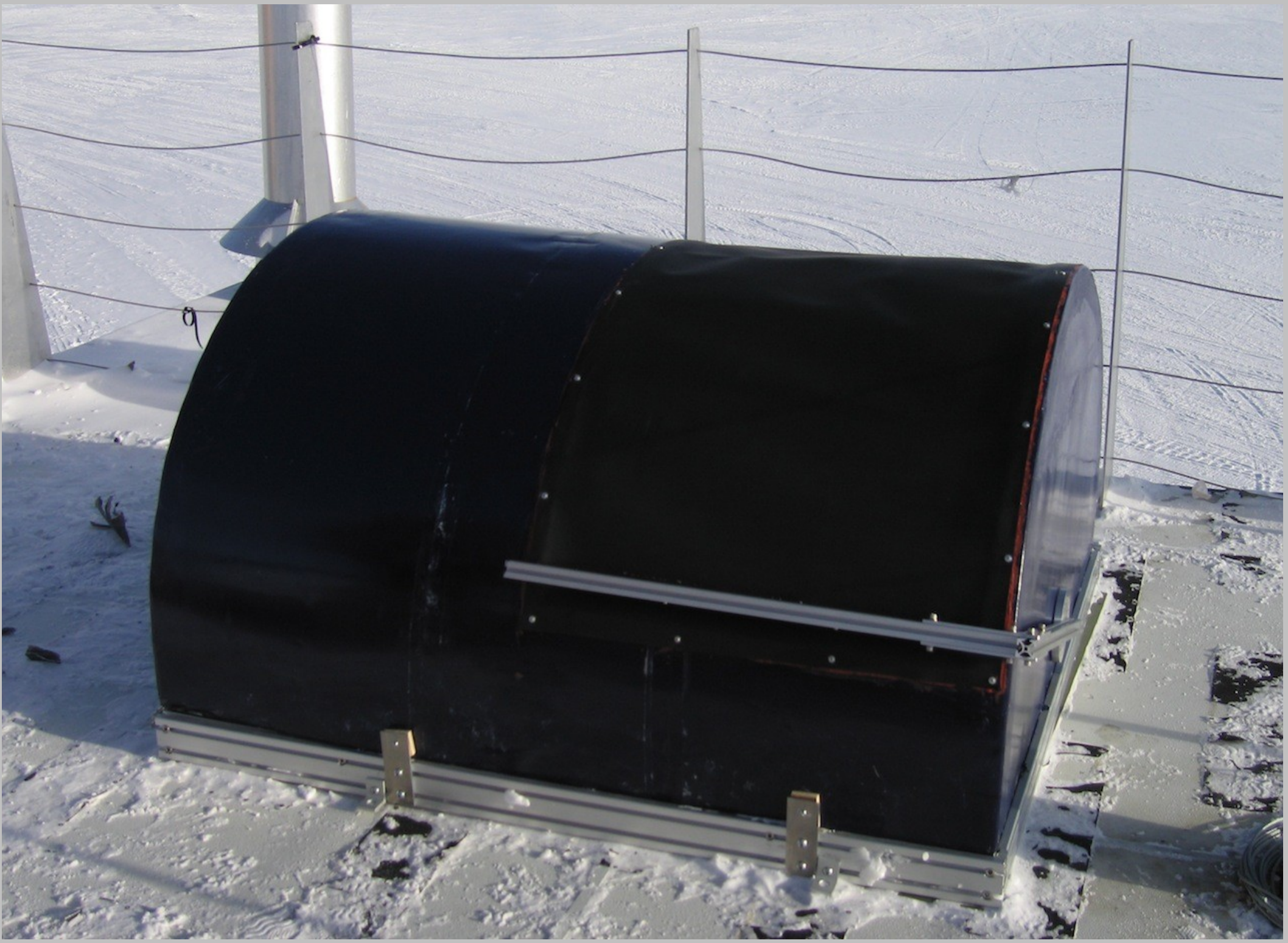
PLATO-F runs without any human intervention on site. In fact, the closest person is over 1000km away and there is no possibility of any maintenance to PLATO-F until January 2013. PLATO-F has to generate its own electricity and heat, and is responsible for its own internet connectivity.

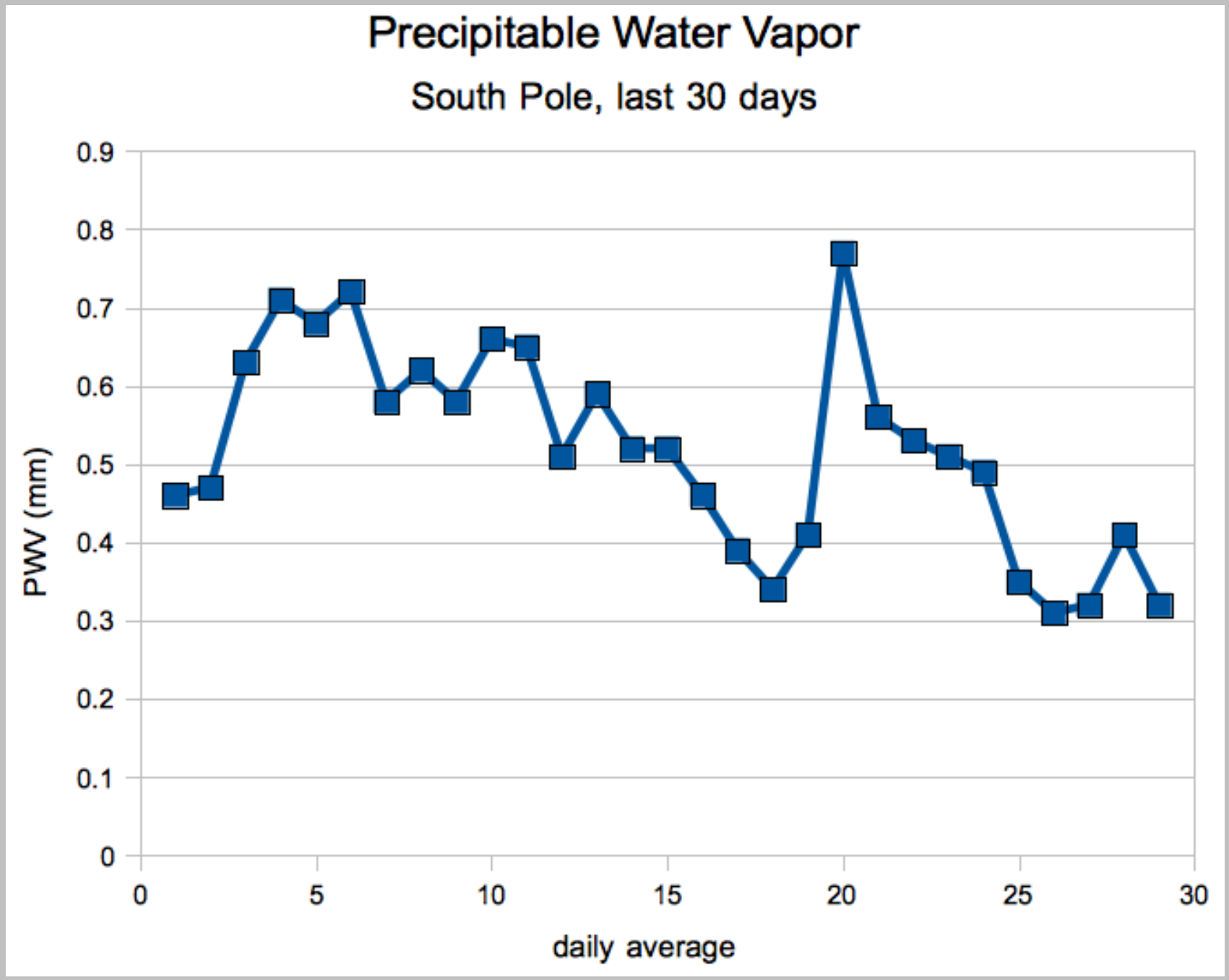
PLATO-F was taken to the Japanese inland station at Dome F by the 52nd JARE expedition in late 2010, by a 1000km traverse over a period of two weeks. PLATO-F is situated at a longitude of +39:41.66, a latitude of -77:19.27, and an elevation of 3802m (as measured with the GPS in the PLATO-F Iridium OpenPort satellite communications system). PLATO-F arrived at Dome Fuji in early January 2011, and began collecting scientific data on the 17th of January. The Mission Time at top right shows how long PLATO-F has been successfully running.

PLATO-F is an evolution of the original PLATO experiment that began operation at the Chinese Kunlun station at Dome A in January 2008. The original PLATO ran continuously for 204 days in 2008, and, following servicing missions in early 2009, and 2010, ran continuously throughout both these years. It is still running at the time of writing (March 2011).

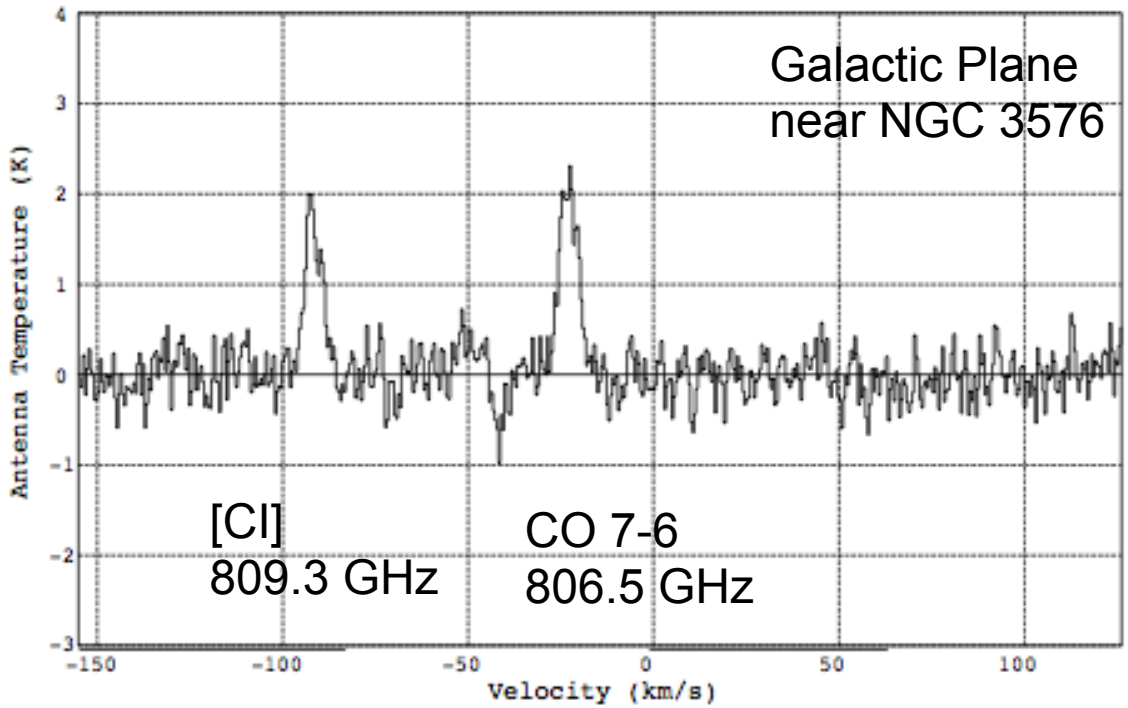

USAP NPX
MAPD
A-149-S
Do NOT DR
FRAGILE
DR3

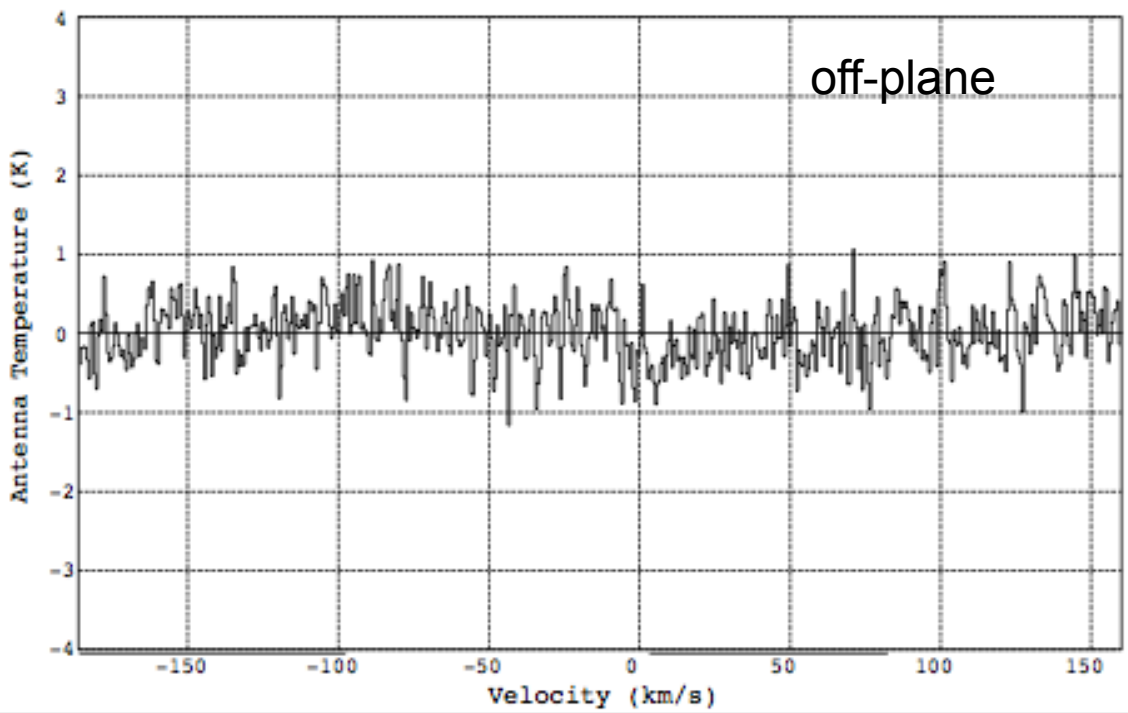

VDI
Virginia Diodes Inc.





current temperature -61C, PWV=0.32mm, transmission at 810 GHz = 26%





810 GHz spectra

accumulated March 15-22


Looking forward to deploying HEAT to
Ridge A in January 2012!



Into the looking glass: 2015 and beyond

- Herschel will be gone.
- ALMA will provide subarcsecond imaging and spectroscopy, < 1 THz
- CCAT will provide filled aperture imaging with 5-15” resolution, < 1 THz
- SOFIA will provide imaging and spectroscopy with 15-30” resolution, > 1 THz
- What's missing?

Terahertz Interferometry from Antarctica

- Goal: 1” resolution at 1 THz
- 1-2 meter aperture 'modules' with cooled HEB mixer receivers. 1-2 kW per module, baselines 10-100m
- 0.8 THz interferometer could be done at South Pole
- > 1 THz requires Dome A or Ridge A
- Sample application: protostellar collapse signatures
- Continued development: low power cryocoolers, sensitivity and stability of detectors at > 1 THz

Thank you!