Two Years at Ridge A:
First Results from the High Elevation Antarctic Terahertz (HEAT) telescope

Craig Kulesa *(University of Arizona)*
On behalf of the entire HEAT and PLATO-R team

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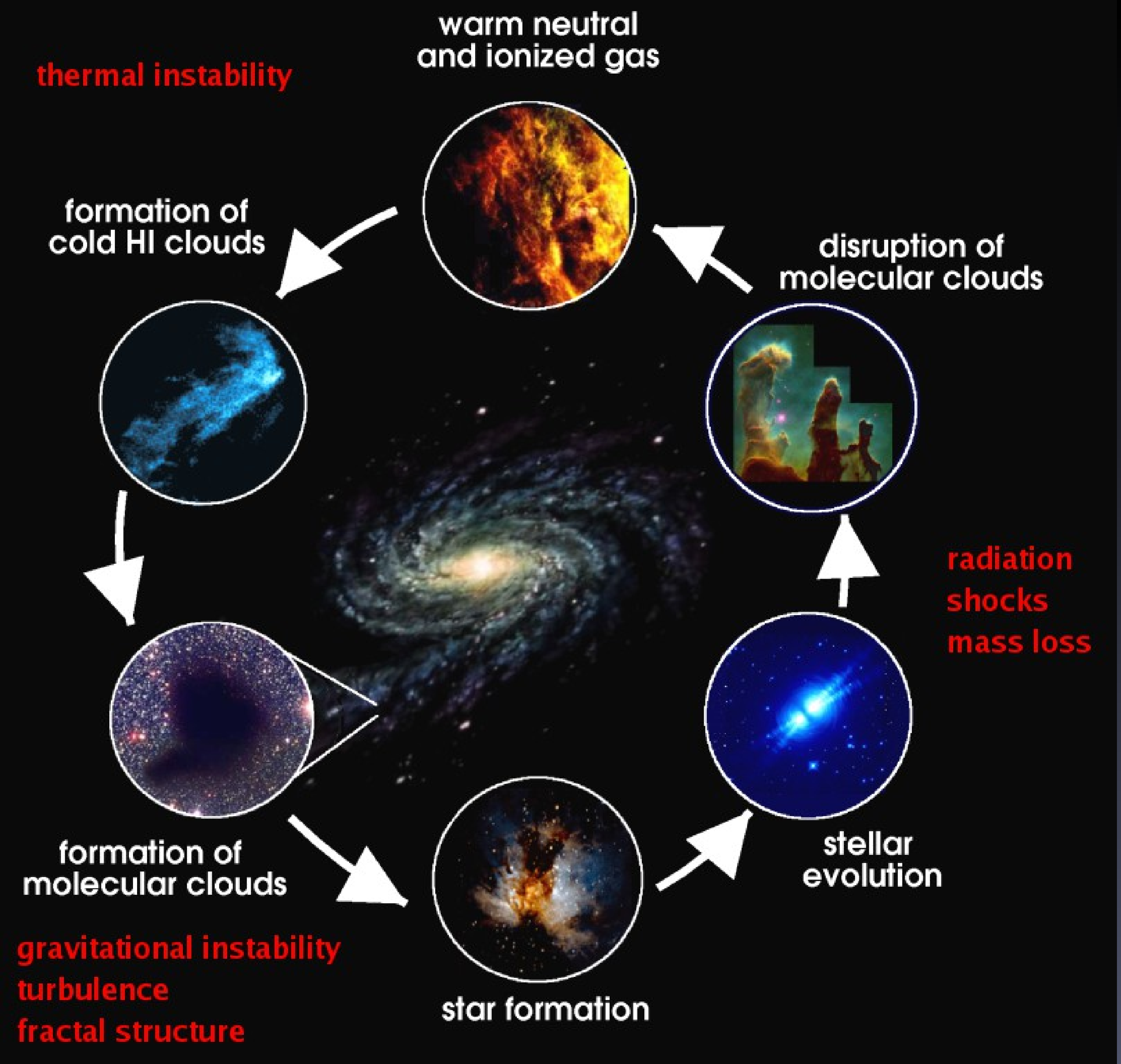
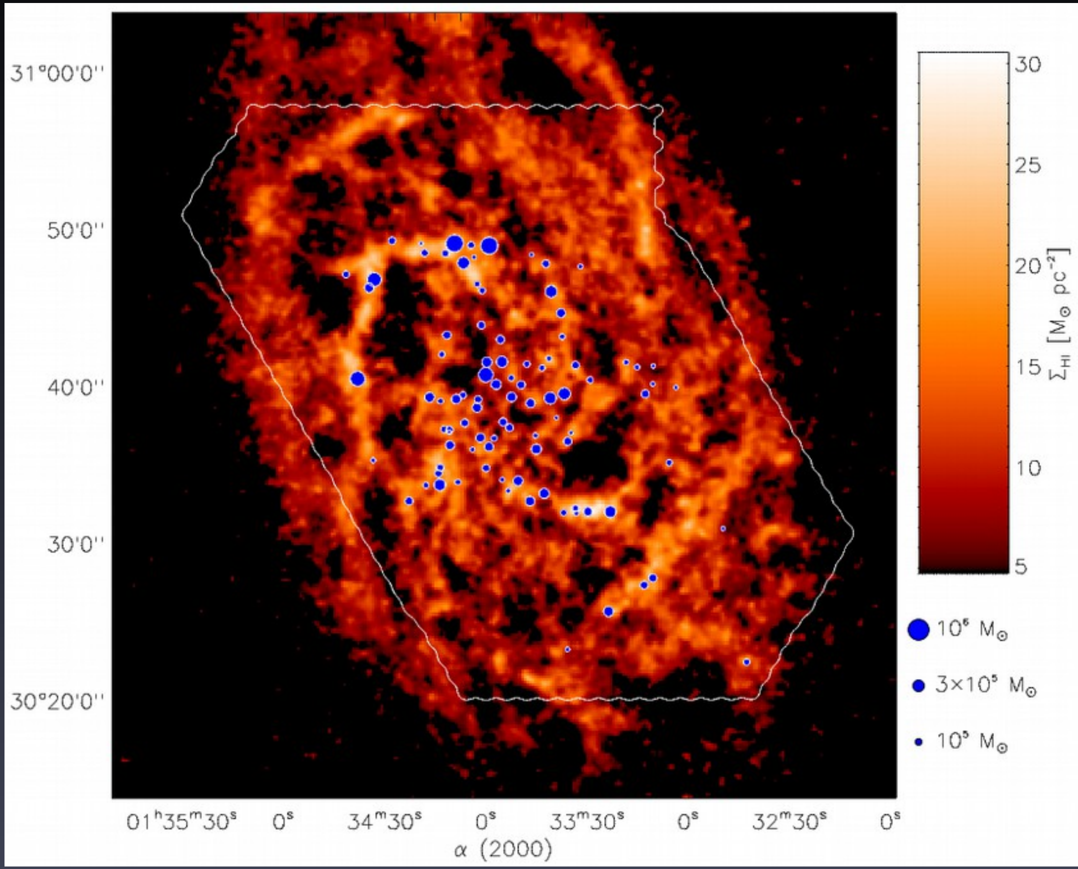
The Life Cycle of matter in the Galaxy



The Formation of Molecular Clouds: rate limiter for star formation in galaxies



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

Why do clouds form?
We don't know.

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

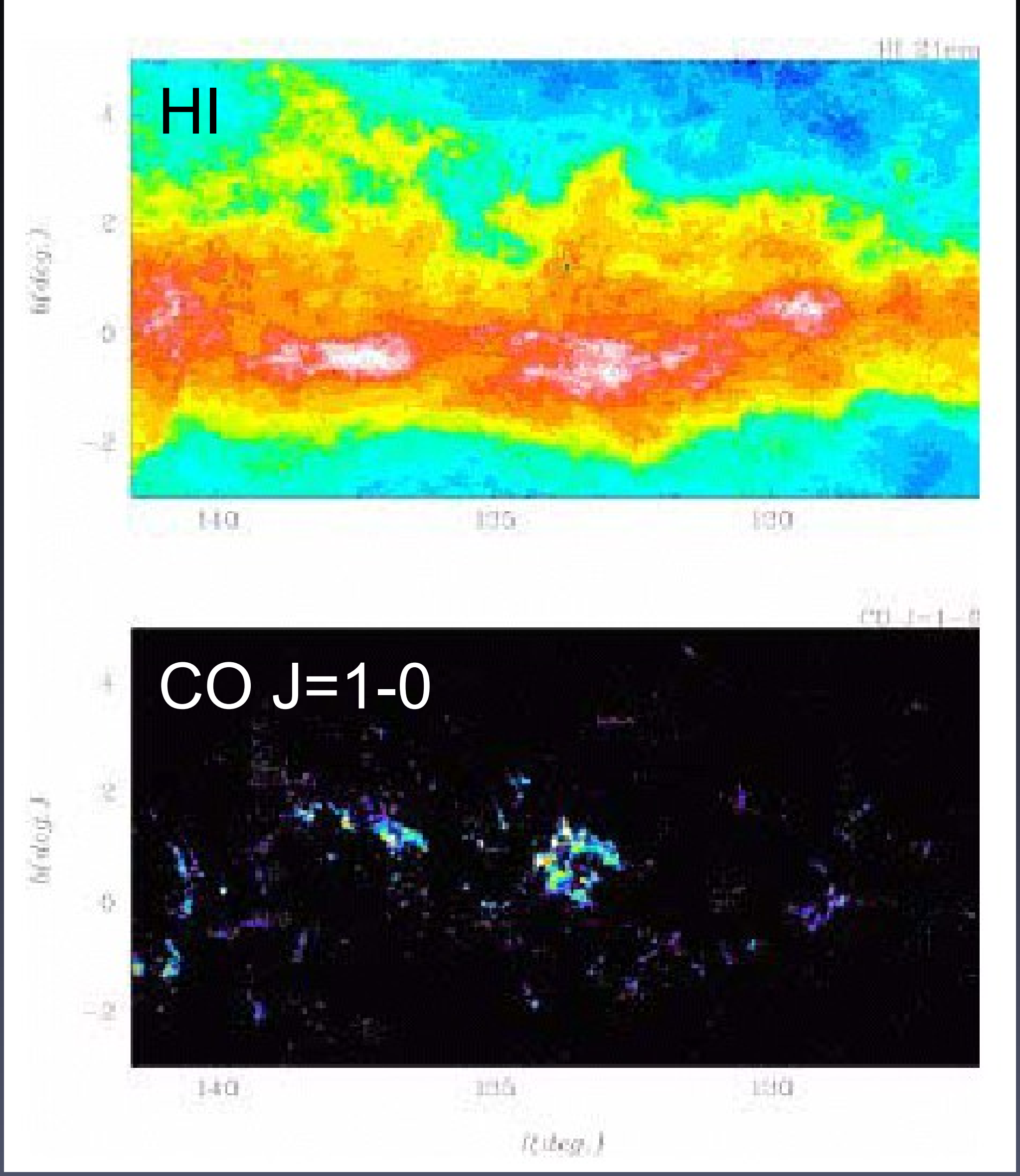
A statistical survey can distinguish between these mechanisms!

Our understanding of the cold ISM is incomplete

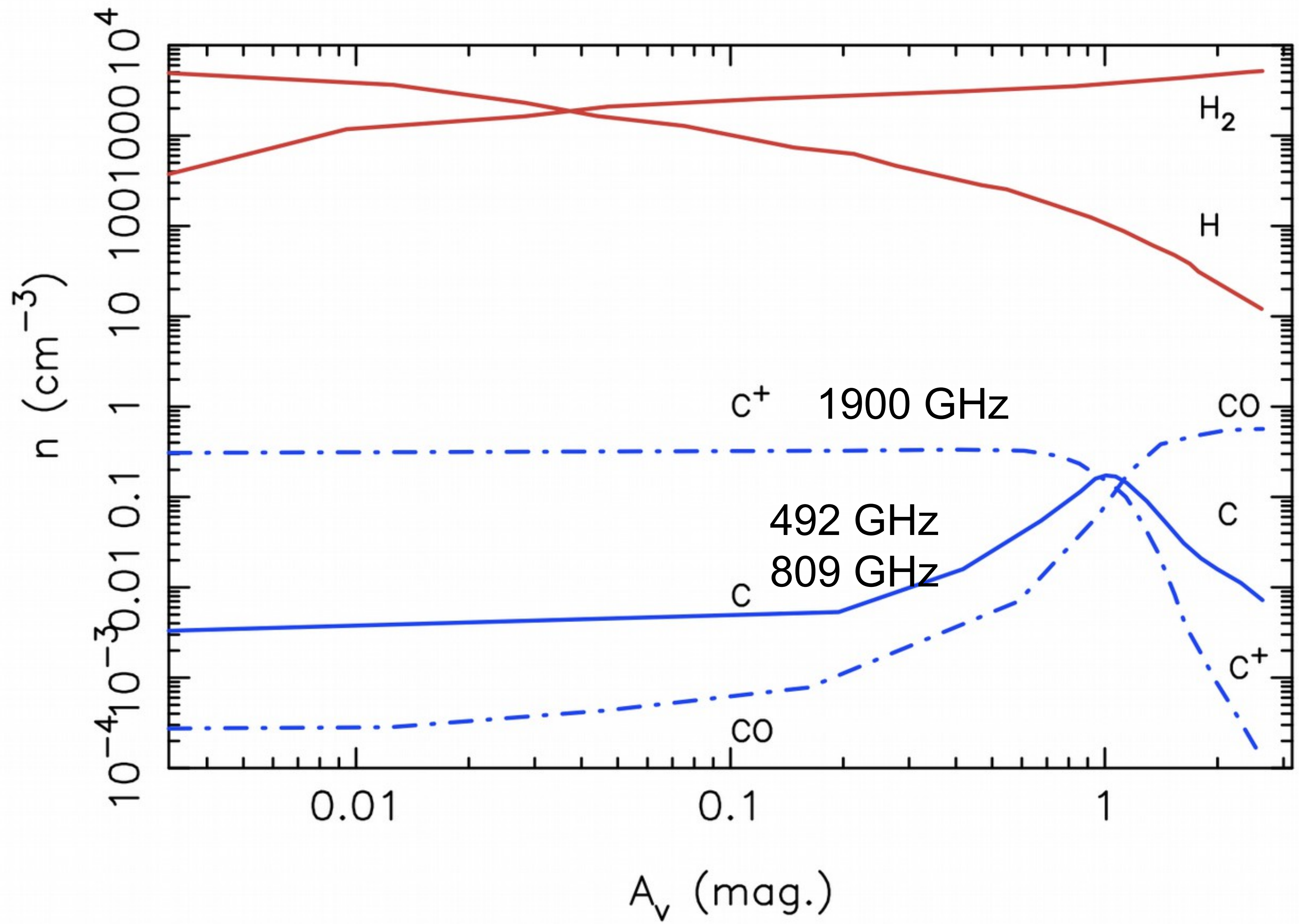
- HI provides a measure column density, but provides little insight into which ISM component it comes from

- CO only probes already-formed molecular clouds

So how can we see the evolution of clouds?



Line emission from C and C^+ show us "hidden" molecular gas not probed by CO



What is needed:

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

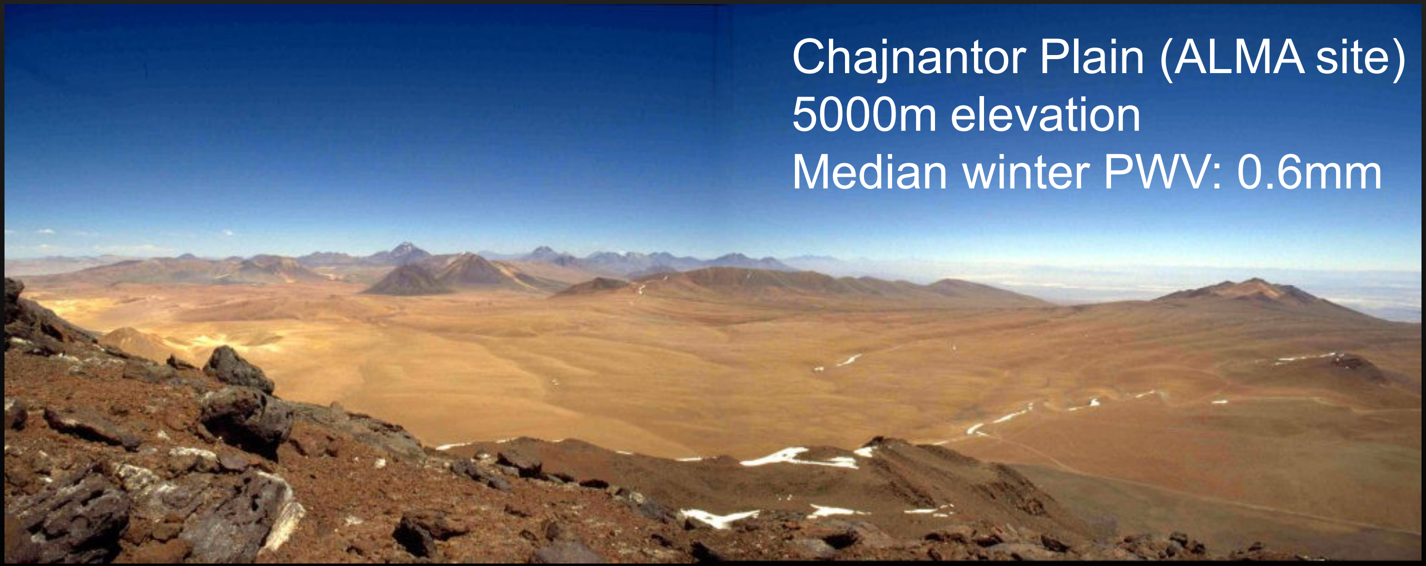
- with high spectral resolution of ~1 km/s

- 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

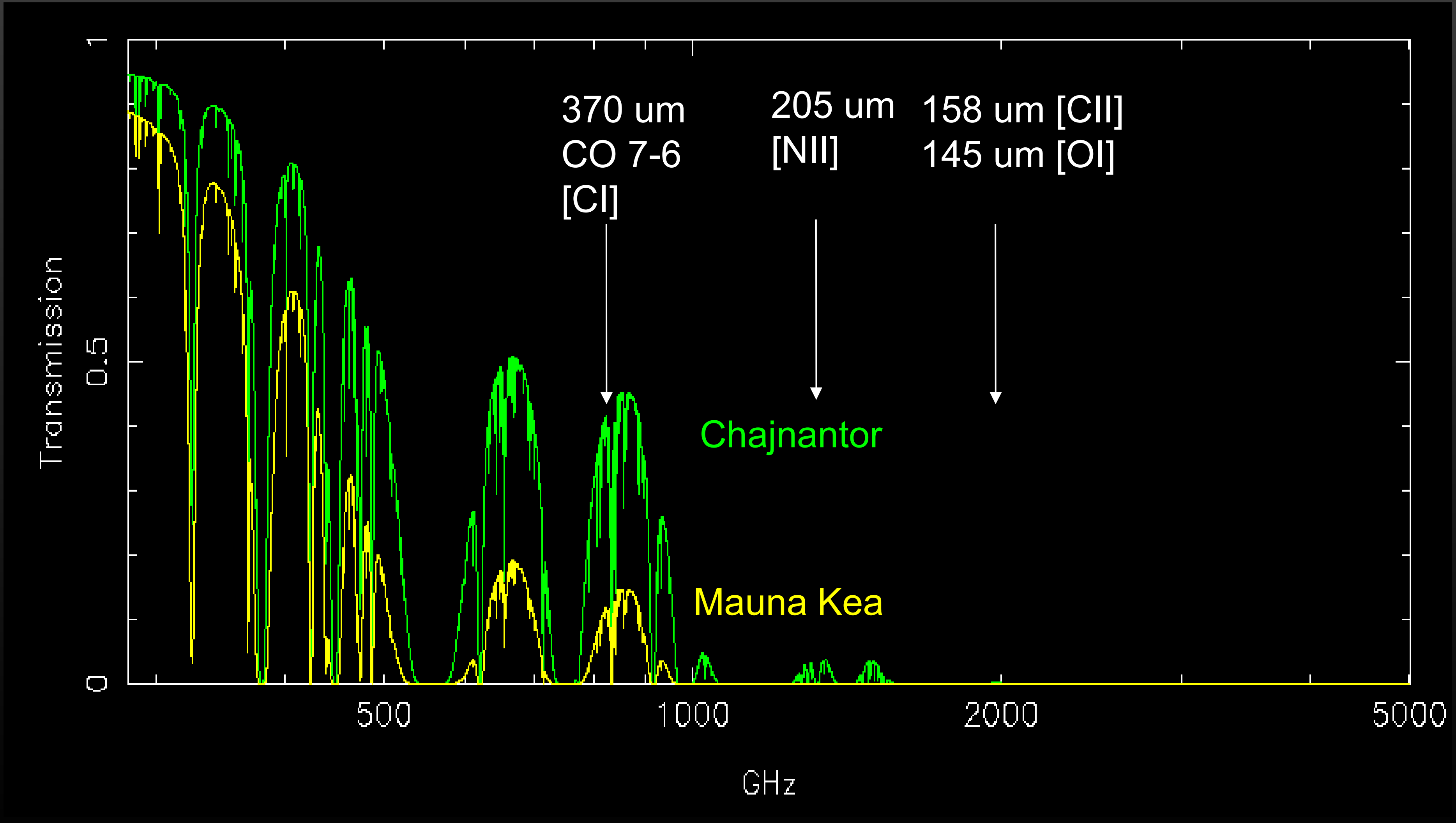
8/24 um portion of Galactic Plane from Spitzer MIPSGAL/GLIMPSE program

Established THz Observing Sites...



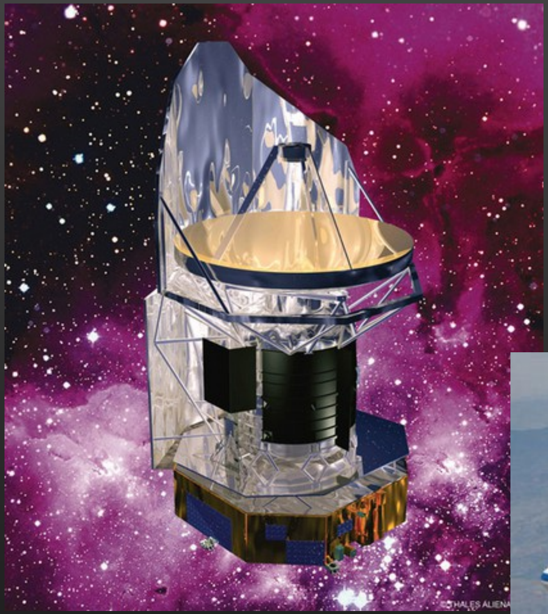
… are simply not good enough.

We need to go higher, drier, and colder…



(Sub)orbital Platforms for THz Astronomy

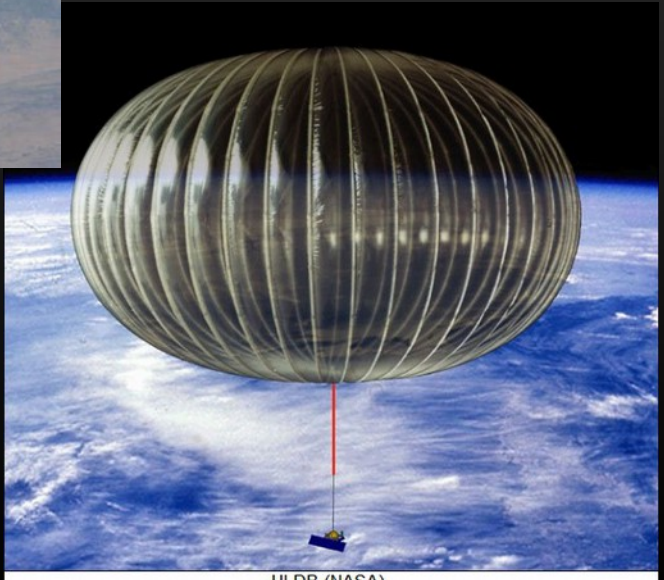
Expensive, w/ limited access and observing time



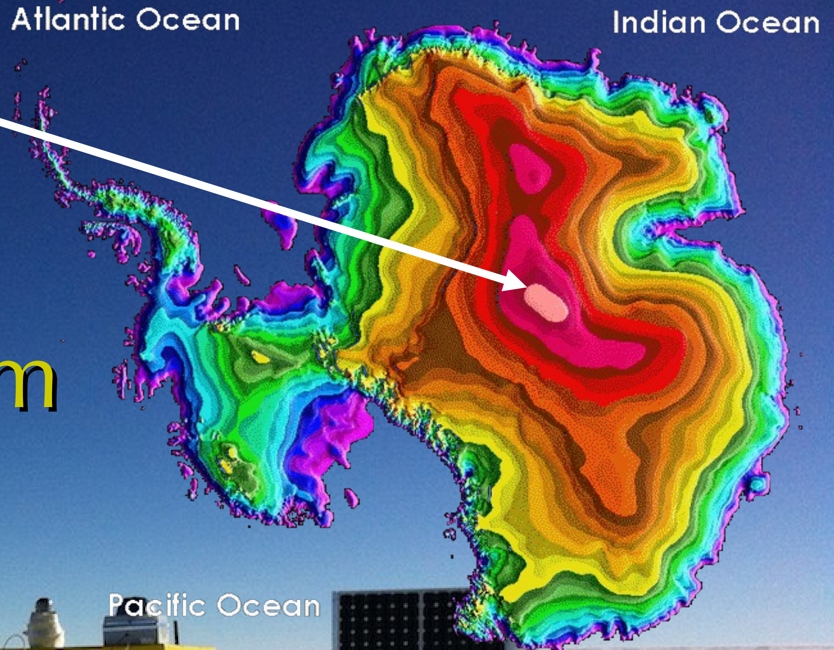
Herschel (2009-2013)
3.5m aperture at L2
$120,000 / hr

SOFIA (2010-2020+)
2.5m aperture at 12 km
$100,000 / hr...
...if it can fly 1000 hr/yr

Long duration balloons
1m aperture at 35 km
$15-25,000 / hr
14-30 day missions


ULDB (NASA)

Antarctica's role as a crucial THz platform



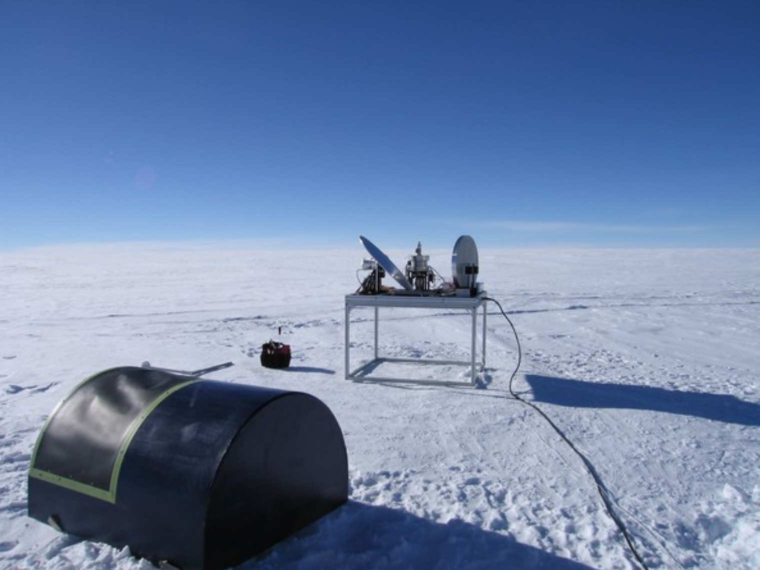
- 1 meter-class robotic telescope at 4.7 km pressure altitude
- Submillimeter (< 1 THz) observing conditions all of the time
- Super-THz (> 1 THz) observing conditions 25% of the time
- By far the best THz transmission and stability on Earth
- You can land a Twin Otter aircraft at your telescope
- **~$100 / hr observing time!**

High Elevation Antarctic Terahertz (HEAT) telescope

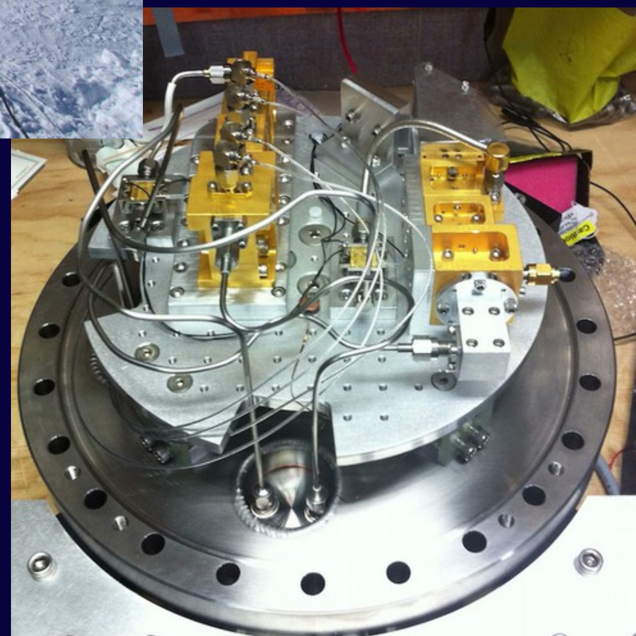
prototype telescope deployed in 2012 to Ridge A with PLATO-R

“farthest reach of the USPS”

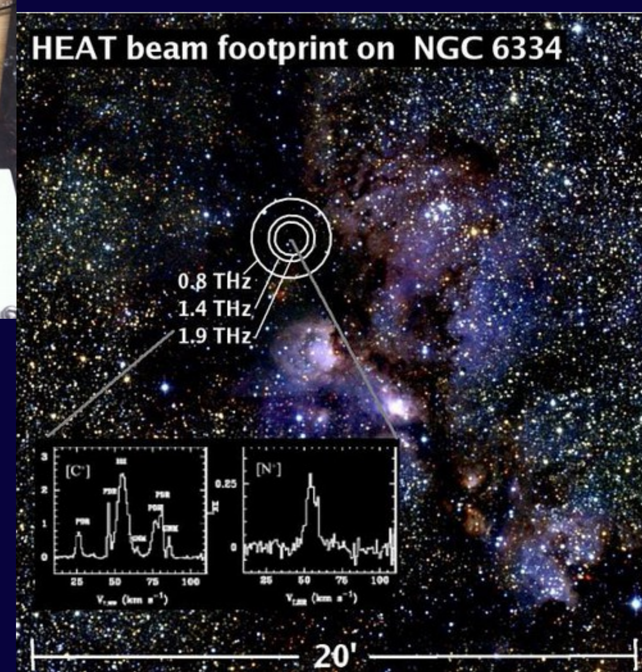
HEAT is...



… a 62 cm off-axis Gregorian telescope



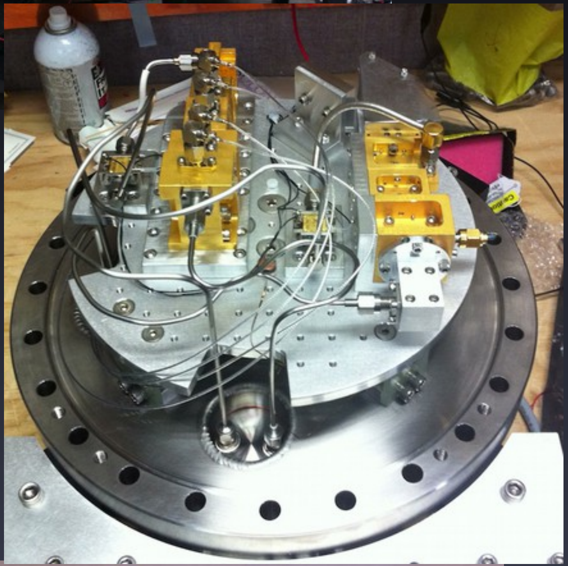
… with cryogenic heterodyne receivers in the far-infrared (150–600 um)



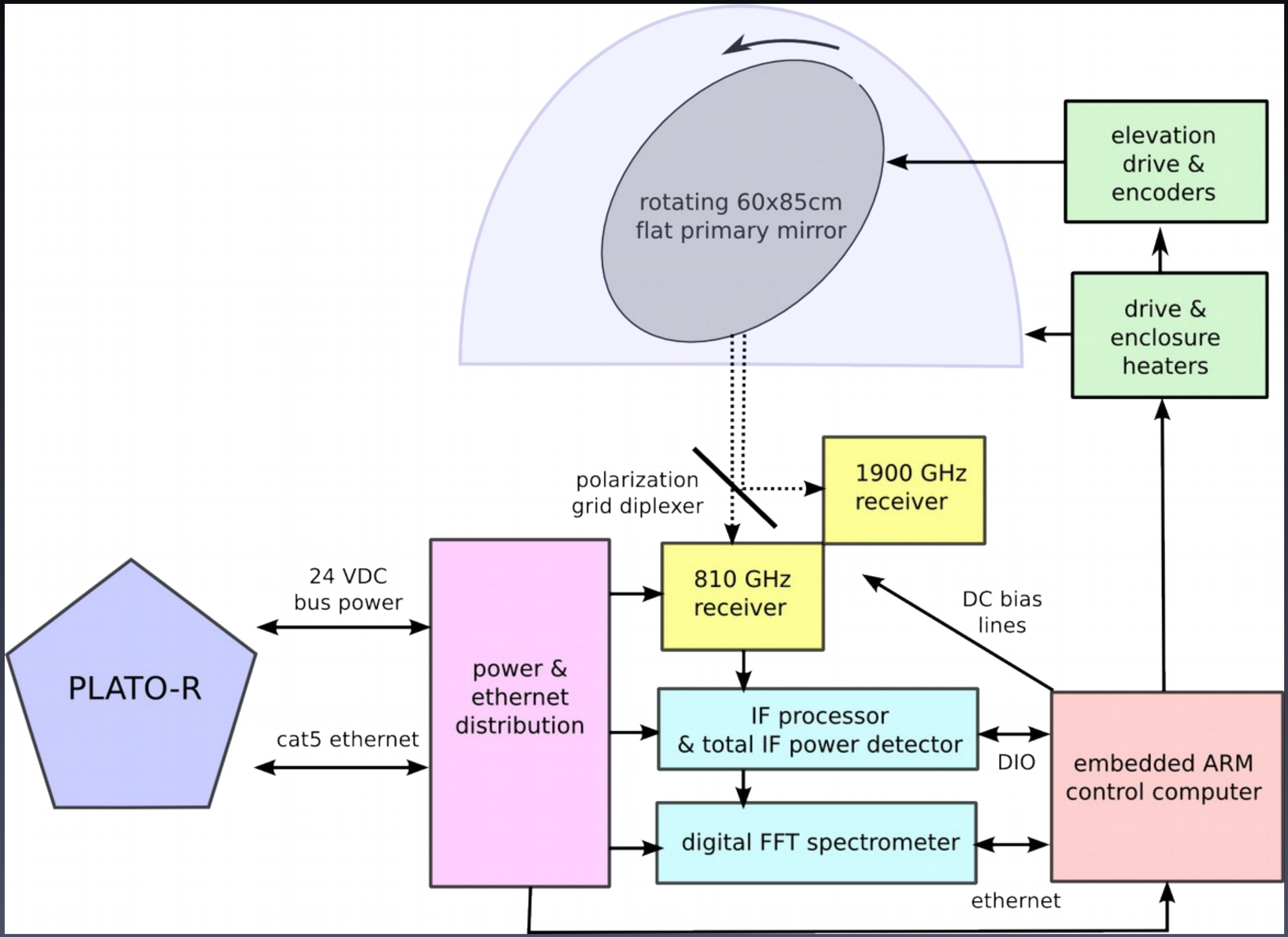
…performing a focused spectroscopic survey of the Milky Way in its most important THz lines of carbon, nitrogen and oxygen.

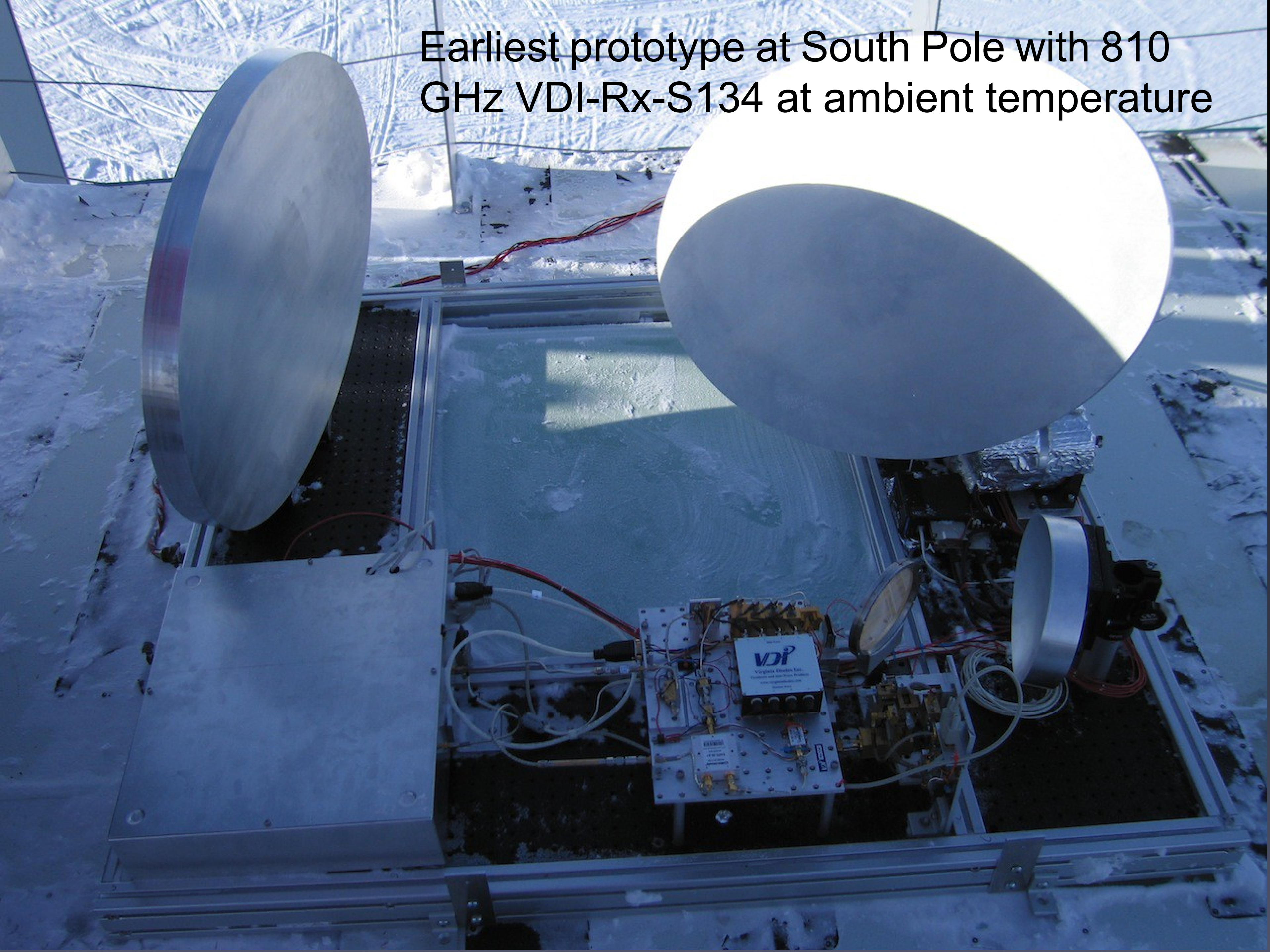
Technical Features

- 60 cm off-axis Gregorian telescope with heterodyne receivers from 0.5-0.8 (2012-13) through 2 THz (2014). 1-2′ angular resolution, 1 km/s spectral resolution
- HEAT's "low frequency" band at 0.8 THz matches other observatories' high band!
- **First unattended cryogenic (50K) receivers on the plateau.** Receivers achieve highest sensitivity for T>4K, with 80W DC power.
- Digital wideband FFT spectrometers (up to 3 GHz, 30W typical)
- Autonomous data pipeline over Iridium
- **A complete THz observatory for <200 watts!**
- Builds technology for future space hardware (synthesizers, amplifiers, control systems)

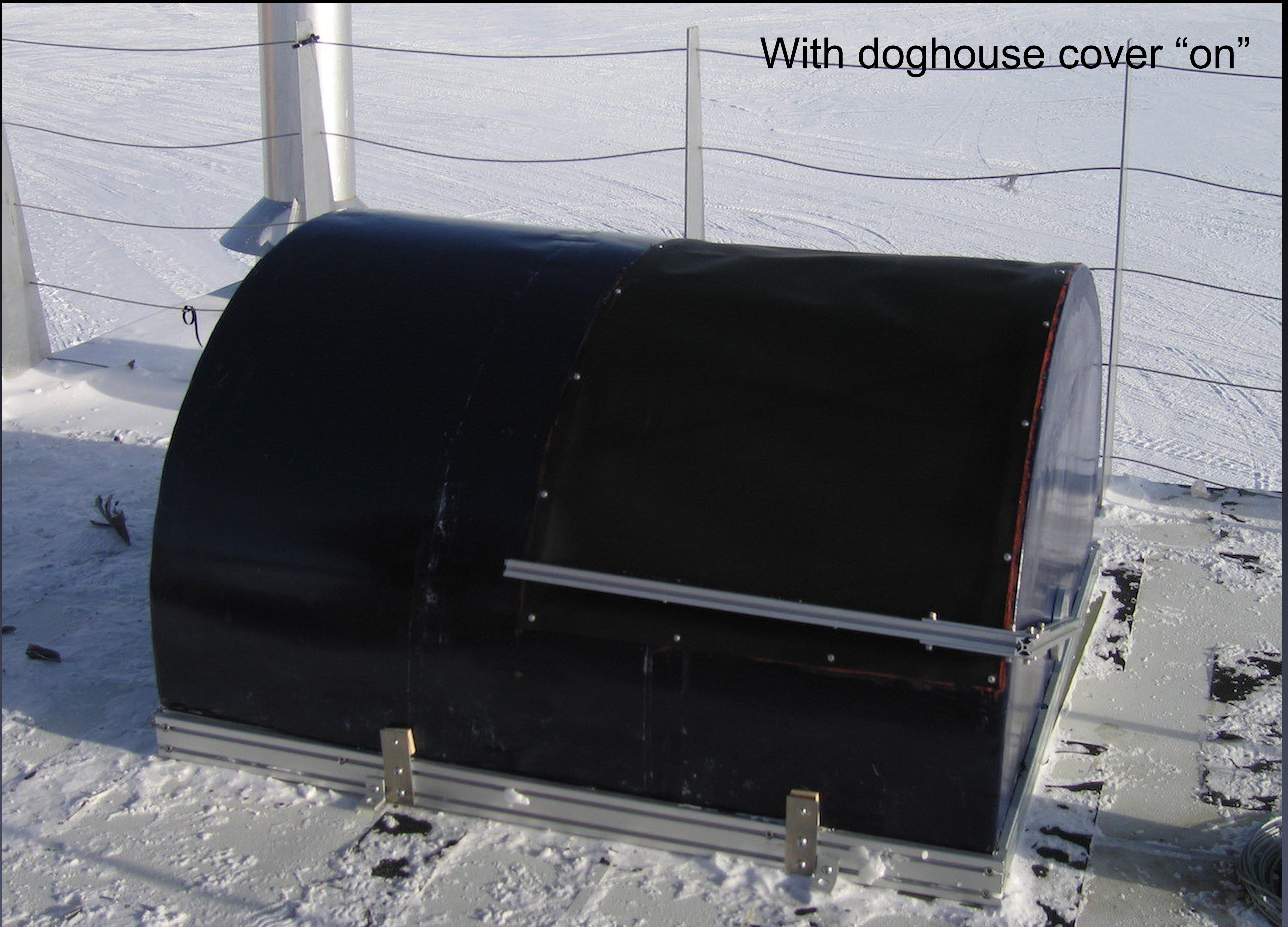


HEAT is a complete THz telescope





Earliest prototype at South Pole with 810 GHz VDI-Rx-S134 at ambient temperature

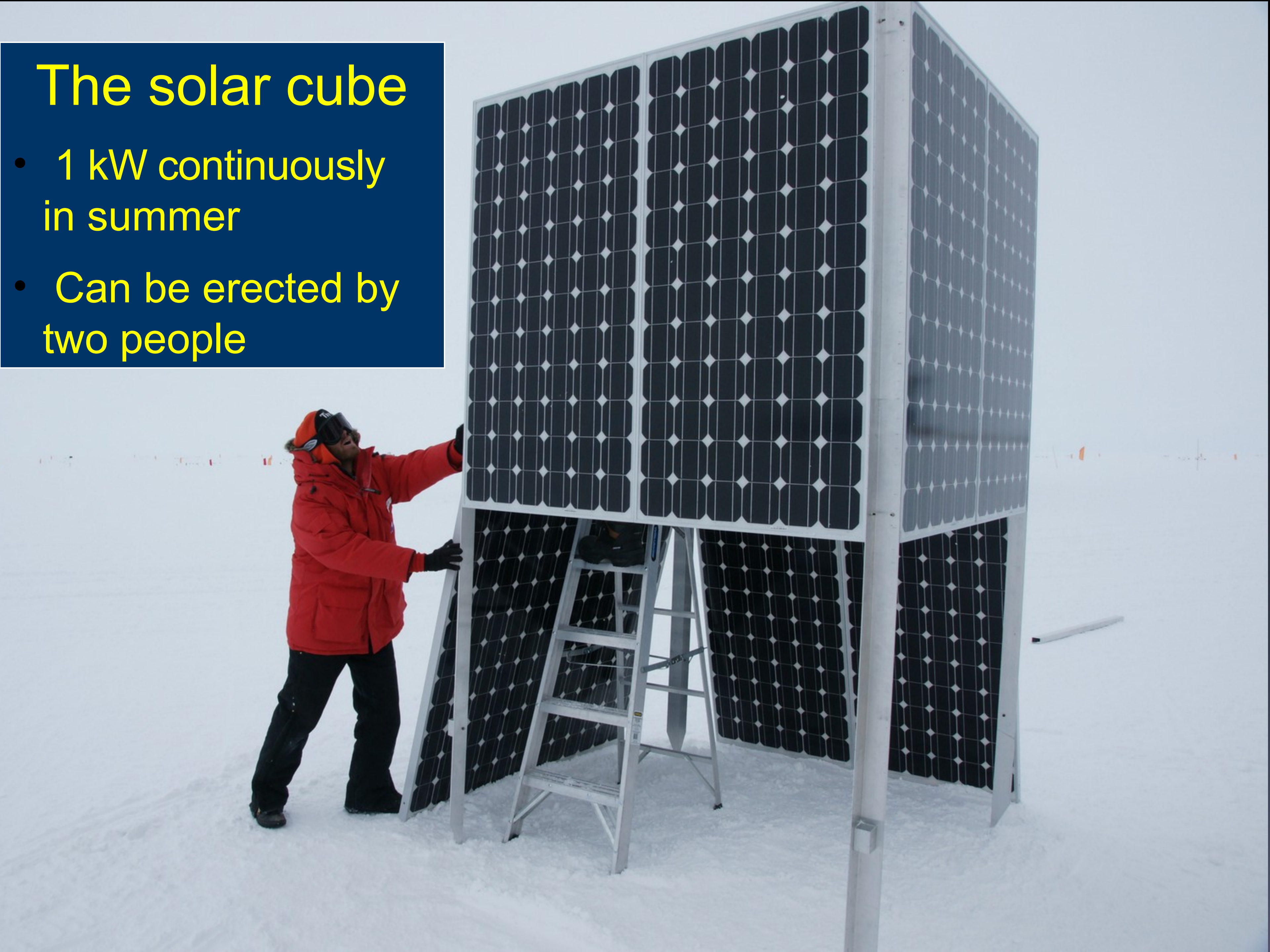

With doghouse cover “on”

The Plateau Observatory (PLATO) supplies HEAT with power and connectivity

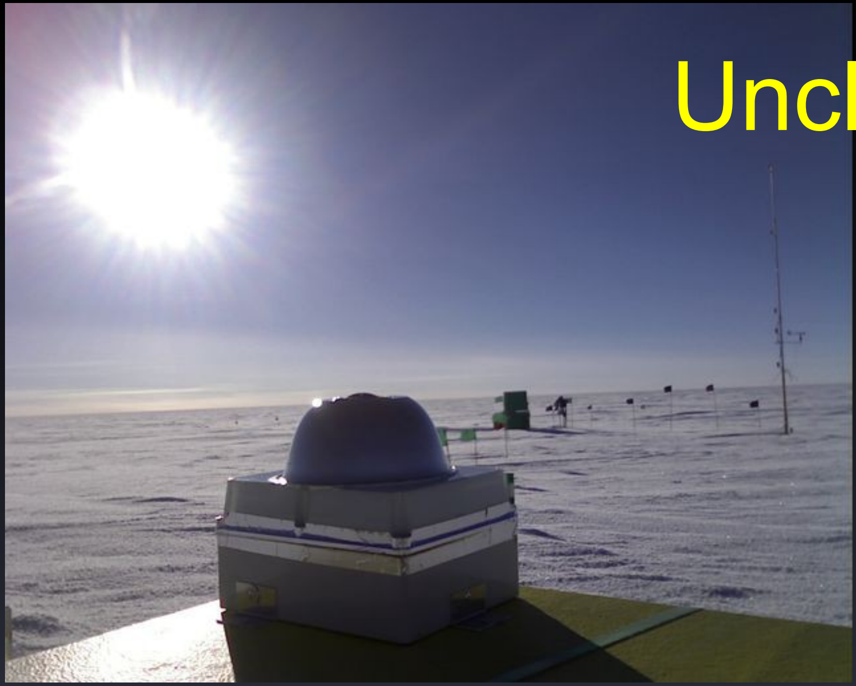

Electronics racks in here
PLATO-
DANGER
WATCH YOUR HANDS AND FINGERS
20 kWhr of LiFePO4 batteries

The solar cube

- 1 kW continuously in summer
- Can be erected by two people

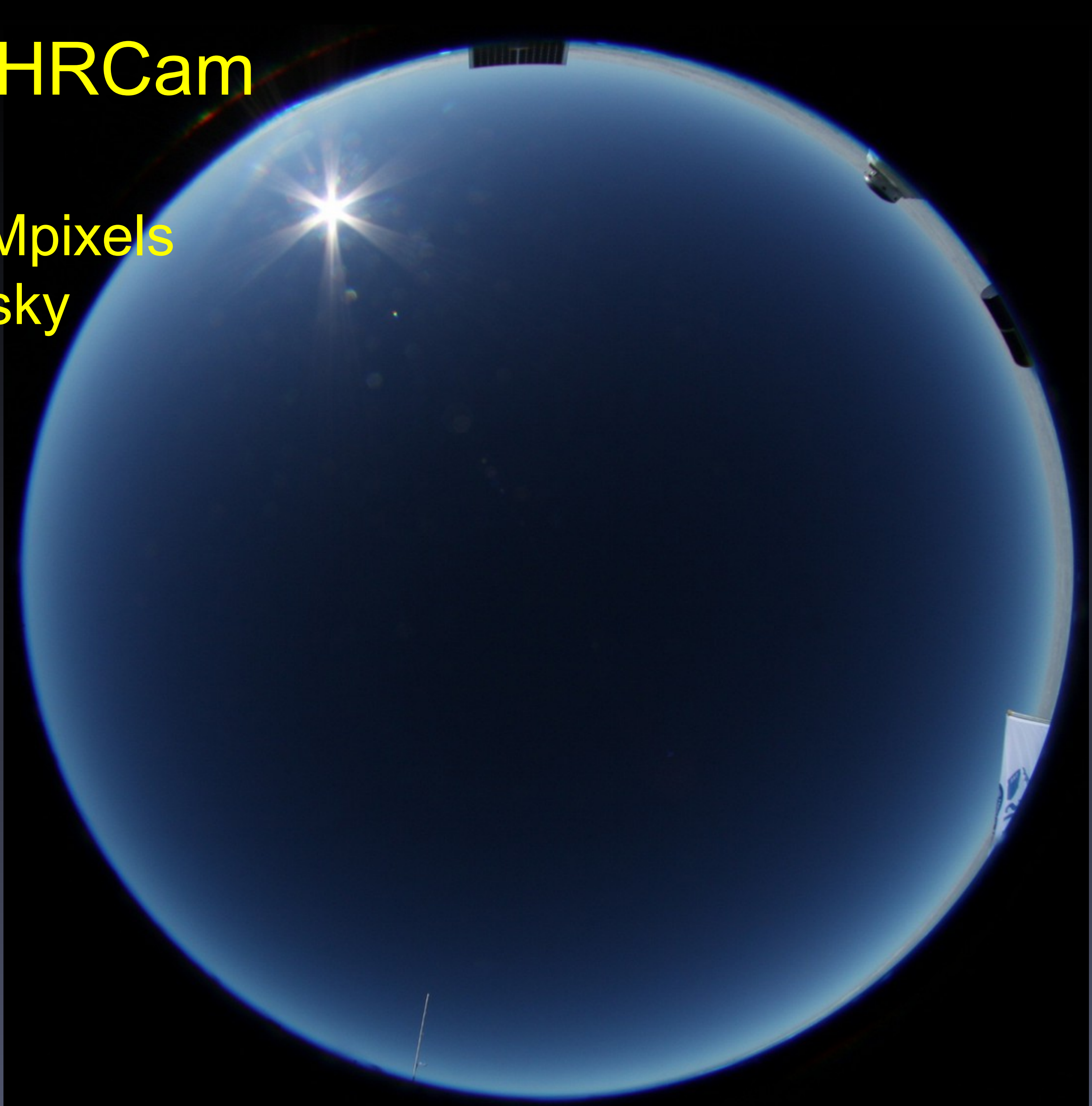


Uncle Bob

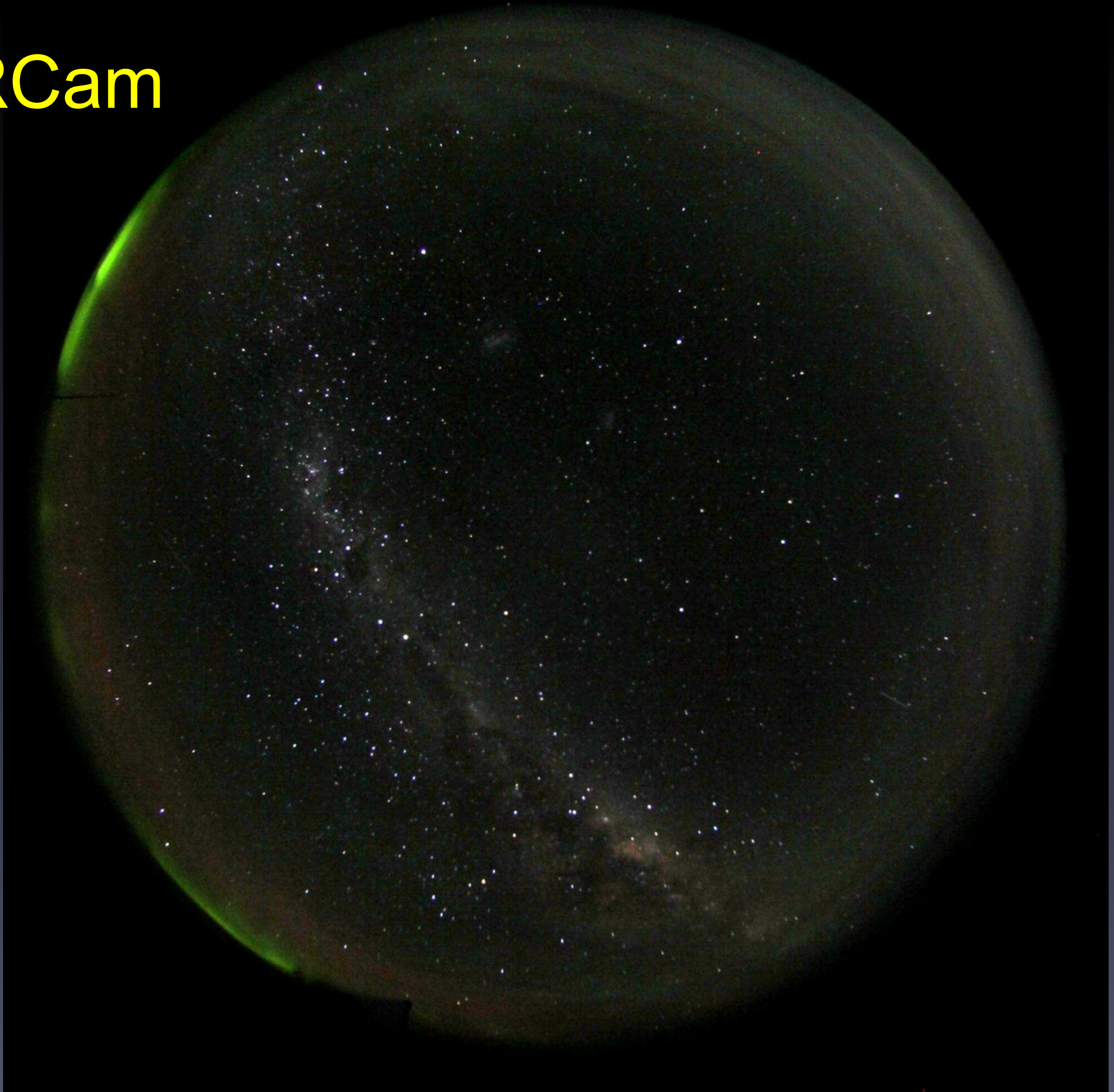



HRCam

- 18 Mpixels
- All-sky



HRCam



HRCam


How do we fit all of PLATO into a Twin Otter?
Image: John Storey

The doors that define HEAT and PLATO-R

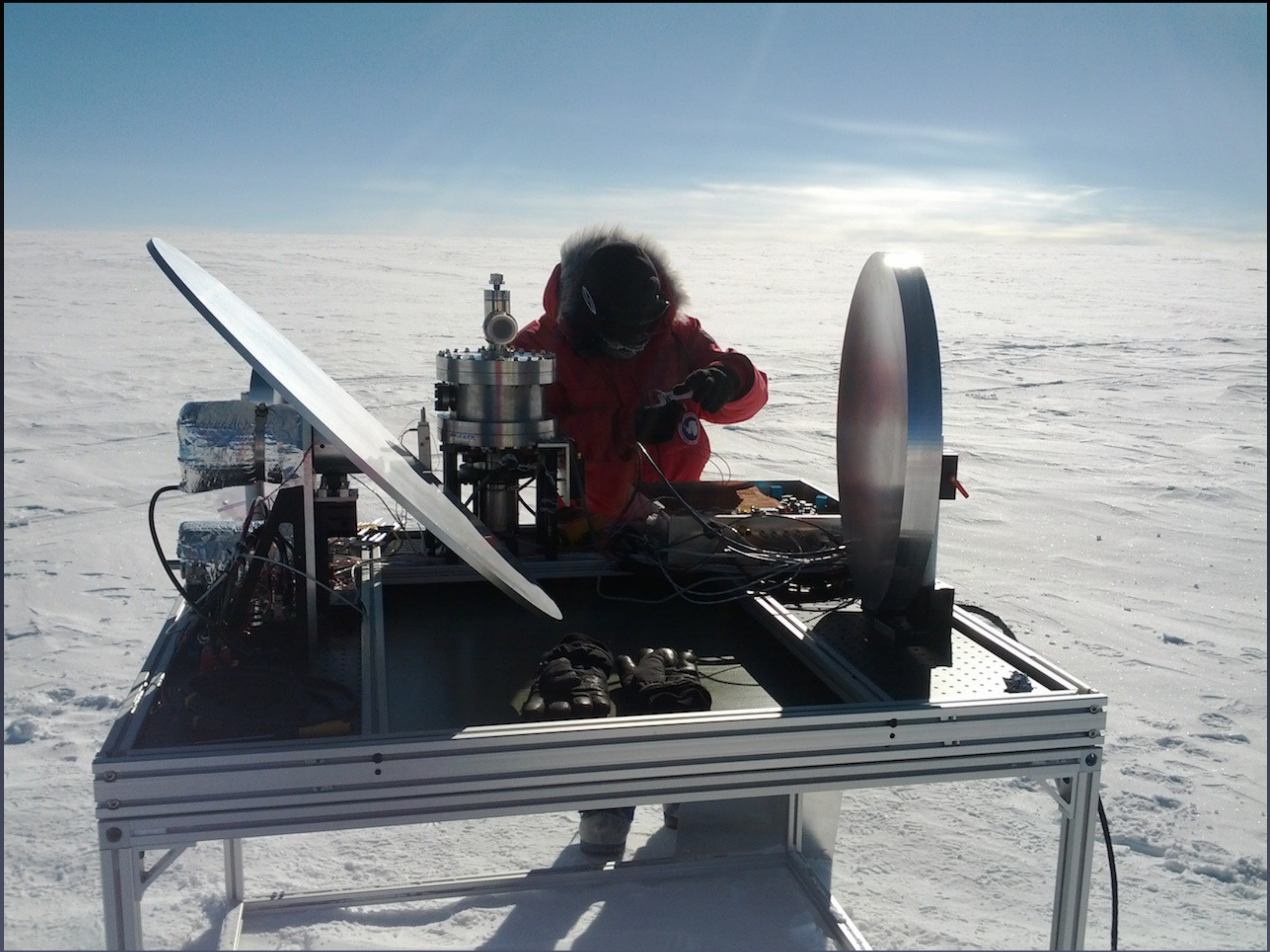
First Ridge A Deployment from South Pole

20-24 January 2012

Final approach to Ridge A

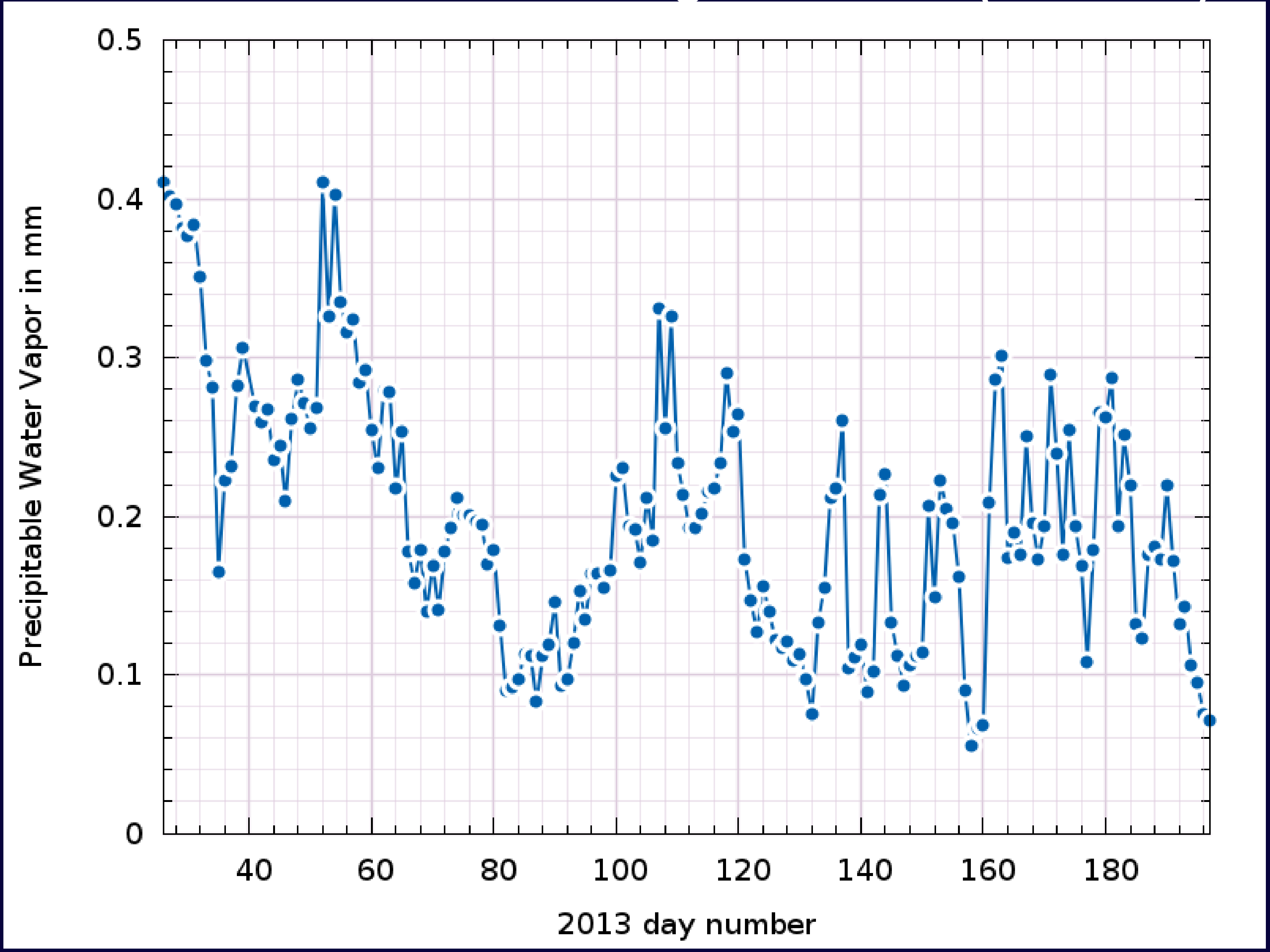

Ridge A International Airport


"Home, home on Ridge A..."
Photo credit: John Storey

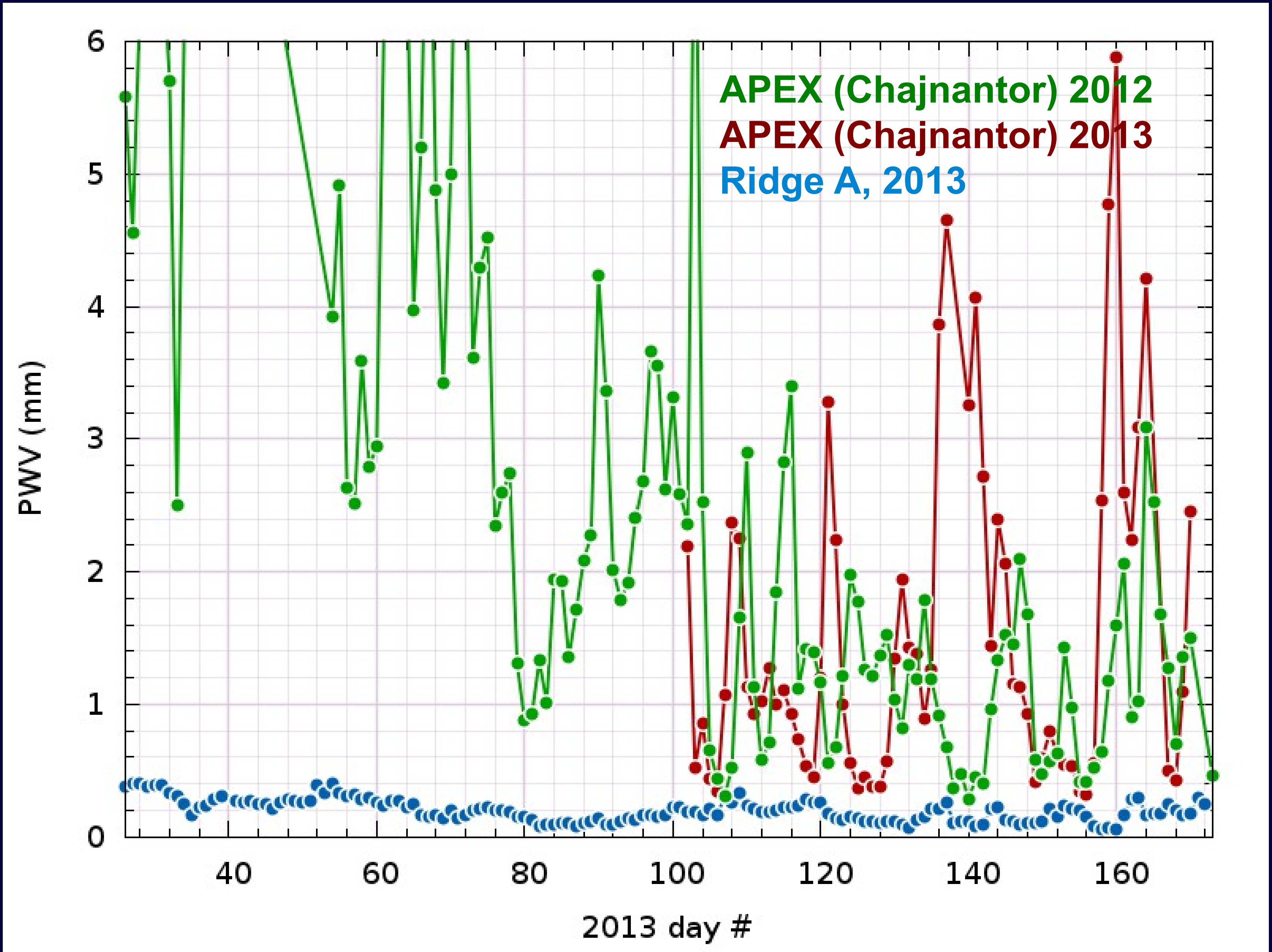


A more lunar surface would be hard to find...

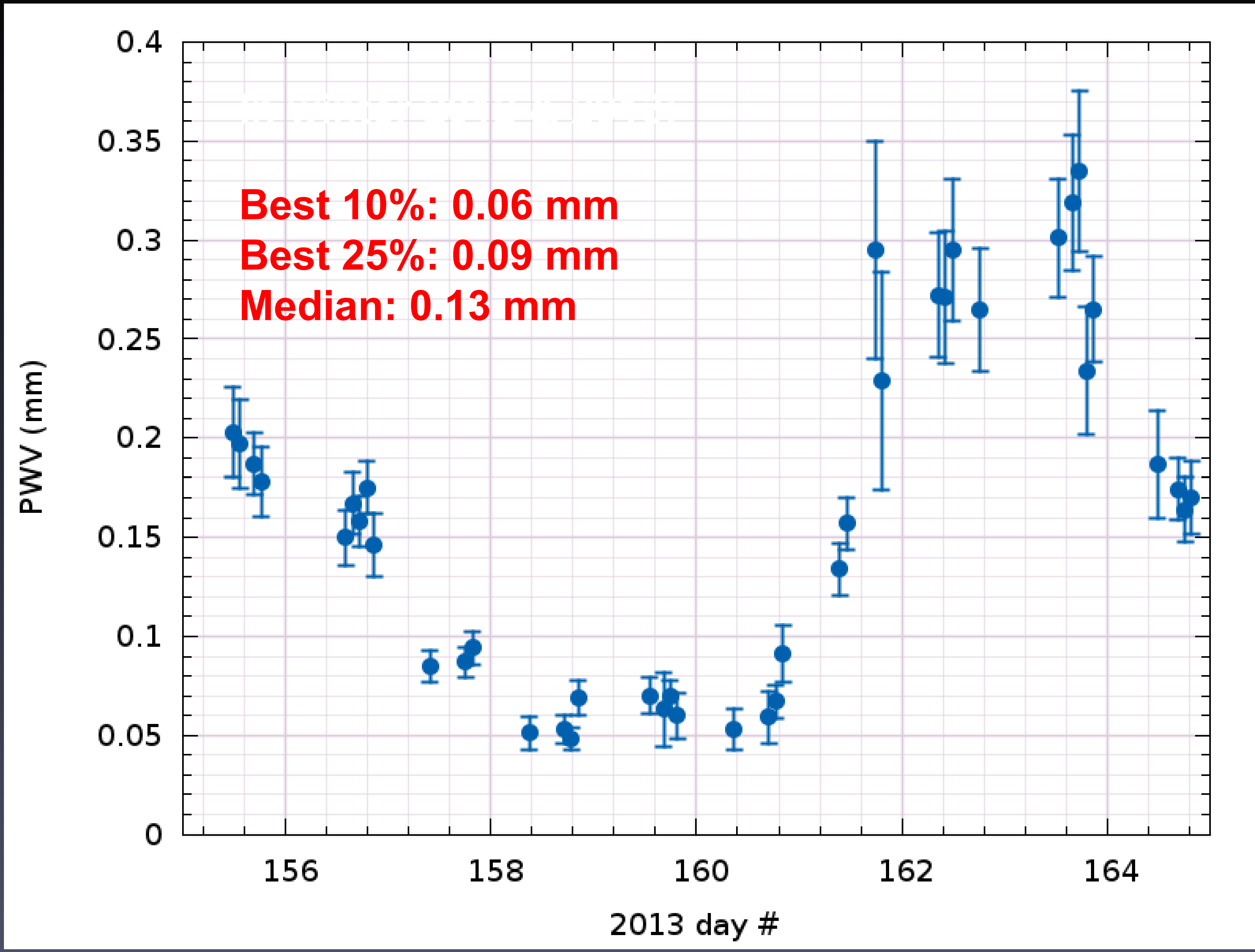
Results: 2013 Site Testing at 370 um (810 GHz)

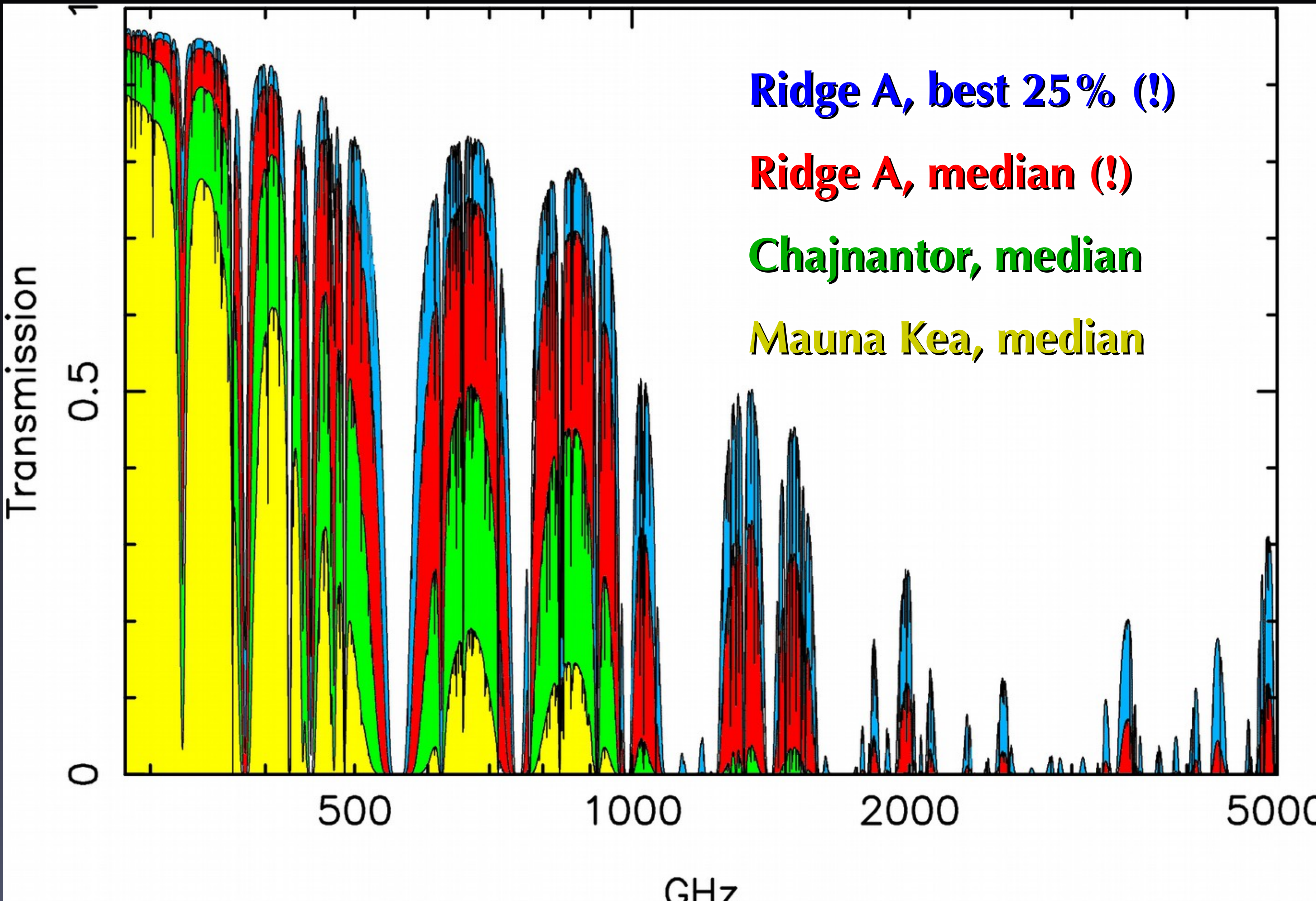


We have to rescale this plot for ALMA...



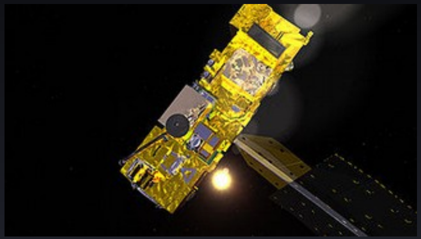
Zoom in on a winter week: An incredibly stable atmosphere




Ridge A, best 25% (!)
Ridge A, median (!)
Chajnantor, median
Mauna Kea, median
Transmission
0
0.5
1
500
1000
2000
5000
GHz

PWV extractions from weather satellites

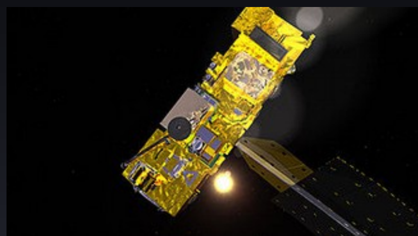
The good, the bad, and the ugly



AIRS	IR spectrometer	- Assumes topography & atm pressure - 45 km resolution
MHS (NOAA 15-19)	183 GHz water radiometer	- no surface assumptions - unknown emissivity of ice
IASI (Metop)	IR Michelson Interferometer	- assumes topography - intermediate resolution & spectral channels
MODIS	Low resolution IR spectro-radiometer	- few spectral channels - best spatial resolution: 5 km

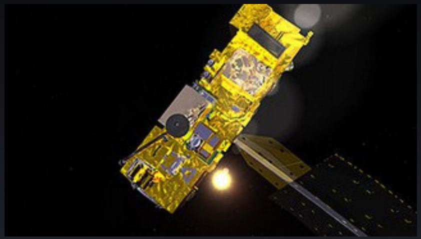
How close do we get to the observed median of 0.12mm at Ridge A?

In detail, all 'level 3' data is slightly wrong.

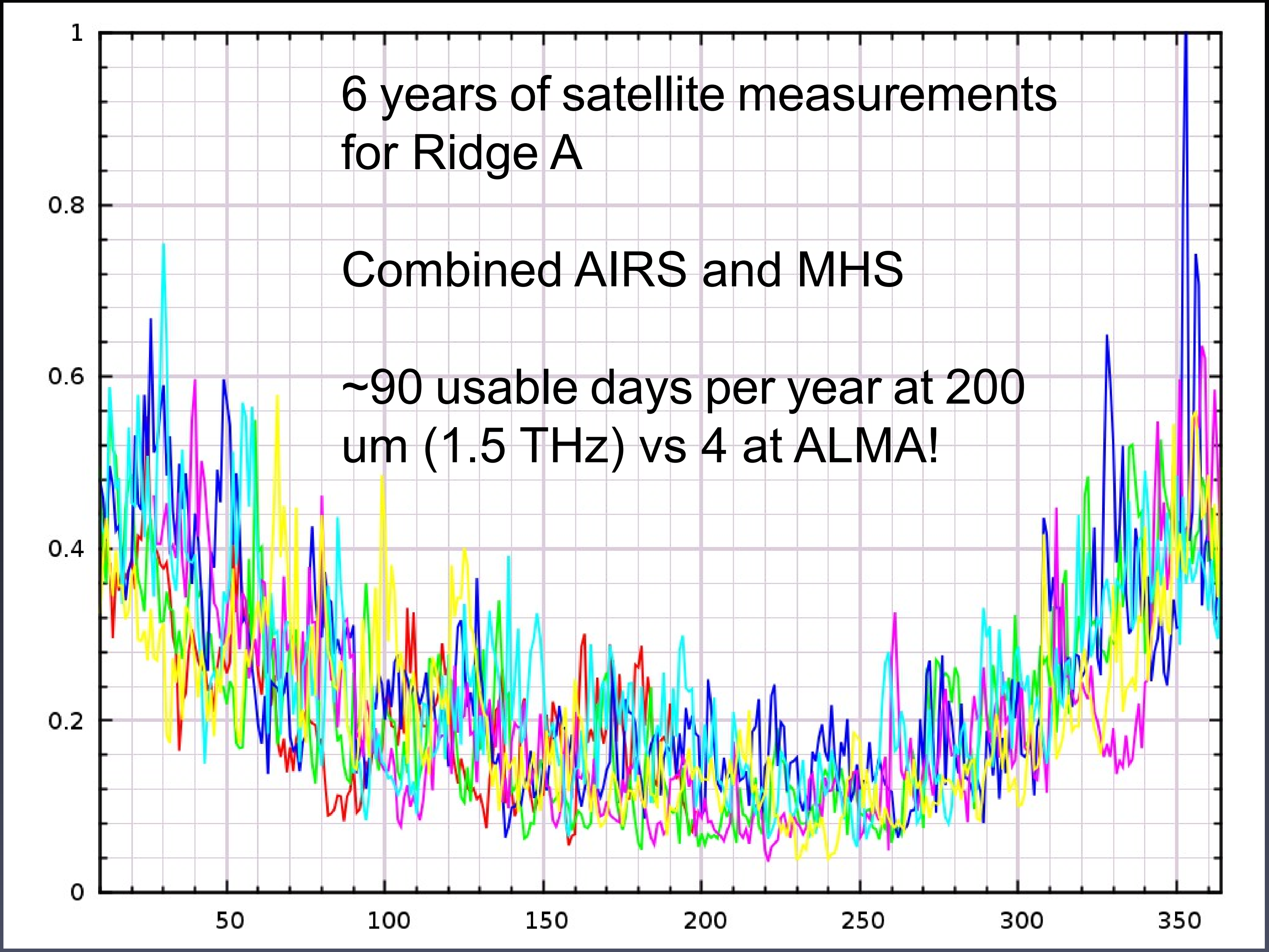


AIRS	**0.15 mm**	Derived 'soundings' are wrong near ground layer
MHS (NOAA 15-19)	**0.10 mm**	Systematics in linear approximations to radiometry
IASI (Metop)	**0.18 mm**	Derived 'soundings' are wrong near ground layer
MODIS	**0.02 mm**	Insufficient spectral information at low PWV

Excellent agreement, to 10 um, with low-level data




AIRS	**0.12 mm**	
MHS (NOAA 15-19)	**0.12 mm**	
IASI (Metop)	**0.18 mm**	Access to lower-level data processing steps?
MODIS	**0.02 mm**	Can't fix?

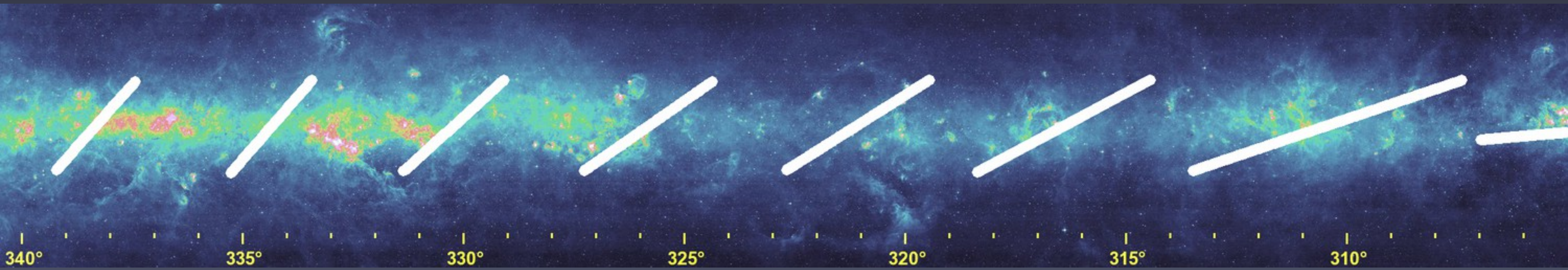


PWV (mm)

2008 through 2013 day number

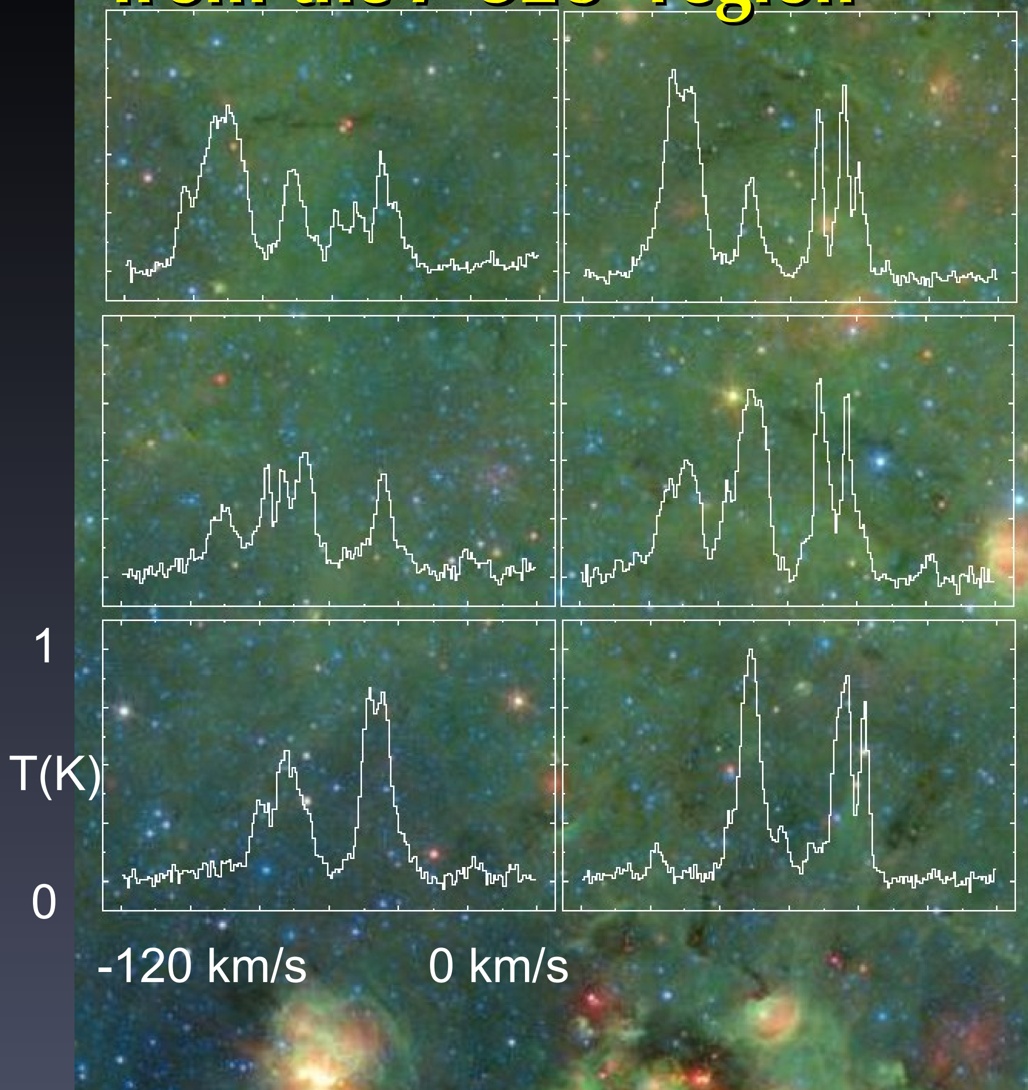
HEAT's First Survey: [CI] and CO at 810 GHz

- 810 GHz was permitted for observations with Herschel/HIFI, owing to its typical difficulty from the ground. From Ridge A, we can observe at 810 GHz almost all the time!
- With a fixed azimuth axis, HEAT performs On-The-Fly maps in strips of constant elevation, the heterodyne equivalent of drift-scanning.
- 15 strips are being observed from *l*=343^{o} to *l*=270^{o}. Over time, the strips will broaden and overlap to provide complete coverage.
- In addition, a 1^{o}x0.6^{o} map at *l*=328^{o} was mapped as a high priority region. A high-sensitivity strip map of the LMC is being observed.



8 of the 15 Galactic strip maps observed by HEAT, atop 8 um MSX

Widespread [CI] emission from the *l*=328° region



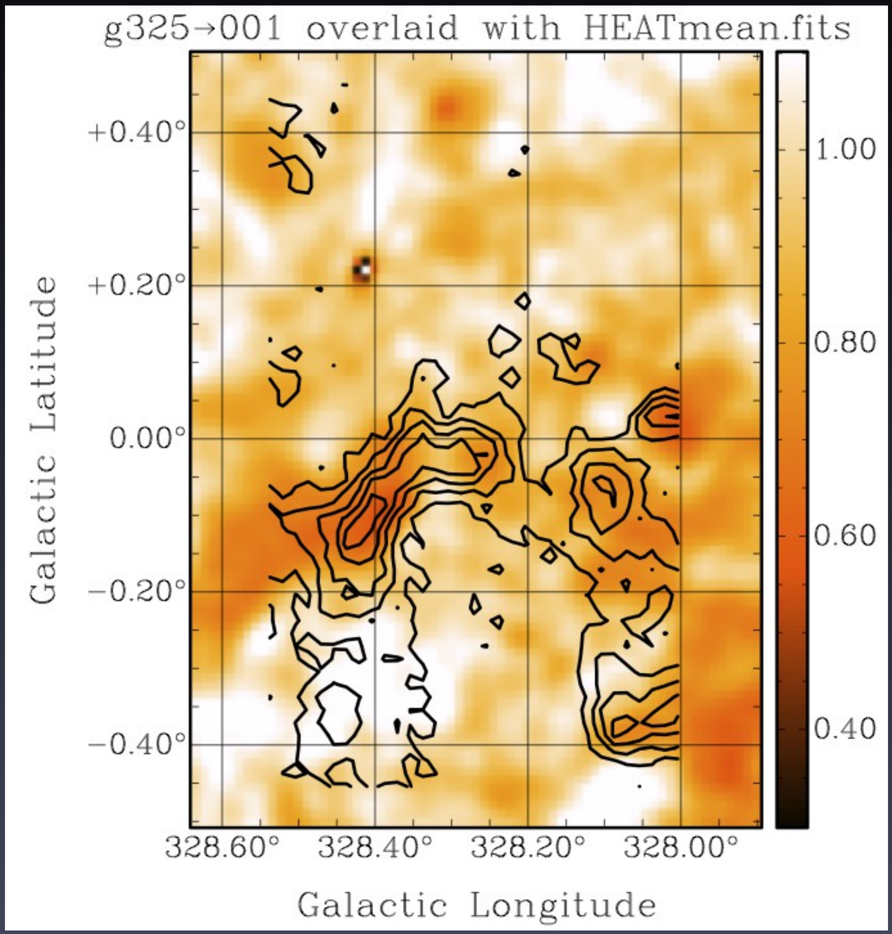
Smoothed 20′ [CI] spectra on T_{mb} scale overlaid on 8/24 um IR emission from Spitzer

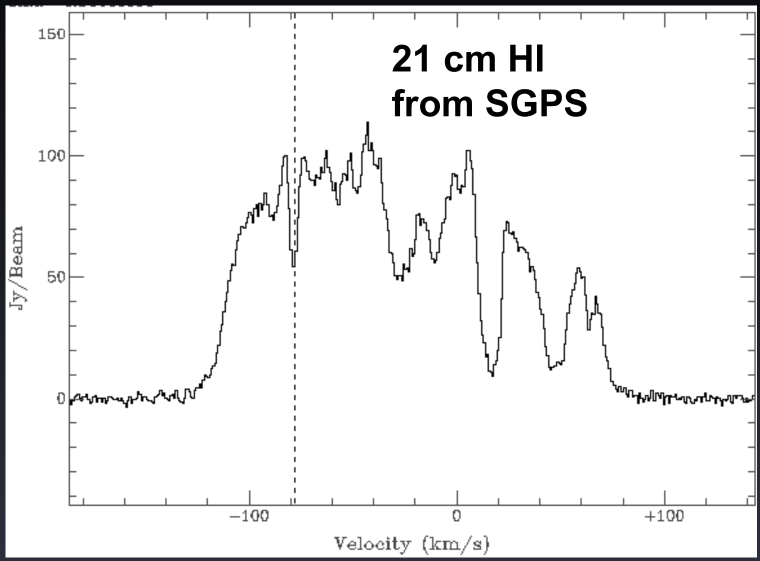
HEAT data directly shows that much of the elemental carbon in dark clouds is actually atomic carbon. There is maybe 50% more star forming gas in the Galaxy than previously thought!

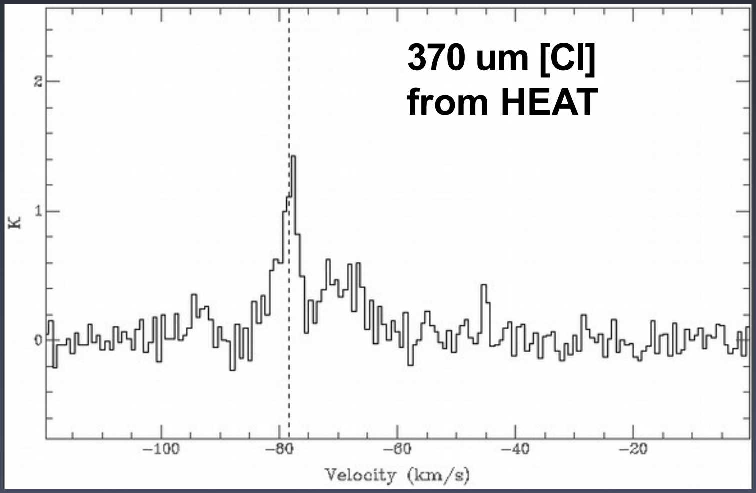
This measurement is cleaner than Herschel's measurement of "dark gas" from [CII], as [CII] comes from *every* phase of the cold and warm ISM, and must be disentangled. [CI] comes from molecular clouds specifically.

There is a lot of molecular material bound up in translucent clouds and PDRs that have been completely missed or underestimated in CO surveys.

Molecular Cloud Formation: a candidate in a G328 HI absorption filament

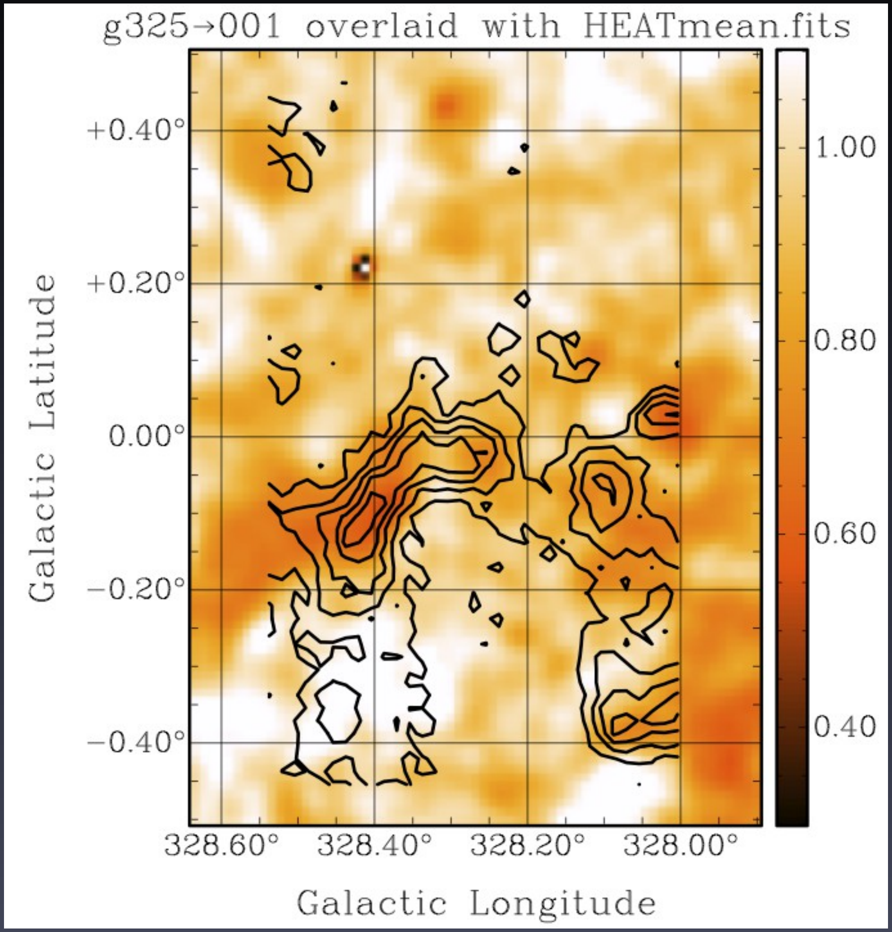






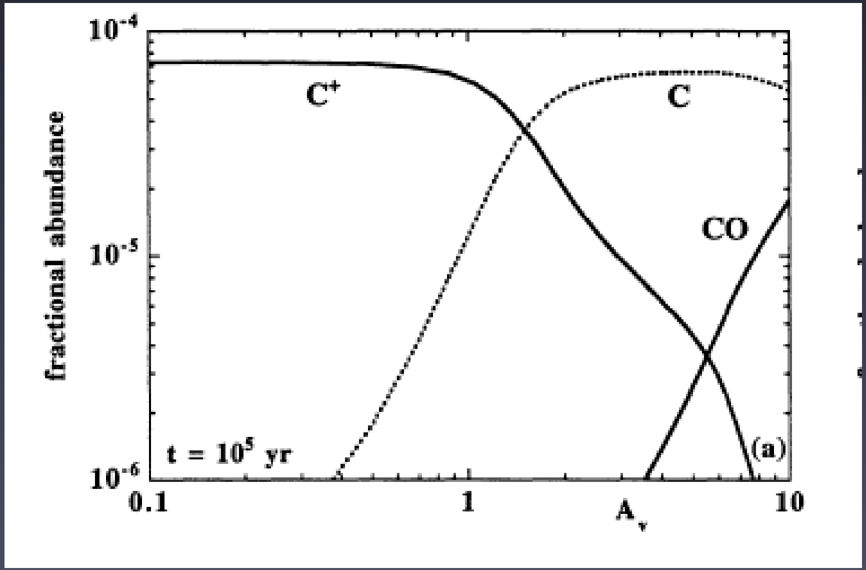
Prominent [CI] emission (contours) coincident with cold HI absorption (color line-to-continuum ratio) from SGPS.

Molecular Cloud Formation: a candidate in a G328 HI absorption filament



Detection of GMCs in the process of forming is within reach!

High C abundance relative to CO is a signature of newly formed molecular material.

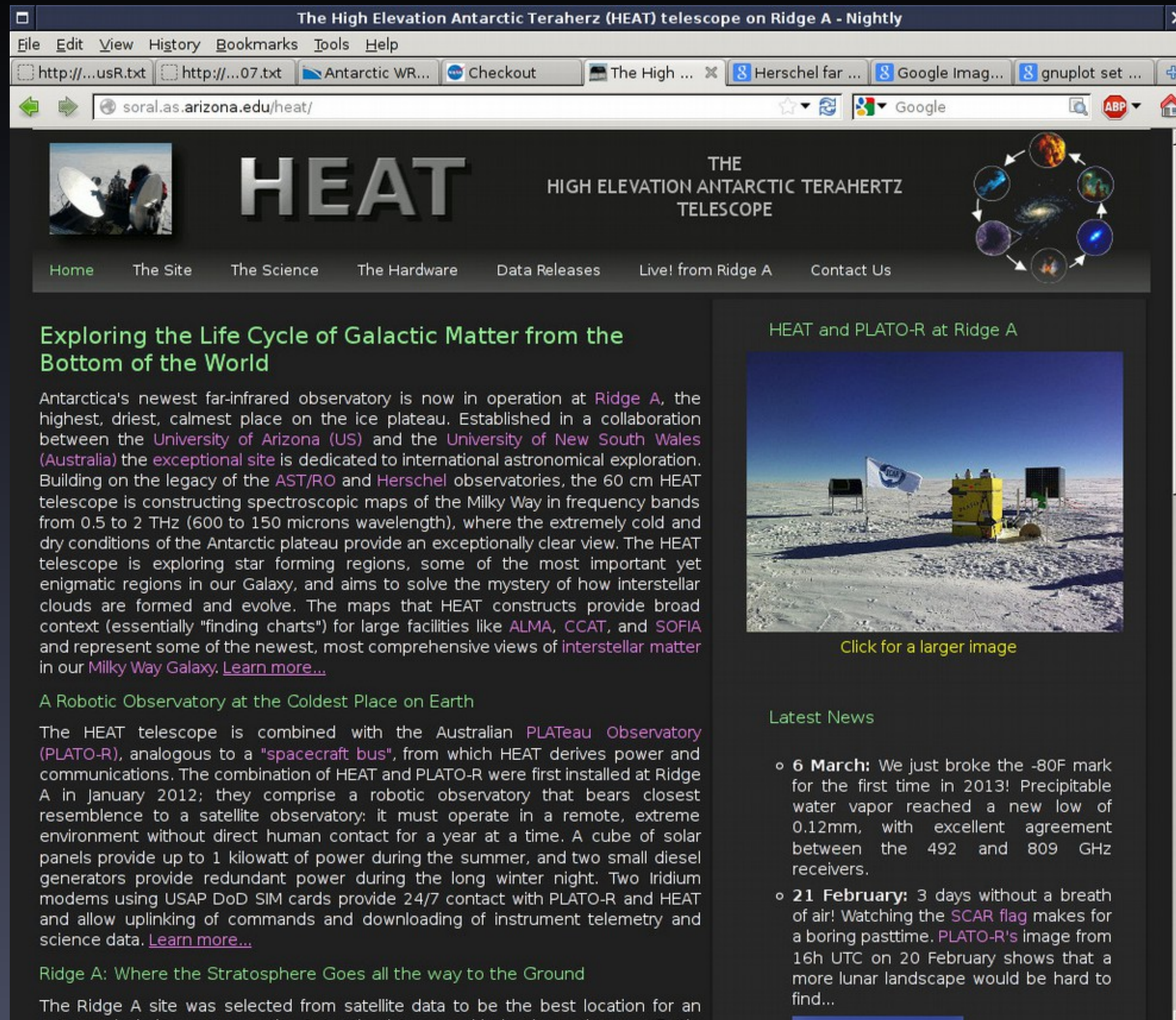


Prominent [CI] emission (contours) coincident with cold HI absorption (color line-to-continuum ratio) from SGPS.

All site-testing and astronomical data is publicly available after processing, with no proprietary period. We want everyone to use it!

Data Release 1 (DR1) coming in October 2013!

Subsequent data releases 1-2 times per year.



http://soral.as.arizona.edu/heat/

Summary

HEAT and PLATO-R are deployed to Ridge A and are delivering excellent data.

Robotic observatories are revolutionizing scientific capabilities on the high Plateau

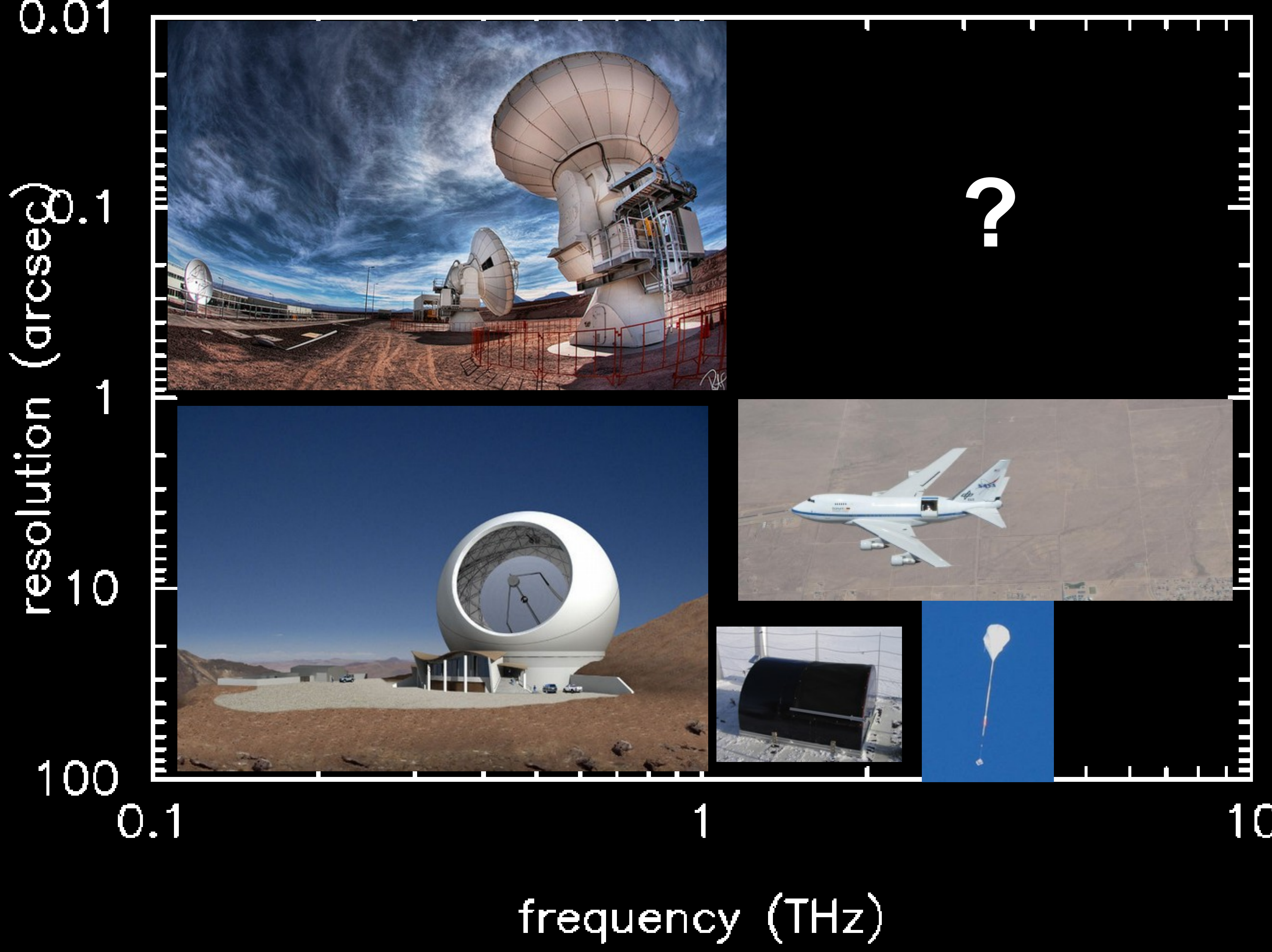
Less than 0.1 mm PWV for 30% of winter, with exceptional stability. THz astronomy from the ground is now practical.

The next servicing mission to Ridge A should increase the complement of HEAT receivers, throughput, and 1-2 THz capability.

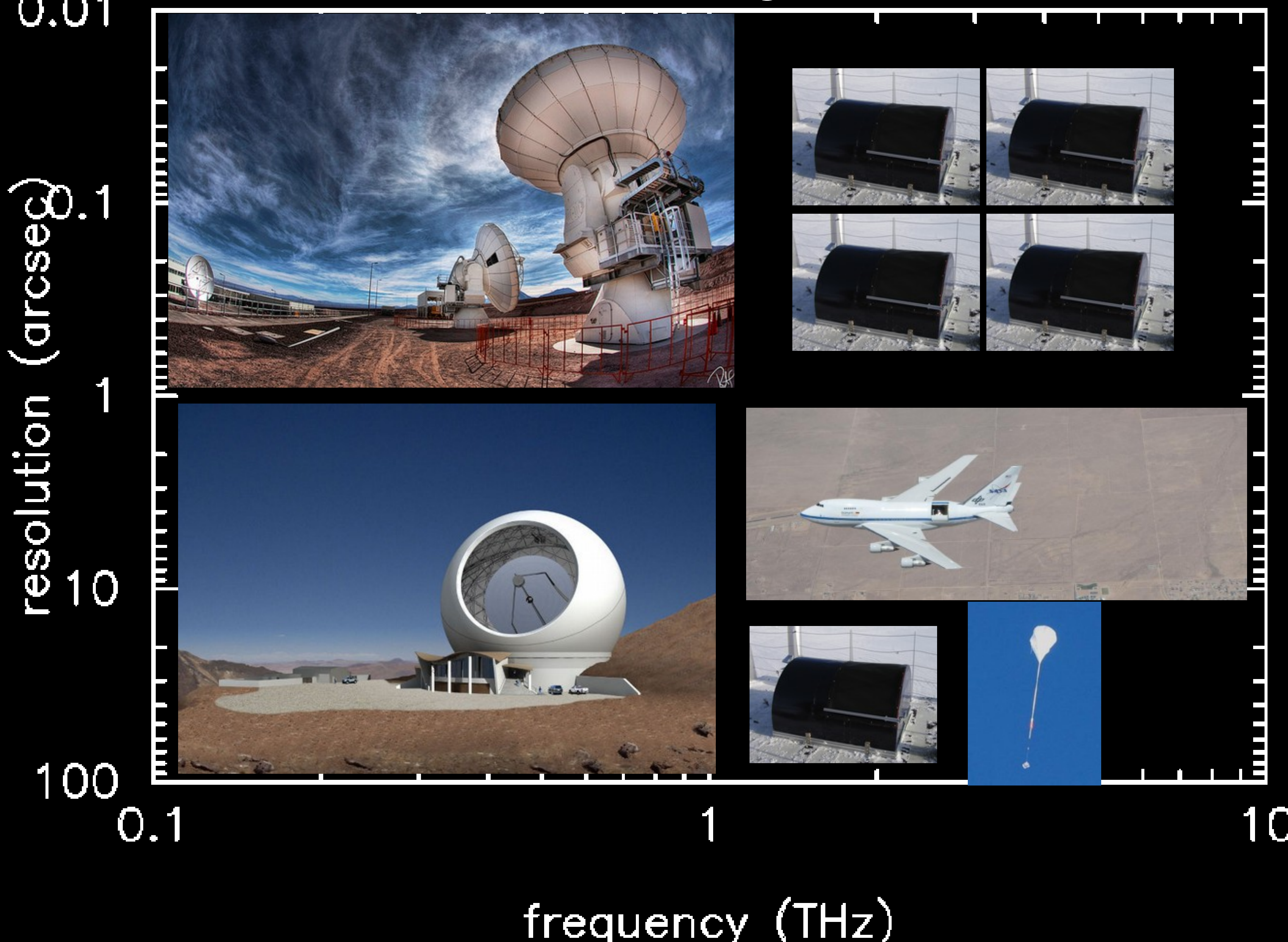
4K closed cycle systems under development (2014-15)

Terahertz interferometry on 50-100m baselines combining both HEAT telescopes (to be proposed in 2014)

Terahertz capabilities by end of decade



Terahertz capabilities by end of decade



Terahertz Interferometry from Dome A / Ridge A

- Goal: 1″ resolution or better at 1 THz
- 1-ish meter aperture 'modules' with cooled Schottky or HEB mixer receivers. 0.5-2 kW per module, baselines 50-100m
- > 1 THz requires Dome A or Ridge A
- Focus on 1.0-1.5 THz (200-300 um)
- Most important lines available: D_2H^+, CO 9-8 to CO 13-12, NH, NH^+, H_2D^+, N^+, CH
- Continued development: low power 4K cryocoolers, sensitivity and stability of detectors at > 1 THz