

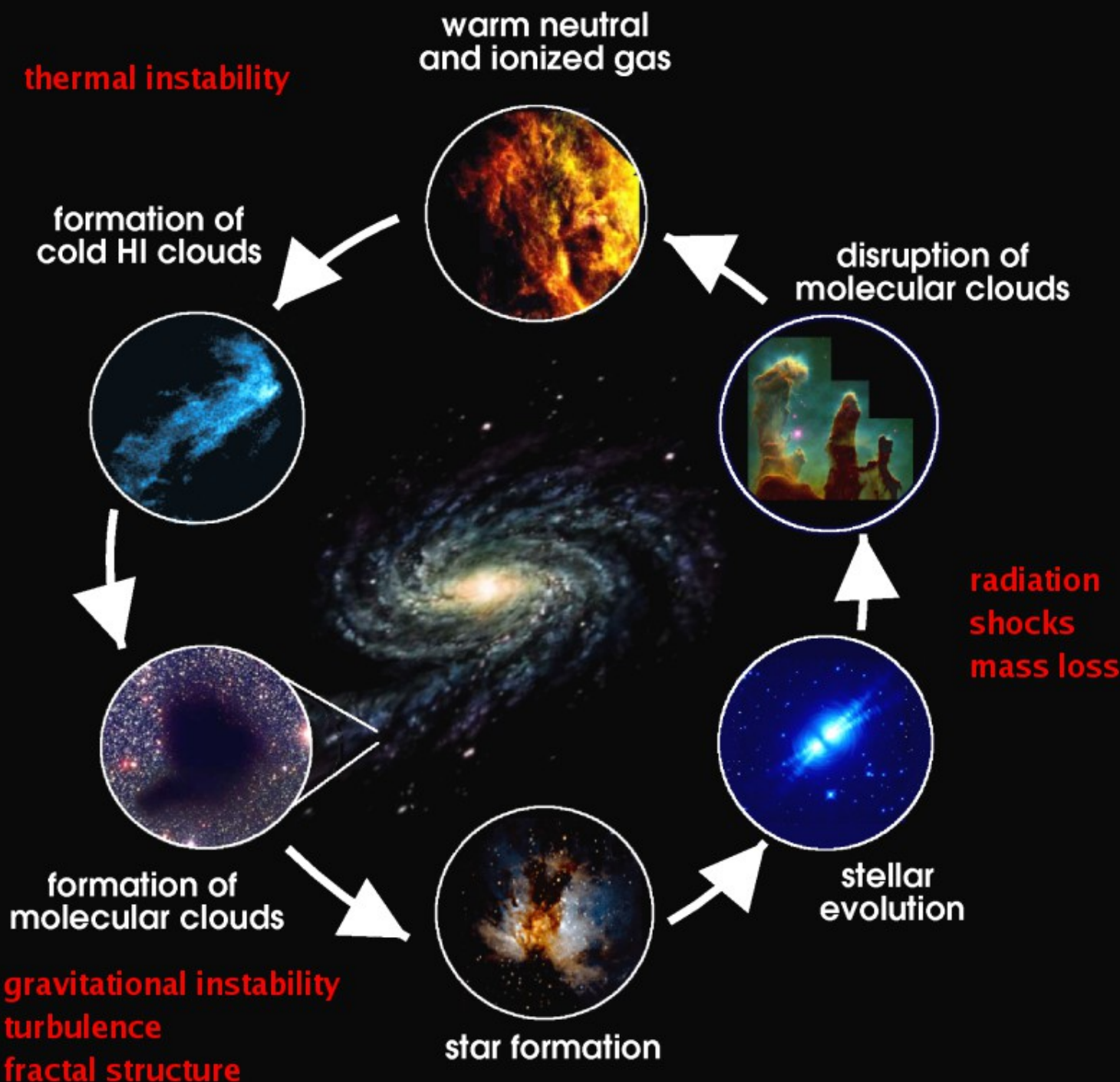
# Two Years at Ridge A: First Results from the High Elevation Antarctic Terahertz (HEAT) telescope



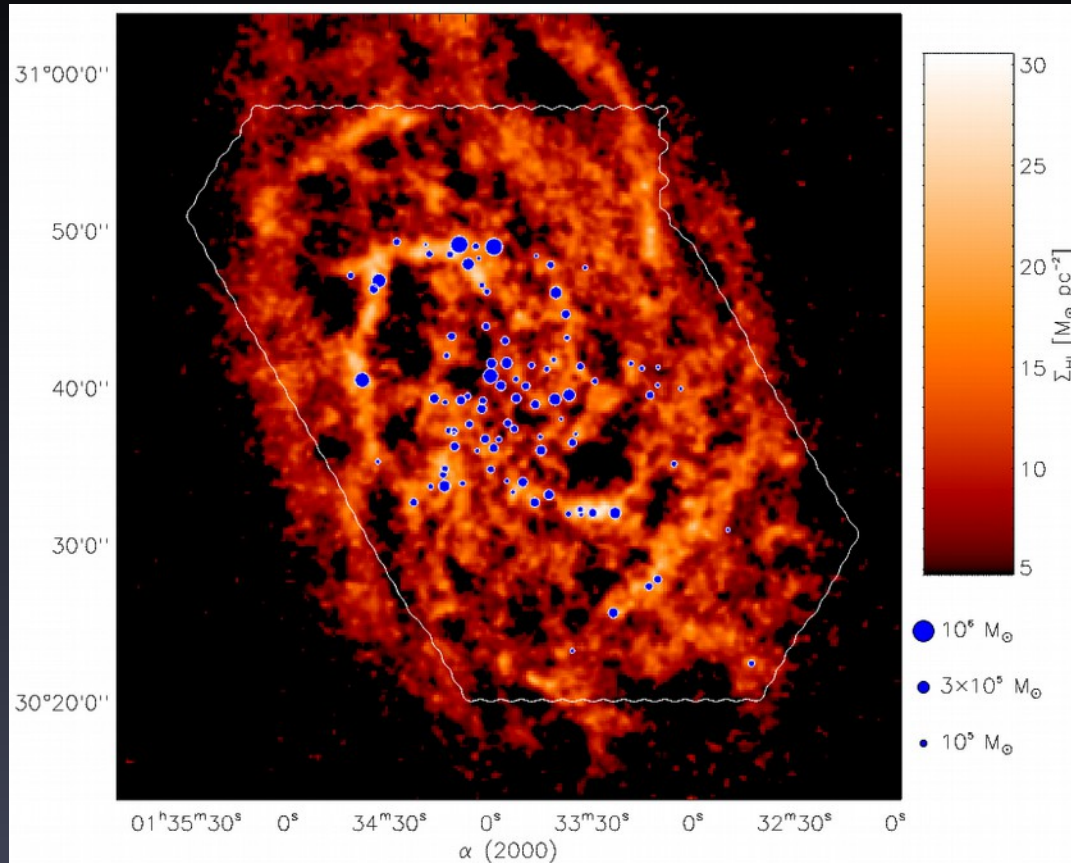
**Craig Kulesa** (*University of Arizona*)  
On behalf of the entire HEAT and PLATO-R team



# 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

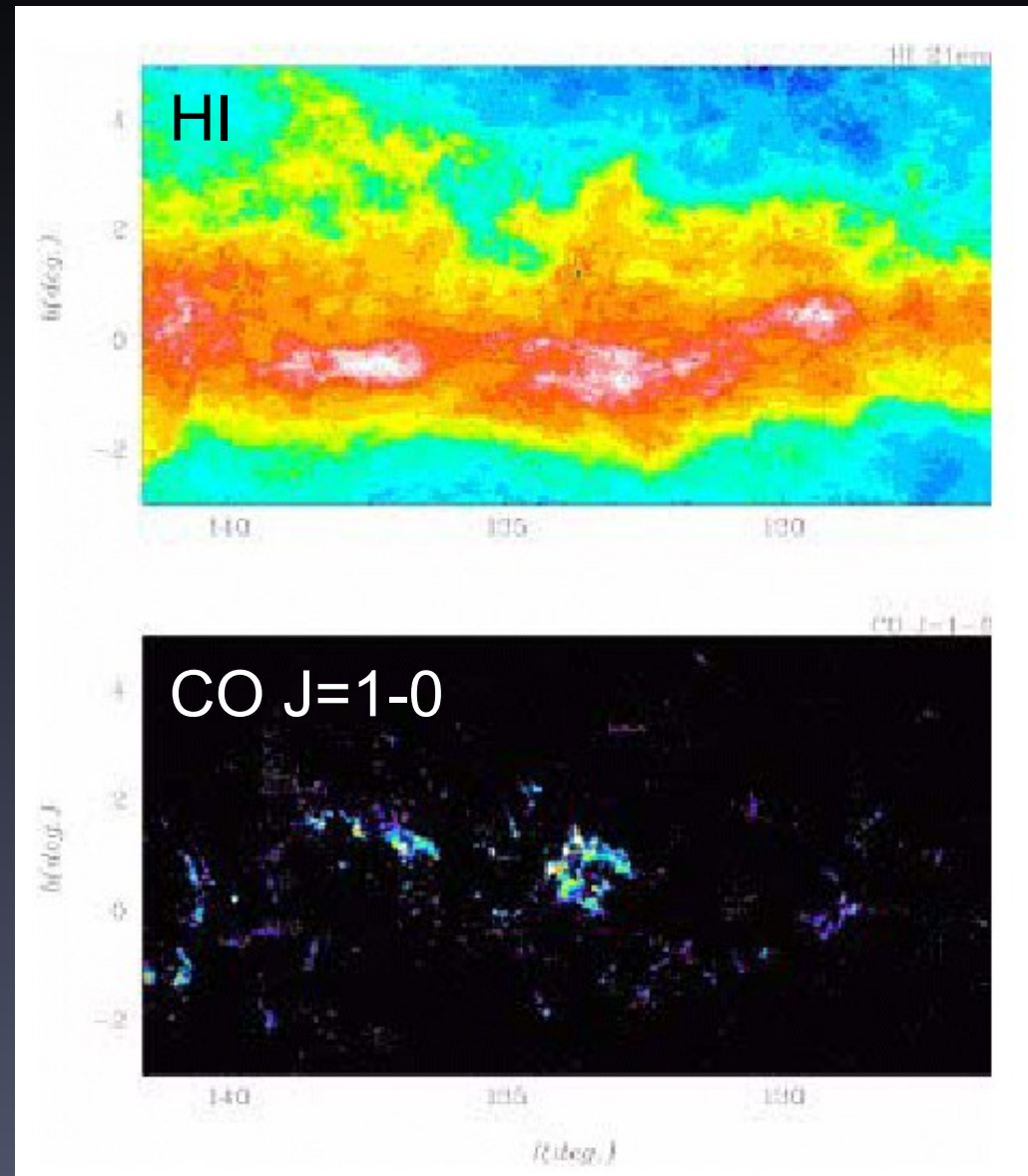
A statistical survey can distinguish between these mechanisms!

# Our understanding of the cold ISM is incomplete

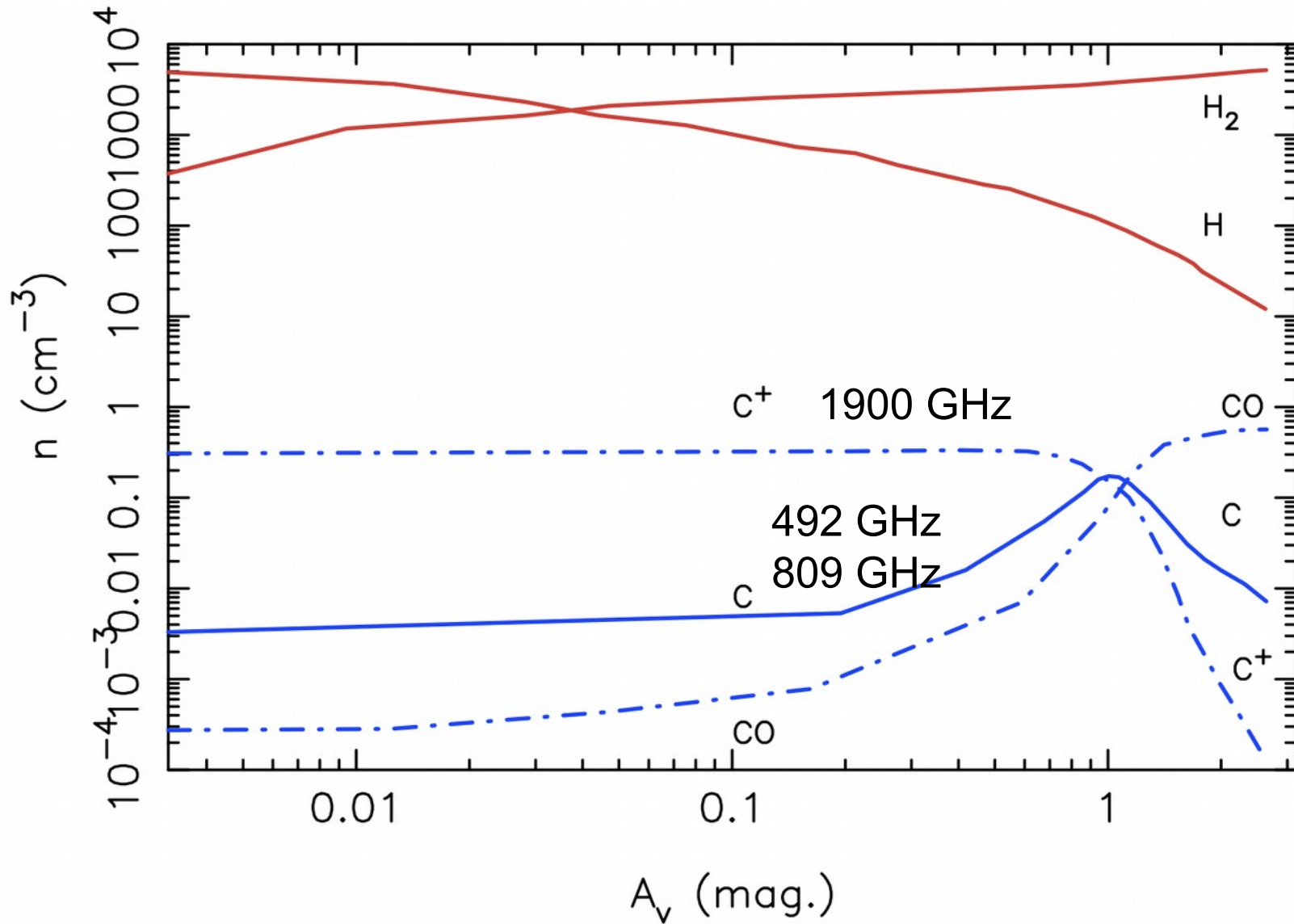
- HI provides a measure column density, but provides little insight into which ISM component it comes from

- CO only probes already-formed molecular clouds

So how can we see the evolution of clouds?



Line emission from C and C<sup>+</sup> show us  
“hidden” molecular gas not probed by CO



# What is needed:

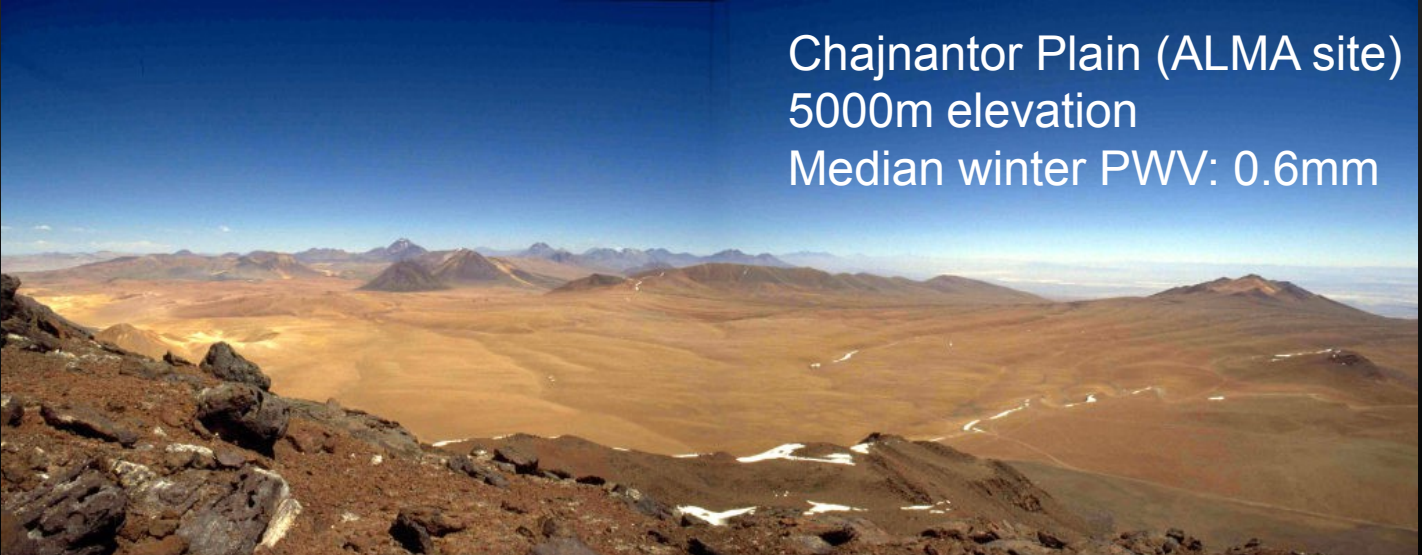
- large scale mapping survey of the Milky Way, of order 100 square degrees
- with high spectral resolution of  $\sim 1$  km/s
- with sufficient angular resolution to resolve clouds across the Galaxy ( $\sim 1$  arcminute)
- at THz frequencies to probe pivotal carbon, nitrogen, oxygen fine structure & molecular lines



## Established THz Observing Sites...

An aerial photograph of the Mauna Kea observatory site. The landscape is a dark, volcanic mountain with several white, dome-shaped telescope enclosures scattered across the ridges. A winding road is visible, and the background shows a vast, hazy valley under a clear blue sky.

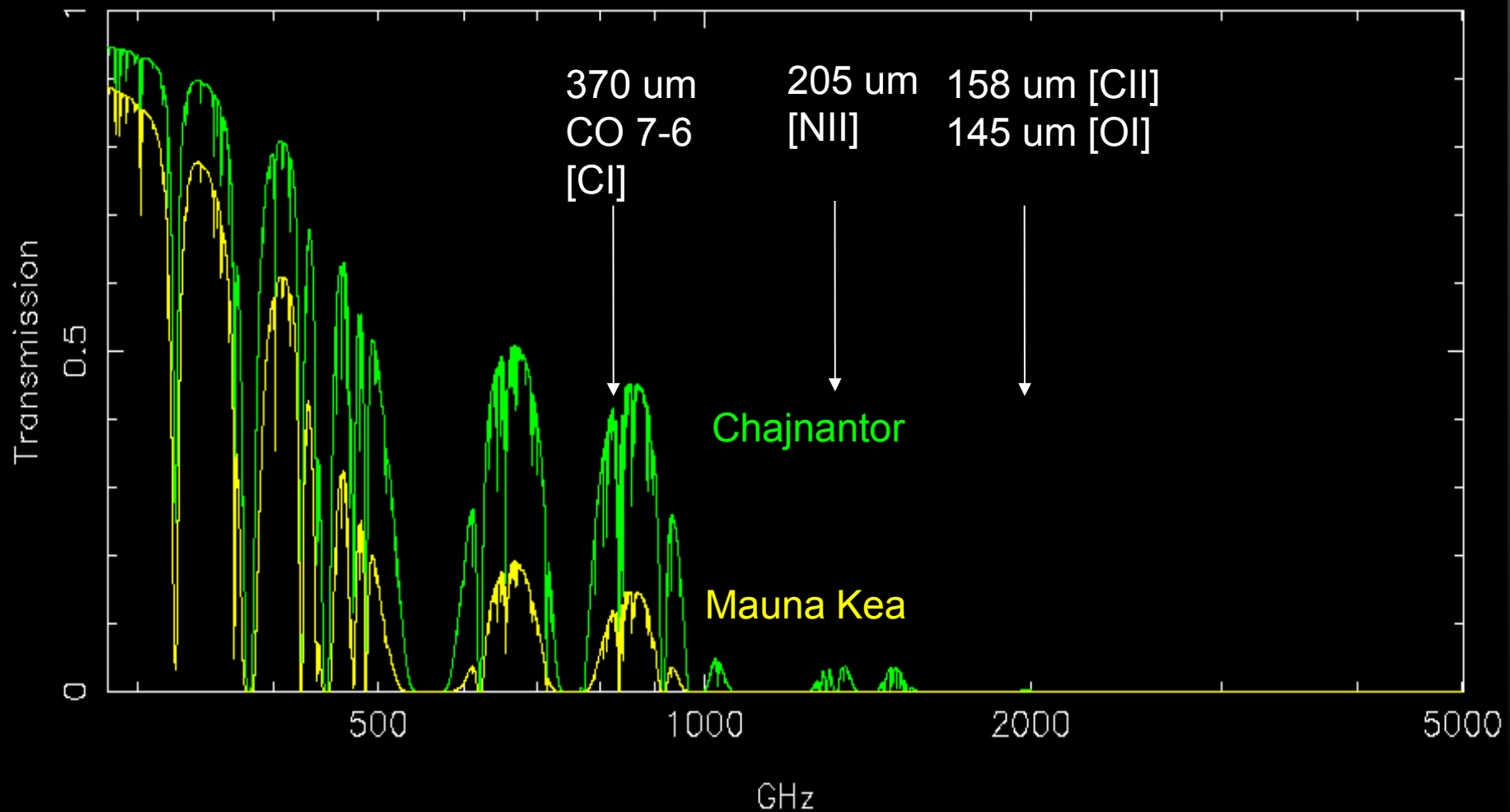
Mauna Kea  
4100m elevation  
Median winter PWV: 1.5 mm

A wide-angle landscape photograph of the Chajnantor Plain. The foreground shows dark, rocky terrain. The middle ground is a vast, flat, brownish-yellow plain with some small patches of snow. In the distance, there are several mountain peaks under a clear blue sky.

Chajnantor Plain (ALMA site)  
5000m elevation  
Median winter PWV: 0.6mm

... are simply not good enough.

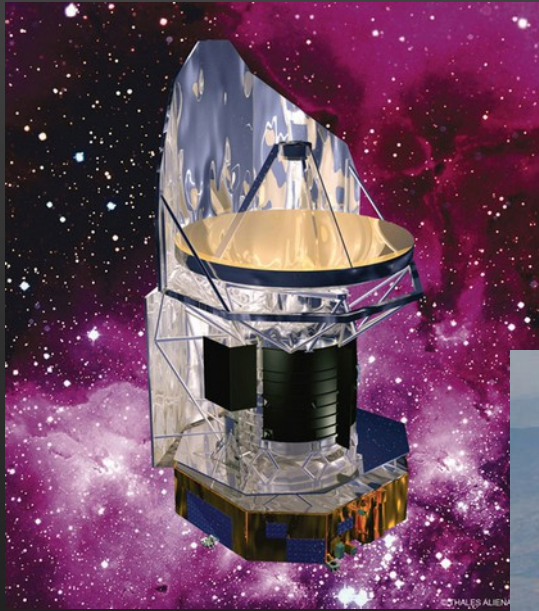
We need to go higher, drier, and colder...





# (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...

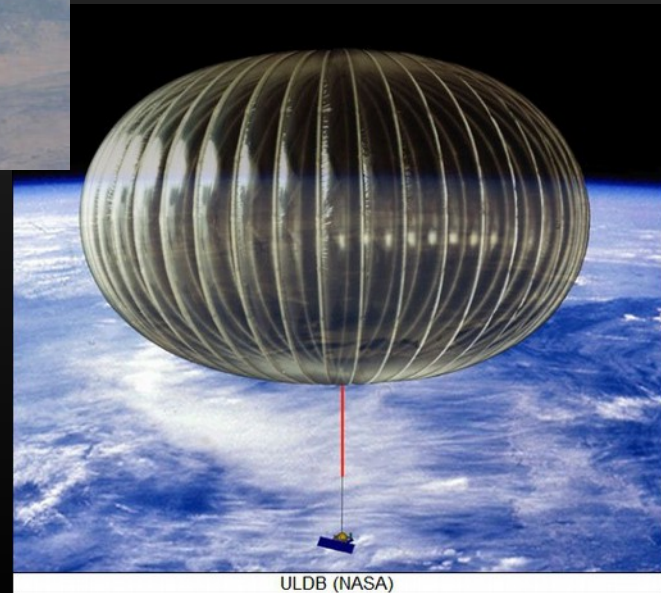
...if it can fly 1000 hr/yr

**Long duration balloons**

1m aperture at 35 km

\$15-25,000 / hr

14-30 day missions



Atlantic Ocean

Indian Ocean

Ridge A

# Antarctica's role as a crucial THz platform

Pacific Ocean



- 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

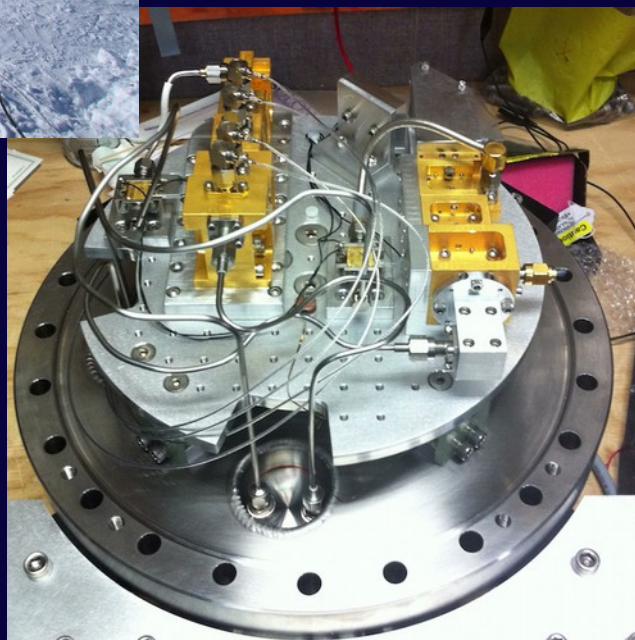
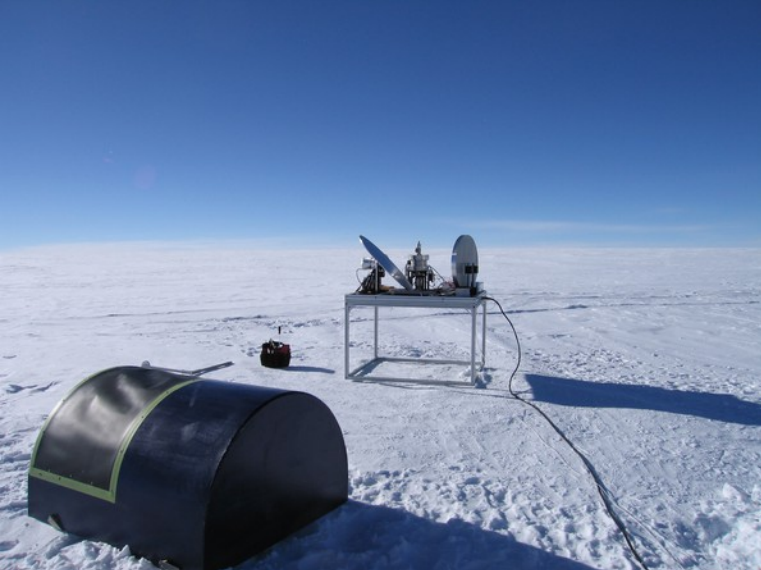
prototype telescope deployed in 2012 to Ridge A with PLATO-R  
“farthest reach of the USPS”



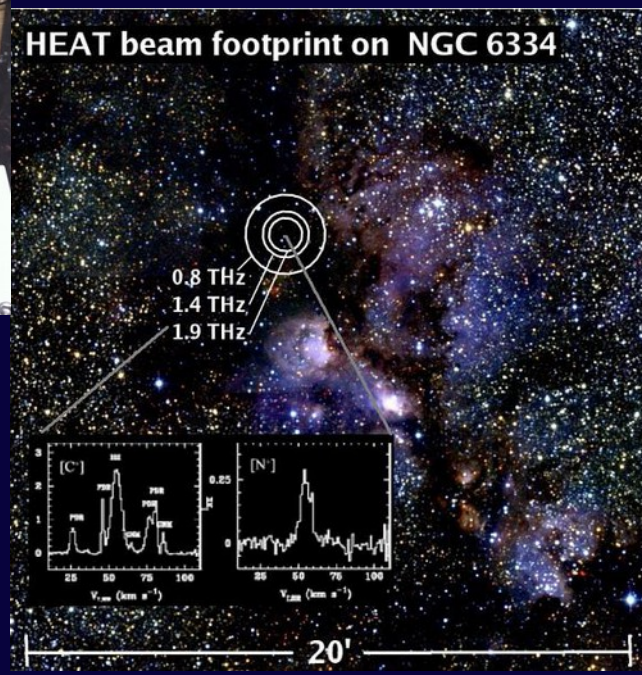
# HEAT is...

... a 62 cm off-axis  
Gregorian telescope

... with cryogenic  
heterodyne receivers  
in the far-infrared  
(150–600  $\mu\text{m}$ )

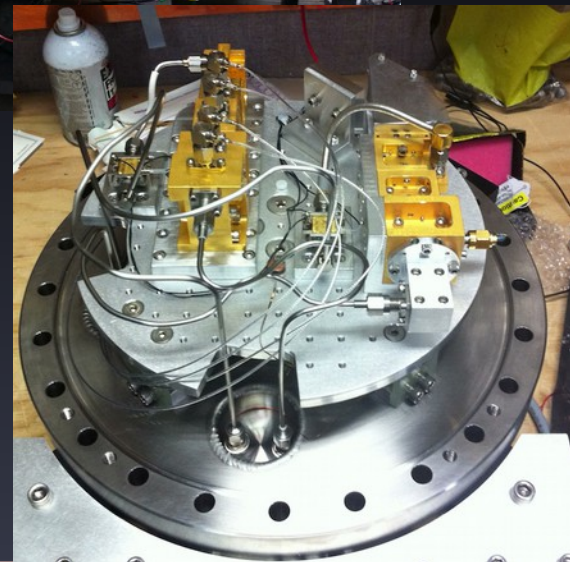


...performing a focused spectroscopic  
survey of the Milky Way in its most  
important THz lines of carbon, nitrogen  
and oxygen.

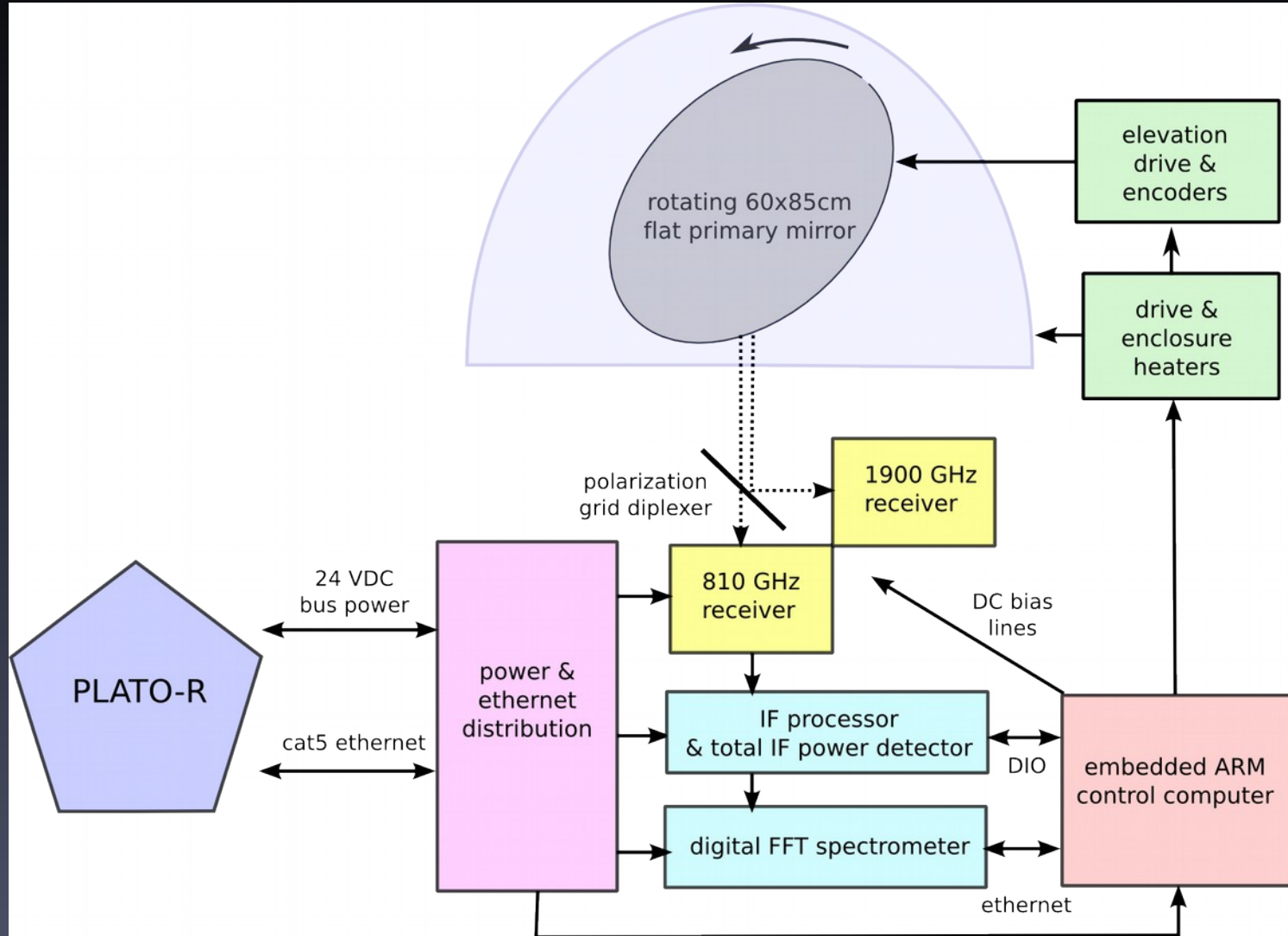


# Technical Features

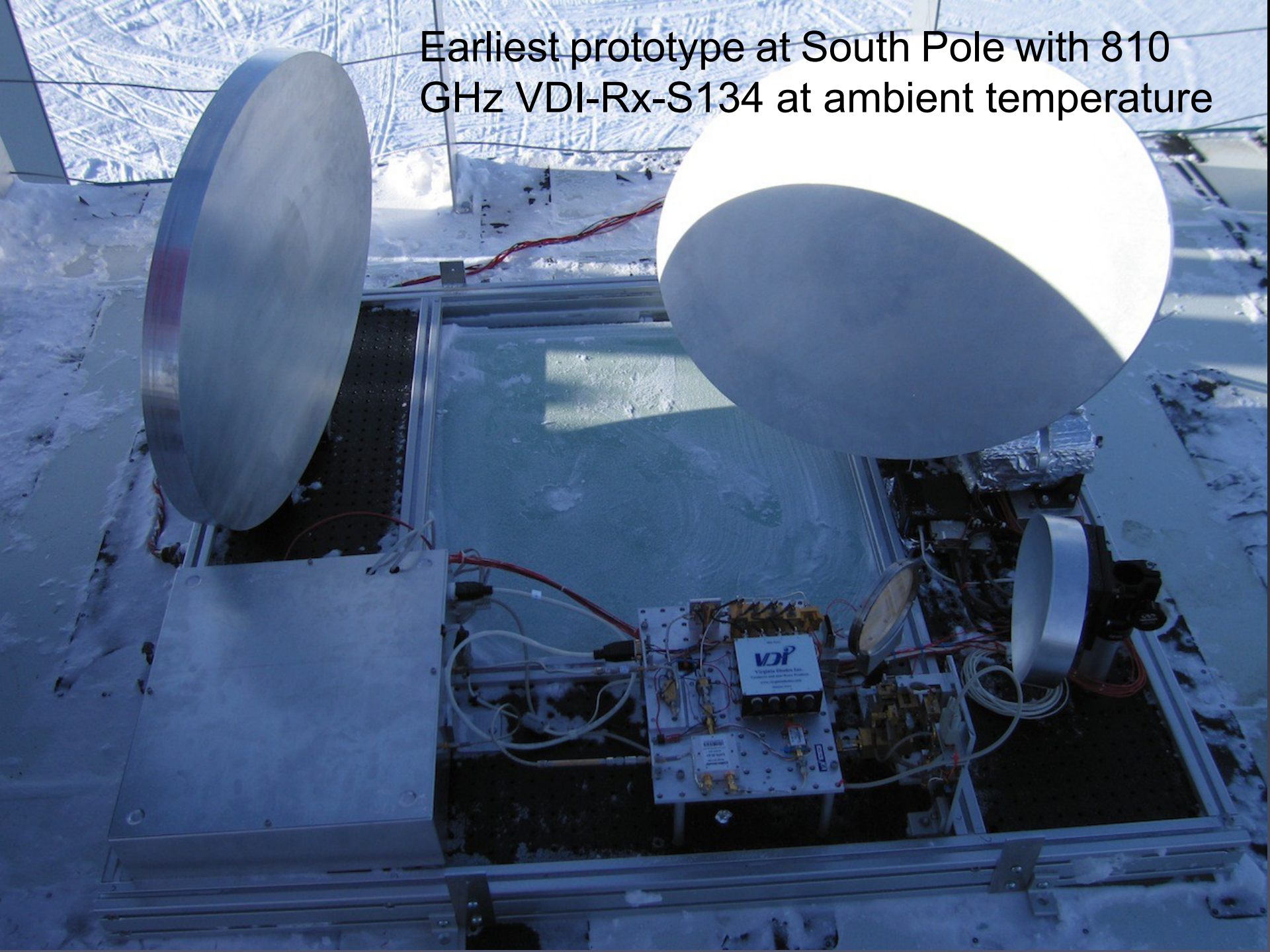
- 60 cm off-axis Gregorian telescope with heterodyne receivers from 0.5-0.8 (2012-13) through 2 THz (2014). 1-2' angular resolution, 1 km/s spectral resolution
- HEAT's "low frequency" band at 0.8 THz matches other observatories' high band!
- **First unattended cryogenic (50K) receivers on the plateau.** 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

Two engines

200 gallons of AN8



Electronics racks in here

20 kWhr of LiFePO4 batteries

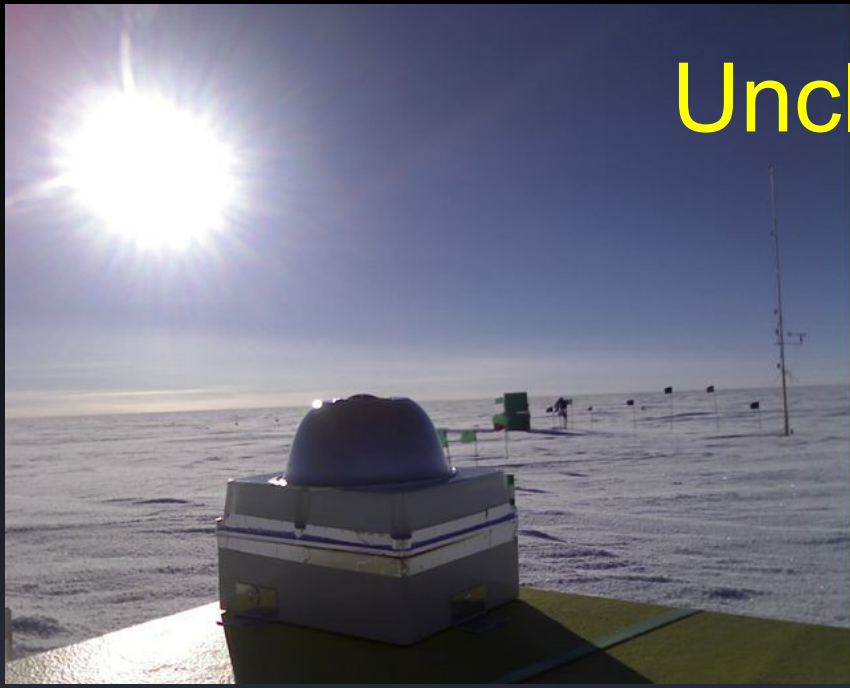


# The solar cube

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

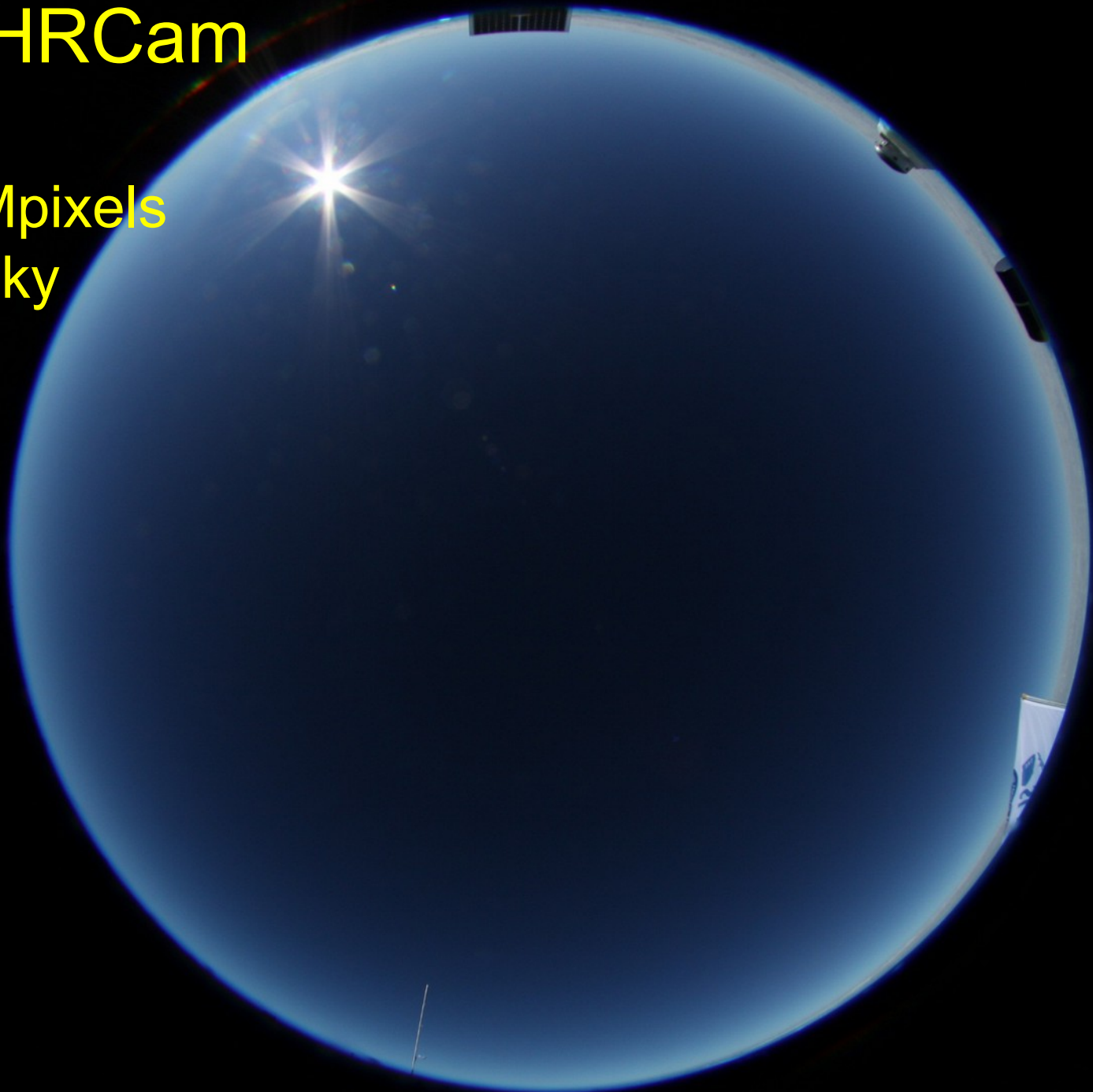


# Uncle Bob

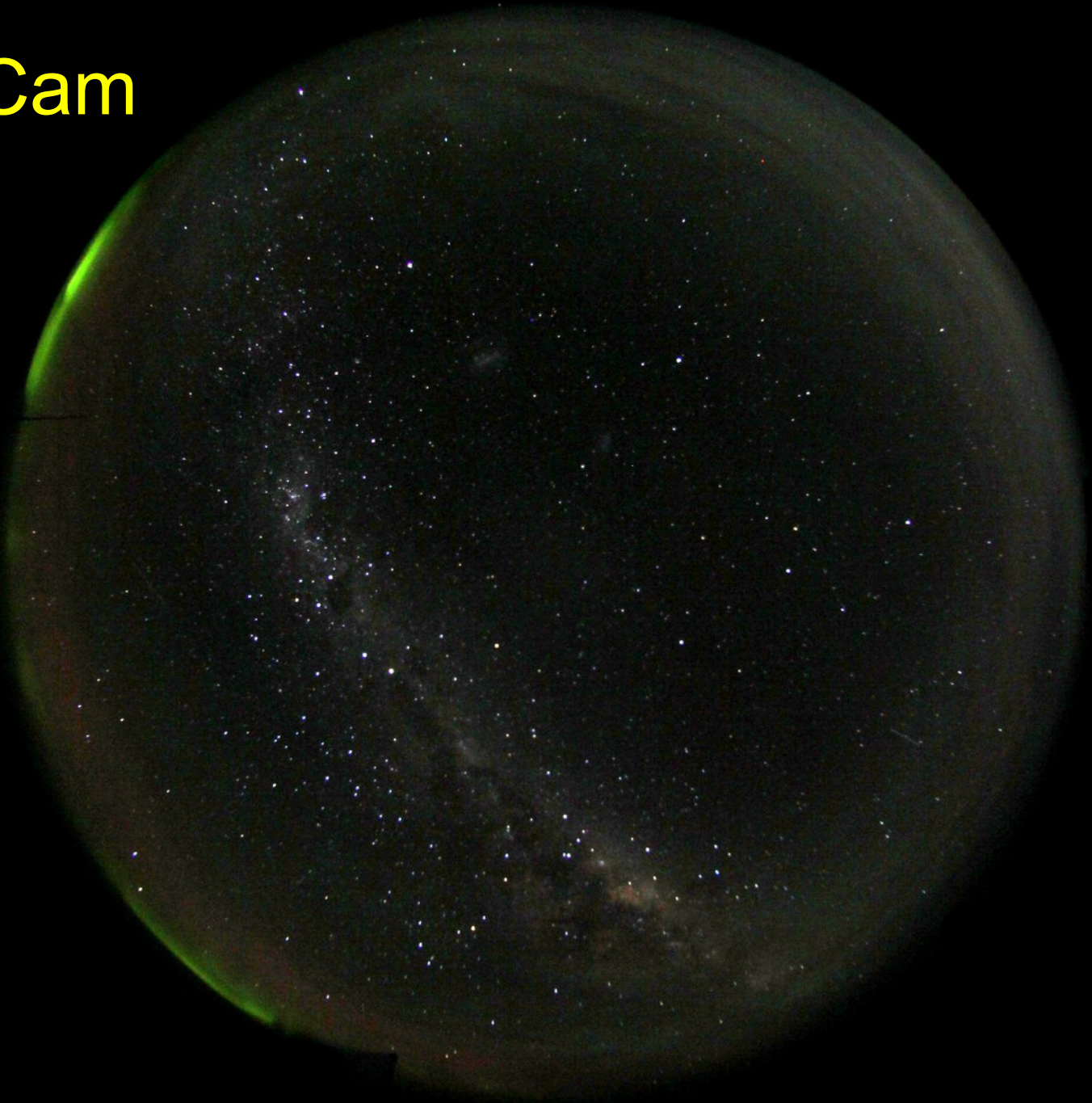


# HRCam

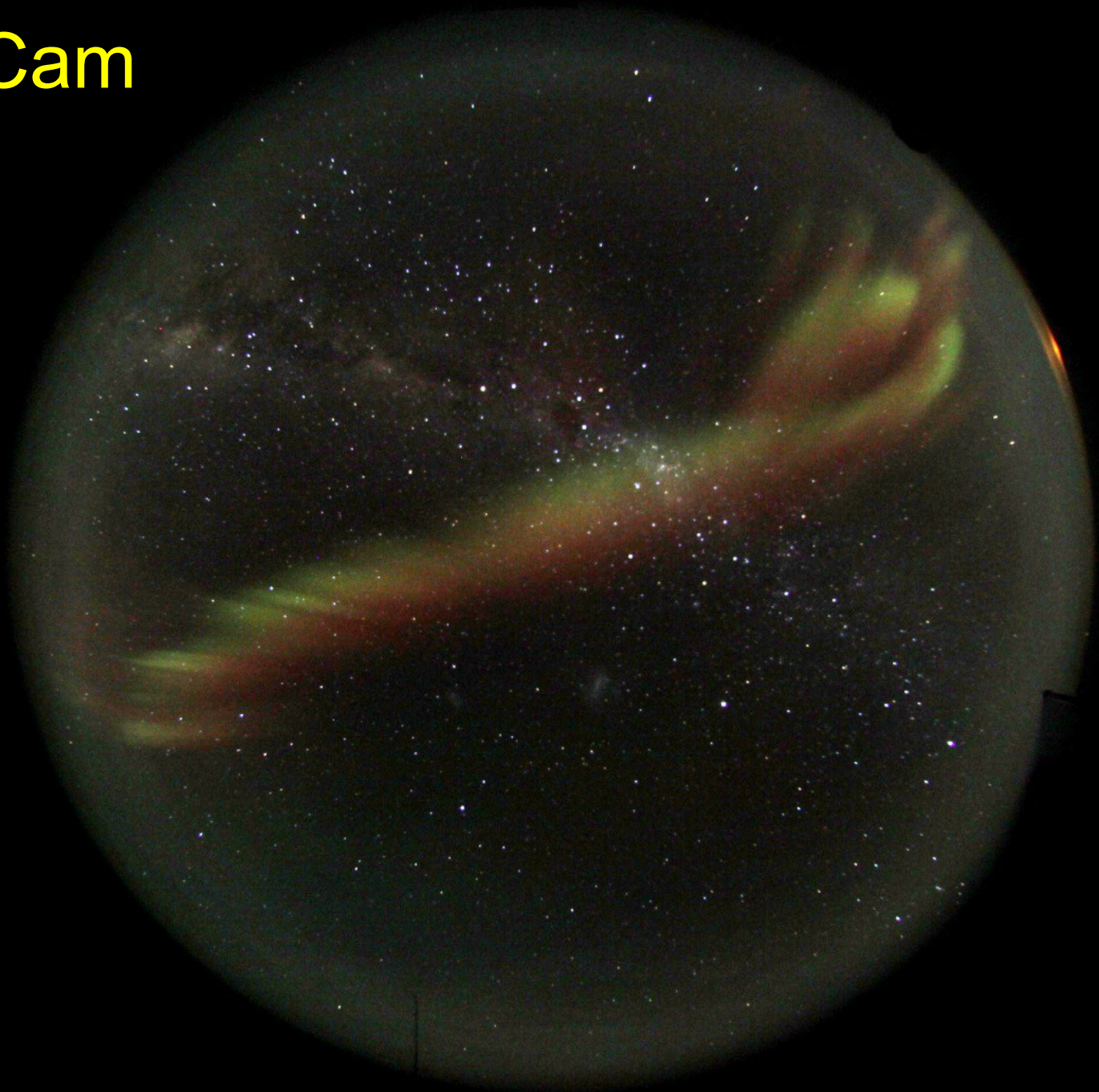
- 18 Mpixels
- All-sky



HRCam



HRCam





How do we fit all of PLATO into a Twin Otter?





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...”



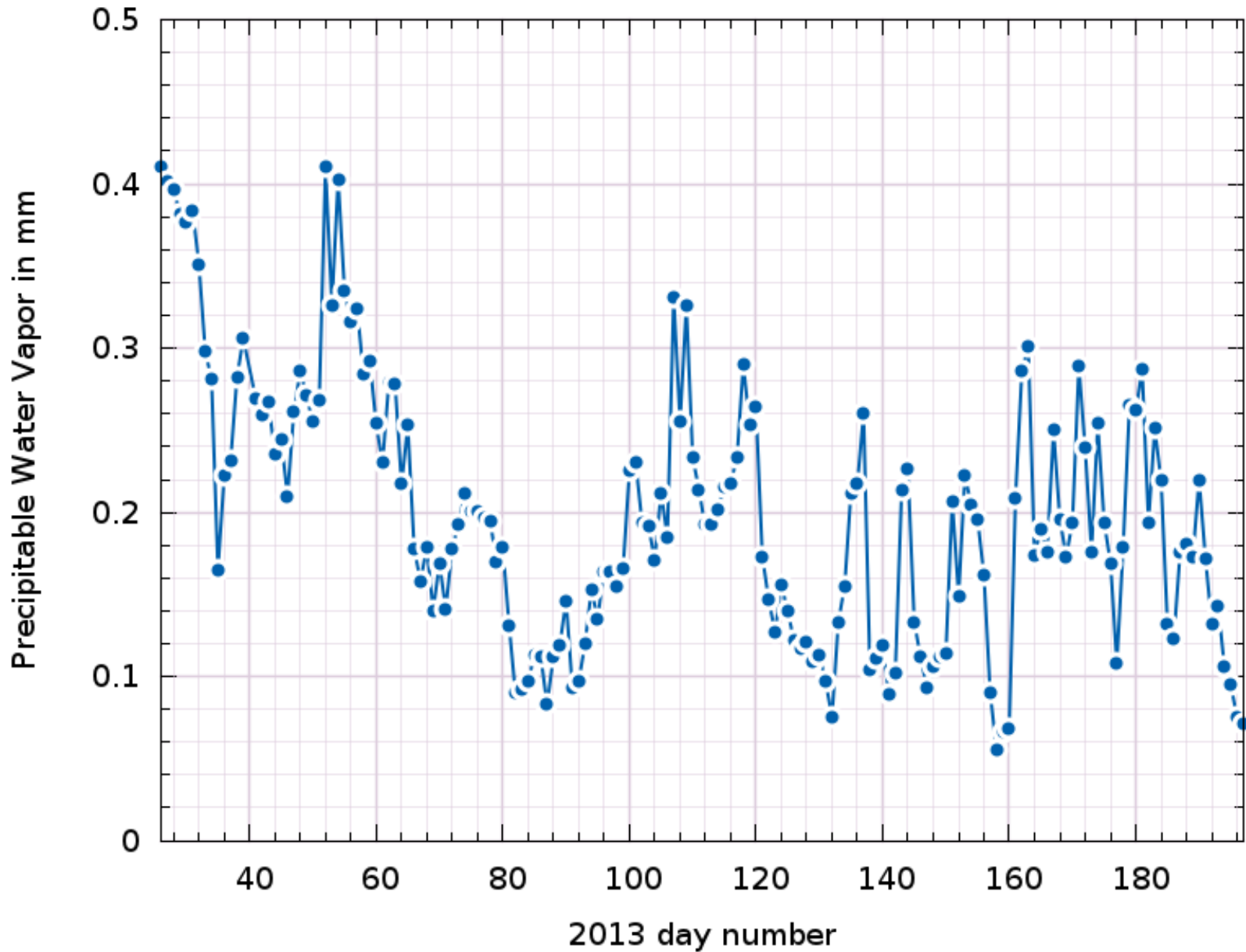
Photo credit: John Storey



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

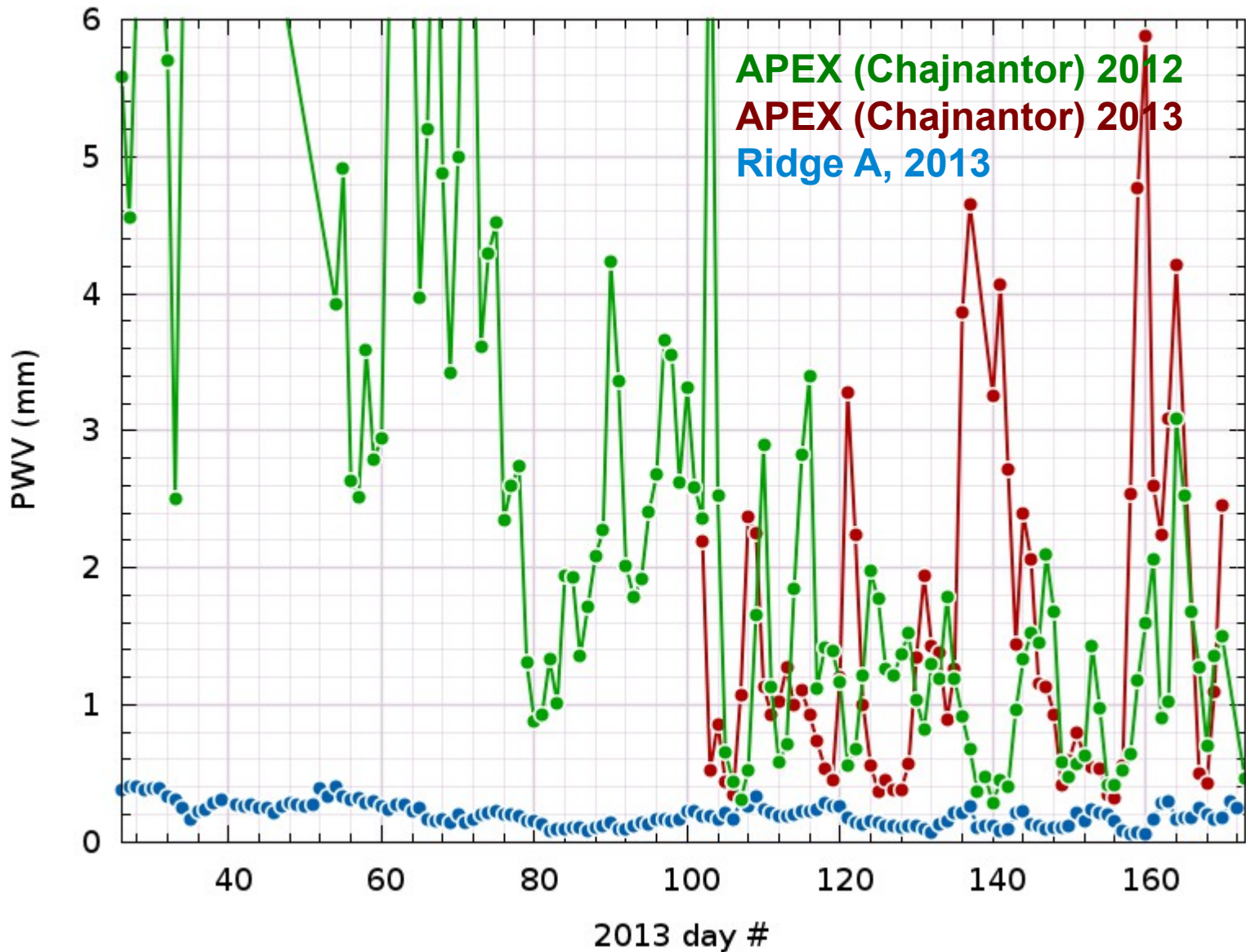


# Results: 2013 Site Testing at 370 $\mu\text{m}$ (810 GHz)

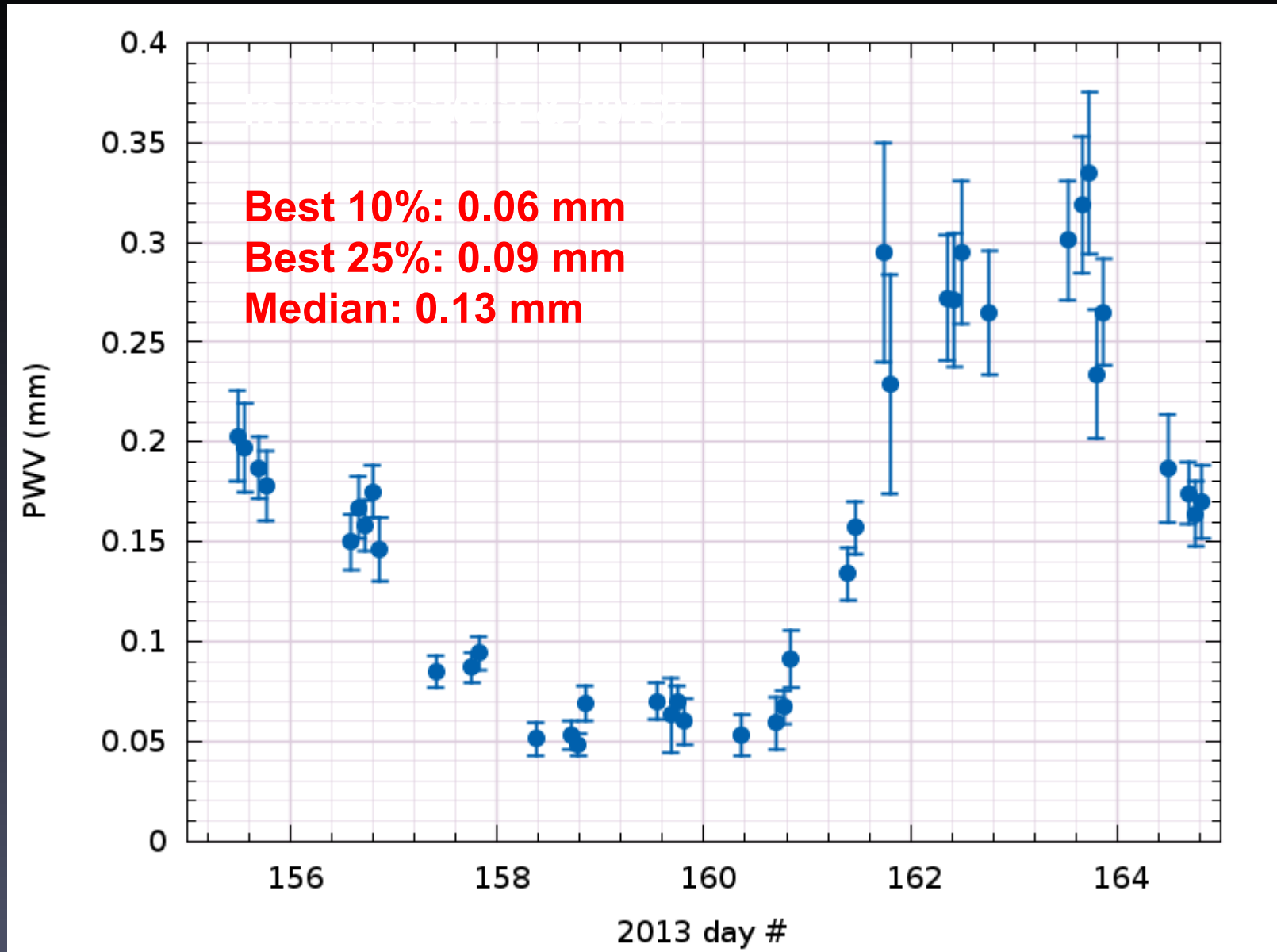


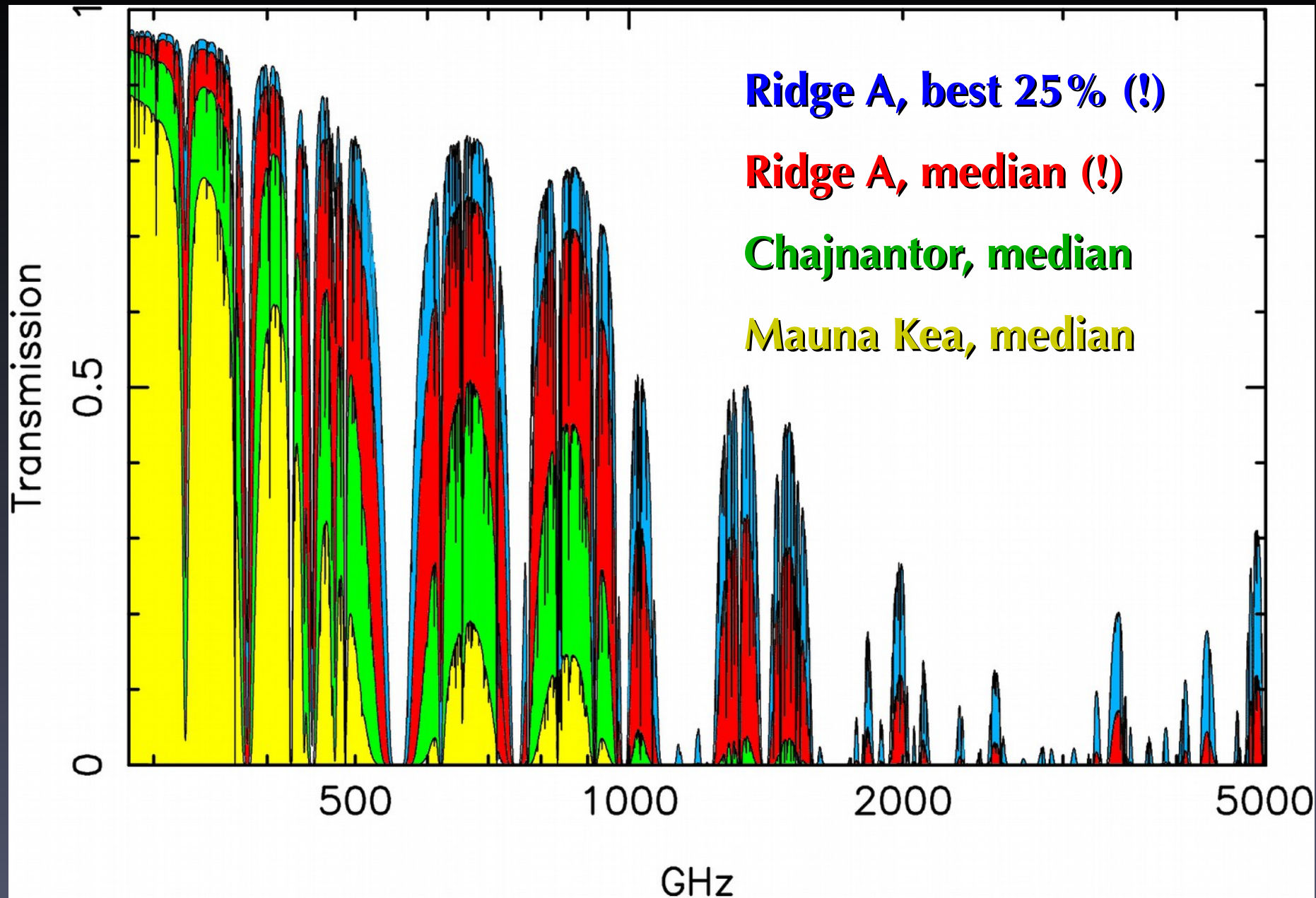


# We have to rescale this plot for ALMA...



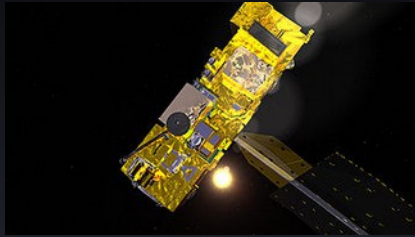
# Zoom in on a winter week: An incredibly stable atmosphere





# PWV extractions from weather satellites

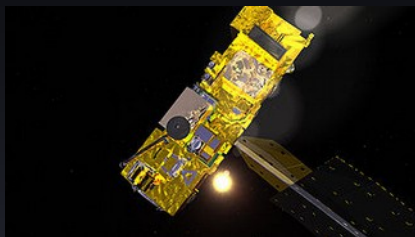
The good, the bad, and the ugly



<b>AIRS</b>	IR spectrometer	<ul style="list-style-type: none"><li>- Assumes topography &amp; atm pressure</li><li>- 45 km resolution</li></ul>
<b>MHS (NOAA 15-19)</b>	183 GHz water radiometer	<ul style="list-style-type: none"><li>- no surface assumptions</li><li>- unknown emissivity of ice</li></ul>
<b>IASI (Metop)</b>	IR Michelson Interferometer	<ul style="list-style-type: none"><li>- assumes topography</li><li>- intermediate resolution &amp; spectral channels</li></ul>
<b>MODIS</b>	Low resolution IR spectro-radiometer	<ul style="list-style-type: none"><li>- few spectral channels</li><li>- best spatial resolution: 5 km</li></ul>

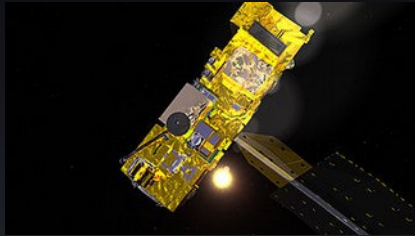
# How close do we get to the observed median of 0.12mm at Ridge A?

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



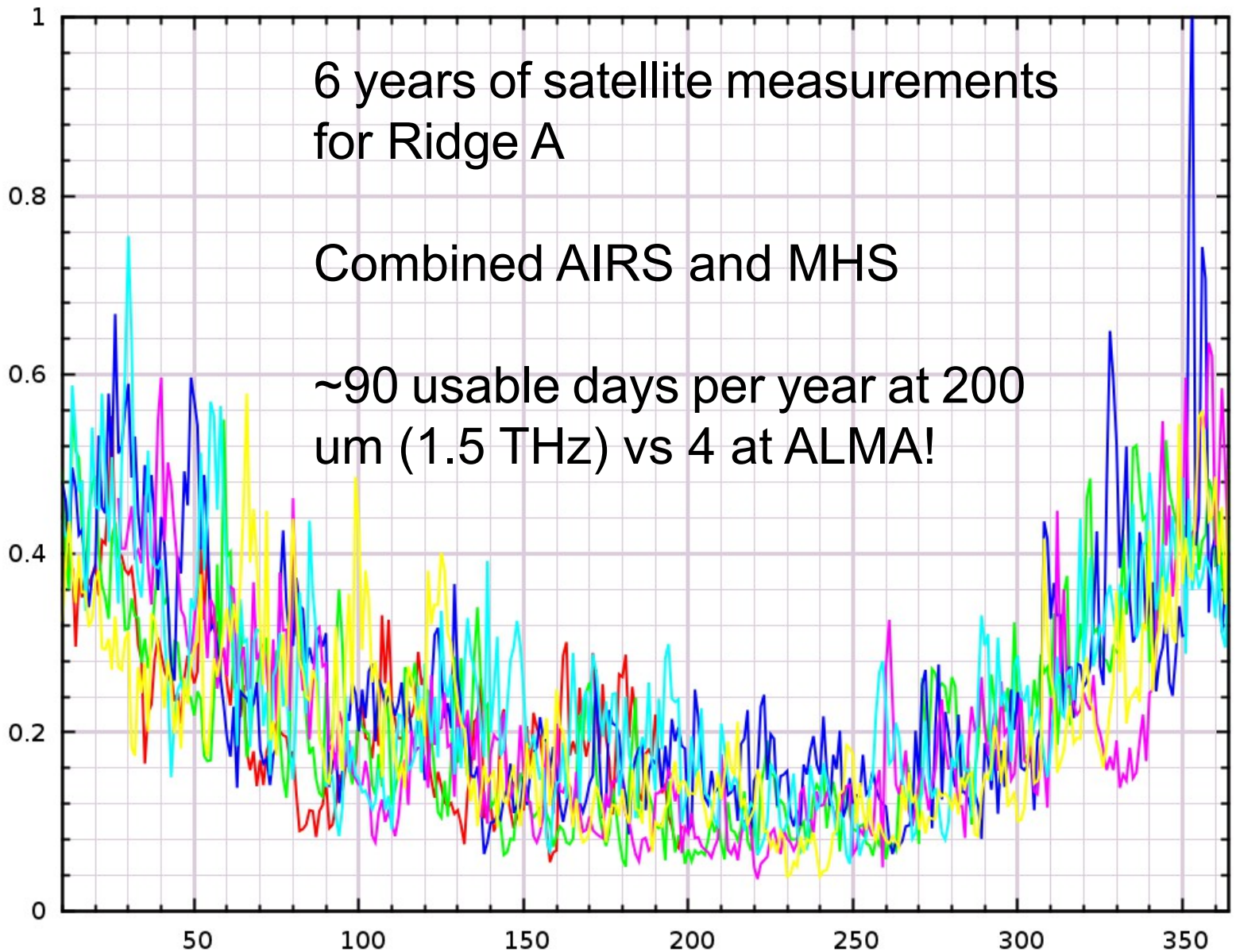
<b>AIRS</b>	<b>0.15 mm</b>	Derived 'soundings' are wrong near ground layer
<b>MHS (NOAA 15-19)</b>	<b>0.10 mm</b>	Systematics in linear approximations to radiometry
<b>IASI (Metop)</b>	<b>0.18 mm</b>	Derived 'soundings' are wrong near ground layer
<b>MODIS</b>	<b>0.02 mm</b>	Insufficient spectral information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

# Excellent agreement, to 10 $\mu\text{m}$ , with low-level data



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

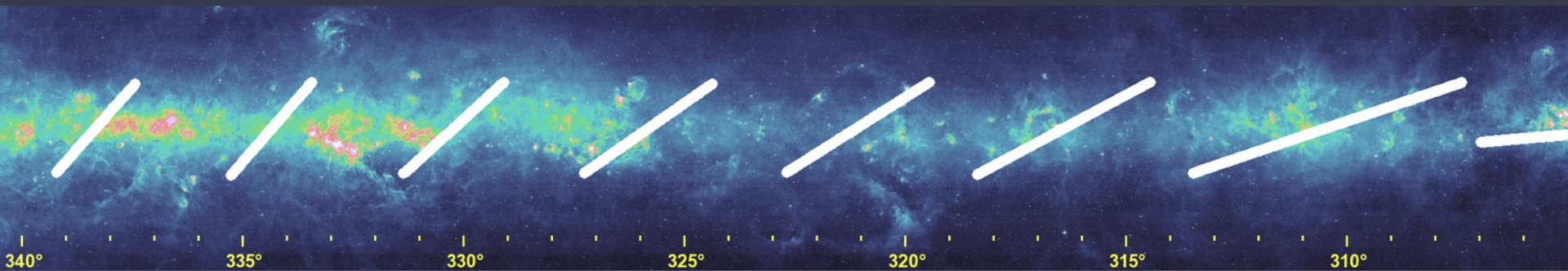
PWV  
(mm)



2008 through 2013 day number

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

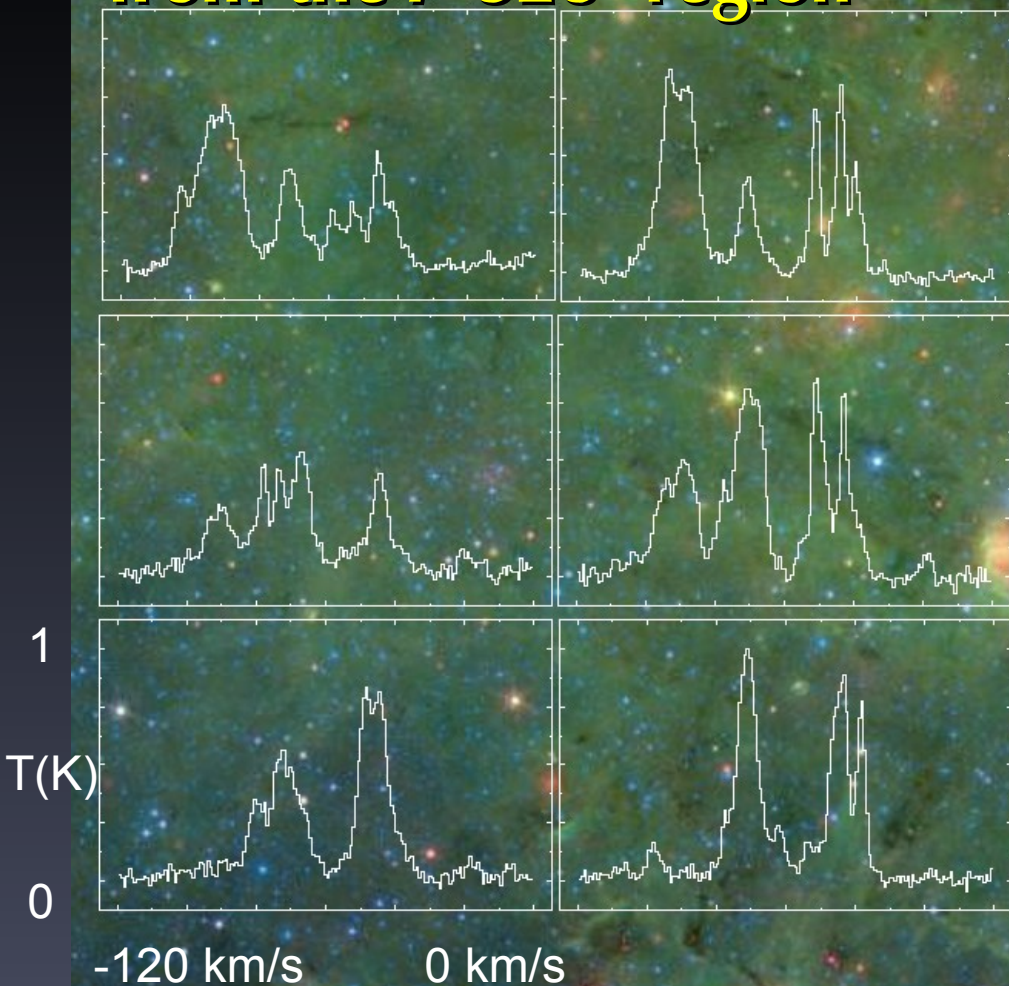
- 810 GHz was permitted for observations with Herschel/HIFI, owing to its typical difficulty from the ground. From Ridge A, we can observe at 810 GHz almost all the time!
- With a fixed azimuth axis, HEAT performs On-The-Fly maps in strips of constant elevation, the heterodyne equivalent of drift-scanning.
- 15 strips are being observed from  $l=343^\circ$  to  $l=270^\circ$ . Over time, the strips will broaden and overlap to provide complete coverage.
- In addition, a  $1^\circ \times 0.6^\circ$  map at  $l=328^\circ$  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 $l=328^\circ$ region



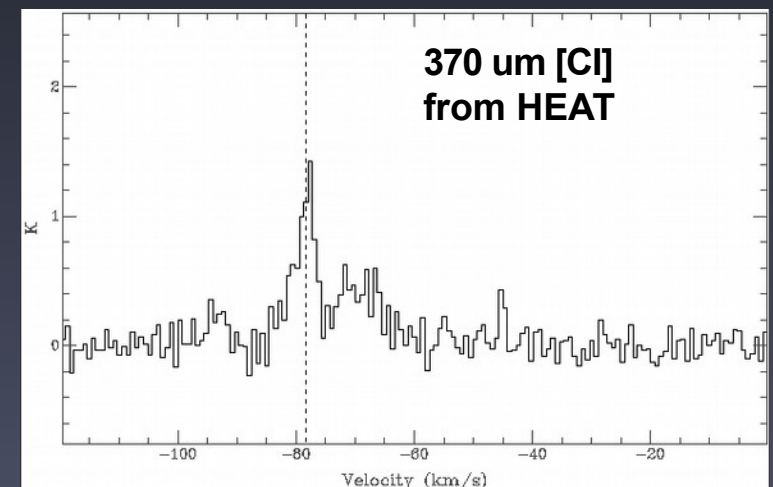
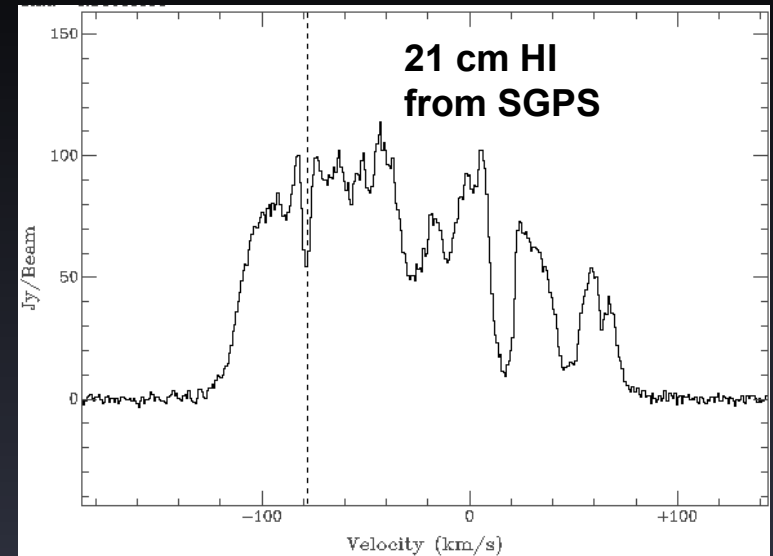
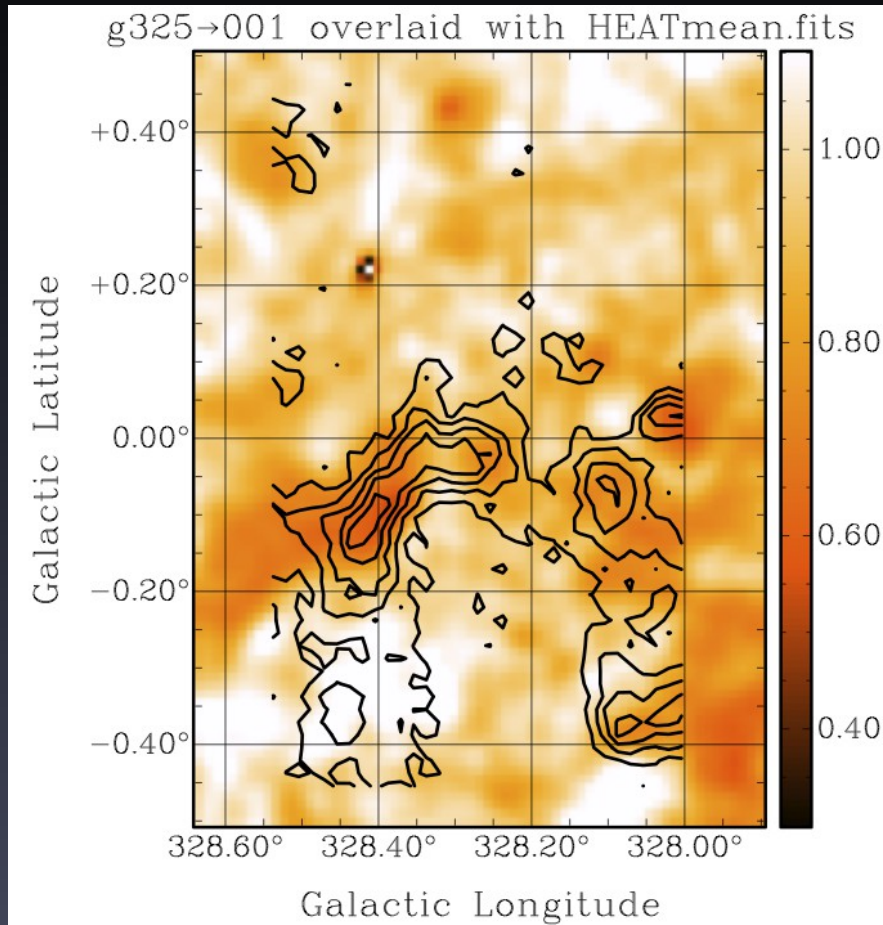
Smoothed 20' [CI] spectra on  $T_{mb}$  scale overlaid on 8/24 um IR emission from Spitzer

**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.

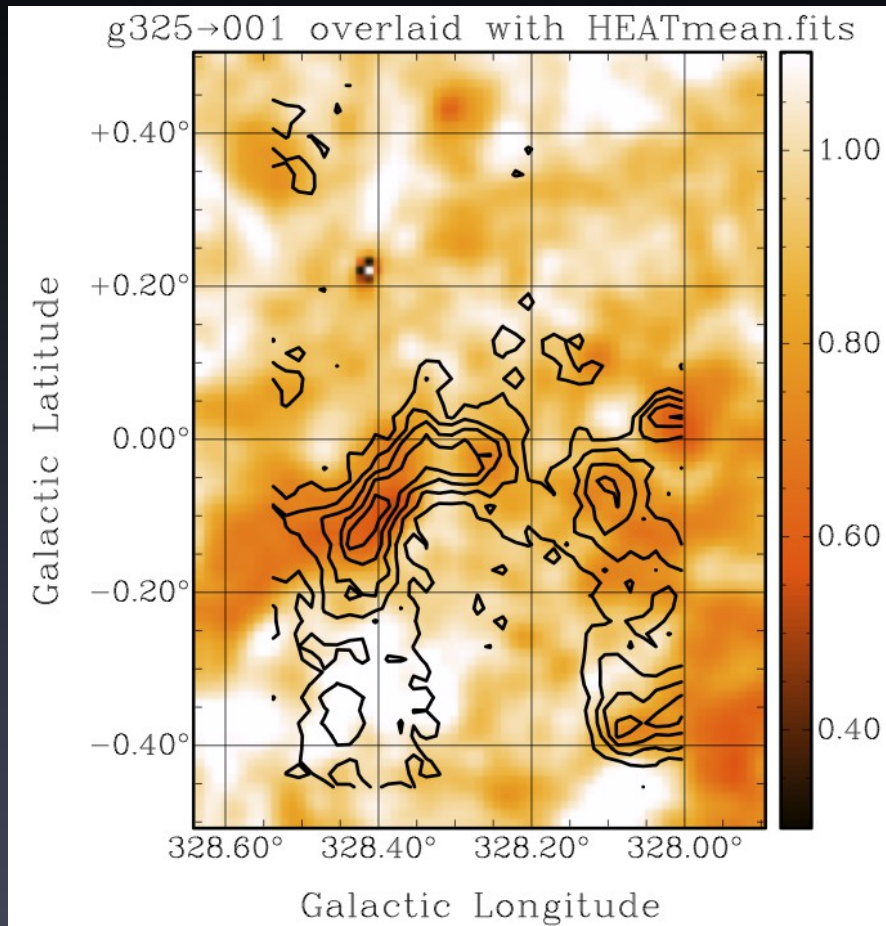
There is a lot of molecular material bound up in translucent clouds and PDRs that have been completely missed or underestimated in CO surveys.

# 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.

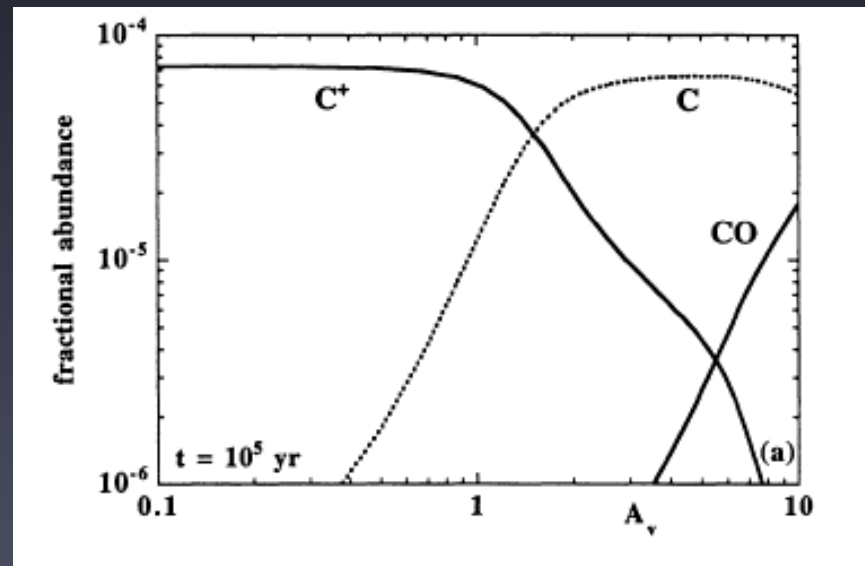
# Molecular Cloud Formation: a candidate in a G328 HI absorption filament



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

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.



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.

A screenshot of a web browser displaying the website for the High Elevation Antarctic Terahertz (HEAT) telescope. The browser's address bar shows the URL 'soral.as.arizona.edu/heat/'. The website header features the HEAT logo and navigation links: Home, The Site, The Science, The Hardware, Data Releases, Live! from Ridge A, and Contact Us. The main content area has a green heading 'Exploring the Life Cycle of Galactic Matter from the Bottom of the World' followed by a detailed paragraph about the telescope's location and mission. To the right, there is a photo of the observatory site with the caption 'HEAT and PLATO-R at Ridge A' and a link to a larger image. Below that is a 'Latest News' section with two entries: '6 March' and '21 February'.

The High Elevation Antarctic Terahertz (HEAT) telescope on Ridge A - Nightly

File Edit View History Bookmarks Tools Help

http://...usR.txt http://...07.txt Antarctic WR... Checkout The High ... Herschel far ... Google Imag... gnuplot set ...

soral.as.arizona.edu/heat/

Home The Site The Science The Hardware Data Releases Live! from Ridge A Contact Us

### Exploring the Life Cycle of Galactic Matter from the Bottom of the World

Antarctica's newest far-infrared observatory is now in operation at Ridge A, the highest, driest, calmest place on the ice plateau. Established in a collaboration between the University of Arizona (US) and the University of New South Wales (Australia) the exceptional site is dedicated to international astronomical exploration. Building on the legacy of the AST/RO and Herschel observatories, the 60 cm HEAT telescope is constructing spectroscopic maps of the Milky Way in frequency bands from 0.5 to 2 THz (600 to 150 microns wavelength), where the extremely cold and dry conditions of the Antarctic plateau provide an exceptionally clear view. The HEAT telescope is exploring star forming regions, some of the most important yet enigmatic regions in our Galaxy, and aims to solve the mystery of how interstellar clouds are formed and evolve. The maps that HEAT constructs provide broad context (essentially "finding charts") for large facilities like ALMA, CCAT, and SOFIA and represent some of the newest, most comprehensive views of interstellar matter in our Milky Way Galaxy. [Learn more...](#)

#### A Robotic Observatory at the Coldest Place on Earth

The HEAT telescope is combined with the Australian PLATEau Observatory (PLATO-R), analogous to a "spacecraft bus", from which HEAT derives power and communications. The combination of HEAT and PLATO-R were first installed at Ridge A in January 2012; they comprise a robotic observatory that bears closest resemblance to a satellite observatory: it must operate in a remote, extreme environment without direct human contact for a year at a time. A cube of solar panels provide up to 1 kilowatt of power during the summer, and two small diesel generators provide redundant power during the long winter night. Two Iridium modems using USAP DoD SIM cards provide 24/7 contact with PLATO-R and HEAT and allow uplinking of commands and downloading of instrument telemetry and science data. [Learn more...](#)

#### Ridge A: Where the Stratosphere Goes all the way to the Ground

The Ridge A site was selected from satellite data to be the best location for an astronomical observatory on the Antarctic plateau, and indeed, anywhere on Earth.

#### HEAT and PLATO-R at Ridge A

[Click for a larger image](#)

#### Latest News

- 6 March: We just broke the -80F mark for the first time in 2013! Precipitable water vapor reached a new low of 0.12mm, with excellent agreement between the 492 and 809 GHz receivers.
- 21 February: 3 days without a breath of air! Watching the SCAR flag makes for a boring pastime. PLATO-R's image from 16h UTC on 20 February shows that a more lunar landscape would be hard to find...

<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

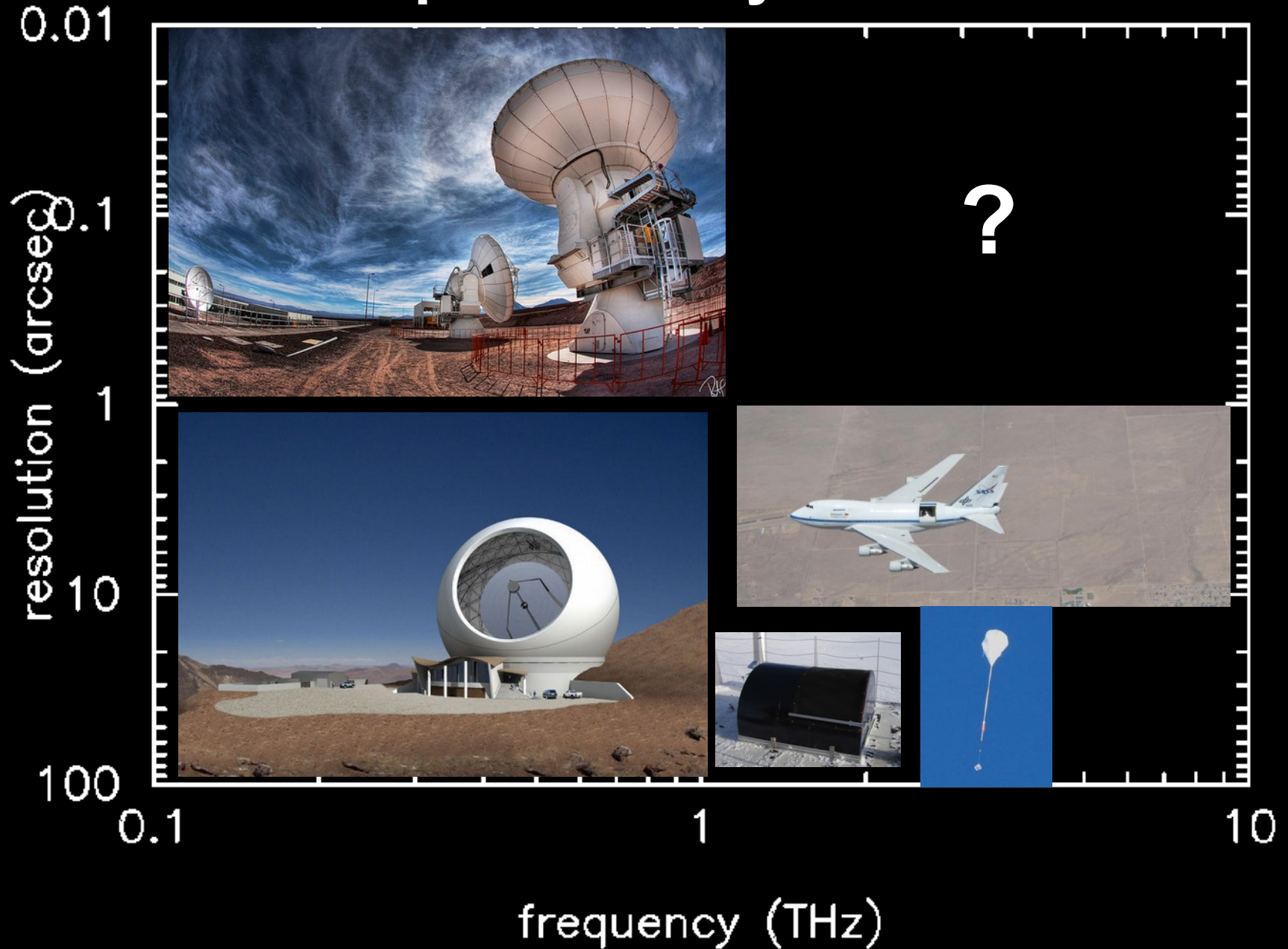
Less than 0.1 mm PWV for 30% of winter, with exceptional stability. THz astronomy from the ground is now practical.

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

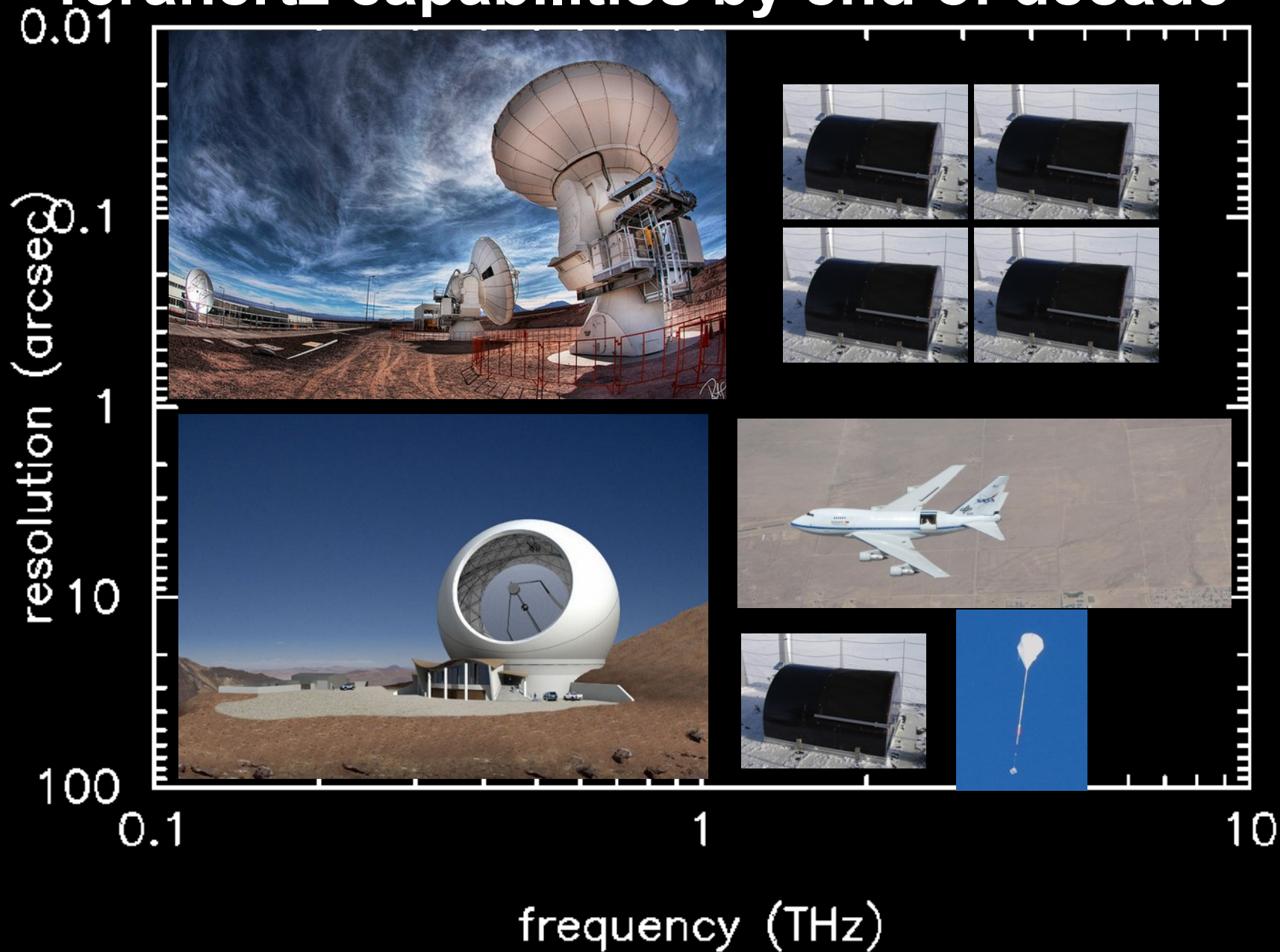
4K closed cycle systems under development (2014-15)

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  $\mu\text{m}$ )
- Most important lines available:  $\text{D}_2\text{H}^+$ , CO 9-8 to CO 13-12, NH,  $\text{NH}^+$ ,  $\text{H}_2\text{D}^+$ ,  $\text{N}^+$ , CH
- Continued development: low power 4K cryocoolers, sensitivity and stability of detectors at > 1 THz