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

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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
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
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.

Solution 1: going to higher altitude reduces pressure broadening of opaque atmospheric lines.

Solution 2: seek colder, drier sites; water is the dominant atmospheric opacity source.
Of course, there's Herschel...

Unprecedented capabilities 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 atmospheric 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

Atlantic Ocean

Indian Ocean

South Pole

Ridge A

Dome A

Dome C

Pacific Ocean

USGS image

Elevation in meters: 0 - 4000
Getting there...

... hitching a lift *might* work ...
PLATO: the Plateau Observatory, 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.
Combined NOAA satellite soundings and Pre-HEAT data show very low precipitable water vapor and high THz atmospheric transmission.
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

Ridge A, best 25%
Dome A, median
Chajnantor, median
Mauna Kea, median
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.
current temperature $-61^\circ\text{C}$, PWV=0.32mm, transmission at 810 GHz = 26%
810 GHz spectra
accumulated March 15-22

Galactic Plane near NGC 3576

[CI] 809.3 GHz
CO 7-6 806.5 GHz

off-plane
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, $< 1 \text{ THz}$
• CCAT will provide filled aperture imaging with 5-15” resolution, $< 1 \text{ THz}$
• SOFIA will provide imaging and spectroscopy with 15-30” resolution, $> 1 \text{ THz}$
• 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!