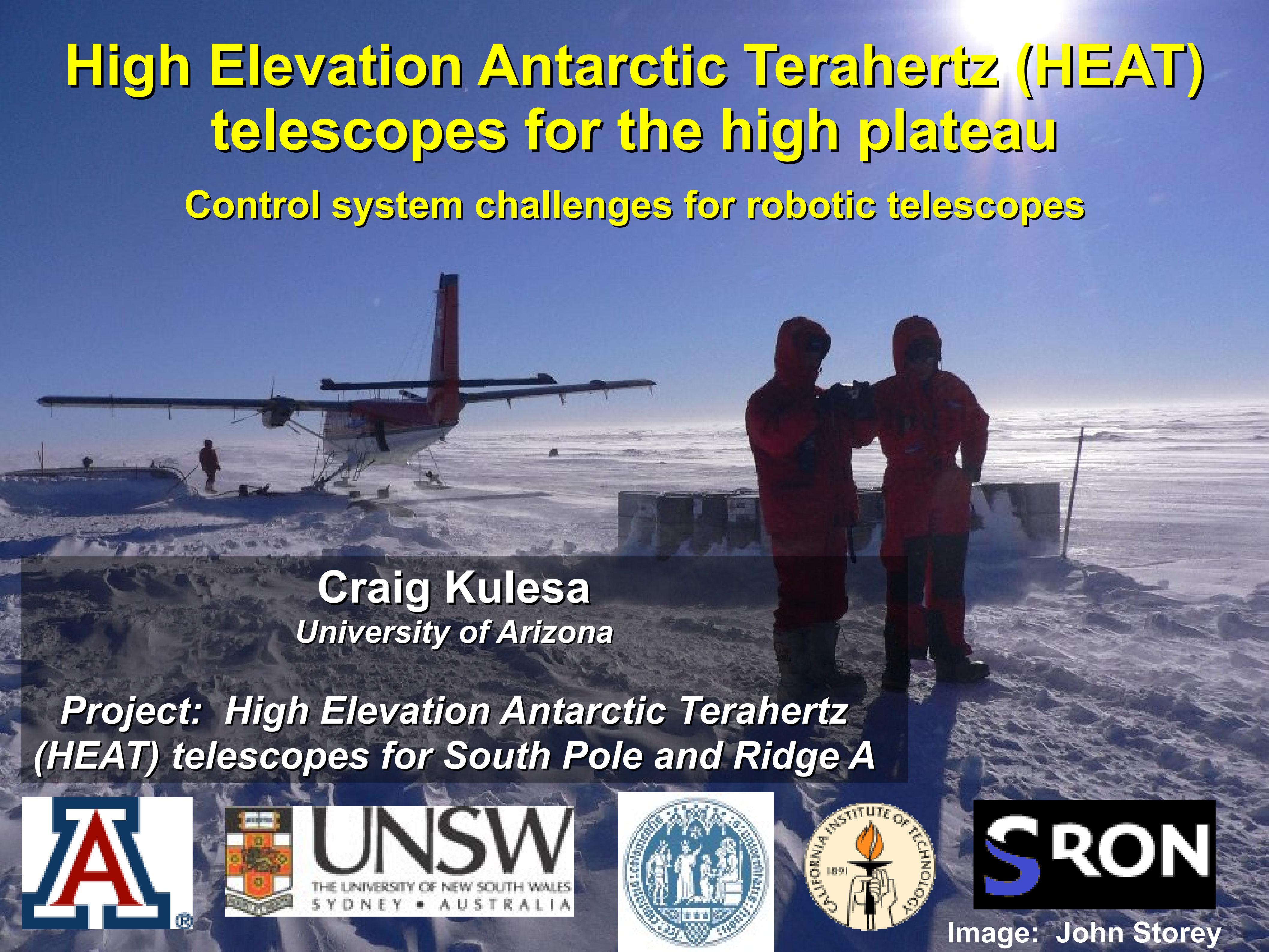
High Elevation Antarctic Terahertz (HEAT) telescopes for the high plateau

Control system challenges for robotic telescopes

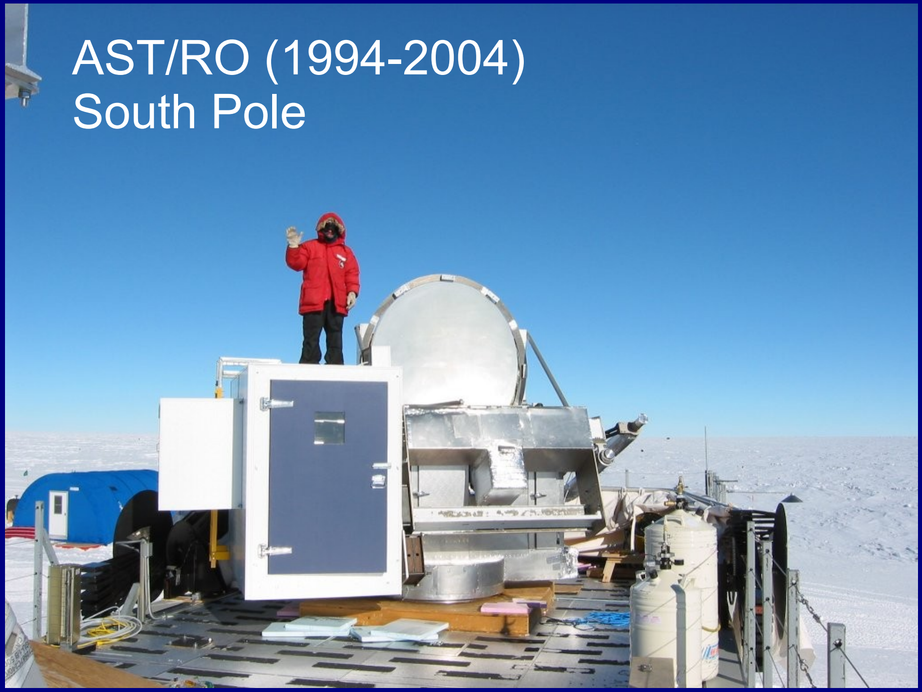


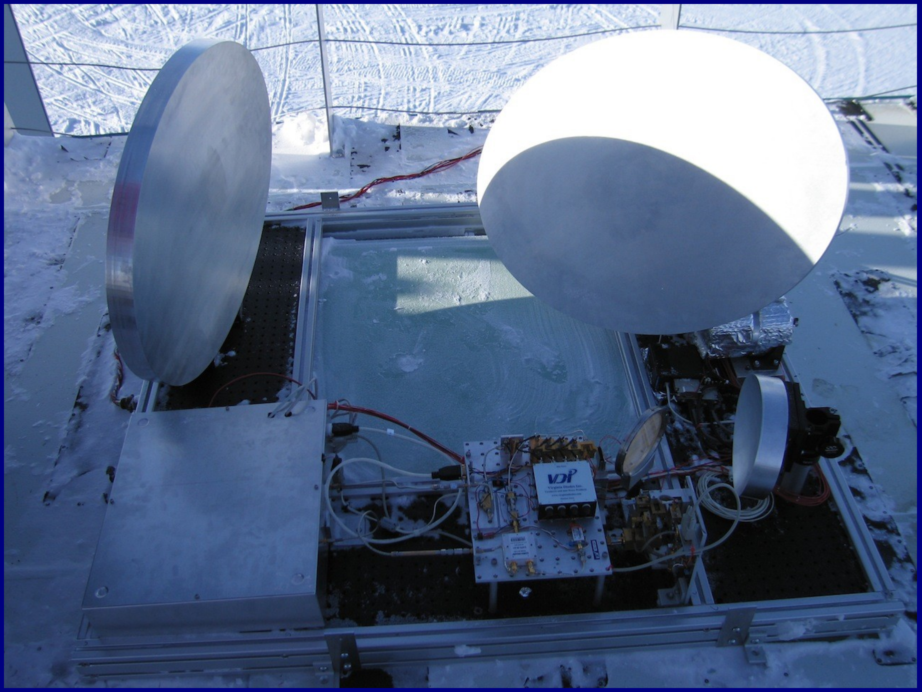
Craig Kulesa

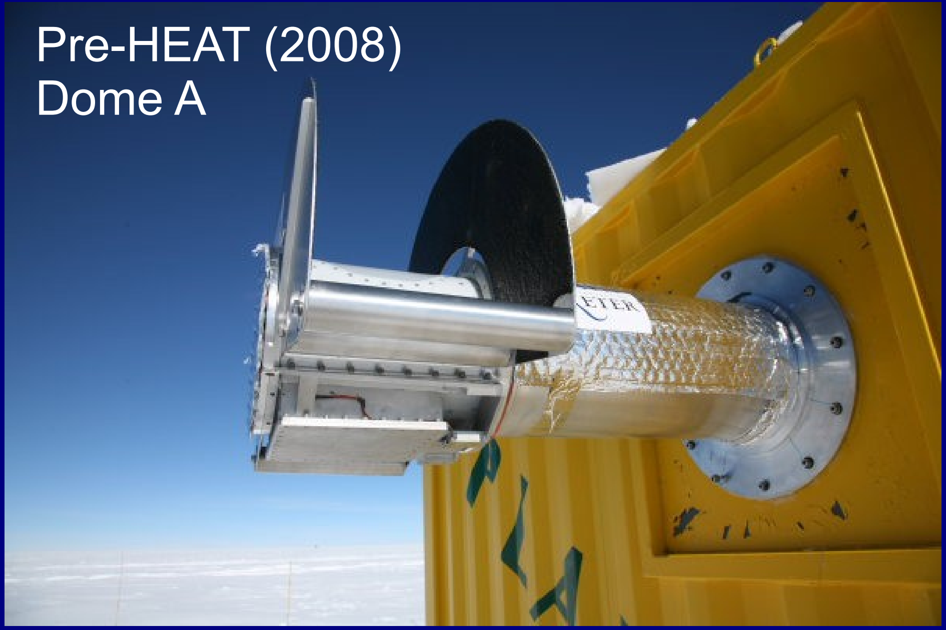
University of Arizona

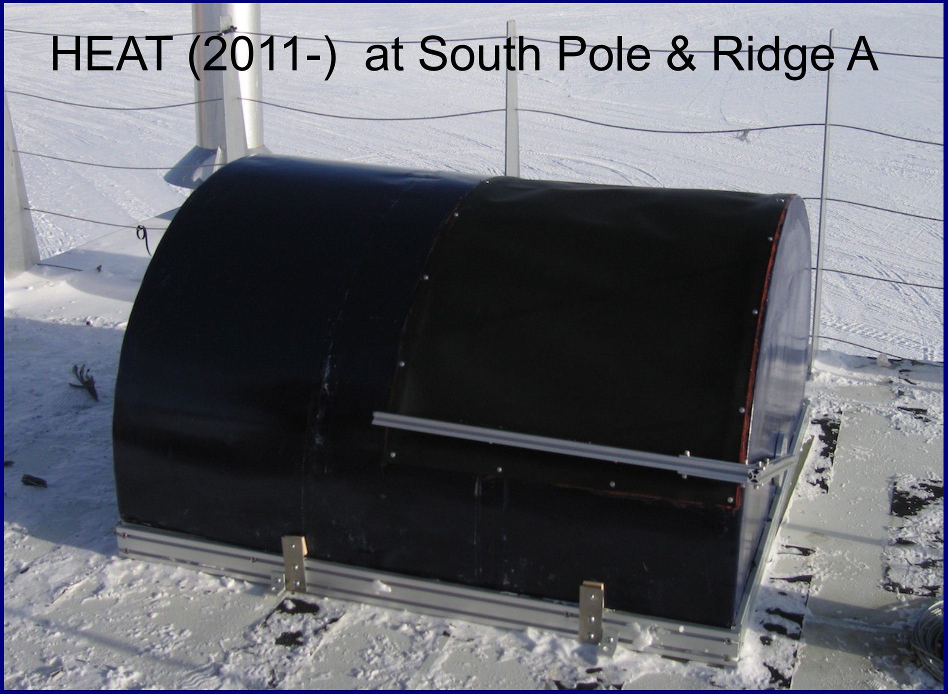
Project: High Elevation Antarctic Terahertz (HEAT) telescopes for South Pole and Ridge A

Image: John Storey


AST/RO (1994-2004)
South Pole




Pre-HEAT (2008)
Dome A


HEAT (2011-) at South Pole & Ridge A

LDB instrumentation can teach us a lot too!

ex. Stratospheric Terahertz Observatory

- test flight from Fort Sumner in Oct 2009
- first Antarctic flight in December 2011?

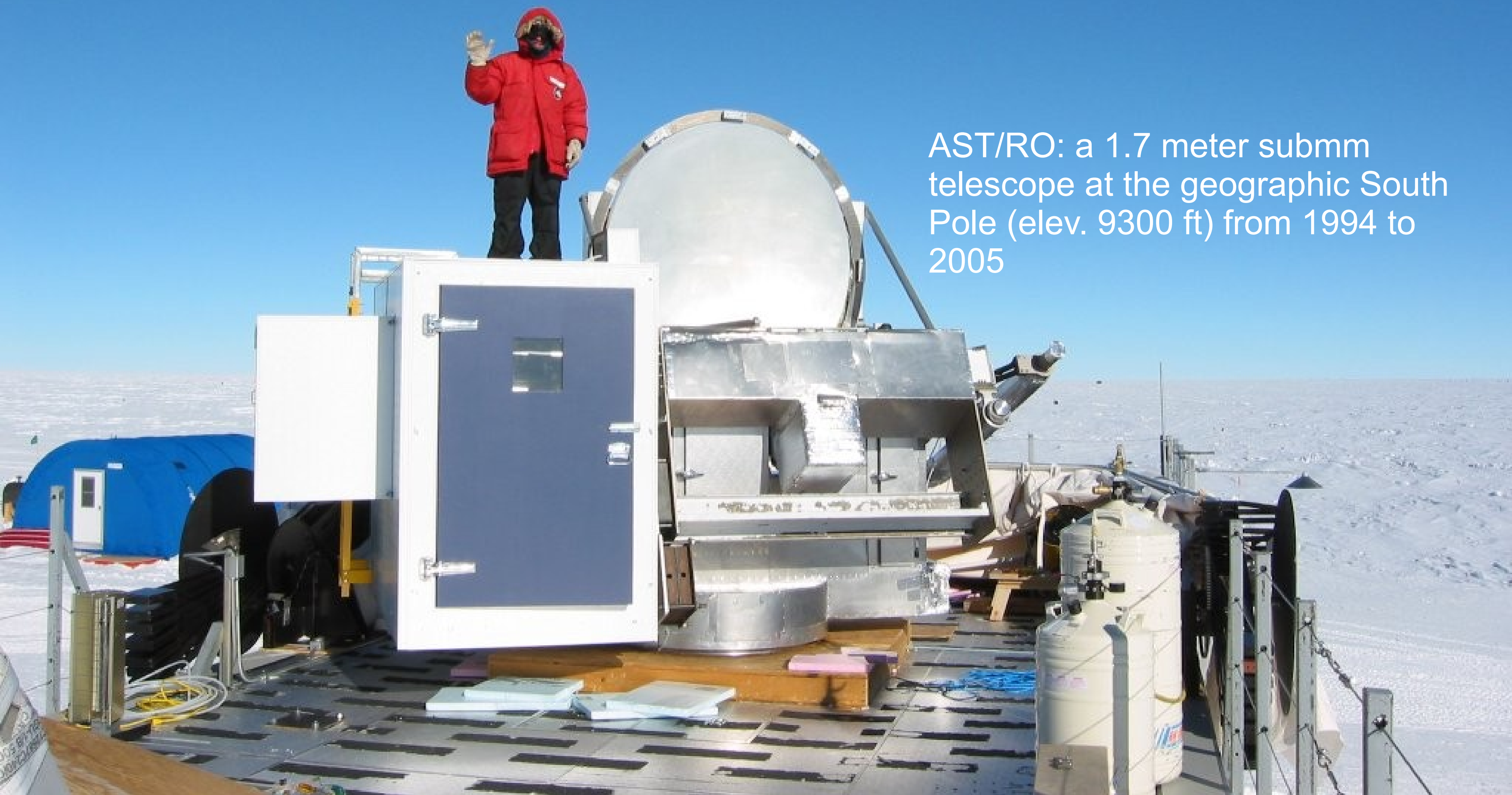
In all of these experiments, it's important to share what worked well...

and what didn't...

from the decommissioning of AST/RO at South Pole

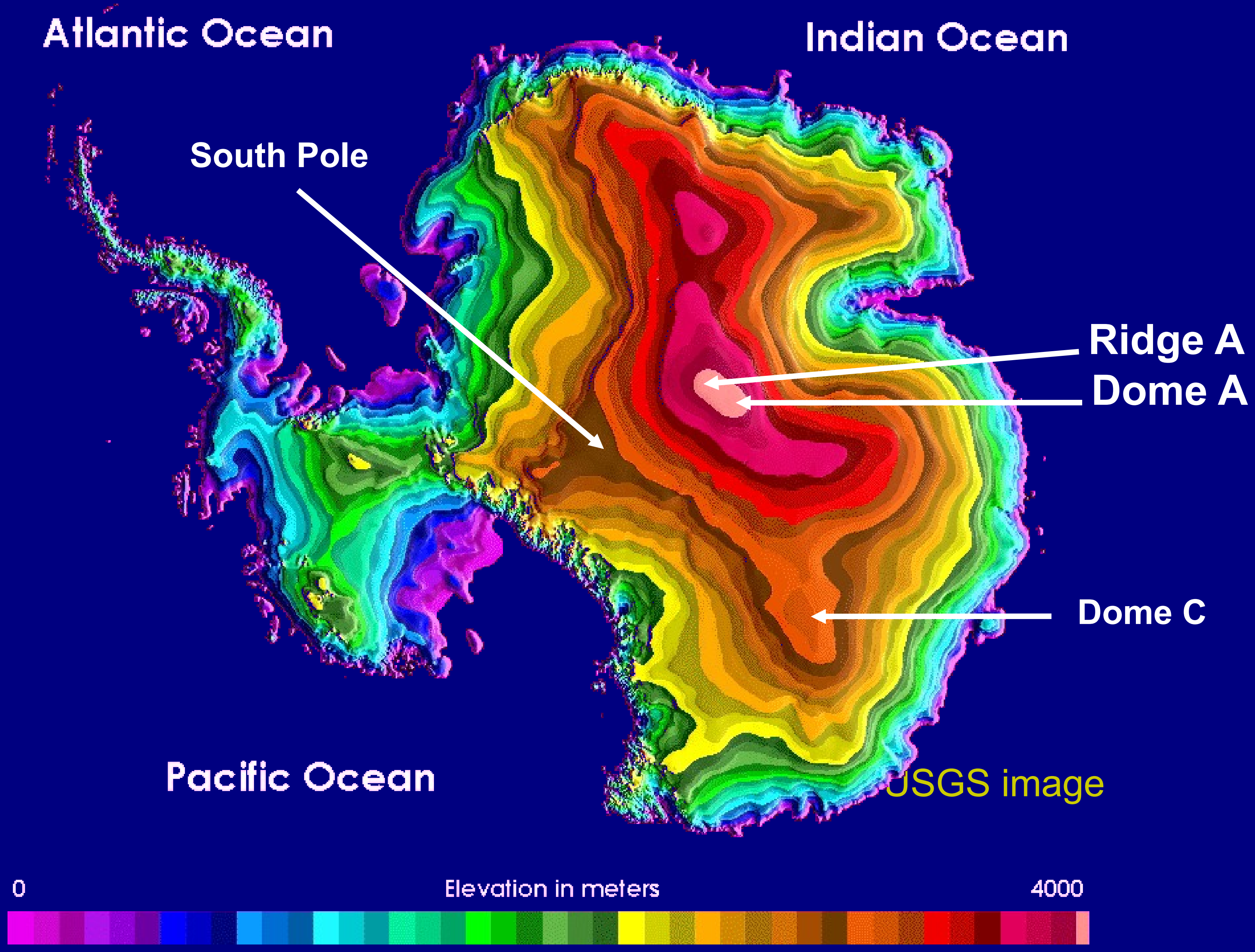
Colder, drier, higher, calmer...

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.

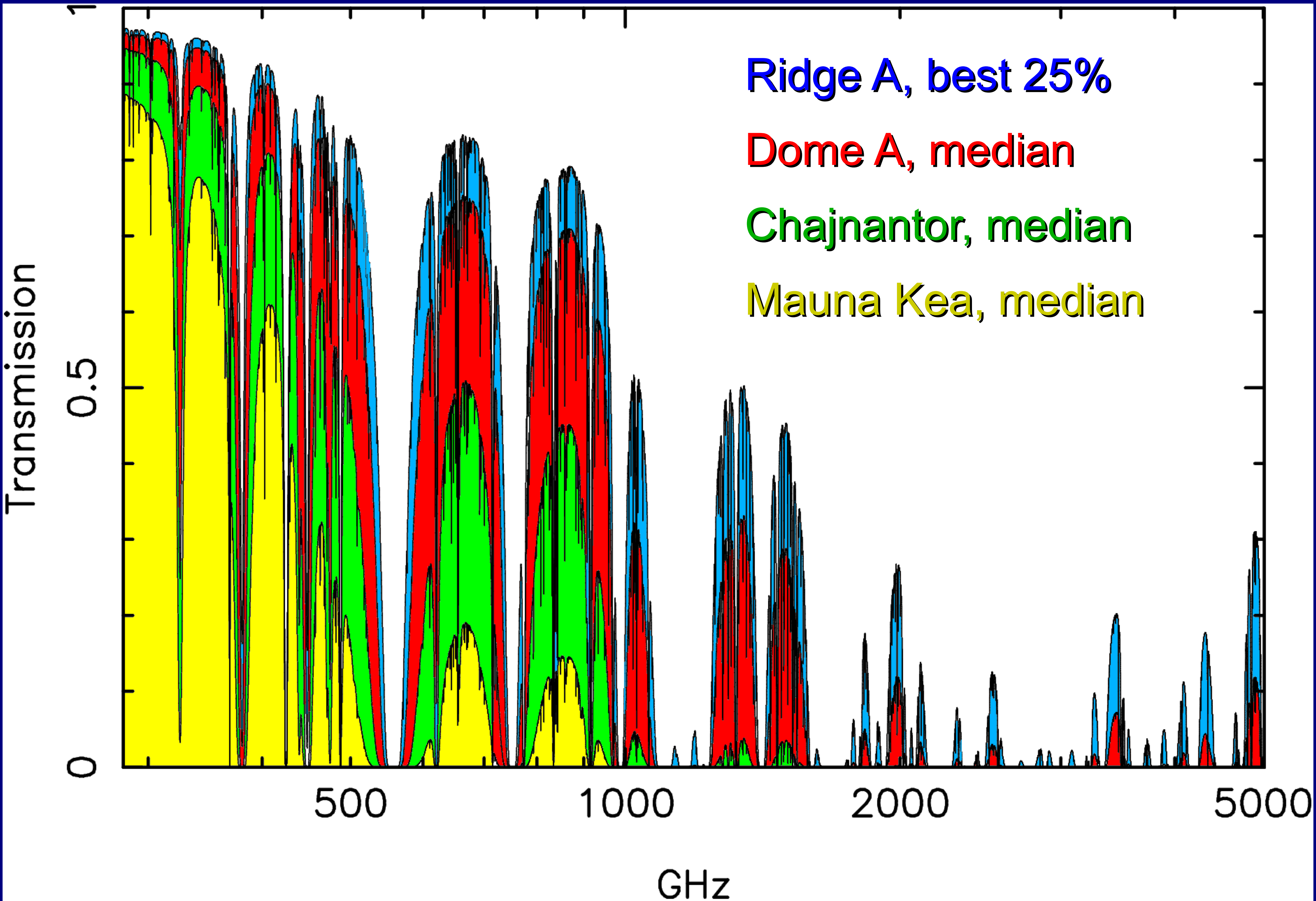


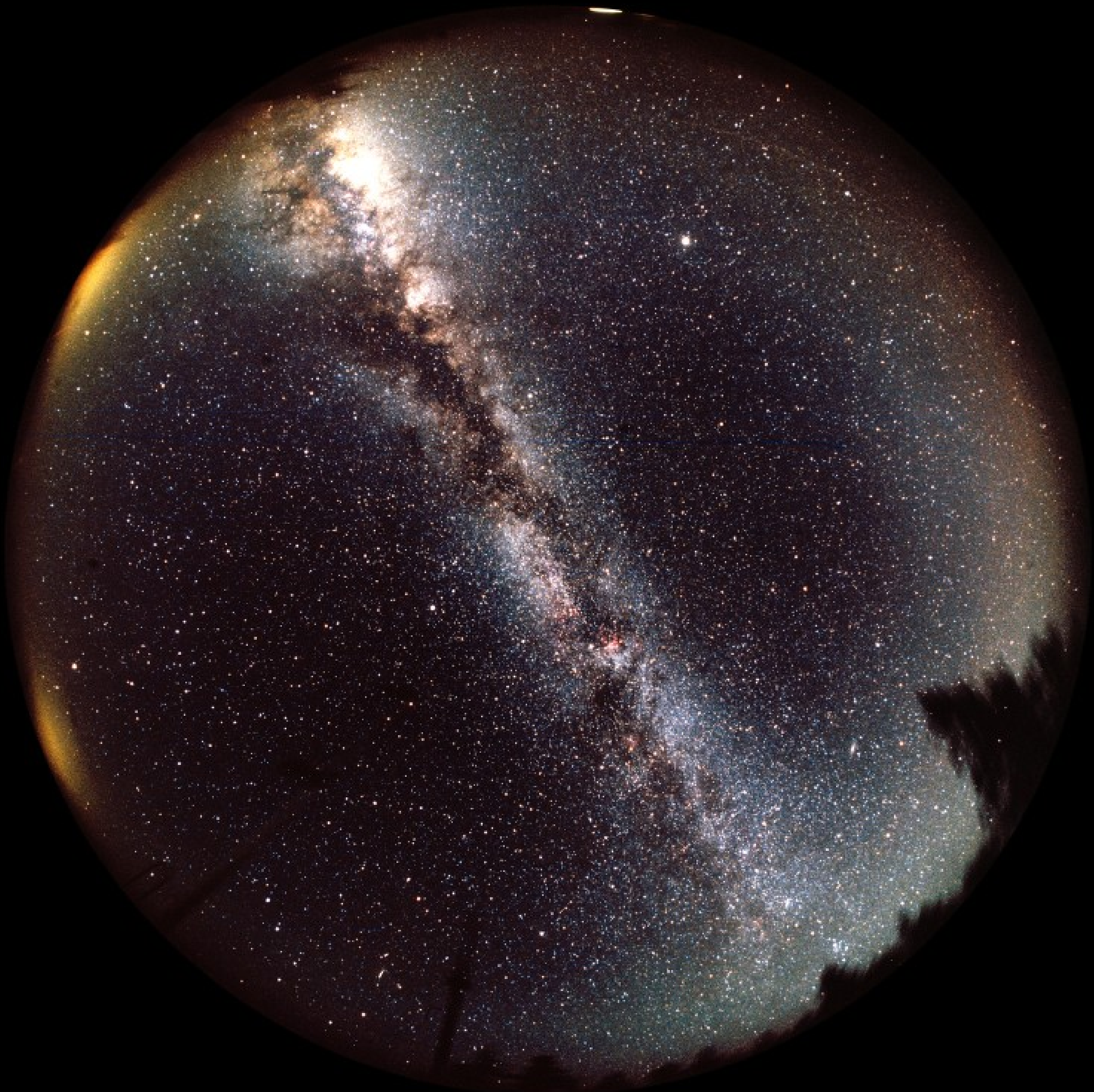
AST/RO: a 1.7 meter submm telescope at the geographic South Pole (elev. 9300 ft) from 1994 to 2005

Contour map of Antarctica



New atmospheric 'windows' open over the High Plateau





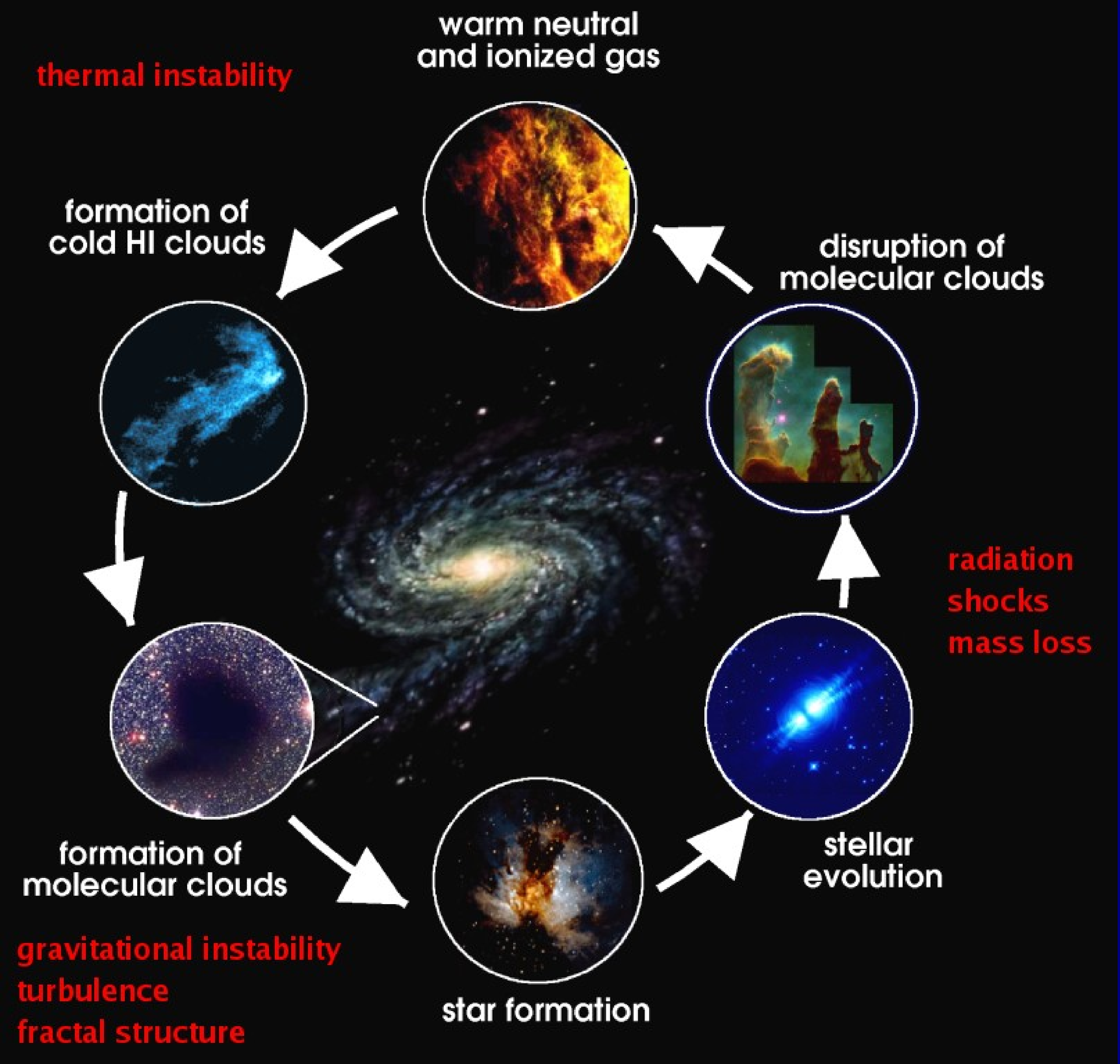
We live in a Galaxy comprised of stars, dust, gas, planets, and people.

Where did it all come from?

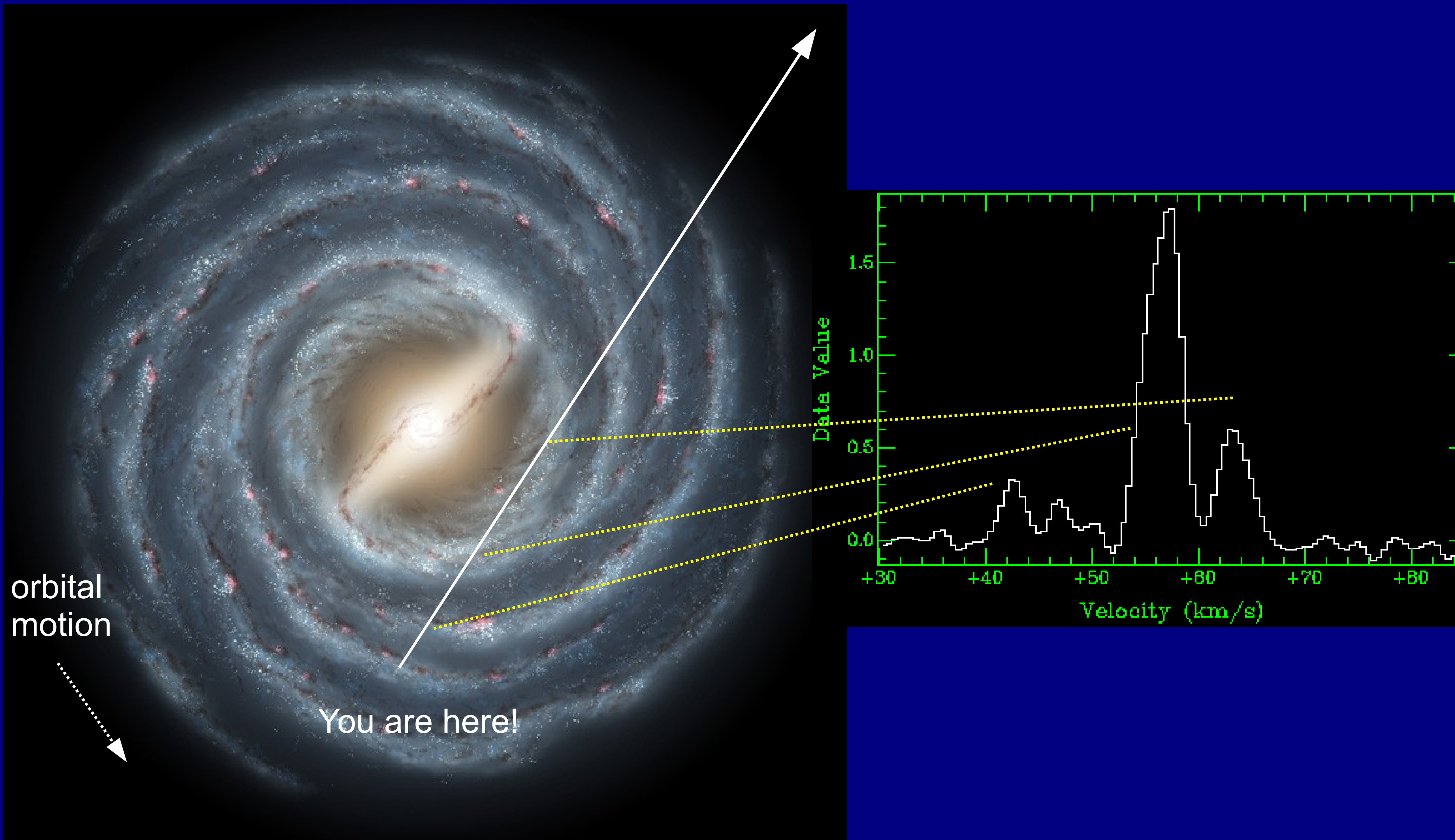
The Life Cycle of matter in the Galaxy

or

'Galactic Ecology'



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

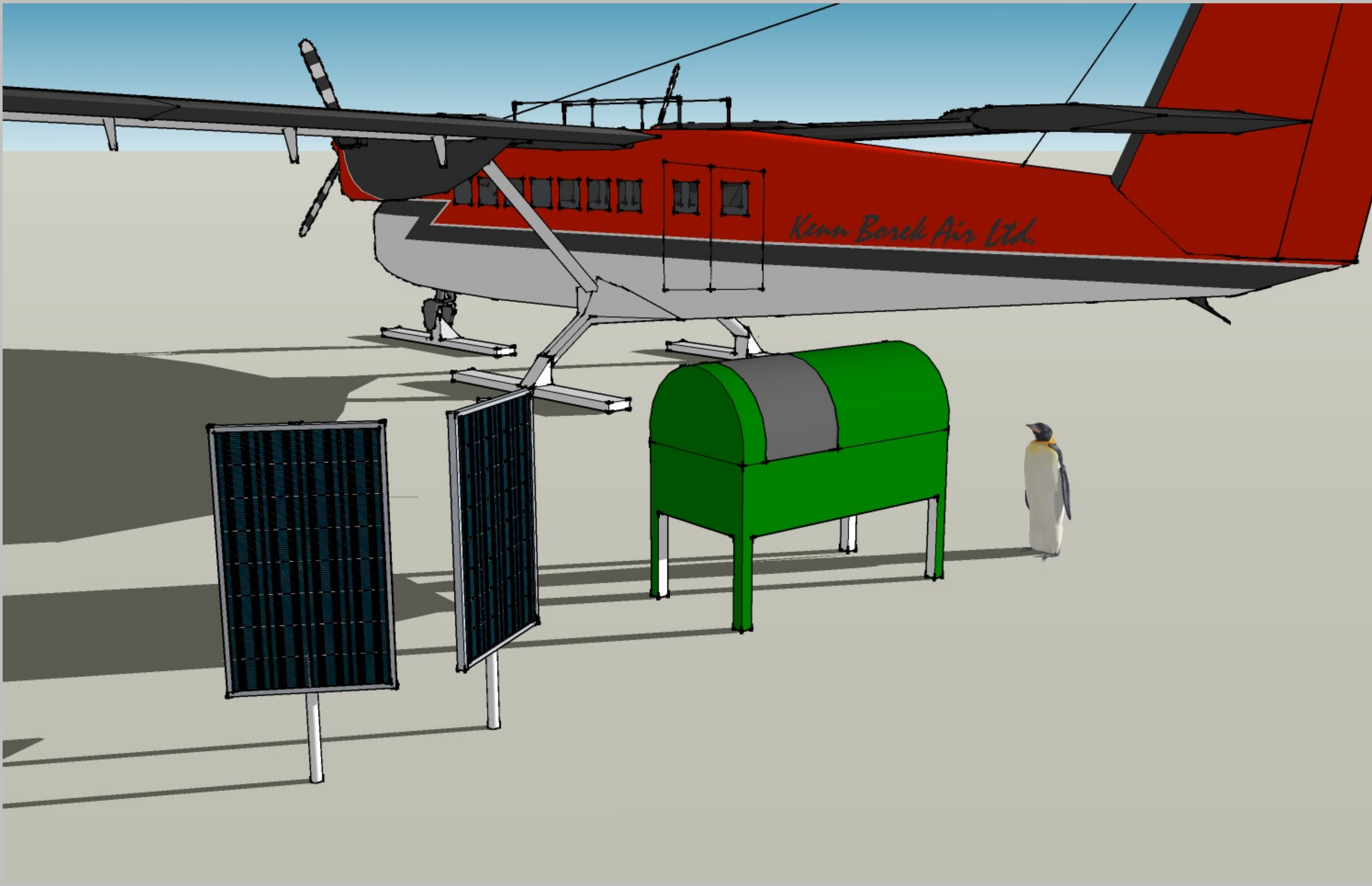


Requirements

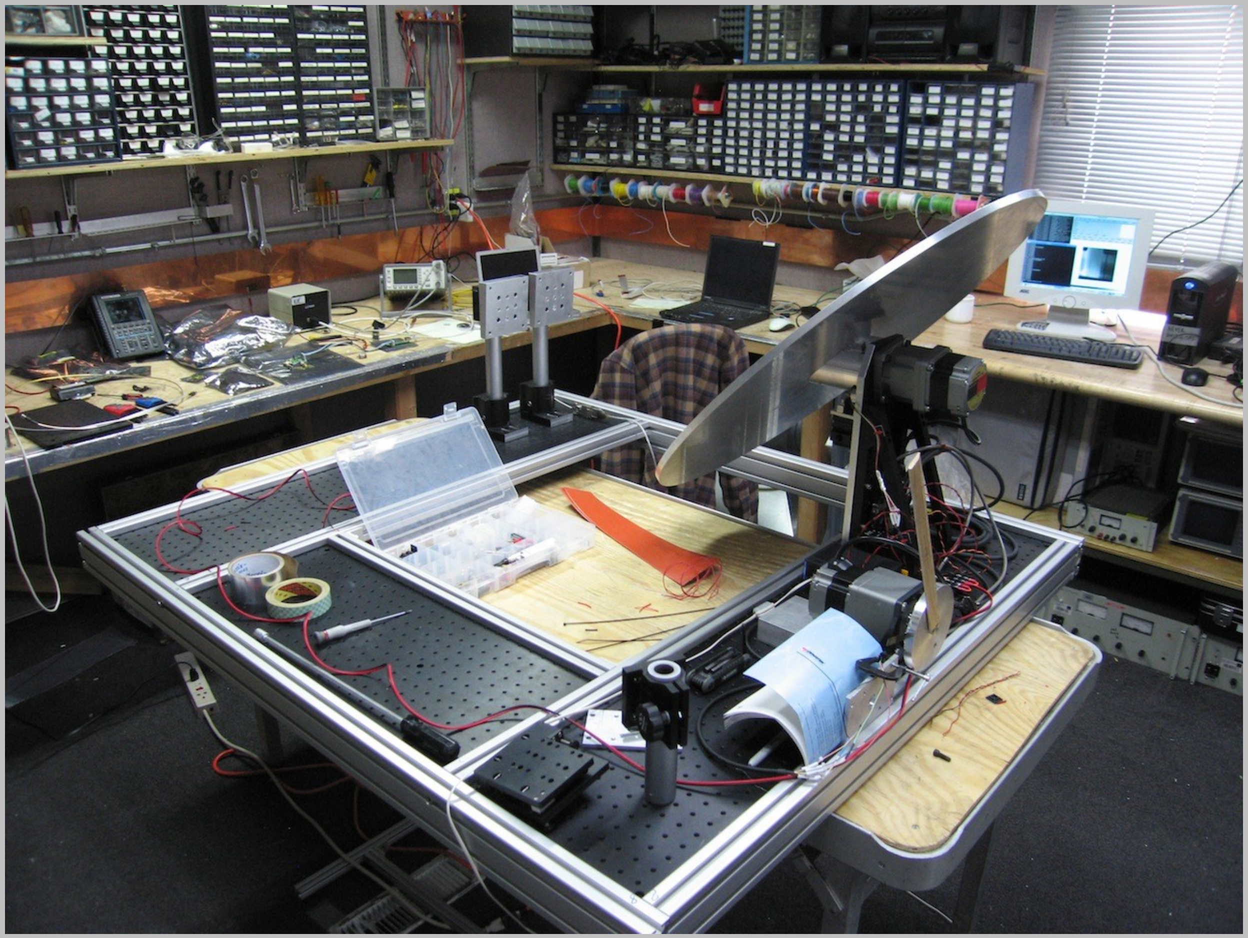
- 0.5-1 meter aperture telescope with at least one moving axis
- Site: **Ridge A**, 150 km inland from the Chinese station at Dome A. Latitude 82 South, elevation 4050m, mean winds ~2 m/s, minimum temperatures -80C
- Year-round operations; July – October is most precious
- Heterodyne receivers & spectrometers operating at an RF frequency starting at 800 GHz... to 2 THz
  - preferably cryogenic
  - even more preferably cooled at 4K. Stop laughing.
- DC power requirements
  - detectors at ambient: 50W
  - detectors at 80K: 130W
  - detectors at 4K: uhmmmm, don't ask
- A fully sampled map of the Galactic Plane is ~1GB per line

So... what are we going to do?

- Build two such HEAT telescopes to be field-swapped annually
- Rapid-prototype the first telescope and test at South Pole Station over 2011
- Starting in January 2012, deploy the 2nd HEAT telescope via Twin Otter from South Pole to Ridge A using a light-weighted UNSW PLATO unit for all observatory support, just as is currently being done at Dome A and Dome F.
- Don't miss Michael Ashley's talk about the PLATO units tomorrow morning at 9:30 AM
- Unit will operate for a year at a time between “servicing mission”.
- Project is scheduled through 2014.

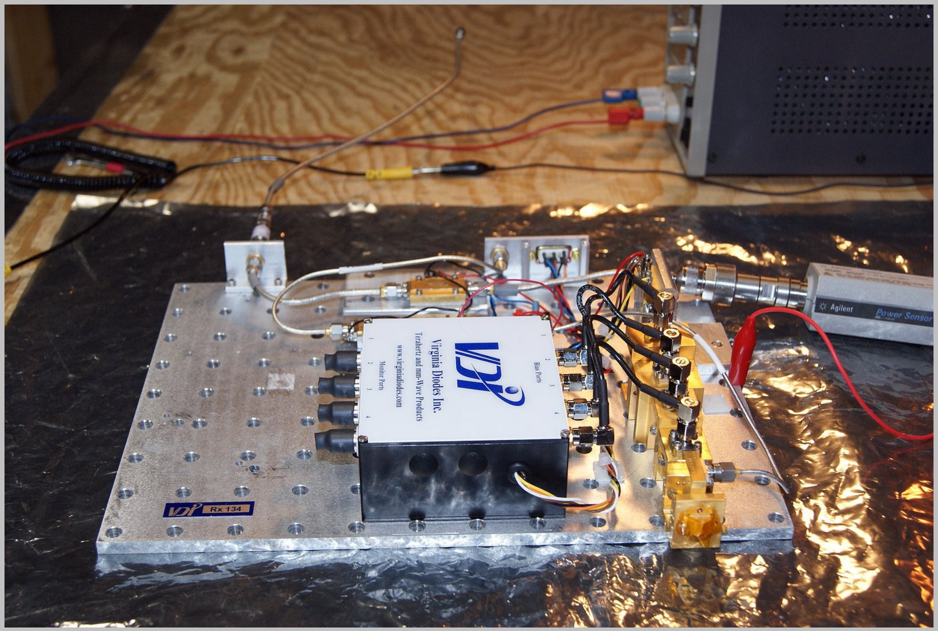

Kenn Borek Air Ltd.

Optomechanics



- All aluminum optics, direct machined.
- Overspec the field of view to make alignment easy. Optical configuration is temperature-compensated.
- Overspec the torque (3.5” stepper with 100:0 harmonic gearhead
- Most motors can be effective cryo motors if you dissect them and replace the lubricants

Cryogenics



Components of a 810 GHz heterodyne receiver

Suitable Stirling engines exist for 80K operation

Example: Sunpower Cryotel MT
(30-80W input power for 2-6 watts of capacity at 80K) P.S. Check Ebay.

For 4K operation, commercial G-M coolers require 1300W input power for 0.1W of capacity at 4.2K

Efforts to develop a helium compressor suitable for polar operations are underway.

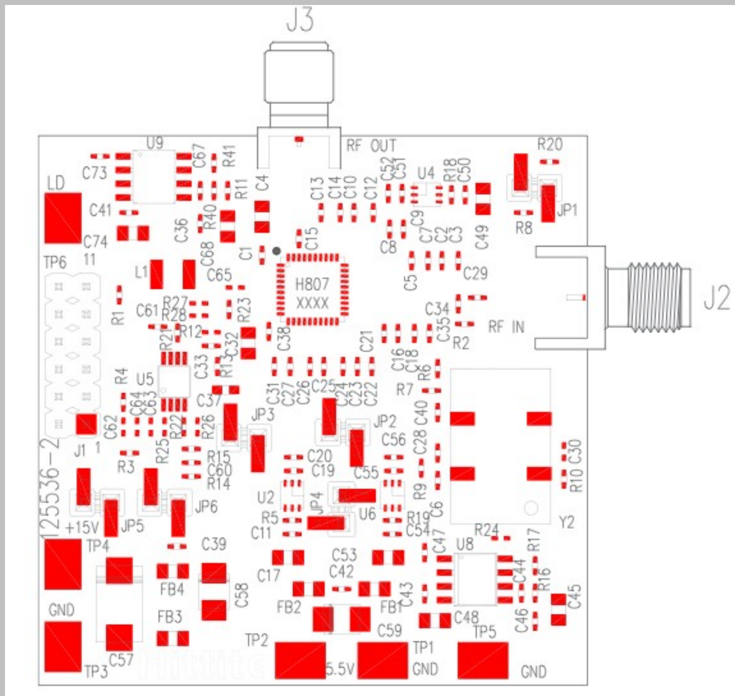
Electronics

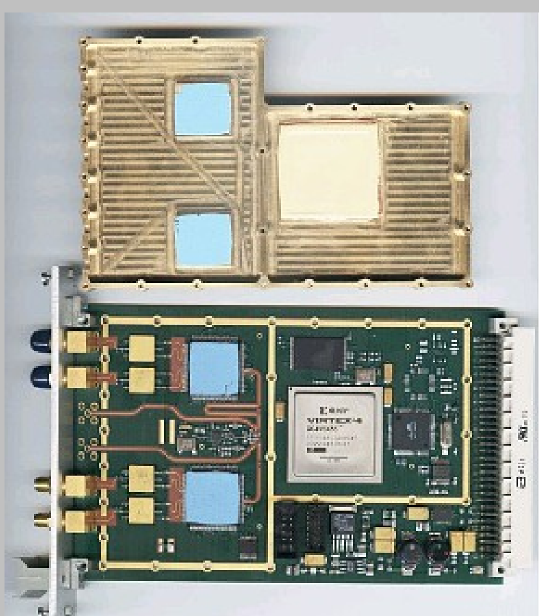
requirements: modular, robust, very simple interfaces, star-ground to 24VDC return

example: DC/DC converters and capacitors

- Excellent success on the plateau and on LDB with TI's PTN series converters
- PI filter on input & output, extra bypass caps on output
- Capacitors are a necessary evil. AVX tantalums and Kemet ceramics have best ESR and rated ripple current. At cold temps, avoid most electrolytics like the plague...

Rules for custom and commercial boards





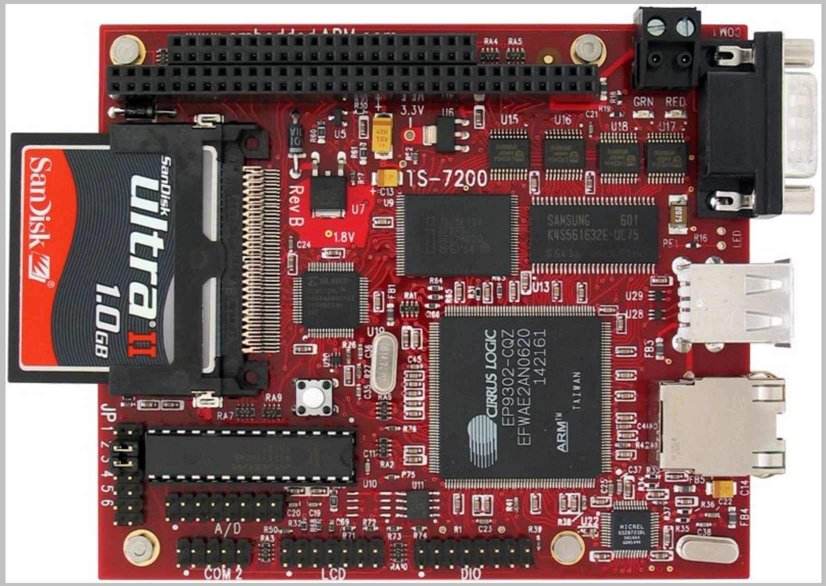
- ICs should be rated to -40C
- Passives should have low thermal coefficients
- Wire and connectors are even more important than you think...
- All boards star-ground to a single return
- Use all waste heat!
- But what happens when you must use an existing commercial board?
  - Reverse engineering: remove or replace offending parts
  - Spot-heat the things you can't change
  - environment-test EVERYTHING

thermal-vac chamber on the cheap

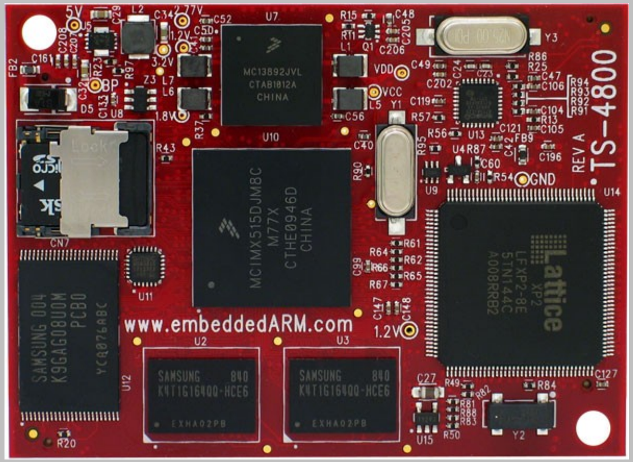
- No really. Costco pressure cooker with minor tweaks to the seal and two solder/welded fittings (1 for power+control, and 1 for vacuum pump)
- Insert into a styrofoam vessel with dry ice for cold testing
- BTW: You can hack your household fridge to reach temps of -30 to -40C
- But nothing beats a good laboratory -80C fridge...

Control Computers

- Embedded systems are robust and simple solutions.



TS-7200: 2 watt, 200 MHz ARM board: CF & USB storage, ethernet, serial, ADC, digital I/O, PC/104 bus (Linux and BSD)



TS-SOCKET daughterboards
2 watt, 800 MHz Coretex-A8 ARM board with FPU: u-SD & USB storage, programmable FPGA, ethernet, serial, digital IO, PC/104 bus (Linux and BSD)

Cold-booting a TS-7200 computer at a temperature of -81°C!

(In the thermal chamber at UNSW, Sydney)

Foundations: NetBSD

- NetBSD (like Linux) is an excellent choice for embedded operations
  - Less chaotic development leads to more stable interfaces that are tested better
  - Built from a single, unified source tree, better hardware abstractions, rock-solid
  - Less “superfluous redesign”, recognition that developer time is finite
  - Cross-compilation is part of the system (build.sh)
  - Kernel debugging and dynamic tracing has always been possible
  - Very open BSD license

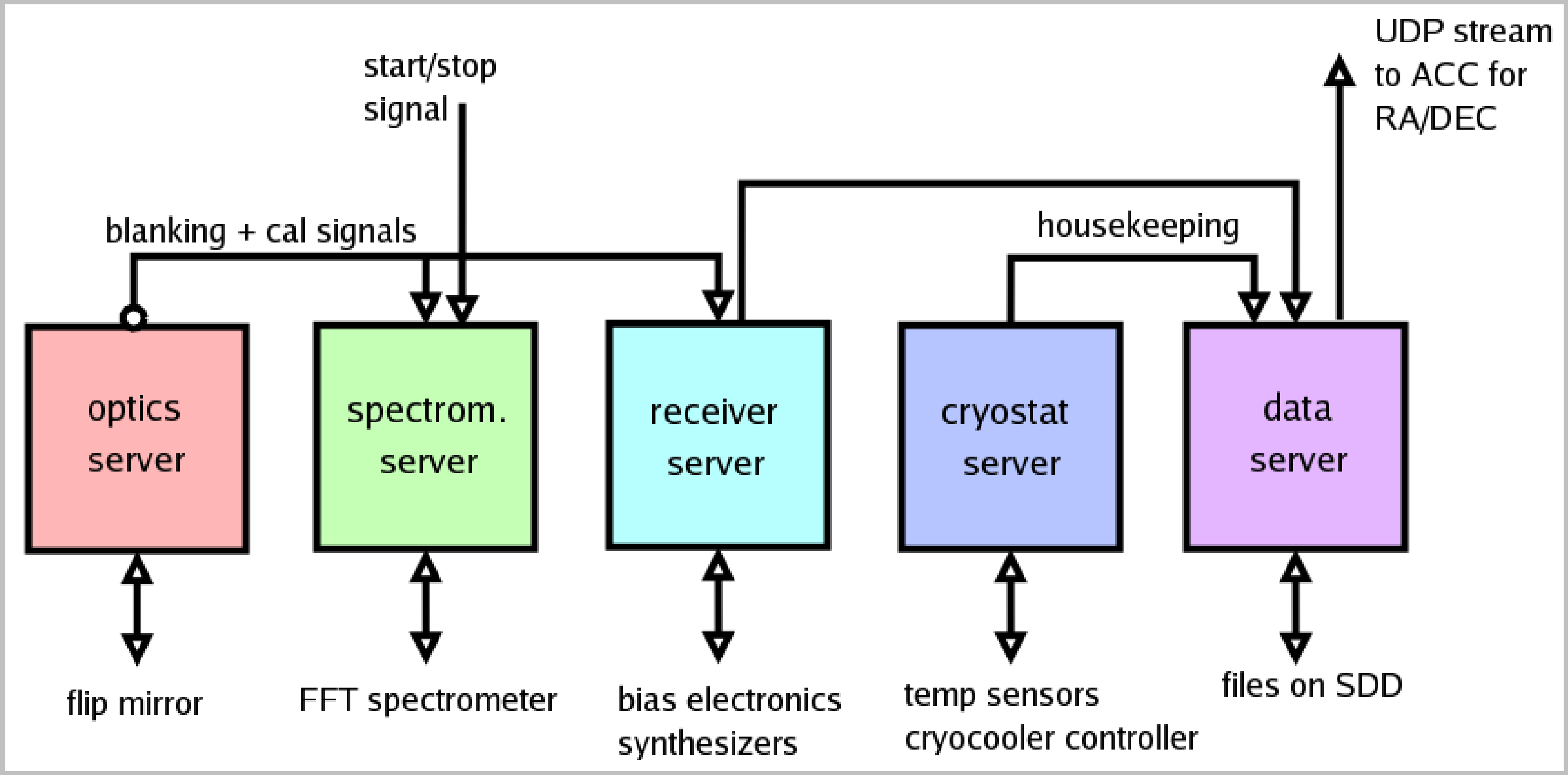
Instrument & Data Mgmt. System

- Items to be controlled:
  - Receiver subsystems (mixer bias, LO, synthesizer, etc...). (RS232 and I^2C, SPI interfaces)
  - IF processor (USB interface)
  - Spectrometer and Data system (UDP over ethernet)
- Interplay of these items
  - data system needs TCS header (timestamp, RA/DEC, etc.)
  - need synchronization with telescope for mapping
  - data system may need to amend observing sequence... or ask for attention!

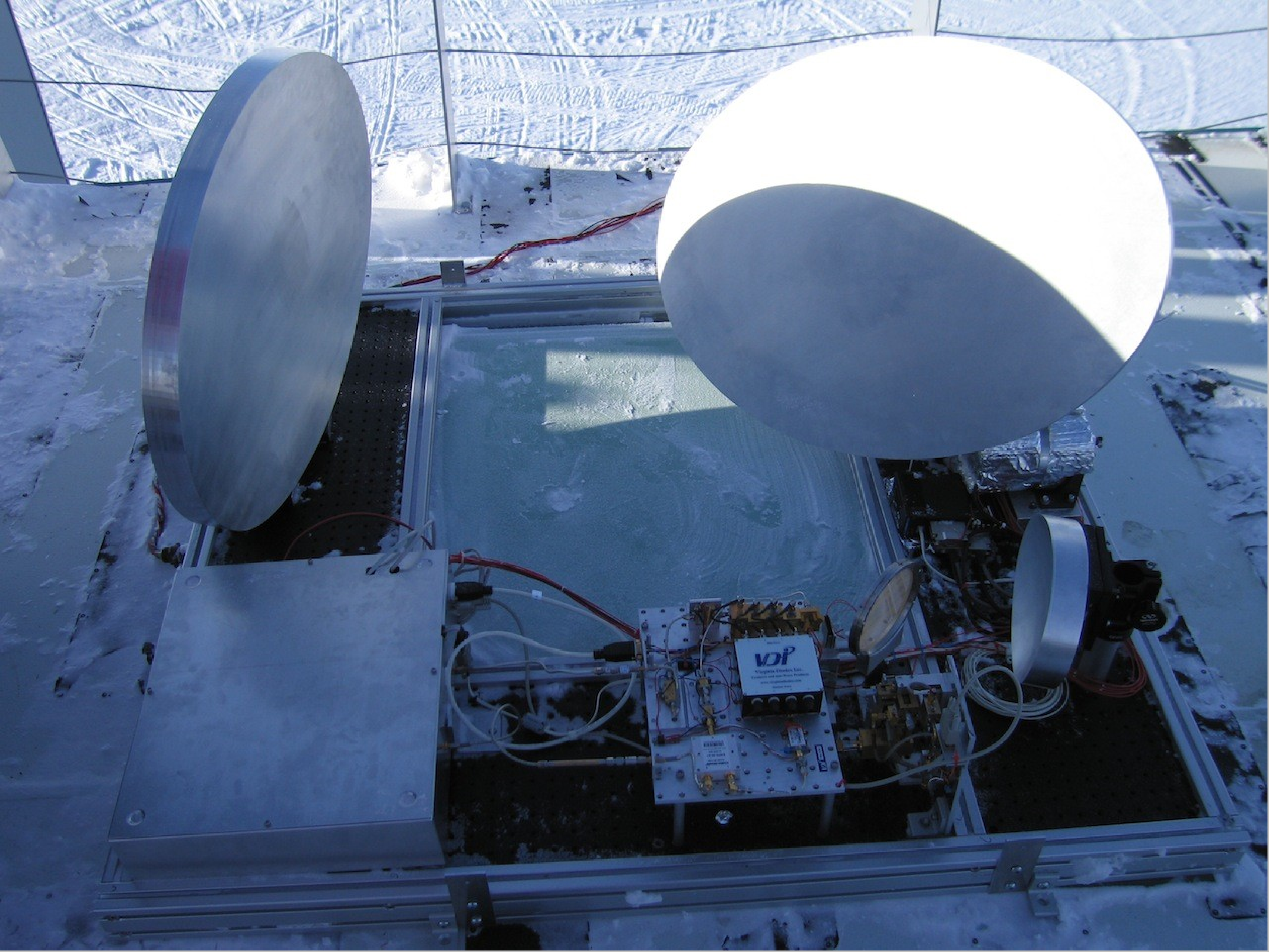
Control Software

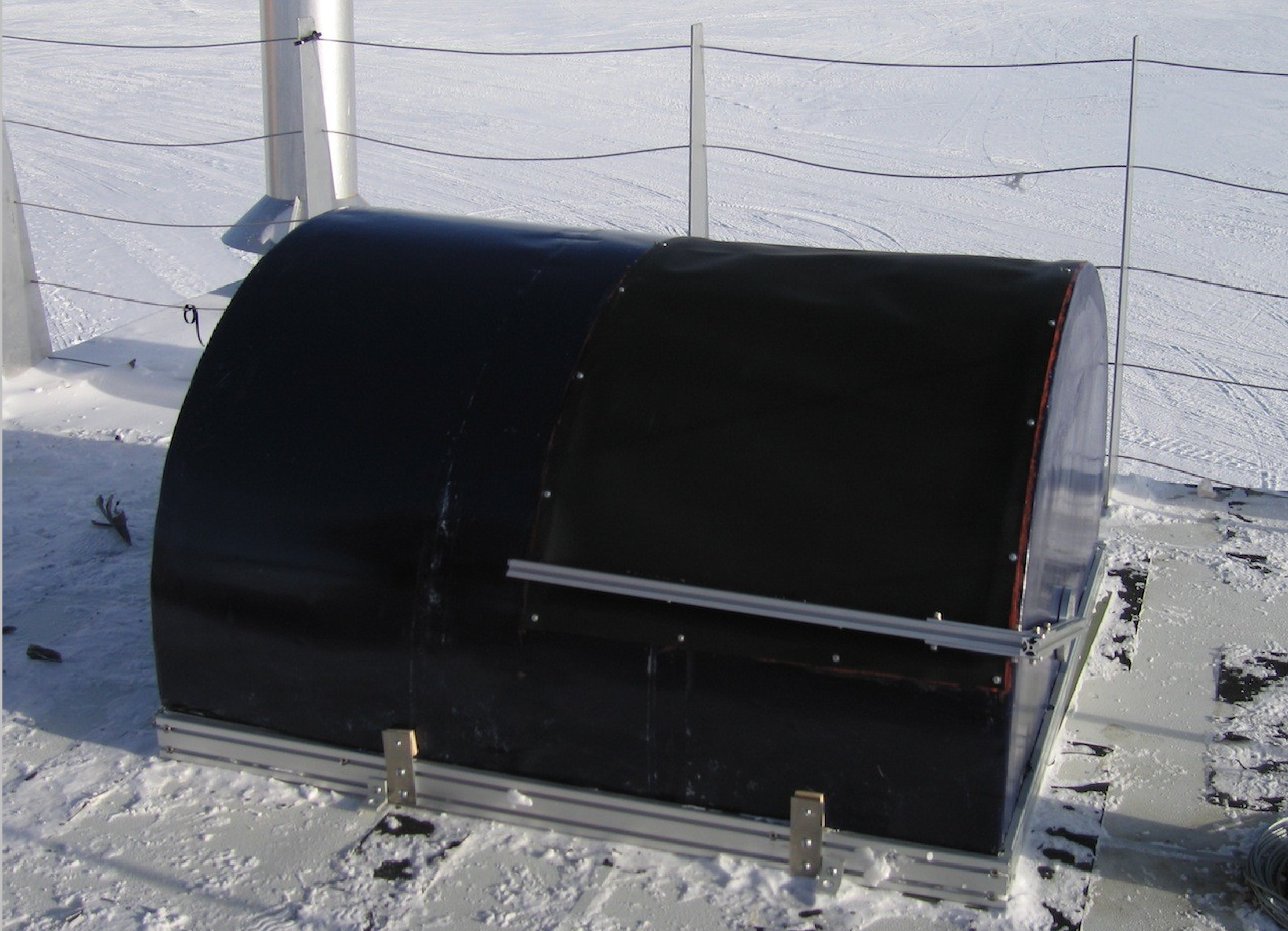
- Each hardware component has a separate TCP/IP socket server associated with it. The server listens on that socket's port for ASCII text commands to perform.
- Watchdog timers allow software and hardware to be automatically reset should they become unresponsive.
- Low-level server code is written in C; client code for observing programs is written in object-based higher level languages; e.g. perl and python.
- Instrument and control interfaces will be performed through a standalone GUI or a web browser.

Simplified view of socket servers



- A Perl or Python script acts as the “glue” to tie it all together
- Software watchdogs restart servers as needed


Virginia Diodes Inc.



Status

- All subsystems are working perfectly. We are operating at 450 GHz and 810 GHz currently.
- We are measuring the atmospheric opacity and beginning to begin our spectroscopic survey of the Milky Way.   We should have mapped the Moon in the past few days to solidify the pointing.
- The snow wiper appears to be working OK, but the membrane-like window is hard to articulate against. “Wipe quickly”.
- Today's temperature is -61C, and the atmospheric transmission at 810 GHz is 25%.
- Production of the 2nd telescope and receiver systems is beginning in April.