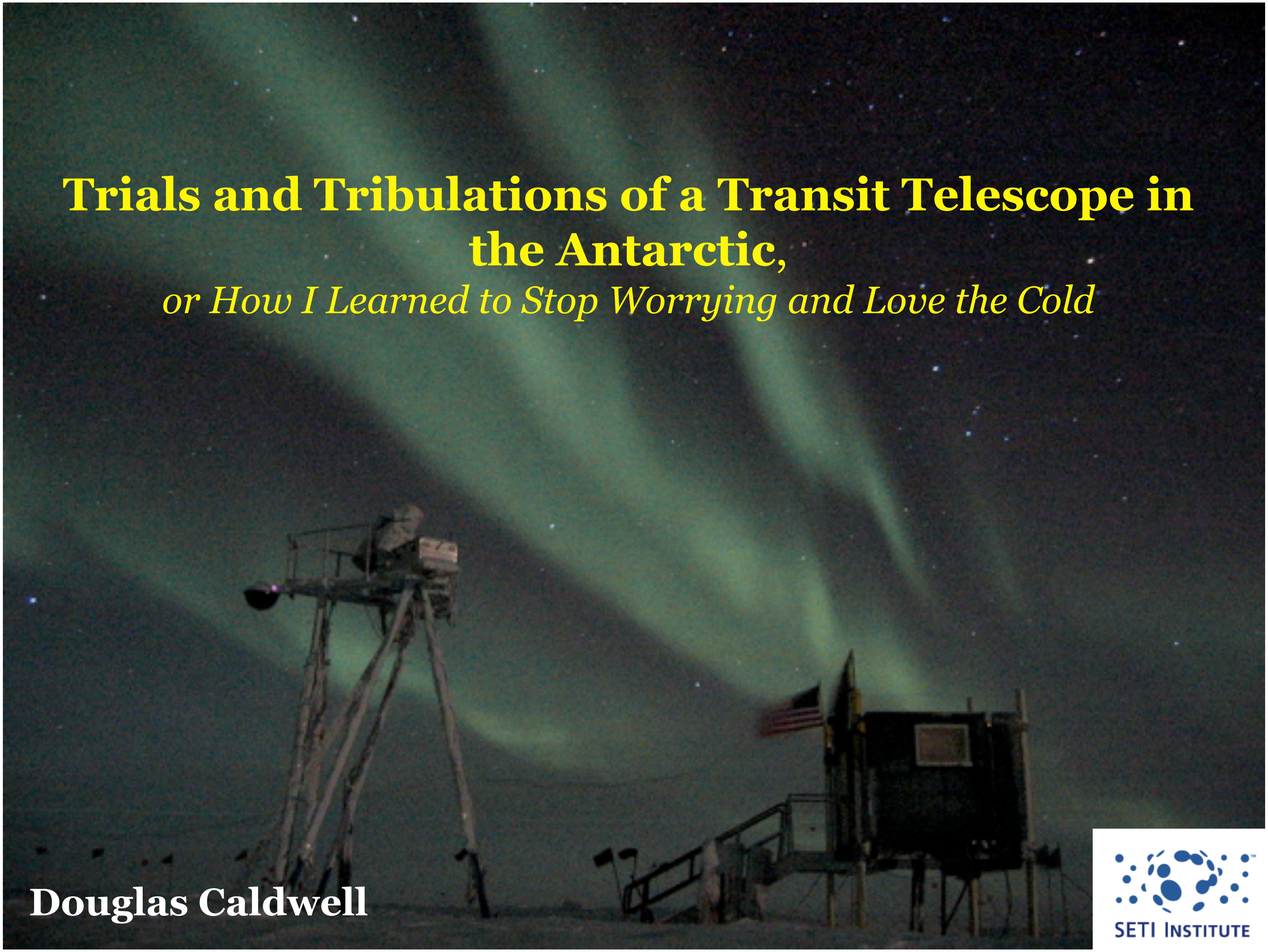


Trials and Tribulations of a Transit Telescope in the Antarctic,

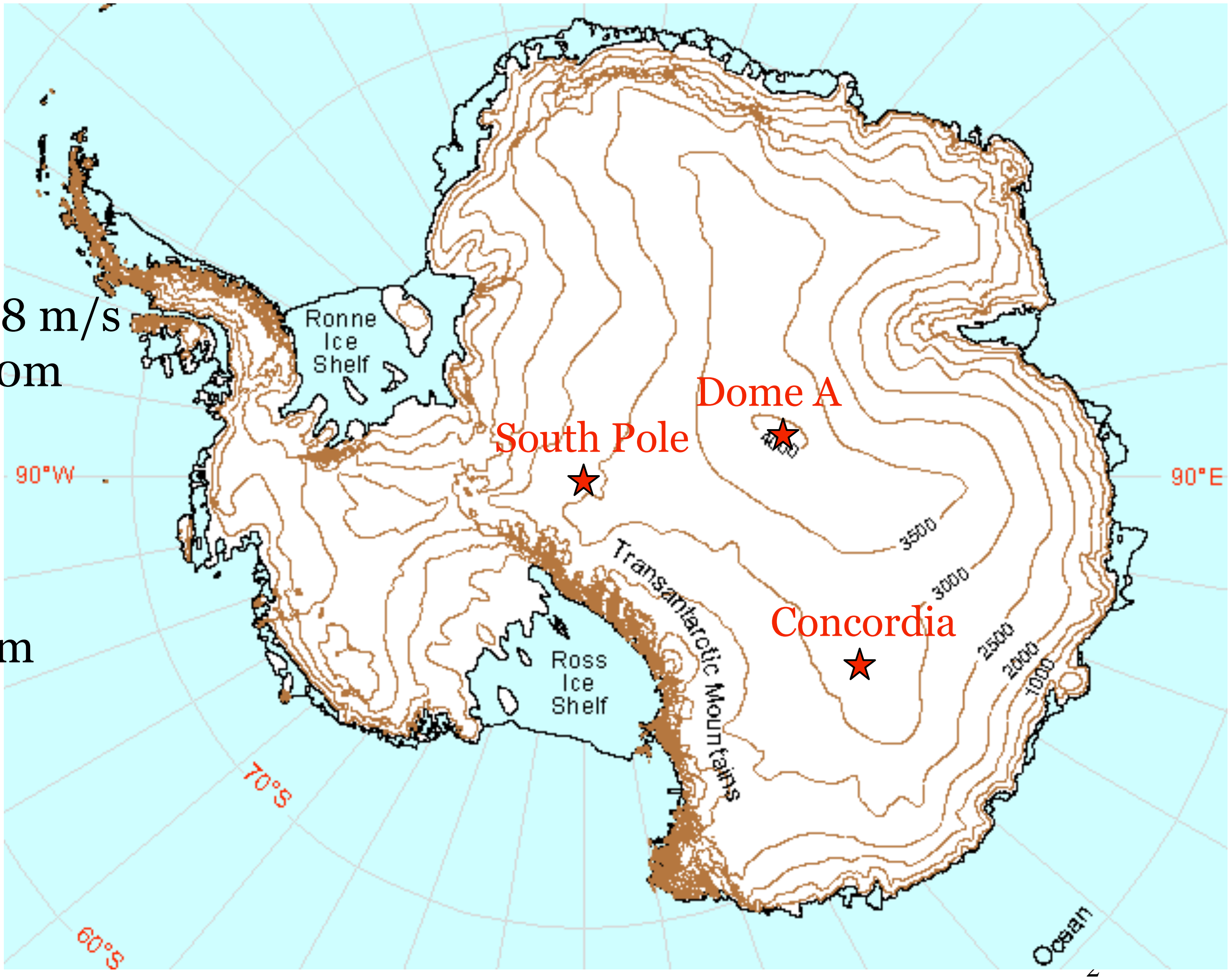
or How I Learned to Stop Worrying and Love the Cold

Douglas Caldwell

SETI INSTITUTE

Antarctic Astronomy Sites

- **South Pole -**
  - elev: 2800 m
  - winter temp. -58 C
  - mean wind speed: 3-8 m/s
  - boundary layer: ~200m
- **Concordia (Dome C) -**
  - elev: 3230 m
  - winter temp. -60 C
  - mean wind: 2.8 m/s
  - boundary layer: ~20m
- **Dome A -**
  - elev: 4080 m
  - winter temp. -60 C
  - mean wind: ~2 m/s
  - boundary layer: ?



Advantages of Antarctica

- Long winter night offers better multi-transit phase coverage (especially at South Pole)
  - Quickly detect hot-Jupiter systems
  - Better chance to find longer period planets (<20 days)
- Stars move at constant airmass (SP only)
  - Flux changes ~10-20% due to extinction at temperate sites
  - Time-scale of extinction changes ~ transit duration
- Low sky background (except for aurora)
- Low scintillation noise (especially Dome C, Dome A?)
- Great seeing on high plateau…. sort of
- Ideal for Adaptive Optics (low altitude boundary layer)
- Galactic Plane high in the sky (rich star fields)

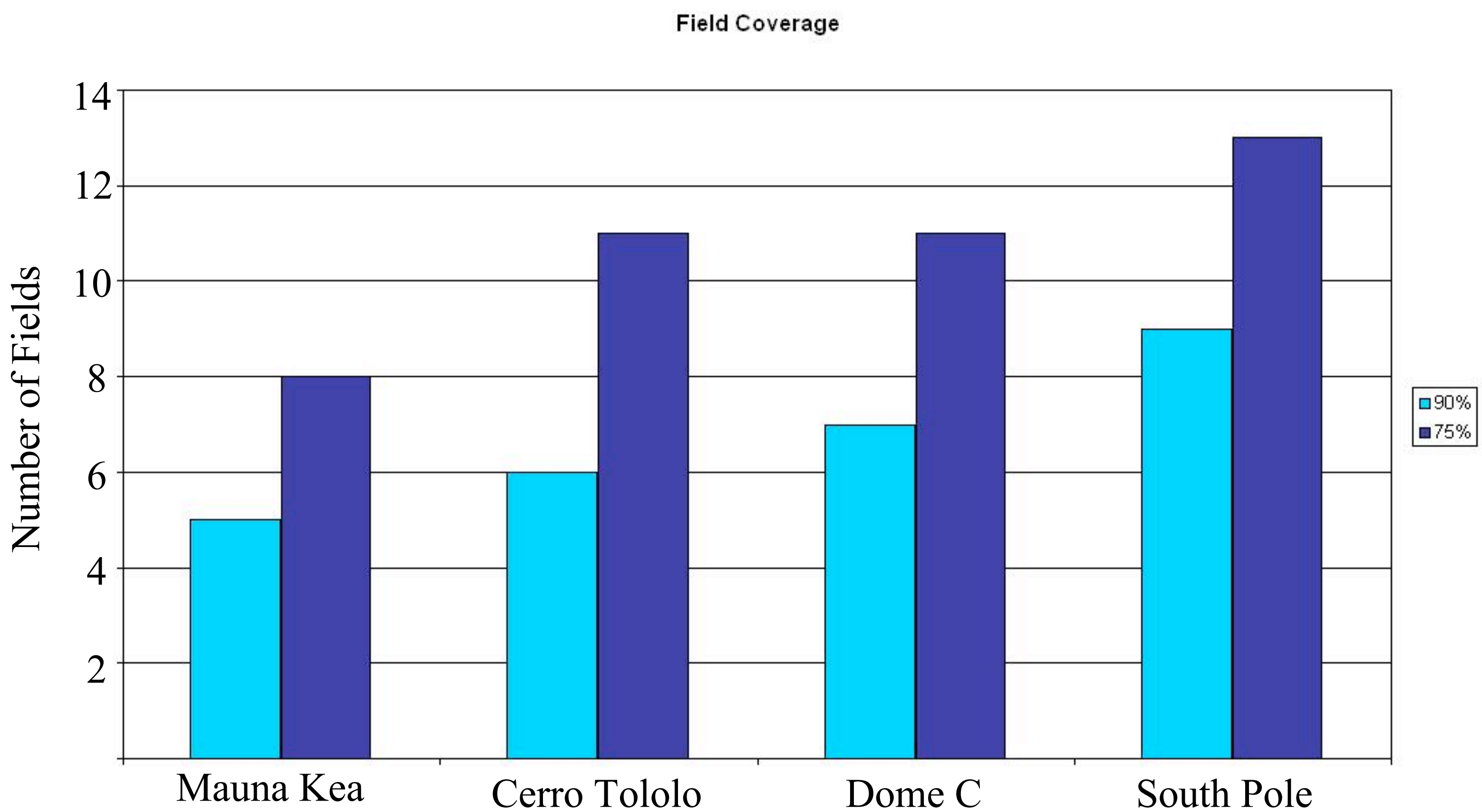
Useful Observing Hours

	Dark hours	Photometric nights	Usable hours
Mauna Kea	3390	45%[a]	1526
Cerro Tololo	3312	60%[b]	1987
South Pole	1959	45%[d]	882
Dome C	1792	96%[c]	1720

Usable dark hours at each of the four sites. "Dark" is defined as when the sun is more than 18° below the horizon. [a]Ortolani (2003), [b]Osmer & Wood (1984), [c]Aristidi *et al*. (2006), [d]Travouillon *et al*. (2003)

Table from Christiansen, et al. 2006, 26th IAU, Special Session 7: *Astronomy in Antarctica*

Transit Phase Coverage



The number of fields able to be covered at each site within a year. The smaller number at each site is for 90% phase coverage in the period range 1-4 days. The larger number is for 75% phase coverage. Figure from Christiansen, et al. 2006, 26th IAU, Special Session 7: *Astronomy in Antarctica*

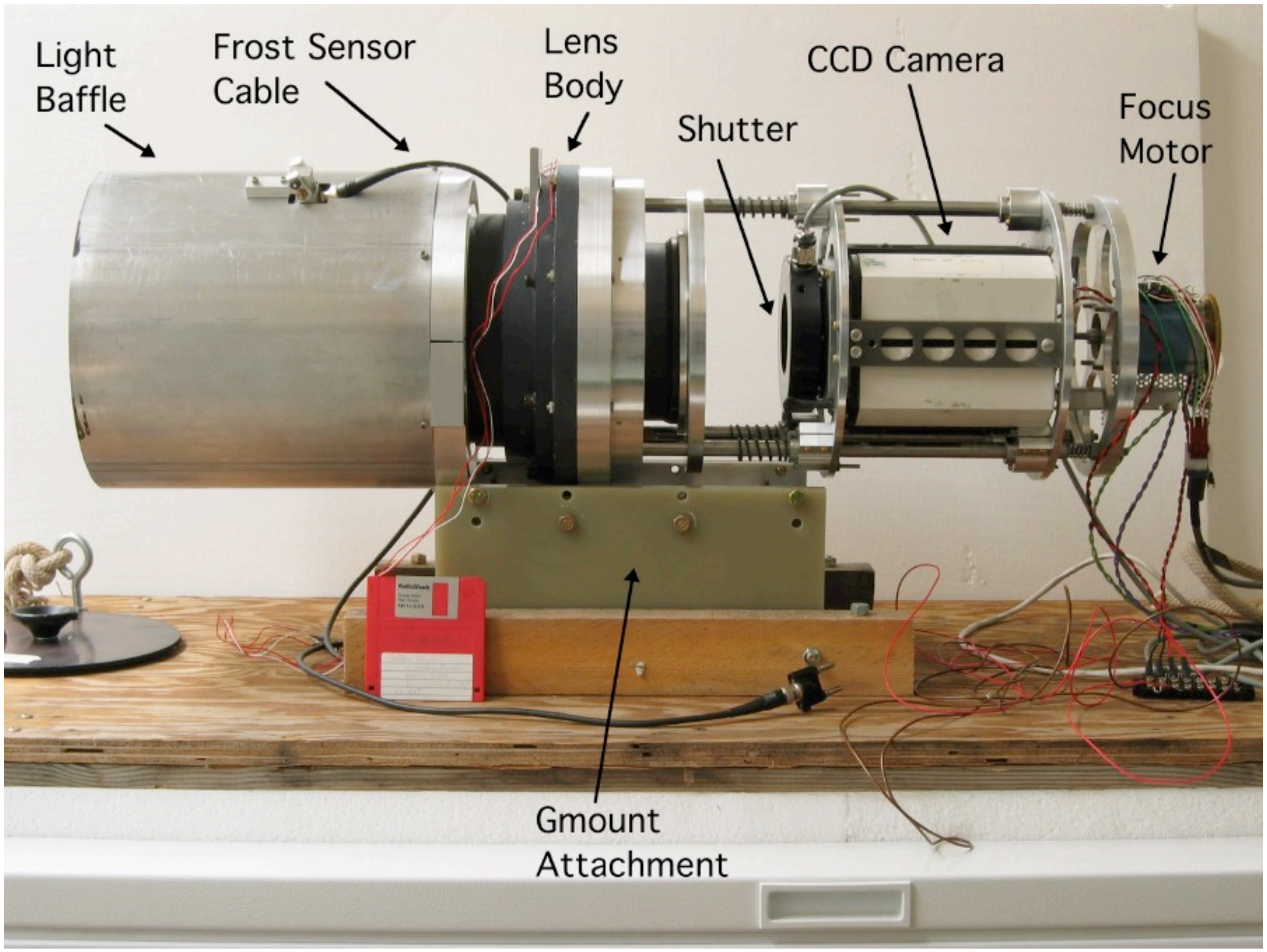
Vulcan-South Project

- Deploy a small photometer to the South Pole to search for transiting hot-Jovians
- Design based on the existing NASA-Ames *Vulcan* photometer at Lick Observatory
  - Wide-field fast optical system
  - 4k x 4k CCD with 9μm pixels gives 7º x 7º FOV
- Collaboration with UNSW & ANU
  - Extensive Antarctic experience
  - GMOUNT developed by RSAA at ANU, successfully operating at the South Pole, is ideal for project
  - AASTO developed by UNSW & ANU demonstrating successful automated operations
- Team members: **Ames:** *Kevin Martin, Fred Witteborn, Bill Borucki;* **UNSW:** *Michael Ashley, Jessie Christiansen, Jess Dempsey, Colin Bonner;* **ANU:** *Mark Jarnyk;* **RIT:** *Zoran Ninkov;* **SETI Inst:** *Laurance Doyle, Gerry Harp, Jennifer Carton, Ruth Pearson*

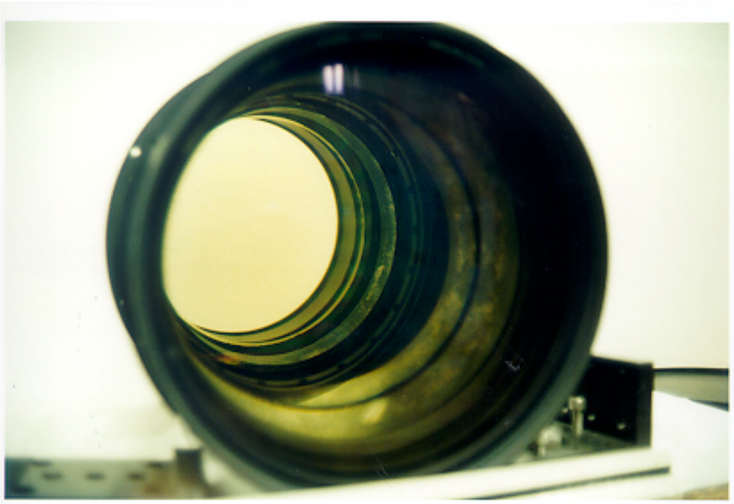
Vulcan South Project

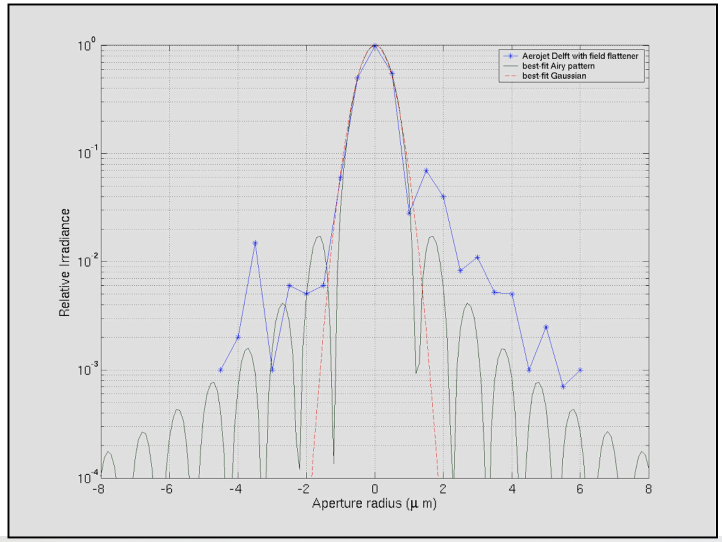
- NSF funding for project: Sept 2002 - 2005
- Photometer deployed January 2004
- Winter 2004:
  - GMount problems delay start of operations; azimuth-only work-around implemented June 8
  - Diode failure on clock board in CCD camera on 10 June proves irreparable in winter.
- Camera shipped back for repair and re-installed Jan/Feb 2005
- Winter 2005:
  - GMount operated in Az-Only mode
  - CCD controller failed in March, repaired in May by winterover tech
  - Analog to digital converter problem leaves bits 6 & 10 stuck on (64 & 1024 DN) in all images
  - Observed field in Carina from 22 June - 20 Aug (13,000 images)

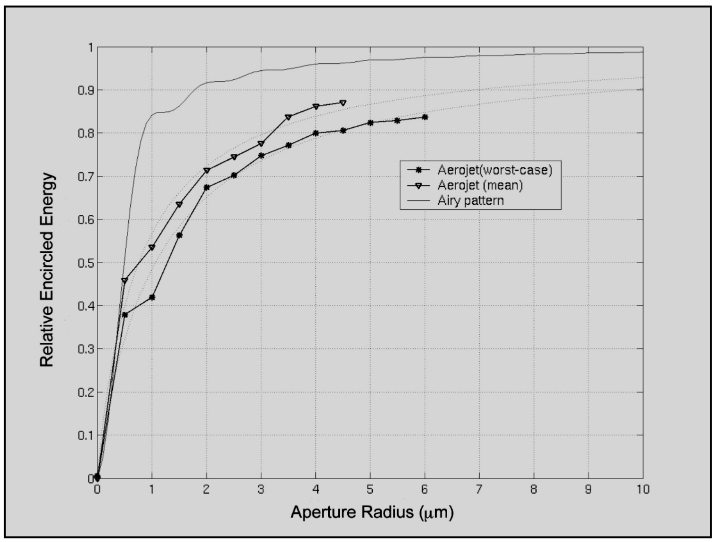
Photometer Construction

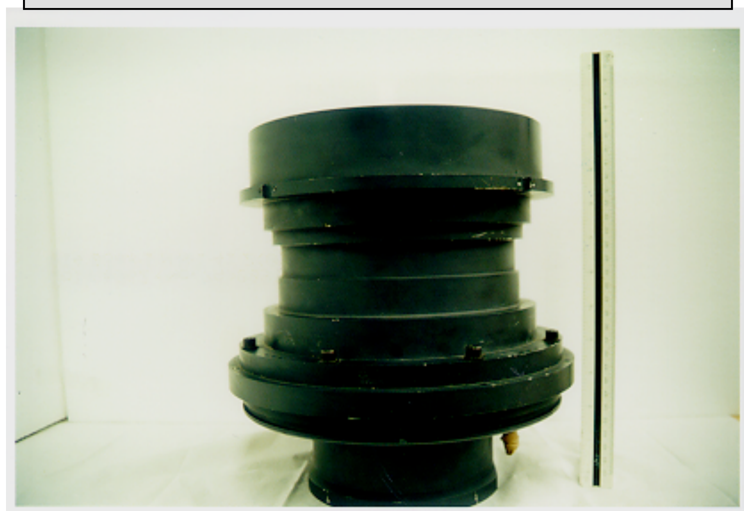


Optics: 12” FL, f/1.5 lens



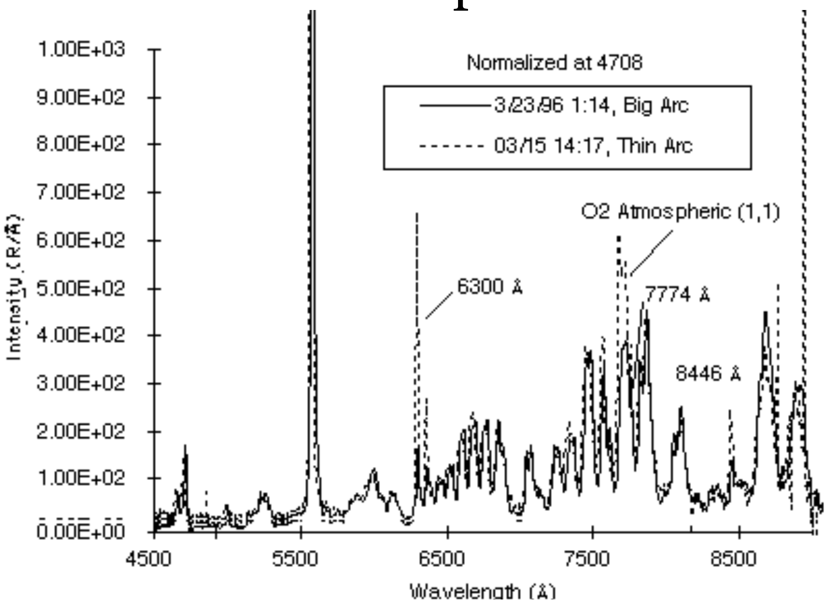






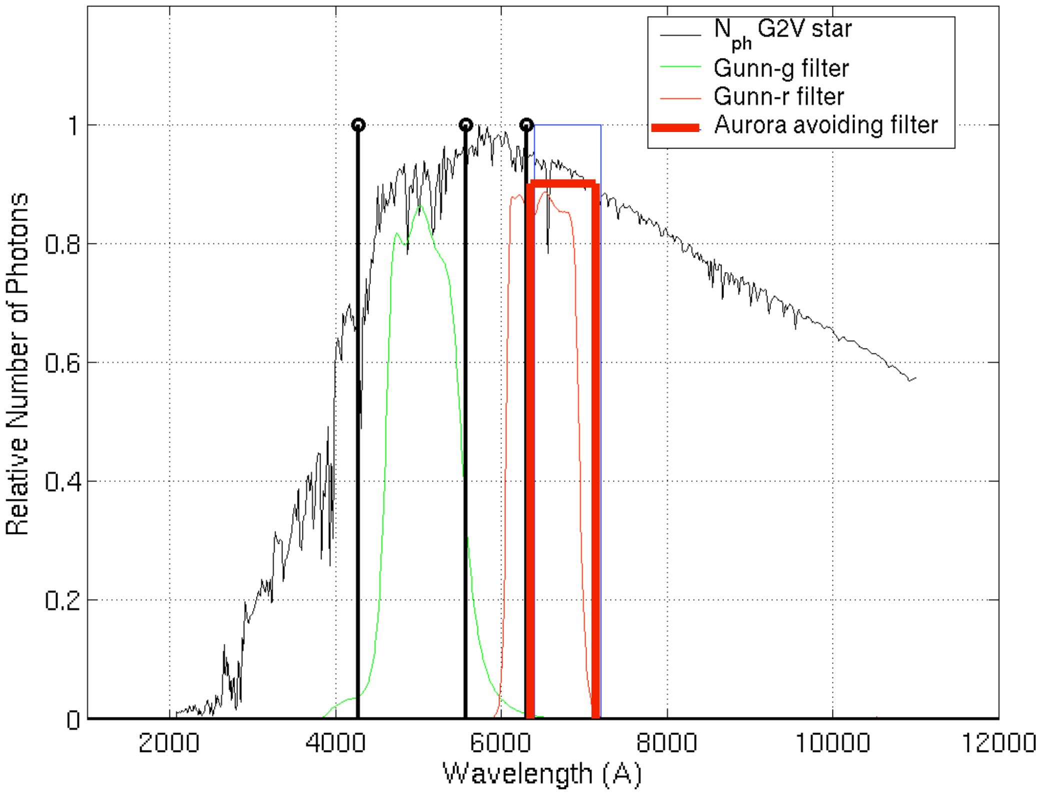
Optics: Aurora filter

Aurora spectrum

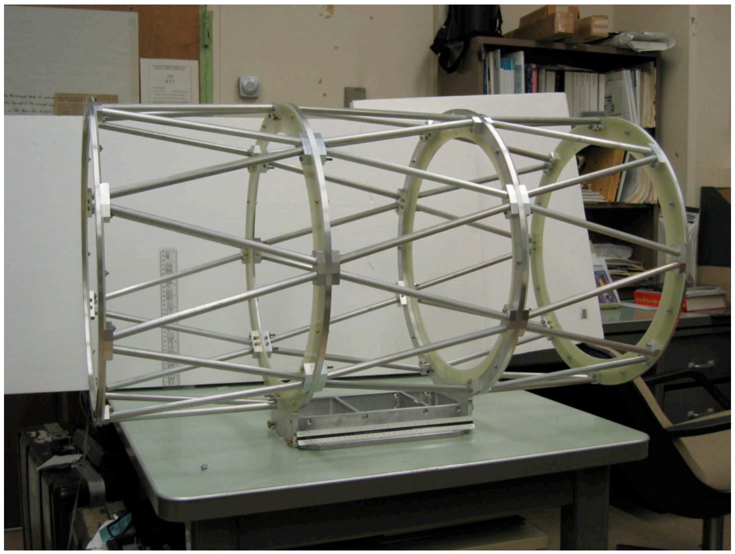


Sometimes the aurora is Red

Vulcan-South filter: λ_o=675 nm ± 30 nm



Photometer Construction

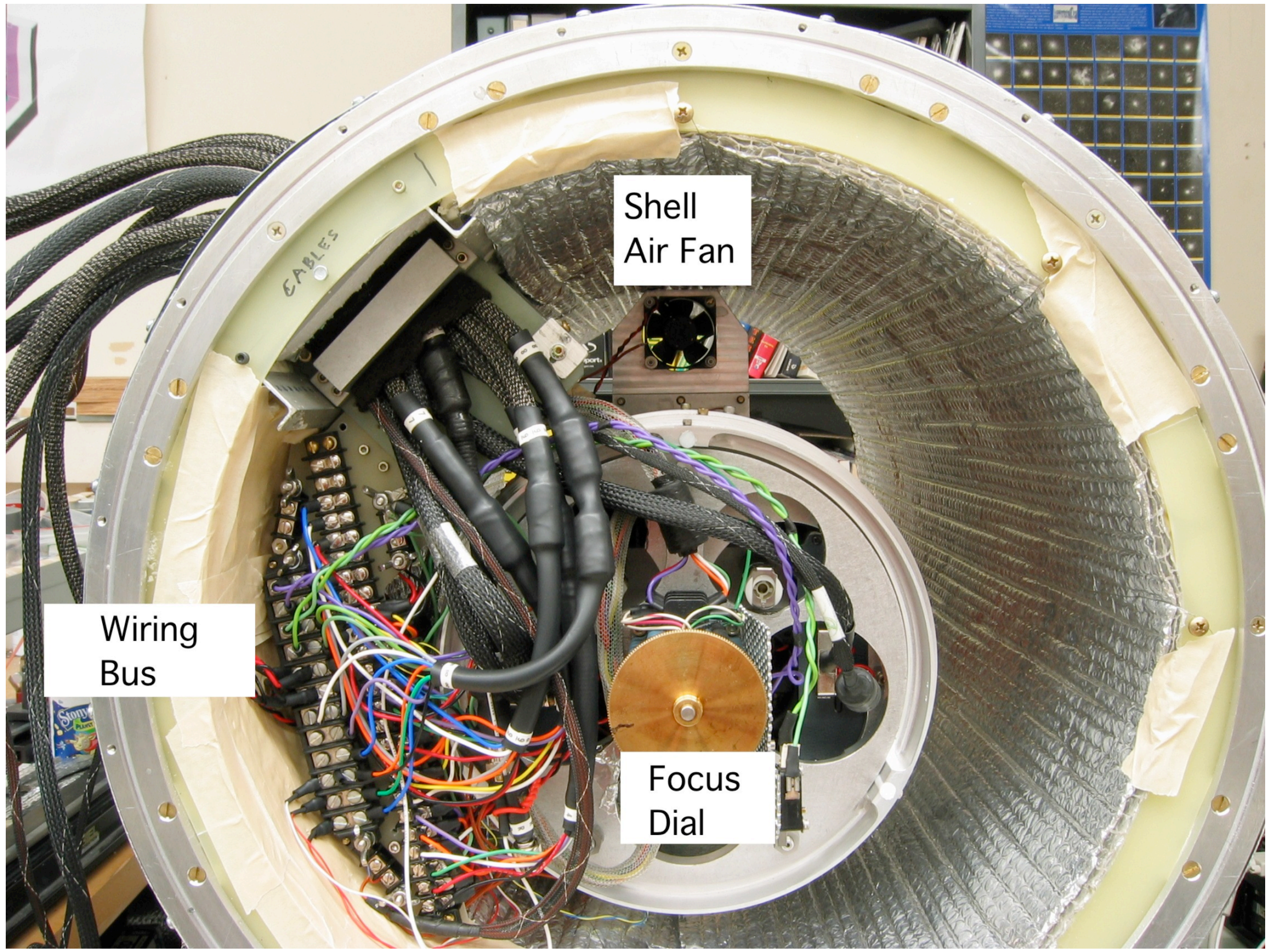


Optical system is enclosed in re-enforced shell for temperature control and protection from weather

Photometer looks through a heated 10” optical window

Photometer Construction

Back end of photometer with camera, focus motor, and thermal monitoring/ control cables

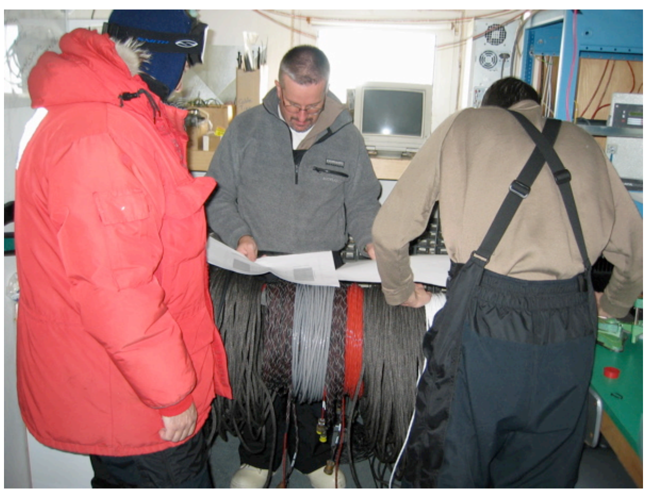


Photometer Deployment

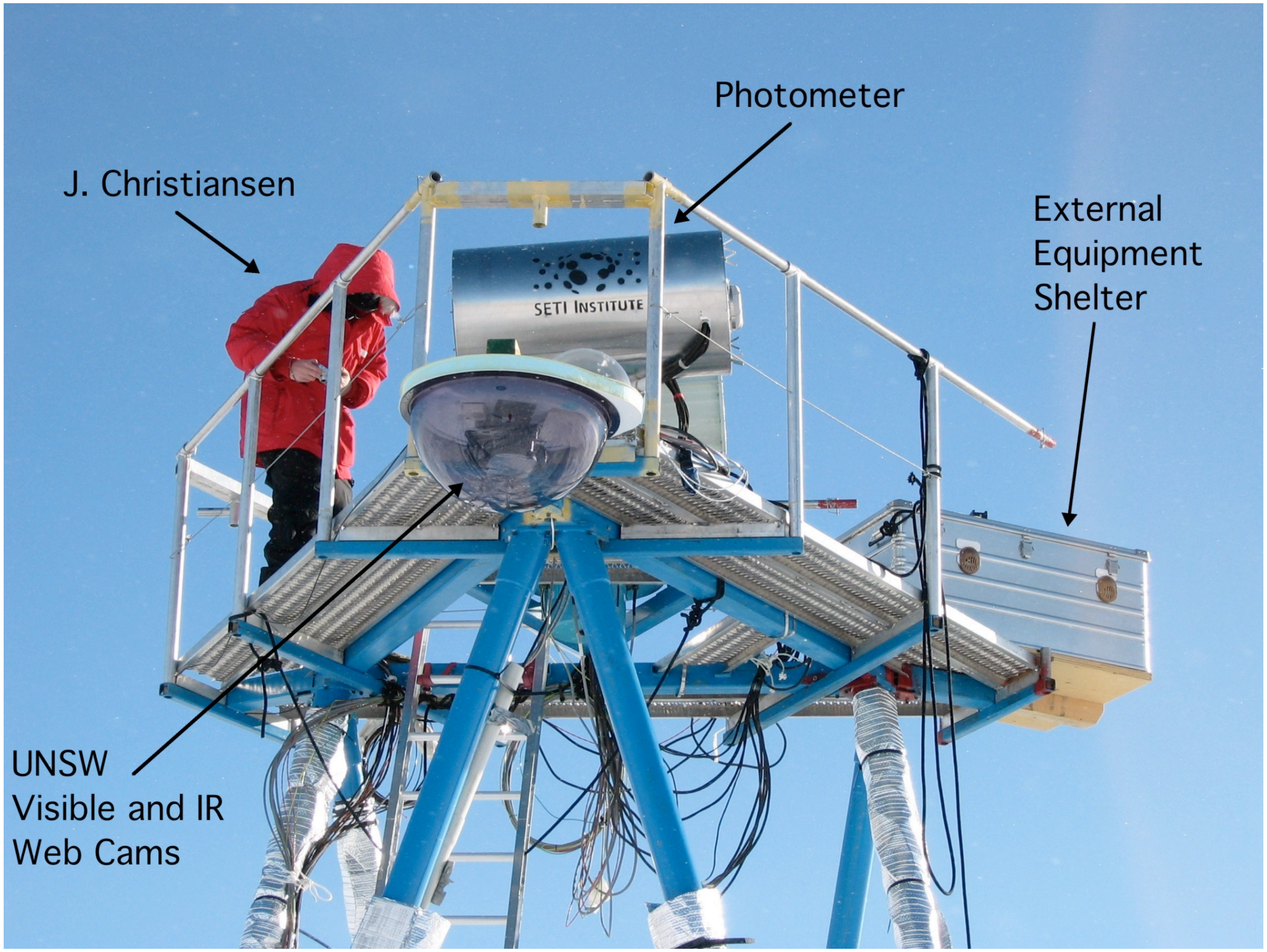
Telescopes installed on GMount

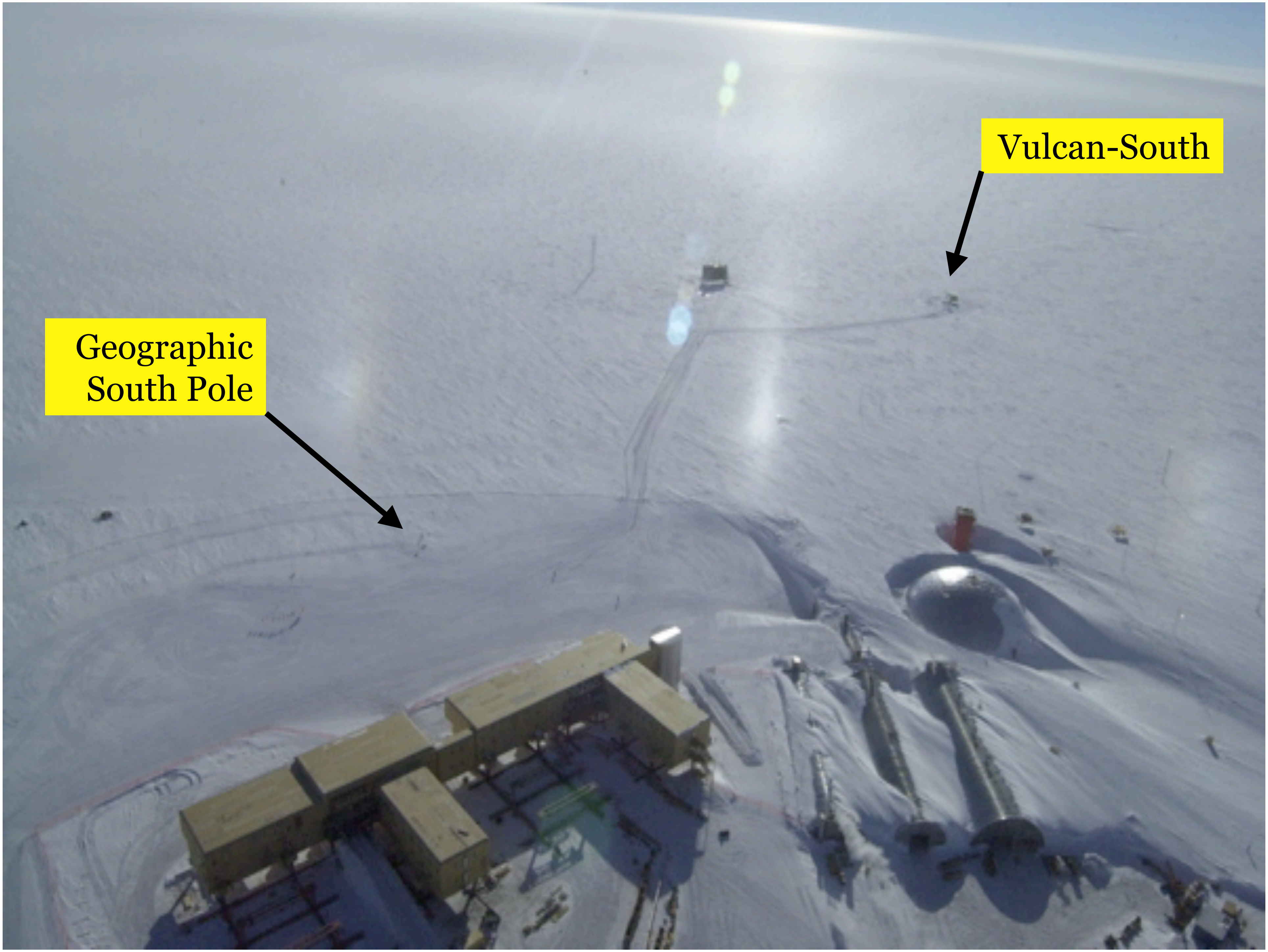
AASTO building, tower, and GMount in place 0.5 km from the South Pole

Organizing cables in the AASTO

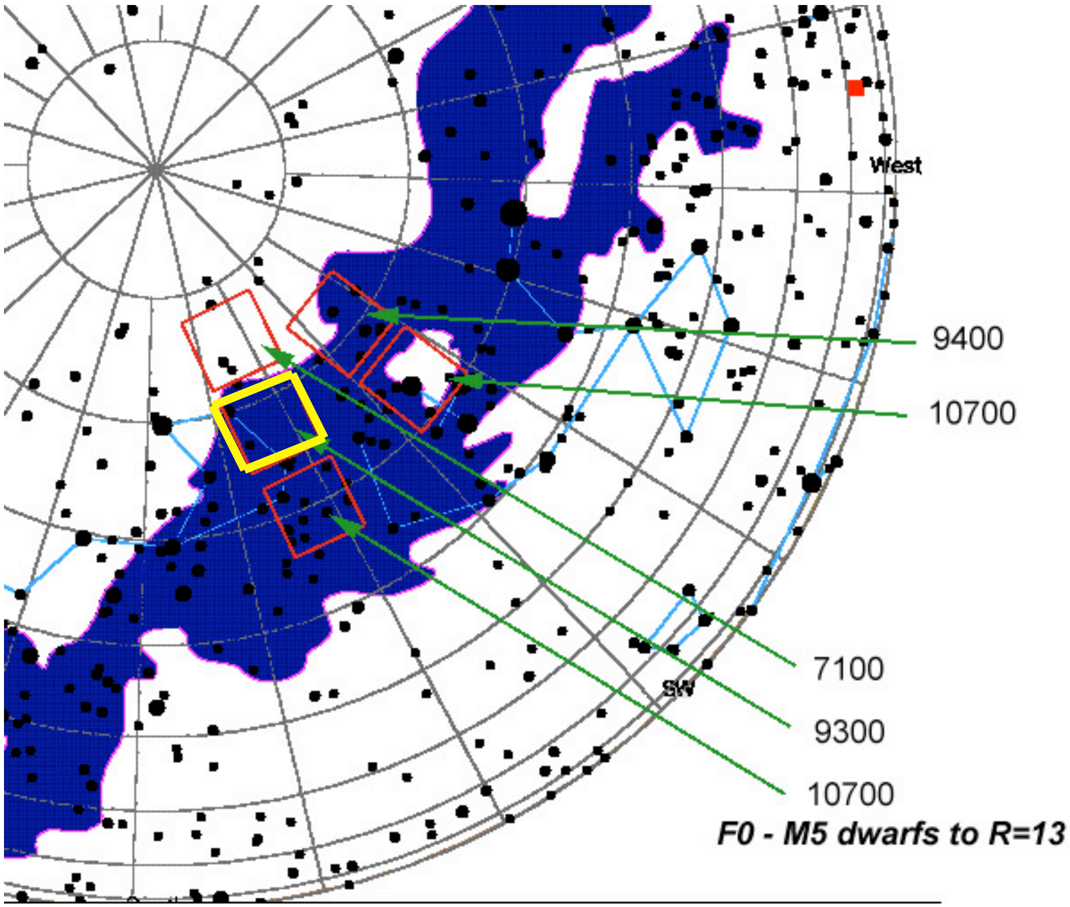


On-site at the South Pole




Vulcan-South
Geographic South Pole

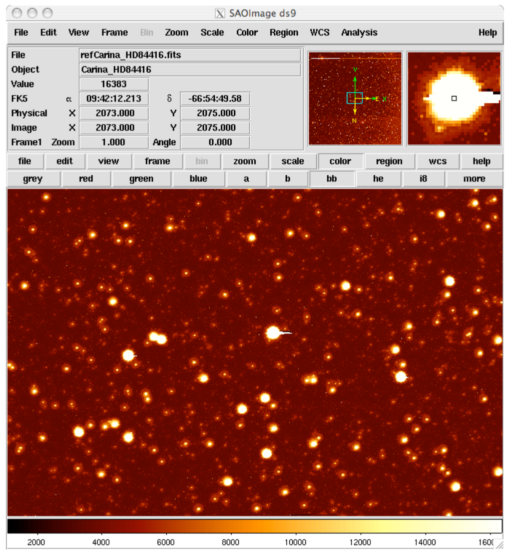
South Pole Target Fields

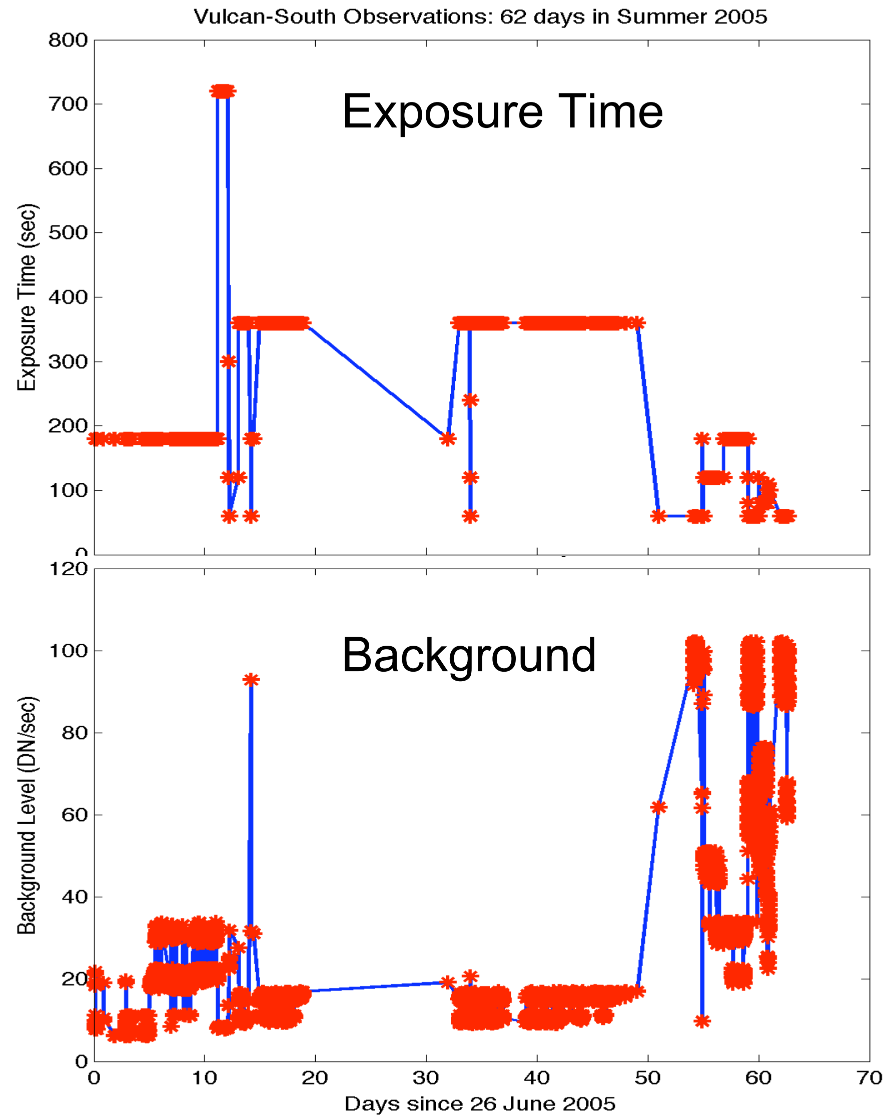


- Numbers of transit target stars in 49 deg^2 based on Besançon Observatory Galactic models.
- The fraction of useful targets (F0-M5 dwarfs) to total stars is ~10%, 30%, 50% at Galactic latitudes b = 0, -10, -20 deg respectively.
- *The numbers of dwarfs drop by more than a factor of three at a limit of R=12*

Vulcan South Observations

Star field centered on HD844116: $9^h42^m12^s$,-66º54’50”





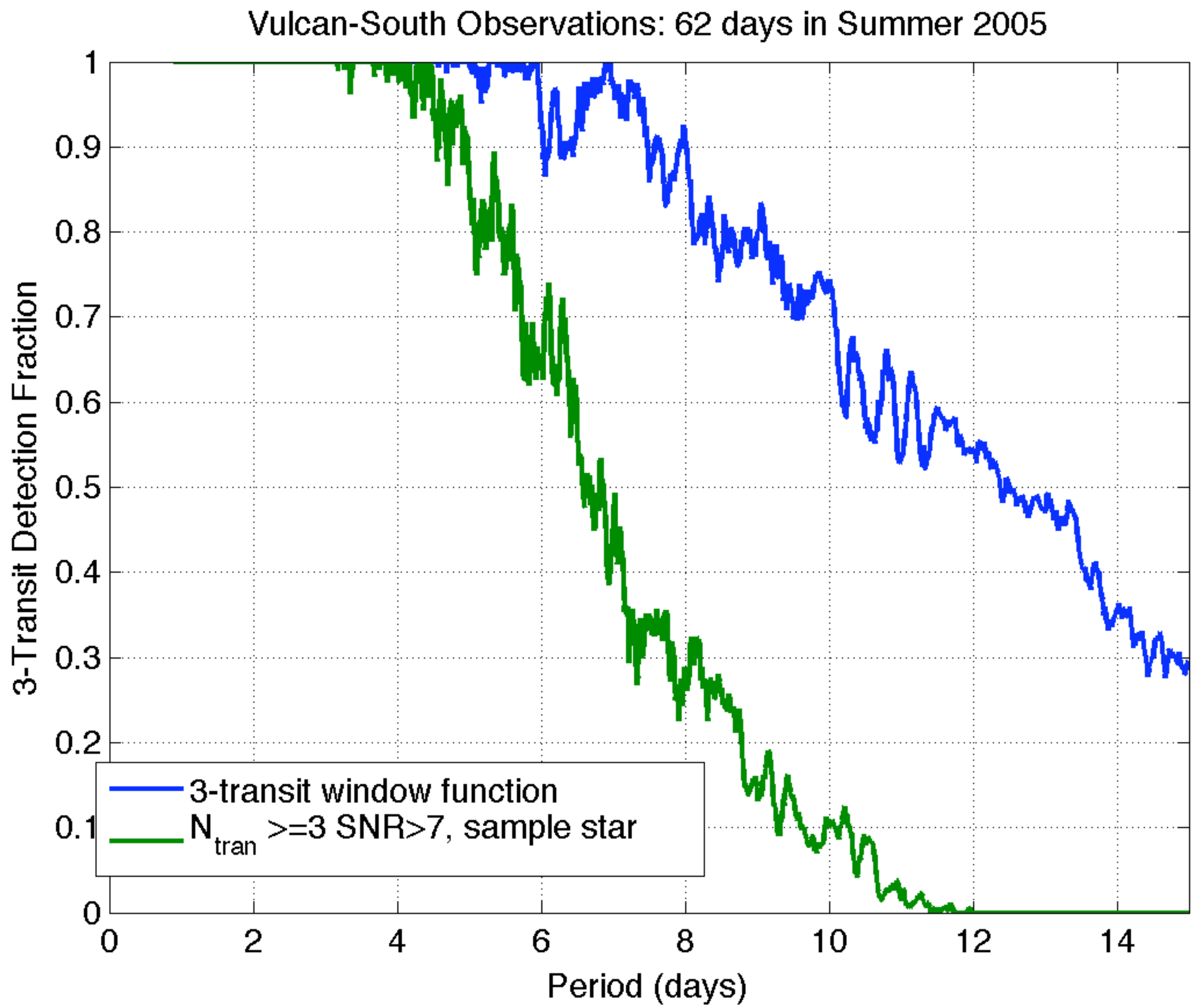
• 8,100 useable images from 26 June to 27 Aug 2005: Shutter open for a total time of 20 days out of 62 (32%)

• Exposures between 1 and 12 minutes, adjusted to account for sky background level

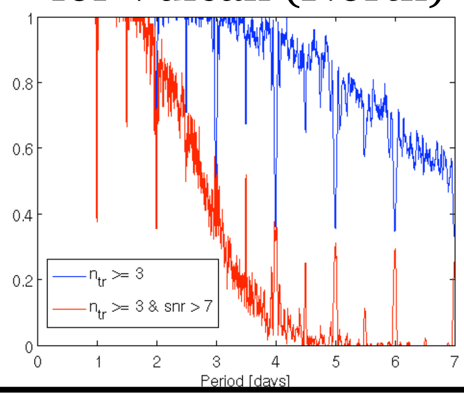
Phase Coverage including S/N limit

South Pole 3-transit window function (blue) and detection fraction using 7σ detection requirement (green), *courtesy N. Batalha*.

The green curve is for a specific target star.



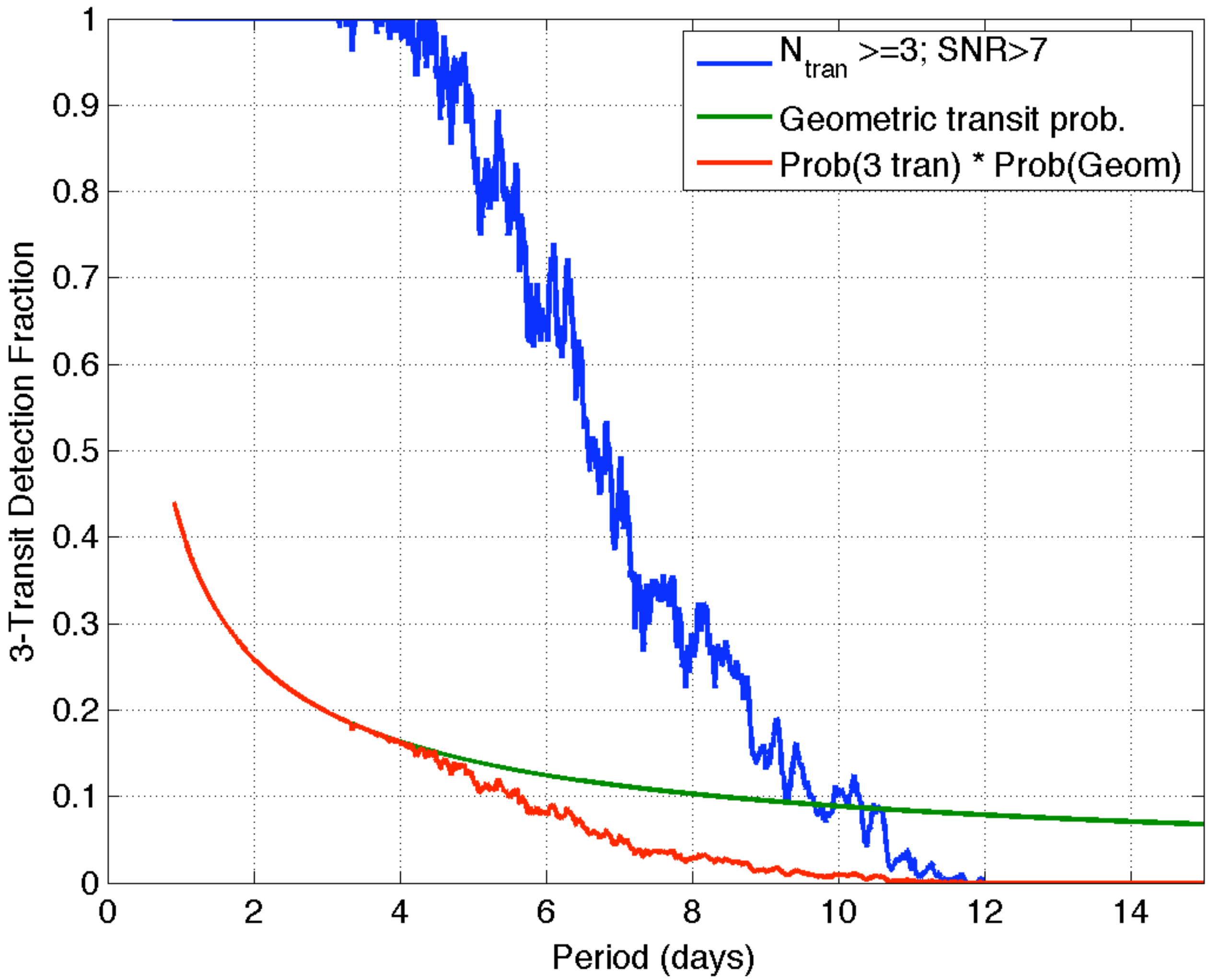
Comparable figure for Vulcan (North)



Geometric Transit Probability

Multiplying by geometric transit probability gives probability of detecting a transiting planet at each period, if it exists there.

All curves are for a single star.

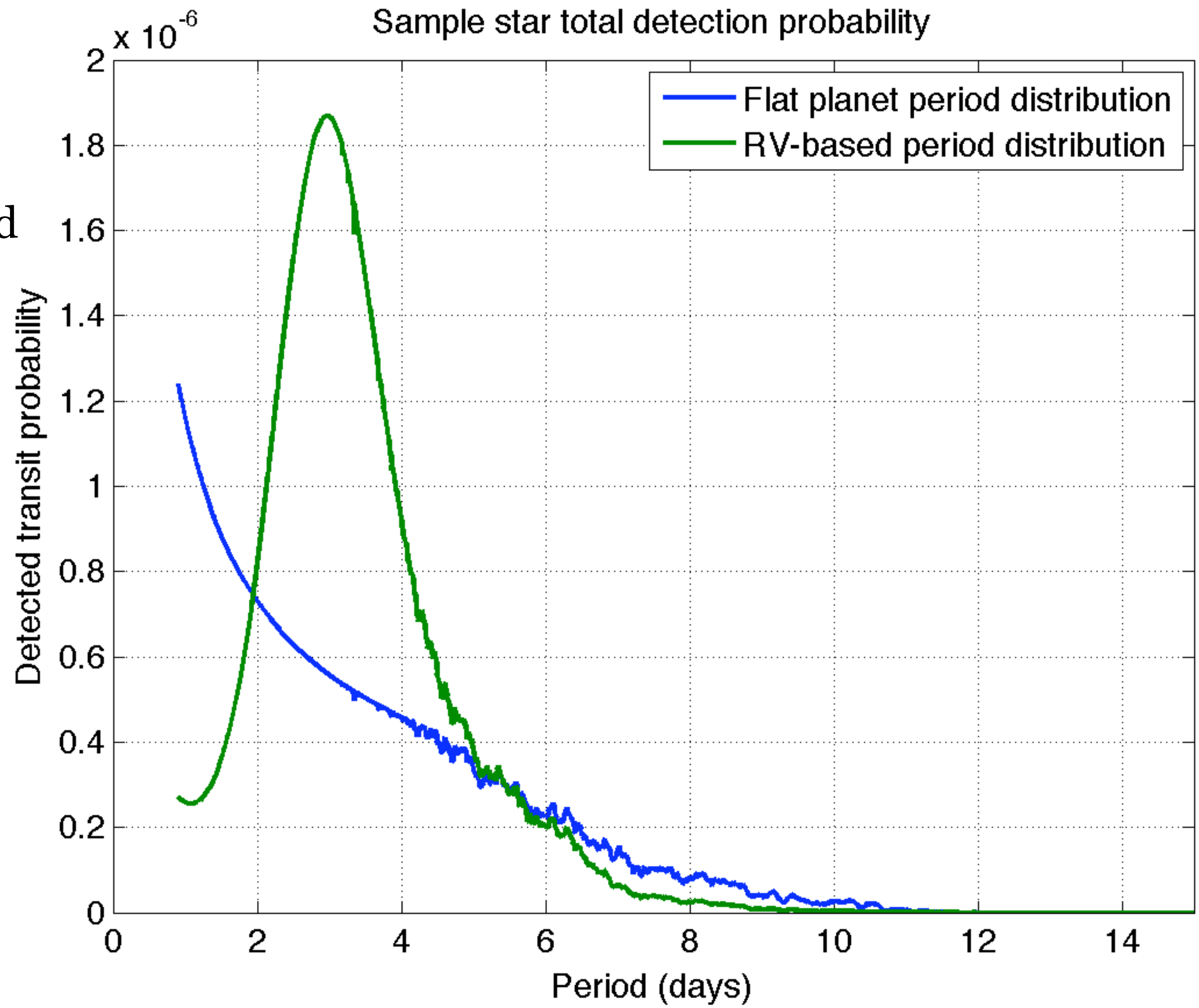


"Total" single-star detection probability

Detection probability using two planet period distribution models: flat and based on RV detections.

Both planet distributions were normalized to give a total planet probability of 0.8% from 1 to 15 days

Both curves are for a single model star.



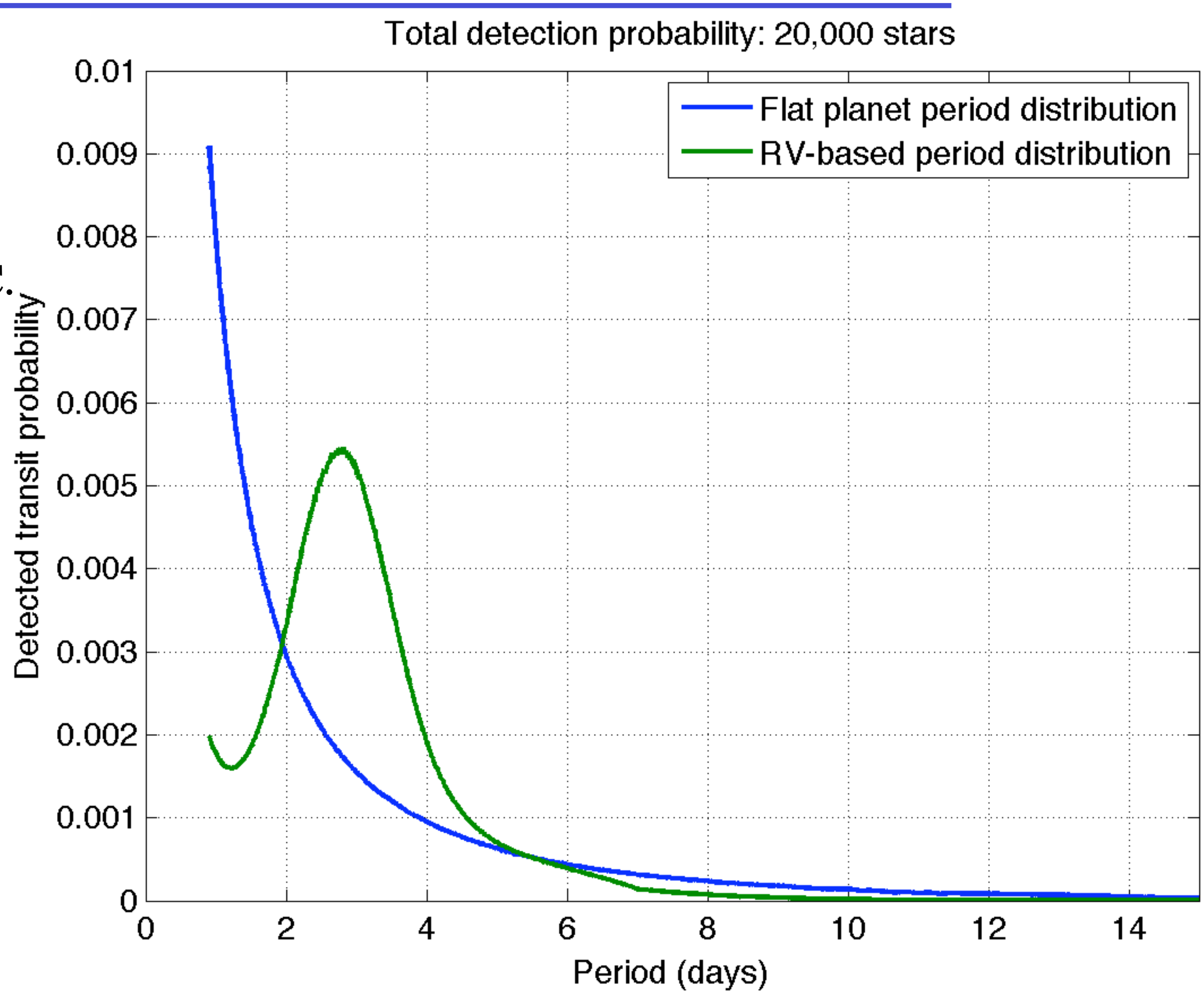
"Total" Field detection probability

Detection probability summed over stars in SP field based on Vulcan (N) stellar distribution from KIC.

The total number of planets expected for the South Pole observations is:

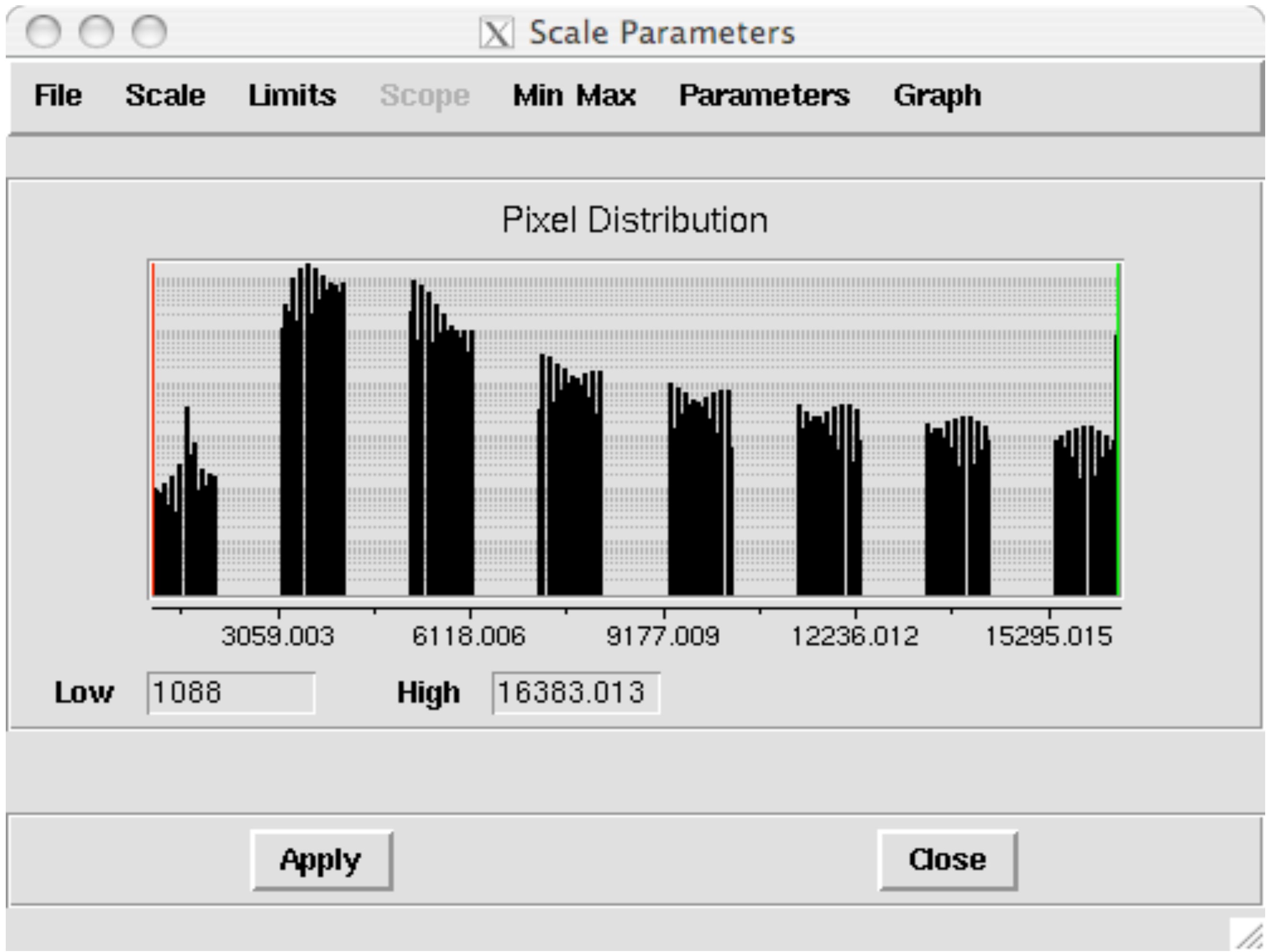
Flat dist: **6.4**
RV dist: **5.0**

Doesn't consider: crowding, binarity…



Vulcan-South Results

Data analysis is proceeding with attempts to correct missing bits by estimating pixel values based on measured noise and fitting a model PSF.



What worked...

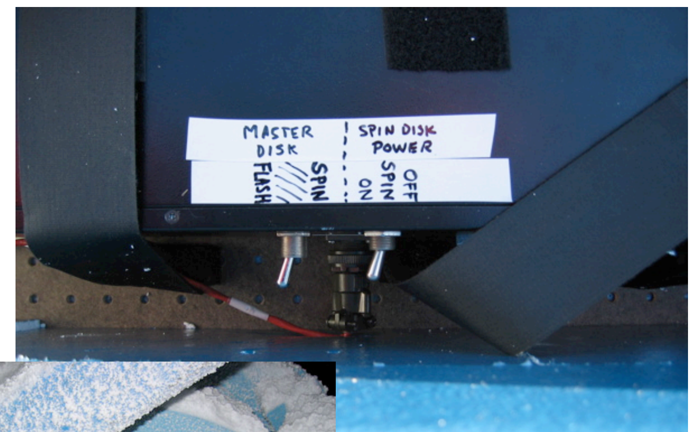
- Photometer thermal design was good: no problems with freezing in photometer; temperatures maintained at desired levels throughout winter
- Focus motor and shutter worked without problems
- Frost detection system worked, but difficult to calibrate
- Extensive telemetry logs (temperatures, voltages, status, warning and error messages) emailed daily to the team were invaluable
- Flexible remote observing allowed on-line observing (for tests and special purpose observations) and scripted observing (for normal observations)
- Batch program delivered subsection of each image daily for data quality check
- Data storage and automated backup system kept data safe on-site despite disk failure
- Winterover support was excellent
- Project team volunteered considerable time and resources

What didn't quite work…

• CCD camera was unreliable. Design required external controller with limited cable length, forcing us to locate a warm equipment shelter on the tower

• Solid state disk problems and marginally cold-tolerant computers resulted in wasted time during deployments

• Overheating problems in both the AASTO building and the equipment shelter

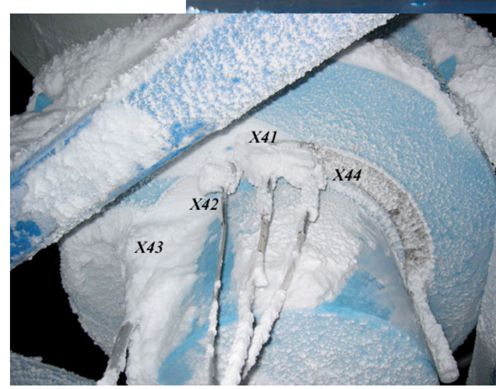


• Optical window heater under powered, leading to frosting during bad weather

• Gmount failures due to lack of maintenance (limited time & resources)

• Control software development was late, resulting in limited testing during deployment

• Much of photometer and equipment shelter could not be maintained during the winter (parts too small, cold sensitive parts)



for Future projects…

- Look for multi-year (~5) funding: expect to take several winters to get a system working
- Plan for on-site analysis: data rate is too low to deliver raw data
- Enlist a resourceful winterover tech
- Use lots of telemetry and log everything
- Save resources (people & time) for data analysis
- Avoid non-cold hardened commercial parts; e.g., power bricks, internal connector wires, plastic closures, plastic buttons/switches, etc.
- Beware of overheating equipment
- Have spare parts for everything on-site and make everything as cold-swappable as possible (with gloves on in the dark!)
- Work with the Australians, or anyone else with lots of experience
- South Pole for small wide-field search (where seeing not important)
- Dome C, or Dome A in several years, for larger telescopes - ideal for follow-up!