Infrared interferometry from Antarctica

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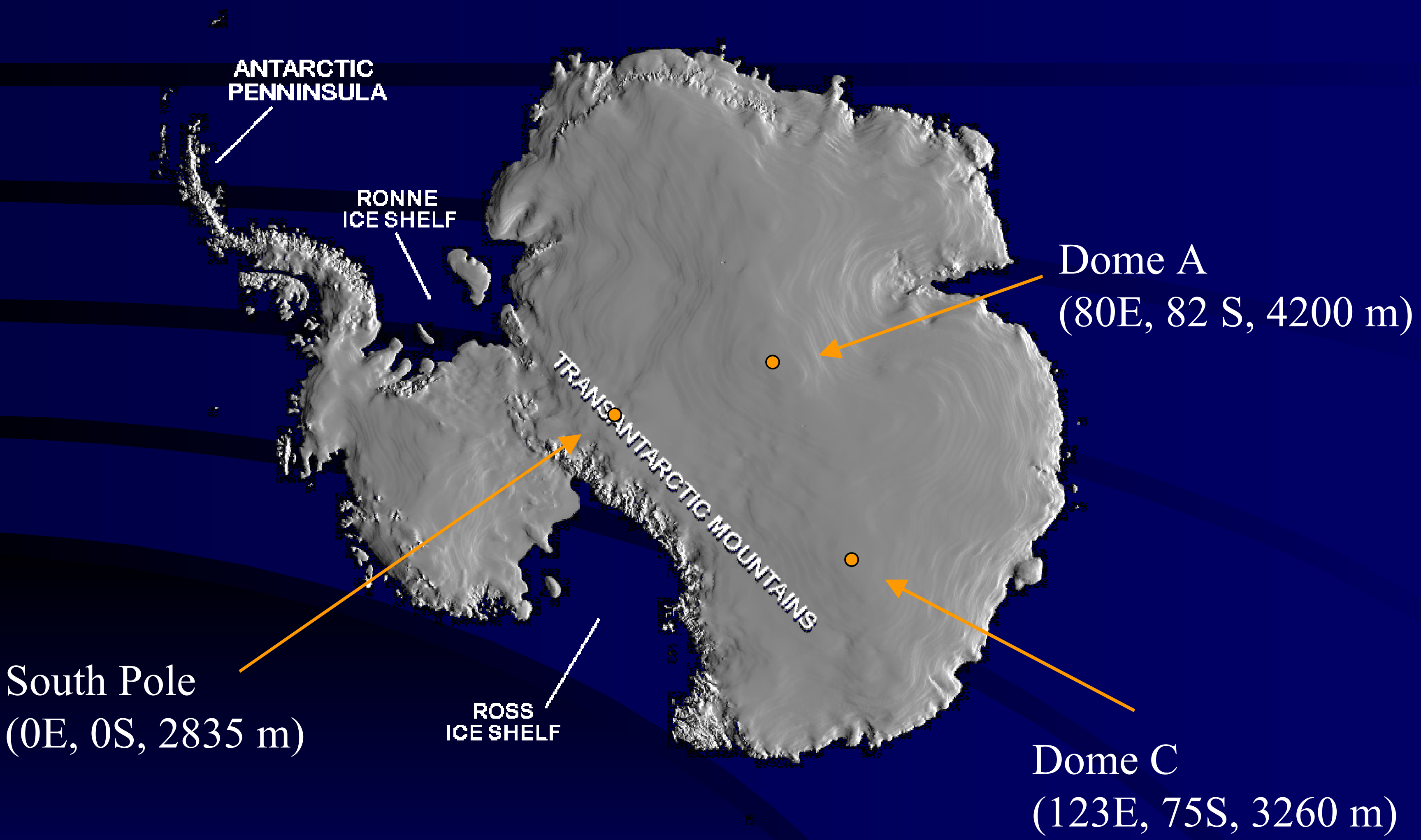
The optimal ground base site for IR interferometry is…

- Cold
  - Lower thermal emission
- Dry
  - Better infrared transparency
  - Better phase stability
- Quiet
  - Good, slow seeing
  - Quiet environment
- Accessible
  - Infrastructure
  - Logistics

Antarctic astronomical sites



Antarctic plateau katabatic winds

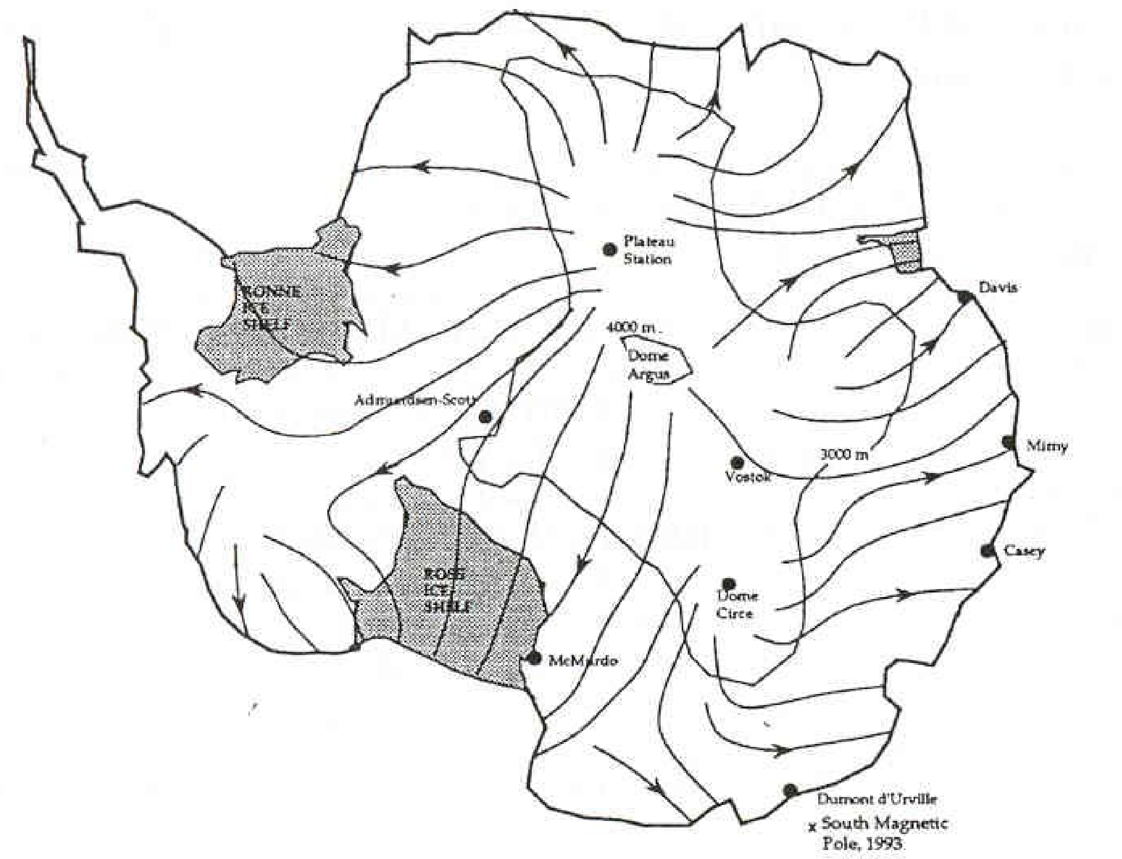
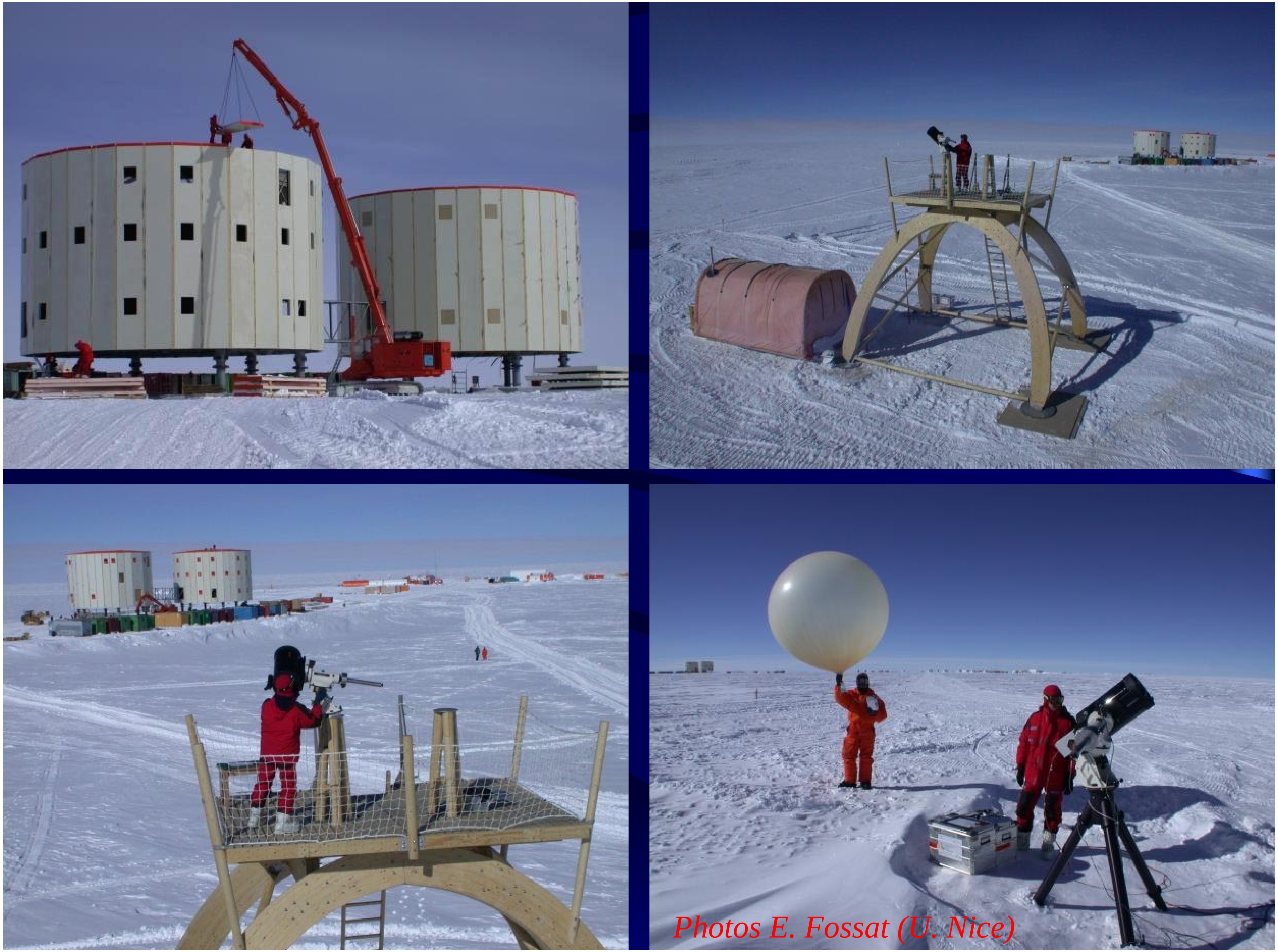


Fig. 8. Contour map of surface wind speeds over Antarctica, from Dopita 1993, based on results of Schwerdtfeger 1984

Dome Concordia base

The most space-like environment accessible on Earth

- Currently a French / Italian station
  - Run by offices of polar programs
  - More institutional support pending
- Summer campaigns since 1998
- First winter-over measurements 2003
  - AASTINO facility
- Permanent station being built
  - First winter-over (16 people) 2005

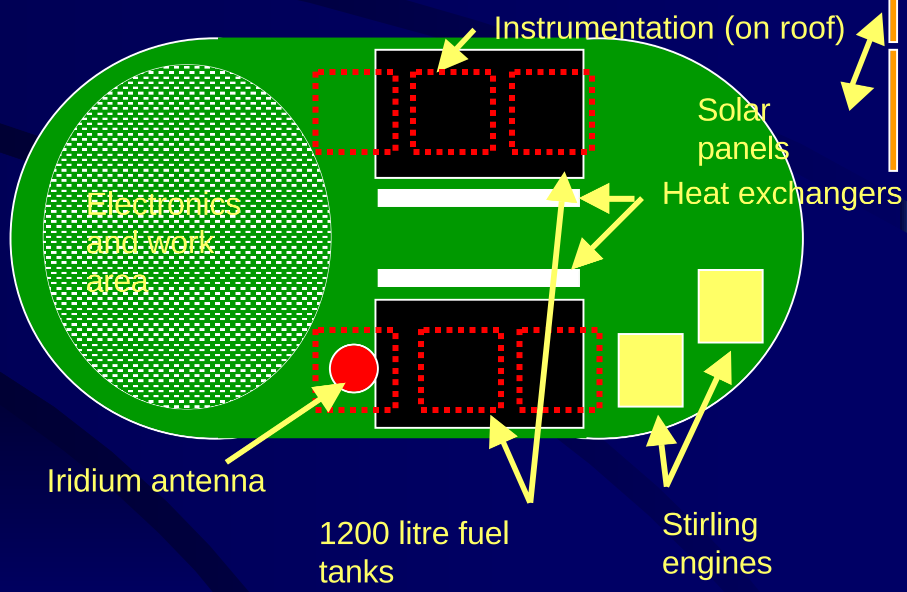


Photos E. Fossat (U. Nice)

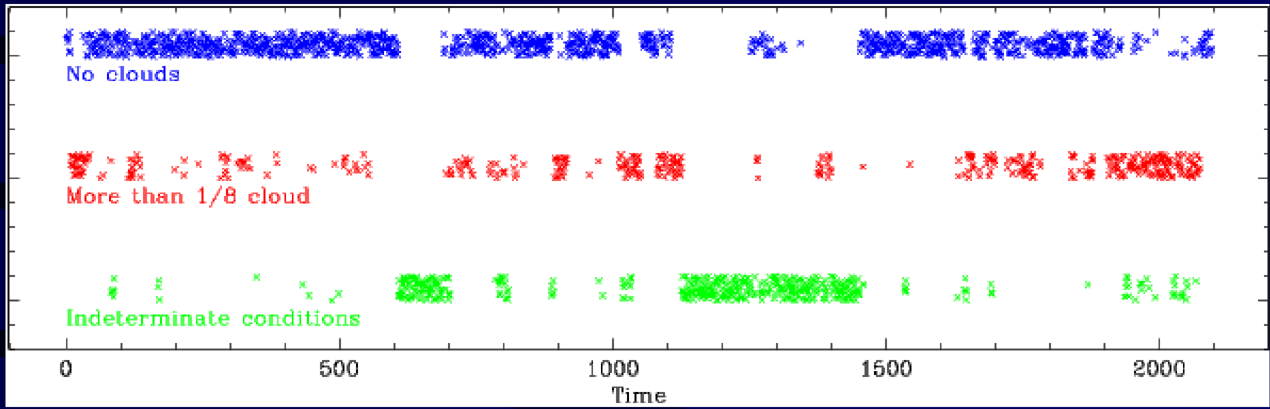
Logistics

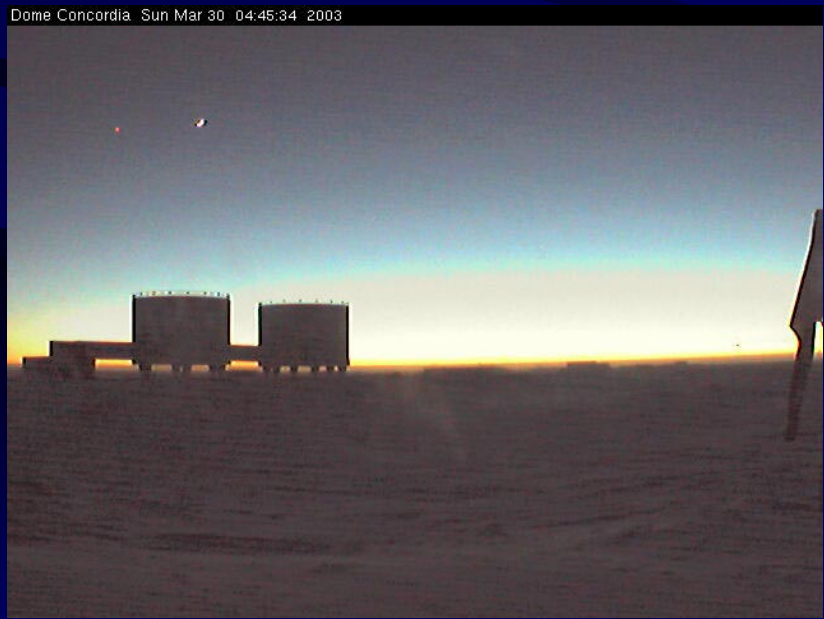
Winter-over remote operations with AASTINO

- An autonomous platform to support small antarctic experiments:
  - Built by University of New South Wales (J. Storey et al.)
  - Remote controlled from Sydney
  - Provides power, thermal management, networking, communications, data storage…
- Current on-board experiments
  - Acoustic radar (SODAR)
  - Atmosphere opacity at 350μm (SUMMIT)
  - Scintillation sensor (MASS)
  - IR sky brightness measurements (NISM/MISM)
  - DIMM? (2004)

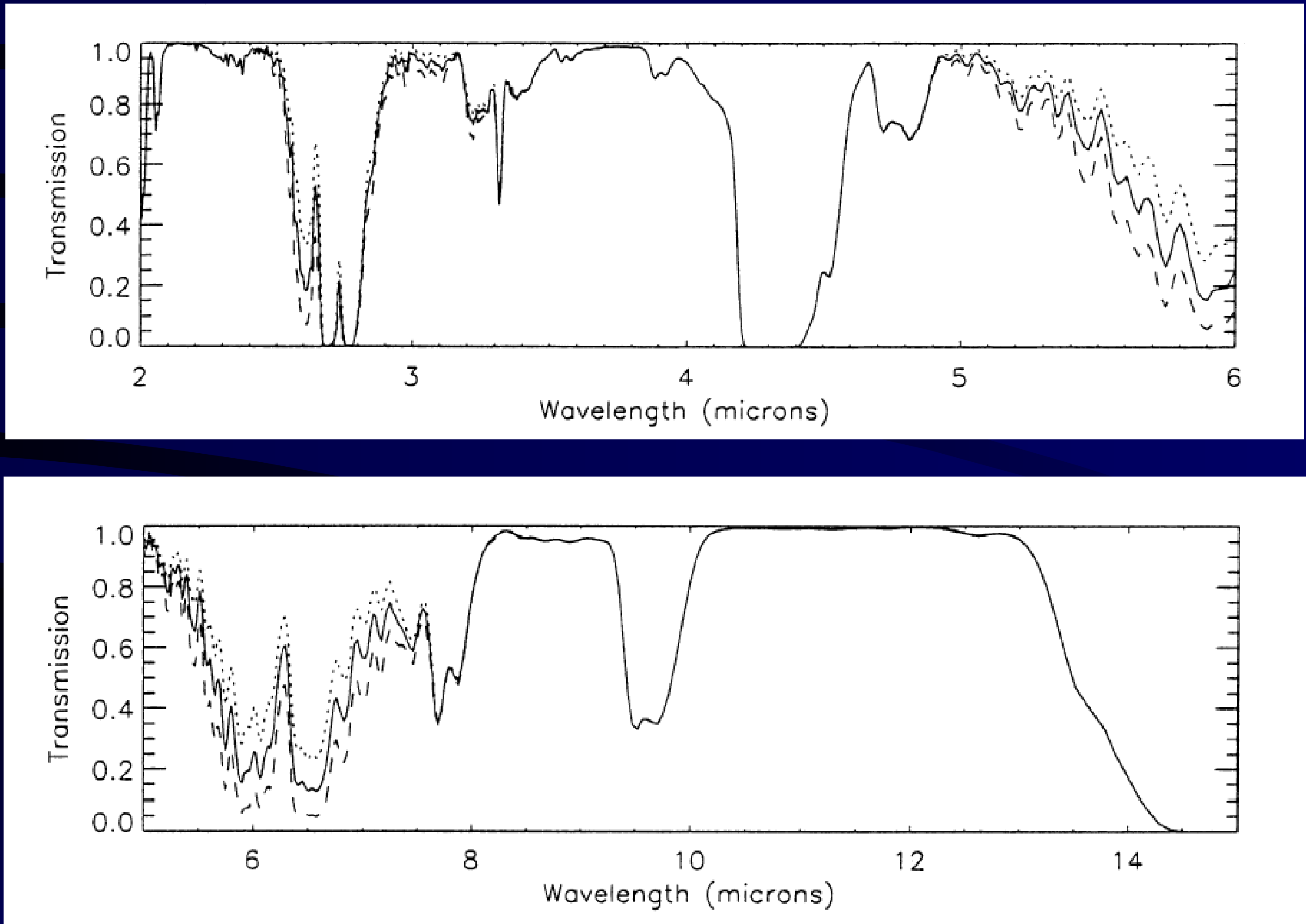


Dome C cloud cover





Infrared transparency



Hidas et al. 2000 (Pub. Astron. Soc. Aus. 17, 260)

Sensitivity increase from reduced sky and instrument background

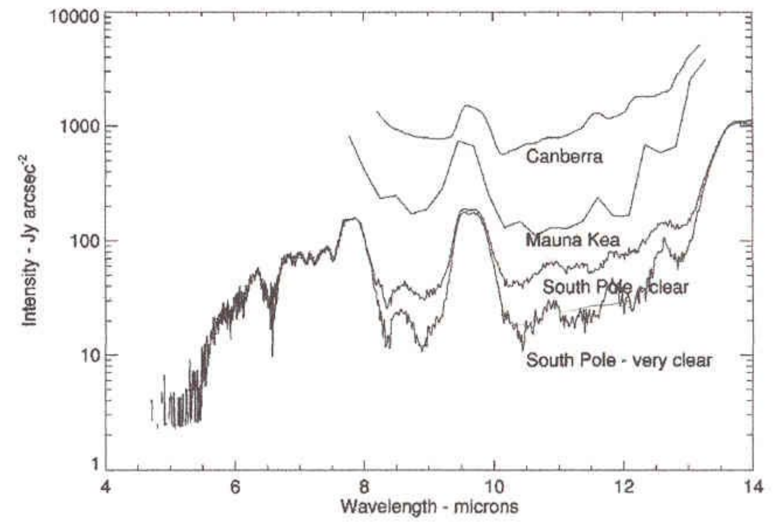


FIG. 13.—Comparison of emission spectra taken in clear conditions at Canberra and Mauna Kea (Smith & Harper 1998) with data from the South Pole (this work).

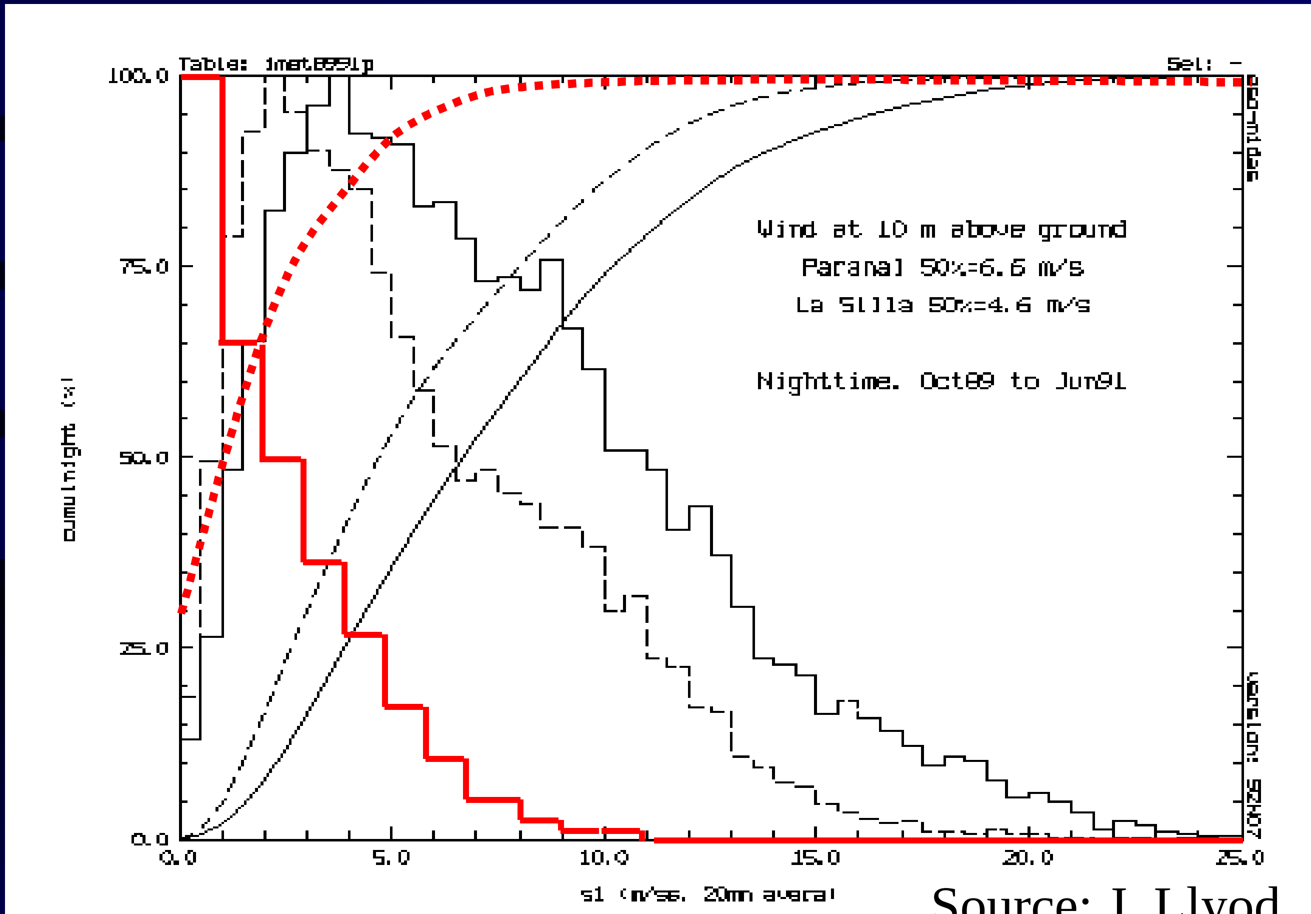
Chamberlain et al. (2000)

- Sensitivity increase relative to temperate site including instrument, sky, and read noise.
- Lower sky background important; sky background limited in K band and in L at 200 K (H band read noise limited).

	H	K	L	M	N
300/220	4	25	11	6	2
300/200	4	31	21	10	3

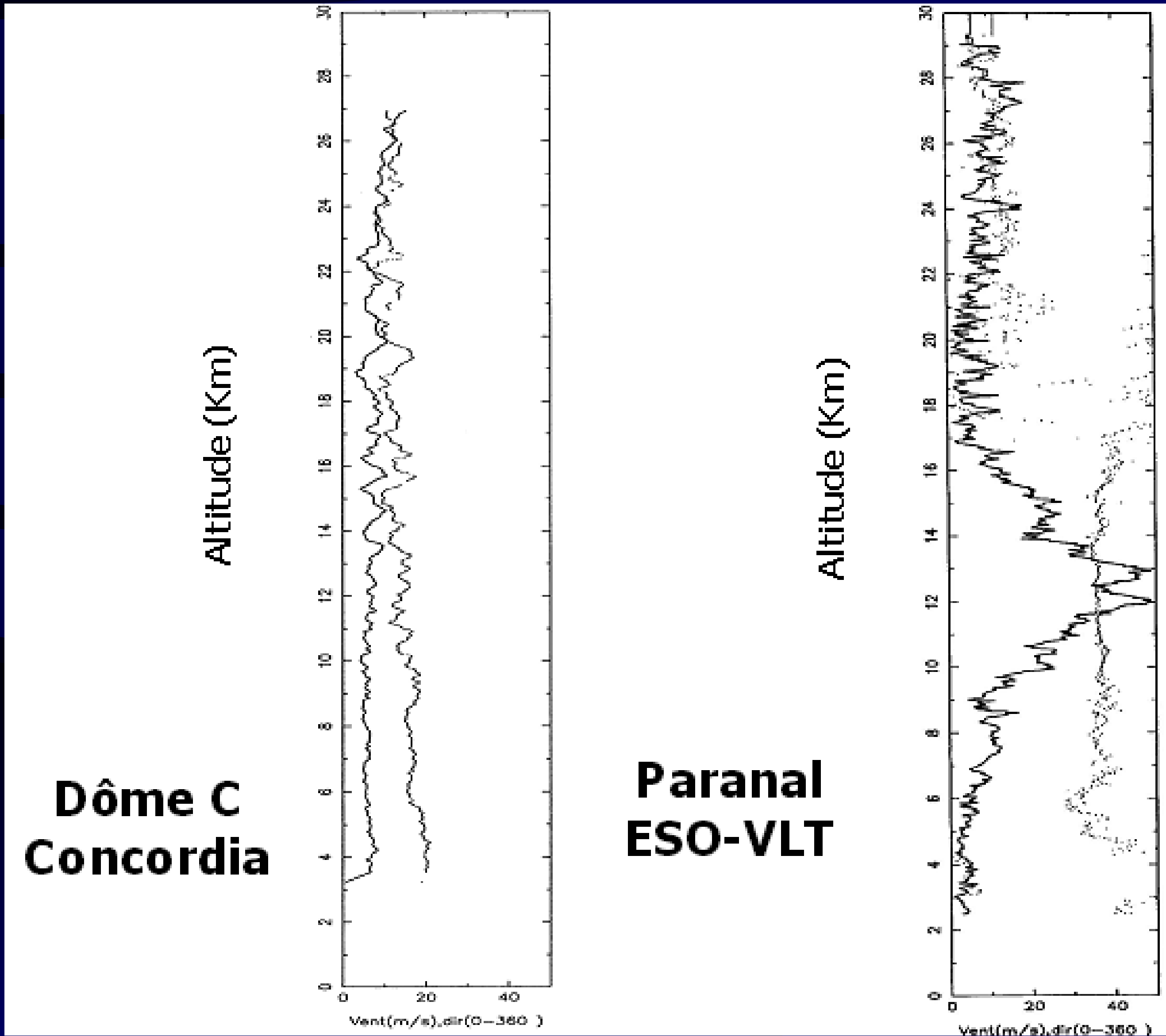
Ratio of background NEP between a temperate site and Dome C including telescope and sky background components.

Compared wind histograms Paranal/La Silla and Dome C

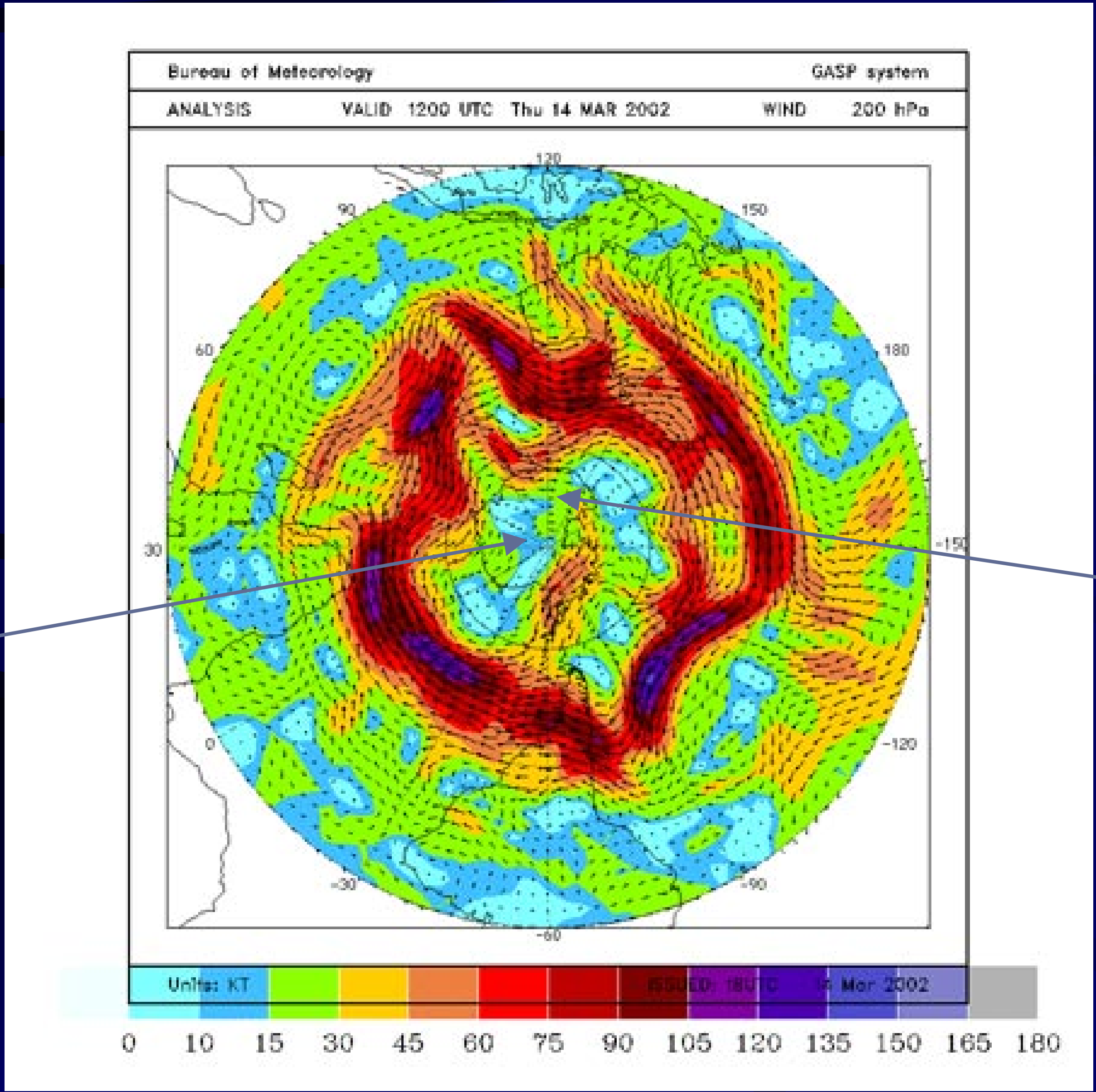


Source: J. Llyod

Compared wind profiles



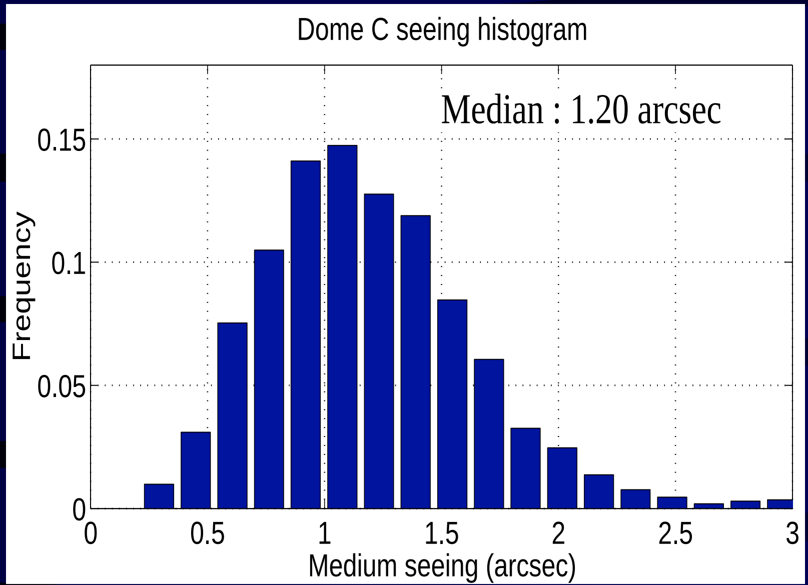
The polar vortex



South Pole

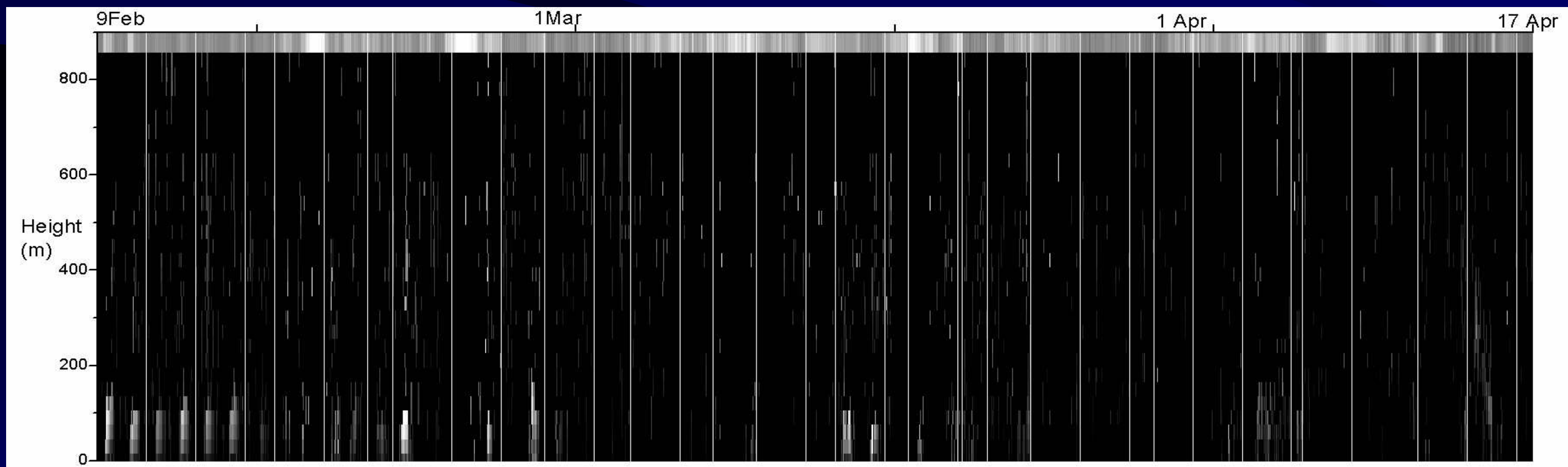
Dome C

Seeing data Dome C



DIMM *summer* 2002:
median seeing 1.1 arcsec
(Aristidi et al, 2003)

SODAR summer / winter 2003:
uncalibrated,
no signal: $C_N^2 = 5 \times 10^{-18}\ m^{-2/3}$
(Travoullion et al, 2003)



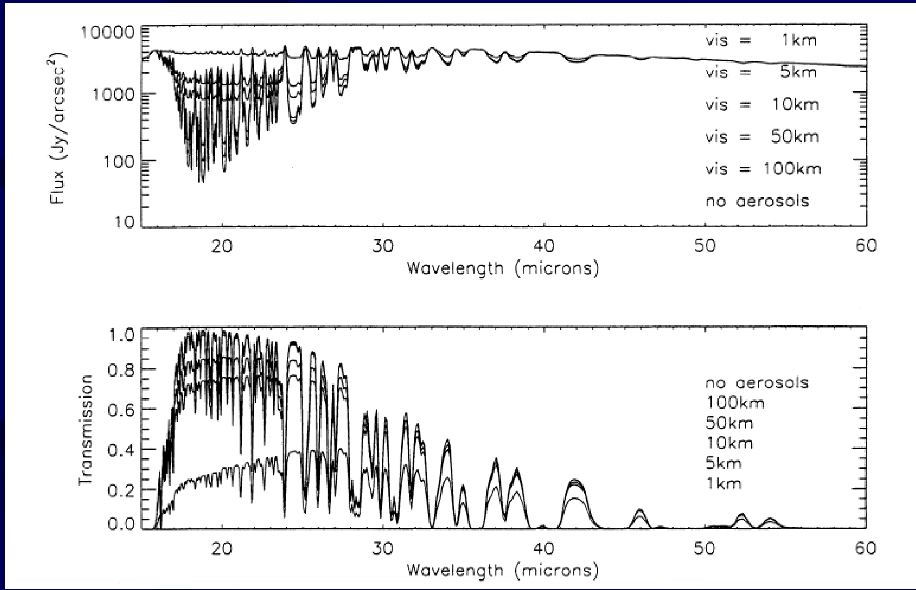
Dome C atmosphere summary

- Low/slow turbulence.
  – Excellent seeing, dominated by thin boundary layer
  – Likely best interferometric atmosphere

  in terms of the combination of r_0,τ_0, and θ_0 accessible on Earth.
- Cold (T~220 K)
  – Increases thermal infrared sensitivity.
  – Darker infrared sky
- Dry (PWV~200 µm)
  – Improved infrared transmission
  – Reduced dispersion
- Stable
  – Reduced dispersion fluctuations.
  – Reduced sky background fluctuations.
- Clean
  – Cleaner optics, lower emissivity

Pending issues…

- Direct measurements of nightime sky properties
  – In progress (DIMM, SODAR…)
  – What about outer scale?
- What about aerosols?



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Current proposals for Concordia

- 30m submillimeter telescope (A. Stark, SAO)
  - 350μm survey of protogalaxies
  - 100 times faster than ALMA!
- Extremely Large Telescope (J. Lawrence, UNSW)
  - Low wind loads
  - Wide field AO
  - A possible site for OWL?
- Wide field deep IR surveys (W. Saunders, AAO; N. Epchtein, U. Nice)
  - Ultra low sky background
- Antarctic Planet Interferometer (M. Swain, JPL et al.)

API

Antarctic Planet Interferometer

Antarctic Plateau Interferometer

- Primary science goals
  - Jovian class planet characterization.
    - SED measurements 1.5 to 28 microns.
    - Observationally test models for planetary atmospheres.
  - Extrasolar planet environments.
    - Dust content of disks.
    - Dust distribution, gaps.
  - Study planet formation in protoplanetary disks.
    - Disk chemistry and dynamics.
    - Observe unique signatures of planet formation.

Benefits from Dome C location

All interferometer modes are dramatically improved!

- Astrometry (~20 x – if free air turbulence ~0)
  - Depends ~ int($h^2 C_N^2$) so low elevation seeing helps.
  - Longer baselines possible (than Mauna Kea).
  - Large isoplanatic angle required to avoid photon limit.
- Differential Phase (~20 x @ 2µm)
  - Water vapor limited sensitivity ~ σ_{PWV}/SNR ~ 25/SNR.
  - Photon limited with phase referencing ~ 20µrad
    (K_{magn} = 5, 10 min int, 1.8 m telescope, 10% throughput).
- Null depth (~20 x @ 5 µm)
  - Reduced sky fluctuations.
  - Water vapor limited sensitivity scales as differential phase.
- Background limited sensitivity (~75x @ 2µm)

Context

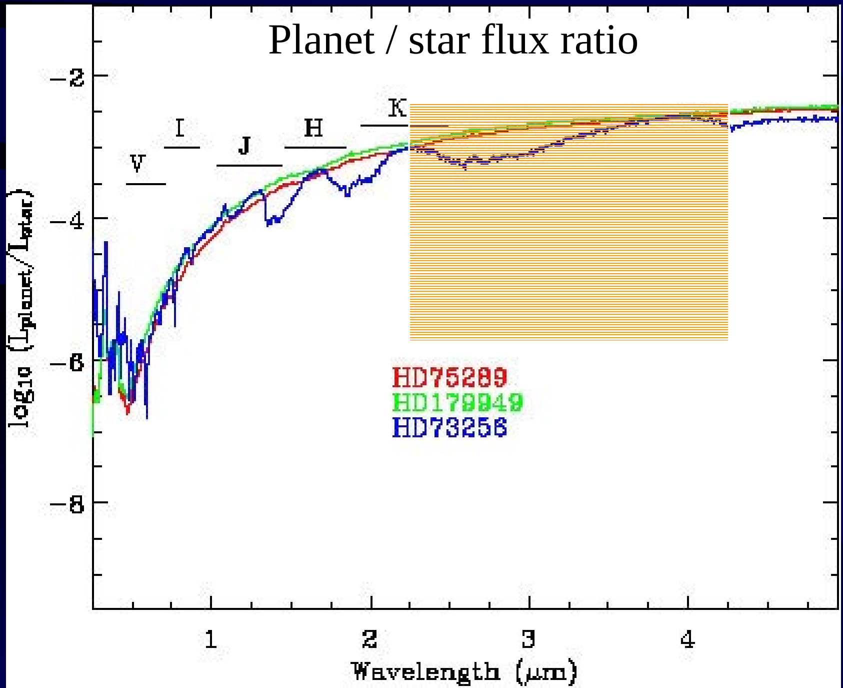
- API related series of proposals (first is submitted)
- Strong institutional team (current partners)
  - Interferometer experience (JPL, SAO, UofA, Obs. Paris, Univ. Nice)
  - Antarctic astronomy experience (SAO, UNSW, UofA, Univ. Nice)
  - Need more European partners!
- European Polar Board and Office of Polar Programs (NSF) potential interest
  - A component of a proposed roadmap for Antarctic astronomy
  - Generated interest outside traditional Antarctic astronomy community
- NASA/ESA potential interest
  - Builds toward a joint TPF/DARWIN mission
  - API as a possible testbed for TPF/DARWIN technical development
  - Concordia selected as Research Site by ESA (human sciences)

Roadmap

- What is the right scale for the API instrument?
- Progressive approach required
  - DIMM/SODAR testing of Dome C (ongoing)
  - Interferometric science demonstrator
    - Demonstrate Dome C interferometric science capability in the shortest possible time frame
    - Accumulate extensive database of atmospheric properties (τ_0, outer scale)
    - Build up expertise in antarctic interferometry operation and logistics models
  - Full scale API

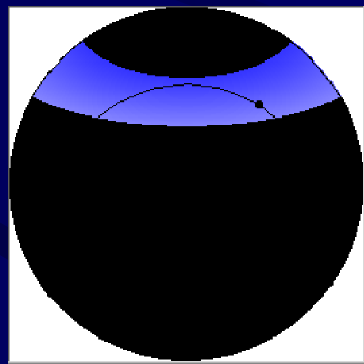
API Science Demonstrator concept

The simplest form of interferometer that can provide a unique (though focused) science result on extrasolar planets



Barman et al., private communication

- Single-mode, single-field interferometer
- High precision (10^{-3}) V^2 interferometry for the direct spectrophotometry of hot-Jupiter type exoplanets
- Spectral range 2.8—4.2μm, $\lambda/\Delta\lambda \sim 20$
- Re-uses existing hardware/software (PTI, fiber beam combiner) in a "winterized" version
- Baseline ~500m with limited stroke (80m) delay line (optimized for three targets)



Sky coverage with 80m delay
(320m offset)
For HD179949 (δ=-24°)

Comparative performance

(Instantaneous (500ms) SNR on a 1000:1 contrast binary with L=5)

Telescope diameter	Location	SNR	Noise sources
0.6m	Dome C	1.7σ	47% thermal 40% detector 13% shot noise
1.80m	Temperate	1.9σ	100% thermal
1.80m	Dome C	42σ	4% thermal 3% detector 92% shot noise

Assumptions:

- Spectral resolution 200nm
- Overall optical transmission 1%
- Emissivity 50%
- Temperature: 293K (temperate site), 220K (Dome C)
- Detector: 5e$^-$ readout noise, 60% QE
- Interferometer point source response: 90%

Conclusion

- Dome Concordia is "space with a free ride"
- Because of its antarctic location developments there are supported beyond the astronomical community
- Dome C might actually become a major observatory in the future (the Mauna Kea of the 2020's ?)
- The potential of the site for IR interferometry (notably exoplanets) needs to be confirmed but if it does the opportunity should not be missed (and integrated into the TPF/DARWIN programs)

Marie Curie Fellowships

PhD exchange students (3–12 months)

http://despa.obspm.fr/Marie.Curie.Training/index.html

Or email to:

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