Antarctic Planet Interferometer
(Mark Swain - Jan 9 2003)

The Antarctic Planet Interferometer (API) is a concept designed to detect and characterize extrasolar planets by exploiting the unique potential of the best accessible site on Earth for thermal infrared interferometry. The best sites on the Antarctic plateau are excellent for infrared interferometry because the atmosphere at these locations is characterized by slow, low-altitude turbulence, low water vapor content, and low temperature. The three high-precision interferometric techniques under development for extrasolar planet detection and characterization (astrometry, differential phase and, nulling) all benefit substantially from these unique properties of the Antarctic plateau atmosphere. At these locations (such as the site being developed at Dome C), an interferometer with two-meter diameter class apertures has the potential to deliver space-like performance

Antarctic Planet Interferometer

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Mission Statement

The goal of API is to characterize extrasolar Jovian planets, their environments and formation mechanisms, and detect ~ Earth mass extrasolar planets using interferometric methods from the best accessible site on earth. The unique properties of the atmosphere at Dome C should enable high contrast, high precision interferometric observations in the1.5 to 28 micron region of the spectrum which are substantially better than would be possible from any other accessible place on Earth.

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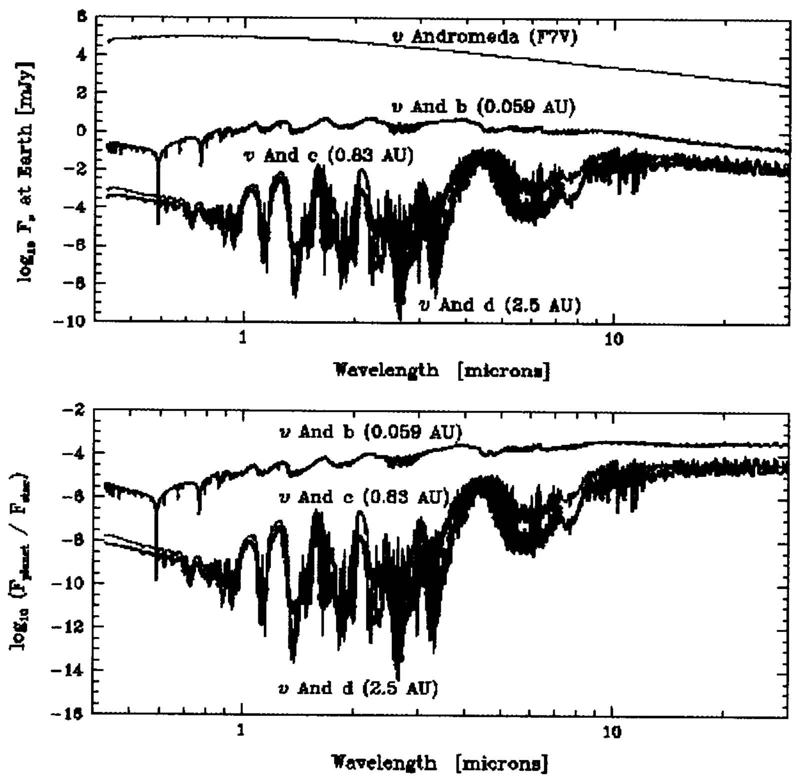
Primary Science Goals

- Detection of Earth mass class planets in habitable zone.
- 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.

Extrasolar Jovian SED

- Models imply a premium on very high contrast measurements.
- Present models do not have all molecular lines which may relax contrast requirements at particular wavelengths.
- Very high contrast ratio observations (~1e5) required for planets in ~ 1 AU orbits.



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Model by A. Burrows

Secondary Science Goals

- YSO and proto-planetary disk formation
- Star formation and the ISM
- Active Galactic Nuclei.
- High angular resolution measurements from 1.5 to 200 microns provide follow on/complementary science for
  - Hubble
  - SIRTF
  - SOFIA
  - Herschel
  - NGST

Instrument Overview

- 2 or more telescopes, 1.8 meter diameter or larger.
- Telescope separation adjustable from few to 250+ meters.
- 1.5 to 200 micron operation (with polarization in selected bands).
- 1.5 to 28 micron “optical” beam train.
- “Dual star” capability.
- V^2, narrow angle astrometry, differential phase, nulling, synthesis imaging, and FTS observing modes.
- Low emissivity, low loss beam train.
- Far-IR/submm beam transport above ground.
- Nominal location – Antarctic Dome C.

Antarctic Dome C

The most space-like environment accessible on Earth.

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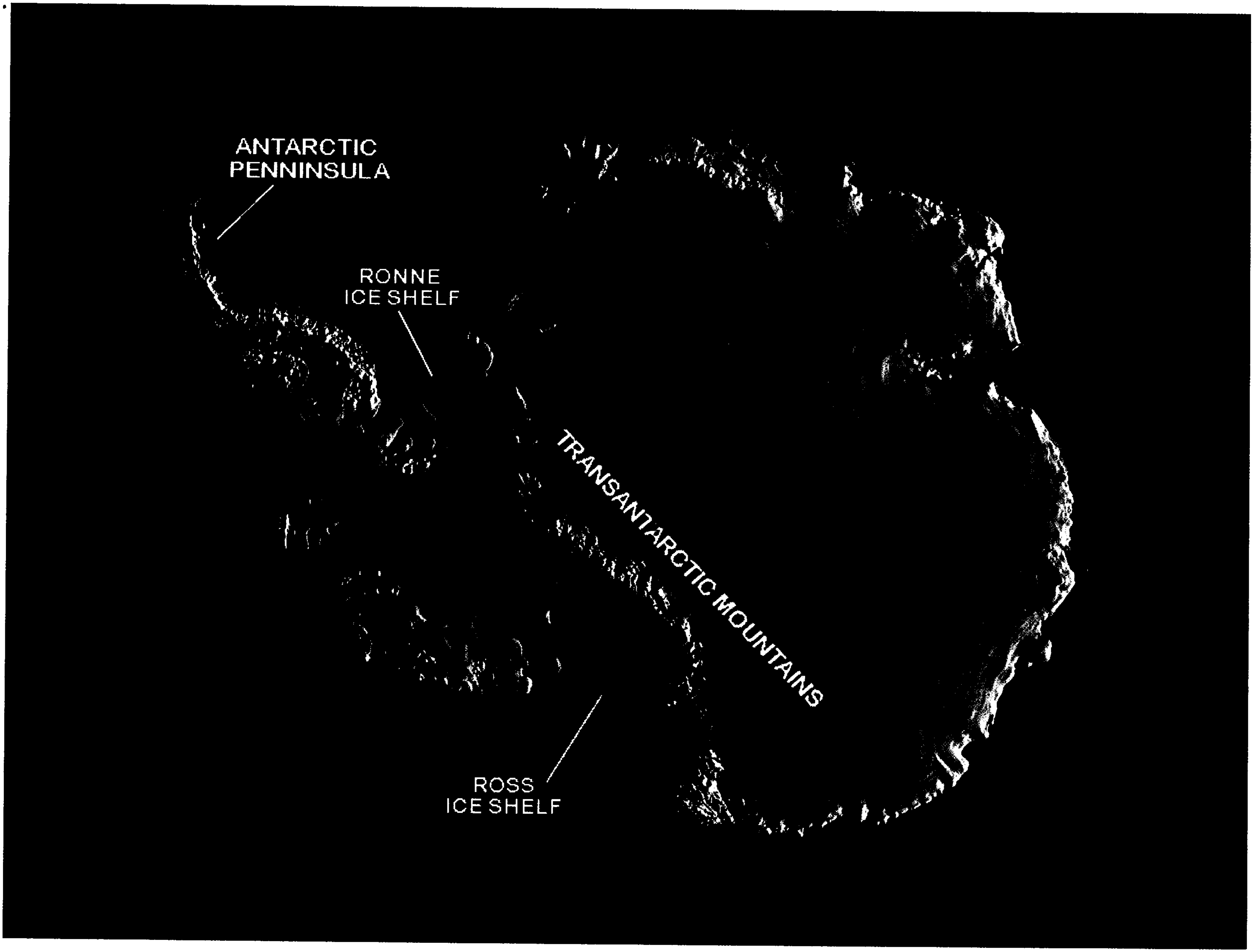
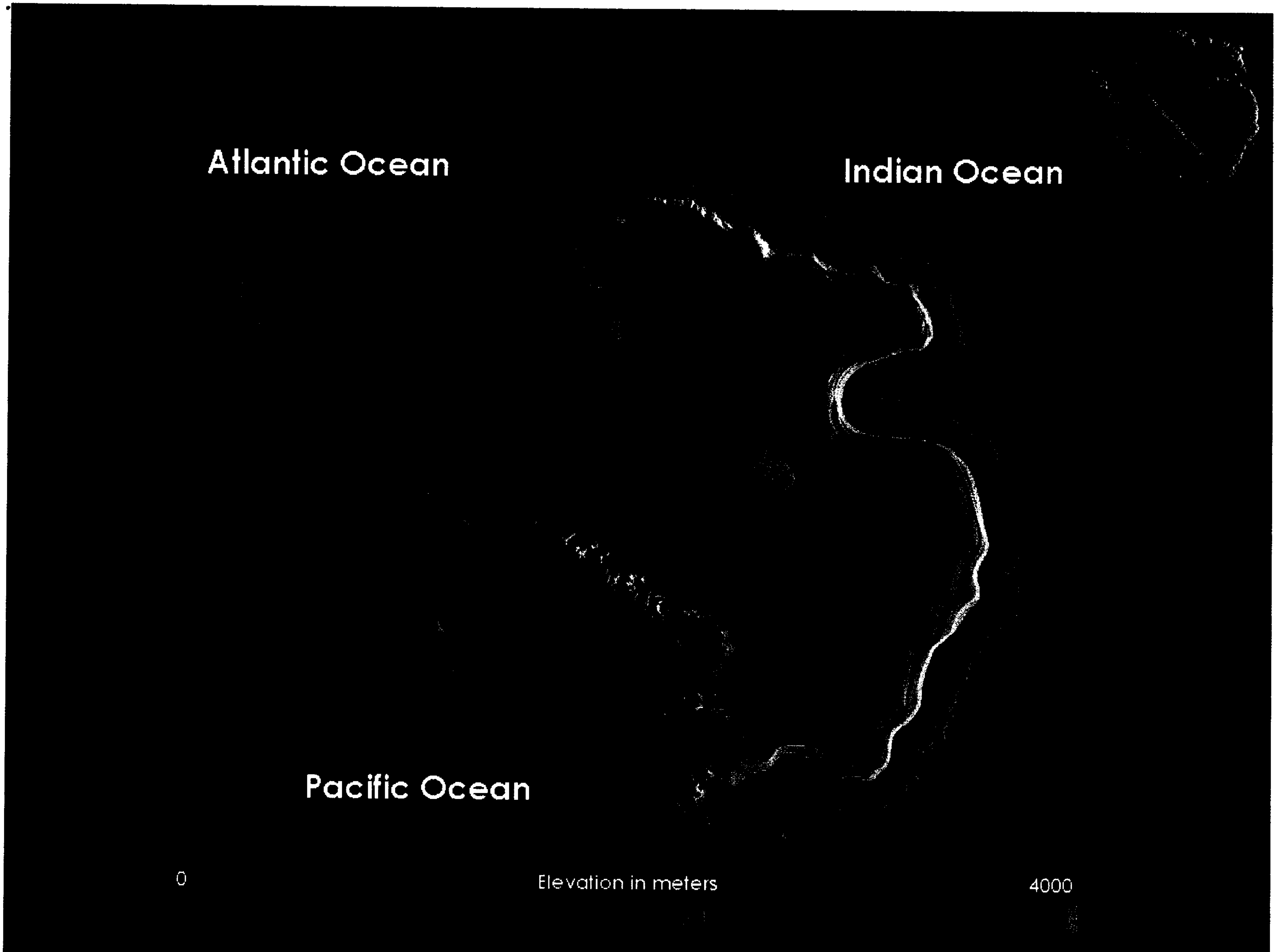

ANTARCTIC
PENNINSULA
RONNE
ICE SHELF
TRANSANTARCTIC MOUNTAINS
ROSS
ICE SHELF


Atlantic Ocean
Indian Ocean
Pacific Ocean
0
Elevation in meters
4000

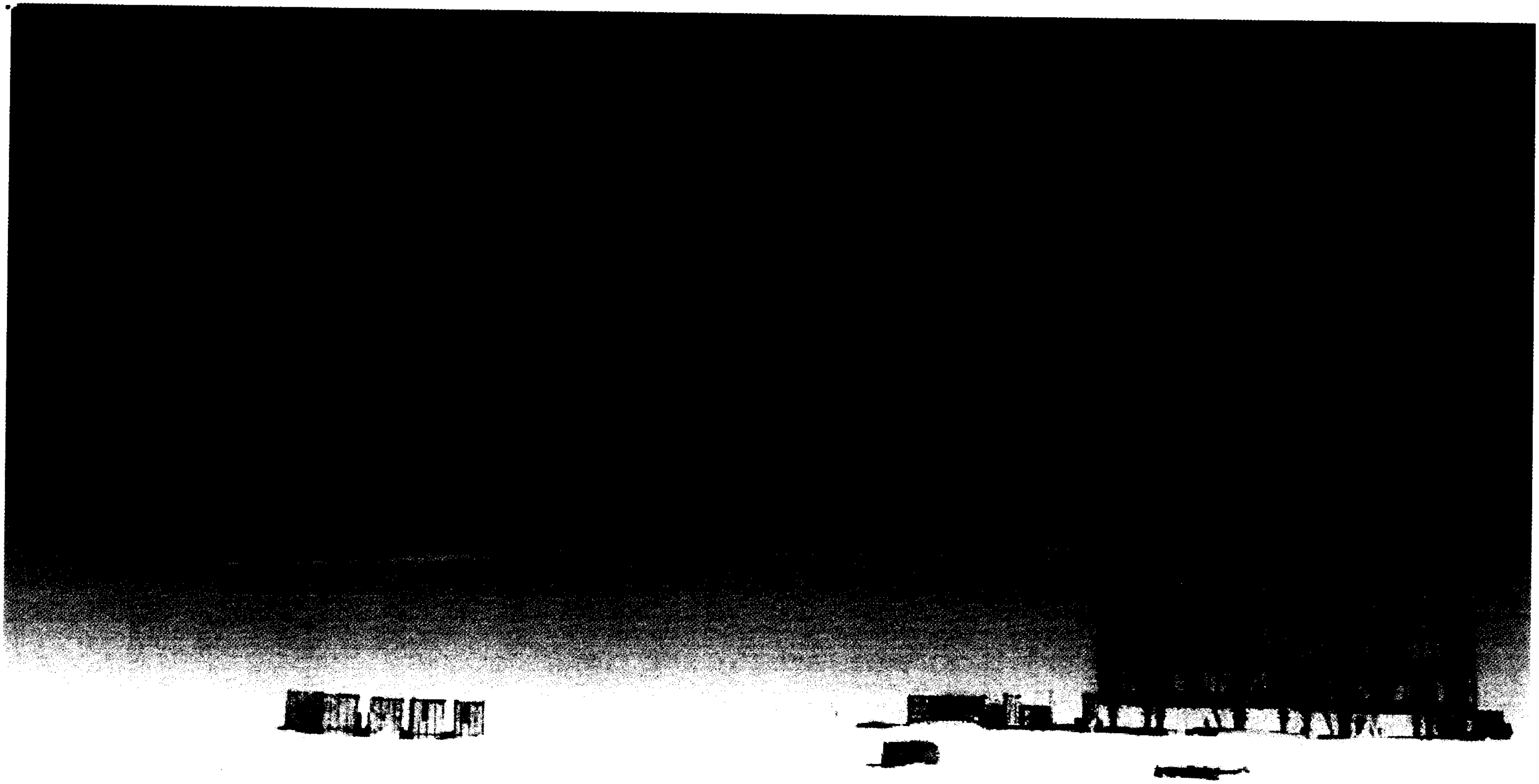


photo by Paolo G. Calisse - 2001

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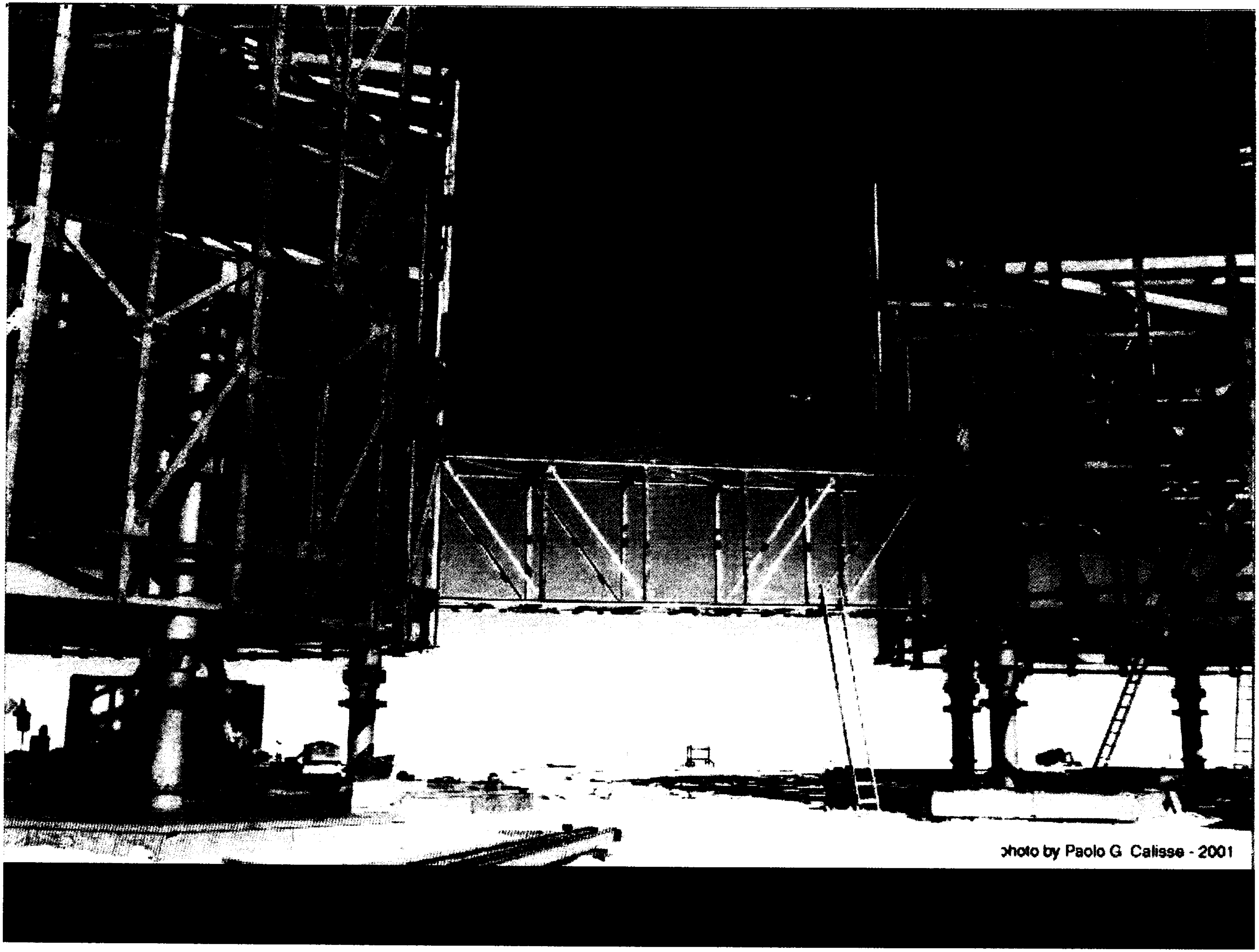
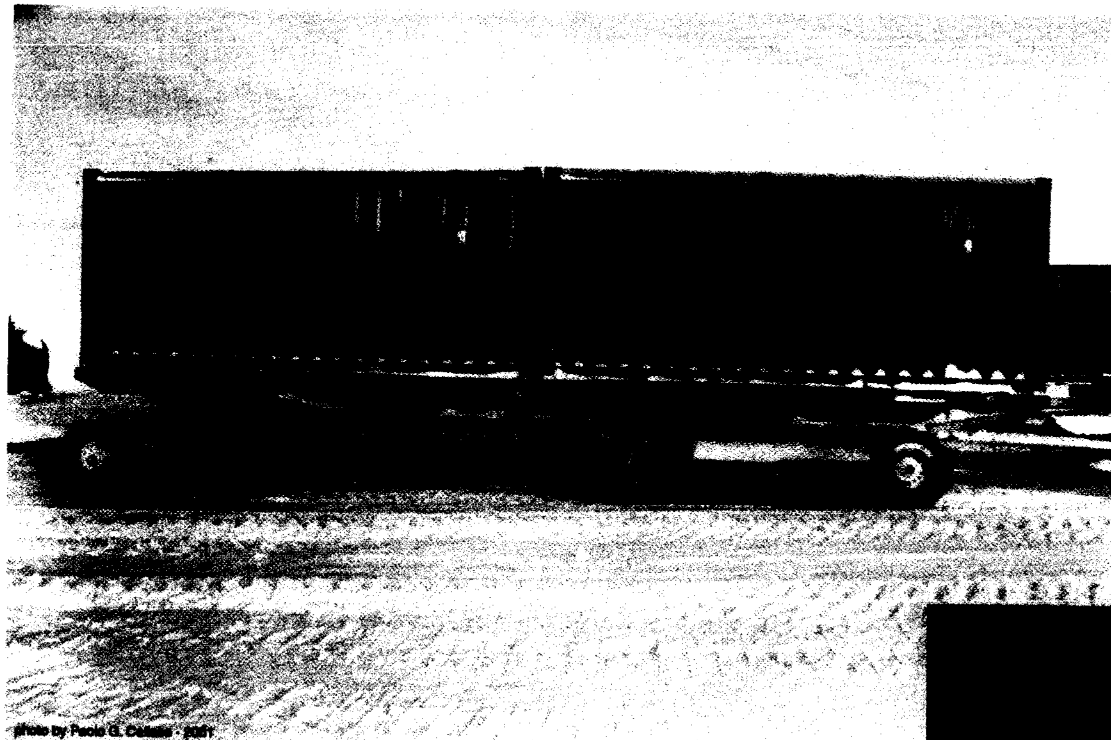


photo by Paolo G. Calisse - 2001

Dome C Transport



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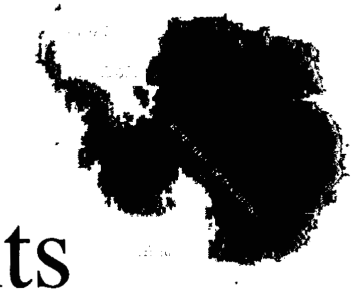
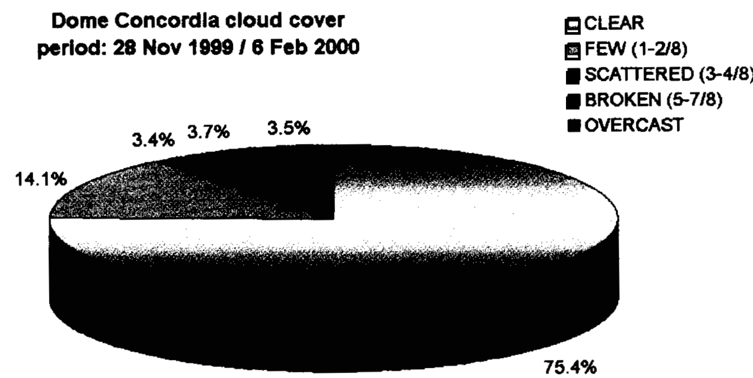


Dome C Astronomy Highlights

- Likely best interferometric atmosphere in terms of the combination of τ_0, r_0, and θ_0 accessible on Earth.
- ~220 K instrument increases thermal infrared sensitivity.
- Low water vapor content; excellent IR transmission.
  - ~200 microns PWV
- Low thermal infrared sky brightness.
  - 20 to 100 x lower than Mauna Kea
- Low wind speed.
  - 2.8 m/s average



source: Dome Concordia Automated Weather Station
courtesy ENEA Peogetto Antartide

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Sensitivity Increase from Reduced Sky and Instrument Background

- Sensitivity increase relative to Mauna Kea 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 at Mauna Kea to Dome C including telescope and sky background components.

Area ratio for a 10 m and a 1.8 m telescope is 30.

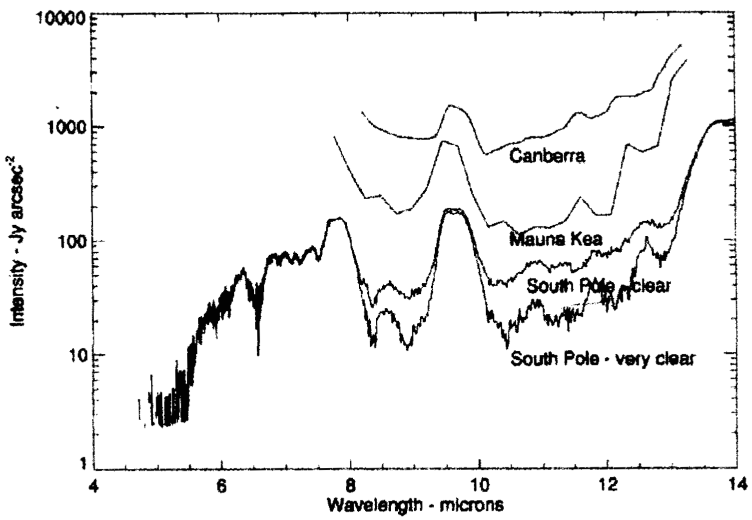
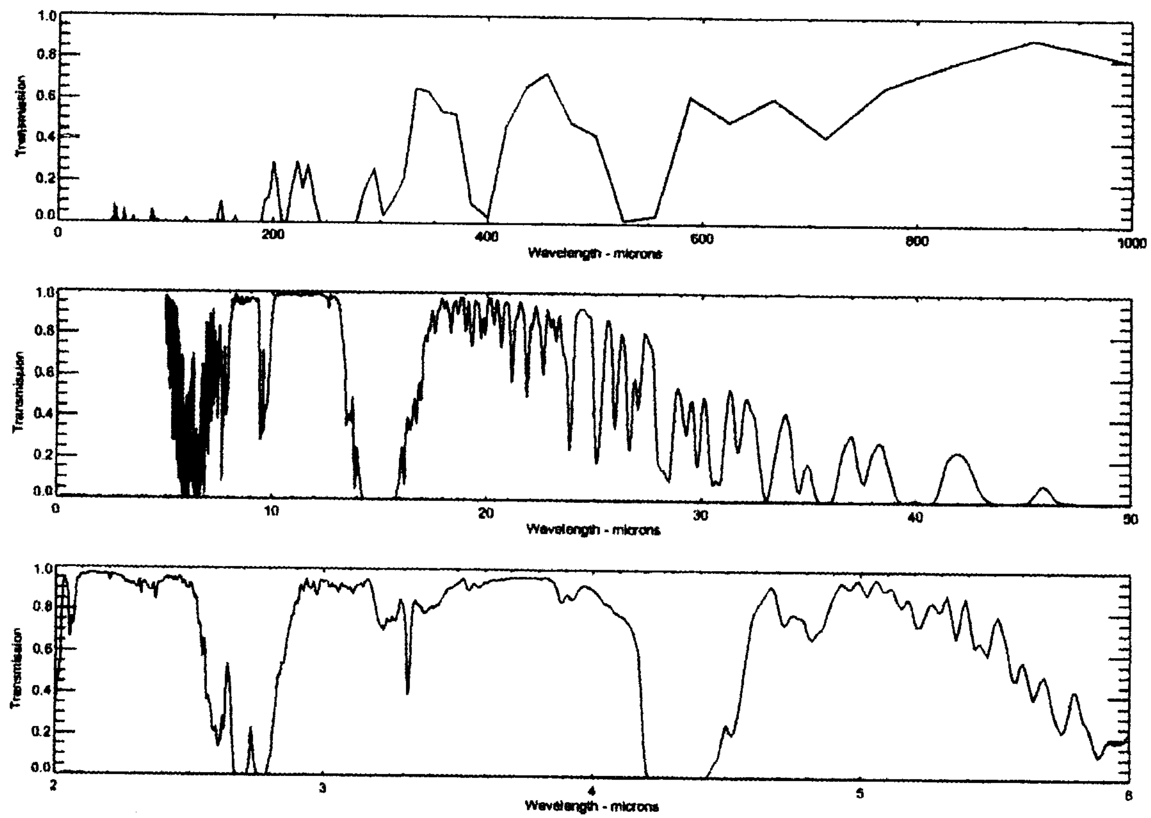


FIG. 13.—Comparison of emission spectra taken in clear conditions at Canberra and Mauna Kea (Smith & Harper 1998) with data from the South Pole (this work).

Chamberlain, ApJ 535, 2000

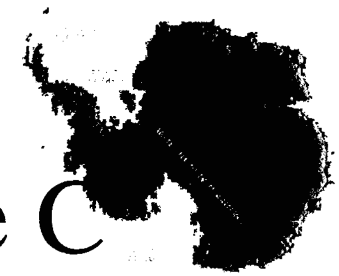
Increased Wavelength Coverage

- Excellent atmospheric transmission in thermal infrared.
- M band improved over mid latitude site.
- Observing bands in the 18 to 28 micron range.
- Based on good South Pole data; Dome C likely better.



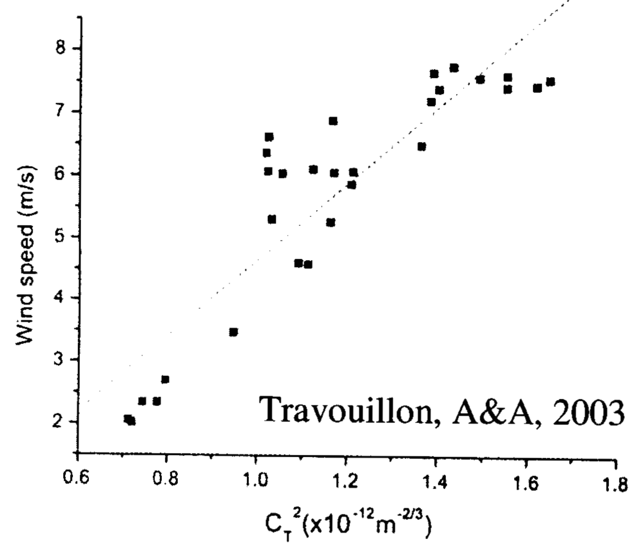
Chamberlain, ApJ, 535, 2000

South Pole C_n^2 scaled to Dome C



corresponds to best 25% weather

- SP "type 1" atm (70 m layer, 6.0 m/s wind)
  - r_0 (2.2 um) = 67 cm
  - τ_0 = 0.1 sec
  - θ_0 = 3 arcmin
  - σ_δ = 2.5 μarcsec (1 hr integration, 250 m baseline)
- Dome C (scale SP type 1 to 30 m layer, 2.5 m/s wind)
  - r_0 (2.2 um) = 151 cm
  - τ_0 = 0.6 sec
  - θ_0 = 30 arcmin
  - σ_δ = 0.56 μarcsec
    - (1 hr integration, 250 m baseline)



Dome C Location Interferometer Sensitivity Improvements

- Astrometry
  - Depends ~ int($h^2 Cn^2$) so low elevation seeing helps
  - Longer baselines possible (than Mauna Kea)
  - Large isoplanatic angle
- Differential Phase
  - Water vapor limited sensitivity ~ σ_{PWV}/SNR ~ 25/SNR
  - photon limited with phase referencing ~ 20 μrad
    (Kmag = 5, 10 min int, 1.8 m telescope, 10% throughput)
- Null depth
  - Optimized experiment design (spacing, cross-combiner)
  - Lower thermal background and long integrations
  - Water vapor limited sensitivity scales as differential phase
- Background limited sensitivity improvement ~sqrt(coherence time)
  - ~ T_{NEP} x sqrt(τ_0) ~ 4.7 mag(K), 2.5 mag(N)

Dome C Location
Implications for Interferometry

- Excellent thermal infrared sensitivity.
- No adaptive optics necessary.
- Reduced phase fluctuations.
- High-precision observations in M band.
- Increased FOV for phase reference.
- Slower fringe tracking.
- Enables 18-28 micron observations.
- Long continuous integration times.
- Excellent u-v coverage.
- **Increased sensitivity in all “precision modes”.**
- **Reduced systematic errors.**
- **Expanded wavelength coverage.**

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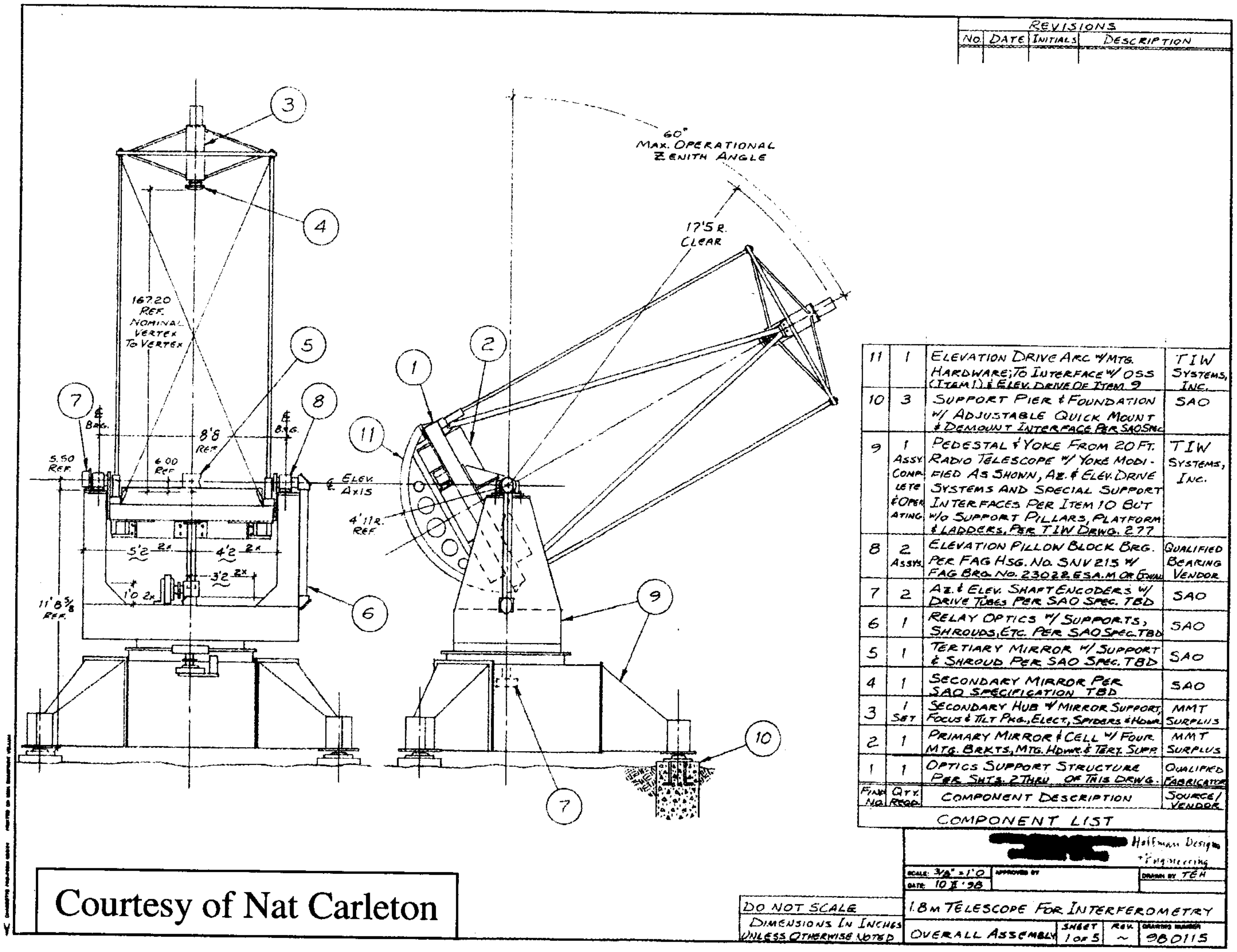
Current Status

- UofA/SAO interested in making the some of the 1.8 meter MMT mirrors available to the API project.
- Extensive SODAR and DIMM site testing of Dome C starting in January 03.
- API testbed proposal planned.
- Interferometer design concepts being evaluated.
- Developing ROM cost estimates for API components.
- Building international collaboration.
- Establishing collaboration science priorities.
- Specific proposal strategies being developed.

SAO Concept Using MMT Mirrors



Courtesy of Nat Carleton

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Approach

- Site testing at Dome C.
- API testbed (APtI) interferometer; operate over winter.
- Build up interferometer unit cell on US mainland; demonstrate remote operation.
- Modify interferometer unit cell if necessary based on testbed and single telescope experience.
- Deploy IF unit cells at Dome C.
- Retain operational engineering model on US mainland.

API Testbed Motivation

- Operational demonstration of interferometer in Antarctic conditions.
  - Likely required by NSF/OPP.
- Direct test of interferometric atmospheric parameters.
  - Prudent prior to full project commitment.
- Early science results.
  - Likely both prudent and required.
  - Capable in principle of better performance that Keck Interferometer outrigger telescopes.
- Operational lessons incorporated in API design.
  - Lowers risk of API instrument.

API Testbed Timeline/Scope

- Explore APtI institutional support (hardware and software contributions).
- Possible June '03 APtI proposal to NSF/OPP.
  - 2 to 3 M over 3 years.
- Build on KI/PTI software and hardware development.
  - Minimize risk, reduce nonrecurring engineering costs.
- APtI similar to a fully "containerized" PTI.
- 40 cm siderostat at Dome C has comparable sensitivity than Keck outrigger telescope on Mauna Kea.
- Design for pair of 2 meter telescopes to replace sids for minimal API instrument.

A Possible "Big Picture"

- Exceptional Extrasolar Planetary science
  - Enabled by the site and optimized instrument design.
- International collaboration
  - Brings together a broad array of technical expertise.
  - Builds toward a joint TPF/DARWIN mission.
  - Essential for the nominal location.
- Strong institutional team
  - Interferometer experience (JPL, SAO, UofA).
  - Antarctic astrometry experience (SAO, UNSW, UofA).
  - Telescope building experience (UofA, SAO).
  - Strong instrumentation heritage (all).
- Substantial institutional contributions to project
- NSF potential interest through Office of Polar Programs
- NASA/ESA potential interest
  - API as a possible testbed for TPF/DARWIN tech. Development.
  - Complimentary science to TPF/DARWIN mission/s.

Dome C Pictures

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Dome C Site Testing

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Dome C Base

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Dome C Transport

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API Backup Material

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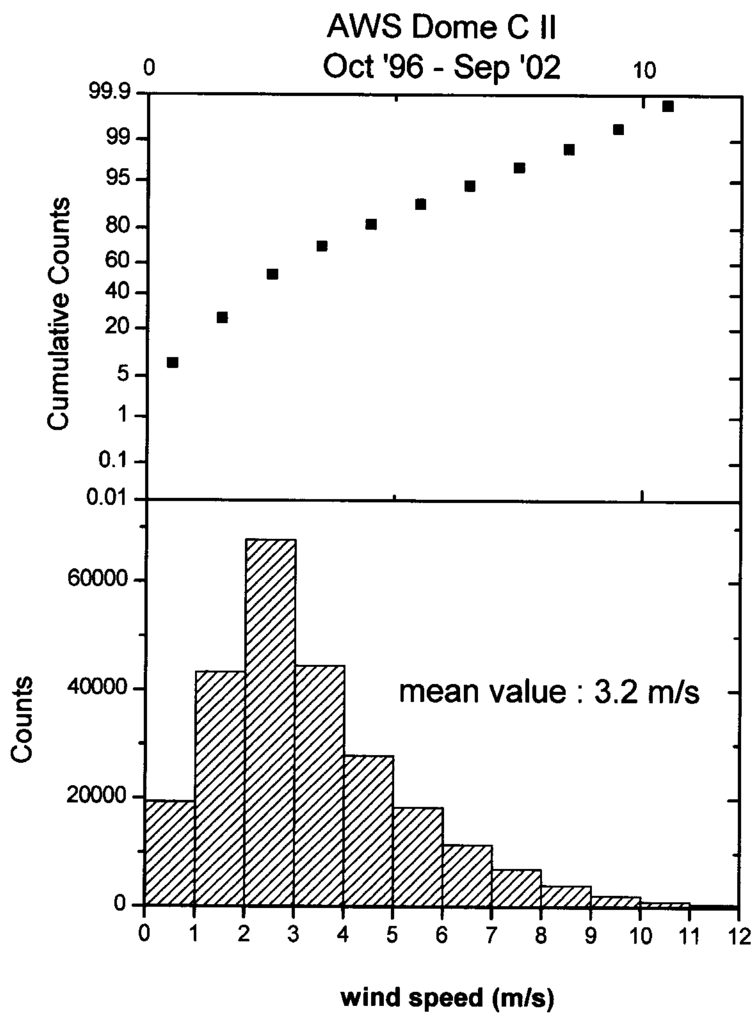
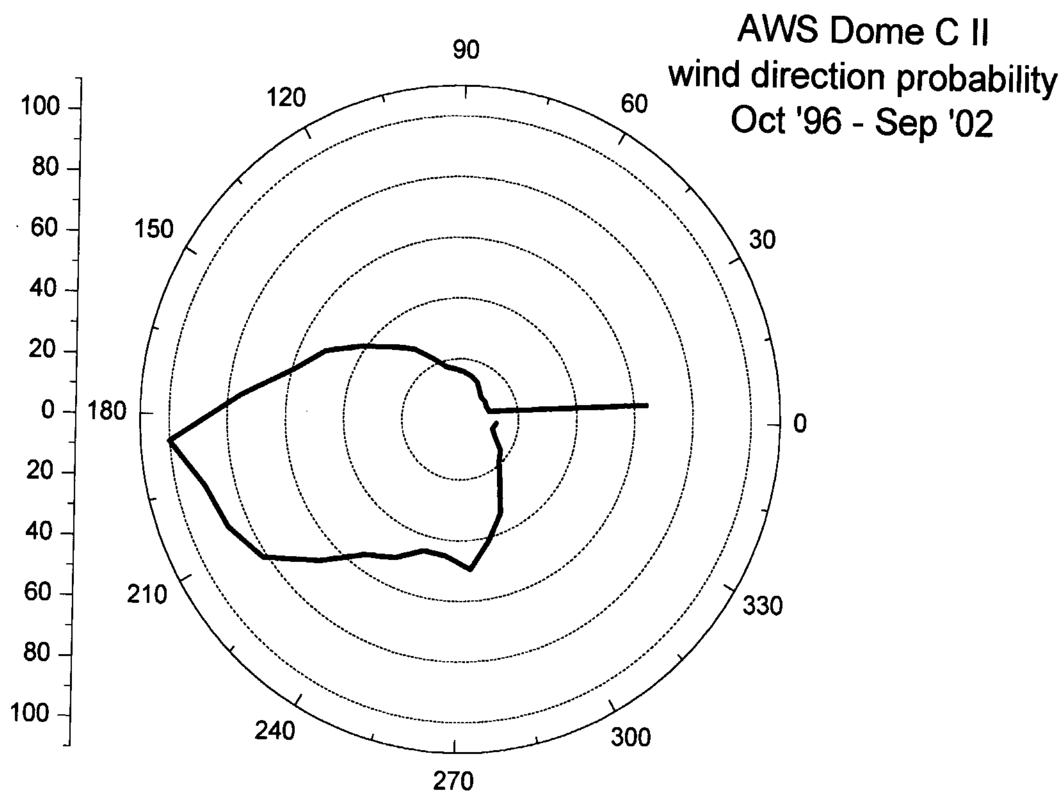
A Comparison of Sites

	Wind Speed (m/s)	PWV (um)	Temp. (K)	R_0 (cm)	Θ_0 (arcmin)	T_0 (s)	Sensitivity Increase (Kmag)	σ_δ (microas)	σ_{DP} (mrad)	Null Depth
Mauna Kea	12	1000	290	150	0.3	0.12	0	30	1	1e3 to 1e4 (N)
South Pole	6	400	220	67	3	0.1	+4.7	2.5		
Dome C	2.5	200	200	150	30	0.6	+4.7	0.6	0.02	1e5 (M)

Dome C Wind Speed Data



Dome C Wind Direction



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