Sky coverage of interferometry and the Antarctic

John Storey

With contributions from
Vincent Coude du Foresto
James Lloyd
Romain Petrov
Mark Swain
Andrei Tokovinin

Image: John Storey
Outline

- Where is Antarctica?
- Site conditions and sky coverage
- Is it practical?
- More on site testing
- Towers
- Some current ideas

Image: Patrik Kaufmann
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Image: Patrik Kaufmann
Antarctica is conveniently located (if you live in Sydney...)

Hobart
Sydney
Dome C

Image: Australian Antarctic Division
Dome C is 15° from the South Pole.
Contour map of Antarctica

- Atlantic Ocean
- Indian Ocean
- Pacific Ocean
- South Pole
- Dome F
- Dome A
- Dome C

USGS image
The Jet Stream

South Pole

Dome C
Peak Ground Acceleration up to $5\text{m/s}^2$: 10% probability of exceedance in 50 years

Source: http://www.seismo.ethz.ch/GSHAP/
Dome C

Is it the best observing site on earth?

Image: Jon Lawrence
Maybe, but the Chinese are also planning a permanent station at Dome A...
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Image: Patrik Kaufmann
Dome C versus conventional sites

- Seeing (above 30 m) 2 – 3x better
- Isoplanatic angle 2 – 3x larger
- Coherence time 2.5x longer
- Scintillation 3 – 4x less
- IR background 20 – 100x less
- Aerosols up to 50x lower
Background reduction 2-5 µm

Sky and instrument background contributions differ.

Net background controlled by emissivity and transmission.

Instruments couple to background components differently.
Interferometry at Dome C

Fringe Tracking Limit for tip-tilt only

6 magnitude improvement over Paranal

Max Telescope diameter (tilt only)

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</table>

magnitude

band
Phase Referenced Interferometer & AO potential at Dome C

**Background Normalized Hypervolume**

incorporating read noise limit

\[ BgLHV = r_0^2 \tau_0^2 \left( \frac{NEP_{300}}{NEP_{220}} \right) \]

- **DC/CP**
- **SP/CP**

Improvement due to turbulence.

Improvement due to background.

Swain, Toulouse conf. proceedings.
Paranal: Fried Parameter=9cm, $L_0 = 25m$, $\theta_0 = 1.9$ arcsec, K-band

Elhalkouj et al, 2006
Dome C: Fried Parameter = 5 cm, $L_0 = 10$ m, $\theta_0 = 5.3$ arcsec, K band

Elhalkouj et al, 2006
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Image: Patrik Kaufmann
The real disadvantages:

- See less of sky
- Less “dark time” (?)
- Ecliptic always low
- Physical isolation in winter
- Difficult to work outside in winter
- “Diamond dust” close to ground
- Wind gusts and icing at 30m (?)
Raw image of March 29th 2006
40sec exposure

Milky way

LMC

SMC

Satellite trail

Image: A. Moore & Gattini Team
Aristidi et al 2005, A&A
Dome C 50% = 2.8 m/s
Myth #5: The violent snow storms will bury the telescope...

Image courtesy Keck Observatory, Mauna Kea.
Ice core taken in 1978

Annual precipitation: 35 g/cm² ie, ~40 mm/year of ice.

Site testing with nuclear weapons...
Launch costs to LEO

- Rocket  $15,000/kg
- Shuttle  $60,000/kg
- Dome C  $5/kg
NSF C130 Hercules can carry 20 tonnes.
PNRA logistical support of Dome C by air.
French traverse from Dumont d’Urville to Dome C.

- Three traverses/year (currently)
- Each traverse delivers ~150 tonnes
- Twelve-metre sleds – essentially no size or weight restrictions

Image: John Storey
Complete 2-metre telescope (minus mirror)
Another 2 m telescope

2 m telescope

And one more...
The new Australian Antarctic Division air-link will be fully operational in 2007.
Ice motion: a manageable challenge

- Flow direction controlled by local slope
- Ice velocity increases with distance from Dome center
- \( V = 2 \text{ mm/yr on Dome} \)
- \( \Delta V = 1 \text{ cm/km/yr} \)
- \( \sim 0.1 \text{ um/hr/100m baseline change} \)
  - regular baseline model updates
- \( \sim 1 \text{ cm relative motions for array elements - manageable} \)
- Potential engineering challenge for delay lines
  - possible solution is OHANA-style multi-pass approach

Vittuari et al. 2004, in press
South Pole 10m: 2006 – 2007

- 240 tonnes
- US$28m (comparable to cost of Atacama version)

Ground Shield

- Operation to $l \geq 200$ mm
- 10m off-axis Gregorian
- Pointing $\sim 1.2''$
- Surface $\sim 20$ mm rms
- Low noise (extensive shielding)
- Low offsets (telescope chopping)

Images: SPT team
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Image: Patrik Kaufmann
Atmospheric transmission, *summer time*, Dome C
Walden et al, PASP, 2005
Atmospheric stability, *summer time*, Dome C

Walden et al, PASP, 2005
Atmospheric stability, *summer time*, Dome C

Walden et al, PASP, 2005
At Dome C, the turbulence at 16 km is *always* less than in Chile, and so astrometry is better and scintillation is less.

Kenyon et al 2006
Site testing: still need to know

- Isopistisonic angle
- Outer scale
- Clear-sky statistics
- Temporal spectrum (not just coherence time)
- Surface layer height and variability
- Kolmogorov?
- Better statistics on all parameters!

Image: Paolo Calisse
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Estimates of the boundary layer thickness at Dome C

“Thin”. Gillingham 1991, Schwerdtfeger plus AWS
< 30 m Lawrence et al 2004, SODAR
> 20 m Agabi et al 2006, DIMM
36 ± 19 m Agabi et al 2006, Balloon μthermal
27 m median Swain & Gallee 2006, modelling
Boundary Layer: height and seeing

Surface wind speed determines the boundary layer height and seeing. Seeing “saturates” above some wind speed. Strong seeing everywhere because wind speed is high enough to put seeing in the “saturated” regime. The difference in the seeing/wind speed profile for Antarctic sites indicates the Dome A/F inversion is stronger. Strong inversion implies more “clear sky” time.

Dome A/F will have fewer clouds than Dome C.

Swain & Gallee, 2006
Elevated Telescopes

~18 m ~21 m ~27 m

Height where Seeing is 0.1'' or better 50% of the time (JJA 2004)

Swain & Gallee, 2006
Boundary layer AO correction at South Pole and Dome C

If BL corrected with AO, no strong Strehl advantage of Dome C.

Swain et al, 2006
Dome C: Tower + AO

Tower + AO ~ HST!

Swain et al, 2006
Deflection under maximum wind gusts at Dome C is less than 25 milli arcsec (Lanford et al 2006)
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PILOT
Pathfinder for an International Large Optical Telescope

Strawman design:
- Dual Nasmyth f/10
- Brushless direct drive
- Fast tip-tilt secondary

Image: EOST
Can PILOT act as a pathfinder for future telescopes (including interferometers), and do good science?

Image: John Storey
A possible ALADDIN concept
(for details see poster #13)

CAD: Alcatel

19 October 2006 ARENA conference — Roscoff
Instrument comparison

- If ALADDIN is not above the ground layer, add either:
  - An AO system for 97% Strehl in the L band
  - Or a 1kHz intensity control loop

19 October 2006   ARENA conference — Roscoff
Performance comparison
ALADDIN vs. GENIE

Methodology:
- Use same end-to-end simulation software (den Hartog & Absil 2004)
- Appropriate instrumental and atmospheric model inputs

Performance gain due mostly to:
- Lower loop frequencies
  - Fringe tracking 4kHz
  - Tip-tilt 1kHz
- Better optical throughput
- Lower, more stable background
- Baseline optimization

Calibration gains not included

$5\sigma$ detectivity of exozodiacal light
in 1800s integration time
(in multiple of solar zodiacaal light units)

<table>
<thead>
<tr>
<th>Source</th>
<th>GENIE 2 x 1.8m</th>
<th>GENIE 2 x 8m</th>
<th>ALADDIN 2 x 1m</th>
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Absil et al., in preparation
Future ideas

- Overwhelmingly Large Array (OLA)
  - 12 x 12 m telescopes @ $700m
- Cold Overwhelmingly Large Array (COLA)
  - 12 x 2m telescopes at $60m
  - Comparable performance
  - 36x larger instantaneous FOV (single mode)
  - Broader wavelength coverage

Image: Paolo Calisse
And a final word from Jamie Lloyd

“Interferometers always expand to occupy the available space on the mountain top.”

USGS image
The end

Images: Michael Ashley & EOST