Astronomy from the Antarctic Plateau

John Storey
The Academia del Cimento’s experiment to observe the focussing of cold, ~1660 AD (G. Martillini, Tribuna di Galileo, Firenze).
Not just cold, but clear and calm.
This would be a good place

Not good for astronomy
The Jet Stream

Dome A
Dome F
South Pole
Stable planetary boundary layer

• The temperature inversion is huge (often 5°C/metre)
• The Stable Boundary Layer is thin (~ 25 metres)
• As a result, the Stable Boundary Layer is *stable*
The atmosphere can be extremely stable.
On the plateau, the sky is clear...
...extremely clear...
Summary of the global oceanic aerosol pattern detected by polar-orbiting satellites between July 1989 and June 1991.
Peak Ground Acceleration up to 5m/s²: 10% probability of exceedance in 50 years

Source: http://www.seismo.ethz.ch/GSHAP/
Light pollution

http://www.lightpollution.it/dmsp/
What makes a good observing site?

- Clear
- High
- Dry
- Cold
- Clean
- Dark
- Low precipitation
- No lightning
- No forest fires
- Low surface wind
- Low wind throughout atmosphere
- No high level turbulence
- Low seismic activity
- Accessible
- Continuous observing possible
- Stable climate

Image: Anna Moore
Conditions on the plateau are very benign

Image courtesy Keck Observatory, Mauna Kea.
…especially in summer.

Pressure altitude: 3600 m
Temperature: -30°C

(Dome C)
One year later…
Astronomy & Astrophysics from Antarctica

Image: © David A. Hardy/www.astroart.org
The SCAR AAA SRP aims to get astronomers working together, and working with researchers in other disciplines, to deliver the best scientific outcomes.
Astronomy & Astrophysics from Antarctica
Scientific Research Programme

Steering Committee:

• Michael Andersen (Denmark)
• Philip Anderson (United Kingdom)
• Michael Burton (Australia)
• Xiangqun Cui (China)
• Nicolas Epchtein (France)
• Takashi Ichikawa (Japan)
• Albrecht Karle (USA)
• James Lloyd (USA)
• Silvia Masi (Italy)
• John Storey (Australia – Chief Officer)
• Lifan Wang (China/USA)
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Four “Themes”

A. Site testing, validation and data archiving.
B. Arctic site testing.
C. Science goals.
D. Major new facilities.
Astronomy & Astrophysics from Antarctica
Scientific Research Programme
Working Group A: Site Testing, Validation and Data Archiving

Jon Lawrence (Convenor), Australia
Tony Travouillon (Co-convenor), USA
Phil Anderson, UK
Eric Aristidi, France
Michael Ashley, Australia
Kim Finney, Australia
Zhaohui Shang, China
Naruhsisa Takato, Japan
Contour map of Antarctica

Atlantic Ocean

South Pole

McMurdo

Indian Ocean

Dome F

Ridge A

Dome A

Ridge B

Dome C

Pacific Ocean

USGS image

Elevation in meters

0

4000
South Pole

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Station owner</td>
<td>USA</td>
</tr>
<tr>
<td>Completion date</td>
<td>1957</td>
</tr>
<tr>
<td>Geostationary</td>
<td>No</td>
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<tr>
<td>satellites visible</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Constant ZD sources</td>
</tr>
</tbody>
</table>
| Disadvantages       | Cloud cover  
|                     | Thick boundary layer  
|                     | Low elevation  |
Amundsen-Scott station, South Pole
### Dome A

<table>
<thead>
<tr>
<th>Station owner</th>
<th>China</th>
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<tbody>
<tr>
<td>Completion date</td>
<td>2014</td>
</tr>
<tr>
<td>Geostationary satellites visible</td>
<td>Almost</td>
</tr>
<tr>
<td>Advantages</td>
<td>Very good THz transmission</td>
</tr>
<tr>
<td></td>
<td>Thin boundary layer</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>?</td>
</tr>
</tbody>
</table>
Dome A
PLATO is a collaboration between China, Australia, USA and UK.
The PLATO Collaboration

- National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China
- Graduate University of Chinese Academy of Sciences, Beijing, China
- Chinese Center for Antarctic Astronomy
- University of New South Wales, NSW, Australia
- Nanjing Institute of Astronomical Optics and Technology, Nanjing, China
- Purple Mountain Observatory, Nanjing, China
- Steward Observatory, University of Arizona, Tucson, USA
- Macquarie University, NSW, Australia
- Anglo-Australian Observatory, Australia
- California Institute of Technology, Pasadena, USA
- Polar Research Institute of China, Shanghai, China
- Tianjin Normal University, Tianjin, China
- Texas A&M University, USA
- Thirty Meter Telescope Project, USA
- University of Chicago, Chicago, USA
- University of Auckland, New Zealand
- European Space Agency, Noordwijk, The Netherlands

Dome A, looking north
Dome A, looking up

Image: PLATO collaboration
Dome A, boundary layer

Data: PLATO collaboration

24 hours

Bonner et al (2010)
Dome A, boundary layer

Bonner et al (2010)
Gattini observations of a bright Cepheid, 35 day period

Differential photometry of $\gamma$ TrA and L Car

Data: PLATO collaboration
Nigel data

Moonlit sky

Strong aurora

Images: PLATO collaboration
Chinese Small Telescope Array (CSTAR)

The CSTAR catalog of over 10,000 stars observed every 20 seconds for six months is available on-line at:

http://archive.bao.ac.cn/en/cstar

Data: PLATO collaboration
## Dome C

<table>
<thead>
<tr>
<th>Station owner</th>
<th>France/Italy</th>
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<tbody>
<tr>
<td>Completion date</td>
<td>2005</td>
</tr>
<tr>
<td>Geostationary satellites visible</td>
<td>Yes, but…</td>
</tr>
<tr>
<td>Advantages</td>
<td>Minimal cloud cover</td>
</tr>
<tr>
<td></td>
<td>Thin boundary layer</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Rapid temperature variations</td>
</tr>
</tbody>
</table>
Dome C

Eric Aristidi et al (2009)
At Dome C, the turbulence at 16 km is always less than in Chile, and so astrometry is better and scintillation is less.

QuickTime® and a decompressor are needed to see this picture.
QuickTime? and a decompressor are needed to see this picture.
Example: CFD of PILOT enclosure
ASTEP-400, Dome C

QuickTime® and a decompressor are needed to see this picture.
## Dome F

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Station owner</td>
<td>Japan</td>
</tr>
<tr>
<td>Completion date</td>
<td>2014</td>
</tr>
<tr>
<td>Geostationary satellites visible</td>
<td>Maybe</td>
</tr>
<tr>
<td>Advantages</td>
<td>High</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Aurora</td>
</tr>
</tbody>
</table>
Contour map of Antarctica

Ridge A

Ridge B

Atlantic Ocean

Indian Ocean

Pacific Ocean

USGS image

Elevation in meters

0 4000
Ridge A and Ridge B

<table>
<thead>
<tr>
<th>Station owner</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completion date</td>
<td>-</td>
</tr>
<tr>
<td>Geostationary satellites visible</td>
<td>Ridge A: no Ridge B: yes</td>
</tr>
<tr>
<td>Advantages</td>
<td>Best overall</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>No-one has ever been there!</td>
</tr>
</tbody>
</table>

Atmospheric boundary layer thickness (m)

QuickTime® and a decompressor are needed to see this picture.

Swain & Gallee, 2006
Surface wind speed (m/s)
Fractional cloud cover

Saunders et al, 2009
Free-atmosphere seeing

Isoplanatic angle

Coherence time

Saunders et al, 2009
Precipitable water vapour (mm)

QuickTime? and a decompressor are needed to see this picture.

Swain & Gallee, 2006
<table>
<thead>
<tr>
<th>Site</th>
<th>25%ile winter PWV (mm)</th>
<th>50%ile winter PWV (mm)</th>
<th>Median winter transmission @0.66 THz (450 μm)</th>
<th>Best 25% winter transmission @1.46 THz (205 μm)</th>
<th>Best 10% winter transmission @1.90 THz (158 μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauna Kea 4100m</td>
<td>1.0</td>
<td>1.5</td>
<td>15%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Chajnantor 5050m</td>
<td>0.35</td>
<td>0.6</td>
<td>47%</td>
<td>7%</td>
<td>0%</td>
</tr>
<tr>
<td>Dome A, 4100m</td>
<td>0.10</td>
<td>0.14</td>
<td>74%</td>
<td>28%</td>
<td>4%</td>
</tr>
<tr>
<td>Ridge A, 4050m</td>
<td>0.08</td>
<td>0.12</td>
<td>77%</td>
<td>33%</td>
<td>11%</td>
</tr>
</tbody>
</table>

Yang et al (2010)
The Users

- Site testers
- Astronomers
- Other disciplines
- Project engineers
Content

- Publication list
- Related documents
- Metadata and statistics
- Database
- Basic graphing capability
- Recommendations/discussions/forum
- Links to research groups and other databases
Locations

• National institutions
• Mirrors in different regions
• Known database centers (IPAC, NCAR, etc..)
• Centralised development
Implementation

• One full time database engineer for 6-12 months?
• Use TMT’s database as basis?
• Funding being sought in Australia.
• Start implementation early 2011 and completion within a year.
Polar Auroras…

…beautiful, but not what astronomers came here to see.

Image: Daniel Luong-van
Polar Auroras

Image: PLATO collaboration
Dome A stable boundary layer

Six days of processed data from acoustic radar (SNODAR)

Data: PLATO collaboration
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Working Group B: Arctic site testing

Michael Andersen (Convenor), Denmark
Eric Steinbring (Co-convenor), Canada
Petre Popescu, Romania
Site testing, Ellesmere Island, Canada

QuickTime? and a decompressor are needed to see this picture.

Carlberg et al, 2010
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Working Group C: Science Goals

Michael Burton (Convenor), Australia
Hans Zinnecker (Co-convener), Germany/USA
Nicolas Epchtein, France
Yuko Motizuki, Japan
Remko Stuik, Netherlands
2. Background

- Extensive site testing activities
  - Antarctic provides a unique environment that is favourable for many kinds of astronomical research programs.

- Astronomical activities already conducted
  - Optical, IR, THz, Sub-mm, CMBR, Solar, Cosmic Rays, Gamma Rays, Neutrinos, Meteorites

- Sources of Material
Optical and Infrared Opportunities I

- First Light in the Universe (2-5µm IR)
  - Pair-instability SN at $z>6$
  - Gamma-ray bursts at high-$z$
  - Star formation history of the Universe ($H\alpha$ at high-$z$; $K_{\text{dark}}$ surveys)

- Equation of State of the Universe
  - Dusty Type 1A SN at high-$z$
  - Weak lensing at $K_{\text{dark}}$ (e.g. cluster masses)
  - Optical weak lensing, not accessible by LSST or PANSTARRS

Soon to be the PILOT trilogy...
THz and Sub-mm Opportunities I

- Formation of Molecular Clouds
- C⁺, C, CO, N⁺ over the Galactic Plane
- Origins of Stellar Mass
- Peak of SED in coldest cores
- Galactic Star Formation Rate
- Calibrating the “Schmidt” Law (SFR & N)
THz and Sub-mm Opportunities II

- Interstellar Medium of the Magellanic Clouds
  - N\(^+\) and C\(^+\)

- Templates for understanding high-z extragalactic emission
  - N\(^+\) and C\(^+\) in our Galaxy applied to interpret ALMA results
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Working Group D: Major new facilities

John Kovac (Convenor), USA
Xuefei Gong (Co-convenor), China
Albrect Karle, USA
Vladimir Papitashvili, USA
Vincent Coude du Foresto, France
## Examples of new projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Leaders</th>
<th>Description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>STO/HEAT</td>
<td>USA</td>
<td>0.5m THz</td>
<td>Balloon/Ridge A</td>
</tr>
<tr>
<td>AST3</td>
<td>China</td>
<td>3 x 0.5m Schmidt</td>
<td>Dome A</td>
</tr>
<tr>
<td>PLT</td>
<td>France</td>
<td>2.5m wide-field IR</td>
<td>Dome C</td>
</tr>
<tr>
<td>AST</td>
<td>France/Italy</td>
<td>25m sub-mm</td>
<td>Dome C</td>
</tr>
<tr>
<td>ALADDIN</td>
<td>France</td>
<td>IR interferometer</td>
<td>Dome C</td>
</tr>
<tr>
<td>KDUST</td>
<td>China</td>
<td>2 - 4m wide-field IR</td>
<td>Dome A</td>
</tr>
<tr>
<td>FIRI-A</td>
<td>UK/ESA</td>
<td>THz interferometer</td>
<td>?</td>
</tr>
</tbody>
</table>

Also small optical/IR and THz telescopes planned for Dome F by Japan, and for Dome A by the China.
ARENA was a European FP6 coordinating action led by the University of Nice.

This four year study has just concluded with a 100-page report.

The results from that study will be absorbed into SCAR AAA.
“[We recommend]…to start immediately, in 2010, a phase B study for PLT…”.
PLT— the Polar Large Telescope

- 2.5 metre infrared telescope
- Wide-field imaging science
- FP7 proposal led by U. Nice
- Sited at Concordia Station, Dome C, Antarctica
- IR detector: 16 4k x 4k arrays

Image: Andrew McGrath
4m optical/IR
Ultra Light Weight and Low Cost Telescope Mount

M. Kurita  Nagoya Univ.
The South Pole Telescope shows that major astronomical facilities are possible in Antarctica
These folk are astronomers, too.
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Upcoming meetings

Astronomy & Astrophysics in Antarctica meeting, Xian, China (August 2010)

Comprehensive Characterization of Astronomical Sites meeting, Kislovodsk, Russia (October 2010)

- SCAR Open Science Conference, Portland, USA (July 2012)
IAU General Assembly, Beijing, China (August 2012)
AAA Kick-off meeting
Sydney, 30 June - 1 July 2011

Image: Brian Corey, MIT
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Thank you.