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PILOT – the Pathfinder for an International Large Optical Telescope

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Abstract

Recent observations of exceptionally low levels of free-atmosphere turbulence at Dome C, combined with earlier measurements of greatly reduced infrared backgrounds, create a compelling case for the construction of a general purpose 2-metre class optical/infrared telescope. The PILOT project brings together astronomers from around the world in a bid to construct a medium-sized telescope that will not only perform unique and valuable science, but will also pave the way for the next generation of large single-mirror telescopes and multi-aperture interferometers in Antarctica.

1. Site conditions at Dome C

Dome C (75.6S 123.21 E, 3250m) has been the subject of intense interest since the announcement by the French and Italian Antarctic programs that a permanent, year-round station, called *Concordia* (Candidi & Lori 2003), would be constructed there. With the station now open, discussions are well underway about the optimum way to move forward towards large, uniquely powerful astronomical facilities costing $100m or more. Based on measurements of the infrared background and sub-millimetre transparency at the South Pole, it was already clear that Concordia would offer an exceptional opportunity for astronomy (eg, Storey et al 2003). So far, only summer-time data are available for Dome C in the submillimetre (Calisse et al 2004) and infrared (Walden et al 2005), yet it is already clear that Dome C is at least as good, if not better, than South Pole – itself an exceptionally good site.

More recently, measurements of the free-atmosphere turbulence (Lawrence et al 2004, Aristidi et al 2005b) have shown that the free atmosphere is considerably more stable than anywhere else on earth. Once the turbulent surface layer has been overcome, either through Ground Layer Adaptive Optics (GLAO) or by mounting the telescope on a small tower or artificial hill, an optical telescope at Dome C will enjoy the best seeing, lowest scintillation, longest coherence times and widest isoplanatic angles of any telescope on earth.

The extremely benign wind conditions (Aristidi et al 2005a) at Dome C are also favourable to the construction of large telescopes. Antarctic astronomy is now developing rapidly (for a review see Storey 2005), and construction of an optical/infrared telescope with performance comparable to the largest existing telescopes elsewhere on earth is an important next step.

2. Logistics

The "baseline" design for PILOT is based on a 2.4m diameter Cassegrain telescope manufactured by EOST in Tucson, Arizona. This telescope can be broken down into four sub-assemblies, the largest of which is roughly the size of a shipping container and the smallest of which contains the primary mirror. The telescope would be assembled and fully tested in Tucson, then broken down into these four pieces for shipping to Hobart via commercial container vessel.

In Hobart, the containers would be transferred to the IPEV icebreaker *l'Astrolabe,* for shipping to Dumont d'Urville. Once unloaded and placed on sleds, the containers could be towed overland to Dome C on one of the three regular summer-time traverses. These typically take 11 days to reach Dome C from the coast.

Assembly at Dome C would be facilitated by the fact that the telescope has already been preassembled into large modules. Alignment and post-assembly adjustment can be kept to a bare minimum. The telescope enclosure is a light-weight structure that takes advantage of the very low wind speeds to save on structural strength. As with the telescope, this would be pre-assembled, then broken down into a small number of component pieces before shipping to Dome C.

3. Future site testing

The members of the PILOT consortium are of the view that enough is already known about site conditions at Dome C that construction of a 2-metre class telescope is not only fully justified, but is an essential next step in properly understanding the ramifications of the unique atmosphere and the unusual operational conditions. In effect, some site testing is best done through the pursuit of challenging scientific programs that push the spatial resolution, sensitivity and stability of the instrumentation to its limits.

Nevertheless, there is still much to be learned about the site through dedicated conventional site-testing instruments, and a vigorous, ongoing campaign of site testing is essential while PILOT is under construction. Key parameters yet to be fully understood include:

- Clear sky statistics
- Optical sky brightness
- Near-ground turbulence
- Atmospheric parameters relevant to adaptive optics and interferometry
- Water vapour statistics and "sky noise".

A series of experiments has been proposed by teams from Nice (France), Arcetri (Italy), UNSW (Australia) and Caltech (USA) to properly quantify each of these parameters.

4. PILOT

PILOT is currently proposed to be based on a conventional 2.4 metre Cassegrain telescope, modified to a Gregorian configuration with two Nasmyth foci. An adaptive secondary mirror would provide correction for the turbulent ground layer, and at the same time reduce wavefront errors created by minor optical misalignment of the telescope and temperature-induced low-order aberrations in the mirrors. PILOT would be based closely on an existing EOST design, thus keeping non-recurrent engineering costs to a minimum.

PILOT is designed for maximum reliability and minimum maintenance. However, when maintenance work is required, or under conditions of unusually high blowing snow, a lightweight enclosure will surround PILOT to provide a more favourable working environment. Such an enclosure must be light-tight, to avoid interference with other optical facilities on site, and could be heated to a comfortable temperature.

To take best advantage of the stable atmospheric conditions, PILOT will normally observe with the enclosure folded down, allowing clean airflow over the telescope and optics. Thermal equilibration will be crucial, and all heat sources in the vicinity of the telescope (including motors and electronics) will need to be actively cooled with the heat dumped well down-wind of the telescope.

The strawman instrument suite includes a diffraction-limited optical imager, a wide-field optical imager, a near-diffraction-limited near and mid-infrared camera, and a multi-pixel terahertz photometer/spectrometer.

5. PILOT science

A comprehensive science case for PILOT has been developed by a team of 27 astronomers from 4 countries, and has recently been published (Burton et al 2005).

Key science programs include:

1. Our solar system and others
    - Orbital debris around earth
    - High resolution planetary imaging (lucky imaging)
    - Photometric planet searches
    - Protoplanetary disks
    - Planetary microlensing

2. Our Galaxy and its environment
    - Stellar oscillations
    - Protostellar survey (submm)
    - Massive star formation
    - Galactic ecology
    - Submillimeter spectral lines
    - Submillimeter continuum
    - Cool brown dwarfs
    - Exosolar giant planets
    - Pulsar wind nebulae
    - Obscured AGB stars in Magellanic Clouds
    - Stellar populations and near-field cosmology
    - Stellar streams and dark matter halos

3. Our universe and its evolution
    - Survey for supernovae in starbursts
    - Time delay in gravitational lenses
    - Galaxy evolution: deep near IR survey
    - Emission line mapping of high-z universe

- Complete star formation history of universe
- Beyond Hubble – a PILOT ultra-deep field
- Probing first light with gamma-ray bursts
- Cosmic shear

5. Beyond PILOT

Once funding approvals and international agreements are in place, PILOT could be operational within 3 – 4 years. Although an operational life of at least ten years is planned, the successful commissioning of PILOT will remove many of the remaining uncertainties that must be resolved before very ambitious projects can be set in motion. These include a large (8-metre class) clear-aperture optical infrared telescope, GMTA (a 25 metre diameter ELT, Angel et al 2004), interferometers with multiple 2-metre apertures distributed over a kilometre or more (du Foresto et al 2003; Vakili et al 2004), and even large sub-mm single dish telescopes such as ASO (Olmi et al 2004). If PILOT can help even a subset of these projects move forward, it will truly have earned the "Pathfinder" element of its name.

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