LAPCAT: the Large Antarctic Plateau Clear-Aperture Telescope

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ABSTRACT

We present a proposal for an 8.4 metre off-axis optical/IR telescope to be located at Dome C, Antarctica. LAPCAT will use a mirror identical to the offset segment recently cast for the Giant Magellan Telescope (GMT) as a completely unobscured f/2.1 primary. With a cooled deformable Gregorian secondary in a dewar following prime focus, LAPCAT will allow for diffraction-limited imaging with only a single reflecting surface at ~ 220K, and thus the lowest possible thermal background obtainable on earth. The exceptionally low atmospheric turbulence above Dome C enables very high contrast imaging in the thermal infrared, and diffraction limited imaging extending to optical wavelengths (20 mas at 800 nm, where Strehl ratios > 60% are projected). As an example, a deep 5 μm exoplanet imaging survey to complement current radial velocity methods could take advantage of both the low background and pupil remapping methods for apodization enabled by the clear aperture. Many new, young, giant planets ($\geq 3M_J$ at 1 Gyr) would be detected in orbits ≥ 5 AU out to 20 pc. By providing a test bed for many of the GMT technologies in an Antarctic environment, LAPCAT also paves the way for the eventual construction of a second GMT at Dome C. Such a telescope would have unparalleled capabilities compared both to other ELTs in temperate sites and to JWST.

Keywords: Telescopes, Antarctica, exoplanets, adaptive optics, infrared, off-axis

1. INTRODUCTION

A decade of astronomical site testing in Antarctica has revealed that conditions on the high plateau are uniquely favourable to optical/IR astronomy (see, for example, Storey 2005 and references therein[1]). The extremely low temperatures result in an infrared sky brightness that is typically 20 to 50 times lower than that at temperate sites, giving an immediate improvement in sensitivity of 4 to 7 times that of a comparably sized telescope elsewhere. In addition, the free-atmosphere seeing is two to three times less than at even the best temperate sites[2], and the high-altitude turbulence is particularly low – promising significant reductions in scintillation, larger isoplanatic angles and increased astrometric accuracy[3]. From a practical point of view, wind speeds are the lowest on earth[4], seismic activity is negligible, and there is no dust. Large astronomical projects such as the 10 metre South Pole Telescope[5] are already demonstrating that logistic and operational hurdles can be overcome, and that the design of precision instruments to work under Antarctic conditions is possible.

Dome C (75 ^{O} 6′ south, 123^{O} 21′ east, 3250 m) is the site of the new French-Italian station of Concordia[6]. Year-round operation of this station, which promises to offer unique opportunities for astronomy[7,8], began in 2005. A recent review of the optical properties of the Dome C site is given in Kenyon and Storey[9]. Summer-time measurements of the infrared background at Dome C confirm expectations based on South Pole data that the infrared transparency, coupled with the low atmospheric temperatures, offers unparalleled observing conditions[10].

Several proposals have been made for the construction of large interferometers and filled-aperture telescopes at Dome C that would ultimately be the most capable telescopes on earth. One such proposal[11] is to construct a copy of the Giant Magellan Telescope[12]. However, before a project of such a scale can be developed, it is important to demonstrate its feasibility by deploying an intermediate scale facility. LAPCAT is designed to take maximum advantage of the unique conditions at a high plateau site such as Dome C by using an unobscured aperture and high efficiency, low emissivity instruments. In addition to being a powerful facility in its own right, LAPCAT is in turn an essential stepping stone to a future generation of facilities with unrivalled capabilities. In this paper we outline the LAPCAT concept, and present a series of ideas on how the telescope might be realized.

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Ground-based and Airborne Telescopes, edited by Larry M. Stepp, Proc. of SPIE
Vol. 6267, 62671E, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.672159

2. THE LAPCAT CONCEPT

LAPCAT is conceived as a versatile optical/IR telescope. The borosilicate primary mirror is identical to one of the off-axis segments of the Giant Magellan Telescope (GMT). Used in this way, an unobscured 8.4 metre aperture with a focal ratio of f/2.1 is achieved. Two foci are envisaged. The first uses a conventional Gregorian secondary to deliver an f/20 beam to a focal station alongside the primary mirror. This focal station can accept a variety of instruments (see Section 5). For example, with an adaptive secondary mirror, diffraction-limited imaging should be achievable even at 800 nm for significant fraction of the time, resulting in an image resolution of 20 mas.

The second focal station is a dedicated cryogenic Gregorian focus optimised for direct imaging of exoplanets at 3–5 microns (See section 4). This top-end instrument can be quite large, as the optical axis of the GMT primary mirrors is some 4.5 metres away from the inner edge of the mirror. Having such a large amount of space available greatly simplifies the mechanical configuration.

In order to place LAPCAT in the clean air above the turbulent boundary layer[13,14] on the Antarctic plateau, LAPCAT will sit on a 25 metre high tower. There is no need for a protective dome; wind speed at ground level has never exceeded 20 m/s during the past 20 years. Winds at an elevation of 50 metres (where the top-end of the telescope will be) can be expected to be somewhat higher than this, but still very low by the standards of conventional sites. There is no need for protection from rain or dust, of course, and the mirrors can be covered during periods of blowing ice crystals by a roller-blind shutter similar to that used on the MMT. The total precipitation at Dome C is low (just 40 mm ice-equivalent per year), and a completely open structure for the telescope appears feasible.

Because there is ample room around the top-end assembly, there is no disadvantage in providing a large elevator system to raise the top-end instrument into position. This is perhaps most easily done by a system of three cables, which pass over permanently mounted pulleys at the top end. Each cable is driven by an electrical winch mounted on the elevation horse-shoe. In this way the entire top-end assembly can be lowered to ground level for maintenance in a warm building at the base of the tower. When raised into position, the top-end assembly is automatically clamped against locating cones, in a similar manner to the system used in several current observatories (for example, the Anglo-Australian Telescope). In this way there should never be any need for people to climb to the top of the telescope (or even to the azimuth ring) except in the event of a breakdown.

Positional repeatability of the top-end assembly should be achievable to better than a micron, eliminating the need for re-collimation after a top-end change. The relatively slow f/2.1 primary mirror of LAPCAT is advantageous here, as it relaxes the tolerances on the positioning of the secondary mirror.

The same top-end cable system can be used as a general-purpose crane for maintenance purposes. In particular the cables can be used to exchange instruments at the lower Gregorian focal station. A small rotation of the telescope about its elevation axis is sufficient to translate the top of the crane over a distance of several metres.

Below LAPCAT, at the base of the tower, a small well-insulated building houses the observing room, an instrument laboratory, and heat exchangers to remove waste heat from the telescope drive motors, bearings etc. This building should be aerodynamically shaped to avoid "lofting" the turbulent boundary layer up into the telescope beam. Experience with the AASTINO[15] at Dome C shows that even a crudely shaped smooth structure can remain remarkably free of snow build-up over a period of years. The directional nature of the prevailing wind at Dome C helps enormously in allowing a tear-drop shaped building to be used to good effect. A port, several metres across, can be opened in the roof of the building to allow the top-end and offset Gregorian instrument packages to be lowered inside.

By making the primary mirror identical to the six off-axis mirrors of the GMT, LAPCAT takes advantage of the production line that is already in place for that telescope. This includes the mirror test tower and null optics. Using stressed-lap polishing, the Mirror Lab at Steward Observatory can produce the primary in about two years. Two further advantages stem from using a mirror identical to those of the GMT – first, there is interchangeability; second, LAPCAT serves as a technology pathfinder for the later construction of a full copy of the GMT on the Antarctic Plateau (see section 6).

It is likely that LAPCAT would operate for at least a decade without any need to re-aluminise the primary mirror. Tests done by UNSW have shown that an overcoated aluminium mirror, exposed to the elements at Dome C for over a year, lost less than 0.5% reflectivity at 500 nm. By the time re-aluminising of LAPCAT was necessary, other very large telescopes should also be operating on the Antarctic Plateau. These could share a common aluminizing tank, or mirrors could be returned by ship to the US or Chile to make use of facilities there.

If the total weight of LAPCAT can be kept to 300 tonnes (for example, through the use of composite materials for some of the main structural elements), a base of only 25 metres by 25 metres is needed to keep the "floor loading" on the ice to 500 kg/square metre. At this pressure and below, snow that has been compacted by bulldozers and rollers will provide a firm and stable base, eliminating the need for more complex foundations. An astronomical telescope of similar size to LAPCAT is already under construction at the South Pole. The SPT (South Pole Telescope)[5] is a 10 metre sub-millimetre telescope designed for large-area surveys of faint, low contrast emission regions and for mapping of cosmic microwave background anisotropies. SPT will stand over 20 metres tall and has an all-up weight of 240 tonnes, plus a very large surrounding ground shield.

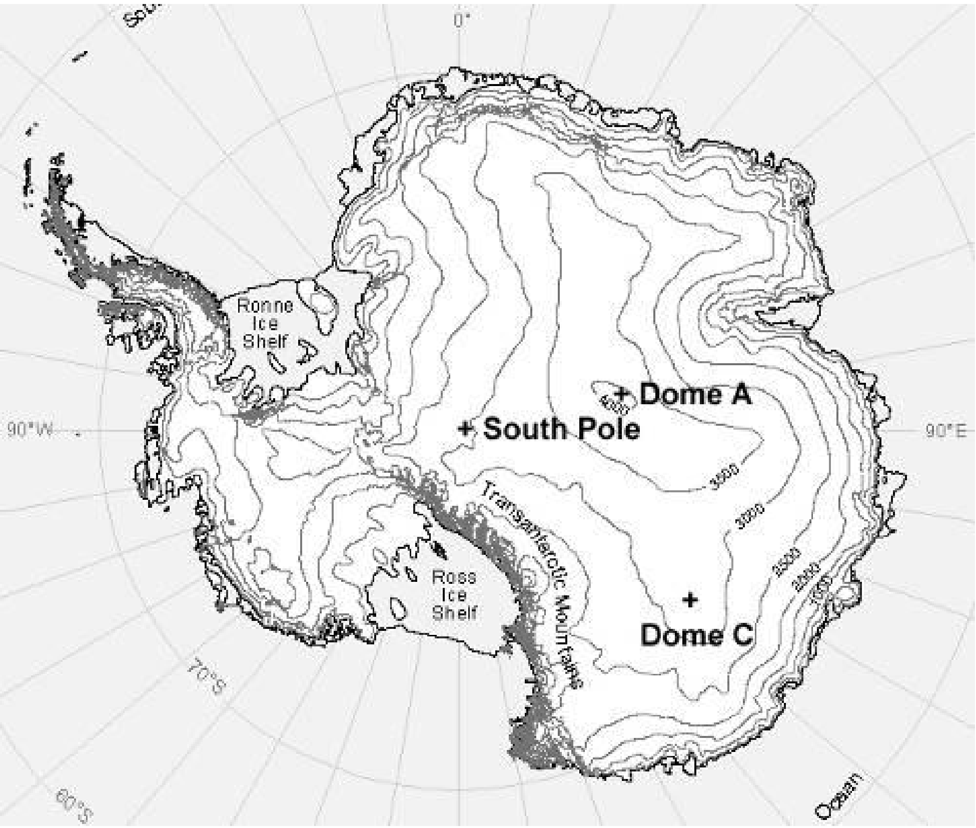

Figure 1. Antarctic map (based on map from the Australian Antarctic Data Centre)

3. OFF-AXIS TELESCOPES

Off-axis telescopes have been used by solar astronomers for many years, and include the famous McMath-Pierce telescope[16] that has operated at Kitt Peak since 1962. Plans for modern off-axis solar telescopes are well underway, including the Advanced Technology Solar Telescope[17] to be constructed at Haleakala in Hawaii. This will be a 4 metre off-axis solar telescope with integrated adaptive optics to achieve diffraction-limited imaging of 30 milli arcseconds at 500nm. Another off-axis solar telescope is the 1.6m diameter New Solar Telescope[18] to be built at Big Bear Observatory, California, and expected to deliver first light in 2008.

Nocturnal astronomers have been slower to adopt the technology, although several telescope concepts have been proposed over the past few years. Amongst these are the 6.5 m New Planetary Telescope[19], mooted as a replacement for IRTF, and the very large High Dynamic Range Telescope[20] proposed as replacement for the Canada France Hawaii

Telescope. An off-axis design was also considered for the SOAR telescope[21], although it was eventually built as a conventional concentric layout.

The performance of off-axis telescopes has been reviewed in detail by Kuhn and Hawley[22]. The advantages of an unobstructed aperture are well known, and include:

- Greatly improved coronagraphic performance
- No thermally emitting structure within the beam, reducing overall emissivity
- No central obstruction, leading to greater optical throughput
- No central obstruction, simplifying AO reconstruction algorithms
- Absence of a central obstruction, leading to an improved point spread function
- Absence of secondary support spider, thus eliminating diffraction spikes
- Absence of all mechanical structures within beam, leading to reduced scattering
- Lower instrumental polarization relative to a Nasmyth or bent Cassegrain layout.

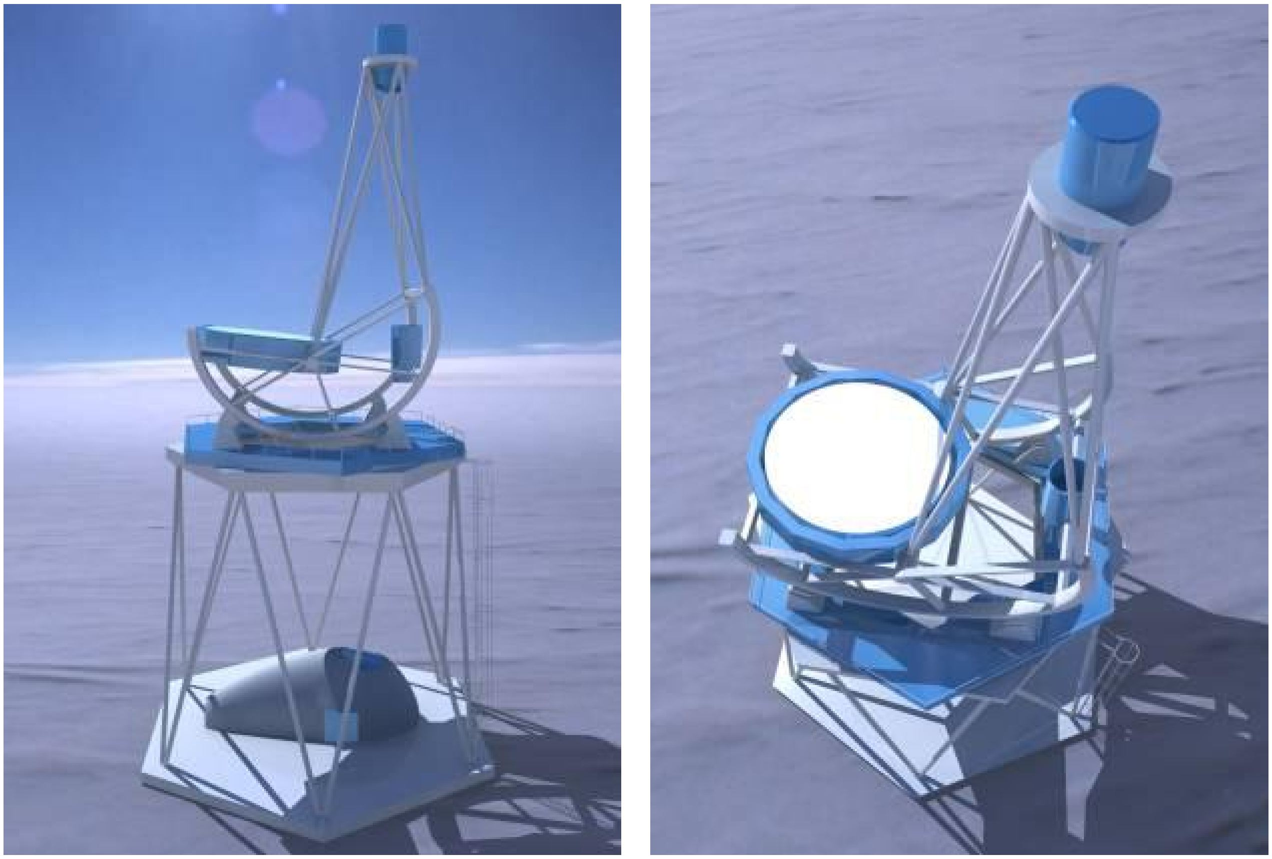

Figure 2. LAPCAT concept designs.

Several of these advantages become crucial for experiments that aim to directly image faint objects in the vicinity of very much brighter ones. Two examples are obvious – imaging of extrasolar planets (which by definition are in orbit about a parent star), and faint-object studies using adaptive optics (which require a bright reference star within the isoplanatic patch).

With an alt-az telescope (the configuration favoured for structural reasons – particularly for large telescopes), the diffraction spikes of a conventional "concentric" telescope rotate with respect to the field as the telescope tracks.

Accurate photometry is thus compromised as the spikes from stars in other parts of the field sweep across the object of interest. This is particularly important for time-resolved observations. Kuhn and Hawley[22] show that for a 5 minute integration, a 13th magnitude star 110 arcseconds away can double the background noise as its diffraction spikes sweep past. A zeroth magnitude star as far as 12 degrees away can similarly double the background fluctuations. The more crowded the field, the more likely a diffraction spike from a random star will sweep through the photometric “aperture” of the star being studied.

The disadvantages of an off-axis telescope have traditionally been the additional cost of mirror fabrication and a slight increase in the weight of the support structure for the same stiffness. However the development of the computer-controlled stressed-lap polishing technique has greatly facilitated the production of fast, aspheric off-axis surfaces[23], leading to a relatively small marginal cost increase over a conventional design.

In Antarctica, the advantages of an off-axis telescope are magnified. In the main infrared photometric bands the sky is so transparent and so cold that the central obstruction of a “concentric” secondary mirror and its supporting spiders can easily dominate the infrared background. Although a cold stop in the dewar can block emission from around the secondary, blocking emission from the spiders (which rotate relative to the field of view) is much more problematic. Similarly, the heat-generating adaptive secondary mirror so well suited to correcting for the turbulent ground layer in Antarctica is placed outside the telescope beam in an off-axis design. This further increases the infrared sensitivity enhancement obtained by using an adaptive secondary[24].

The atmospheric scattering on the Antarctic plateau is also believed to be much lower than other sites. Although this has yet to be quantified at Dome C, measurement of the aerosol absorption coefficient for light at 550 nm at South Pole give a best value that is 50 times lower than the best values at Mauna Loa[25]. The fact that the atmosphere is essentially dust free should also allow the mirror to be kept perfectly clean and free of dust and large scattering particles. Small ice-crystals are carried in the air, but these should be relatively easy to sublime from the mirror surface with gentle heating. The combination of reduced atmospheric scattering, a perfectly clean mirror surface (perhaps superpolished) and an unobscured beam leads to the possibility of carrying out the highest dynamic range imaging possible from any site on the surface of the earth.

4. PRIMARY LAPCAT SCIENCE

One of the primary science drivers for LAPCAT will be to directly image exo-planets. The high thermal infrared sensitivity, the high level of correction achievable with its adaptive optics system, and the telescope optical configuration make LAPCAT uniquely capable for such science.

While detailed models must be developed to determine the exact performance and optimum configuration of the LAPCAT adaptive optics system, first order scaling laws can be used to determine system performance compared to existing AO facilities at mid-latitude sites. The main sources of AO system error, which are dependent on atmospheric characteristics (coherence time, coherence length, isoplanatic angle) are each reduced at Dome C relative to mid-latitude sites (due to the more stable atmosphere). The combination of these reduced error sources leads to an expected total wavefront error for LAPCAT some 60-70% of that achievable on a similar sized telescope at a good quality mid-latitude site. This results in a higher Strehl ratio at mid-infrared wavelengths, and allows reasonable levels of correction to be extended towards shorter wavelengths in the near-infrared.

The primary source of noise for exo-planet imaging at close angular separations arises from scattered starlight at the position of planet. Traditional coronagraphic and apodisation techniques can suppress the stellar PSF, but have significant limitations in the achievable resolving power and throughput. Techniques currently being investigated, such as the Phase-Induced Amplitude Apodization Coronograph (PIAAC) proposed by Guyon et al. (2005)[26], should allow stellar suppression to inner working angles of several times the diffraction limit with very high efficiency. This equates to 3.5 AU at 10 pc for M band imaging with LAPCAT. Although apodised pupil masks can be used to suppress spider vane diffraction in Lyot coronographs, residual spider diffraction increases noise and can effect speckle statistics[27]. The PIAAC technique is likely to suffer from similar limitations, and thus the un-obscured primary of LAPCAT is advantageous.

While coronagraphic techniques suppress the scattered stellar PSF, they do not entirely suppress the speckle pattern resulting from the uncorrected stellar halo[28]. To gain the full advantage of the small inner working angle achievable with the PIAAC technique, efficient mechanisms for the suppression of this speckle noise must be employed[29]. Various techniques have been proposed to eliminate speckle noise, although the effectiveness of these techniques is still to be determined. The small increase in Strehl ratio of LAPCAT compared to mid-latitude sites at the mid-infrared L and M bands (both systems are close to diffraction limited at these wavelengths) provides only a small reduction to the speckle noise. At shorter wavelengths (H, K) this speckle noise reduction should be larger.

In Figure 3 the capabilities for mid-infrared M band exo-planet imaging with LAPCAT is analysed. Here we assume a perfect coronagraph and ignore speckle noise, i.e., the limitation primarily results from sky and telescopes thermal emission noise. In a 24 hour integration, LAPCAT should detect a 1.2 M_J mass 1 Gyr old planet at 10 pc, or a more mature 5 Gyr planet of 4.2 M_J. These are significantly lower masses than are detectable with existing facilities, and are comparable with the detection limits of future Extremely Large Telescopes at mid-latitude sites. Younger (100 Myr) Jupiter mass planets at very wide (~20 AU) orbits should be detectable with LAPCAT out to ~60 pc. LAPCAT thus provides a significant extension of the parameter space of other planet detection methods. The higher spatial resolution of ELT class telescopes will enable imaging of planets at closer orbits than LAPCAT. An ELT located in Antarctica[11] would thus be an exceptionally powerful facility for this science.

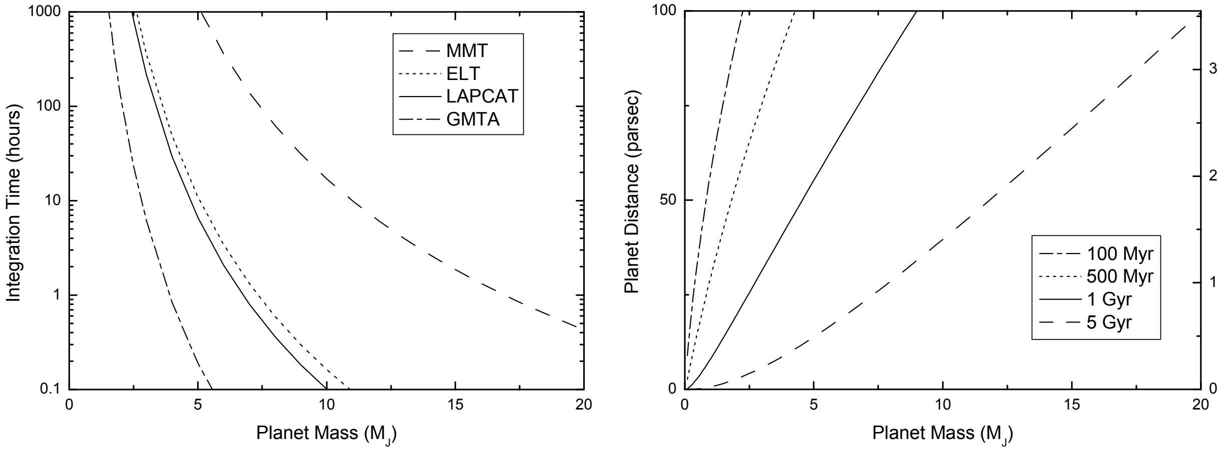

Figure 3. (a) M band integration time required as a function of planet (aged 5 Gyr) mass for the 8.4 m LAPCAT compared to the 6.5 m MMT, a 20 m mid-latitude ELT, and an Antarctic clone of Giant Magellan Telescope (GMTA). (b) Planet distance and corresponding minimum planet orbit (at $3\lambda/D$) as a function of planet mass and planet age for M band detection in 24 hours with LAPCAT. Model parameters are: SNR=10, pixel scale Nyquist sampled, signal summed over 7x7 pixels for background subtraction, total optical efficiency 20%, dark current 75 e/s/pixel, read noise 700 electrons/pixel, mid-latitude sky emission 40 Jy.arcsec^{-2}, Antarctic sky emission 0.3 Jy.arcsec^{-2}, telescope thermal emission 6 % at 0° C (mid-latitude) and -50° C (Antarctic). Planet flux is interpolated from Burrows et al. 2003[30]. Sensitivity model is consistent with MMT background limit[31].

5. OTHER LAPCAT SCIENCE PROGRAMS

The top-end focal station of LAPCAT can be replaced by a Gregorian adaptive secondary mirror to provide a second, f/20 offset Gregorian focal station alongside the primary mirror. This creates an opportunity to deploy a variety of additional instruments, greatly increasing LAPCAT's versatility.

Estimates of the point source sensitivity that an 8.4m telescope situated on a summit of the Antarctic plateau would deliver in median natural seeing conditions are given in the table below. These calculations are based on those presented in Table 1 of Burton et al.[32], with the fluxes scaled for background limited performance using an 8.4m telescope. We note that at optical wavelengths these sensitivities are typically a magnitude better than an 8m telescope on a good temperate site like Mauna Kea, rising to 3 magnitudes better in the thermal infrared.

Band	**Sensitivity** **SNR = 10, t = 1 hour**		**Gain over Mauna Kea 8m**
	μJy	Mags.	Mags
V (0.55)	0.05	27.2	0.9
R (0.65)	0.05	26.8	0.9
I (0.80)	0.08	26.0	0.9
J (1.2)	0.4	24.2	1.2
H (1.65)	0.5	23.3	1.5
K (2.30)	0.3	23.4	2.2
L (3.76)	8	18.7	2.0
M (4.66)	15	17.5	3.1
N (11.5)	5E2	12.1	1.4
Q (20)	3E3	8.6	1.4

Table 1: Seeing limited point source sensitivities for an SNR=10 in 1 hour of integration, in μJy and Vega-magnitudes, for the wavebands listed. The spatial resolution is obtained by convolving the diffraction limit with the natural seeing. The gain, in magnitudes, over an 8m telescope on Mauna Kea is also listed.

Projects that could be conducted range from studying weather patterns on Solar System objects to the formation of the first stars in the Universe. Some examples are presented below.

5.1 High resolution planetary imaging

By using the technique of selective imaging (or "lucky imaging", Baldwin et al. 2001)[33] it is possible to obtain diffraction-limited images of a bright source by selecting and co-adding short (10-50ms) exposures of frames that are near-diffraction-limited. For LAPCAT this would provide a resolution of 0.015″ at 500nm and 0.06″ at 2μm. For such a technique to work it is essential to have excellent seeing, in order that a sufficient number of frames occur in a reasonable time to achieve this performance over the angular size of the planets, which will be ~15–30″.

5.2 Searches for brown dwarfs and free-floating extrasolar giant planets

Brown dwarfs are sub-stellar mass objects whose mass is too low for nuclear fusion of hydrogen to sustain the luminosity over the bulk of their lifetime. They are born hot, and then spend their lives cooling (see e.g. Burrows et al. 2001)[34]. As they do their spectra change, initially resembling M-dwarfs, and then passing through the L- and T-dwarf stages as first dust emission dominates, to be swamped by methane absorption. They may end up looking spectrally like planets such as Jupiter. Giant extrasolar planets fall into the same class of objects as brown dwarfs, though their origins are probably quite different (formed in a disk rather than being the centre of a self-gravitating cloud). While brown dwarfs do not account for the missing mass, they are a fundamental part of the study of stars, and their mass distribution (particularly their occurrence in binary systems) has yet to be determined.

Age	**Spectral Type**	**K Flux (2.3μm)**	**L Flux (3.8μm)**	**M Flux (4.7μm)**	**Distance (pc) SNR=5 for τ = 1 hour**		
Years		Jy	Jy	Jy	K	L	M
10^7	M	3 (-1)	3 (-2)	3 (-2)	15,000	800	600
10^8	L	5 (-3)	1 (-3)	5 (-3)	2000	150	200
10^9	T	1 (-5)	1 (-5)	5 (-4)	80	15	70

Table 2: Fluxes in Jy of a 15 $M_{Jupiter}$ brown dwarf at 10 pc distance, in the infrared K, L and M wavebands (adapted from Burrows et al. 2001), as a function of age. The distance away in parsecs that LAPCAT could detect such objects (SNR=5 in 1 hour) is given.

The table provides estimates of the distance to which brown dwarfs of differing age (and therefore spectral types) could be detected by LAPCAT based on model fluxes for the evolution of a 15 $M_{Jupiter}$ brown dwarf. While young brown dwarfs are hot (and relatively luminous), the vast majority of them will be cool and faint (i.e. T dwarfs), and so can only be detected relatively close to the Sun. With a 10′ field of view, a KLM camera with dichroic beam splitters (to image the three bands simultaneously) would be able to survey a degree-sized region in 1-2 weeks, to find all brown dwarfs in the field out to a distance of ~70 pc.

5.3 Stellar populations and near-field cosmology

Our understanding of the formation and evolution of galaxies has largely rested on measurement of global quantities such as their luminosity, mass, colour and type. Recent measurements of stellar populations in a few nearby galaxies, however, have shown that these global quantities hide a richer past. For instance, in our sister galaxy in the Local Group, M31, such data show a population of intermediate age stars (7 – 9 Gyrs old) in the halo that is not present in the Milky Way (Brown et al. 2003)[35], showing that M31 has experienced a different accretion history. To identify the stellar populations which might reveal what this history is for galaxies in the Local Group, it is necessary for photometric observations to reach to below the main sequence turn-off on the HR diagram for an old stellar population.

For distances out to ~2 Mpc this requires measurements to V=29, or in the near-IR to reach J=25 or K=25. The best colour baselines will use V-K to identify the stellar populations present. LAPCAT will be able to reach these magnitudes in ~8, 1 and 6 hours at V, J and K, respectively, with an SNR = 5. The main source of confusion comes from fluctuations due to unresolved stars. The ability to image with a 0.2″ PSF, fully-sampled over a 5′ or larger field of view, minimises this confusion. To follow the accretion history across the Local Group it would be necessary to sample the stellar populations in the halos of ~20 different galaxies, covering a range of group densities. LAPCAT would be well suited to undertake such a project, an investigation into the near-field cosmological history of the assembly processes of galaxies in the Local Group. It would require about 1 month of observing time.

5.4 The evolution of galaxy mass and morphology – a LAPCAT Ultra Deep Field

Our view of the high-redshift Universe was revolutionized through the deep, high-resolution images obtained by the HST. These have shown that galaxies are spread throughout the sky, at number densities of up to one for every square arcsecond. They also show that star formation rates are much higher in the past than today, appearing to peak at redshifts from z=1-4. Such deep fields obtained by HST are inherently biased, however, as in the optical they sample the rest-frame UV radiation, where only young, massive stars contribute to the flux. They appear to select regions of great disturbance, with many galaxies showing unusual morphologies in comparison with those in the nearby universe. Older and redder objects, with more typical stellar population components, are missed by these surveys. Deep surveys in the infrared are needed to properly characterise the galaxies in the high-z universe, for these will sample the rest wavelengths where the bulk of the stellar light emerges. For instance, the Gemini Deep Deep Survey has found that massive, old galaxies exist at least as far as z=2 (the GDDS; Glazebrook et al. 2004)[36].

High angular resolution over wide fields is also essential, in order to resolve the galaxy morphologies and to obtain statistically useful samples of their population distribution. The K–dark "cosmological" window at 2.4μm is attractive for such studies from Antarctica. LAPCAT would be able to obtain an SNR = 25 for K = 24 mags per square arcsecond in 100 hours of integration. This is sufficient to determine the morphology of resolved objects with 0.2″ resolution. Within a 20′ field of view, we would anticipate many thousands of objects being found. Such a survey would represent a several order of magnitude improvement in the cosmological volume sampled over any previous project at this sensitivity level.

5.5 Gamma ray bursts and the first light in the Universe

Gamma Ray Bursts (GRBs) are the most powerful energetic explosions in the Universe. GRBs can now be readily found and located, using satellites such as Swift. They can be hundreds of times more luminous than quasars for a few days, before they fade. There is strong evidence that GRBs are related to the collapse of massive stars, with the rate of GRBs being associated with the rate of massive star formation in galaxies (e.g. Kulkarni et al. 1998)[37]. If so, GRBs provide a probe of the star formation rate of the high-redshift universe, back to the epoch of the first star formation, a few tens of million years (between z=7 and z=20) after the Big Bang. At the highest redshifts, all the light from GRBs is shifted into the thermal infrared and longer, and so observation at these wavelengths is required if we are to probe back to the “first light” in the Universe.

While the effects of distance and redshift act to reduce the flux of a GRB in a given observing band, time dilation acts to increase the flux at a fixed time of observation from when the GRB erupts, since afterglow intensities tend to decrease with time. Thus, in a given spectral band there is little decrease in the intensity of a GRB with redshift, if observed at a fixed time after the GRB occurred. Based on fitting the spectral energy distribution to one GRB, Lamb & Reichart (2001)[38] estimate that the flux of a GRB, one day after its burst, will range from 10 – 20μJy in the K, L and M bands for redshifts from $z = 3$ to $z = 20$ (except for K-band at $z = 20$, when the flux is shifted out of the band). In 5 minutes of observations, LAPCAT would detect these objects with an SNR of a few hundred at K band, and to an SNR of ~5 at L– and M–bands. At earlier times than one day, with the flux estimated to vary as $t^{-4/3}$, higher SNRs would be anticipated, for example up to two order of magnitude greater within the first hour of the burst. A GRB found only in M–band would have a redshift > 30. These are the most interesting objects, probing furthest back in time.

The IR fluxes of many GRBs at high redshift shortly after their bursts are sufficiently strong that it would be possible to undertake low resolution spectroscopy as well as photometry, with spectral resolutions of $R \sim 100 – 300$. This would make it possible to probe the gas in the early universe and the host galaxies of the GRBs, measuring elemental abundances as well as large-scale structure from the metal forest absorption lines and the amount of re-ionization from the shape of the Ly-α edge. LAPCAT would thus make possible to study the era when the first stars formed in the Universe.

6. FROM PILOT TO LAPCAT TO GMTA

While continued site-testing at Dome C delivers still greater understanding of the potential of the site and the optimum configuration for a large telescope, it is important to explore the operational constraints of an Antarctic optical/IR telescope as soon as possible. This requires the deployment of a telescope that is large enough to be competitive with the best telescopes at temperate sites in a number of scientific areas. The SPIREX[39,40] telescope at South Pole has already shown that there are no insurmountable technical difficulties to be addressed with Antarctic operation and, despite its diminutive size of only 60 cm, delivered a useful amount of important science. The IRAIT[41] telescope is an 80 cm mid-infrared telescope, due to be installed at Dome C at the end of 2006. This will be the first telescope at Dome C that is not fully dedicated to site testing.

The proposed PILOT[42] telescope (Pathfinder for an International Large Optical Telescope) would be the natural technological pathfinder for LAPCAT. PILOT is currently envisaged as a 2.4 metre conventional Gregorian telescope (although it might also be built as a 2.0 meter off-axis telescope) with a pair of Nasmyth focal stations. Technological challenges that PILOT would explore include:

- Operation of a large telescope at -70° C
- Choice of bearings and lubricants
- Low-temperature encoders and motors
- Operation of an adaptive secondary mirror at low temperatures
- Protection from ice crystals
- Removal of heat, and turbulence control
- Routine maintenance under Antarctic conditions

PILOT is not yet funded, but once underway could be commissioned within three years and the results from field operation used to guide the engineering development of LAPCAT. In the meantime, the conceptual design phase of LAPCAT can begin immediately, with a view to first light at or before the time that the first Extremely Large Telescopes are being commissioned at temperate sites. The total cost of LAPCAT is unlikely to exceed $100m, putting it well within reach of a national or international university consortium.

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