PILOT

Pathfinder for an International Large Optical Telescope

SCIENCE REQUIREMENTS DOCUMENT

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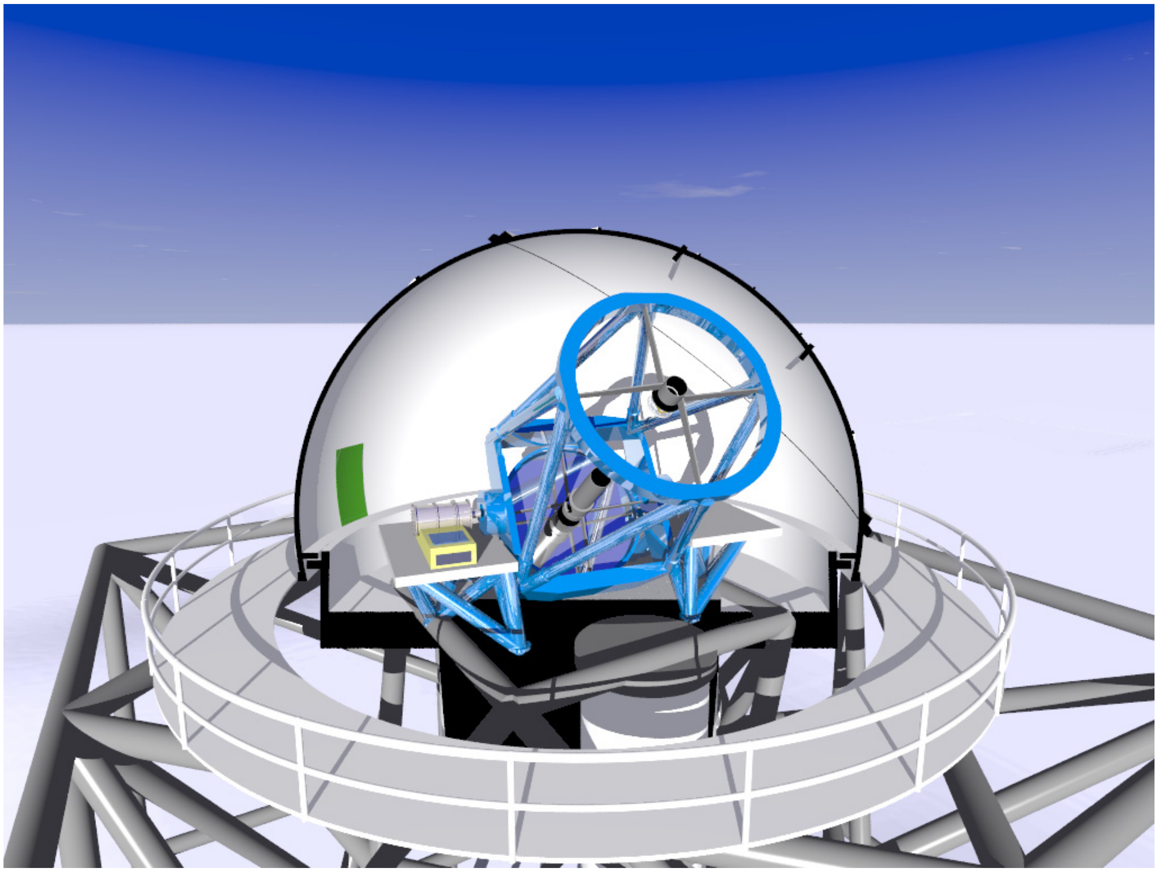

1 Introduction

1.1 Scope

PILOT (the Pathfinder for an International Large Optical Telescope) is a proposed 2.4 m optical/infrared telescope to be located at Dome C on the Antarctic plateau. The purpose of this document is to define the specific requirements that the scientific and technological objectives make on the design for the PILOT telescope, observatory, and instrumentation suite. The scientific and technological objectives, which are defined in detail in the *PILOT Science Case Document*, are intended to firstly maximise the scientific output from the facility by taking full advantage of the site conditions, and secondly to ensure that the facility plays a key role as a technological pathfinder for future larger scale Antarctic optical and infrared projects.

This document is intended as a link between the high level science case described in the *Science Case Document* and the lower level PILOT systems engineering documents. These documents are the *Operations Concept Document*, which describes the facility and science governance and operation; and the *Functional and Performance Requirements Document*, which specifies all technical requirements for the PILOT system. Detailed design study and technical notes are given in the *Design Study Report*. The current document lies at the same level as the *Dome C Environmental Conditions Document* that describes the relevant atmospheric and site conditions at Dome C and also provides input into the lower level systems engineering documents.

This document was produced by the University of New South Wales and the Anglo-Australian Observatory. It is based upon work carried out during the PILOT conceptual design study, funded through the Australian Department of Education, Science, and Training through the National Collaborative Research Infrastructure Strategy (NCRIS) scheme, and the University of New South Wales through the UNSW PILOT Science Office. Addition input, giving key science drivers and instrument specifications, has been provided by the University of Madrid and the CEA, Saclay, and many individual contributors from around the world.

1.2 Dome C site characteristics

The science and technological demonstrator goals for PILOT are driven by the unique meteorological atmospheric conditions and astronomical site conditions at Dome C, which are described in detail in the *PILOT Dome C Environmental Conditions Document*. These conditions allow PILOT to take advantage of the following capabilities:

- High resolution near diffraction-limited imaging in the visible over small fields (resulting from the exceptional free atmospheric seeing, the wide isoplanatic angle, and the long coherence time).
- Moderate resolution seeing-limited imaging in the visible and near infrared (resulting from the exceptional free atmospheric seeing), and moderate resolution

imaging in the mid-infrared (limited by the telescope aperture rather than the atmospheric conditions).

- Wide field imaging in the visible and near infrared with partial (tip-tilt) correction of the residual boundary layer turbulence (resulting from the exceptional free atmospheric seeing, the low height of the turbulent boundary layer, the wide isoplanatic angle, and the long coherence time).
- High sensitivity in the near-infrared (arising from the low atmospheric thermal emission) and the mid-infrared (arising from a combination of the low atmospheric thermal emission and the high atmospheric transmission).
- High photometric precision in the optical (enabled by the low atmospheric scintillation) and the infrared (enabled by the stable atmospheric thermal emission).
- Continuous coverage (due to the high latitude of the Dome C site and the high cloud free fraction).

1.3 PILOT Science Case

The *PILOT Science Case Document* discusses in detail the impact and observational requirements for a range of science cases. Table 1 identifies the primary capabilities required for each science case. These capabilities must be met by the telescope and instrument suite design. The key science drivers are briefly summarised here:

First light in the Universe: a near-infrared search for pair instability supernovae (via a dedicated wide field survey) and gamma-ray burst afterglows (via alerts from high energy satellite detections), events which represent the final evolutionary stages of the first stars to form in the Universe; and a deep and wide survey in the near-infrared to study galaxy structure, formation, and evolution via the detection of a large sample of high redshift galaxies.

Assembly of evolution of structure: a wide-area optical survey that will probe the evolution of dark matter and dark energy via the observation of weak gravitationally-lensed galaxies; a near-infrared search for Type Ia supernovae to obtain light curves that are largely unaffected by dust extinction and reddening, allowing tighter constraints to be placed on the expansion of the Universe; and a study of a sample of moderate-redshift galaxy clusters aimed at understanding galaxy cluster growth, structure, and evolution.

Star and planet formation: a southern Galactic Plane survey of molecular hydrogen in the mid-infrared in order to further our understanding of the ecology of star formation; and a series of mid-infrared spectrophotometric surveys searching for signatures of embedded protostars, crystalline silicates, and circumstellar disks around young stellar objects and brown dwarfs.

Stellar properties and populations: an optical/near infrared survey of disk galaxies in the local group to study the processes of galaxy formation and evolution; an infrared survey of nearby satellite galaxies to trace their outer morphology, structure, age and metallicity; a deep mid-infrared survey of the Large and Small Magellanic clouds in order to understand star formation processes; and asteroseismic optical observations of several nearby globular and open clusters to study age metallicity relationships and test various aspects of stellar evolution theory.

Exoplanet science: the search for free-floating planetary mass objects; the follow-up of gravitational microlensing candidate detections based on alerts from dedicated survey telescopes; and the collection of high precision photometric near- and mid-infrared light curves for secondary transits of previously discovered exoplanets.

Lucky Imaging science: a range of projects for high resolution imaging in the optical over small fields ("Hubble from the ground") including solar system science and emission line mapping of galaxy centres.

Table 1. The key capabilities for each of the PILOT science drivers. The primary science cases are identified in bold. High resolution (high res.) refers to imaging at the diffraction limit of the telescope in the visible. Moderate resolution (mod. res.) refers to imaging limited by the atmospheric seeing for visible and near infrared wavelengths, and the telescope diffraction limit in the mid-infrared. Field of view (FOV) refers to the wide field capability. Infrared sensitivity (IR sens.) refers to high sensitivity achievable in the near and mid-infrared. Photometric precision (photo. prec.) refers to the low scintillation noise, and cadence refers to the possibility of long time series observations.

Science case	high res.	mod. res.	FOV	IR sens.	photo. prec.	cadence	Cam
Pair instability SN			×	×			NIR
Gamma ray bursts			×	×		×	NIR
K_d galaxy survey		×	×	×			NIR
Weak lensing		×	×				VIS
Dusty SN		×	×	×			NIR
Cluster assembly		×	×		×		VIS
Galactic H2 survey			×	×			MIR
Star and planet formation		×	×	×			MIR
Local group survey	×	×	×	×			VIS/ NIR
MC and satellite galaxy surveys		×	×	×			NIR
Astero-seismology		×	×		×	×	VIS
Free floating objects			×	×			NIR
Gravitational microlensing		×				×	VIS
Secondary transits				×	×		NIR/ MIR
Hubble from the ground	×						LIC
Pathfinding	×	×	×	×	×	×	ALL

1.4 Instrument suite

The baseline instrument suite for PILOT includes four imaging cameras. These have been designed to satisfy the requirements of the key science drivers.

- PVISC (PILOT VISible Camera): a wide-field optical camera with ground layer tip-tilt correction.
- PNIRC (PILOT Near-InfraRed Camera): a wide-field near infrared camera with ground layer tip-tilt correction and adjustable pixel scales matched to the diffraction limit at short and long wavelengths.
- PMIRIS (PILOT Mid-InfraRed Imaging Spectrometer): a wide-field mid-infrared instrument with a tuneable Fabry-Perot filter or a GRISM spectrometer, and two separate arms with short and long wavelength ranges.
- PLIC (PILOT Lucky Imaging Camera): a fast optical camera for diffraction limited imaging over relatively small fields in the visible.

Table 2 lists the key features of these instruments, and maps each to appropriate science cases. The detailed requirements for each of these instruments are specified in Chapter 3. More general requirements on the telescope and observatory are specified in Chapter 2.

Additionally, there are several “advanced technology” instruments that are also being considered. These are either instruments for a generic 2 m class Antarctic telescope that are being developed independent to the PILOT project, or instrument configurations that involve a significant extension to the baseline specifications. They include:

- SMILE (Sub MILlimetEr camera): an instrument with a sub-millimetre detector array and a short wavelength (mid-infrared) channel.
- AIFS (Antarctic Integral Field Unit): an integral field spectrograph fed with a fibre array to operate in the near infrared.
- Polar Bear: a dual-channel Imaging Fourier Transform Spectrometer to operate in the near infrared.
- PSDC (PILOT Satellite Debris Camera): a wide field imaging camera consisting of a large array of fast guiding CCDs for satellite debris tracking.

While no specific requirements on PILOT are defined here based on these additional instrument configurations, it is desired that the PILOT telescope and observatory design be generic enough so as not to preclude these specific instruments, or other future instrument upgrades.

Table 2. PILOT candidate first generation instruments, their indicative main parameters, and associated science drivers.

Instrument	Primary science	Secondary science	Pix scale (″/px)	λ (μm)	FOV
PILOT Visible Camera (PVISC)	weak lensing	cluster assembly, local group survey, asteroseismology, , gravitational micro-lensing	0.08	0.4–1	40′ × 40′
PILOT Near Infrared Camera (PNIRC)	first light in the universe, high z galaxy survey	dusty supernovae, nearby galaxy studies, free-floaters and transits	0.06 0.15	1–2.5 1–5	4′ × 4′ 10′ × 10′
PILOT Mid Infrared Imaging Spectrometer (PMIRIS)	galactic ecology	star and planet formation studies, exoplanet secondary transits	0.8 1.3	7–25 17–40	14′ × 14′ 5′ × 5′
PILOT Lucky Imaging Camera (PLIC)	pathfinding “Hubble from the ground”	planetary science, local group galaxy survey	0.03	0.4–1	0.5′ × 0.5′

2 Telescope and observatory science requirements

2.1 Telescope science requirements

Requirement	Description	Science case justification
Telescope diameter SR.2.1.01	PILOT should have an aperture diameter between 1.8 m and 2.5 m, with a preference for the largest size possible.	The size of the main mirror diameter is driven by requirements on sensitivity and spatial resolution from the majority of science cases.
Wavelength range SR.2.1.02	PILOT should nominally operate over a wavelength range which at least includes 0.4–40 μm. There is a preference for UV observations down to a wavelength of 0.35 μm, and sub-millimetre observations up to a wavelength of 450 μm.	This wide wavelength range is based on the breadth of science drivers so far identified for the facility.
Zenith angles SR.2.1.03	The telescope shall be able to point to all elevations greater than 20° at all azimuths, with a preference for 15°.	This zenith angle limit allows ~50% of the total sky to be observable in a given 24 hour period, and a large fraction to be observable continuously.
Field of view SR.2.1.04	The PILOT telescope optical and mechanical design should allow a field of view of diameter at least 40′, with a preference for at least 1°.	Allows wide field instruments dedicated to large area survey projects.
Image quality SR.3.1.05	The entire PILOT system should be capable of producing diffraction-limited (Strehl > 0.8) images on-axis at 1 μm in ideal conditions (i.e., with no atmospheric seeing), and wide-field diffraction-limited imaging at 2.4 μm in the best quartile conditions.	The efficiency of many science programs is strongly dependent on the obtained image quality. This specification allows the instrument configurations to take advantage of the best seeing conditions.
Slew rate SR.2.1.06	PILOT should be able to slew from any point on sky to any other point on sky, acquire a target, and be ready to begin observations within 3 minutes.	A reasonably fast slew rate is motivated by the transient science cases, i.e., for fast follow-up of gamma-ray bursts, supernovae, and exoplanet gravitational lens candidates.

Tracking SR.2.1.07	Subject to elevation and azimuth limits, the telescope shall allow indefinite tracking of sidereal and solar-system sources.	This requirement is motivated by science cases requiring continuous or long time series coverage (see Table 1).
Instrument changes SR.2.1.08	Mounted PILOT instruments should be remotely changeable and be ready to begin observation within 5 minutes.	The capability for reasonably fast instrument change time is motivated by the transient science cases, i.e., for fast follow-up of gamma-ray bursts, supernovae, and exoplanet gravitational lens candidates.
Instrument mounting SR.2.1.09	Dismounting and mounting instruments should together take less than 12 hours.	This capability enables a range of science cases to be performed throughout the year with different telescope/camera configurations.
Instrument configuration SR.2.1.10	It should be possible to permanently mount the PLIC and PNIRC instruments on the telescope. Additionally, one of either PVISC or PMIRIS should be mounted at any time of the year. There is a preference for all four instruments to be mounted permanently.	This configuration ensures that the priority science instruments are always mounted, and enables a range of science cases to be performed throughout the year with different telescope/camera configurations.
Simultaneous use SR.2.1.11	There is a preference to allow simultaneous use (i.e., observing the same field) of either PVISC and PNIRC or PNIRC and PMIRIS.	This allows science return to be maximised by taking simultaneous observations at several wavelengths.
Additional instruments SR.2.1.12	There is a preference that the telescope design does not preclude the addition of advanced technology instruments or future instrument upgrades (outside the four baseline instruments).	This allows science return to be maximised by taking advantage of more sophisticated instrument concepts that may be developed throughout the lifetime of the facility.

2.2 Observatory science requirements

Requirement	Description	Science case justification
Telescope operation SR.2.2.01	The telescope and instrumentation should be operated autonomously as far as practical. Real-time control is required by the winter-over astronomer. Script-based control is required for remote observers.	The key science projects will require observations performable by automated scripts and a trained winter-over observer, but may require input from key science personnel.
Operational efficiency SR.2.2.02	The complete observatory should be capable of operating continuously with a maximum down time of 10% during the winter months. Down time during the summer months for servicing may be higher.	This will allow the scientific return to be maximised.
Data storage SR.2.2.03	The majority of data should be stored on site for retrieval at the end of the Antarctic winter. Appropriate mechanisms for high reliability data back-up are required.	Most science cases do not require data in real time. Data security is a high priority.
Data reduction SR.2.2.04	Real time automated data reduction systems should be in place, which provide a summary of instrument performance and scientific output in the form of source lists and parameters, which can be transferred at low bandwidth.	This allows the ongoing progress of each science project to be monitored throughout the observing season, and changes to be implemented if required.
Transient flagging SR.2.2.05	Transient detections (changes in previously observed fields) should be automatically detected, flagged and all relevant data transferred, as close to the time of observation as possible.	This allows the rapid follow up of e.g., microlensing or supernovae events.
Data transfer SR.2.2.06	Allowance for data transfer of up to 500 MB/day is desired. This transfer will include lists of extracted sources, subsets of science data, and telescope, instrument, and observatory housekeeping data.	This data rate will allow a significant subset of science results to be returned and analysed.
Site monitoring SR.2.2.07	The observatory should contain sufficient "site-testing" instrumentation to enable a continuous monitoring of atmospheric conditions. This should include at least a seeing monitor, cloud and infrared emission monitors, and a water vapour monitor.	This will allow the scientific return to be maximised via a dynamic queue scheduled observing strategy.

3 Instrument science requirements

3.1 PILOT Visible Camera (PVISC)

The PILOT Visible Camera (PVISC) is a wide field imaging only camera using a mosaic of large format CCD arrays. PVISC should include a tip-tilt guiding and correction system to remove tower shake and residual boundary layer turbulence. The main science driver for this instrument is the wide area weak lensing survey. Secondary science includes time series observations of stellar clusters, galaxy cluster assembly, near field cosmology, and follow-up for gravitational microlensing events. These science drivers require a wide field of view, high spatial resolution, a stable PSF across the field, and excellent astrometric stability.

Requirement	Description	Science case justification
Wavelength range SR.3.1.01	PVISC should operate from 0.4–1.0 µm, with a preference for 0.35–1.0 µm. Performance should be optimised for 0.8 µm.	The optimum wavelength to perform the weak lensing survey is ~0.8 µm.
Pixel scale SR.3.1.02	The pixel scale for PVISC should provide good sampling (at least 2–3 pixels/FWHM) of the median tip-tilt corrected seeing at 0.8 µm.	The majority of the optical science cases are enabled by high spatial resolution and thus require appropriate pixel sampling.
Focal plane field of view SR.3.1.03	The imaging field of view for PVISC should be at least 0.25 deg^2, with a preference for a field larger than 0.5 deg^2.	The weak lensing survey requires a large field of view to cover a large area of sky in a reasonable time. Stellar cluster studies require a field of view consistent with the cluster size (~40′ diameter).
Median image quality SR.3.1.04	The image quality delivered by PILOT+PVISC under median atmospheric conditions should be no more than 120% of the median free atmospheric seeing at 0.8 µm.	The majority of the optical science cases are enabled by high spatial resolution.
Image quality SR.3.1.05	The image quality delivered by PILOT+PVISC in the best quartile atmospheric conditions should be no more than 120% of the best quartile free atmospheric seeing at 0.8 µm.	The efficiency of the weak lensing survey is greatly increased for observations under the best seeing conditions.

PSF stability SR.3.1.06	The delivered PSF under median seeing conditions must be uniform and symmetric to within 5% in FWHM across the total field of view, and must be modellable to within 0.25% for colour and position-dependent errors.	The weak lensing science case requires an accurate determination of the shapes of distant galaxies.
Filter set SR.3.1.07	PVISC should contain a remotely settable filter mechanism with at least 4 positions. The filter set will include at least the following baseline filters: *griz*, and an ultra-wideband filter. There is a preference also for *u*. Total filter capacity (whether fixed or interchangeable) is a minimum of 8 filters.	Weak lensing requires a wideband filter, stellar cluster studies requires *g* and *r* filters, galaxy cluster studies require *r*, *i*, *z* filters.
Sky coverage factor SR.3.1.08	The sky coverage factor for tip-tilt compensation of PVSIC should be greater than 95% at the galactic pole in *griz* bands, with a preference for 99%. Image rotation or recentering is allowable to reach this target.	A high sky coverage factor increases the probability that targeted observations (exoplanet and gravitional microlensing) can be performed on a given field, and limits the gaps in survey project areas.
Throughput SR.3.1.09	The total throughput for PVISC should be optimised for use over 0.7–0.9 µm, but should exceed 25% at 0.4 µm and 50% over the wavelength range 0.5–1.0 µm.	High throughput ensures that the sensitivity limits allow the survey projects (weak lensing, stellar clusters, near field cosmology) to be accomplished in a reasonable time to an appropriate depth.
Data storage and reduction SR.3.1.10	The data storage and reduction facilities should be capable of reducing and storing a maximum number of 500 frames per day, for up to 200 days use.	This frame rate allows multiple short exposure (~3 minute) observations for transient science cases (stellar clusters).
Continuous observations SR.3.1.11	PVISC should be capable of operating for 6 months continuously throughout the Dome C winter with a maximum down time of 10% of astronomical dark time.	This increases the observing efficiency of large optical survey projects, and maximises the temporal coverage for transient science projects.

Atmospheric Dispersion Compensation SR.3.1.12	An ADC shall be included giving efficient correction (such that the image quality as defined by SR.3.1.04 is not degraded) to a minimum zenith angle of 70°.	The majority of the optical science cases are enabled by high spatial resolution, which should be independent on zenith distance.
Pixel alignment SR.3.1.13	The alignment of the PVISC camera should be configurable such that stars are always located at the same position to ± 1 pixel on the detector for observations at the same zenith angle. It is desirable that stars are always located at the same position to ± 1 pixel on the detector independent of zenith angle.	This ensures high photometric precision, which is important for the stellar clusters project.
Calibration SR.3.3.14	Provision will be made for obtaining calibration data, sufficient that data uniformity and linearity is limited by photon or sky noise.	This means the calibrations are good enough to do justice to the intrinsic quality of the telescope and site.

3.2 PILOT Near Infrared Camera (PNIRC)

The PILOT Near InfraRed Camera (PNIRC) is a wide field imaging only camera using a mosaic of infrared arrays. PNIRC should include a tip-tilt guiding and correction system to remove tower shake and residual boundary layer turbulence. The three main science drivers for this instrument are the search for high redshift supernovae, gamma ray bursts, and galaxies. Secondary science includes studies of high-mass protostars, exoplanet secondary transits, and nearby galaxy population studies. These science drivers require a wide field of view, a wide wavelength range, relatively high spatial resolution, and high sensitivity in the thermal infrared.

Requirement	Description	Science case justification
Wavelength range SR.3.2.01	PNIRC should operate from 1–5 μm. The imaging performance should be optimised for 2.4 μm. Emissivities should be minimised for 2.4–5 μm.	The wide wavelength range is primarily motivated by the search for high redshift gamma ray bursts. The optimum wavelength to search for high redshift galaxies is 2.4 μm (K_d).
Pixel scale SR.3.2.02	PNIRC should have 2 remotely selectable pixel scales: a wide field mode (for operation at 1–5 μm) sampled at 1.5–2.0 pixels per diffraction limited resolution element at 2.4 μm, and a high resolution mode (for operation at 1–2.5 μm) sampled at 2–3 pixels per diffraction limited resolution element at 1 μm.	The near infrared science cases are enabled by either high spatial resolution or wide field of view, and thus require appropriate pixel sampling.
Focal plane field of view SR.3.2.03	The imaging field of view of PNIRC should be at least 8′ × 8′ in wide field mode, and at least 2′ × 2′ in high resolution mode. The PNIRC design should allow an upgrade path to allow at least 14′ × 14′.	The search for pair instability SN, and other survey projects requires a large enough field of view to cover a large area of sky in a reasonable time.
Median image quality SR.3.2.04	The image quality delivered by PILOT+PNIRC under median atmospheric conditions should be as good as the combined median free atmospheric seeing plus diffraction limit at 2.4 μm.	Many of the infrared science cases are enabled by high spatial resolution. This should not be limited by the optical quality of the telescope or instrument.
Best image quality SR.3.2.05	PILOT+PNIRC should be capable of diffraction-limited (Strehl > 0.8) imaging at 1 μm should atmospheric conditions allow.	This allows PNIRC to take advantage of the best anticipated conditions.

PSF stability and calibration SR.3.2.06	The delivered PSF under median seeing conditions must be uniform and symmetric to within 10% in FWHM across the total field of view, and must be modellable to within 0.5% for colour or position-dependent errors.	Cluster mass determination via strong lensing requires a uniform and reproducible PSF.
Filter set SR.3.2.07	PNIRC should contain a remotely settable filter mechanism with the following baseline filters available in wide field mode: $Y\ J\ H\ K_d\ L\ M$ and the following baseline filters available in high resolution mode: $Y\ J\ H\ K_d$. Additional capacity is required to give a total of at least 12 permanently available filters.	The search for high redshift gamma ray bursts requires sequential observations in a series of filters from Y to M. SN searches require observations from J to M.
Sky coverage factor SR.3.2.08	The sky coverage factor for tip-tilt compensation of PNIRC should be greater than 95% at the galactic pole for $Y\ J\ H\ K_d\ L\ M$ with a preference for 99%.	A high sky coverage factor increases the probability that targeted observations (high redshift gamma ray bursts and exoplanet secondary transits) can be performed on a given field, and limits the gaps in survey project areas.
Throughput SR.3.2.09	The total throughput for PILOT+PNIRC in wide-field mode should be at least 50% over the full wavelength range (1–5 μm).	High throughput ensures that survey projects (e.g., high redshift galaxies and supernovae) can be accomplished in a reasonable time to an appropriate depth.
Thermal background SR.3.2.10	The thermal background from the instrument, telescope, ground, non-imaged sky, and out-of-band imaged sky, as seen by the detectors, should be such that the thermal background from the telescope amounts to no more than 10% of in-band imaged sky at 2.4 μm or 100% at 4.66 μm.	Low thermal emission from the telescope and optics ensures that the survey projects (e.g., high redshift galaxies and supernovae) can be accomplished in a reasonable time to an appropriate depth.
Data storage and reduction SR.3.2.11	The data storage and reduction facilities should be capable of storing/reducing a maximum number of 10,000 frames per day, for up to 200 days use.	This allows storage of all raw frames (~10 second exposures) for later reduction.

Continuous observations SR.3.2.12	PNIRC should be capable of operating for 6 months continuously throughout the Dome C winter with a maximum down time of 10% of astronomical dark time.	This increases the observing efficiency of large survey projects, and maximises the chance of observation for follow-up transient projects (e.g., gamma-ray bursts).
Calibration SR.3.2.13	Provision will be made for obtaining calibration data, sufficient that data uniformity and linearity is limited by photon or sky noise.	This means the calibrations are good enough to do justice to the intrinsic quality of the telescope and site.

3.3 PILOT Mid-infrared Imaging Spectrometer (PMIRIS)

The PILOT Mid-InfraRed Imaging Spectrometer (PMIRIS) is a wide field low to moderate resolution imaging camera using a mosaic of infrared arrays. PMIRIS should include a slow guiding capability. The main science driver for this instrument is to perform a wide area survey of molecular hydrogen in the Galaxy. Secondary science drivers include studies of circumstellar discs, Young Stellar Objects, and crystalline silicates. These science drivers require a wide field of view, a wide wavelength range, diffraction-limited spatial resolution, high thermal infrared sensitivity, and moderate-resolution spectroscopic capabilities.

Requirement	Description	Science case justification
Wavelength range SR.3.3.01	PMIRIS should operate from 7–25 μm. There is a preference for a second "red" arm covering the wavelength range 17–40 μm.	The lower wavelength range is motivated by the circumstellar disc project, the upper wavelength range is motivated by the crystalline silicates science case.
Pixel scale SR.3.3.02	The pixel scale for PMIRIS should be sampled at 1.5–2.5 pixels per diffraction limited resolution element at 17 μm (blue arm) and 30 μm (red arm).	The majority of the mid infrared science cases are enabled by (relatively) high spatial resolution, and thus require appropriate pixel sampling.
Focal plane field of view SR.3.3.03	The imaging field of view of PMIRIS should be at least 10′ × 10′ in the blue arm, and at least 4′ × 4′ in the red arm, with a preference for the largest size possible.	All of the mid infrared survey projects require a large enough field of view to cover a large area of sky in a reasonable time.
Image quality SR.3.3.04	The point spread function for PMIRIS in median conditions should be diffraction limited for all wavelengths from 7–45 μm.	The majority of the mid-infrared science cases require a high spatial resolution. This should not be limited by the telescope or instrument optics.
Modes of operation SR.3.3.05	PMIRIS should be capable of the following modes of operation: wide-band imaging, narrow-band imaging, and spectroscopy with a grism at the pupil and a slit at the image plane.	Wide band imaging and high resolution imaging are required by star and planet formation studies, narrow band imaging is required by the galactic ecology project.

Filters and dispersers SR.3.3.06	Broad-band imaging will be possible in at least N and Q bands. Narrow-band imaging should be possible at least at wavelengths of 12.3, 12.8, 17.0, 28, 34.8 μm. The resolution will be not less than R=3000, with a preference for R=30,000. In this mode, the phase shift will be not more than 1/1000, with a preference for 1/3000. Grism spectroscopy will be possible at resolutions R=100–1000. Each arm should have a minimum of 8 filter/grism choices permanently available.	Wide band imaging and high resolution imaging are required by star and planet formation studies, narrow band imaging is required by the galactic ecology project.
Throughput SR.3.3.07	The total throughput for PILOT+PMIRIS should be at least 25% over the full wavelength range.	High throughput ensures that the sensitivity limits allow the survey projects to be accomplished in a reasonable time to an appropriate depth.
Thermal background SR.3.3.08	The thermal background from the instrument, telescope, ground, non-imaged sky, and out-of-band imaged sky, as seen by the detectors, will be no greater than 50% of in-band imaged sky in narrow-band use at 17.0 μm.	Low telescope and instrument thermal emission ensures that the sensitivity limits allow the survey projects (galactic ecology, studies of star and planet formation regions) to be accomplished in a reasonable time to an appropriate depth.
Data storage and reduction SR.3.3.9	The data storage and reduction facilities should be capable of storing/reducing a maximum number of 10,000 frames per day for 200 days.	This allows storage of all raw frames (~10 second exposures) for later reduction.
Continuous observations SR.3.3.10	PMIRIS should be capable of operating for 6 months continuously with a maximum down time of 10%.	This increases the observing efficiency of large survey projects.
Daytime observing SR.3.3.11	PMIRIS should be useable at any time of the year.	This increases the scientific return by allowing the mid-infrared science observations to be done during the summer months.
Calibration SR..3.312	Provision will be made for obtaining calibration data, sufficient that data uniformity and linearity is limited by photon or sky noise.	This means the calibrations are good enough to do justice to the intrinsic quality of the telescope and site.

3.4 PILOT Lucky Imaging Camera (PLIC)

The PILOT Lucky Imaging Camera (PLIC) is a fast, low noise imaging camera using a frame transfer detector array. PLIC utilises the lucky imaging technique where multiple frames taken at high frequencies are selected, registered and co-added to build up high resolution images. One of the main motivations for PLIC is as a pathfinding instrument, which will demonstrate the turbulence characteristics of the Dome C site. Several science cases, such as planetary imaging, emission line mapping of galaxy centres, and stellar population studies of Local Group galaxies will also take advantage of the high resolution. With the expected retirement of HST, and JWST's limited optical capability, this capability will be unique, and expected uses are both widespread and unpredictable.

Requirement	**Description**	**Science case justification**
Wavelength range SR.3.4.01	PLIC should operate from 0.4–1 μm.	The wavelength range allows the instrument to observe at lower wavelengths with higher efficiency than lucky imaging cameras at mid-latitude sites.
Pixel scale SR.3.4.02	The pixel scale for PLIC should provide good sampling (at least 2–3 pixels per diffraction-limited resolution element) at 0.5 μm.	This instrument enables high spatial resolution observations in the visible, and thus requires appropriate pixel sampling.
Focal plane field of view SR.3.4.03	The imaging field of view for PVISC should be at least 30″ × 30″.	This field of view is large enough to allow useful high resolution science.
Image quality SR.3.4.04	PILOT+PLIC should together be capable of delivering instantaneous images with Strehl ratio > 0.25 at 0.5 μm, should atmospheric conditions allow.	This instrument enables high spatial resolution observations in the visible approaching the diffraction limit. The resolution should thus not be limited by the telescope or instrument optics.
Filter set SR.3.4.05	PVISC should contain a remotely settable filter mechanism with the following baseline filters: *g r i z* . Additional capacity is required to give a total of at least 8 filters.	The filter set should be appropriate for a wide range of science cases enabled by the high spatial resolution.
ADC SR.3.4.06	PVISC will contain an ADC, allowing diffraction-limited correction for atmospheric dispersion in *g r i z* bands to ZD = 70°.	An ADC is required to obtain diffraction-limited broadband images.

Sky coverage factor SR.3.4.07	The sky coverage factor for r band (0.62 μm) observations for PLIC should be greater than 35% at the Galactic pole, with a preference for the largest value possible.	A high sky coverage factor increases the probability that targeted observations can be performed on a given field.
Throughput SR.3.4.08	The total throughput for PILOT+PLIC should exceed 25% at 0.4 μm and 50% over the wavelength range 0.5–1.0 μm. This throughput does not include amplification noise in the detector.	High throughput should ensure that the camera achieves the appropriate sensitivity limits.
Data storage and reduction SR.3.4.09	The data reduction facilities should be capable of storing and reducing the PLIC data in real time (i.e., select, register and co-add frames). The maximum storage of data should be 50 GB/day (compressed) for up to 200 days.	This allows storage of all reduced frames for later reduction.
Continuous observations SR.3.3.10	PLIC should be capable of operating for 6 months continuously with a maximum down time of 10%.	This increases the observing efficiency for this instrument.
Calibration SR.3.4.11	Provision will be made for obtaining calibration data, sufficient that data uniformity and linearity is limited by photon or sky noise.	This means the calibrations are good enough to do justice to the intrinsic quality of the telescope and site.
Frame rate SR.3.4.12	PLIC will be able to take frames at a rate of 20 Hz, with a preference for 50 Hz.	The frame rate must be faster than the timescale for changes in the instantaneous seeing.