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CALTECH OPTICAL OBSERVATORIES
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Palomar Adaptive Optics Interface Control Document (ICD)

Version 2.0

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Abstract

This document defines the interface between the Palomar observatory physical infrastructure and Palomar Adaptive Optics system (PALAO), and AO-fed instruments at the primary AO science focus. Unless explicitly stated, all interface definitions are also applicable to the upgraded AO system PALM-3000.

Version History

Version	Date	Author	Comments
0.5	2005-11-21	NTh	Created
0.6	2005-11-22	FCl	Sections added
0.7	2005-12-15	FCl	Updated and expanded post PDR
1.0	2006-01-25	ABo	First Caltech Draft of SWIFT interface to PALAO
1.1	2006-02-22	CSh	Added optical interface description
1.2	2006-05-08	ABo	Updated sections
1.3	2006-07-05	AMo	Rehack of 1.2 for SWIFT deadline
2.0	2006-07-18	AMo	Converted to Word format, converted to a general purpose instrument interface to PALAO, updated sections

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Table of Contents

1 Introduction

Please abide by Word formatting rules when editing this document, in particular, use only the provided styles (there are 35).

Dimensions given without units are in SI (millimeter) format.

1.1 Overview

This generic document is intended for any science instrument wishing to interface to the PALAO system.

The Palomar adaptive optics system, PALAO, including the laser guide star facility, has been designed, built and commissioned by Palomar observatory and their partners JPL & the University of Chicago. An upgrade (to PALM3K) is foreseen for ~2009. Several instruments will take advantage of the current and future upgraded systems.

The Palomar High Angular Resolution Observer, PHARO, is an adaptive optics assisted near-infrared camera and spectrograph and is the existing science unit behind PALAO. It was designed and built by Cornell University and has been operating since 1999.

SWIFT is an adaptive optics assisted *I/z* integral field spectrograph under development at the University of Oxford. The instrument, together with a high order laser guide star assisted adaptive optics system (PALAO or PALM-3K), will be installed and commissioned at the Cassegrain focus of the Palomar 200-inch Hale telescope. SWIFT is designed to take advantage of the enhanced performance of PALM3K in the *I/z* bands, but will initially be commissioned with PALAO in 2008A.

Due to the physical size of SWIFT, combined with certain optical requirements, some changes to the current PALAO interface are required. These changes are discussed specifically where appropriate.

1.2 Scope

This document defines the interface between the Palomar observatory physical infrastructure and Palomar Adaptive Optics system (PALAO), and AO-fed instruments at the primary AO science focus. Unless explicitly stated, all interface definitions are also applicable to the upgraded AO system PALM-3000.

1.3 Reference documents

[1] PALAO design specifications (Dekany *et al*., 1998, SPIE, **3353**, 56)

[2] PALAO LGS upgrade (Velur *et al*., 2004, SPIE, **5490**, 1033)

[3] PALAO PSF stability (Bloemhof *et al*., 2000, SPIE, **4007**, 889)

[4] PALAO performance results (Troy *et al*., 2000, SPIE, **4007**, 31)

[5] PALAO upgrade to PALM3K (Dekany *et al*. 2000, SPIE, **4007**, 175)

[6] PHARO (Hayden, T.L. *et al*, 2001, PASP, **113**, 779)

[7] SDSU Gen-III Controller (Leach, B. & Low, F., 2000, SPIE, **4008**, 337)

[8] `cfitsio` software library (Pence W.,1999, ASPC, **172**, 471)

1.4 Reference links

PALAO (JPL): http://ao.jpl.nasa.gov/Palao/PalaoIndex.html

PALAO (COO): http://www.astro.caltech.edu/palomar/AO/

PHARO: http://astrosun2.astro.cornell.edu/research/projects/PHARO//pharo.html

PALAO software interface document http://www-astro.physics.ox.ac.uk/instr/swift/PDRdocs/PALAO_command_interface.txt

Hale Telescope and PALAO bench optical specification: http://www.astro.caltech.edu/twiki_oir/bin/view.cgi/Palomar/SWIFT/ICDs TBD

PALAO bench mechanical drawings:TBD

SWIFT: http://www-astro.physics.ox.ac.uk/instr/swift/dphilproject.html

1.5 Acronyms

AO	Adaptive Optics
BFL	Back Focal Distance
Cass	Cassegrain focus of the Hale telescope
CCD	Charge Coupled Device
CG	Center of Gravity
COO	Caltech Optical Observatories
DEC	Declination
DM	Deformable Mirror
FoV	Field of View
FWHM	Full Width at Half Maximum
FM	Fold Mirror
HOWFS	High Order Wavefront Sensor
JPL	Jet Propulsion Laboratory
LLT	Laser Launch Telescope
LGS	Laser Guide Star
NGS	Natural Guide Star

PA	Position Angle
PALAO	Palomar Adaptive Optics system
PALM3K	Palomar next generation adaptive optics system
PSF	Point Spread Function
PHARO	Palomar High Angular Resolution Observer
RA	Right Ascension
SSM	Star Selector Mirror
Spaxel	Spatial size of sky in each Pixel
SWIFT	Short Wave Integral Field Spectrograph
UPS	Uninterruptible power supply
UTC	Coordinated Universal Time
WFS	Wavefront sensor

2 Optical interface basics

The PALAO optical bench is shown in Figure 1 with relevant components labelled.

2.1 Entrance beam focal ratio

The entrance beam focal ratio is f/15.64 ± 0.01

2.2 Plate scale

The instrument focal plane plate scale is 2.583±0.001” mm^{-1}.

2.3 Back focal distance

The chief ray distance from OAP2 to the instrument focal plane is 1.77208±0.002m. The instrument focal plane radius of curvature is 1.314m, convex towards telescope. This is opposite that of the native telescope, which has a radius of curvature of 3.352m, concave towards telescope.

The BFD will be cross-checked with the updated zemax model of the PALAO optics, based on physical measurements taken on June 28th 2006.

2.4 Location of entrance pupil

The exit pupil of AO is 13.510±1.0m towards telescope from output focal plane. The chief ray distance from OAP2 to focal plane is 1.77208m, so the instrument entrance pupil is 11.738±1.0m towards telescope from OAP2.

A mechanism should be included in the instrument to allow alignment of the instrument's pupil to that of the telescope and AO system. On PHARO, this adjustment is performed at the start of every run, by imaging the telescope pupil with the science detector, while observing the interior of the dome. The pointing of the entire instrument is adjusted manually (primarily in the plane of the AO bench) until the instrument's pupil masks are aligned with the telescope's pupil.

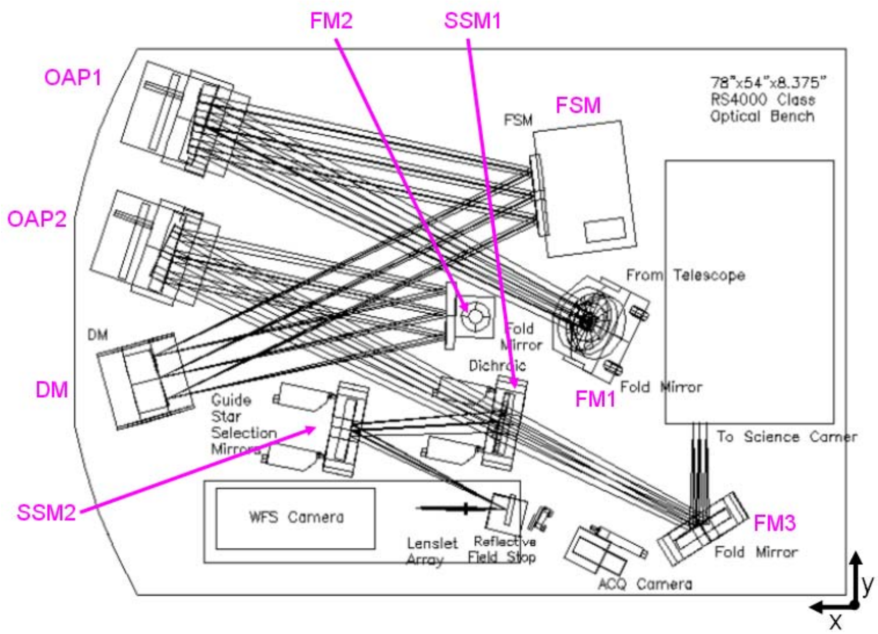

Figure 1: A schematic of the PALAO optical bench with critical components labelled. The telescope axis is coincident with the fold mirror FM1. The global X, Y coordinates are labelled and are coincident with the bottom right corner of the optical bench. Note that this diagram is a mirror image of the PALAO system displayed as if all components were seen *through* the optical bench.

2.5 Diameter of entrance pupil

The entrance pupil diameter is 866.38±87.0mm. (1158.7mm for the telescope alone, without AO). The tolerance of the entrance pupil size is much tighter if expressed in angular units, i.e., the output f/number is well constrained. The distance to the exit pupil depends closely on the DM to OAP distances.

2.6 Diameter of central obscuration

The prime focus cage has an exterior diameter of 72 inches, versus a primary mirror diameter of 201 inches, leading to an obscuration ratio of 0.358±0.005.

2.7 Diameter of unvignetted field of view

The optical design passes a field of 120 arcsec diameter, but vignetting by the AO stimulus package limits this to 90 arcsec diameter.

2.8 Beam height

The current beam height above the PALAO bench was measured on June 28th 2006 by propagating a HeNe laser beam from the stimulus unit through the AO system with the PHARO instrument removed. The beam height through the system changes slightly and is documented elsewhere. The beam height at the focus position is 6.739inches (171.2mm) and is tilted with respect to the optical bench by 0.7^{o} about the x axis (such that *dz/dy* is positive).

It is undecided as to the amount of PALAO realignment to be performed after the planned recoating of the PALAO optics towards the end of 2007 and the subsequent adjustment of the beam height. This outstanding issue will be resolved as soon as possible.

2.9 Focus location on AO bench

Here we discuss the location of the PALAO focus relative to the optical bench.

The PALAO focus position can be changed by translating the secondary mirror of the Hale telescope along the optical axis. The focus position also varies as a function of temperature. We present here nominal focus positions corresponding to the secondary mirror configured at approximately central position.

2.9.1 Current

The current focus position on the PALAO bench was measured on June 28th 2006 by propagating a HeNe laser beam from the stimulus unit through the AO system with the PHARO instrument removed. The measurement is approximate and will be cross-checked with results from the zemax model of PALAO currently in the process of being updated.

The current focus position in bench coordinates in mm is [371.8, 418.5, 171.17].

The current focus position in bench coordinates in inches is [14.6, 16.5, 6.739].

2.9.2 Future

The PALAO focus position will be changed after recoating of the PALAO optics towards the end of 2007. This is to provide a workable solution for the SWIFT instrument that will interface to the PALAO system in early 2008. The resulting beam exiting optical element SSM1 will remain permanent for PHARO and any other instrument interfacing to the PALAO system. The location of the last optical element of the PALAO system, fold mirror FM3, can, however, vary with instrument. For example, there will be a unique FM3 located inside the SWIFT enclosure. For PHARO there will be a separate unit containing FM3 that is installed along with the PHARO dewar.

For SWIFT, the focus position will be adjusted to the following with the SWIFT FM3 fold mirror located at [228.60, 40.41, 171.17]:

Future focus position in bench coordinates in mm will be [228.60, 73.63, 171.17].

Future focus position in bench coordinates in inches will be [9.00, 2.90, 6.739].

2.9.3 Implementing the SWIFT focus change

The required focus change for the SWIFT instrument is [-143.2, -344.87, 0]. If the PALAO optics were to remain unchanged, except for a suitable movement of FM3 to [228.60, 40.41, 171.17], the resulting image would be out of focus given the new distance from OAP2 to the focus position would be ~60mm smaller than the BFD. This distance must be accounted for by a change in the current PALAO optical set-up.

The beam angle from OAP2 to the SWIFT FM3 position, relative to the PALAO bench, will also likely be altered slightly to implement the SWIFT focus change. The requirement is that the chief ray from OAP2 must intersect the coordinate [228.60, 40.41, 171.17], this being the center of the SWIFT FM3. The current beam angle, as measured on June 28th 2006, is ~26.6^{o}, relative to the +X axis measured in an anti-clockwise direction.

The options for implementing the SWIFT focus change currently being investigated are:

- Rotation of the entire PALAO optical system about the optical axis of the telescope, together with a slight rotation of the OAP mirrors
- Change of OAP mirrors with a slightly different focal length

This issue will be finalized as soon as possible.

2.9.4 Adjustment to PHARO

We will replace the current PHARO FM3 mount with one which attaches to a kinematic base plate, allowing FM3 to be installed when PHARO is in use. This base will be centered at an X coordinate of 371.8mm, matching the current X coordinate position of the PHARO focus. The Y coordinate will be selected shortly.

By keeping the adjusted PHARO focus to an X coordinate of 371.8mm the PHARO instrument does not require adjustment along this axis from the current configuration, a desirable outcome. An adjustment in the Y coordinate position of PHARO is required, however, and there is adequate space existing for this adjustment.

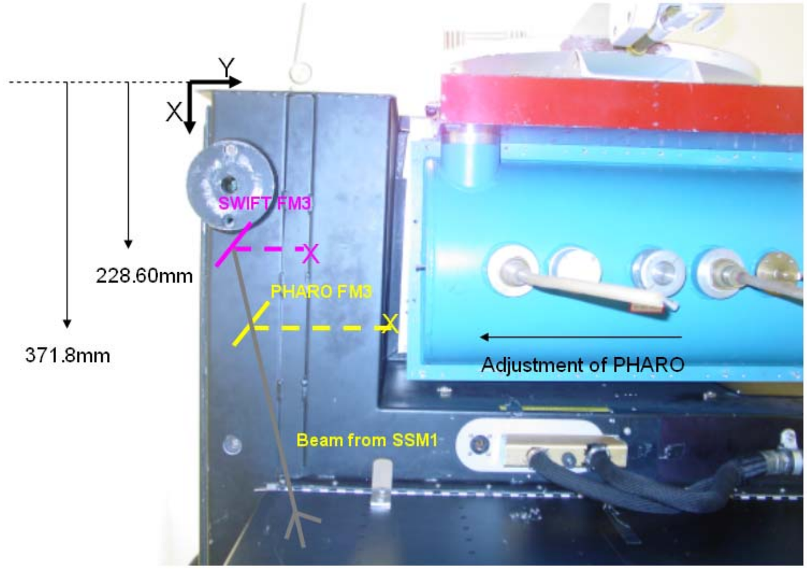

Figure 2: A zoomed image of the exsiting PALAO bench showing the PHARO dewar (light blue) and the location relative to the enclosure. The approximate locations of the SWIFT and PHARO optical foci are shown, with exact X axis dimensions given along the bench coordinate axis. For this arrangement to function the PHARO dewar must be translated along the –Y axis. No X axis translation is required.

3 Specific PALAO optical components

3.1 Deformable mirror

The PALAO deformable mirror has sufficient stroke (5µm peak-to-valley) to compensate for all image plane aberrations in the non-common path to the WFS (from the SSM1 dichroic to the image slicer, and from SSM1 to the HOWFS detector). This is done by specifying a vector of non-zero centroids to which the high-order wavefront sensor drives the stellar or LGS spots. The non-common-path aberrations to the PHARO detector corrected for in this manner are of order ~200nm RMS, and are corrected to a residual level of ~40nm RMS.

However, this method relies on well-sampled imaging of the PSF on the science instrument. COO continues to evaluate solutions for the case where the science instrument cannot deliver an adequately sampled image. These include:

- Using pre-defined offsets compiled from measurements made with the PHARO science detector
- Using pre-defined offsets compiled from measurements made with the PHARO science detector, in combination with predictions of the high order optical aberrations in the science instrument

- The inclusion of a separate PSF camera to directly measure the non-common path aberrations. This is the most reliable method but requires the design of a new sub-system.

3.2 Dichroic (SSM1)

The dichroic element SSM1 divides the science and wavefront sensor light. The science light passes through the element and onwards to the science instrument via fold mirror FM3. The wavefront sensor light is reflected towards the mirror, SSM2, and onwards to the wavefront sensor and acquisition units.

The current SSM1 (PHARO configuration) is a long pass filter with 50% reflectivity at 1100nm manufactured by Barr associates (quotation number 9601-406C). Science instruments requiring performance bluer than this wavelength must provide a suitable dichroic element with physical dimensions based on the current SSM1 element.

3.2.1 SSM1 specifications

- SSM1diameter is 4 inches
- SSM1 thickness is 10mm ± 2mm
- Material is Haraeus Infrasil 301
- Angle of Incidence is 15^o
- Wedge < 5.0 ± 0.2 arcmin
- Surface quality is 60/40
- Surface roughness is l/4 P-V @633nm
- For 500nm-1000nm
  - Trans<2% average
  - Reflectance>90%
- For 1000-3500nm
  - Transmission>85% average
  - Reflectance<5% average

3.3 Fold mirror (FM3)

FM3 is a fold mirror and is the last element of the PALAO system. It directs science light that is transmitted through the SSM1 dichroic to the science instrument. Currently the mechanical mount of FM3 is permanently fixed to the PALAO bench as the PHARO enclosure is sufficiently small enough to fit behind. We would like to provide the maximum volume available for science instruments wishing to mount to the PALAO bench and therefore the current FM3 mount will be re-designed.

We will replace the current PHARO FM3 mount with one which attaches to a kinematic base plate, allowing FM3 to be removed when PHARO is not in use. The defining points will be located at an approximate X coordinate of 371.8mm with the Y coordinate to be determined shortly. The base will be designed to avoid interference with future instruments.

4 Location of reference stars

4.1 Location of NGS reference stars

In NGS mode, the field of regard of the HOWFS determines the distance from an NGS to which the center of the science camera field can be pointed. Guide stars up to 60" from the optical axis may be used over a restricted PA range for any setting of the Cassegrain rotation ring (see Figure 3). This is significantly larger than the isoplanatic angle in the near-infrared or visible (10-30"). In LGS mode, the HOWFS field of regard limits how far the LGS may be directed off the optical axis, though the LLT field of view limits this as well.

4.2 Location of LGS reference stars

In LGS mode, the patrol field of the LOWFS determines the distance from the tip/tilt/focus NGS to which the laser can be pointed. In most cases, the LGS will be placed on or near the science target. The shape of the LOWFS patrol field is circular, its center shifted 10" from the location of the HOWFS field stop (marked LGS in the left panel of Figure 3). NGS up to 45" from the LGS may be used at an arbitrary science camera PA, and up to 60" off axis over a restricted PA range.

5 Telescope interface basics

5.1 Telescope Orientation Limits

NGSAO observations are limited only by the telescope declination limit for tracking of $\delta<88^o$ and hour angle limit of -6h40m < HA < 6h40m. However, the design of the laser beam transfer optics limit LGS observations to the declination range $-11.6^o < \delta < 65.2^o$. In addition, present agreements with the Federal Aviation Administration (FAA) limit LGS observations to the elevation range $45^o < el < 90^o$. We plan to request clearance to observe as low as el=30^o once shared-risk LGS observations begin in early 2007.

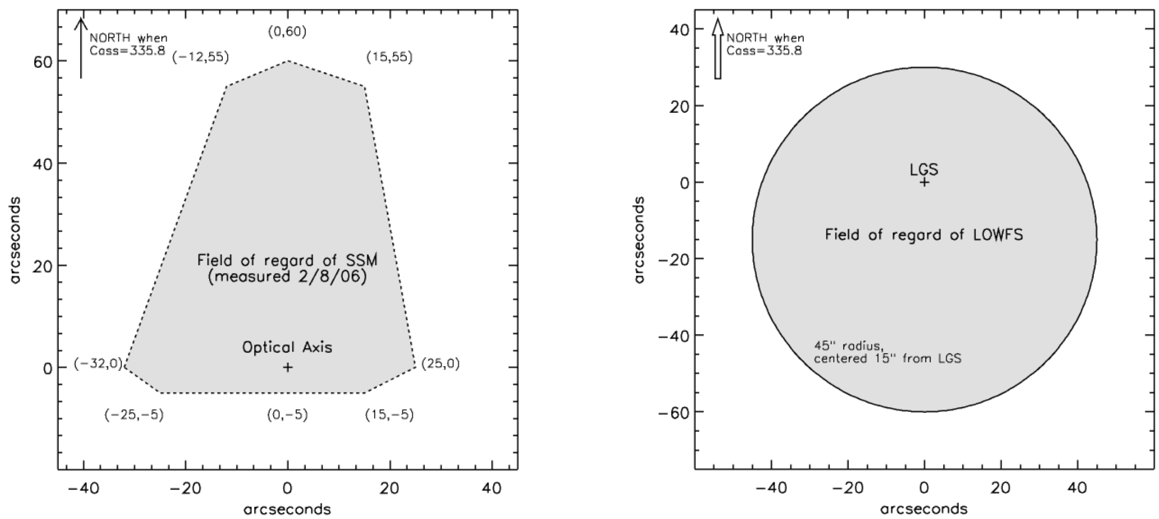

Figure 3: *Left*: The shaded region indicates the approximate field of regard of the SSMs with respect to the telescope optical axis, within which NGS can be observed by the HOWFS. *Right*: The patrol field of the LOWFS, with respect to the pointing location of thelaser. Only NGS located within the shaded region may be used for tip/tilt and focus control.

5.2 Instrument Orientation Limits

In addition to the permitted telescope orientations the PALAO bench including the science instrument can be orientated in any direction about the AO bench spit rotation axis when located on the spit in the AO lab. This is not an absolute requirement placed on the science instrument though can lead to simplifications regarding the access of the PALAO optics with the science instrument in situ.

5.3 Environmental limits

Operational temperature limits are -10^{o}C to +25^{o}C.

Humidity ranges from 10% to 100% though these values represent extremes. Running averages of temperature, pressure and humidity can be found at the following link:

http://www.palomar.caltech.edu:8000/maintenance/weather/user_gen.tcl

6 Mechanical interface basics

In the discussion which follows, a coordinate system whose origin is coincident with the corner of the AO bench nearest FM3 will be used, as shown in Figure 1.

X represents distance along the long axis of the bench, *Y* is the distance along the narrow axis of the bench, and *Z* is distance from the bench surface away from the sky. By default all units are in millimeters, though equivalent values are given in inches (for those who think it's a good thing for spacecraft to crash on the surface of Mars).

6.1 Physical dimensions

The largest allowable rectangular volume which meets all of the requirements expressed below and allows full rotation of the Cass ring can be defined by opposing vertices at:

[X, Y, Z] = [0,0,0] and [457.2, 1371.6, 955.8]

and in inches:

[X, Y, Z] = [0,0,0] and [18.0, 54.0, 37.63].

The available footprint is shown schematically in Figure 4.

6.2 Mass limits

The interfacing science instrument shall have a mass of <200kg, including cryogen and cables.

This is our current best estimate at a maximum mass for which the telescope can be balanced for all instruments. The mass limits set by the strength of the Cass ring bearing and the PALAO mounting pins are expected to be substantially higher, thus the mass limit or rotation is identical.

The uncertainty is due in part to our lack of knowledge of the mass of PALAO and recent add-ons such as the Multiple Guide Star Unit. The observatory is currently reviewing the issue of instrument balance and will raise this maximum mass if deemed unnecessarily restrictive. We understand that this is substantially below the mass budget agreed to in the MOU, and will endeavor to clarify this situation as soon as possible.

6.3 Torque limits

The maximum torque allowed by an instrument in the plane perpendicular to the telescope optical axis is 250 ft-lb. This is below the static friction of the Cass ring bearing with the brakes unclamped, thus keeping the instrument from spinning around if the brakes should fail. However, the PALAO mass distribution is at present poorly known, so it is not possible at this time to estimate the torque budget.

7 PALAO enclosure

The PALAO enclosure must be modified to accommodate the SWIFT instrument as it encloses the volume surrounding FM3, which the current SWIFT design requires. A schematic of the current enclosure is shown in Figure 4. The minimum alteration would be to remove the enclosure extension surrounding FM3 and provide a separate enclosure for the PHARO FM3 when installed.

It is possible that an entirely new enclosure will be made for the PALAO bench as part of the Palm3k upgrade. Such an enclosure will still provide the previously allocated volume for any science instrument.

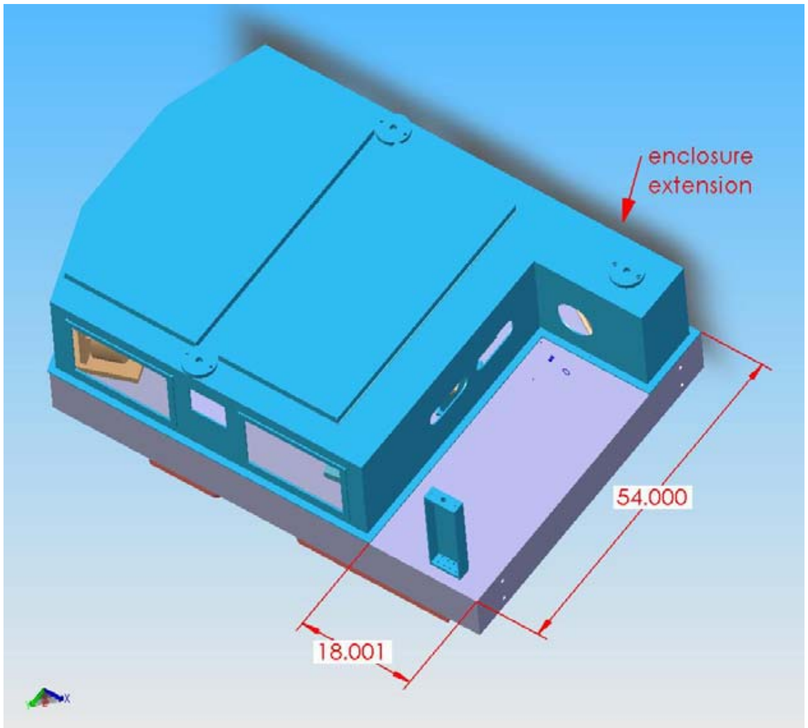

Figure 4: The AO bench footprint available to the science instrument. Dimensions shown are in inches.

8 Instrument interface to AO bench

Any science instrument is required to mount to the surface of the PALAO optical bench using 0.25" diameter, 20 thread per inch holes located in a 1" rectangular grid. The holes are located at x=3, 4, 5,... and y=2, 3, 4,...51, 52, following the coordinate convention summarized in Section 6.

Regardless of how the science instrument is attached to the PALAO optical bench, all mounting hardware must be fully removed during an instrument change.

COO is in the process of designing a generic interface mount for all instruments wishing to interface to the PALAO system.

9 Instrument adjustment while on AO bench

9.1 Focus adjustment

PALAO will provide ±2mm of focus adjustment for initial set-up after an instrument change and for during observations to account for thermal and mechanical movement of the optical elements.

9.1.1 Current focus control

The back focal distance varies by ~±1mm due to changes in the temperature of the PALAO bench and optical mounts.

Small focus adjustments can be made by PALAO by modifying the centroid positions to which the WFS spots are driven, adding focus to the DM's default shape. However, using the WFS quad cells off null reduces the AO system bandwidth and can lead to PSF artifacts.

For PHARO, this adjustment is performed before each AO run (monthly), and during the afternoon after large changes in night-time temperature. With PALAO mounted on the telescope and with the DM flat, the white light pseudo-star in the stimulus unit is imaged in PHARO's finest platescale. PHARO is unclamped from its cradle, translated manually along its optical axis until the FWHM of the stimulus image is minimized and tightened. This adjustment is difficult to make accurately due to the lack of a micrometer screw or other focus fiducial. An alternative focus adjustment, satisfying the requirements of all future science instruments, is therefore preferable.

9.2 Pupil alignment

10 Instrument mounting

10.1 Possible configurations

The science instrument will need to be operated at Palomar Observatory in the following configurations:

[IC1] Mounted on PALAO optical bench at the Cassegrain focus of the Hale telescope;

[IC2] Mounted on PALAO optical bench on the AO spit in the Palomar AO lab;

[IC3] Mounted on the instrument handling cart in the Palomar AO lab;

In addition, the instrument will be transported within the dome (but not operated) in the following configurations:

[IC4] Mounted on the instrument handling cart, optics down;

and, for instruments of the equivalent size as PHARO or less:

[IC5] Mounted on the PALAO optical bench and on the PALAO handling cart;

Finally, we require that it be possible to mount the instrument on PALAO optical bench in the following locations:

[IC6] When PALAO is on the AO spit in the AO lab;

[IC7] When PALAO is at the Cassegrain focus of the Hale telecope;

The interface definitions which follow will reference these 7 configurations when appropriate.

10.2 Larger instruments and [IC4]

Configuration [IC4] only applies to instruments equivalent or smaller in size and mass than PHARO. For larger instruments, such as SWIFT, substantial modifications are required to the PALAO handling cart and elevator doors in order to transport the assembled system inside the dome. In addition, the structure of the science instrument is required to support the weight of the PALAO assembly when placed in configuration [IC4]. Given these issues, we have removed the requirement that instruments of this size must satisfy configuration [IC4].

Such instruments will be mounted onto the telescope using the science instrument handling cart only. The cart must fit inside the available space allowed by the hole in the Cassegrain cage. This is discussed further in Sections 10.4 and 10.6.

10.3 PALAO handling cart

The PALAO handling cart is shown in schematic form in Figure 5 (left). The cart supports the entire PALAO optical bench, with PHARO attached, while off the telescope. It is used to remove the PALAO system from the Cass rotator and transport it to the AO lab on the ground floor of the Palomar dome. The PALAO handling cart provides Z translation of the PALAO optical bench only. This fine motion is advantageous when mating the PALAO bench to the Cass rotator.

The locations of the supports, and estimated maximum load, are listed in Table 1.

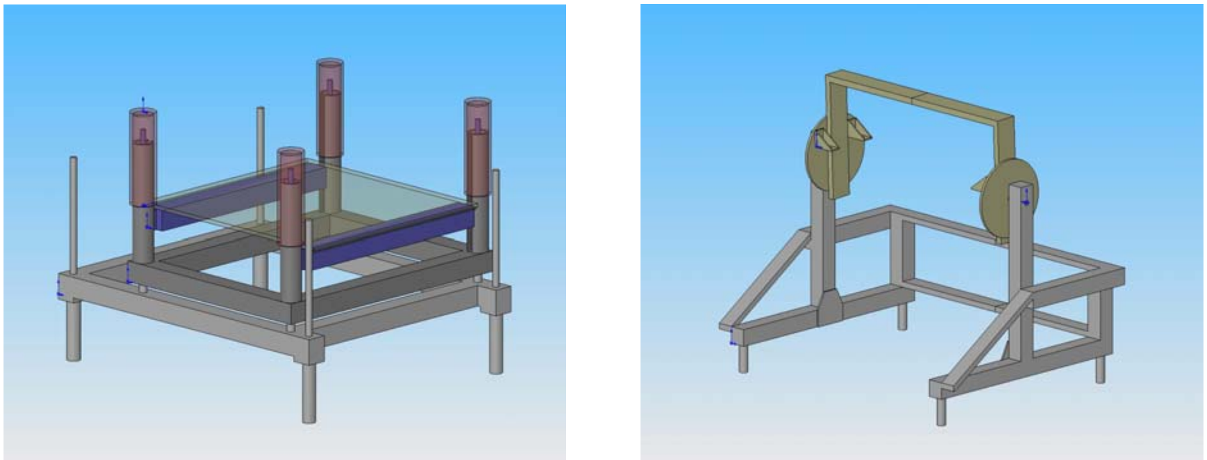

Figure 5: *Left* The PALAO handling cart used to support the PALAO optical bench during instrument interchange and for transport inside the Palomar dome; *Right*: The PALAO spit, permanently housed inside the AO room on the ground flour of the Palomar dome, is used to support and rotate the PALAO optical bench with science instrument during testing off the telescope.

For instruments equivalent in size to PHARO the same handling cart can be used for instrument removal.

	X	Y	Z	Load
Cart Support 1	152.4 (6.0)	69.85 (2.75)	406.4 (16.0)	?
Cart support 2	165.1 (6.5)	1308.1 (51.5)	406.4 (16.0)	?

Table 1: Location of the PALAO handling cart support points

10.4 Cassegrain cage

To install the PALAO system onto the Cass rotator of the telescope requires that the PALAO handling cart be lifted through the floor of the Cass cage on the hydraulic lift (136.0" diameter, centered below the telescope). The floor opening is 58.0" in width, with a horizontally projected length of 83.2". The PALAO bench is 54.0" x 78.0" long the central axes, leaving only 2" clearance on either side of the bench during this operation.

For the safety of both the instrument and personnel during this operation, we require that the science instrument fit entirely within the footprint of the AO bench. This defines the maximum length of the science instrument: Y ≤ 54.0".

The maximum volume which allows full rotation within the Cass cage is cylindrically symmetric, shaped somewhat like a cone, which tapers downward to a flattened point. The largest inscribed rectangular box with can fit in this volume and be contained within the X-Y footprint of the AO bench has a height of Z ≤ 37.63". To extend further downward, the outer corners of the instrument would have to taper towards the optical axis of the telescope, with a taper angle of 61.5^{o}.

10.5 PALAO spit

The PALAO spit is shown in Figure 5 (right) and is located permanently in the AO lab on the ground floor of the Palomar 200" dome. It is used to support the PALAO optical bench with science instrument attached and provide rotation of the system about a horizontal axis.

The science instrument handling cart must fit underneath the PALAO spit, with PALAO bench in place, for removal and mounting of the science instrument. This is discussed further in Section 10.8.

10.6 Instrument handling cart

The science instrument should be provided with a handling system, which will facilitate safe transportation of the instrument within the observatory, and mating to the PALAO bench on the Hale telescope and on the PALAO spit. In addition, the handling system should facilitate the inversion of the instrument from its optics-down installation orientation, to an optics-up orientation for instrument maintenance.

Possible solutions are:

1. A handling cart with a built-in spit, which can support the instrument either optics-down (for installation) or optics-up (for maintenance) and flip it between the two configurations. The space for a clamping mechanism and bearings at the ends of the instrument bench would be extremely limited, as the entire device would have to fit through the Cass cage opening. This handling cart could then be lifted vertically using a separate electric or hydraulic lifting device.
2. A handling cart with built-in lift which safely supports the science instrument in either optics-up or optics-down orientations, and facilitates mounting to the telescope.
3. A separate inverting device, which could be bolted to the ends of the instrument and supported by a crane when inverting the science instrument for maintenance.

10.7 Mating to PALAO on the telescope

To be mated to PALAO on the telescope the science instrument has to be lifted vertically through the hole in the Cass cage. While this hole measures only 58.0" wide at the southern end, its 64.0" wide northern end can be used instead by rotating the Cass ring to 155^{o}.

The hydraulic lift built into the observatory floor can be raised to within 5 inches of the level of the Cass cage floor, ~68" from the AO bench surface. Thus the science instrument handling cart must be capable of lifting the mounting surface of the instrument at least this high. While doing so, the science instrument and the handling cart must extend no more than 62" wide (to provide 1.0" clearance on either end of the instrument).

Mechanical drawings of the Hale Cass cage are available for cross-check.

10.8 Mating to PALAO in the AO lab

Mating the science instrument to PALAO when installed on the AO spit in the downstairs lab requires that the science instrument be lifted vertically up to the AO bench surface, which is located 68.63" above the floor. The requirements on the vertical reach of the handling system are thus similar, though clearance issues may be different. Any proposed handling cart design should be tested against the CAD model of the AO spit before acquisition.

10.9 Freight elevator and doorways

For reference, Table 2 lists the dimensions of the freight elevator and doorways. None of these pose restrictions more stringent than installation on the telescope while mated to PALAO.

	Width	Depth	Height
Freight elevator	178cm	224cm	249cm
Elevator ground floor doors	176.5cm	-	235.2cm
Elevator observing floor doors	176.5cm	-	241.3cm
AO lab doors	177cm	-	240.5cm

Table 2: Frieght elevator and doorway dimensions

11 Cryogenic interface

11.1 Spillage of cryogen

Spillage of cryogen at extreme telescope orientations is allowed, but not recommended.

11.2 LN_2 consumption

The observatory can provide 160 liters of LN_2 per day.

11.3 Cryostat hold time

The minimum cryostat hold time is 24 hours.

11.4 Pressure values

With current standard vacuum connectors a pressure of 1.33 X 10^-7 Bar (approximately 1 X 10^-4 Torr) can be readily obtained.

11.5 Vacuum connectors

The standard vacuum connector used at Palomar has a KF25 fitting.

11.6 Overpressure

Cryostat overpressure is allowed for inverted fill demands.

12 Electrical interface

12.1 Electronics rack

Space for one full-sized electronics rack mounted along the South-East side of the Cass cage will be made available for the science instrument. For mounting compatibility, the rack and associated hardware listed in Table 3 should be purchased, and delivered to Palomar, where observatory staff will add mounting hardware and necessary bracing. The modified rack may then be shipped to the instrument lab for integration.

The fully loaded rack should not exceed 200kg in weight not including external cabling. Note that the above rack, with required modifications, weights approximately 85kg.

The science instrument electronics unit will be removed along with the instrument during an instrument exchange. This mirrors the current procedure.

Mfr.	Part	#	Description	Newark Stock[1]
Bud Ind.	ER-16523	1	Economizer cabinet rack (sand)	89F1140
Bud Ind.	RC-7758-PR	2	Heavy duty ball bearing casters	93B5210
Bud Ind.	H-9183-B	2	Diecast aluminum handles	69F205

Table 3: Computer rack parts information. Two sets of casters and two handles are needed for each rack. These stock numbers were drawn from Newark InOne catalogue \#123 (see www.newark.com).}

12.2 Cable lengths

Electrical connections between the science instrument electronics rack and instrument should be through a small number of cable bundles, preferably from connectors on the front of the instrume\nt rack, across the Cass cage floor, and up to the instrument along the telescope optical axis. This requires a cable length of roughly 25ft, with a minimum value of 15ft.

12.3 UPS

12.3.1 Cassegrain cage

Power from three 120VAC 60Hz circuits is available to the instrument electronics rack when mounted in the Cass cage. All three are protected by 15amp circuit breakers, the trip curve of which is reproduced in Figure 6.

One circuit (with 4 available outlets) is on the observatory UPS. We estimate this voltage should drop no more than +5%-10% at 15amps for the UPS circuit during utility power outages. Voltage regulation is within ~2% at the UPS, but there is ~150ft of cabling from there to the Cass cage, consisting of several 14-gauge conductors ganged together.

The other two circuits (with a total of 12 available outlets) are utility (non-UPS) power. The observatory does not currently supply 230V 50Hz power in either the Cass cage or the AO lab.

12.3.2 AO lab

Both utility and UPS 120VAC, 20 amps, 60Hz power are now available in the AO lab. 15amp circuit breakers are provided as above.

12.4 LAN and Fiber

12.4.1 Ethernet connections

There is no Cat5 or Cat6 cabling to the Cass cage, but many coaxial cable connections are available from the computer room or control room to the Cass cage. One or more of these can be used for 10base-2 ethernet connectivity (l0Mbps).

Alternately, one or more pairs of optical fibers (see below) can be used for 100base-fx ethernet connectivity (100Mbps). The observatory can provide media converters to change either 10base-2 or 100base-fx to 10/100base-t (Cat5) at the control room end of the fibers. If this solution is chosen, the science instrument should provide the media converter at the instrument end.

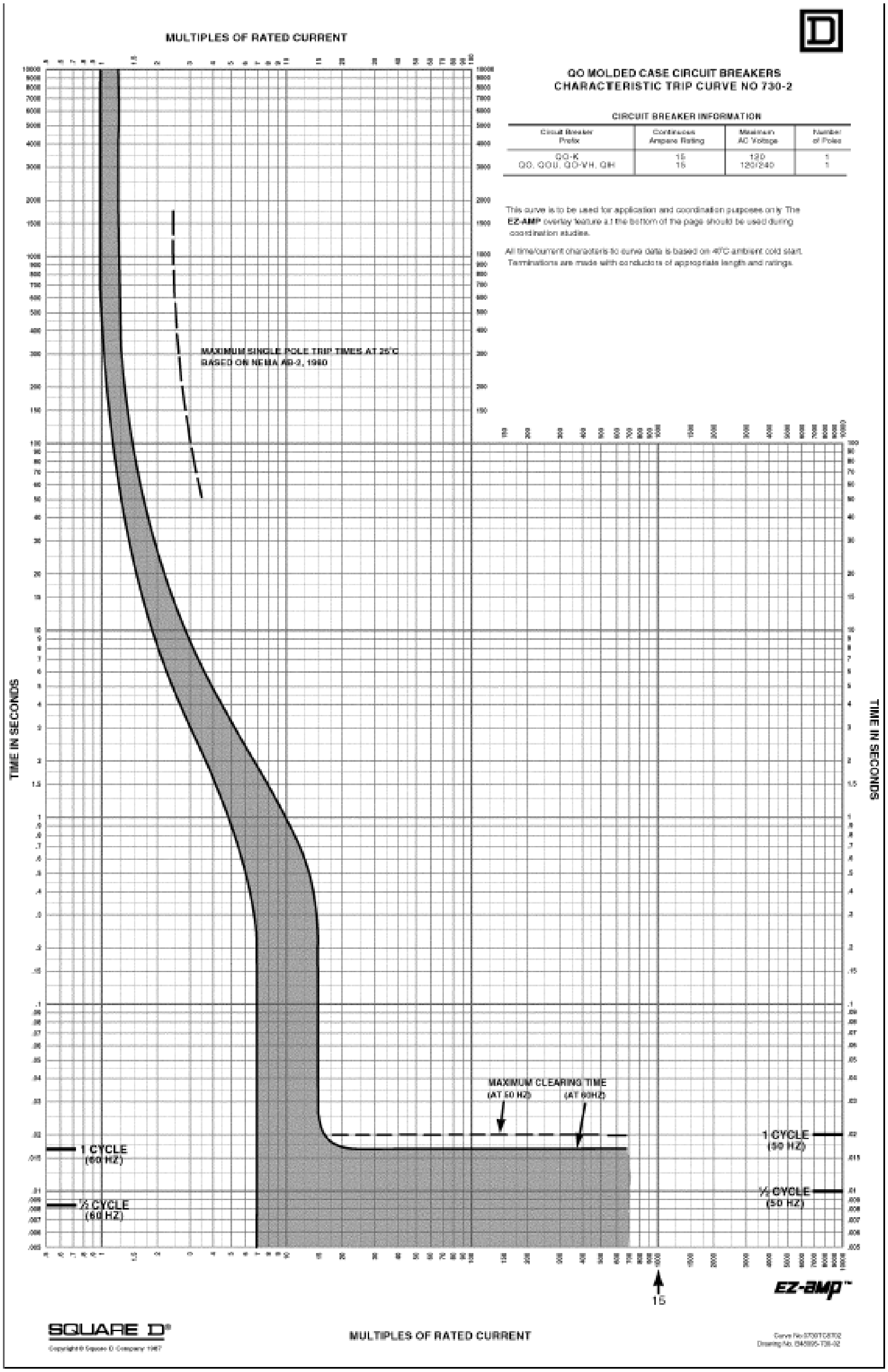

Figure 6: Trip curve for Square D 15amp circuit breakers provided on all Cass cage and AO lab circuits.

12.4.2 Fibre connections

There are 24 fibers (62.5/125μm multimode) running from the Cass cage to the computer room, in 12 pairs. A patch panel in the computer room is available to run these to the control room. 8 of the fibers are currently used by PALAO, 4 by the Cass ring, and 4 by the prime focus instrument, leaving 8 available for the science instrument. ST-style connectors are provided at all patch panels, and ST-to-SC jumper cables are on hand.

It is likely that 24-48 additional 62.5/125μm multimode fibers will be run between the Cass cage and control room before the instrument commissioning begins.

12.5 Fast signals for shutter control

A 5V TTL signal (5V = open, 0V = closed) along a coaxial cable will be used by the AO system to control the fast shutter of any science camera. This is identical to the current control of the PHARO fast shutter.

13 Software Interface

13.1 Interface with PALAO

13.1.1 Socket interface

The science instrument and PALAO will communicate via a socket interface.

13.1.2 AO message header

All messages in the socket interface will have a message header as defined below, followed by a message body to be defined for each message type:

```
typedef struct msg_hdr {
          U32     msg_id;
          U32     src_id;          /* sender application id
(see net_ao.h) */
} MSG_HDR;
```

13.1.3 AO status message

The AO status, configuration and performance data message (as defined in `ao_msg.h` in Appendix 15.1) will be sent to the science instrument at the rate of once per second upon the network connection. It also is sent to the instrument upon detection of a loss of network connection with the AO real-time system (AOCP).

13.1.4 TCS status message

The TCS status message (as defined in `ao_tcs_if.h` in Appendix 15.2) will be sent to the science instrument at the rate of once per second upon the network connection. It also is sent to the science instrument upon detection of a loss of network connection with TCS.

13.1.5 Instrument status message

The science instrument status message (to be defined, but see `ao_if.h` in Appendix 15.3 for PHARO example) shall be sent to AO upon change in the status of any of the instrument mechanisms, as well as upon completion of detector readout.

13.1.6 Instrument commands to PALAO

All command messages to (and from) the science instrument consist of a standard message header followed by an ASCII command text string. The command syntax and semantics, and their respective responses, are defined below.

```
typedef struct cmd_msg {
          MSG_HDR hdr;
          char    cmd[MAX_CMD_LEN];
} CMD_MSG;
```

A command response message, when required, will have the following structure:

```
typedef struct rsp_msg {
          MSG_HDR hdr;
          char    rsp[MAX_RSP_LEN];
} RSP_MSG;
```

The following AO commands and their responses shall be defined:

13.1.6.1 Set DM mode

```
command:   set dm {on | off}
response:  set: completed. dm = on
set: completed. dm = off
set: rejected. Invalid command.
```

13.1.6.2 Set tip/tilt mode

```
command:   set tip-tilt {on | off}
response:  set: completed. tip-tilt = on
set: completed. tip-tilt = off
set: rejected. Invalid command.
```

13.1.6.3 Move telescope in RA/Dec (units of arcseconds)

```
command:   move_tel  [+|-]xxxx.xxx  [+|-]xxxx.xxx
response:  move_tel: completed.
move_tel: rejected. Invalid command.
```

13.1.6.4 Other TCS commands

```
. Source position
coords ... (five or six arguments)
. Define Current Position of Telescope
tx
. Move Telescope
ret
. Zero DRA and DDEC Display Offsets
z
```

13.1.6.5 Command responses

The response to the above commands can be one of the following:

```
<command_name>: completed.
<command_name>: rejected. Unrecognized command.
<command_name>: rejected. Invalid parameter(s).
<command_name>: rejected. Unable to execute at this time.
<command_name>: processing.
```

13.1.7 PALAO commands to the science instrument

There is currently no need for commands from PALAO to the science instrument.

13.2 Interface with the TCS

The science instrument will interface with the 200-inch TCS via PALAO, using the above command set. t will not interact directly with the TCS.

14 Appendix A: Expected A.O. Performance

Would you like to add any minimum specs here, such as limiting guide star magnitude, expected/measured Strehl under certain atmospheric conditions, ability to track on non-sidereal sources, laser star magnitude, limiting tip-tilt star magnitude. There should be a second set of specs for PALM3K, these could be minimum specs rather than predicted values.

14.1 General Specifications}

The Palomar adaptive optics system, PALAO, utilizes an off-axis paraboloid relay, at fast tip/tilt mirror, a 349 actuator (241 active) Xinetics, Inc. deformable mirror, and a SciMeasure Analytical Systems, Inc. wavefront sensor camera to partially correct the atmospheric wavefront disturbances at the Cassegrain focus of the 5.1 m Hale telescope. The real-time control computer allows the tip/tilt and deformable mirror control loops to be run at frame rates up to 2.0 kHz, and provides extensive telemetry recording capability. This natural guide star (NGS) adaptive optics system is currently being upgraded with a laser guide star (LGS), dramatically increasing its sky coverage.

14.2 Definition of A.O. system specifications

{\it FC: Here we need to specify things like bandpass of the wavefront sensor (i.e. transmission curve at (and including) WFS detector), bandpass of tip-tilt sensor -- both for the purposes of computing differential atmospheric refraction, and transmission of A.O. optical train as a function of wavelength.}

14.3 NGS performance

In median atmospheric conditions (Fried parameter r0=10 cm, turbulence-weighted wind velocity v0=10 m/s), the performance of the PALAO system on bright guide stars is limited by fitting error to an RMS wavefront error of 225 nm. This corresponds to an on-axis Strehl ratio of 0.57 at K band (2.15 m) and 0.23 at J band (1.25 m). The wavefront error increases gradually with increasing guide star magnitude, to a maximum guide star magnitude of V13.5.

If there is a table of performance limits for different conditions, it would be good to add that here. We also need to generate a prediction of perfomance (limiting magnitude) with a new dichroic using on light <650nm...

14.4 Predicted LGS performance

The PALAO system is currently being upgraded with a sodium laser developed by the University of Chicago, with the PALM-LGS system is expected to be available for science in fall 2006. In LGS mode, the high-order wavefront sensor observes the resonantly scattered laser radiation from the mesospheric sodium laser, while a separate low-order wavefront sensor observes a nearby NGS to measure tip/tilt and focus.

In median atmospheric conditions and with the current laser performance (5 W projected on the sky), we expect the PALM-LGS system to deliver an RMS wavefront error of 270 nm when using bright tip/tilt stars on-axis, corresponding to a Strehl of 0.53 at K and 0.15 at J. The low- order wavefront sensor is designed to operate on stars as faint as V=17.0, and may be useable to V=18.5 with some modifications. With a V=16.0 NGS on axis, the predicted total RMS wavefront error is 350 nm, corresponding to a Strehl of 0.28 at K and 0.04 at J.

14.5 Nodding

The Star Selector Mirrors (SSMs) limit nodding performance. Value TBR.

14.6 Tracking

No differential tracking between the science camera and wavefront sensors is currently implemented. Requirements are to be reviewed.

14.7 Safety

To be defined.

15 Appendix B: Software Interfaces

15.1 Ao_msg.h

15.2 Ao_tcs_if.h

15.3 Ao_if.h