NFIRAOS — Multiconjugate AO System for TMT

Glen Herriot[1a], David Andersen[1], Jenny Atwood[1], Peter Byrnes[1], Corinne Boyer[2], Kris Caputa[1], Carlos Correia[1], Jennifer Dunn[1], Brent Ellerbroek[2], Joeleff Fitzsimmons[1], Luc Gilles[2], Paul Hickson[3], Alexis Hill[1], John Pazder[1], Vlad Reshetov, Malcolm Smith[1], Jean-Pierre Véran[1], Lianqi Wang[2] , Ivan Wevers[1]

[1]NRC-HIA, 5071 West Saanich Rd, Victoria, Canada
[2]TMT, 1111 S. Arroyo, Pasadena CA
[3]UBC, Physics & Astronomy, 6224 Agricultural Road, Vancouver, Canada

Abstract. NFIRAOS, the Adaptive Optics system for the Thirty Meter Telescope, is a Multiconjugate Adaptive Optics System of order 60x60 with two deformable mirrors and six laser guide star wavefront sensors. NFIRAOS is 8 x 10 x 5 m (L x W x H) on a Nasmyth Platform and supports three client instruments operating over 0.8 – 2.5 µm wavelength range. In this paper we discuss: NFIRAOS' requirements and architecture; changes to NFIRAOS since the last AO4ELT conference; interior details of NFIRAOS; interfaces to instruments; integration and verification plans. Top-level science requirements include 50% sky coverage at the galactic pole with <187 nm wavefront error. Astrometry is an important science driver – to minimize image distortion (0.0017 %), we have recently revised the optical design to use four off-axis paraboloidal mirrors. We have vastly simplified the laser WFS trombone optics and moved them inside the cold enclosure. To control image magnification, differential magnification and tip/tilt/focus, NFIRAOS' client instruments have three low-order warfront sensors monitoring near-infrared natural guide stars. These stars are sharpened by NFIRAOS, which assists sky coverage. NFIRAOS will have high throughput and low thermal background – it will be cooled to -30 °C. The insulated walls have a buried cold plate to intercept heat leakage and isothermalize the interior of NFIRAOS. Instruments have stringent requirements on heat leakage and must provide their own rotator and interface to NFIRAOS, including a rotating seal. For wavelength and flat field calibration of client instruments, a NFIRAOS Science Calibration Unit (NSCU) feeds light in the entrance window, through NFIRAOS, to instruments. Inside NFIRAOS are deployable light sources simulating natural and laser guide stars, a focal plane mask with pinholes illuminated by the NSCU, as well as a turbulence phase screen. A prototype screen has been manufactured by magneto-rheological machining. We are currently updating the NFIRAOS preliminary design.

1. Introduction

NFIRAOS, the Narrow Field InfraRed Adaptive Optics System, will be the first-light adaptive optics system on the Thirty Meter Telescope.[1] NFIRAOS is currently under design at the Herzberg Institute of Astrophysics of the National Research Council of Canada. It will stand on one of the two Nasmyth platforms of TMT, and be fed by the articulated tertiary mirror (M3) located in the centre of the primary mirror. The corrected beam from NFIRAOS will be sent to three client instruments, represented by cylinders on the top bottom and side of Figure 1. The electronics cabinet is shown beside the human figure on the Nasmyth platform. In front

[a] glen.herriot@nrc-cnrc.gc.ca

of NFIRAOS at its upper corner in this view, is a science calibration unit (NSCU) that sends wavelength and flat field calibration sources through NFIRAOS to client instruments. When observing, the beam from the telescope passes through the NSCU and enters NFIRAOS. During commission and early operations, there will be an acquisition camera on a side port, which will be replaced by an instrument eventually.

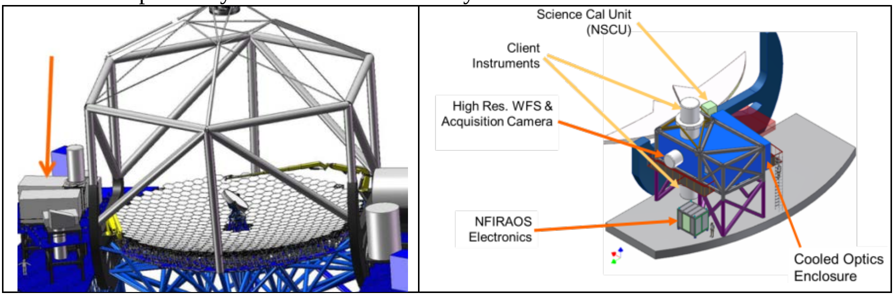


Fig. 1. Left: TMT Telescope. Right NFIRAOS on Nasmyth platform with client instruments.

2. Top Level Requirements

The requirements for NFIRAOS flow down from the science requirements for TMT. Chief among the specifications are the following:

- Throughput: >80%, 0.8 to 2.5 μm
- Background Thermal Emission: < 15 % of sky and telescope
- Wavefront Error: 187 nm RMS on-axis, and 191 nm RMS on a 17” FoV
- Sky coverage: 50 % at the Galactic pole
- Differential photometry 2% for a 2 minute exposure on a 30” FoV at $\lambda = 1$ μm
- Differential Astrometry[2]: 50 mas for a 100 s exposure on a 30” FoV in the H band
- Available from standby: <10 minutes
- Acquire a new field: < 5 minutes
- Downtime: < 1 per cent unscheduled

3. NFIRAOS Architecture

To meet the requirements listed above, NFIRAOS is a multi-conjugate adaptive system with two deformable mirrors. This provides a wide uniformly-corrected field of view that helps sky coverage, astrometry and photometry. To control the DMs, NFIRAOS uses atmospheric tomography with six laser guide stars. These are in an asterism with five beacons in a pentagon of 70 arcseconds circumscribed diameter, plus a sixth in the centre, on-axis. Tip, tilt and focus is sensed in the near-infrared (J+H bands) on three natural guide star images sharpened by the high order correction controlled by the laser guide stars. These three natural guide star sensors are within client instruments. To achieve the high throughput, there are a minimum number of optical surfaces: seven reflections plus a beamsplitter and a window. Together with cooling the system to -30°C, this optical design minimizes thermal background.[10]

4. Sky Coverage

We define sky coverage as the probability of reducing wavefront error below the 191 nm requirement over a 17” science field of view. This probability must be greater than 50% at the Galactic Pole and is mainly limited by the brightness and density of the natural guide stars necessary for sensing tip tilt and focus together with image magnification and distortion modes. Figure 2 is a Mercator projection of the sky in galactic coordinates, with the Galactic pole along the top edge and the galactic equator running across the centre of the plot. The colour scale is the probability of achieving ≤191 nm RMS wavefront error, and shows that NFIRAOS will reach its requirements. The black regions are where the objects are too low in the sky for good correction, and the solid red line shows the limit of TMT to point up to 65 degrees from zenith. The dashed green lines indicate where guide stars are very numerous and therefore the limitation on image quality is mostly due to zenith angle rather than guide star density.[3]

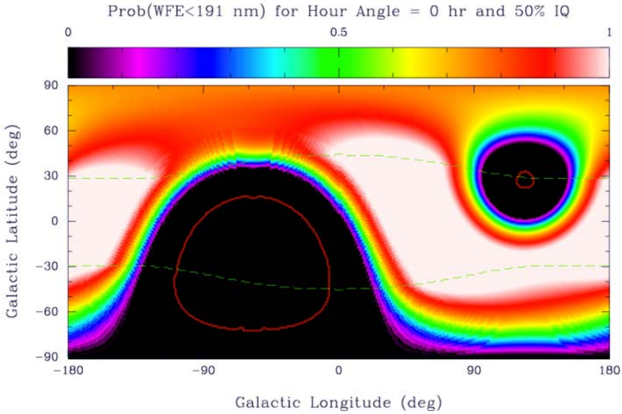


Fig. 2. Sky coverage versus galactic coordinates.

5. Fundamental Design Parameters of NFIRAOS

NFIRAOS will deliver a 60 arcminute diameter beam to science instruments. The chief motiv–ation for this beam diameter is to provide sufficient search area for natural guide stars. Client instruments have one natural guide star tip/tilt/focus sensor (2x2 SH WFS, sensing in J + H band) as well as two tip/tip sensors.

There will be six laser guide star wavefront sensors, each of order 60 x 60. These wavefront sensors will have polar coordinate CCD detectors, with 204792 pixels measuring 5792 gradients per WFS. Near to the centre of the pupil, 6x6 islands of 0.5 arcsecond pixels digitize the Shack-Hartmann spots, and at the edge of the pupil, these islands increase in size to 6x15 pixels, oriented radially along the elongated spots. NFIRAOS’ real time controller processes 1.23 mega-pixels from the LGS wavefront sensors into ~35,000 gradients and solves the tomography problem to control ~7000 DM actuators at 800 Hz.[8]

NFIRAOS has two deformable mirrors. DM0 conjugate to the ground has 63x63 actuators, and is mounted on a tip/tilt stage. DM11 has 76x76 actuators and is conjugate to 11.2 km.[4]

6. Optical Path

Figure 3 shows an isometric view of the optical path for science light. All of the science path optics lie in an horizontal plane. Light from TMT enters through an evacuated double-paned entrance window and traverses a pair of off-axis paraboloid relays, each with a DM and reaches an instrument selection mirror that sends the light up, down or sideways to instruments.

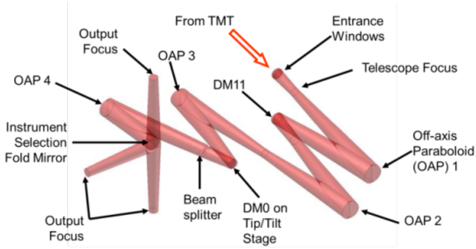


Fig. 3. Science path isometric view.

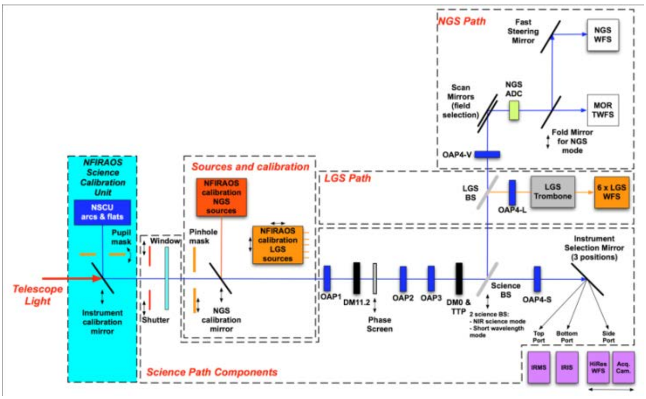


Fig. 4. Schematic block diagram of NFIRAOS optics

The block diagram in Figure 4 depicts the science path as the horizontal blue line running left to right near the bottom of the figure. The telescope light passes through the NFIRAOS science calibration unit (NCSU). When deployed the NSCU sends wavelength and flat-field calibration light through NFIRAOS, and includes a rotating pupil mask. The light from TMT enters NFIRAOS by a window with a shutter, and into a region with deployable calibration equipment: a pinhole mask at the input focal plane, which is illuminated by the NSCU;

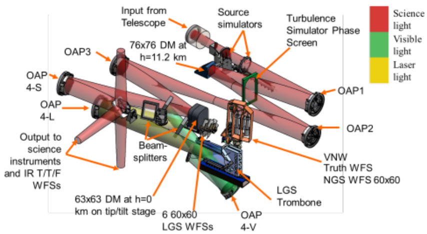
adjustable-brightness natural guide star simulators; and a LGS source simulator that translates along the beam. You can see the two OAP relays, containing the two DMs and a turbulence phase screen and beamsplitter on a changer. The science IR light transmitted through the beamsplitter is directed to the three client instruments. During early operations, one instrument position will hold a diagnostic patrolling high-resolution WFS and acquisition camera.

The visible light reflected from the beamsplitter travels upward, and immediately the laser light is split off and is imaged by OAP-4L, focussed by a trombone and feeds six LGS WFSs. The natural visible light continues upward in the diagram, to a pair of scanning mirrors that select an individual star, send its light through an atmospheric dispersion compensator (ADC) and (when using lasers) into moderate order (12x12) radially symmetric mode sensing truth wavefront sensor. (MOR TWFS). NFIRAOS can also operate in classic NGS AO mode by deploying a fold mirror to send the light towards a 60x60 NGS WFS. A fast steering mirror in this path dithers the beam to calibrate centroid gain of the NGS WFS in real time, to compensate seeing variations.

7. Opto-Mechanical Design

Following the first edition of this conference in 2009 we have made substantial improvements and cost savings to the design of NFIRAOS.[5] A new four-OAP design dramatically reduced image distortion. Incorporating this optical design increased the size of NFIRAOS about 2x, but the larger volume permits simplifications and savings. NFIRAOS now uses a space frame design for optics support. There is a simplified turbulence simulator (simply a phase screen in collimated space, instead of a telescope simulator in front of NFIRAOS).[11] The laser guide star wavefront sensor subsystem uses a common trombone, thereby removing 20 motors from NFIRAOS. Rather than using very expensive super-insulation we now intercept heat leakage with a buried cold plate within the enclosure walls. Moving the acquisition camera to a side port meant that the instrument selection fold mirror can now be a single-axis device. The acquisition camera now patrols the output field, reducing its instantaneous field of view and cost. The optical source simulators are simple pinholes deployed into the beam, without any auxiliary optics.

All of these components are shown in the left panel of Figure 5, which is drawn from the same viewpoint as Figure 3. Again, the infrared science light path is in red, and we have added the natural visible light in green and the laser light is yellow. Near the top of this figure, you can see the frames for the source simulators and for the turbulence simulator phase screen. In the foreground is OAP-4V that reimages the NGS light, suspended below the plane of the science optics. Above that is the LGS trombone and then the VNW (Visible Natural Wavefront sensor) bench supporting the Truth Wavefront Sensor and the NGS-mode WFS. The right hand panel of Figure 5shows the opto-mechanics supported by a truss space-frame. In this view, the entrance window is on the left and the laser WFS trombone is on the right. In the right hand panel, the curving thick purple object on the lower right is the wiring for DM0. Just below this, and above the science beam heading to the side instrument port, you can see one of three bipods, which penetrate the cold enclosure and support the space frame.



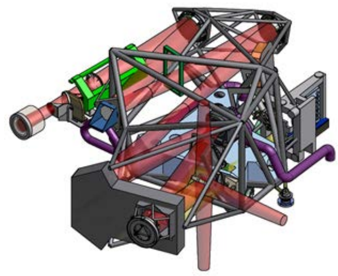


Fig. 5. Optomechanics and space frame support.

7.1. Cooled Enclosure

NFIRAOS and its client instruments are supported by a steel exoskeleton that surrounds the cooled optical enclosure. This enclosure will be slightly pressurized to keep moisture from leaking into NFIRAOS. During initial cooling, two large air-handling units will bring NFIRAOS down to operating temperature in under 15 hours. Then these units will be switched off, and the temperature will be maintained by cold plates sandwiched into the insulated walls. These plates intercept heat from the dome, and maintain an isothermal environment within NFIRAOS. To service NFIRAOS, it will be warmed up to dome temperature before opening.

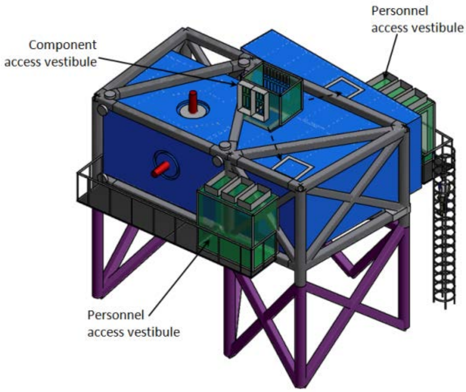


Fig. 6. Access to optics enclosure

Deployable personnel access vestibules will be installed over access hatches to permit people and equipment to enter NFIRAOS. These vestibules will be equipped with air knives using filtered air to reduce particulate contamination of NFIRAOS.

Gate valves inside each instrument port, together with removable insulated covers permit exchanging instruments without warming NFIRAOS. Instruments have their own rotator bearings supported by NFIRAOS exoskeleton. Each instrument supplies rotating seals that mate with the buried cold plate inside the walls of NFIRAOS and keep the cold dry air inside NFIRAOS.

8. Summary

NFIRAOS' requirements and architecture have been defined. Its optics have been redesigned using four off-axis paraboloids for low image distortion. The interior details, and access and servicing procedures are well advanced. The interface to instruments is designed. We are on track for a major design review late in 2011, and look forward to building NFIRAOS and testing it on the sky at TMT.

9. References

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