Installation, alignment and preliminary performance of the Thai National Telescope Focal Reducer

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ABSTRACT

The National Astronomical Research Institute of Thailand (NARIT) is currently developing a new kind of focal reducer for the 2.4 m Thai National Telescope (TNT). The objective is to image a circular Field Of View (FOV) of 15 arcminute diameter with an image quality close to the seeing limit over the spectral bands B, V, R and I. This focal reducer comprises one doublet lens L1 located on one robotic rail mounted on the telescope fork and one triplet lens L2 mounted on the instrument cube in front of the camera.

First, we remind the specifications and the optical design of the instrument. Second, we present the method used to assemble the lenses inside the barrels. Third, we describe the procedure we have used to integrate the focal reducer on the TNT. We describe the robotic rail on which L1 is mounted and we present the results of the wavefront measurement performed to verify the optical quality of the TNT equipped with L1. We also describe the operations of the installation of L2, the filter wheel and the camera on the telescope. Fourth, we present the preliminary performance of the focal reducer measured on-sky with the TNT. We show that the focal reducer provides a resolution close to 1.5'' over a FOV equal to 12'x12' limited by the dimensions of the current filters. We also show that the plate scale is equal to 0.6''/pixel and is stable over the B, V, R and I bands.

Keywords: Telescope design, focal reducer, wide-field camera, robotic systems.

1. INTRODUCTION

The Thai National Telescope (TNT) is a 2.3 m Ritchey-Chretien telescope of aperture number \( F_{\text{TNT}} = 10 \) [1] mounted on a alta-azimuthal mount and located at the Thai National Observatory (TNO) represented in Figure 1. This observatory is situated in the Doi Inthanon National Park at the altitude equal to 2457 m close to the Doi Inthanon summit, the highest peak of Thailand. In this site, the seeing in median conditions is equal to 0.9'' [2]. This telescope includes one instrument cube on which three instruments are currently permanently mounted: two cameras and one medium resolution spectrograph. The ULTRASPEC camera [2] is a high speed photometric imager used to measured time-domain phenomenon (transiting exoplanets, flares, etc…). The ULTRASPEC FOV is equal to 7.7’x7.7’ and this camera provides images with narrow-band and wideband filters over the spectral band [330 nm , 1000 nm]. The 4K camera is a cryogenic camera that comprises a thinned CCD with 4k x 4k x 15µm pixels. The 4K camera provides images over a FOV equal to 8.8’ x 8.8’ through the Johnson-Cousin filters U, B, V, R and I. The Medium Resolution Spectrograph (MRES) is an echelle spectrograph that provides spectrum over the spectral domain [400 nm, 800 nm] with a spectral resolution close to 15,000.

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In this context, we have designed a new kind of cost-effective focal reducer to i) reduce the TNT aperture number to F# ≈ 6.3, ii) image a circular FOV of diameter equal to 14.6′ (TNT specified FOV) on the 4K camera and iii) provide a resolution close to the seeing limit [3,4]. This instrument has been designed with the objective to keep the position of the 4K camera as close as possible to the original position with a maximum shift along the optical axis equal to a few centimeters.

In Section 2, we provide an overview of the specifications of the focal reducer and we briefly describe the optical design. Section 3, we present the procedure used to integrate the lenses of L1 and L2 on their barrels. We also describe the tools manufactured at the NARIT mechanical workshop that have been used to perform these activities. Section 4, we explain the procedure used to integrate the focal reducer on the TNT elevation axis. First, we describe robotic rail located on the TNT central section and used to position L1 on the optical axis. Then, we present the operations we have performed to install the lens L2, the filter wheel and the 4K camera on the TNT instrument cube. Finally we discuss in Section 5 the preliminary on-sky results we have obtained with the focal reducer. We show that i) the FOV is limited to 12′×12′ by the current size of the 4K camera filters, ii) the resolution of the camera is close to 1.5″ over the specified spectral bands and ii) the camera is free of significant chromatic aberrations.

2. FOCAL REDUCER SPECIFICATIONS AND DESIGN

The focal reducer has been specified to image on the 4K camera a FOV equal to 14.6′ with an angular resolution better than 1.3″ in median seeing conditions. This, over the spectral bands B, V, R and I of the Johnson-Cousin Photometric system. The focal of the TNT equipped with the focal reducer is equal to 14.5 m and the aperture number is equal to 6.3. The maximum distortion has been specified to be equal to 1% and the maximum angle of incidence of the chief ray on the filter will be lower than 5°. This, in order to make sure that the spectral transmission of the interference filters will be stable over the specified FOV. The optical design has been specified to comprise only common glasses and spherical surfaces to make sure that the system will be cost-effective.

The optical design of the Thai National Telescope (without the focal reducer) is represented in Figure 2 left-panel. The concave hyperbolic mirror M1 reflects the incident light beam toward the hyperbolic mirror M2. This mirror reflects the beam toward the plane mirror M3. This mirror reflects the light toward the baffle [5] and the folding mirror M4 that reflects the beam toward the instrument mounted on the instrument cube.

Figure 2 right-panel represents the optical design of the focal reducer. The beam reflected by M1, M2 and M3 is incident on the achromatic lens L1 that transmits the beam toward the baffle and the mirror M4. The beam reflected by M4 is transmitted by the achromatic triplet L2 toward the filter wheel and the camera. L1 comprises two lenses L11 and L12 of material N-BK7 and F2 of diameter close to 23 cm. L1 is mounted on one robotic rail (described in Section 4) that positions L1 on the optical axis during the observations with the focal reducer. During the observations with the other instruments, the robotic rail removes L1 and place the extension of the TNT baffle on the optical axis.
The lens L2 comprises three lenses L21, L22 and L23 of material S-PHM52, SF1 and N-PSK53A respectively. The diameter of each lens is close to 15 cm. This lens L2 is mounted on the instrument cube via a mechanical part called the spacer and represented in Figure 3. This spacer aims at i) carrying the weight of L2 and locating this lens at the correct location inside the instrument cube, ii) carrying the weight of the 4K camera and the filter wheel and iii) shifting by 46.1 mm along the optical axis the filter wheel and of the 4K camera.

![Figure 2. Left-panel: ZEMAX model of the TNT optical design without the focal reducer. Right-panel: Focal reducer optical design.](image-url)

![Figure 3. Solidwork view of the spacer mounted on the instrument cube, the achromatic triplet L2, the filter wheel and the 4K camera.](image-url)

3. **ASSEMBLY OF THE LENSES INSIDE THE BARRELS**

The company Optimax [6] manufactured and delivered each single lenses and the NARIT precision mechanical workshop manufacture the barrels. The assembly operations have thus consisted on inserting and fixing each lenses inside the barrel at the correct location. In order to perform these operations, we have developed a dedicated tool represented in Figure 4-left panel. This tool comprises one base, three support pins, one translating platform, one long screw and one actuator. The base is used to place the tool on a table located inside a laminar flux hood. The translating platform aims at adjusting the height of the barrel during the assembly process. This platform is mounted on two carrier that can be translated along two vertical high precision rails to adjust the height of the barrel. The platform height is adjusted by rotating the actuator.
The three support pins are made of stainless steel metallic cylinders of length equal to 120 mm and diameter equal to 1.6 mm. Each pin comprises one polished face that is put in contact with the lens optical surface during the integration process. The other face of the pin is threaded and is screwed inside the tool base. It is important to precise that the L1 and L2 barrels comprises some holes of diameter equal to 2 mm to let the support pins passing through these barrels (Figure 5-right panel). The tool base has been designed to integrate L1 and L2 and comprises the threaded holes required to integrate L11, L12, L21, L22 and L23. The support pins were thus moved before the integration of each single lens inside L1 or L2 barrel.

![Assembly tool and L1 barrel](image)

Figure 4. left-panel: assembly tool used to install the L1 and L2 lenses on the barrels, right-panel: L1 barrel mounted on the translating platform and ready for the integration of L12.

The assembly method consisted of i) using the support pins to hold each lens in a fixed position and ii) moving the lens holder to translate the lens inside the barrel until the lens reaches the desired position. We have represented in Figure 5 the different steps of the integration of the lens L1. In a first step, we adjusted the height of the barrel to make the support pins passing through this barrel to carry L12. Figure 5 (a) represents L12 positioned on the support pins above the barrel and ready for integration on L1 barrel. In a second step, we slowly increased the height of the barrel to insert L12 inside this barrel until L12 reaches the reference bore. Then, we screw a retainer ring by using a dedicated tool to lock the L12 position (Figure 5 (b)).

The third step consisted of i) changing the position of the pins on the base to support the lens L11 and ii) adjusting the height of the platform to be able to install the lens L11 on the support pins. Figure 5 (c) represents the lens L11 mounted on the support pins and ready for the assembly on the L1 barrel. The fourth step consisted increasing the height of the barrel until L11 reaches the reference position in the barrel. Finally, we screwed the retainer ring to fix the position of L11 on the barrel.

We integrated the L2 lenses inside the barrel by using the same procedure and the same tool. Figure 6 represents the lens L2 after assembly. We performed the assembly of each lens L1 and L2 in less than one hour. For each lens, the first tentative of assembling the lenses on the barrel was successful.
Figure 5. (a) L12 installation on the support pins. (b) Operator screwing the retainer ring to fix L12 position inside the barrel. (c) L11 installation on the support pins. (d) Operator screwing L11 retainer ring.

Figure 6. L2 achromatic triplet mounted on the assembly tool.
4. FOCAL REDUCER INTEGRATION ON THE TNT AND OPTICAL ALIGNMENT

4.1 The robotic rail

The focal reducer comprises one robotic rail represented on Figure 7. Before each observation with the focal reducer, the robot translates L1 vertically until the center of the lens is positioned on the TNT optical axis. Before observation with another instrument such as ULTRAPSEC or MRES or else, the robot removes the lens L1 and positions the baffle extension on the TNT optical axis.

This rail comprises one tip-tilt mount on which is mounted the lens L1. The orientation of the lens is performed by adjusting the height of three SM-25 Vernier micrometers manufactured by Newport that act as push-screws. The accuracy of these micrometers is equal to 1 μm and the travel range is equal to 25 mm. The L1 orientation can thus be controlled with an accuracy better than 1 arcsecond over a maximum angular range higher than 5 degree. The tip-tilt mount also includes three pull screws which are used to lock the orientation of L1.

The L1 tip-tilt support is mounted on a high precision linear translating stage which is used to translate horizontally the lens. This, by assuming that the telescope elevation is equal to zeros degree (nominal position for L1 alignment for reason of accessibility). The fine adjustment of the horizontal position is performed by using one micrometer SM-25. The L1 horizontal position can thus be adjusted with an accuracy equal to 1 μm over a travel range equal to 25 mm. The L1 tip-tilt support and the horizontal translating mechanism are mounted on a high precision linear stages of length equal to 1.2 m. These rails are mounted vertically (at telescope elevation equal to zeros degree).

In practice, the robot moves the L1 mount until this support comes in contact with one SM-25 micrometer. This micrometer is used to adjust the vertical position on the lens with an accuracy equal to 1 μm and a travel range equal to 25 mm. The full operation that consists of removing the baffle extension from the optical axis to position the lens L1 takes less than 30 seconds. It is important to mention that we have verified during L1 optical alignment with a Micro alignment Telescope (MAT) that the robot is able to remove L1 and put it back on the optical axis with an accuracy better than 100 μm.

Figure 7. Left-panel: L1 mounted on the robotic rail during the alignment process. Right-panel: full view of the robotic rail after integration on the TNT.
4.2 L1 optical alignment on the TNT optical axis

The L1 optical alignment aimed at i) positioning the L1 center on the optical axis and ii) making the L1 optical axis parallel to the TNT optical axis. It is important to mention that in the TNT, the optical axis of the beam reflected by the M3 is coincident with the elevation axis of the ala-azimuthal mount. The L1 alignment thus consists of i) positioning L1 on the TNT elevation axis and ii) orienting the L1 faces perpendicular to the TNT elevation axis. The procedure comprises five steps described hereafter.

In a first step, we installed the equipment needed for L1 alignment (Figure 8). First, we installed on the TNT instrument cube one Micro Alignment Telescope manufactured by Brunson (model 2024BL) equipped with the associated tip-tilt mount. This mount was mounted on the instrument cube via one platform mounted on two high precision translating rails. The horizontal position of the MAT was controlled by using one micrometer pushing the platform. The vertical adjustment of the MAT position was performed by adjusting the height of the MAT tip-tilt mount.

In a second step, we adjusted the TNT elevation to zeros degree and we installed the target A on the TNT central section, Then, we changed the TNT elevation axis to 90 degree and we observed the figure depicted by the target center. We deduced from this figure the modification in the target position required to center it on the elevation axis. We repeated these steps until the center of the target A was fixed during a TNT rotation of 90 degree around the elevation axis. We estimated that the distance between the target center and the elevation axis was less than to 500 microns after alignment. That correspond to the precision of the measurement of the position of the target center.

In a third step we installed one string target (called target B) on the lens L1 and we integrated L1 on the robotic rail. Then, we positioned the center of the target B on the elevation axis. This, by using the procedure that was used to position the target A on the elevation axis. In a fourth step, we aligned the MAT line of sight one the TNT elevation axis and we turned “On” the internal LED source of the MAT to use this alignment telescope as an autocollimator. We adjusted the focus to observe the images of the MAT internal source reflected by the L1 faces and we adjusted the orientation of the lens L1 to center these images on the MAT reticulate.

We concluded that the faces of the lens L1 were perpedicular to the TNT elevation axis. Finally, we verified that the center of the targets A and B were still was located on the MAT line of sight. We concluded that i) the L1 center was positioned on the TNT elevation axis and ii) the L1 optical axis was coincident with the TNT elevation axis and thus with the TNT optical axis.

![Figure 8](https://www.spiedigitallibrary.org/conference-proceedings-of-spie)
4.2 Wavefront Error measurement

We measured the on-axis WaveFront Error (WFE) of the TNT with and without the lens L1 positioned on the optical axis. This, in order to verify that L1 does not introduce significant wavefront distortions induced by the manufacturing, assembly and alignment errors. We used the WaveFront Sensor (WFS) Shackscope 40x40 manufactured by the company Alcor-System [7]. This Shack-Hartmann wavefront comprises i) one matrix of 40x40 microlenses, ii) one 14 bits Cooled camera, down to 35°C with respect to ambient temperature, iii) the calibration and source pinhole subsystem and iv) one collimator adapted to the beam aperture of the TNT (F# = 10) and that images the TNT pupil on the WFS microlenses matrix.

In first step, we calibrated the WFS by placing one pinhole at the WFS collimator object plane. In a second step, we pointed a star of magnitude 9 and of elevation close to 50 degree and we measured the WFS transmitted by TNT with L1 positioned on the optical axis (figure 9-left panel). In a third step, we removed the lens L1 from the optical axis, we adjusted the M2 focus and we repeated the wavefront measurement in the same conditions of observations (figure 9-right panel). The two measurements were separated by 40 minutes approximately.

We notice on Figure 9 that the wavefront error is equal to 239 nm rms before the installation of the lens L1 and is equal to 324 nm RMS after positioning L1 on the optical axis. The Table 1 represents the standard zernike coefficients of the Astigmatism, Coma and Spherical aberrations before and after the installation of the lens L1 on the optical axis.

We notice that the spherical aberration coefficient increases from -26 nm to +176 nm. We attribute this increase of the spherical aberration coefficient to the conditions of the WFE measurement. Indeed, the TNT image plane without L1 is located 65 mm behind the instrument cube flange. After the installation of the lens L1, this distance is increased to 215 mm. It is important to precise that the position of the WFS is fixed during the WFE measurements and after positioning L1 on the optical axis, we need to translate the mirror M2 along the optical axis by approximately 3 mm to collimate the beam incident on the matrix of microlenses.

By using the ZEMAX model of the TNT, we estimate that the theoretical variation of the aberration coefficient should be $\delta A11_{\text{theoretical}} \approx 286$ nm. The measured variation of $\delta A11$ is thus smaller than expected and the potential contributor to this discrepancy are: (i) different “WFS - instrument cube flange” distance between the ZEMAX model and the real conditions of observations, (ii) spherical aberration induced by the L1 optical surfaces.

We also notice that the amount of astigmatism increases since $Z5$ (respectively $Z6$) varies from -2 nm to -114 nm (respectively from 81 nm to -118 nm). The total amount of coma also increases since the coefficient $Z8$ varies from 155 nm to -40 nm. We attribute these variations to the assembly error of the lens in the barrels and to the alignment errors in L1 position and orientation.

Figure 9. Results of wavefront measurements with and without L1 located on the TNT elevation axis (left and right panel respectively). Star magnitude 9, elevation close to 50 degree, integration time equal to 45 s, camera cooled down to -40 degree below ambient temperature.
Table 1. First standard coefficients of the TNT with and without the lens L1 mounted on the optical axis.

<table>
<thead>
<tr>
<th>Zernike coefficient</th>
<th>TNT without L1</th>
<th>TNT with L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astigmatism +45° (Z5)</td>
<td>2 nm</td>
<td>-114 nm</td>
</tr>
<tr>
<td>Astigmatism -45° (Z6)</td>
<td>81 nm</td>
<td>-118 nm</td>
</tr>
<tr>
<td>Coma X (Z7)</td>
<td>21 nm</td>
<td>19 nm</td>
</tr>
<tr>
<td>Coma 90° (Z8)</td>
<td>155 nm</td>
<td>-40 nm</td>
</tr>
<tr>
<td>Spherical aberration</td>
<td>-26 nm</td>
<td>176 nm</td>
</tr>
</tbody>
</table>

We have developed a ZEMAX model in order to calculate the spot diagram of the TNT equipped with the lens L1. The ZEMAX model comprises one paraxial lens and one Zernike Fringe Phase surface. The stop has a diameter equal to 2.3 m. This stop is located on the paraxial lens which focal equal to 25.8 m that correspond to the TNT focal. The normalization radius of the Zernike Fringe Phase surface is equal to 1.15 m (TNT pupil radius) and we have set the values of the first 20th Zernike coefficients as variables. The optimization process has consisted of optimizing these variables to make the Zernike coefficients of the ZEMAX model output wavefront equal to TNT measured Zernike coefficients.

We have represented in Figure 10-left panel the wavefront map of the Zemax model at the wavelength equal to 550 nm. We notice that the overall shape of the wavefront map is similar to the measured one. However, the wavefront error of the ZEMAX model is equal to 253 nm RMS that is smaller than the measured value equal to 324 nm. We attribute the difference to the fact that the WFE value presented in Figure 9 are based on a zonal reconstruction while the WFE value of the ZEMAX is based on a modal reconstruction.

Figure 10-right panel represents the spot diagram at the wavelength equal to 550 nm and we have represented the specified angular resolution by a black circle. The rms spot size is equal to 50 microns that corresponds to an angular size equal to 0.4 arcseconds. circle. We thus deduce that the spot image is approximatively three times smaller than the specified angular resolution. We concluded that the image quality of the TNT equipped with the lens L1 was acceptable. Furthermore, the preliminary on-sky results obtained with the focal reducer and presented in the next section tend to show that the image quality close to the optical axis is very good. The wavefront error induced by L1 thus does not seem to have a significant impact on the on-axis image quality.

Figure 10. left-panel: ZEMAX simulation of the measured wavefront. Right-panel: spot diagram of the ZEMAX model. The black circle represents the TNT specified angular resolution equal to 1.3''.

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4.3 L2, filter wheel and 4K camera installation on TNT instrument cube

The first step of the installation of L2, the filter wheel and the 4K camera has consisted of installing the spacer on the TNT instrument cube as represented in Figure 11-left panel. In a second step, we inserted and we fixed the lens L2 inside the instrument cube (Figure 11 right-panel). Then, we verified that the mirror M4 was able to rotate by 360 degree without touching L2. In a third step, we mounted the filter wheel on the spacer, we installed the 4K camera on the filter wheel and finally we connected them to the TNT control system (Figure 12). The full operations were successfully performed by four persons (two technicians and 2 engineers) in less than three hours.

Figure 11. left-panel: installation of the spacer on the TNT instrument cube. Right-panel: view of the M4 and L2 inside the instrument cube.

(a) Filter wheel installation on the spacer  (b) 4K camera installation on the filter wheel  (c) Connection to TNT control system

Figure 12. (a) installation of the filter wheel on the instrument cube. (b) fixation of the 4K camera on the filter wheel, (c) connection of the 4K camera and filter wheel to the TNT control system.
5. PRELIMINARY RESULTS

We tested on-sky the TNT focal reducer during the nights of the 18th and 19th May 2019. We selected two objects to analyze the performance: the planetary nebula M27 and the globular cluster M13. We recorded images of M27 (respectively of M13) with the filters B, V and R (respectively with the filters B, V, R and I). Figure 13 left-panel shows the raw image of M27 taken the 18th May 2019 with a V-band filter, an integration time equal to 15 seconds and a binning equal to 3x3 pixels. The temperature of the camera during the acquisition was equal to -10 degree Celsius. Figure 13-right panel represents the globular cluster M13 taken in identical conditions. The only difference is the integration that was equal to 30 seconds for M13.

We notice that the FOV is currently limited to a square area of 12 arcminutes per 12 arcminutes. We identified that the origin of this limitation of the FOV was due to the vignetting induced by the filters currently located inside the filter wheel. Indeed, these filters have been specified for observations over a square FOV of 8 arcminutes length without the focal reducer and their length is equal to 65 mm. We used the non-sequential model of the TNT equipped with the focal reducer to estimate that the length of the filter should be equal to 90 mm to avoid vignetting.

We also notice that the useful FOV is not centered on the camera. We performed some investigation to understand the origin of this phenomenon. We found that the filter wheel was not able to center the filter on the camera and was at the origin of the filter position error. We thus decided to re-design and manufacture the filter wheel to accommodate six filters of 90 mm diameter with the objective to test the focal reducer over the full specified FOV starting January 2020.

![M27-V Band](image1.png) ![M13-V Band](image2.png)

Figure 13. Left-panel: image of the planetary nebula M27 acquired with the 4K camera and the focal reducer, V-Band filter, integration time equal to 15s and a binning equal to 3x3. Right-panel: globular cluster M13 acquired in the V-Band with an integration time equal to 30 seconds and a binning equal to 3x3. The circle represents a circular FOV of diameter equal to 14’.

We used the software Aperture Photometry Tool from Astrometry.net to estimate the variations of the star image Full Width at Half Maximum (FWHM) over the FOV and the value of the plate scale. We have represented in Figure 14-left panel the value of the FWHM for the stars of the M13 images not saturated and the right-panel represents the histogram of the FWHM. We have measured of this object a median FWHM equal to 1.72” in the B-band, 1.54” in the V-band, 1.62” in the R-band and 1.51” in the I-band. During the observations of M27, the conditions of observations were a little bit worse and the seeing was higher. We thus measured a median FHWM close to 2” in the B, V and R bands.

We thus conclude that the angular resolution of the TNT equipped with the focal reducer is close to 1.5” in the V-Band that is close to the specified value. The potential limits of the measured angular resolution are the following: atmospheric turbulences (seeing) at the moment of the observations, wavefront distortions induced by the TNT and the focal reducer optical surface errors and misalignments.
The future investigations will thus aim at identifying the origin of the angular resolution performance limitation. In a first step, we will measure the variation of the WFE over the FOV at the TNT image plane. This, in order to estimate the amount of the wavefront distortions induced by the alignment errors between the mirrors M1 and M2. In a second step, we will optimize the position and the orientation of the M2 position to optimize the star image FWMH.

We calculated that the plate scale was equal to 0.623 arcsec/pixel in the B-band, 0.620 arcsec/pixels in the V-band, 0.613 arcsec/pixel in the R-band and 0.623 arcsec/pixel in the I-band. We also estimated that the maximum difference in the star PSF centroid position between the different spectral bands is always smaller than 0.3″. We thus deduce that the angular resolution focal reducer is free of significant chromatic error.

Figure 14. Left-panel: FWHM of the unsaturated stars of the M13 image taken in the V-band. Right-panel: histogram of these FWHM.

CONCLUSIONS

In this paper we presented the status of the development of the focal reducer and we showed the first on-sky results we have obtained. This instrument has been successfully designed, manufactured (lenses excepted), assembled and integrated at NARIT. The first results are very promising and show that the instrument is already able to provide images with a resolution close to 1.5 arcseconds over a FOV of 12 arcminutes x 12 arcminutes in the photometric bands B, V, R and I. The next steps of the development of this instrument will consist of i) designing and manufacturing a new filter wheel to accommodate large filters of 90 mm diameter, ii) procuring these large filters and ii) performing the commissioning tests over the full specified FOV and providing the instrument to the scientific community during the 2019-2020 observing season.

REFERENCES

[1] C. Buisset; A. Prasit; A. Leckngam; T. Lépine; S. Poshyaajinda; B. Soonthornthum; P. Irawati; A.Richichi; U. Sawangwit; V.Dhillon; L. K. Hard, “Progress on the prevention of stray light and diffraction effects on the Thai National Telescope”, SPIE 9626, Optical Systems Design 2015: Optical Design and Engineering VI, 96262E (2015);