User manual
for the ARC 4K camera

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Introduction

The ARC 4K camera is an imaging camera with 4096 x 4096 pixels, from the Astronomical Consultants & Equipment (ACE), Inc [1] and it has been installed at the Thai National Observatory (TNO) since 2013. The camera consists of back illuminated scientific e2V 231-84 CCD chip [2] with thinned, astronomical broadband AR coated, grade one CCD. The camera system has been designed and warranted by Astronomical Research Cameras (ARC), Inc [3]. The original field of view (without focal reducer) was 8' x 8' and the readout noise (RON) is 4e-. The camera has 4 readout modes with amplifiers; A, B, C and D. In general, the camera is performed using only one amplifier (e.g., mode D). The gain and readout noise of the camera (from vendor) are 1.84 e-/ADU and 3.9e-, respectively. In May 2019 (cycle 7), a focal reducer has been installed to the 2.4m Thai National Telescope (TNT). The ARC 4K camera is now fitted with the focal reducer which enlarges the instrument's field of view to about 14' with image quality close to the seeing limit [4]. In cycle 8 (CfP: 2020 - 2021), new filter wheel is installed replacing the old one, to fit the operational field of view. The commissioning tests for the TNT focal reducer and the new filters had been done in the last observing season.

Instrument overview

Figure 1: The ARC 4K camera and ACE system including filter wheel and cooling system were mounted to the instrument cube of the TNT-2.4m. (Credit: NARIT's OPD team)

1) The TNT focal reducer

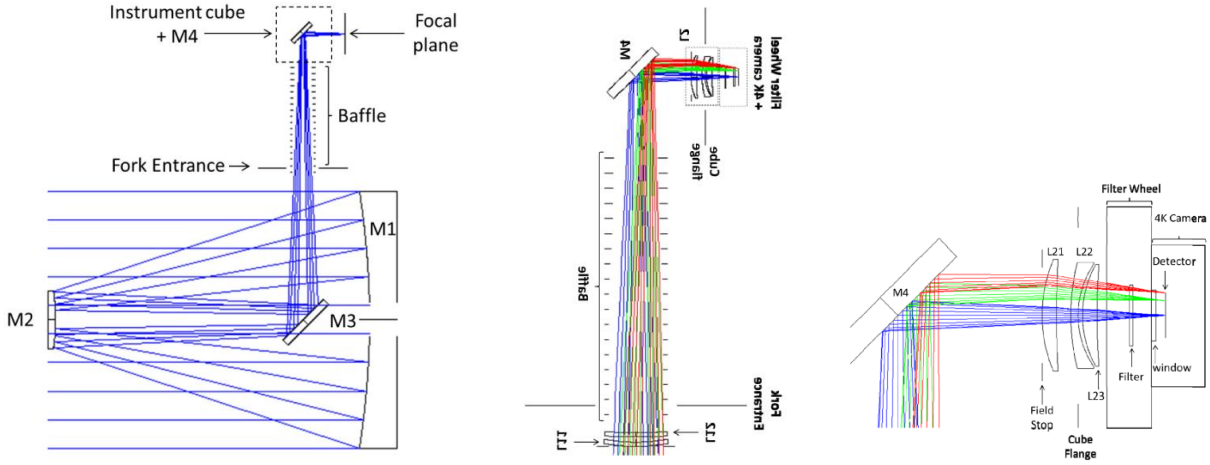


Figure 2: The TNT optical model (left panel), the focal reducer (middle panel), the ARC 4K camera (right panel)

(Credit: [5])

Table 1: Optical performance specifications of the TNT focal reducer

Parameter	Specification
Nominal spectral band	400 nm-800 nm
Photometric filter spectral bands	B, V, R and I Johnson-Cousins filters
Telescope pupil diameter	2300 mm
Telescope effective focal length	14470 mm
CCD pixel size (2x2 binning case)	30 µm
CCD format (2x2 binning case)	2048 x 2048
Pixel scale	0.42”/pixel
Field of view	14.6’
Angular resolution	1.3”
Chief ray maximum incidence angle on the filter	5°
Maximum distortion	1%
Design	Spherical surfaces and common glasses only

(Credit: [5])

Note: For more information about the TNT focal reducer, see [4] and [5]

2) The ARC 4K camera

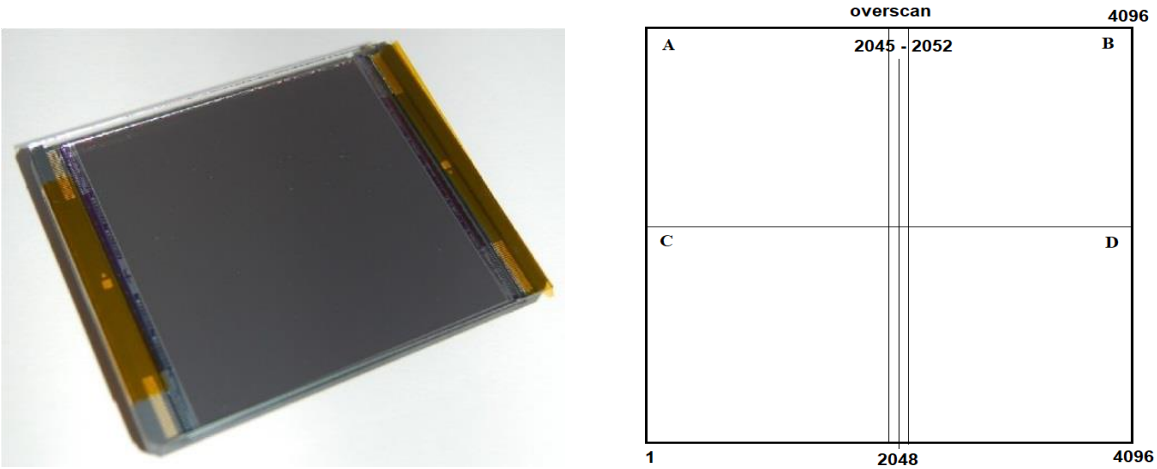


Figure 3: the CCD 231-84 back illuminated sensor with 4096 x 4096 pixels and pixel size 15 micron square

(Credit: [2])

The special feature of the camera is low readout noise with 1 or 4 outputs (4 readout modes: A, B, C, D or four quadrants together). The spectral range of the ARC 4K camera covers 350 – 900 nm. The liquid nitrogen with -110 Centigrade is used for cooling the camera system. The original filter wheel was designed by the Astronomical Consultants & Equipment (ACE), Inc [1]. The ACE filter wheel is controlled by ASCOM driver provided by ACE. The control system will be explained in the next section.

Table 2: Operational characteristics of the ARC 4K camera (operating temperature: -110C)

Amplifier	Noise (e)	Noise (ADU)	Gain (e/ADU)	Bias (median)	Readout time (s)
D (bin 1x1)	3.837	2.051	1.871	458.9	75
D (bin 2x2)	4.489	2.388	1.880	585.9	24
D (bin 3x3)	3.809	1.815	2.099	620.6	
D (bin 4x4)	4.196	2.193	1.913	630.8	9
4 quadrants					18

Table 3: Physical characteristics of the ARC 4K camera

Description	2019 without FR	2019 (FR & filters)	2020 (FR & new filters)
Detector	E2V ccd 231-84		
Pixel size	15 x 15 microns		
Image area	61.4 x 61.4 mm		
Field of view	8.79’ x 8.79’	14.2’ x 14.2’	14.1’ x 14.1’
Pixel scale	0.515 "/pixel (bin 4)	0.420 "/pixel (bin 2) 0.623 "/pixel (bin 3)	0.207 "/pixel (bin 1) 0.414 "/pixel (bin 2)
Filters	UBVRI	UBVRI	BVRI

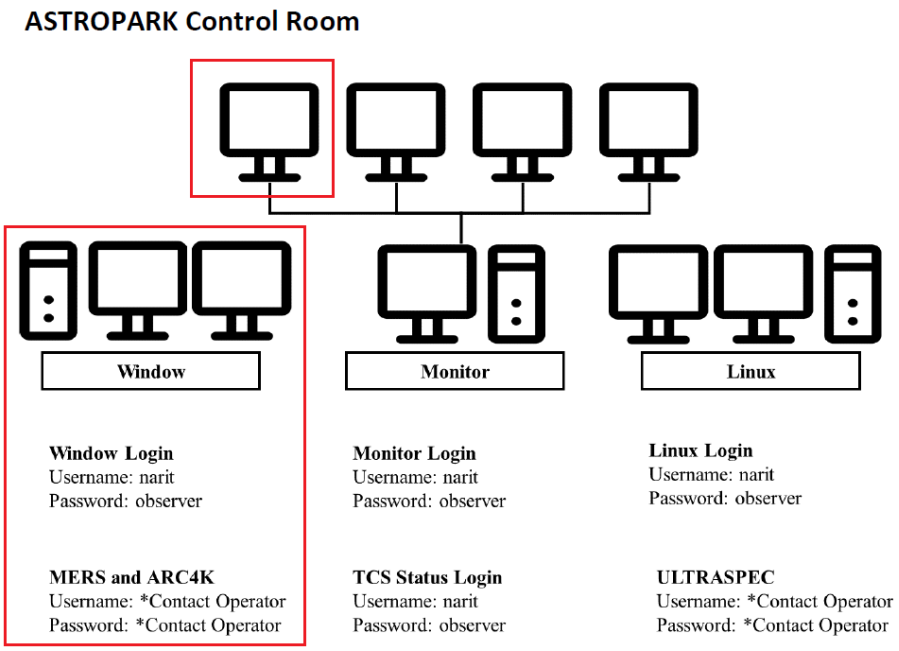
For Observation

Please contact operator@narit.or.th, IP phone: 611, Skype: ControlRoom TNO

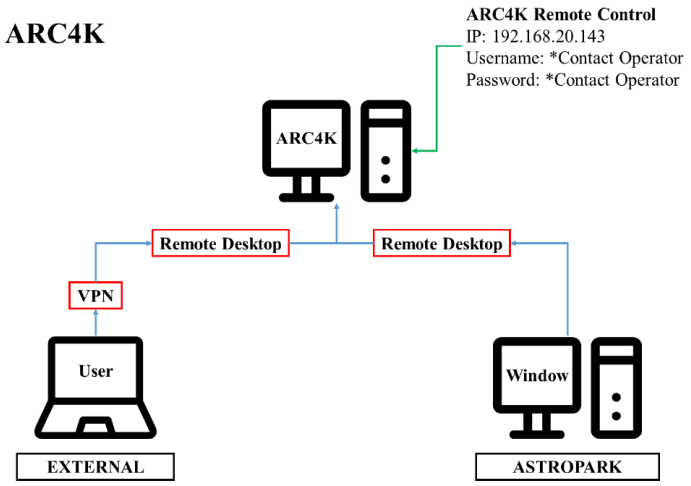
Preparation time (liquid nitrogen filling): 05.00 – 05.30 p.m. and 07.00 – 07.30 a.m.

Observing time: 05.30 p.m. – 07.00 a.m.

1) Remote observation at AstroPark control room



2) Remote observation via NARIT VPN



For more information about VPN, please contact telescope operation or email to operator@narit.or.th

Data acquisition

To use the ARC 4K camera after login to the server IP: 192.168.20.143 to remote desktop. Before starting the observation, there are software we have to deal with e.g., ACE connect client (ACE client gui) and python script. The series of imaging can be done automatically after editing and running the python script. For individual exposure, it can also be operated on the ACE client gui by hand without Python.

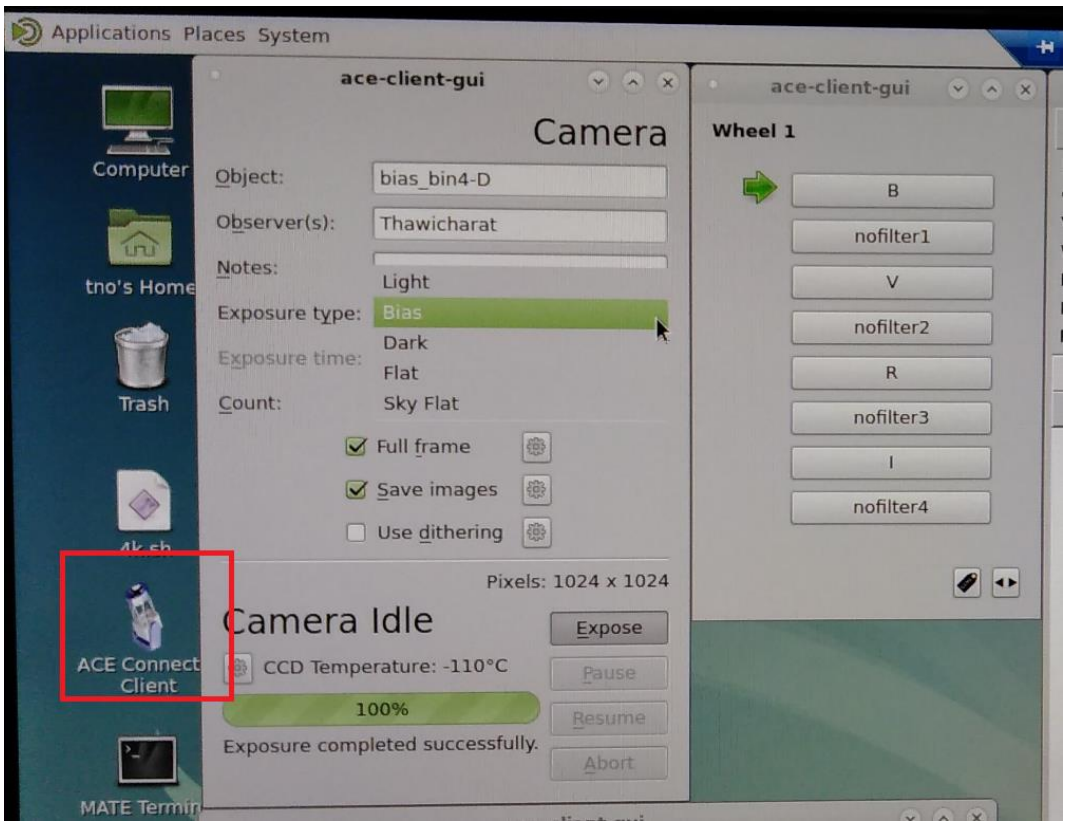


Figure 4: the main GUI for operating the camera and data acquisition

For individual exposure (to check the focusing, to test the exposure time, to take calibration images)

1) At the ace-client-gui, the camera gui or the main gui (see Fig. 4)

Key object's name

Key observer's name

Select the exposure type (Light, Bias, Dark, Flat)

Key exposure time

Key count or exposure number

2) At the filter wheel gui; select the filter (B, nofilter, V, nofilter, R, nofilter, I, nofilter)

3) At the main gui, click the **Full frame** icon (see Fig. 5 for detailed setting),
to select the readout mode (fixed mode D), key the binning number (1x1, 2x2, 3x3 or 4x4), then click OK

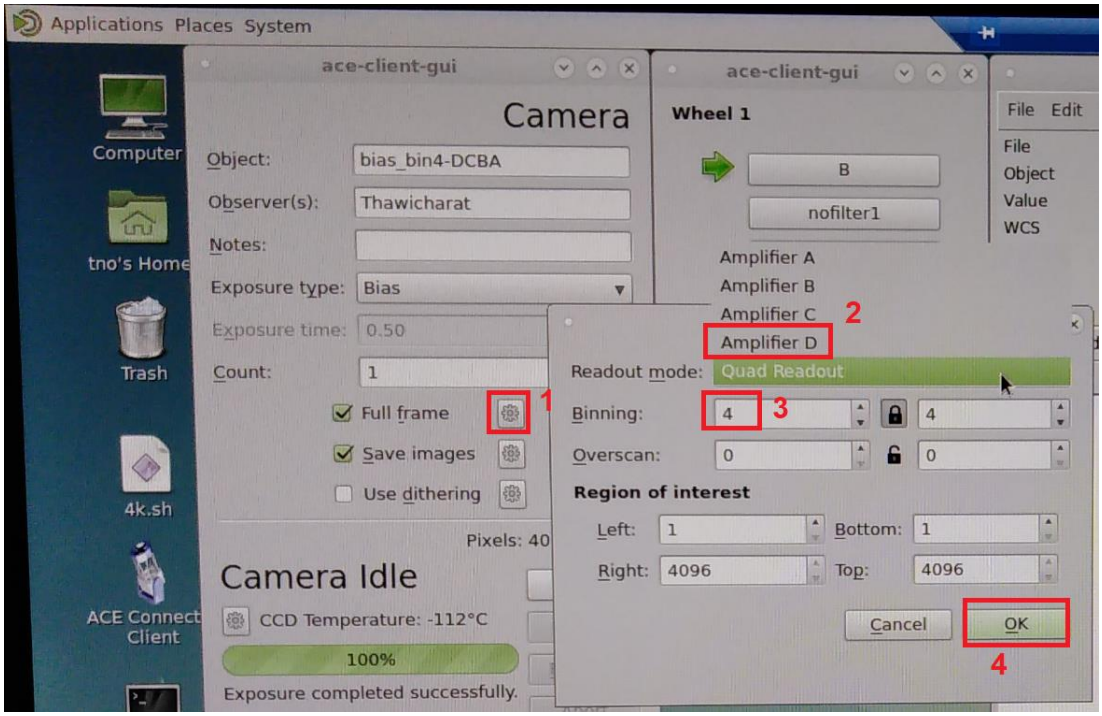


Figure 5: the detailed setting for **Full frame** icon

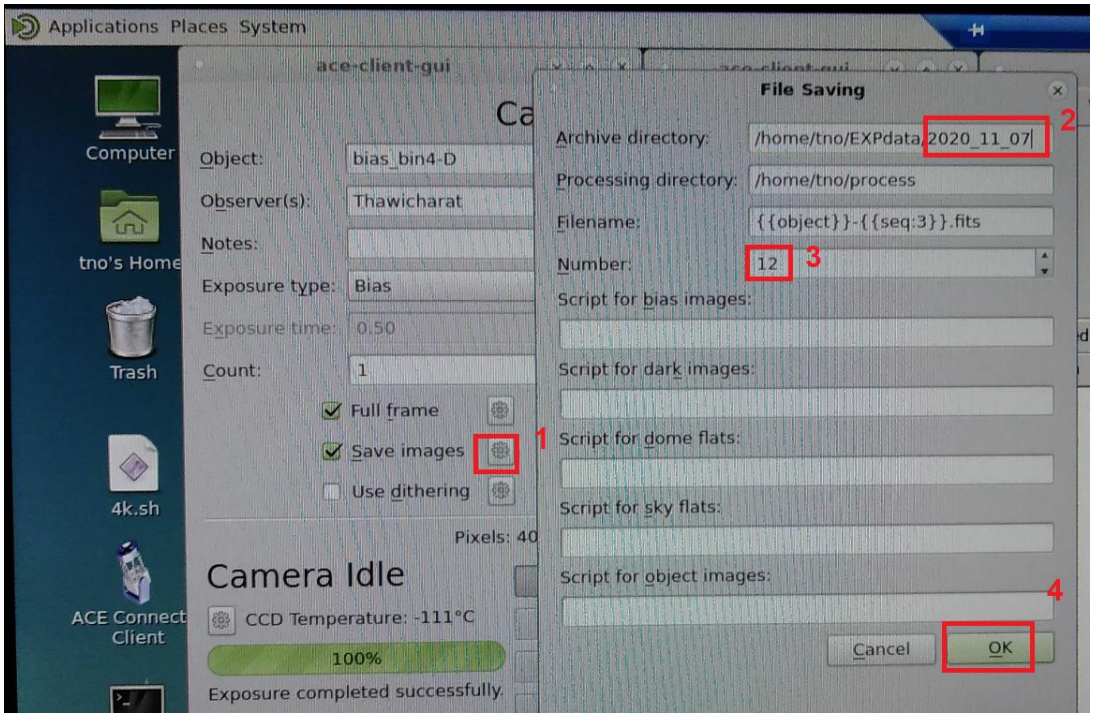


Figure 6: the detailed setting for **Save images** icon

4) At the main gui, click the **Save images** icon (see Fig. 6 for detailed setting), to set directory path, key the starting **Number** (e.g. 1 for 001, 002, 003… as order number)

5) After setting all above, at the main gui, the **Cemara Idle**, click **Exposure** to start acquisition

Note: these info setting from above will appear on the header of Fit image file

For a series of exposures (e.g. BVRI, BVRI, BVRI…) as automatic acquisition mode

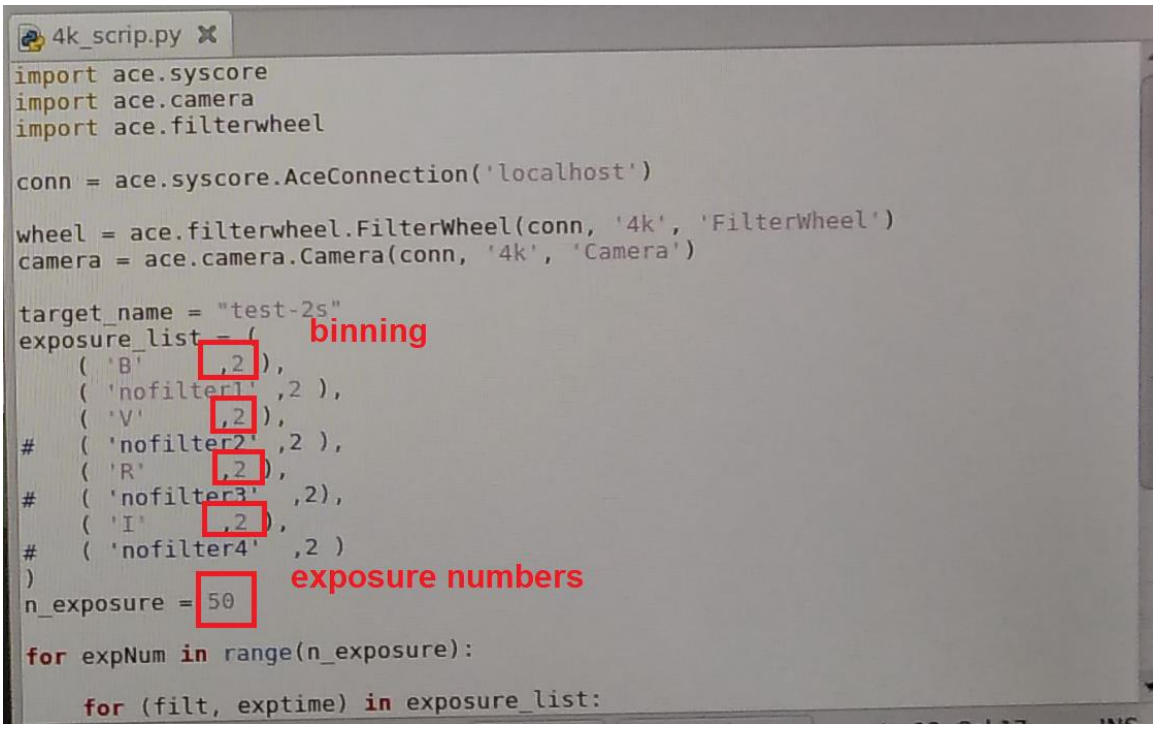


Figure 7: the detailed setting for python script in automatic acquisition mode

Open the file 4k_scrip.py (see Fig. 7), key the filter and binning number, key the exposure number, then click save the file. Run the python script from the **Terminal** in the linux system by typing python3 4k_scrip.py and press **Enter**. The exposure will start automatically as BVRI, BVRI, BVRI and the acquisition will stop when it reach the setting number.

The optical extinction at TNO

During observing cycle 7 (2019 - 2020), Dr R. K. Yadav and his student had carried out the measurement of optical extinction at the Thai National Observatory by using the TNT-2.4m (ARC 4K camera) and the TNO-1m, respectively. The preliminary results are listed in the table 4 and the comparison to the other observatories is plotted in Fig 8.

Table 4: Atmospheric extinction coefficients (mag/airmass) in UBVRI bands

Date	Coeff. of U filter	Coeff. of B filter	Coeff. of V filter	Coeff. of R filter	Coeff. of I filter
Nov 15th, 2019	0.3930 ± 0.0210	0.2720 ± 0.0190	0.1540 ± 0.0210	0.1260 ± 0.0070	0.0860 ± 0.0040
Nov 17th, 2019	-	0.3881 ± 0.0283	0.0981 ± 0.0244	0.0635 ± 0.0293	0.0503 ± 0.0255
Dec 12th, 2019	0.454 ± 0.041	0.221 ± 0.023	0.117 ± 0.026	0.085 ± 0.006	0.061 ± 0.012
Mean	0.424 ± 0.023	0.294 ± 0.014	0.123 ± 0.014	0.091 ± 0.010	0.066 ± 0.009

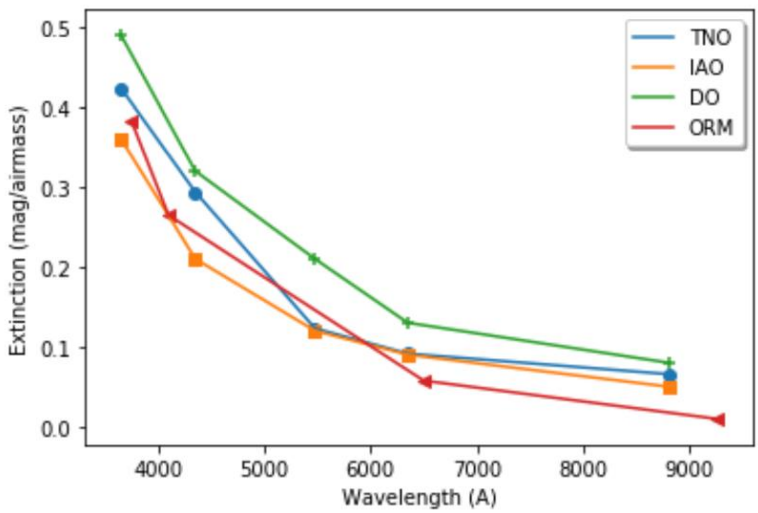


Figure 8: Comparison of TNO mean atmospheric extinction coefficients with other observatories

Credit [7]

Acknowledgement and authorship policy

Any publication resulting from observations and data obtained by the TNT-2.4m MUST include the following sentence; ***"Based on observations made with the ARC 4k camera at the Thai National Observatory under program ID [ID], which is operated by the National Astronomical Research Institute of Thailand (Public Organization)."***

The ARC 4k camera is being offered on a shared risk basis and under commissioning terms for up to **TWO** cycles. Please note that any publication resulting from data taken with the instrument during the commissioning phase **MUST** include the focal reducer development team members (PI. Christoph Buisset) as the co-authors beside the normal TNT acknowledgment rules given above.

Further information, please contact

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Mr. Boonchoo Sukaum boonchoo@narit.or.th

References

[1] https://www.astronomical.com/ace-filter-wheels/

[2] https://www.teledyne-e2v.com/markets/space/astronomy-imaging/ccd231-84/

[3] http://www.astro-cam.com/arcpage.php?txt=overview.php

[4] Prasit, A., Buisset, C., Lepine, T., et al. 2019, proceeding of the SPIE, 11116, 1

[5] Buisset, C., et al. 2016, OSA, 24, 1416 (DOI:10.1364/OE.24.001416)

[6] Buisset, C., et al. 2019, *"TNT Focal Reducer installation report and preliminary test results"*

[7] Boonprakom, S., Yadav, R. K., Wannawichian, S., 2020, *"Atmospheric Extinction at Thai National Telescope"*, Siam Physics Congress 2020