European Organisation for Astronomical Research in the Southern Hemisphere

Programme: Technology Development

Project/WP: NEAR

NEAR Commissioning Report

Document Number: ESO-331355

Document Version: 1

Document Type: Technical Report (TRE)

Released On: 2019-05-22

Document Classification: ESO Internal [Confidential for Non-ESO Staff]

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Change Record from previous Version

Affected Section(s)	Changes / Reason / Remarks
All	New Document

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1. Introduction

1.1 Scope

NEAR implements new instrumental features to VISIR at UT4. This includes using AO supported imaging as offered by the DSM, new AGPM coronagraphic elements, and internal chopping using a Dicke switch. The later device is implemented for the first time in a MIR imaging instrument. In this document, we describe the performance of these new functionalities during the on-sky commissioning early April 2019. The report includes some of the science operational aspects and testing of the robustness and user friendliness of our specific design of the acquisition and science observing templates for NEAR. The AO functional verification using GRAAL MCM has been summarised in RD4. The demand for on-sky observing time has been reduced to the minimum possible thanks to intensive warm tests in Garching and in the NIH. Results of these warm tests are reported in (RD2). Our on-sky activities followed RD3 with results described in this document. The commissioning run with data taken under program ID:`60.A9106(A)` completed with a science operational NEAR instrument at UT4 offering world leading instrument performances in sensitivity and unparalleled MIR image quality.

1.2 Definitions, Acronyms and Abbreviations

This document employs several abbreviations and acronyms to refer concisely to an item, after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression:

AGPM	Annular Groove Phase Mask
AO	Adaptive Optics
AOF	Adaptive Optics Facility (UT4 with DSM)
BLIP	Background Limited Performance
DS	Dicke switch
DSM	Deformable Secondary Mirror
ELFN	Extra Low Frequency Noise
GUI	Graphical User Interface
ICS	Instrument Control Software
KTO	Kampf Telescope Optics
LCU	Local Control Unit
LPO	La Silla Paranal Observatory
MIR	Mid Infrared
NEAR	New Earth in α Cen Region
NGC	Next Generation Controller
NIH	New Integration Hall
RTD	Real Time Display
SCIOPS	Scientific Operations

TIMMI2	Thermal Infrared MultiMode Instrument
TS	Technical Specification
TTR	Technical Time Request
UT	Unit Telescope
VFM	VISIR Flange Module
WFS	Wavefront Sensor

2. Related Documents

2.1 Applicable Documents

The following documents, of the exact version shown, form part of this document to the extent specified herein.

AD1 NEAR Top Level Requirements ;
ESO-286912 - Version 1

AD2 Technical Specifications for the VISIR Flange Module ;
ESO-287968 - Version 1

AD3 NEAR Experiment Verification & Compliance Matrix ;
ESO-299449 - Version 2

2.2 Reference Documents

The following documents, of the exact version shown herein, are listed as background references only. They are not to be construed as a binding complement to the present document.

RD1 VISIR web page ;
http://www.eso.org/sci/facilities/paranal/instruments/visir.html - last update 1.09.16

RD2 NEAR PAE Test Plan ;
ESO-299446 – Version 1

RD3 *Report on Technical Time Request TTR-102.0015 VISIR Upgrade to NEAR* ;
ESO-331351 - Version 1

RD4 AOF Common Features Commissioning Report ;
ESO-298149 - Version 1

RD5 DSM binary chopping test report ;
ESO-318150 - Version 2

3. System Overview

3.1 NEAR Overview

The science objective of the NEAR experiment is the detection of potentially habitable planets around α Centauri A and α Centauri B in the N-band. It will be conducted with AO high-contrast coronagraphic imaging using an upgrade of the VISIR instrument including the DSM at UT4 Cassegrain. A schematic overview of some of the key science parameters is provided in Figure 1.

ESO, in collaboration with the Breakthrough Initiatives, has modified the Very Large Telescope mid-IR imager (VISIR) that greatly enhance its ability to search for potentially habitable planets around both components of the binary α Centauri, part of the closest stellar system to the Earth. The concept combines adaptive optics using the deformable secondary mirror at Unit Telescope 4, a new annular groove phase mask (AGPM) coronagraph optimised for the most sensitive spectral bandpass in the N-band, and a novel internal chopper system for noise filtering based on a concept for longer wavelengths invented by the microwave pioneer Robert Dicke. During the commissioning of the NEAR experiment its relevance to the mid-infrared METIS instrument on the Extremely Large Telescope, has been demonstrated by knowledge gained, and proof of concepts that will be transferable. In particular the AGPM coronagraph has shown features during on-sky measurements that has not been detected in the laboratory check-out.

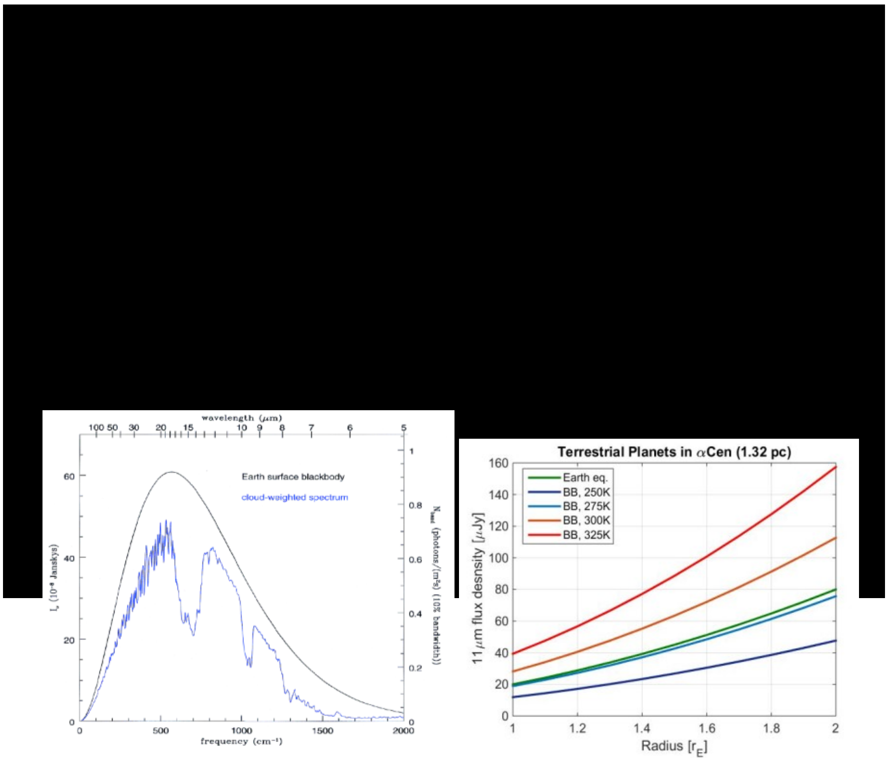


Figure 1: Overview of the science potentials of the New Earth in the αCen Region (NEAR) experiment. Key science parameters are listed top-right, the apparent and real trajectory of αCen between 2000 and 2015 are shown top-left. The expected spectral shape of the potential planet assuming a black-body (black line) and a cloud weighted (blue line) spectrum is shown bottom-right, and the expected 11μm flux density for planet radii and temperatures are shown bottom-left.

3.2 VISIR to NEAR

The VISIR[1] instrument was upgraded to the needs of the NEAR experiment. VISIR has been moved from UT3 to the Cassegrain of UT4 and was upgraded with a wave-front sensor (WFS), which controls the deformable secondary mirror (DSM) for AO and static aberration correction. The system offers superb image quality reaching a Strehl ratio of 100-ε (%) in the MIR. The DSM offers high frequency chopping (10Hz), which enables correction of the disastrous extra low frequency noise component (ELFN) of the Aquarius detector that is implemented at present in VISIR. It also allows chopping-only observation, which reduces overheads.

Previously VISIR has already included a small inner working angle coronagraph (annular groove phase mask, AGPM), whose efficiency is limited by the inability of VISIR to actively control position and shape of the PSF. With the NEAR experiment, the PSF position and shape is controlled by the AO, and the coronagraph can be used effectively. The existing AGPM is quite achromatic over a large wave-band. For optimum sensitivity, the αCen observing campaign will be carried out at wavelengths from 10–12.5μm, and include a newly procured and on-sky tested AGPM optimized for operation in this band centered at 11.25 μm.

3.3 Internal Chopping with a Dicke switch

MIR observations usually employ 1-5 Hz on-sky chopping to compensate instrumental effects and subtraction of the sky-induced background signal. Unfortunately, on-sky chopping introduces unavoidable self-subtraction of the signal when applied on large crowded fields such as molecular clouds. The technique also minimizes the operational range of the detector and its electronics. In order to avoid such problems and to not depend on M2-chopping induced telescope and image quality issues an alternative method using internal chopping has been implemented.

We installed a shutter in form of a D-shaped mirror which makes VISIR looking either into the sky or into a matched load, which is an integrating sphere with a black-body and temperature adjusted to match the sky brightness. Such devices are known as Dicke switch. The Dicke switch motor is set to a predefined rotation frequency. A switch produces the timing signal that triggers the NGC electronics to execute exactly one predefined read-out sequence corresponding to one chopping cycle per trigger pulse.

3.4 Warm Calibration Unit

In order to make space for the Dicke switch and the AO-WFS camera the warm calibration unit of VISIR has been re-arranged. Basically all its components apart from the Offner relay was recycled. The calibration unit was not part of VISIR science operations.

4. Commissioning Tests Summary

NEAR on-sky commissioning at UT4 has taken place in 3-12th of April, 2019 in period 103. The different test phases were followed as described in the RD2. This has allowed to minimize the required on-sky telescope time. The test campaigns included:

[1] http://www.eso.org/sci/facilities/paranal/instruments/visir.html

1. Garching, TIMMI2 and use of a VFM trigger to activate the read-out of NGC
2. Garching, TIMMI2 for the functional test of the Dicke switch in warm and cold environment and with artificial sky; this included testing of the configuration to be used when VISIR returns to UT3
3. Garching, TIMMI2 for laboratory tests of the AGPM
4. Garching, acceptance of parts for modification of VFM module beyond the Dicke switch
5. Paranal, GRAAL MCM test run with VISIR (TTR-101.0048). Results are described in RD3.
6. Paranal, NIH, warm testing of VISIR, Dicke switch and modified calib unit. Results are described in RD3.
7. Paranal, NIH, redo of the Garching warm test of AO-WFS-camera and associated opto-mechanics. Results are described in RD3.
8. Paranal, NIH, cold testing of VISIR and functionality of Dicke switch with artificial sky. Results are described in RD3.
9. Paranal, UT4, on-sky commissioning. Results are described in this report.

4.1 Integration of GRAAL-RTC with NEAR AO

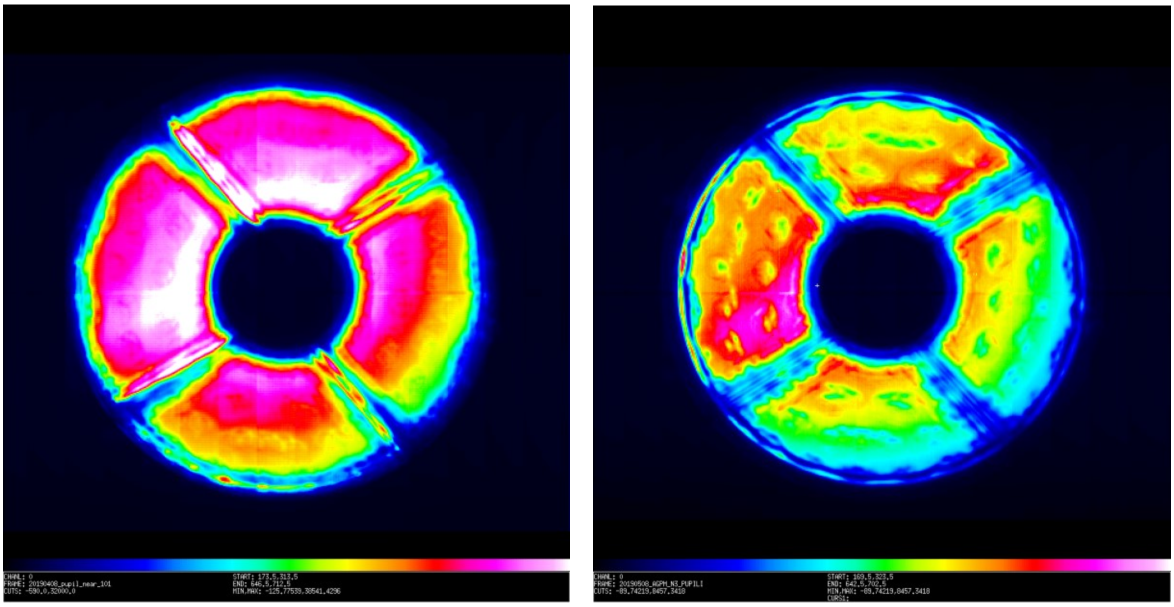
Task Number:	Switch between GRAAL and NEAR AO config
Category: mandatory	Purpose: establish functionality, evaluate switching time and procedure
Description of Procedure:	
Run instrument startup for GRAAL and NEAR Switch the RTC between the two configurations and run some sanity checks (tbd) to establish success Evaluate time needed	
Input and requirements:	
VISIR in NEAR config, at Cassegrain, fully cold etc. GRAAL available	
Output: report	Evidence: documentation
	Status: done
Results: GRAAL was successfully switched to NEAR AO configuration and back. Takes about 3 minutes, so there are little operational constraints for NEAR.	
Evaluation: Activity was successful	
Compliance: C	
Comments: To evaluate whether a switching between NEAR and GRAAL during the night is feasible. 4h daytime	

4.2 Pupil Alignments Checks

Task Number:	Title: Pupil Alignments Checks

Category: mandatory	Purpose: test to validate VISIR cold stop alignment with telescope and to find the angular ranges for aligning the Lyot Stop with the telescope spider etc
Description of Procedure:	
Take pupil images with the cold VISIR in standard procedure for the respective filters and the standard filter. Repeated measurements while varying the rotator angle	
Input and requirements:	
VISIR, twilight.	
Output: report, files	Evidence: documentation
	Status: done
Results: A large variety of pupil images has been recorded with different filters, with and without Lyot masks on them. The NEAR campaign Lyot stop NEAR_101 is a good clocking match for the VLT pupil for a Cassegrain rotator angle of -122 degrees. This is then the DSM to WFS clocking for which the AO control matrix is calculated. The VLT pupil position has been measured wrt to the VISIR cold stop (to which the Lyot masks have been centered in the NIH) during the initial check night on 24 March. During an intervention on the Az platform end of March, a correction was applied by tilting the cold instrument wrt to the VISIR flange. We carried out the commission with this alignment shown in Figure 2 (left panel). This alignment was not yet perfect and showed a vertical shift of 1-1.5%, which may have presented a limitation for the coronagraphic performance. A second iteration alignment early May was able to remove this vertical shift and produce a near perfect match of the positions of the VLT pupil and the Lyot stop (Figure 2, right panel).	
Evaluation: manually	
Compliance: C	
Comments: 2 x 1h twilight	

Figure 2. Left: Lyot stop alignment during commissioning, a small vertical shift of ~1-1.5% pupil diameter is still present. Right: same image recorded after the final adjustment of early May. The centring is now near perfect.



4.3 Functionality of VISIR DS on Sky

Task Number:	Establish Functionality of VISIR Dicke switch on Sky
Category: mandatory	Purpose: to verify the proper functionality of the DS on sky
Description of Procedure:	
Execute test exposures with the Dicke switch using the read-out modes verified in tests in NIH Verify proper functionality of the Dicke switch brightness control provided in closed loop relative to the fluctuating sky brightness. Tuning of control parameters Verify that the spatial distribution of the Dicke switch extended source radiation and that of the real sky are similar Verify the absence of ghosts, stray light etc. and assess the quality of baffling by ensuring that flat fields taken with DS open and DS closed do not show artificial structures exceeding 1-2% of the background signal (bias corrected). take data cubes staring (DS open) to establish with the standard procedures via pseudo-chopping the noise level versus chopping frequency as reference (3 filters [Neii], B10.7 and new NEAR filter) take chopped sky images with the filters above (chopping only and chopping and nodding) with the DS at various chopping frequencies to establish the noise level and residuals which can be achieved with the DS. The DS operation should result in exactly the noise figures retrieved from the pseudo chopping data. Measure ELFN	

Input and requirements:	
VISIR in NEAR config, at Cassegrain, fully cold etc. Standard tests with calib. unit successfully passed. A few twilights, just on sky but no science time necessary. Sky quality should be photometric and low humidity.	
Output: report, files, data cubes	Evidence: documentation
	Status: done
Results: Here, we summarize the results from the measurements described in section 7.6 The Dicke Switch has been operated at frequencies between 1 Hz and 10 Hz. Depending on atmospheric conditions and also filter (the NEAR_101 filter employs a Lyot stop cutting light from inside the central obscuration, outside the pupil, and spider vane emission), the Dicke-Switch blackbody has to be set to temperatures between about -60C (NEAR 101) and -10 (B10p7) to match the flux of the sky. It can be set to a maximum of around 30C, so all required background levels can be reached. The background following loop has been implemented and is working well once the BB temperature is close to the target value. Bringing it into this range has been done by manually setting the BB temperature from the ICS panel. The reason for this approach is that the response of flux vs temperature is very non-linear, and no single set of control parameters was found to provide both, a low response time and little overshoot, over the whole temperature range. A JIRA ticket (VLTSW-13810) has been opened by Gerard Zins to improve on this with the help of the control engineers. The spatial light distribution with the Dicke Switch is not identical to the one of the sky. As already indicated by the PAE laboratory testing, the residuals after Dicke chopping subtraction are of the order of ±2 percent over the majority of the field of view. At the upper edge of the field of view the intensity provided by the black-body increases leading to a negative residual in the Dicke-subtracted images of the sky (see Figure 21). The BG following loop has been adjusted to minimize the chopping residuals in the center of the field around the position of the coronagraphs. The ELFN calibration performance is very good, and a sensitivity of about 2000 uJy 10σ/h is reached for a Dicke-chopping frequency of 10 Hz. Compared to 10 Hz chopping the ELFN penalty in SNR with the B10p7 filter is 1.3, 2.2 and 3 for chopping at 5, 2 and 1Hz, respectively. The spatial non-uniformity discussed above, however, requires calibration by off-axis sky images, which are taken before and after the science observations by the template. The time-scales at which these sky images have to be recorded and the level spatial filtering (e.g. median-filtering), which can be applied to minimize the introduction of additional noise, has to be evaluated.	
Evaluation: Largely successful, with the limitation of the spatial uniformity mentioned in the paragraph above. Dicke-chopping will be very valuable for the observation of extended sources, which do not provide nearby empty sky. Nevertheless, the campaign will be carried out with DSM chopping, because it offers superior sensitivity when compared to Dicke-chopping.	
Compliance: C	
Comments: the outcome of this test determines whether the NEAR campaign should be done with the DS or with DSM chopping. 2 x 2h (partly) twilight.	

4.4 NEAR Acquisition

<table>
<tr><td>Task Number:</td><td>NEAR Acquisition</td></tr>
<tr><td>Category:
Mandatory</td><td>Purpose: Evaluate acquisition sequences for observation with the Dicke switch and DSM chopping</td></tr>
<tr><td colspan="2">Description of Procedure:
Telescope preset
Acquire AO NGS (GRAAL MCM acquisition)
Close AO loop
For Dicke chopping
Switch on the Black-Body and set temperature to an average value
Set Dicke switch chopping frequency and start motor
Wait until rotation is stabilized
Setup VISIR (DIT, filter, coro etc.) and start observing
Start Background following loop
Wait until blackbody flux matches the sky (error margin tbd)
For DSM chopping
Start telescope chopping, template automatically opens AO loop, offsets the AO star to a position half-way between the binary components, and closes AO loop
Manual rough centring of NGS on the VISIR coronagraph
Start Coronagraph Centring Loop / QACITS</td></tr>
<tr><td colspan="2">Input and requirements:</td></tr>
<tr><td colspan="2">NEAR AO
BB loop (not needed for DSM chopping)
Coro centring loop</td></tr>
<tr><td>Output: report, data cubes, files</td><td>Evidence: documentation</td></tr>
<tr><td></td><td>Status: done</td></tr>
<tr><td colspan="2">Results:
Acquisition sequence as described above has been implemented and acquisition template “VISIR_near_acq_MoveToCoro “ is commissioned. The acquisition of a new star is fast and takes less than 5 minutes including the telescope preset.</td></tr>
<tr><td colspan="2">Evaluation:
The acquisition of targets with DSM and Dicke chopping is largely automated. Only the rough centring of the target star (typically one arcsecond) with the WFS field selector on the QACITS capture range is still done manually in the case of coronagraphic observations.</td></tr>
<tr><td colspan="2">Compliance: C</td></tr>
</table>

Comments: The existing VISIR acquisition template needs to be upgraded to the needs by NEAR which includes set-up of GRAAL, selection of coronagraph and centering procedure, selection of DS or DSM chopping, etc. This template upgrade will be done by Gerard Zins and then tested on-sky. Use alpha Cen or a star of similar brightness (e.g. Hya at 09 27 35, -08 39 30.96) depending on commissioning date. Concerning item 9: QACITS see Sect. 5.11 6h night

4.5 AO Operation

Task Number:	AO operation
Category: mandatory	Purpose: Make DSM AO with NEAR operational
Description of Procedure:	
Running VISIR on a bright star and in pupil tracking. Set rotator to the default coronagraphic angle. Calculate synthetic control matrix for the rotator angle. Optimize also the scaling and shift of the DSM/WFS registration.	
Input and requirements:	
Acquisition until AO closed loop.	
Output: report, data cubes, files	Evidence: documentation
	Status: done
Results: The procedure to obtain a control matrix for our default rotator angle of -122 degrees matching VLT pupil with the NEAR-internal Lyot stop NEAR_101: Record IM on sky. Use J. Kolb's procedure to estimate shift, rotation and scaling. Calculate and use synthetic AO control matrix. Concerning Operations: The field selector was tested for offsets of +-1" around the field center. Larger offsets could be possible, the FoV of the WFS path is +-5", but field aberrations in the WFS arm and potentially mis-registrations would have to be evaluated. NEAR employs a field stop with diameter 2.8" in front of the WFS. The subapertures are sampled by 0.8" pixels. Despite the low transmission towards the NEAR WFS (dichro with an average reflectivity of ~30%, 800nm long-pass filter), we successfully observed the following reasonably faint stars: BD-16 4816 (R~8.8) and HD 100456 (R~6). The former provided very little flux per subaperture and frame (faint SHS spots barely visible), so the limiting magnitude of NEAR is around R~9 give or take depending on observing conditions. There are no limitations for bright stars like Cen.	
Evaluation: The method works flawlessly. Given the good stability of VISIR and also the WFS arm in the VFM, we operated the AO with the same control matrix at zenith angles between 0 and 60	

degrees over several nights.
Compliance: C
Comments: Use Cen or a star of similar brightness (e.g. Hya at 09 27 35, -08 39 30.96) depending on commissioning date. 3h night

4.6 AO Optimization

Task Number:	AO optimization
Category: mandatory	Purpose: Maximize AO corrected Strehl ratio
Description of Procedure:	
Running VISIR on a bright star and in pupil tracking. AO closed loop operational. Maximize Strehl ratio by adjusting a) low order Zernike modal offsets, and b) the number of control modes.	
Input and requirements:	
AO closed loop operational.	
Output: report, data cubes, files	Evidence: documentation
	Status: done
Results: Different number of control modes were already tested during the DSM chopping tests with HAWKI (see **Error! Reference source not found.**). Larger numbers of corrected modes increase the control radius and slightly reduce the fitting error. In the N-band, our outer search radius of ~1.5" separation corresponds to roughly 100 control modes. Also, the Strehl ratio penalty through the fitting error is very small (see PSFs throughout this report). Therefore, we do not have to control a large number of modes and can put more emphasis on a robust AO performance. We found that filtering 800 modes, so correcting for ~350 modes, provides a Strehl ratio near 1 and a very loop good robustness. The loop gain was set to a nominal 0.5.	
Evaluation: With the chosen setting of the AO loop, a robust performance of a Strehl ratio near one and a good control over the required scientific field of view was achieved.	
Compliance: C	
Comments: Use Cen or a star of similar brightness (e.g. α Hya at 09 27 35, -08 39 30.96) depending on commissioning date. 2h night	

4.7 AO characterization

Task Number:	AO characterization
Category: mandatory	Purpose: Explore magnitude limits in view of potential applications for NEAR besides the α Cen campaign.
Description of Procedure:	
Running VISIR on some fainter stars and in pupil tracking. Set rotator to the default coronagraphic angle. Measure Strehl ratio performance as a function of guide star magnitude. Adjust AO loop gain if necessary.	
Input and requirements:	
AO loop closed and optimized.	
Output: report, data cubes, files	Evidence: during observations in M17
	Status: done
Results: A field in M17 was observed and the AO loop was closed on a R=8.8mag bright star BD-16 4816. Despite very faint spots (barely visible by eye on the RTD for our fixed AO framerate of 1kHz and an L3 gain for the WFS of 200), the AO loop was robustly closed and the PSF core became more brilliant and stable. The poor sensitivity in N-band, prevented from the deep image suitable for accurate Strehl ratio calculation, but the qualitatively there was still an obvious improvement of the PSF. Due to a lack of time and the low priority of this test, no further attempts to explore the faint end were carried out. We are confident that with a lower framerate and the WCOG centroiding algorithm, the magnitude limit could be improved further.	
Evaluation: AO worked well with an R~8.8 star.	
Compliance: No requirement apart from Cen (R ~ -1)	
Comments: 2h night	

4.8 QACITS, coronagraph automatic centring

Task Number:	QACITS
Category: Mandatory	Purpose: functionality indispensable for “pupil tracking mode” and coronagraphy
Description of Procedure: see below	
Running VISIR on a bright star in DS-mode, observing in pupil tracking. Verification of differential tracking by taking time series and by deliberately offsetting the telescope from	

console to see if loop recovers and centers the star wrt the coronagraphic mask.	
Input and requirements:	
AO loop closed, NGC reading VISIR science detector, AGPM inserted	
Output: report, data cubes, files	Evidence: documentation
	Status: done
Results: Improved centering using QACITS established. More details are given below.	
Evaluation: During	
Compliance: C	
Comments: Use Cen or a star of similar brightness (e.g. Hya at 09 27 35, -08 39 30.96) depending on commissioning date. 6h night	

The QACITS centering loop was tested on the night of April 11th on an observing sequence of alpha Hya taken with the AGPM_N3 vortex mask and the NEAR_101 filter in DSM-chopping and field-tracking modes. Tip-tilt estimates were made every ~10s. The first tests were made in open loop to check that QACITS is able to measure correctly known offsets applied manually with the field selector (Figure 3). Then, the QACITS loop was closed and monitored for about 1min. The AGPM was centered manually at the beginning of each test. Graphics implemented by G. Zins (ESO) allow to monitor the coronagraphic centering and the position of the field selector on the telescope console (

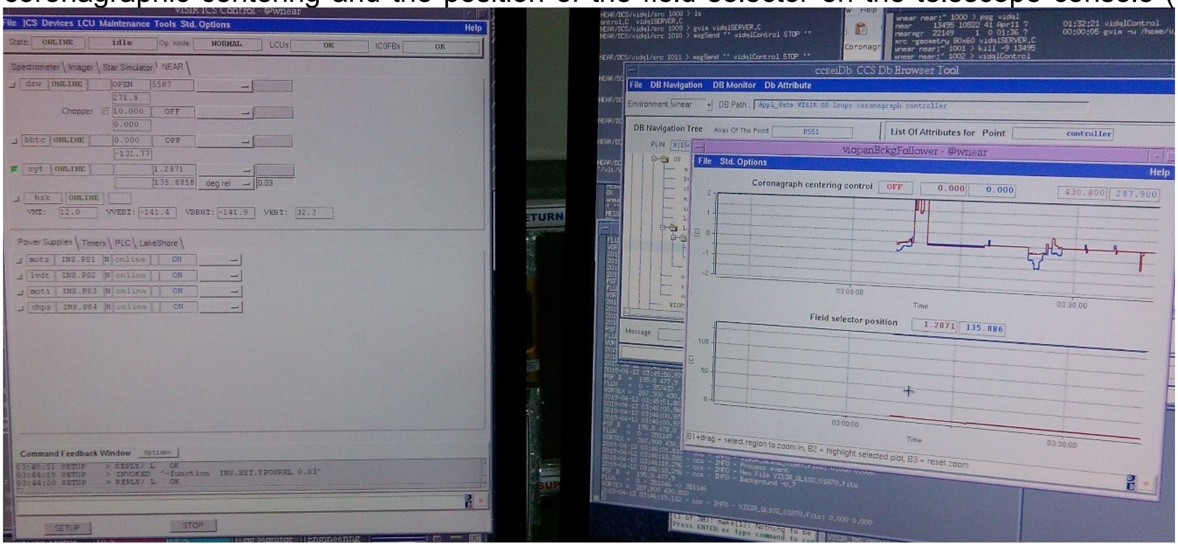


Figure 4). The open-loop test demonstrated that QACITS is able to detect manual offsets applied with the field selector. The closed-loop test demonstrated that the tip-tilt corrections estimated from the QACITS measurements are well transferred to the telescope control and that the star was re-centered behind the coronagraph as expected. We also applied two manual offsets with the field selector in one direction each and QACITS was able to detect them and send the right correction offsets for the field selector to progressively put the star back behind the AGPM (Figure 5).

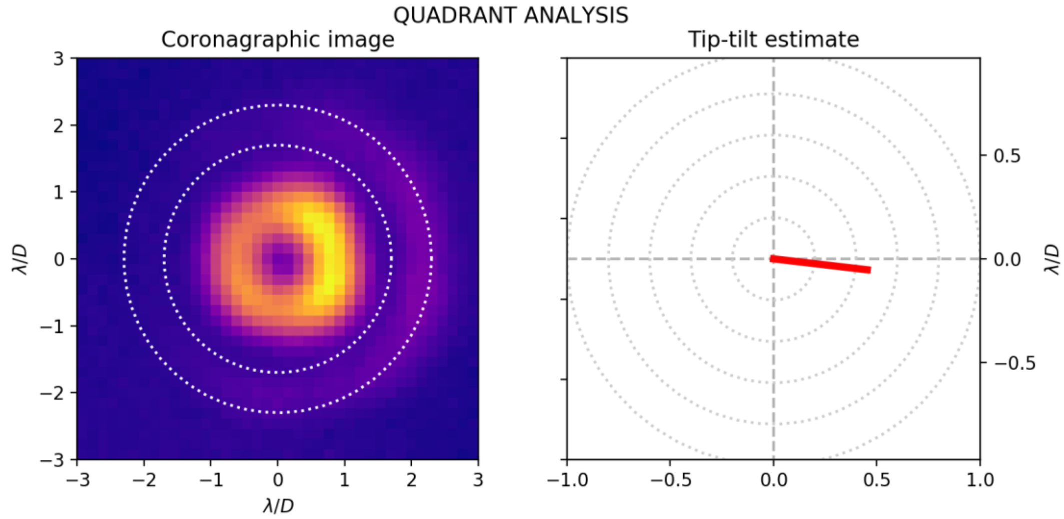


Figure 3: Illustration of the principle of the QACITS tip-tilt measurements (see Huby et al. 2015 for details). The left panel displays an example of coronagraphic image recorded during the observing sequence used for the QACITS check list with the white dotted circles indicating the area where the differential intensities used to estimate the image tip-tilt are computed. The right panel shows the QACITS tip-tilt estimate in the x/y plane (Δx=0.45 λ /D, Δy=0.05 λ /D). Note the different xy-ranges between the two panels.

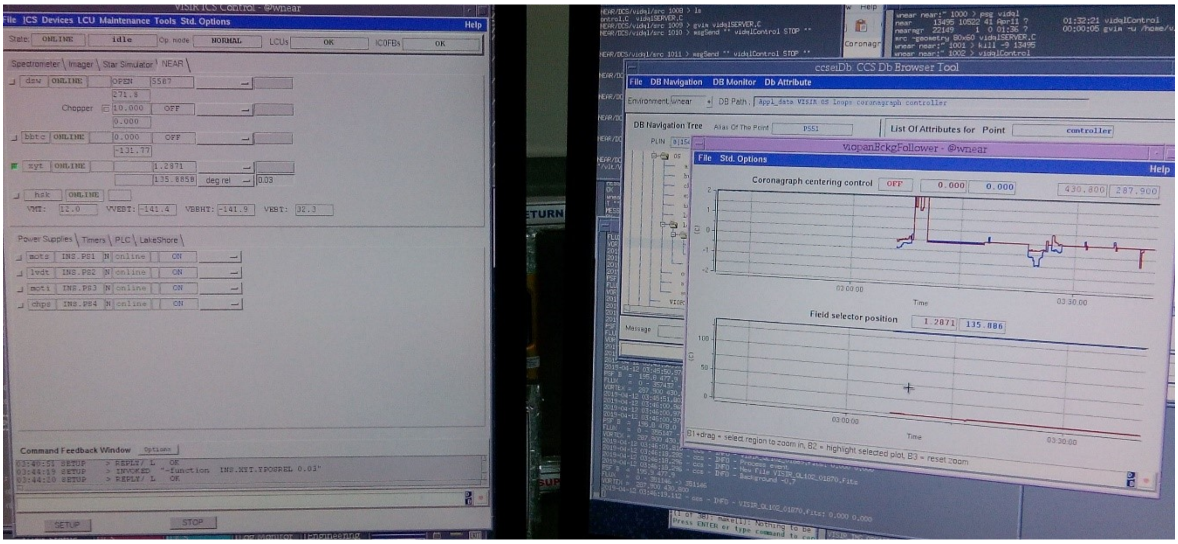


Figure 4: Screen shots of the console interface used during the observing sequence for the QACITS check list. The left panel displays the control panel of the field selector, which was used to apply manual offsets. The right panel shows monitoring plots of the QACITS tip-tilt estimates and of the position of the field selector.

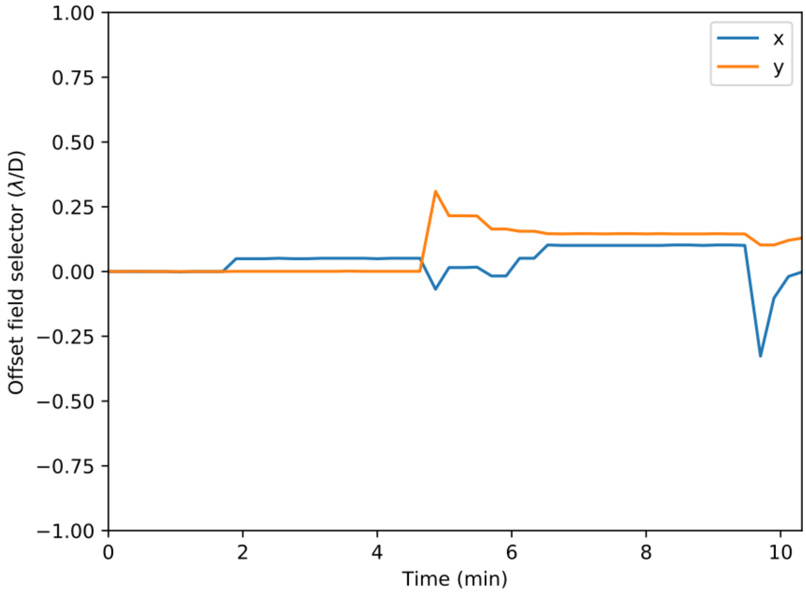


Figure 5: Diagram showing the position of the field selector during the QACITS closed-loop test (relative to the position at the beginning of the test). Two manual offsets were applied with the field selector around T=5 min (positive in y) and around T=9.5 min (negative in x). The field selector was then progressively put back to its original positions using the QACITS offset measurements.

4.9 NEAR contrast and sensitivity with AO

Task Number:	NEAR contrast and sensitivity
Category: Mandatory	Purpose: Evaluate N-band performance of NEAR. Impact of nodding? DS vs DSM chopping?
Description of Procedure: - Close AO loop in different chopping configurations (Dicke switch or DSM) - Activate Nodding - Record VISIR coronagraphic data in NEAR (10-12.5μm) filter and B10.4 filter for sensitivity and contrast evaluation	
Input and requirements:	
NEAR AO BB loop (not needed for DSM chopping) DSM Chopping and Dicke switch Coro centering loop VISIR	
Output: report, data cubes, files	Evidence: see Sect. 5.12.1
	Status: done
Results:	

We observed alpha Cen in the NEAR configuration several times during the commissioning. We typically observe sensitivities of 850 μJy [5σ/h] in the NEAR configuration. This value was estimated on the residual chopping-only images after spatial high-pass filtering (see Figure 6). It also takes into account that we can only make use of one chopping half-cycle where the star is on the coronagraph. For comparison with VISIR one needs to apply the definition of the QC sensitivity parameter of VISIR. In that definition all four observing beams on the detector are integrated to derive the total SNR ratio during the observation of a standard star, and the SNR ratio is extracted by selecting the aperture photometry providing the best SNR. Therefore, the NEAR configuration is about a factor 3 more sensitive than the median of all QC sensitivities that have been obtained by VISIR since the Aquarius detector upgrade in 2011. For more details see section 6.5. The raw PSF contrast (Figure 7) for the coronagraphic observations is between 1-2x10^{-5} at angular separations larger than 1" (~3 λ/D). This corresponds to more than a factor 100 improvement over classical VISIR observations. The high stability of VISIR and the NEAR PSF makes us confident that a 10^{-6} 5-sigma imaging contrast can be reached assuming a typical ADI calibration efficiency of a factor 50-100.
Evaluation: Both, sensitivity and contrast of NEAR are marginally compliant with the NEAR specifications (80 μJy [5σ/100h], 10^{-6} contrast). The above quoted sensitivity will take a small but non-zero hit through the ADI subtraction process. The contrast improvement expected from ADI calibration can only be confirmed on the final long duration data set.
Compliance: C
Comments: Use very MIR-bright star, e.g., gamma Crux 12 31 09.96, -57 06 47.57, 800 Jy, apparent diameter ~21 mas) or α Sco (16 29 24.46, -26 25 55.21, 2200 Jy, apparent diameter ~41 mas). Perform deep observations. Evaluate sensitivity and contrast for DSM-chopping and Dicke switch. Evaluate benefit of nodding. Determine NEAR campaign observing mode. 6h night

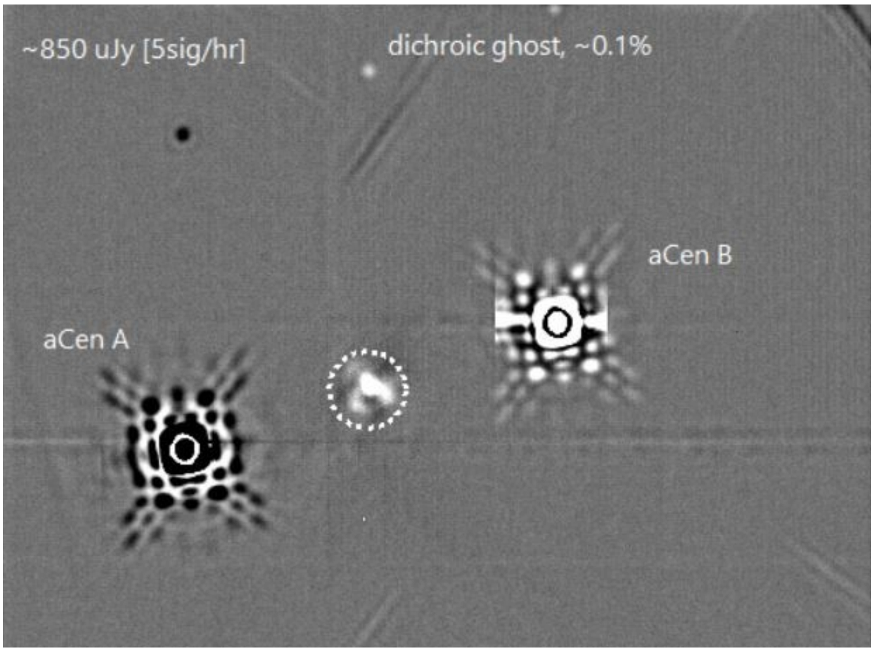


Figure 6. Cen observed in the NEAR campaign mode. The figure shows a chopped image after spatial high-pass filtering, a standard pre-processing step in high-contrast imaging.

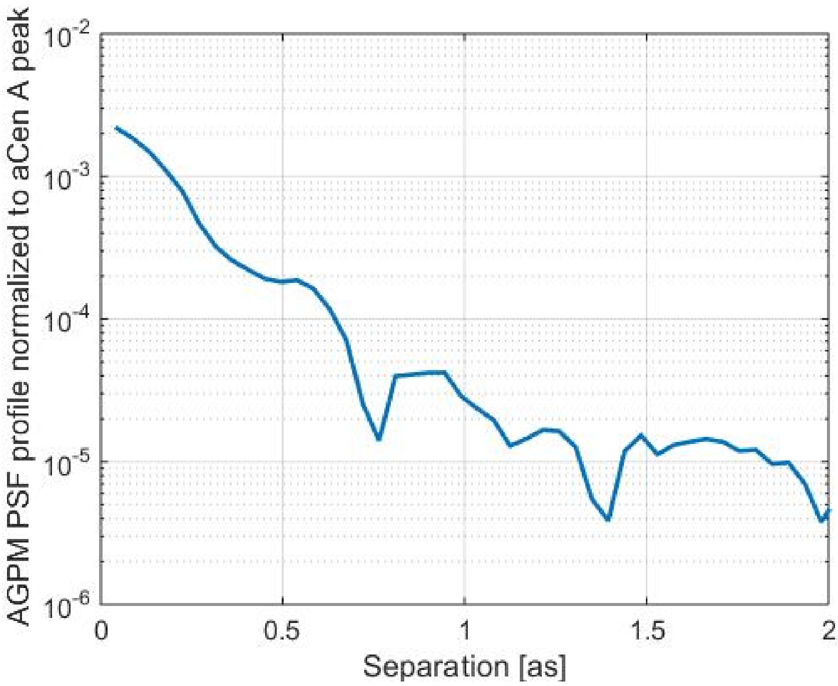


Figure 7. Raw PSF contrast calculated in the central area of the figure above.

4.10 ELFN vs DSM chopping frequency

During the commissioning, we always used 10 Hz chopping with the DSM, and achieve a very good sensitivity. Chopping slower would have the advantage of a slightly higher duty cycle, e.g. 90% for 5 Hz vs 80% for 10 Hz. We will carry out these tests during the technical nights before the campaign.

For the ELFN improvement obtained with the Dicke-switch, see section 4.3.

4.11 Non-common Path Aberrations

<table>
<tr><td>Task Number: 4.7.7</td><td>Estimate NCPA</td></tr>
<tr><td>Category:

Mandatory</td><td>Purpose: Estimate NCPA and stability of NEAR</td></tr>
<tr><td colspan="2">Description of Procedure:

Manual check-out astigmatism. Coma, and focus

Use ZELDA mask and take pupil image

Take deep (~45min) coronagraphic high contrast images

Repeat step 1 and 2 for about 2 hours</td></tr>
<tr><td colspan="2">Input and requirements:</td></tr>
<tr><td colspan="2">NEAR AO

BB loop (not needed for DSM chopping)

DSM Chopping and Dicke switch

Coro centering loop

VISIR</td></tr>
<tr><td>Output: report, data cubes, files</td><td>Evidence: documentation</td></tr>
<tr><td></td><td>Status: done</td></tr>
<tr><td colspan="2">Results:

NCPAs have been measured in various ways:

1/ With the WFS using an RS fiber in the input focus: -75 nm rms of defocus, 50 nm rms astig 0deg (see Figure 8)

2/ With the WFS observing the CU source: 60 nm rms of defocus, 180 nm rms of astig 0deg (see Figure 9)

3/ ZELDA (VISIR focal plane) observing the CU source: -250 nm of defocus, 285 nm of astig 0deg (see Figure 10)

All other aberrations are at the level of a few tens of nm rms and below.

Assuming that the reflection off the dichro and the WFSU M1 folding mirror do not introduce astigmatism, 1/ and 2/ indicate a CU source aberration on the dichro front side of 135 nm defocus and 180-50=130 nm rms of 0deg astig.

Knowing that the dichro (10mm thick, 45 deg) introduces 300 nm rms of 0deg astig, one would expect either 300-130=170 nm rms of astig0 or 430 nm rms of it. Modal sweeps of focus and astigmatism indicates a that we’d need only an offset of 200 nm rms of astigmatism to achieve a good coronagraphic performance and PSF peak intensity. This needs to be repeated with a more accurate pupil centring allowing for</td></tr>
</table>

a deeper and more sensitive coronagraphic performance.
Evaluation:By analysis see Fig.8-10
Compliance: C
Comments: Use very MIR-bright star, e.g., 12 31 09.96, -57 06 47.57, 800 Jy, apparent diameter ~21 mas) or Sco (16 29 24.46, -26 25 55.21, 2200 Jy, apparent diameter ~41 mas). 2 x 2h night

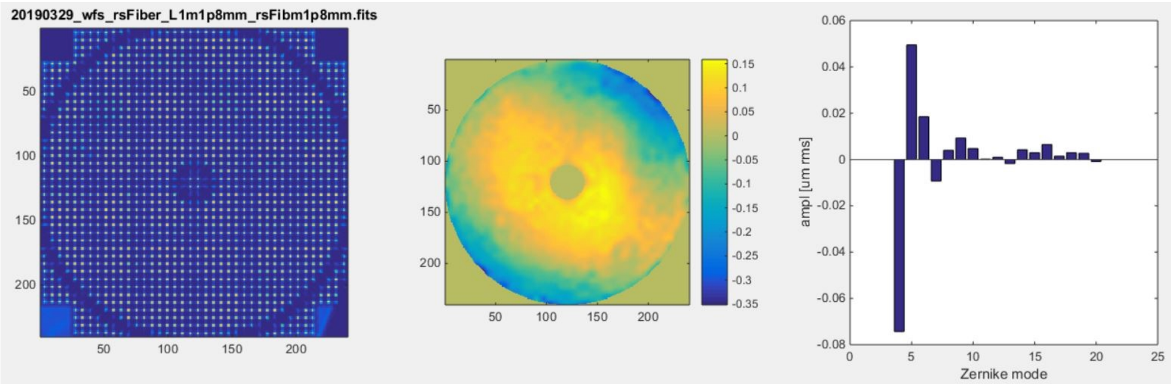


Figure 8. Wavefront measured by WFS with a reference fiber in the input (VLT) focal plane. These correspond to the WFSU NCPA which are calibrated by the reference slopes.

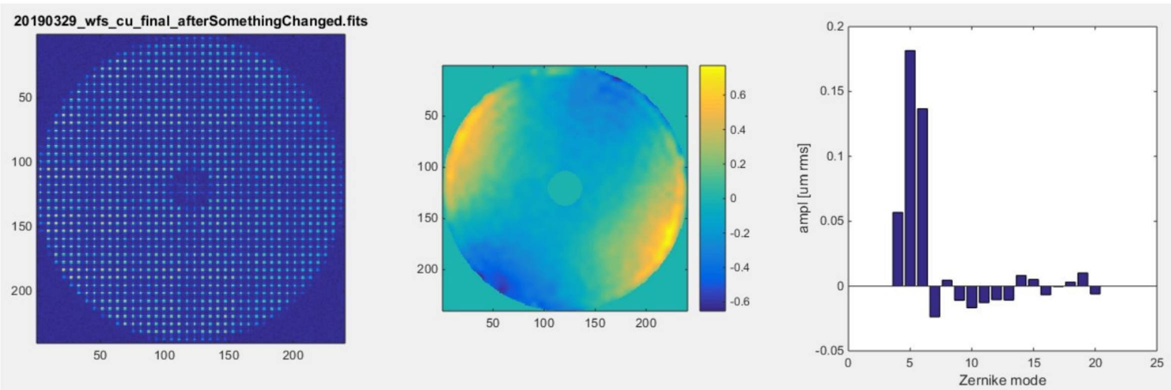


Figure 9. Wavefront measured by WFS with the CU source. These add WFSU NCPA and CU aberrations.

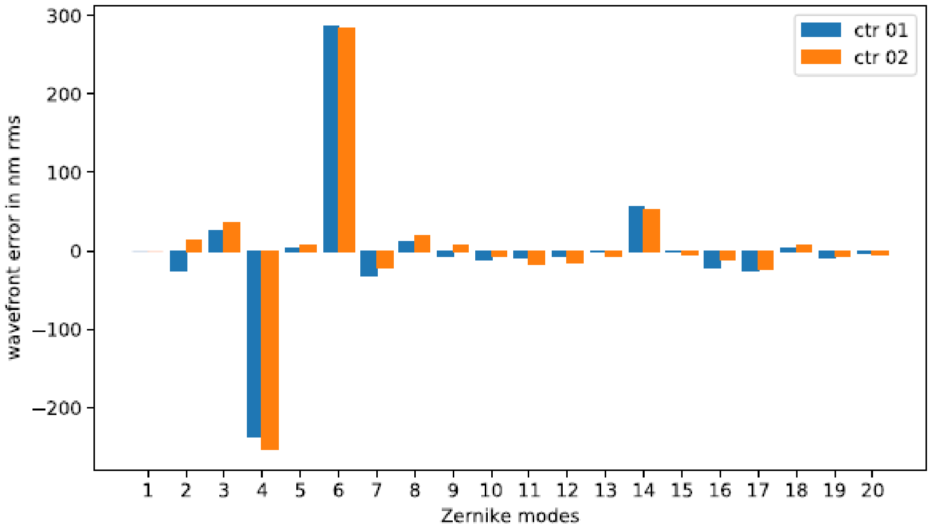


Figure 10. Zernike aberrations reconstructed by ZELDA from measurements with the VISIR calibration unit (CU) source. These aberrations include the effect of the entrance window and the CU itself. Calculation and plot by M. N'Diyae.

5. Science Operations

The focus of the commissioning run was enabling science operations for the NEAR experiment with a minimum of needed on-sky observing time. A science operational re-commissioning of VISIR at UT4 was not possible because the software required for the chopping and nodding observing technique with the DSM is not yet commissioned. We could not investigate in this run on-sky telescope time for commissioning a chop-nod AOF observing sequences that is not part of the NEAR experiment.

5.1 DSM binary chopping

We implemented DSM binary chopping using binary star Hip 76276 with 4" separation and αCen with 5.1" separation as test cases. The chopping orientation was set by drawing a line on the VISIR RTD through the stars, and setting the PA such that the two stars moved along this line. We find that PA parameter has to be set as:

PA_chop = 180° - PA_catalogue

The actual binary separation can also be measured on the RTD. Synchronizing the VISIR NGC with the chopping DSM turned out to require introducing a short delay on the NGC.

After this initial calibration Johann Kolb deployed a method to accurately determine separation and PA of a binary star from the AO loop data while chopping. This enables setting the chopping parameters such that either one of the binary stars hop straight on the WFS center in one chopping half cycle while during the next half-cycle the other star is on the WFS center. In Figure X we show a 10s chopped image of αCen with 10Hz DSM chopping, in filter B10p7, and AO correcting for 350 modes with loop gain of 0.5.

We performed a long-time test and stayed in this configuration for 30 min. Fortunately both PSFs remained "rocksteady" with some slight rotation with the field. We also confirm our sensitivity expectations and measure a sensitivity of 950μJy/10σ/1h. Note that the central object in this observation is actually the difference between αCen A and αCen B, where the former star is two times brighter than the latter. Still for the central object a number of Airy rings are visible confirming the high precision that we have reached in the procedure calibrating the chopping amplitude and PA for the DSM binary chopping.

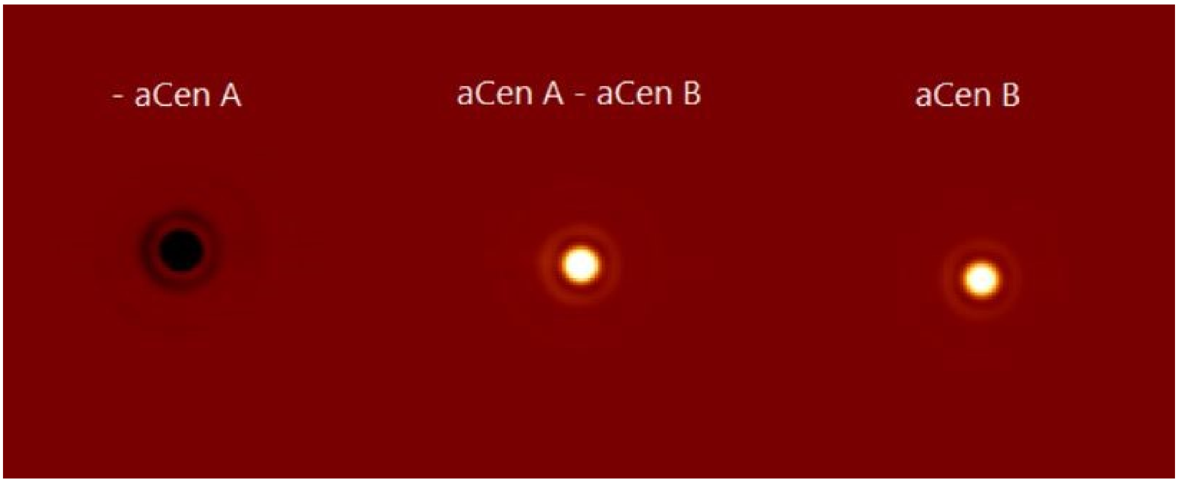


Figure 11: Binary chopping on the αCen system in filter B10.7.

5.2 DSM single-star chopping

We verified that our implementation of binary-chopping is also working when applied to a single-star despite that single star DSM chopping has never been commissioned. This is fortunate as otherwise the target list would have been restricted drastically. We use a particular feature how SPARTA-AOF-RTC is working. It skips frames whenever there is not enough flux in the sub-apertures, and so does not update the DSM shape and the AO controller. Therefore, half-cycle frames where the star is on the WFS are AO corrected, whereas for the other half-cycle frames where the star is off the WFS there is no AO correction and the DSM shape is not updated. The image shown in is the figure below for 10 Hz binary-chopping on a single star. Note the various Airy rings demonstarting the high image quality achieved with our DSM binary-choping procedure when applied on a single-star. The **Strehl ratio** drops from around 100% to 90% in the non-A0-corrected image, still much higher than the typical 50% achieved by classical VISIR.

As for binary chopping, the **chop throw** is limited to 5.5”. In the case of a single star, and if the science objective allows it, it is recommended to use a throw around 4”. This leaves a comfortable stroke margin on the DSM edge actuators, and also moves the star sufficiently far away to avoid light leaking into the 1.4” radius FoV of the WFS Shack-Hartmann sensor.

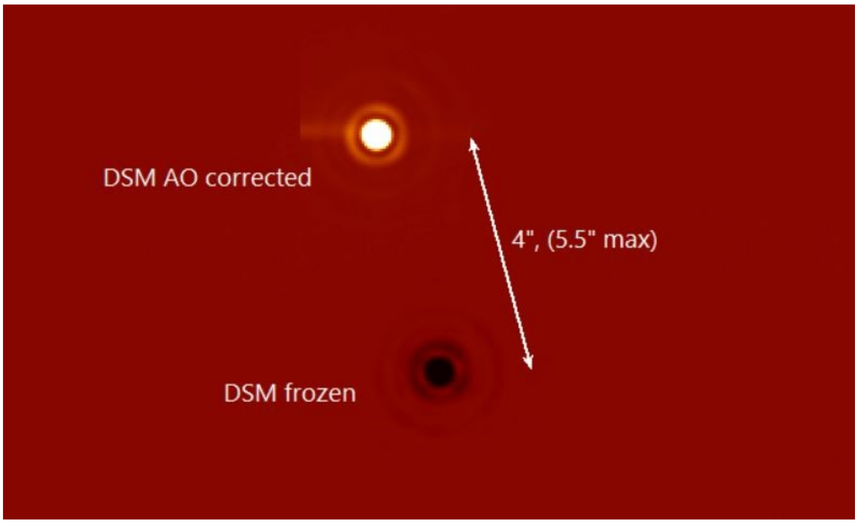


Figure 12: Binary-chopping on a single star. Chop throw is 4" and chop frequency is 10Hz. In the ON position AO correction is applied whereas in the OFF position the DSM is frozen. Top left of the ON position some electronic ghost from the Aquarius detector is visible. The artifical detector features can in most cases *not* be corrected when applying nodding or ADI. The various Airy rings demonstrate the high image quality of NEAR.

5.3 Instrument Package

The instrument package of VISIR was updated to scope with the new acquisition and science templates that are detailed below.

5.4 Calibration templates

All information that are required for the calibration of the α Cen data is provided by the observation of this binary system itself. In that respect the observations are self-calibratable and dedicated calibration templates are not required. The NEAR observing templates can be executed on VISIR photometric standard stars. This allows photometric calibration of other science imaging observations where a suitable calibration star is not in the field. The other VISIR calibration templates for the imaging mode are used for QC monitoring and health checks.

5.5 Observing templates

For NEAR two new templates have been designed. There is one for the acquisition and another one for the science observation. The particular new feature is the interaction with the DSM and the combined SPARTA-AOF-RTC system as well as the optional use of the internal Dicke switch chopping. The present visitors observing tool (VOT) display of NEAR is shown in Figure 13.

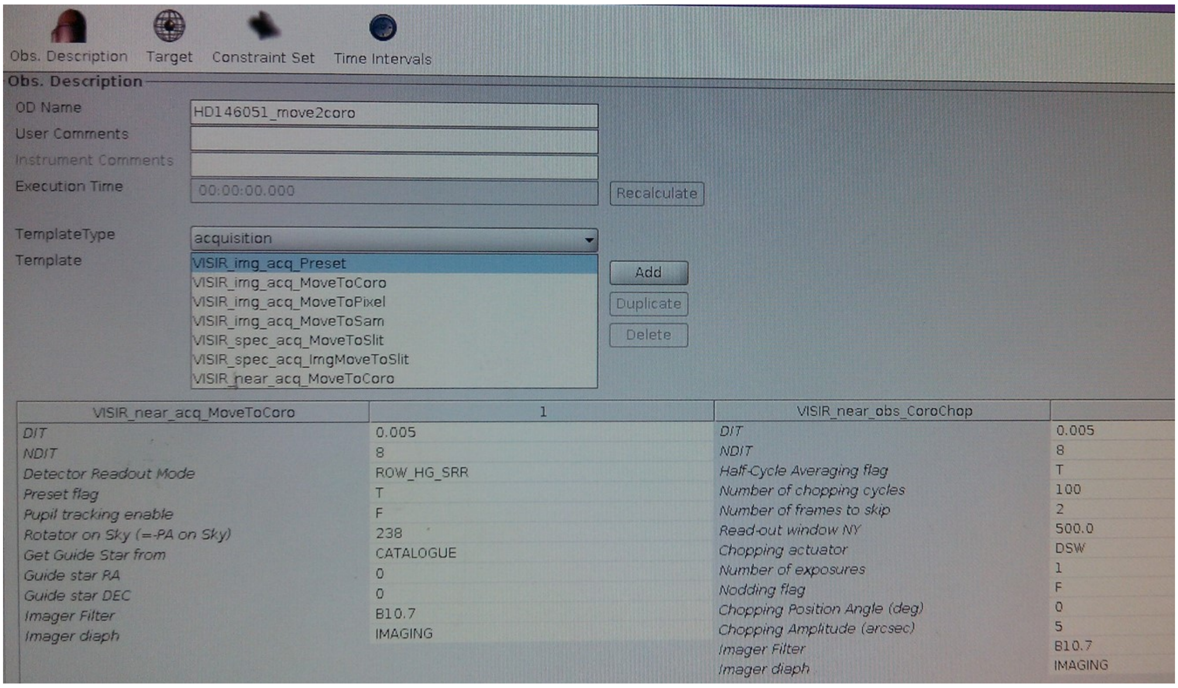


Figure 13: VOT panel of NEAR with the selection of the acquisition and science template.

Acquisition:
The NEAR acquisition template is called VISIR_near_acq_MoveToCoro. It is based on the VISIR_img_acq_MoveToPixel template. It was re-written by Gerald Zins and considers the AO and Dicke switch. We make use of the full speed of DSM chopping. This is the offered maximum 10Hz chopping frequency. The detector setting was derived from the sky background and the optimal read-out scheme is "ROW_HG_SRR" with DIT=5msec, hence NDIT=8 and NDITskip=2. During the sequence one selects the filter and the diaphragm is set to either imaging or one of the various coronagraphs, see Figure X. The acquisition template allows chopping of a single or of a binary star system such as αCen A and B. For the later see the templates with example parameters as provided in Table 1. Note the parameter "Rotator on Sky (-PA)" which was carefully calibrated and set to -122°. This ensures chopping on αCen A and αCen B for the On and OFF position, respectively.

Science:
The NEAR science observing template is called VISIR_near_obs_CoroChop. It is based on the VISIR_img_obs_AutoChopNod template. It was re-written by Gerald Zins and considers selection of the read-out window and DSM or Dicke switch chopping, see Table 1 for a typical example.

Table 1: NEAR acquisition and observing science template

VISIR_near_acq_MoveToCoro		VISIR_near_obs_CoroChop	
DIT	0.005	DIT	0.005
NDIT	8	NDIT	8
Detector Readout Mode	"ROW_HG_SRR	Half-Cycle Averaging flag	F
Preset flag	T	Number of chopping cycles	600
Pixel Field of View	SF	Number of frames to skip	2
Preset flag	T	Detector Readout Mode	ROW_HG_CDS
Pupil tracking enable	F	Read-out window NY	500.0
Type of given target	COORDINATE	Chop flag	T
coordinate for the target	" "	Chopping actuator	TEL
Delta coordinate for the target	" "	Chopping guide window	BOTH
Equinox	2000.0	Number of exposures	1

Rotator on Sky (=-PA on Sky)	-122	Nodding flag	F
RA additional tracking velocity	0.0	offset for background	-30
DEC additional tracking velocity	0.0	Delta offset for background	0
Proper Motion Alpha	0.0	Skip chop setup?	F
Proper Motion Delta	0.0	Chopping Pos Angle (deg)	0
Epoch	2000.0	Chopping Amplitude (arcsec)	5
Get Guide Star from	CATALOGUE	Imager Filter	B10.7
Guide star RA	0	Instrument Mode	NODEFAULT
Guide star DEC	0	Imager diaph	IMAGING
Imager Filter	B10.7	Data Prod. Categ.	DPR.CATG
Instrument Mode	NODEFAULT	Data Prod. Tech.	DPR.TECH
Imager diaph	IMAGING	Data Prod. Type	DPR.TYPE
Detector source	SKY		

5.6 Pipeline

For analysis of the calibration plan we requested to install the VISIR pipeline on UT4. However, as the chopping and nodding technique is not commissioned for the DSM we could not make use of the ESO pipeline. Data of this campaign have been reduced using the IDL VISIR pipeline developed by Eric Pantin[2].

For any new filters an update of the static calibration files (especially the database of standard star fluxes) included in the VISIR pipeline was updated. This update is needed in any case for both reduction systems. The updated calibration file was sent to Lars Lundin for possible implementation in the ESO pipeline.

5.7 QC parameters

There is no issue for our experiment that QC1 parameters cannot be properly derived by the ESO pipeline when VISIR is used in the NEAR configuration.

5.8 Data

Proprietary rights of the data were discussed in accord with the contract with the Break Through Initiative and the Director General. The implementation of data rights has been coordinated with DMO. Physical transfer and flags for the proprietary right settings has been set-up together with Nathalie Fourniol. All science templates have been executed using proposal ID VM 60.A-9106(A).

[2] https://tel.archives-ouvertes.fr/tel-00553645

6. Commissioning: on-sky results

6.1 First NEAR images on αCen

After functional system set-up has been completed first light NEAR images on the αCen system were taken on 11 April 2019. In Figure 14 we show the NEAR image of αCen in filter B10.7 and DSM binary chopping mode. The chopping throw was calibrated to match precisely the angular separation of both stars (5.1”). From the image a sensitivity of 900μJy/10σ/1h is derived. This is spectacular when compared to the offered[3] median VISIR sensitivity in the same filter of 4000μJy [10σ/1h]. On point sources a factor 4 gain in sensitivity has been established. A happy commissioning team is shown in Figure 15.

The gain in point-source sensitivity is provided thanks to the high frequency chopping (10Hz) offered by the deformable M2 (DSM) of UT4, and the superb Strehl ratio reaching 100-ε (%) in the MIR by the AO system, and the new N band optimized entrance window.

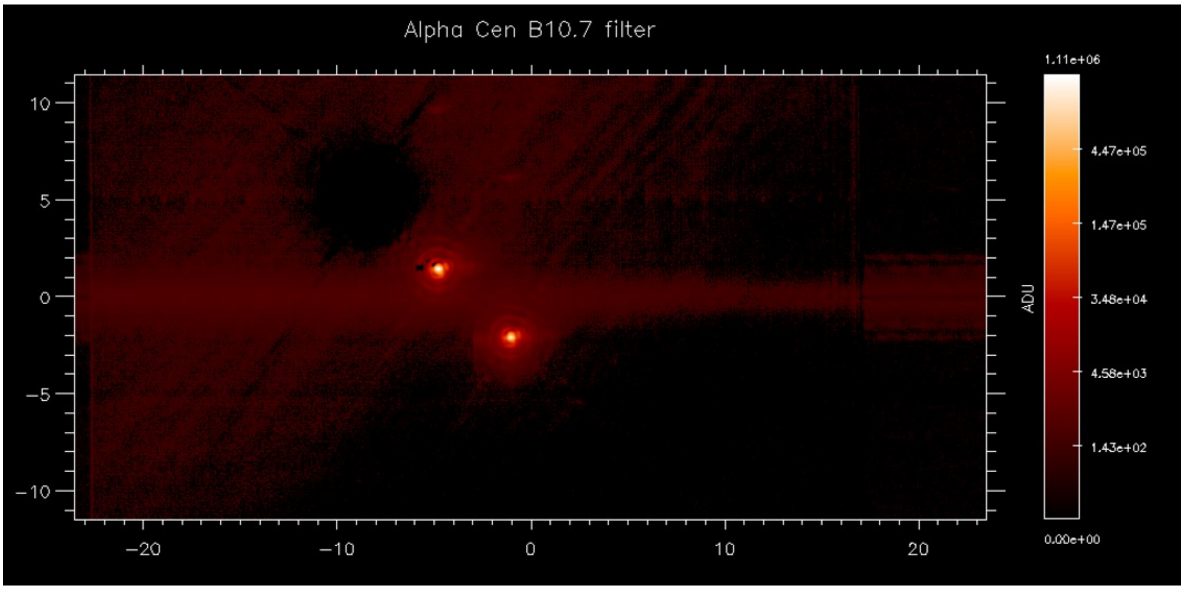


Figure 14 : NEAR first light image of the αCen system in filter B10.7 and DSM chopping mode. Note the spurious electronic ghost from the Aquarius detector.

[3] http://www.eso.org/sci/facilities/paranal/instruments/visir.html

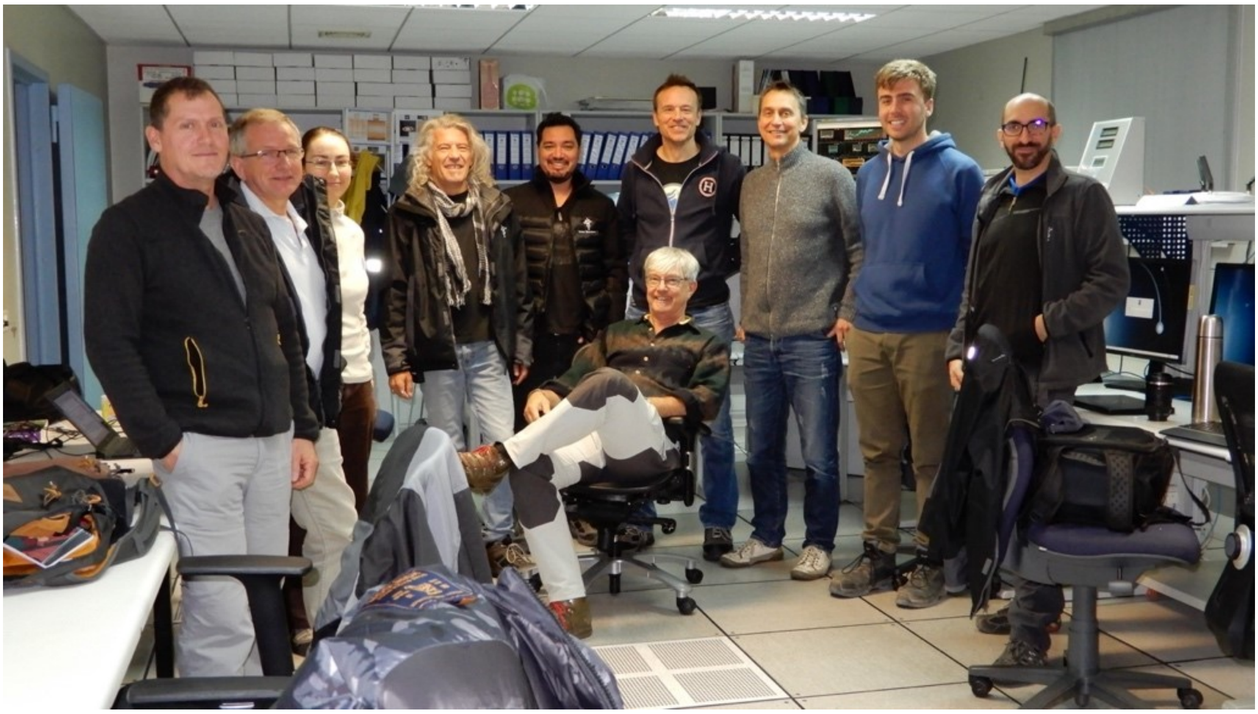


Figure 15: NEAR commissioning team.

For the first-time a mid-infrared instrument has broken the 1000μJy [10σ/1h] sensitivity-barrier in that filter. The instrument is now and 16 years after first-light reaching a sensitivity which is close to the theoretical limit of background-noise limited performance (BLIP) despite the short comings of the Aquarius detector with its spurious electrical ghosts and the compromising extra low frequency noise component (ELFN). This systematic error by the Aquarius detector has a marginal impact on the point-source sensitivity a statement not applicable to extended sources. These detector features can often not be corrected even when.

We take the observed 1st light PSF of αCen A and compare it to a theoretical PSF in **Figure 16**. The theoretical PSF is computed using a model of the pupil followed by multi-chromatic average over the filter bandpass B10.7. The estimated Strehl ratio in this first-light dataset is 66 %. This subpar performance is due to not yet calibrated none common path aberrations and the 2” bad seeing conditions.

After further calibrations and fine-tuning of the non-common path aberrations (focus, astigmatism) and under better seeing conditions a Strehl Ratio of 100-ε%

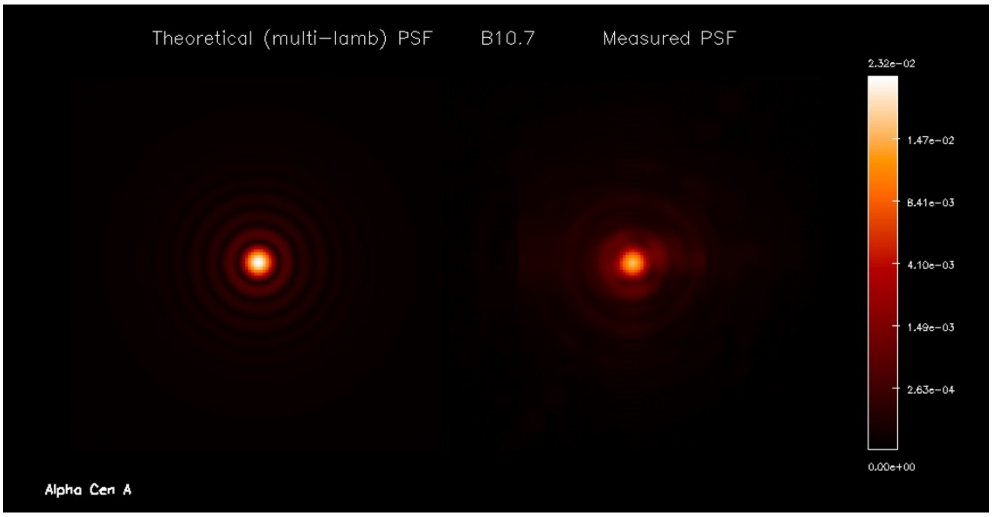


Figure 16: Theoretical (left) and measured PSF (right) as of Figure 5 of NEAR in B10.7μm.

6.2 Non-common path aberrations

The non-common path aberrations (NCPA) where that were still included in the first light observations have been reduced by calibrating focus and astigmatism using the ZELDA mask supplied by LAM. After the calibration we observed Gamma Crux as PSF reference star. The AO corrected PSF in filter B10.7 displays about more than 10 Airy rings resulting in a Strehl ratio of 100-ε (%), see Figure **17**

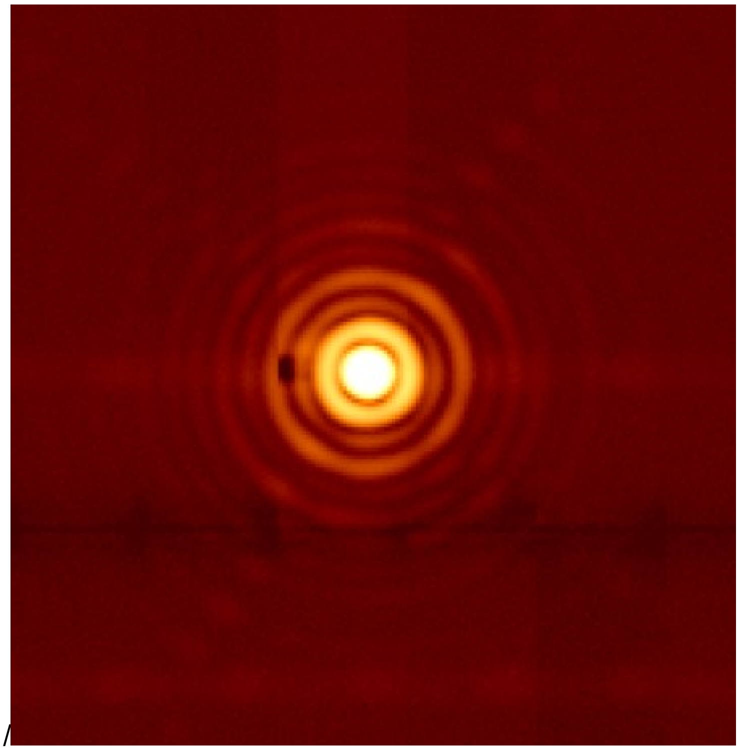


Figure 17: AO corrected PSF in median seeing conditions after calibrating the NCPA. More than 10 Airy rings are visible resulting in a Strehl Ratio of 100-ε (%).

6.3 Annular Groove Phase Mask

We observed Gamma Crux inserting the Annular Groove Phase Mask (AGPM) with the BT4 and N3 mask. A bright hot spot when looking onto the blank sky is detected which we refer to as center glow (Figure 18). Such an artificial star features has already been noticed using the AGPM inserted in VISIR at UT3. However here at UT4 the hot spot brightness is about a factor 2 stronger. We speculate that this hot spot might be related to background flux from M2 and its wind-shield, which is the most prominent difference between UT3 and UT4. The part of the flux which hits the AGPM is then projected by this device to the field center.

Interestingly, the central glow disappears when observing the uniform instrumental background provided by the Dicke switch. The central glow is removed by DSM chopping. However, the spurious light component increases the photon noise. Fortunately, in our region of interest for detecting the planet, say at 1" separation from the star, the sensitivity is only reduced by a few tens of % (Figure below).

The hot spot is due to the vortex phase mask property of moving light in and out of the pupil. Part of the background emission coming from outside the telescope pupil and crossing the vortex center will be re-injected inside the telescope pupil and will make its way to the detector. This only happens for light crossing the vortex center, hence the bright spot at the center. Note that this would not happen if the vortex were located downstream of a cold stop as confirmed by testing by Oliver Absil (priv comm).

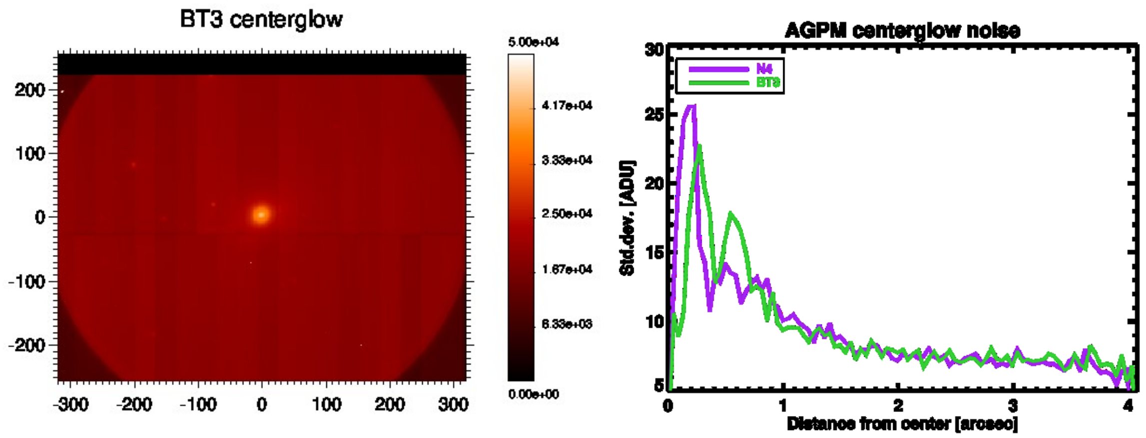


Figure 18 : On sky image using BT3 shows an artificial hot spot, also referred to as center glow (left). The excess light of the center glow results after DSM chopping an increase of the shot-noise which becomes marginal at separation larger than 1".

6.4 Shaped pupil mask

Cen observed with the shaped pupil mask Near105 designed by Alexis Carlotti is shown in Figure 19. The PSF features 2 high-contrast regions; the first one near to the star at 0.9" - 1.5" where a planet could orbit, and a second one at a separation range 3"-7" where it would not impact on the contrast of the binary companion. The bar like horizontal structure in the lower part of the image is an electronic ghost by the Aquarius detector. Qualitatively the shaped pupil PSF is as designed. Compared to the Vortex observations, the main drawback is the non-attenuated PSF, which produces the horizontal ghosts and would prevent us from obtaining a good PSF contrast in this direction. The measured PSF throughput (flux in the central 8-px wide aperture) is about a factor 2.3 lower than for the vortex coronagraph. This is partly compensated by

a) Also the noise is reduced by a factor of ~1.3, because of the lower throughput of the mask,

b) the possibility to also use the off-axis PSFs for science recovers a sqrt(2) in sensitivity.

Compared to the shaped pupil mask, the total sensitivity of the AGPM coronagraph is about 2.3/1.3/sqrt(2) = 1.25 times higher. It also suffers much less from electronics ghosts, because the lioght from the star is dimmer by a factor of a few hundred. So, the AGPM will be the choice for the NEAR campaign.

The shaped pupil mask, instead, does not leak extended emission into a ring-like structure (see Figure 20, and has a spatially invariant PSF facilitating de-convolution and PSF subtraction techniques. It is therefore an interesting option for the observation of extended emission around stars like disks and shells and later evolution stages.

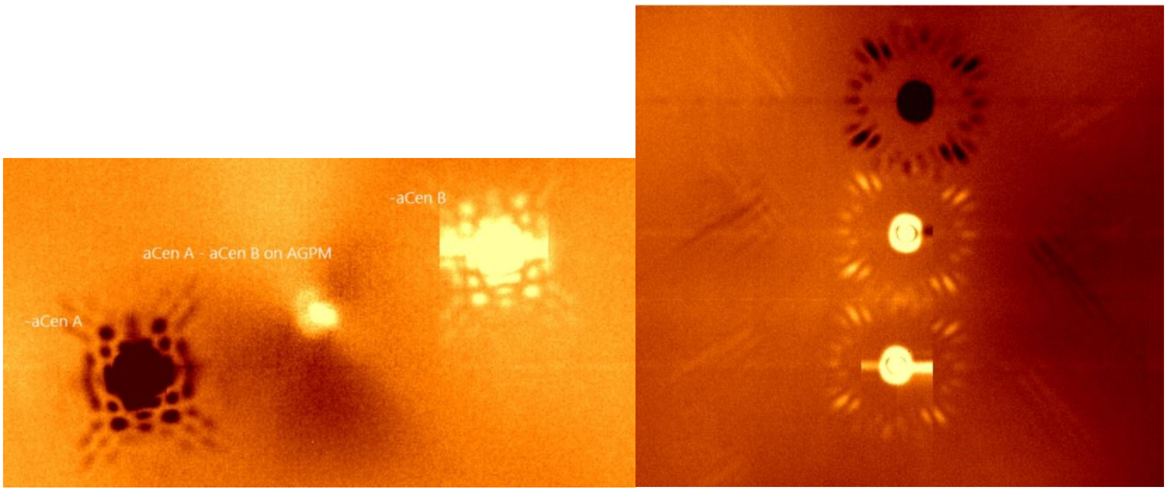


Figure 19: αCen observed with AGPM N4 (left) and the shaped pupil mask Near105 (right). The inner high-contrast region of the shaped pupil mask extends from 0.75” to 2”. The outer one from 3” to 7”.

Figure 20. AGPM PSF of HD100456, a young star with extended disk emission. The disk emission within the diffraction limit is leaked by the vortex into the ring-like structures.

6.5 Sensitivity DSM chopping

The sensitivity of VISIR is measured on standard stars observed in chopping and nodding sequences with amplitudes so that all (4) observing beams are located on the detector. For comparison with VISIR we apply the definition of the QC sensitivity parameter of VISIR. In that definition all four observing beams on the detector are integrated to derive the total SNR ratio and the SNR ratio is extracted by selecting the aperture photometry providing the best SNR. The obtained SNR in the given observing time is then extrapolated to a point source sensitivity in units mJy/10σ/1h.

Initial functional tests of the observing templates allowing derivation of the sensitivity were done in observing nights 98 and 99. Performance test of the achievable NEAR sensitivity was taken during nights 100 and 101. Results are in detailed in Table 2. We find in filter B10.7 a sensitivity of 0.8 (mJy/10σ/1h), and in filter N_101 the sensitivity range between 0.6 – 1.0 at a median of s ~ 0.76 (mJy/10σ/1h). Therefore, the NEAR configuration is about a factor 3 more sensitive than the median of all QC sensitivities that have been obtained by VISIR of s ~ 2.6 (mJy/10σ/1h) after the exchange of the entrance window in 2017. Note that we did not apply nodding for the NEAR observations, which may have an impact on the comparison to the original VISIR values.

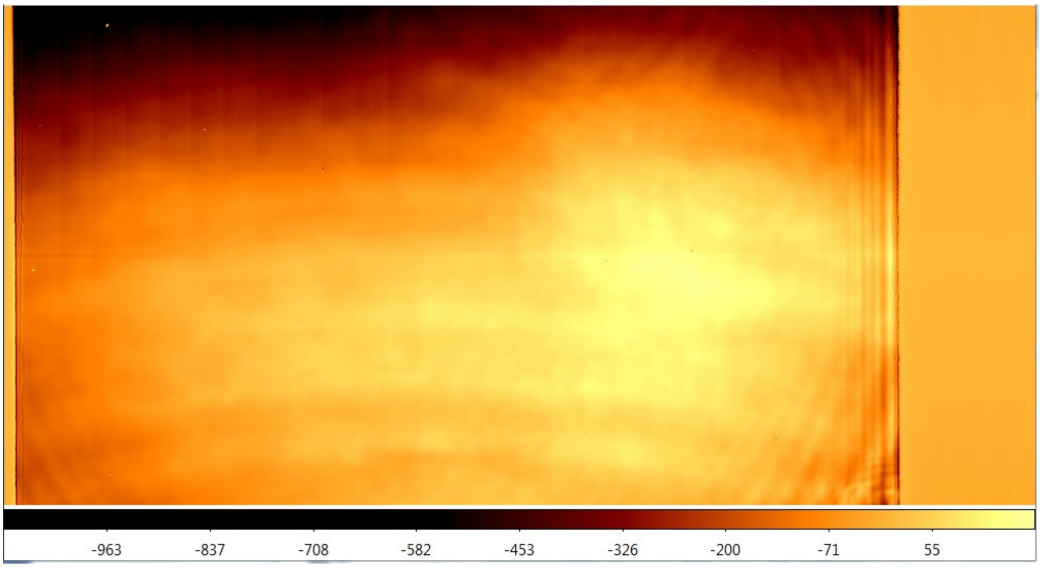
Table 2: NEAR sensitivities are given for the specified target, observing night, filter, AGPM, and observing time. Observations are performed with DSM chopping at 10 Hz.

Target	Night	Filter	AGPM	t	sensitivity
	2019			s	(mJy/10σ/1h)
HD146051	100	B10.7	-	80	0,8
HD146051	100	N_101	N3	40	0,8
αCen	100	N_101	N4	80	0,7
αCen	100	N_101	N3	160	0,7
αCen	100	N_101	BT3	40	0,7
αCen	101	N_101	N4	240	0,7
αCen	101	N_101	N3	240	0,7
αHya	101	N_101	N4	96	1,0
αHya	101	N_101	N3	96	0,7
αHya	101	N_101	N3	288	0,6

6.6 Sensitivity Dicke switch

The standard star HD099167, 16.6 Jy at 11um, was observed with Dicke chopping in the B10p7 filter on 12 Apr 2019. The chopping frequency was varied between 1 and 10 Hz. Each data sequence consisted of 1x 10-s exposure sky, 10x 10-s exposures star, 1x10-s exposure sky. Note that the actual time spend either on sky or on the star is half that time. The other half of the time is spent on the blackbody. So sensitivities with the Dicke-Switch are automatically lower than with on-sky chopping by a factor sqrt(2).

The spatial residual after chopping with the Dicke switch is not flat. Figure 21 shows the residuals after subtracting the blackbody flux from the sky. The residuals are very stable, so one could envision a very deep (noiseless) on sky image to calibrate the data,



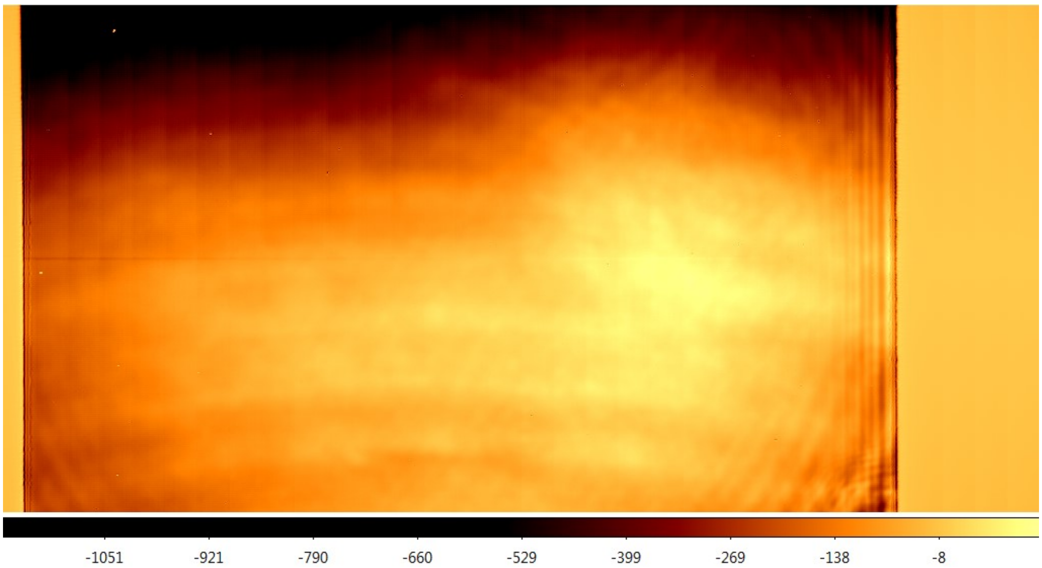


Figure 21. Dicke-chopping residuals. There is a 25-minute time gap between the top and bottom images.

After subtraction of the sky residuals shown in Figure 21, the star images for different chopping frequencies are shown below in Figure 22 below.

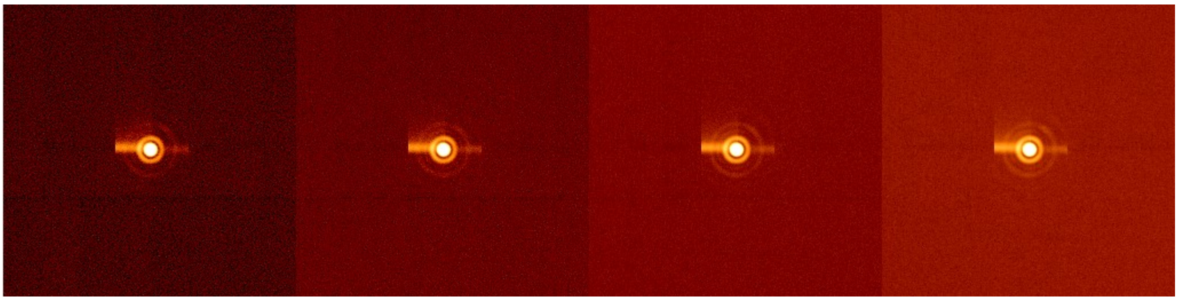


Figure 22. 50-s exposures of HD099167 obtained with Dicke-chopping. The horizontal bar is produced by the electronic noise, which is largest when the spot falls between two channels as in this case. From left to right: 1, 2, 5, 10 Hz.

The noise in these images is dominated by the sky frames used to subtract out the residuals, which amount to 20-s of data. Hence, the sensitivities shown in the table below could be reduced, if a long-exposure (noiseless) Dicke-chopped skyframe would be available. The values in brackets show the result, if one would take the correction into account.

Table 3. Data for Dicke-chopping taken on 12 Apr 2019. The last column shows the calculated sensitivity with the number in brackets considering that the short exposure sky image dominates the sensitivity.

SKY	OBS	File	Chop Freq	Sensivity [10σ/h on source] sky-subtra image, limited by sky noise.
12		VISIR.2019-04-13T02_01_16.724.fits	10 Hz	
	103-112	VISIR.2019-04-13T02_01_37.328.fits – … VISIR.2019-04-13T02_03_29.357.fits	"	3 (1.9) mJy
13		VISIR.2019-04-13T02_03_54.139.fits	"	
14		VISIR.2019-04-13T02_05_00.730.fits	5 Hz	
	113-122	VISIR.2019-04-13T02_05_20.135.fits – … VISIR.2019-04-13T02_07_02.825.fits	"	4 (2.5) mJy
15		VISIR.2019-04-13T02_07_26.122.fits	"	
16		VISIR.2019-04-13T02_08_42.702.fits	2 Hz	
	123-132	VISIR.2019-04-13T02_09_01.150.fits – … VISIR.2019-04-13T02_10_42.183.fits	"	6.7 (4.2) mJy
17		VISIR.2019-04-13T02_11_06.147.fits	"	
18		VISIR.2019-04-13T02_12_11.759.fits	1 Hz	
	133-142	VISIR.2019-04-13T02_12_31.175.fits – … VISIR.2019-04-13T02_14_12.302.fits	"	9 (5.7) mJy
19		VISIR.2019-04-13T02_14_37.137.fits	"	
20		VISIR.2019-04-13T02_15_35.713.fits	2 Hz	
	143-152	VISIR.2019-04-13T02_15_55.115.fits – … VISIR.2019-04-13T02_17_35.798.fits	"	6.7 (4.2) mJy
21		VISIR.2019-04-13T02_18_00.144.fits	"	
22		VISIR.2019-04-13T02_19_18.733.fits	5 Hz	
	153-162	VISIR.2019-04-13T02_19_37.196.fits – …	"	4.2 (2.7) mJy

		VISIR.2019-04-13T02_21_20.007.fits		
23		VISIR.2019-04-13T02_21_43.125.fits	“	
24		VISIR.2019-04-13T02_22_42.756.fits	10 Hz	
	163-172	VISIR.2019-04-13T02_23_02.166.fits – … VISIR.2019-04-13T02_24_54.390.fits	“	3.3 (2.1) mJy,
25		VISIR.2019-04-13T02_25_20.151.fits	“	

NEAR with 10Hz Dicke-chopping therefore obtains a sensitivity of better than 2 mJy (10 σ/h). While this is still about a factor 2 from the result obtained with DSM chopping, it is still significantly better than the 3 mJy typically delivered by VISIR in the B10p7 filter. There is still an important sensitivity gain (ELFN reduction) brought by increasing the chopping frequency from 5 to 10 Hz. Dicke chopping presents therefore a good alternative for observations where classical chopping is not feasible (extended objects, which do not provide a nearby “empty” sky).

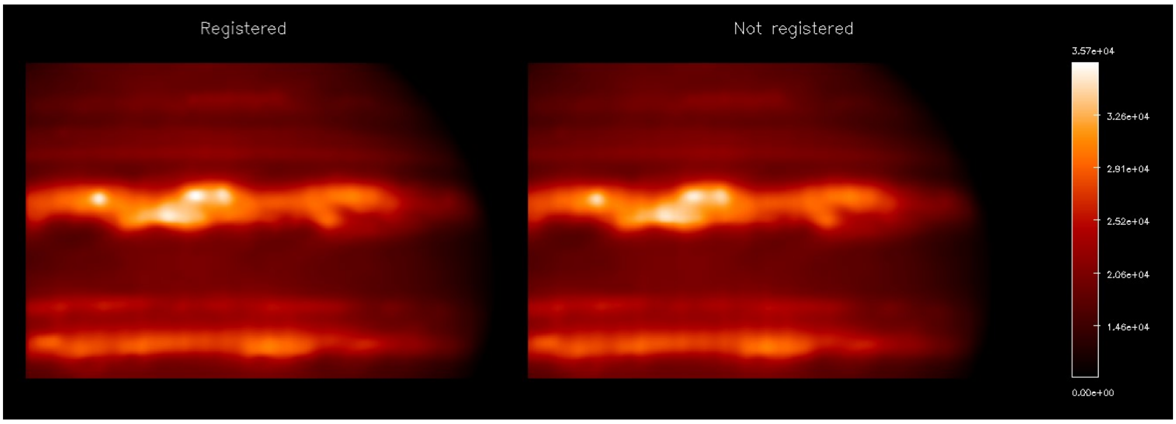


Figure 23. Jupiter observed in B10p7 with 10 Hz Dicke chopping. No AO guide star was available, such that classical shift and add was used to register the image in the left panel.

6.7 SV run constraints

VISIR in the NEAR configuration is considered for a dedicated SV run for which some constrains need to be considered.

The AO star requires a brightness of R <8.5 magnitude, and with a field-selector offset < 2” the star needs to be located close to the center of the detector.

The DSM chopping is limited to chop throw 3-5.5” for chopping on a binary star and for the more frequently available single star chopping a chop throw of 4” is recommended.

NEAR observations are performed in pupil stabilized imaging only. If one would like to offer VISIR in field stabilized observations and with a similar sensitivity as achieved with NEAR, one would have to apply DSM 10Hz chopping. Field stabilized observations with AO would also require the rotation of the AO control matrix for the DSM at the rate of the pupil rotation. While such a feature is nowadays quite regularly used, e.g., for NAOMI, it has not yet been commissioned for the AOF.

Dicke switch imaging shows residuals that need to be further improved with sky images taken after or during (nodding) the observation. Depending on the temporal stability of the residual pattern (appears to be very high), one very high SNR sky recorded e.g. once per night could be used. One must to use a sky image with a sufficiently high SNR to not dominate the final sensitivity.

7. Conclusions

The NEAR configuration of VISIR has been successfully commissioned to start the experiment on αCen using AO supported high contrast diffraction limited coronagraphic angular differential imaging. The acquisition and science observing templates are robust, user friendly, and ready for science operations offering chopping on single and binary stars. During the observing period the on-sky point-source sensitivity of filter B10.7 of 800 (μJy/10σ/1h), and for the NEAR filter N101 with bandwidth 10-12.5μm the sensitivity range between 570 – 880 at a median of 760 (μJy/10σ/1h). The excellent sensitivity increase, by more than a factor 3 when compared to VISIR as offered, is provided by the high frequency chopping (10Hz) offered by the deformable M2 (DSM) of UT4, the N band optimized new entrance window, and the superb Strehl ratio reaching 100-ε (%) in the MIR by the AO system (as compared to ~50% without AO). For the first-time a mid-infrared instrument has broken the 1000 μJy/10σ/1h sensitivity-barrier.

The instrument is now and 16 years after first-light reaching a sensitivity which is close to the theoretical limit of background-noise limited performance (BLIP) despite the shortcomings of the Aquarius detector with its spurious electrical ghosts and the compromising extra low frequency noise component (ELFN). The imaging performances are reached in chopping-only observations. Still some residuals of electronic ghosts are visible in the final image and often cannot be further reduced even when applying nodding. Observing in chopping-only mode is of great advantage as it reduces overheads and extra subtraction of noisy sky images.

In the NEAR campaign observing mode the sensitivity has been estimated to be around 850 μJy [5σ/1h], because only the half cycle with the star on the coronagraph can be used. This sensitivity should allow us to come within reach of our goal of 80 μJy [5σ/100h] for the observations of alpha Cen, assuming that noise scales with observing time as expected.

Despite sensitivity, NEAR also has to achieve a high imaging contrast. As NEAR is aiming for an imaging contrast of 10^{-6} at 1” separation (~3 λ/D at 11μm), and angular differential imaging (ADI) techniques typically provide a contrast improvement of factors 50-100, the raw PSF contrast before ADI should be of the order 1-2 x 10^{-5}. This raw PSF contrast is achieved by AO in combination with vortex coronagraphy and we reached a contrast slightly better than 2 x 10^{-5} at a separation of 1” from the star. NEAR provides a deeper raw PSF contrast than SPHERE at a similar angular separation, and benefits in addition from the much more favourable planet to star contrast for room temperature planets in the thermal IR.

The VISIR upgrade included mounting a Dicke switch for internal chopping. This is the first time such a devise is implemented in a MIR imaging instrument. Standard chop-nodd observations introduce unavoidable self-subtraction of the signal when applied on large crowded fields such as star forming regions. The Dicke switch technique avoids such systematic errors. We demonstrated the benefit of internal Dicke switch chopping by observing Jupiter for a solar system application. Despite spending 50% of the time looking into the blackbody, 10Hz Dicke-chopping with NEAR and AO provides a sensitivity of about 1.9 mJy/10σ/1h, which a factor 1.5 better than the original VISIR. In Dicke switch imaging significant residuals are visible that need to be correction by performing off source measurements in a kind of nodding sequence where sky images are taken at a sufficiently high SNR in order not to limit the sensitivity.

Finally, NEAR is also a path finder for the ELT instrument METIS. It enables on-sky verification on how to achieve best Strehl and high contrast vortex coronagraphic performances, which requires special techniques (QACITS) for precise centring the star on the coronagraph. It enables verification of various background subtraction strategies such as the use of internal chopping with a Dicke switch, or the use of chopping-only observations in combination with angular differential imaging. On-sky testing with NEAR has provided valuable experience regarding vortex coronagraphy, where features have been detected that are hidden in the laboratory.

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