Science Verification for the VISIR Upgrade

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The Very Large Telescope spectrometer and imager for the mid-infrared (VISIR) was upgraded in 2015 with new detectors and several new modes were added. Science Verification (SV) is carried out for new ESO instruments as well as for substantial upgrades to existing instruments. Sparse aperture masking and coronagraphy in the mid infrared have now been added to VISIR's capabilities and during SV these new observational modes, together with the recommissioned burst mode, were used to demonstrate the observational capabilities of the instrument. The SV process for VISIR is briefly described and some results from the successful observations are presented. All SV data are publicly available.

The VISIR upgrade project (Käufl et al., 2015) replaced the *N*-band low-resolution grating by a prism, the old detectors by new AQUARIUS (1024 × 1024 pixel) detectors, and added to the high spatial resolution capabilities by deploying coronagraphic and sparse aperture masking modes. In addition, support is now provided for monitoring of the precipitable water vapour integrated column through the atmosphere to enable the best mid-infrared observing conditions to be selected. The VISIR burst mode, which enables very high time resolution sampling, was recommissioned shortly before the Science Verification run.

Proposal solicitation and submission

The call for VISIR upgrade Science Verification proposals was issued[1] on 15 November 2015 and advertised through the ESO Science Newsletter[2] on 18 November. Thirty-five proposals had been received by the deadline on 15 December 2015. The VISIR upgrade SV team evaluated all the proposals. Two SV proposals that requested the same targets and observing modes as Period 97 programmes were rejected. A few other programmes requesting instrument modes that were not part of the upgrade were also rejected. The cut-off line was defined at 44 hours of allocated time, which meant that 22 programmes could receive an allocation. All PIs were informed of the outcome of the selection on 27 January 2016 and the Phase 2 material was submitted by all successful PIs by 12 February 2016.

A wide range of science topics were allocated time. They included the imaging of Solar System objects (including the companions of asteroids), exoplanetary systems, protoplanetary and debris discs around young stars, the environments of evolved stars and nearby active galactic nuclei (AGN).

Observations

The VISIR upgrade Science Verification took place on VLT Unit Telescope 3 in February and March 2016. Originally, the nights from 23 to 27 February 2016 were scheduled, but as these SV nights were very strongly affected by adverse atmospheric conditions, three half nights from 19 to 21 March were added. The 22 observing programmes selected required a total of 43.6 hours of telescope time. Of these programmes, 12 were fully completed and another six received partial data. Only four programmes could not be observed at all. The instrument worked without major fault and no substantial loss for technical reasons was recorded.

The conditions during the first run of SV nights were extremely poor. Out of the four nights 1.5 nights were lost to bad weather with the telescopes closed. The remaining time suffered from high humidity in the atmosphere above Paranal. During the 2.7 nights when the telescope was open, the precipitable water vapour, as measured by the dedicated LHATPRO

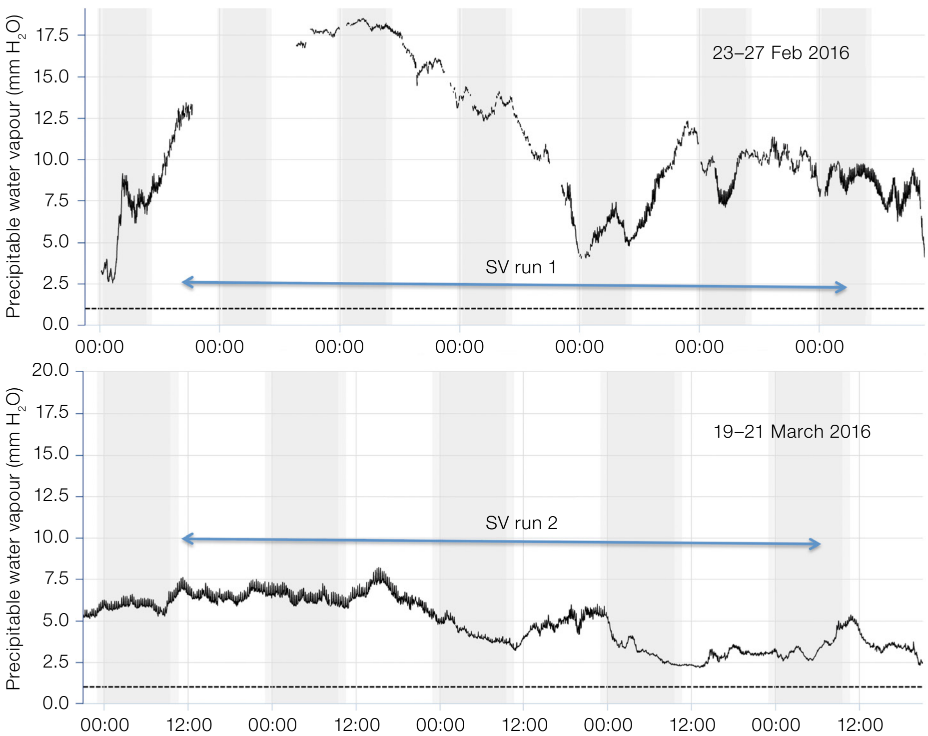

Figure 1. The precipitable water vapour record from the LHATPRO radiometer over the two runs of VISIR SV in February and March 2016.

radiometer installed on Paranal as part of the VISIR upgrade project (Kerber et al., 2015) never dropped below 4 mm, with an average around 10 mm. Figure 1 (upper panel) shows the log of the precipitable water vapour measurements spanning the time of the SV observations. For comparison, median precipitable water vapour conditions on Paranal are around 2.4 mm (Kerber et al., 2014). Technically, most of the SV run was unsuitable for mid-infrared observations.

Given this unsuccessful run, ESO allocated another three half nights between 19 and 21 March 2016 to recover some of the SV observations. This second run was much more successful (see Figure 1, lower panel) and yielded data for a majority of the SV programmes. These data are of excellent quality and in almost all cases we were able to obtain unique high-contrast observations. All new VISIR modes were used during SV and worked as expected. A few minor technical problems were uncovered, which were remedied for regular operations, starting with Period 97 (1 April–30 September 2016).

Archive and data processing

All raw data have been archived and are publicly available. The automatic data processing and transfer worked well, considering the high data rates produced by the new modes of VISIR, especially the burst mode, which yields up to 200 GB/hour worth of data.

The VISIR upgrade SV web page[3] contains direct links to the raw data. A new version of the VISIR data reduction pipeline was released and now supports basic reduction for all the new modes tested during SV, except for sparse aperture masking. The pipeline can be accessed through the SV upgrade web page[3] or via the VLT pipelines page[4].

A few first results

VISIR observations of Jupiter were obtained in burst mode. Figure 2 shows the southern hemisphere of Jupiter in the *M*-band (4.8 μm). This is the first *M*-band image of Jupiter's springtime hemisphere from an 8-metre-class telescope, allowing us to probe deeper into Jupiter's atmosphere than was possible with any other instrument. The VISIR images will also be used by the proposing team to select regions of interest for closer scrutiny by the *Juno* mission once it arrives at Jupiter in late 2016.

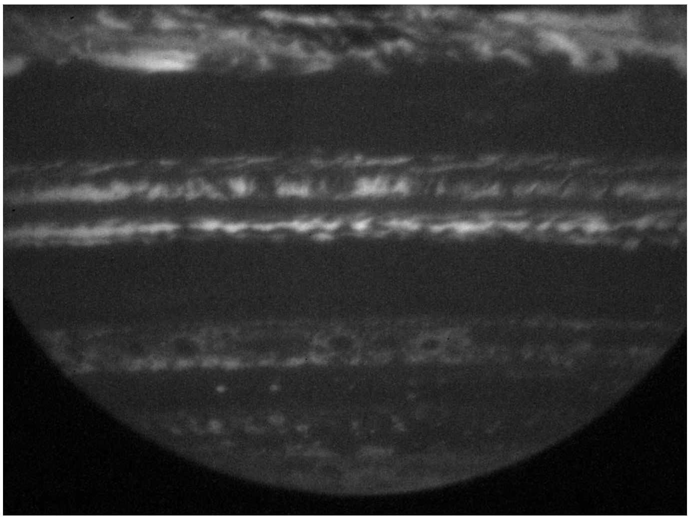

Figure 2. The southern hemisphere of Jupiter imaged with VISIR in the *M*-band utilising burst mode.

The sparse aperture masking mode was used to image the massive young stellar object NGC 3603 IRS9A, complementing VLT NAOS–CONICA sparse aperture masking data in the *Ks*- and *L*-bands (Sanchez-Bermudez et al., 2016).

Figure 3 shows the interferograms at 10.5 μm of NGC 3603 IRS9A (left upper) and the calibrator star HD 96918 (left lower). The fuzzier appearance of NGC 3603 IRS9A with respect to the calibrator star demonstrates that the science target is clearly resolved at the baselines corresponding to the sub-apertures of the sparse aperture mask. The right panels show the spatial Fourier transform of the interferogram which can, in a second processing step, be converted to visibility. In comparison to the calibrator, the disappearance of visibility at the highest

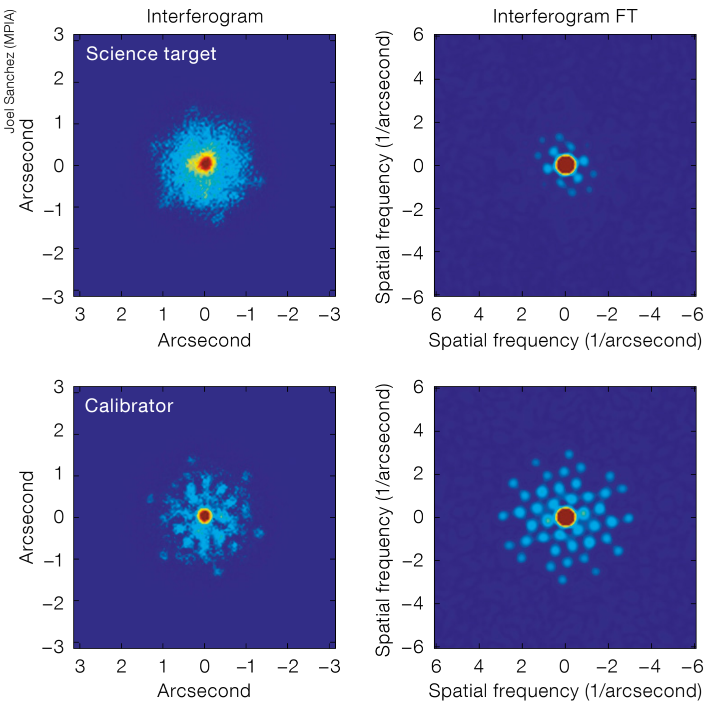

Figure 3. Interferograms at 10.5 μm from VISIR sparse aperture masking of NGC 3603 IRS9A (left upper) and the calibrator star HD 96918 (left lower). The right-hand panels show the Fourier transform (FT) of the interferograms of both target (upper) and calibrator (lower), where the asymmetry of the envelope of NGC 3603 IRS9A is apparent.

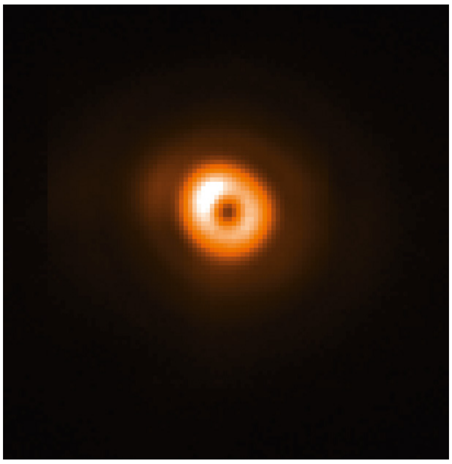

Figure 4. The mid-infrared extended dust emission around the Wolf–Rayet star WR104 is revealed by the VISIR coronagraphic annular groove mask.

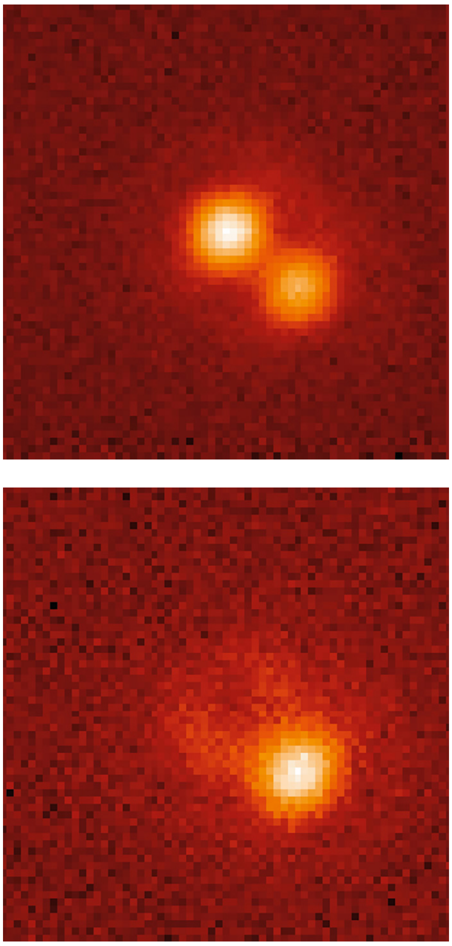

Figure 5. Demonstration of the AGPM coronagraph on the visual binary star η Oph (HR 6378) with the broad 12.4 μm filter. The upper image shows the binary without the annular groove phase mask, and the lower image with the coronagraph occulting the left-hand star.

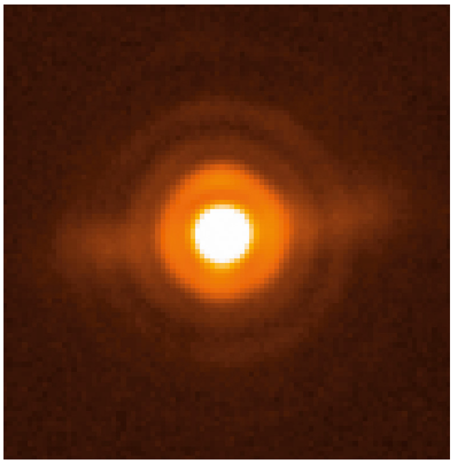

Figure 6. VISIR burst mode image of the close vicinity of the Circinus AGN taken with the PAH2_2 narrow filter.

spatial frequency is a measure of the spatial extent of the object. The goal of the observations is to constrain the position angle of the presumed bipolar cavities and the morphology of the outer envelope surrounding the central source. A preliminary analysis shows that the target has an angular size of at least ~ 450 milliarcseconds, which is consistent with the size of the 11.7 μm envelope reported by Vehoff et al. (2010) and by Sanchez-Bermudez et al. (2016) at lower wavelengths. With an angular resolution of $\lambda/2D$, where D is the maximum diameter of the sparse aperture mask, and a robust calibration in the closure phases, the new sparse aperture masking mode of VISIR is the only technique that enables the different contributions to the NGC 3603 IRS9A morphology at the half-arcsecond angular scale to be disentangled in the mid infrared.

The Wolf–Rayet star WR104 is carbon-rich and classified as a late WC-type. It shows an inner structure indicative of a binary system and an infrared excess presumably arising from warm and hot dust components. WR104 was observed at 12.4 μm with the new annular groove phase mask coronagraph to detect the extended dust surrounding the central star. Figure 4 shows the outer structure with the central star light blocked behind the coronagraphic mask. An attenuation of the light of the central star by a factor of 42 is achieved by the coronagraph.

A further example of an observation with the coronagraphic annular groove mask is shown in Figure 5. This observation shows the binary star η Oph (HR 6378) with and without the mask inserted. In the right image with the mask inserted, the cancellation of the star beneath the mask is excellent. These observations were taken during commissioning of the annular groove phase mask in January 2016.

Circinus is one of the nearest galaxies to the Milky Way with an active nucleus. It is hidden behind the Galactic Plane and oriented almost edge-on, so that its nucleus can be observed best in the infrared. The goal of the VISIR burst mode observations was to investigate a possible emission of dust outside the AGN torus and situated in the polar region, on scales of a few parsec from the centre. The image shown in Figure 6 was obtained using the PAH2_2 filter at ~ 12 μm. It is dominated by the bright central point-like source, which is responsible for the Airy rings, illustrating the superb image quality that VISIR reaches in burst mode. The unresolved emission comes from warm dust surrounding the AGN. Owing to the excellent image quality, an extended, bar-like structure becomes nicely visible. This emission traces dust along the edge of the ionisation cone on scales of tens of parsecs, well outside the expected AGN torus.

References

Käufl, H. U. et al. 2015, The Messenger, 159, 15
Kerber, F. et al. 2014, MNRAS, 439, 247
Kerber, F., Querel, R. R. & Neureiter, B. 2015, J. Phys., Conf. Ser., 595, 012017
Sanchez-Bermudez, J. et al. 2016, A&A, 588, A117
Vehoff, S. et al. 2010, A&A, 520, 78

Links

[1] Call for VISIR upgrade SV proposals: http://www.eso.org/sci/publications/announcements/sciann15081.html
[2] ESO Science Newsletter November 2015: http://www.eso.org/sci/publications/newsletter/nov2015.html
[3] VISIR upgrade SV page: http://www.eso.org/sci/activities/vltsv/visir-upgrade.html
[4] VLT instrument pipelines: http://www.eso.org/sci/software/pipelines/