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VIRCAM Operations End at VISTA

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The VISTA InfraRed CAMera (VIRCAM) at the Visible and Infrared Survey Telescope for Astronomy (VISTA) made its last observation on the night of 5/6 March 2023 after more than a decade of infrared surveys. Its place at VISTA's focal plane is soon to be taken by the 4-metre Multi-Object Spectroscopic Telescope (4MOST) working in the visible region. Here we look back and summarise the experience gained and the great legacy of VIRCAM.

Introduction

The Visible and Infrared Survey Telescope for Astronomy (VISTA) was conceived in the UK and in late 1998 a consortium of UK universities, led by Queen Mary University of London (PI: J. Emerson), successfully applied for funding from the UK's Joint Infrastructure Fund. The original proposal envisaged constructing VISTA, equipped with interchangeable infrared (IR) and visible-light cameras, near Gemini South at Cerro Pachón in Chile. It later became clear that Cerro Paranal, also in Chile, was a better option for the location of VISTA. ESO was originally prepared to host VISTA for the UK university consortium, in exchange for telescope time. As interactions with ESO progressed very well the consortium later agreed that VISTA could became an ESO telescope as part of the UK's in-kind contribution when the UK joined ESO in 2002. This played a key financial role in enabling the UK to realise its long-held wish to join ESO. As the VLT Survey Telescope (VST) was being built for ESO surveys in the visible wavelength regime it was decided to forego the visible camera on VISTA in favour of using funds to fill more of the field of view in the IR camera.

Building VIRCAM

VISTA was designed, at the UK's Astronomy Technology Centre at the Royal Observatory Edinburgh, not as a general purpose telescope, but rather was optimised to host a wide-field near-infrared camera, the VISTA InfraRed CAMera (VIRCAM), operating in the *J*, *H* and *Ks* filters. It turned out that the system response was also good at shorter wavelengths so *Z* and *Y* filters were later added, along with NB118 for the UltraVISTA

Figure 1. VIRCAM insertion into M1 of VISTA.

ultra-deep survey. VIRCAM was built at the Space Science division at the UK's Rutherford Appleton Laboratory (RAL) and arrived at Paranal on 28 January 2007. It is described by Dalton et al. (2010), and, more accessibly along with the telescope, by Emerson et al. (2004) (design) and by Sutherland et al. (2015) (as built).

Although almost everything else was ready to start system integration and testing, the polishing of VISTA's 4-metre primary mirror (M1), in Russia, took very much longer than advertised, mainly because it was the most curved large mirror that had ever been polished. It finally arrived in Paranal on 27 March 2008, during the making of the James Bond movie *A Quantum of Solace*. After the M1 had been coated and installed, the camera was mated to the telescope (Figure 1). The first infrared light for VIRCAM followed on 24 June 2008. Finally the UK team integrating, testing, and commissioning the whole VISTA system could begin its year-long task of dealing with the various issues, mostly mechanical, that arose during testing. Following reviews of the operation of all parts of the system, and closing off all the outstanding actions, the UK team's final task was to ensure that ESO had all the necessary information to successfully operate VISTA.

System verification was carried out by ESO in August–September 2009 and Science Verification between 15 October and 3 November 2009 (Arnaboldi et al., 2010). The first VIRCAM data in the ESO Science Archive are from Science Verification on the night of 15/16 October 2009.

Impact on ESO operations

VISTA's surveys required new observing concepts to be developed for the survey telescopes (Bierwirth et al., 2010). To define the pointings of tiles that create a contiguously surveyed area of the desired shape, and efficiently identify suitable stars for guiding and active optics corrections, the VISTA project developed the Survey Area Definition Tool. This tool was subsequently adapted to enable quick tiling of large areas with the OmegaCAM camera at the VST as well (Arnaboldi et al., 2008). To enable the generation of many hundreds of similar Observation Blocks (OBs) as well as implementing machine-readable observing strategies with concatenated, grouped or time-linked observations, new observation preparation and short-term scheduling tools were developed by ESO (Arnaboldi et al., 2008). These tools, originally implemented on VISTA, were subsequently ported to also support operations at ESO's Very Large Telescope (VLT) and the VLT Interferometer and were further developed, adding programmatic interfaces and new services (Beccari et al., 2022).

Many changes in the day and night operations were implemented to allow on-site operations with only one telescope instrument operator shared between VISTA and the VST. Telescope presets for short observations, such as for the VVV (VISTA Variables in the Via Lactea) survey, which requires six presets in less than five minutes, were then executed automatically. The connection of the scheduler to the atmospheric site monitor enabled further streamlining of survey operations. To do that the scheduler automatically reads ambient conditions and filters executable observations for the current conditions, ranking the OBs such that the most difficult observations that fulfill all the constraints are scheduled first. The top-ranked OB gets automatically pulled and its acquisition starts as soon as the previous OB is executed. On-the-fly automatic analysis of the resulting data allows the telescope instrument operator to assess whether the conditions requested by the PI were met.

VIRCAM created very little work on daytime operations, requiring only a minimum of additional calibrations. The only necessary data taken were some dome flats and a linearity test once a week. Named 'barbecue flats' since they were taken parallel to the weekly barbecue on Sundays, they became a tradition and fixed point in the weekly schedule on Paranal.

VISTA's large data volumes were a strong driver for the installation of a fast fibre data link to Paranal through the EU-funded EVALSO programme. This enabled VISTA's raw data to be shipped to Garching each night over the internet instead of being shipped on hard disks (Comerón et al., 2012).

Observations

VISTA was designed to enable high survey speed in the near-IR and most of its time was dedicated to large-scale public surveys. The Public Survey Panel (PSP), composed of experts from the community, recommended an initial set of six such surveys to the Observing Programmes Committee (OPC), which were then scheduled by ESO for execution: VVV, a multi-purpose, multi-epoch survey of the inner Milky Way; VMC (VISTA near-IR YJKs survey of the Magellanic Clouds system); VHS (the VISTA Hemisphere Survey); VIKING (the VISTA Kilo-degree INfrared Galaxy survey); VIDEO (VISTA Deep Extragalactic Observations); and UltraVISTA, an ultra-deep survey with VISTA. See Arnaboldi et al. (2007) for a brief description.

'Dry run' observations of these public surveys started on 4 November 2009; the survey teams were told that in the first months ESO would be further optimising the instrument and telescope (hence 'dry run'), training staff and implementing operations processes and tools to make efficient survey operations. Nevertheless, it was expected that the time would be used to start advancing the survey observations.

The first night VISTA was operated after being "provisionally accepted by ESO and handed over by STFC to ESO on December 10" was 11 December 2009. The official start of public survey operations was in P85 (April 2010), but effectively several hundreds of hours (per survey) had been observed before then. P85 was the first time VISTA was also offered to the community for shorter 'normal' programmes. Over the years these amounted to around 9% of VISTA time.

In 2015, as the initial set of six public surveys approached its sixth year of operations and some surveys were approaching completion, ESO issued a call for Letters of Intent for the second cycle of public surveys with VIRCAM@VISTA. Following a competitive process with Letters of Intent and then review of proposals by the PSP, the OPC recommended extending VVV (as VVVx) and UltraVISTA and adding five new surveys, as described by Arnaboldi et al. (2017).

The second set of surveys included: GCAV (Galaxy Clusters at VIRCAM), VEILS (VISTA Extragalactic Infrared Legacy Survey), SHARKS (Southern H-ATLAS Regions *K*s-band survey), VISIONS (VISTA Star Formation Atlas), and VINROUGE (VISTA Near infrared Observations Unveiling Gravitational wave Events).

The sky coverage, in any filter, of each survey is shown in Figure 2 which, unsurprisingly, shows that VHS has the greatest coverage by area in both *J* and *Ks*. Other surveys have targeted smaller areas to greater depth and sometimes in more filters, with the UltraVISTA survey going deepest on the smallest area of just one fully covered field of view of VIRCAM.

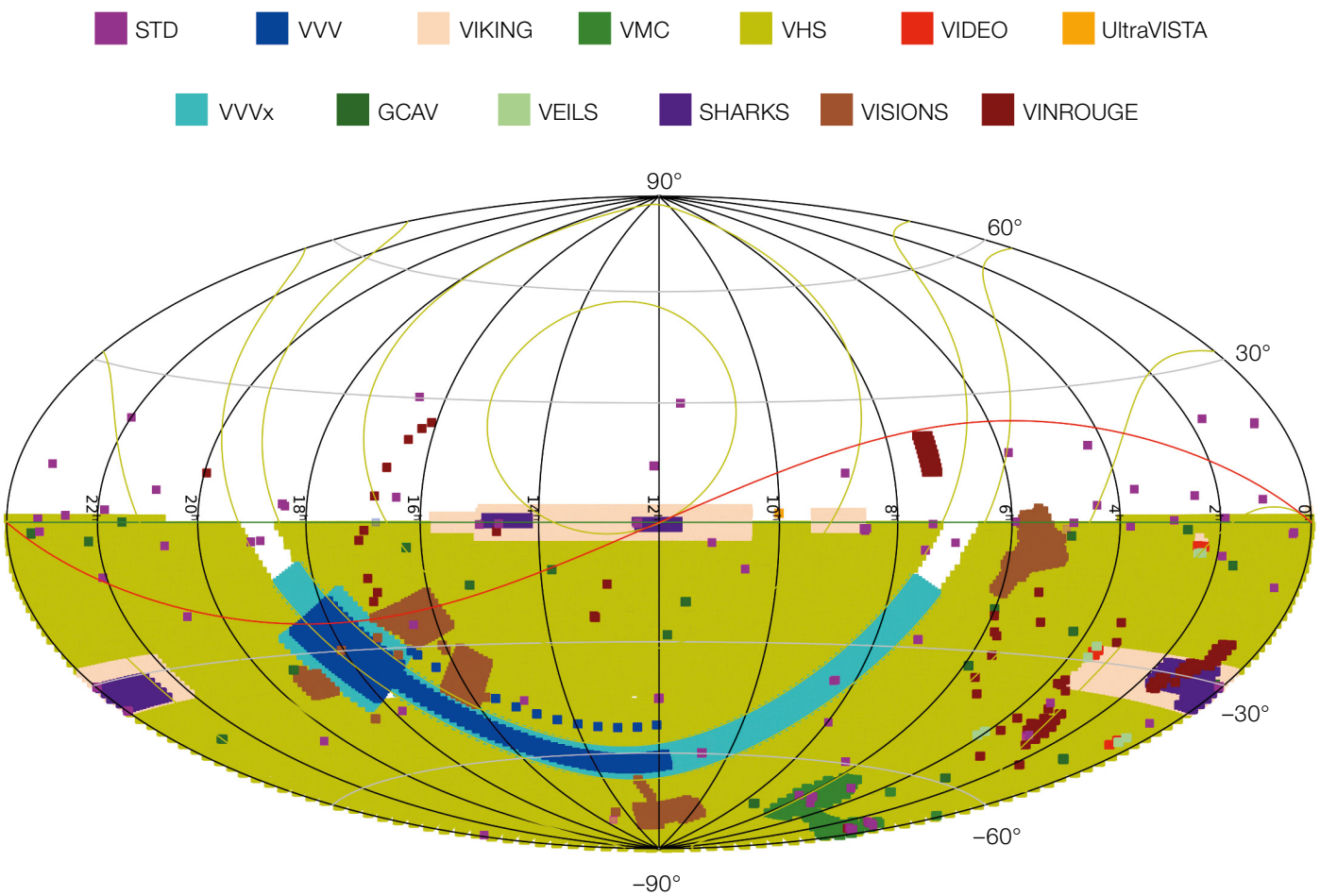
By the end of VIRCAM operations in March 2023 all public survey observations had been completed.

Data products

VIRCAM was always intended to produce large-scale surveys with continuing archival value. Whilst the *JHK*s 2MASS survey has a much more uniform three-band sky coverage to its (shallower) survey depth, VIRCAM surveys at VISTA go much deeper and have higher image quality. Therefore, for many purposes users may find much more useful data in the VIRCAM archives.

All VIRCAM raw data are in the ESO archive and were also automatically transferred to the Cambridge Astronomical Survey Unit (CASU). At CASU a pipeline reduced and calibrated all VIRCAM data, both for public surveys and any other observations, using all the knowledge gained from processing all data produced by the instrument. This pipeline was developed by CASU's Jim Lewis who also delivered and maintained a version based on ESO's Common Pipeline Library for ESO's VIRCAM Quality Control and health monitoring process. The calibration method is described by González-Fernández et al. (2018). The reduced calibrated data were routinely

Figure 2. VIRCAM public surveys coverage (any filter) in Aitoff projection. For a breakdown of coverage by filter, or for a different projection, see CASU's survey progress page[1] or the ESO Science Archive[3].



Observing dates: 20091015–20230305
Cambridge Astronomy Survey Unit

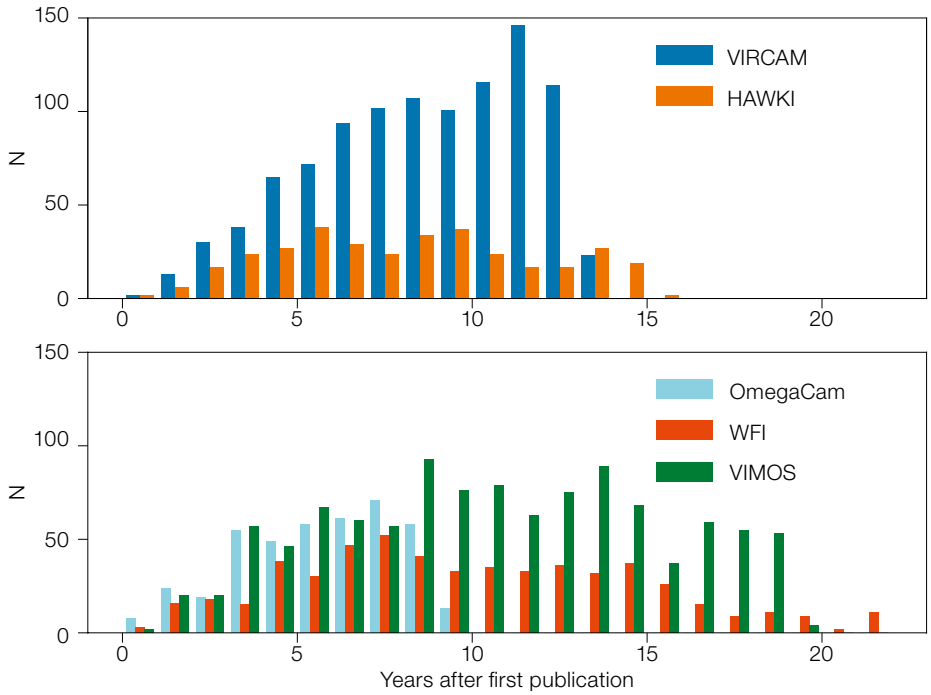


Figure 3. VIRCAM's publication history compared with another ESO IR imager (upper) and some visible wide-field cameras (lower).

uploaded to the VISTA Science Archive (VSA)[2] at the Wide Field Astronomy Unit at the Royal Observatory Edinburgh where it is archived. The VSA worked with five of the six first-generation VISTA surveys to help deliver their data products to ESO's Science Archive[3], and also to external archive sites like VizieR[4]. ESO's list of public VISTA survey data releases[5] is the route to finding reduced observations, and in some cases object catalogues, to download. UltraVISTA and some of the second-generation public surveys have done their own data processing.

The final images and catalogues for the public surveys can be downloaded by users from the ESO archives and the VISTA science archive.

Although all the VIRCAM public surveys have finished taking data, several of the teams are continuing to work on the data releases. Thus, although raw data are publicly available immediately, more and more data products, including higher-level catalogues are becoming available in the ESO archive.

Subject to resource availability, calibrated images and catalogues may be provided for individual VISTA pawprints and tiles not included in the public survey releases, on request to casuhelp@ast.cam.ac.uk or vsa-support@roe.ac.uk

Publications

At the time of writing there are 1029 refereed publications using VISTA data in the ESO Telescope Bibliography system[6] Most come from the original six public surveys with two having over 250 publications each (VVV 316, UltraVISTA 266). Figure 3 shows that the annual number of publications (N) from VIRCAM compares well with those from related ESO imaging instruments. The most cited VIRCAM paper, with nearly 800 citations, is by Minniti et al. (2010), describing the VVV survey.

The future

ESO is organising a workshop entitled A Decade of ESO Wide-field Imaging Surveys[7] from 16 to 20 October 2023 with invited talks covering all VISTA (and VST) public surveys, which will further explore the legacy of VIRCAM.

VIRCAM is soon to be replaced by the 4-metre Multi-Object Spectroscopic Telescope (4MOST; de Jong et al., 2019). For now, VIRCAM is kept as a backup instrument for VISTA, but once 4MOST is in full operation, it is hoped that VIRCAM will become its own legacy and will be put on display for visitors to Paranal, showcasing and highlighting large-scale surveys, which form an important part of astronomy research these days and are often forgotten about at a time when many telescopes concentrate on more detailed views of galaxies/objects, with small fields of view.

VIRCAM has been a great success and the legacy of its infrared imaging data will continue to be mined for many years. 4MOST will finally deliver the V in VISTA's name and is shaping up to make a big impact (see articles in The Messenger 175 and 190).

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Links

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[2] VISTA Science Archive: http://vsa.roe.ac.uk
[3] ESO Science Archive: http://archive.eso.org/scienceportal/home
[4] VizieR archive: https://cdsarc.u-strasbg.fr/
[5] Overview of Phase 3 data Releases: www.eso.org/rm/publicAccess#/dataReleases
[6] ESO Telescope Bibliography: https://telbib.eso.org
[7] A Decade of ESO Wide-field Imaging Surveys workshop: https://www.eso.org/sci/meetings/2023/surveys.html