Ten Challenges of Producing an Astronomical Gigapixel Image

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Summary

Public outreach involves developing new methods, testing new technologies and integrating new ideas. Sometimes, the craft of outreach even leads into completely unknown territory. This is the story of a project that led into astronomical and technological *terra incognita*. It is about the production of a mosaic of the central parts of the Milky Way made with ESO's VISTA telescope as part of the VVV survey. The outreach system at ESO was tested to its limits, and beyond, by the production of what is still likely to be the largest astronomical image in the world. Several significant challenges had to be overcome, extensive hardware and software upgrades were undertaken and compromises had to be made to produce this stunning image for the public.

VISTA and the VVV survey

VISTA — the Visible and Infrared Survey Telescope for Astronomy — is part of ESO's Paranal Observatory and is the largest survey telescope in existence. It is also the most powerful near-infrared survey telescope ever built. The telescope has a 4.1-metre primary mirror and is dedicated to conducting wide-angle surveys of the skies with its 67-megapixel digital camera.

VISTA's observing time is entirely devoted to mapping the sky systematically and six huge public surveys will take up the majority of the telescope's first years of operation. One of these surveys is the VVV — or VISTA Variables in the *Vía Láctea* — survey, which started in 2010 and was granted a total of 1929 hours of observing time over a five-year period. The survey is scanning the southern plane and bulge of our galaxy — 520 square degrees in total — in five near-infrared filters.

When the survey is completed in 2016, the outcome will be a catalogue with around one billion point sources, including about a million variable objects. This will be used to create a three-dimensional map of the bulge of our galaxy, the Milky Way, to calculate the ages of stellar populations and study the evolution of globular clusters.

In addition to its scientific purpose, VISTA's superb image quality and the wide field of view make the telescope an excellent source of stunning images to be used for public outreach. As of March 2015 ESO has published 17 press releases based on results delivered by VISTA, seven of which were directly related to the VVV survey.

The final image

The image which tested the limits of ESO's system, and its team members, covers about 315 square degrees (20.4 × 15.4 degrees) and shows the centre of the Milky Way. The observations were carried out using three different near-infrared (*JHK*) filters and the resulting image is monumental. It is 9 gigapixels in size, measuring 108 199 by 81 503 pixels[1]. The image is so large that, if printed with the resolution of a typical book, it would be nine metres across and seven metres tall. This makes it likely the largest astronomical image in the world.

The gigantic dataset contains about 173 million objects, out of which about 84 million have been confirmed as stars, which is ten times as many stars as in any previous study. It is a major step forward in our understanding of our home galaxy.

Ten problems to solve

Work on the image began in 2012 with the preparation of a science release[2] based on a paper by Saito et al. (2012). The ESO public outreach team quickly realised that the huge mosaic of the central Milky Way could be the main focus of a release. When the work on the image began the team was confronted with ten major problems which had to be solved.

Problem 1: Getting the astronomical data

Simply moving the raw data from place to place turned out to be a great challenge. Early on it was decided — on an exceptional basis and only because of the sheer amount of data — that the data had to be down-sampled by a factor of almost two. Ordinarily ESO always releases images pixel by pixel as they are observed, to make sure that the images the end-user receives are optimal. With the support of ESO's helpdesk the available storage on the ESO FTP server was extended and the vast quantities of data — 166 gigabytes of FITS[3] files — could be moved back and forth between science team member Ignacio Toledo (Atacama Large Millimeter/submillimeter Array [ALMA]) and ESO over several iterations.

Problem 2: Distortions over the large field

The next problem occurred during the astronomical data processing. Due to the large field of view, the image happened to have significant projection and distortion effects. Most of these problems were

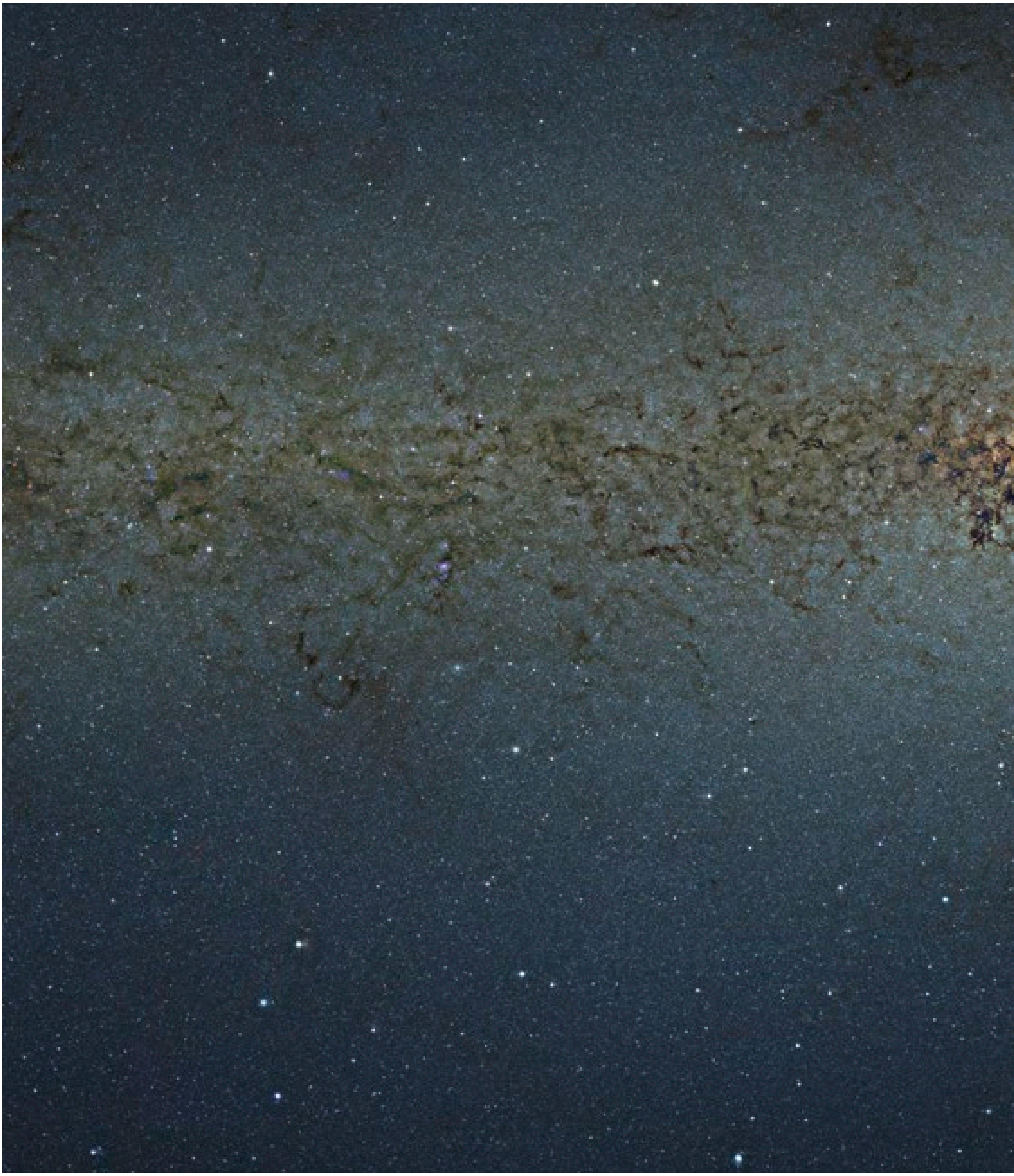
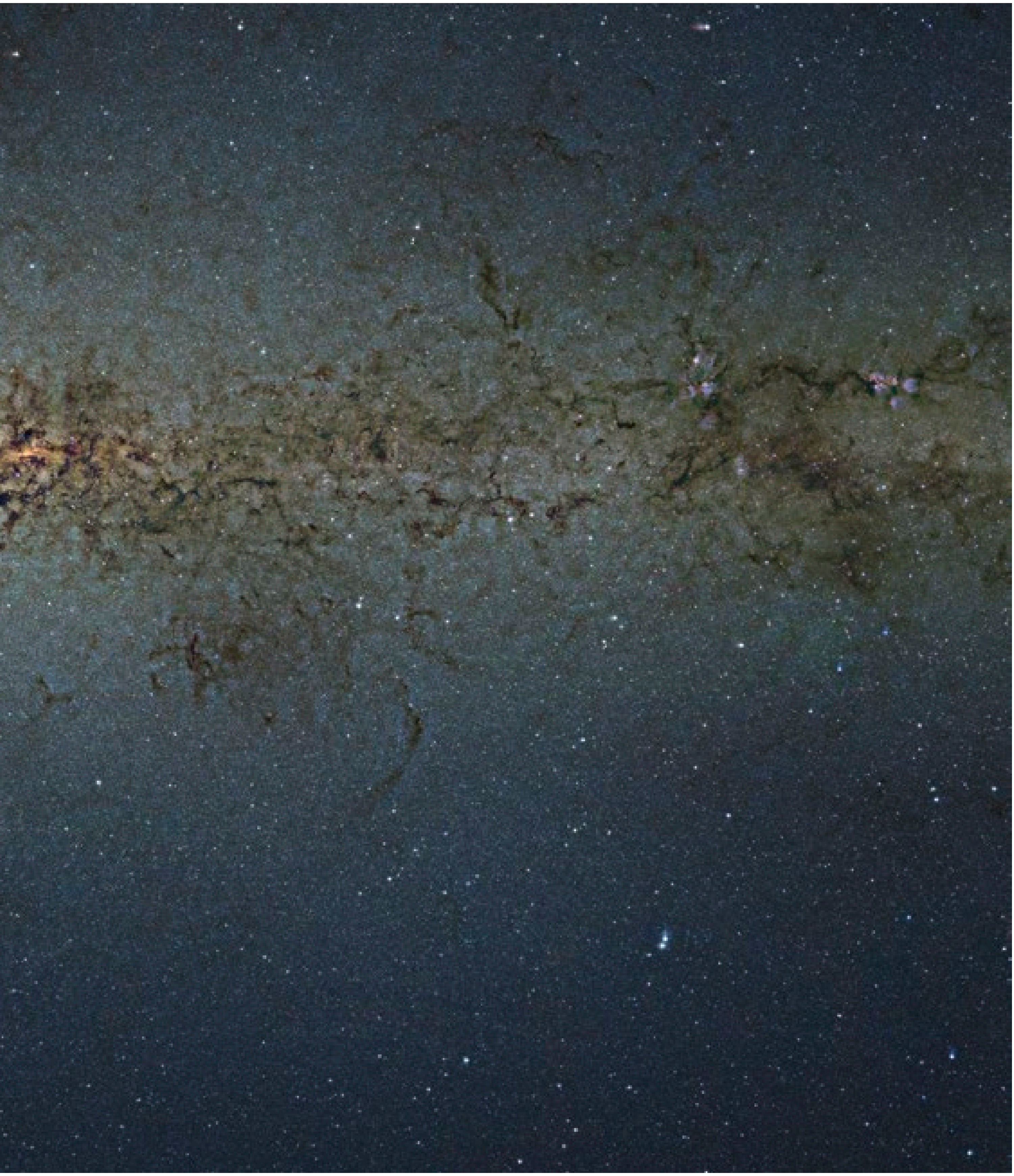


Figure 1. *This striking view of the central part of the Milky Way was obtained with the VISTA survey telescope at ESO's Paranal Observatory in Chile. This huge picture is 108 200 by 81 500 pixels and contains nearly nine billion pixels. It was created by combining thousands of individual images from VISTA. Credit: ESO/VVV Survey/D. Minniti*



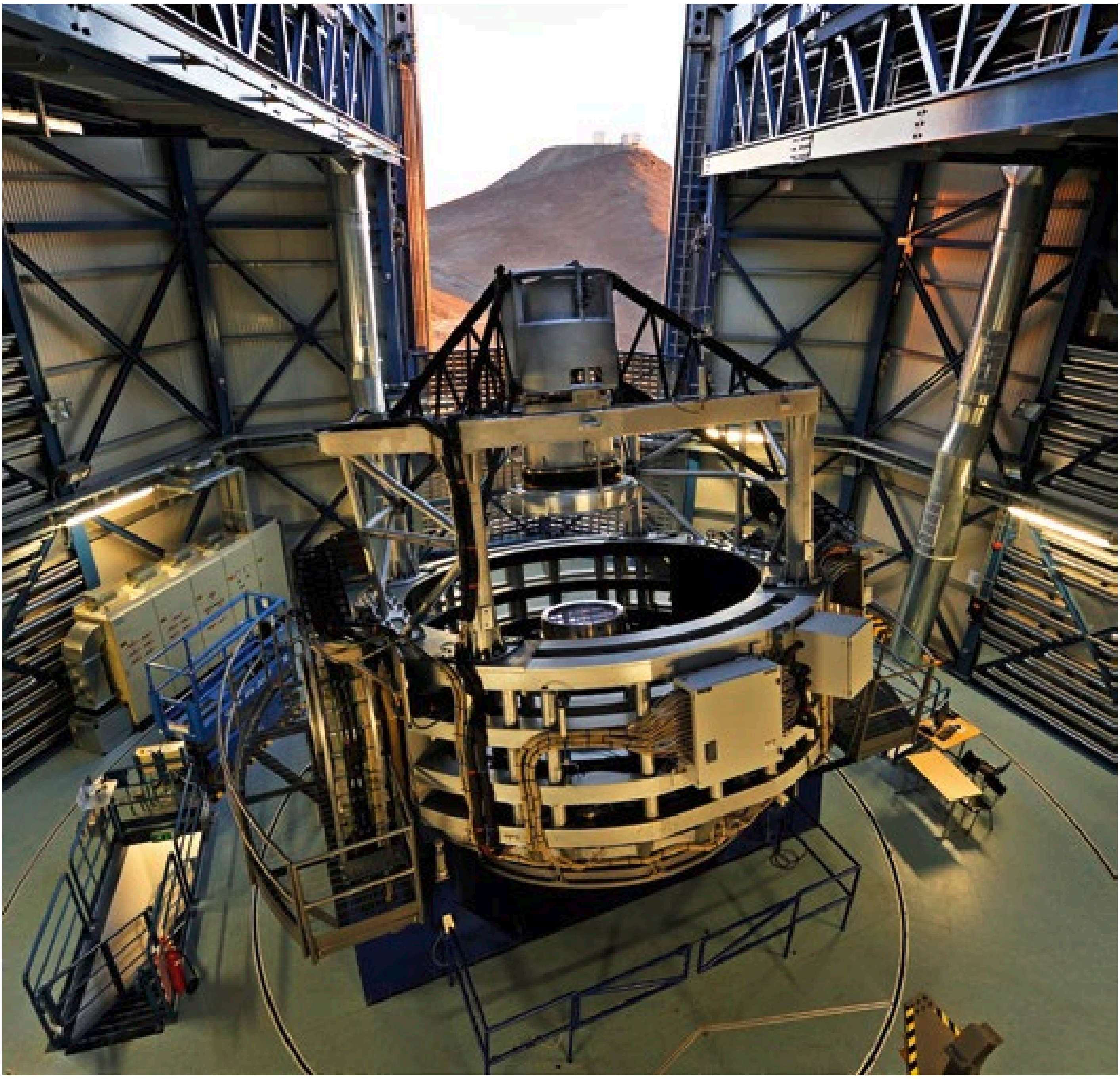


Figure 2. *VISTA is the largest telescope in the world dedicated to surveying the sky. Its primary mirror is 4.1 metres in diameter and it has a huge camera that is sensitive to near-infrared wavelengths. Credit: ESO*

corrected by Ignacio Toledo. However, a much smaller residual misalignment of only a few pixels between the three different exposures (*JHK* filters) had to be corrected manually in Photoshop later on.

Problem 3: Dynamic range compression

The normal dynamic range compression, which converts files from FITS format to tiff format, failed as the ESO/ESA/NASA FITS Liberator programme[4] was unable, at the time, to create tiff files above 2 gigabytes. Since the dynamic range in the dataset was not extremely large, the team reverted to using a less interactive method, using the software STIFF[5] which can create BigTIFF[6] files of almost unlimited size. Meanwhile, the FITS Liberator programme has now been updated to write BigTIFF files as well.

Problem 4: Reading BigTIFF

Not only did the available version of the FITS Liberator prove to be inadequate, but Photoshop 5, which was used by ESO at the time, also fell short as it could not read BigTIFF files properly. Thankfully, and as a matter of pure luck, Photoshop 6 was released only a few weeks before the start of the project and this version was able to read BigTIFF files. With the new

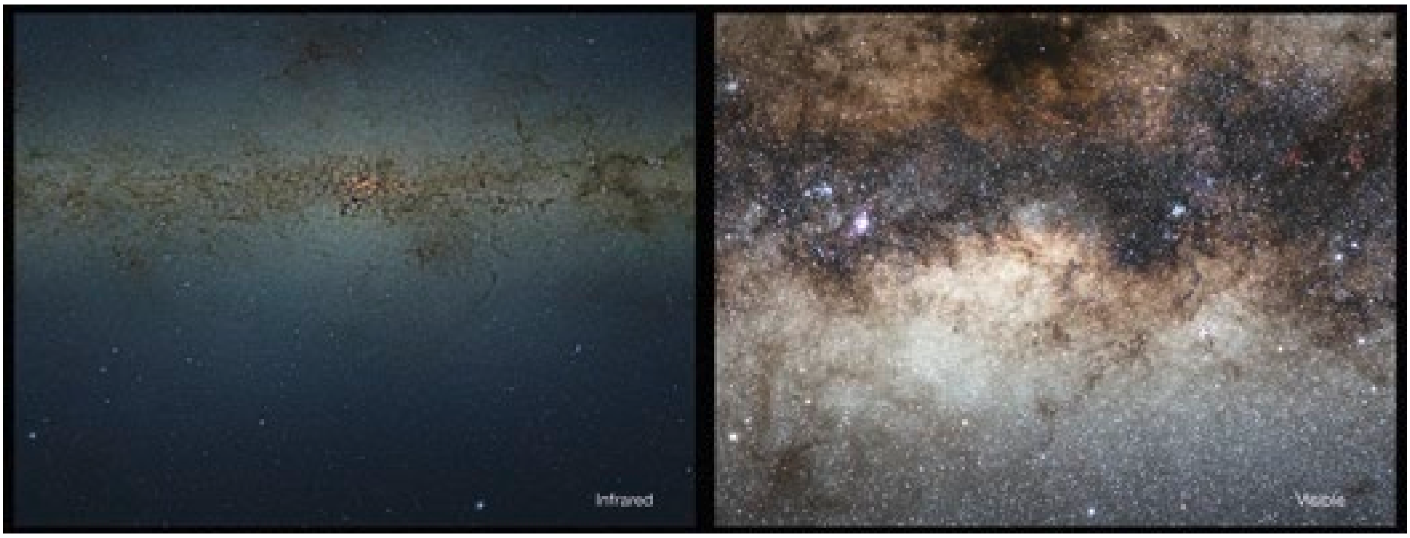


Figure 3. *This view compares the huge mosaic in infrared light from the VISTA survey telescope and a visible-light mosaic view of the same region taken with a small telescope. Credit: ESO/VVV Survey/D. Minniti/Serge Brunier. Acknowledgement: Ignacio Toledo, Martin Kornmesser*

software installed, the images could finally be opened in Photoshop; and due to their size had to be reduced to eight-bit colour depth immediately — normally astronomical images have 16-bit colour depth and hence have twice the size. This is something which is otherwise only done at the last stage in the production of an astronomical colour composite.

Problem 5: Swapping 600 gigabytes

As soon as the team started to work on the image in Photoshop the next challenge emerged. Working on three 9-gigapixel *JHK* layers with corresponding adjustment layers in Photoshop used unforeseen amounts of memory — up to 600 gigabytes of memory/swap space. To perform the swapping a state-of-the-art solid-state disk (SSD) was quickly procured to give a workable solution by providing a pseudo-memory delivering up to 1000 megabits per second in real throughput.

Problem 6: Graphics card

Even with the SSD onscreen interaction with the image for the clean-up in Photoshop, the image was impossible to handle. Besides the new SSD, a modern graphics card was added to the system to provide the necessary speed and onboard memory for the onscreen navigation in Photoshop.

Problem 7: Cosmetic cleaning

The next step was a cosmetic cleaning stage to remove instrumental artefacts and other blemishes of a non-cosmic origin. ESO normally uses an outsourcing company, but in this case the transport of the individual layers was impractical and the clean itself would have been too costly as it is paid for per megapixel. Therefore it was decided to perform a more modest, but sufficient, in-house cleaning. This led to some interesting feedback from the public later on, which will be discussed in the lessons learned.

Problem 8: Distribution file format

It was clear that the final image should be accessible to as many people as possible, so the team had to look for the most appropriate and viewable final file format. Unfortunately Photoshop 6 does not write BigTIFF, so an alternative format was needed. In the end only Photoshop's proprietary PSB format proved itself suitable for formats above 65 000 pixels. Since this is a much less used format than formats like TIFF, this was naturally a compromise. The final PSB file was 24.6 gigabytes in size; but smaller intermediate size formats of 40[7], 25[8] and 10[9] thousand pixels were also created and made available in TIFF format for download.

Problem 9: Zoomable version

Assuming that very few users would be able to actually handle the full 9-gigapixel image, ESO wanted to offer a zoomable image[10] as the main vehicle for delivering the experience to the public. However Zoomify[11], the usual tool for creating zoomable products at ESO, did not work with PSB files. The tools Krpano[12] and Panotour Pro from Kolor[13] were finally used and proved themselves to be very good alternatives.

Problem 10: Web serving

The final challenge that the team had to face was to actually serve the large individual files and the panorama to the public. The news of the image spread like wildfire. The image is the most successful ESO release to date with many more than one million visitors to the press release on the ESO page alone. At the time of publication this success nearly melted the servers at ESO Headquarters during the peak load — they were sluggish for days and at times the available slots for download were all filled, which undoubtedly left some visitors disappointed. Therefore the large 24.6 GB PSB file first had to be moved to another server and finally to peer-to-peer distribution in Bittorrent as it took up too many slots for too long. After a couple of weeks the normal distribution system was reinstated, but the image is still downloaded many times per day. Since the release the ESO server system has been upgraded to a more resilient system.

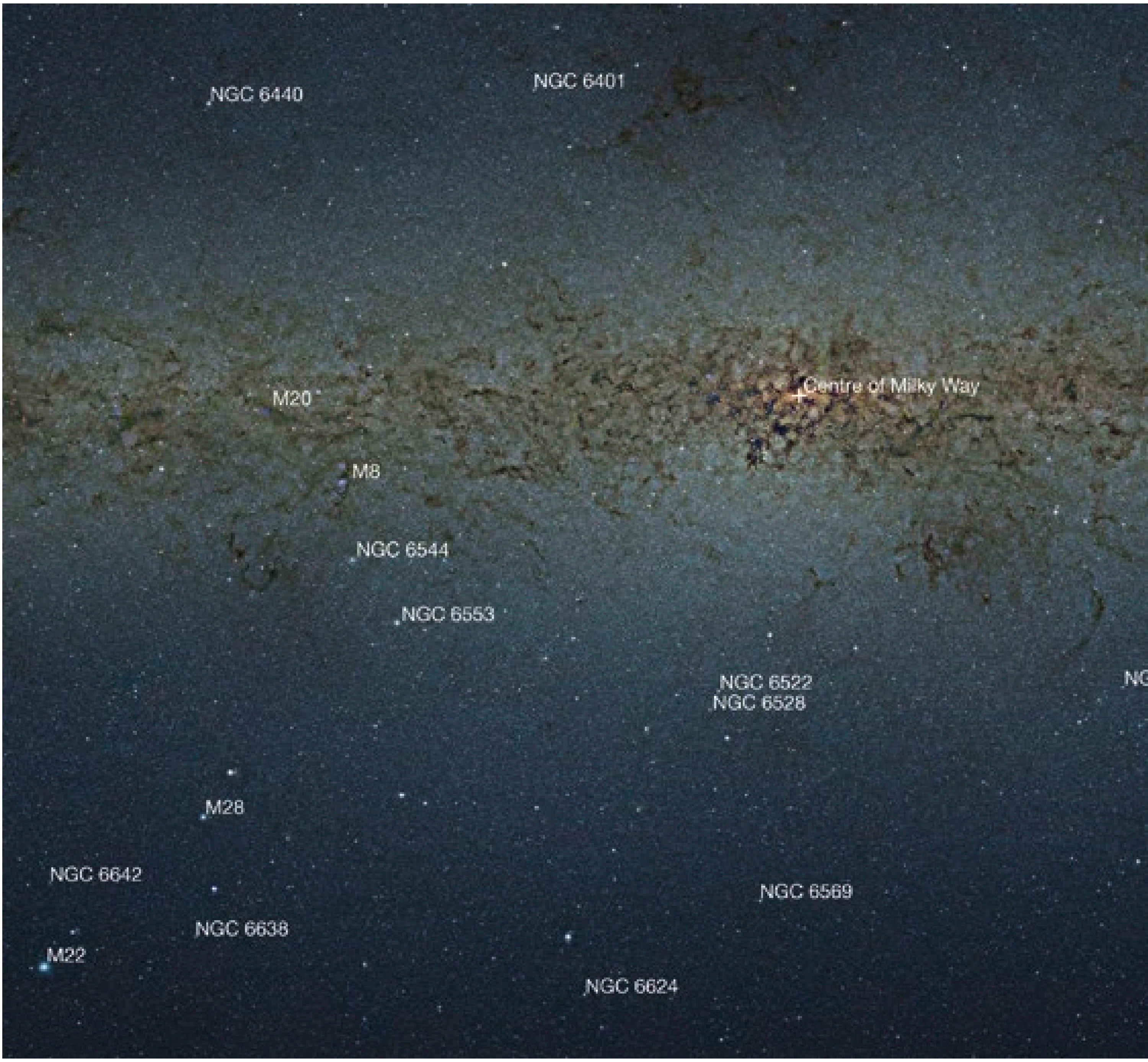


Figure 4. *Central part of the big VVV image with some prominent objects labelled. Credit: ESO/VVV Survey/D. Minniti. Acknowledgement: Ignacio Toledo, Martin Kornmesser*

Lessons learned

The completion of the project — despite the setbacks — and its great success made everyone involved proud of the result. The aftermath of the release was also a good time to summarise the lessons learned during the project; and there are almost as many as there were challenges.

The first and most obvious lesson learned was the fact that the data volumes of the new survey telescopes are a new paradigm for the creation of astronomical images. A significant investment in the design of new outreach pipelines and in modern hard- and software is needed to handle, edit and publish the images produced by these telescopes.

It is also of the upmost importance not to underestimate the needs of the target groups. In far more cases than one might expect the public prefers the largest files in the highest resolution. This also indicates that the users have the capabilities to handle and use these files.

The overloaded ESO servers showed that alternative ways of content delivery have to

be found and used. Peer-to-peer networks like Bittorrent turned out to be an excellent way to carry out distributed content delivery. Content distribution networks may also be an interesting solution to take the load off the central server.

As already mentioned above, the team learned that it is necessary to remove every single artefact from the image at the cosmetic cleaning stage. The in-house cleaning left some artefacts, such as black spots in the centres of saturated stars, in the image. As a consequence, ESO is still receiving feedback from hopeful people, who report spotting possible new transiting planets around a few of the bright stars.

The last and final lesson learned was probably the most important one: teamwork. Without an amazing team of experts in the areas of astronomy, technology and graphics it would have been impossible to overcome the individual challenges. In particular this project was made possible due to a collaboration between Olivier Hainaut (project lead, PhD astronomer), Martin Kornmesser (graphic designer), Richard Hook (astronomer, press officer), Mathias Andre (developer), Davide de Martin (engineer and amateur astronomer), Kaspar Nielsen (PhD physicist and developer), Luis Calçada (graphic designer), Georgia Bladon (science communicator) and Lars Lindberg Christensen (astronomer, head).

Producing colour composites from astronomical data is an important way of illustrating astronomical progress to the public. Sometimes, work such as this brings us to the forefront of existing technology and stretches the imaginations of the science communicators. The VVV image is such a case, but in turn it has also managed to make a significant impact on the public.

References

Saito et al. 2012, Astronomy and Astrophysics, 544.

Notes

1. Download the full VVV image: http://www.eso.org/public/archives/images/original/eso1242a.psb
2. ESO science press release: http://www.eso.org/public/news/eso1242/
3. FITS is a specialised format used in the astronomical community.
4. ESO/ESA/NASA FITS Liberator: http://www.spacetelescope.org/projects/fits_liberator/
5. The software STIFF: http://www.astromatic.net/software/stiff
6. More about bigTIFF files: http://bigtiff.org/
7. Download the 40 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff40k/eso1242a.tif
8. Download the 25 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff25k/eso1242a.tif
9. Download the 10 000 pixel VVV image: http://www.eso.org/public/archives/images/publicationtiff10k/eso1242a.tif
10. The zoomable VVV image: http://www.eso.org/public/images/eso1242a/zoomable/
11. The Zoomify tool: http://www.zoomify.com/
12. Zoom tool Krpano: http://krpano.com/
13. Zoom tool Panotour Pro from Kolor: http://www.kolor.com/

Biographies

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