VVV Survey - ESO Phase 3 - Data Release 4.2

Authors: D. Minniti, P. Lucas, and M. Hempel, for the VVV Science Team

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Abstract

The VVV Survey data delivered to ESO in this “DR4.2” release of the “VVV” Data Collection includes the two-epoch ZYJHKS band-merged tile catalogues that were created by the Wide Field Astronomy Unit (WFAU) at the Royal Observatory, Edinburgh, using single-band catalogues created from the tile images by the Cambridge Astronomical Survey Unit (CASU). These data files were uploaded via the Phase 3 tool to the ESO Archive in July 2020. The data are from ESO programme 179.B-2002, with the VIRCAM instrument, using ZYJHKS filters, with total sky coverage of 540 sq. deg.

Overview of Observations

This Phase 3 release contains observations up to 26 September 2015 with all the approved data from CASU v1.3 pipeline reduction, including images and merged source catalogs. We refer to this release as DR4.2, building on the single band catalogues (known as “source lists” in ESO parlance) and tile images and pawprint images released in DR4.1.

DR4.2 replaces the previous releases of band-merged tile catalogues in DR2 that were derived from the CASU v1.1 or v1.2 pipelines. DR4.2 provides additional data: the band-merged catalogues now include two separate epochs of contemporaneous JHKs photometry and two separate epochs of contemporaneous ZY photometry. There are also two significant improvements to the data quality compared to the earlier pipelines: (1) the improved photometric calibration procedures implemented in the v1.3 pipeline; (2) more extensive Quality Control (QC) to identify bad data. Despite these improvements, this release is not the final word on absolute photometric calibration on of VVV and some deficiencies are known to exist in the more crowded inner bulge fields. Further improvements have been made, first with the v1.5 pipeline (Gonzalez-Fernandez et al. 2018) and more recently the forthcoming VVV/VICAL procedure (L. Smith et al. in prep.) which fixes the crowded-field issue noted in Hajdu et al.(2020).

The file list for DR4.2 has 348 band-merged catalogues. The list also includes 7 single-band source lists and associated images that were included in order to provide complete provenance data for the band-merged catalogues because they were missing from DR4.1. In total the band-merged catalogues comprise 505 GB of data in uncompressed FITS format.
The VVV photometric dataset is divided into different disk and bulge tiles. The tile nomenclature goes from d001 to d152 in the disk, and from b201 to b396 in the bulge. The coordinates of the tile centers are listed in Tables 1 and 2 below, for the bulge and disk, respectively. These Tables contain the tile ID, Equatorial coordinates RA and DEC (J2000), and Galactic coordinates l and b in degrees. The map with the field IDs is shown in Figures 1a and 1b, overlapped on the extinction map of the inner Milky Way from Schlegel et al. 1997.

Figure 1. Maps showing the VVV tile numbers for the bulge (upper panel) and the disk (lower panel).

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VVV_DR4.2_description
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VVV observations took place from 2010-2015. They comprised multi-epoch Ks observing blocks (OBs) and two epochs of contemporaneous multi-filter OBs, with JHKs OBs and ZY OBs taken separately in order to comply with ESO policies on maximum OB duration. All planned VVV observations from 2010-2015 have now been completed but the new VVVX extension to the VVV survey is continuing and it includes sparsely sampled data at the original VVV tile positions.

The files for this VVV Survey DR4.2 include only data that have passed the Quality Control (QC) procedures designed to remove individual bad observations.

**Release Notes**

**Data Reduction and Calibration**

All DR4 data are based on the CASU version v1.3 pipeline, which produces publication quality results provided that appropriate checks are made. The main changes to the pipeline since version 1.1 are as follows.

(i) The magnitude zero point error estimate for tiles is now calculated from the zero-point variation in the component pawprint images;

(ii) All tile catalogues have been re-grouted taking into account both detector level magnitude zero points variations and atmospheric seeing variations. (“Grouting” refers to the process of constructing calibrated tile images and catalogues from the 6 overlapping VIRCAM pawprint images).

(iii) A bug involving how the aperture 2 correction was calculated is now fixed and tile catalogues have now been re-grouted to include this. The change in the associated apermag2 results (source magnitudes in aperture 2) is typically at the level of ~0.05 mag.

(iv) Prior to re-grouting all the stacked pawprint photometric zero-points were recomputed using the latest version of the photometry software.

(v) Post re-grouting all the tile photometric zero-points have also been updated.

Full details of the pipeline procedure and the version changes can be found at: [http://apm49.ast.cam.ac.uk/surveys-projects/vista/data-processing/](http://apm49.ast.cam.ac.uk/surveys-projects/vista/data-processing/)
The photometric and astrometric calibrations are both derived from the 2MASS Point Source Catalogue. The photometric calibration includes an additional colour term designed to correct for the effect of interstellar extinction on the 2MASS to VISTA photometric transformations. This works well in the J, H and Ks bandpasses and improvements in the pipeline between v1.1 and v1.3 have fixed the calibration of a small number of tiles that previously appeared to have problems at the 0.1 mag level (by comparison with 2MASS and by using the tile overlap regions). Remaining fields with slightly poorer than average photometric calibration in J, H or Ks are solely due to poor and changing weather conditions, which will be apparent from the pawprint and tile zero points and the seeing given in the FITS catalogue headers.

The only changes to individual DR4 FITS images are in the headers. The zero points will in general be slightly different than in the previously releases owing to slight improvements in the calibration procedure as noted above. Also, the ESO Grades describing data quality for each OB have in some cases been updated. A very small change to the astrometric WCS coefficients was also implemented, affecting only data taken after 20101201. The effect on the astrometry is much less than 1 arcsecond. The PV2_3 and PV2_5 FITS header keywords for subsequent data changed from 42.0, -10000.0 to 44.0, -10300.0.

The tile catalogues have slightly changed photometry compared to previous releases, owing to the updated zero points and the new aperture corrections for aperture 2. Most users will wish to use aperture 1, aperture 2 or aperture 3 magnitudes, which correspond to aperture diameters of 1.0, √2 and 2.0 arcsec respectively. The trade off is between a smaller and more accurate aperture correction for larger apertures vs. increased effects of overlapping apertures on the photometry in crowded fields. The CASU aperture photometry does attempt to deblend the fluxes of adjacent sources with overlapping apertures but the results are not as good as profile fitting photometry (which is much more computationally intensive). We plan to supply profile fitting photometry products in the near future.

The team has worked on the quality control using the v1.3 data, as detailed below.

The limiting magnitudes are similar to the ones for DR1 since we cover the same fields. Maps of limiting magnitudes are given in Saito et al. (2012). In addition, the calibration of the VVV Survey photometry was investigated as function of crowding in the bulge and disk fields, using the overlap regions between adjacent tiles and adjacent pawprint.

The VVV saturation limit ranges between Ks=10-12 mag, with multi-filter disk observations featuring a fainter saturation limit due to the slightly longer exposure time, e.g. DIT_{Ks}=10s in multicolor observations, as compared for DIT_{Ks}=4s in the variability study. DIT=4s was used for all Ks observations in the bulge. The saturation limit also varies between the 16 VIRCAM detectors. For brighter magnitudes the 2MASS photometry should be preferred. The photometric limit is typically Ks=17.5 mag, but in high density fields like the in the Galactic center region it can be Ks<16 mag (see photometric completeness in Saito et al.2012).

The photometric catalogues contain calibrated aperture photometry, and the limiting magnitudes correspond to the aperture photometry. For some specific scientific purposes it is better to obtain profile fitting (PSF) photometry and we plan to supply band-merged PSF photometry products in the near future.
Data Quality

The same words of caution as before apply as in previous releases: even though we checked the images for defects, we are still identifying images that need to be reprocessed or reacquired.

The Quality Control for the Phase 3 data from v1.3 was performed with involvement of ESO and of most of the scientists from the VVV Survey Science Team. We checked image defects, telescope problems, seeing, zero points, magnitude limits, ellipticities, airmass, etc. Algorithmic quality control cuts to remove images with low zero points (after correcting for the seasonal trend), seeing that was significantly outside specification, or high average ellipticity were also applied.

Some additional quality control procedures were implemented for DR4 that identified a small number of tiles or pawprints where telescope guiding had been lost and fields with blurred or distorted image profiles. In addition we also identified some bad tiles where there was a large variation in the seeing or in the zero points between the 6 constituent pawprints, even though the values for the tile had passed the quality threshold. Furthermore, since we now have full confidence in the photometric calibration of the J, H and Ks data we decided to release some tile images and catalogues that had been removed from previous releases. In some cases this was because the improved calibration meant that the image now pass the seasonally adjusted threshold for the zero points. In other cases, some Ks images have variations in the background level that cause a poor cosmetic appearance without significantly affecting the time series photometry, which we consider to be the most important VVV science product. A good cosmetic appearance was required for all of the ZYJHKs master images from 2010-11 and 2015 in order to be part of this release.

There are a number of well known image defects intrinsic to VISTA, many of which are illustrated with pictures in the CASU web page located at:
casu.ast.cam.ac.uk/surveys-projects/vista/technical/known-issues

Known Issues

1) The Z and Y calibration is fairly good for fields located >2° off the Galactic equator but at present it remains unreliable for fields at latitudes |b|<2°. It had been hoped that ESO observations of standard fields in all filters in the 1st year of observation would provide data to calibrate the VVV Z and Y data but in the event there was insufficient data at similar times and airmasses to VVV.

2) The 2MASS-based calibration in all filters is less reliable in the most crowded inner bulge fields, approximately at Galactic coordinates -6° < l <6°, -3°<b<2.5°, see Hajdu et al.(2020). An improved “VICAL” calibration procedure (L. Smith et al., in prep.) has recently been implemented for VVV PSF photometry products that effectively uses field overlaps to provide a more uniform calibration that is anchored to uncrowded fields with low extinction in the lower bulge. We plan to supply these products to ESO in the near future. For the most part they will supersede this DR4.2 release, except for stars at or above the saturation limit.
Data Format

File Types

There are 6 types of file, all in FITS format. The main product is the 348 tile catalogues (filenames ending in “.fits”). There is also a meta-file containing the column description information reproduced below.

The other file types are 14 compressed “.fits.fz” image files (6 multi-extension VIRCAM pawprint images, 1 tile mage and the 7 associated weight maps) and 7 single-band source lists “.fits” files. These 14 images are provided because they were missing from DR4.1, which contains the rest of the images and single-band source lists that were used to create the DR4.2 two-epoch multi-filter catalogues.

Catalogue Columns

In the table below, the FITS format types are: A – ASCII string, I – signed 2 bit integer, J – signed 4 bit integer, K – signed 8 bit integer, D – double precision (64 bit) floating point variable, E – single precision (32 bit) floating point variable, B – unsigned byte.

All magnitudes are on the Vega system.

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Format</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>IAUNAME</td>
<td>29A</td>
<td>IAU Name (not unique)</td>
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<tr>
<td>sourceID</td>
<td>K</td>
<td>Unique ID of this merged detection as assigned by merge algorithm</td>
</tr>
<tr>
<td>cuEventID</td>
<td>J</td>
<td>Unique ID of the VISTA Science Archive curation event giving rise to this record</td>
</tr>
<tr>
<td>frameSetID</td>
<td>K</td>
<td>Unique ID of the set of frames that this merged source comes from.</td>
</tr>
<tr>
<td>ra2000</td>
<td>D</td>
<td>Celestial Right Ascension</td>
</tr>
<tr>
<td>dec2000</td>
<td>D</td>
<td>Celestial Declination</td>
</tr>
<tr>
<td>l</td>
<td>D</td>
<td>Galactic longitude</td>
</tr>
<tr>
<td>b</td>
<td>D</td>
<td>Galactic latitude</td>
</tr>
<tr>
<td>lambda</td>
<td>D</td>
<td>SDSS system spherical co-ordinate 1</td>
</tr>
<tr>
<td>eta</td>
<td>D</td>
<td>SDSS system spherical co-ordinate 2</td>
</tr>
<tr>
<td>priOrSec</td>
<td>K</td>
<td>Seam code for a unique (=0) or duplicated (!=0) source (eg. flags overlap duplicates).</td>
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<td>h_1mks_1Pnt</td>
<td>E</td>
<td>Point source colour H_1-Ks_1 (using aperMag3)</td>
</tr>
<tr>
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<td>Error on point source colour H_1-Ks_1</td>
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<tr>
<td>h_2mks_2Pnt</td>
<td>E</td>
<td>Point source colour H_2-Ks_2 (using aperMag3)</td>
</tr>
<tr>
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<td>Error on point source colour H_2-Ks_2</td>
</tr>
<tr>
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<td>Point source colour J_1-H_1 (using aperMag3)</td>
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<td>Error on point source colour J_1-H_1</td>
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<td>Point source colour J_2-H_2 (using aperMag3)</td>
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<td>Error on point source colour J_2-H_2</td>
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z_1my_1PntErr  E  Error on point source colour Z_1-Y_1
z_2my_2Pnt  E  Point source colour Z_2-Y_2 (using aperMag3)
z_2my_2PntErr  E  Error on point source colour Z_2-Y_2
mergedClassStat  E  Merged N(0
mergedClass  I  Class flag from available measurements (1|0|-1|-2|-3|-9=galaxy|noise|stellar|probableStar|probableGalaxy|saturated)
pStar  E  Probability that the source is a star
pGalaxy  E  Probability that the source is a galaxy
pNoise  E  Probability that the source is noise
pSaturated  E  Probability that the source is saturated
z_1Mjd  D  Modified Julian Day in Z_1 band
Point source Z_1 aperture corrected mag (1.0 arcsec aperture diameter)
z_1AperMag1  E  Error in point source Z_1 mag (1.0 arcsec aperture diameter)
z_1AperMag1Err  E  Default point source Z_1 aperture corrected mag (2.0 arcsec aperture diameter)
z_1AperMag3  E  Error in default point source Z_1 mag (2.0 arcsec aperture diameter)
z_1AperMag3Err  E  Point source Z_1 aperture corrected mag (2.8 arcsec aperture diameter)
z_1AperMag4  E  Error in point source Z_1 mag (2.8 arcsec aperture diameter)
z_1AperMag4Err  E  RMS of axes of ellipse fit in Z_1
z_11EA  E  1-b/a
z_1PA  E  ellipse fit celestial orientation in Z_1
z_1ErrBits  J  processing warning/error bitwise flags in Z_1
z_1AverageConf  E  average confidence in 2 arcsec diameter default aperture (aper3) Z_1
z_1Class  I  discrete image classification flag in Z_1
z_1ClassStat  E  S-Extractor classification statistic in Z_1
z_1ppErrBits  J  additional WFAU post-processing error bits in Z_1
z_1SeqNum  J  the running number of the Z_1 detection
z_1Xi  E  Offset of Z_1 detection from master position (+east/-west)
z_1Eta  E  Offset of Z_1 detection from master position (+north/-south)
z_2Mjd  D  Modified Julian Day in Z_2 band
Point source Z_2 aperture corrected mag (1.0 arcsec aperture diameter)
z_2AperMag1  E  Error in point source Z_2 mag (1.0 arcsec aperture diameter)
z_2AperMag1Err  E  Default point source Z_2 aperture corrected mag (2.0 arcsec aperture diameter)
z_2AperMag3  E  Error in default point source Z_2 mag (2.0 arcsec aperture diameter)
z_2AperMag3Err  E  Point source Z_2 aperture corrected mag (2.8 arcsec aperture diameter)
z_2AperMag4  E  Error in point source Z_2 mag (2.8 arcsec aperture diameter)
z_2AperMag4Err  E  RMS of axes of ellipse fit in Z_2
z_2Ell  E  1-b/a
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<td>average confidence in 2 arcsec diameter default aperture (aper3) Z_2</td>
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<td>S-Extractor classification statistic in Z_2</td>
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<td>Point source Y_1 aperture corrected mag (2.8 arcsec aperture diameter)</td>
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<td>y_1AperMag4Err</td>
<td>E</td>
<td>Error in point source Y_1 mag (2.8 arcsec aperture diameter)</td>
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<td>Default point source Y_2 aperture corrected mag (2.0 arcsec aperture diameter)</td>
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<td>y_2AperMag3Err</td>
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<td>Error in point source Y_2 mag (2.8 arcsec aperture diameter)</td>
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<tr>
<td>y_2Gausig</td>
<td>E</td>
<td>RMS of axes of ellipse fit in Y_2</td>
</tr>
<tr>
<td>y_2PA</td>
<td>E</td>
<td>ellipse fit celestial orientation in Y_2</td>
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<tr>
<td>y_2ErrBits</td>
<td>J</td>
<td>processing warning/error bitwise flags in Y_2</td>
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</table>
y_2AverageConf E average confidence in 2 arcsec diameter default aperture (aper3) Y_2
y_2Class I discrete image classification flag in Y_2
y_2ClassStat E S-Extractor classification statistic in Y_2
y_2ppErrBits J additional WFAU post-processing error bits in Y_2
y_2SeqNum J the running number of the Y_2 detection
y_2Xi E Offset of Y_2 detection from master position (+east/-west)
y_2Eta E Offset of Y_2 detection from master position (+north/-south)
j_1Mjd D Modified Julian Day in J_1 band
Point source J_1 aperture corrected mag (1.0 arcsec aperture diameter)
j_1AperMag1 E
j_1AperMag1Err E Error in point source J_1 mag (1.0 arcsec aperture diameter)
Default point source J_1 aperture corrected mag (2.0 arcsec aperture diameter)
j_1AperMag3 E
j_1AperMag3Err E Error in default point source J_1 mag (2.0 arcsec aperture diameter)
Point source J_1 aperture corrected mag (2.8 arcsec aperture diameter)
j_1AperMag4 E
j_1AperMag4Err E Error in point source J_1 mag (2.8 arcsec aperture diameter)
j_1Gausig E RMS of axes of ellipse fit in J_1
j_1Ell E 1-b/a
j_1PA E ellipse fit celestial orientation in J_1
j_1ErrBits J processing warning/error bitwise flags in J_1
j_1AverageConf E average confidence in 2 arcsec diameter default aperture (aper3) J_1
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Point source J_2 aperture corrected mag (1.0 arcsec aperture diameter)
j_2AperMag1 E
j_2AperMag1Err E Error in point source J_2 mag (1.0 arcsec aperture diameter)
Default point source J_2 aperture corrected mag (2.0 arcsec aperture diameter)
j_2AperMag3 E
j_2AperMag3Err E Error in default point source J_2 mag (2.0 arcsec aperture diameter)
Point source J_2 aperture corrected mag (2.8 arcsec aperture diameter)
j_2AperMag4 E
j_2AperMag4Err E Error in point source J_2 mag (2.8 arcsec aperture diameter)
j_2Gausig E RMS of axes of ellipse fit in J_2
j_2Ell E 1-b/a
j_2PA E ellipse fit celestial orientation in J_2
j_2ErrBits J processing warning/error bitwise flags in J_2
j_2AverageConf E average confidence in 2 arcsec diameter default aperture (aper3) J_2
j_2Class I discrete image classification flag in J_2
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<td>RMS of axes of ellipse fit in H_1</td>
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<td>processing warning/error bitwise flags in H_1</td>
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<td>average confidence in 2 arcsec diameter default aperture (aper3) H_1</td>
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<td>S-Extractor classification statistic in H_1</td>
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<td>additional WFAU post-processing error bits in H_1</td>
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Acknowledgments

Please use the following statement in your articles when using these data: Based on data products from VVV Survey observations made with the VISTA telescope at the ESO Paranal Observatory under programme ID 179.B-2002.

Further Details

More detailed information can be found at: - the CASU webpages http://casu.ast.cam.ac.uk/surveys-projects/vista/

- by contacting the VVV Science Team Members listed at the VVV Survey webpage http://vvvsurvey.org
  - Photometric calibration papers


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- the VVV Science Team papers:


