The GALACTICNUCLEUS survey (195.B-0283)

Abstract

The GALACTICNUCLEUS (GNS) survey is a single-epoch catalogue of the Galactic Centre in the near infrared bands JHKs. The observations were optimised for the Galactic Centre: high angular resolution (0.2") to overcome the extreme source crowding, and high dynamic range to minimise saturation issues. The data were acquired with the HAWK-I instrument at the ESO VLT unit telescope 4. The catalogue covers an area of ~0.3 deg^2 (~6000 pc^2) distributed across seven regions that correspond to the nuclear stellar disc (NSD), the inner Galactic bulge, and the transition region between them. In this catalogue data release, we present accurate PSF photometry of ~3.3×10^6 stars, detecting around 20% in J, 65% in H, and 90% in Ks. The catalogue reaches 5-sigma detections for J~22, H~21, and Ks~21 mag. Photometric uncertainties are below 0.05 mag at J~21, H~19, and Ks~18 mag. The zero point was calibrated using the SIRIUS/IRSF catalogue (e.g. Nagayama et al. 2004, Nishiyama et al. 2006), with a systematic uncertainty of 0.04 mag in all three bands.

Overview of Observations

The GNS survey consists of 49 individual pointings for each band carried out between 2015-2018. We used the fast photometry mode to obtain a series of short-exposure frames with an exposure time of DIT = 1.26 s. This allowed us to apply the speckle holography technique (e.g. Schödel et al. 2013) to improve the angular resolution of the final images. The used observing mode required to window the detector, which resulted in a field of view of 2048 x 768 pixels for each of the four detectors comprising the HAWK-I camera. To cover the gap between the detectors, we applied a jitter box of 30'' (for 2015 data), that was later increased up to 1' (2016-2018 data). Each of the detectors was treated independently to obtain the final photometry (for further details see Nogueras-Lara et al. 2018, 2019). We applied a dedicated sky subtraction, observing sky frames right before or after the science target (using a large infrared dark cloud approximately 31' to the East of Sgr A*, as described in Nogueras-Lara et al. 2018). Figure 1 (adapted from Nogueras-Lara et al. 2019 Fig. 2) shows the observed pointings.

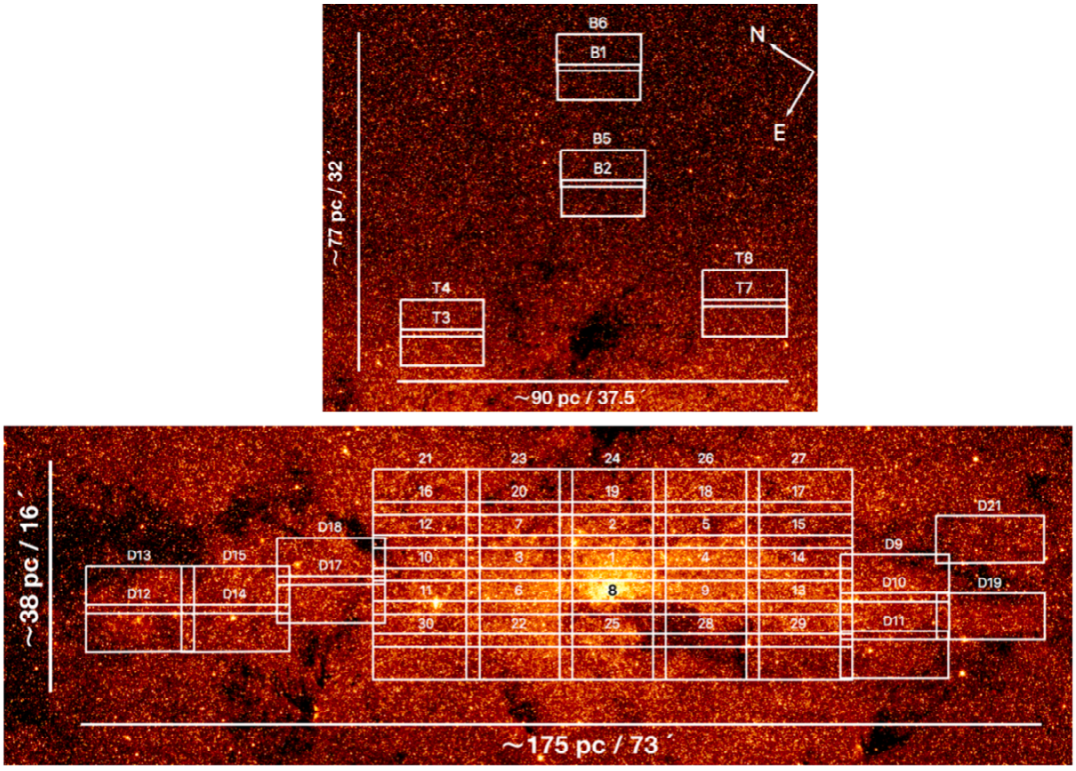

Figure 1. Scheme of the pointings observed in the GNS survey (adapted from Fig. 2 in Nogueras-Lara et al. 2019). Fields in the NSD, the transition regions, and the inner Galactic bulge are identified by the labels "D", "T", and "B", respectively. Fields in the central region are identified by numbers 1-30.

The GNS data release consists of catalogues of seven regions that were created combining the photometry obtained from the previous pointings. The regions are:

- Central -> Poitings from 1-30.
- Nuclear stellar disc East (NSD E) -> D12, D13, D14, D15, D17, D18
- Nuclear stellar disc West (NSD W) -> D9, D10, D11, D19, D21
- Transition East (T E) -> T3, T4
- Transition West (T W) -> T7, T8
- Inner bulge South (I B S) -> B2, B5
- Inner bulge North (I B N) -> B1, B6

Release Content

The data release contains a catalogue for each of the seven regions covered in the GNS survey. These are: Central, NSD E, NSD W, T E, T W, I B S, and I B N. The catalogues include accurate photometry in J, H, and Ks for ~3.3 × 10^6 stars obtained after combining the different detectors and pointings. We detect around 20% in J, 65% in H, and 90% in Ks. The pixel scale is 0.053''/pixel and the final angular resolution is ~0.2'' for all the catalogues. The catalogues also include absolute coordinates for each of the detected sources, combining the detections in multiple bands, and the coordinates of each source in the band where it is detected. The specific content of the catalogues is detailed in Sect. Data Format.
The associated catalogues are:

- Central -> central_catalogue.fits (2,009,482 rows, 460.2 MB)

- NSD E -> NSD_East_catalogue.fits (488,147 rows, 111.8 MB)
- NSD W -> NSD_West_catalogue.fits (199,445 rows, 45.7 MB)
- T E -> T_East_catalogue.fits (162,763 rows, 37.3 MB)
- T W -> T_West_catalogue.fits (167,972 rows, 38.5 MB)
- I B S -> IB_South_catalogue.fits (159,572 rows, 36.6 MB)
- I B N -> IB_North_catalogue.fits (90,265 rows, 20.7 MB)

There are two gaps in the catalogue associated to bad weather conditions. The corresponding pointings are: F7 J band, and B6 H band. The total sky area of the survey is ~0.3 square degrees. The catalogues reach 5-sigma detections at J~22, H~21, and Ks~21 mag.

Moreover, this data release also includes science images for each of the detectors and bands that were used to obtain the photometry for the previous catalogues. We also include the associated noise maps. The names of the files are:

- Science frames: identifier + # pointing (according to Fig. 1) + #chip + band + .fits
- Error maps: identifier + # pointing (according to Fig. 1) + #chip + band + 'error_map' .fits

The identifiers for each region are: Central 'F', NSD 'D', transition regions 'T', and bulge 'B'.

For example, B1_chip1_J.fits corresponds to the chip #1 of the first pointing in the bulge for the J band.

The number of files for each region are:

- Central: J band 116 science frames + 116 associated error maps (the files corresponding to F7 are not included due to bad weather conditions during the observations). H band 120 science frames +120 associated error maps. Ks band 120 science frames +120 associated error maps.

- NSD E: J band 24 science frames + 24 associated error maps. H band 24 science frames + 24 associated error maps. Ks band 24 science frames + 24 associated error maps.

- NSD W: J band 20 science frames + 20 associated error maps. H band 20 science frames + 20 associated error maps. Ks band 20 science frames + 20 associated error maps.

- T E: J band 8 science frames + 8 associated error maps. H band 8 science frames + 8 associated error maps. Ks band 8 science frames + 8 associated error maps.

- T W: J band 8 science frames + 8 associated error maps. H band 8 science frames + 8 associated error maps. Ks band 8 science frames + 8 associated error maps.

- I B S: J band 8 science frames + 8 associated error maps. H band 8 science frames + 8 associated error maps. Ks band 8 science frames + 8 associated error maps.

- I B N: J band 8 science frames + 8 associated error maps. H band 4 science frames + 4 associated error maps (the files corresponding to B6 are not included due to bad weather conditions during the observations). Ks band 8 science frames + 8 associated error maps.

Release Notes

The GNS catalogue includes accurate PSF photometry in the NIR HAWK-I filters JHKs using the Vega photometric system.

Data Reduction and Calibration

The final science image for each detector was obtained using a specially developed pipeline to process the images. First, we applied standard reduction (dark, bias, flat fielding, sky subtraction, and bad pixels and cosmic rays removal). We then corrected for geometric distortions using VVV images (e.g. Minitti et al. 2010) as a reference. Finally, to apply the speckle holography algorithm (e.g. Schödel et al. 2013), we divided the images corresponding to each detector into small sub-fields of 1 square arcminute. In this way, we avoided possible PSF variations across the field (mainly due to anisoplanatic effects), that might affect the speckle holography technique. The images were finally reassembled, taking any offsets into account. A detailed description of the whole process is available in Nogueras-Lara et al. (2019).

We obtained PSF photometry using the STARFINDER software package (Diolaiti et al. 2000) and a 5-sigma detection limit. We estimated the error associated to each source by means of comparing three independent speckle holography images (sub-images) created using one third of the data. We used a conservative strategy to remove spurious sources considering as real stars only those detected in all three sub-images, and also in the final holographic product. We also estimated the PSF variability for each detector, pointing, and band, in an independent way (see Sect. 3.1.2 in Nogueras-Lara et al. 2018).

The lists of stars were astrometrically calibrated using the VVV catalogue as a reference. The photometry was calibrated using the SIRIUS/IRSF survey for the Galactic centre. For the calibration, we removed saturated stars, stars with large uncertainties (more than 5%), and stars with close neighbours. In the final catalogues, we detected saturation for stars with Ks<11.5 mag. The J and H bands are more affected by extinction, being the saturation less important for them. In particular, some saturation is detected for J and H $\lesssim$11 mag, but it affects a low number of stars given the high extinction for these bands (see Fig. 6 in Nogueras-Lara et al. 2019).

To merge the final lists for each detector and band, we first combined all four chips corresponding to the same pointing taking care of possible photometric offsets between them. We then combined all the pointings corresponding to a given region to create a final list for a given band. We recalibrate the ZP during the process to avoid small offsets that might appear when adding new pointings to the final catalogue. We finally combined all three bands into a single catalogue for each of the regions previously specified.

Data Quality

The data quality was assessed comparing the final results with previous data from the VVV catalogue, the SIRIUS/IRSF catalogue, and small regions previously observed using HAWK-I. For further details see Sect. 5 in Nogueras-Lara et al. (2019).

We checked that the ZP might vary between different pointings and solved this issue by recalibrating it after combining all the detectors and pointings. To check the uniformity of the photometric calibration across the survey region, we compared common stars in the overlapping regions between pointings and different catalogues. We estimated that the ZP uncertainty is ~0.04 mag in all three bands, combining the ZP systematic from the reference catalogue (SIRIUS/IRSF) and also the statistical uncertainty obtained when comparing common stars from different catalogues (for further details see Sect. 4.4. in Nogueras-Lara et al. 2019).

The contamination of the source catalogue is expected to be negligible given the conservative approach used to accept a source as a real star (see previous Sect.).

The completeness of the data is limited by the extreme source crowding. We used the Central region as a test case to compute the completeness, given that it is the most crowded region, and thus the incompleteness due to crowding is maximum. We estimated it to be above 80% level at J~18.4, H~18.3, and Ks~16.3 mag (see Nogueras-Lara et al. 2020).

Known issues

The catalogues corresponding to the seven regions covered by the GNS survey published in Nogueras-Lara et al. (2019) included a low fraction of duplicated sources. We have fixed that problem in the current data release (see Nogueras-Lara et al. submitted). Nevertheless, given the design of the GNS survey as a set of seven independent catalogues, the final combined catalogue contains some duplicated detections that correspond to the overlapping regions between the Central and the NSD E tiles, and the Central and the NSD W tiles. They were intentionally included to allow photometric comparison between catalogues belonging to different regions (for further details see Sect. 4.2 in Nogueras-Lara et al. 2019). Given the different observing dates and the presence of a significant number of variable stars in the Galactic centre (in addition to ZP uncertainties, see Sect. 4.2 in Nogueras-Lara et al. 2019), some photometric variation might be possible between the common sources.

Data Format

Files Types

This data release consists of 7 catalogue files, 580 science images corresponding to the detectors and the photometric bands J, H, and Ks, and 580 associated uncertainty maps. The naming convention is specified in Sect. Release Content.

Catalogue Columns

Each of the catalogue files consists of 27 columns following the scheme presented in Sect. 4.4. of Nogueras-Lara et al. 2019. This is:

- Column 1 indicates the IAU name. The identifier is not unique given the overlap between the Central catalogue and the NSD East and West ones (see Sect. Known issues).

- Mean right ascension (column 2) and declination (column 4) using J2000 coordinates, and associated uncertainties (columns 3, and 5) of the sources. These coordinates are an average over the detections of the same star in different bands. If the star is detected in a single band, they coincide with the position and uncertainties in that band. The uncertainties refer to the standard deviation of the different measurements. The coordinates and uncertainties are in units of degrees.

- Coordinates (in units of degrees) obtained for the detection in each band. For each of the bands, columns from 6-17 indicate the associated coordinates and uncertainties. Namely, columns 6-9 indicates the right ascension, declination, and their associated uncertainties for detections in J band. Analogously, columns 10-13 and 14-17 correspond to H and Ks band, respectively. A value of 'NaN' indicates that a star was not detected for a given band or that it was not detected in more than one pointing. If the uncertainty associated to a given coordinate has a value of 'NaN', the associated uncertainty is 30 milliarcsec, that corresponds with the upper limit of the astrometric uncertainty obtained by com-

paring the coordinates in all three bands of a given star (see Fig. 4 in Nogueras-Lara et al. 2019).

- Photometry and associated uncertainty for each band: columns from 18-23 correspond to J, dJ, H, dH, Ks, and dKs. A value of 'NaN' indicates that a given star was not detected for a particular band. The obtained angular resolution after applying speckle holography (Schödel et al. 2013) is ~0.02''. The particular seeing conditions for each pointing and date can be found in Appendix A in Nogueras-Lara et al. 2019.

- Columns from 24-26 indicate the number of multiple detections in overlapping pointings for a given band (J, H, and Ks, respectively). A value of -1 indicates that the star was found to be duplicated after the merging process, and was fixed combining the multiple detections.

- Column 27 corresponds to a fake identifier to correctly merge the catalogues corresponding to each region considering the duplicated sources given the overlap between catalogues (Central and NSD E and NSD W).

Acknowledgements

Users of data from this release should cite Nogueras-Lara et al. 2018, A&A, 610, A83; and Nogueras-Lara et al. 2019, A&A, 631, A20.

Any publication making use of this data, whether obtained from the ESO archive or via third parties, must include the following acknowledgment:

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