

ELT Guide Star Catalogue 1.0

Abstract

The ELT Guide Star Catalogue version 1.0 (ELT-GSC1.0) is the first public release of the all-sky reference catalogue that will support guiding and adaptive-optics (AO) operations of ESO's Extremely Large Telescope (ELT) and its first-generation instruments, including MICADO and the MORFEO multi-conjugate AO module. ELT-GSC1.0 is built directly on the JWST Guide Star Catalogue version 3.1 (GSC3.1), kindly made fully available to ESO by the Space Telescope Science Institute (STScI). GSC3.1 became the operational catalogue for the JWST Guide Star Selection Subsystem in December 2024 and represents the current state of the art in all-sky guide-star catalogues, combining Gaia DR3 astrometry and photometry with measurements from several surveys including 2MASS, Pan-STARRS, SDSS, SkyMapper, the NOIRLab Source Catalog, and the VVV / VIRAC and Galactic Nucleus surveys.

With respect to GSC3.1, ELT-GSC1.0 is limited to objects with declination (Dec) lower than 30 deg and adds a small set of derived columns that are needed for ELT operations and have no equivalent in the source catalogue: synthetic 2MASS J, H and Ks magnitudes for sources with optical photometry but no measured near-infrared magnitudes; a flag identifying sources with sufficient photometric coverage to be treated as bona-fide stars, an operational effective temperature derived from broad-band colours, and two suitability flags marking objects that can be used as guide stars (GS) for telescope guiding and as natural guide stars (NGS) for AO wavefront sensing. This is a catalogue data release; no new observations are involved.

Overview of Observations

ELT-GSC1.0 is a derived catalogue and contains no original observations. All photometric and astrometric measurements ingested in the catalogue originate from the surveys feeding GSC3.1, namely:

- Gaia Data Release 3 (Gaia DR3), providing the astrometric backbone (positions, proper motions, parallaxes) and the G, BP, RP photometry;
- 2MASS, providing all-sky J, H, Ks photometry;
- Pan-STARRS DR1, SDSS, SkyMapper DR4 and the NOIRLab Source Catalog, providing optical ugrizy photometry over their respective footprints;
- VISTA / VHS and the VVV / VIRAC surveys, providing additional Z, Y near-infrared photometry over the southern sky and the inner Galactic plane;
- The Galactic Nucleus Survey (GNS), used by GSC3.1 to fill in the high-extinction region around Sgr A*.

The reader is referred to the JWST Guide Star Catalog documentation maintained by STScI for the full description of the survey content, cross-matching procedure and validation of GSC3.1¹.

Release Content

ELT-GSC1.0 is a single catalogue covering the whole sky at declination lower than 30 deg, distributed as a set of FITS files, one per sky tile, following the same tiling scheme as GSC3.1. The release inherits all sources, all columns and all selection criteria of GSC3.1 and augments them with four additional columns described in the section "Catalogue Columns".

¹ <https://jwst-docs.stsci.edu/jwst-observatory-characteristics-and-performance/jwst-pointing-performance/jwst-guide-stars/jwst-guide-star-catalog-updates#JWSTGuideStarCatalogUpdates-ImprovementsToTheGuideStarCatalog>

- **Sky region:** all-sky with Dec<30deg, with no further nominal gaps. Completeness, depth, photometric coverage and source classification follow the underlying GSC3.1 footprint and are inherited from it without modification.
- **Detection band:** not applicable. ELT-GSC1.0 does not perform detection; sources are inherited from GSC3.1, which is itself a cross-match of the surveys listed above with Gaia DR3 as the primary astrometric reference.
- **Limiting magnitude:** inherited from GSC3.1; the effective faint limit varies across the sky according to the survey coverage entering the cross-match (Gaia DR3 reaches $G \sim 21$, with deeper limits in regions covered by Pan-STARRS, SDSS, SkyMapper or NSC).
- **Number of sources:** inherited from GSC3.1 (of order 10^9 entries).

Release Notes

Short descriptions of the processing applied to GSC3.1 to produce ELT-GSC1.0, of the calibrations used for the derived quantities, and of the data-quality checks performed.

Data Reduction and Calibration

ELT-GSC1.0 is produced from GSC3.1 by a single Python ingestion script. While sources with Dec>30 deg are removed, no astrometric or photometric measurement is modified, and no re-calibration of the inherited columns is performed. The astrometric and photometric reference systems are therefore those of GSC3.1: positions and proper motions are on the Gaia DR3 / ICRS system, and photometry is reported in the native systems of the contributing surveys (Vega for 2MASS, AB for SDSS / Pan-STARRS / SkyMapper, Gaia DR3 system for G, BP, RP).

The four added columns are derived as follows.

- **Star_Flag** — a source is flagged as likely-stellar (STAR_FLAG = 1) when more than three of its broad-band magnitude columns hold a valid value ($0 < \text{mag} < 30$); otherwise STAR_FLAG = 0. This is a cut whose purpose is to retain sources for which a meaningful colour, and hence an operational temperature, can be derived. It is not a star/galaxy classifier and does not replace the GSC3.1 CLASSIFICATION column.
- **JSYNTMAG, HSYNTMAG, KSYNTMAG** — synthetic 2MASS J, H and Ks magnitudes, computed from SDSS g, r, i photometry using the two-colour transformation for dwarfs of Bilir et al., MNRAS 384, 1178 (2008). Each synthetic magnitude is a linear combination of the (g-r) and (r-i) colours plus a constant, with the coefficients given by that work. They are computed only for sources with valid SDSS g, r and i photometry; where the transformation cannot be applied the columns are set to 0. The synthetic near-infrared magnitudes extend the NIR magnitude coverage to sources that have optical photometry but lack measured 2MASS magnitudes down to HSYNTMAG=21, which is needed for the AO reference selection in regions of incomplete 2MASS coverage. They are operational quantities and must not be used for science.
- **TeffObs** — operational effective temperature and its provenance tag. TEFFOBS is computed, for sources with STAR_FLAG = 1, from broad-band colour-temperature calibrations for dwarfs assuming solar metallicity, applied in the following priority order:
 - (i) Gaia BP-RP colour, calibration of Mucciarelli, Bellazzini & Massari, A&A 653, A90 (2021), Eq. 1 with dwarf, $[\text{Fe}/\text{H}] = 0$ coefficients from their Table 1 (TEFFOBS_REC = 'Gaia');

- (ii) 2MASS J-Ks colour, calibration of Casagrande et al., A&A 512, A54 (2010), Eq. 3 with dwarf, $[Fe/H] = 0$ coefficients from their Table 4 (TEFFOBS_REC = '2MASS_JK');
- (iii) SDSS-system colours g-r, g-i, g-z, applied in this order, calibration of Yuan, Liu & Xiang, MNRAS 430, 2188 (2013), for dwarfs at solar metallicity (TEFFOBS_REC = 'SDSS_GR', 'SDSS_GI' or 'SDSS_GZ').

In each case the relation $T_{\text{eff}} = 5040 / \theta$ is used, with θ the polynomial in colour defined by the cited authors; the calibration of highest available priority is applied to each source and recorded in TEFFOBS_REC. Metallicity is fixed to $[Fe/H] = 0$ because no metallicity information is available at the catalogue level for the great majority of sources, and because the residual sensitivity of the broad-band colour-temperature relations to metallicity is small compared to the precision required for operations. TEFFOBS is rounded to integer Kelvin, and any unphysical negative result is reset to 0.

- **GS_FLAG and AO_FLAG** — Guide Star and AO reference suitability flags. They are evaluated only for sources with STAR_FLAG = 1. For these, the nearest neighbour in the catalogue is identified using a 2D angular match on the Gaia DR3 / ICRS coordinates; the angular separation to that neighbour and the magnitude difference to it are then combined with a magnitude-range cut. In particular:
 - **GS_FLAG** is set to 1 when the source has a Gaia RP magnitude in the operating range $5 < \text{GAIARPMAG} < 17$ and is sufficiently isolated, i.e. the nearest neighbour is more than 1 arcsec away or, if closer, fainter by more than 3 mag in Gaia RP.
 - **AO_FLAG** is set to 1 when the source has an H-band magnitude in the operating range $9 < H < 21$ and is sufficiently isolated with respect to the tighter 0.6 arcsec threshold (or a neighbour fainter by more than 3 mag in H). The H magnitude used follows the priority measured 2MASS H, then synthetic H (HSYNTMAG), then Gaia RP as a last resort.
- **Flag value 2** — either flag (GS and/or AO) is promoted from 1 to 2 when, in addition to fulfilling the requirements for flag value 1, the source has a reliable operational temperature in the range $1000 \text{ K} < \text{TEFFOBS} < 10000 \text{ K}$ and is classified as a star in GSC3.1 (CLASSIFICATION = 0). Flag = 2 therefore marks the best references, for which the colour-dependent, airmass-dependent centroid correction can be applied with confidence.

The 1 arcsec / 0.6 arcsec isolation thresholds reflect, respectively, the spatial scale at which a contaminating source measurably perturbs the centroid measured by the ELT guide probe, and the tighter constraint imposed by the smaller sub-field of AO wavefront sensors. The 3-mag tolerance ensures that a clearly fainter near neighbour does not disqualify an otherwise good reference.

Important note. TEFFOBS, the synthetic JHKs magnitudes and the STAR_FLAG / GS_FLAG / AO_FLAG flags are operational quantities. The bandpass of the ELT guide probe is broad, so the precise centroid of a guide star depends on airmass and on the observed colour (and hence effective temperature) of the star; TEFFOBS and the synthetic magnitudes are provided to enable the corresponding selection and correction during operations. None of these added columns is a measurement of a stellar property and **none must be used for any scientific purpose.**

Data Quality

Because ELT-GSC1.0 inherits all astrometric and photometric measurements from GSC3.1 unchanged, the astrometric and photometric quality is identical to that of GSC3.1 and is described in the STScI documentation. Quality verification specific to this release is therefore limited to the added columns and consisted of the following checks:

- Coverage of Star_Flag = 1 across the sky was inspected on a HEALPix grid; the spatial pattern reproduces the GSC3.1 photometric-survey footprints (e.g. the SDSS / Pan-STARRS / SkyMapper boundaries) as expected.
- The synthetic JHKs magnitudes were compared, for sources that also have measured 2MASS photometry, with the measured values; the residuals are consistent with the scatter of the Bilir et al. (2008) transformation and increase, as expected, towards reddened and non-dwarf sources. This way the JHKs coverage can be extended down to 21 magnitudes in each synthetic band. Still, we noted a systematic offset of -0.3, -0.2 and -0.2 of the JHKs synthetic magnitudes with respect to the 2MASS ones. While an investigation of the nature of such an offset is well behind the scope of this release it is acknowledged that such an offset is fully acceptable for the operational purposes of the synthetic magnitudes. As such it was decided to not apply any offset to the synthetic JHKs magnitudes.
- The TEFFOBS distribution was compared, on a representative subset of common sources, with independent temperature estimates; the agreement is consistent with the typical precision of broad-band colour-temperature relations over the operating range, and degrades — as expected — at the cool ($T_{\text{eff}} < 3500\text{K}$) and hot ($T_{\text{eff}} > 6200\text{K}$) ends and in regions of high reddening, where the $[\text{Fe}/\text{H}] = 0$ assumption and the absence of a reddening correction become limiting factors.
- The fraction of sources flagged as suitable Guide Stars and AO references was verified to be uniform on scales much larger than the GSC3.1 tile, with localised reductions in dense fields (Galactic plane, Magellanic Clouds, globular clusters) as expected from the isolation criterion.
- The pipeline was run end-to-end on a sample of GSC3.1 tiles and its output cross-checked against an independent re-implementation of the colour-temperature relations and the nearest-neighbour search.

Known issues

- The synthetic JHKs magnitudes and TEFFOBS assume dwarf stars at solar metallicity ($[\text{Fe}/\text{H}] = 0$) and apply no reddening correction. For giants, metal-poor or metal-rich stars, and sources in high-extinction regions (Galactic bulge, parts of the Galactic plane, the GNS-covered area around Sgr A*), the synthetic magnitudes and TEFFOBS are systematically biased. This is acceptable for operations but reinforces that these columns must not be used for science.
- The synthetic JHKs magnitudes are derived from SDSS g, r, i only; they are not populated for sources lacking SDSS optical photometry, where the columns are set to 0.
- For sources with STAR_FLAG = 0, no TEFFOBS is computed and GS_FLAG / AO_FLAG are left at 0. Such sources may still be physically suitable references but cannot be qualified by this release.
- The nearest-neighbour isolation test does not distinguish physical binaries from chance projections. A close pair of bright stars will be flagged as not suitable in both cases, which is the desired conservative behaviour for operations.
- A value of 0 in any of the added magnitude or temperature columns denotes 'not available' rather than a measured value; users must treat 0 as a null indicator.
- All known issues of GSC3.1 propagate unchanged to ELT-GSC1.0.

Previous Releases

This is the first release of the ELT Guide Star Catalogue. No previous Phase 3 release exists for this data collection.

Data Format

Catalogue Columns

The columns inherited from GSC3.1 are documented in the GSC3.1 release notes² maintained by STScI and are not repeated here. The columns added by ELT-GSC1.0 are listed below.

Label	Format	Description
<i>GSC3.1 columns</i>	<i>various</i>	<i>All columns of the GSC3.1 source catalogue are preserved unchanged. These include the source identifier, equatorial coordinates (RA, DEC) and their uncertainties, proper motions, the GSC3.1 star/non-star CLASSIFICATION flag, and multi-band photometry: Gaia DR3 (GAIAGMAG, GAIABPMAG, GAIARPMAG), SDSS / Pan-STARRS / SkyMapper / NSC optical bands (SDSSUMAG, SDSSGMAG, SDSSRMAG, SDSSIMAG, SDSSZMAG, SDSSYMAG and equivalents), and 2MASS (TMASSJMAG, TMASSHMAG, TMASSKSMAG). Refer to the GSC3.1 documentation maintained by STScI for the full column list, units, and provenance.</i>
STAR_FLAG	INT	Likely-stellar flag. Set to 1 when more than three of the available broad-band magnitude columns (all columns whose name ends in MAG) hold a valid value, defined as $0 < \text{mag} < 30$; set to 0 otherwise. This flag selects sources with enough photometric coverage for a meaningful colour and operational temperature to be derived. It is not a star/galaxy classifier and does not replace the GSC3.1 CLASSIFICATION column.
JSYNTMAG	FLOAT [mag]	Synthetic 2MASS J-band magnitude, computed from SDSS g, r, i photometry using the two-colour dwarf transformation of Bilir et al. (2008). Populated only for sources with valid SDSS g, r and i; set to 0 where the transformation cannot be applied. Provided for operations to extend NIR magnitude coverage where 2MASS photometry is missing; not a measured magnitude and not for science use.
HSYNTMAG	FLOAT [mag]	Synthetic 2MASS H-band magnitude, computed from SDSS g, r, i photometry using the two-colour dwarf transformation of Bilir et al. (2008). Populated only for sources with valid SDSS g, r and i; set to 0 otherwise. Used, when no measured 2MASS H is available, in the AO reference selection (see AO_FLAG). Operational quantity, not for science use.
KSYNTMAG	FLOAT [mag]	Synthetic 2MASS Ks-band magnitude, computed from SDSS g, r, i photometry using the two-colour dwarf transformation of Bilir et al. (2008). Populated only for sources with valid SDSS g, r and i; set to 0 otherwise. Operational quantity, not for science use.
TEFFOBS	INT [K]	Operational effective temperature in Kelvin, derived from broad-band colour-temperature calibrations for dwarfs at

² <https://outerspace.stsci.edu/spaces/MASTDATA/pages/176435491/Releases>

Label	Format	Description
		solar metallicity ($[Fe/H] = 0$). The calibration adopted depends on which bands are available, in priority order: (i) Gaia BP-RP colour following Mucciarelli, Bellazzini & Massari (2021); (ii) 2MASS J-Ks colour following Casagrande et al. (2010); (iii) SDSS colours g-r, then g-i, then g-z, following Yuan, Liu & Xiang (2013). Computed only for sources with STAR_FLAG = 1; rounded to integer Kelvin; negative results reset to 0. TEFFOBS is for operations only and must not be used for science.
TEFFOBS_REC	STRING	Provenance tag for TEFFOBS, recording which calibration was used: 'Gaia', '2MASS_JK', 'SDSS_GR', 'SDSS_GI' or 'SDSS_GZ'. Empty when no temperature could be derived.
GS_FLAG	INT	Guide Star suitability flag. 0 = not suitable. 1 = suitable for guiding: the source has a Gaia RP magnitude in the range $5 < GAIARPMAG < 17$ and is sufficiently isolated (nearest catalogue neighbour more than 1 arcsec away, or, if closer, fainter by more than 3 mag in Gaia RP). 2 = as flag 1 and, in addition, $1000 \text{ K} < TEFFOBS < 10000 \text{ K}$ and CLASSIFICATION = 0 (i.e. a star with a reliable operational temperature).
AO_FLAG	INT	Adaptive Optics reference suitability flag. 0 = not suitable. 1 = suitable: the source has an H-band magnitude in the range $9 < H < 21$ and is sufficiently isolated (nearest neighbour more than 0.6 arcsec away, or, if closer, fainter by more than 3 mag in H). The H magnitude used follows the priority measured 2MASS H (TMASSHMAG), then synthetic H (HSYNTMAG), then Gaia RP as a last resort. 2 = as flag 1 and, in addition, $1000 \text{ K} < TEFFOBS < 10000 \text{ K}$ and CLASSIFICATION = 0.

Acknowledgements

ELT-GSC1.0 is entirely built upon the JWST Guide Star Catalogue version 3.1 (GSC3.1) produced by the Space Telescope Science Institute (STScI). The authors are deeply grateful to the GSC team at STScI for kindly making GSC3.1 fully available to ESO and for the support provided during the construction of this release. Users of ELT-GSC1.0 are kindly requested to acknowledge GSC3.1 and its underlying surveys (Gaia DR3, 2MASS, Pan-STARRS, SDSS, SkyMapper, NOIRLab Source Catalog, VVV / VIRAC, GNS) according to the policies of the respective projects. An extensive list of publications related to the development and use of the original GSC are available at

<https://outerspace.stsci.edu/spaces/MASTDATA/pages/176435505/Publications> and

<https://archive.stsci.edu/publishing/mission-acknowledgements#section-9fa6bc58-9705-49f1-8999-7fdde1e76a64>.

The synthetic JHKs magnitudes are computed using the photometric transformation of Bilir et al. (MNRAS 384, 1178, 2008). The colour-temperature calibrations used to compute TEFFOBS are taken from Mucciarelli, Bellazzini & Massari (A&A 653, A90, 2021), Casagrande et al. (A&A 512, A54, 2010) and Yuan, Liu & Xiang (MNRAS 430, 2188, 2013). The corresponding works should be cited when the synthetic magnitudes or TEFFOBS are used.