



Publication Year	2023
Acceptance in OA	2025-02-28T13:25:49Z
Title	Gaia Data Release 3. Processing and validation of BP/RP low-resolution spectral data
Authors	De Angeli, F., Weiler, M., MONTEGRIFFO, Paolo, Evans, D. W., Riello, M., Andrae, R., Carrasco, J. M., Busso, G., Burgess, P. W., Cacciari, C., Davidson, M., Harrison, D. L., Hodgkin, S. T., Jordi, C., Osborne, P. J., PANCINO, Elena, ALTAVILLA, Giuseppe, Barstow, M. A., Bailer-Jones, C. A. L., BELLAZZINI, Michele, Brown, A. G. A., CASTELLANI, Marco, Cowell, S., Delchambre, L., DE LUISE, Fiore, Diener, C., Fabricius, C., Fouesneau, M., Frémat, Y., Gilmore, G., Giuffrida, G., Hambly, N. C., Hidalgo, S., Holland, G., Kostrzewa-Rutkowska, Z., van Leeuwen, F., Lobel, A., MARINONI, Silvia, Miller, N., Pagani, C., Palaversa, L., PERSIMONI, Anna Marina, Ragaini, S., RAINER, Monica, Richards, P. J., Rixon, G. T., Ruz-Mieres, D., SANNA, Nicoletta, Sarro, L. M., Rowell, N., SORDO, Rosanna, Walton, N. A., Yoldas, A.
Publisher's version (DOI)	10.1051/0004-6361/202243680
Handle	http://hdl.handle.net/20.500.12386/36331
Journal	ASTRONOMY & ASTROPHYSICS
Volume	674

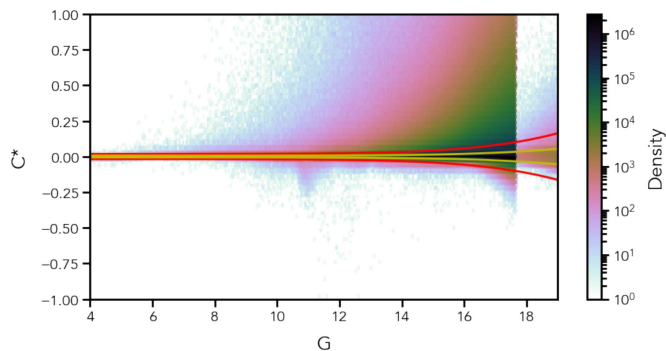


Fig. 30. Distribution of C^* vs. magnitude for all sources with BP/RP spectra in *Gaia* DR3. Also shown are the 1- and 3- σ curves in yellow and red, respectively, as defined in Riello et al. (2021).

sought is in the bluest wavelength range covered by BP (350 – 400 nm) where the small fraction of calibrators makes the flux and LSF calibration particularly challenging. The effect of this can be seen in some systematic offsets in the bluest part of the wavelength range covered by BP/RP data. These can be quantified when comparing BP/RP spectra with external absolute spectra (Montegriffo et al. 2023) and/or synthetic photometry generated from BP/RP spectra in various bands and photometric systems versus existing catalogues (Gaia Collaboration 2023c). In particular, in the latter work, the comparison of synthetic photometry from externally calibrated BP/RP spectra with state-of-the-art ground-based photometric standard stars suggests that, in the wavelength range spanned by SDSS u -band (and/or Johnson-Kron-Cousins U), differences can be as large as 20% for some spectral types and in some colour ranges. In the range covered by SDSS g -band (and/or Johnson-Kron-Cousins B -band), systematic errors reach the 5% level at most, while for redder passbands they are typically below the 2% level.

Acknowledgements. We are very grateful to the anonymous Referee for a careful and constructive report, that improved the quality of the manuscript. We would also like to thank R. Blomme for kindly reviewing an earlier version of this manuscript. This publication made extensive use of the online authoring Overleaf platform (<https://www.overleaf.com/>). The data processing and analysis made use of matplotlib (Hunter 2007), NumPy (Harris et al. 2020), the IPython package (Pérez & Granger 2007), TOPCAT (Taylor et al. 2005). This work presents results from the European Space Agency (ESA) space mission *Gaia*. *Gaia* data are being processed by the *Gaia* Data Processing and Analysis Consortium (DPAC). Funding for the DPAC is provided by national institutions, in particular the institutions participating in the *Gaia* MultiLateral Agreement (MLA). The *Gaia* mission website is <https://www.cosmos.esa.int/gaia>. The *Gaia* archive website is <https://archives.esac.esa.int/gaia>. Full acknowledgements are given in Appendix F.

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- ¹ Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
- ² Institut de Ciències del Cosmos (ICC), Universitat de Barcelona (IEEC-UB), c/ Martí i Franquès, 1, 08028 Barcelona, Spain
- ³ INAF – Osservatorio di Astrofisica e Scienza dello Spazio di Bologna, Via Gobetti 93/3, 40129 Bologna, Italy
- ⁴ Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
- ⁵ Institute for Astronomy, School of Physics and Astronomy, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, UK
- ⁶ Kavli Institute for Cosmology, Institute of Astronomy, Madingley Road, Cambridge CB3 0HA, UK
- ⁷ INAF – Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 5, 50125 Firenze, Italy
- ⁸ INAF – Osservatorio Astronomico di Roma, via Frascati 33, 00078 Monte Porzio Catone (Roma), Italy
- ⁹ Space Science Data Center – ASI, Via del Politecnico SNC, 00133 Roma, Italy
- ¹⁰ School of Physics & Astronomy, University of Leicester, Leicester LE9 1UP, UK
- ¹¹ Leiden Observatory, Leiden University, Niels Bohrweg 2, 2333 CA Leiden, The Netherlands
- ¹² Institut d’Astrophysique et de Géophysique, Université de Liège, 19c, Allée du 6 Août, 4000 Liège, Belgium
- ¹³ INAF – Osservatorio Astronomico d’Abruzzo, Via Mentore Maggini, 64100 Teramo, Italy
- ¹⁴ Royal Observatory of Belgium, Ringlaan 3, 1180 Brussels, Belgium
- ¹⁵ IAC – Instituto de Astrofísica de Canarias, Via Láctea s/n, 38200 La Laguna S.C., Tenerife, Spain
- ¹⁶ SRON Netherlands Institute for Space Research, Niels Bohrweg 4, 2333 CA Leiden, The Netherlands
- ¹⁷ Rudar Bošković Institute, Bijenička cesta 54, Zagreb, Croatia
- ¹⁸ INAF – Osservatorio Astronomico di Brera, Via E. Bianchi, 46, 23807 Merate (LC), Italy
- ¹⁹ STFC, Rutherford Appleton Laboratory, Harwell, Didcot OX11 0QX, UK
- ²⁰ Dpto. de Inteligencia Artificial, UNED, c/ Juan del Rosal 16, 28040 Madrid, Spain
- ²¹ INAF – Osservatorio Astronomico di Padova, Vicolo Osservatorio 5, 35122 Padova, Italy

Appendix A: Downloading BP/RP data from the *Gaia* DR3 archive

Not all sources included in *Gaia* DR3 will have BP/RP spectra available. The main `gaia_source` table in the archive contains a field `has_xp_continuous` that is `true` if a BP/RP spectrum is available for that source. Users can therefore query the `gaia_source` table to select sources with their favourite combination of parameters and use the additional criterion `has_xp_continuous='true'` to restrict their selection to sources that have BP/RP spectra available from the archive.

The support of the Datalink feature in the archive includes an independent service for the serialization of the BP/RP spectra. Other types of data such as photometric light curves are served using similar services. A dedicated tutorial is available [here](#).

In this section we provide an example of how to download BP/RP spectra using the Python programming language. By splitting the list of sources identifiers (`ids['source_id']` in the following code snippet), users can overcome the Datalink limitation on the number of sources. A bulk download option will also be implemented for users interested in getting all the BP/RP spectra in *Gaia* DR3.

```

1 from astroquery.gaia import GaiaClass
2
3 # Connect to Gaia archive
4 gaia = GaiaClass(gaia_tap_server='https://gea.esac.
    esa.int/', gaia_data_server='https://gea.esac.
    esa.int/')
5 gaia.login()
6
7 # Run your ADQL query to get a list of source_ids
8 example_query = "select TOP 1000 source_id from
    gaiadr3.gaia_source where has_xp_continuous = '
    True'"
9 job = gaia.launch_job_async(example_query,
    dump_to_file=False)
10 ids = job.get_results()
11
12 # Now retrieve the BP/RP mean spectra in the
    continuous representation
13 result = gaia.load_data(ids=ids['source_id'],
    format='csv', data_release='Gaia DR3',
    data_structure='raw', retrieval_type='
    XP_CONTINUOUS', avoid_datatype_check=True)
14
15 # Result will be a dictionary, so you can check the
    available keys by running result.keys()
16 # In this example we are looking in particular for
    the XP_CONTINUOUS_RAW key
17 continuous_key = [key for key in result.keys() if '
    continuous' in key.lower()][0]
18 # The first element is the result we want as an
    Astropy table
19 data = result[continuous_key][0]
20 # Astropy has a 'write' method for tables
21 # Write the table to CSV
22 data.write('filename.csv', format='csv')
```

The data can be downloaded in different file formats. For a complete list of the available formats and for instructions on alternative download procedures, please refer to the archive pages and tutorials.

Once downloaded, the files can be given in input to *GaiaXPY* utilities to obtain sampled spectra or synthetic photometry. *GaiaXPY* also offers the possibility of providing a list of source IDs. In this case, the download of the spectra from the archive

is done within the *GaiaXPY* utility (users will be prompted for credentials).

Appendix B: Data format details

This section provides more detailed information on the structure of the data representing BP/RP mean spectra in the archive. For completeness, all fields are described here, even though some have been mentioned and explained in the main text. Detailed descriptions are also available from the *Gaia* DR3 documentation and from the archive documentation.

We first describe the fields available via DataLink when retrieving `XP_CONTINUOUS` data:

- `source_id` Source identifier. Among other information, this encodes the approximate position of the source in the equatorial system (ICRS) using the nested HEALPix scheme at level 12 ($N_{\text{side}} = 4096$), which divides the sky into ≈ 200 million pixels of about 0.7 arcmin^2 .
- `bp/rp_basis_function_id` Identifier of the set of bases functions used in the Source Update process (see Sect. 3.3). Different sets were used during trial runs and validation but all the released spectra were created using the same set of bases. This implies that the identifier in *Gaia* DR3 is different for BP and RP spectra, but the same for all sources in each band. When sampling the spectra in the internal reference system, care must be taken to ensure that the right basis configuration is used.
- `bp/rp_degrees_of_freedom` Number of degrees of freedom in the Source Update least squares solution.
- `bp/rp_n_parameters` Number of parameters in the Source Update least squares solution. This will be always 55 for the *Gaia* DR3 BP/RP spectra.
- `bp/rp_n_measurements` Number of measurements contributing to the Source Update least squares solution. This counts the single samples contributing rather than full epoch spectra.
- `bp/rp_n_rejected_measurements` Number of samples rejected in the Source Update least squares solution. This is based on a k -sigma rejection algorithm.
- `bp/rp_standard_deviation` The final standard deviation of the Source Update least squares solution for this BP/RP and source.
- `bp/rp_chi_squared` The χ^2 of the Source Update least squares solution for this BP/RP and source.
- `bp/rp_coefficients` The array of coefficients of the mean spectrum representation as a superposition of basis functions. These are the $b_{s,n}$ in Eq. 4. This array will have length equal to `bp/rp_n_parameters`.
- `bp/rp_coefficient_errors` The errors on the coefficients, one error per coefficient. This array will have length equal to `bp/rp_n_parameters`. The errors in this array are computed multiplying the formal errors (as obtained from the covariance matrix of the source update least square solution) by the standard deviation of the solution. This is a standard methodology and can also account for when the modelling of the data introduces a systematic error that adds a pseudo-random error to the individual input data not accounted for in quoted errors.
- `bp/rp_coefficient_correlations` The matrix containing the information on correlations between coefficients. Only the elements located in the upper triangular section of the matrix, excluding the diagonal where all elements are equal to 1.0 by definition, are stored as an array of constant size $n(n-1)/2$ where n is equal to `bp/rp_n_parameters`.

The order of the elements in the linear array follows a column-major scheme, i.e. for $n = 55$,

$$\mathbf{M} = \begin{bmatrix} 1 & C[0] & C[1] & C[3] & C[6] & \cdots & C[1431] \\ & 1 & C[2] & C[4] & C[7] & \cdots & C[1432] \\ & & 1 & C[5] & C[8] & \cdots & C[1433] \\ & & & 1 & C[9] & \cdots & C[1434] \\ & & & & 1 & \cdots & \vdots \\ & & & & & 1 & C[1484] \\ & & & & & & 1 \end{bmatrix}$$

- `bp/rp_n_relevant_bases` Number of coefficients that were considered above the noise according to the criterion described in Sect. 3.4.3.
- `bp/rp_n_relative_shrinking` Ratio between the L2-norm of the truncated and full BP/RP spectrum.

In the following, we also describe the additional fields available in the `xp_summary` table (fields that duplicate information given in the above data structure are not repeated here):

- `bp/rp_n_transits` Number of epoch spectra contributing to the mean spectrum.
- `bp/rp_n_contaminated_transits` Number of transits assessed as contaminated among those that contributed to the mean spectrum. A transits is considered contaminated when some of the flux within the window is estimated to come from a nearby (on the focal plane) source located outside the acquired window. Crowding assessment for *Gaia* DR3 was based on the *Gaia* DR2 source catalogue. The contaminating flux was estimated as detailed in Sect. 3.1 in Riello et al. (2021).
- `bp/rp_n_blended_transits` Number of transits assessed as blended among those that contributed to the mean spectrum. A transit is considered blended when more than one source is within the acquires window. A transit is flagged as blended also when the non-target source is just outside the window (within five TDI periods in the AL direction and two pixels in the AC direction).

Appendix C: Bases configuration and spectrum sampling

The optimised bases finally adopted to represent the *Gaia* DR3 mean spectra are defined as an orthogonal transformation of the first N Hermite functions. The orthogonal transformations are different for BP and RP, and the $N \times N$ transformation matrices are denoted $\mathbf{V}_{BP}$ and $\mathbf{V}_{RP}$, respectively, where $N = 55$ for both. The two transformation matrices are embedded in the Python package *GaiaXPy*, which uses them when computing sampled mean spectra in the internal reference system. The same `xml` configuration file used in *GaiaXPy* is also available via Zenodo¹¹.

Users that prefer to use this file directly rather than relying on *GaiaXPy* will have to pay attention to the following:

- The file contains a `bpConfig` and an `rpConfig` element. Each configuration element is identified with a unique ID (`uniqueId`) which must agree with the `bp/rp_basis_function_id` parameter in the *Gaia* DR3 BP/RP spectral data.
- The ranges `range` and `normalizedRange` give the conversion rule from the pseudo-wavelength system to the argument of the Hermite functions. With reference to Eq. 4, the scaling factor Θ will be given by $\Theta = (r_+ - r_-)/(n_+ - n_-)$ while

the offset $\Delta\theta$ will be given by $\Delta\theta = r_- - n_- \cdot \Theta$ where $r_{\pm}$ and $n_{\pm}$ are used to indicate the higher (+) and lower (−) boundaries of the ranges `range` and `normalizedRange` respectively.

- The element `transformationMatrix` lists all matrix elements for $\mathbf{V}_{BP}$ and $\mathbf{V}_{RP}$, stored in a row-major scheme.

The sampled spectrum on a discrete grid of n pseudo-wavelengths $u = [u_i]_{i=1,\dots,n}$ is computed easily in a matrix formalism. First, the values of the first N Hermite functions are computed on the pseudo-wavelength grid and arranged into an $n \times N$ matrix $\mathbf{D}$. The elements of this matrix are

$$D_{i,j} = \varphi_{j-1} \left(\frac{u_i - \Delta\theta}{\Theta} \right). \quad (\text{C.1})$$

Multiplying this matrix with $\mathbf{V}_{BP/RP}^T$ from the right transforms from Hermite functions to the optimised Hermite basis. The sampled spectrum $f(u)$ is thus obtained as

$$f(u) = \mathbf{D} \mathbf{V}_{BP/RP}^T \mathbf{c}_{BP/RP}. \quad (\text{C.2})$$

The covariance matrix for $f(u)$, $\mathbf{C}^u$ is

$$\mathbf{C}^u = \mathbf{D} \mathbf{V}_{BP/RP}^T \mathbf{C}^{BP/RP} \mathbf{V}_{BP/RP} \mathbf{D}^T, \quad (\text{C.3})$$

with $\mathbf{C}^{BP/RP}$ the covariance matrix for the coefficient vector $\mathbf{c}_{BP/RP}$. Correlations might not be negligible in $\mathbf{C}^u$. In particular if $n > N$, $\mathbf{C}^u$ is singular.

If users desire to apply the suggested truncation, they will simply have to drop coefficient, coefficient error, and associated row/column in the correlation matrix with index larger than `bp/rp_n_relevant_bases`. Only the first `bp/rp_n_relevant_bases` columns of the `transformationMatrix` will be required.

Appendix D: The BP/RP split-epoch validation dataset

During the validation activities leading to *Gaia* DR3 (see Sects. 5.1 and 6.2) and in the preparation of Andrae et al. (2023) and *Gaia* Collaboration (2023c), one particular dataset was found to be very useful; it contains about 43 000 sources for which two mean spectra per source were generated using only about half of the available epoch spectra (randomly chosen to avoid possible problems due to the distribution in time of their observations). This dataset, referred to as BP/RP split-epoch validation dataset, is made available via Zenodo¹², in the same format used in the archive for mean BP/RP spectra (with the exception of the truncation-related parameters `bp/rp_n_relevant_bases` and `bp/rp_n_relative_shrinking` that will not be available). We hope the wider community will find this useful to assess the uncertainties of their particular science cases.

The source list for this dataset was initially defined as a selection of the flux and LSF calibrators but was later augmented to include more bright sources and to increase the number of sources in the magnitude range [11, 12], that is, around the boundary between 1D and 2D BP/RP configurations. The dataset covers the magnitude range $4.2 \leq G \leq 20.7$ mag and the colour range $-0.6 \leq G_{BP} - G_{RP} \leq 7.1$ mag. While the initial selection came from the set of calibrators that were selected to have at least ten usable FoV transits (thus leading to at least five transits when these are split in two groups, although the random generation of the two groups could in fact lead to smaller numbers), the following additions included also sources with fewer transits.

¹¹ <https://doi.org/10.5281/zenodo.6799330>

¹² <https://doi.org/10.5281/zenodo.6802733>

Moreover, the criterium based on the number of FoV transits for the selection of the calibrators was assessed on the number of usable observations and these were then subject to availability of calibrations and outlier rejection which could have the effect of decreasing the number of transits contributing to the mean spectrum below the quoted limit. This implies that this dataset contains mean spectra that have been generated from a number of transits that is lower to the limit adopted for the release. About 6 000 of these sources will not have BP/RP spectra in *Gaia* DR3, mostly because their magnitude is fainter than 17.65 (see Sect. 4). Nevertheless they were not excluded from this dataset as they provide an opportunity to probe uncertainties at fainter magnitudes where some BP/RP spectra are still released.

Users are strongly discouraged from trying to look for consistency in the number of transits and measurements between this dataset and the *Gaia* DR3 catalogue of BP/RP spectra: rejection and filtering at epoch and sample level will act differently depending on the list of transits available to the software.

Appendix E: Acronyms

Table E.1 lists the acronyms used in the paper. Each acronym is also defined at its first occurrence in the text.

Table E.1. Acronyms used in the paper.

Acronym	Description	See
AC	ACross scan direction	Sect. 2
AF	Astrometric Field	Sect. 2
AL	ALong scan direction	Sect. 2
BP	Blue Photometer	Sect. 1
CCD(s)	Charge Coupled Device(s)	Sect. 2
DPAC	Data Processing and Analysis Consortium	Sect. 1
DR	Data Release	Sect. 1
ESA	European Space Agency	Sect. 1
FoV(s)	Field(s) of View	Sect. 2
LSF	Line Spread Function	Sect. 2
OBMT	On-Board Mission Time	Sect. 2
OBMT-Rev	On-Board Mission Time in units of satellite revolutions	Sect. 2
RP	Red Photometer	Sect. 1
RVS	Radial Velocity Spectrometer	Sect. 1
SSC	Spectrum Shape Coefficient	Sect. 3.1
TDI	Time Delayed Integration	Sect. 2
WC(s)	Window Class or strategy	Sect. 2

Appendix F: Funding Agency Acknowledgements

This work presents results from the European Space Agency (ESA) space mission *Gaia*. *Gaia* data are being processed by the *Gaia* Data Processing and Analysis Consortium (DPAC). Funding for the DPAC is provided by national institutions, in particular the institutions participating in the *Gaia* MultiLateral Agreement (MLA). The *Gaia* mission website is <https://www.cosmos.esa.int/gaia>. The *Gaia* archive website is <https://archives.esac.esa.int/gaia>.

The *Gaia* mission and data processing have financially been supported by, in alphabetical order by country:

- the Algerian Centre de Recherche en Astronomie, Astrophysique et Géophysique of Bouzareah Observatory;

- the Austrian Fonds zur Förderung der wissenschaftlichen Forschung (FWF) Hertha Firnberg Programme through grants T359, P20046, and P23737;
- the BELgian federal Science Policy Office (BEL-SPO) through various PROgramme de Développement d’Expériences scientifiques (PRODEX) grants and the Polish Academy of Sciences - Fonds Wetenschappelijk Onderzoek through grant VS.091.16N, and the Fonds de la Recherche Scientifique (FNRS), and the Research Council of Katholieke Universiteit (KU) Leuven through grant C16/18/005 (Pushing AsteRoseismology to the next level with TESS, GaiA, and the Sloan Digital Sky Survey – PARADISE);
- the Brazil-France exchange programmes Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - Comité Français d’Evaluation de la Coopération Universitaire et Scientifique avec le Brésil (COFECUB);
- the Chilean Agencia Nacional de Investigación y Desarrollo (ANID) through Fondo Nacional de Desarrollo Científico y Tecnológico (FONDECYT) Regular Project 1210992 (L. Chemin);
- the National Natural Science Foundation of China (NSFC) through grants 11573054, 11703065, and 12173069, the China Scholarship Council through grant 201806040200, and the Natural Science Foundation of Shanghai through grant 21ZR1474100;
- the Tenure Track Pilot Programme of the Croatian Science Foundation and the École Polytechnique Fédérale de Lausanne and the project TTP-2018-07-1171 ‘Mining the Variable Sky’, with the funds of the Croatian-Swiss Research Programme;
- the Czech-Republic Ministry of Education, Youth, and Sports through grant LG 15010 and INTER-EXCELLENCE grant LTAUSA18093, and the Czech Space Office through ESA PECS contract 98058;
- the Danish Ministry of Science;
- the Estonian Ministry of Education and Research through grant IUT40-1;
- the European Commission’s Sixth Framework Programme through the European Leadership in Space Astrometry (ELSA) Marie Curie Research Training Network (MRTN-CT-2006-033481), through Marie Curie project PIOF-GA-2009-255267 (Space AsteroSeismology & RR Lyrae stars, SAS-RRL), and through a Marie Curie Transfer-of-Knowledge (ToK) fellowship (MTKD-CT-2004-014188); the European Commission’s Seventh Framework Programme through grant FP7-606740 (FP7-SPACE-2013-1) for the *Gaia* European Network for Improved data User Services (GENIUS) and through grant 264895 for the *Gaia* Research for European Astronomy Training (GREAT-ITN) network;
- the European Cooperation in Science and Technology (COST) through COST Action CA18104 ‘Revealing the Milky Way with *Gaia* (MW-Gaia)’;
- the European Research Council (ERC) through grants 320360, 647208, and 834148 and through the European Union’s Horizon 2020 research and innovation and excellent science programmes through Marie Skłodowska-Curie grant 745617 (Our Galaxy at full HD – Gal-HD) and 895174 (The build-up and fate of self-gravitating systems in the Universe) as well as grants 687378 (Small Bodies: Near and Far), 682115 (Using the Magellanic Clouds to Understand the Interaction of Galaxies), 695099 (A sub-percent

- distance scale from binaries and Cepheids – CepBin), 716155 (Structured ACCREtion Disks – SACCRED), 951549 (Sub-percent calibration of the extragalactic distance scale in the era of big surveys – UniverScale), and 101004214 (Innovative Scientific Data Exploration and Exploitation Applications for Space Sciences – EXPLORE);
- the European Science Foundation (ESF), in the framework of the *Gaia* Research for European Astronomy Training Research Network Programme ([GREAT-ESF](#));
 - the European Space Agency (ESA) in the framework of the *Gaia* project, through the Plan for European Cooperating States (PECS) programme through contracts C98090 and 4000106398/12/NL/KML for Hungary, through contract 4000115263/15/NL/IB for Germany, and through Programme de Développement d'Expériences scientifiques (PRODEX) grant 4000127986 for Slovenia;
 - the Academy of Finland through grants 299543, 307157, 325805, 328654, 336546, and 345115 and the Magnus Ehrnrooth Foundation;
 - the French Centre National d'Études Spatiales (CNES), the Agence Nationale de la Recherche (ANR) through grant ANR-10-IDEX-0001-02 for the 'Investissements d'avenir' programme, through grant ANR-15-CE31-0007 for project 'Modelling the Milky Way in the *Gaia* era' (MOD4Gaia), through grant ANR-14-CE33-0014-01 for project 'The Milky Way disc formation in the *Gaia* era' (ARCHEOGAL), through grant ANR-15-CE31-0012-01 for project 'Unlocking the potential of Cepheids as primary distance calibrators' (UnlockCepheids), through grant ANR-19-CE31-0017 for project 'Secular evolution of galaxies' (SEGAL), and through grant ANR-18-CE31-0006 for project 'Galactic Dark Matter' (GaDaMa), the Centre National de la Recherche Scientifique (CNRS) and its SNO *Gaia* of the Institut des Sciences de l'Univers (INSU), its Programmes Nationaux: Cosmologie et Galaxies (PNCG), Gravitation Références Astronomie Métrologie (PNGRAM), Planétologie (PNP), Physique et Chimie du Milieu Interstellaire (PCMI), and Physique Stellaire (PNPS), the 'Action Fédératrice *Gaia*' of the Observatoire de Paris, the Région de Franche-Comté, the Institut National Polytechnique (INP) and the Institut National de Physique nucléaire et de Physique des Particules (IN2P3) co-funded by CNES;
 - the German Aerospace Agency (Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR) through grants 50QG0501, 50QG0601, 50QG0602, 50QG0701, 50QG0901, 50QG1001, 50QG1101, 50QG1401, 50QG1402, 50QG1403, 50QG1404, 50QG1904, 50QG2101, 50QG2102, and 50QG2202, and the Centre for Information Services and High Performance Computing (ZIH) at the Technische Universität Dresden for generous allocations of computer time;
 - the Hungarian Academy of Sciences through the Lendület Programme grants LP2014-17 and LP2018-7 and the Hungarian National Research, Development, and Innovation Office (NKFIH) through grant KKP-137523 ('SeismoLab');
 - the Science Foundation Ireland (SFI) through a Royal Society - SFI University Research Fellowship (M. Fraser);
 - the Israel Ministry of Science and Technology through grant 3-18143 and the Tel Aviv University Center for Artificial Intelligence and Data Science (TAD) through a grant;
 - the Agenzia Spaziale Italiana (ASI) through contracts I/037/08/0, I/058/10/0, 2014-025-R.0, 2014-025-R.1.2015, and 2018-24-HH.0 to the Italian Istituto Nazionale di Astrofisica (INAF), contract 2014-049-R.0/1/2 to INAF for the Space Science Data Centre (SSDC, formerly known as the ASI Science Data Center, ASDC), contracts I/008/10/0, 2013/030/I.0, 2013-030-I.0.1-2015, and 2016-17-I.0 to the Aerospace Logistics Technology Engineering Company (ALTEC S.p.A.), INAF, and the Italian Ministry of Education, University, and Research (Ministero dell'Istruzione, dell'Università e della Ricerca) through the Premiale project 'Mining The Cosmos Big Data and Innovative Italian Technology for Frontier Astrophysics and Cosmology' (MITiC);
 - the Netherlands Organisation for Scientific Research (NWO) through grant NWO-M-614.061.414, through a VICI grant (A. Helmi), and through a Spinoza prize (A. Helmi), and the Netherlands Research School for Astronomy (NOVA);
 - the Polish National Science Centre through HARMONIA grant 2018/30/M/ST9/00311 and DAINA grant 2017/27/L/ST9/03221 and the Ministry of Science and Higher Education (MNiSW) through grant DIR/WK/2018/12;
 - the Portuguese Fundação para a Ciência e a Tecnologia (FCT) through national funds, grants SFRH/BD/128840/2017 and PTDC/FIS-AST/30389/2017, and work contract DL 57/2016/CP1364/CT0006, the Fundo Europeu de Desenvolvimento Regional (FEDER) through grant POCI-01-0145-FEDER-030389 and its Programa Operacional Competitividade e Internacionalização (COMPETE2020) through grants UIDB/04434/2020 and UIDP/04434/2020, and the Strategic Programme UIDB/00099/2020 for the Centro de Astrofísica e Gravitação (CENTRA);
 - the Slovenian Research Agency through grant P1-0188;
 - the Spanish Ministry of Economy (MINECO/FEDER, UE), the Spanish Ministry of Science and Innovation (MICIN), the Spanish Ministry of Education, Culture, and Sports, and the Spanish Government through grants BES-2016-078499, BES-2017-083126, BES-C-2017-0085, ESP2016-80079-C2-1-R, ESP2016-80079-C2-2-R, FPU16/03827, PDC2021-121059-C22, RTI2018-095076-B-C22, and TIN2015-65316-P ('Computación de Altas Prestaciones VII'), the Juan de la Cierva Incorporación Programme (FJCI-2015-2671 and IJC2019-04862-I for F. Anders), the Severo Ochoa Centre of Excellence Programme (SEV2015-0493), and MICIN/AEI/10.13039/501100011033 (and the European Union through European Regional Development Fund 'A way of making Europe') through grant RTI2018-095076-B-C21, the Institute of Cosmos Sciences University of Barcelona (ICCUB, Unidad de Excelencia 'María de Maeztu') through grant CEX2019-000918-M, the University of Barcelona's official doctoral programme for the development of an R+D+i project through an Ajuts de Personal Investigador en Formació (APIF) grant, the Spanish Virtual Observatory through project AyA2017-84089, the Galician Regional Government, Xunta de Galicia, through grants ED431B-2021/36, ED481A-2019/155, and ED481A-2021/296, the Centro de Investigación en Tecnologías de la Información y las Comunicaciones (CITIC), funded by the Xunta de Galicia and the European Union (European Regional Development Fund – Galicia 2014-2020 Programme), through grant ED431G-2019/01, the Red Española de Supercomputación (RES) computer resources at MareNostrum, the Barcelona Supercomputing Centre - Centro Nacional de Supercomputación (BSC-CNS) through activities AECT-2017-2-0002, AECT-2017-3-0006, AECT-2018-1-0017, AECT-2018-2-0013, AECT-2018-3-0011, AECT-2019-1-0010, AECT-2019-2-0014, AECT-2019-3-0003, AECT-2020-1-0004, and DATA-2020-1-0010, the Departament

d’Innovació, Universitats i Empresa de la Generalitat de Catalunya through grant 2014-SGR-1051 for project ‘Models de Programació i Entorns d’Execució Parallels’ (MPEXPAR), and Ramon y Cajal Fellowship RYC2018-025968-I funded by MICIN/AEI/10.13039/501100011033 and the European Science Foundation (‘Investing in your future’);

- the Swedish National Space Agency (SNSA/Rymdstyrelsen);
- the Swiss State Secretariat for Education, Research, and Innovation through the Swiss Activités Nationales Complémentaires and the Swiss National Science Foundation through an Eccellenza Professorial Fellowship (award PCEFP2_194638 for R. Anderson);
- the United Kingdom Particle Physics and Astronomy Research Council (PPARC), the United Kingdom Science and Technology Facilities Council (STFC), and the United Kingdom Space Agency (UKSA) through the following grants to the University of Bristol, the University of Cambridge, the University of Edinburgh, the University of Leicester, the Mullard Space Sciences Laboratory of University College London, and

the United Kingdom Rutherford Appleton Laboratory (RAL): PP/D006511/1, PP/D006546/1, PP/D006570/1, ST/I000852/1, ST/J005045/1, ST/K00056X/1, ST/K000209/1, ST/K000756/1, ST/L006561/1, ST/N000595/1, ST/N000641/1, ST/N000978/1, ST/N001117/1, ST/S000089/1, ST/S000976/1, ST/S000984/1, ST/S001123/1, ST/S001948/1, ST/S001980/1, ST/S002103/1, ST/V000969/1, ST/W002469/1, ST/W002493/1, ST/W002671/1, ST/W002809/1, and EP/V520342/1.

The GBOT programme uses observations collected at (i) the European Organisation for Astronomical Research in the Southern Hemisphere (ESO) with the VLT Survey Telescope (VST), under ESO programmes 092.B-0165, 093.B-0236, 094.B-0181, 095.B-0046, 096.B-0162, 097.B-0304, 098.B-0030, 099.B-0034, 0100.B-0131, 0101.B-0156, 0102.B-0174, and 0103.B-0165; and (ii) the Liverpool Telescope, which is operated on the island of La Palma by Liverpool John Moores University in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias with financial support from the United Kingdom Science and Technology Facilities Council, and (iii) telescopes of the Las Cumbres Observatory Global Telescope Network.