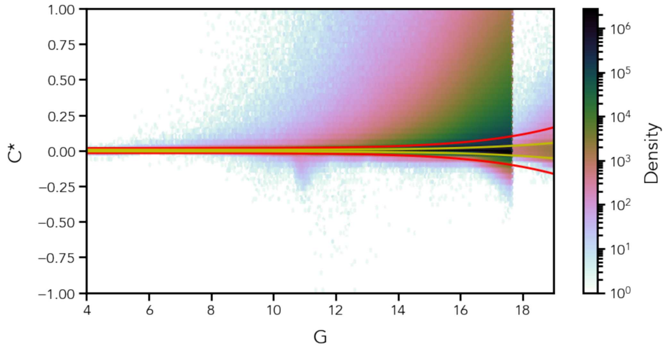

Fig. 30. Distribution of $C^{\star}$ vs. magnitude for all sources with BP/RP spectra in *Gaia* DR3. Also shown are the 1- and 3-σ curves in yellow and red, respectively, as defined in Riello et al. (2021).

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.

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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.

```python
from astroquery.gaia import GaiaClass

# Connect to Gaia archive
gaia = GaiaClass(gaia_tap_server='https://gea.esac.esa.int/', gaia_data_server='https://gea.esac.esa.int/')
gaia.login()

# Run your ADQL query to get a list of source_ids
example_query = "select TOP 1000 source_id from gaiadr3.gaia_source where has_xp_continuous = 'True'"
job = gaia.launch_job_async(example_query, dump_to_file=False)
ids = job.get_results()

# Now retrieve the BP/RP mean spectra in the continuous representation
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)

# Result will be a dictionary, so you can check the available keys by running result.keys()
# In this example we are looking in particular for the XP_CONTINUOUS_RAW key
continuous_key = [key for key in result.keys() if 'continuous' in key.lower()][0]
# The first element is the result we want as an Astropy table
data = result[continuous_key][0]
# Astropy has a 'write' method for tables
# Write the table to CSV
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 ($Nside = 4096$), which divides the sky into $\simeq 200$ 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 Zenodo[11].

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 $u = [u_i]_{i=1,...,n}$ 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 $\mathbf{V}^{\mathsf{T}}_{BP/RP}$ from the right transforms from Hermite functions to the optimised Hermite basis. The sampled spectrum $f(u)$ is thus obtained as

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

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

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

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 Zenodo[12], 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 $4.2 \le G \le 20.7$ mag and the colour range $-0.6 \le G_{\rm BP} - G_{\rm RP} \le 7.1$ 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

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