Gaia: Ten Years of Surveying the Milky Way and Beyond

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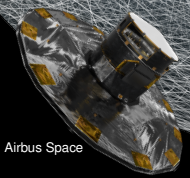
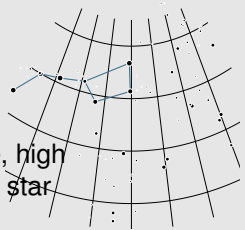


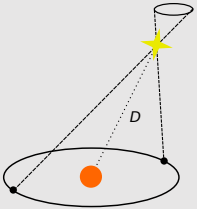
Airbus Space

ESA/Gaia/DPAC

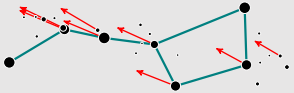
Gaia collects fundamental astronomical data

All-sky, complete, high accuracy star atlas

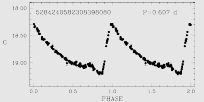


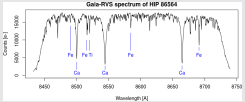


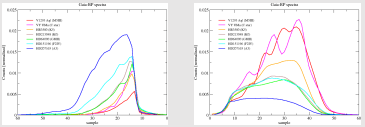
Parallaxes and proper motions

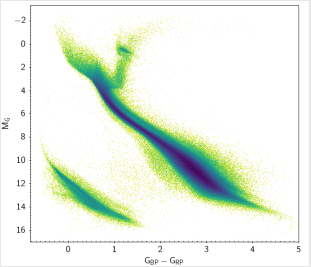


Astrometric, photometric, spectroscopic, radial velocity time series









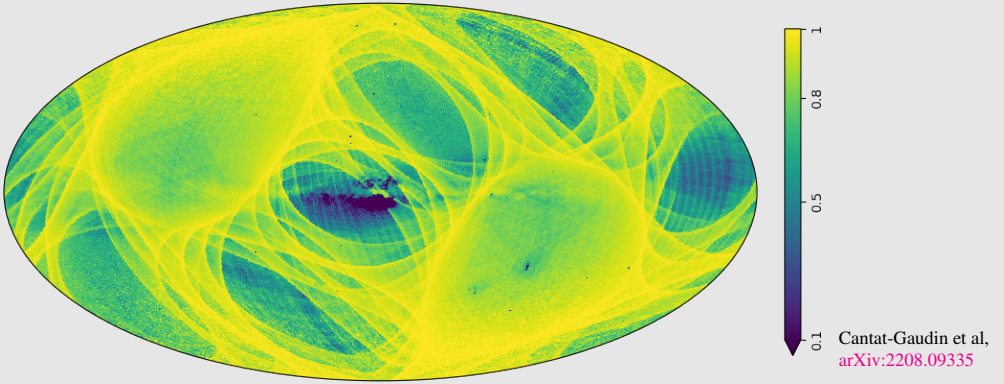
Astrophysical properties

GaiaUnlimited

Funded by the European Union's Horizon 2020 research and innovation program under grant agreement No 101004110

GaiaUnlimited: selection function tools for your science

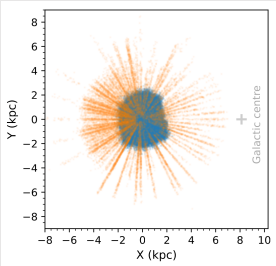
Completeness at $G = 20.9$

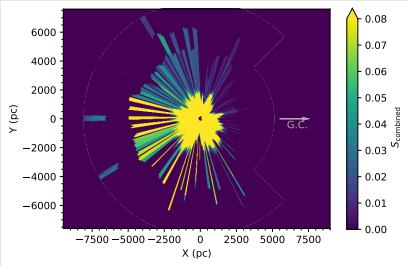


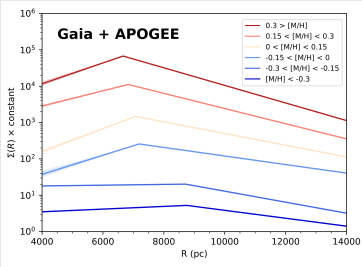
Cantat-Gaudin et al,
arXiv:2208.09335

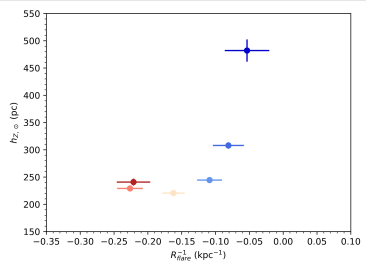
- https:/gaia-unlimited.org
- https://github.com/gaia-unlimited
- https://gaiaunlimited.readthedocs.io

Milky Way disk with Gaia-GSP-Spec/APOGEE combination





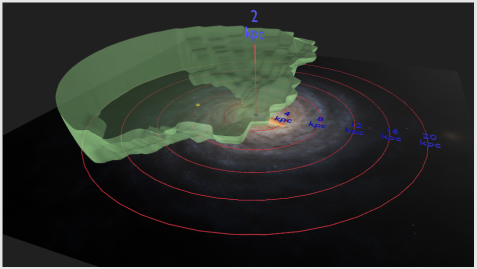


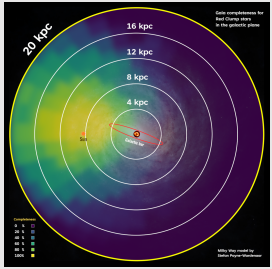


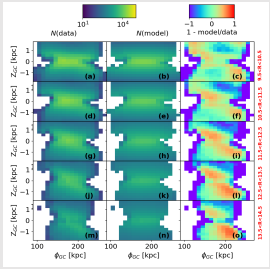
- Selection functions constructed for Red Clump stars: APOGEE DR17, GSP-Spec, and combination
- Joint sample used to study density profile of mono-abundance populations in different metallicity ranges
- Density profiles steepen with metallicity
- Metallicity-dependent flaring of $[\alpha/\mathrm{Fe}] < 0.1$ disk

Cantat-Gaudin et al,
arXiv:2401.05023

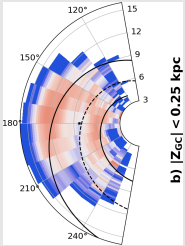
The disk in Red Clump stars from Gaia+AllWISE





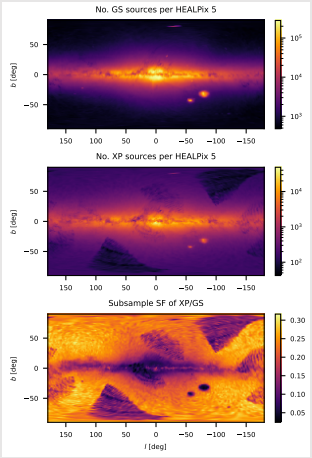


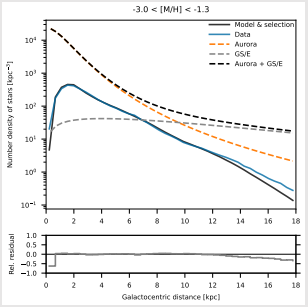
- Construction of combined Gaia+AllWISE selection function for Red Clump stars
- Disk structure for this sample: flared thin disk + shorter/thicker disk with no flare
- Outer disk shows clear signs of the warp
- Model + selection function residuals near disk plane show hints of spiral arms

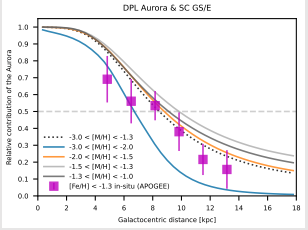


Khanna et al,
arXiv:2410.22036

Aurora and Gaia-Enceladus from XP-based RGB sample



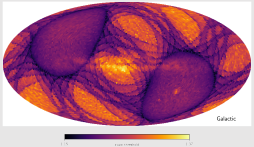




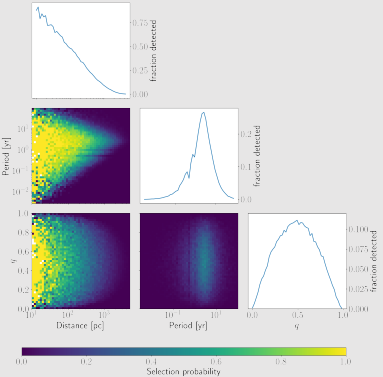
Kurbatov et al,
arXiv:2410.22250

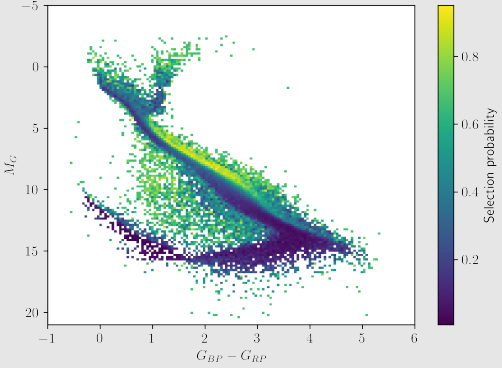
- Metal poor RGB stars, selection function: $G < 16$, $\varpi > 4\sigma_{\varpi}$, metallicities from XP spectra
- Density + luminosity function + extinction model for Aurora and Gaia-Enceladus populations
- Model predicts observables, accounting for selection function and parallax uncertainties
- Fairly complex model available in Python/Jupyter from GaiaUnlimited repository

Binaries selected on the basis of RUWE



- Sky-dependent RUWE threshold for selecting candidate binary stars
- Translation to selection effects on underlying binary orbital parameters
- Tools available to simulate selection effects for your favourite binary population



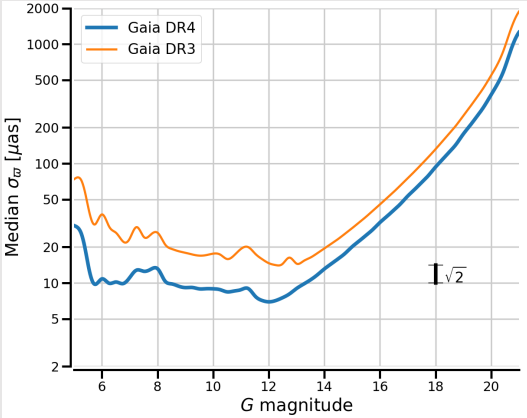


Castro-Ginard et al,
arXiv:2404.14127

Gaia DR4 Preview

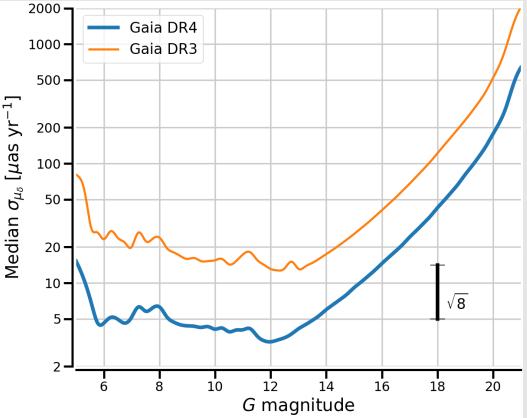
Gaia DR4 astrometric uncertainties (median value vs. G)

Parallax



expected improvement surpassed for $G < 13$

Proper motion

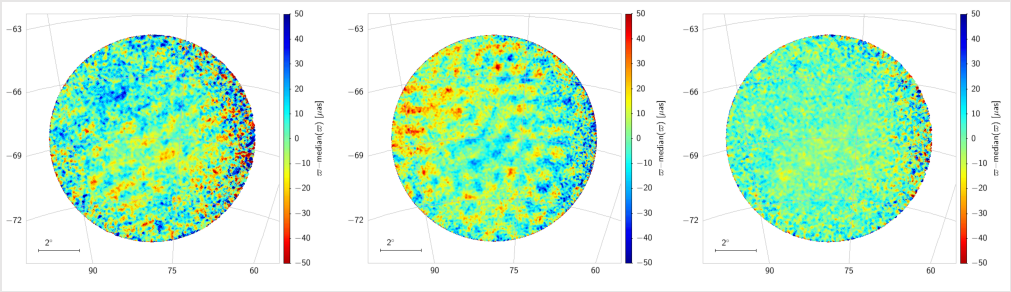


DPAC/ CU3/ AGIS/ DPCE team

expected improvement reached for all G

Astrometric solution quality

Reduced parallax systematic errors in LMC region



DPAC/ CU3/ AGIS/ DPCE team

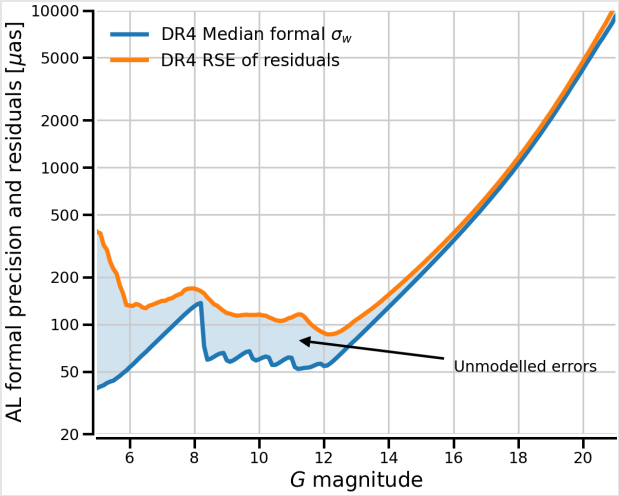
Gaia DR3

DR3 code applied to DR4 data

Gaia DR4: after extensive optimization of calibration models

- Quality of the astrometric solution significantly improved with respect to Gaia DR3
- Extra astrometric solutions for additional sources in nine pre-selected crowded regions
- Brand-new data product: epoch astrometry
  - Will allow all consumers to reproduce and/or modify astrometric solutions
  - Users can change: source model, transit selection, error model (weights), source selection

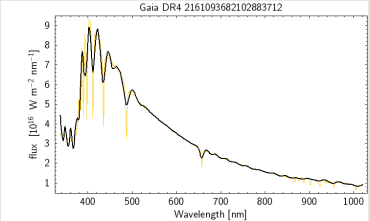
Epoch astrometry uncertainties

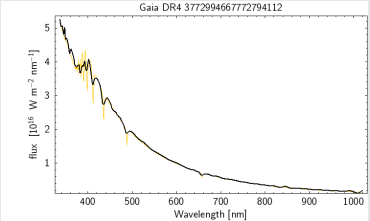


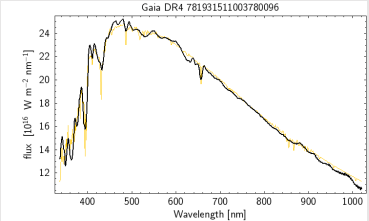
DPAC/ CU3/ AGIS/ DPCE team

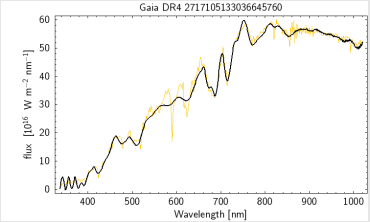
- Gaia DR4 formal per CCD astrometric uncertainties ~ 50 μas at $G \lesssim 13$ (~ 15 μas averaged over 9 CCDs)
- **But:** total uncertainties limited by calibration errors to $\sim$ 80–150 μas (30–50 μas averaged over 9 CCDs)

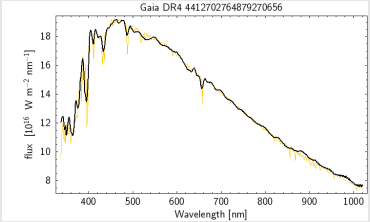
Example XP spectra for spectrophotometric standard stars





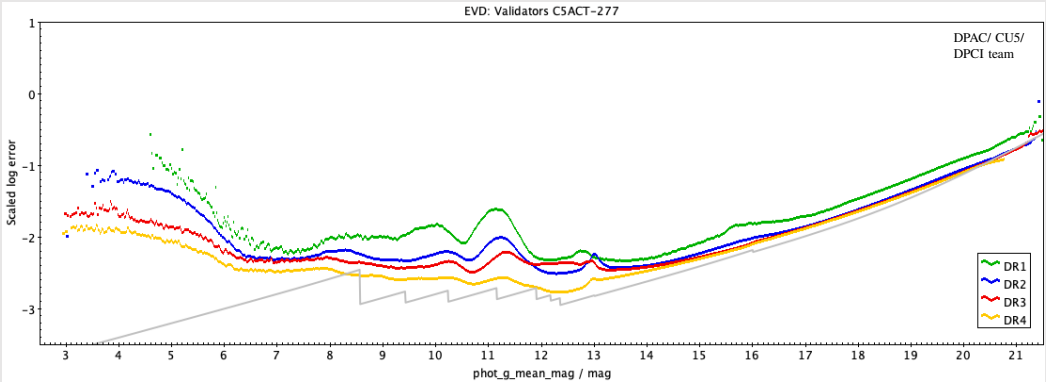






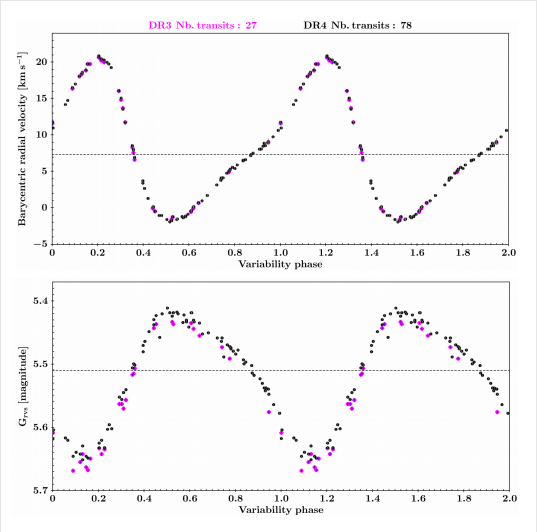
DPAC/ CU5/
DPCI team

Photometric uncertainties across releases



- Uncertainties are scaled to single CCD transit
  - shows the improvements in photometric processing from one release to the next
- The uncertainties on the means will include the effect increasing number of observations

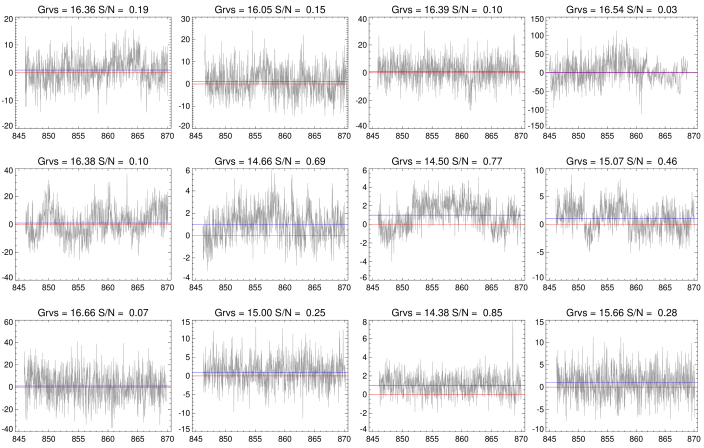
Gaia DR4 radial velocities



- Gaia DR4 includes time series for all bright sources ($G_{\mathrm{RVS}} < 14$)
- Figure shows example of pulsational RV variations for a Cepheid variable

DPAC/ CU6/
DPCC team

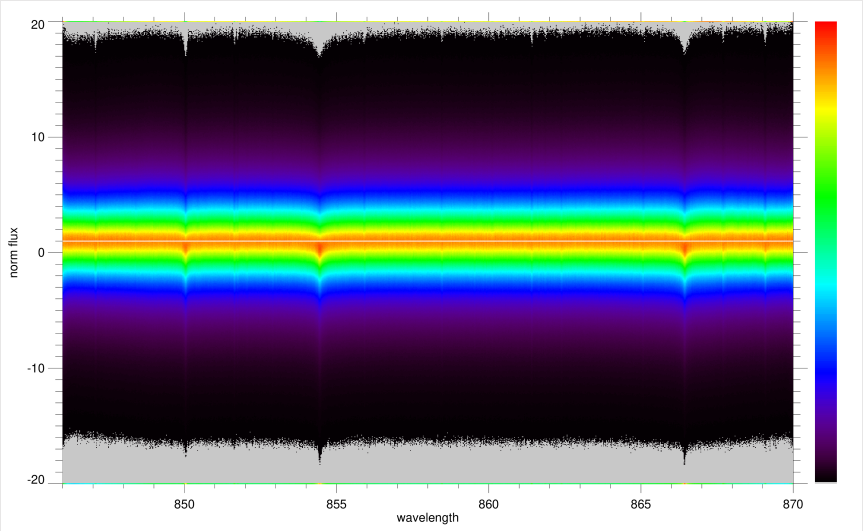
Gaia DR4 faint source spectroscopy



- RVS epoch spectra are processed up to the faintest possible magnitudes.
- At the faint end, an epoch spectrum has a very low S/N, typically < 1.0

These are normalized spectra. Red line: zero-level. Blue line: continuum (1.0). DPAC/ CU6/ DPCC team.

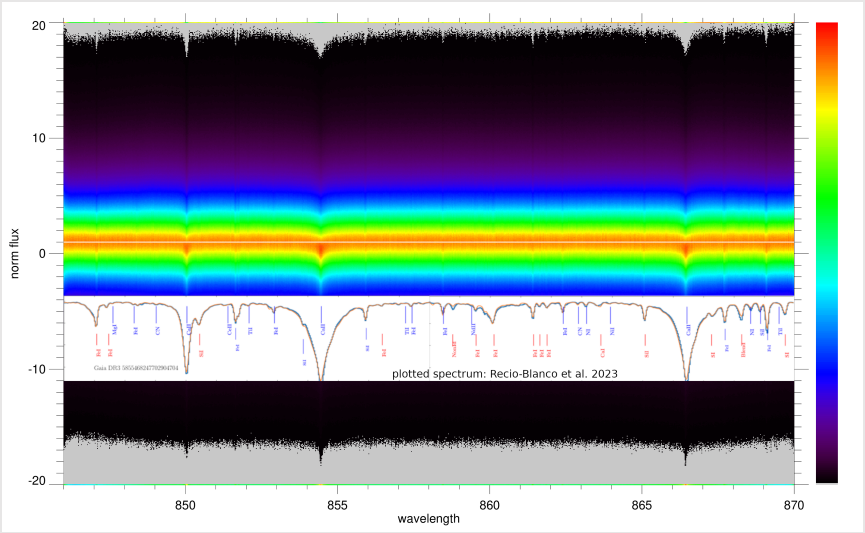
Gaia DR4 faint source spectroscopy



Combining a large number of spectra clearly shows the presence of the spectral lines in the RVS range.

Approximately 6 million faint ($G_{\mathrm{RVS}} > 14$) spectra are combined here. The colour scale shows the number density of the fluxes at each wavelength bin. DPAC/ CU6/ DPCC team.

Gaia DR4 faint source spectroscopy

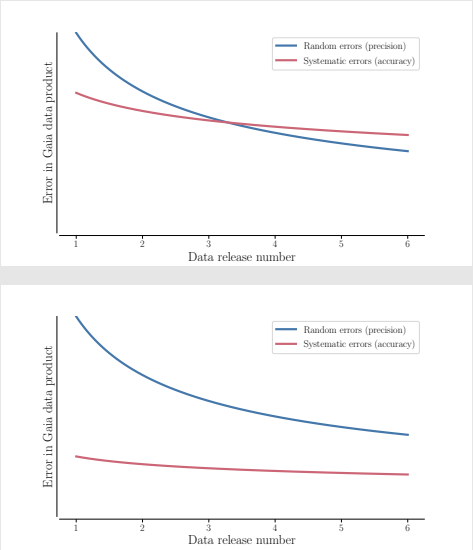


Not only the calcium lines are present, but also much weaker spectral lines, as the comparison with a high S/N spectrum shows.

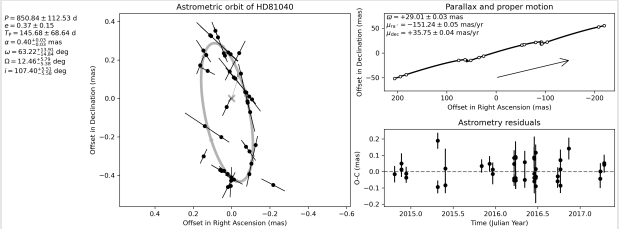
DPAC/ CU6/
DPCC team

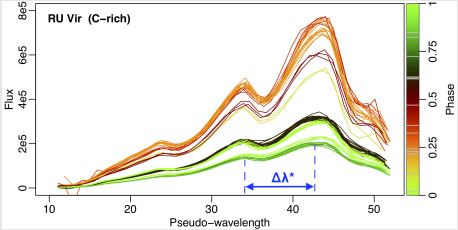
Gaia DR4 schedule

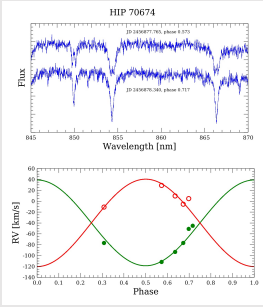
- Core processing pipelines will finish data production soon (astrometry, photometry, spectroscopy)
- Next: non-single stars (including exoplanets), extragalactic contents, astrophysical parameters, variability analysis, solar system objects
- All teams need time to understand and reduce systematic errors that show up at increased precision levels.
- Gaia DR4 not before mid-2026

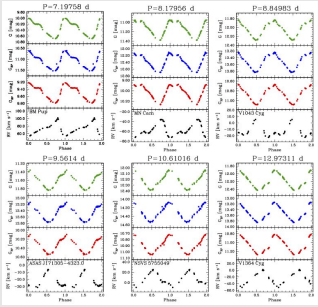


Gaia DR4: time series data for all sources!









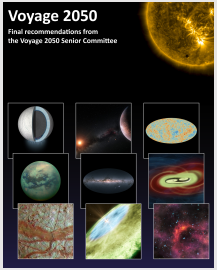
DR4 will contain $\sim$ 2.5 billion sources

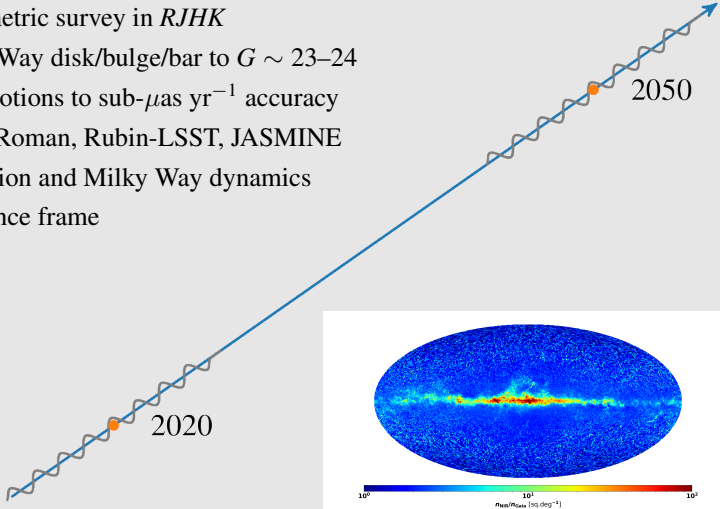
- Epoch astrometry
- Light curves
- Radial velocity time series
- XP spectra time series
- RVS spectra time series

Switch to Infrared

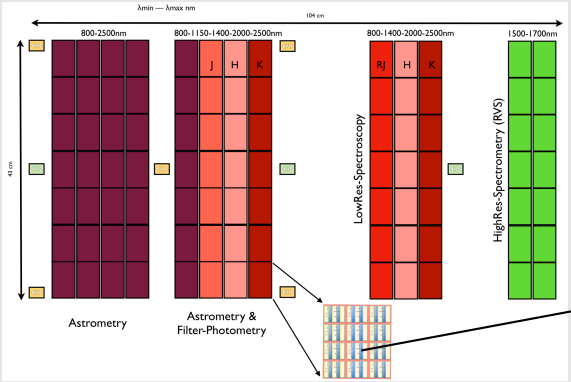
The Galactic Ecosystem with Astrometry in the Near-infrared

- All sky astrometric and photometric survey in *RJHK*
- $>$ 10 billion stars in the Milky Way disk/bulge/bar to $G \sim 23$–24
- Combined with Gaia: proper motions to sub-μas yr^{-1} accuracy
- Similar synergies with Euclid, Roman, Rubin-LSST, JASMINE
- Direct link between star formation and Milky Way dynamics
- Maintenance of celestial reference frame

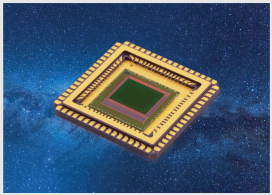




GaiaNIR design evolution



Hobbs et al., in prep.

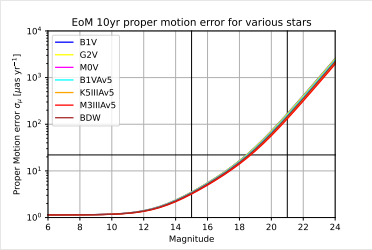


Leonardo SAPHIRA
320 × 256 pixel APD

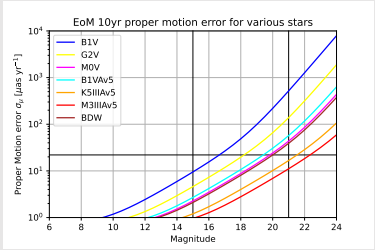
- Detectors: avalanche photodiode arrays: high frequency readout, very low read-out noise
- Low and high resolution spectroscopy: astrophysical parameters and radial velocities
  - The spectra are an essential part of the success of Gaia
- Exploring segmented 3-m sized mirrors to overcome crowding in Milky Way disk

GaiaNIR performance

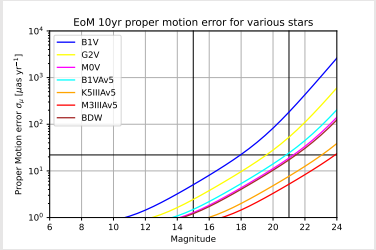
Gaia 10 yr



GaiaNIR 1.7 m mirror, 10 yr



GaiaNIR 3.4 m mirror, 10 yr

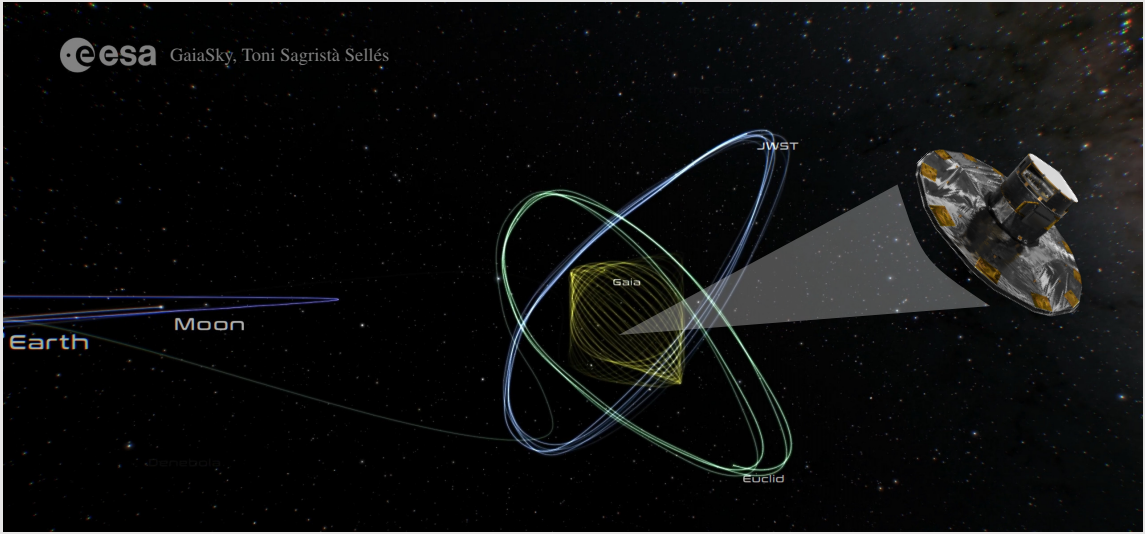


Hobbs et al., in prep.

- APDs are game-changer for GaiaNIR
- TDI mode observations are possible, simplifying design and calibrations
- Low read-out noise leads to better performance than Gaia for similar mirror size
- Segmented 3+ m mirror leads to significantly better performance and also mitigates crowding

Almost there. . .

Launch 19.12.2013, end of observations 15.01.2025



https://www.cosmos.esa.int/web/gaia/end-of-observations

Gaia data is brought to you by

Please credit the team!

- Cite the data release and data processing papers
- https://gea.esac.esa.int/archive/documentation/credits.html