The Gaia mission and stellar physics

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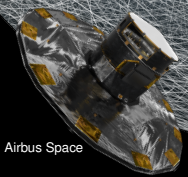


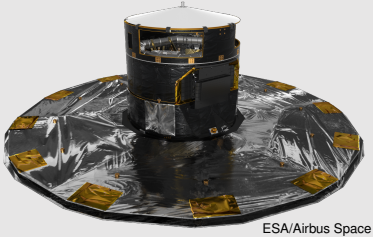
Airbus Space

ESA/Gaia/DPAC

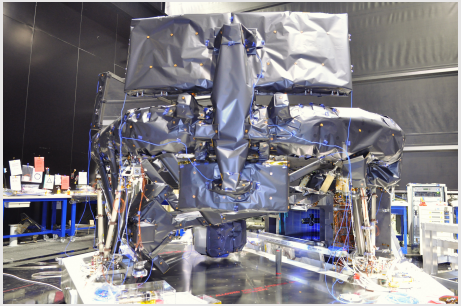
Gaia summary

- Astrometry and spectrophotometry for >1 billion objects
- Radial velocities for >100 million objects
- Survey
  - Complete to $G = 20.7$ ($V = 20$–22)
  - Observing programme: autonomous on-board detection and unbiased
  - Quasi-regular time-sampling over 5 years (~ 70 observations)
- Launch December 2013
- Operational at L2 since July 2014

- Gaia end-of-life estimated at early 2025
- Mission extended to end 2022
- With indicative approval to 2025



ESA/Airbus Space



Status of the Gaia mission

Spacecraft and payload

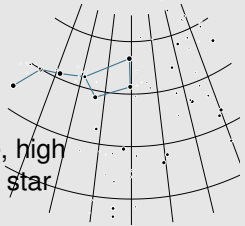
- All instruments in good shape, no concerns
- Radiation damage to CCDs steadily increasing but still factor ~ 6 below pre-launch predictions
- Micro-propulsion fuel estimated to run out by early 2025 $\rightarrow$ end of mission

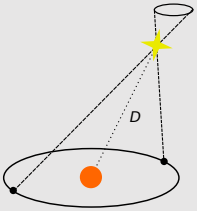
Extended mission

- Gaia mission is formally extended to end 2022
- Indicate approval given for extension to end 2025
  - formal decision expected early 2023
- Gaia DR4 data processing started
  - will include 66 months of data
  - scheduled not before the end of 2025
- Gaia DR5 will be based on full extended mission $\rightarrow$ 10+ years of data
  - schedule TBD

Gaia collects fundamental astronomical data

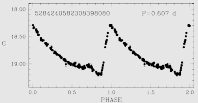
All-sky, complete, high accuracy star atlas

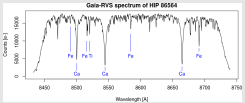


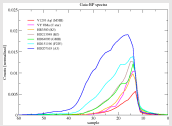


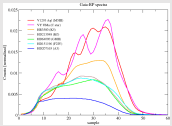
Parallaxes and proper motions

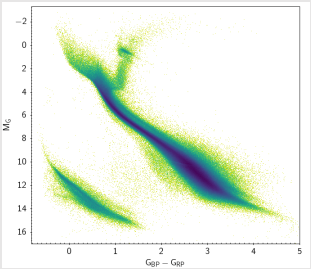
Astrometric, photometric, spectroscopic, radial velocity time series





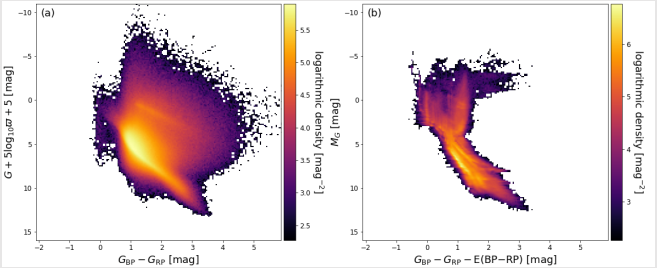






Astrophysical properties

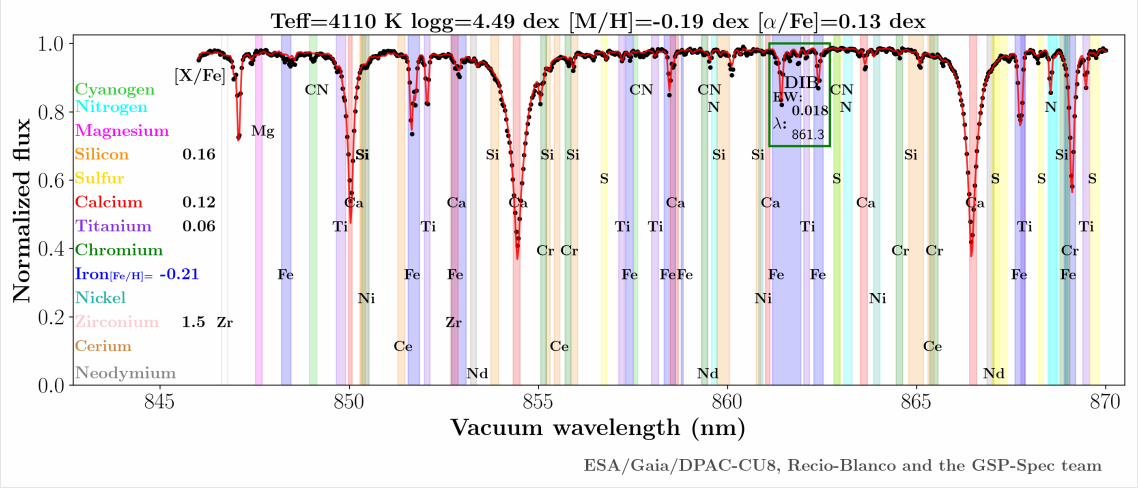
Astrophysical parameters for 471 million stars



- $T_{\rm eff}$, $\log g$, [M/H], A_G, $E(G_{\rm BP} - G_{\rm RP})$, stellar radius, distances from BP/RP spectra
- mass, age, evolutionary stage (128 million stars)
- $2500 < T_{\rm eff} < 55\,000$ K
- $0 < A_G < 10$
- $G < 19$

See webinar on Gaia DR3 astrophysical parameters

Astrophysical parameters and chemical compositions from RVS spectra

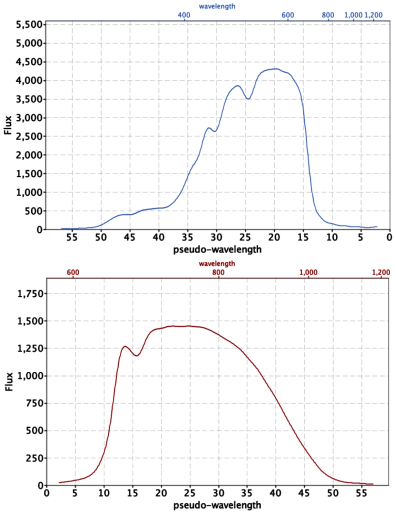


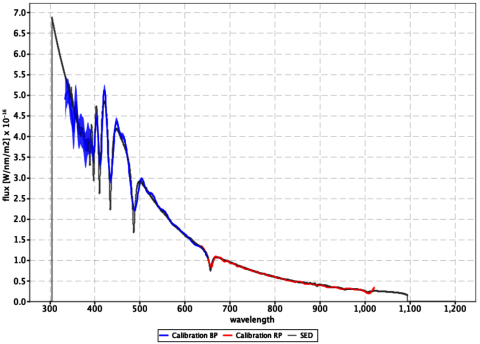
- Astrophysical parameters for 5.6 million sources, DIB parameters for 472 000 sources
- chemical abundances for 2.5 million sources (up to 13 species)
- Spectra for 1 million sources, covering a range of SNR

Recio-Blanco et al, arXiv:2206.05541

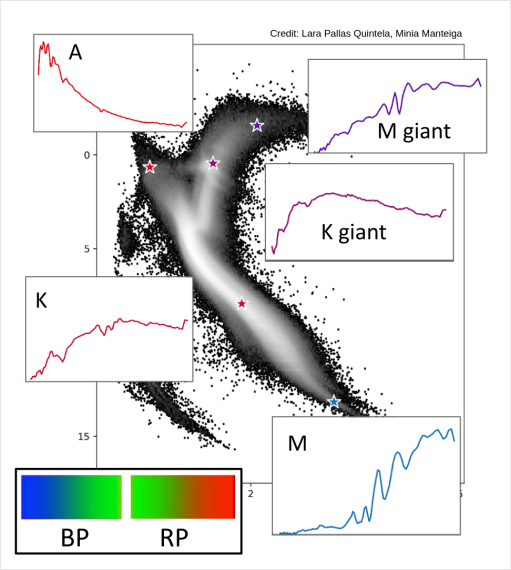
Low resolution spectra

219 million BP/RP spectra, mostly at $G < 17.65$
Tool for working with the spectra: https://gaia-dpci.github.io/GaiaXPy-website/



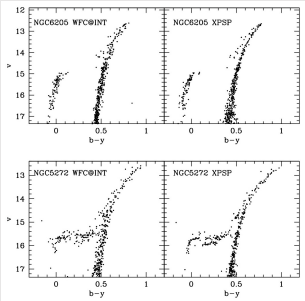


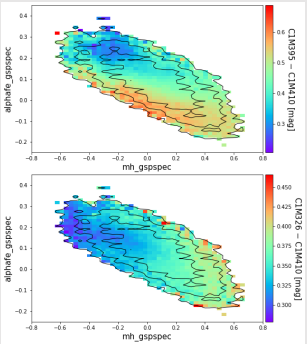
Low resolution spectra



De Angeli et al, arXiv:2206.06143; Montegriffo et al, arXiv:2206.06205

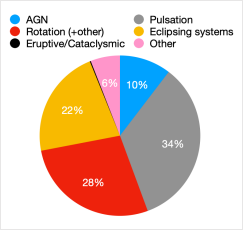
The Galaxy in your preferred colours



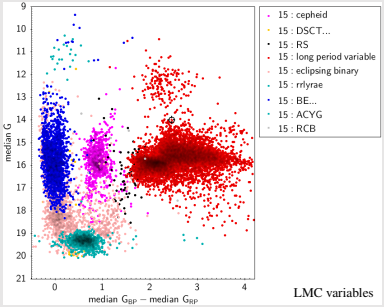


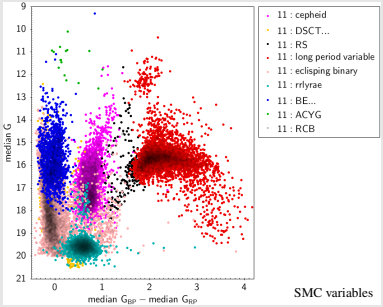
- Precise synthetic photometry can be calculated from the BP/RP spectra
- All-sky, precise (mmag), homogeneous
- GaiaXPy: synthetic photometry for arbitrary optical bands
- Data analysis with taylored passbands, testing of not yet existing photometric passbands
- Catalogue of precomputed synthetic photometry available in Gaia archive

Variable sources



- 10.5 million variable sources with light curves
- 24 variability types
- DPAC papers: see list at
  https://www.cosmos.esa.int/web/gaia/dr3-papers

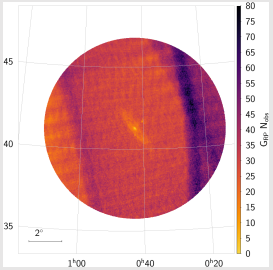


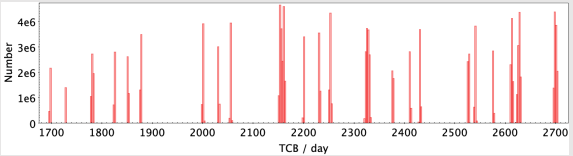


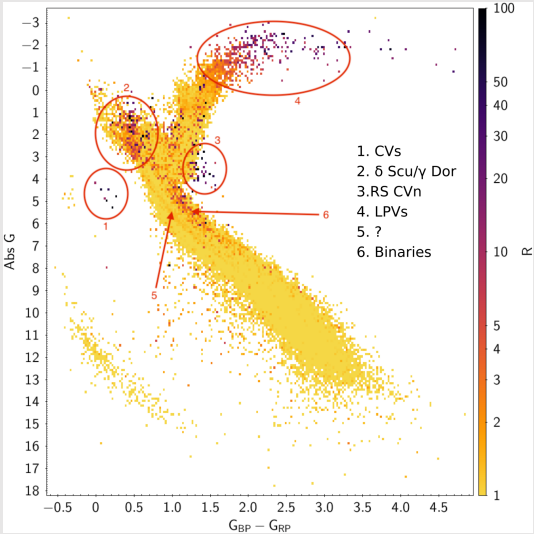
Gaia Andromeda Photometric Survey (GAPS)

- G/ G_{BP}/ G_{RP} time series for all 1.3 million sources in 5.5° radius around M31
- Well populated Milky Way CMD, M31 sources

- Diversity of scanning conditions
- Validate searches for variables using `gaia_source` fields
- Taster for Gaia DR4



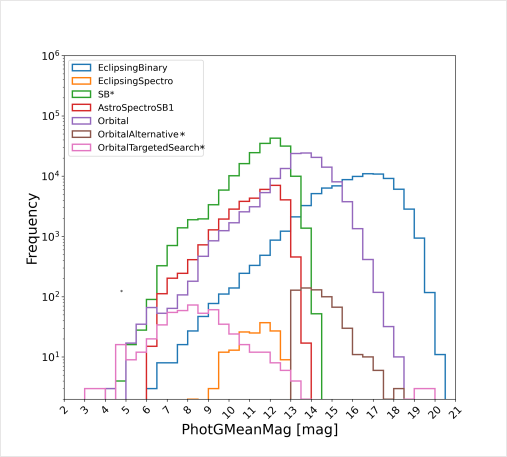


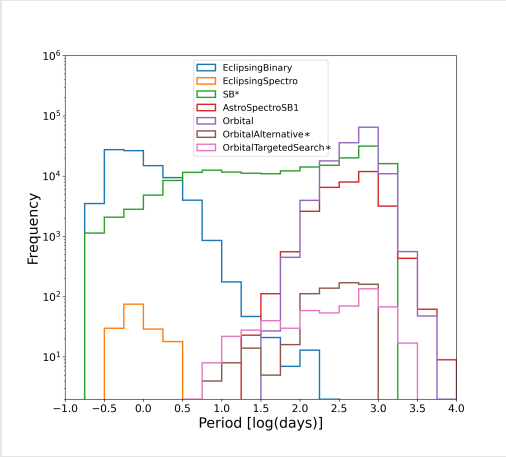


Non-single stars

- Read Gaia Collaboration, Arenou et al (arXiv:2206.05595) for a detailed assessment, and guidance on the use, of the Gaia DR3 non-single star contents
- Types available: orbital solutions, non-linear proper motions, non-linear RV trends, variability induced movers
- For substellar objects (low S/N solutions) look for orbital solutions $\rightarrow$ solution type 'OrbitalAlternative' and 'OrbitalTargetedSearch' (known systems)
  - Details in Holl et al (arXiv:2206.05439)
- Astrometric orbits in terms of Thiele-Innes elements
  - See Halbwachs et al (arXiv:2206.05726) for details
  - Be careful when transforming to more familiar elements (a, i, ω, Ω), see Babusiaux et al (arXiv:2206.05989) for details

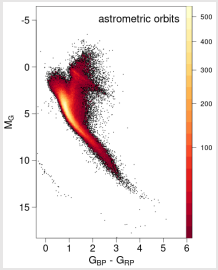
Non-single stars

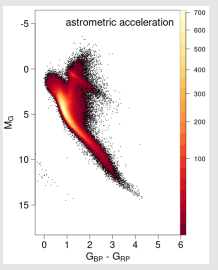


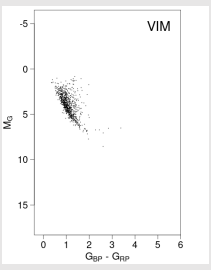


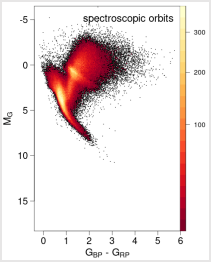
Gaia Collaboration, Arenou et al, arXiv:2206.05595

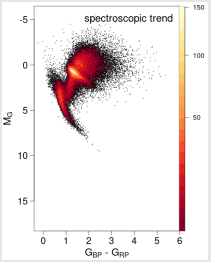
Non-single stars

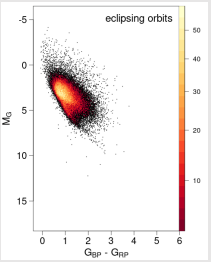










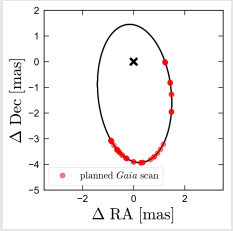


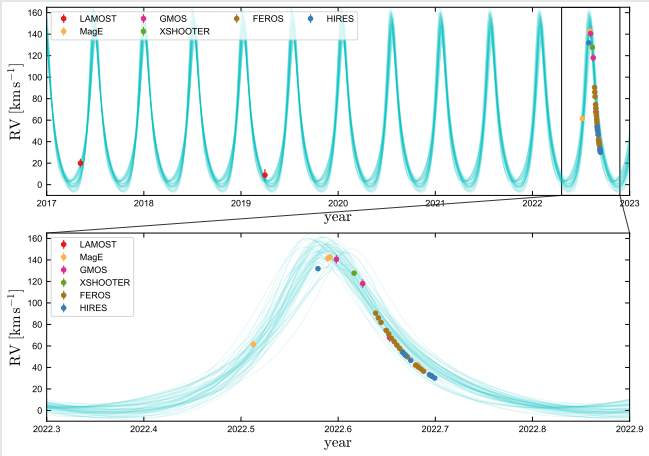
Gaia Collaboration, Arenou et al, arXiv:2206.05595

Gaia BH1

- BH candidate identified through high value of $4\pi/(P^2G)(a_0/\varpi)^3$
- Astrometric solution was considered doubtful by DPAC
  - Period three times Gaia spin axis precession period, high σ_{a_0}, σ_{ϖ}
- RV follow-up validates Gaia solution
  - RV curve alone sets lower limit of 5 $M_\odot$ on M_2
- $9.8 \pm 0.2\ M_\odot$ black hole orbited by solar type star!
- Independently discovered by Chakrabarti et al (arXiv:2210.05003)

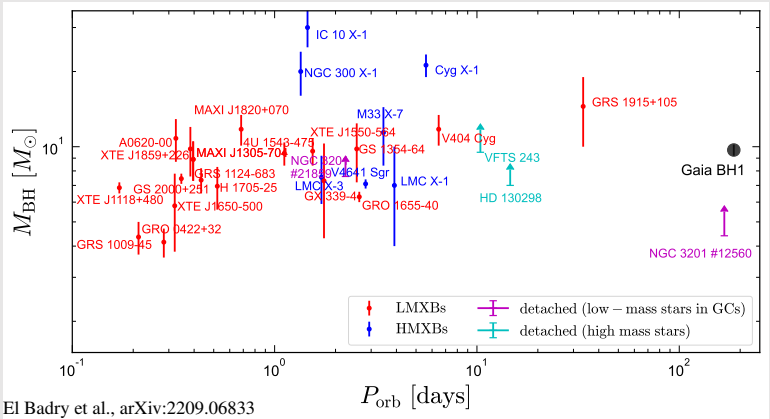
$P_{\rm orb} = 185.63 \pm 0.05$ d
$a = 1.41 \pm 0.01$ au
$e = 0.454 \pm 0.005$





El Badry et al., arXiv:2209.06833

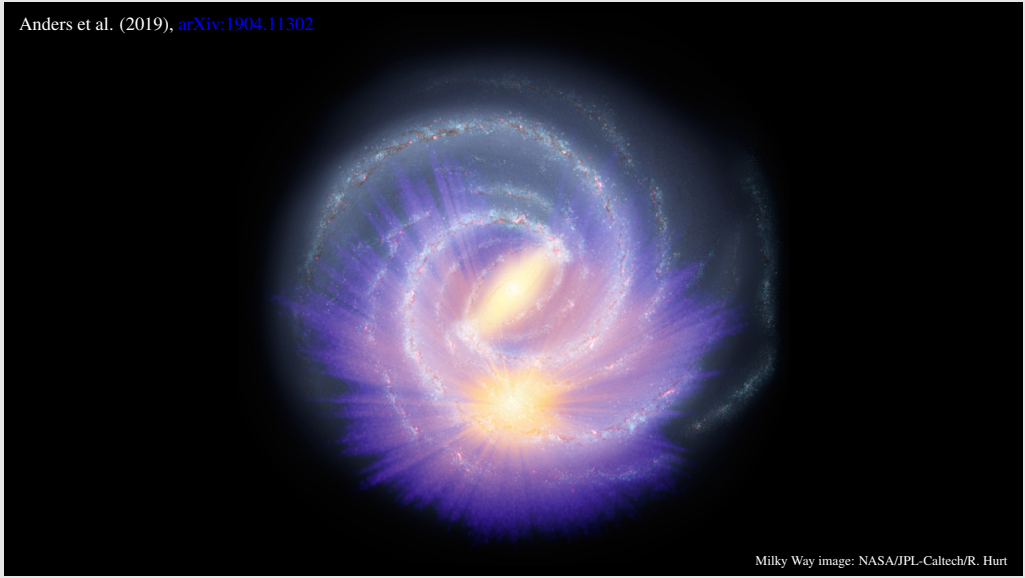
Gaia BH1



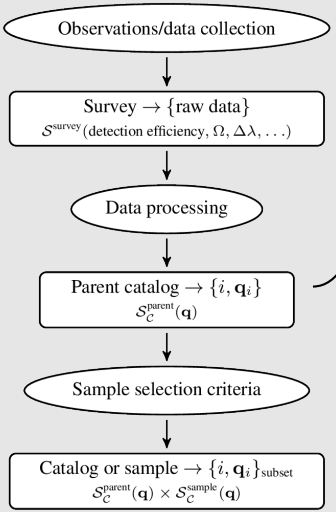
El Badry et al., arXiv:2209.06833

- Unique system among the known black holes: solar type star on wide orbit around dormant BH
- Evolutionary path to make such systems is unclear
- Gaia DR4 may uncover dozens more cases

GaiaUnlimited: the Gaia survey selection function



GaiaUnlimited: the Gaia survey selection function



$\mathcal{S}_{\mathcal{C}}(\boldsymbol{q}_i)$: probability that source i with observables $\boldsymbol{q}_i$ is contained in catalogue or sample $\mathcal{C}$

GaiaUnlimited will provide:

- Selection function of parent Gaia catalogue
  - all sources with $\boldsymbol{q}_i = \{\alpha_i, \delta_i, G_i, \ldots\}$
- Selection function for subsets
  - 5-parameter astrometry, radial velocity, RUWE $< x$, ...
- Selection functions for combinations of Gaia and other surveys
  - Photometric and spectroscopic surveys
- Examples of specific Gaia selection functions
  - For example: binaries, Cepheid variables

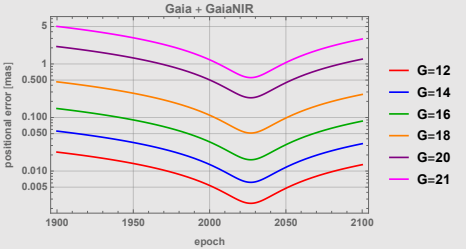
References: Rix et al., 2021; Cantat-Gaudin et al.

Web: https://github.com/gaia-unlimited/gaiaunlimited; https://gaia-unlimited.org/

GaiaNIR proposal

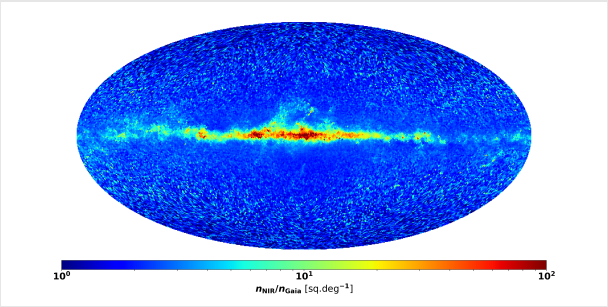
ESA Voyage 2050 Senior Committee recommendation: Focus on ‘Characterisation of Temperate Exoplanets’ and ‘Galactic Ecosystem with Astrometry in the Near-infrared’

- GaiaNIR: Gaia-type mission covering optical to near-IR
  - overlap with Gaia wavelength range; long time baseline proper motions accurate to better than few μas yr^{-1}
  - dense phase space sampling of obscured regions
  - direct observations of link between star formation and Milky Way structure and dynamics
  - synergy with SDSS-V, Roman telescope, Euclid, …
  - reference maintenance
- Challenges
  - TDI/drift-scanning in the near-infrared
  - if not possible, how to realize a revolving scanning mission without TDI-capable detectors
- See https://ui.adsabs.harvard.edu/abs/2021ExA...tmp...16H



Hobbs et al. 2021

What will GaiaNIR observe?



- Star count ratio between GaiaNIR and Gaia gives 5 times more stars for a H-band limit of 20th mag and 6 times more stars for a K-band limit of 20th mag
  - About 10 or 12 billion stars for H or K-band cut-offs.
- The star count ratio in the disk is uncertain due the extinction model used (older models give a ratio of 3 instead of 5)
- This uncertainty is a key science case in itself that cannot be resolved by Gaia alone

GaiaNIR detector status

Options for TDI operation are Gaia-like CCDs with wavelength range extended to $\sim$ 1400–1800 nm, or Avalanche Photodiodes (APDs) operating over range 800–2500 nm (up to 3500 nm)

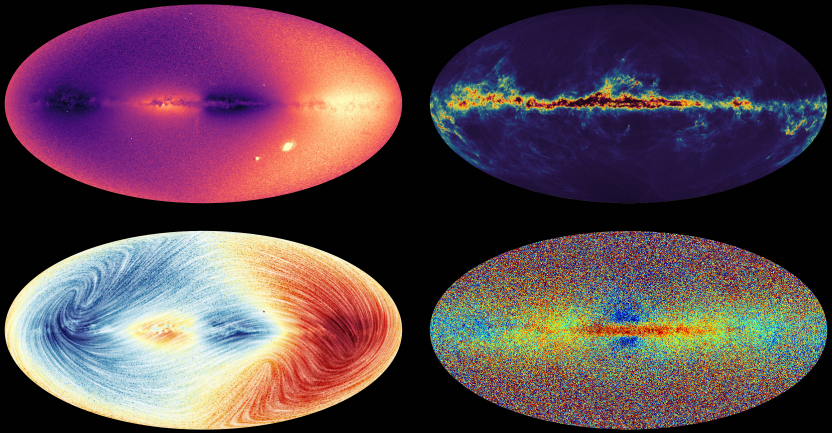
- For Gaia CCDs we reproduce the nominal Gaia accuracy
- For APDs we get better astrometric performance for several reasons
  - Reverting back to optimal scanning law parameters (e.g. sun aspect angle, scan rate, etc.)
  - Broader wavelength range more than compensates for longer observing wavelength
  - Lower read noise and lower background noise are game changers for astrometry!
- Instead of going to longer (i.e. to 3500 nm) wavelengths it may better to go fainter
- The combinations of these improvements results in a new mission that can outperform Gaia!
- Radial velocity spectrograph possible with APD detectors and slow scan rate for part of the mission
  - could give a revolutionary deep all-sky astrometric and RV/chemistry survey!

Community building to start soon: get in touch if you want to contribute

More detailed presentation: https://doi.org/10.5281/zenodo.7068309

Gaia data is brought to you by

GAIA: EXPLORING THE MULTI-DIMENSIONAL MILKY WAY



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