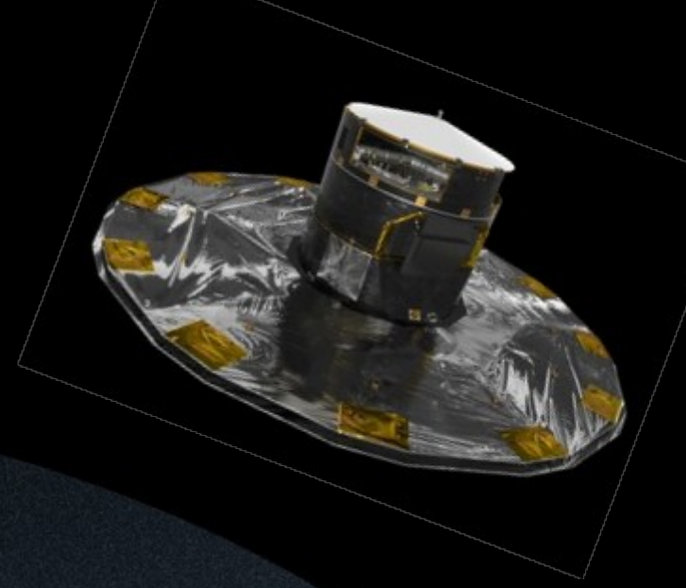
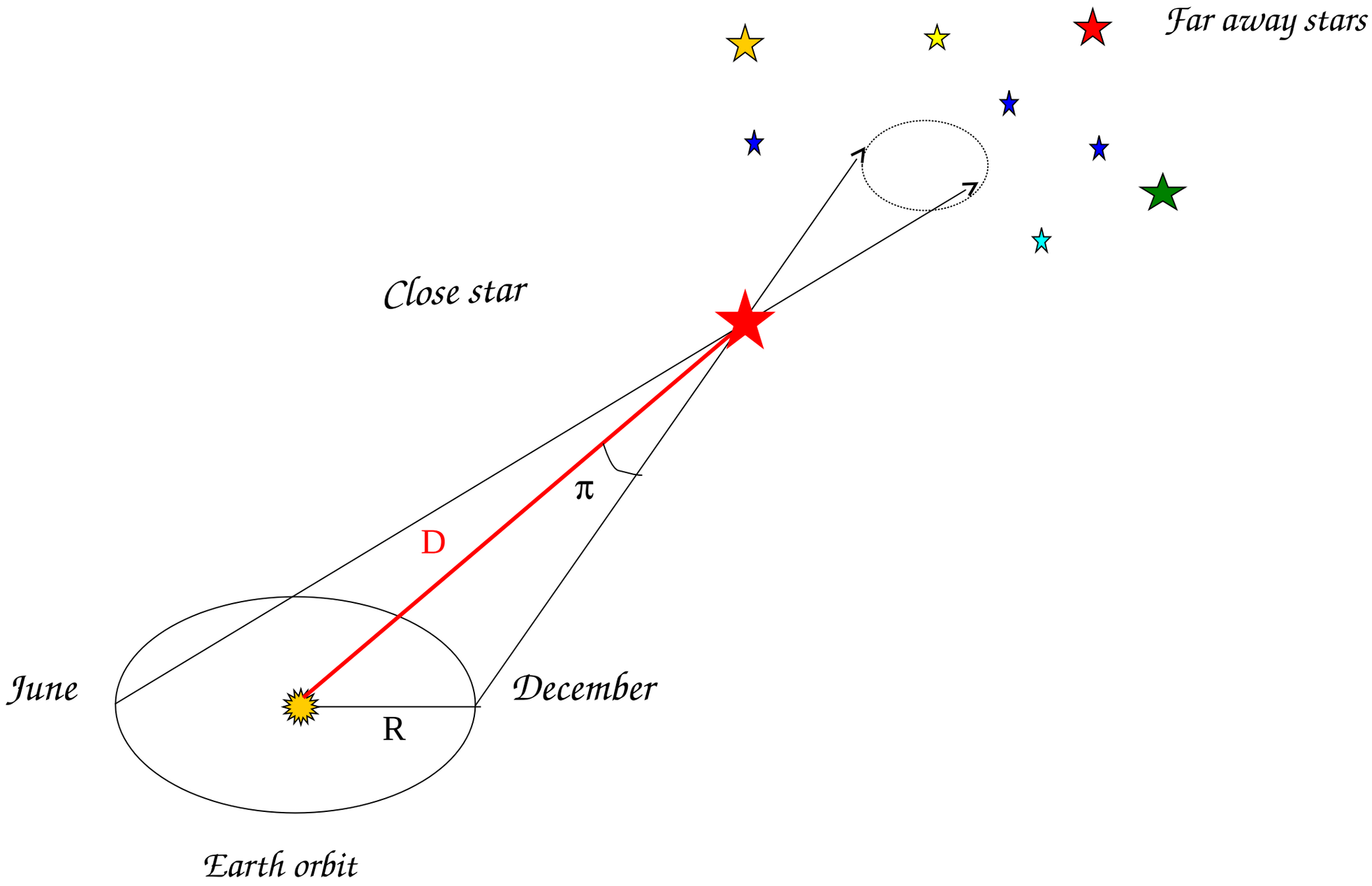
The Milky Way

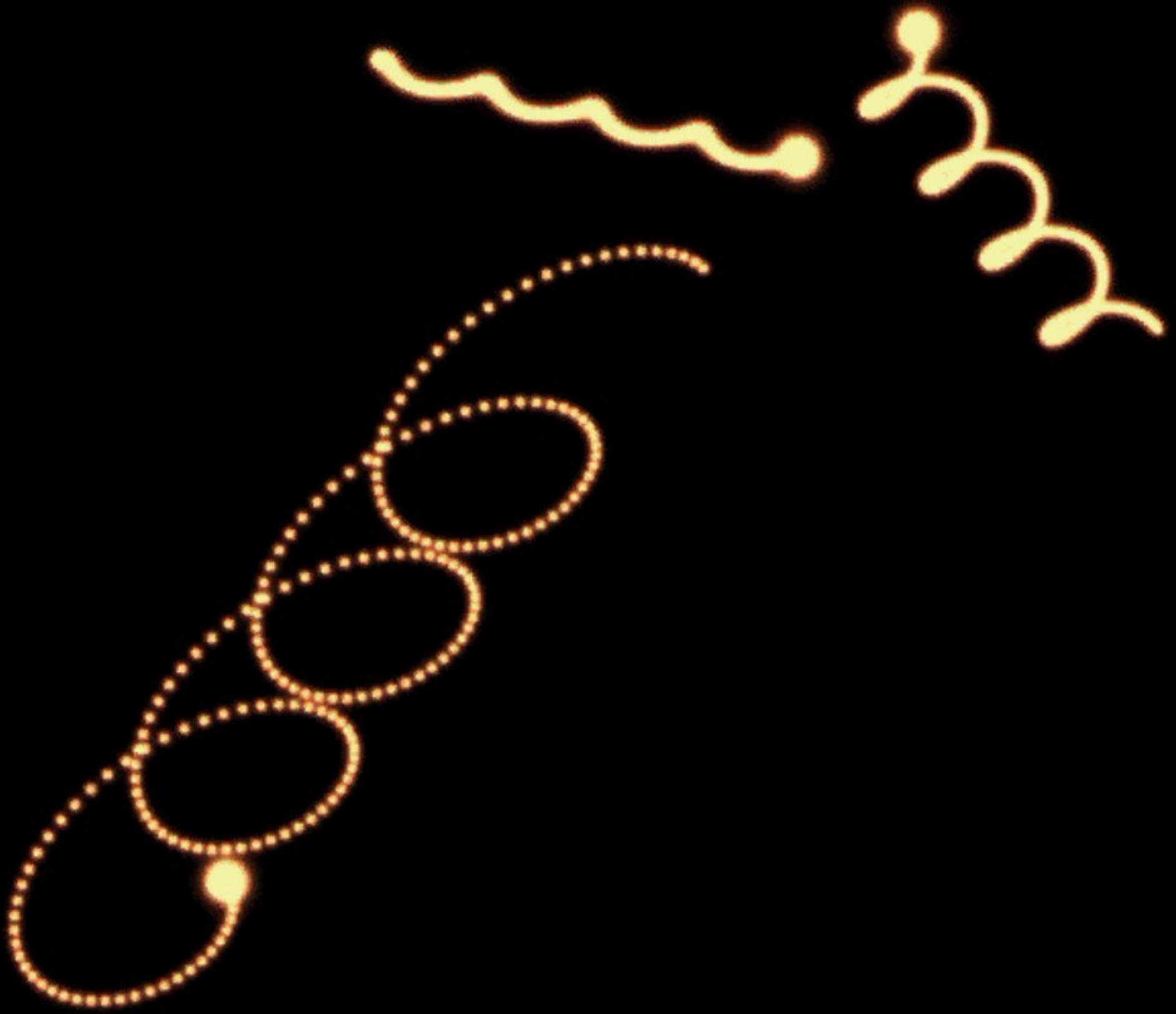


seen by the *Gaia mission*

Carine Babusiaux

Direct distances with the parallax





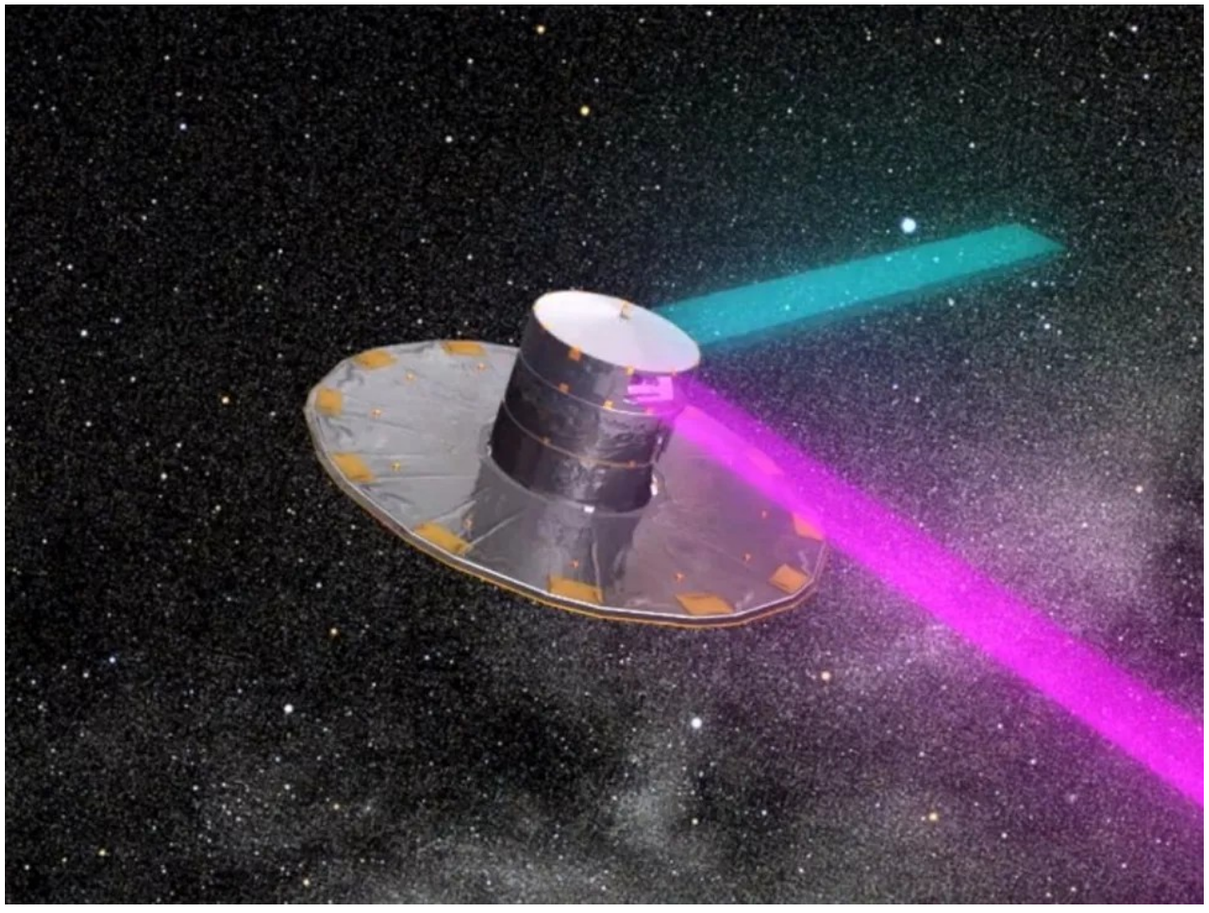
The Gaia mission

ESA mission launched end 2013

5 years (+) of mission

3 instruments

- Astrometry
- Spectrophotometry
- Spectroscopy (RVS)

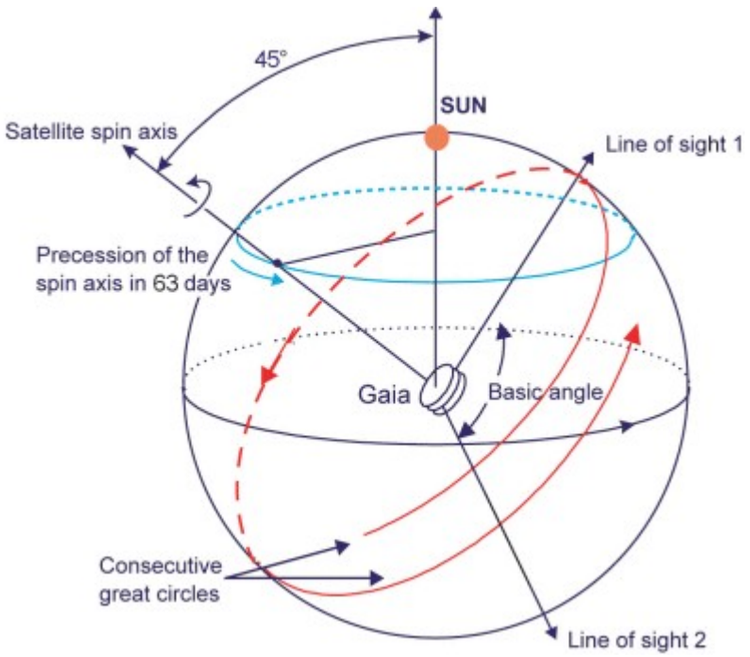


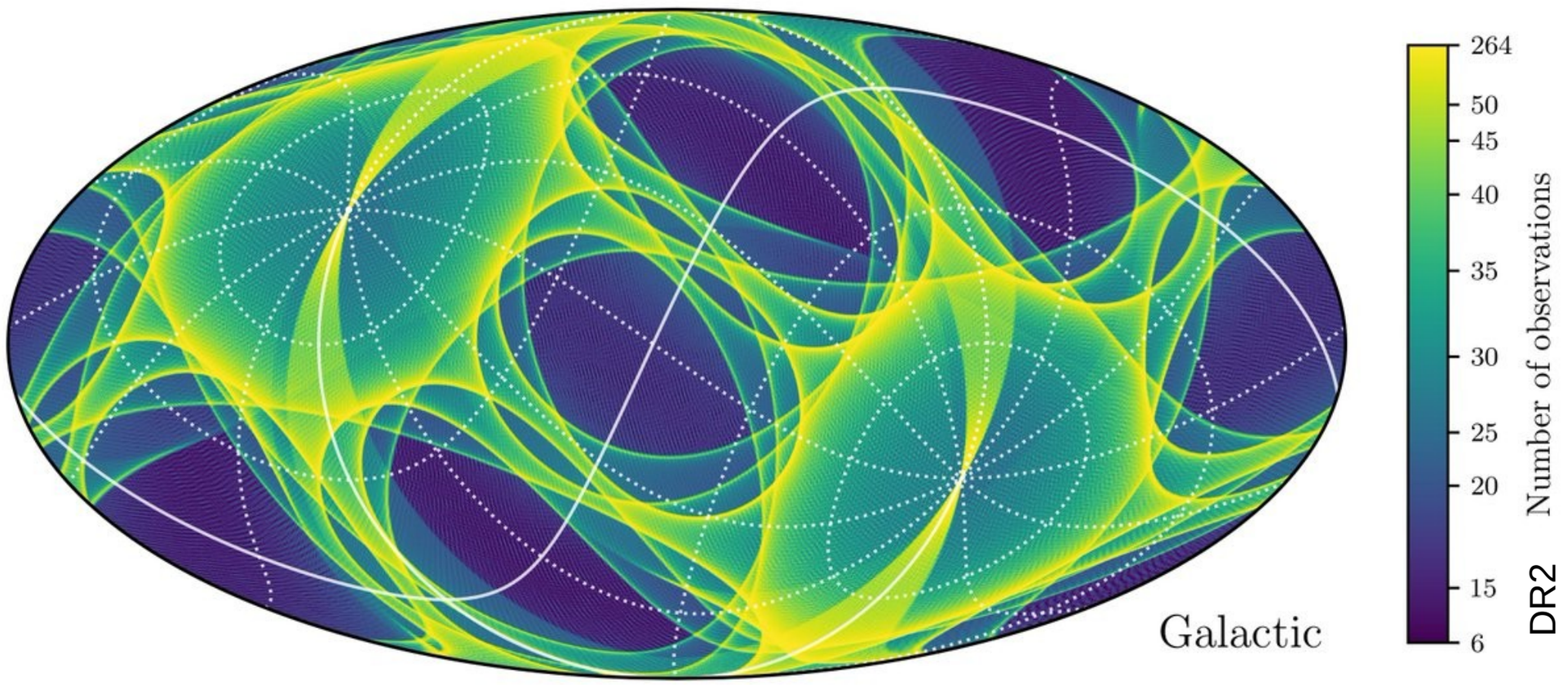
© ESA

2 billion stars 3 < **G < 20.7**

~ 70 observations per source

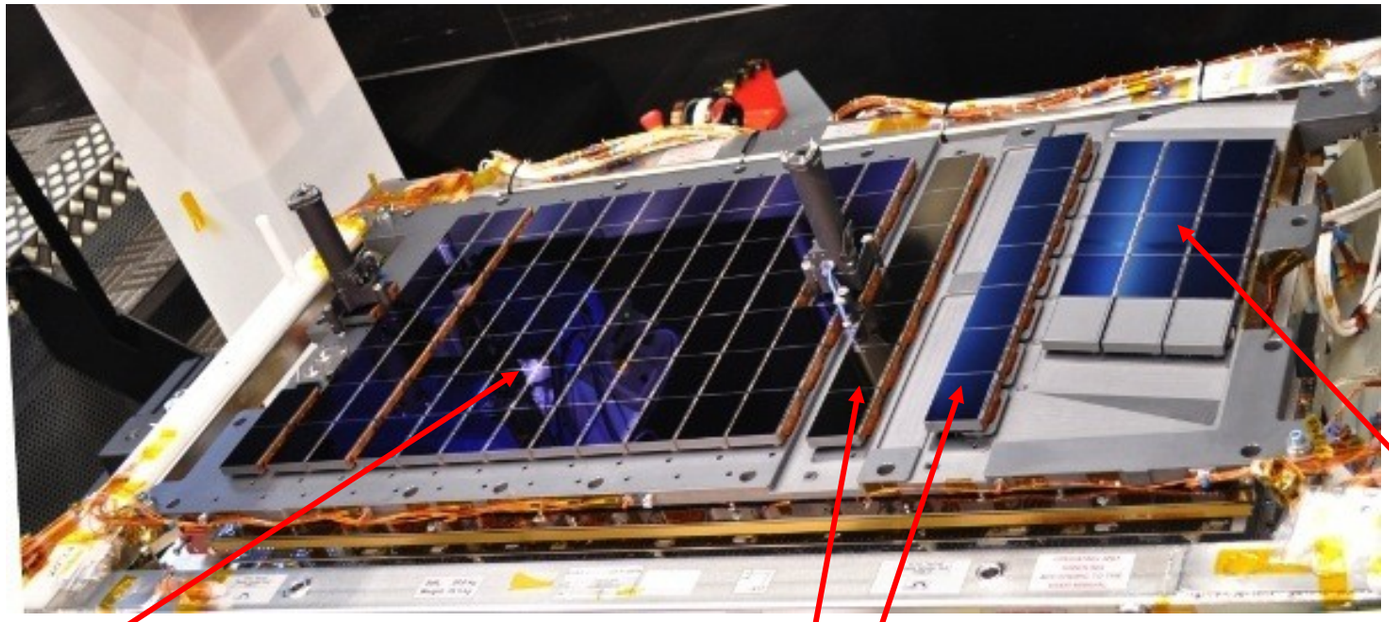
Gaia scanning law





Boubert et al. 2020

Gaia instruments and measurements

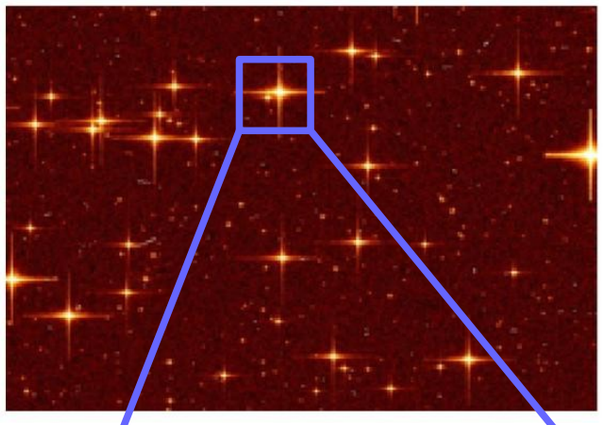


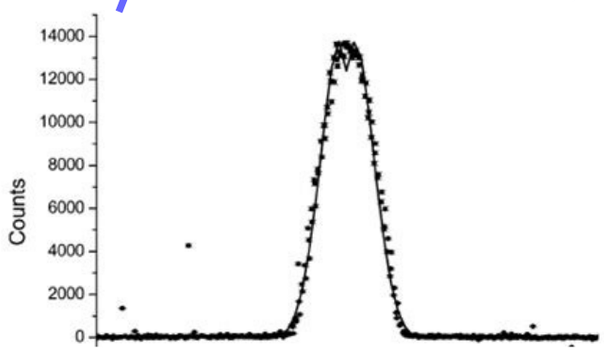
~ one billion pixels

Astrometry

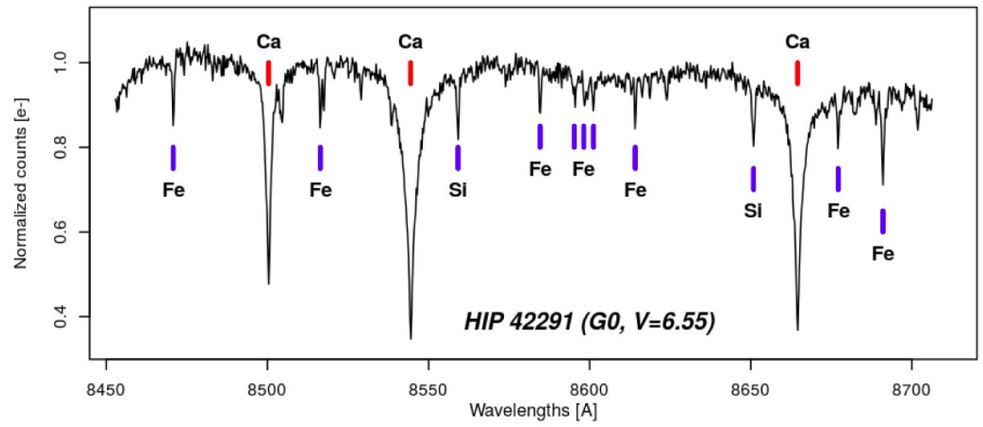
Spectroscopy

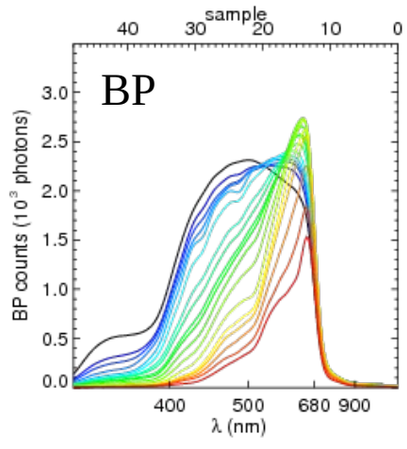
Spectrophotometry

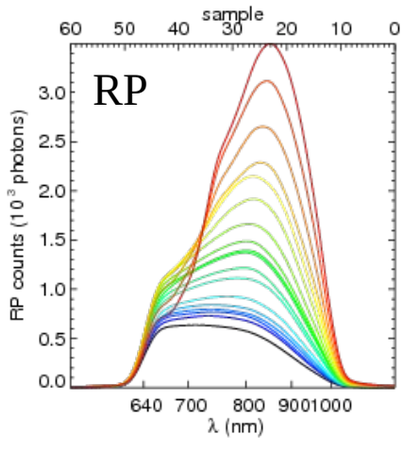




along scan LSF



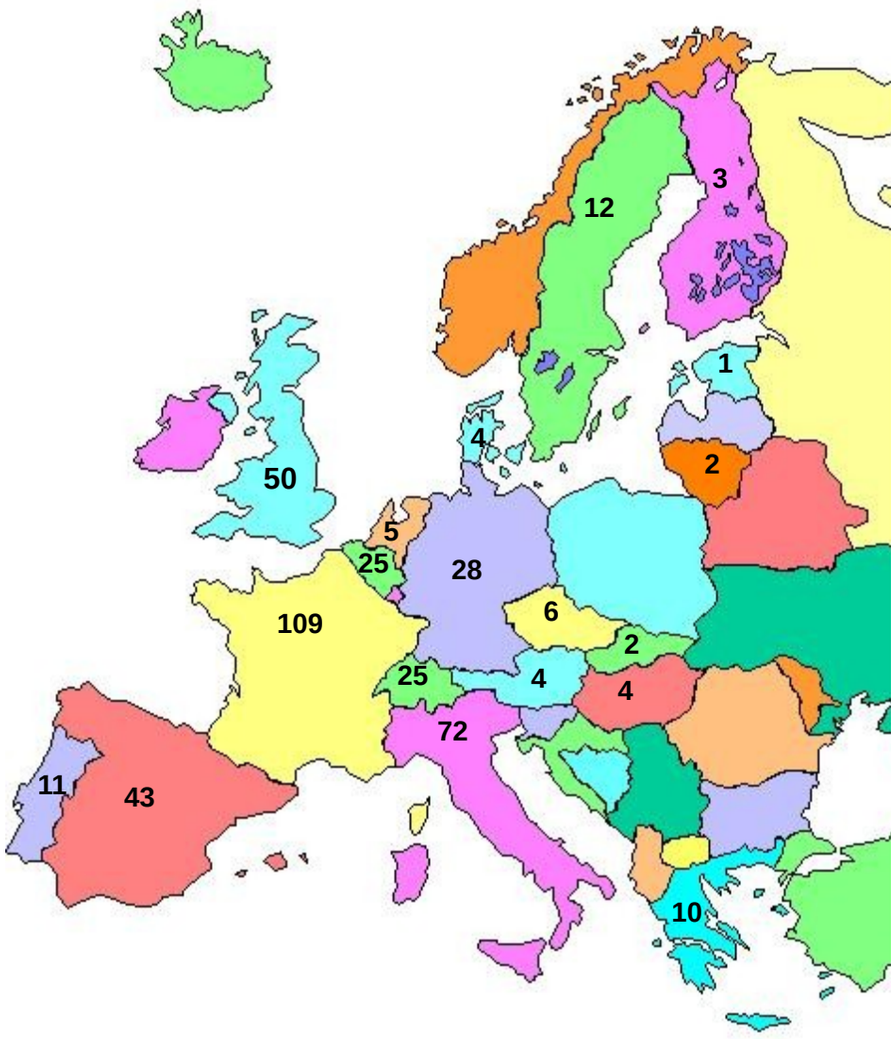


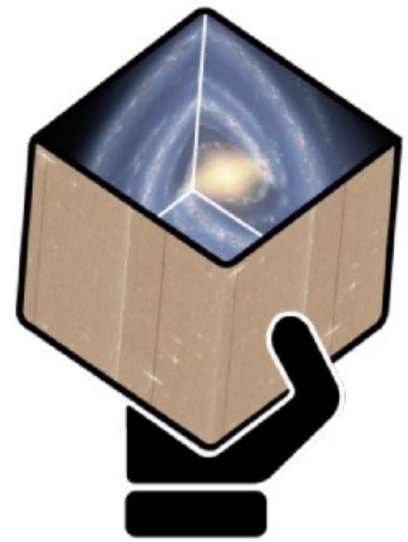


Teamwork to deliver the promise of Gaia

- 20+ years of effort
- 450 scientists and engineers
- 160 institutes
- 24 countries and ESA
- 6 data processing centres

Cyclic data processing of a self calibrating instrument





α δ ϖ $\mu_{\alpha*}$ μ_δ G …

Courtesy F. Mignard 2013

The Gaia schedule

1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028

Proposal

Concept study

Mission selection

Definity

Selection (EADS Astrium)

Implementation

Launch

Operation

Gaia DPAC

Studies | Software development | Data processing

Data releases

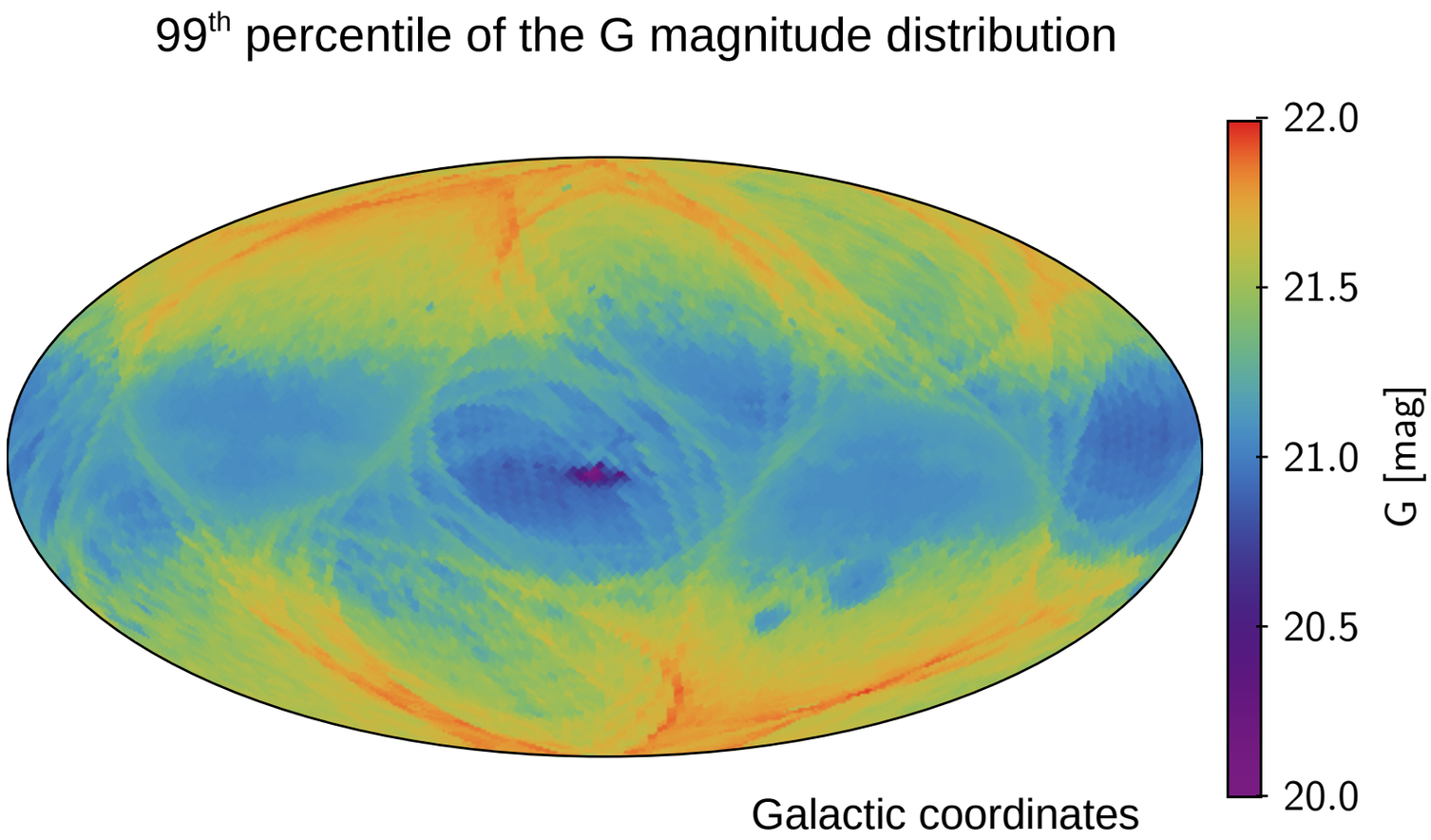
DR1 DR2 EDR3 DR3 DR4 **Final**

Figure adapted from Michael Perryman and François Mignard

Gaia EDR3 in context

	DR2 25 April 2018	EDR3 3 Dec 2020	DR3 2022	DR4 2025?
Parallaxes and proper motions	Full Sample	++		++
Photometry	G, G_{BP}, G_{RP}	++		++
Variables	550 000		++	++
Radial velocities	RVs at G_{RVS}<12		++	++
SSOs	pre-selected asteroids		New SSOs	++
Astrophysical parameters	for G < 17 : Teff, A_G Radii and luminosities *from integrated phot*		Classification + Parameters from BP/RP + RVS spectra	++
Systems			Non-single catalogue	Exoplanet list
Spectra			Mean BP/RP spectra Mean RVS spectra	++
Epoch data				All epoch data
	1.8 year		*2.8 year*	*5 year*

Completeness

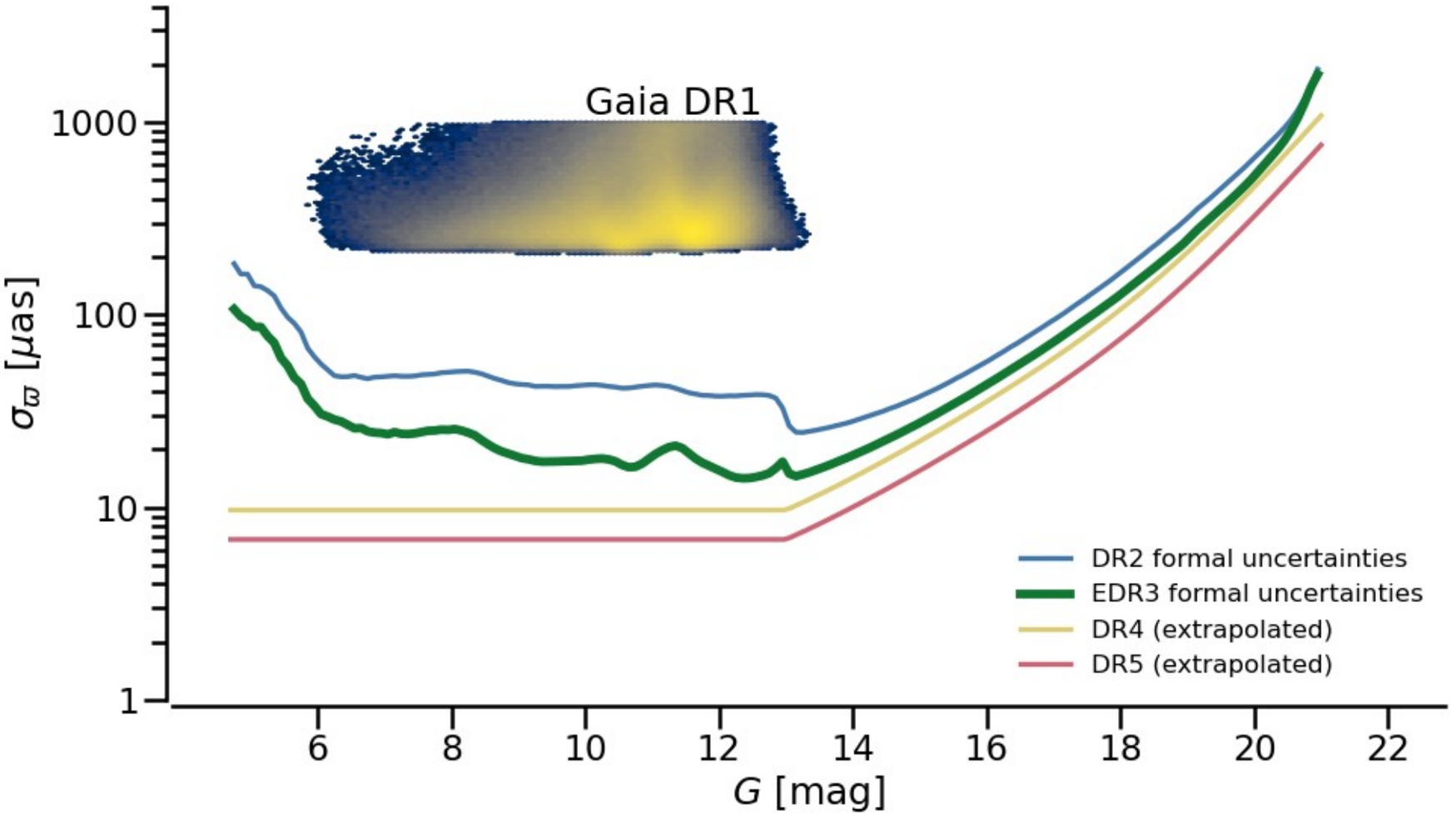


Completeness in crowded regions improved

Spatial resolution improved

Fabricius et al. 2020

Astrometry: parallax



Typical parallax precision:

- G=15: 0.03 mas
- G=17: 0.07 mas
- G=20: 0.5 mas

Still single-star solution

Systematics below 0.05 mas

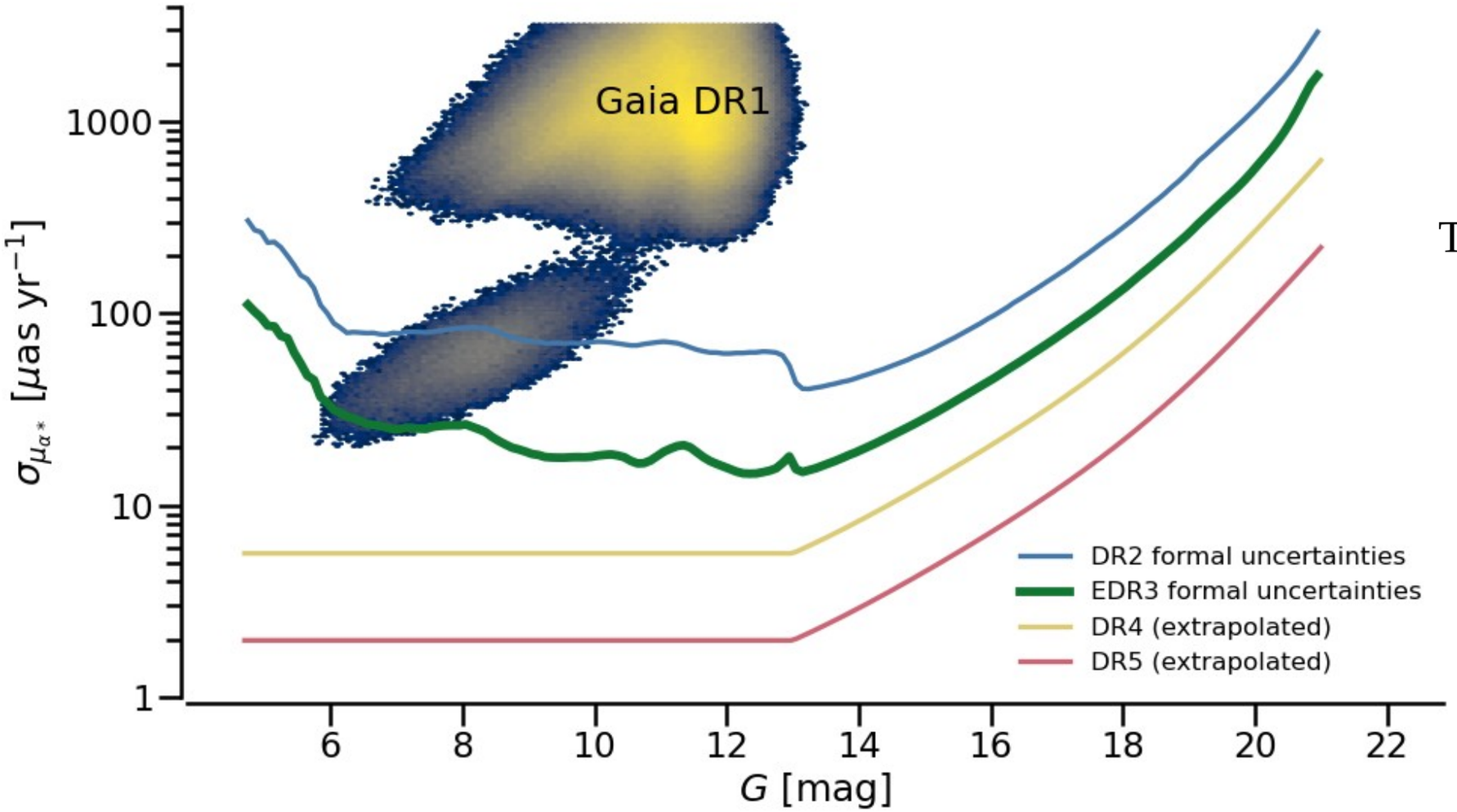
Global zero point ~ -0.017 mas

Spatial correlations at ~ 1 and ~ 20 degree scales

Precision improved by 30%

Lindegren et al. 2020 a & b

Astrometry: proper motion

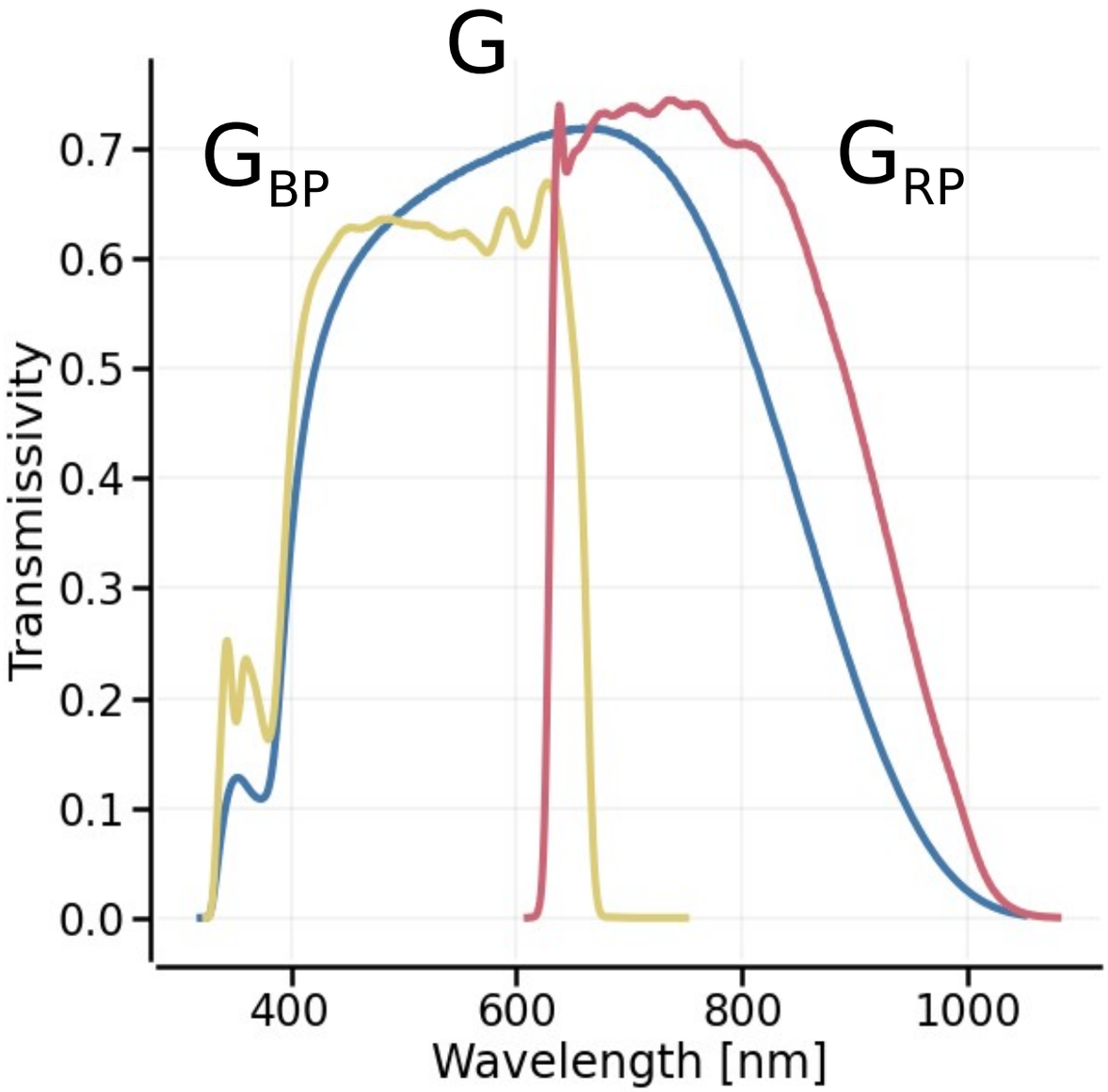


Typical proper motion precision:
G=15: 0.03 mas/yr
G=17: 0.07 mas/yr
G=20: 0.5 mas/yr

Factor 2 improvement in the precision

Lindegren et al. 2020 a

Photometry



G=17: σ_G~0.001 mag
σ_{XP}~ 0.01 mag

G=20: σ_G~0.006 mag
σ_{XP}~0.1 mag

! No deblending

Riello et al. 2020

Gaia Archive

- Main table: `gaiaedr3.gaia_source`
- DR2 to EDR3 match table: `dr2_neighbourhood`
- Gaia-CRF3 tables:
  - `agn_cross_id`, `frame_rotator_source`
- Simulations, GUMS and GOG version 20:
  - `gaia_universe_model`, `gaia_source_simulation`
- Gaia pointing: `commanded_scan_law`
- Pre-computed cross-matches
  - Hipparcos, Tycho-2 merged with Tycho Double Star Catalogue
  - 2MASS, SDSS DR13, Pan-Starrs1 DR1.1
  - SkyMapper DR2, AllWise, URAT1, GSC2.3
  - APASS DR9, RAVE DR5

`https://gea.esac.esa.int/archive/`

Further information

Gaia EDR3 pages: https://www.cosmos.esa.int/web/gaia/early-data-release-3

Papers

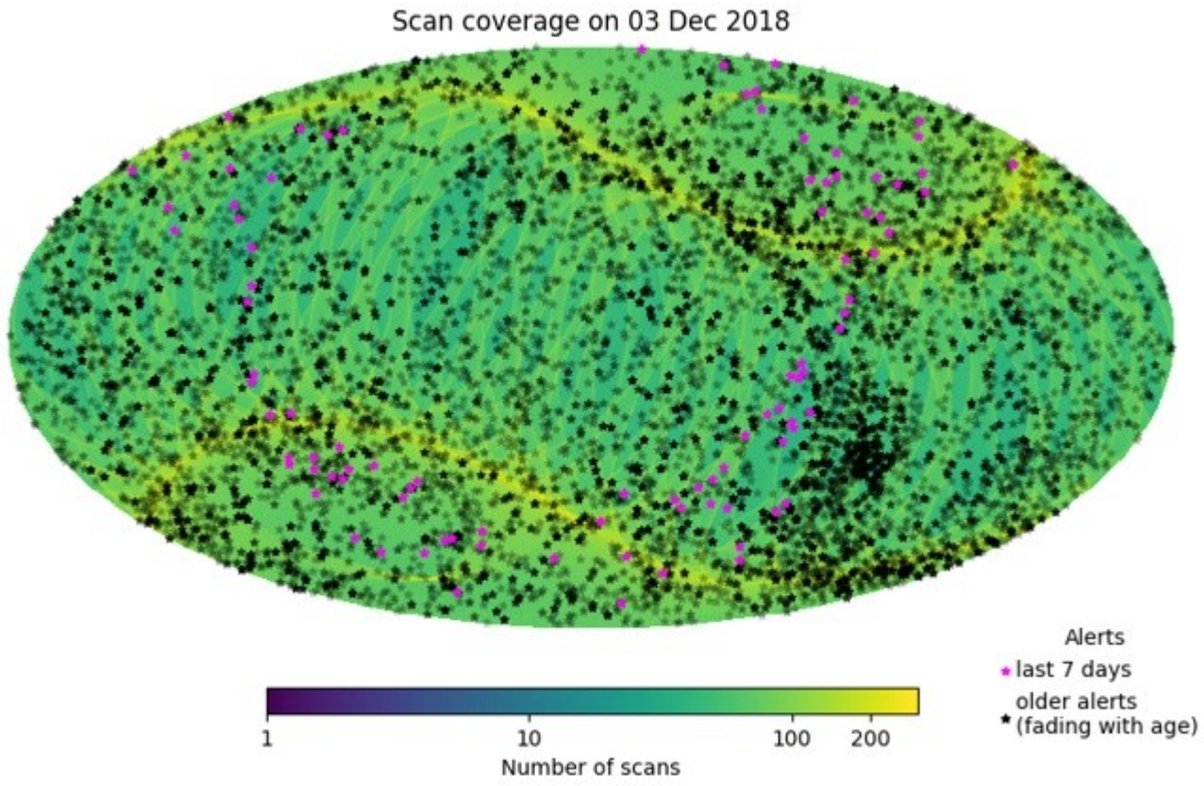
- *Summary of the contents and survey properties*, Gaia Collaboration, Brown et al
- *The astrometric solution*, Lindegren et al
- *Photometric content and validation*, Riello et al
- *Parallax bias versus magnitude, colour and position*, Lindegren et al
- *The celestial reference frame (GAIA-CRF3)*, Klioner et al
- *Updated radial velocities from Gaia DR2*, Seabroke et al
- *Catalogue Validation*, Fabricius et al
- *Building the Gaia DR3 source list - Cross-match of Gaia observations*, Torra et al
- *Modelling and calibration of Gaia's point and line spread functions*, Rowell et al
- *Cross-match with external catalogues - Algorithm and results*, Marrese et al

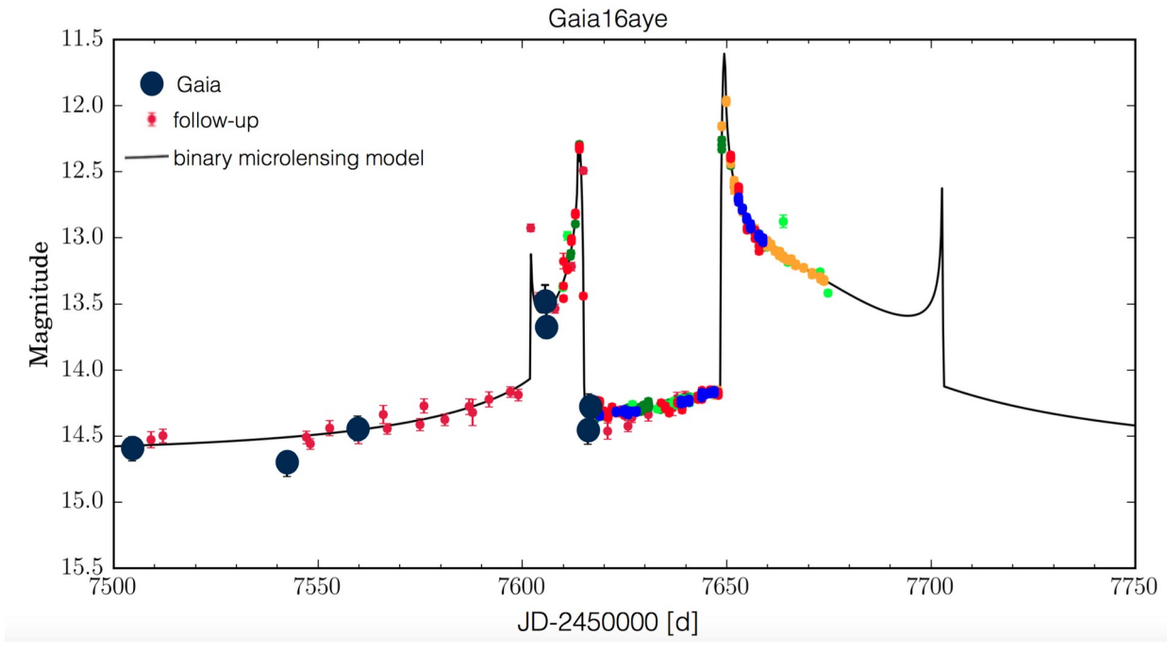
Performance verification papers

- *The Gaia catalogue of nearby stars*, Gaia Collaboration, Smart, et al
- *Structure and properties of the Magellanic Clouds*, Gaia Collaboration, Luri, et al
- *The Galactic anticentre*, Gaia Collaboration, Antoja, et al
- *Acceleration of the solar system from Gaia astrometry*, Gaia Collaboration, Klioner, et al

Gaia Photometric Science Alerts

started publishing alerts in July 2014



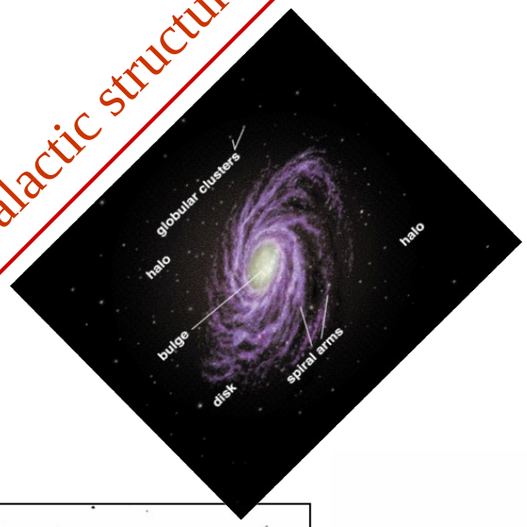


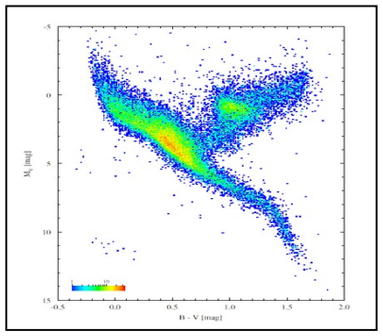
http://gsaweb.ast.cam.ac.uk/alerts

A very large science case

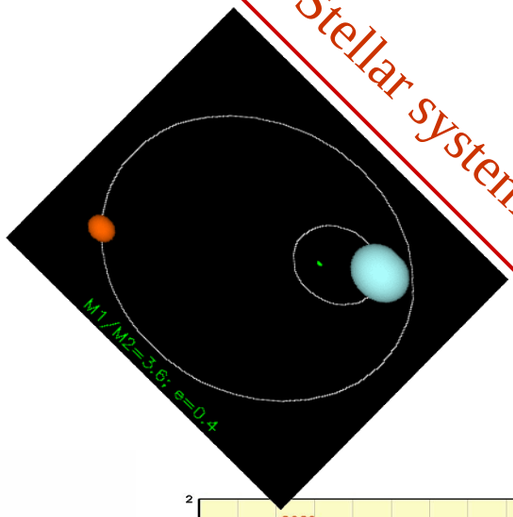
Stellar Physics

Galactic structure

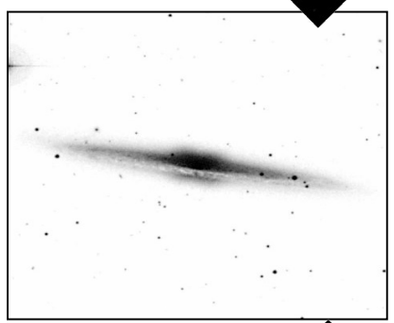


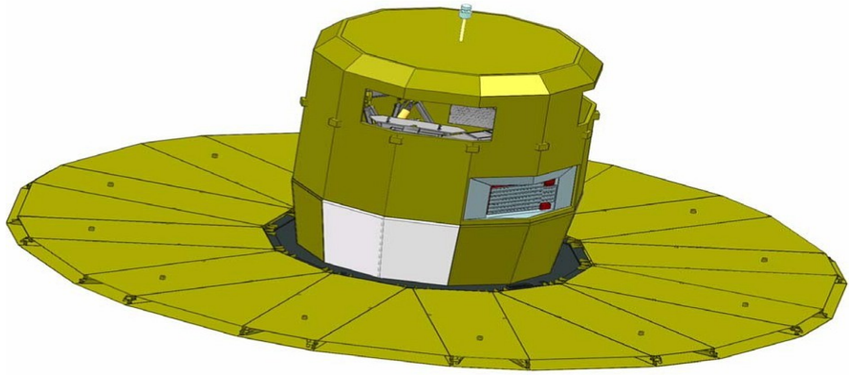


Stellar systems

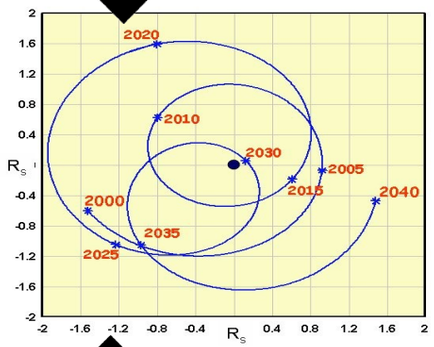


Quasars and galaxies

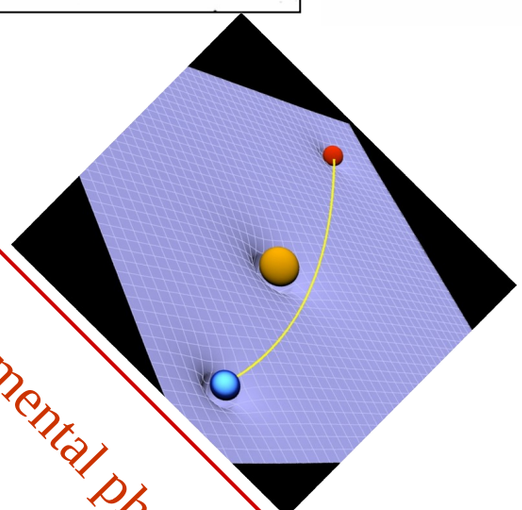


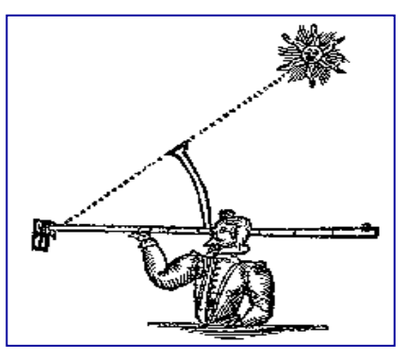


Exoplanets

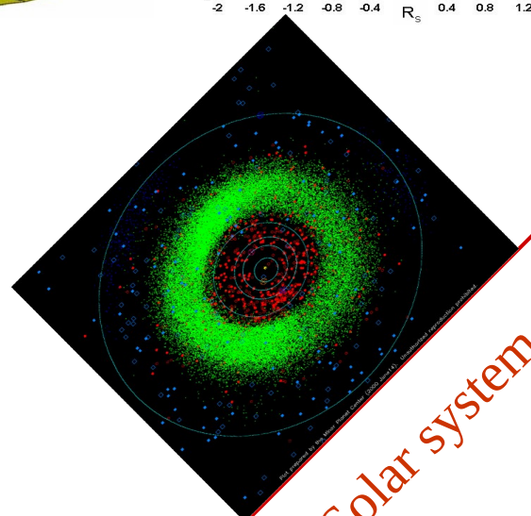


Fundamental physics



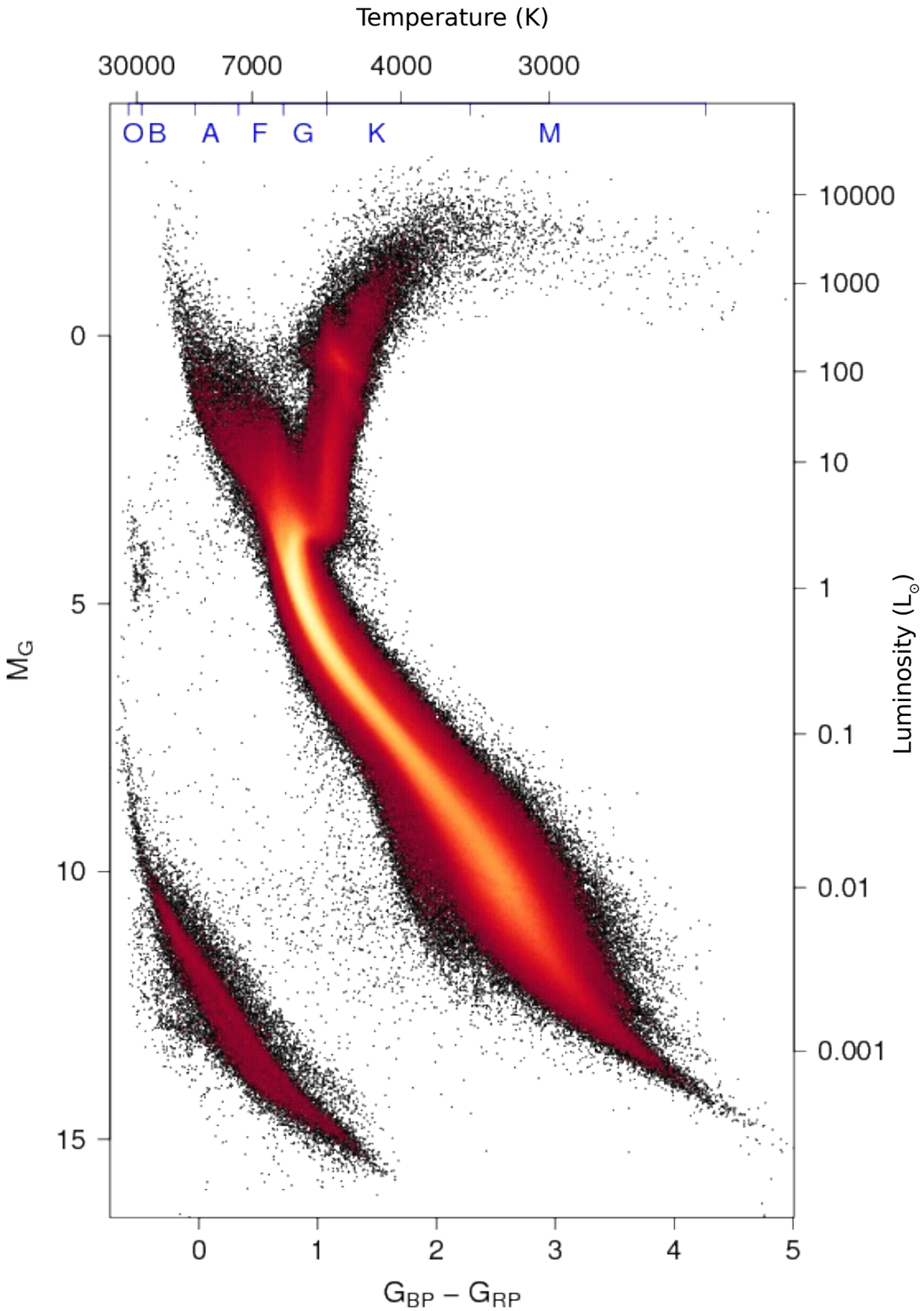


Solar system



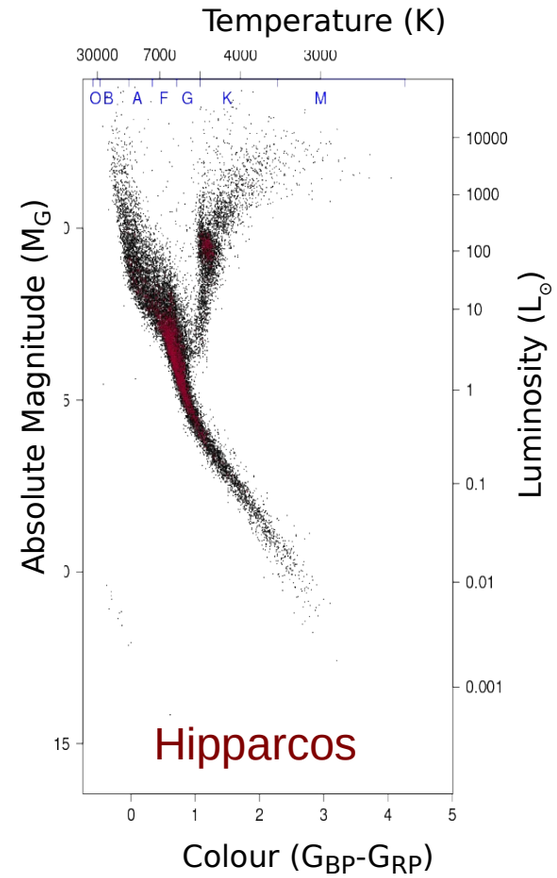
Reference system

Gaia H-R diagram



$\sigma_\pi/\pi < 10\%$, E(B-V)<0.015

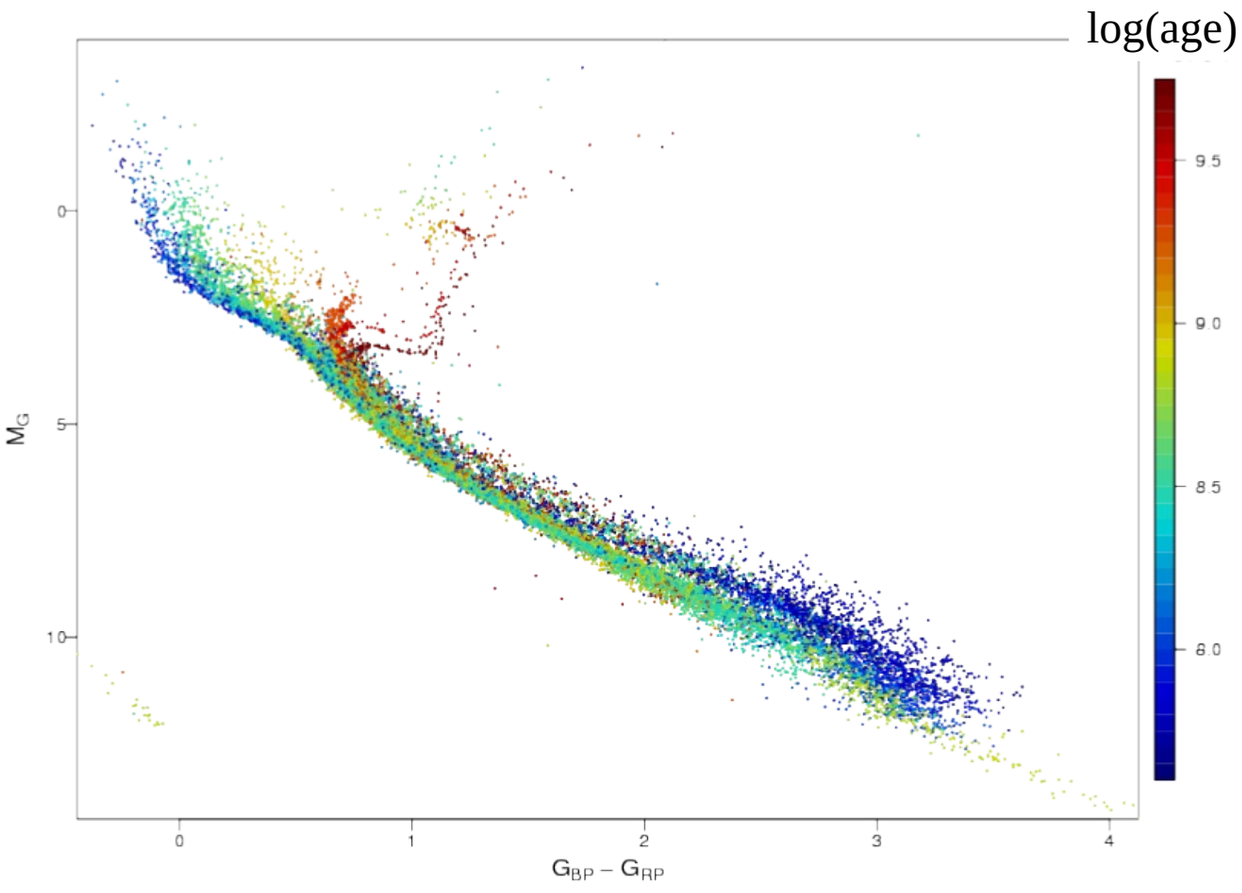
~ 4 000 000 stars, < 2 kpc



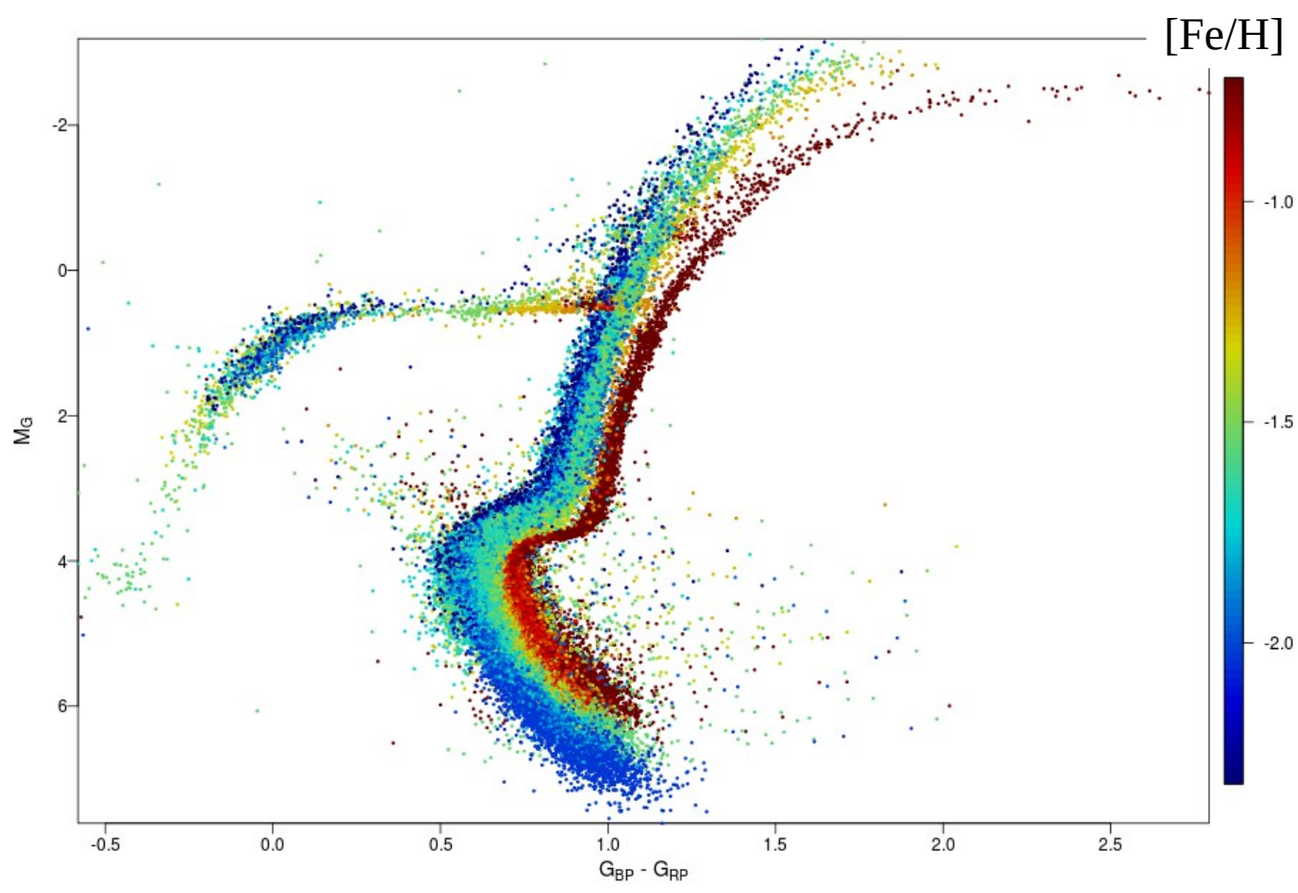
Gaia Collaboration, Babusiaux et al. 2018

Clusters → empirical isochrones

32 open clusters

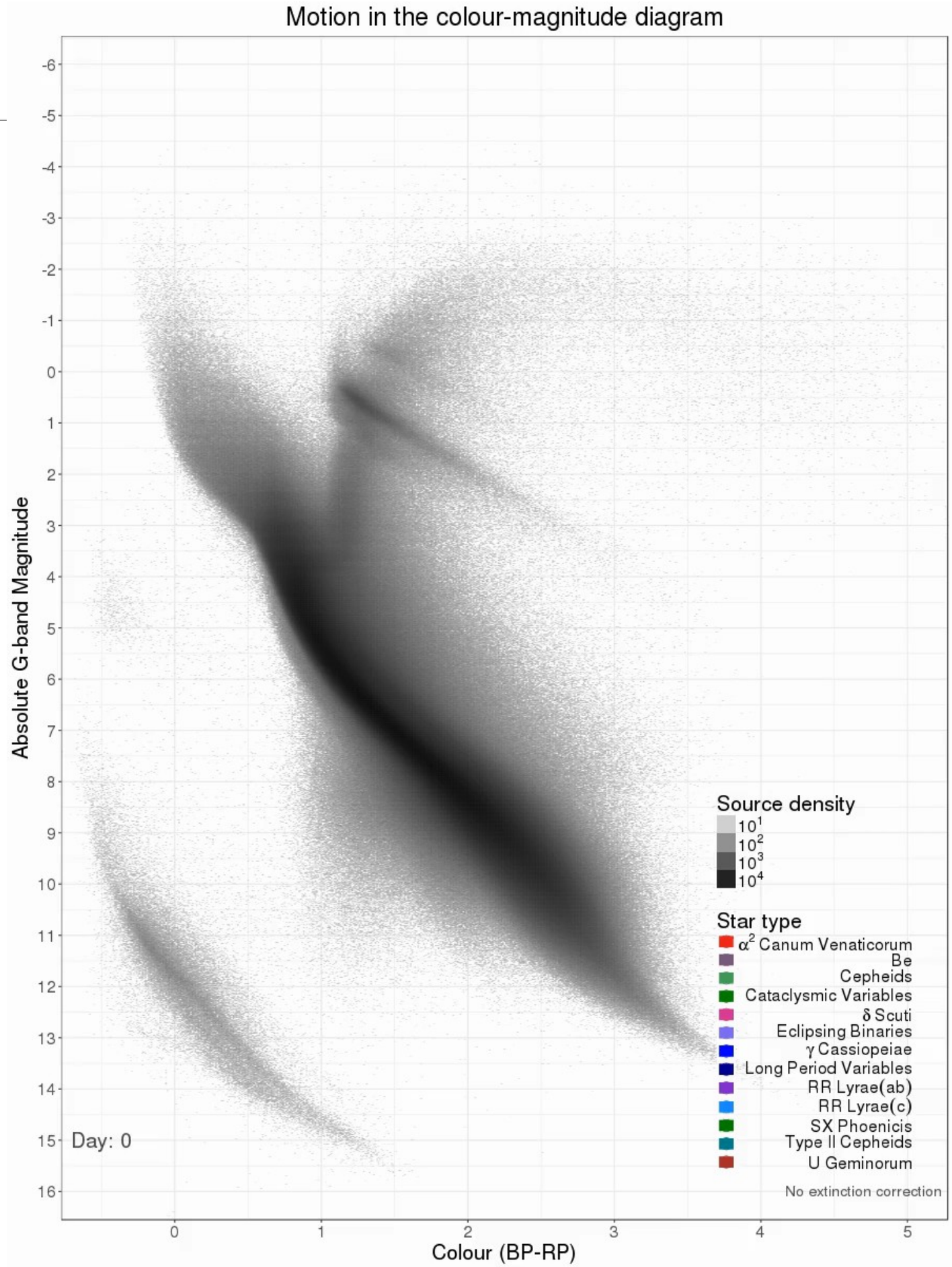


14 globular clusters



Gaia Collaboration, Babusiaux, van Leeuwen et al. 2018

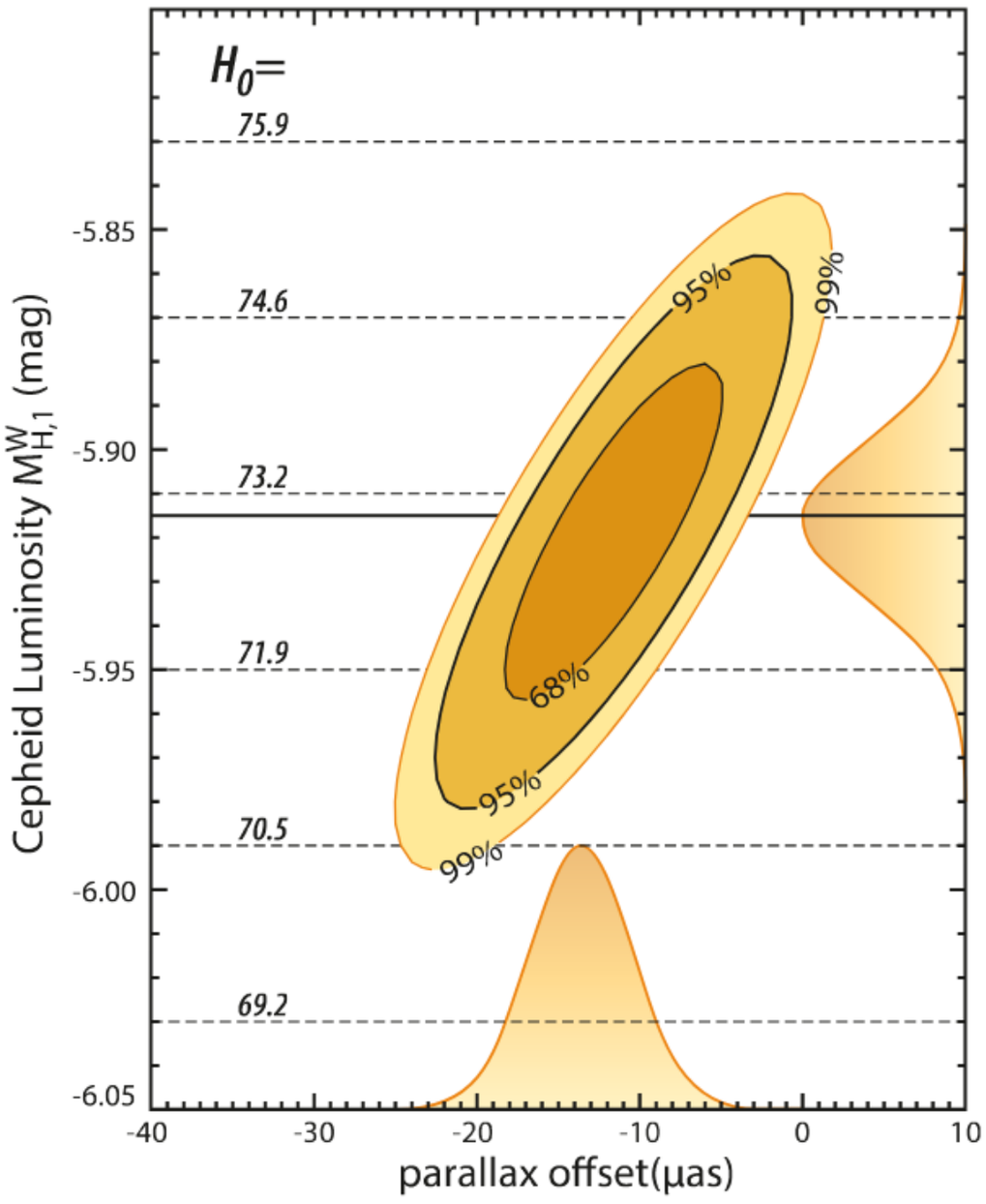
Variability in the HRD



Gaia Collaboration, Eyer et al. 2018

crédit ESA/Gaia/DPAC/CU7

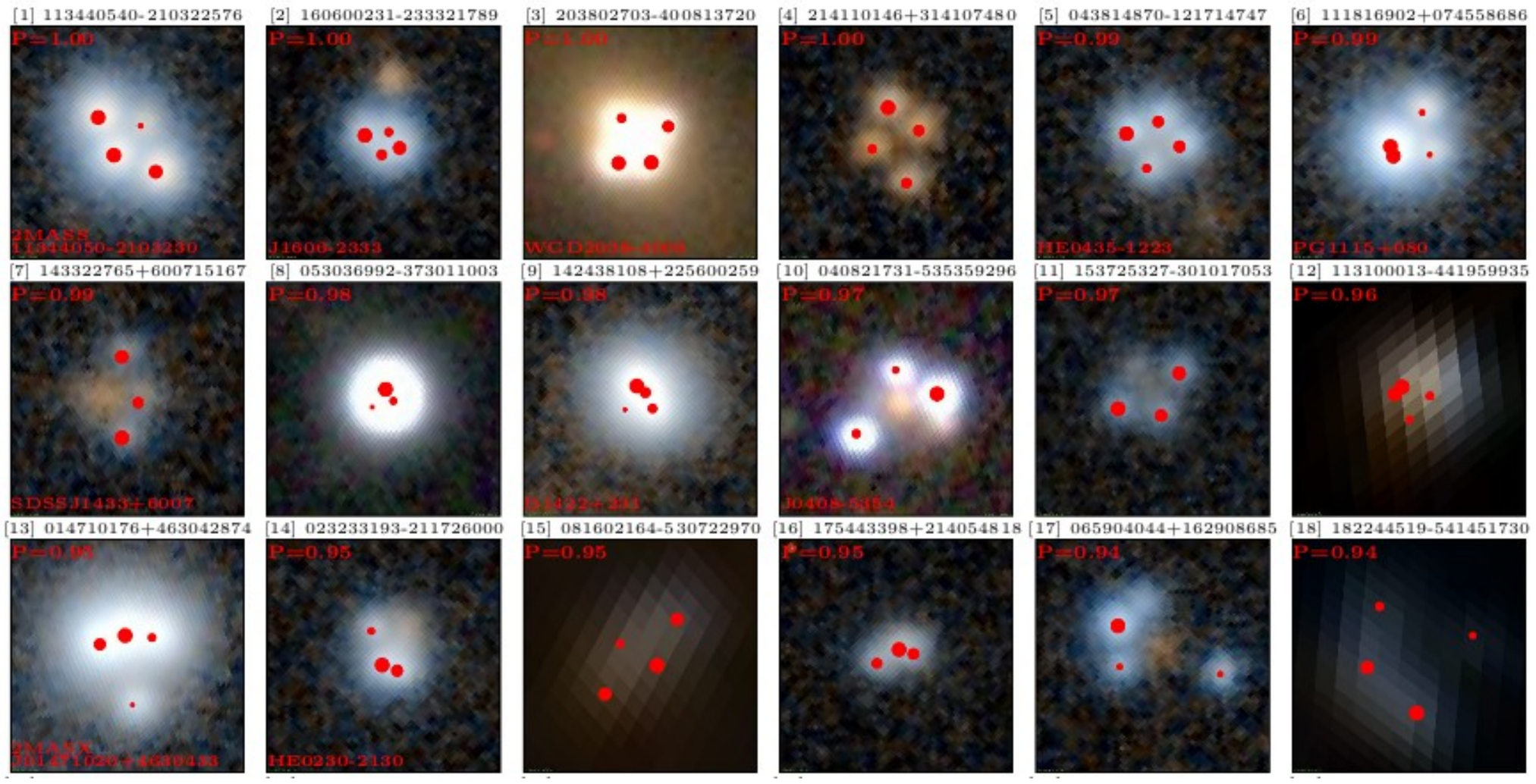
Cepheids distance scale



Reiss et al. 2021 submitted

Using DR2: Reiss et al. 2018, Shanks et al. 2018, Groenewegen et al. 2018

Gravitational lenses

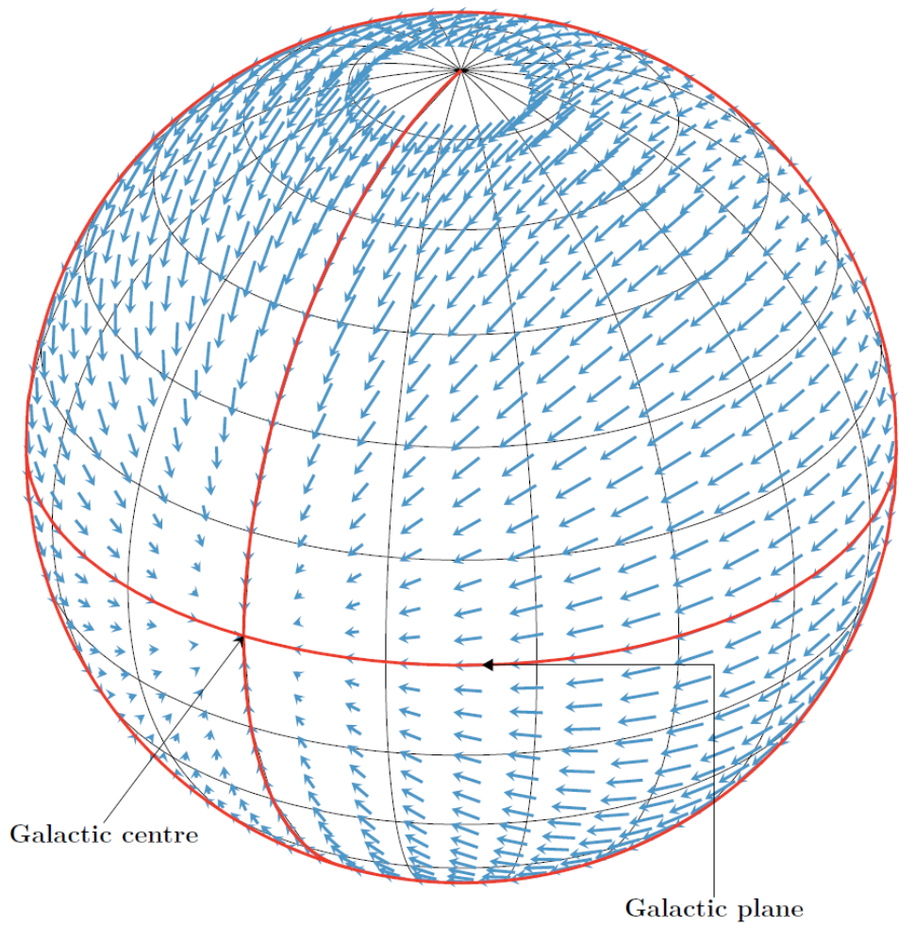


Search for gravitational lens systems in Gaia DR2

Delchambre et al. 2018

Acceleration of the solar system

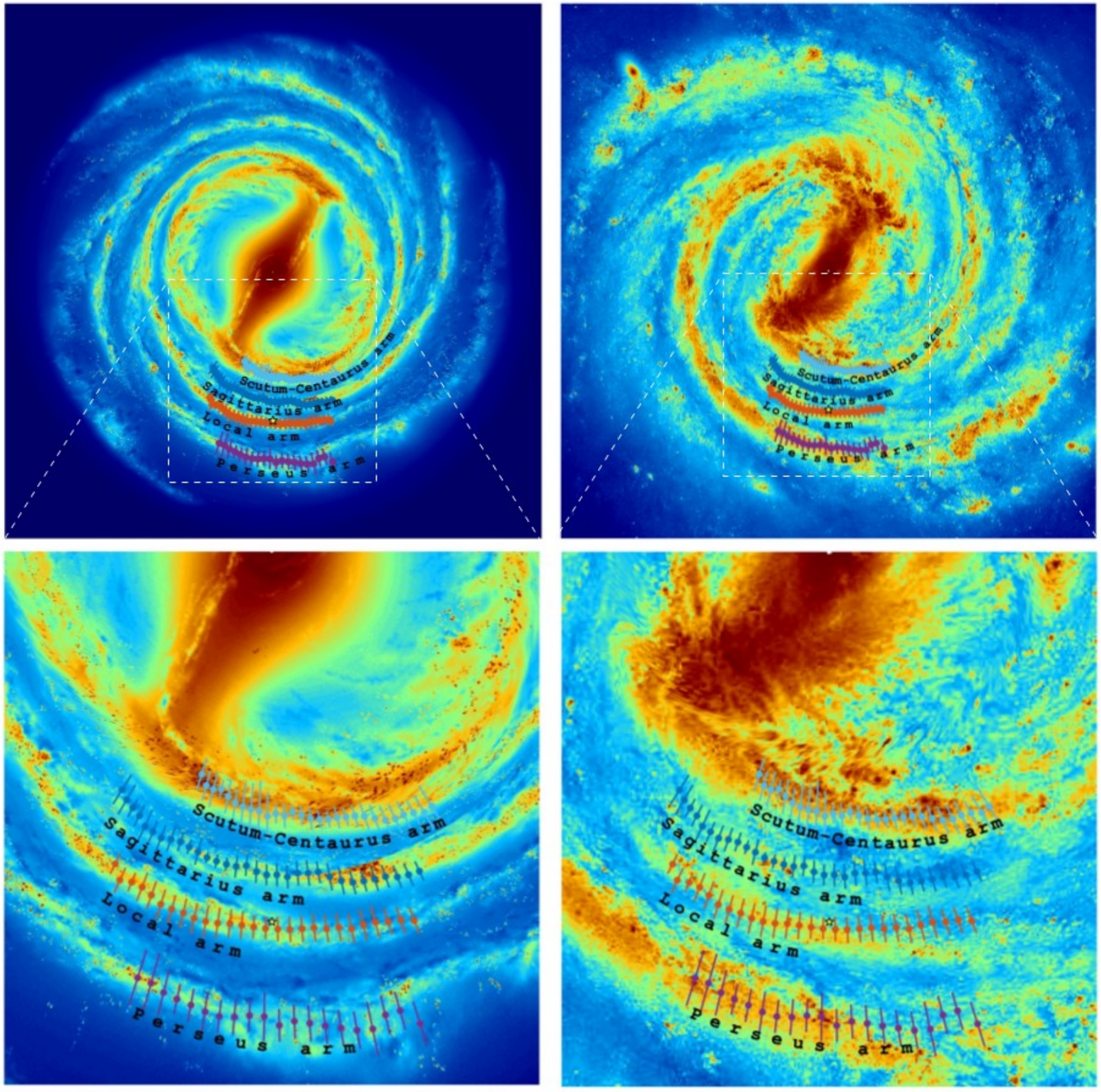
aberration-induced proper-motion field of QSOs



→ Acceleration of 7.33 ± 0.51 km s^{-1} Myr^{-1} towards the galactic center

Gaia Collaboration, Klioner et al. 2020

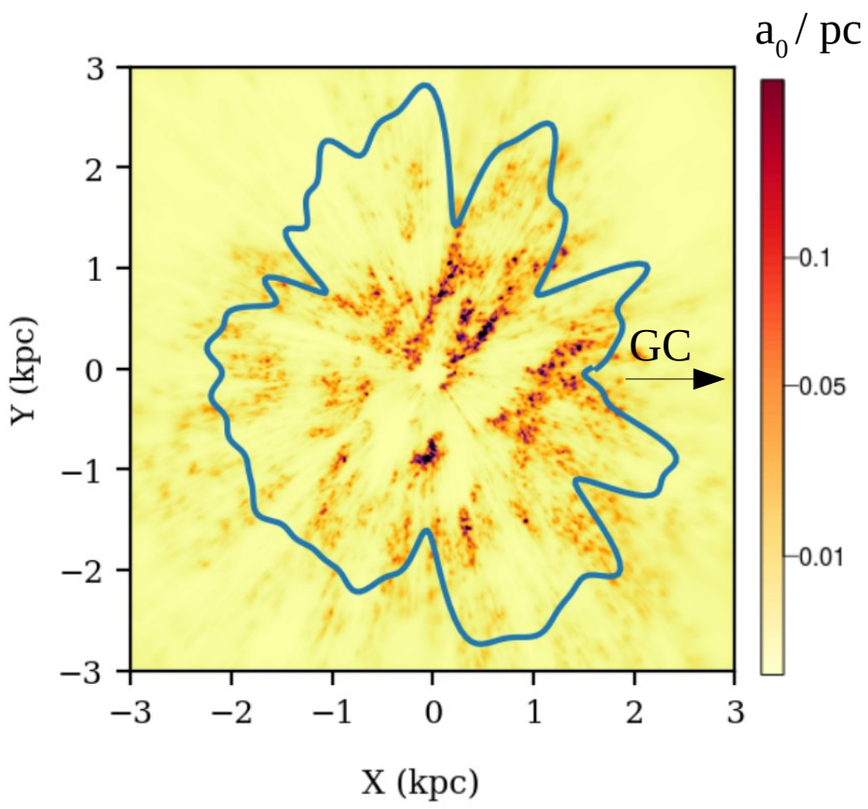
The spiral structure seen in the velocities

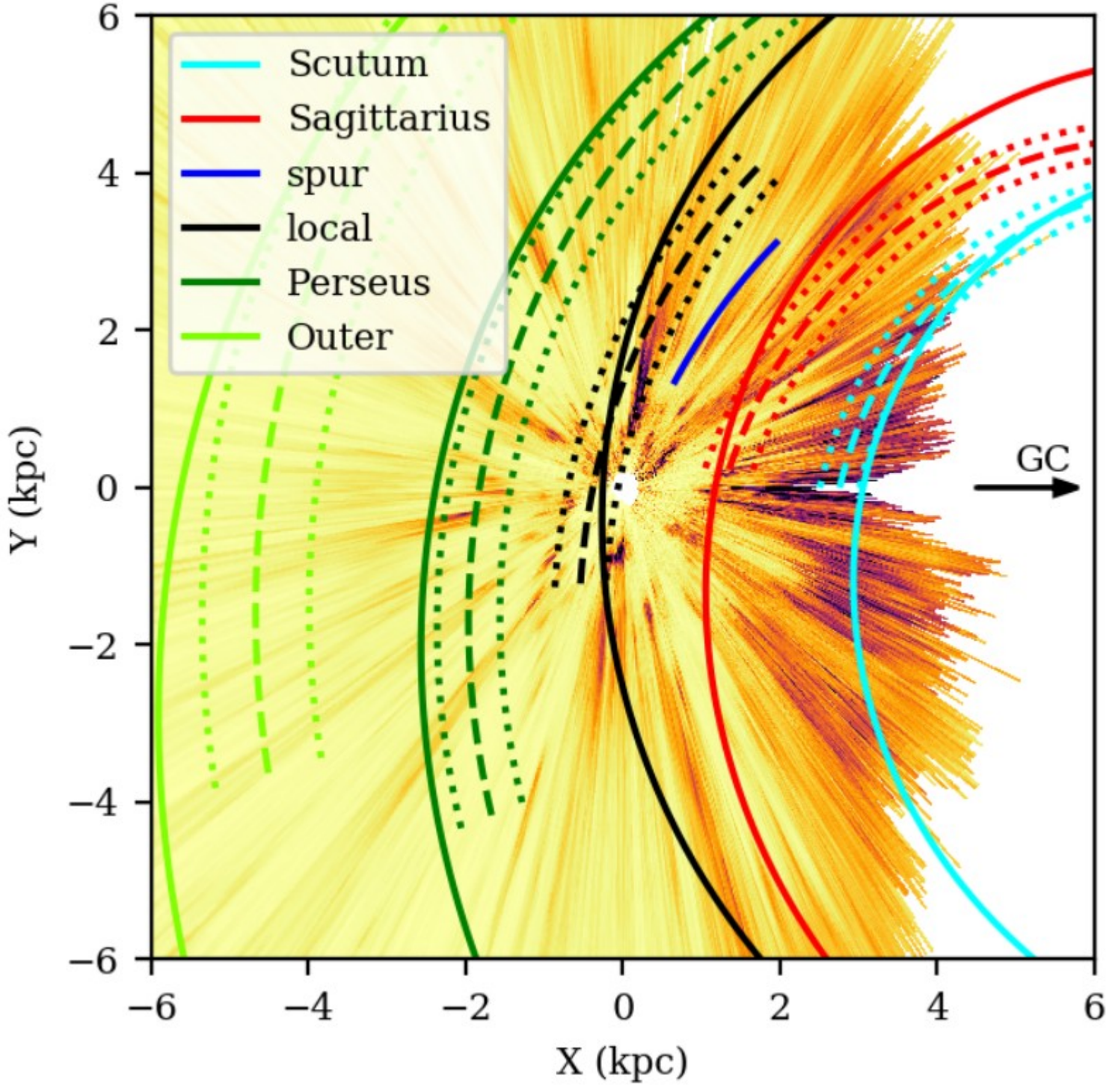


Khoperskov et al. 2020

… not so obvious in the dust

Extinction a_0 (at 550 nm)
in the Galactic plane



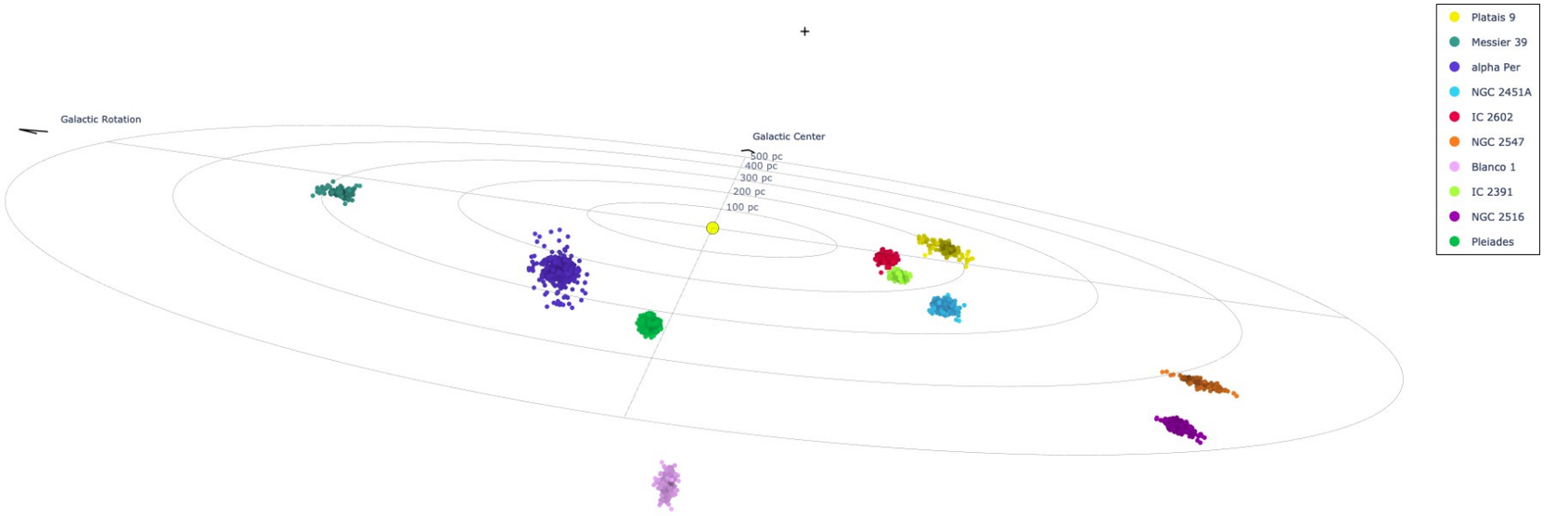


Lallement, Babusiaux et al. 2018

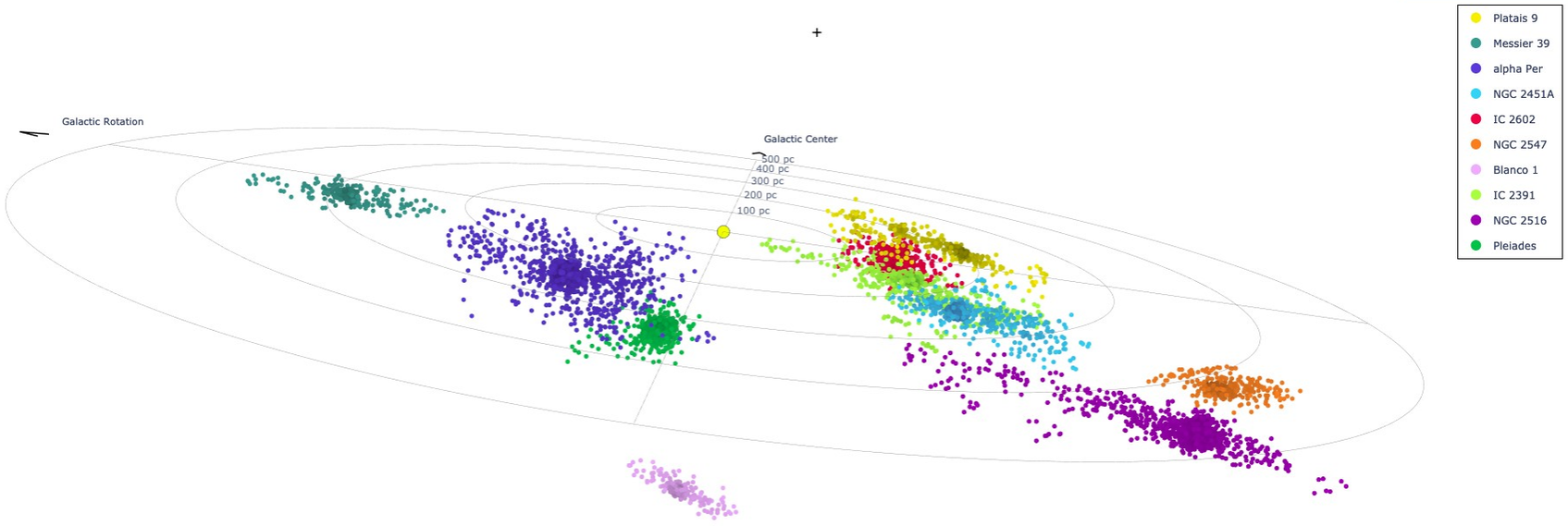
Hottier, Babusiaux et al. 2020

The extent of star clusters

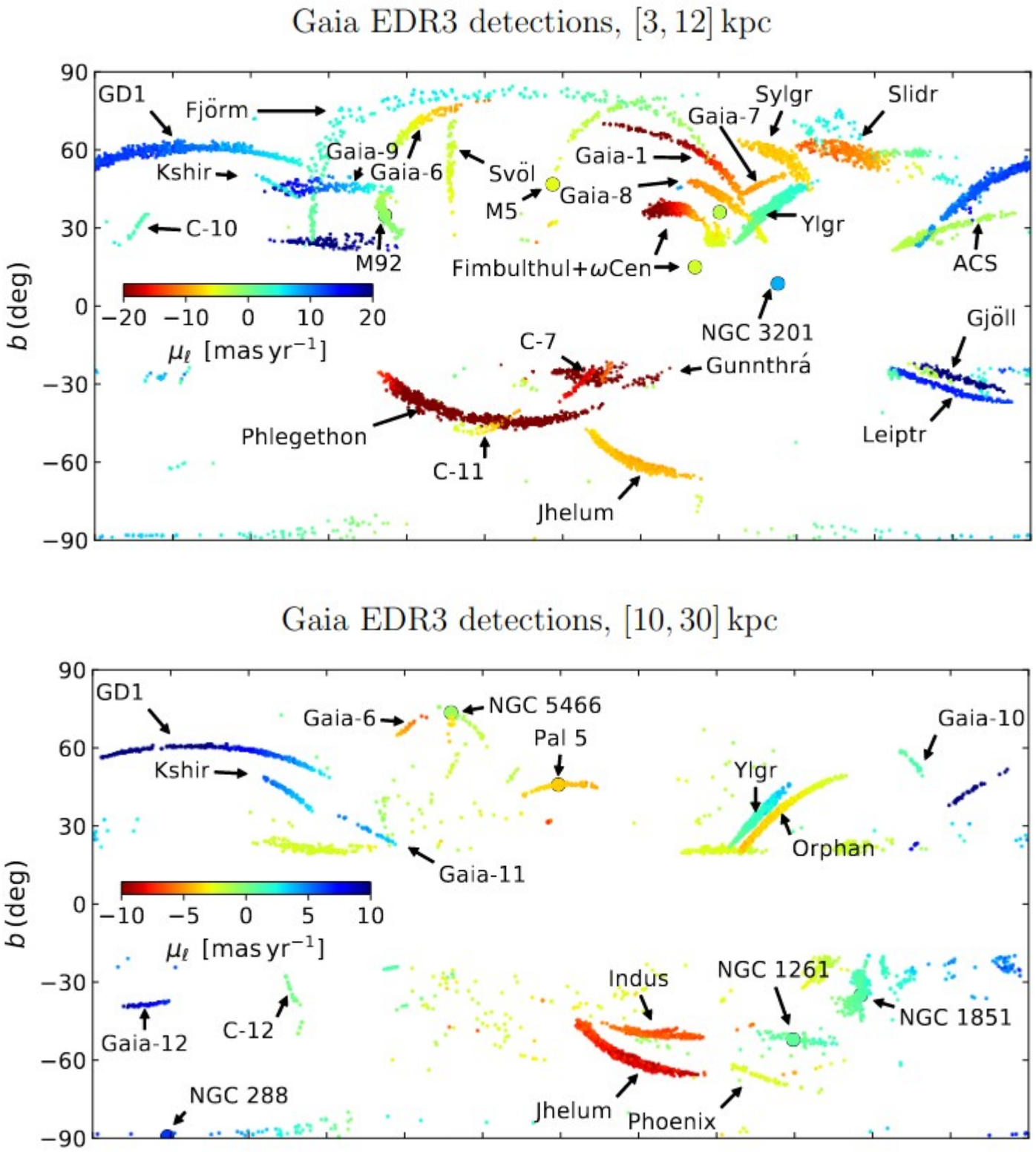
Cantat-Gaudin et al. 2018



Meingast et al. 2020



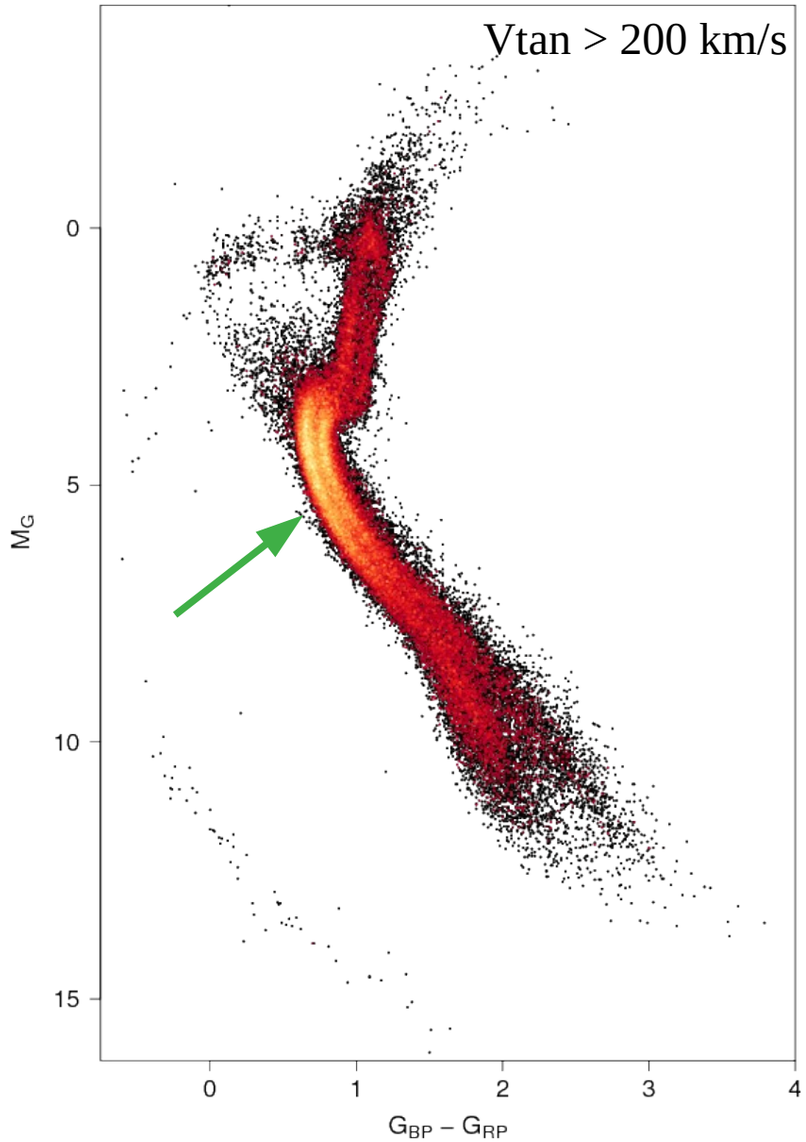
Stellar streams in the halo



Ibata et al. 2021

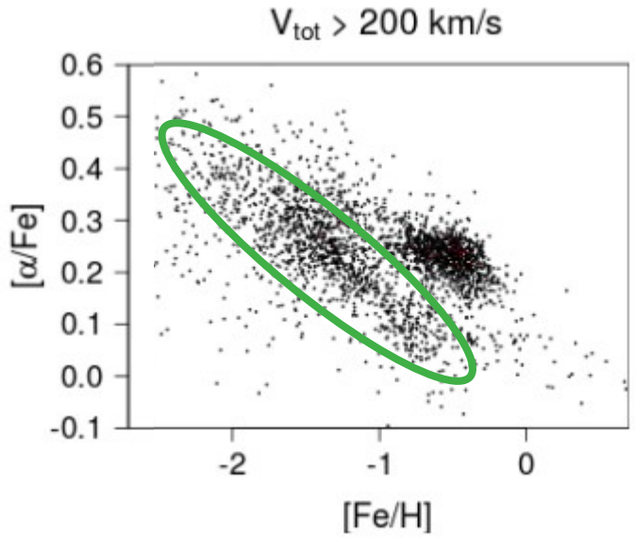
Gaia-Enceladus the last big merger shaping both the halo and the thick disk

Gaia HR diagram

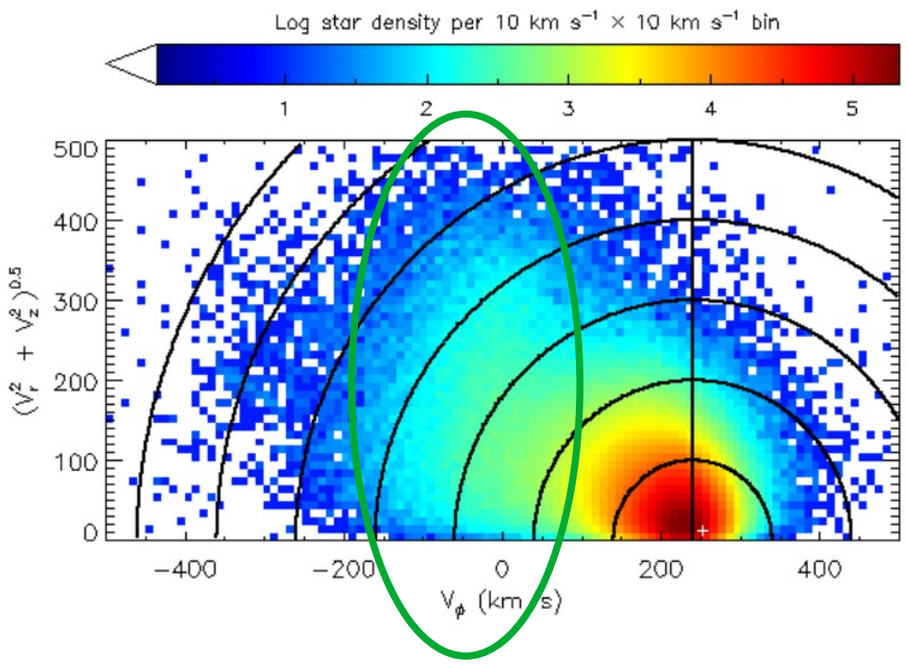


Gaia Collaboration, Babusiaux et al. 2018

APOGEE spectroscopic data



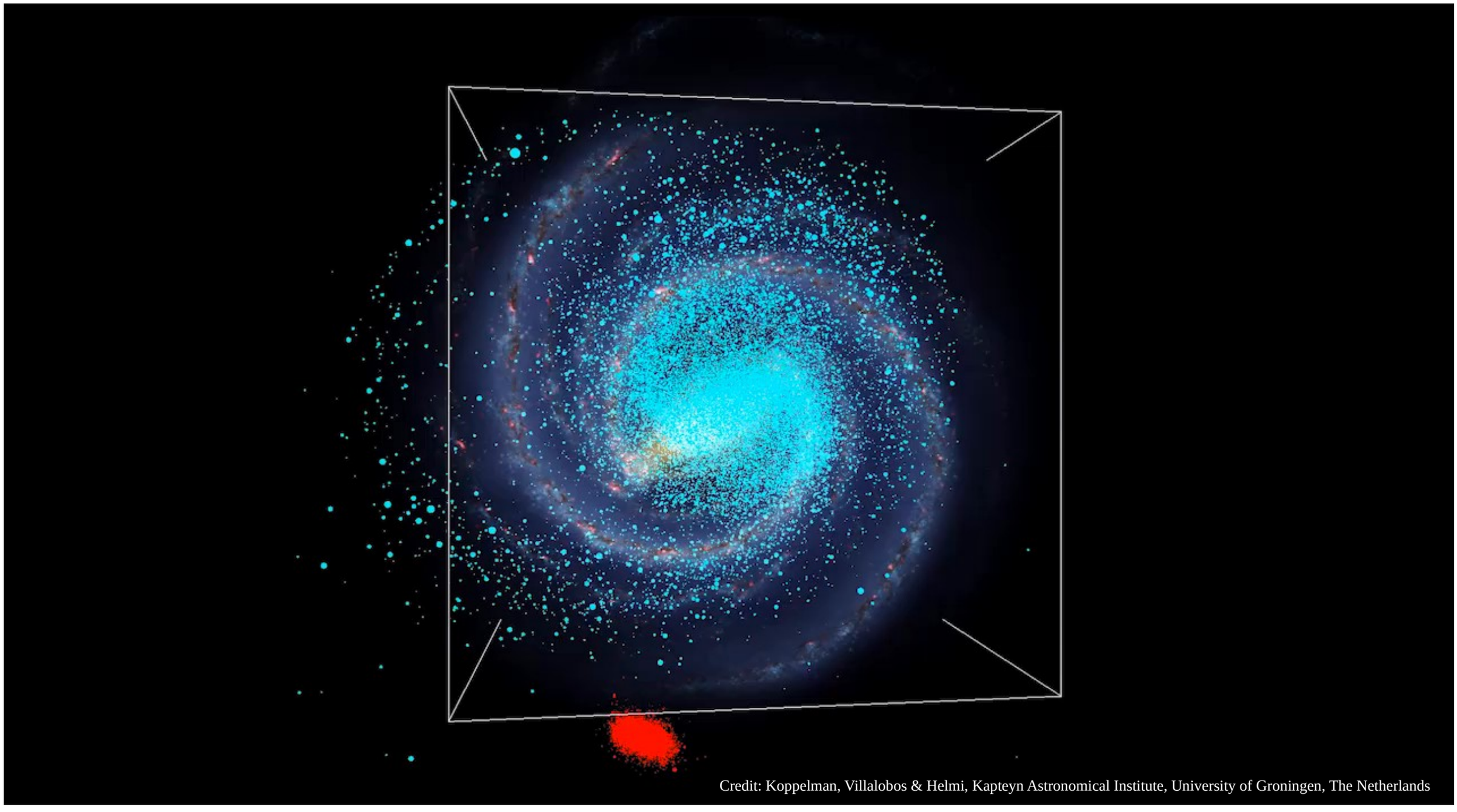
Gaia Toomre diagram



Gaia Collaboration, Katz et al. 2018

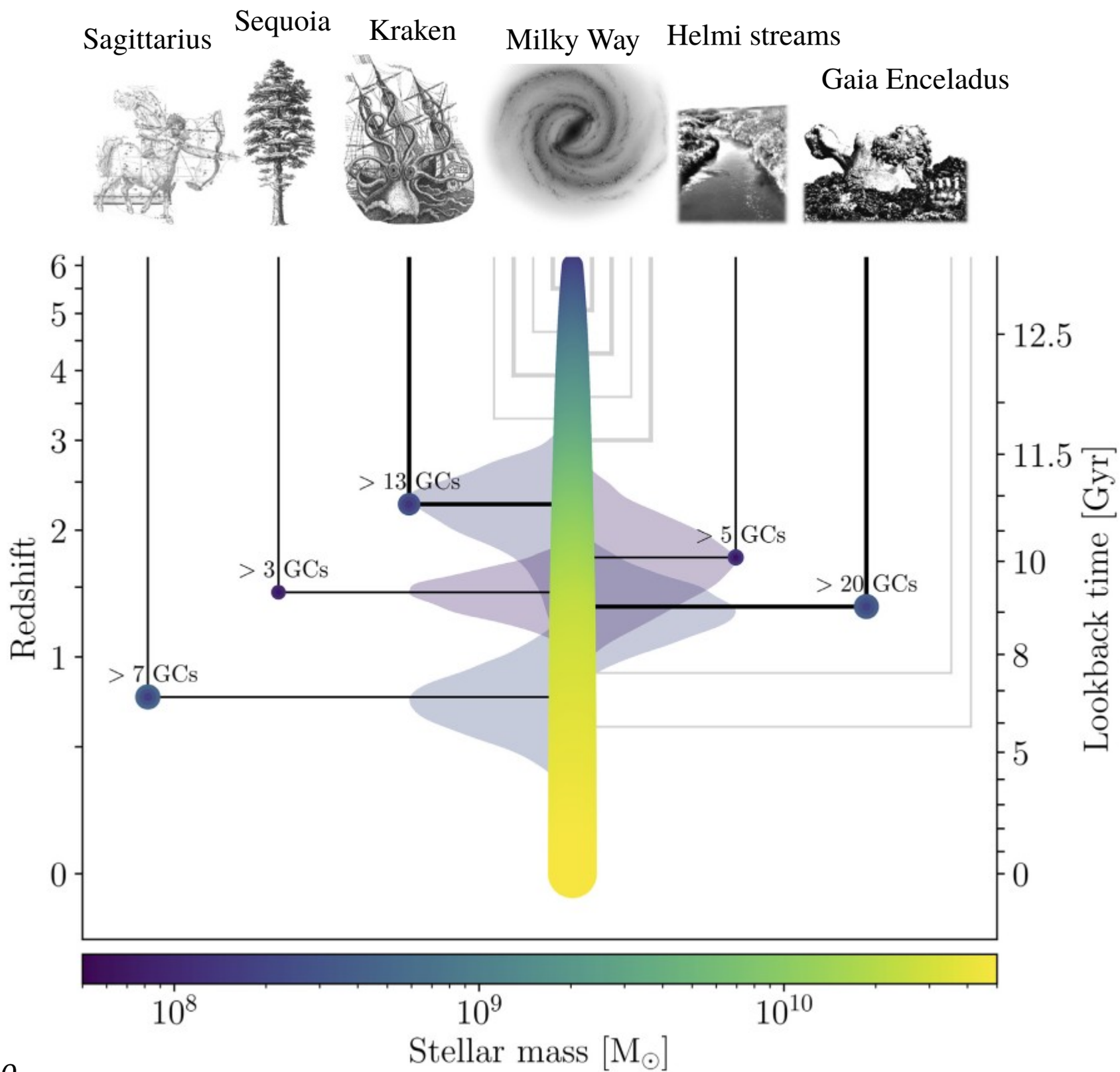
Helmi, Babusiaux et al. 2018; Belokurov et al. 2018++: the Gaia Saussage*; Haywood et al. 2018*: where is the inner halo?

Gaia-Enceladus the last big merger shaping both the halo and the thick disk



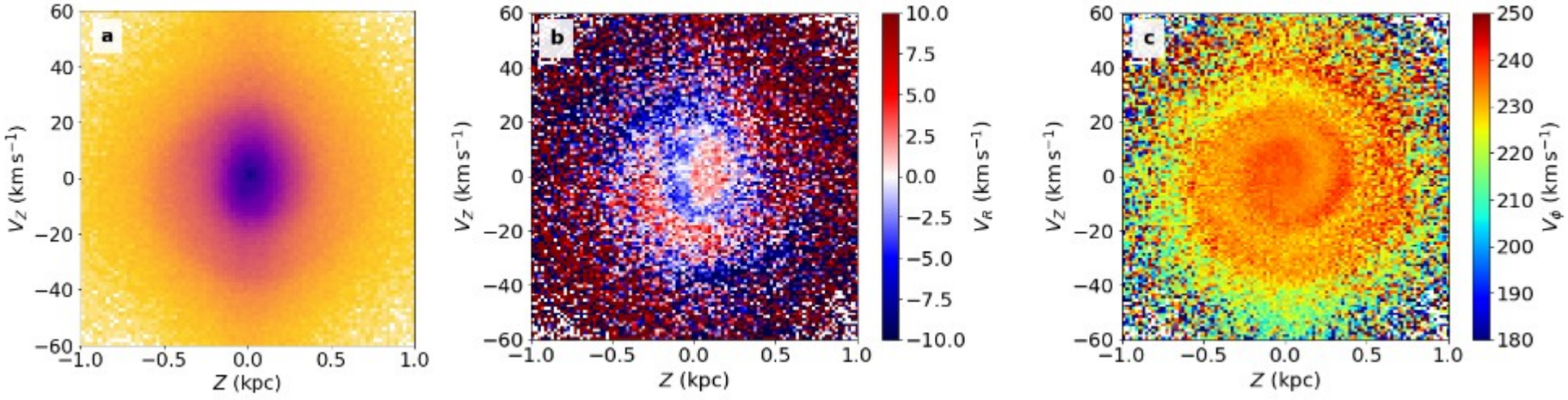
Merger with a galaxy ~ ¼ of the Milky Way mass at the time, ~ 10 Gyrs ago

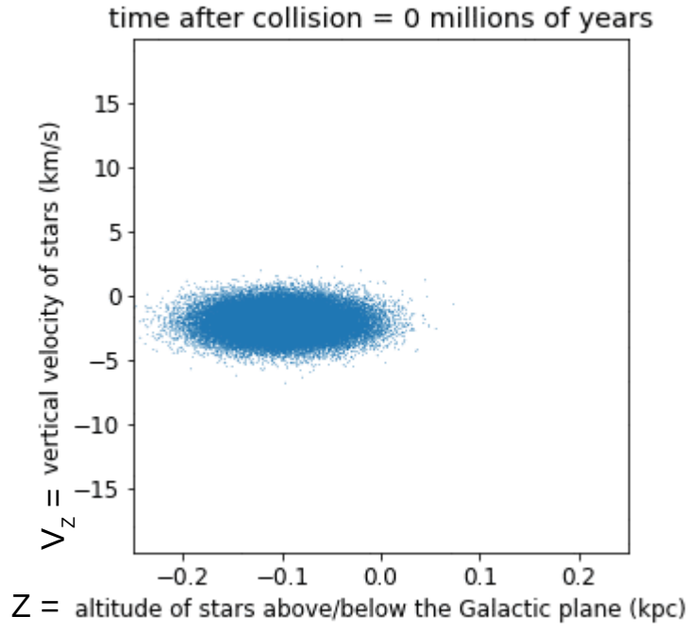
Reconstructing the merger history



Kruijssen et al. 2020

The perturbed Milky Way disk

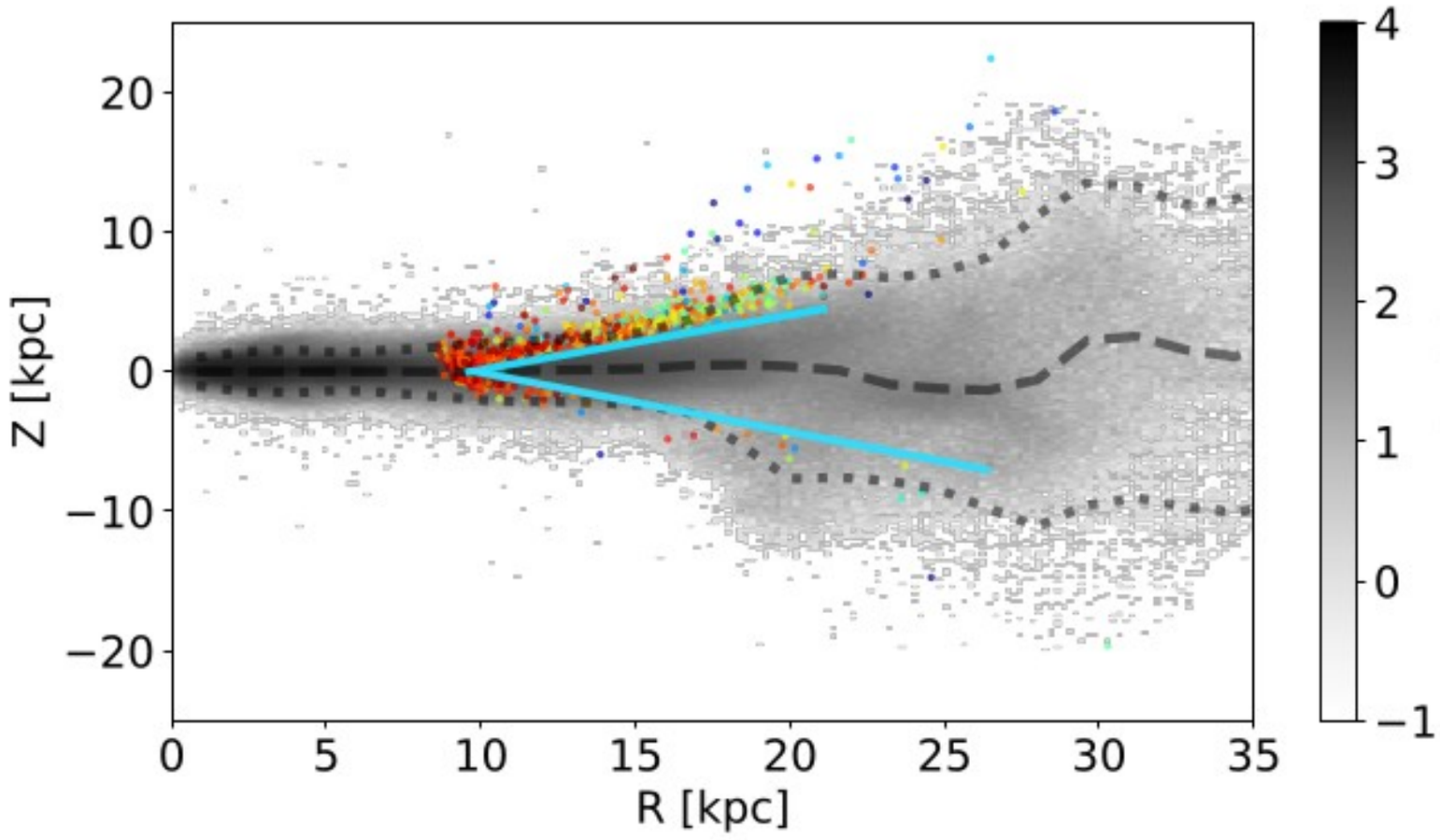




Perturbation by the Sgr dwarf galaxy

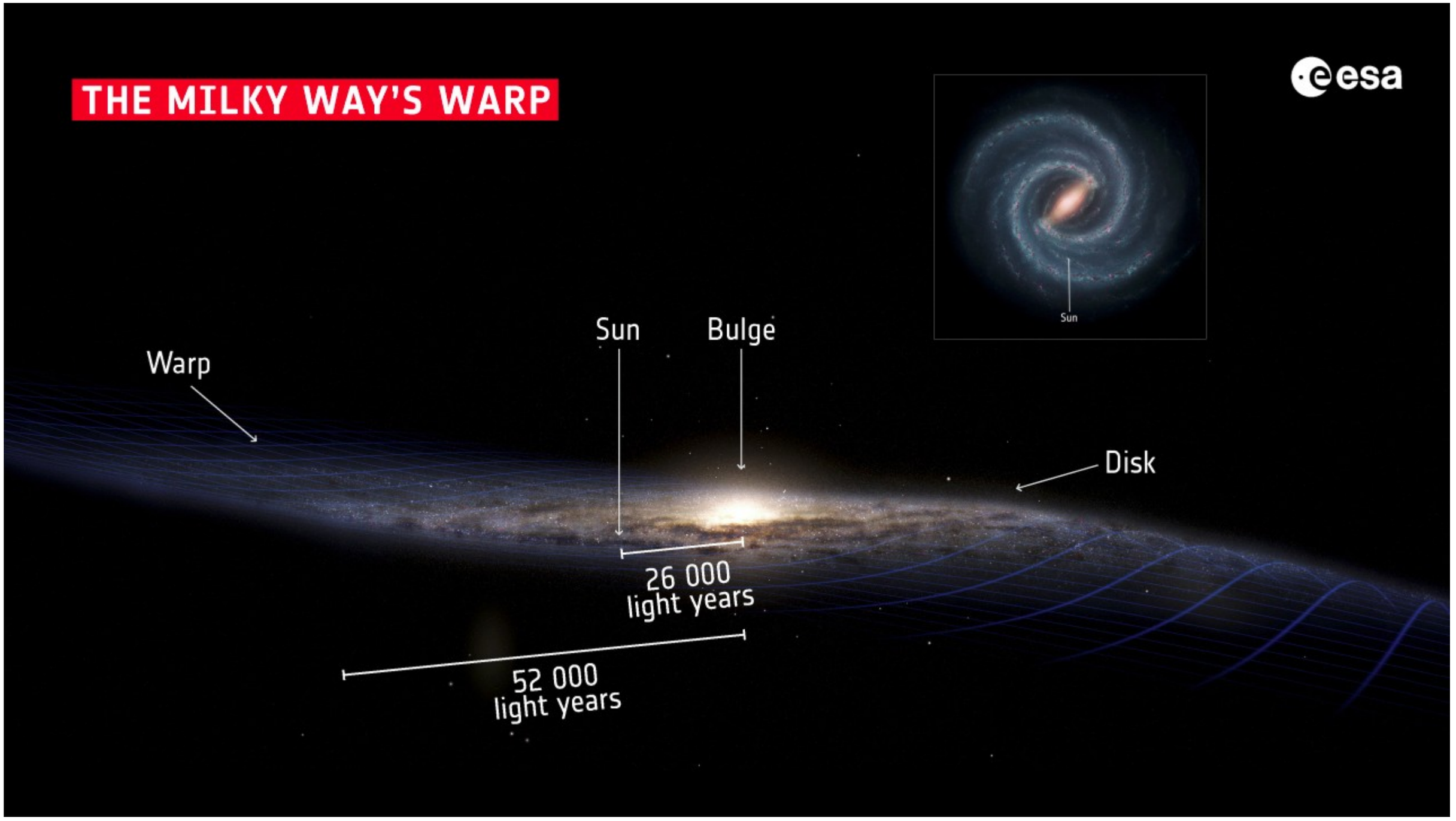
Antoja et al. 2018

The disc flare due to the Sgr dSph repeated passage ?



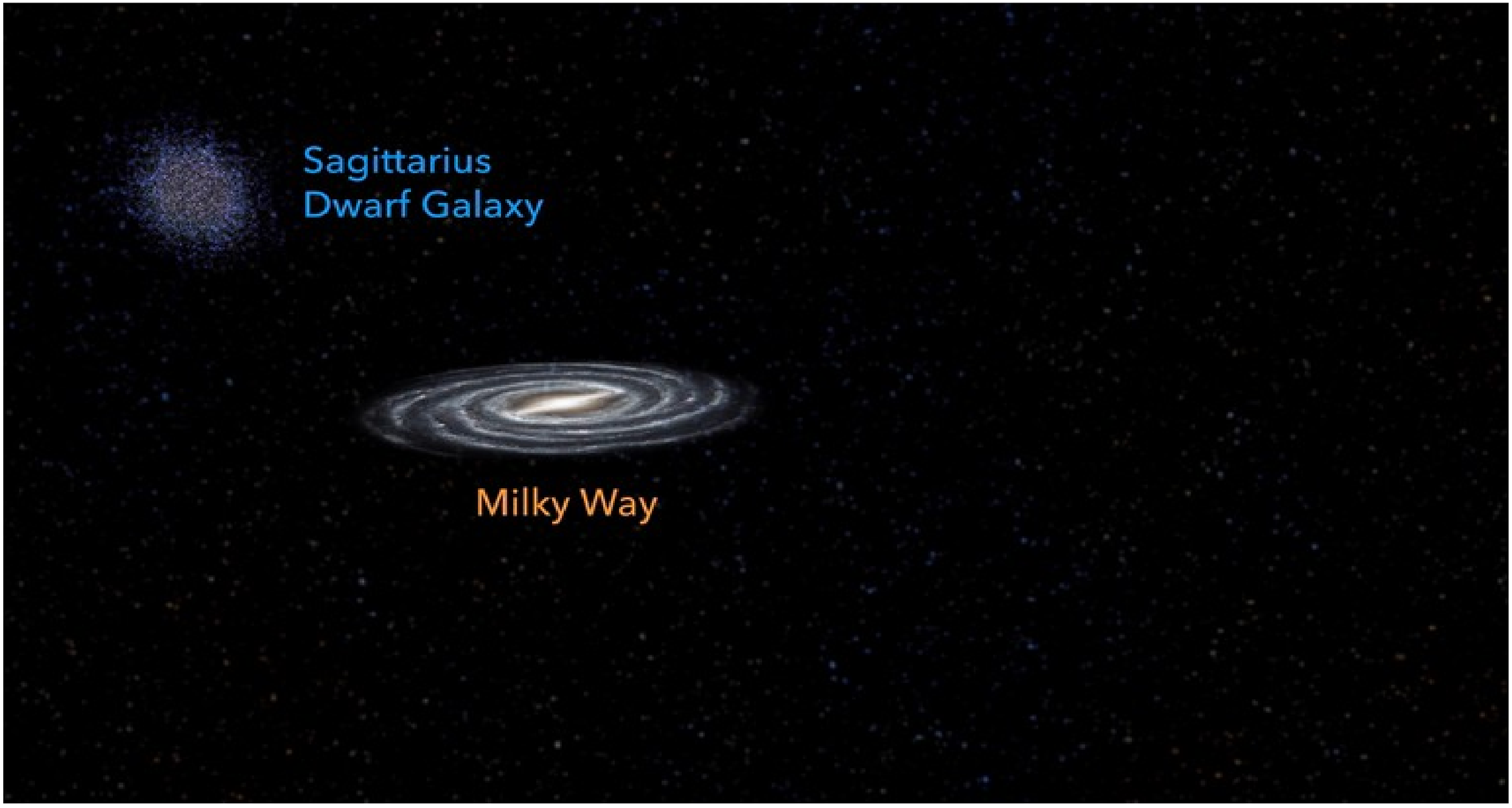
Thomas et al. 2018
CFIS data on Laporte et al. 2018 simulation

A dynamically evolving warp



Poggio et al. 2020

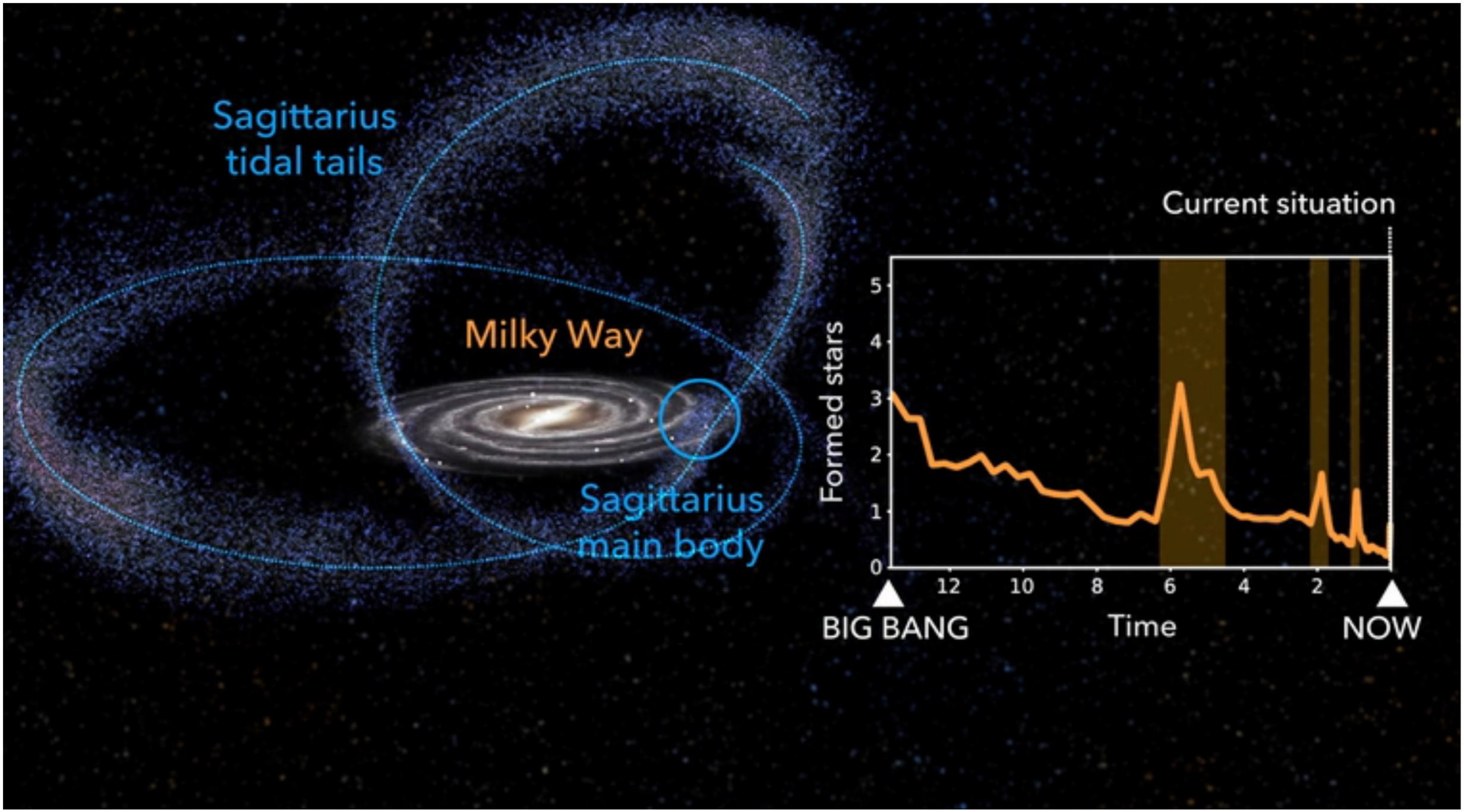
The formation of our Solar System linked to Sgr?



Crédit: Gabriel Pérez Díaz, SMM (IAC)

Ruiz-Lara et al. 2020

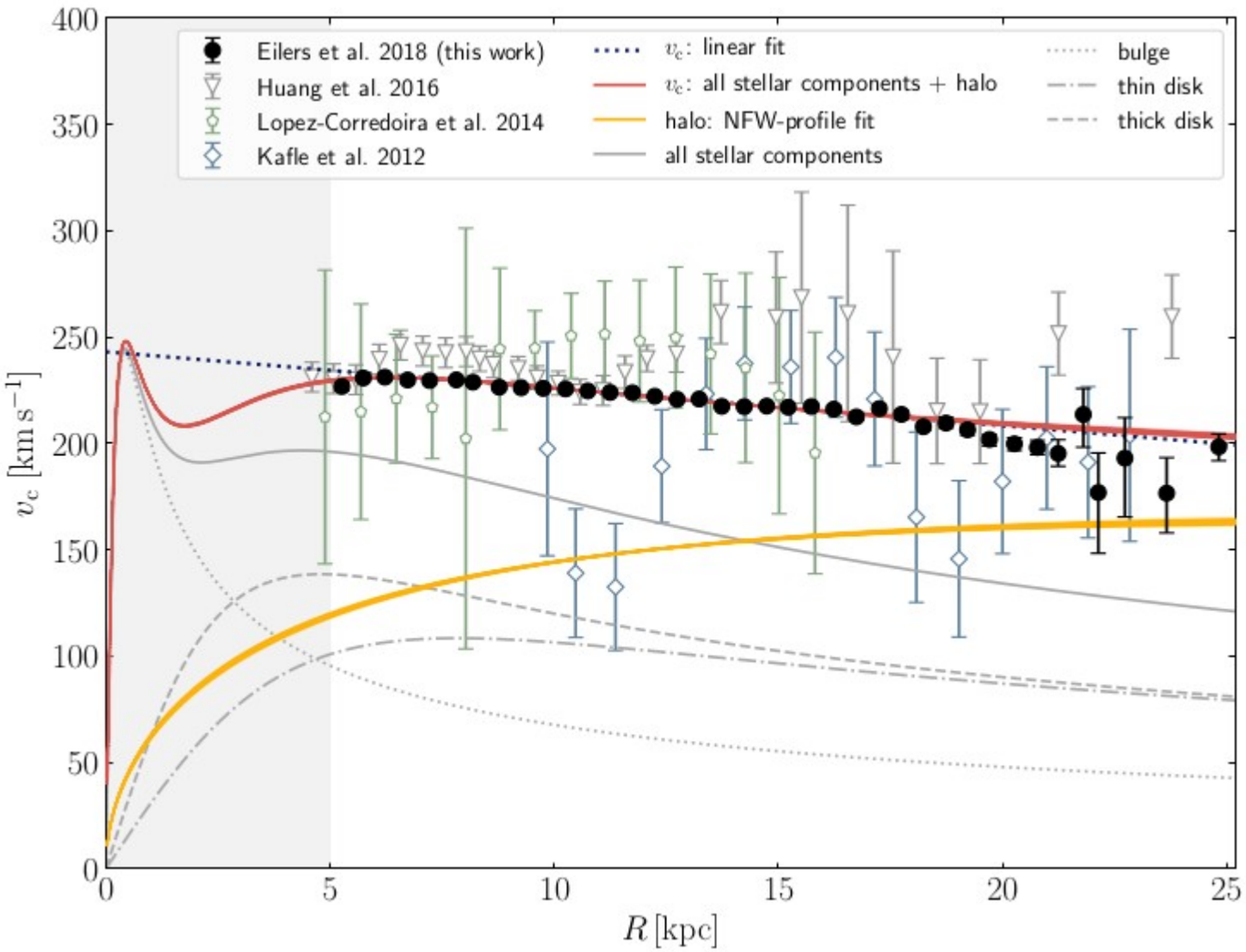
The formation of our Solar System linked to Sgr?



Crédit: Gabriel Pérez Díaz, SMM (IAC)

Ruiz-Lara et al. 2020

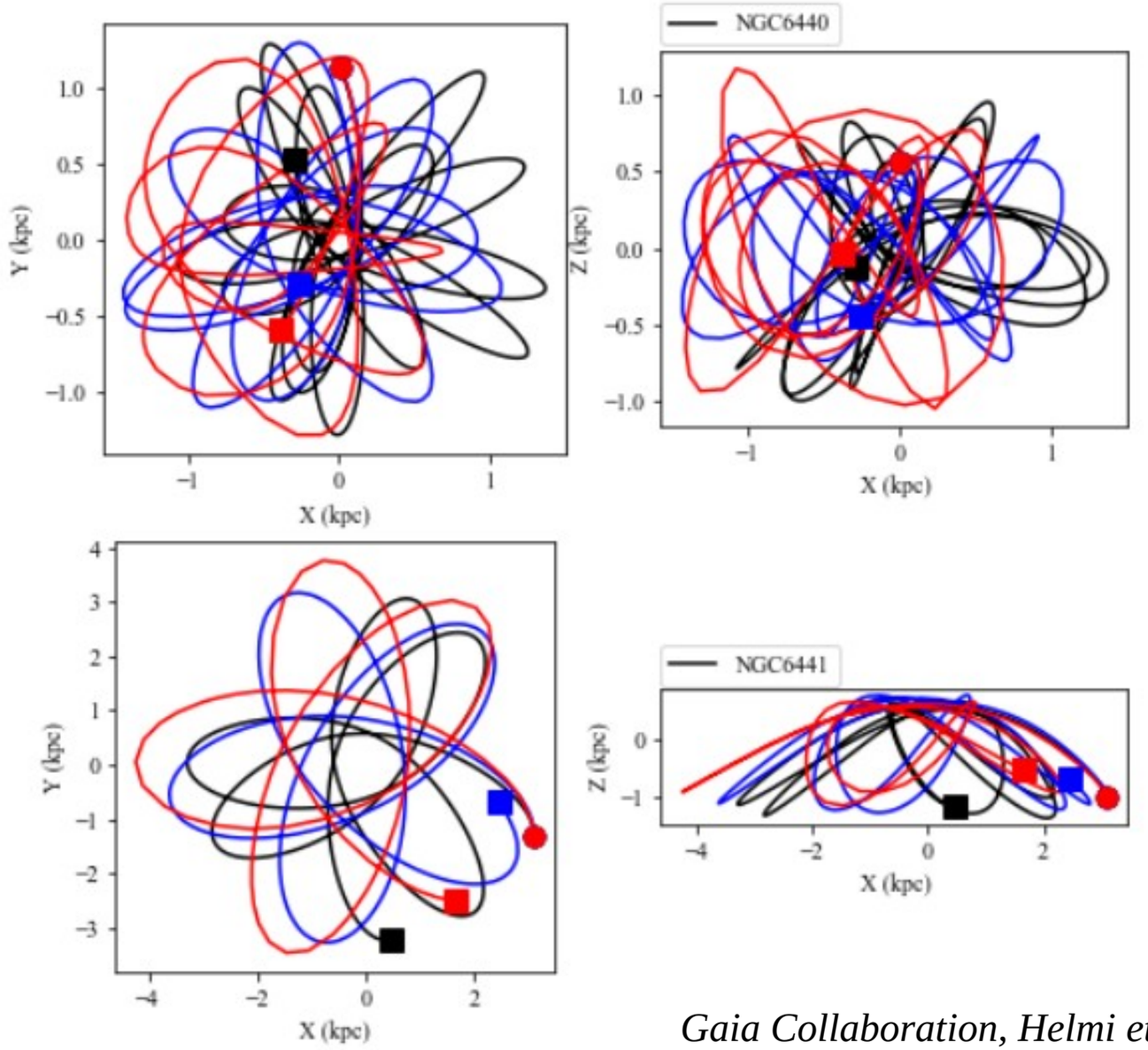
The Milky Way circular velocity curve



ρ_{DM} ($R_\odot$) = 0.30 ± 0.03 GeV cm^{-3}

Eilers et al. 2018

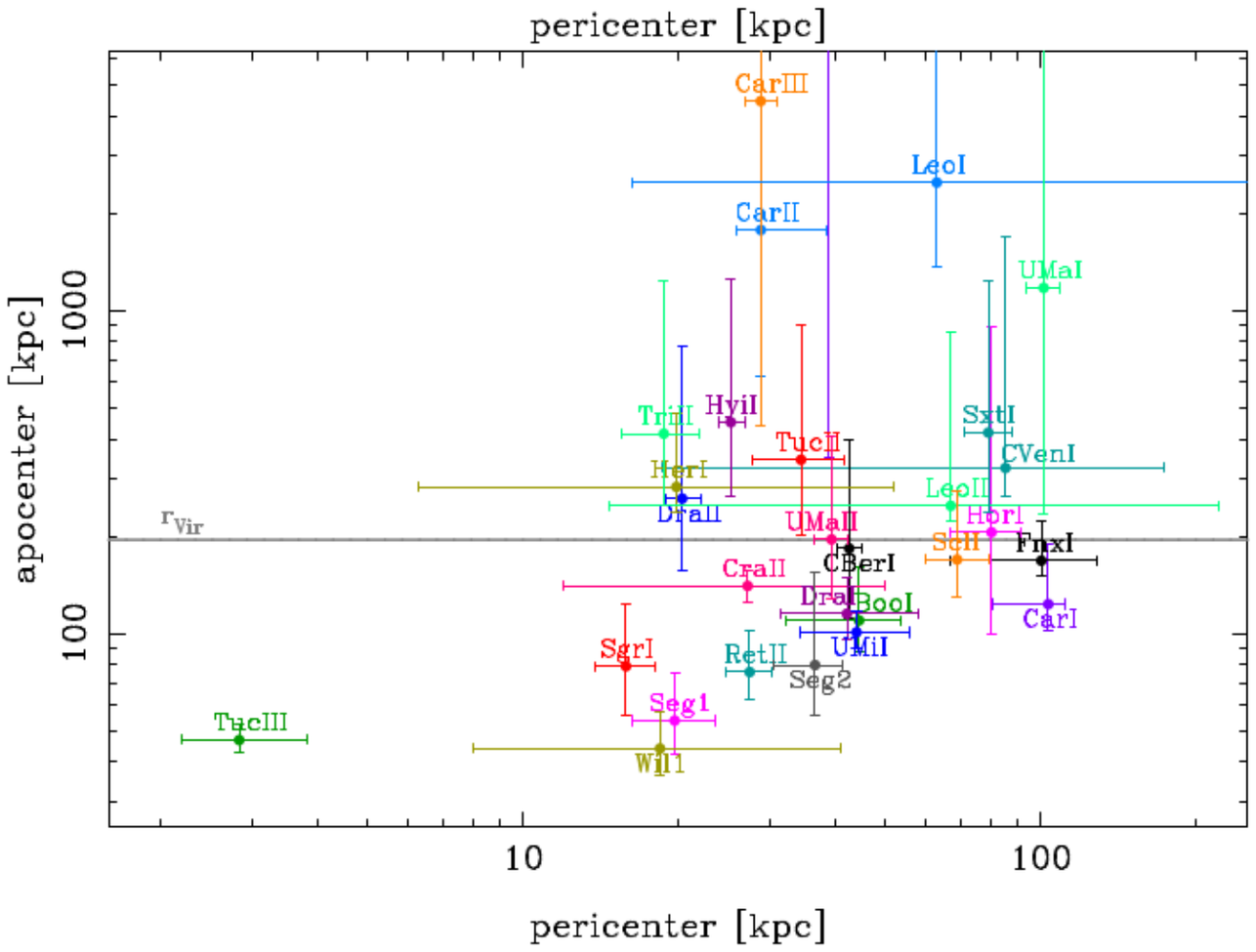
Globular Clusters



Gaia Collaboration, Helmi et al. 2018

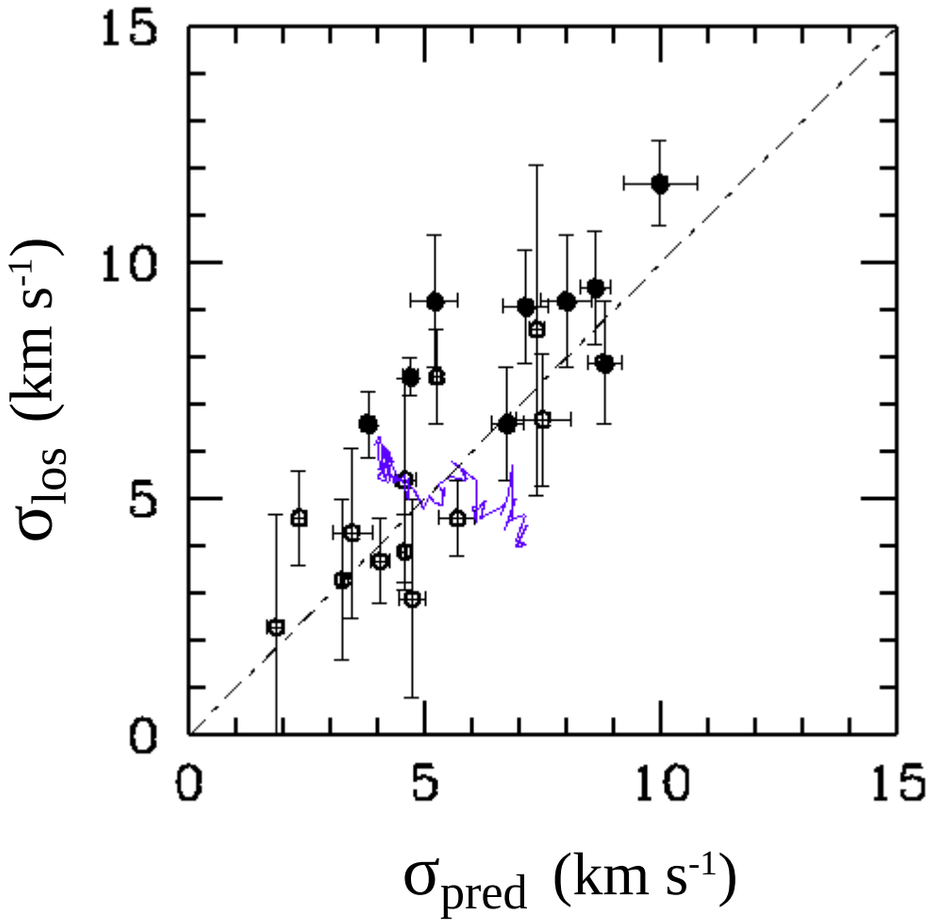
Used to derive the mass of the MW + DM:
Watkins et al. 2018, Posti & Helmi 2018

Dwarf spheroidals



Orbit determinations :
Gaia Collaboration, Helmi et al. 2018
Fritz et al. 2018

No more need for DM in dSph ?



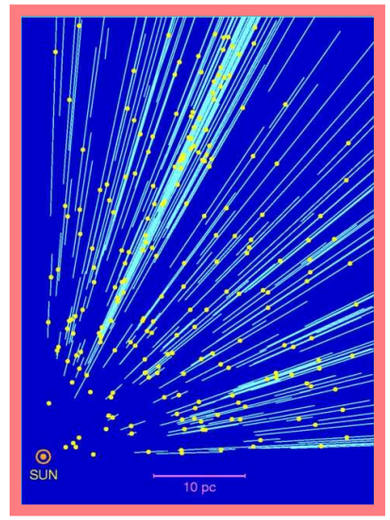
Velocity dispersion predicted by a model where dSph are at their first passage

Hammer et al. 2018, Hammer et al. 2020

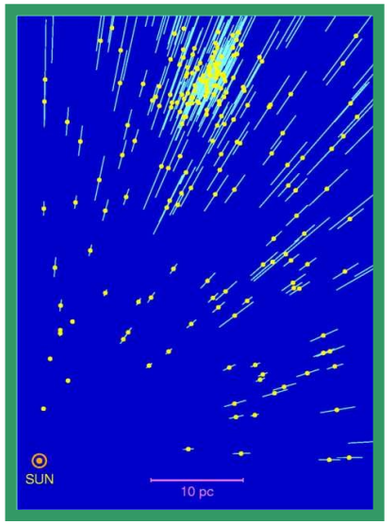
More than yesterday, less then tomorrow...

	DR2 (25 April 2018)	DR3 (3 Dec 2020 / 2022)	DR4 (TBD)
Parallaxes and proper motions	Full Sample	++	++
Photometry	G, G_{BP}, G_{RP}	++	++
Variables	550 000	++	++
Radial velocities	RVs at G_{RVS}<12	++	++
SSOs	pre-selected asteroids	New SSOs	++
Astrophysical parameters	for G < 17 : Teff, A_G Radii and luminosities *from integrated phot*	Classification + parameters from BP/RP + RVS spectra	++
Systems	-	Non-single catalogue Extended Objects	Exoplanet list
Spectra	-	Mean BP/RP spectra Mean RVS spectra	++
Epoch data	-	-	All epoch data

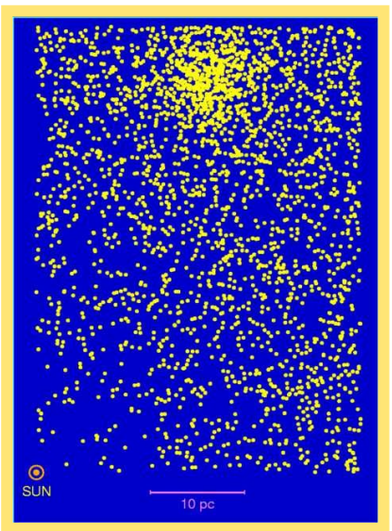
Hyades



1960



1990 (Hipparcos)



2025 (Gaia)