The mission Gaia of the European Space Agency

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What is Gaia all about ?

- ESA cornerstone mission for research of the Galaxy.
- Astrometric satellite; successor of Hipparcos 1990-93. Includes optical photometry to 20th mag. & spectroscopy
- 5+5 years of observations with production of Gaia catalog.
- Astronomers involved in production of Gaia catalog.
- What does Gaia teach us about the formation, structure and evolution of our Galaxy?

Launch in Dec 2013

Wrapping up Gaia for shipping to Kourou

Getting ready for launch

Science with Gaia data

What do 1.8 billion stars in 3-D allow us to do?

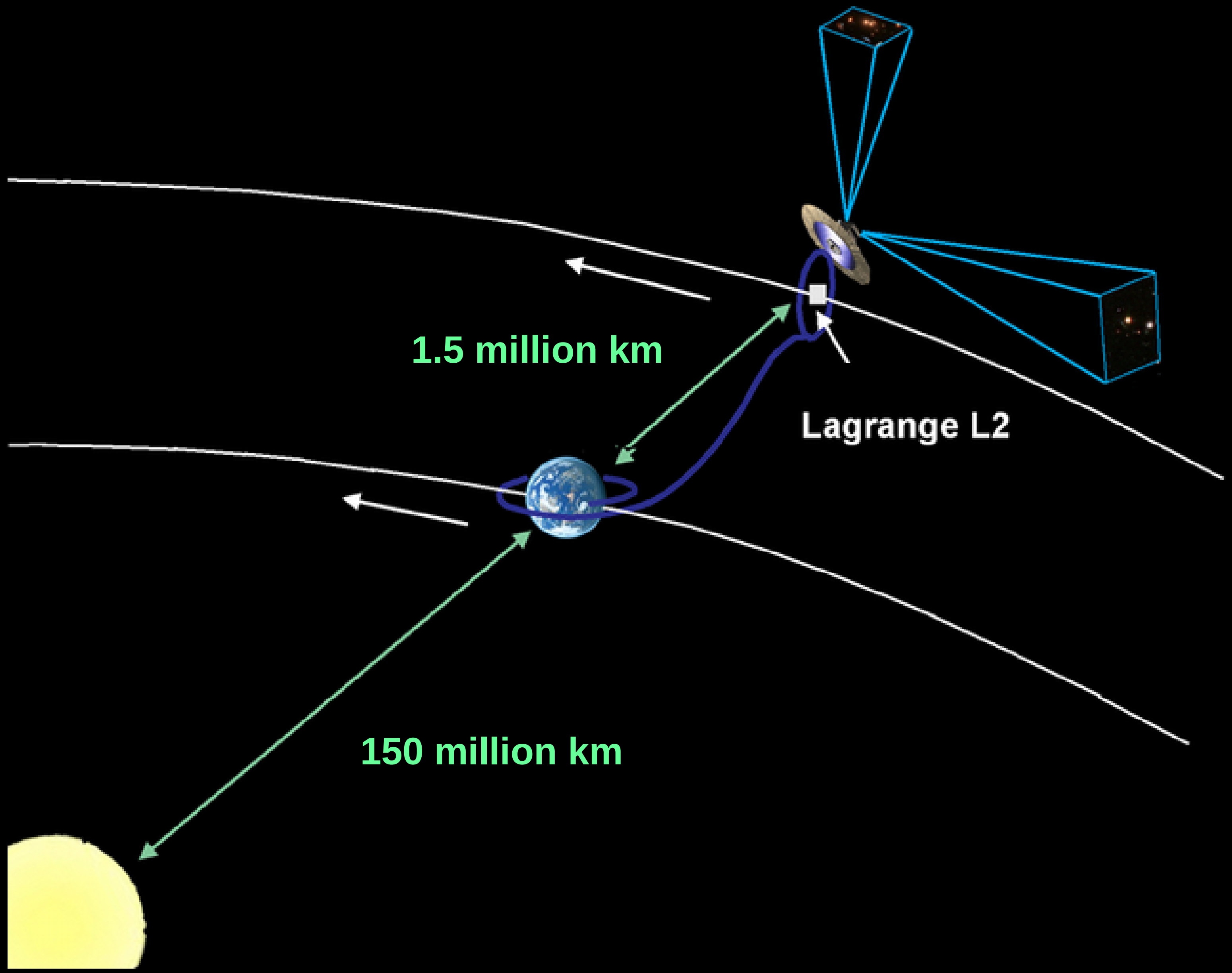
In our Milky Way, research of…

- Accurate distances and velocities of 1.8 billion stars
- Stucture and kinematics of the Milky Way disk, bar & halo
- Formation history of the Milky Way
- Foundation for star evolution theories, chemical composition
- large-scale census of asteroids
- census of binary stars, variable stars, exoplanets
- study of dark matter in the Milky Way

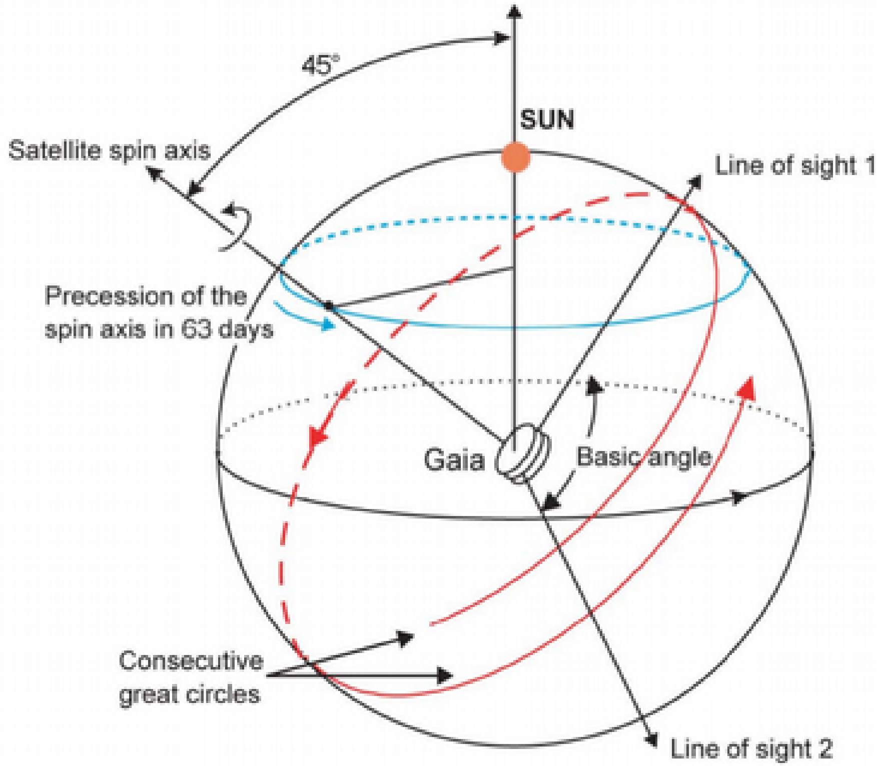
... and far beyond our Milky Way...

- standard candles for measuring distances beyond Magellanic clouds
- zero-point calibration of abs. distance scale, PL calibration Cepheids
- quasar detections & variability, definition of celestial reference frame
- census of galaxies with accurate red-shifts

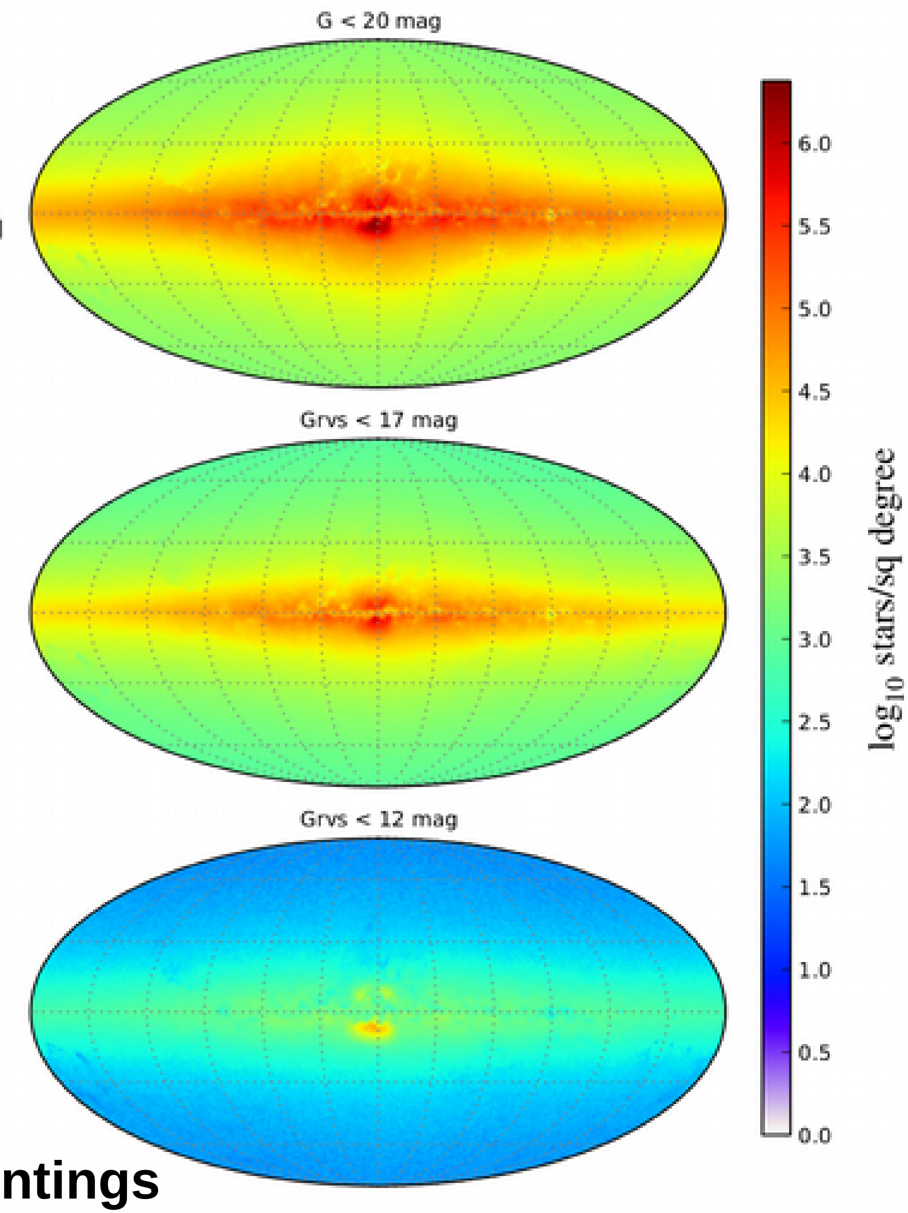
Gaia in the second Lagrange point L2



Gaia rotates around its axis, scans the sky

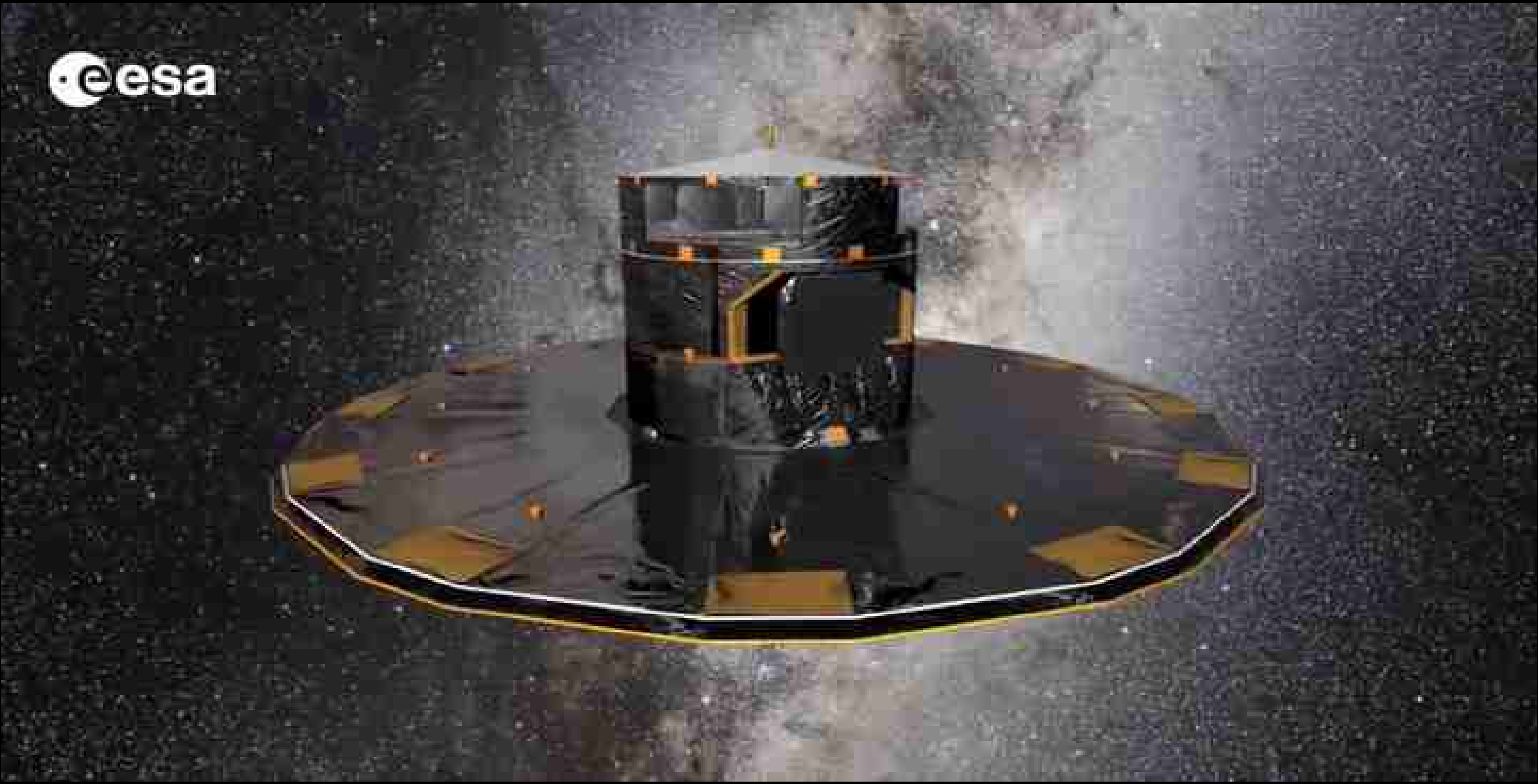


Simulated Gaia sky — Robin et al., arXiv:1202.0132



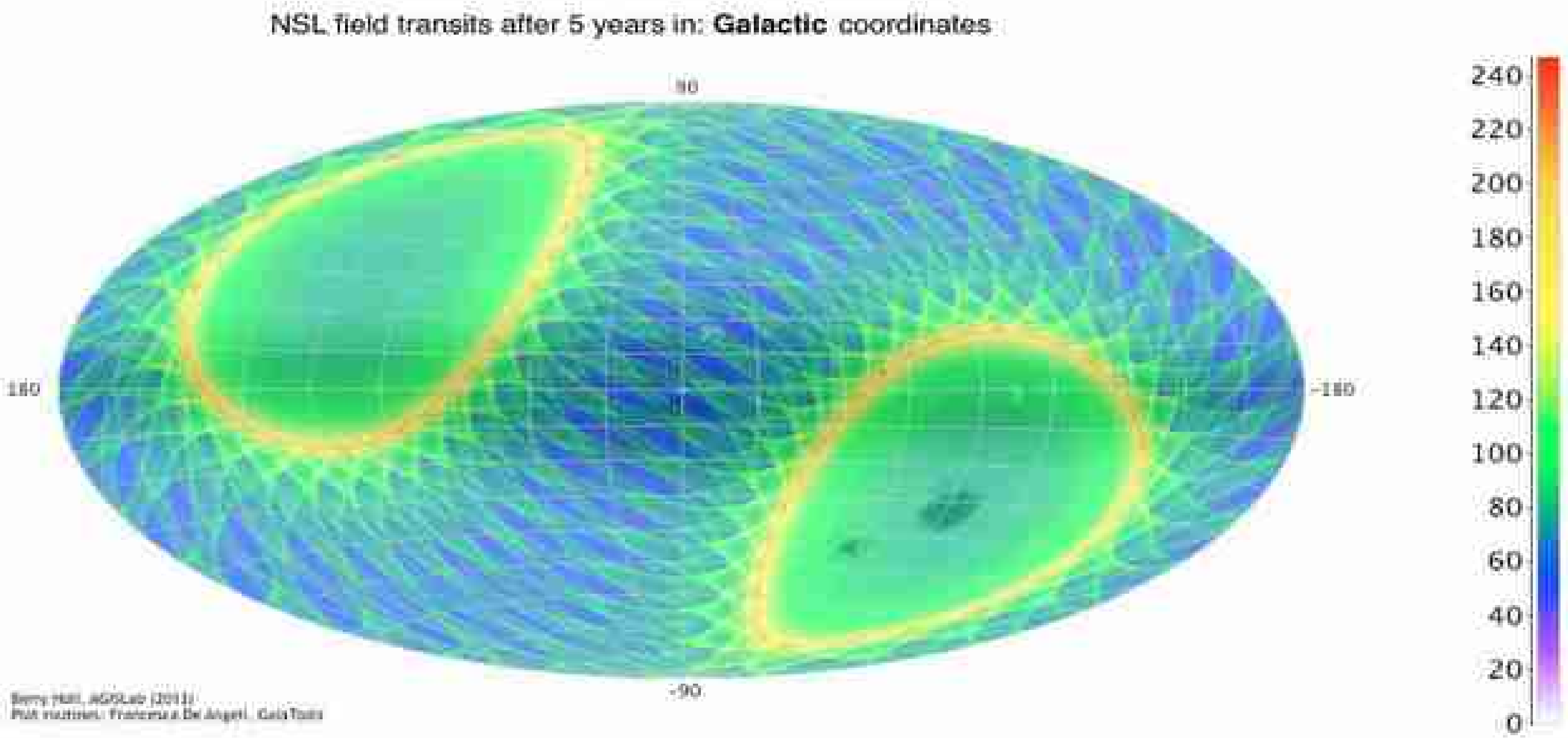
- **Rotation axis: 45 deg. wrt Sun**
- **Rotation period: 6 hours**
- **Observes all sources $6^m < G < 20^m$**
- **No input catalog, no positional pointings**

Gaia scans the complete sky



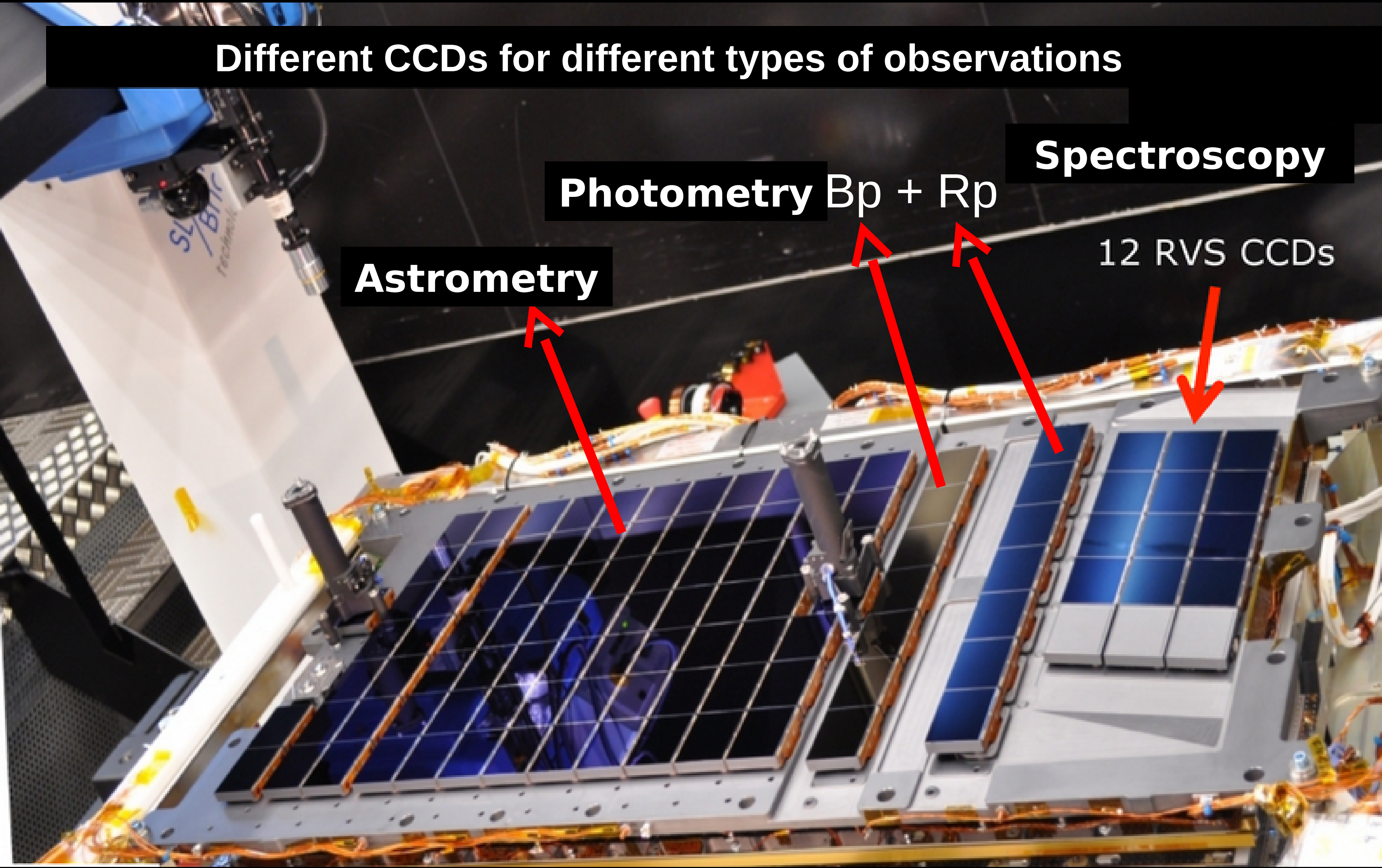
Gaia scans optical sources several times

Map of amounts of Gaia scanning observations during 5 years



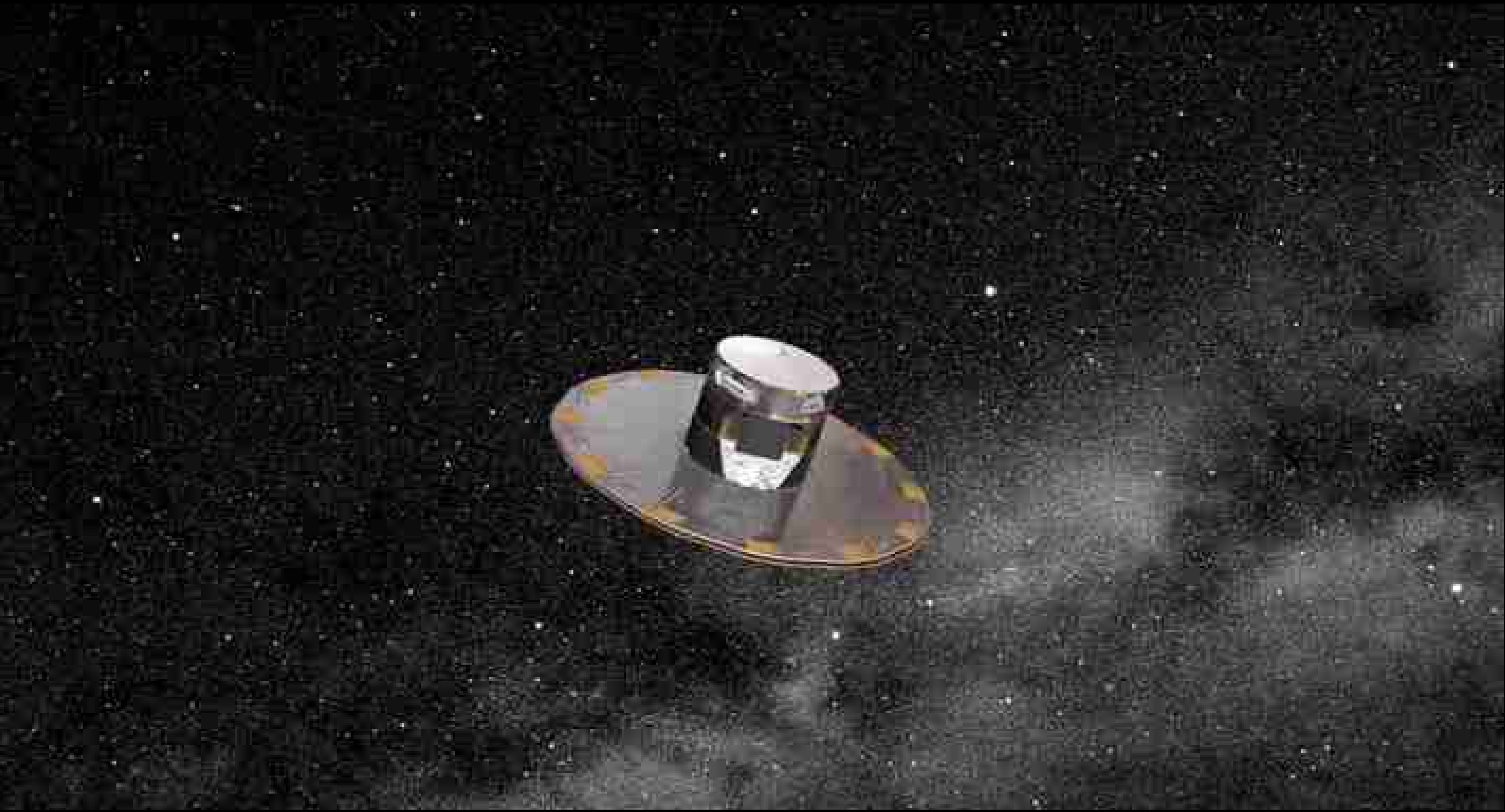
- **Observes about 1.8 billion stars on average 70 times to *G* = 20 mag.**
- **Astrometry with blue & red photometry of each source.**
- **Astrometric accuracy in final catalog to ~10 µ arcsec (*G* < 15 mag.)**

Gaia's CCD detectors

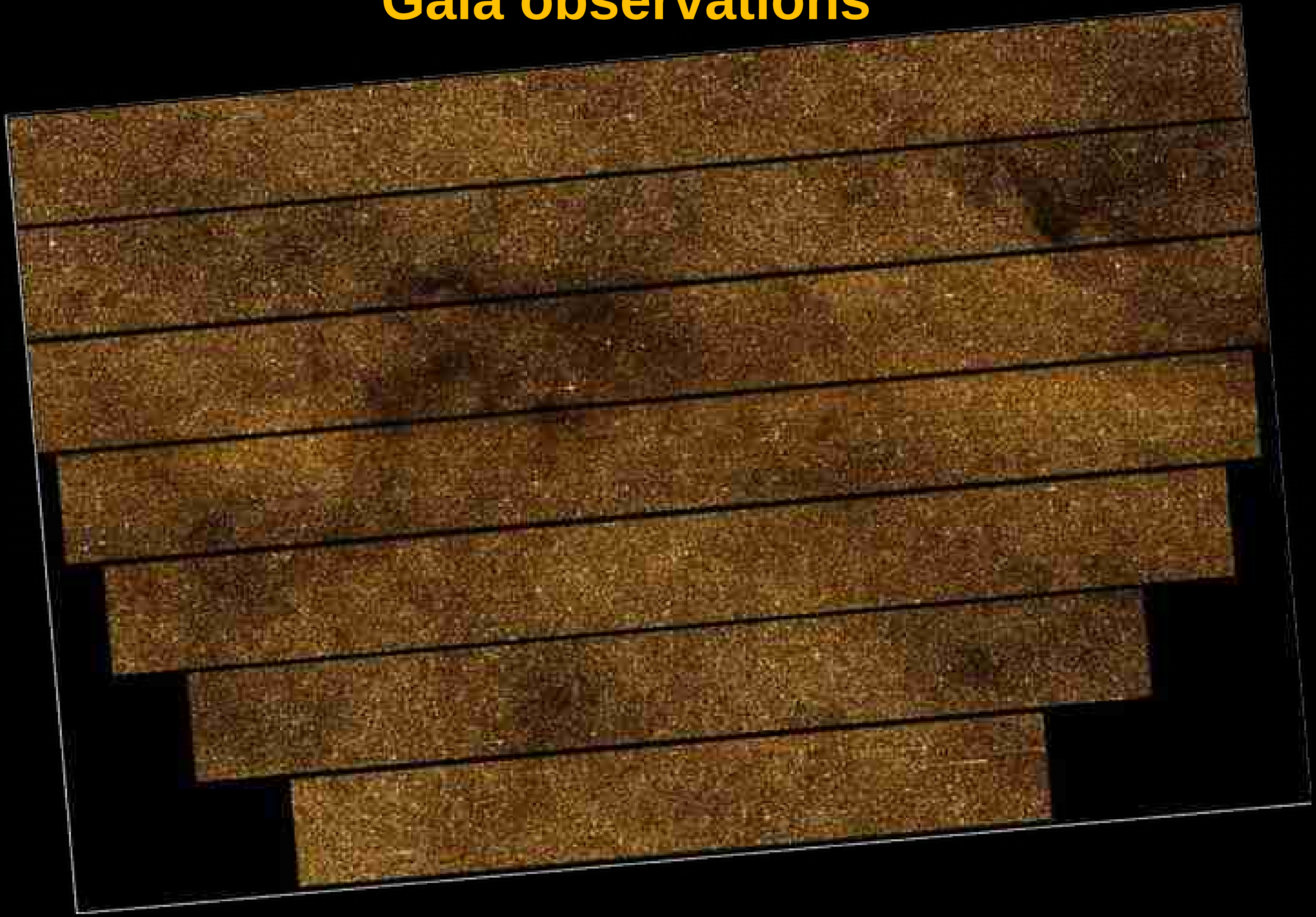


106 CCDs ≅ 938 million pixels

The Billion Star Surveyor

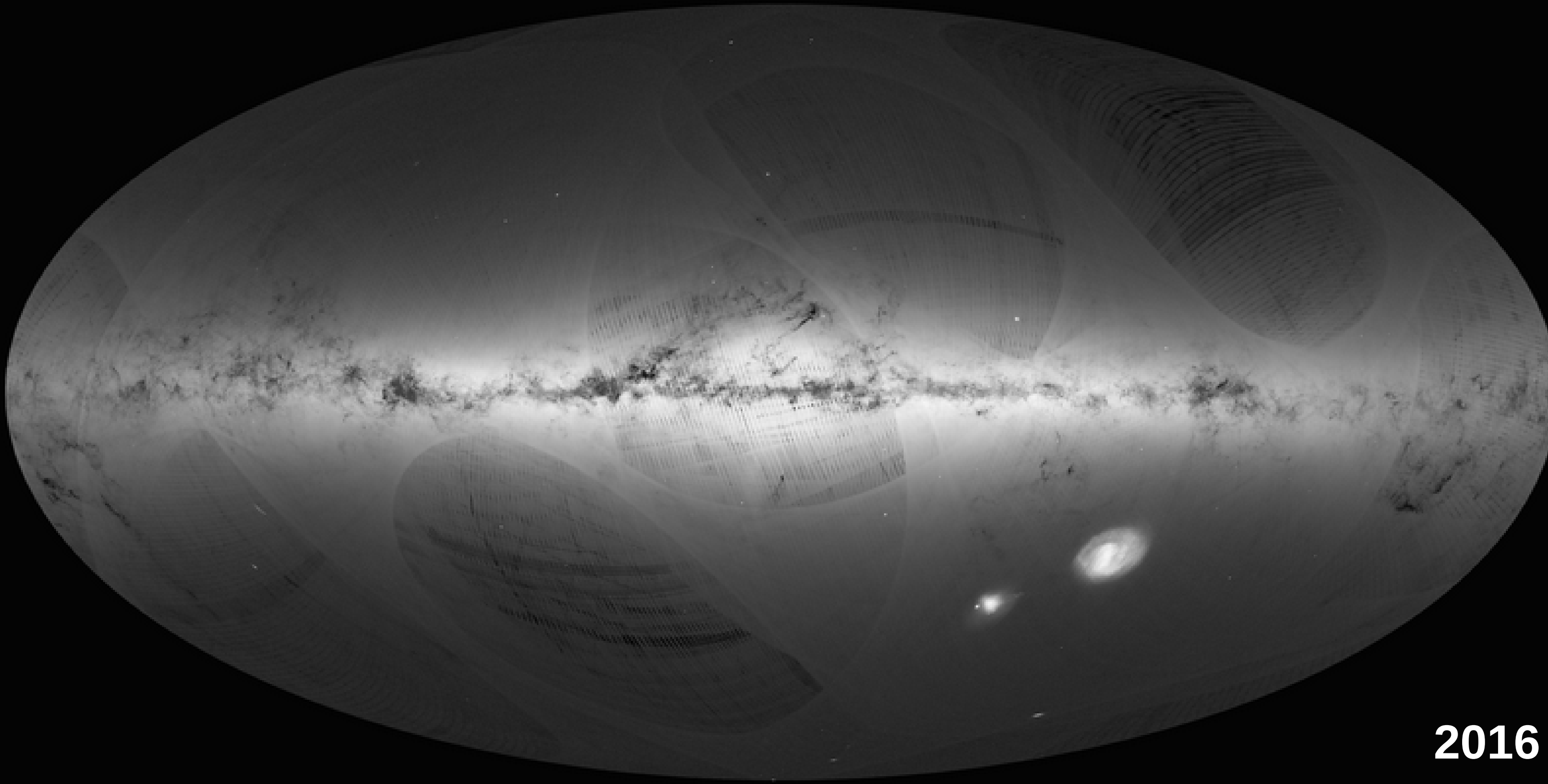


Gaia observations



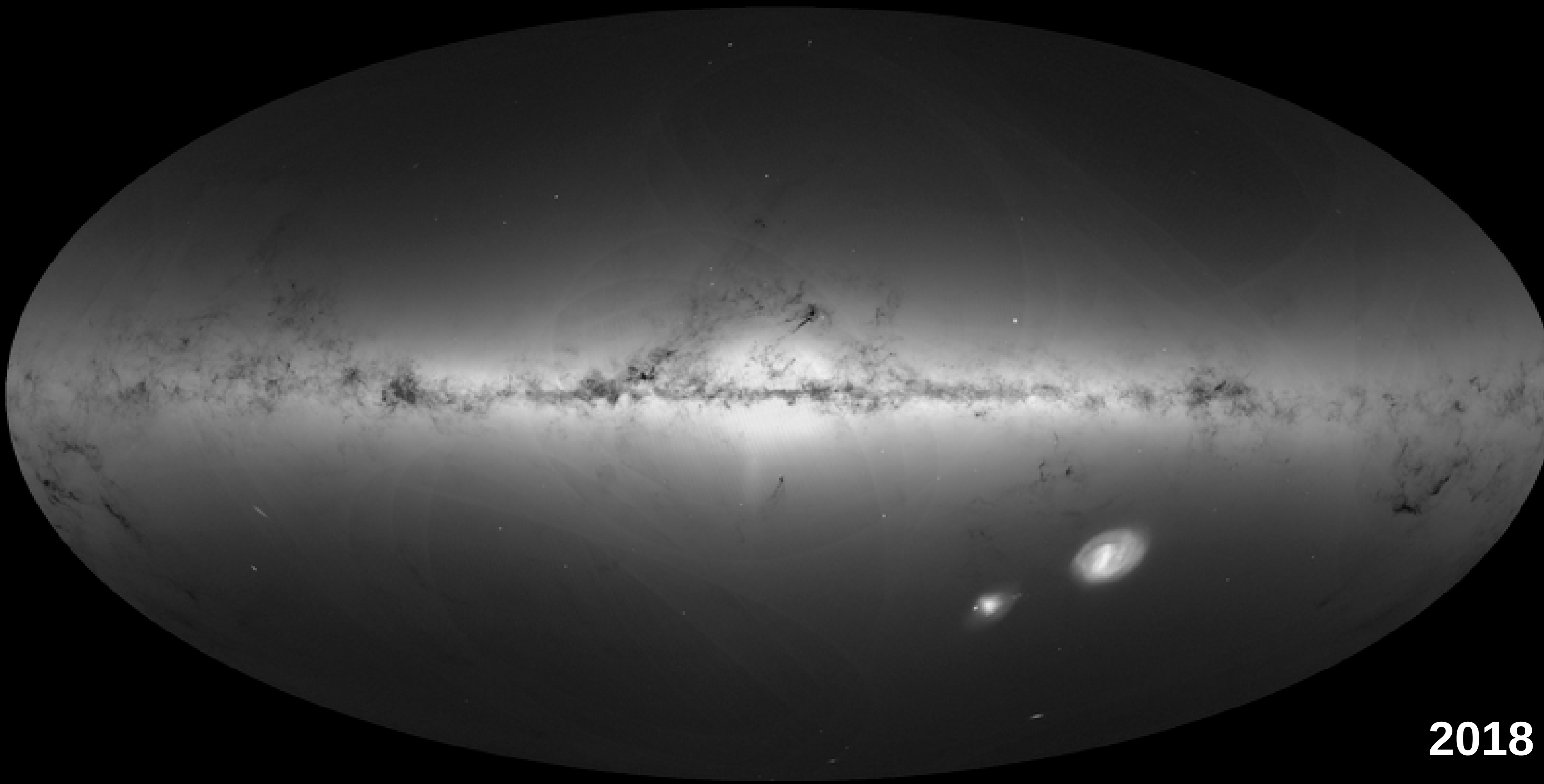
in 1 minute 100,000 stars are being observed

Position and brightness of 1.1 billion stars



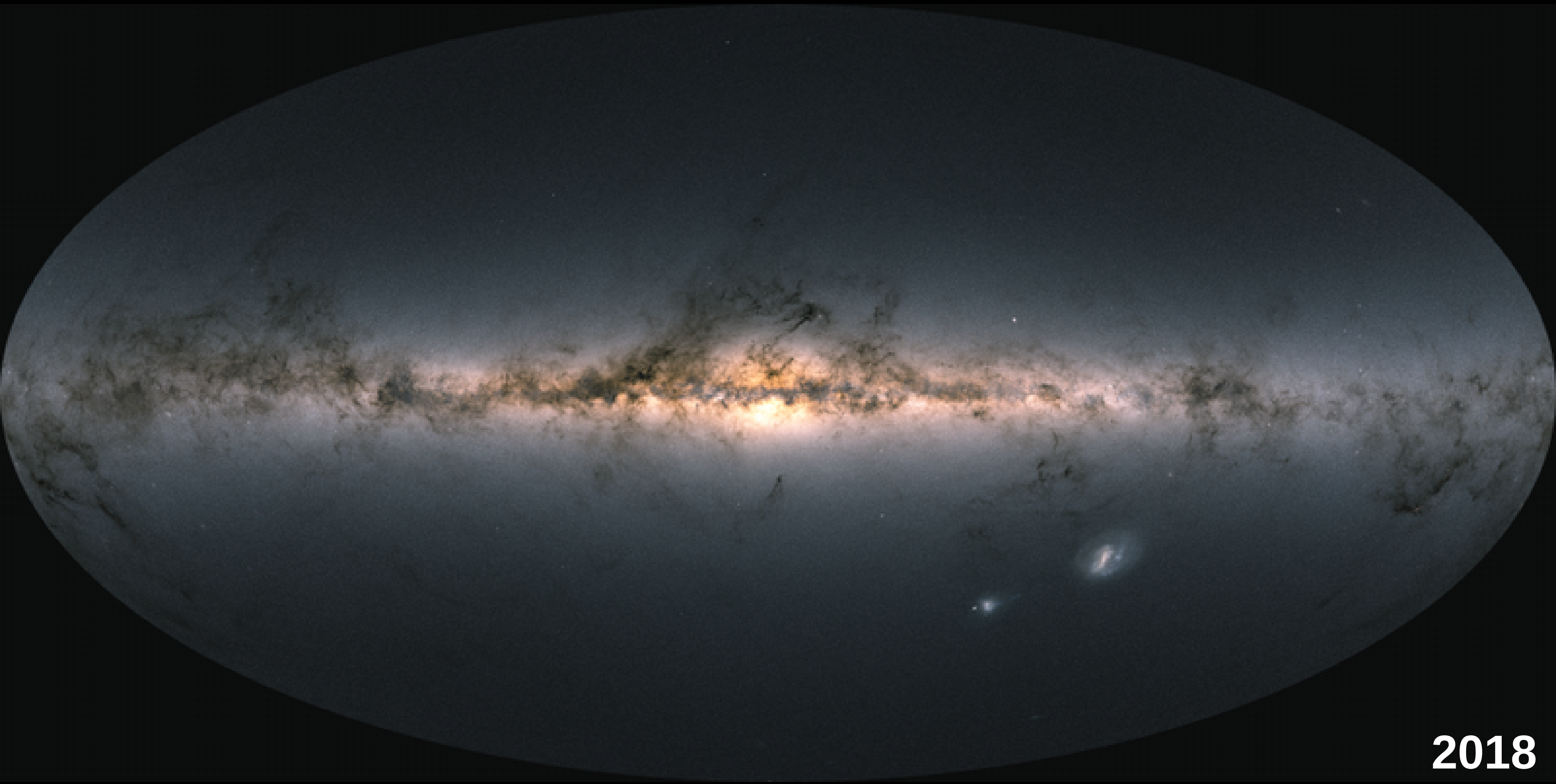
2016

Position and brightness of 1.7 billion stars



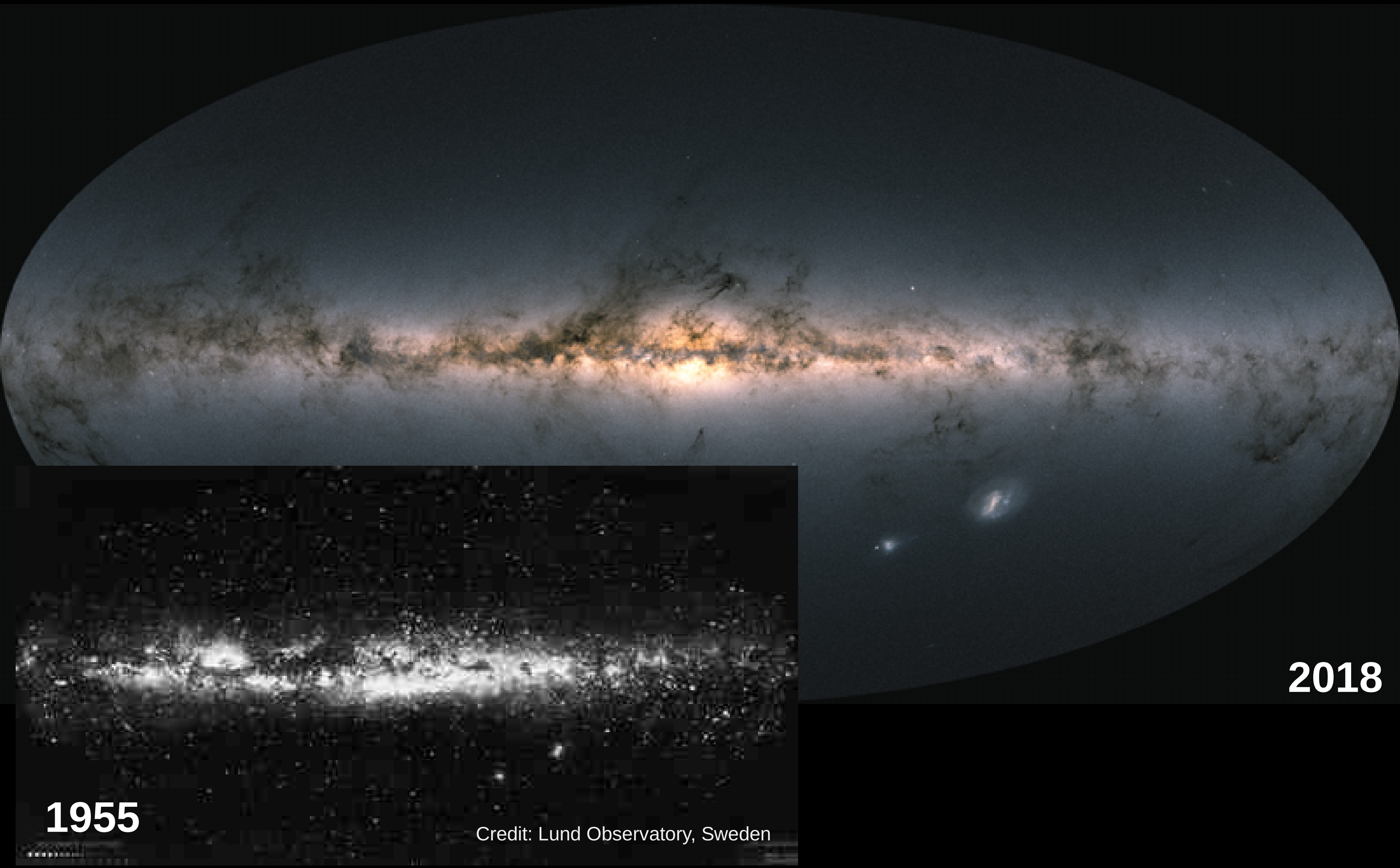
2018

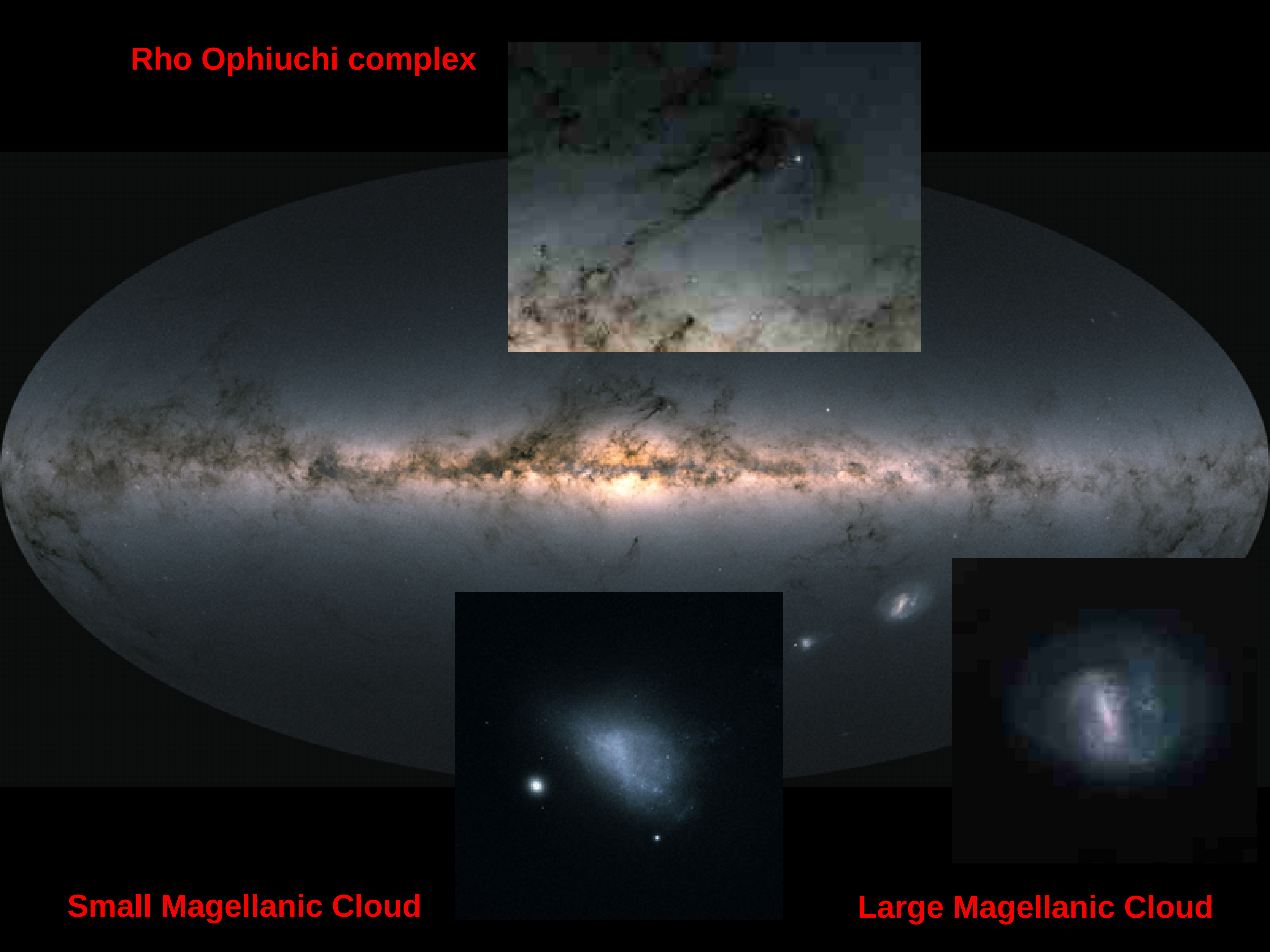
Map of star colors with 1.3 billion stars



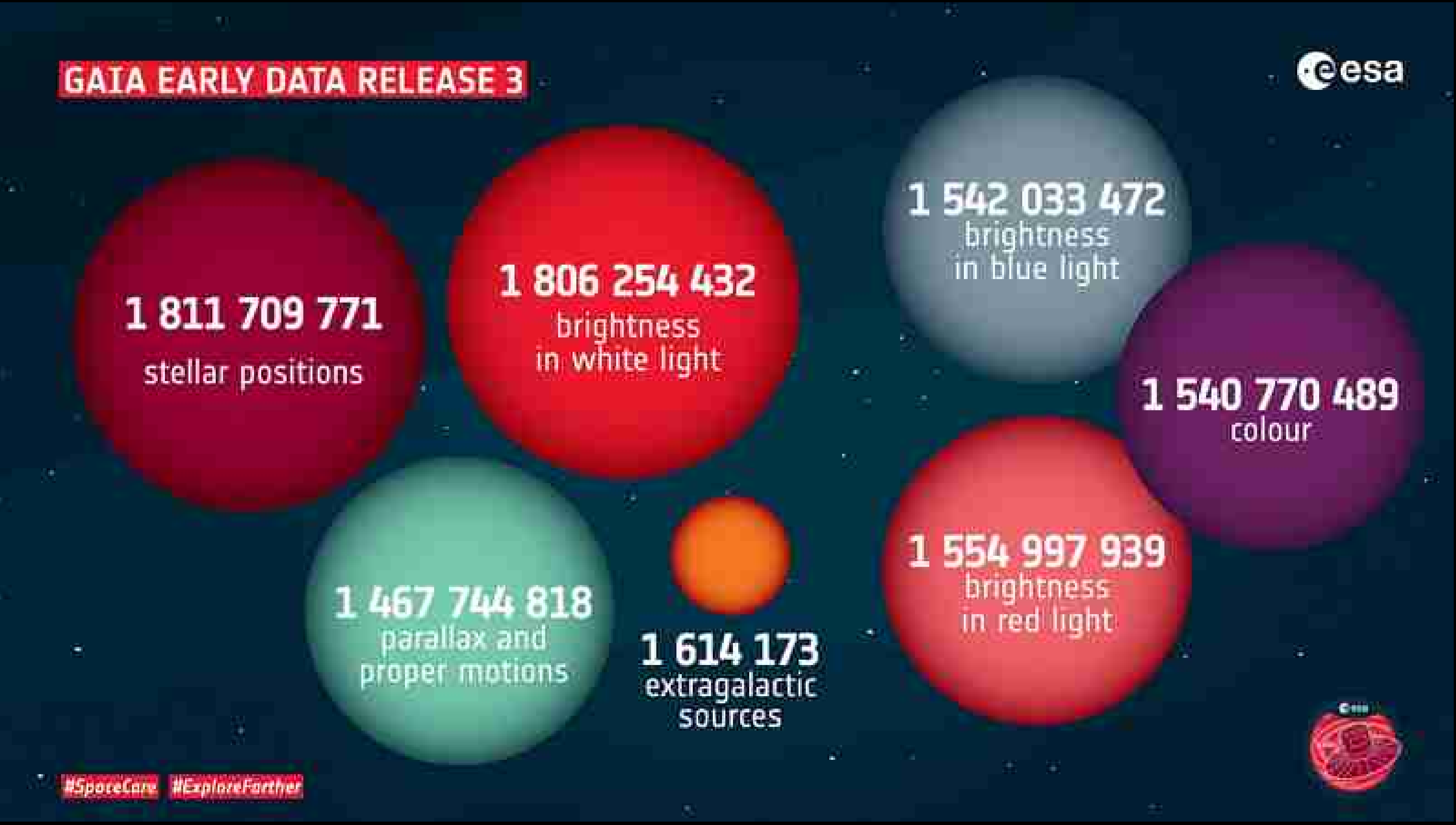
2018

Map of star colors with 1.3 billion stars

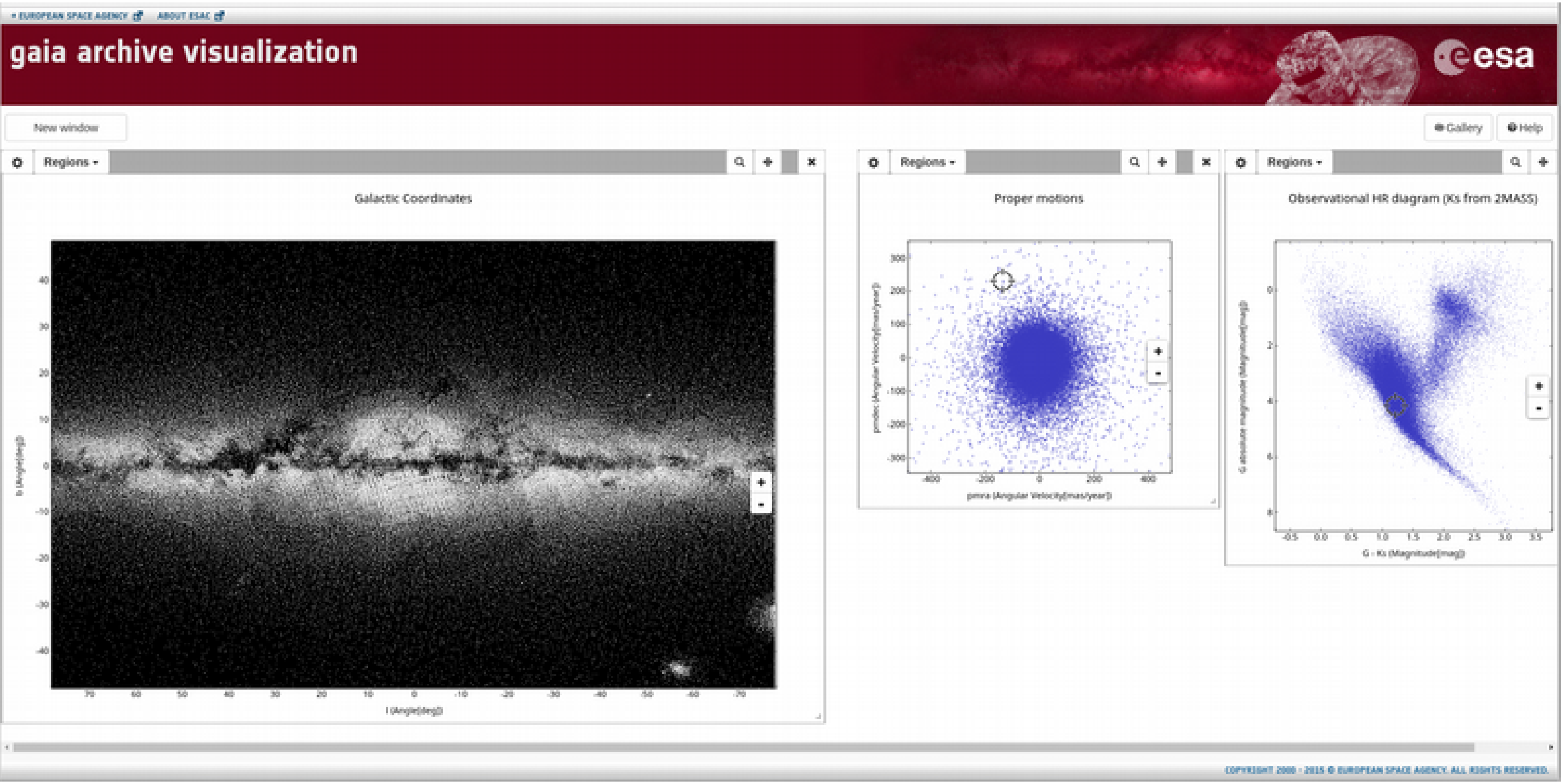



Rho Ophiuchi complex
Small Magellanic Cloud
Large Magellanic Cloud

Number of stars and objects in Gaia's Third Data Release



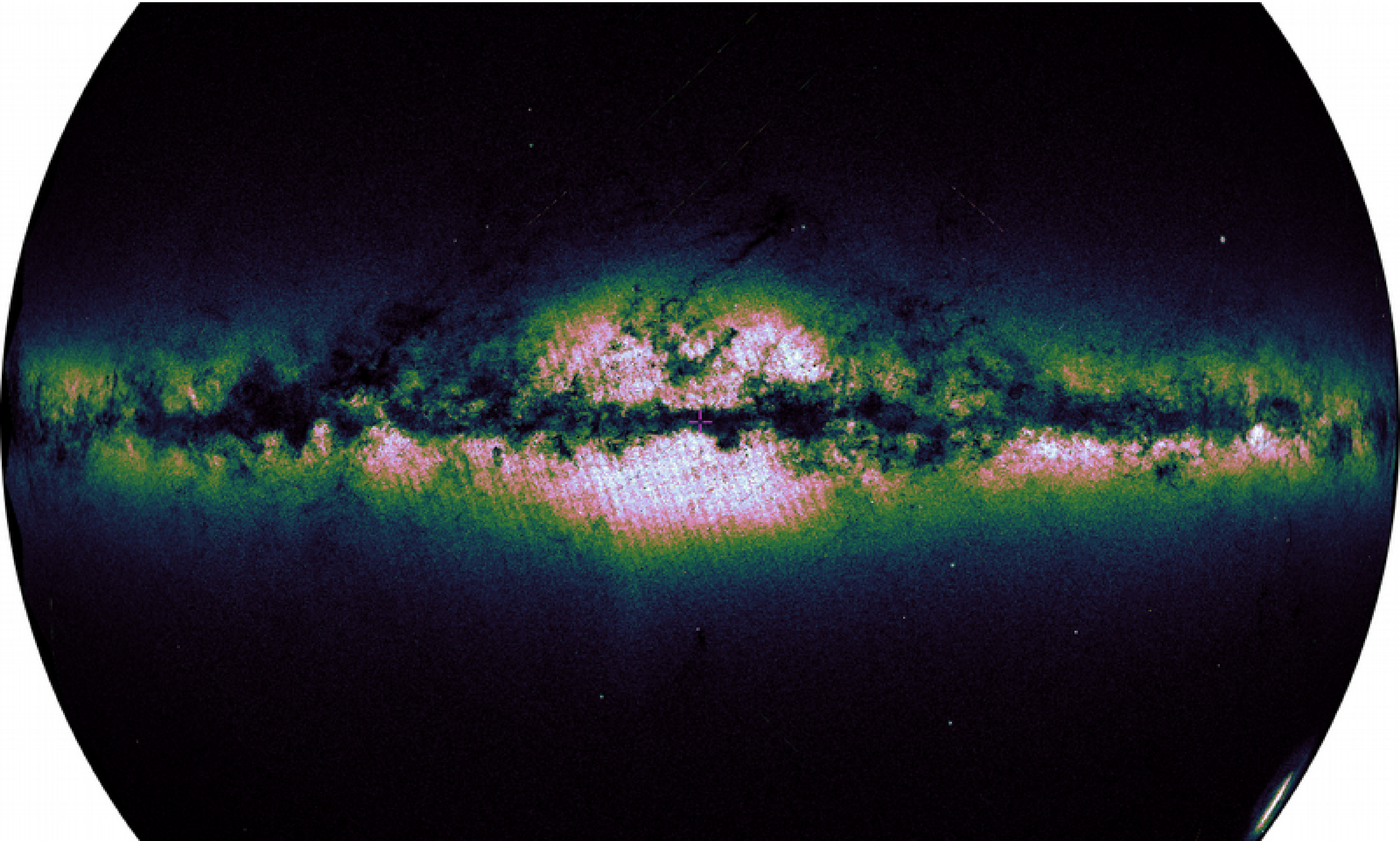
Online public Gaia Data Archive



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

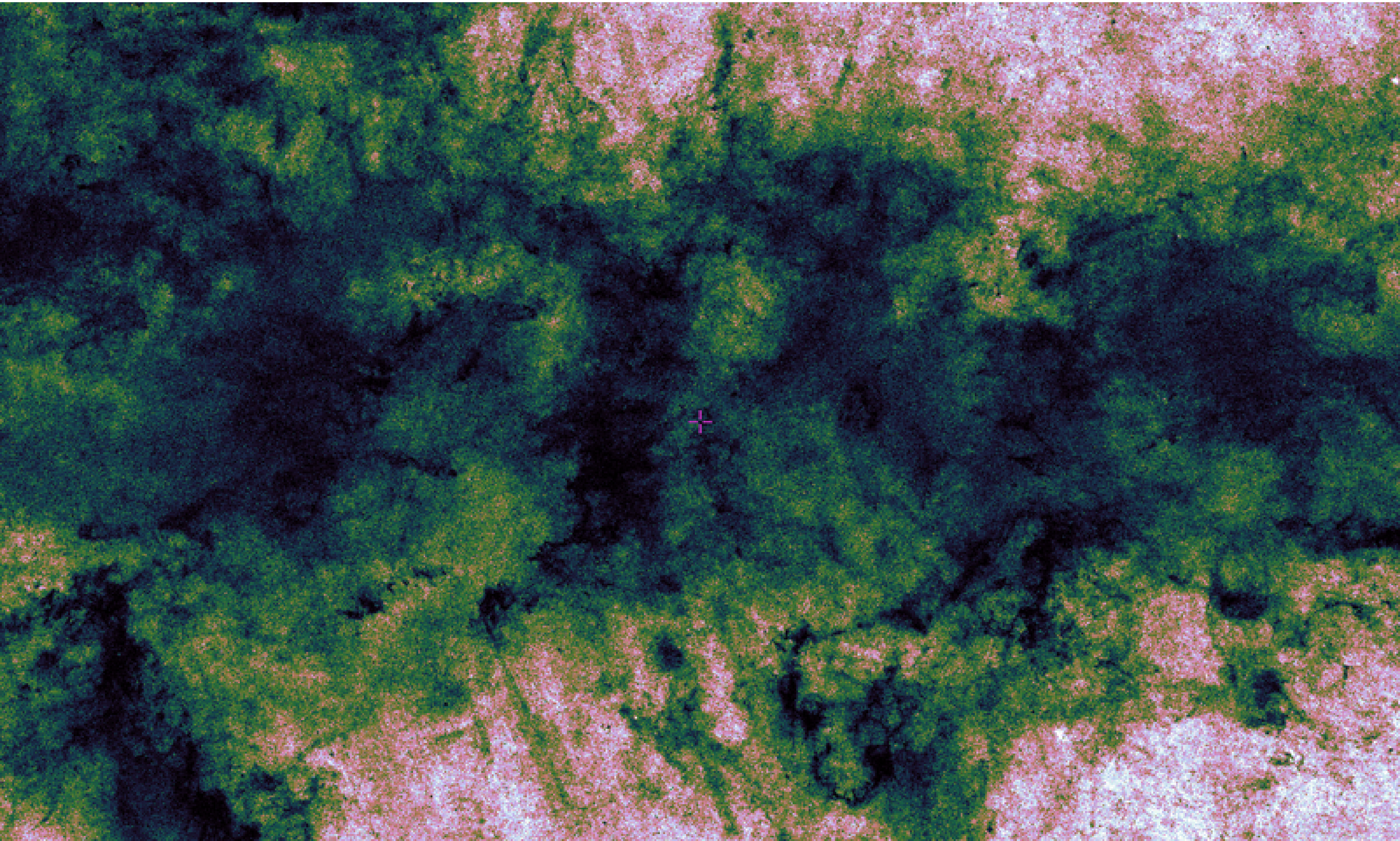
Gaia DR3 Archive interactive map of stars

Map of star density



Gaia DR3 Archive interactive map of stars

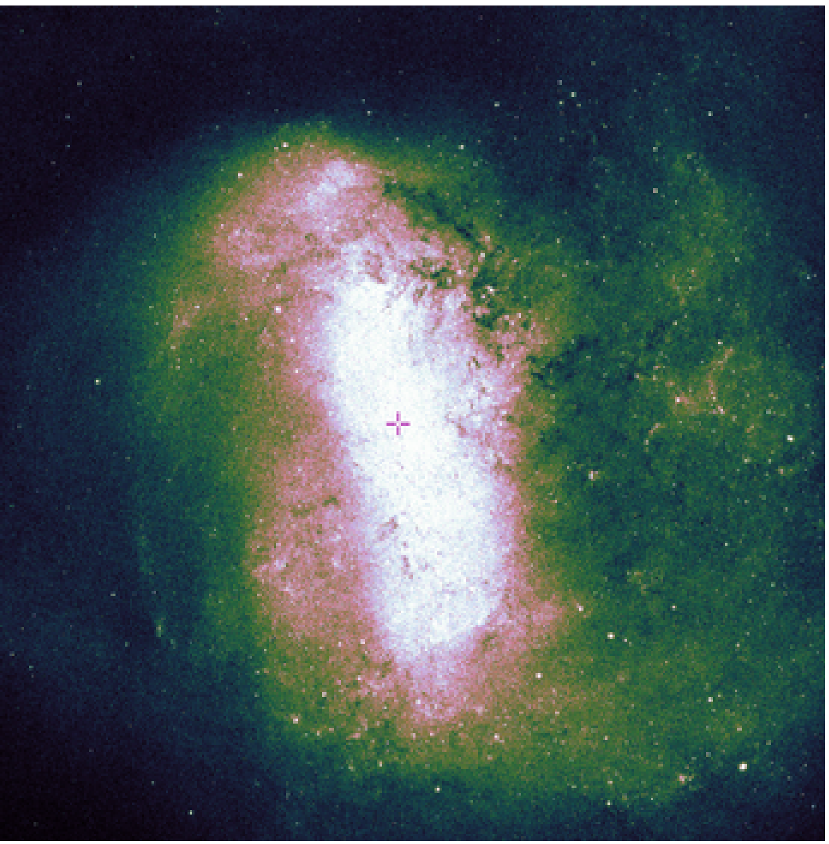
users can interactively pan and zoom in

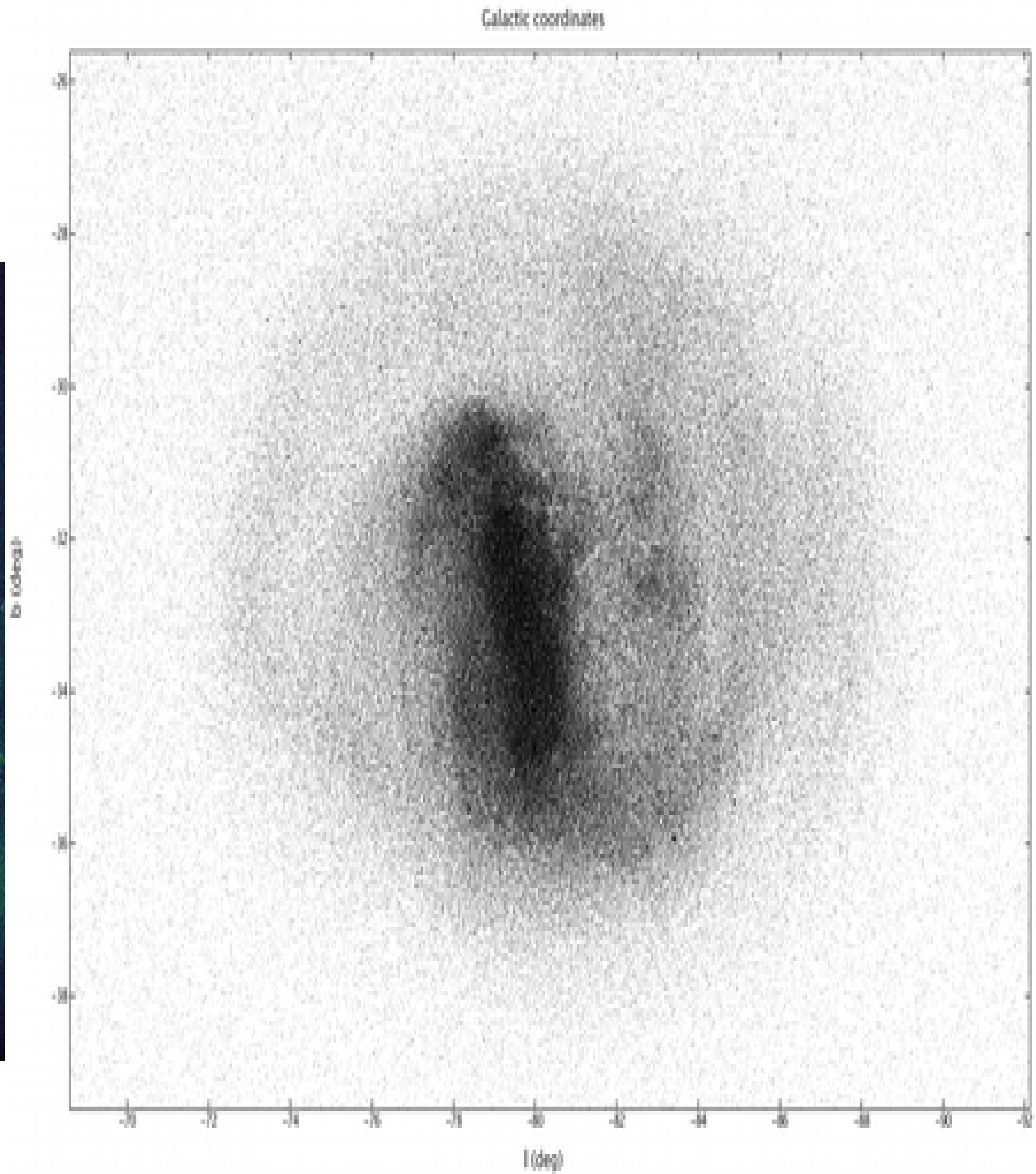


Gaia DR3 Archive interactive map of stars

Center objects interactively

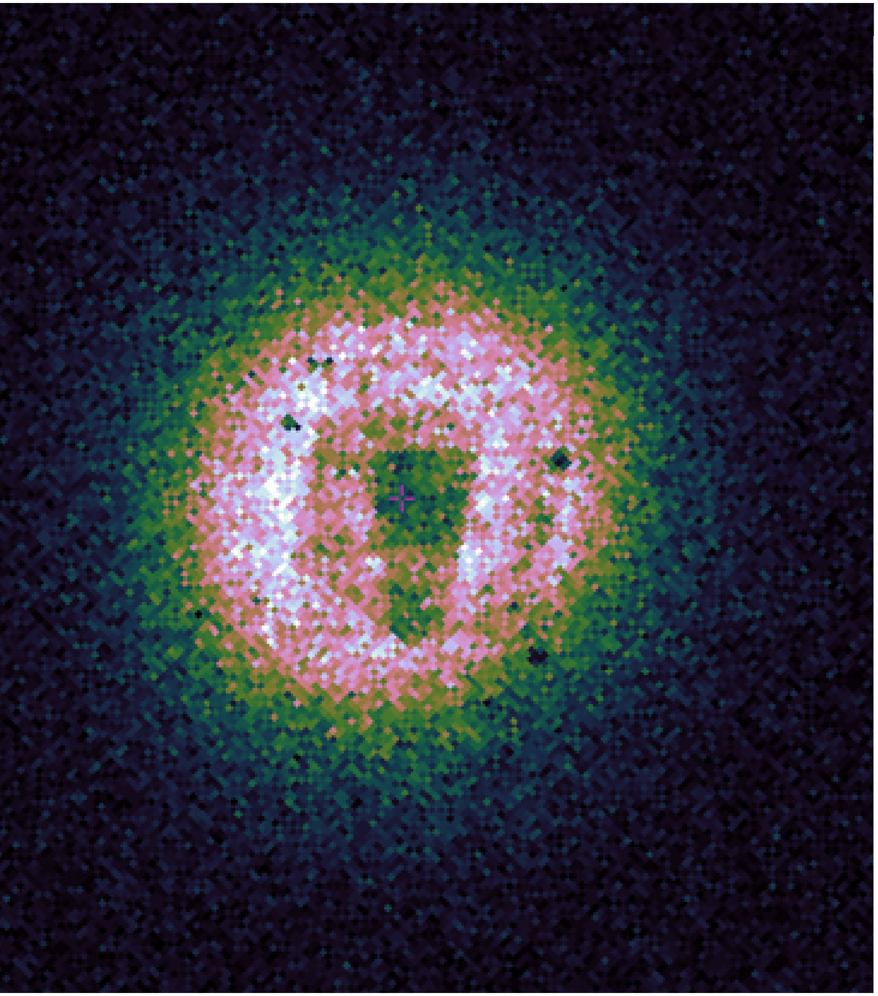
Large Magellanic Cloud



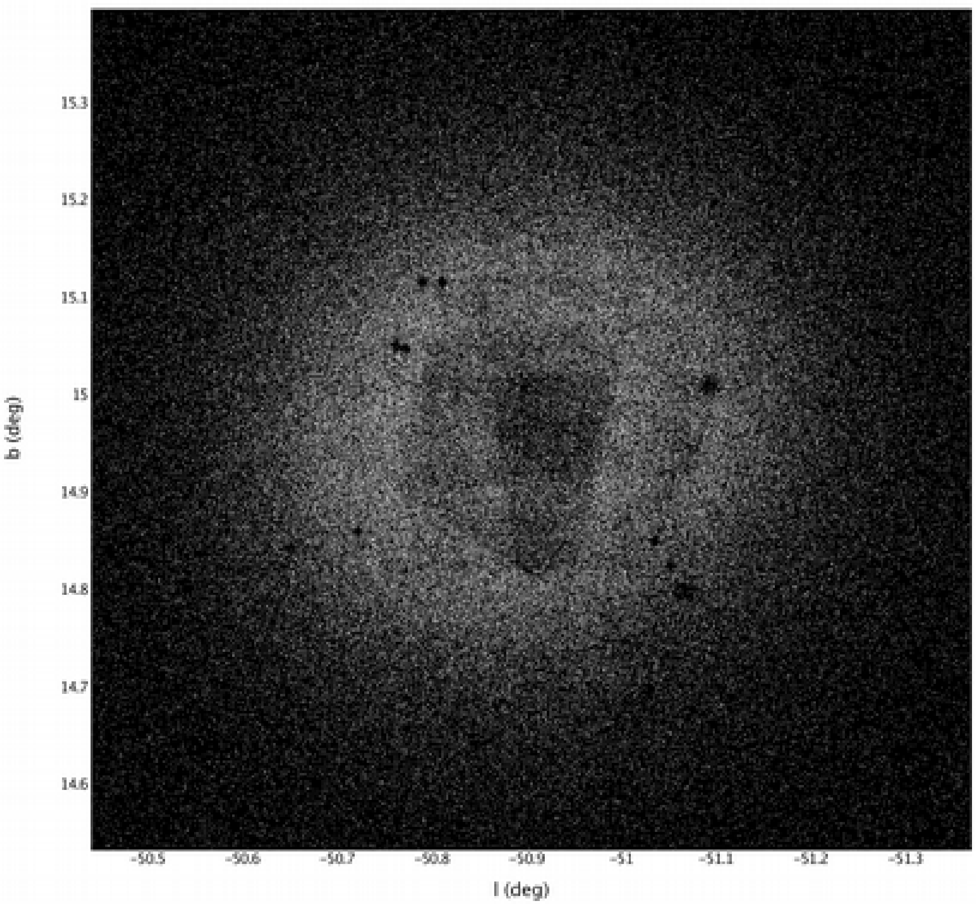


Gaia DR3 Archive interactive map of stars

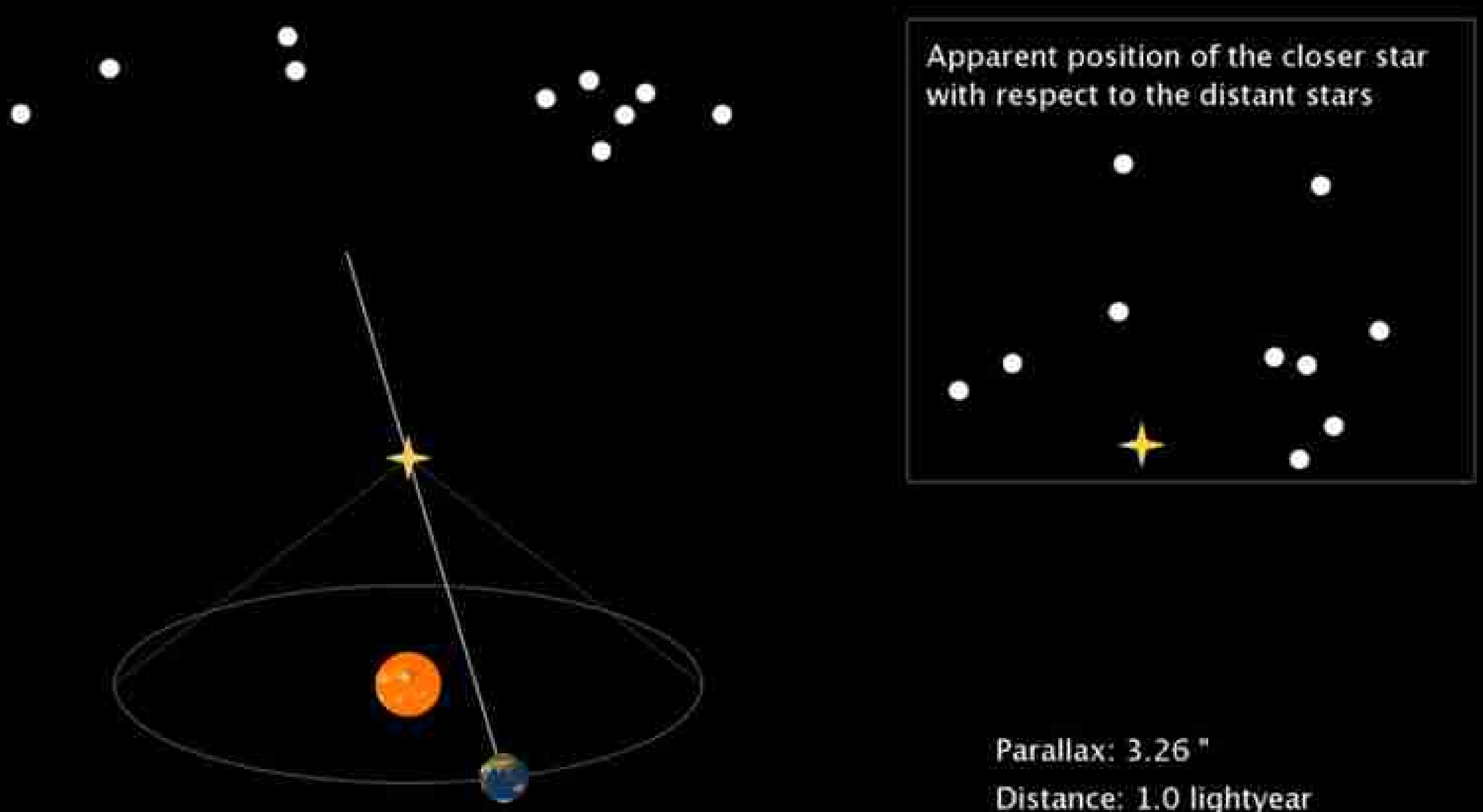
Omega Cen globular cluster



Zoom in on individual stars

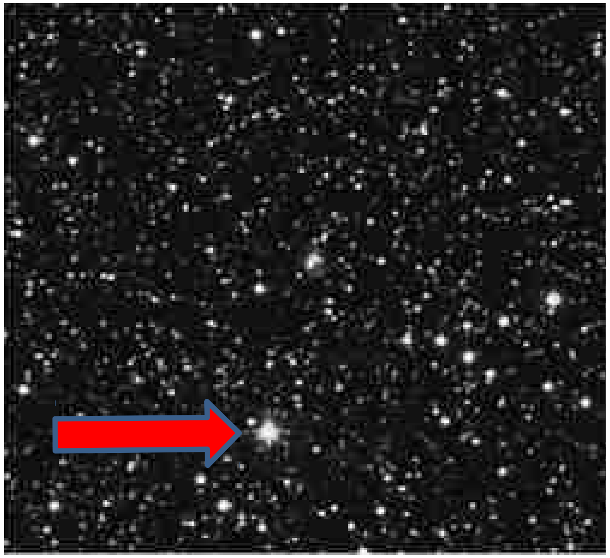


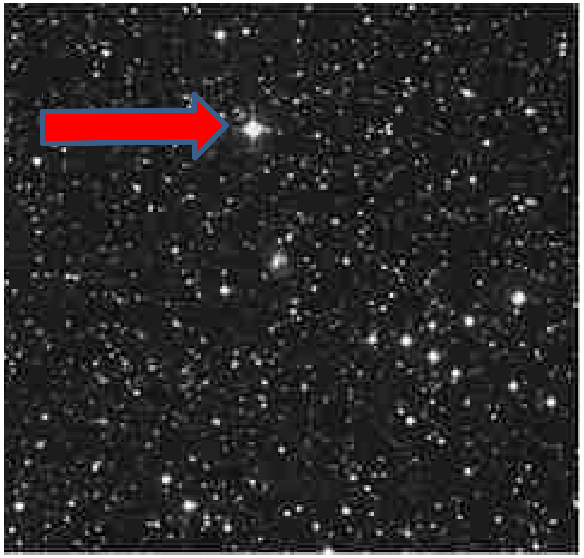
Stellar parallax measurements by Gaia



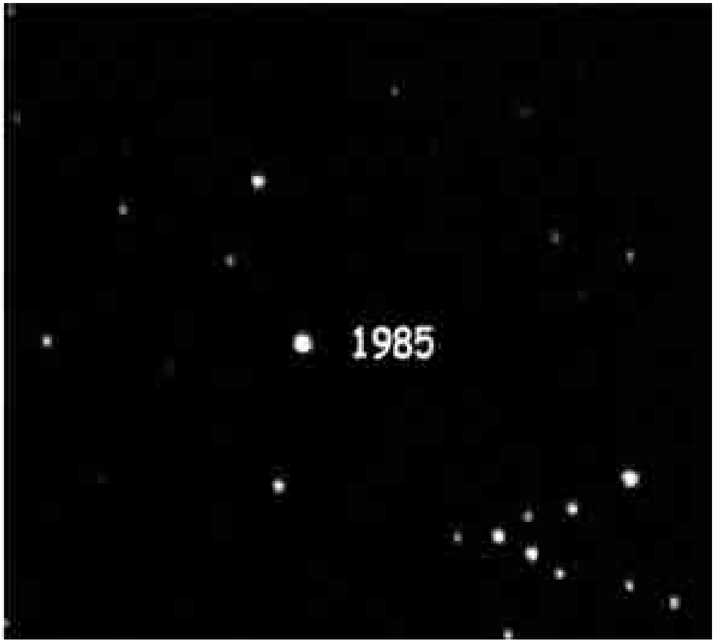
Large proper motion of Barnard's star

1985



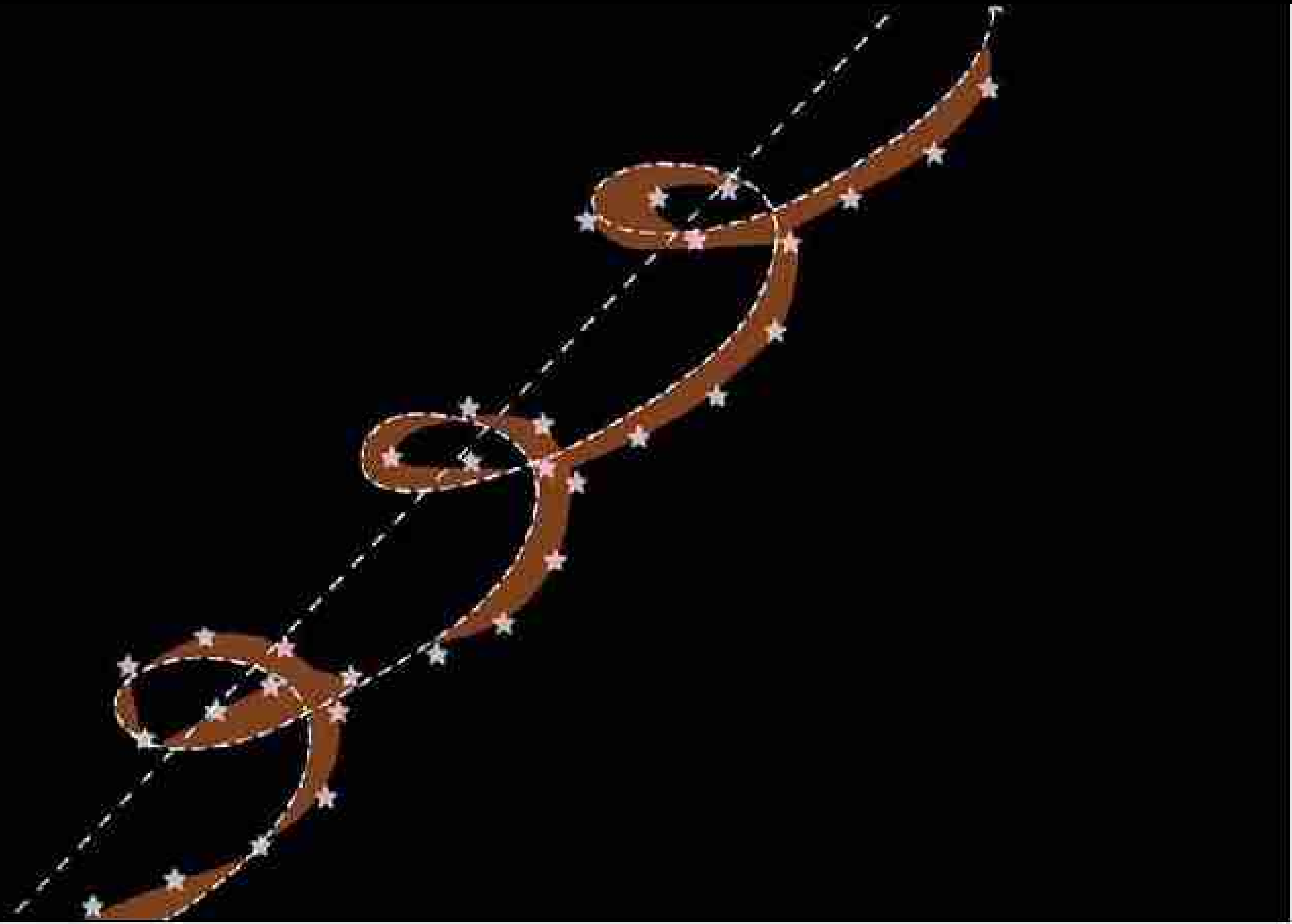


2005

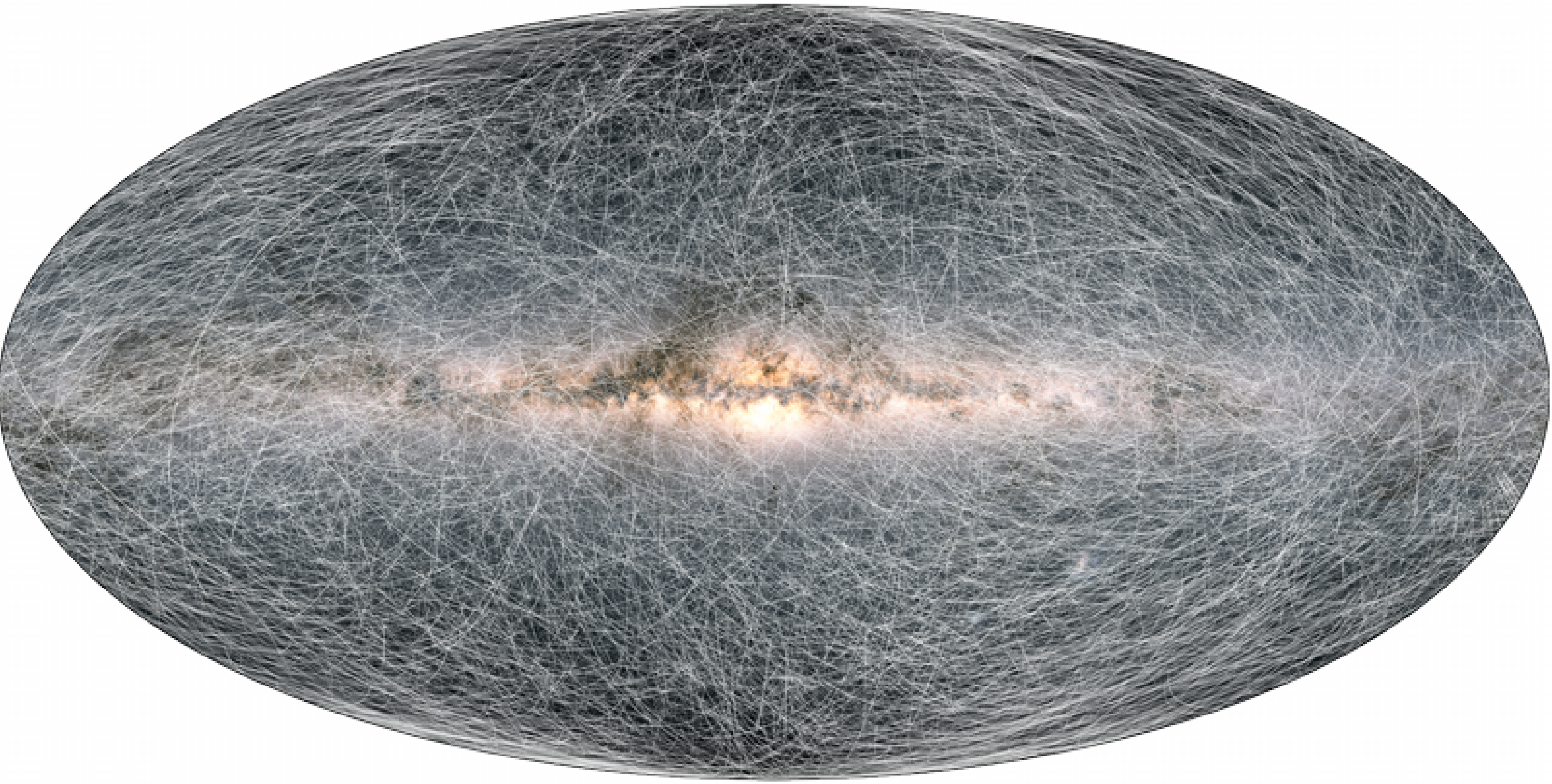


Parallax and proper motion with Gaia

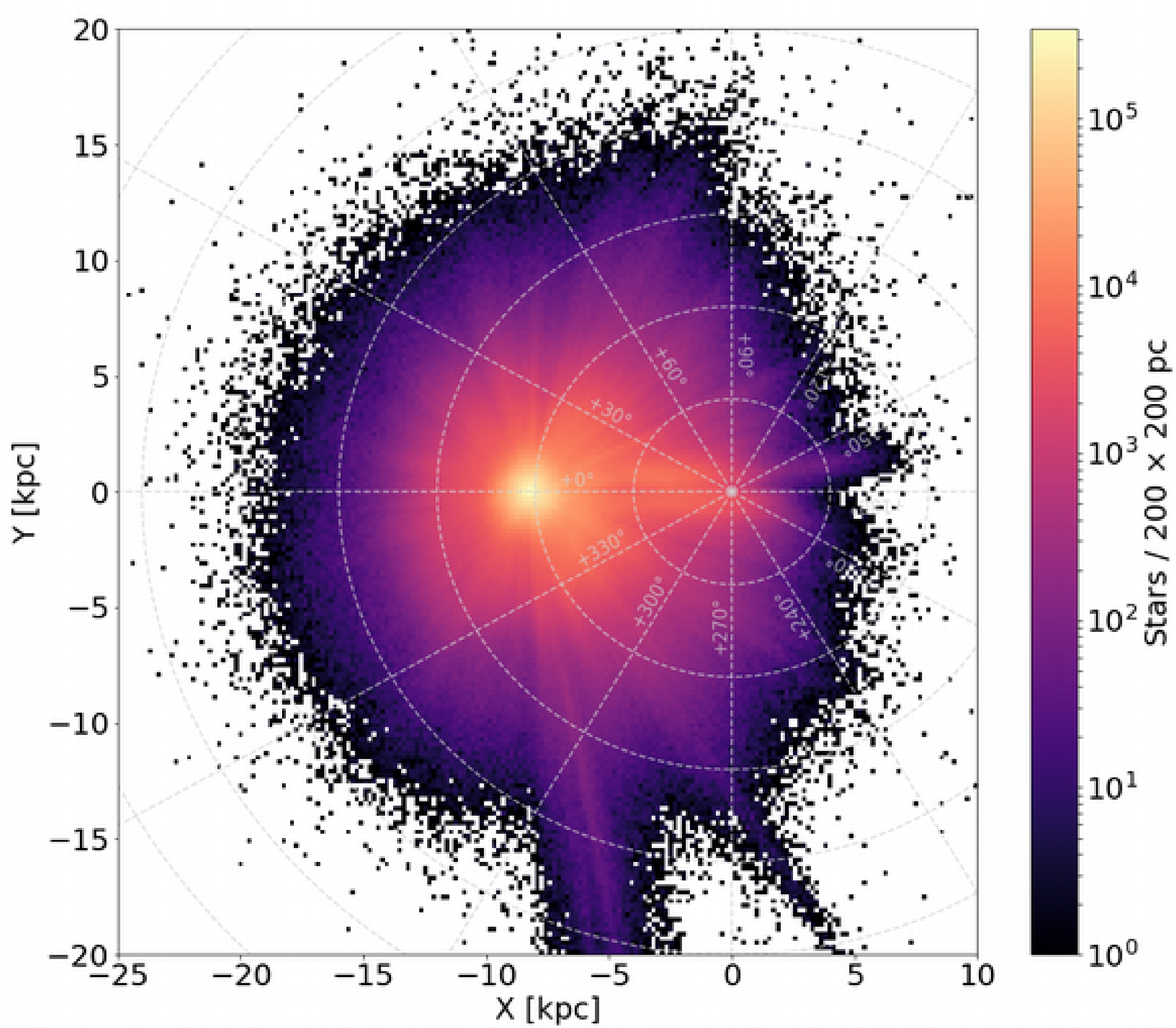
Parallax and proper motion from Gaia



Stellar proper motion tracks observed by Gaia



Map of distances to stars measured by Gaia



Gaia's unparalleled astrometric accuracy

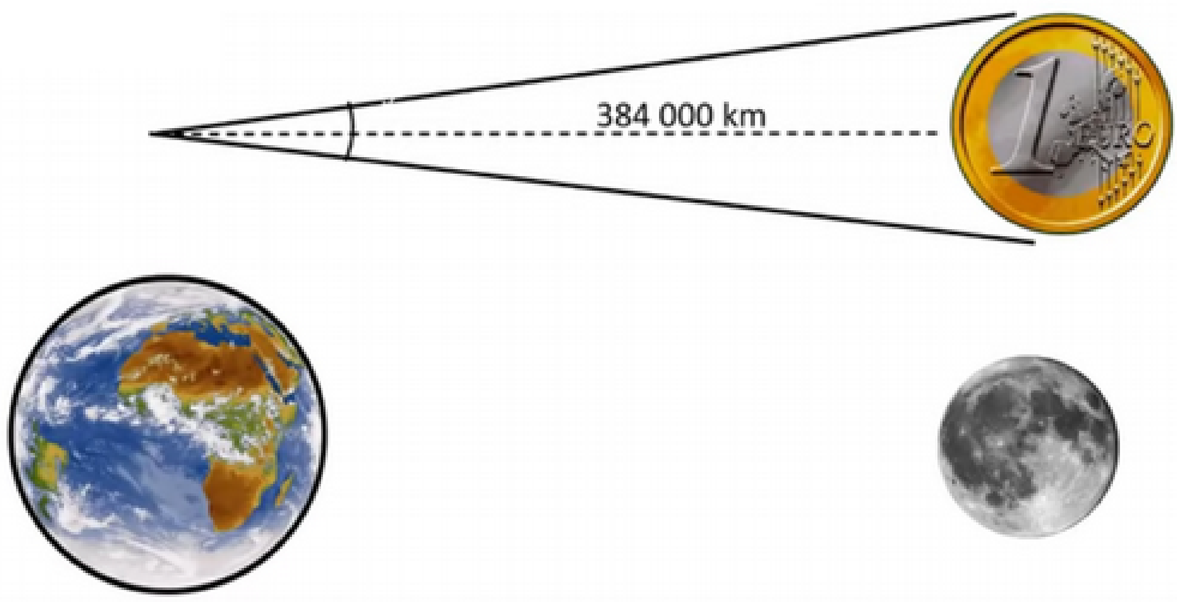
Most accurate parallax measurements: 10 micro arc seconds

1 arc second = 1 / 3600 degrees
$= 4{,}8 \times 10^{-6}$ radians

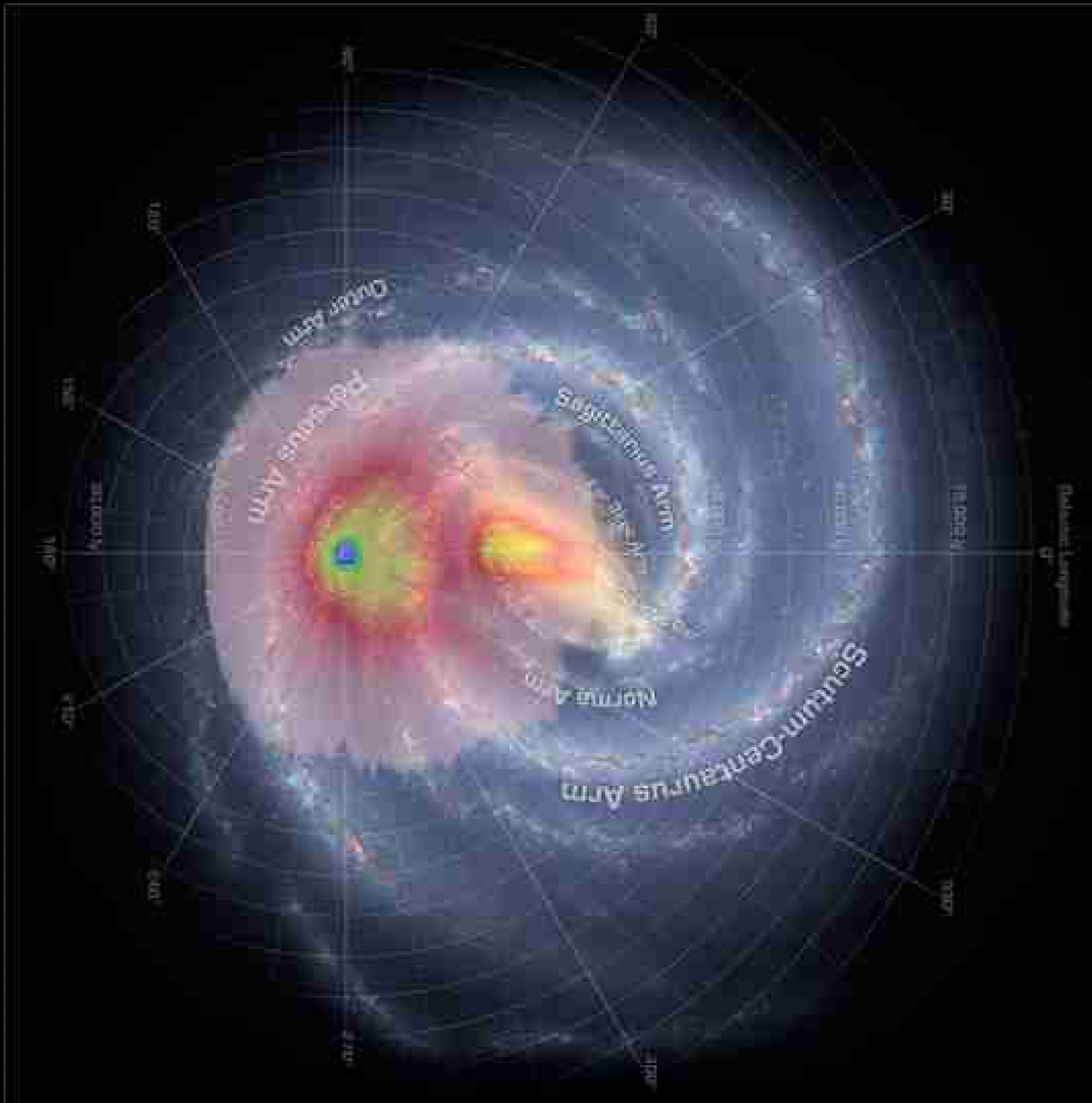
-> 10 % uncertainty for distance of 32,000 light years

-> Displacement of Barnard's star during 30 seconds

-> Apparent size of 100 CLP coin on the Moon seen from Earth

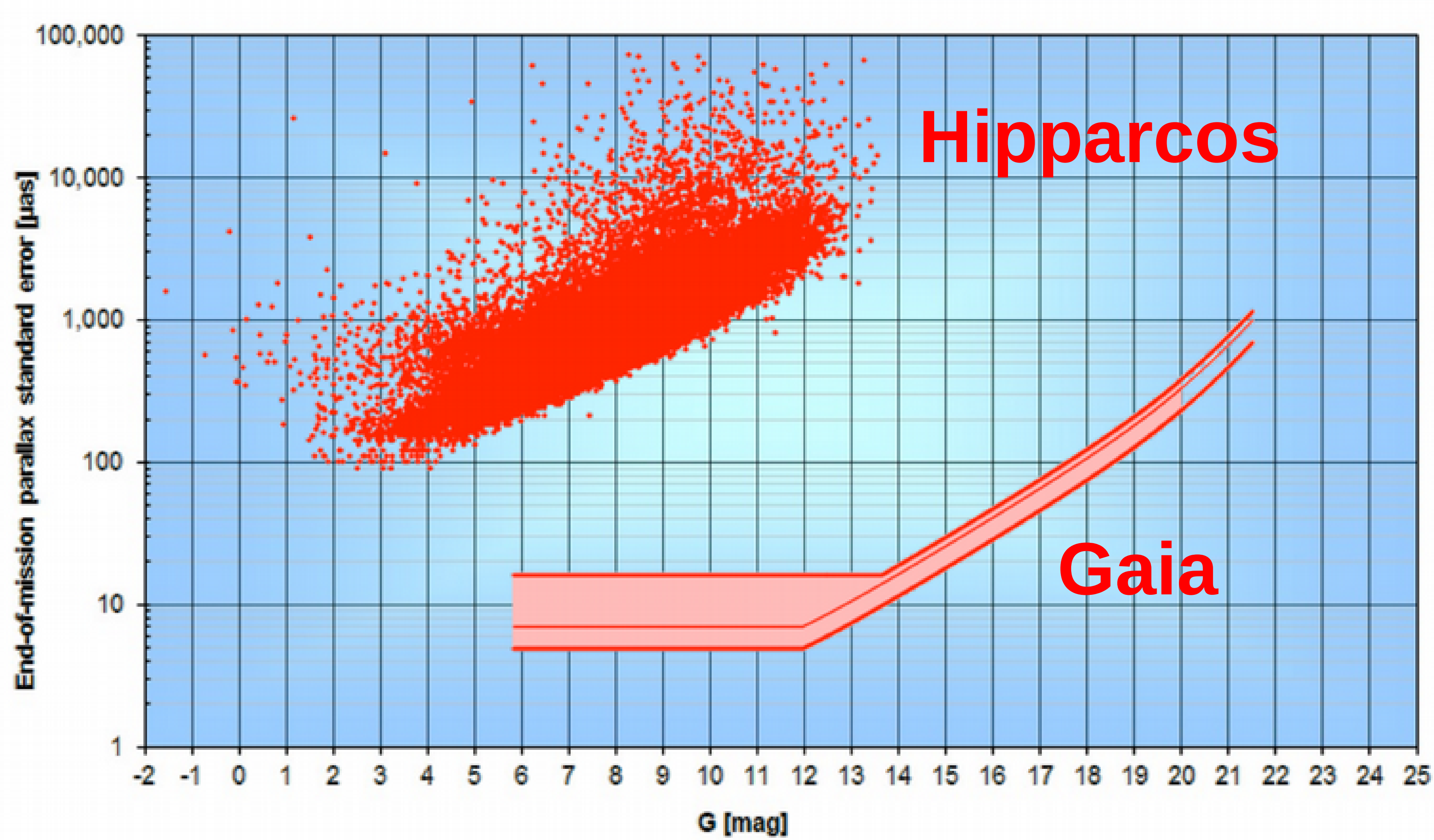


Accuracy of distances reduces farther away



Accuracy of Gaia parallax measurements

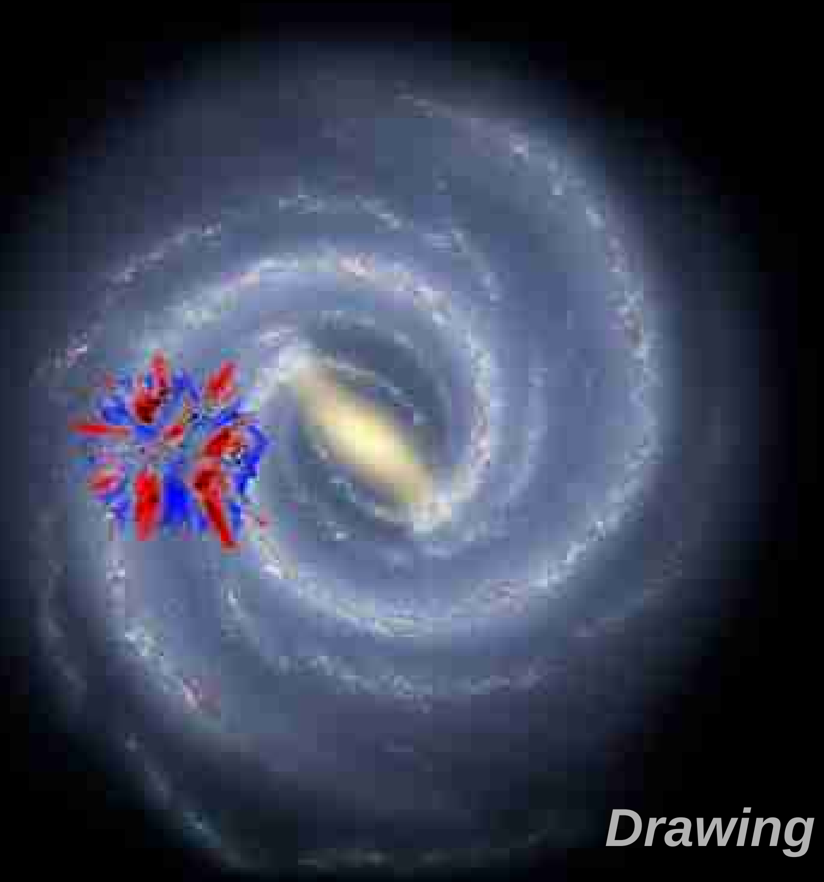
Distance errors : < 0.1% for 700,000 stars   < 1% for 21 million to 2.5 Kpc   < 10% for 220 million to 25 Kpc

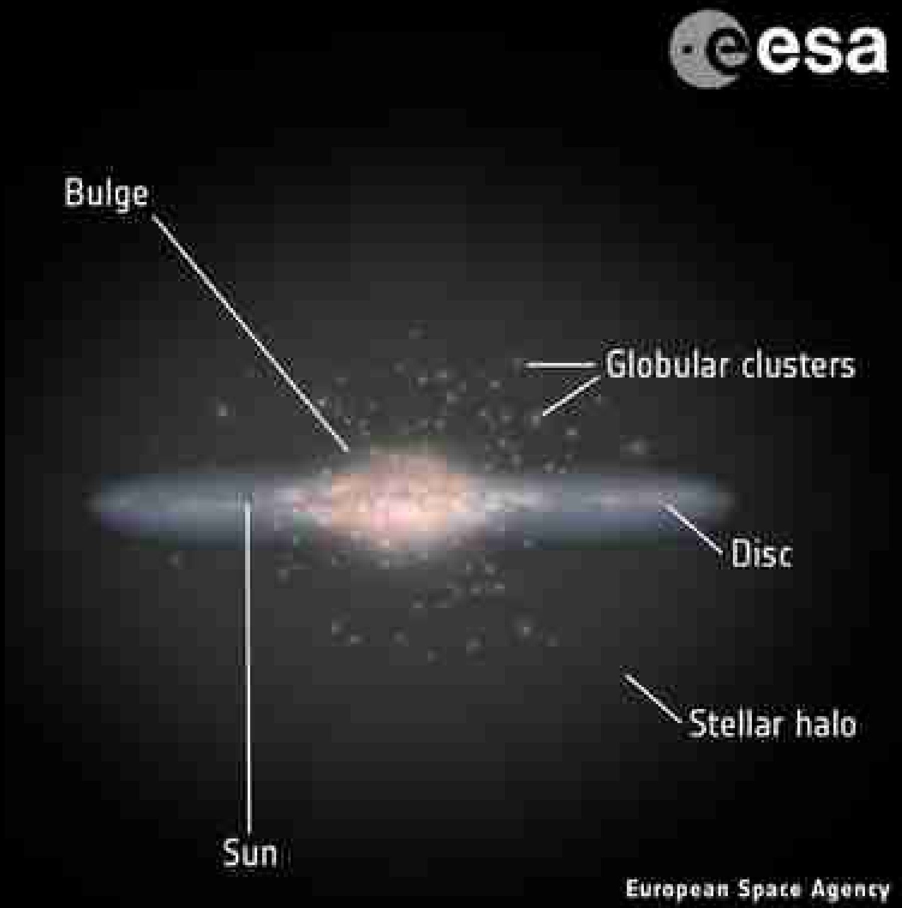


Gaia limit for reliable distances: 10 Kpc. Compare this to 100 pc for Hipparcos mission.

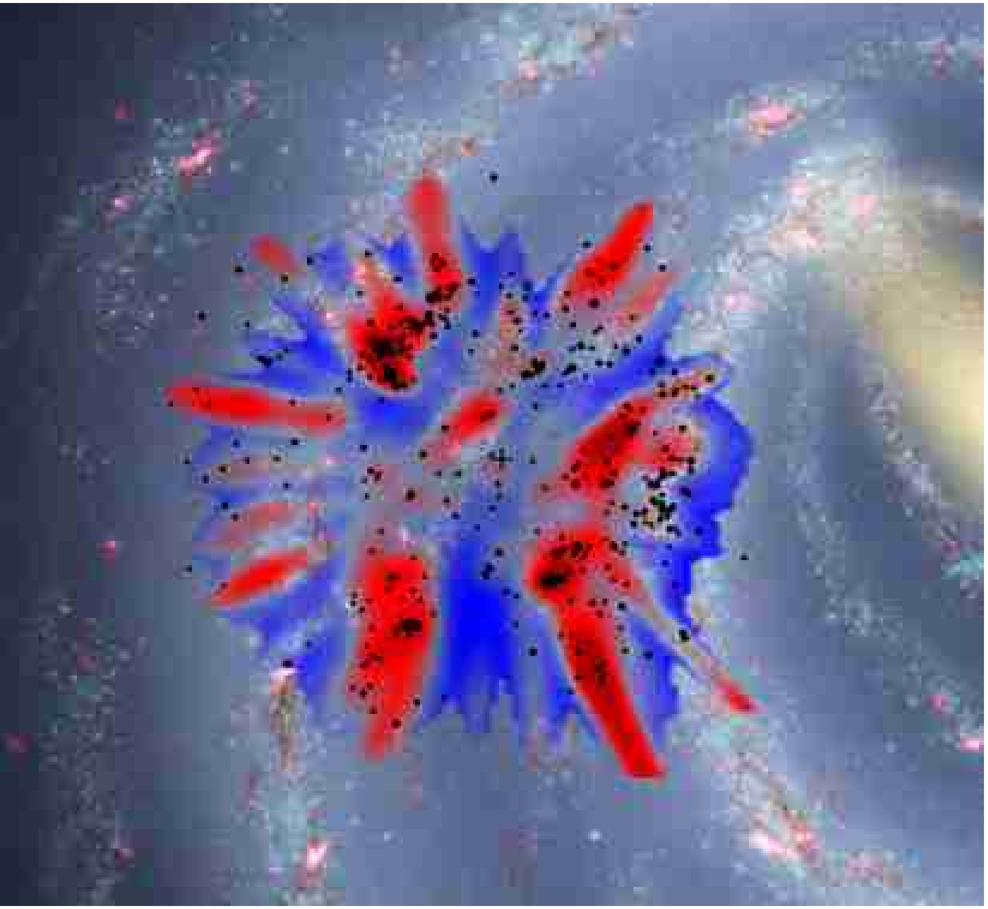
Rotation of the Galaxy

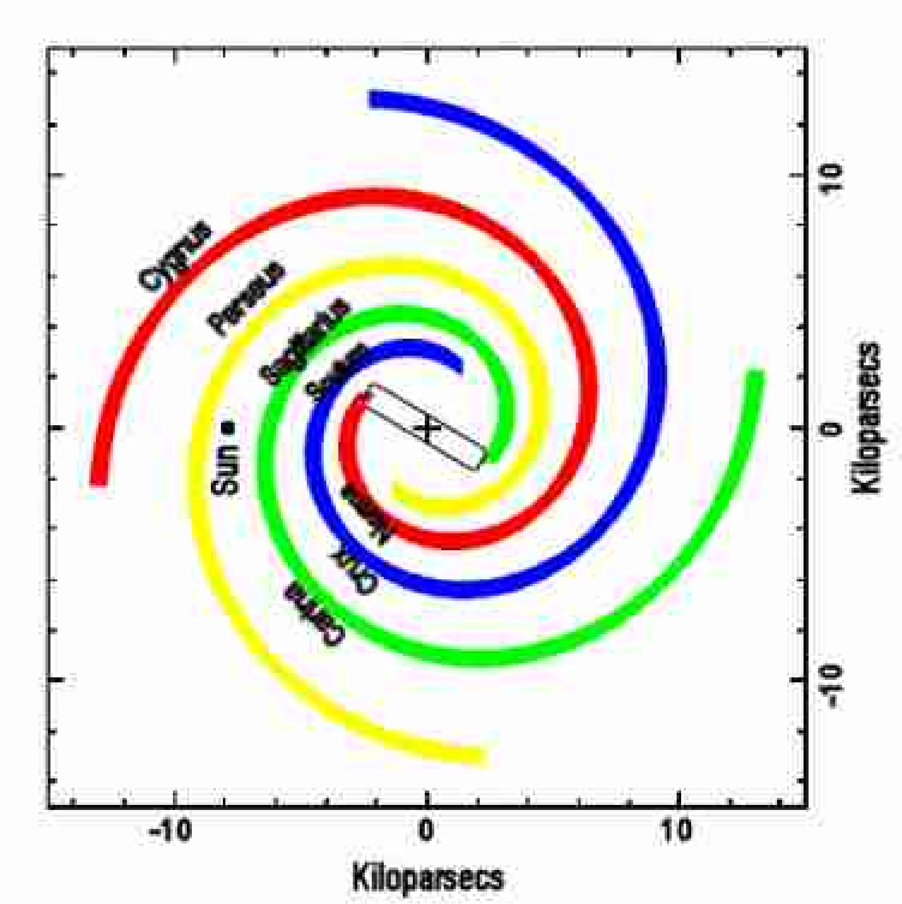
Structure of spiral arms in the solar neighborhood



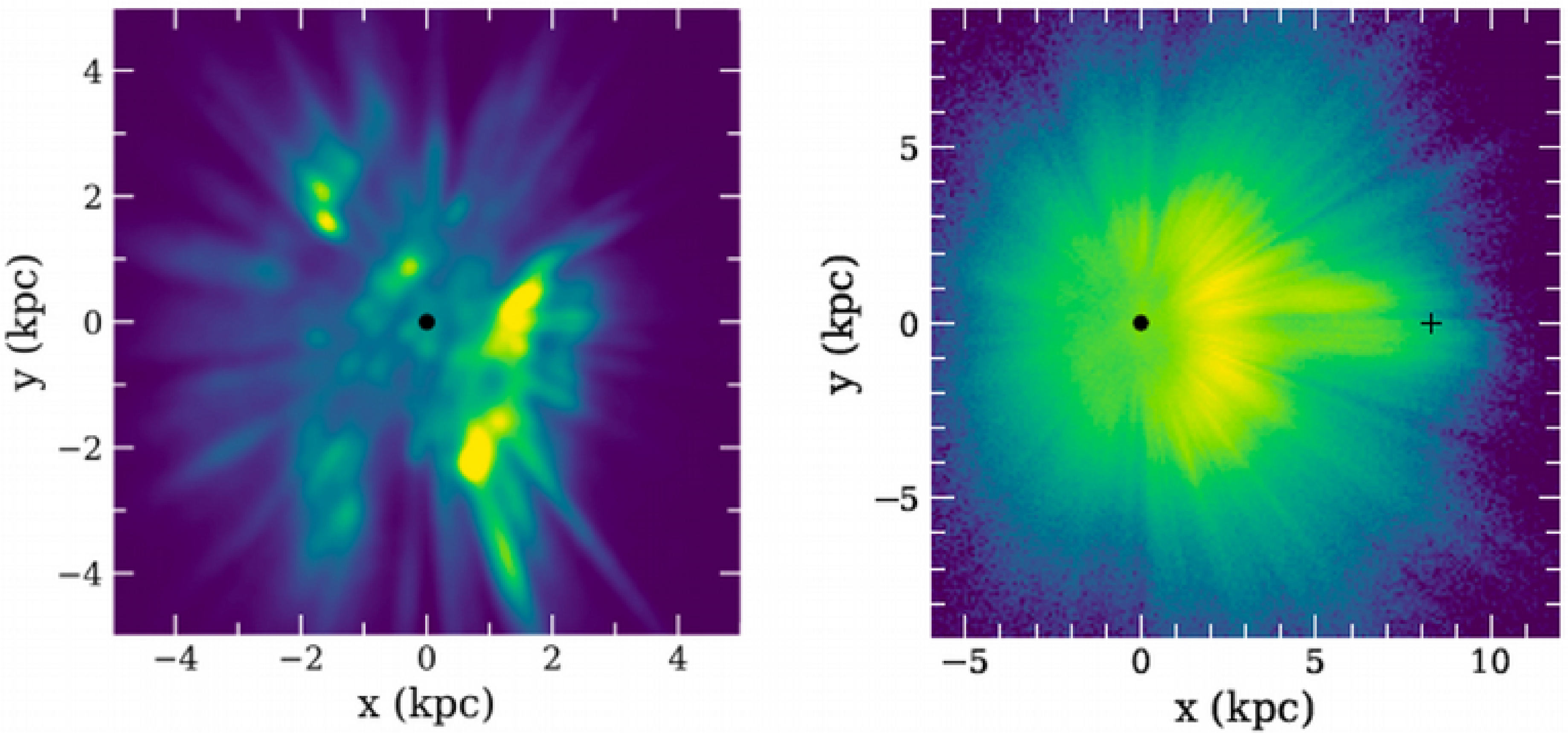


Structure of spiral arms in the solar neighborhood

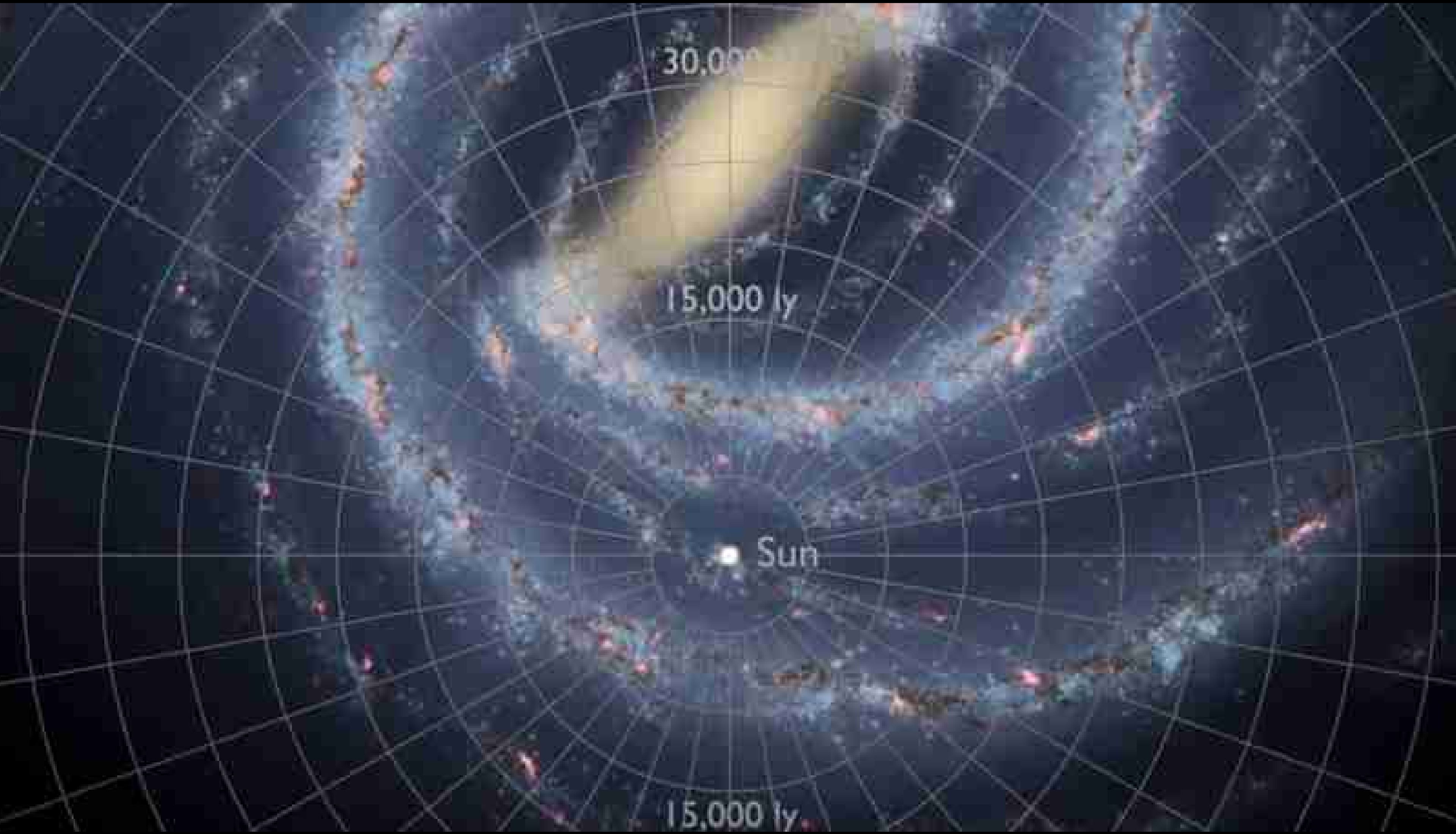




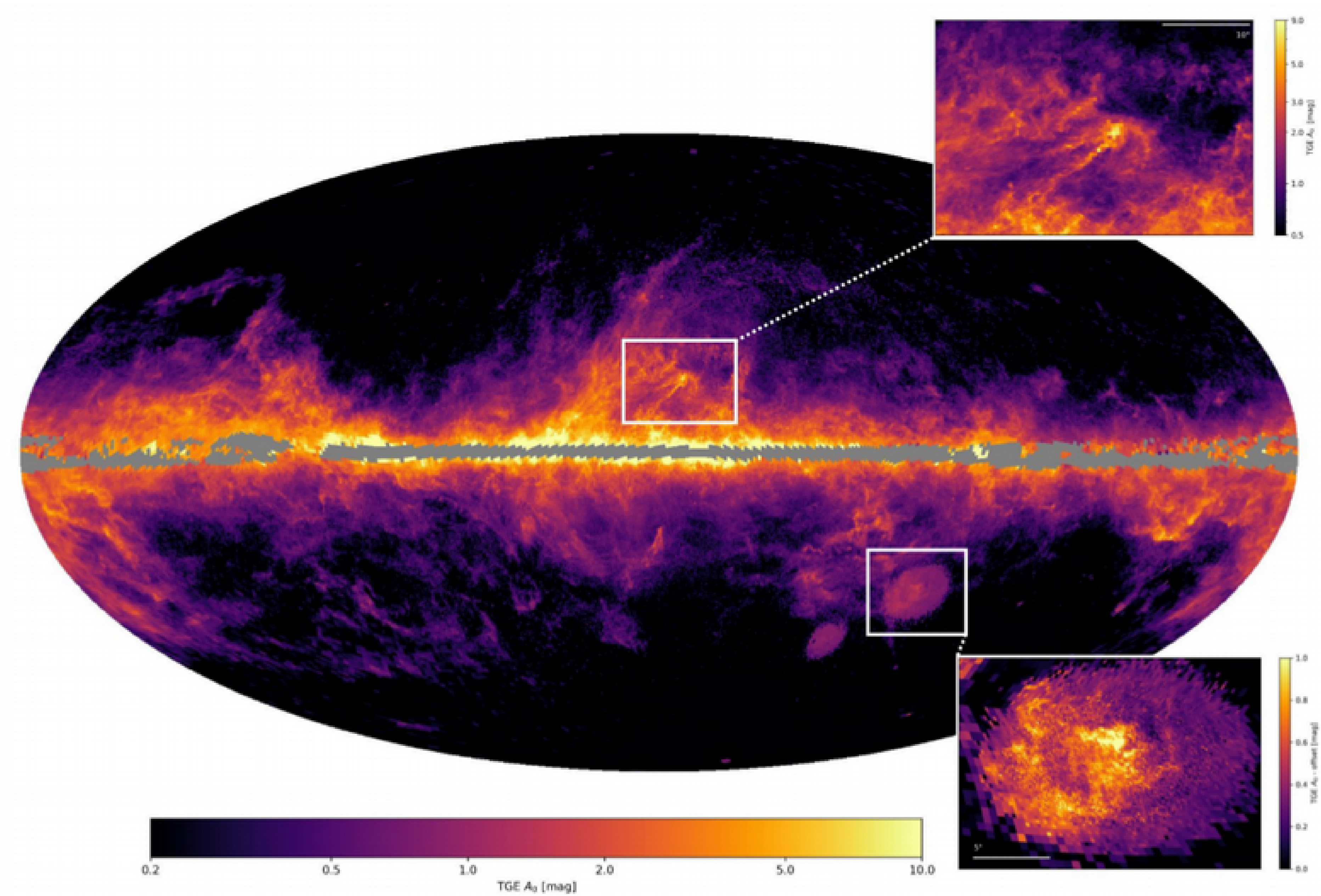
Spatial distribution of young and old stars



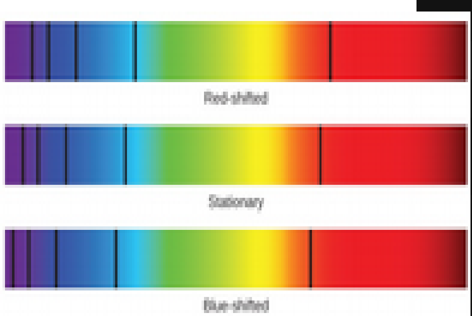
Dust & gas in the Milky Way

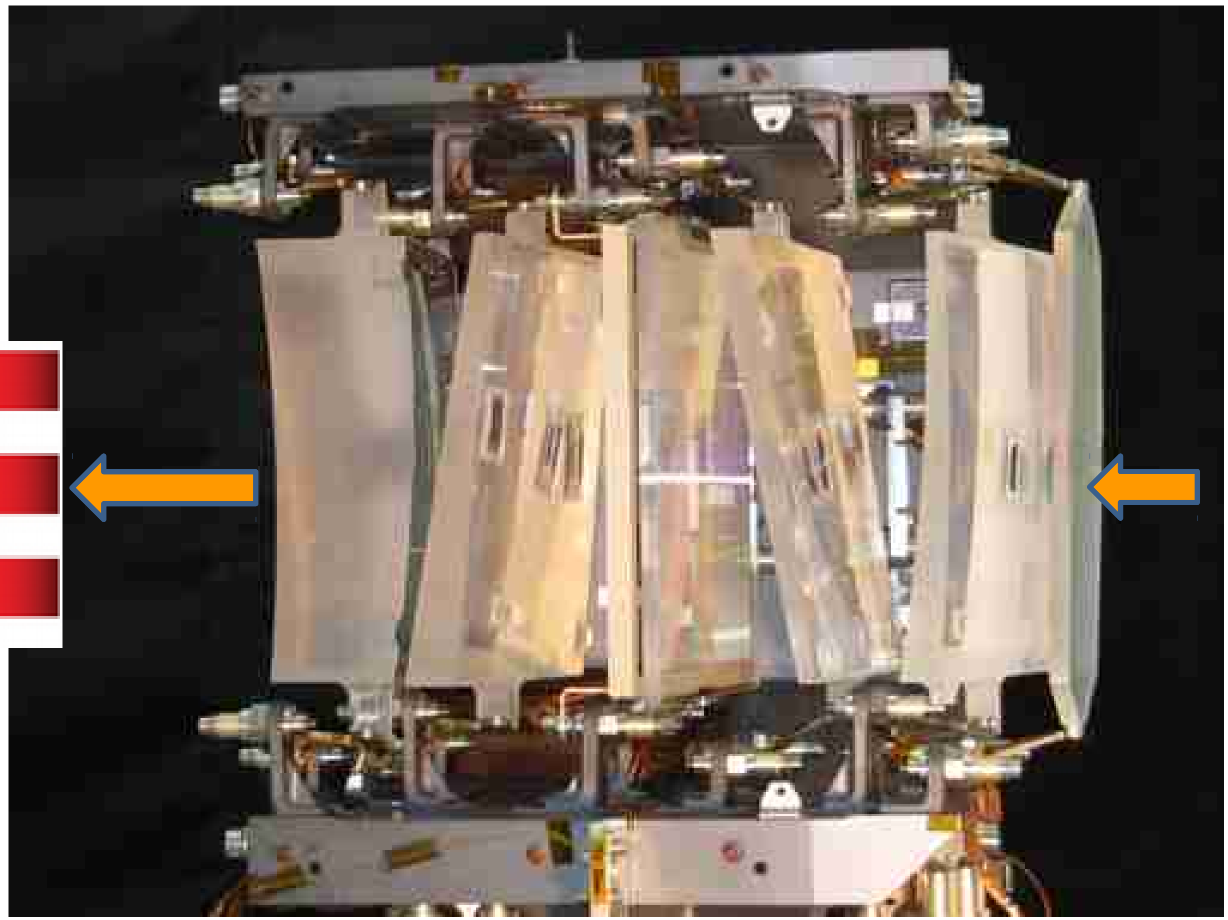


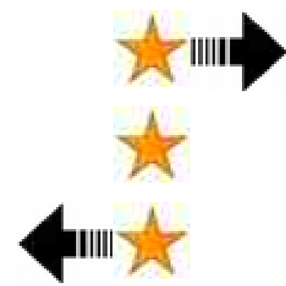
Map of dust & gas based on star colors and distances



Gaia Radial Velocity Spectrometer



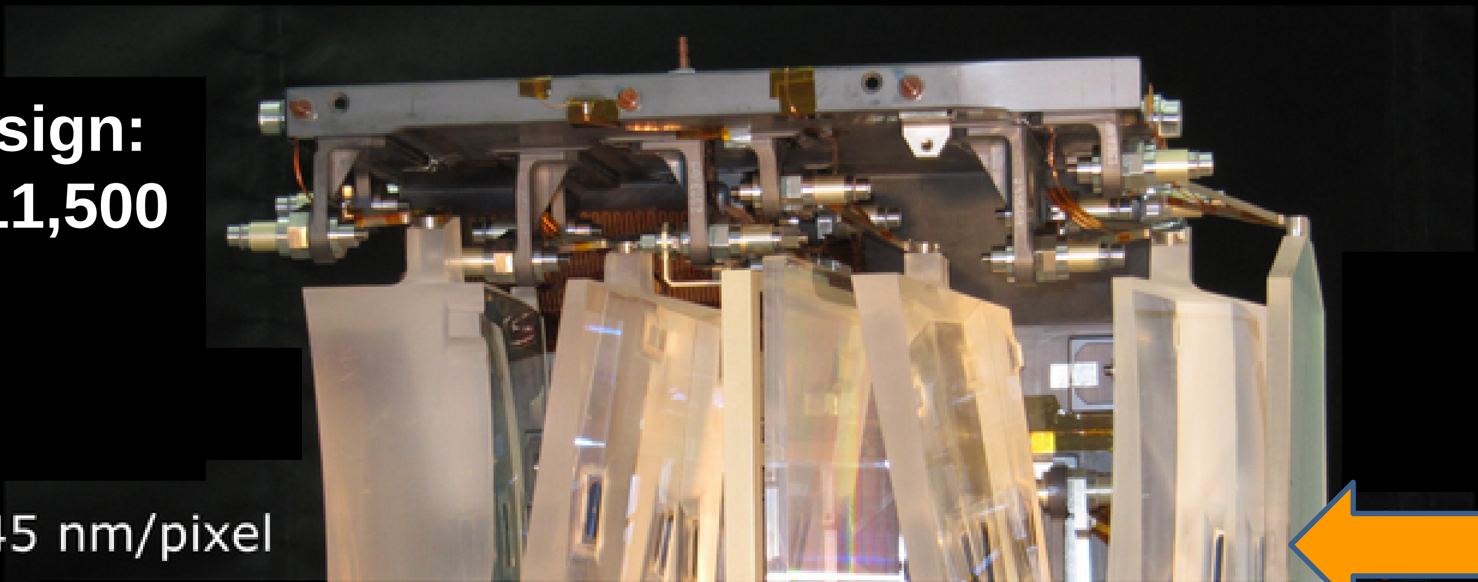


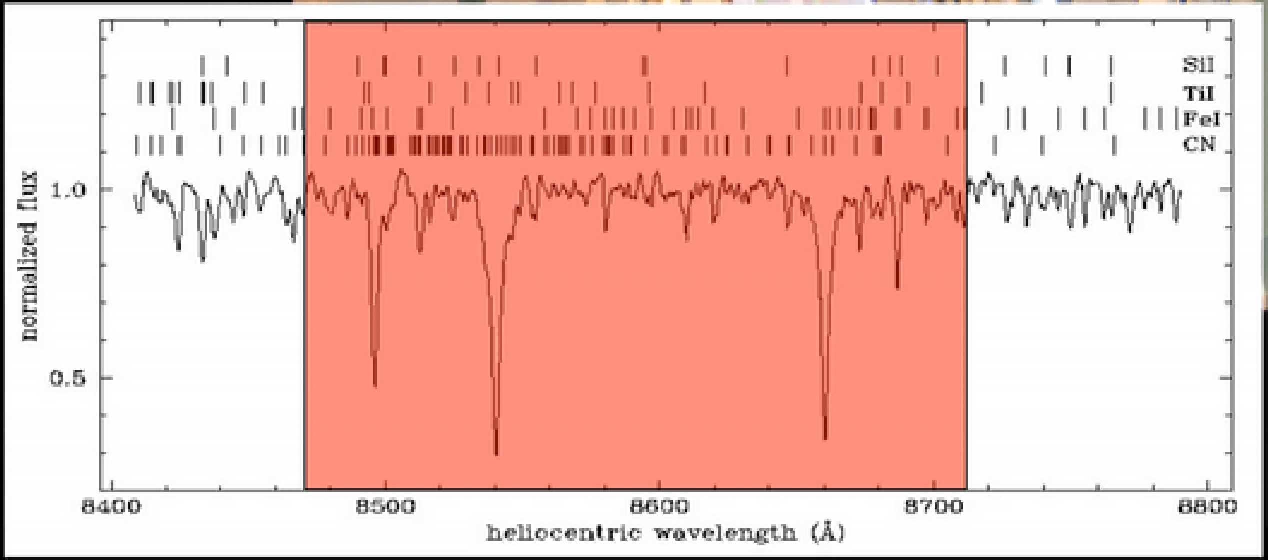


Gaia's spectrometer in the near-IR

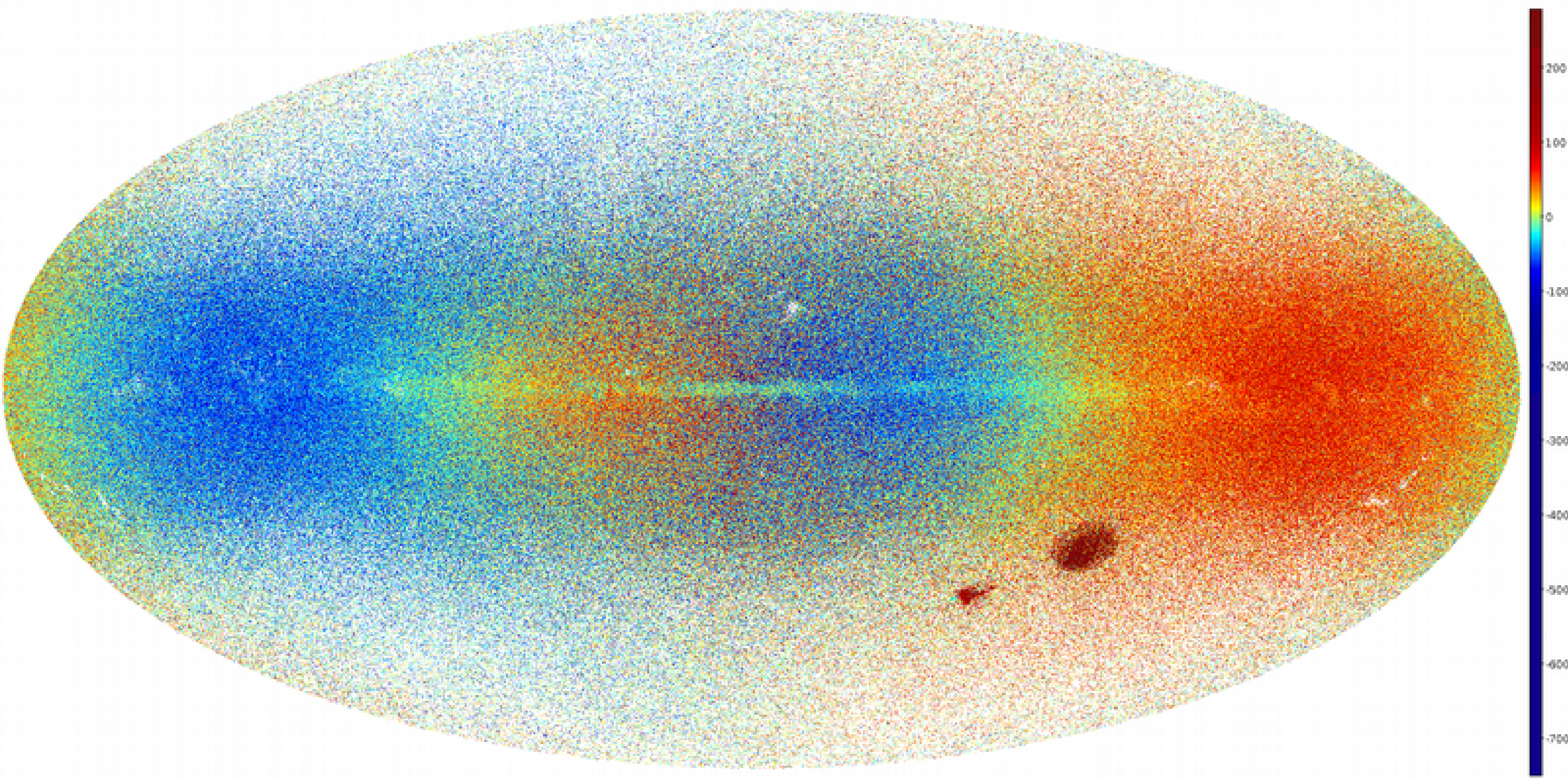
Design:
R=11,500

0.0245 nm/pixel

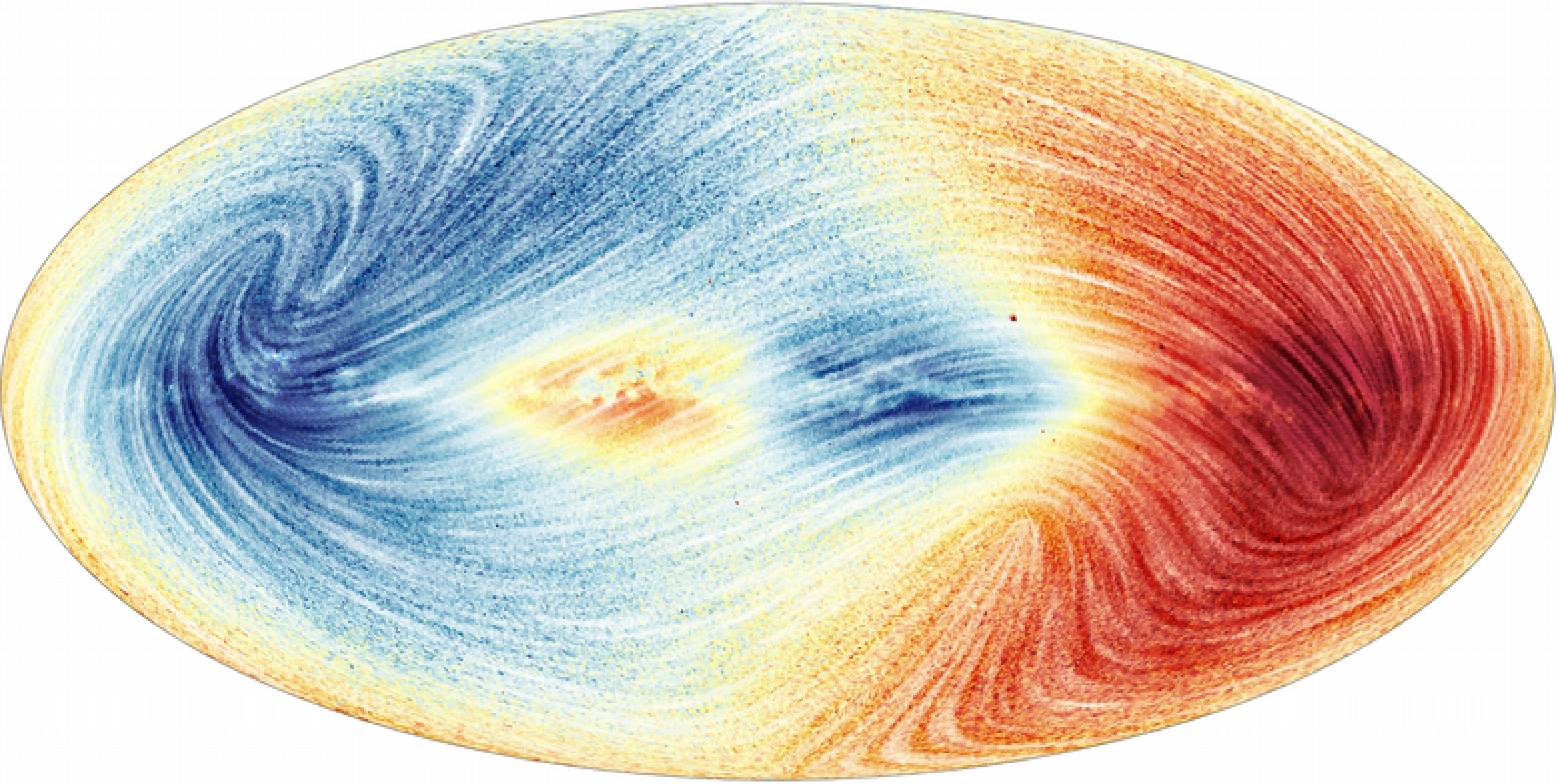




Sky map of stellar radial velocities

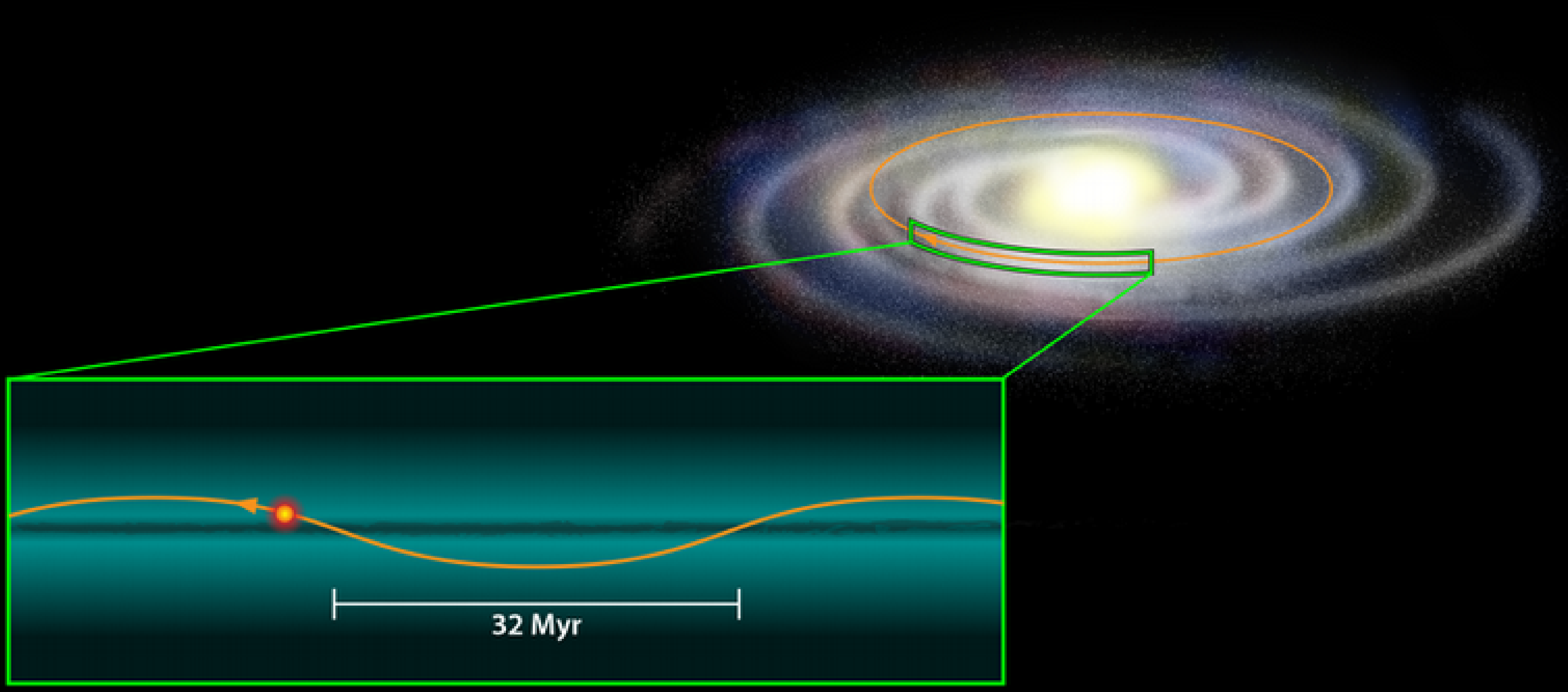


Radial velocities combined with proper motions

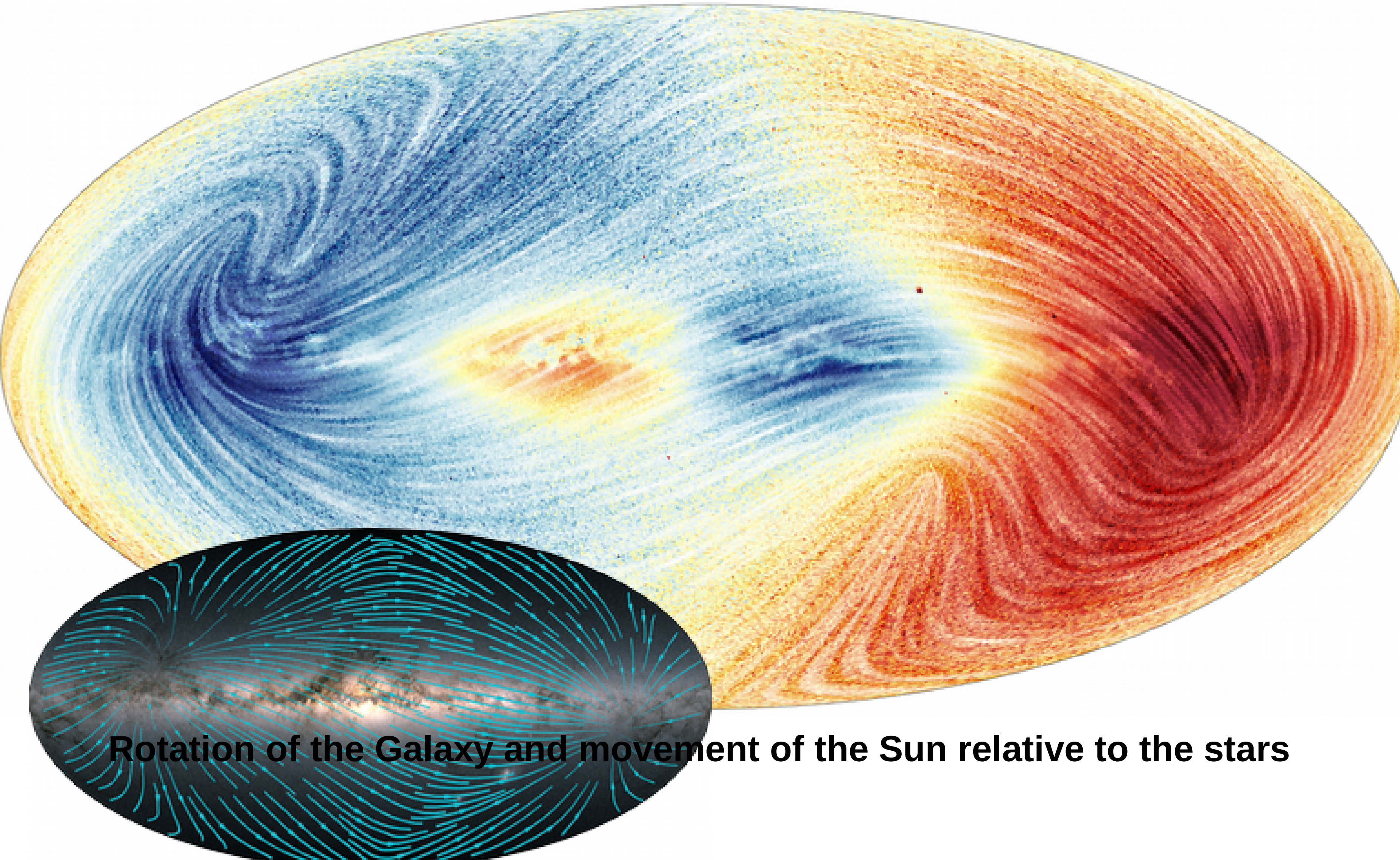


Rotation of the Galaxy and movement of the Sun relative to the stars

Motion of the Sun through the Milky Way plane

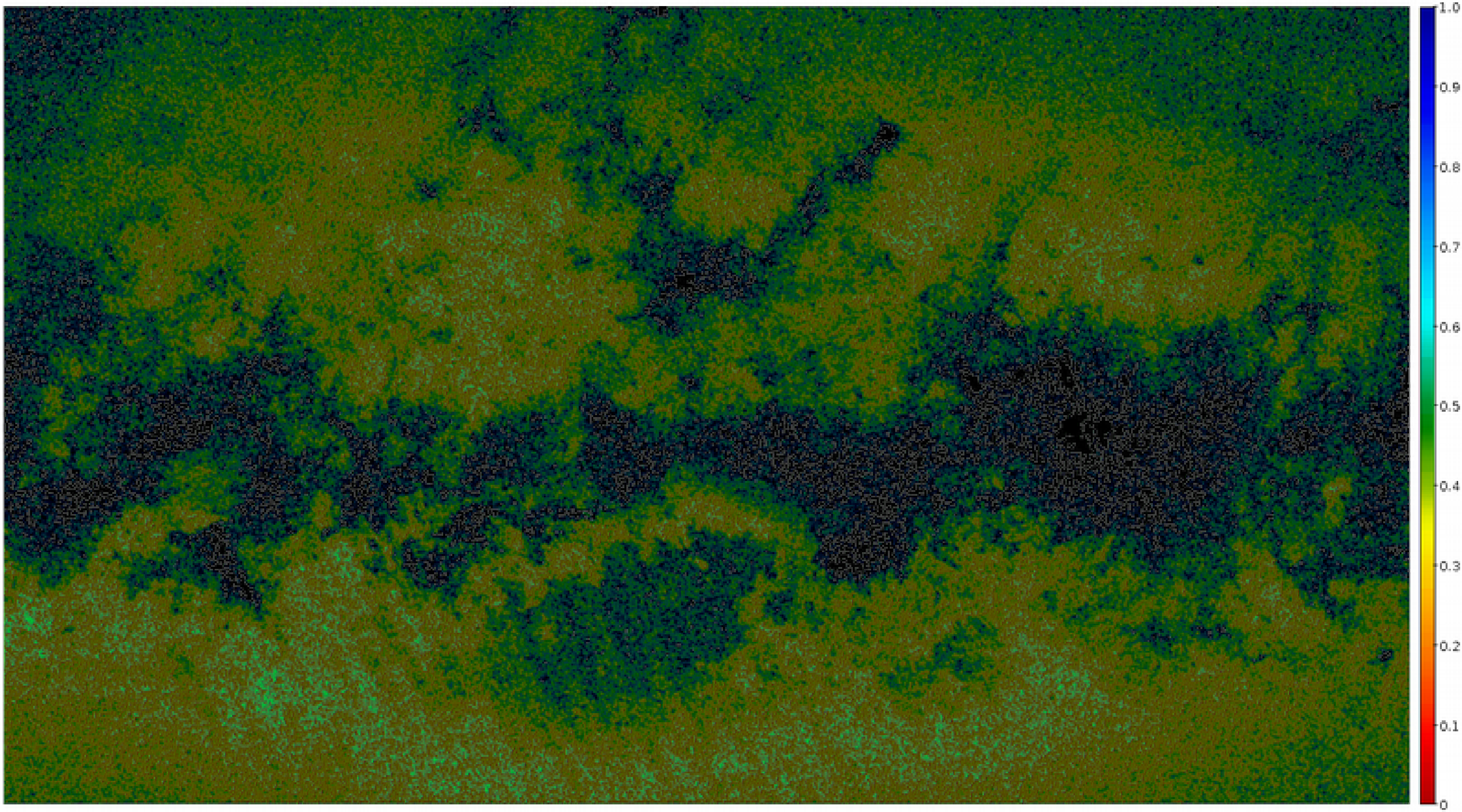


Radial velocities combined with proper motions

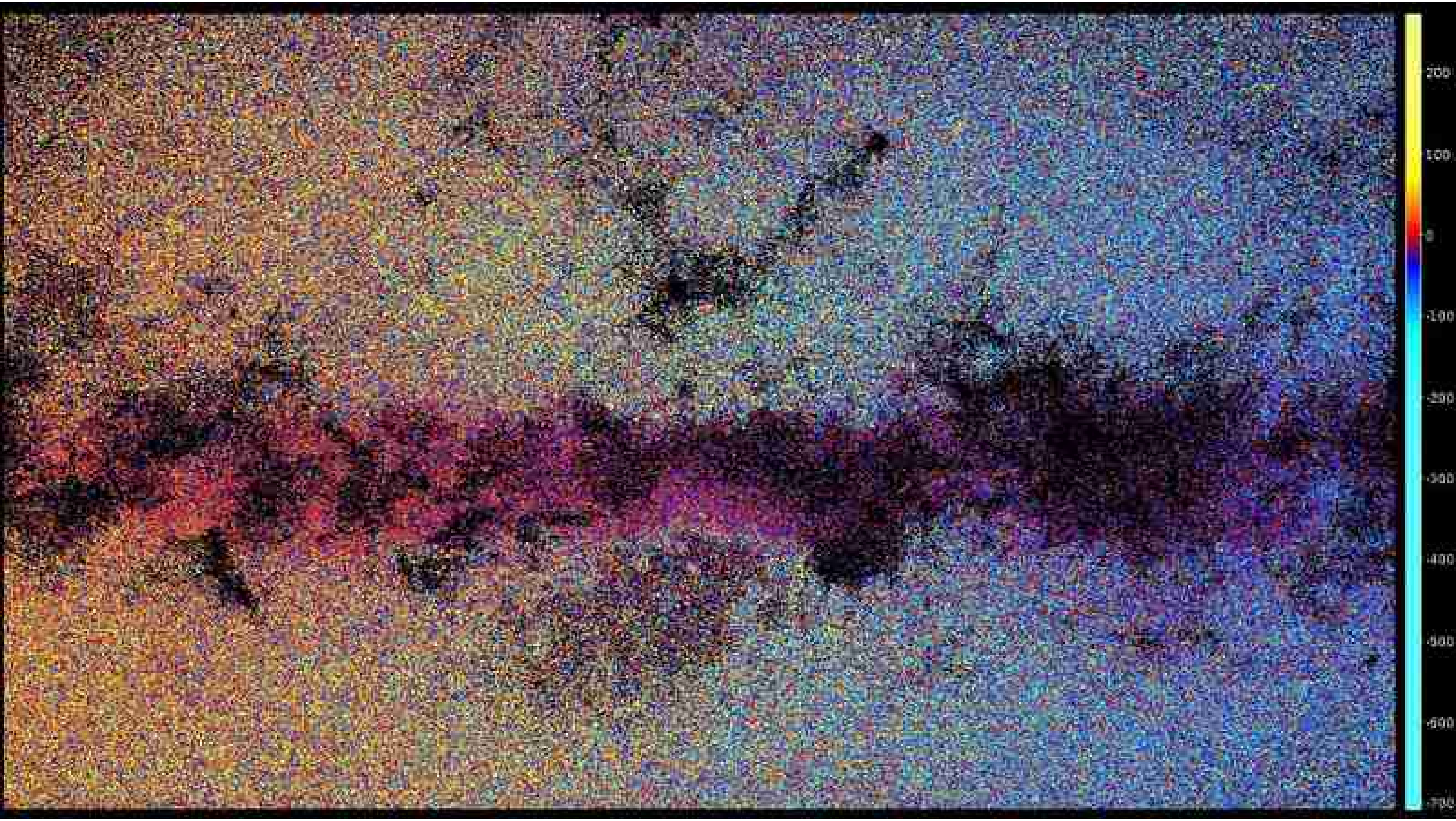


Rotation of the Galaxy and movement of the Sun relative to the stars

Accurate map of star densities around Galaxy center

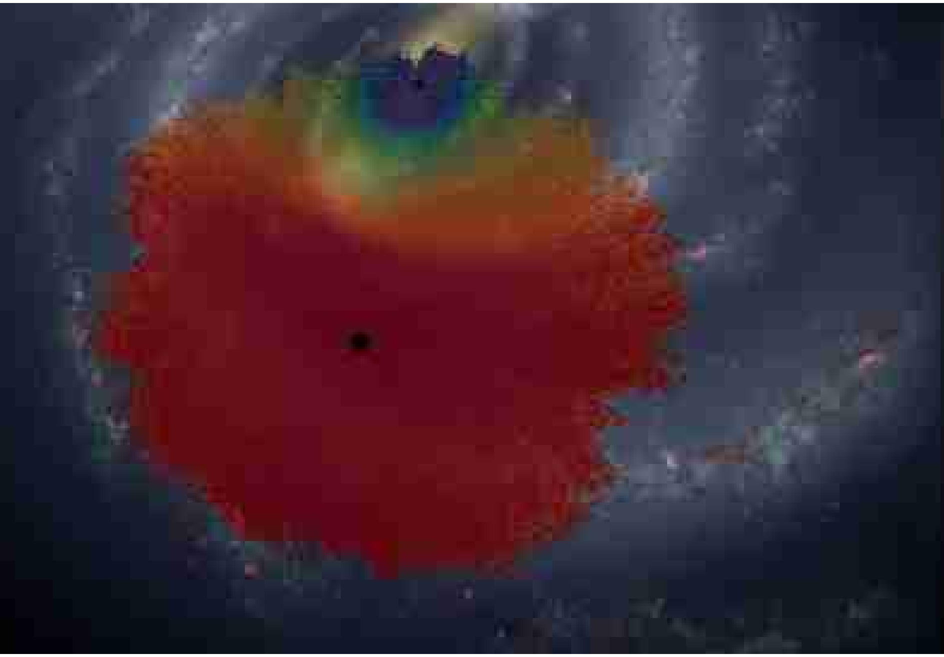


Accurate map of radial velocities around the center

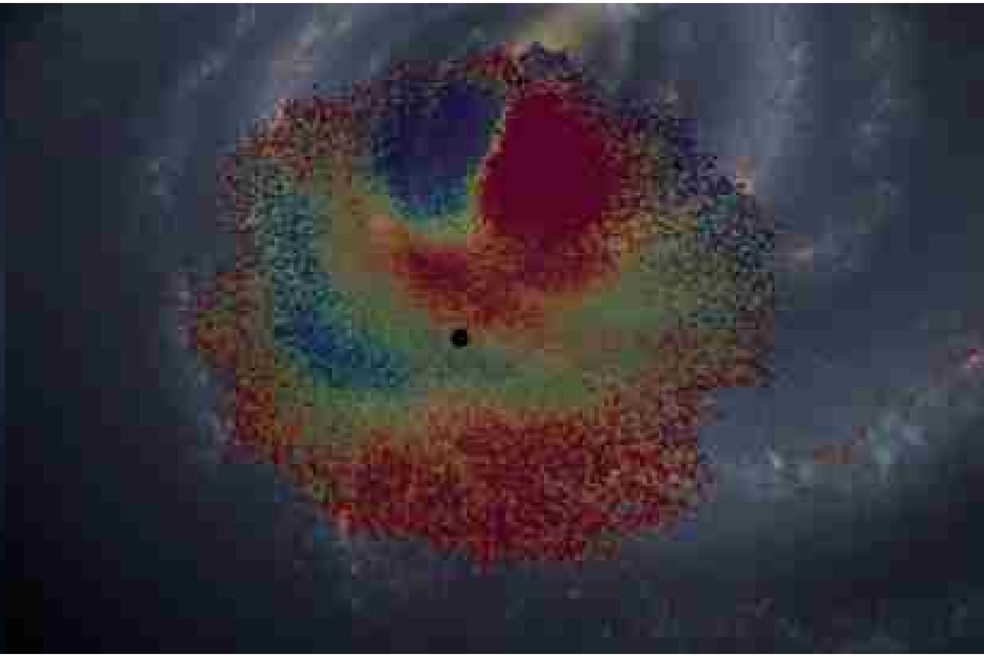


Tangential velocity structure of galactic rotation

Radial velocity structure of galactic bar rotation



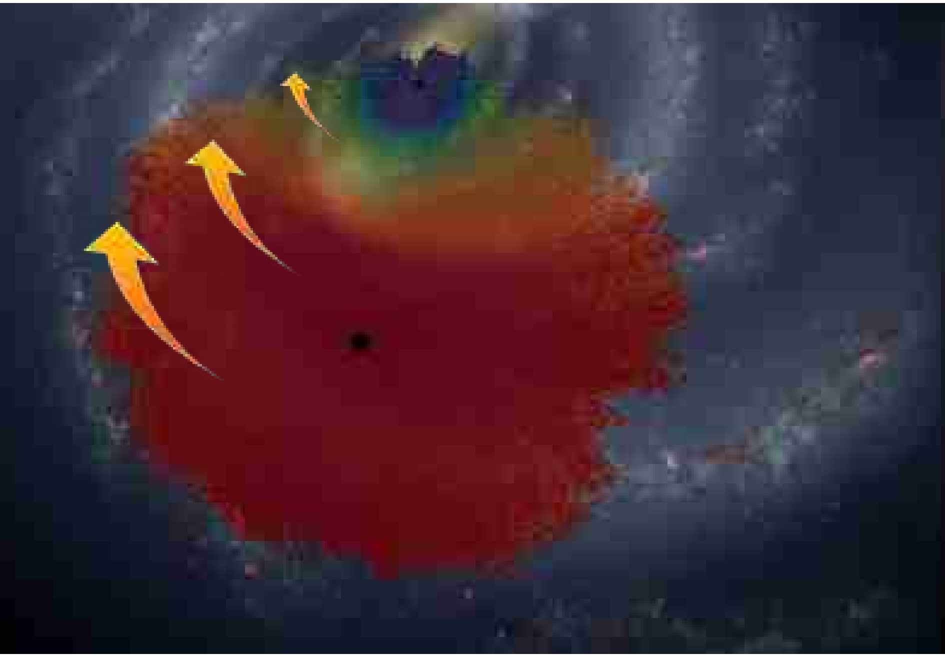
Tangential velocity map

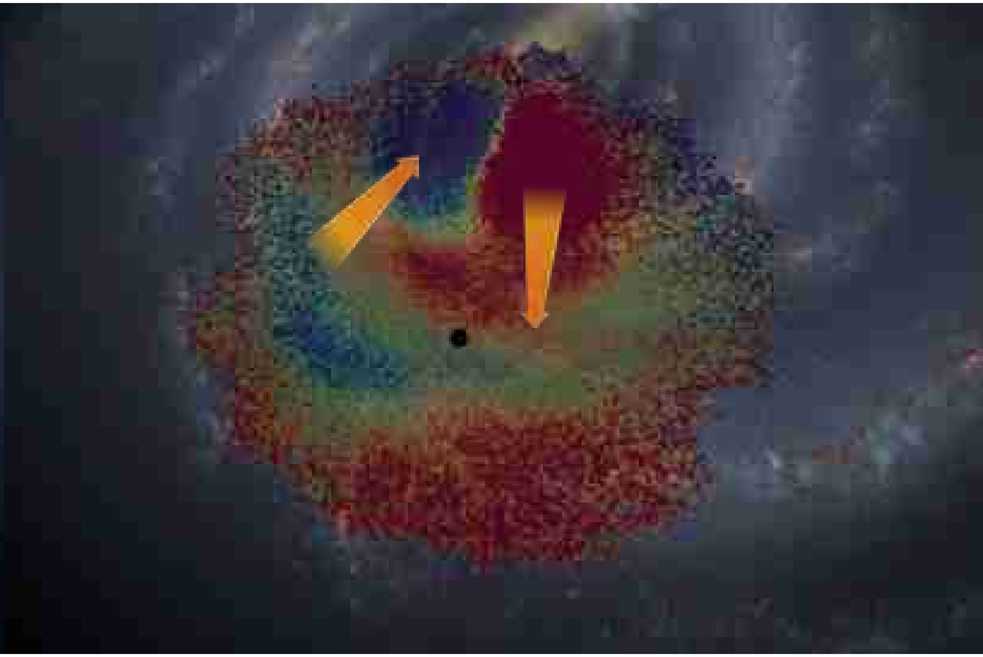


Radial velocity map

Gaia Collaboration, A&A 2022

Radial velocity structure of galactic bar rotation



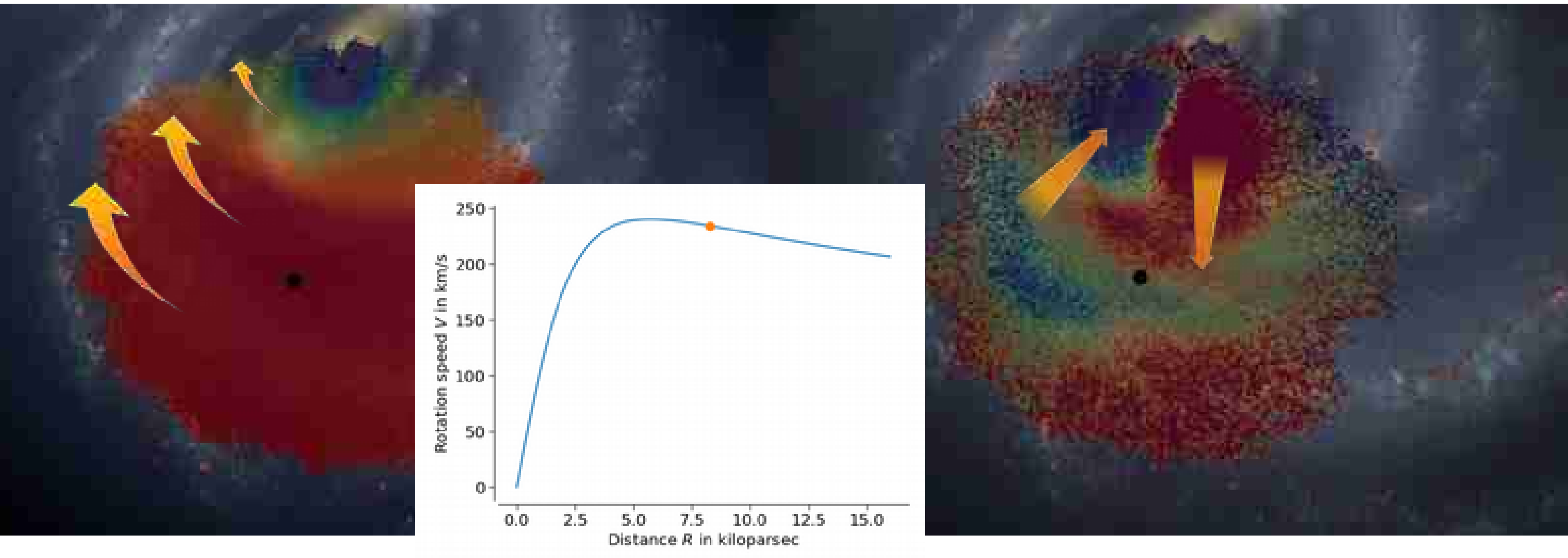


Tangential velocity map

Radial velocity map

Gaia Collaboration, A&A 2022

Radial velocity structure of galactic bar rotation

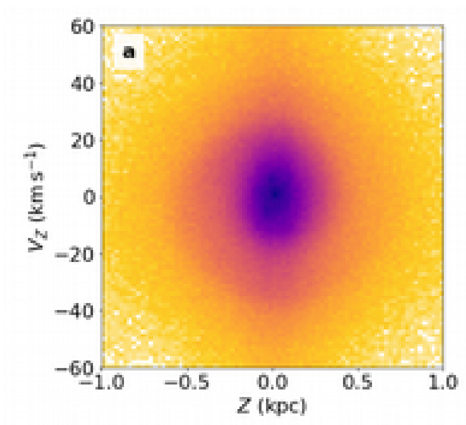


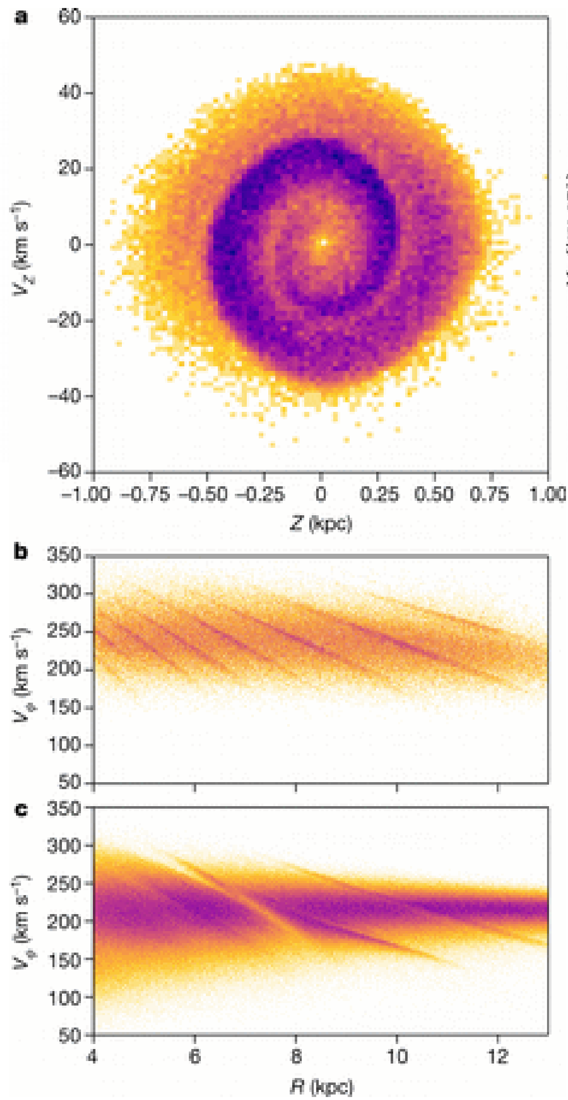
Tangential velocity map

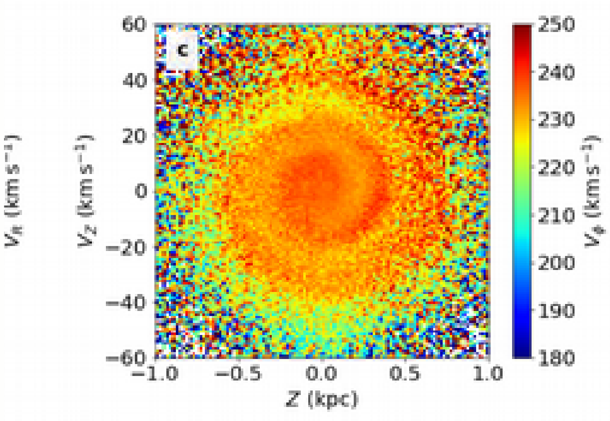
Radial velocity map

Gaia Collaboration, A&A 2022

Gaia phase spirals across the Milky Way plane

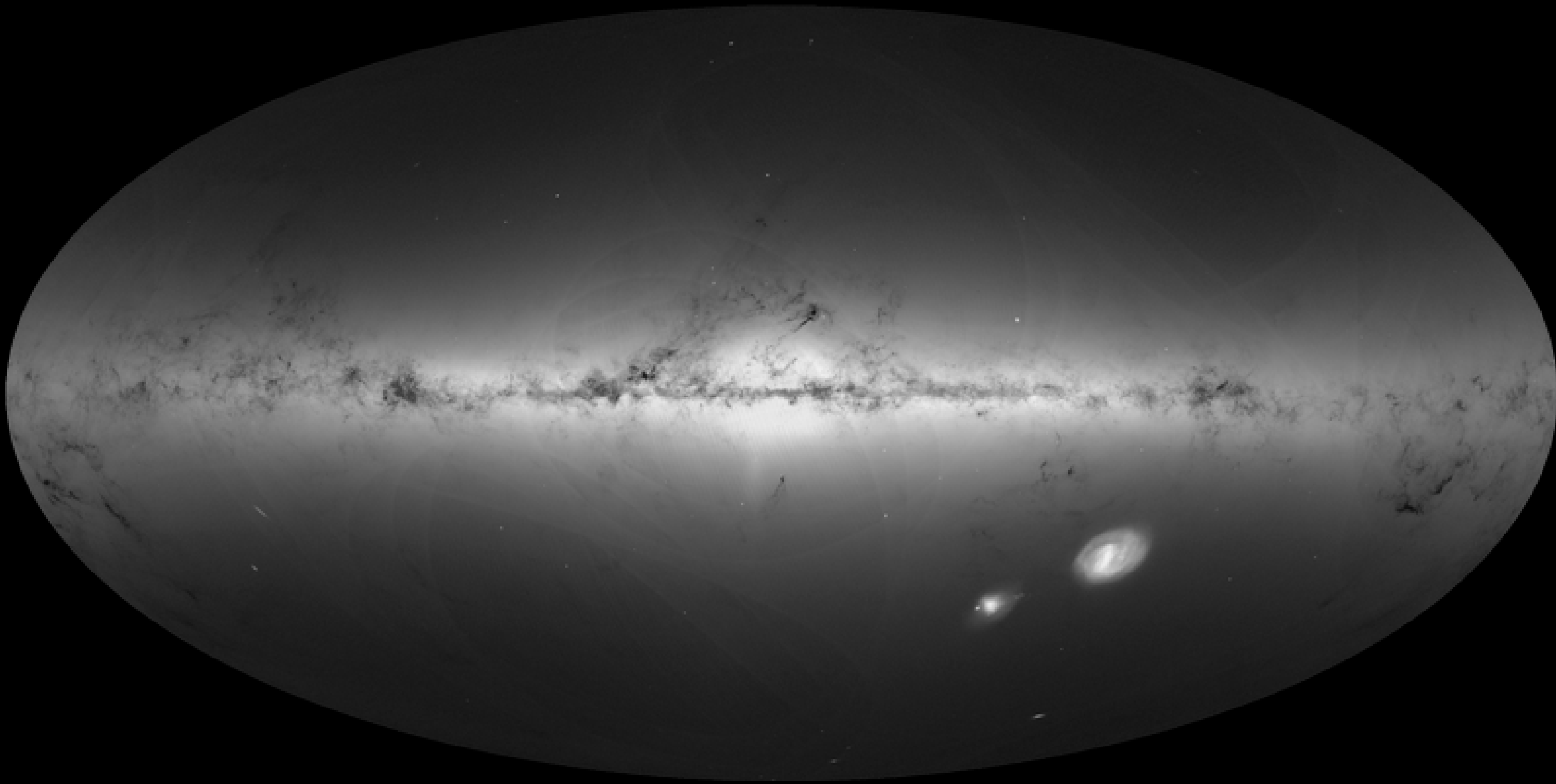




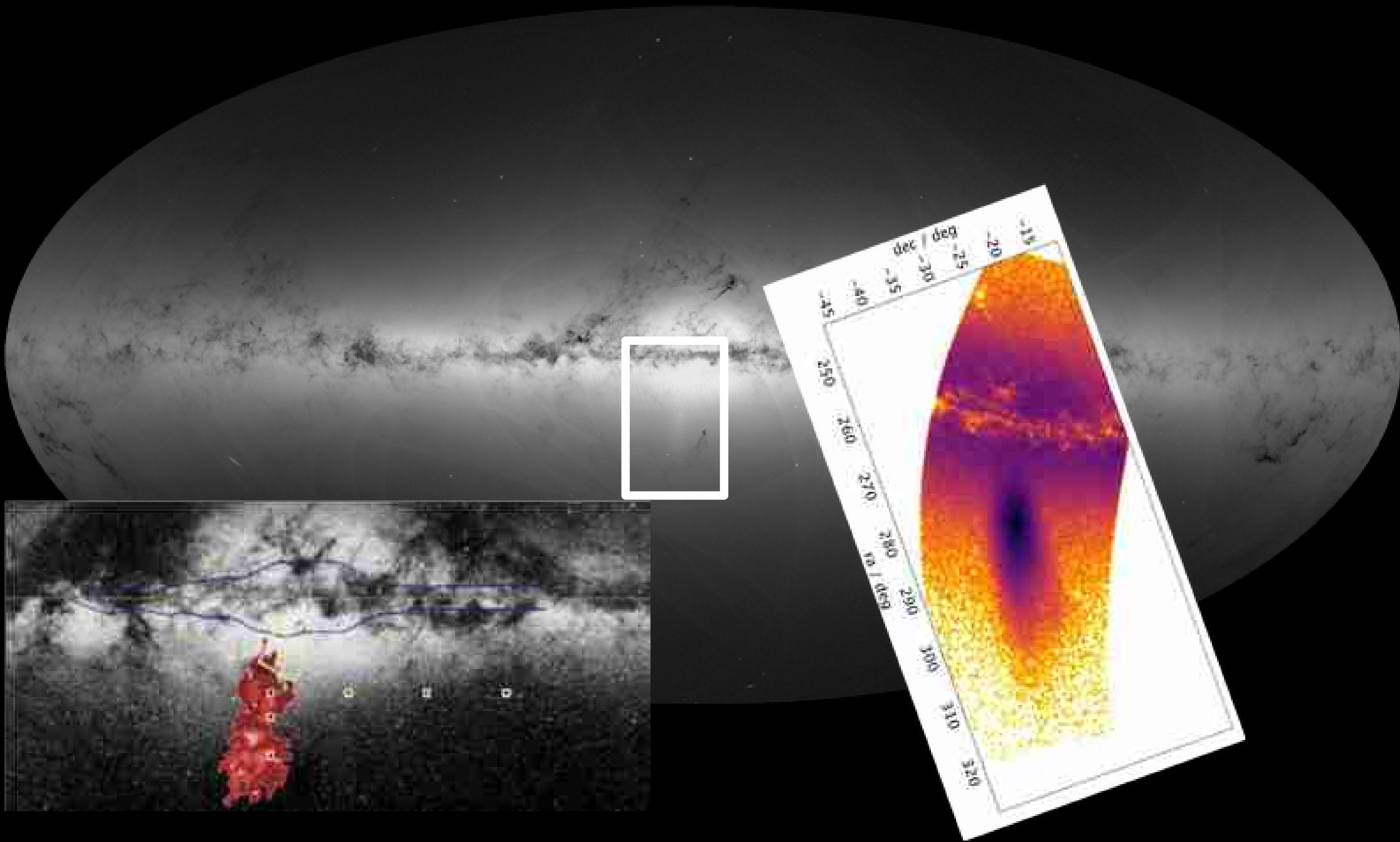


- **Phase spirals are observed everywhere in the plane of the Milky Way**
- **Revealing that star movements seek equilibrium from non-equilibrium**

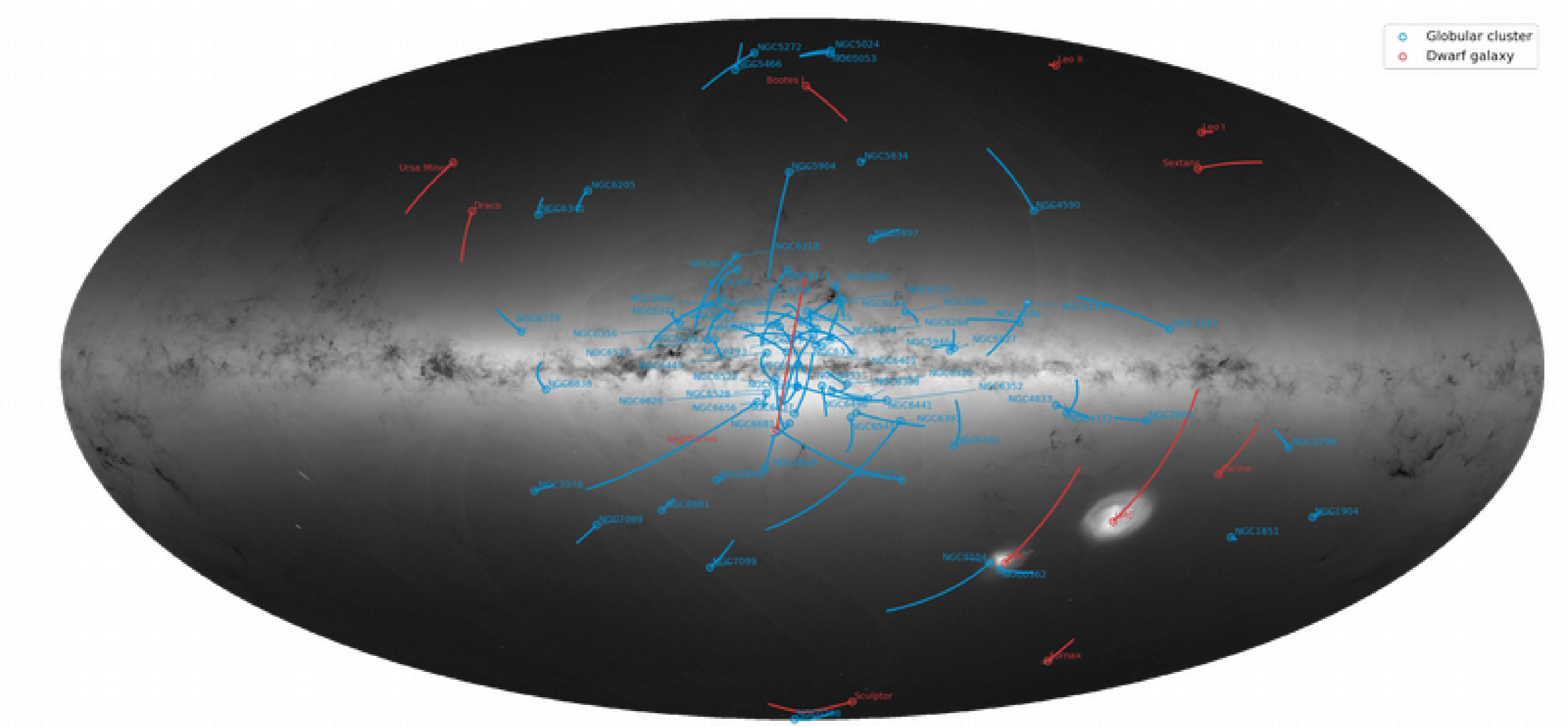
Position and brightness of 1.7 billion stars



Sagittarius Dwarf Galaxy



Motion of dwarf galaxies and globular clusters

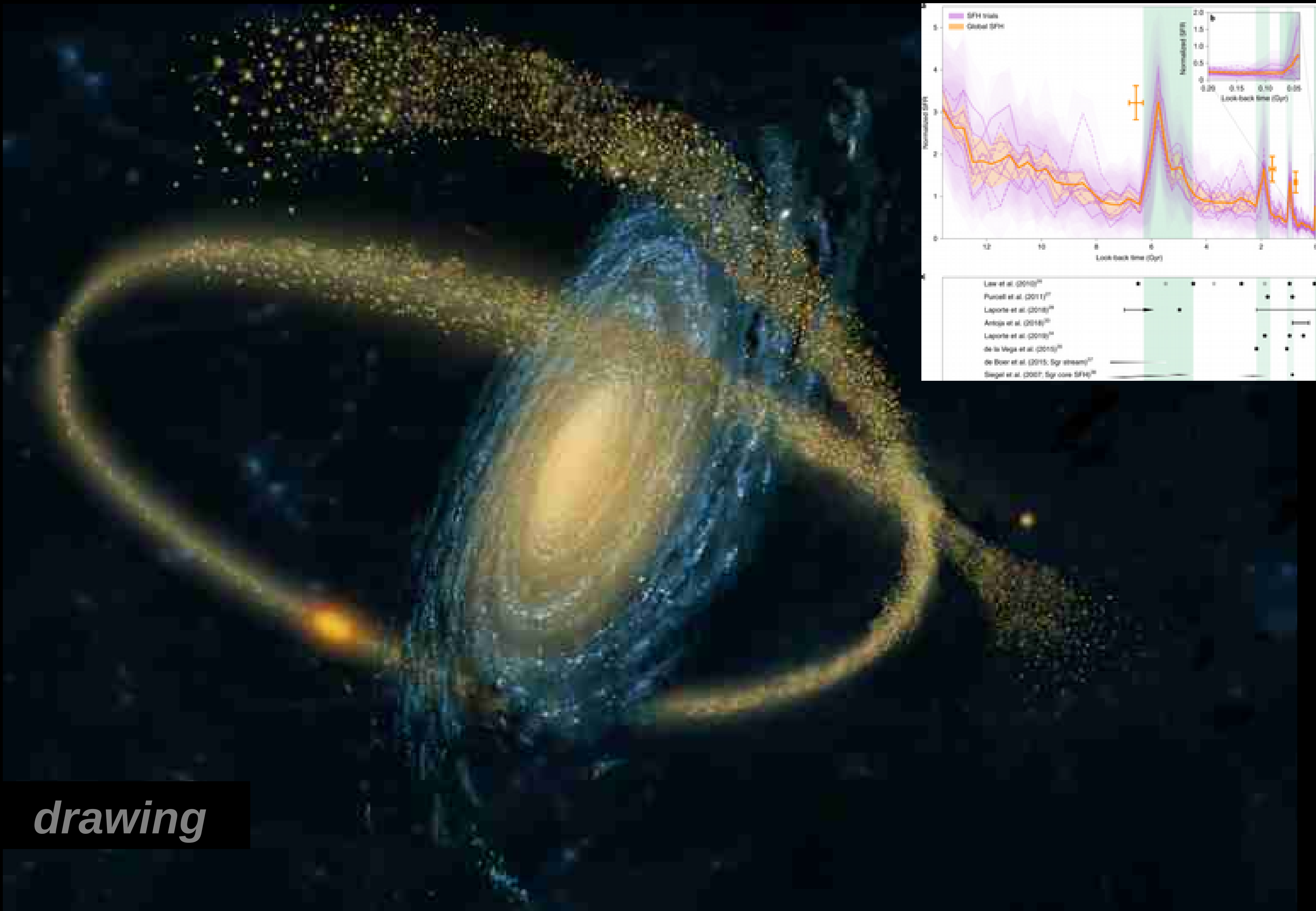


- **dwarf galaxies do not move in the same plane but there is some degree of coherence (groups fall in along filaments)**

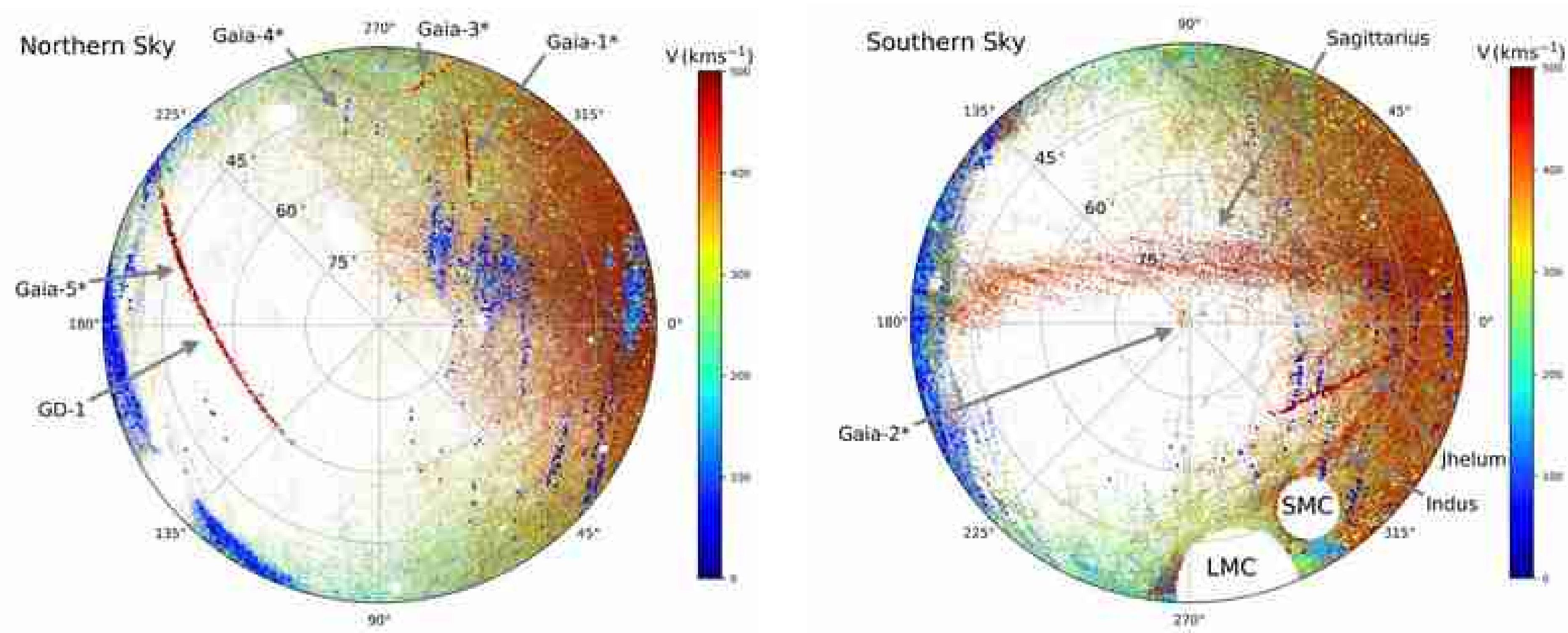
- **globular clusters exhibit more random motion but sometimes in pairs**

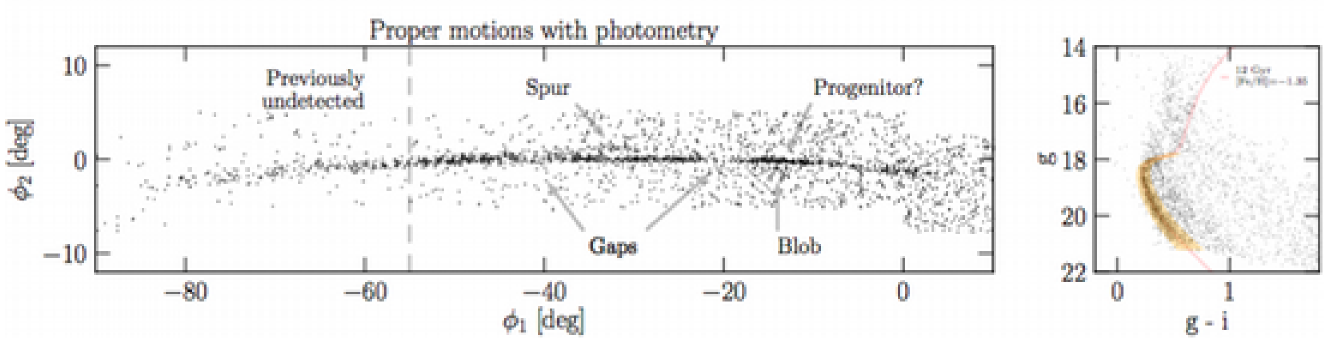
Repeated collisions of the Sagittarius dwarf galaxy with the plane of our Milky Way

Sagittarius stellar stream in the Milky Way halo



Narrow tidal stellar streams in the Milky Way halo





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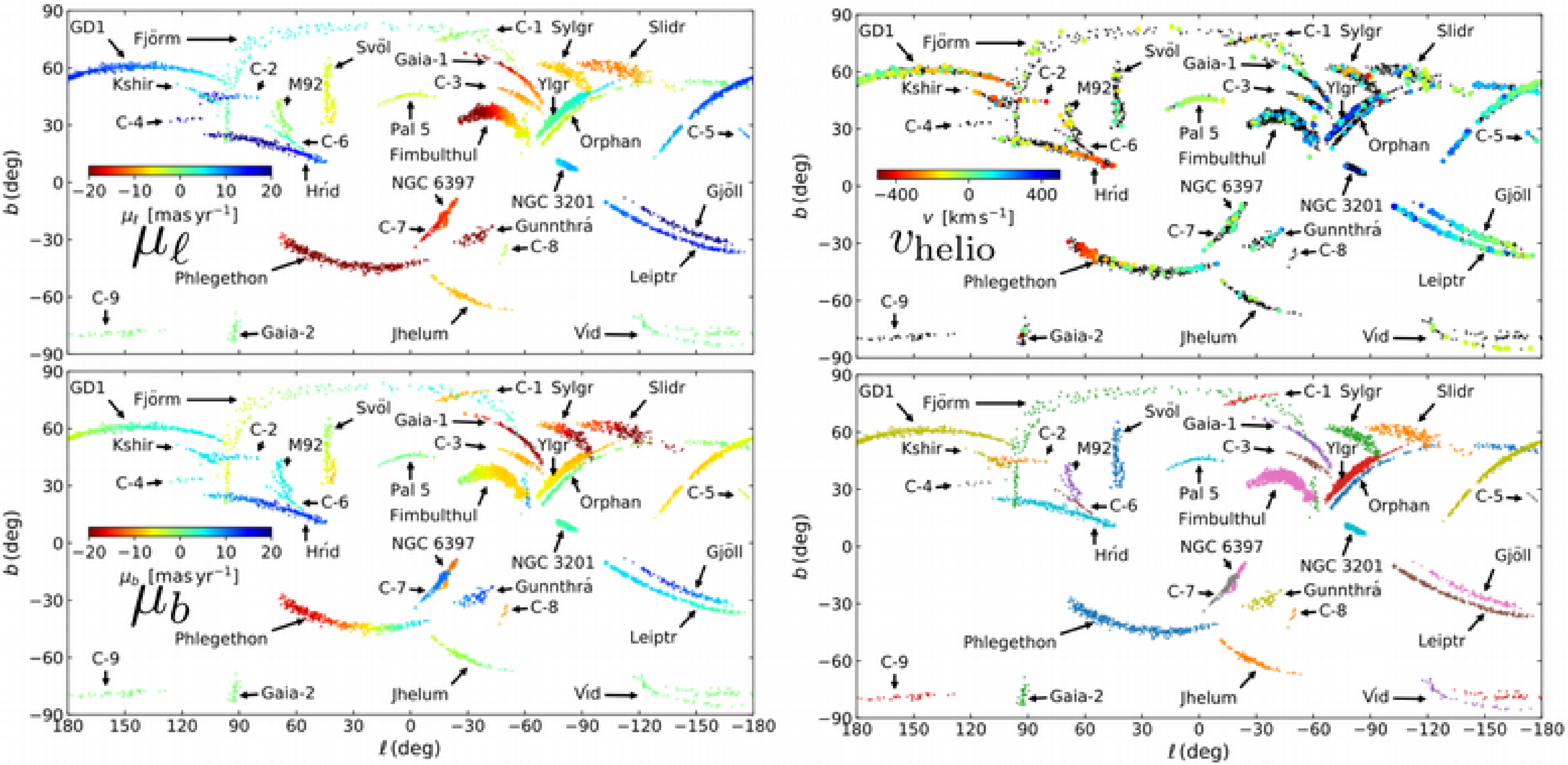
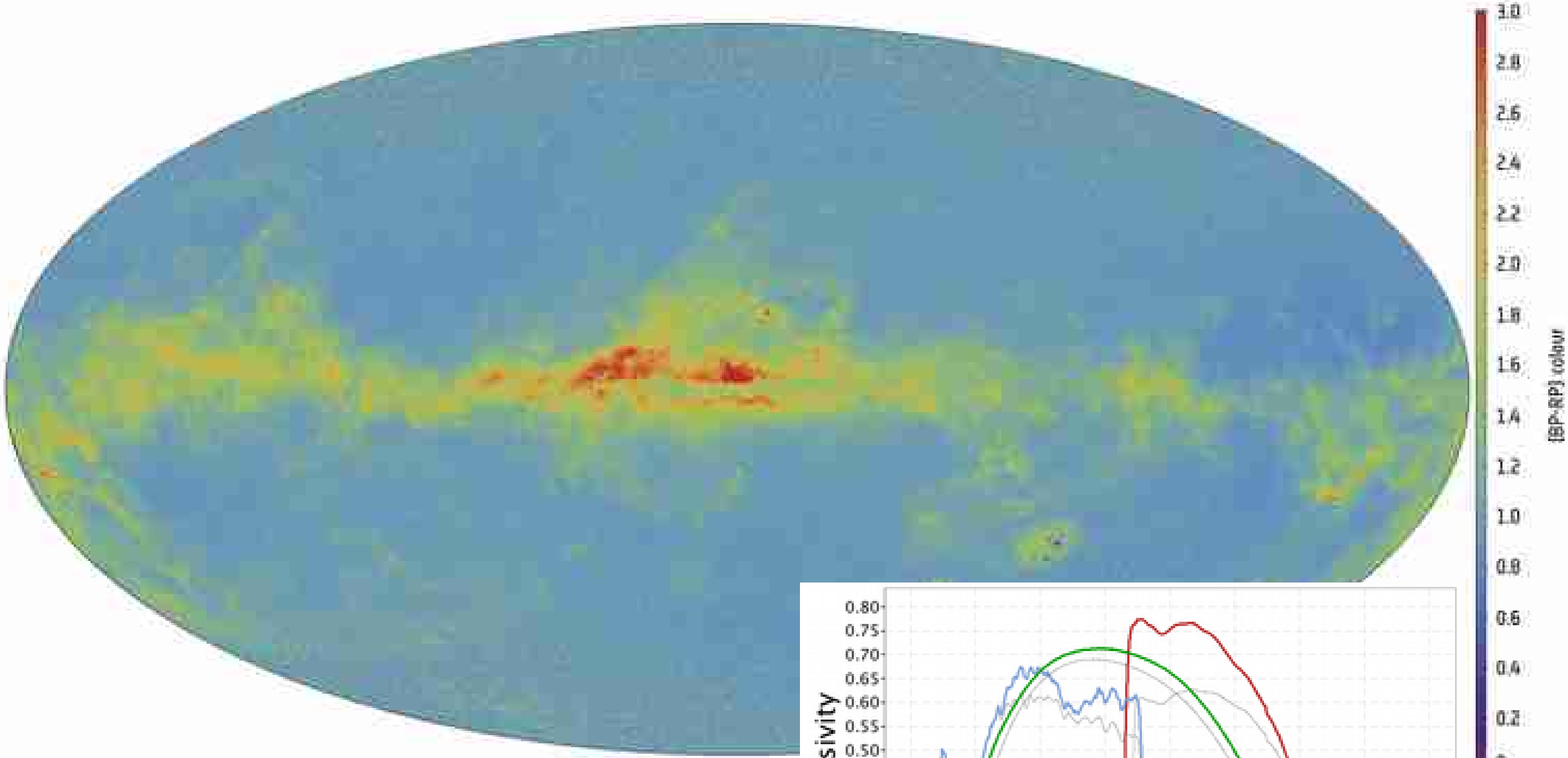


Extra-galactic stellar streams

Gaia map of photometric colors of stars

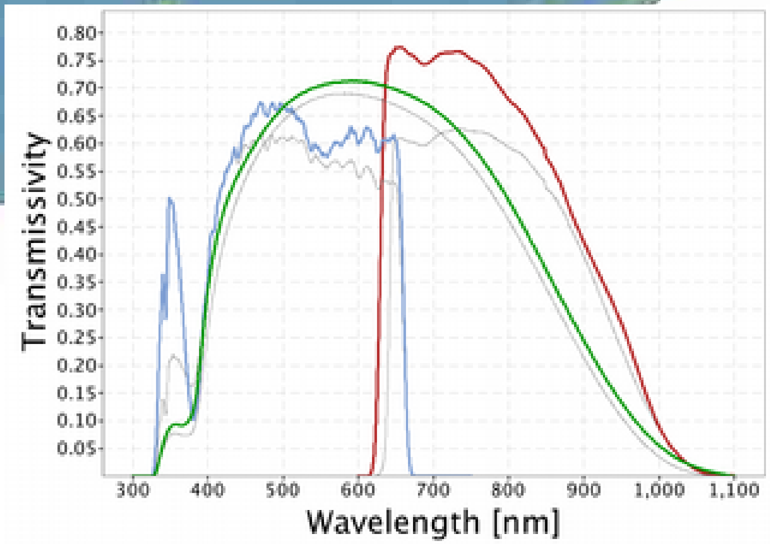


Gaia photometric filters

G: 330 – 1050 nm

Bp: 330 – 680 nm

Rp: 640 – 1050 nm



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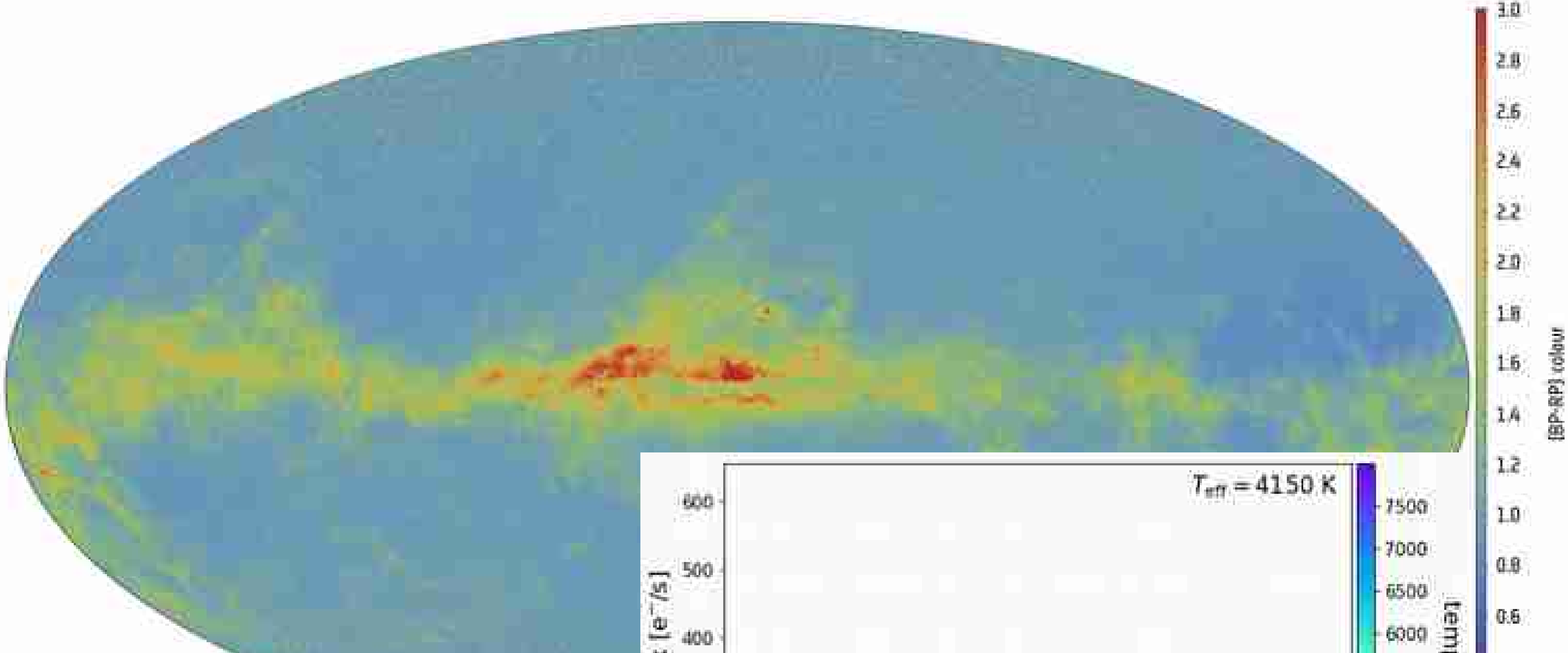

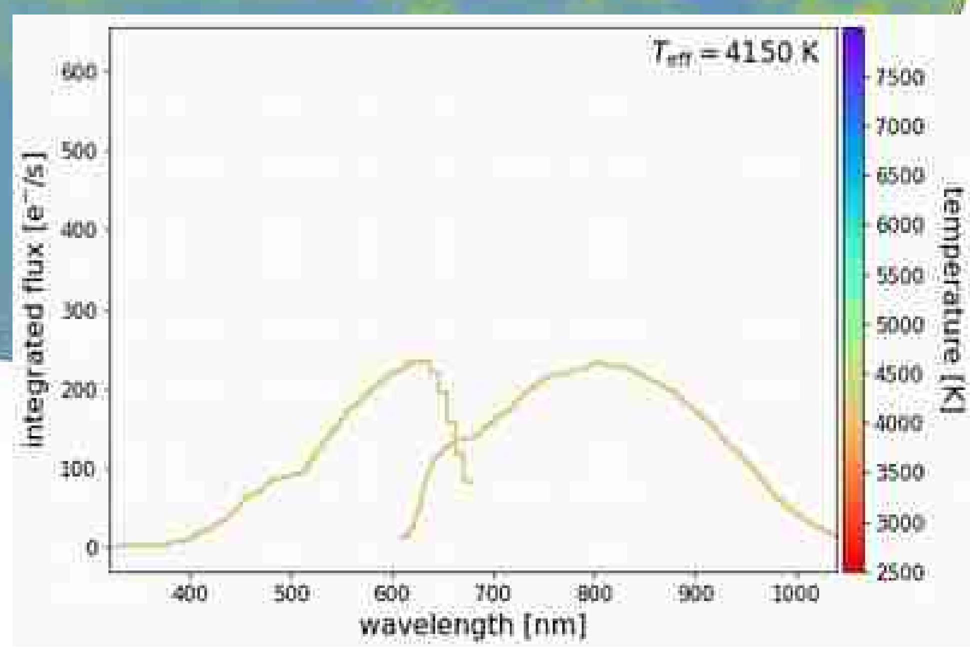

Gaia fotometric filters

G: 330 – 1050 nm

Bp: 330 – 680 nm

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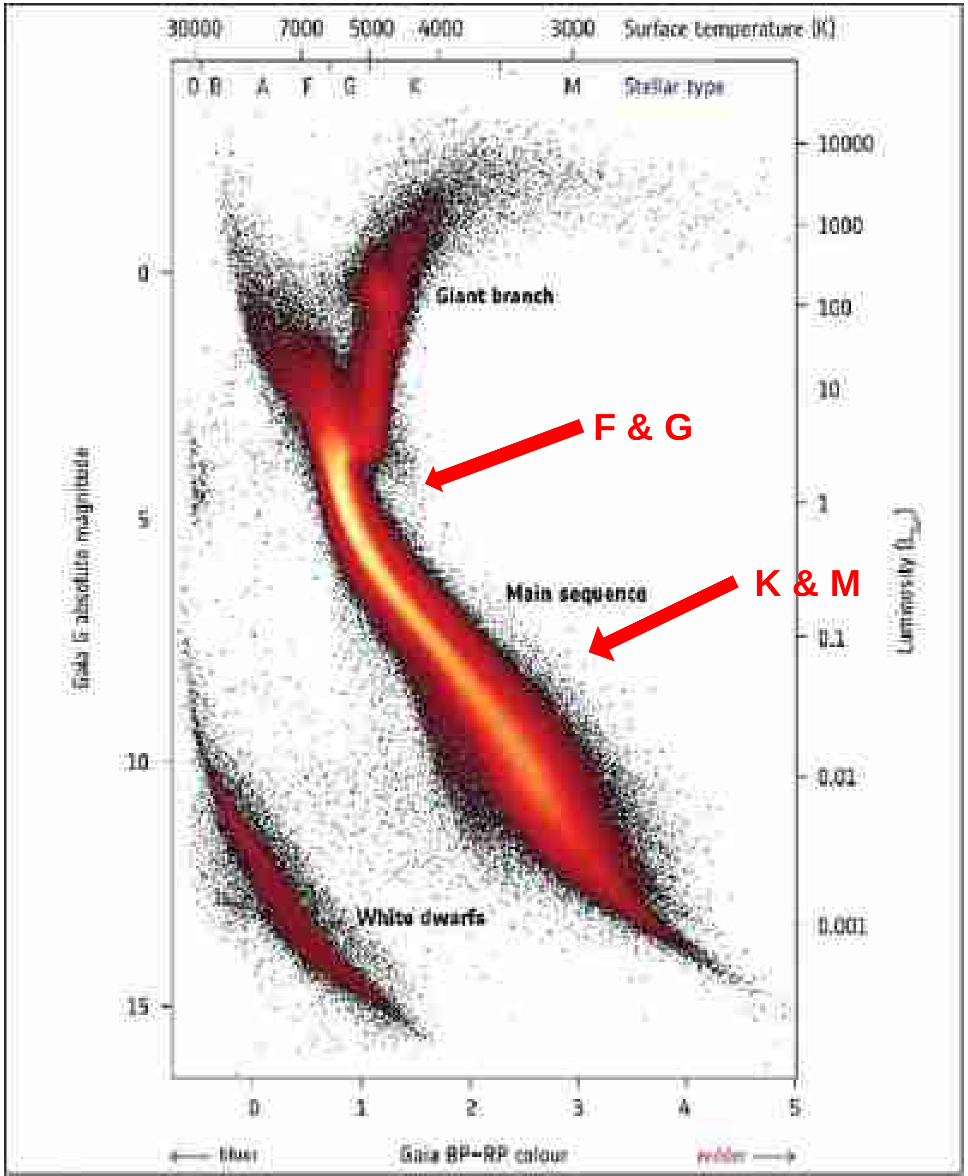
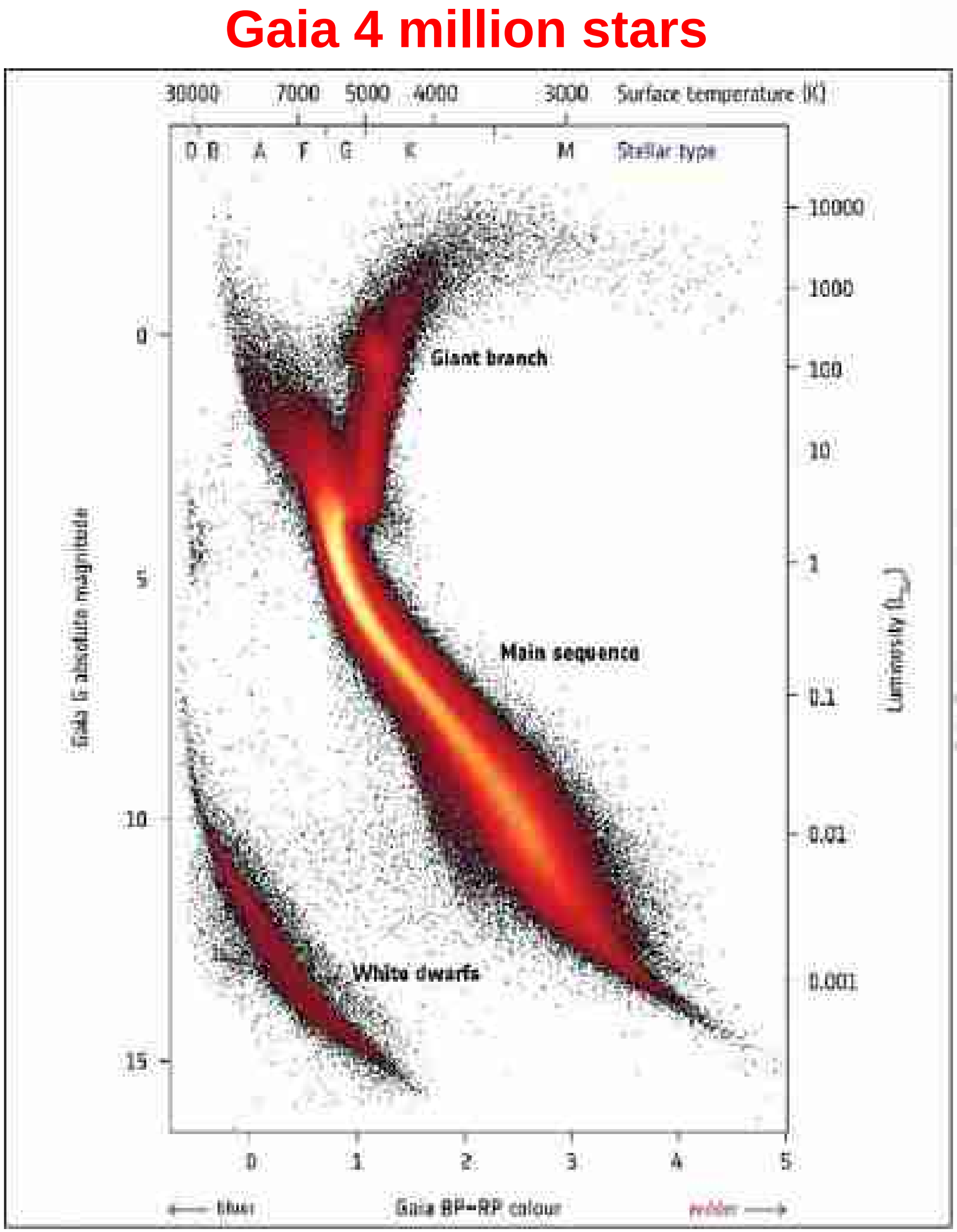
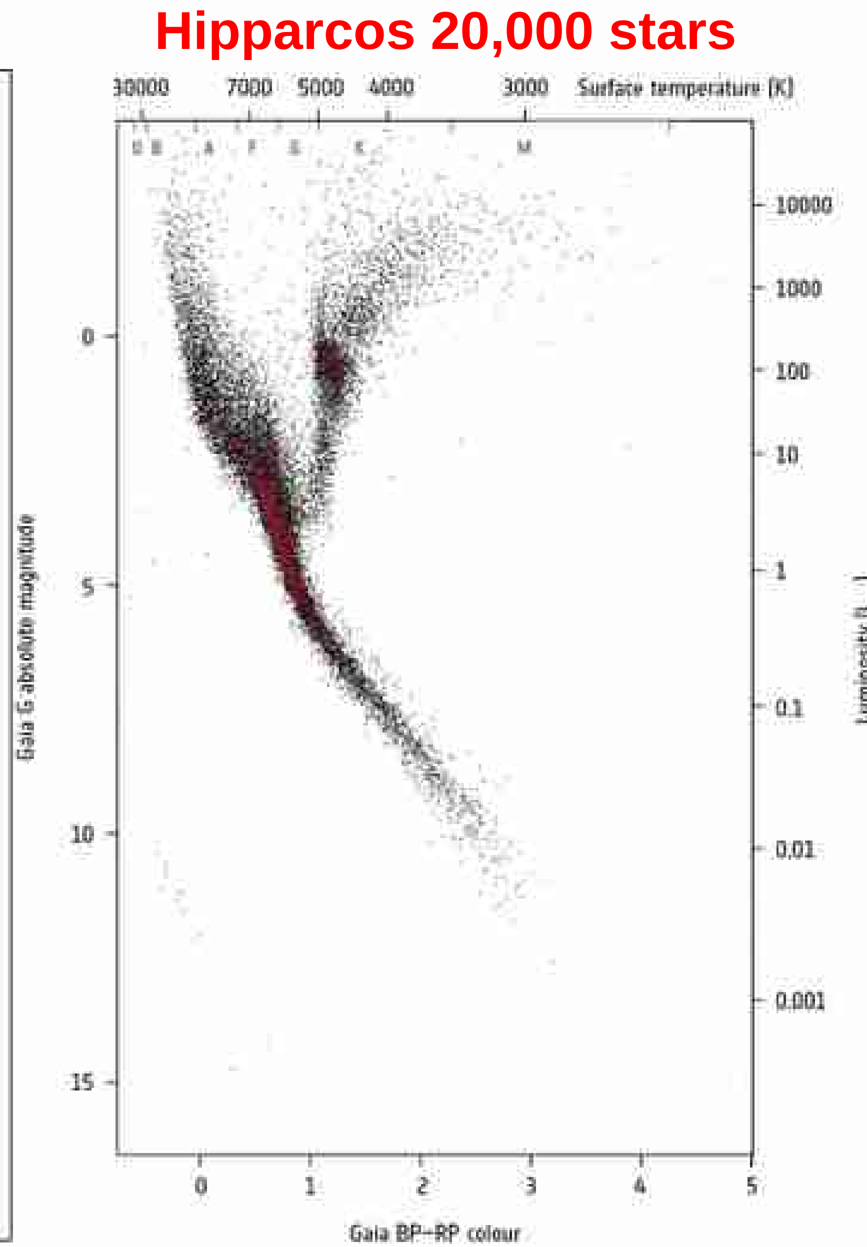
Gaia color-magnitude diagram

Field stars within 200 pc with low interstellar reddening



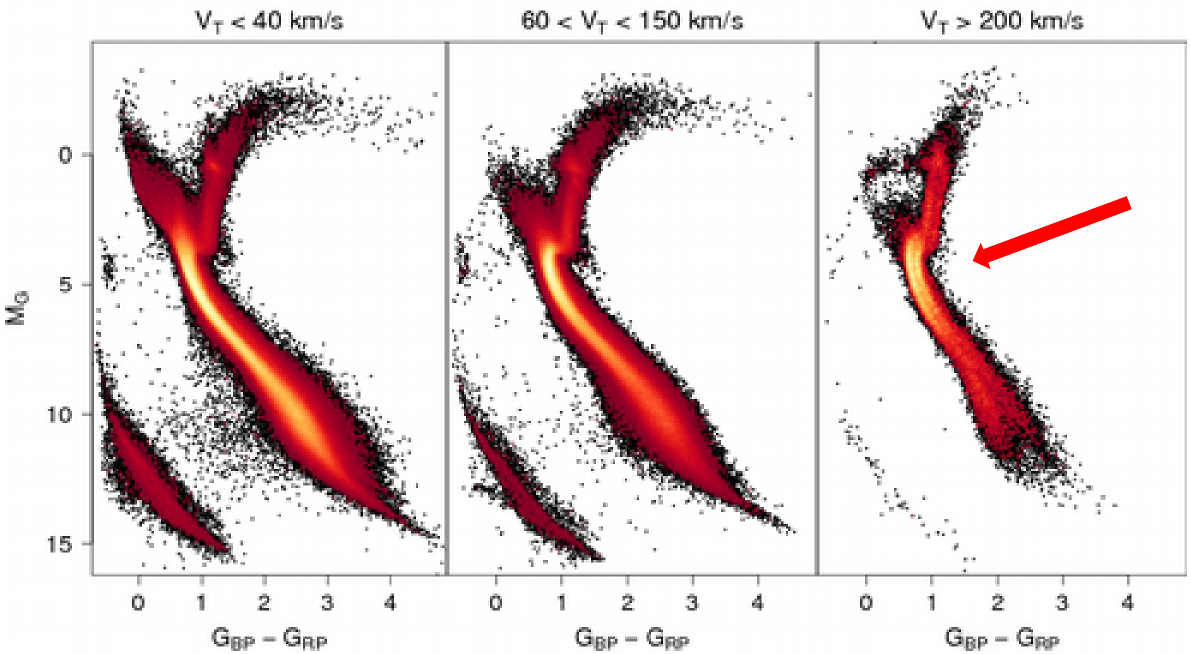
Gaia color-magnitude diagram



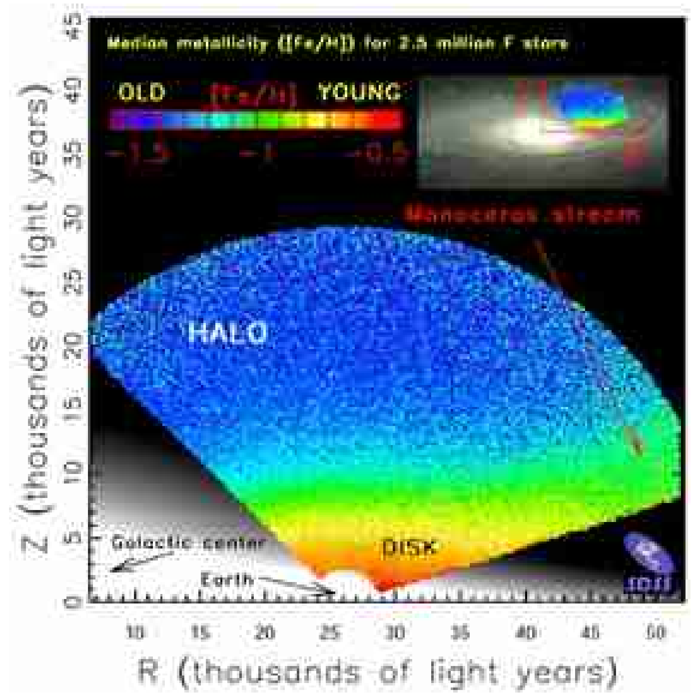


Gaia color-magnitude diagram

diagrams of tangential velocities

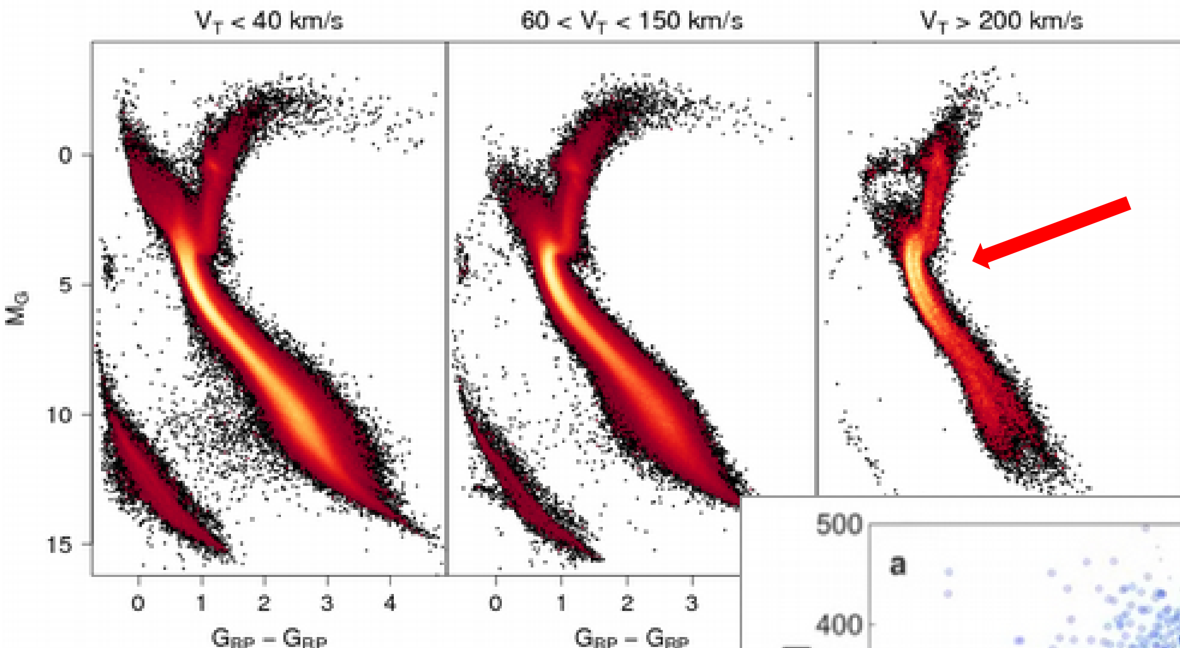


stars in halo show double main sequence due to difference in metal content [Fe/H] = -1.5 & -0.5



Gaia color-magnitude diagram

diagrams of tangential velocities



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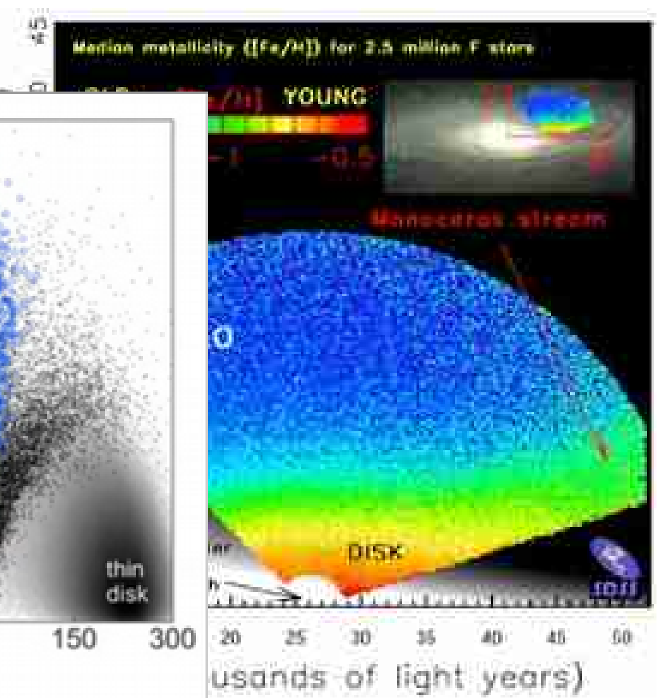
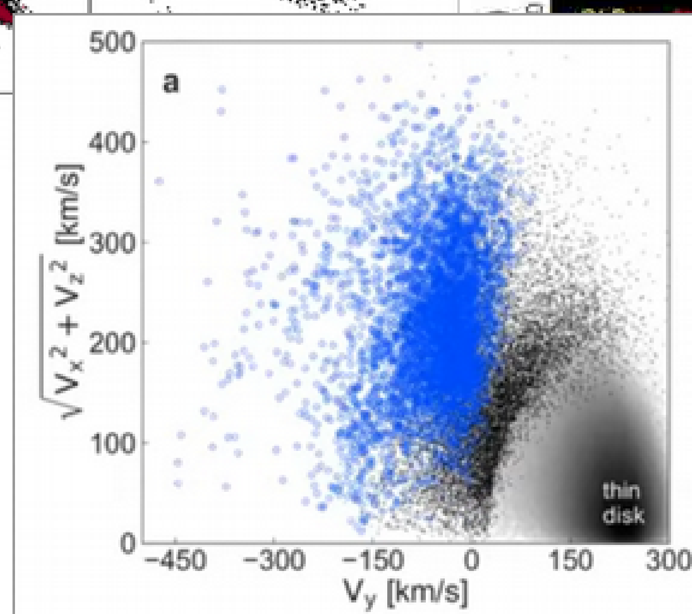
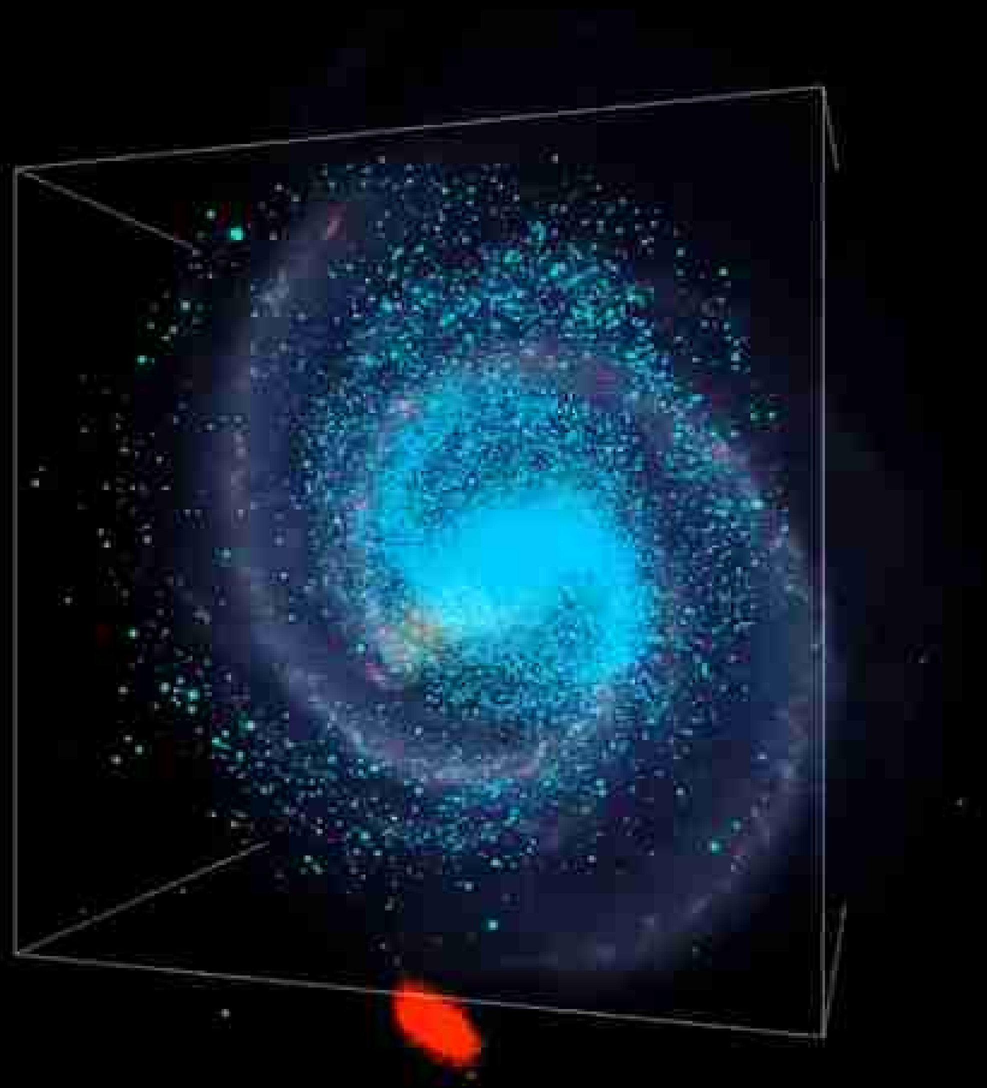


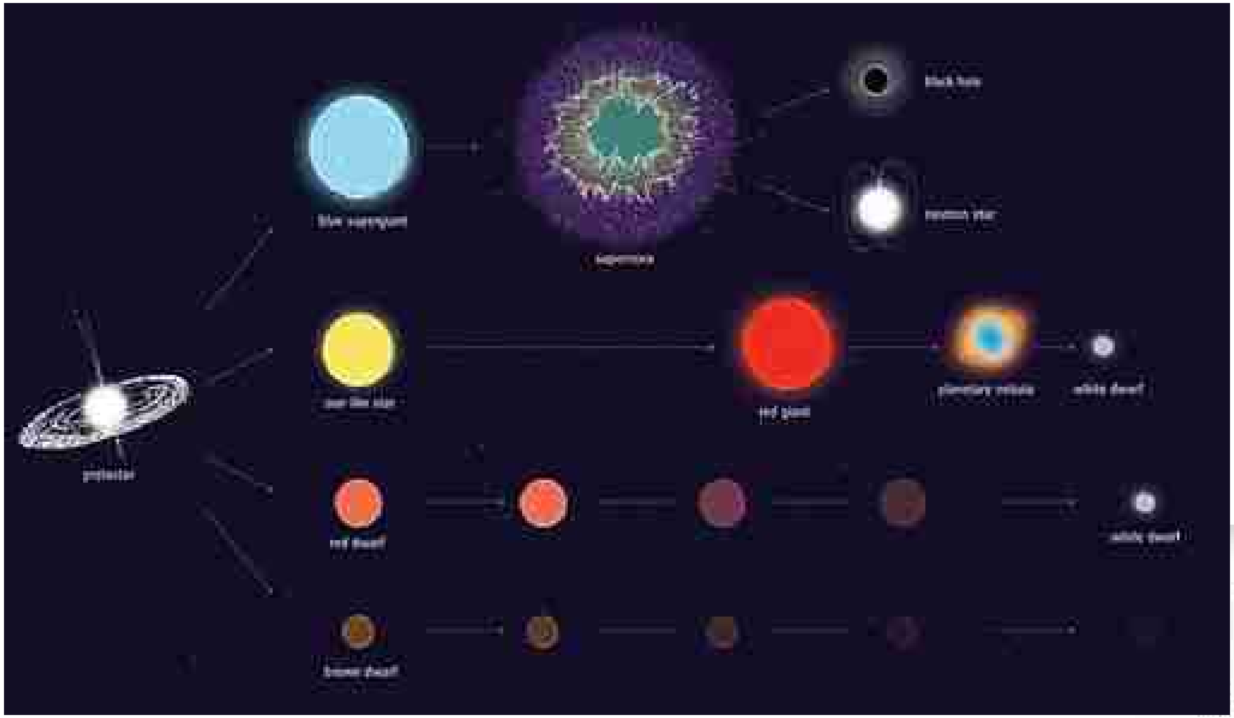


Old stars of halo show rotation direction opposite to the Sun around Milky Way center

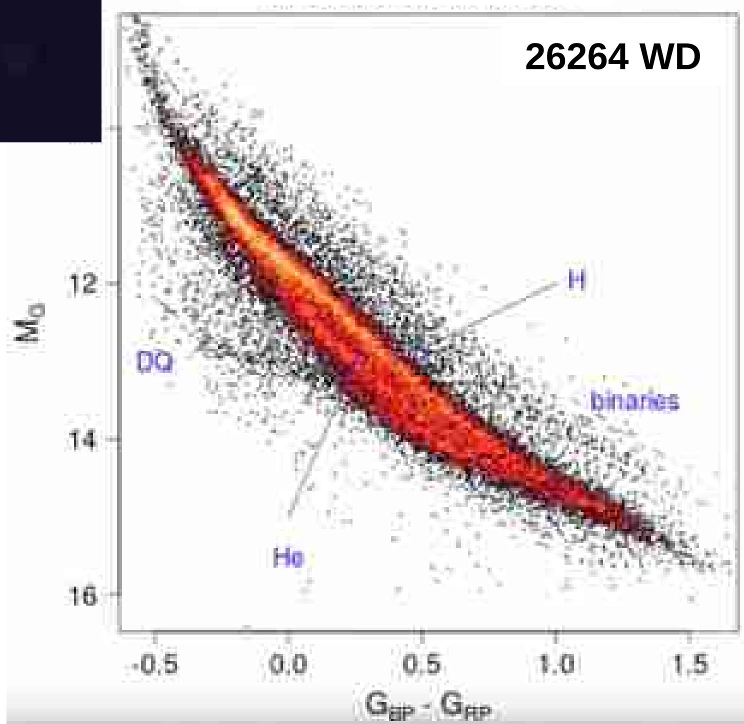
Gaia-Enceladus major merger event with the Milky Way disk of 8 to 11 billion years ago



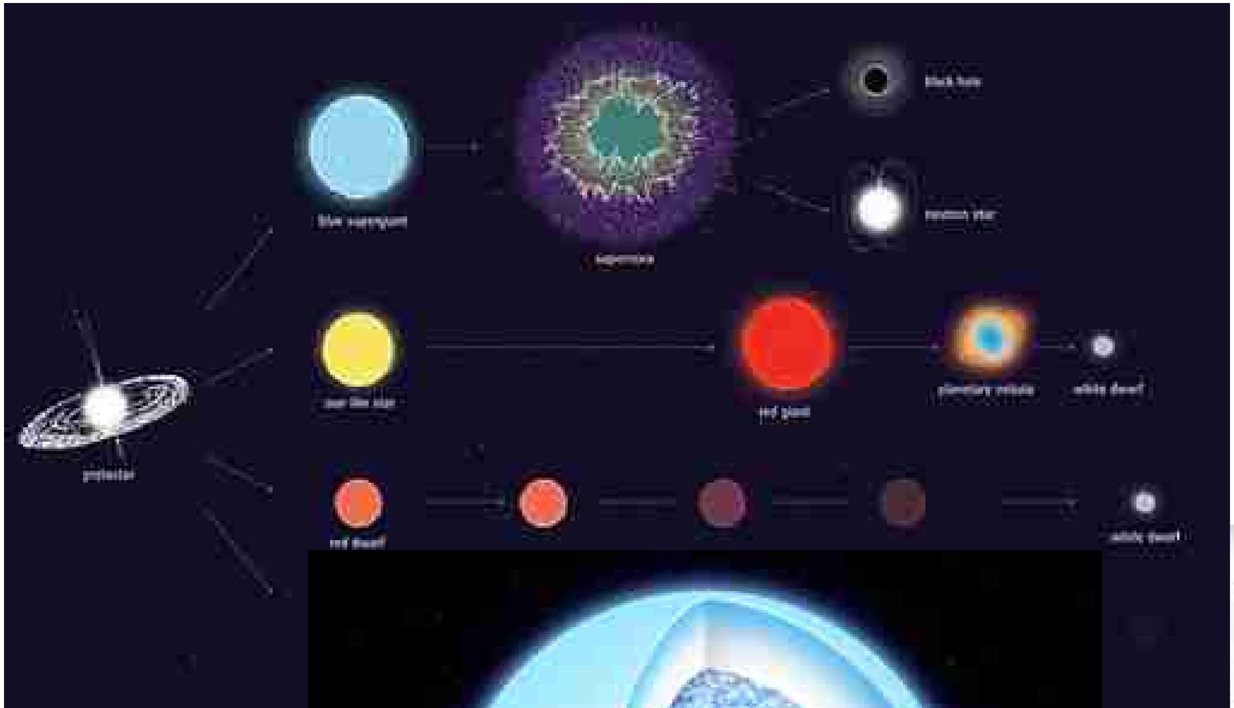
Gaia color-magnitude diagram of white dwarfs

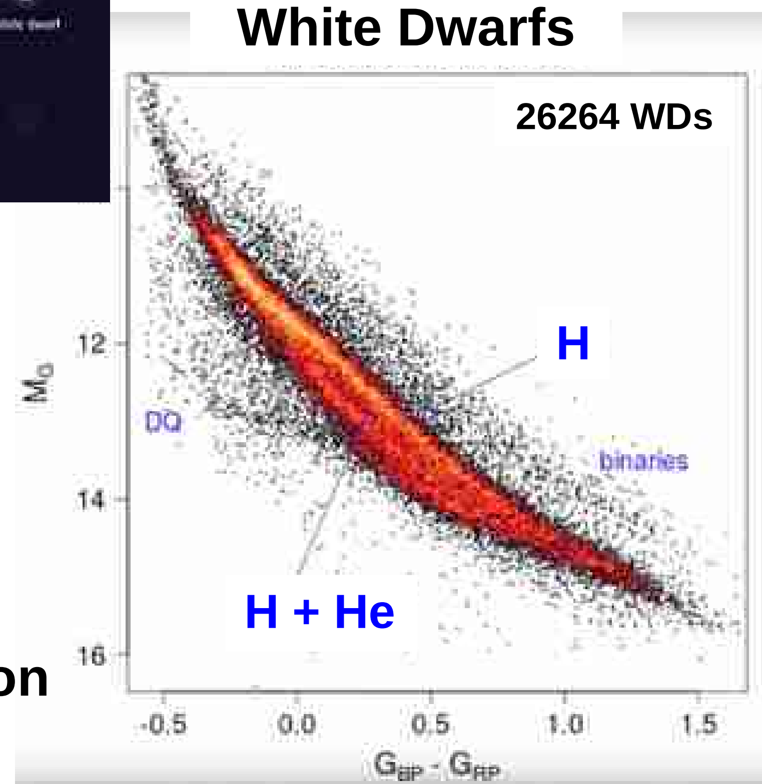


Differentiation between H- en He-rich white dwarfs



Gaia color-magnitude diagram of white dwarfs

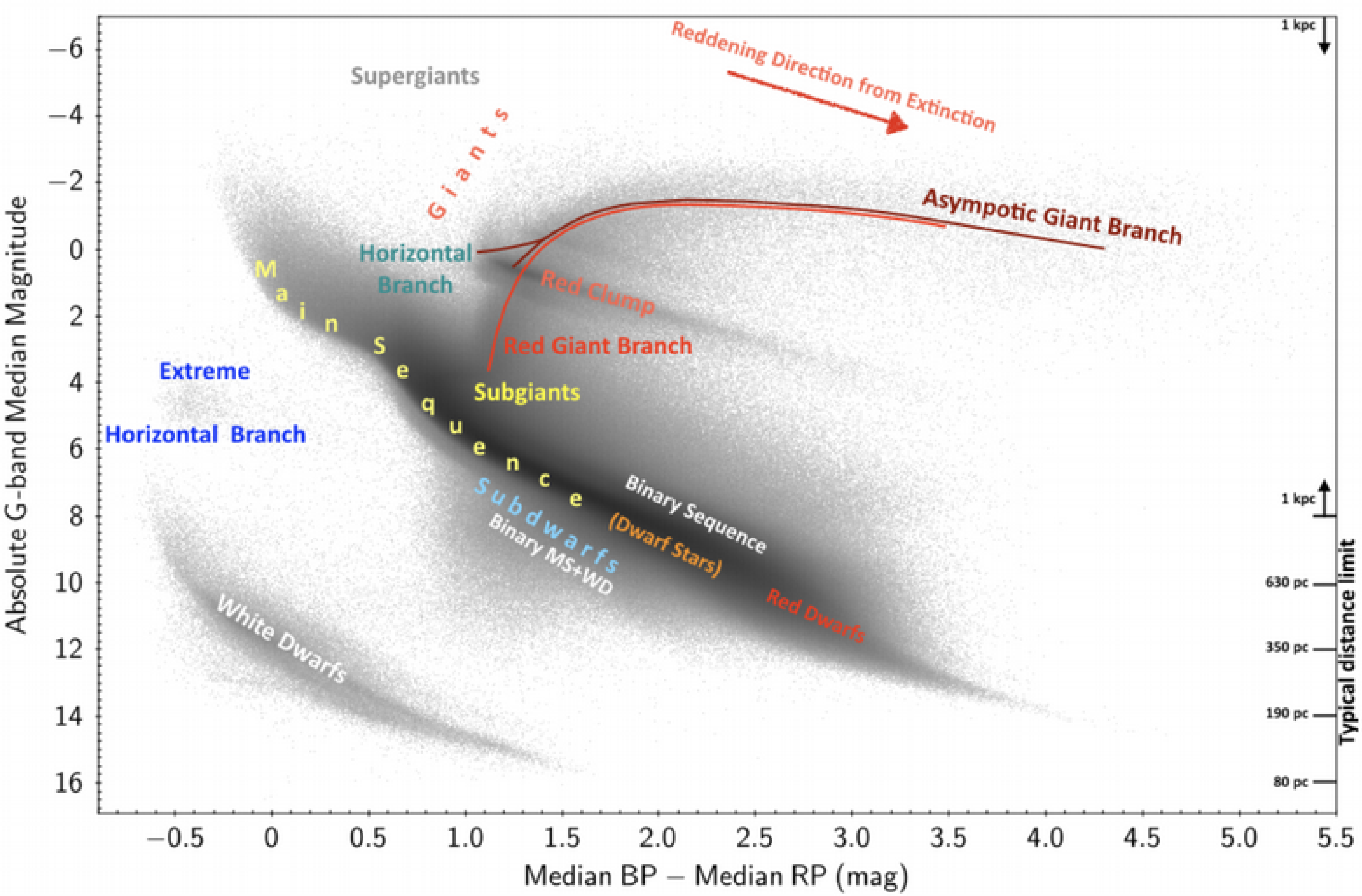




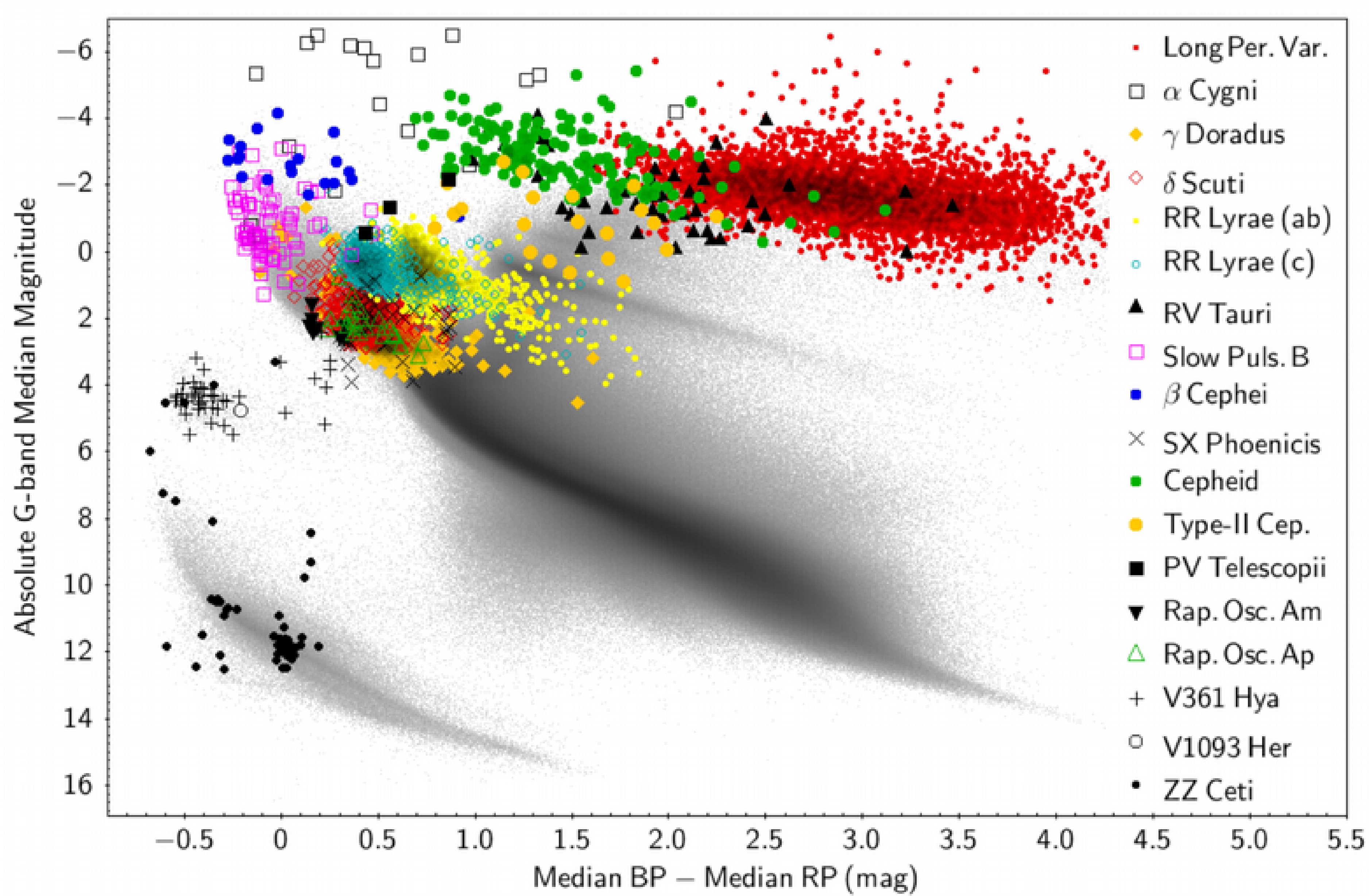
DQ branch by cooling and core crystallization

→ huge diamonds in space ...

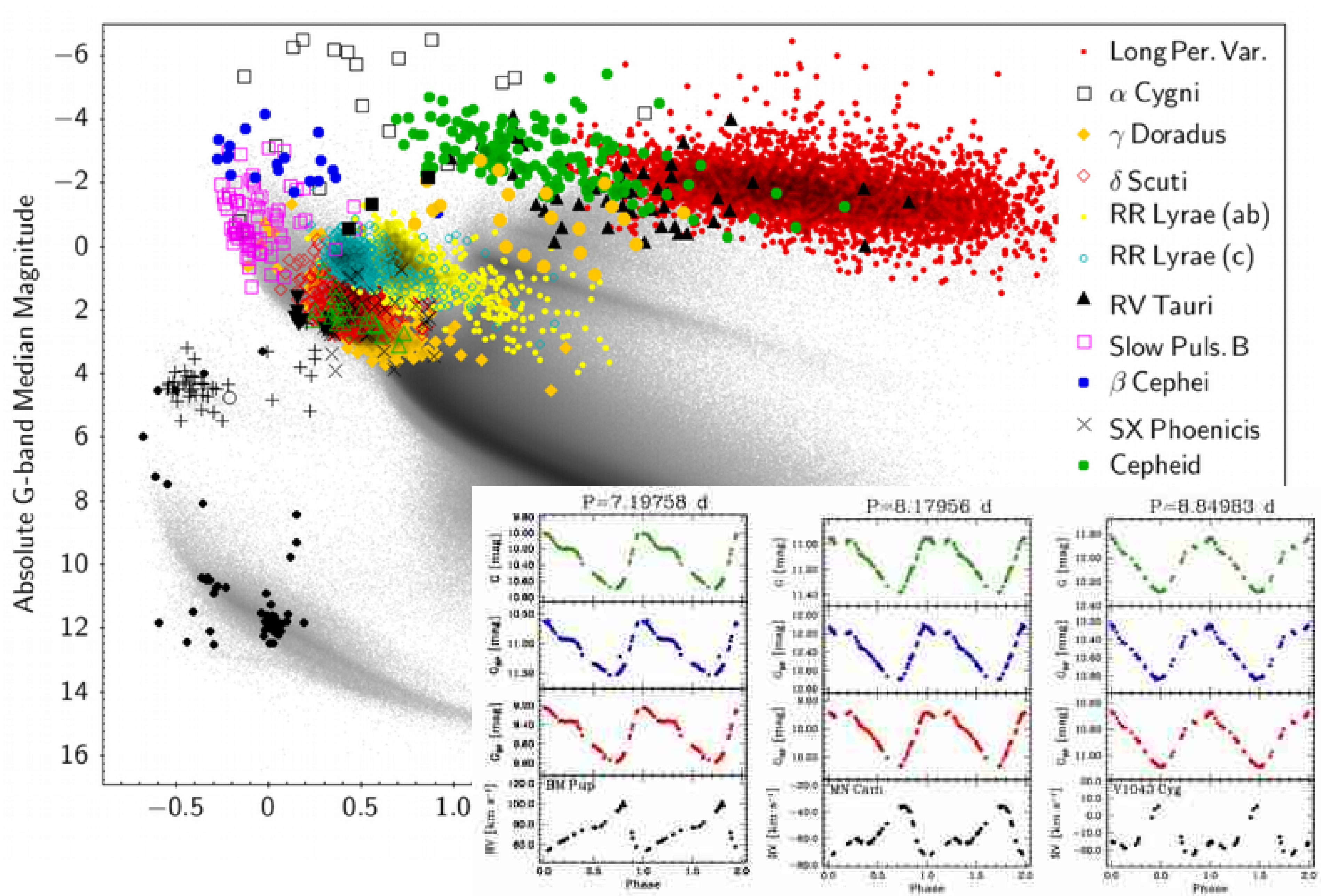
Gaia Hertzsprung-Russell diagram



Types of pulsating stars in H-R diagram

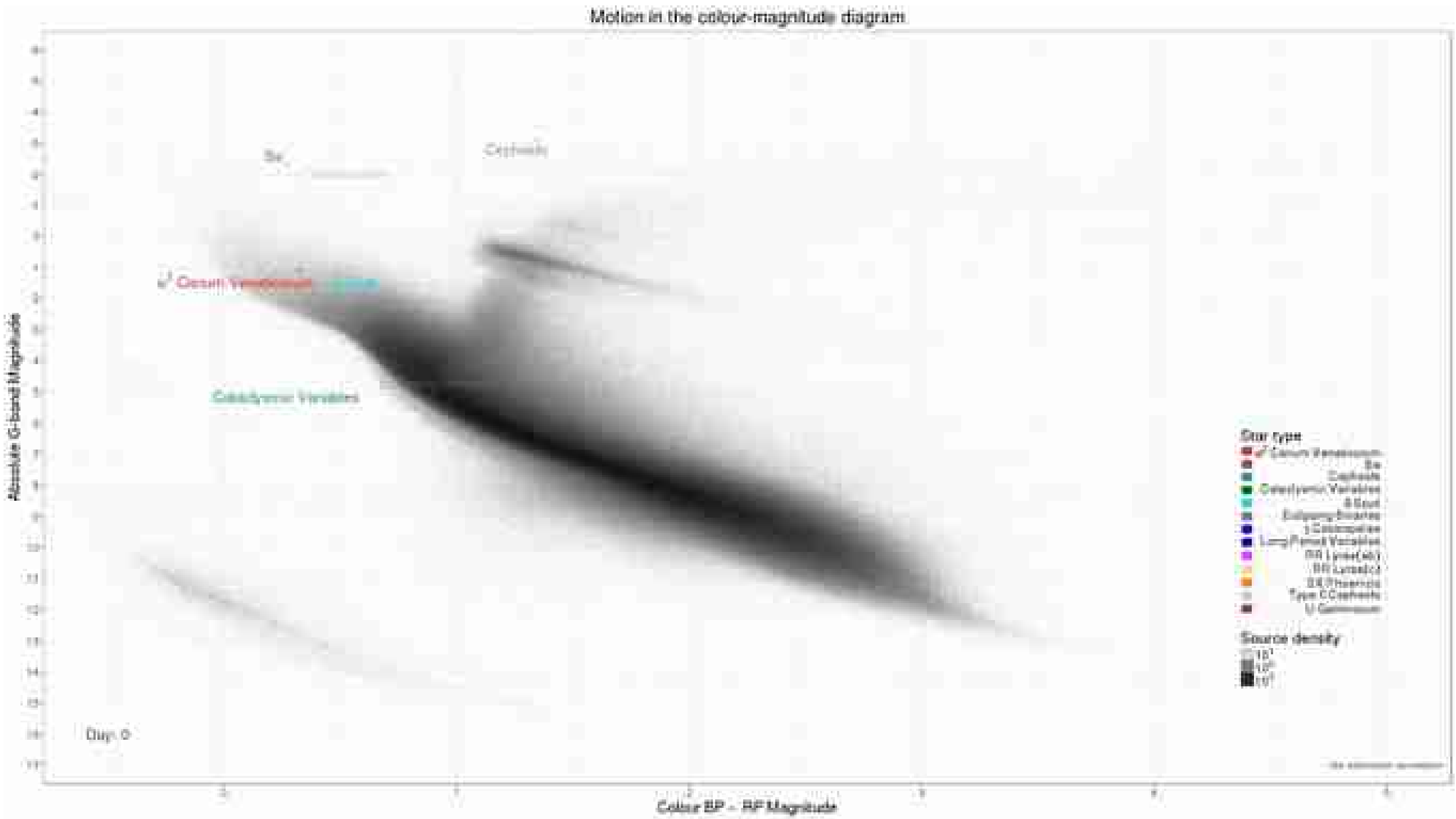


Types of pulsating stars in H-R diagram



Variable stars in the H-R diagram

brighter



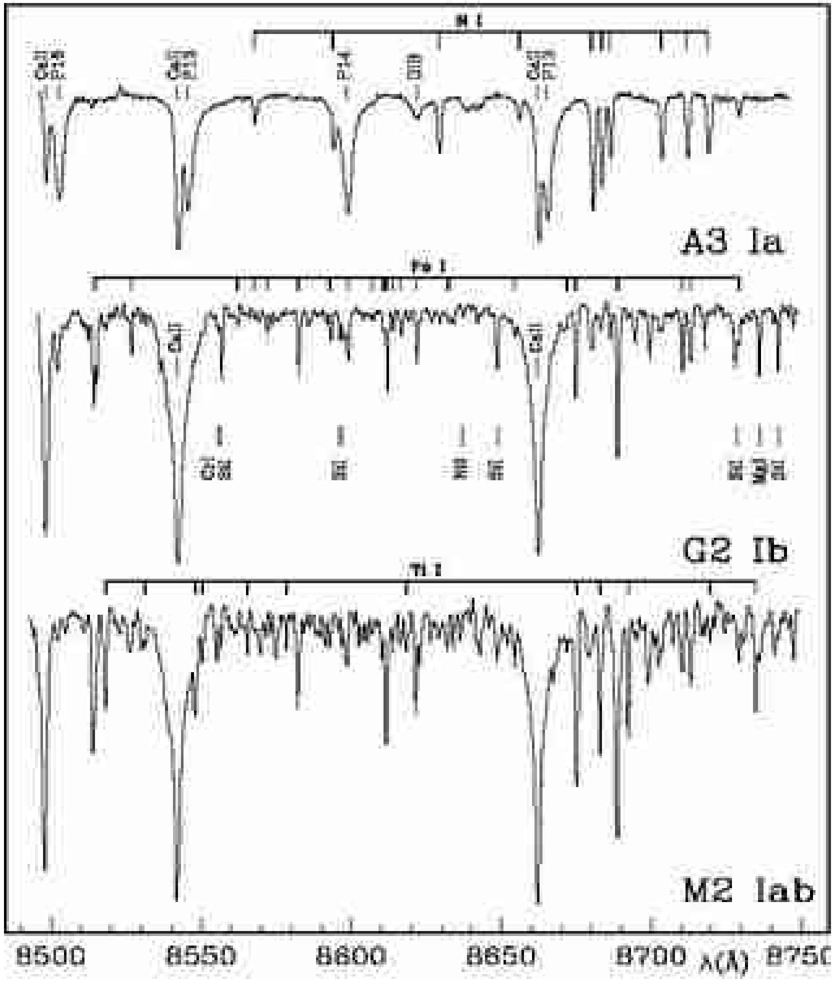
dimmer

warmer

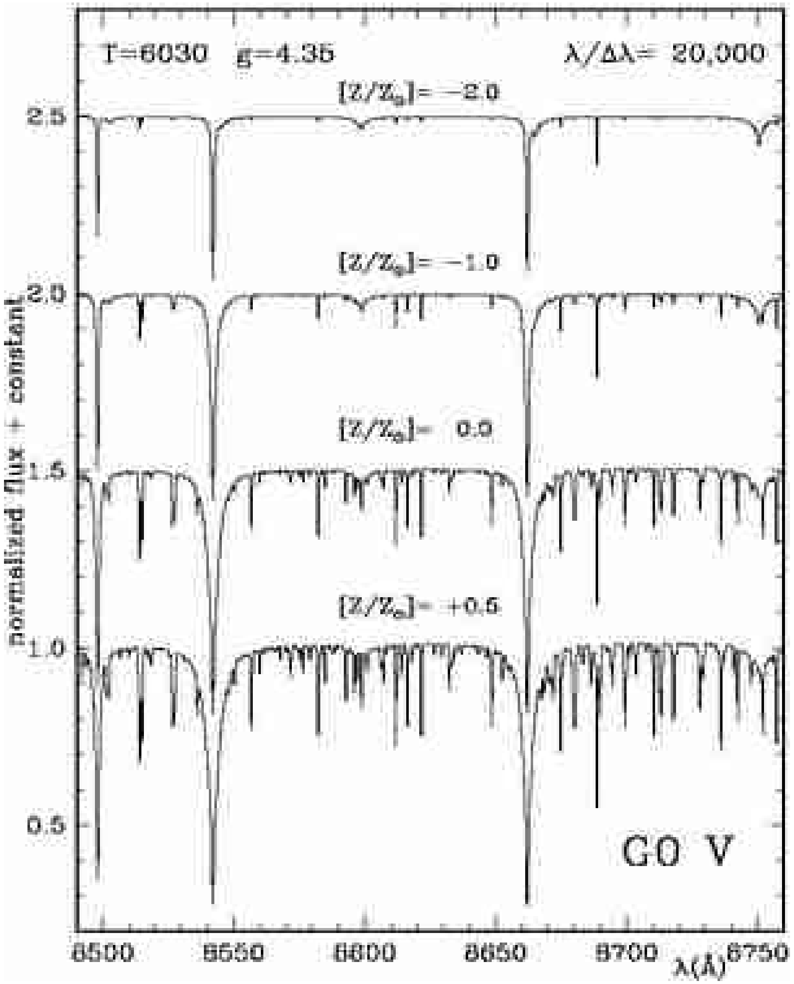
cooler

- Many different types of variable stars in the H-R diagram.
- Cyclic changes in photometric G magnitude and colors (Bp – Rp).
- Cepheids are important for reliable distance measurements.

Spectral series of stars around the Ca II triplet

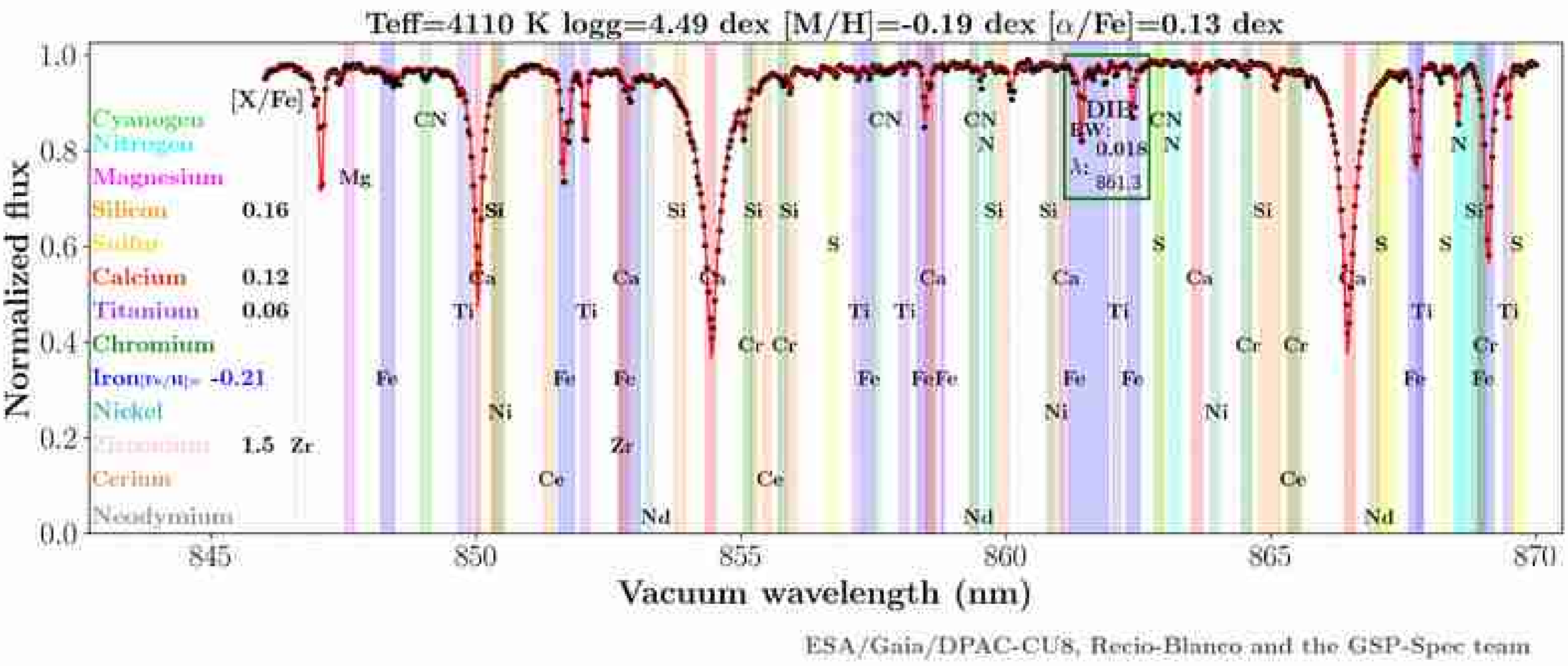


Effects of temperature: A to M types



Effects of metal content in G-type stars

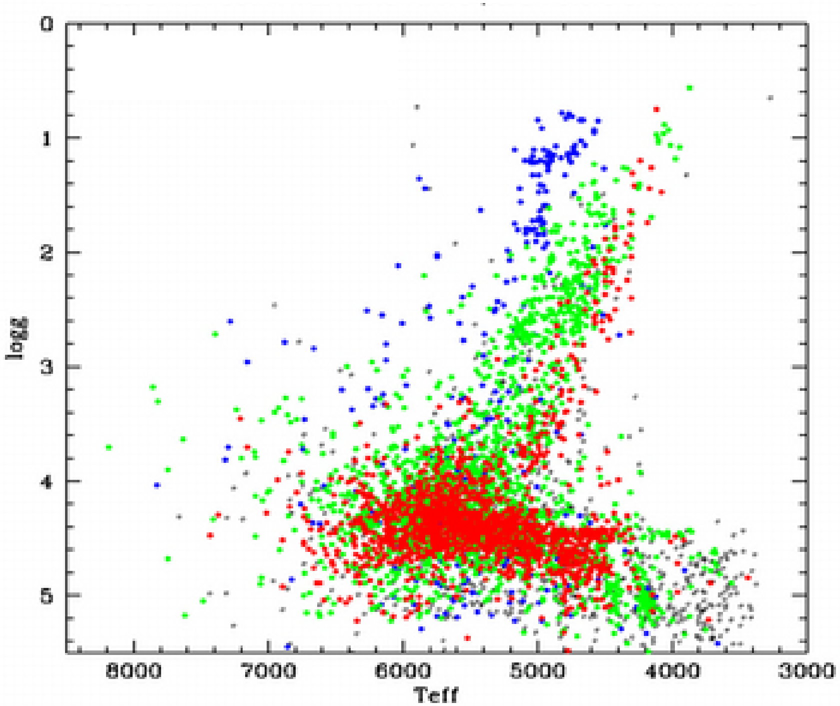
Spectral series of stars around the Ca II triplet



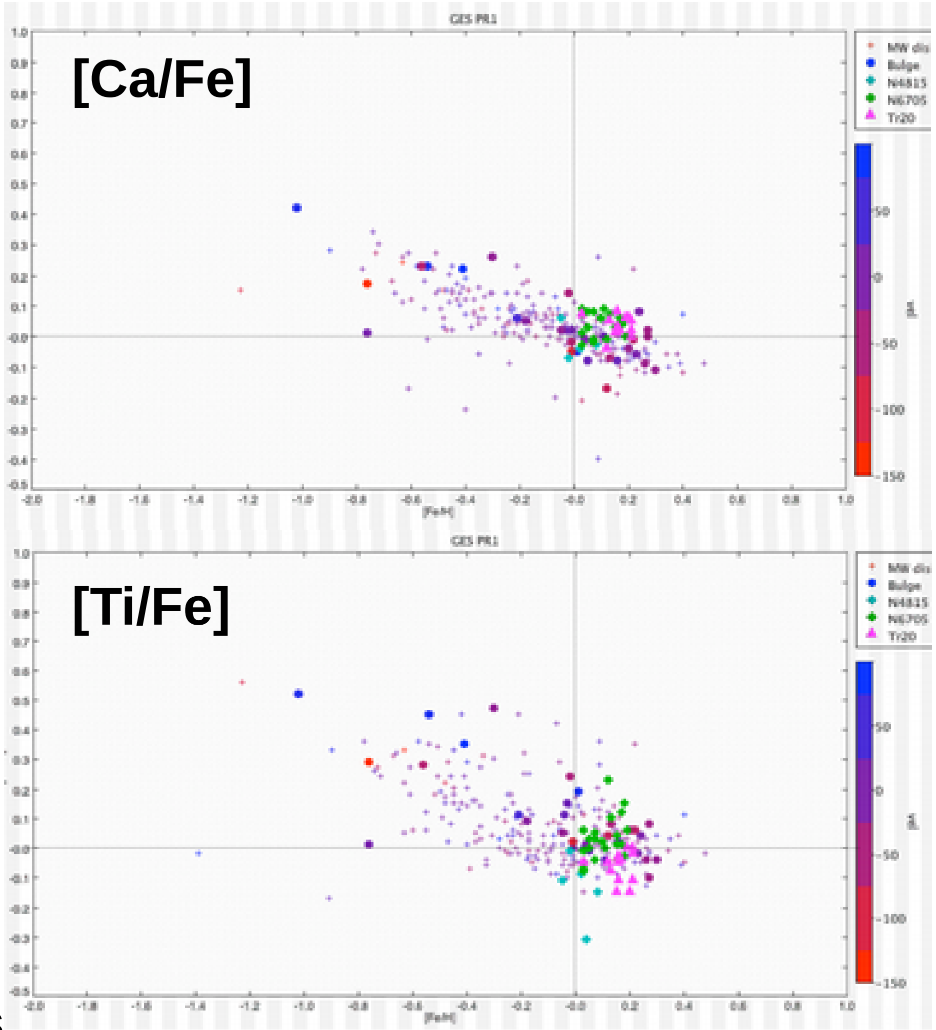
Different spectral line strenghts are observed due to different metal content [Fe/H] and α-elements in stellar atmospheres

Astrophysical parameters & chemical abundances

Color scale according metal content

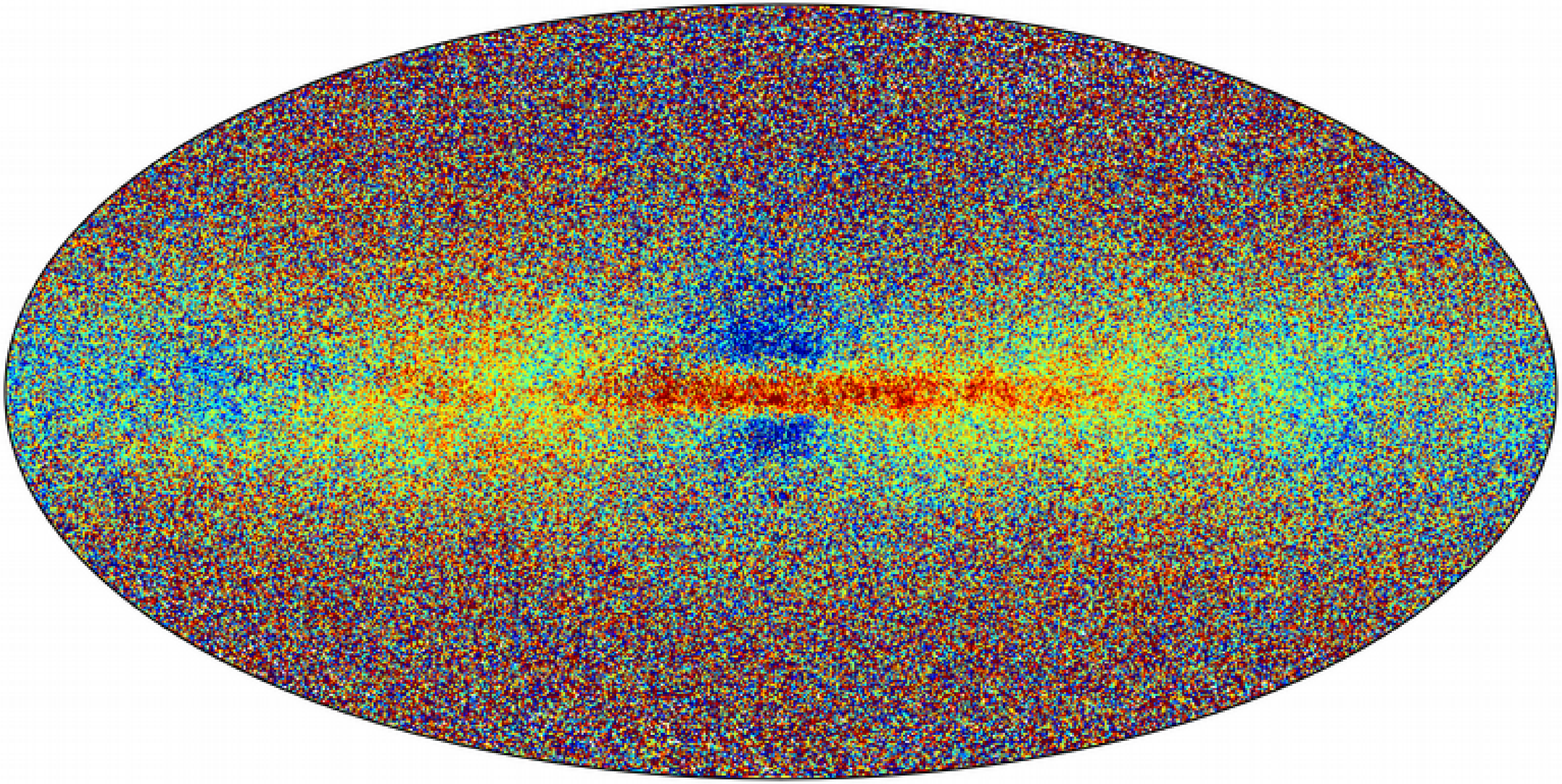


Teff vs. Log*g* ⇒ evolutionary status



[Fe/H] vs. [α/Fe] ⇒ stellar ages

Chemical abundances and stellar ages



- **Younger stars with larger metal content in the thin Milky Way disk (yellow & red).**
- **Older stars with lower metal content in the thick Milky Way disk and halo (blue).**


RVS = Radial Velocity Spectrograph
Here we are using the metal abundances derived
from the RVS to colour the stars.

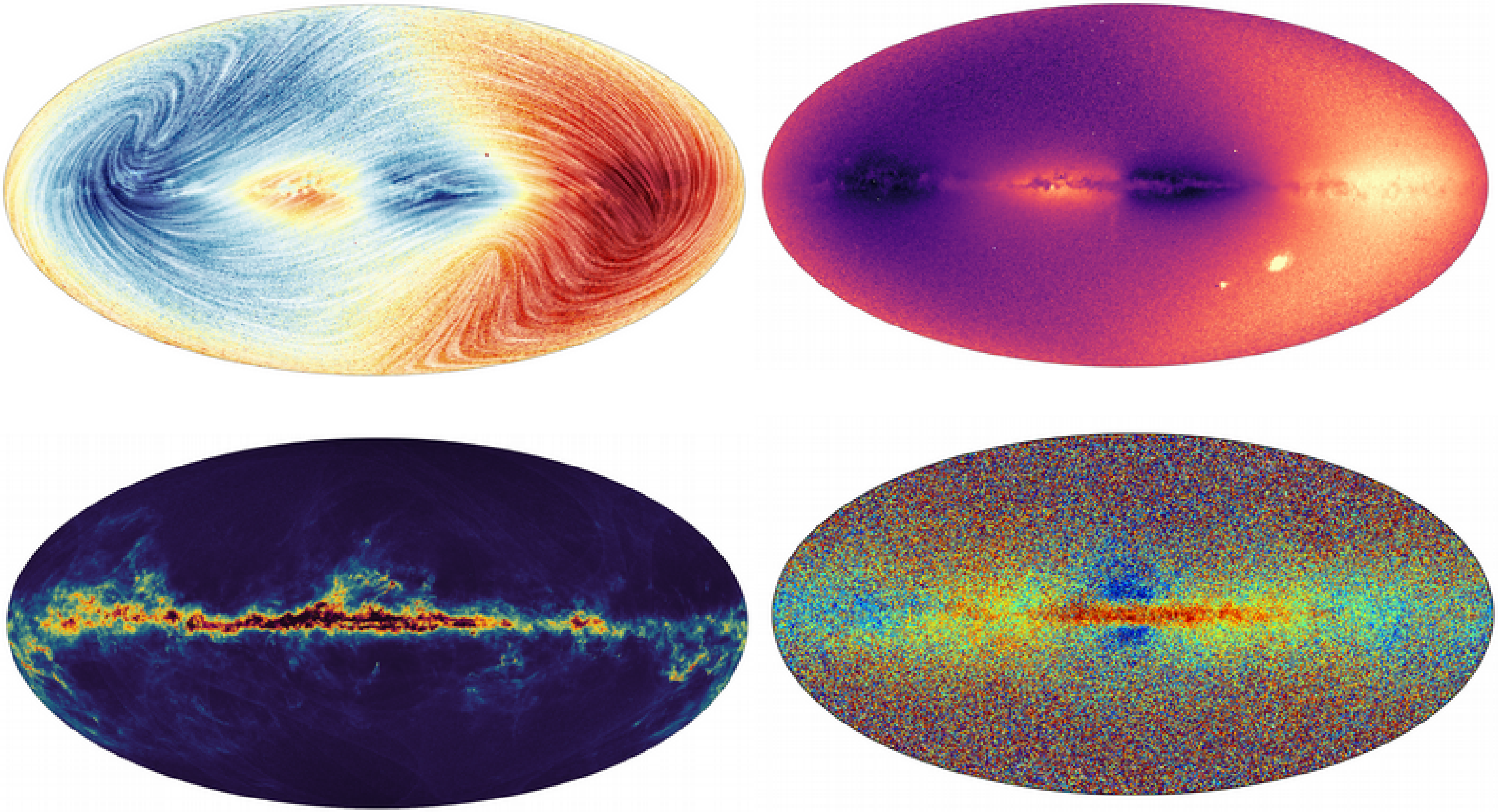
Summary

- Gaia is causing a revolution in many research fields of astronomy and astrophysics.

- Preparations for the Fourth Gaia Data Release in 2026 are in full swing. DR4 release will cover 66 months of observations.

- Degradation of accuracy in star positions over the next few decades will require new astrometric missions: GaiaNIR?

All eyes on Gaia Data Release 4



All eyes on Gaia Data Release 4

** Space still contains infinite unknowns*

Thank you for the invitation