Gaia Data Release 3

Rocio Guerra (Gaia SOC)

Gaia

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Gaia space telescope rocks the science of asteroids

A 'tsunami' for astrophysics: New Gaia data reveals the best map of our galaxy yet

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NEWS · 25 APRIL 2018

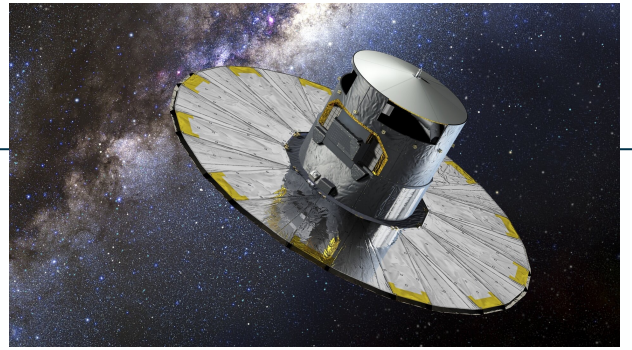
Billion-star map of Milky Way set to transform astronomy

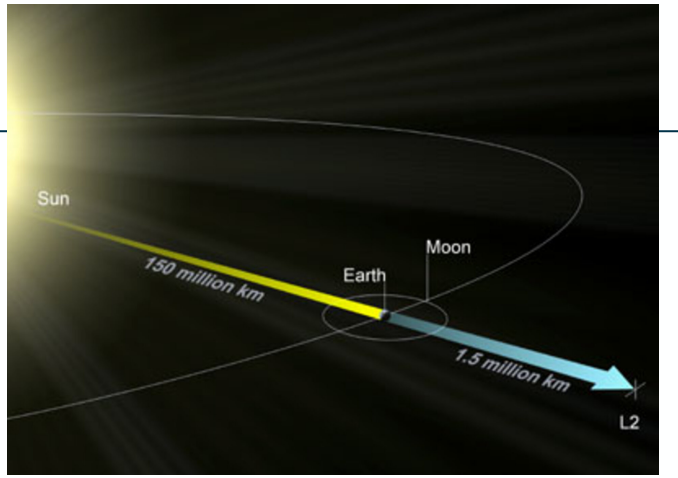
European Gaia spacecraft's first major data dump — the most detailed 3D chart yet of our Galaxy — will keep researchers busy for decades.

ESA's Gaia Mission Sheds New Light on Past and Future of Our Sun

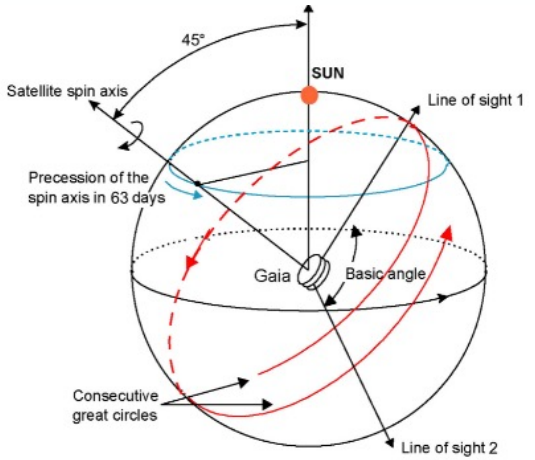
La misión Gaia revoluciona el conocimiento de la Vía Láctea

Gaia

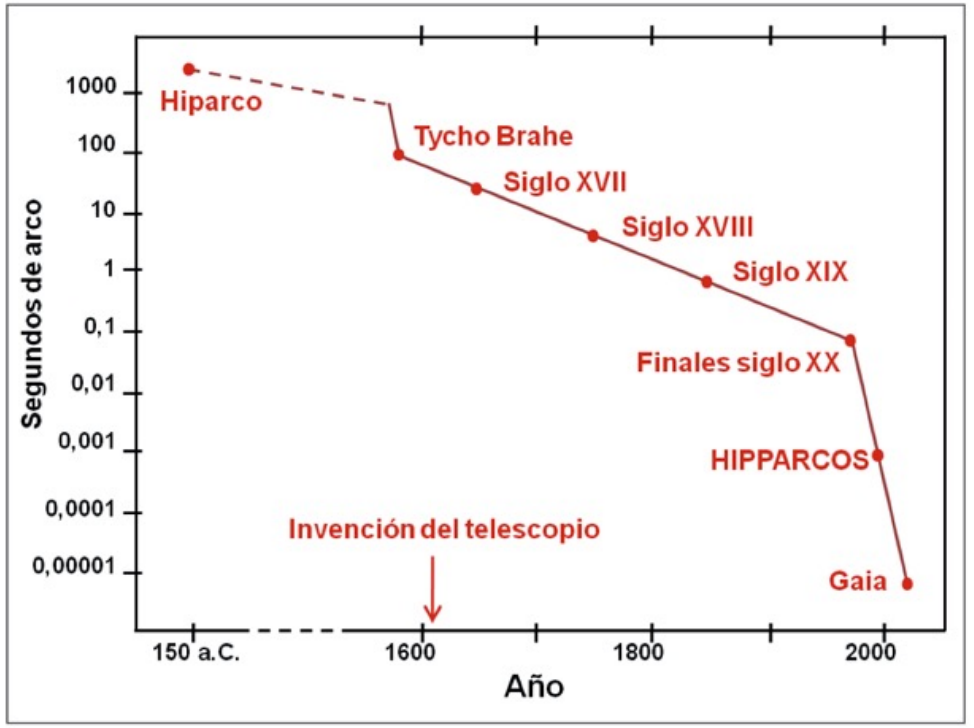


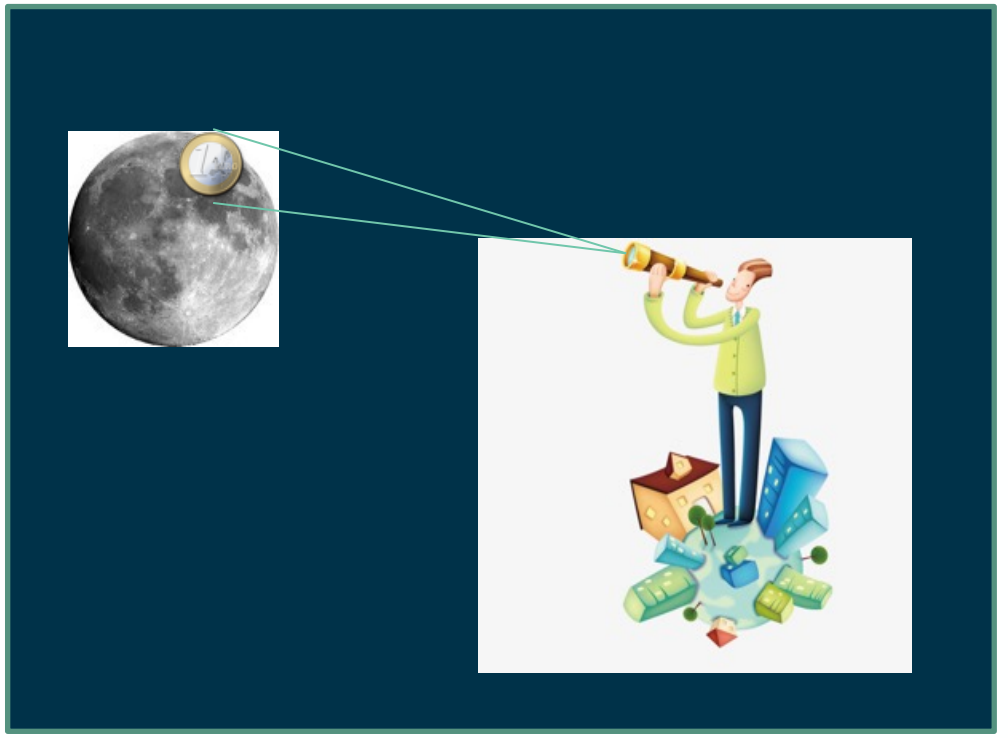


- **Gaia is an astrometric mission**
  - Astrometry is the science of charting the sky
- **Goal: make the largest, most precise multi-dimensional map of the Milky Way by surveying an unprecedented 1% of the galaxy's population of 1.8 billion of stars**
- **Gaia Facts**
  - Fully European mission designed, built and operated by ESA
  - Launched on 19 December 2013 from Kourou (French Guyana)
  - Lissajous Orbit in L2 (thermal stability)
  - Gaia is a survey mission; It scans the sky revisiting the stars periodically
  - Data Processing entitled to the Data Processing Analysis Consortium (DPAC)
  - 5 years of nominal mission -> currently in extended phase



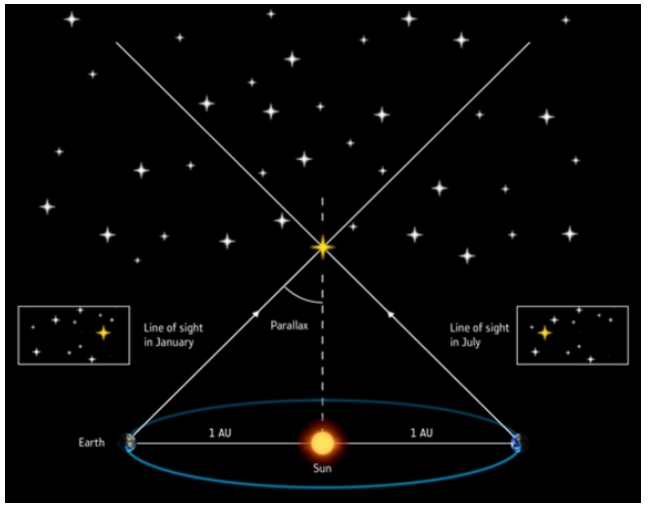
Unprecedented Accuracy: Microarcseconds!

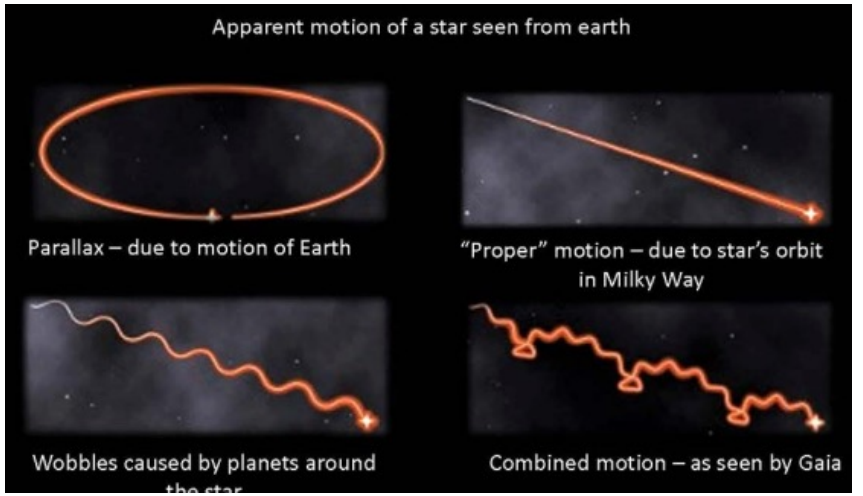




- It is the angle of a euro coin on the surface of the moon seen from the Earth
- Or the width of a hair seen from 500km
- Or a 100m building in Uranus seen from the Earth

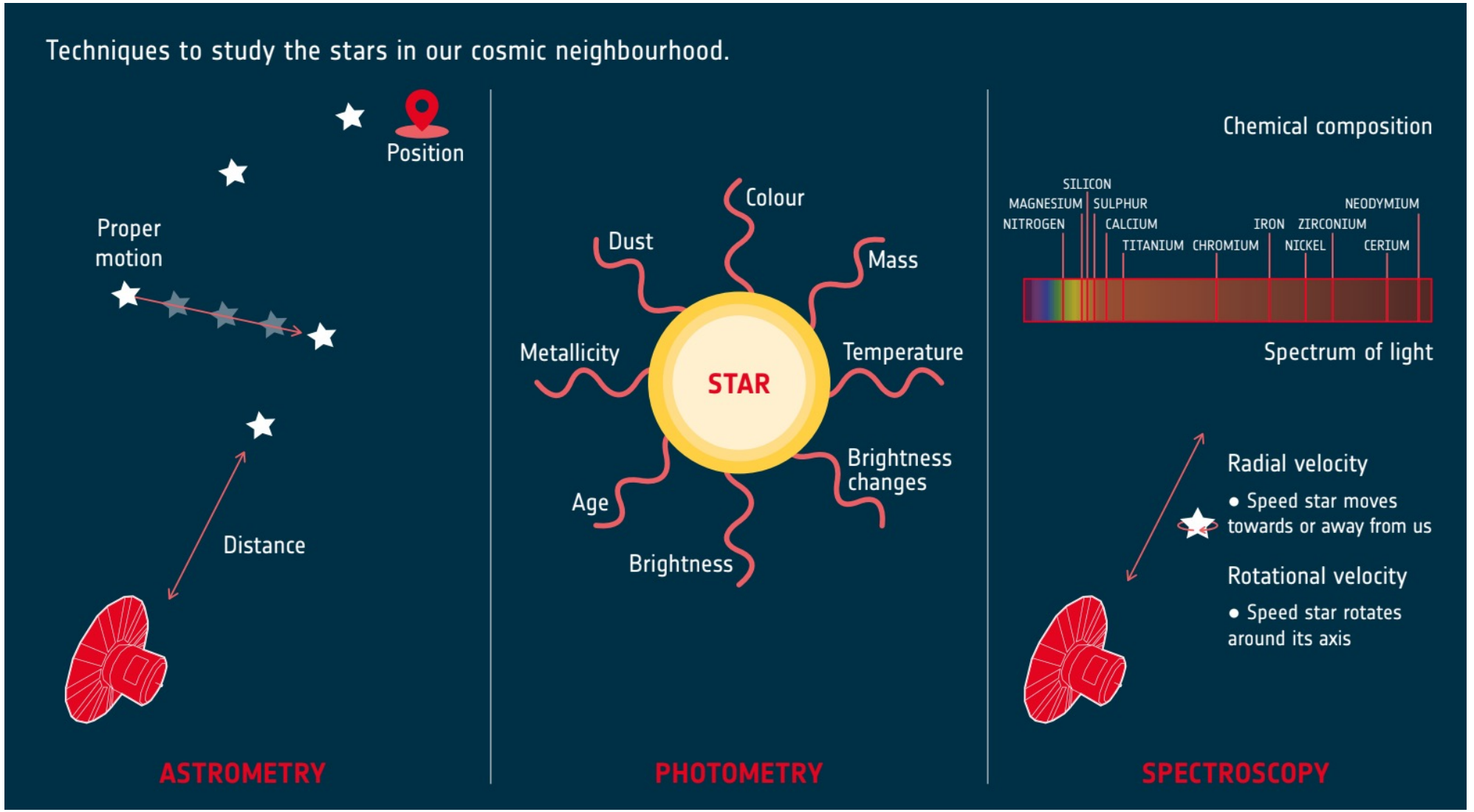
Multi-dimensional Map





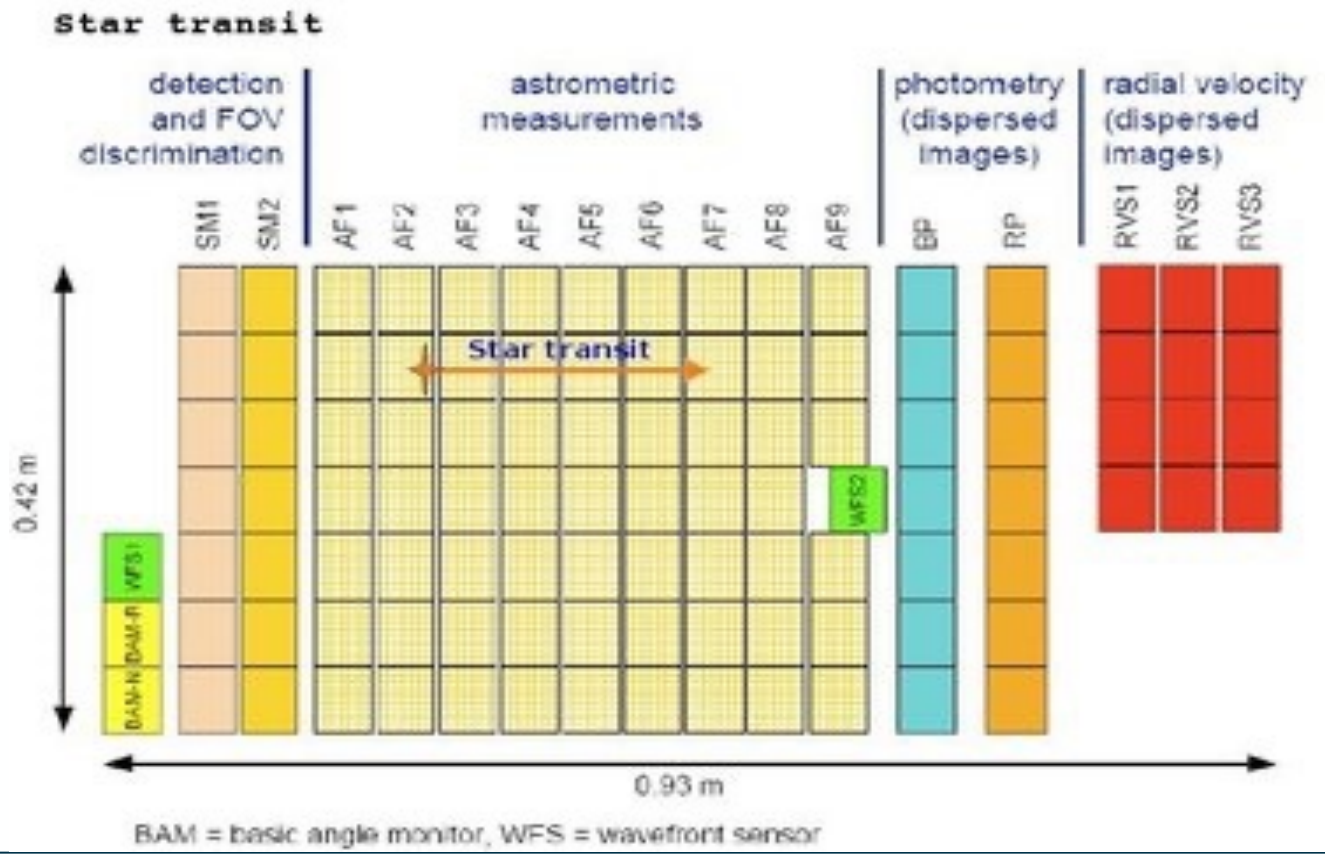
- The parallax is an apparent movement of a foreground object with respect to its background owing to a change in the observer's position
- Using multiple repeated observations of 1.8 billion of stars, Gaia determines 5 parameters:
  - Star position projected on the sky
  - Proper motion (projected movement on the sky of the real start movement)
  - Parallax
- But not only that…

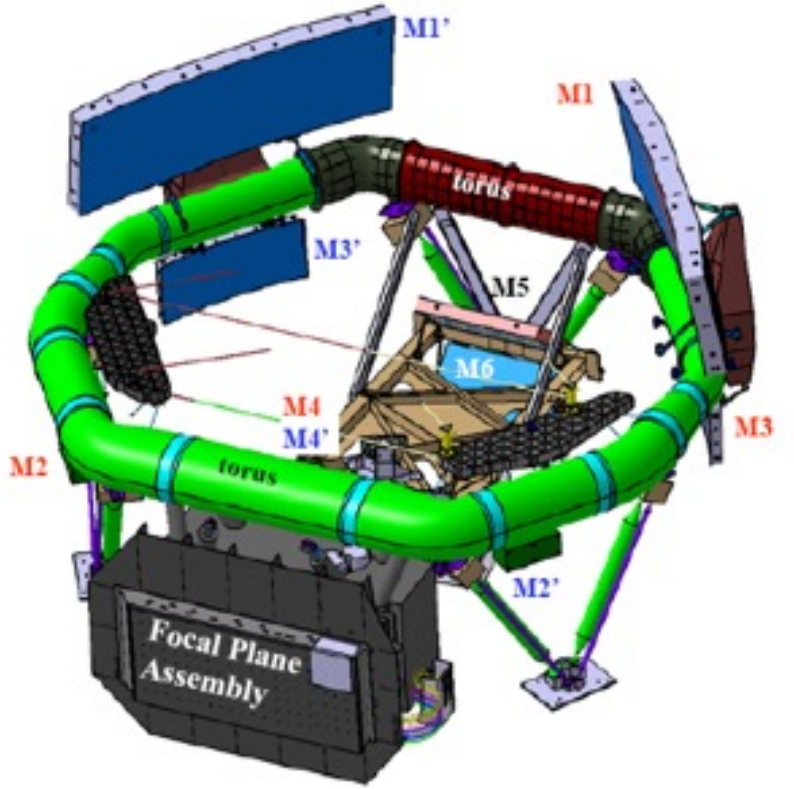
Gaia's Observing Techniques



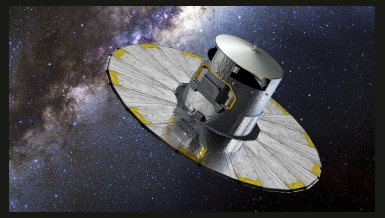
Gaia Focal Plane

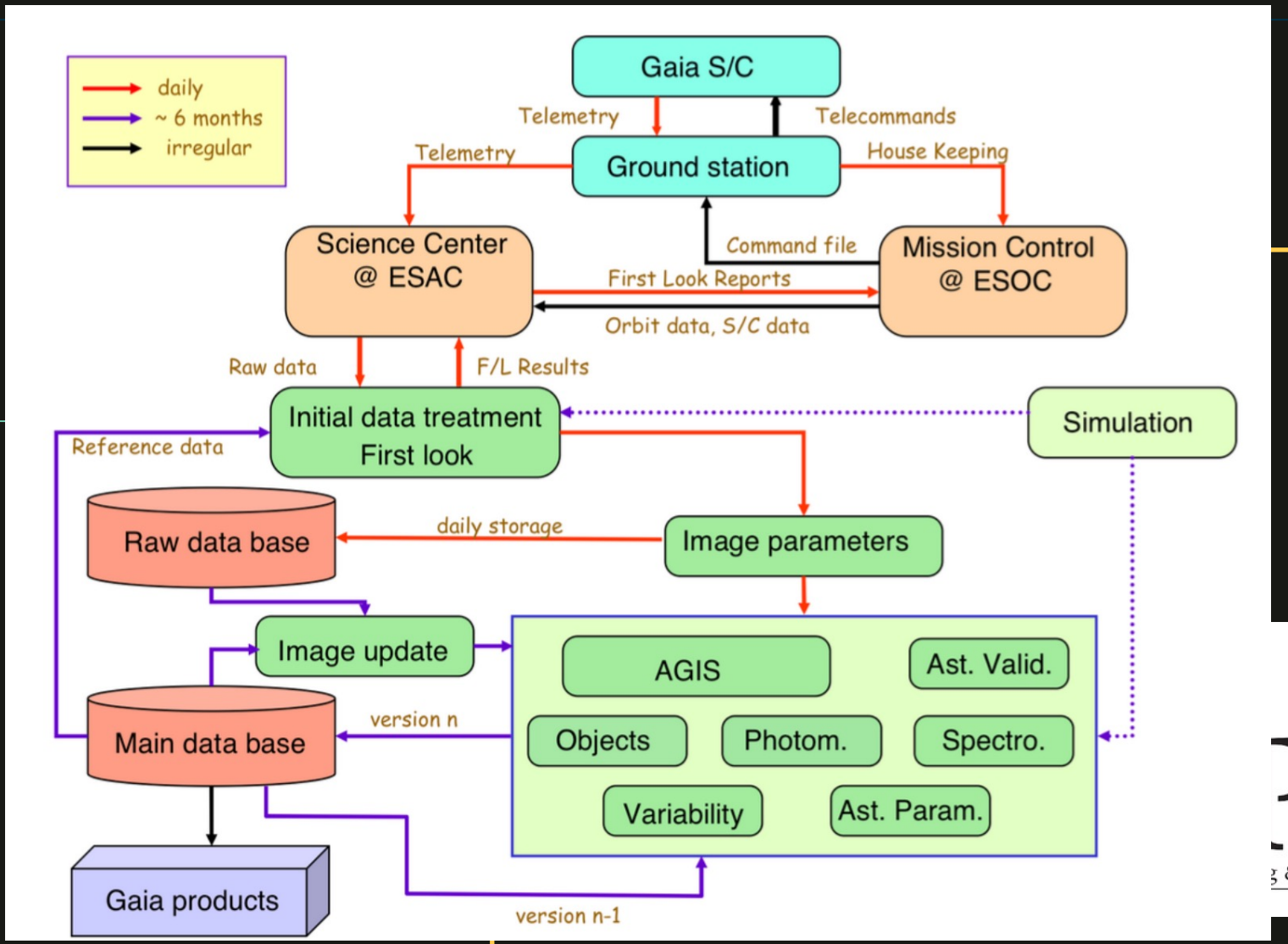
106 CCDs – 1B pixel camera
2 - Basic Angle Monitoring (106.5deg)
1 - Wavefront Sensor to measure the wave front sensor errors of the two telescopes
2 strips - Sky Mappers: detection of sources
9 strips AF, 2 Photometers (red and blue), 2 RVS





Data Processing

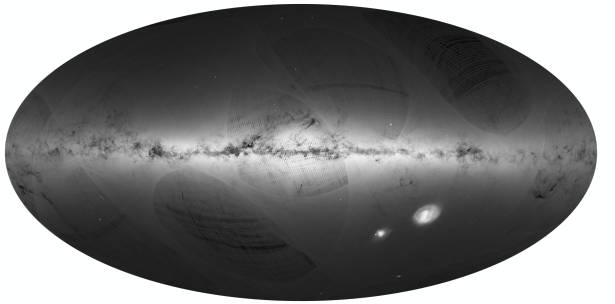




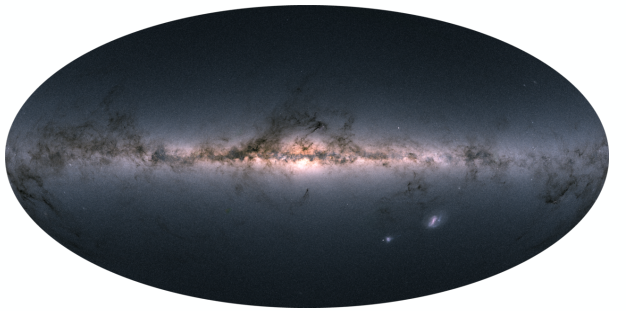
Gaia
PAC
& Analysis Consortium

Gaia Data Releases

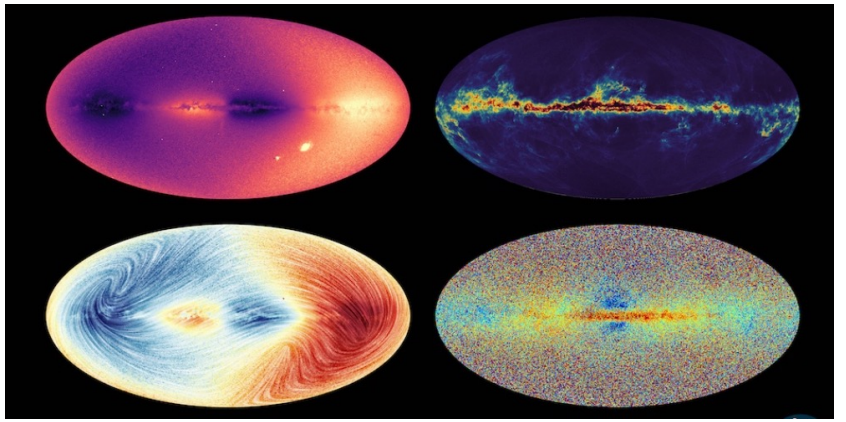
- **First Release (DR1): 14 September 2016**
  - Based on observations collected between 25-Jul-2014 and 16-Sep-2015 (14mo)



- **Second Release (DR2): 25 April 2018**
  - Based on observations collected between 25-Jul-2014 and 23-May-2016 (22mo)



- **Third Release (DR3): EDR3 and DR3**
  - Based on observations collected between 25-Jul-2014 and 28-May-2017 (34mo)
  - Gaia EDR3: 3 December 2020
  - **Gaia DR3: 13 June 2022**



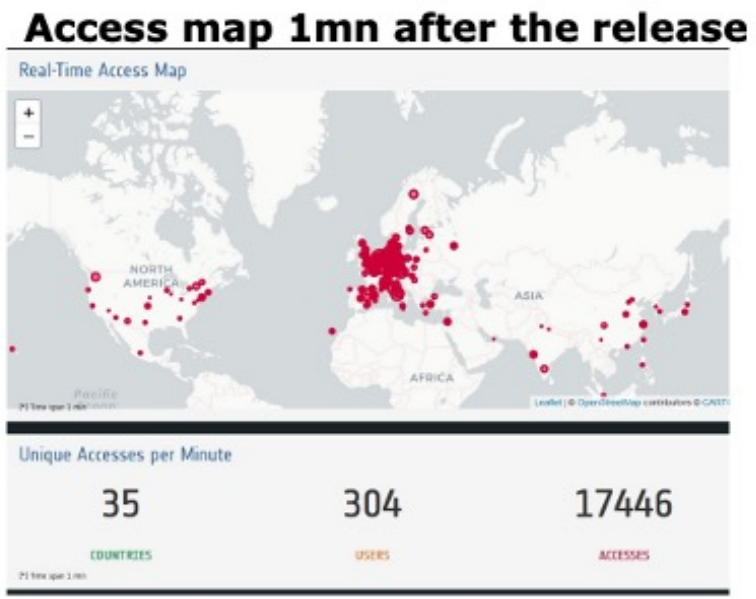
Gaia DR3 Content

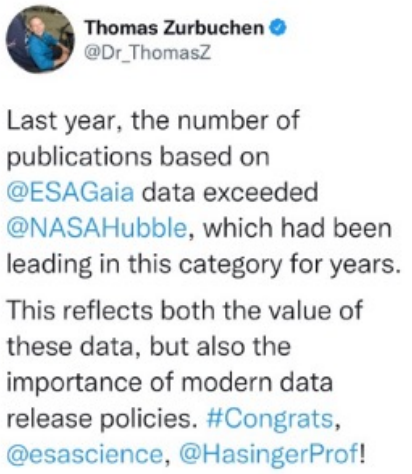
	# sources in Gaia DR3	# sources in Gaia DR2	# sources in Gaia DR1
Total number of sources	**1,811,709,771**	**1,692,919,135**	**1,142,679,769**
	Gaia Early Data Release 3		
Number of sources with full astrometry	1,467,744,818	1,331,909,727	2,057,050
Number of 5-parameter sources	585,416,709		
Number of 6-parameter sources	882,328,109		
Number of 2-parameter sources	343,964,953	361,009,408	1,140,622,719
Gaia-CRF sources	1,614,173	556,869	2191
Sources with mean G magnitude	1,806,254,432	1,692,919,135	1,142,679,769
Sources with mean G_{BP}-band photometry	1,542,033,472	1,381,964,755	-
Sources with mean G_{RP}-band photometry	1,554,997,939	1,383,551,713	-
	New in Gaia Data Release 3	Gaia DR2	Gaia DR1
Sources with radial velocities	33,812,183	7,224,631	-
Sources with mean G_{RVS}-band magnitudes	32,232,187	-	-
Sources with rotational velocities	3,524,677	-	-
Mean BP/RP spectra	219,197,643	-	-
Mean RVS spectra	999,645	-	-
Variable-source analysis	10,509,536	550,737	3,194
Variability types (supervised machine learning)	24	6	2
Supervised machine-learning classification for variables	9,976,881	390,449	3,194
Specific Object Studies – Cepheids	15,021	9,575	599
Specific Object Studies – Compact companions	6,306	-	-
Specific Object Studies – Eclipsing binaries	2,184,477	-	-
Specific Object Studies – Long-period variables	1,720,588	89,617	-
Specific Object Studies – Microlensing events	363	-	-
Specific Object Studies – Planetary transits	214	-	-
Specific Object Studies – RR Lyrae stars	271,779	140,784	2,595
Specific Object Studies – Short-timescale variables	471,679	3,018	-
Specific Object Studies – Solar-like rotational modulation variables	474,026	147,535	-
Specific Object Studies – Upper-main-sequence oscillators	54,476	-	-
Specific Object Studies – Active galactic nuclei	872,228	-	-
Photometrically-variable sources with radial-velocity time series	1,898	-	-
Sources with object classifications	1,590,760,469	-	-
Stars with emission-line classifications	57,511	-	-
Sources with astrophysical parameters from BP/RP spectra	470,759,263	161,497,595	-

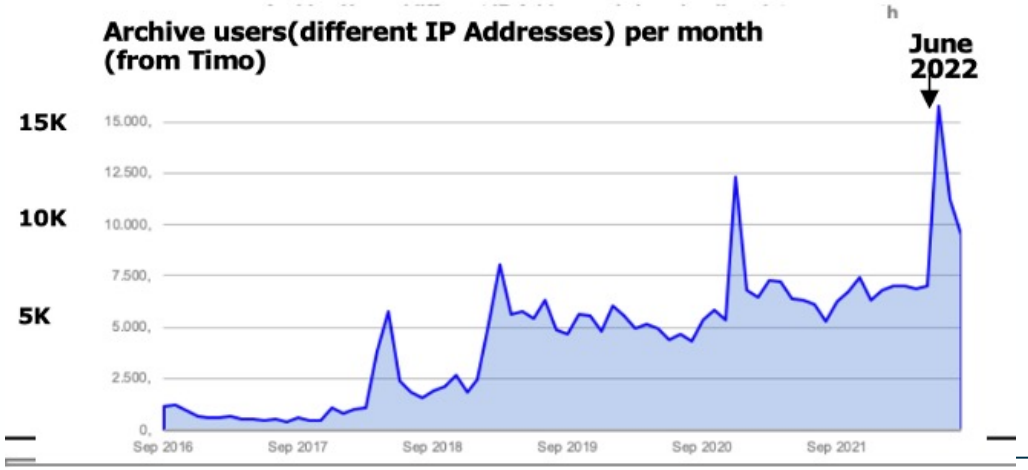
Gaia DR3 Content (II)

Sources with astrophysical parameters assuming an unresolved binary	348,711,151	-	-
Sources with spectral types	217,982,837	-	-
Sources with evolutionary parameters (mass and age)	128,611,111	-	-
Hot stars with spectroscopic parameters	2,382,015	-	-
Ultra-cool stars	94,158	-	-
Cool stars with activity index	1,349,499	-	-
Sources with H-alpha emission measurements	235,384,119	-	-
Sources with astrophysical parameters from RVS spectra	5,591,594	-	-
Sources with chemical abundances from RVS spectra (up to 13 species)	2,513,593	-	-
Sources with a diffuse interstellar band (DIB) in their RVS spectrum	472,584	-	-
Non-single stars (astrometric, spectroscopic, eclipsing, orbits, trends)	813,687	-	-
Non-single stars - orbital astrometric solutions	169,227	-	-
Non-single stars - orbital spectroscopic solutions (SB1 / SB2)	186,905	-	-
Non-single stars - eclipsing binaries	87,073	-	-
QSO candidates	6,649,162	-	-
QSO candidates - redshifts	6,375,063	-	-
QSO candidates - host galaxy detected	64,498	-	-
QSO candidates - host galaxy surface brightness profiles	15,867	-	-
Galaxy candidates	4,842,342	-	-
Galaxy candidates - redshifts	1,367,153	-	-
Galaxy candidates - surface brightness profiles	914,837	-	-
Solar system objects	158,152	14,099	-
Solar system objects - epoch astrometry (CCD transits)	23,336,467	-	-
Solar system objects - orbits	154,787	-	-
Solar system objects - average BP/RP reflectance spectra	60,518	-	-
Solar system objects - planetary satellites	31	-	-
All-sky total galactic extinction maps at different spatial resolutions	HEALPix levels 6, 7, 8, and 9	-	-
Gaia Andromeda Photometric Survey (GAPS) with lightcurves for all objects	1,257,319	-	-

DR3 published and very successful!!

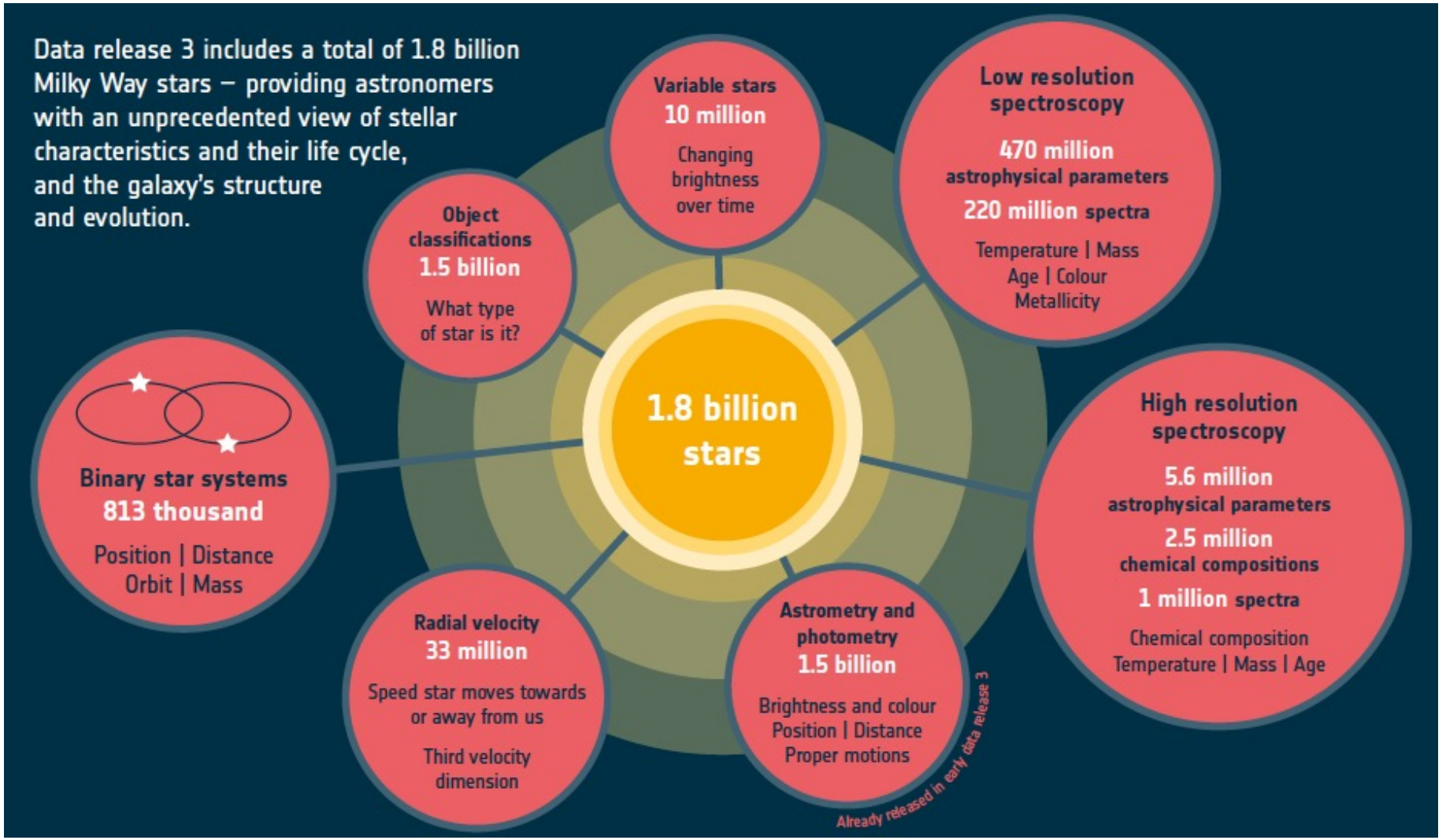






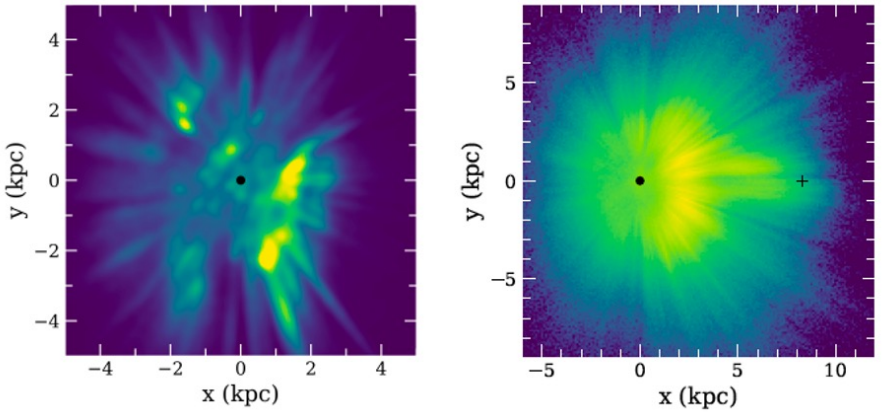
> 100 papers released based in DR3 data

DR3 Milky Way Stars

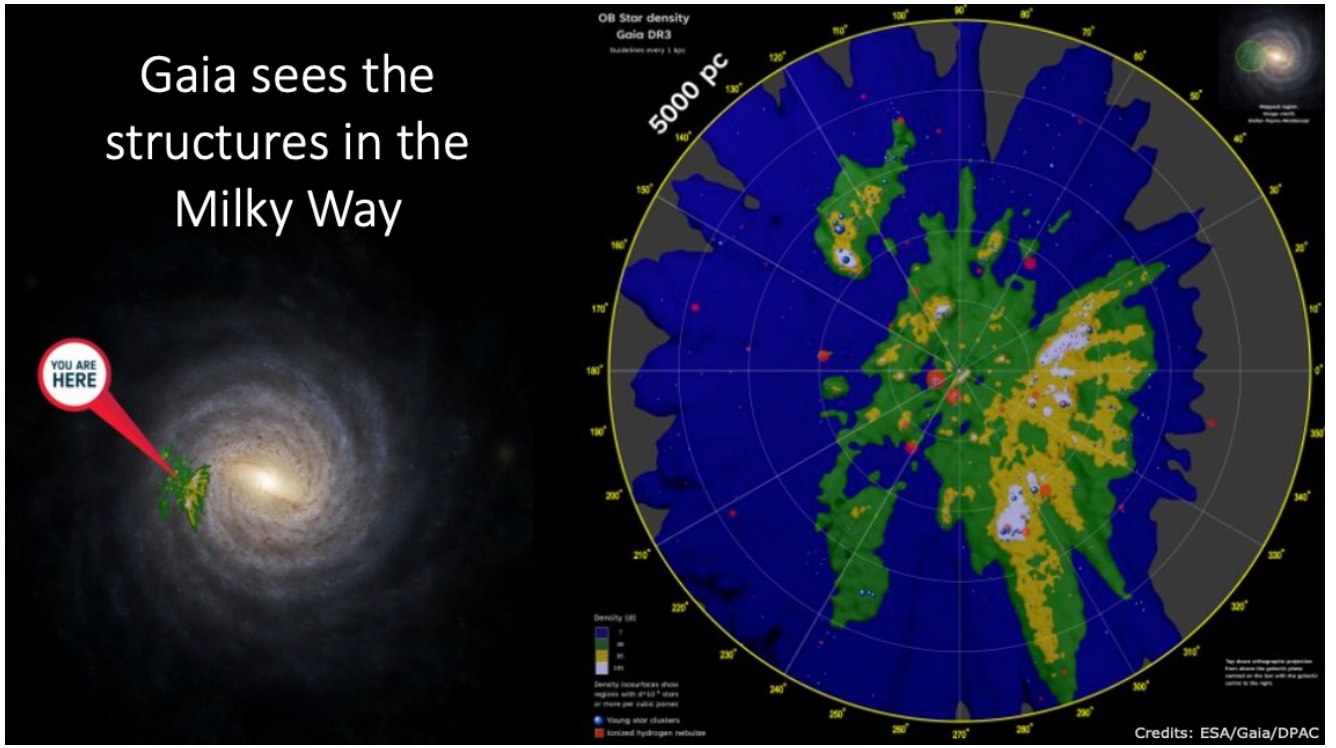


Milky Way structure

- Detailed structures in the Sun's vicinity, signatures of the spiral arms
- Astrophysical parameters allow to differentiate between stars: young stars (OB type and older stars).
  - Older stars are more dispersed than young stars (that follow the star formation of the arms)
  - Density of the stars provide insight of the structure of our Galaxy

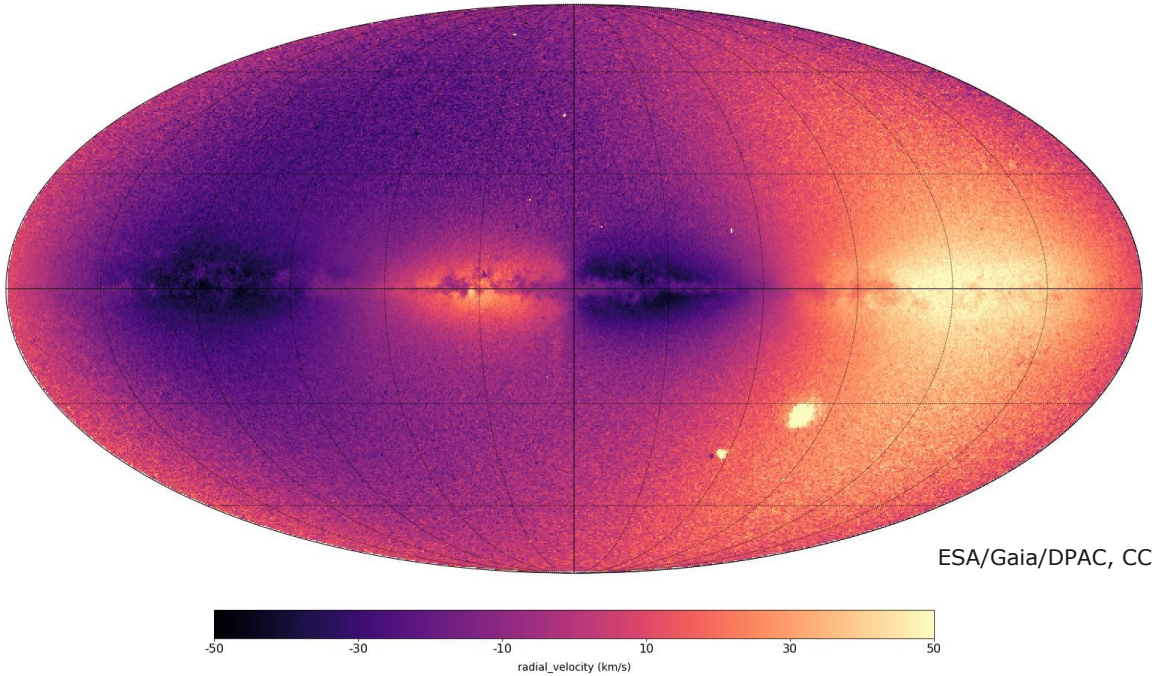


Drimmel et al 2022 , CC BY-SA 3.0 IGO.



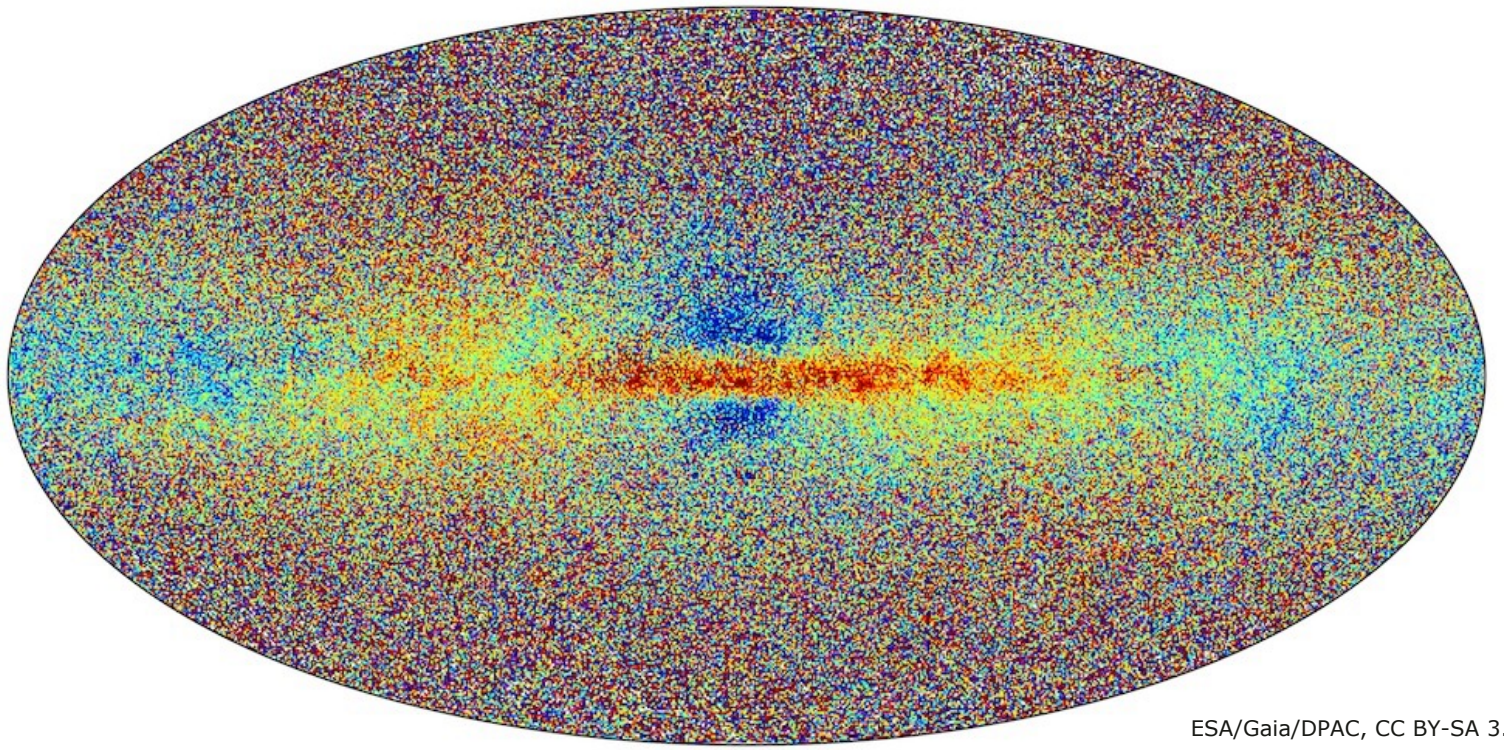
Radial Velocity

- DR3 shows the rate at which more than 30millions of stars of the Milky Way are approaching or moving away from us.
- This is called “radial velocity” and provides the 3rd dimension of velocity on the Gaia map (in addition to the proper motion). It is based on the Doppler effect (shift of a star’s spectral line with respect to wavelengths at rest)
- The rotation of the Galactic disk – together with the Sun’s own motion –causes an alternating positive-negative variation in the LoS velocities



Stellar Metallicity

- Gaia provides elemental information on stars in the form of metallicity estimates and stellar abundances
- They give information of the origin of the stars and trajectories
- Redder stars are richer in metals. In the Galactic plane, the higher values of the thin disc are visible. In the central Galactic regions, a more metal-poor mix of bulge and thick disk populations is present (blue).

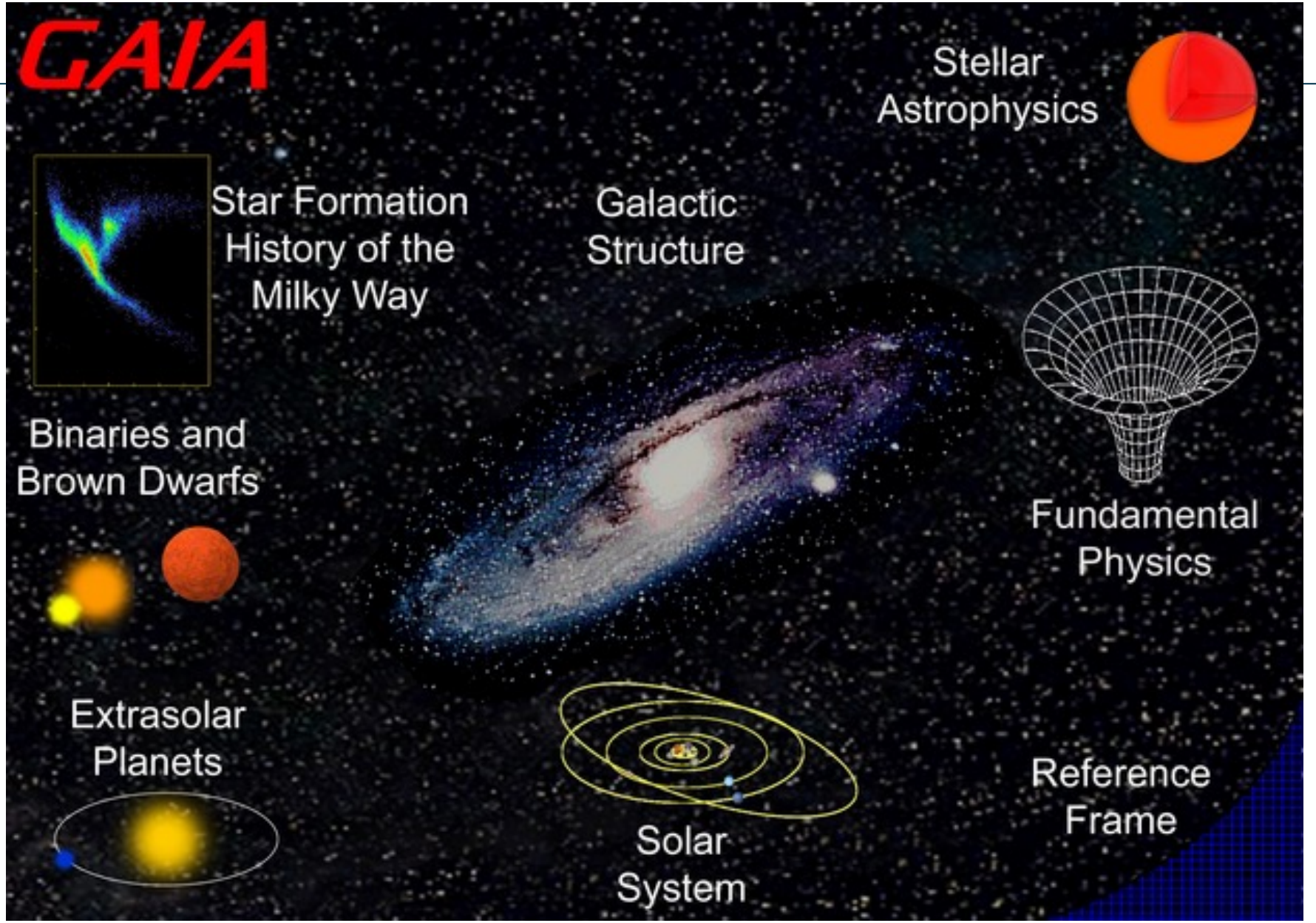


Gaia - Enceladus

- Gaia helps astronomers to understand the origins and evolution of the Milky Way

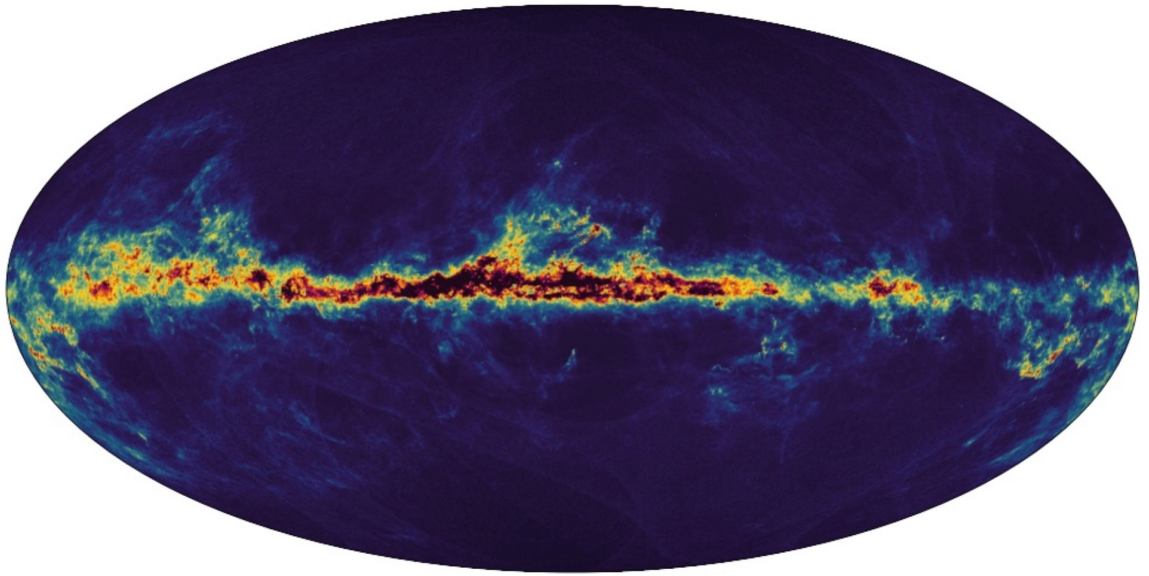
- Helmi et al. (2018) The merger that led to the formation of the Milky Way's inner stellar halo and thick disk
- Abstract: "The assembly of our Galaxy can be reconstructed using the motions and chemistry of individual stars…"
- They found out that among 7M stars sample (stars with radial velocities in DR2), ~30000 were part of an 'odd collection' moving through the Milky Way with different chemical composition
- Gaia-Enceladus: 10 billion years ago, a merge with another large galaxy plausibly created the stellar halo and thick disk

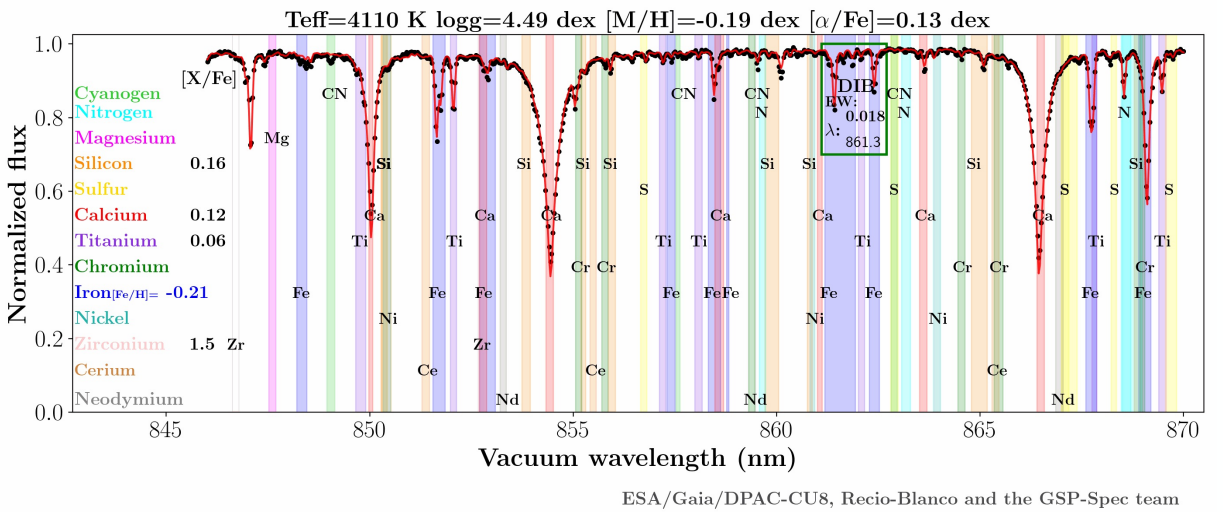
Helmi et al (2018)


GAIA
Stellar Astrophysics
Star Formation History of the Milky Way
Galactic Structure
Binaries and Brown Dwarfs
Fundamental Physics
Extrasolar Planets
Solar System
Reference Frame

Interestellar Medium

- The space between the stars is not empty but mostly filled with dust and gas: star forming regions
- Light is scattered at different wavelengths, this allow to reconstruct the amount of extinction
- A sky dust map is created from the Gaia data based on 470 million stars
- Gaia allows the measure of the chemical imprints of the dispersed light of stars, like the Diffuse Interstellar Bands (absorption features attributed to organic molecules)
- Also, what molecules are present in the dust? What are the characteristics of the macromolecules in the gas?



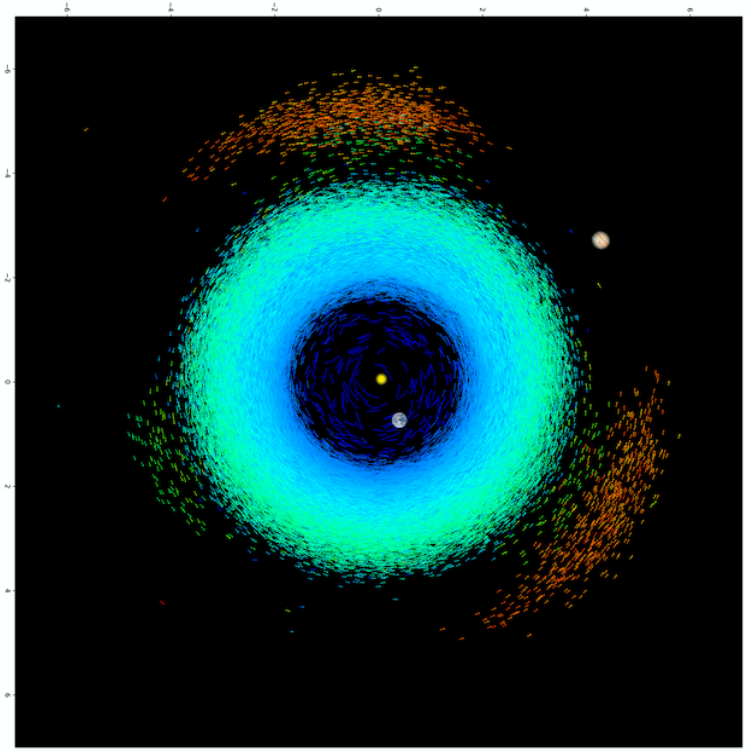


ESA/Gaia/DPAC-CU8, Recio-Blanco and the GSP-Spec team

Solar System Objects

- 158,152 Solar System Objects (asteroids + 31 moons of planets)

  Near-Earth, Main belt, Mars Crossers, Jupiter trojans, Centaurs, Trans-Neptunians
- Position, orbit and brightness (shape and rotation)
- Colour/composition details for 60,000 (origin and classification)



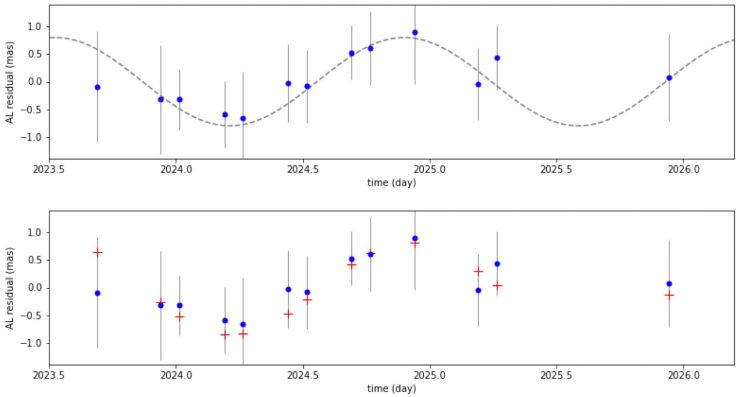
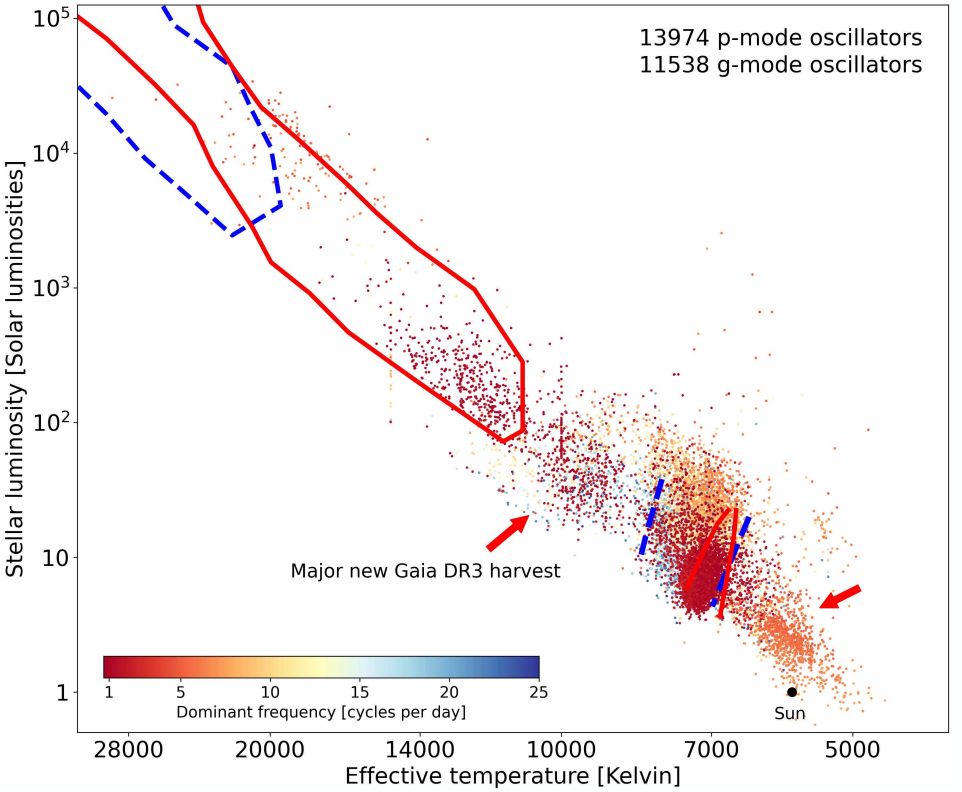


Figure 4. The case of the asteroid 4337 Arecibo is emblematic. The presence of a companion has not been discovered by Gaia, but from the ground by two stellar occultations. A first look in Gaia data revealed the periodic oscillation of the asteroid trajectory, thus resulting in the first astrometric signature detected for an asteroid satellite. Image credit: Tanga, et al. 2022 - CC BY-SA 3.0 IGO.

Starquakes!

- DR3 publishes ~10 millions of variable stars
- Most stars experience non-symmetrical oscillations (up-and-down motions of the gas inside the stars)
- Gaia time-series photometry allows to detect those starquakes for hot massive stars (~100,000): key to understand the internal physics and chemistry
- Follow-up of these stars will be made by more specific satellites



Outside our Galaxy

Unlike other missions that target specific objects, ESA's Gaia is a survey mission. This means that while surveying the entire sky multiple times, it is bound to see objects outside the Milky Way as well, such as quasars and other galaxies. Gaia's data release 3 provides astronomers with details on a few million extragalactic objects.

1.9 million quasars

Supermassive black holes accreting matter

Redshift | Brightness | Colour

Host galaxy detected for 60 thousand quasars

2.9 million galaxies

Brightness | Colour

Star formation history | Shape

Gaia DR3: a release of superlatives

Beyond the largest and most accurate astrometric and photometric survey to date (Gaia EDR3):

- Largest ever spectrophotometric survey
- Largest ever radial velocity survey
- First space-based all-sky survey of QSO galaxy hosts and of the surface brightness profiles of galaxies in the local universe
- Highest accuracy spectrophotometric-dynamical survey of asteroids
- For many classes of variable stars: largest survey ever
- Largest ever collection of astrophysical data for stars in the Milky Way
- Non-single star survey that surpasses all the work on non-single stars from the past two centuries

What's next

- Two more Data Releases:
  - DR4 not before end 2025
  - DR5 by 2030

In the future, Gaia is expected to release even more accurate and additional data:

- Full astrometric and photometric catalogues
- Radial velocity of fainter stars
- High-resolution spectra of 150 million stars
- All available variable stars and binary star systems
- Improved distances (parallaxes) and motions across the sky (proper motions)
- Improved source classifications (for example whether a star is hot or cold)
- Extended list of exoplanets
- Gravitationally lensed objects

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