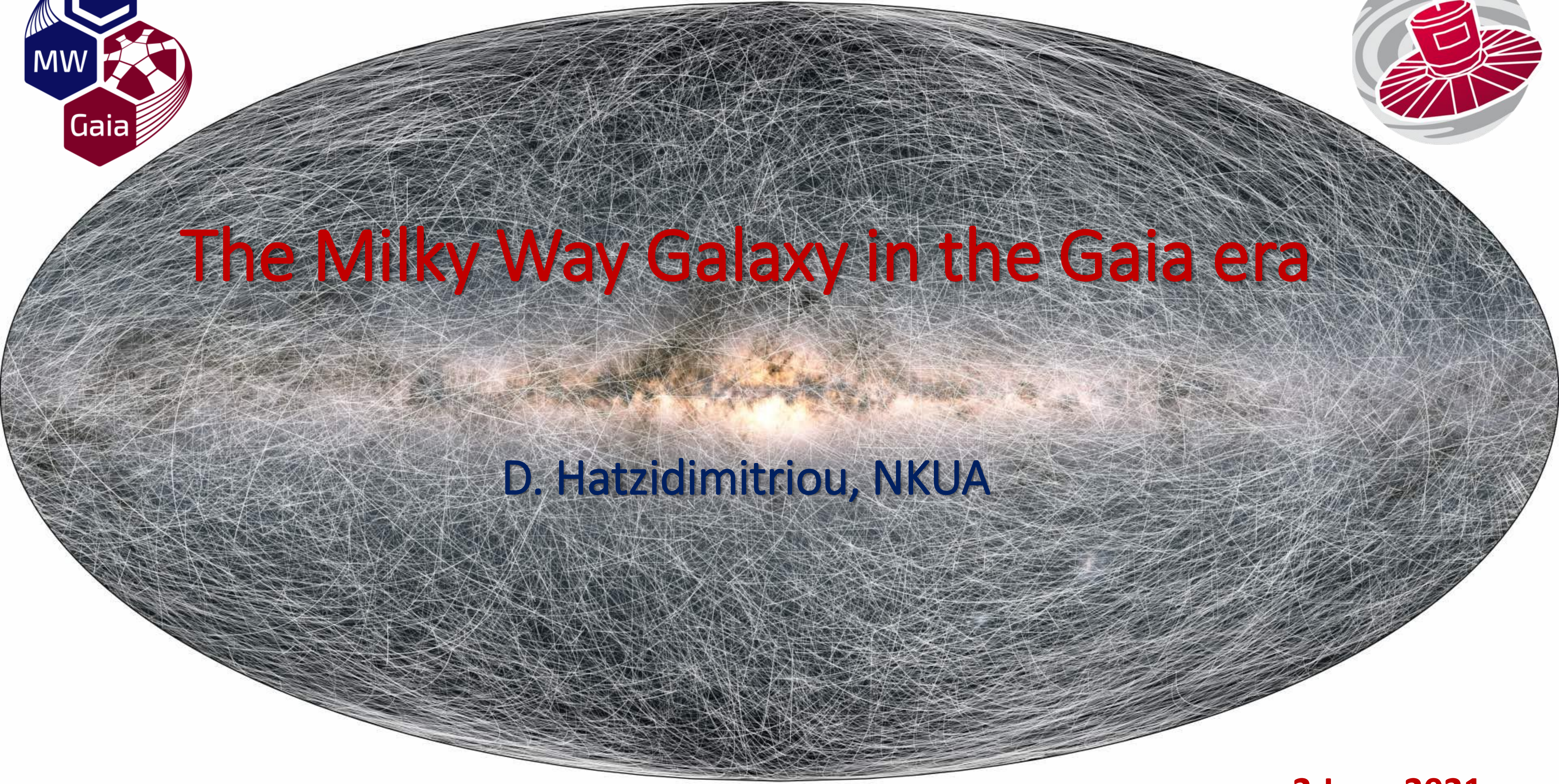
Online Workshop MW-Gaia: Bringing the Milky Way to schools 2021

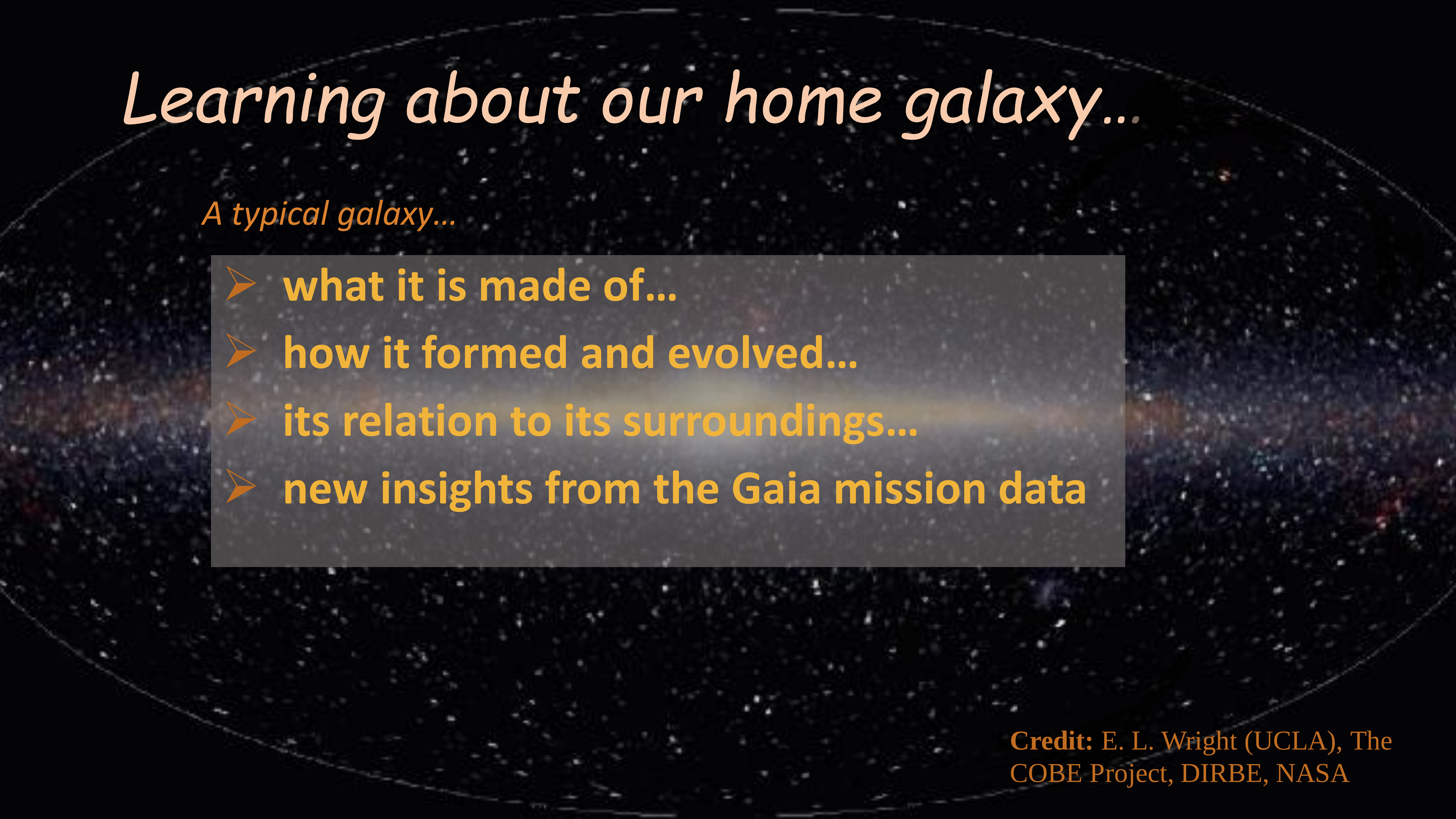


The Milky Way Galaxy in the Gaia era

D. Hatzidimitriou, NKUA

2 June 2021

Learning about our home galaxy…



A typical galaxy…

- **what it is made of…**
- **how it formed and evolved…**
- **its relation to its surroundings…**
- **new insights from the Gaia mission data**

Credit: E. L. Wright (UCLA), The COBE Project, DIRBE, NASA

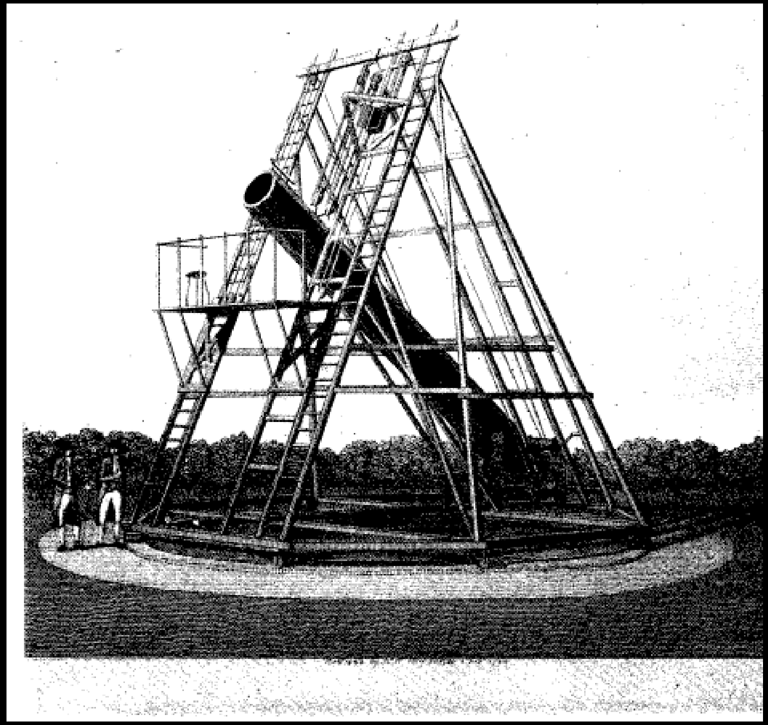
The Milky Way as seen from the Northern and Southern Hemispheres

Credit: ***Institute of Atrophysics, FORTH, Greece***

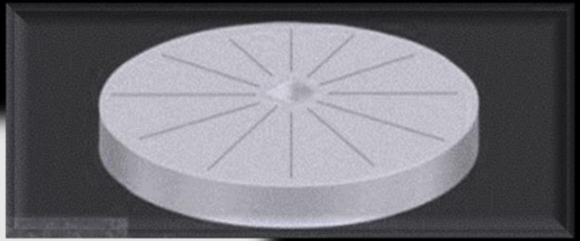
Credit: ***Ángel R. López-Sánchez (AAO/MQU)***

A little history....

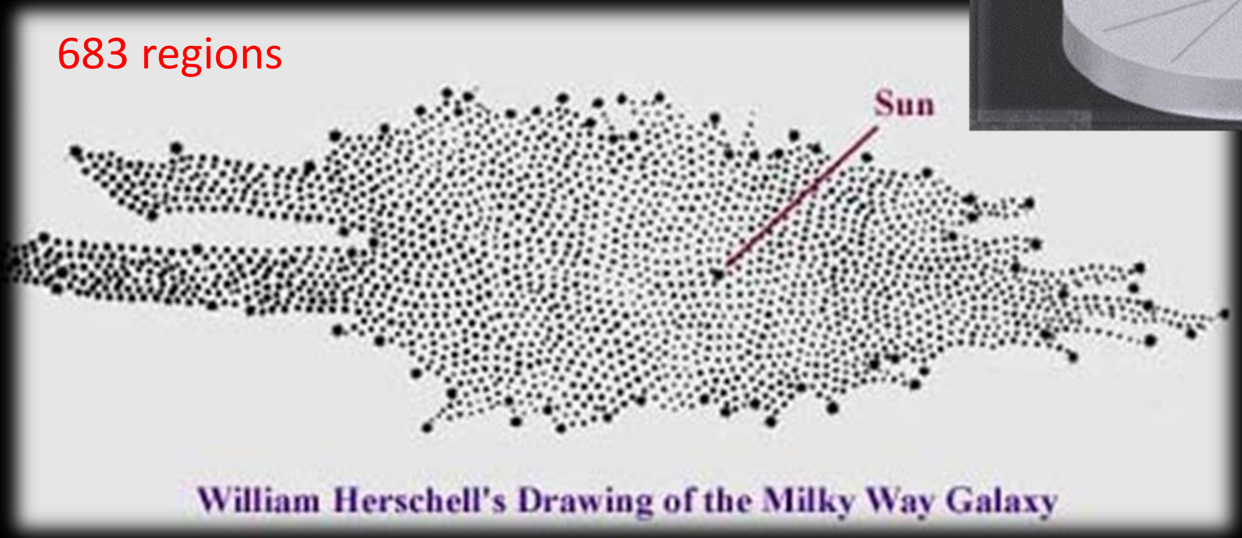
1785: **William Herschel**
attempted to map the shape of the Milky Way by counting and plotting stars using his newly built 20 foot long reflector with an 18 inch mirror.



Herschel's 20ft, 18.7in reflector telescope 1783
J.A. Bennett, 1976, QJRAS vol. 17, p.303



683 regions



How can we study the Milky Way

- We are inside the Galaxy
- Mapping it and understanding its structure requires knowledge of distances to stars
- Observations are obscured by dust. Using only optical wavelengths does not allow us to see through to the inner parts of the galaxy

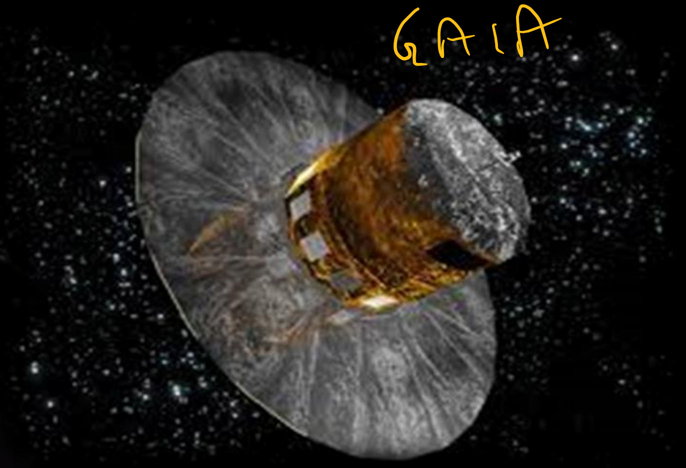
So, we need (at the very least)

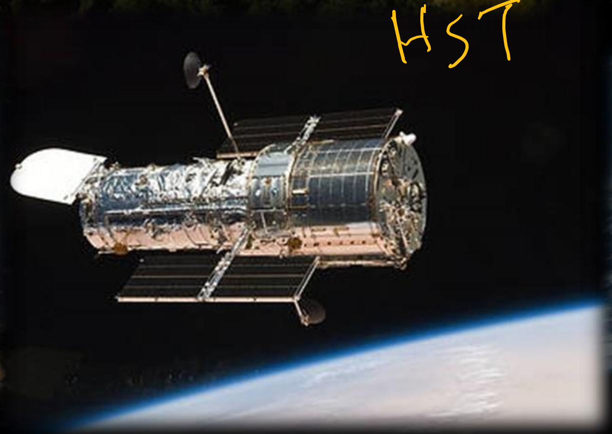
- Multiwavelength measurements
- Ways to measure distances
- Measurement of space motion of stars

Parallaxes
Proper motions
Radial Velocities

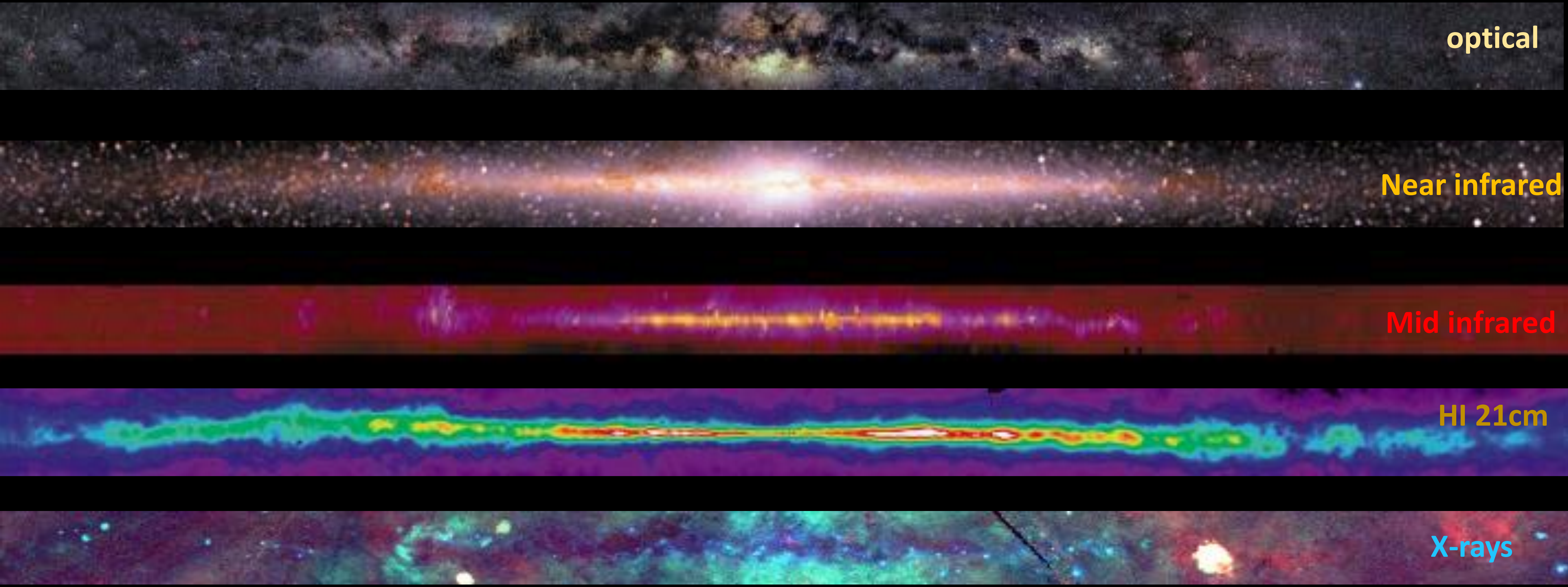
Multiwavelength studies from the ground and space

Important spectroscopic surveys APOGEE, GES, SDSS, RAVE, GALAH, SEGUE,…



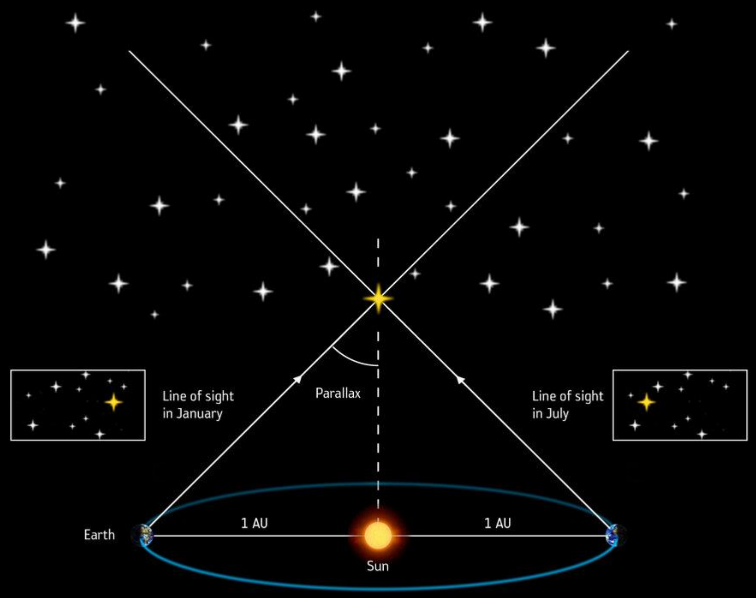


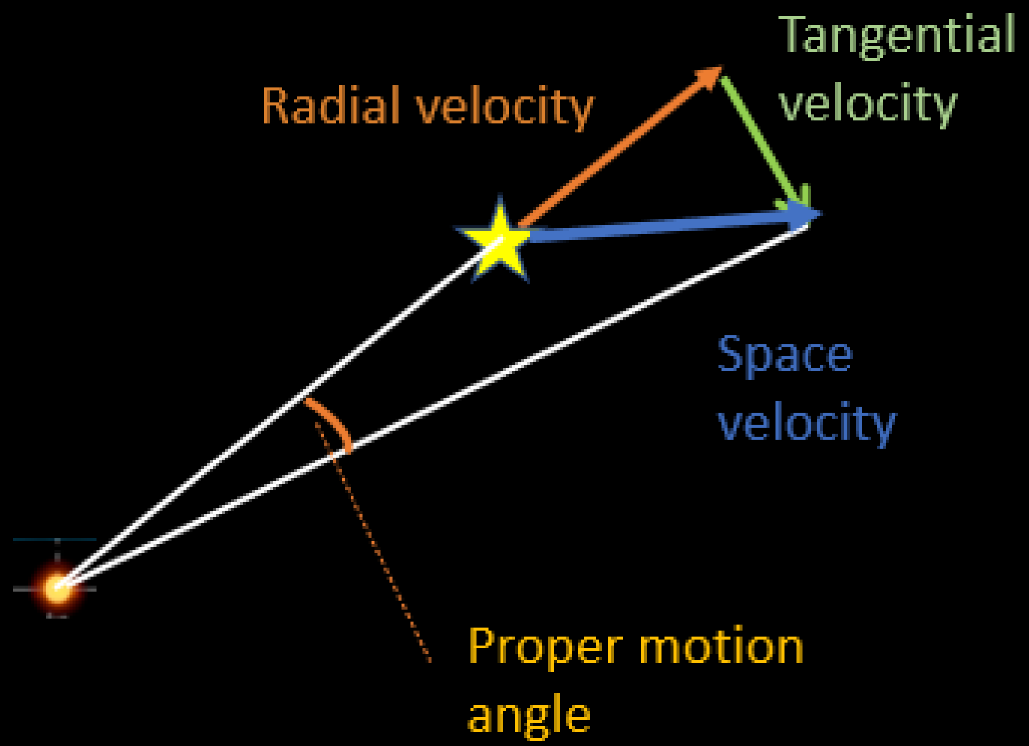
How does the Galaxy look like in different wavelengths



https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html

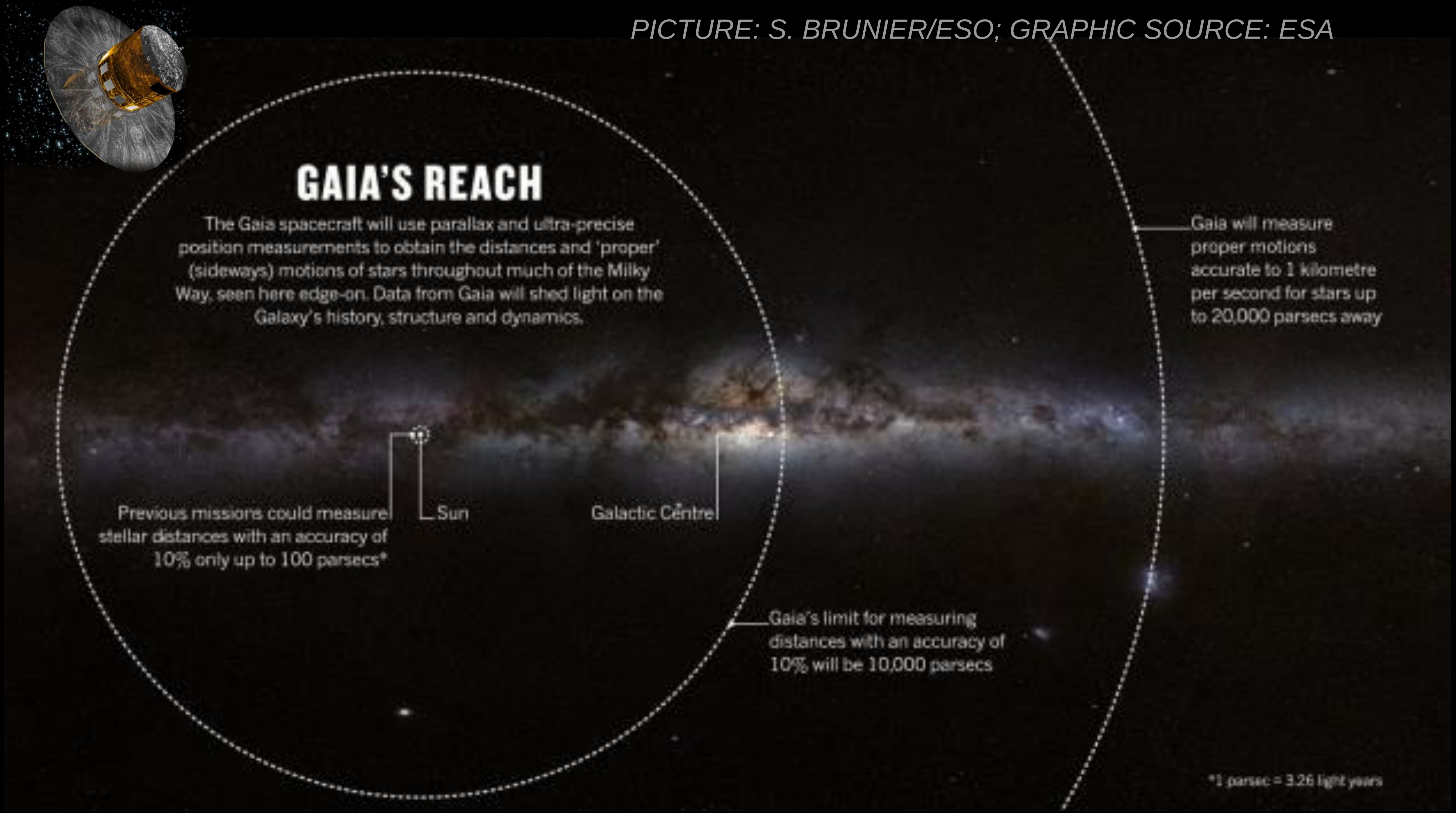
Measurement of parallaxes (→distances) and space velocities (proper motion + radial velocities)

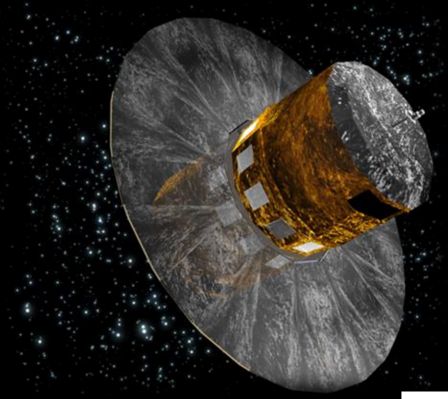




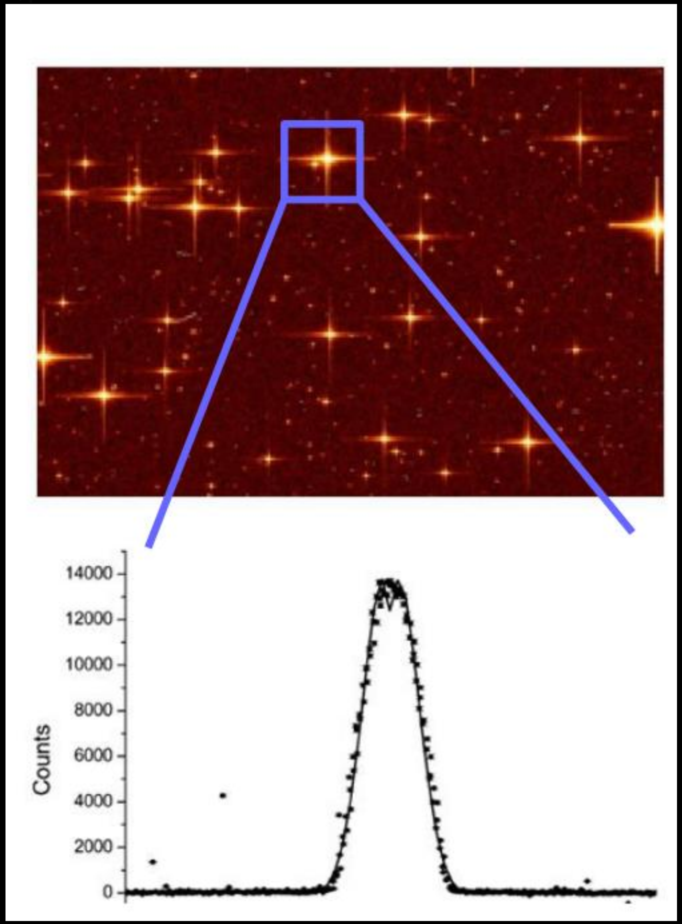
http://www.esa.int/Science_Exploration/Space_Science/Gaia/How_does_Gaia_study_the_Milky_Way

PICTURE: S. BRUNIER/ESO; GRAPHIC SOURCE: ESA





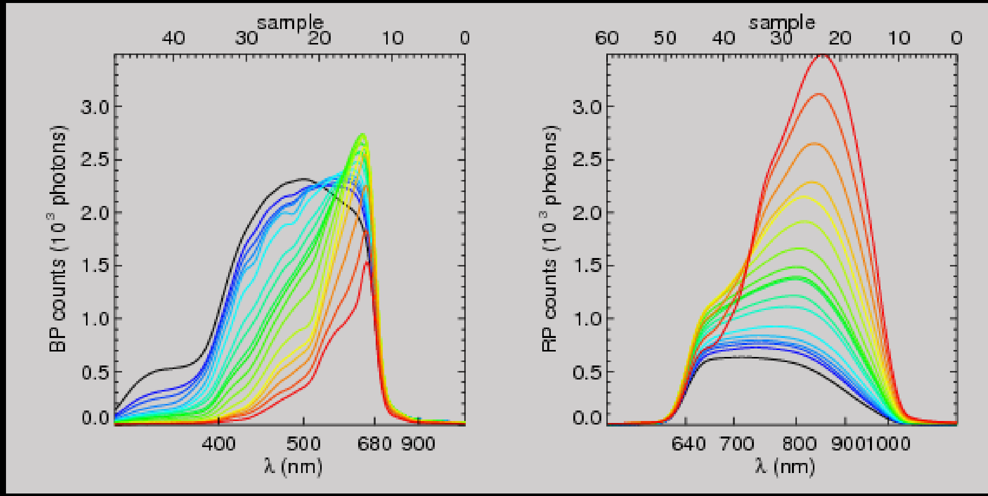
Astrometry



Spectrophotometry

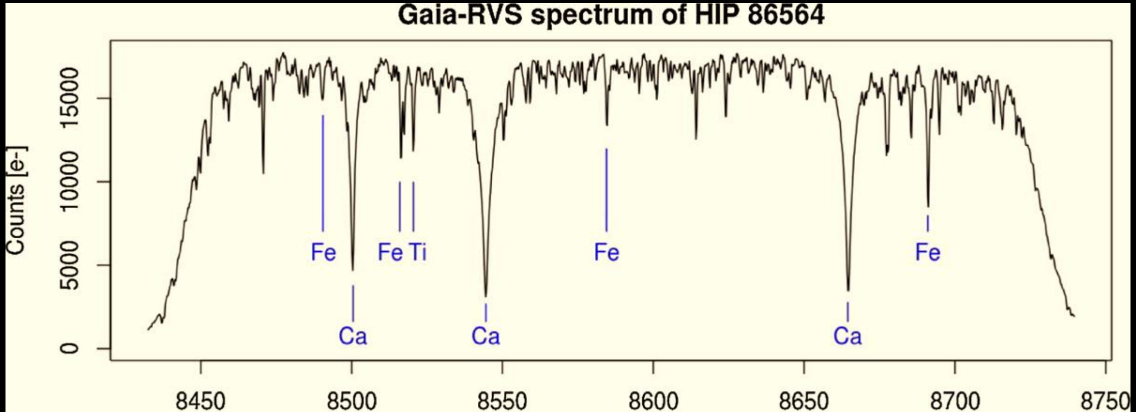
Blue photometer

Red photometer



Spectroscopy

Radial Velocity Spectrometer



Cropper et al. 2018

GAIA EARLY DATA RELEASE 3

esa

1 811 709 771
stellar positions

1 806 254 432
brightness in white light

1 542 033 472
brightness in blue light

1 540 770 489
colour

1 554 997 939
brightness in red light

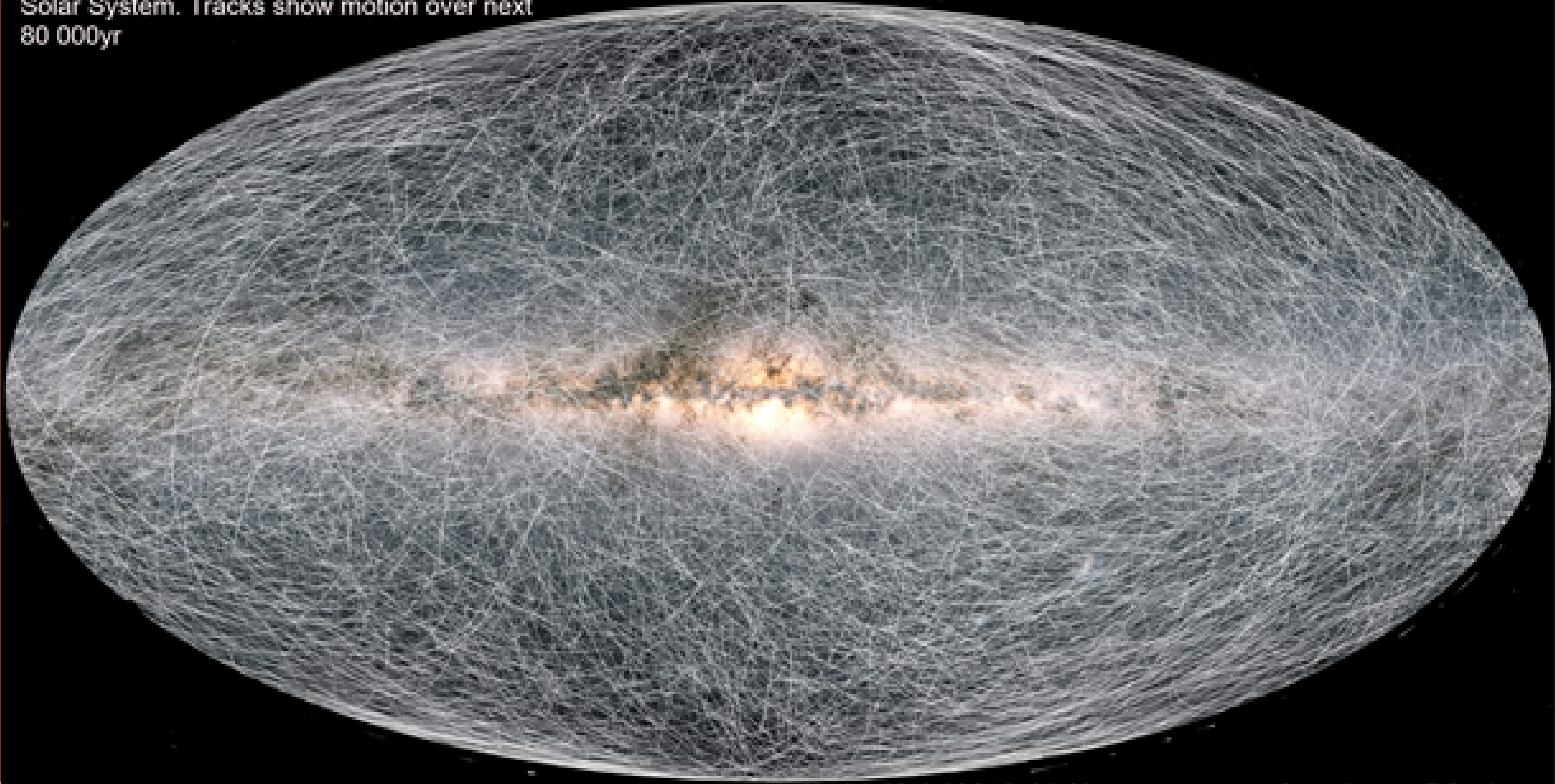
1 467 744 818
parallax and proper motions

1 614 173
extragalactic sources

#SpaceCare #ExploreFarther

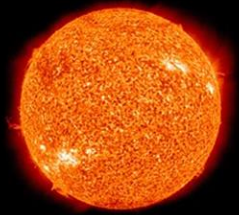
esa gaia

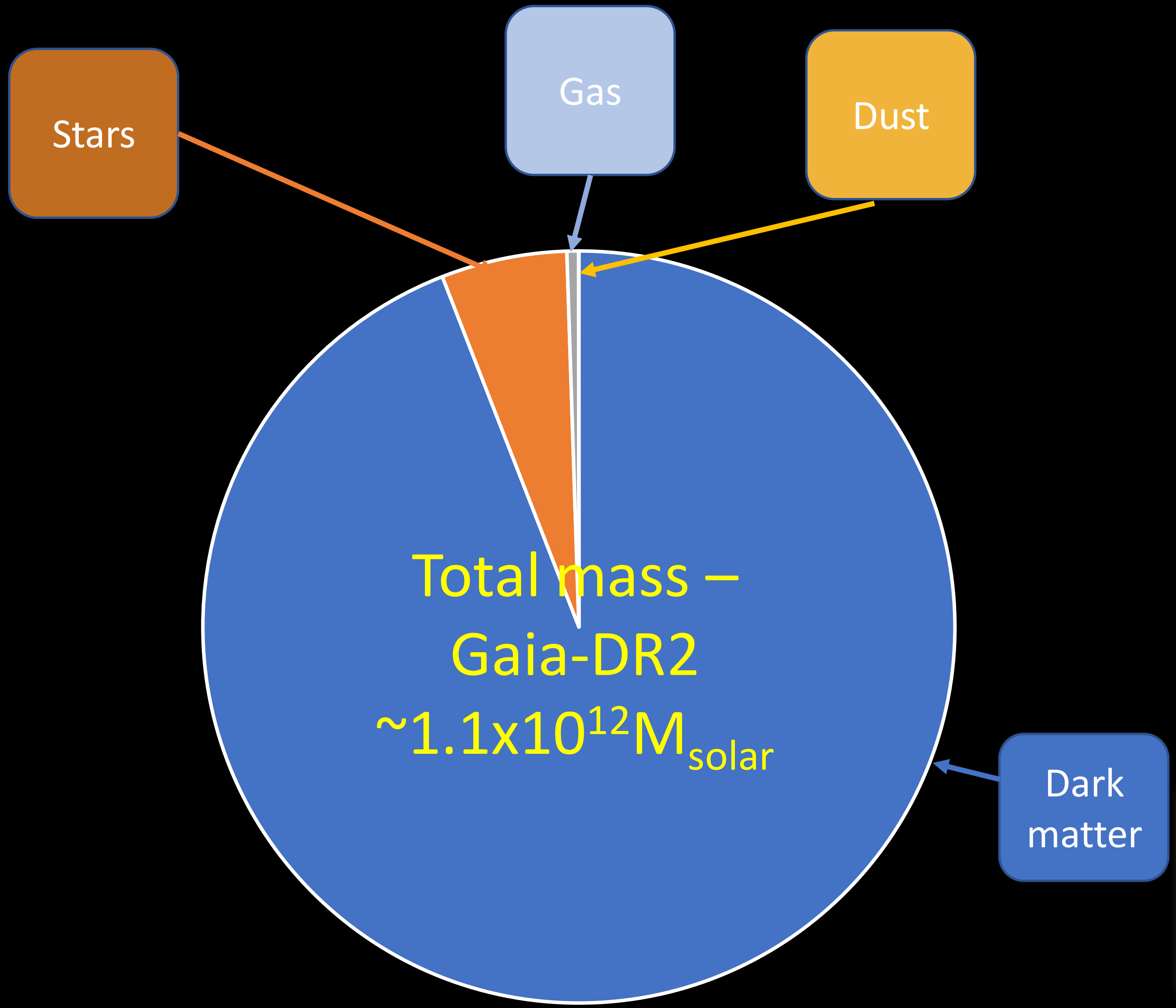
Proper motions of 40 000 stars, located within 100 parsecs of the Solar System. Tracks show motion over next 80 000yr



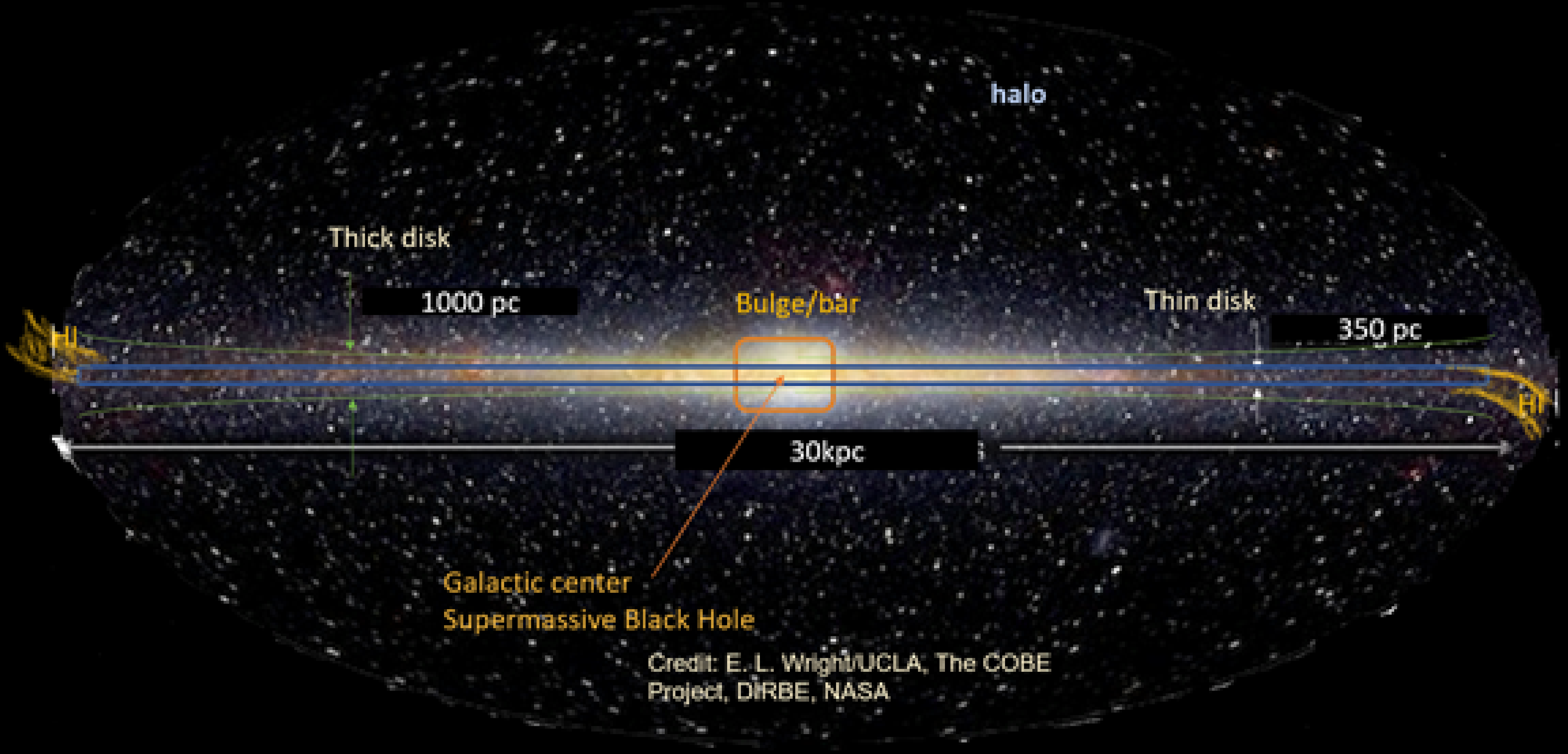
ESA/Gaia/DPAC; CC BY-SA 3.0 IGO. Acknowledgement: A. Brown, S. Jordan, T. Roegiers, X. Luri, E. Masana, T. Prusti and A. Moitinho.

What does our Galaxy consist of…





Structural components of the Galaxy



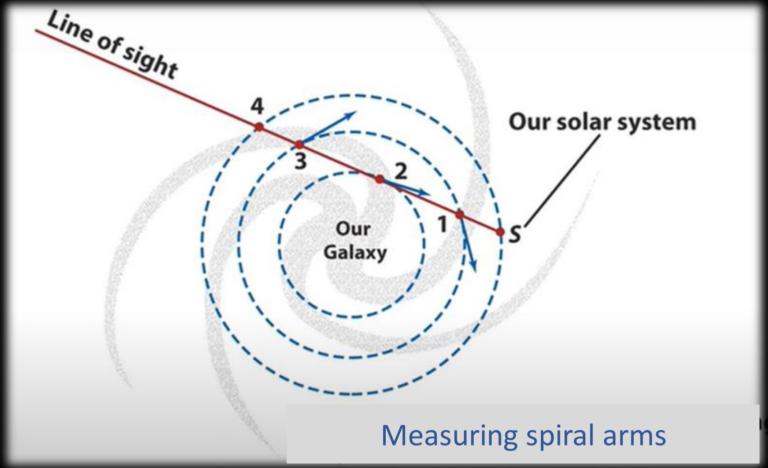
The disk

- Total mass in stars ~6x$10^{10}M_{solar}$
- Thin disk (stars, gas and dust)
  - 95% of the disk stars
  - thickness ~350 pc, length ~30kpc
  - Stars from newborn to very old (up to 8-9Gyr)
  - Dust and gas (100pc thickness) – sites of star formation
  - Current star formation rate ~ 1.6 M_{solar} / year
- Thick disk (stars)
  - 5% of the disk stars
  - thickness ~1000pc
  - "Hotter" component (slower rotation, higher random motion)
  - Stars older than the oldest thin disk (by ~1.6Gyr) and generally lower abundance

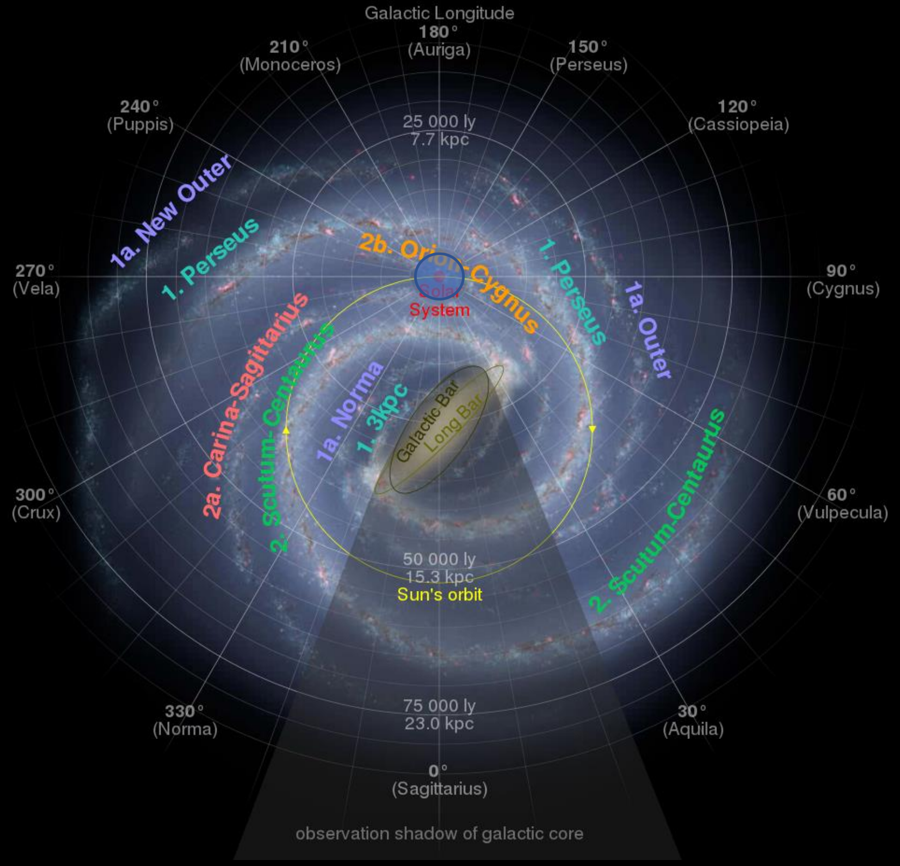
Chemodynamical differences between thin and thick disks

- Disk is rotating – most stars in almost circular orbits
- Spiral arms (4 main + 1 broken)

Review by A. Helmi, 2020, Ann. Rev. Astron. Astrophys.



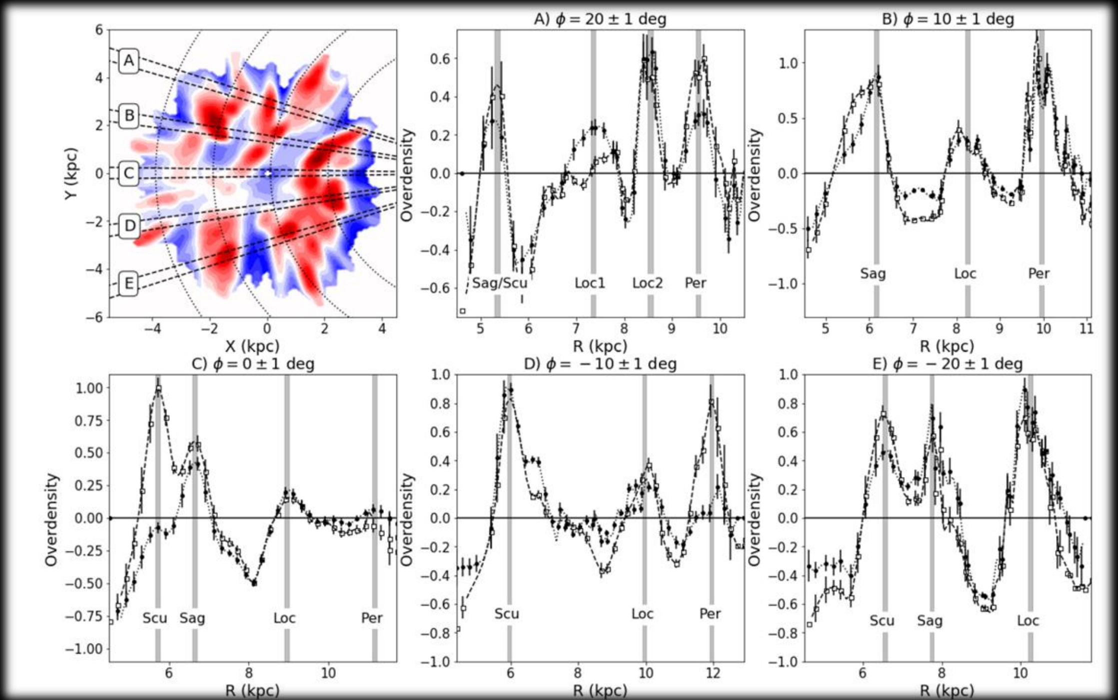
Measuring spiral arms



Artist's concept of our Milky Way galaxy, as seen from far galactic north (the direction of the constellation Coma Berenices) via NASA/ JPL-Caltech/ R. Hurt/

Tracing spiral arms with Gaia eDR3

- astrometry and integrated photometry from the Gaia Early Data Release 3
- Density variations in the distribution of very young populations (young Upper Main Sequence stars, open clusters and classical Cepheids) in the Galactic disk within several kiloparsecs of the Sun.
- Maps of relative over / under-dense regions for UMS stars in the Galactic disk



Poggio et al. 2021 Astronomy and Astrophysics

→large-scale arches, that extend in a clumpy but coherent way over the entire sampled volume

→indicating the location of the spiral arms segments in the vicinity of the Sun.

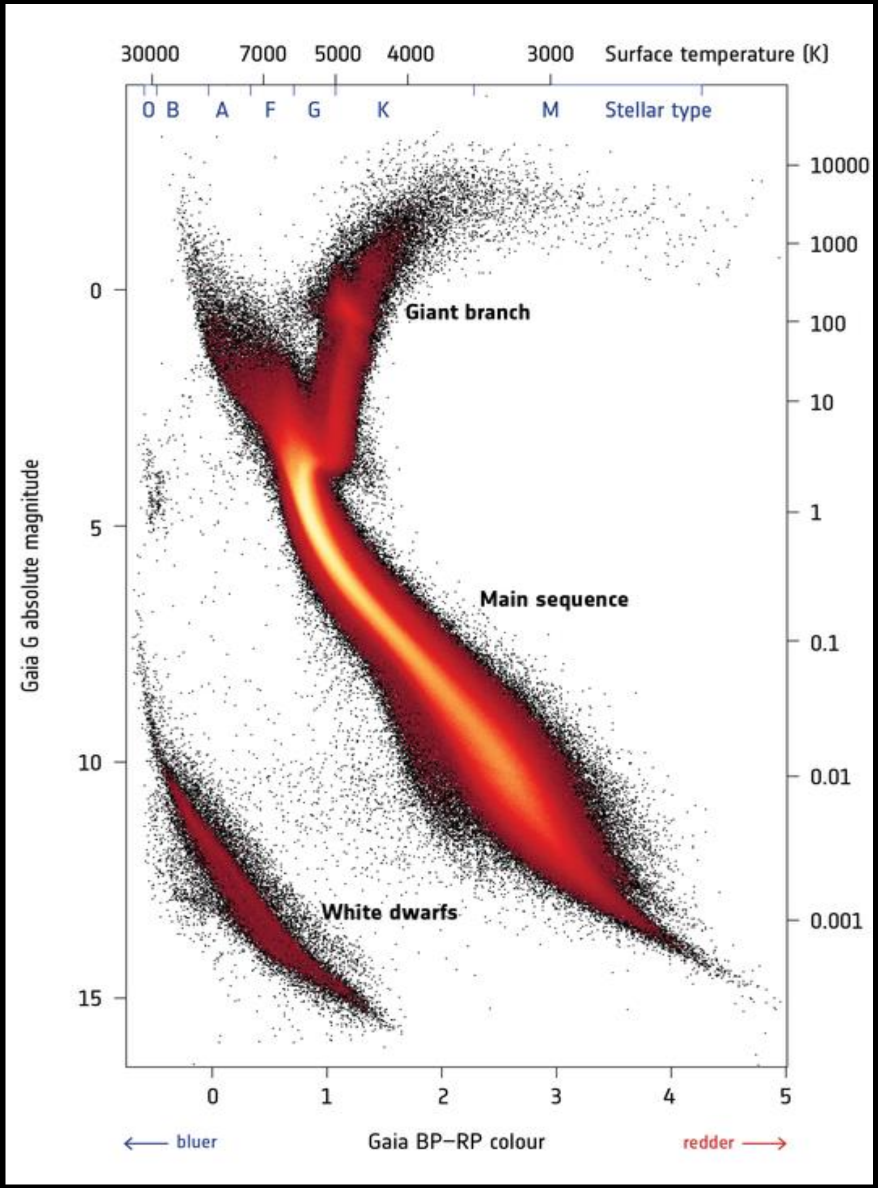
Made possible by accurate distances from Gaia

Gaia
DR2

Star formation history near the sun (100pc)

- Maximum of star formation activity about 10 Gyr ago
- Followed by a decrease in star formation up to a minimum level occurring around 8 Gyr ago.
- After a quiet period, star formation rises to a maximum at about 5 Gyr ago, forming stars of solar metallicity ($Z = 0.017$).
- Finally, star formation has been decreasing until the present, forming stars of $Z = 0.03$ at a residual level.

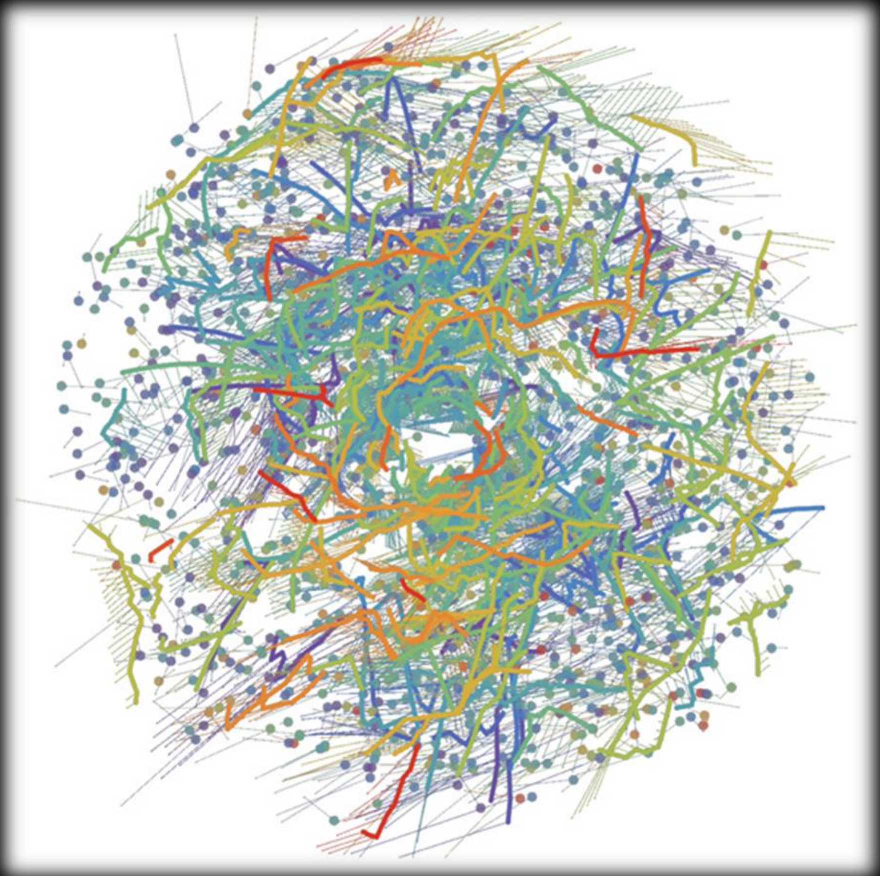
Alzate et al. 2020



STELLAR GROUPS AND STRINGS IN THE MILKY WAY

Clusters and co-moving groups of stars within 3000 light-years from the Sun

Gaia DR2

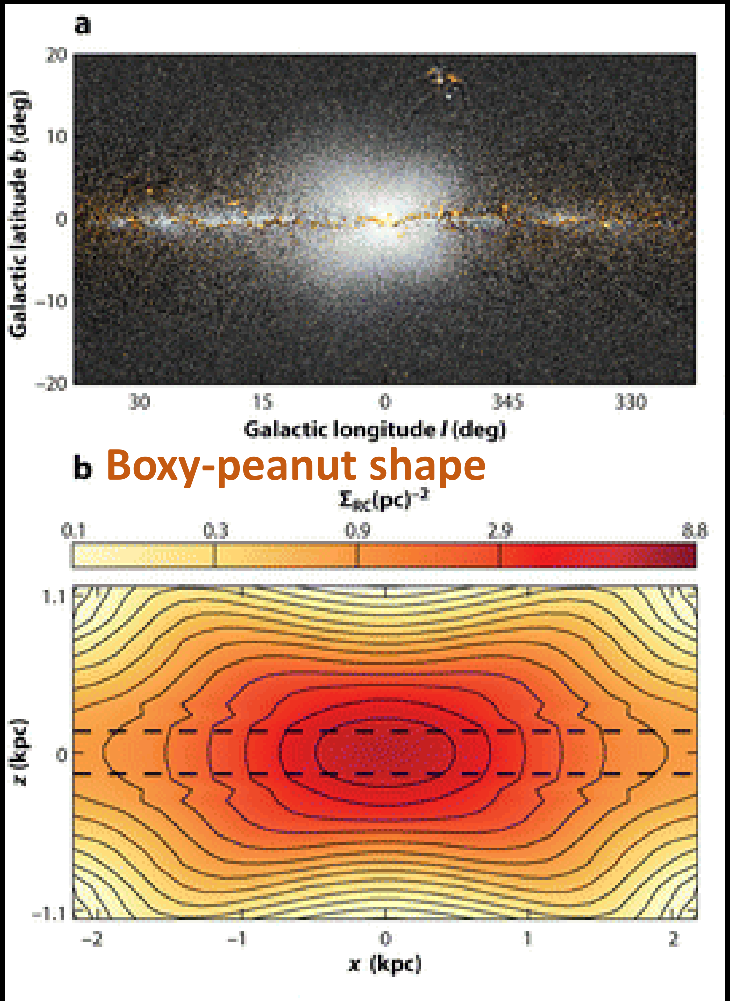


M. Kounkel & K. Covey (2019)

The bulge/bar

Heavily obscured

- The bar/bulge is the more centrally concentrated component of the Galaxy
- Most of the bulge is a rotating triaxial structure, i.e. a **Bar** **(V_{rot}~ 35-40km/s/kpc, period ~160-180 Myr)**
- There may also be a classical bulge component but <8%
- Mixture of populations, some very old (>13Gyr) and metal rich
- Contains ~ 2x10^{10} M_{solar}

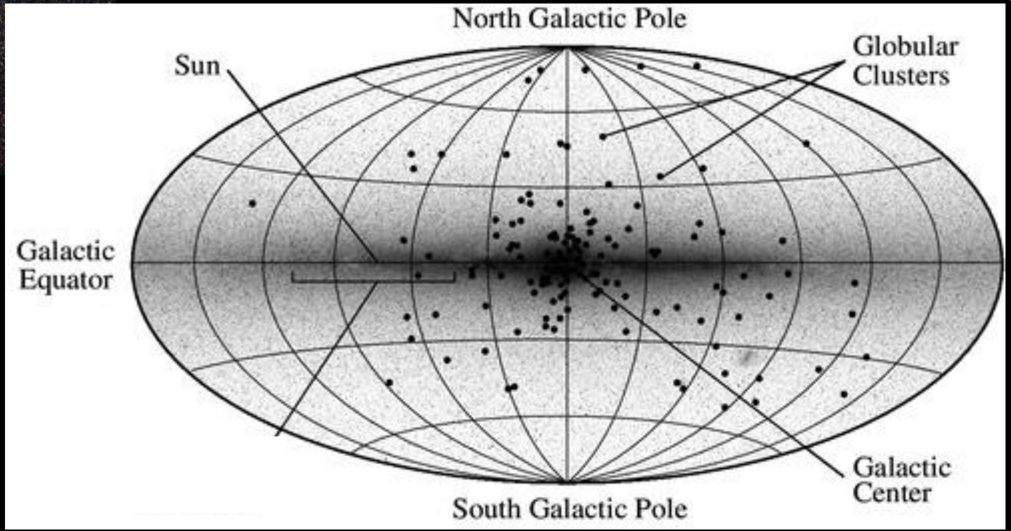


Barbuy, Chiappini, Gerhard 2018

Shen and Zheng 2020, review
Barbuy, Chiappini, Gerhard 2018 ARAA

The stellar halo

Gaia is currently driving a true revolution in our understanding of the inner Galactic halo

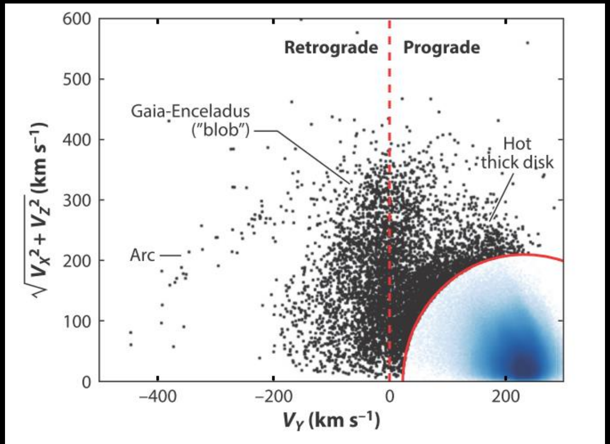


Copyright 2010, Professor Kenneth R. Lang, Tufts University

- Globular clusters, stars
- Most extended component
  (144 globular clusters within 42pc, 6 at 69-123kpc))
- At the same time quite centrally concentrated (half light radius 0.5kpc)
- Very old and metal poor stars
- Total mass ~1.3 x 10^9 M_{solar}
- A large fraction of the stellar halo near the Sun appears to be debris from a single object – a dwarf galaxy, named Gaia-Enceladus, which merged with our galaxy ~10Gyr ago

Shen and Zheng 2020, review
Barbuy, Chiappini, Gerhard 2018 ARAA

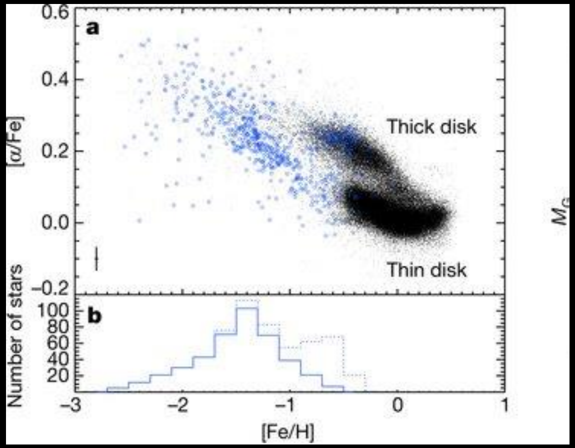
Gaia DR2



Koppelman et al. (2018)

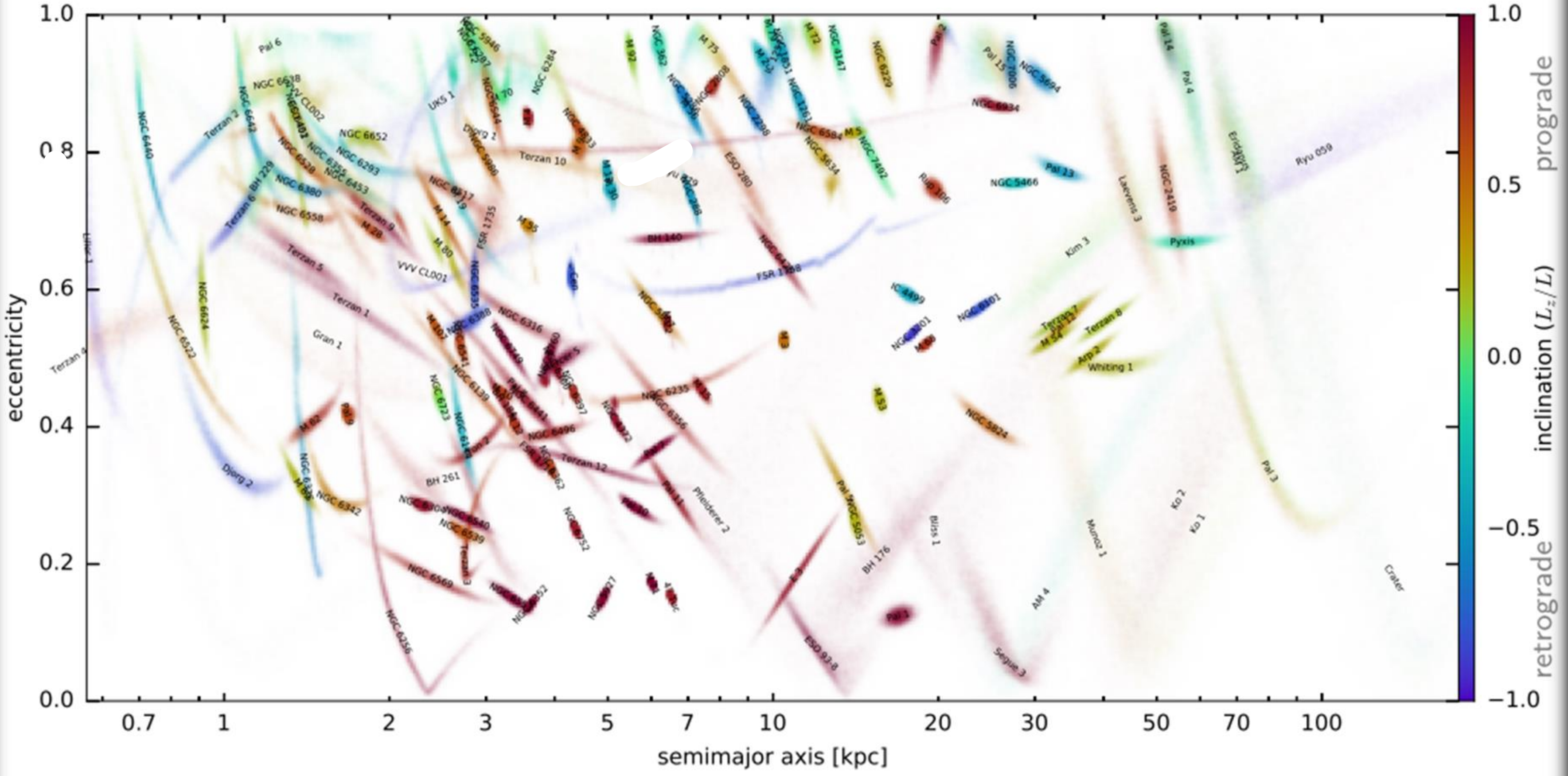
X

Apogee



Helmi et al. 2018

Orbits of clusters in the Milky Way



distance errors are the major source of uncertainty in orbit parameters

Vasiliev 2021

Halos are VERY extended ….

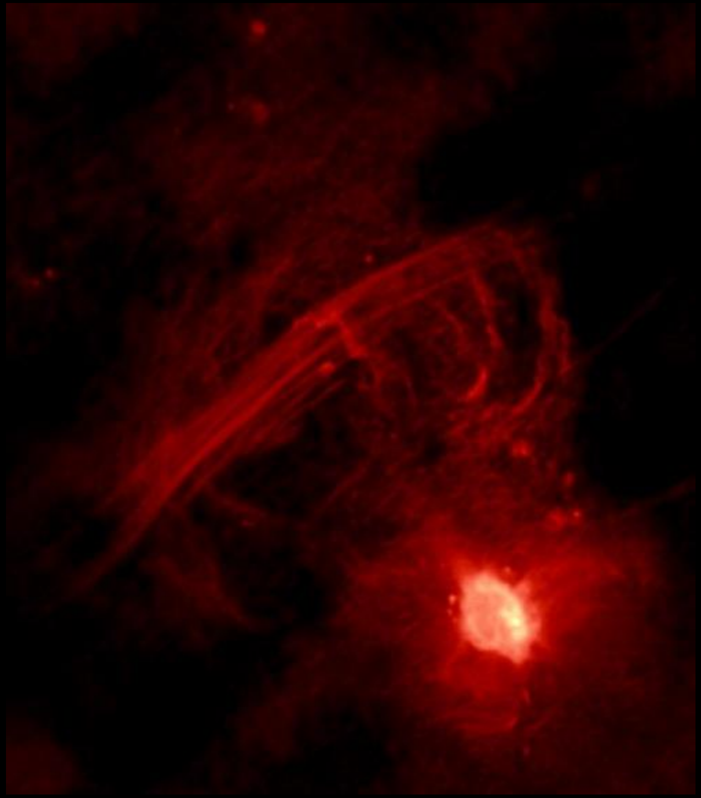
Credits: NASA, ESA, and E. Wheatley (STScI)

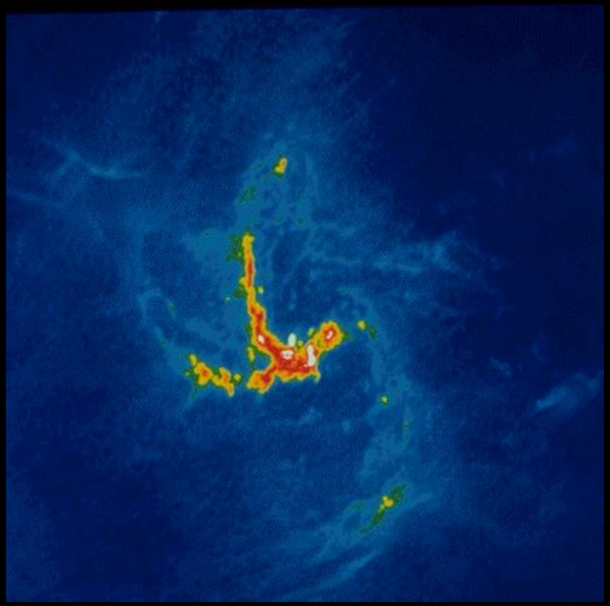
The center of the Galaxy

- Cannot be accessed directly with Gaia due to high obscuration

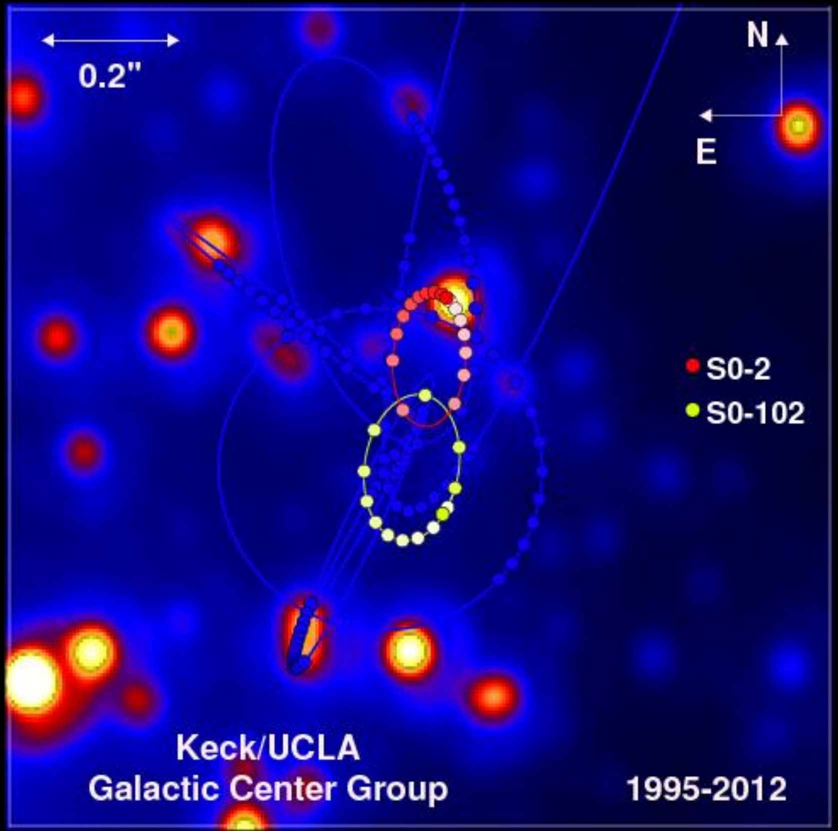
M= $3.6^{+0.2}_{-0.4} \times 10^{6} M_{\odot}$

radio





*The mini-spiral in the GC, centered on Sgr A**



Science*, *5 October 2012: Vol. 338, pp. 84 – 87 **A. A. Ghez, R. Genzel**
Nobel prize 2020

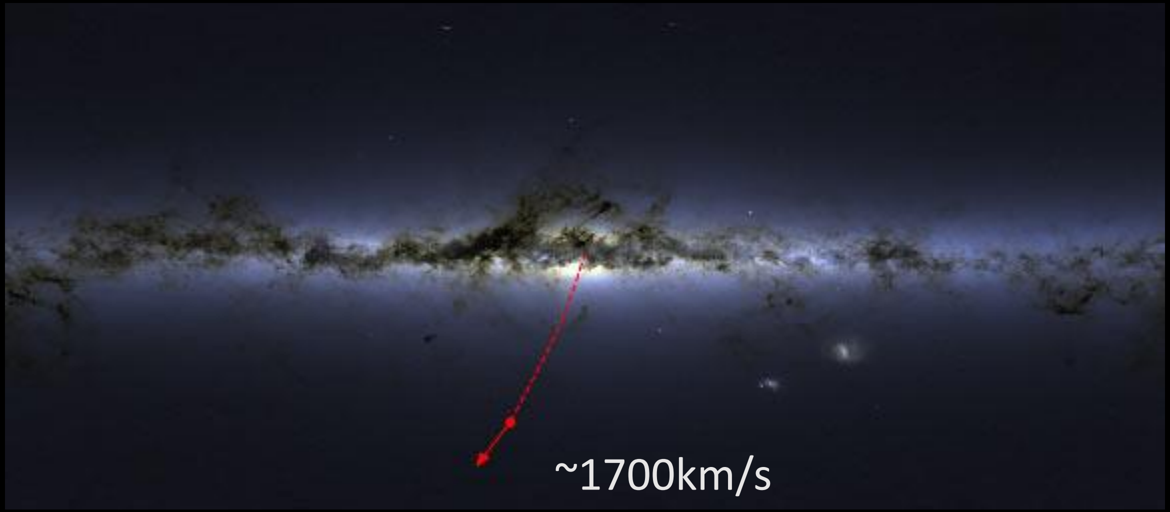
Hypervelocity stars

Superfast stars can be ejected by black holes via the Hills mechanism,

From Hill's 1988 Nature paper

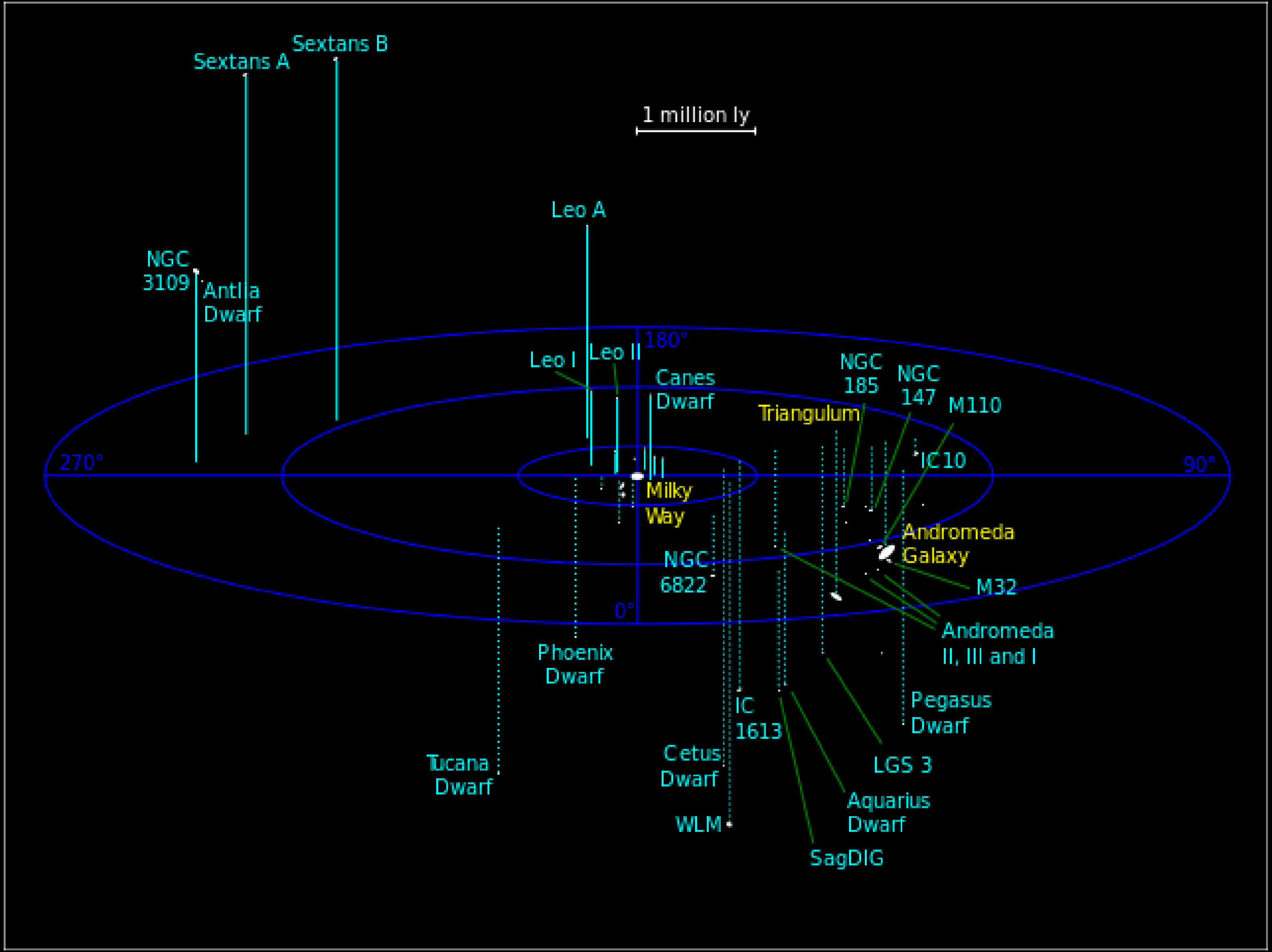
¨A close but newtonian encounter between a tightly bound binary and a $10^6\ M_\odot$ black hole causes one binary component to become bound to the black hole and the other to be ejected at up to 4,000 km^{-1}. The discovery of even one such hyper-velocity star coming from the Galactic centre would be nearly definitive evidence for a massive black hole. The new companion of the black hole has a high orbital velocity which increases further as its orbit shrinks by tidal dissipation.

A first …..

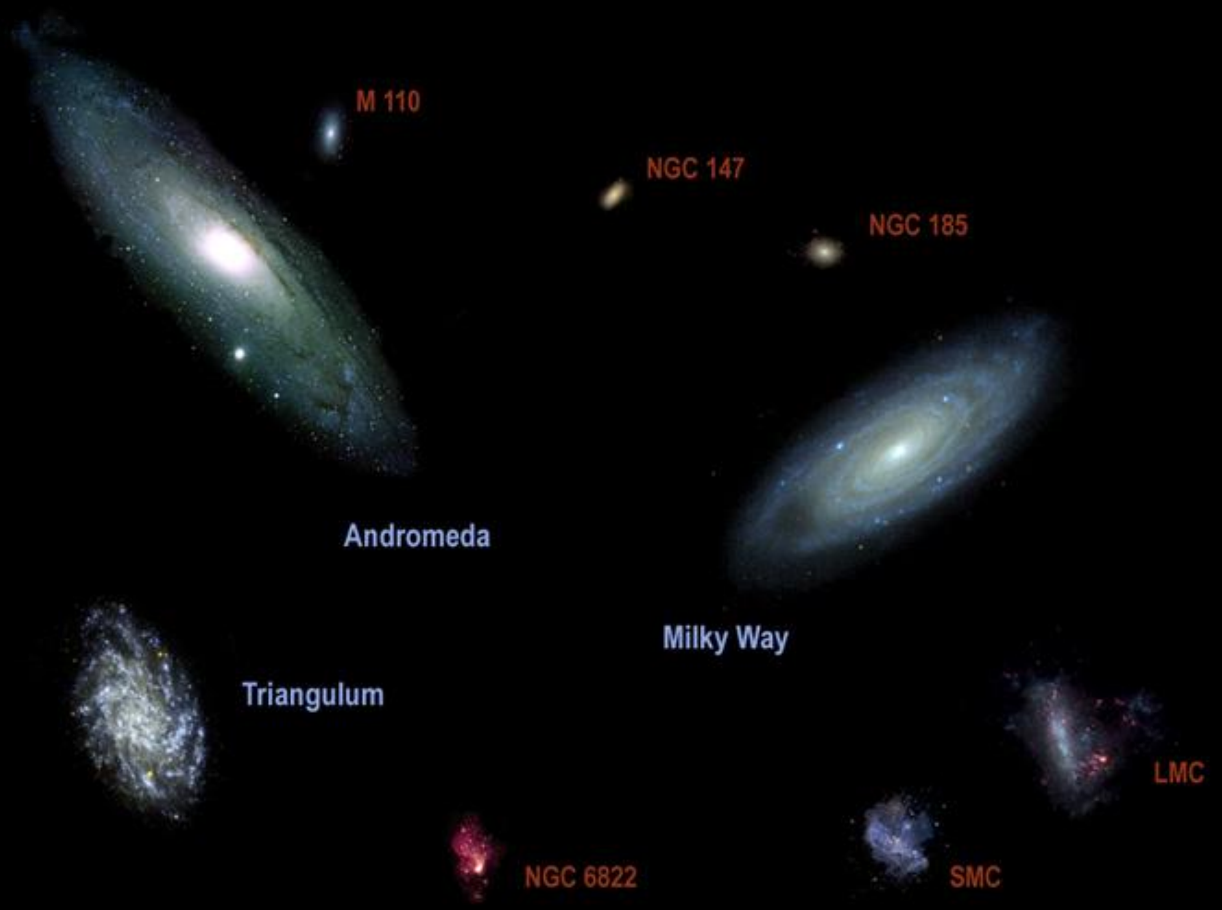


Gaia + AAT Koposov *et al*. 2019

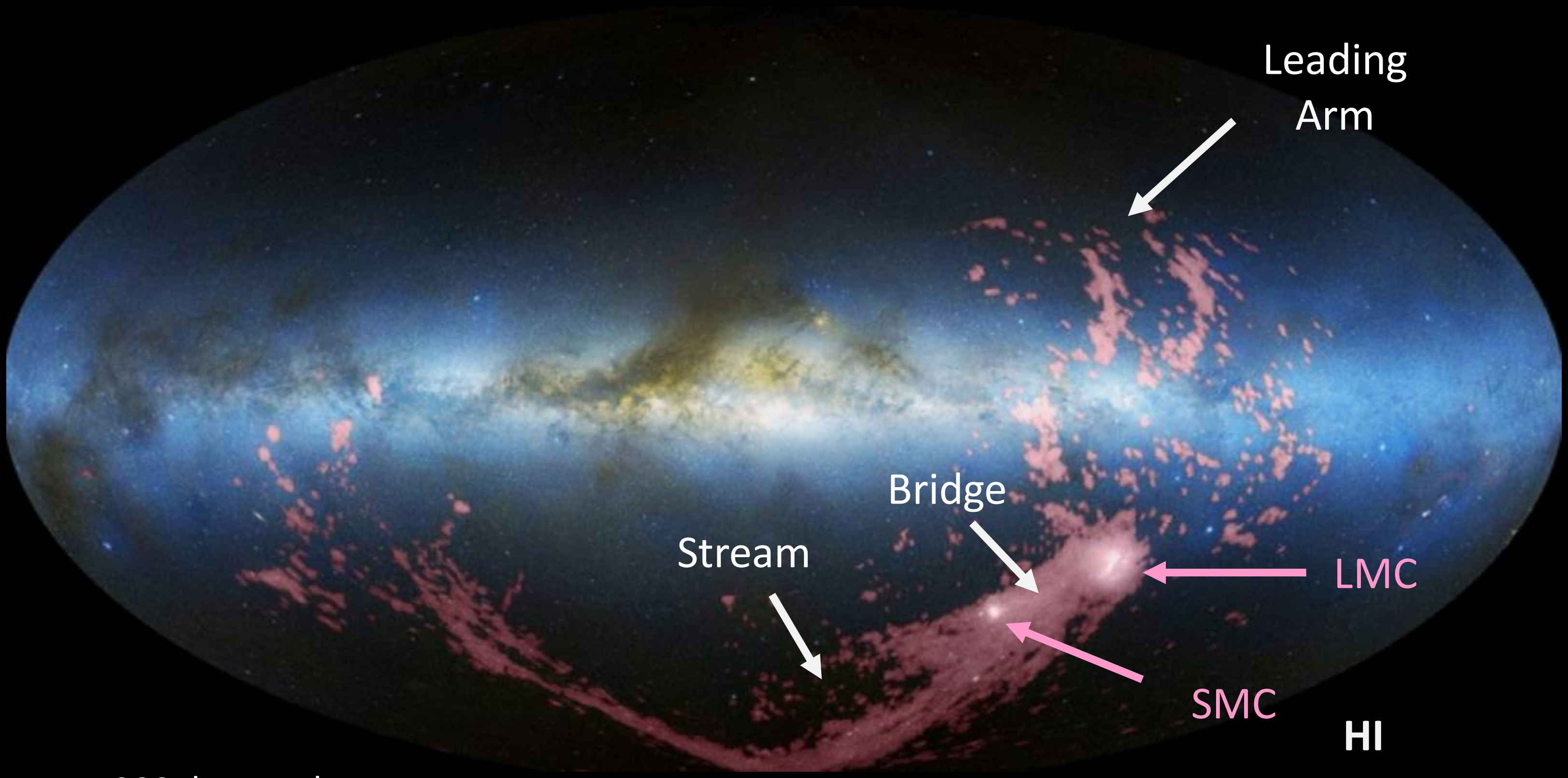
The larger picture: The Local System of Galaxies



Some of the members of the Local Group of galaxies



The Magellanic system : an interacting system of galaxies

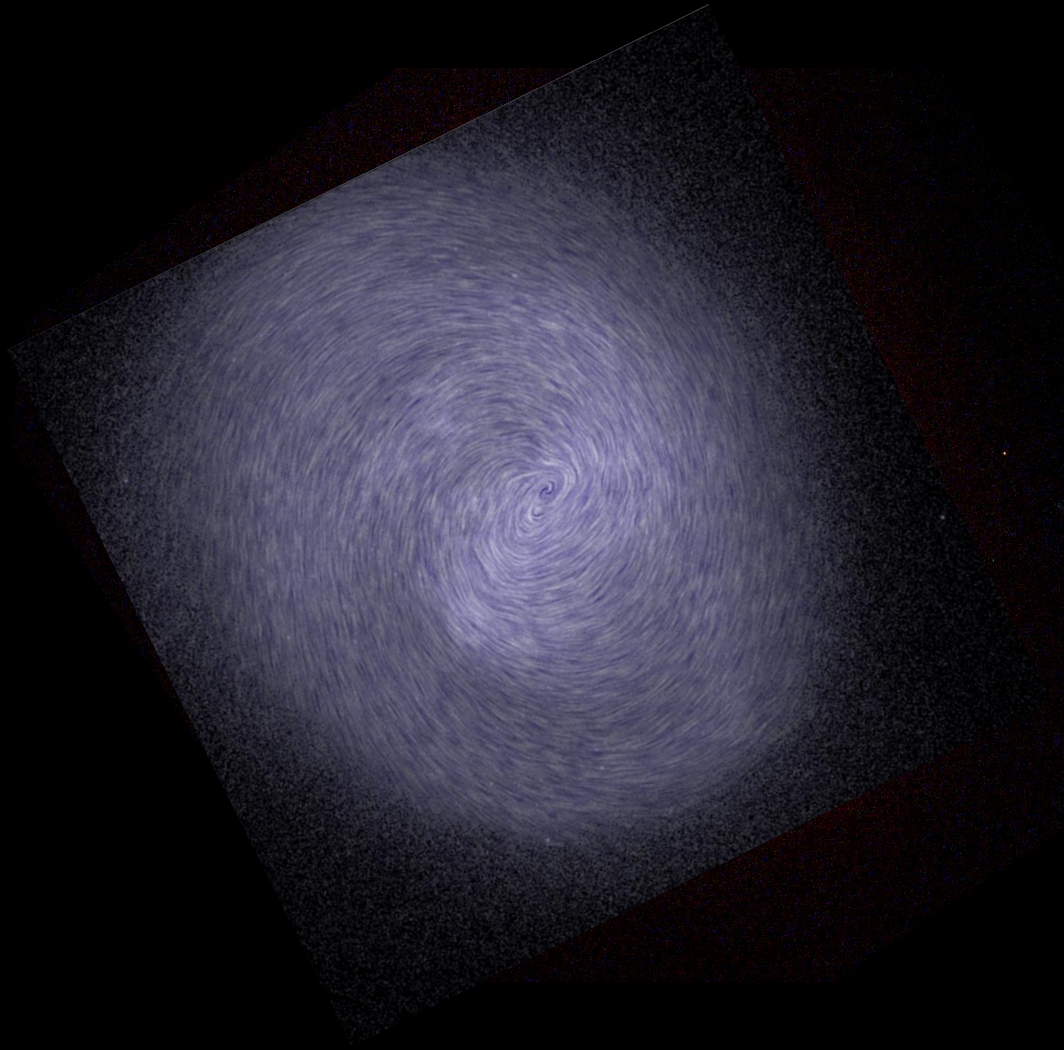


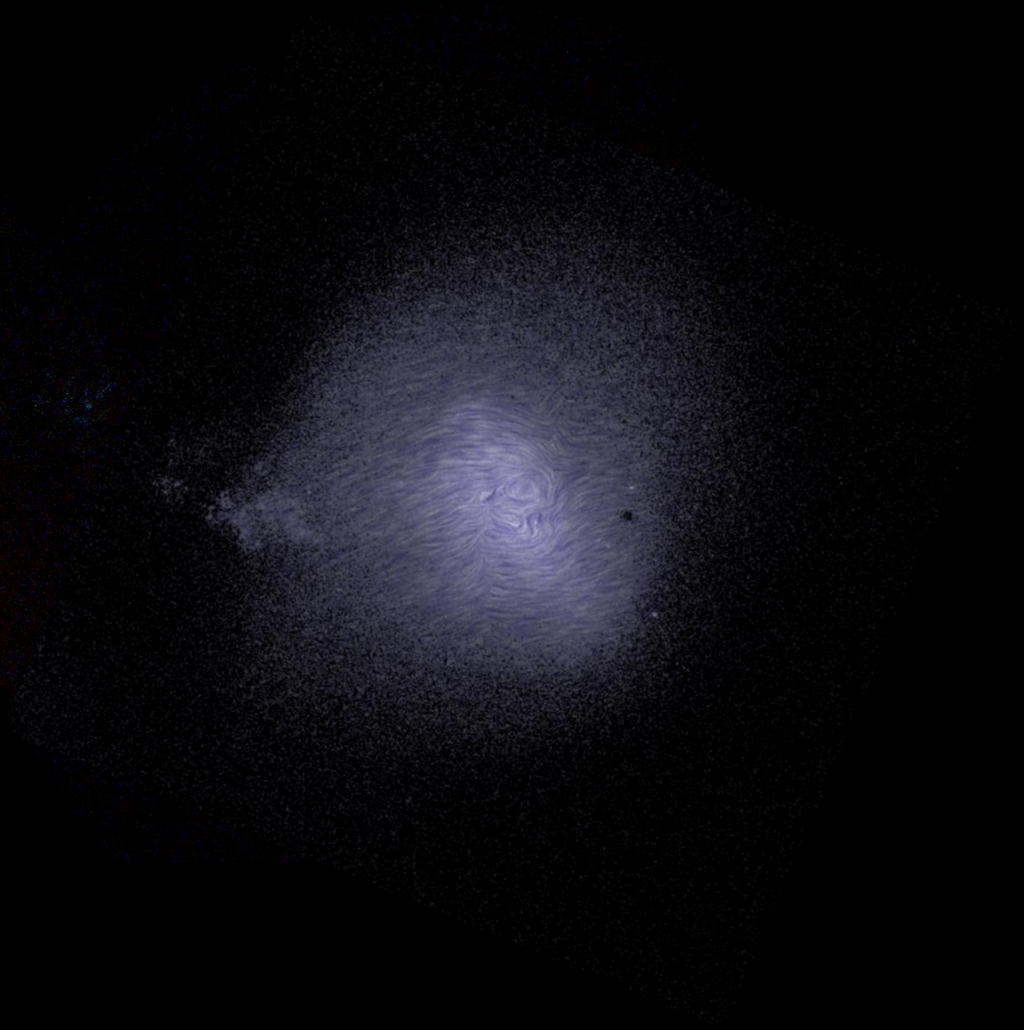
Stream - 200 degrees long

HI mass of Stream : 8.4 x10^8 M⊙
(Brüns et al 2005)

Magellanic Clouds with Gaia EDR3

Magellanic Clouds with Gaia EDR3 – proper motions





Galaxy interactions create stellar streams

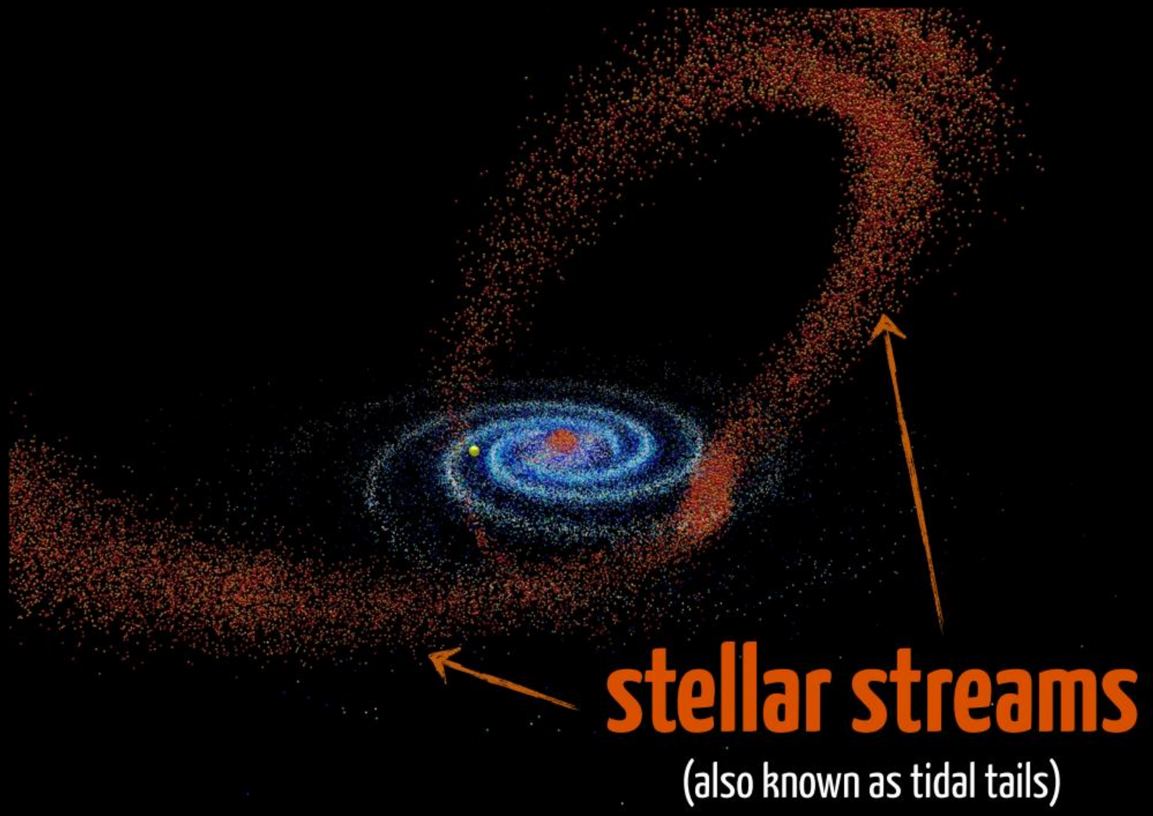
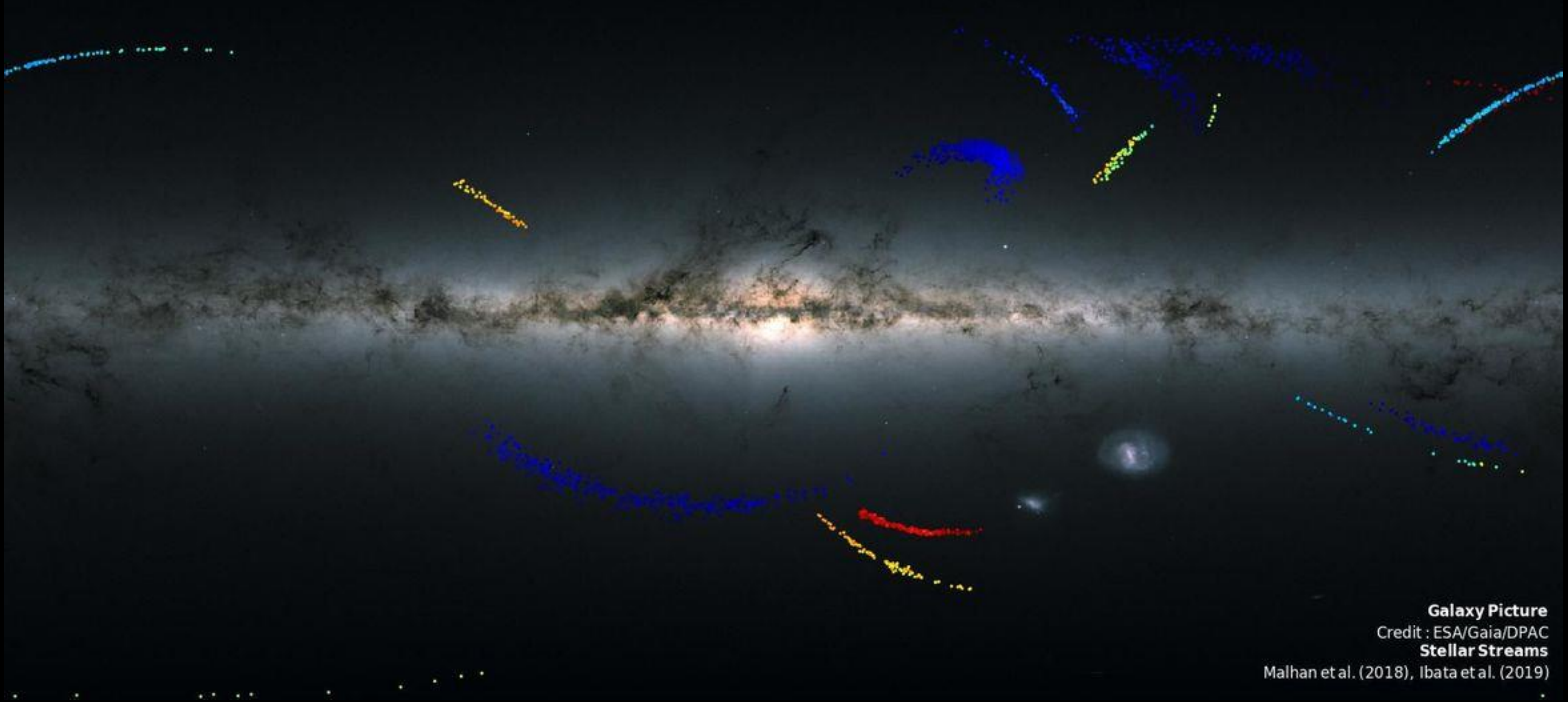
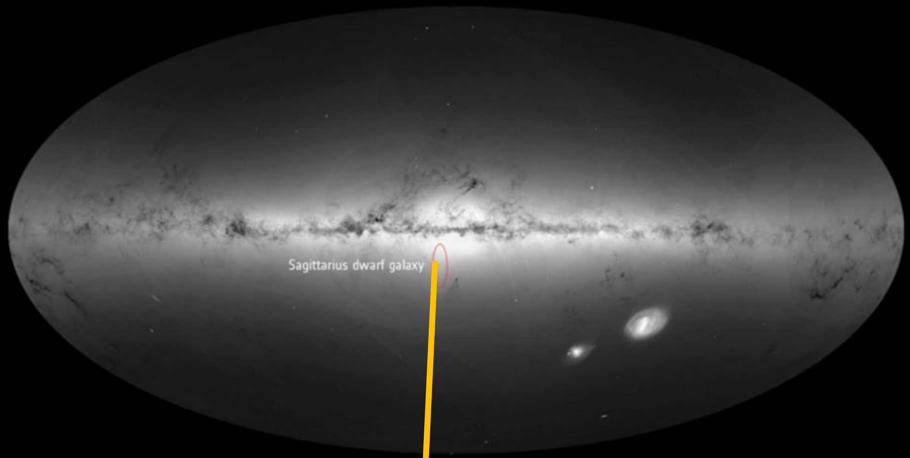


Image Credit: David Law (University of Toronto)

Stellar Streams in the Halo -Gaia DR2

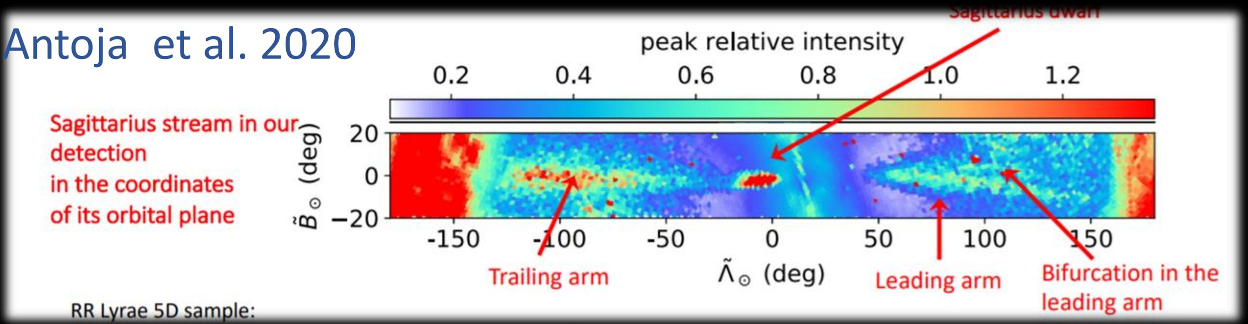
most of the streams appear to be debris of inner-halo globular clusters





ESA/Gaia/DPAC, CC BY-SA 3.0 IGO

Antoja et al. 2020



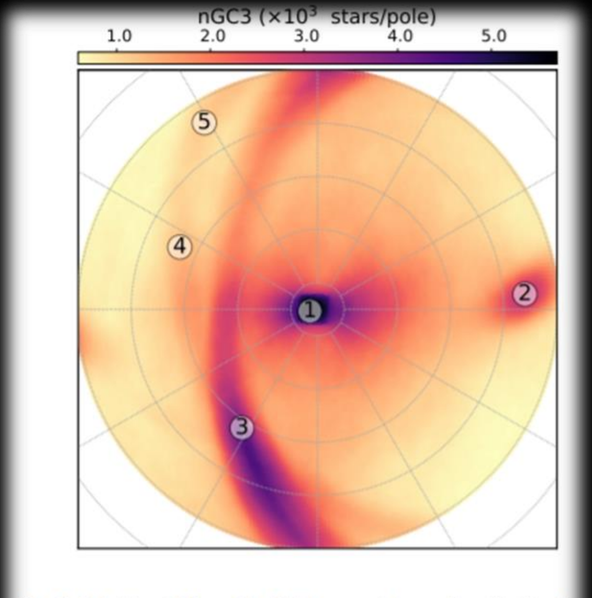
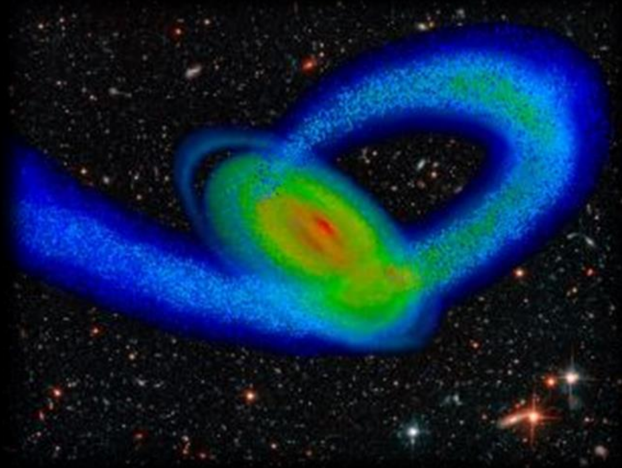


Fig. 1. Pole Count Map of the RR Lyrae catalogue described in Sect The Galactic disc produces the large concentration at (1), while peaks (3),(4), and (5) are related to the Large and Small Magella clouds. The prominent signal on the right, (2), is caused by the stream.

Ramos et al. 2020



The Sagittarius dwarf seems to have collided with the MW twice, 1.9 and 0.9 Gyr ago. Simulation by Purcel et al. 2011

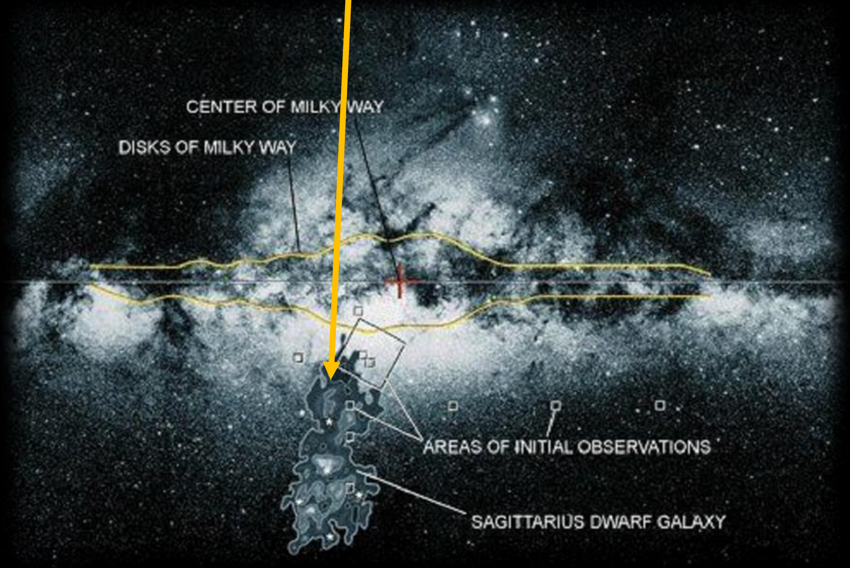


Image Credit: R. Ibata (UBC), R. Wyse (JHU), R. Sword (IoA)

Thank you for your attention