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Gaia

Global ***A***strometric ***I***nterferometer for ***A***strophysics

- ***Gaia:*** space observatory, designed for global astrometry

- **main goal:** make the *largest, most precise 3-D map* of our Galaxy through surveying an unprecedented 1% of the galaxy's population.

- **Launch date:** 19/12/2013

- **Mission duration:** 5 years (in plan); may extend by 1-4 years

A fully European mission by ESA (European Space Agency)

Outline

- Introduction of Astrometry
- Basic information about *Gaia* satellite
- Scientific highlights
- Summary

What is Astrometry?

Astrometry: get the precise measurements of the positions and movements of stars and other celestial objects.

What do we want to learn?

- **What do we want to learn:**
  - kinematical and dynamical structure and evolution of the galaxy
  - stellar structure and evolution etc.
    - If have Photometry/ Spectroscopy： chemical structure and evolution of the galaxy
- **people need:**
  - precise measurement of position and proper motion
  - photometry+spectroscopy measurement
  - large sample

Before *Gaia: Hipparcos*

High **p**recision **par**allax **co**llecting **s**atellite

- **mission duration :** 1989.8.8-1993.8.15

- **method :** parallax

- **two missions:**

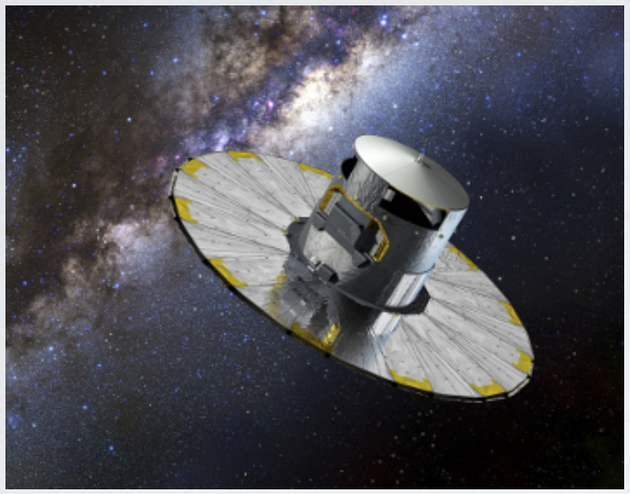
  - Hipparcos catalogue: 118,200 stars with parallax+proper motion

  - Tycho-2 catalogue: 2.5 million stars with B-V

Hipparcos
greek astronomer

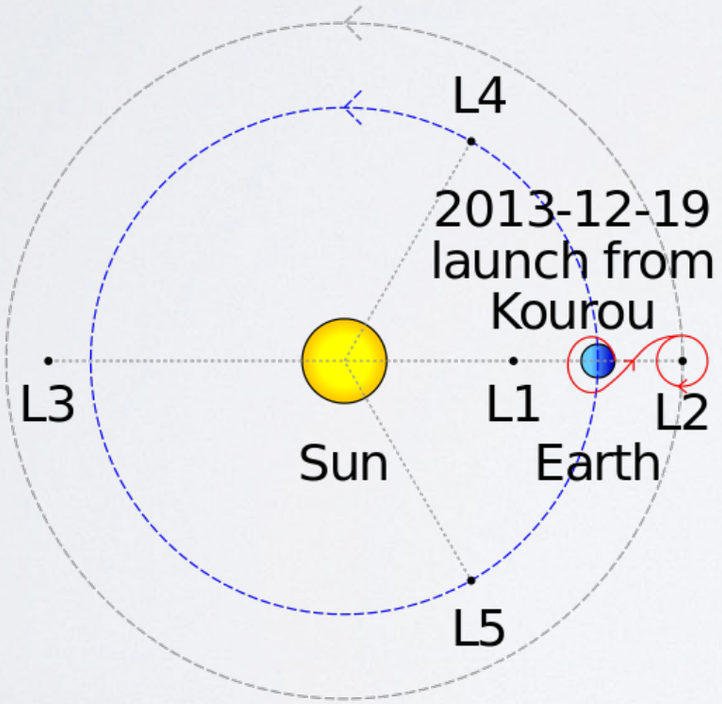
Gaia-spacecraft&payload

Global **A**strometric **I**nterferometer for **A**strophysics**...?**



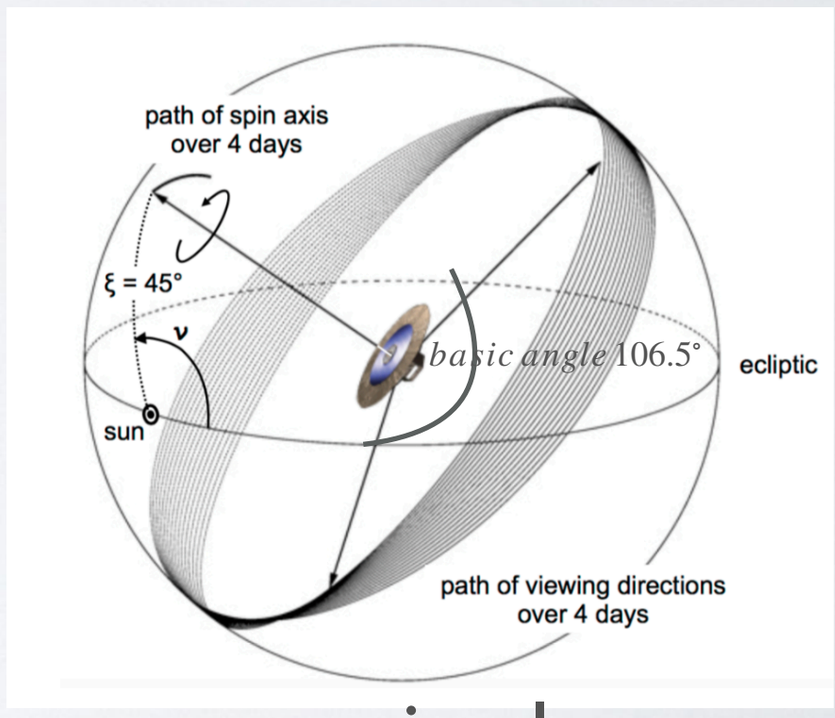
measure the absolute parallax based on direct imaging on CCDs by large telescopes

full sky coverage!



orbit: Sun-Earth L2 Lagrangian point

credit: wikipedia



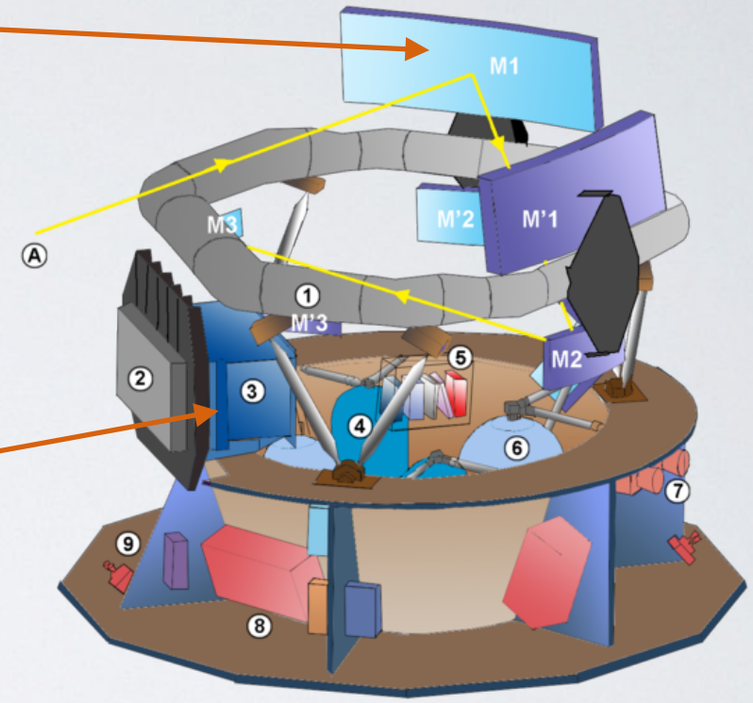
scanning law

Gaia-spacecraft&payload

primary mirrors
(1.45 m × 0.5 m)

reflection mirrors

focal plane
(CCDs)



Astrometry
(Astro)

Photometry
(BP/RP)

Radial-Velocity
Spectrometer
(RVS)

sky mapper
(get brightness)

G band
330-1050nm
G<20.7mag

Blue band:
330-680nm
Red band:
640-1050nm

G_{RVS} ~15 mag
narrow band, at
847-874 nm

G band
brightness

Gaia-performance

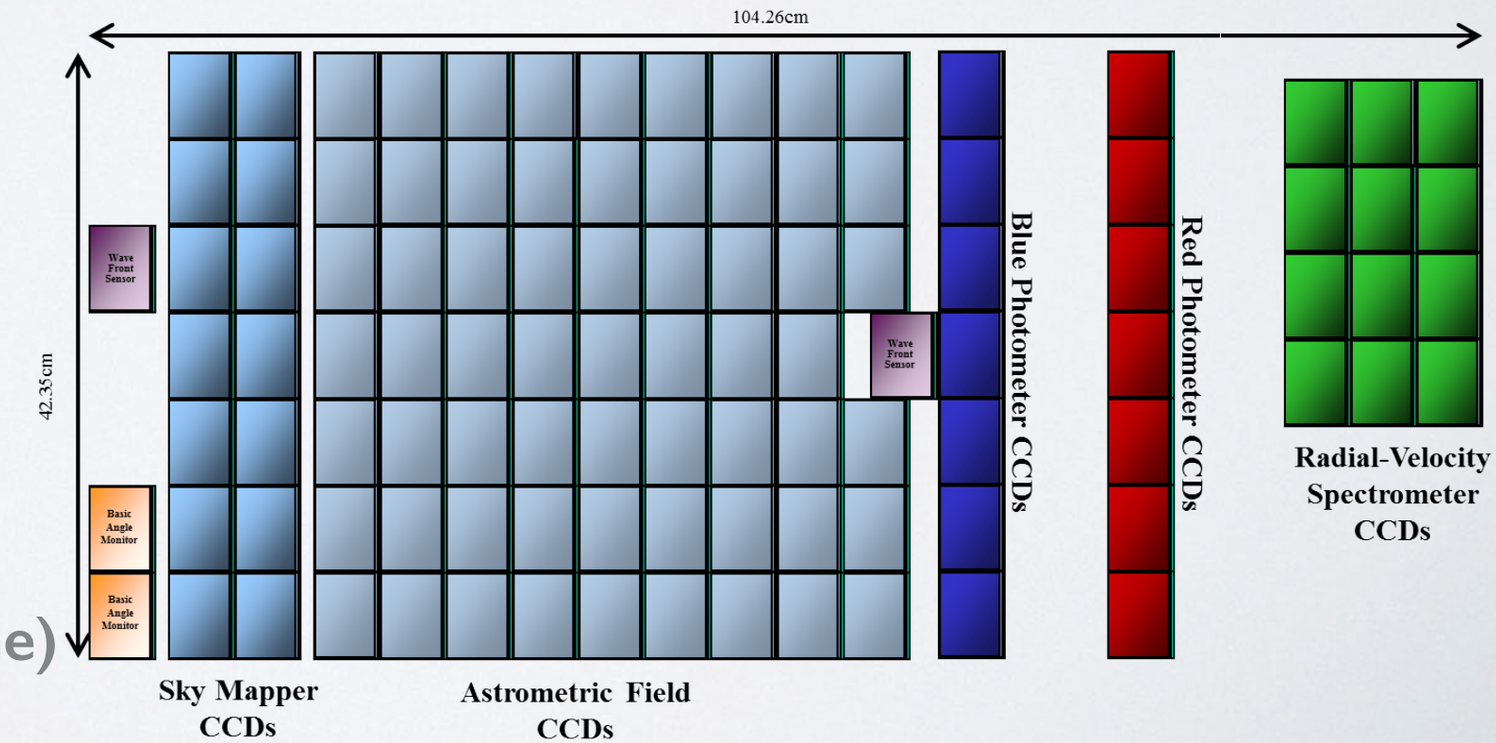
- Astrometry (Astro): ~1.3 billion stars;

magnitude	G=15	G=20
parallax accuracy	12-25 μas (1-2% at 1kpc)	100-300 μas

- BP/RP: ~5 milli-magnitude error
- RVS:
  - cover ~7million stars with V<15.7;
  - with 1~15% accuracy

self-calibration mission

5 years — observe 1 billion sources for about **70 times**



(CCDs on the focal plane)

Hipparcos vs Gaia

	Hipparcos	***Gaia***
sample	120,000	1.3 billion
accuracy	$1mas$	$12-25\mu as$
depth	G~12.4	G~20.7
time	1989-1993	2013-
cost	€600 million	€740 million

Gaia-Scientific Highlights

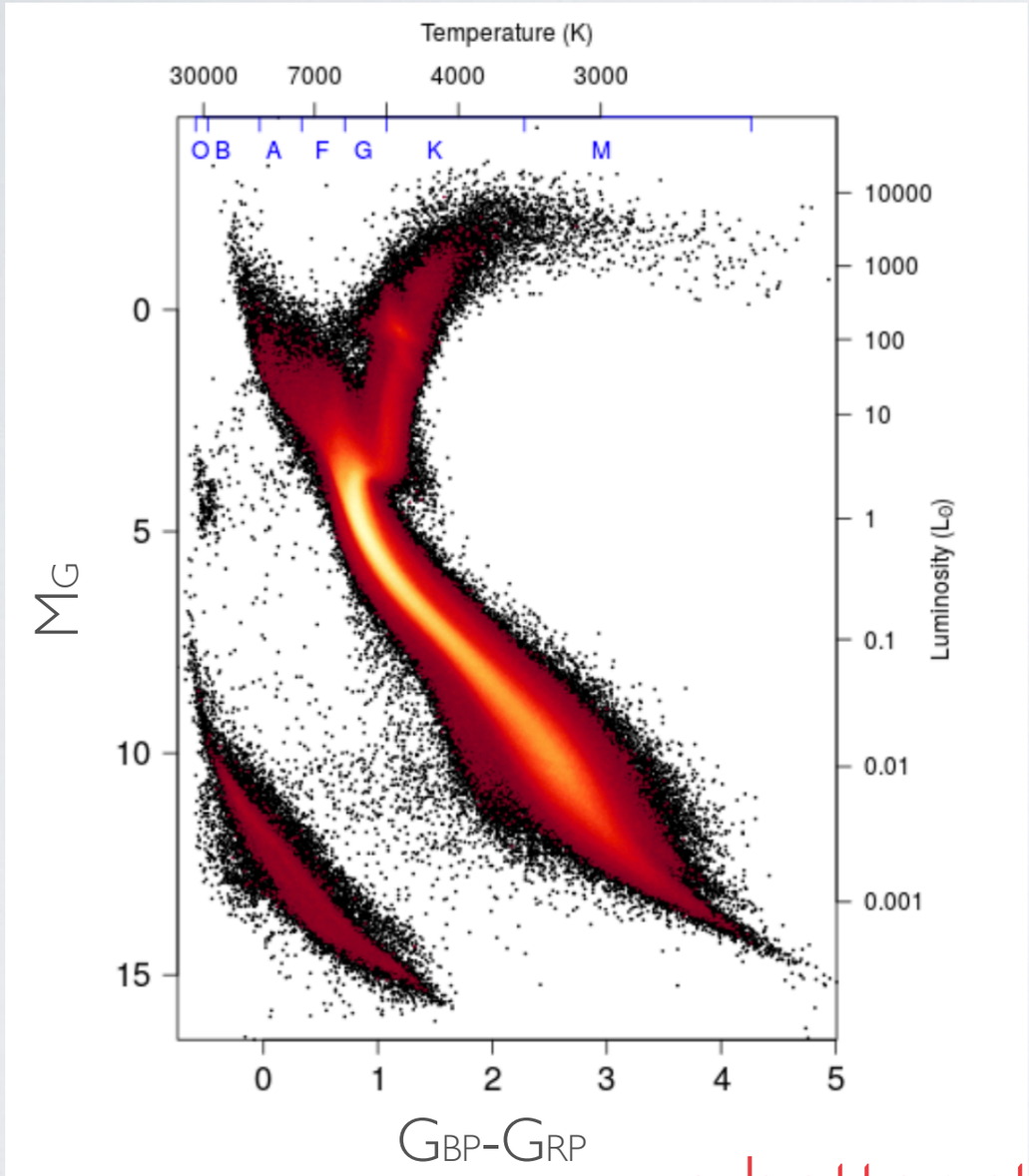
- **Stellar physics and evolution**
  - Fine structure of H-R diagram
    - white dwarfs of different types
    - separate binary stars and get binary fraction
    - planetary nebulae
  - variable stars
- **Extroplanet Detection:** will discover ~20,000 Jupiter mass exoplanets
- **Fundamental physics:** test GR and etc.

- **Dynamics, structure and evolution of the Galaxy**
  - potential model of the MW
  - stellar streams (trace the potential & mass distribution of MW)
  - phase mixing phenomena(perturbation of the potential…)
  - trace black holes
  - kinematics of globular clusters around MW
  - …

Gaia-Scientific Highlights

Stellar physics and evolution

Gaia-HRD



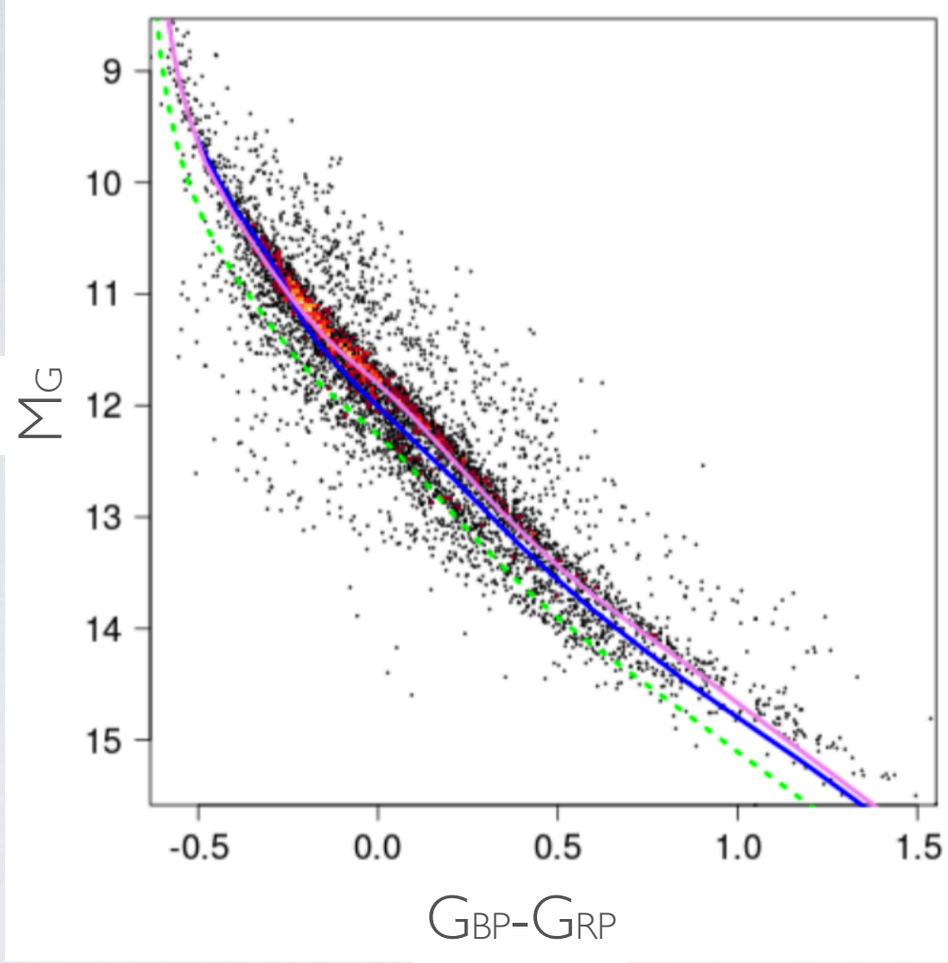
get fine structure of field stars' H-R diagram

- planetary nebulae & post-AGB star
- white dwarfs
- down to the brown dwarfs

a better stellar evolution model !

Credit: Collaboration G, Babusiaux C, Van Leeuwen F, et al., 2018

Gaia-HRD



Gaia white dwarfs in HRD

models:

Magenta:

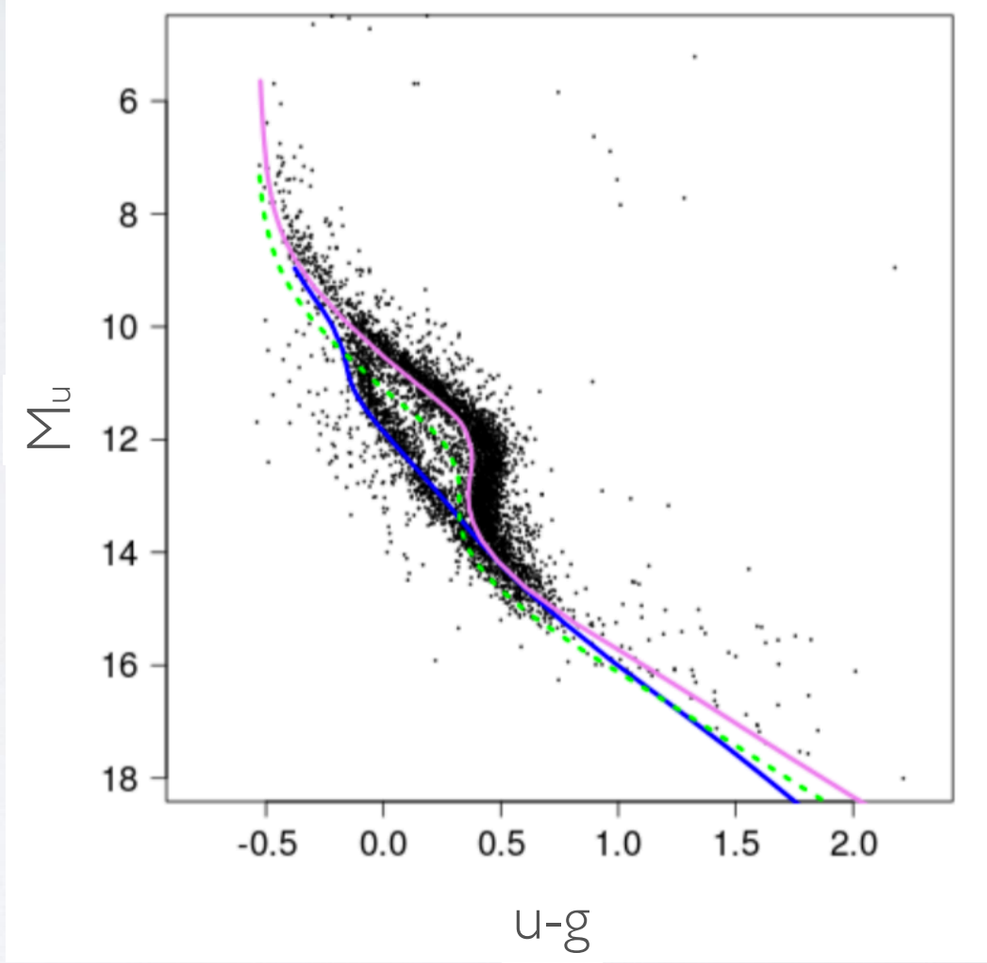
0.6 M⊙ pure H;

green dashed:

0.8 M⊙ pure H;

blue:

0.6 M⊙ pure He



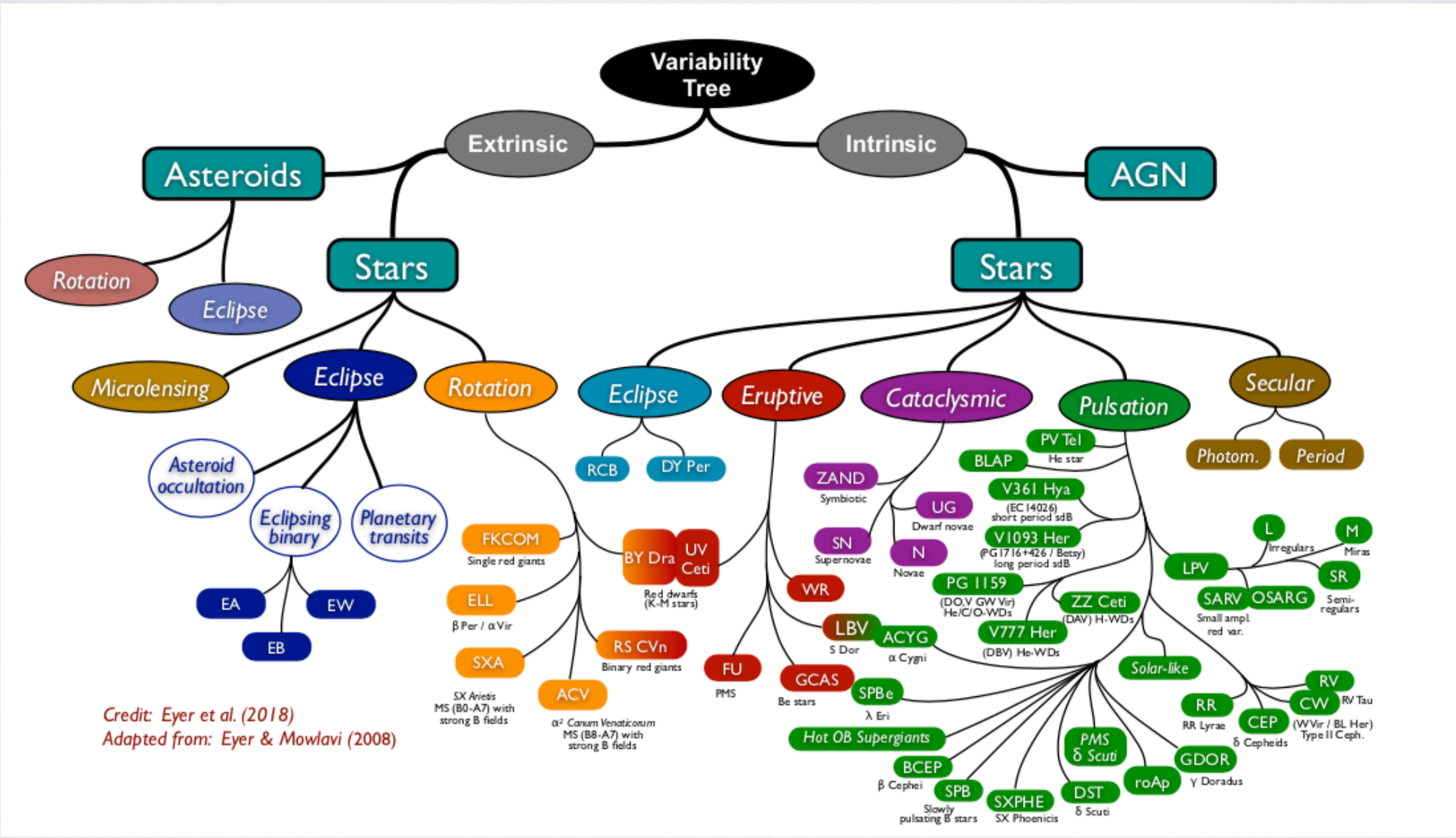
SDSS white dwarfs

The first time resolve different types of WDs in HRD!

Credit: Collaboration G, Babusiaux C, Van Leeuwen F, et al., 2018

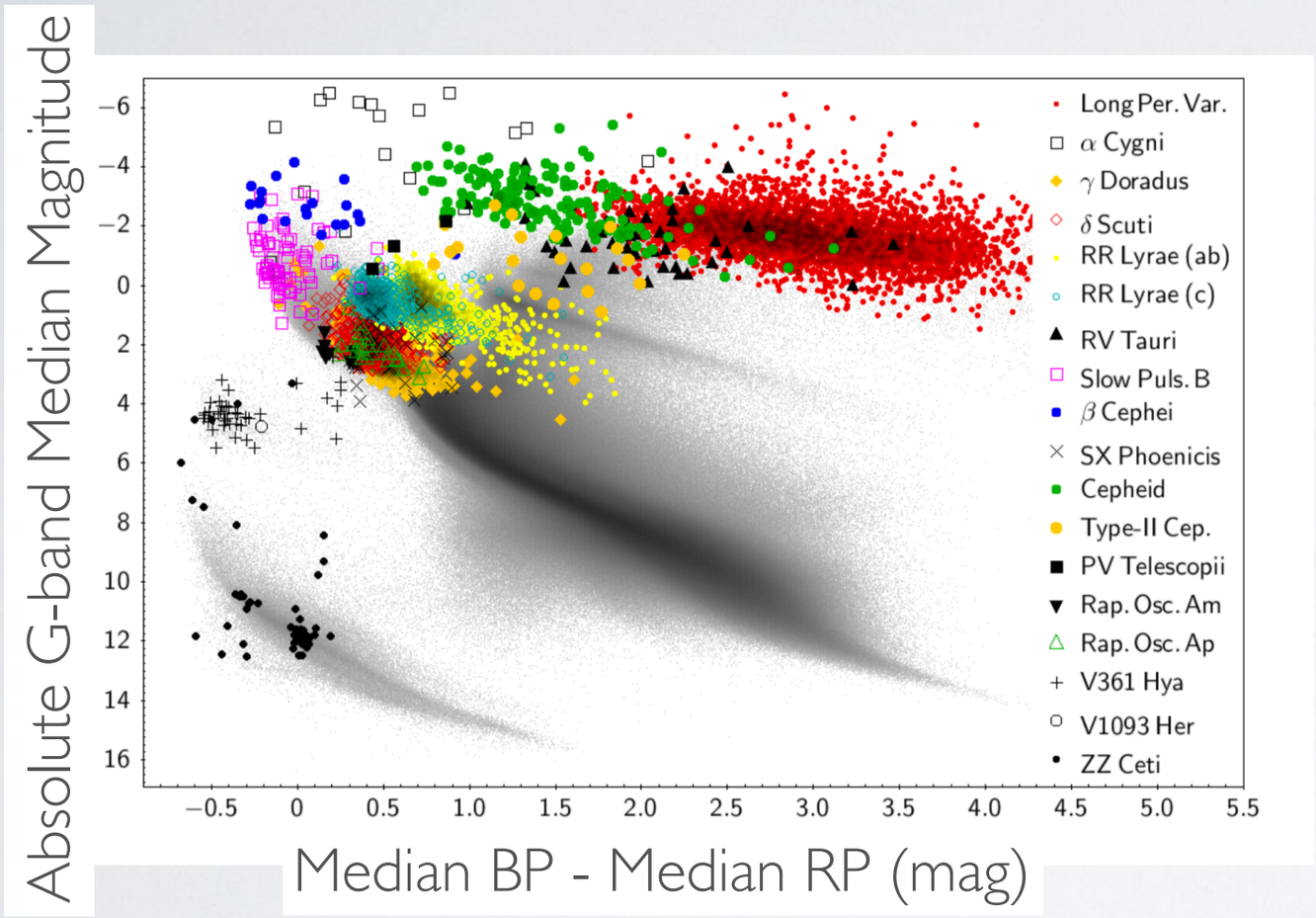
Gaia-Variable stars

variable stars: stars whose brightness change, either irregularly or regularly.



Credit: Eyer et al. (2018)
Adapted from: Eyer & Mowlavi (2008)

Gaia-Variable stars



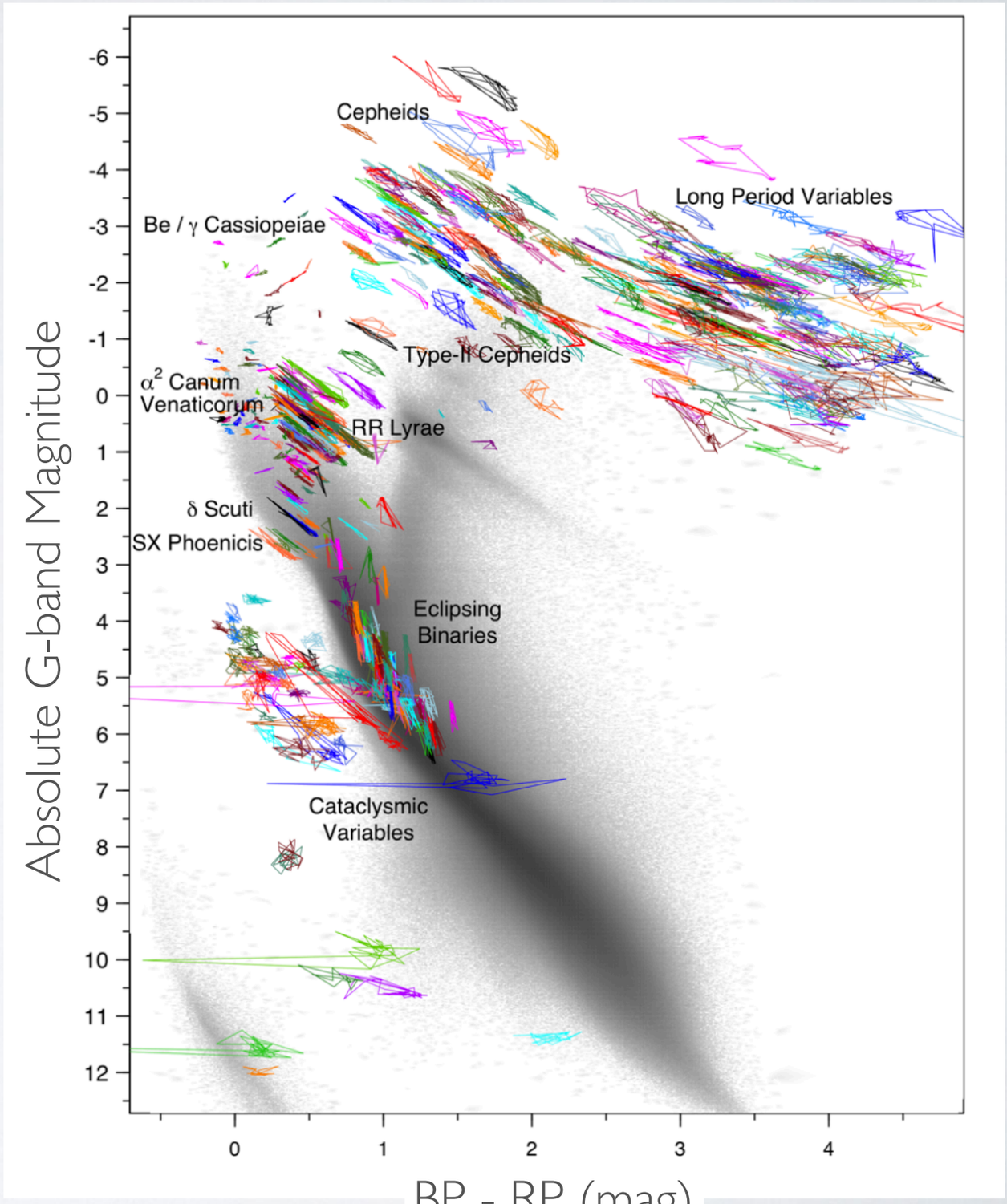
Gaia time series data + Gaia parallaxes:

Time-dependent colour-absolute magnitude diagram (CaMD) towards any direction in the Milky Way !

Credit: Bland-Hawthorn et al., 2018, arXiv 1809,02658B

Gaia-Variable stars

the ‘motion’ of variable stars in CaMD

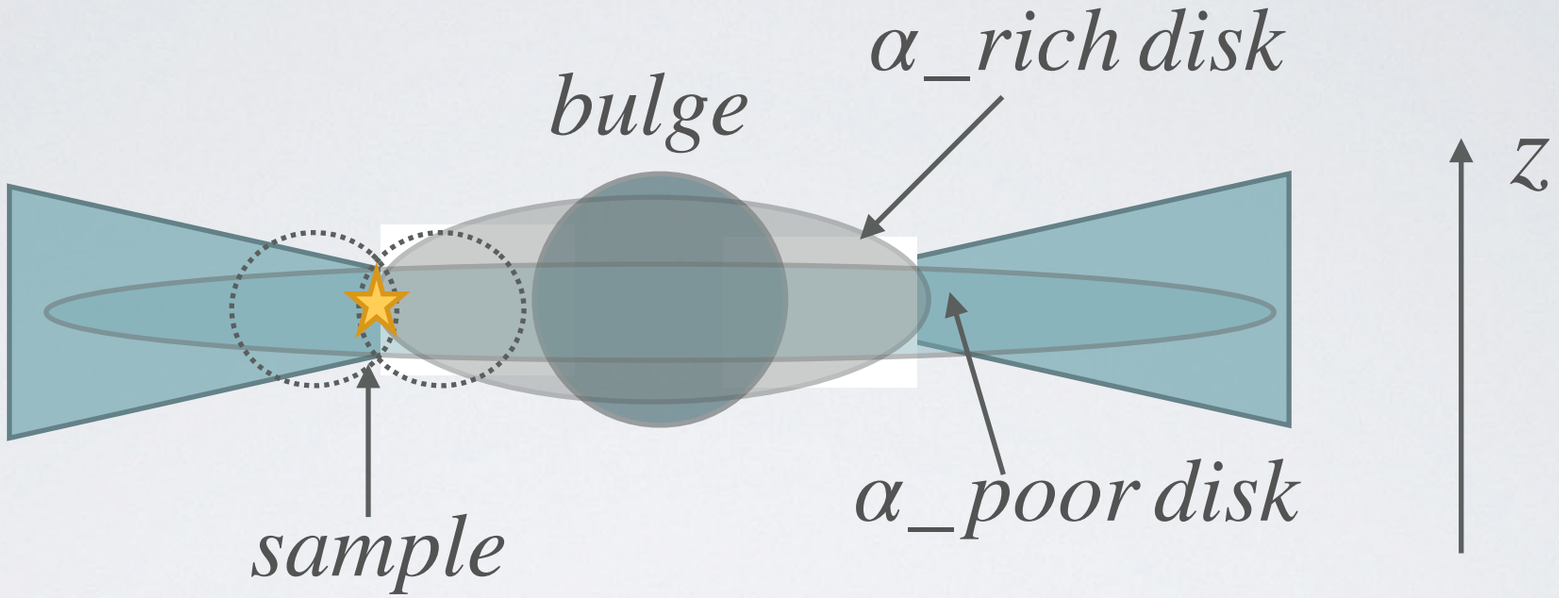


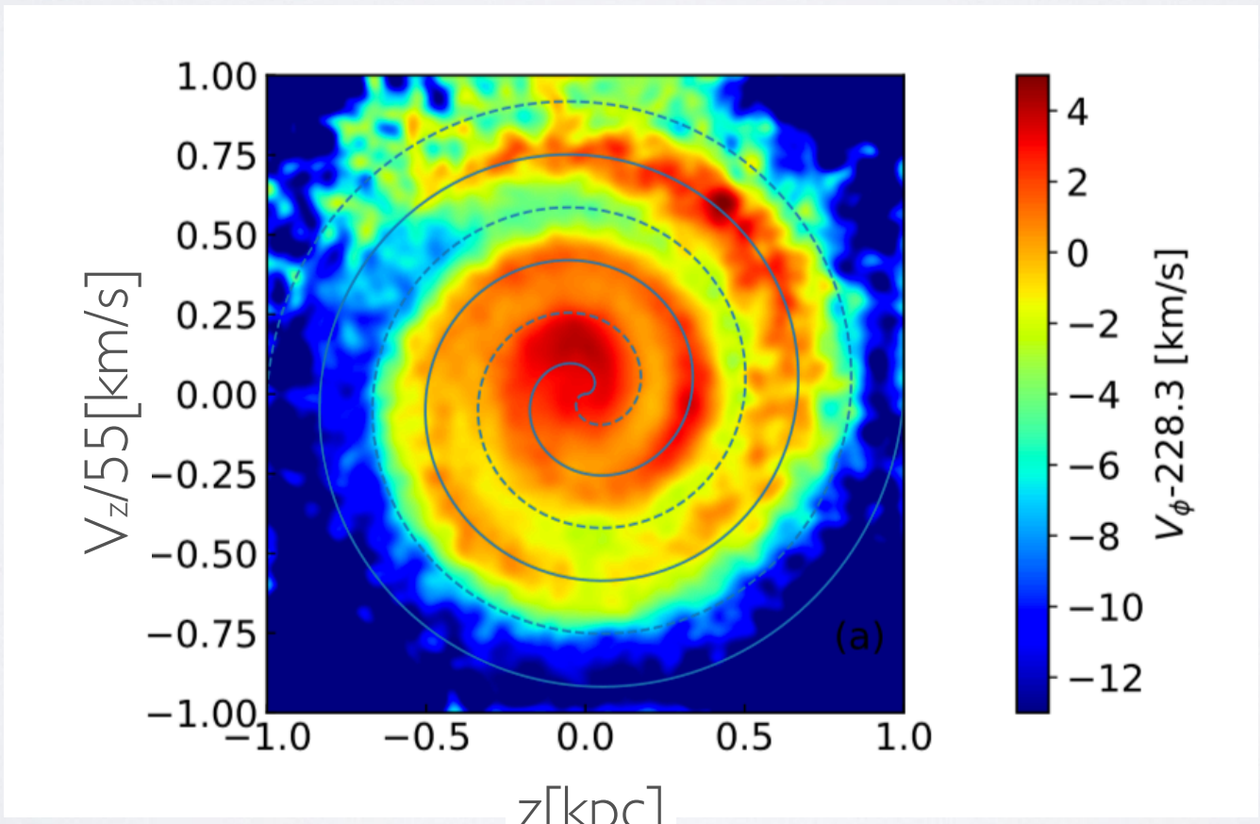
Credit: Collaboration G, L Eyer et al., 2018

Gaia-Scientific Highlights

dynamics, structure and evolution of the Galaxy

Gaia-phase mixing

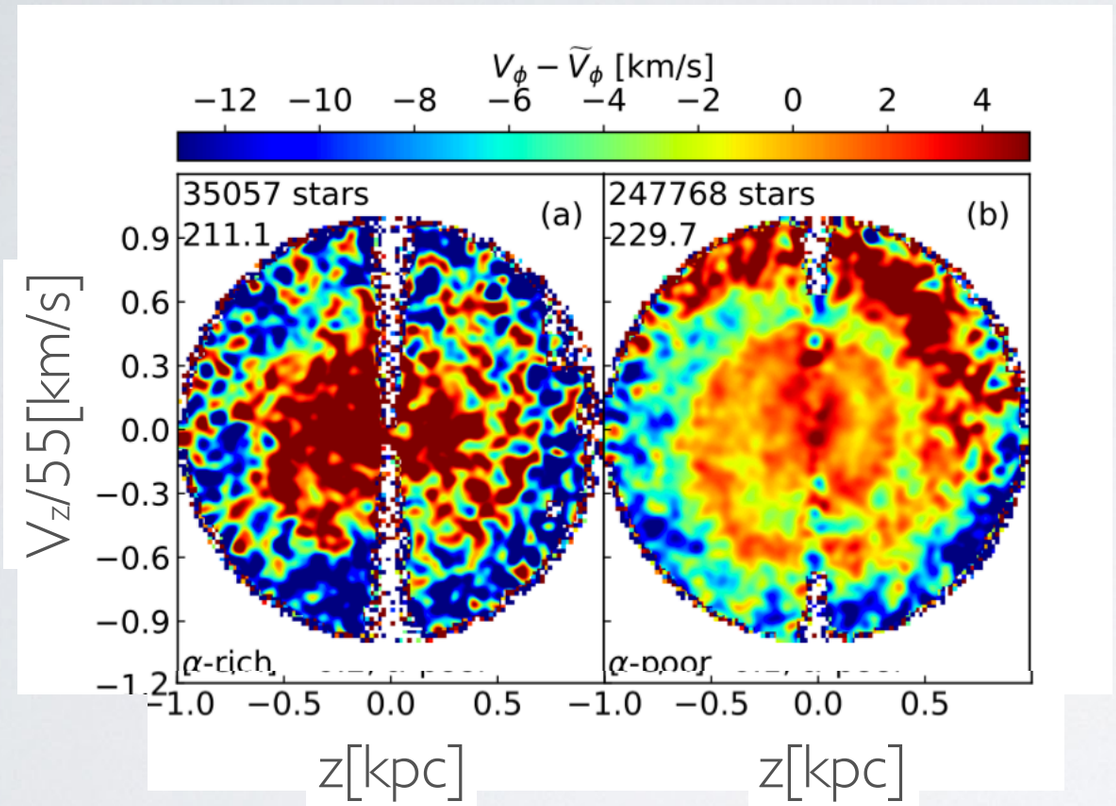


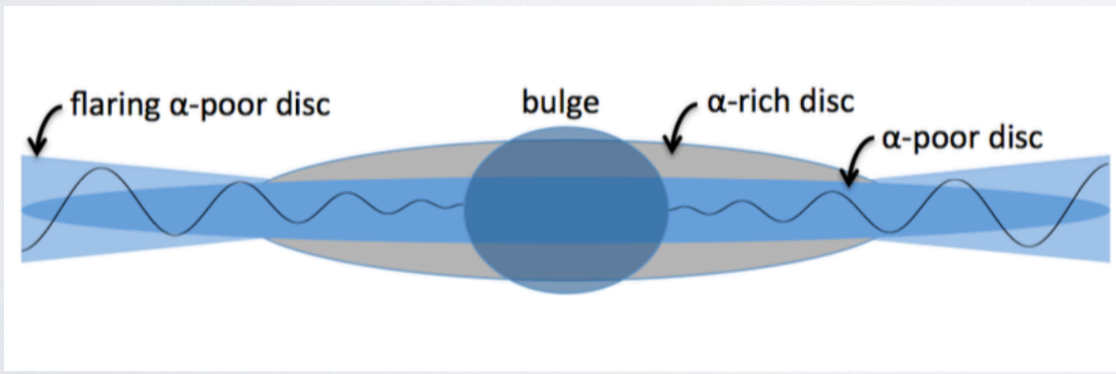


"phase spiral"

Credit: Bland-Hawthorn et al., 2018, arXiv 1809,02658B

Gaia-phase mixing





A sketch of the corrugated disk

Credit: Bland-Hawthorn et al., 2018, arXiv 1809,02658B

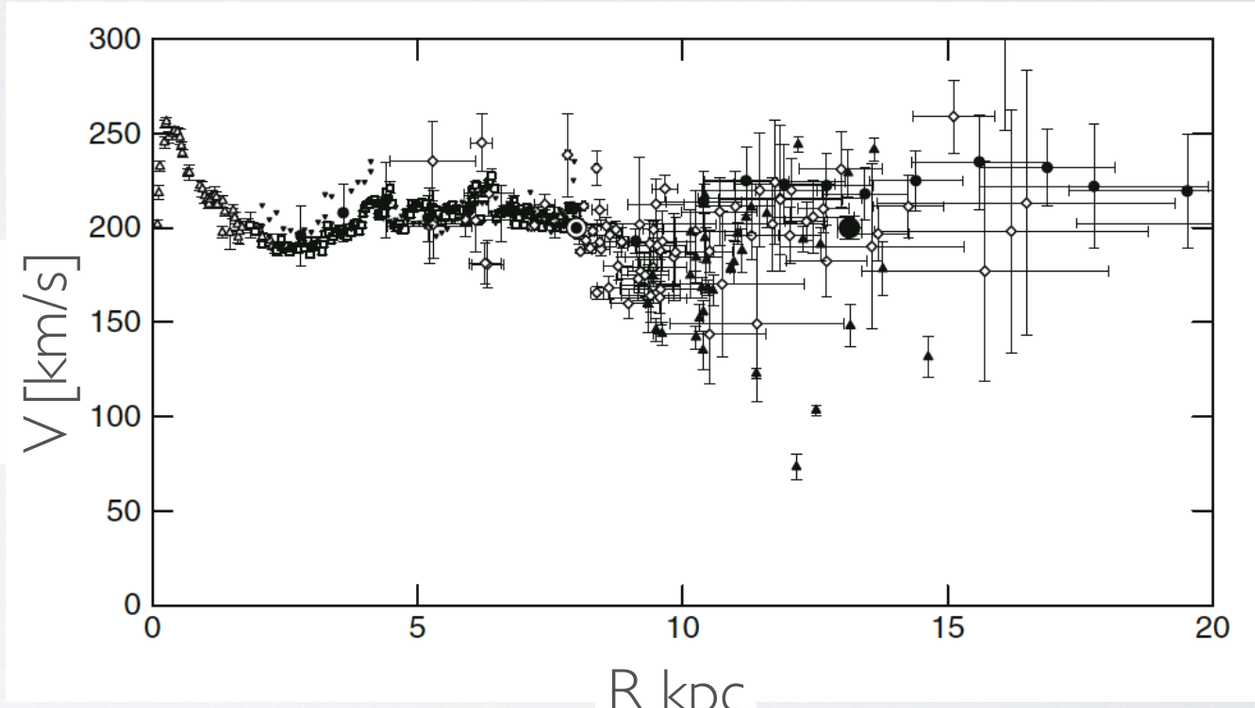
phase mixing for α_rich and α_poor stars

tidal pull of the galaxy by passing substructure?
(possibly Sgr dwarf)

Gaia-stellar streams

Constrain the mass distribution of MW:

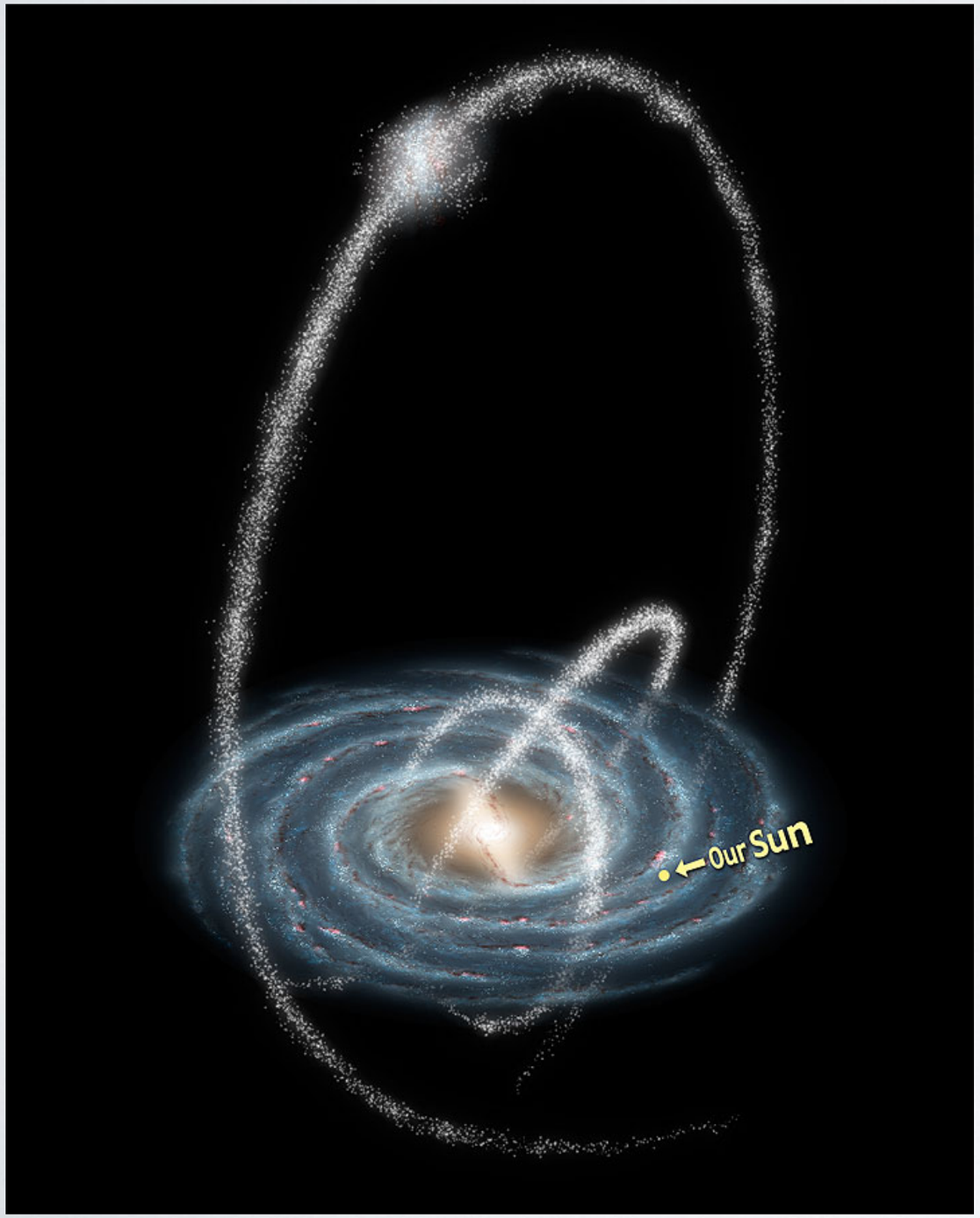
- rotation curve
- distribution functions (metallicity, momentum etc.)
- orbital analyses of satellites
- stellar streams
- …



rotation curve of MW

(Sofue et al., 2009)

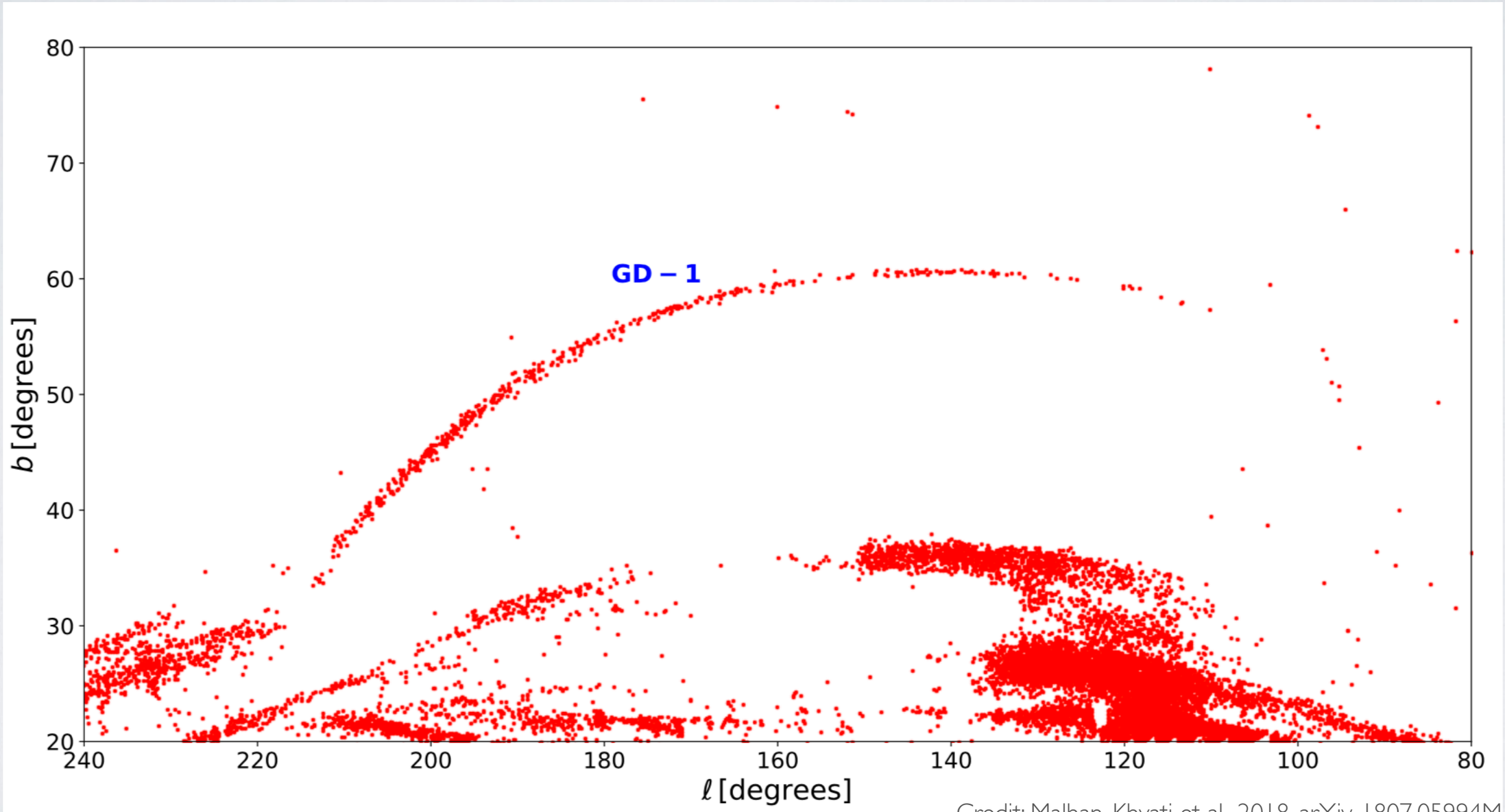
Gaia-stellar streams



Stellar stream: structures formed via **tidal disruption** of **globular clusters** or **dwarf galaxies** as they orbit around their host galaxy

Credit: Bland-Hawthorn et al., 2018, arXiv 1809,02658B

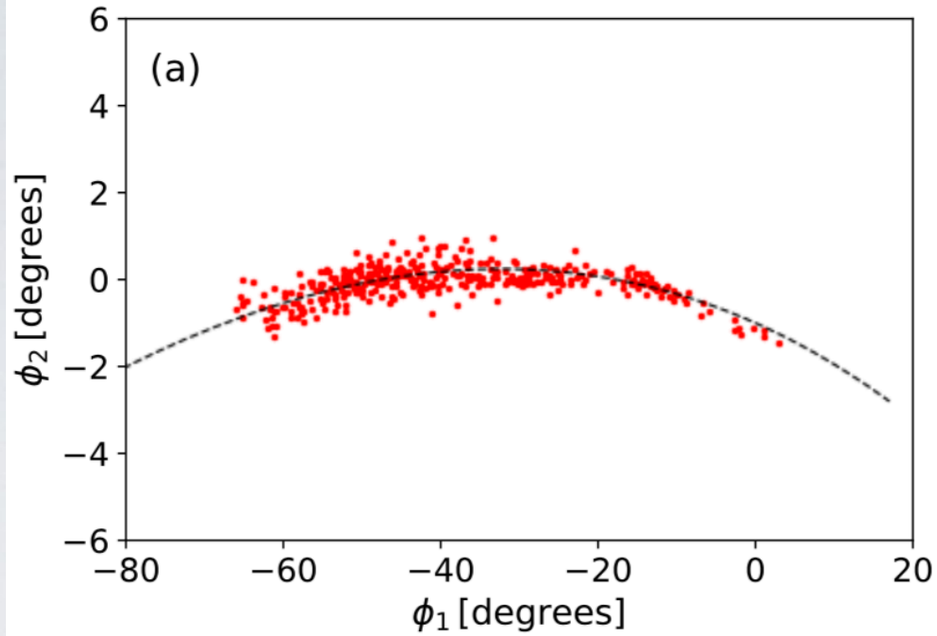
Gaia-stellar streams

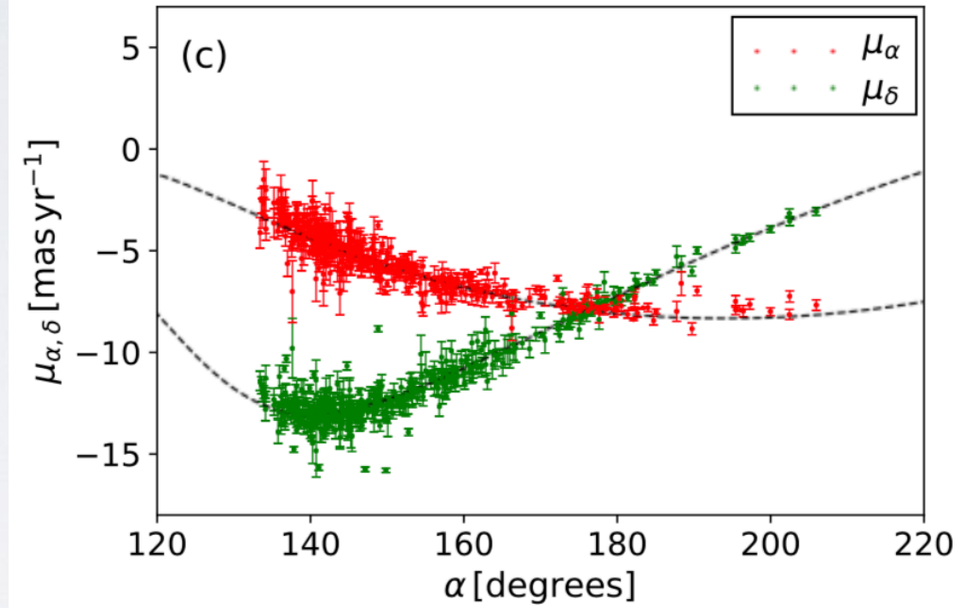


Credit: Malhan, Khyati et al., 2018, arXiv, 1807.05994M

GD-1 stream in the STREAMFINDER density map

Gaia-stellar streams





use orbital fitting procedure with potential models.

(Here shows NFW halo profile fitting)

axisymmetric NFW halo model:

bulge $\rho_b(r) = \rho_{bo}\left(\frac{r_1}{r}\right)^{\alpha} e^{-(r/r_c)^2}$

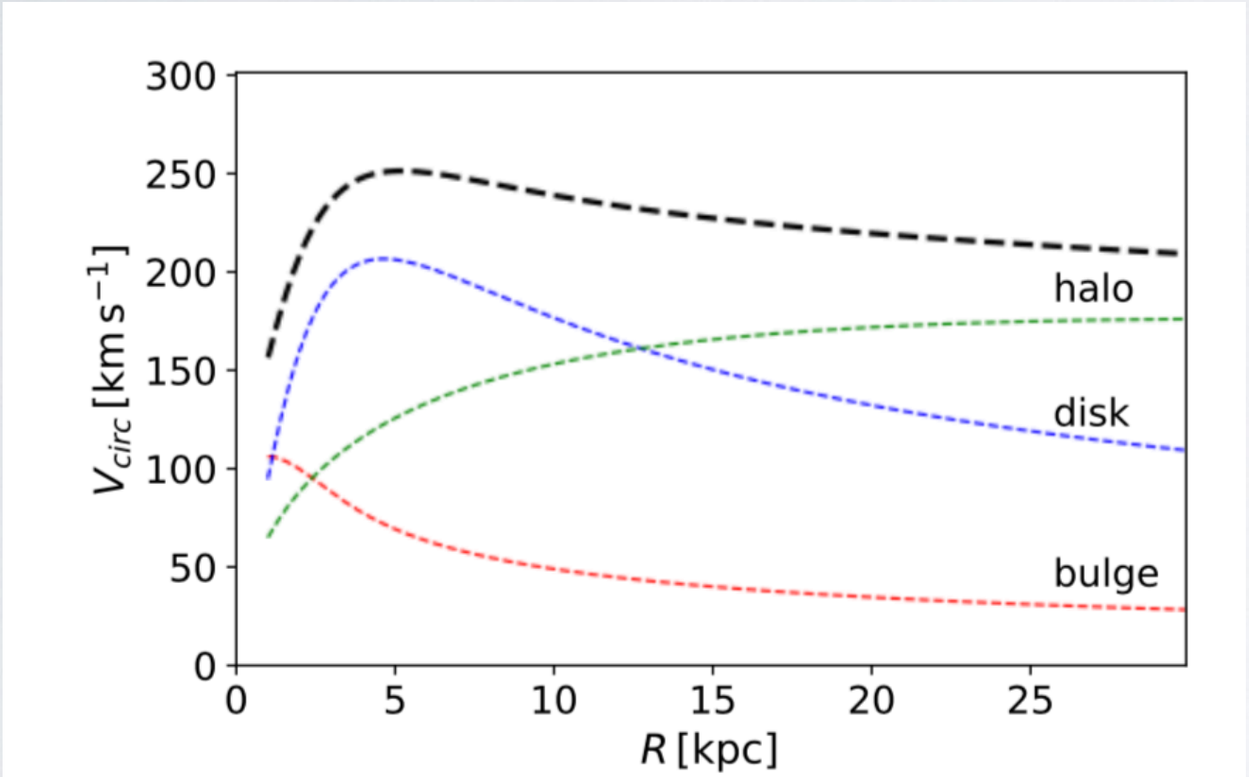
DM halo $\rho_h(x,y,z) = \frac{M_{vir}}{4\pi r_s^3}\frac{1}{(m/r_s)(1+m/r_s)^2}$,

where

$m = x^2 + \frac{y^2}{(b_h/a_h)^2} + \frac{z^2}{(c_h/a_h)^2}$.

Credit: Malhan, Khyati et al., 2018, arXiv, 1807.05994M

Gaia-stellar streams



NFW fitting result

rotation curve of MW

constrain $(v_{cir}(R_\odot), q_\rho)$ parameters of MW:

$$(V_{\rm circ}(R_\odot), q_\rho) \;=\; (244^{+6}_{-2}\,{\rm km\,s^{-1}}, 0.86^{+0.04}_{-0.07})$$

constrain mass of MW

$$M_{\rm MW}(< 14.5\,{\rm kpc}) = 1.75^{+0.06}_{-0.05} \times 10^{11}\,{\rm M}_\odot$$

Analyses only one stellar stream can get really good constrain!

Credit: Malhan, Khyati et al., 2018, arXiv, 1807.05994M

Gaia-The study of MW?

The study of MW

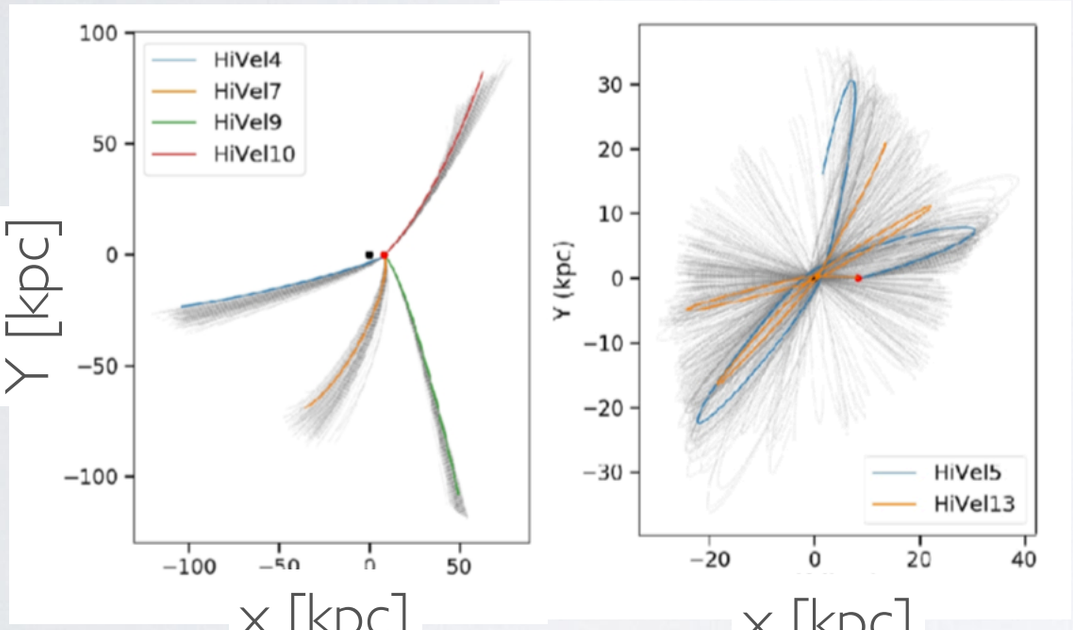
a better understanding of **other (spiral) galaxies**

Gaia & LAMOST

LAMOST: better spectroscopy

- provide radial velocity, chemical information, T_{eff} $log\, g$ etc.

LAMOST+Gaia:



from tidal debris of dwarf galaxy or globular cluster?

Interaction related to galactic center

Credit: Du, Cuihua et al., 2018

High velocity stars:

- stars interact with BH at galactic center
- binary stars interact with BH
- tidal debris of accreted & disrupted dwarf galaxy/cluster
- surviving companion stars of supernova explosion
- …

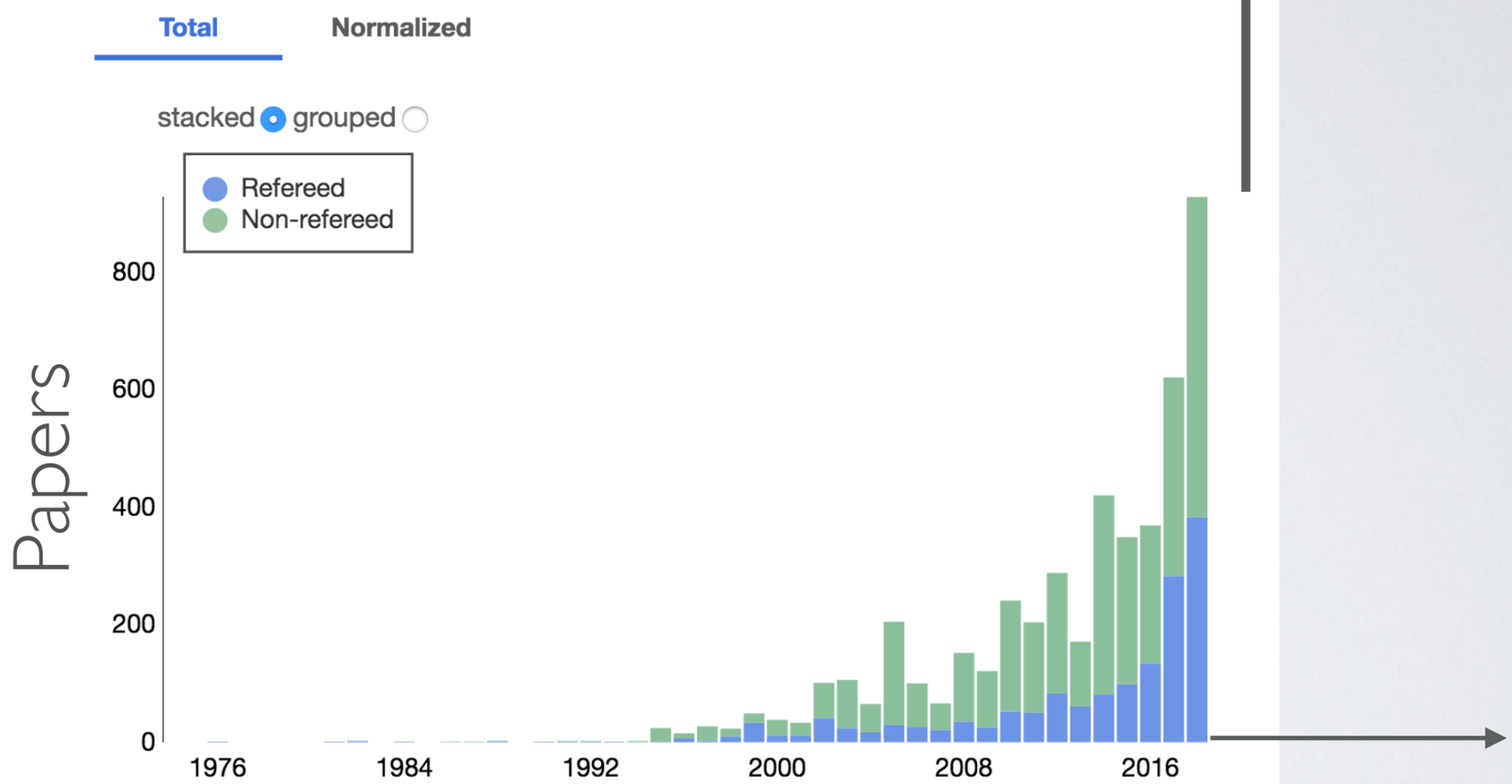
Gaia-data release

- ***Gaia* DR1: 14 September 2016**
  - positions and G magnitude for all source (~1.1 billion)
  - position, parallax and proper motions for stars in common between Tycho-2 and Gaia
- ***Gaia* DR2: 24 April 2018**
  - position, parallax and proper motions for 1.3 billion sources
  - median radial velocity for about 7.2 million bright stars
- ***Gaia* DR3: likely the first half of 2021**
  - improved astrometry and photometry
  - non-single star catalogues will be released

Gaia-papers!

???

	Totals	Refereed
Number of papers	4733	1531
Normalized paper count	2027.0	535.2



Summary

- Astrometry is important for understanding stellar & galaxy evolution
- *Gaia* would get high precise astrometry measurement + photometry
    - How does Gaia achieve the performance: spacecraft, payload
- Scientific highlights:
    - stellar physics
    - MW structure
- Output of *Gaia*

Reference

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https://en.wikipedia.org/wiki/Gaia_(spacecraft)