Gaia: mission status and results from the second data release

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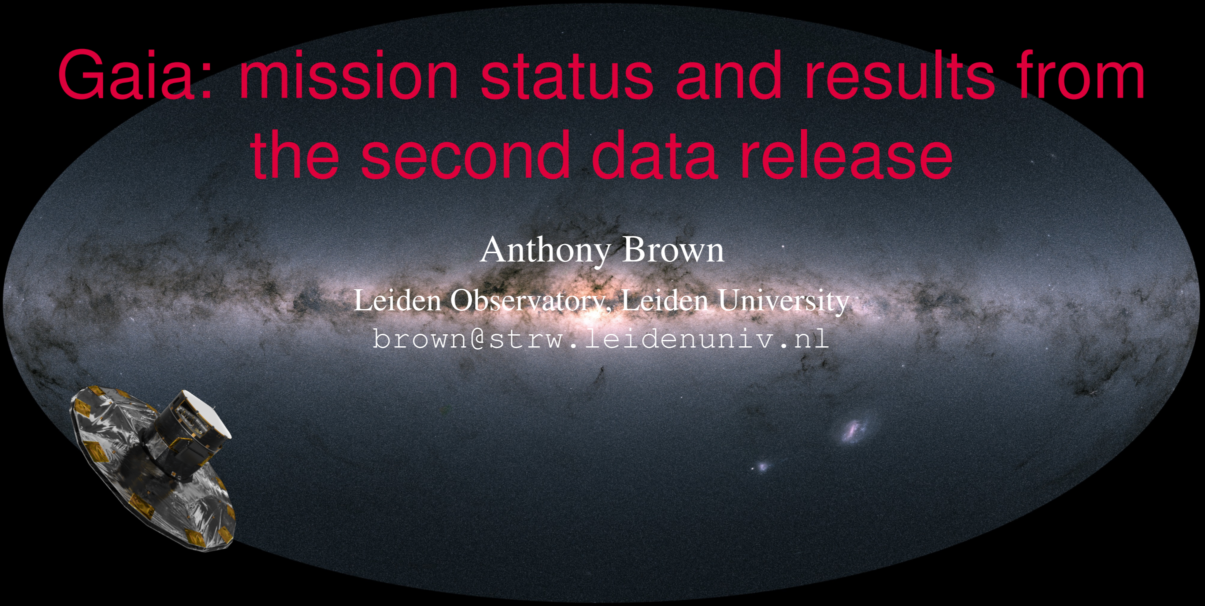
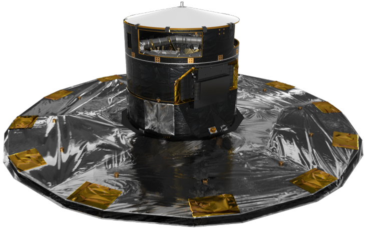


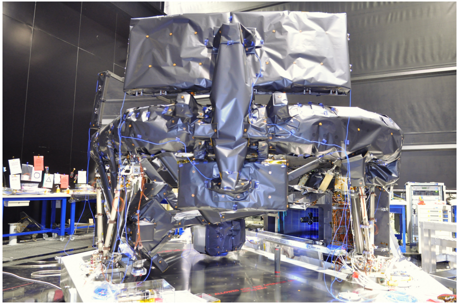
ESA/Gaia/DPAC

Gaia

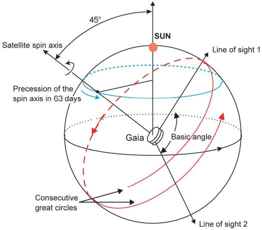
- Astrometry and spectrophotometry for > 1 billion sources
- Radial velocities for > 100 million sources
- Survey
  - Complete to $G = 20.7$ ($V = 20$–22)
  - Quasi-regular time-sampling over 5 years (~ 70 observations)
- Launch December 2013
- 5 years of nominal operations at L2
  - mission extended to end 2020 (+1.5 yr)

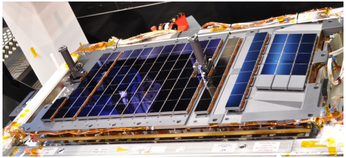
- Second data release April 25 2018
- Photometric alerts started in 2014
- Alerts on new solar system objects started end 2016

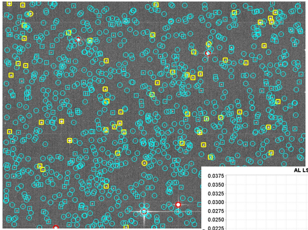


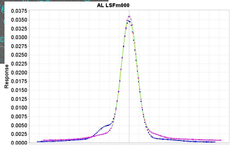


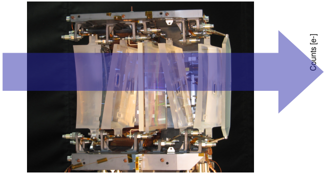
Gaia instruments and measurements

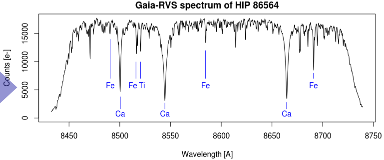


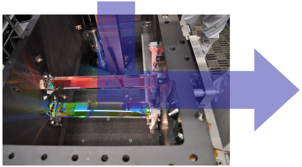


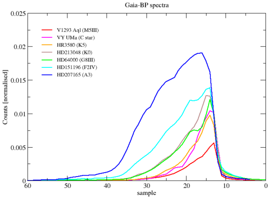


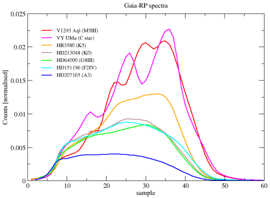












gaia

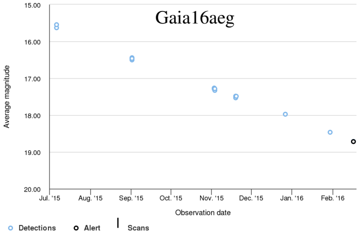
Gaia DPAC

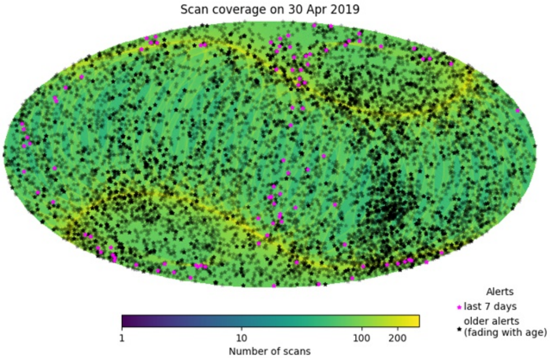
AIRBUS DEFENCE & SPACE

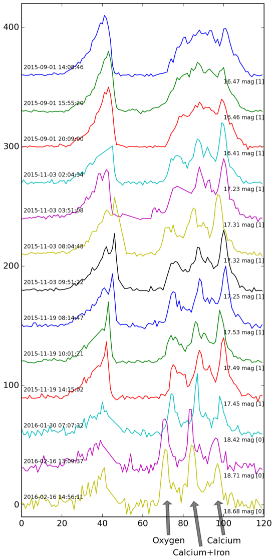
Photometric alerts

ESA/Gaia/DPAC/Gaia Science Alerts Team/Morgan Fraser/Simon Hodgkin/Lukasz Wyrzykowski

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







Solar system alerts

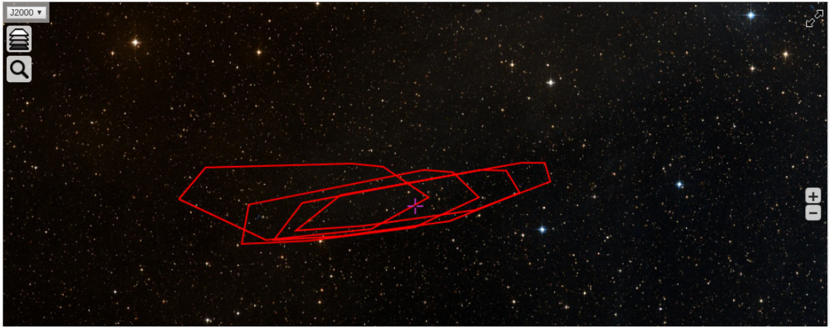
- **Gaia ID:** -4194951672
- **Database ID:** 51453
- **Name:** g2h09E
- **Magnitude (V):** $19.4^{+0.1}_{-0.1}$
- **Date of observation:** 8/21/2018

Back to Gaia alerts

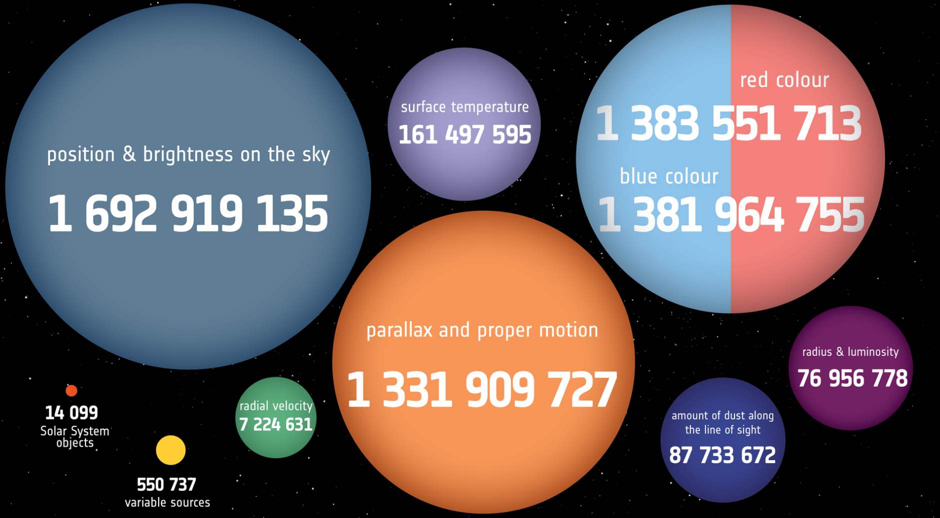
https://gaiafunsso.imcce.fr/index.php

B. Carry (OCA), W. Thuillot (IMCCE)

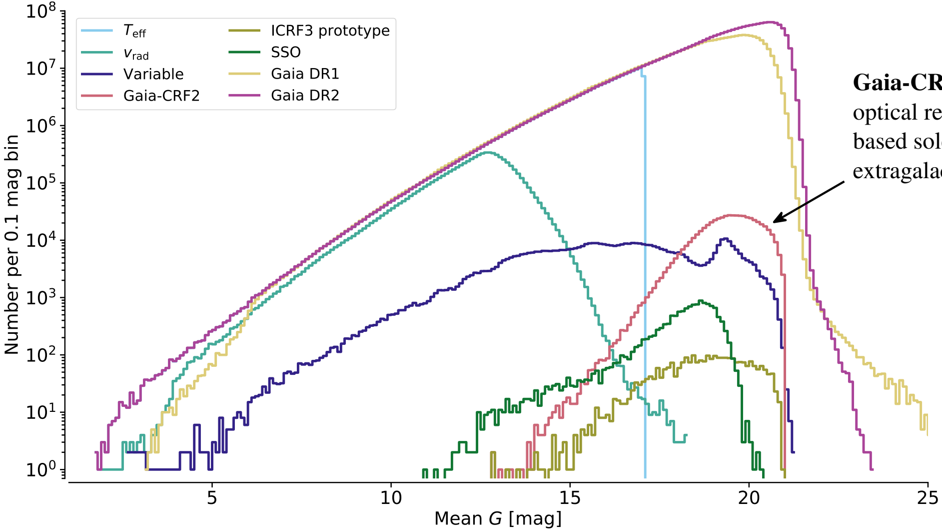
Sky view with Aladin -- Object expected magnitude V= $19.4^{+0.1}_{-0.1}$



Gaia DR2 in numbers



Source counts



Gaia-CRF2: First optical reference frame based solely on extragalactic sources

GAIA DR2 INFO

Information on Gaia Data Release 2 contents, completeness and limitations.

GAIA DR2 PAPERS

Titles and links to papers describing the data processing and demonstrating the science potential of Gaia Data Release 2.

GAIA DR2 DOCUMENTATION

The full documentation for the second data release, both on webpages and with a downloadable PDF-file

GAIA DR2 DATA

Gaia Data Release 2 data is now available.

GAIA DATA CREDITS

When using Gaia data, please acknowledge the work of the people involved and provide credits and necessary citations.

GAIA DR2 KNOWN ISSUES

Issues with the Gaia DR2 data important for the users to know that were discovered after the release of data and documentation

TUTORIALS AND HELP

Help is available to guide you through the process of getting the data you need. Check out the tutorials as they are very instructive!

LEARN ADQL

Gaia Data Release 2 contains a lot of data. While downloading the data will be possible, you can also bring your code to the data and access the data in a smart way. You can use ADQL queries to extract the data and then download the resulting table.

GAIA DR2 VIRTUAL REALITY RESOURCES

An overview of some visualisations and virtual reality resources available for exploring the Gaia data.

GAIA DR2 MEDIA STORIES

Here links to a selection of media stories on Gaia Data Release 2 can be found.

GAIA DR2 IN-DEPTH STORIES

A selection of in-depth stories on the processing towards data release 2 and the science potential of the data.

GAIA'S FAMILY PORTRAIT

An interactive visualisation of the Gaia Data Release 2 Hertzsprung-Russell diagram

Contents of Gaia EDR3/DR3

Schedule

- Gaia EDR3 in third quarter of 2020
- Gaia DR3 second half 2021
- Both releases based on same input data and same source list
  - 34 months of input data

Gaia EDR3 contents

- Astrometry ($\sim$ 1.8 billion sources)
  - including new quality indicators: RUWE and source image quality descriptors
- Integrated G, $G_{\rm BP}$, $G_{\rm RP}$ photometry and corresponding passbands
- Cross-match with external catalogues, Gaia-CRF, DR2-to-DR3 match table
- **New:** QSO host and galaxy morphological characterization (based on input list, $\sim$ 3 million sources)

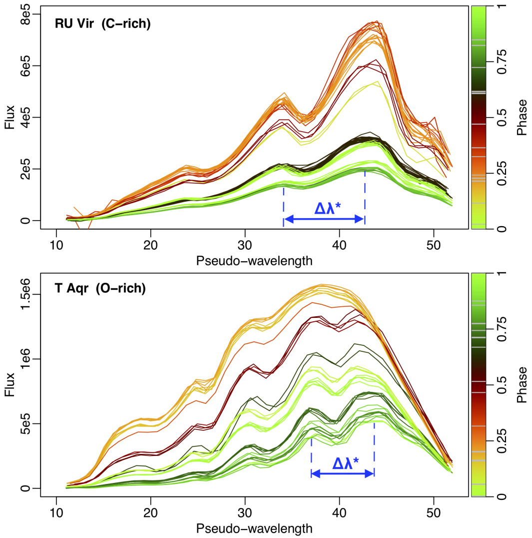
Contents of Gaia EDR3/DR3

Gaia DR3 contents

- Repeat of EDR3 contents
- Classification and astrophysical parameters for TBD subset of sources ($\gtrsim$ 300 million)
  - **New:** based on the BP/RP spectra
- Radial velocities; goal is to include all sources to $G = 14$ ($\sim$ 30 million)
- **New:** Mean BP/RP/RVS spectra for TBD subset of sources
- Photometric variability characterization for $\sim$ 7 million sources
- Astrometry photometry for $\sim$ 100 000 solar system objects
  - **New:** orbital parameters
  - **New:** mean reflectance spectra for $\sim$ 5000 SSOs
- **New:** Catalogue of astrometric, spectroscopic, eclipsing binaries
  - including acceleration solutions
  - combined solutions where possible

Gaia DR4

- Final release for the nominal mission
  - 60 months input data; schedule TBD
- Foreseen data products
  - Full astrometric, photometric, and radial-velocity catalogues
  - All variable-star and non-single-star solutions
  - Source classifications (probabilities) plus multiple astrophysical parameters (derived from BP/RP, RVS, and astrometry) for stars, unresolved binaries, galaxies, and quasars
  - Catalogue of binaries and exo-planets
  - Image reconstruction results
  - All epoch and transit data for all sources, including all BP/RP/RVS spectra



Overall gain in precision for DR3 and DR4: factors 1.2 and 1.7 with respect to DR2

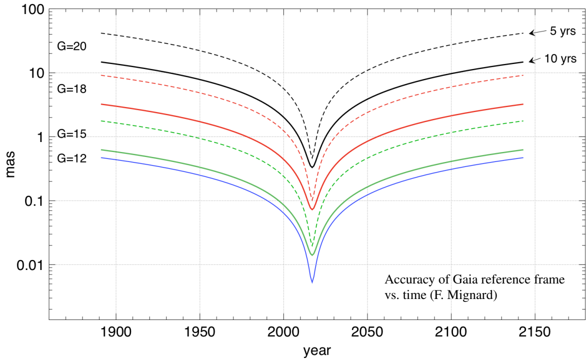
- proper motions improve by factors 1.9 and 4.5

Image credits: ESA/Gaia/DPAC, Mowlavi et al.

Gaia extension

- Nominal Gaia mission ends mid-2019 after 5 years of measurements
- Hardware in good shape, only limiting factor is micro-propulsion fuel
  - mission can continue to mid 2024
- Proposal submitted to ESA for 5 year extension
  - approved to end 2020, preliminary approval to end 2022, submit proposal for 2023–2024 in 2020

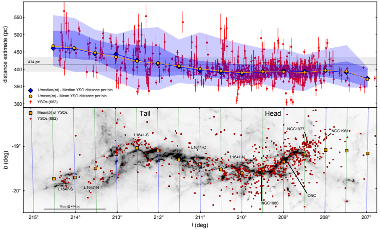
- Parallaxes, photometry, radial velocities improve by 40% with respect to DR4
- Proper motions improve by factor of 2.8 with respect to DR4
  - Improvement of more complex motions (e.g., planets) up to factors of 20
- Accurate tangential motions over 22.6× larger volume



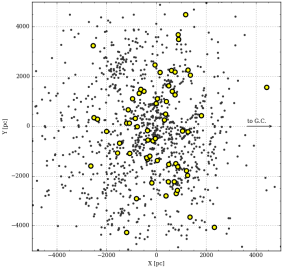
Accuracy of Gaia reference frame vs. time (F. Mignard)

Over 1200 papers since April 25 2018

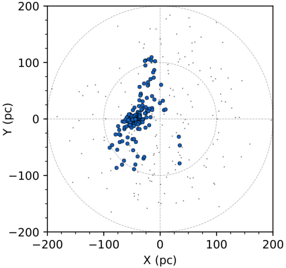
Großschedl et al.



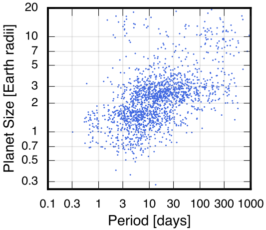
Cantat-Gaudin et al.



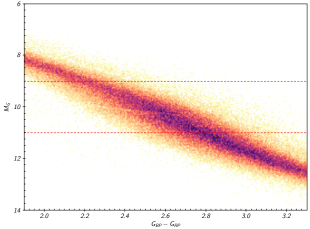
Meingast & Alves; Röser et al.



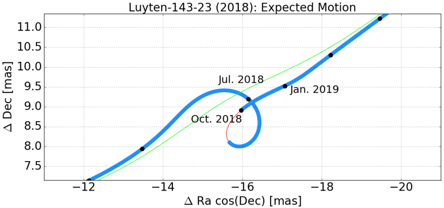
Fulton & Petigura



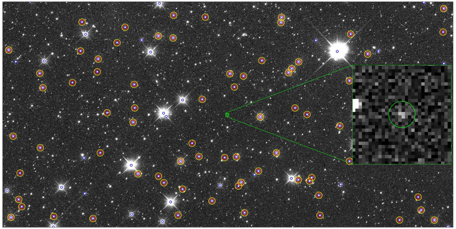
Jao et al.



Klüter et al.

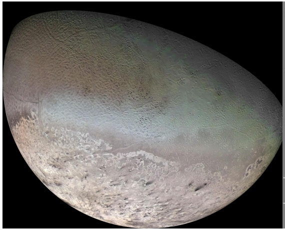


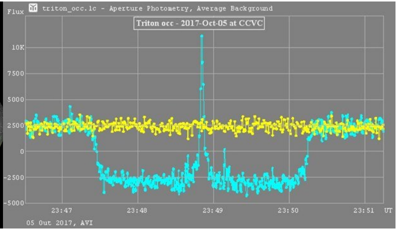
Solar system navigation and occultation planning



Porter et al., arXiv:1805.02252, Stern et al., arXiv:1901.02578

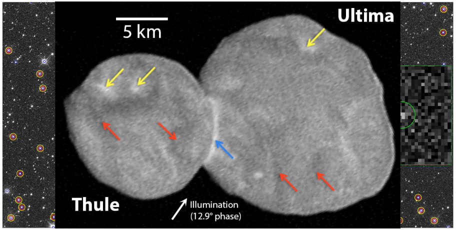
- Navigation of New Horizons mission to 2014 MU_{69} Kuiper-belt object with aid of pre-release Gaia DR2 astrometry
    - accurate MU_{69} orbit; occultation campaign to study the object (size estimate helpful in planning observations during flyby)
- Flyby January 1 2019





- Triton's atmosphere acts as 'bad lens', producing caustics in the refracted star light that reaches earth during occultation
- Precise occultation paths allow studying these caustics and inferring the properties of Triton's atmosphere
- Gaia DR2 pre-release astrometry enabled precise prediction of location where 'central flash' could be observed

Solar system navigation and occultation planning



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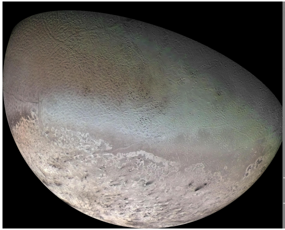

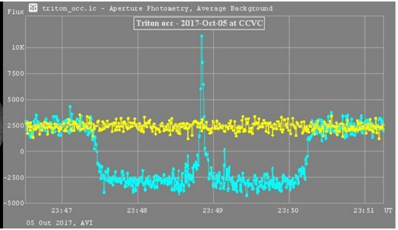

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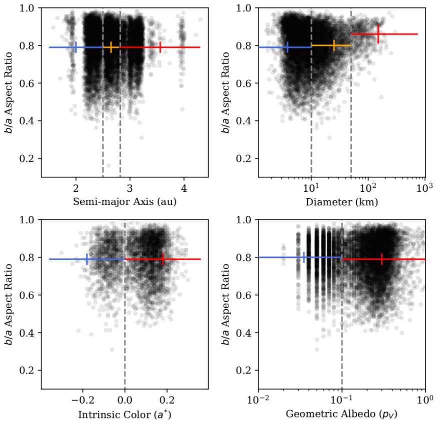
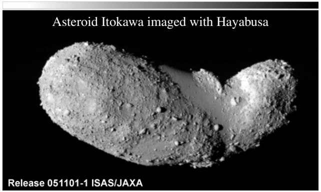
Asteroid shape distribution information from Gaia DR2

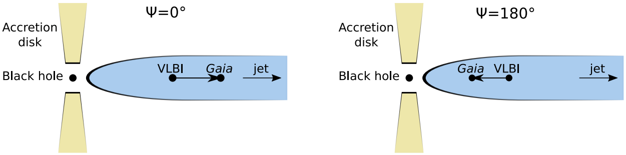


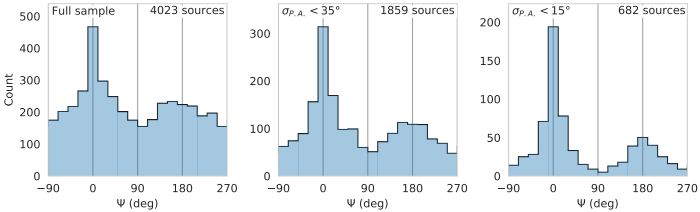
Mommert et al., arXiv:1808.08988

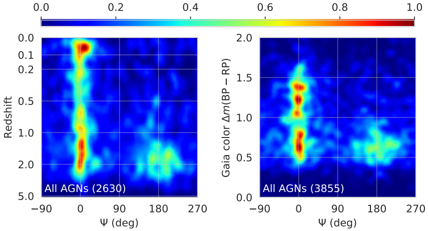


- Analysis of asteroid light curves to derive upper limits on amplitude
  - brightness variations in relation to shape, spin, orientation of asteroids
- Simple triaxial shape model employed, with $a > b$ and $b = c$, to model light curve amplitudes
  - larger asteroids tend to be rounder
  - hints at variations of shape statistics with colour, albedo, semi-major axis

Gaia-radio position offsets



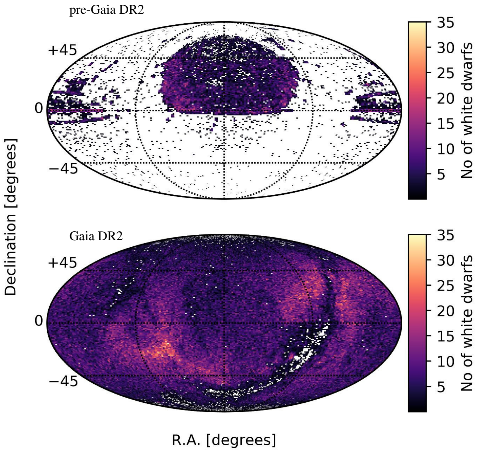




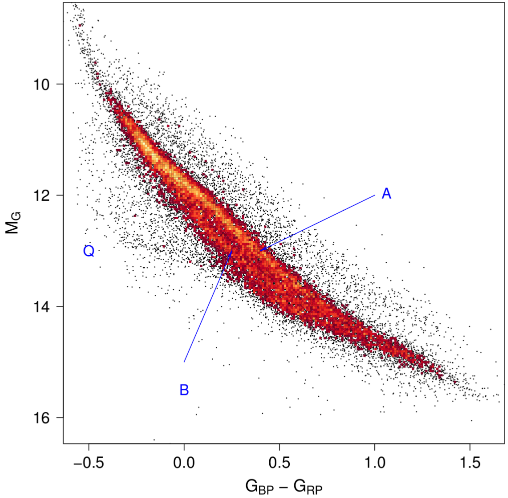
Plavin et al., arXiv:1808.05115

- Analysis of offsets between Gaia and radio positions of AGNs
  - position angle of offsets shows preference for alignment along AGN jets
- Statistics with redshift and colour consistent with unified model for AGN
  - varying contributions from accretion disk and jet

White dwarfs

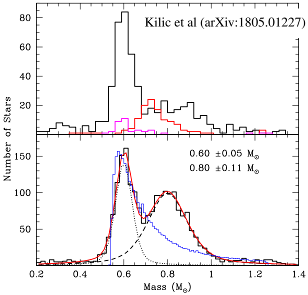


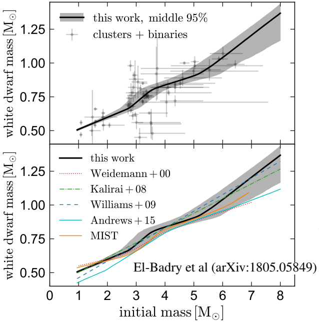
Gentile Fusillo et al., arXiv:1807.03315
See also: Jiménez-Esteban et al., arXiv:1807.02559
Hollands et al., arXiv:1805.12590

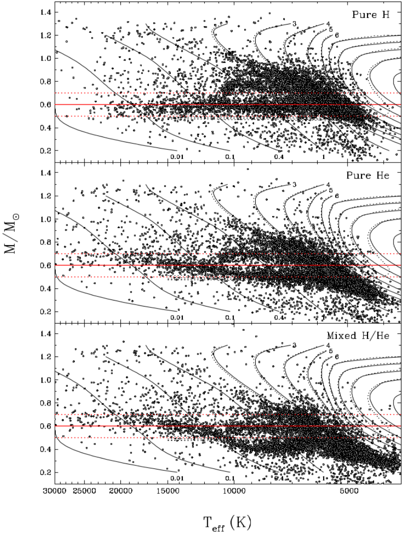


Gaia Collaboration, Babusiaux et al., 2018, arXiv:1804.09378

White dwarfs



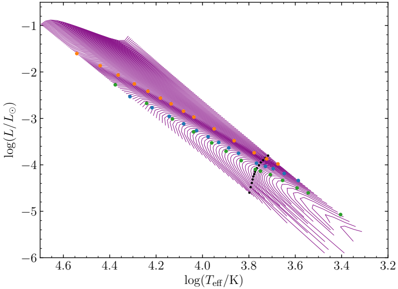


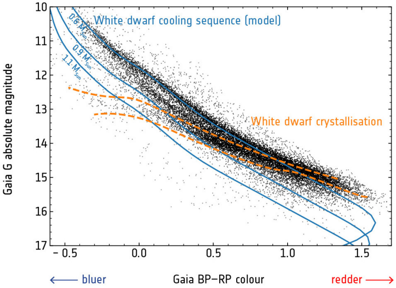


Bergeron et al (arXiv:1904.02022)

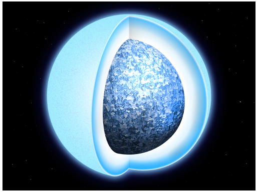
- Early explanations of WD CMD structure invoked structure in mass distribution
  - mergers (left); shape of initial-final mass relation (middle)
- Inferred mass depends on assumed atmospheric composition (right)
  - 0.8 $M_\odot$ peak may be artificial; full picture not clear yet

White dwarfs

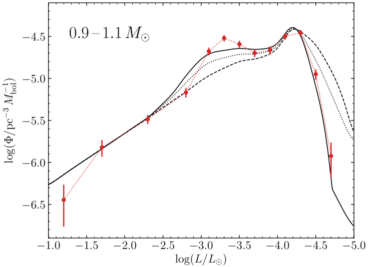




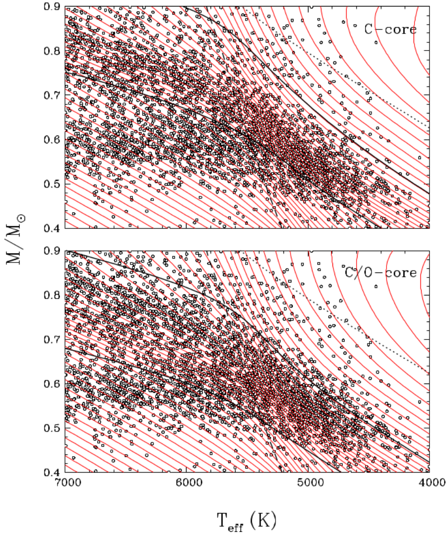
Tremblay et al., 2019, Nature 565, 203



- Clear evidence for crystallization of WD interiors
  - mass dependent pile-up of WDs along cooling track
- Luminosity function modelling must take crystallization into account for accurate Milky Way disk age
  - modelling details of the luminosity function will lead to better understanding of crystallization and ^{16}O sedimentation processes



White dwarfs

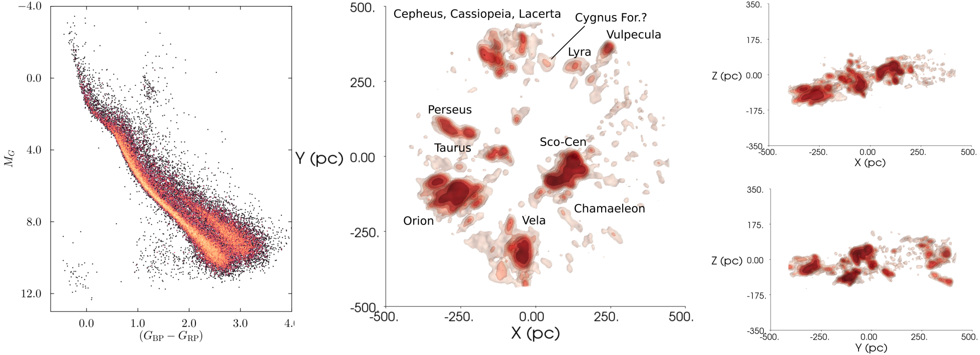


Bergeron et al (arXiv:1904.02022)

- Location of cooling sequence isochrones and crystalization band depend on strongly on core composition
- Empirical demonstration that cores of most white dwarfs consist of a mixture of C and O

Mapping the young stellar population near the Sun

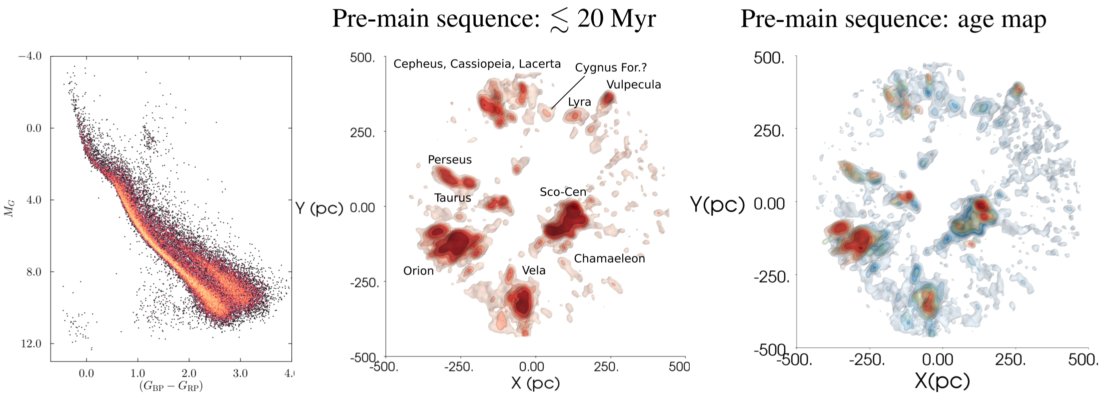
Pre-main sequence: $\lesssim 20$ Myr



Zari et al., 2018, A&A 620, A172 (arXiv:1810.09819)

- Selection of young stars in HRD after correctioning for extinction using Gaia DR2 A_G, $E(\mathrm{BP}-\mathrm{RP})$
- Further selection on tangential motions
- Global mapping of space, age distribution and kinematics of young stars near sun

Mapping the young stellar population near the Sun



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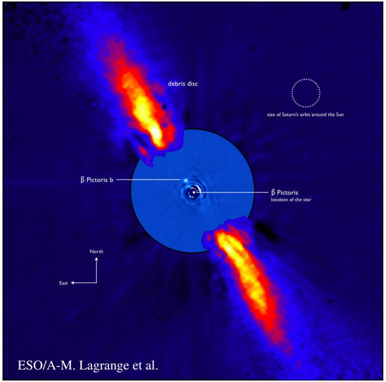
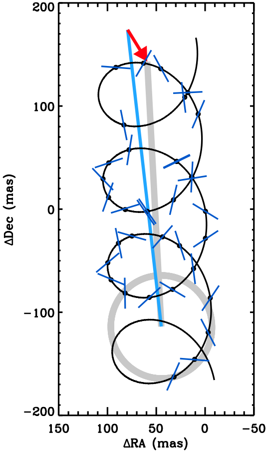
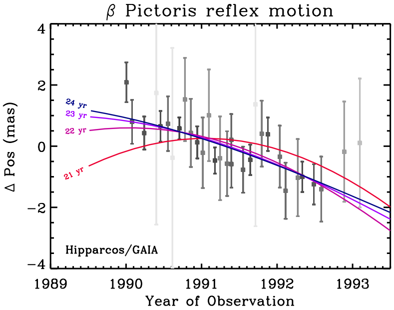
Beta Pictoris b







Snellen & Brown, Nature Astronomy, arXiv:1808.06257

See also: Calissendorff & Janson, arXiv:1806.07899

Brandt et al., arXiv:1811.07283, 1811.07285

Kervella et al., arXiv:1811.08902

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- Difference Hipparcos and Hipparcos-Gaia proper motions reveals mass of planet ($11 \pm 2\ M_{\rm Jup}$)
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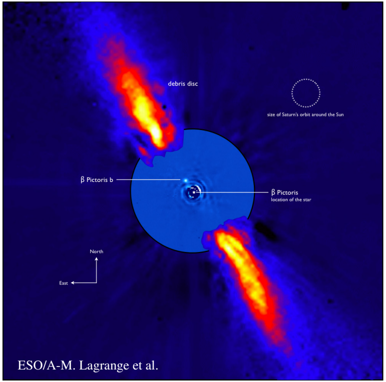
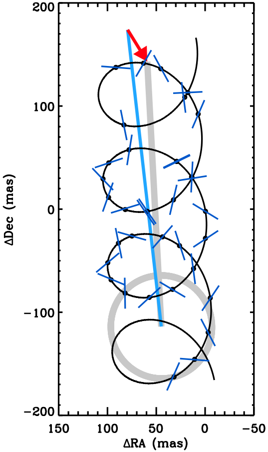
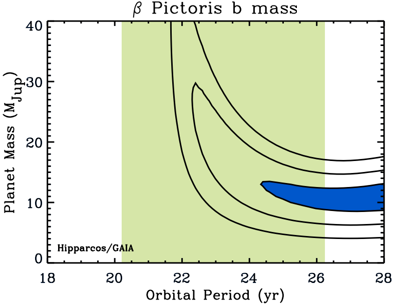
Beta Pictoris b







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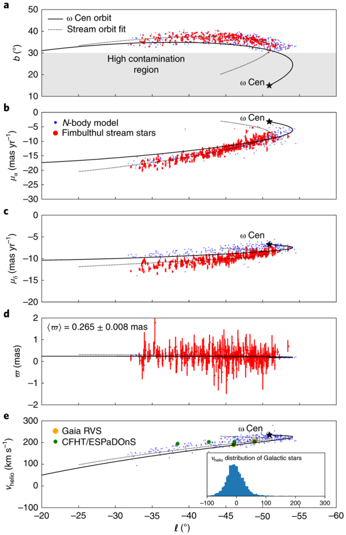
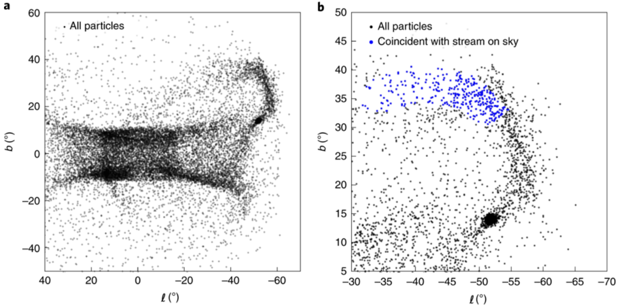
The stream of ω Centauri





Ibata et al., 2019, Nature Astronomy, arXiv:1902.09544

- Earlier discovered ‘Fimbulthul’ structure matches ω Cen orbit on the sky and in proper motion
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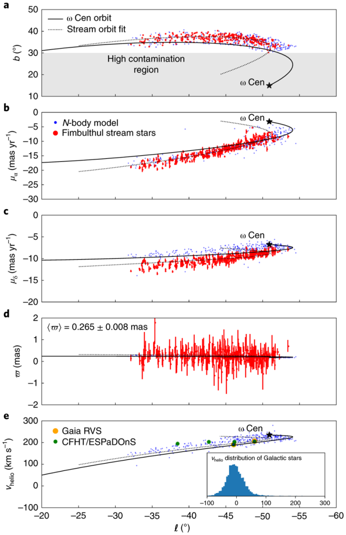

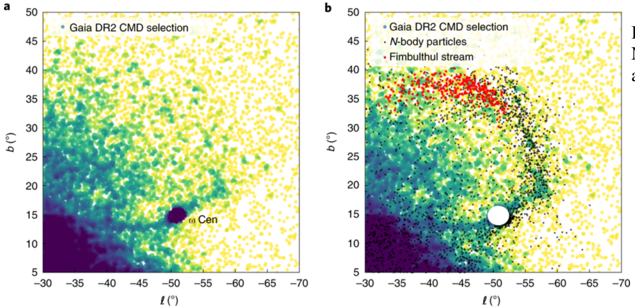

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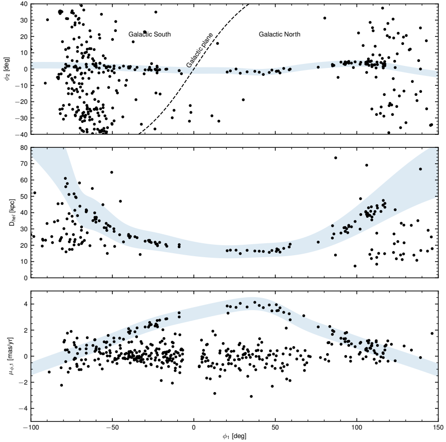
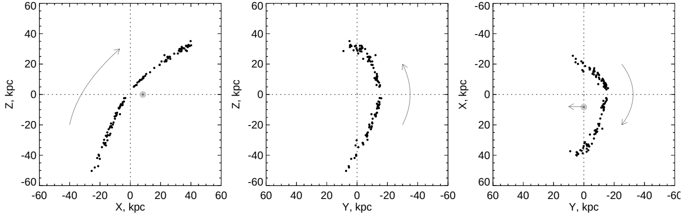
The Orphan stream and the total mass of the LMC



Koposov et al., arXiv:1812.08172



- Orphan stream traced in Gaia DR2 RR Lyrae over 210° on the sky (150 kpc)
  - also traced in Gaia DR2 red giants and DECaLS
- Strong misaligment between debris track and streaming velocity
  - ‘orbital plane’ pole varies over 20° in orientation along debris track
- Clear hints of interaction with massive perturber

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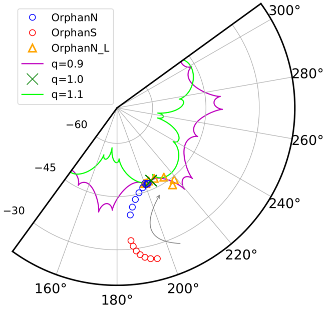

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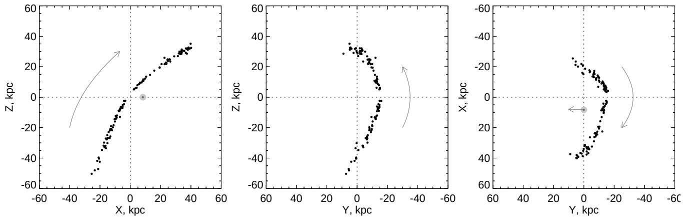

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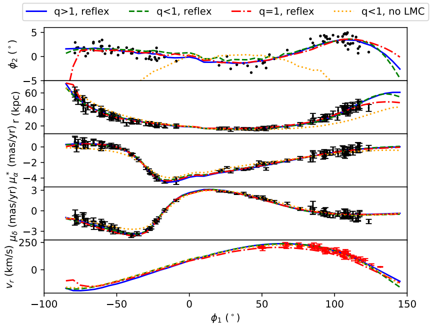
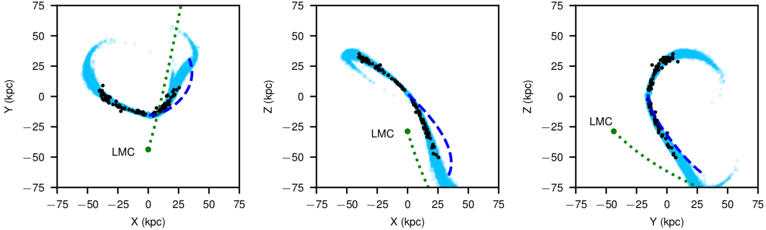
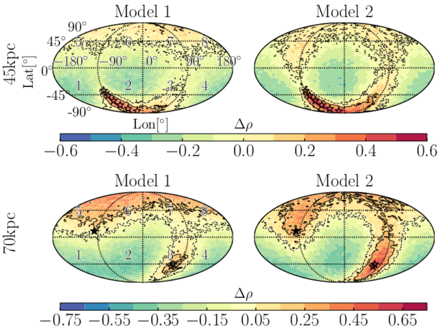


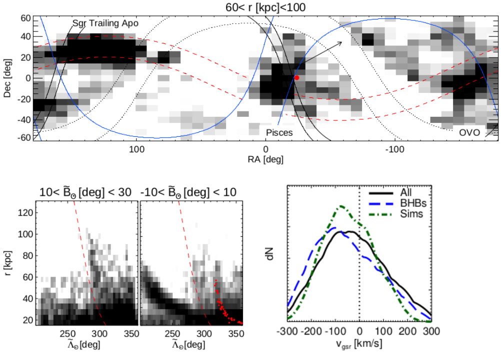
- Model of stream perturbed by LMC is necessary to reproduce observations
  - LMC total mass inferred to be $1.38^{+0.27}_{-0.24} \times 10^{11}$ $M_\odot$
- LMC has large and measurable effect on structures orbiting Milky Way
  - LMC should be accounted for when studying Milky Way potential/mass tracers
  - Milky Way reflex motion predicted to lead to ~ 40 km s^{-1} bulk 'upward' motion of outer halo ($r \gtrsim 30$ kpc) stars



Erkal et al., arXiv:1812.08192

Hunting for the dark matter wake of the LMC





- LMC should perturb MW halo through dynamical friction and resonances
  - Detailed predictions (left) by Garavito-Camargo et al. (arXiv:1902.05089) on resulting ‘wakes’
  - Proposed Pisces Overdensity as good hunting ground
- Analysis of Gaia DR2 and PS1 RR Lyrae by Belokurov et al. (right, arXiv:1904.07909)
  - overdensity in Pisces stretched out in galactocentric distance; looks like field halo stars
  - average negative galactocentric radial velocity
  - first detection of signature of LMC wake

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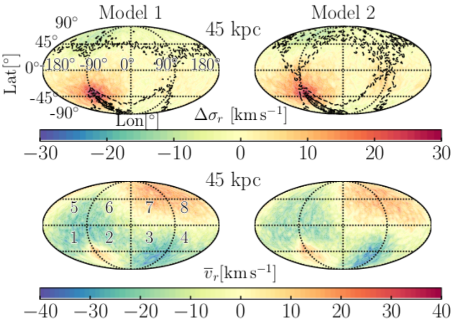

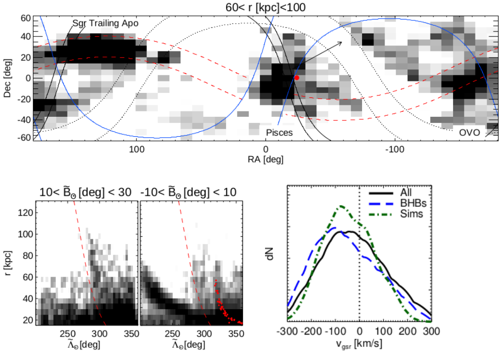

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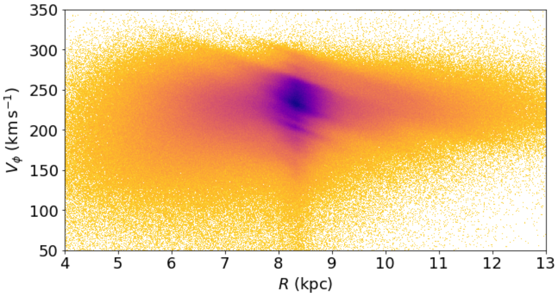
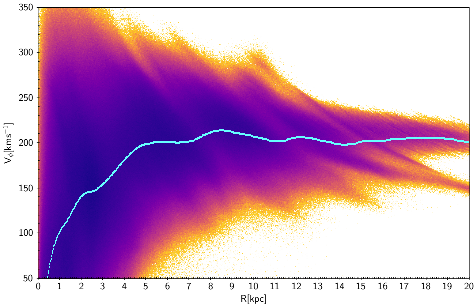
Milky Way insights from Gaia DR2: rotation curve

Data: Antoja et al., arXiv:1804.10196



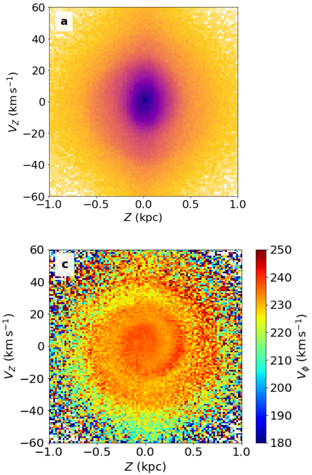
Simulation: Martinez-Medina et al., arXiv:1812.11190



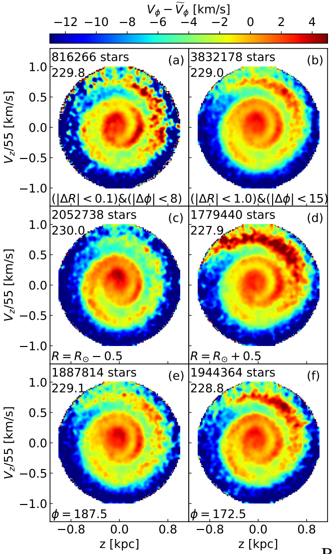
See also:
Kawata et al., arXiv:1804.10175
Hunt et al., arXiv:1806.02832
Eilers et al., arXiv:1810.09466

- Azimuthal velocity vs. radius shows prominent ridges
- Effect of spiral arms and bar
  - ridges coincide with locations of constant angular momentum L_z
  - seen as wiggles in the 'rotation curve' (mean azimuthal velocity)

Milky Way insights from Gaia DR2: the phase spiral



Antoja et al., 2018, Nature
arXiv:1804.10196

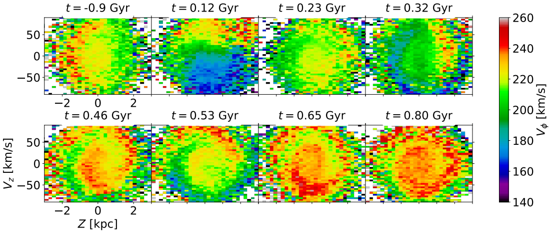


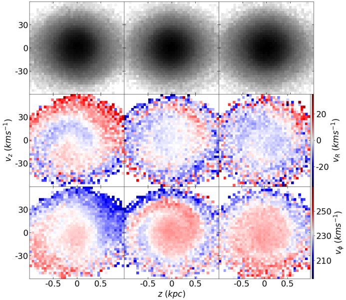
Bland-Hawthorn et al., arXiv:1809.02658

- Never before seen spiral pattern in phase space
  - Points to Milky Way disk in the process of phase mixing from an out of equilibrium state
- Analysis of phase spiral with GALAH data
  - Slicing according to location in disk, [Fe/H], [α/Fe], age
  - Shows that phase spiral is a disk-wide phenomenon
- Illustrates the need for *precise and dense sampling* of Milky Way disk kinematics

Milky Way insights from Gaia DR2: the phase spiral

Laporte et al., arXiv:1808.00451



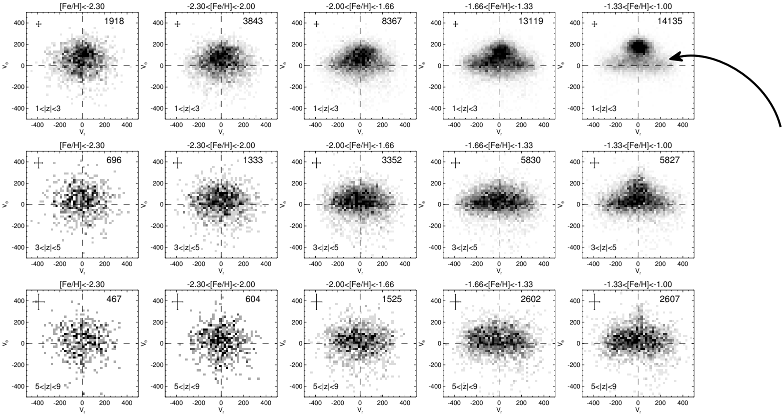


Darling & Widrow, arXiv:1807.11516

Explanations for coupled perturbations in vertical and in-plane directions in disk

- Simple analytical models in Antoja et al. and Binney & Schönrich (arXiv:1807.09819)
- Interaction of Sgr dwarf with MW disk (Antoja et al., Bland-Hawthorn et al., Laporte et al.)
- Vertical bending oscillations in disk (Darling & Widrow)
- Long lasting phase-spiral due to bar buckling instability (Khoperskov et al. arXiv:1811.09205)
- To be continued

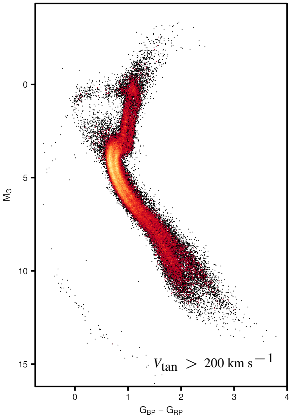
Milky Way insights from Gaia DR2: formation history

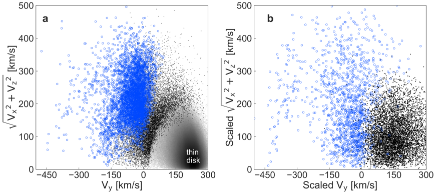


Belokurov et al., 2018, MNRAS, arXiv:1802.03414

- Analysis of proper motions from Gaia DR1+SDSS
- Stellar debris inner halo deposited during major accretion event; satellite with $M_{\rm vir} > 10^{10}\,{\rm M}_\odot$, $\sim$ 8–11 Gyr ago
- Halo kinematic anisotropy due to radialisation of the progenitor's orbit

Milky Way insights from Gaia DR2: formation history

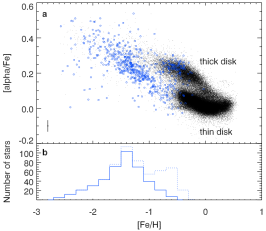




Gaia Collaboration, Babusiaux et al., 2018, A&A, arXiv:1804.09378

Helmi et al., 2018, Nature, arXiv:1806.06038

Haywood et al., 2018, ApJ, arXiv:1805.02617



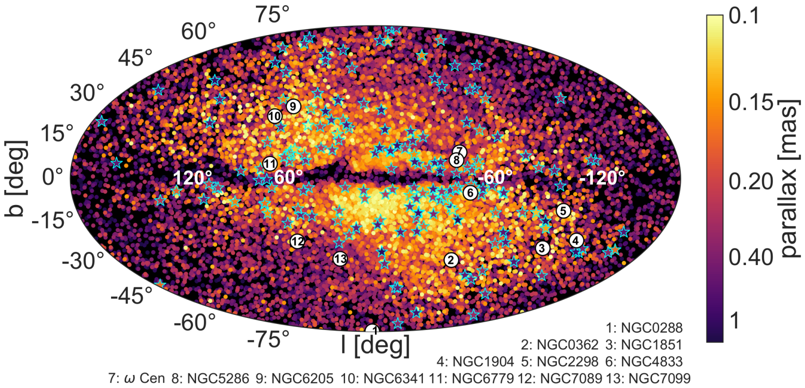
- Halo near sun dominated by slightly retrograde population
- APOGEE abundances reveal a sequence consistent with a population that formed over $\sim$ 2 Gyr time span at $\sim$ 0.3 $M_\odot$/yr in a system different from the thick disk
- This population lies on the blue sequence in the HRD, ages roughly 10 to 13 Gyr

Milky Way insights from Gaia DR2: formation history

Helmi et al., 2018, Nature, arXiv:1806.06038

Myeong et al., 2018, ApJ, arXiv:1805.00453

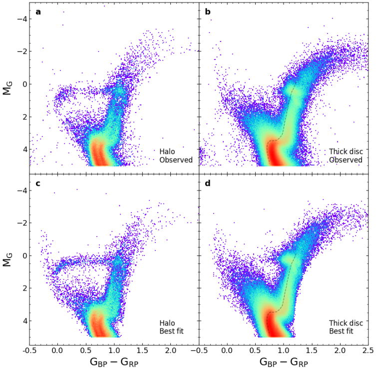
Kruijssen et al, 2018, MNRAS, arXiv:1806.05680

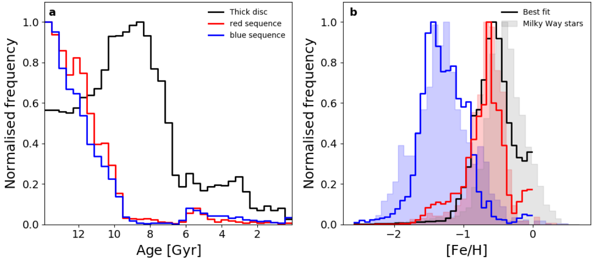


- Accreted galaxy comparable in mass to present-day SMC; fell in when progenitor of the Milky Way thick disk was in place
- Accompanied by substantial population of globular clusters
- 4:1 mass ratio merger $\sim$ 10 Gyr ago, contributing to heating and formation of thick disk

Milky Way insights from Gaia DR2: formation history

Gallart et al., arXiv:1901.02900

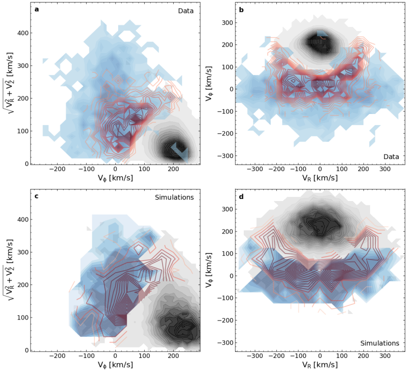


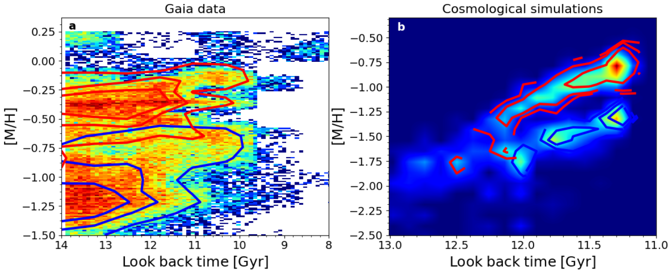


- CMD modelling of halo population provides consistent picture on early formation history Milky Way
- Blue sequence ↔ major accretion event; red sequence ↔ halo population formed in-situ
  - more massive in-situ population naturally more metal rich; heated to halo kinematics by merger
  - both populations formed very early on and stopped growing after merger
  - merger mass-ratio consistent with previous conclusions
- Old-age tail of thick disk formed in main Milky Way progenitor

Milky Way insights from Gaia DR2: formation history

Gallart et al., arXiv:1901.02900





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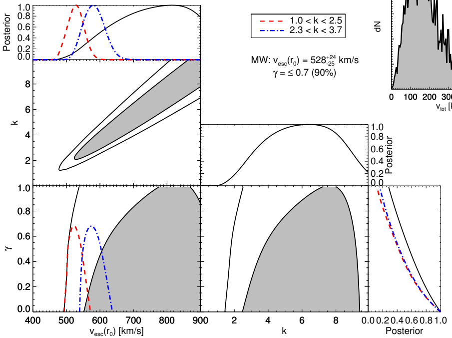
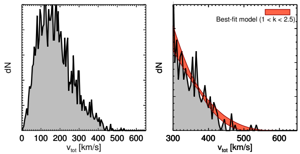
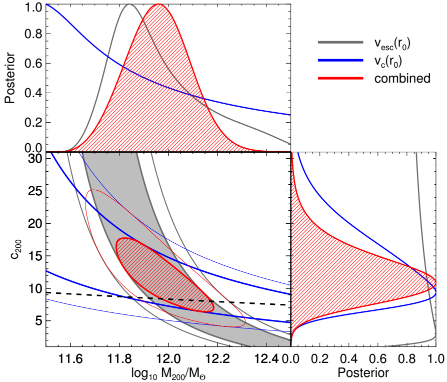
Milky Way insights from Gaia DR2: mass from escape speed

Deason et al., arXiv:1901.02016







- Estimate of Galactic escape speed from velocity distribution of population of retrograde stars
- Fit of $(v - v_{esc})^k$ to high velocity tail; $v_{esc} = v_{esc,0}(r/r_0)^{-\gamma/2}$
- Prior range on k motivated from cosmological simulations and known radial anisotropy of halo distribution function: $v_{esc} = 528^{+24}_{-25}$ km s^{-1}, $M_{200,tot} = 1.00^{+0.31}_{-0.24} \times 10^{12}\ M_\odot$

Your papers are the best argument for an extended Gaia mission

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