Gaia DR2 Early Science

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Overview

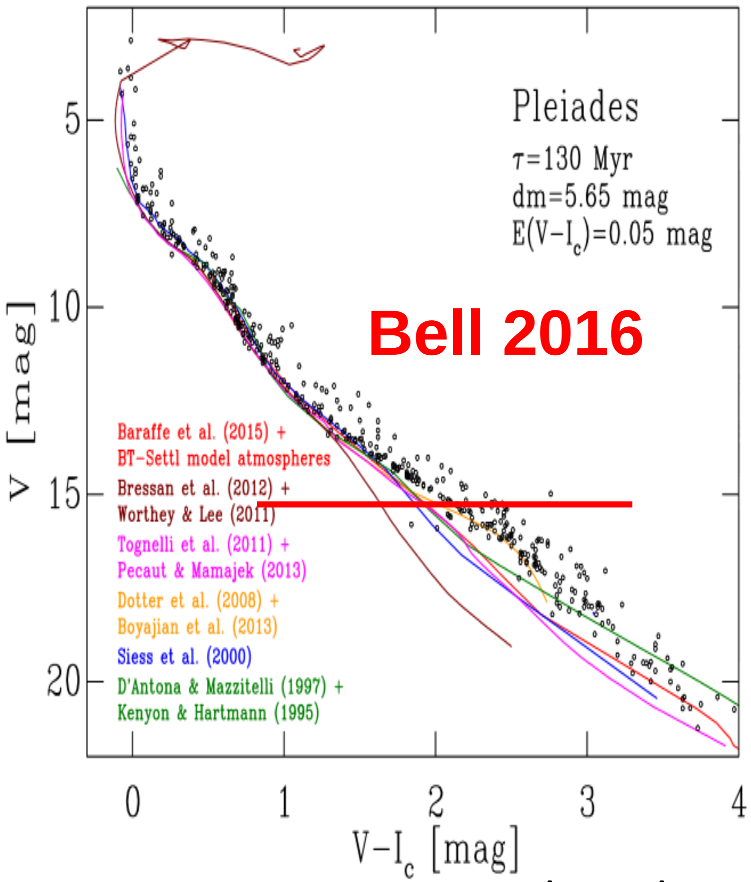
- Gaia impact
- Stars and stellar systems
- The MW formation
- Climbing the distance ladder

Gaia DR2 impact

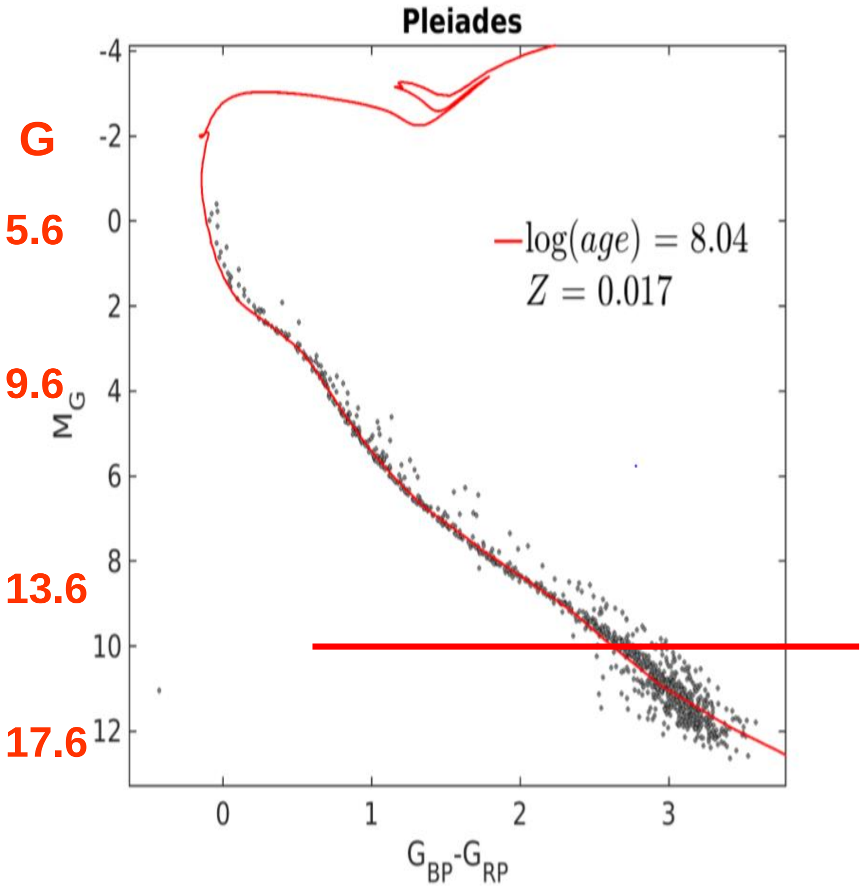
- 7 Science verification+ 18 processing Gaia Consortium papers for DR2 on A&A Special Edition
- Now available at https://www.aanda.org/articles/aa/abs/2018/08/contents/contents.html
- Gaia Collaboration 2018 has 282 citations (according to ADS)
- Many workshops/meetings/sprint based on Gaia DR2
- Wide variety of science topics, from Milky Way structure to exoplane host stars
- Combinations with other surveys/data from spectroscopy+photometry (HST, LAMOST, 2MASS, RAVE, APOGEE, GES, PANSTARRS, SEGUE....) very powerful

Improving stellar models

Pre-Gaia



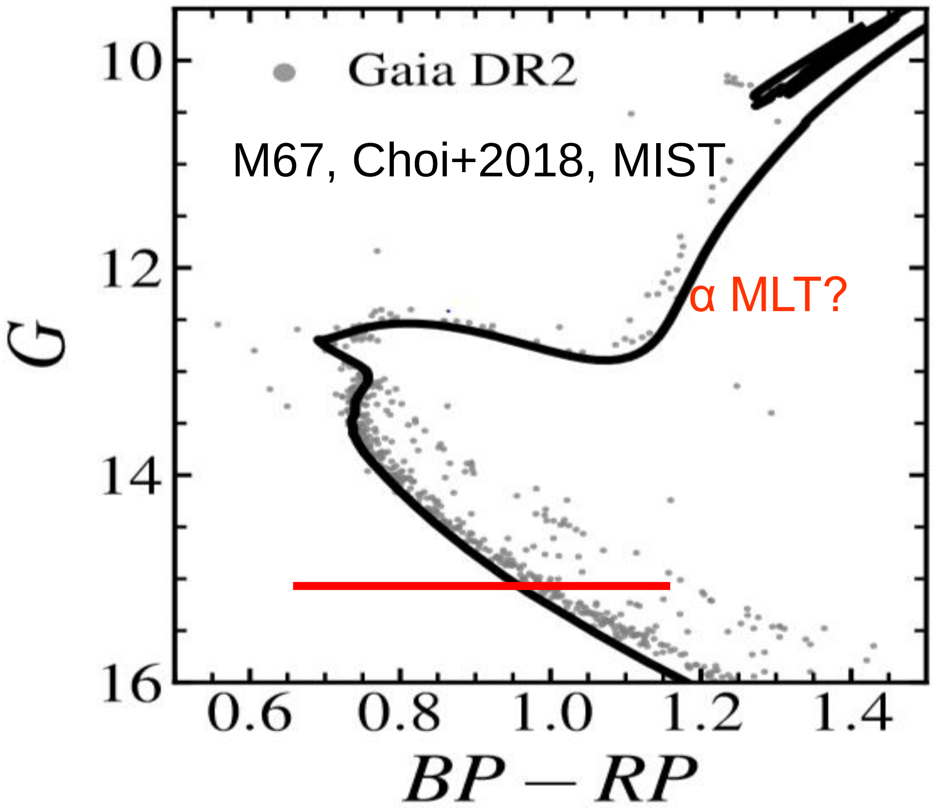
Gaia Coll., Babusiaux et al 2018
Parsec isochrones

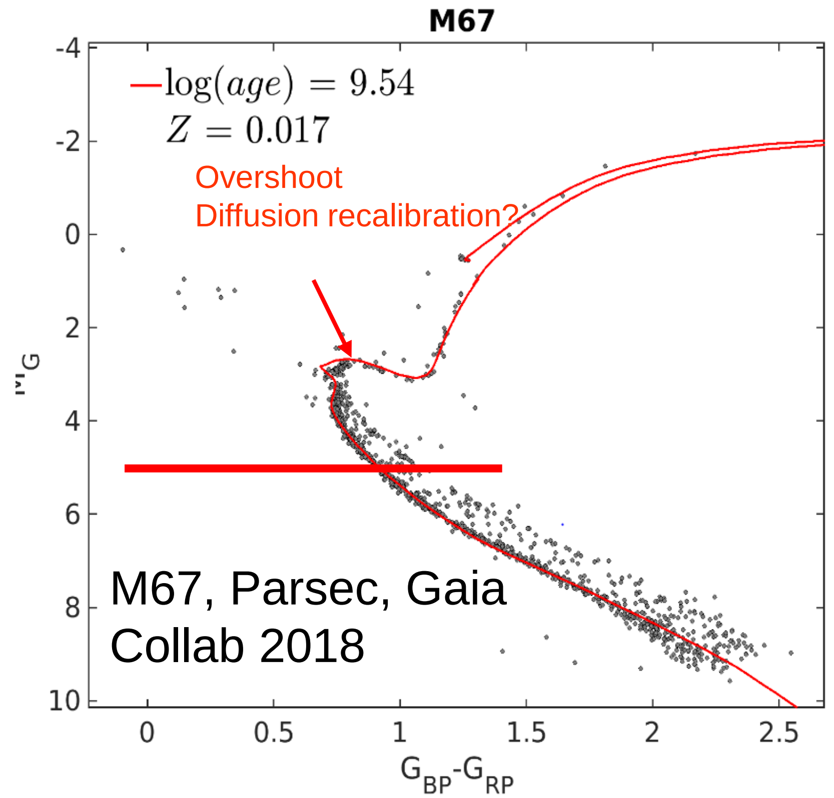


the relation between the temperature and Rosseland mean optical depth T-τ from BT-Settl(Asplund 2000)

Calibrated to the empirical M-radius relation (Cheng 2014)

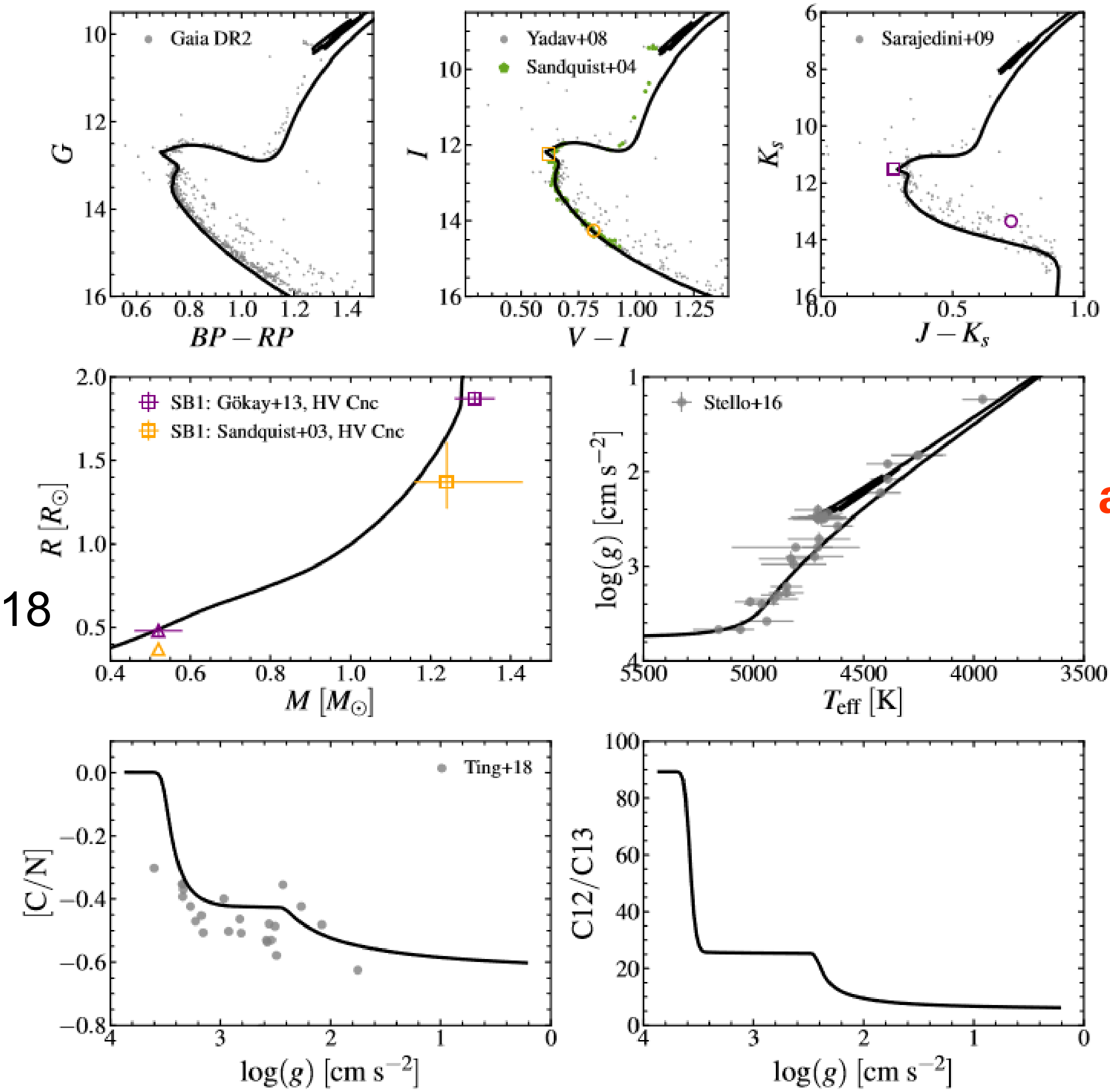
Stellar models:the case of M67





$m - M = 9.73$, $[Fe/H] = -0.01$, log(Age) [yr] = 9.58, and $A_V = 0.18$

A way forward



photometry

asteroseismology

APOGEE

M67, Choi+2018

Figure 9. Same as Figure 8 except now for M67, a solar-metallicity and solar-age (4 Gyr) open cluster. The top left panel shows photometry of likely cluster members selected using the *Gaia* DR2 data while the middle and right panels show stars with > 50% membership probabilities as determined by Yadav et al. (2008). The Sandquist (2004) is a sample of likely single star members selected based on their proper motions. The MIST CMDs, shown in black, adopt $m-M = 9.73$, $[\mathrm{Fe/H}] = -0.01$, $\log(\mathrm{Age})\ [\mathrm{yr}] = 9.58$, and $A_V = 0.18$ (see text for more details). The left panel in the middle row shows two measurements of the stellar parameters of HV Cnc (Sandquist & Shetrone 2003; Gökay et al. 2013) with the MIST mass-radius relation. The open symbols indicate that the system is a single-lined (SB1) spectroscopic binary system. When available, the individual EB components are also shown in the CMDs, where the square, triangle, and circle symbols correspond to the primary, secondary, and tertiary components, respectively. The right panel shows the asteroseismic $\log g$ inferred from the scaling relations (Stello et al. 2016) with the effective temperatures from the Casagrande & VandenBerg (2014) color-temperature relations. The surface

Fine details of stellar populations

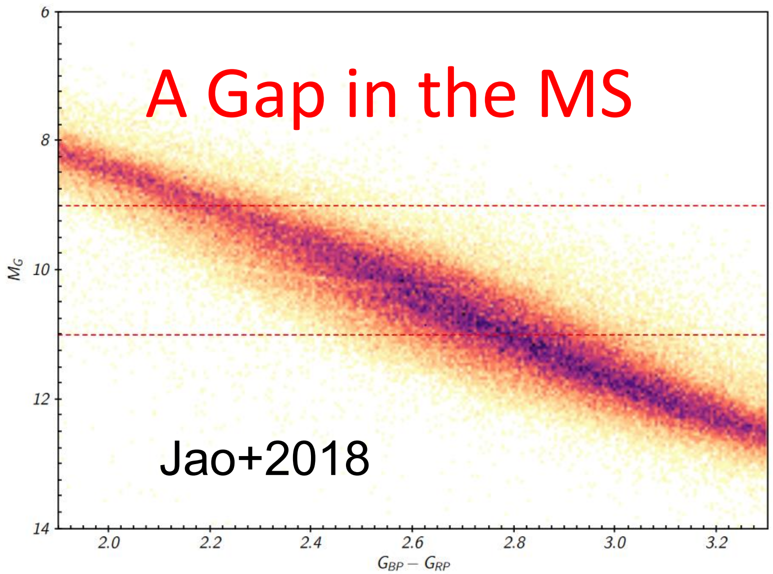
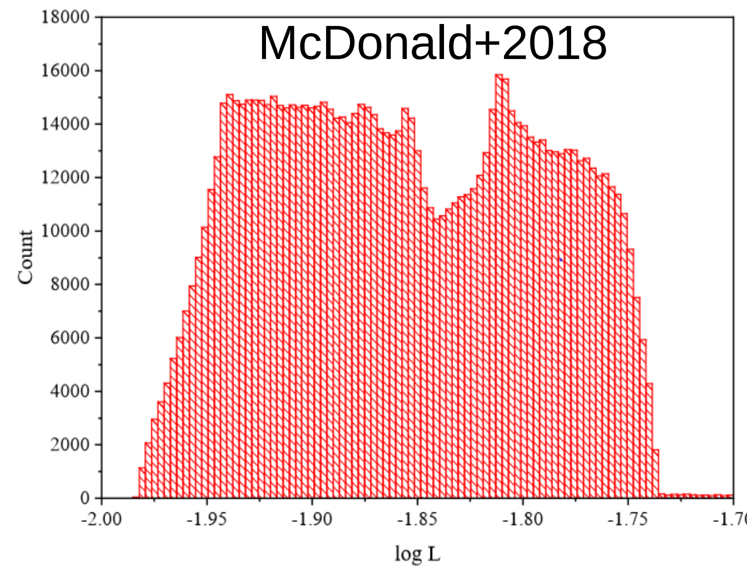
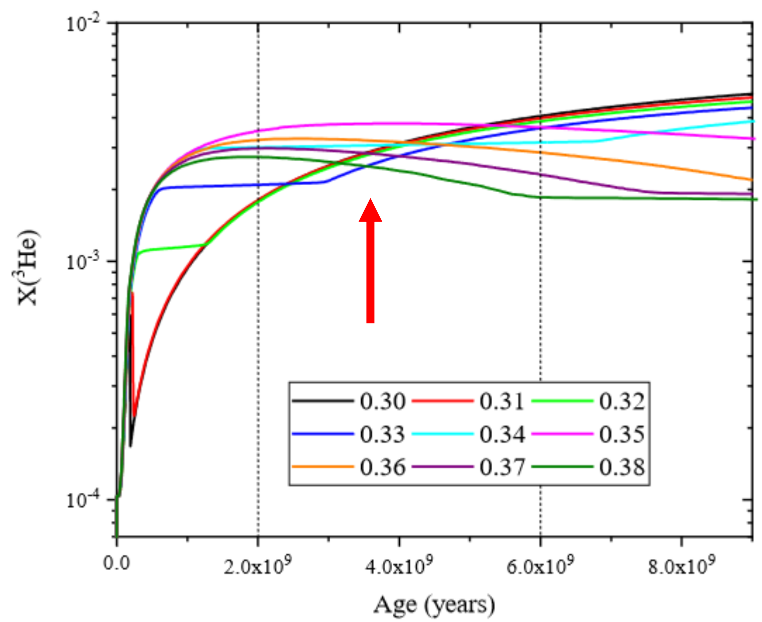


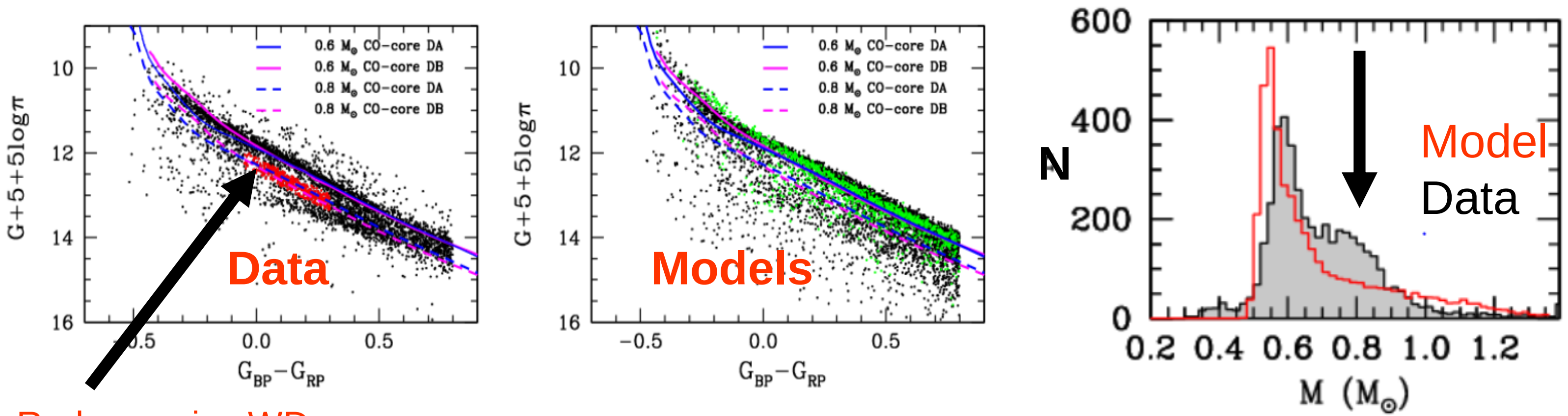
Figure 1. A portion of the observational HRD for stars within 100 pc in the *Gaia* DR2 dataset, using M_G and $G_{BP} - G_{RP}$. A thin, low density, gap is seen cutting through the main sequence. Two dashed lines ($M_G = 9$ and 11) represent a region selected for further discussion, and plotted in Figure 2.



- A gap in the MS at MG= 10 (Jao+2018) of 0.05 mag
- M dwarf transition from partially to totally convective
- Stars in the range 0.31-0.34 Mo experience a merge of convective core-convective envelope with sudden change in 3He central content and in luminosity(McDonald&Gizis 2018)



A new view of local WDs



Red: massive WDs
30-40% He rich atmospheres

Jimenez-Esteban 2018

- WDs can provide information on the MW history(disk, Ocs, bulge, halo) due to the long cooling time(Torres 2018,vanOirschot+2014, Garcia Berro 2004)
- A Catalog of 72,000 WDs, 8500 inside 100 pc. Gaia has discovered all WDs inside 100 pc(Jimenez-Esteban 2018)
- A new WD distribution (Gaia Collaboration, Babusiaux et al, Kilic+ 2018, Jimenez-Esteban 2018, Hollands +2018)
- Merge of binaries in post-MS and evolution as a single WDs? (Kilic+2018)
- Merge of giant with MS or WD(Rebassa-Mansergas et al. 2015)
- Recent burst of SF? Torres & Garć ıa-Berro (2016)
- Initial to final WD mass depending on magnetic field? (el Badry+2018)

Candidate for Double Degenerate Double detonation SNIa?

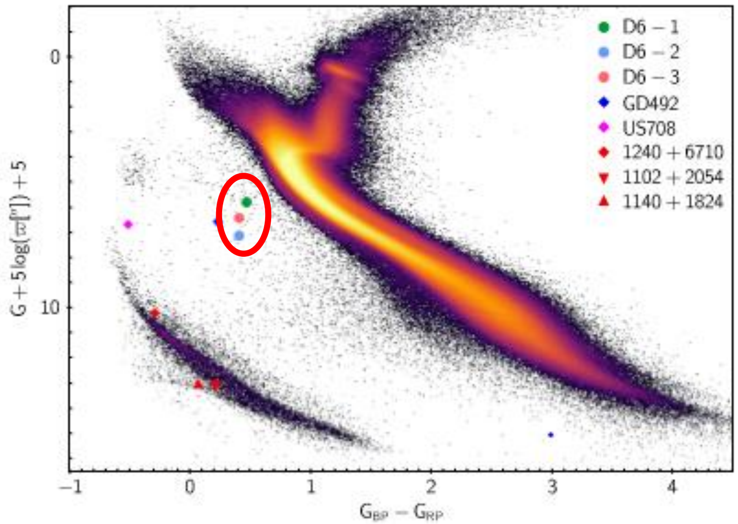
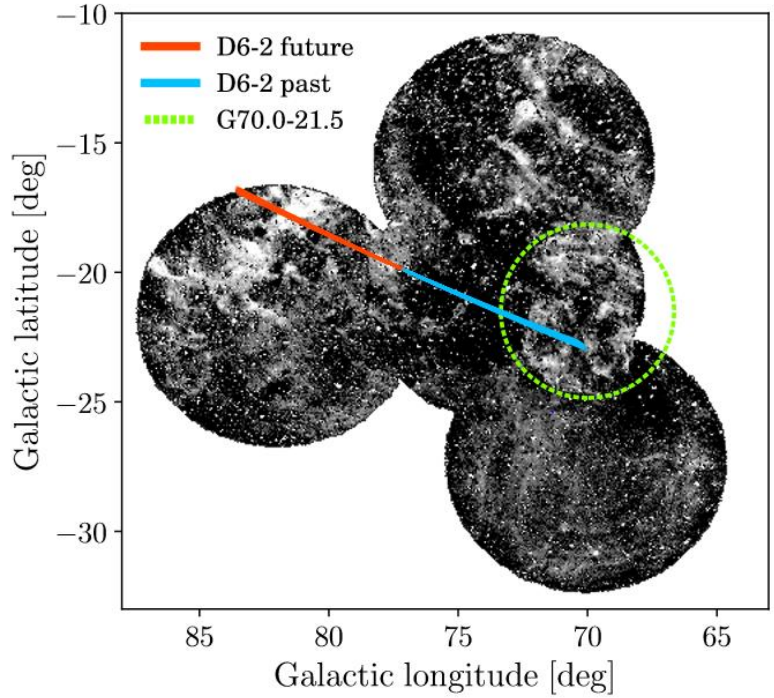
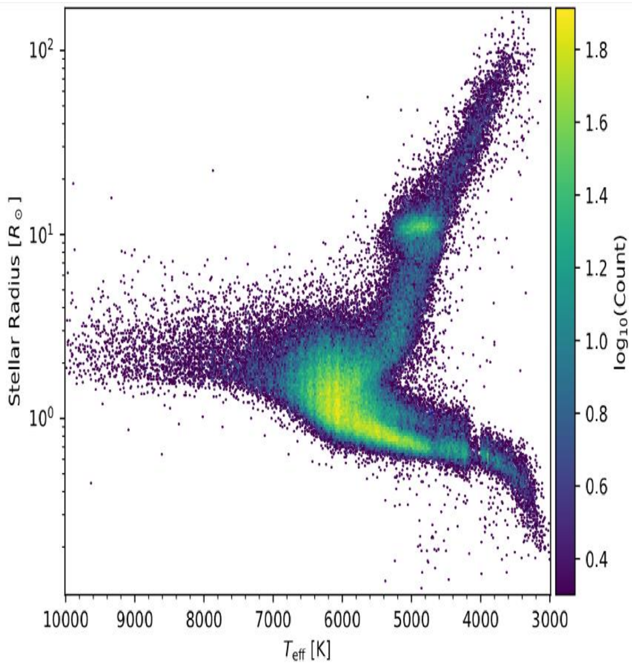


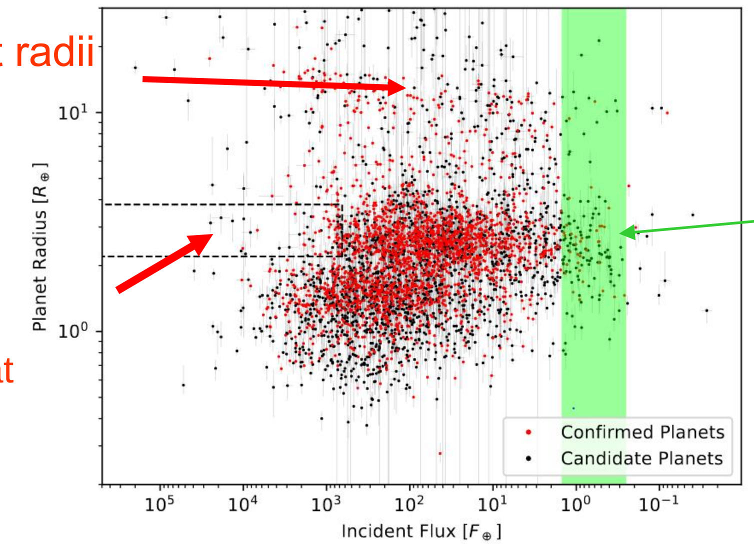
Figure 10. Color-magnitude diagram of the three hypervelocity candidates, GD 492, US 708, and three chemically peculiar WDs (colored symbols). Black circles and colored regions show reliably measured stars from *Gaia*.



- Studies of hypervelocity stars (Raddi+2018,Irrgang+2018,Ruiz-LaPuente+2018,Li+2018, Kenyon+2018)
- Out of 28 , 14 hypervelocity unbound stars from the LMC or a disrupted dwarf? (Marchetti+2018)
- SNIa: Mass transfer in double WDs leads to detonation of the He shell that sets off a C-core detonation in C/O WD (Bildsten 2007, Dan 2015) .The companion WD survives the explosion and is flung away with a velocity equal to its > 1000km/s
- 7 high velocity DR2 candidates + Vrad from spectroscopy: 1 candidate associated with a SN remnant (Shen +2018) some 10E4 yr ago

Radii of stars and planets



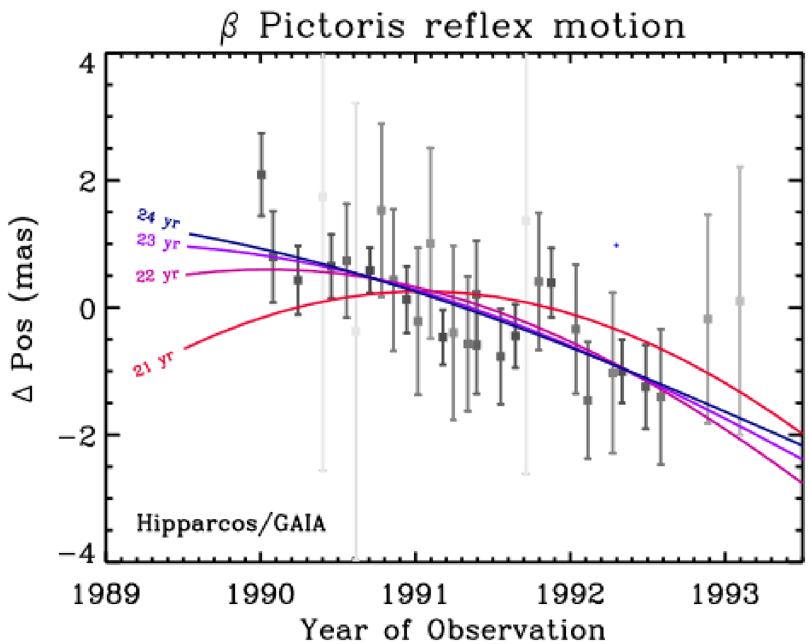


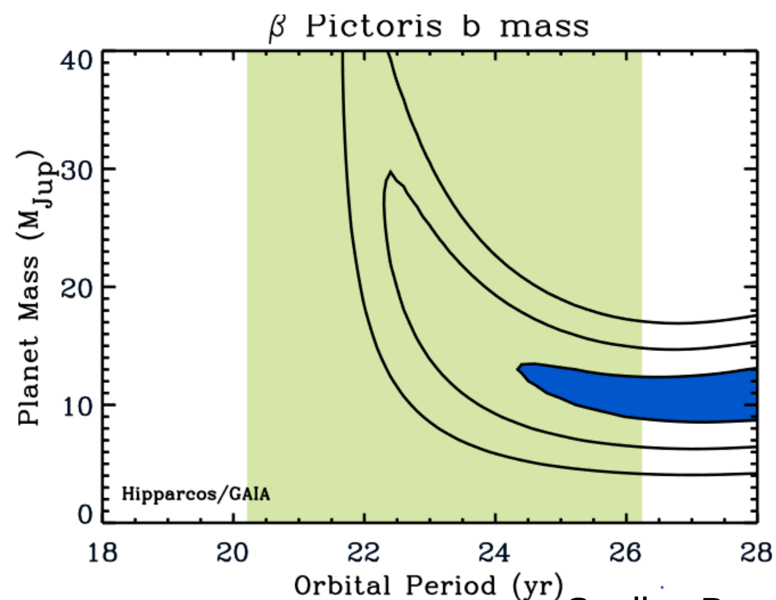
Berger 2018

Figure 9. Planet radius versus incident flux for *Kepler* exoplanets. Red and black dots are confirmed and candidate exoplanets, respectively. We also plot our asymmetric error bars in transparent gray. The dashed line box represents the extension of the super-Earth desert identified in Lundkvist et al. (2016), while the green bar indicates the approximate optimistic habitable zone for FGK stars as detailed in Kane et al. (2016).

- Stellar radii mass and density very important for exo-planet characterization
- Gaia+Kepler photometry+ California Kepler spectroscopy →Stellar radii at 2%, and planet radii at 5% precision (Fulton 2018) → a factor of 6-7 to previous determinations
- Several know features in planetary radii distribution seen with higher precision: super-earth desert, bi-modal radii distribution (rocky super-earth &gas sub-neptunes), giant planet radii inflation with F
- First Kepler HRD (nearly) independent from models for 177,000 stars from Gaia Parallaxes and photometry, and stellar parameters from Kepler +spectroscopy(Berger 2018)

Mass of Beta Pictoris b planets





Snellen Brown 2018

Fig. 3: Constraints on the mass and orbital period of the young exoplanet Beta Pictoris b. The

- Beta Pict is a saturated star (G=3.86) in GDR2
- Combining with Hipparcos pm precision of 0.02 mas
- Planet discovered in 2009 by imaging
- Previous mass limit < 20-30 Mj
- Short periods (< 22.2 y) not consistent with the data
- Planet mass of 11 ± 2 Mj

Towards a chemodynamics of the MW

Total velocity distribution vs radius

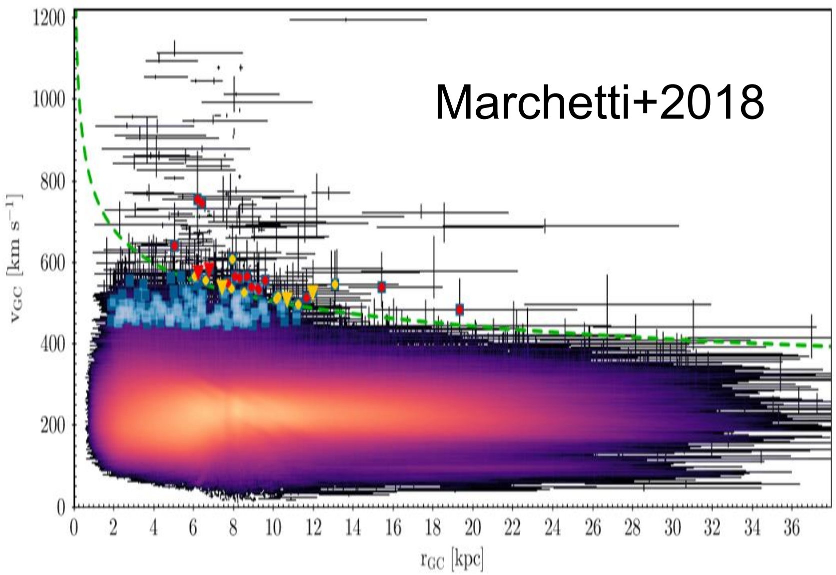
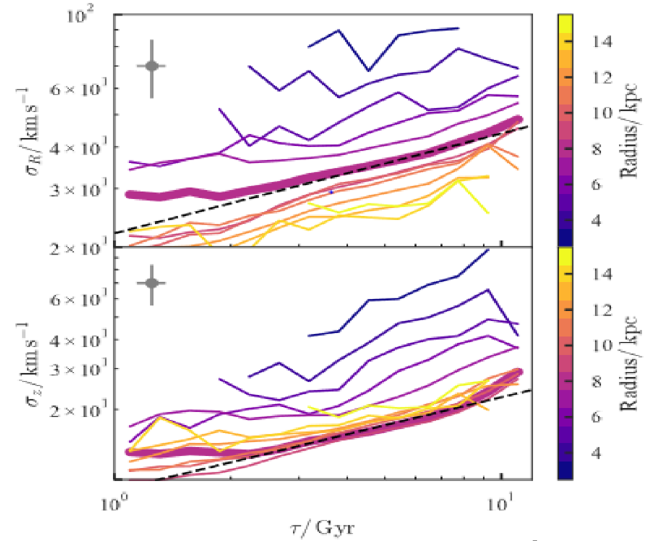


Figure 2. Total velocity in the Galactic rest-frame v_{GC} as a function of Galactocentric distance r_{GC} for all the 6869707 stars in *Gaia* DR2 with relative error on total velocity < 0.2. Colour is proportional to the logarithmic number density of stars. The green dashed line is the median posterior escape speed from the Galaxy from (Williams et al. 2017). We overplot in blue the "clean" high velocity star sample introduced in Section 4. Circles and triangles correspond, respectively, to HRS and HVS candidates discussed in Section 5, colored in yellow (red) if $P_{MW} > 0.5$ ($P_{MW} < 0.5$).

Disk age-velocity distribution

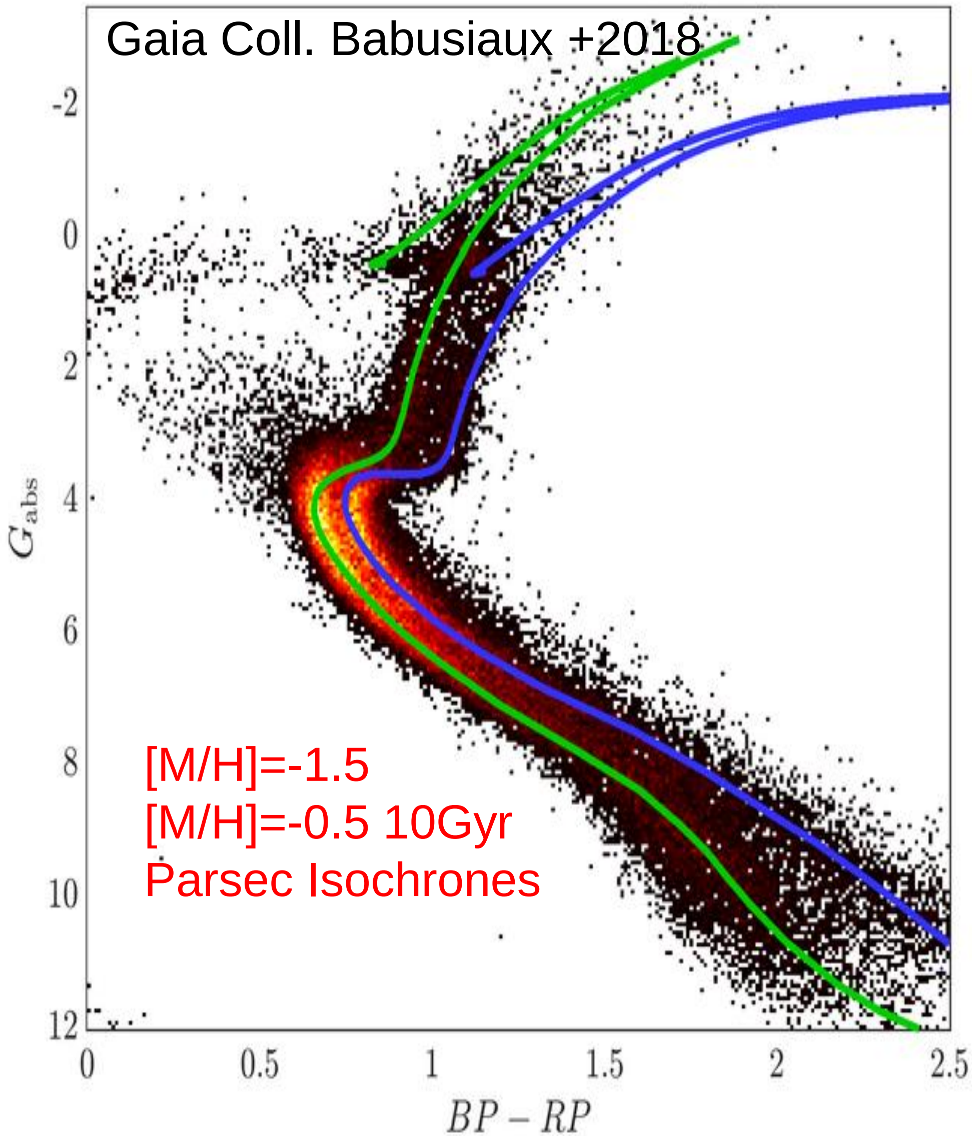


Sanders+2018

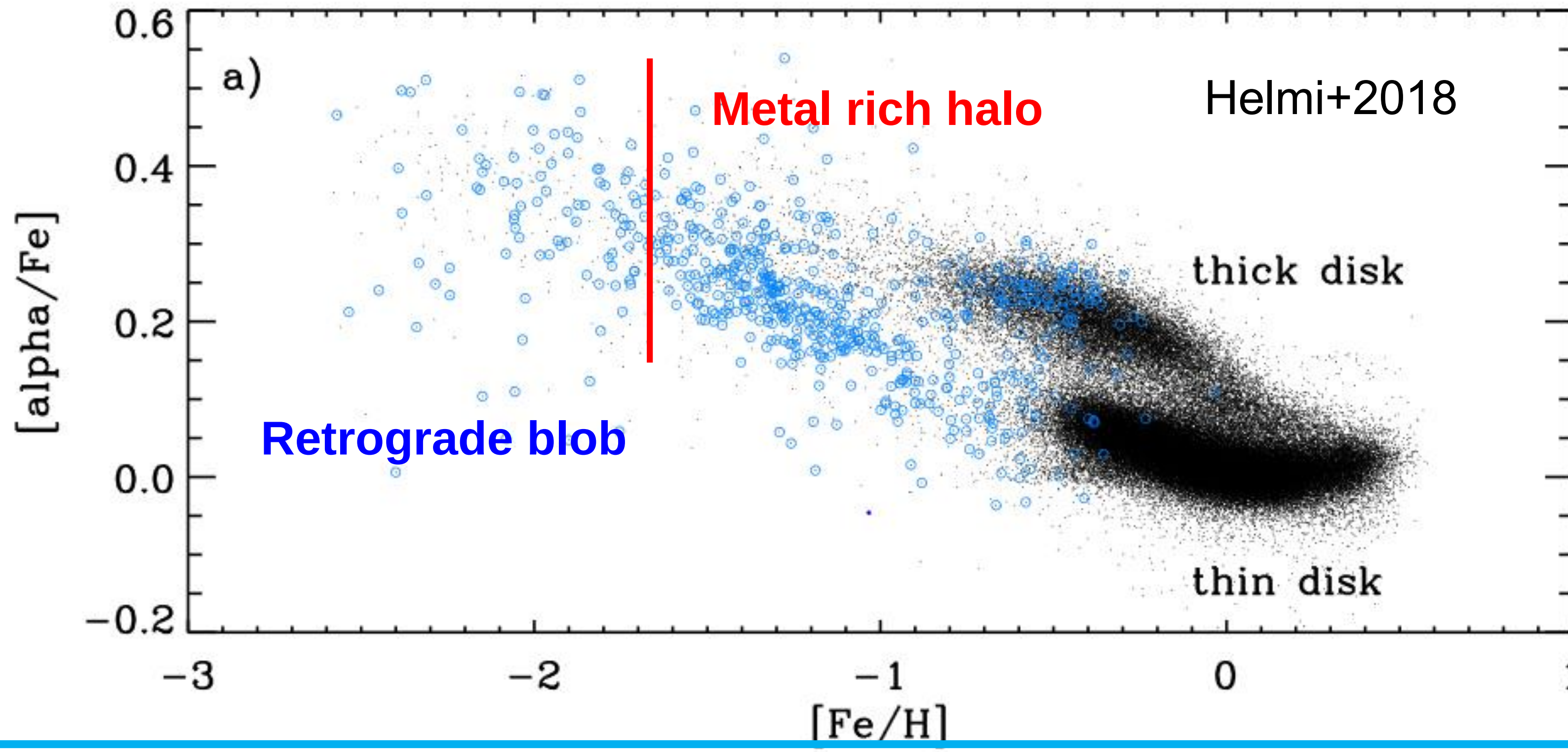
Figure 10. Velocity dispersions against age for a series of radial bins (for giant and turn-off stars with $|z| < 0.6$ kpc and [M/H] > -1 dex). Each line is coloured by the mean Galactocentric radius of the bin. The top panel shows

- Ages for 3 million stars using DR2 parallaxes, +SEGUE, GALAH, GES, LAMOST, APOGEE chemical information
  - Uncertainties from 16%(APOGEE) to 40%(RAVE, GES)
  - However: dependence on priors and selection function
  - Age-velocity dispersion in the disk shows no break at intermediate ages: consistent with heating from GMC (Sanders+2018, Ting &Rix 2018)
- A Catalog of velocity for 7million stars (Marchetti et al 2018) http://home.strw.leidenuniv.nl/~marchetti/research.html

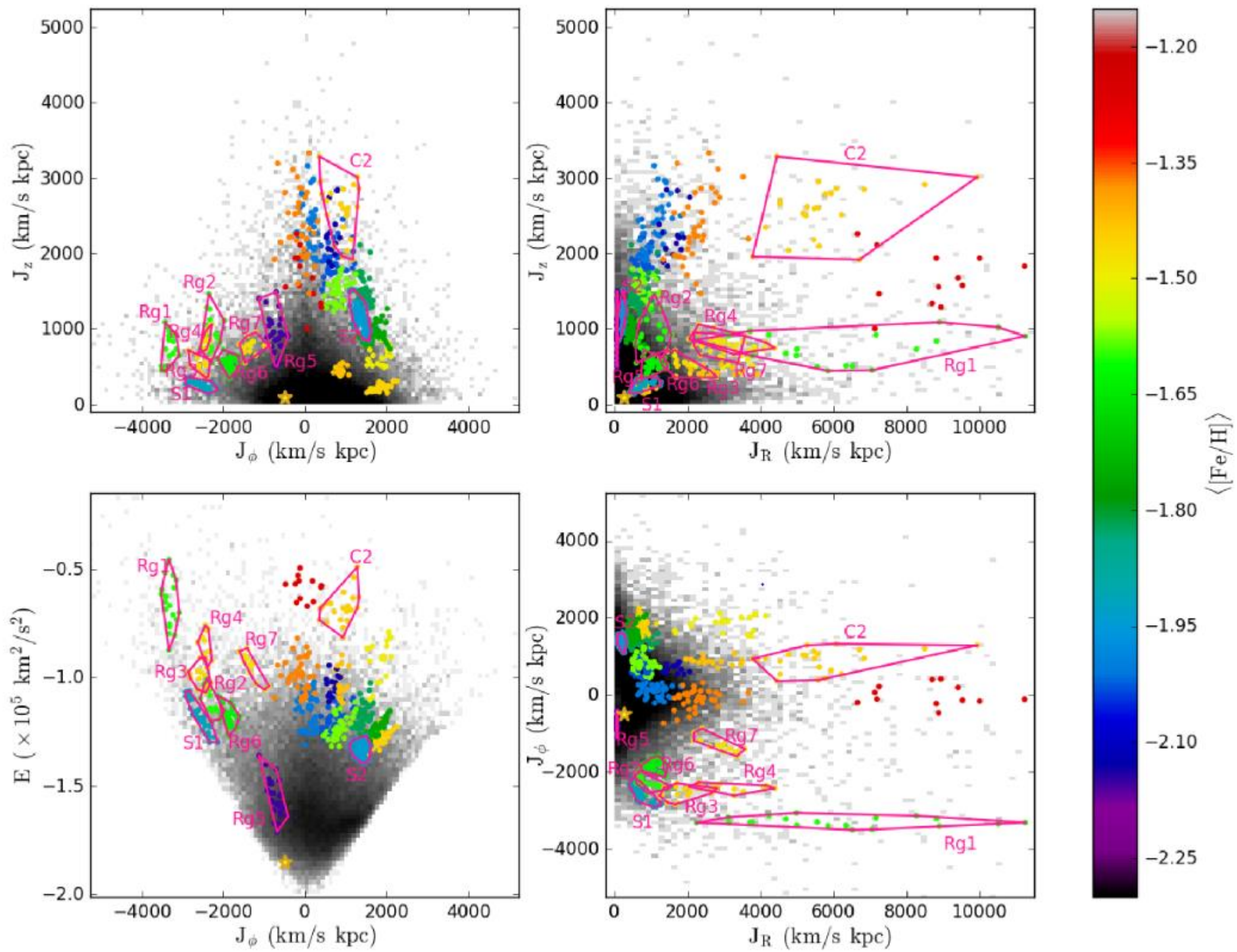
Gaia DR2 new view of the Halo



- Kinematically selected halo stars having [Fe/H] > -1 (Bonaca +2017)
- Local Halo merging history from TGAS+ RAVE (Helmi 2017, Myeong+2017)
- Haywood +2018: using Nissen &Schuster +APOGEE metallicity confirm that red sequence is thick disk; the blue accreated halo stars
- Gaia Sausage/Enceladus retrograde stars are on the blue sequence(Helmi+2018)
- Accretion events with DR2 found in the halo using a variety of data (Belokurov et al. 2018; Myeong et al. 2018a,b; Deason et al. 2018; Kruijssen et al 2018,Koppelman+ 2018, Lancaster+2018…)

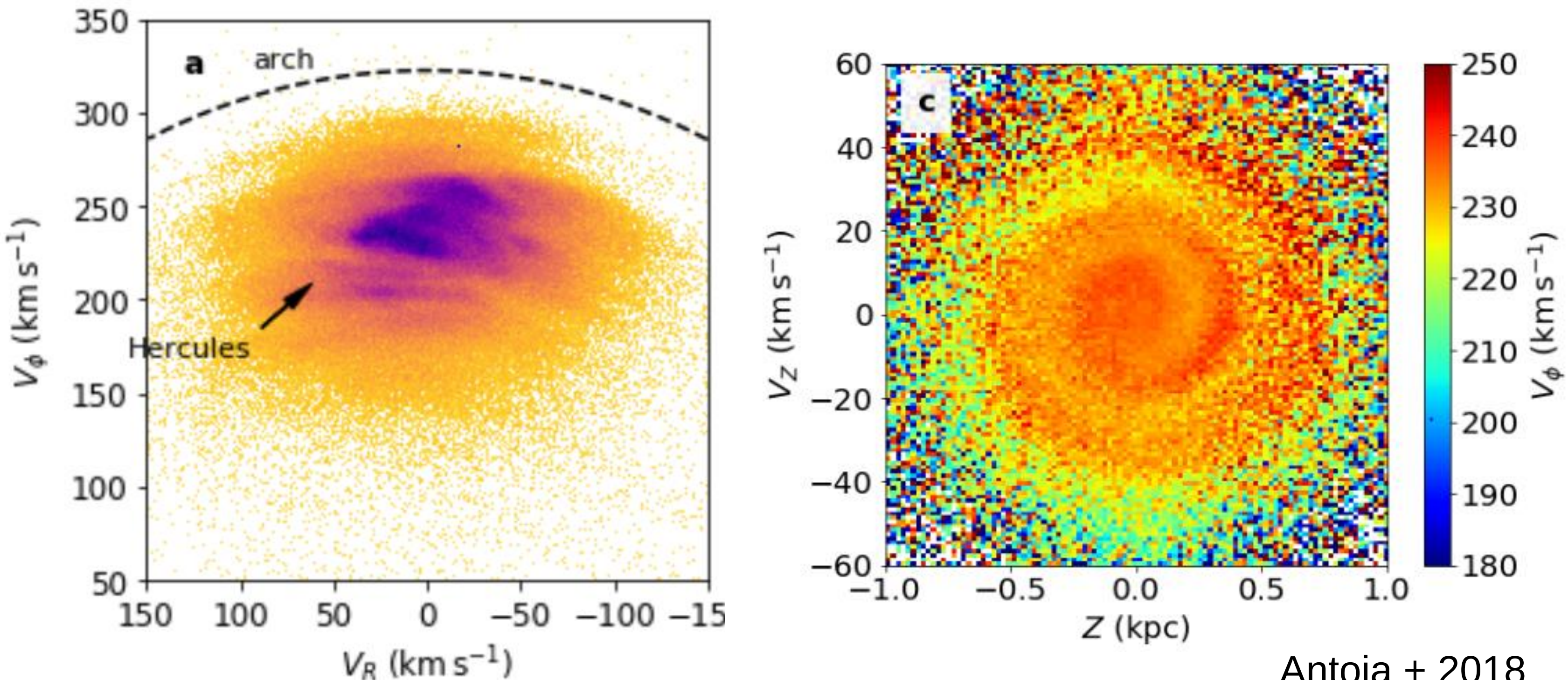


- Gaia+SDSS data : Gaia Sausage contributing to 50% mass of the halo within 25 Kpc (Belokurov+2018, Lancaster+2018, Kruijssen+2018)
- 100,000 stars DR2+APOGEE within 5 Kpc (Helmi+ 2018)
- Inner 30 Kpc the stellar halo could be largely dominated by a single, ancient, extremely radial merger 10 Gyr ago
- High mass progenitor :$10^{9\text{-}10}$ Mo
- [alpha/FeH] different from thick disk: long lasting SF
- High e stars with abundances of dwarf satellites (APOGEE)(Mackereth+2018)



- In addition we have a superposition of minor mergers
- 21 new sub-structures found in the halo using SDSS +Gaia data (Myeong+2018) in the high metallicity regime

Disk perturbations



Antoja + 2018

The disk is out of equilibrium state (Gaia Collab., Antoja+2018, Kawata+2018, Trick +2018)

Bending modes excited by dark matter halo (Chesquers 2018)

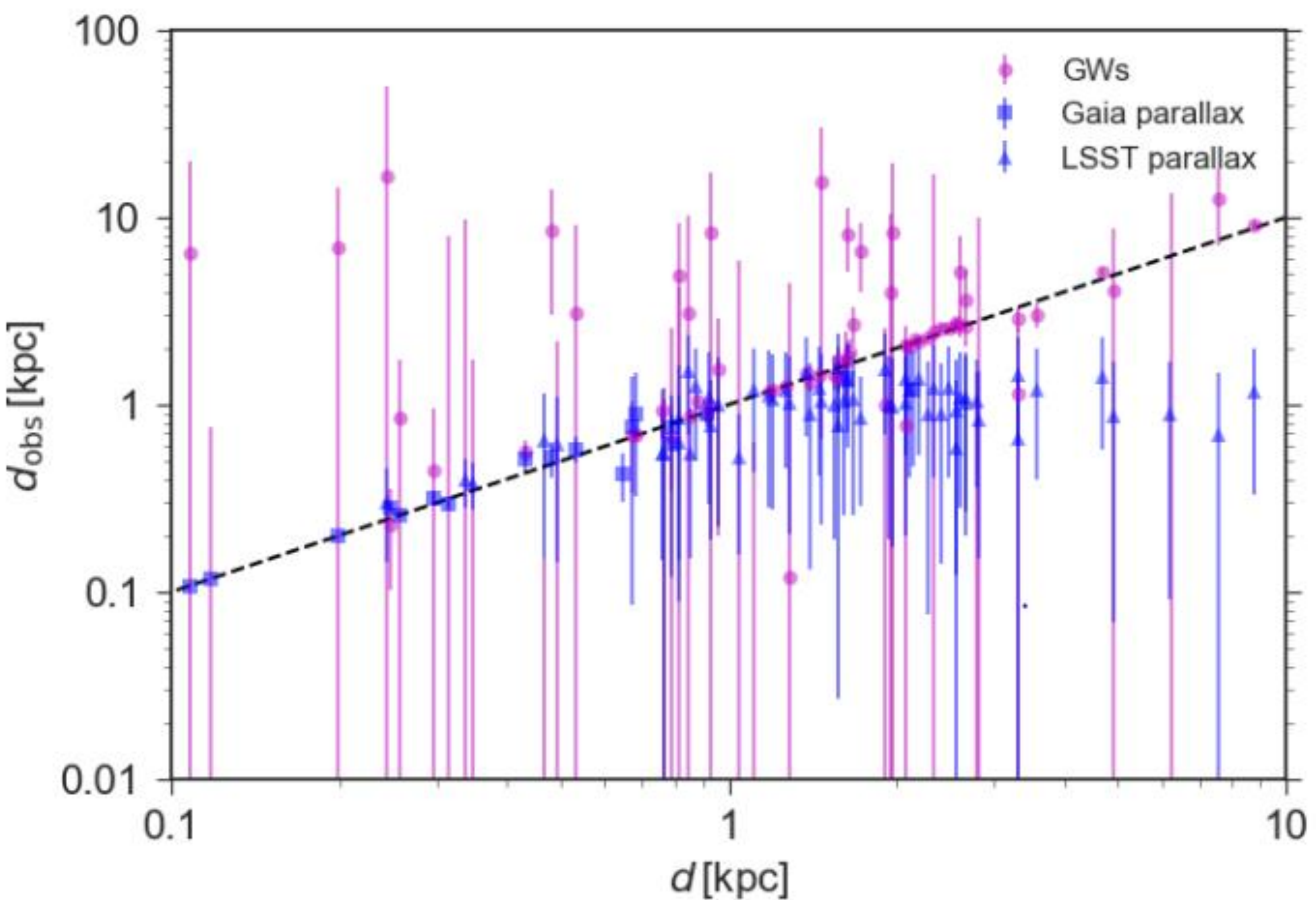
vertical waves from a perturbing satellite (Binney Schoenrich 2018)

Perturbations created by spiral arms (Hunt+2018, Quillen+2018)

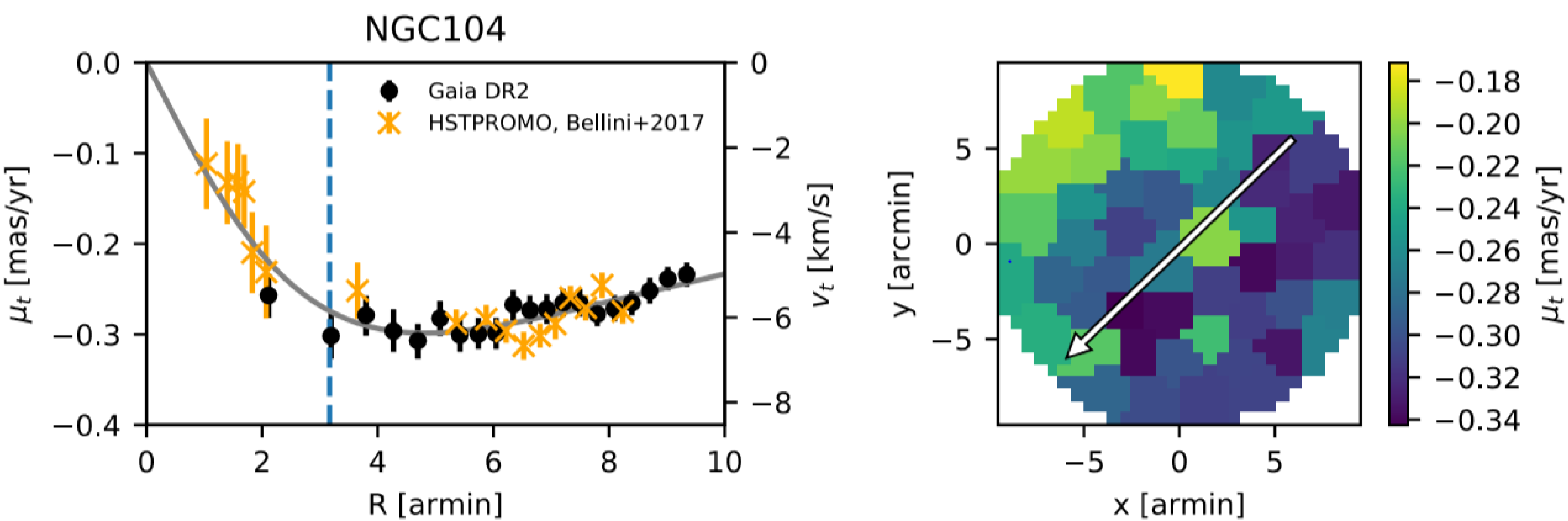
Bar perturbations (Gaia Collab 2018)

Multi-messanger Galaxy

Lisa,Gaia,LSST: 100,000 ultra-compact binary WDs to trace the barionic mass in disk and bulge (Korol 2018)



Internal kinematics of GCs



- Rotation is fossil record of primordial formation conditions(Tiongco et al 2017)
- Little work on rotation on the plane of the sky
- Clear differential rotation in 5 GCs (Gaia Collab 2018)
- Expansion and contraction of GC
- Core collapse and halo expansion in NGC6397 (Gaia Collaboration+2018)
- Se also Bianchini+ 2018: rotation in 11 out of 51 GCs

Multiple populations in GCs:47Tuc

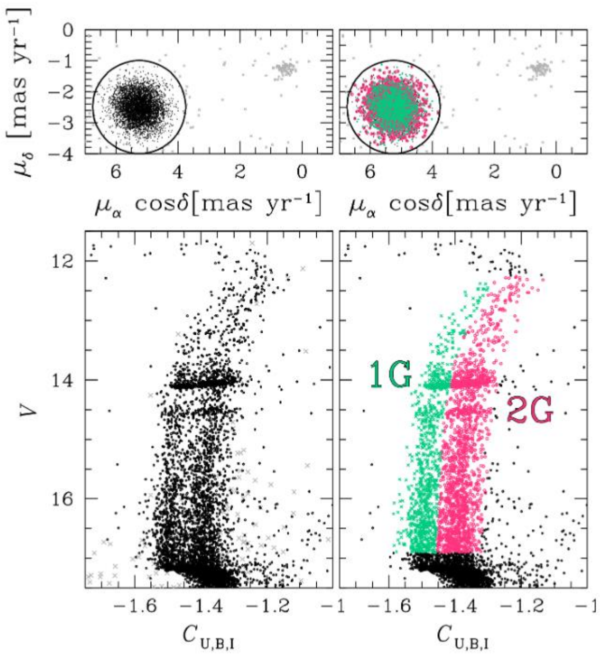


Figure 1. V vs. $C_{U,B,I}$ pseudo-CMDs (lower panels) and vector-point diagrams of stars in 47 Tuc (upper panels). The black circle in the vector point diagram separates cluster members from field stars, which are colored black and gray, respectively in the left panels. Note the Small-Magellanic Cloud stars clustering around ($\mu_\alpha cos\delta; \mu_\delta$)~(−0.5; −1.2). In the right-panels we used aqua and magenta colors to represent 1G and 2G stars.

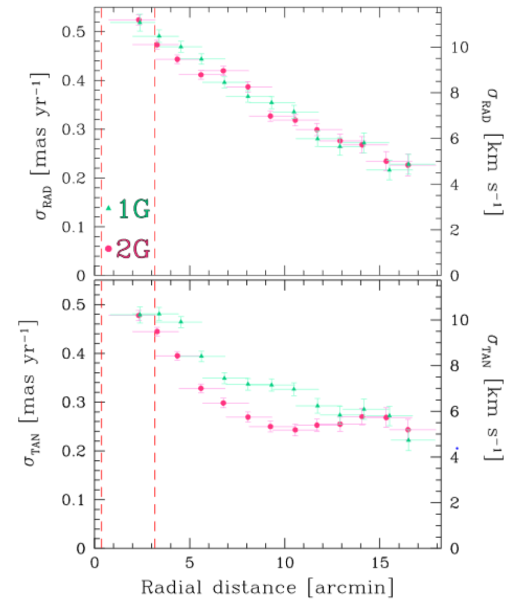


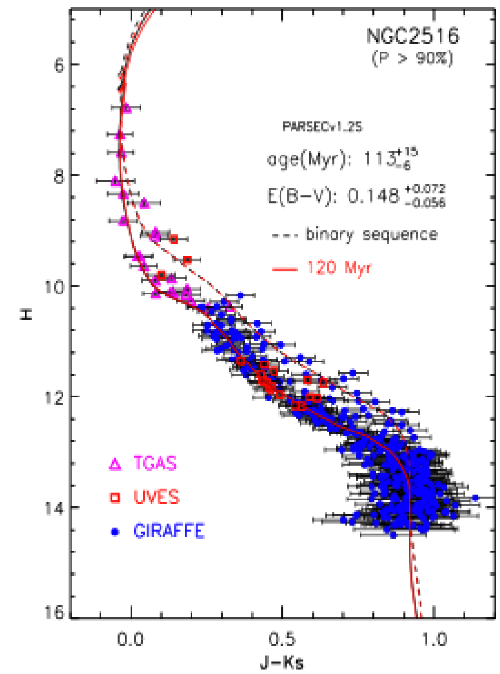
Figure 4. Tangential velocity dispersion (upper panel) and radial velocity dispersion (lower panel) as a function of the radial distance from the cluster center for 1G (aqua triangles) and 2G (magenta circles) stars.

- The presence of different rotation patterns in the two generations is controversial (Bellazzini 2012, Bellini 2018, Cordero 2017,Pancino 2007)
- N Body shows that they are related to the formation mechanism and initial configuration
- In 47Tuc 1G and 2G are not yet fully mixed: initial conditions still retained
- Second-generation stars: anisotropies and smaller tangential-velocity dispersion (Milone et al 2018). Possibly consistent with diffusion of a second generation that formed centrally
- concentrated in a disk configuration from mass loss gas Mastrobuono-Battisti +2016 ?

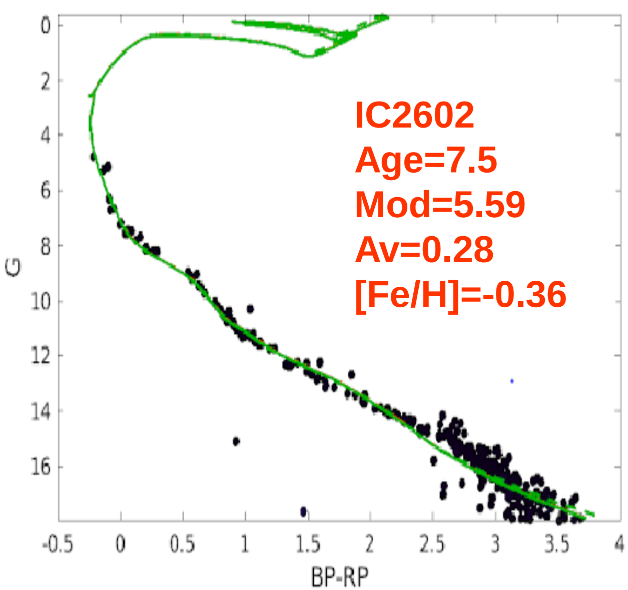
Ocs Parameter revision

- Parallax-Pms revision for 150 OCs in the inner 2 Kpc in DR1 and 1200 in DR2 (Cantat-Gaudin+2018)
- Ages for 80 Ocs (Gaia collab, van Leeuwen+, 2017, 2018, Randich 2017, Cantat+2018) and more than 300 in DR2 (Bossini +2018)
- Upmask(Krone-Martins 2014)+ Bayesian age determination

Randich+2017



Bossini+2018



Cantat-Gaudin+2018

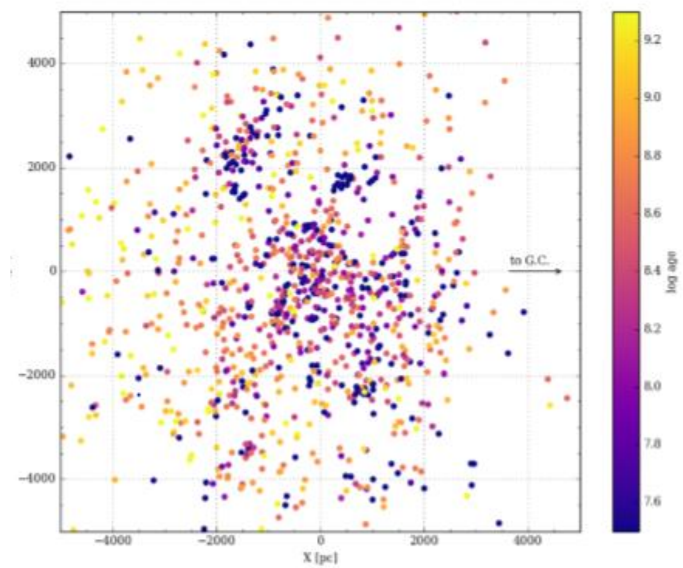
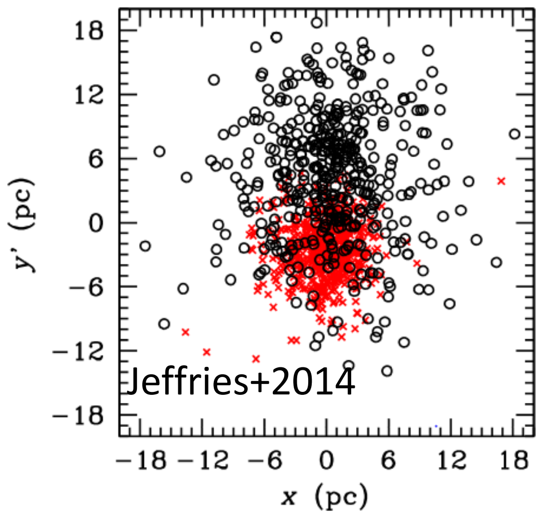
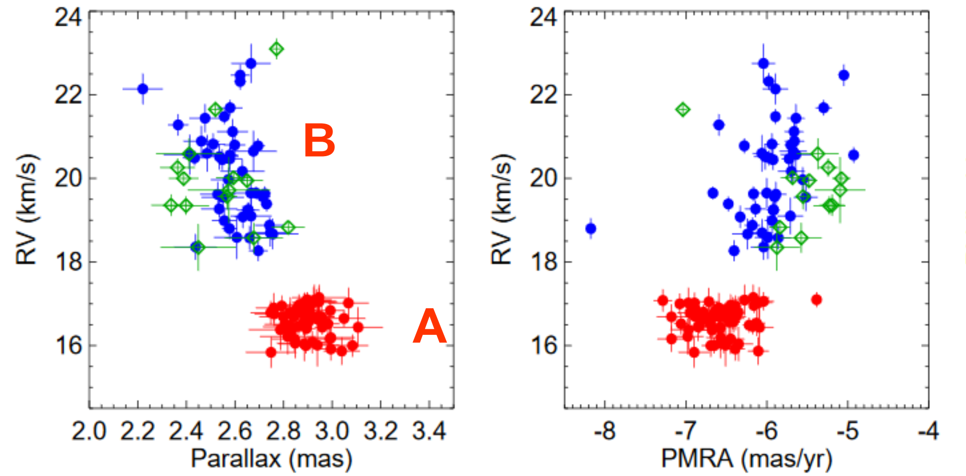


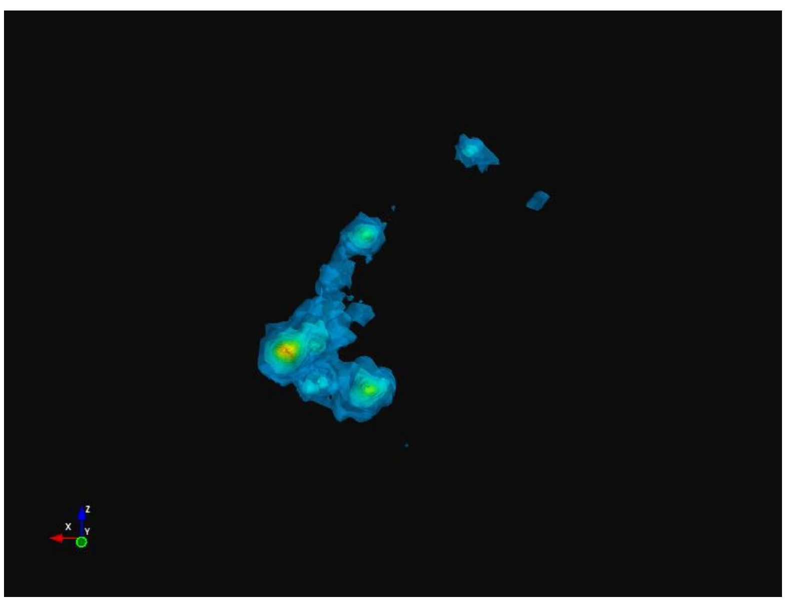
Fig. 11. Left: location of the OCs projected on the Galactic plane, using the distances derived in this study. The yellow dots indicate the objects newly identified in this study. Right: same sample of OCs, colour-coded by age (as listed in MWSC). Superimposed is the spiral arms model of Reid et al. (2014).

Cluster formation : Gamma 2Vel





Franciosini+2018



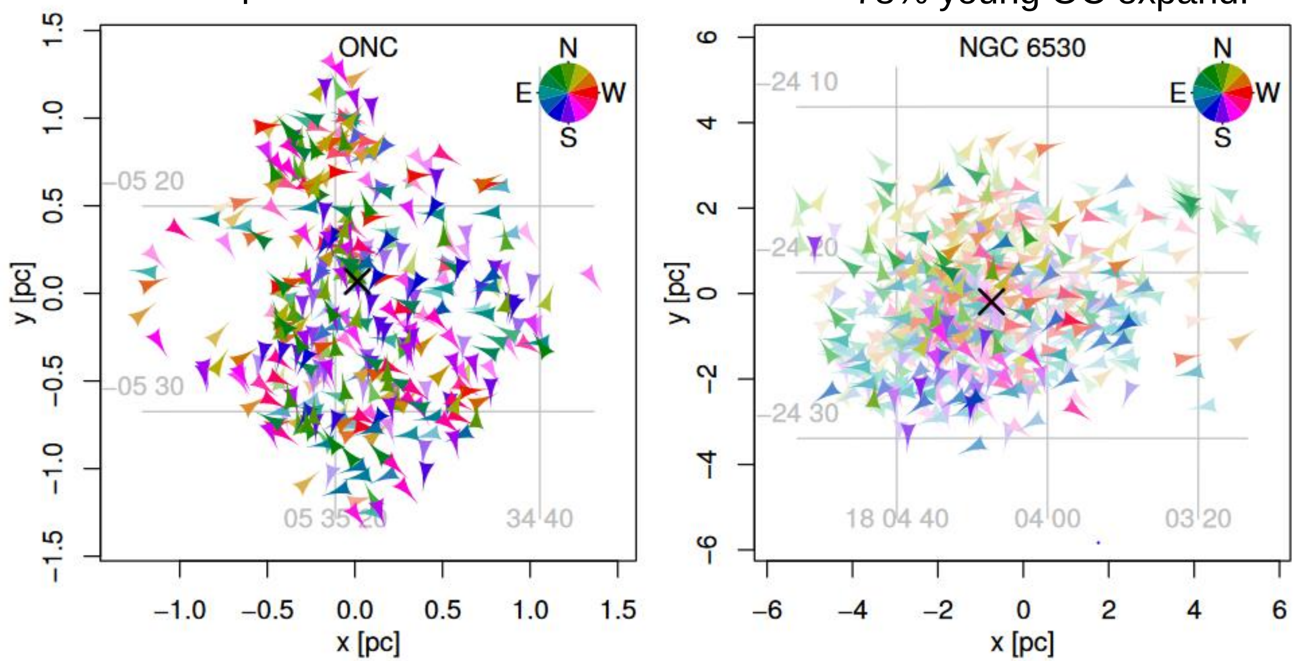
Cantat et al 2018:3D structure of Vela OB

- Clusters in 7D
- A is closer than B
- B is expanding and moving away
- A is bound B is unbound
- A and B are coeval
- In the whole area, 4 Ocs formed together 10 Myr ago and the whole region surrounds a bubble and is expanding

Young OC expansion?

No expansion

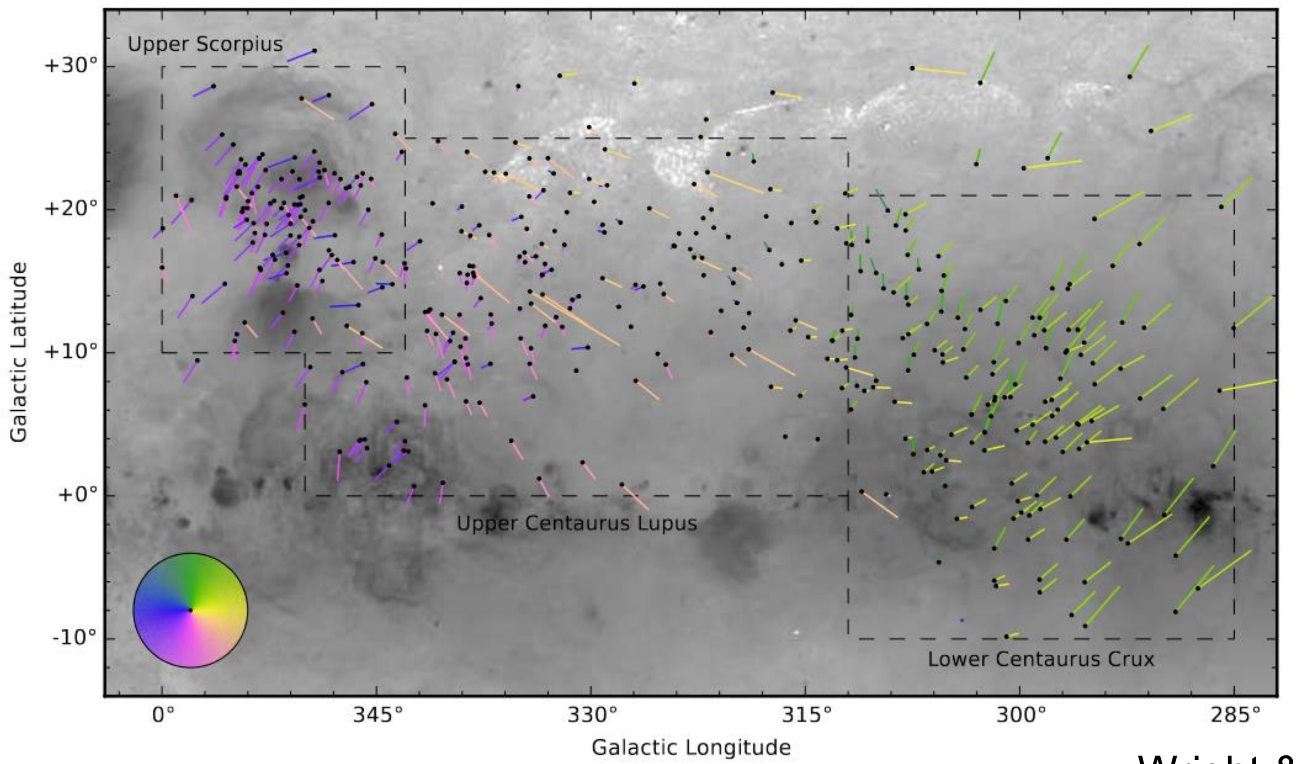
78% young OC expand!



Kuhn+2018

Figure 3. Direction of motion of individual stars in the rest frame of the cluster. Diagrams are shown for the ONC (left) and NGC 6530 (right). The orientations of the arrows and their hues indicate their direction, while saturation indicates weighting based on statistical uncertainty. In the ONC stars with different velocities are mixed together, while, in NGC 6530, many stars have directions of motions away from the cluster center (as indicated by the outward pointing arrows and color segregation by azimuth). Plots for other clusters are included in an online figure set.

- First direct evidence that clusters are dispersed after formation (possibly by gas expulsion)
- No convergent motion in large forming regions

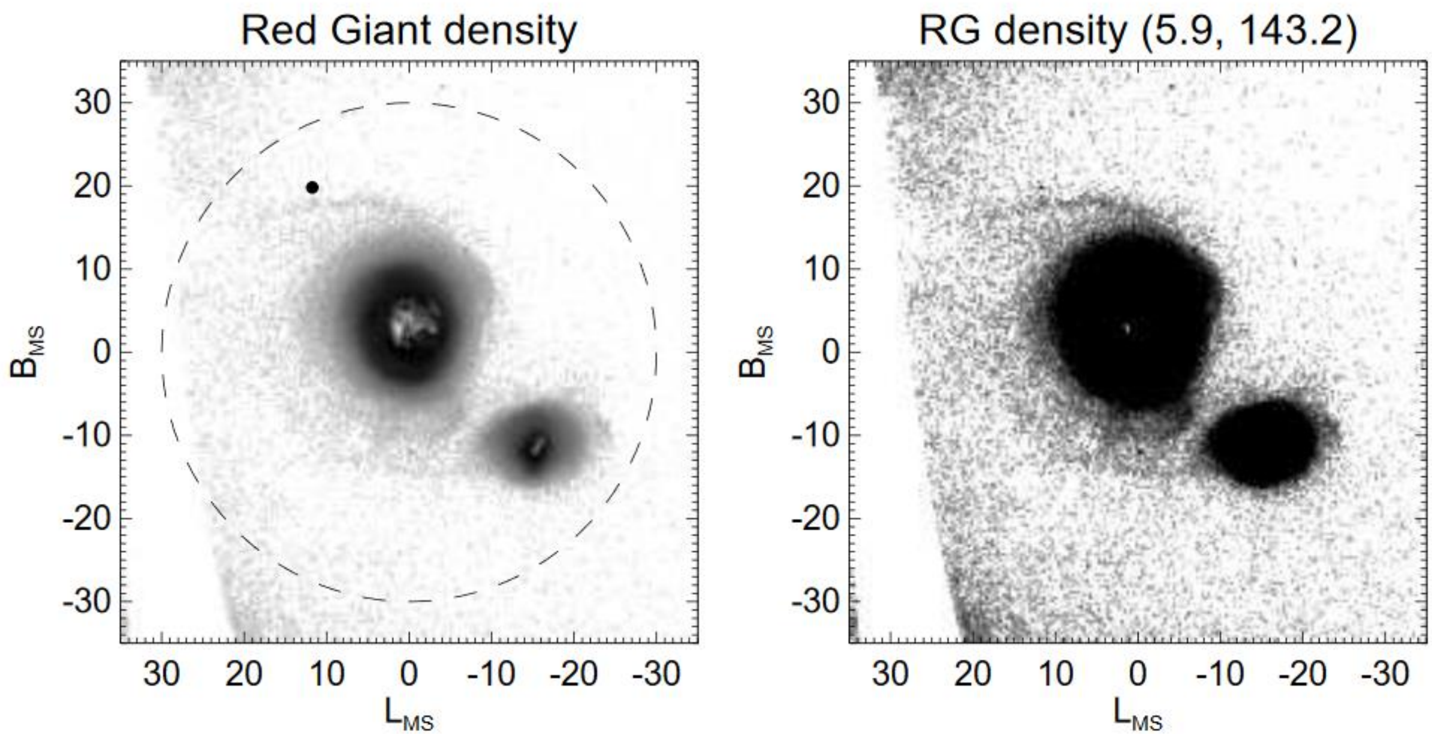


Wright & Mamajek +2018

Figure 12. Proper motion vector map for the entire Sco-Cen association projected onto an inverted Hα image from Finkbeiner (2003). The proper motions were corrected for radial streaming motion according to the equations in Brown et al. (1997) and using bulk (median) RVs of -6.2, 2.8 and 13.0 km/s for the three subgroups. Points show the current positions of stars and vectors show the proper motions over 0.5 Myr with the bulk (median) proper motion of the entire association subtracted to show the relative motion. The vectors have been colour based on their direction of motion (see colour wheel in lower-left) to highlight kinematic substructure.

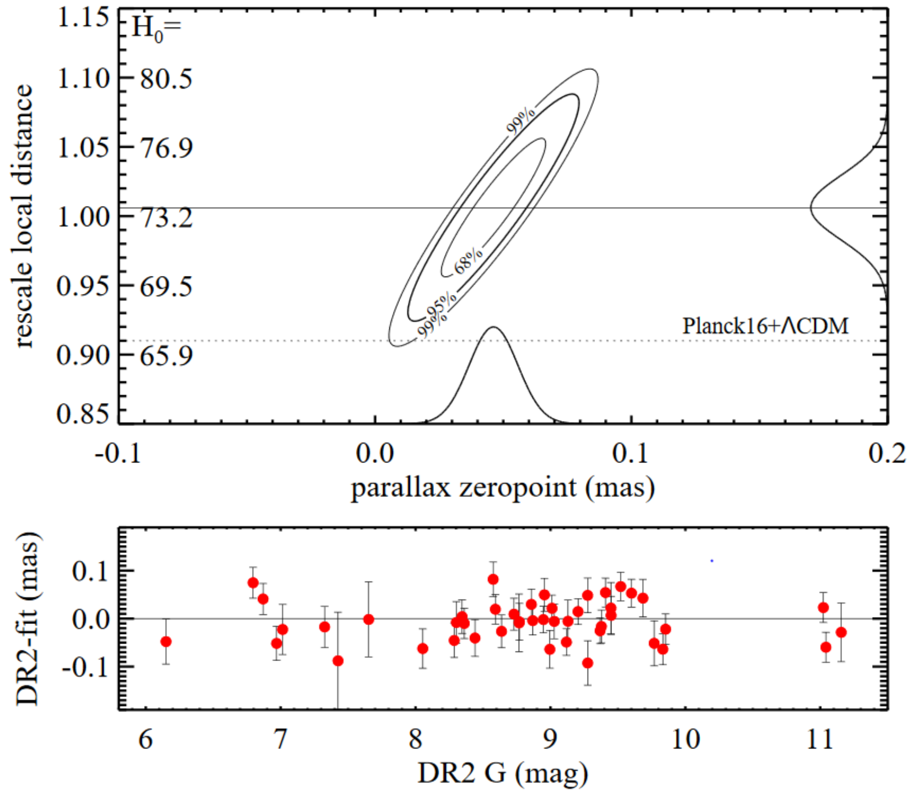
- Little evidence that large clusters form by merger at later time
- Lack of coherent expansion in OB associations suggests that they formed in multiple small scale formation events

LMC (and SMC)



- Giants from Gaia DR2 photometry and astrometry
- A wealth of tiny and unseen structures and streams
- The two main arms in the LMC due to the combined effects of MW and SMC interaction(Belokurov+2018)
- Rotation and bar perturbations (Gaia Collaboration+2018)
- Vasiliev(2018) (modeling internal LMC kinematics)

Climbing distance ladder with DR2



- HST observations of 70 Cepheids, P > 8 days, AH < 0.4 mag, V > 6 mag and D < 7 kpc to calibrate extragalactic Cepheids in SNIa hosts
- Comparing predicted vs Gaia DR2 parallaxes, the distance scale is α = 1.010 ± 0.029 2.9 sigma out of α = 0.91 needed to match Planck Ho= 66.93±0.62, but consistent with H0 = 73.52 ± 1.62 kms−1 Mpc−1(Riess 2018)

More exciting science to come