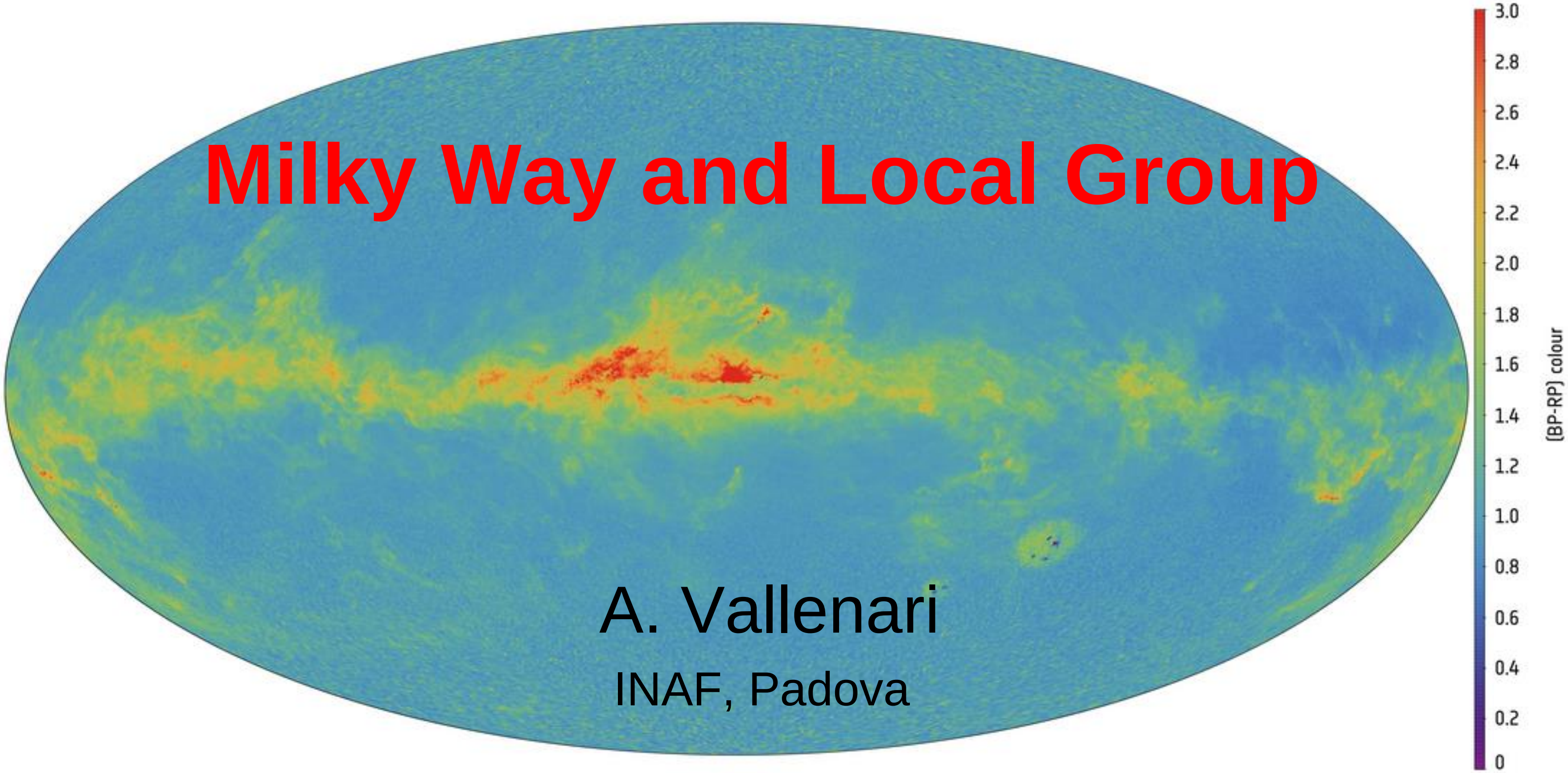
Milky Way and Local Group



A. Vallenari

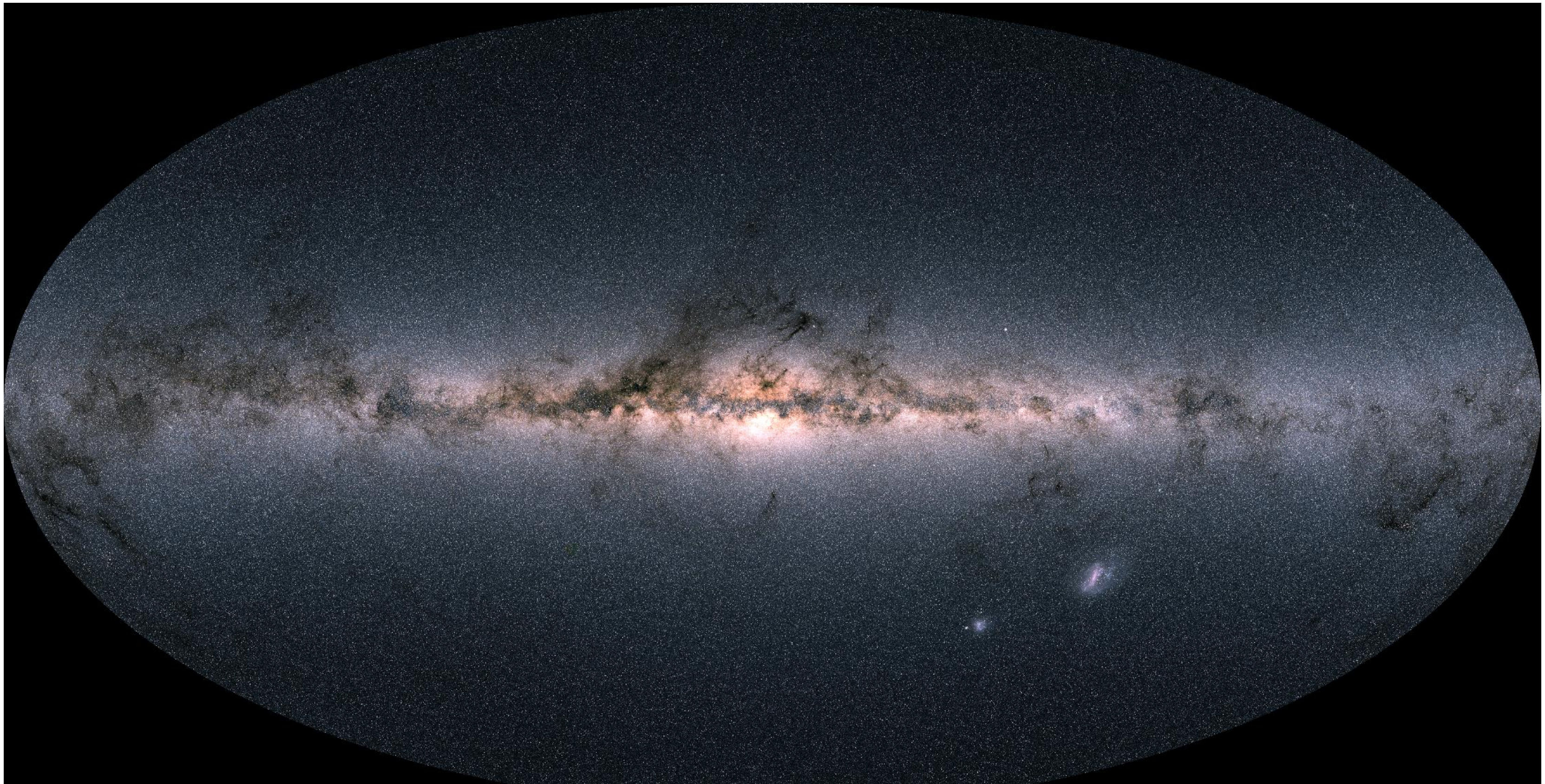
INAF, Padova

The Big Question

- How do galaxies form?
- observe distant galaxies at high redshifts in various stages of formation and evolution
- Galactic archeology

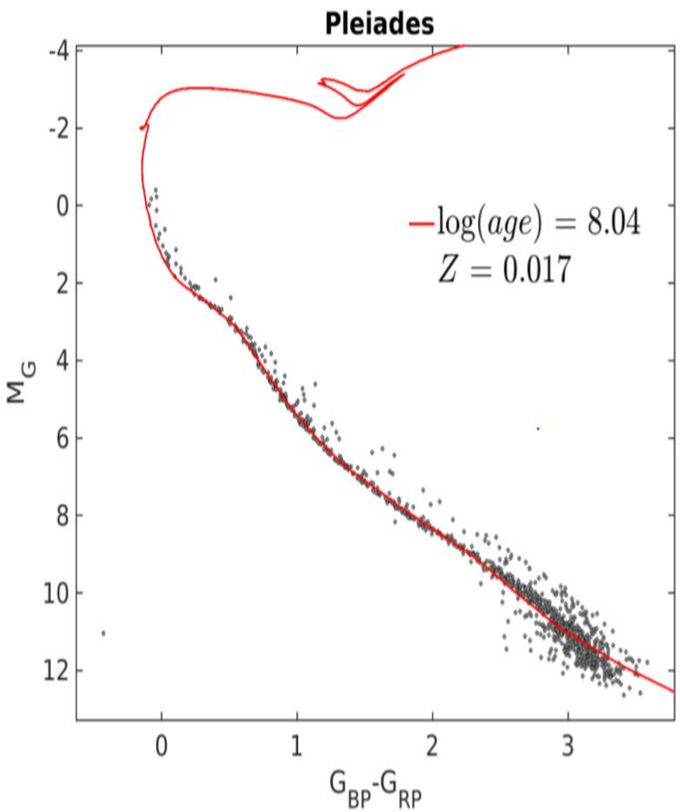
The Big Questions: I

- How was the Milky Way assembled and how did it evolve?
- the formation of the sub-galactic structures in the Milky Way
  - Chemo-dynamical evolution of the sub-galactic structures
  - the formation and chemo-dynamical evolution of stellar clusters
  - the star formation history in the MW



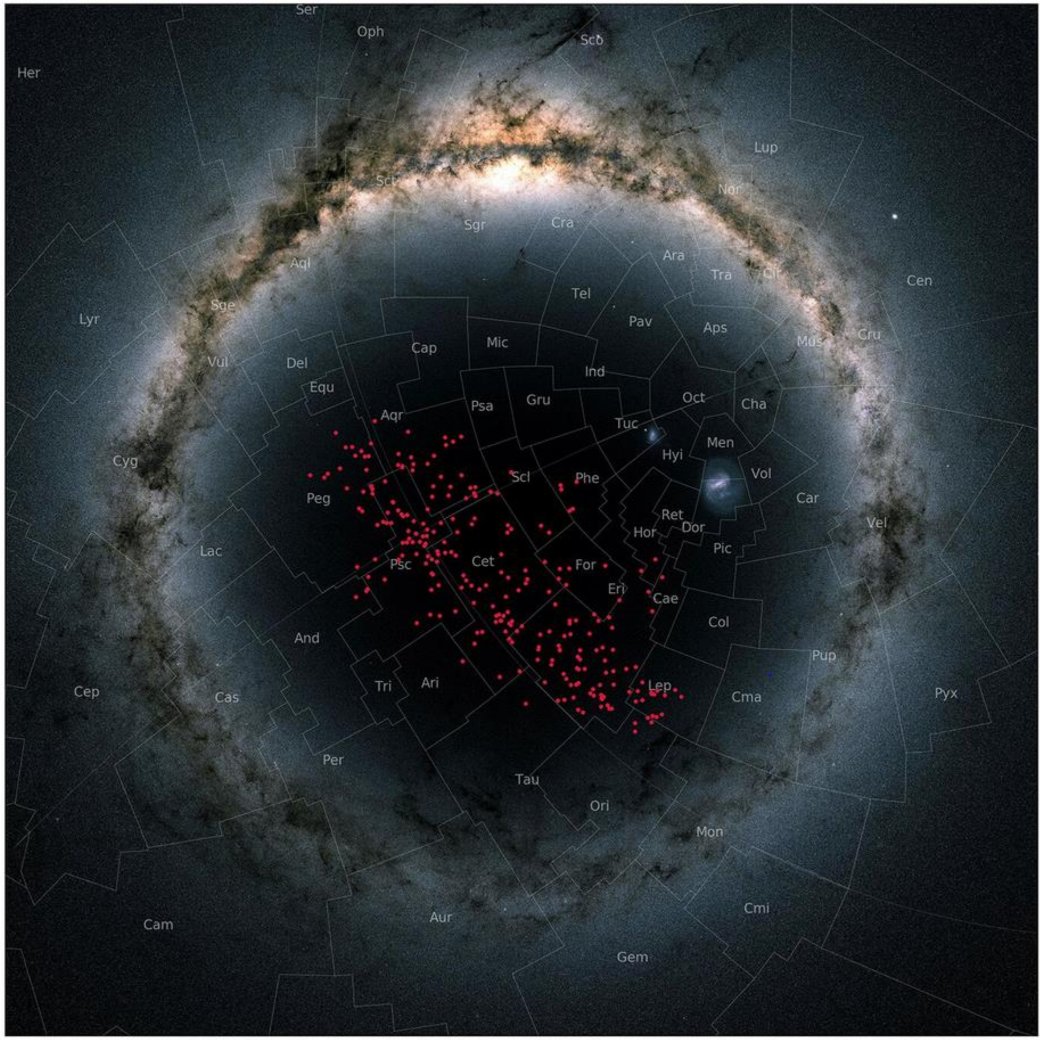
The observables

- parallax, velocities, M, L, Teff, log g, [Fe/H], [X/Fe], age,....
- → spectroscopy, astrometry to built a detailed chrono-chemo-kinematical extended map of our Galaxy (Gaia, GES@VLT, TNG, LBT..)
- → stellar evolution as fundamental tool
- →galaxy formation&evolution models



Gaia Coll., Brown, Vallenari + 2018

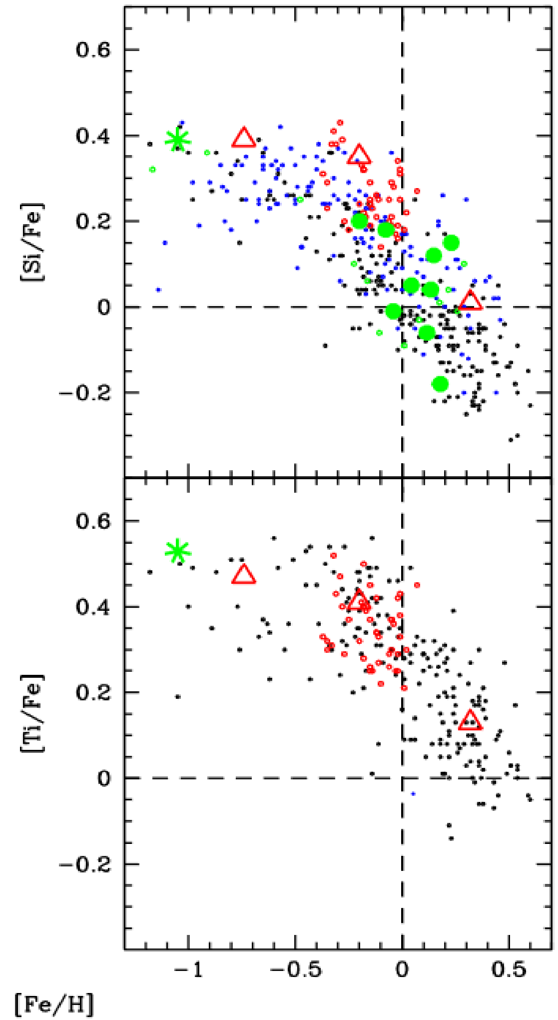
- Do Galaxies form from primordial building block or from systems where the SF already took place?
- Halo: in situ vs accreted?
  (Babusiaux+2018, Helmi+2018, Battaglia 2018)
  - What is the total mass of the Milky Way? What is the shape of the Galactic gravitational potential? (Battaglia + 2015, Koposov+ 2009)
  - Where are the most metal-poor stars in the Milky Way, what are their properties, and what do they tell us about the physics of the early Universe? (Caffau+2011)
- dSph and UDFs : the role of disrupted dwarfs (Fabrizzio+2015, Tolstoy+2009)



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…). Almost 50% of local halo (20-30 kpc) formed by accretion

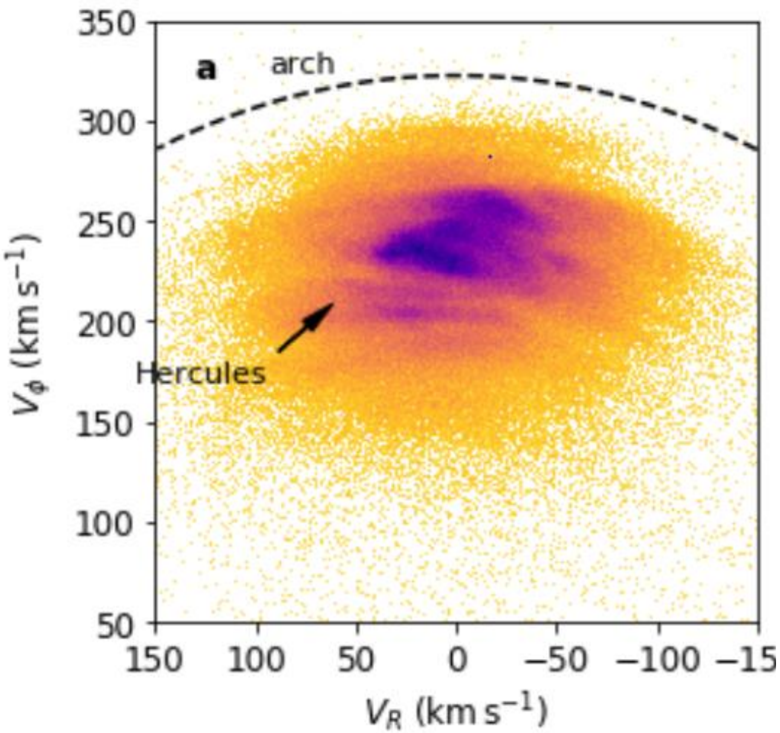
The Bulge

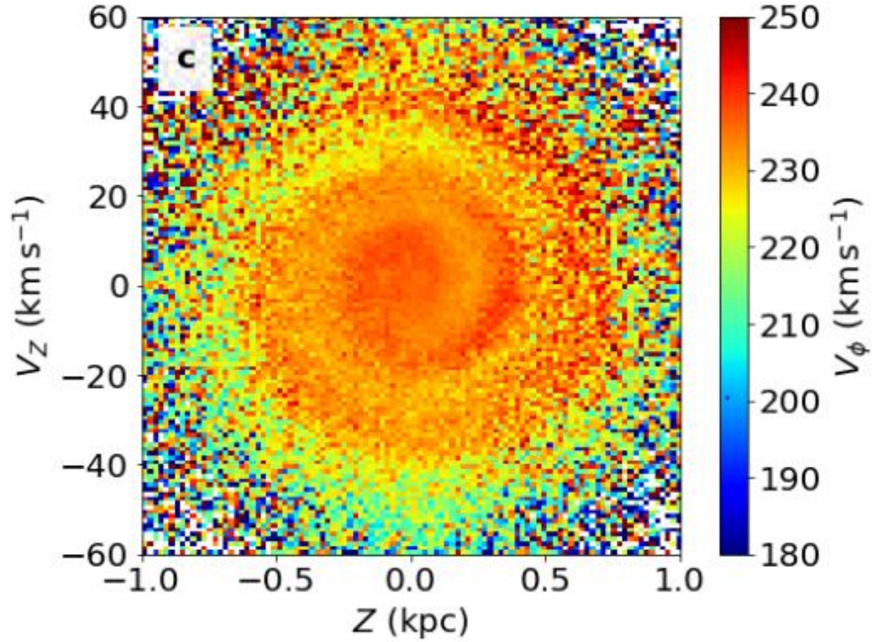
- What is the origin of the Bulge? (Renzini 2018)
- Very complex age-abundance pattern from metal-rich young alpha-poor to metal-poor and very old alpha-rich populations (for example, Ness et al., 2013; Bensby et al., 2017, Ryde +2016, Spagna+2015)
- The alpha-rich bulge and disk population share the same origin?
- Is there a classical bulge made by merger? (Barbuy et al., 2018)
- What is the influence of the bulge/bar on the Galactic disk? (Kushniruk et al., 2017)
- what is the story of the Bulge as told by its clusters (Ferraro+ 2016, Origlia+ 2011, Saracino+2016, Origlia+2019)



Ryde+2016
△ Terzan 5

The Disk or The Disks?

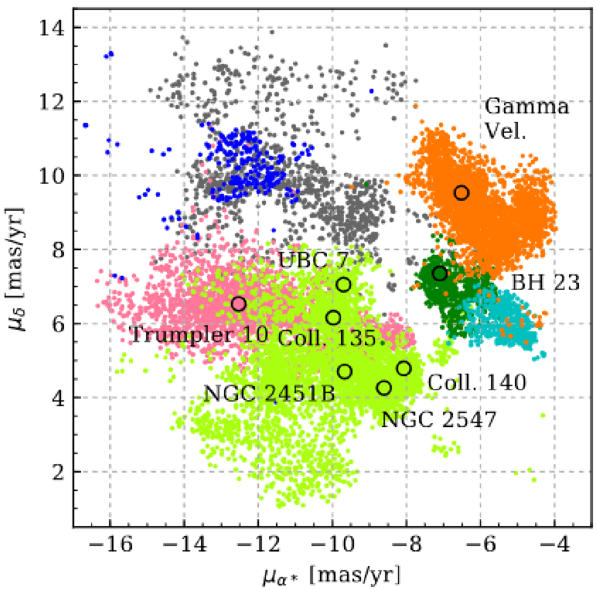


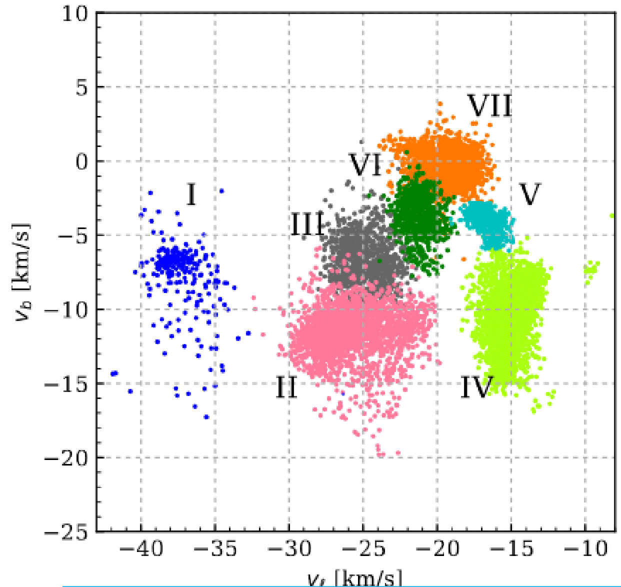


Katz+2018, Antoja + 2018

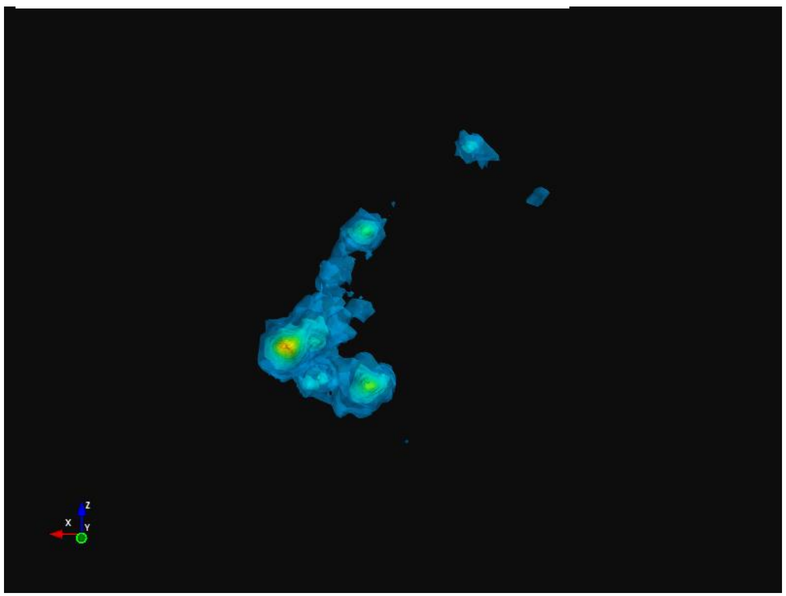
- The disk is out of equilibrium state (Katz+2018, Antoja+2018, Kawata+2018, Trick +2018, Poggio+ 2018)
- The roles of hierarchical formation and secular evolution in shaping the Galaxy
  - Are thin and thick disk different entities? (Re Fiorentin+2019)
  - what are the roles of spirals (+ number of arms, pitch angle, pattern speed?) and the bar (length, pattern speed?) (Helmi+2006, Schoenrich & Binney 2009, Minchev+2015, Spagna 2014)
  - What is the role of stellar migration?

Cluster formation : Vela-Puppis





Cantat+2019

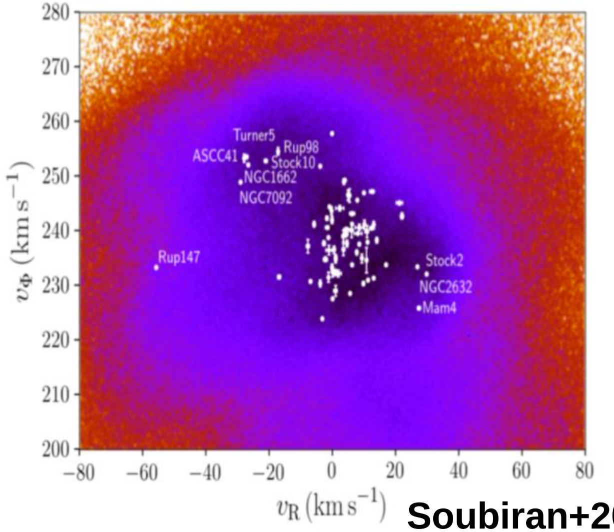


Cantat et al 2019:3D structure of Vela OB2

- First direct evidence that clusters are dispersed after formation(Guarcello+2018, Paltrinieri+2018, Lanzafame 2018, Prisinzano+2018,2019)
- Which formation model? Surround &squash (Krause+2018)?

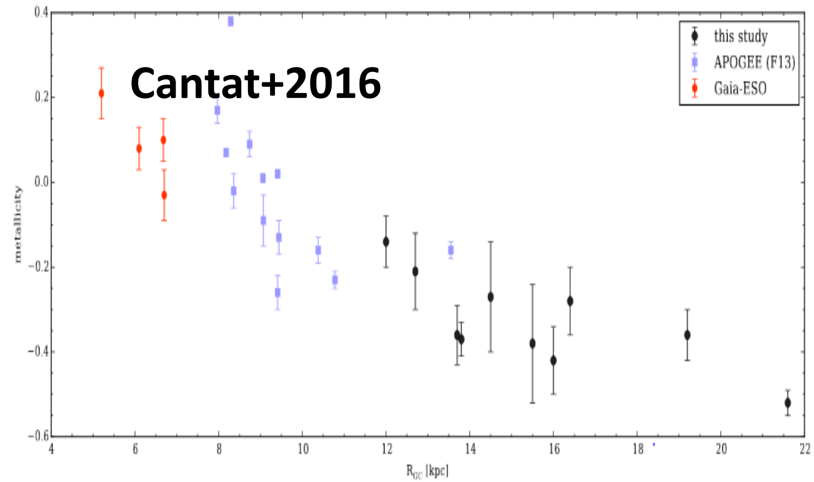
- In the whole Vela OB2, 4 Ocs formed together 10 Myr ago and the whole region surrounds a bubble and is expanding(Franciosini+2018, Spina+2018, Beccari+2018…)

Clusters as disk tracers



Soubiran+2018

Fig. 8. Velocity distribution of nearby OCs (dist ≤ 500 pc) in (V_R, V_ϕ),

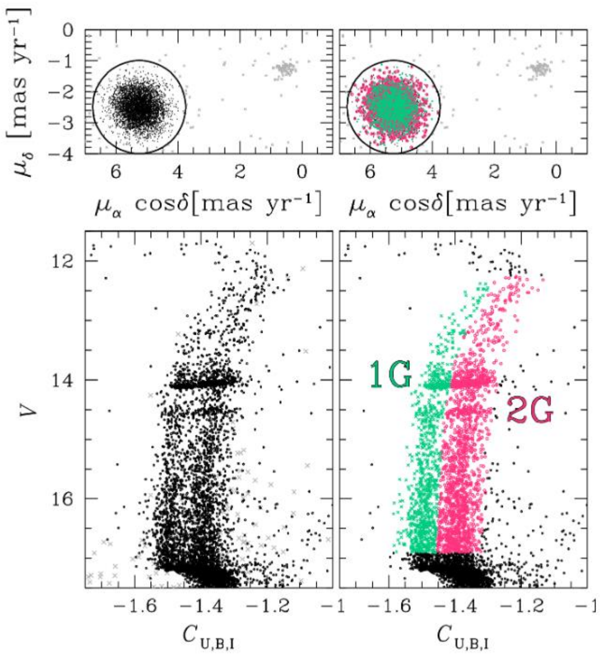


- Can we put further constraints on stellar physics to safely use stars as fossils for the Galactic formation and evolution?

- What is the GC contribution in halo shaping? How multiple populations formed in GCs?
- How do stars and clusters form and dynamically evolve to populate the MW field? (Carrera+2018, Pancino2010)
- What is the chemical evolution traced by the open clusters? (Magrini+ 2010, Jacobson+2016 Bragaglia+ 2006, Sestito + 2008, Cantat+2016, Donati+2012, Bossini+2018, Carrera+2018)

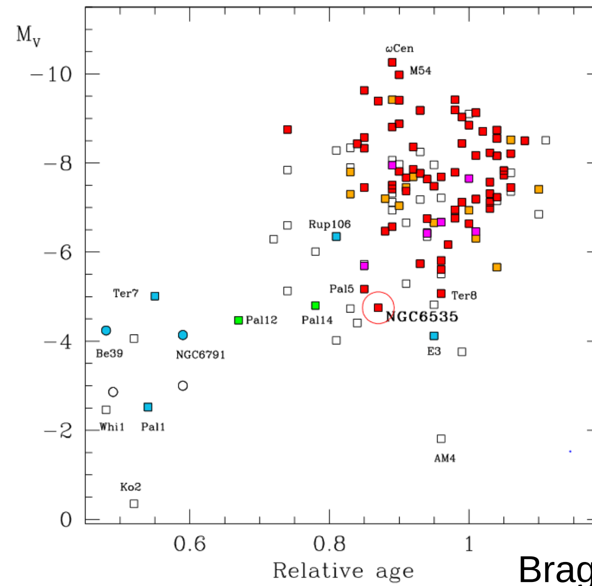
- How OCs trace the kinematics and dynamics and structure of the disks? (Soubiran+ 2018)

Multiple populations in GCs



Milone+2018

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 separates cluster members from field stars, which are colored black and gray, respectively in the left panels. Note the Small-Magellanic Cloud s 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.



Bragaglia+2017

Fig. 9. Relative age and absolute V mag for the GCs presently in the MW (open squares), including those associated with the Sgr dSph and for old open clusters (circles). Coloured symbols indicate clusters for which a) there is positive indication of multiple population from high-resolution spectroscopy (red) or from photometry or low-resolution spectroscopy (orange); b) there are uncertainties, but the presence is probable (magenta) or unlikely (green); and c) a negative answer has been found (light blue). A few interesting objects are labelled.

- How are multiple populations formed? (Bellazzini +2012, Bellini +2018, Cordero+ 2017,Pancino+ 2007, Bianchini+2018, Carretta+2016,2009, Gratton+2012, Marino+2009, Dalessandro+2018, D'Orazi+2015, Milone+2017)
- How much of the halo population is built by GCs? (Martell+ 2011, Bragaglia+ 2017, Mucciarelli+2013)

The Big Questions:II

- How was the Milky Way assembled and how did it evolve?
- the formation of the sub-galactic structures in the Milky Way: local scale
  - Chemo-dynamical evolution of the sub-galactic structures
  - the formation and chemo-dynamical evolution of stellar clusters
  - the star formation history in the MW

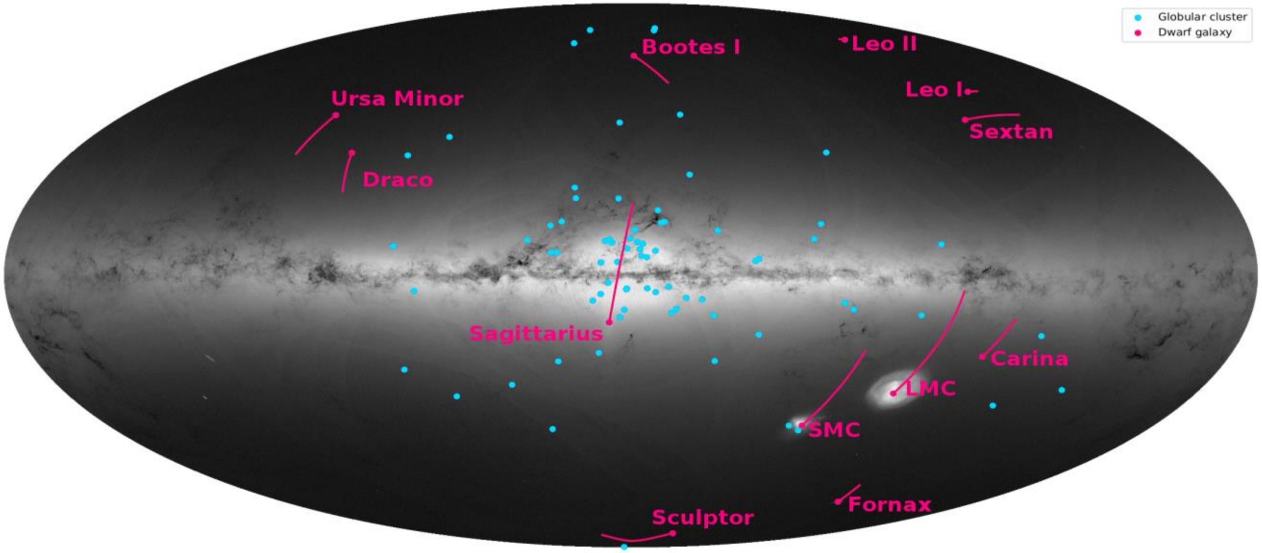
- The formation of the sub-galactic structures in the Milky Way: Galactic scale

How much substructure does the Galactic dark matter distribution? How do they interact with cold streams? (Yoon + 2011, Bland-Hawthorn &Gerhard 2016, Bonaca +2018)

  - Probing halo assembly at larger distances
  - Deriving mass and potential
  - Exploring the dark matter distribution

  - Resolved stellar populations trace the density and distribution of dark matter over orders of magnitude in halo mass
  - faint dwarf galaxies being particularly important probes

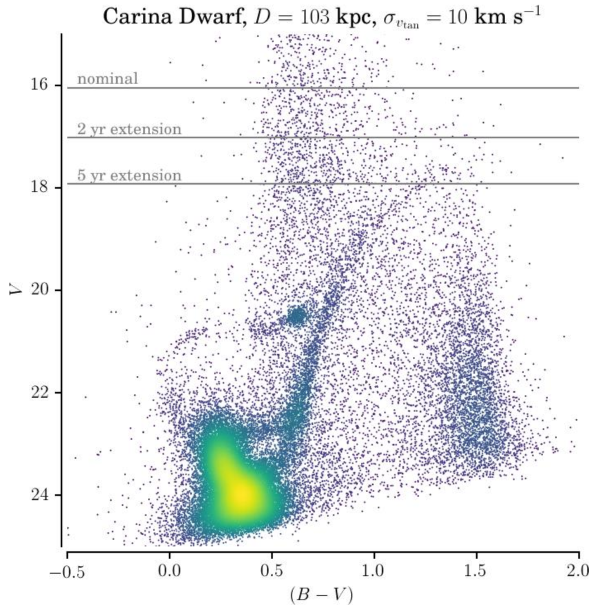
Mapping science into instruments: Next 5-10 years: Gaia

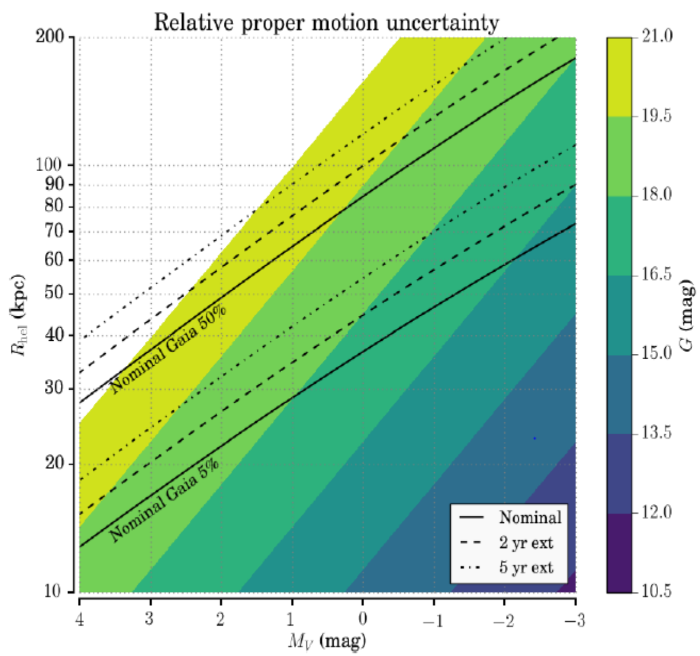


- 869 papers in 2018, 9 Nature articles + 316 preprints in the queue
- Next to come:
  - **2020 (E)DR3** –astrometry + photometry
  - 2021 DR3 –Vrad, classification, variables, minor planets, binaries, Mean Spectra
  - 2024 (?) DR4
  - **2028 (?) final Data Release**
- Overall gain in precision: factors 1.2 (DR3) and 1.7 (DR4) with respect to DR2
- proper motions improve by factors 1.9 and 4.5 with respect to DR2
- improvements by factors 2.3 in overall precision and 12.7 in proper motions for 10 year mission with respect to DR2 + gain in accuracy

Gaia 5-y extension

- Factor 20 the volume in which star clusters are resolved reaching inner and Perseus spiral arms (at 0.3 km/s at 3 Kpc)
- Reference frame: now at 0.3 mas degradation of the order of 40 mas over 50 years
- Internal kinematics of local group galaxies
- Brightest populations in classical dwarf galaxies at 100 kpc only reachable with 5 yr extension
- Probing the halo at 100Kpc and debris beyond 20-30 Kpc





Improvement factor for mission length increase from 5 to 10 years	Distance increase at the same accuracy	Volume increase at the same accuracy
Parallax	1.4	2.8
Proper motion	2.8	23

Mapping science into instruments: Next 5 years: Large spectroscopic surveys

- Pioneering work in GES (final DR next months)
- The spectroscopic surveys of the next decade) will yield samples at least 10−100×larger than the current ones.
  - WEAVE@WHT -2020 (open to the community at 30% time)
  - MOONS @VLT -1000 targets on 500 arcmin2, H=15-16: bulge, GCs
  - 4MOST @VST call for 30% of open time survey (mid-2019): ready by 2023
  - Mauna Kea Spectroscopic explorer (11m) R=5000,40000

→astrometry for 2+ billion stars + chemistry and fundamental parameters for millions of stars

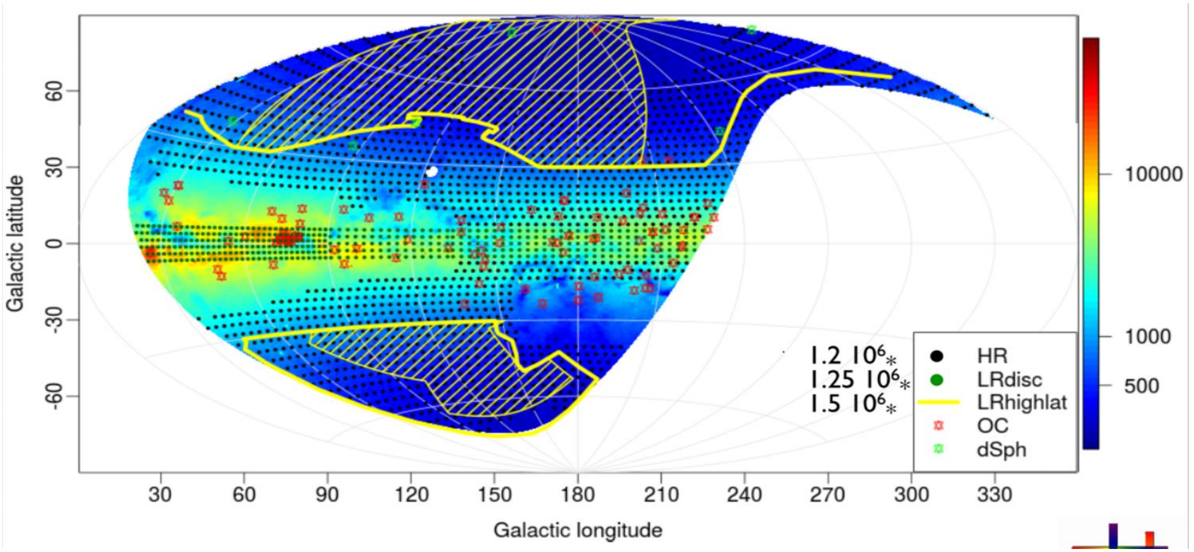
→ a multi-dimensional map of the Milky Way(Dey & Najita et al., 2019), allowing for detailed exploration of the dark matter distribution, Galactic substructure, and rare objects like the most metal-poor stars

→ from the local to the Galactic scale

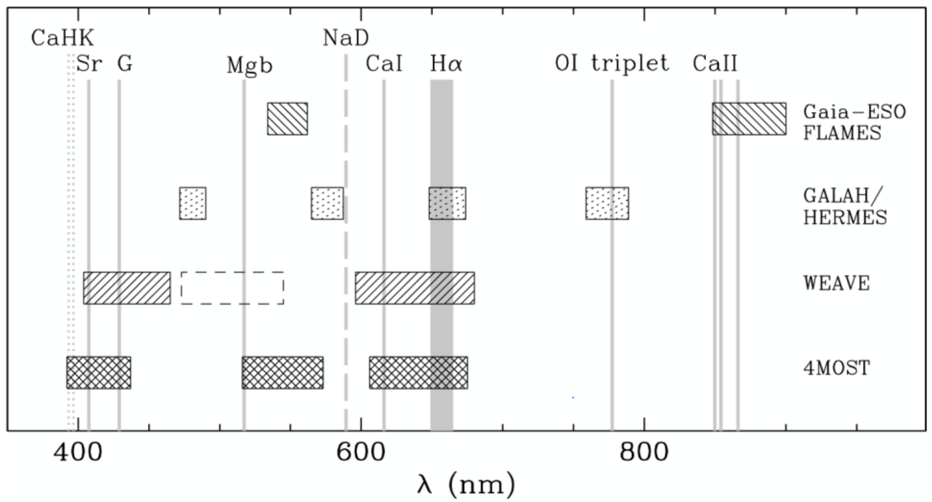
→ mapping the Galactic populations at large distances

→ Mapping stellar cluster formation and evolution in the whole Galaxy

WEAVE-4MOST



WEAVE - GA ~3-4 million stars to unravel the MW history !



Feltzing 2018

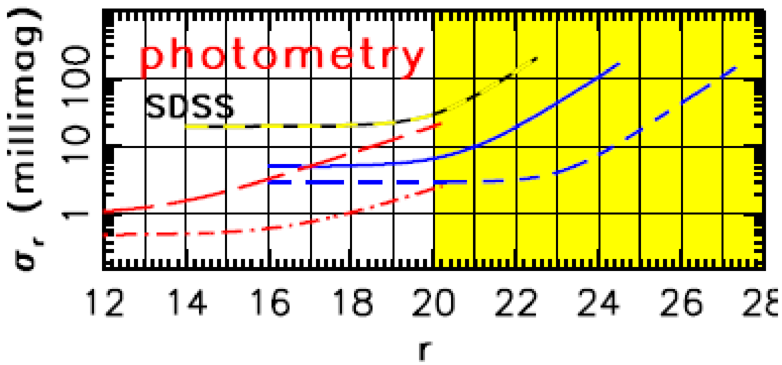
Gaia-LSST

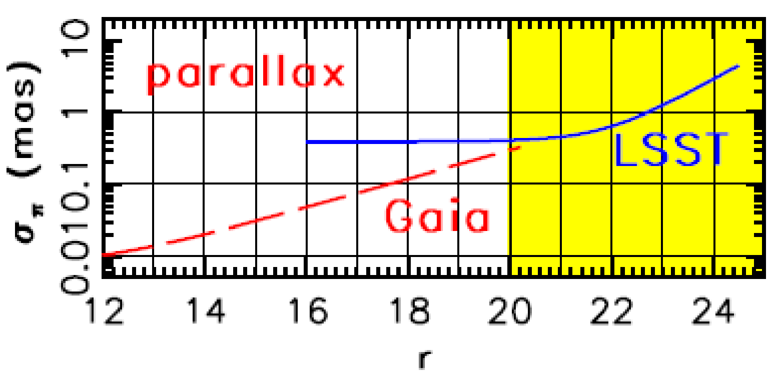
LSST Science Book: **http://ls.st/sb**

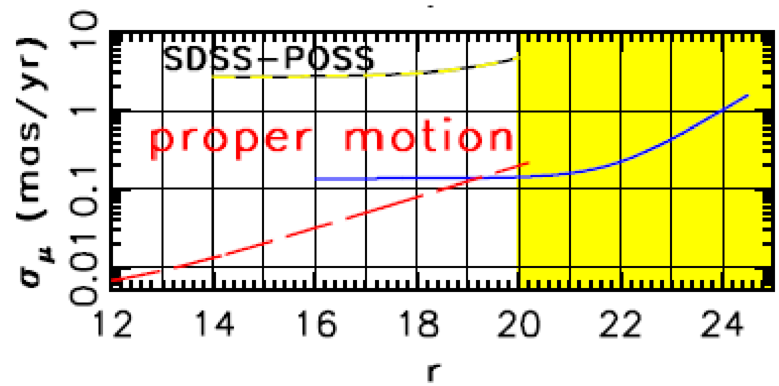
Gaia: **http://sci.esa.int/gaia**

Table 6.6: Adopted Gaia and LSST Performance

Quantity	Gaia	LSST
Sky Coverage	whole sky	half sky
Mean number of epochs	70 over 5 yrs	1000 over 10 yrs
Mean number of observations	320[a] over 5 yrs	1000[b] over 10 yrs
Wavelength Coverage	320–1050 nm	*ugrizy*
Depth per visit (5σ, r band)	20	24.5; 27.5[c]
Bright limit (r band)	6	16-17
Point Spread Function (arcsec)	0.14×0.4	0.70 FWHM
Pixel count (Gigapix)	1.0	3.2
Syst. Photometric Err. (mag)	0.001, 0.0005[d]	0.005, 0.003[e]
Syst. Parallax Err. (mas)	0.007[f]	0.40[f]
Syst. Prop. Mot. Err. (mas/yr)	0.004	0.14







- MS at turnoff Mr=4.5 detected by Gaia at 10 Kpc, by LSST at 100Kpc (24.5)

The Big Questions:III

- How was the Milky Way assembled and how did it evolve?
- the formation of the sub-galactic structures in the Milky Way: local scale
  - Chemo-dynamical evolution of the sub-galactic structures
  - the formation and chemo-dynamical evolution of stellar clusters
  - the star formation history in the MW

- the formation of the sub-galactic structures in the Milky Way: Galactic scale

- From the Galaxy to galaxies: near field cosmology (Weisz +2019)
- Is the MW a Rosetta Stone for galaxy formation? → history of cosmic structure formation

  High z galaxies formed between 12 and 8 Gyr
  - The properties of low mass galaxies in the Local Volume
  - the star formation history in the Local Group and beyond
  - the resolved and unresolved stellar populations by means of well-behaved tracers.

Mapping science into instruments: Next 10 years:galactic archaeology

- Surveys with HST (Sacchi+2018, Cignoni+2018, Tosi+2015…), VLT, LBT (D'Annibali+2019….) have played a crucial role in deciphering the star formation and chemical enrichment histories of galaxies in the Local Volume
- Larger telescopes
  - E-ELT MOS(I=24 -- I=27 R=1000 – 20,000?) LG galaxies
  - E-ELT MIDIR- HIRES (R=100,000 at R=21)(2027+)
  - E-ELT MICADO high spatial resolution data
  - JWST
- In the next decade, surveys with e.g. JWST and the ELTs will make deconstruction of the star formation histories of galaxies across the Hubble sequence possible

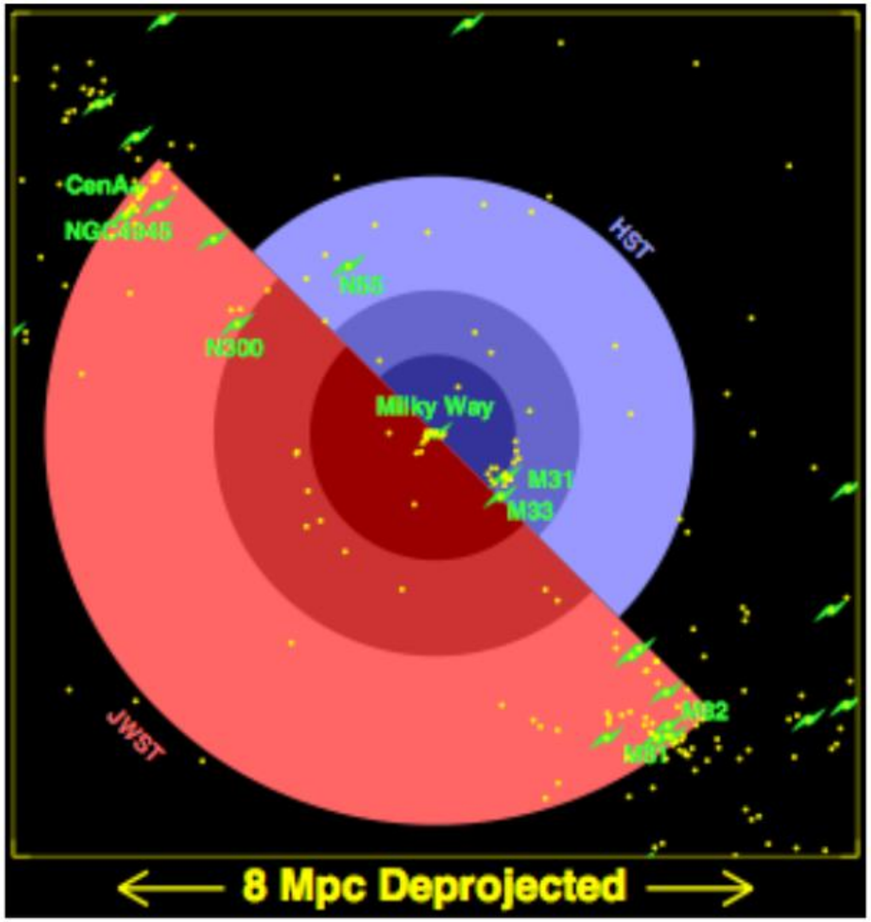
→From the Galaxy to galaxies: galactic archaeology

→How representative is the MW?

→How is the SF proceeding in different galaxies?

→From star cluster formation in the MW to Local Group galaxies

Local Group & beyond:SFH



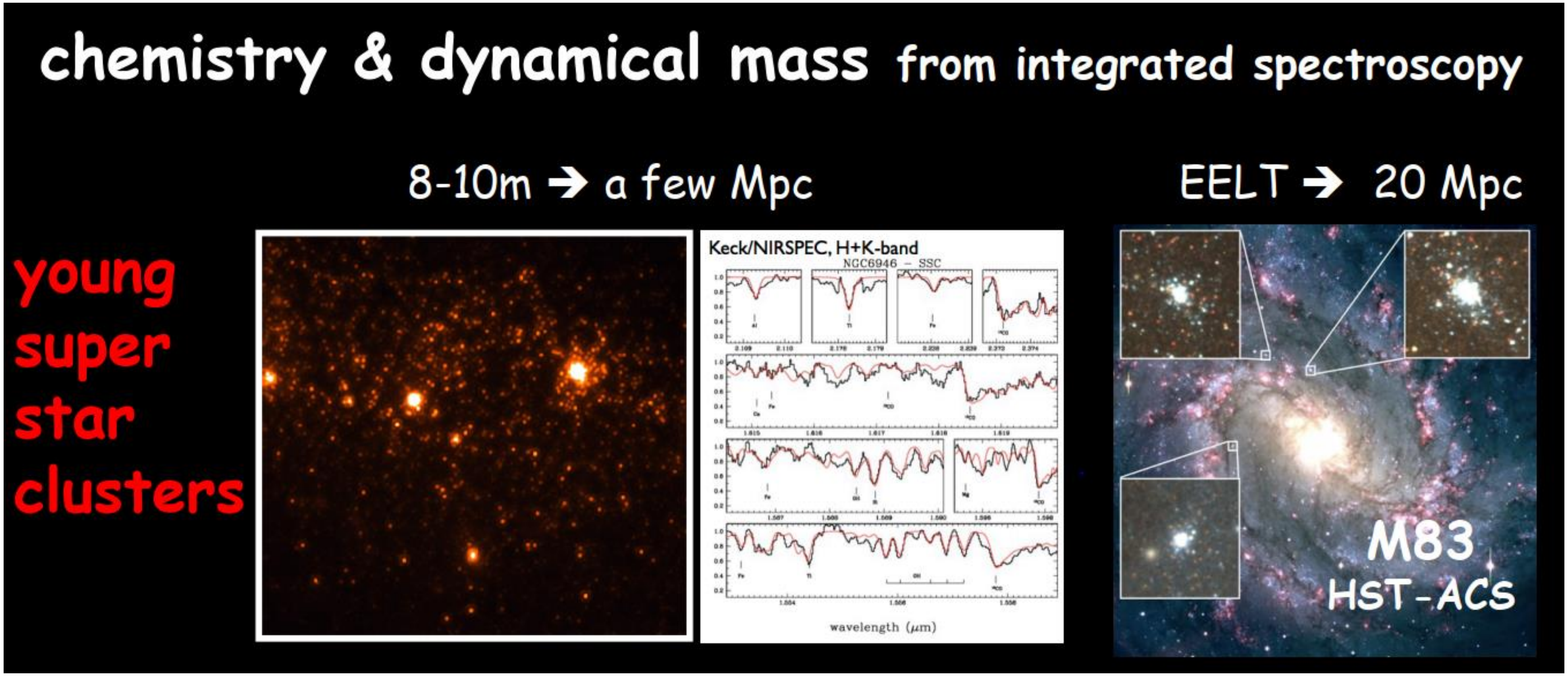
JWST can survey many Local Group galaxies
and also reach the Sculptor Group (e.g., NGC300 and NGC55)

Bright red stars (Mj< -4) up to 40 Mpc(Brown 2008)

E-ELT MICADO can measure HB stars in crowded regions up to 4 Mpc (Fiorentino 2017) or giants in the Virgo E (Greggio+2017)

10, 100, and 1000 hours with JWST (red) and HST (blue),
0.5 mag below the turnoff at 12 Gyr (Brown+2018)

Distant object Spectroscopy

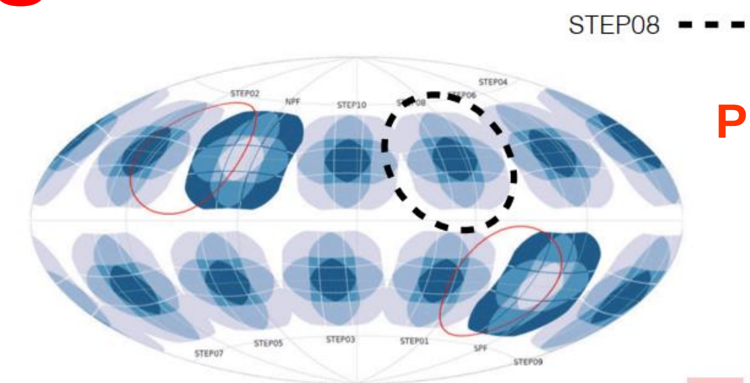


Maiolino+ 2013 slide from Origlia 2016

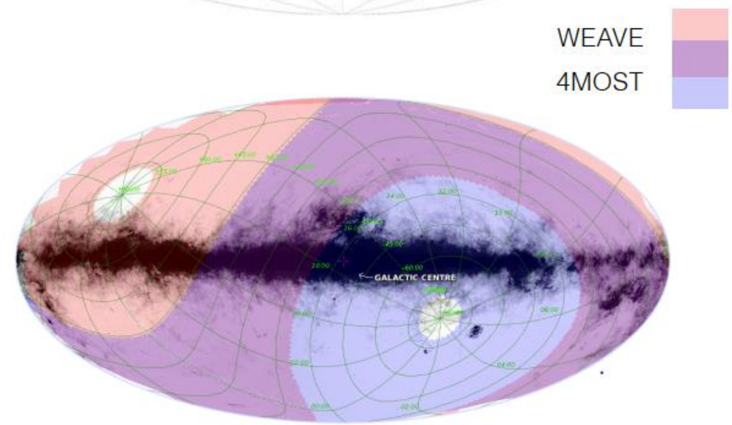
Resolved object spectroscopy with E-ELT HIRES up to2-4 Mpc (Sculptor Group,M83)
Detailed chemical abundances of clusters up to 15-20 Mpc

Space Missions

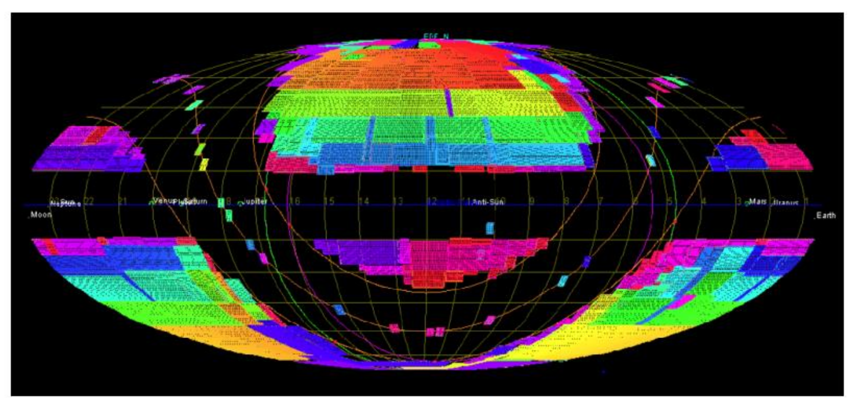
- (TESS) PLATO (2026+) 85,000 stars
  →asteroseismology ages +Gaia
  →Galactic-chrono-kinematics
  up to 10 Kpc
- Euclid(2022+) ~15,000 deg2, in VIS & Y,J, and H bands
- LISA (2034)
- WFIRST (2025+)→ Galactic Bulge Survey + astrometric capabilities
- A new astrometric space mission in the IR??



PLATO

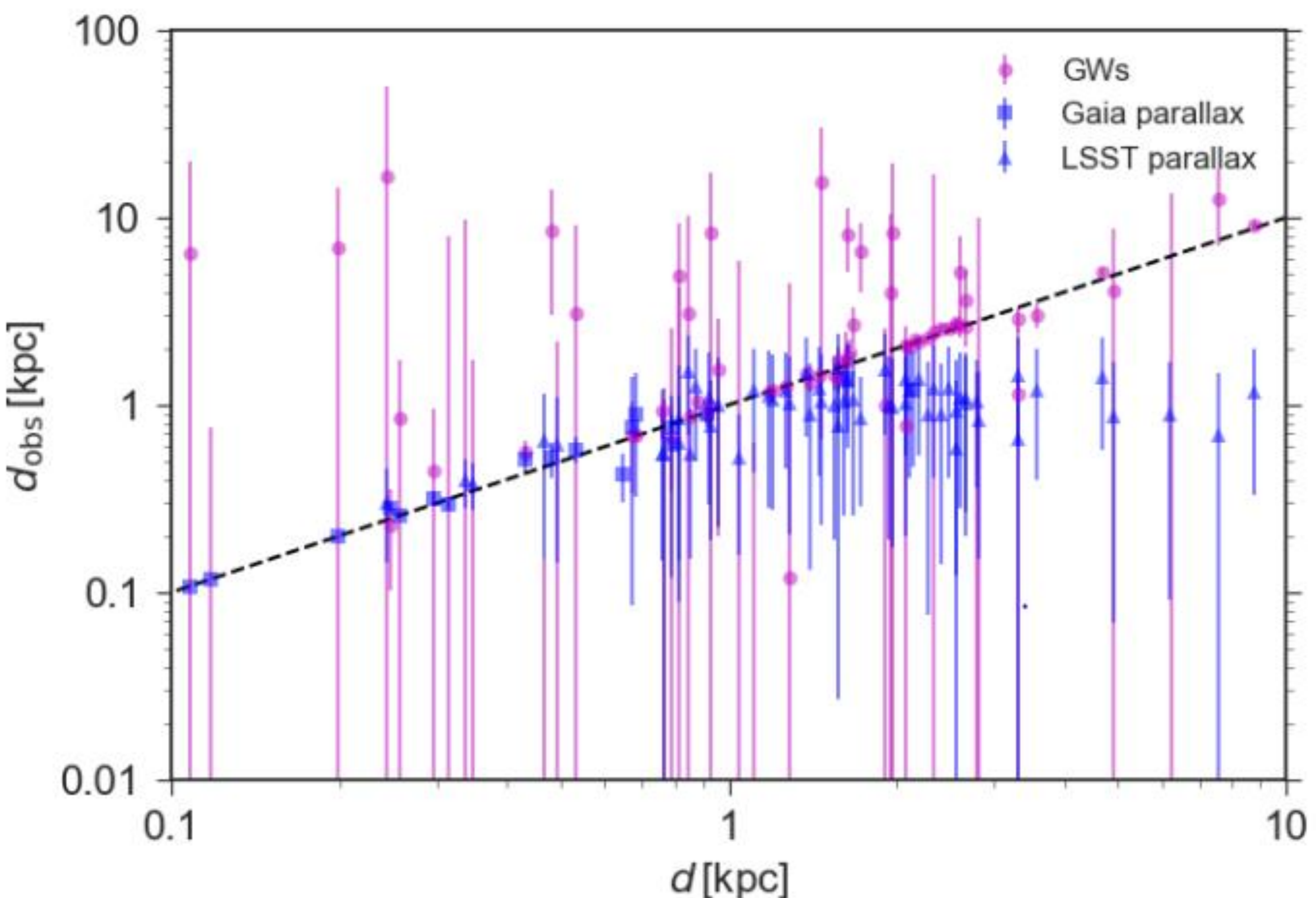


Euclid



Multi-messenger Galaxy

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

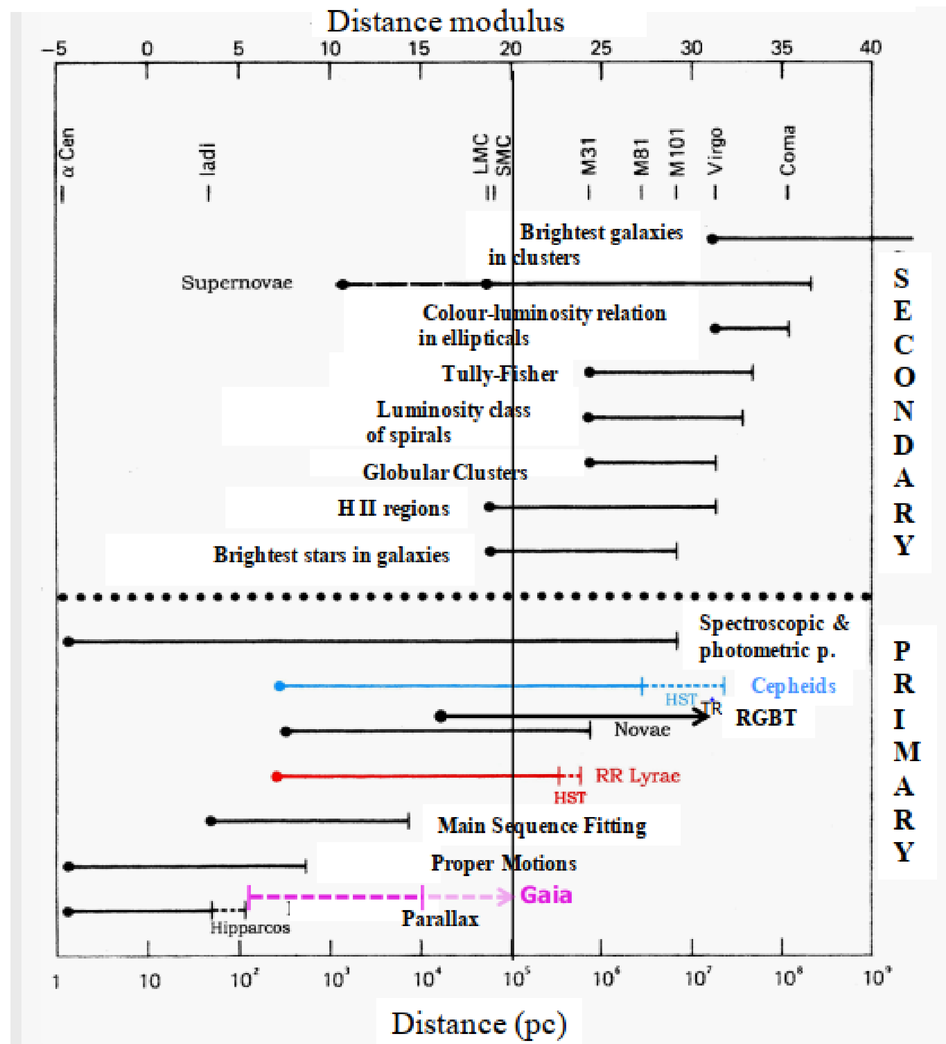


Distance ladder

- An important challenge for next decade astrophysics is the determination of distances with a precision better than 5% from the Local Group to about 200 Mpc

- Standard candles in the Local Group (RR Lyrae stars, MV-[Fe/H], PLKZ relations) and beyond, up to 20-30 Mpc (Cepheids, PL, PLC,PW relations)
  ⇒ calibration of secondary indicators ⇒ measure of H0 (Riess+2018)
- Gaia: Multi-epoch all sky survey down to Glim~20.7 mag for astrometry & photometry, ~16 mag for spectroscopy:
  - discovery of thousands of new Cepheids and RR Lyrae stars
  - parallax at ~10 μas accuracy for those with G<12-13 mag

- ¾ of Galactic Cepheids will have parallaxes at 3%



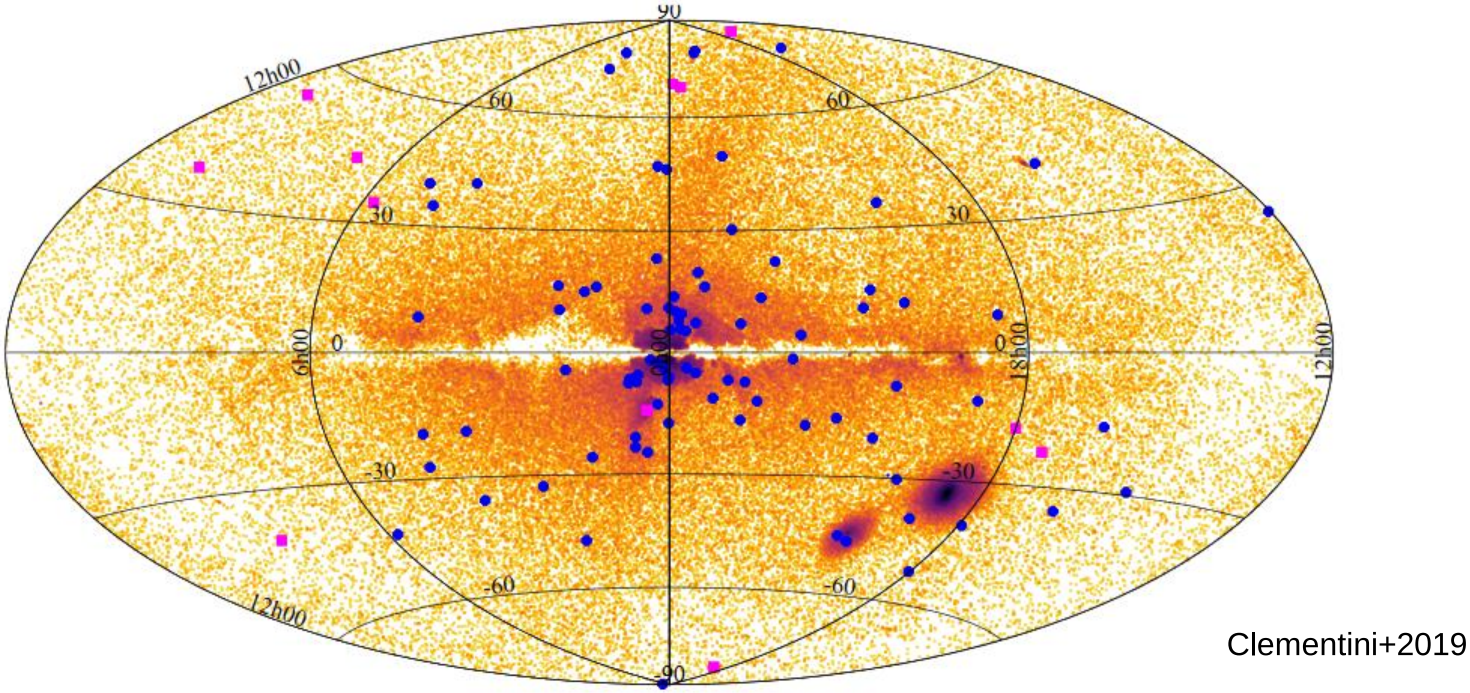


Fig. 45. Distribution on sky in galactic coordinates of RR Lyrae stars within the limiting magnitude of *Gaia* (orange points). The map combines known literature sources with and without a *Gaia* counterpart and new RR Lyrae stars discovered by *Gaia* and confirmed by the SOS Cep&RRL pipeline for more than 223 000 RR Lyrae stars in total. Blue filled dots and magenta filled squares indicate 87 globular clusters and 12 dwarf spheroidal galaxies (classical and ultra-faint) in which *Gaia* has observed RR Lyrae stars that are confirmed by the SOS Cep&RRL pipeline.

- The present: 9000 cepheids +140,000 RRLyrae in DR2(Clementini+2019)
  - Synergies Gaia+ Optical and IR surveys from the ground: OGLE, EROS, LINEAR, CATALINA, PTF, ASAS, PanSTARRS…
- The immediate future:
  - Need to characterize Cepheids & RR Lyrae stars:
    WEAVE, MOONS, 4MOST
    LSST: extending Gaia capabilities 5 magn fainter
- The far future
  - JWST+E-ELT: Classical Cepheids up to the Coma Cluster and RR-Lyrae up to 6 Mpc

How to get there

- Form young researcher with expertise in stellar models, asteroseismology, chemo-modelling, spectroscopy, astrometry, data mining
- Support the exploitation of next generation spectroscopic multiplex surveys
- Support the development of
  - theoretical tools: new generation of models (i.e. data driven…)
  - data mining and, in general methods and tools for the scientific exploitation
  - Free access common Tools/ Data processing facilites
- Archiving facilities