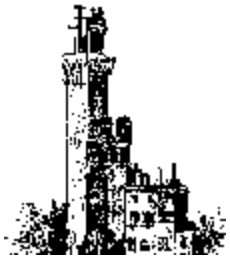

Galactic stellar populations

A. Vallenari

&

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S. Marinoni, Bellazzini, A. Spagna,S. Randich

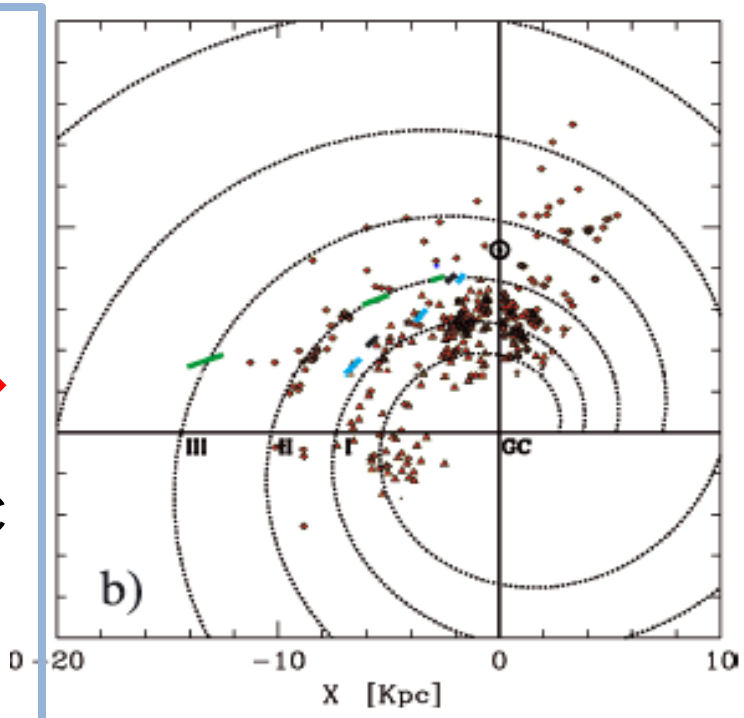
INAF, Padova, Bologna, Roma, Torino, Firenze

Overview

- Gaia Open and Globular cluster
- Clusters in the early releases
- Clusters as tracers of the Galactic populations
- Getting ready for Gaia

Clusters as population tracers

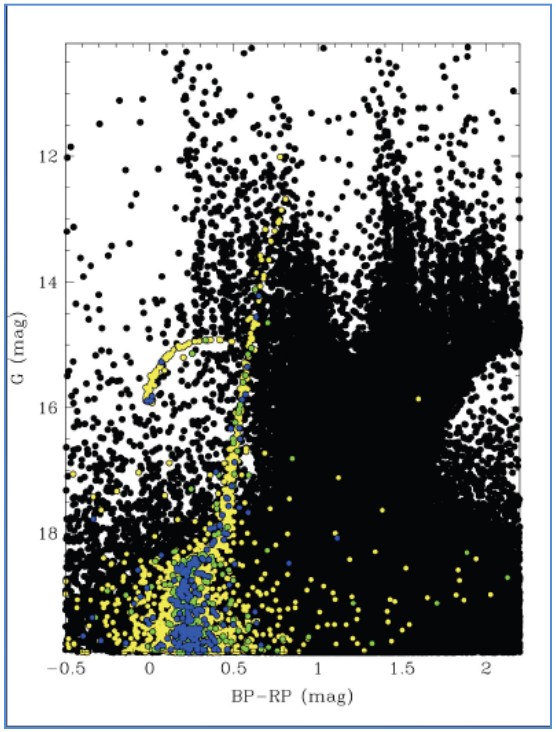
- Open Clusters age, metallicity, position
  - trace the spiral arms(Naoz &Shaviv 2007)
  - trace the disk chemical gradient disk
    → disk formation process (Magrini+2009, Chiappini+2001)
- Their internal kinematics/ dynamical evolution→ birth, evaporation, disruption,
  trace the Galactic environment:Tidal field, GMC
- Less affected by radial migration ?
  (Wu+2007, vandePutte+ 2011)



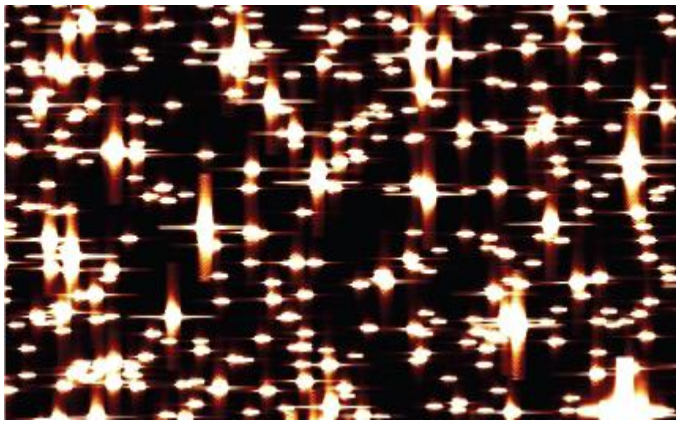
- Globular clusters are old objects
- They trace the thick disk, halo, bulge : tidal field, formation process
- Their multiple populations → cluster formation process (Carretta+ 2010)

Globular clusters as seen by Gaia

d=10 Kpc, c=2.5, bulge

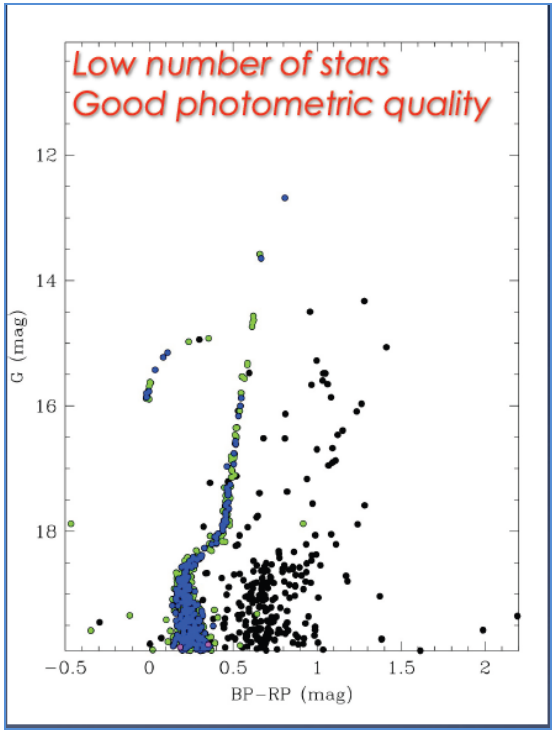


Gaia GIBIS FoV



Pancino+2013

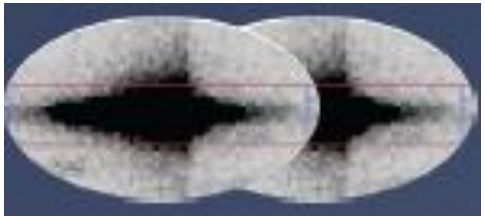
p.m selection



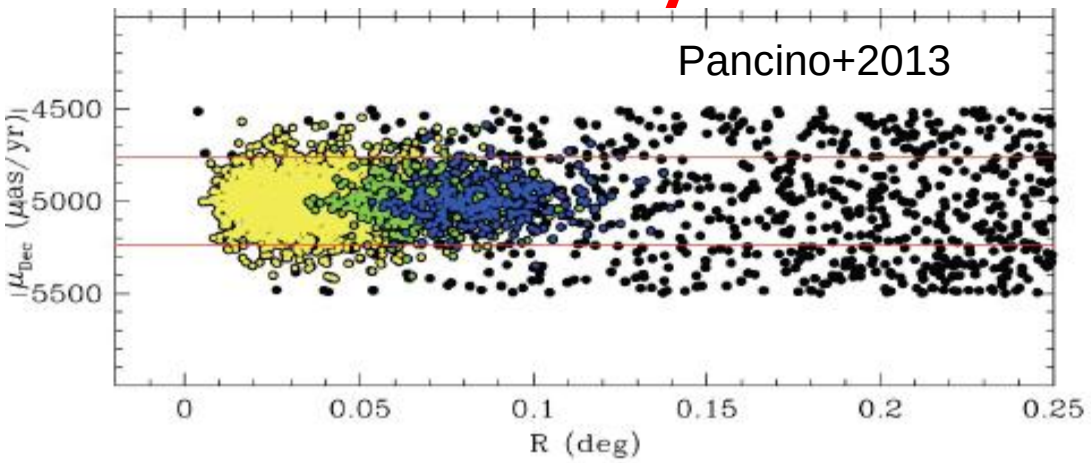
Non rotating 3D cluster (Kupper + 2011) +field stars

Generating Gaia images

crowding (partial superposition)

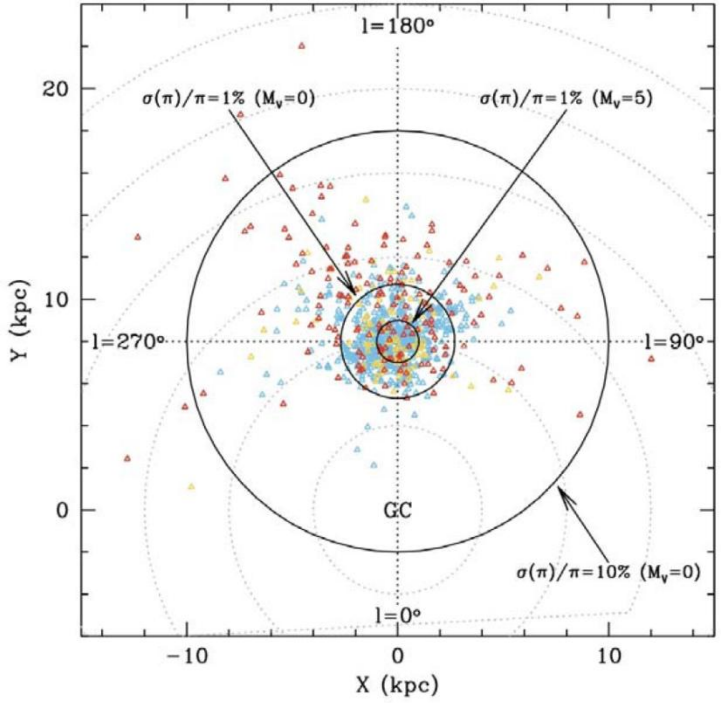


Globular clusters as seen by Gaia



- 80 of 150 GCs
- d < 10 Kpc
- Proper motions – orbits – maybe tidal tails → halo potential
- Membership determination of 100/10000 stars(outside the half light radius, 3-5 μarcsec/yr at 10 Kpc)
- More than 5000 stars for half of the clusters
- Mean distances to < 1 % for about 80 clusters
- Mean distances to < 5 % for all clusters
- Spectra of stars above G=17 for Rv
- Missing detailed chemical abundances for G>11-12

Gaia view of OCs



Present situation: 2095 known OCs
1193 with distance
100 with a [Fe/H] estimate(Dias+2010)

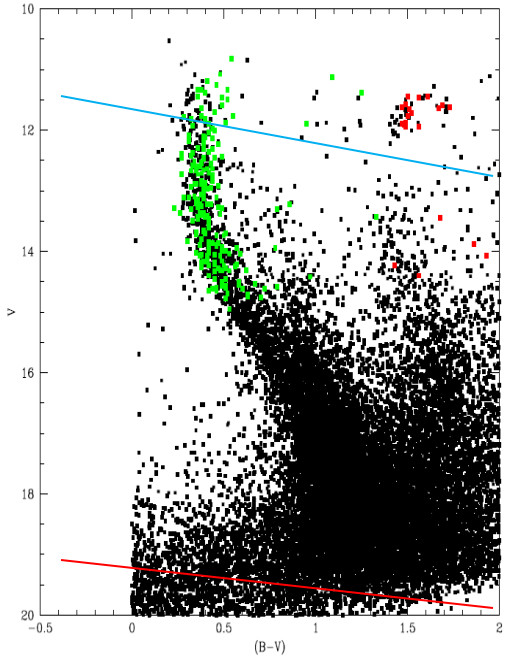
Gaia: Derive distances + pm of individual stars in Ocs
- at 1% for Mv=5 d < 1.5kpc
- at 1% for M=0 d < 4kpc
-at 10% for almost all known cluster
→ accurate membership-- orbits

Small velocity dispersion in OCs (1 - 2 km/sec) → studies of the internal dynamics require ~ 0.2 km/sec

– Gaia: accuracy better than 1% for transverse velocity
G0 stars brighter than V~13 (d<500pc), K1 III (red clump in old OCs) V<14 :d < 5 kpc.

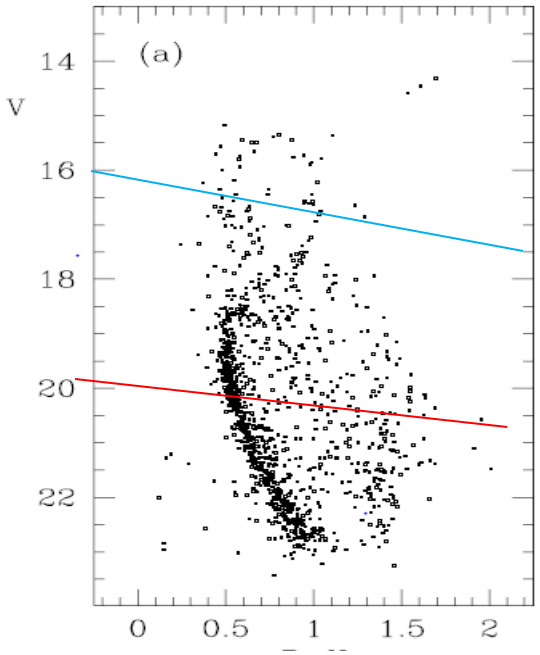
Missing: Detailed chemical abundances for G>11-12

Gaia view of OCs



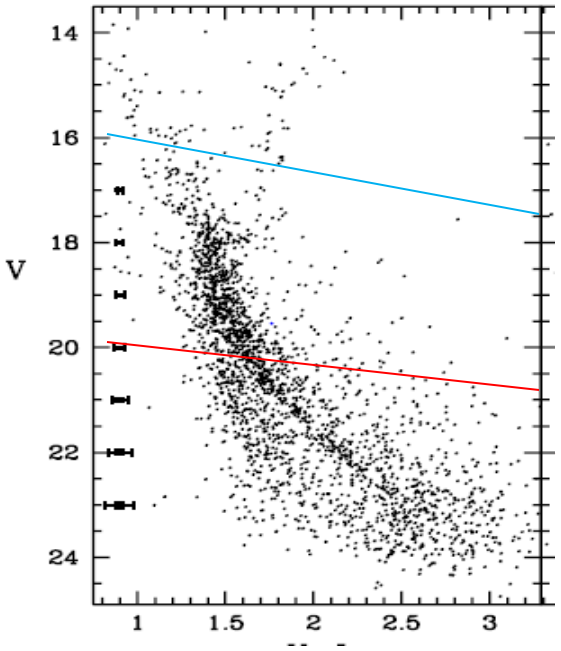
B-V

NGC 6705
(Vallenari+2013)
D=1800 pc,
Age=250 Myr



V-I

Be 17
(Vallenari+1999, Bragaglia+ 2006)
D=2600 pc,
Age=10 Gyr



B-V

Be 29 (Tosi, Bragaglia 2006)
D=13.05 Kpc,
Age=3.7 Gyr

Early releases

Launch +22 months:

- Hundred Thousand Proper Motion catalog
- Proper motion accuracy of at least 48-65-μas/yr
- Radial velocities for 35495 Hipparcos stars (Gontcharov 2006)
- EPC data: for early testing

Launch +28 months:

- early classification based on BP/RP integrated photometry
- five parameters astrometry
- mean Radial velocity

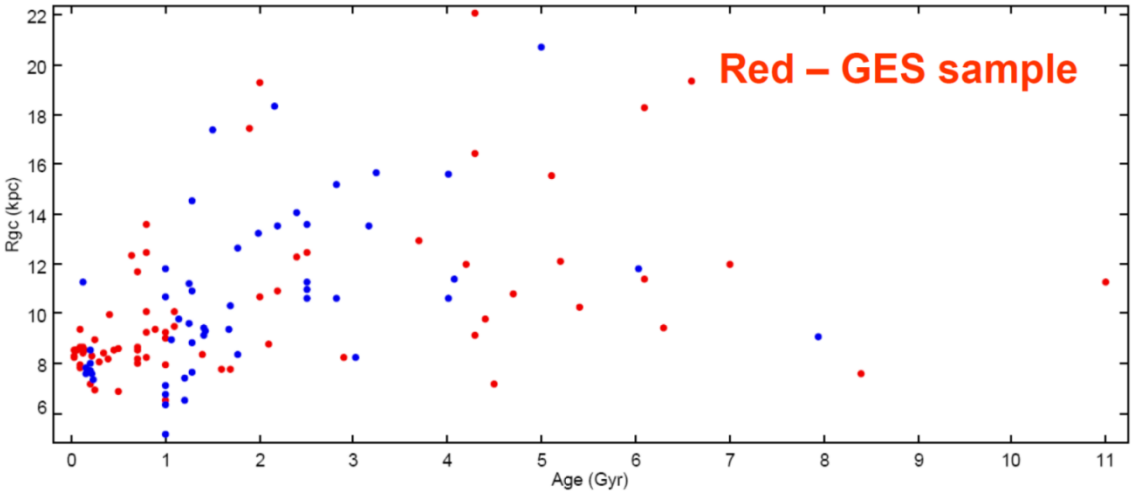
Clusters in early releases

- Hundred Thousand Proper Motion catalog:
  - All OCs closer than 300 pc + the richest OCs up to 500 pc (19 objects)
  - 150 stars in Hyades to 40-10 stars in distant OCs (V=12)
  - 500 nearby field subdwarf stars used as Population II calibrators for globulars (Carretta + 2010) → old GCs distance and age revision
- Larger sample of Ocs and GCs down to V=20 in the second+ releases

Preparing for Gaia

- BOCCE project on Ocs: photometry, spectroscopy for 50 Ocs: metallicity, extinction (Tosi & Bragaglia 2006, ..Ahumada+ 2013)
- Photometry, age determination for a large sample of Ocs (Bragaglia, Tosi, Vallenari+ 2013)
- OCs from the North: 25 Ocs > 0.5 Gyr, : red giants FIES@NOT 2.5 m (Carrera, Pancino+ 2013)→ Galactic anticenter OCs
- GCs spectroscopy (1200 RG in 19 GCs, Carretta, Bragaglia+2010)
- GES (OCs and a few GCs)
- Future surveys: WEAVE

GES OCs



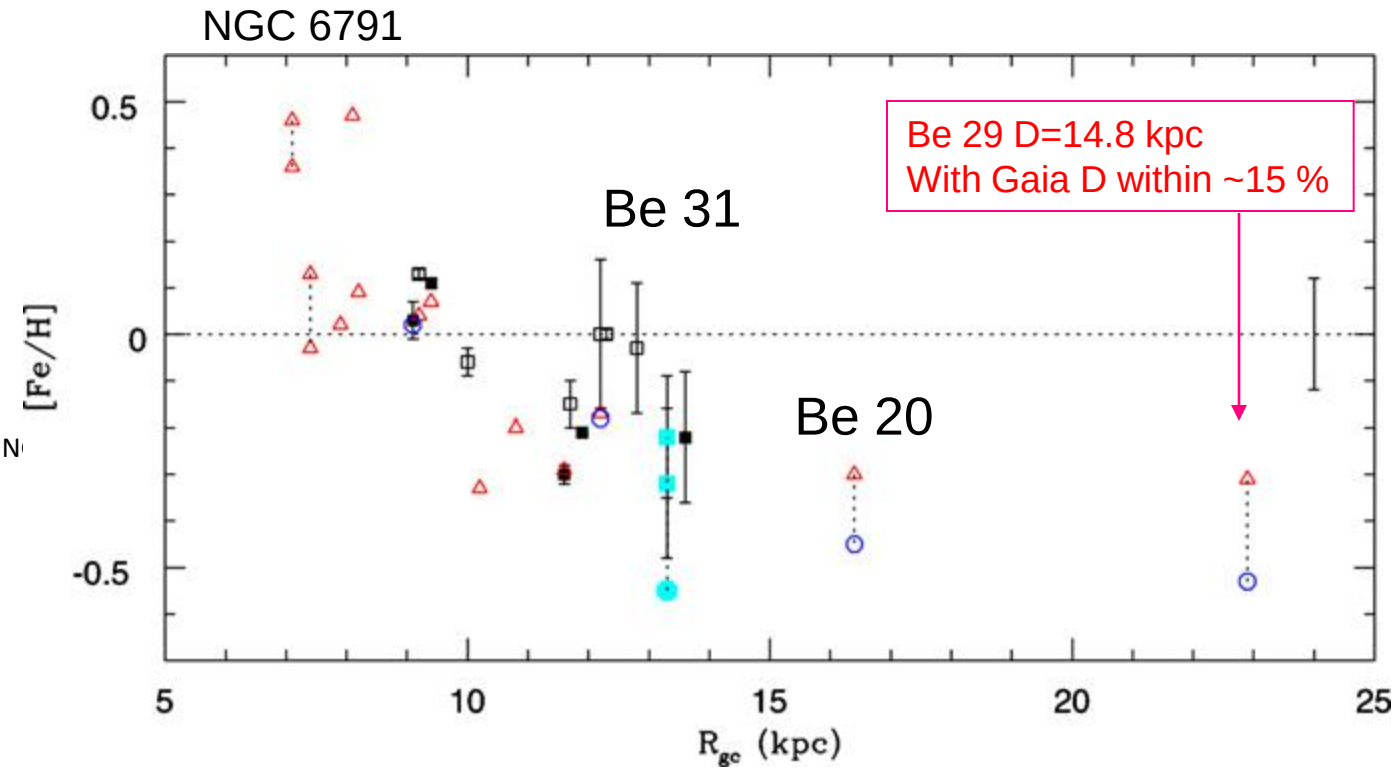
see Sofia talk

- Young: 1-100 Myr → evolution of OCs from birth to dissolution: IMF, stellar evolution : stars down to M dwarfs

  requirement: vrad< 0.3 m/s for a M star, Gaia 1% precision

  → dc=1.5 kpc: 30 OCs
- Intermediate age : 100-500 Myr req. 1) → dc=700 pc : 15 Ocs
- Old age : > 500 Myr ; large dist → stellar evolution; galactic evolution : red clump stars : 50 Ocs

Gaia+GES: disk formation history



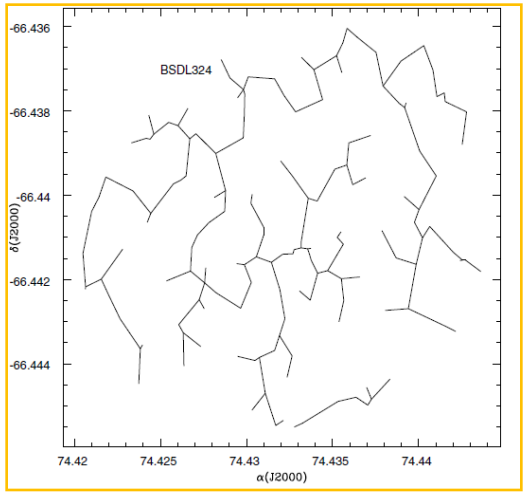
Friel et al 2010

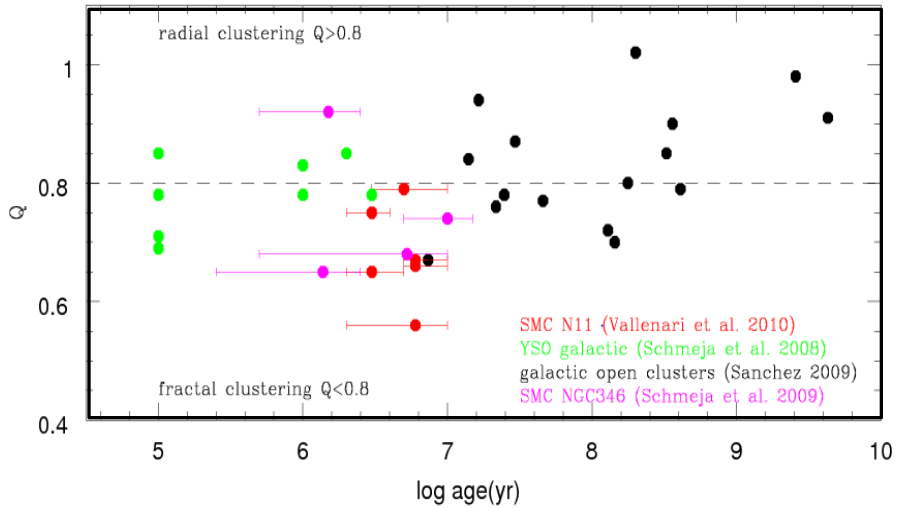
- Accurate distances fundamental + orbits->migration → birthplace

  - inner disk (Dsun=2-3 kpc) and at slope change (Rgc=10-12 kpc, Dsun=2-5 kpc) → for both error on distance < 5%

- NGC: 6791: Distance 4 Kpc age =7Gyr He enhanced (Brogaard et al 2010)
  Distance 3.6 kpc age =12 (Stetson 2003)

Gaia+GES: Two modes of SF?





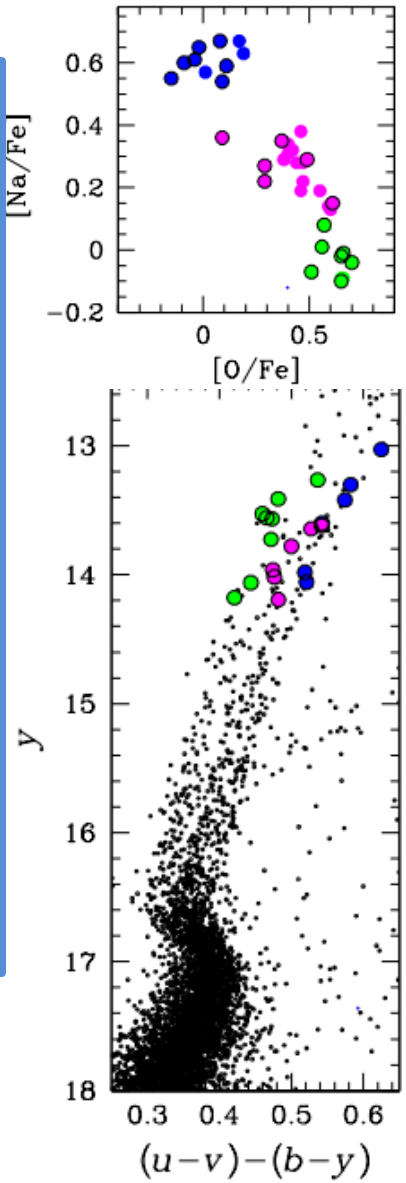
- All stars form in clusters → dispersed in the field (e.g. Lada & Lada, 2003)
- In Orion nebula, 20% of stars are distributed→ formed in isolation? (Allen et al 2007)

- Hierarchical formation (Klessen + 2008, Carthwright + 2004)
- High environmental density → bound OCs
- Low density environment → unbound structures/ dispersed SF (Gieles& Portegies Zwart 2011, Bressert et al 2010).

→ **Role of the environment in OC formation**

Halo formation from GCs

- The halo-GC connection is unclear
- GCs are 1% of the mass of the halo
- Multiple population in GCs are expected
  if the GCs were much more massive
  than today (Piotto+2007, Carretta+2010)
  →star evaporation due to tidal field, disk shocking
- GAIA+ GES, Pan-Starrs, HERMES, APOGEE
  →tagging GC stars in the halo
- Halo assembly :accretion (Cooper 2010) vs in situ
  (gas rich mergers) (Zolotov 2009, Font 2011)

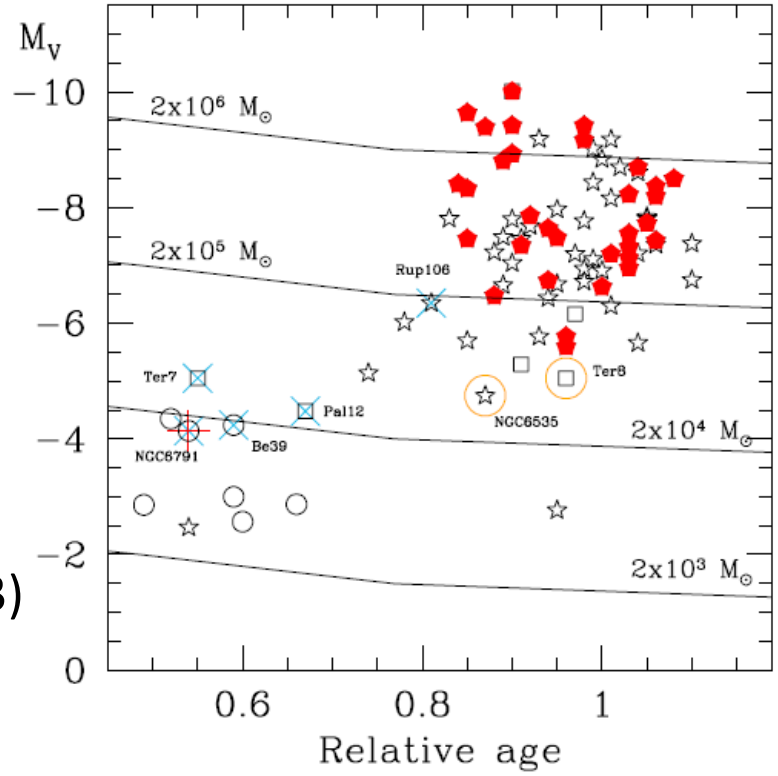


NGC 6752, Milone + 2013

Gaia+GES: multiple populations

- OCs as link between GCs and field stars
- Which is the mass limit for multiple populations?

  Pancino+2010, Bragaglia+2011



(Bragaglia+2013)

Using OCs for Catalog Validation

- Ocs are single stellar population: same age and metallicity
- Ideal tests of Gaia astrometry, stellar parameters
- Cross match with external Catalogs+comparison with stellar models
- Pleiades MS problem and 10% distance discrepancy: sistematics over 1 deg in Hipparcos data? (Narayanan & Gould 1999)
- A clear challenge due to multi-dimensional Gaia Catalog, different accuracy of ground-based Catalogs

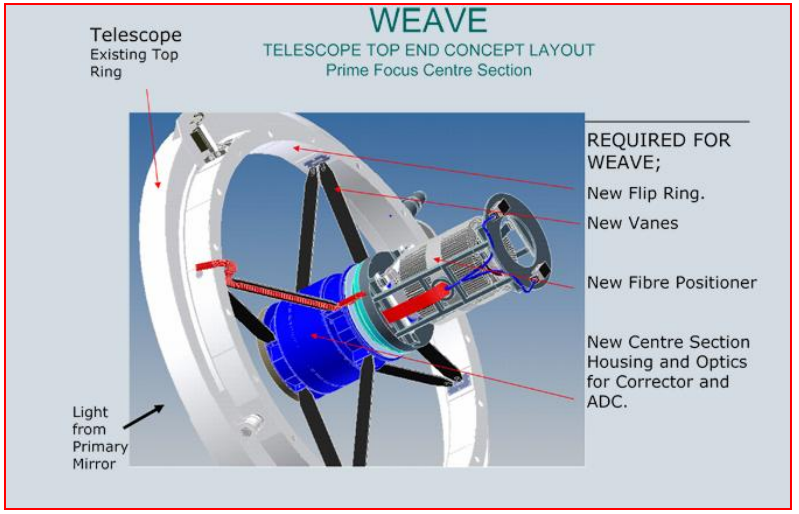
Table 1. Pleiades parallaxes (updated from Soderblom *et al.* 2005)

Method	π_{abs} (mas)	D (pc)	m−M	Ref.
Hipparcos all-sky	8.45±0.25	118.3±3.5	5.37±0.06	2
Hipparcos new reduction	8.18±0.13	122.2±1.9	5.44±0.03	7
Main-sequence fitting	7.58±0.14	131.9±2.4	5.60±0.04	1
Allegheny Observatory parallaxes	7.64±0.43	130.9±7.4	5.59±0.11	3
Interferometric orbit	7.41±0.11	135.0±2.0	5.65±0.03	4
Dynamical parallax	7.58±0.11	131.9±3.0	5.60±0.05	5
HST FGS parallax of 3 Pleiads	7.43±0.17	134.6±3.1	5.65±0.05	6

WEAVE Survey

- WHT (Spain, UK, France, Netherlands)
- PI. G. Dalton
- Part of the Science Team
- 2017 + 5 years, D=2deg field, 1000 fibers
- 1) R=20000, Vlim = 17 mag → *chemical labelling*
- 2) R=5000 Vlim = 20 mag → *radial velocity*
- HR spectral range: [450-680]nm

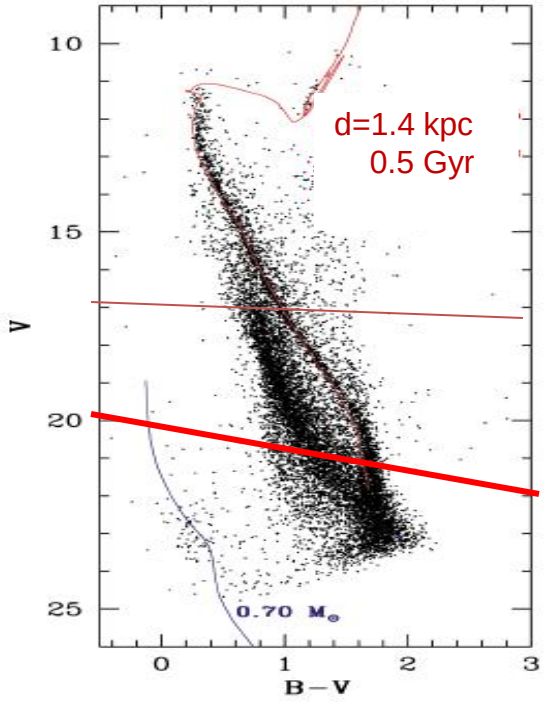
- Goal: complement Gaia
  - field (10^6 stars) → external disk
  - -halo formation: streams (vrad<5 km/s)
  - -thin/thick disk : kinematics and metallicity
  - -60 Ocs
- Expected accuracy for OCs: vrad < 1 km/s
- Chemical labelling : 0.1-0.2 dex



WEAVE- WHT OC Survey

- About 300 OCs visible from N
- [Fe/H] available only for a few (< 40)
- Gaia distances < 2% for 240 OCs
- Young (age < 500 Myr): 130 OCs
  diameter>20': 100 Ocs

Goals:
-Tracing the external disk
-OCs associated to streams
-OC –field star relation
-Key cases .Be 17- NGC 6791



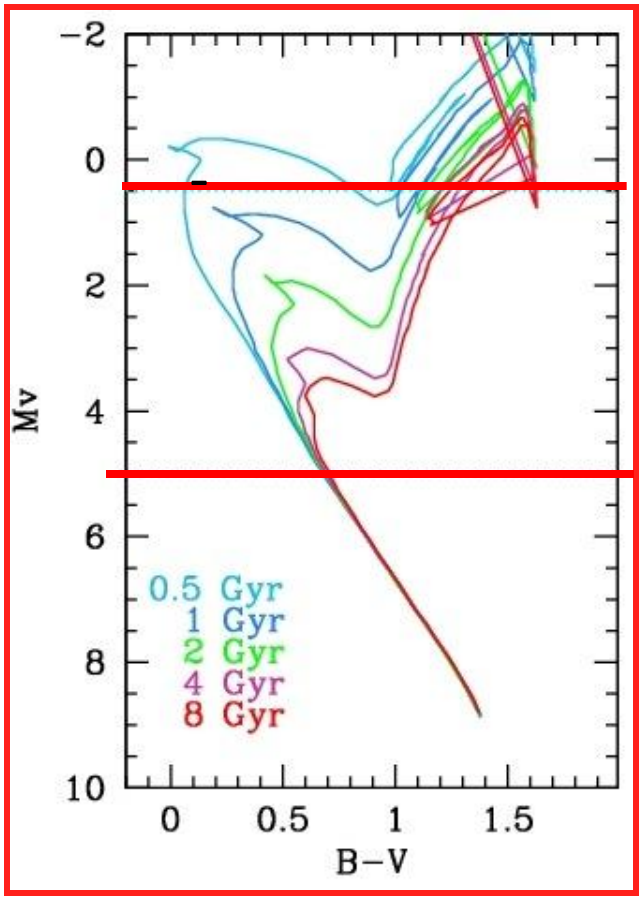
Kalirai et al 2001

Red clump stars as tracers: age > 0.5 Gyr
Mv(RC)=0.5 → V=12 at dist=2 Kpc : 60 OCs
→ V=13.5 at dist=4 Kpc : 10 OCs
→ V=15.0 at dist=8 Kpc : a few

Conclusions

- Clusters are tracers of the Galactic populations
- Several observational projects have been started or are forseen in the coming years to complement Gaia
- Italian Community is preparing for Gaia scientific exploitation

Gaia accuracy



	dist (kpc)	V	σπ/π
Mv=+0.5	1	10.5	<0.01
	2	12.1	0.02
	5	14.0	0.05
	10	15.5	0.13
Mv=+5.5	1	15.5	0.01
	2	17	0.14
	4	19	0.55

Data release scenario: II

Fourth release: launch + 65 Months Mar-2019	Updates of all above + • **Variable star classifications and parameters** as available, and the epoch photometry • **Solar system results** with preliminary orbital solutions and individual epoch observations • Non-single star catalogue
Final release: End Mission + 3 years (36 months) **Mar-2019/2020** **Mar-2022/2023**	Full astrometric, photometric, radial velocity catalogue • All available variables and non-single stars solutions • Source classifications (probabilities) plus multiple astrophysical parameters derived from BP/RP, RVS and astrometry for stars, unresolved binaries, galaxies and quasars. Precision improved with respect to 4th release. Some parameters may not be available for fainter stars. • Non Single Stars solutions and exoplanet list • All epoch and transit data for all sources • All Ground Based Observations made for data processing purposes (or links to it)