

ASTR 511

Galactic Astronomy

Lecture 04

Clusters & “Simple” Stellar Populations

Prof. James Davenport (UW)

Winter 2023

Reminder: materials on website!

The screenshot shows a website for a graduate-level Astronomy course. At the top, there's a navigation bar with links to 'James R. A. Davenport' (highlighted in blue), 'Courses', 'Media', 'Research Interests', and 'Student Collaborators'. Below the navigation, the title 'ASTR 511 Winter 2023' is displayed in large, bold letters. Underneath the title, the subtitle 'Galactic Astronomy' is shown in a smaller font. A descriptive paragraph follows, stating: 'This is the website for the graduate level Astronomy 511, Winter 2023 edition. This course is cross-listed as ASTR 497-C for senior-level astro majors.' The 'Resources' section contains two items: a link to the 'Syllabus' and a link to 'Dynamics and Astrophysics of Galaxies' by Jo Bovy. The 'Schedule' section is described as a preliminary outline, mentioning lectures posted as they are written/recorded. A list of lectures is provided, each with links to 'Slides' and 'Video': Lecture 01 (Jan 03) - Introduction & Review, Lecture 02 (Jan 05) - The Solar Neighborhood, NO CLASS Jan 10 & 12: (AAS 241) (Homework 1 due Jan 13), Lecture (Jan 17) - AAS Debrief, Lecture 03 (Jan 19) - History of Galactic Astronomy, Lecture 04 (Jan 24) - Clusters and "Simple" Stellar Populations, and Lecture 05 (Jan 26) - Mass and Luminosity Functions.

James R. A. Davenport Courses Media Research Interests Student Collaborators

ASTR 511 Winter 2023

Galactic Astronomy

This is the website for the graduate level Astronomy 511, Winter 2023 edition. This course is cross-listed as ASTR 497-C for senior-level astro majors.

Resources

- [Syllabus](#)
- [Dynamics and Astrophysics of Galaxies](#) (Jo Bovy)

Schedule

This is a preliminary course outline. Lectures will be posted here as they are written/recorded

- Lecture 01 (Jan 03) - Introduction & Review, [Slides](#), [Video](#)
- Lecture 02 (Jan 05) - The Solar Neighborhood, [Slides](#), [Video](#)
- NO CLASS Jan 10 & 12: ([AAS 241](#))
 - [Homework 1](#) due Jan 13
- Lecture (Jan 17) - AAS Debrief
- Lecture 03 (Jan 19) - History of Galactic Astronomy, [Slides](#), [Video](#)
- Lecture 04 (Jan 24) - Clusters and "Simple" Stellar Populations, [Slides](#)
- Lecture 05 (Jan 26) - Mass and Luminosity Functions

HW 2 now posted!

<https://jradavenport.github.io/astr511wi23/>

Goals Today...

- Open vs Globular (vs Dwarf Galaxy)
- Clusters as source of star formation & stars in the Galaxy
- Clusters as “simple stellar populations”



Clusters

open (“galactic”) clusters

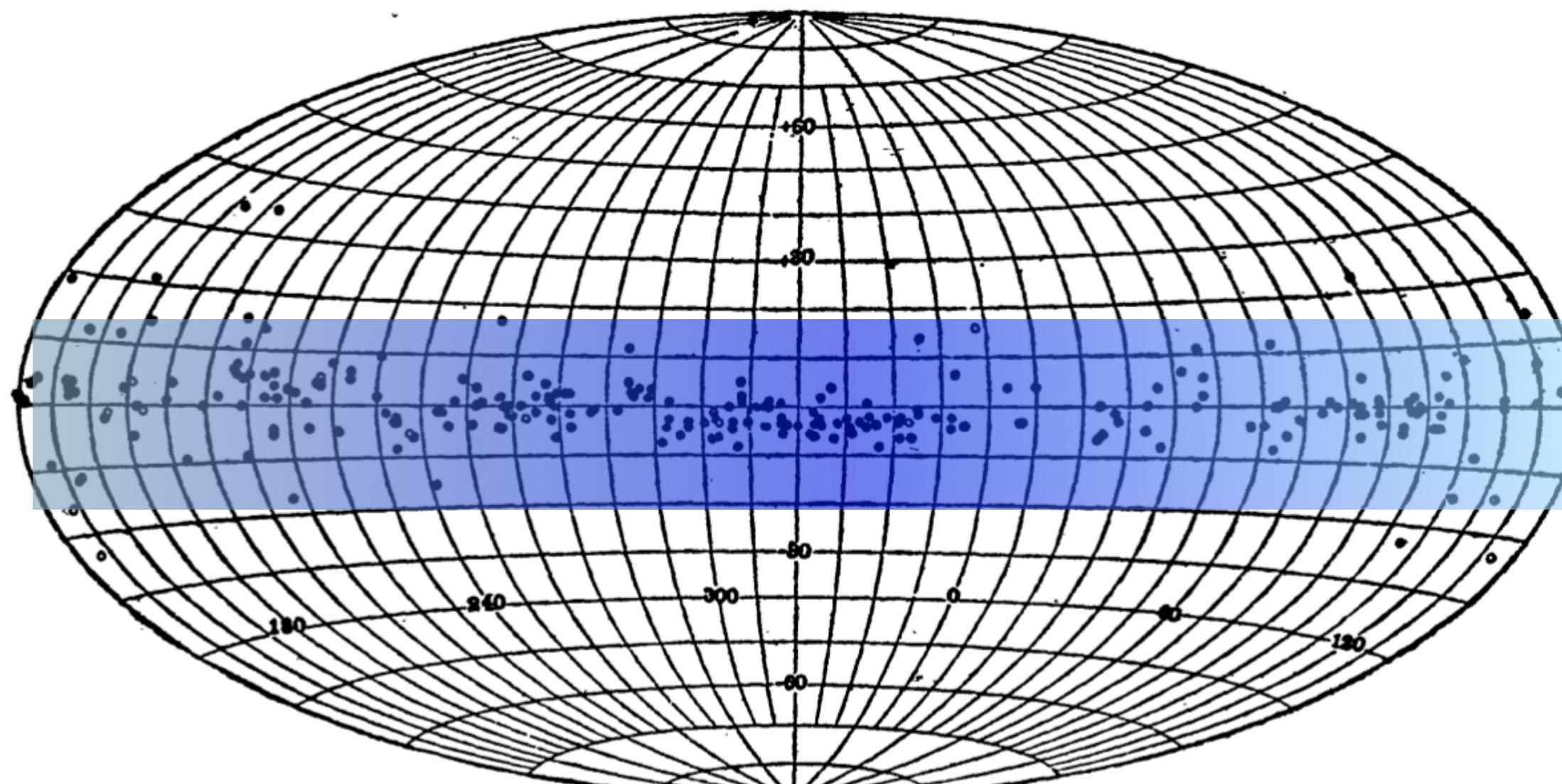


FIGURE II, 2.

Distribution of galactic clusters in galactic coordinates. Cluster classes are indicated as follows: c, O; d, \oplus ; e, \ominus ; f, Θ ; g, \bullet .

globular clusters

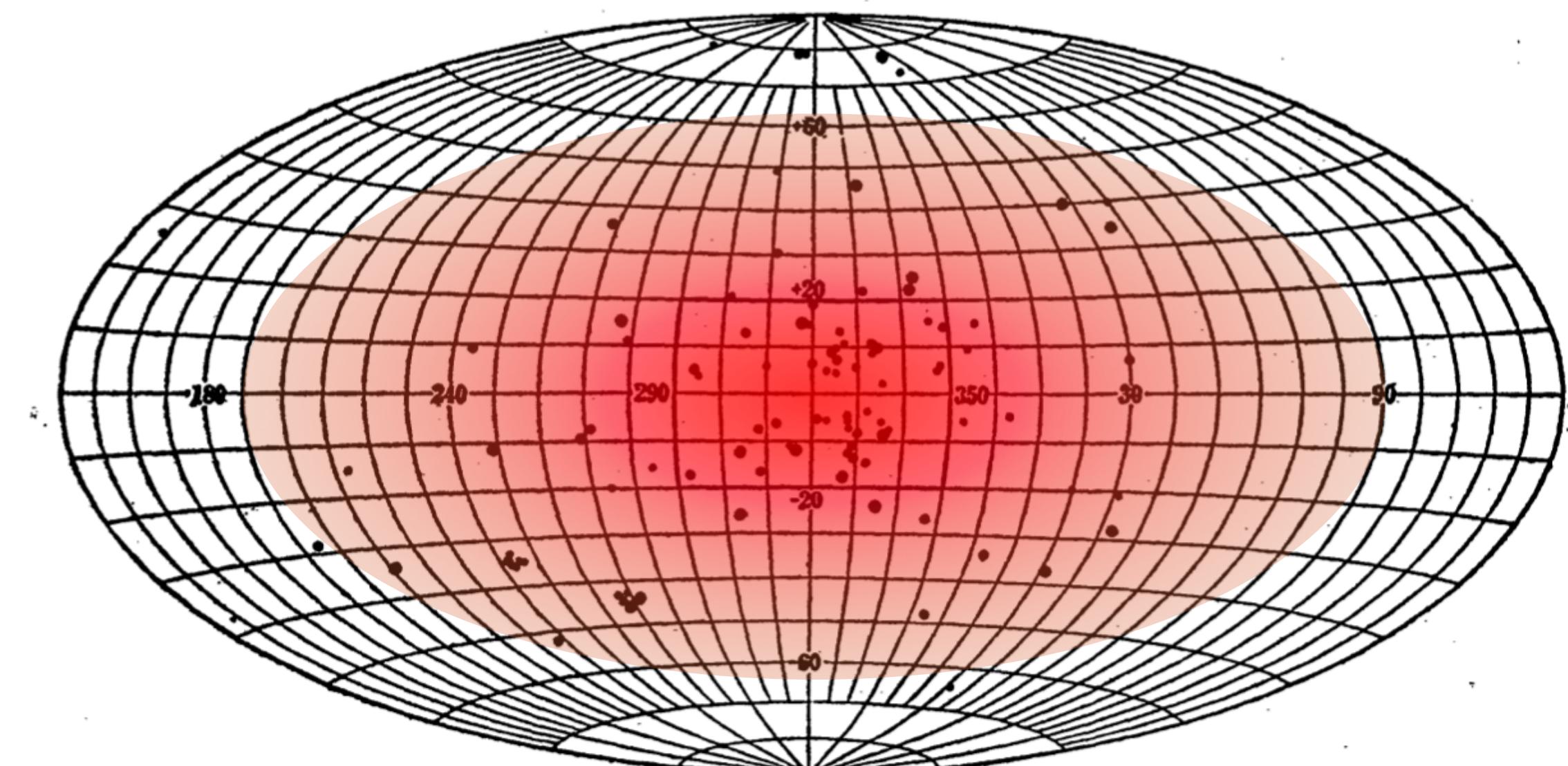


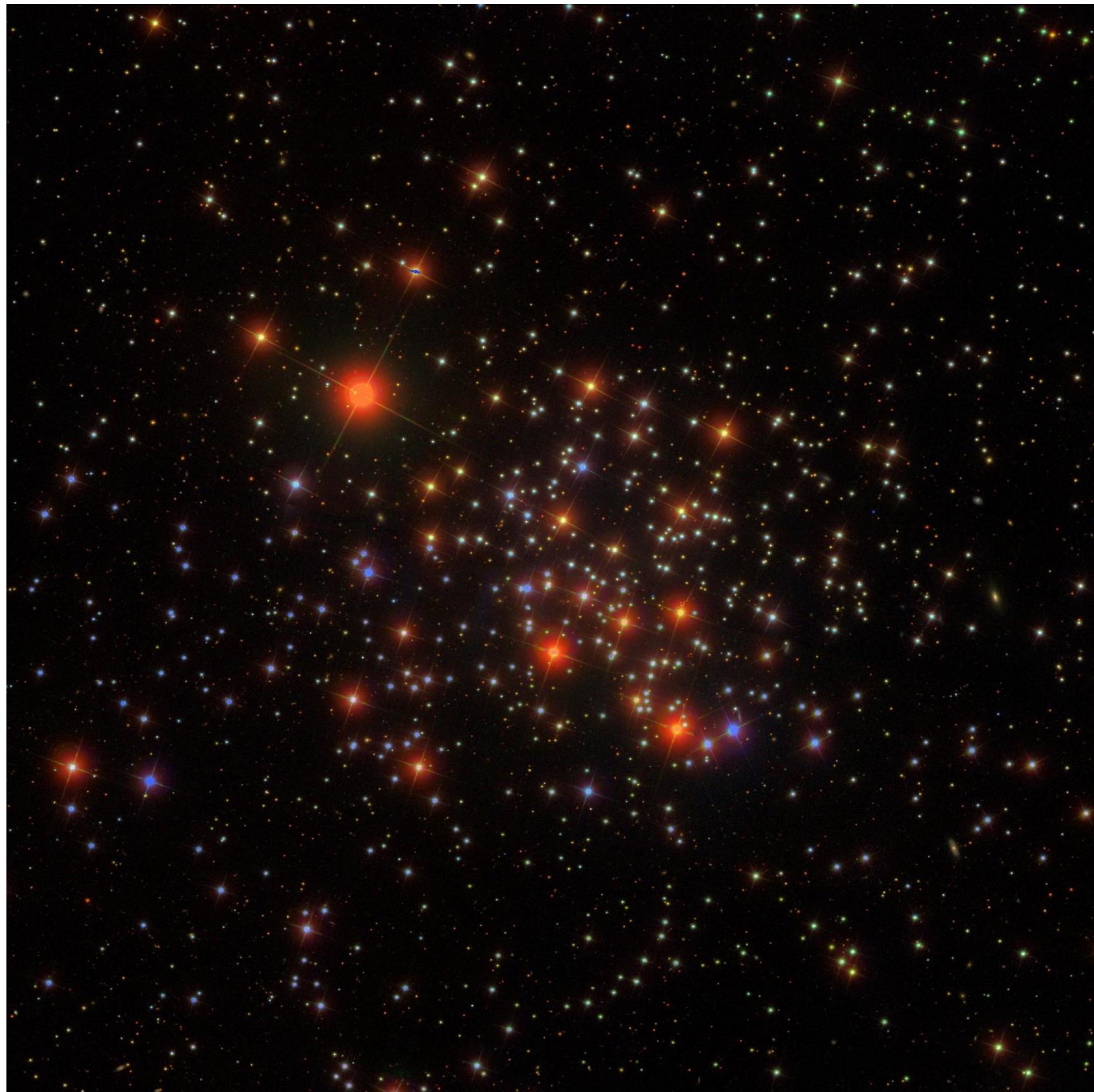
FIGURE II, 4.

Distribution of globular clusters in galactic coordinates.

Shapley (1930)

Clusters

open (“galactic”) clusters



M 67

globular clusters



M 15

Clusters

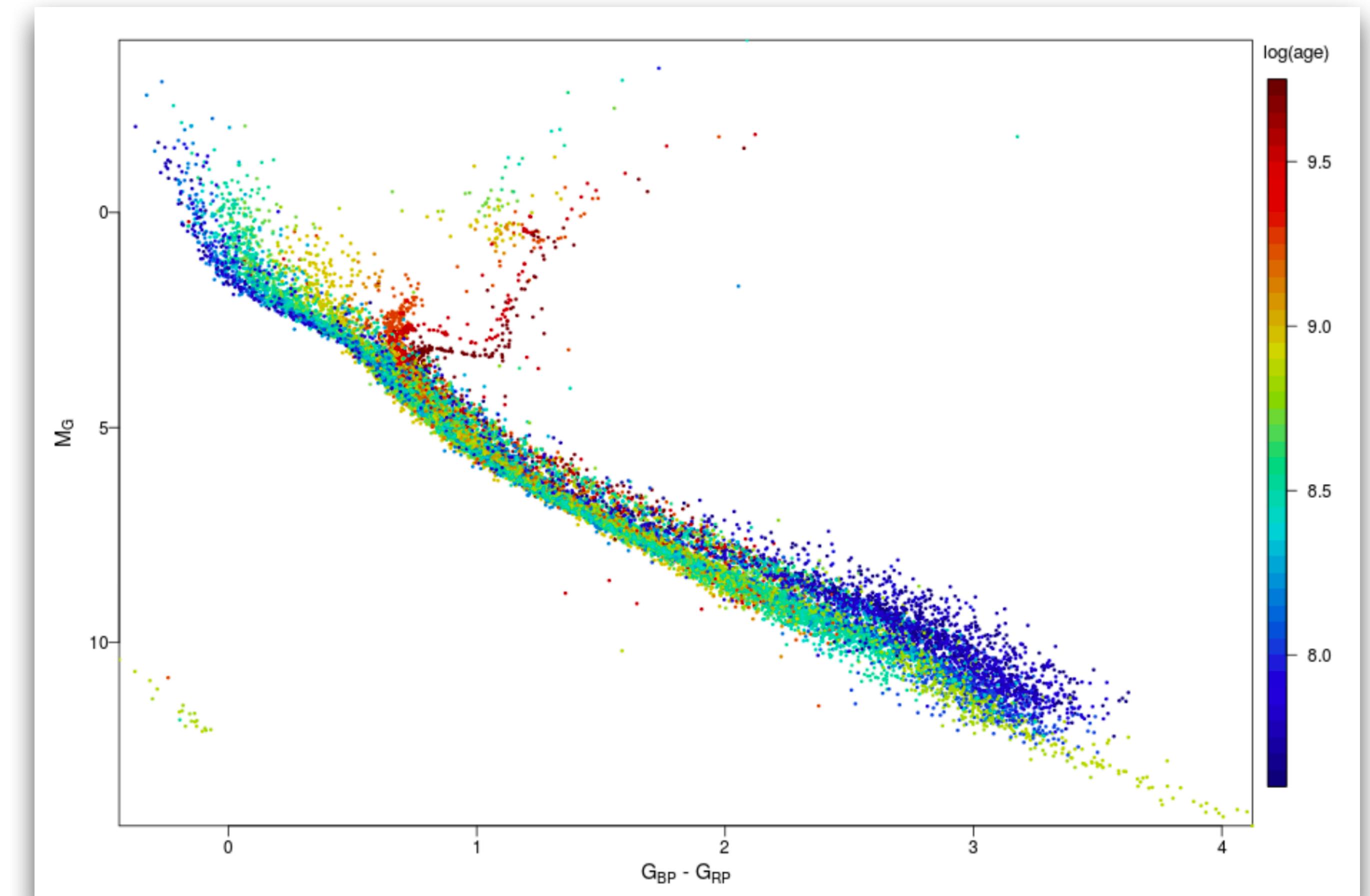
open (“galactic”) clusters



- Typically younger (usually up to 100's of Myr, very few +Gyr)
- Sparse, can count the stars - look “open”
 - $10^0 – 10^3$ stars
- Found mostly in the galactic disk, usually fairly nearby (< few kpc)
- More metal rich
- Thousands of OC's known in Milky Way
- Gaia finding a LOT more...

Clusters

open (“galactic”) clusters



Gaia DR2

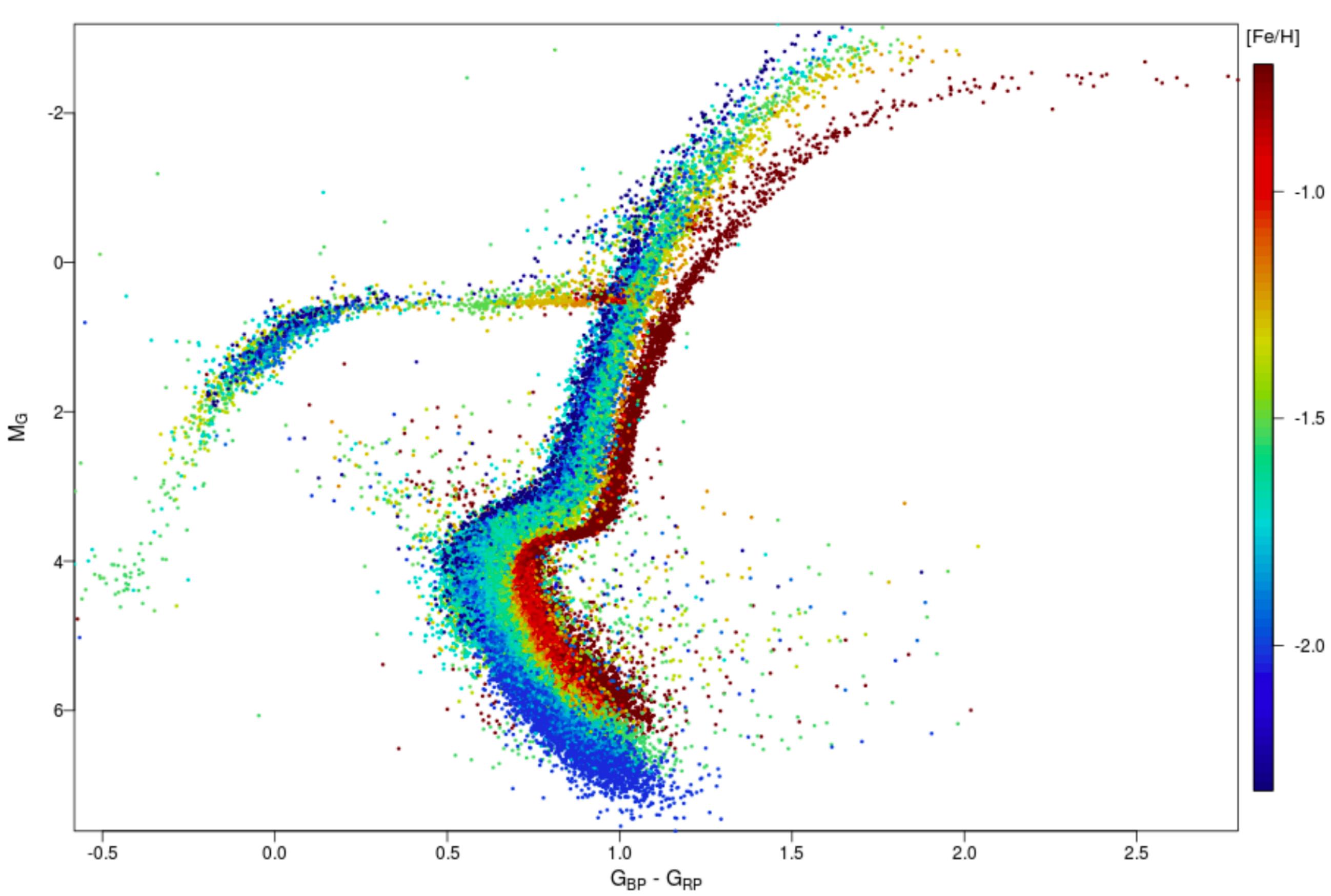
Clusters

- Old (many Gyr!)
- ~150 known in MWY
- Metal poor
- Found mostly in halo, far away (many kpc)
 - Though sub-populations exist
- Massive, $> 10^4$ stars
- Very dense, centrally concentrated, “mass segregation”

globular clusters



Clusters



Gaia DR2

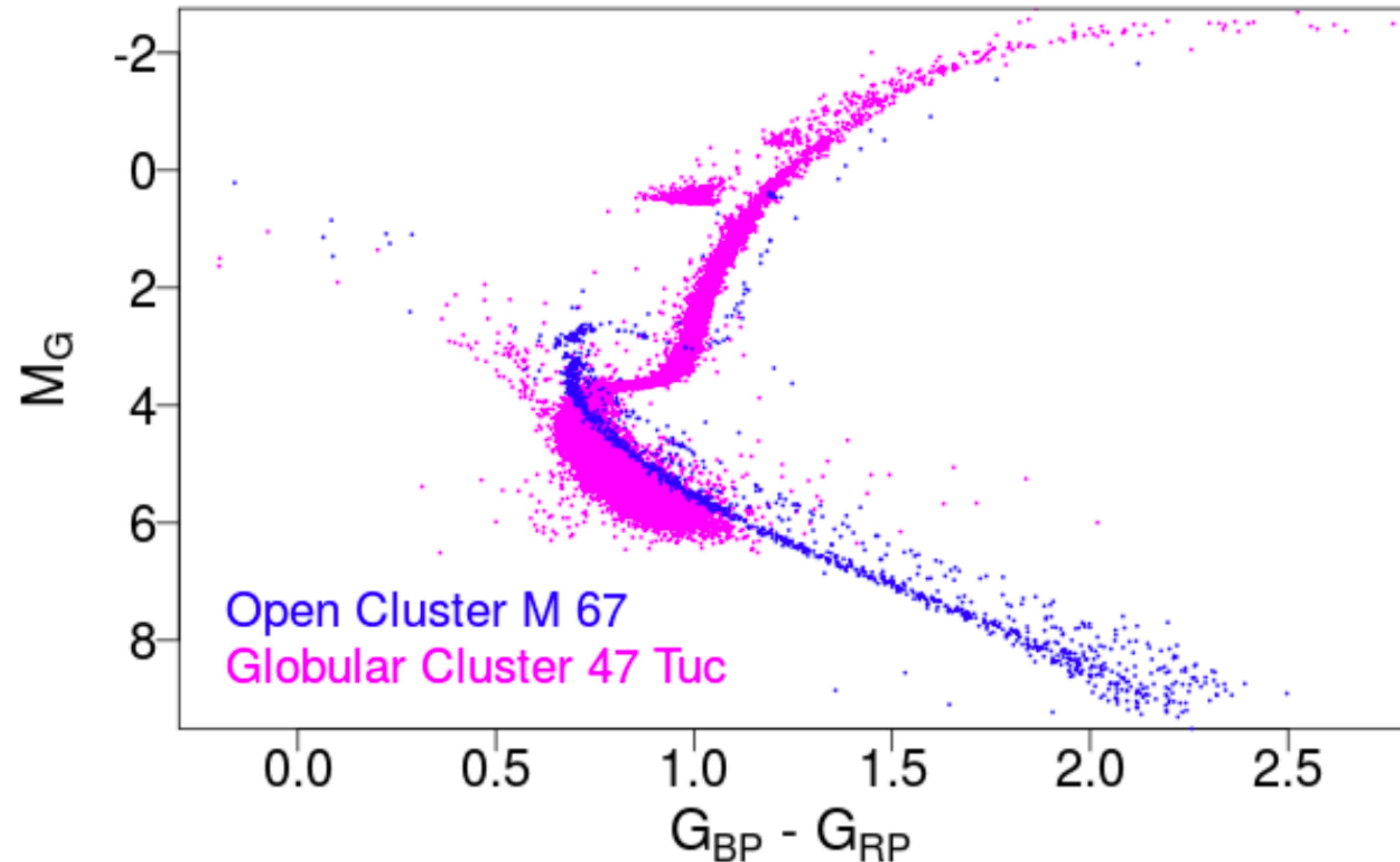
globular clusters



M 15

Clusters

- Super quick review of CMD...



Gaia DR2

M 15

Cluster Formation

Classical Ideas

- Clusters come from a single Giant Molecular Cloud
 - All stars simultaneously, with same composition, at the same distance
 - “Simple Stellar Population”
- All stars born in clusters
 - We only see the biggest or youngest clusters today



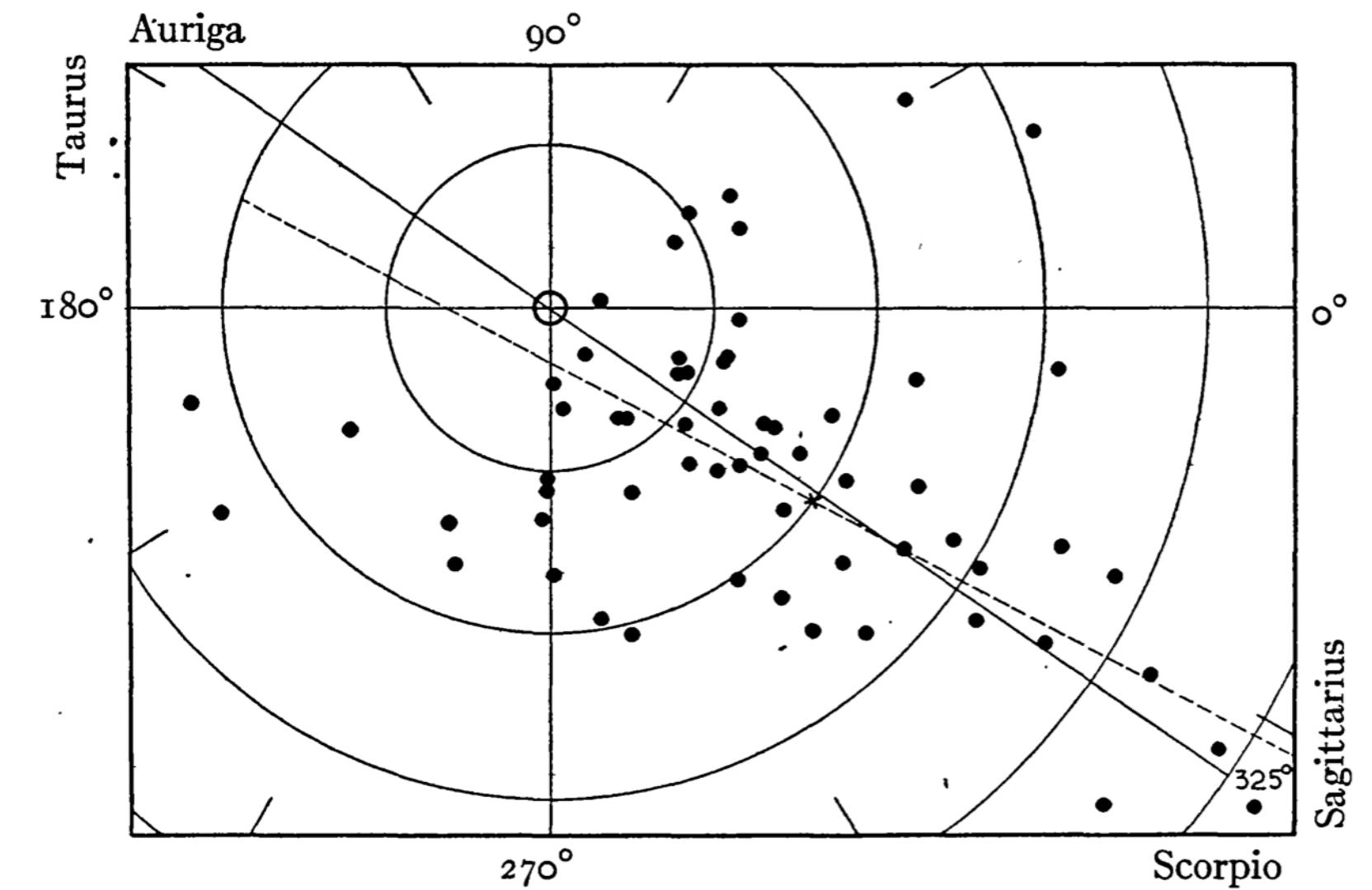
Cluster Formation

- Modeling formation is very challenging
 - Need to combine gas physics/feedback with stellar evolution and tidal dynamics in a dense environment!
 - Binary stars & multiple systems turn out to be VERY important (esp. for globular cluster survival)
 - N-body dynamics & external tidal stripping change the cluster a LOT during its lifetime

Cluster Formation

Clusters as a Benchmark

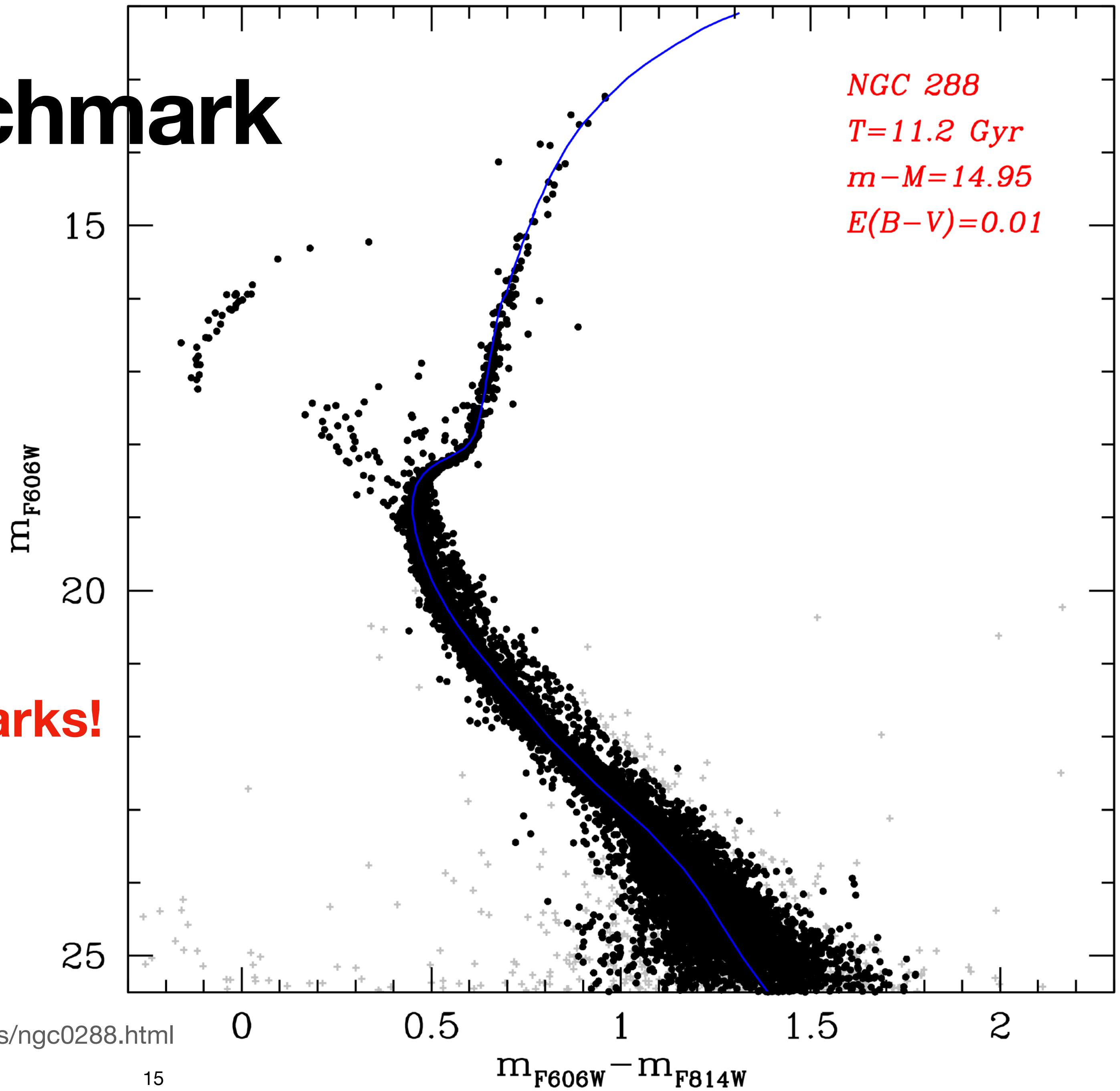
- Talked last time about clusters as key to “great debate” type things
- “Simple Stellar Population” model is key takeaway here
 - Clusters are considered the ultimate benchmark test for stellar evolution, anchor **EVERYTHING!**
 - We’re **STILL** testing all areas of stellar astrophysics w/ clusters, trying to find clusters of all ages/metallicities/ masses... and still relying (some) on clusters to anchor our distance ladders



Shapley (1919)

Clusters as a Benchmark

- DO use them as your benchmarks!



**This simple story is only
true to first order**

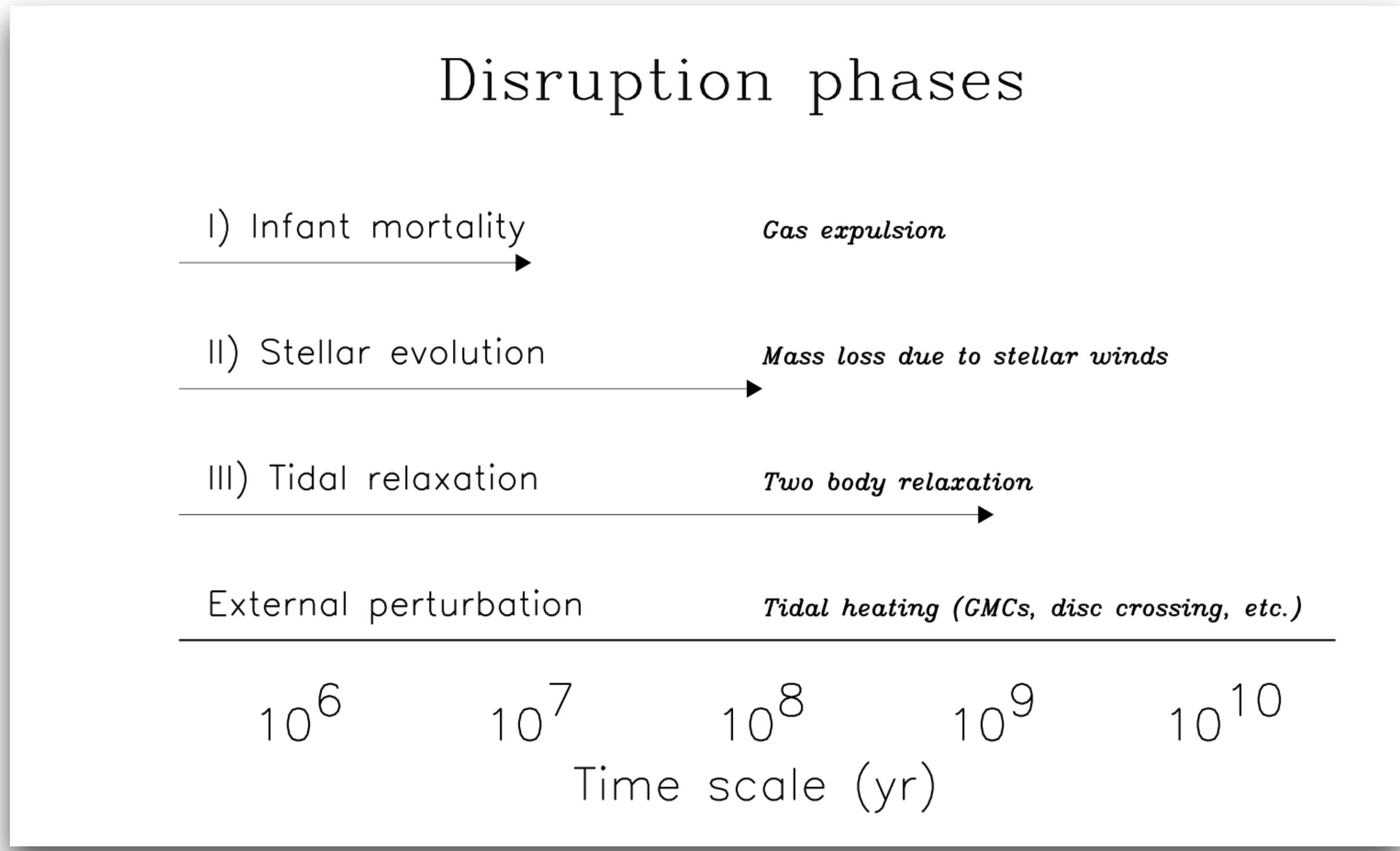
Some Problems to Clusters as Benchmarks...

- Obvious problems include:
 - Stars don't form at a single *moment* (timescales for 1 vs $20 M_{\odot}$ star)
 - K/M dwarfs still forming when O/B stars exploding!
 - GMCs are *huge*, and collapse can't be triggered instantaneously
 - Also feedback!
 - Dynamics, cluster disruption... what are we seeing *now* vs. *formation*?

Cluster Disruption/Dissolution

- Almost all clusters are destroyed!
 - First hint of this is big drop of open clusters past ~600Myr
 - Only big clusters survive
- Tidal streams
- Mass segregation and stripping

Cluster Disruption/Dissolution



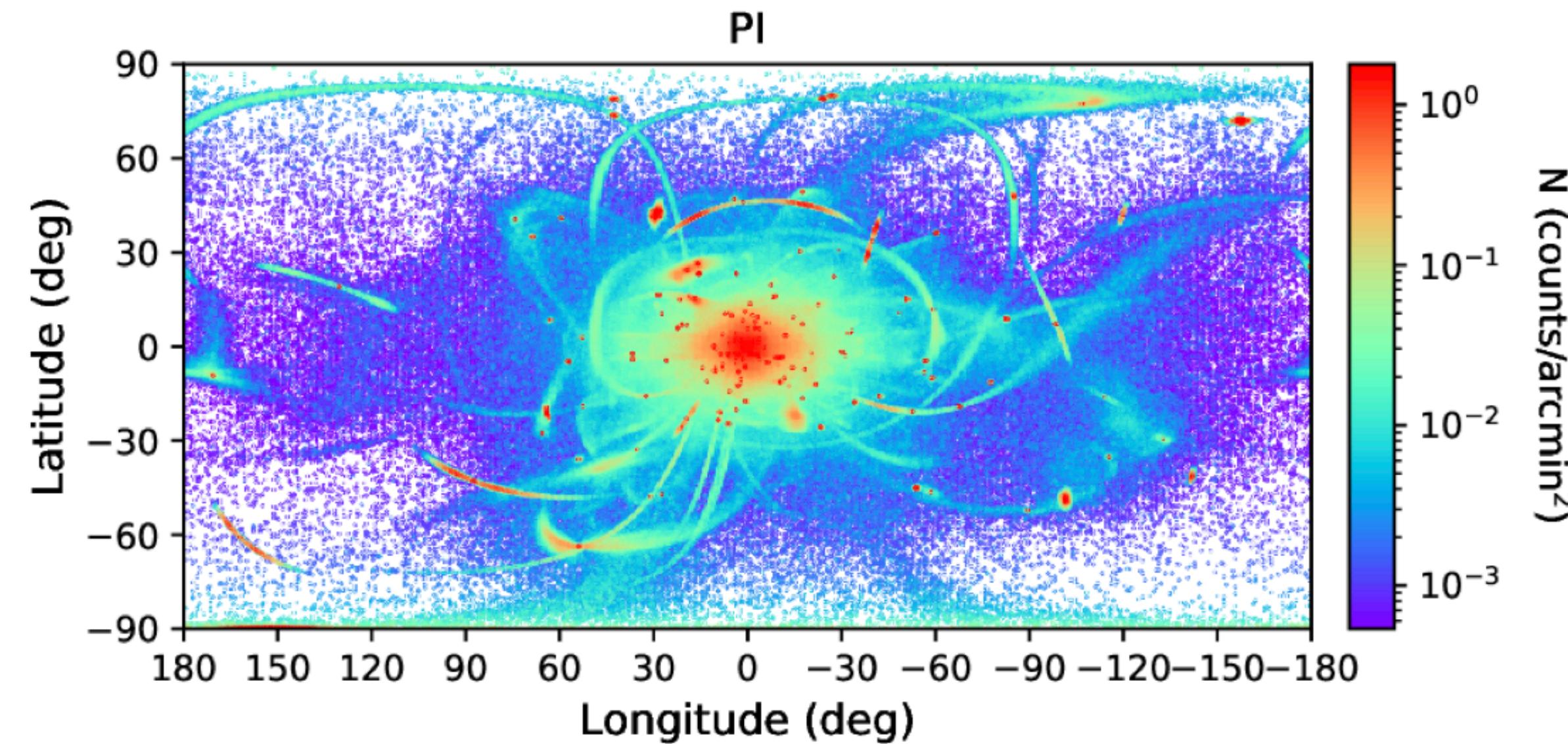
60-90% of clusters
are destroyed



Bastian & Giles (2006)
(for H.J.G.L.M. Lamers)

Cluster Disruption/Dissolution

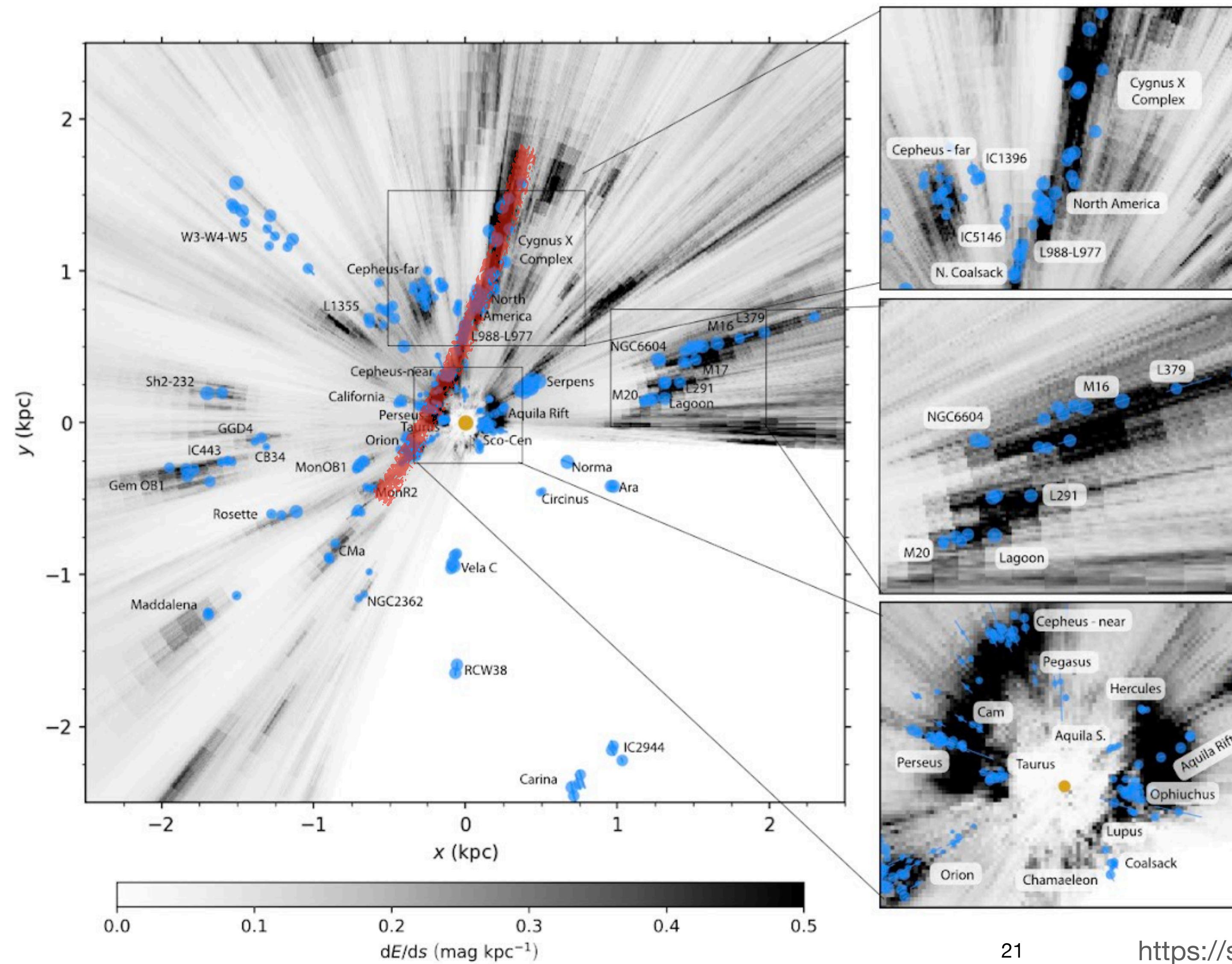
- Probably half of the *current* Globular Cluster population mass has been lost to the Milky Way
- NOT enough mass to create the Halo!
 - Need WAY MORE clusters to create the halo we observe
 - & prob more low-mass clusters
 - Gnedin & Ostriker (1997)



Ferrone+2023

From Lecture 2

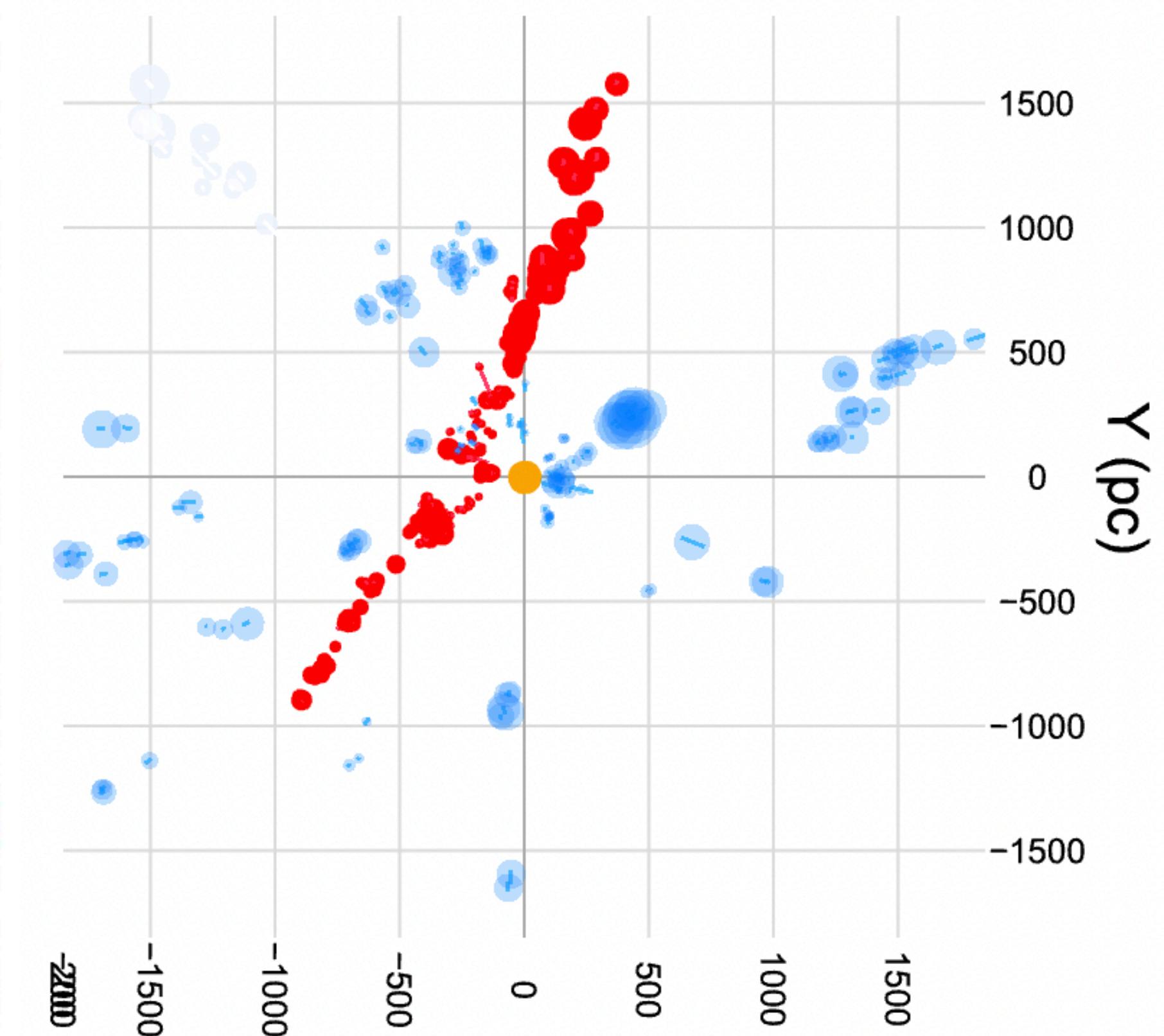
$d < 500\text{pc}$



“Radcliffe Wave”

C. Zucker+2020

Long line of star forming regions

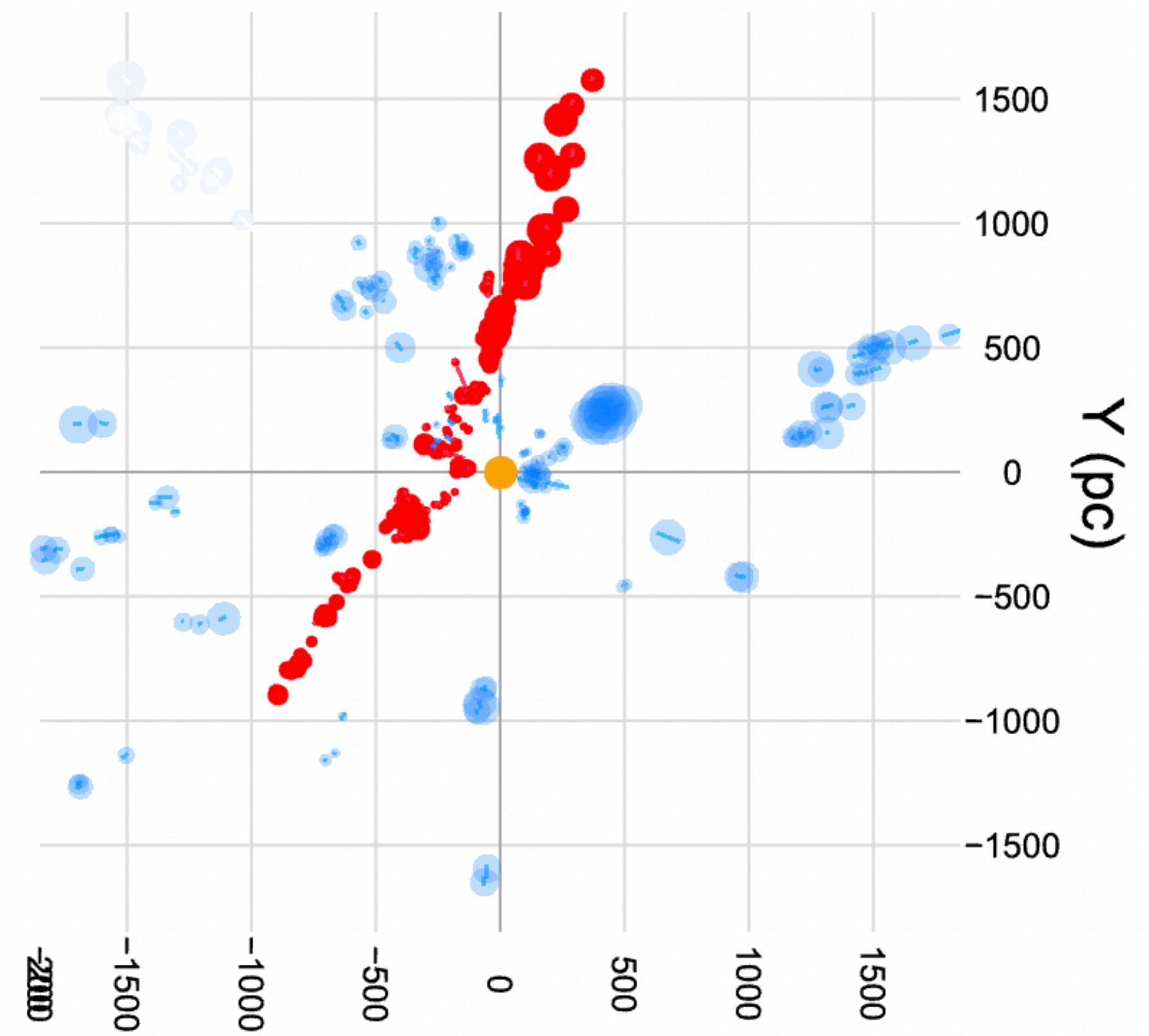


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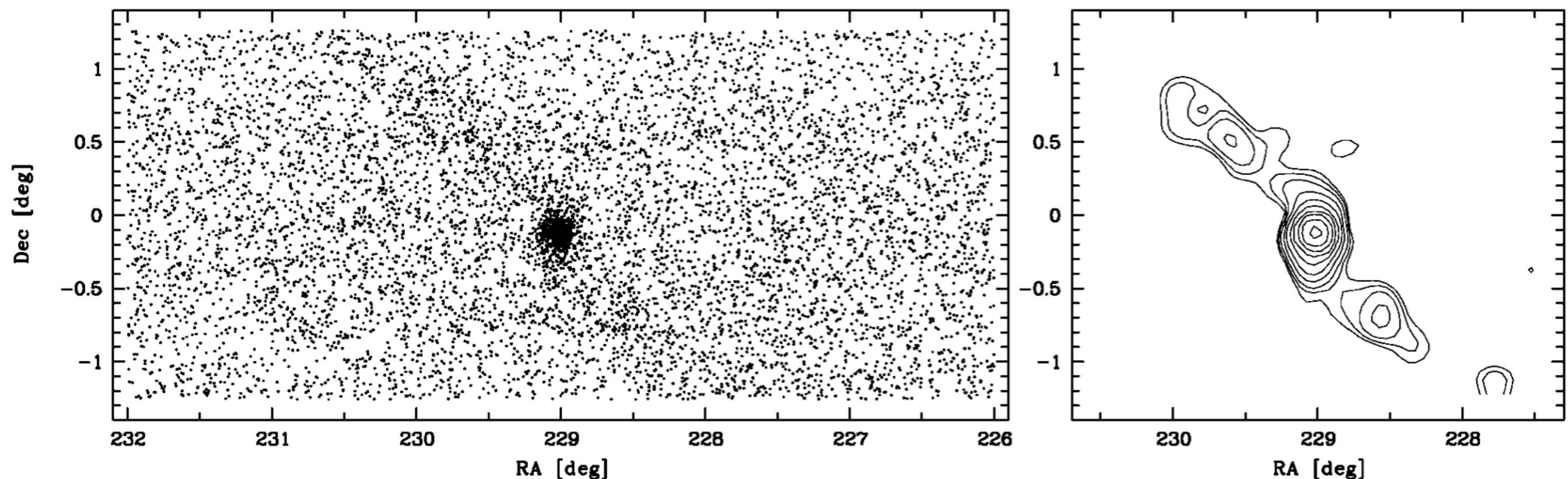
- For disk:
 - We see stars forming
 - We see loose clusters being destroyed
 - Disk can have lots of material from mergers



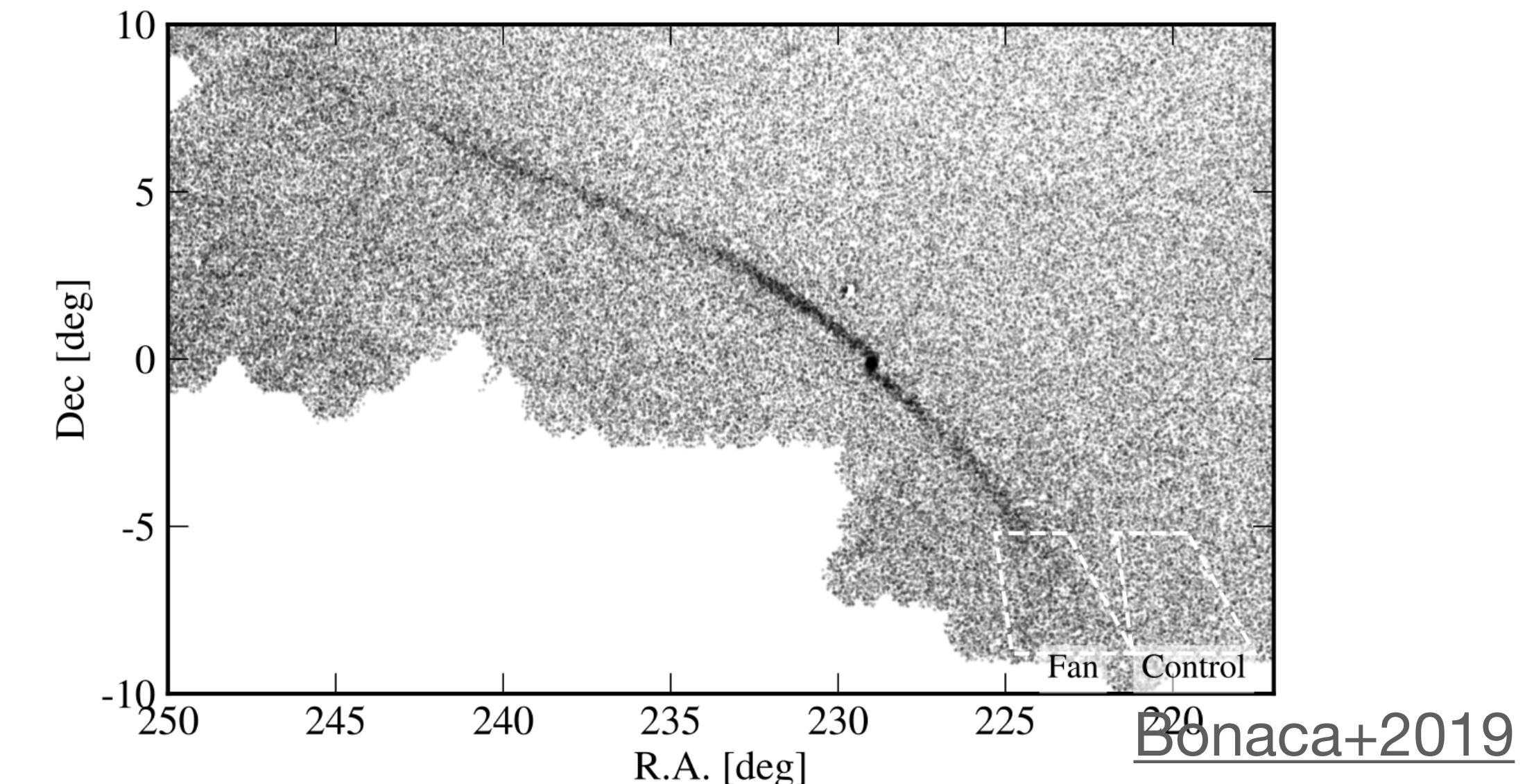
Tidal Tails/Streams

- Most famous: globular cluster **Palomar 5**
- Discovered by SDSS in 2001

Odenkirchen+2001

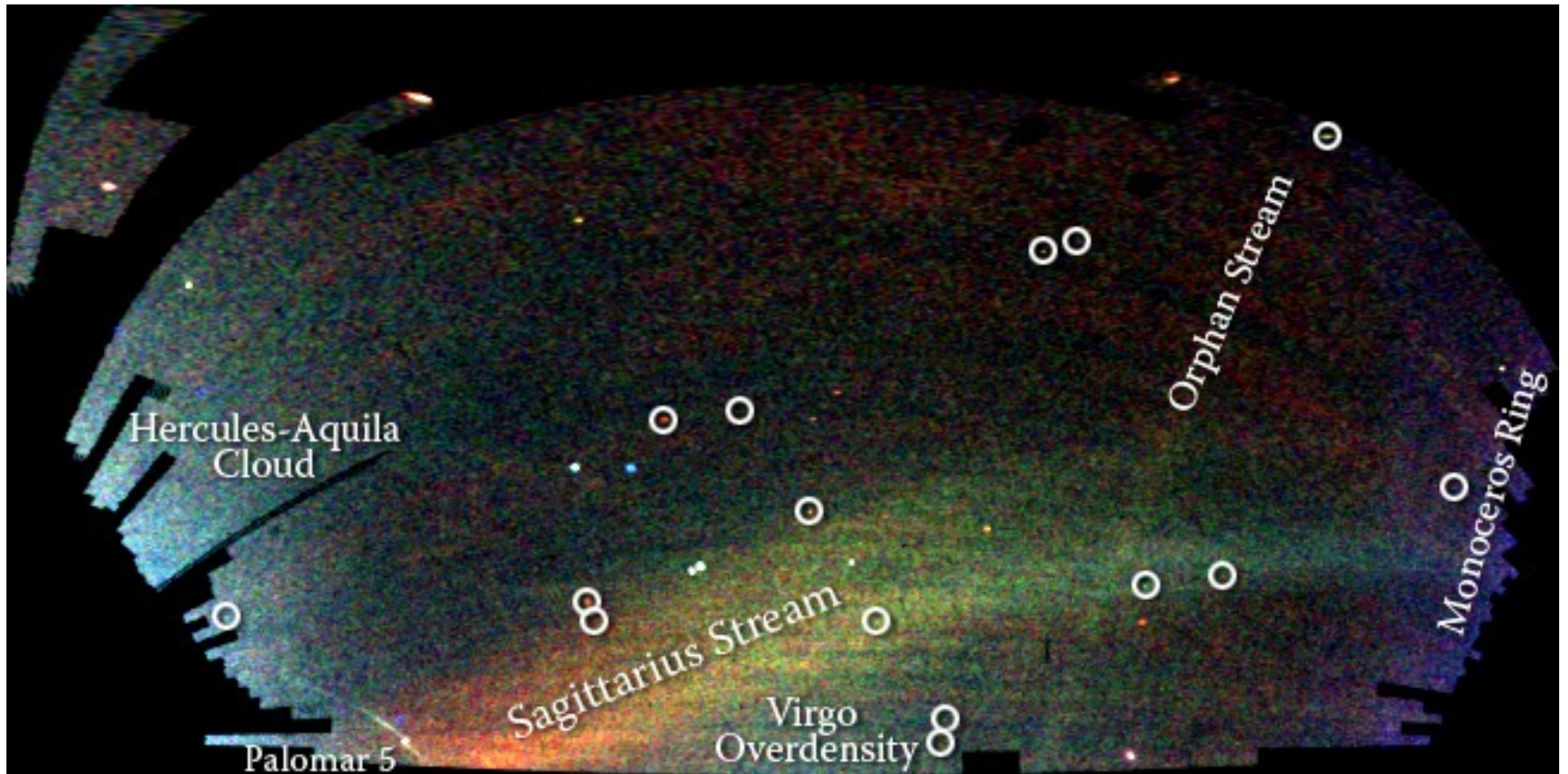


- Now traced over 20kpc (and 30 deg)!



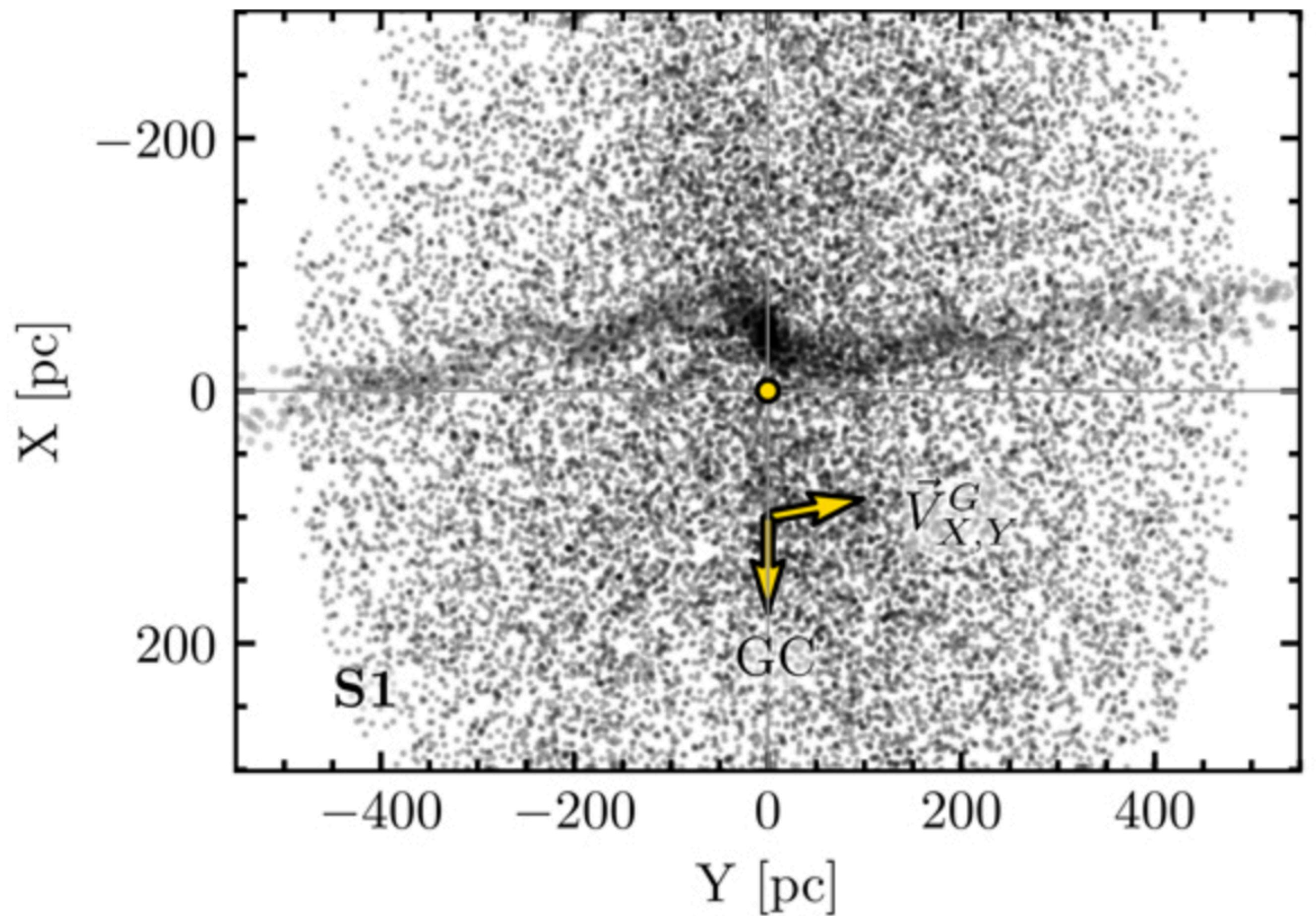
Tidal Tails/Streams

- “Field of Streams”
Belokurov+2006
- Now ~100
MWY streams
identified
- galstreams

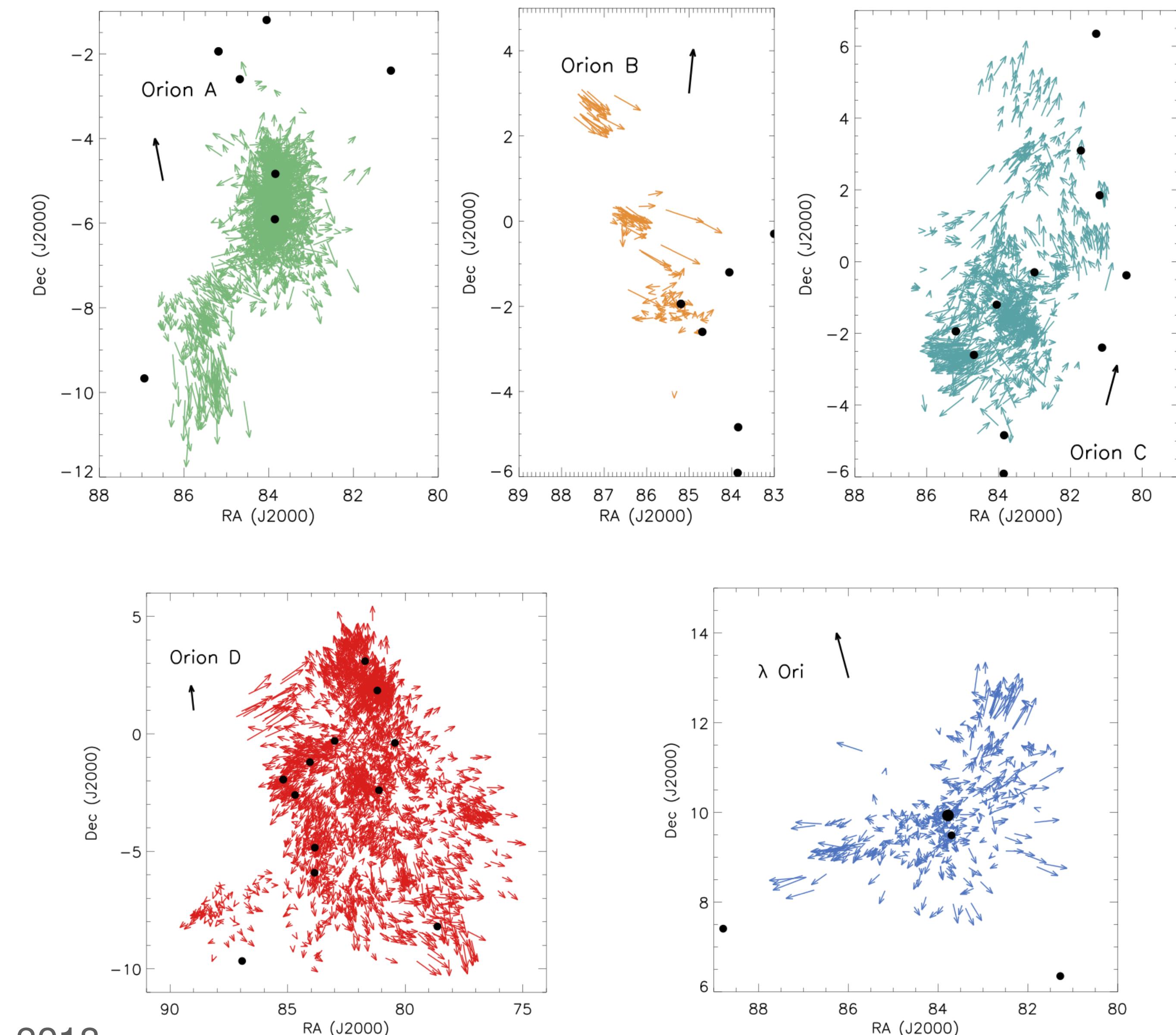
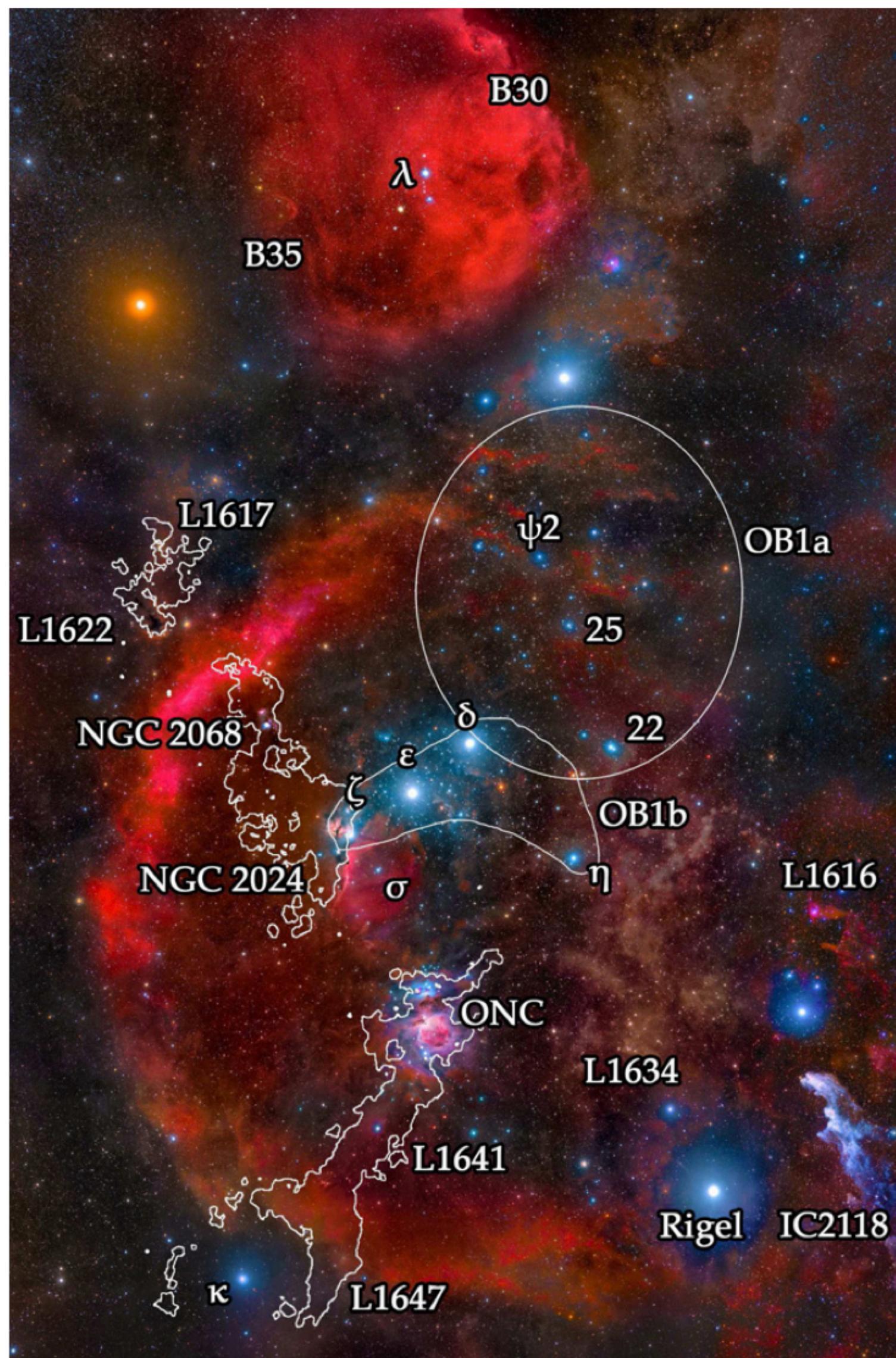


Tidal Tails/Streams

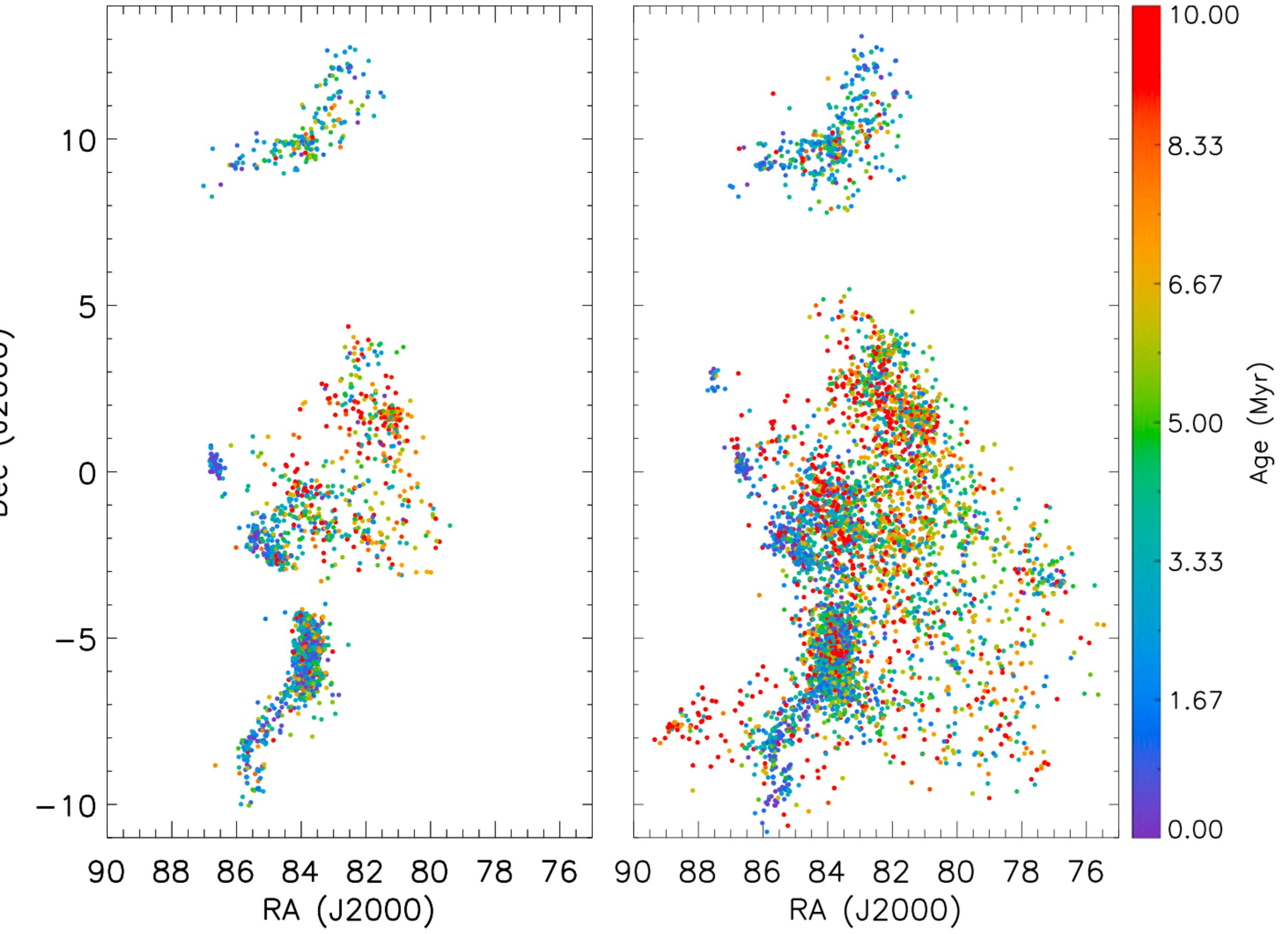
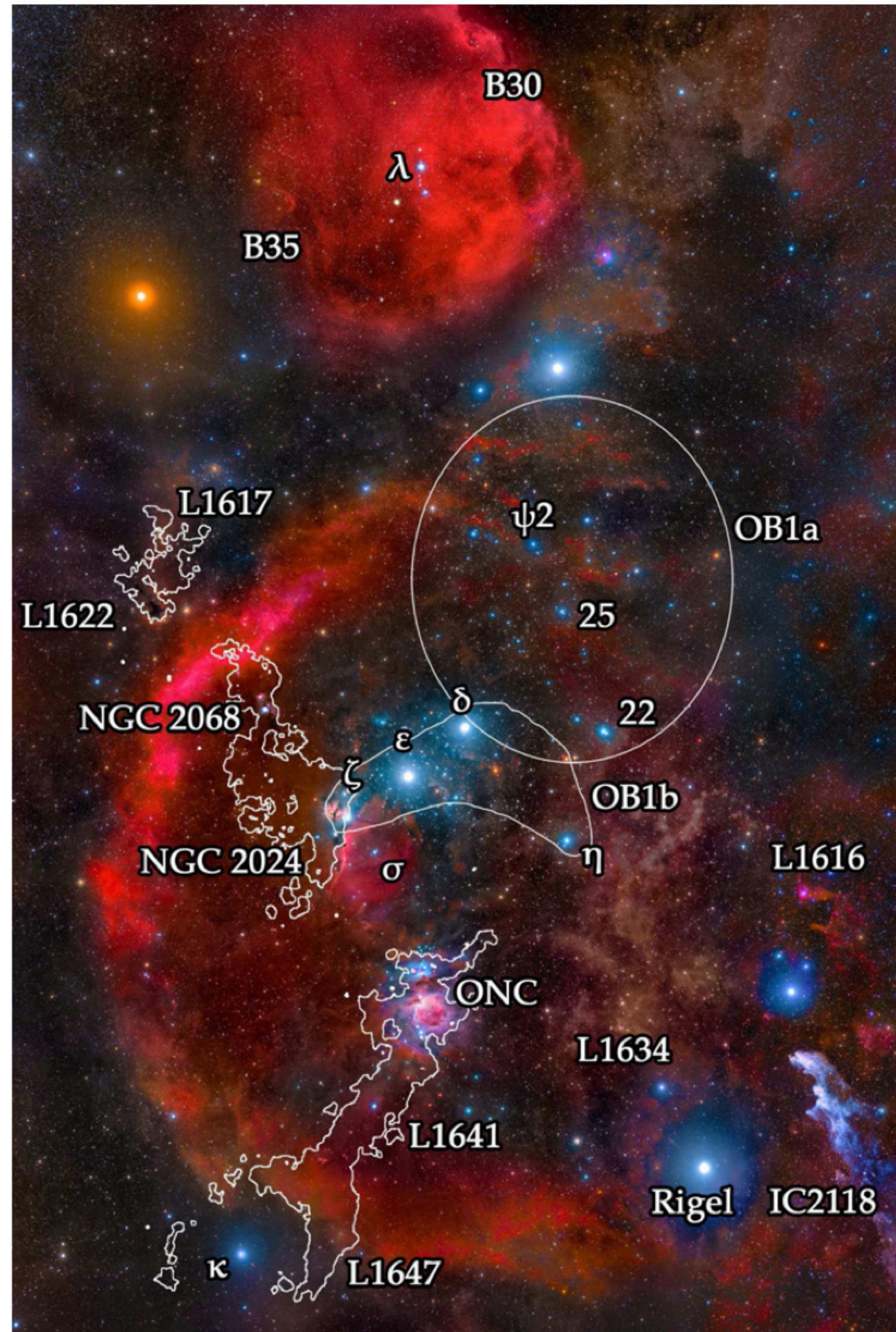
- Open clusters have them too!
- Hyades has 800 pc tails?!
 - Jerabkova+2021
- Older open clusters (e.g. M67) have been searched as well...



Cluster Age Spread



Cluster Age Spread

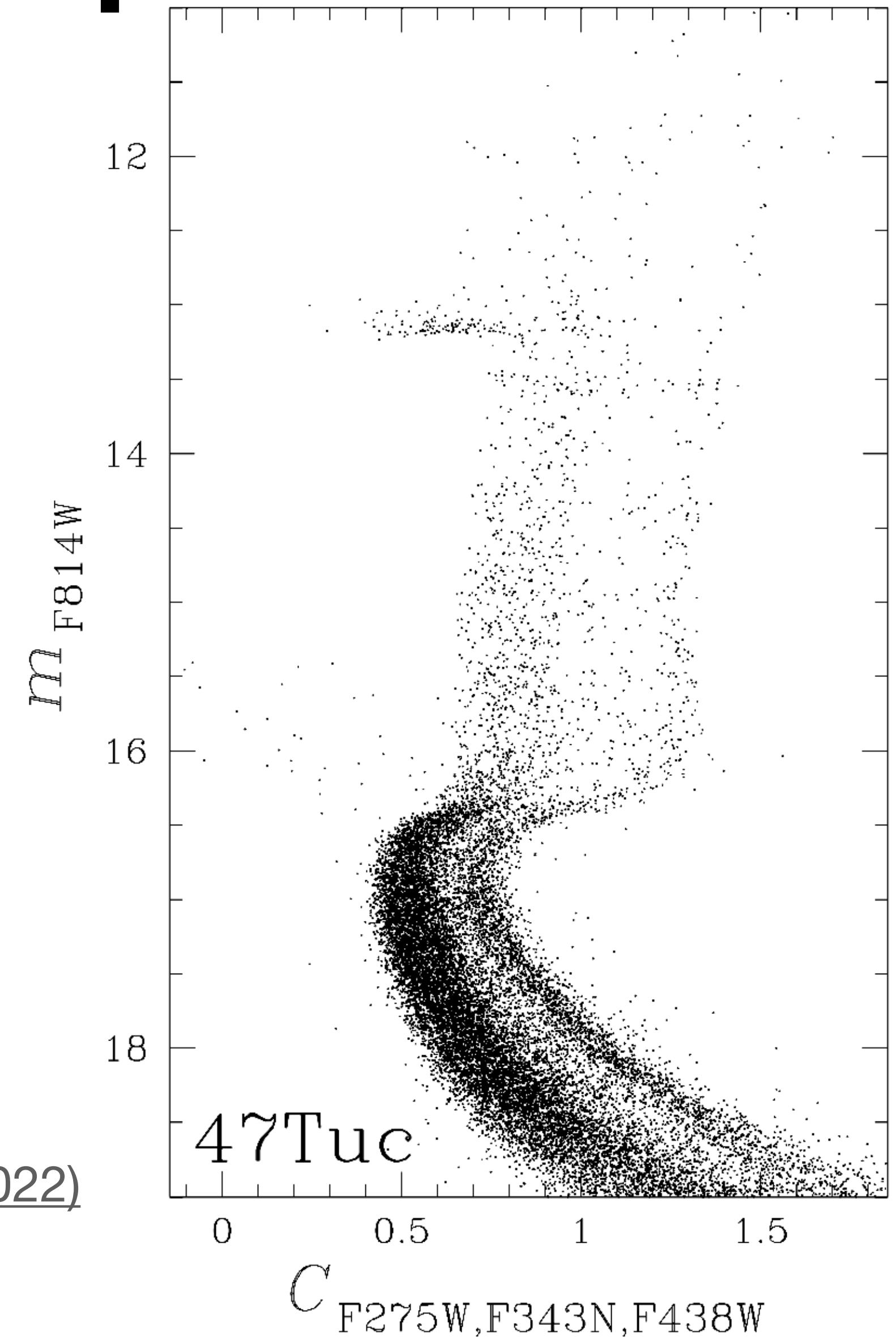


Kounkel+2018

Clusters NOT simple stellar pops

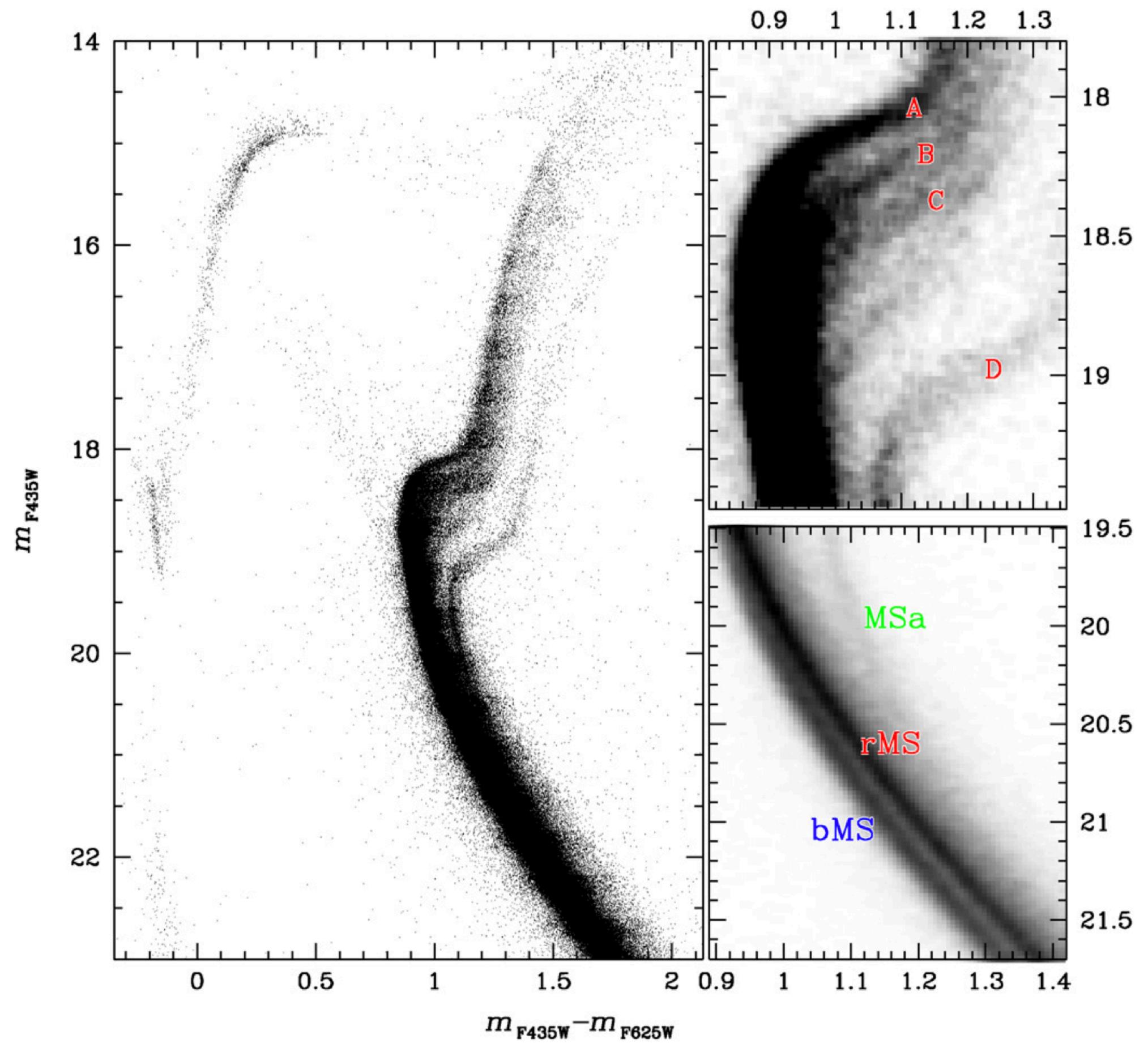
- **Multiple Populations** in many Globular Clusters!
 - ~59 MWY GC's!
 - Multiple turn-offs, MS, RGB...
 - HST key to discovering these (super precise & deep CMDs), also found in spectra: [Na/O]
 - Looks like usually 2 populations of stars, some kind of self-enrichment going on
 - Sometimes MORE than 2 populations...

Milone & Marino (2022)



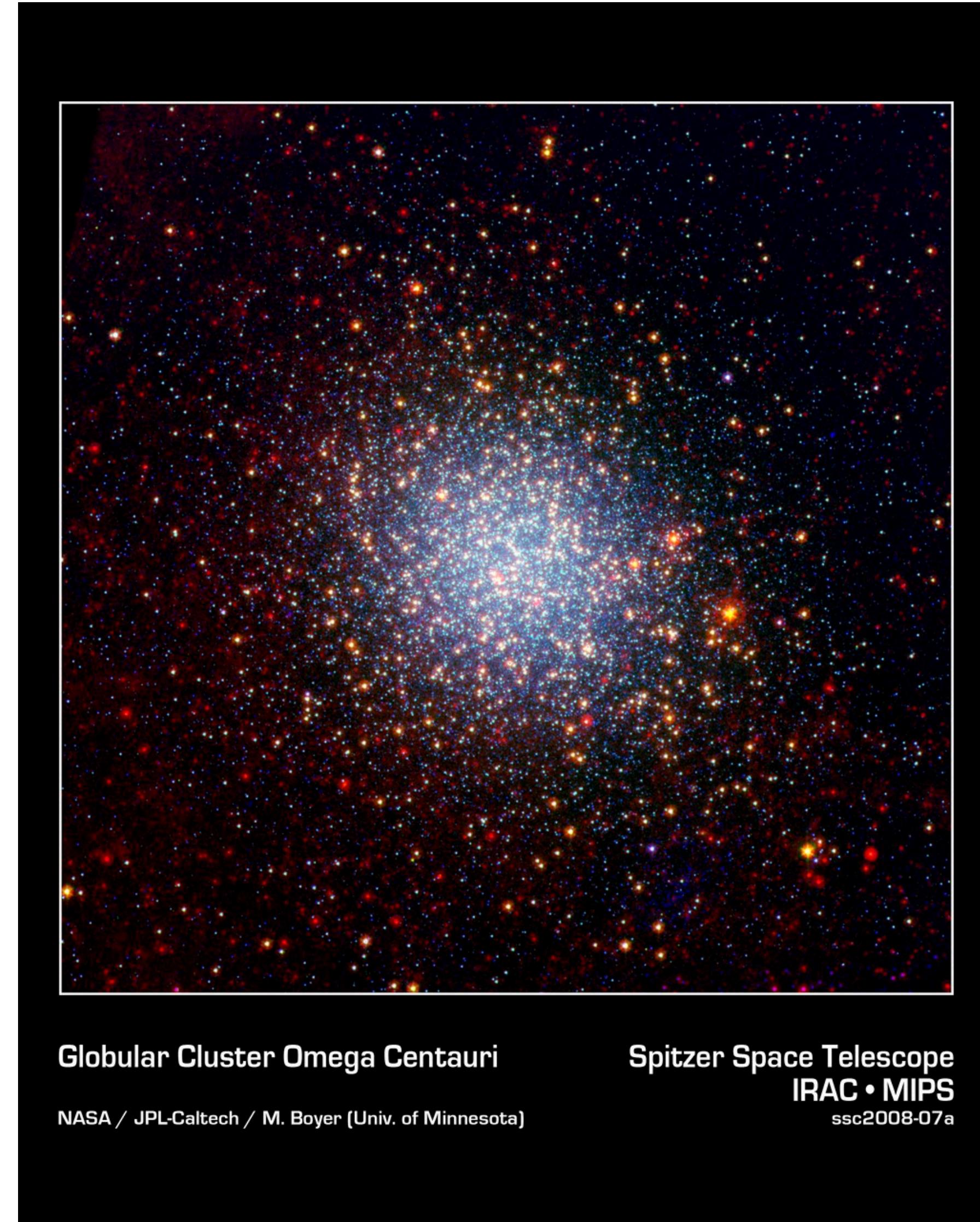
Some clusters really aren't clusters!

- Omega Cen and the dSph remnants



e.g. Bellini+2010

29



Binary Clusters

- Somewhat rare, but its a thing (Gaia finding some new candidates)
- Most Famous:
The “Double Cluster”, NGC 869 and
NGC 884, aka “**h and χ Persei**”
 - ~13 Myr
 - Are they the same age?
 - Possibly few Myr spread?
 - Maybe not!
 - How similar are they?! I’d love to know the Gaia answer...



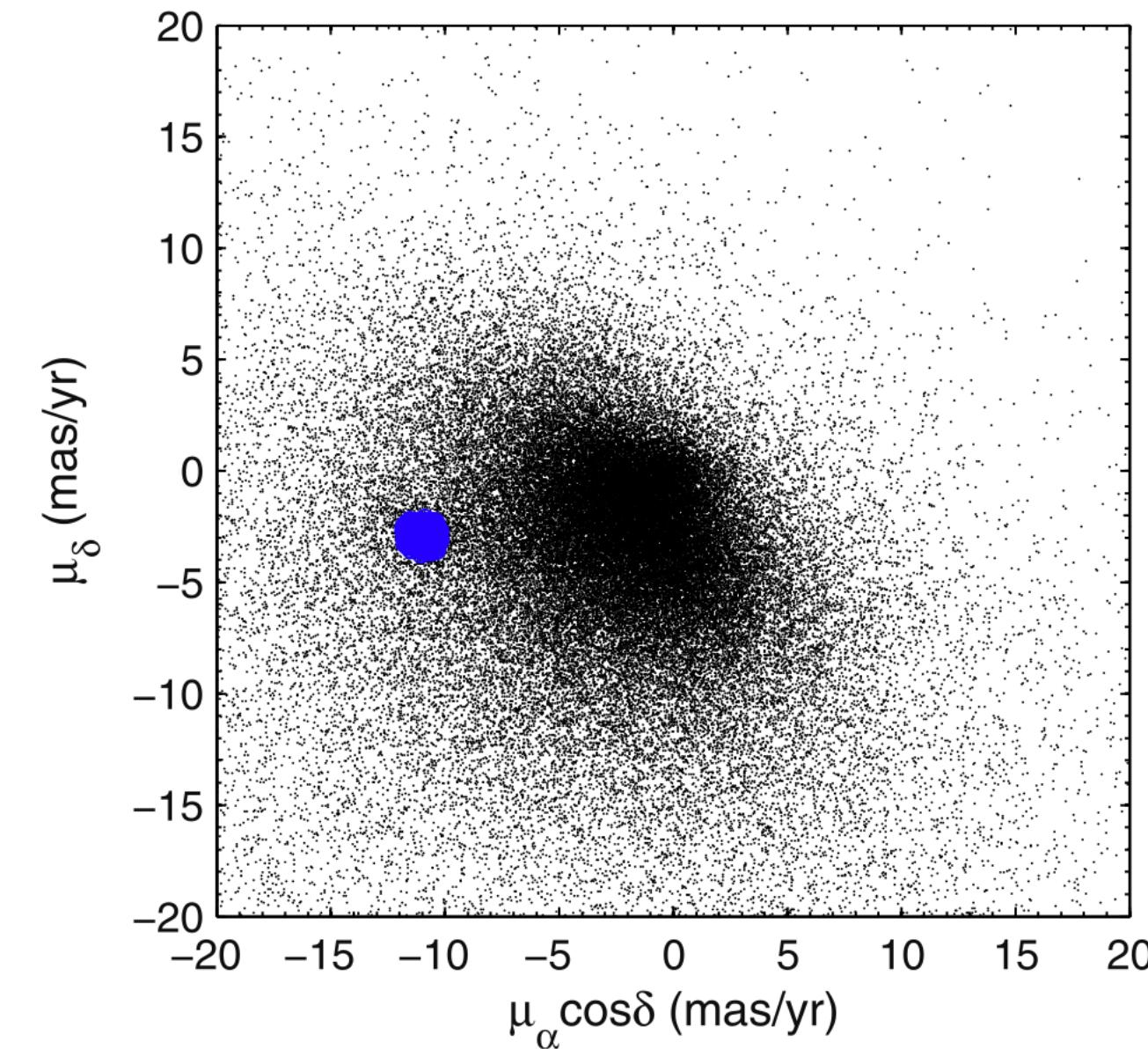
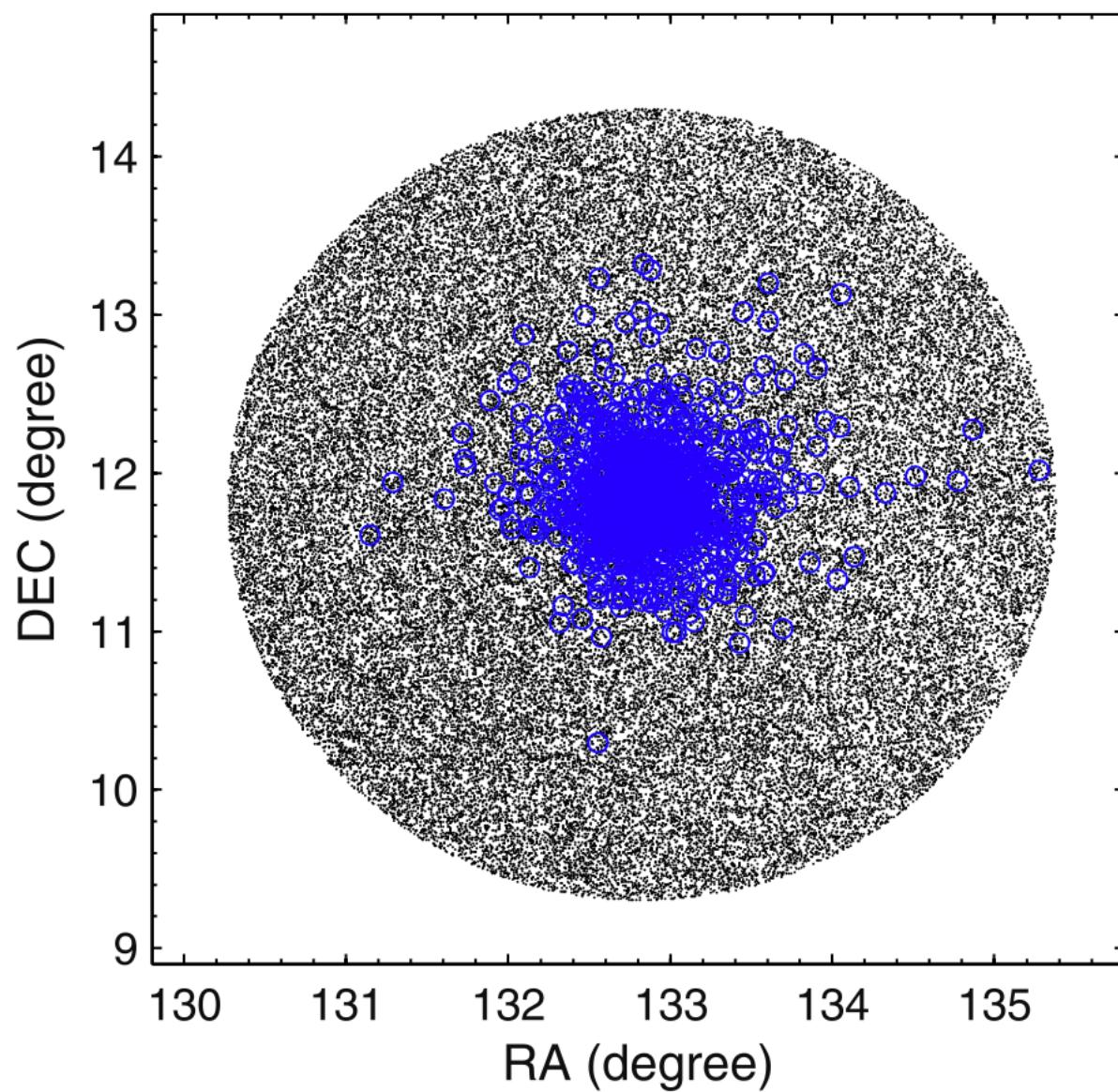
Cluster Identification

- Stand out in various parameter space:
 - CMD space, obviously
 - Proper motion/dynamical space
 - This is very easy when cluster is small/dense/bound
 - This is hard when cluster is spread out (have to look in action angle or various phase spaces)
 - Velocities very useful, but usually too expensive

Cluster Identification

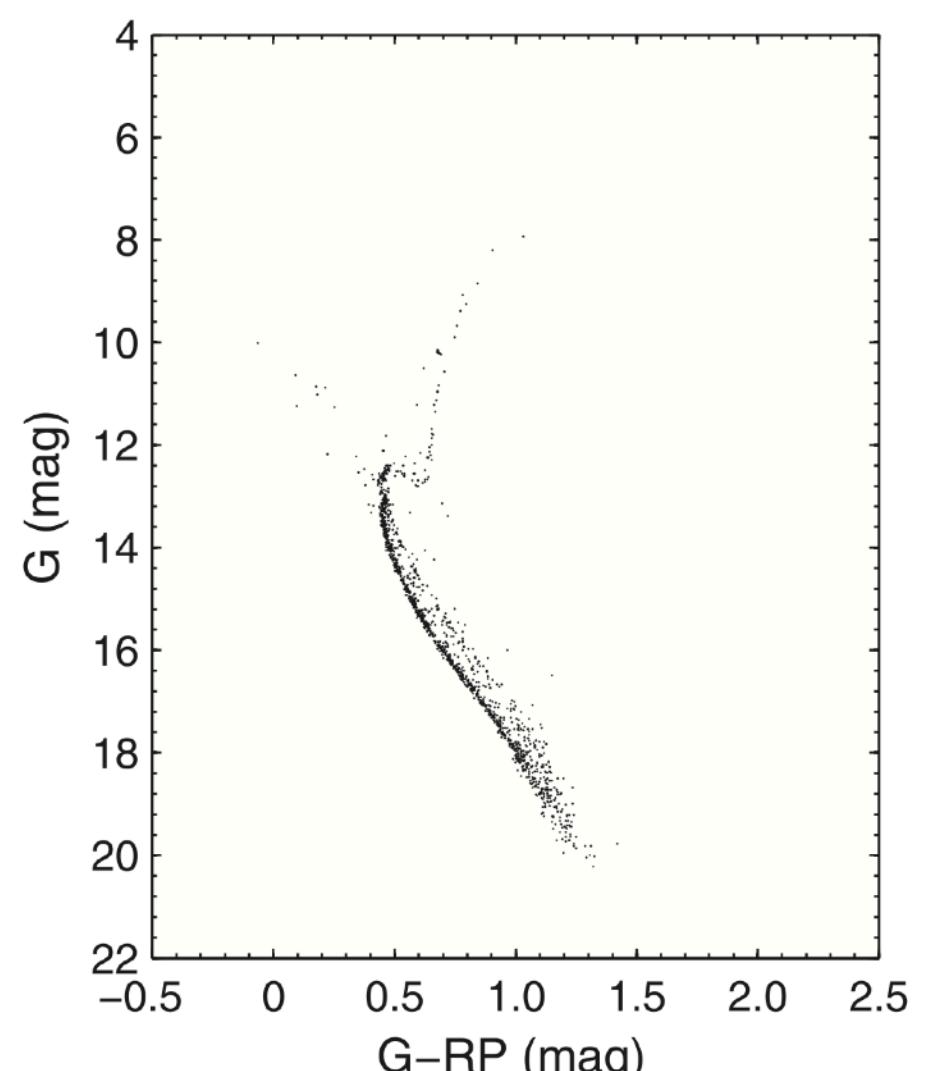
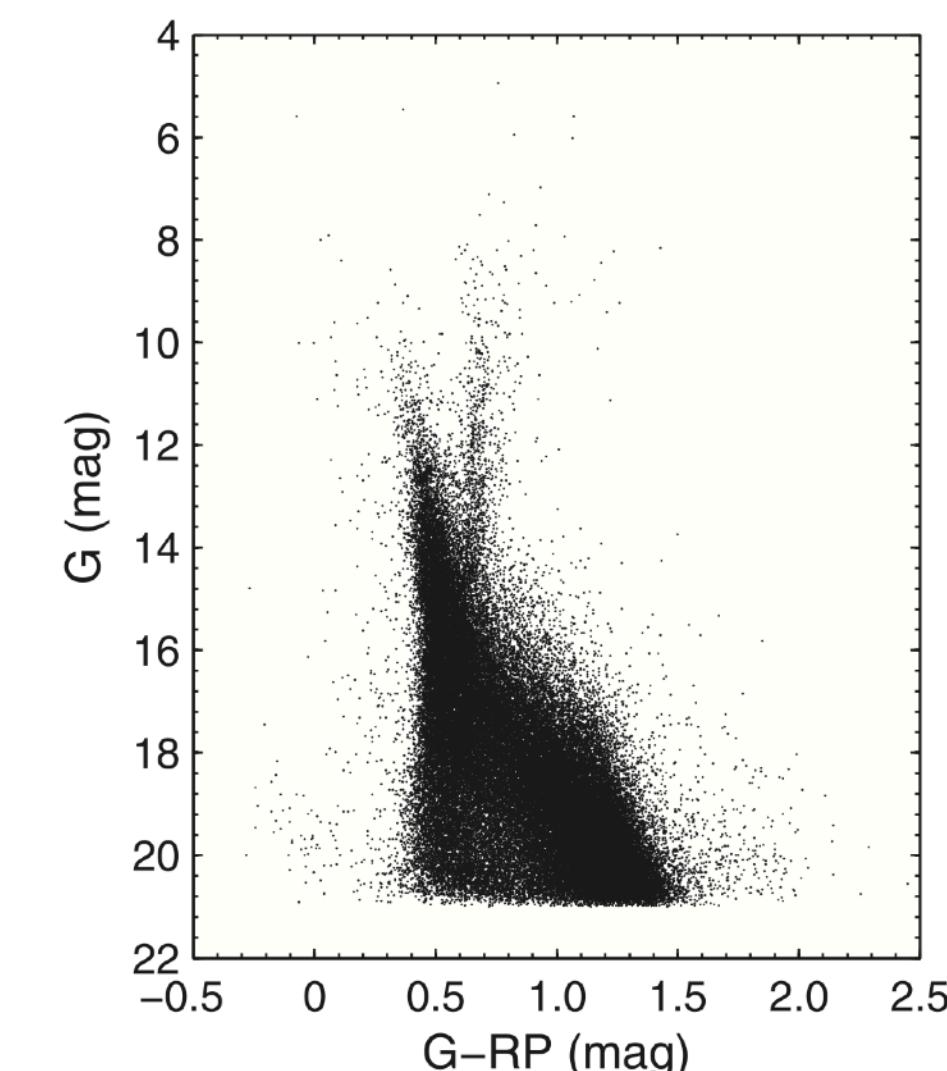
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Cluster Identification



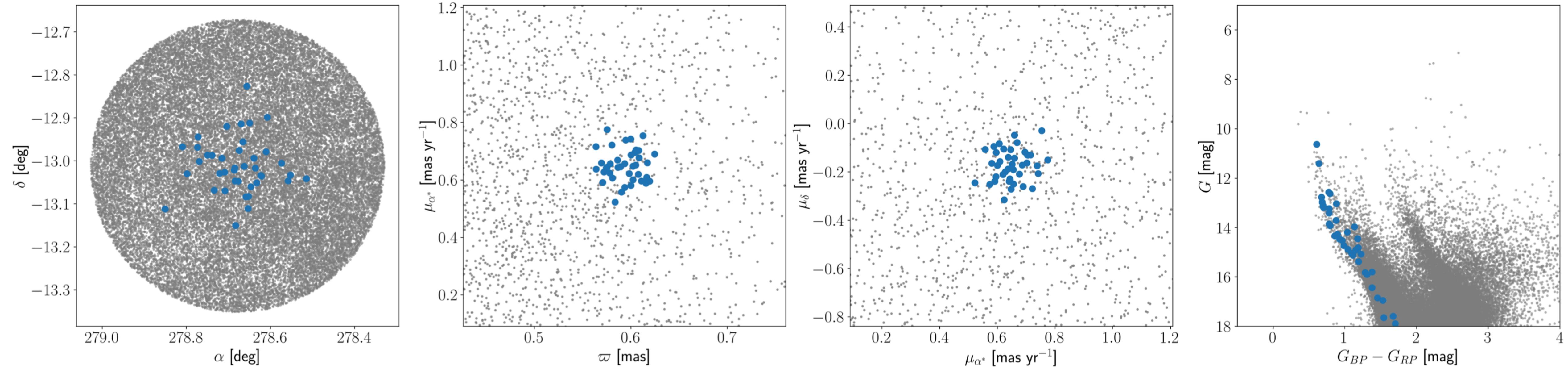
Gao (2018)

- CMD still very useful
- So is spatial (radial) location
- Combo of features to learn on!



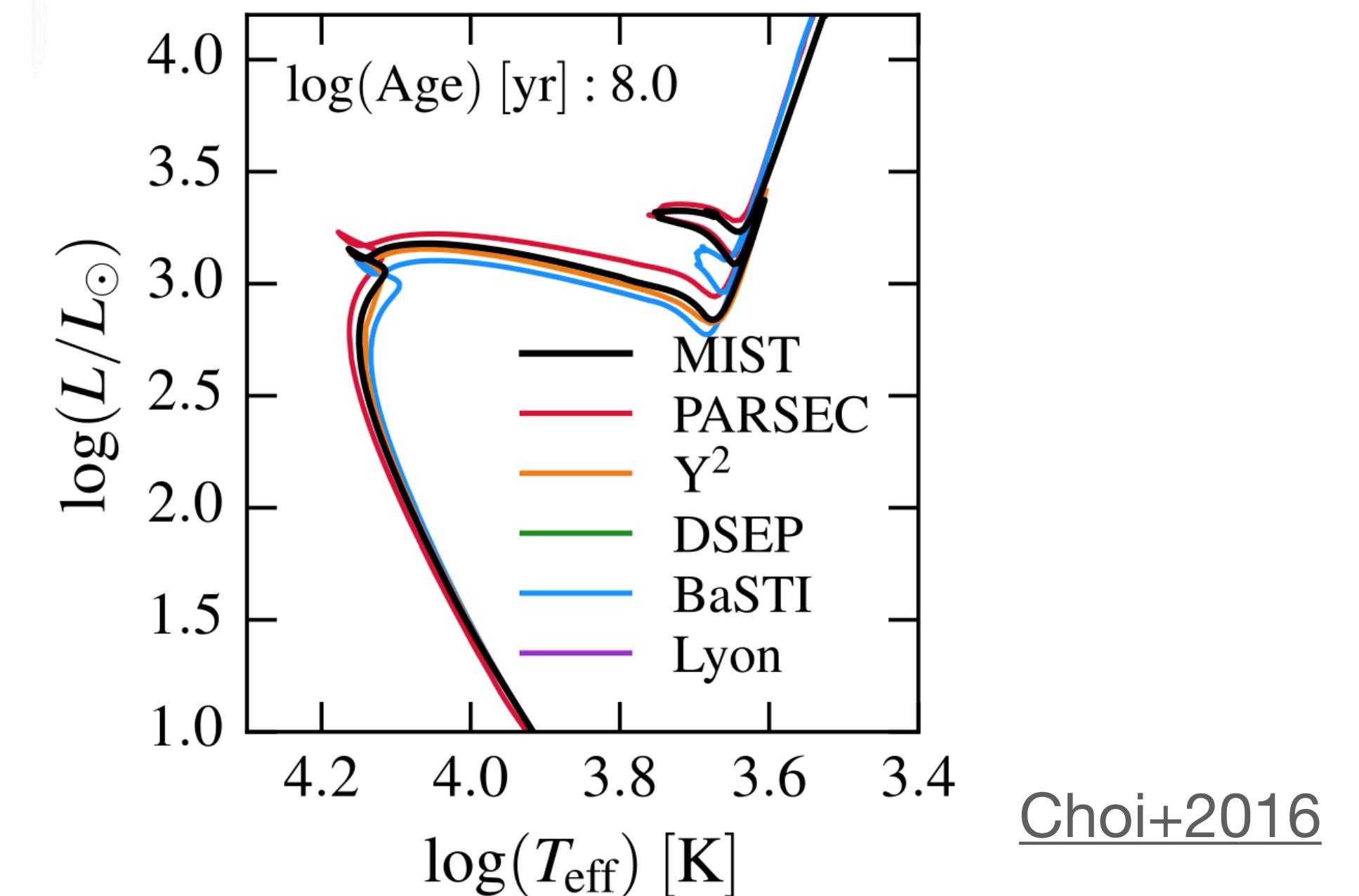
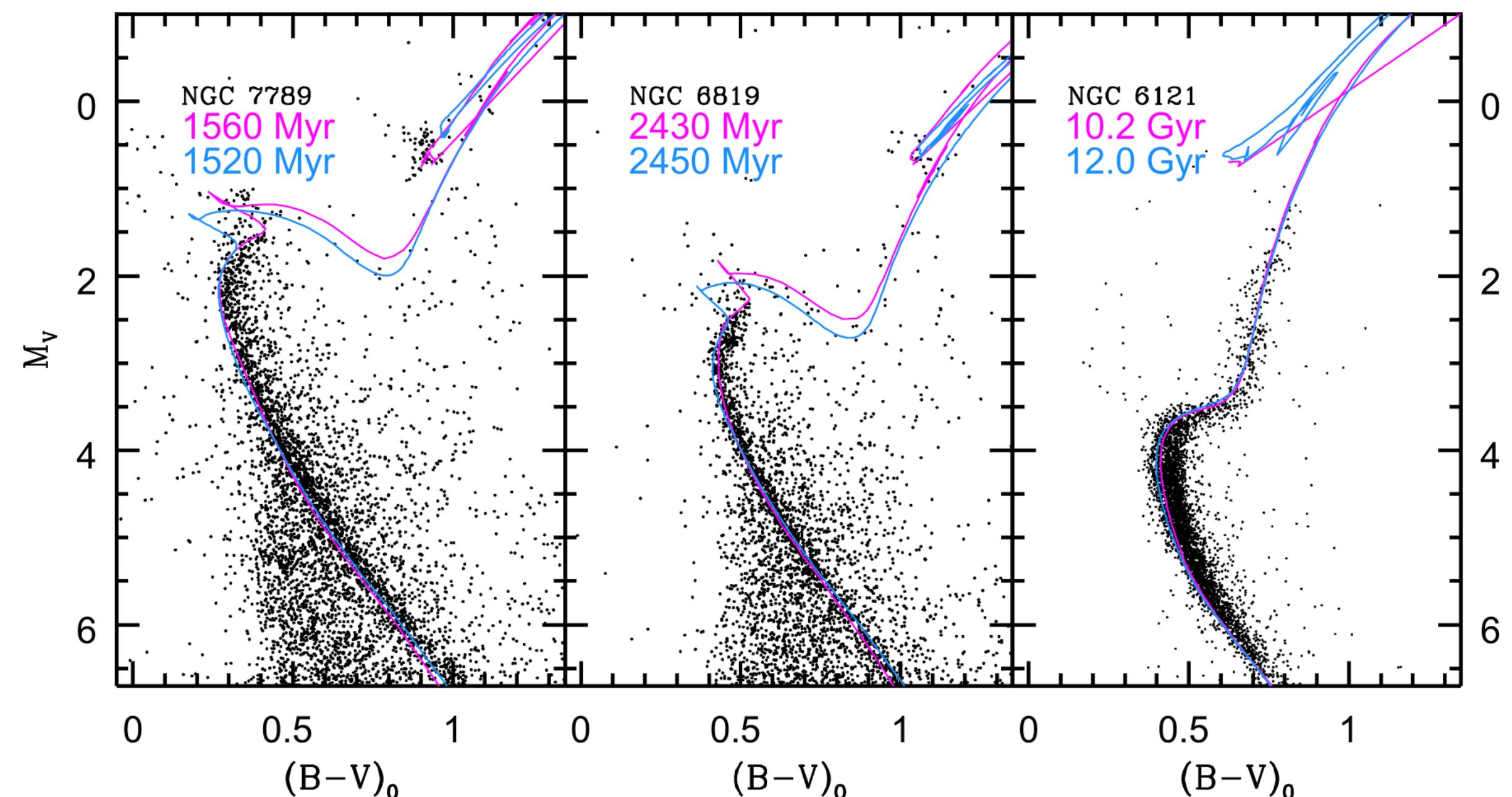
Cluster Identification

- Gaia is busting this field WIDE OPEN!
- Many competing papers in last 2 years doing searches for new clusters/ associations/groups
- Hundreds found!



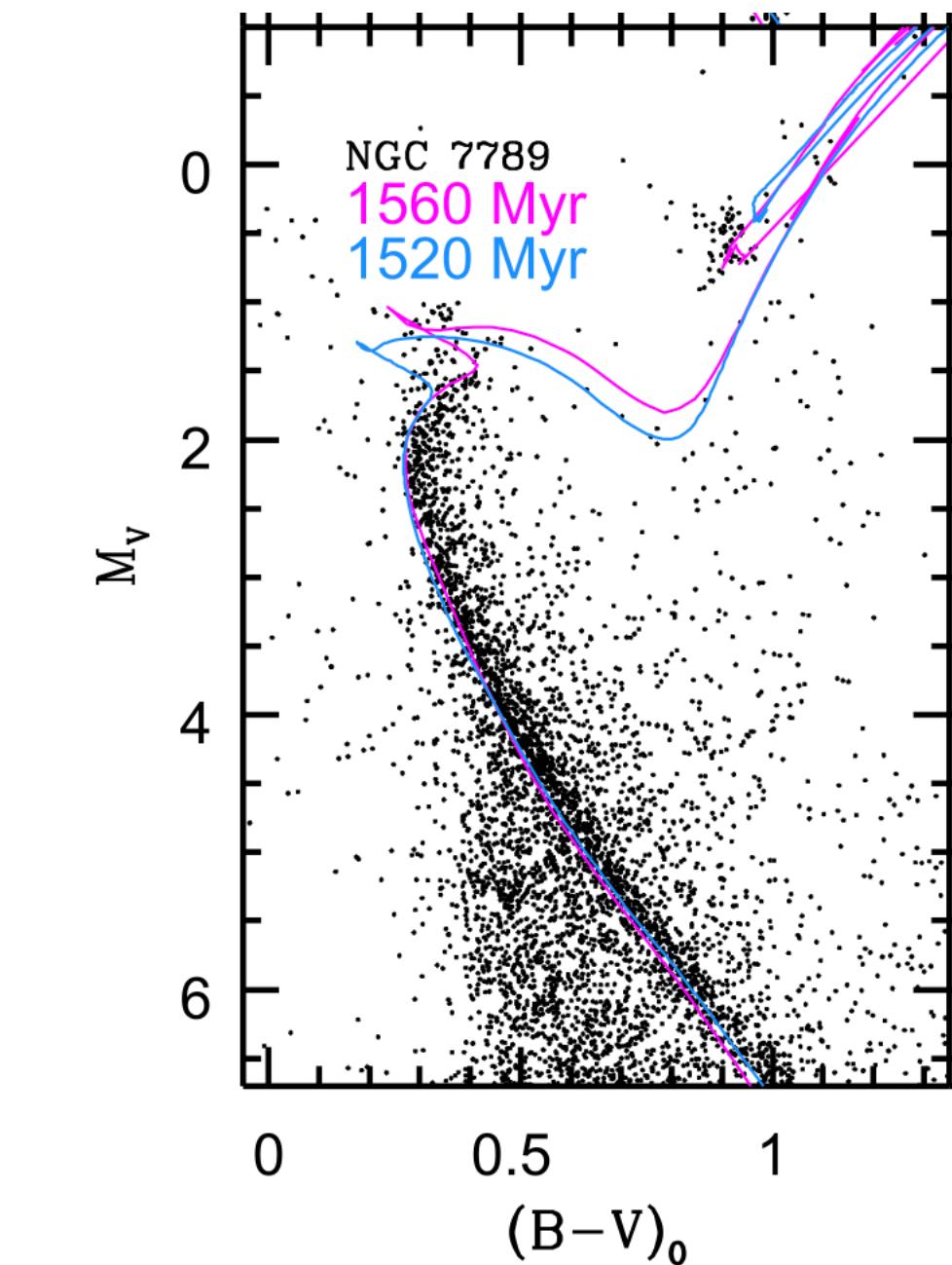
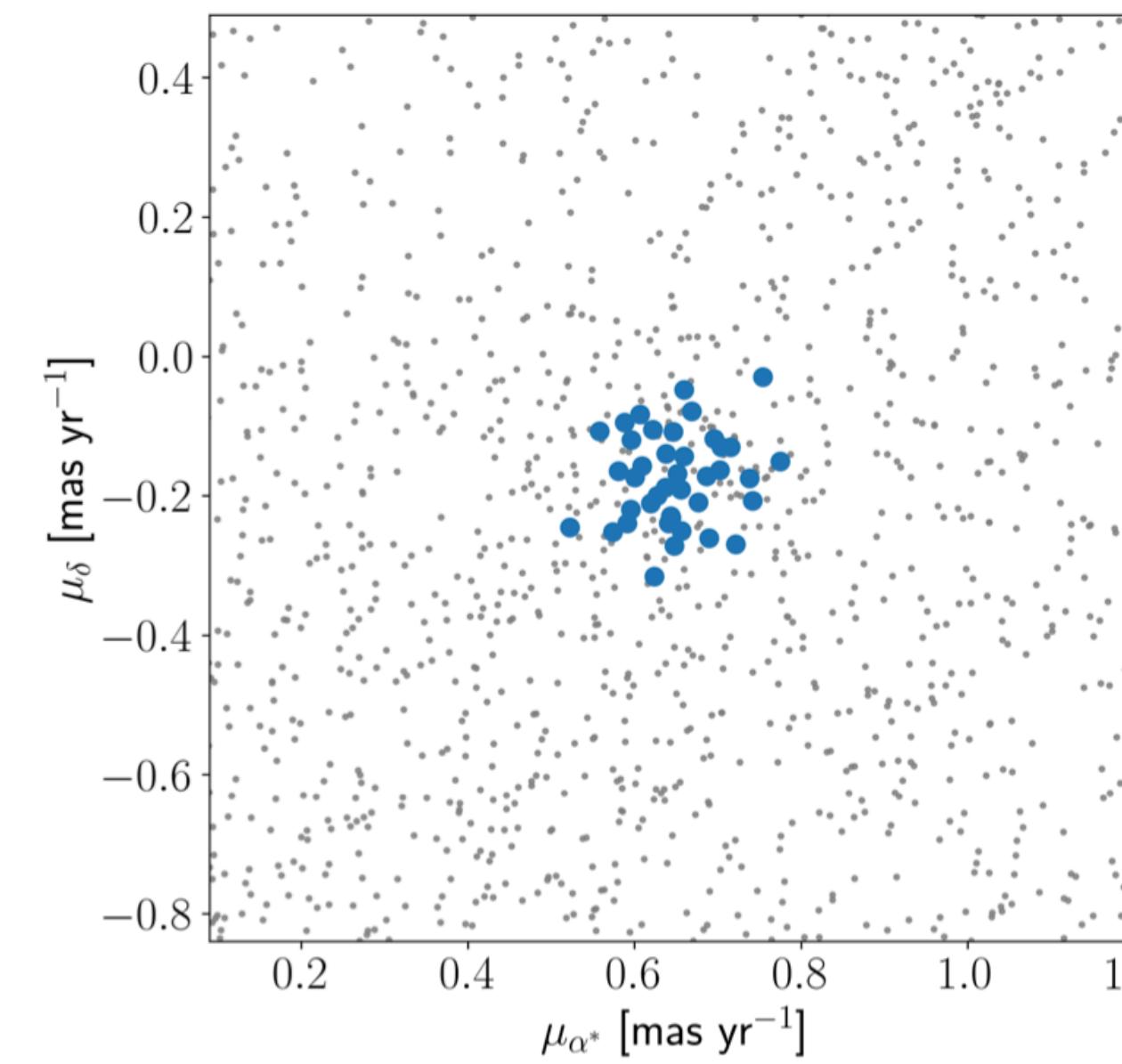
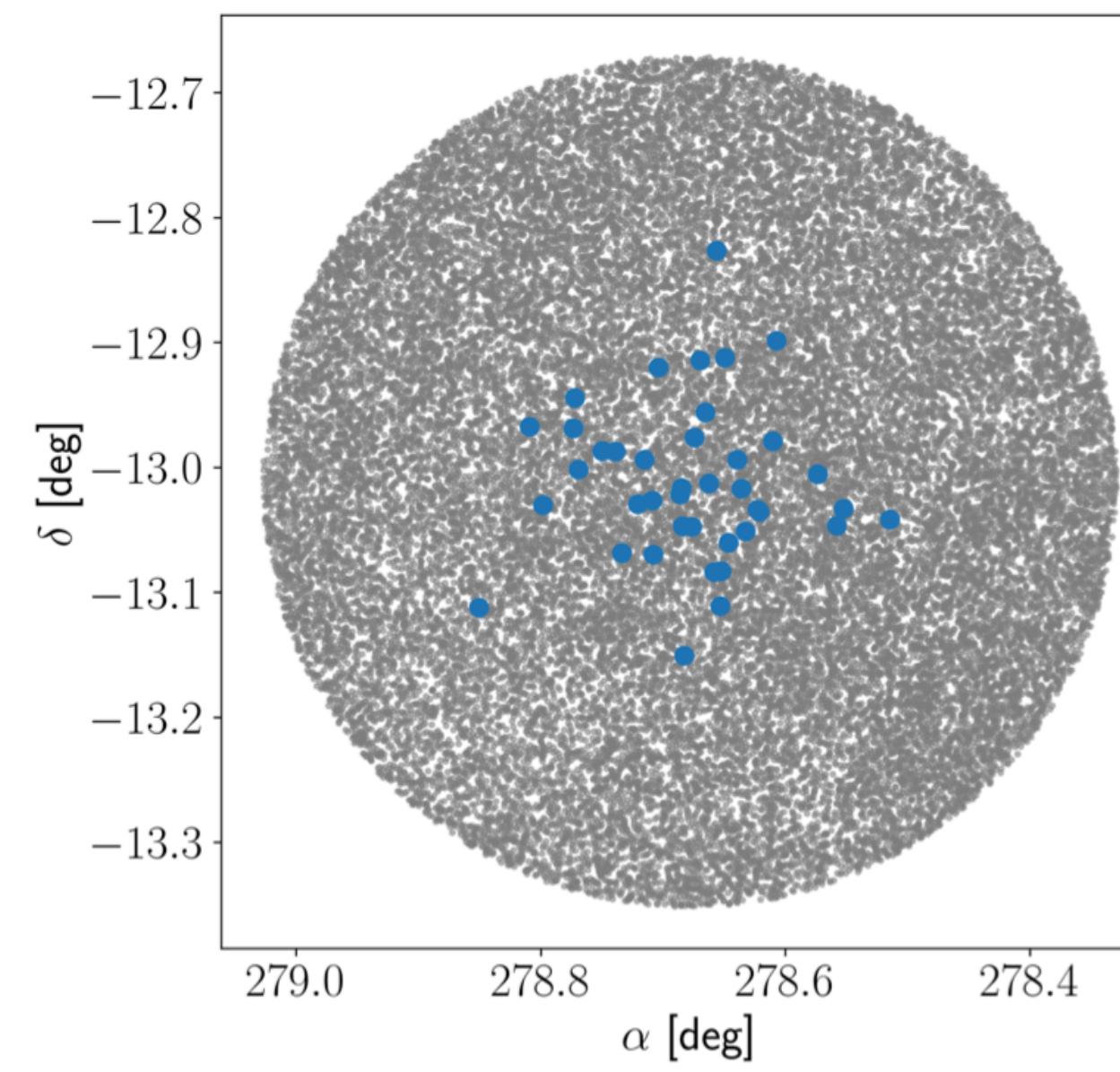
Isochrones

- Literally: Lines of Constant Age
- Based on stellar evolution & atmosphere models (e.g. MESA)
- “Grids” produced as useful model tracks as function of age, metallicity
 - And sometimes other physics too!
- Useful for identifying clusters AND characterizing them
 - e.g. measuring distance, extinction, age, mass, size...



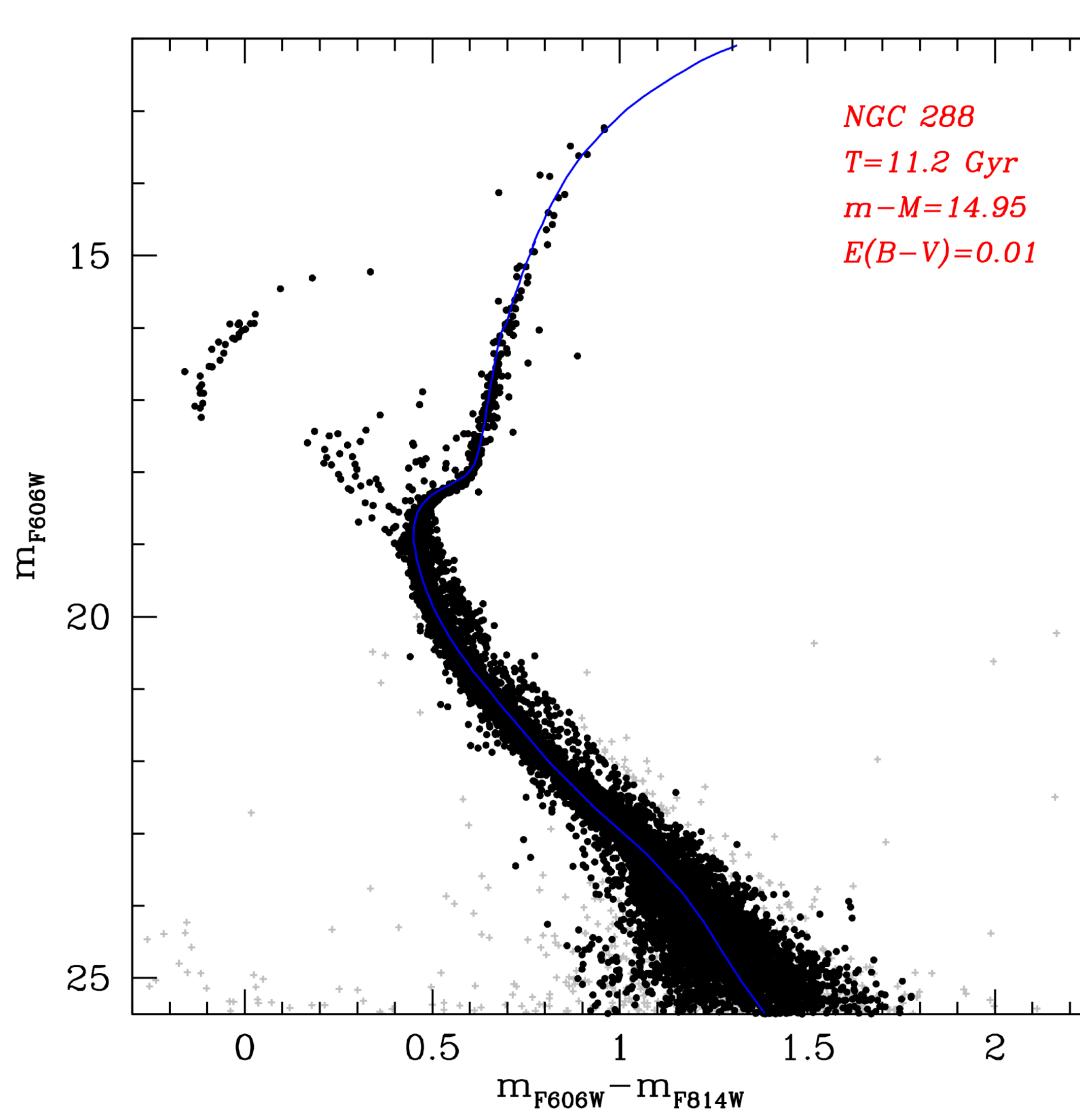
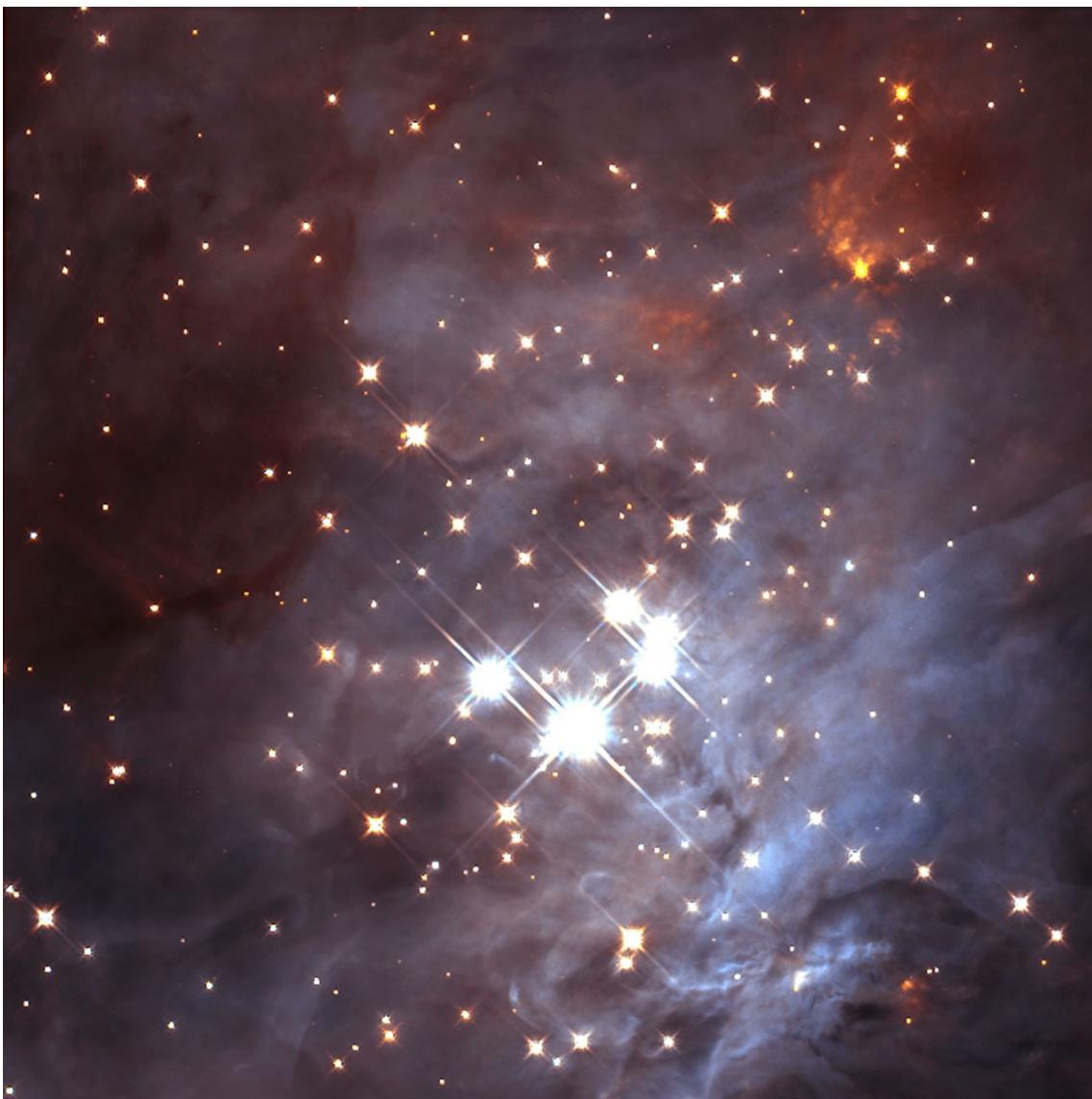
Clusters as Benchmarks

- Homework 2 now posted!
 - Your mission is to find and characterize a (known) open cluster using Gaia DR3 + Isochrones



Clusters Rock!

- The environment for star formation, the source of stars in galaxies
- Benchmarks for stars, planets, astrochemistry
- Interesting dynamics
- Touch almost every area of astronomy...



Next time:

- Mass & Luminosity Functions

