ASTR 511

Galactic Astronomy

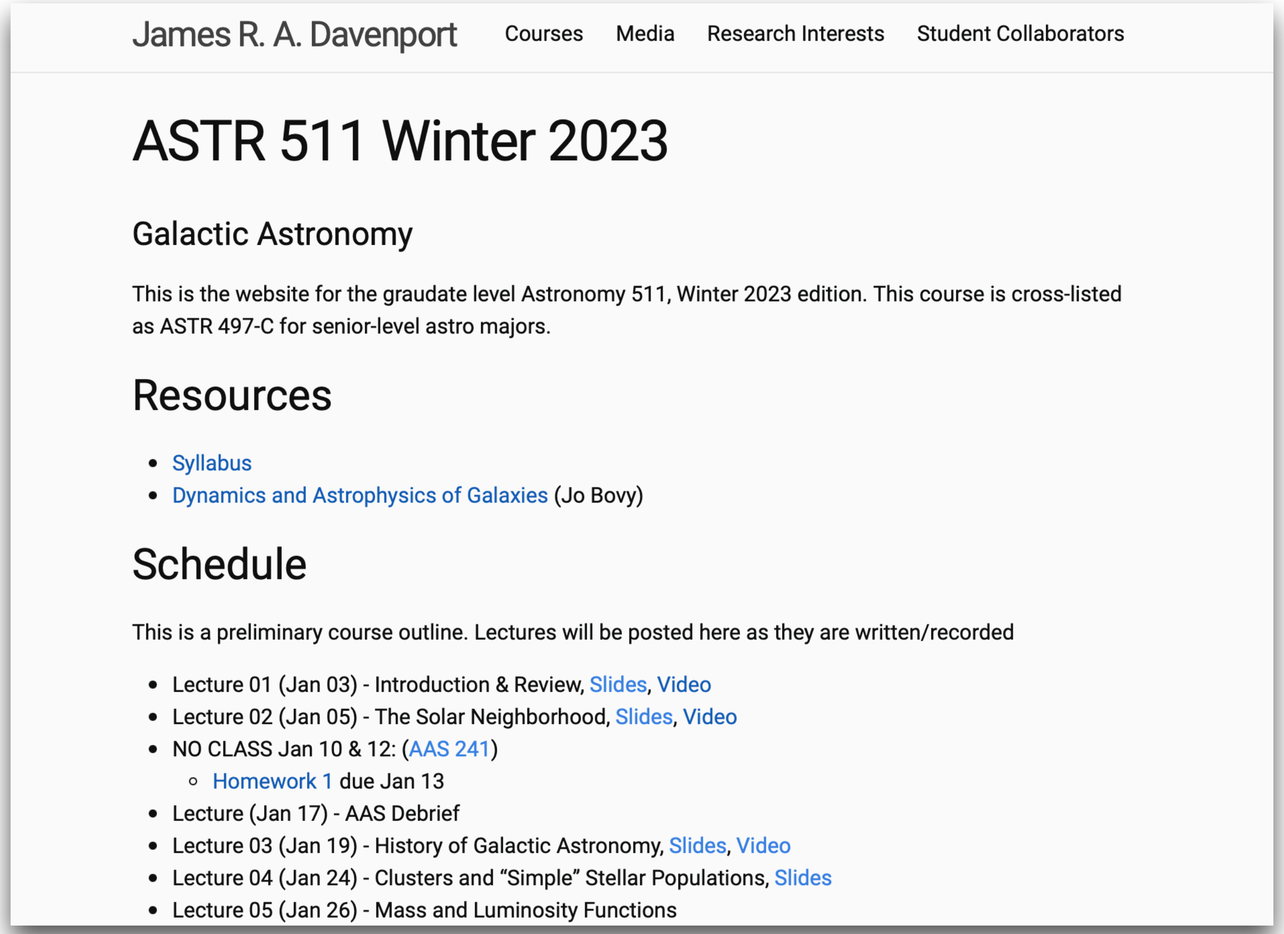
Lecture 04

Clusters & “Simple” Stellar Populations

Prof. James Davenport (UW)

Winter 2023

Reminder: materials on website!



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

ASTR 511 Winter 2023

Galactic Astronomy

This is the website for the graudate 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

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

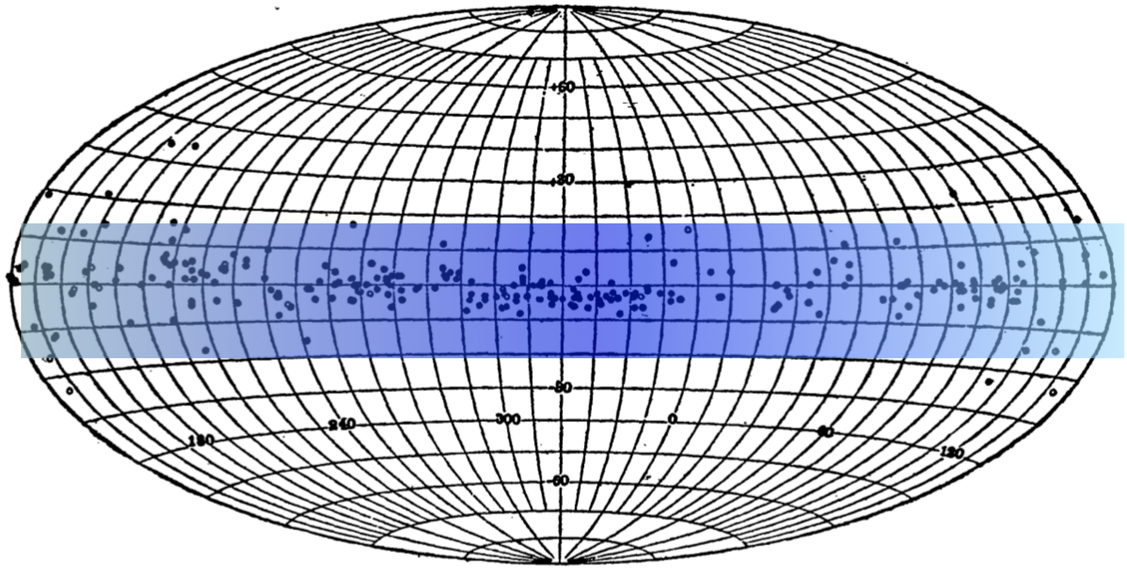


FIGURE II, 2.

Distribution of galactic clusters in galactic coordinates. Cluster classes are indicated as follows: c, ○; d, ⊕; e, ◑; f, ◒; g, ●.

globular clusters

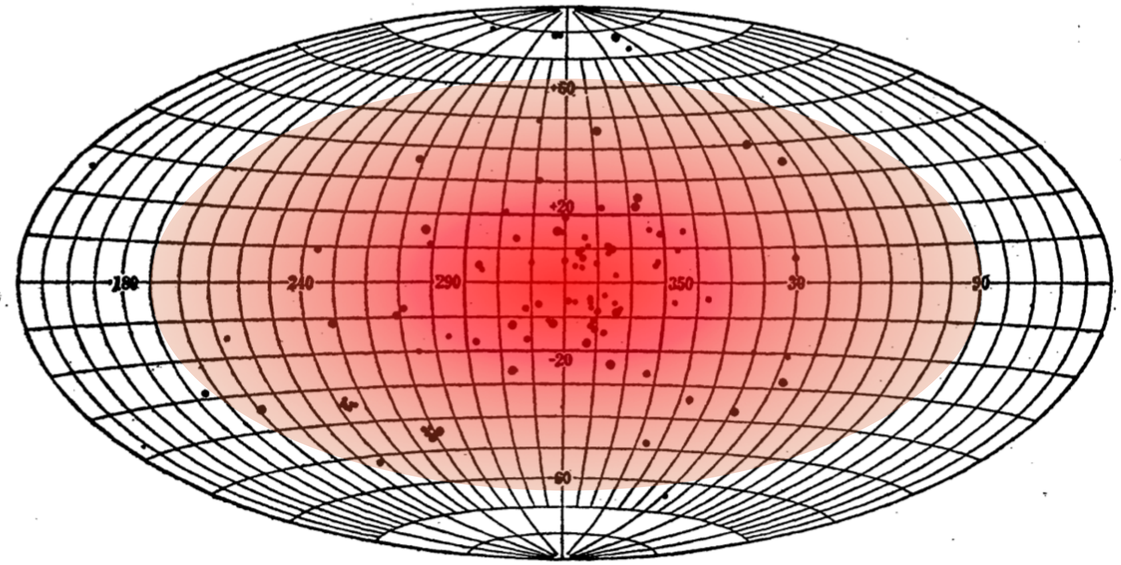


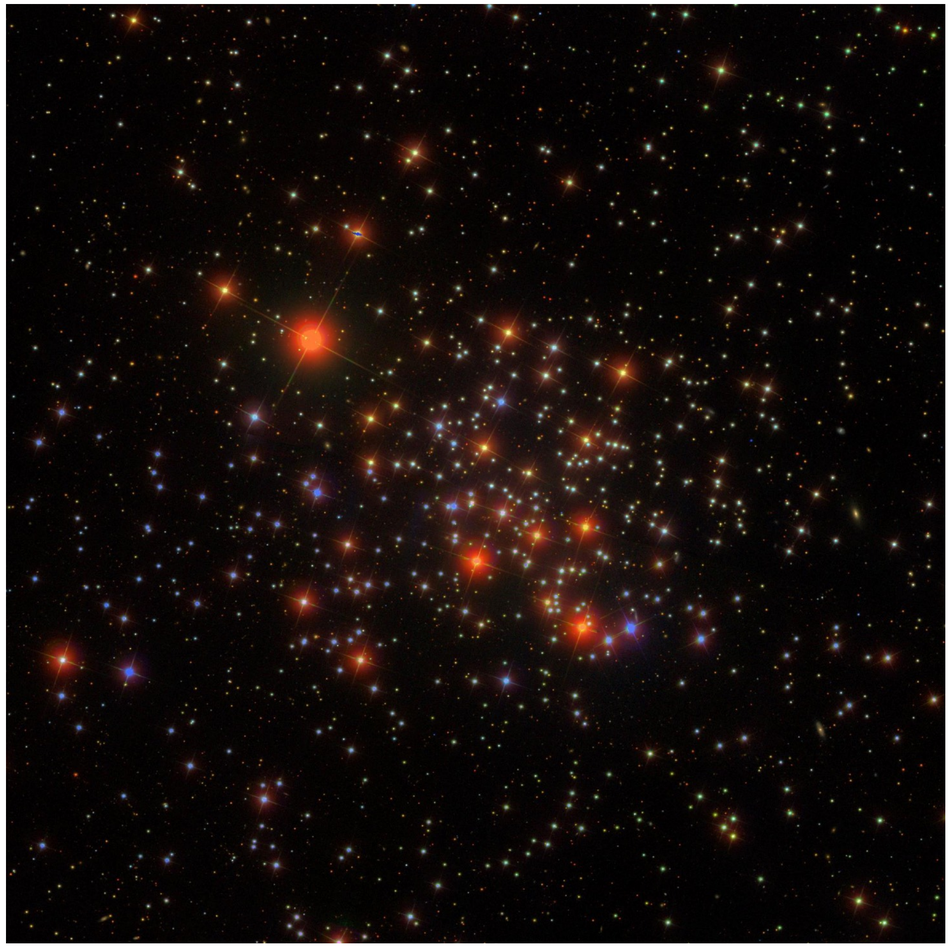
FIGURE II, 4.

Distribution of globular clusters in galactic coordinates.

Shapley (1930)

Clusters

open (“galactic”) clusters



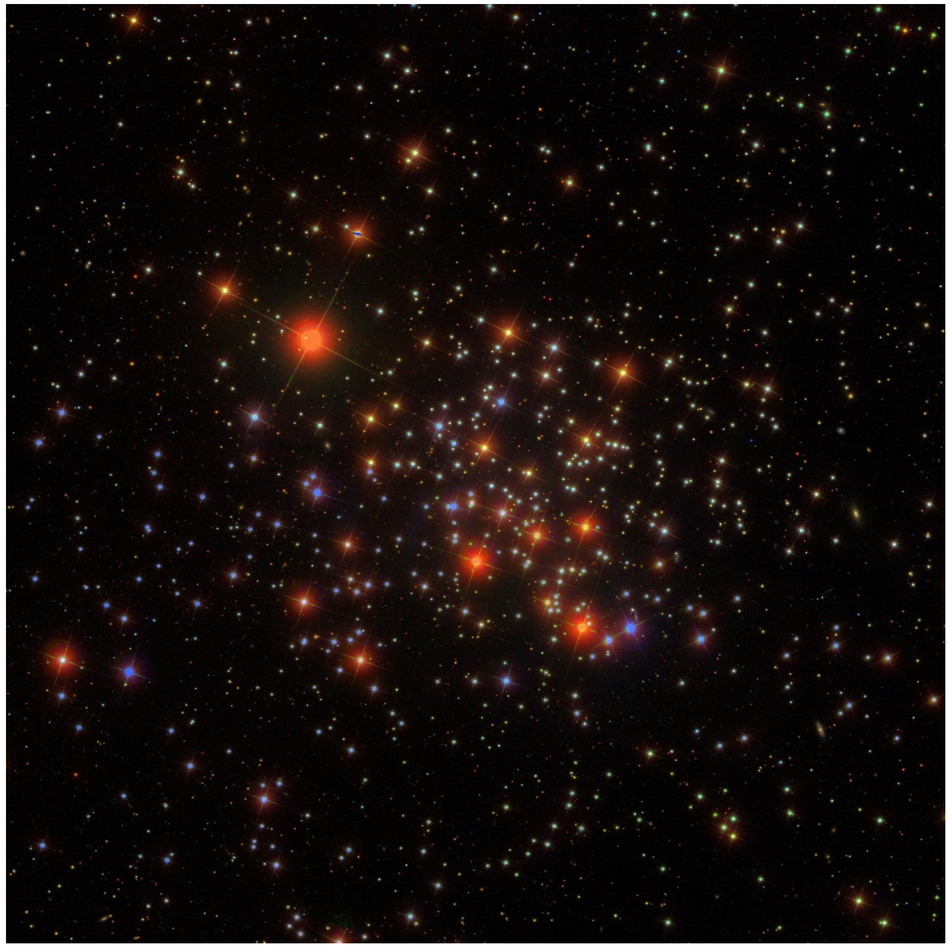
M 67

globular clusters

M 15

Clusters

open (“galactic”) clusters

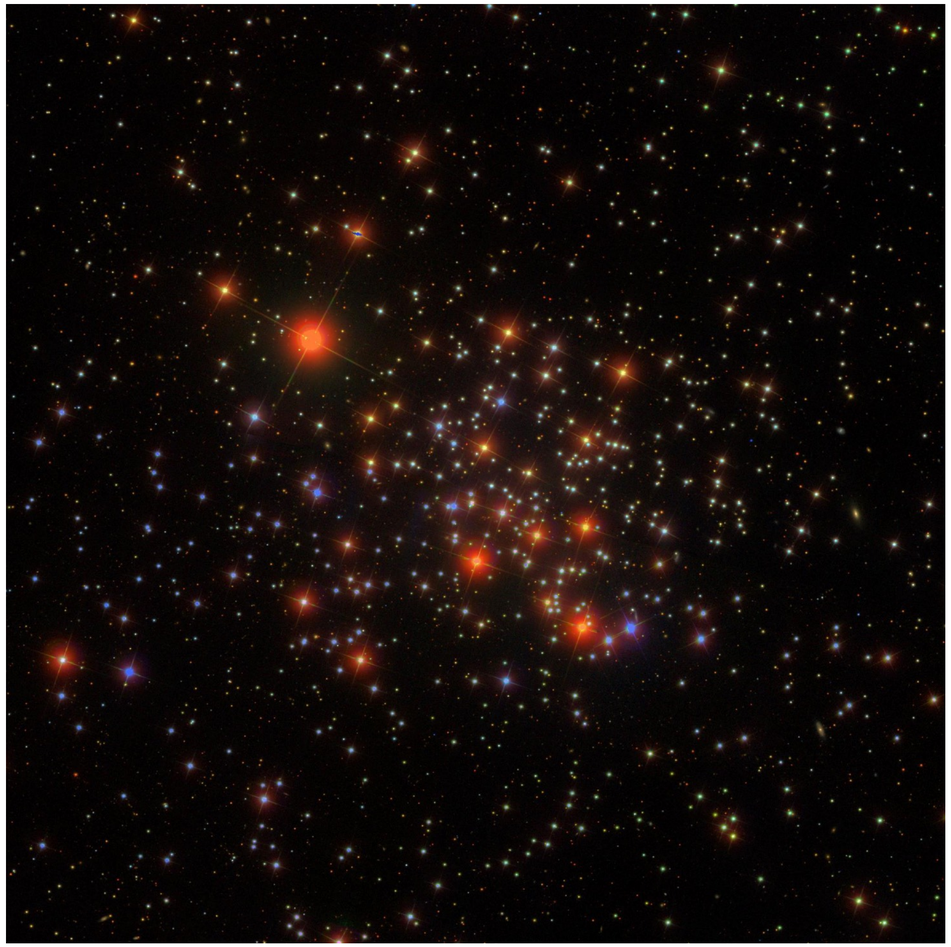


M 67

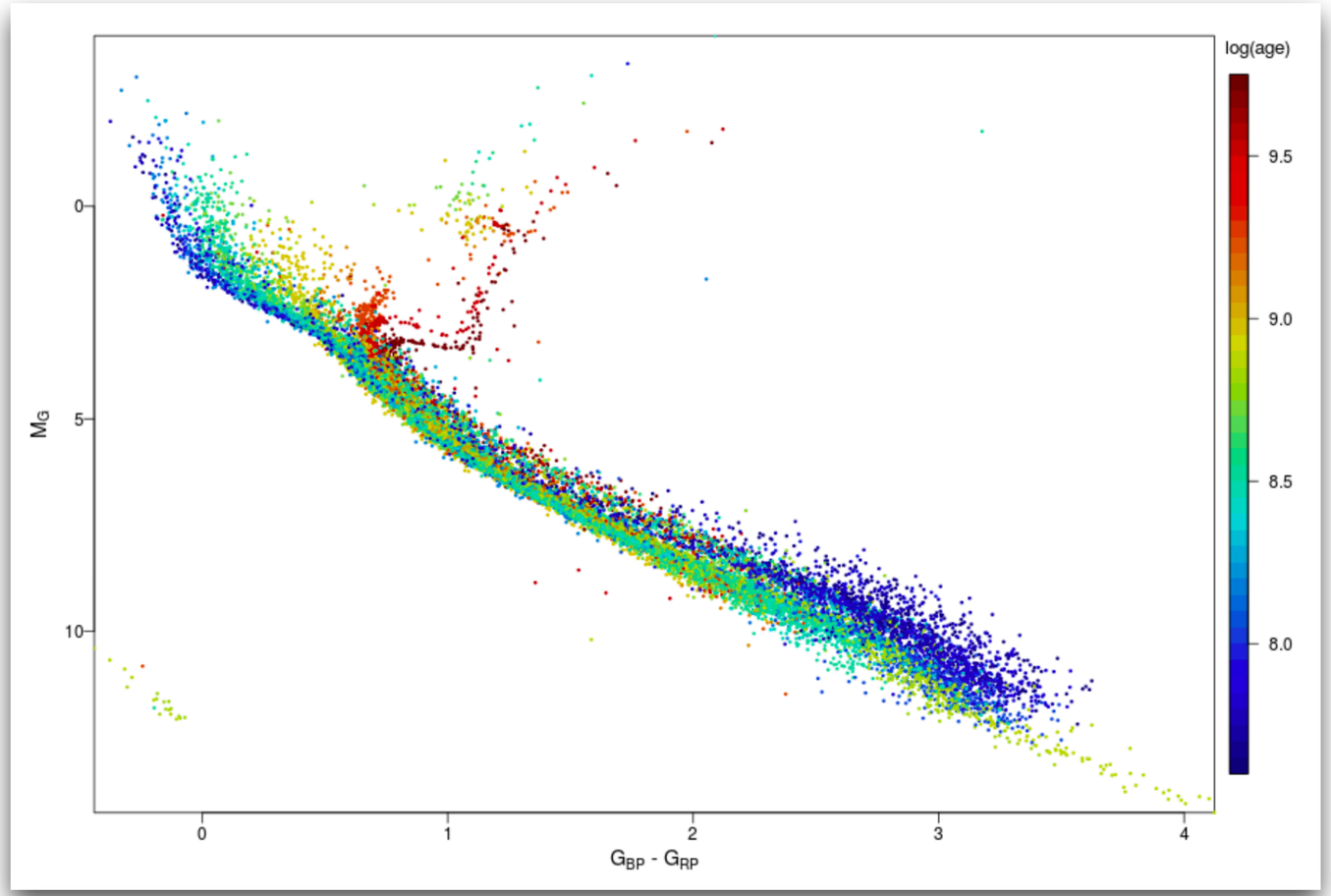
- Typically younger (usually up to 100’s of Myr, very few +Gyr)
- Sparse, can count the stars - look “open”
  - $10^0 - 10^3$ stars
- Found mostly in the galactic disk, usually fairly nearby (< few kpc)
- More metal rich
- Thousands of OC’s known in Milky Way
  - Gaia finding a LOT more…

Clusters

open (“galactic”) clusters



M 67



Gaia DR2

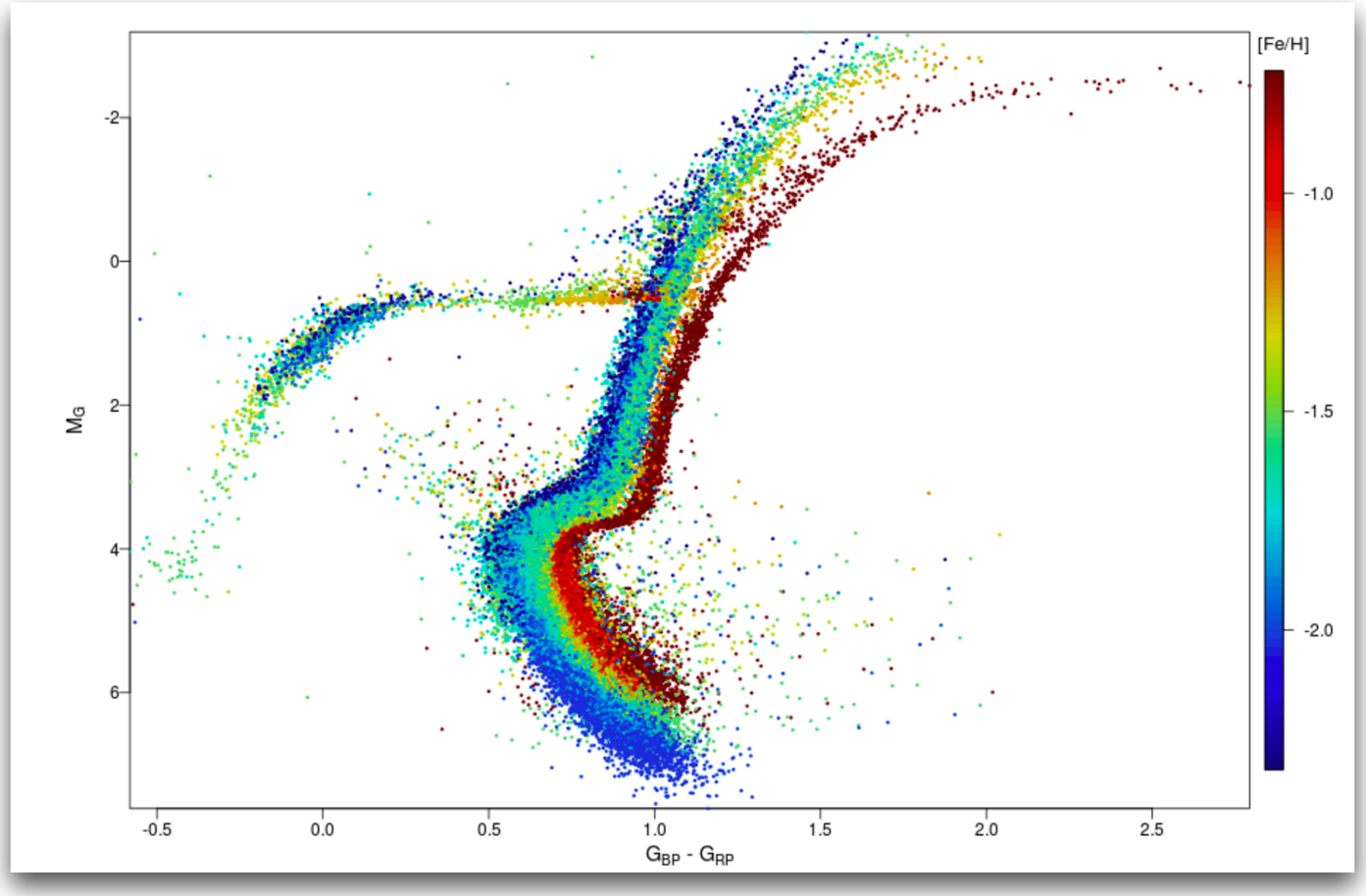
Clusters

- 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

M 15

Clusters



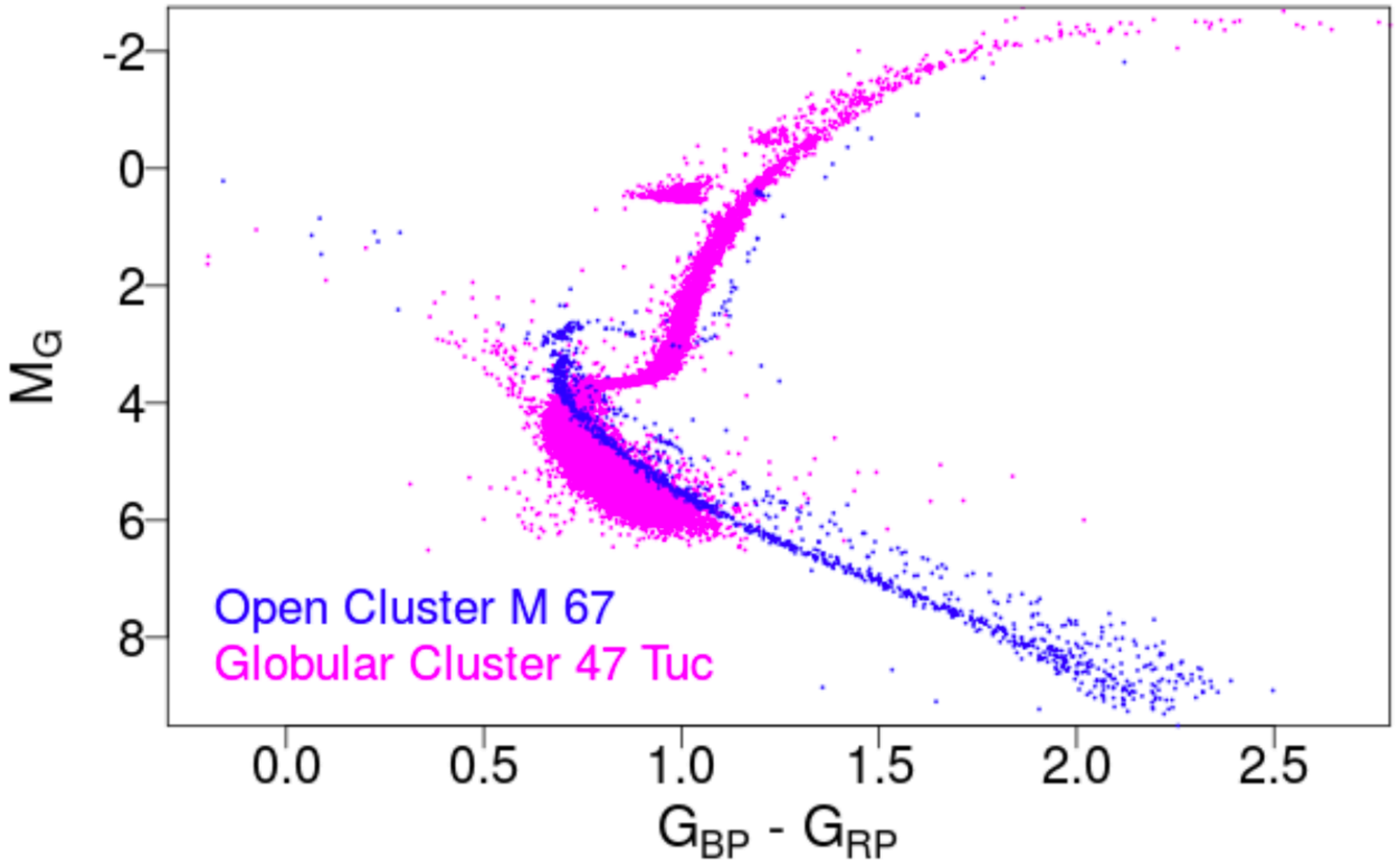
Gaia DR2

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

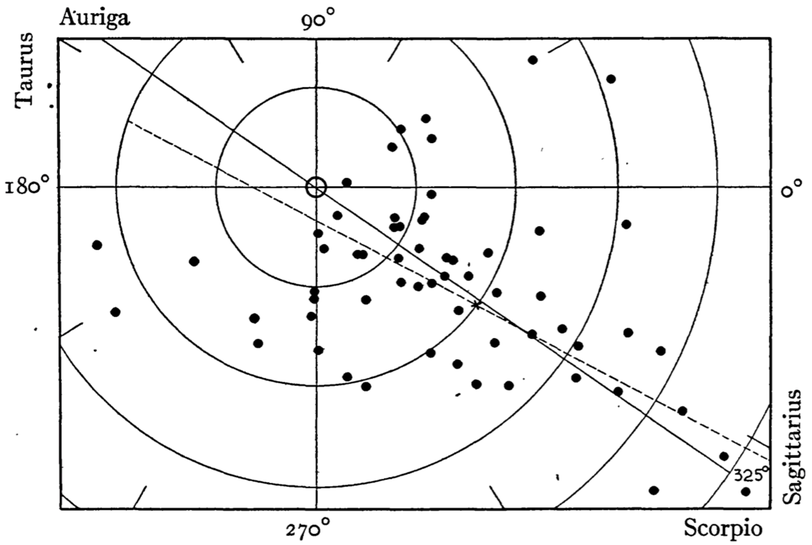
- Modeling formation is very challenging
  - Need to combine gas physics/feedback with stellar evolution and tidal dynamics in a dense environment!
  - Binary stars & multiple systems turn out to be VERY important (esp. for globular cluster survival)
  - N-body dynamics & external tidal stripping change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

Cluster Formation

https://www.cfca.nao.ac.jp/en/pr/20220608

Clusters as a Benchmark

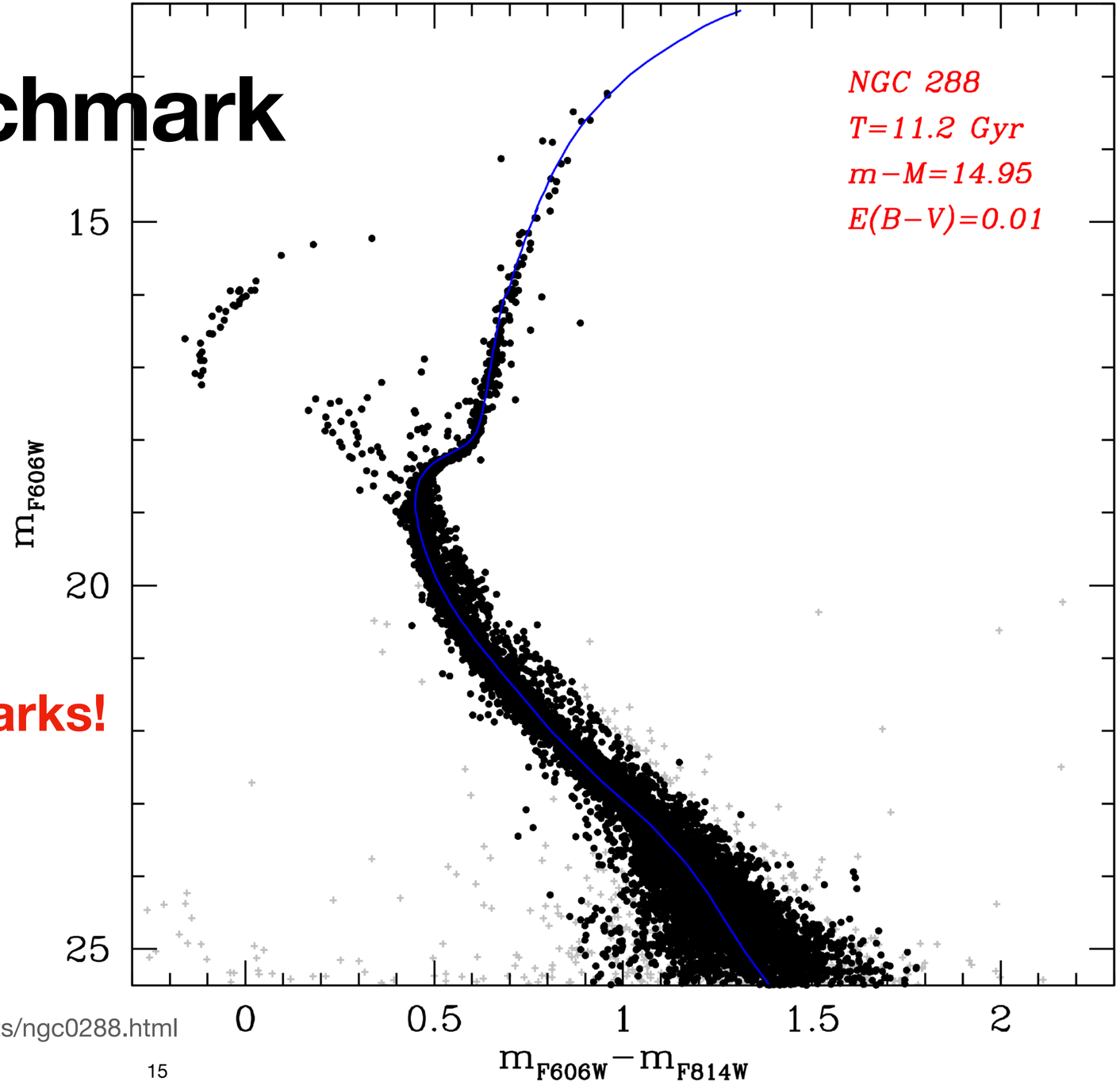
- Talked last time about clusters as key to “great debate” type things
- “Simple Stellar Population” model is key takeaway here
  - Clusters are considered the ultimate benchmark test for stellar evolution, anchor EVERYTHING!
  - We’re STILL testing all areas of stellar astrophysics w/ clusters, trying 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!**



https://people.smp.uq.edu.au/HolgerBaumgardt/globular/fits/ngc0288.html

This simple story is only true to first order

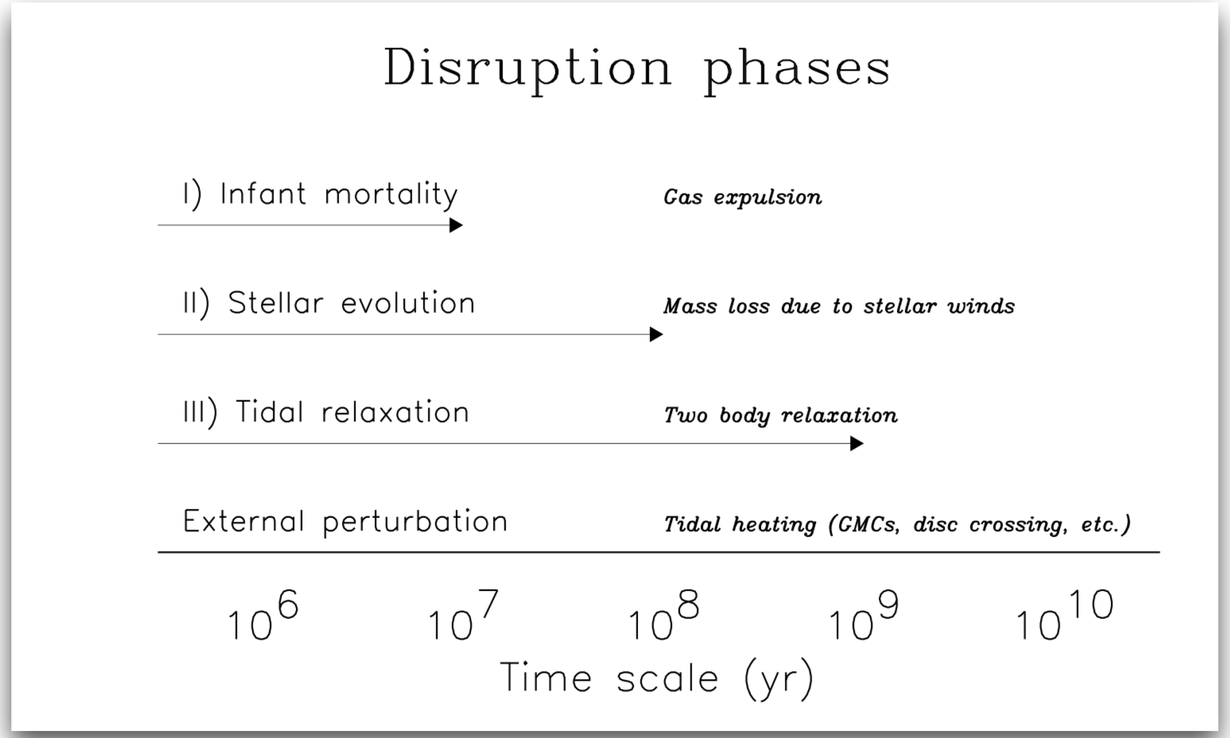
Some Problems to Clusters as Benchmarks…

- 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

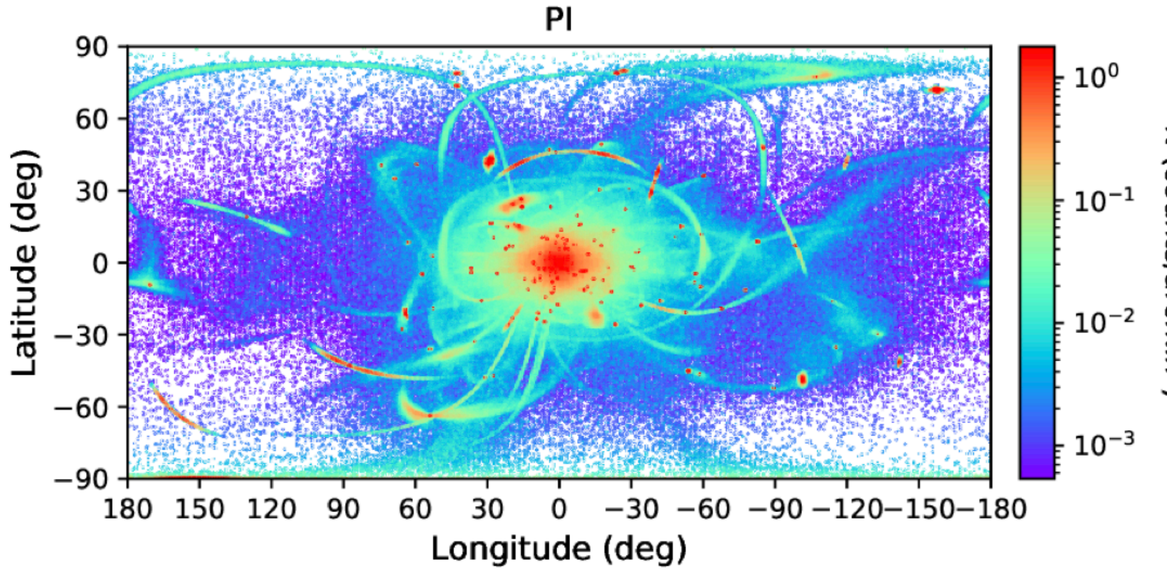


60-90% of clusters are destroyed

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)



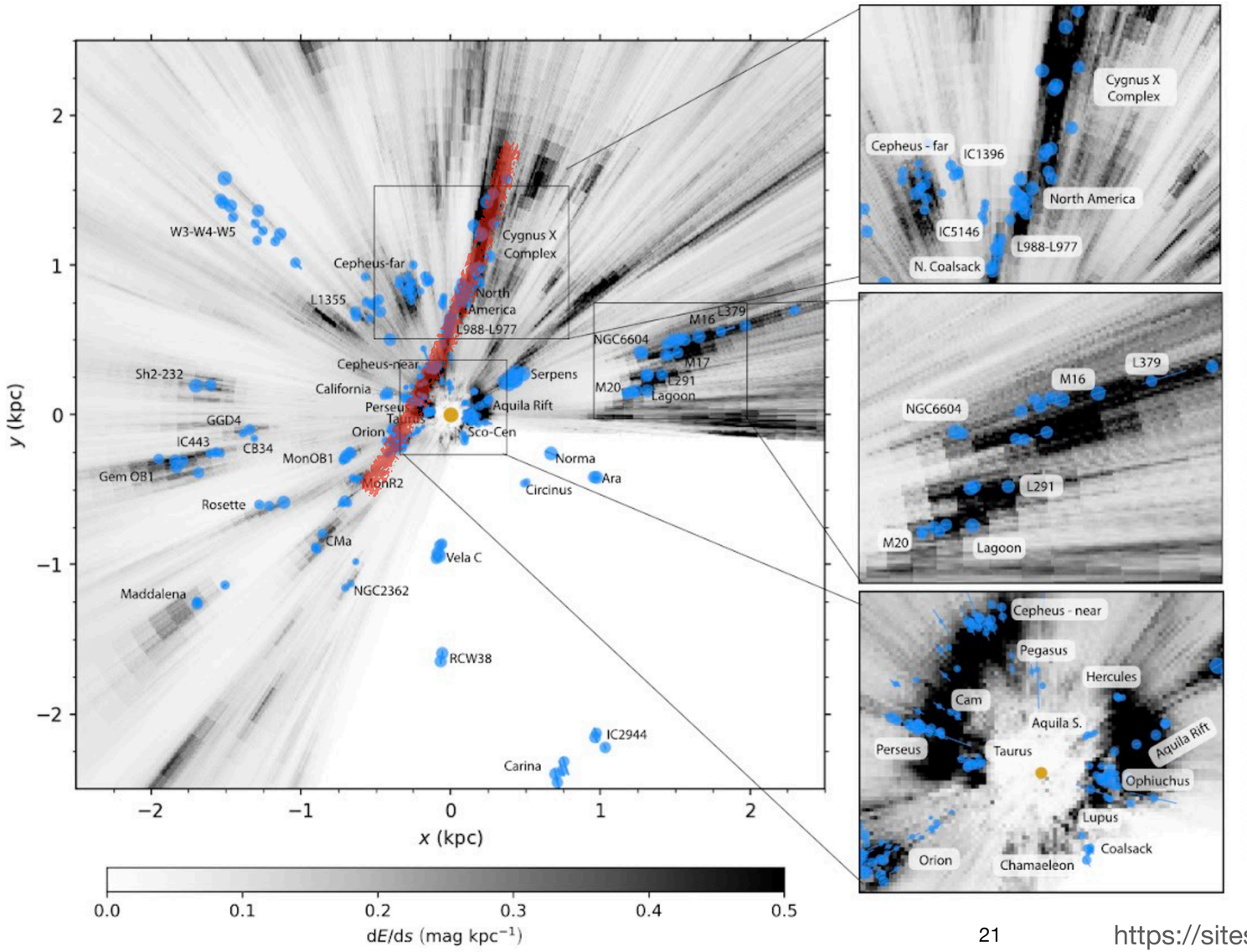
Ferrone+2023

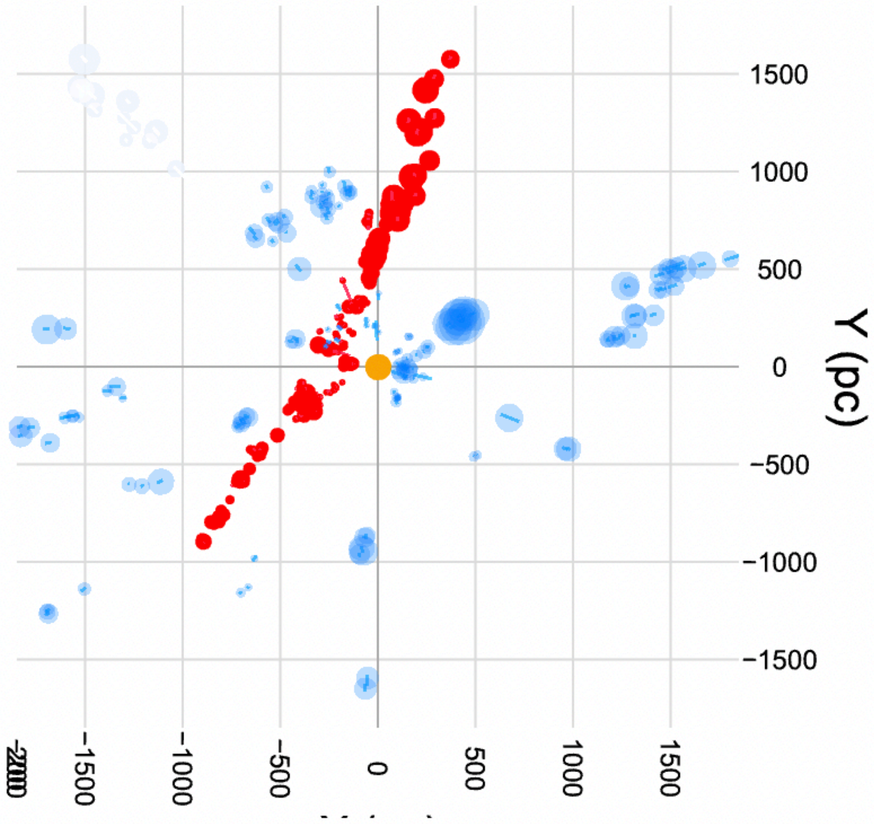
From Lecture 2

$d < 500\text{pc}$

“Radcliffe Wave”
C. Zucker+2020

Long line of star forming regions



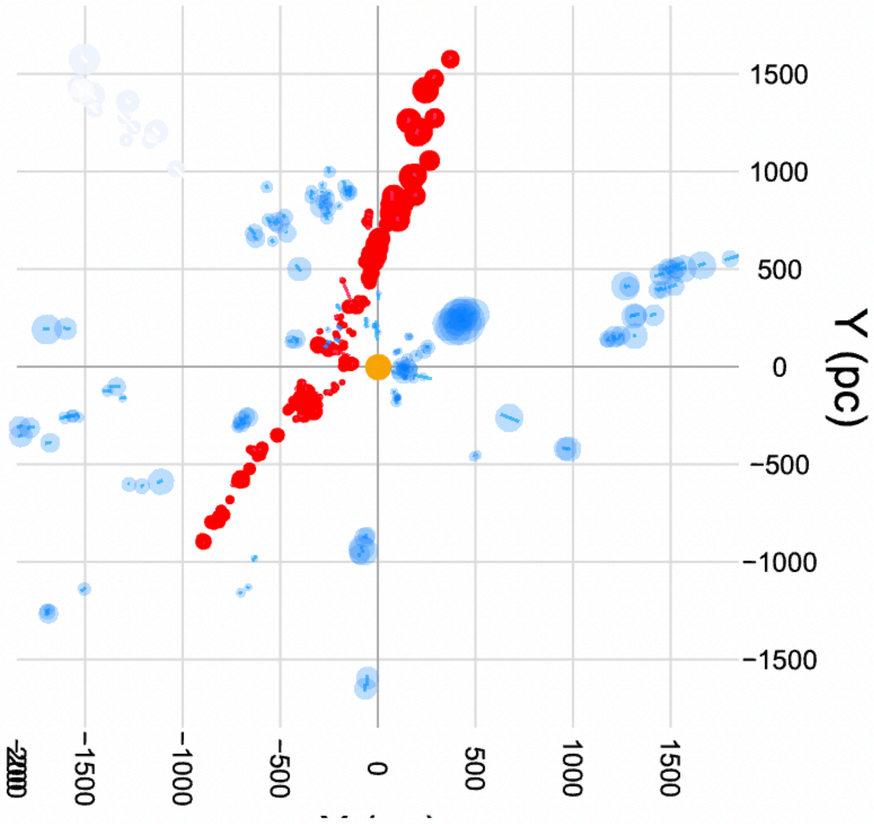


https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

“Radcliffe Wave”
C. Zucker+2020

Long line of star forming regions

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

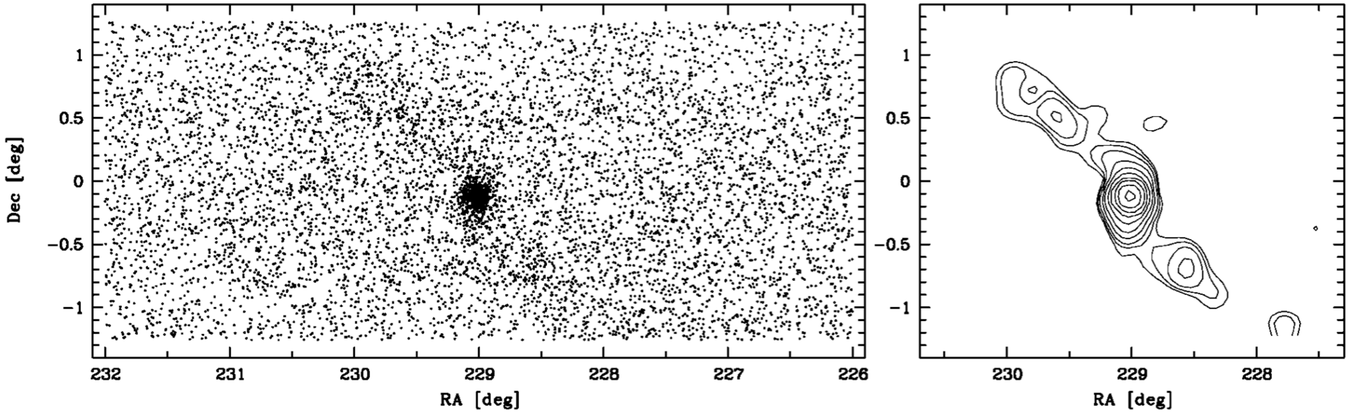


https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

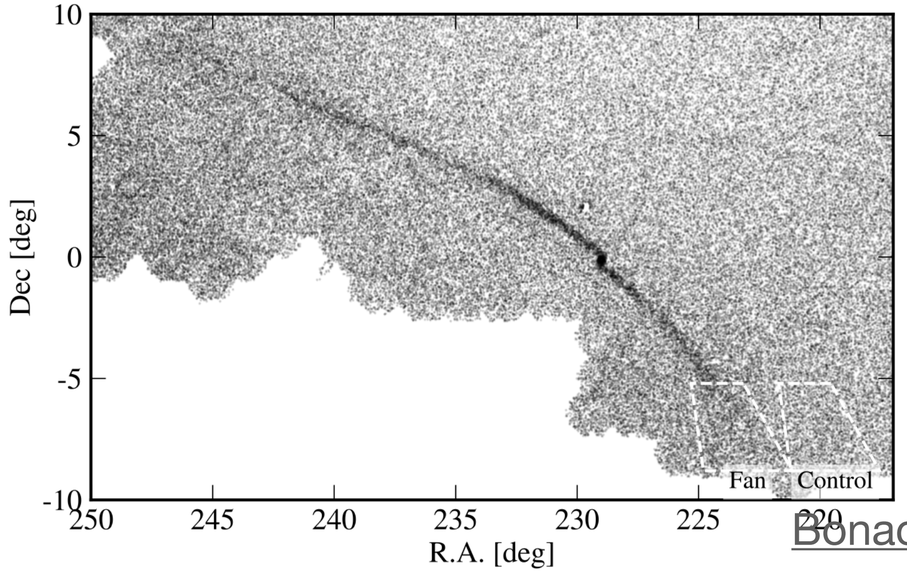
Tidal Tails/Streams

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

Odenkirchen+2001



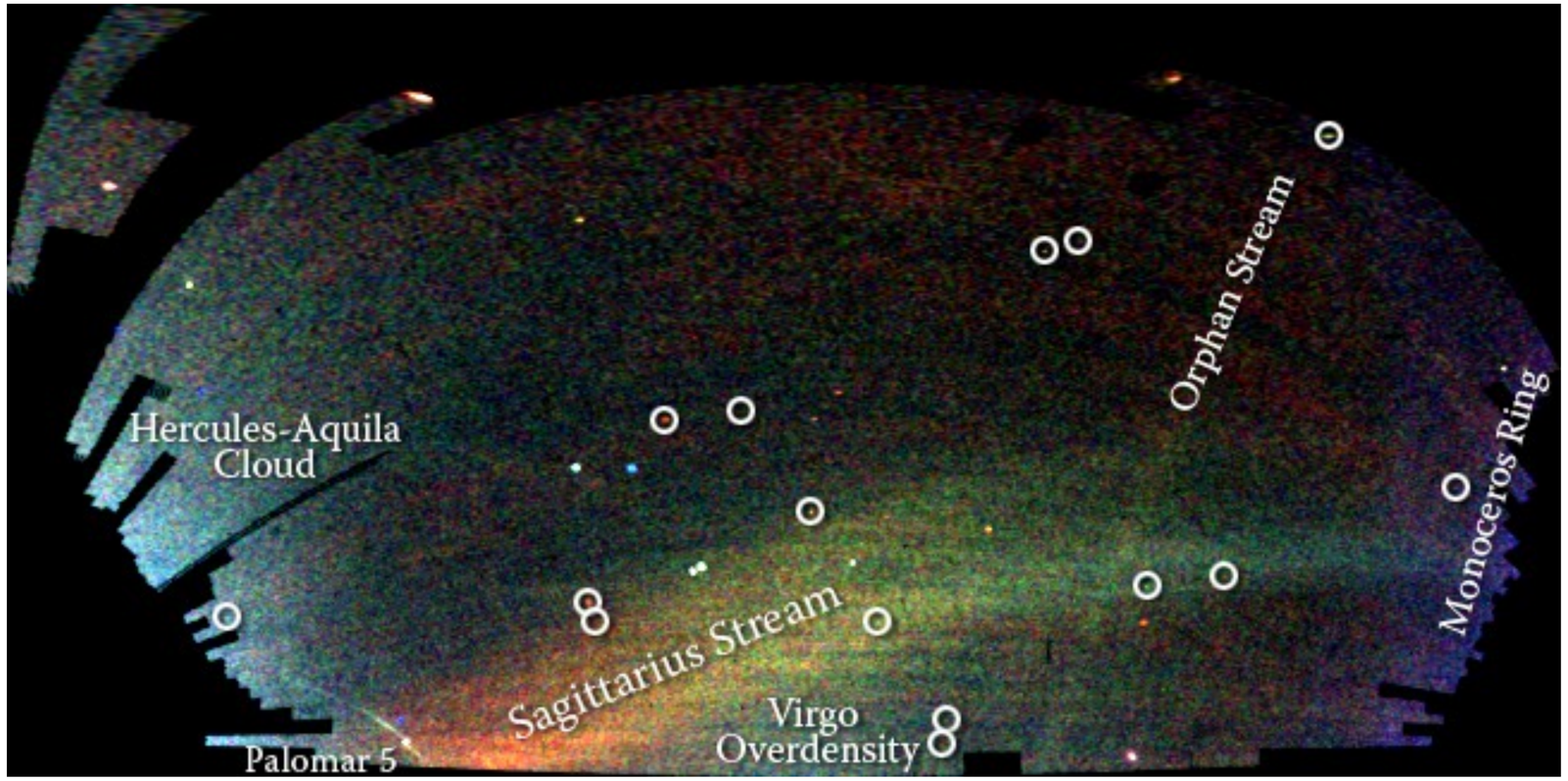
- Now traced over 20kpc (and 30 deg)!



Bonaca+2019

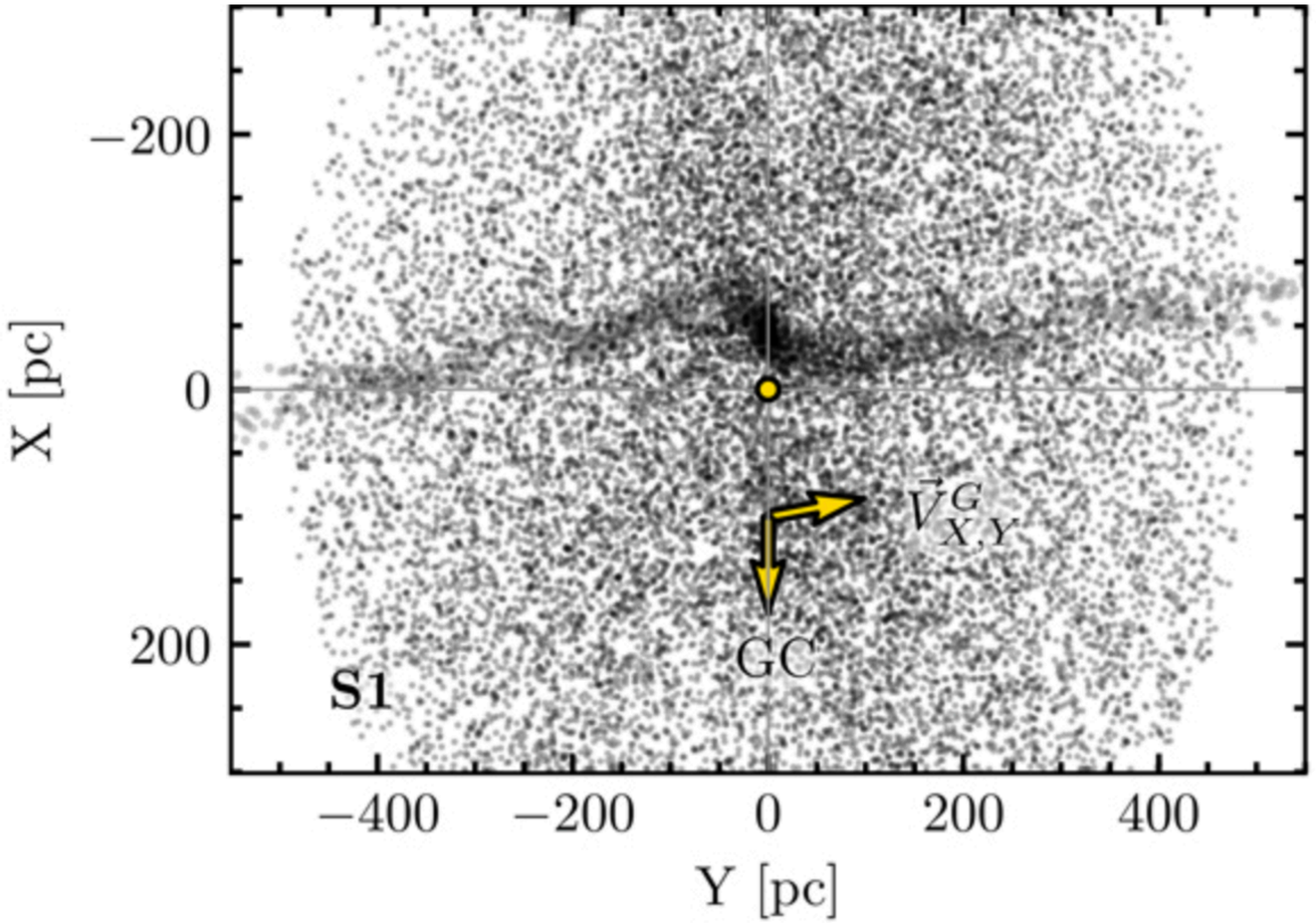
Tidal Tails/Streams

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

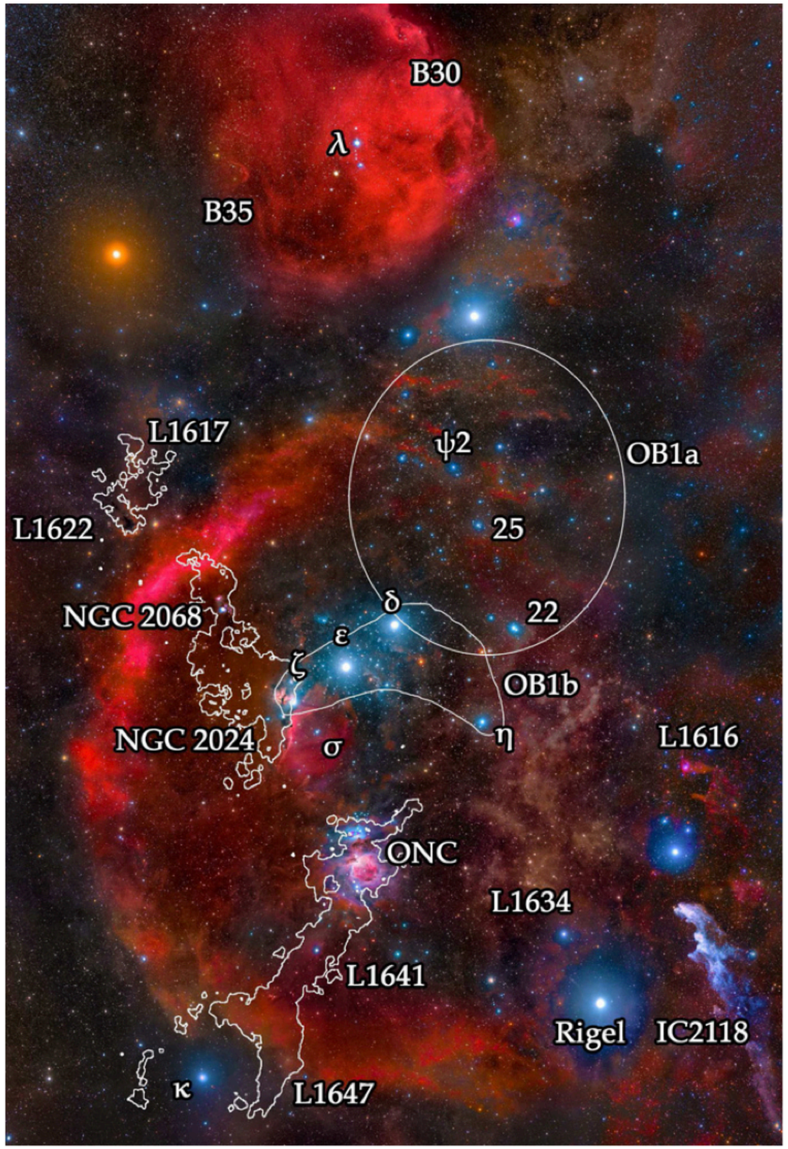


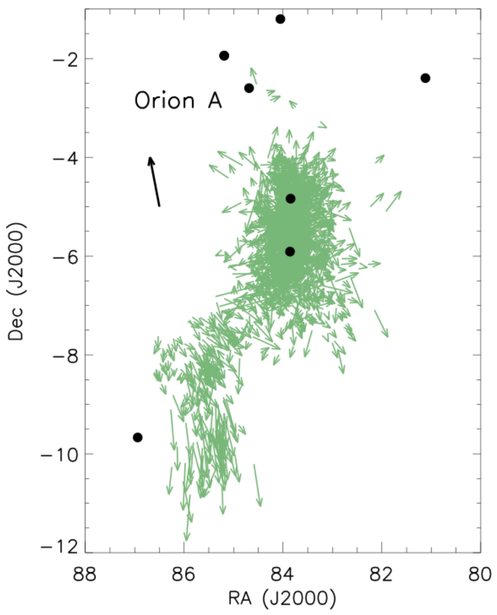
Tidal Tails/Streams

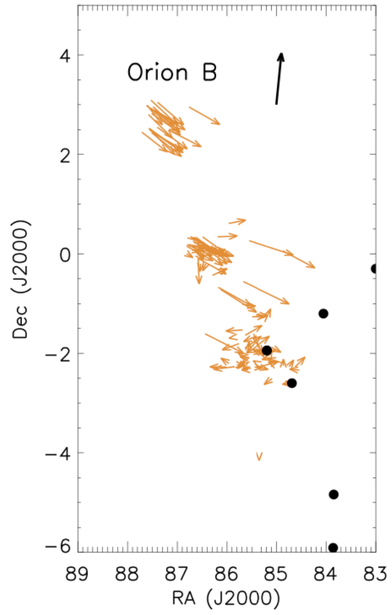
- Open clusters have them too!
- Hyades has 800 pc tails?!
  - Jerabkova+2021
- Older open clusters (e.g. M67) have been searched as well…

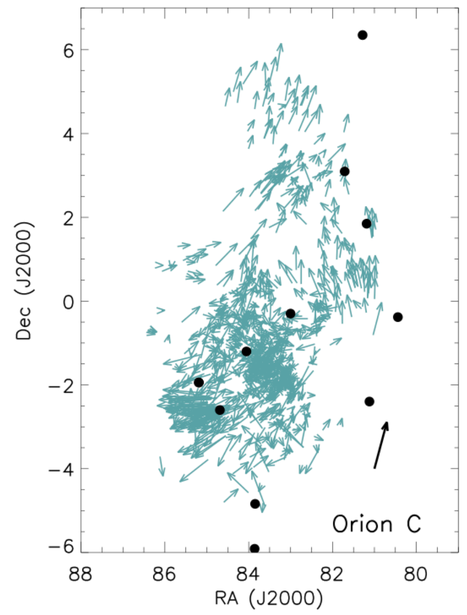


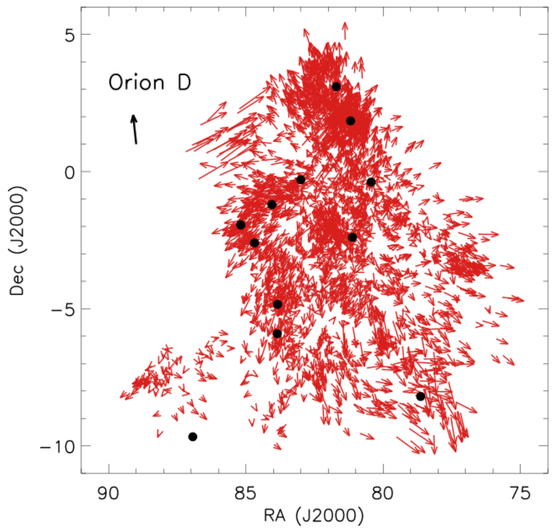
Cluster Age Spread

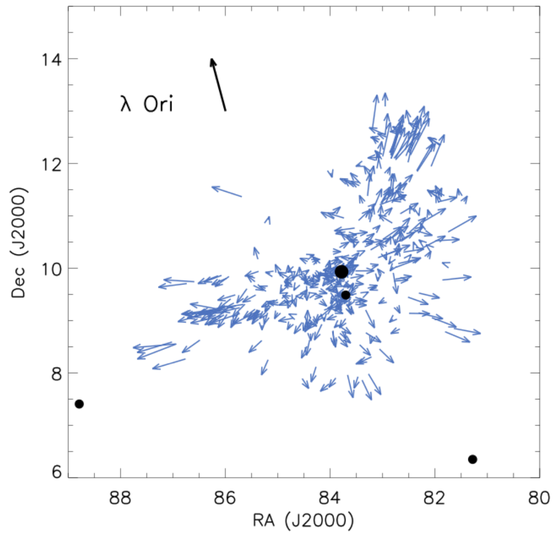












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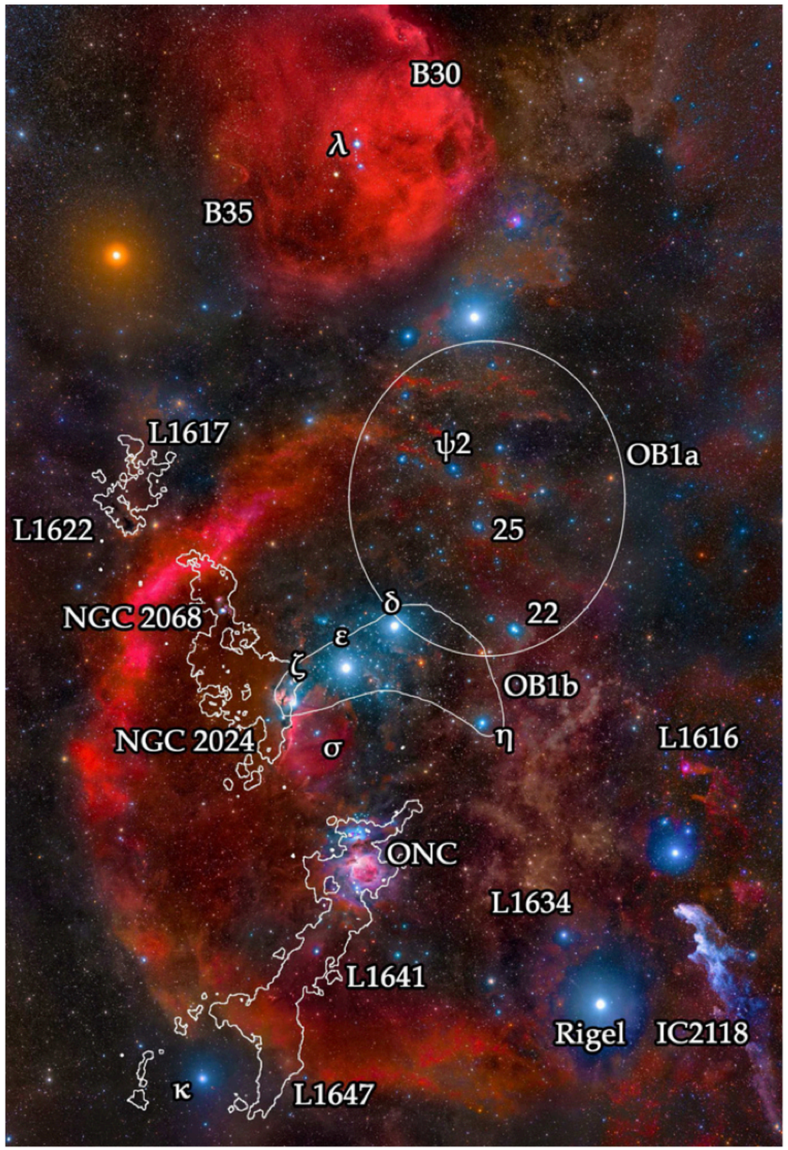
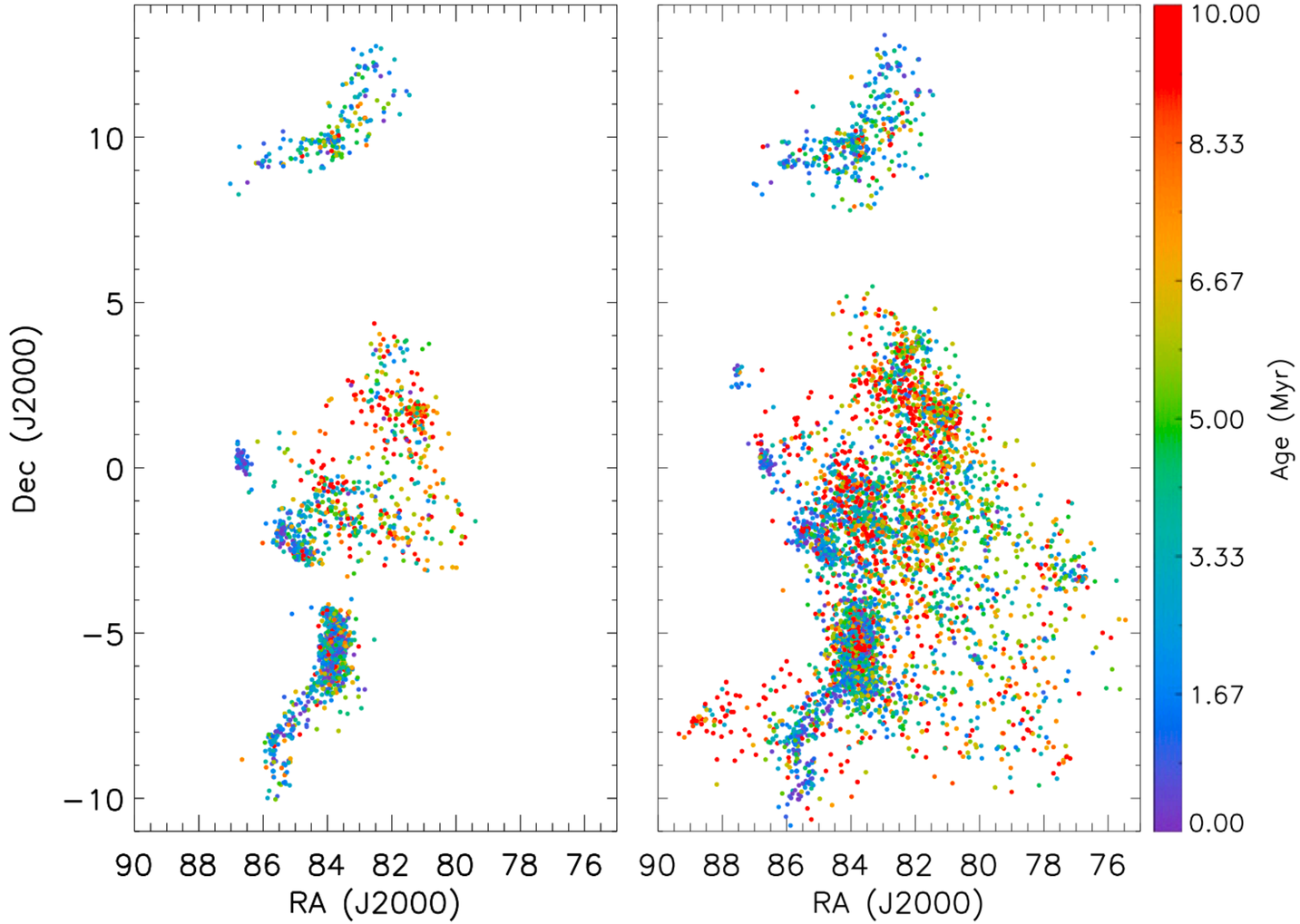
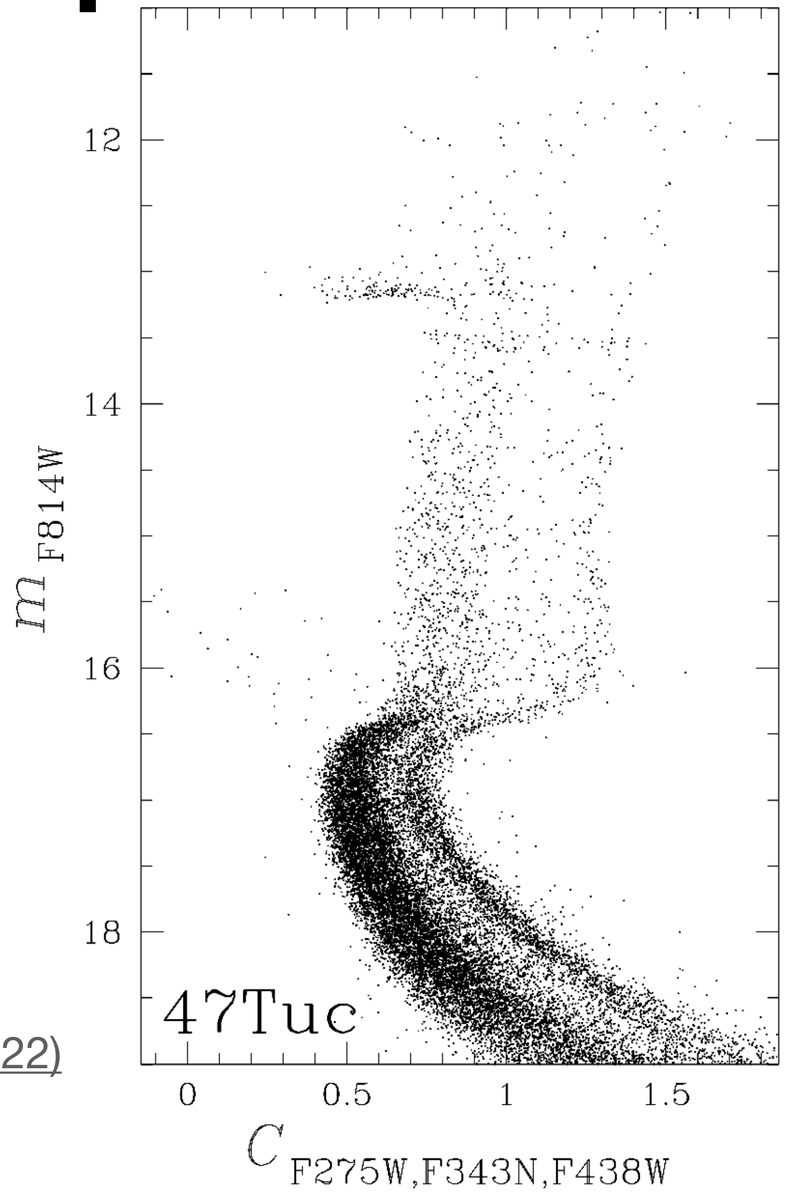




Clusters NOT simple stellar pops

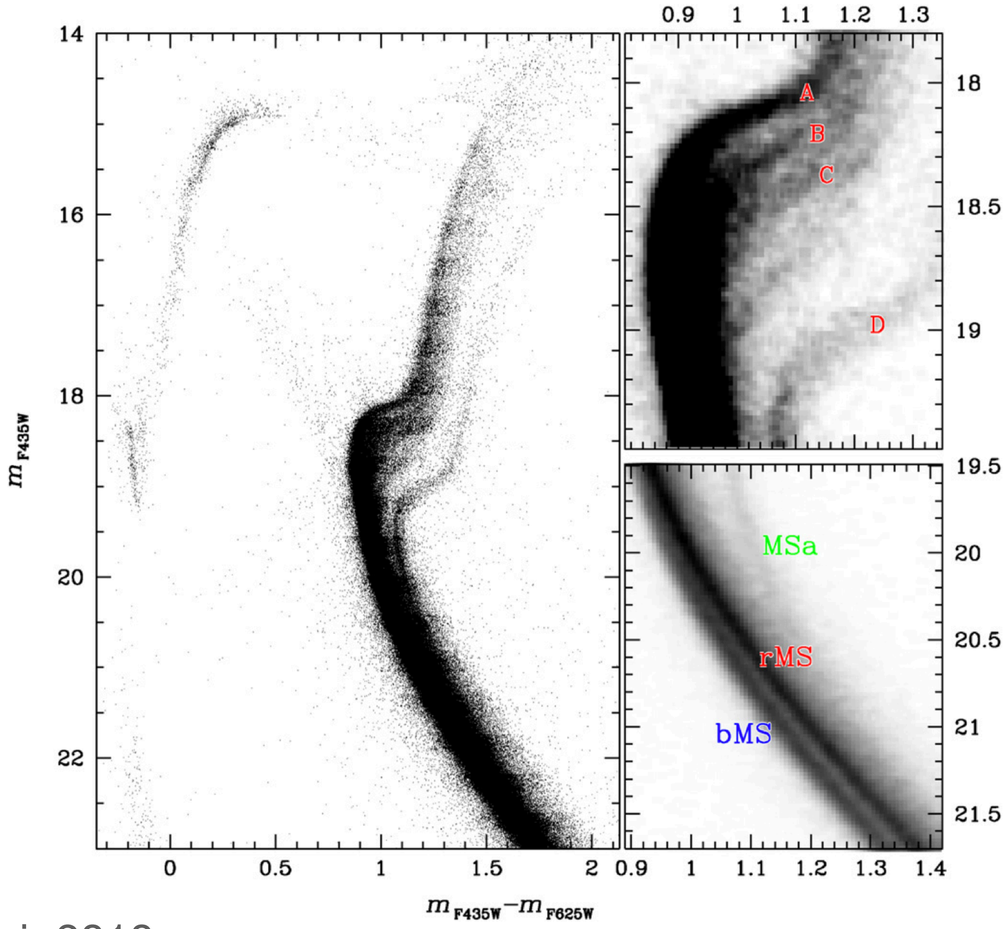
- **Multiple Populations** in many Globular Clusters!
  - ~59 MWY GC's!
  - Multiple turn-offs, MS, RGB…
- HST key to discovering these (super precise & deep CMDs), also found in spectra: [Na/O]
- Looks like usually 2 populations of stars, some kind of self-enchrichment going on
- Sometimes MORE than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



Milone & Marino (2022)

Some clusters really aren't clusters!

- Omega Cen and the dSph remnants



e.g. Bellini+2010

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 clusters 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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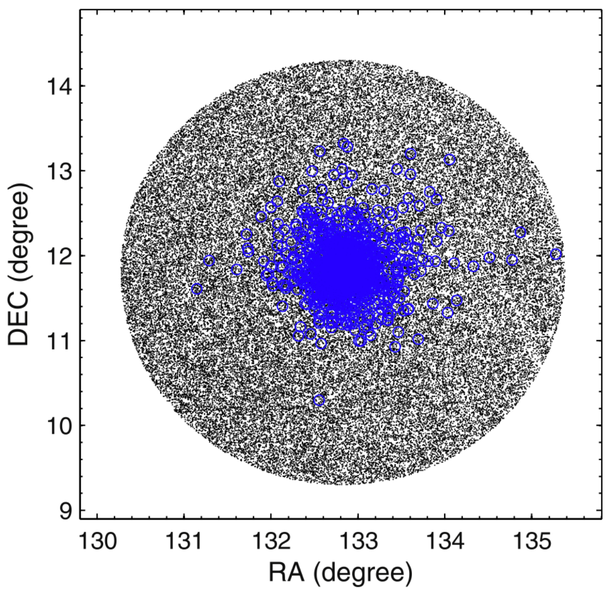
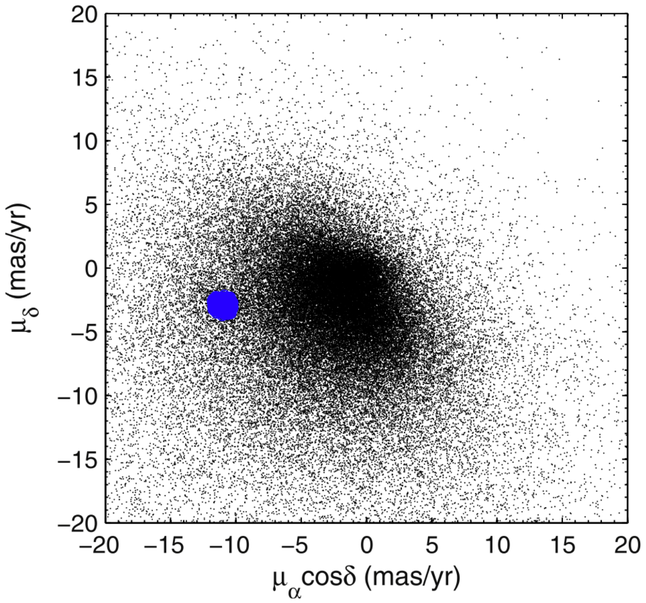
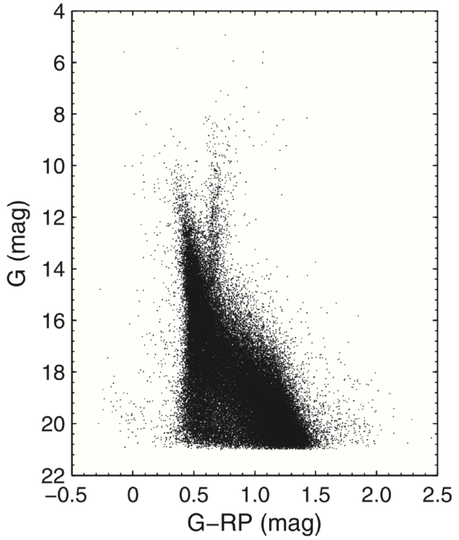


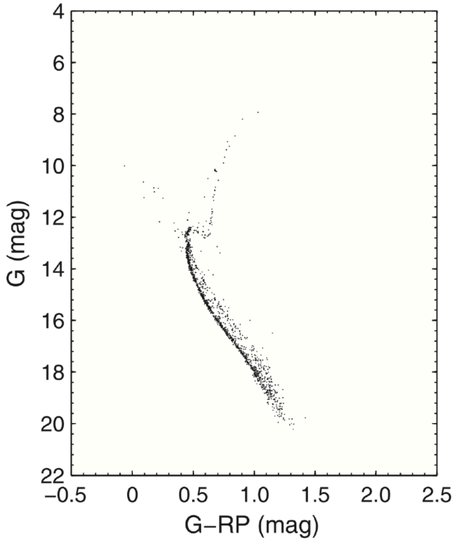


- Cluster is bound and moving relative to field stars… has distinct proper motion!
- Proper motion is often gold standard (use in HW2)

Gao (2018)

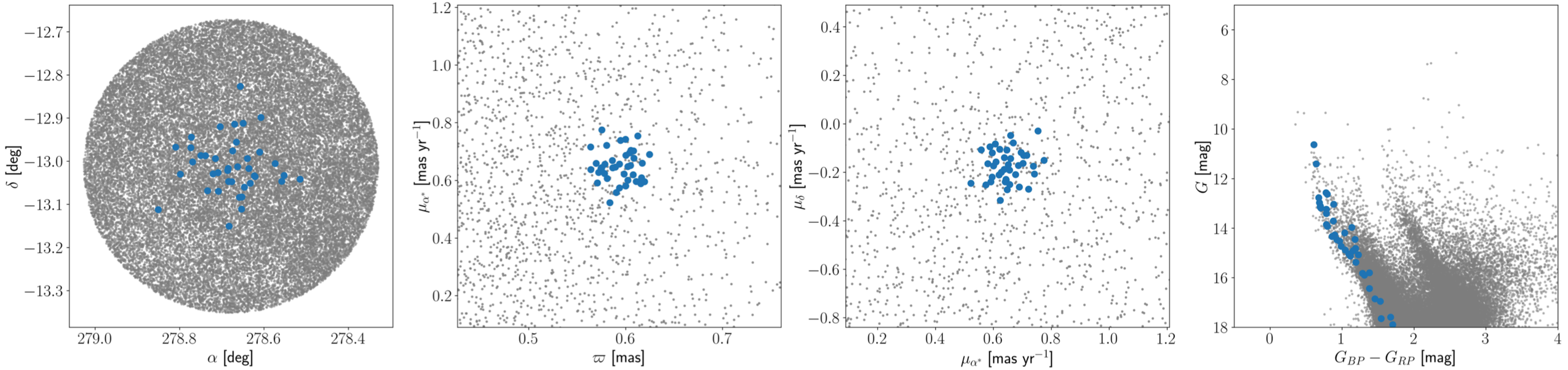
- CMD still very useful
- So is spatial (radial) location
- Combo of features to learn on!





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!

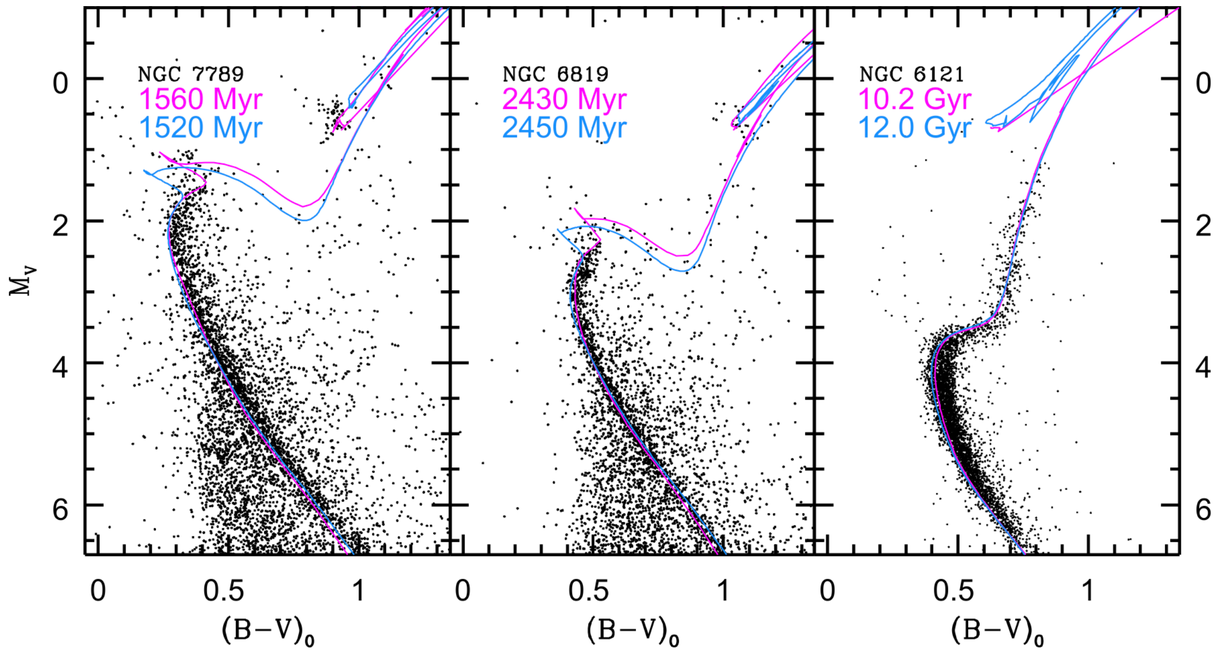


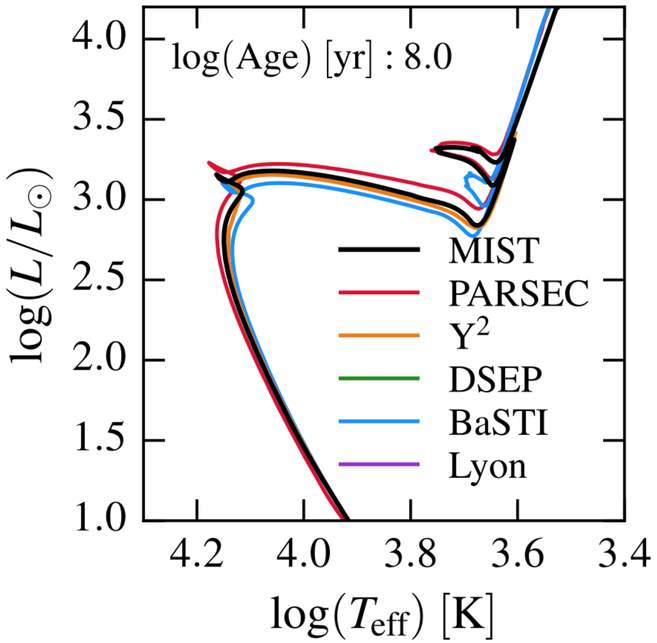
Castro-Ginard+2022

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…

Cummings+2018

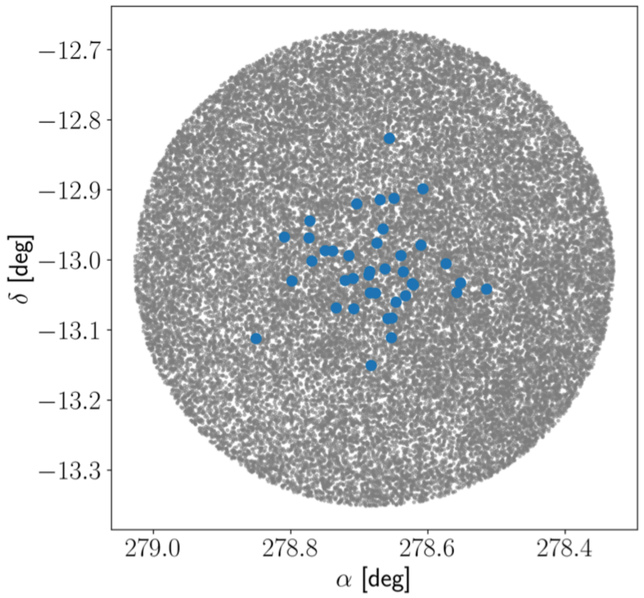


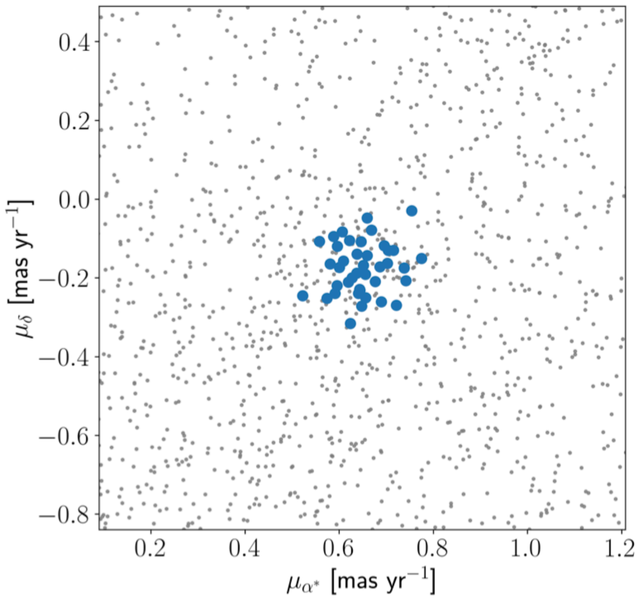


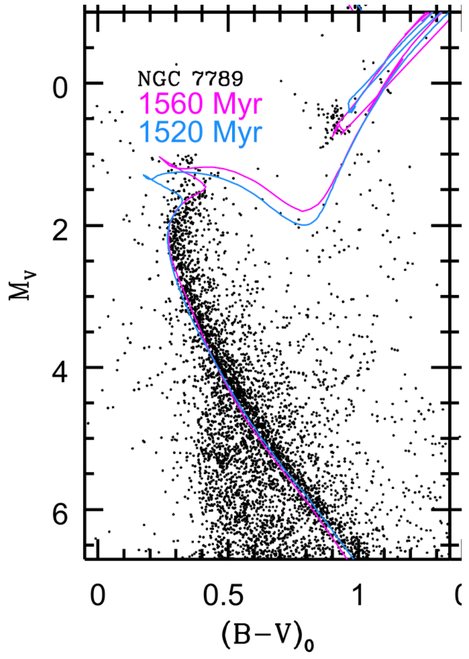
Choi+2016

Clusters as Benchmarks

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

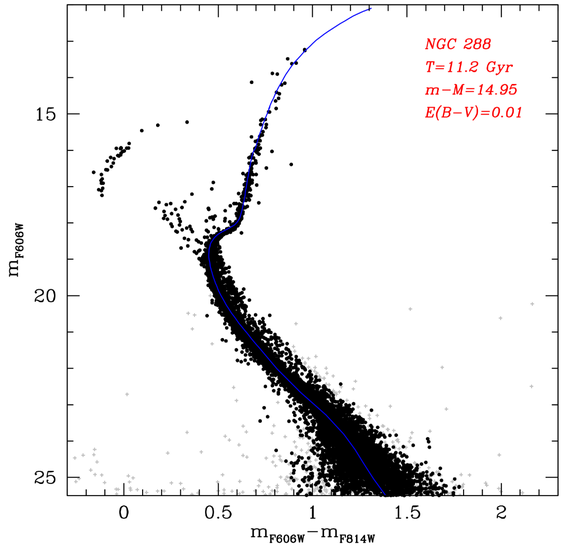






Clusters Rock!

- 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