# ASTR 511

## Galactic Astronomy

# Lecture 04

## Clusters & “Simple” Stellar Populations

Prof. James Davenport (UW)

Winter 2023

# 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

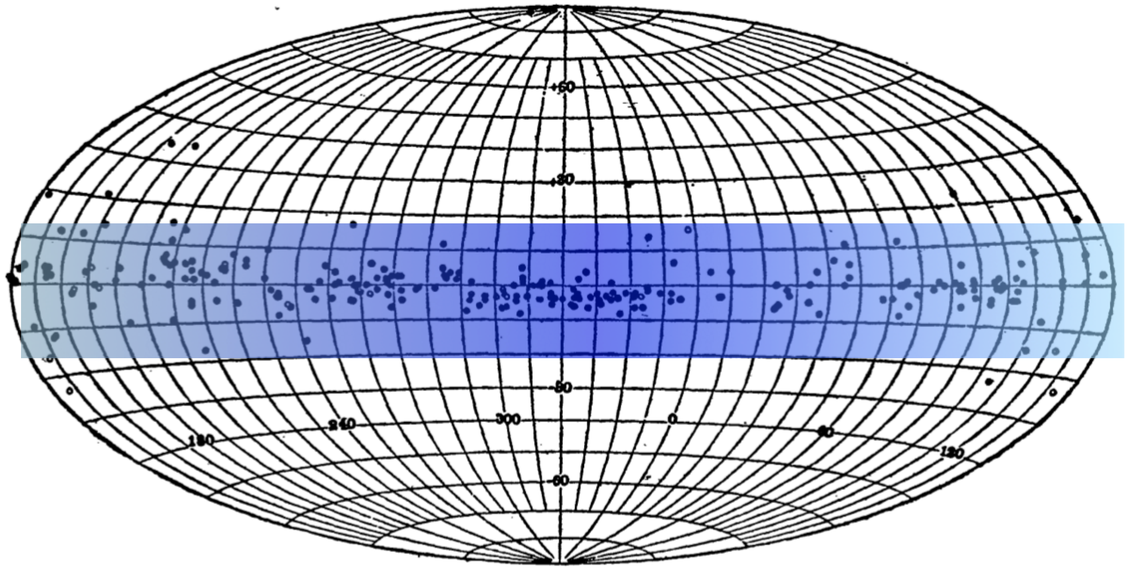



FIGURE II, 2.

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

## globular clusters

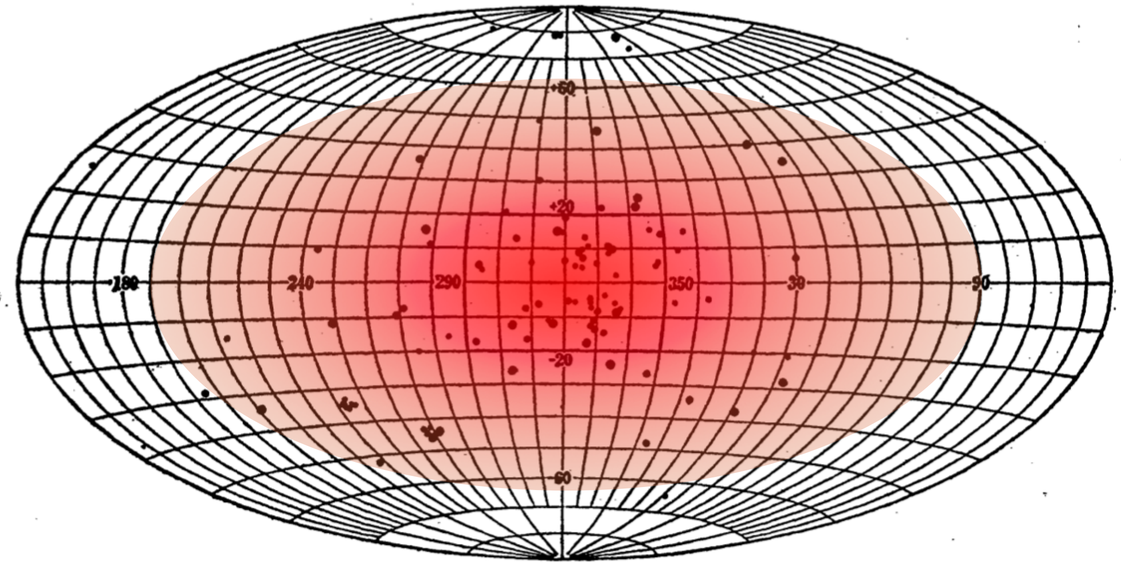


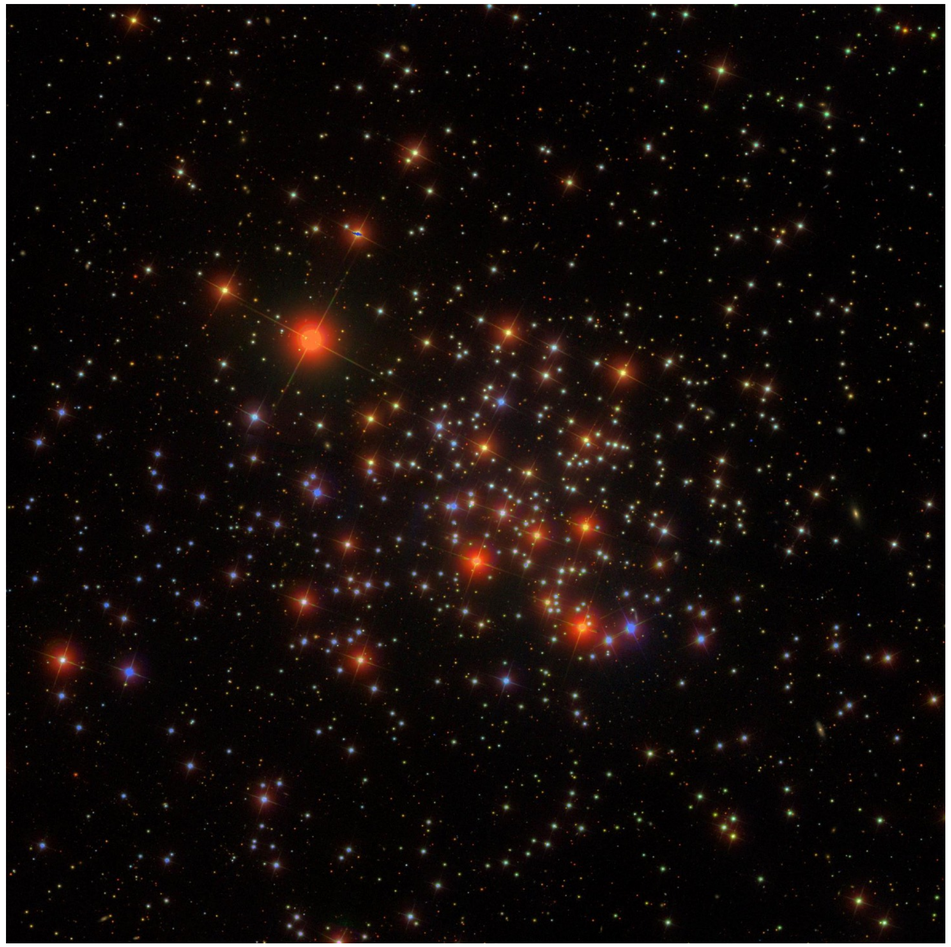

FIGURE II, 4.

Distribution of globular clusters in galactic coordinates.

Shapley (1930)

# Clusters

open (“galactic”) clusters



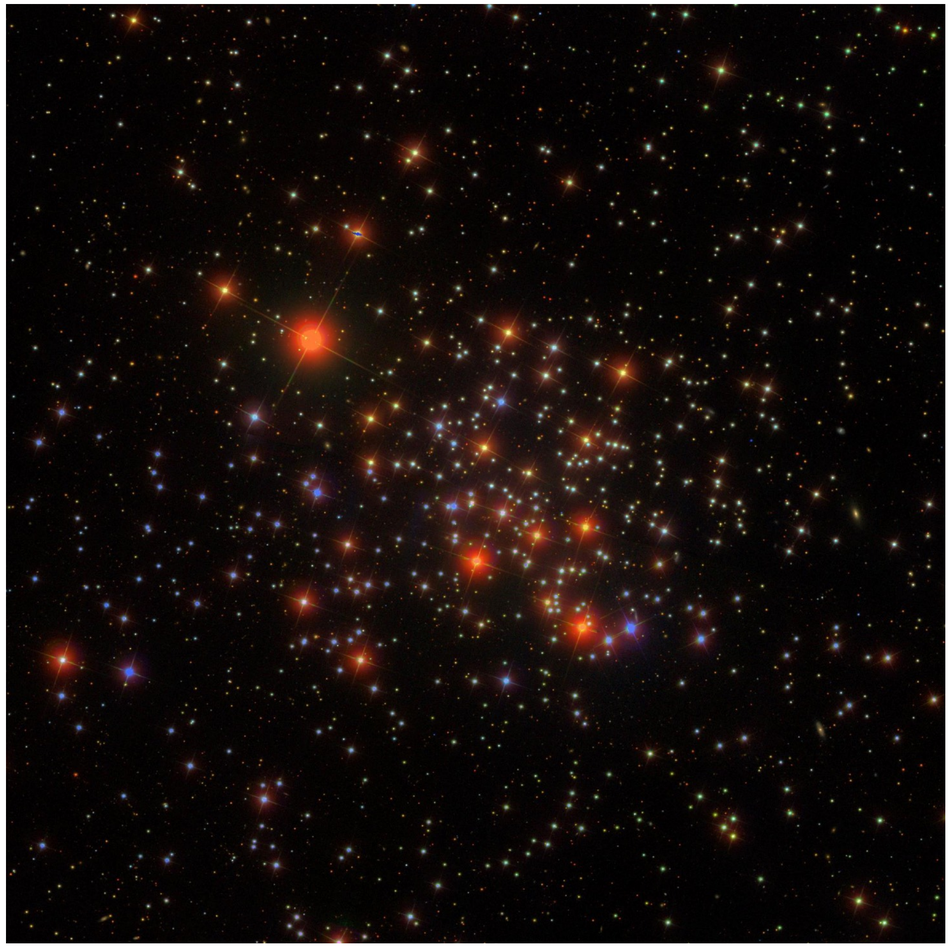
M 67

globular clusters

M 15

# Clusters

open (“galactic”) clusters

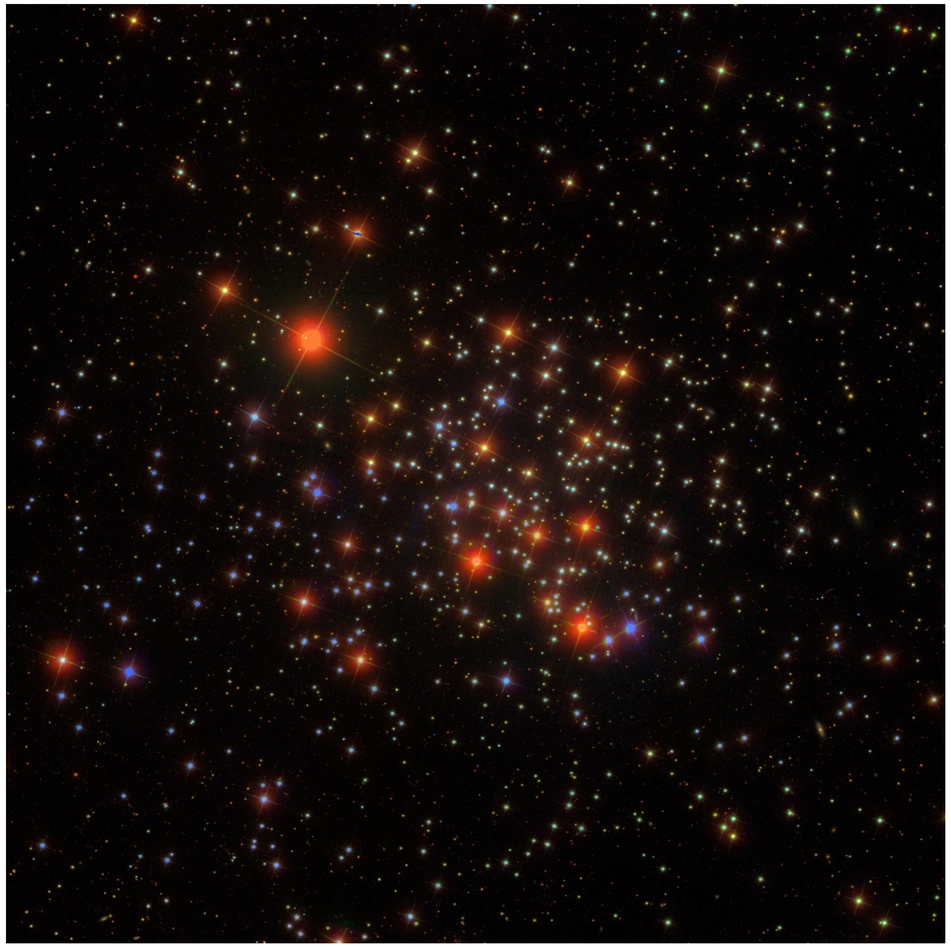


M 67

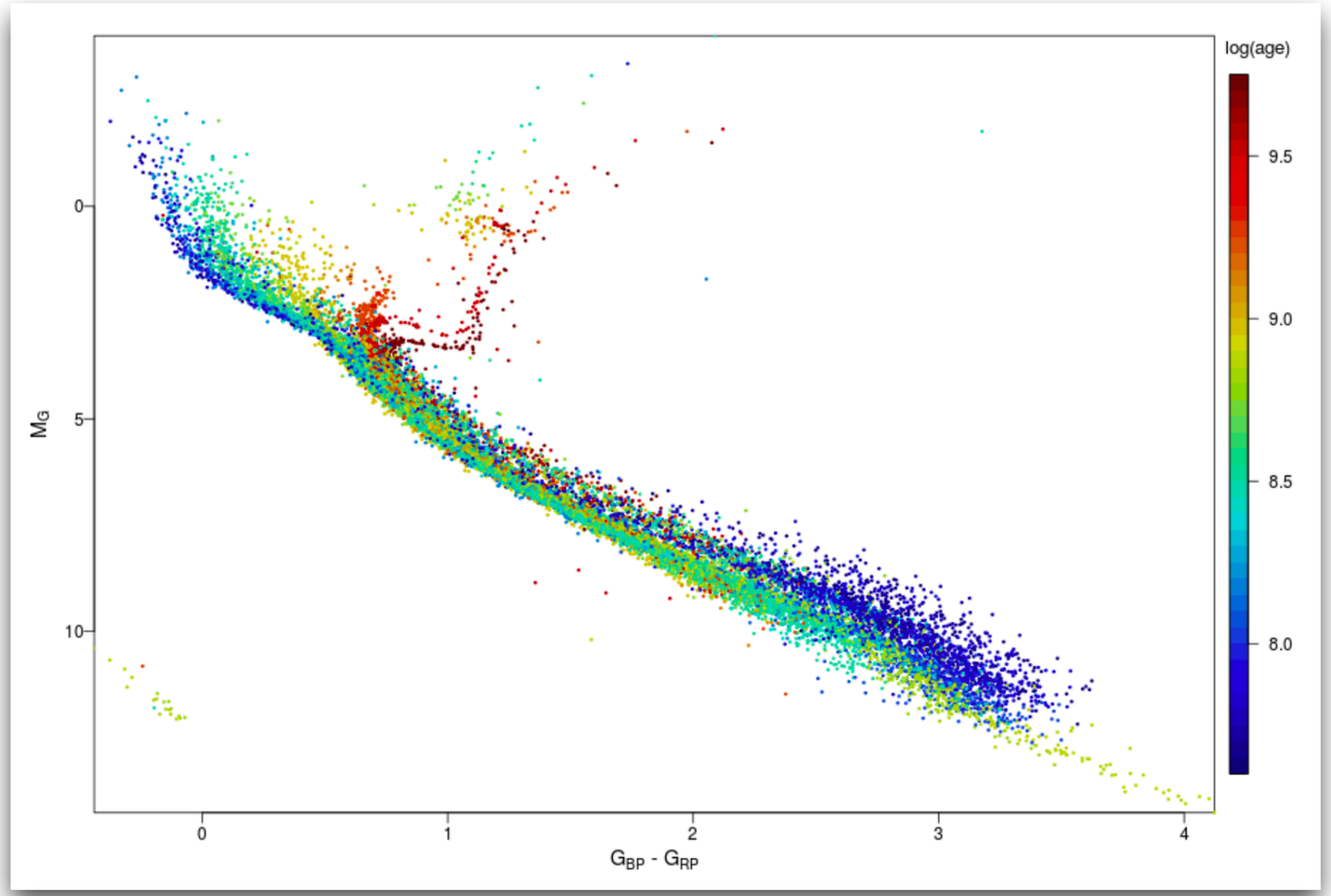
- Typically younger (usually up to 100’s of Myr, very few +Gyr)
- Sparse, can count the stars - look “open”
  - $10^0 - 10^3$ stars
- Found mostly in the galactic disk, usually fairly nearby (< few kpc)
- More metal rich
- Thousands of OC’s known in Milky Way
  - Gaia finding a LOT more…

# Clusters

open (“galactic”) clusters



M 67




Gaia DR2

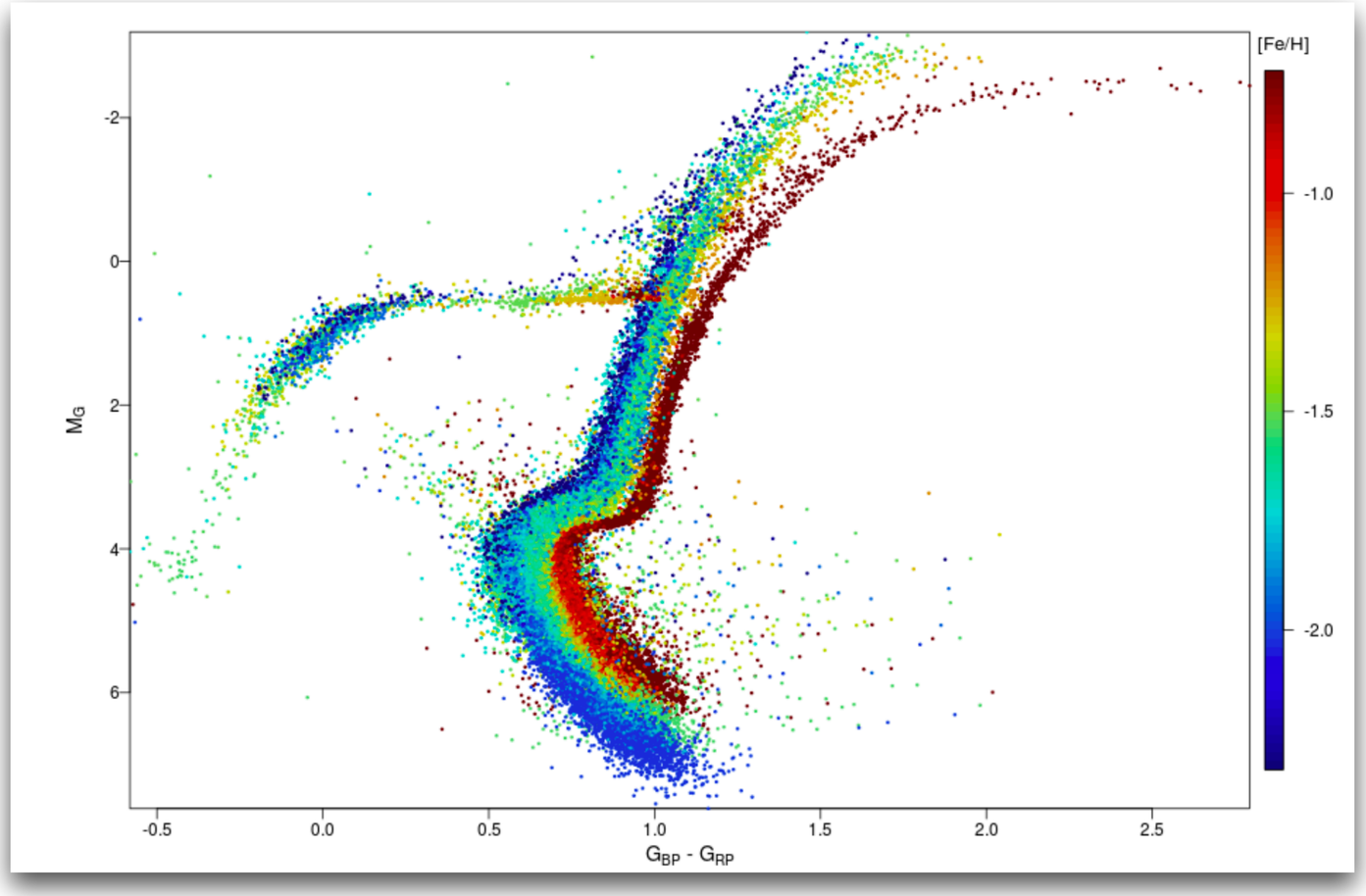
# Clusters

- 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



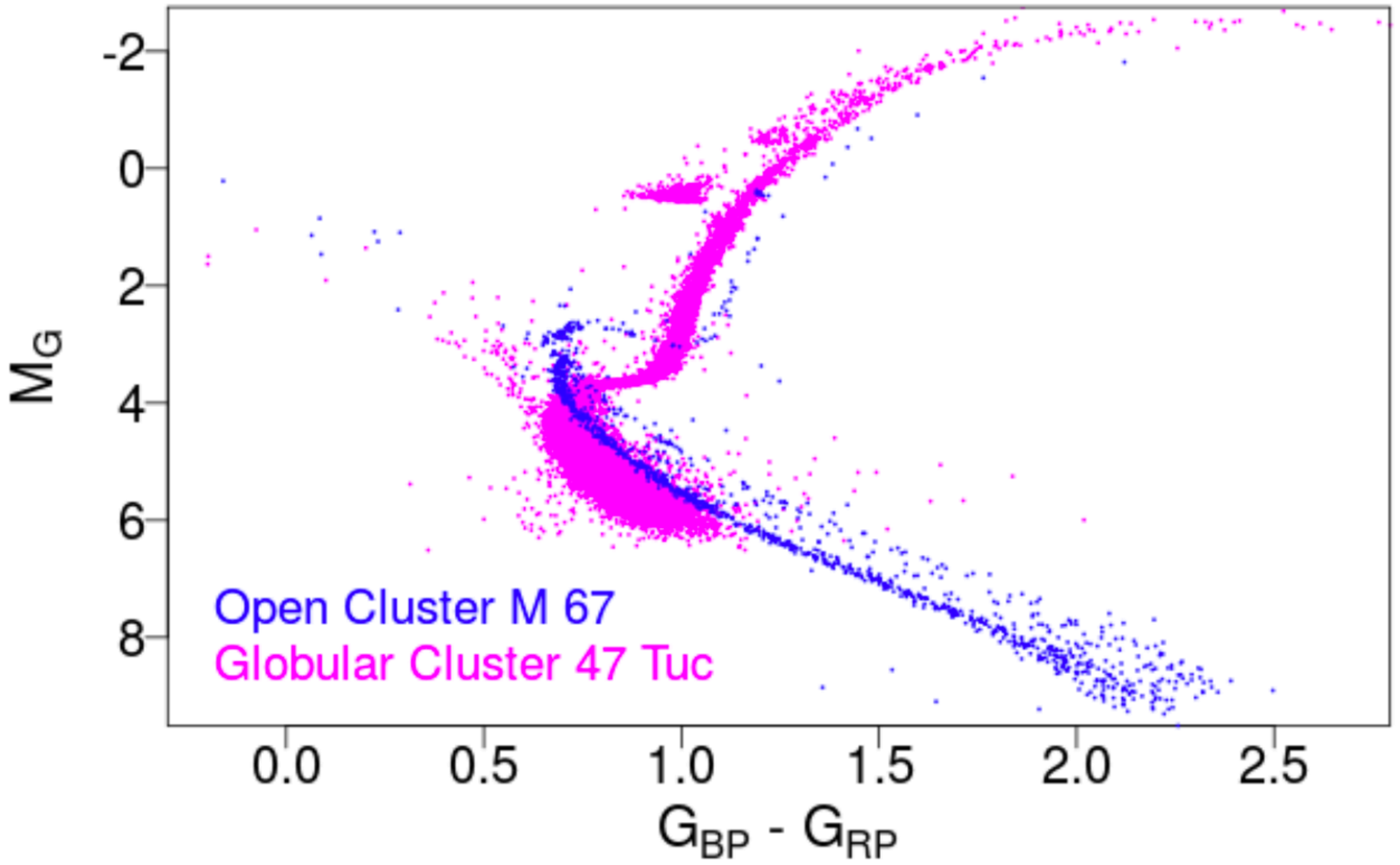

Gaia DR2

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

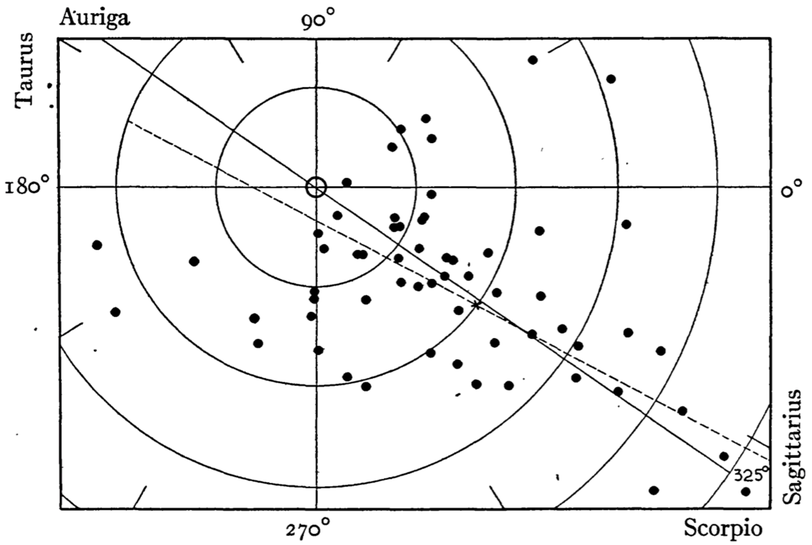
- Modeling formation is very challenging
  - Need to combine gas physics/feedback with stellar evolution and tidal dynamics in a dense environment!
  - Binary stars & multiple systems turn out to be VERY important (esp. for globular cluster survival)
  - N-body dynamics & external tidal stripping change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

# Cluster Formation

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

# Clusters as a Benchmark

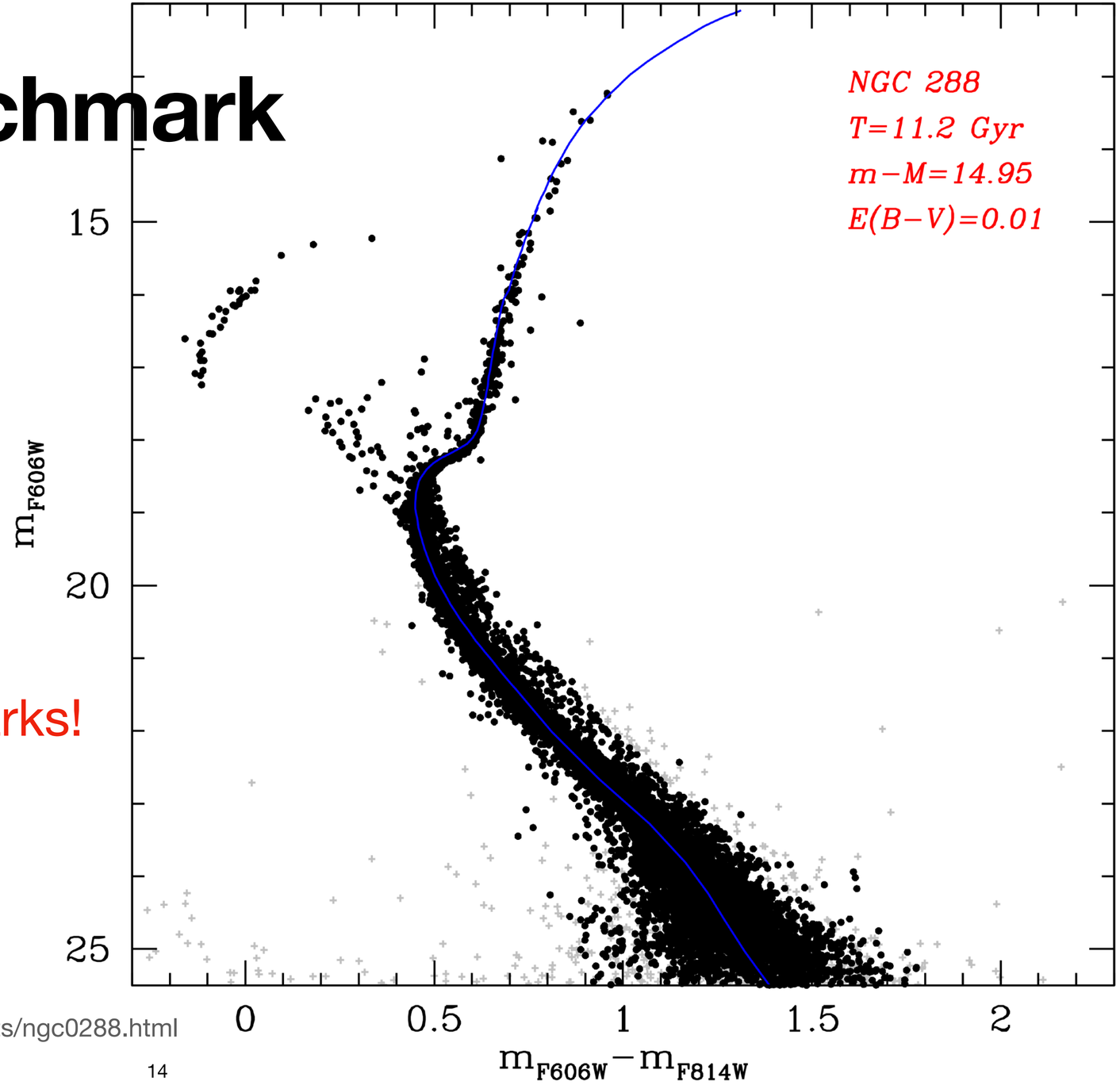
- Talked last time about clusters as key to “great debate” type things
- “Simple Stellar Population” model is key takeaway here
  - Clusters are considered the ultimate benchmark test for stellar evolution, anchor EVERYTHING!
  - We’re STILL testing all areas of stellar astrophysics w/ clusters, trying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

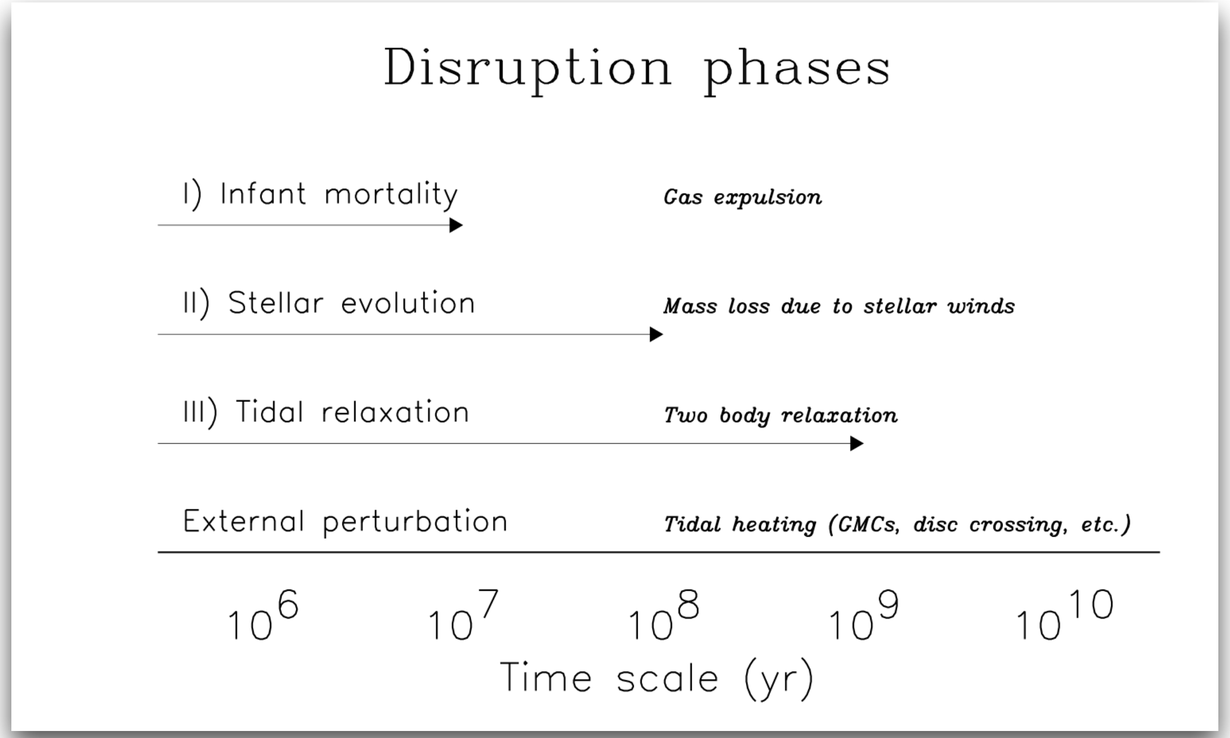
# Some Problems to Clusters as Benchmarks…

- 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

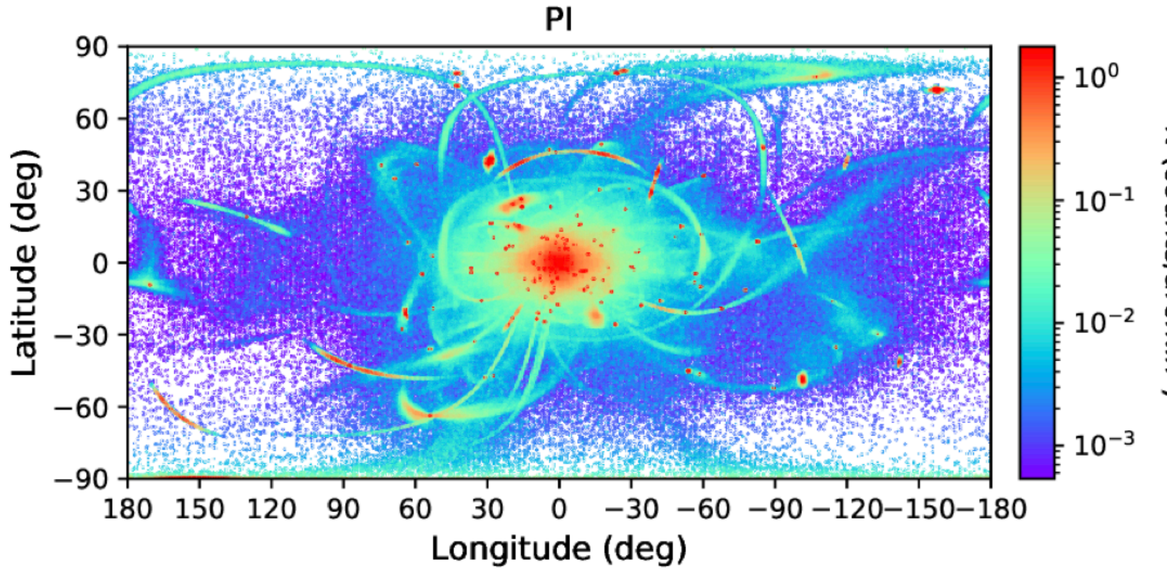



60-90% of clusters are destroyed

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)



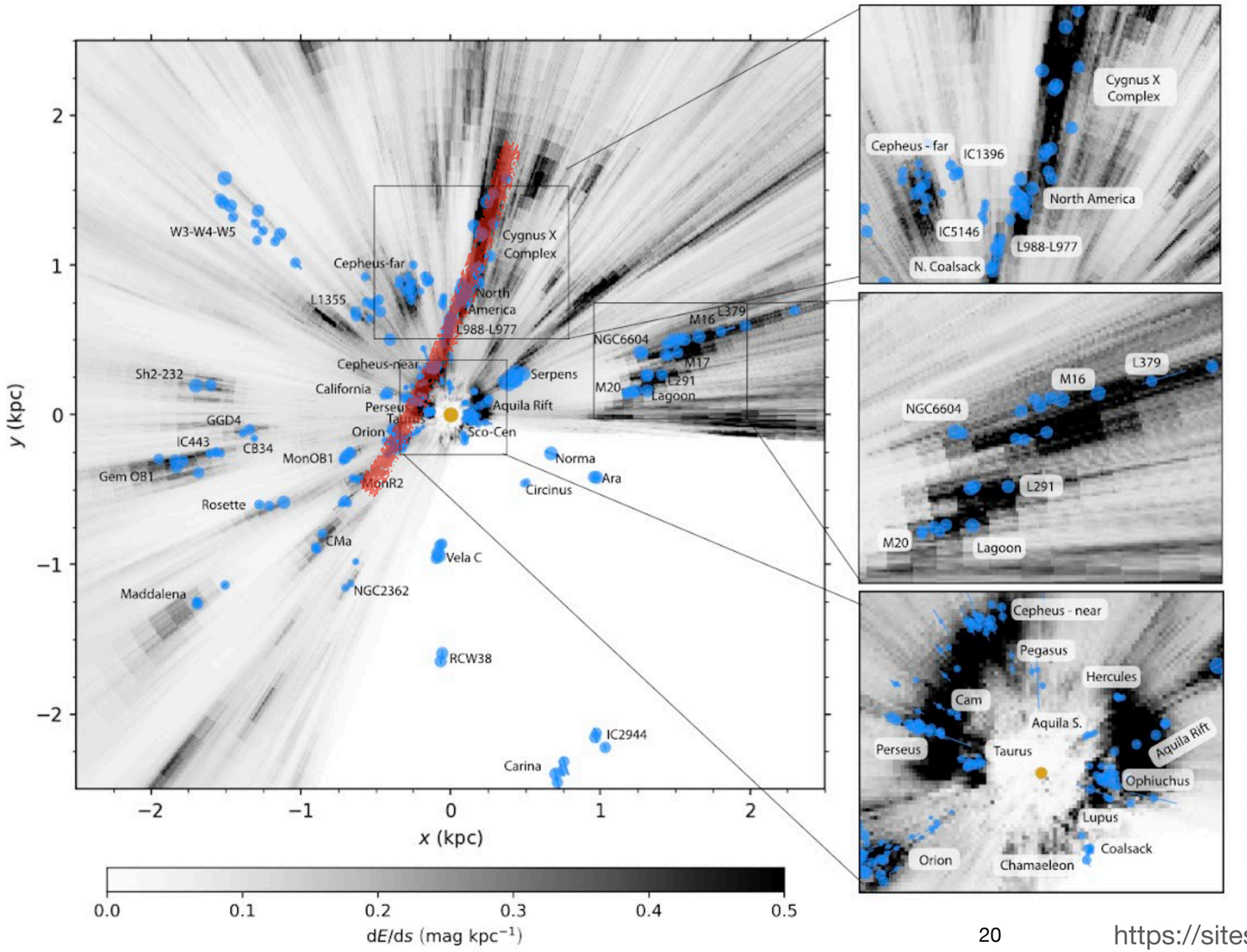

Ferrone+2023

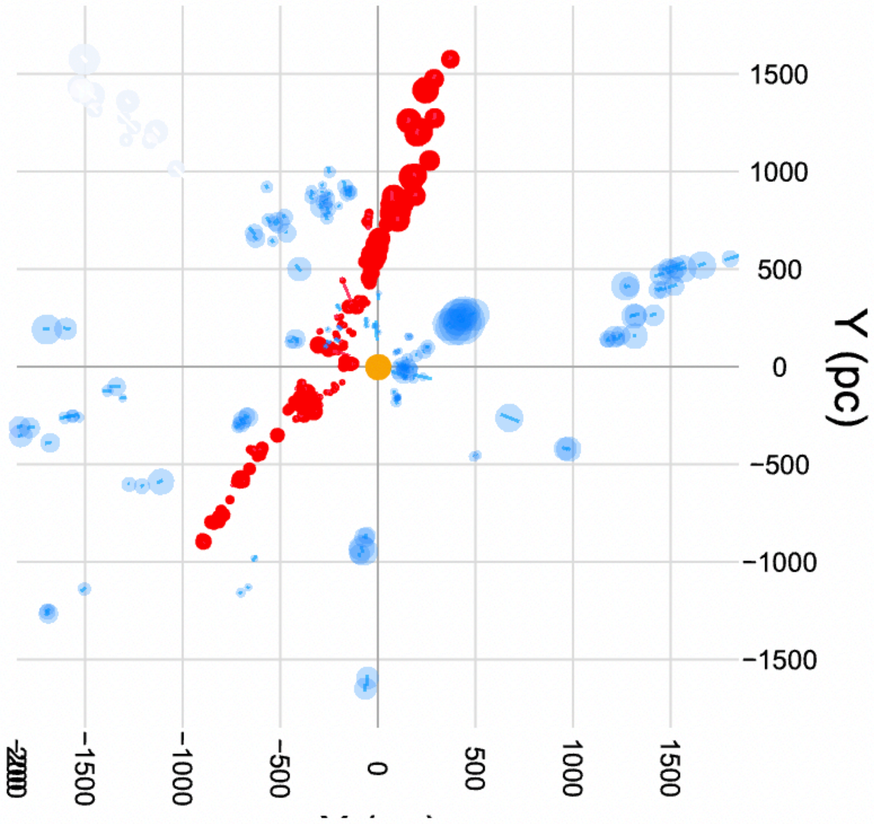
From Lecture 2

$d < 500\text{pc}$

**“Radcliffe Wave”**
C. Zucker+2020

Long line of star forming regions



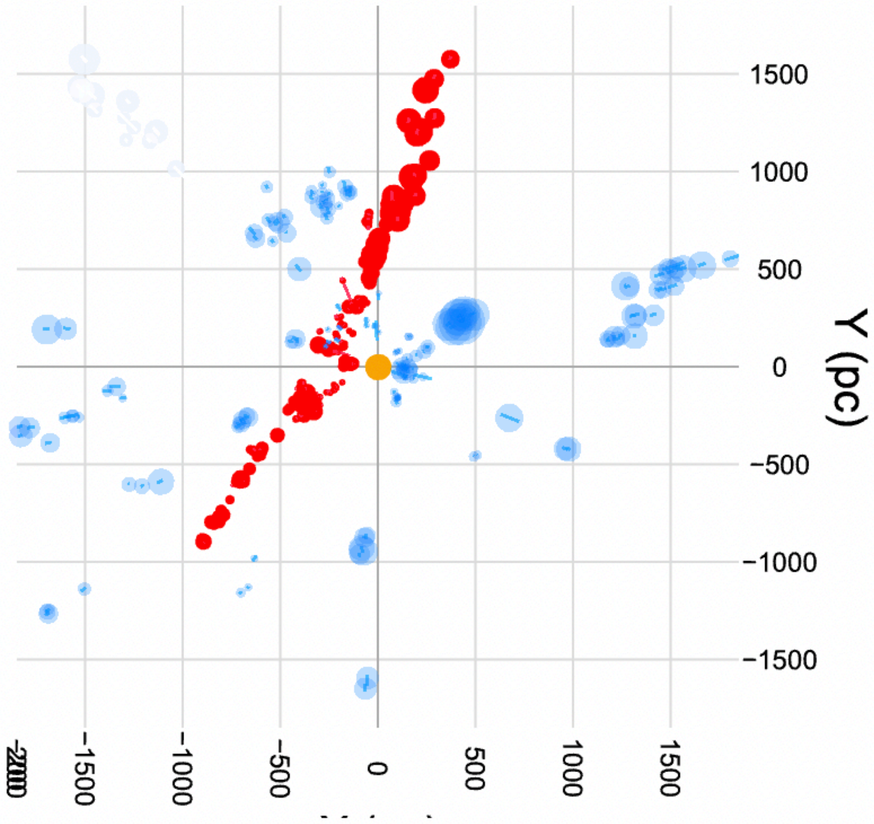



https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

**“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



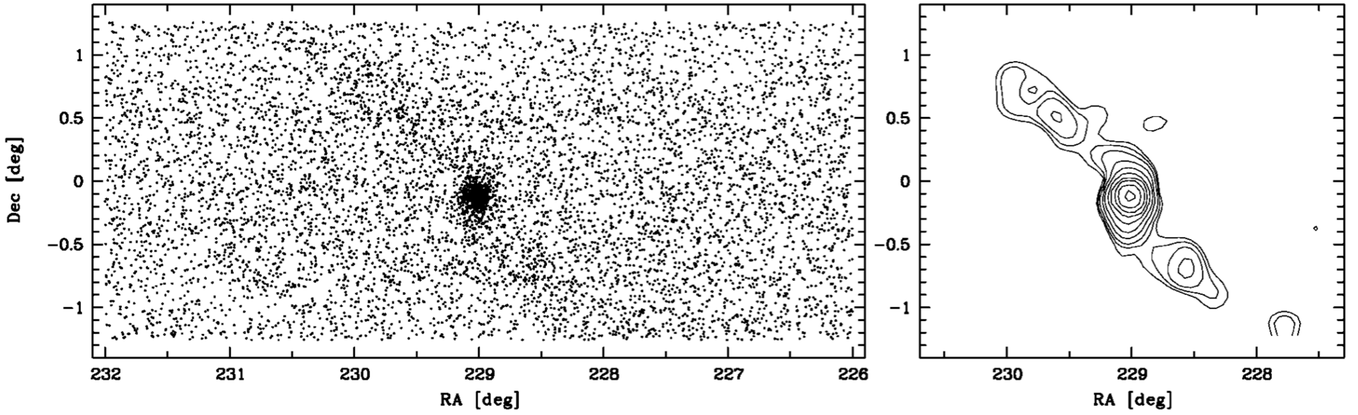



https://sites.google.com/cfa.harvard.edu/radcliffewave/home?authuser=0

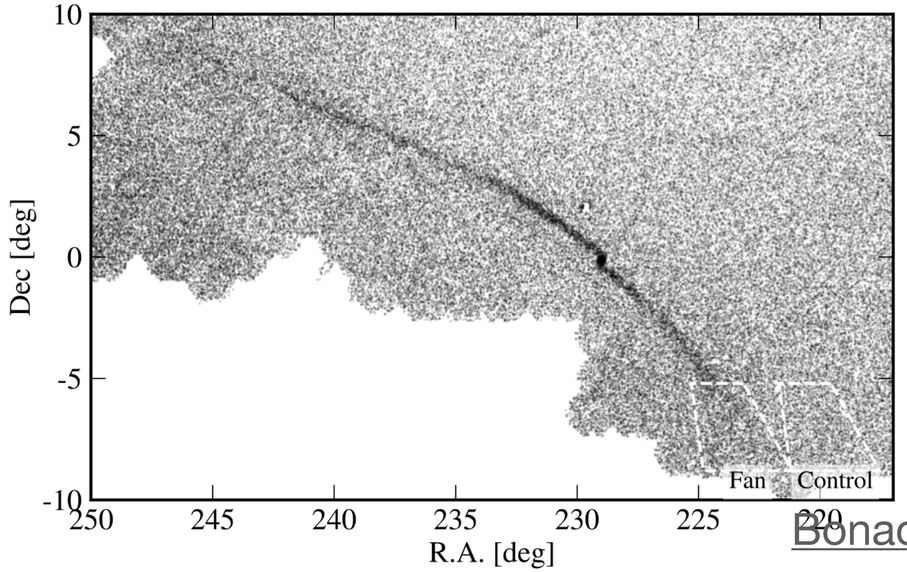
# Tidal Tails/Streams

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

Odenkirchen+2001



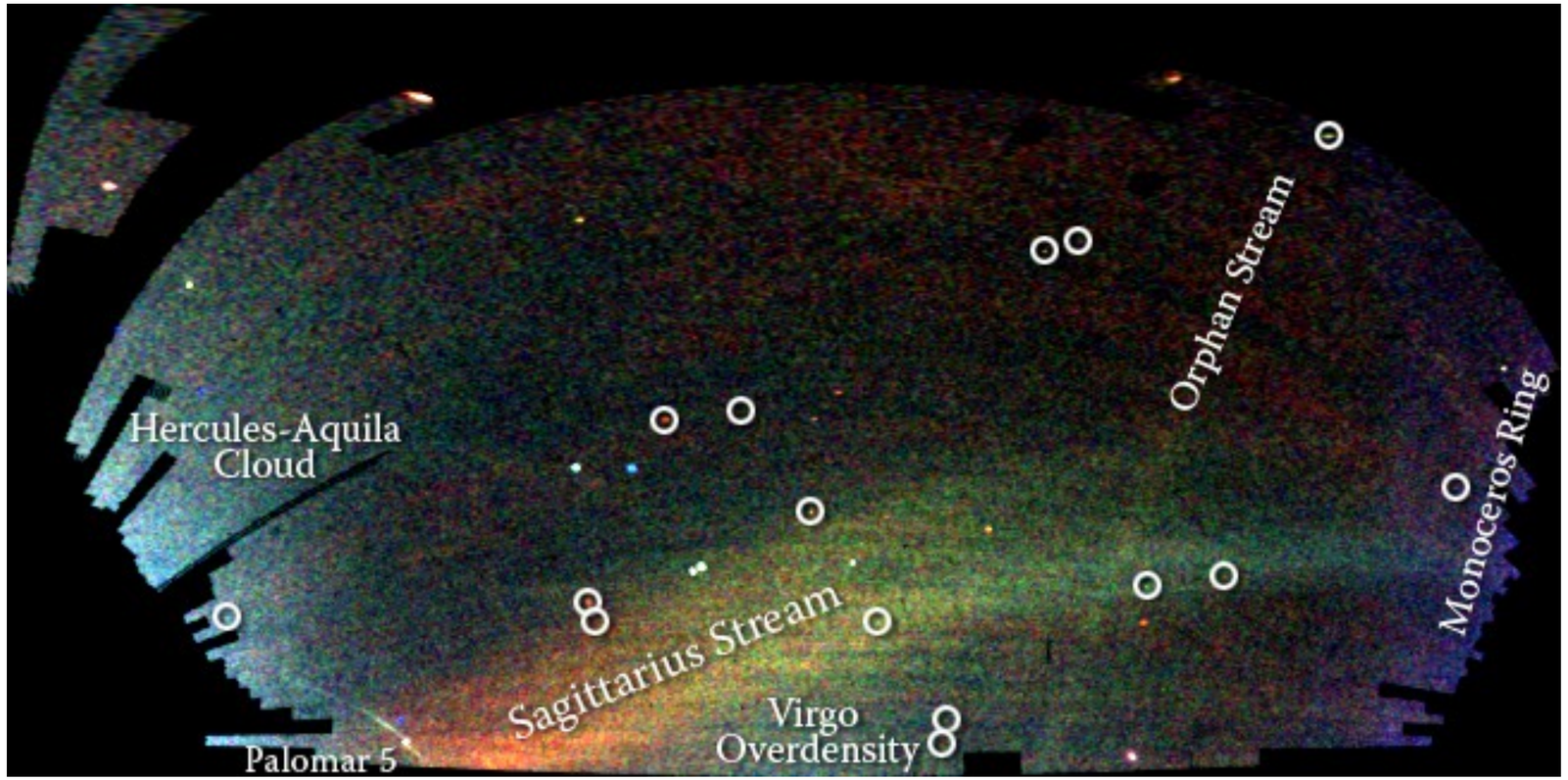

- Now traced over 20kpc (and 30 deg)!




Bonaca+2019

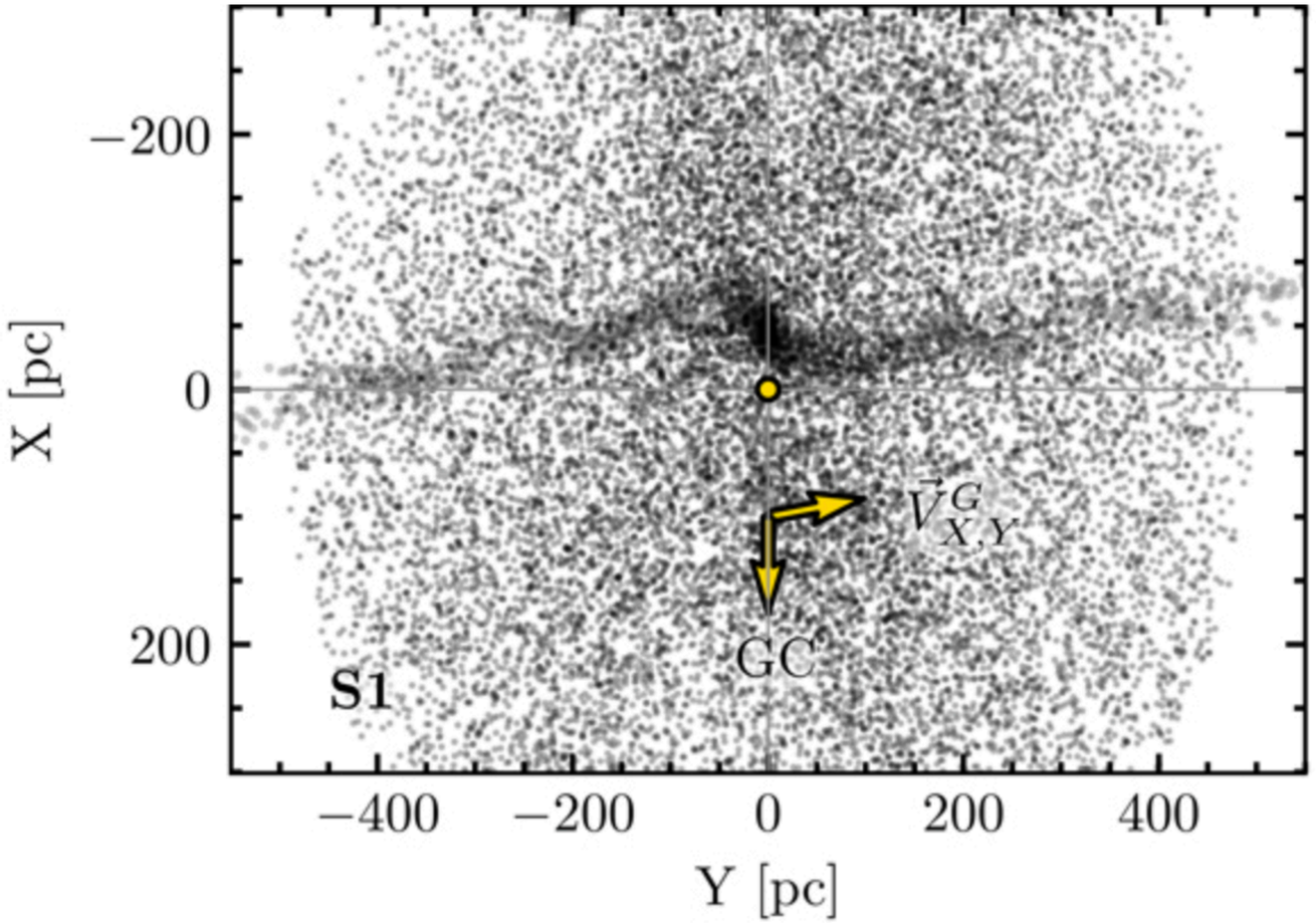
# Tidal Tails/Streams

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

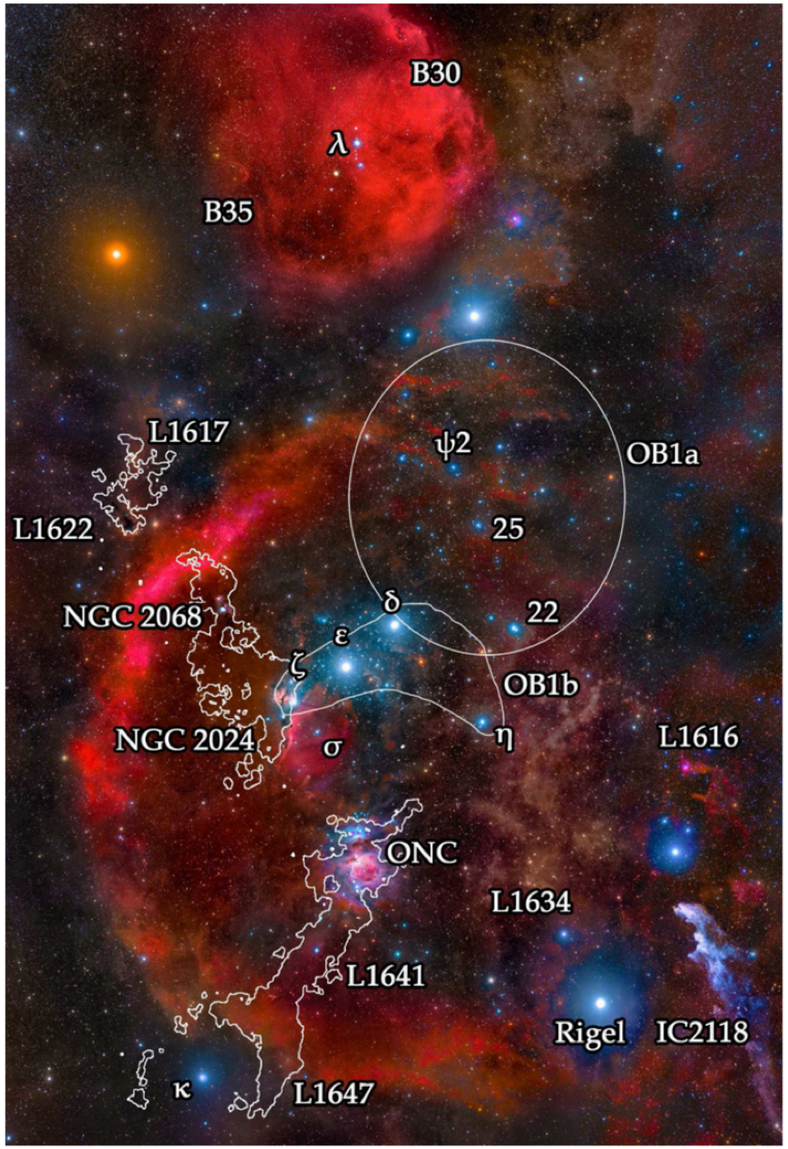


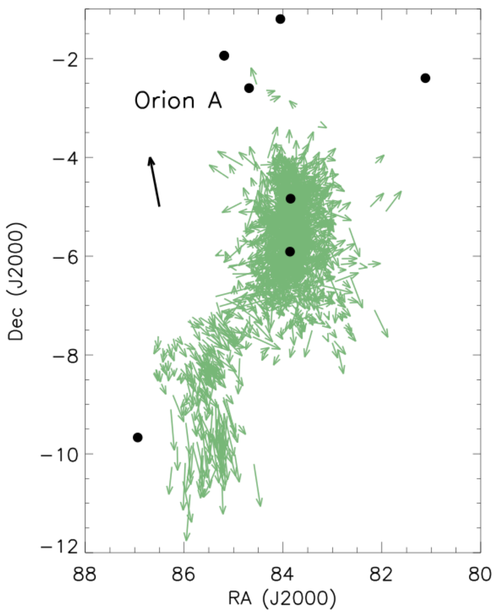
# Tidal Tails/Streams

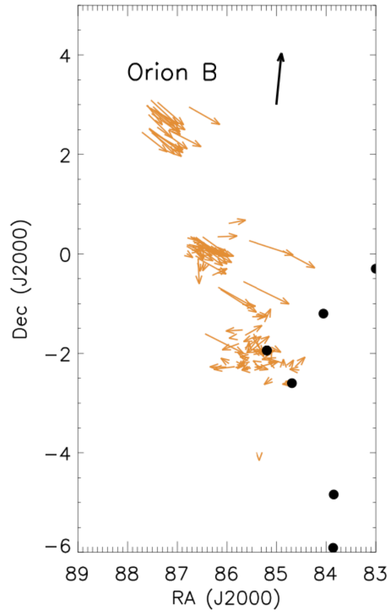
- Open clusters have them too!
- Hyades has 800 pc tails?!
  - Jerabkova+2021
- Older open clusters (e.g. M67) have been searched as well…

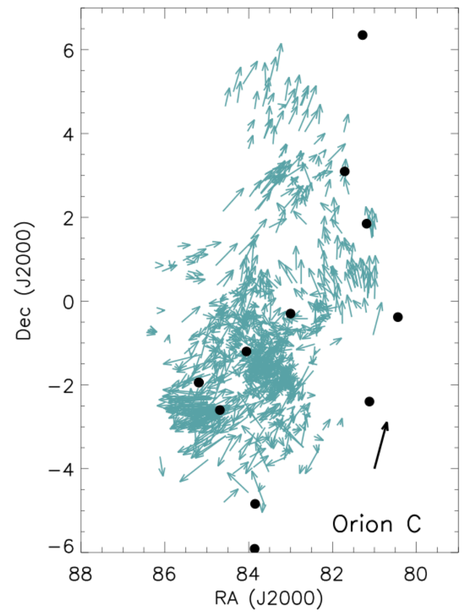


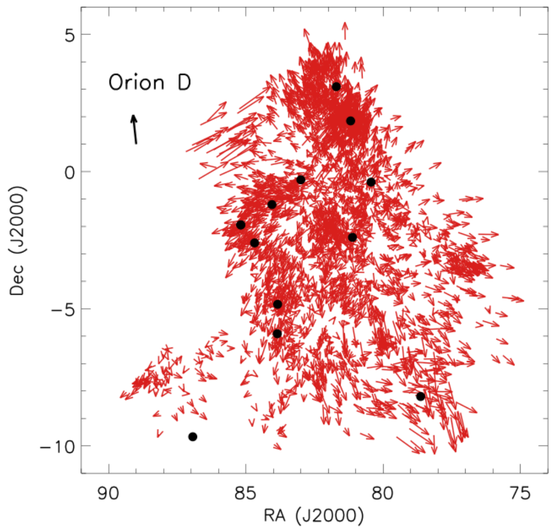
# Cluster Age Spread

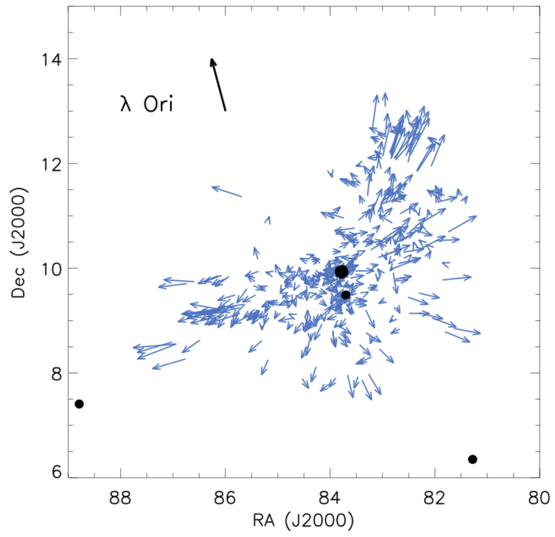


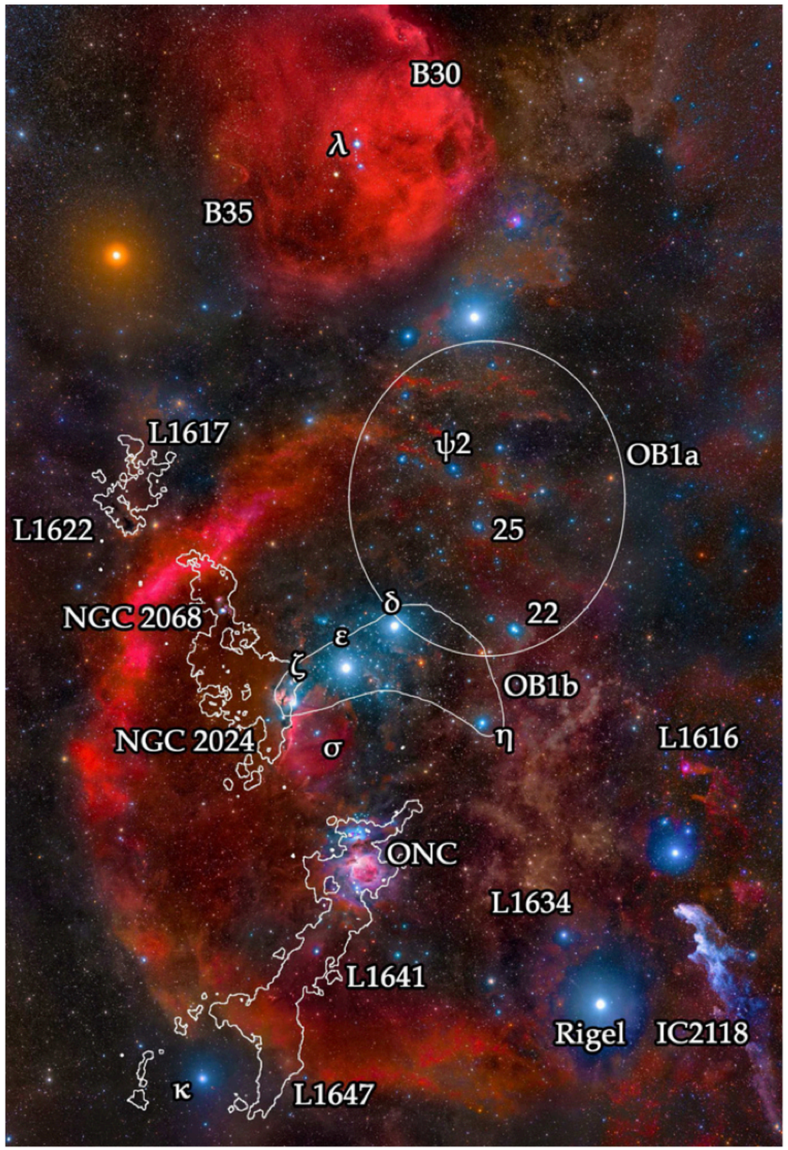



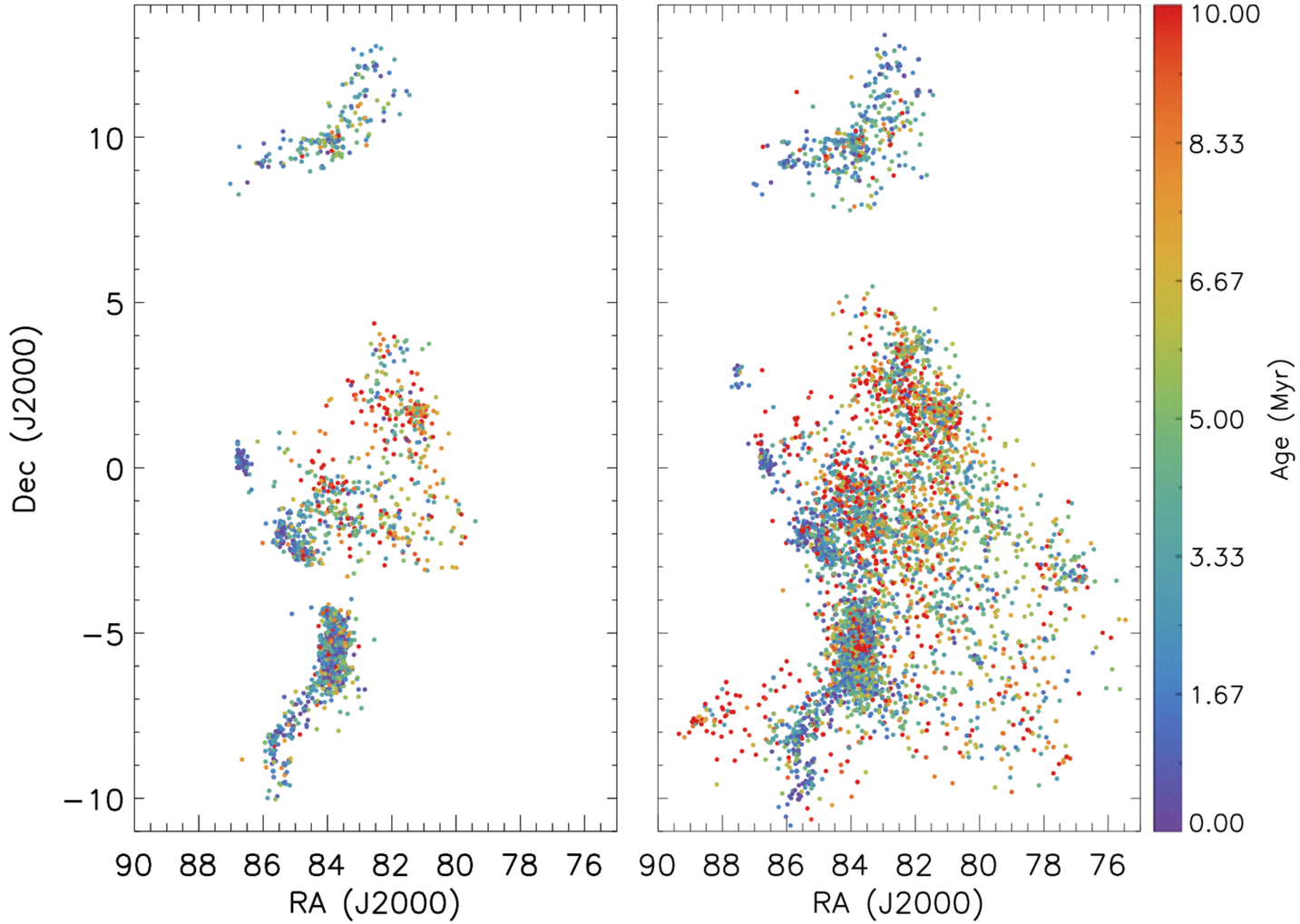



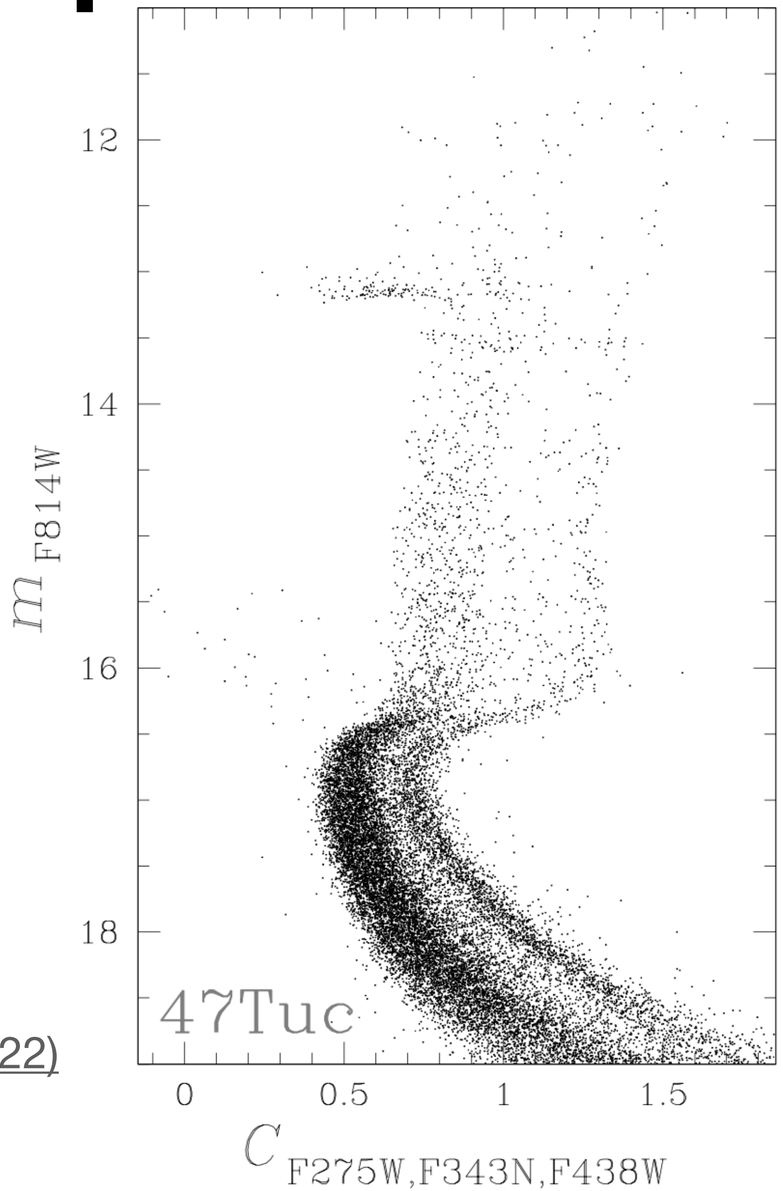
# Cluster Age Spread



# Clusters NOT simple stellar pops

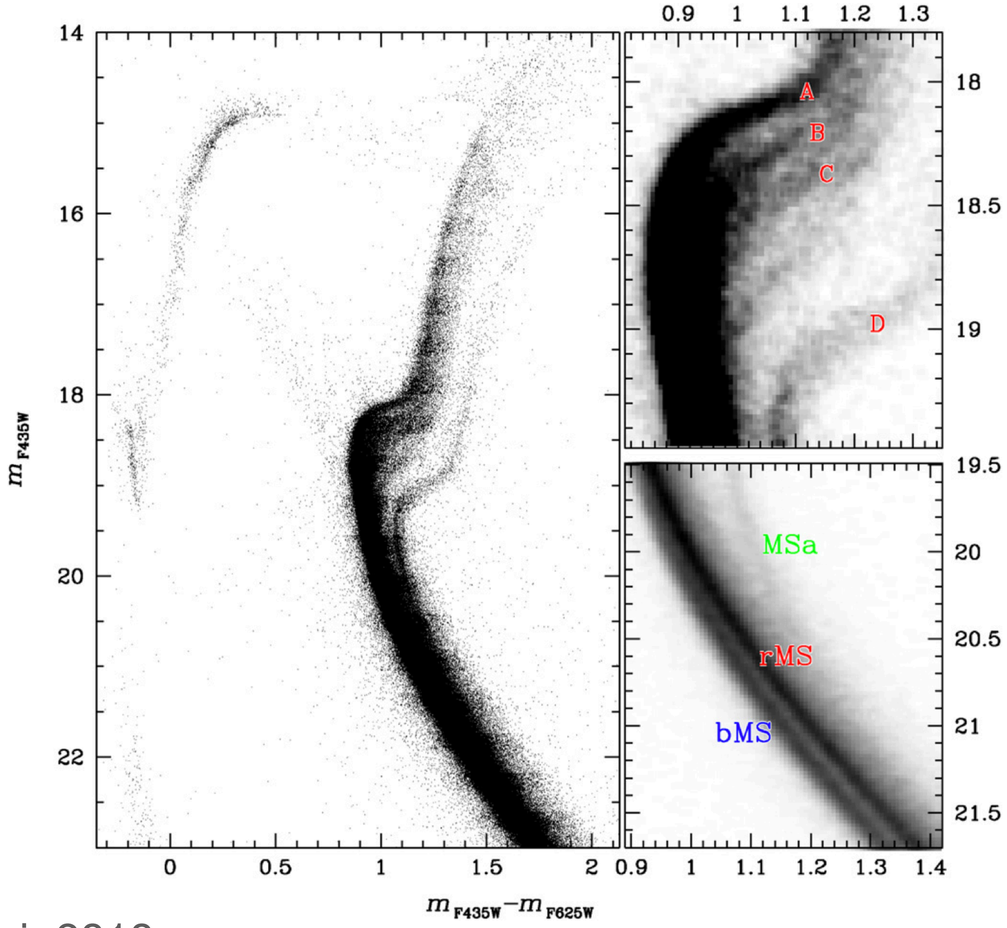
- Multiple Populations in many Globular Clusters!
  - ~59 MWY GC's!
- HST key to discovering these (super precise & deep CMDs)
- Looks like usually 2 populations of stars, some kind of self-enchrichment going on
- Sometimes MORE than 2 populations…




Milone & Marino (2022)

# Some clusters aren’t clusters!

- Omega Cen and the dSph remnants





e.g. Bellini+2010

# Binary clusters

- Its rare, but its a thing (Gaia finding a few new candidates)
- The “Double Cluster”, NGC 869 and NGC 884, aka “h and $\chi$ 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…**

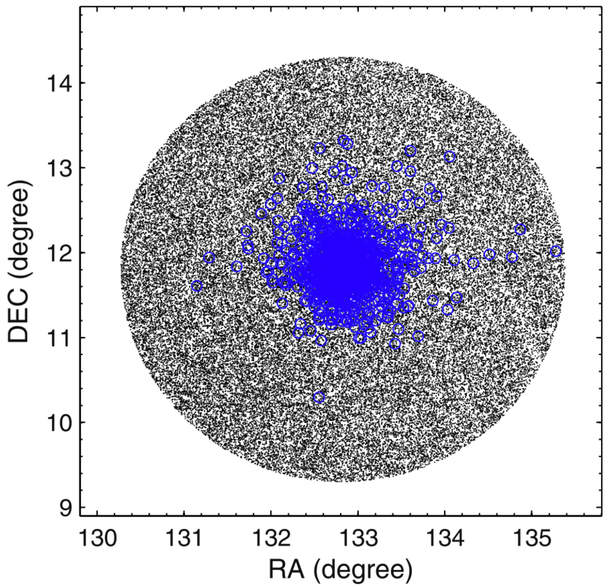
# Cluster Identification

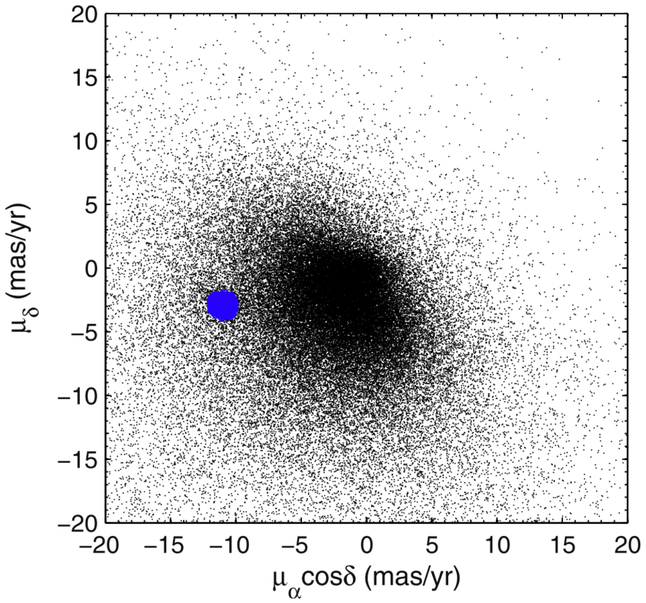
- Stand out in various parameter space:
  - CMD space, obviously
  - Proper motion/dynamical space
    - This is very easy when clusters is small/dense/bound
    - This is hard when cluster is spread out (have to look in action angle or various phase spaces)
    - Velocities very useful, but usually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

# Cluster Identification

- 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

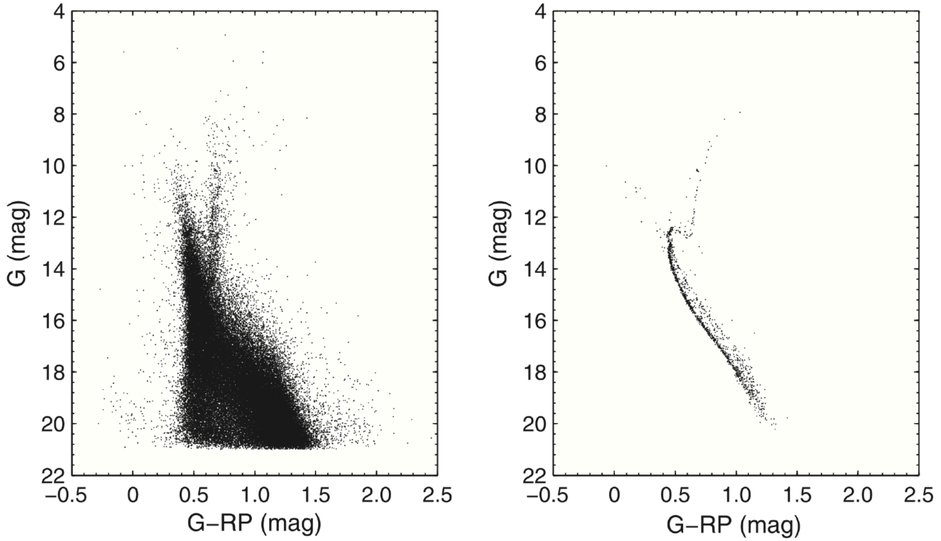



- Cluster is bound and moving relative to field stars… has distinct proper motion!
- Proper motion is often gold standard (use in HW2)

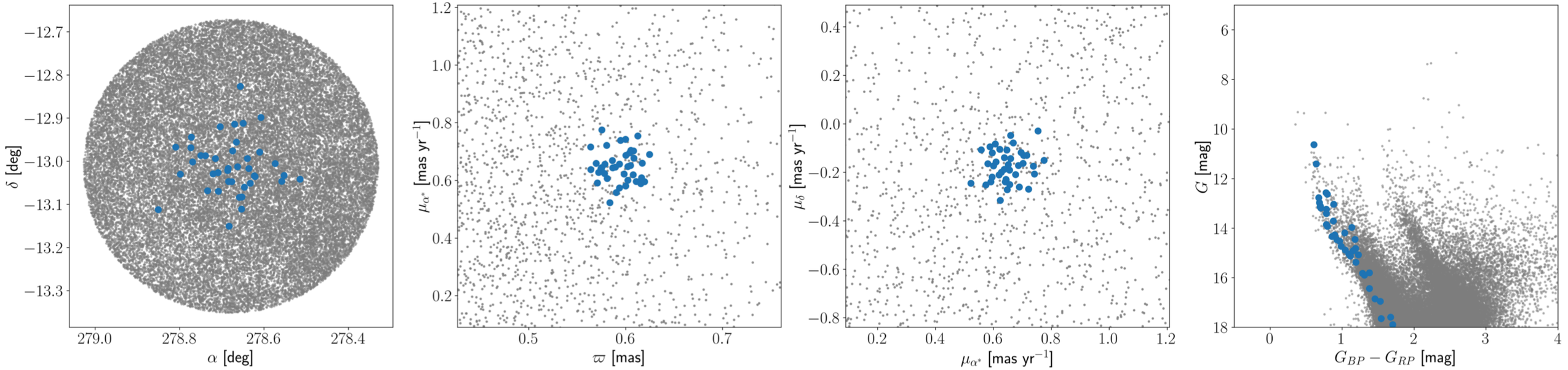
Gao (2018)

- 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!

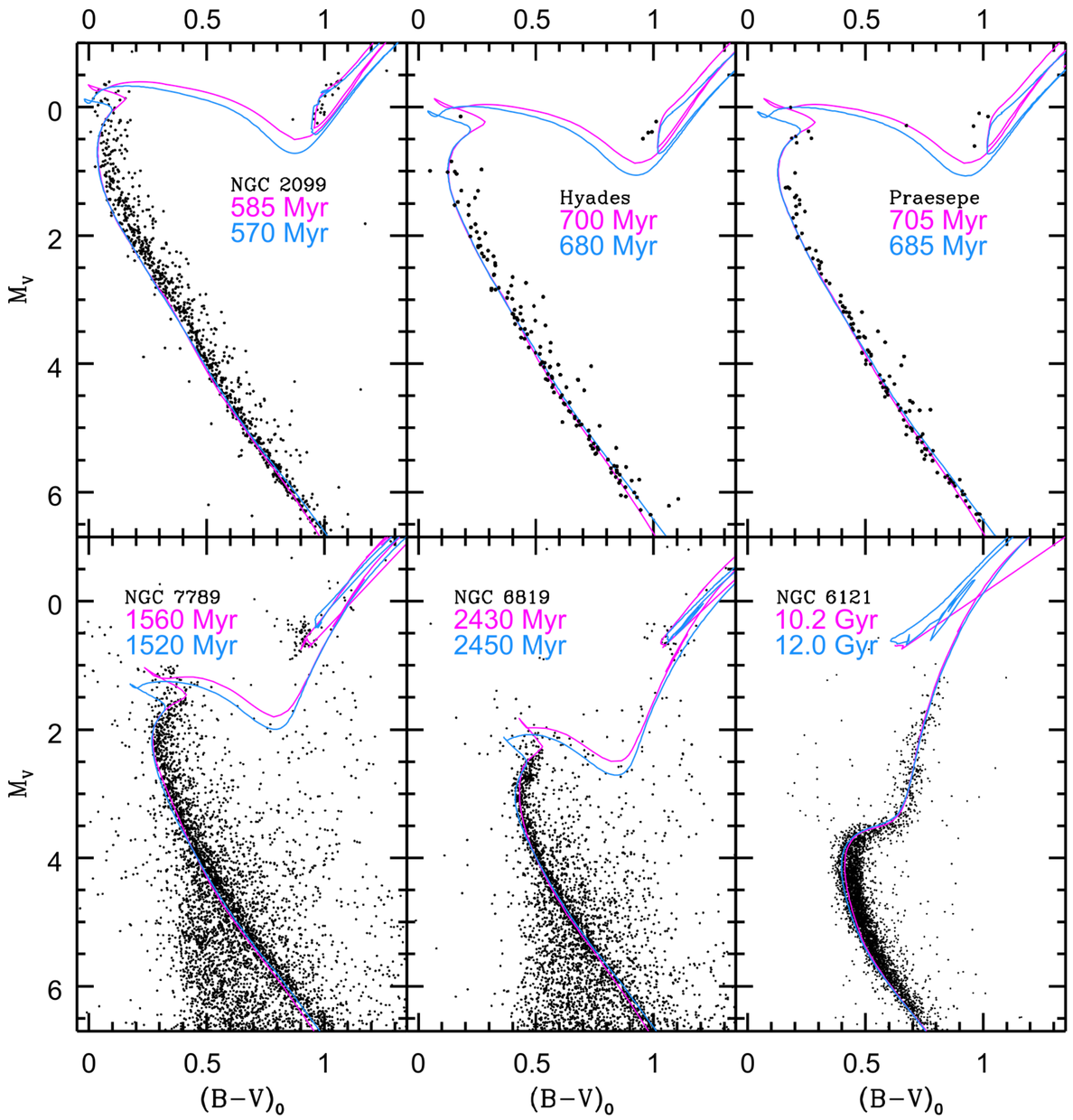





Castro-Ginard+2022

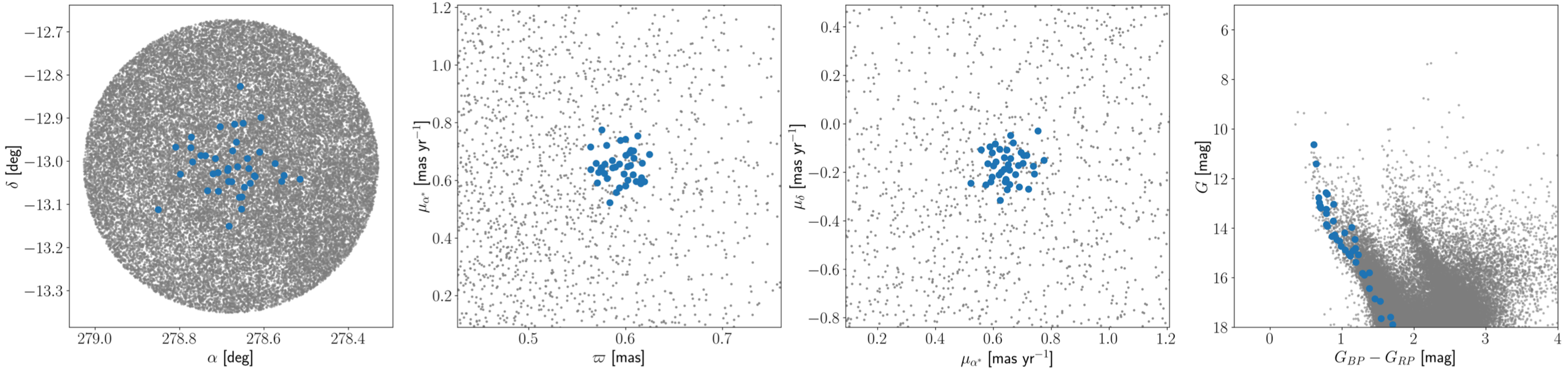
# Isochrones

- 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…



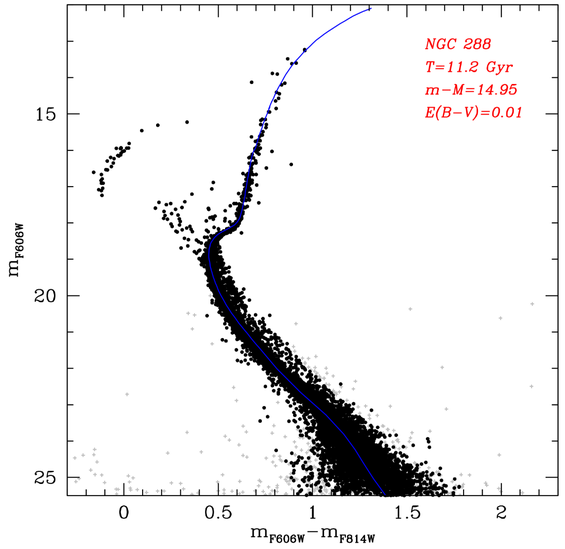
# Clusters as benchmarks

- Homework 2 (will be posted soon)
  - Your mission is to characterize an open cluster!



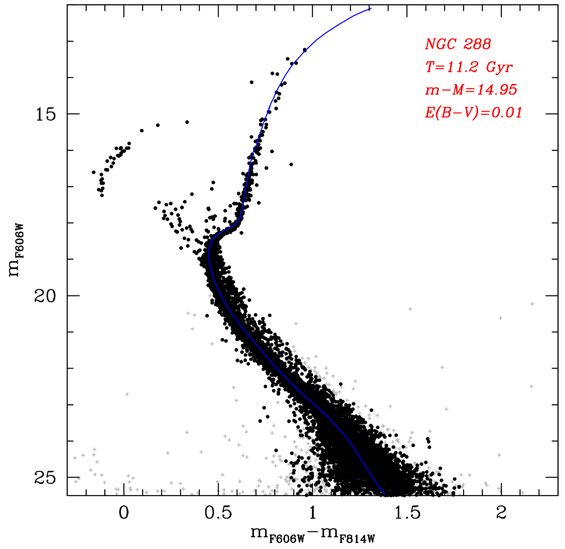
# Clusters Rock

- 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




# Clusters in other galaxies

- Nearby galaxies, open and globular… lots of comparisons.
- M31 has way more (and younger) GC’s than MWY
- PANDAS, clusters between galaxies!