Observing Globular Clusters

TAAS Astronomy 101
Jon Schuchardt
August 2016
Outline

• What are globular clusters?
• Historical significance
• Shapley-Sawyer classification
• How to find, observe, and report on globular clusters
What are Globular Star Clusters?

- Densely packed, spherical agglomerations of $10^4$ to $10^7$ very old stars (12-14 billion years old) that surround a galactic nucleus
- Most in the Milky Way are 10,000 to 50,000 light years away from us
- Diameters: 10s to 100s of light years
- Densities: average about 1 star per cubic light year, but more dense in the core
- About 150 globular clusters known in the Milky Way
What are Globular Star Clusters?

• Some globular clusters, e.g., M15, have undergone gravitational collapse in their cores

• Glob cores can be millions or even billions of times more densely populated than our solar neighborhood
  
  • Imagine a night sky with thousands of stars brighter than Sirius!

• Black holes of low stellar mass (10-20 solar masses) may be common at the center of globular clusters. They have been detected (2012-2013) in M22 (a pair) and M62 by detecting radio emissions using the Very Large Array

M62 (Ophiuchus)
Easier to “see” the black holes using radio emissions and the VLA versus a Hubble view of M22 (Sagittarius)

Figure 1: VLA radio continuum image of the core of the globular cluster M22. The two bright circled objects are the sources identified as stellar-mass black holes, M22-VLA1 and M22-VLA2. These sources have flux densities of 55–58 μJy at 5.9 GHz. We obtained the data in two separate 1 GHz basebands centered at 5 and 6.75 GHz, allowing a measurement of the spectral index of the radio emission between these frequencies. Both sources have flat radio spectra, with $\alpha = 0 - 0.2$, assuming $S_\nu = \nu^\alpha$. The faint circled object is a known millisecond pulsar. A red cross marks the photometric cluster center. 20" corresponds to approximately 0.3 pc at the distance of M22. The apparent elongation of the sources is due entirely to the elongated synthesized beam; all three circled sources are unresolved. North is up and east is to the left in this image.

Figure 2: Optical images of M22 and the candidate companion stars to the radio sources. (a) Ground-based image that shows the approximate location of the sources in the context of the star cluster. (b) and (c) show the zoomed-in location of the radio sources on an archival high-resolution Hubble Space Telescope/Advanced Camera for Surveys F814W image. These circles have radii of 0.3" for clarity; the uncertainty in the astrometric matching of the optical and radio data is < 0.1". The image orientation is as in Fig. 1. (Image credit for (a): Doug Matthews/Adam Block/NOAO/AURA/NSF)

Hertzsprung-Russell diagrams: Typical globular cluster (left) and M55 (right).

Note the "knee".
The “knee” shows where stars begin to depart the Main Sequence on their path to becoming giants.

Can be used to estimate the age of the cluster.
“The thing’s hollow -- it goes on forever -- and -- oh my God! -- it’s full of stars!”

Commander David Bowman

2001: A Space Odyssey

Arthur C. Clarke (1968)
How “full of stars” is a globular cluster?

Radius of star = 700,000 km (like our Sun)
Radius of a globular cluster = 10 parsecs (3.1 x 10^{14} km).
Volume of a sun-like star = \( \frac{4}{3} \pi (700,000 \text{ km})^3 \) = \( 1.4 \times 10^{18} \text{ km}^3 \).
Assume 500,000 stars in the cluster.

Volume of the stars = 500,000 \times 1.4 \times 10^{18} \text{ km}^3 = 7.2 \times 10^{23} \text{ km}^3.
Volume of the cluster = \( \frac{4}{3} \pi (3.1 \times 10^{14} \text{ km})^3 \) = \( 1.2 \times 10^{44} \text{ km}^3 \).

Thus, the stars only fill \( \frac{7.2 \times 10^{23} \text{ km}^3}{1.2 \times 10^{44} \text{ km}^3} = 6.0 \times 10^{-21} \text{ of the cluster's total volume.} \)

The stars are therefore separated by many astronomical units (Earth-Sun distance)

Source: Dr. Christopher Palma, Dept. of Astronomy & Astrophysics, Penn State Univ.
Historical Importance

“It is believed that the great mass of the stars ... are arranged in the form of a lens- or bun-shaped system ... considerably flattened towards one plane ... the Sun occupies a fairly central position.”

—Arthur Eddington, 1914

“It is worthy of notice...that the brighter [Cepheid] variables have longer periods.”

—Henrietta Swan Leavitt, 1908
“Since the variables are probably at nearly the same distance from the Earth, their periods are apparently associated with their actual emission of light, as determined by their mass, density, and surface brightness.”

--Henrietta Swan Leavitt (1912)
Schematic light curves for types of variable stars

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<td>Mira-type</td>
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Variable behaves the same way in nearby stars, globular clusters, or galaxies!

RR Lyrae variables: more prevalent in globs than Cepheids, but hard to detect in other galaxies.

S. Schneider et al., *Pathways to Astronomy* (2007)
Harlow Shapley’s approach

• Collect data about absolute magnitudes (roughly, L) of close RR Lyrae variable stars determined from their measured distances

• Locate RR Lyrae stars in globular clusters

• Assume RR Lyrae stars in globulars are like other RR Lyrae stars and have about the same L (almost independent of period), i.e., about 80-100x that of the Sun
  • Actual value: about 40x

• Use the “inverse square” law (brightness decreases with the square of the distance)
  • $B = \frac{L}{4\pi d^2}$

• From observed B and known L, calculate distance to the globular cluster
The period-luminosity relation

Following up Leavitt, Shapley (1918) publishes the period-luminosity relation for Cepheid-type variable stars.

Ability to relate "apparent" magnitude to "real" magnitude \( \Rightarrow \) Distance!

("Easier" solution for RR Lyrae variables, for which L is independent of period.)
“The system of globular clusters, which is coincident in general, if not in detail, with the sidereal arrangement as a whole, appears to be somewhat ellipsoidal.... The center of the sidereal system is distant from the Earth ...”

--Harlow Shapley (1918)
“If I have seen farther than others . . .

“The physical universe was anthropocentric to primitive man.... the significance of man and the Earth in the sidereal scheme has dwindled with advancing knowledge of the physical world...”

***

“From the new point of view our galactic universe appears as a single, enormous, all-comprehending unit... The adoption of such an arrangement leaves us with no evidence of a plurality of stellar “universes.”

--Harlow Shapley
• Shapley correctly shows that we are not at the center of our galaxy.

• However, only a few years later, Hubble applies Shapley’s method with Cepheid variables to show (in 1924) that “island universes” are the rule.

• **Key:** Luminosity of Cepheids = $10,000x$ that of Sun versus $40x$ for RR Lyrae variables, therefore we can more easily detect Cepheids beyond the Milky Way.

... it is because I stood on the shoulders of giants.”

--Isaac Newton
Hubble’s Luminosity Curve for Cepheid Variable found in M31 (the Andromeda Galaxy)

Period: 31.4 days. Maximum mag: 18.0, minimum mag: 19.2

“Here is the letter that destroyed my universe.”

--Harlow Shapley
Harlow Shapley

• Born 1885 (Nashville, MO, died 1972)
• Fifth-grade dropout later becomes a valedictorian
• Studies astronomy when U of MO’s School of Journalism postpones his admission
• Grad school: Princeton (with H. Russell) studies period-luminosity relation for Cepheid variable stars
• Shows that Cepheids are most likely pulsating single stars
• Director, Harvard College Observatory (31 years)
• Many papers, books published
The Shapley-Sawyer Classification of Globular Clusters

• Established in 1927 based on comparison of “Bruce photos” taken in Arequipa, Peru

• “Instead of classing the clusters . . . in two or three broad and obvious categories, we arrange them in finer subdivisions, in a series of grades on the basis of central concentration . . . Class I represents the highest concentration toward the center, and Class XII the least.”
Boyden Station, Arequipa, Peru (1889-1927)

The Bruce 24” doublet refractor
**Classification of Globular Clusters**

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From: Shapley & Sawyer, Harvard Bull. 849 (1927) 11

Extra credit if you can name the missing Messier glob!
Shapley-Sawyer Classification of Globular Clusters (1927)
Fig. 1: Comparison Pictures for Determining the Shapley-Sawyer Concentration Class

(CCD images by Brian Kimball)

From “Guide to the Globular Cluster Observing Club,” an Astronomical League publication
Astronomical League--Observing Program

• Formerly a “visual” program only, now has an option for imagers

• First award: certificate and pin; completion of the other program earns a certificate only

**WARNING:** Astronomical League observing programs can be highly addictive!
Astronomical League--Observing Program

• Requirements:
  • AL League member
  • Observe or image 50 of 190 objects listed in the AL’s *Guide to Observing the Globular Cluster Program* (buy online)
  • Use any method for locating the clusters (GOTO allowed)
  • Estimate the Shapley-Sawyer concentration class for each cluster
  • Visual observers: 1 challenge object; imagers: 3 challenge objects
  • Record date, time, location, sky conditions, equipment used as in other AL programs
  • Follow submission directions at AL website
Good recordkeeping matters for the AL. Only 1 sketch needed.

Challenge object: NGC 5466 (Boo)
Some fun facts

- 29 of Messier’s 110 objects are globular clusters
- 33 additional globular clusters are Herschel 400 objects
  - M107 is on both the Herschel 400 and Messier lists
- Only 2 globular clusters are Herschel II objects
  - NGC 5053 and NGC 6717
- NGC 5053 is a good “challenge object” for the globular clusters program because of its proximity to M53
- The entire globular clusters program can be completed during a single summer season!

*Pocket Sky Atlas, p. 45*
Helpful references for observers new & old:

**STAR WATCH**
The Amateur Astronomer's Guide to Finding, Observing, and Learning About Over 125 Celestial Objects

Philip S. Harrington

**Pocket Sky Atlas**

Sky & Telescope's

Roger W. Sinnott
Finder chart for Messier objects in Scorpius. *Star Watch*, Philip S. Harrington
Please fasten seatbelts. Where we’re going . . .

. . . we don’t need no stinkin’ hand controller!
Let’s find M13:

- High overhead in the summer sky
- Use the Summer Triangle with Vega as a pointer
- Or look between Vega and Arcturus
- Find the 4 naked eye stars of the “Keystone”

From S. French, *Celestial Sampler*
To the atlas, Batman!

- Locate Eta (\(\eta\)) and Zeta (\(\varsigma\)) of the Keystone
- Center crosshairs on the line between \(\eta\) and \(\varsigma\)
- Look for the “fuzzy star” in the finderscope or binoculars
- A 4\(^{\circ}\) field of a finder will fit M13 and Eta
- Start with low power
A low-power view of M13 can show NGC 6207:

12” f5 Dob, 27 mm Panoptic = 56X

Note the helpful “sentry stars” to the S and E of M13
Got M13? Try for M92

Use $\pi$ and $\eta$ to locate the 5/6$^{\text{th}}$ mag pair at the head of Hercules

Continue another 3° NE to target area; look for a faint fuzzy star

Use low power eyepiece first

Pocket Sky Atlas, p. 52
Got M92? Try for NGC 6229

Follow the arm from $\eta$ to $\sigma$ to $\tau$ to 52 Her

Look for star patterns that will fit within the 4° view of the finder

Stars plotted (to 7th mag) in the PSA are visible in a 9x50 finder or binoculars
Use stars you can see in the finder or a low-power eyepiece to pinpoint the cluster’s location.

The only limit to how you get there is your imagination!

*Pocket Sky Atlas, p. 52*
M5 in Serpens is worth the hop!

From S. French, *Celestial Sampler*
1. First, locate Serpens Caput. Distinctive Corona Borealis may be easier to spot to its north.

2. Find the “head” of the Serpent, then continue south to α Serpentis.
M5, continued

3. Use $\lambda$ and $\alpha$ to find a flat pyramid of 6th mag. suns to the SW about 1.5 finder views away.

4. M5 sits just N of 5 Serpens and seems a “fuzzy star” in binoculars or a 9x finder.

5. Once found, view at low power, then pump up the magnification and enjoy!

*Pocket Sky Atlas, p. 55*
There’s more globular booty within the Summer Triangle!

From S. French, *Celestial Sampler*
Let’s find M56 in Lyra:

1. Find brilliant Vega, brightest star in the Summer Triangle.

2. Connect the dots from $\beta$ to $\gamma$ Lyrae (stop by the Ring Nebula, M57!).

3. Find Albireo.

4. Look 45% of the way back from Albireo to $\gamma$.

Another “faint fuzzy” is in the bag!

Pocket Sky Atlas, p. 63
We’re in the right neighborhood for M71 (Sagitta)

1. Use Albireo to locate four 4th mag. stars of Sagitta, the Arrow, two 4° finder views to the SSE.

   Or, start with 1st mag. Altair and go < 2 finder views to the N.

2. Locate δ and γ Sagittae.

3. Look about halfway between and just SE of the connecting line.

   While there, visit the Coathanger and the Dumbbell Nebula (M27)!

*Pocket Sky Atlas*, p. 64
Globs abound low in the South, but our time is short.

Tea, anyone?

From S. French, *Celestial Sampler*
The Sagittarius Teapot brims with globular clusters. How many can you count?

M22
M28
M54
M70
M69
+ many NGCs

Pocket Sky Atlas, p. 67
Odds and ends

- Although many deep sky objects are best appreciated at low or medium power, higher powers (e.g., 150-200X) can make globular clusters pop.

- More aperture => more light gathering => more resolved stars in globular clusters.

- Use low power until you find the target of interest, then increase the magnification to see more details.

- Estimating Shapley-Sawyer concentration is easier for Messiers, harder for NGCs.

- With practice, you will better appreciate the limits of your equipment, the limits of sky conditions, and the difference between “great” (M5, M13) and “ordinary” globular clusters.
Jim K’s Observing Questions for Describing Globular Clusters:

- What is the general size and overall brightness?
- Is the core bright, compact, or not distinguishable?
- Are the stars concentrated in any one area? Highly concentrated?
- Are the stars resolved fully or just at edges or are they diffuse?
- Are there brighter stars in the cluster, do any stand out in color?
- Are there areas where stars are absent within the cluster?
- Does the size or shape change when using averted vision?
- Are other objects of interest in the same field of view?
Final thoughts

• Goodness gracious, these great balls of fire never fail to please!

• A key stepping stone to proving our non-centric position in the galaxy and the existence of the “island universes”

• A source of continuing wonder: black holes!

• An observing program within a summer’s grasp

• Shapley-Sawyer classification: a way to organize our thoughts

• Star-hop your way to discovering these wonderful objects
Thanks for your attention!

Visit [www.taas.org](http://www.taas.org) to learn more about what TAAS has to offer!