Moving On Out

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FRS: Sizing Up The Universe
Variable Stars

- **Extrinsic**
  - Sunspots
  - Eclipsing Binary
    - Algol (1200 BC, 1669 AD)
  - Star with Planet
    - Kepler and Tess Missions

- **Intrinsic – Standard Candles**
  - Cepheid Variable
    - Fixed period-luminosity relationship, yellow supergiants, periods are about a week
  - RR-Lyrae
    - Dimmer and faster – periods are about a day (or less)
  - Mira Variable
    - Very Dim and Red – periods are more than 100 days
  - Most all stars
    - Sun – 0.1% fluctuation over an 11-year period
  - Nova
  - Supernova
Outline

- A Few of my favorite “dynamic” and “star cluster” astrophotos
- Hertzsprung-Russell (HR) Diagrams and Stellar Evolution
- HR Diagrams from Gaia data
- HR Diagrams using pictures I took
- RR-Lyrae variable stars
- Using HR diagrams to measure distance
Any Questions?
Hertzsprung-Russell Diagrams

The Hertzsprung-Russell diagram is a Two Dimensional graph for plotting the relationship between a star's color index and its absolute magnitude, representing the evolution of a star over its lifetime. Stars are categorized into main-sequence stars, supergiants, giants, white dwarfs, etc., based on their position on the diagram. The main sequence forms the largest part of the graph, with blue stars being hotter and red stars being cooler.
Star Types

Hertzsprung–Russell diagram

Spectral type

Main sequence ("dwarfs")

-15

Hypergiants

-10

Supergiants

-5

Bright giants

0

Giants

Subgiants

+5

Subdwarfs

+10

White dwarfs

+15

Red dwarfs

+20

Brown dwarfs
Stellar Evolution

Animated movie traces evolution of stars in dwarf galaxy.
Any Questions?
Open Cluster M44 (Beehive)
Open Cluster M44 (Beehive)

Hertzsprung–Russell Diagram for M44

Brightness (apparent magnitude)

Color index (B−R)
Open Cluster M44

Gaia–Apparent Mag.
Open Cluster M44 Gaia–Absolute Mag.
Globular Cluster M13
Hertzsprung-Russell Diagram for M13

- Brightness (apparent magnitude)
- Color index (B-R)
Globular Cluster M13

Tolga
Hertzsprung-Russell Diagram for M13

Brightness (apparent magnitude) vs. Color index (B-R)
Globular Cluster M13
HR-Diagrams of Globular Clusters
Using Gaia Data
M53  Hertzsprung-Russell Diagram using Gaia Data
HR-Diagrams of Globular Clusters

Using Gaia Data
HR-Diagrams of Open Clusters
Using Gaia Data
NGC 6819  Hertzsprung-Russell Diagram using Gaia Data
NGC 7789  Hertzsprung-Russell Diagram using Gaia Data
HR-Diagrams of Open Clusters
Using Gaia Data
Any Questions?
M13 Hertzsprung-Russell Diagram using Gaia Data
HR-Diagram Showing RR-Lyrae Stars

Hertzsprung-Russell Diagram for M15

Brightness (apparent magnitude) vs. Color index (B-R)
HR-Diagram Showing RR-Lyrae Stars
RR-Lyrae distance: 258 parsecs
RR-Lyrae distance: 258 parsecs
**Resolution**

Full-width half-max (FWHM) = $1.22 \frac{\lambda}{D}$

$\lambda$ = wavelength, $D$ = aperture diameter
Camera/Telescope Details

Aperture: $D = 10$ inches $= 254$ mm

Wavelength: $\lambda \approx 5080$ Angstroms $= 508$ nm $= 0.508$ microns $= 0.000508$ mm

FWHM $= 1.22 \frac{\lambda}{D} = 1.22 \frac{0.000508}{254} = 0.00000244$ radians $= 0.503$ arcseconds

Focal Length: $f = 90$ inches $= 2286$ mm

FWHM in microns $= 0.00000244$ radians $\times 2286$ mm $\times 1000$ microns/mm $= 5.58$ microns

Pixel Size: $9.08$ microns/pixel

FWHM in pixels: $5.58/9.08 = 0.61$ pixels
Any Questions?
Assuming that the distance to RR-Lyrae is known, we can overlay an image of RR-Lyrae on an image of M13 to estimate the distance to the cluster. The two data points brighter than magnitude 8 are the two instances of RR-Lyrae. The RR Lyrae type variable stars in M13 sit on the so-called horizontal branch of the HR diagram. As we can see, the RR-Lyrae type variable stars in M13 are about 7 magnitudes fainter than RR-Lyrae itself. From this magnitude difference, we can estimate how much further away M13 is than RR-Lyrae: $\sqrt{10^{7/2.5}} \approx 25$. Finally, given that RR-Lyrae is 860 lightyears away, we get that M13 is about $25 \times 860 \approx 21,500$ lightyears away. This is not far from the correct answer of 22,200 lightyears.
M3/M13 Comparison: Here’s M3
M3/M13 Comparison: Here’s M13
M3/M13 Comparison

Hertzsprung-Russell Diagram for M3 and M13
M3/M13 Comparison

Click here to see the Python code.

The fits files can be accessed here:
https://vanderbei.princeton.edu/FRS_131/python/fits_files/m3-RGB.fit
https://vanderbei.princeton.edu/FRS_131/python/fits_files/m13-RGB.fit

Here's the output from Python:

difference in brightness is about 0.7 magnitude
difference in flux = $10^{(0.7/2.5)} = 1.90546071796$
relative distance factor = $\sqrt{\text{flux}} = 1.3803842646$

From Wikipedia, we see that the true distances are:

M3 = 10.4 kpc and M13 = 6.8 kpc
true distance ratio = $10.4/6.8 = 1.52941176471$
A Brief Step Back Toward Home
Earth “Passed” Mars in Oct. 2020
Questions?