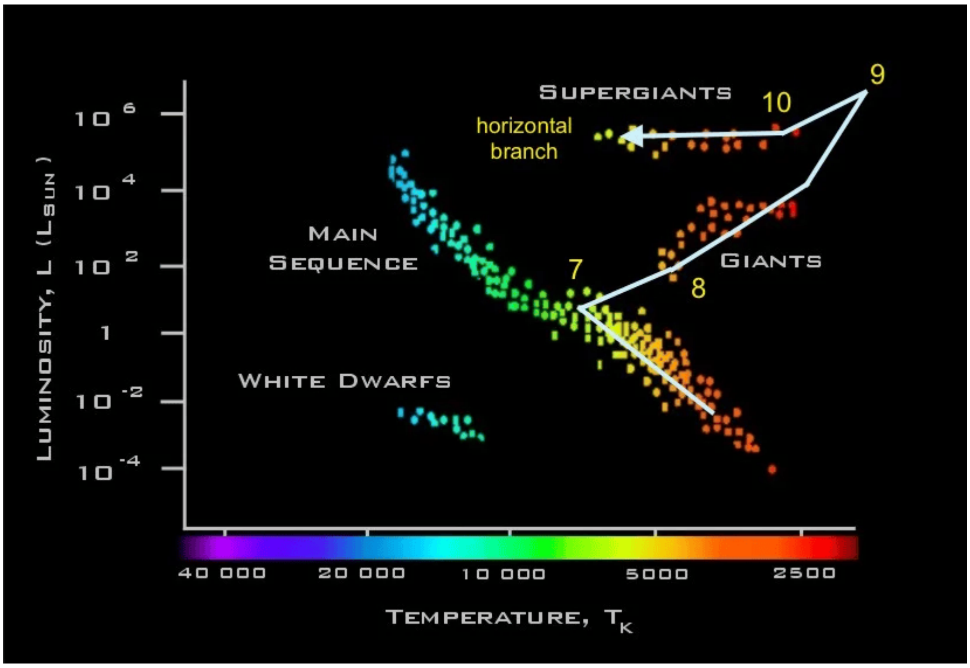
TRGB Distance Measurements

Krittika Winter Projects 2025

M.Manikantan

IISER Pune



GitHub Repository:
`https://github.com/Mani-Blaze/Kcap_winter2025`

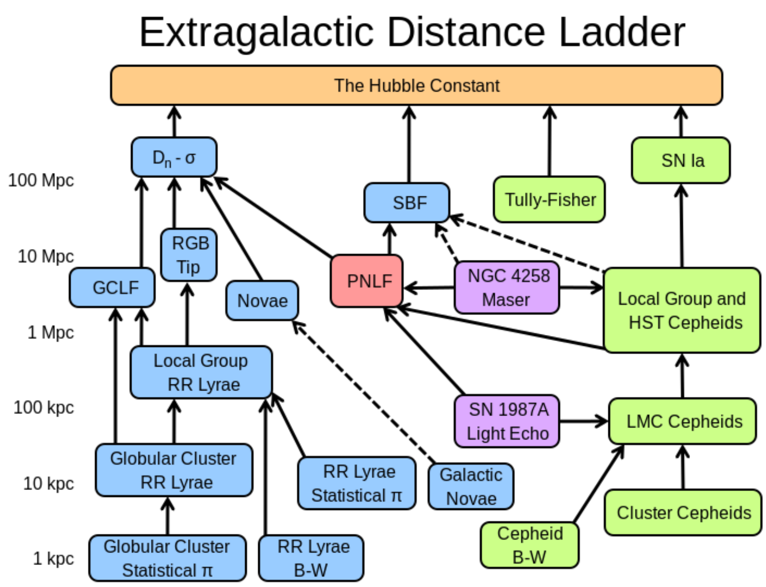
Contents

1. Overview of Distance calculation

1.1 Distance ladder

The cosmic distance ladder is the succession of methods by which astronomers determine the distances to celestial objects.The techniques for determining distances to more distant objects are all based on various measured correlations between methods that work at close distances and methods that work at larger distances. Several methods rely on a standard candle, which is an astronomical object that has a known luminosity.

- **Radar Ranging** — up to $\sim 10^{-4}$ pc (Solar System)
- **Stellar Parallax** — up to $\sim 10^{3}$ pc
- **Spectroscopic Parallax** — up to $\sim 10^{4}$ pc
- **Cepheid Variables** — up to $\sim 10^{7}$ pc
- **Tip of the Red Giant Branch (TRGB)** — up to $\sim 10^{7}$ pc
- **Type Ia Supernovae** — up to $\sim 10^{9}$ pc
- **Hubble–Lemaître Law** — beyond $\sim 10^{9}$ pc



1.2 Standard Candle

Objects of known brightness are termed standard candles

$$d = 10^{(m-M+5)/5} \tag{1}$$

The brightness of an object can be expressed in terms of its absolute magnitude(M).The apparent magnitude(m) can be measured using bolometer.This gives the distance through the above formula

2. TRGB

2.1 Helium Flash

At a certain point, the helium at the core of the star will reach a pressure and temperature where it can begin to undergo nuclear fusion through the triple-alpha process. For a star with less than 1.8 times the mass of the Sun, this will occur in a process called the helium flash. The evolutionary track of the star will then carry it toward the left of the HR diagram as the surface temperature increases under the new equilibrium. The result is a sharp discontinuity in the evolutionary track of the star on the HR diagram. This discontinuity is called the tip of the red-giant branch.

2.2 TRGB as standard candle

It uses the luminosity of the brightest red-giant-branch stars in a galaxy as a standard candle to gauge the distance to that galaxy.TRGB at helium flash has an almost absolute magnitude.It changes slightly based on metallicty of the star.

3. Observational astronomy

3.1 Hertzsprung–Russell Diagram

A Hertzsprung–Russell diagram is a scatter plot of stars showing the relationship between the stars' absolute magnitudes or luminosities and their stellar classifications or effective temperatures. In observational astronomy, we often use color-magnitude diagrams (CMDs), which plot apparent magnitude against color index.

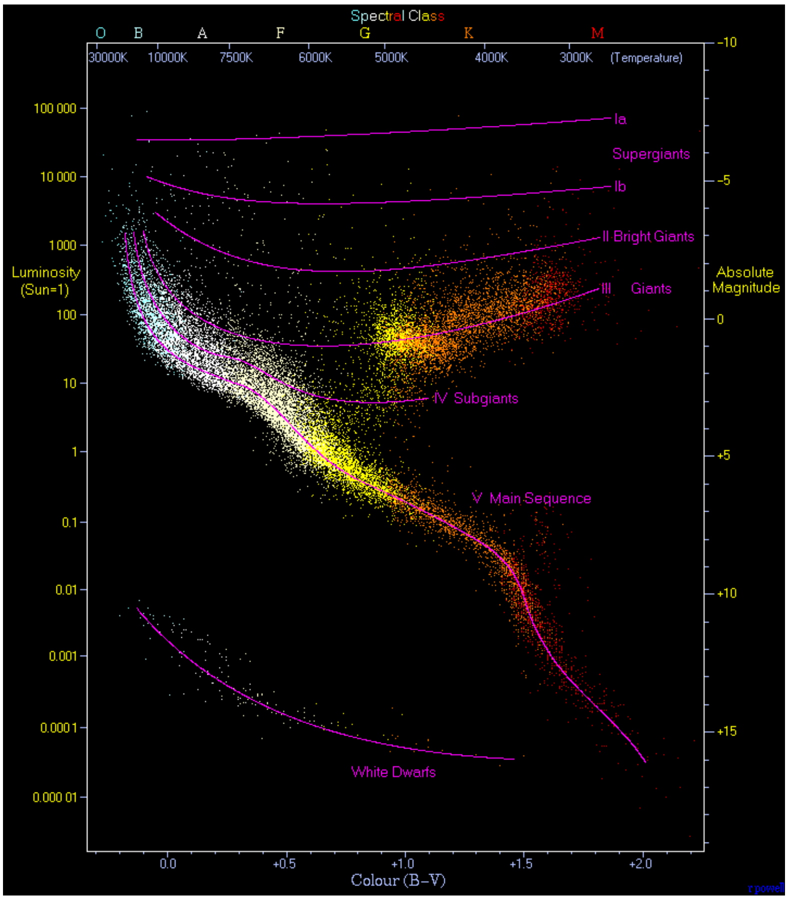


Figure 1: Example HR diagram showing main sequence, red giant branch, and TRGB location

3.2 Photometry

Photometric measurements relate instrumental magnitudes to standard magnitudes through the photometric equation:

$$m = m_{\text{inst}} + ZP \tag{2}$$

where m_{std} is the calibrated magnitude in a standard system, m_{inst} is the instrumental magnitude, and ZP is the zero-point offset determined from standard stars.

4. Tasks

4.1 Task 1: Getting magnitude

From the 12 FITS files (6 in g-band and 6 in i-band), instrumental PSF magnitudes were extracted using SExtractor and PSFEx. The zero-point calibration was performed by cross-matching detected sources with the Pan-STARRS1 (PS1) catalog. For each image, a plot of instrumental magnitude versus PS1 catalog magnitude was created, with the zero-point determined as the offset between the two.

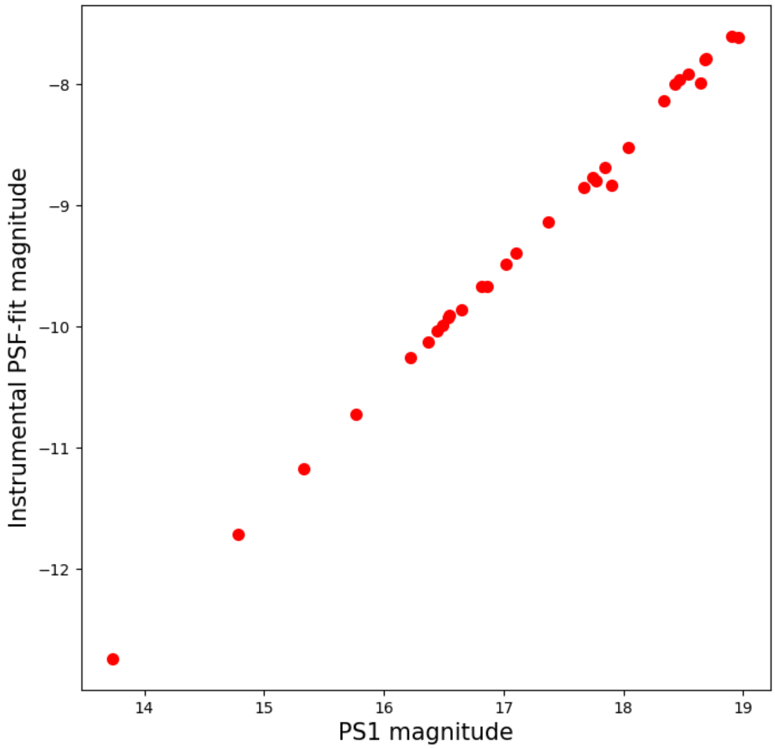


Figure 2: Example zero-point calibration plot showing instrumental PSF magnitude vs. PS1 catalog magnitude. The zero-point offset is 25.92 mag for this image.

Using this zero-point and instrumental magnitudes, we can calculate the apparent magnitude of any source using the photometry equation (2).

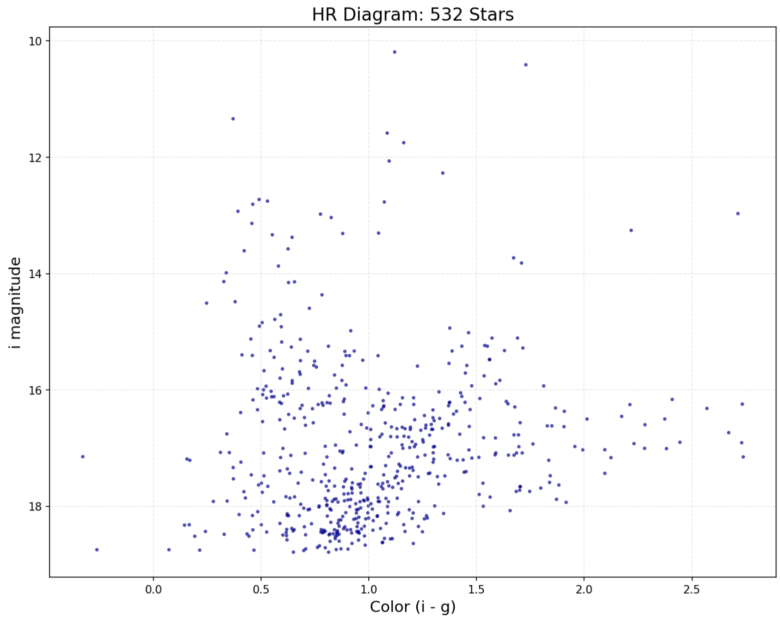
4.2 Task 2: Plotting HR diagram

Table 1: Image Data with Filters and Extracted Sources

Image Name	Filter	Sources Extracted
20251017141-300-RA	i	52
20251017135-101-RA	g	47
20251017135-812-RA	i	72
20251017140-542-RA	g	29
20251017151-115-RA	i	29
20251017150-403-RA	g	24
20251017145-642-RA	i	52
20251017144-929-RA	g	31
20251017144-208-RA	i	102
20251017143-456-RA	g	66
20251017142-734-RA	i	52
20251017142-022-RA	g	38

The 6 g filter and i filter FITS files and matched spatially and the data is pooled together.This gives a combined g filter magnitude and i filter magnitude respectively.Now i magnitude vs g-i magnitude is plotted

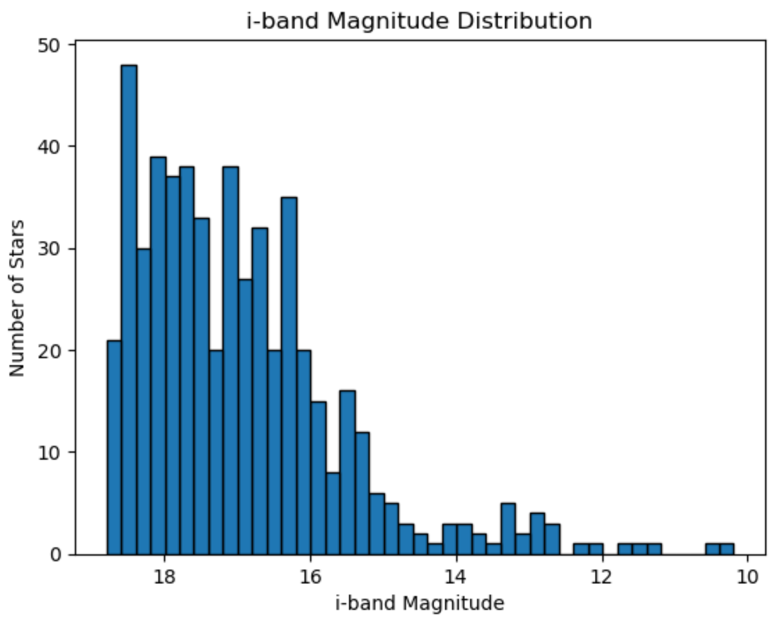
Figure 3: HR diagram



4.3 Task 3: Finding TRGB

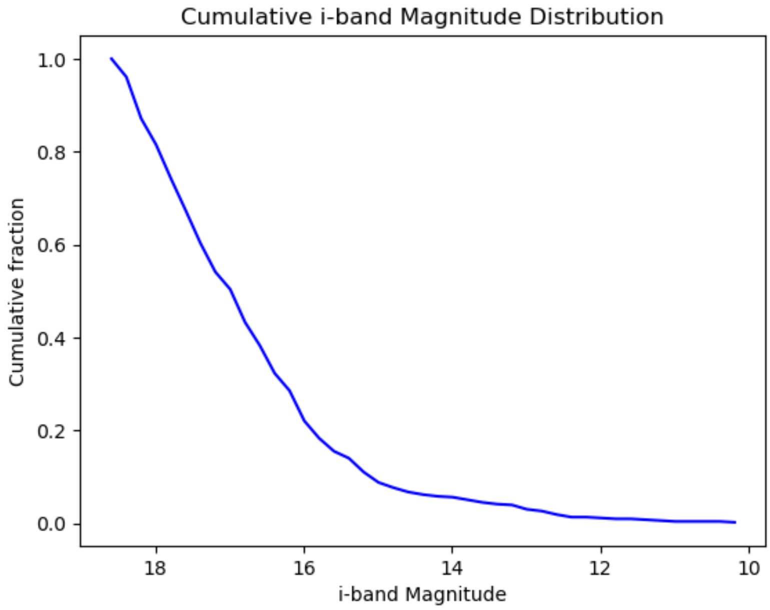
To identify the TRGB, a histogram of stellar number counts as a function of i-band magnitude is plotted. However, the TRGB is not clearly identifiable in the histogram due to photometric noise and binning effects.

Figure 4: Histogram of star counts as a function of i-band magnitude.



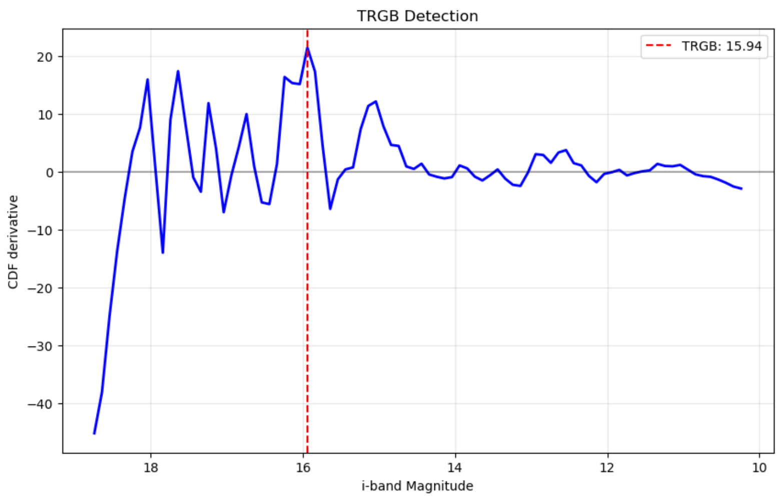
To improve the visibility of the TRGB, the cumulative distribution function (CDF) of the i-band magnitudes was computed. The CDF provides better method of viewing the count as the binning size does not effect this uncertainties.To reduce this noise, the CDF was smoothed using a Savitzky–Golay filter, producing a smooth curve

Figure 5: Smoothed cumulative distribution function (CDF) of i-band magnitudes.



The second derivative of the smoothed CDF was then computed.The TRGB corresponds to a sharp change in the luminosity function and is the highest peak in the second derivative

Figure 6: TRGB detection



4.4 Task 3: Finding distance

Now we have the apparent magnitude of the TRGB and the absolute magnitude of the TRGB from literature.Using the distance modulus equation we can find the distance to the object.

1. **Statistical error from TRGB detection**: 0.1 mag (from histogram bin size)
2. **Systematic photometric error**: 0.101 mag (from zero-point calibration and PSF fitting)
3. **Absolute magnitude uncertainty**: 0.12 mag (from metallicity dependence and age dependence)

The total magnitude error is calculated by adding these errors in quadrature:

$$\sigma_{\text{total}} = \sqrt{0.1^2 + 0.101^2 + 0.12^2} = \sqrt{0.01 + 0.0102 + 0.0144} = \sqrt{0.0346} = 0.186 \text{ mag}$$

Using distance modulus relation 1 and standard deviation we get the distance=97.01±3.61kpc

References

1. https://arxiv.org/pdf/astro-ph/0003223
2. https://iopscience.iop.org/article/10.3847/1538-4357/ab9cbb/pdf