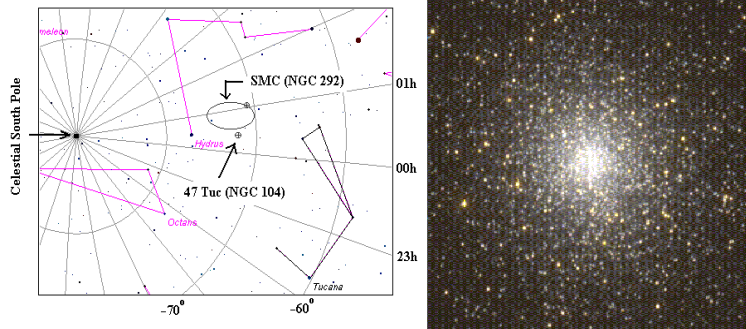


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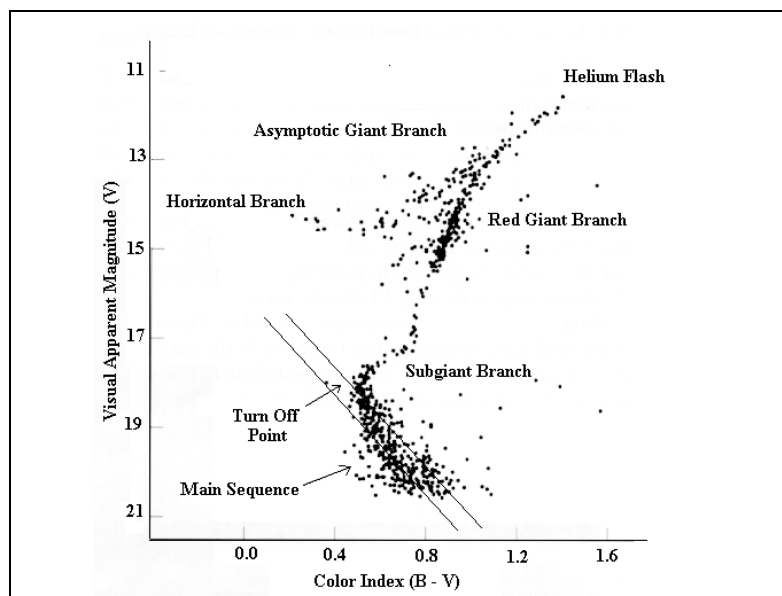
Project VI – The Age of a Globular Cluster



The Toucan (Tucana) is one of the circumpolar southern constellations. If you live north of Mexico City or Bombay you won't find it. The constellation is famous for two deep sky objects: the large globular cluster known as 47 Tucanae (NGC 104), and the Small Magellanic Cloud (SMC), an unusual naked-eye galaxy (NGC 292).

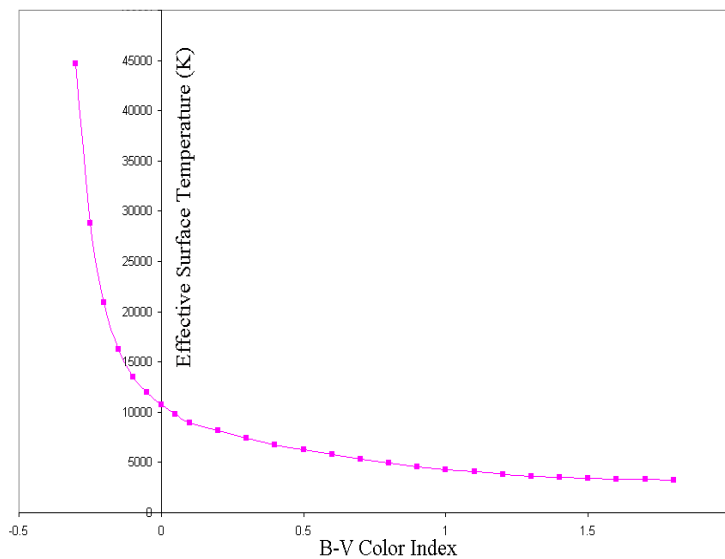
The Figure above on the left shows the location of *47 Tuc* in the southern sky next to *SMC*, while the Figure on the right shows a picture of *47 Tuc*. Globular clusters are very old systems of 0.1-1 millions stars gravitationally bound into a single structure about 100 light-years across. Approximately 150-200 globular clusters have been observed orbiting around our Galaxy.

The typical HR diagram of individual stars in a globular cluster looks like this



Shown above is an example of an HR diagram for the globular cluster M13. Various regions of the HR diagram are identified: the Main Sequence (MS); the Turn off point (TO); the Subgiant (SGB) and Red Giant (RGB) Branches; the Helium Flash (HF); the Asymptotic Giant Branch (AGB); and the Horizontal Branch (HB). A crucial assumption in understanding the evolution of a globular cluster is to assume that all members of the cluster are of the **SAME AGE**.

NOTE: The color index $(B - V) = m_B - m_V$ of a star represents the difference between its apparent magnitude in the blue (B) range and its apparent magnitude in the yellow (V) range. A hot star will have $m_V > m_B$, and thus a negative color index $(B - V) < 0$, while a cold star will have $m_V < m_B$, and thus a positive color index $(B - V) > 0$.



The Turn Off point is especially important since its location on the Main Sequence allows us to determine the age of the globular cluster. Once the absolute magnitude at the Turn Off point is obtained from the cluster's HR diagram, the graph of the MS lifetime versus (visual) absolute magnitude can be used to determine the age of the cluster.

3 Steps for Determining the Age of a Globular Cluster

- Step 1. Draw an HR diagram of representative stars of the Globular Cluster.
- Step 2. Determine absolute magnitude of the Turn Off point by using the Main Sequence (MS) line as a reference.
- Step 3. Use plot of the MS lifetime versus absolute magnitude (see below) to determine the age of the Globular Cluster.

Age of Globular Cluster = MS Lifetime at Turn Off Point
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The Data Table below contains information about the visual absolute magnitude (M_V) and the color index ($B - V$) for a representative group of 20 stars belonging to the globular cluster *47 Tuc*.

Star	Color Index $B - V$	Absolute Magnitude M_V
1	0.98	6.7
2	0.93	6.5
3	0.88	6.2
4	0.83	5.9
5	0.69	5.2
6	0.65	4.9
7	0.60	4.5
8	0.57	4.1
9	0.58	3.8
10	0.65	3.2
11	0.73	2.3
12	0.82	1.6
13	0.85	1.0
14	0.99	0.1
15	0.69	0.1
16	0.79	0.1
17	0.59	0.1
18	1.10	-0.4
19	1.25	-1.3
20	1.45	-1.9

(a) **STEP 1.**

First, place the following two Main-Sequence reference stars on a HR diagram (place the B-V Color Index on the horizontal axis and the Absolute Magnitude on the vertical axis of your HR diagram) and draw a straightline joining the two reference stars.

Color Index $B - V$	Absolute Magnitude M_V
0.08	2.0
1.04	7.0

Next, place the 20 *47 Tuc* stars in the Table above on your HR diagram.

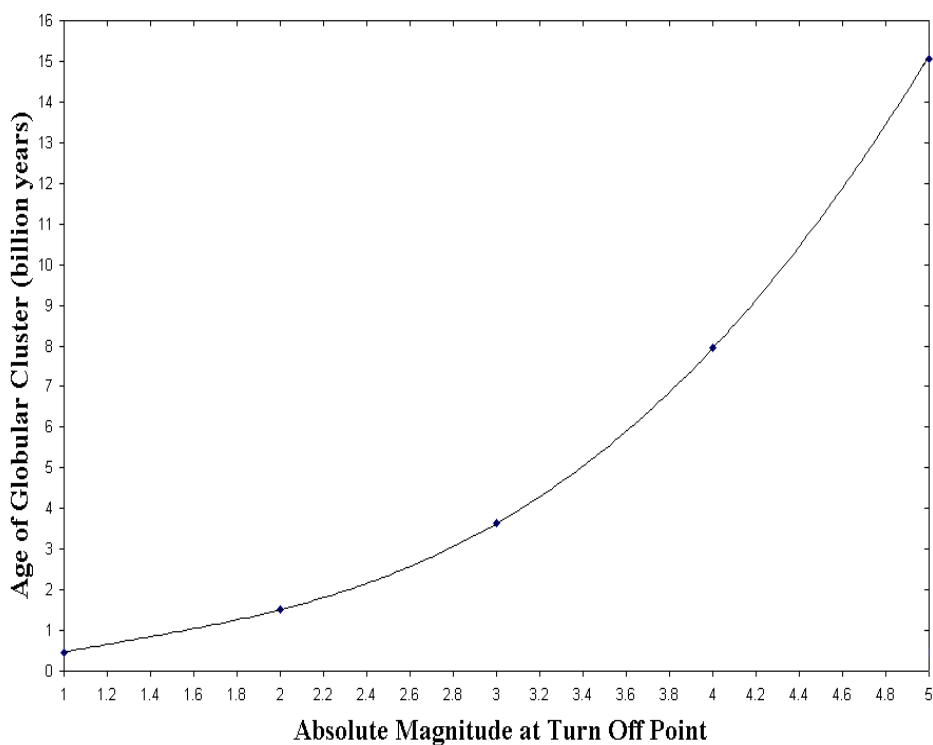
(b) **STEP 2.**

Determine the absolute magnitude $M_V^{(\text{TO})}$ of the Turn Off (TO) point on the HR diagram of *47 Tuc*. (Once again the Turn Off point is observed at a location on the Main Sequence line beyond which stars of the Globular Cluster move away from the Main Sequence.)

$$M_V^{(\text{TO})} = \underline{\hspace{2cm}}$$

(c) **STEP 3.**

Using the graph below



convert the absolute magnitude $M_V^{(\text{TO})}$ to the age of globular cluster *47 Tuc*

$$t_{47 \text{ Tuc}}(10^9 \text{ y}) = \underline{\hspace{2cm}}$$

(d) The distance modulus $m - M = 5 \log(D/10)$ of a globular cluster is approximately constant for all its stars and yields the distance D to the cluster.

Determine the distance of the globular cluster *47 Tuc* if its distance modulus is approximately $(m - M)_V = 13.9$.

$$D = \underline{\hspace{2cm}}$$

