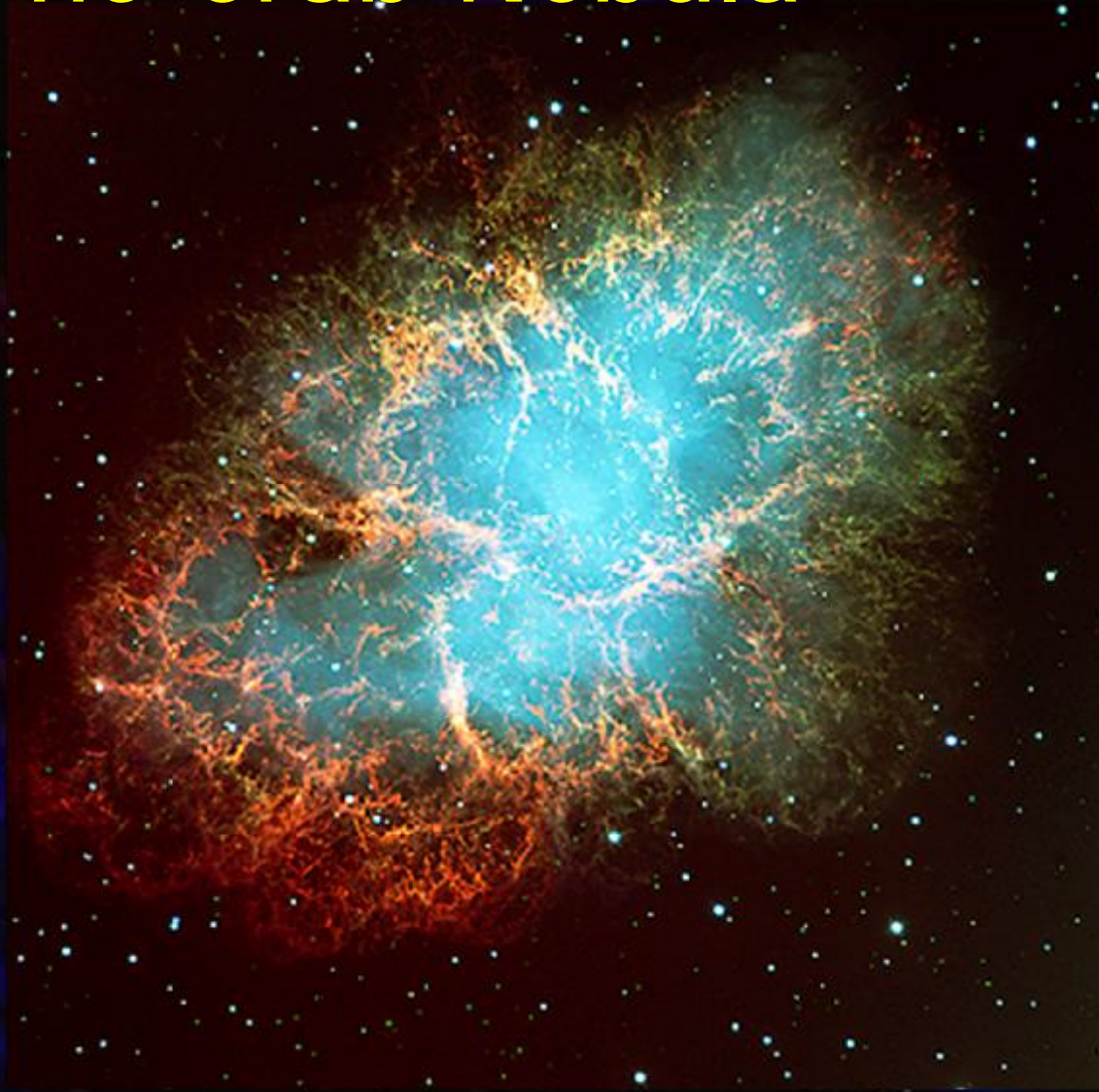


M1 - The Crab Nebula

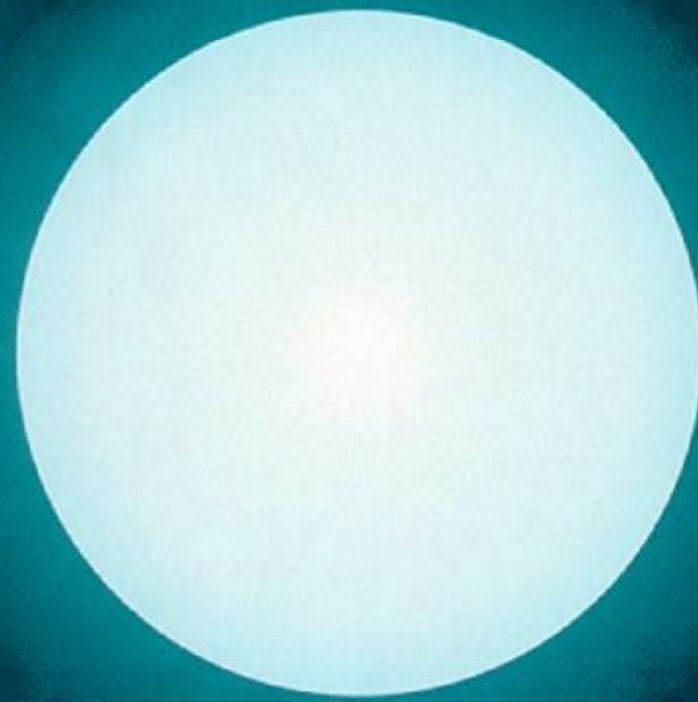


Crab Nebula





Earth

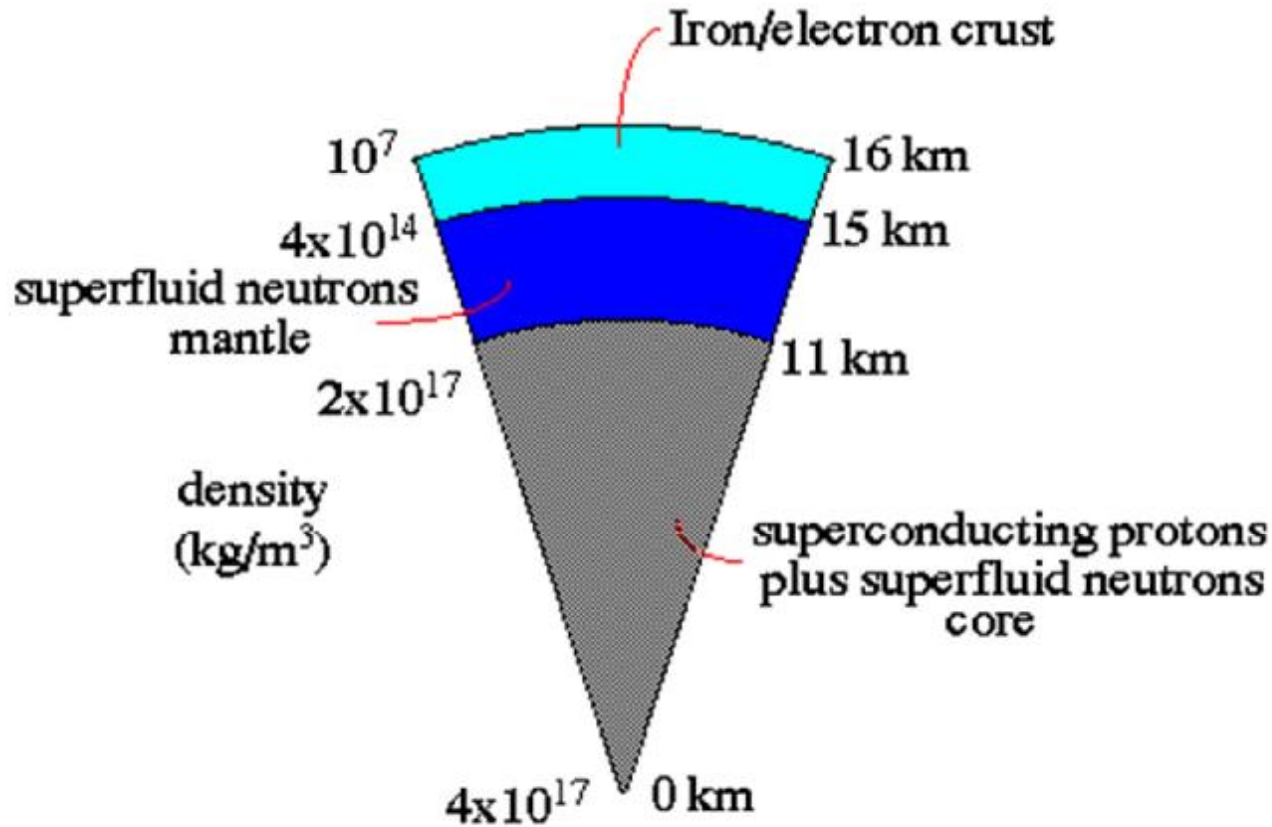


Solar-mass white dwarf



neutron star

Neutron Star Interior



220,000,000 tons
per cubic inch

Limit ~ 3 solar M

Spin up to 38000 rpm
Mag field: 10^{14} gauss

How do we know that neutron stars actually exist?

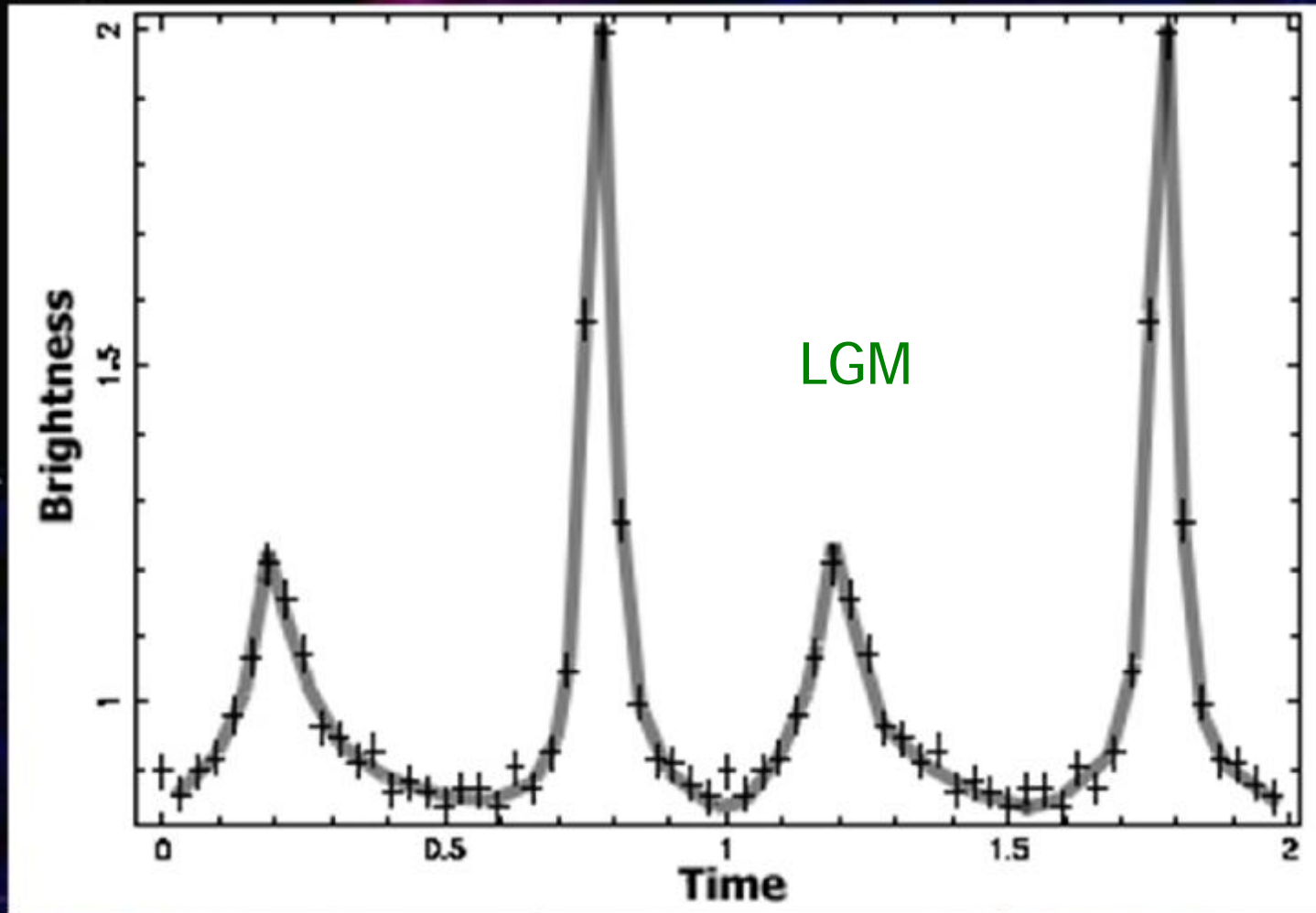
§ First theorized in the 1930's

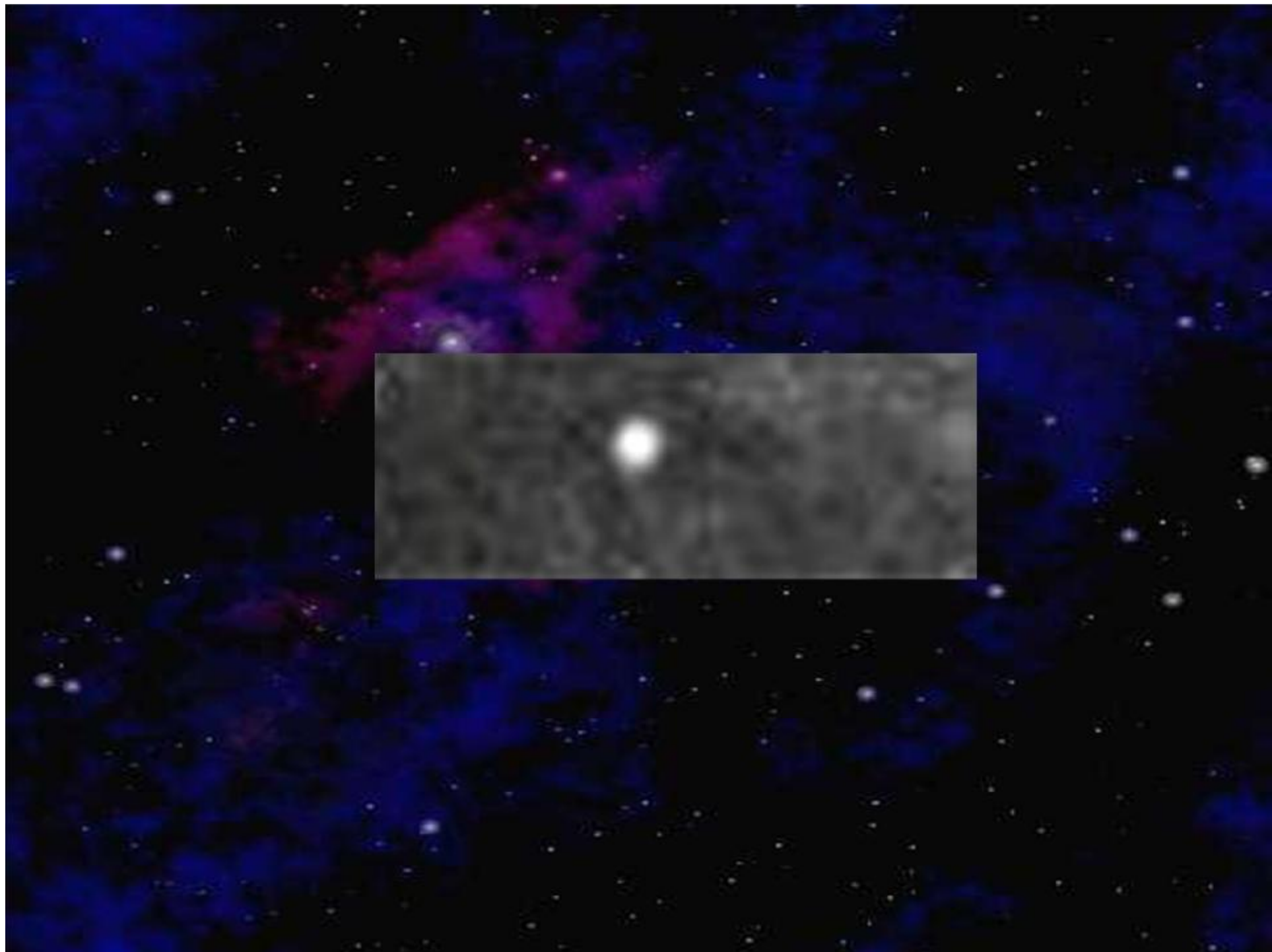
§ First discovered in 1967

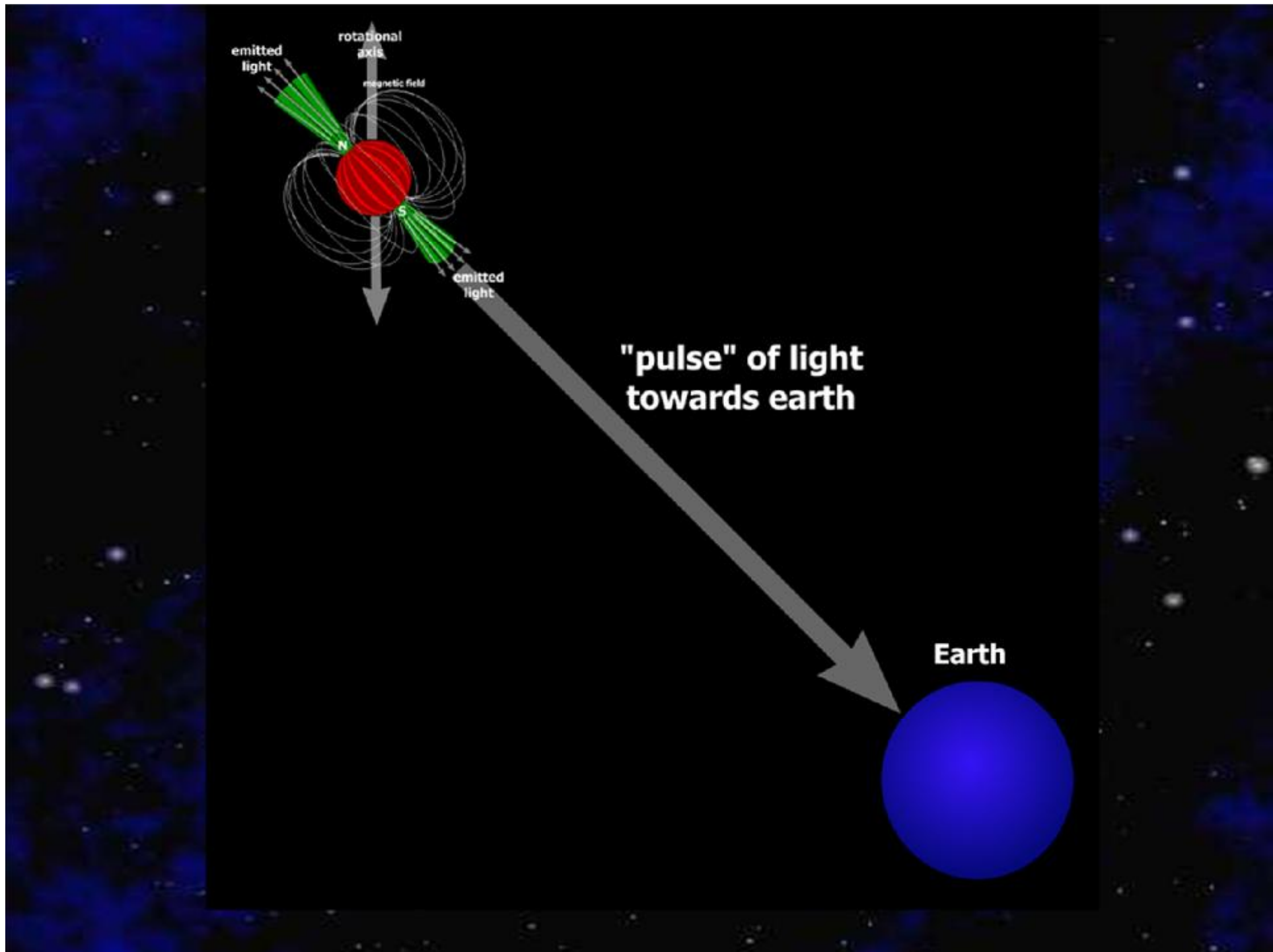




“pulsed” energy every 1.34 seconds







MPIfR-Bonn Pulsar Group





Rapidly rotating neutron star

-or-

PULSAR

What if the iron core $> 3.0M_{\odot}$.

§ Degeneracy pressure is overcome by gravity

§ The core continues to shrink producing NO HEAT.

§ No force in nature can stop the collapse

ESCAPE VELOCITY

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$



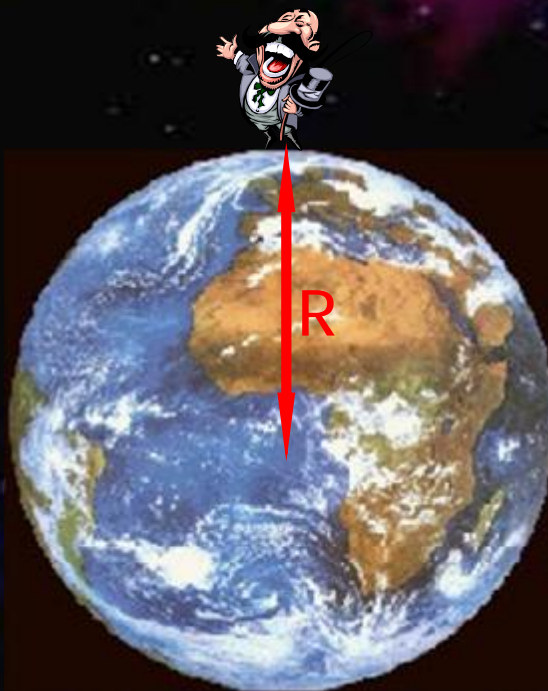
G = Universal Gravitational Constant

M = Mass of the gravitating body

R = Radius of the gravitating body

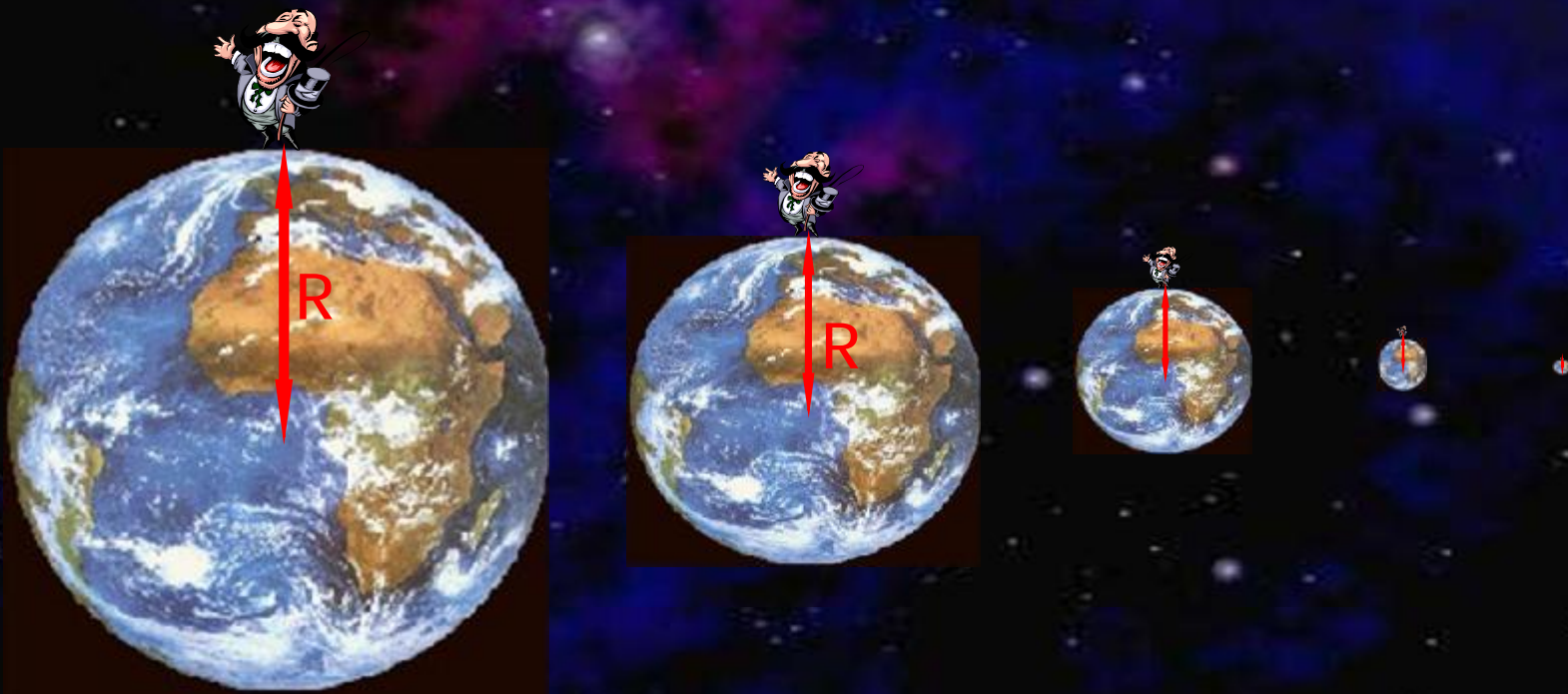
$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

$$F = \frac{Gm_1m_2}{r^2}$$



$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

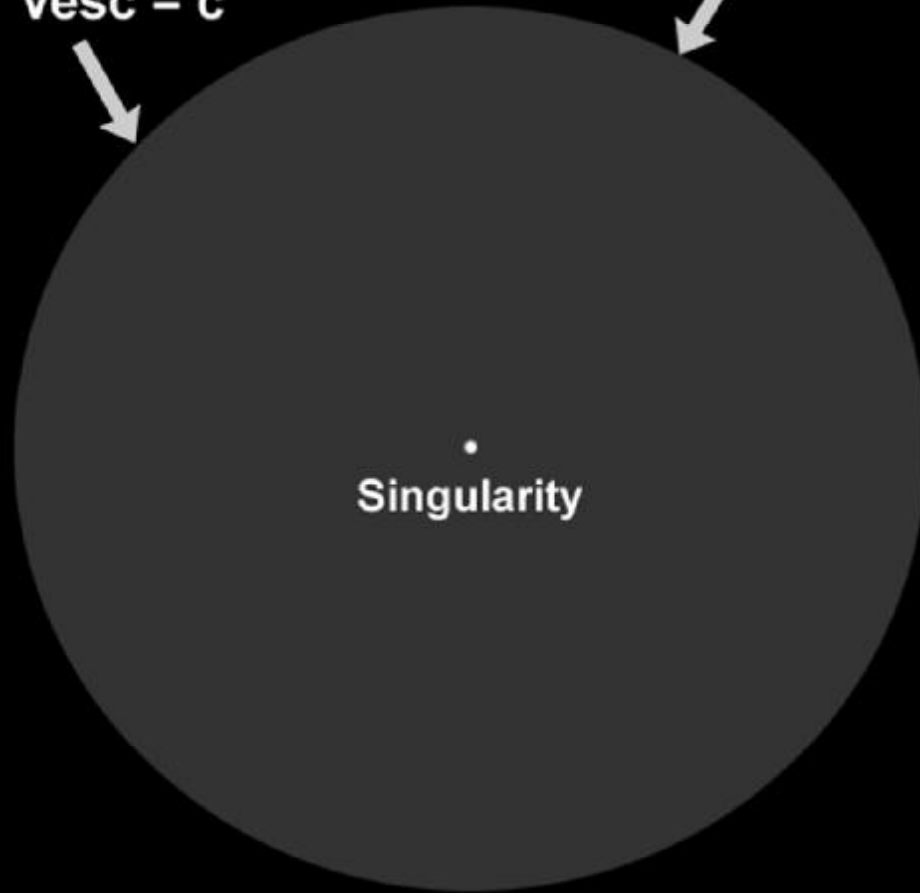
$$F = \frac{Gm_1m_2}{r^2}$$



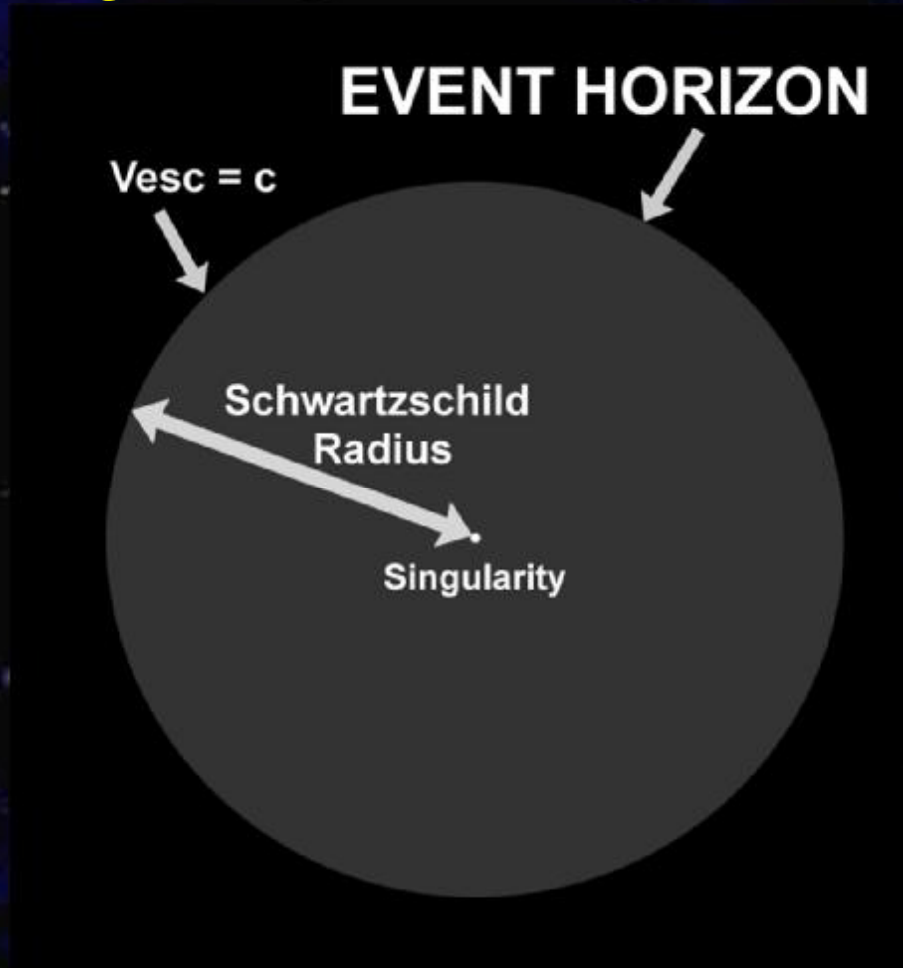
EVENT HORIZON

$V_{esc} = c$

Singularity



Physical Properties of Black Holes



$$R = \frac{2GM}{c^2}$$

$R =$ Schwarzschild Radius

Size of event horizon depends only on MASS

Examples

$$M = 3 M_{\odot}$$

$$R_S = 9\text{km (5.4 mi)}$$

$$M = 1 M_{\odot}$$

$$R_S = 3\text{km (1.8 mi)}$$

$$M = 1 M_{\text{earth}}$$

$$R_S \sim 1 \text{ cm}$$

A deep space photograph showing a galaxy cluster. The background is a dark blue field filled with numerous small, distant stars. In the center, there is a prominent, irregularly shaped structure of glowing purple and red filaments, likely representing a complex of gas or dust within the cluster. The overall scene is a vast, multi-colored cosmic landscape.

**If we can't see 'em, how do
we find 'em?**

Solitary stellar mass black hole





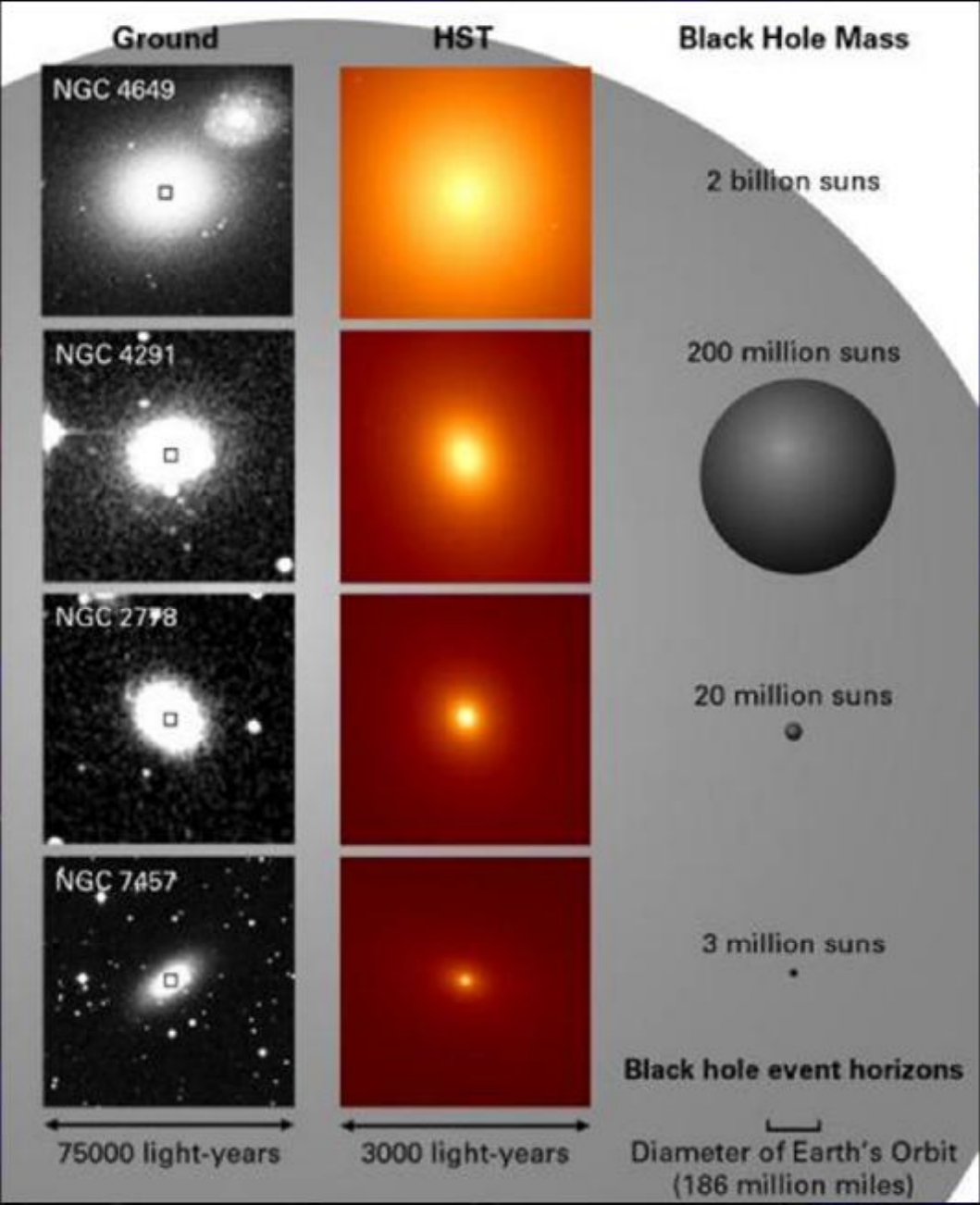
www.spacetelescope.org



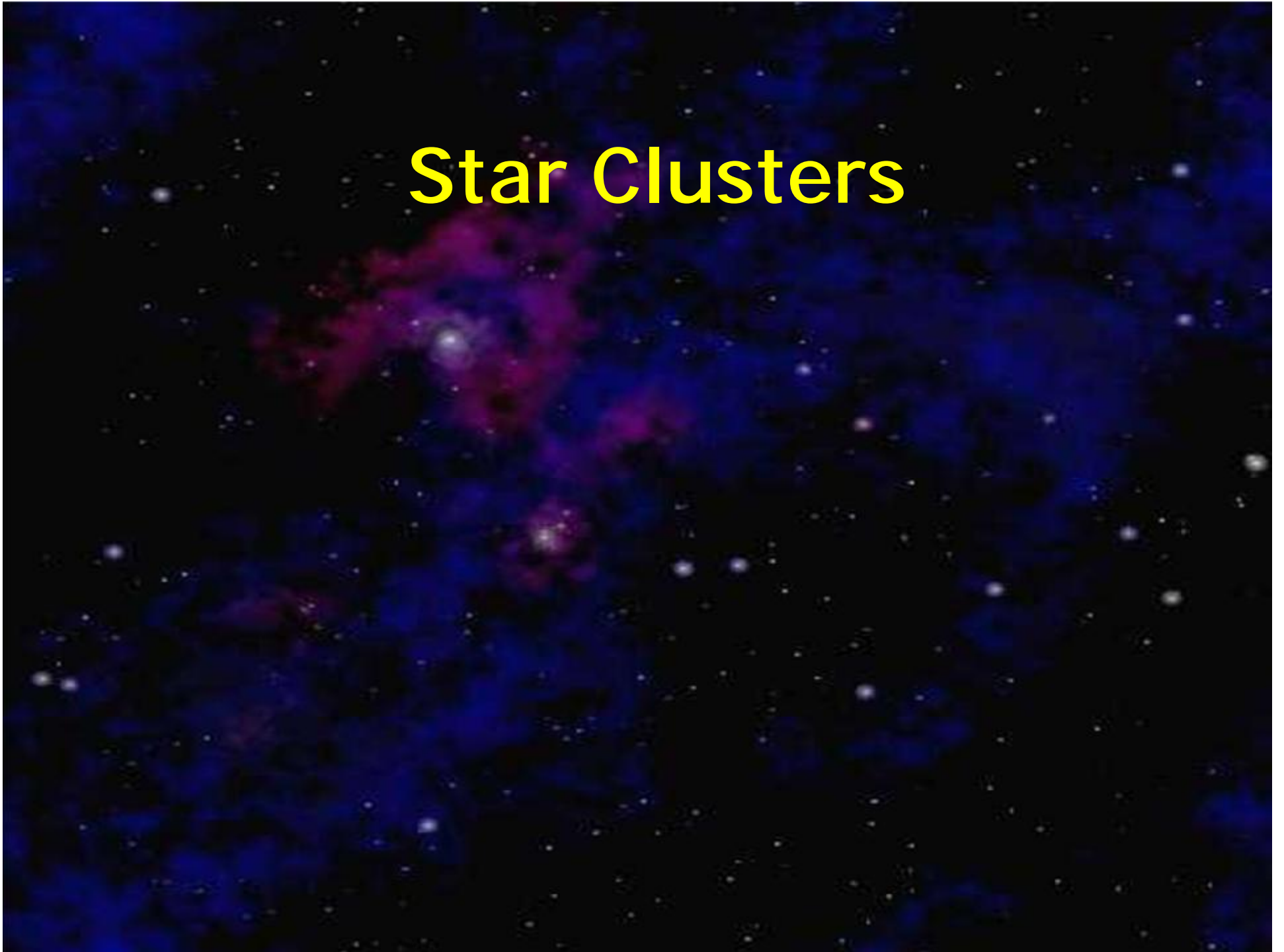
www.spacetelescope.org

Solitary stellar mass black hole





Star Clusters



Open Cluster M6



Open Cluster M7



Open Cluster M38

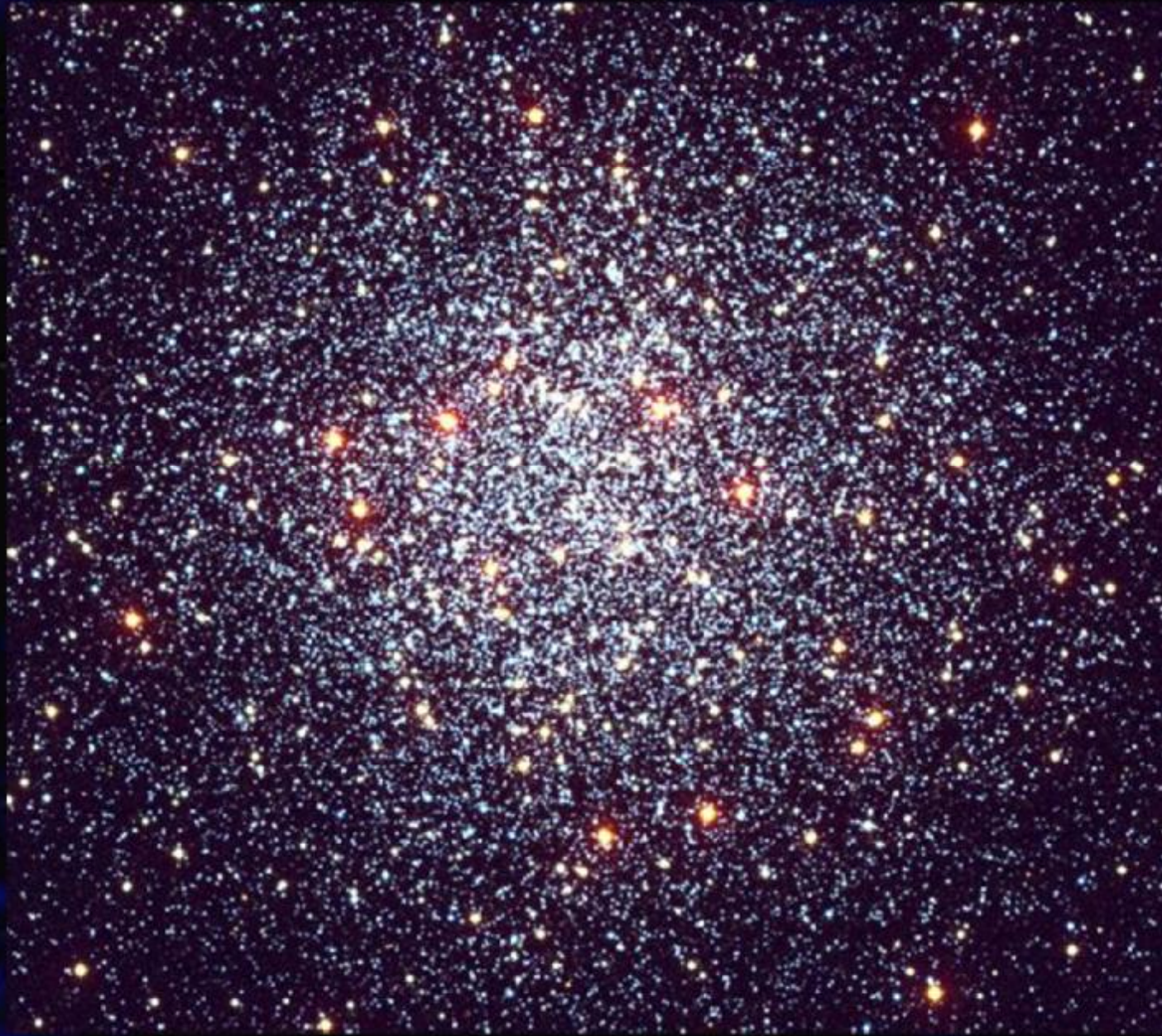




Globular Cluster M55

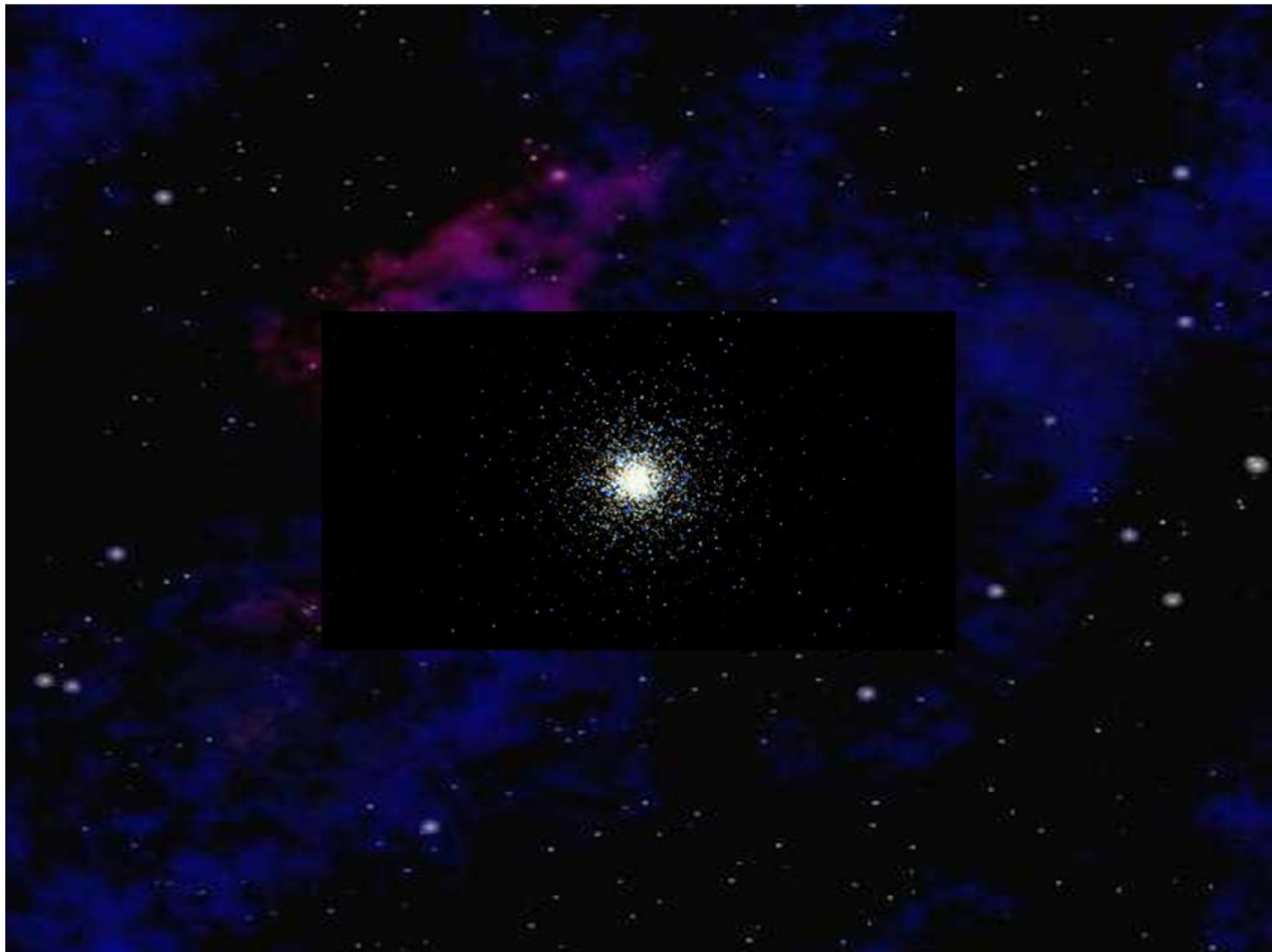


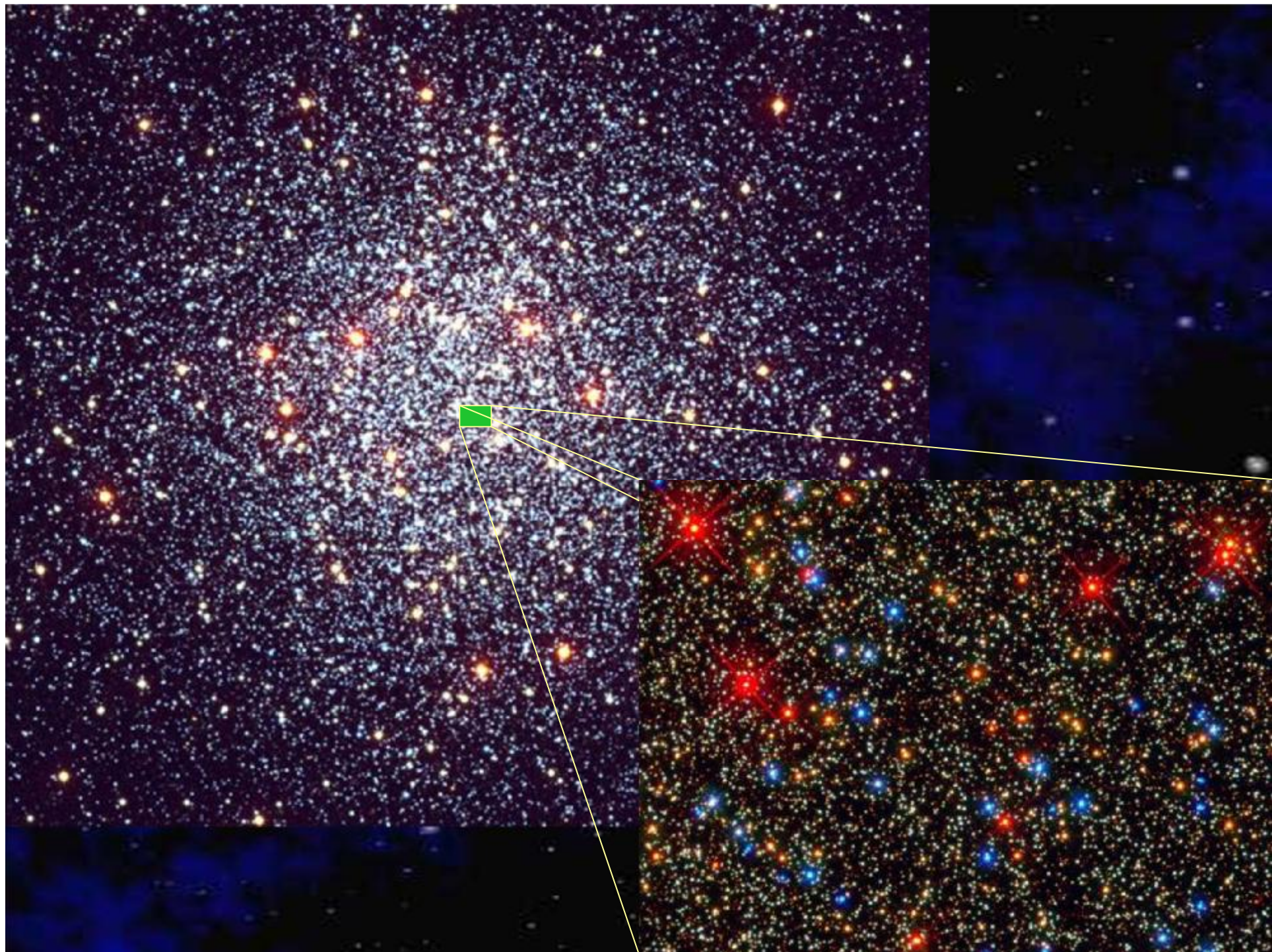
Globular Cluster M55



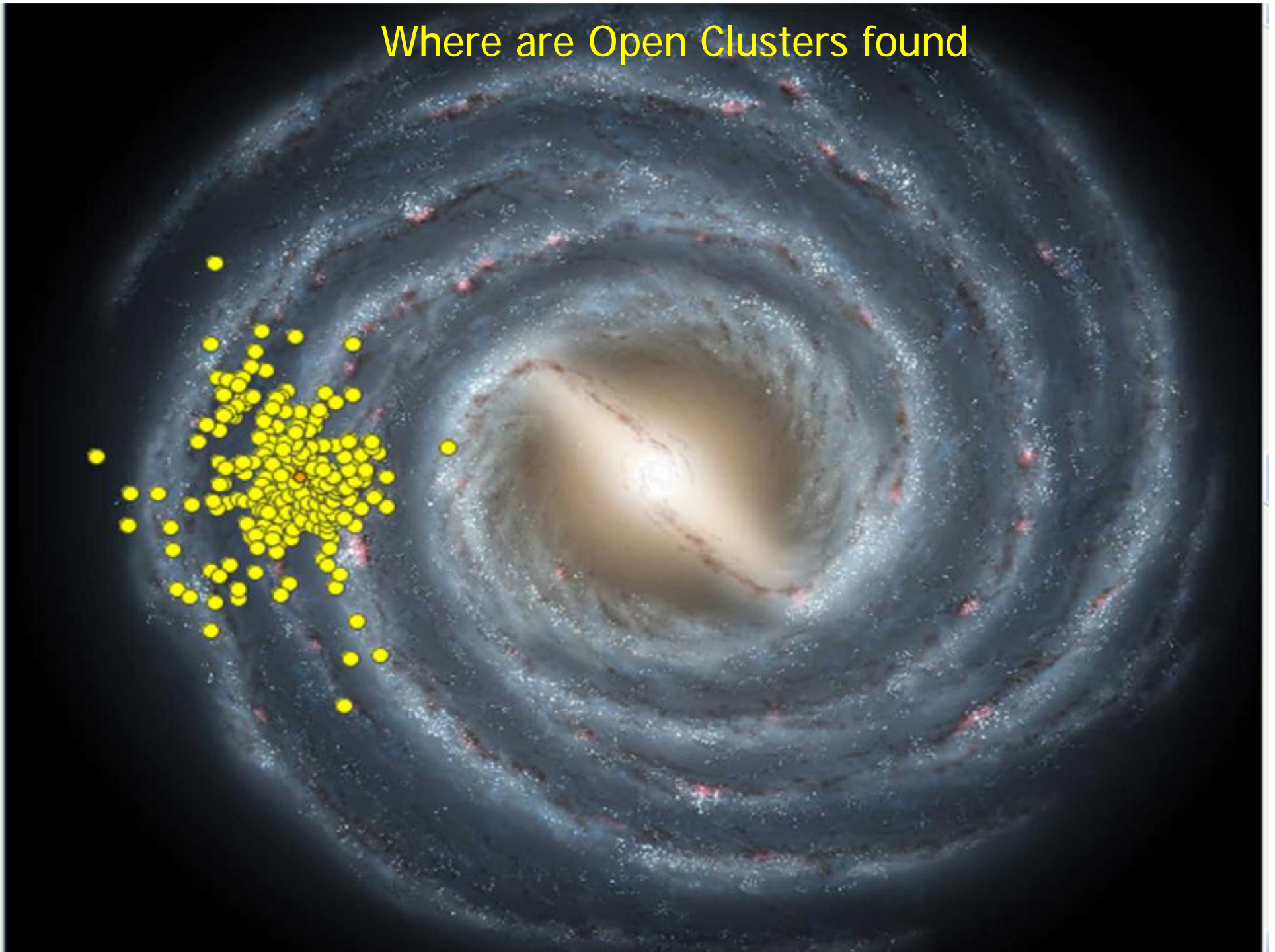


www.spacetelescope.org





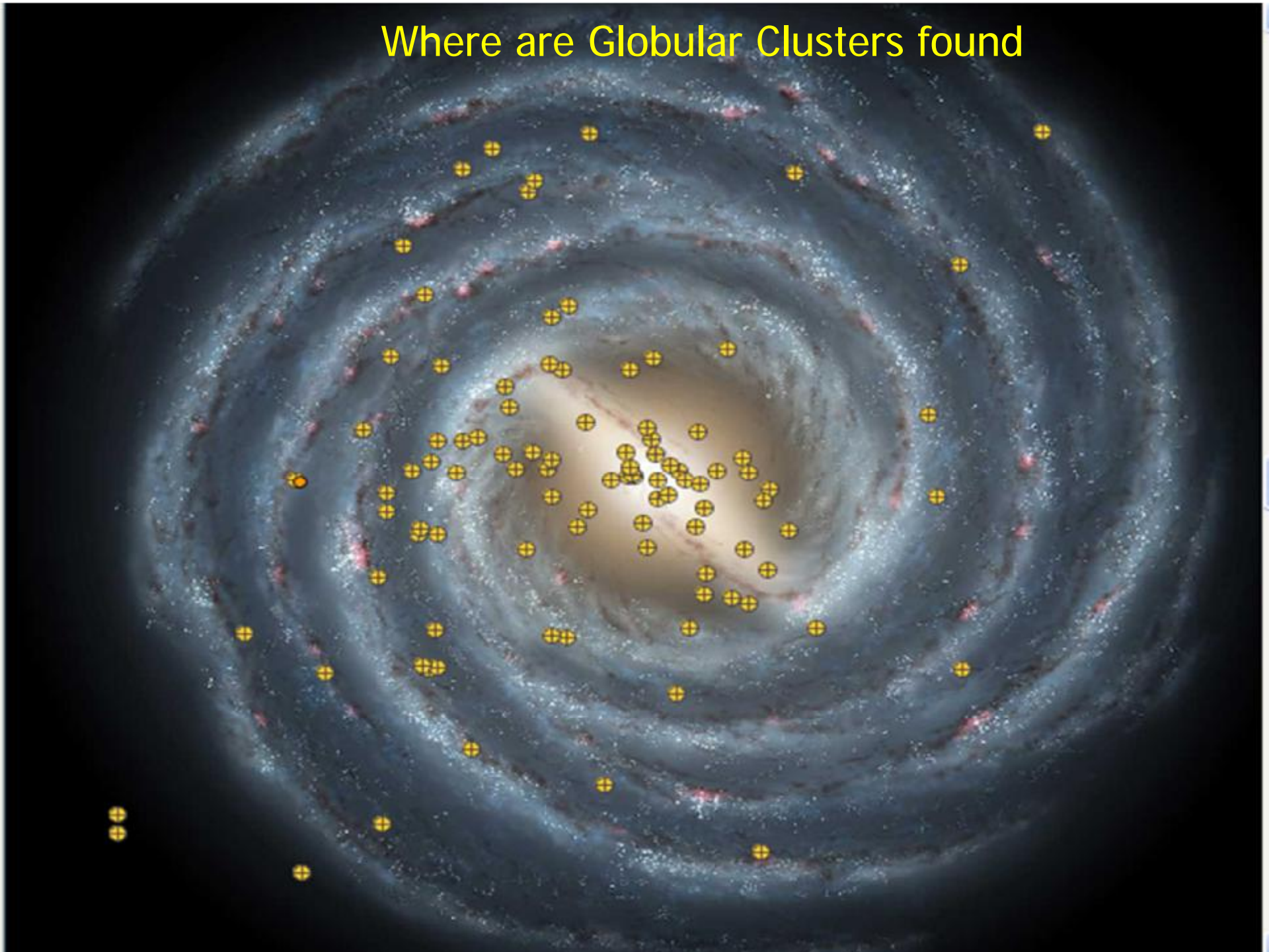
Where are Open Clusters found



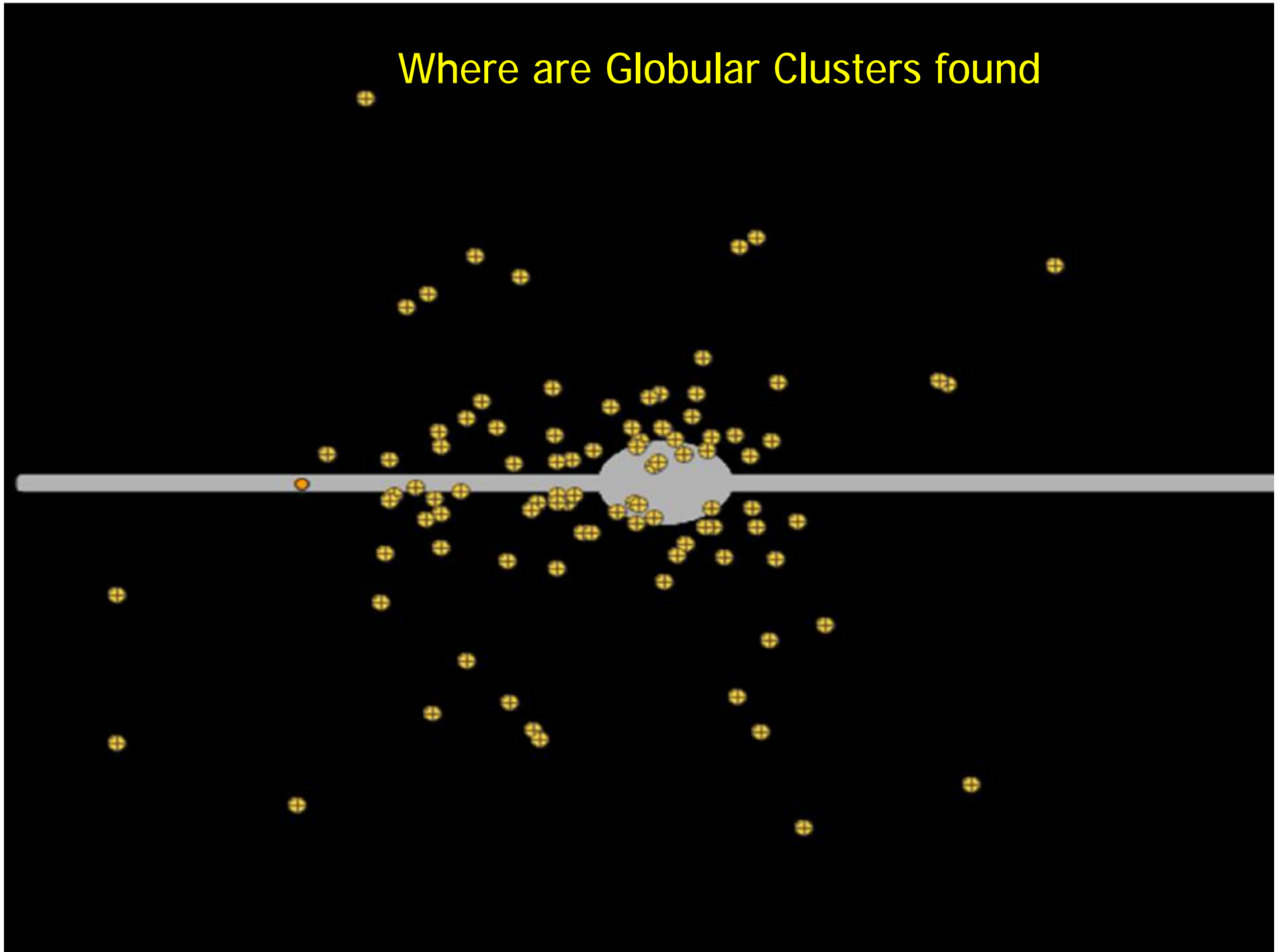
Where are Open Clusters found



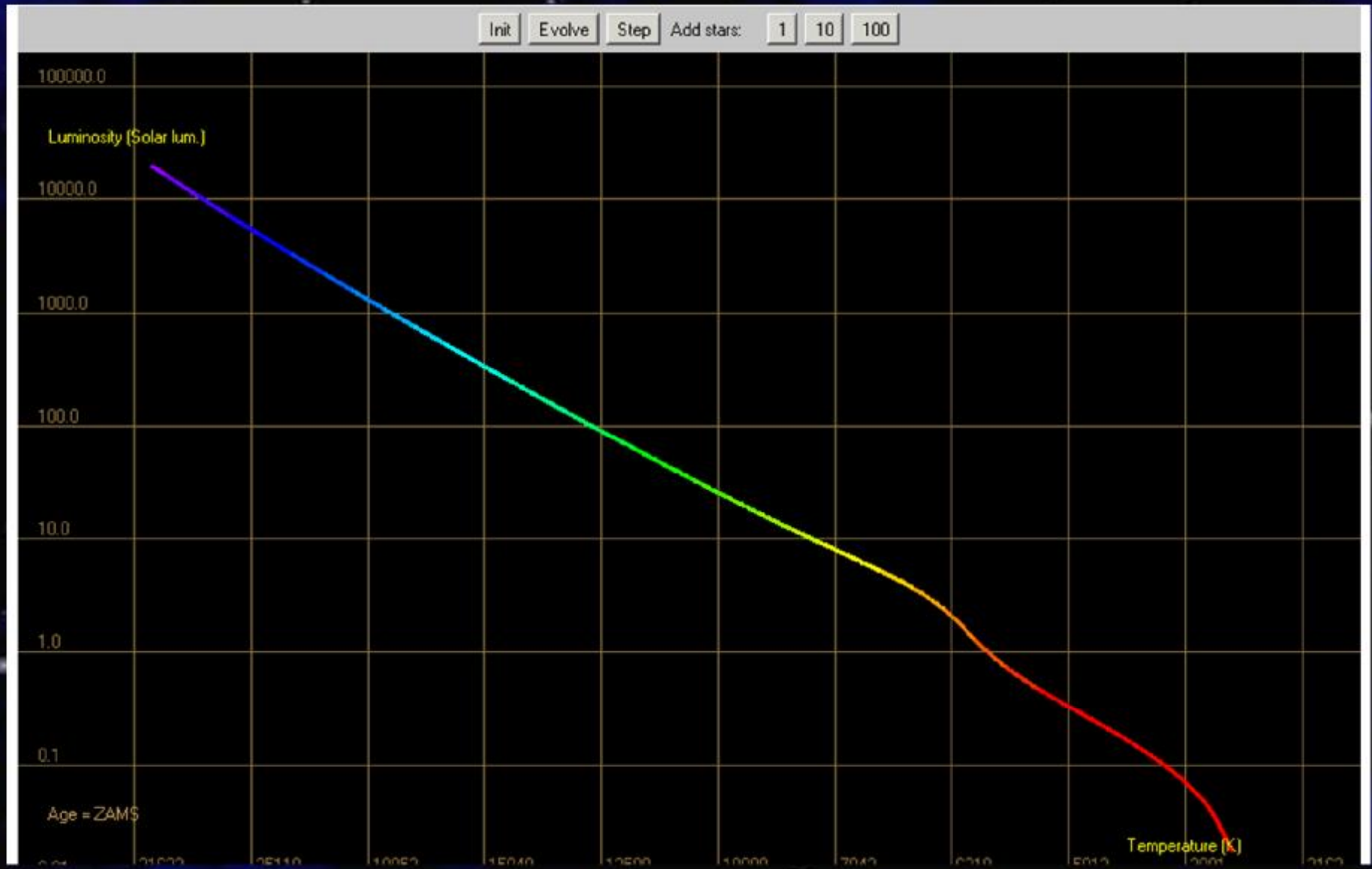
Where are Globular Clusters found



Where are Globular Clusters found



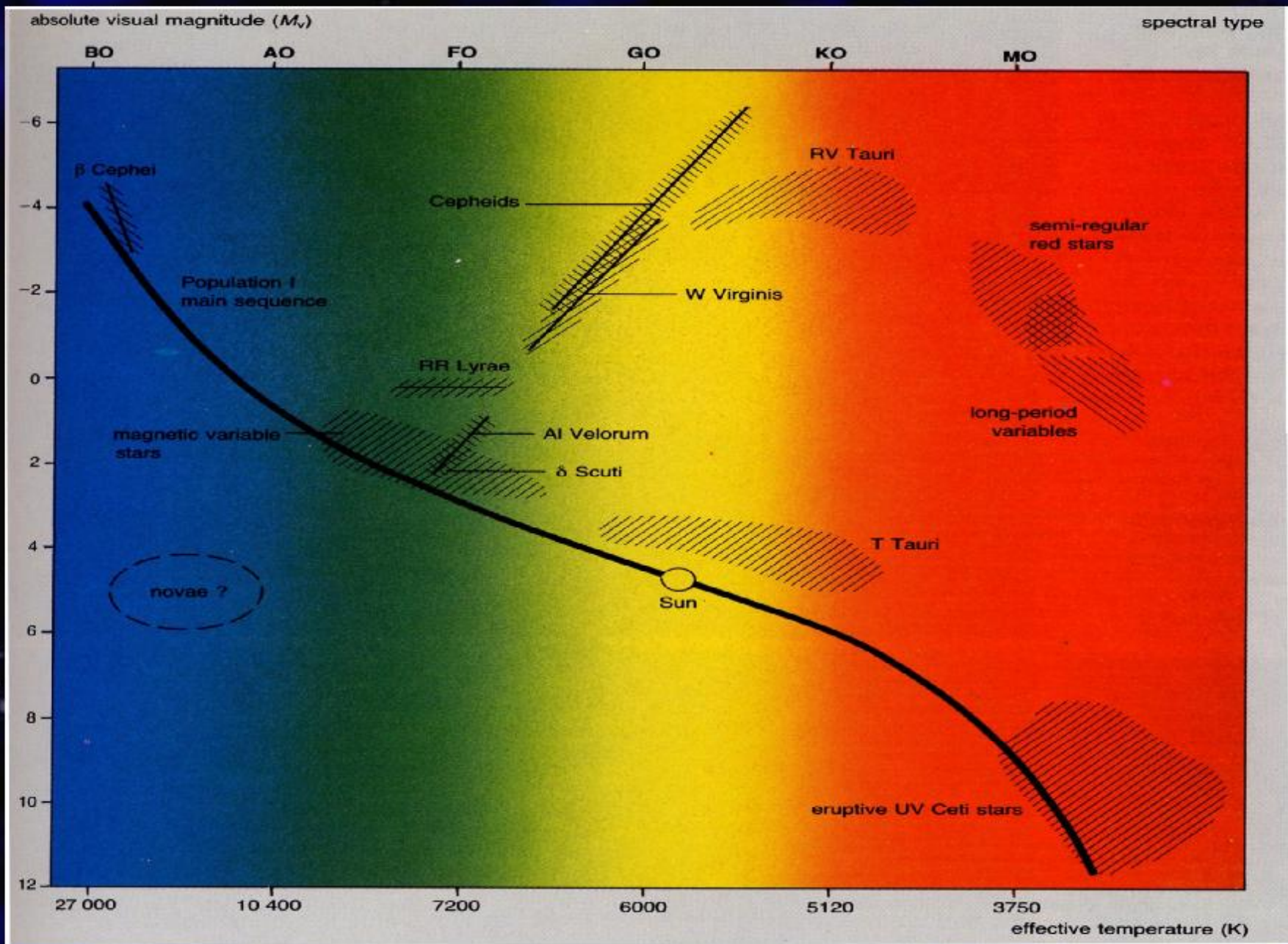
Recall the lifespan of a star depends on its Mass



As Observed from the earth, the distance to all the stars within a cluster are ~ the same

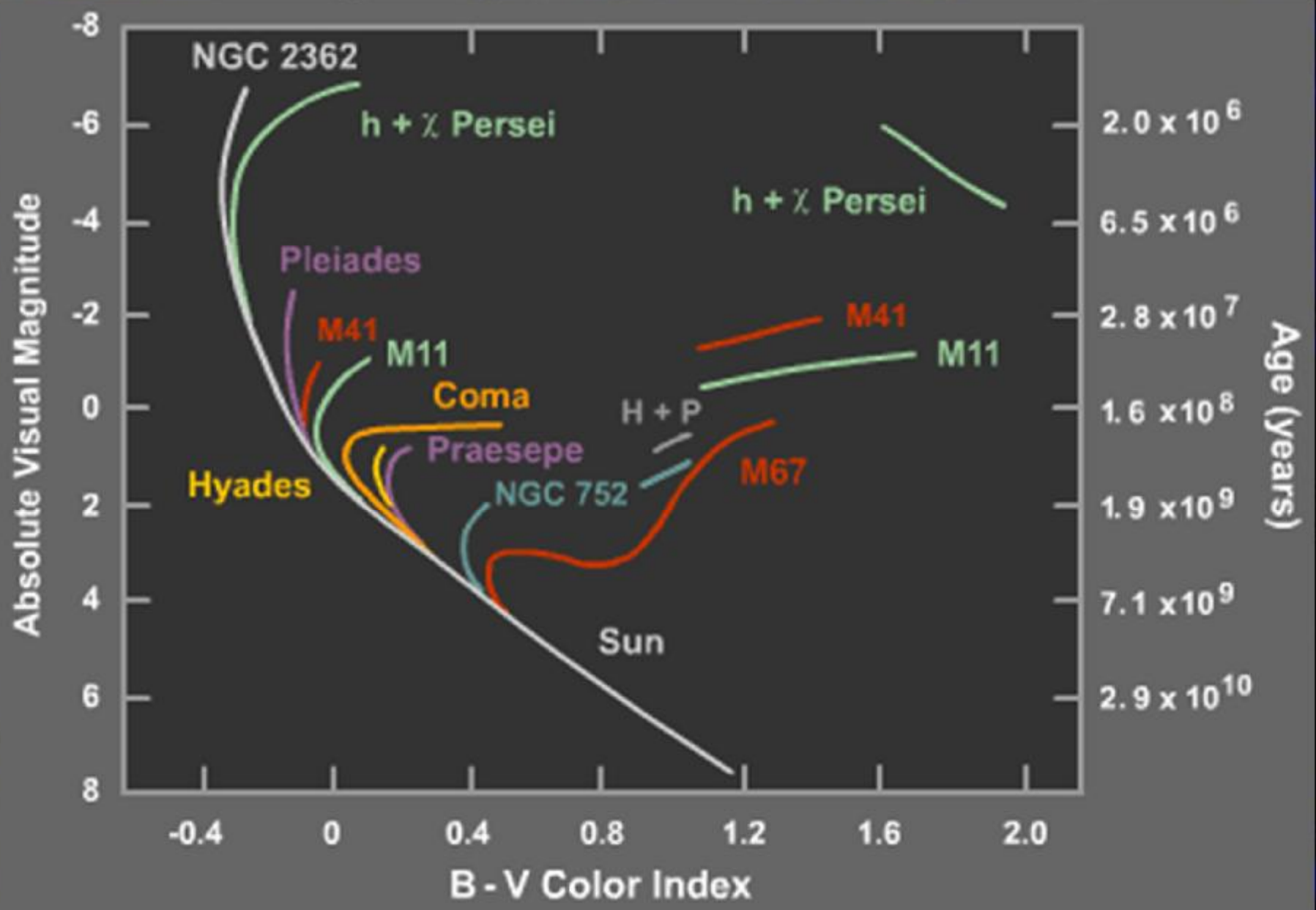
Therefore the differences in brightness are directly related to the differences in Luminosity or energy output.

- distance effects are removed

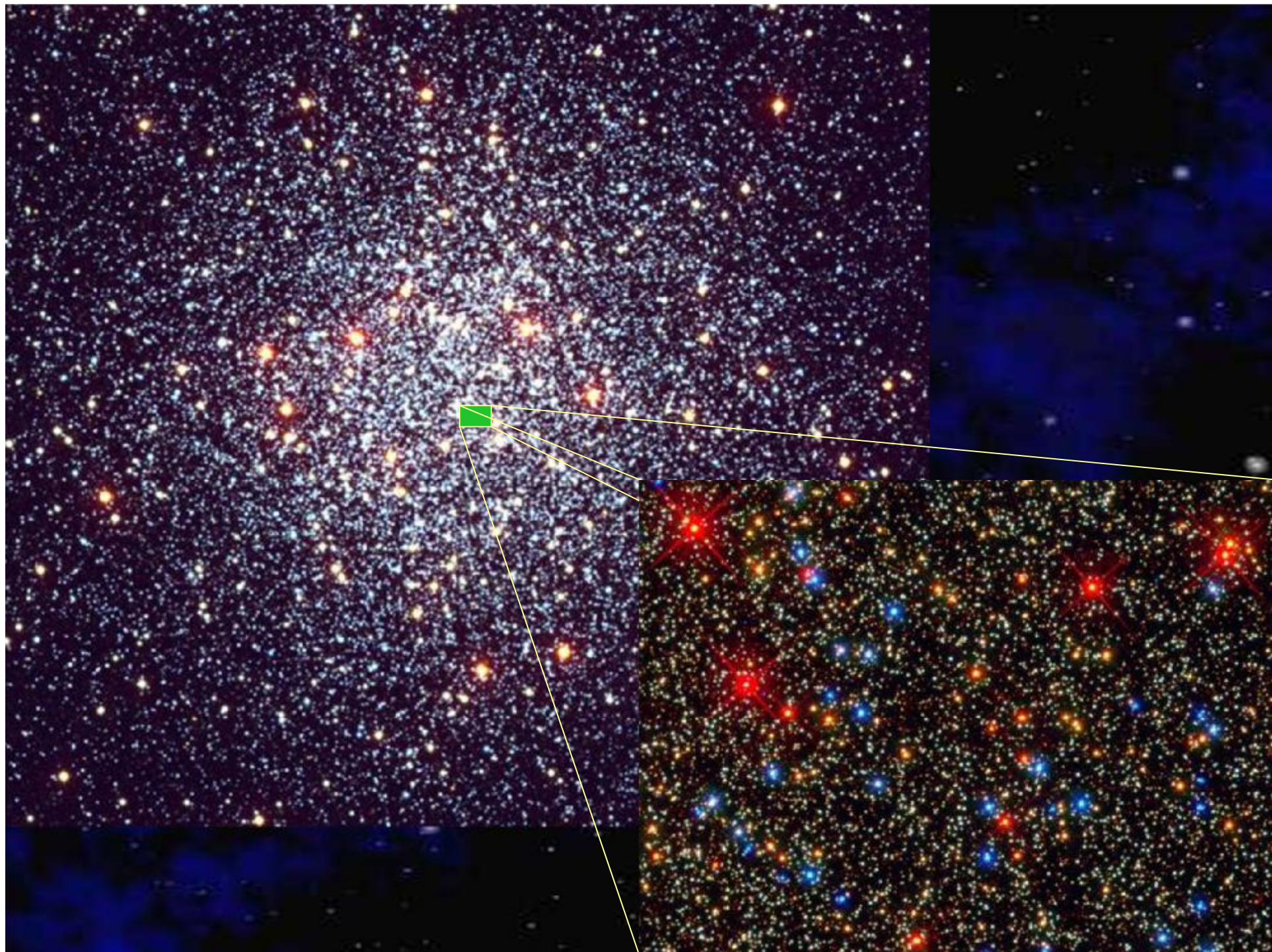


Open Cluster M7





HR Diagrams for Various Open Clusters





www.spacetelescope.org

Equations of Interest for the HR Diagram and how Stars move around on the Diagram

$$L = 4\pi R^2 \sigma T^4$$

$$L \propto M^4$$

$$\text{Lifetime of star on MS} \propto 1/M^3 = M^{-3}$$

- A low mass star, e.g. $0.1M$, lives about 10 trillion years.
- A high mass star, e.g. $10M$, lives about 10 million years.
- Our sun, e.g. $1M$, lives about 10 billion years.

The History of Astronomy is a history of the displacement of man from being the Center of everything

Pre 1500's

Earth and man center of all there is (Universe)

After Copernicus (~1500)

OK, sun is at the center, but man is center of everything, center of galaxy, center of Universe

1910-1920

Oh no! we are not at center of galaxy but out toward the edge but at least our galaxy is at the center of everything!!

-study of globular clusters, their distribution and variables contained in them

1925-1930

The Universe is full of galaxies, rushing away from each other we have no special place whatsoever!!

-study of variable stars (pulsating) in distant galaxies



<1910 The "galaxy" is at the center of the Universe

-and of course we (the solar system) is at the center
of the galaxy

All other structures (nebulae) are just part of our galaxy
- even spiral nebulae were just solar systems
in formation

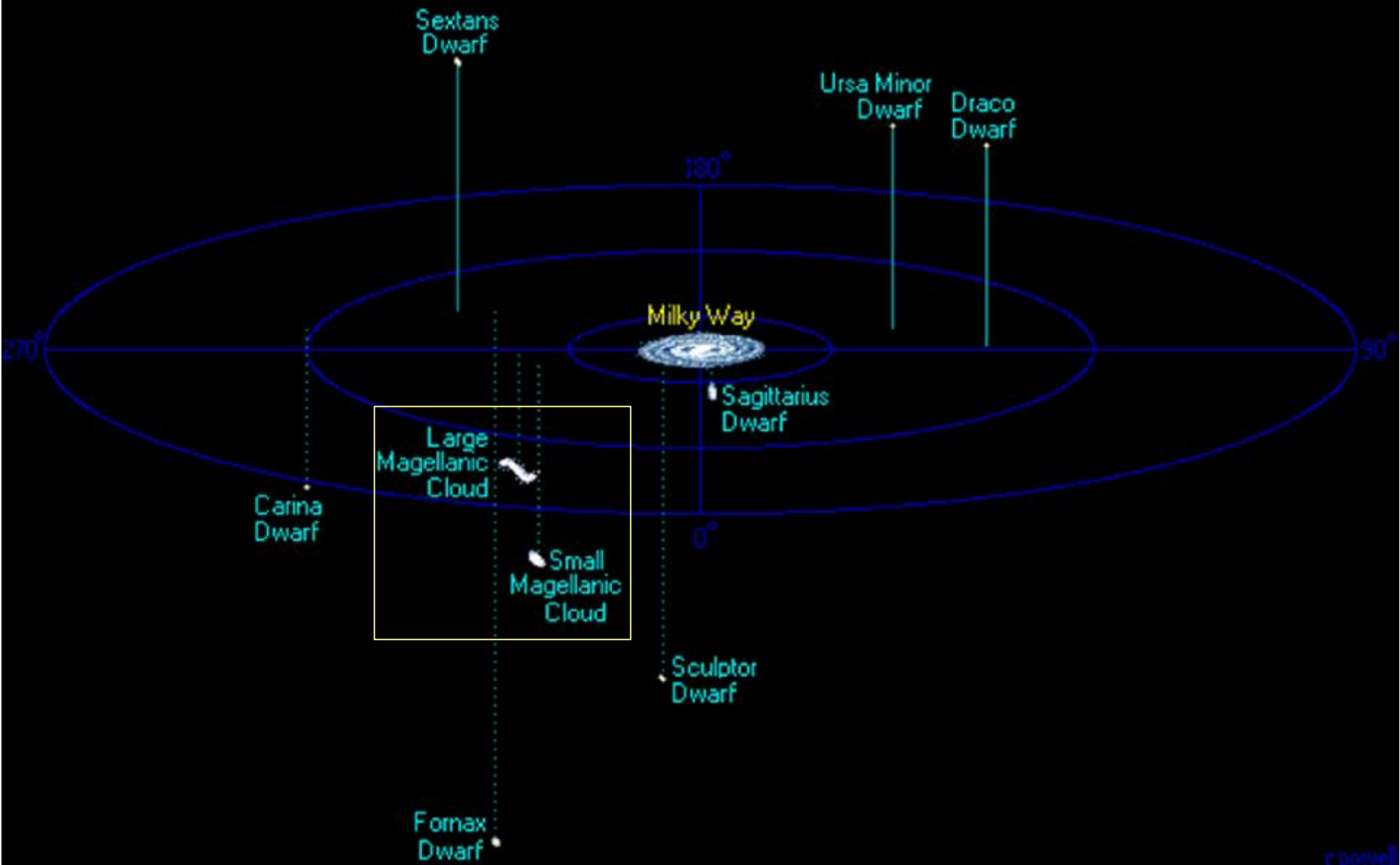
Telescope/photographic plates could not yet resolve stars
in many of these nebulae

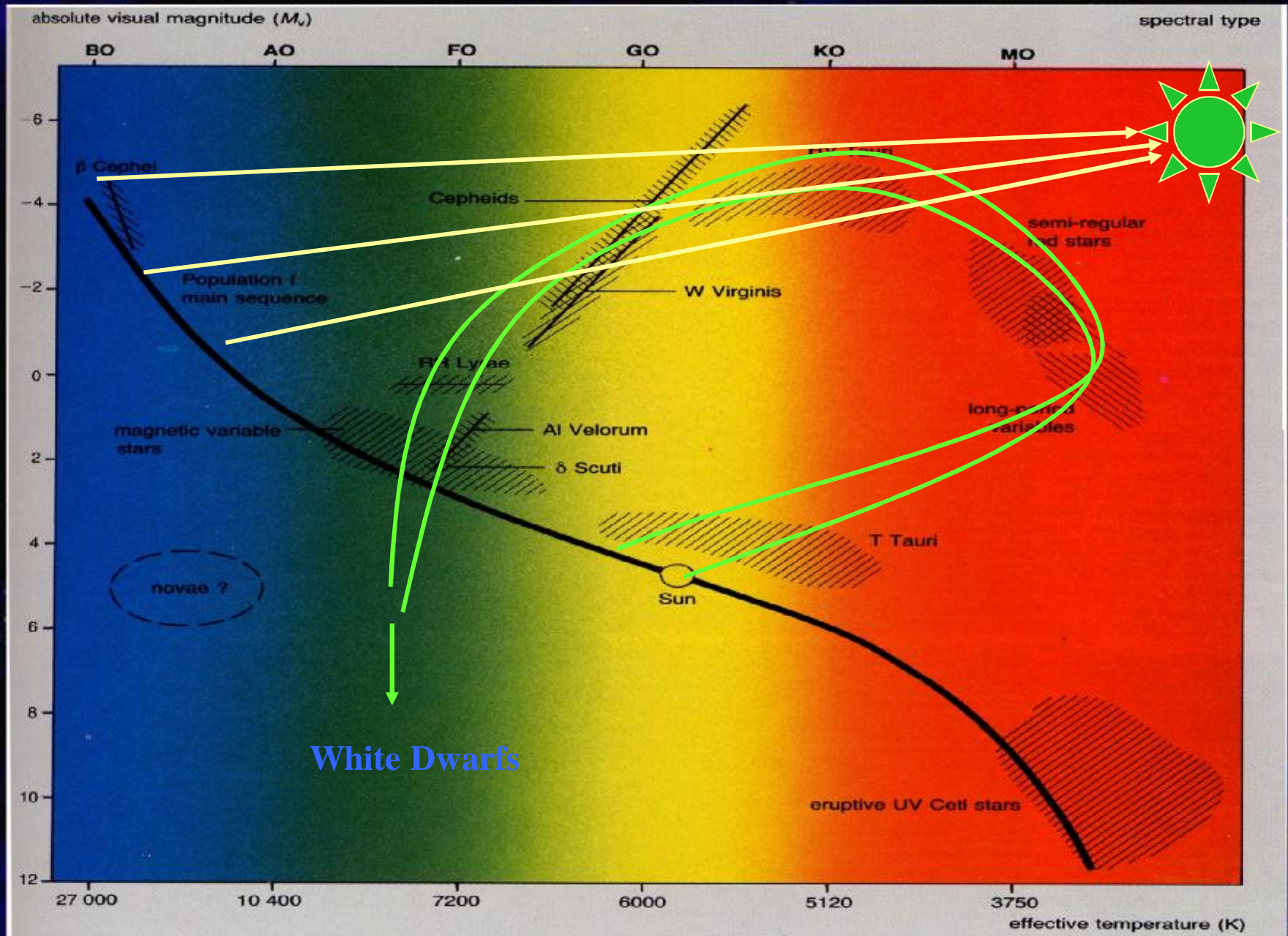


...the Milky Way is a
"spiral" galaxy



100 000 ly

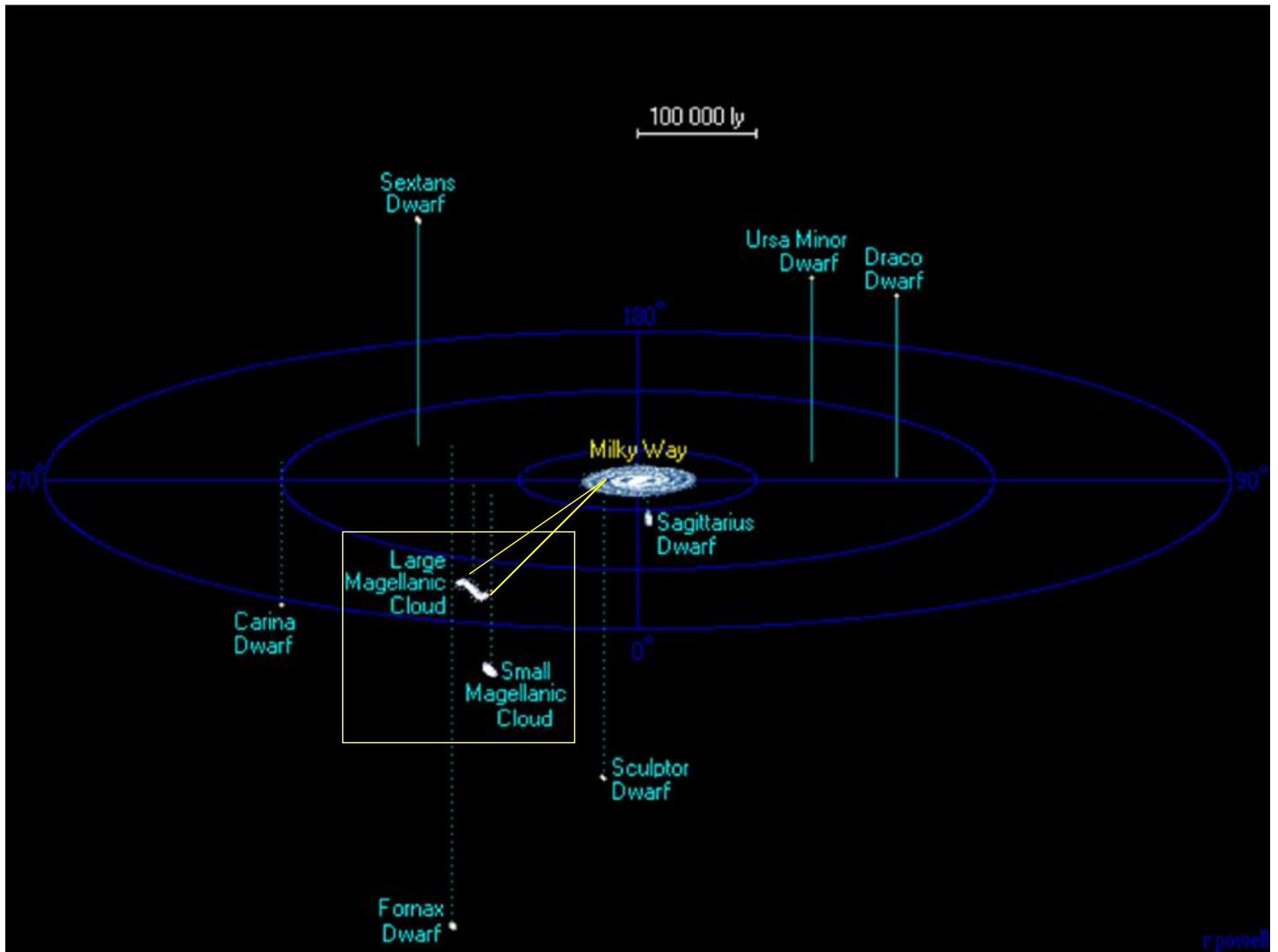


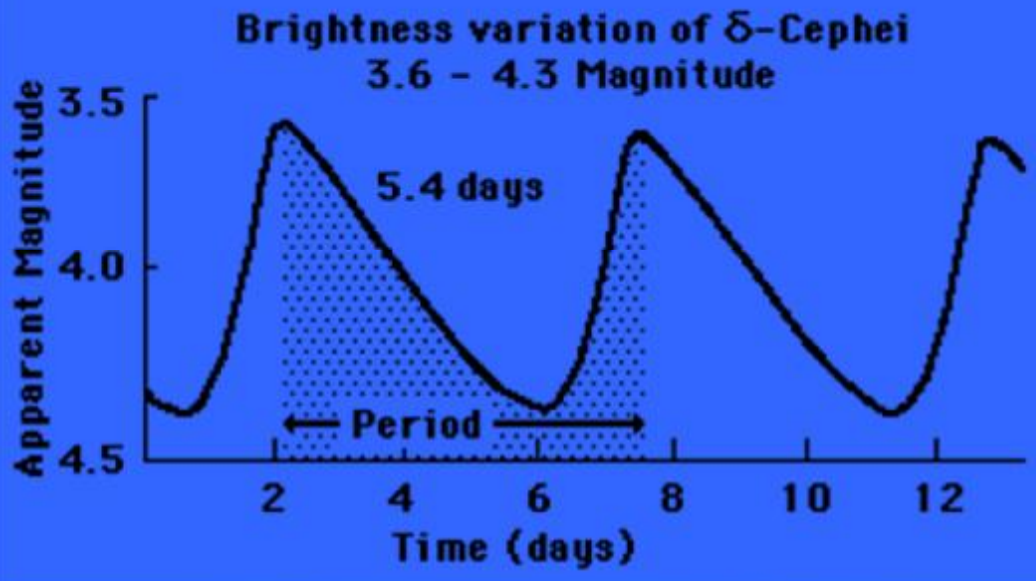


As Observed from the earth, the distance to all the stars within a cluster are ~ the same

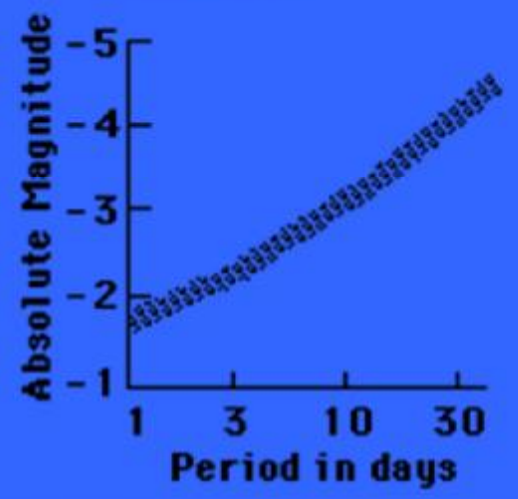
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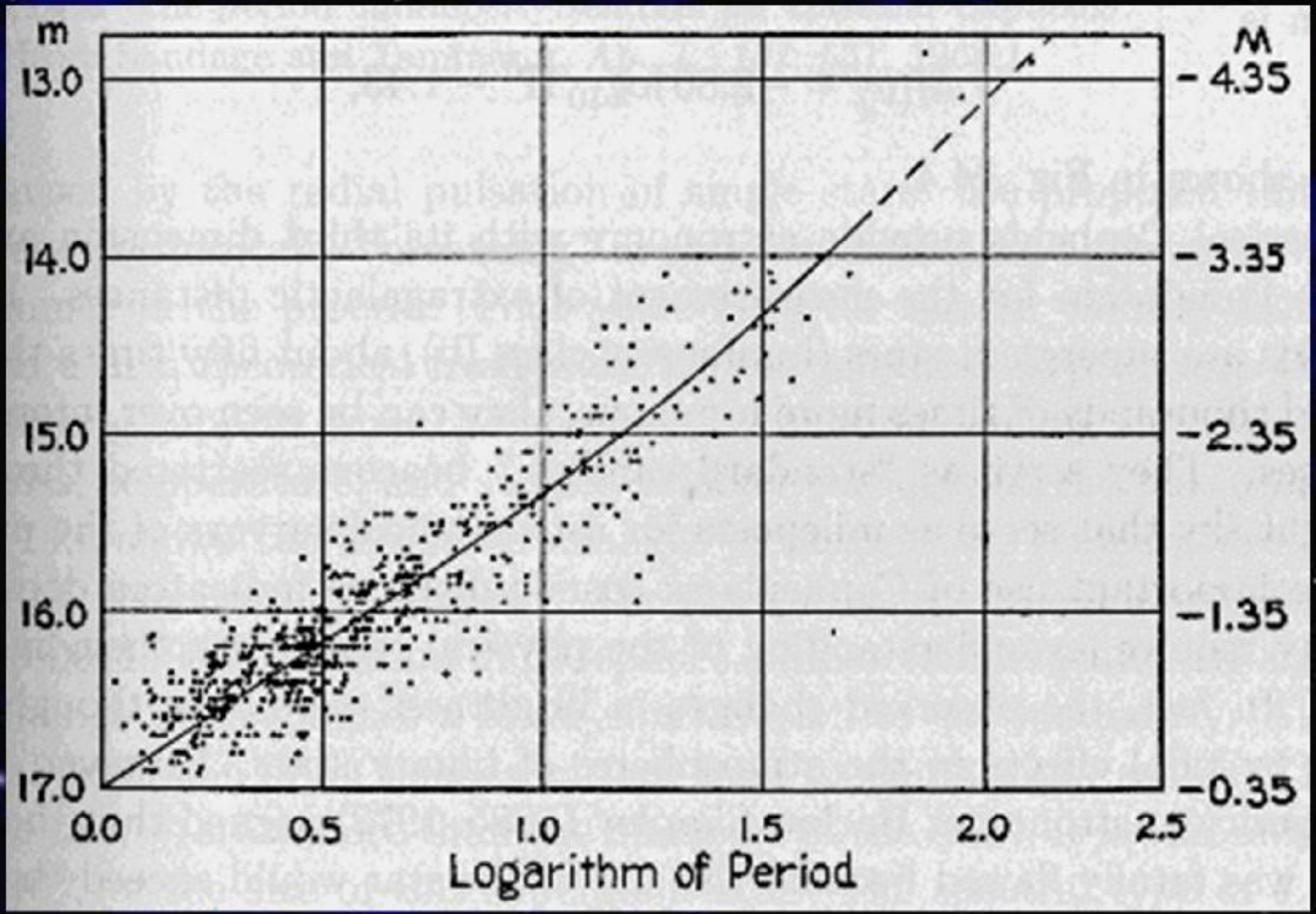
- distance effects are removed





The period-luminosity relation for Cepheid variables.

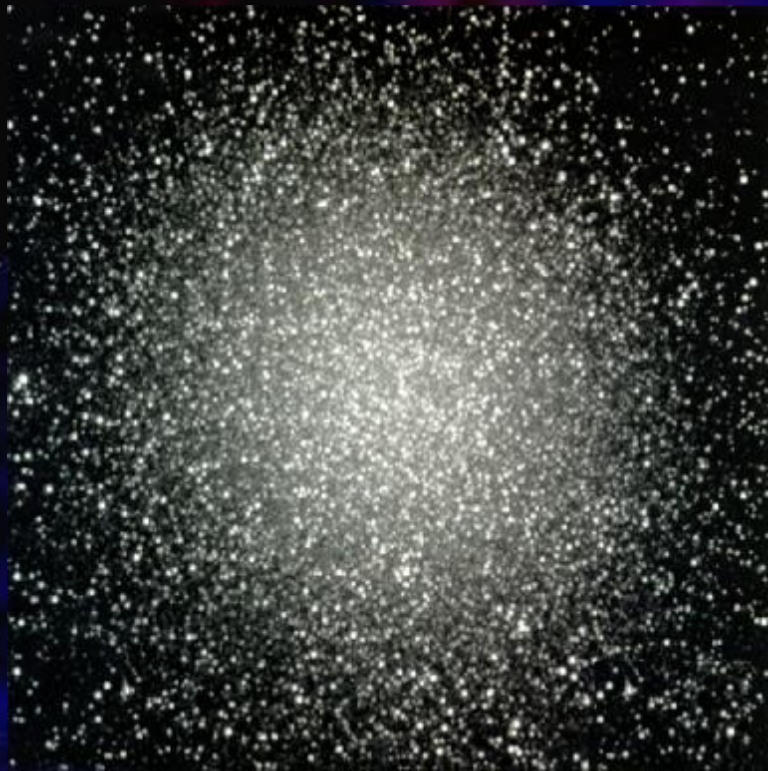


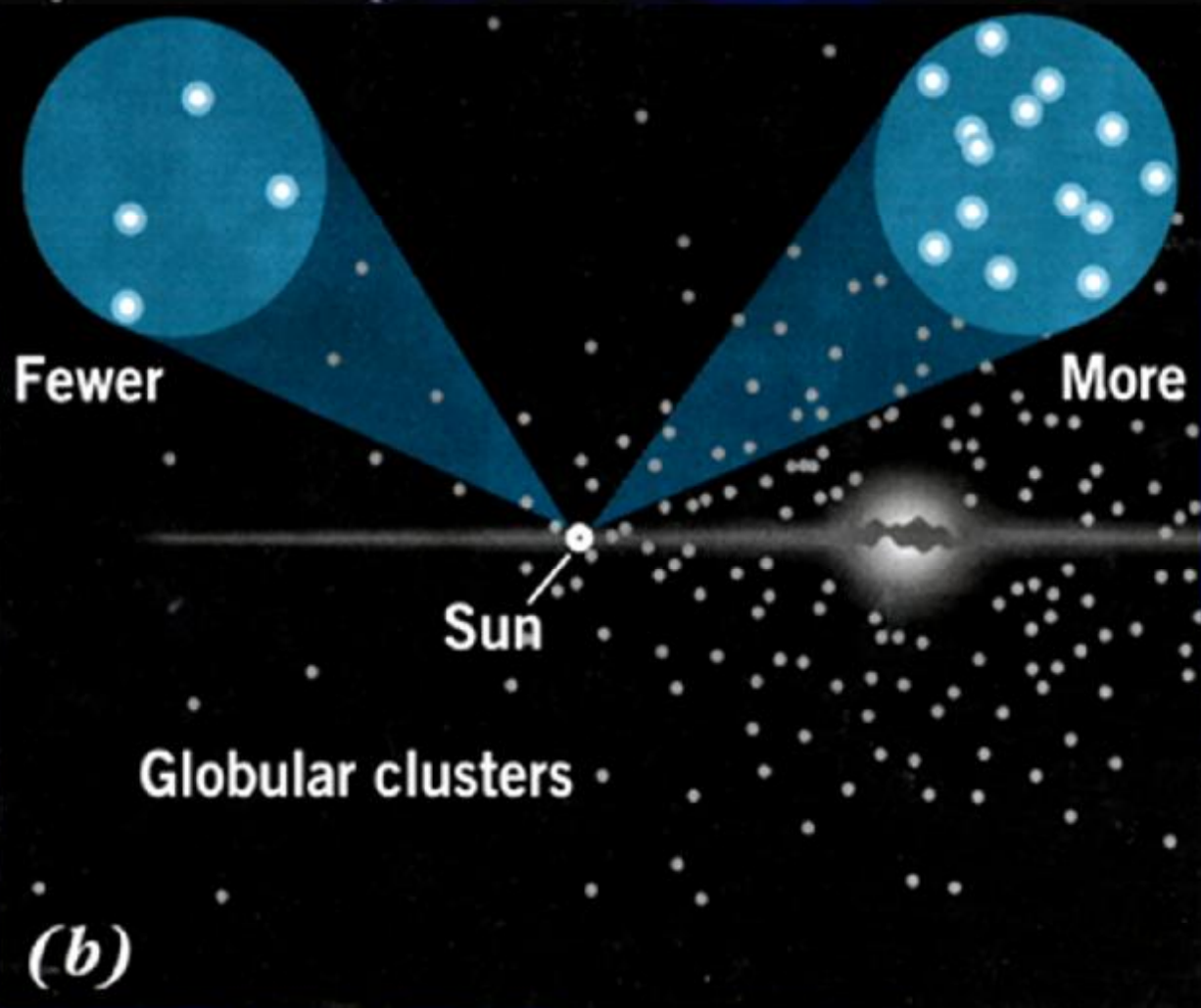


Where is the Sun located in the Milky Way?

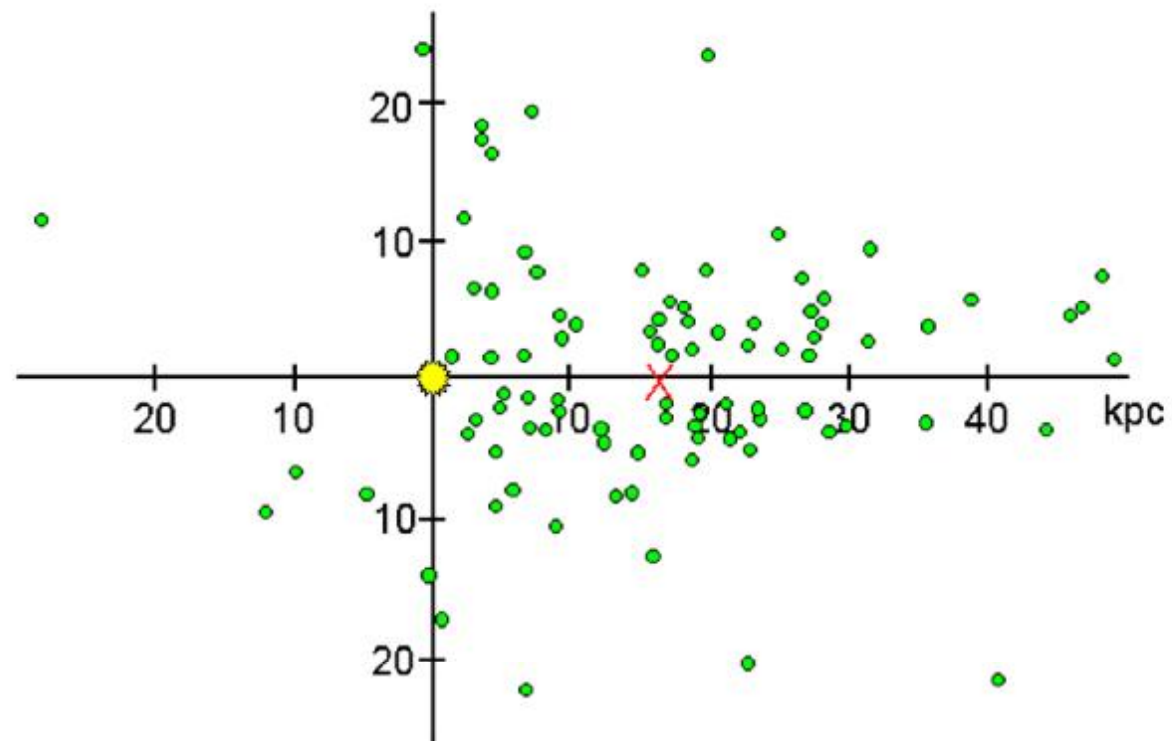
§ Harlow Shapley (1915)

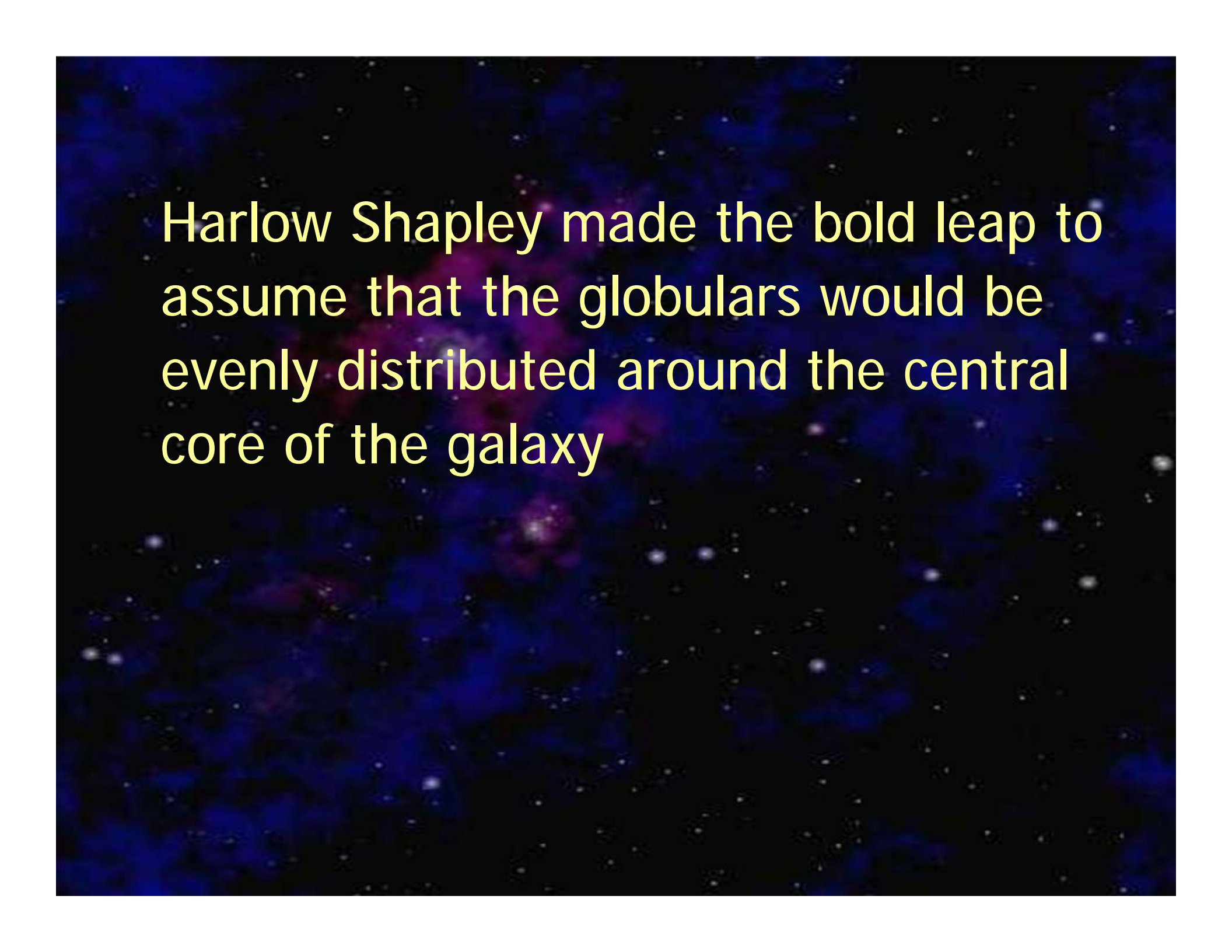
§ Globular Clusters





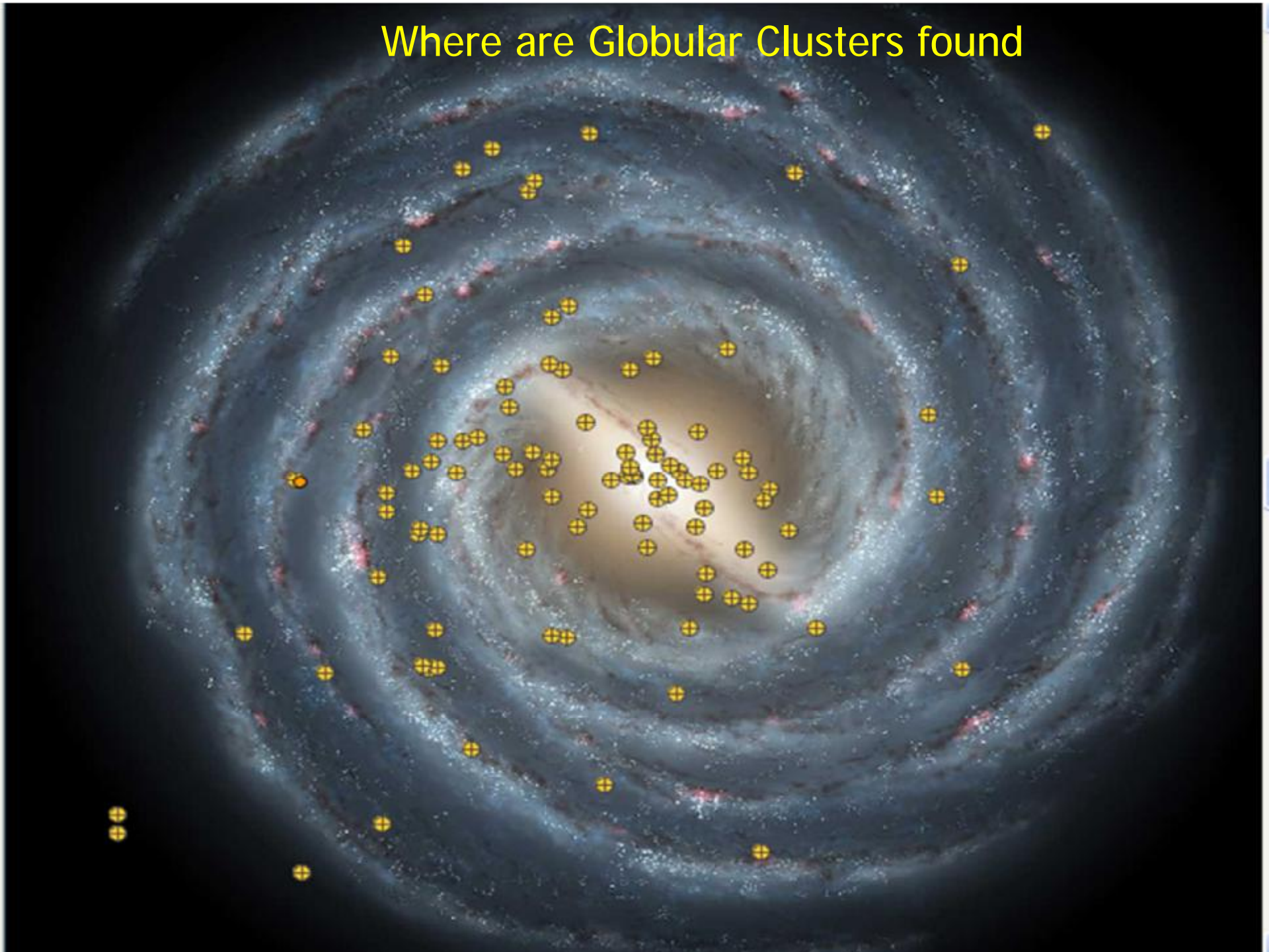
Shapley's Globular Cluster Distribution



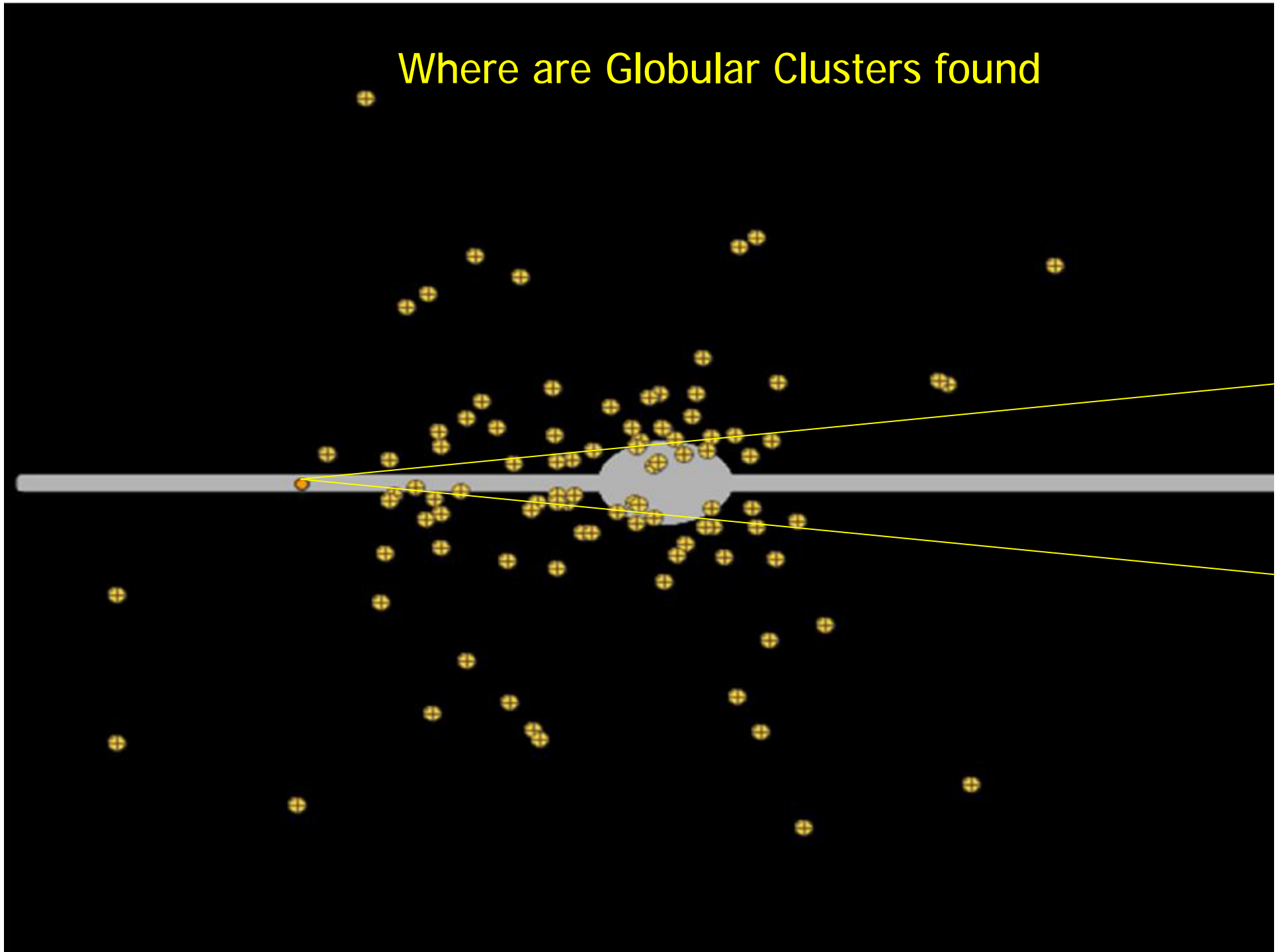


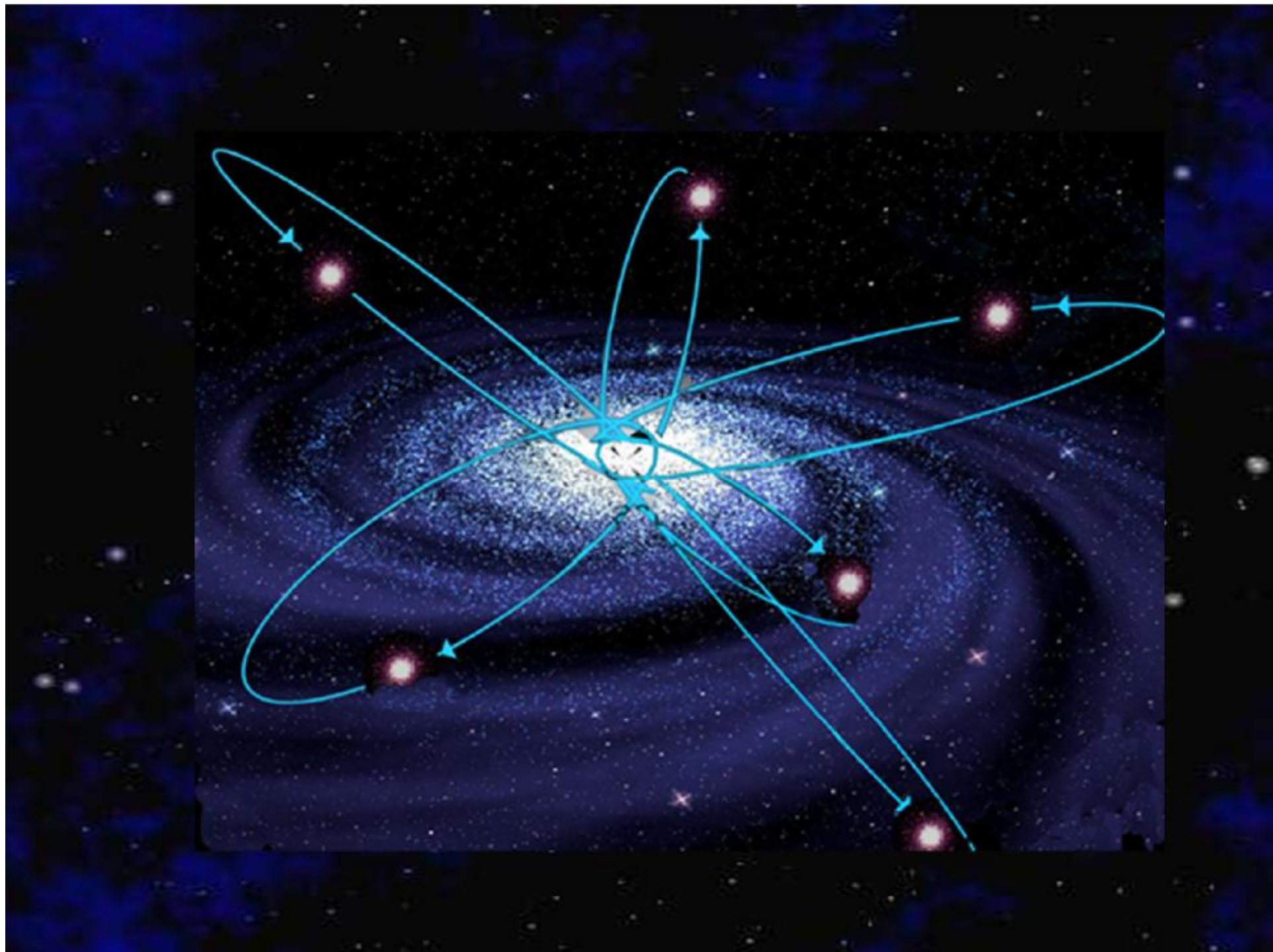
Harlow Shapley made the bold leap to assume that the globulars would be evenly distributed around the central core of the galaxy

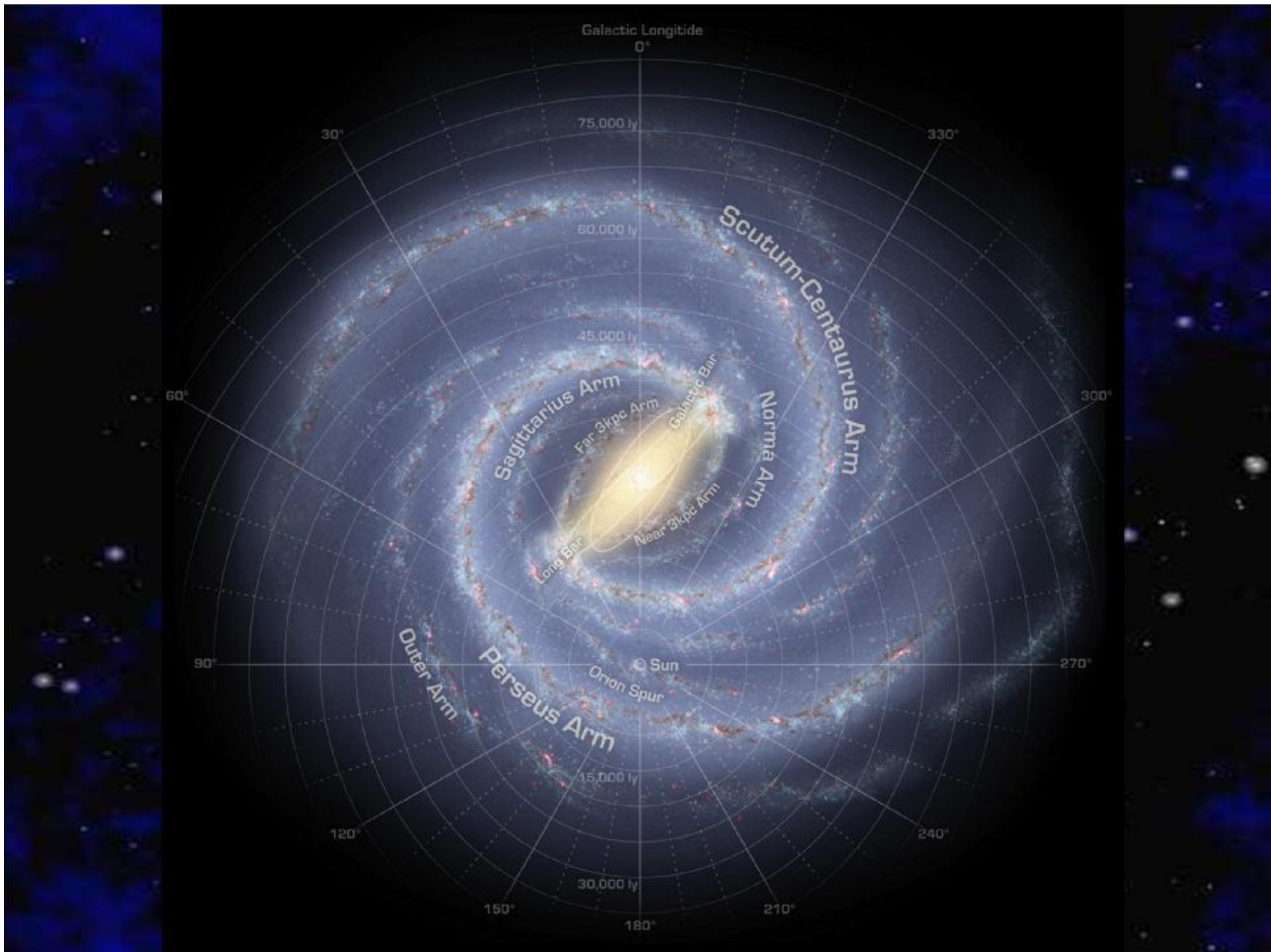
Where are Globular Clusters found



Where are Globular Clusters found







Cepheid Variable in M100
HST-WFPC2

