

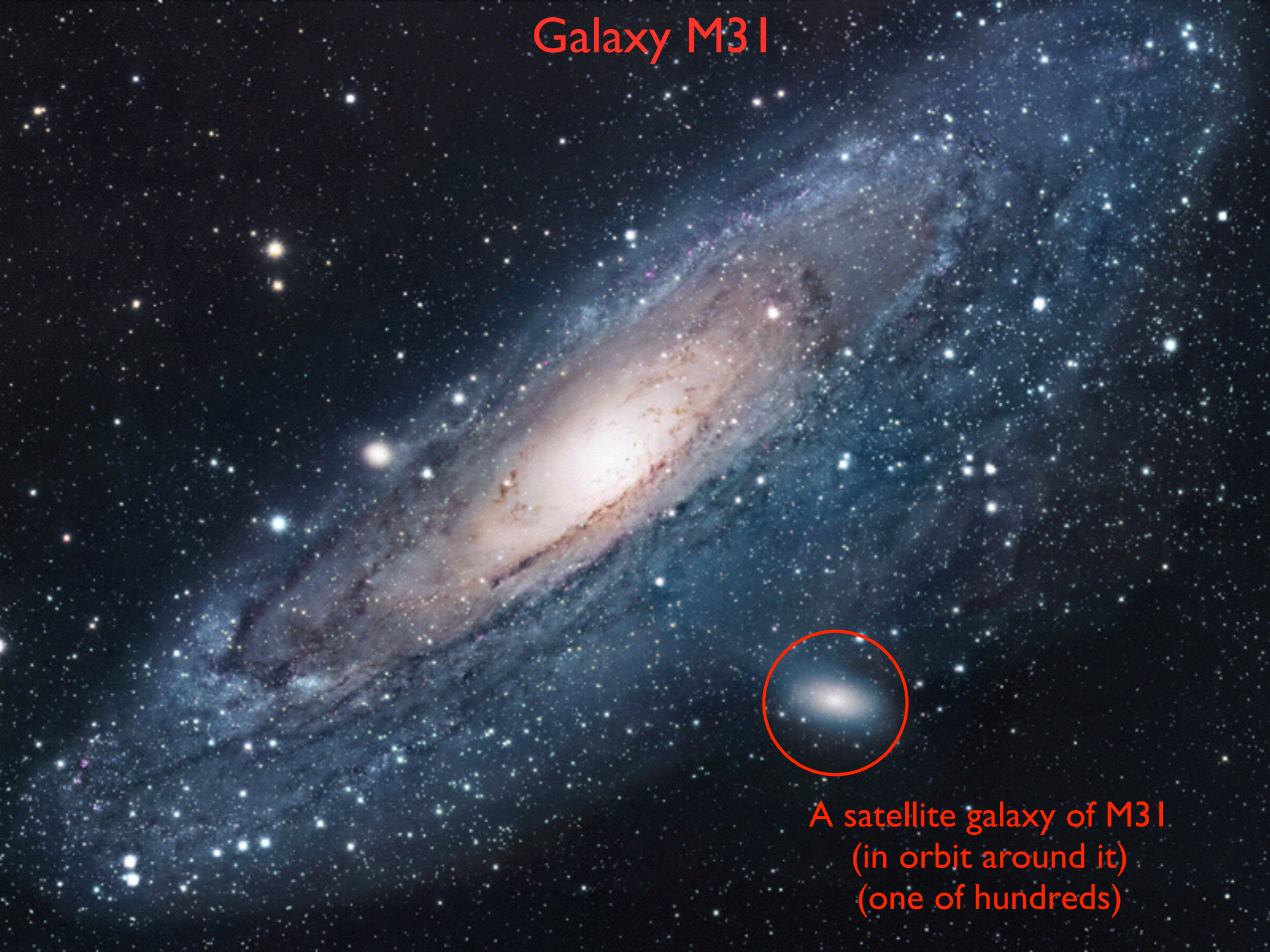
# Galaxy M31 or “Andromeda”



A Milky Way twin  
Visible with binoculars



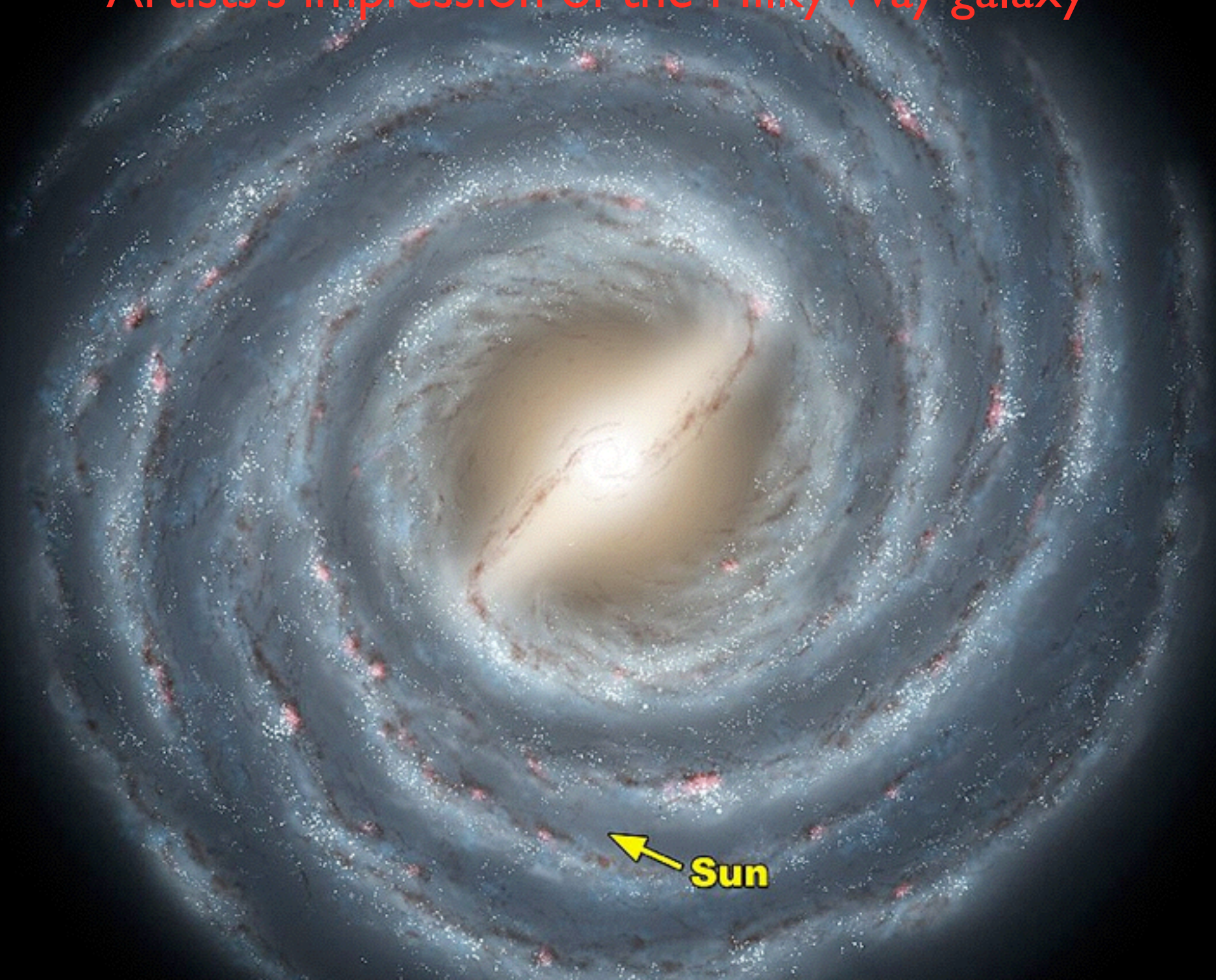
# Galaxy M31



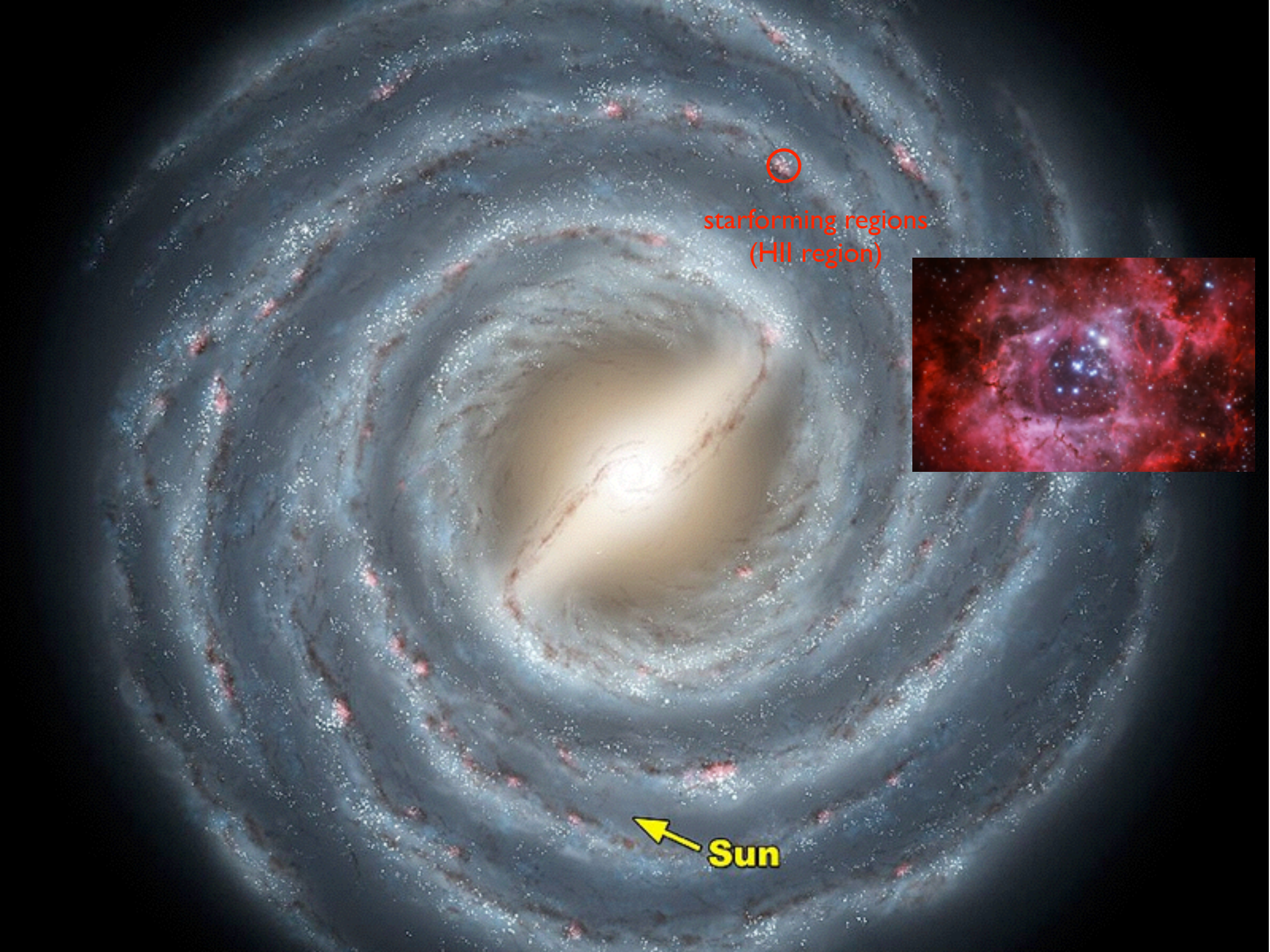
A satellite galaxy of M31  
(in orbit around it)  
(one of hundreds)



# Artists's impression of the Milky Way galaxy







starforming regions  
(HII region)



Sun

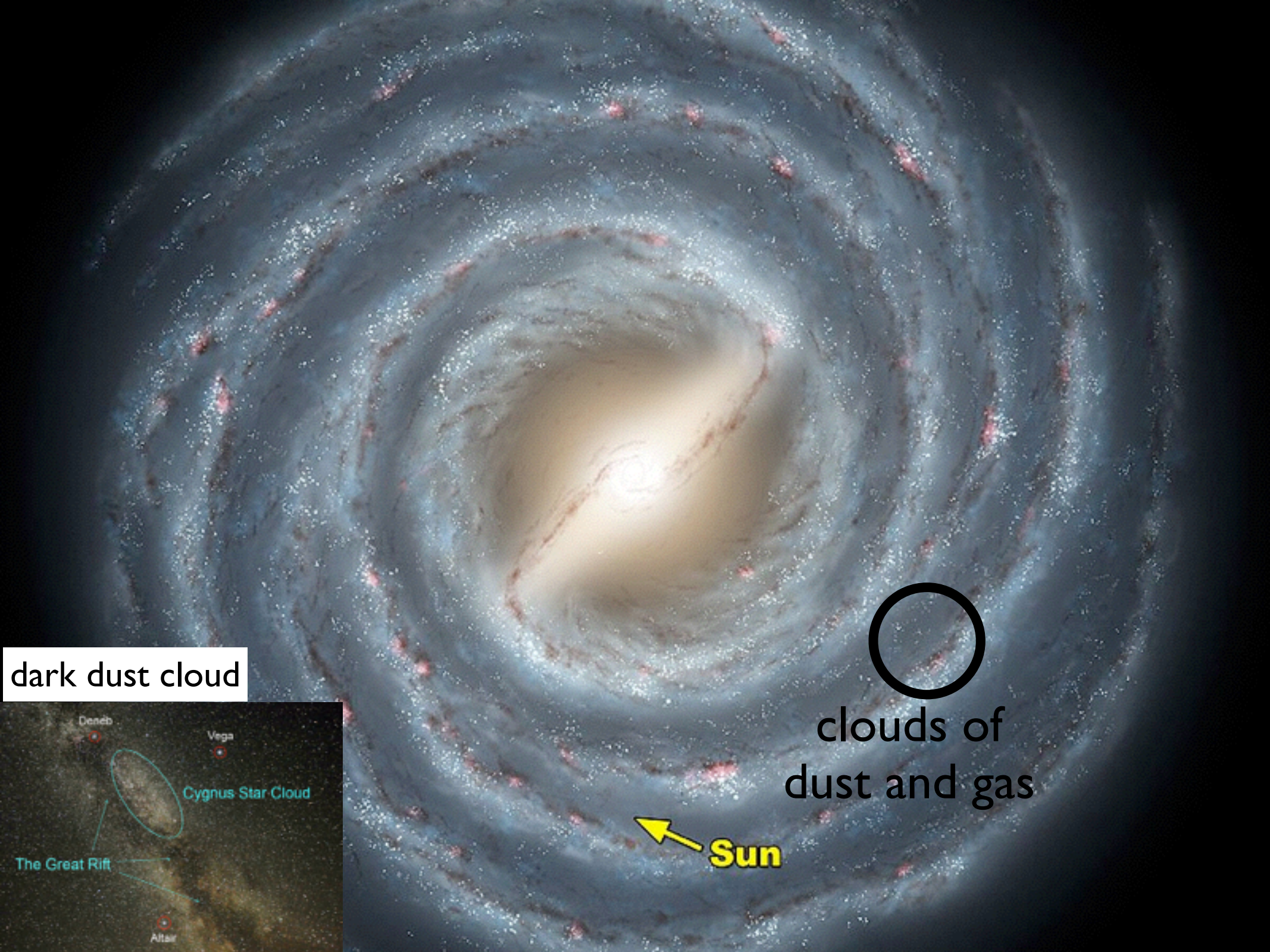




blue disc of stars  
(and gas and dust)

 **Sun**





dark dust cloud

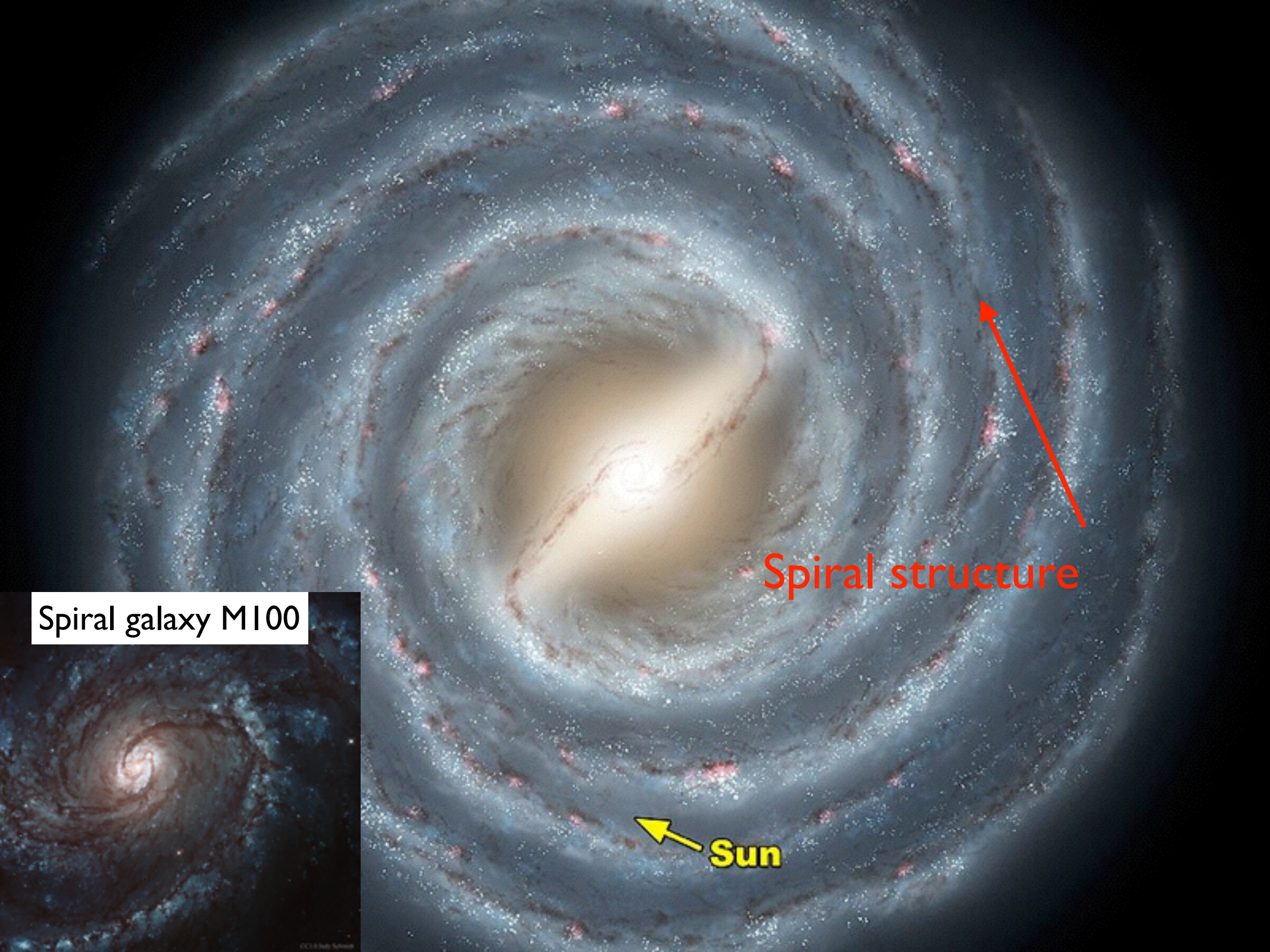


clouds of  
dust and gas

 **Sun**





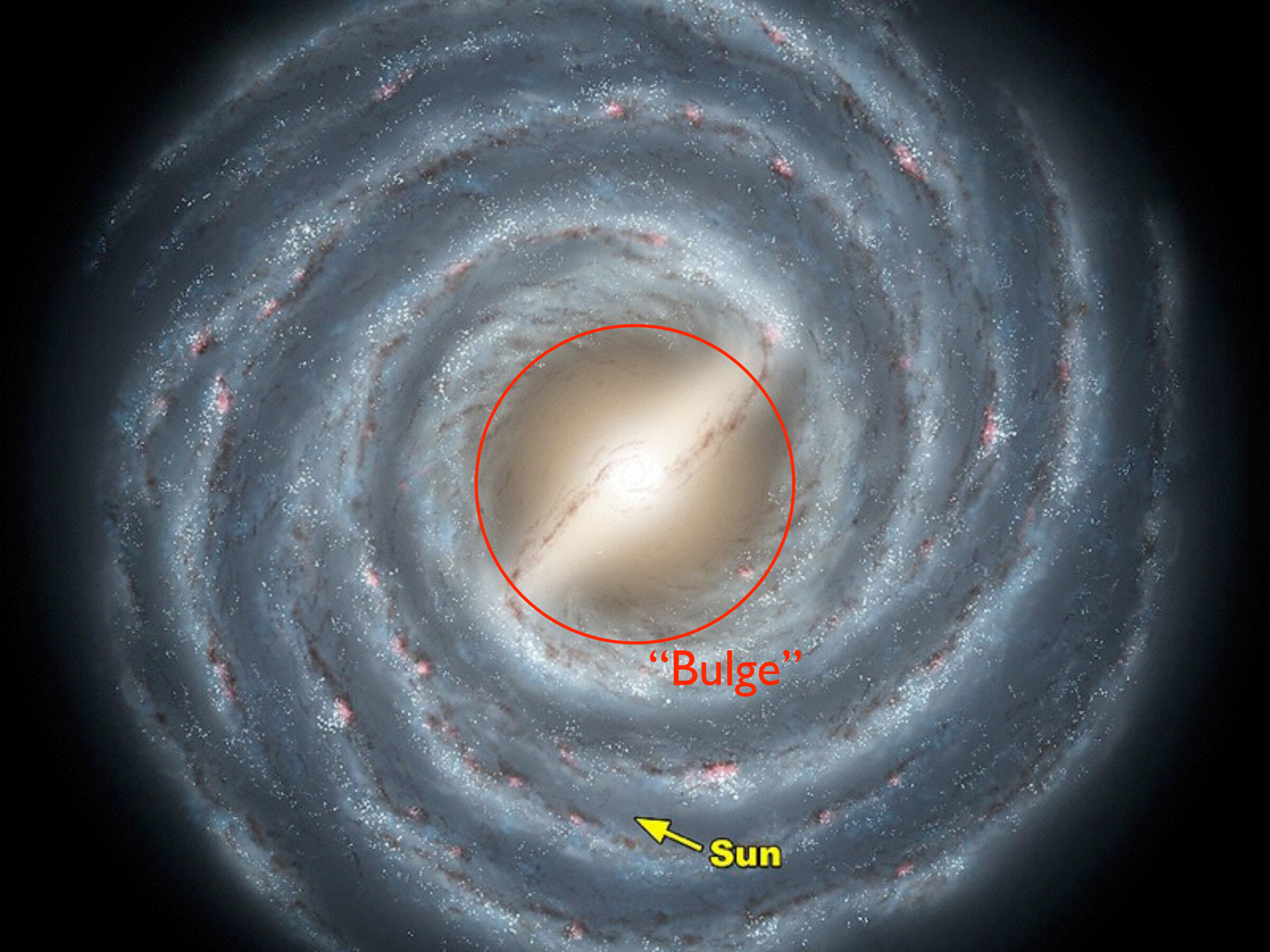


Spiral galaxy M100

Spiral structure

Sun

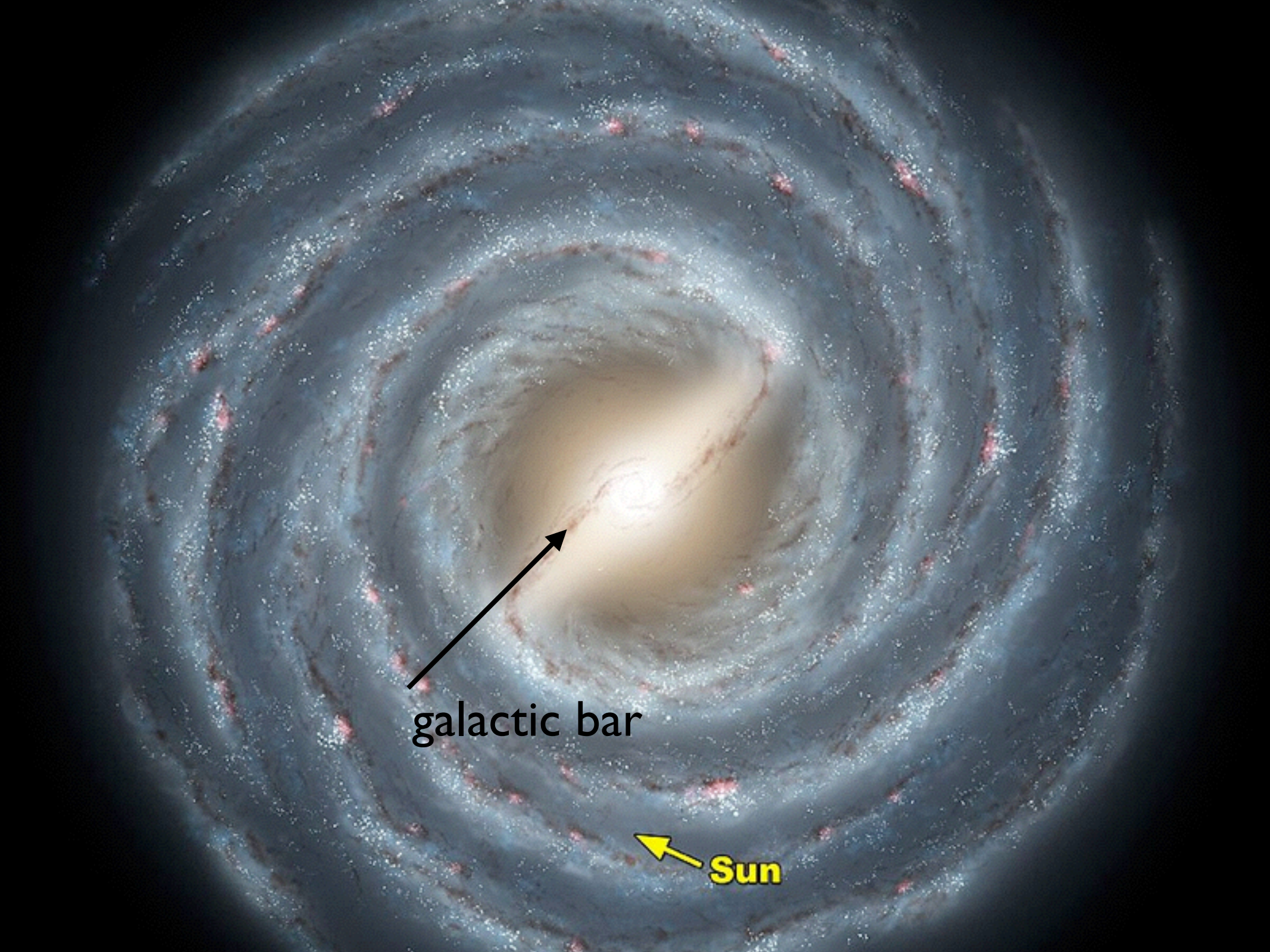




“Bulge”

→ Sun

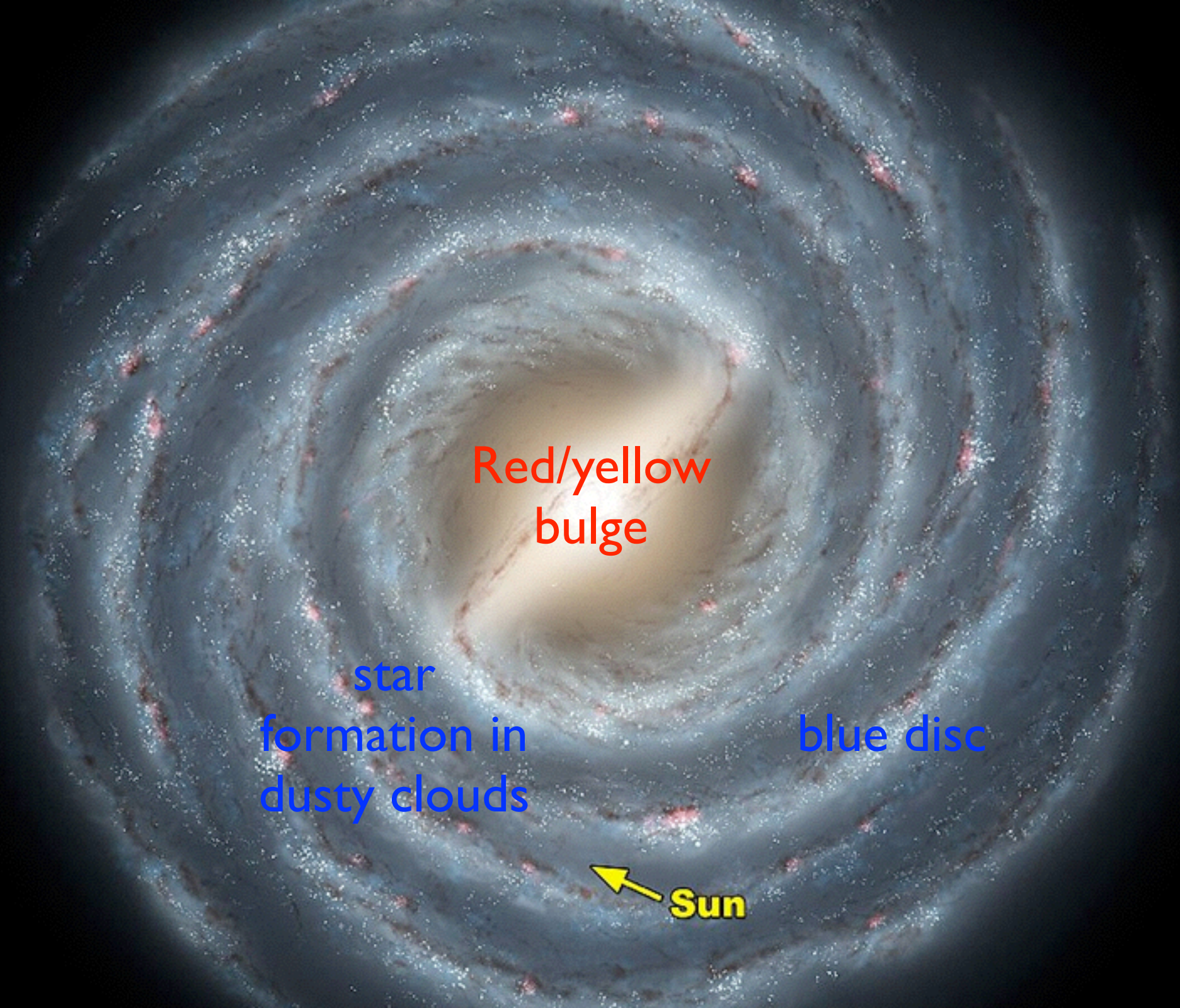




galactic bar

Sun





Red/yellow  
bulge

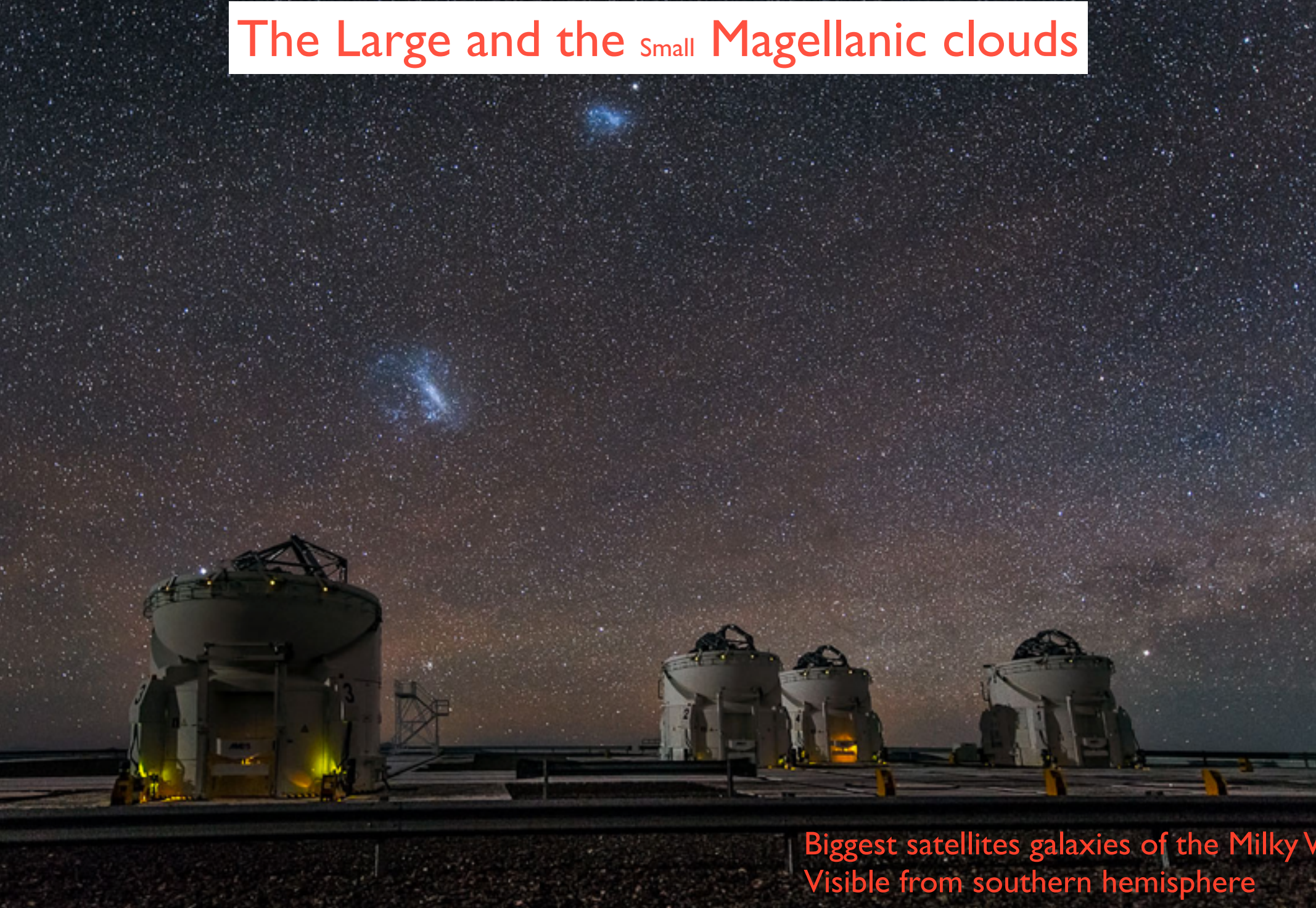
star  
formation in  
dusty clouds

blue disc

→ Sun



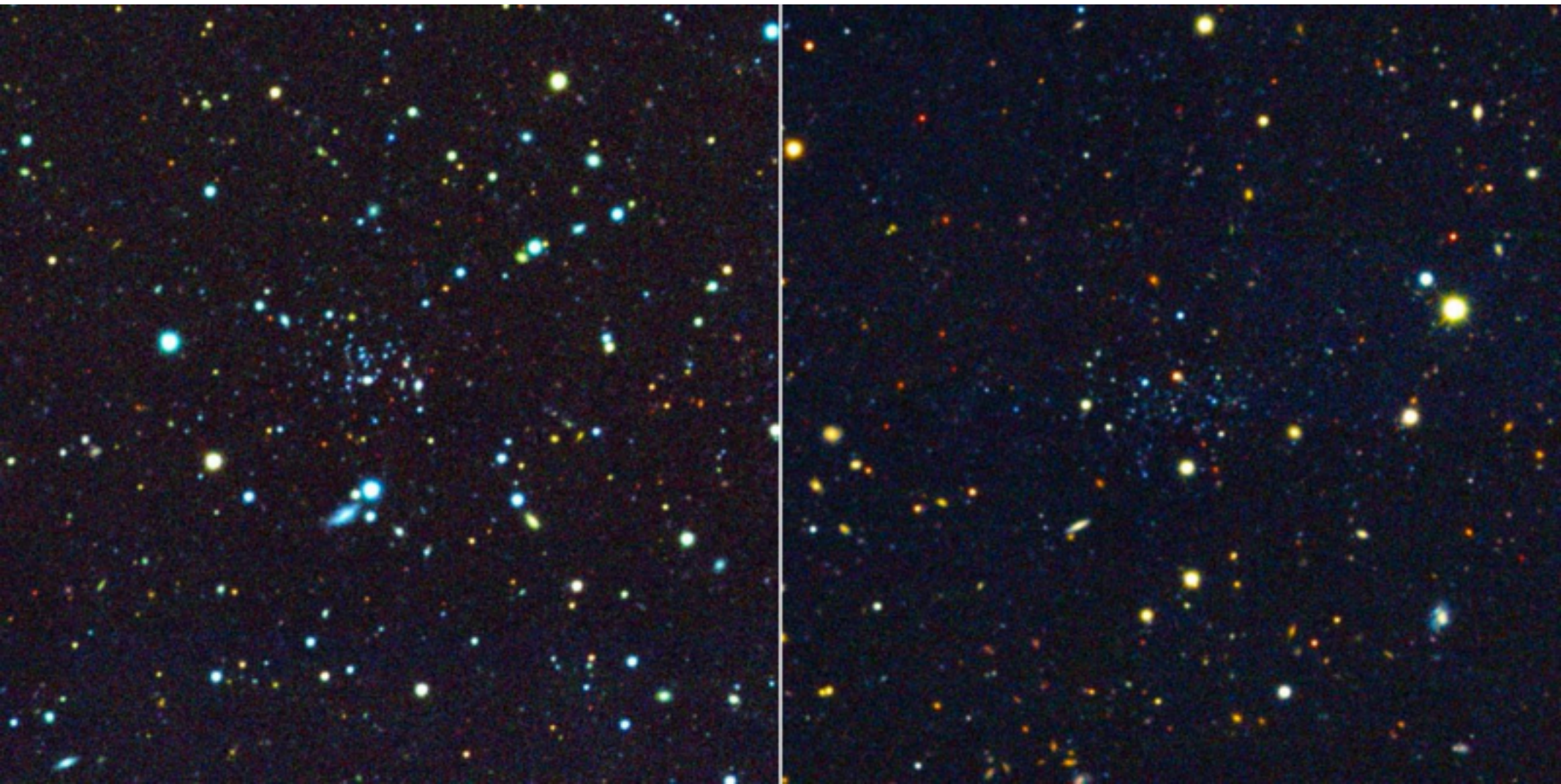
# The Large and the Small Magellanic clouds



Biggest satellites galaxies of the Milky Way  
Visible from southern hemisphere



# Ultra-faint satellite galaxies of the Milky Way



May contain as few as a few hundred of giant stars  
Many discovered over past ten years



# Andromeda

star forming regions



dust

bulge

blue disc

satellite



foreground Milky Way star





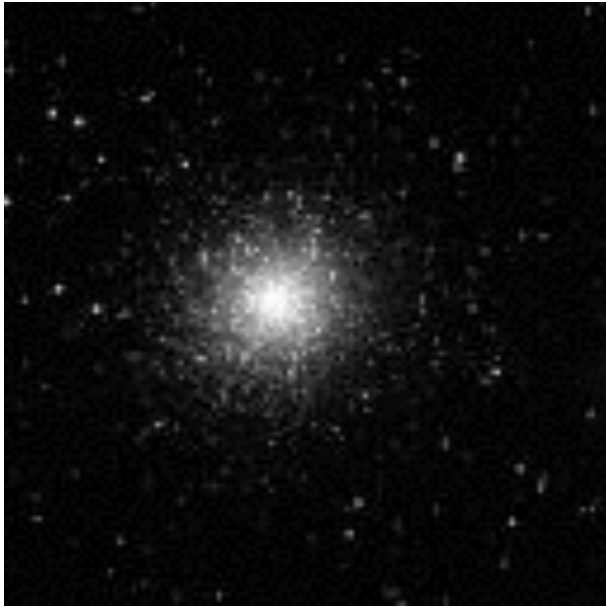


The MW at night

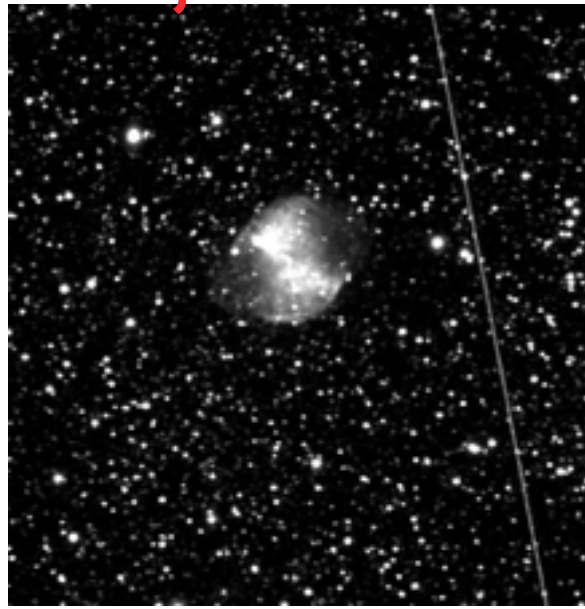




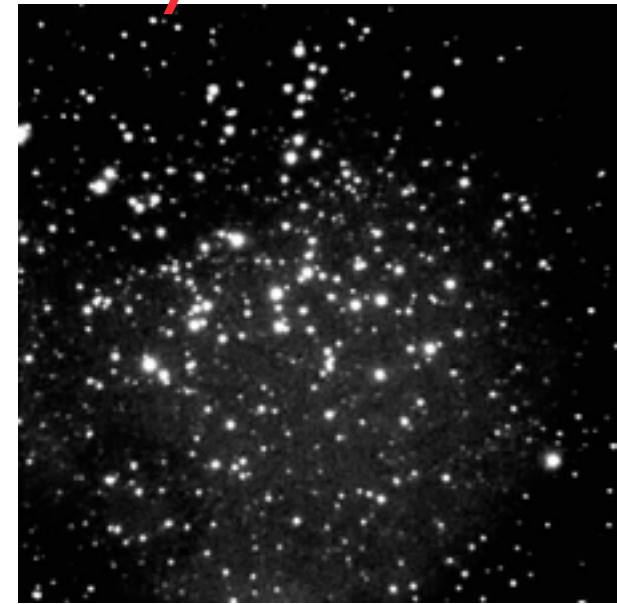
# Other extended objects on the night sky



Globular cluster



planetaire nebula



open cluster (M38)



star forming region (Orion)



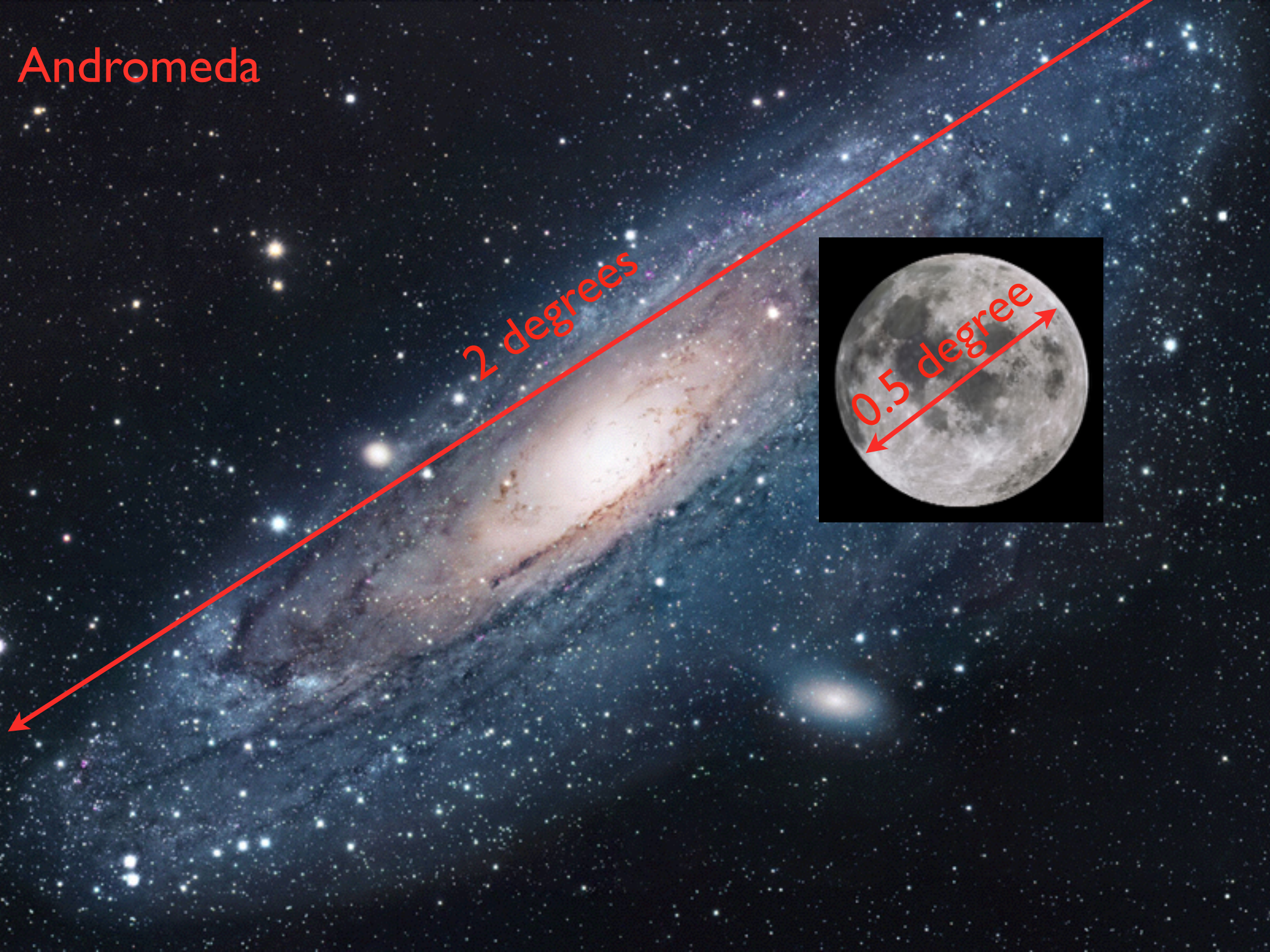
planet (mars)



super nova  
remnant  
(Crab nebula)



Andromeda

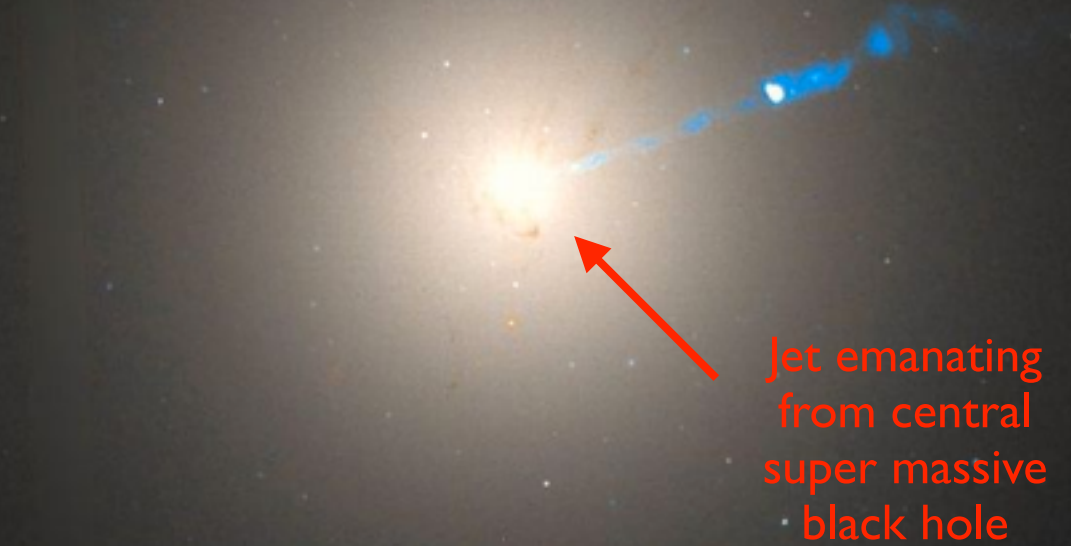








# Elliptical galaxy M87



looks very different:

- no blue disc
- no dust

why is that?



# Hubble deep field



image credit HST



# Other spiral galaxies





# Other elliptical galaxies



E0

E2

E3

E4

E5



E<sup>+</sup>0

E<sup>+</sup>2

E<sup>+</sup>3

E<sup>+</sup>4

E<sup>+</sup>7



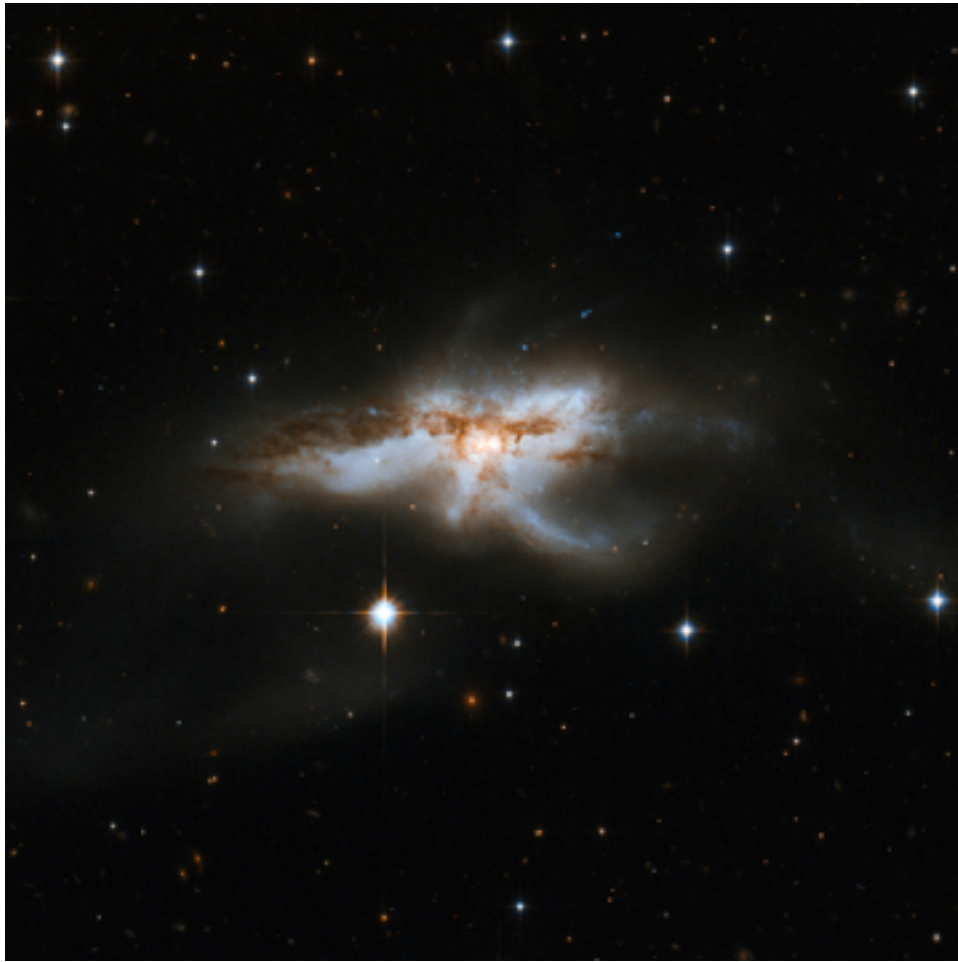
## Irregular galaxy



NGC 4214



# Interacting galaxies



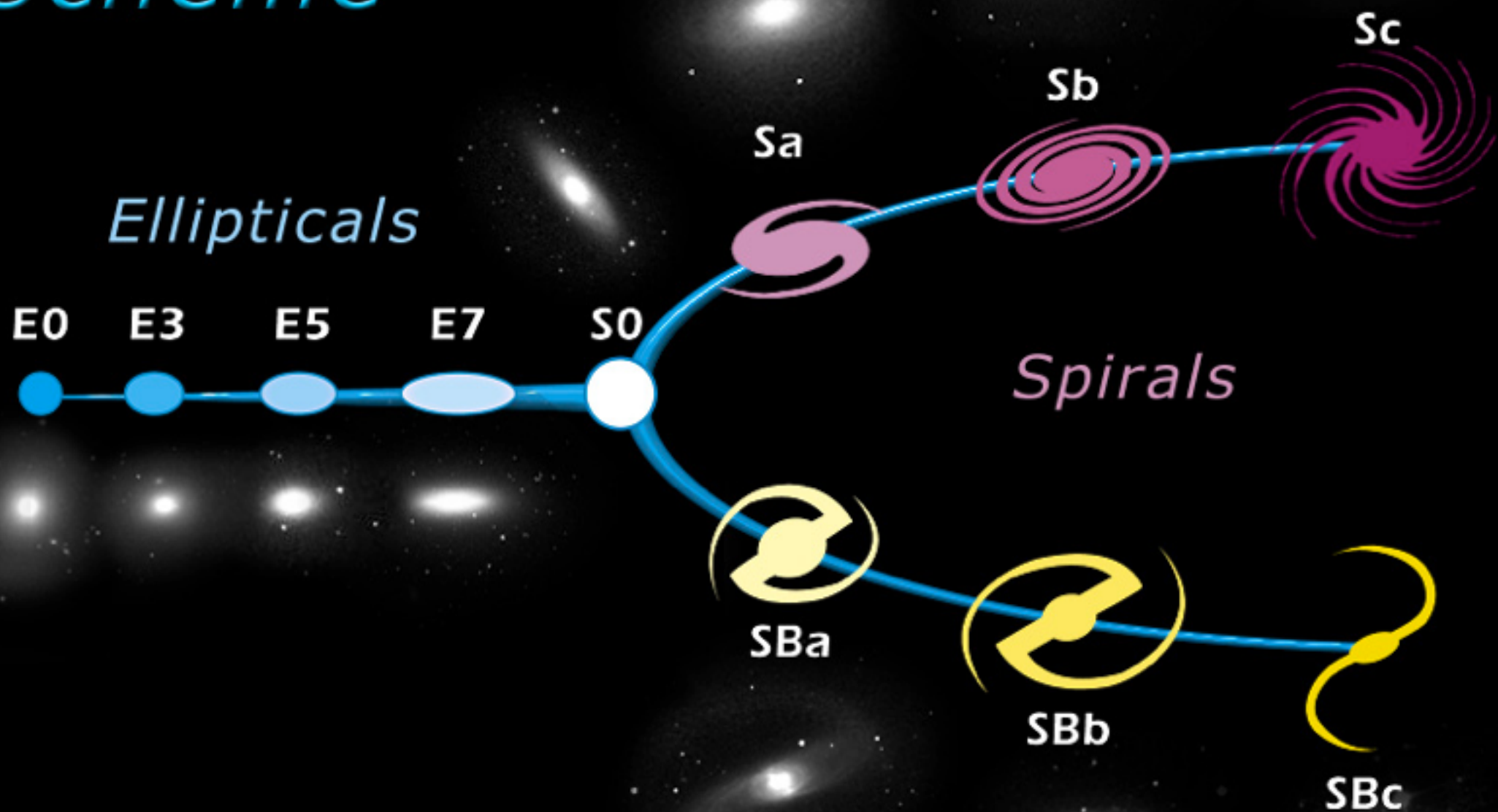
NGC 6240



NGC 2207 and IC 2163



# Edwin Hubble's Classification Scheme









# HARVARD COLLEGE OBSERVATORY.

CIRCULAR 173.

## PERIODS OF 25 VARIABLE STARS IN THE SMALL MAGELLANIC CLOUD.

Harvard College Observatory Circular, vol. 173, pp.1-3,  
1912, [Leavitt & Pickering](#)

variables alike, is about 1.2 magnitudes. 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.

$\delta$  - CEPHEI LIGHT CURVES

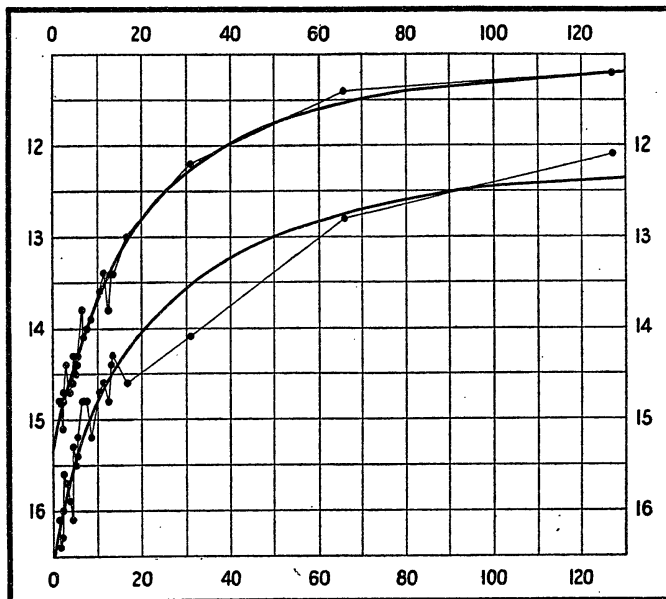
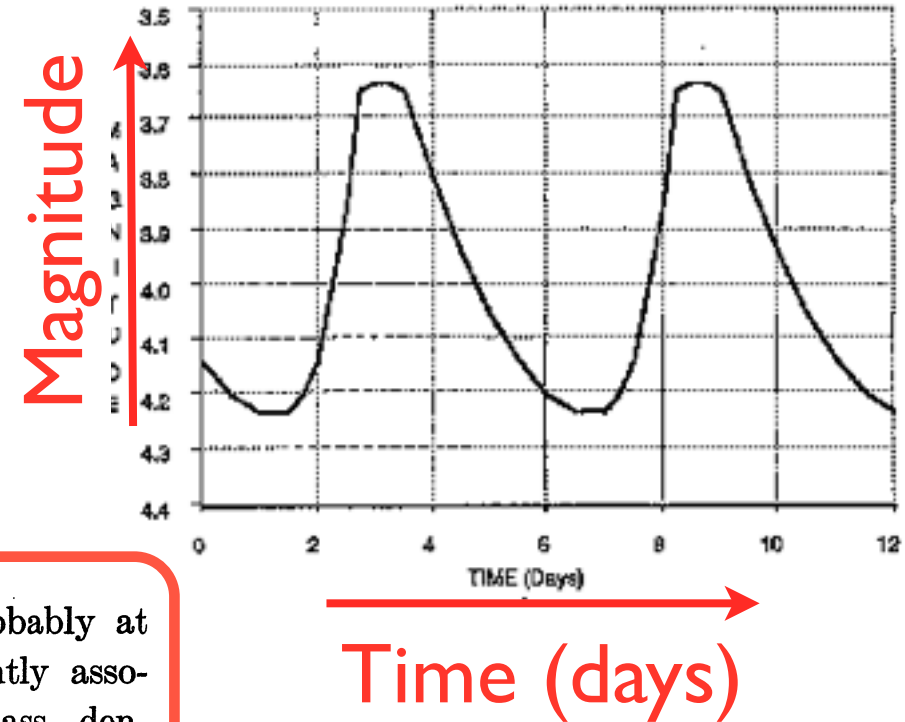


FIG. 1.

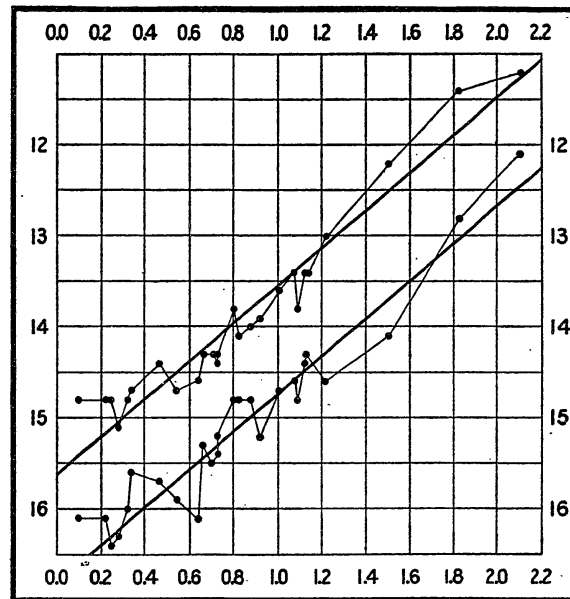
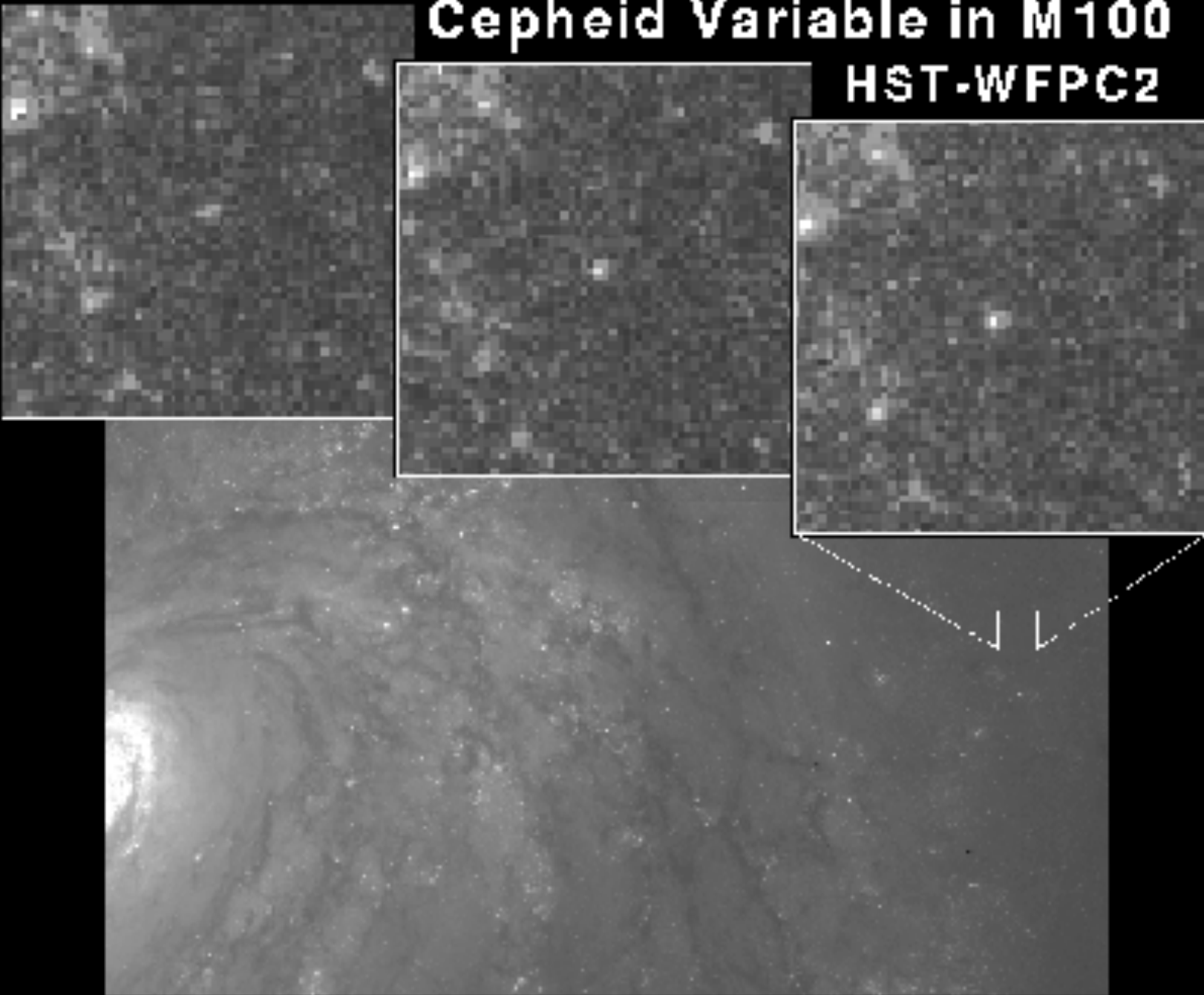


FIG. 2.

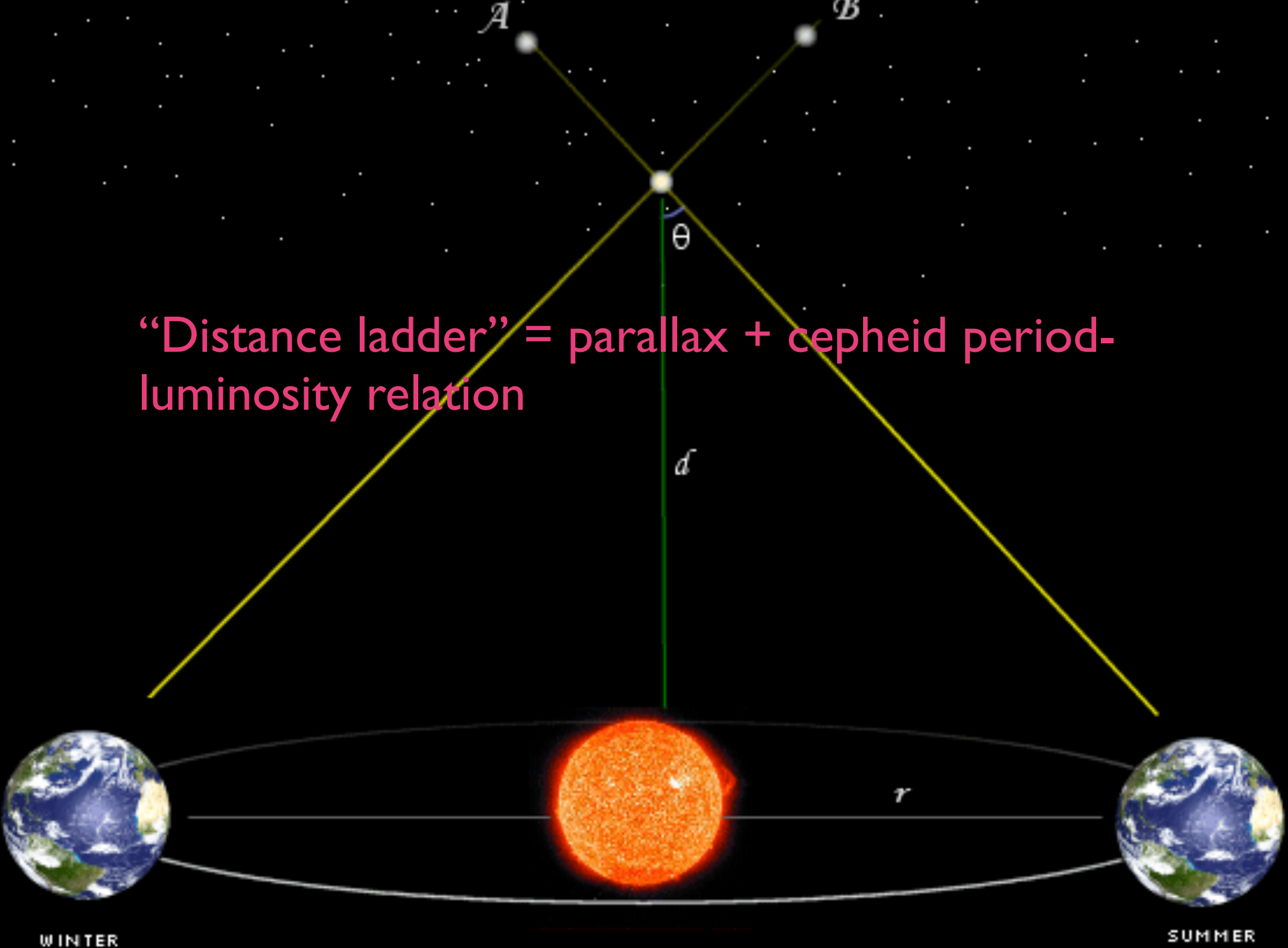


# Cepheid Variable in M100

## HST-WFPC2













# Elliptical galaxy

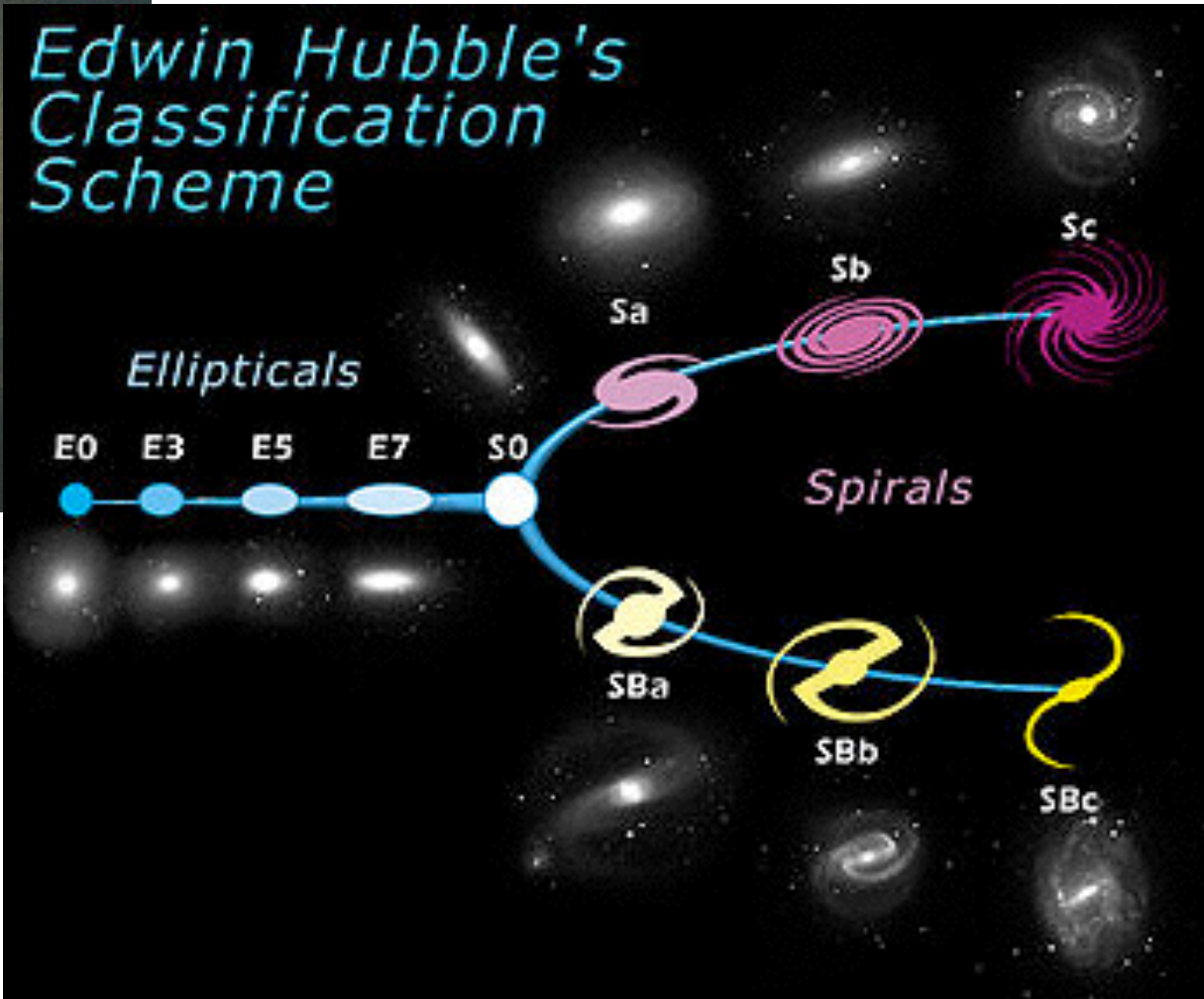


M87    © Anglo-Australian Observatory  
Photo by David Malin



# Elliptical

## Edwin Hubble's Classification Scheme



spiraal (Sc)





## Milky Way dwarfs

$L = 1000 L_{\text{sun}}$

300 lt yrs



W1

$L = 500,000 L_{\text{sun}}$

1500 lt yrs



Leo II



# When is a galaxy not a galaxy?



Cornell University  
Library

[lanl.arXiv.org](#) > [astro-ph](#) > [arXiv:1101.3309](#)

[Astrophysics](#) > [Galaxy Astrophysics](#)

## What is a Galaxy? Cast your vote here...

[Duncan Forbes](#) (Swinburne, Melbourne), [Pavel Kroupa](#) (AlfA, Bonn)

*(Submitted on 17 Jan 2011 (v1), last revised 22 Jan 2011 (this version, v2))*

Here we have accepted the popular definition of a galaxy requiring that it be both gravitationally bound and consist of a system of stars. As such criteria would include globular (star) clusters, additional criteria are required to define a galaxy. We suggest that the next best criterion is a dynamical one, i.e. that the stars are collisionless, subject to the general gravitational field of the system. This can be usefully quantified using the two-body relaxation time.



# Colours



Visual



UV

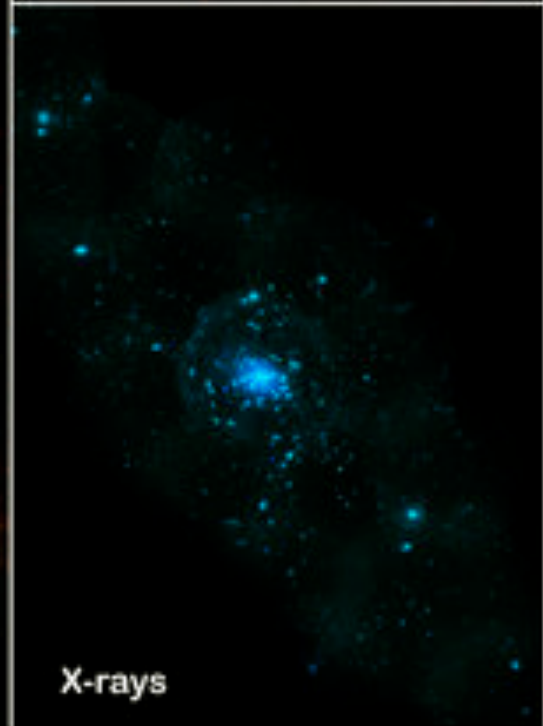
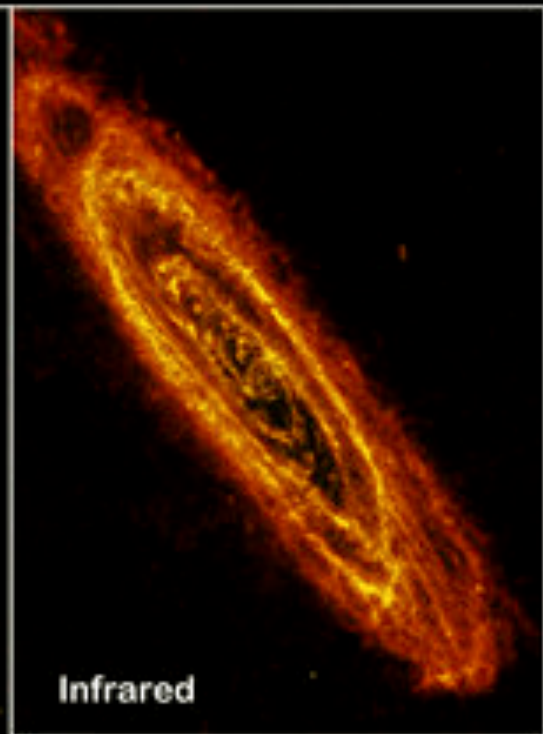


Common silverweed as we see it (top) and under UV light (below). © Bjørn Rørslett/NN

Meadow cranesbill



# Andromeda





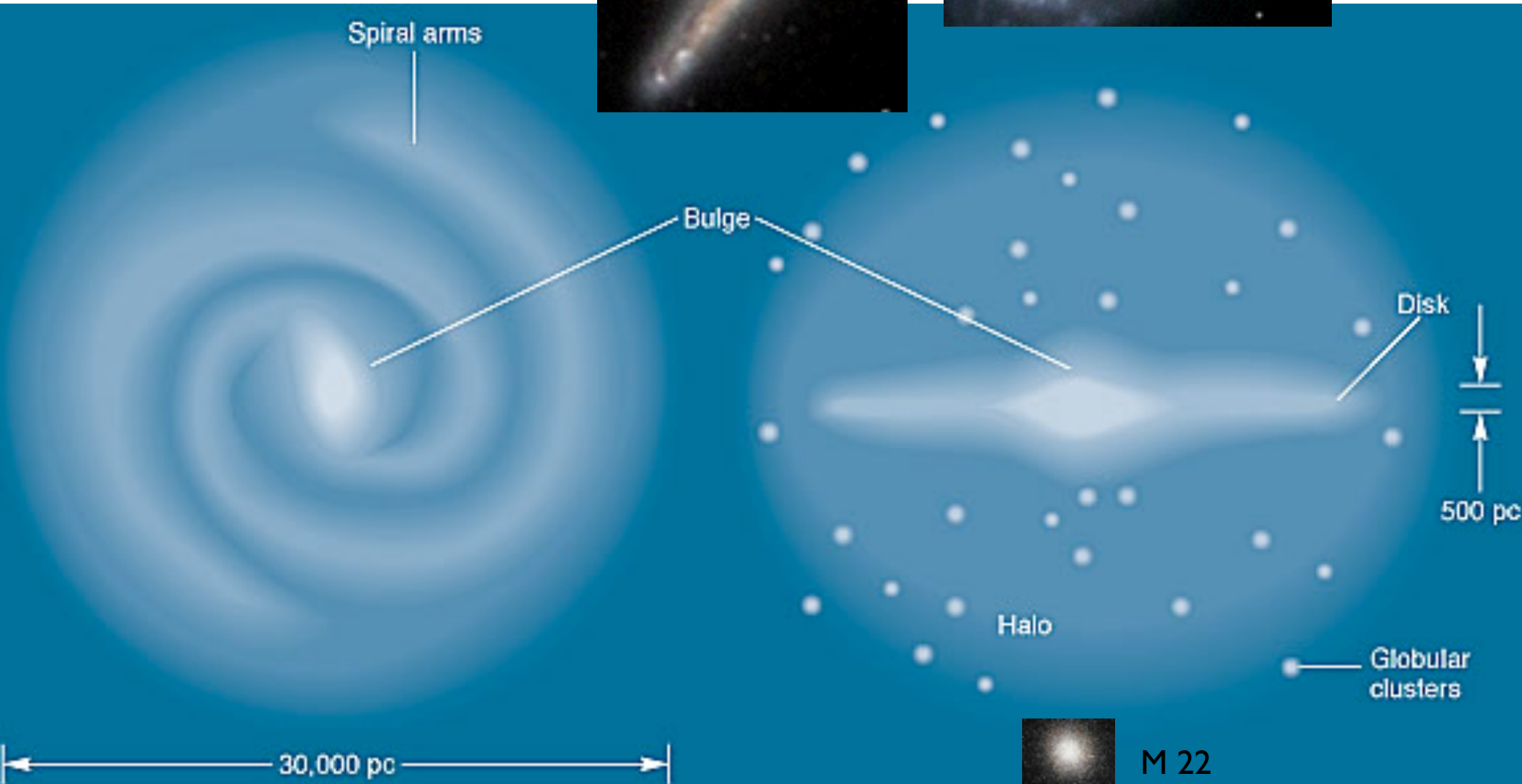
# The Milky Way in numbers

- 200 billion stars
- radius 15 kpc (1 pc = 3.26 light years)
- distance to centre 8 kpc
- stellar mass:  $2 \cdot 10^{10}$  solar masses
- oldest star:  $10^{10}$  jaar
- current star formation rate: 2 solar masses / year
- speed: 600 km/s

200 billion galaxies brighter  
than Milky Way within visible  
horizon

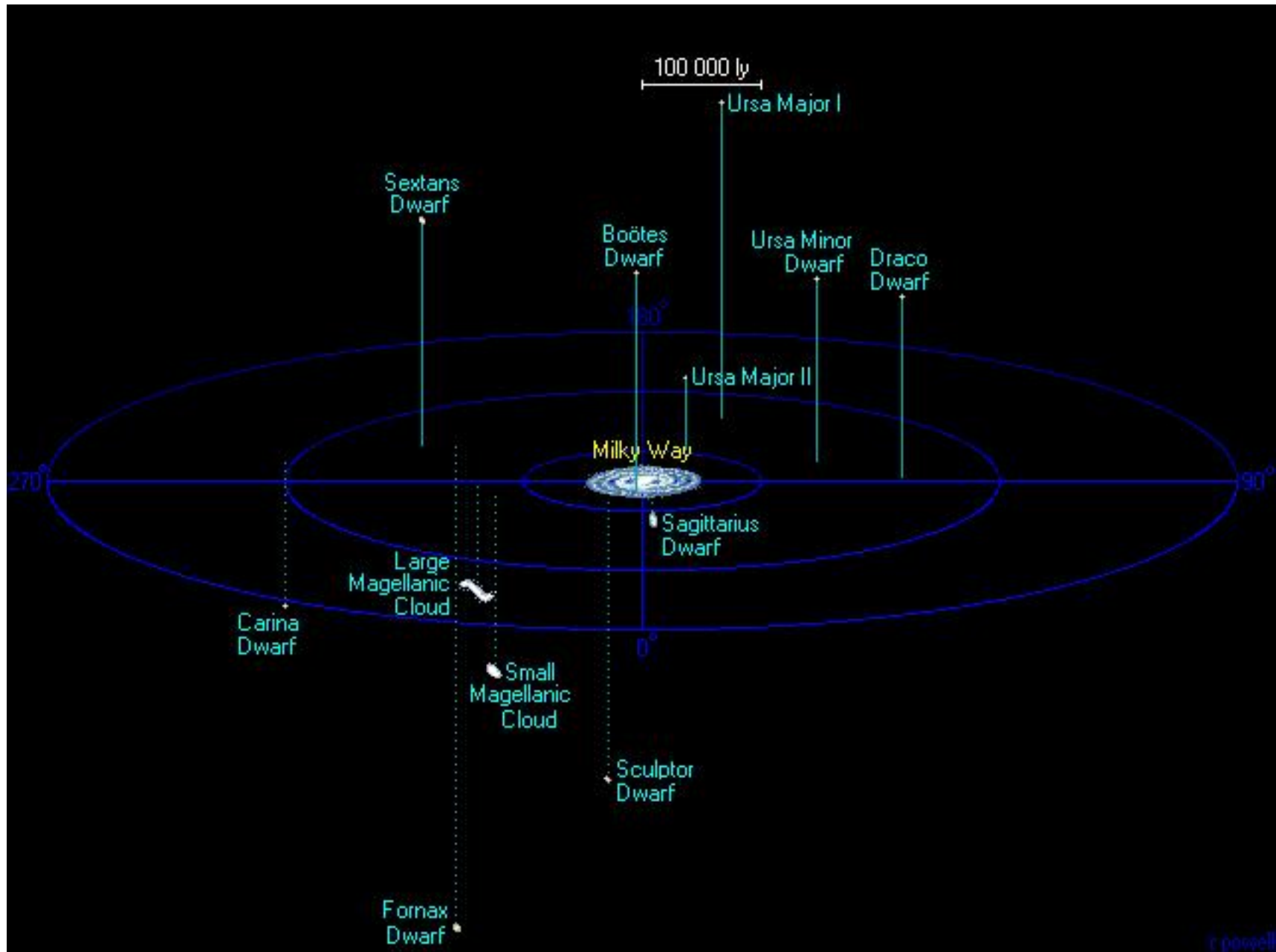


# Milky Way's structure:





# Local Group





# Large Magellanic cloud (LMC)





## Milky Way dwarfs

$L = 1000 L_{\text{sun}}$

300 lt yrs



W1

$L = 500,000 L_{\text{sun}}$

1500 lt yrs

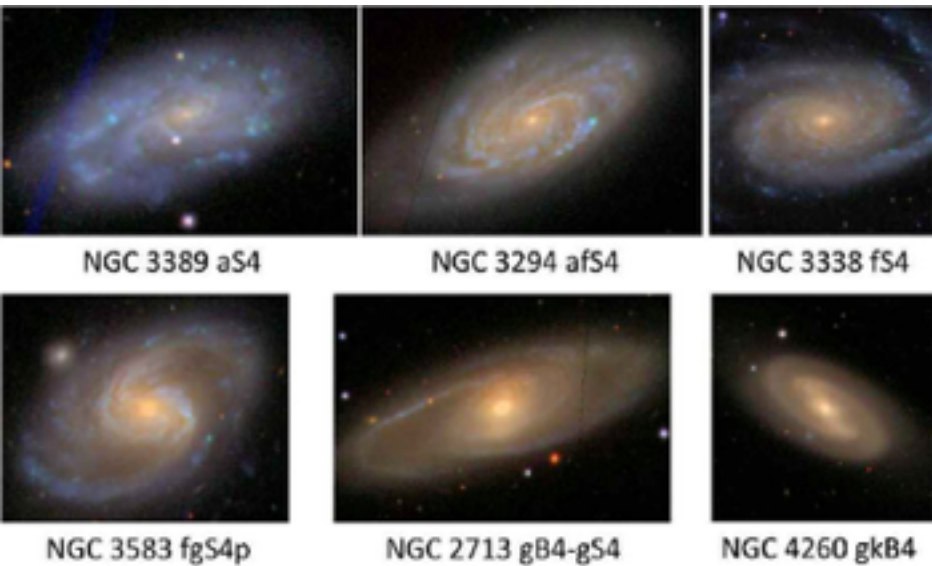


Leo II



# The three main galaxy types

## Spiral galaxies



## Elliptical galaxies



## Irregular galaxies



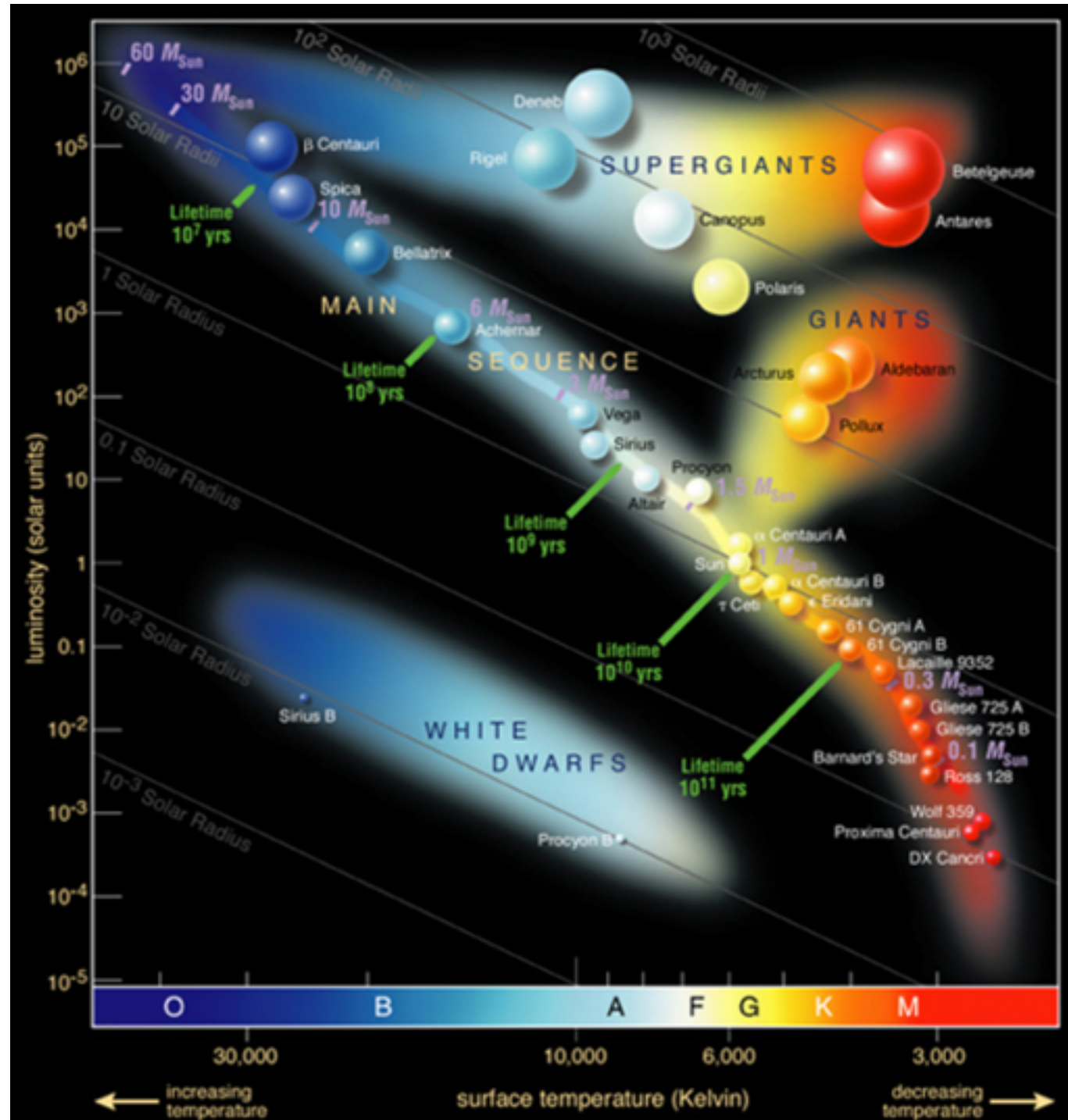


The 3D shape of ellipticals is thought to be triaxial - a squashed rugby ball





colour of galaxy: mostly set by relative amount of  
recent star formation





# Hubble's Galaxy Classification Scheme





# The Spitzer Infrared Nearby Galaxies Survey (SINGS) Hubble Tuning-Fork

The Spitzer Space Telescope observed 75 galaxies as part of its SINGS (Spitzer Infrared Nearby Galaxies Survey) Legacy Program. The galaxies are presented here in a Hubble Tuning Fork diagram, which groups galaxies according to the morphology of their nuclei and spiral arms. The designation of these galaxies and their placement in the diagram is based on their visible-light appearance. The main goal of the SINGS program is to characterize the infrared properties of a wide range of galaxy types. The images of the galaxies are composites created from data taken by IRAC (the Infrared Array Camera) at 3.6 and 8.0  $\mu\text{m}$ , and MIPS (the Multiband Imaging Photometer for Spitzer) at 24  $\mu\text{m}$ .

The infrared range probed by these and other observations taken for the SINGS project allows for the detailed study of star formation, dust emission, and the distribution of stars in each galaxy. Light from old stars appears as blue in the images, while the lumpy knots of green and red light are produced by dust clouds surrounding newly born stars. The elliptical galaxies on the left are almost entirely made of old stars, while spiral galaxies like our own Milky Way are rich in young stars and the raw materials for future star formation.

More information can be found at:  
<http://sings.stsci.edu/>

Ellipticals

Irregulars

Strong Bulge

Strong Bulge

Weak Bulge

Unbarred Spirals

Intermediate Spirals

Weak Bulge

Barred Spirals

Poster and composite images created from  
SINGS observations by Karl D. Gordon (PI, STScI)  
Blue=IRAC 3.6  $\mu\text{m}$  (stars)  
Green=IRAC 8.0  $\mu\text{m}$   
(aromatic features from dust grains/molecules)  
Red=MIPS 24  $\mu\text{m}$  (warm dust)

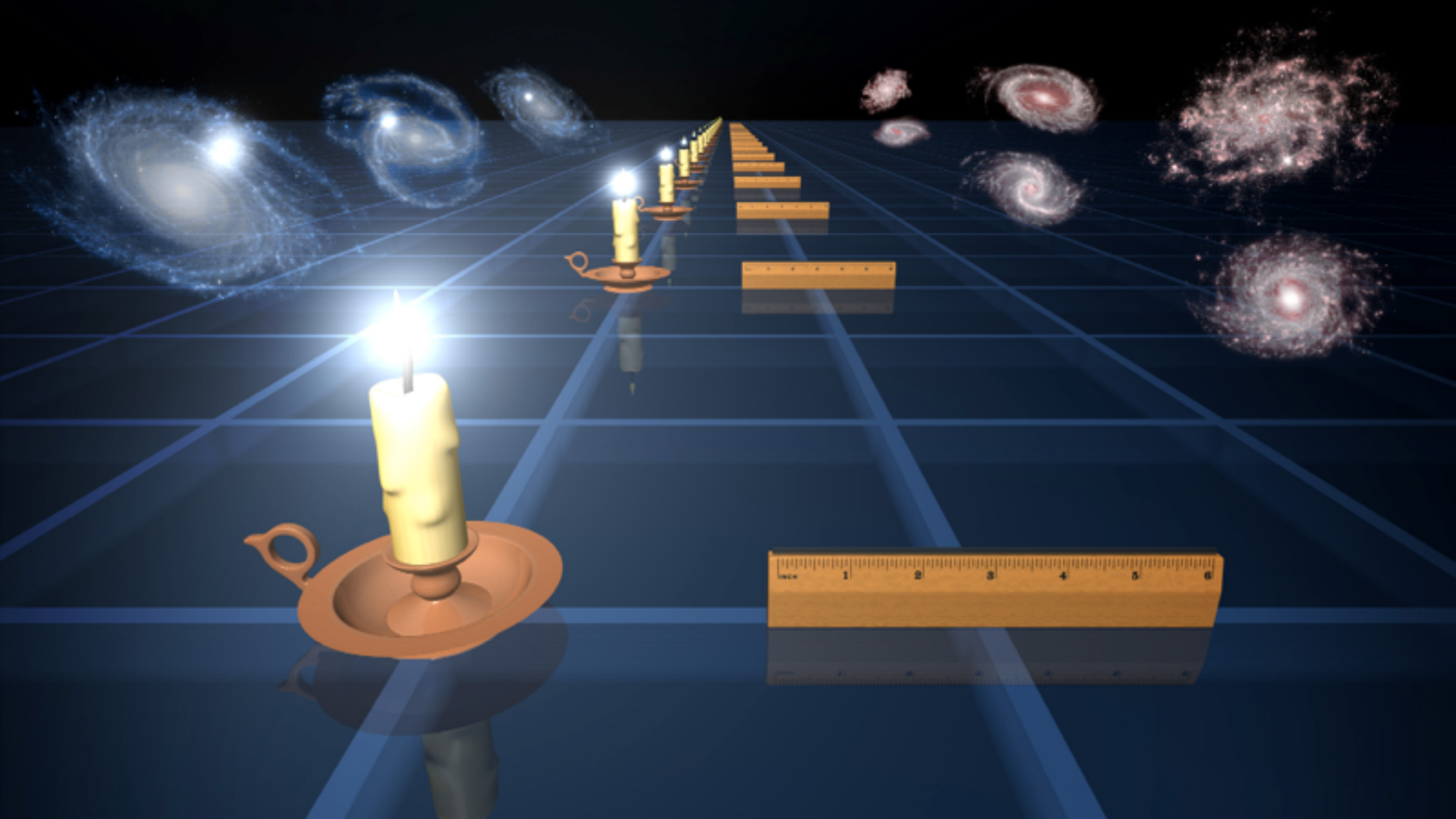
## SINGS Team

Robert Kennicutt, Jr. (Principal Investigator), Daniel Calzetti (Deputy Principal Investigator), Charles Engelbracht (Technical Contact), Lee Anna, George Bendo, Caroline Bot, Brent Buckalew, John Cannon, Daniel Dale, Bruce Draine, Karl Gordon, Albert Grauer, David Hollenbach, Tom Jarrett, Lisa Kewley, Claus Leitherer, Algen Li, Sangmita Mahata, Martin Meyer, John Moustakas, Eric Murphy, Michael Regan, George Rieke, Marcia Rieke, Helene Roussel, Kirk Sheth, J.D. Smith, Michele Thornley, Fabian Walter & George Huxley





# Standard candles

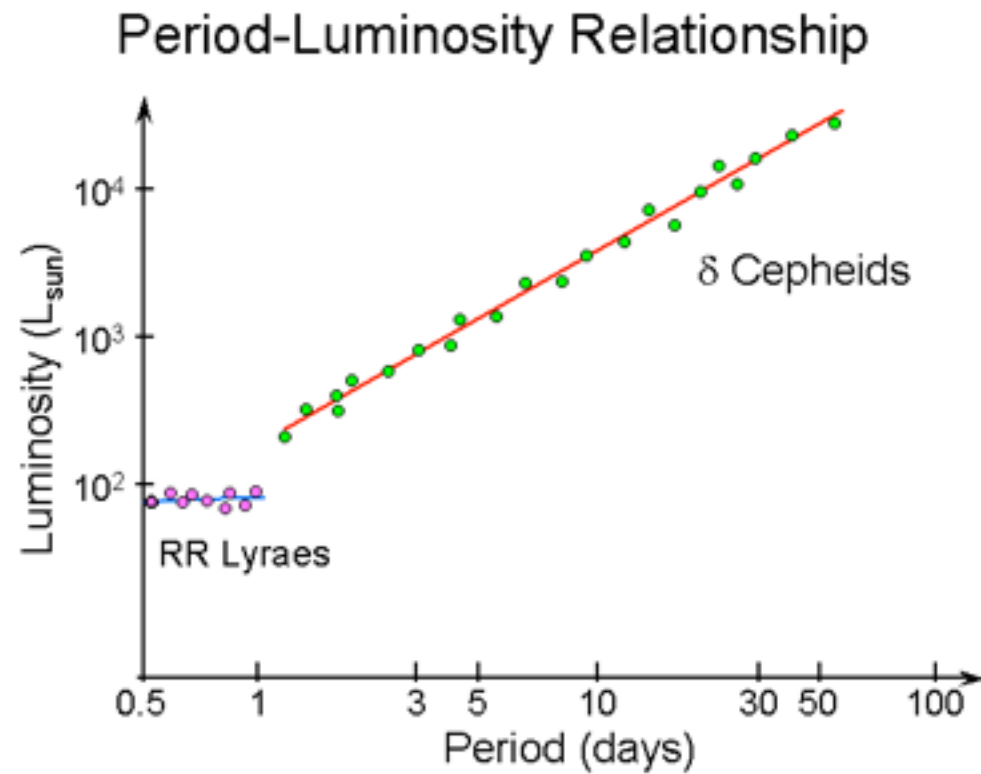




# Cepheid variables as standard candles



Henrietta Leavitt (1912)





# 1777 VARIABLES IN THE MAGELLANIC CLOUDS.



BY HENRIETTA S. LEAVITT.

| A. G. C. | R. A. 1900. |    |       | Dec. 1900. |     |    | $x$  | $y$   | A. G. C. | R. A. 1900. |    |       | Dec. 1900. |     |     | $x$  | $y$   |       |       |
|----------|-------------|----|-------|------------|-----|----|------|-------|----------|-------------|----|-------|------------|-----|-----|------|-------|-------|-------|
|          | A.          | m. | s.    | h.         | m.  | s. |      |       |          | A.          | m. | s.    | h.         | m.  | s.  |      |       |       |       |
| 45       | 0           | 3  | 44.41 |            | -74 | 47 | 40.3 | 1606  | 3218     | 960         | 0  | 57    | 37.19      |     | -73 | 14   | 8.5   | 14504 | 9959  |
| 193      |             | 12 | 21.88 |            | -70 | 31 | 8.7  | 1220  | 19235    | 969         |    | 58    | 10.43      |     | -72 | 5    | 10.5  | 14772 | 14120 |
|          |             |    |       |            | 72  | 31 | 58.6 | 3320  | 11841    | 1021        | 1  | 1     | 8.21       |     | -72 | 47   | 17.2  | 15490 | 11542 |
| 534      |             | 31 | 34.28 |            | 72  | 5  | 32.7 | 7360  | 13909    | 1042        | 2  | 7.73  |            | -71 | 28  | 8.0  | 15977 | 16313 |       |
|          |             |    |       |            | 74  | 30 | 32.5 | 8776  | 5226     | 1043        | 2  | 7.84  |            | -73 | 5   | 8.0  | 15710 | 10458 |       |
|          |             |    |       |            | 73  | 41 | 14.6 | 8638  | 8205     | 1092        | 5  | 30.63 |            | -72 | 22  | 9.3  | 16752 | 13002 |       |
|          |             |    |       |            | 74  | 17 | 2.4  | 10038 | 6119     | 1121        | 7  | 4.04  |            | -73 | 29  | 22.1 | 16910 | 8922  |       |
|          |             |    |       |            | 71  | 42 | 59.3 | 9816  | 15428    | 1137        | 8  | 9.00  |            | -73 | 32  | 57.0 | 17175 | 8686  |       |
|          |             |    |       |            | 73  | 8  | 30.2 | 10602 | 10282    | 1269        | 15 | 27.14 |            | -74 | 40  | 46.7 | 18618 | 4450  |       |
|          |             |    |       |            | 72  | 40 | 31.6 | 11464 | 11999    | 1271        | 15 | 40.04 |            | -73 | 14  | 48.9 | 19206 | 9612  |       |
|          |             |    |       |            | 73  | 13 | 21.0 | 11956 | 10024    | 1295        | 16 | 54.06 |            | -72 | 19  | 40.4 | 19884 | 12887 |       |
|          |             |    |       |            | 74  | 21 | 58.5 | 13247 | 5882     | 1449        | 25 | 58.66 |            | -72 | 27  | 31.2 | 22394 | 12103 |       |
|          |             |    |       |            | -73 | 36 | 31.6 | 13396 | 8624     | 1496        | 27 | 59.13 |            | -73 | 41  | 16.6 | 22151 | 7620  |       |
|          |             |    |       |            | -70 | 42 | 56.8 | 14456 | 19103    | 1544        | 30 | 57.40 |            | -71 | 22  | 46.4 | 24293 | 15758 |       |

variables alike, is about 1.2 magnitudes. 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.

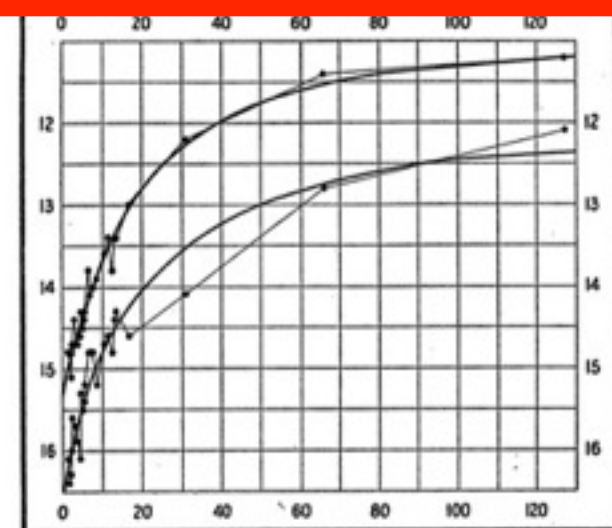


FIG. 1.

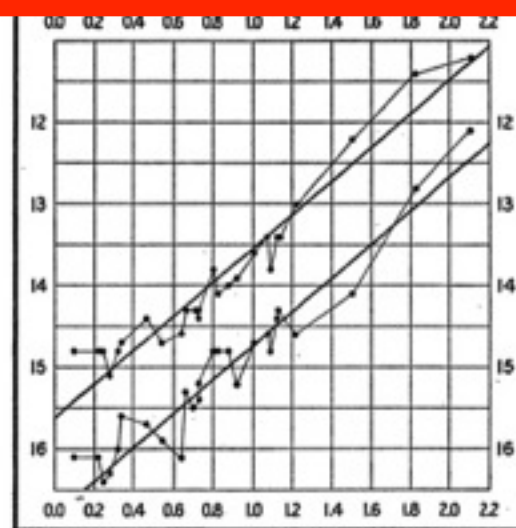


FIG. 2.

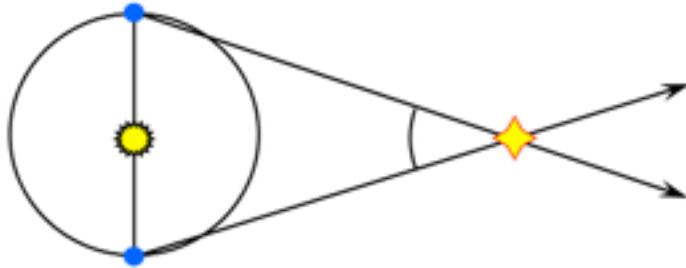
EDWARD C. PICKERING.

MARCH 3, 1912.

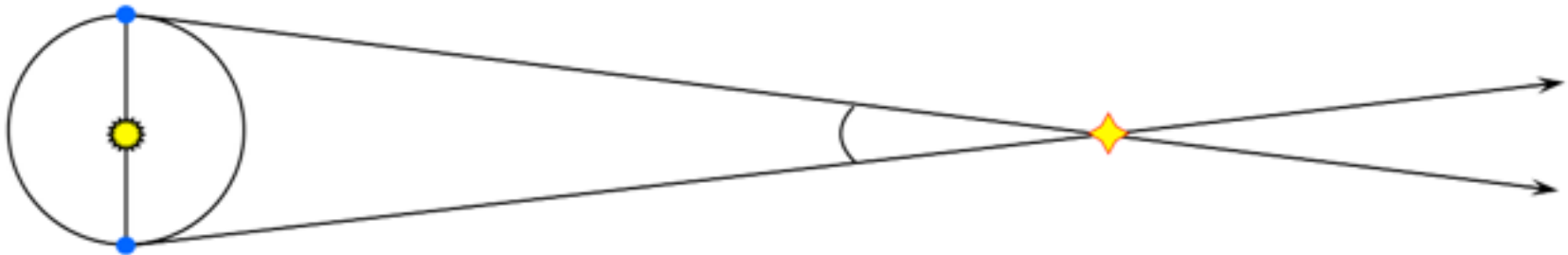


# Parallax distance measurements

*Closer stars have larger parallaxes:*

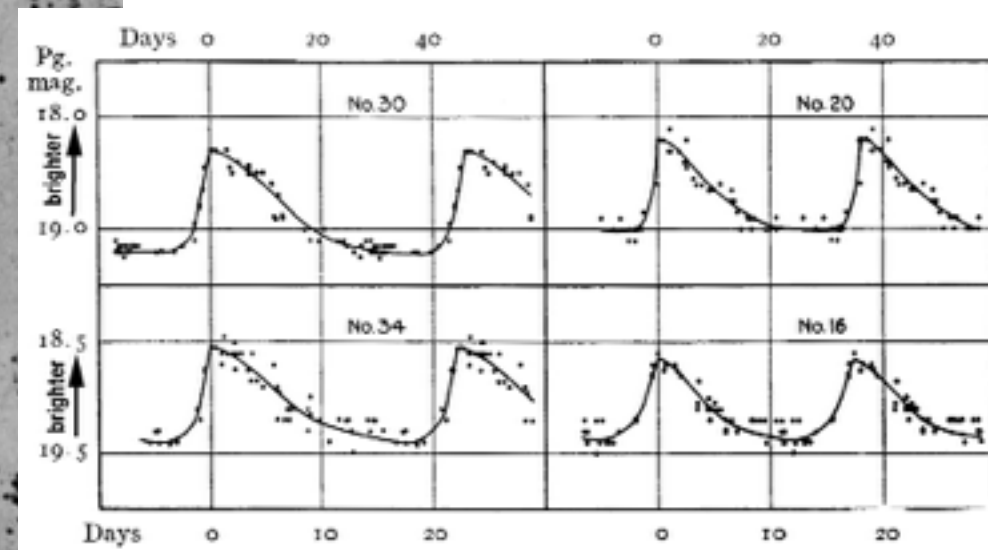
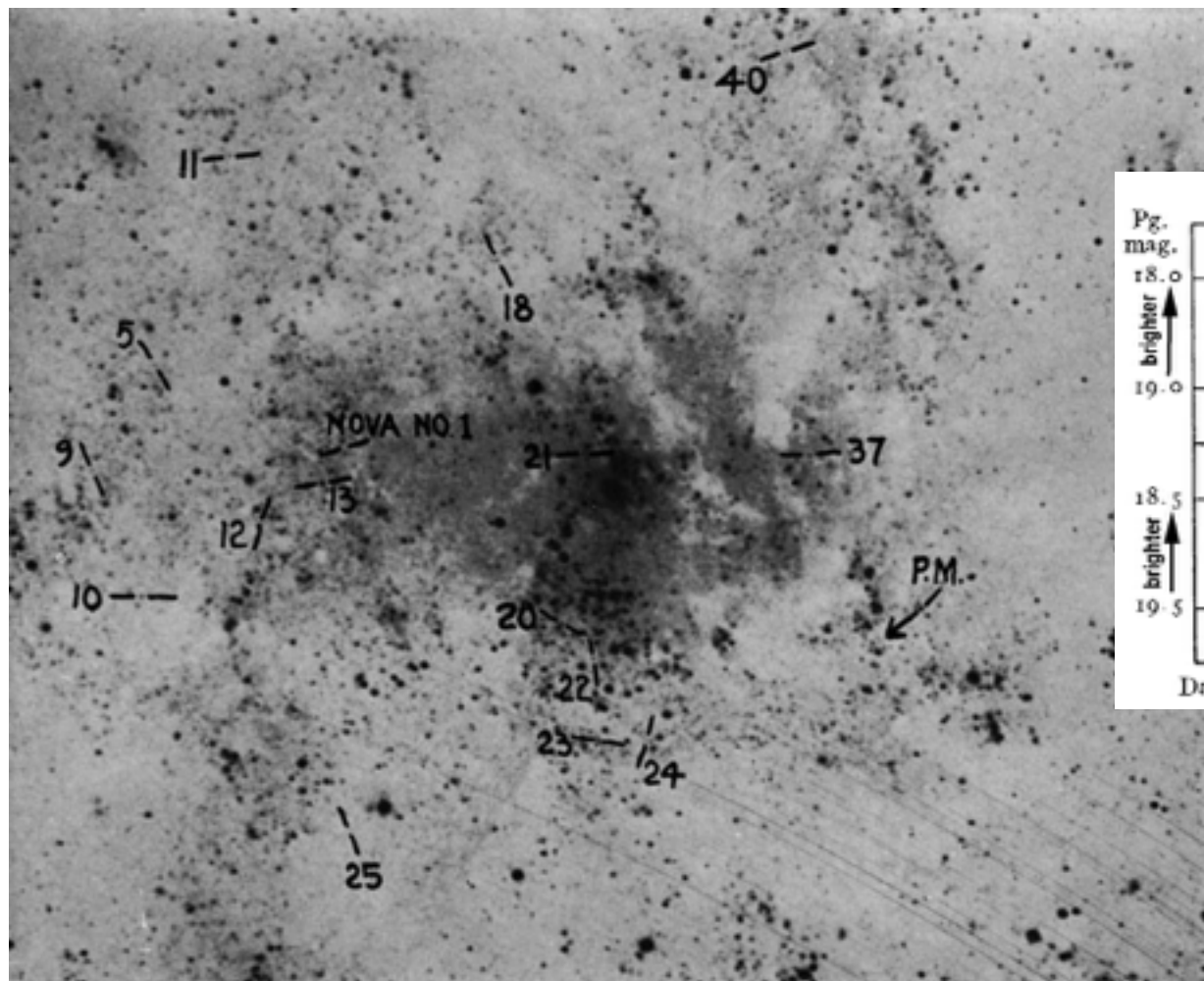


*Distant stars have smaller parallaxes:*





# Hubble's measurements of Cepheids in Andromeda



36,000 × 12,000 light-years for M 31 and 22,000 × 16,500 light-years for M 33, which are of the order of a "universe."

In the discussion Mr. Goodacre, Dr. Stevenson, the Rev. T. E. R. Phillips, Capt. Ainslie, Mr. Scattergood, Dr. Crommelin, and Mr. Waterfield joined.

Mr. Doig read a second paper on "An Estimate of the Distances of Fourteen Open Clusters." The diameters of the clusters were found to be of the order of 10 to 60 light-years. Dr. Crommelin and Major Hepburn joined in the discussion.

Mr. J. W. Wilson read a note on the Meteoric Origin of the Lunar Craters. If these formations are due to direct hits by meteors on the Moon's surface, the energy required to change the configuration of the surface by impact is drawn from the kinetic energy or energy of motion of the meteor, and some of it (according to the impact theory) must have been utilised in raising up the material of the Moon's surface from its original level to that which it occupies when forming a crater of the observed size and shape. To produce Copernicus the meteor would have to be at least 220 yards in diameter if moving at 20 miles per second, or 80 yards at 100 miles per second, and no known meteor is as large as this. But the impact of the meteor may have acted merely as a trigger for the release of internal lunar volcanic energy. In the case of a small crater of about 4 miles diameter it is possible that such might be formed by a meteor without assistance from internal volcanic energy. A meteor of about 4 feet in diameter, and moving at 50 miles per second, would be capable of producing a crater of about a mile in diameter. If such were produced to-day it would probably escape notice except in the case of a very well charted region.

Mr. Goodacre described an observation of colour presented by the well-known bright ray or streak, which runs S.E. from Proclus, on one day after Full Moon during the previous lunation.

which gradually merged into a light brown at the opposite edge.

#### *Cepheids in Spiral Nebulae\*.*

MESSIER 31 † and 33, the only spirals that can be seen with the naked eye, have recently been made the subject of detailed investigations with the 100-inch and 60-inch reflectors of the Mount Wilson Observatory. Novæ are a common phenomenon in M 31, and Duncan has reported three variables within the area covered by M 33 ‡. With these exceptions there seems to have been no

\* Abstract of paper read at the Thirty-Third Meeting of the American Astronomical Society. From *Popular Astronomy*, vol. XXXII. No. 4, April 1925.

† Messier 31 is the Andromeda Nebula.

‡ *Publications of the Astronomical Society of the Pacific*, XXXV. p. 290 (1922).

TABLE II.  
*Cepheids in M 31. †*

| Var. No. | Period<br>in Days. | Log. P. | Photographic<br>Magnitude,<br>Max. |
|----------|--------------------|---------|------------------------------------|
| 5 .....  | 50.17              | 1.70    | 18.4                               |
| 7 .....  | 45.04              | 1.65    | 18.15                              |
| 16 ..... | 41.14              | 1.61    | 18.6                               |
| 9 .....  | 38                 | 1.58    | 18.3                               |
| 1 .....  | 31.41              | 1.50    | 18.2                               |
| 12 ..... | 22.03              | 1.34    | 19.0                               |
| 13 ..... | 22                 | 1.34    | 19.0                               |
| 10 ..... | 21.5               | 1.33    | 18.75                              |
| 2 .....  | 20.10              | 1.30    | 18.5                               |
| 17 ..... | 18.77              | 1.28    | 18.55                              |
| 18 ..... | 18.54              | 1.27    | 18.9                               |
| 14 ..... | 18                 | 1.26    | 19.1                               |

greater reliability of the magnitude determinations. When this is done, the resulting values of  $M-m$  are  $-21.8$  and  $-21.9$  for M 31 and M 33 respectively. These must be corrected by half the average ranges of the Cepheids in the two spirals, and the final values are then on the order of  $-22.3$  for both nebulae. The corresponding distance is about 285,000 parsecs \*. The greatest uncertainty is probably in the zero-point of Shapley's curve.

The results rest on three major assumptions: (1) The variables are actually connected with the spirals; (2) The amount of absorption due to amorphous matter in the spirals; (3) The nature of Cepheid variation is the same throughout the observable portion of the universe. As the weighty arguments based on analogy and probability, it may be mentioned that no Cepheids have been found on the several plates of the neighbouring selected areas Nos. 21 and 45, on a special series of plates centred on BD+35°207, just midway between the two spirals, nor in ten other fields well distributed in galactic latitude, for which six or more long exposures are available. The second assumption is very strongly supported by the small dispersion in the period-luminosity curve for M 33. In M 31, in spite of the somewhat larger dispersion, there is no evidence of an absorption-effect to be measured in magnitudes.

These two spirals are not unique. Variables have also been found in M 81, M 101, and N.G.C. 2403, although as yet sufficient plates have not been accumulated to determine the nature of their variation.

EDWIN P. HUBBLE.

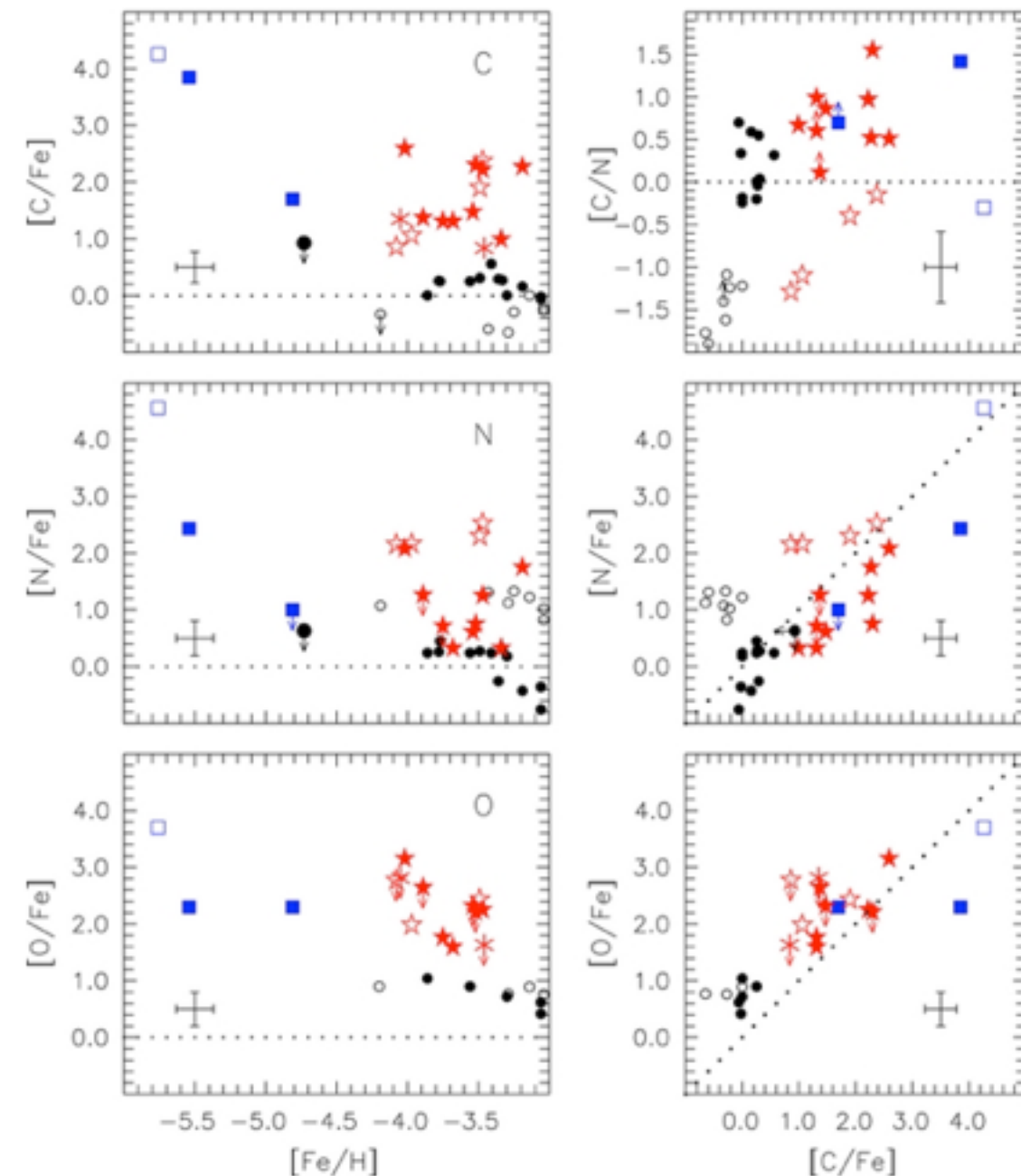


# Galactic archaeology



One of the very first stars  
of the MW?

## THE MOST METAL-POOR STARS. IV. THE TWO POPULATIONS WITH $[\text{Fe}/\text{H}] \sim -3.0$



Unusual element abundances: evidence for unusual SN progenitors?

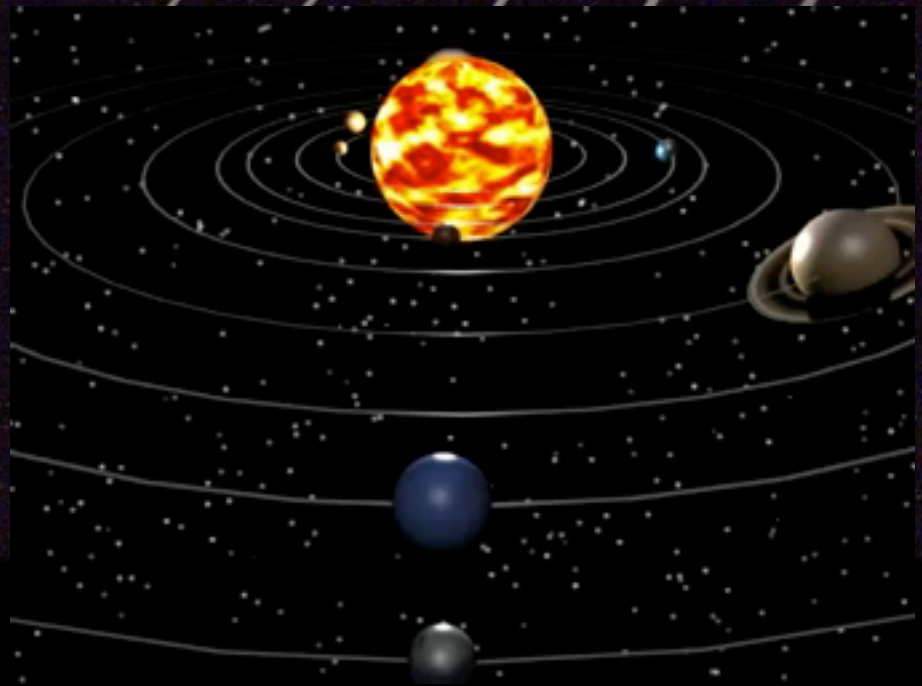
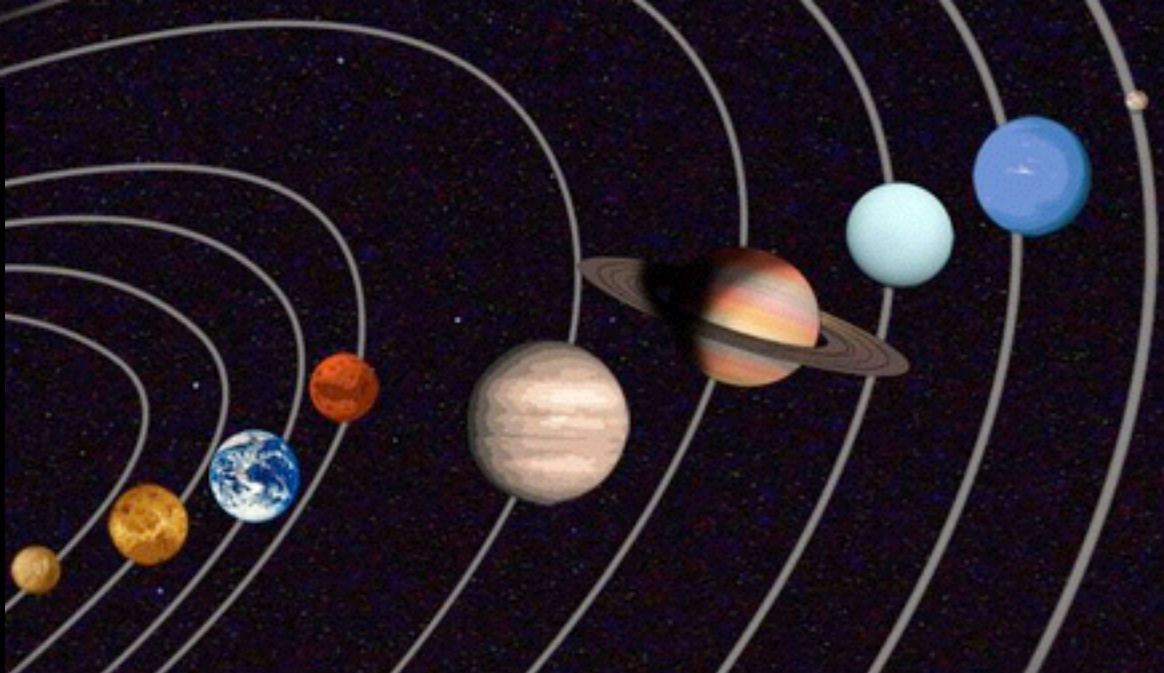
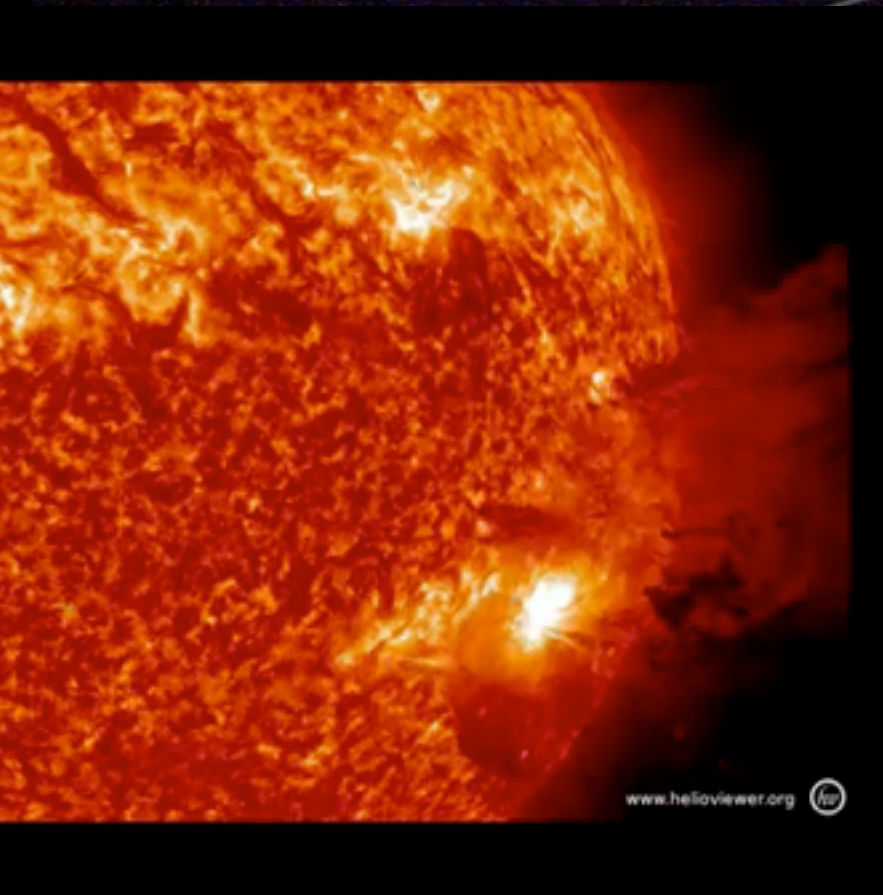




# How to weigh the Milky Way?





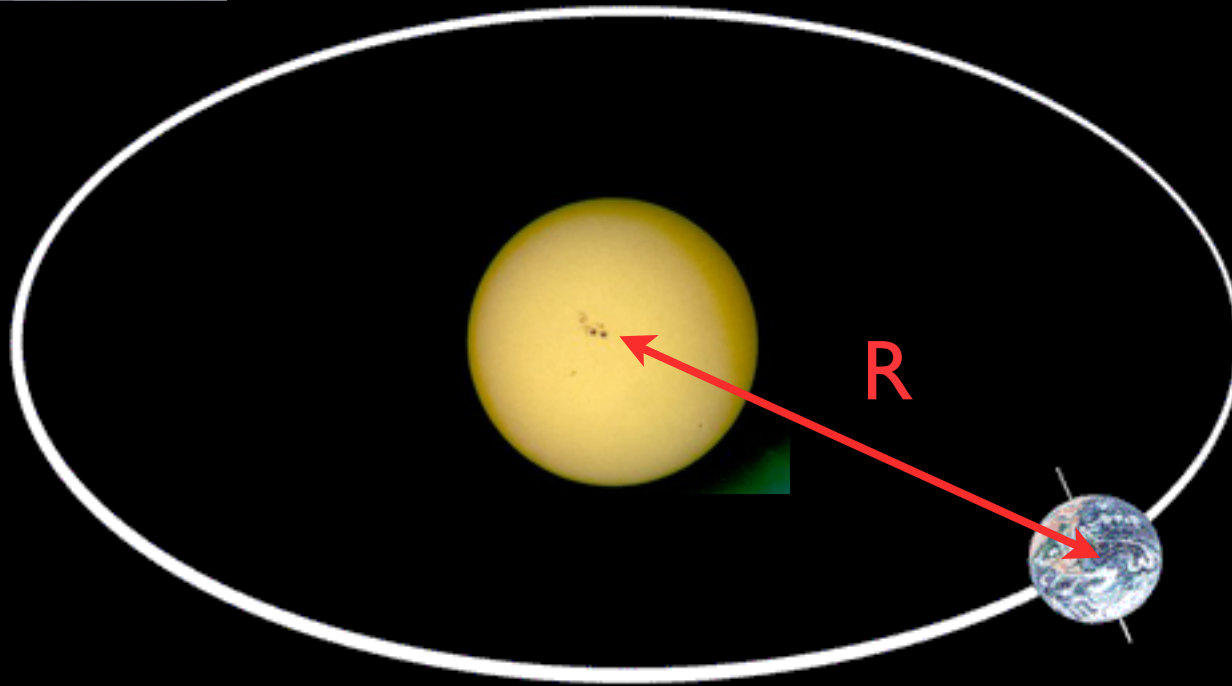


The solar system

# How to weigh a Milky Way?



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





## Speed of earth around the Sun

$$\begin{aligned} V &= \frac{2\pi R}{P} \\ &= \frac{2\pi \times 150 \times 10^6 \text{ km}}{365 \times 24 \times 3600 \text{ s}} \\ &= 30 \text{ km s}^{-1} \end{aligned}$$

$$10^{33} \text{ g} = 1\,000\,000 \dots (33) \dots 000 \text{ g}$$

## Mass of the Sun

$$\begin{aligned} M &= \frac{V^2 R}{G} \\ &= \frac{(30 \times 10^5 \text{ cm s}^{-1})^2 \times 1.5 \times 10^{13} \text{ cm}}{G} \\ &= 2 \times 10^{33} \text{ g} \end{aligned}$$



Why are Milky Way stars in a disc?

and why is this not the case for the stars in an elliptical galaxy?



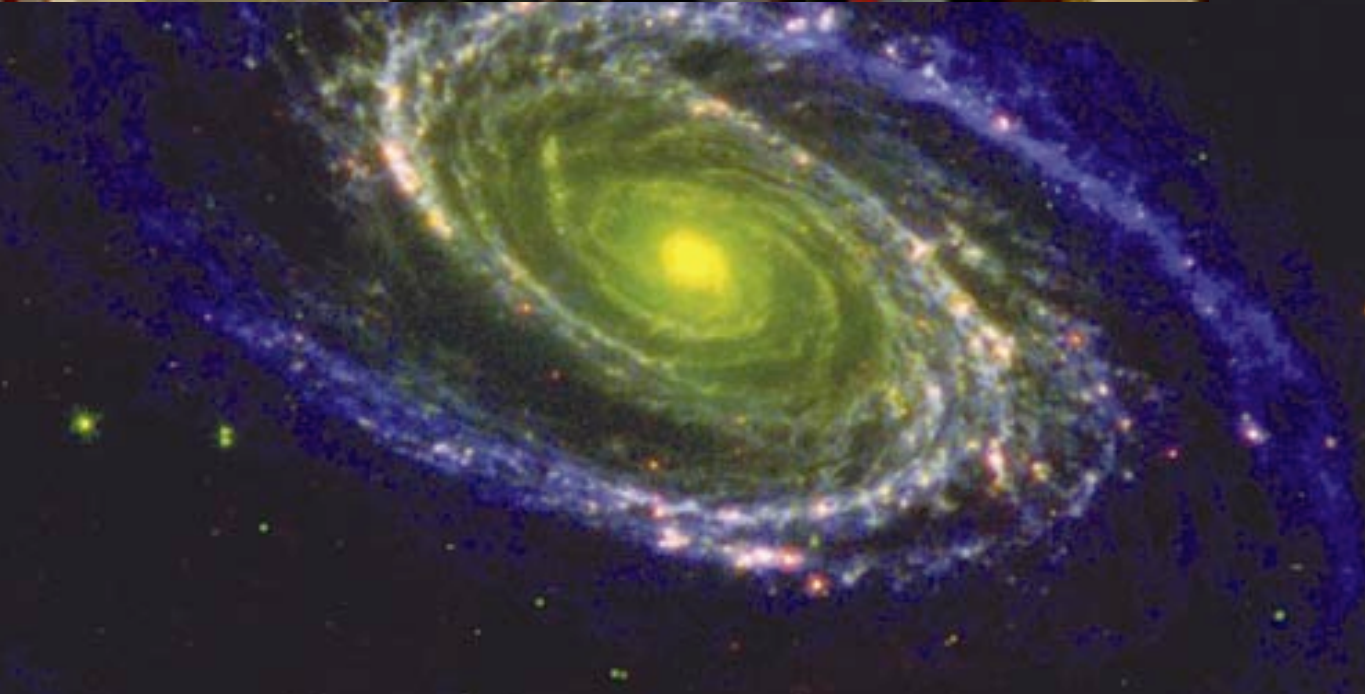
# Why are Milky Way stars in a disc?

- angular momentum
- cooling

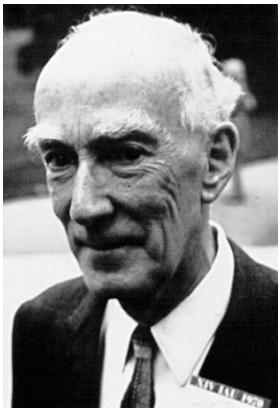
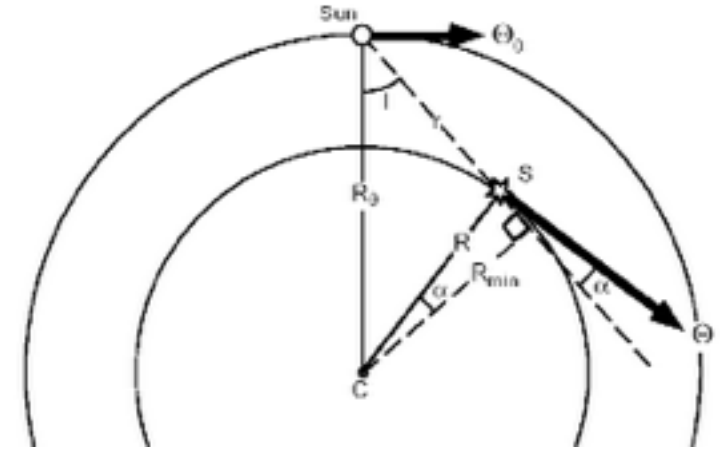
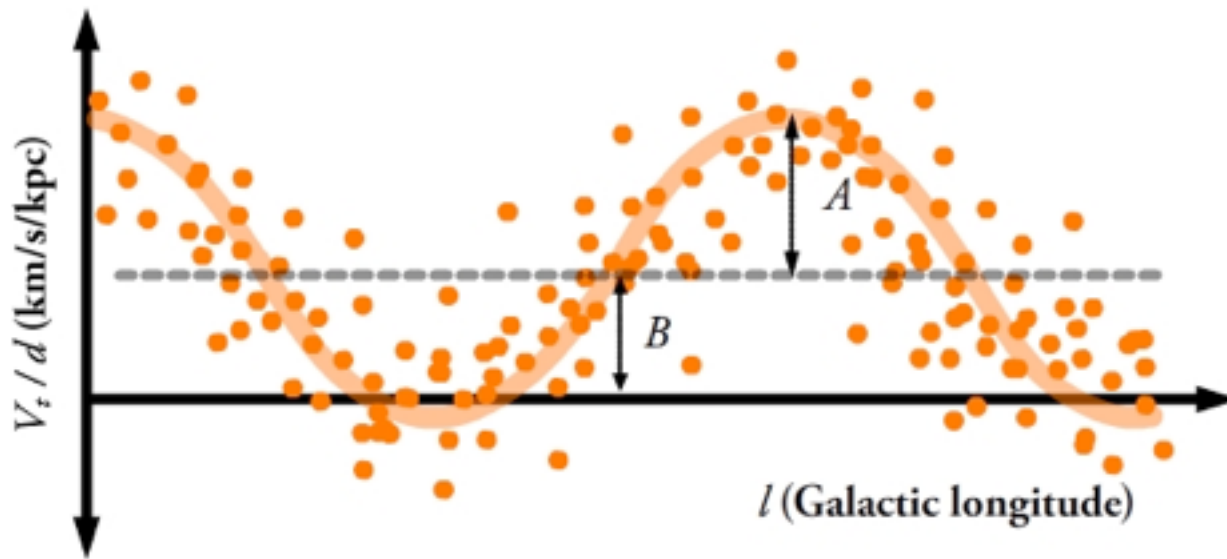
and why is this not the case for the stars in an elliptical galaxy?

?

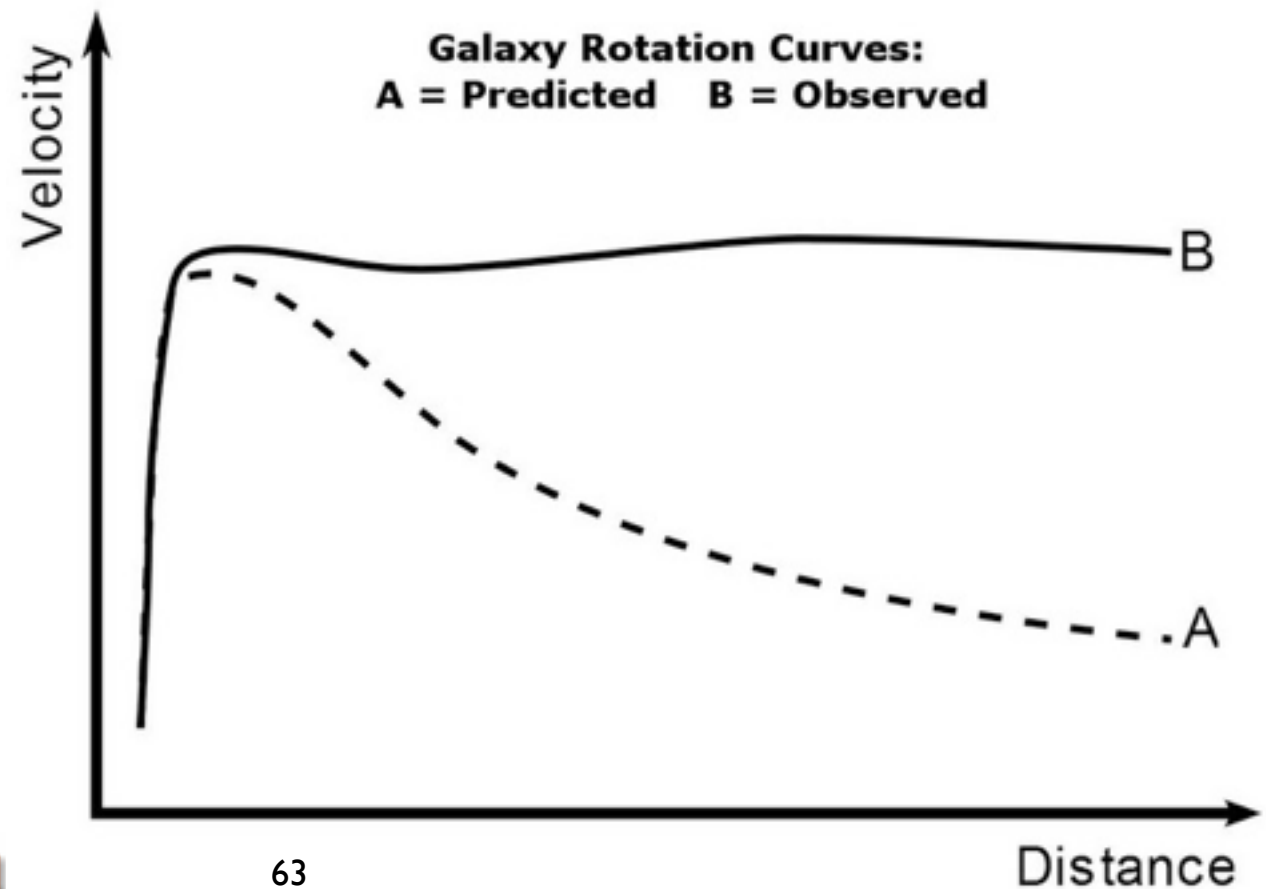
Rotation!

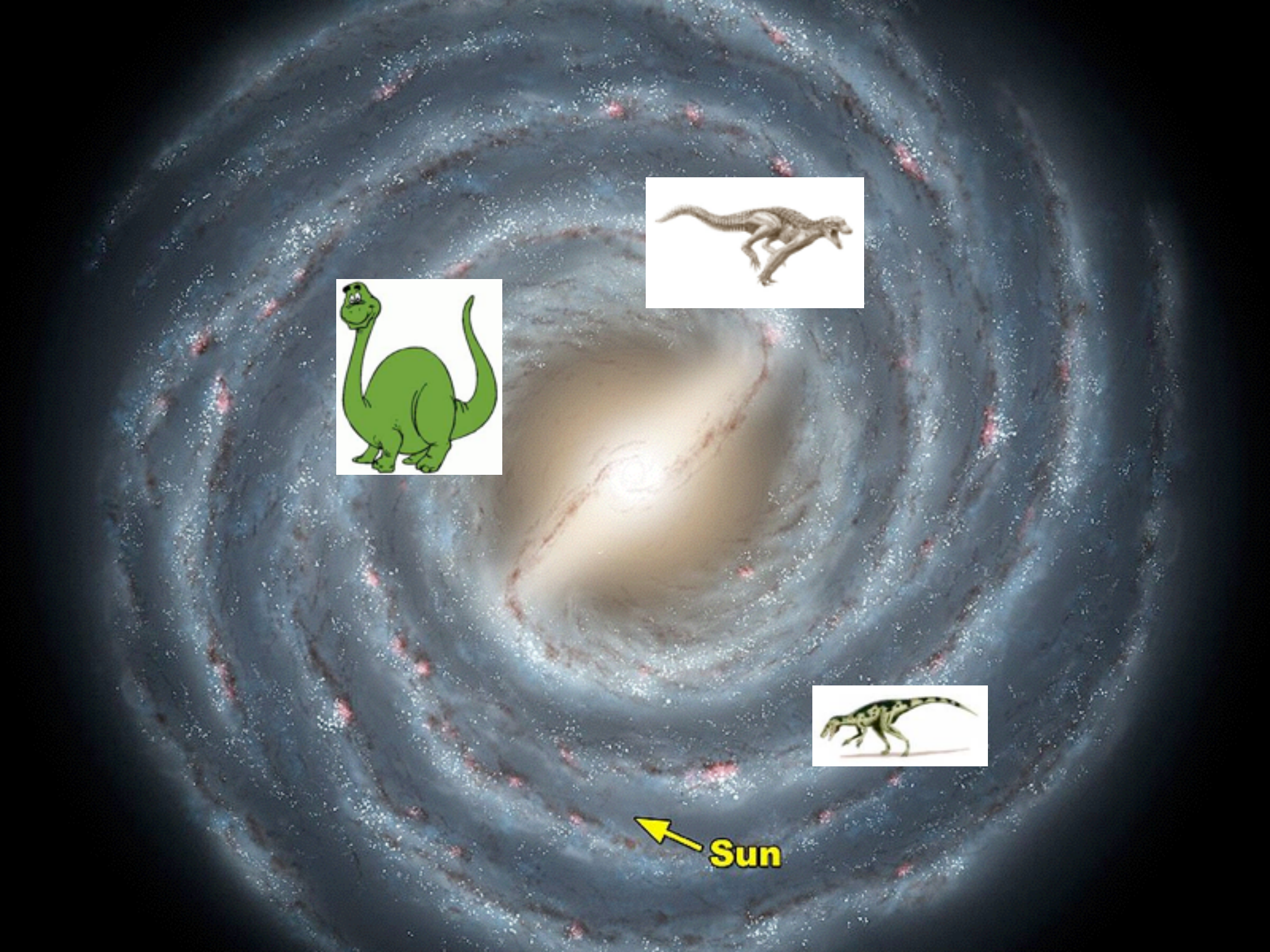






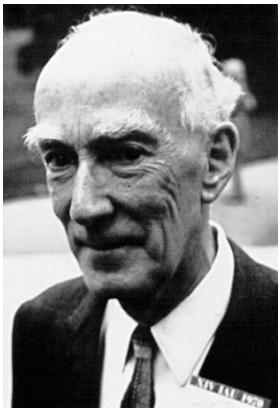
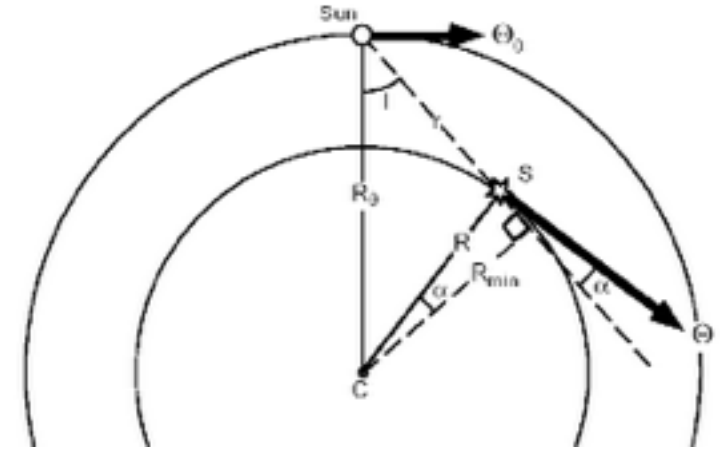
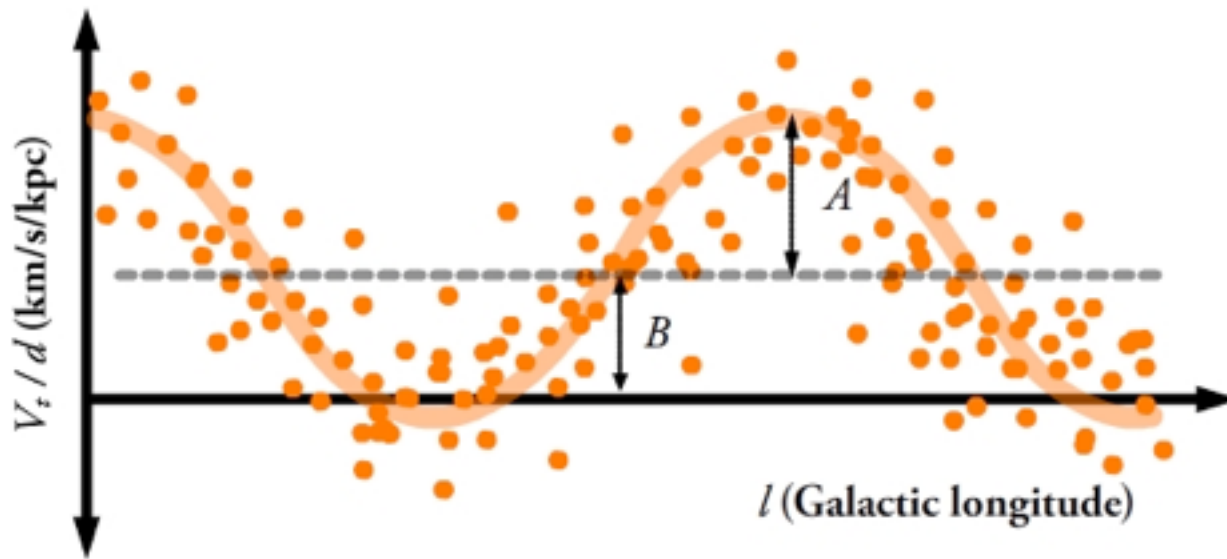
Jan Oort



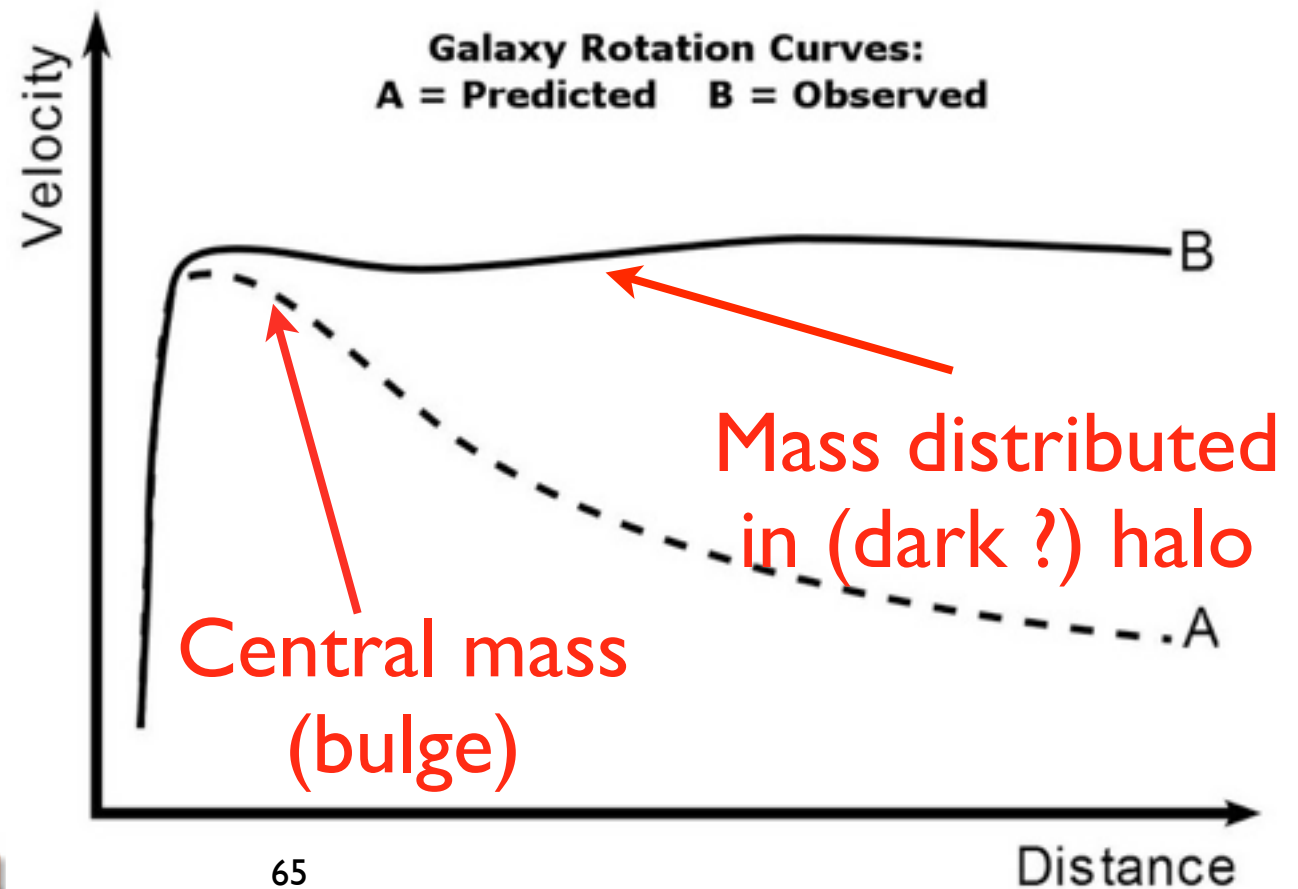


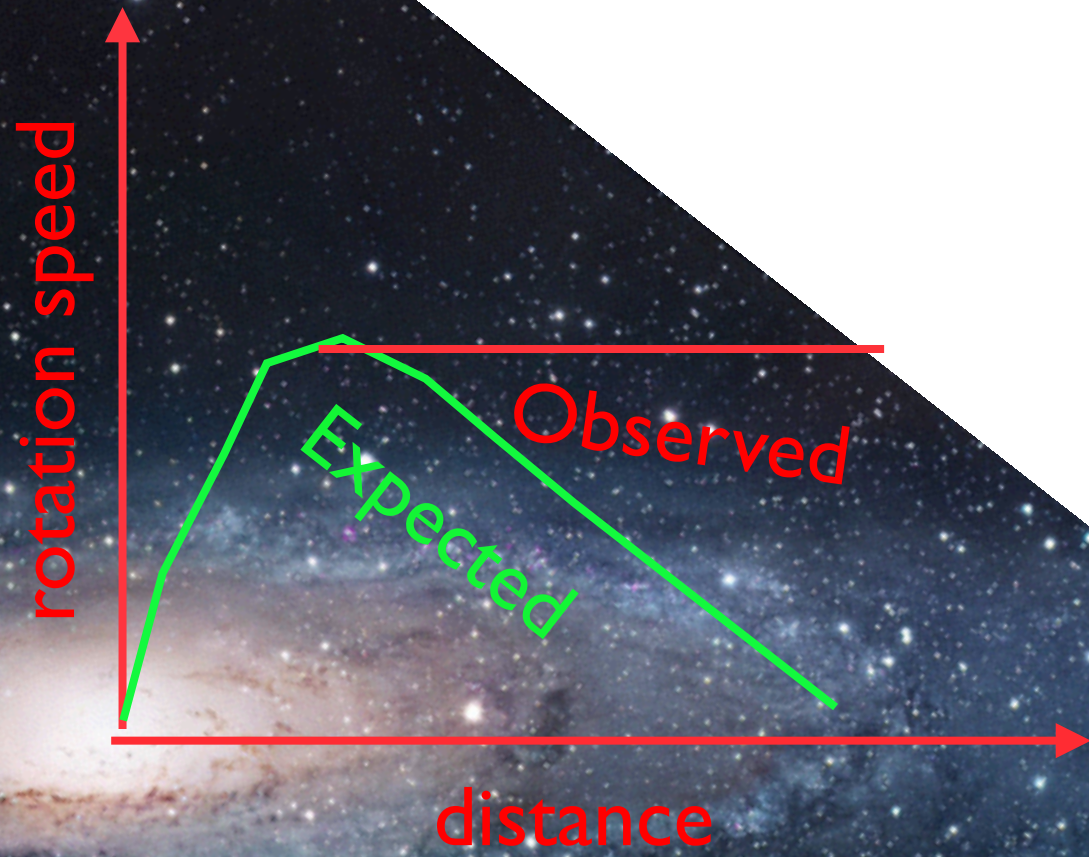
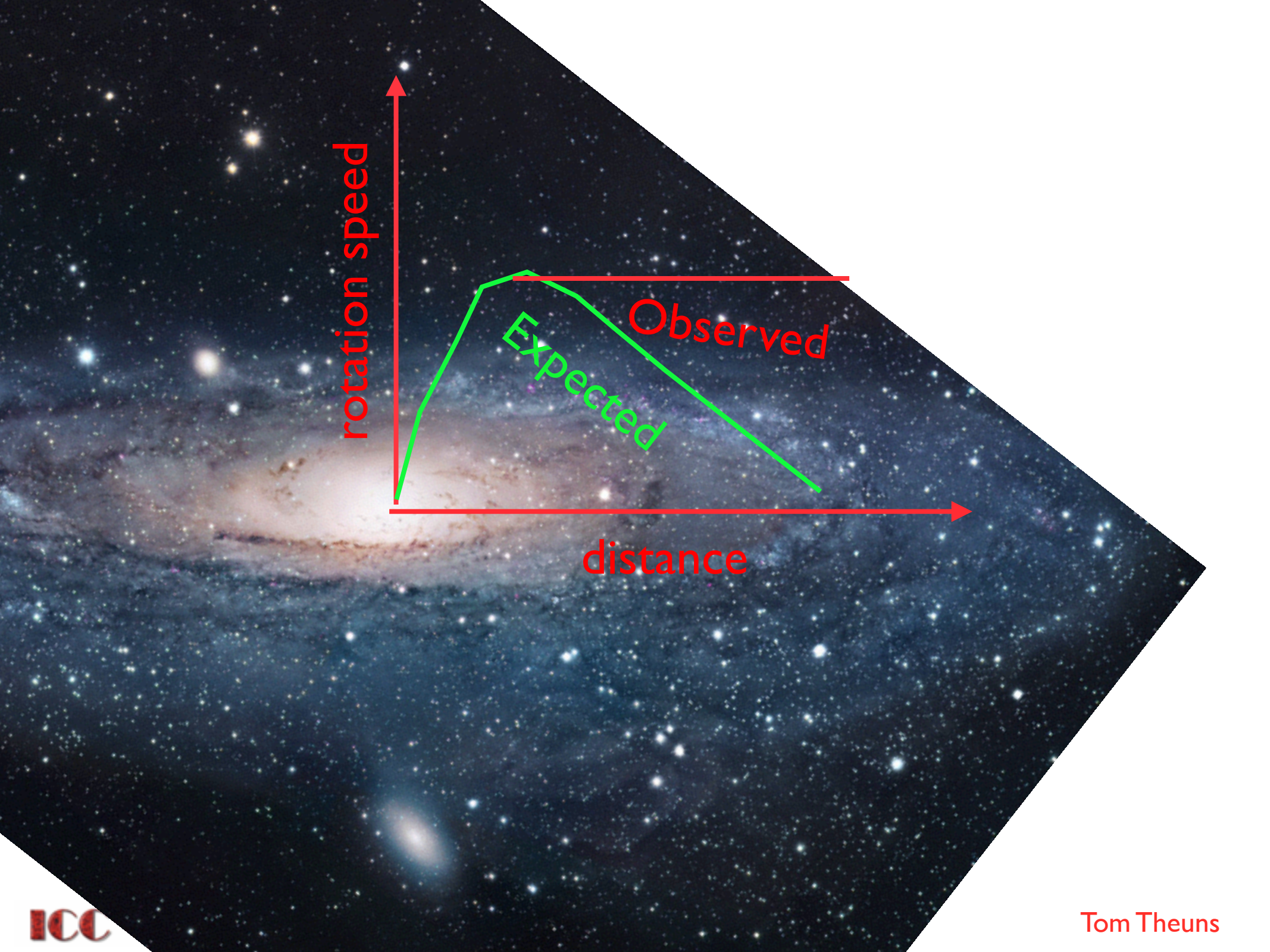
→ Sun





Jan Oort







# Archeology: MW contains some very old stars



# Contents:

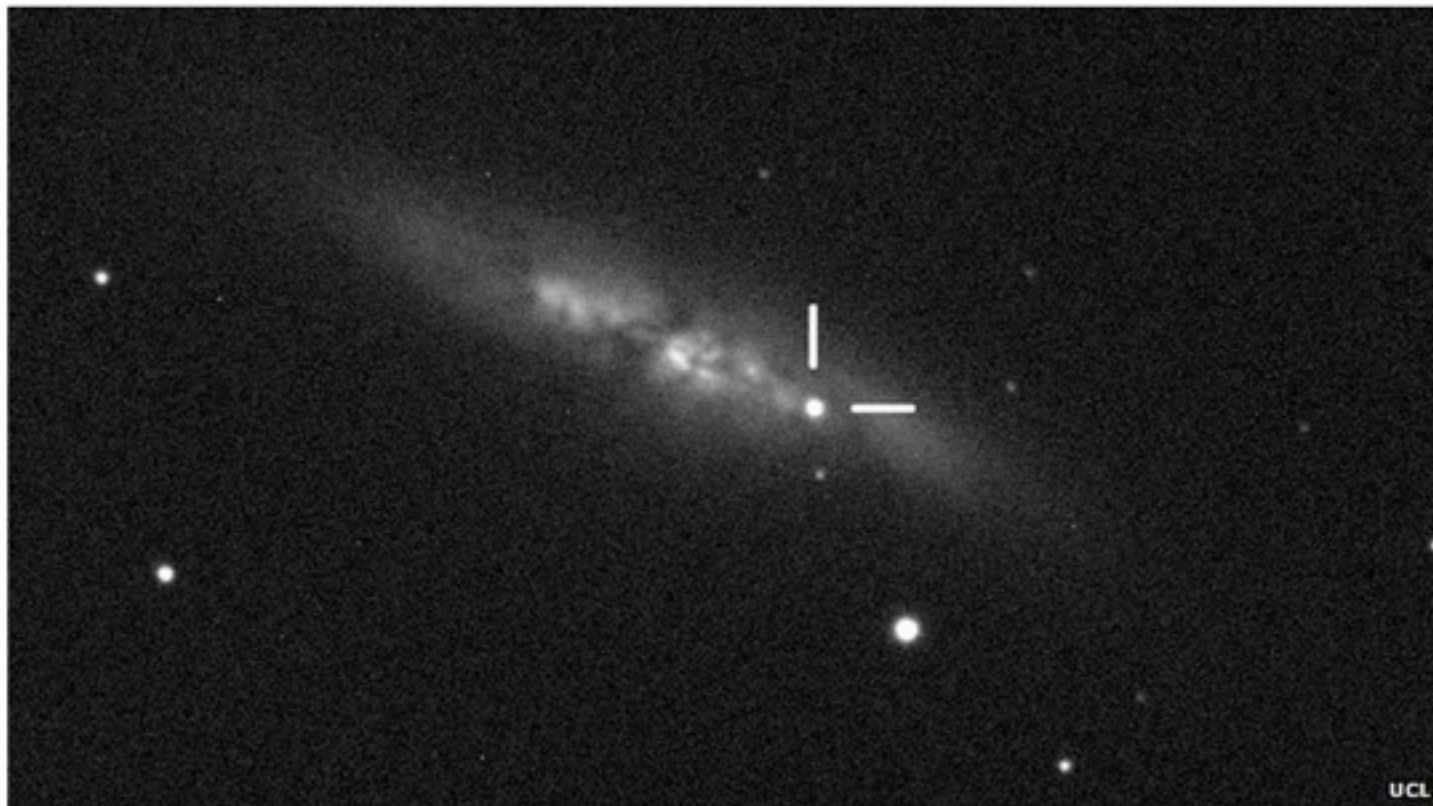
- What is a galaxy? Properties of the Milky Way galaxy
- The Milky Way in numbers
- Observations of young galaxies
- Theoretical models
  - cosmology and the formation of structure
  - what is a “numerical simulation”?
  - dark matters
- Simulating the formation of a galaxy
- The formation of the Milky Way
- The future of the Milky Way galaxy



23 January 2014 Last updated at 12:11



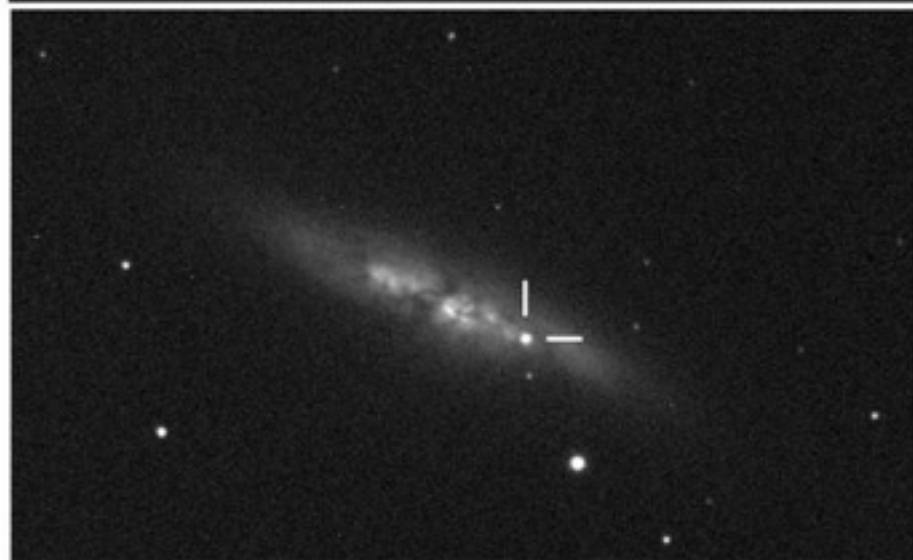
## Nearby supernova dazzles astronomers



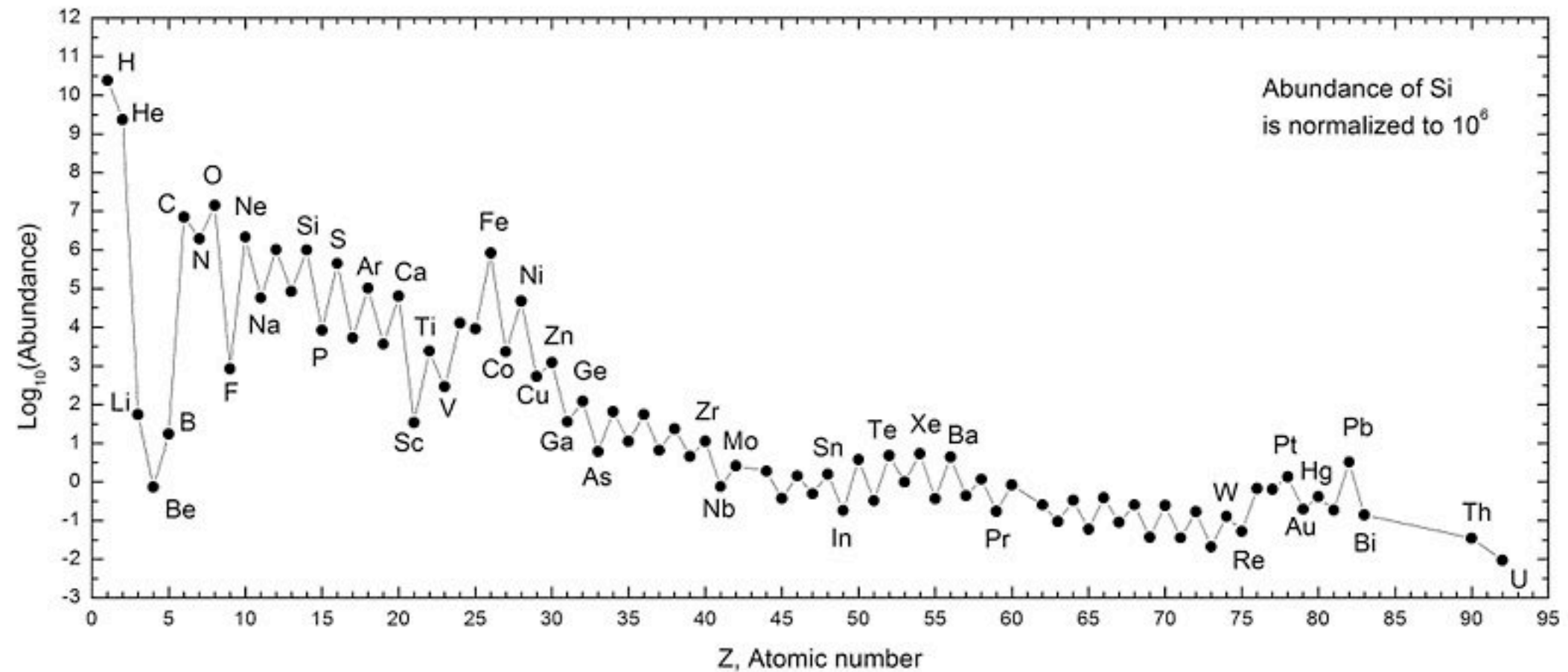
The supernova may be visible to stargazers through binoculars - and could grow brighter in coming weeks





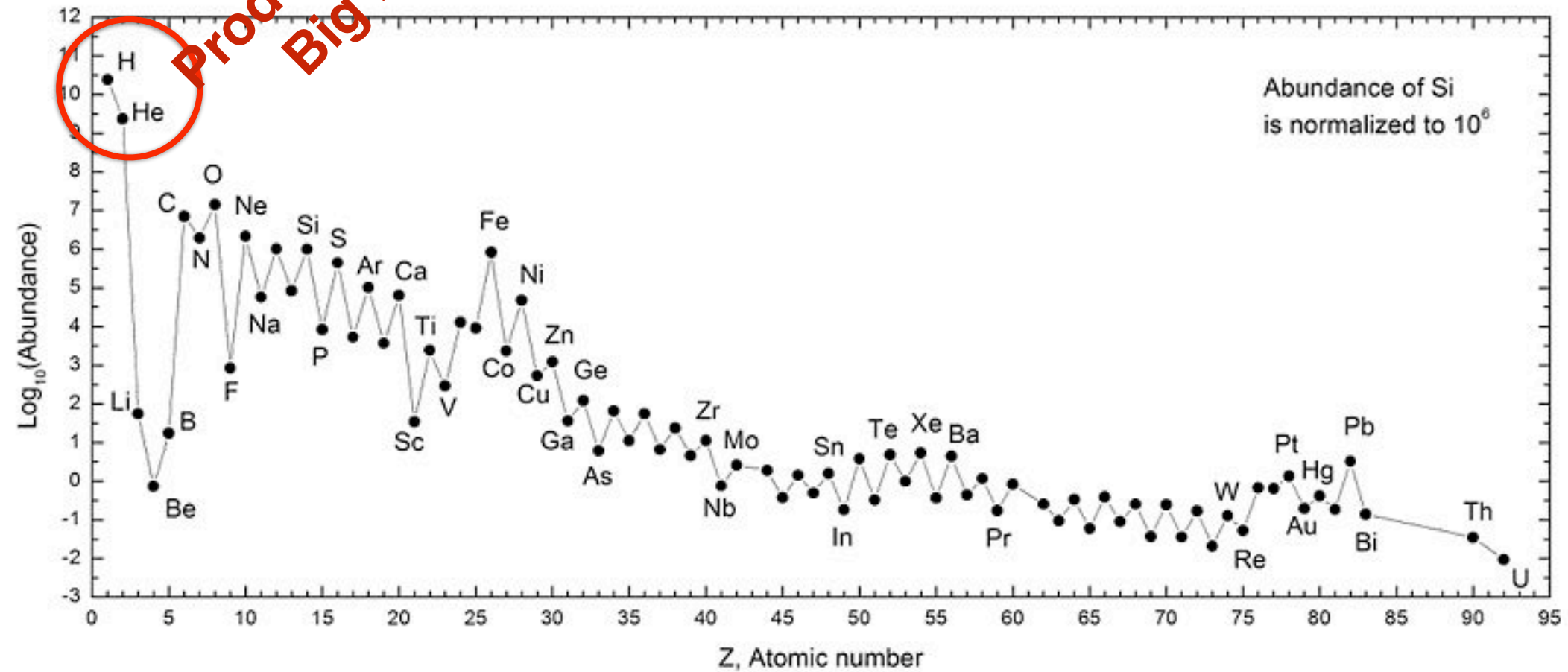


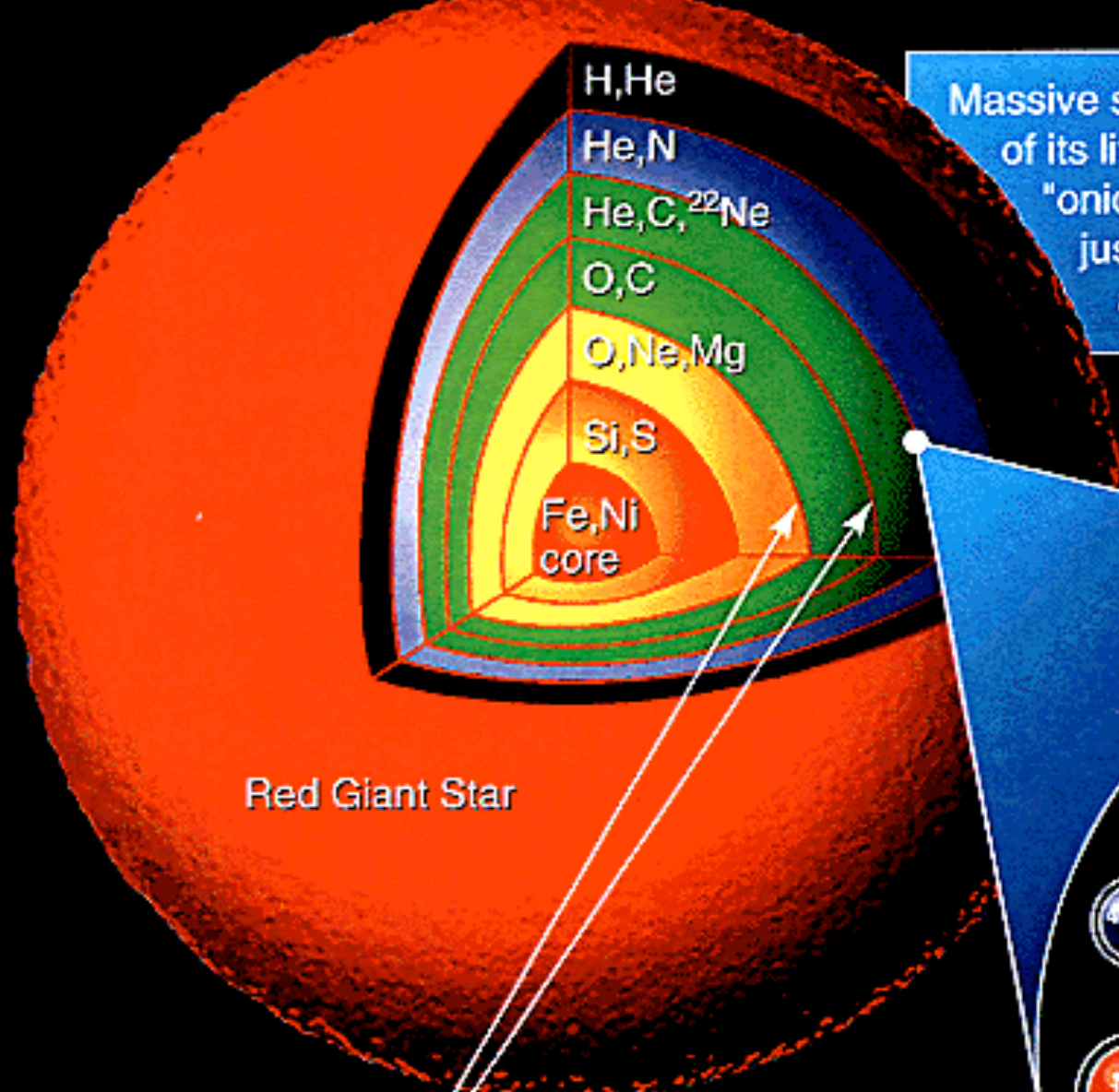
# Abundance of elements compared to Si





Produced in the  
Big Bang

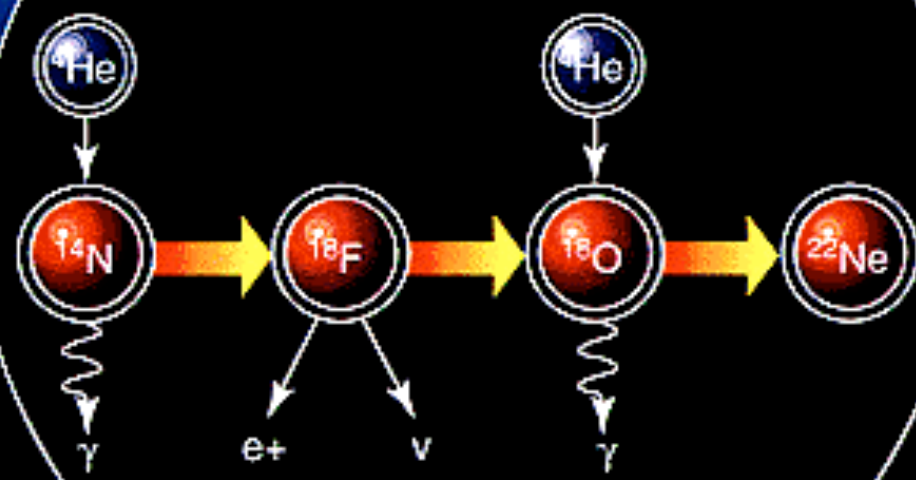




Massive star near the end of its lifetime has an "onion-like" structure just prior to exploding as a supernova

Red Giant Star

Nuclear burning occurs at the boundaries between zones



Example of nuclear reactions that build neutron-rich isotopes



# REVIEWS OF MODERN PHYSICS

VOLUME 29, NUMBER 4

OCTOBER, 1957

## Synthesis of the Elements in Stars\*

E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

*Kellogg Radiation Laboratory, California Institute of Technology, and  
Mount Wilson and Palomar Observatories, Carnegie Institution of Washington,  
California Institute of Technology, Pasadena, California*

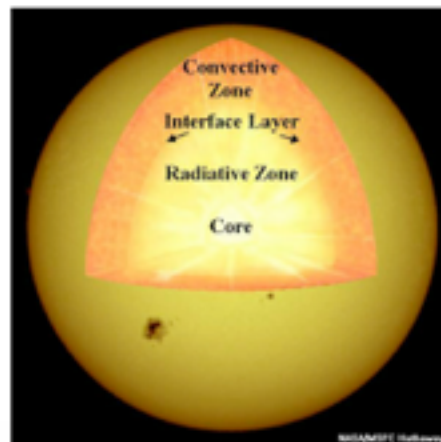
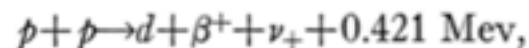
"It is the stars, The stars above us, govern our conditions";  
(*King Lear*, Act IV, Scene 3)

but perhaps

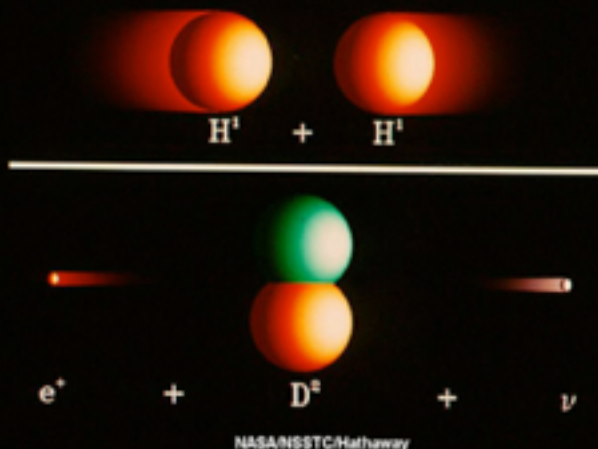
"The fault, dear Brutus, is not in our stars, But in ourselves,"  
(*Julius Caesar*, Act I, Scene 2)

### B. Pure Hydrogen Burning

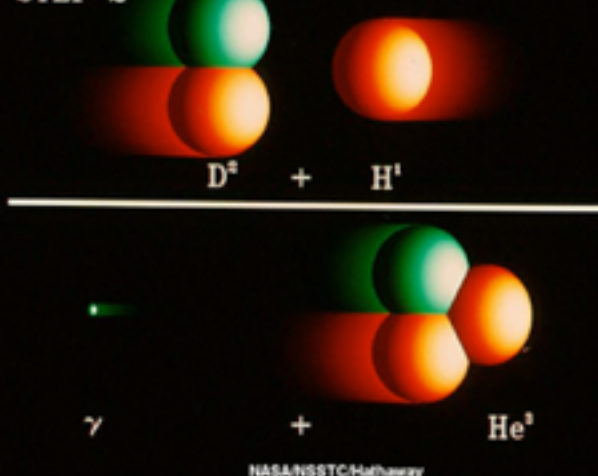
The point of view that element synthesis begins with pure hydrogen (primordial or continuously produced) condensed in stars is based on the existence of the so-called direct  $pp$  chain of reactions by which hydrogen is converted into helium. This chain is initiated by the direct  $pp$  reaction



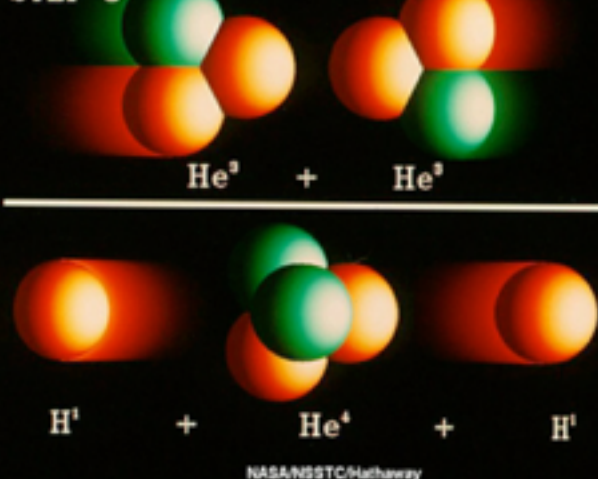
STEP 1



STEP 2

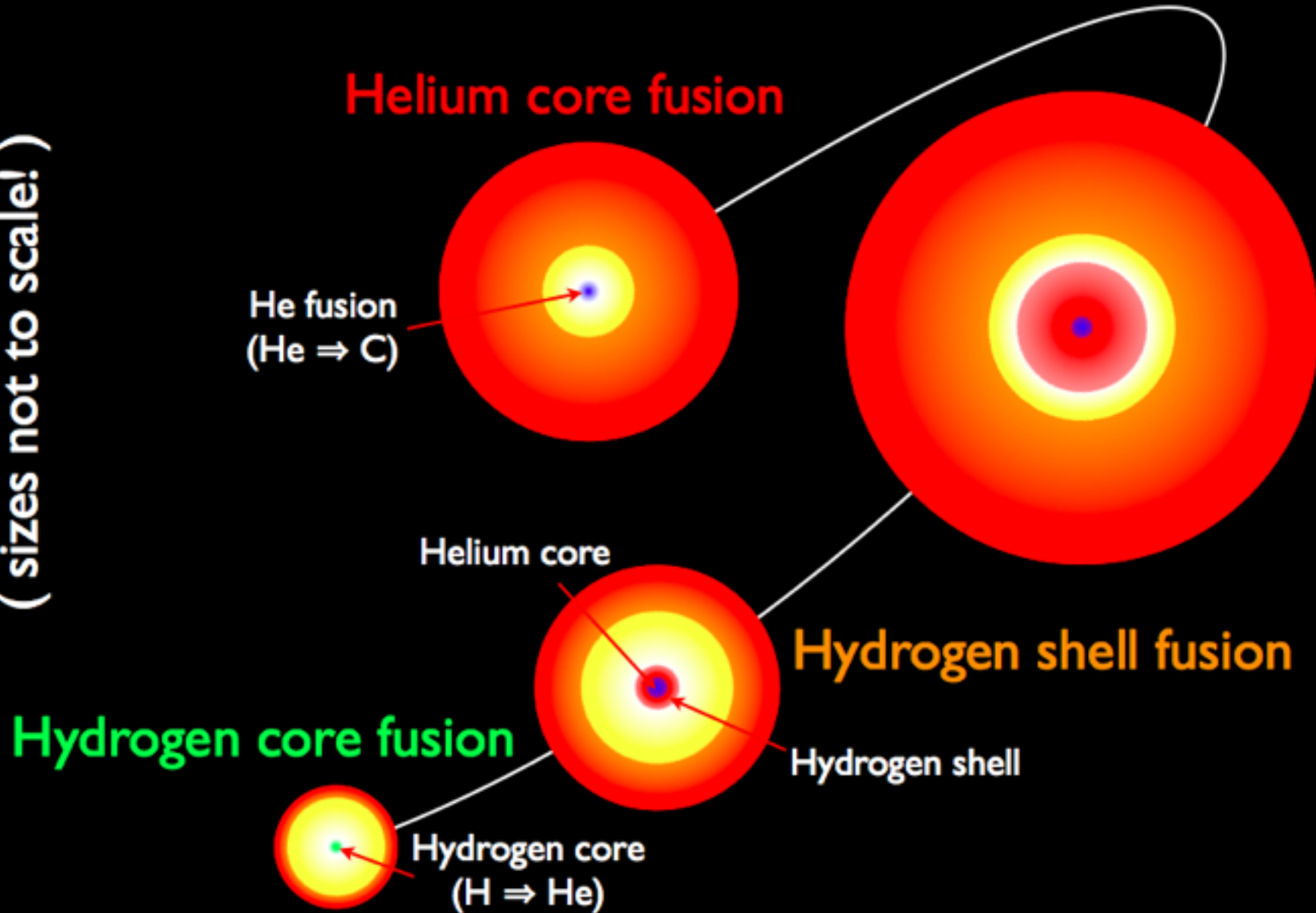


STEP 3

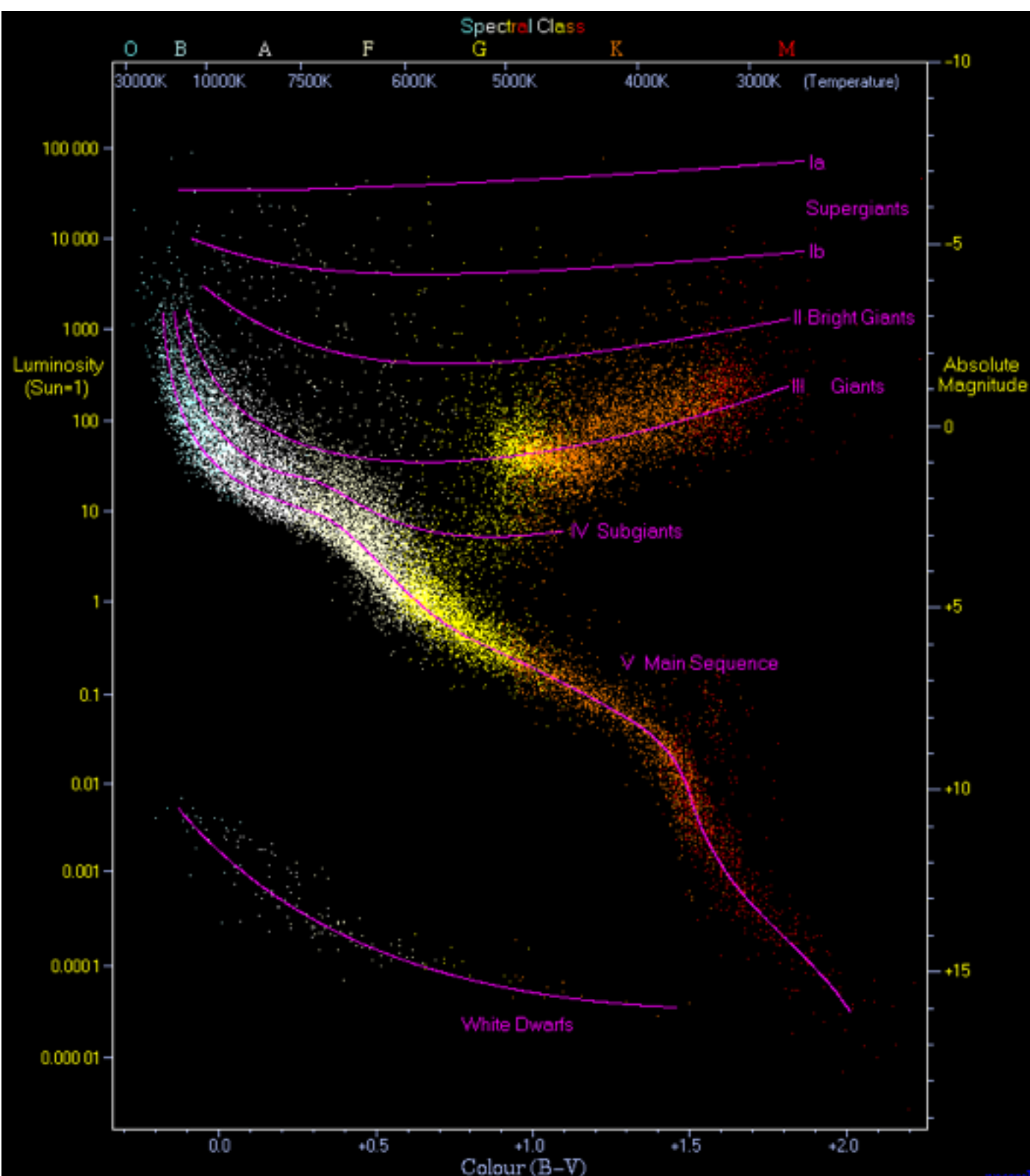


# Stellar evolution

( sizes not to scale! )





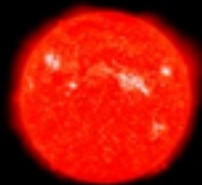


The Sun



5800 K

Smallest Kepler  
red giant



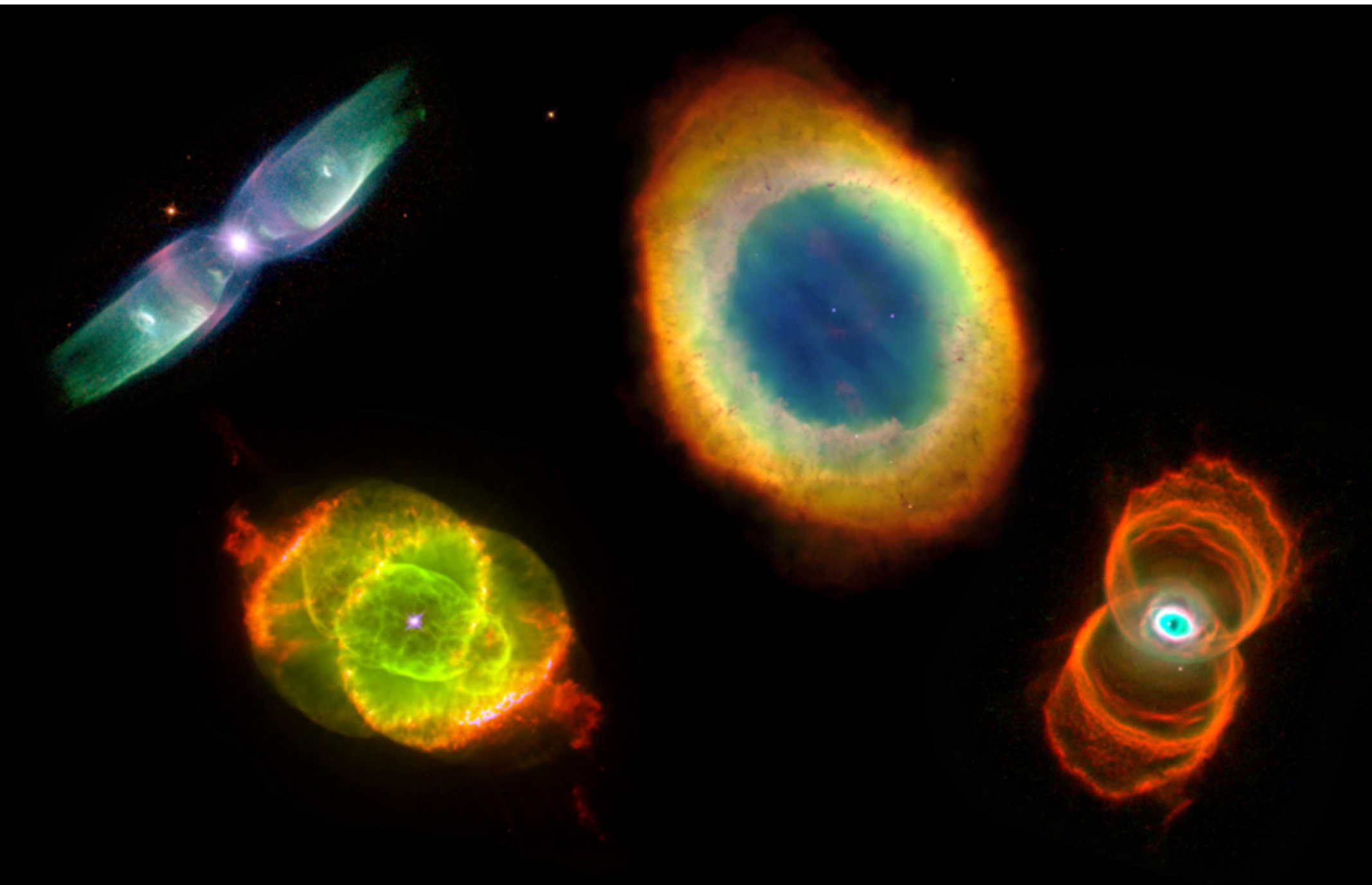
5000 K

Largest Kepler red giant



4500 K





# White Dwarf Deflagration

Resolution: 6 km

Initial Bubble Radius: 18 km

Ignition Offset: 42 km

Variable 1: Density [ $1.5\text{e}+07$  -  $2.0\text{e}+07$ ]

Variable 2: Reaction Progress [0.0 - 1.0]