



# **Astronomy 350L**

**(Spring 2005)**



## **The History and Philosophy of Astronomy**

**(Lecture 23: Hubble I)**

Instructor: Volker Bromm  
TA: Amanda Bauer

The University of Texas at Austin

# Edwin P. Hubble: Mariner of the Nebulae



- 1889 (Missouri) — 1953 (Pasadena)
- leading observational astronomer of 20<sup>th</sup> century:
  - discovers galaxies (1924):
    - à Milky Way but one of innumerable “island universe”
  - expansion of the universe (1929):
    - à Hubble’s Law:
$$v = H_0 \times d$$

# Hubble's Early Life



Hubble memorial in Marshfield

- 1889: born in Marshfield, Missouri
- born into upper middle-class family
- 1899: family moves to Illinois (Evanston/Wheaton)
- 1906: Graduation from High-School

# Undergrad at University of Chicago



- 1906-10: physics, mathematics, and (at insistence of father) law
- great athletic aptitude

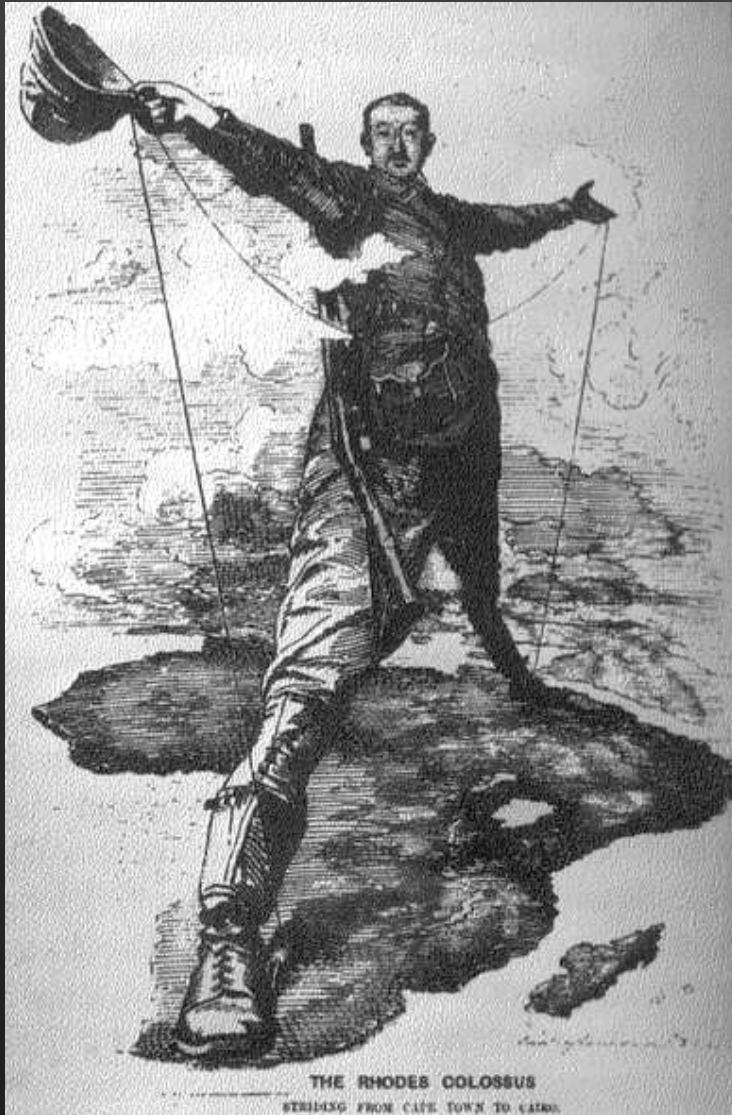


# Rhodes Scholar at Oxford



- 1910-12: Queen's College
- continued athletic prowess

# Cecil Rhodes: Archimperialist



Cecil Rhodes (1853-1902)

- 1903: Rhodes Scholarship program established!

# PhD Thesis at Yerkes, Univ. of Chicago



- PhD 1917: “Photographic Investigations of Faint Nebulae”

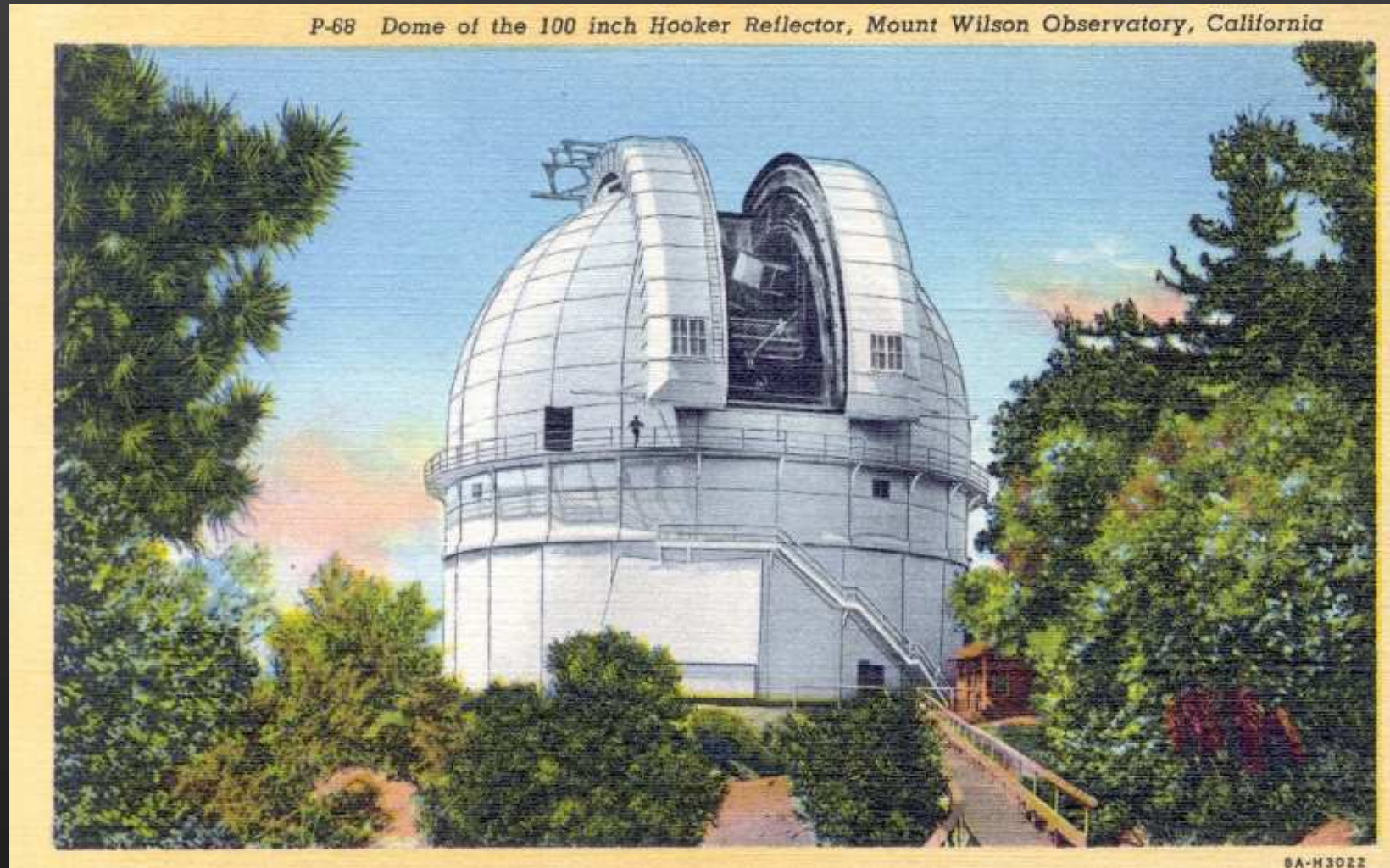
# Hubble joins Army in WW I



- 1917-19: Major Hubble, 86<sup>th</sup> Division



# Mount Wilson Observatory

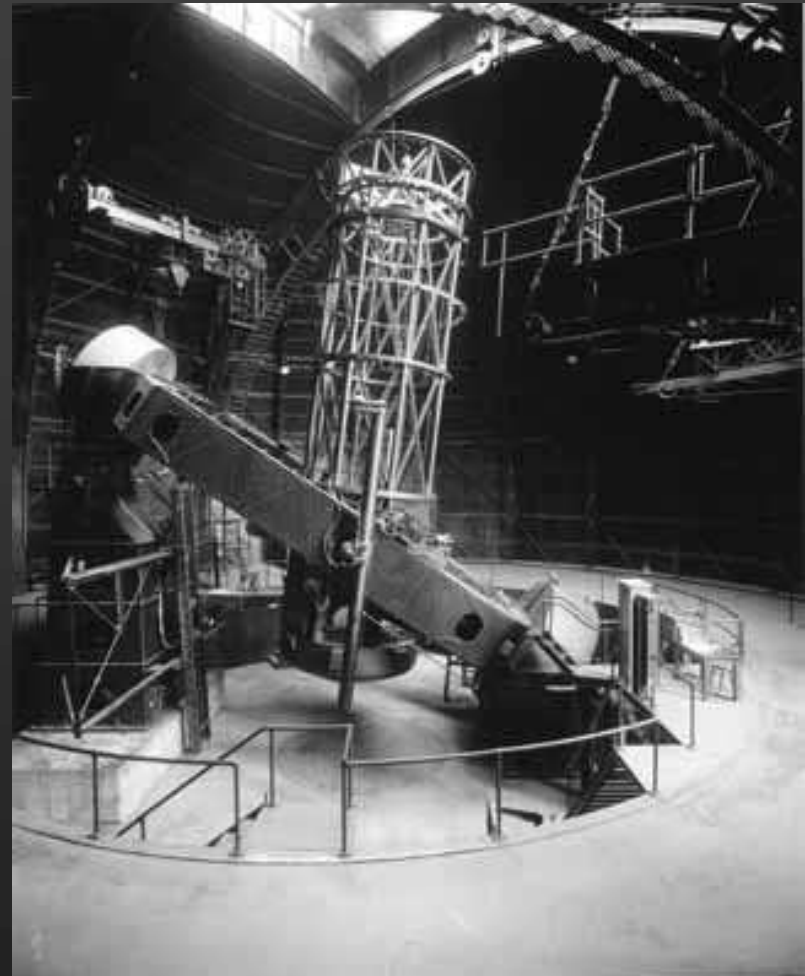


- 1919 onwards: world's largest telescope

# Mount Wilson Observatory



George Hale (1868-1938)



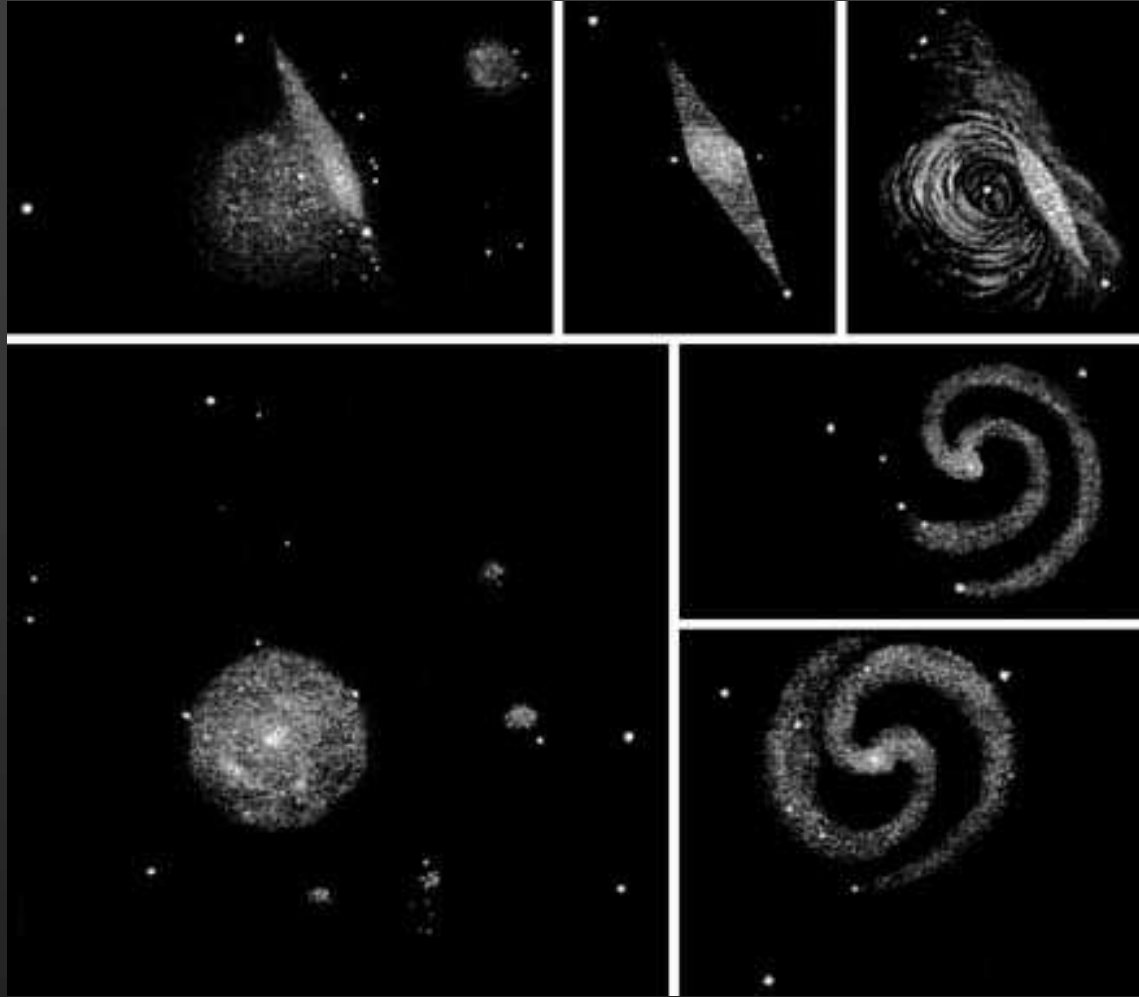
100-inch Hooker Telescope

# Mount Wilson Observatory



**“The Monastery”: Mt Wilson’s library**

# The Riddle of the Nebulae



- Big Q: What are the (Spiral) Nebulae?
  - à part of the Milky Way?
  - à “Island Universes” in their own right?



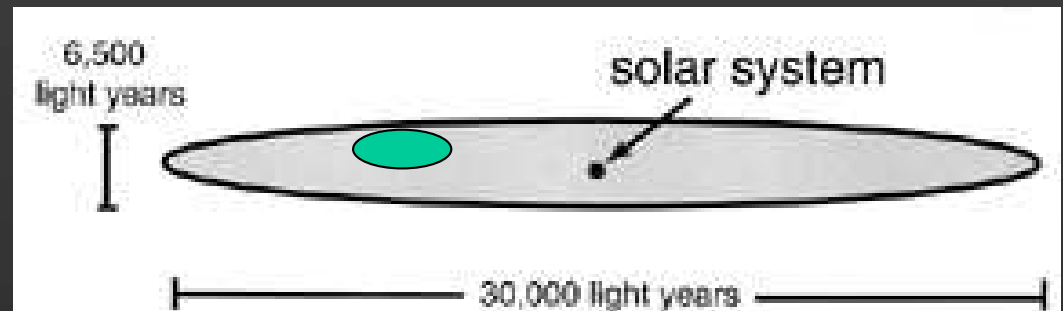
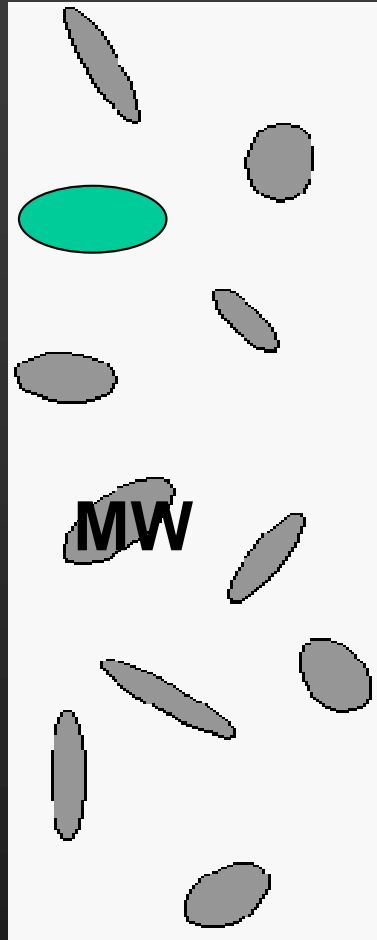
# The Earl of Rosse discovers Spiral Nebulae



- His sketch of M51 (1845): First Spiral Nebula
- Speculate: -- Galaxy in rotation?  
-- A galaxy (system of stars), or gaseous nebula?

# Riddle of the (Spiral) Nebulae

- Two basic models:



One-island universe (Kapteyn):

- model accepted ~1900
- basis for Einstein's static GR model of the universe

Many-island universe (Kant)

## April 1920: The Great Debate

- National Academy of Sciences, Washington, D.C.
- Resolved: “What is the nature of the Spiral Nebulae?”



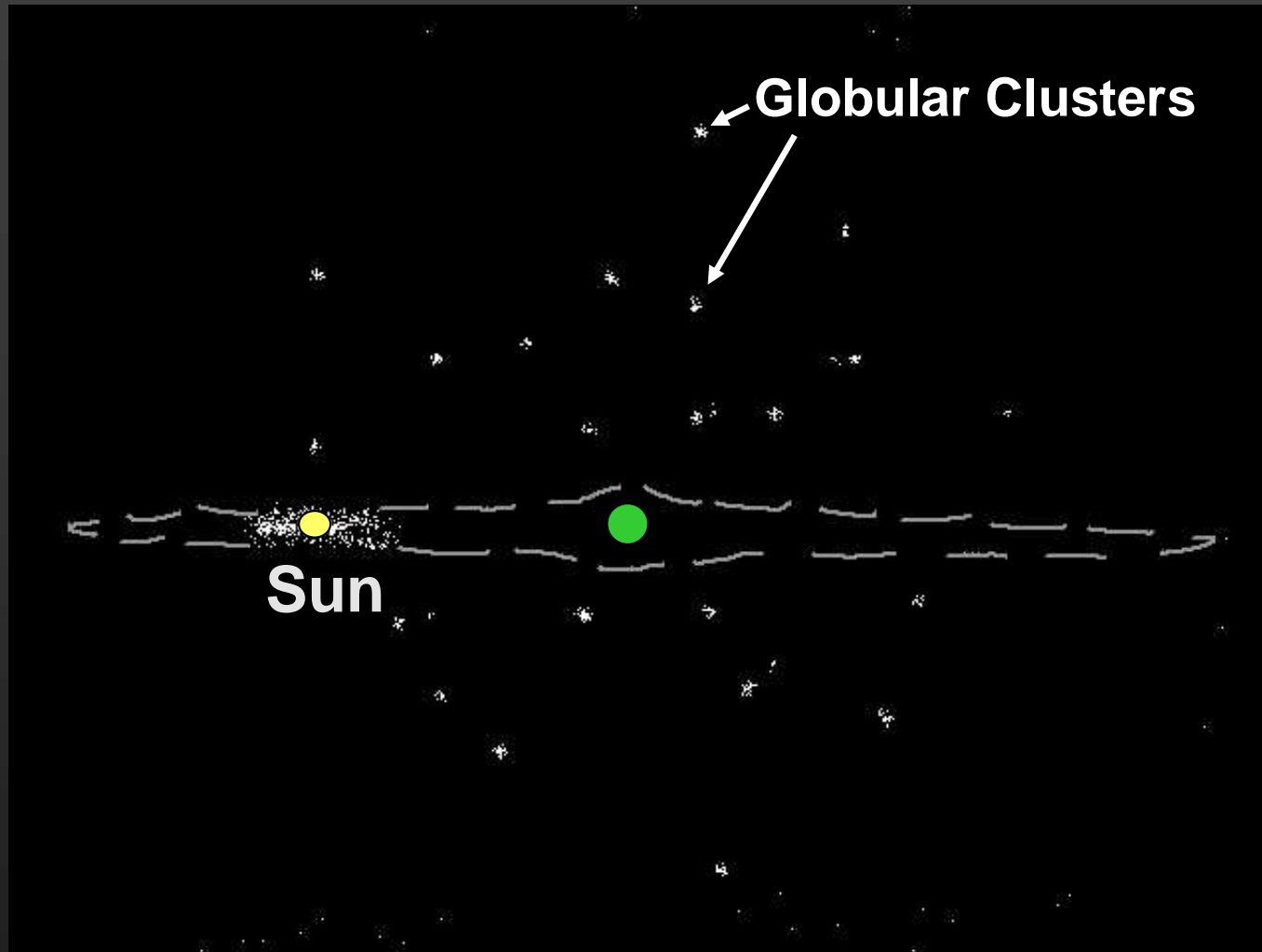
**Harlow Shapley**  
(Mt. Wilson Obs.)

**VS**



**Heber Curtis**  
(Lick Observatory)

# Shapley demotes Sun from Galactic Center (1918)



- Sun's true location is ~30,000 LY away from Center of the Milky Way!



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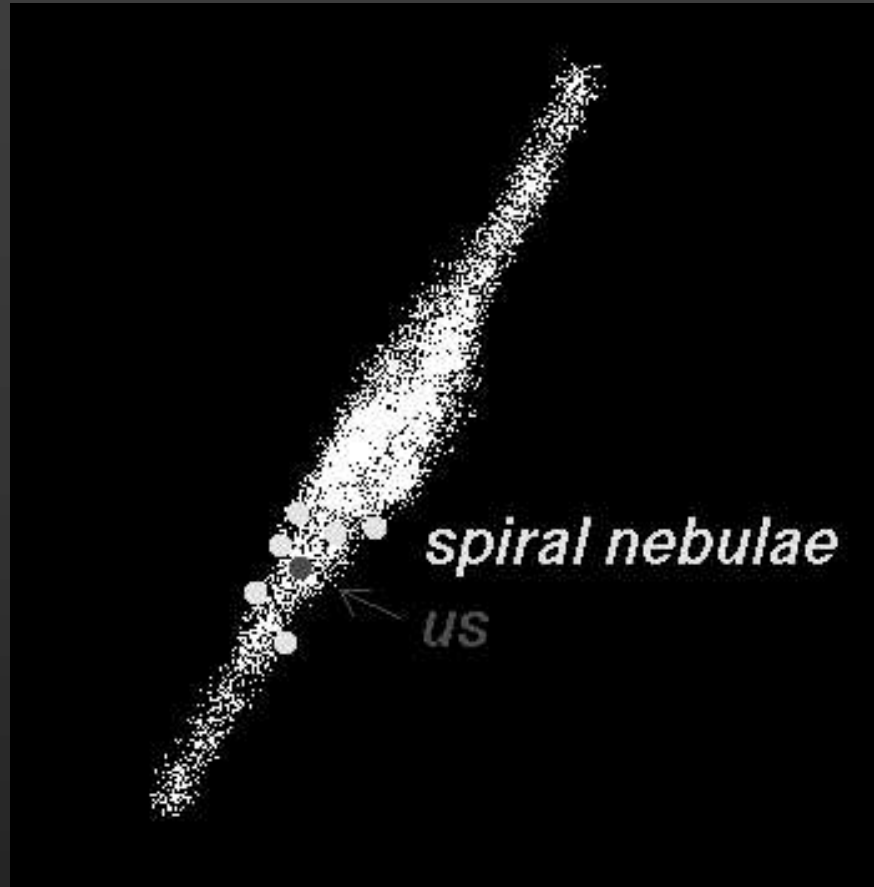
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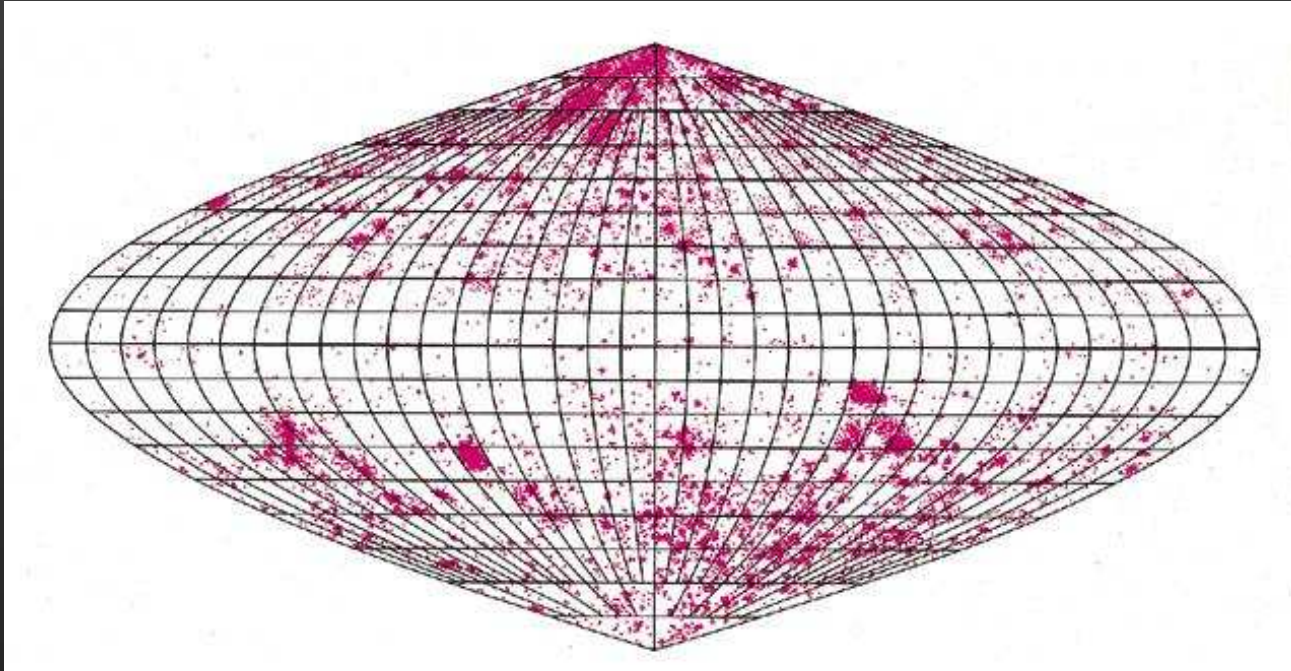
# Great Debate: Shapley's Argument



- Spiral nebulae are part of MW (=Universe)!

# Great Debate: Shapley's Evidence I

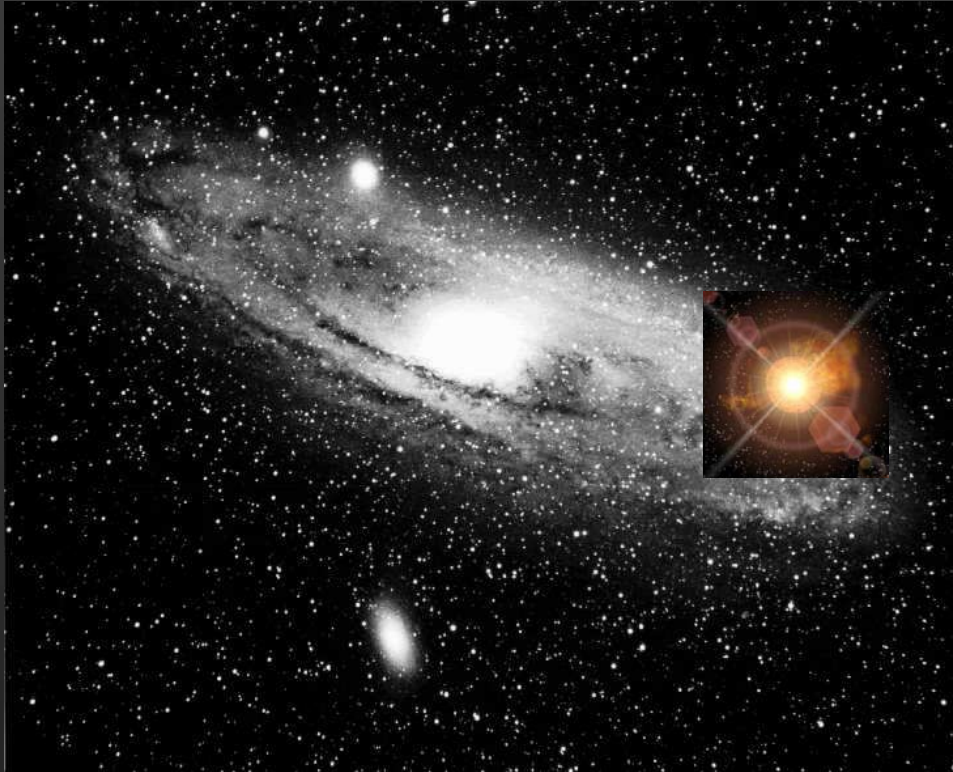
- all-sky map of nebulae (NGC): “Zone of Avoidance”



- Q: If nebulae *were* truly extragalactic, they should be seen all over the sky!

## Great Debate: Shapley's Evidence II

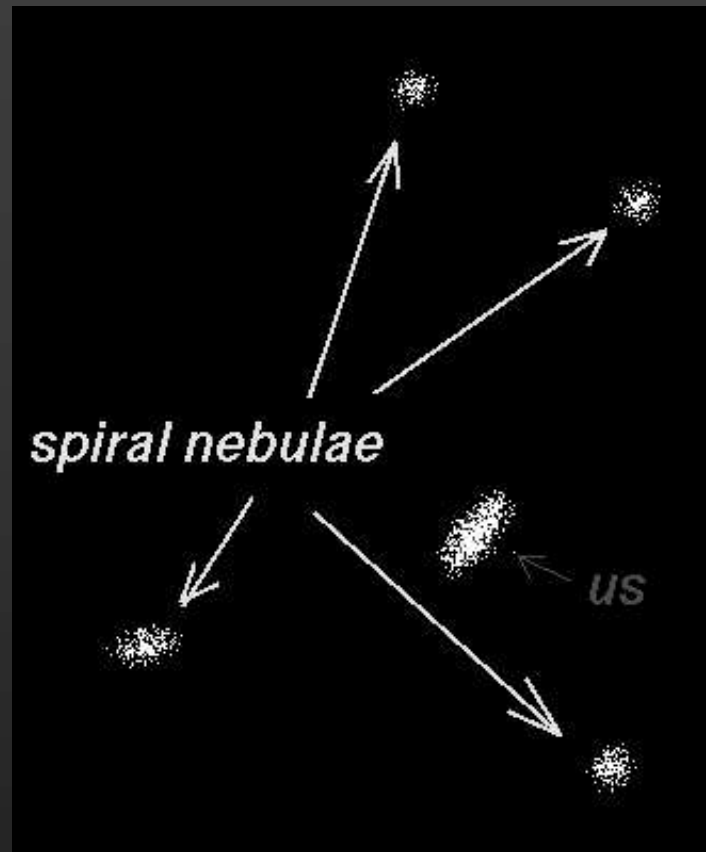
- 1885 Nova in Andromeda Nebula (S Andromedae)



- If Andromeda were truly extragalactic (i.e., very distant), nova would have had luminosity of 100 million Suns! → preposterous!?



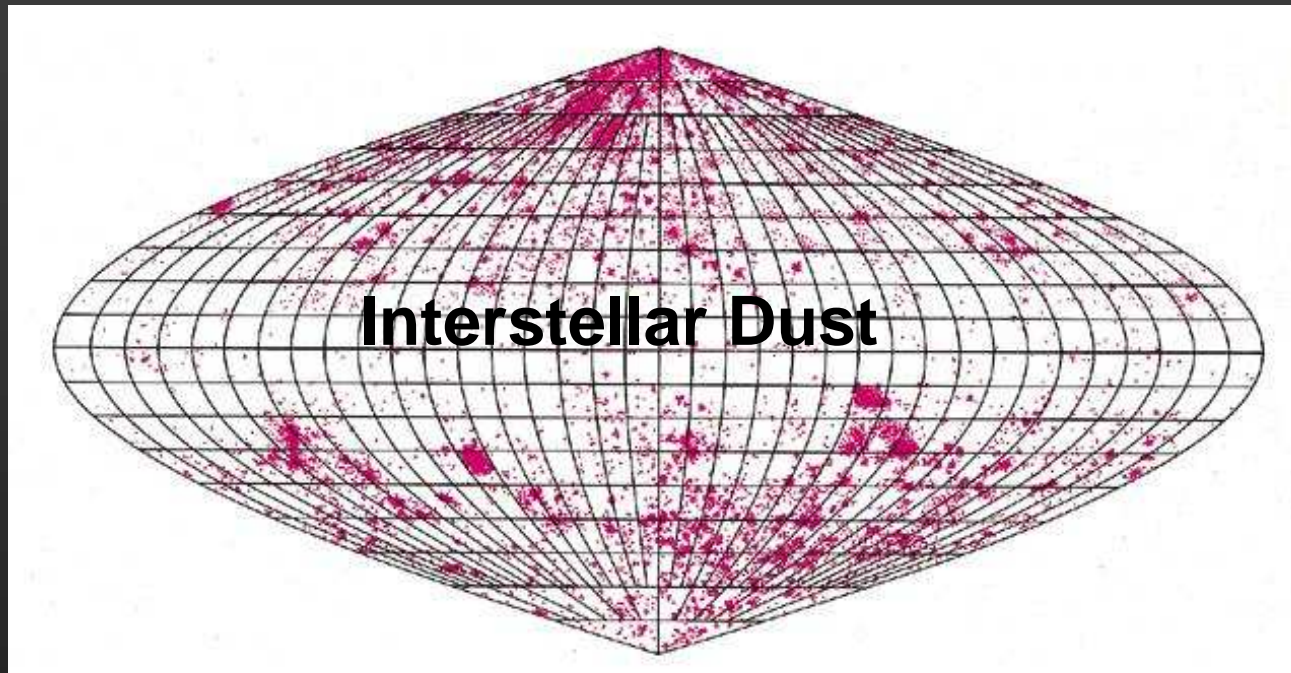
# Great Debate: Curtis' Argument



- Spiral nebulae are “island universes” (=galaxies) in their own right, consisting of billions of stars!

# Great Debate: Curtis' Rebuttal I

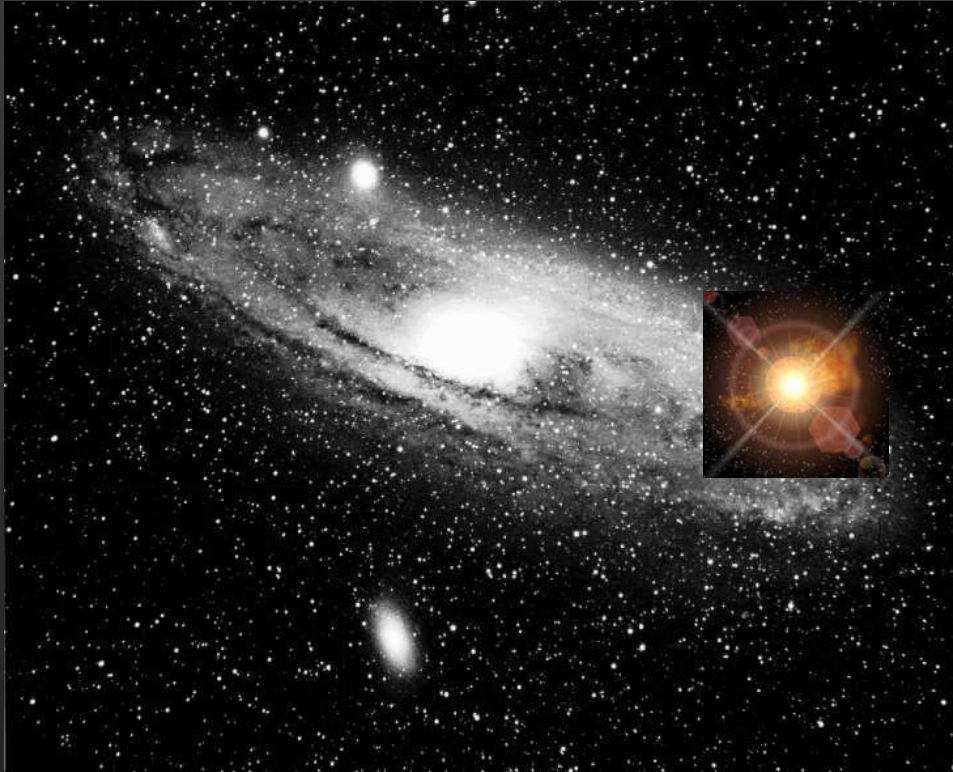
- all-sky map of nebulae (NGC): “Zone of Avoidance”



- “Zone of Avoidance” is due to interstellar dust obscuration! → Nebulae *can* be all over the sky!

## Great Debate: Curtis' Rebuttal II

- 1885 Nova (?) in Andromeda Nebula (S Andromedae)



- Curtis claims: S Andromeda likely abnormal!  
(We now know this is correct: S And was a supernova!)

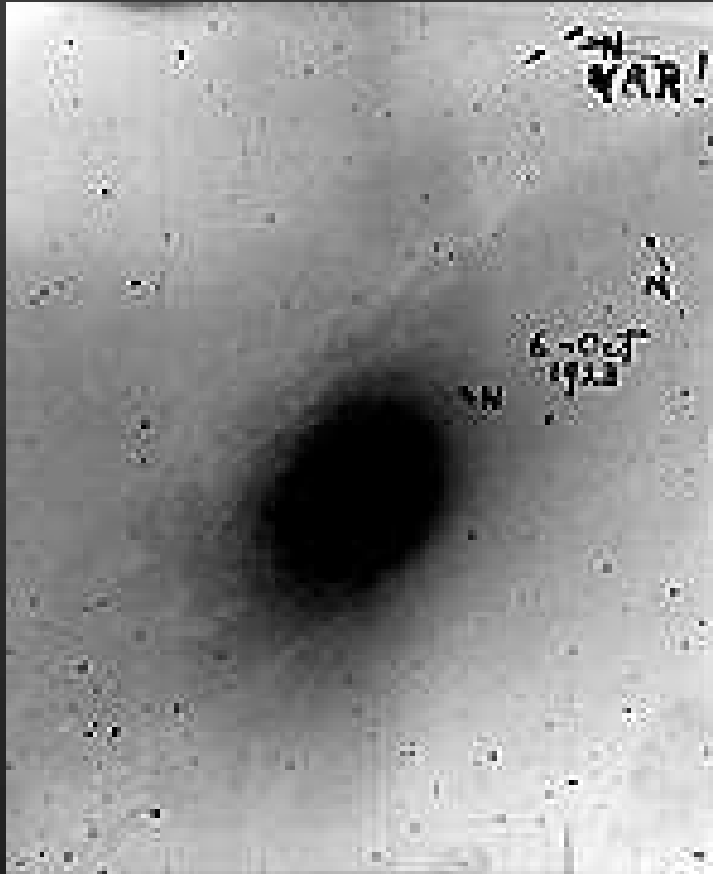
## Great Debate: Who won?

- With hindsight, we know that Curtis was right
- But: Scientific controversies cannot be decided by debate, only by hard evidence!
- To empirically decide the issue: Need to measure distance to the spiral nebulae!
- Big Q: How to achieve this???
  - parallax method only works for nearest stars

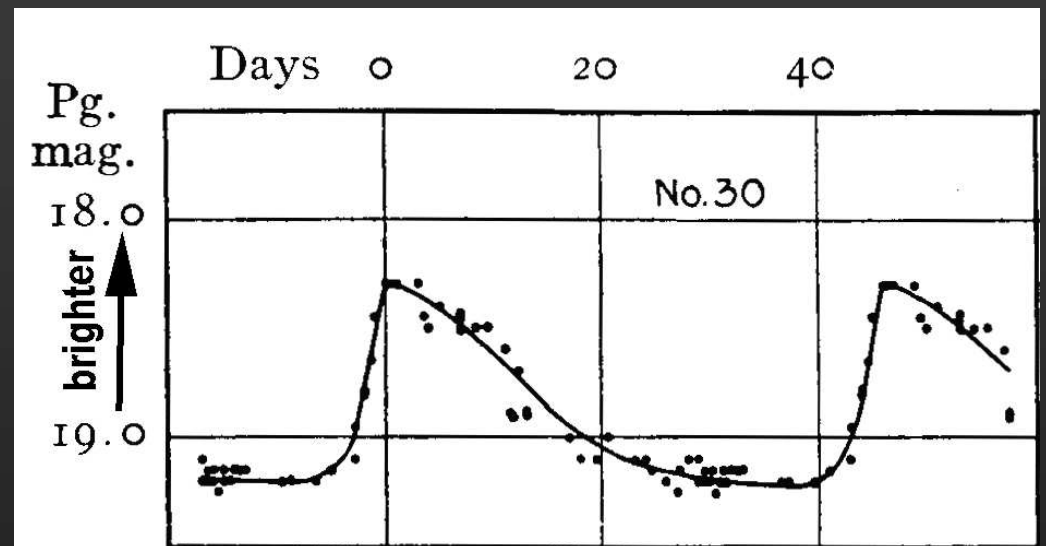


# Hubble and the Distance to Andromeda (M31)

- October 1923: He obtains photograph of M31



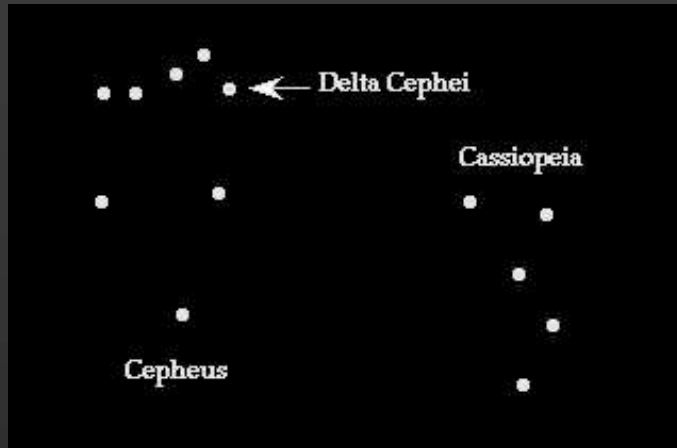
## Brightness vs time



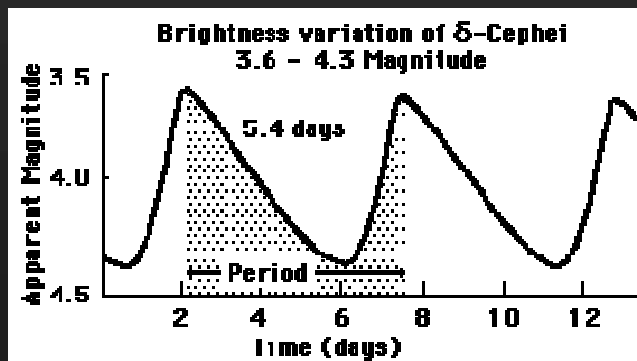
- Hubble discovers a Cepheid variable in Andromeda!

# Discovery of Cepheid Variables

- 1784: John Goodricke discovers delta Cephei



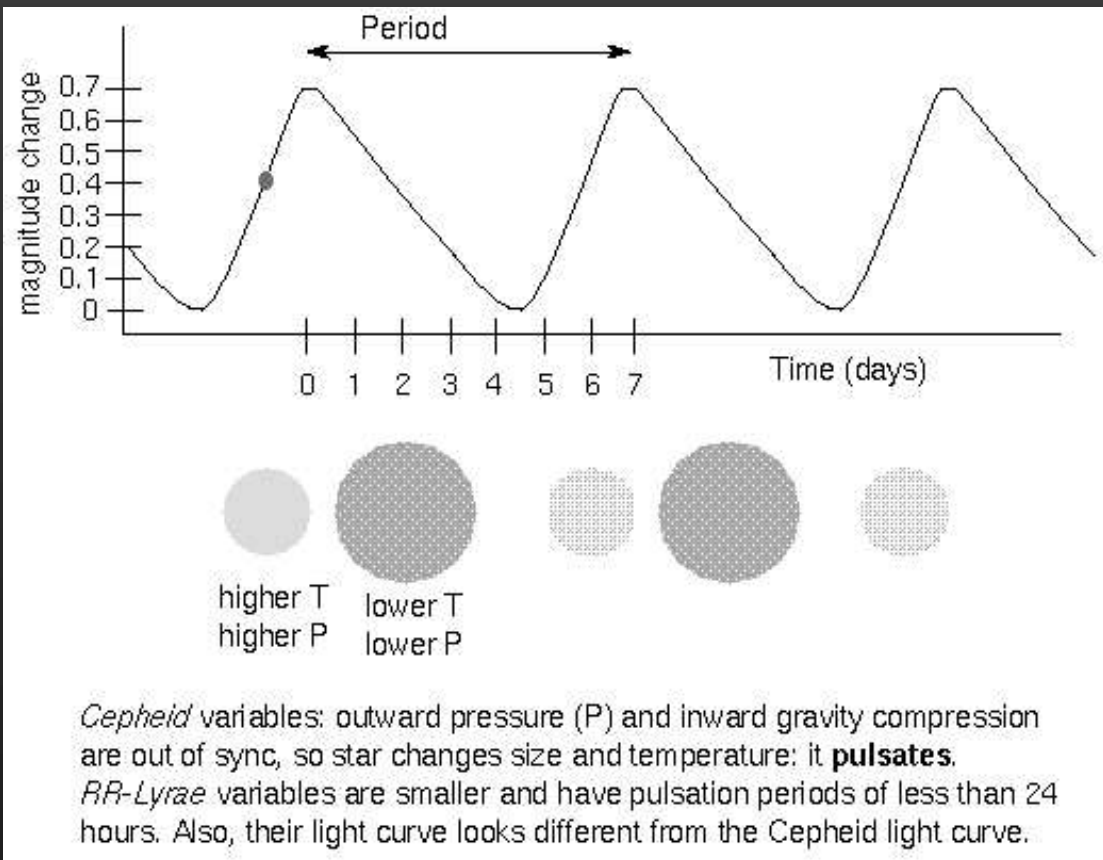
## Lightcurve



**John Goodricke (1764-86)**  
- also discovered Algol binary system

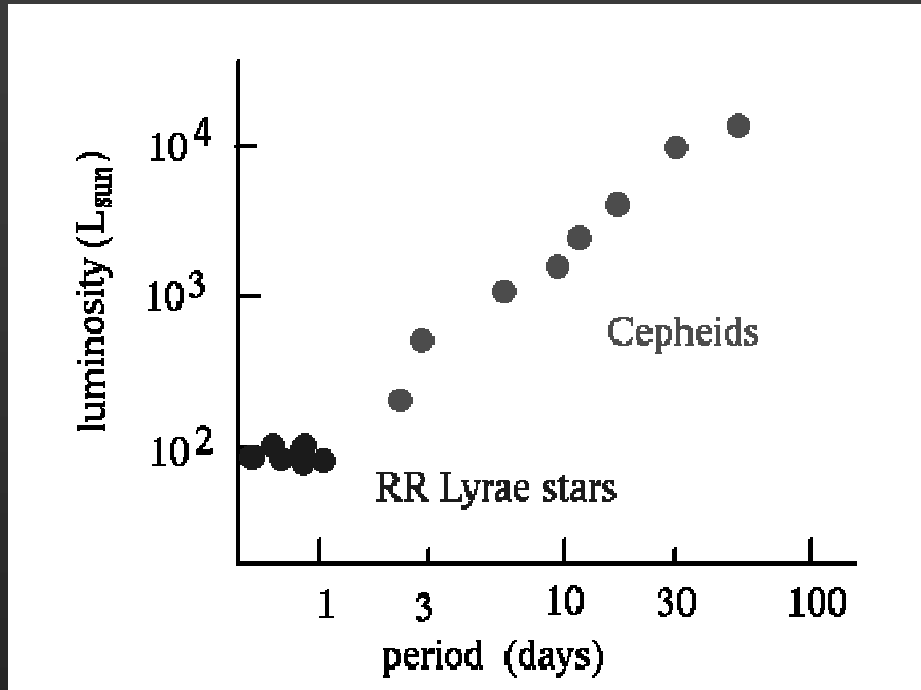
# What are the Cepheids?

- A: Pulsating stars (periods of ~ few days)



# Cepheids: Period-Luminosity Relation (1908)

- for Cepheids: longer period  $\Rightarrow$  higher luminosity!



- Cepheids in Small Magellanic Cloud (SMC):
  - can assume that they are all at same distance

**Henrietta Leavitt (1868-1921)**  
- part of the famous team of women “computers” at Harvard Observatory

# Cepheids as Standard Candles

## Standard Candle

As a car approaches on a highway, its lights appear to get brighter. However, the amount of light or energy produced by the lights is constant.

The apparent brightness of the headlights is a function of how far away the car is.

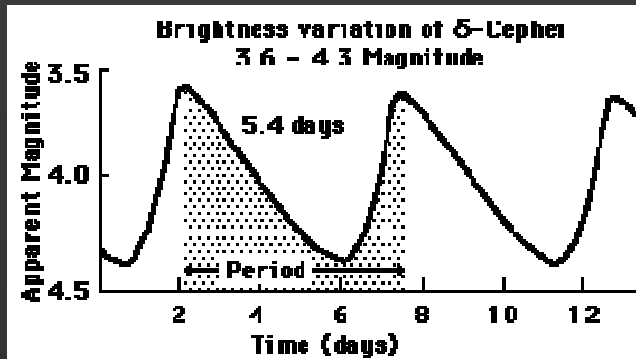
The closer the car, the brighter the headlights. Astronomical objects that produce specific amounts of energy can be used to determine the distance to that object if the apparent brightness is measured. These objects are known as Standard Candles.



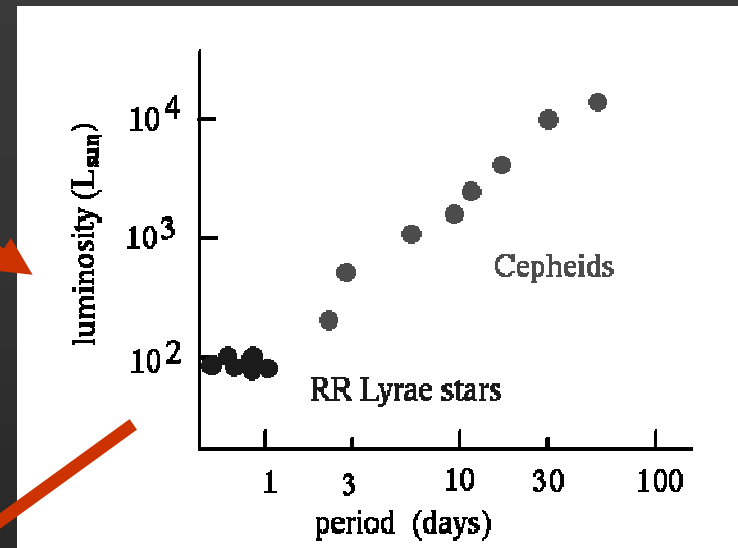


# Cepheids as Standard Candles

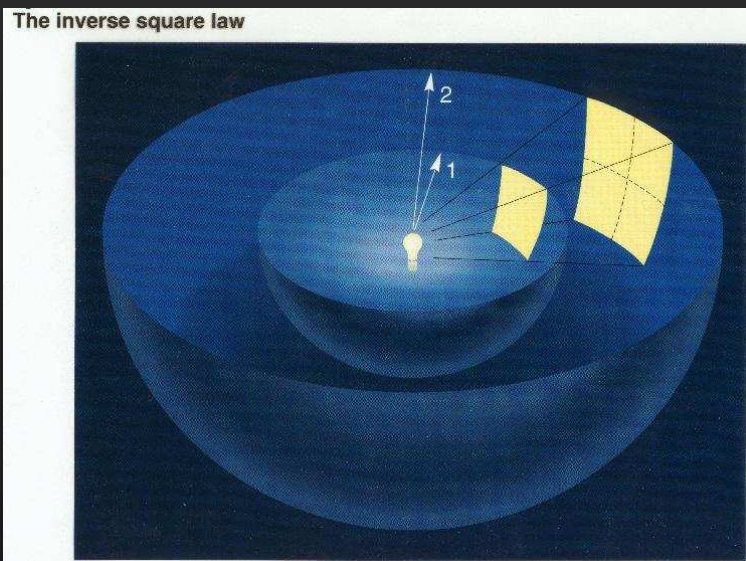
## 1) Measure Period



## 2) Calculate luminosity



## 3) Calculate distance

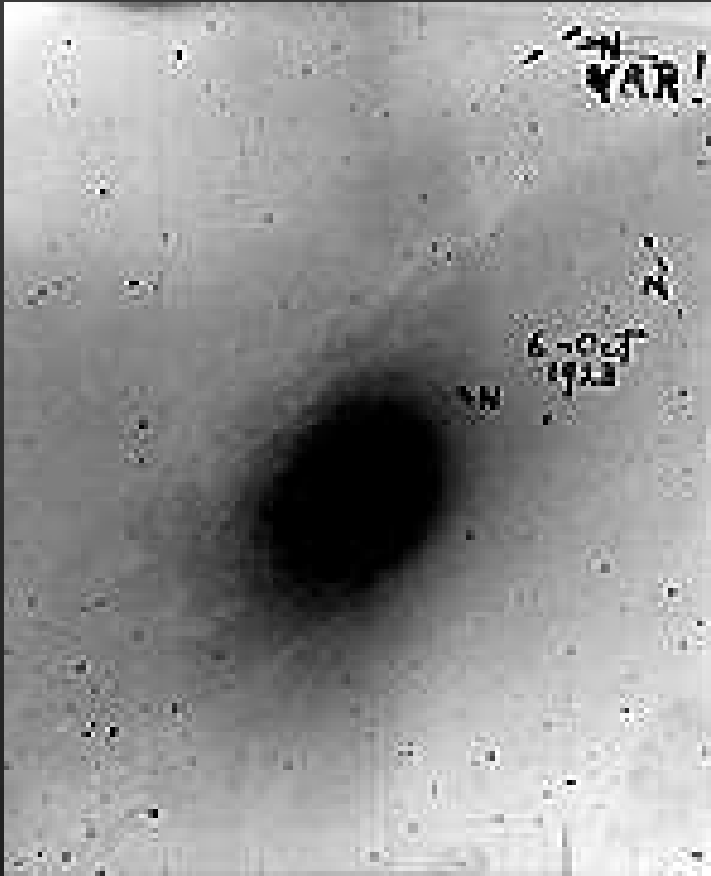


- inverse-square law:  
 $\text{flux} = \text{luminosity} / \text{distance}^2$

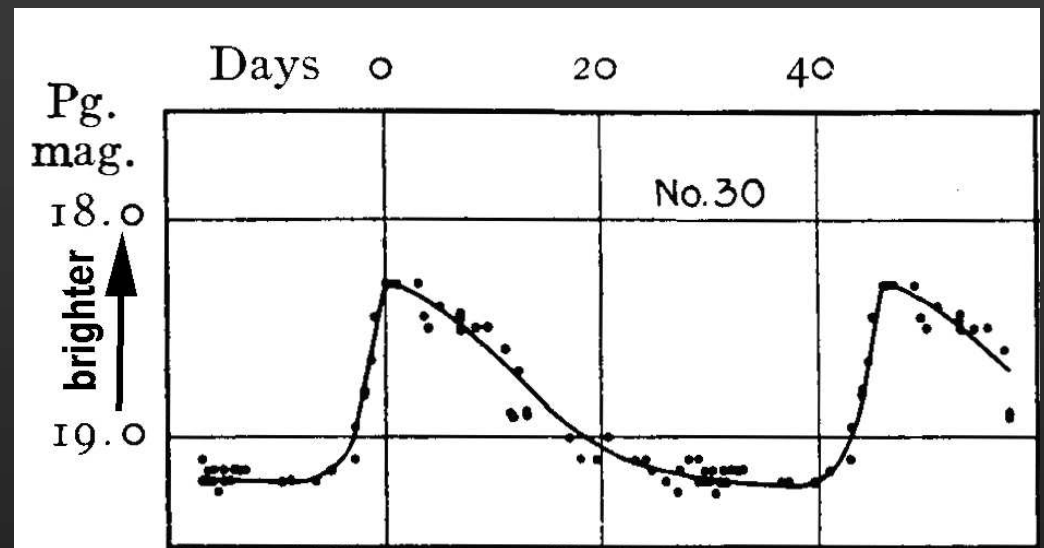
measure

# Hubble and the Distance to Andromeda (M31)

- October 1923: He detects Cepheid in M31

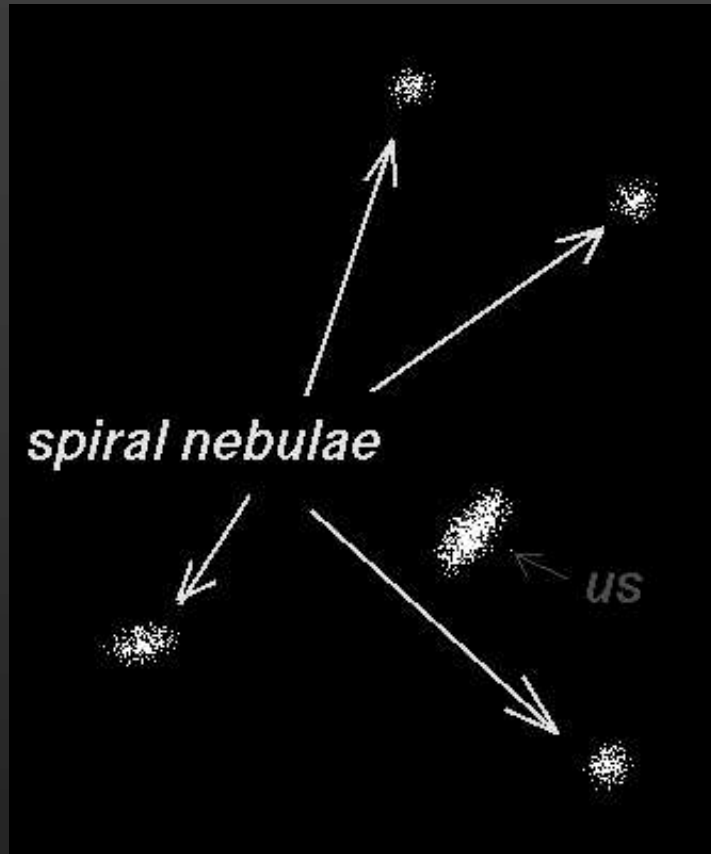


## Brightness vs time



- Cepheid distance =  $\sim 900,000$  Lightyears !
- Compare to size of MW ( $\sim 100,000$  LY)!

# Great Debate: Hubble's Empirical Answer



- Andromeda is typical example of spiral nebulae
- Andromeda lies outside of Milky Way, and by extension *all* spiral nebulae do!

- Spiral nebulae are “island universes” (=galaxies) in their own right, consisting of billions of stars!

## Hubble (part 1)

- Early Life:

- 1889: born in Marshfield, Missouri
- 1906-10: Undergraduate at University of Chicago
- 1910-13: Rhodes Scholar in Oxford
- 1917: PhD from Yerkes, Univ. of Chicago
- 1917-19: Army officer during WWI
- 1919 onwards: joins Mount Wilson Observatory

- True Nature of Spiral Nebulae (1923-24):

- resolves Cepheid variables in Andromeda (M31)
- estimates distance: ~ 900,000 LY
- this safely places M31 outside of the MW (size: ~100,000 LY)
- Kant (and Curtis in “Great Debate”) was correct:
  - Spiral Nebulae are “Island Universes” (=galaxies)