# Lecture 6 : The extragalactic universe I

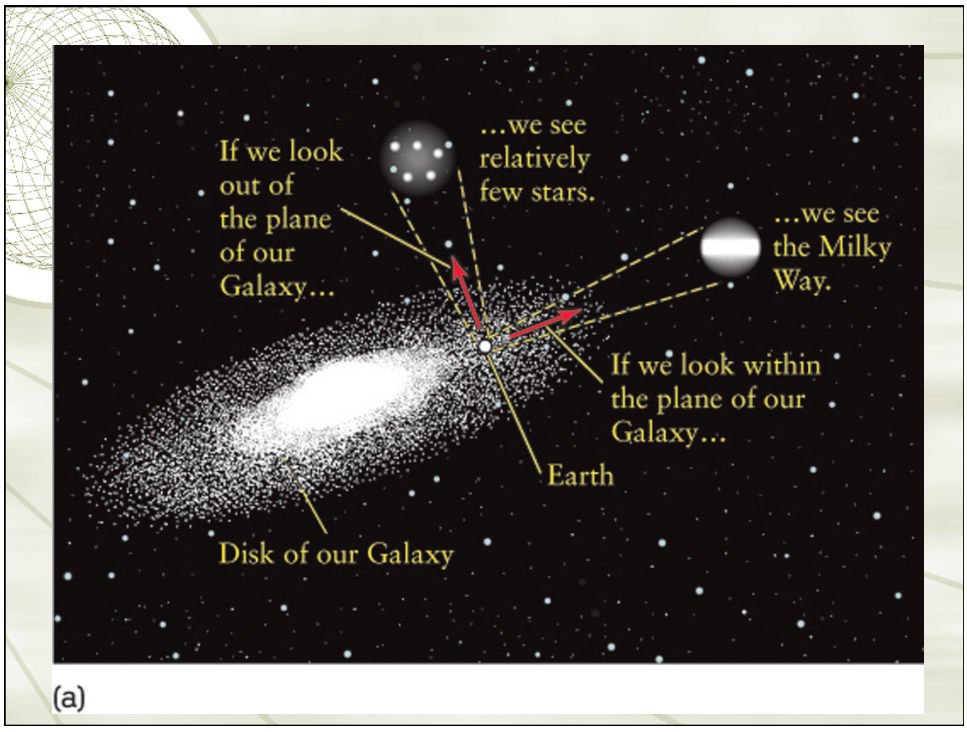
- Our place in the Galaxy
- The Great Debate
- Measuring distance in astronomy
  - Parallax and Cepheids
- Hubble's (first) great discovery

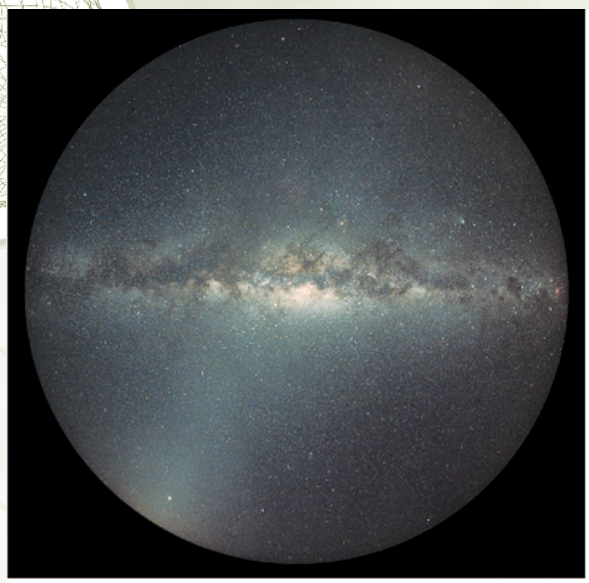


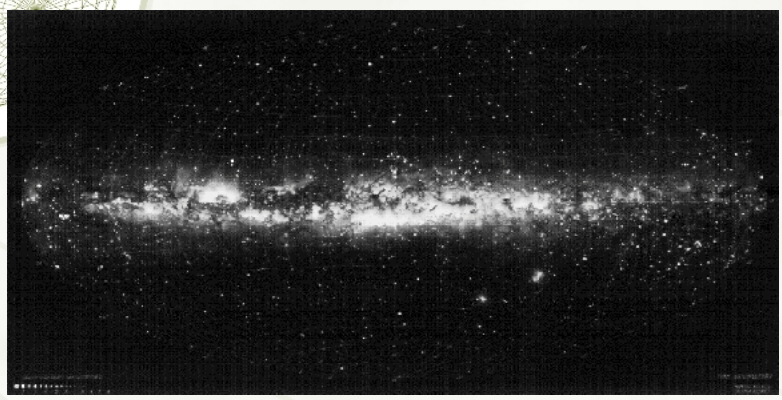


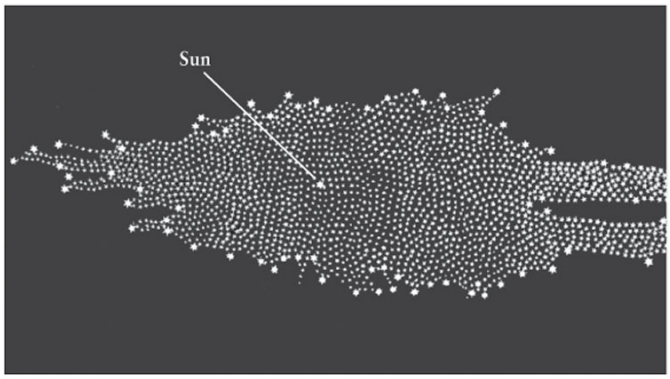
## I : Our place in the Galaxy

- We live in a large disk galaxy
  - We live in the disk, towards the edge (8kpc~25,000lyr out)
  - Projected onto the sky, this disk of stars looks like a band of light that rings the sky… the Milky Way
- This realization came somewhat slowly…
  - Disk-like nature of galaxy realized by Thomas Wright (1780); refined by Kant
  - First attempt to map out galaxy made by William Herschel (1785); refined by Kapteyn in 1920
  - Herschel came to the conclusion that we sit at the center of the Galactic disk. In fact, he was wrong… had not accounted absorption by dust!

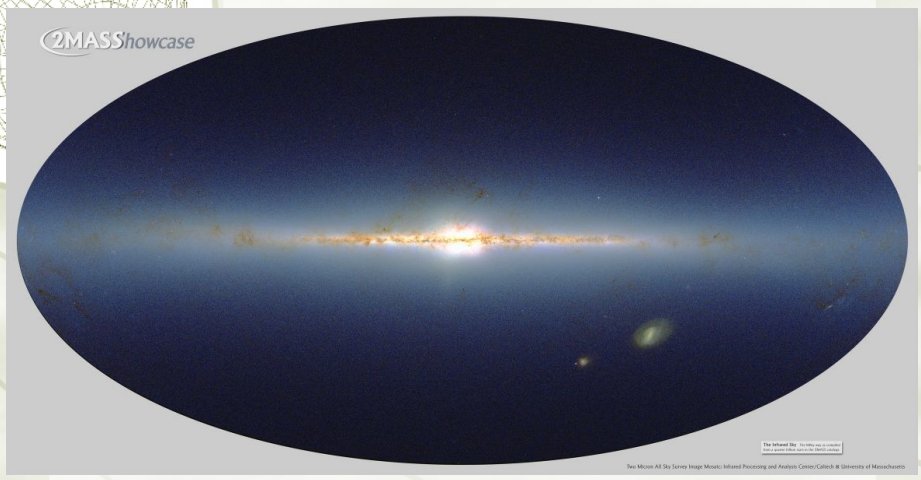

If we look out of the plane of our Galaxy…
…we see relatively few stars.
…we see the Milky Way.
If we look within the plane of our Galaxy…
Earth
Disk of our Galaxy
(a)

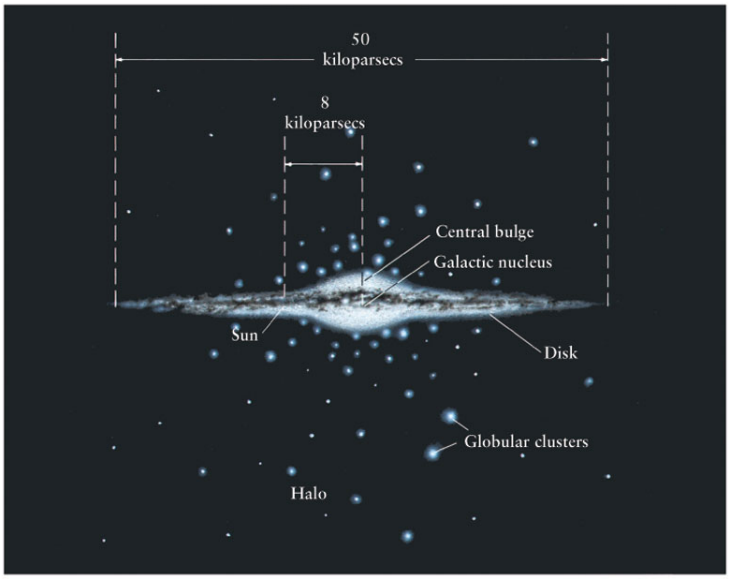

View out of the plane of our Galaxy
View within the plane of our Galaxy
View out of the plane of our Galaxy
(b)

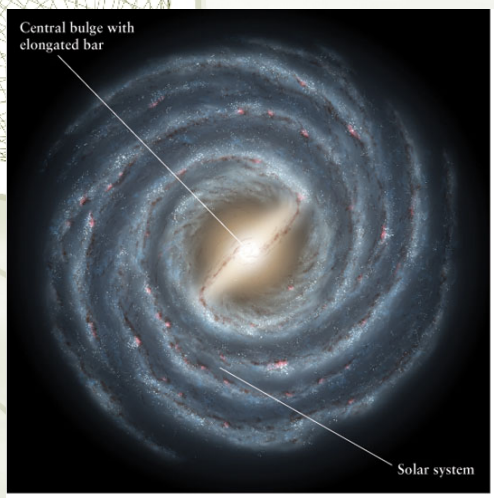




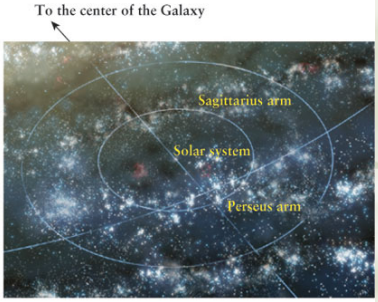

Herschel's map of the Galaxy






(a) The structure of the Milky Way's disk




(b) Closeup of the Sun's galactic neighborhood

## II : The Great Debate… "what are spiral nebulae?"

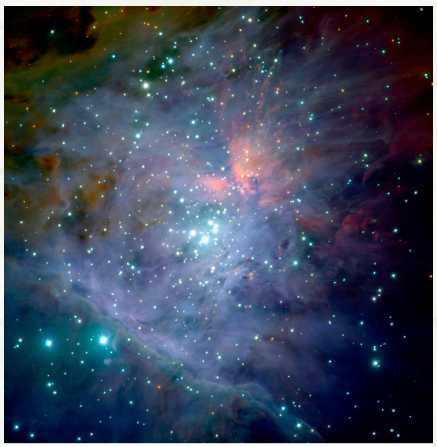
- Early 20th century…
  - Knew that we lived in a large disk galaxy
  - But what was the nature of the larger Universe?
  - Two opposing ideas:
    - Our galaxy is alone, sitting in the middle of otherwise empty space
    - Our galaxy is one of many galaxies that fill space (so-called "Island Universes")
  - The debate rapidly focused on the nature of **nebulae**

- Nebulae have been studied for ages
- Messier (1780)
  - Systematically catalogued over 100 bright nebulae
  - Main reason for doing this was so that comet hunters knew which "fuzzy patches" to ignore!
  - But what were these nebulae? Possibilities:
    - Glowing patches of gas (e.g., Orion)
    - Clusters of many stars within our Galaxy (e.g., the Globular cluster M13)
    - Whole other galaxies!!
  - Of special interest were the "spiral nebulae" that showed Milky Way like spiral structure… the brightest spiral nebulae was the **Andromeda nebula**

## *Messier actually cared about comets*

Credit : A. Dimai

## *The Orion Nebula (M42)*

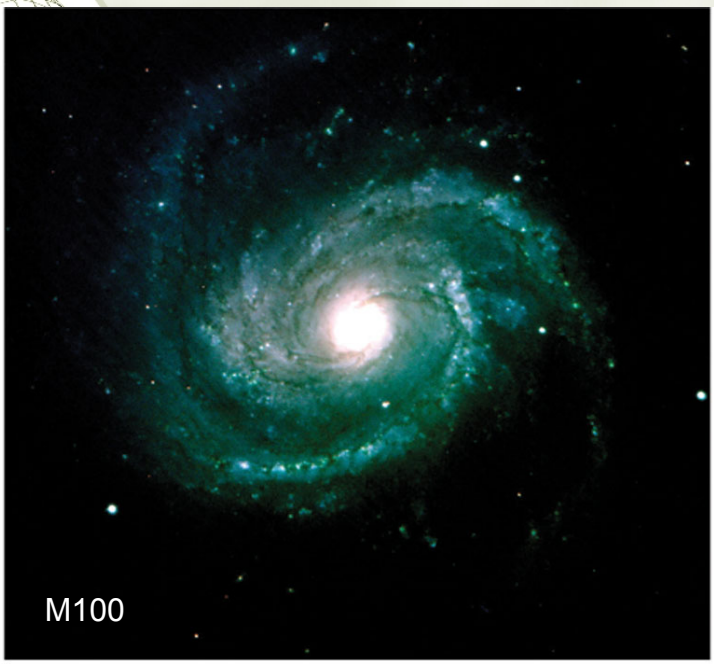


The Orion Nebula and Trapezium Cluster
(VLT ANTU + ISAAC)

ESO PR Photo 03a/01 (15 January 2001)

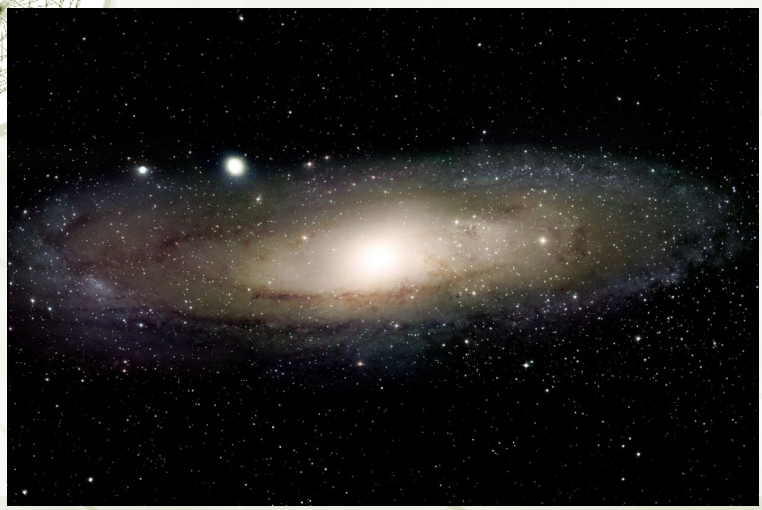
# Globular cluster (M13)

Credit: Yuugi Kitahara



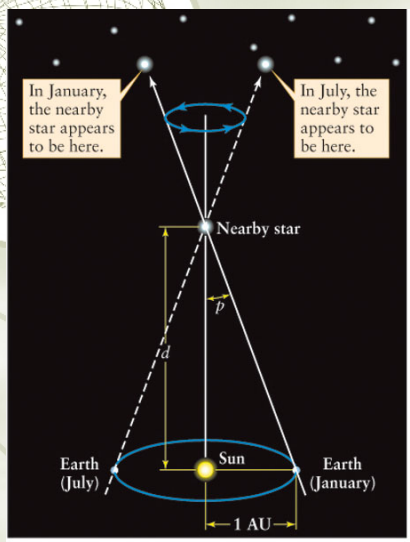
- Two misleading events…
  - Van Maanen reported observations showing that the spiral structure in the Andromeda nebula was rotating.
    - If Andromeda was outside of our galaxy, the rotation would have to be much faster than speed of light!
    - Argued for Andromeda being inside of our Galaxy
  - 1885 : A "new star" appeared in Andromeda nebula
    - This was interpreted as a stellar nova
    - Scaling from known nearby novae, it was concluded that Andromeda lay will inside our Galaxy
    - It wasn't realized at the time that this was actually a **supernova**, not a regular nova.
- 1920 : The two points of view were debated by Shapley & Curtis in the "Great Debate"

## *Andromeda "Nebula" (M31)*

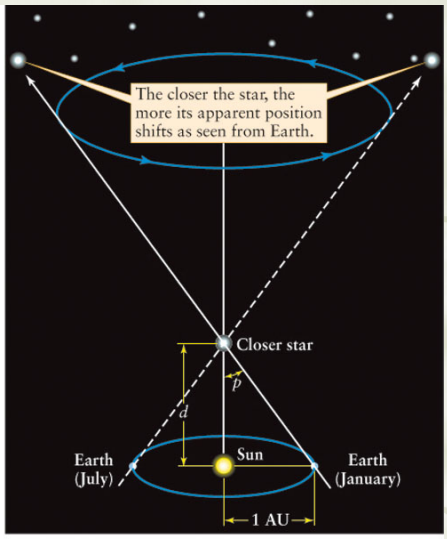


# III : Measuring distances in astronomy

- The **distance** to any astronomical object is the most basic parameter we want to know
  - Require knowledge of distance in order to calculate just about any other property of the object
  - Distance is often difficult to determine!
- Most direct method for measure distances to "nearby" stars uses an effect called **parallax**
  - As Earth orbits Sun, we view a star along a slightly different line of sight
  - This causes the star to **appear** to move slightly with respect to much more distant stars
  - We can currently use this technique to measure stellar distances out to ~3000 light years from Earth



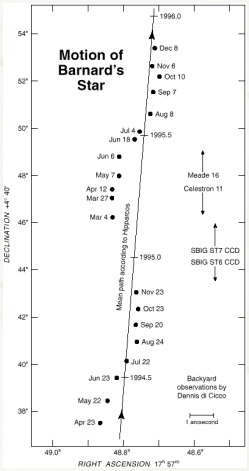

(a) Parallax of a nearby star




(b) Parallax of an even closer star

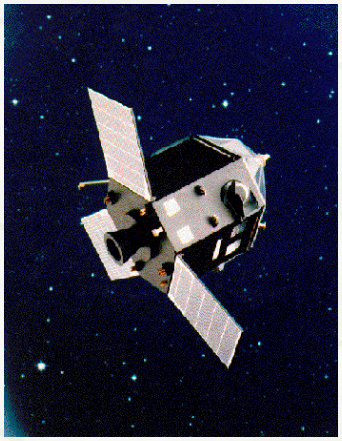
- If star wobbles with amplitude of 1 arc-second, then it is at distance of **1 parsec** (definition of parsec).
- 1pc = 3.26 lt-yr
- In general,

$$D(\text{pc}) = \frac{1}{\theta_{wobble}(\text{arcsec})}$$

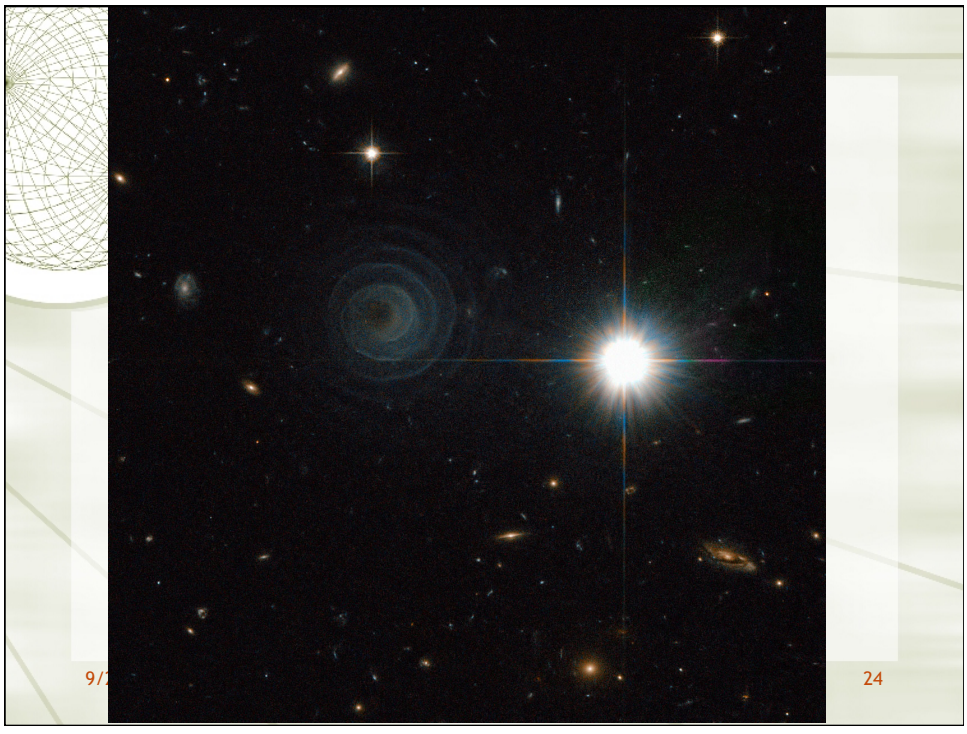





- Until 1990s, could only detect parallax out to 50pc.
- Hipparcos satellite
  - Designed to measure parallax of stars
  - Can detect wobble out to distance of about 1kpc (1000pc)
  - Used to map out locations of nearby stars.
- GAIA satellite
  - Due to launch 2012
  - Can map out positions and motions of stars across the whole galaxy!!



Hipparcos (ESA)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# Beyond parallax?

- Definition : The **observed flux** of a star is the energy received from the star per unit time per unit area.
- Definition : The **luminosity** of a star is the energy per unit time (i.e. power) emitted by the star
- If the star is at distance D and emits equally in all directions (i.e. it emits isotropically), then the observed flux F and luminosity L are related by

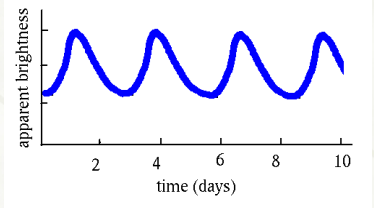
$$L = 4\pi D^2 F \quad \text{or} \quad F = \frac{L}{4\pi D^2}$$

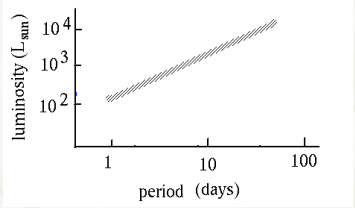
- Suppose we know the luminosity of some object… then we can use its measured flux to determine the distance! Objects with known luminosities are called **standard candles**.

Henrietta Leavitt
ph.credit: AAVSO

# Cepheid variables

- Henrietta Leavitt discovered (1912) that a certain class of variable stars called Cepheids had properties that meant they could be used as standard candles
  - She studied Cepheids that are close enough for parallax to be measured… found that the luminosity is related to the period of fluctuations in brightness
  - So, if you measure the period of a Cepheid, you can determine its luminosity. Measuring flux then gives you distance, even if its too far for parallax!






*graphics: University of Oregon Astronomy Dept*

# Edwin Hubble




# Hubble's observations

- Hubble found Cepheid Variables in Andromeda
  - Measured period and flux, and hence distance
  - Concluded that Andromeda must be well outside of the Milky Way Galaxy
  - Thus, the Great Debate was settled… the MW is just one of many many many galaxies
- Modern measurements
  - Distance to Andromeda 2 million lyr
  - About 20x MW diameter




## *Cepheids in the **Virgo galaxy cluster** with Hubble Space Telescope (16 Mpc away…)*