Unit VI: Large Scale Structure and Cosmology

Astronomy and Astrophysics

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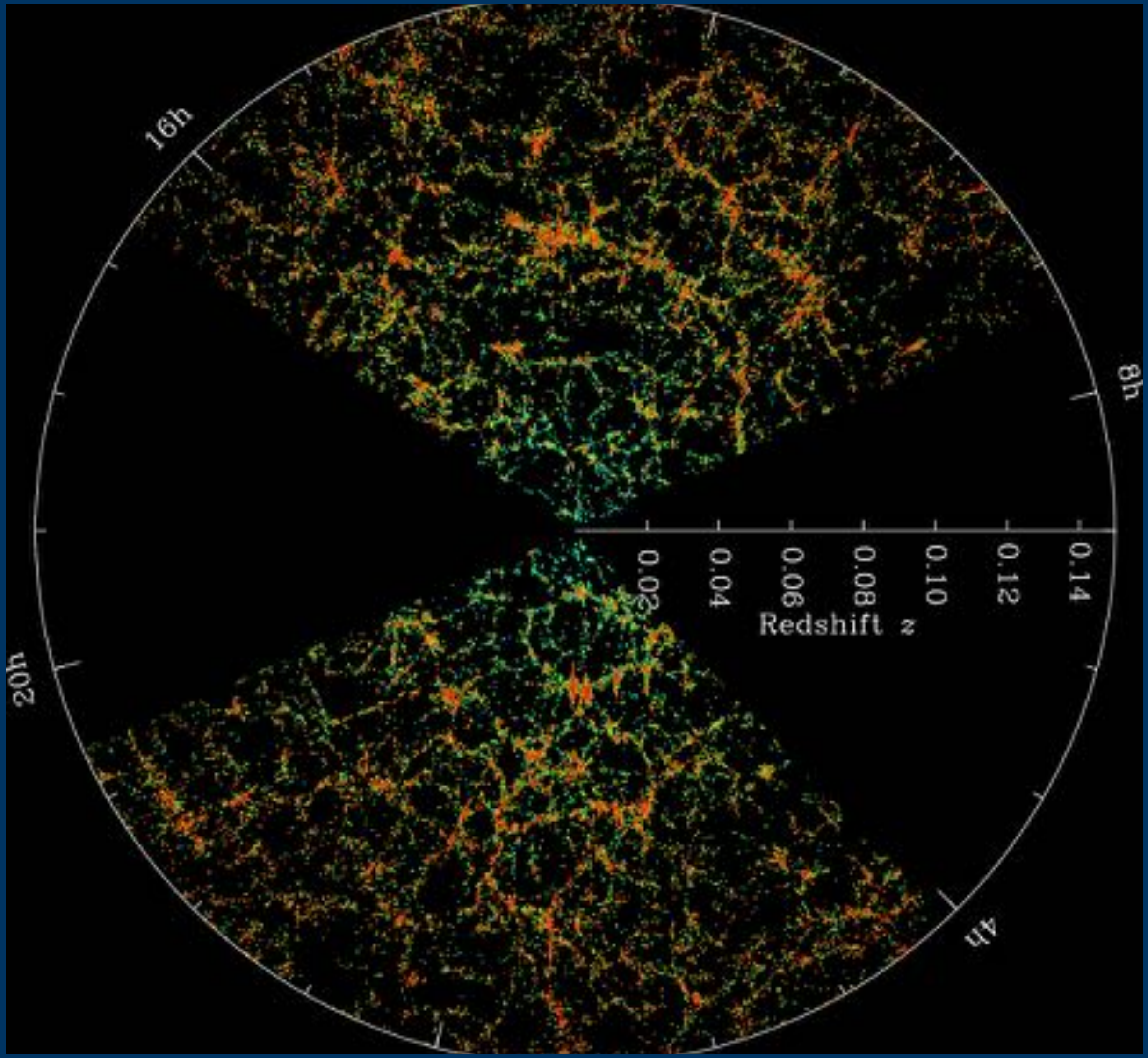
- The Large Scale Structure (LSS) of the universe refers to the patterns of galaxies and matter on scales much larger than individual galaxies or groupings of galaxies.

- These correlated structures can be seen up to billions of light years in length and are created and shaped by gravity.

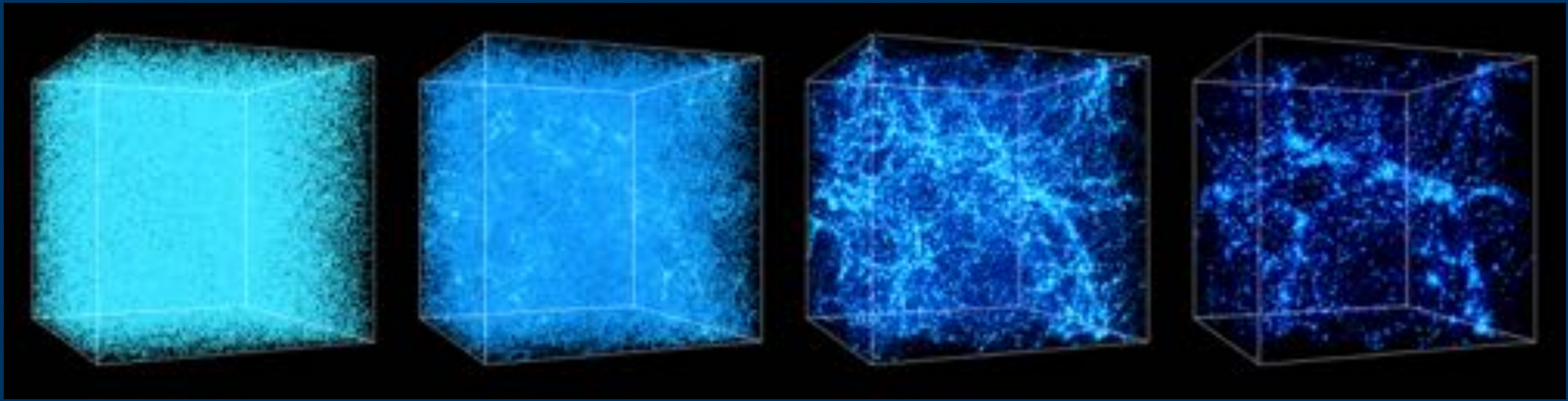
- Just as gravity on smaller scales pulls together gas particles to make stars, and pulls together stars to make galaxies, it also pulls together galaxies and matter into patterns on larger scales.

- These patterns often contain large filaments of galaxies, and voids in between, somewhat resembling a spider web, which is why it is often referred to as 'the cosmic web'.



This figure shows galaxies discovered by the Sloan Digital Sky Survey (SDSS). Red points are galaxies with more red star light, indicating older and often larger galaxies. The web-like distribution of galaxies on large scales can be seen by eye. A larger redshift corresponds to a larger distance from Earth, which is at center of the figure. The figure shows galaxies out to around 2 billion lightyears away. The Dark Energy Survey will map galaxy positions out to roughly redshift 1.3 or so, around six times as distant as the furthest galaxies seen here. Figure Credit: M. Blanton and SDSS

- Studying LSS tells astronomers about the strength of gravity in the universe.
- Astronomers can **measure galaxies at different distances away** from the Earth, which correspond to different times in the universe's history, due to the time their light takes to reach us.
- We can tell that over time, gravity is attracting more and more matter together, clustering the universe further and further.
- Large Scale Structure also tells us about dark energy. Most theoretical models of dark energy act to slow down this process of gravity creating large structures. Essentially, as the universe accelerates in its expansion, it takes more time for matter to come together because it must travel more distance.

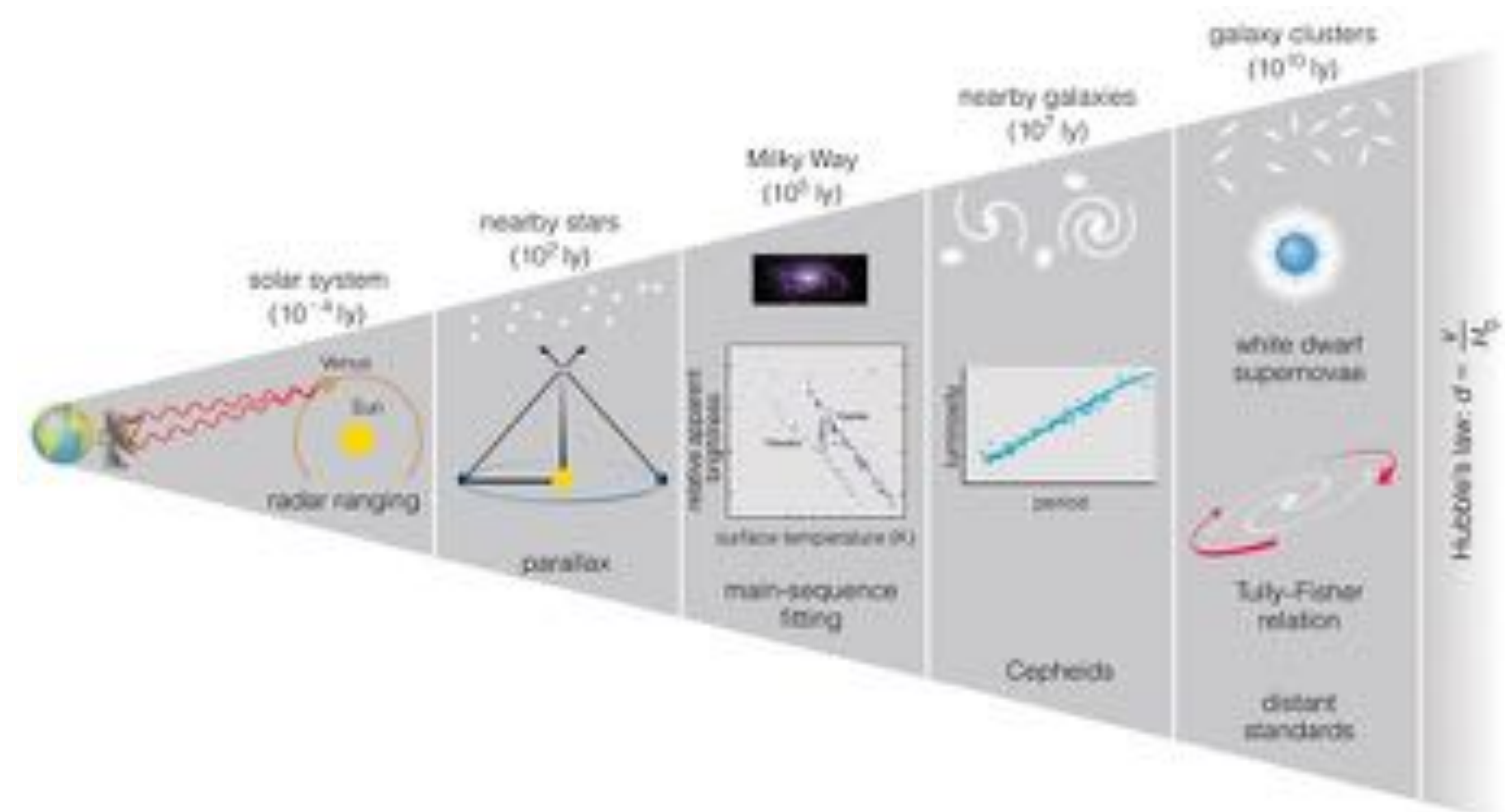


This figure shows a simulation of gravity in an expanding Universe. As time goes on (left to right), gravity pulls together matter into large scale patterns. Notice that the pattern on the right (present day) has much more clustered structure than the left-most box (early in the Universe). Also, the Universe expands with time, so every 'box' in the Universe is also growing in size. (The expansion has been much bigger since the beginning of the Universe than can be shown here.) These simulations help cosmologists know how gravity is predicted to cluster the Universe over time, which we can compare with our observations. Figure Credit: Andrey Kravtsov, Anatoly Klypin, National Center for Supercomputer Applications (NCSA)

Distance Ladder

How we measure an infinite universe?

- When humans look up at the night sky, they naturally ask the question: How far away is that planet, or that star, or that galaxy?
- Distance is one of the most fundamental measurements astronomers make, but it's also one of the most challenging.
- Fortunately, astronomers have a vital tool to help them answer that central question: how far? That tool is the cosmic distance ladder.



- This ladder has “rungs” of objects with certain properties that let astronomers confidently measure their distance.

- Jumping to each subsequent rung relies on methods for measuring objects that are ever farther away.

- For example, once astronomers measure the distance to a galaxy using one rung, they can then measure the distance using the next rung and match the two.

That allows them to move outward and measure even greater distances, rung by rung.

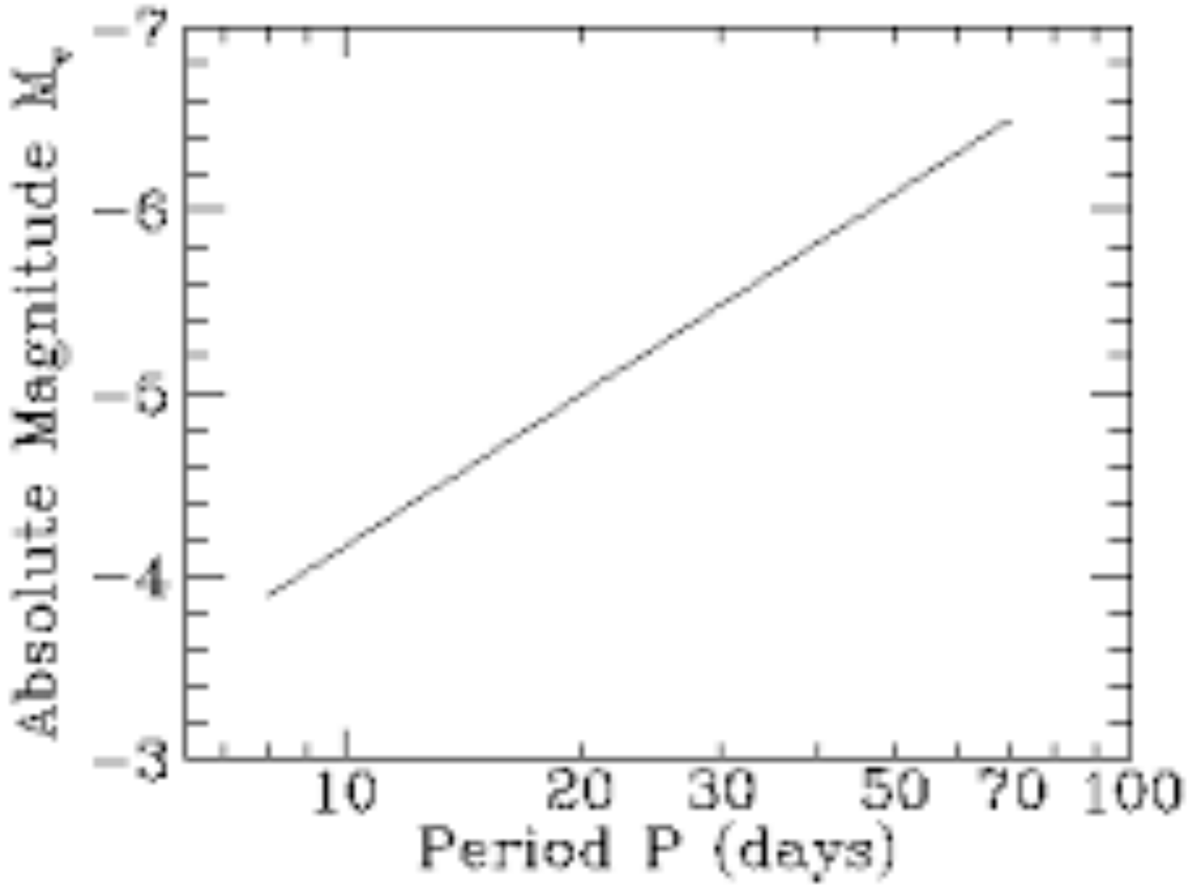
- Step one: Stellar Parallax.
- Spectroscopic Parallax (Main sequence Fitting)
- Standard Candles

1. Cepheid Variables
2. Type Ia Supernovae

- Hubble's Law

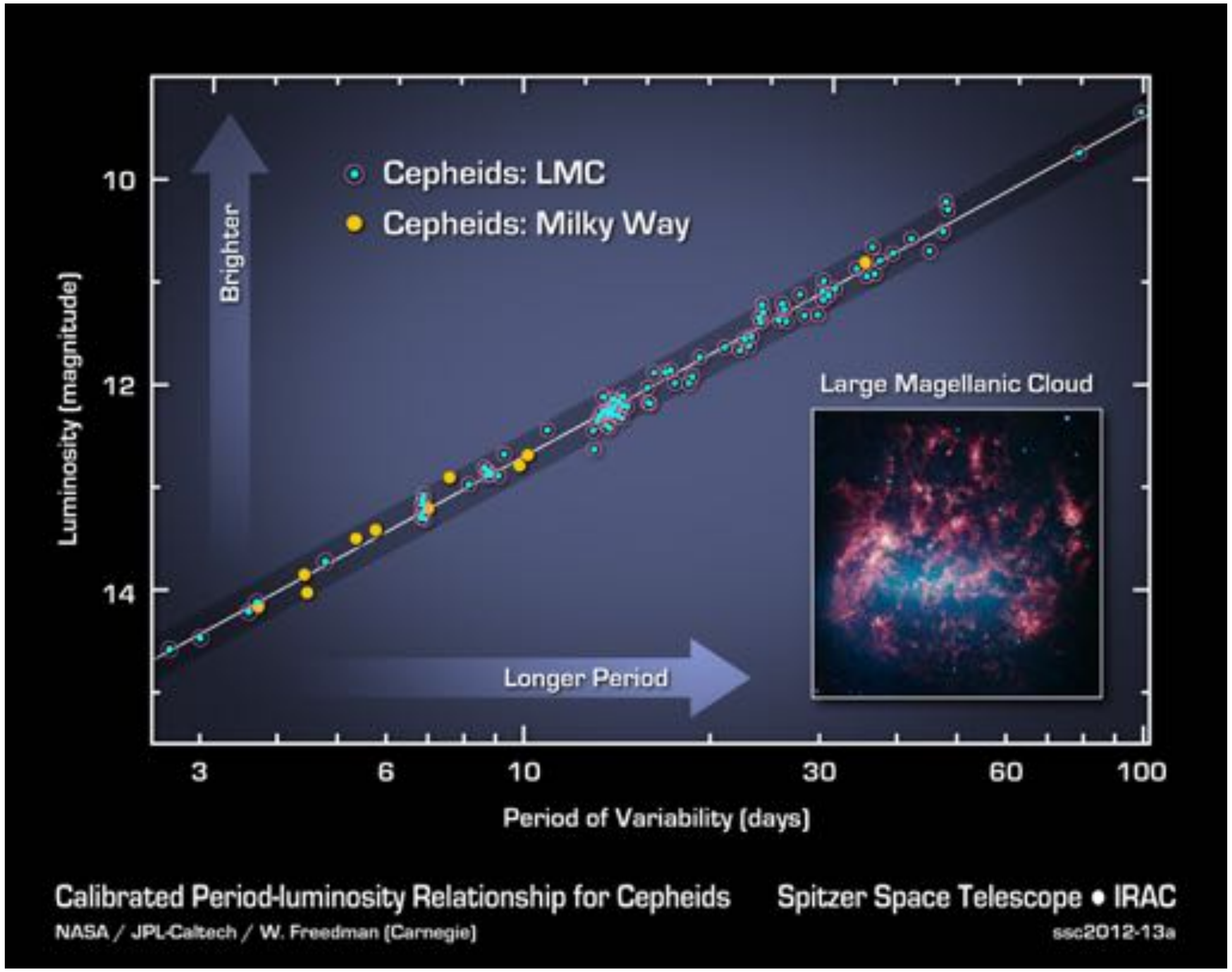
Cepheid Variables:

- first rung in the extragalactic distance ladder
- hold a special place in the subject because they were used by Hubble in his first radial velocity vs. distance plot that led to the discovery of the expanding Universe.
- Cepheids are a class of variable stars located in the upper H-R diagram
- period-luminosity relation: the longer the period of their variability, the brighter their absolute magnitude.



Period-Luminosity relatioship of cepheid variable

By measuring the period of an extragalactic Cepheid star, it is possible to deduce its distance modulus by comparing its observed magnitude with the absolute magnitude, provided the period-luminosity relationship has been calibrated with the known distances of nearby Cepheids in the Milky Way.



Cepheids: LMC
Cepheids: Milky Way
Brighter
Longer Period
Large Magellanic Cloud
Luminosity (magnitude)
10
12
14
3
6
10
30
60
100
Period of Variability (days)
Calibrated Period-luminosity Relationship for Cepheids
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / W. Freedman (Carnegie)
ssc2012-13a

Edwin Hubble, using Cepheids as standard candles, was one of the first to measure distances to other galaxies

By measuring distances to galaxies, Hubble found that redshift and distance are related in a special way

Velocity-Distance Relation among Extra-Galactic Nebulae.

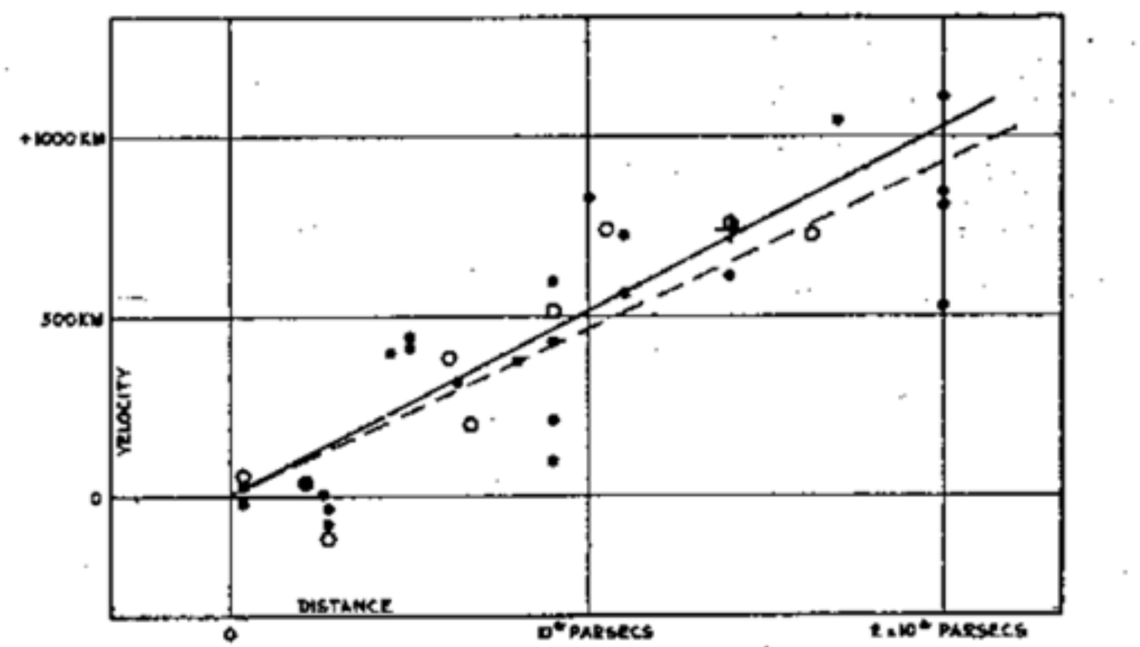
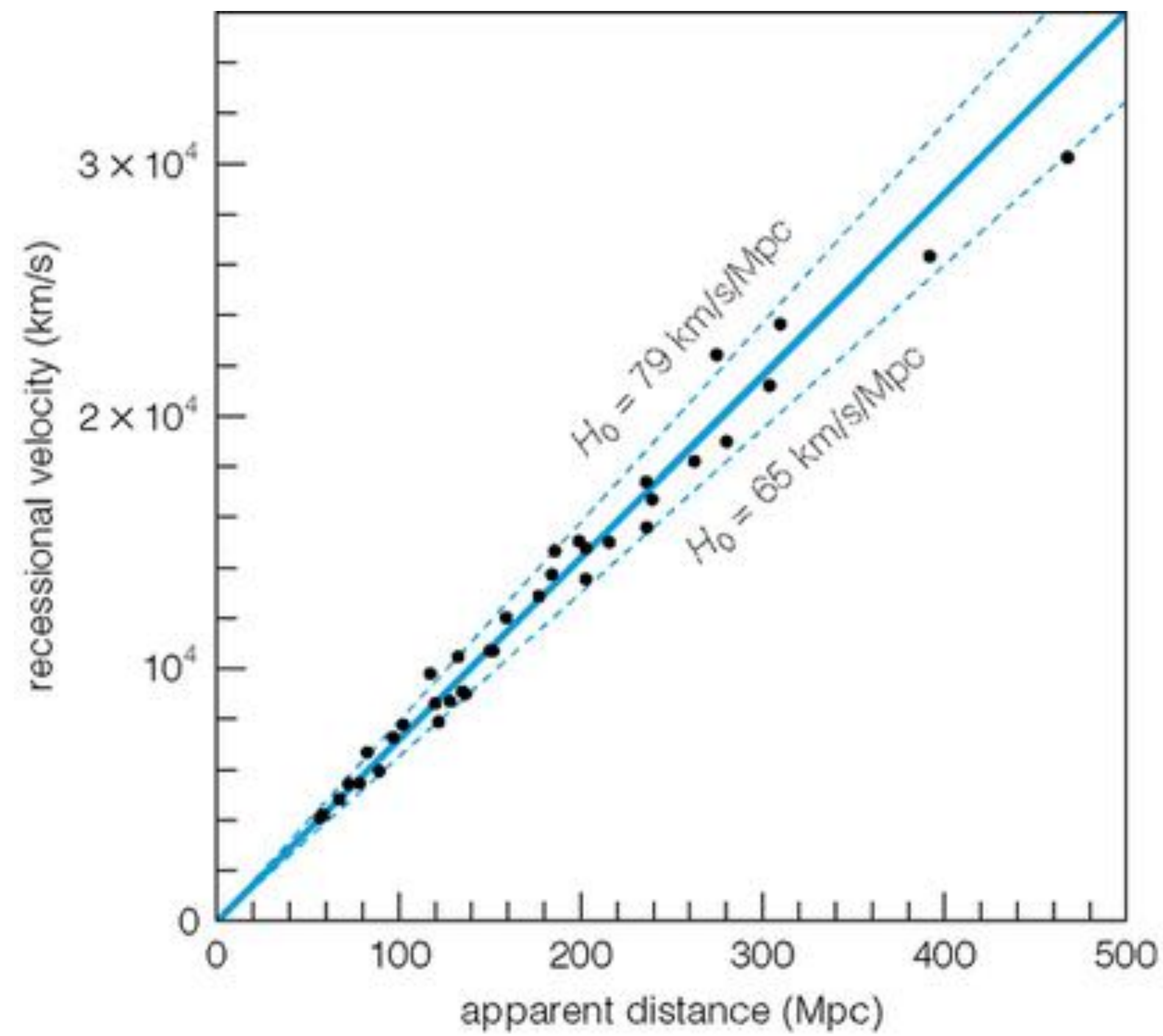


FIGURE 1

The Hubble Law:

velocity = (H_0) • (distance)

$$v = H_0 d$$



v : recession velocity of the celestial body
H_0 : Hubble's Constant
d : distance between the celestial object and Earth