5 ideas that changed our understanding of the Universe in the last century.

A brief introduction

Fr. Richard D’Souza, SJ, Vatican Observatory.

Fundamental Questions in Astronomy

- How big is the Universe?
- Where do we come from?
- Where are we going?
- Are we alone in the Universe?

Topics

The revolution in our understanding of the Universe in the 20th Century

- The size of the Universe
- The origin of the Universe
- The origin of the elements that make up life on earth
- The end of the Universe
- Discovery of extra-terrestrial planets and the search for signatures of life.

Topics

Our past understanding of the Universe in the 19th Century

The revolution in our understanding of the Universe in the 20th Century

- The size of the Universe
- The origin of the Universe
- The origin of the elements that make up life on earth
- The end of the Universe
- Discovery of extra-terrestrial planets and the search for signatures of life.

Topics

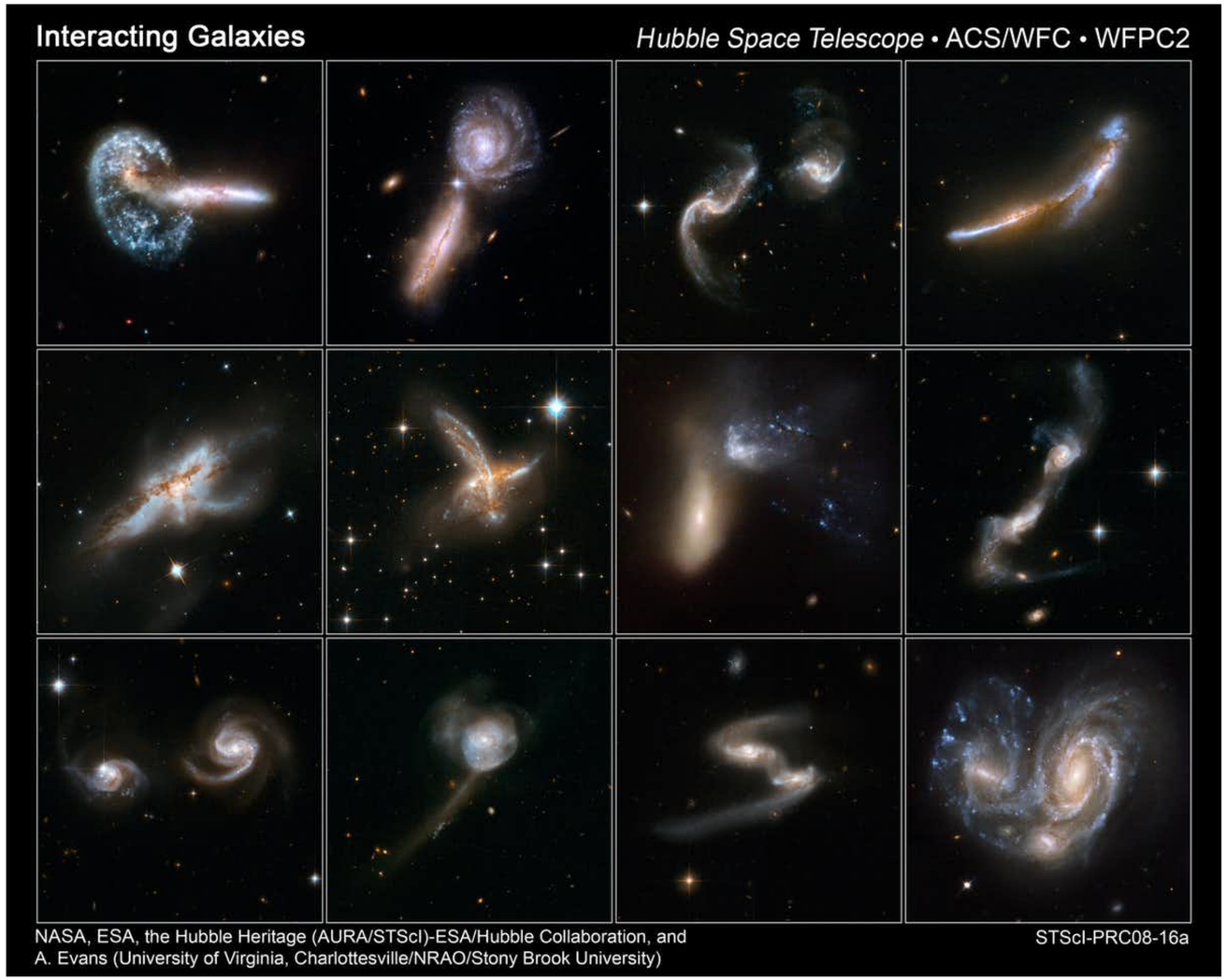
Our past understanding of the Universe in the 19th Century

The revolution in our understanding of the Universe in the 20th Century

- The size of the Universe
- The origin of the Universe
- The origin of the elements that make up life on earth
- The end of the Universe
- Discovery of extra-terrestrial planets and the search for signatures of life.

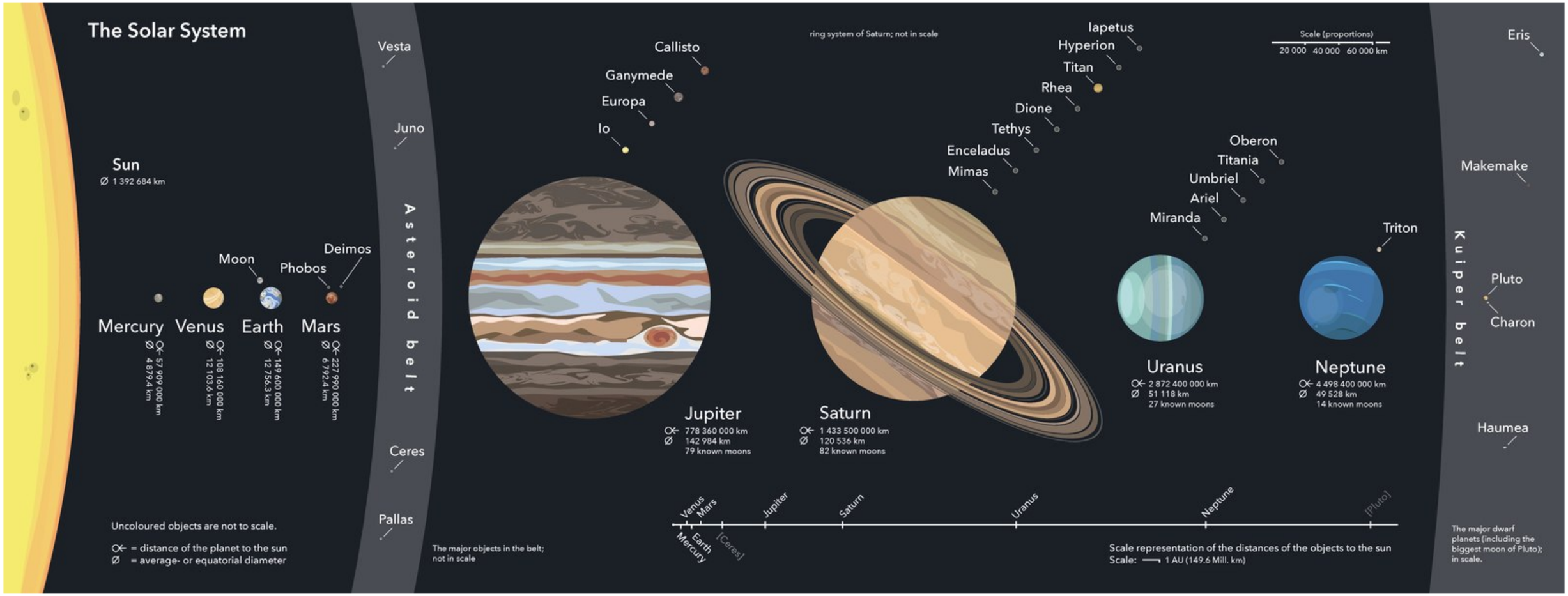
Scope & limitations

- General overview of the topic. Cruising at ~10000 meters. Hence, will not get into details.
- Enough to understand the basic concepts and to develop intuition.
- My choice of recounting the story of astronomy (there are other choices).
- Will not comment on the intersection of science and faith.



I. Our understanding of the Universe in the 19th Century

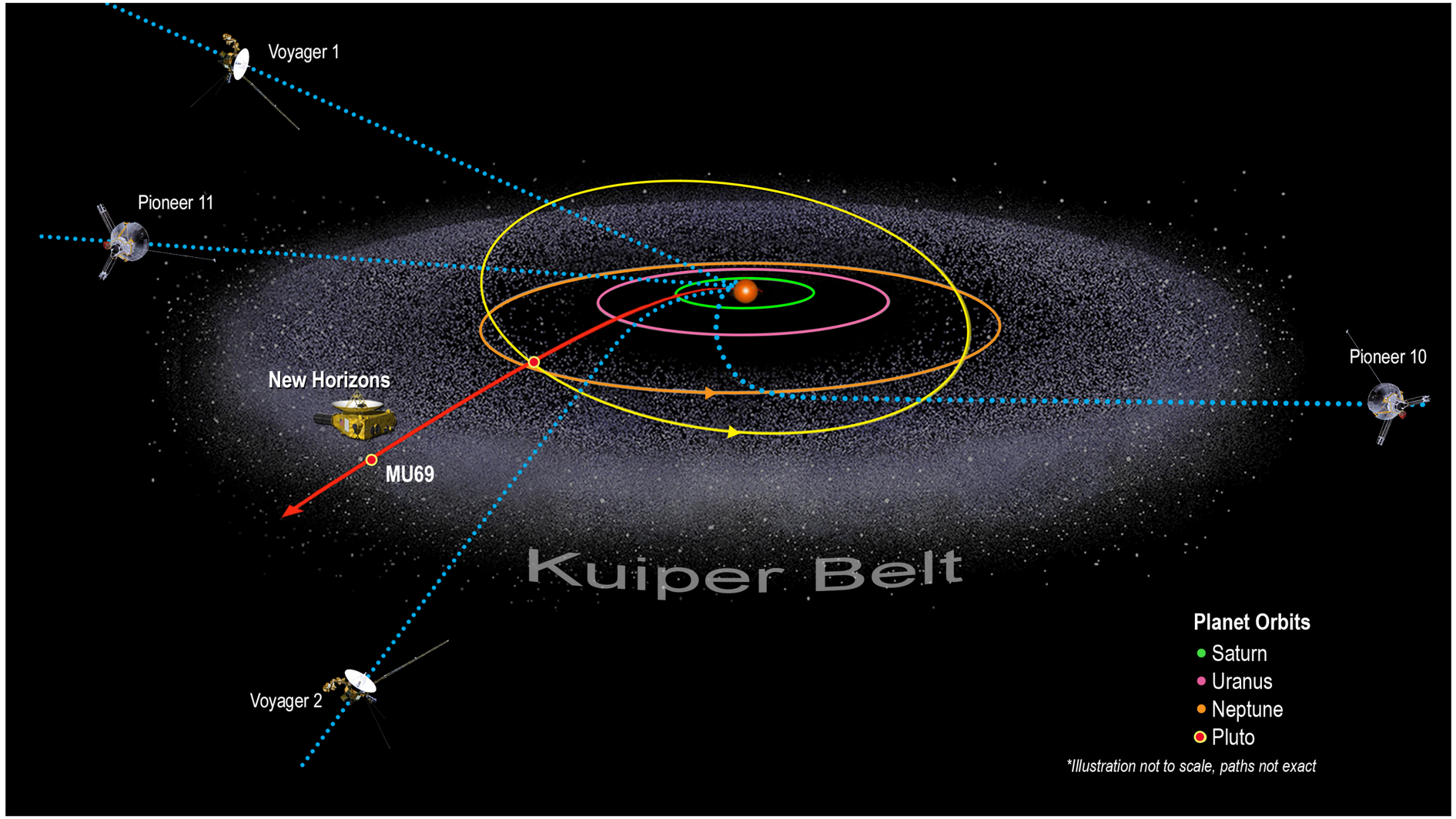
Planets and the Solar System



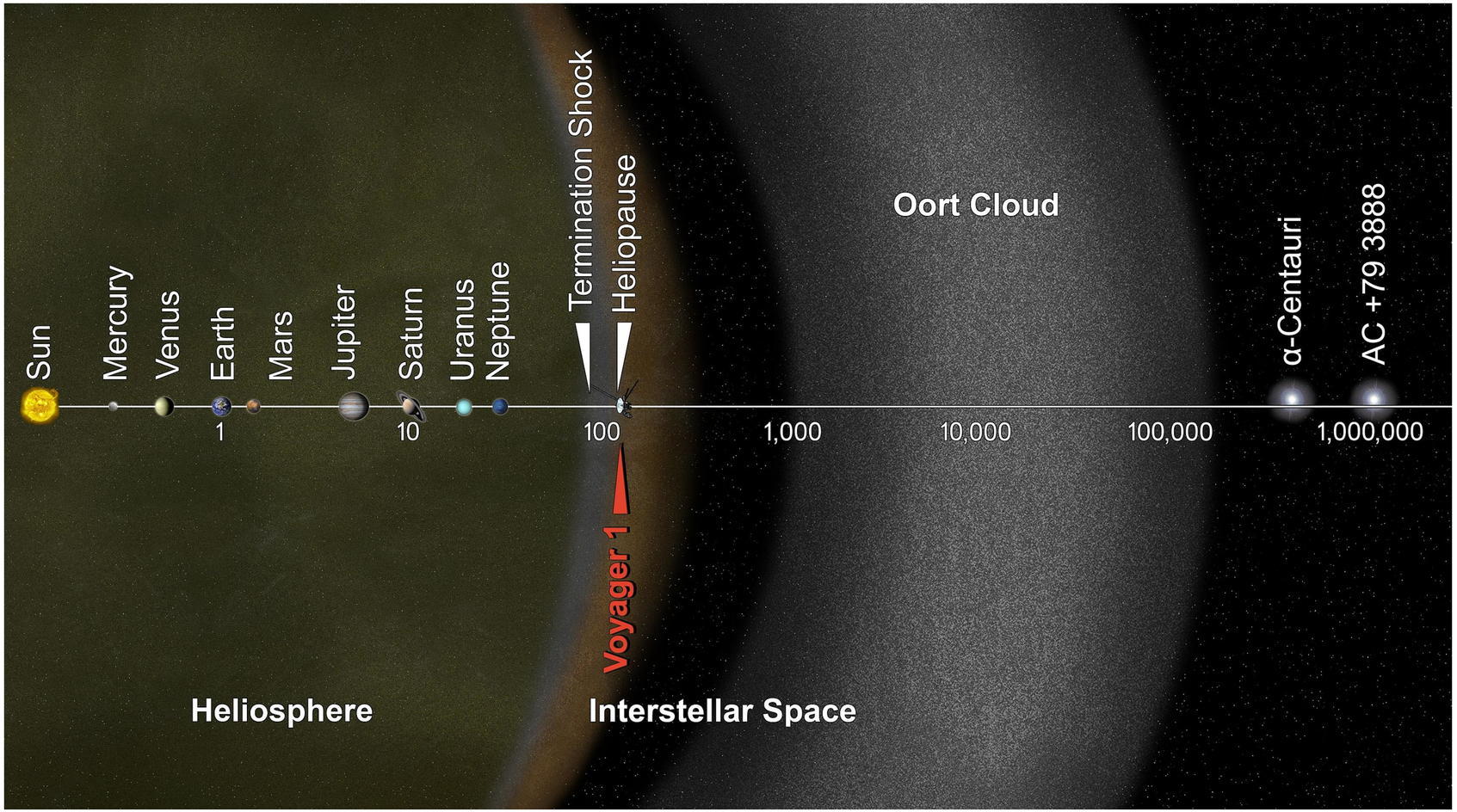
1 Astronomical Unit (1 AU) = 1.5 x 10^8 km

Comets

Comets


Voyager 1
Pioneer 11
New Horizons
MU69
Pioneer 10
Kuiper Belt
Voyager 2
Planet Orbits
Saturn
Uranus
Neptune
Pluto
*Illustration not to scale, paths not exact

Comets


Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Termination Shock
Heliopause
Voyager 1
1
10
100
1,000
10,000
100,000
1,000,000
Heliosphere
Interstellar Space
Oort Cloud
α-Centauri
AC +79 3888

Parallax

Trigonometric distances

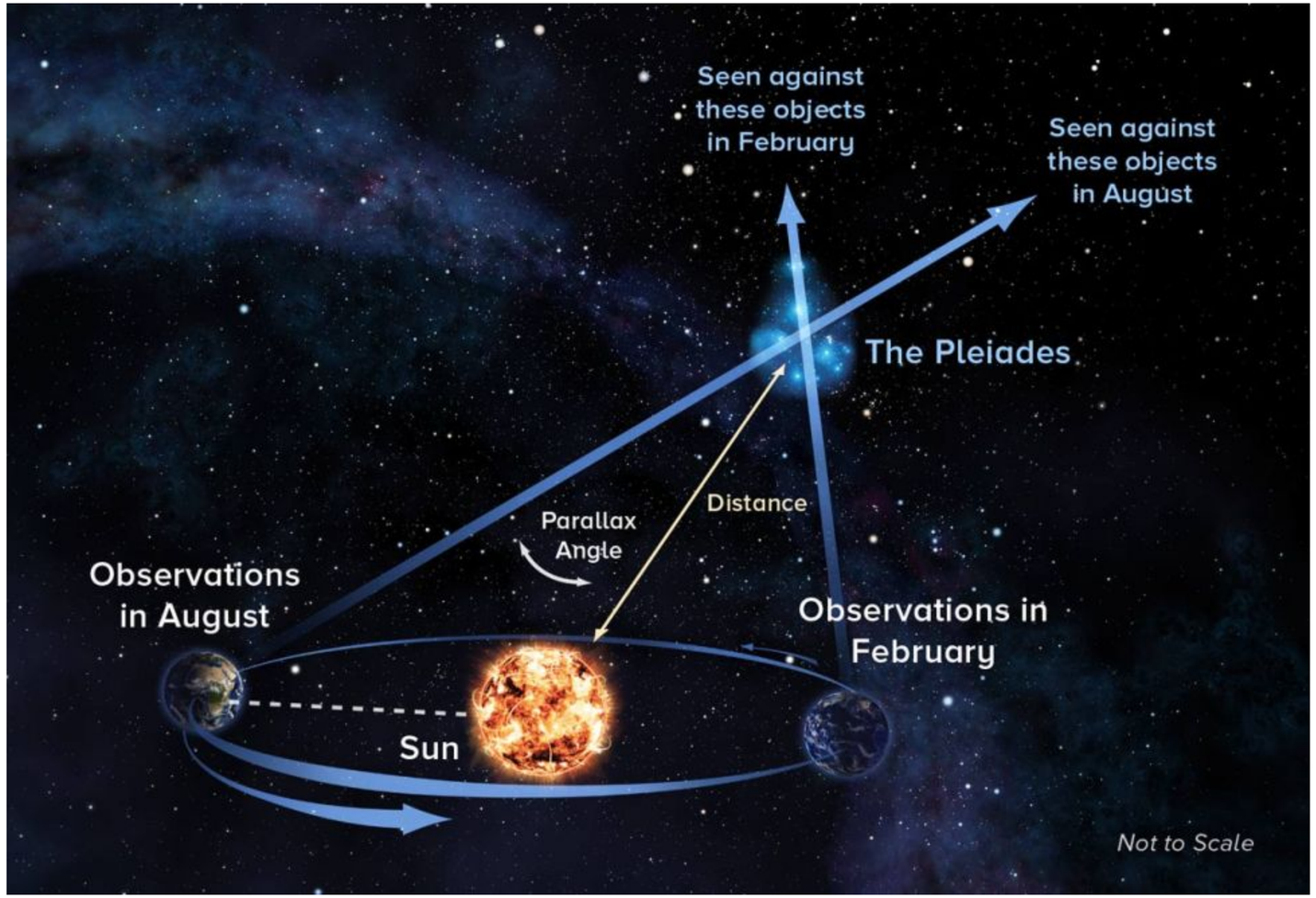
Measuring distances in astronomy is hard.

The intrinsic brightness of stars varies-

Brighter stars appear closer.

Need a method independent of brightness.

First parallax of stars are measured by Frederich Bessel in 1838.



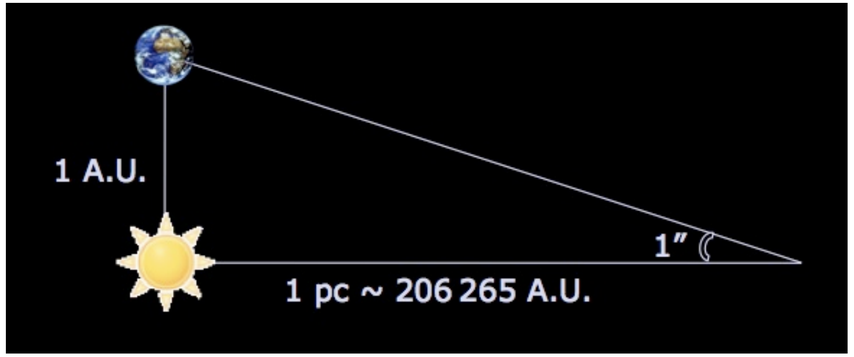
Parallax

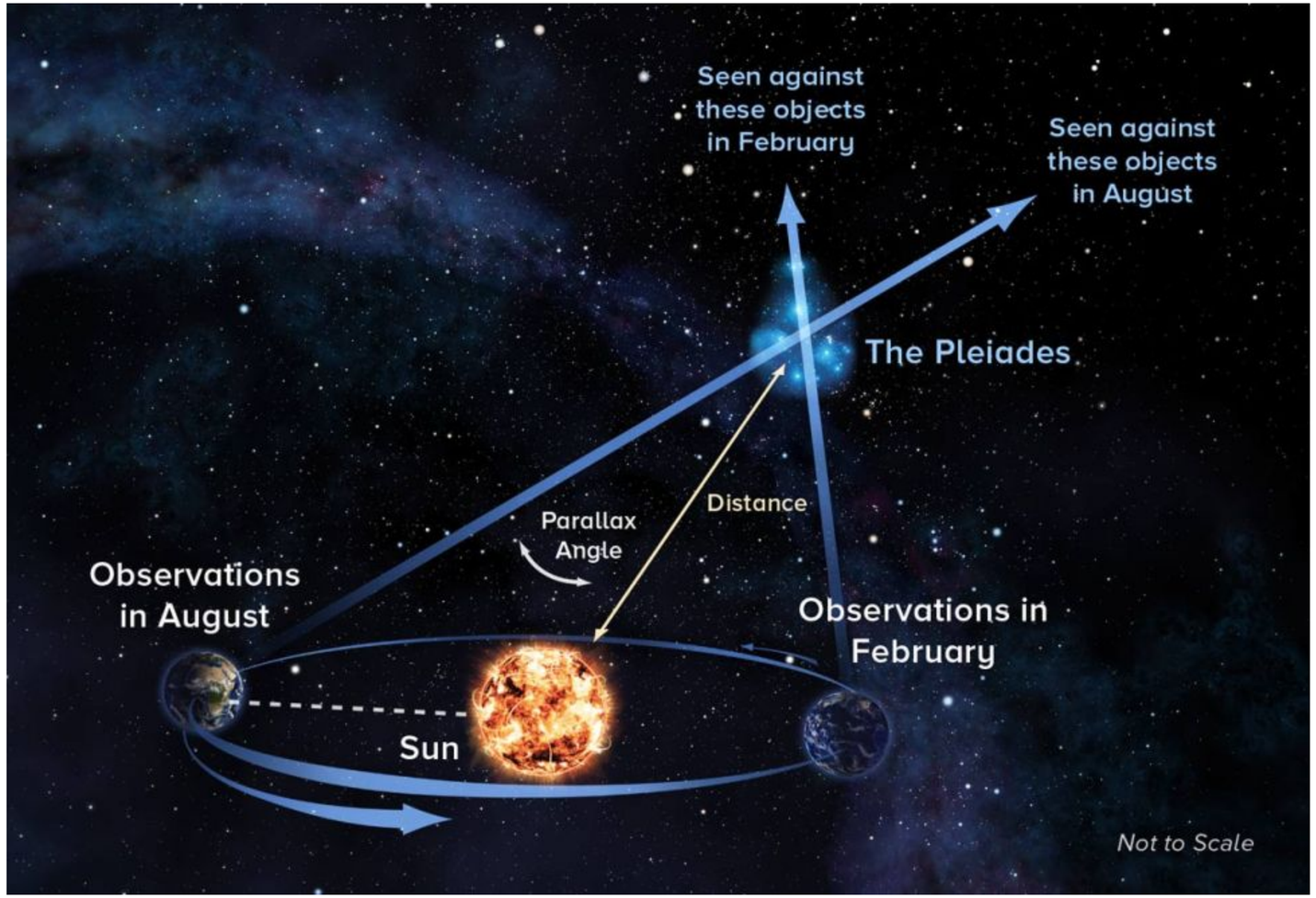
Trigonometric distances

1 AU ~140000000 kms

1 Light year ~ 63241 AU

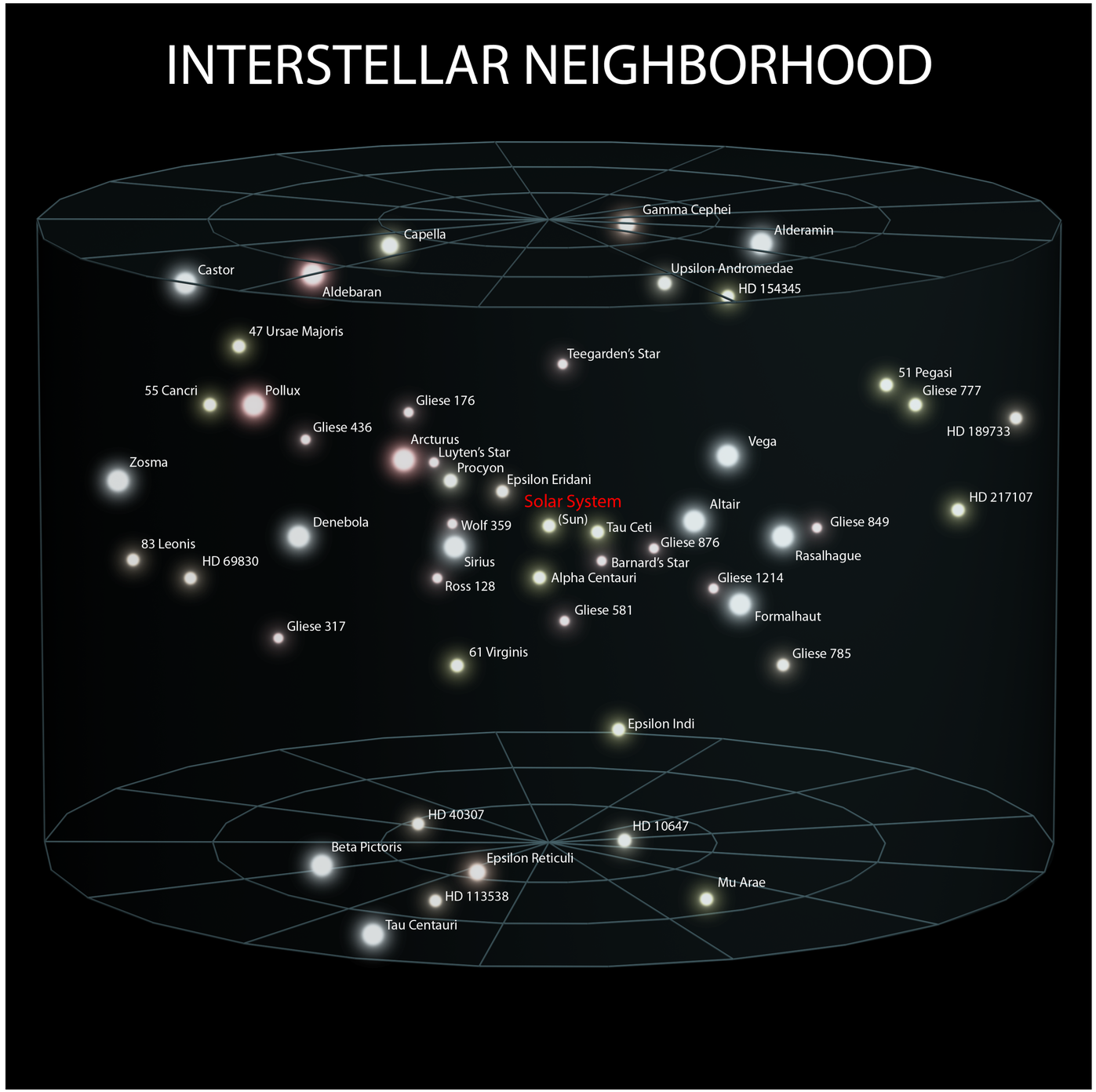
1 pc ~ 206265 AU





Nearby stars

- Alpha Centauri ~ 4.37 ly ~ 1.34 pc
- Arcturus ~ 11 pc
- Vega ~ 7 pc
- At the end of the 19th century, distances to only 60-100 stars were measured.



Messier objects

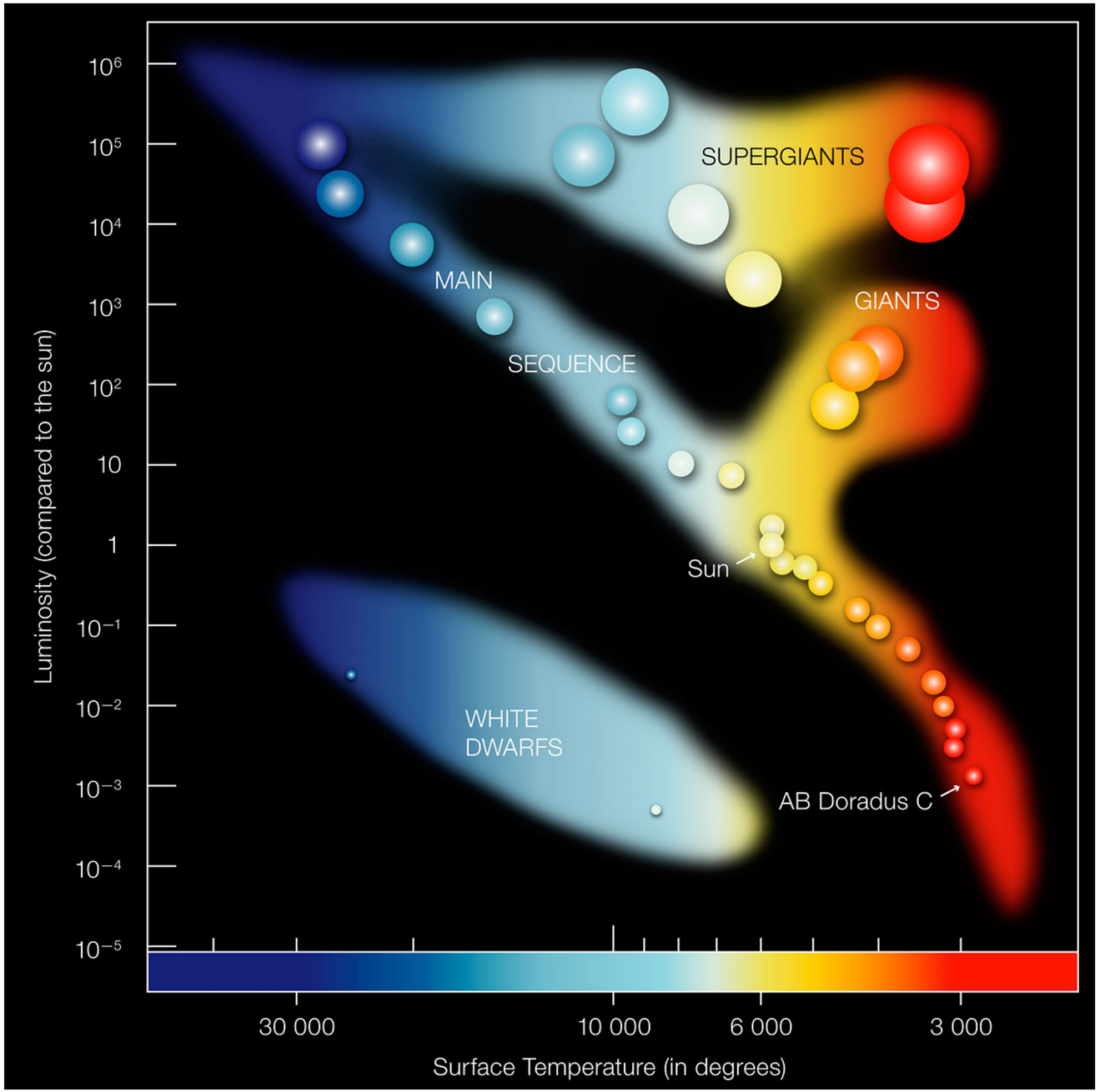
110 stationary astronomical objects (1774)

II. The Universe gets bigger

Stars around us

The diversity of stars

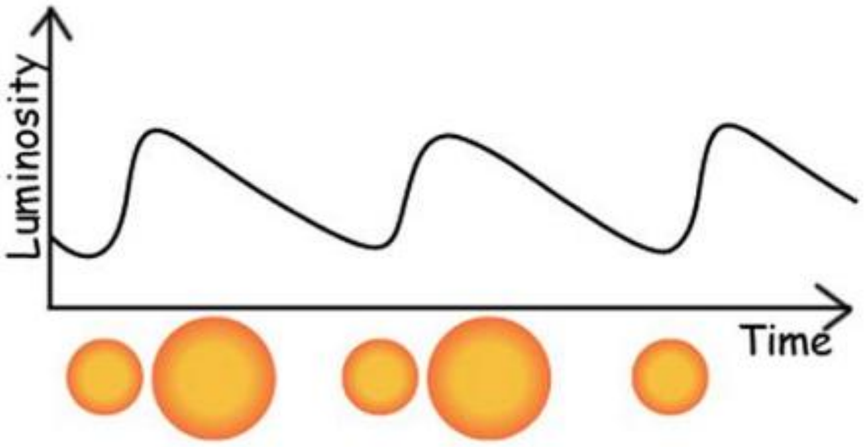
- Luminosity Temperature relationship of stars.
- Need correct distances to stars to understand their Luminosities.
- Temperature is measured using a proxy called “colour” - the difference between two filters.
- Stars evolve along the relationship.

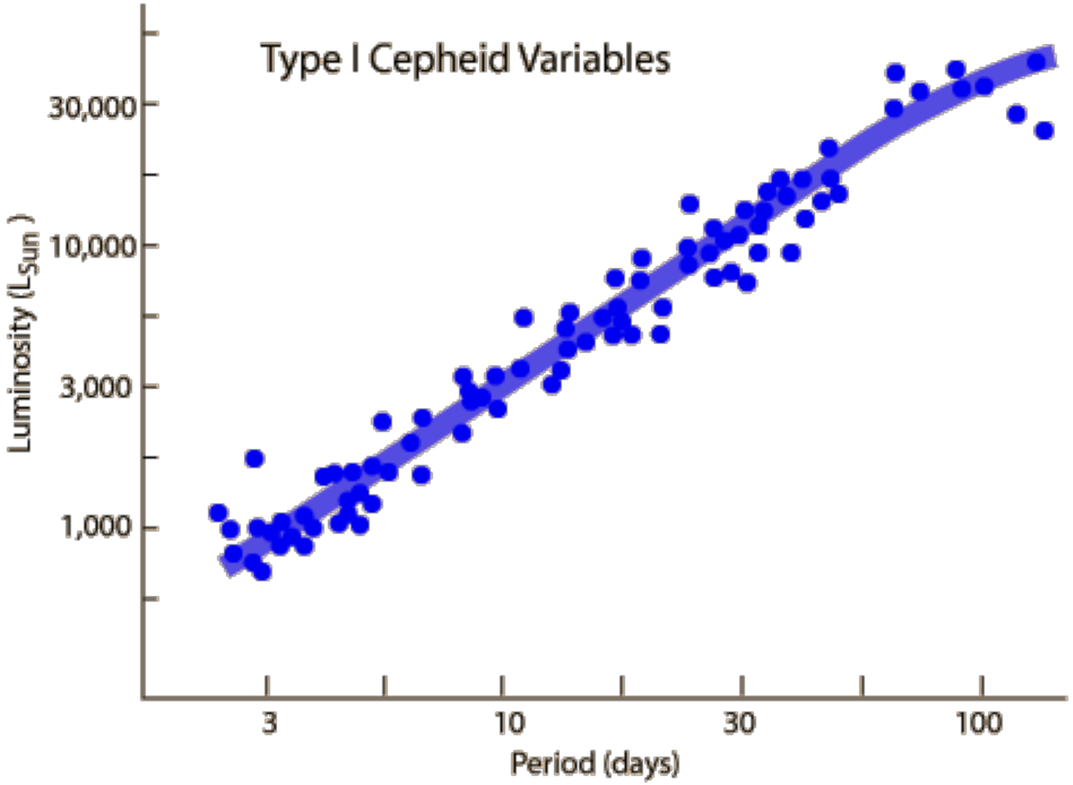


Cepheid Variables

An independent distance to stars

- Period-luminosity relationship discovered by Henrietta Swan Leavitt in 1908.
- Cepheids are one of the many “standard candles” in astronomy.
- Can find distances to stars in objects beyond trigonometric parallax distances.

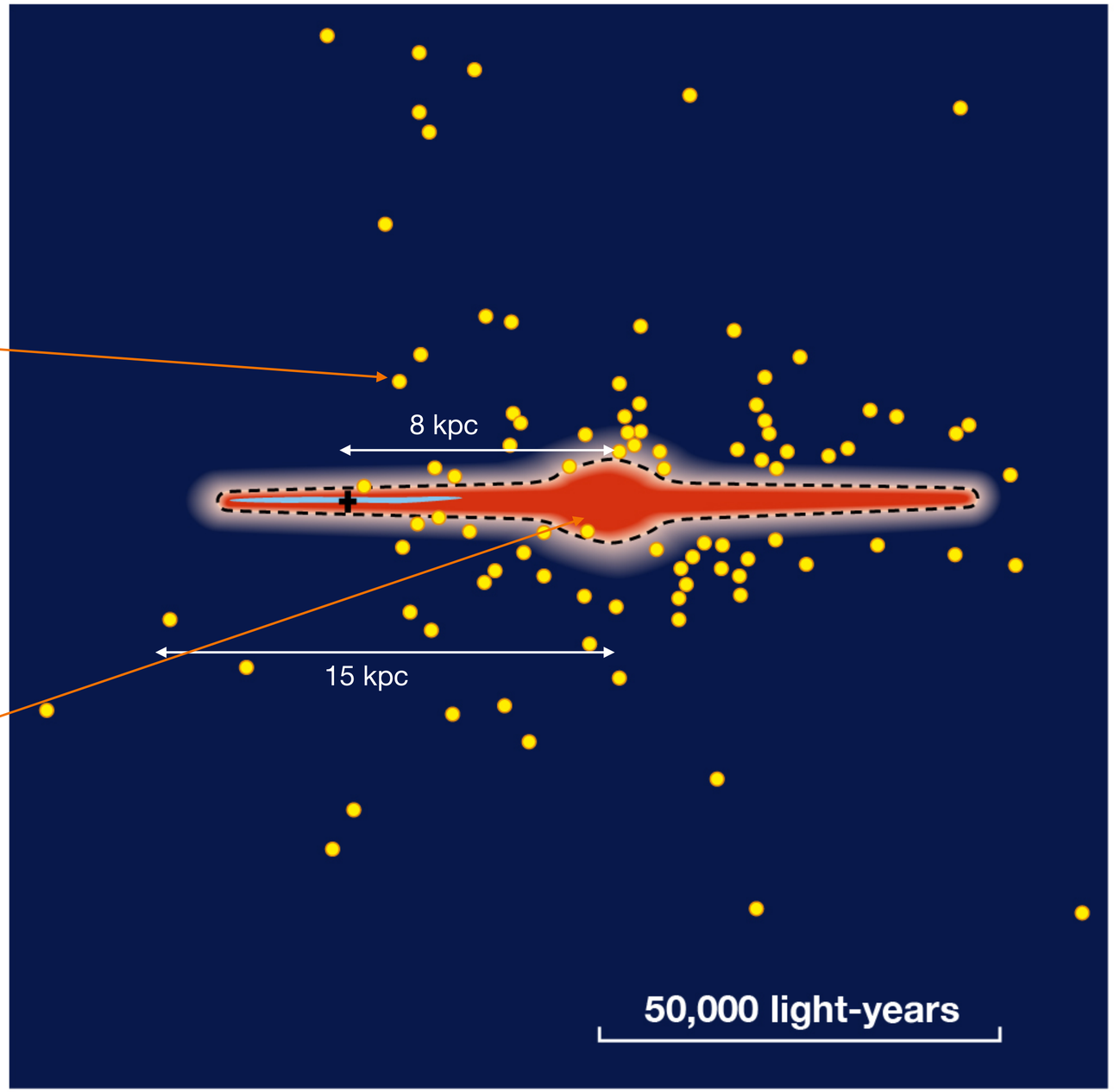




Our understanding of the Universe
By Harlow Shapley (~1920)

Globular clusters
~10^5 stars

Milky Way with its dust lanes

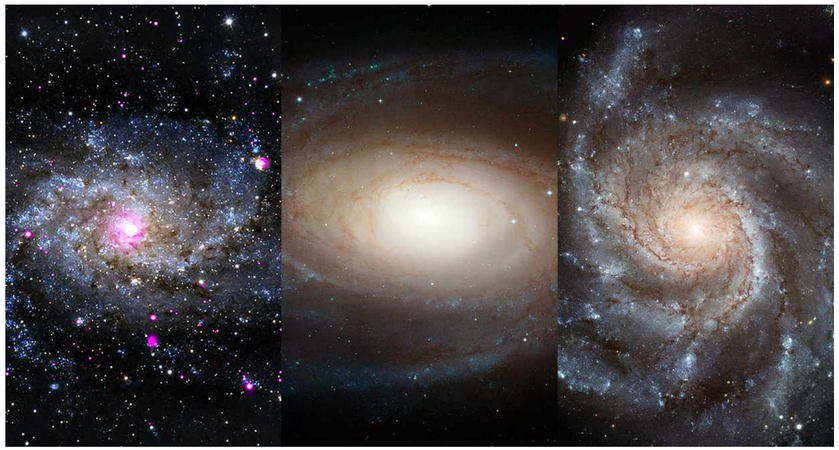


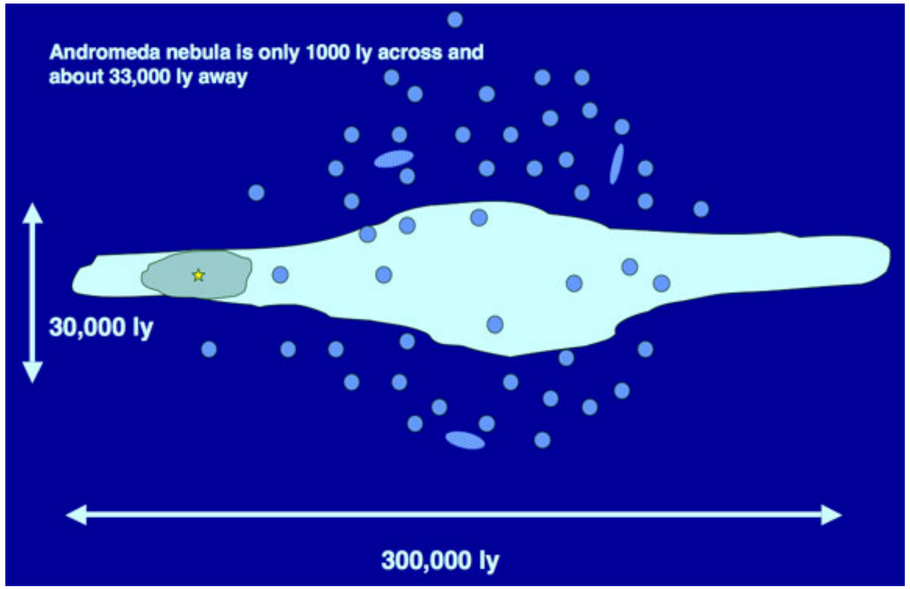
The galaxy has about a billion stars.

The Great Debate (1920)

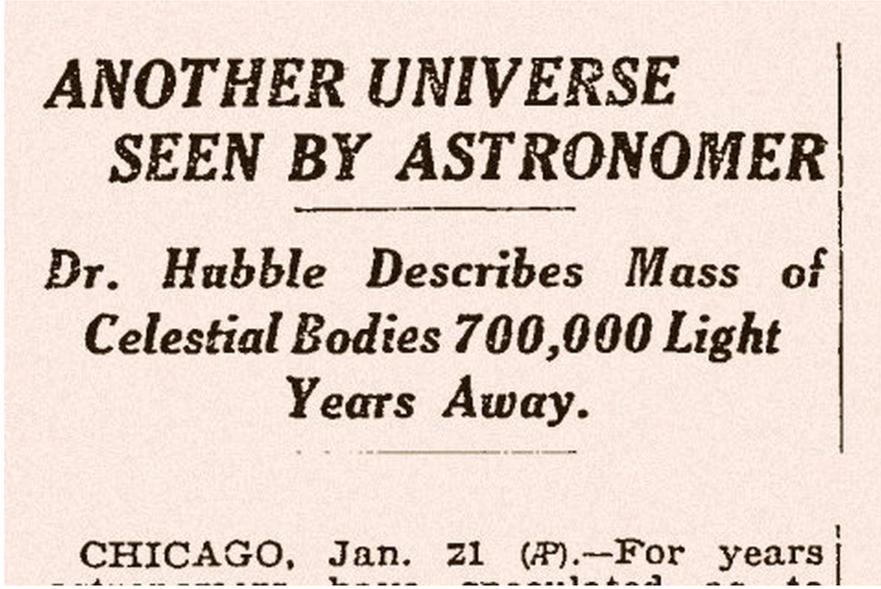
How big is our galaxy/Universe?
By Harlow Shapley and Heber Curtis

Are these nebulae within or outside our galaxy?





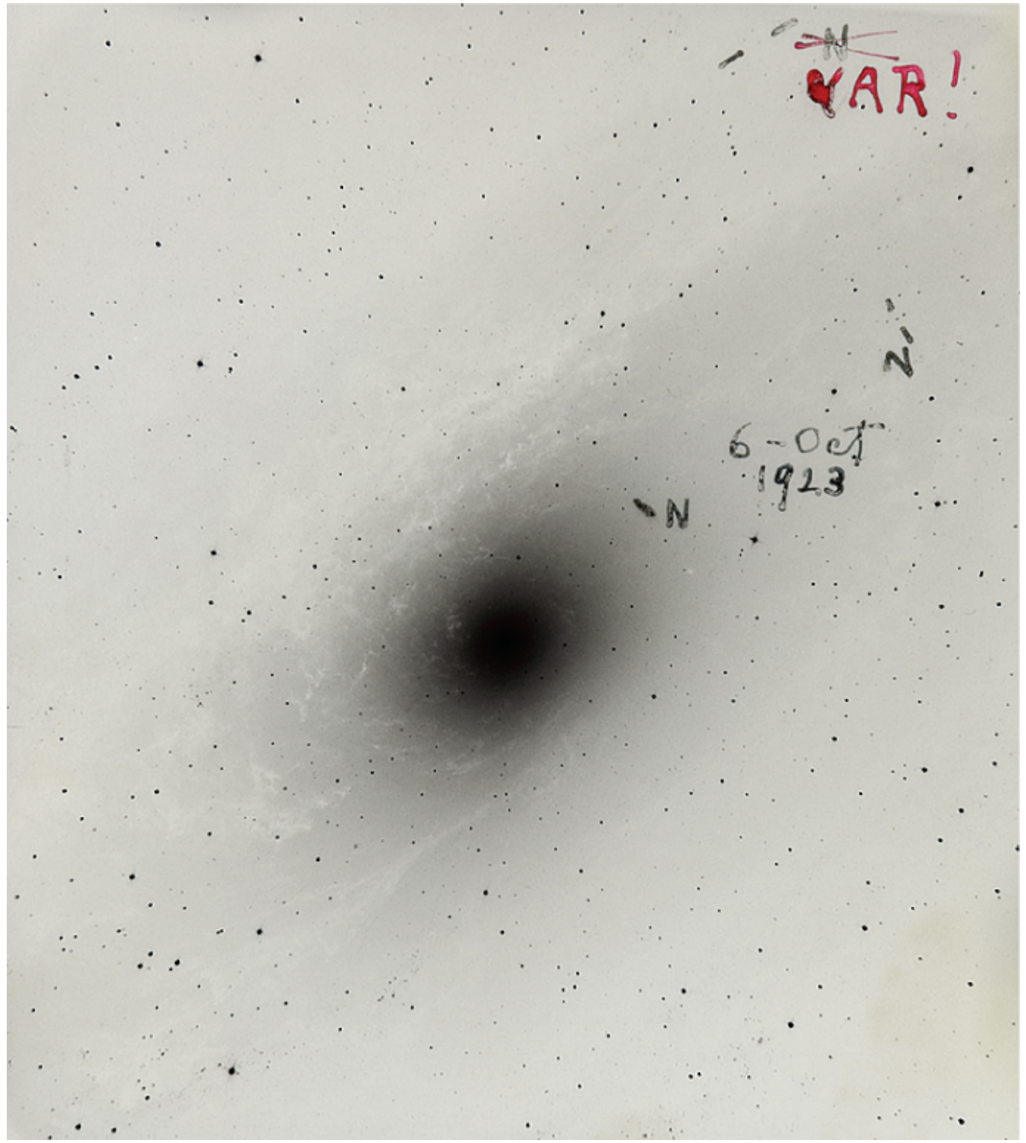
In 1925, Edwin Hubble discovers that the Andromeda nebula is a galaxy and is nearly 800 kpc away.



ANOTHER UNIVERSE SEEN BY ASTRONOMER

Dr. Hubble Describes Mass of Celestial Bodies 700,000 Light Years Away.

CHICAGO, Jan. 21 (AP).—For years



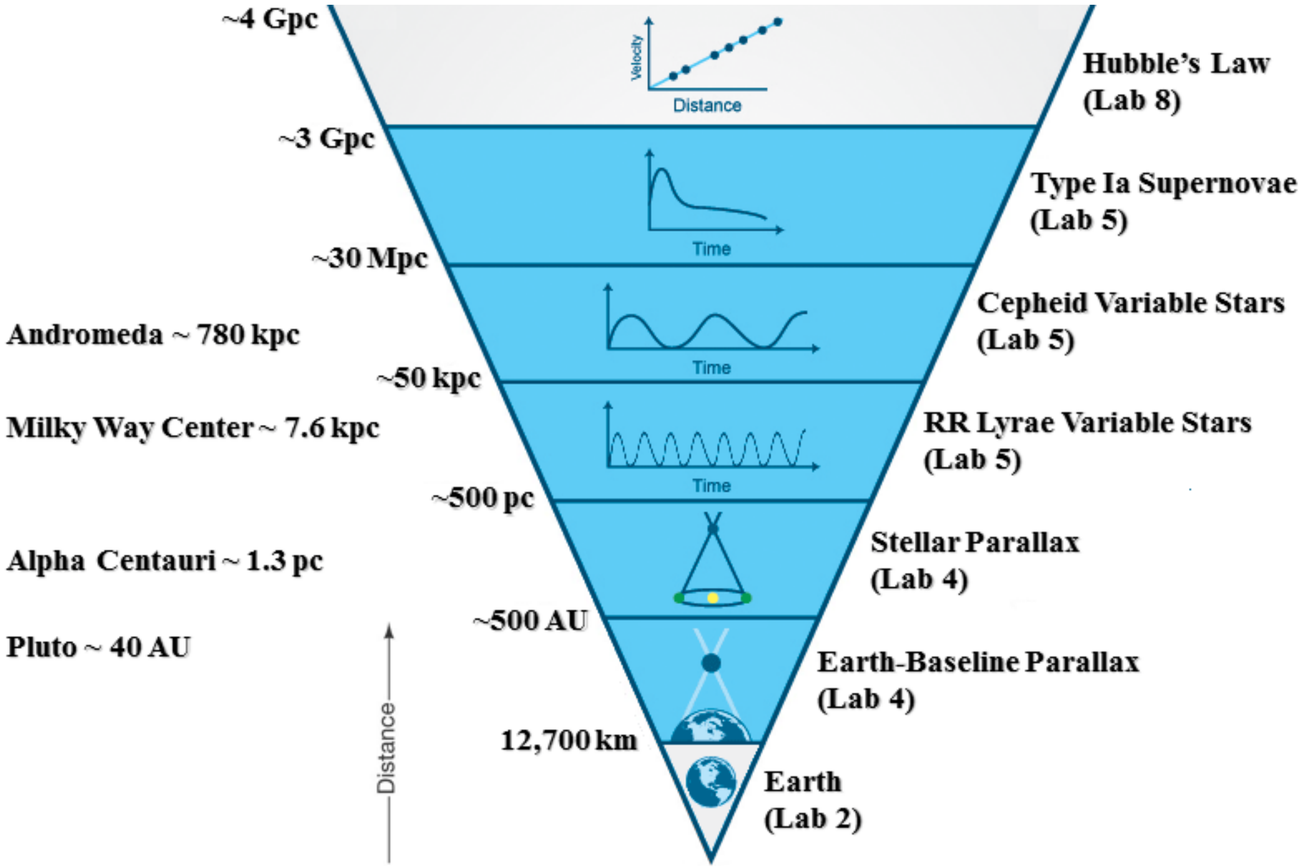

Andromeda's Distance From Us (to Scale)
100,000
light years
2.5 million
light years
140,000
light years
Milky Way
Andromeda

~800 kpc

Cosmic Distance Ladder

Measuring distances are hard in astronomy

- Different techniques are used for different distances.
- One stitches these techniques together.
- Allows us to measure distances from 10 AU to about ~1000 Mpc.

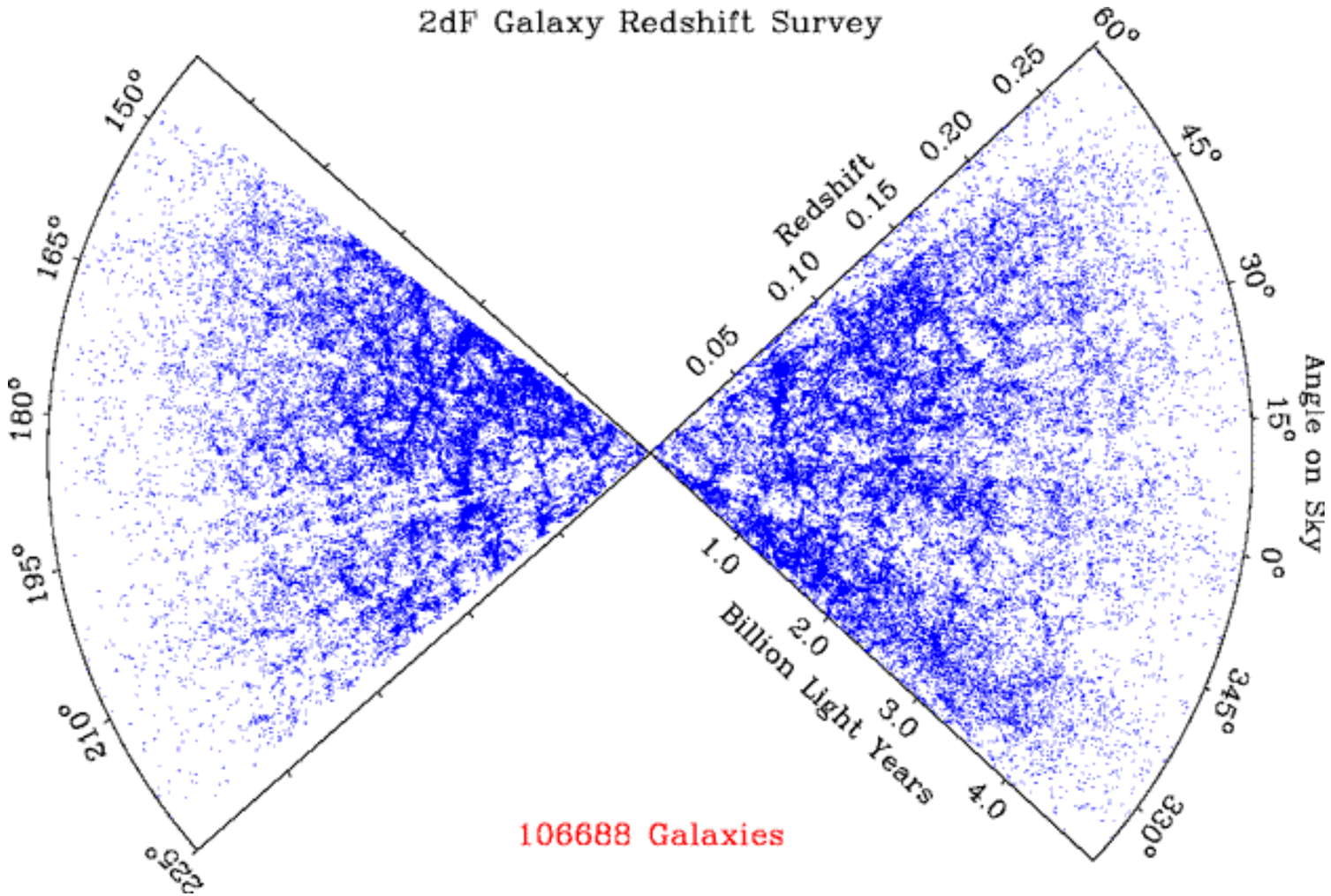


Hubble Ultra Deep Field

The large scale structure of the Universe

Searching for galaxies further out …

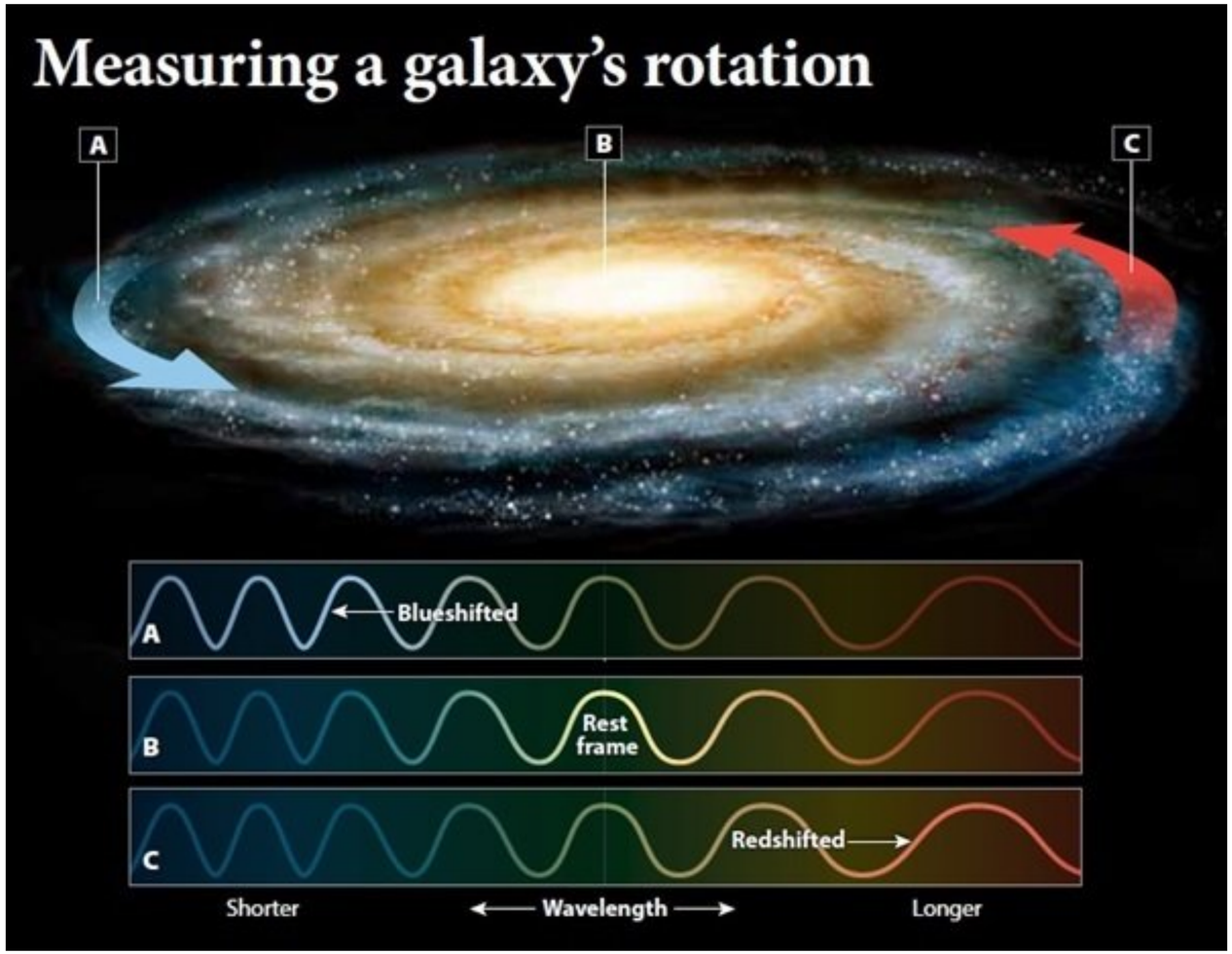
- Typical distance between galaxies like the Milky Way is 1000 kpc or 1 Mpc.
- Galaxies clump into groups.
- 307 Mpc ~ 1 Billion Lyrs.



III. The beginning of the Universe

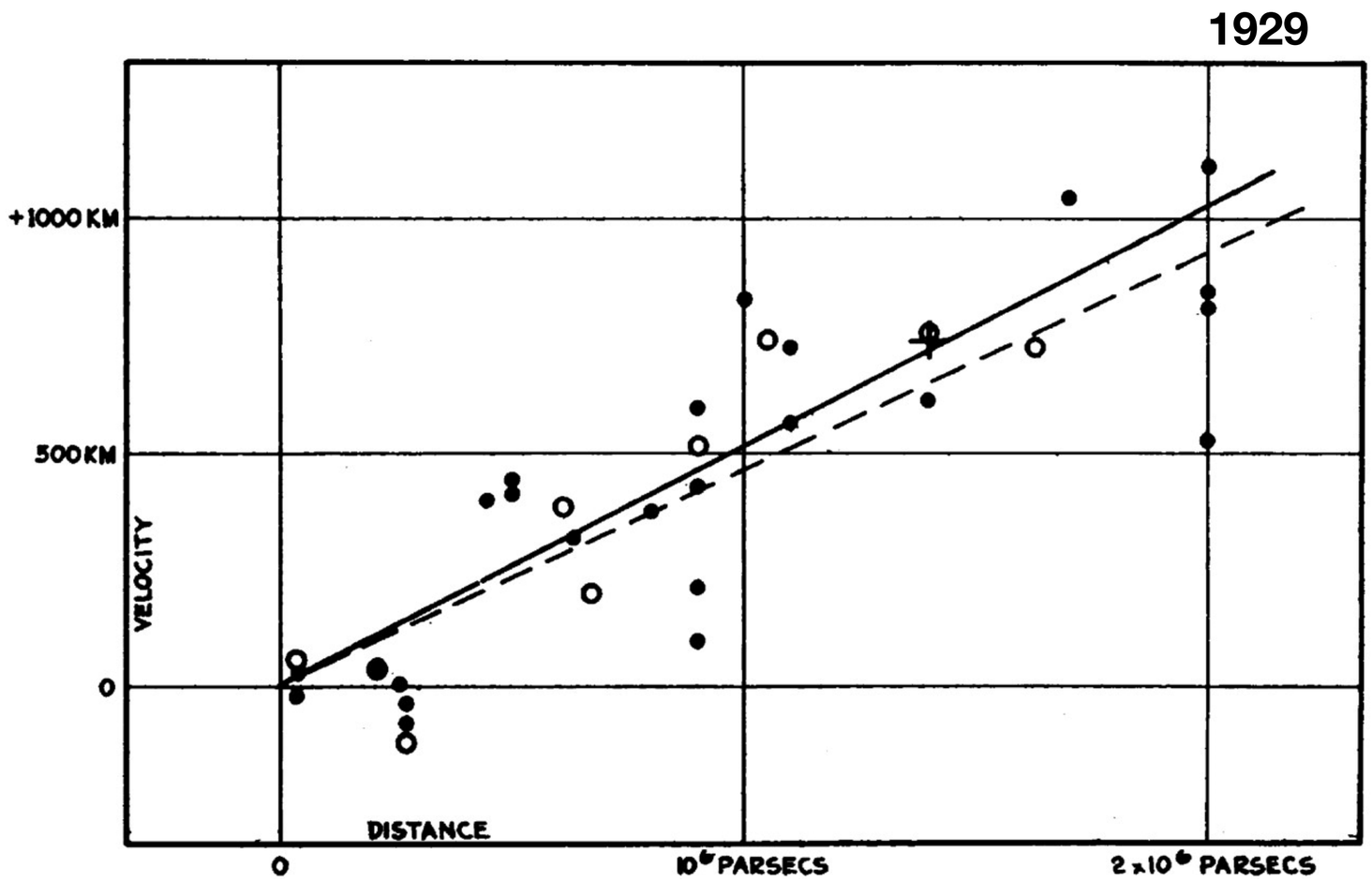
Measuring a galaxy's velocity

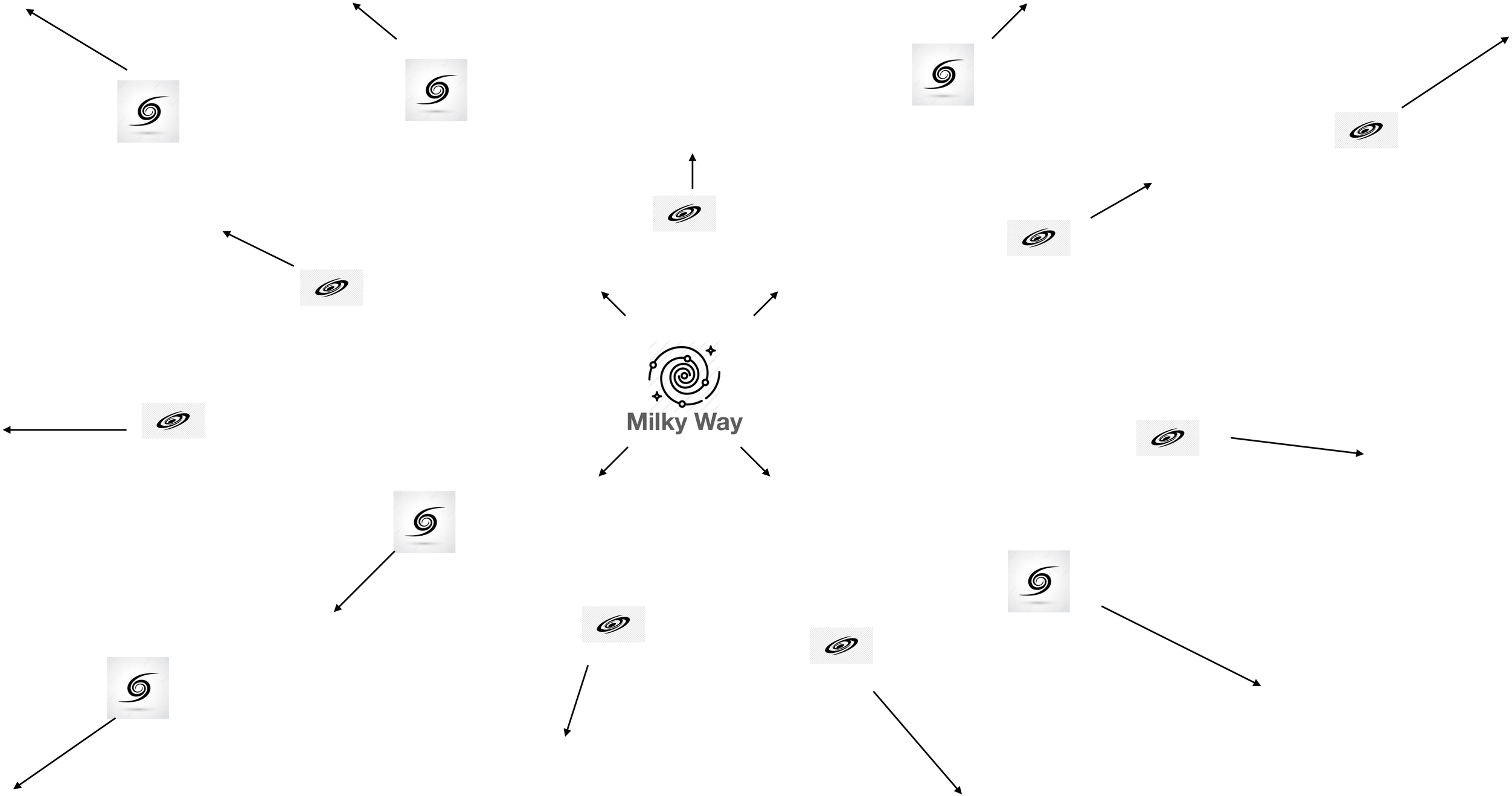
- Motion causes a change in the wavelength of light.
- Moving towards us - blueshifted.
- Moving away from us - redshifted.
- The shift in wavelength (or colour) depends upon velocity.

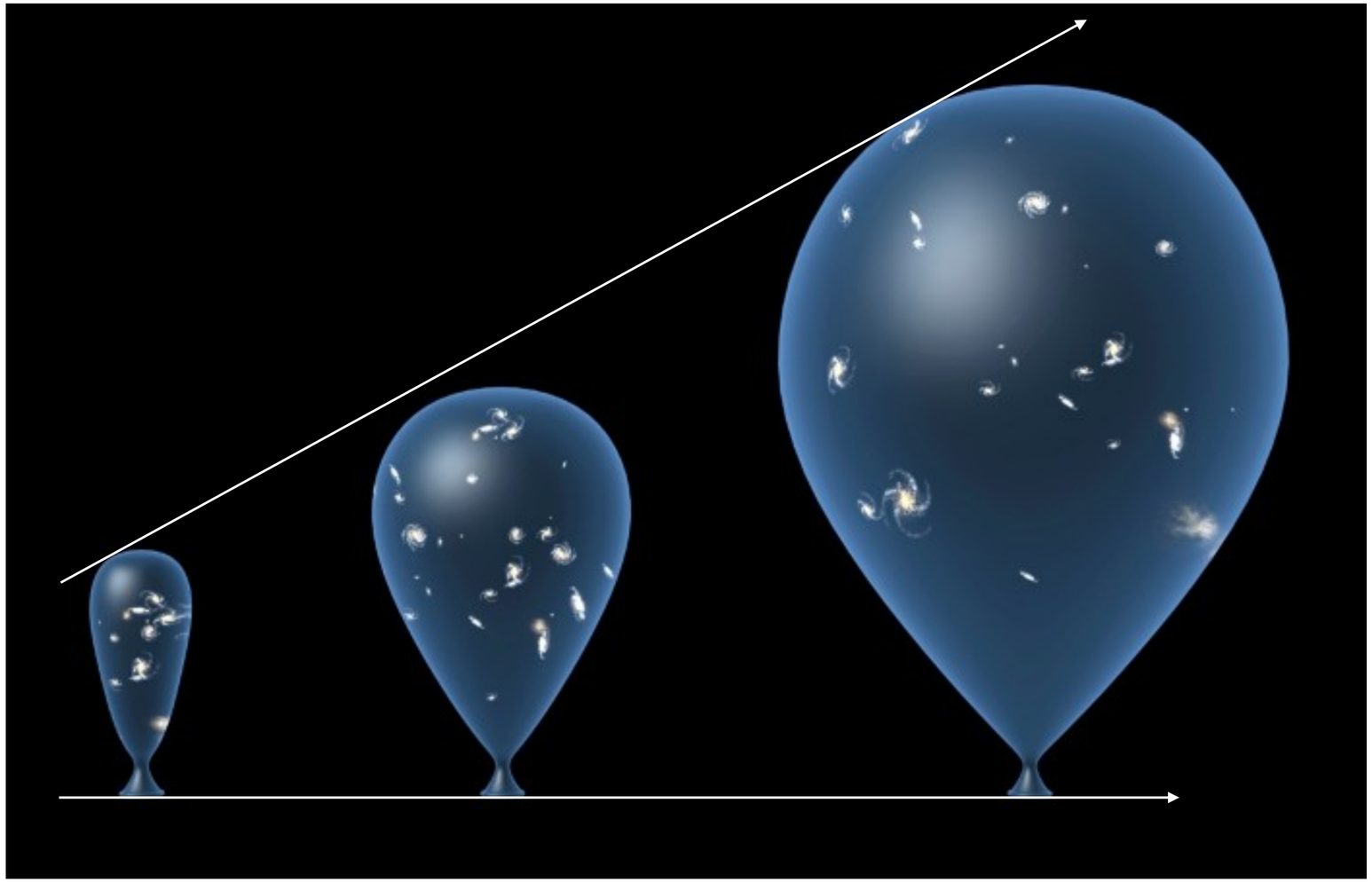


Hubble's Velocity Distance Relationship

- Hubble discovered that galaxies at larger distances are moving faster away from us in 1929
- Velocity= Constant x distance
- Fr. George Lemaitre proposed this idea earlier in 1927.



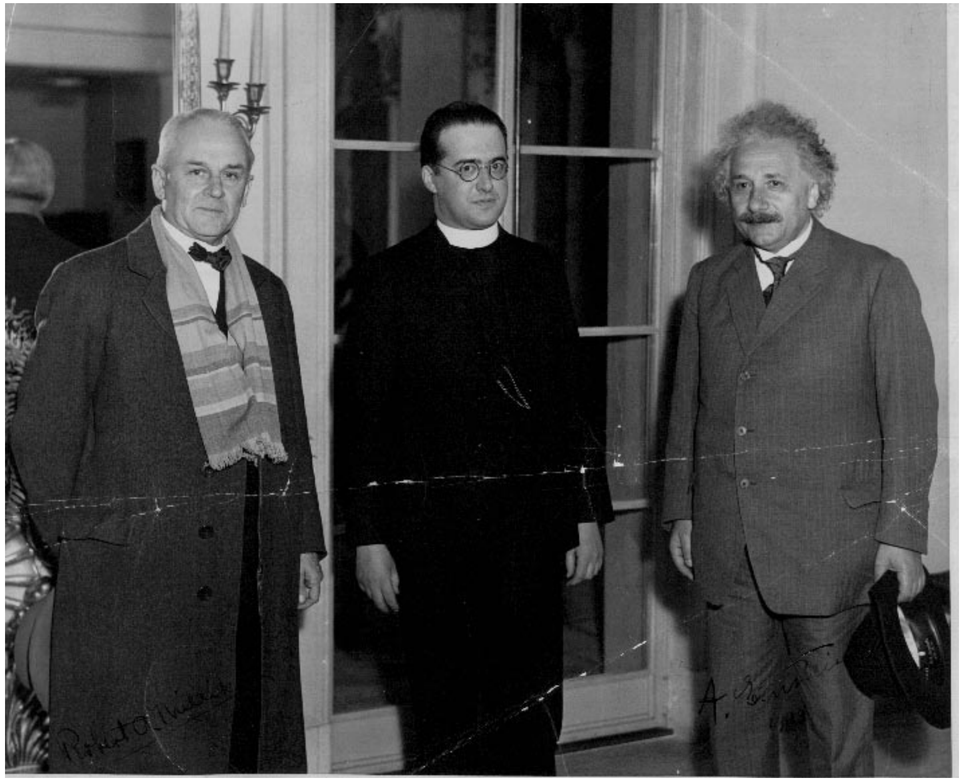

Milky Way

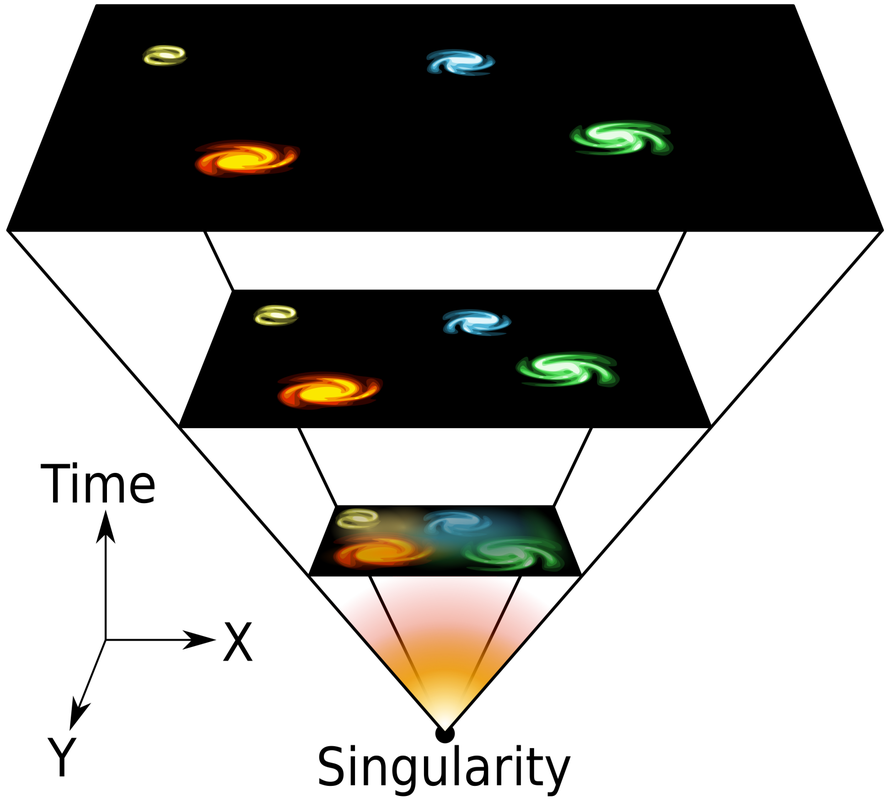


Time

The Big Bang

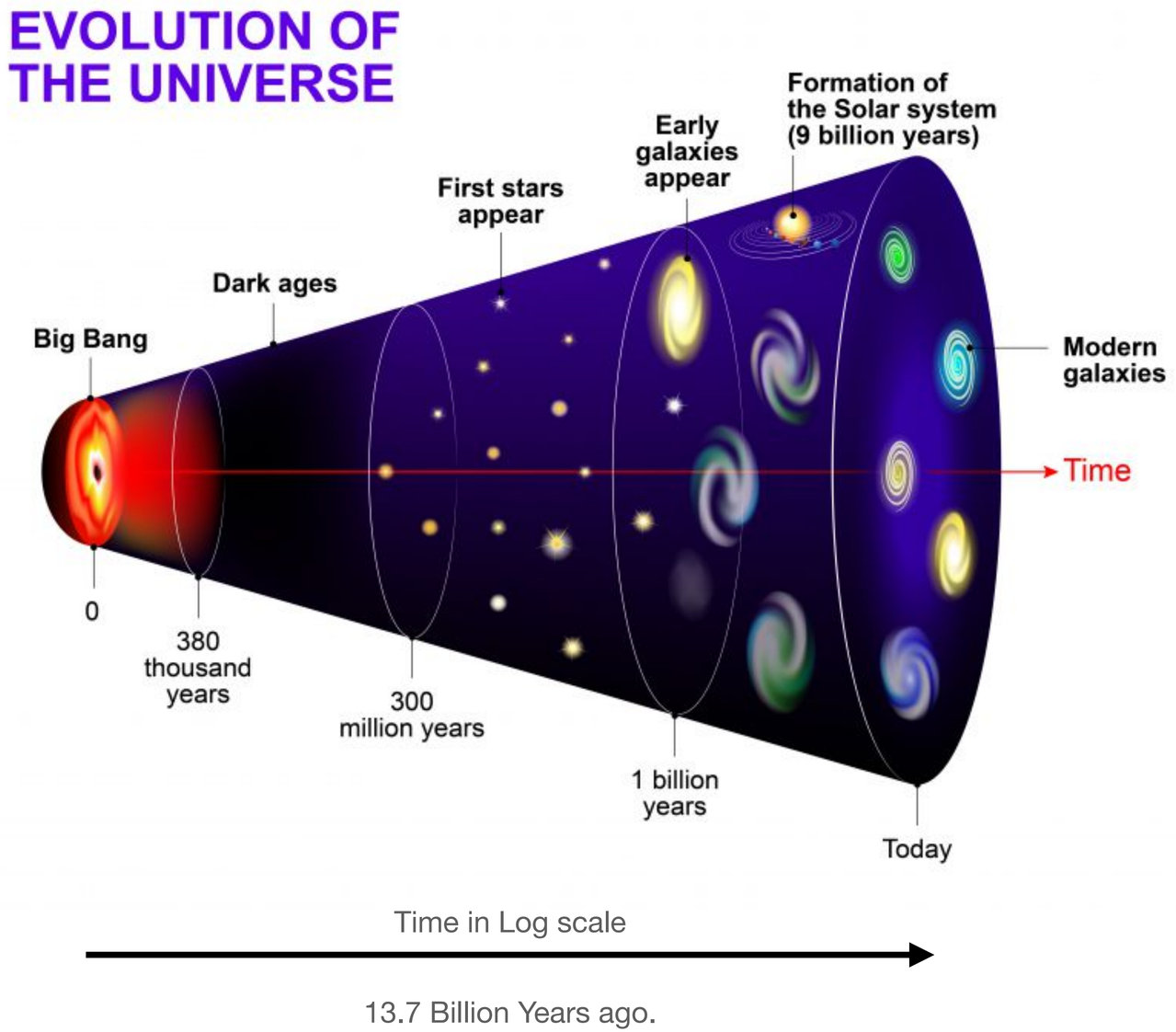
The Primordial Atom by
Fr. George Lemaitre (1927)





The beginning of the Universe

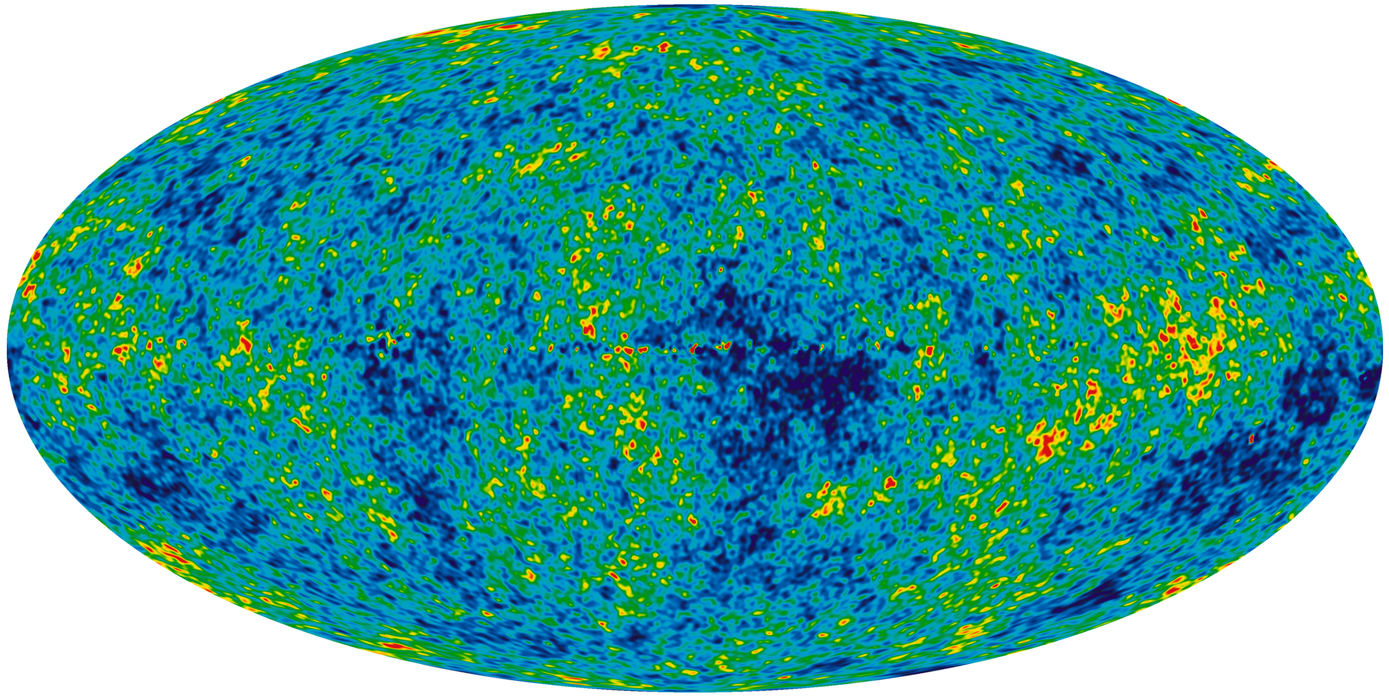
- From the expansion, extrapolate back in time to get the age of the Universe to ~ 13.7 Billion years old.
- Our understanding of the age of stars is consistent with this estimate.
- Using radio waves, we can also direct observe the **cosmic microwave background radiation**, which is a relic of processes a few seconds before the “Big Bang”.



Cosmic Microwave Background

The echo of the Big Bang

- Uniform radiation at 2.72 K
- Discovered by Penzias and Wilson in 1965.
- Originated 380,000 years after the Big Bang, when high radiation was last scattered by the plasma.
- Cooled by an average factor of 1090 times due to the expansion of the Universe.



Conclusions

Part I

- Before the turn of the century (~ 1900), our understanding of the Universe was very small. We knew about the solar system, and the distance to about ~65 stars.

- With the help of Cepheids and the distance ladder, we realised that our Universe is much, much larger. We know the structure of the galaxy, and that other galaxies are much further away. The Universe is really huge!

- Galaxies are receding away from us. The Universe is expanding. This implies that some point in the past, the Universe was much smaller. Extrapolating further, the Universe begins with a point named the “Big Bang”. The age of the Universe is ~13.7 Billion Years.