The Continuing Copernican Revolution...

from Heliocentricity to the Cosmological Principle

Astro 203
Vanderbilt University
2006/10/19

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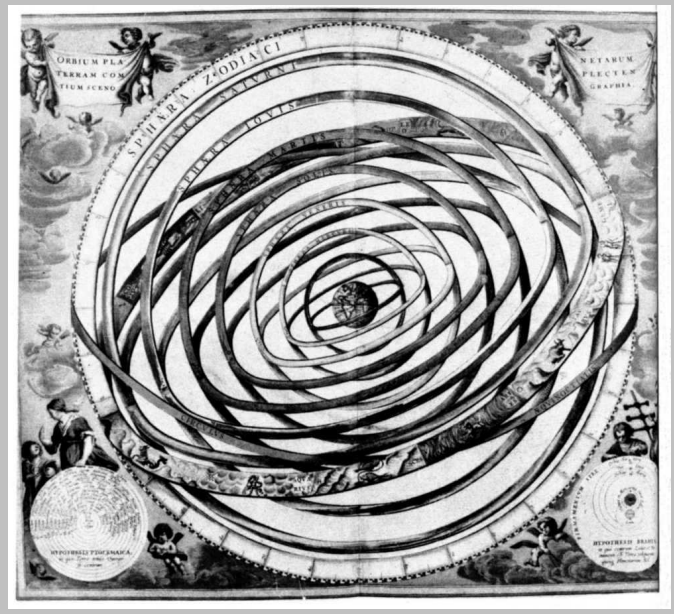
Slides online at:

http://brahms.phy.vanderbilt.edu/~rknop/classes/talkslides#awayfmctr

The Ptolemaic Universe



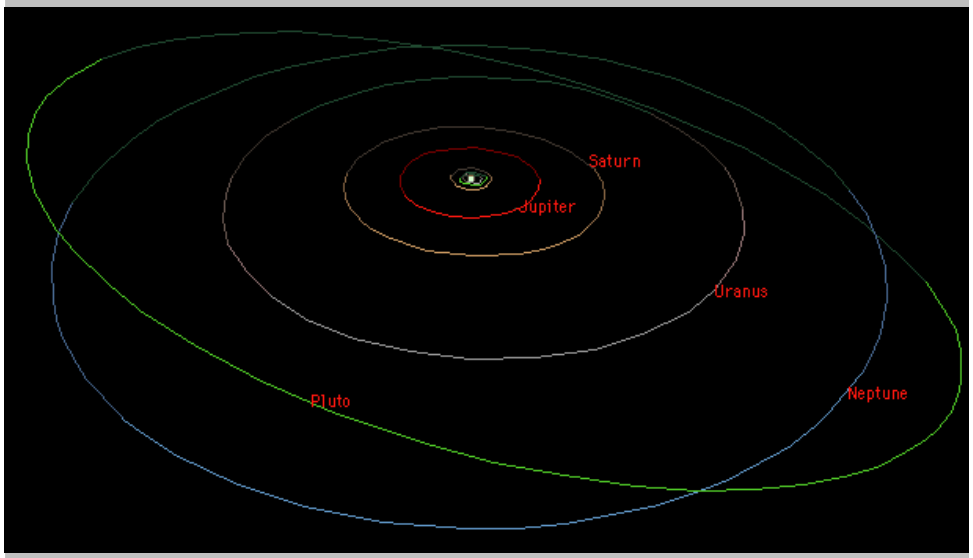
Copernicus' Postulates

- There is not a single center for all the celestial orbs or spheres
- The center of the Earth is not the center of the world, but only of the heavy bodies and of the lunar orb
- All the orbs encompass the Sun which is, so to speak, in the middle of them all, for the center of the world is near the sun.
- The distance from the Sun to the Earth is insensible in relation to the height of the firmament.
- Every motion that seems to belong to the firmament does not arise from it, but from the Earth ... the firmament, or last heaven, remains motionless.

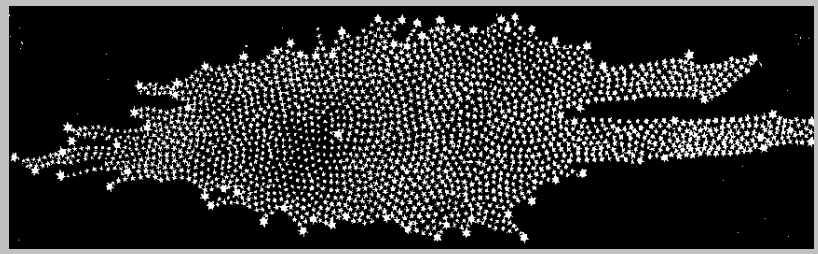
Copernicus' Postulates (continued)

- The motions that seem to us proper to the Sun do not arise from it, but from the Earth and our orb, with which we revolve around the Sun like any other planet. In consequence, the Earth is carried along with several motions.
- The retrograde and direct motions which appear in the case of the planets are not caused by them, but by the Earth. The motion of the Earth alone is sufficient to explain a wealth of apparent irregularities in the heavens.

Copernicus / Kepler (~1500-1600)



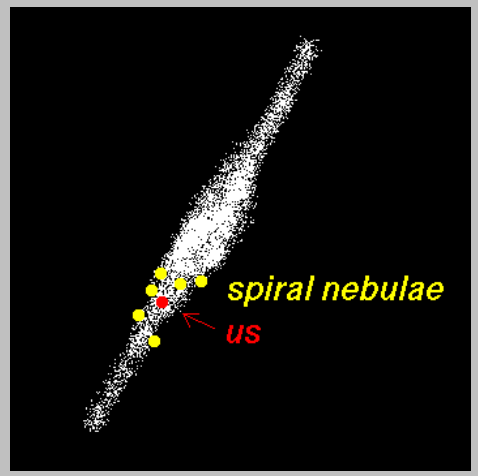
William Herschel's Galaxy (1785)



"Star Gaging"

We seem to be ... *close* ... to the center of the Galaxy...

Harlow Shapley (1919)



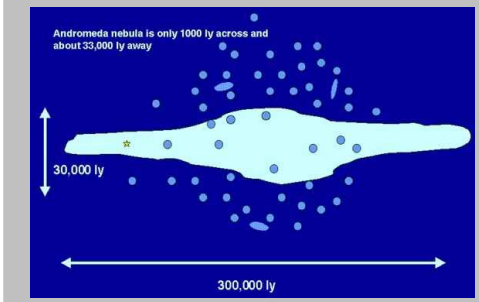
Globular clusters are :

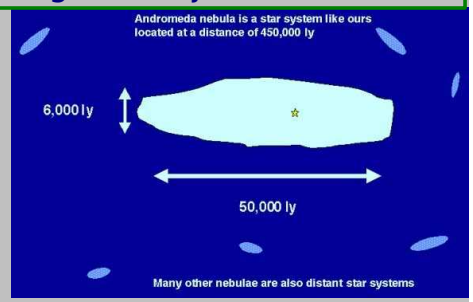
(a) evenly distributed on either side of the Milky Way in the sky

(b) much more common in the direction of Sagittarius than in the opposite direction

The "Great Debate" of 1920

Shapley	Curtis
• We are well away from the center of the disk-shaped Galaxy	• ~~We are at (or close to) the center of a lens-shaped Galaxy~~
• ~~"Spiral Nebulae" are gas clouds in our Galaxy.~~	• "Spiral Nebulae" are "island universes," other galaxies just like ours.





Images: Barbara J. Becker, UCI

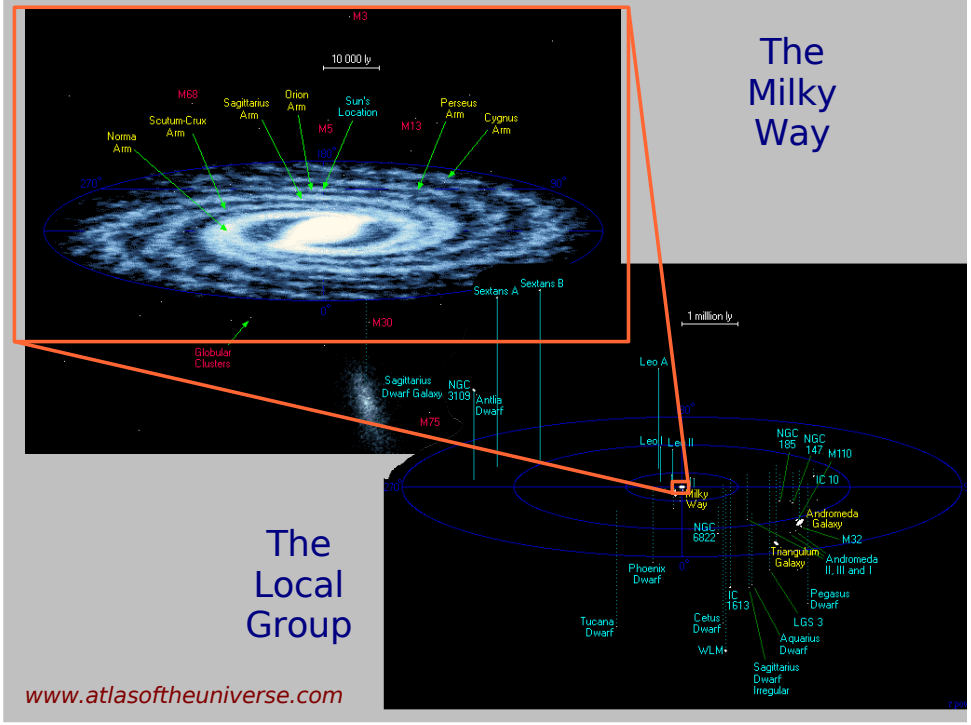
Edwin Hubble, 1924

Measures the distance to the Andromeda Galaxy, M31.

...it's clearly outside our own galaxy.

(Modern value : ~3,000,000 lyr)

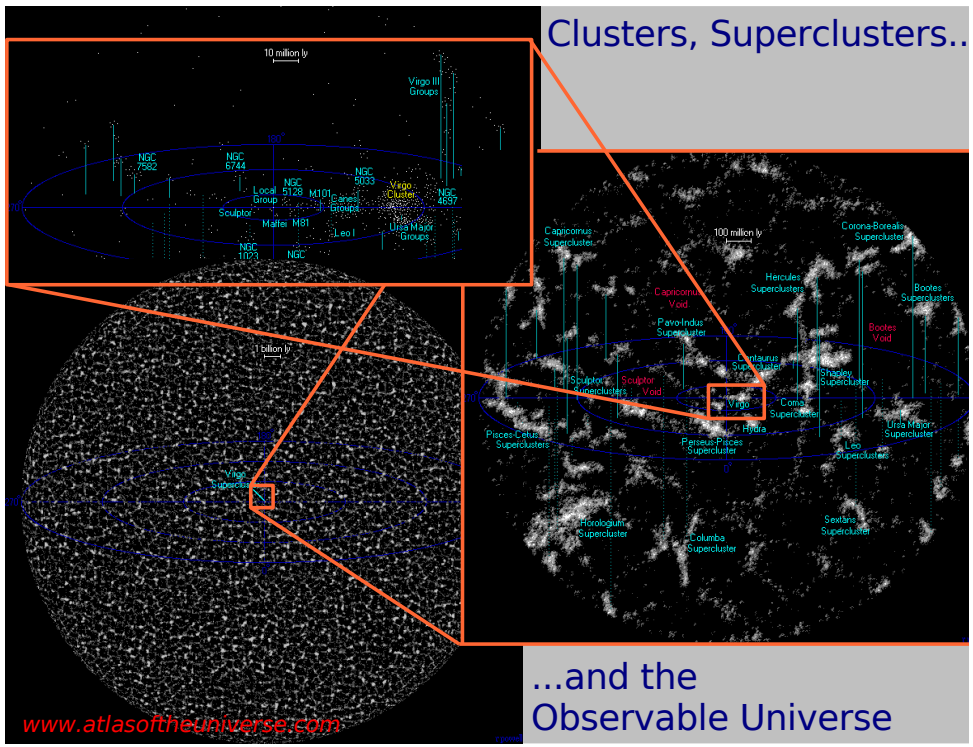
The Milky Way



The Local Group

www.atlasoftheuniverse.com

Clusters, Superclusters..



www.atlasoftheuniverse.com

...and the Observable Universe

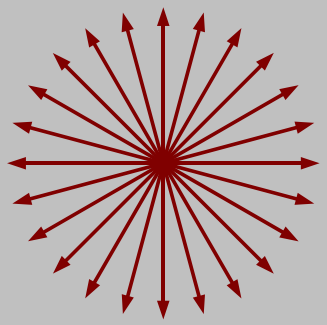
The Cosmological Principle

"We are nowhere special"

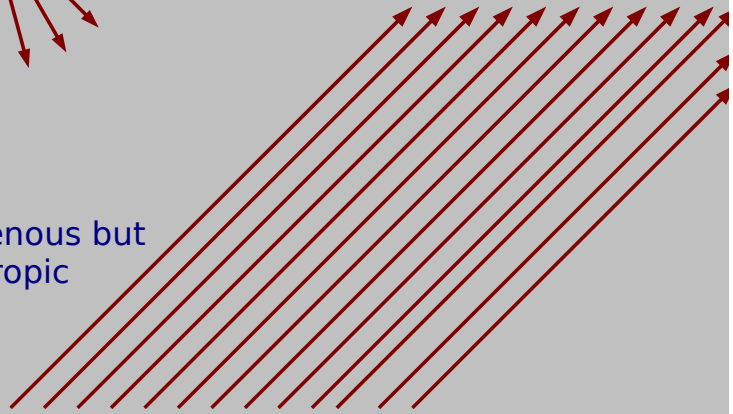
More precisely: On the largest scales, the Universe is *homogenous* and *isotropic*.

Homogenous : the same everywhere

Isotropic : the same in all directions

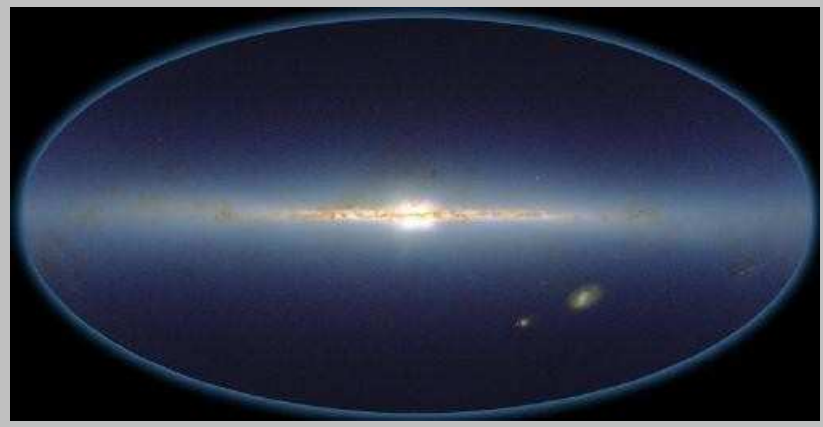


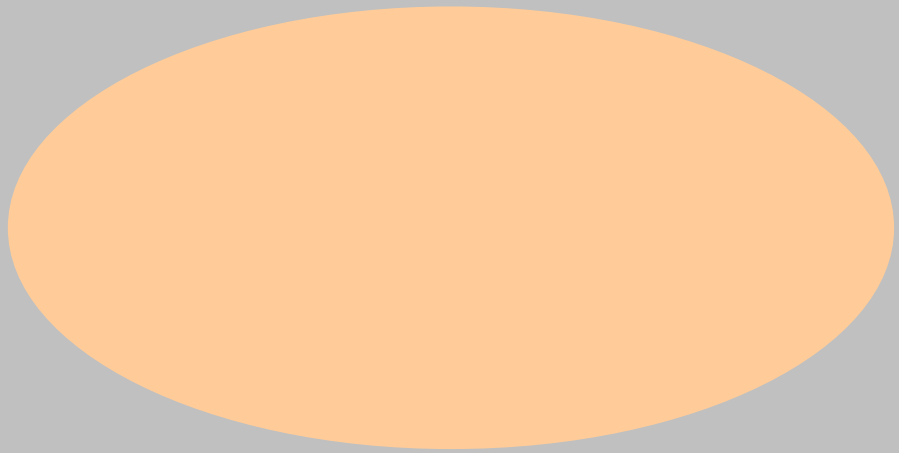
Isotropic (about the center point) but not homogenous



Homogenous but not isotropic

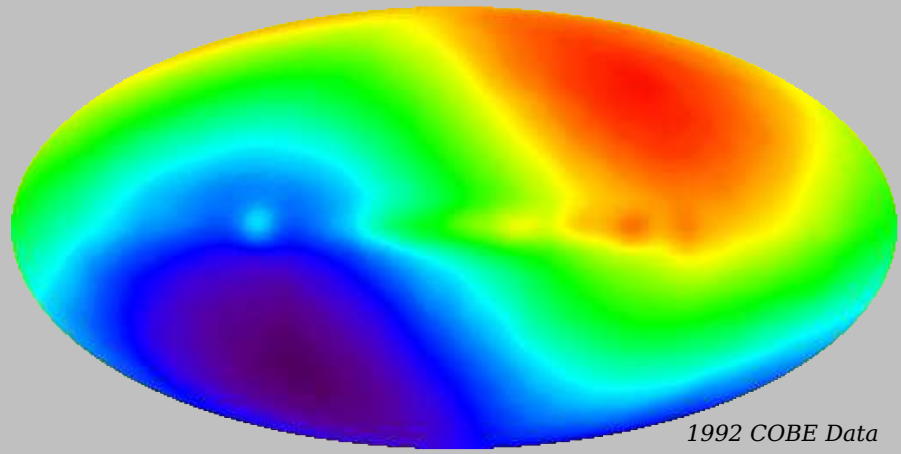
All-Sky Map (near-infrared from 2MASS) showing the Milky Way





All-Sky Map: the Cosmic Microwave Background

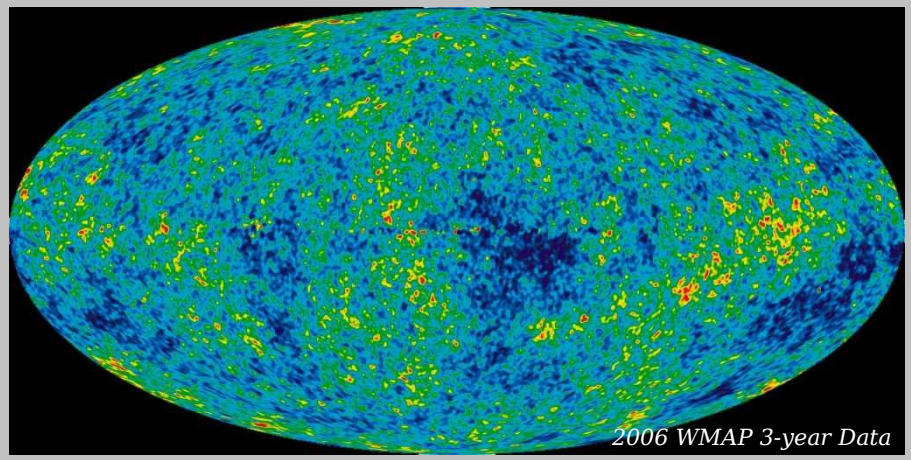
Temperature : 2.7 K



CMB Fluctuations 1 : Dipole

Amplitude : 0.003 K

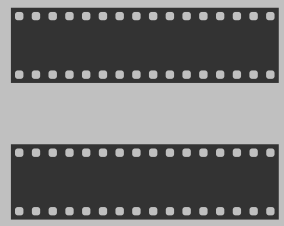
(A Doppler shift due to our Galaxy's 370 km/s motion)

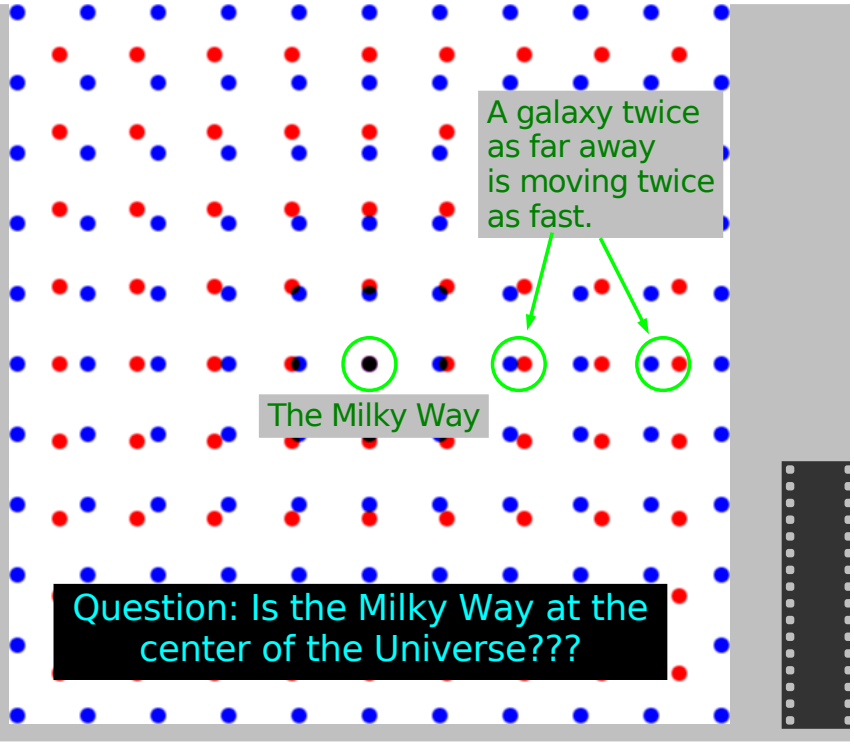


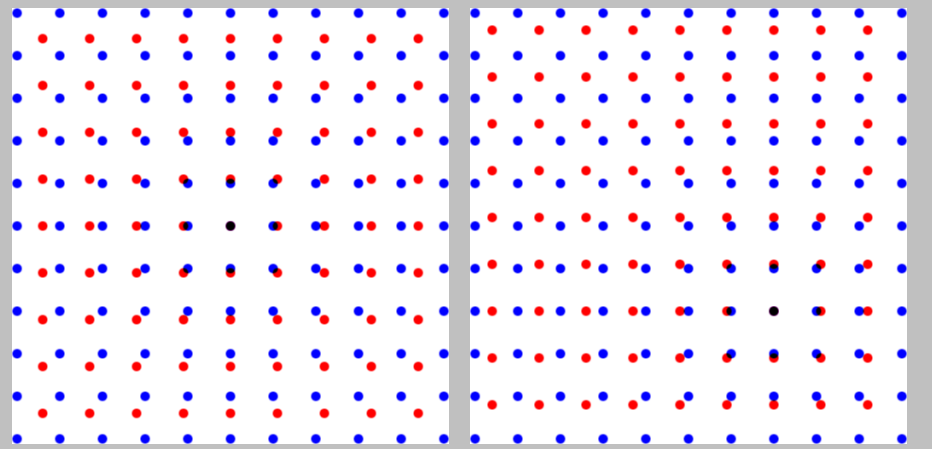
CMB Fluctuations 2 : The Source of Structure

Amplitude : 0.00007 K

Visualizing the Expanding Universe







Observations from within a Uniform Expansion:

1) Rate of recession increases with distance
2) Every point is equivalently the center

Where was the Big Bang?

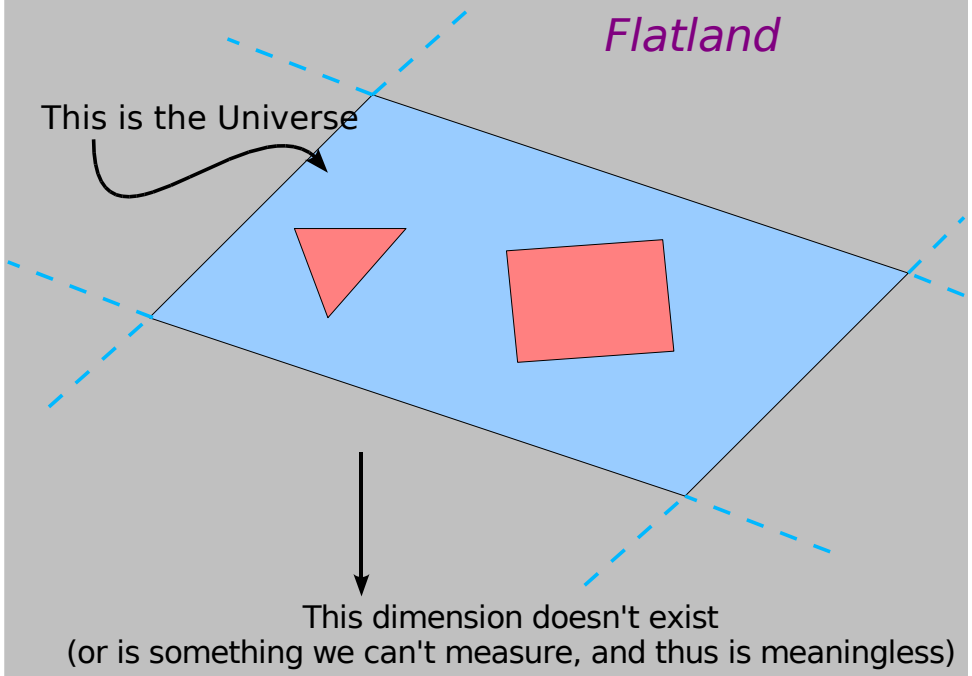
A distant point from which all galaxies are moving away?

Right here?

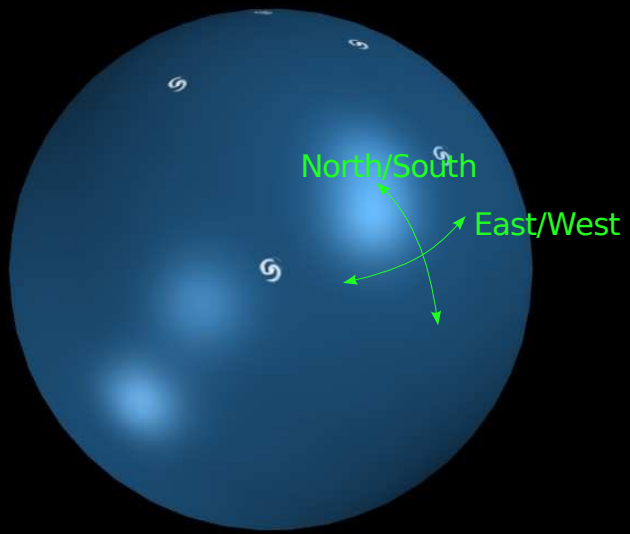
"Yes and No" to both.

The Big Bang was *EVERYWHERE*.

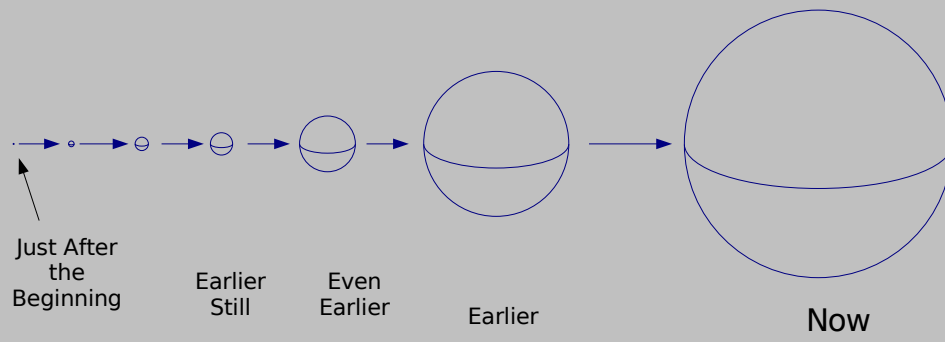
Flatland



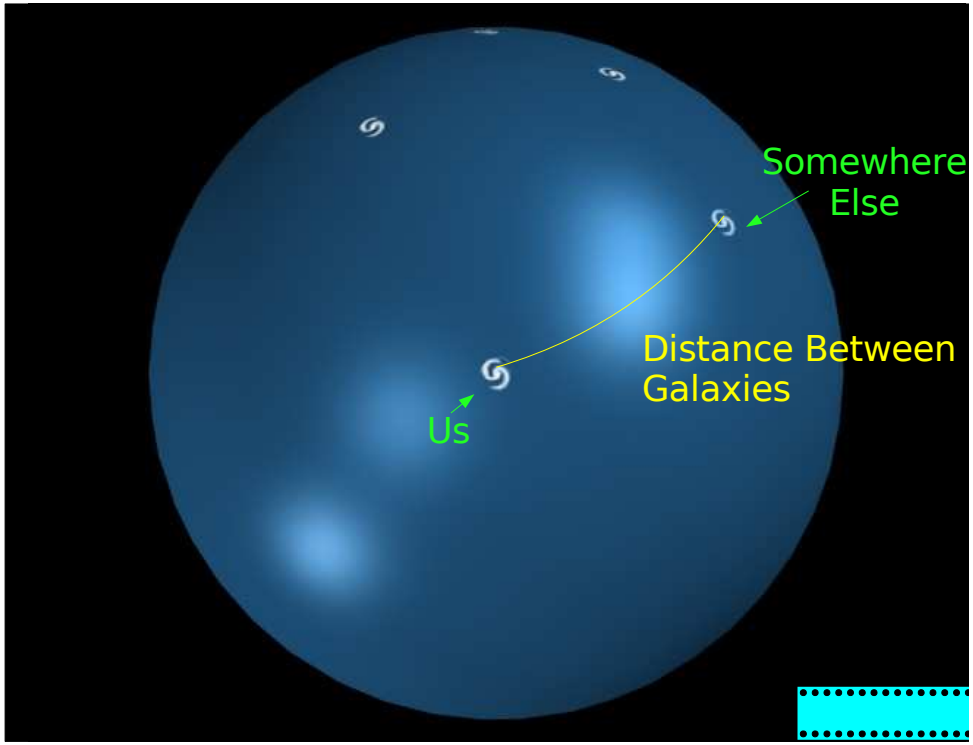
A model 2-d closed Universe:
the ***surface*** of a sphere

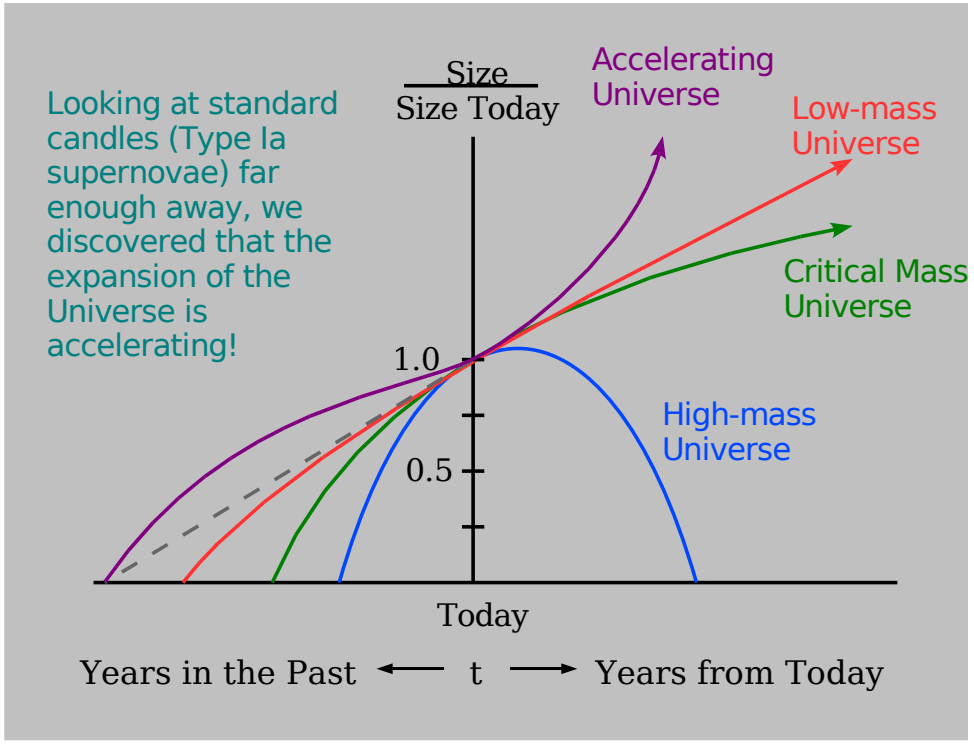


Taking the expansion back in time
towards the beginning....



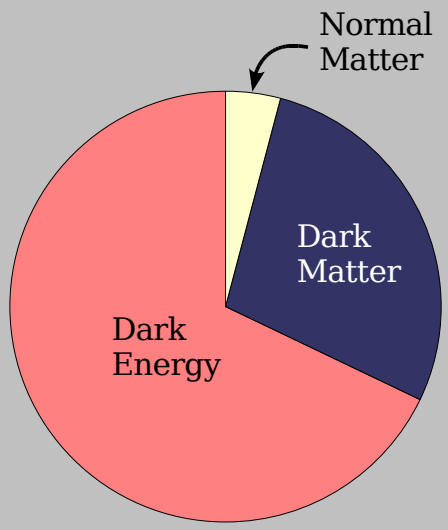
Where, on the *surface* of this
sphere, is the center?





A Consistent Picture of the Universe

- 13.7 Billion Years Old
- Flat (Euclidean) Spatial Geometry
- Critical Mass+Energy Density
- Expansion Accelerating

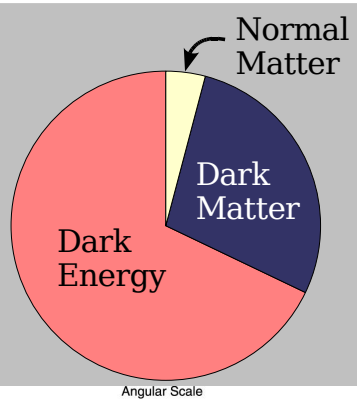


Primary evidence

- CMB fluctuations
- Cluster frequency & dynamics
- Expansion history from Supernovae

Where are we now?

- A consistent picture verified by multiple different observations
- A good mathematical model that precisely matches data

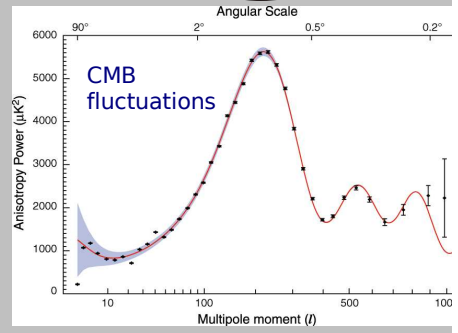


Do we have a physics to explain it?

- General Relativity gives the overall expansion
- Gravity & plasma physics give the fluctuations & structure growth

...but...

- What's Dark Energy?????
- "Inflation" – where do the primordial fluctuations come from???



Spergel et al., 2006, astro-ph/0603449

How's the cosmological principle doing?

- ✓ Universe is homogenous & isotropic
- ✓ On large scales, we're nowhere special

...but...

"The Cosmological Fine-Tuning Problem"

Why are we so lucky as to see the matter and Dark Energy densities so similar????

- More dark energy in the early Universe – universe expands too fast, structure doesn't form;
- Much more matter, Universe collapses before galaxies form;
- Earlier, it was almost all matter. Later, it's almost all Dark Energy. Why are we here *now*, when they're balanced????