Astronomy 150: Killer Skies
Lecture 35, April 23

Assignments:

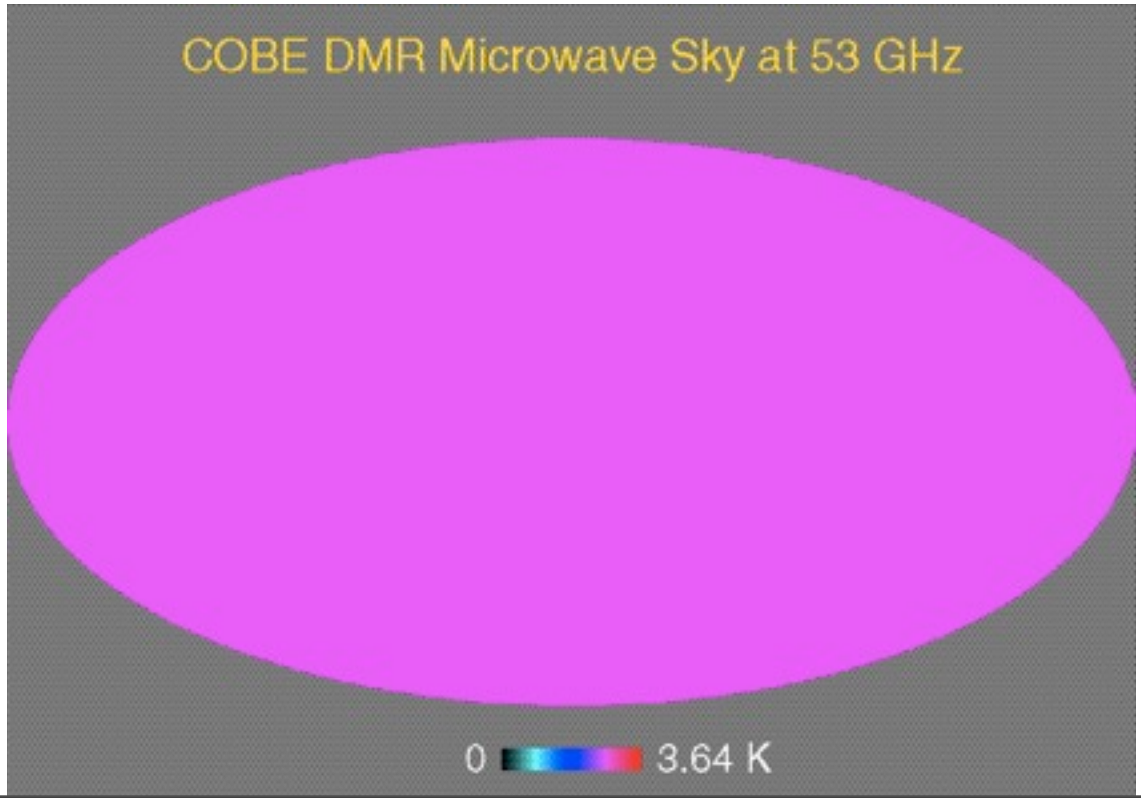
- ICES available online
- HW11 due next Friday: last homework!

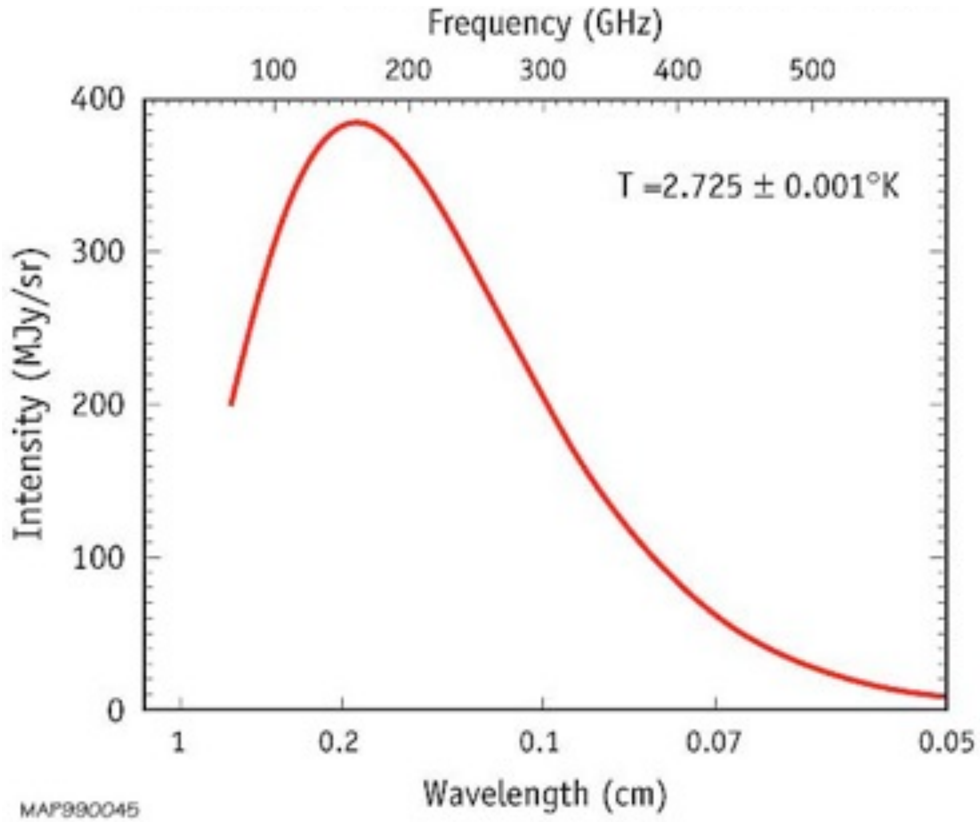
  note: lowest HW score dropped

  but: HW11 material will be on Exam 3, so be sure to look at it

Last time: When Galaxies Collide

Today: The Big Bang





ICES

ICES course evaluation is now available, done online.

Please do it!

- **Written comments are the most useful and important**
- **I do read the comments, and I do modify the course as a result.**
- **Note that this course is relatively new, so your comments will have a particularly large impact.**

Prelude

Here at the University of Illinois...

we promise the Universe:

it’s right there in the name!

This week: we deliver!

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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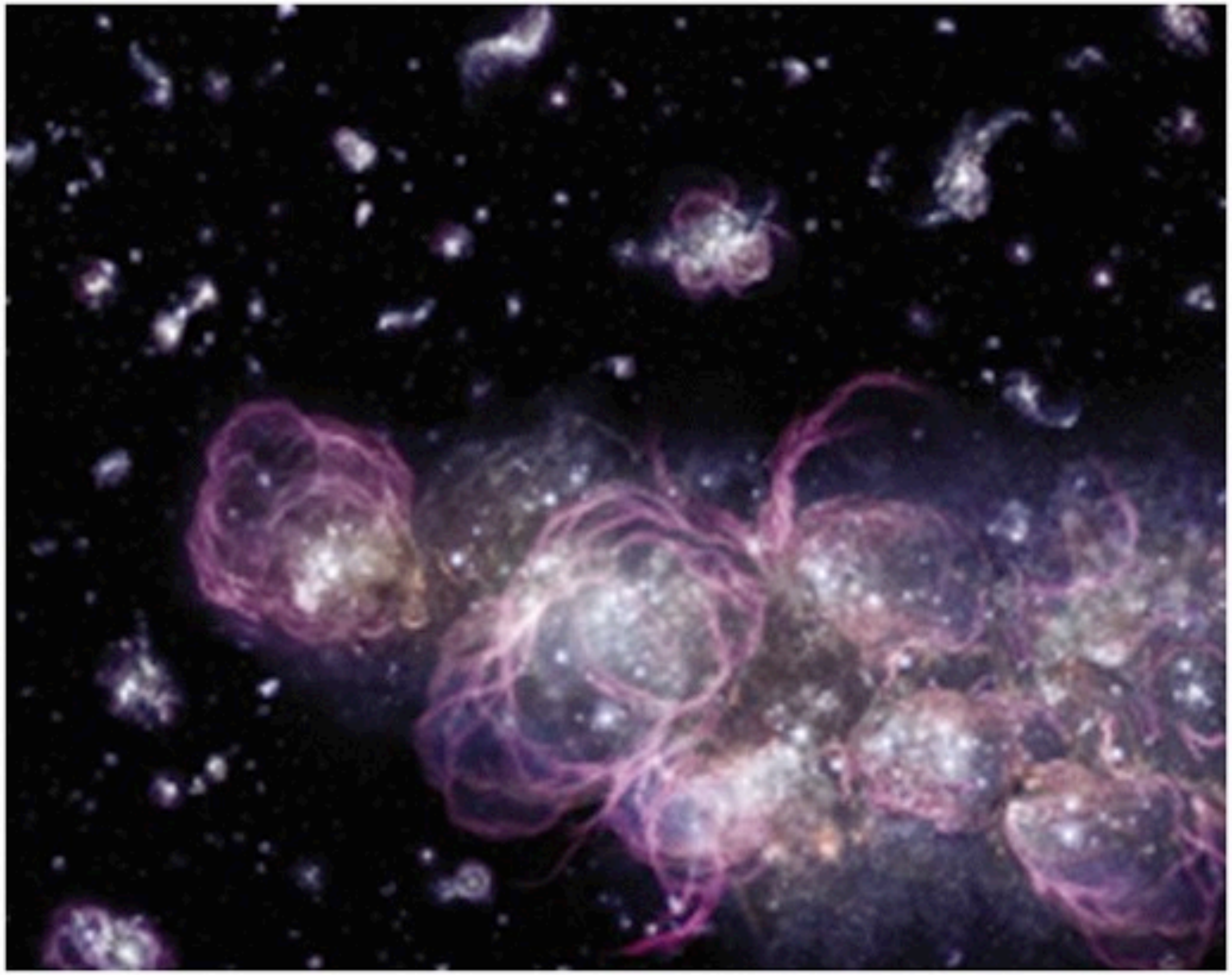
Cosmology

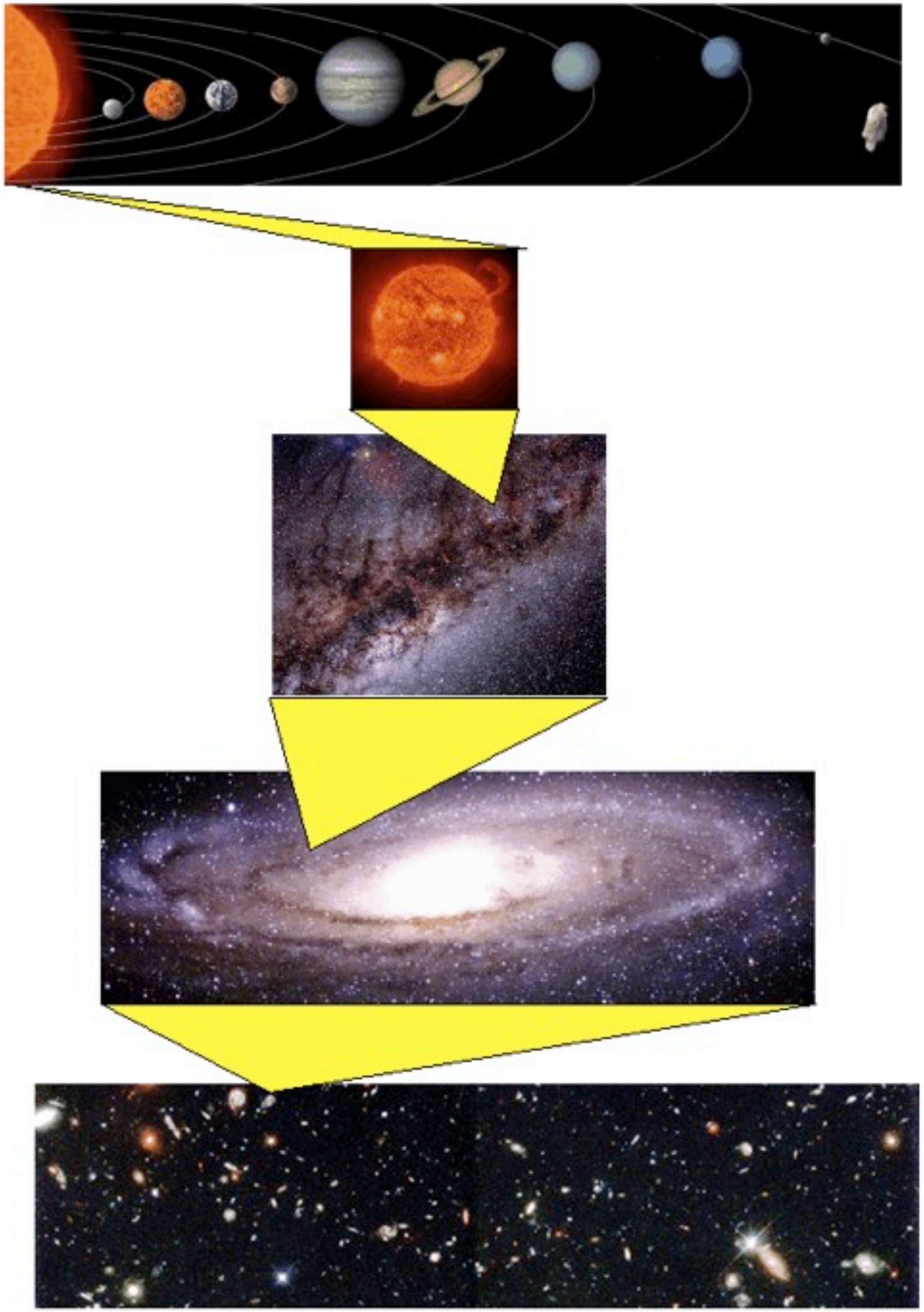
What is the Universe?

- All the matter, energy, space, and time we can ever detect

Cosmology is the study of the origin, structure, and evolution of the Universe



Astronomy: The Big Picture



Arguably, the biggest fish of all: Cosmology

- What is the Universe made of?
- How big is it?
- How old is it?
- How did it form?
- What will happen to it?

Slices of the Universe

Map construction:

- center of “pizza” = our location
- each dot: location of one galaxy

Focus on the innermost half of the region

Squint: focus on large-scale features

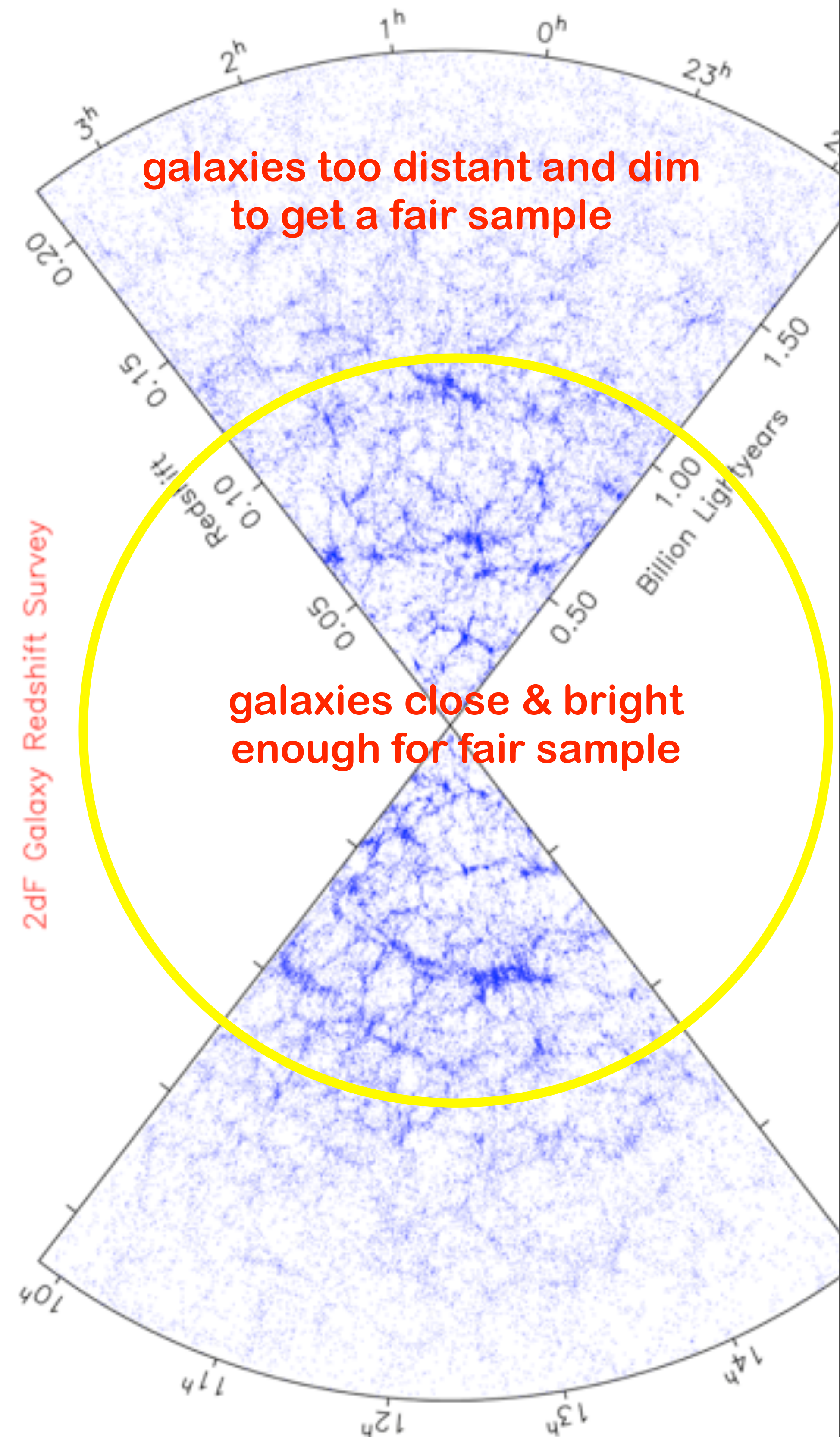
- galaxies smoothly and randomly fill space
- not all located in one place
- not all avoiding some other place

Look closely : focus on small-scale features

- on small scales, galaxies fill space unevenly
- some regions almost empty: “voids”
- some have a few galaxies near each other: “groups”
- some have huge numbers of galaxies in small region: “rich clusters”

What about most distant regions?

- galaxies so far away, can’t see a representative sample
- looks like running out of galaxies, but really just seeing brightest ones: tip of the iceberg



The Large-Scale Structure of the Universe

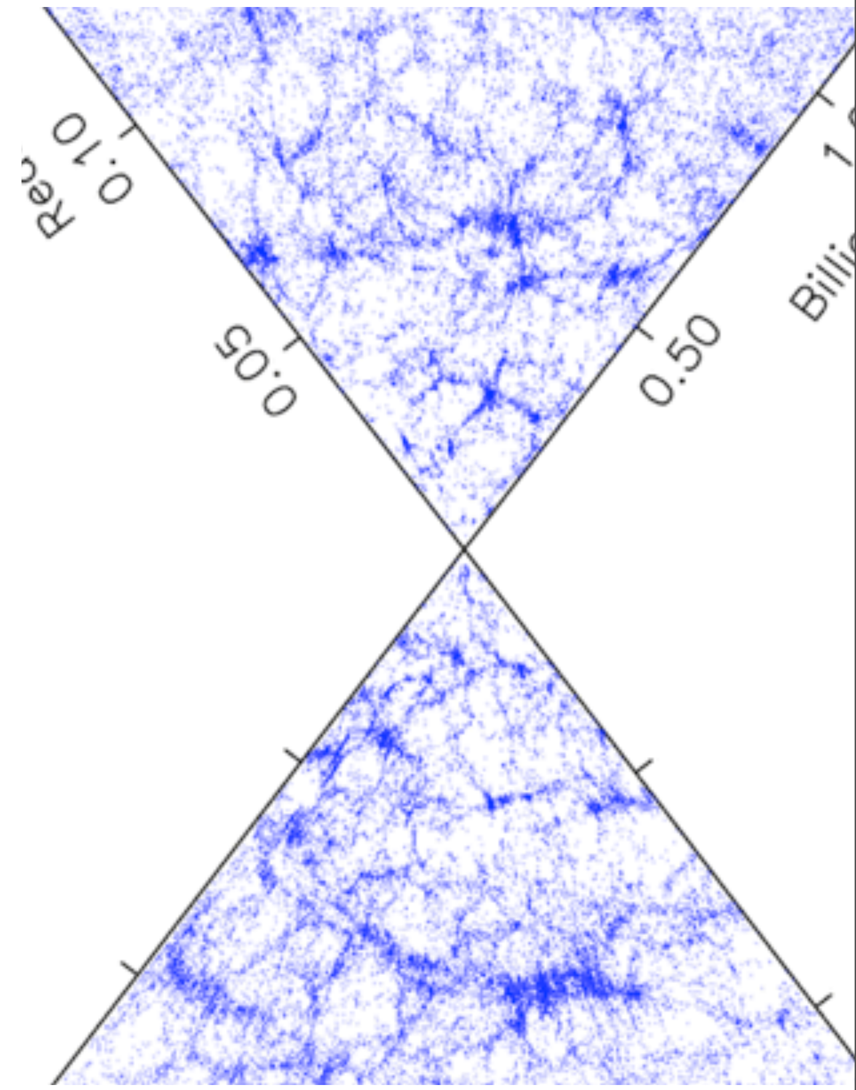
Observations teach us that, on average:

the Universe today is

1. homogeneous: average properties same at all points
   - matter smoothly fills universe, evenly distributed everywhere
   - e.g., mass density anywhere is same as mass density everywhere!

and

2. isotropic: looks same in all directions



universe is homogeneous & isotropic:

- the "cosmological principle"
- first guessed(!) by A. Einstein (1917)

Do you need both?

- Q: e.g., how can you be isotropic but not homogeneous?
- Q: e.g., how can you be homogeneous but not isotropic?

Cosmo principle is a kind of cosmic democracy:

- Universe has no center, and no edge
- no special places, no special directions!

The Night Sky: Group

What is special about the night sky?

Imagine a universe that is

- homogeneous:
  filled smoothly with stars everywhere
- infinitely old, and
- infinitely large

What would the night sky look like in such a universe?

Press A on your iclicker when your groups has a guess.

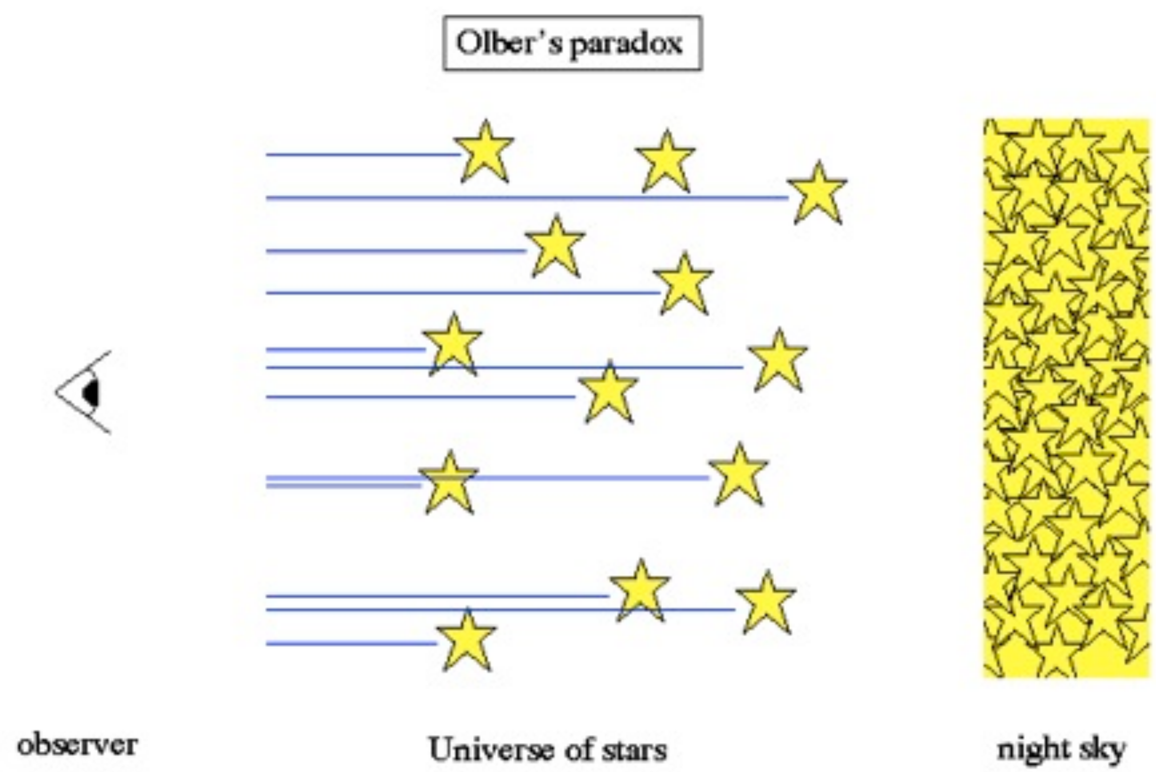
The Night Sky: Olber's Paradox

What is special about the night sky?

If the Universe is infinitely old and infinitely large we would see light everywhere from all the stars.

Thus: in an infinitely old and large universe:

- in any direction you look, that sightline lands on the surface of a star
- so the entire night sky should be as bright as the surface of a star!
- the entire sky should be as bright as the Sun!
- Obviously this is crazy!
- Q: so what's the lesson?



So: the darkness of the night sky contains important information about the universe:

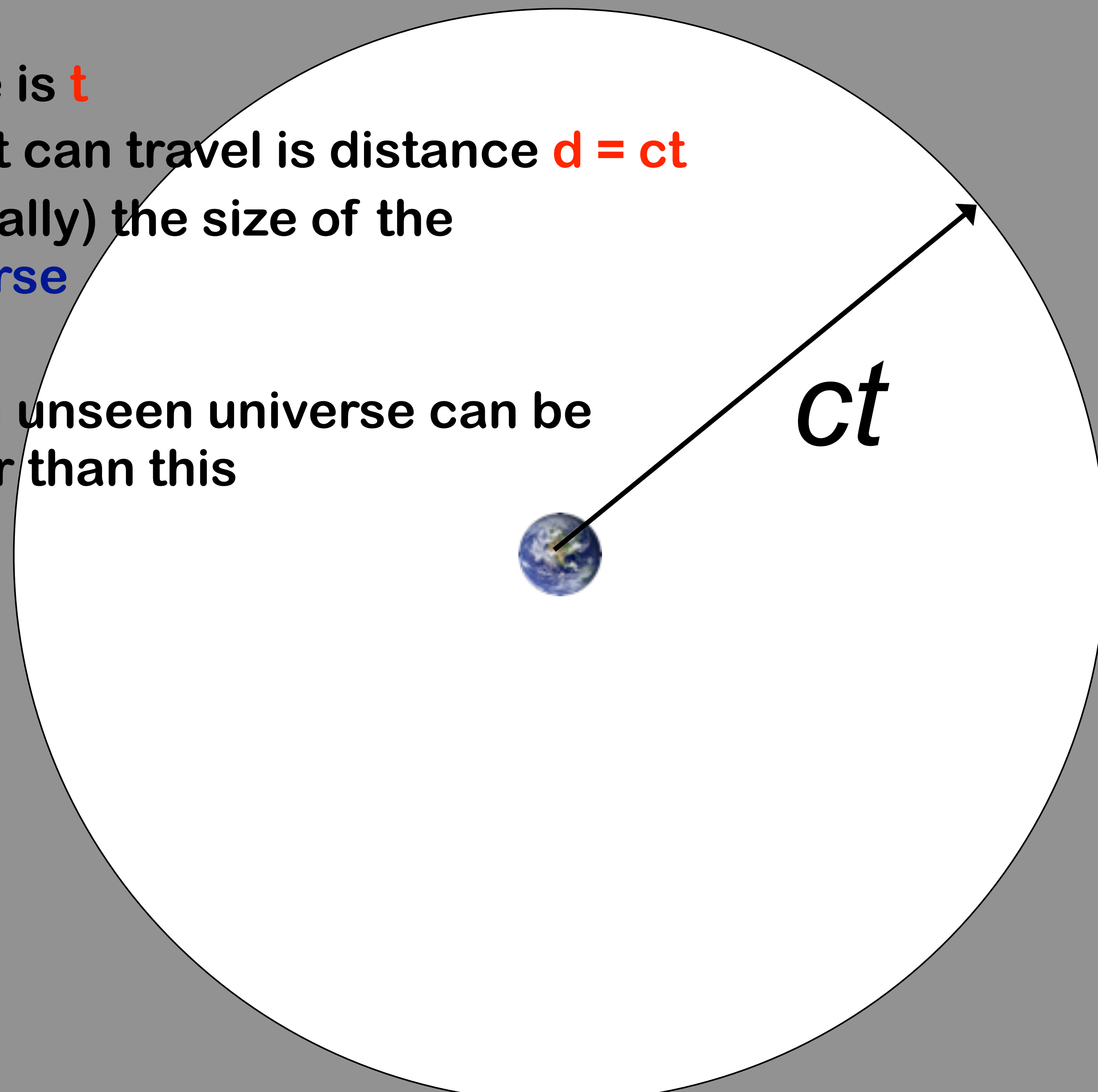
- One of our assumptions must be wrong!
- In fact: the Universe has not existed forever.
- It must have lived forever, but instead the Universe has a finite (non-infinite) age!
- the Universe had a beginning in time!

Looking Back in Time: The Observable Universe!

The universe is finite in age

If age of universe is t
then furthest light can travel is distance d = ct
so this is (essentially) the size of the observable universe

but the remaining unseen universe can be much much larger than this



t = age of Universe

Not to scale!

Edwin P. Hubble and the Dynamic Universe

- Grew up & educated in the Great State of Illinois!
- The first great observer of galaxies

Measured galaxy

✓ Distance

✓ Speed

Hubble, the man

Cosmic Flashback!

It's 1928.

Hubble is measuring galaxy velocities, distances.

What will Edwin find?

(a) **More galaxies approaching than receding**

(b) **More galaxies receding than approaching**

(c) **About equal numbers of each**

Cosmic Present!

It's 2011.

We have measu d s ions of

(a) M

(b)

(c)

(d) ore ng

More than 99.999% of galaxies are receding!

What Does This Mean?

All galaxies show redshifts, not blueshifts

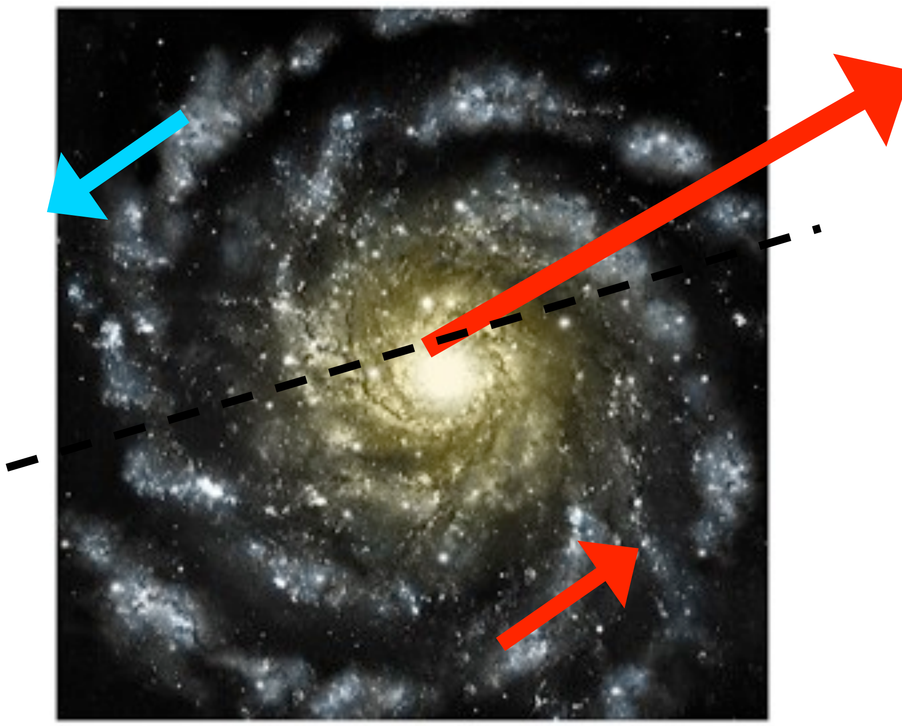
All galaxies are moving away from us.

The farther away, the faster they are moving away.

Or speed is proportional to distance

- Hubble's Law
- mathematically: $v = H_o \times D$

H_o = 70 km/s /Mpc, a constant



What does this mean?

Key to understanding the Universe!

Apply it?

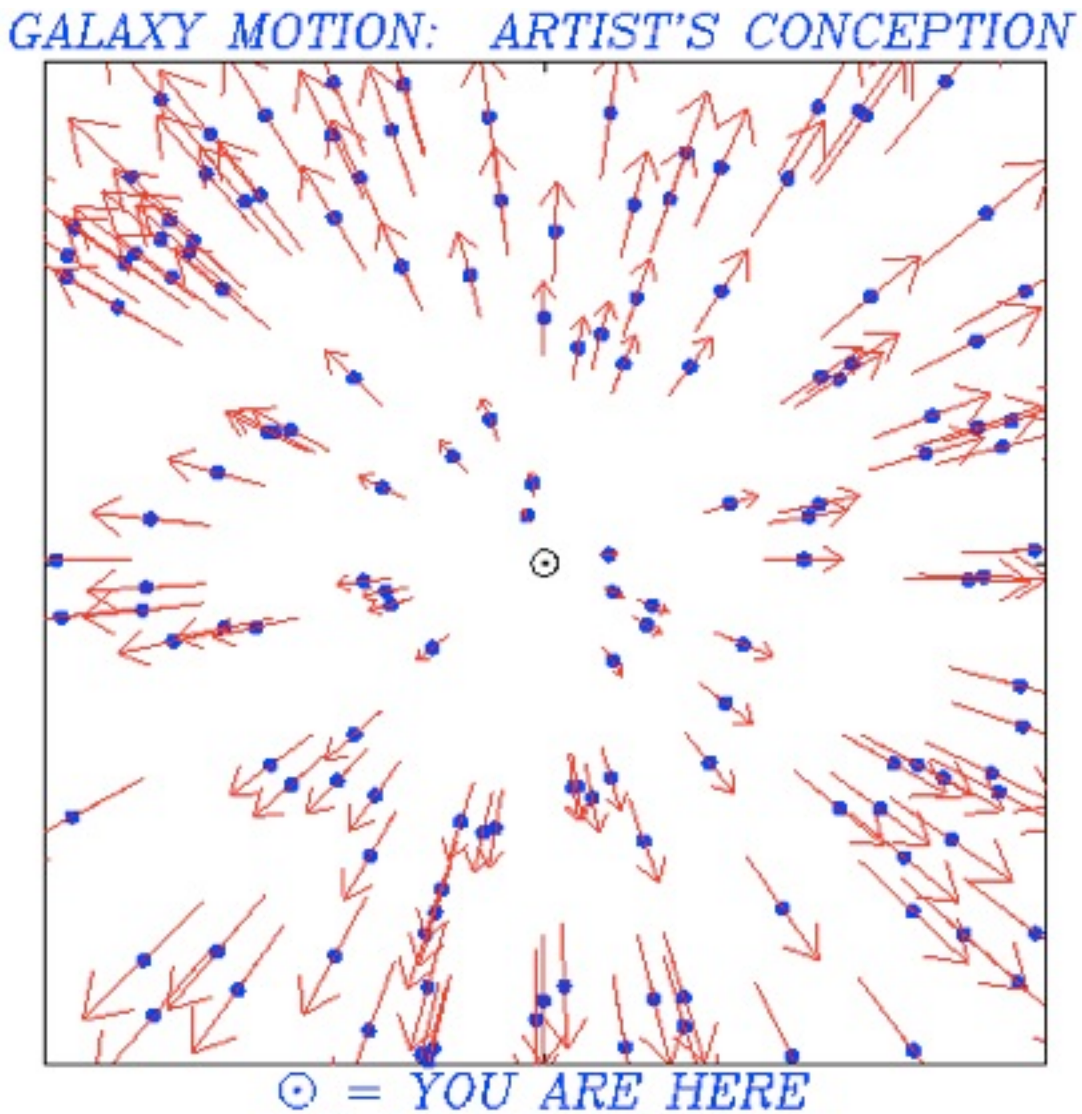
In a homogenous Universe, what does the farther away the faster the galaxies move away mean?

$v = H\ d$ **Draw it.**

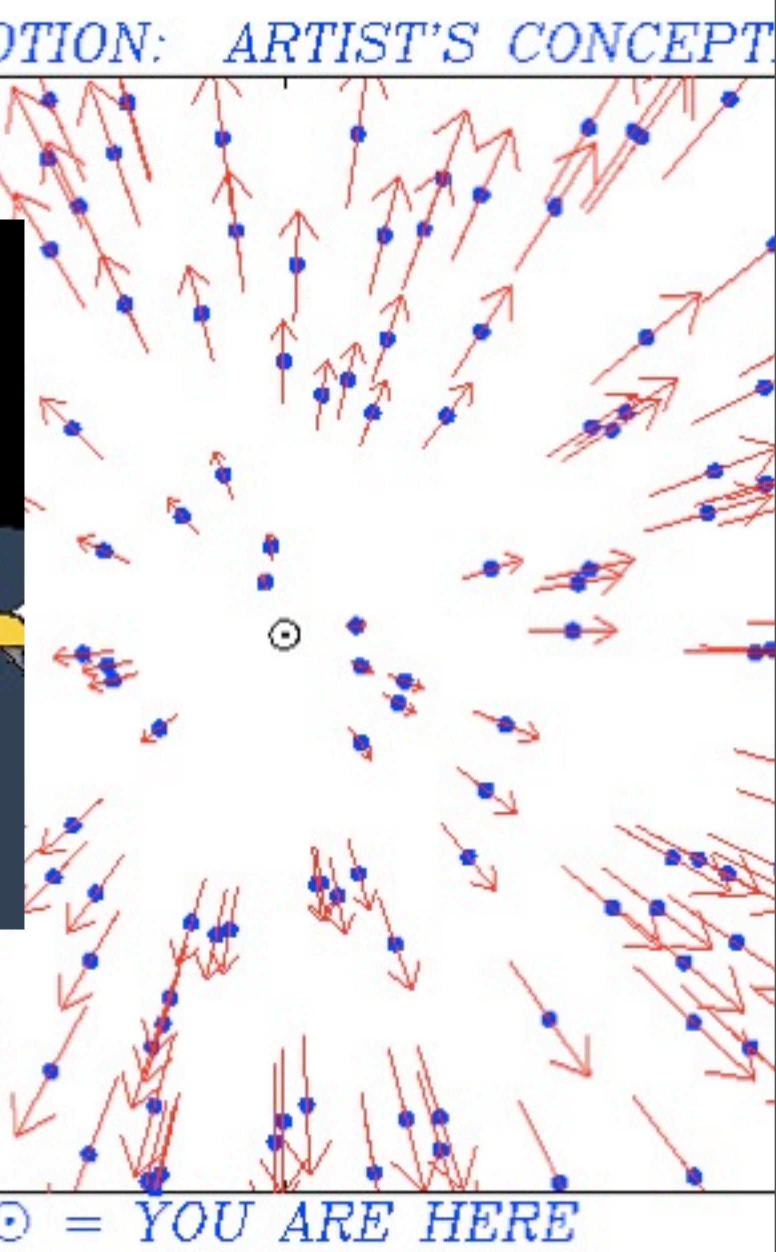
Highly organized, special pattern

- clearly trying to tell us something!
- But what?

Q: logical possibilities?

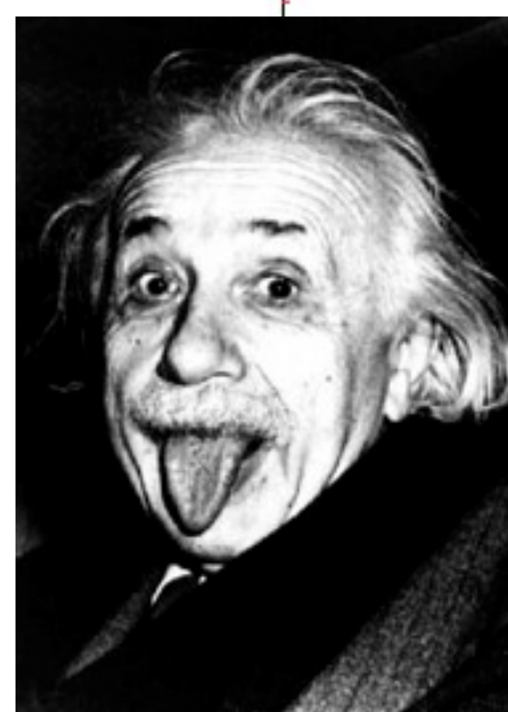


Interpretation:
View of the Universe

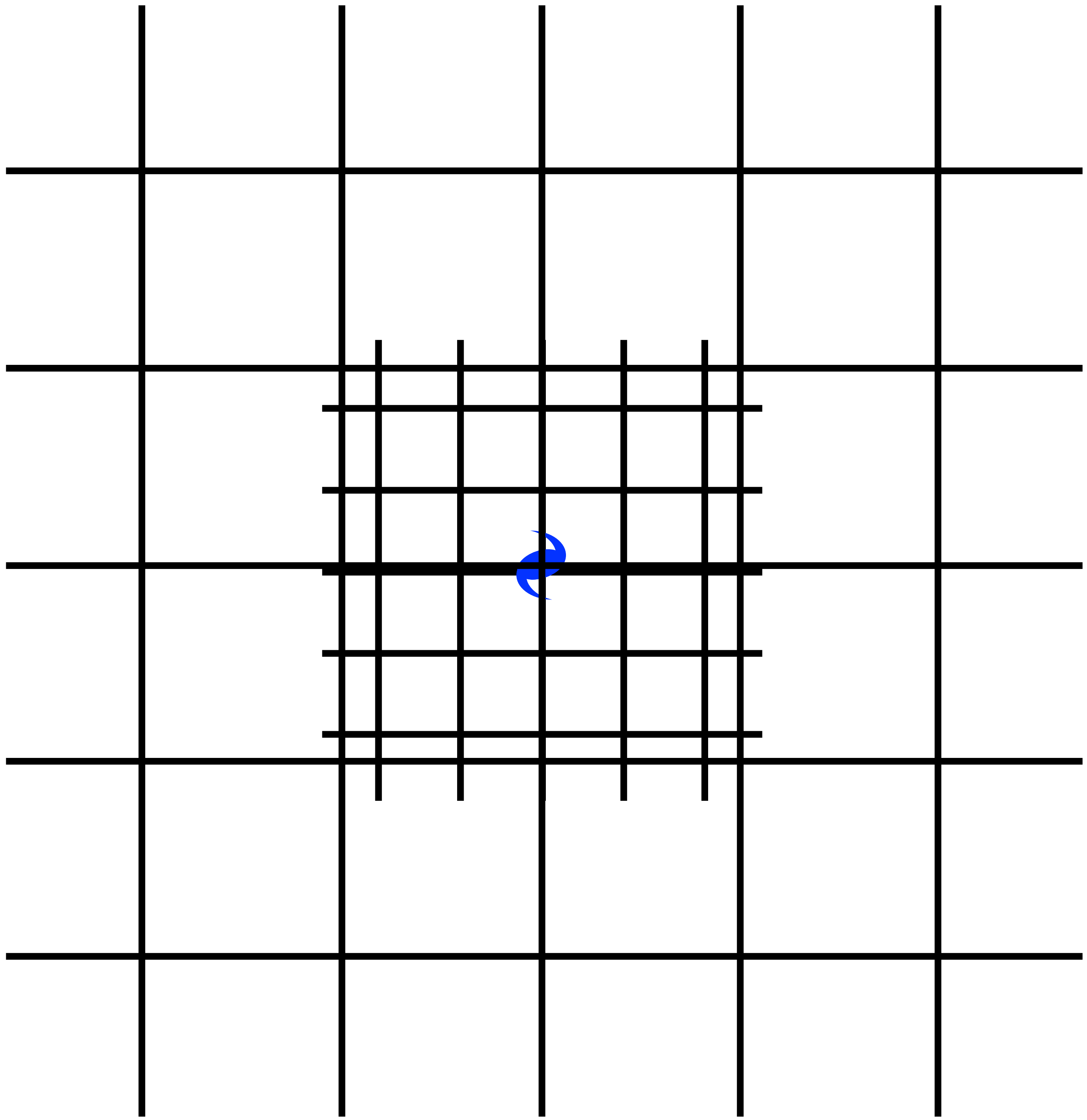


Egoist view– We are at the center of the Universe.

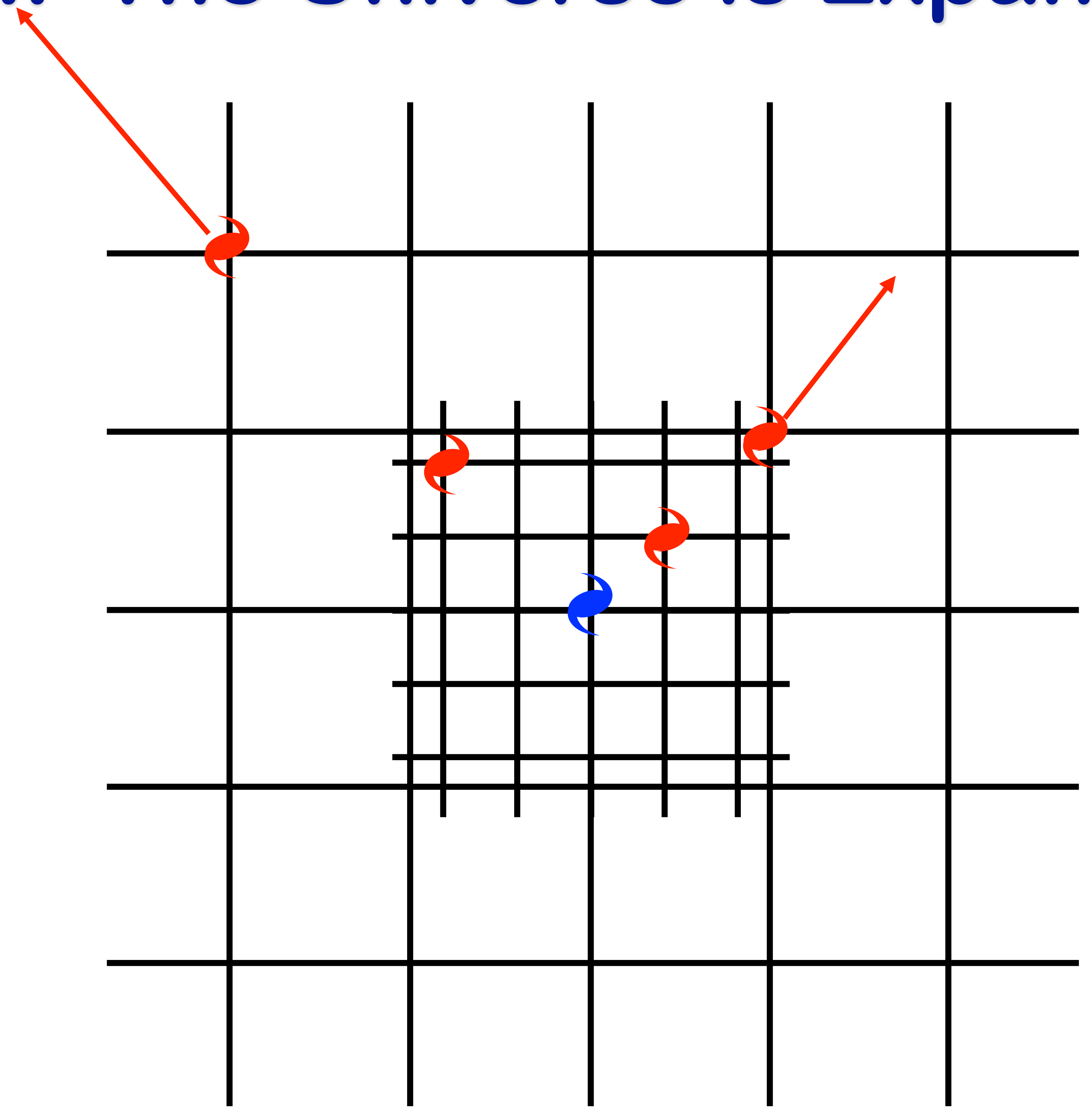
Einstein's view– The Universe is expanding, and there is no center!



Dude, The Universe is Expanding.



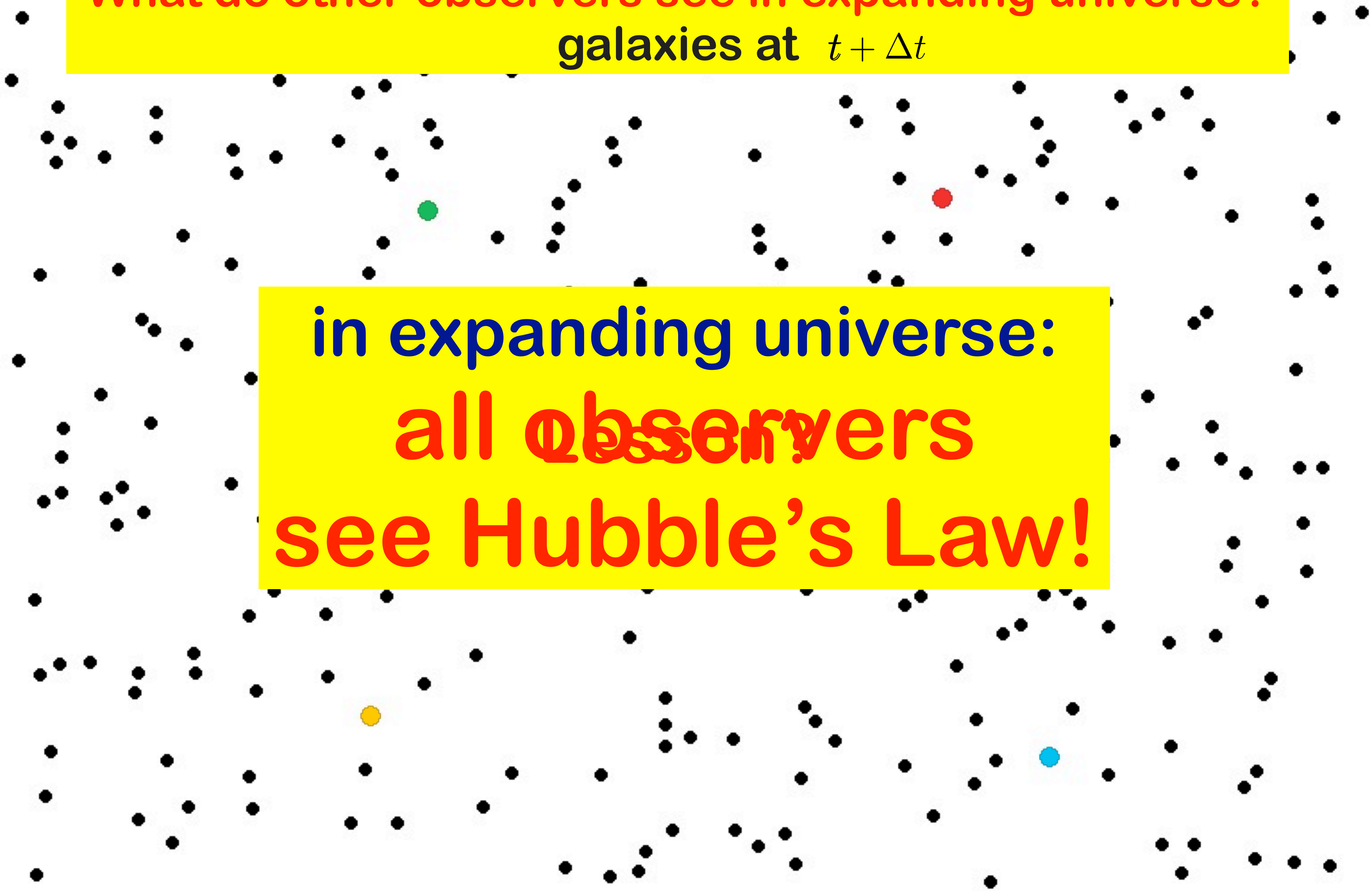
Wow. The Universe is Expanding.



Expansion and Dynamics

What do other observers see in expanding universe?

galaxies at $t + \Delta t$



in expanding universe:

Lesson?

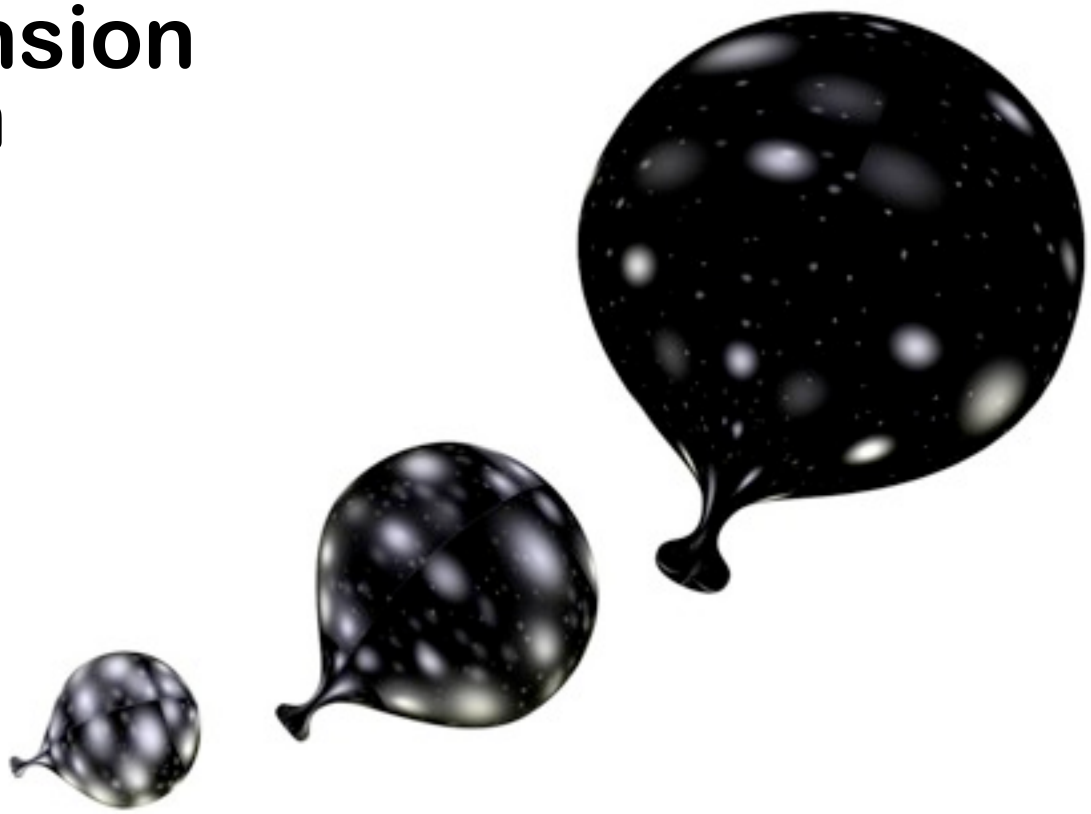
all observers see Hubble's Law!

Hold on a minute there!

- Why don't we expand with the Universe?
- Note: average density of Universe today is tiny
  - on average, a few atoms for every 1 meter cube!
    so gravity between nearby average regions is weak
  - people, planets, stars, galaxies: much denser
- Other forces hold us together
  - Atoms - nuclear forces
  - Molecules & living beings – electromagnetic forces
  - Planets, stars, galaxies, even galaxy clusters – much denser than average universe, held together by their own gravity
- But gravity can't hold larger things together
  - Expansion grows stronger with distance (more expanding space)
  - Gravity grows weaker with distance (inverse square law)

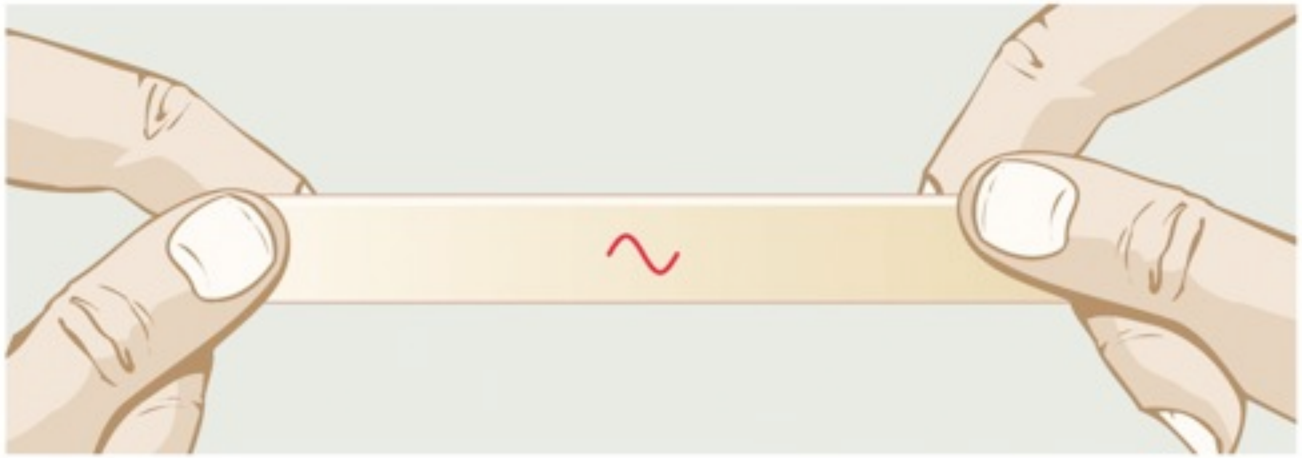
Common Misconception

- Its common to think of the expansion of the Universe like an explosion
  - Galaxies hurled away from each other through space
- This is incorrect!
- Einstein's General Theory of Relativity
  tells us that
  - space, time, & matter related
  - in presence of matter, space is dynamic and changing
    - recall lensing & wierdo black hole effects
  - in the case of the Universe: space itself is expanding!
    - Like an inflating balloon



Analogy - Rubber Band

- Space expands, like stretching a rubber band
- Not only do distances grow…
- Even the light's wavelengths get stretched!
  - Increasing wavelength = redder!
  - Cosmological redshift



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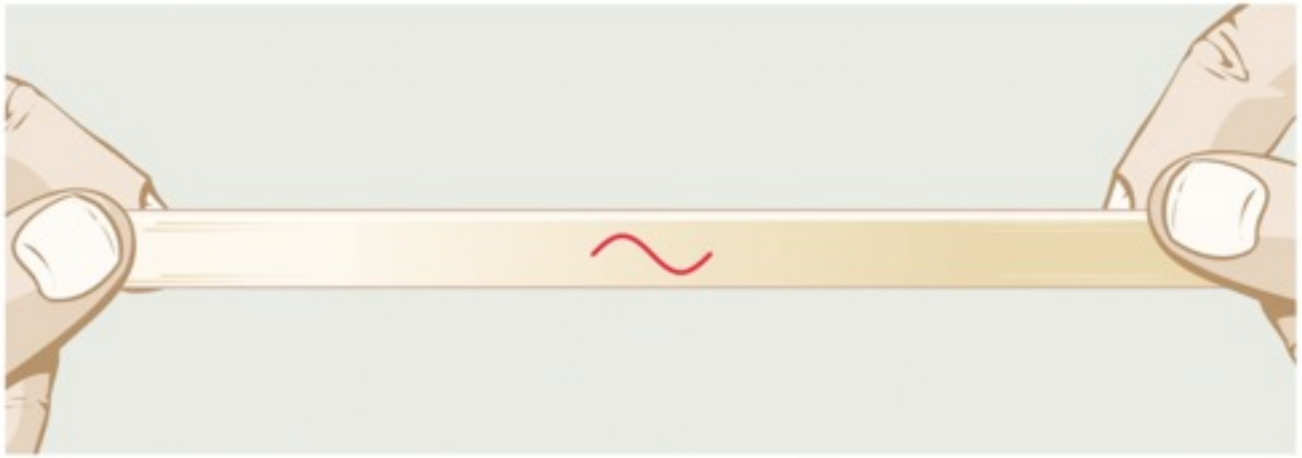

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Reality

- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center.
- The Universe has no edge.
- Concept of time and space began with the Universe, can not apply the concepts so easily.

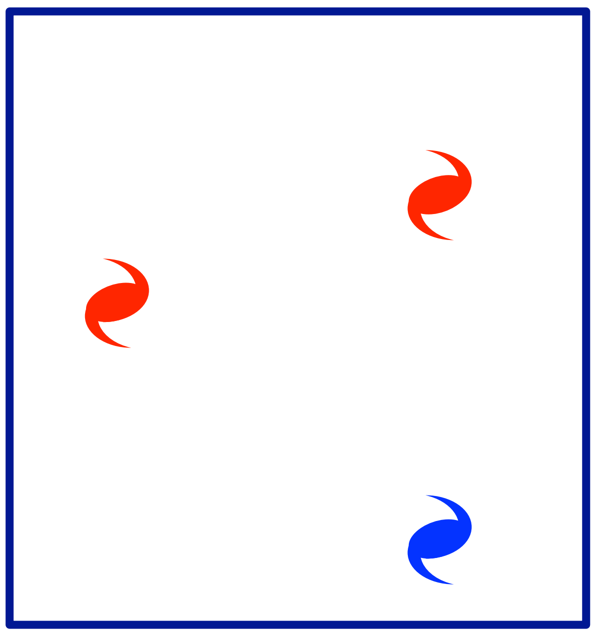
http://universe.gsfc.nasa.gov/images/reach-for-the-universe.jpg

Living in an Expanding Universe

Consider a large "box" containing many galaxies

- **Total mass in box today: M_{today}**
- **Total volume in box today: V_{today}**
- **Density today = M_{today} / V_{today}**

The Universe box



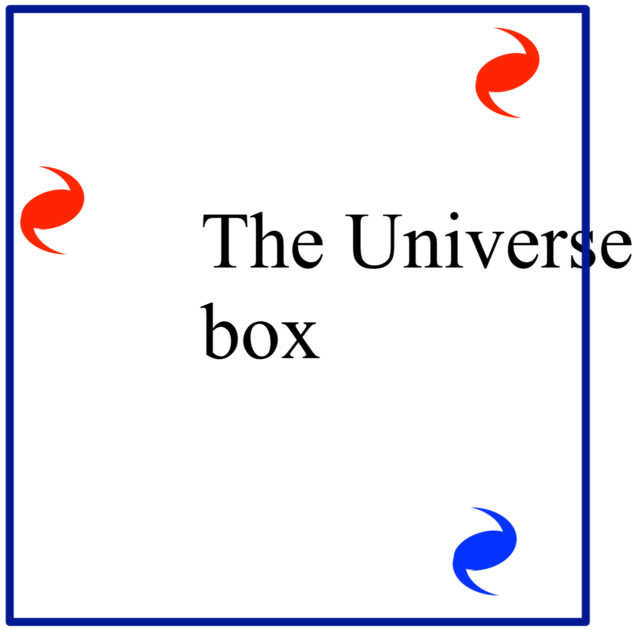
How does the density of the Universe change with time?

Living in an Expanding Universe

How does the density of the Universe change with time?
As the Universe expands:

- $M_{tomorrow}$ stays the same
- $V_{tomorrow}$ becomes larger
- Density $M_{tomorrow}/V_{tomorrow} \Rightarrow$ smaller

$$M_{tomorrow}/V_{tomorrow} < M_{today}/V_{today}$$

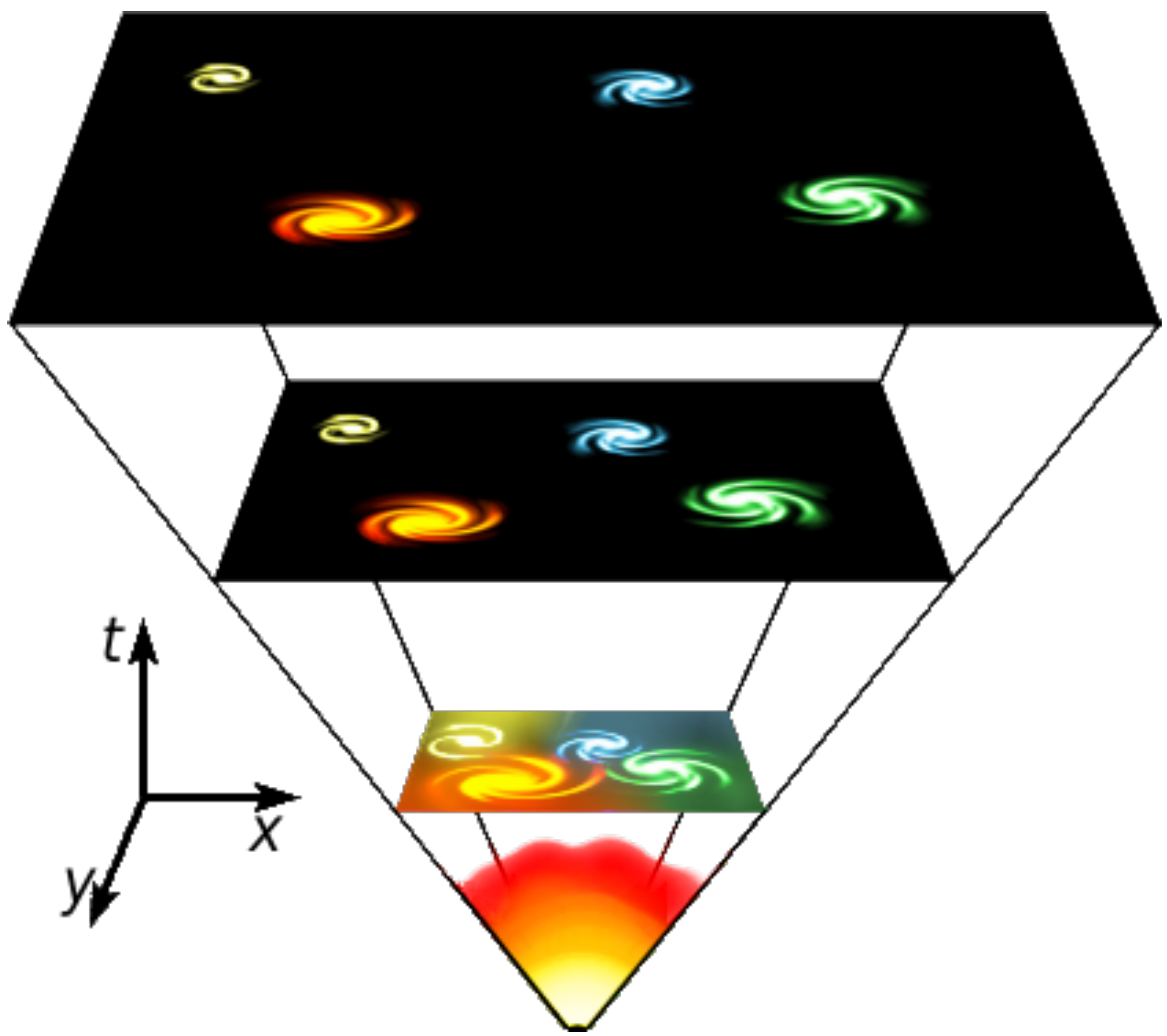


Density changes with time!

- Universe was denser in the past
- Universe will be less dense in the future

Putting it all together:

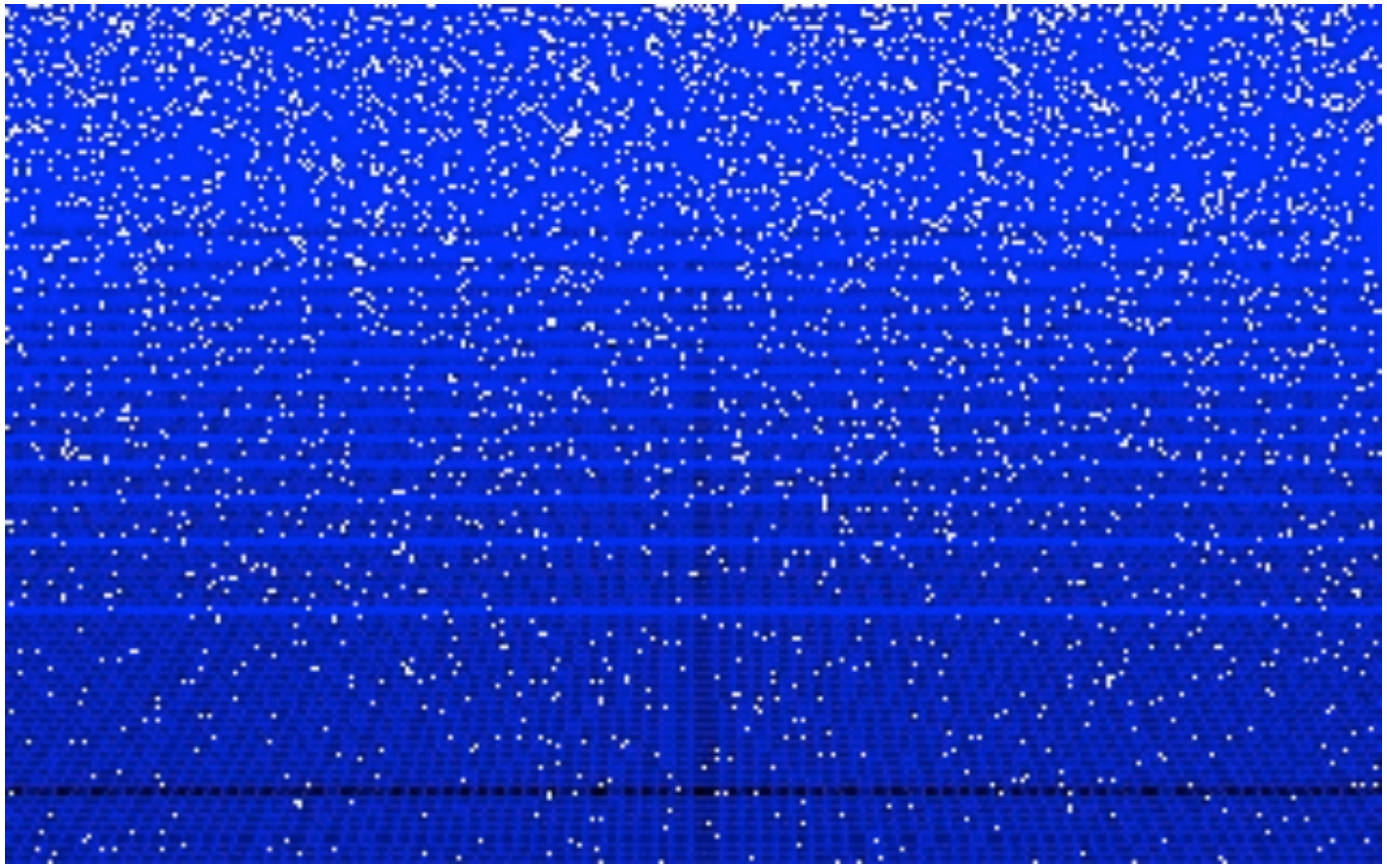
1. The Universe is expanding
2. Earlier Universe was more dense
3. Earlier Universe was hotter.



Hot, dense origin of the universe: Big Bang!

The Big Bang

- No special points or locales
- Expansion of all space
- As spacetime expanded, the Universe became less dense and cooler
- Eventually forming the stars and galaxies we see today



Q: so where did the big bang happen?

http://www.atlasoftheuniverse.com/bigbang.html

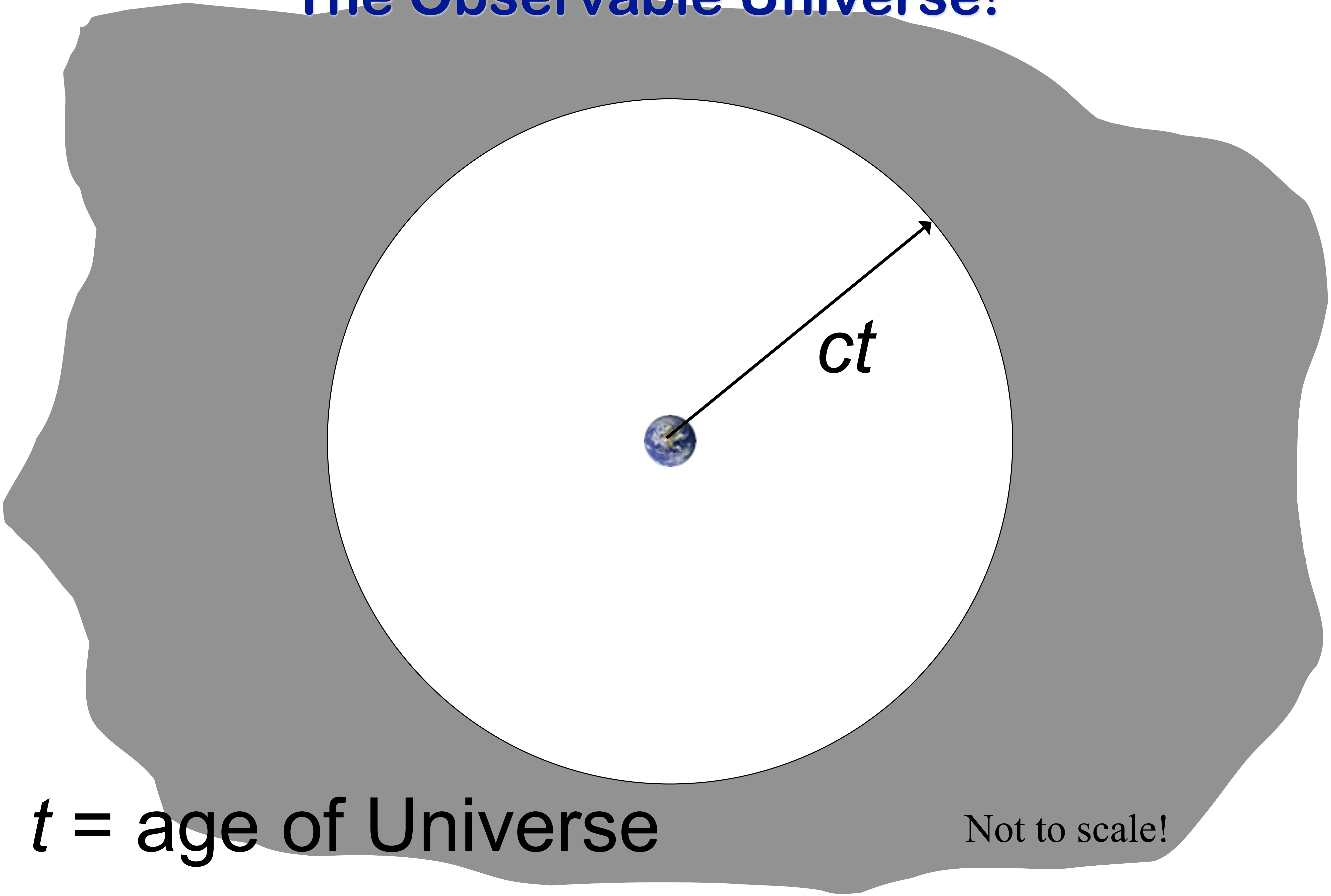
The Big Bang

- Big Bang has no center
- Happened everywhere!
- Wherever you go, there was the big bang!
- So as we talk about the very dense early universe, remember that we are talking about what happened not just far away at the edge of the Universe, but right here! ...smooshed up small, but still right here!

The 3rd Revolution

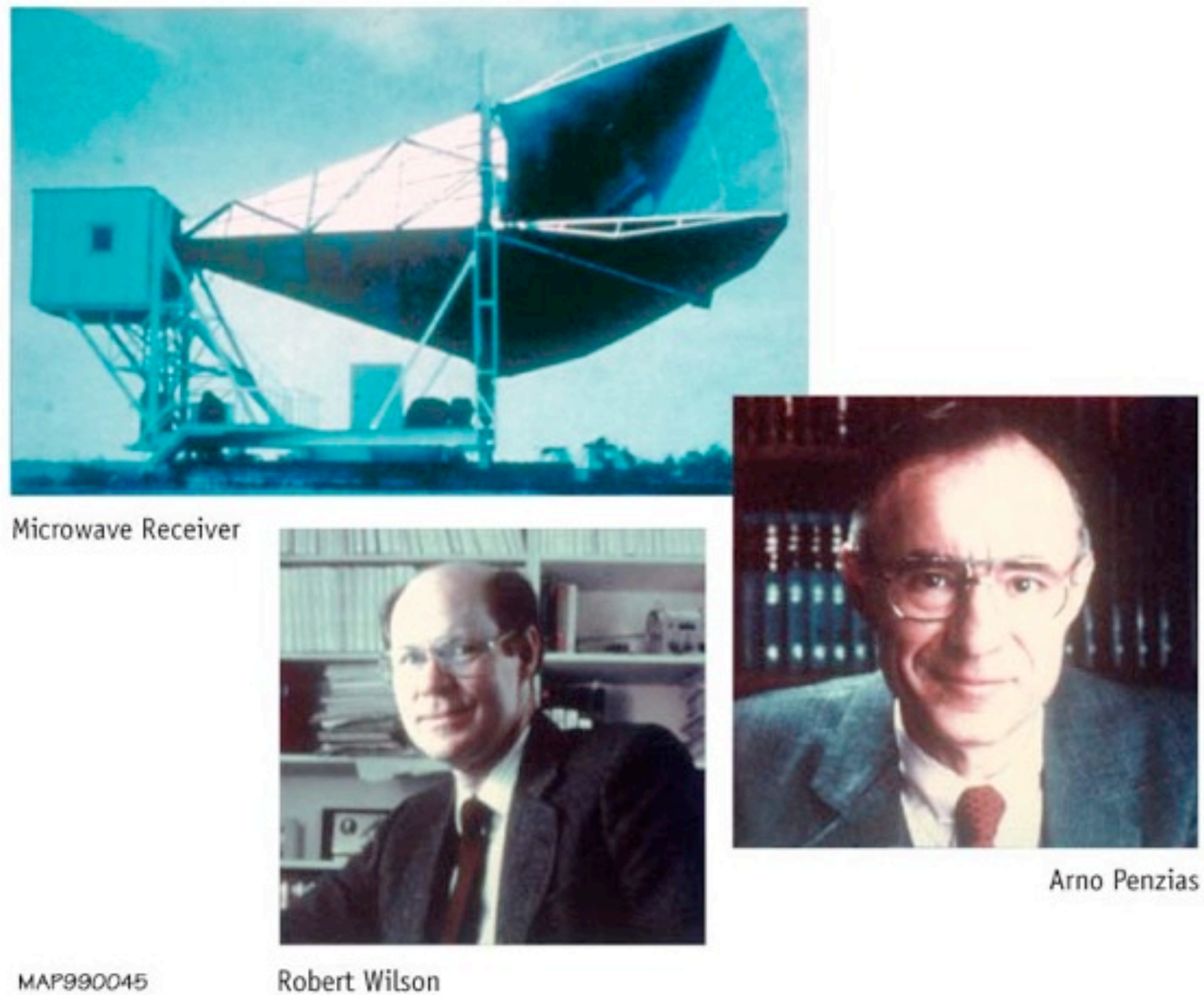
1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet among many.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star among many.
3. Hubble and others: We are not in the center of the Universe; indeed the Universe has no center at all! The Milky Way is a typical galaxy among many.

Looking Back in Time: The Observable Universe!

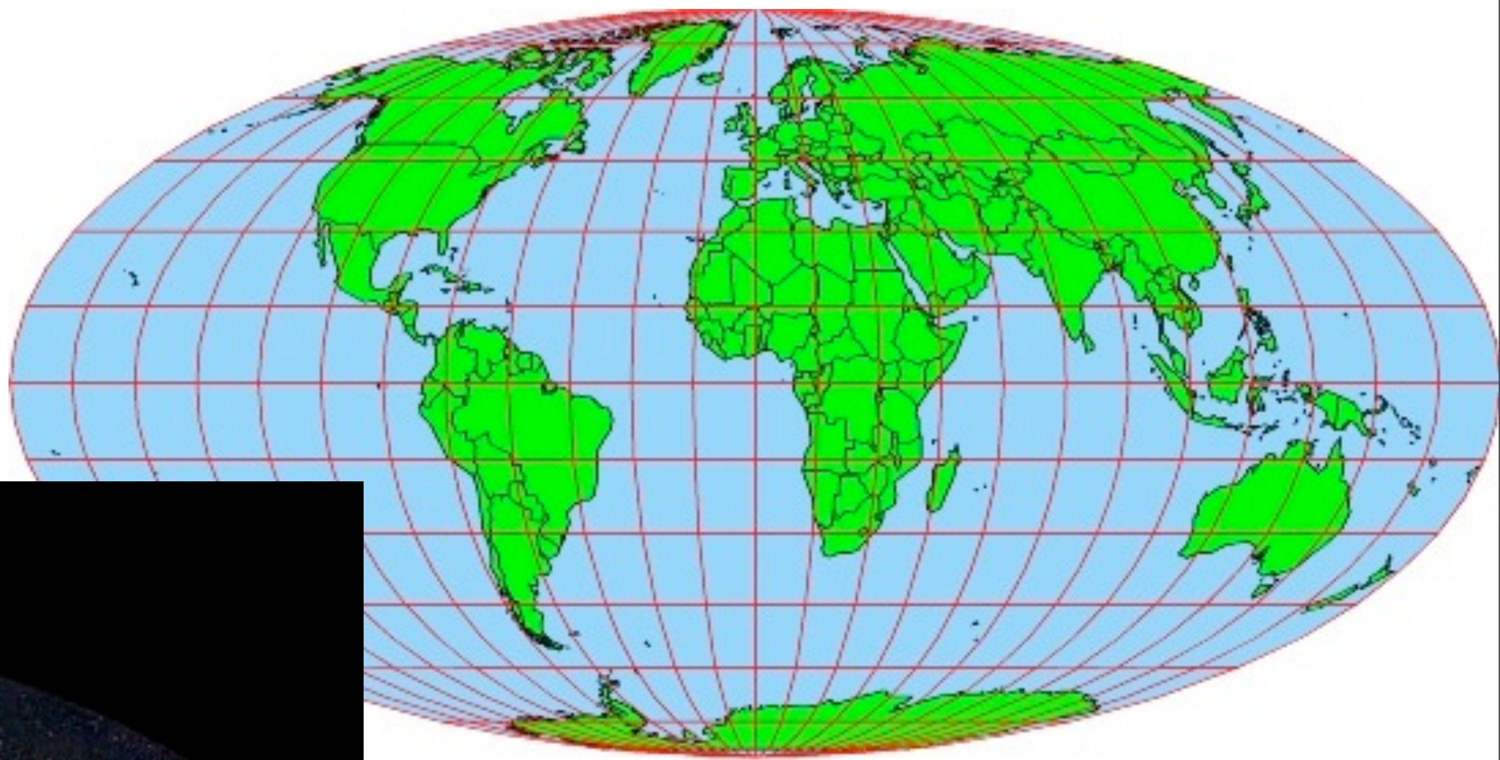


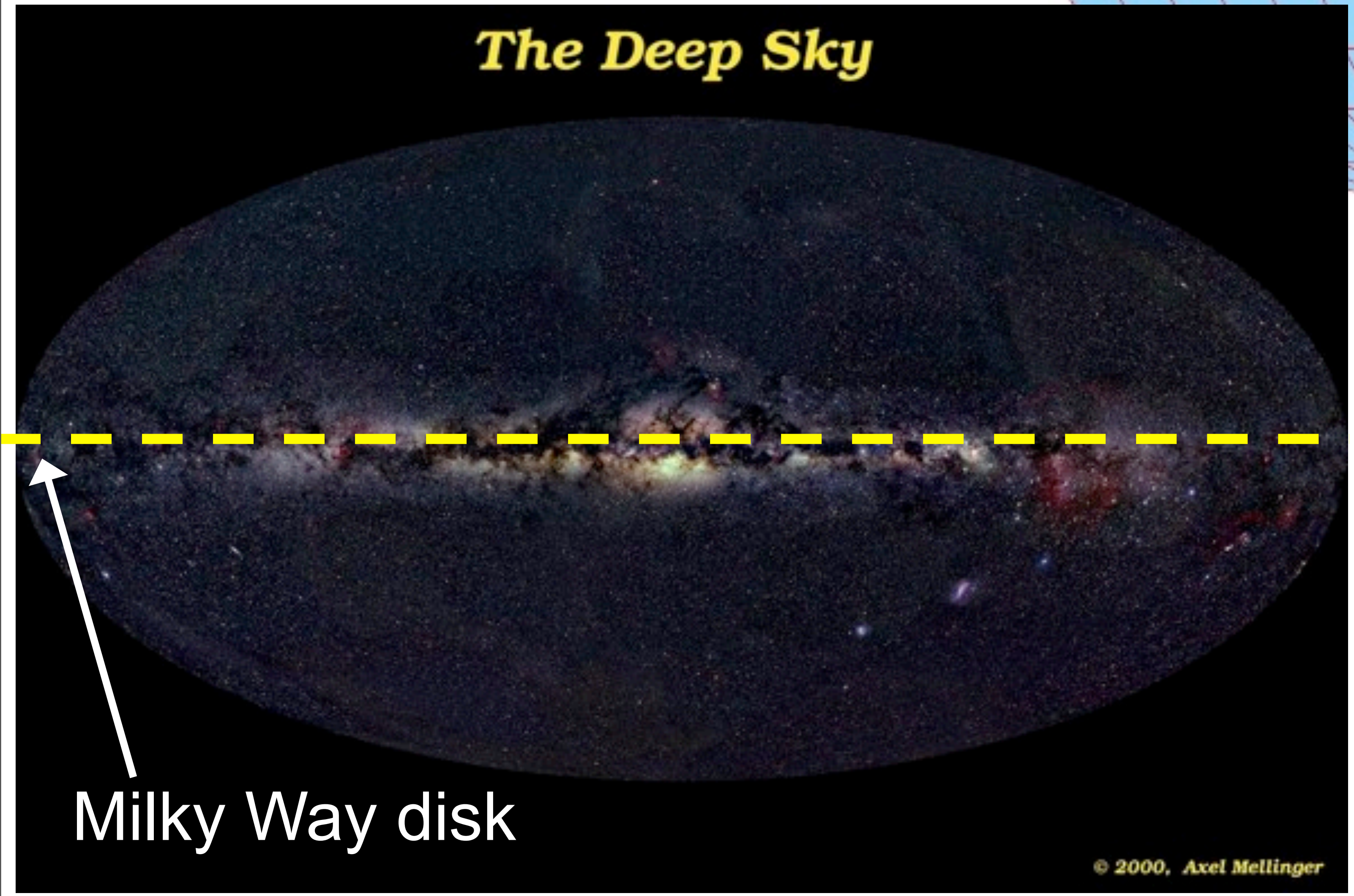
The Early Universe was HOT!

- Recall: hot objects glow!
- If the early Universe was so hot, we should be able to see it glowing too. Right?
- Yep, we do! But, as the Universe expanded, the glow redshifted down to the microwave--invisible to our eyes.
- Now, it is called the Cosmic Microwave Background (CMB).
- First detected by Robert Wilson and Arno Penzias.



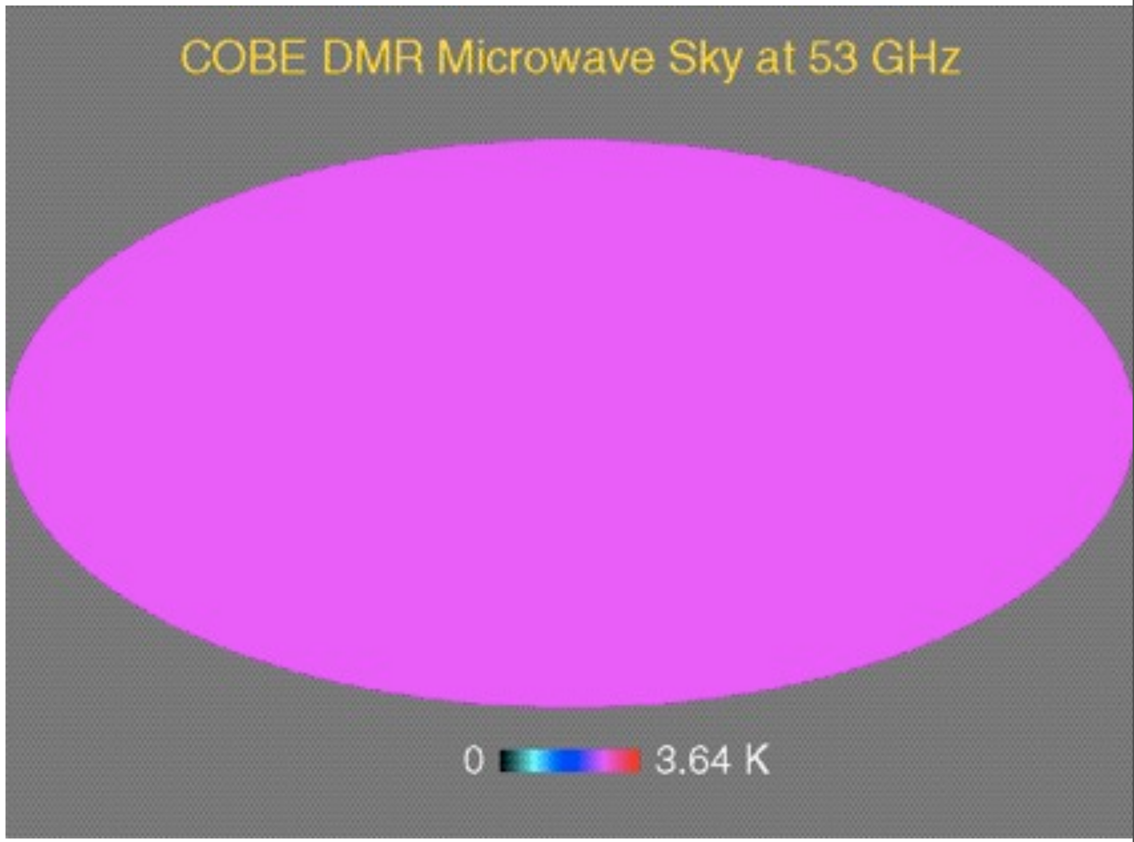
How to Understand Sky Maps



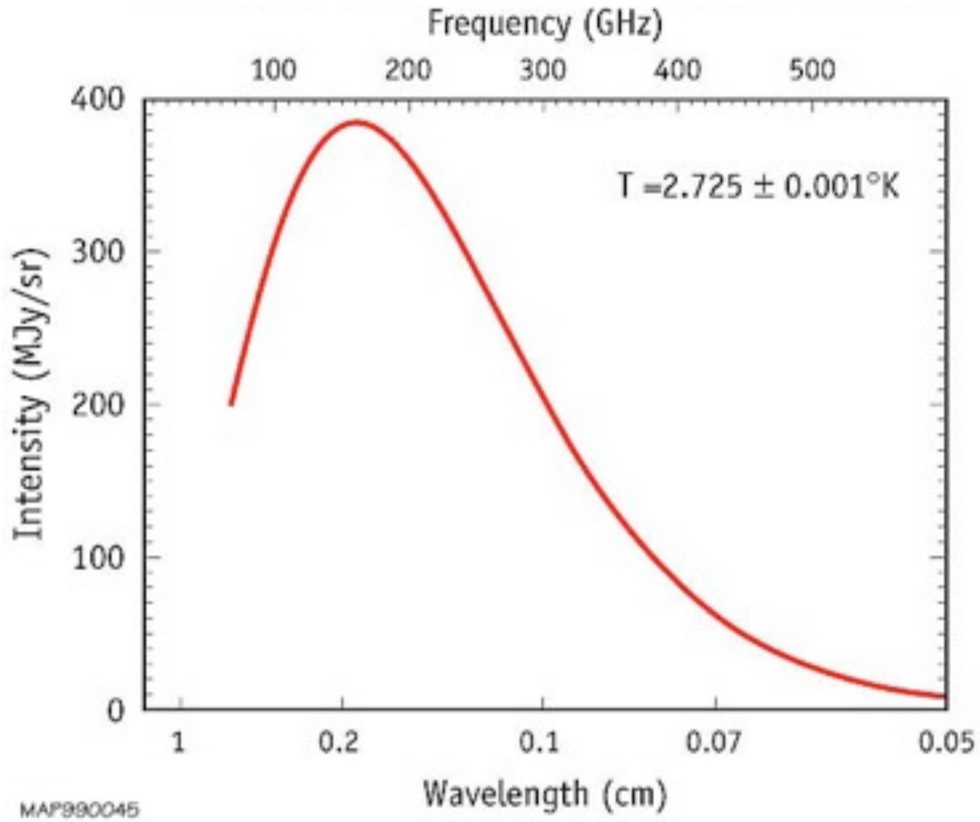


In Fact, a Fantastically Uniform Blackbody

- All over the sky, we see blackbody radiation
  - the Universe has a temperature!
  - in fact: T = 2.73 K
    - cold! barely above absolute zero!
- Provides compelling evidence for the Big Bang Theory
- Temperature nearly the same in all directions
    - very isotropic!
- Indicates that, over large scales, the Universe is indeed smoothly filled with matter: homogeneous

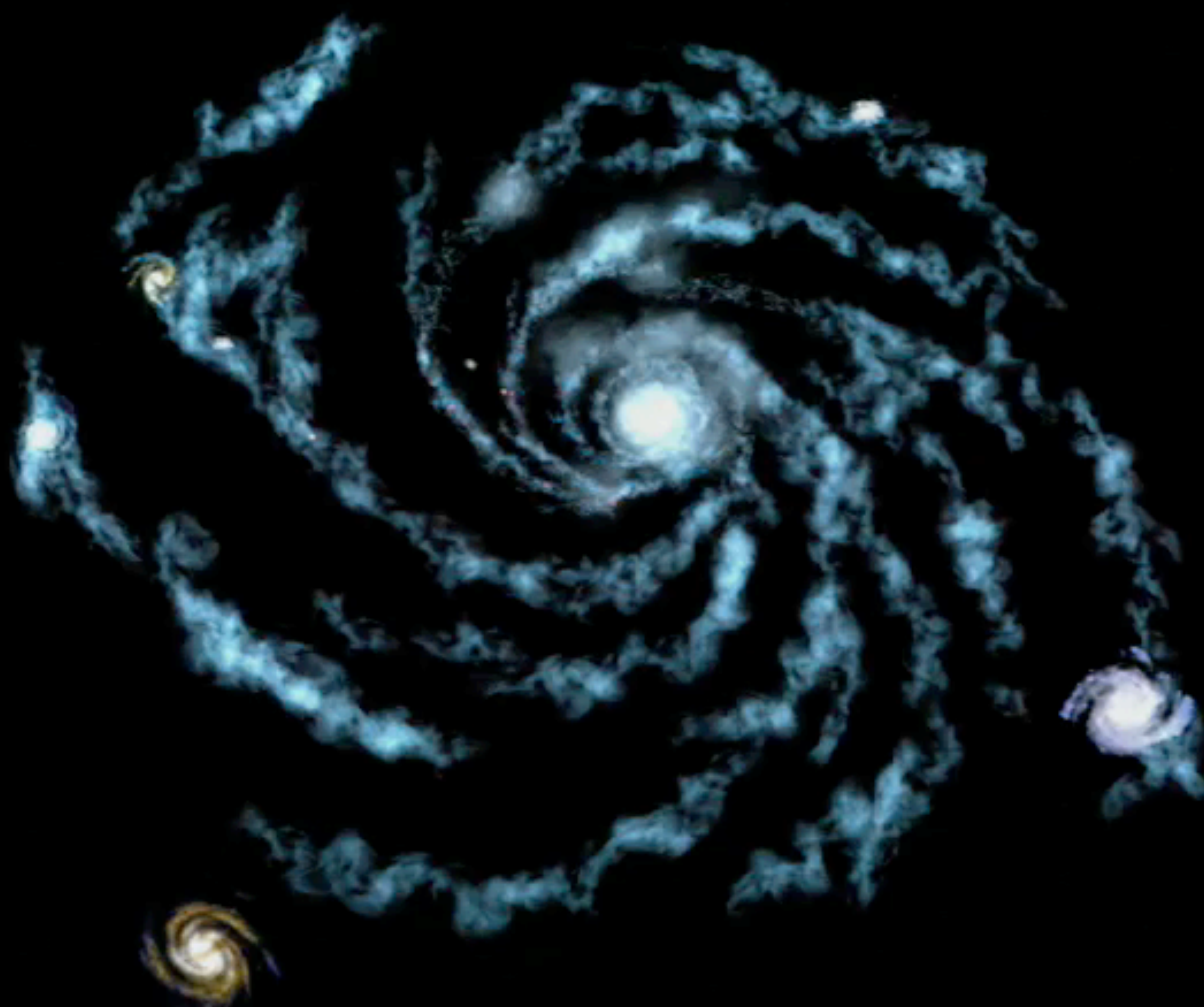


Cosmic Background Explorer (COBE) satellite (launched 1989)



Turning Up the Contrast
Is the CMB temperature perfectly uniform?

http://map.gsfc.nasa.gov/media/030640/index.html



Turning Up the Contrast

Is the CMB temperature perfectly uniform?

No! T fluctuates across sky:
differences in 5th decimal place!