

# **HW2: due Jan 23**

**download from the usual place**

<https://faculty.washington.edu/balick/astro190/Homework/HW2.pdf>

# *The Simplest Universe*

★ Infinite

★ Ageless

★ Static

★ Empty





**Gravity.**

It's not just a good idea.  
It's the Law.

W  
sky fallen?



# *Newton's Conundrum*

**Why hasn't the sky fallen?**

- **Infinite Size**
- **Finite Age**
- **Expanding**
- **(Or any combination)**

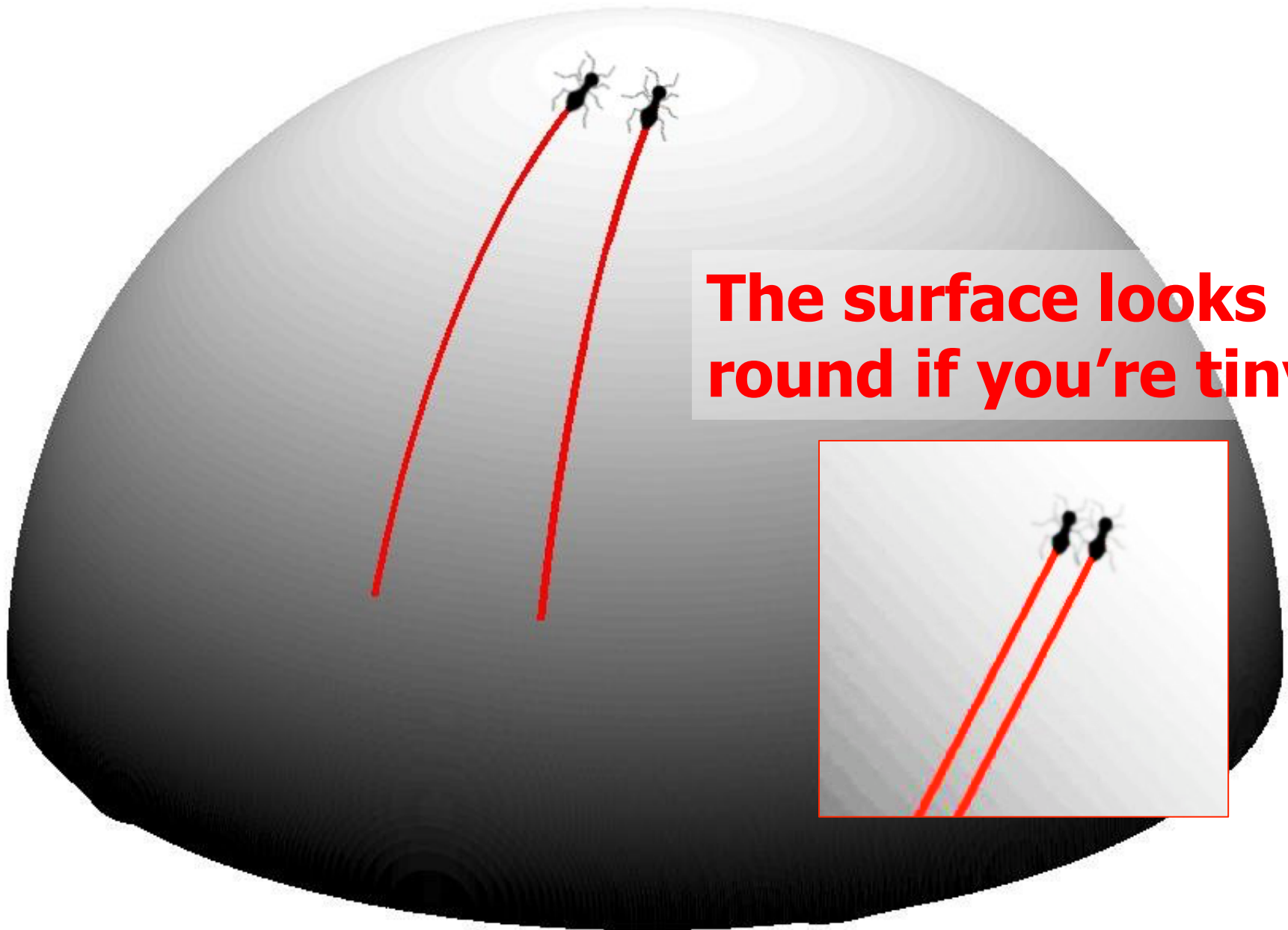


# Skipping Ahead

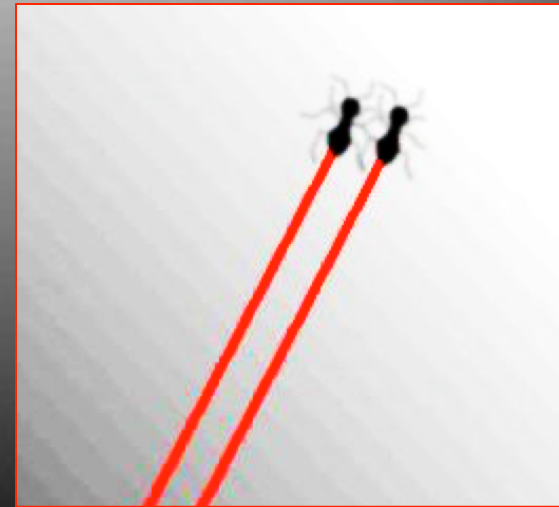


**The surface looks  
round if you're big**





**The surface looks round if you're tiny**



**This is the view seen from everywhere**

*The Big Bang!*

$t = 0$

**Opaque!**

**time**

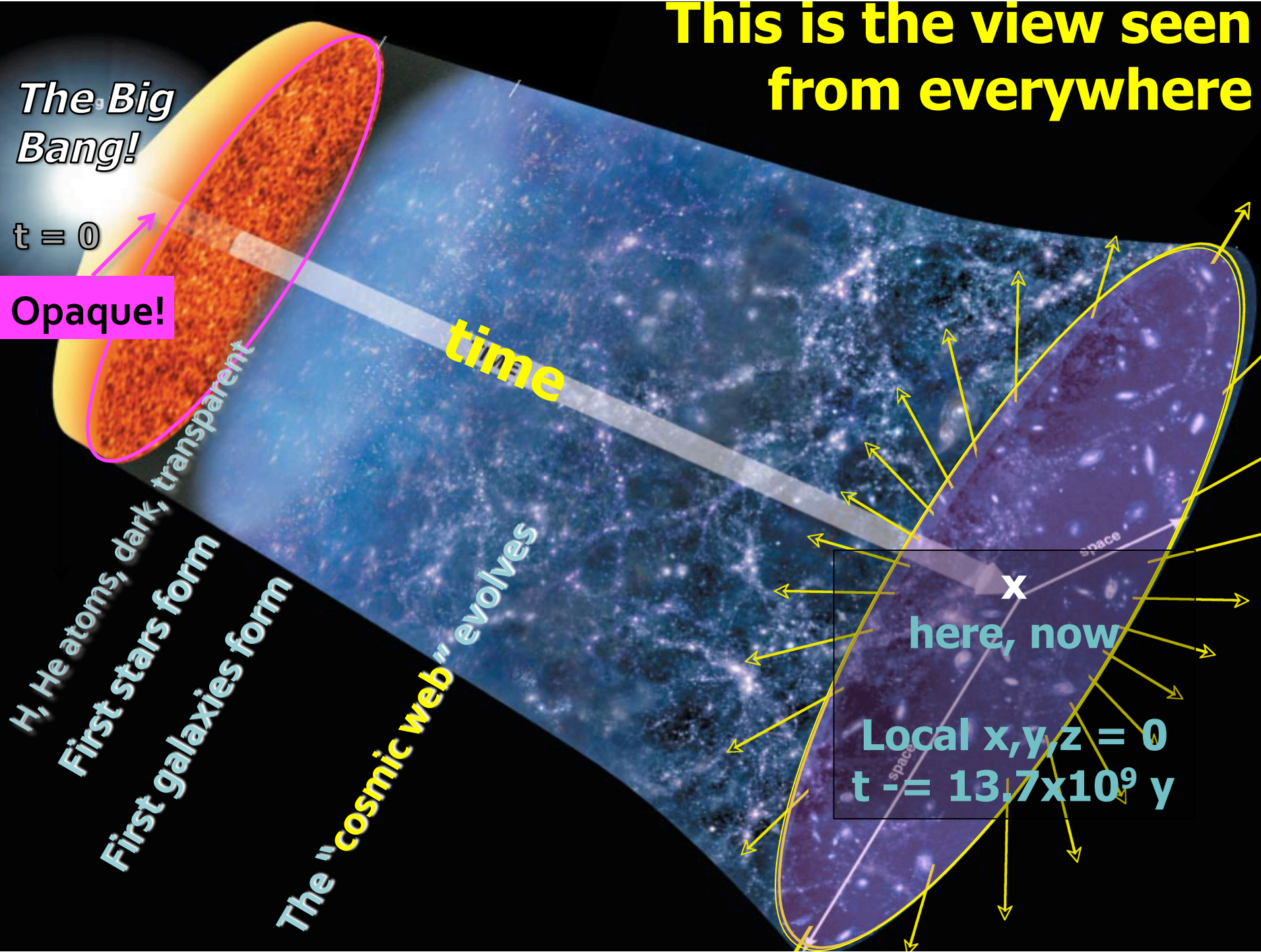
H, He atoms, dark, transparent

First stars form

First galaxies form

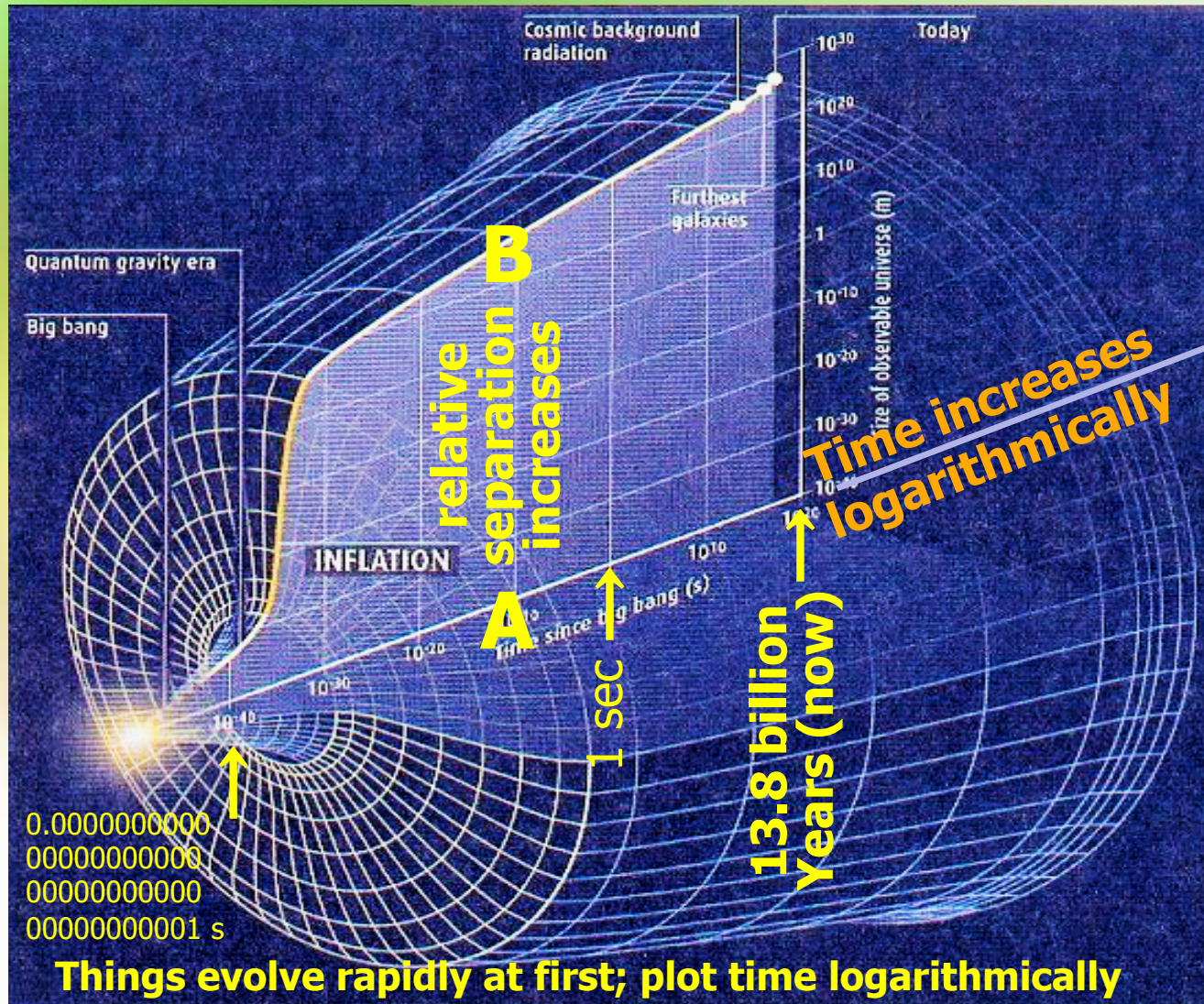
The "cosmic web" evolves

**x**  
here, now  
Local  $x, y, z = 0$   
 $t = 13.7 \times 10^9$  y





# The Stretching of Space



The changing scale of space is measured by measuring the **separations** of all pairs of points

**"SPACE METRIC"**

**"Inflation"**

# The State of Matter



# Same Content, Different Perspective



Where are

- You?
- Youngest Galaxies?
- Contemporary Galaxies?
- Nearby Stars?
- Big Bang?

# Essential Cosmological Observations

WE WILL RE-INTRODUCE AND DISCUSS THESE LATER

1. The Universe is not empty
  2. The night sky is dark
  3. The Universe is expanding (Hubble Law)
  4. The expansion is accelerating
  5. The physical state of matter evolves  
(hot → cold, dense → sparse, etc)
  6. The lightest elements came first
    - 6a. Deuterium/Hydrogen ( ${}^2\text{H}/{}^1\text{H}$ )  $\approx 0.01$
  7. Cosmic Microwave Background (CMB) radiation is ubiquitous
  8. The "Cosmic Web": from CMB ripples to filaments of galaxies and clusters
- "Dark Matter": dominates cosmic mass-energy now
- "Dark Energy": the latest and biggest enigma

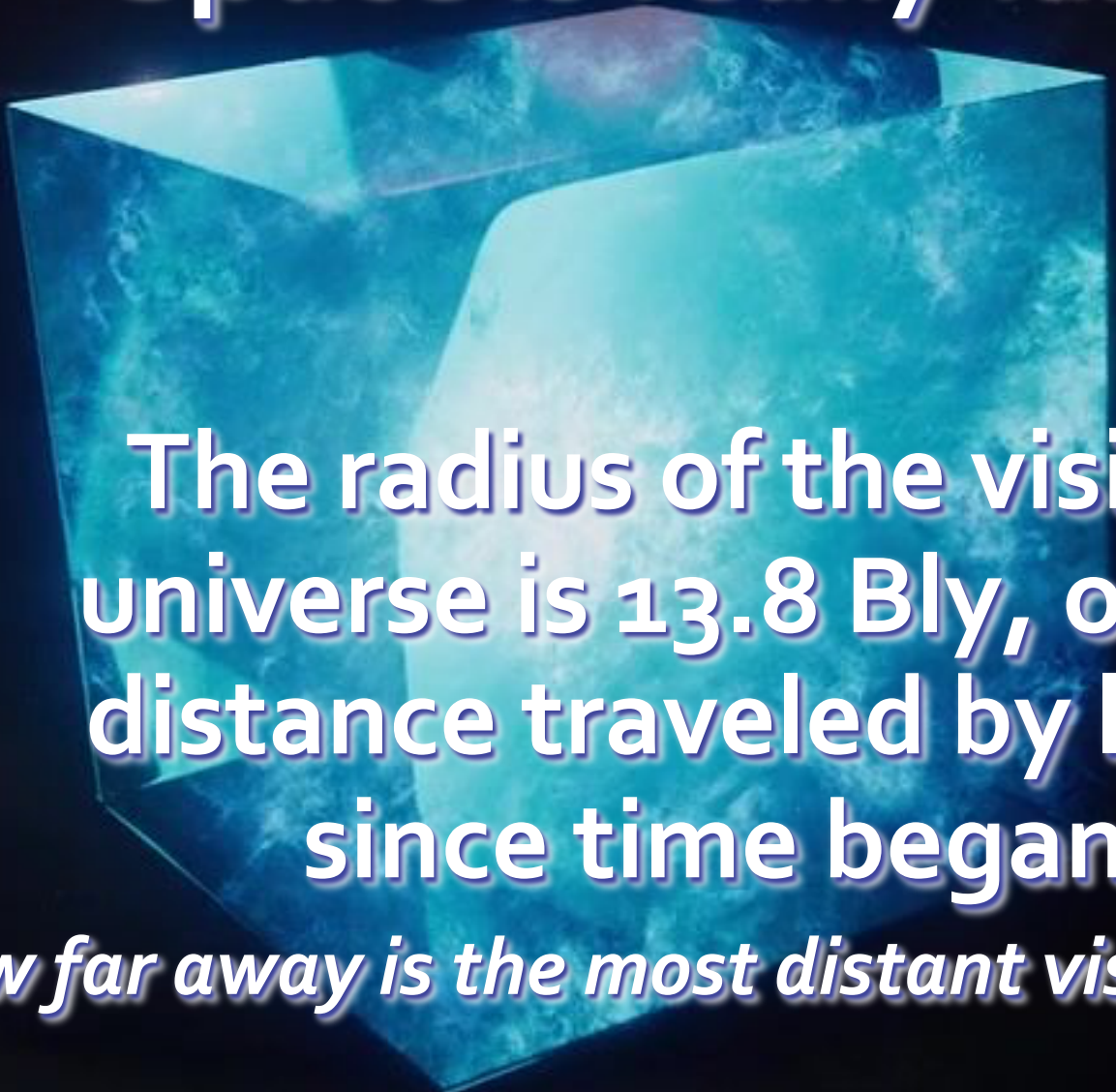
# Space is Transparent (Now)

**Galaxies: tracers of space**

Analogies: stars trace the grand structure of the Milky Way, dust traces air flow, etc.



# Space is really large!



The radius of the visible universe is 13.8 Bly, or the distance traveled by light since time began

*(how far away is the most distant visible object?)*



# Space is Malleable!

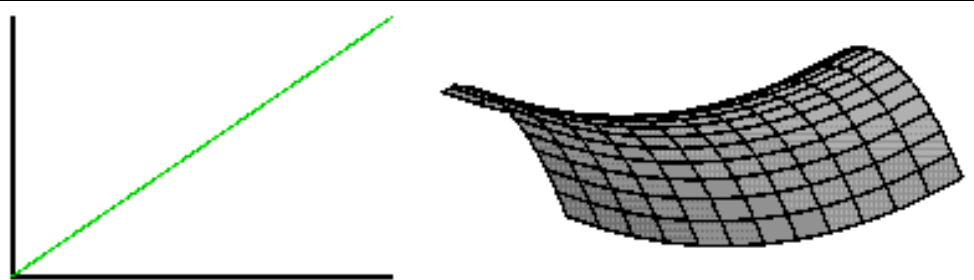
Gravity = Mass = Distortion = Bent light rays

# The Shape of Space:

The shape of space is set at  $t=0$ , its size will change

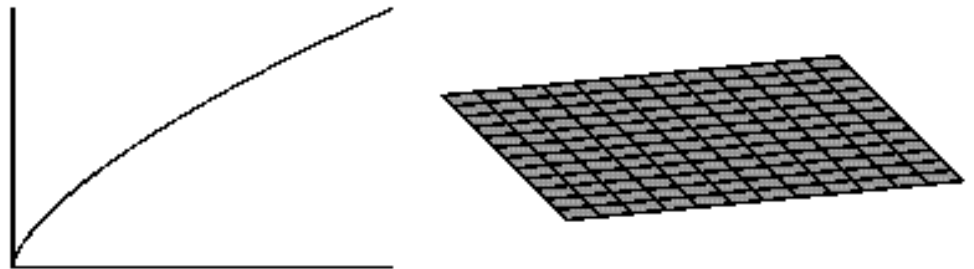
## Open

Infinite, positive curvature  
Fate: expand forever



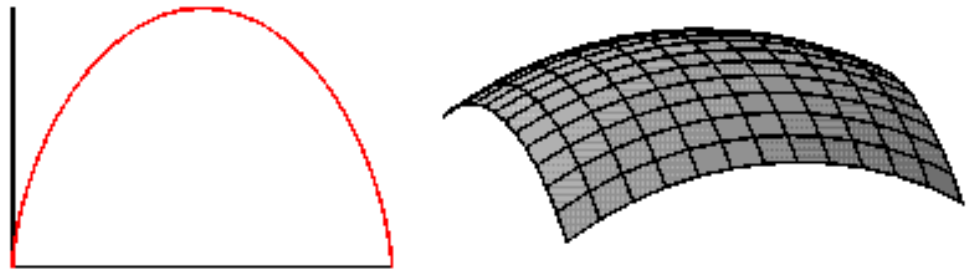
## Just right

zero curvature  
Fate: expansion stops @  $t = \infty$



## Closed

Finite: negative curvature  
Fate: collapse

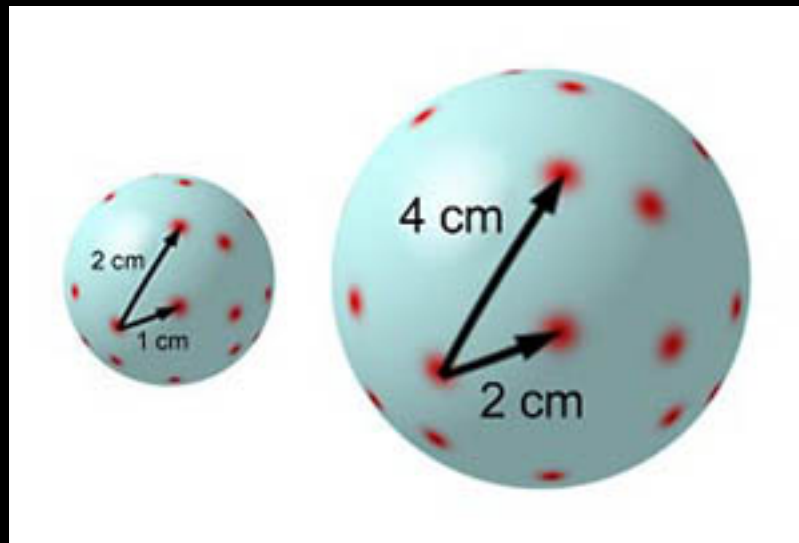




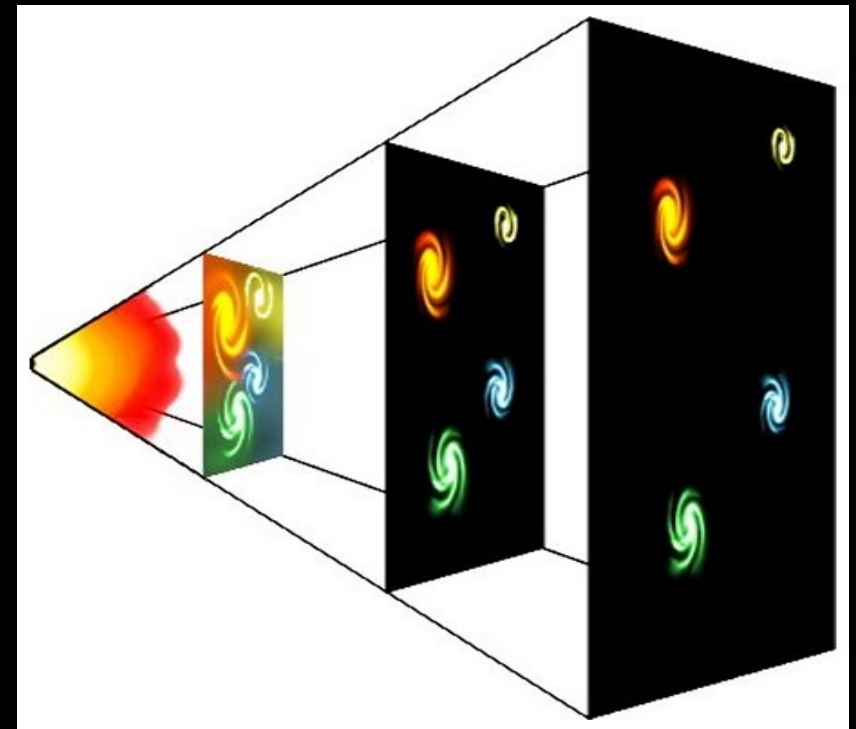
# Depicting the Expansion of Space: *Changes in the separations of two markers*

~~A static space: separations don't change~~

**Expanding Space: separations steadily increase**



**Time →**



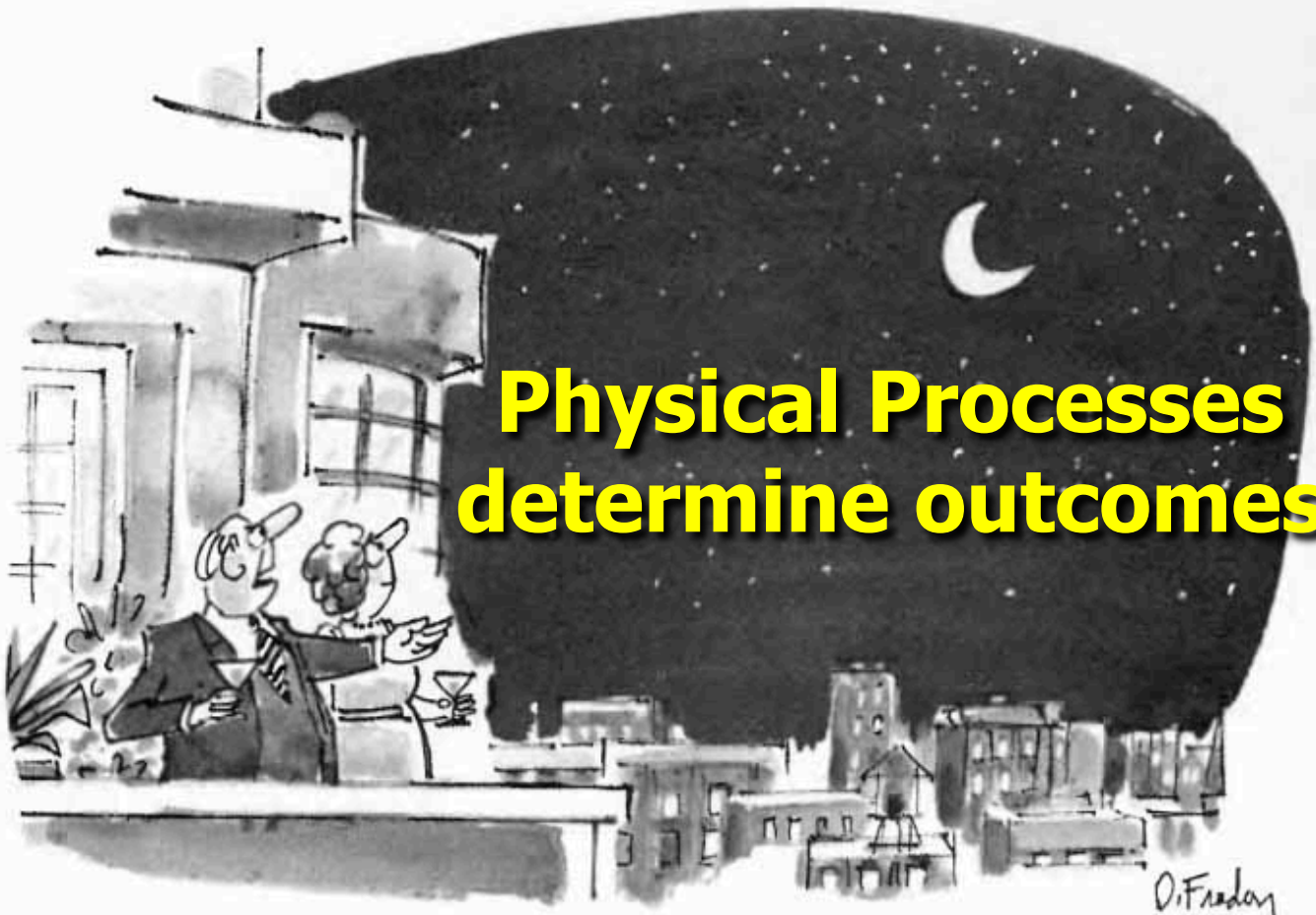
# Understanding Cosmology

## *Guiding Principles*

# Preparing for Cosmology

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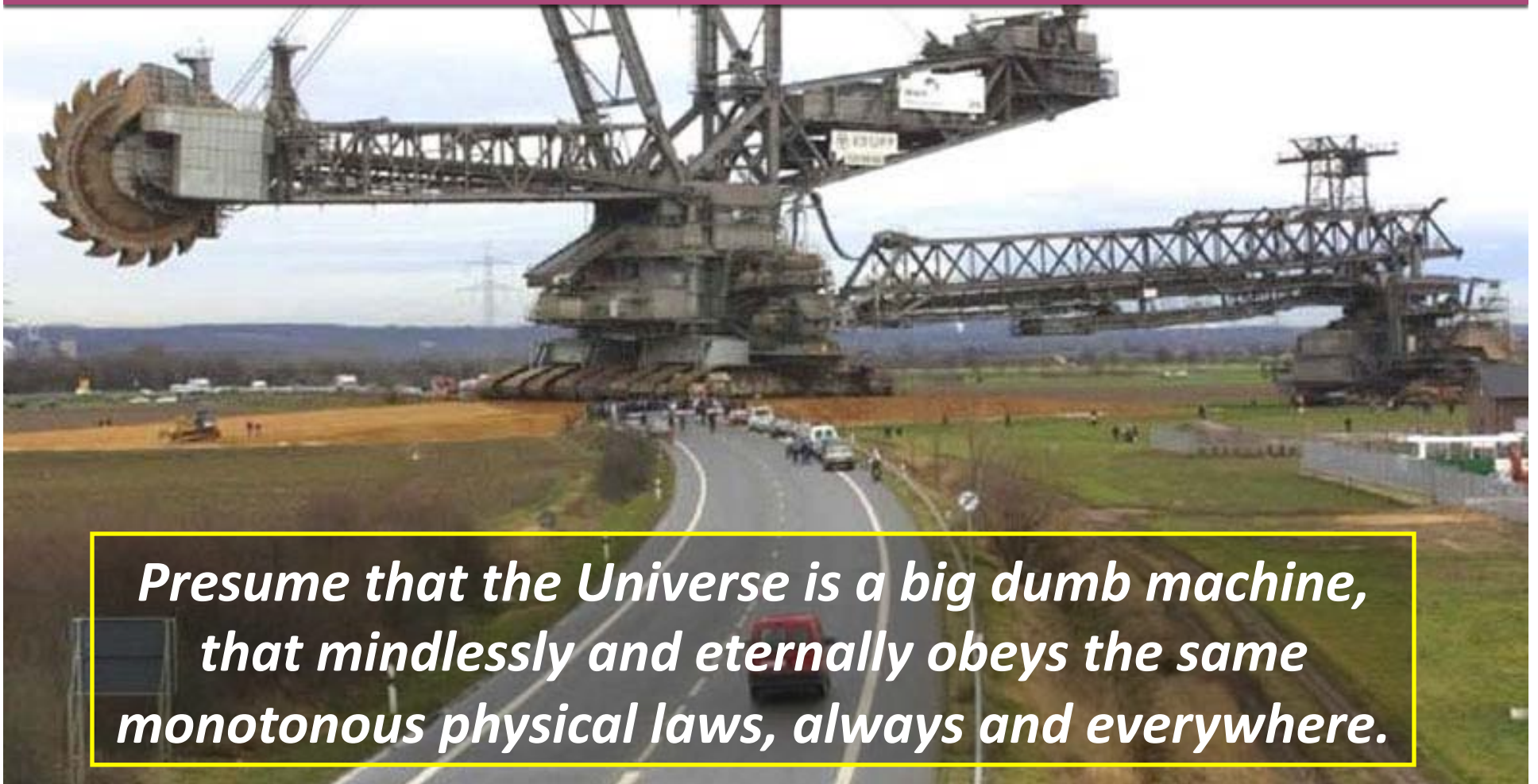
**Physical Processes  
determine outcomes**

*"Do you know why the universe works so well?  
God runs it like a business, that's why."*

Bucket-Wheel Excavator  
Picture Credit: T  
Hesse Krupp Technologies  
ap/leetDave

# Cosmological Principle I

*“Uniform Physics” . The same set of physical laws apply everywhere and everywhen.*



*Presume that the Universe is a big dumb machine, that mindlessly and eternally obeys the same monotonous physical laws, always and everywhere.*

# Cosmological Principle II

## *“structural Uniformity” (in Space)*

*“Copernican Principle”: the Earth and solar system are typical, not special*

*Our view of the Universe is also typical.*

*The entire Universe looks much the same and behaves in the same way everywhere.*

*All cosmic astronomers will agree on the current statistical properties of the Universe.*

**Cosmological Principle III**  
**"Evolutionary Uniformity"**  
**(in time).**

**The gross properties of the  
Universe can evolve through time**  
(at any and every given time, the spatial uniformity is maintained)

**The Universe that we see today  
hasn't necessarily always been  
this way.**

**If we can look back in time we'll see the  
Universe in a more youthful state**

**Fortunately this is easy to do! (Why??)**

# Big Bang Cosmology

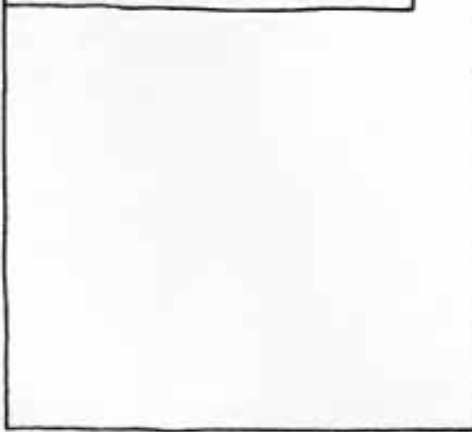
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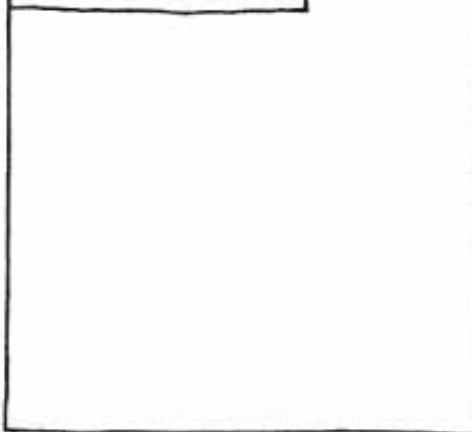
## BIG BANG COMIX

*ZUCKER*

A WHOLE LOT OF NOTHING...



THE BIG EMPTY...



STILL ZILCHVILLE...



DIDDLY-SQUAT-O-RAMA...



SUDDENLY!



AT LONG LAST — STUFF!



NEXT WEEK: ORIGINS OF THE THEORY OF CLOSET SPACE

# Homework 2 due Jan 23



**13.8 billion light years**