

# Cosmology & Culture

## Lecture 5

Wednesday April 29, 2009

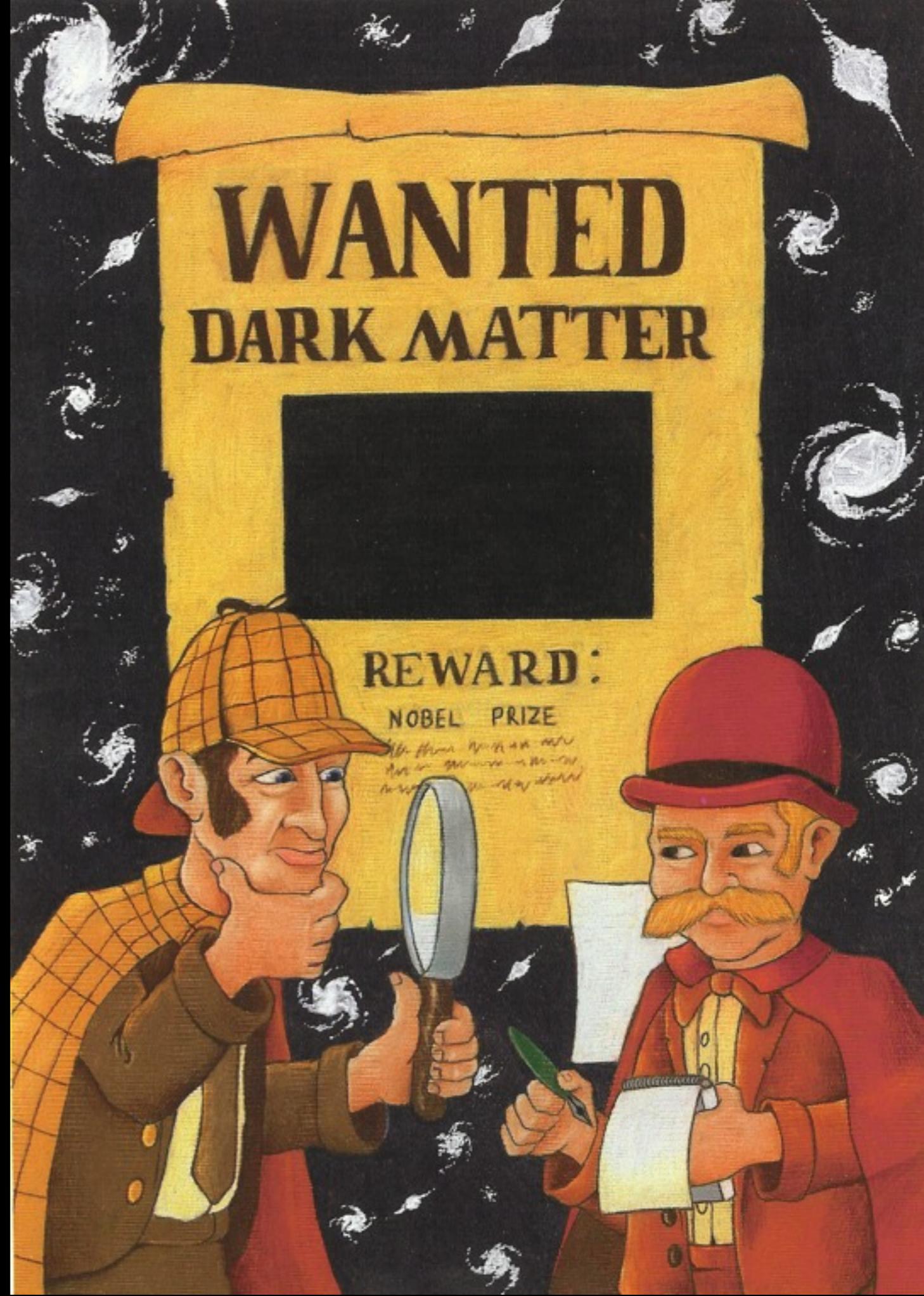
The Cosmic Uroboros

# “The Case of the Dark Matter”

from *World Book  
Science Year 1990*



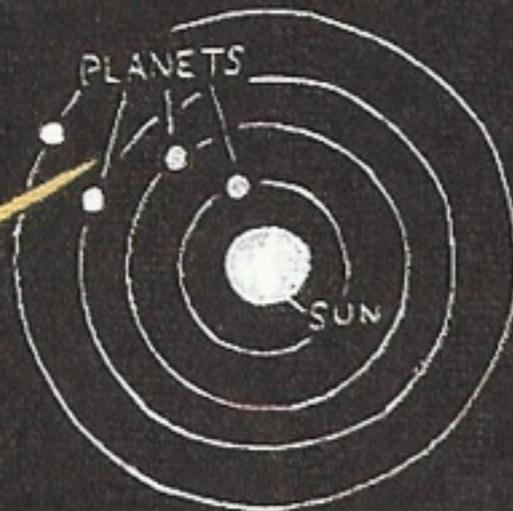
by Joel R. Primack



## Evidence for Dark Matter

Evidence that there is more matter in the universe than is visible rests on a theory of gravity, the force that keeps planets, stars, and other celestial objects in their orbits. The strength of this force depends on the mass of the orbiting objects and the distance between them. The amount of mass in the objects and their distance from each other determine the orbital speeds of the objects. Knowing orbital speeds and the distance between objects, astronomers can calculate the total mass in the orbital system.

THE PLANETS NEAREST THE SUN ORBIT FASTER THAN THOSE FARTHER AWAY. THIS IS BECAUSE THE SUN ACCOUNTS FOR ALMOST ALL OF THE MASS IN OUR SOLAR SYSTEM.



LIKE CARS TRAVELING AT DIFFERENT SPEEDS.

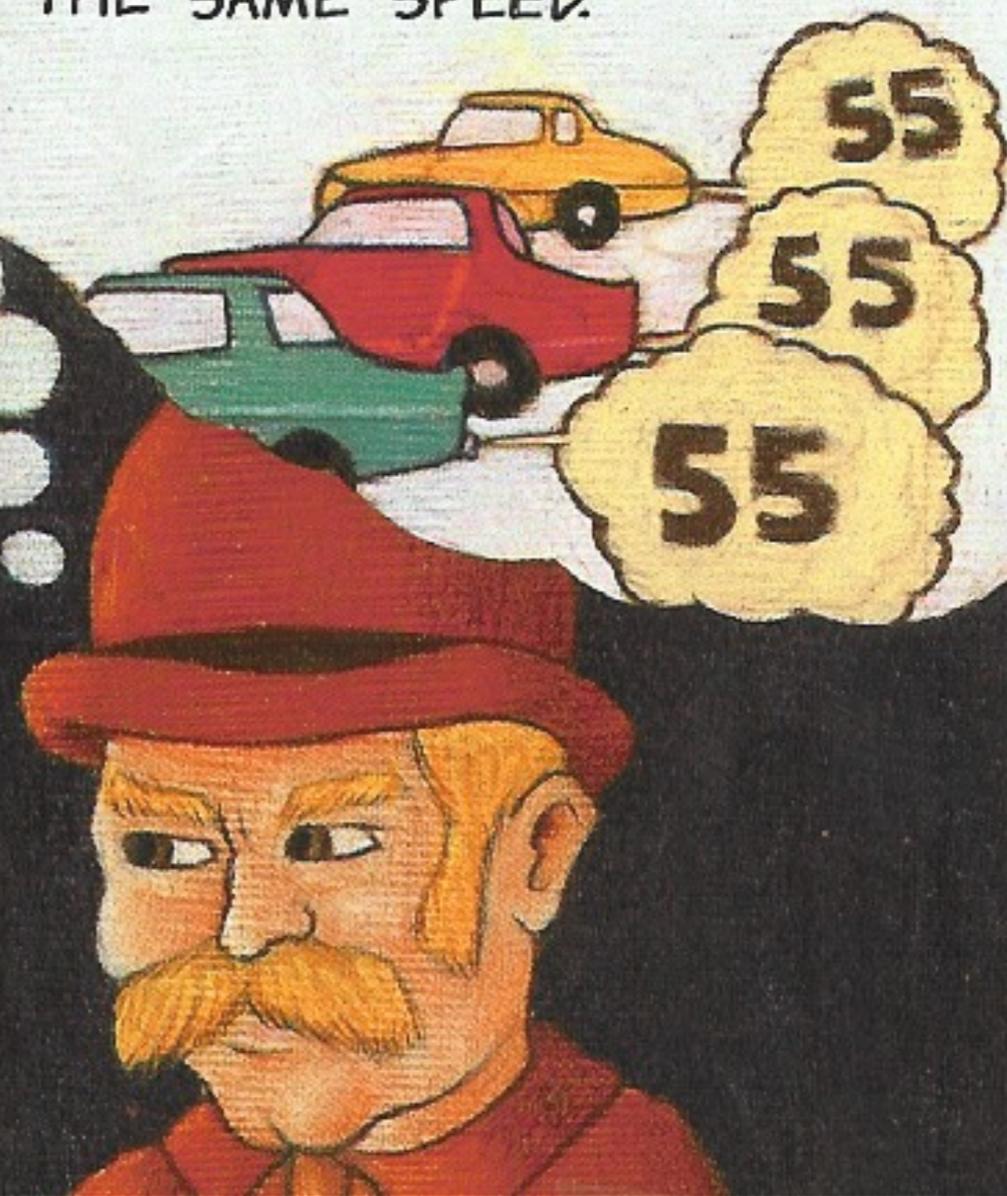
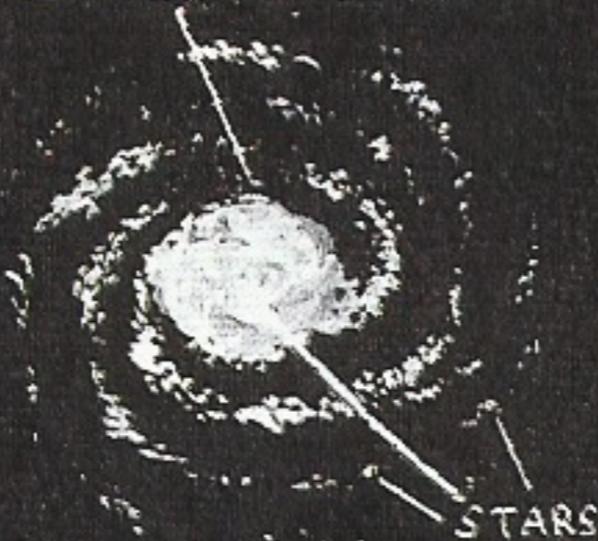


STARS IN GALAXIES  
ORBIT AT ABOUT THE  
SAME SPEEDS NO MATTER  
HOW FAR THEY ARE FROM THE  
MASSIVE GALACTIC CENTER. SO  
THERE MUST BE MUCH MORE  
MATTER IN THE OUTER REACHES  
OF THE GALAXY THAN IS VISIBLE.

LIKE CARS WITH THEIR  
CRUISE CONTROLS SET  
AT THE SAME SPEED.

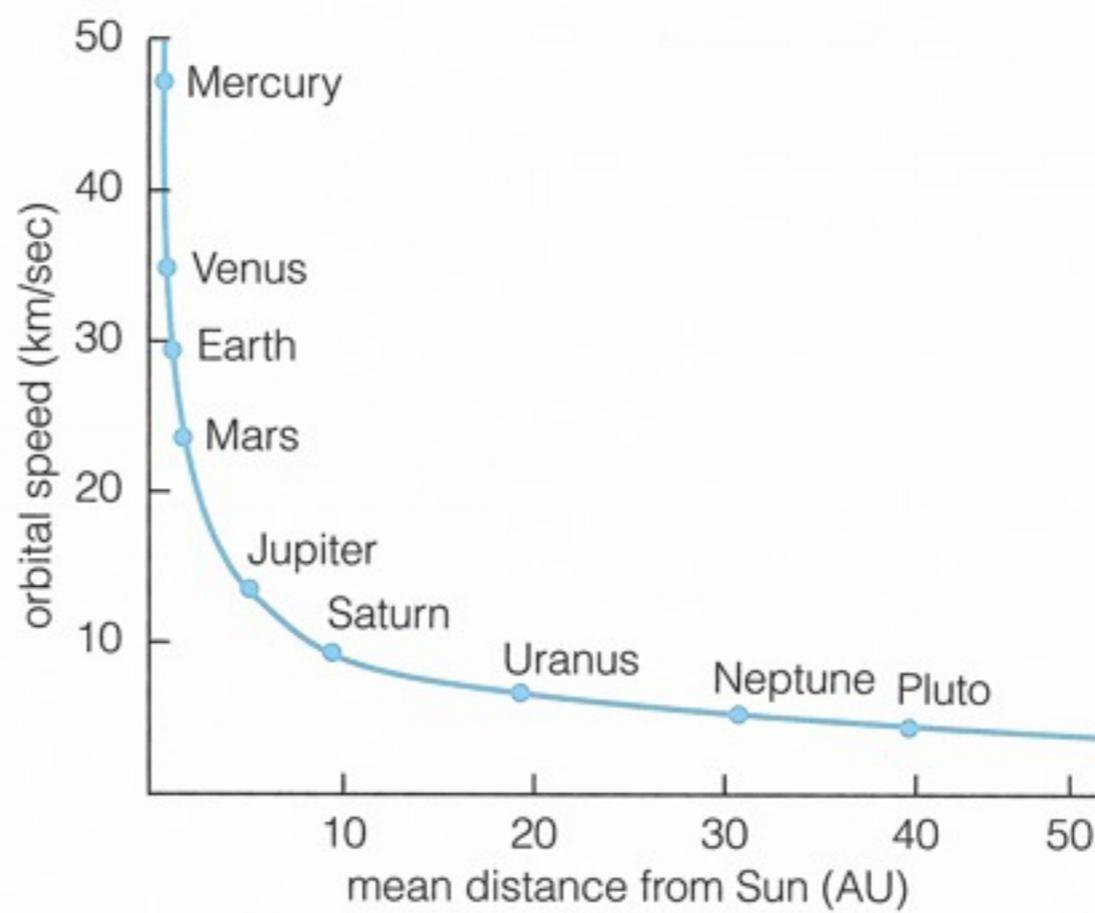


CENTER OF GALAXY



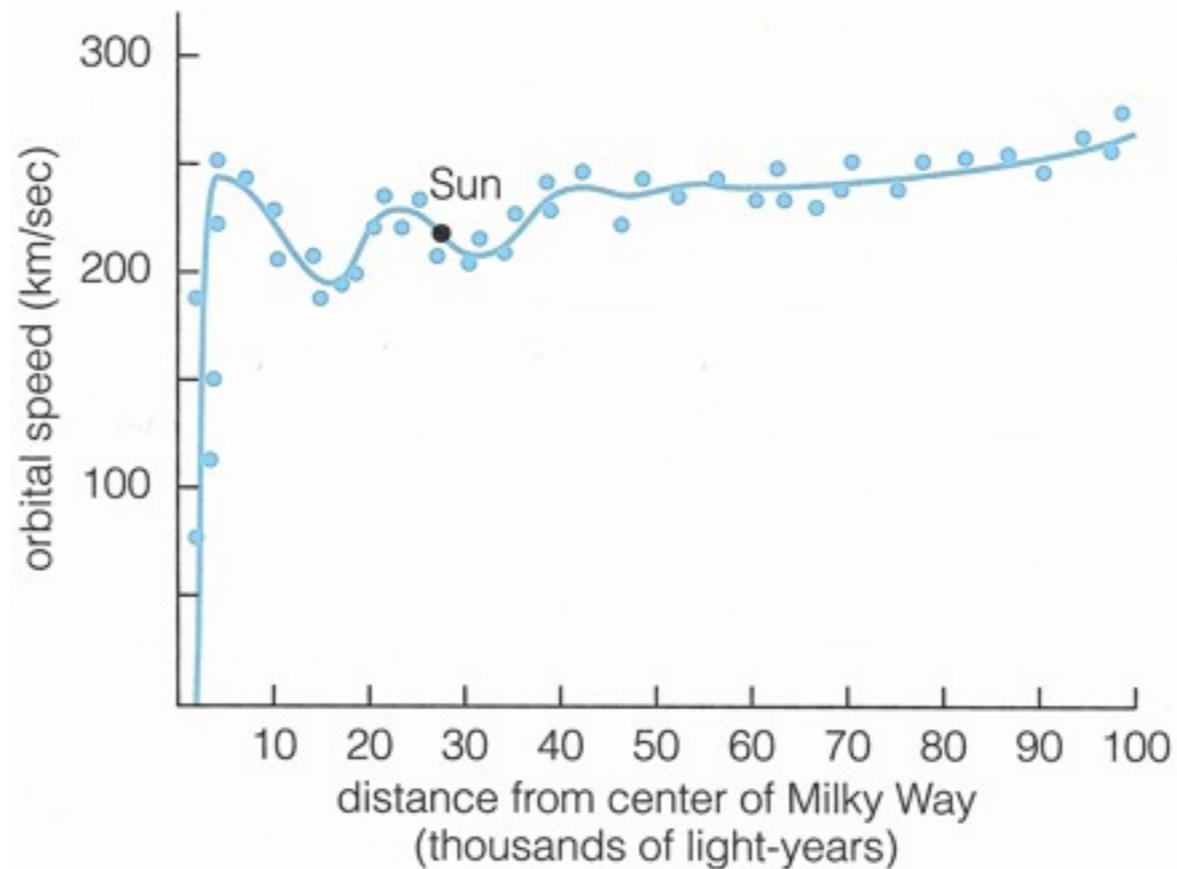
# Rotation Curves

## Solar System



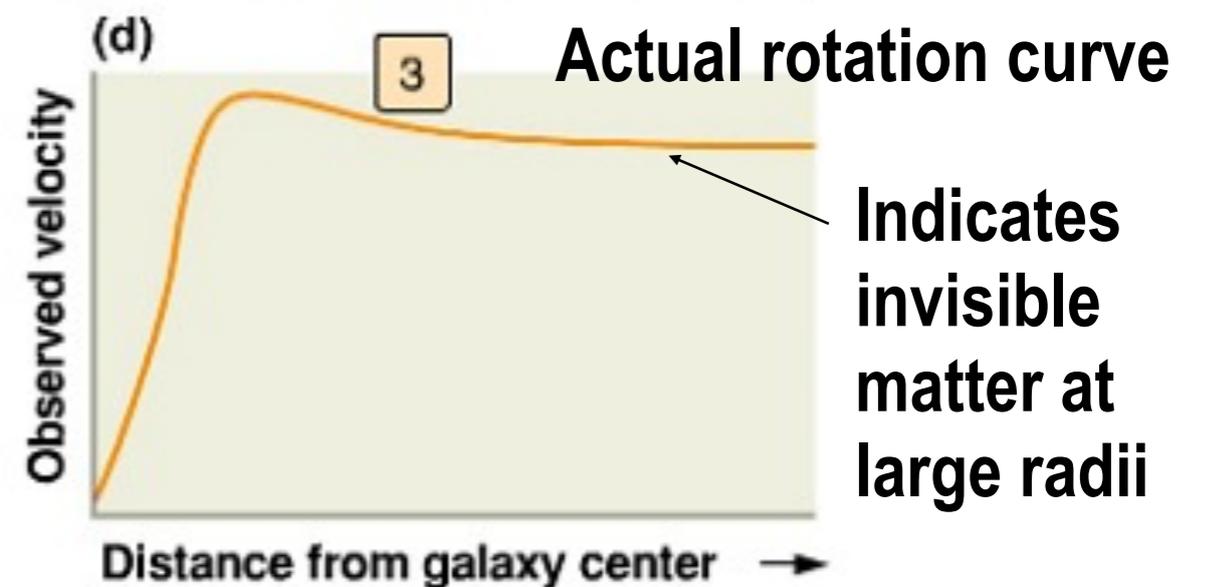
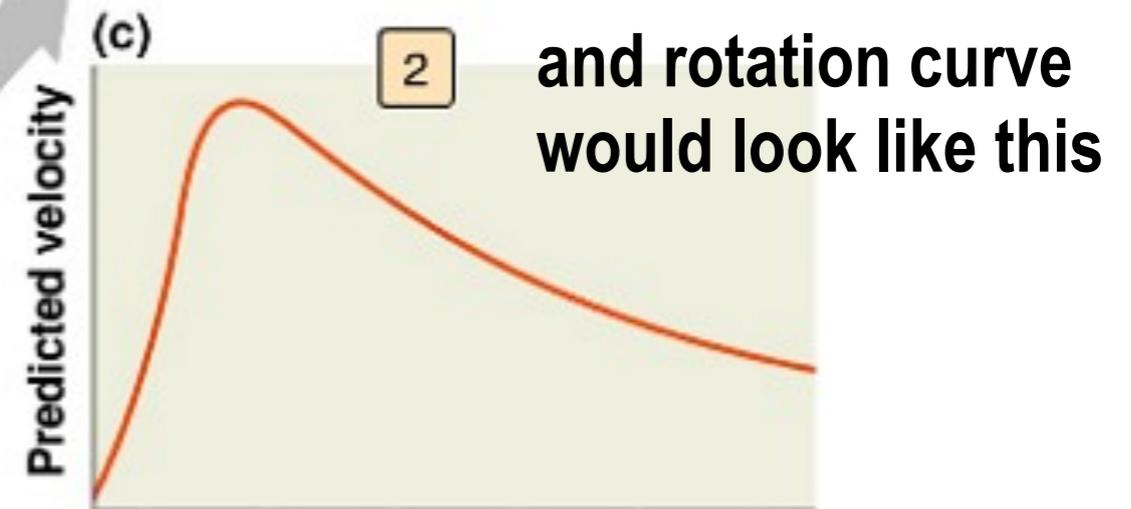
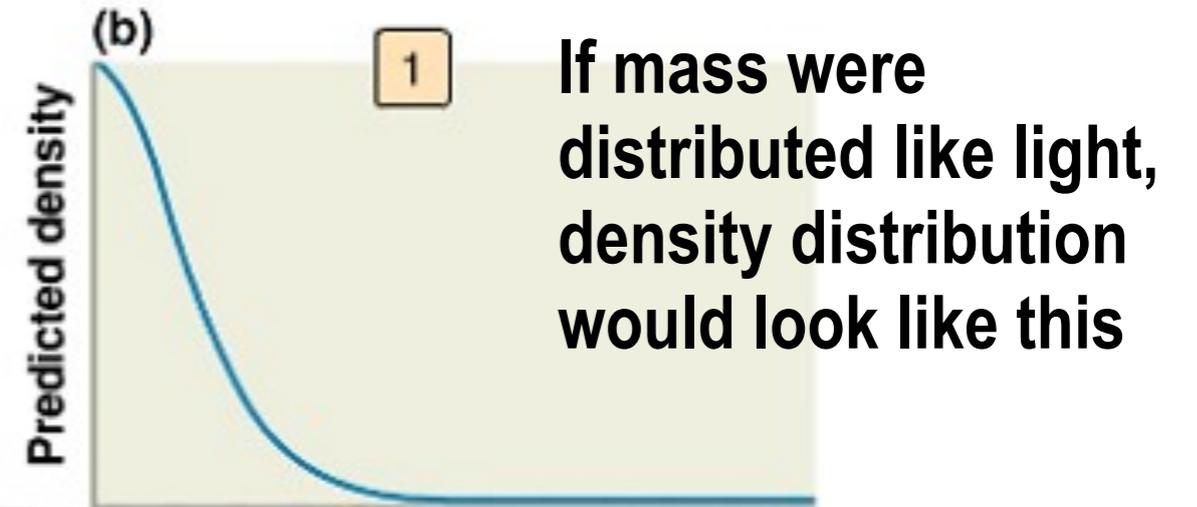
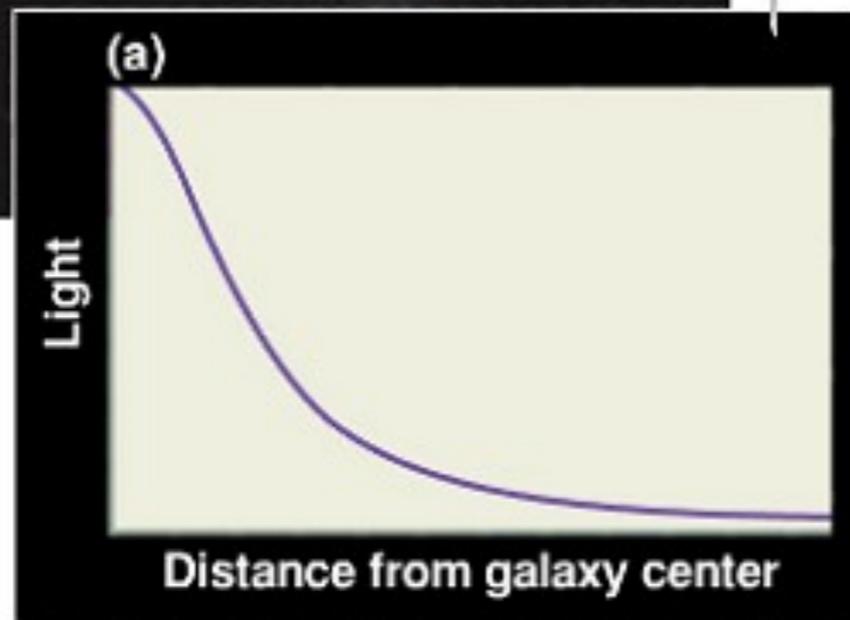
The rotation curve for the planets in our solar system.

## Milky Way



The rotation curve for the Milky Way Galaxy.

# Galaxies are held together by dark matter



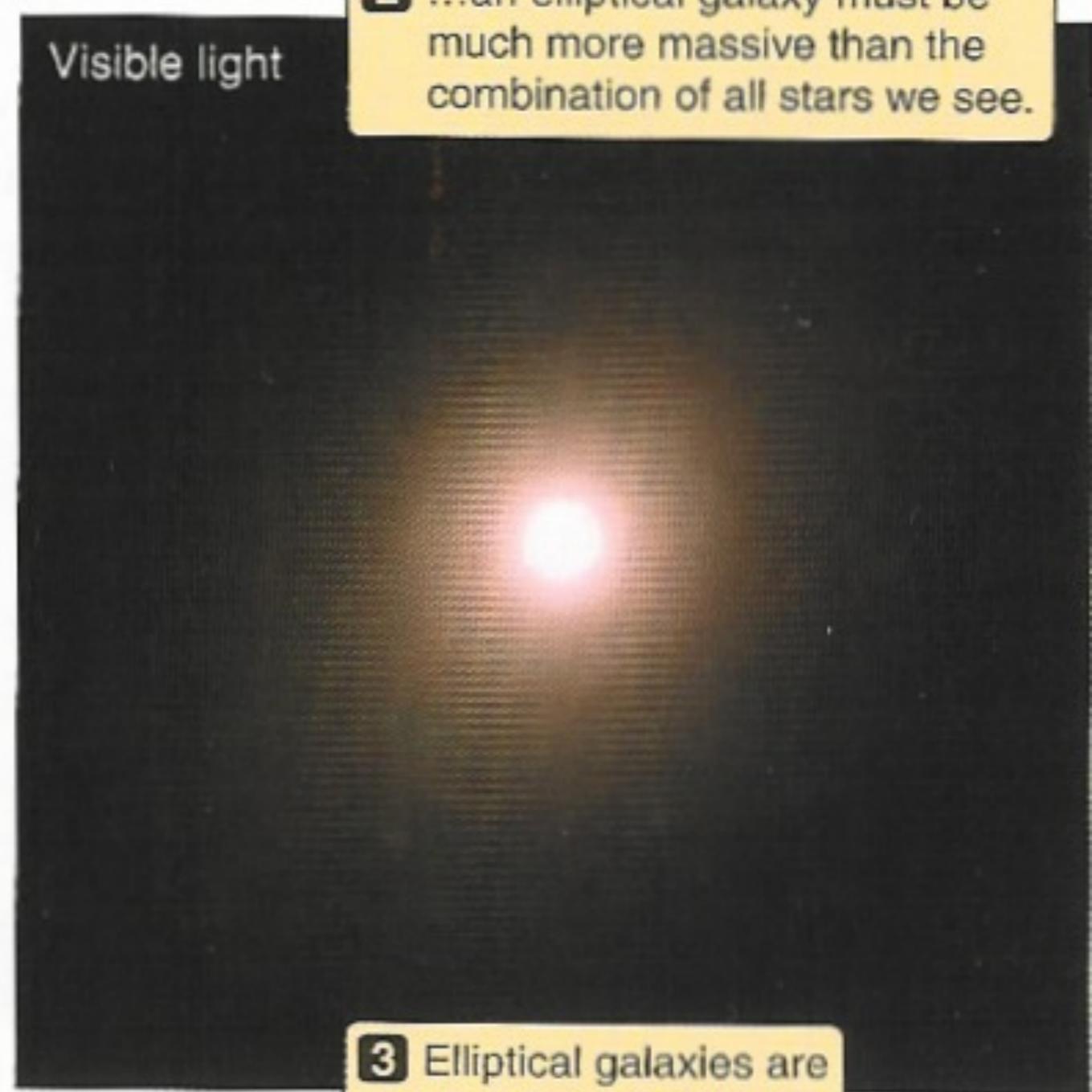
**1** For gravity to hold onto this hot X-ray emitting gas...

X-rays



**2** ...an elliptical galaxy must be much more massive than the combination of all stars we see.

Visible light



**3** Elliptical galaxies are mostly dark matter.

# Most of the Mass is in the Dark Matter Halo

Normal luminous matter galaxy

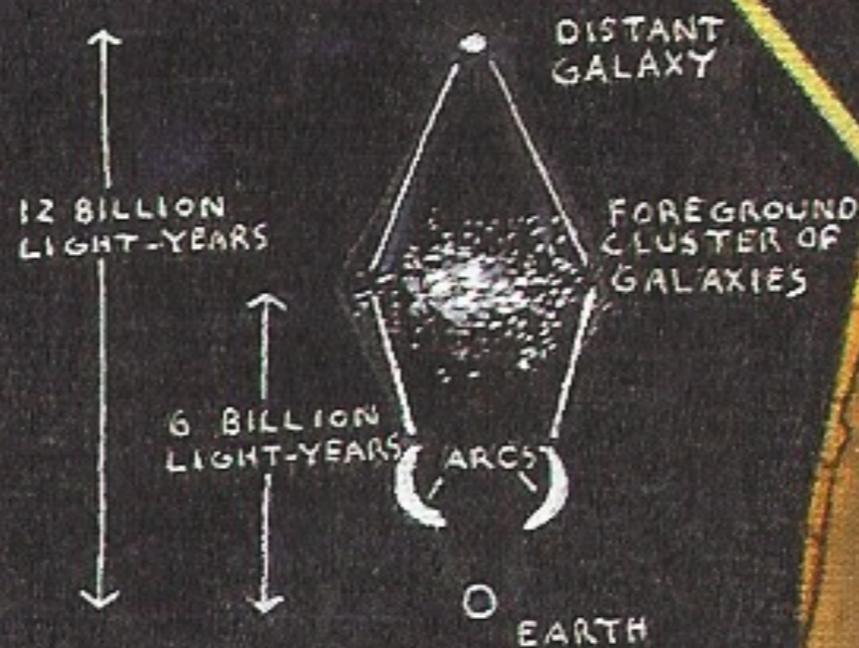
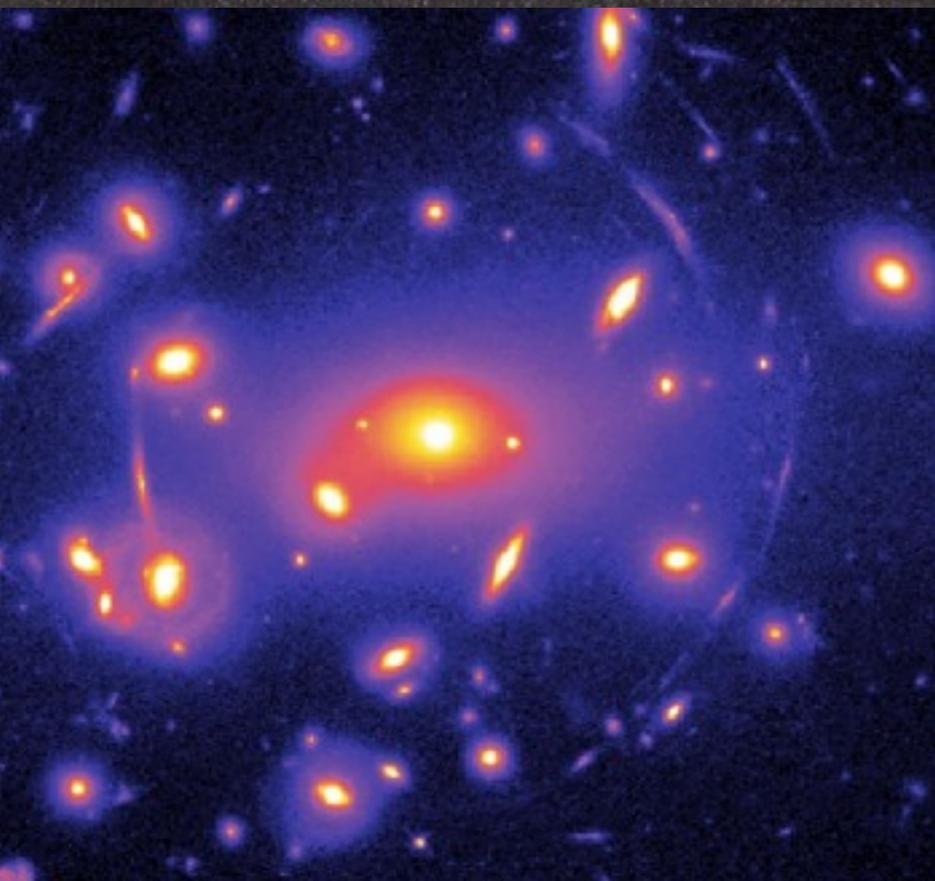
Radius of Dark Matter Halo

Dark matter halo (denser in center)



# Gravitational Lensing Confirms Dark Matter in Galaxy Clusters

LIGHT COMING FROM A DISTANT GALAXY IS BENT BY THE GRAVITATIONAL FIELD OF AN OBJECT BETWEEN IT AND EARTH. THE DISTANT GALAXY'S LIGHT APPEARS AS ONE OR MORE ARCS, AS SEEN FROM EARTH.



# Jupiter-sized objects are not good dark matter suspects

JUPITER-SIZED OBJECTS ARE NOT GOOD SUSPECTS. THERE PROBABLY COULDN'T BE OBJECTS MADE OF ORDINARY MATTER OUT THAT FAR FROM THE CENTER OF THE GALAXY. THEY'D HAVE FALLEN IN TOWARD THE CENTER THE WAY THE VISIBLE STARS AND GASES HAVE.

DARK MATTER HALO

GALAXY

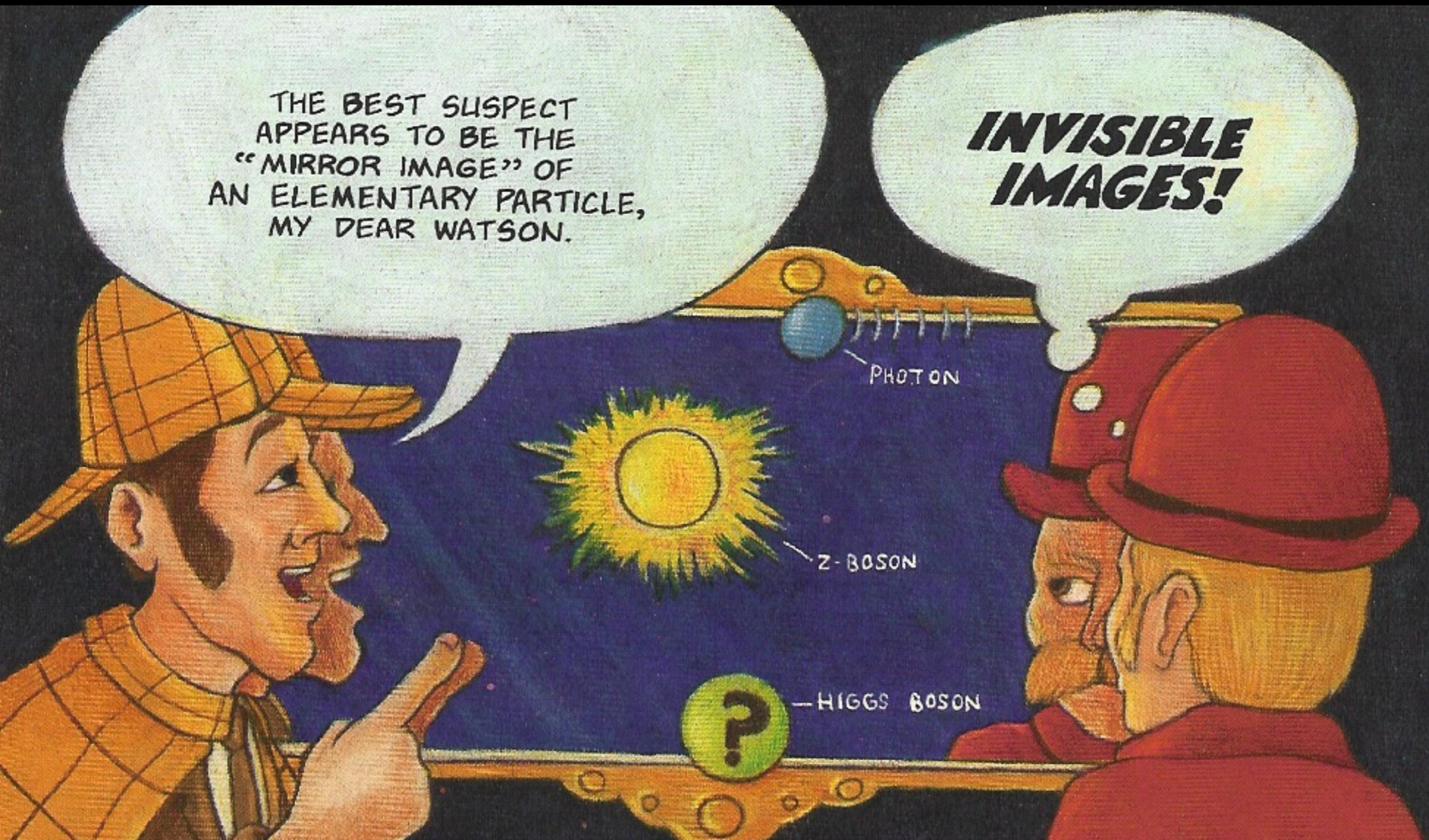
GAS BALLS



# Black Holes are not good suspects either



# Photon, Z, and Higgs Supersymmetric Partners (*Photino, Zino, Higgsino*) are Prime Suspects

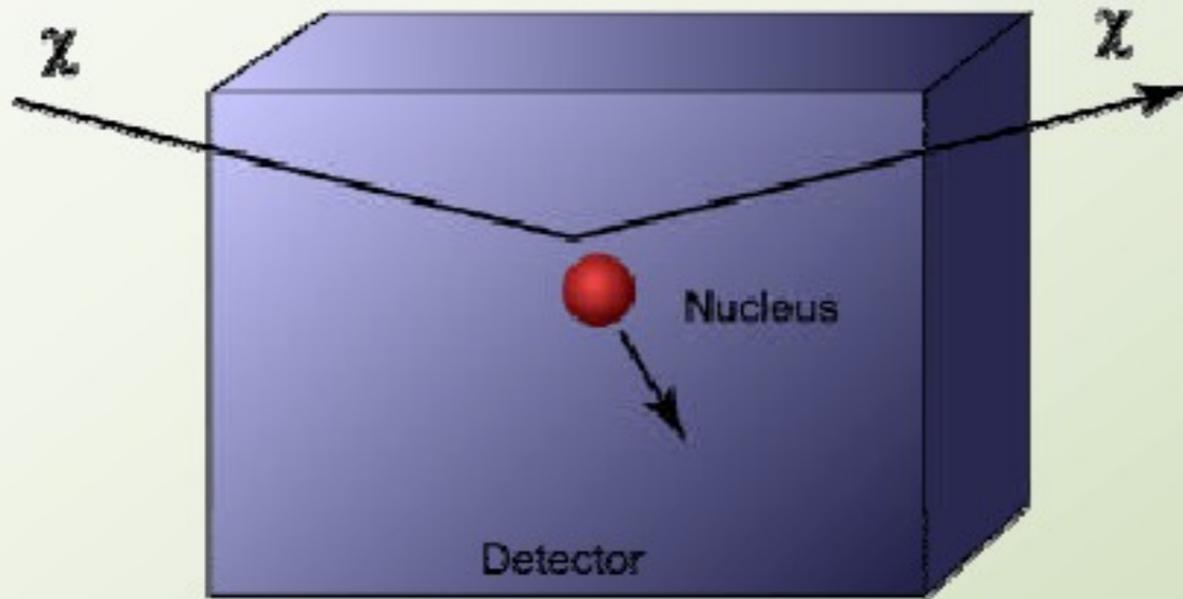


Supersymmetry is the basis of most attempts, such as superstring theory, to go beyond the current “Standard Model” of particle physics. Heinz Pagels and Joel Primack pointed out in a 1982 paper that the lightest supersymmetric partner particle is a good candidate for the dark matter particles – weakly interacting massive particles (**WIMPs**).

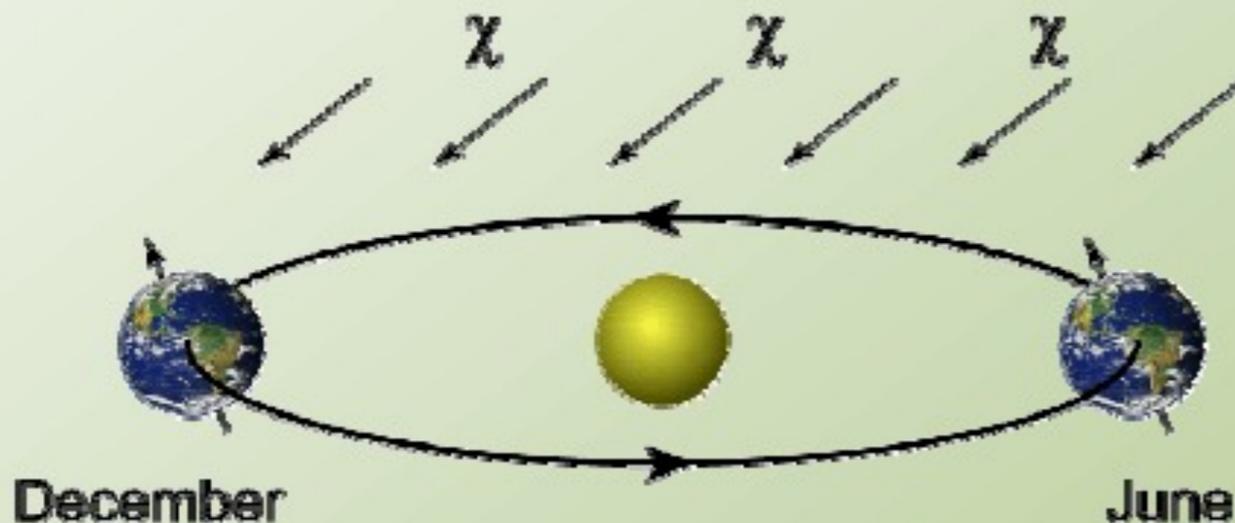
Michael Dine and others pointed out that the **axion**, a particle needed to save the strong interactions from violating CP symmetry, could also be the dark matter particle. Searches for both are underway.

# Experiments are Underway for Detection of WIMPs

## Direct detection - general principles



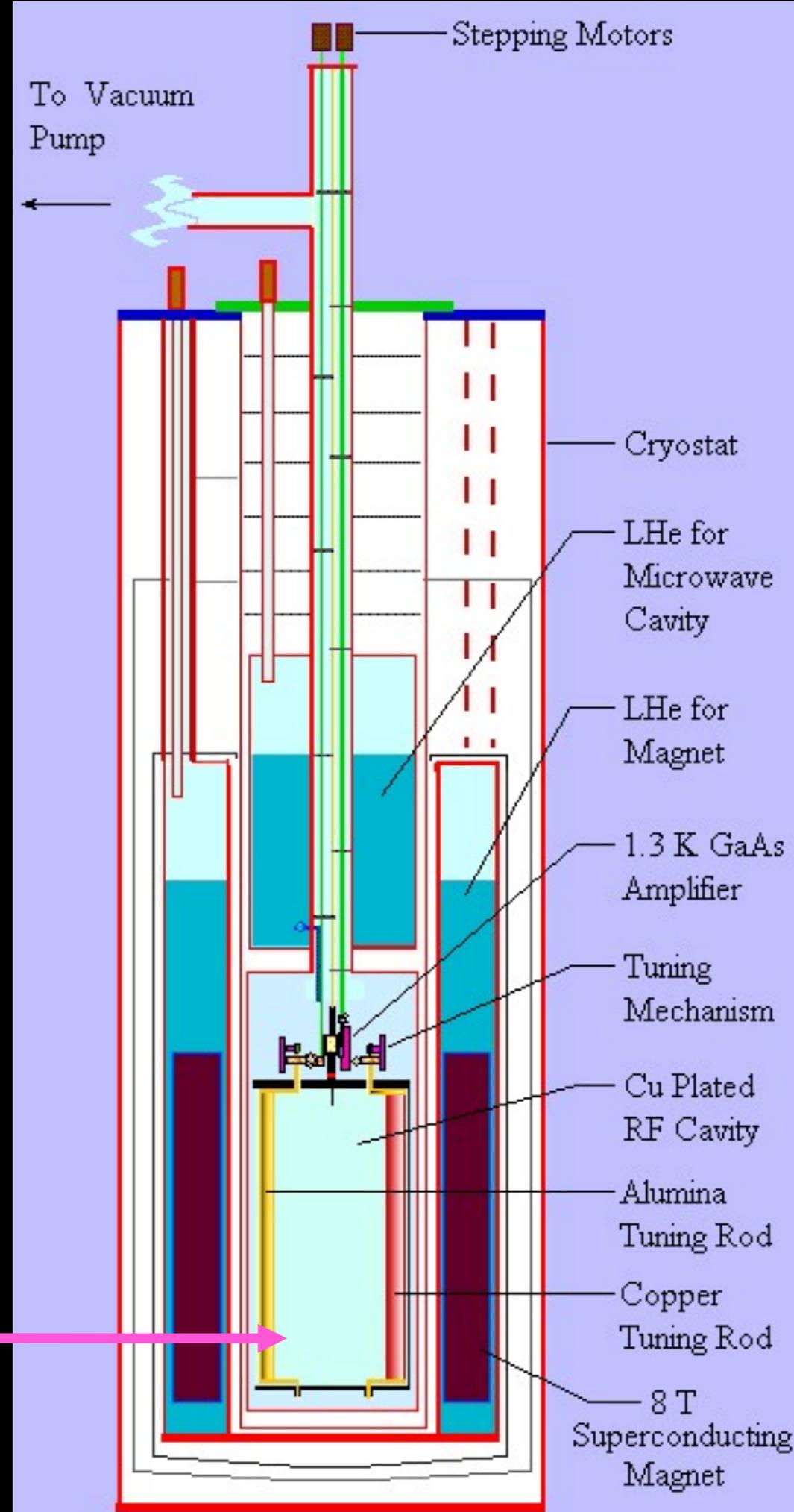
- WIMP + nucleus  $\rightarrow$  WIMP + nucleus
- Measure the nuclear recoil energy
- Suppress backgrounds enough to be sensitive to a signal, **or...**



- Search for an annual modulation due to the Earth's motion around the Sun

and also AXIONS

The diagram at right shows the layout of the axion search experiment now underway at the Lawrence Livermore National Laboratory. Axions would be detected as extra photons in the Microwave Cavity.



# Supersymmetric WIMPs

Spin is a fundamental property of elementary particles. Matter particles like electrons and quarks (protons and neutrons are each made up of three quarks) have spin  $\frac{1}{2}$ , while force particles like photons, W,Z, and gluons have spin 1. The supersymmetric partners of electrons and quarks are called selectrons and squarks, and they have spin 0. The supersymmetric partners of the force particles are called the photino, Winos, Zino, and gluinos, and they have spin  $\frac{1}{2}$ , so they might be matter particles. The lightest of these particles might be the photino. Whichever is lightest should be stable, so it is a natural candidate to be the dark matter WIMP.

Supersymmetry does not predict its mass, but it must be more than 50 times as massive as the proton since it has not yet been produced at accelerators. But if it exists it might be made soon at the Large Hadron Collider in Geneva, Switzerland.

# Supersymmetric WIMPs

When the British physicist Paul Dirac first combined Special Relativity with quantum mechanics, he found that this predicted that for every ordinary particle like the electron, there must be another particle with the opposite electric charge – the anti-electron (positron). Similarly, corresponding to the proton there must be an anti-proton. Supersymmetry appears to be required to combine General Relativity (our modern theory of space, time, and gravity) with the other forces of nature (the electromagnetic, weak, and strong interactions). The consequence is **another doubling** of the number of particles, since supersymmetry predicts that for every particle that we now know, including the antiparticles, there must be another, thus far undiscovered particle with the same electric charge but with *spin* differing by half a unit.

Spin	Matter (fermions)	Forces (bosons)
2		graviton
1		photon, $W^\pm$ , $Z^0$ gluons
1/2	quarks $u, d, \dots$ leptons $e, \nu_e, \dots$	
0		Higgs bosons axion

# Supersymmetric WIMPs

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after doubling

Spin	Matter (fermions)	Forces (bosons)	Hypothetical Superpartners	Spin
2		graviton	<u>gravitino</u>	3/2
1		photon, $W^\pm, Z^0$ gluons	<u>photino</u> , winos, <u>zino</u> , gluinos	1/2
1/2	quarks $u, d, \dots$ leptons $e, \nu_e, \dots$		squarks $\tilde{u}, \tilde{d}, \dots$ sleptons $\tilde{e}, \tilde{\nu}_e, \dots$	0
0		Higgs bosons axion	<u>Higgsinos</u> <u>axinos</u>	1/2

Note: Supersymmetric cold dark matter candidate particles are underlined.

## An Open or Shut Case

Astronomers want to know for sure whether dark matter exists so they can calculate how much matter there is in the universe. The total amount of matter will determine the ultimate fate of the universe, which right now is expanding rapidly in all directions like an enormous balloon.

IF THERE IS NOT ENOUGH MATTER, THE UNIVERSE WILL CONTINUE TO EXPAND FOREVER UNTIL ALL THE STARS BURN OUT. THIS ICY ENDING WOULD BE **THE BIG CHILL.**

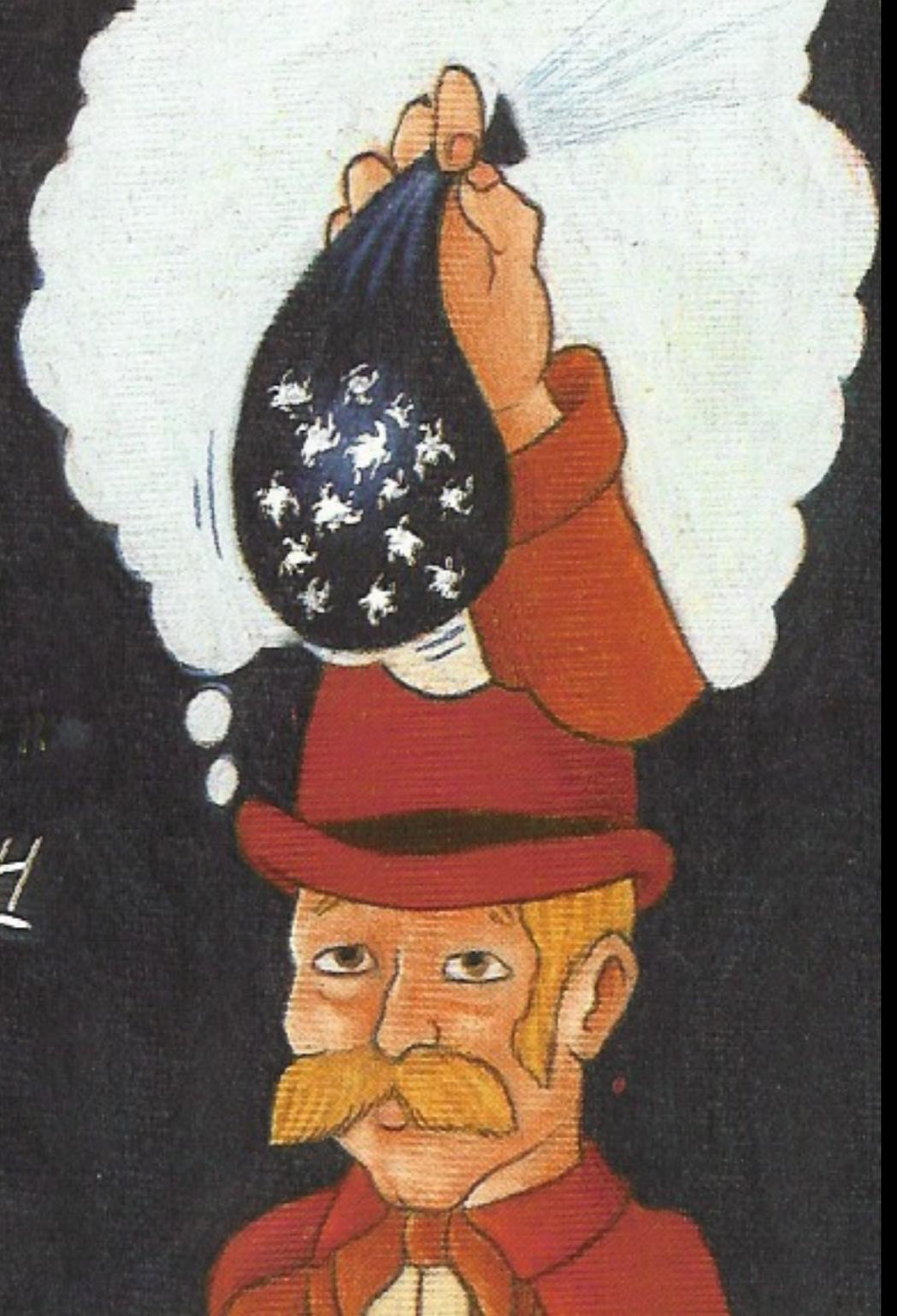


BIG CHILL



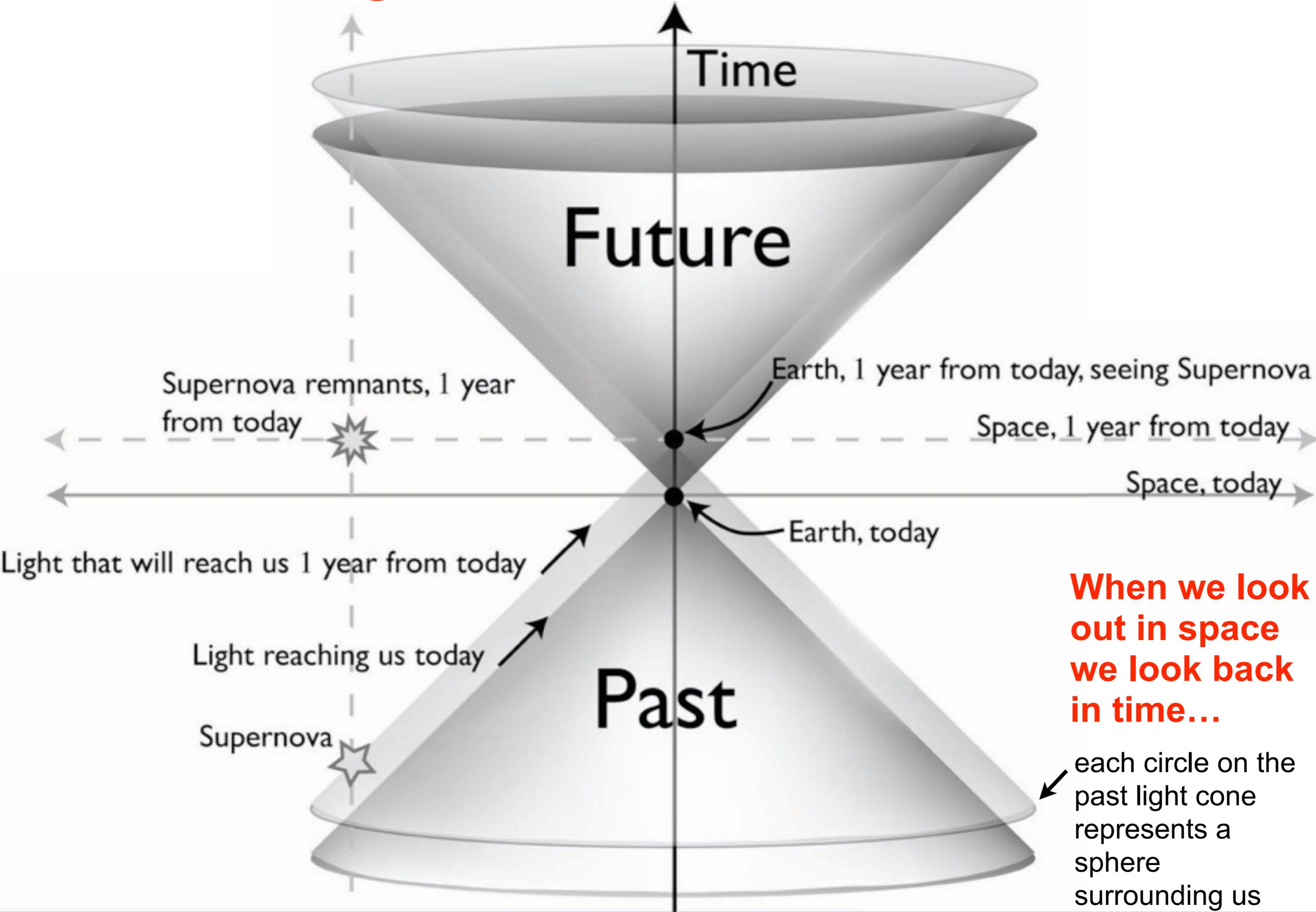
IF THERE IS TOO MUCH  
MATTER, THE UNIVERSE'S  
EXPANSION WILL EVENTUALLY  
HALT DUE TO THE FORCE OF  
GRAVITY, AND THE UNIVERSE  
WILL BEGIN TO SHRINK  
UNTIL IT COLLAPSES IN  
WHAT IS CALLED  
*THE BIG CRUNCH.*

BIG CRUNCH



**We now know that there is not nearly enough matter for a big crunch.  
Instead, Dark Energy is making the universe expand faster and faster.**

# Lightcone of Past and Future



# Einstein's Special Theory of Relativity



<http://physics.ucsc.edu/~snof/er.html>

[About Einstein's Rocket](#)[Thought Experiments](#)[1-D Space Rally](#)[Games](#)[Credits](#)

## About Einstein's Rocket

### General Info

This set of Java applets is designed to teach the basic principles of special relativity. The first applet goes through various thought experiments to give you an understanding of why relativity works the way it does. The second applet (1-D Space Rally) helps demonstrate why the "twin paradox" is, in fact, not a paradox. And the third applet contains several games which allow you to get a better intuition about the effects of relativity on motion at high velocities. To access the applets, simply click the links at the top of this page.

This page is best viewed in a [modern browser](#) with support for [CSS](#).

If the applets will not load, check to make sure that your browser supports Java and has Java enabled.

### Background

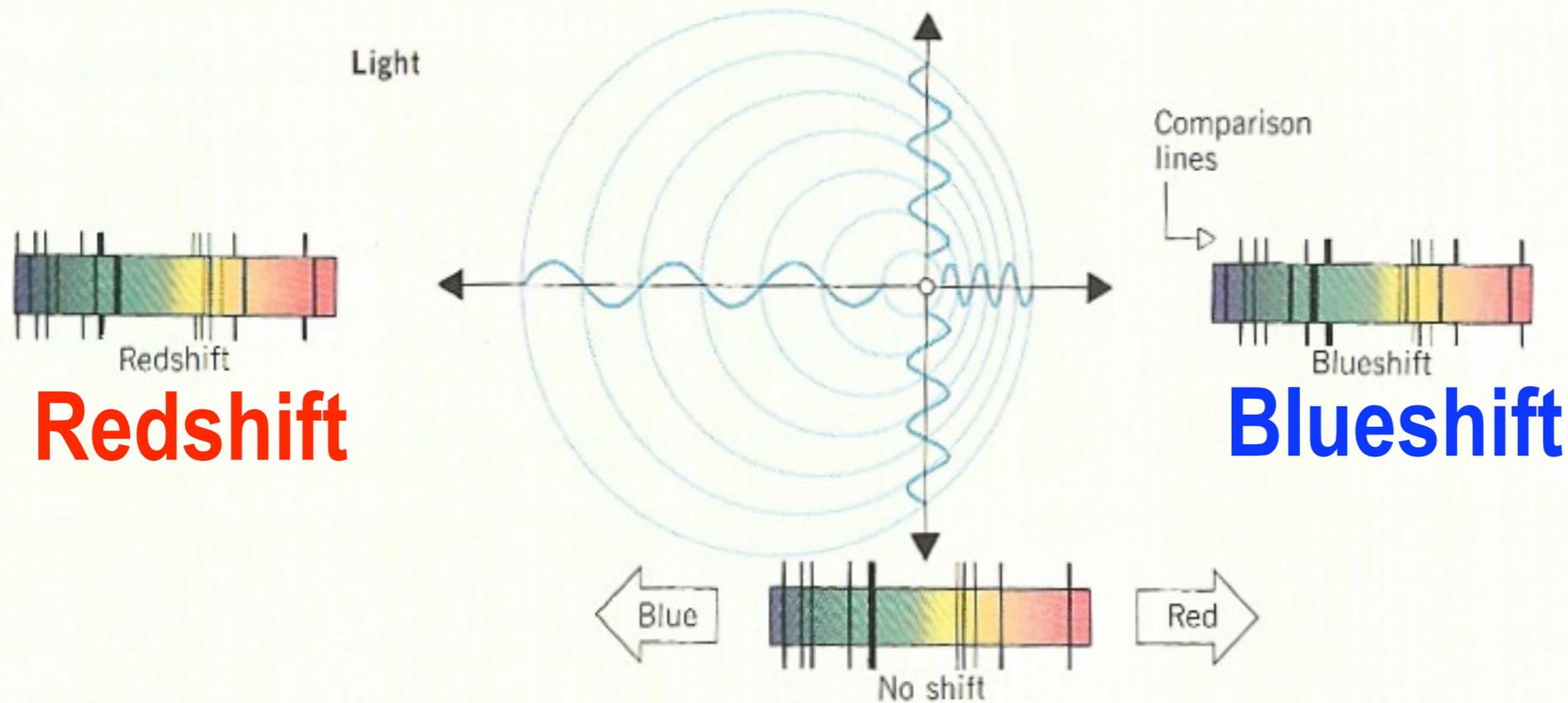
These three programs were originally designed and written for an Apple II by [Joel Primack](#) and Eric Eckert in the early 1980s. The Java version was coded by Devin Kelly-Sneed under the supervision of Joel Primack.

### Contact Info

If you encounter a bug in any of the applets or in the website, please send an email describing the problem to [EinsteinsRocket@gmail.com](mailto:EinsteinsRocket@gmail.com). If possible, also include what operating system and browser you're using, as well as any other info that you think may helpful to us in solving the problem. Non-bug related feedback is also welcome at the same email address.

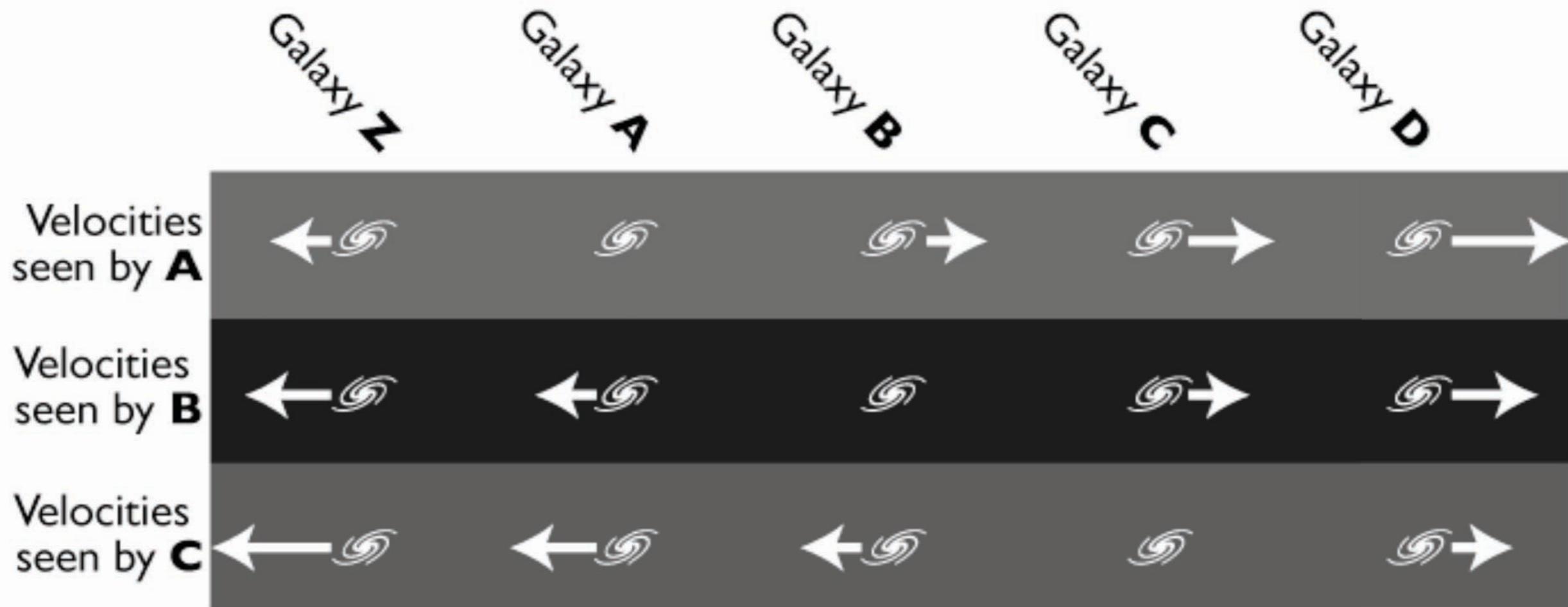
# Motion Away from Us: Redshift

The Doppler shift for light waves. In the direction of the motion, the waves appear compressed, so a blueshift is seen in the positions of the spectral lines of the source. If the source is moving away, the waves appear to be stretched out, and a redshift is seen. At right angles to the motion, no shift is seen in the spectral lines.



# How redshift shows that the universe is expanding

- The laws of physics are the same throughout the universe
- Hot atoms emit characteristic patterns of colors
- The whole pattern is shifted toward red (longer wavelengths) if atoms are moving away from us
- Galaxy redshifts increase with the distance of distant galaxies, showing that the universe is expanding.



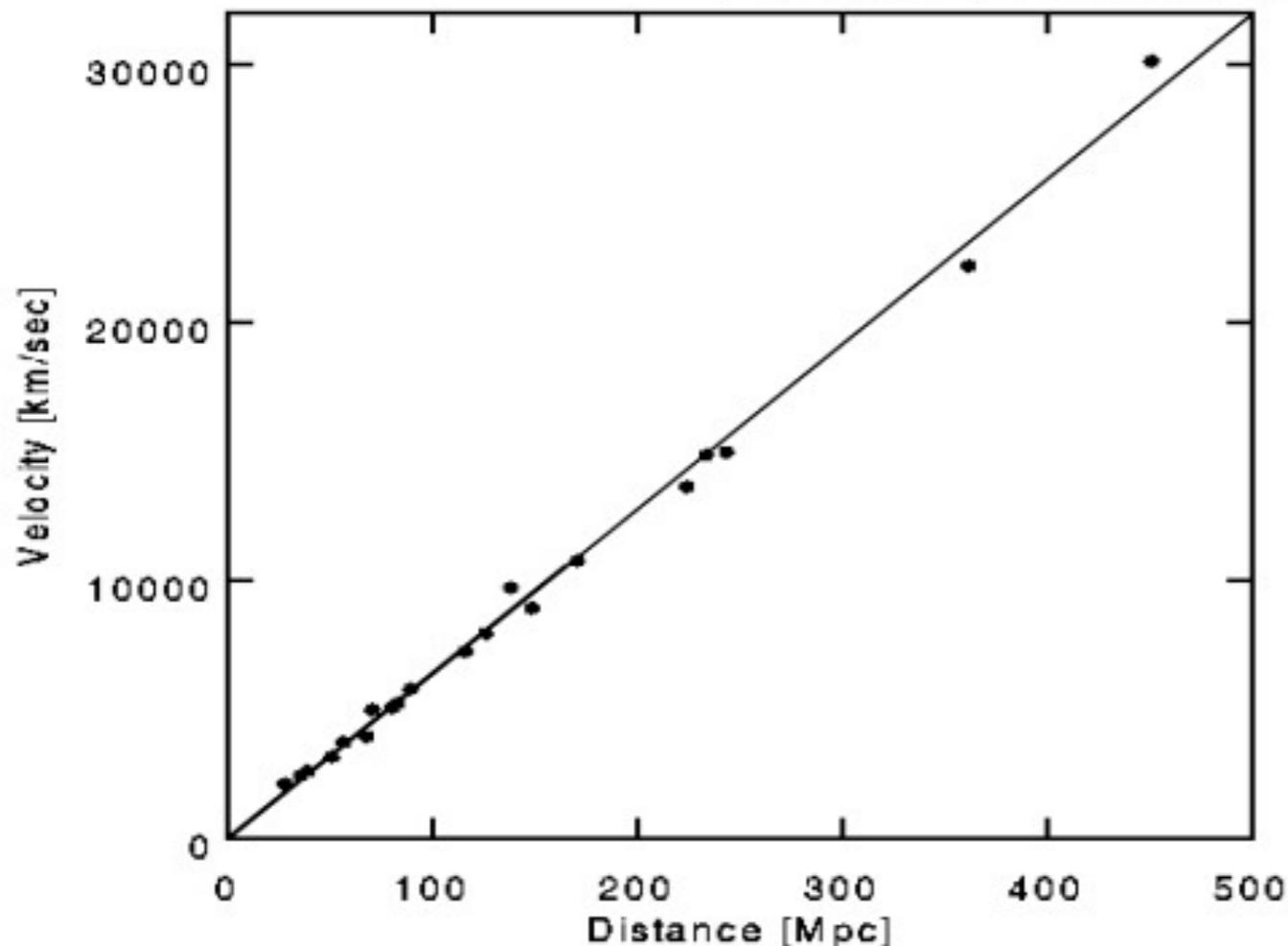
# Modern Cosmology

A series of major discoveries has laid a lasting foundation for cosmology. Einstein's **general relativity** (1916) provided the conceptual foundation for the modern picture. Then Hubble discovered that "spiral nebulae" are large galaxies like our own Milky Way (1922), and that distant galaxies are receding from the Milky Way with a speed proportional to their distance (1929), which means that we live in an **expanding universe**. The discovery of the **cosmic background radiation** (1965) showed that the universe began in a very dense, hot, and homogeneous state: the **Big Bang**. This was confirmed by the discovery that the cosmic background radiation has exactly the same spectrum as heat radiation (1989), and the measured **abundances of the light elements** agree with the predictions of Big Bang theory if the abundance of ordinary matter is about 5% of critical density (1997).

# Three Pillars of the Big Bang

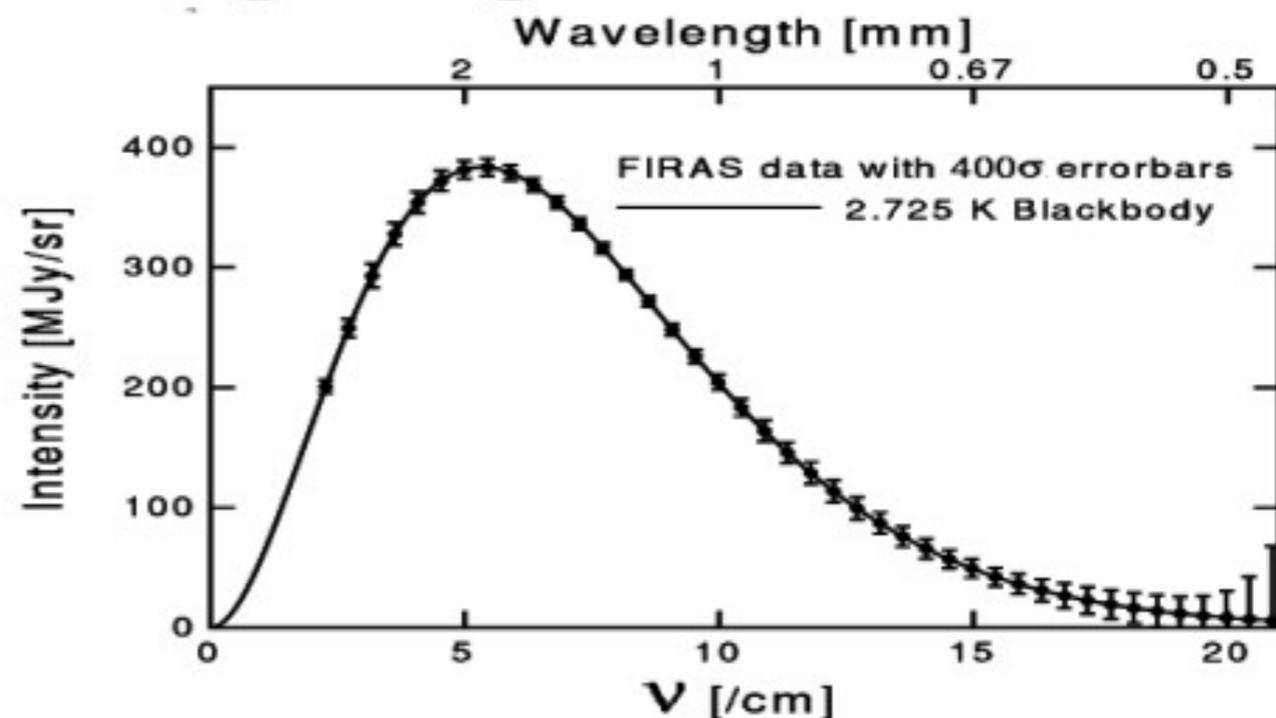
- Expansion: Velocity proportional to Distance
- Cosmic Background Radiation: heat of the Big Bang itself
- Light Element Abundances agree with predictions

# Three Pillars of the Big Bang

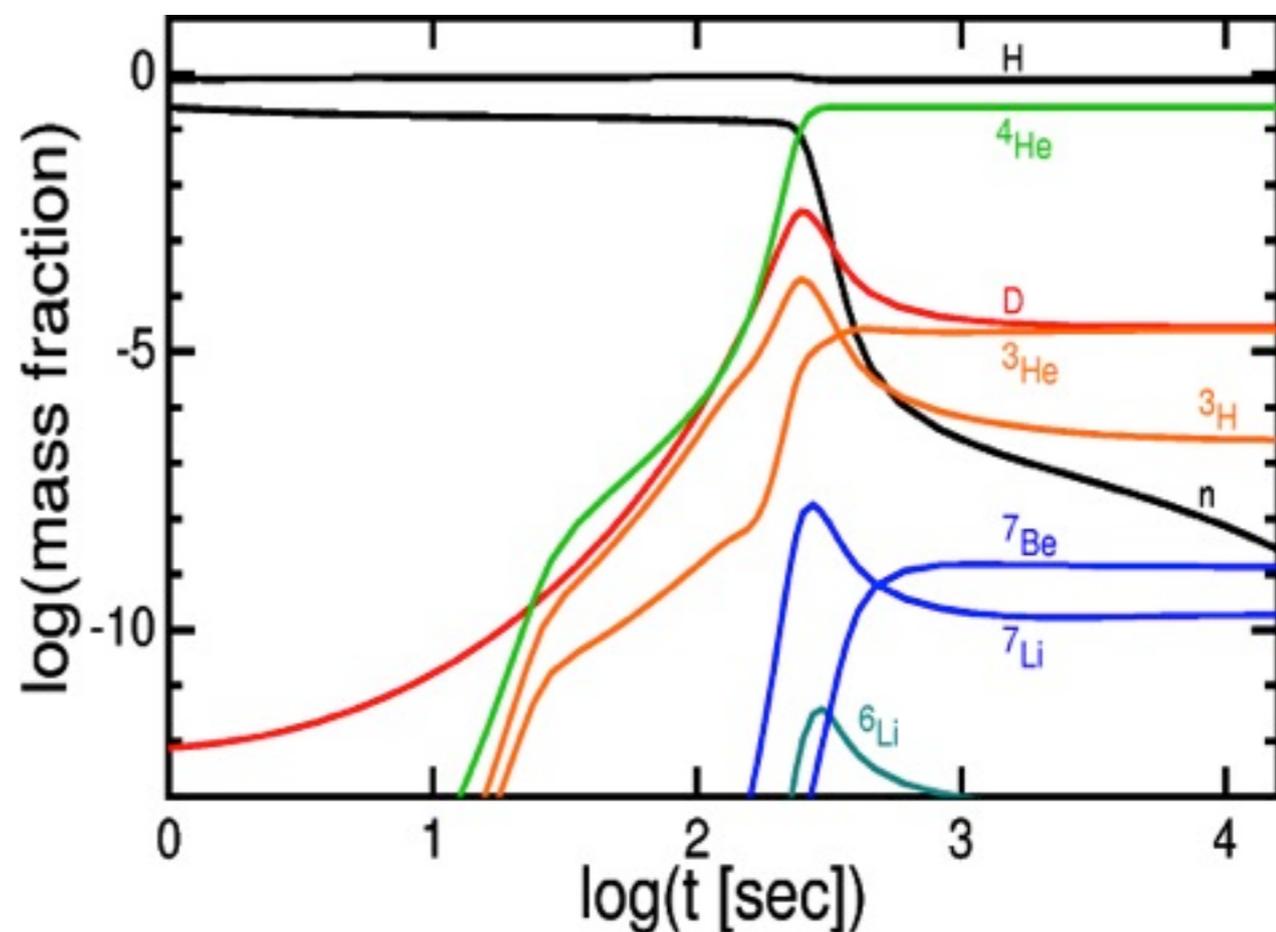


A modern illustration of Hubble's Law, displaying the increase of recession speed of galaxies growing in direct proportion to their distance.

The detailed production of the lightest elements out of protons and neutrons during the first three minutes of the universe's history. The nuclear reactions occur rapidly when the temperature falls below a billion degrees Kelvin. Subsequently, the reactions are shut down, because of the rapidly falling temperature and density of matter in the expanding universe.



The variation of the intensity of the microwave background radiation with its frequency, as observed by the COBE satellite from above the Earth's atmosphere. The observations (boxes) display a perfect fit with the (solid) curve expected from pure heat radiation with a temperature of 2.73°K.



# Cosmology & Culture

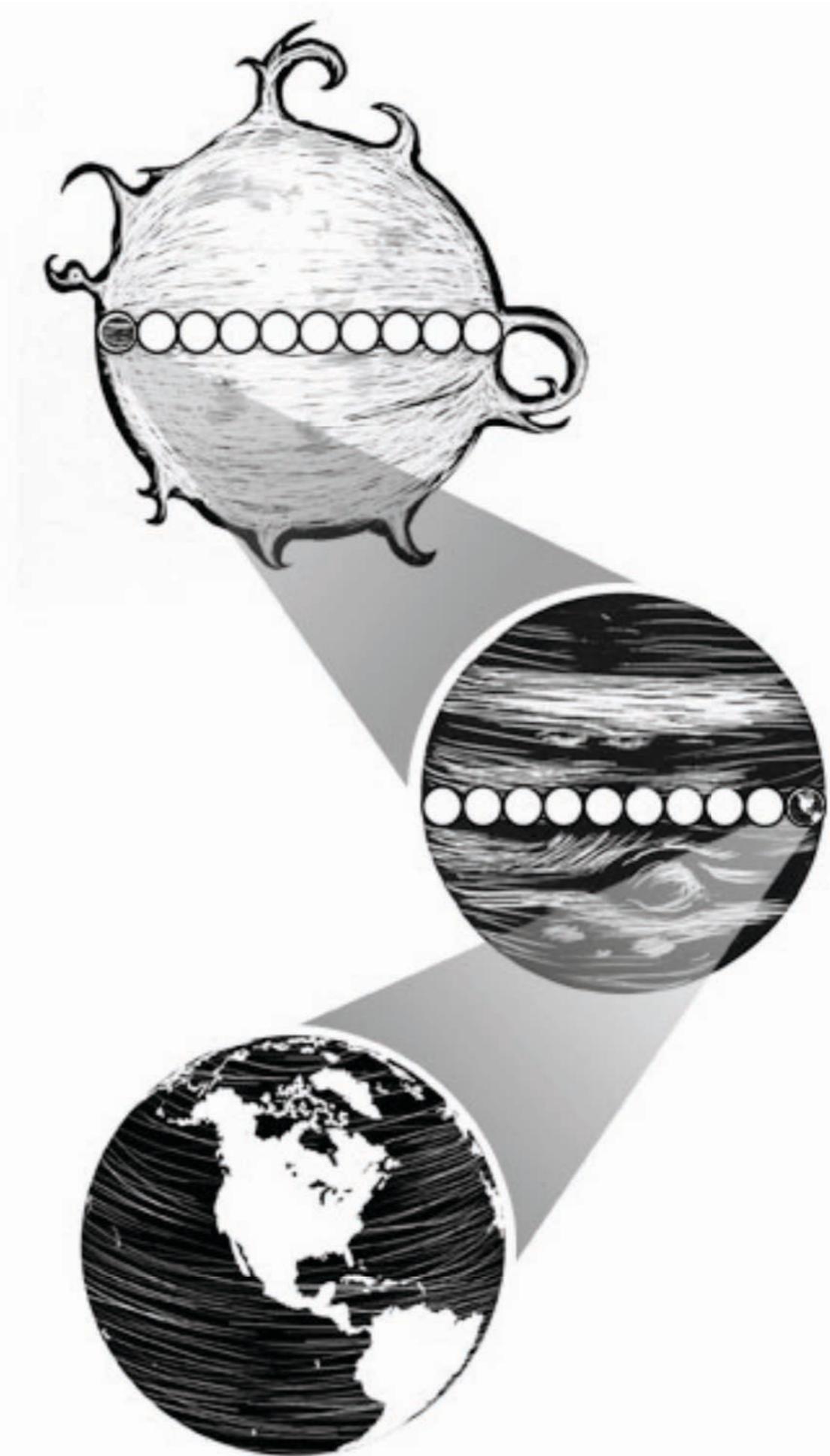
Size Scales in  
the Universe



# Size Scales

**This figure shows that the diameter of Earth is a tenth the diameter of Jupiter, which is a tenth the diameter of the sun.**

Therefore the *volume* of Earth, or the amount of space it occupies, is only a thousandth the volume of Jupiter, which is a thousandth the volume of the sun.



# Sizes in the Universe

TABLE 3. Metric Prefixes

Name	Multiplies By:	Comes From:	Meaning:
tera	$10^{12}$	Latin	Monster
giga	$10^9$	Latin	Giant
mega	$10^6$	Greek	Great
kilo	$10^3$	Greek	Thousand
milli	$10^{-3}$	Latin	Thousand
micro	$10^{-6}$	Greek	Small
nano	$10^{-9}$	Greek	Dwarf
pico	$10^{-12}$	Italian	Small
femto	$10^{-15}$	Danish	Fifteen
atto	$10^{-18}$	Danish	Eighteen

PARTICLE PHYSICS

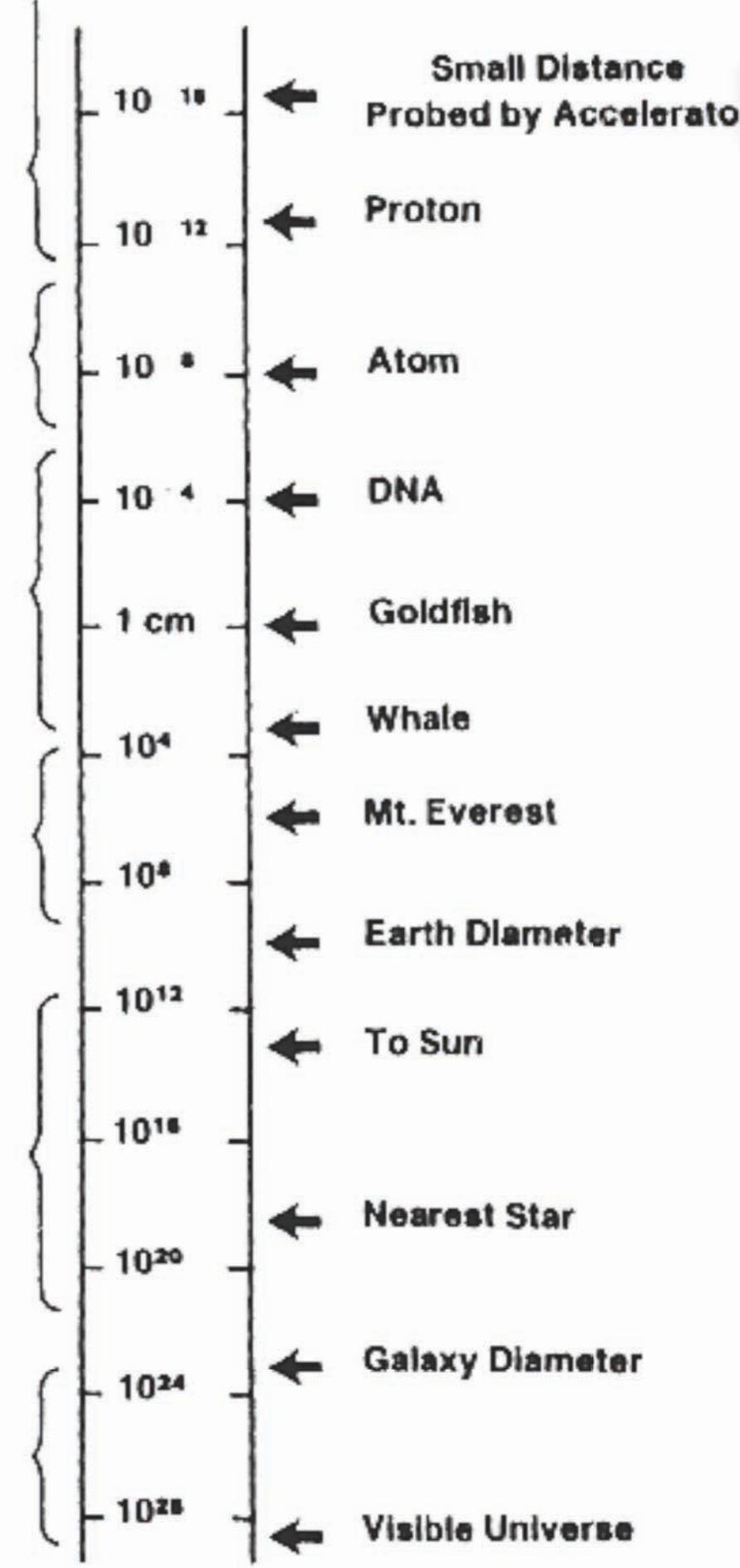
ATOMIC PHYSICS

BIOLOGY

GEOLOGY

ASTRONOMY

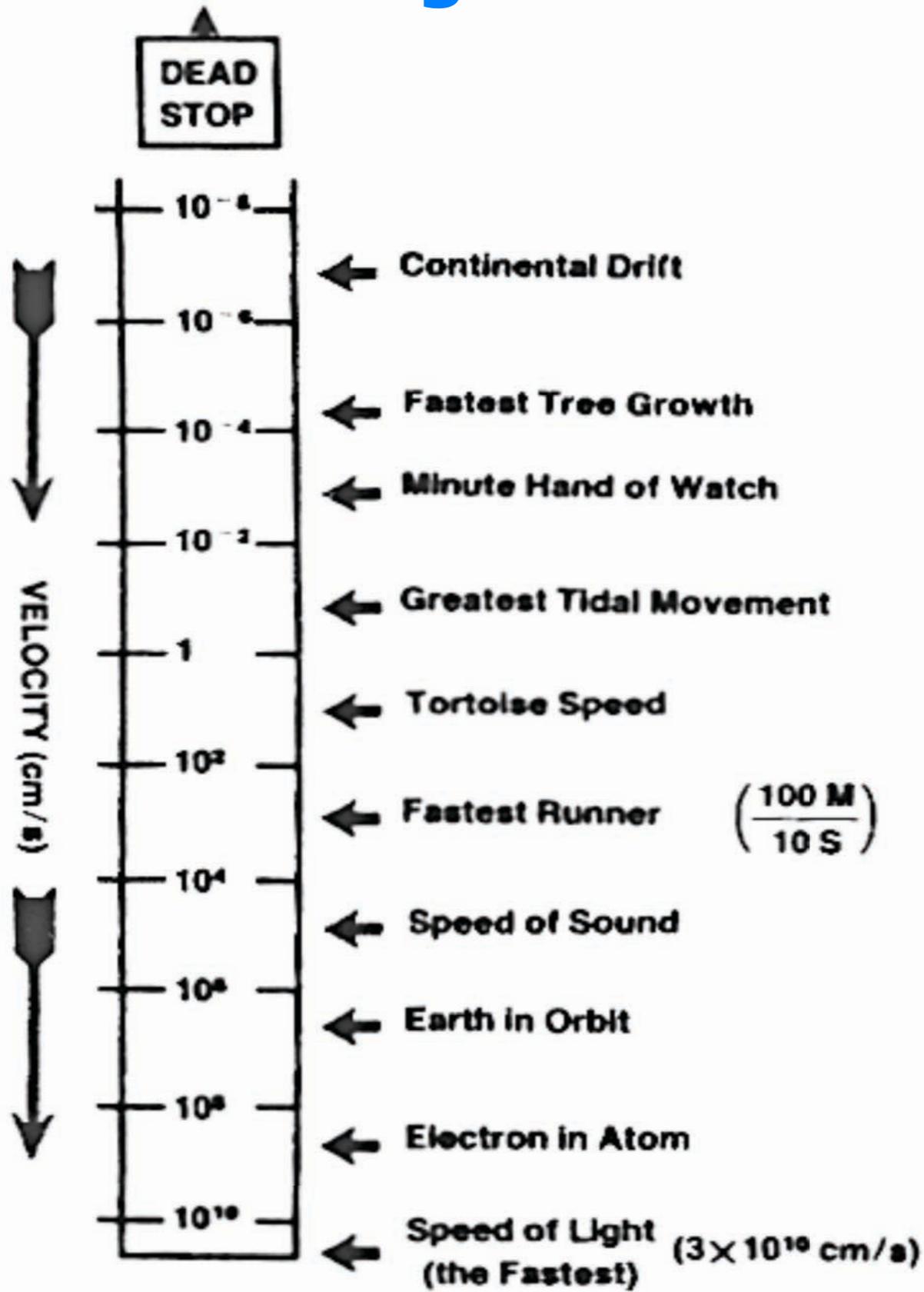
COSMOLOGY



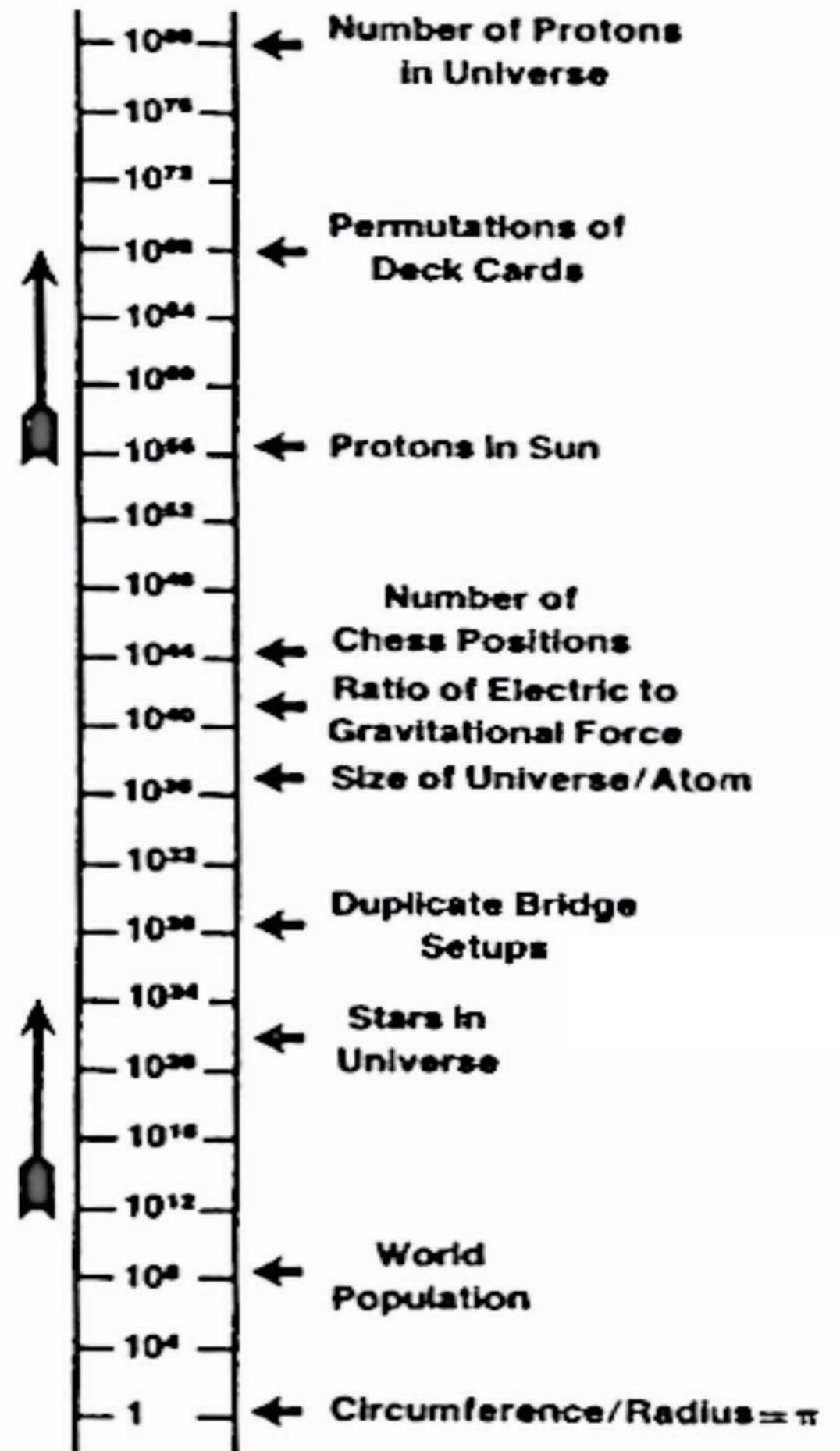
Thinking in Powers of 10

Distances large and small in centimeters.

# Thinking in Powers of 10

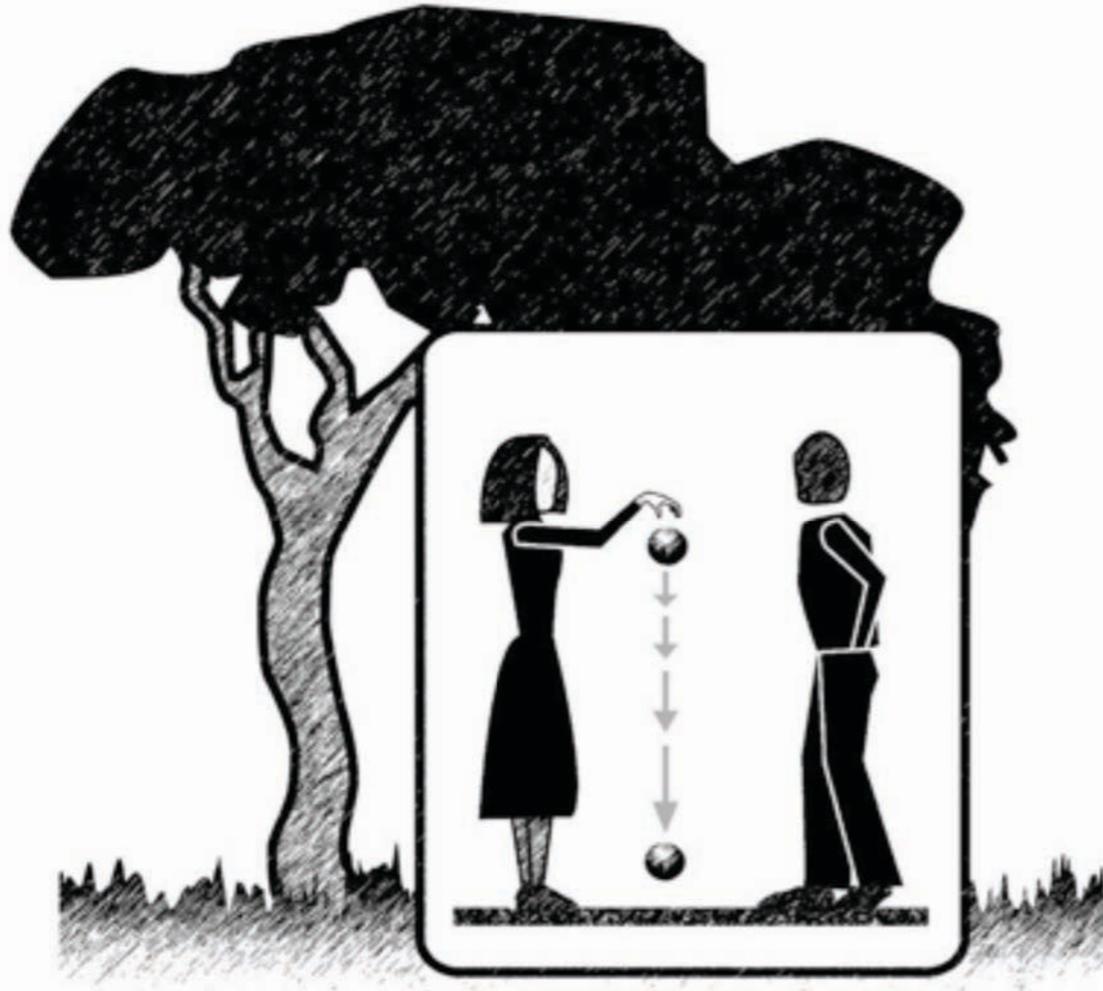


Speeds



Pure Numbers

# Einstein's Principle of Equivalence: GRAVITY = ACCELERATION



=

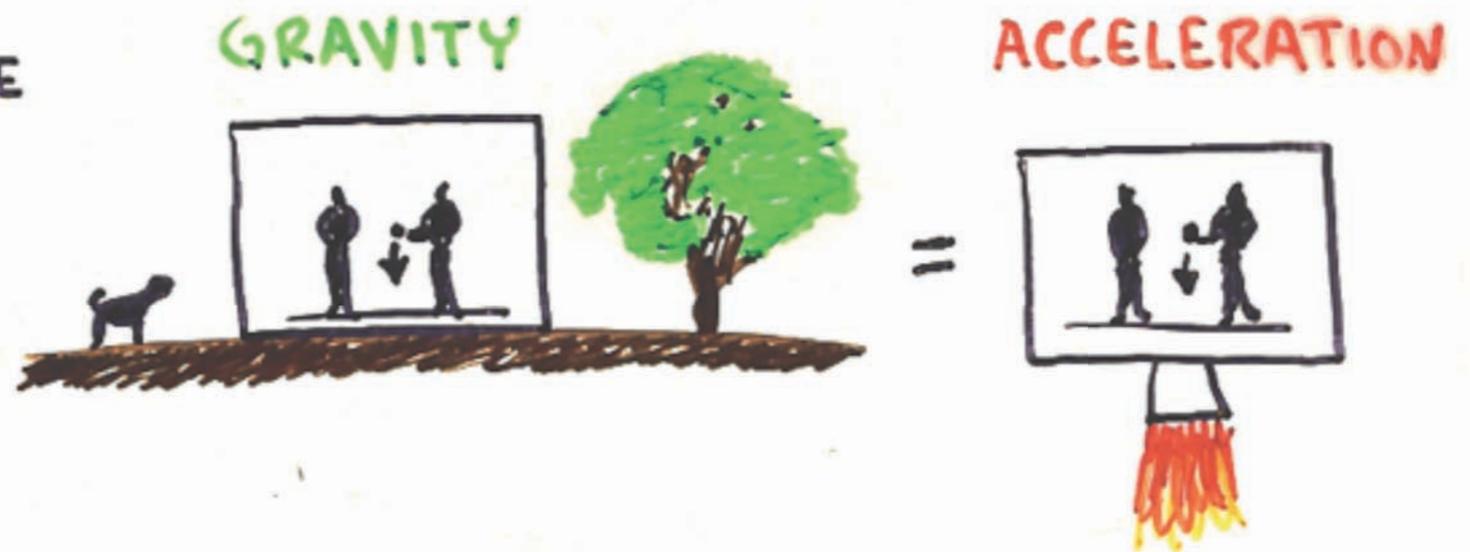


# GRAVITY

ACCORDING TO GENERAL RELATIVITY

## PRINCIPLE OF EQUIVALENCE

CURVED SPACE TELLS  
MATTER HOW TO MOVE.



## EINSTEIN FIELD EQUATIONS

MATTER TELLS SPACE  
HOW TO CURVE.

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu}$$

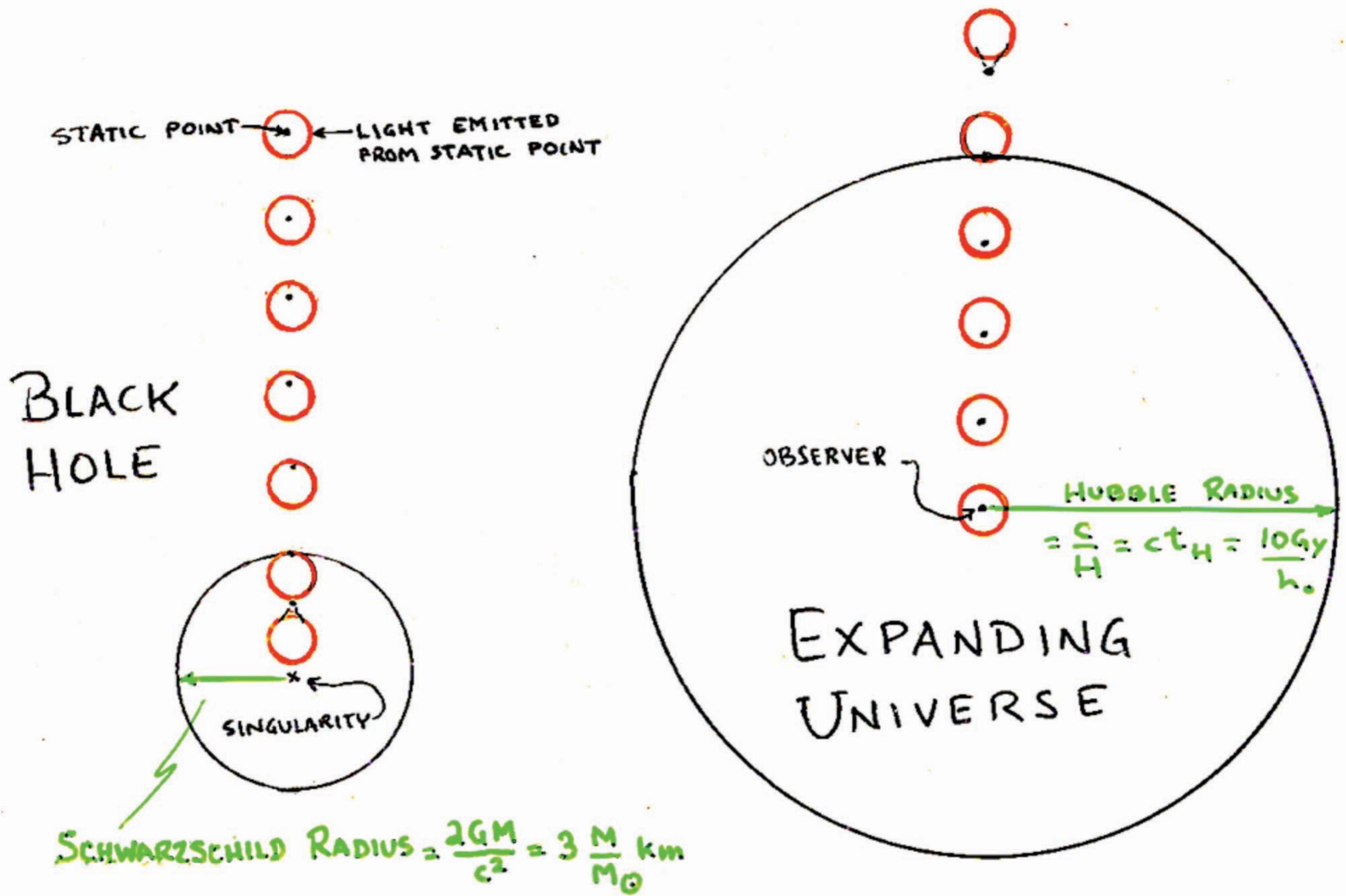
CURVATURE

MASS + ENERGY DENSITY?

COSMOLOGICAL CONSTANT

CURVED SPACE-TIME IS NOT JUST AN ARENA IN WHICH THINGS MOVE, IT IS DYNAMIC. CURVATURE CAN CAUSE HORIZONS, BEYOND WHICH INFORMATION CANNOT BE SENT.

CURVED SPACE-TIME IS NOT JUST AN ARENA IN WHICH THINGS MOVE, IT IS DYNAMIC. CURVATURE CAN CAUSE HORIZONS, BEYOND WHICH INFORMATION CANNOT BE SENT.

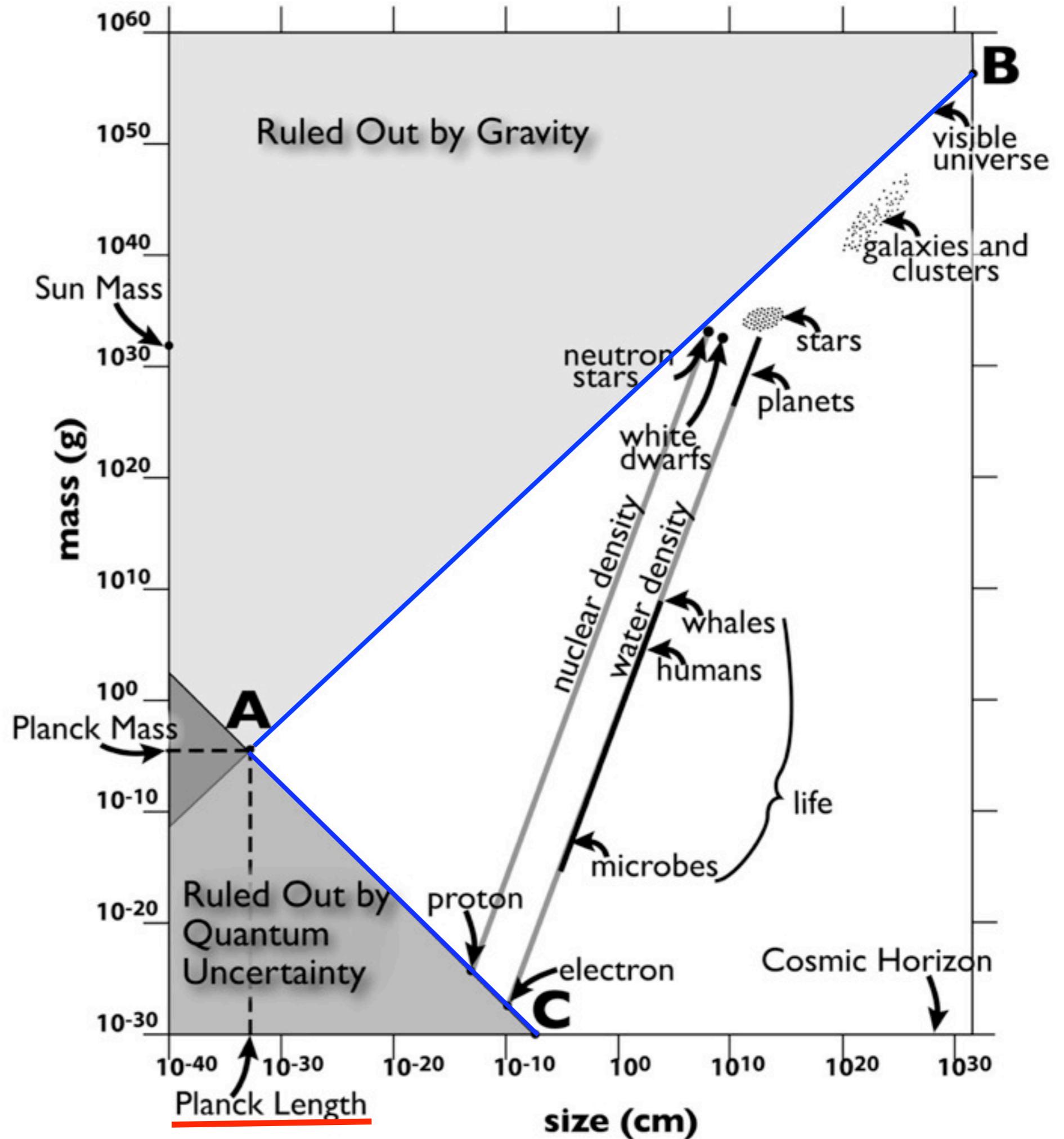


# The Wedge of Material Reality

General Relativity and Quantum Uncertainty



a smallest size, the **Planck length**



# The Planck Length

$$l_{Pl} = \sqrt{\frac{hG}{2\pi c^3}} = 1.6 \times 10^{-33} \text{ cm}$$

is the smallest possible length.

Here  $h$  is Planck's constant

$$h = 6.626068 \times 10^{-34} \text{ m}^2 \text{ kg} / \text{s}$$

The Planck Mass is

$$m_{Pl} = \sqrt{\frac{hc}{2\pi G}} = 2.2 \times 10^{-5} \text{ g}$$

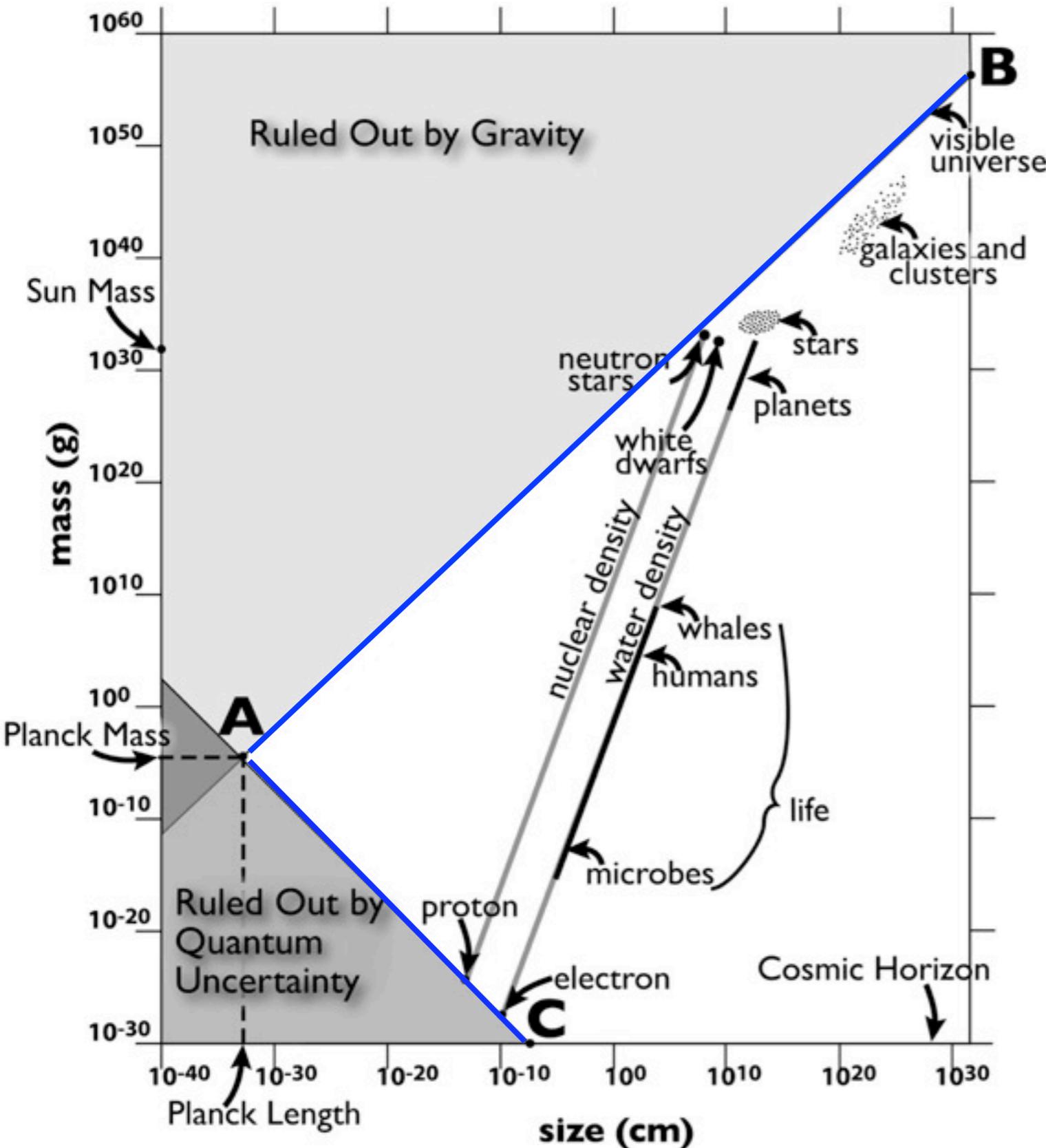
The Compton (i.e. quantum)

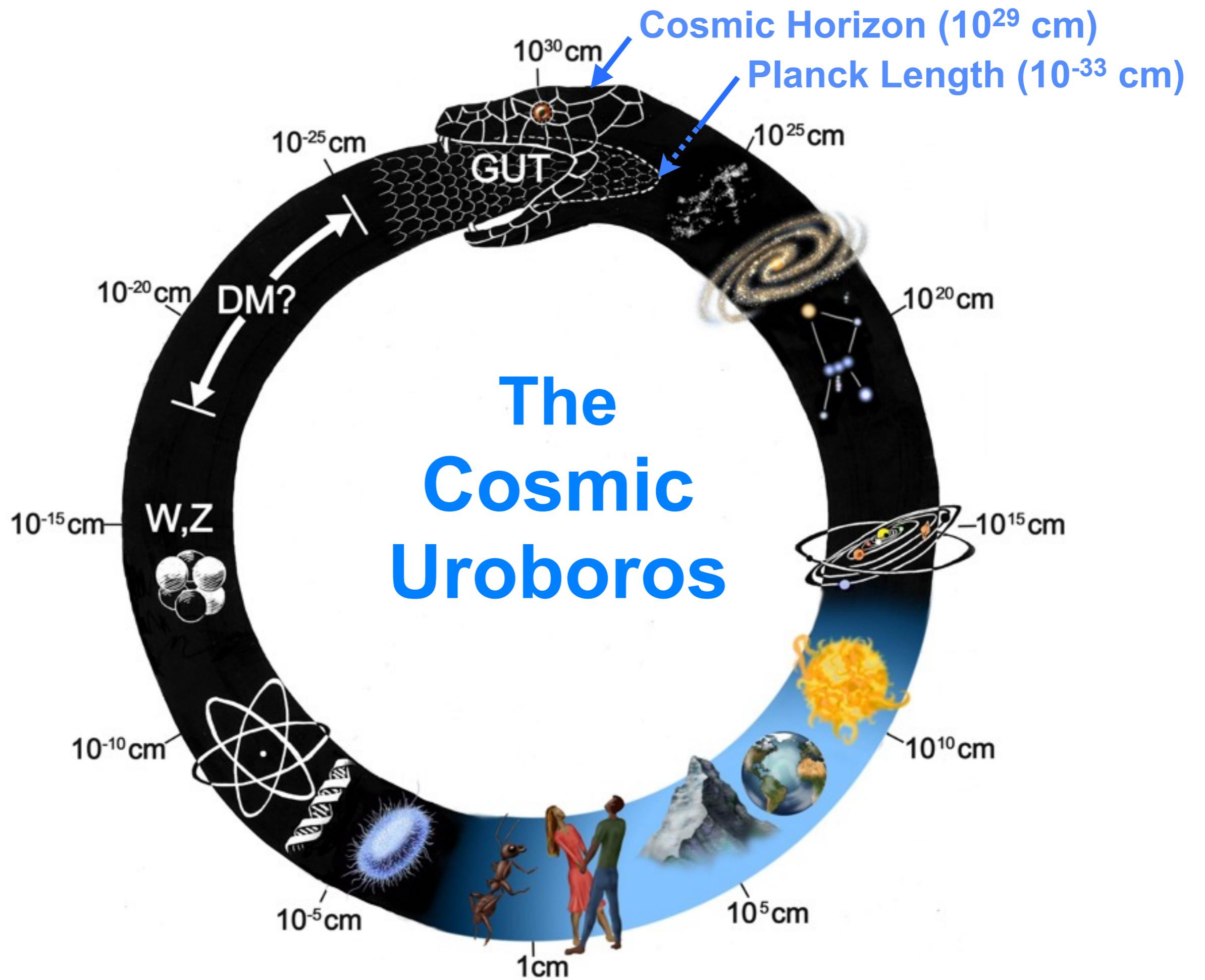
wavelength 
$$l_C = \frac{h}{2\pi mc}$$

equals the Schwarzschild

$$l_S \approx \frac{Gm}{c^2}$$

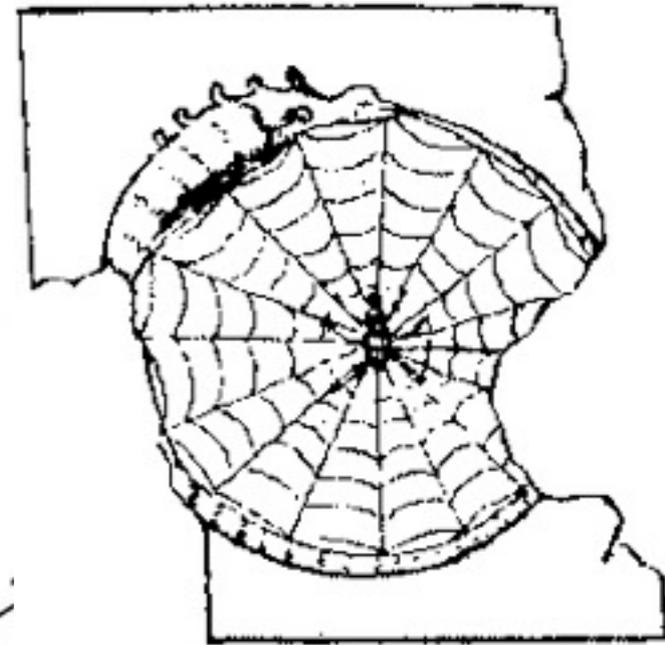
when  $m = m_{Pl}$





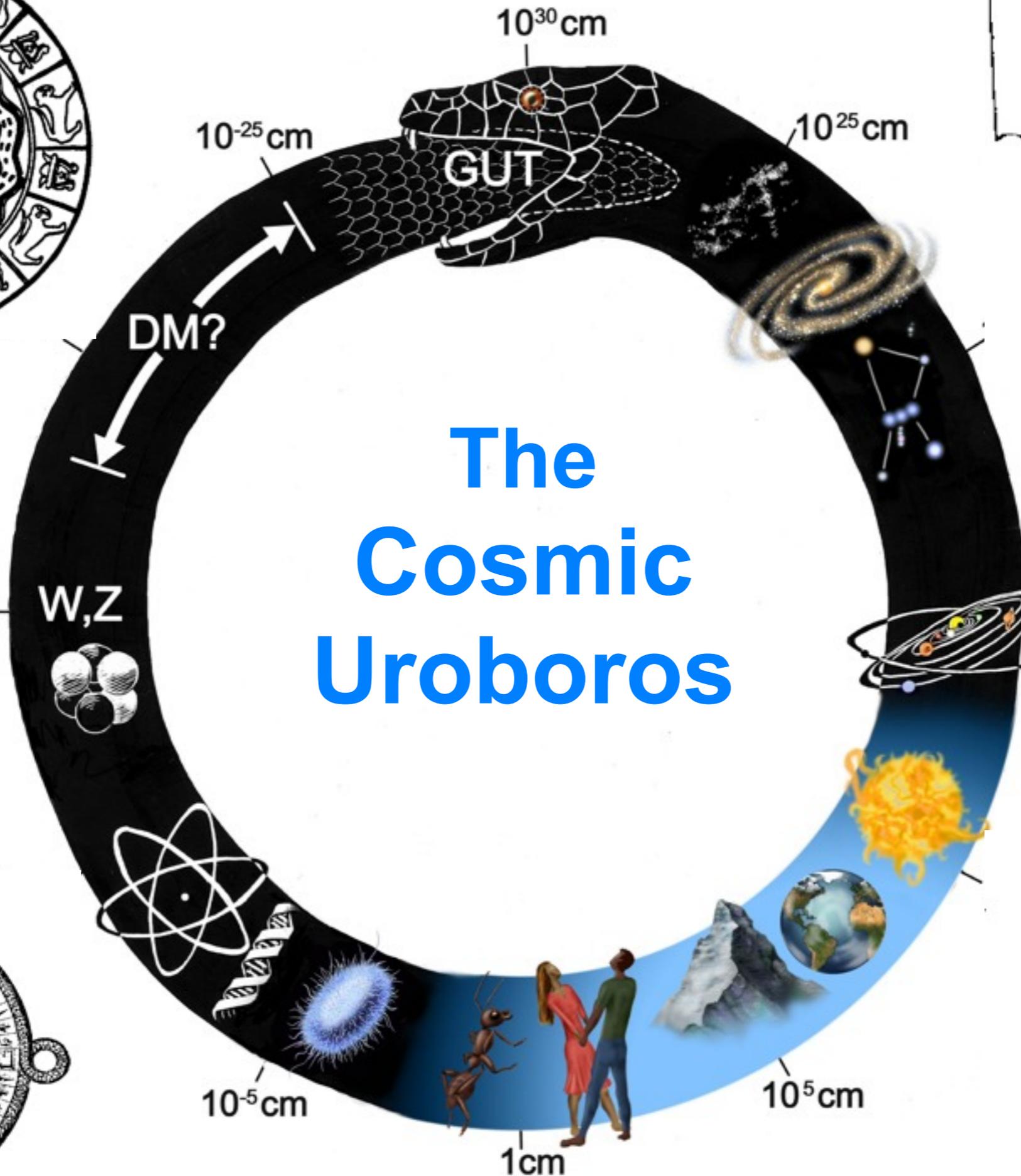


Nigeria



India

# The Cosmic Uroboros



Sheldon Glashow



Mexico



superstrings?

Dark Matter?

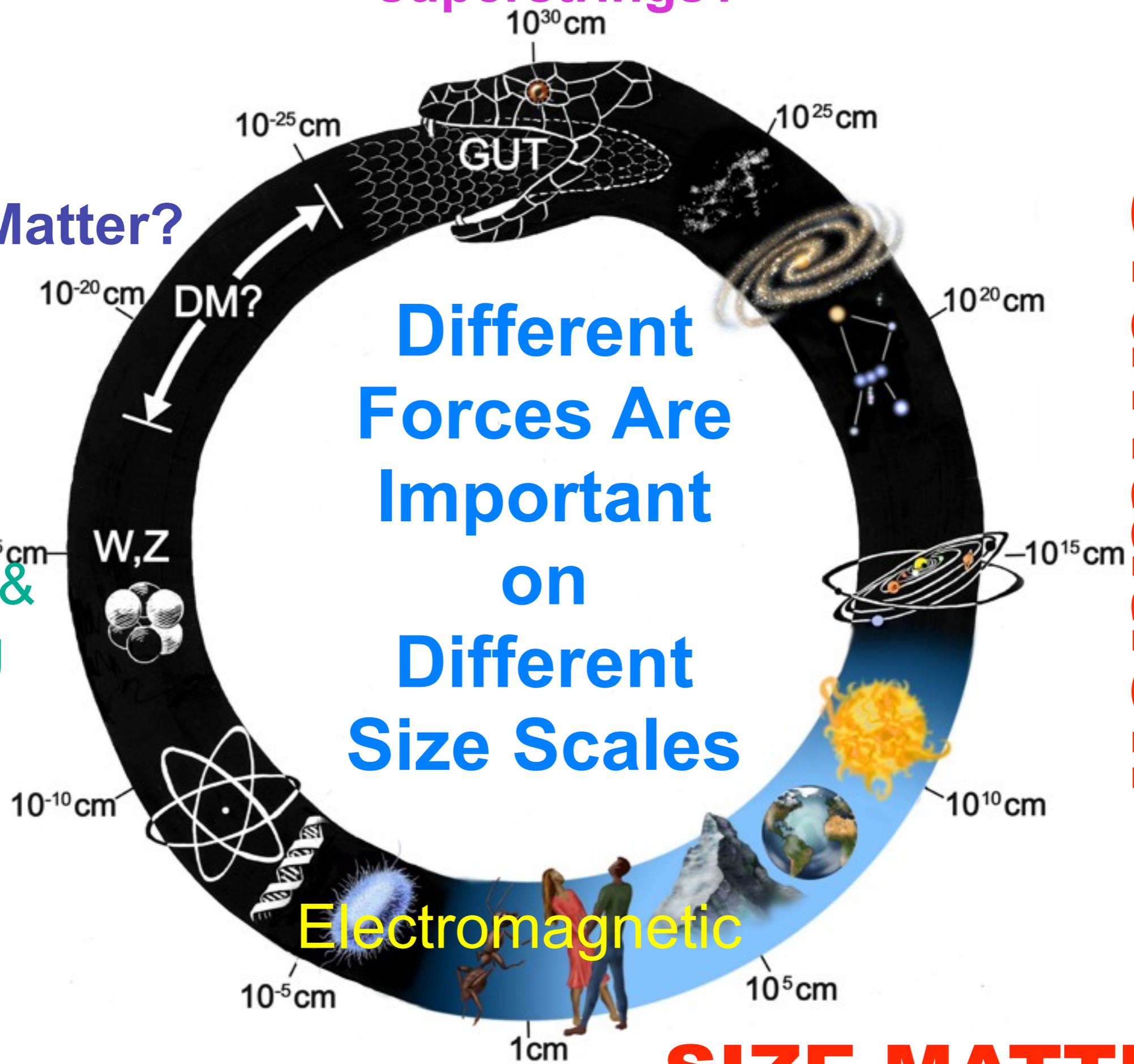
Weak & Strong

Electromagnetic

SIZE MATTERS!

Gravitation

Different Forces Are Important on Different Size Scales

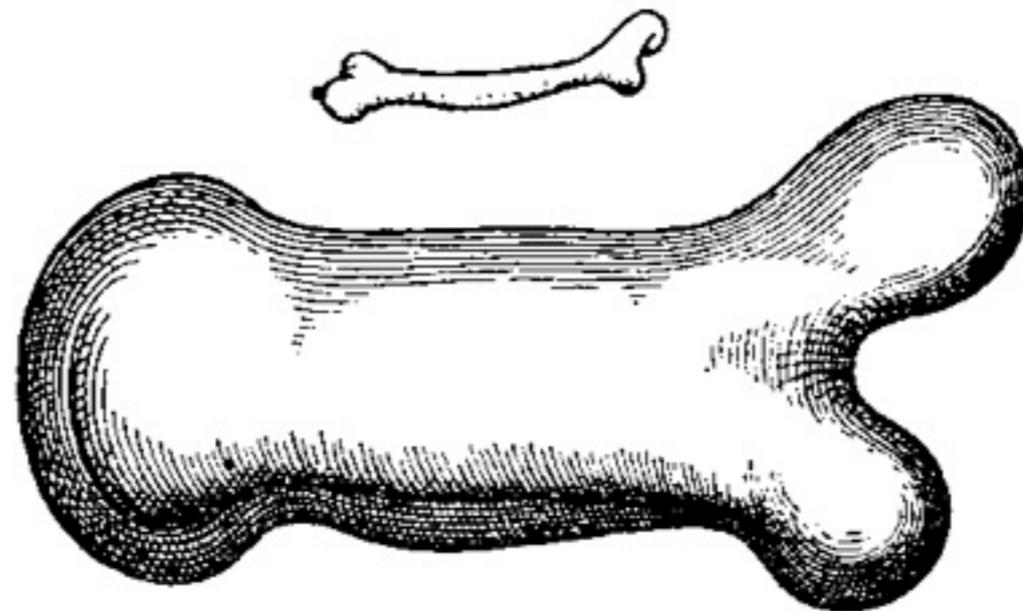


# SIZE MATTERS!

The importance of each law of physics changes with scale

Electrical forces are far more important than gravity on the small scales at the bottom of the Cosmic Uroboros, but gravity is far more important on large scales.

Galileo's example: an animal three times taller must have bones that are much thicker since it will be  $3 \times 3 \times 3 = 27$  times heavier.



# SIZE MATTERS!

No animal could be 3 times its normal height and stay the same shape, simply scaled up.

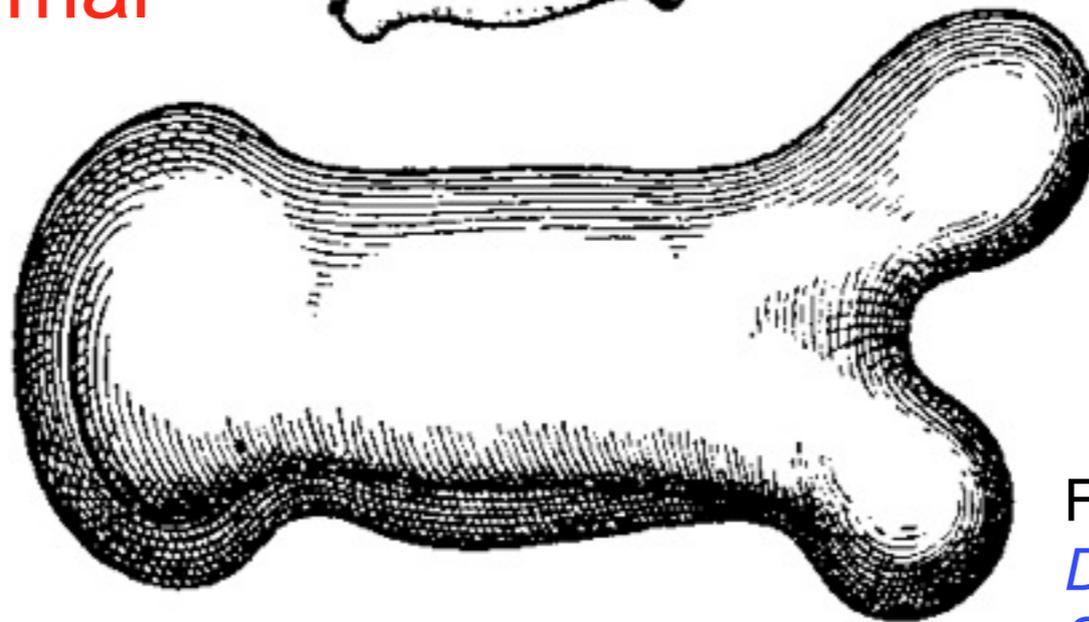
If height increases 3 times,  
strength of bones increases  $3 \times 3 = 9$  times.  
But weight increases  $3 \times 3 \times 3 = 27$  times.  
Its weight would crush its bones!

That is why an elephant does not look like a large gazelle.

Bone of small animal



Bone of animal  
3 times longer



From Galileo's last book,  
*Discourses On Two New  
Sciences* (1638).

# King Kong

To the mouse and any smaller animal [gravity] presents practically no dangers. You can drop a mouse down a thousand-yard mine shaft; and, on arriving at the bottom, it gets a slight shock and walks away. A rat is killed, a man is broken, a horse splashes.

– J.B.S. Haldane

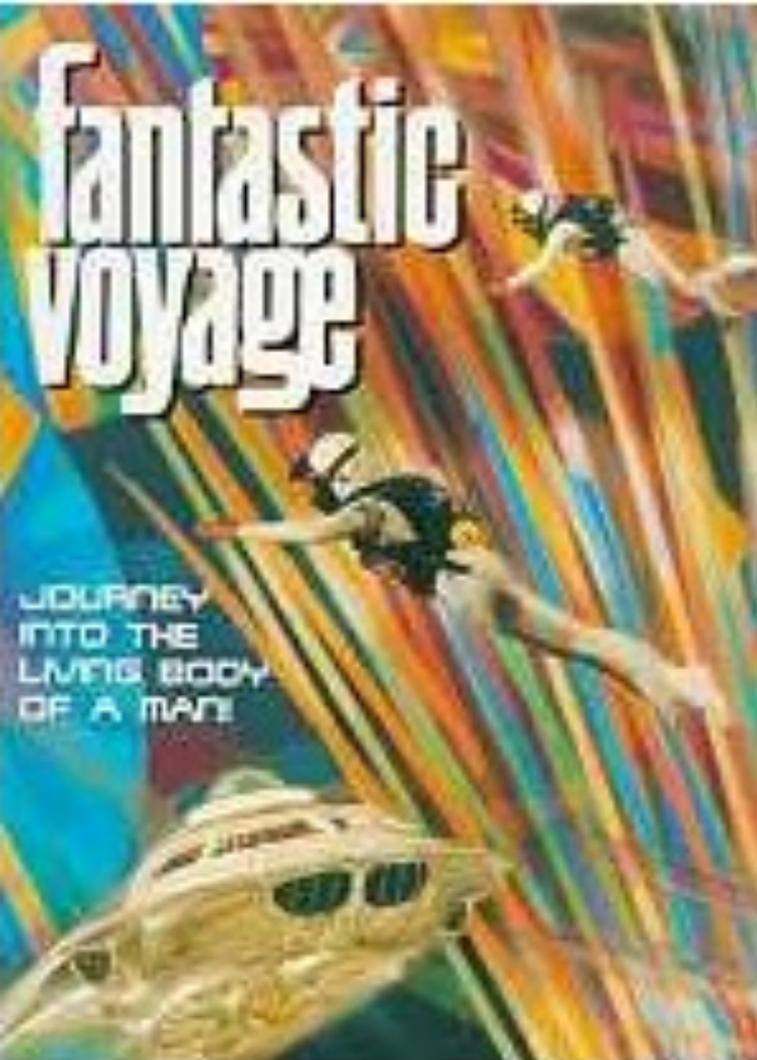
When King Kong fell from the Empire State Building, pink mush should have covered the streets of Manhattan!



# SIZE MATTERS!

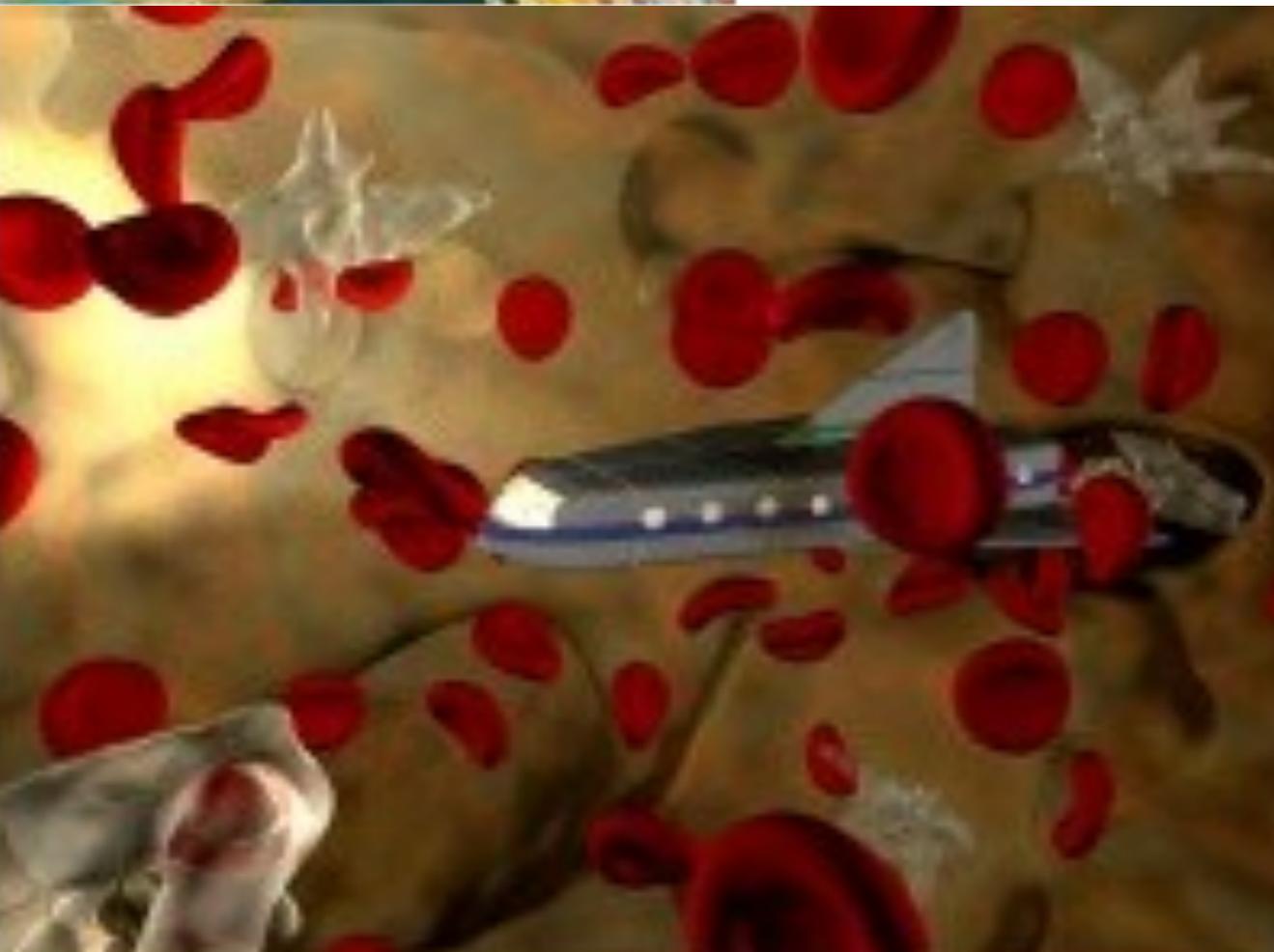
“Humans are affected by gravity--we get flat feet and bad backs from standing upright. But bacteria living in a liquid medium don't experience gravity at all. They are affected seriously by Brownian motion--the random thermal motions of molecules in liquid, a force which fortunately does not send us reeling from one side of the room to the other.”

-- R.C. Lewontin, *Hidden Histories of Science*



**King Kong showed that scaling up to larger size doesn't work.**

**Neither does scaling down.**



**In *Fantastic Voyage* (1966), the miniature submarine crew spends time enjoying the scenery as they cruise inside someone's arteries, but how do they see? Their eyeballs are much smaller than the wavelength of visible light.**

# Fantastic Voyage – Approximate Relative Sizes

blood cell  $10^{-4}$  cm

human being  $10^2$  cm

Ratio: a factor of  $10^6$

(thus everything is reduced to one millionth normal)

Shrunken person  $10^{-4}$  cm

Their shrunken cells  $10^{-10}$  cm

BUT an atom is  $10^{-8}$  cm

**Thus the shrunken cell is one hundredth the size of an atom.**

*Can you shrink an atom?*

The size of an atom is  $h^2/(4\pi^2 m_e e^2)$

Thus the size is completely determined by constants of nature – Planck's constant, and the mass and charge of the electron. It cannot be shrunken! So what are the hemonauts' cells made of ??

*Answer: science fiction!*

1. King Kong is about 5 times the height of an ordinary lowland gorilla. He is not realistic because

- A. His weight would be 25 times that of an ordinary lowland gorilla.
- B. His weight would be 125 times that of an ordinary lowland gorilla.
- C. His bones and limbs would have to be much thicker in proportion to his height in order to support his weight.
- D. A and C.
- E. B and C.



2. In the movie *Fantastic Voyage*, a small submarine and its crew are shrunk to only a millionth of their normal size in order to travel through the bloodstream of an injured person and remove a blood clot from his brain. This is supposedly possible because, as one of the crew members says, “Man is the center of the universe. We stand in the middle of infinity, between outer and inner space, and there is no limit to either.”

The movie is inconsistent with the laws of physics and this statement is untrue because ...

- A. There actually is a smallest and largest possible size.
- B. Each cell of their bodies would be only 1/100 the size of an atom.
- C. The submarine would be constantly tossed about by blood molecules bumping into it.
- D. All of the above.

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# Scale Chauvinism

is the error of assuming that one scale is fundamental.

**Examples:**

1. Everything is random – many modern physicists. *Regards quantum level as primary.*
2. You are just your DNA's method of self-propagation – Richard Dawkins. *Regards molecular level as primary.*
3. The earth is a self-regulating organism, Gaia – James Lovelock. *Regards global level as primary.*

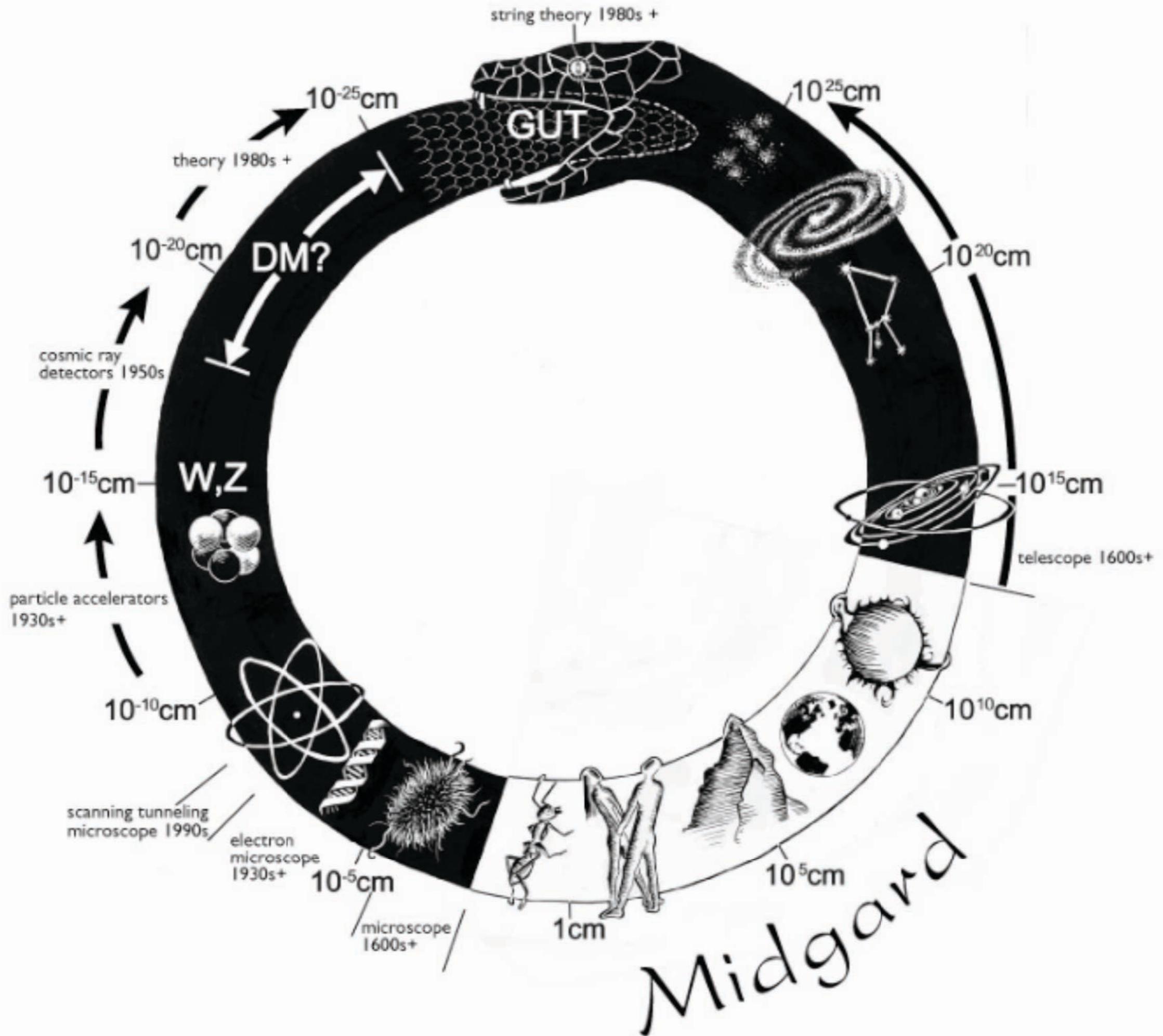
**Willful scale chauvinism is the only way to understand a scale. You must believe in it. And there is no reason not to, since it is real. But at the same time you can laugh, because things are happening on every scale from the Planck size to the cosmic horizon, and who is to say which is primary? The universe is on all scales. Beware of becoming imprisoned in one instance of the universe, cut off from most of reality, disparaging all larger or smaller views.**

# Scale Confusion

is the error of applying the laws and viewpoint appropriate to one scale, to phenomena on another scale.

## Examples:

1. Imagining that the Big Bang can be understood using just commonsense physics. *The high temperatures and densities require relativistic quantum physics.*
2. Applying the concept of phase transition to one or just a few molecules. *It takes millions of water molecules to make the smallest snowflake!*
3. Regarding the human size as insignificant compared to cosmic scale. *Anything, even gravity, is insignificant on some scales.*





Midgard



# Implications of Midgard

Midgard is what most people think of as reality itself, but it's just a special piece.

**MIDGARD IS EVERYWHERE IN THE UNIVERSE** – it's not a place but a setting of the intellectual zoom lens. It delimits human intuition.

**“Does God exist?”**

Real question: **what does “exist” imply outside Midgard?**

# Implications of Midgard

## UNIVERSAL PATTERN: MORE IS DIFFERENT!

**Exponential growth of complexity happens in human interactions.**

**People can be kind, generous, honorable, patriotic, etc.  
Groups cannot.**

**Groups of humans don't act like humans.**

**(We are made of elementary particles, but we don't act like them.)**

**But people are still thinking about global politics and economics with understandings, moral judgments, and a sense of time appropriate only to smaller size scales.**

**Extinction is forever.**

# Implications of Midgard

**Changes in ethics are required when modern leaders control events on time and size scales no religious or political tradition ever contemplated.**



**Traditions can't tell us what is right or wrong *on a global scale* any more than they can tell us what is scientifically correct.**