

# Things My Mother Never Told Me About the Universe

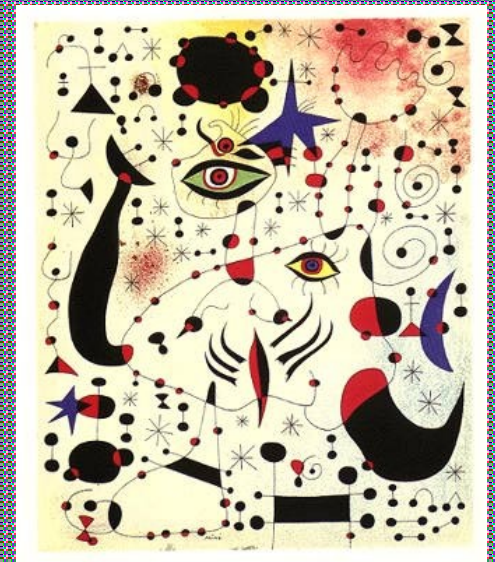


Professor Lynn Cominsky  
Sonoma State University

# Outline

---

- My Mom and the Constellations
- Mass, Weight and Acceleration
- Einstein, Mass and Energy
- What's the Matter?
- Matter and Energy in the Universe
- Going Beyond Einstein
- Some Last Words



# My Mom and the Constellations

---



- I first learned about the stars from my Mom
- She taught me the constellations on camping trips with our girl scout troop
- And so I started looking up at the night sky in wonder...

# Fly Me to the Moon

---

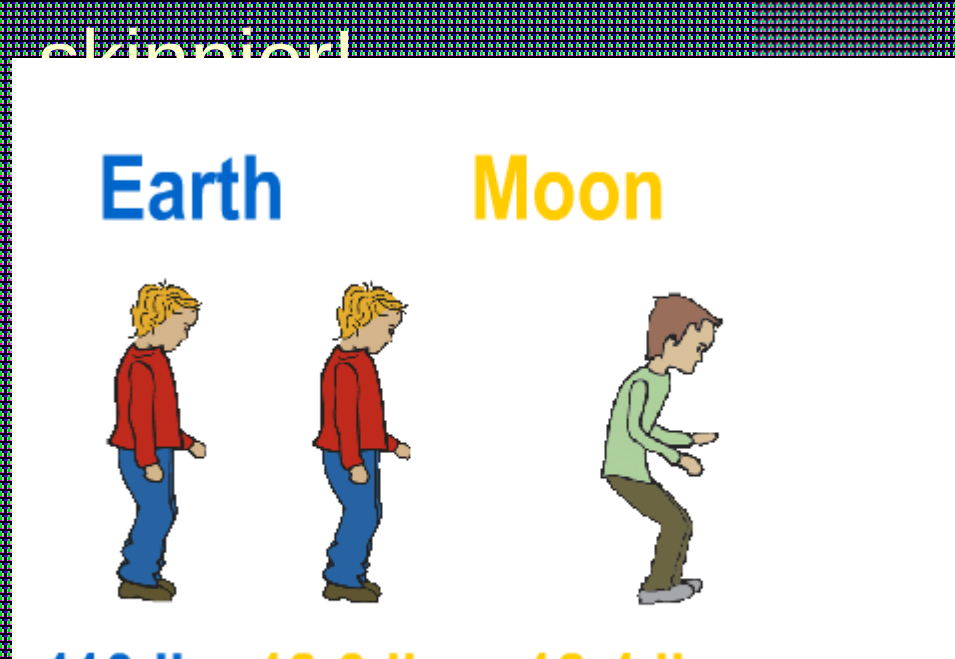
- In 1969, humans first went to the Moon



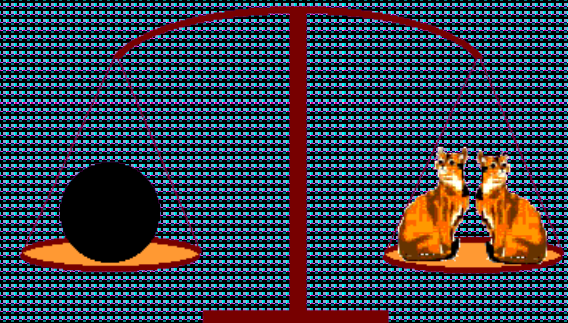
- I thought a trip to the moon would be an easy way to lose weight!

# Mass and weight on the Moon

- But the astronauts didn't look any skinnier!



# Mass and weight



- On the moon, it is the **weight** that changes, not the **mass**.
- **Mass** is the quantity of stuff that makes up an object. It is measured in grams (or slugs).
- **Weight** is the force of gravity on mass. It is measured in Newtons (or pounds).
- Here on earth, we often use the terms interchangeably (and incorrectly). We say “1 kg = 2.2 pounds” but 1 kg **weighs** 2.2 pounds

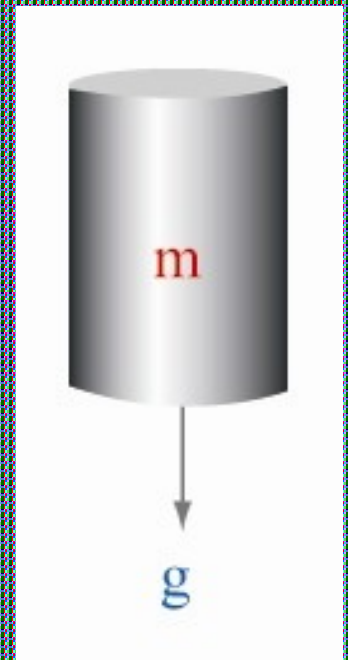
# “Weightless” in space?

- So, then how do astronauts in the Space Shuttle float around, seemingly weightless?
- Astronauts are in orbit about 250 km above the Earth



# “Weightless” in space?

- On the Earth,  $F = mg$  where  $g = 9.8 \text{ m/s}^2$  is the gravitational acceleration at the surface of the Earth
- In general,  $F = GmM/r^2$  where  $G$  is the Universal gravitational constant
- Therefore  $g = GM_e/R_e^2$  where  $R_e = 6378 \text{ km}$  is the Earth's radius, and  $M_e = 5.972 \times 10^{24} \text{ kg}$  is the Earth's mass



# “Weightless” in space?

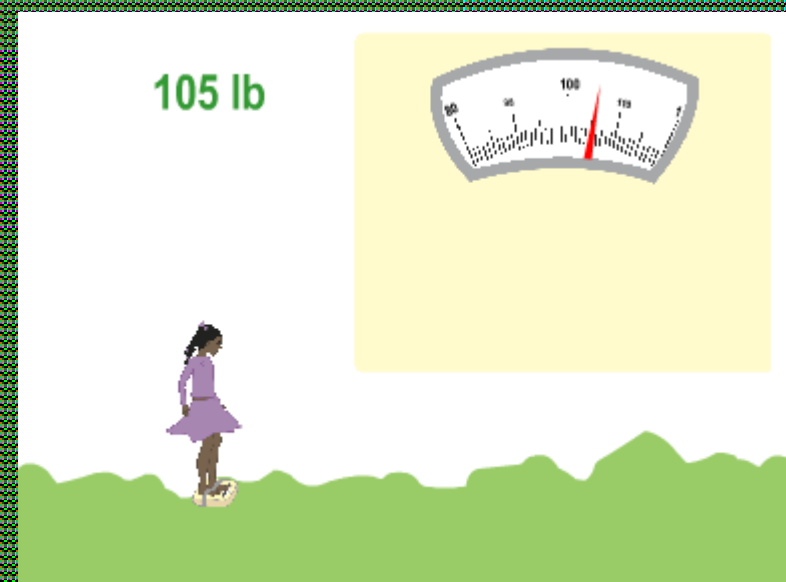
- Astronauts orbit at  $R_e + 250 \text{ km}$   
 $= 6628 \text{ km}$
- Solving for  $g_{\text{orbit}} \rightarrow$   
 $9 \text{ m/s}^2$
- This is not zero gravity!!



(Not to scale)

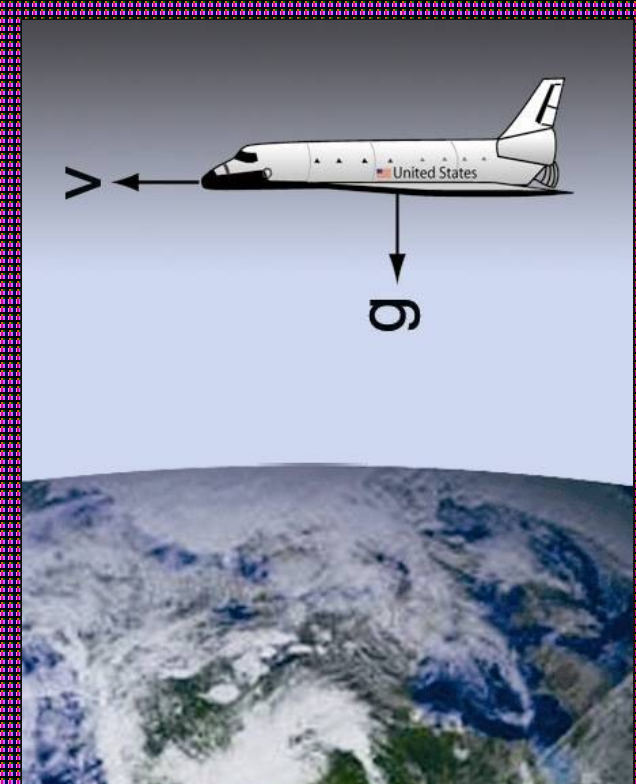
# “Weightless” in space?

- Astronauts seem “weightless” because they are in freefall – they are constantly falling inside their falling spaceships
- Jump in the air, or from a diving board and you too can be in freefall or “weightless”



# “Weightless” in space?

- Of course, the astronauts are in freefall for much longer, because they are in orbit, traveling around the Earth while falling continuously
- So they don't feel the Earth's gravity until they reenter the atmosphere, which pushes on them so hard, that they temporarily weigh more than on Earth



# Mass and Acceleration

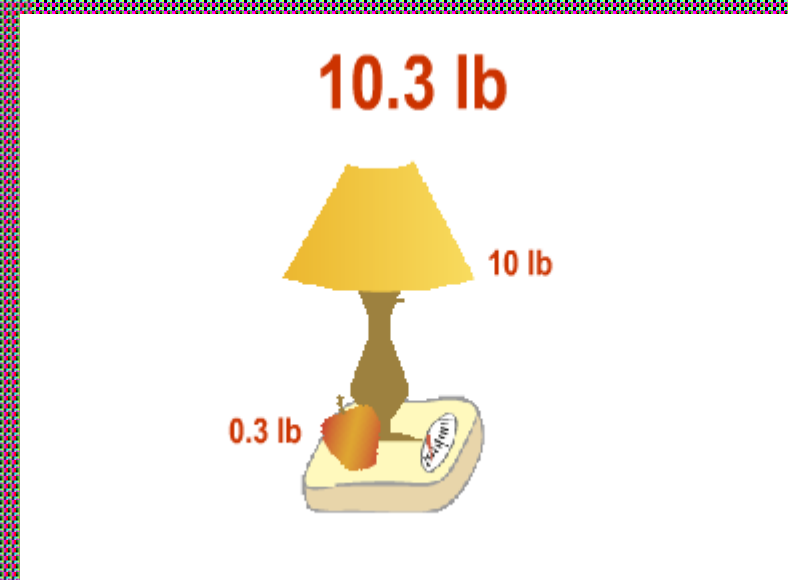
---

- Galileo showed that since the acceleration due to gravity is a constant, two bodies of different mass will fall at the same rate
- In other words:
- $F = ma = mg$
- So  $a=g$   
(mass cancels)



# Mass conservation

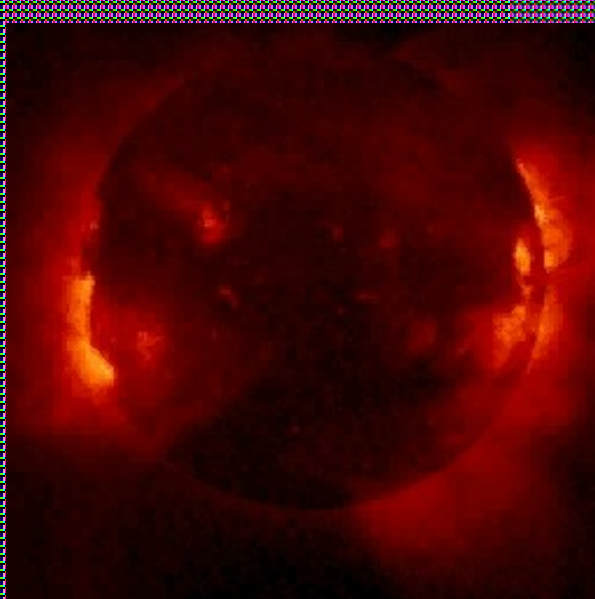
- In most everyday situations, mass is *conserved*.
- $M_1 + M_2 = M_{1+2}$



# Mass conservation

- **BUT:** Mass is not conserved in extreme environments, such as inside the Sun or at particle accelerators

Sun's  
image in  
X-rays  
from  
Yohkoh



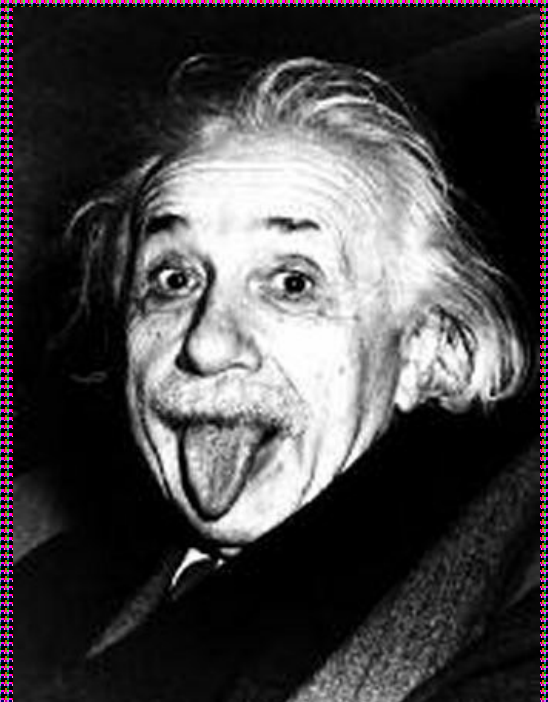
SLAC

# Mass and energy

- My mom told me about Einstein
- But I had to go to college to learn the meaning of his famous equation:

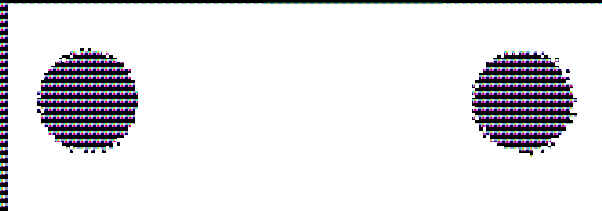
$$E = mc^2$$

- Einstein realized that mass and energy were equivalent and interchangeable
- **SO:** It is the **total** of **mass** & **energy** that is really conserved.



# Creating Energy from Mass

- When two oppositely charged particles meet in flight, they can **annihilate** to create two gamma-ray photons traveling in opposite directions



- The rest mass of an electron or its anti-particle, the positron, is  $511 \text{ keV}/c^2$
- Annihilating an electron creates  $E = 511 \text{ keV}$

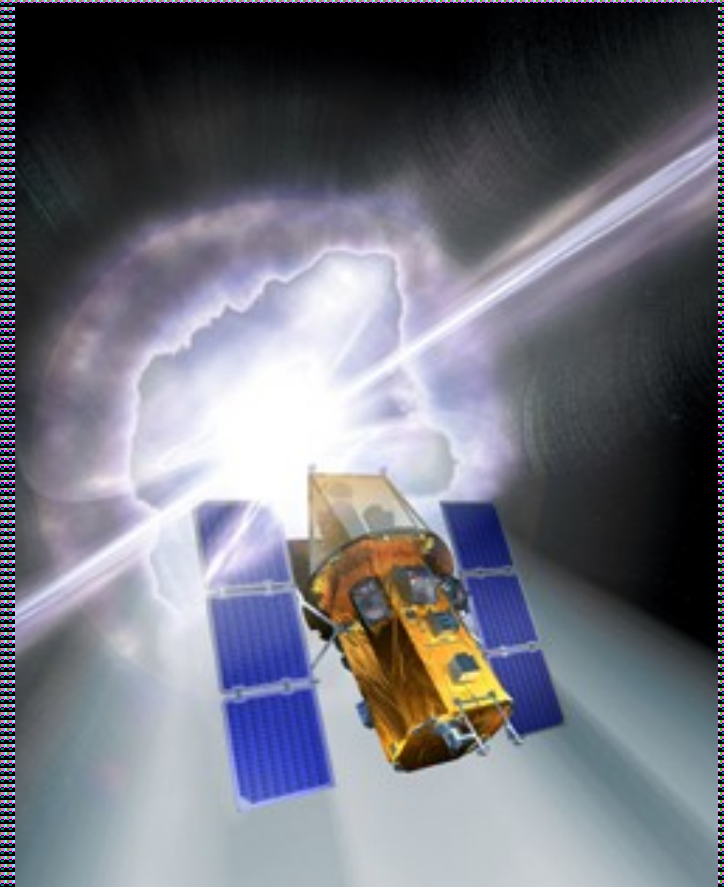
# Explosions in Space

- Energy is also created from mass when stars explode
- Supernovae herald the deaths of stars
- Gamma-ray Bursts signal the deaths of even more massive stars
- They are the birth cries of black holes



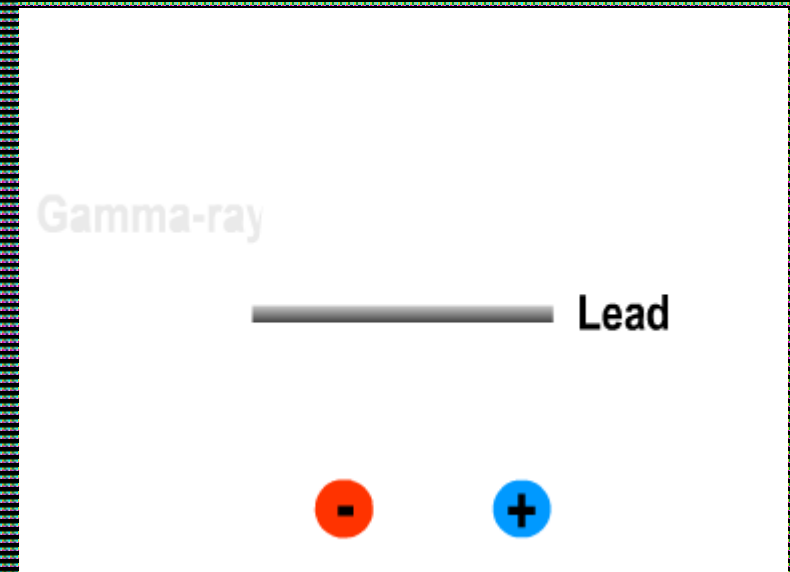
# Swift Gamma-ray Burst Mission

- Will study Gamma-Ray Bursts with a “swift” response
- To be launched in 2004
- Nominal 2-year lifetime
- Will see ~150 GRBs per year



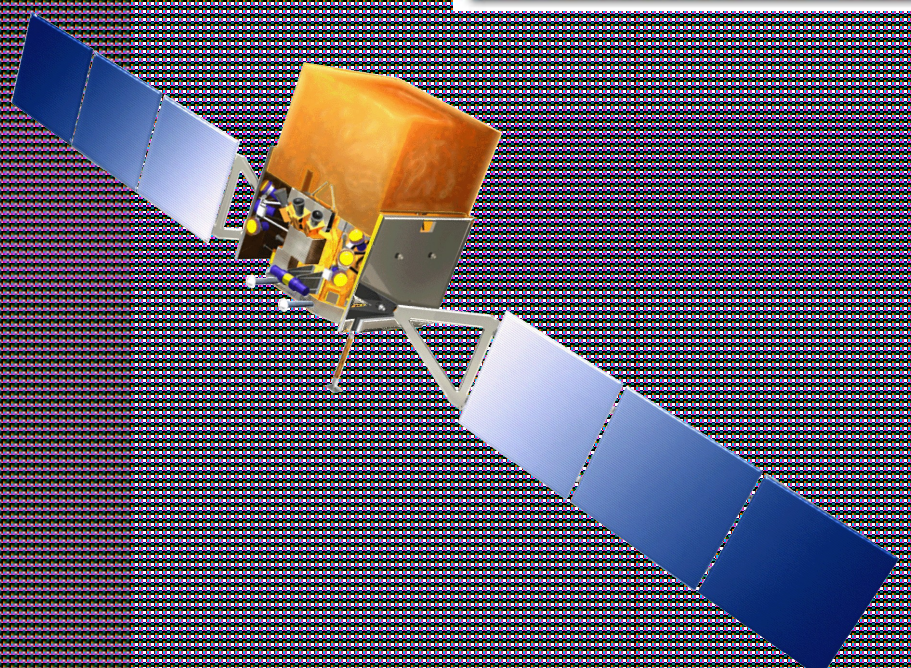
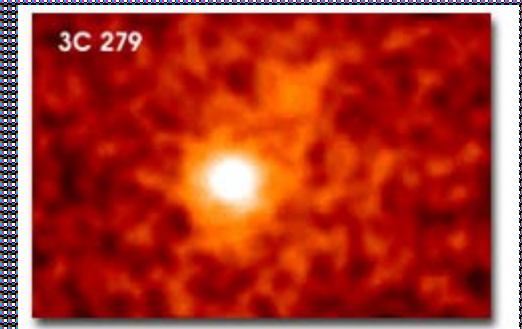
# Creating Mass from Energy

- Pairs of oppositely charged particles can be **produced** from a single energetic gamma-ray photon, interacting with converter material



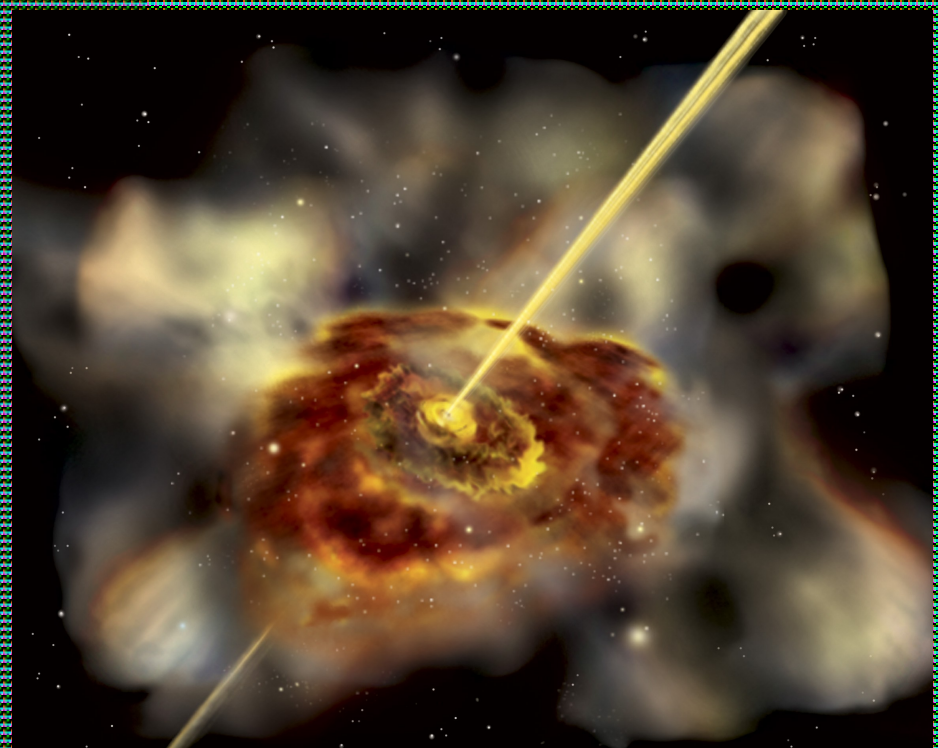
# Pair production in space

- NASA is launching a telescope in 2006 that uses pair production to track gamma-rays from space to their sources – often huge black holes!



# GLAST sees the Universe

- The Gamma-ray Large Area Space Telescope will locate thousands of super-massive black holes that are beaming jets of gamma-rays towards the Earth
- We want to figure out what types of matter are in the jets and how they are made



# What's the matter?

- Growing up in Buffalo, we didn't see too many different types of matter
- Instead of ice, liquid water and steam, we had snow, snow and more snow!



# Three states of matter

■ My mom told me there are three states of matter:

■ Solids



Liquids



Gases



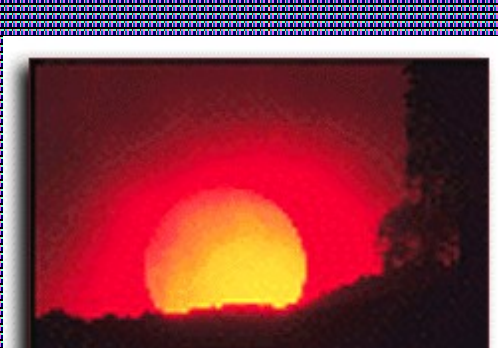
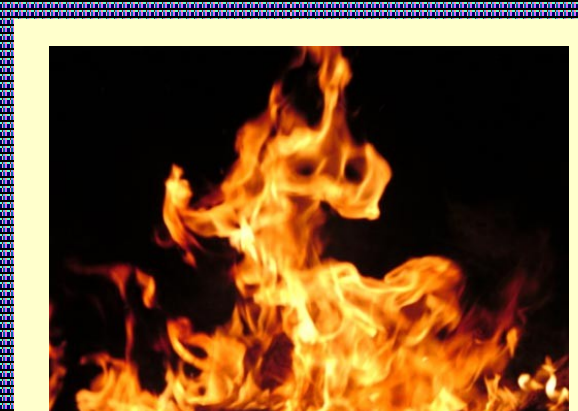
# How many states of matter?



- The state of California science standards agree with my Mom:
  - *Students know matter has three forms: solid, liquid and gas (3)*
  - *Students know the states of matter (solid, liquid, gas) depend on molecular motion (8)*
- **BUT:** Are there really **3** states of matter?

# A fourth state of matter

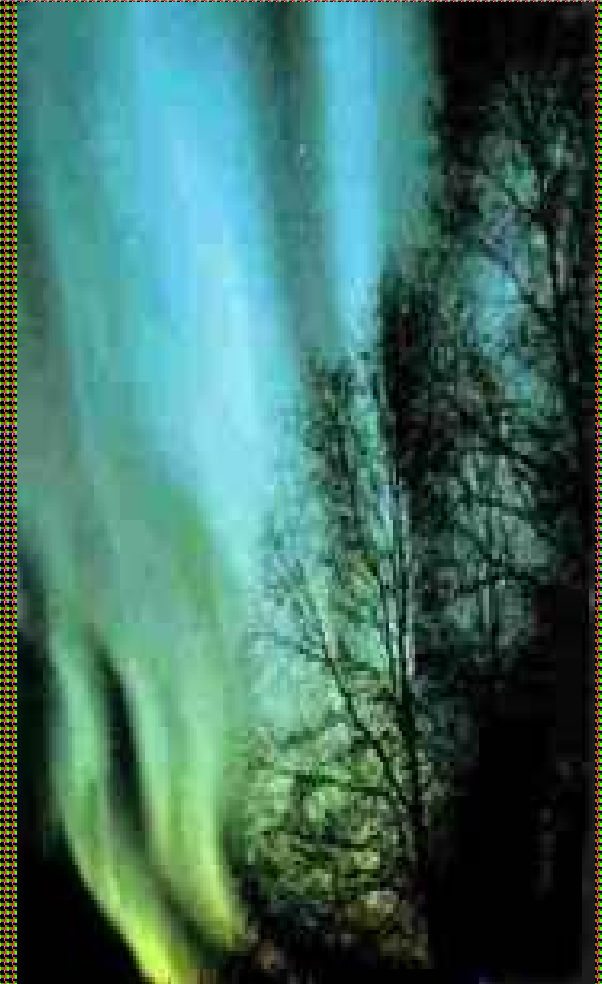
- But even the ancients knew that there are **four** types of matter: Earth, Air, Water and
- **FIRE**



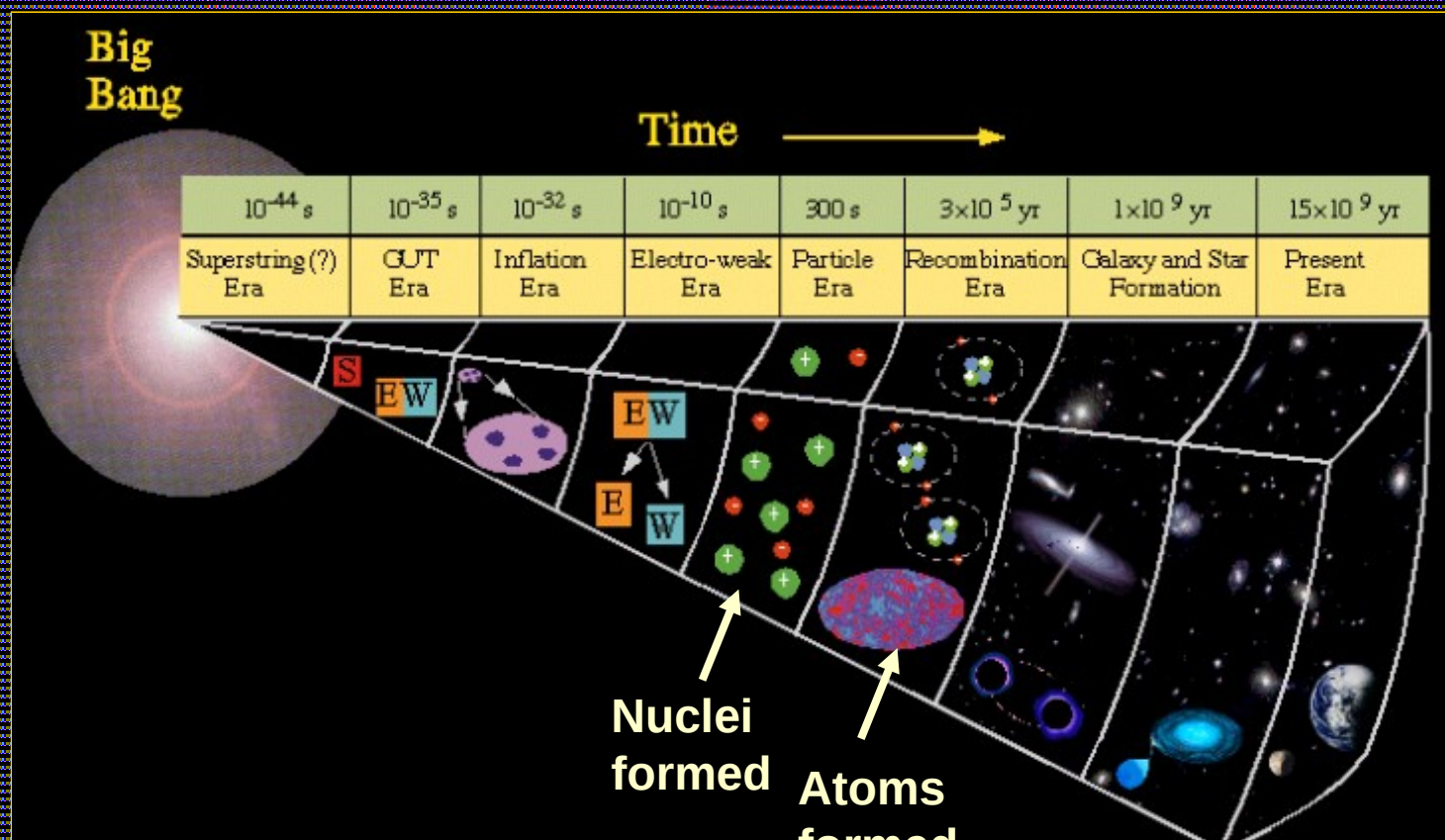
- So, what is the matter in fire?
- Or the Sun?
- Or inside fluorescent light bulbs?

# Plasma – the fourth state

- Plasma makes up more than 99% of everything in the Universe that is luminous
- Plasma is **ionized** atomic matter
- The electrons are dissociated from their nuclei and are free to move around, interacting with any remaining neutral atoms

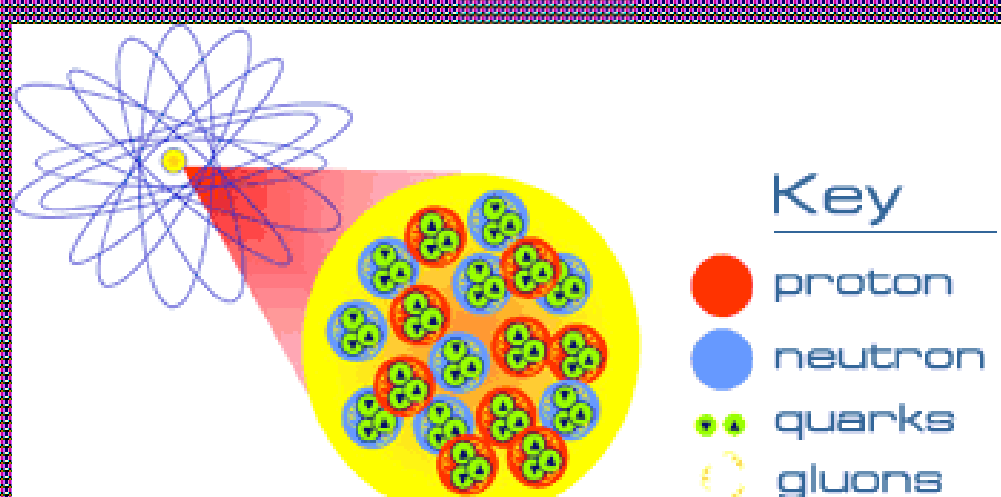


# Creating matter in the Universe



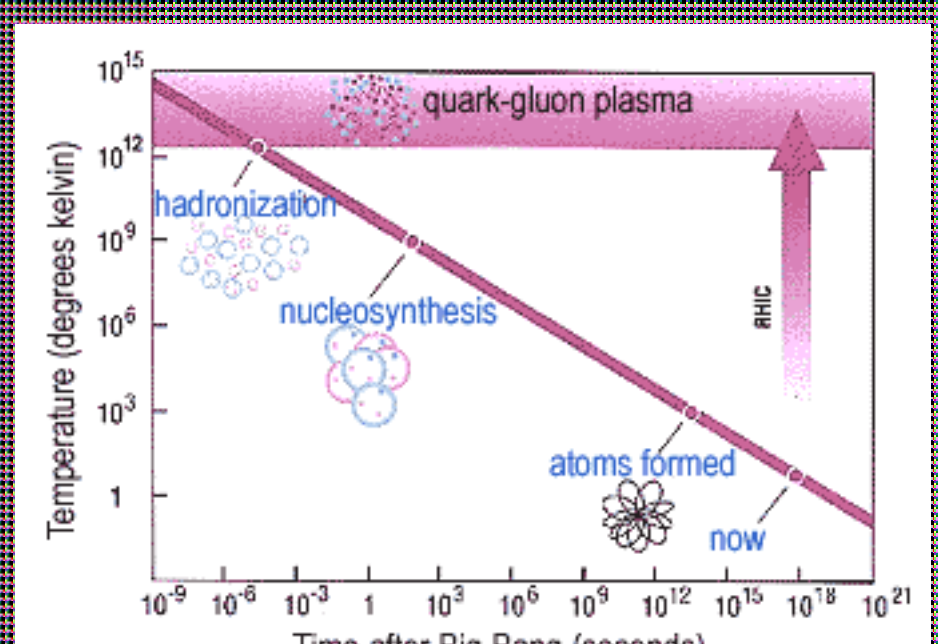
# A new type of matter?

- Scientists at Brookhaven are now trying to break down nuclear matter to create a plasma from quarks and gluons



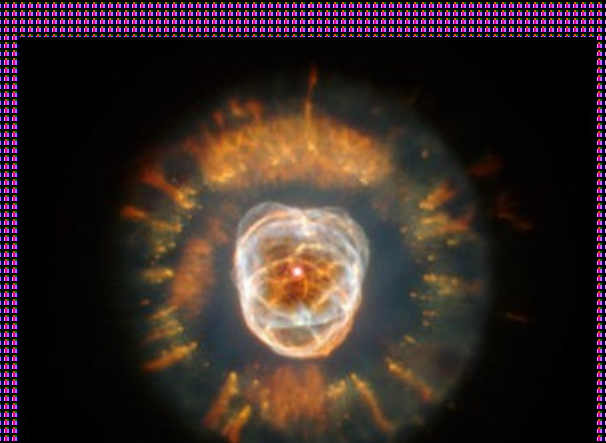
# Quark-Gluon Plasma

- QGP formed:
  - after the Big Bang
  - before the formation of protons, neutrons and atoms
  - with the first light



# Seeing the Light in the Universe

- We see light across the entire energy spectrum:
  - Radio waves (cold gas)
  - Infrared (warm dust)
  - Visible and ultraviolet (hot stars and galaxies)
  - X-rays and gamma-rays (stellar explosions)



HST/Eskimo  
nebula

# THE ELECTROMAGNETIC SPECTRUM

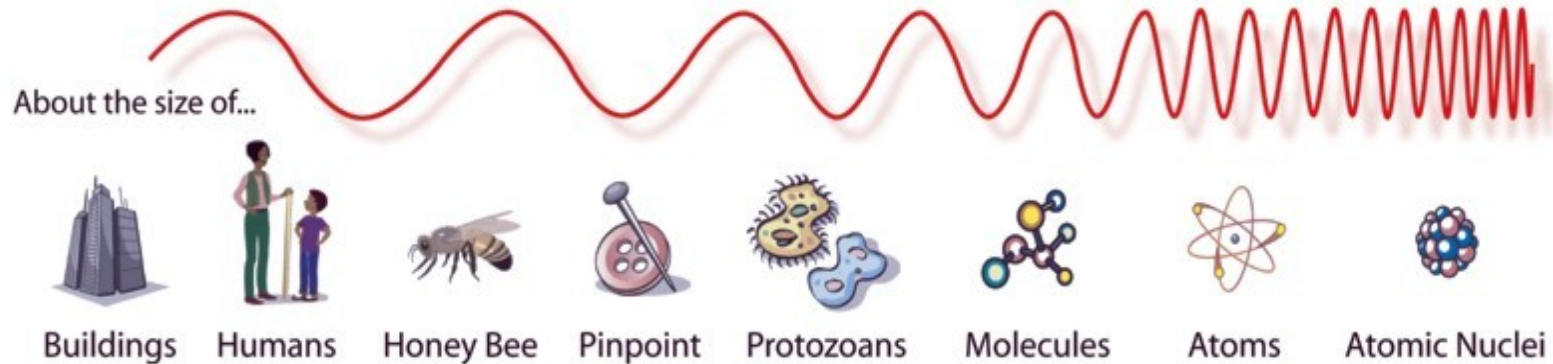
Penetrates  
Earth  
Atmosphere?



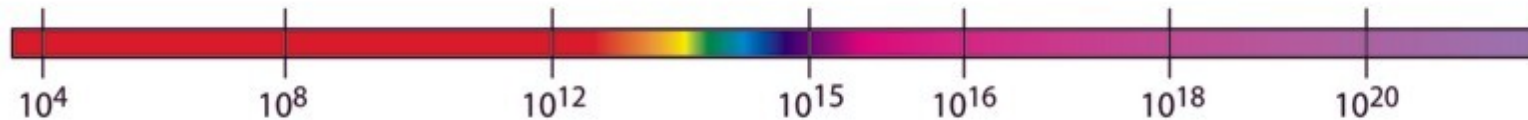
Wavelength  
(meters)



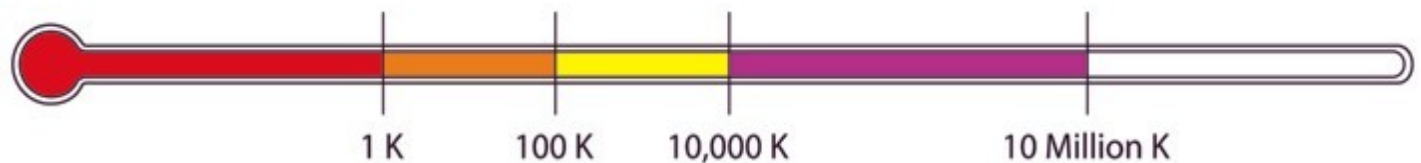
About the size of...



Frequency  
(Hz)

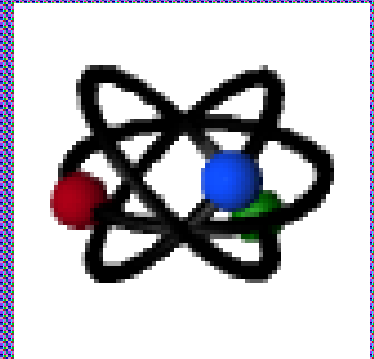


Temperature  
of bodies emitting  
the wavelength  
(K)



# What's the Matter in the Universe?

---

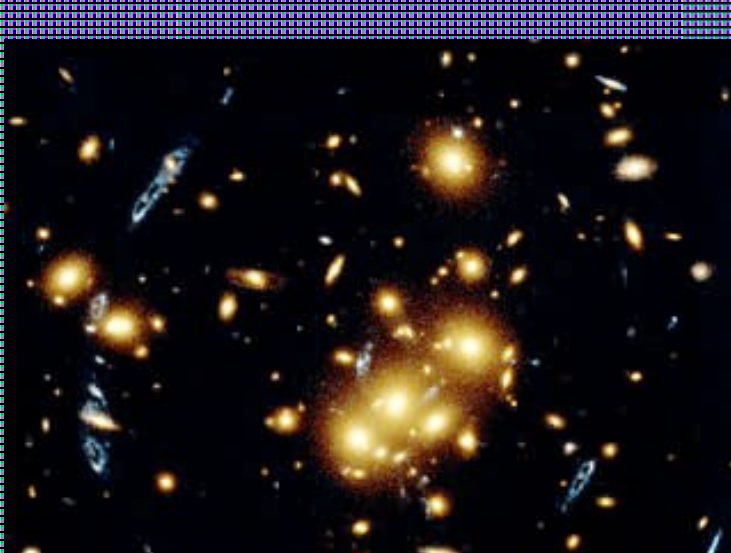


- Most normal matter is in the form of atoms of hydrogen and helium
- Normal matter (even including plasma) only makes up 5% of the mass-energy of the Universe
- Is there matter that does not emit light?
- Can we feel it, even if we can't see it?

# Dark Matter

---

- Dark matter emits no light, but it interacts with luminous matter through gravity

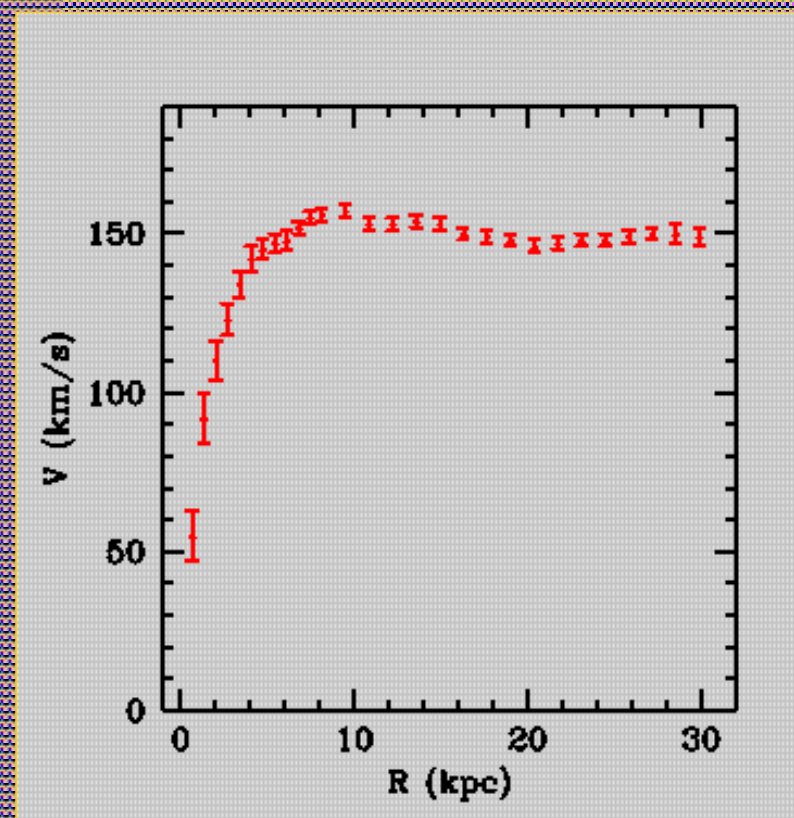


The blue arcs are images of a blue galaxy that is being lensed gravitationally by dark matter in the yellow-orange galaxy cluster

HST/CL0024+1654

# Dark Matter

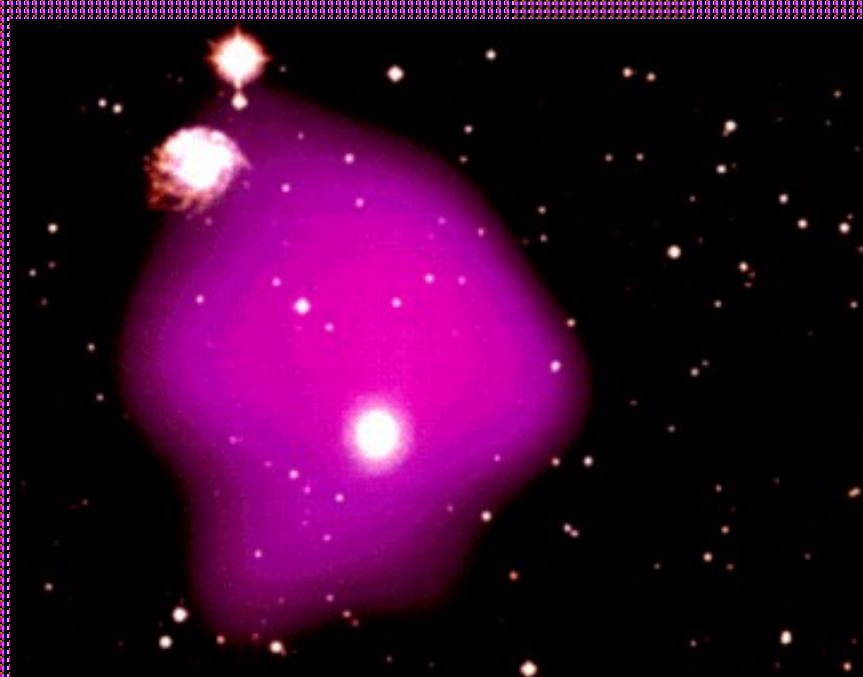
- Dark matter holds in rapidly orbiting stars in the outer parts of galaxies
- It also flattens a galaxy's rotation curve



NGC 3198

# Dark Matter

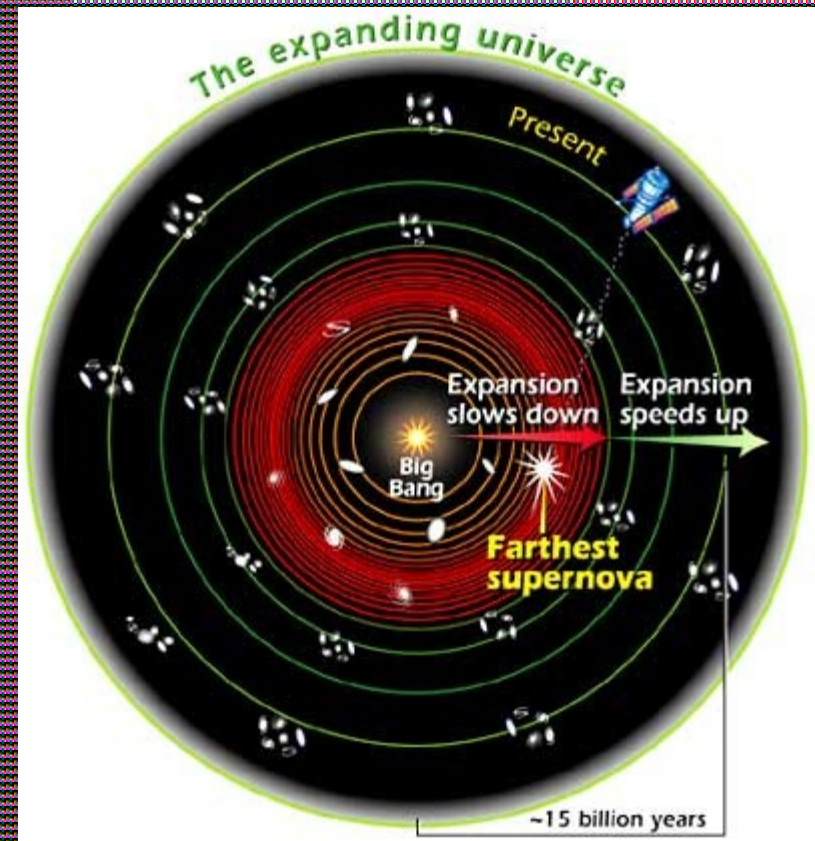
- Dark matter holds x-ray heated gas inside of clusters of galaxies



Overlay of  
visible light  
image of  
galaxy cluster  
with x-ray  
heated gas  
(purple)

# Dark Energy

- In 1998, two teams of researchers announced that they had found evidence for the acceleration of the expansion of the Universe
- Some type of new “anti-gravity” seems to be at work, driving this acceleration
- It is known as the mysterious **dark energy**



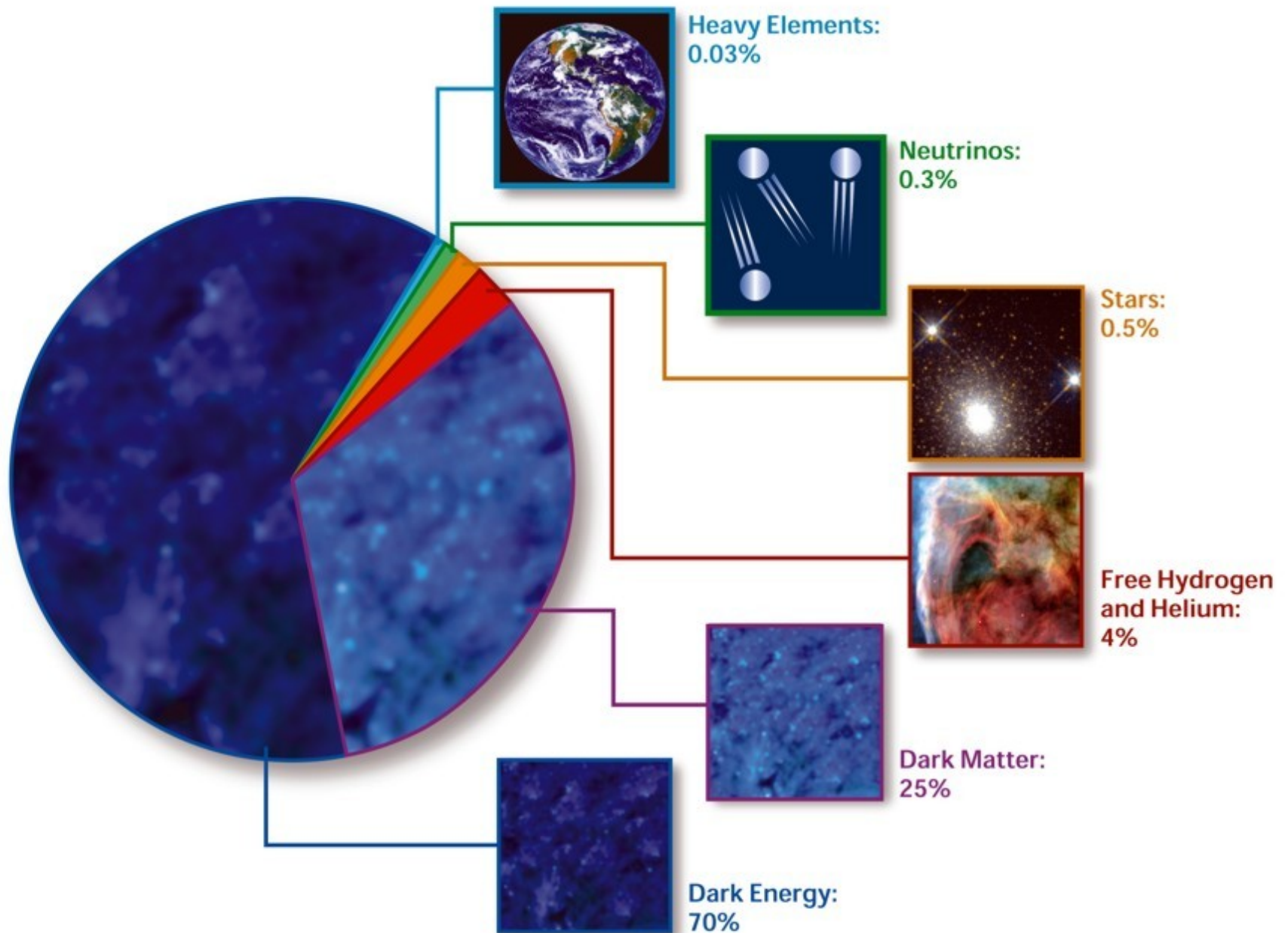
# Dark Energy

- A form of DE was predicted by Einstein to solve a problem with his Theory of General Relativity
- GR predicted that the Universe would either expand or collapse
- However, Einstein believed it should be stable
- When the Universe was found to expand, Einstein called this his “biggest blunder”

**EVERYONE  
HAS PROBLEMS  
SOMETIMES**



# COMPOSITION OF THE COSMOS



# Going Beyond Einstein

---



- NASA is beginning a new program to test predictions of Einstein's theories:
  - What happens at the edge of a black hole?
  - What powered the Big Bang?
  - What is the mysterious Dark Energy that is pulling the Universe apart?
- Do Einstein's theories completely describe our Universe?

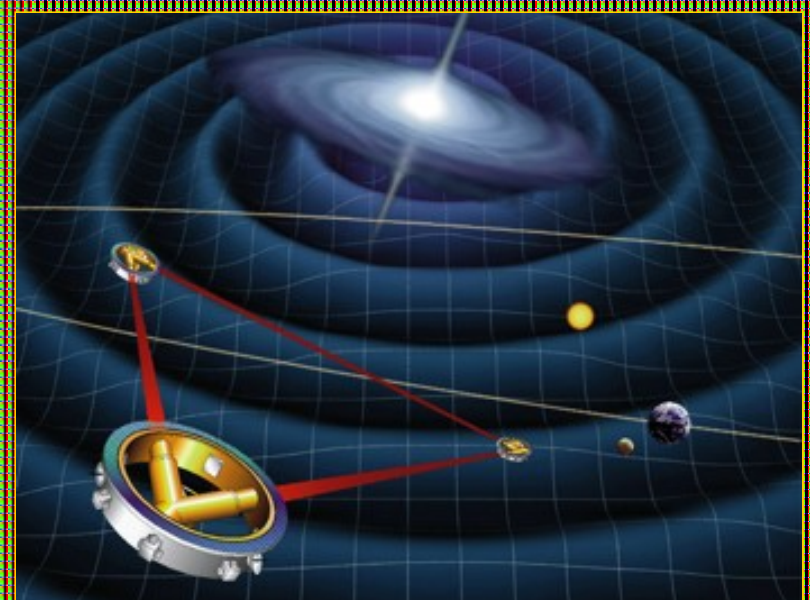
# BE Great Observatories

## Constellation X



**Four X-ray telescopes  
flying in formation**

## LISA



**Three satellites, each with 2  
lasers and 2 test masses**

# Beyond Einstein Probes

---

Black Hole Finder



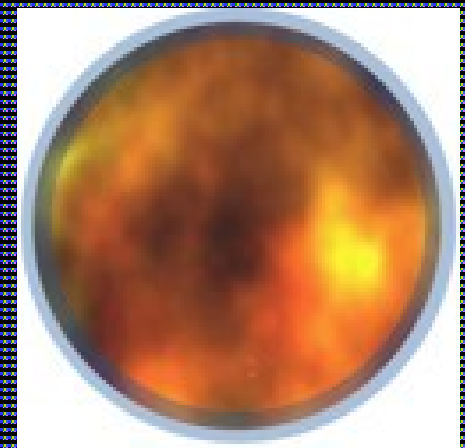
Census of  
hidden  
Black Holes

Dark Energy



Measure  
expansion  
history

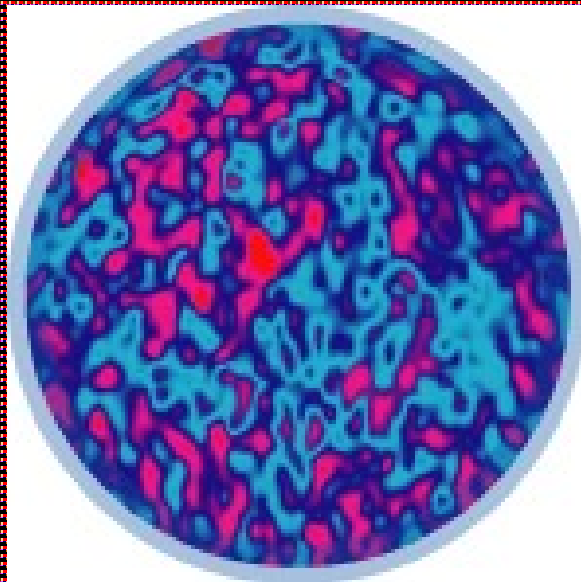
Inflation



Polarization  
of CMB

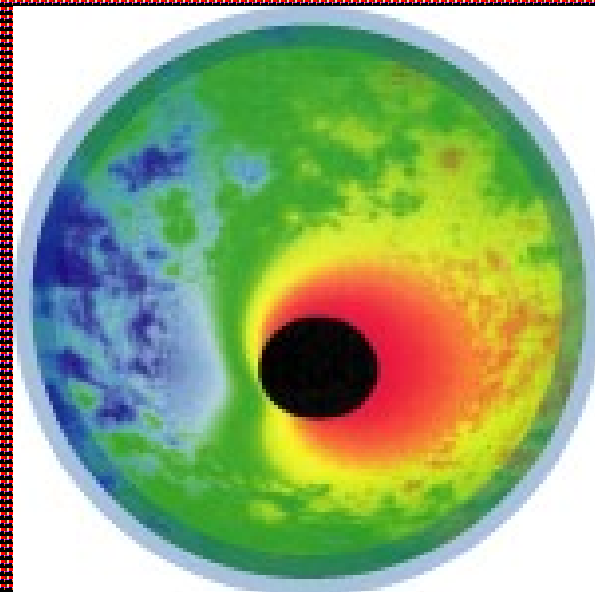
# Beyond Einstein Vision Missions

## Big Bang Observer



Direct detection of  
gravitational waves  
from Big Bang

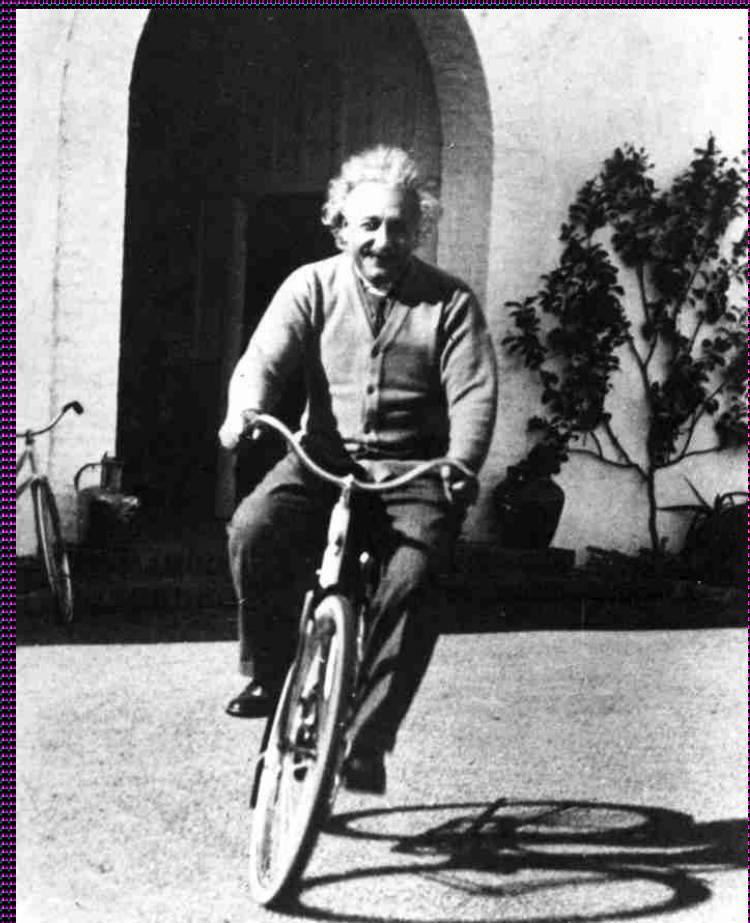
## Black Hole Imager



Resolved image of  
the Event Horizon

# Some last words from Einstein

- “The most incomprehensible thing about the Universe is that it is comprehensible”

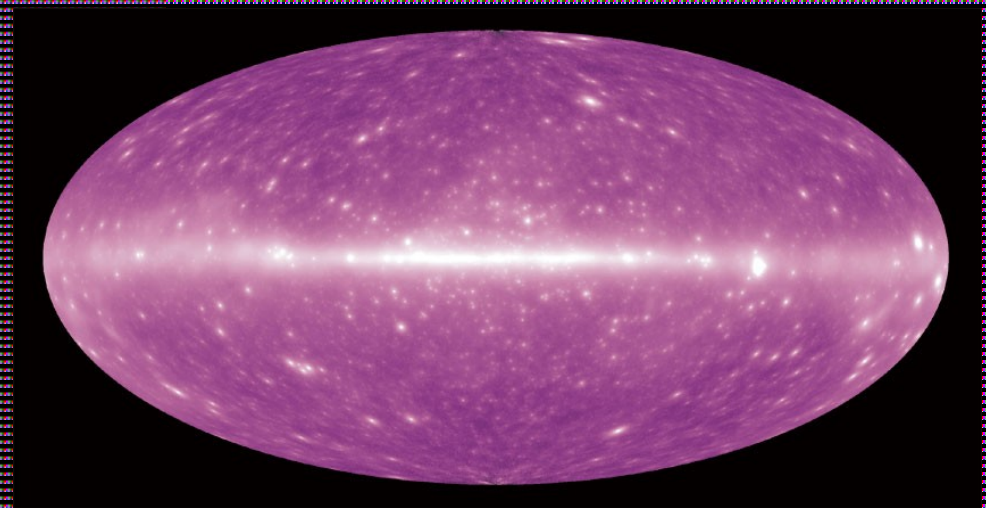


# And some last words about my Mom...



- *When my mother taught me a few stars, she opened my eyes to the entire Universe*

Gamma-ray sky that  
will be seen by  
GLAST



# Resources

- <http://glast.sonoma.edu>
- <http://imagine.gsfc.nasa.gov>
- <http://regentsprep.org/Regents/physics/phys01/accgravi/nogravsm.htm>
- <http://scidiv.bcc.ctc.edu/wv/0001-02-statesofmatter.html>
- <http://www.plasmacoalition.org/>
- <http://universe.gsfc.nasa.gov>
- Uwe R. Zimmer - [transit-port.net/Galleries/Germany/ pages/Full  
%20moon.htm](http://transit-port.net/Galleries/Germany/pages/Full%20moon.htm)
- <http://www.bnl.gov/rhic/primer.htm>
- <http://www.nobel.se/>



# “Super” states of matter & energy

- Superfluids, superconductors, Bose-Einstein condensates and lasers
- Many Nobel prizes have been won for explaining these phenomena
- All involve unusual physical manifestations in which the particles/photons have the same properties on a quantum level

