

**What we don't know about the  
Universe?**

**Dr Chris Pearson : RAL Space**

# Cosmology

- How did the Universe Begin ?
- How old is the Universe ?
- How big is the Universe ?
- What is the Universe made of ?
- Will the Universe end ?

# Cosmology: A Tale of 3 Numbers

**H**

**Hubble parameter**

(how fast is Universe expanding)

**$\Omega$**

**Density parameter**

(how much stuff is in the Universe)

**$\Lambda$**

**Cosmological Constant**

(is the Universe accelerating or decelerating)

# Our Place in the Universe

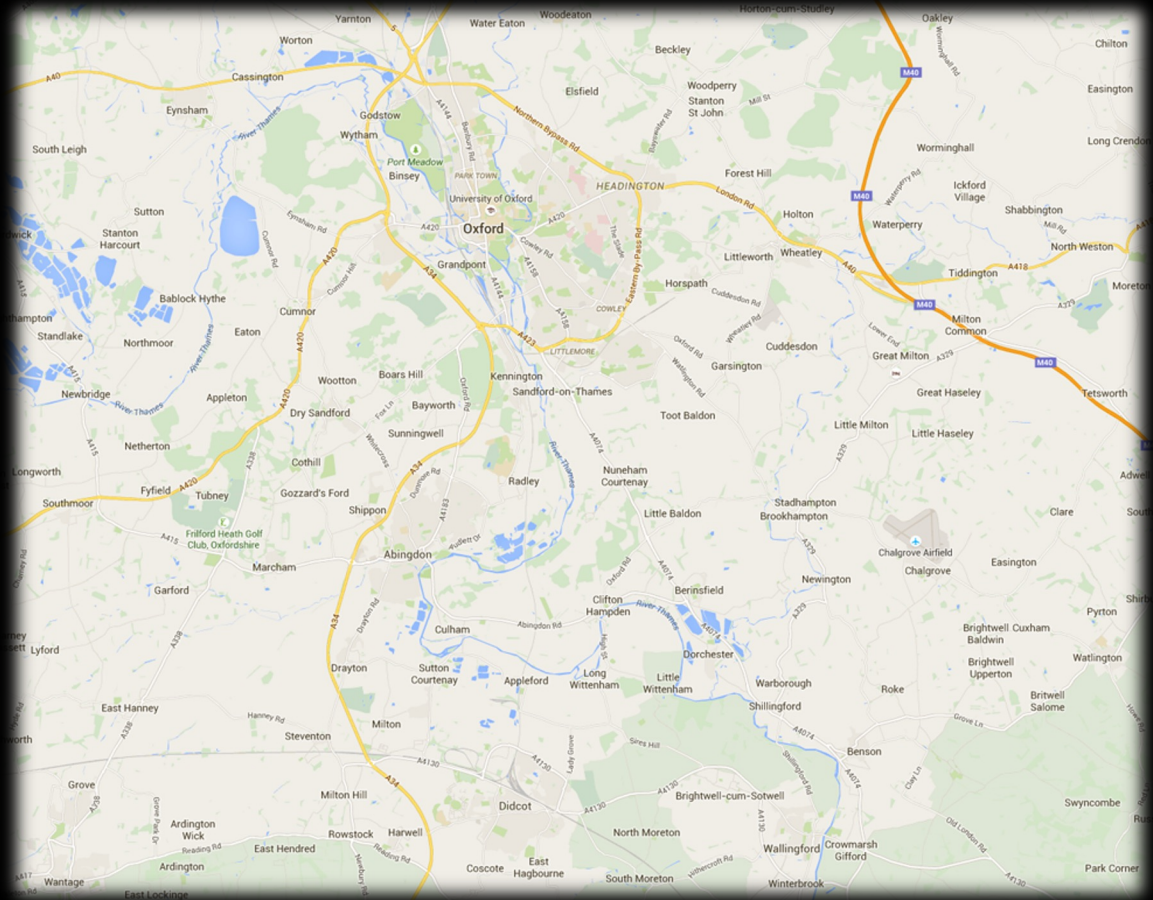
Rutherford Appleton Laboratory



Scale  $\sim 1$  km

# Our Place in the Universe

Rutherford Appleton Laboratory  
Oxfordshire



Scale ~ 10 km

# Our Place in the Universe

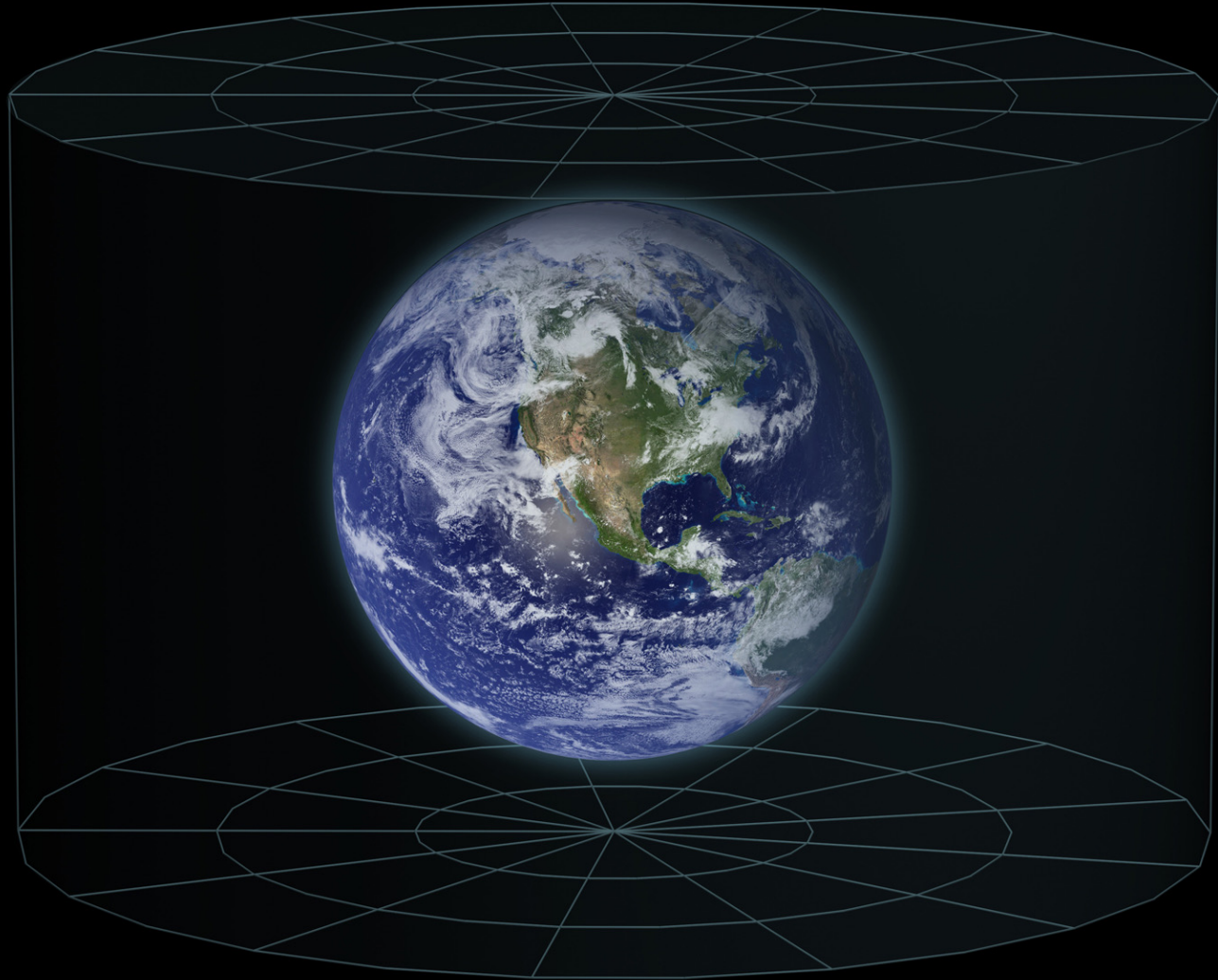
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom



Scale ~ 100 km

# Our Place in the Universe

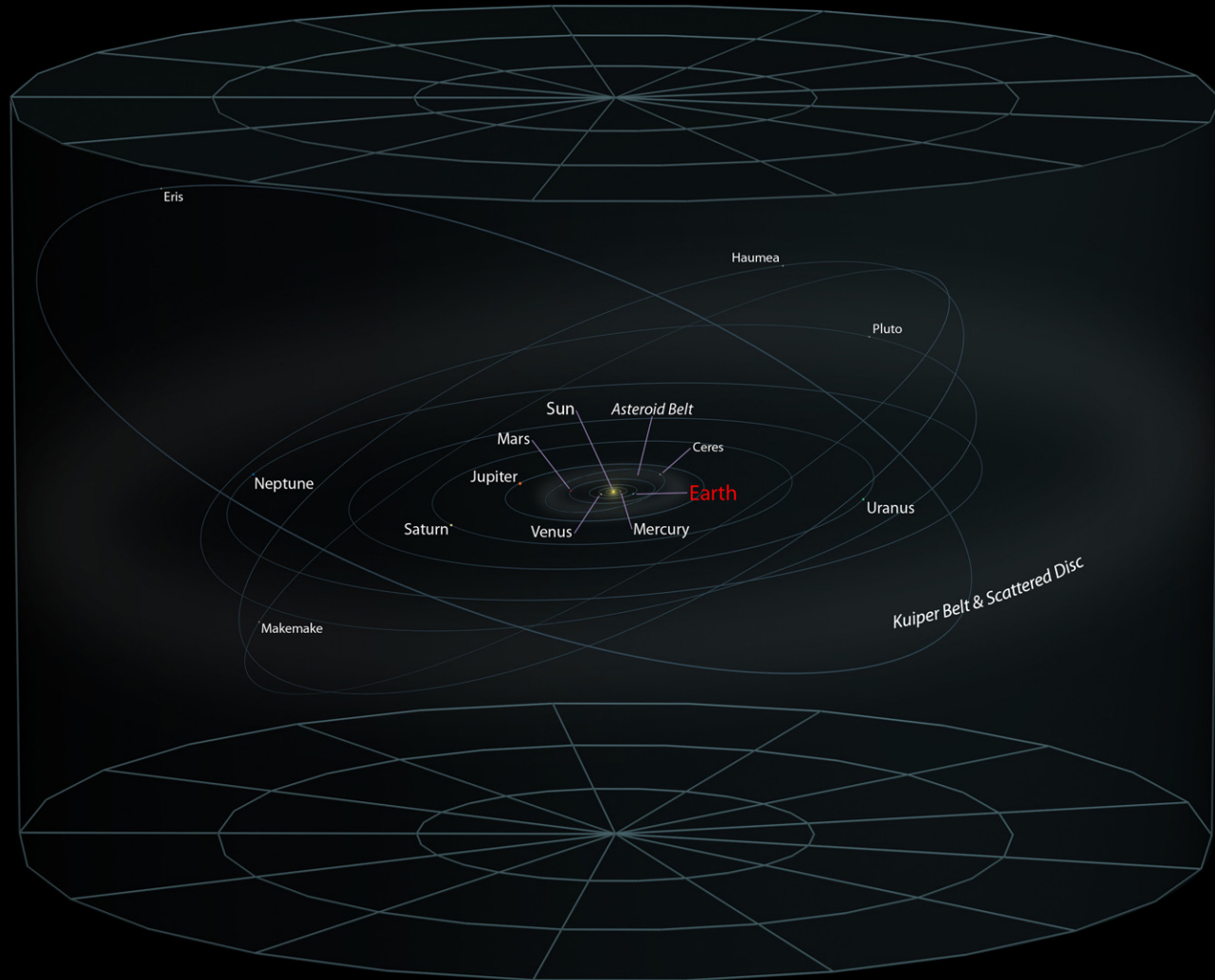
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth



Scale  $\sim$  1000 km

# Our Place in the Universe

Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System

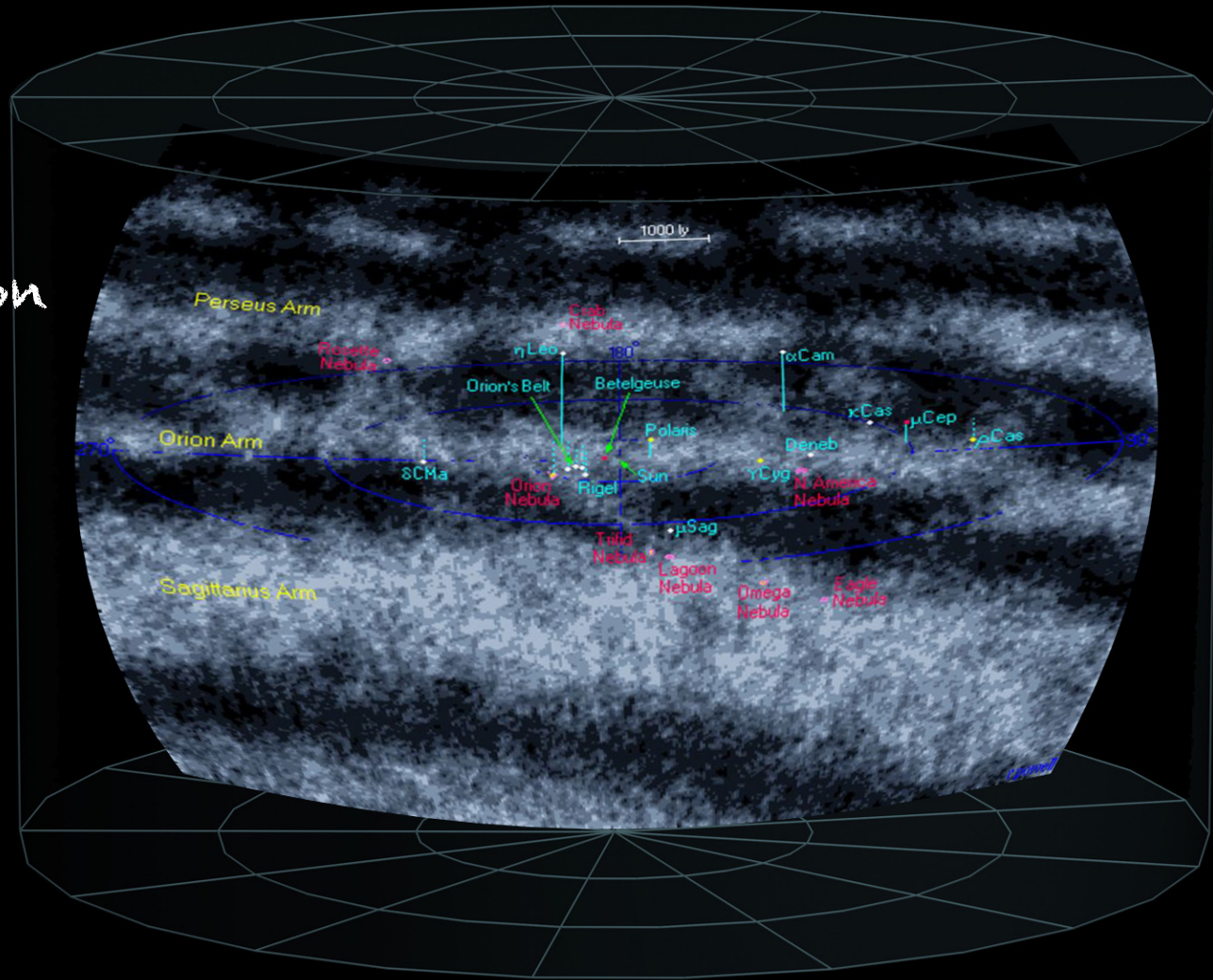


Scale  $\sim 1 \text{ A.U.} = 1.5 \times 10^8 \text{ km}$  or 7 Lm



# Our Place in the Universe

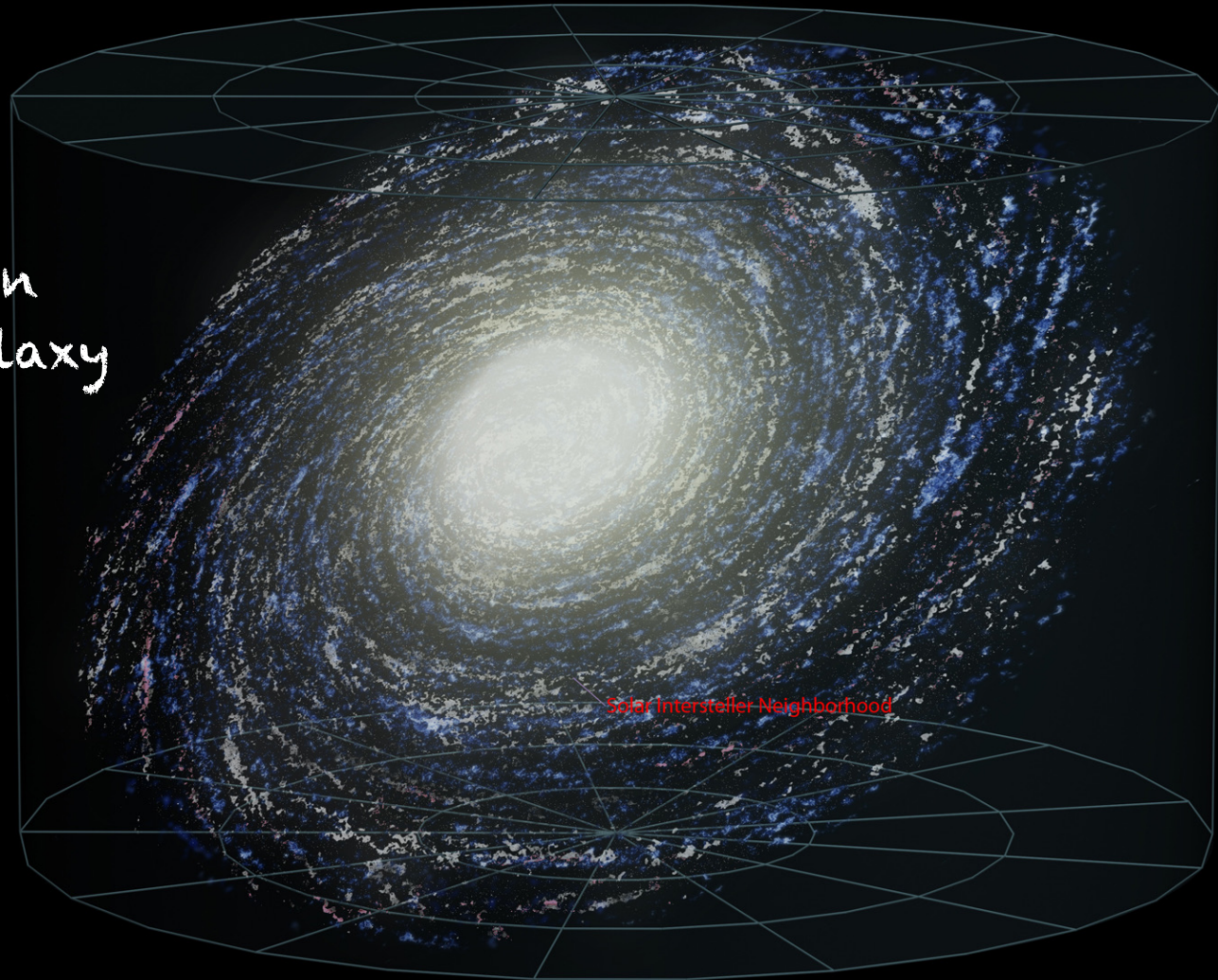
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion



Scale  $\sim$  1000 light years =  $9.5 \times 10^{15}$  km

# Our Place in the Universe

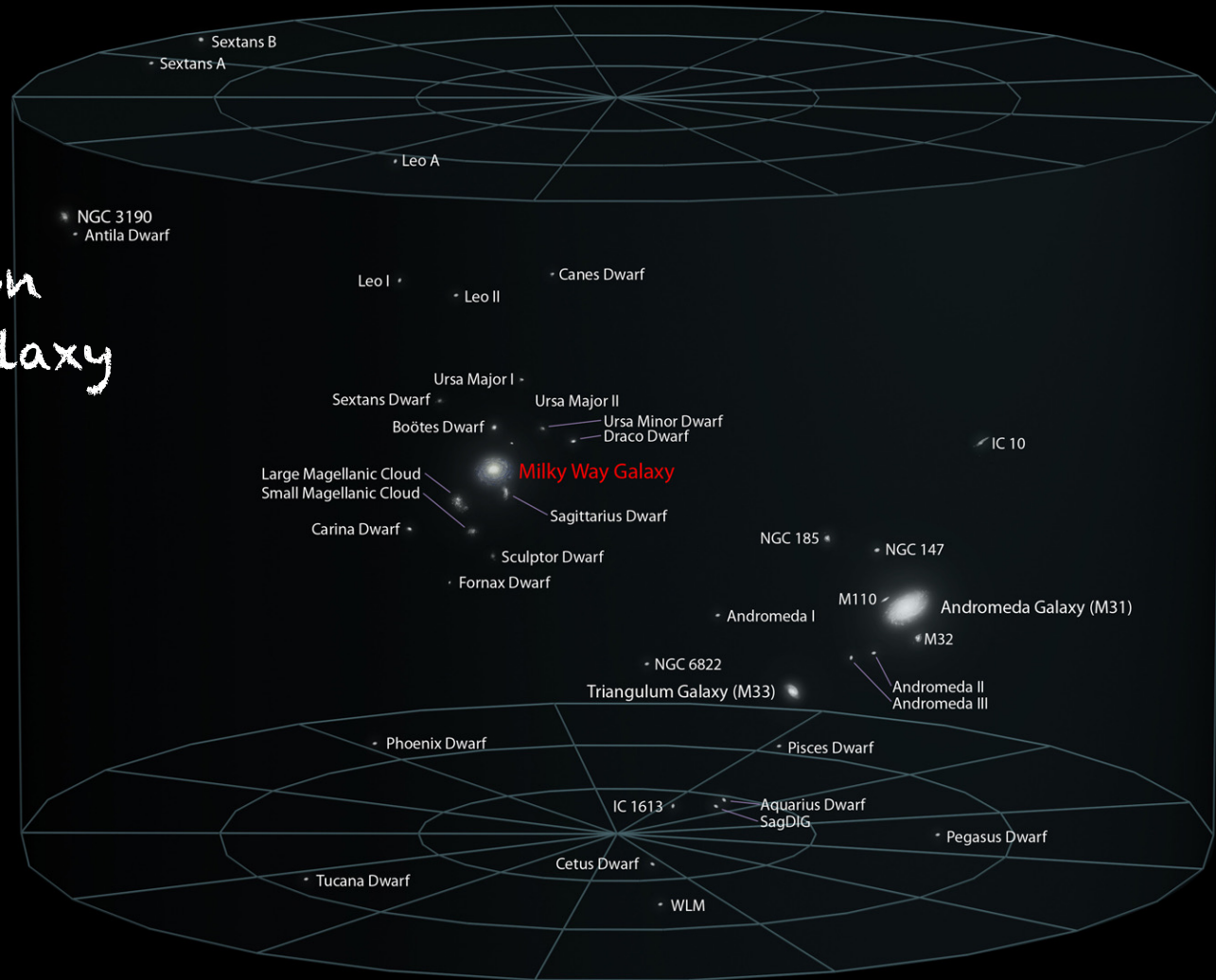
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion  
The Milky Way Galaxy



Scale  $\sim$  100,000 light years  $\sim$  30 kpc

# Our Place in the Universe

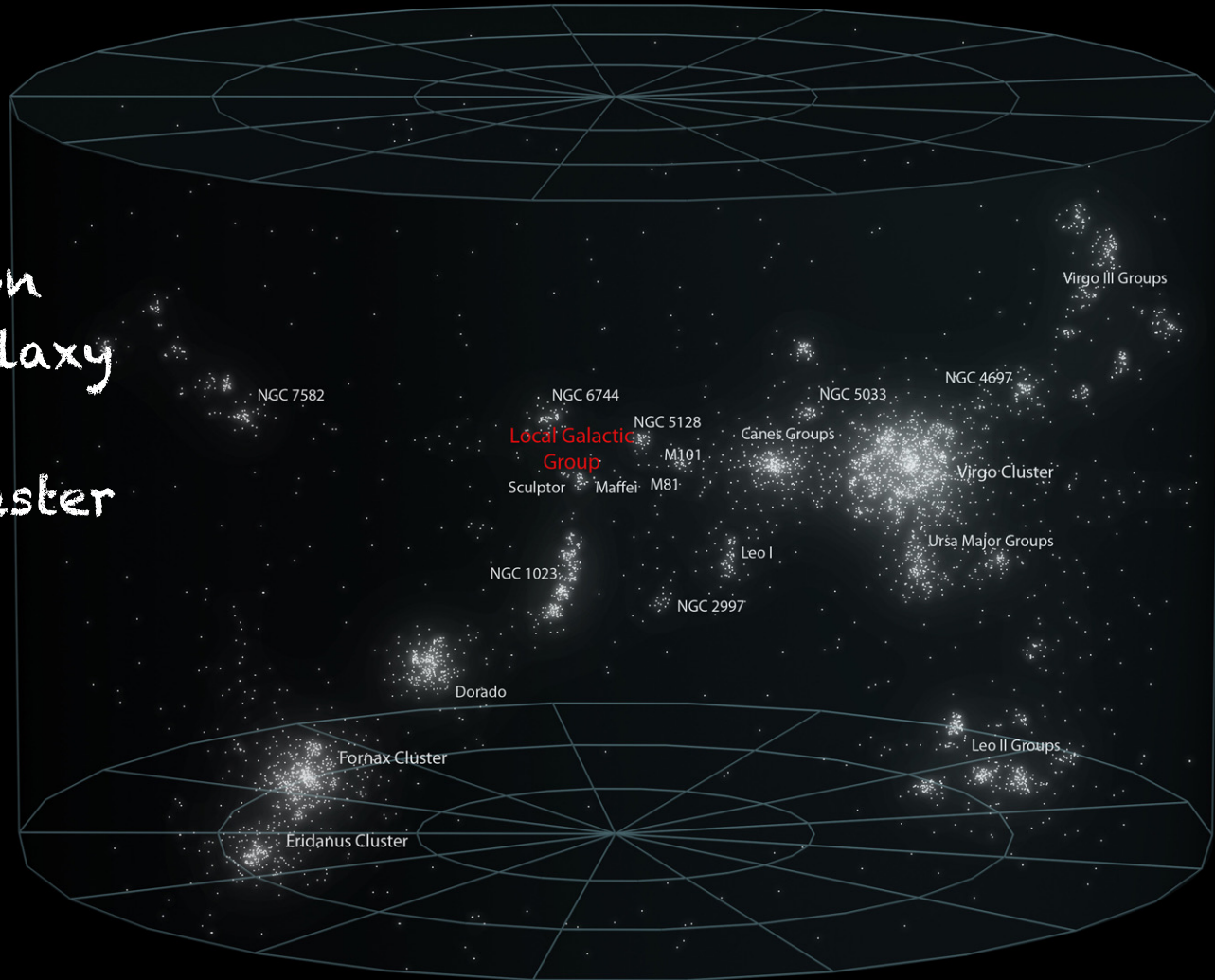
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion  
The Milky Way Galaxy  
The Local Group



Scale ~ 1 million light years ~ 0.5 Mpc

# Our Place in the Universe

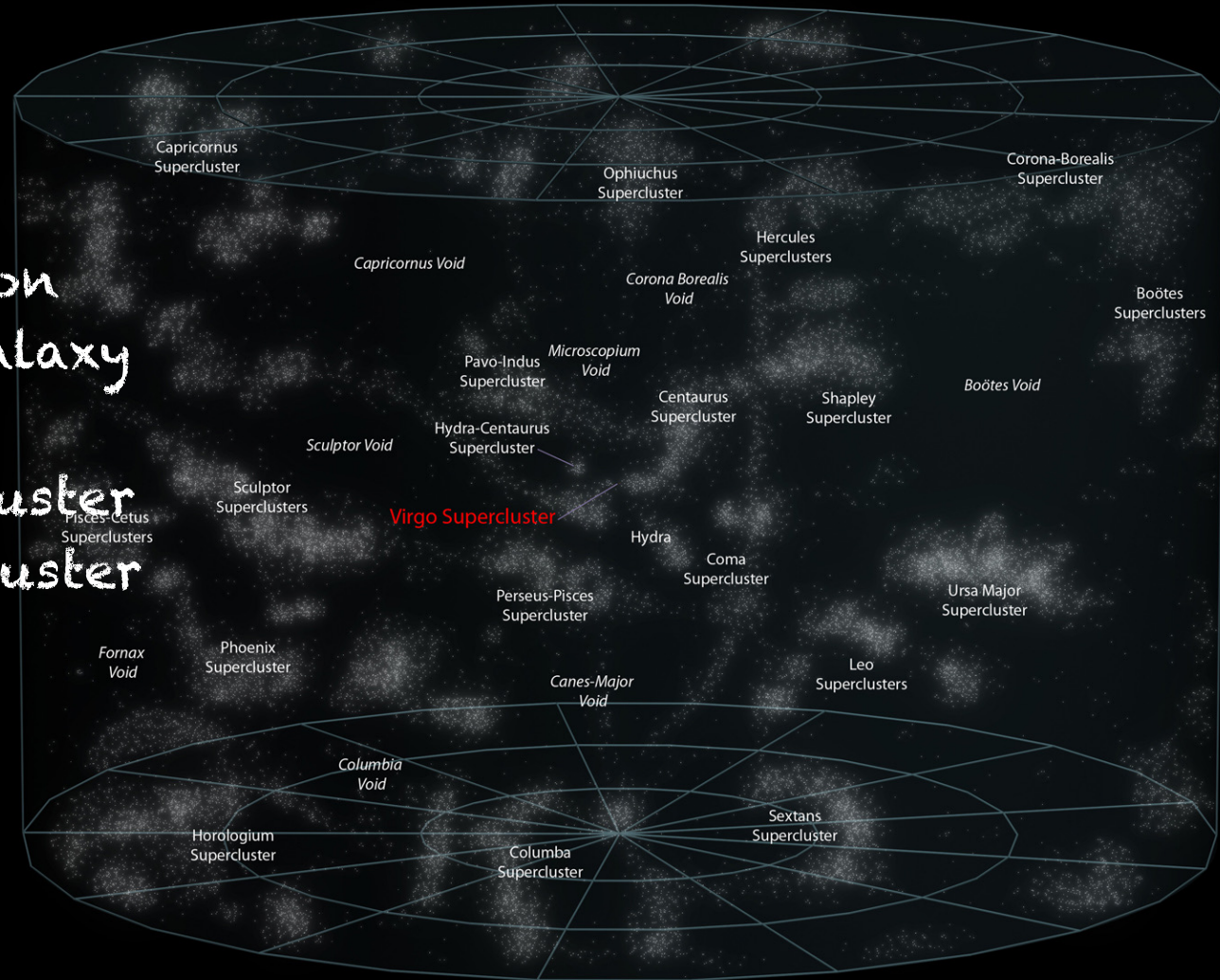
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion  
The Milky Way Galaxy  
The Local Group  
Near the Virgo Cluster



Scale ~ 50 million light years

# Our Place in the Universe

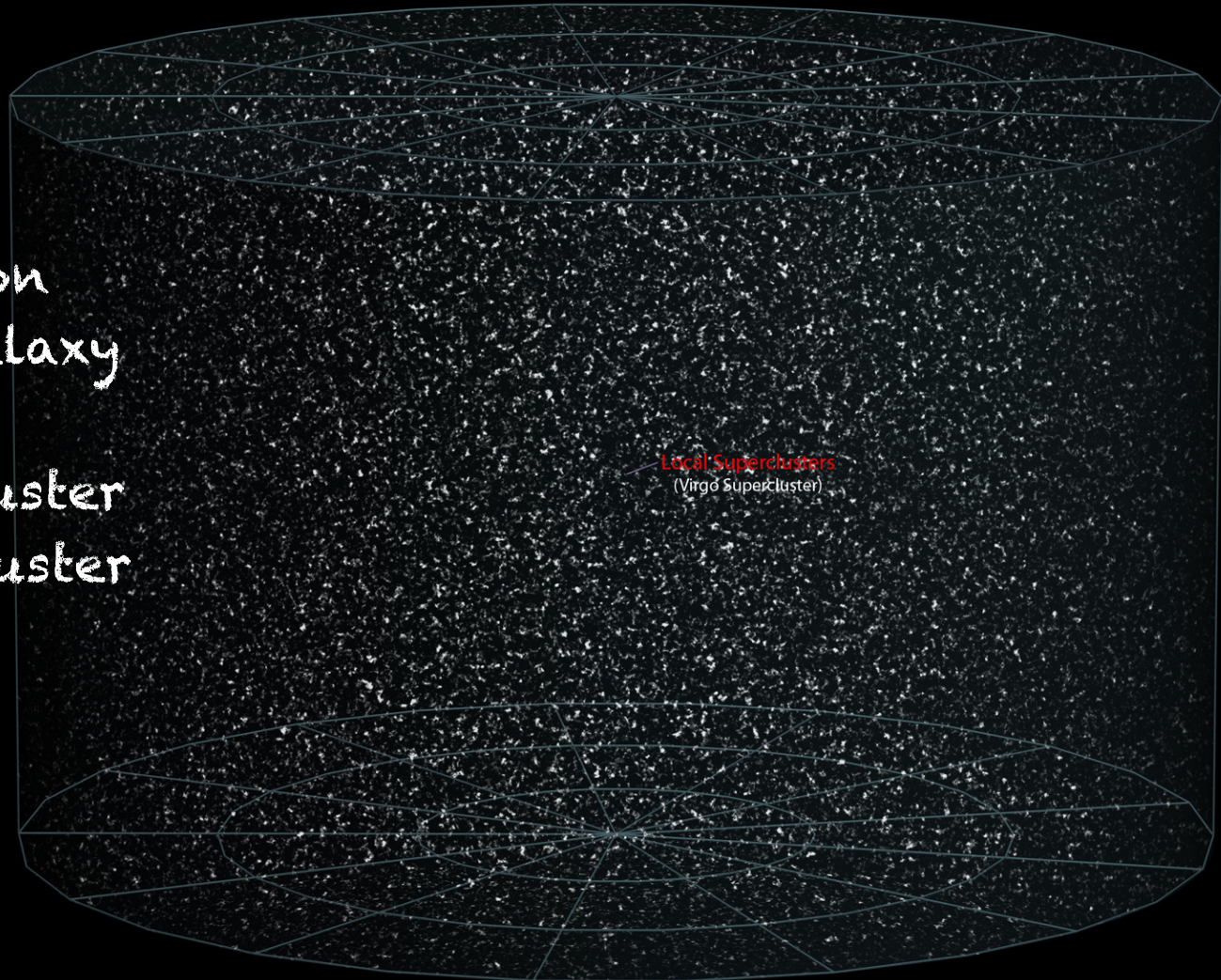
Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion  
The Milky Way Galaxy  
The Local Group  
near the Virgo Cluster  
The Local Supercluster



Scale ~ 100 million light years

# Our Place in the Universe

Rutherford Appleton Laboratory  
Oxfordshire  
United Kingdom  
Planet Earth  
Solar System  
Spiral Arm of Orion  
The Milky Way Galaxy  
The Local Group  
near the Virgo Cluster  
The Local Supercluster  
The Universe



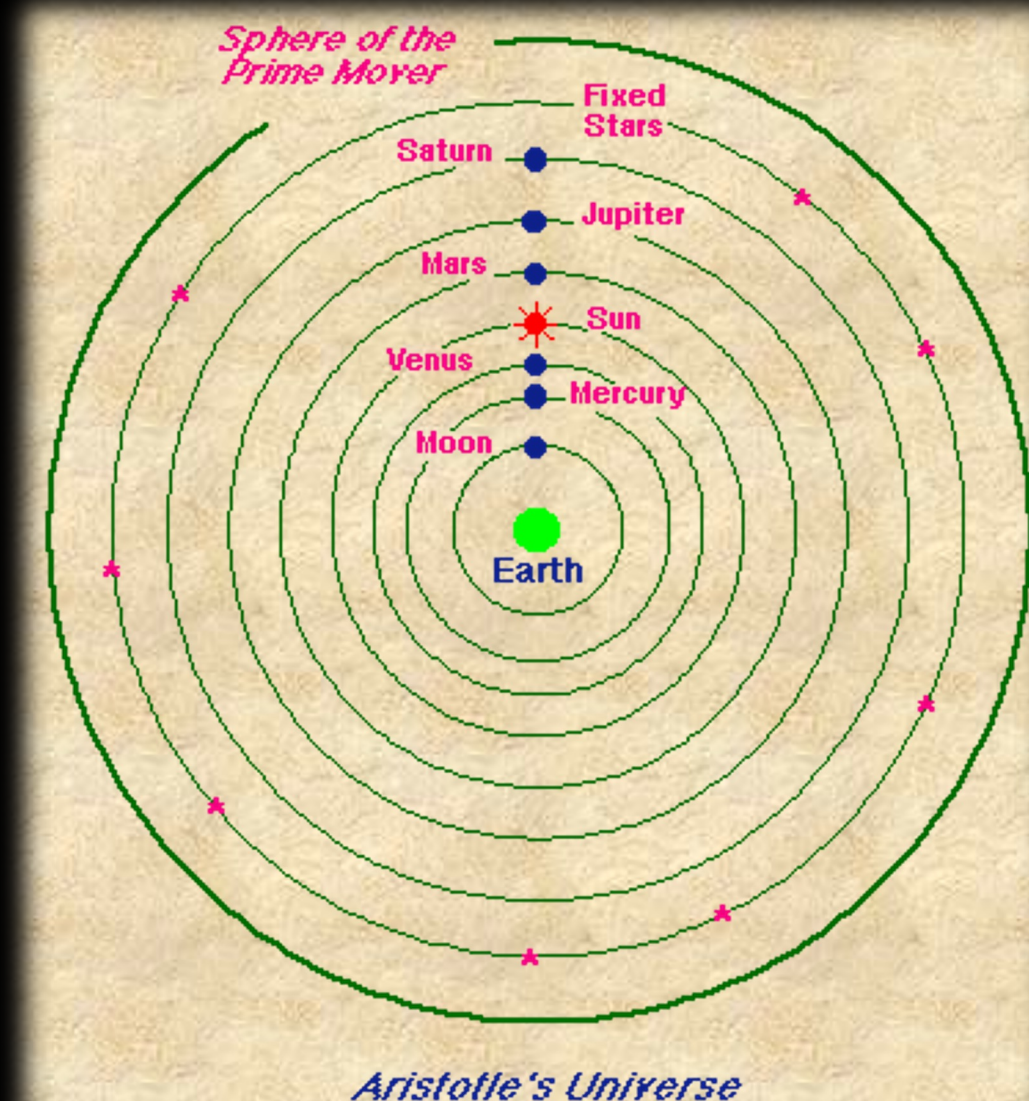
Scale ~ 90 billion light years ~ 28 Gpc

# The Birth of Cosmology

Ancient Greeks: The first cosmological model

Aristotle (384-322 B.C.)

Geocentric

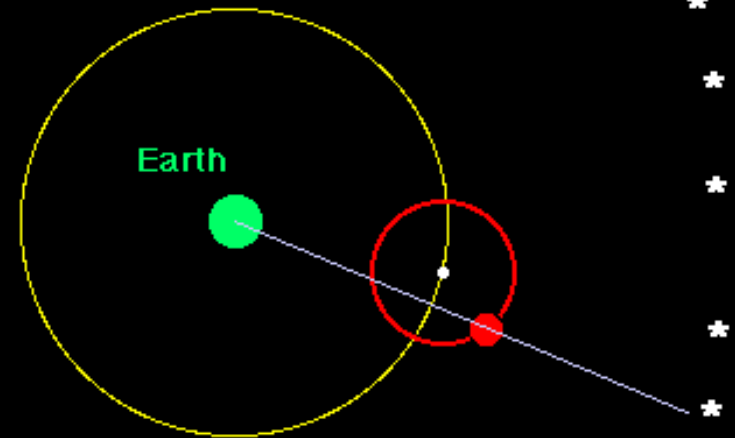
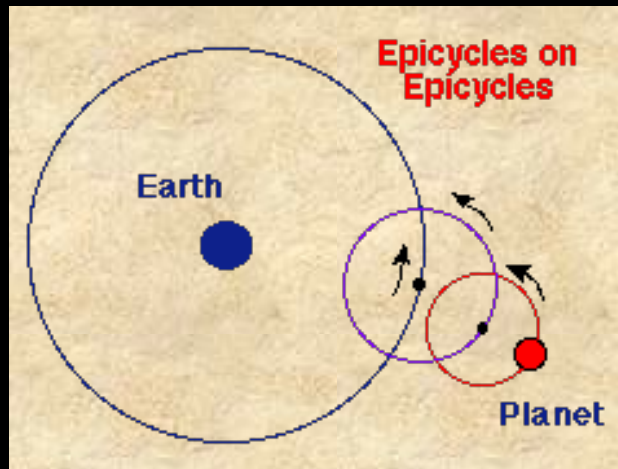


# The Birth of Cosmology

Ptolemy (90-168 A.D.)

Geocentric

Perfect motion should be in circles,  
so the stars and planets,  
being heavenly objects, moved in circles.

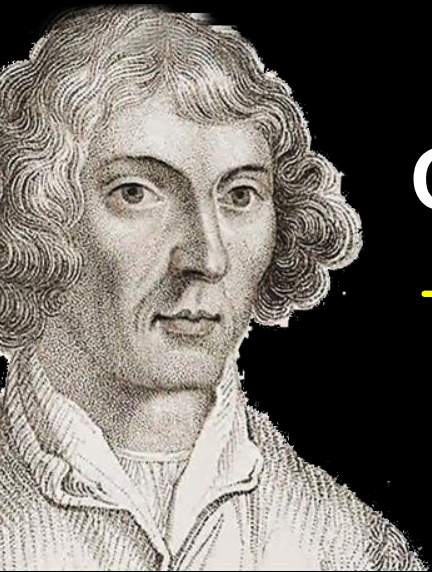




# The Birth of Cosmology

Copernicus (1473-1543)

Heliocentric

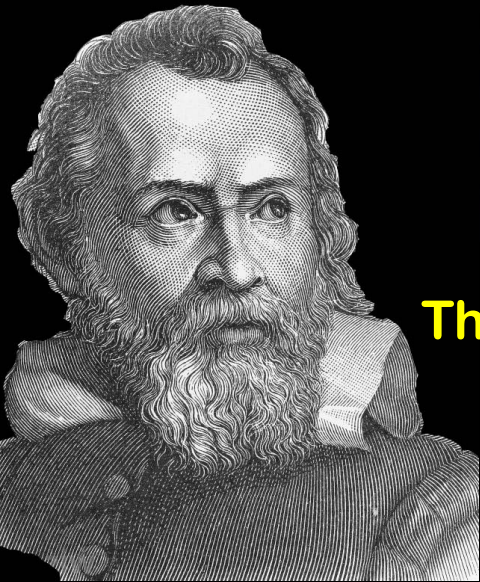


## Copernican Cosmological Principle

The Earth does not occupy a special place in the Universe

# The Birth of Cosmology

Galileo Galilei (1564-1642)  
and the telescope



The Earth does not occupy a special place in the Universe

# The Birth of Cosmology

Edwin Hubble (1929)

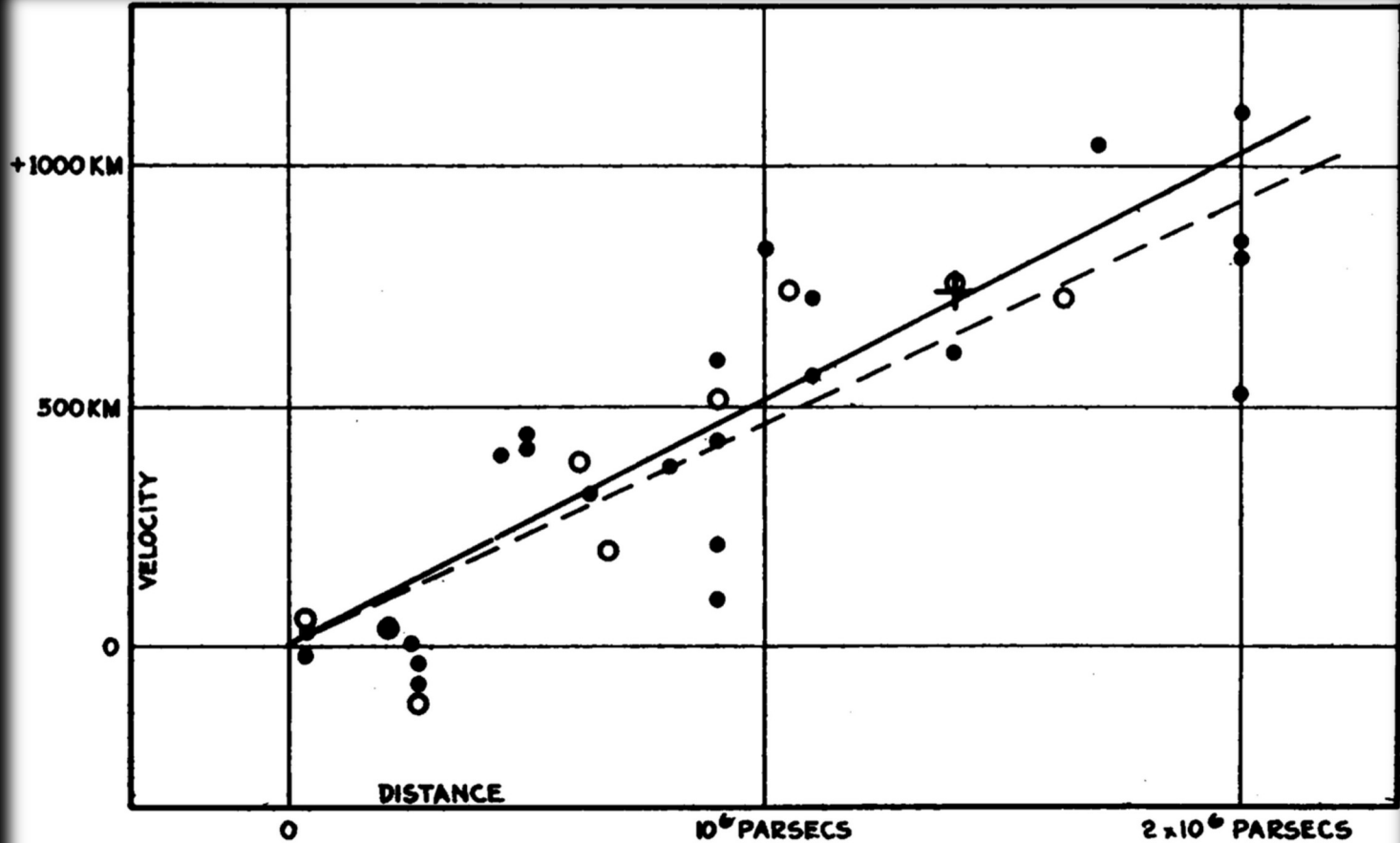
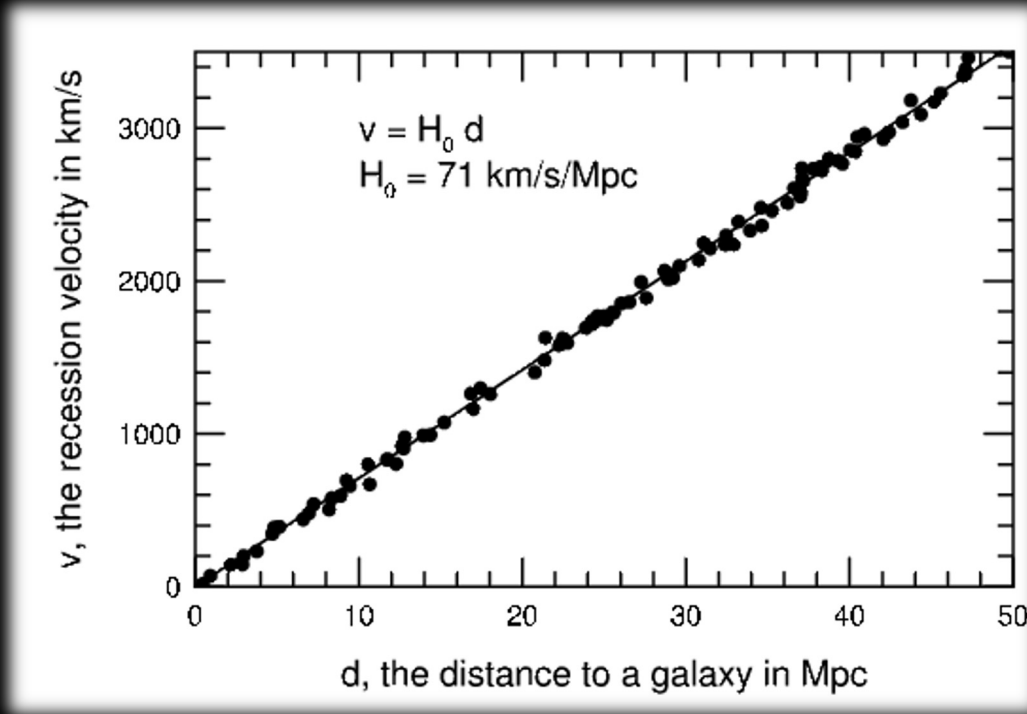


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.



# The Birth of Cosmology



- 1) (almost) all galaxies are moving *away* from us
- 2) More *distant* galaxies are moving away *faster*

$$v \propto d$$

$$v = H_0 d$$

$H_0$  : The Hubble Constant

# Cosmology: A Tale of 3 Numbers

**H**

**Hubble parameter**

(how fast is Universe expanding)

**$H_0 = 67.3$  km/s/Mpc**

**$\Omega$**

**Density parameter**

(how much stuff is in the Universe)

**$\Lambda$**

**Cosmological Constant**

(is the Universe accelerating or decelerating)

# The Cosmological Principle

## Copernican Cosmological Principle

The Earth does not occupy a special place in the Universe

## The Cosmological Principle

At any single time: the Universe appears homogeneous and isotropic to everyone

**Homogeneity:** *No preferred locations*

Same picture of Universe at any time seen by all observers.

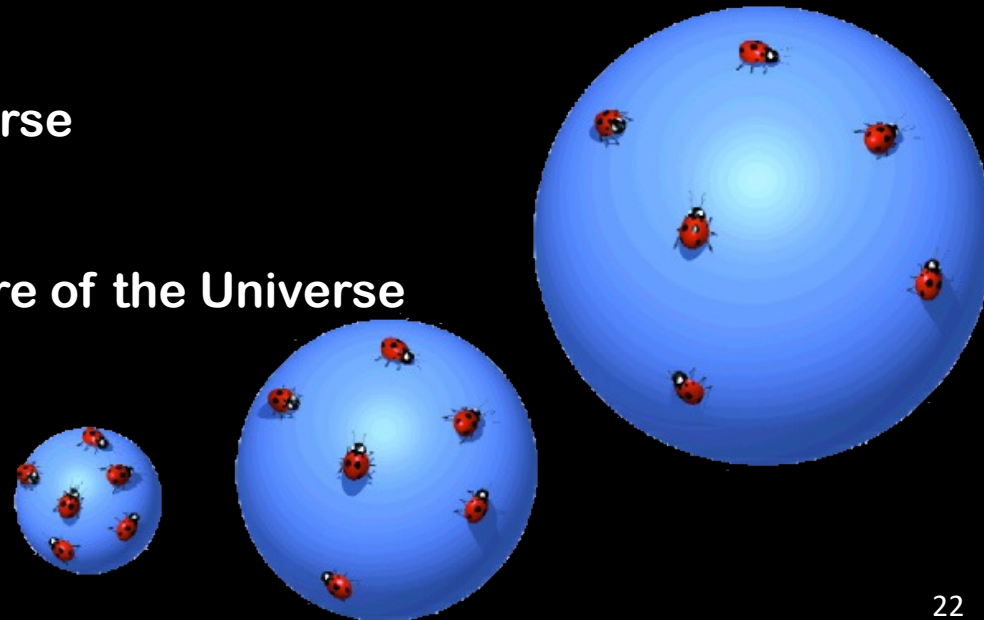
**Isotropy:** *No preferred Directions*

The Universe looks the same in all directions to all observers.

There is no preferred place in the Universe

There is no centre to the Universe

.... or everyone thinks they are the centre of the Universe



# The Big Bang



# The Big Bang

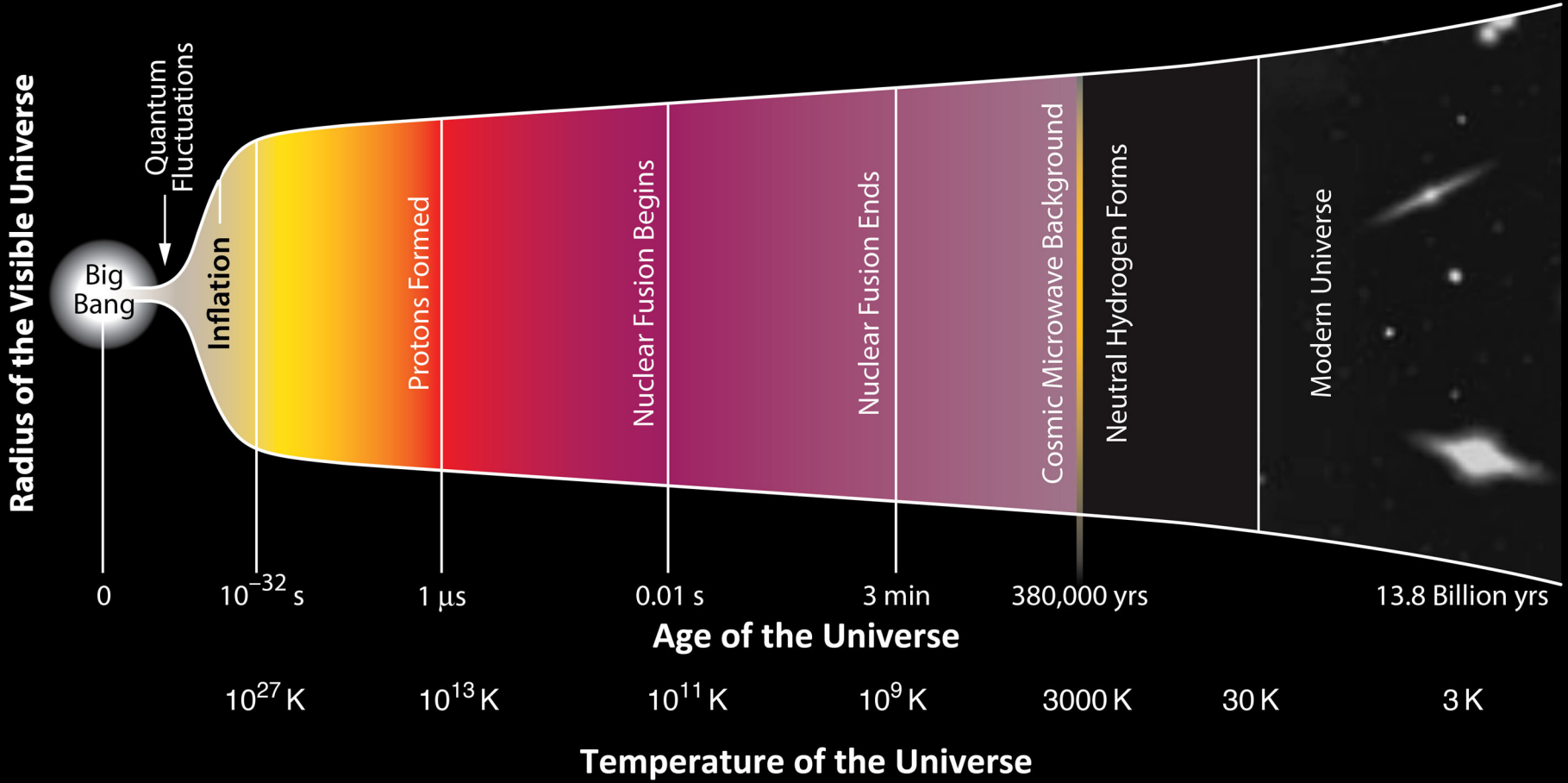
Running Time backwards

$$\left. \begin{array}{l} t \rightarrow 0 \\ R \rightarrow 0 \\ T \rightarrow \infty \\ \rho \rightarrow \infty \end{array} \right\}$$

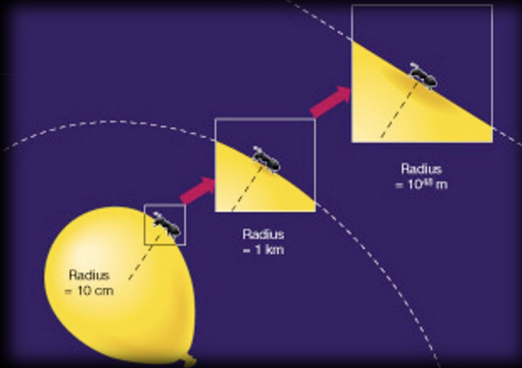
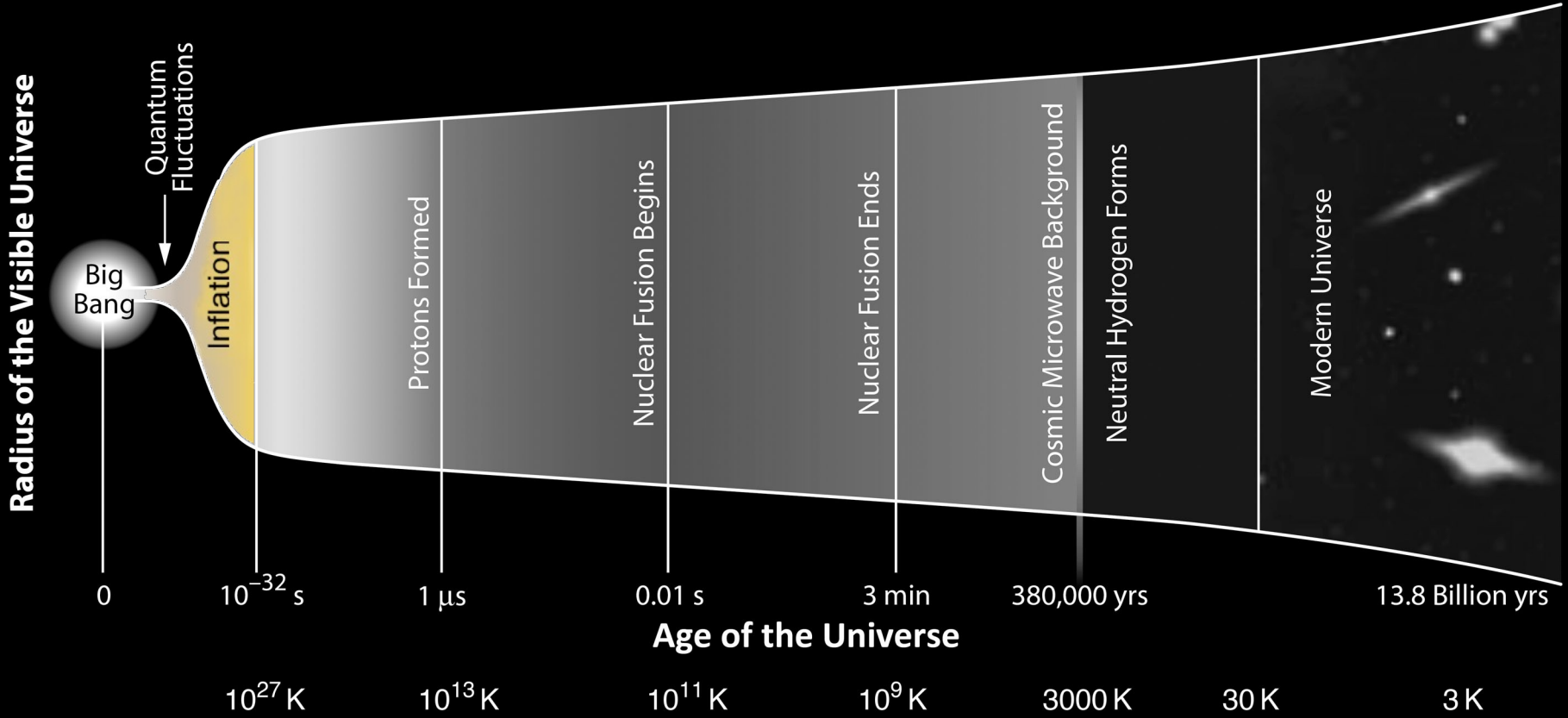
Initial singularity - The Creation Event



# The Big Bang



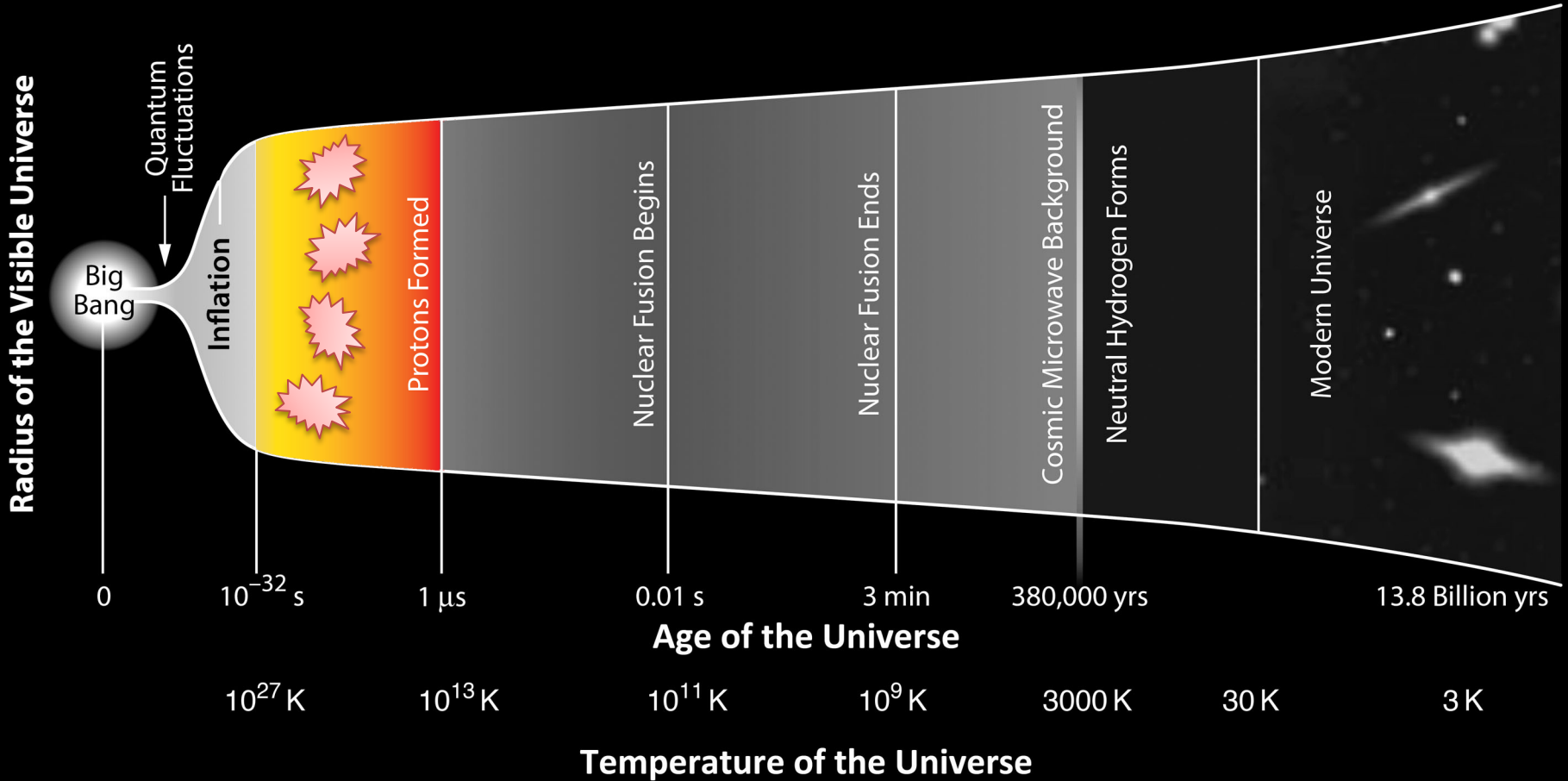
# The Big Bang



**Inflation Period**  
**Universe expands exponentially**  
 **$10^{-34}$  s to  $10^{-32}$  s ~ 100 e foldings**

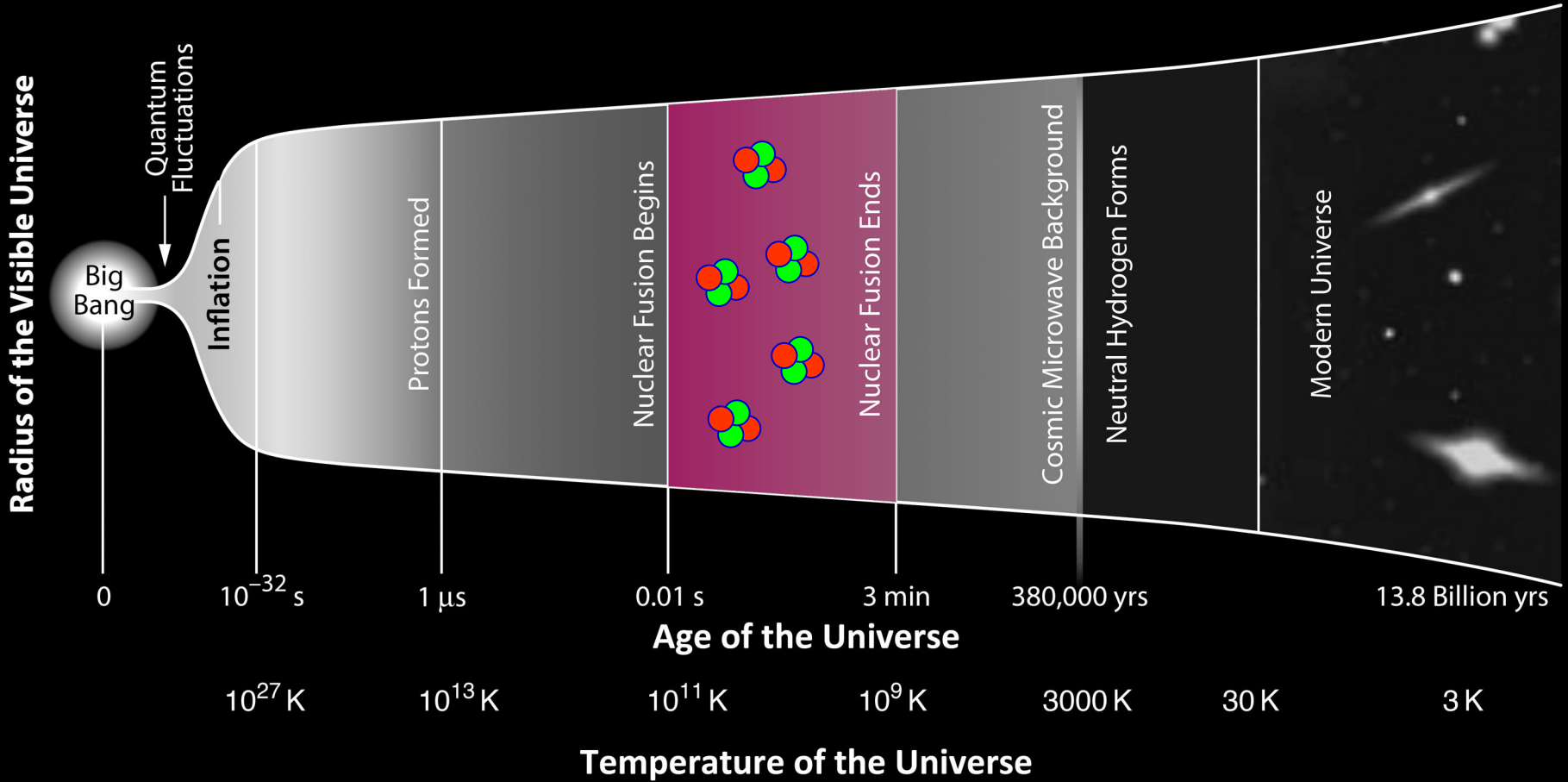
**Quantum fluctuations -> macroscopic scales -> seed Structure Formation**

# The Big Bang

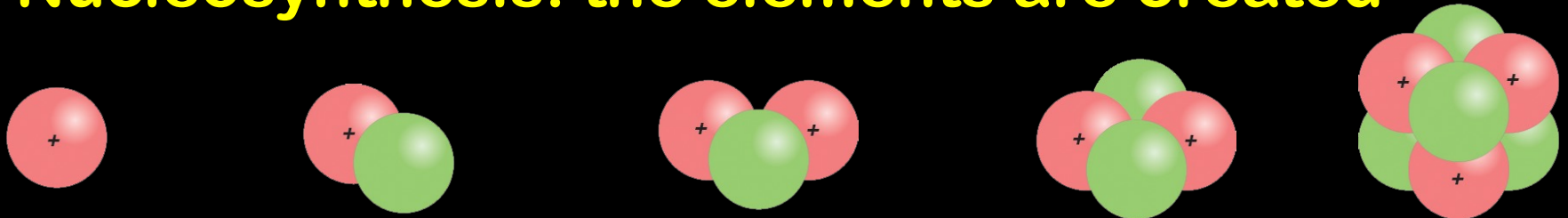


**matter and antimatter annihilate**  
**creates the photon background**  
**Small asymmetry in matter/antimatter**  
**Small excess of matter remains**

# The Big Bang



## Nucleosynthesis: the elements are created



# The Big Bang

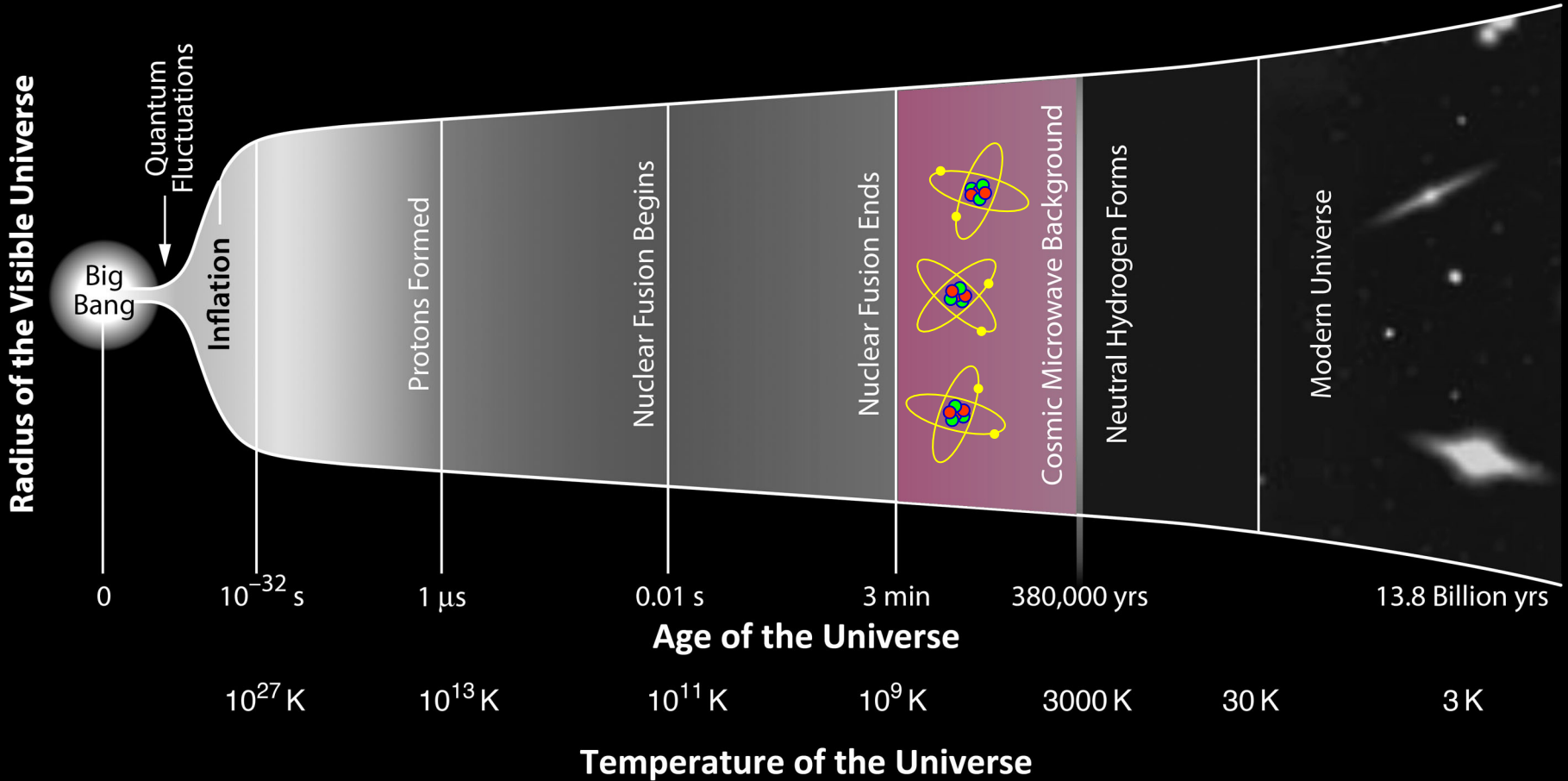
Periodic Table of the Elements

1 IA 11A <b>H</b> Hydrogen 1.008																	18 VIII A 8A <b>He</b> Helium 4.003	
3 <b>Li</b> Lithium 6.941		4 <b>Be</b> Beryllium 9.012											5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.011	7 <b>N</b> Nitrogen 14.007	8 <b>O</b> Oxygen 15.999	9 <b>F</b> Fluorine 18.998	10 <b>Ne</b> Neon 20.180
11 <b>Na</b> Sodium 22.990	12 <b>Mg</b> Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 <b>Al</b> Aluminum 26.982	14 <b>Si</b> Silicon 28.086	15 <b>P</b> Phosphorus 30.974	16 <b>S</b> Sulfur 32.066	17 <b>Cl</b> Chlorine 35.453	18 <b>Ar</b> Argon 39.948	
19 <b>K</b> Potassium 39.098	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.956	22 <b>Ti</b> Titanium 47.88	23 <b>V</b> Vanadium 50.942	24 <b>Cr</b> Chromium 51.996	25 <b>Mn</b> Manganese 54.938	26 <b>Fe</b> Iron 55.933	27 <b>Co</b> Cobalt 58.933	28 <b>Ni</b> Nickel 58.693	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.732	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.922	34 <b>Se</b> Selenium 78.972	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 84.80	
37 <b>Rb</b> Rubidium 84.468	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.906	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.906	42 <b>Mo</b> Molybdenum 95.95	43 <b>Tc</b> Technetium 98.907	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.906	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.868	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.904	54 <b>Xe</b> Xenon 131.29	
55 <b>Cs</b> Cesium 132.905	56 <b>Ba</b> Barium 137.327	57-71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.948	74 <b>W</b> Tungsten 183.85	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.967	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.383	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.980	84 <b>Po</b> Polonium [208.982]	85 <b>At</b> Astatine 209.987	86 <b>Rn</b> Radon 222.018	
87 <b>Fr</b> Francium 223.020	88 <b>Ra</b> Radium 226.025	89-103	104 <b>Rf</b> Rutherfordium [261]	105 <b>Db</b> Dubnium [262]	106 <b>Sg</b> Seaborgium [266]	107 <b>Bh</b> Bohrium [264]	108 <b>Hs</b> Hassium [269]	109 <b>Mt</b> Meitnerium [268]	110 <b>Ds</b> Darmstadtium [269]	111 <b>Rg</b> Roentgenium [272]	112 <b>Cn</b> Copernicium [277]	113 <b>Uut</b> Ununtrium unknown	114 <b>Fl</b> Flerovium [289]	115 <b>Uup</b> Ununpentium unknown	116 <b>Lv</b> Livermorium [298]	117 <b>Uus</b> Ununseptium unknown	118 <b>Uuo</b> Ununoctium unknown	
Lanthanide Series	57 <b>La</b> Lanthanum 138.906	58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.908	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium 144.913	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.966	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.925	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.930	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.934	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967			
Actinide Series	89 <b>Ac</b> Actinium 227.028	90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.036	92 <b>U</b> Uranium 238.029	93 <b>Np</b> Neptunium 237.048	94 <b>Pu</b> Plutonium 244.064	95 <b>Am</b> Americium 243.061	96 <b>Cm</b> Curium 247.070	97 <b>Bk</b> Berkelium 247.070	98 <b>Cf</b> Californium 251.080	99 <b>Es</b> Einsteinium [254]	100 <b>Fm</b> Fermium 257.095	101 <b>Md</b> Mendelevium 258.1	102 <b>No</b> Nobelium 259.101	103 <b>Lr</b> Lawrencium [262]			

Only the very lightest elements are created in the Big Bang

Everything else is made in Stars 10 -100 million years later !

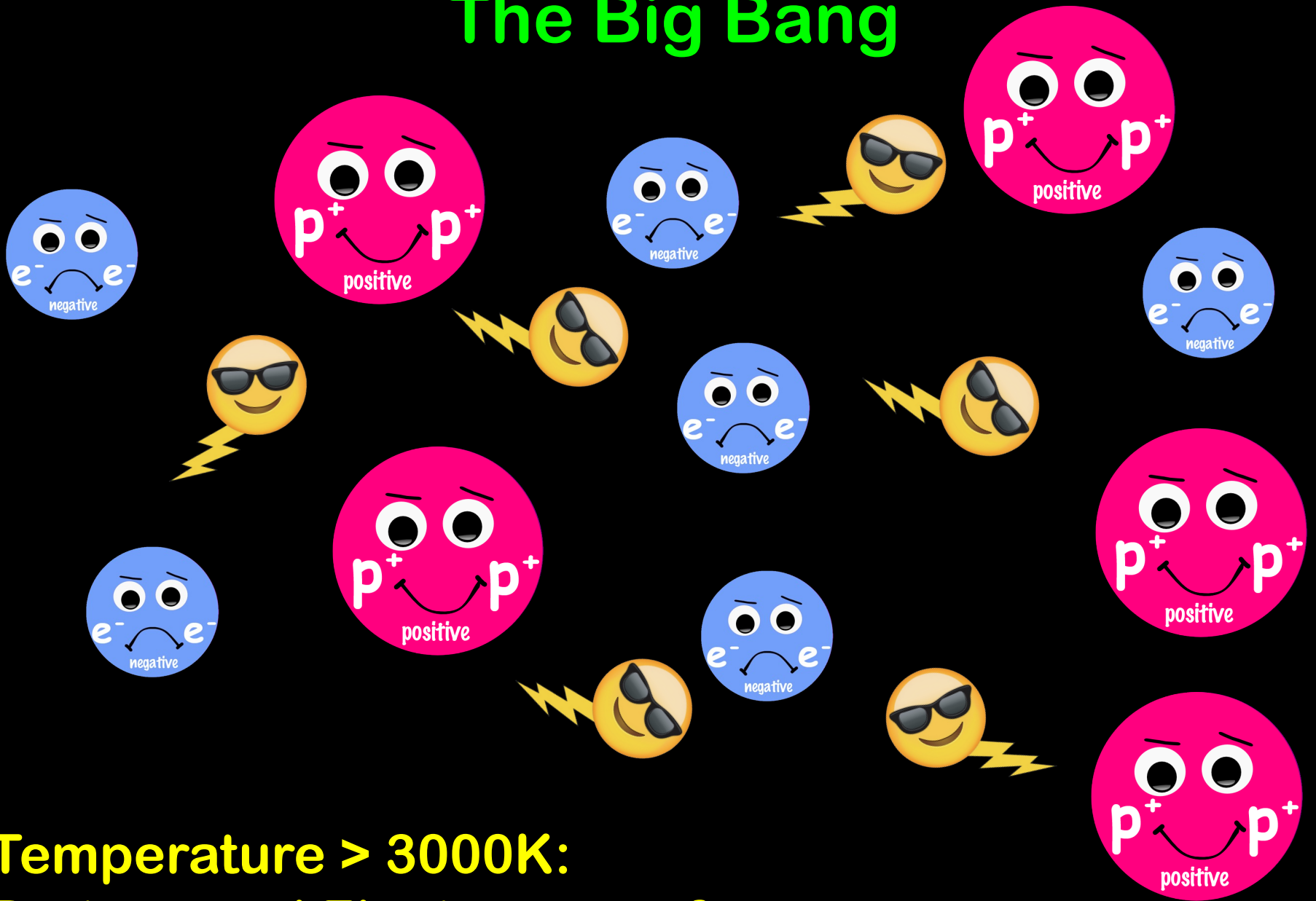
# The Big Bang



**Atoms are made: Protons can capture electrons**

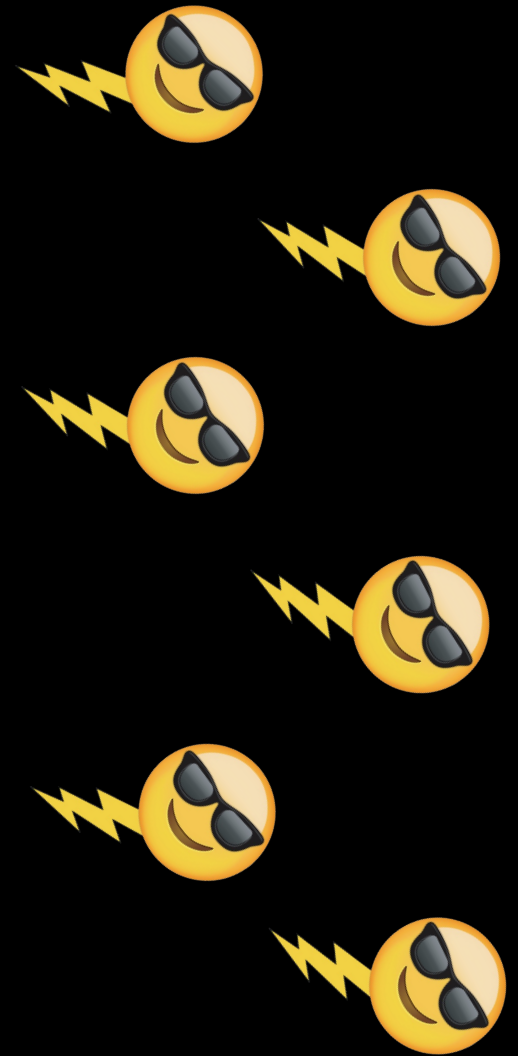
**Atoms “recombine”**

# The Big Bang



Temperature  $> 3000\text{K}$ :  
Protons and Electrons are free  
lots of electric charge means photons are trapped

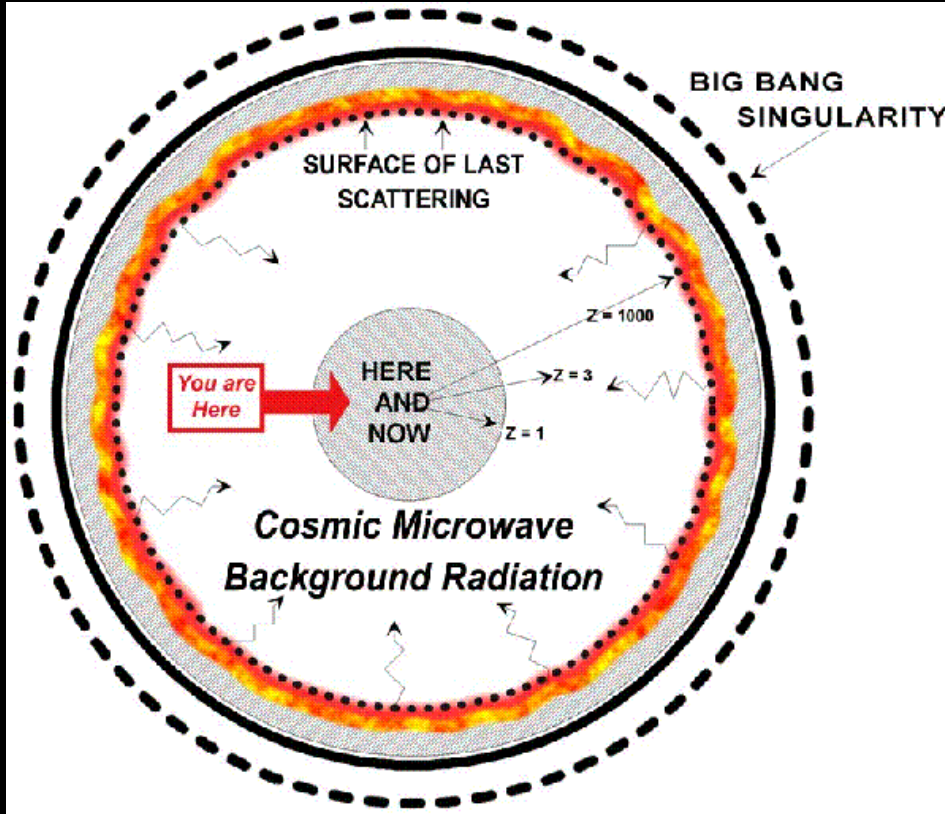
# The Big Bang



Temperature  $< 3000K$ :  
Protons and Electrons recombine to make atoms  
Atoms neutral means the photons (light) are free



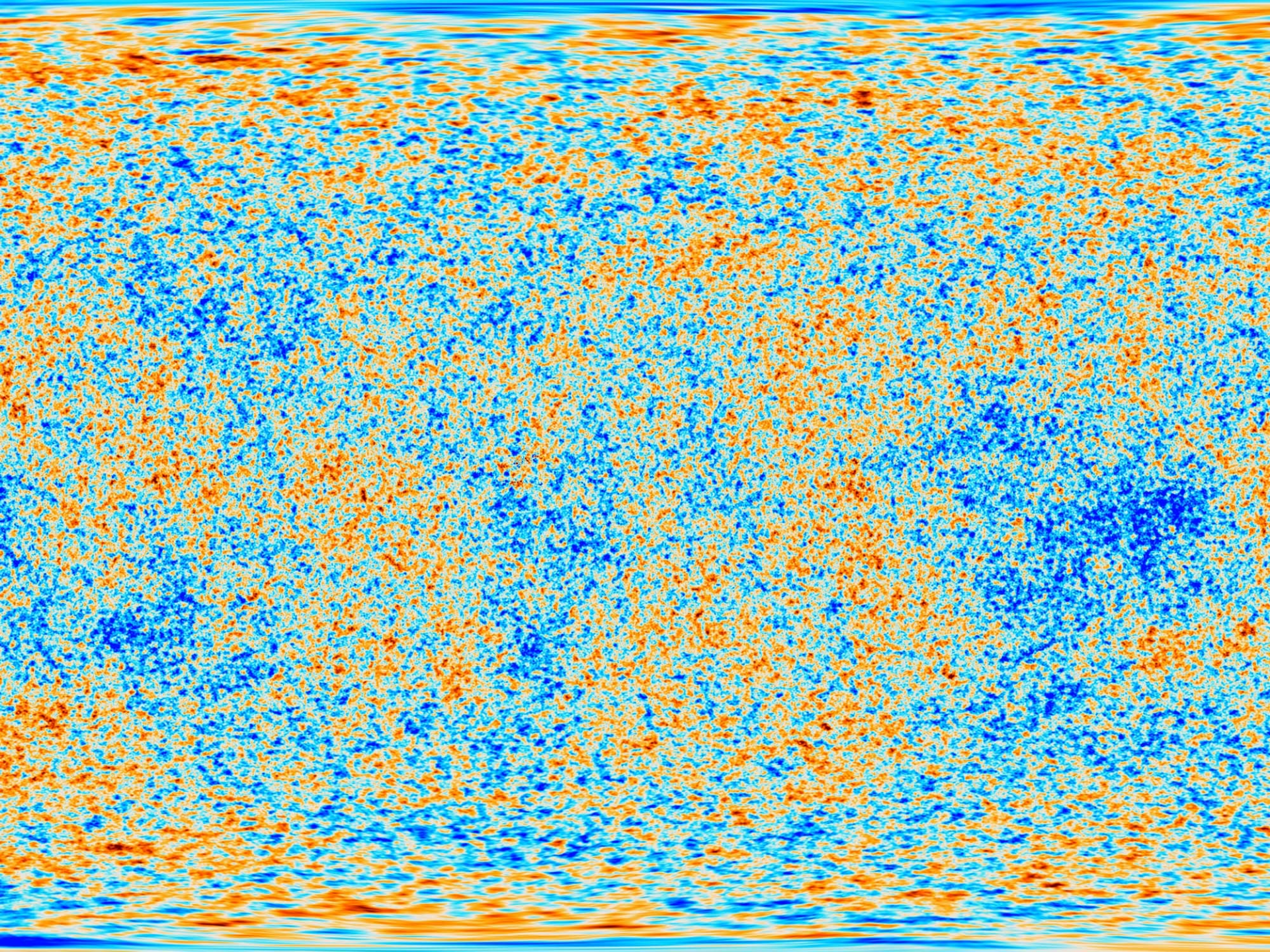
# The Oldest Light in the Universe



These light particles have been travelling through space ever since and are 13.8 billion years old when they hit your eyes !

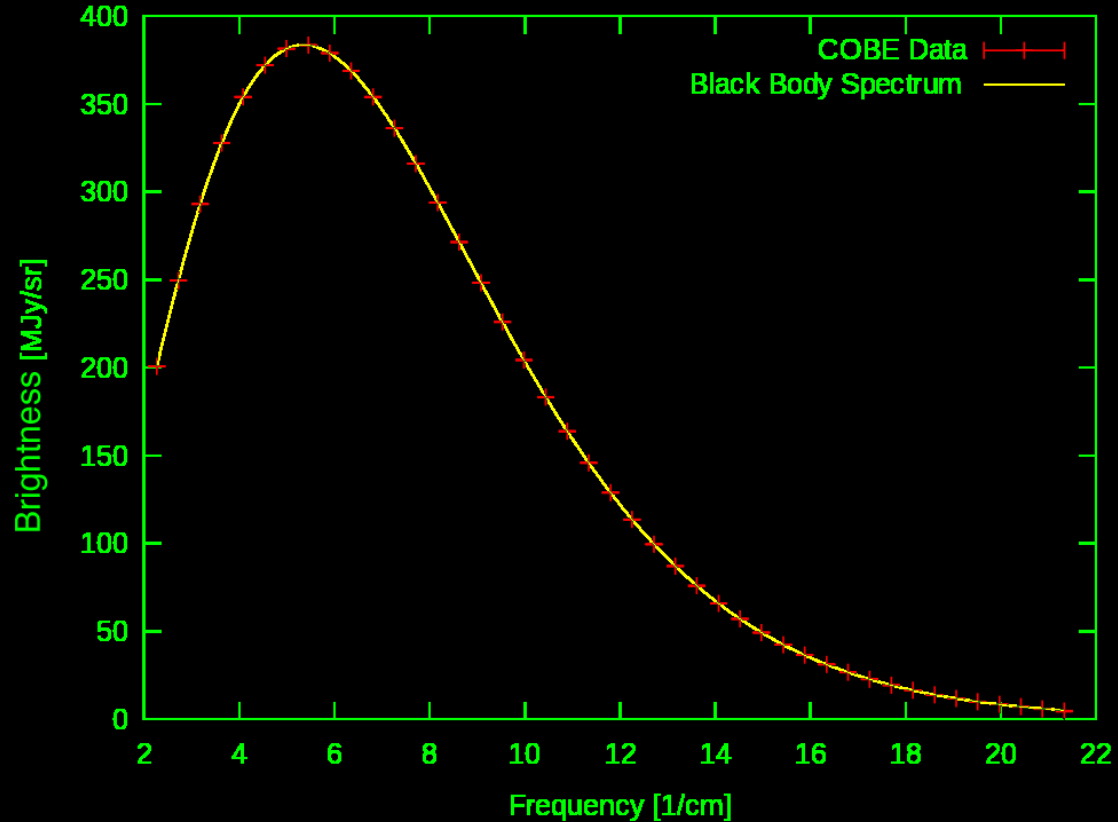
# The Oldest Light in the Universe

The oldest photo of the universe



# The Oldest Light in the Universe

Penzias and Wilson (1964)



The temperature of space  
2.7K (~ -270 Celsius)

# The Future of the Universe

What is the fate of the Universe ?

Will it expand forever ?

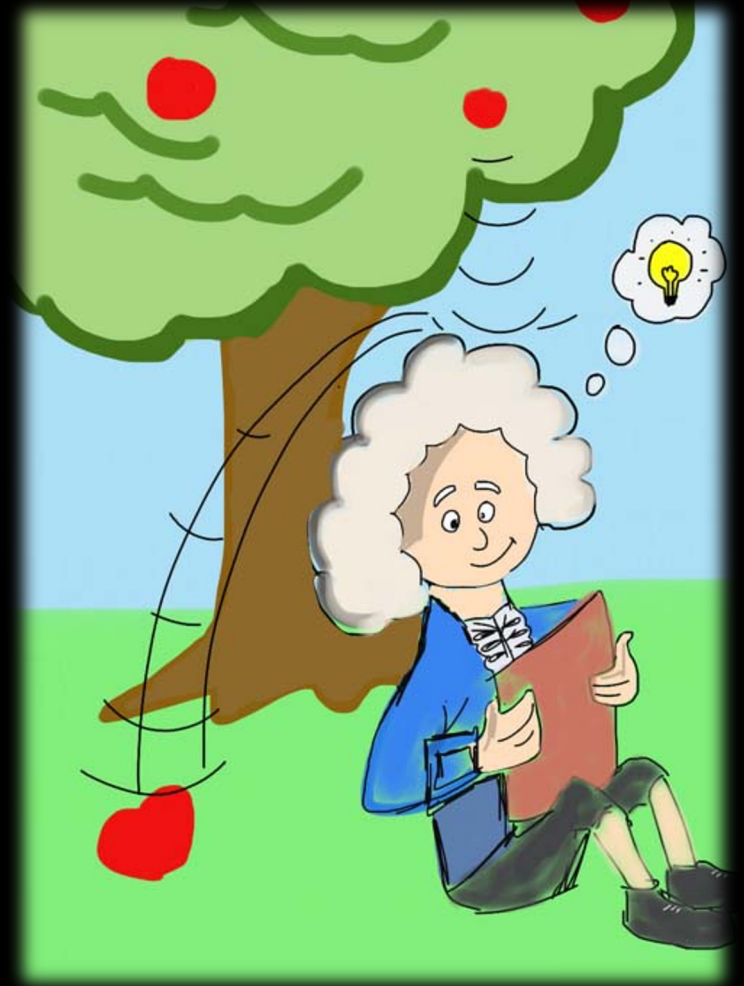
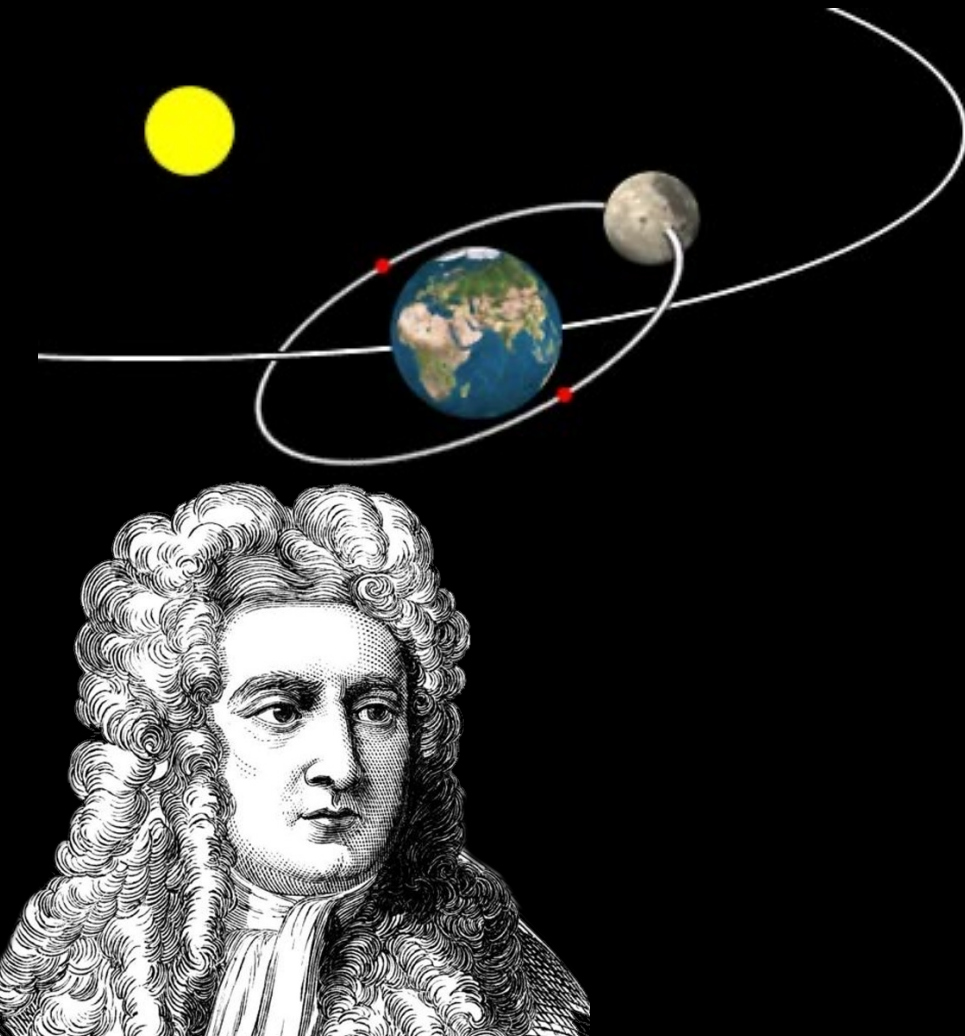
To understand what will happen to our Universe  
we must go back to school 😊

..... And talk about apples

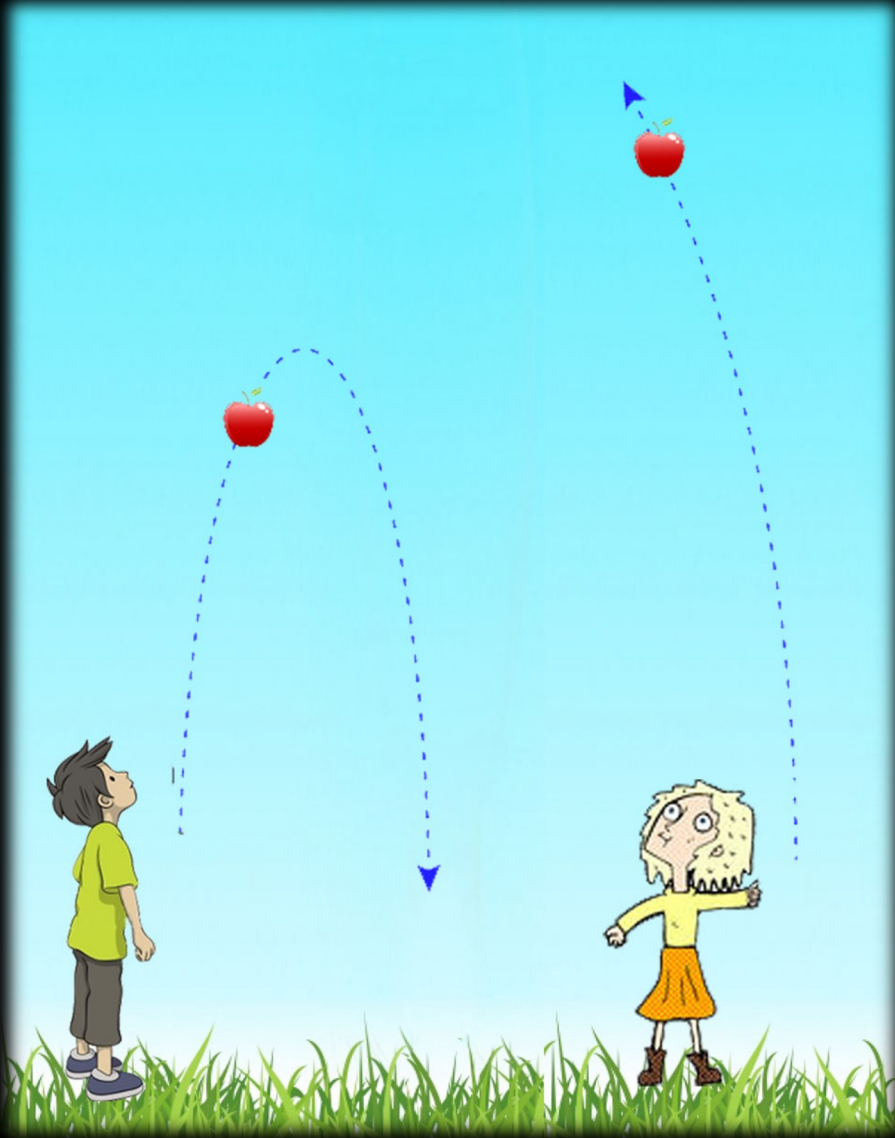
# Gravity

Sir Isaac Newton (1642-1727)

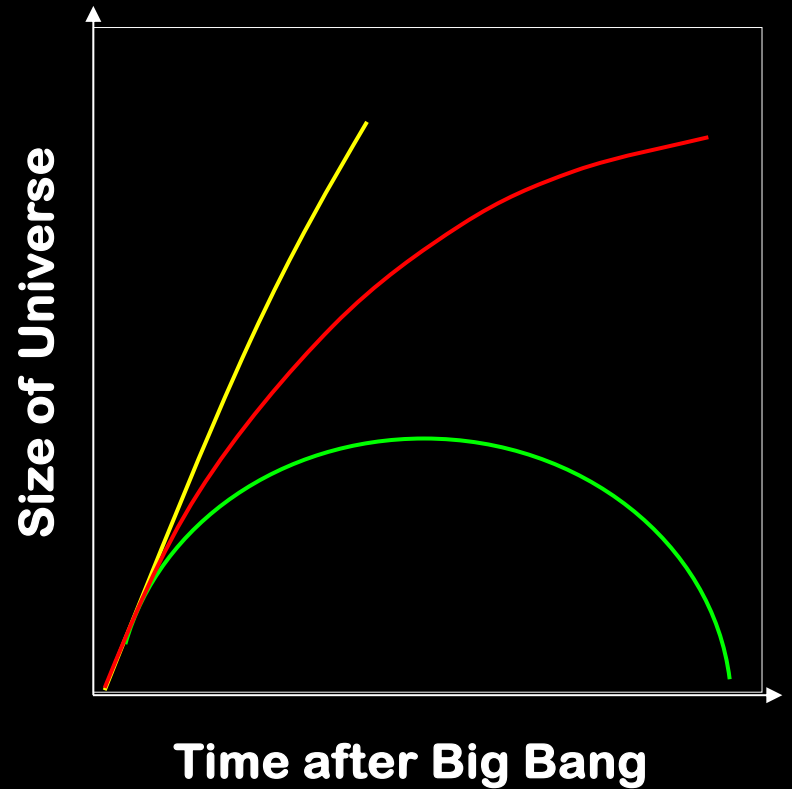
Laws of motion Universal gravitation



# Gravity



## Future of the Universe



The fate of the Universe has a lot to do with apples

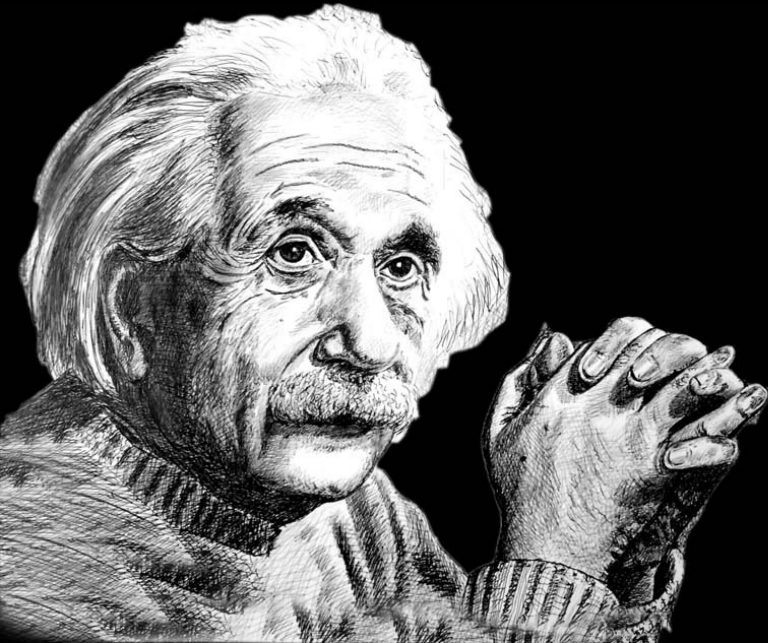
# Einstein's Theory of Gravity

Albert Einstein (1879 – 1955)

The theory of General Relativity (1905-1915)

Space and Time are interwoven together

Gravity: not a force but a consequence of Geometry





# Einstein's Theory of Gravity

## Einstein Equation:

Relates the Matter Energy to the Geometry of the Universe

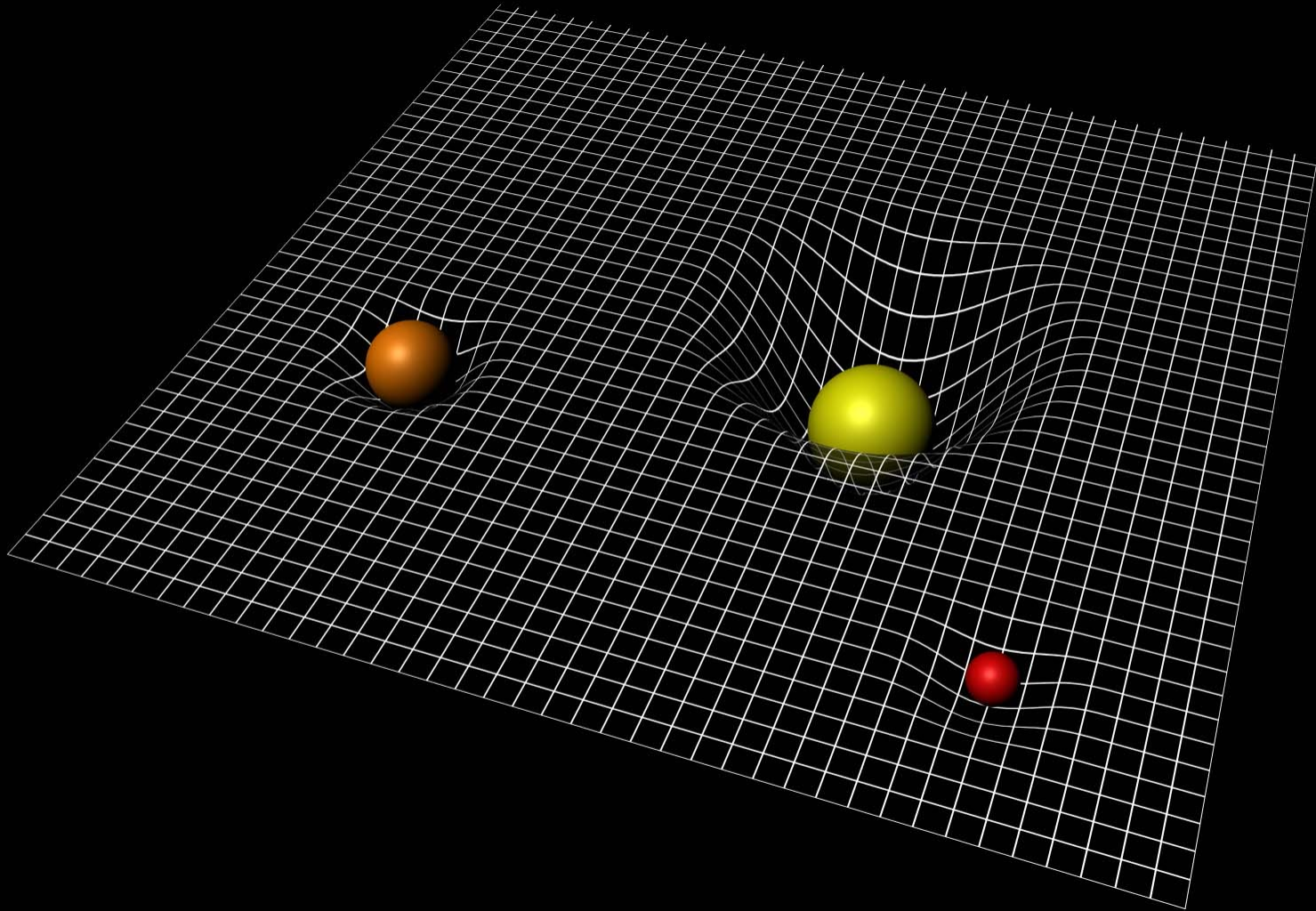
$$G_{ik} = \frac{8\pi G}{c^4} T_{ik}$$

geometry

matter

Space tells Matter how to move  
Matter tells Space how to curve

# Einstein's Theory of Gravity

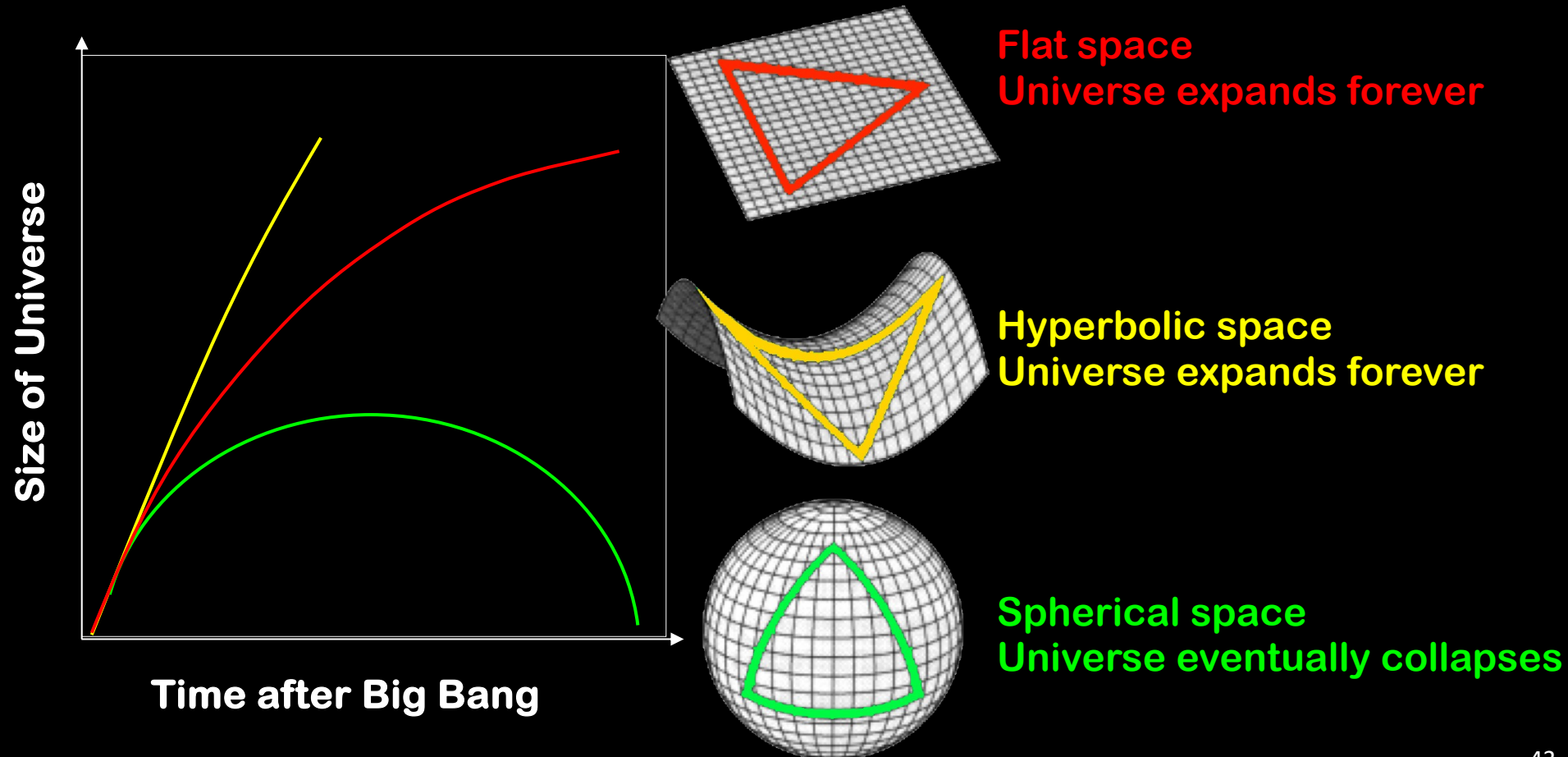


**Space tells Matter how to move  
Matter tells Space how to curve**

# What Universe do we live in ?

Shape (geometry) of Universe decides its fate

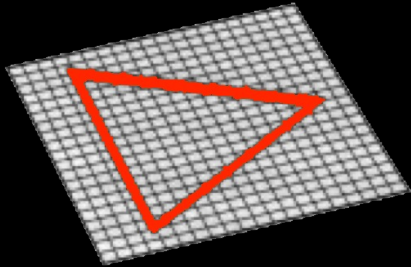
Amount of stuff in the Universe decides its shape



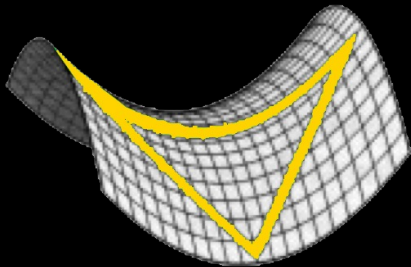
# What Universe do we live in ?

How much stuff do we need to STOP th Universe expanding?

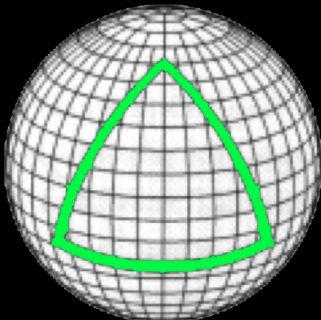
define  $\Omega = \frac{\rho}{\rho_{critical}}$   $\rho_{critical} \approx 10^{-26} \text{ kg / m}^3$



$\Omega = 1: \rho = \rho_{critical}$  **Critical value**



$\Omega < 1: \rho < \rho_{critical}$  **Universe expands**

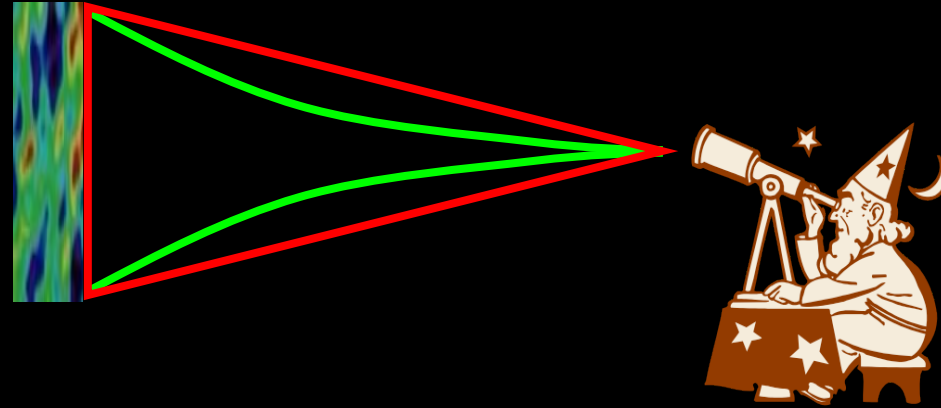
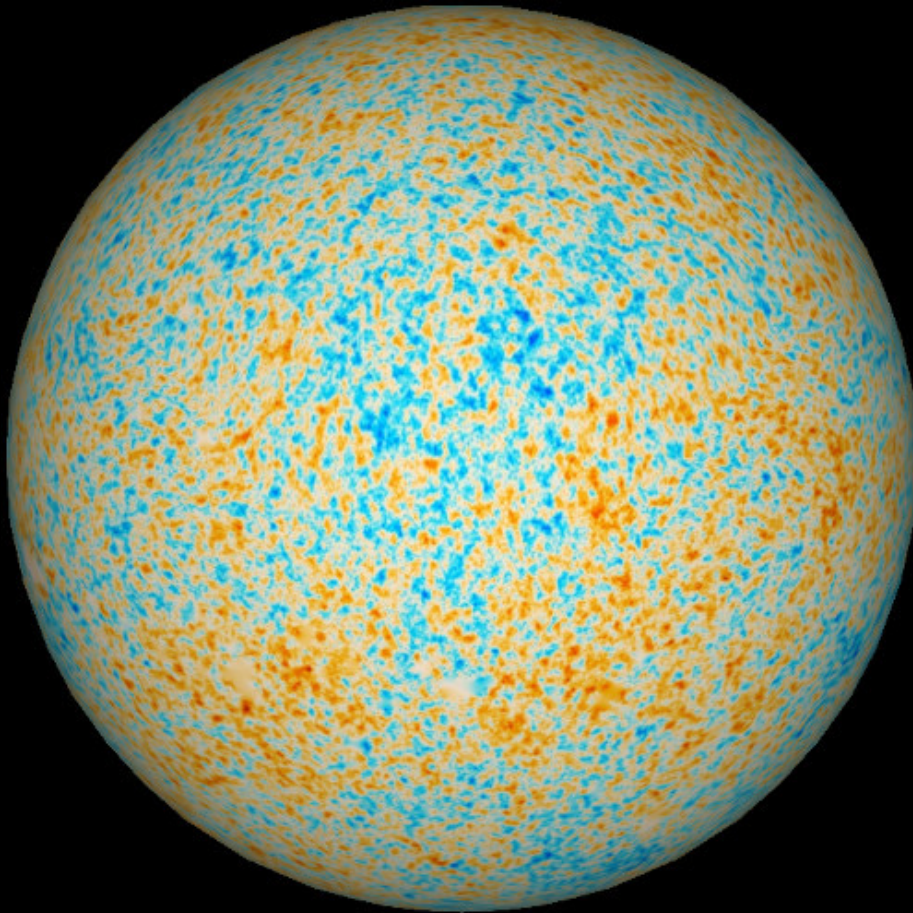


$\Omega > 1: \rho > \rho_{critical}$  **Universe contracts**

# What Universe do we live in ?

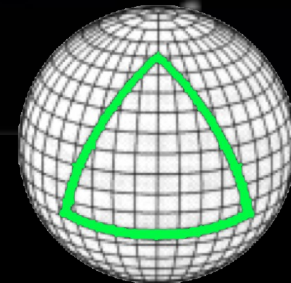
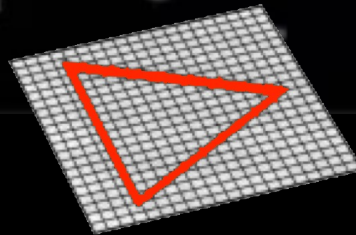
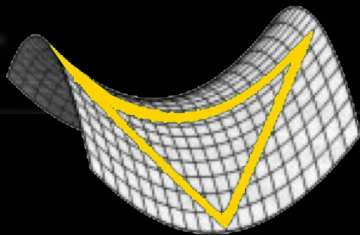
Shape (geometry) of Universe decides its fate

Amount of stuff in the Universe decides its shape



# What Universe do we live in ?

We live in a Flat Universe



# Cosmology: A Tale of 3 Numbers

H

**Hubble parameter**

(how fast is Universe expanding)

$H_0 = 67.3 \text{ km/s/Mpc}$

$\Omega$

**Density parameter**

(how much stuff is in the Universe)

$\Omega_{\text{total}} = 1$

$\Lambda$

**Cosmological Constant**

(is the Universe accelerating or decelerating)

# The Problem of Missing Mass

Recall from Big Bang Nucleosynthesis

Baryon density  $\rho_{\text{baryons}} \sim 0.05 \times 10^{-26} \text{ kg/m}^3$

BUT.....

Inflation + Cosmic Background tells us the Universe is flat !

$\Omega = 1: \rho = \rho_{\text{critical}} \approx 10^{-26} \text{ kg/m}^3$

$\rho_{\text{baryons}} / \rho_{\text{critical}} = \Omega_{\text{atoms}} = 0.05$



# Cosmology: A Tale of 3 Numbers

H

**Hubble parameter**

(how fast is Universe expanding)

$H_0 = 67.3 \text{ km/s/Mpc}$

$\Omega$

**Density parameter**

(how much stuff is in the Universe)

$\Omega_{\text{total}} = 1, \quad \Omega_{\text{atoms}} = 0.05$

$\Lambda$

**Cosmological Constant**

(is the Universe accelerating or decelerating)

# The Problem of Missing Mass



**The End of the Story?**

still many missing pieces

# The Problem of Missing Mass

Fritz Zwicky 1933: weighed clusters of galaxies

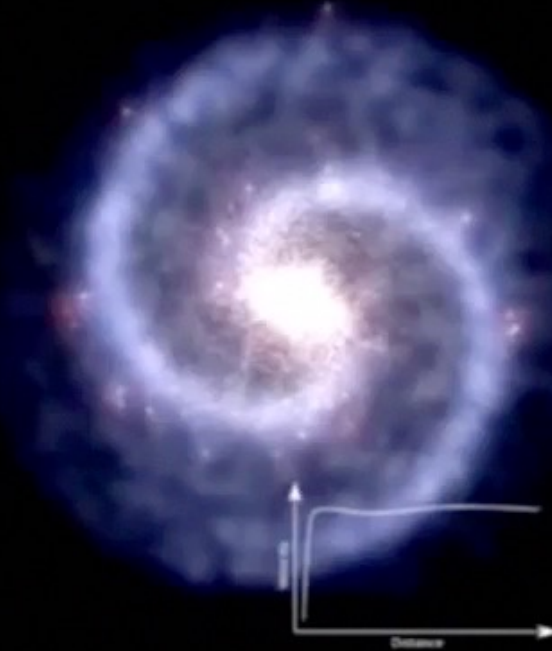


# The Problem of Missing Mass

Vera Rubin 1970s : Galaxy Rotation Curves



Galaxy Without Dark Matter



Galaxy With Dark Matter



# The Problem of Missing Mass

Galaxies are surrounded by an enormous halo of nonluminous (dark) matter!



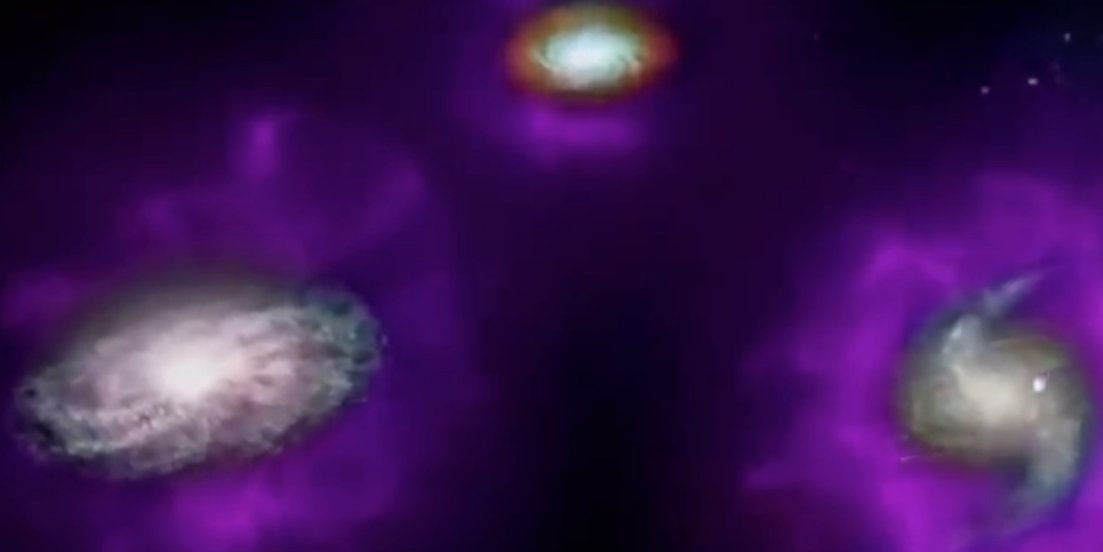
Luminous matter is concentrated at the center

# The Problem of Missing Mass

The Problem of **MISSING MASS**

More accurately the problem of **MISSING LIGHT**

→ giant **Dark Matter** spherical halos



$$\Omega_{\text{Dark Matter}} \approx 0.27$$

# The Problem of missing mass (or light)

Compared to what we observe; 5x the mass is missing !  
Problem of **MISSING MASS ?** → rather **MISSING LIGHT !**



~5% Visible Matter

~27% Dark Matter

# Non-Baryonic Dark Matter

To be born Dark, to become dark, to be made dark, to have darkness

**COLD DARK MATTER**

Non Relativistic at decoupling

Heavy Neutrino

SUSY Particles

Axions

} WIMPs

**HOT DARK MATTER**

Relativistic at decoupling

Light Neutrino

**COSMIC RELICS**

Symmetry Defects

Monopoles

Cosmic Strings

Cosmic Textures



# Cosmology: A Tale of 3 Numbers

H

**Hubble parameter**

(how fast is Universe expanding)

$$H_0 = 67.3 \text{ km/s/Mpc}$$

$\Omega$

**Density parameter**

(how much stuff is in the Universe)

$$\Omega_{\text{total}} = 1, \quad \Omega_{\text{atoms}} = 0.05, \quad \Omega_{\text{DM}} = 0.27$$

$\Lambda$

**Cosmological Constant**

(is the Universe accelerating or decelerating)

# The Problem of missing mass (or light)

Still not enough to flatten the Universe



~5% Visible Matter

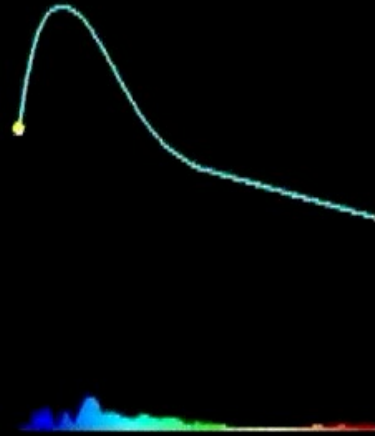
~27% Dark Matter



**The End of the Story?**  
still many missing pieces

# The Supernova Catastrophe

Saul Perlmutter 1998



Measure distances in Cosmology using

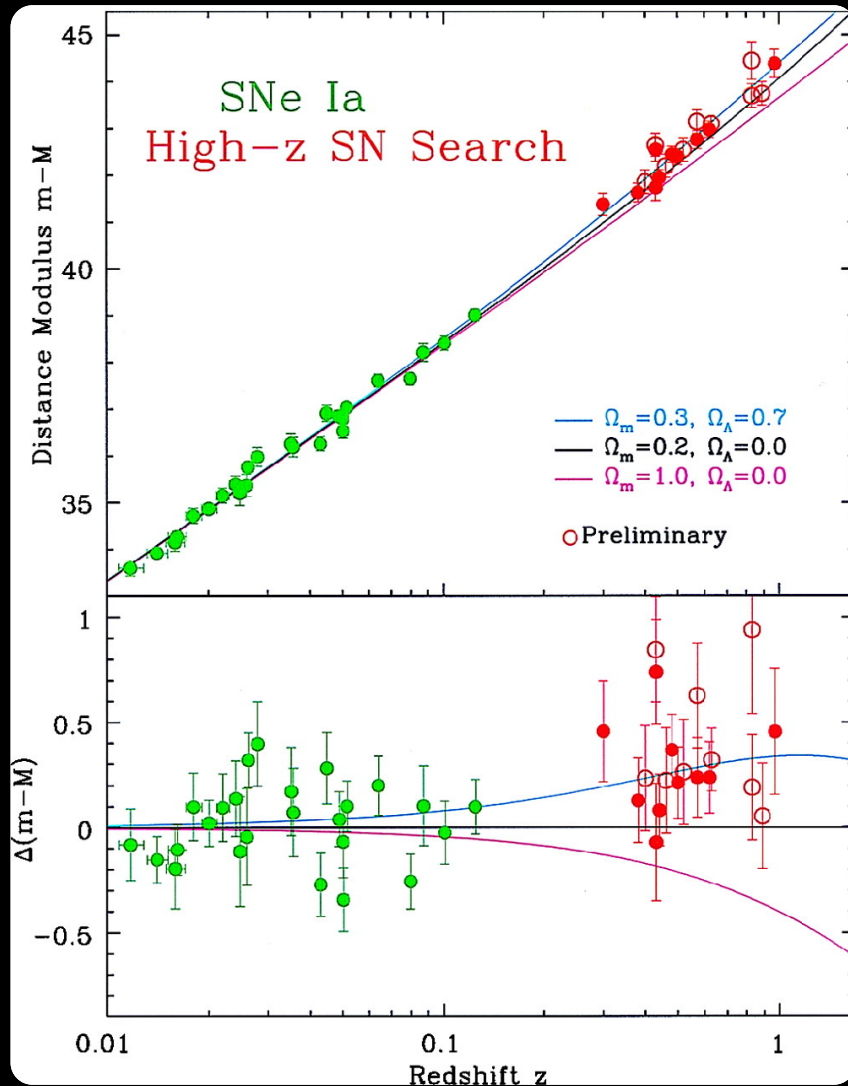
- Standard Ruler: objects of known standard proper size.
- Standard Candles: objects of known luminosity.

can then calculate

- Distance  $\rightarrow$  cosmological parameters  $H_o$   $\Omega_m$   $\Omega_\Lambda$

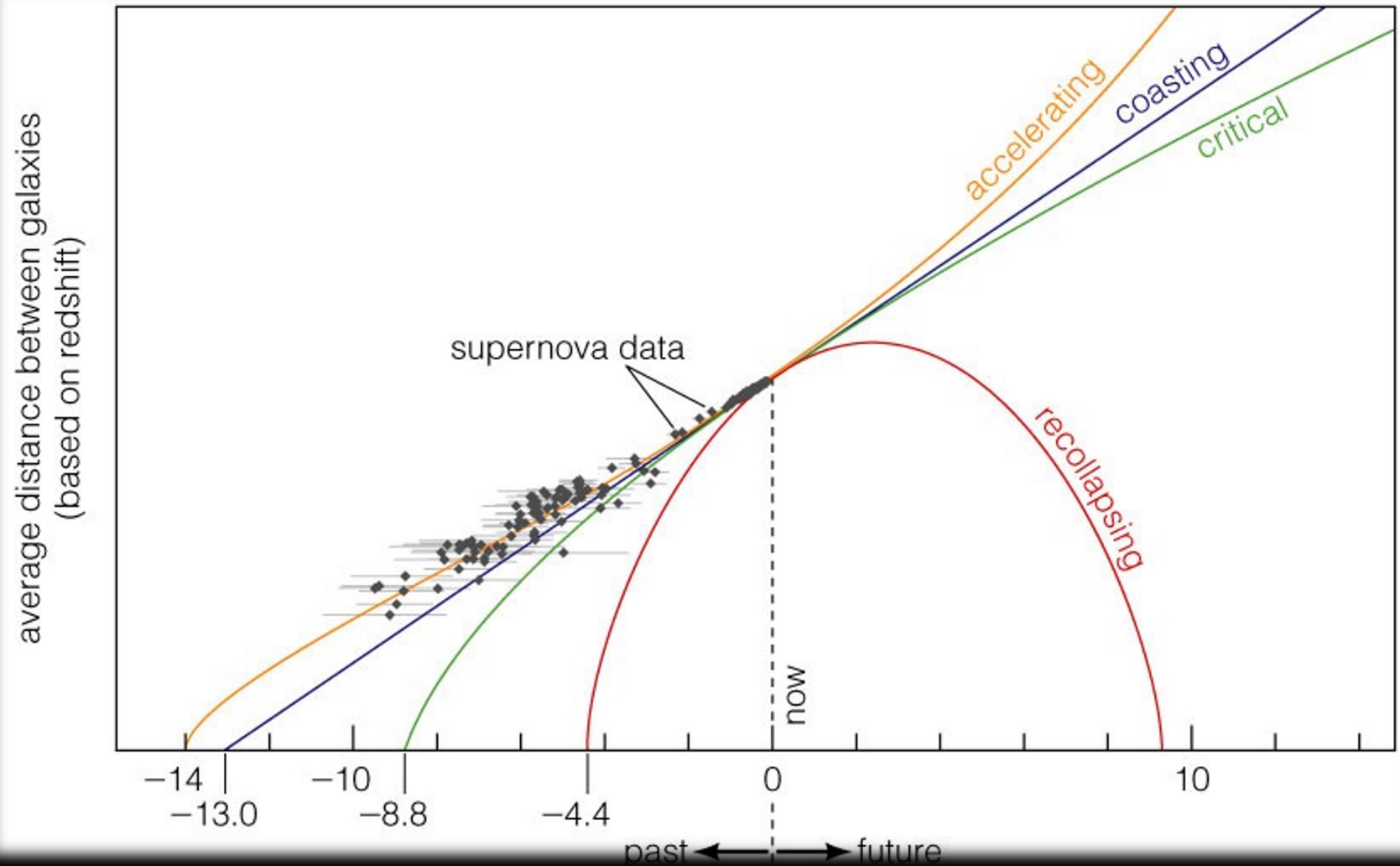


# The Supernova Catastrophe



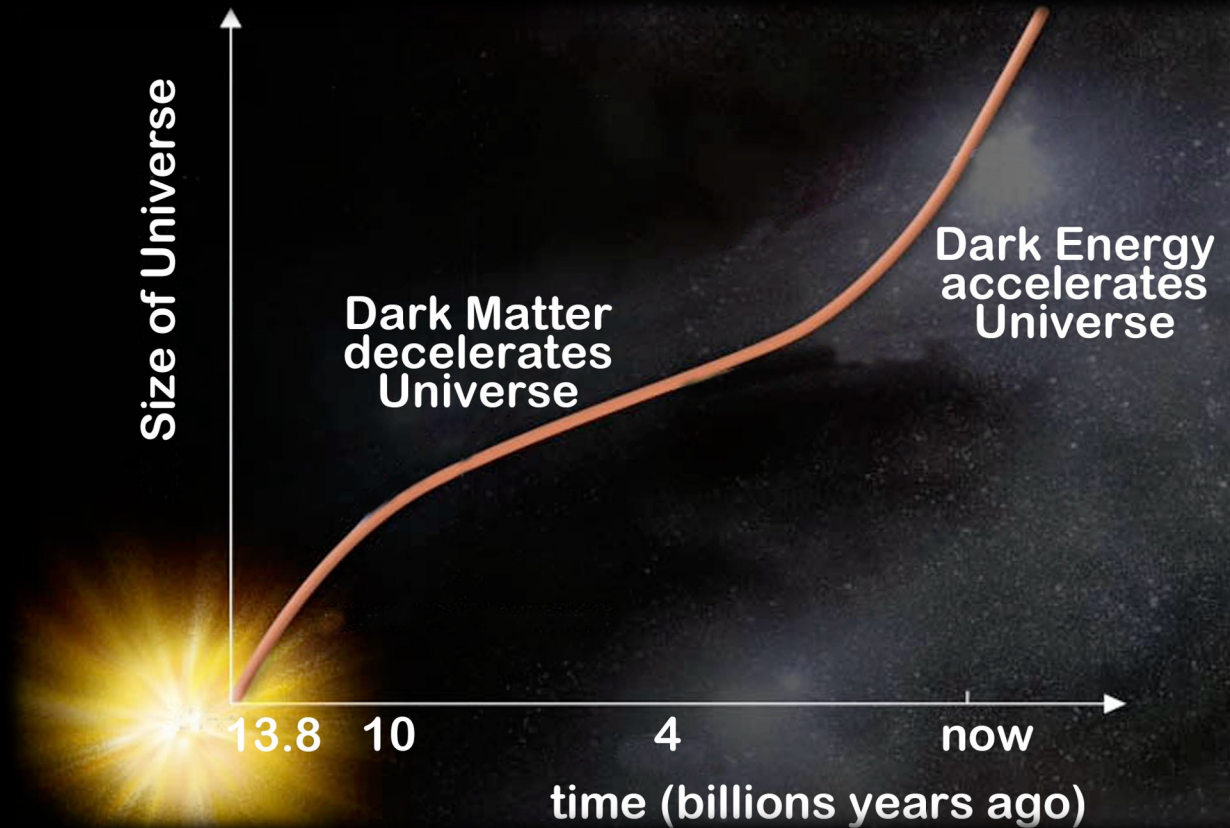
Universe is accelerating  $\rightarrow$  standard candle of lower brightness.  
Universe is decelerating  $\rightarrow$  standard candle of higher brightness

# The Supernova Catastrophe



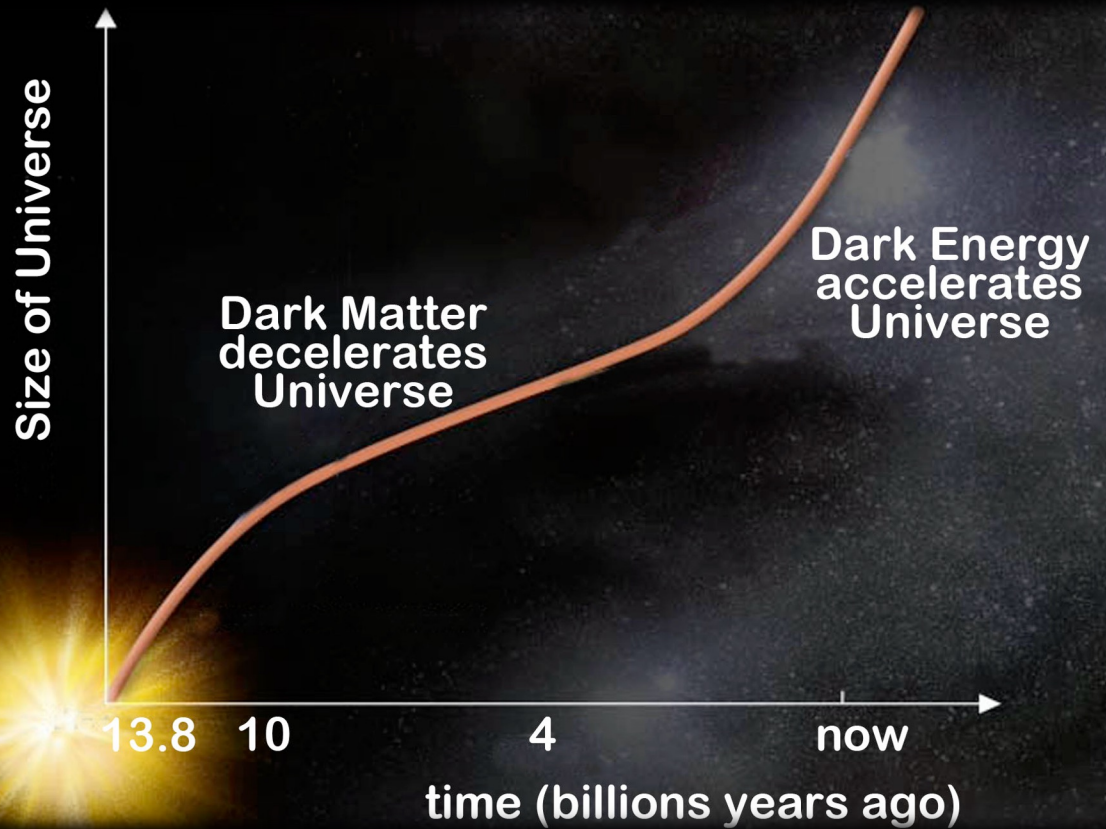
Supernova data show we are living in a Universe that is accelerating

# A Universe Dominated by Dark Energy



**Our Universe is accelerating due to a repulsive force equivalent to  $\Omega_{\Lambda} \sim 0.7$  Dark Energy**

# A Universe Dominated by Dark Energy



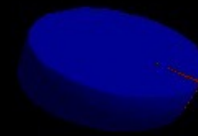
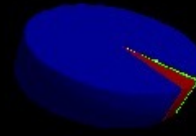
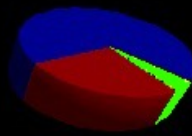
size =  $\frac{1}{4}$

size =  $\frac{1}{2}$

size = 1

size = 2

size = 4



time






# What the Universe is made of

**DARK ENERGY 68 %**

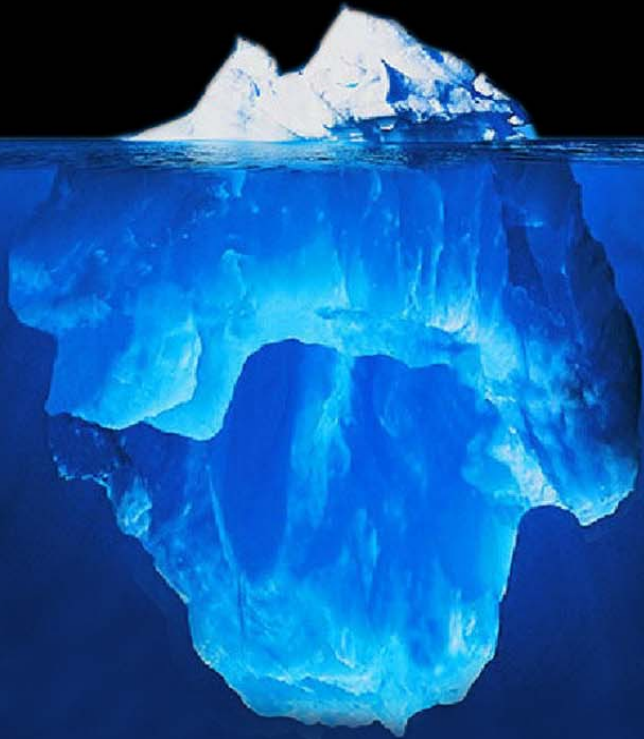
**DARK MATTER 27 %**

**ATOMS 5 %**

-  Visible matter: atoms and stuff (we know what this is)
-  Dark Matter (we don't know what this is)
-  Dark Energy (we don't know what this is)

# What the Universe is made of

~5% Visible Matter



# What the Universe is made of

~5% Visible Matter

Periodic Table of the Elements

1 1A 11A																	18 VIII 8A
1 <b>H</b> Hydrogen 1.008	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	2 <b>He</b> Helium 4.003
3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012											5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.011	7 <b>N</b> Nitrogen 14.007	8 <b>O</b> Oxygen 15.999	9 <b>F</b> Fluorine 18.998	10 <b>Ne</b> Neon 20.180
11 <b>Na</b> Sodium 22.990	12 <b>Mg</b> Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 <b>Al</b> Aluminum 26.982	14 <b>Si</b> Silicon 28.086	15 <b>P</b> Phosphorus 30.974	16 <b>S</b> Sulfur 32.066	17 <b>Cl</b> Chlorine 35.453	18 <b>Ar</b> Argon 39.948
19 <b>K</b> Potassium 39.098	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.956	22 <b>Ti</b> Titanium 47.88	23 <b>V</b> Vanadium 50.942	24 <b>Cr</b> Chromium 51.996	25 <b>Mn</b> Manganese 54.938	26 <b>Fe</b> Iron 55.933	27 <b>Co</b> Cobalt 58.933	28 <b>Ni</b> Nickel 58.693	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.39	31 <b>Ga</b> Gallium 69.732	32 <b>Ge</b> Germanium 72.61	33 <b>As</b> Arsenic 74.922	34 <b>Se</b> Selenium 78.972	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 84.80
37 <b>Rb</b> Rubidium 84.468	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.906	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.906	42 <b>Mo</b> Molybdenum 95.95	43 <b>Tc</b> Technetium 98.907	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.906	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.868	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.71	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.6	53 <b>I</b> Iodine 126.904	54 <b>Xe</b> Xenon 131.29
55 <b>Cs</b> Cesium 132.905	56 <b>Ba</b> Barium 137.327	57-71	72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.948	74 <b>W</b> Tungsten 183.85	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.22	78 <b>Pt</b> Platinum 195.08	79 <b>Au</b> Gold 196.967	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.383	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.980	84 <b>Po</b> Polonium [208.982]	85 <b>At</b> Astatine 209.987	86 <b>Rn</b> Radon 222.018
87 <b>Fr</b> Francium 223.020	88 <b>Ra</b> Radium 226.025	89-103	104 <b>Rf</b> Rutherfordium [261]	105 <b>Db</b> Dubnium [262]	106 <b>Sg</b> Seaborgium [266]	107 <b>Bh</b> Bohrium [264]	108 <b>Hs</b> Hassium [269]	109 <b>Mt</b> Meitnerium [268]	110 <b>Ds</b> Darmstadtium [269]	111 <b>Rg</b> Roentgenium [272]	112 <b>Cn</b> Copernicium [277]	113 <b>Uut</b> Ununtrium unknown	114 <b>Fl</b> Flerovium [289]	115 <b>Uup</b> Ununpentium unknown	116 <b>Lv</b> Livermorium [298]	117 <b>Uus</b> Ununseptium unknown	118 <b>Uuo</b> Ununoctium unknown

Lanthanide Series	57 <b>La</b> Lanthanum 138.906	58 <b>Ce</b> Cerium 140.115	59 <b>Pr</b> Praseodymium 140.908	60 <b>Nd</b> Neodymium 144.24	61 <b>Pm</b> Promethium 144.913	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.966	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.925	66 <b>Dy</b> Dysprosium 162.50	67 <b>Ho</b> Holmium 164.930	68 <b>Er</b> Erbium 167.26	69 <b>Tm</b> Thulium 168.934	70 <b>Yb</b> Ytterbium 173.04	71 <b>Lu</b> Lutetium 174.967
Actinide Series	89 <b>Ac</b> Actinium 227.028	90 <b>Th</b> Thorium 232.038	91 <b>Pa</b> Protactinium 231.036	92 <b>U</b> Uranium 238.029	93 <b>Np</b> Neptunium 237.048	94 <b>Pu</b> Plutonium 244.064	95 <b>Am</b> Americium 243.061	96 <b>Cm</b> Curium 247.070	97 <b>Bk</b> Berkelium 247.070	98 <b>Cf</b> Californium 251.080	99 <b>Es</b> Einsteinium [254]	100 <b>Fm</b> Fermium 257.095	101 <b>Md</b> Mendelevium 258.1	102 <b>No</b> Nobelium 259.101	103 <b>Lr</b> Lawrencium [262]

# What the Universe is made of



**~5% Visible Matter**

**~27% Dark Matter**

**~68% Dark Energy**

# Cosmology: A Tale of 3 Numbers

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(how fast is Universe expanding)

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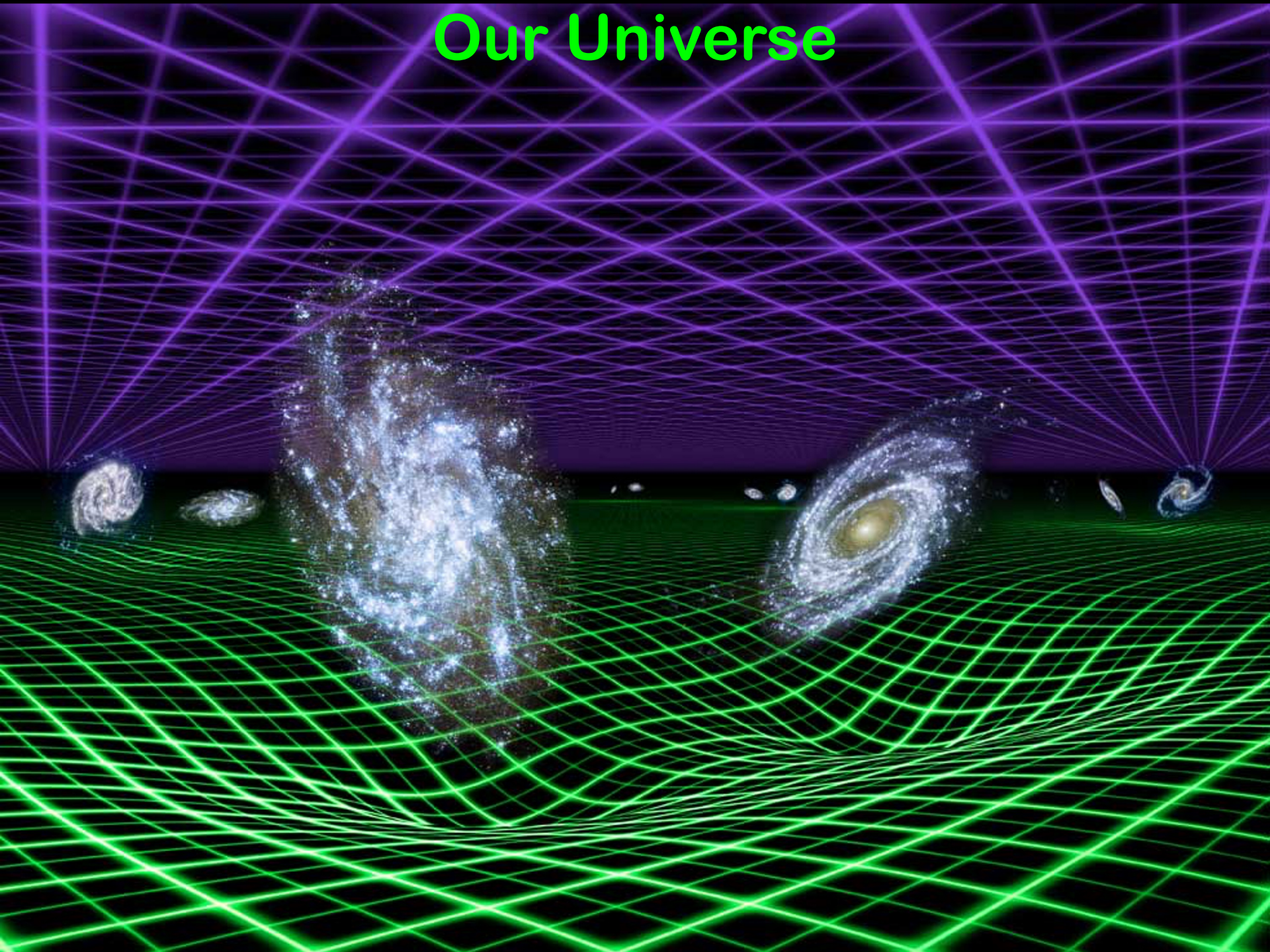
## $\Lambda$

**Cosmological Constant**

(is the Universe accelerating or decelerating)

$$\Omega_{\text{total}} = 1, \quad \Omega_{\Lambda} = 0.68$$

# Our Universe



# Our Universe

- began in a Big Bang event ~ 13.8 Billion Years ago

Big Bang Theory has had great success in predicting fine details of;

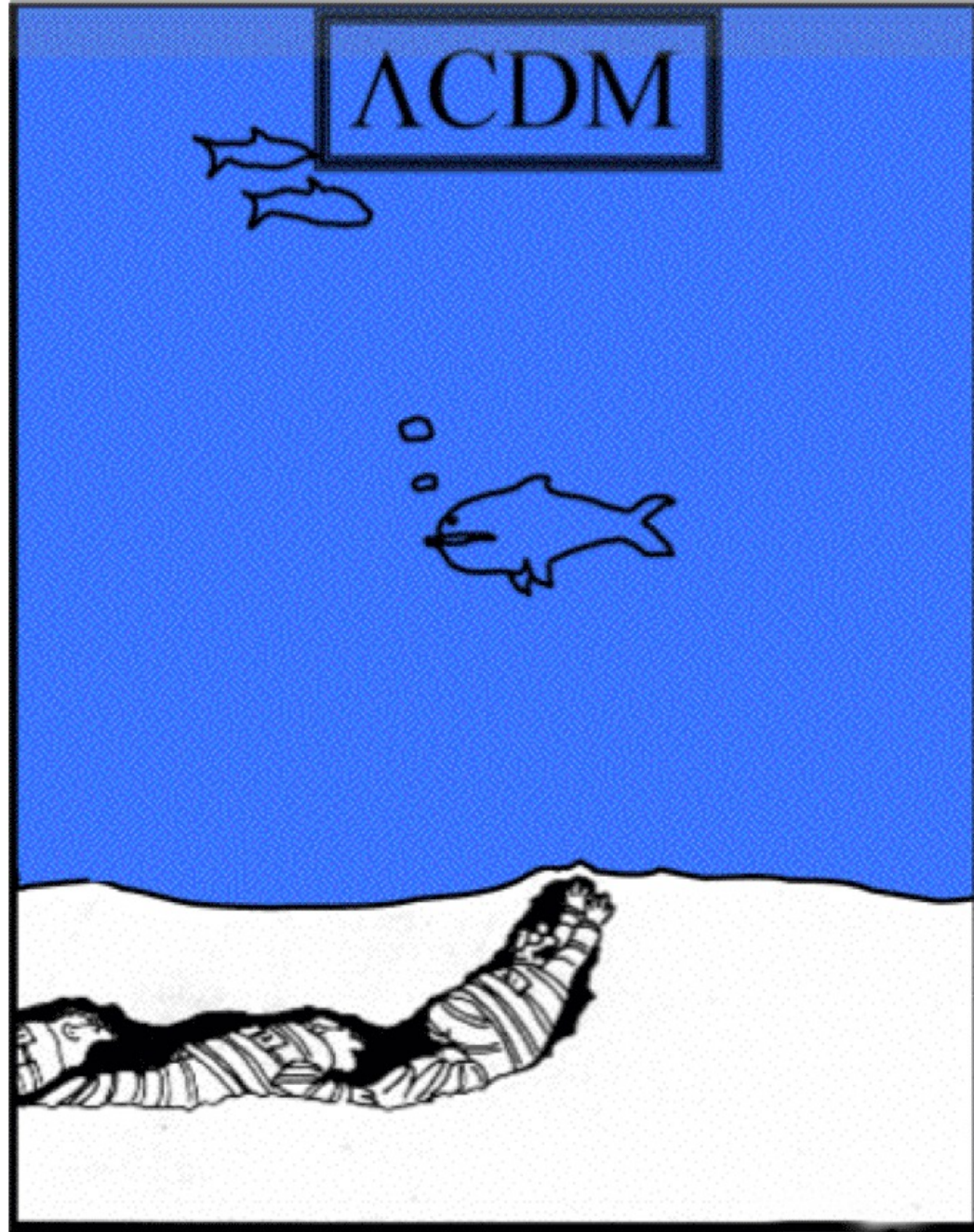
- The expanding Universe
- Primordial Nucleosynthesis and the light element abundances
- The Relic Radiation from the fireball
- The beginning of structure formation

# Our Universe

- began in a Big Bang event ~ 13.8 Billion Years ago
- has been expanding ever since
- started accelerating about 4 billion years ago

- contains 6x as much Dark (non-baryonic) matter than normal matter
- and is dominated by a Dark Energy 3x greater than the dark matter
- so we don't really know what 95% of our Universe is made of





We're almost free, I just felt the first drops of rain

**Thank you for Listening**