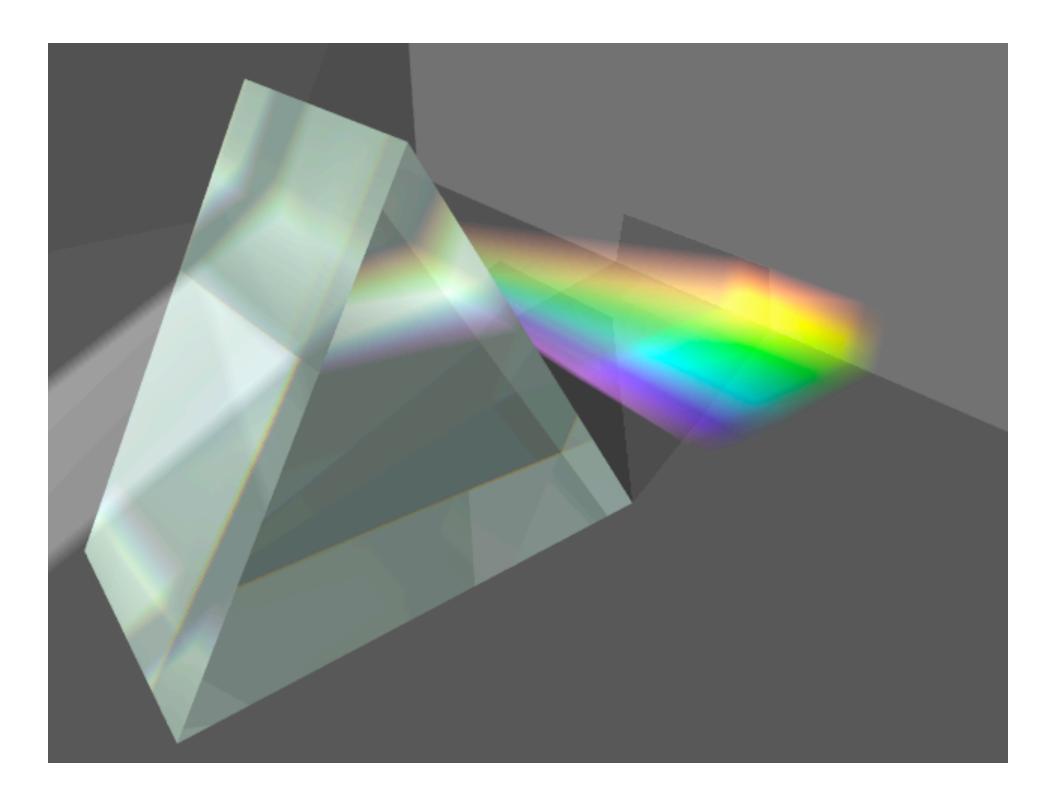
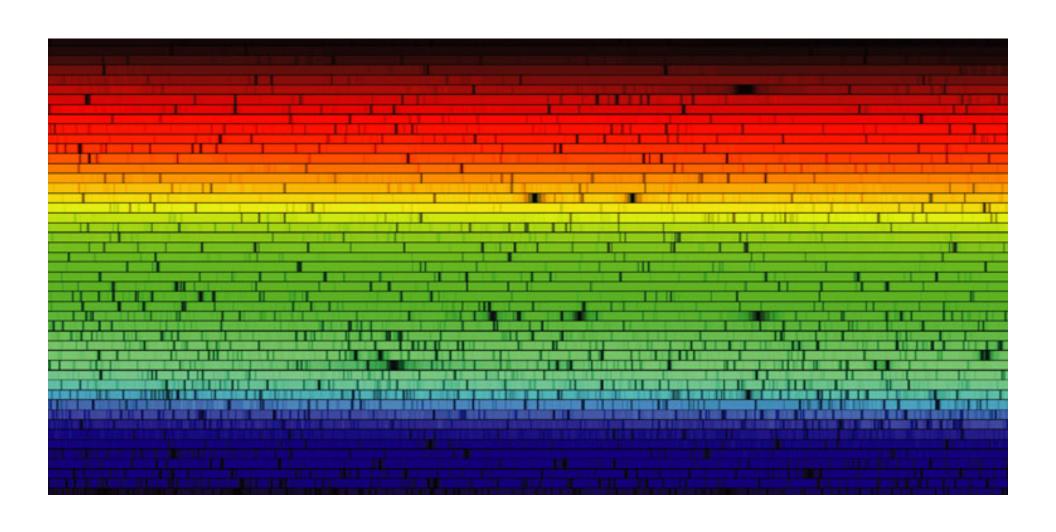
## The Big Bang Theory & Expansion of the Universe

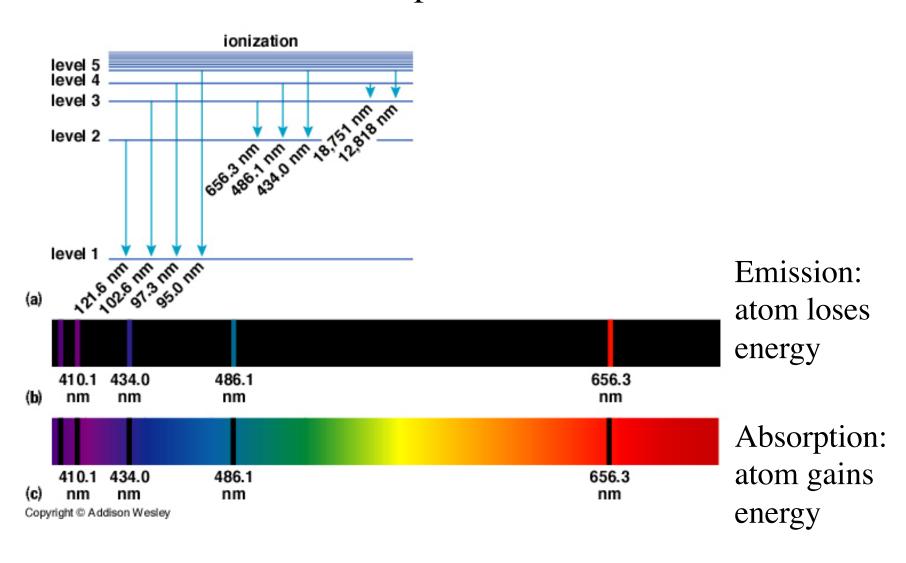




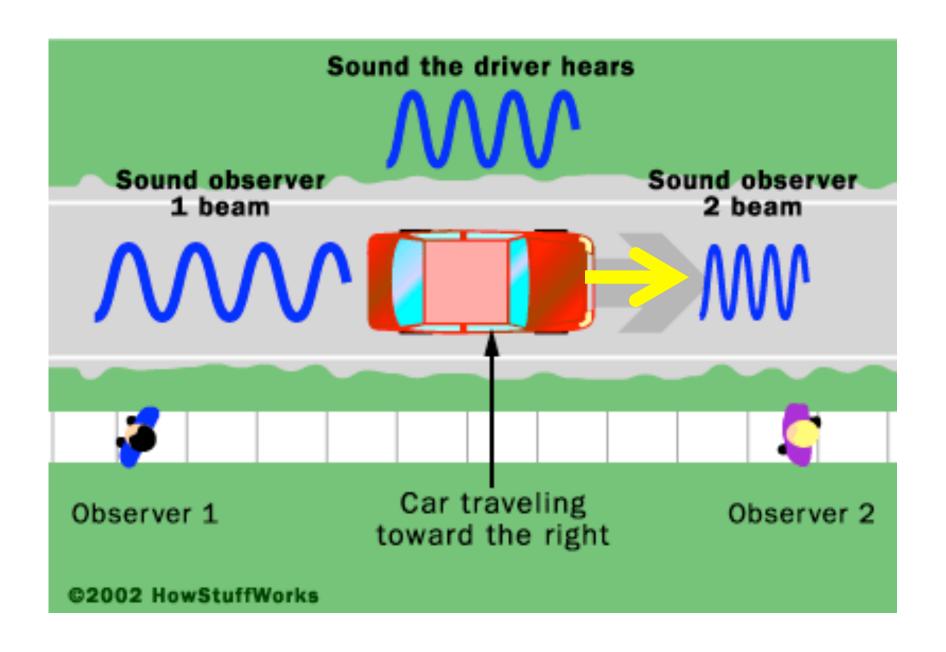
## Example: the Sun's Spectrum



## Distinct energy levels lead to distinct emission or absorption lines.

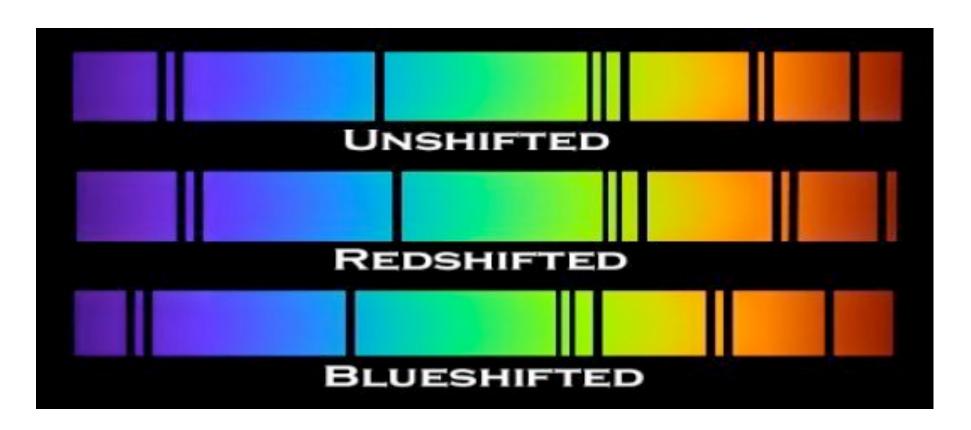


## Doppler Shift

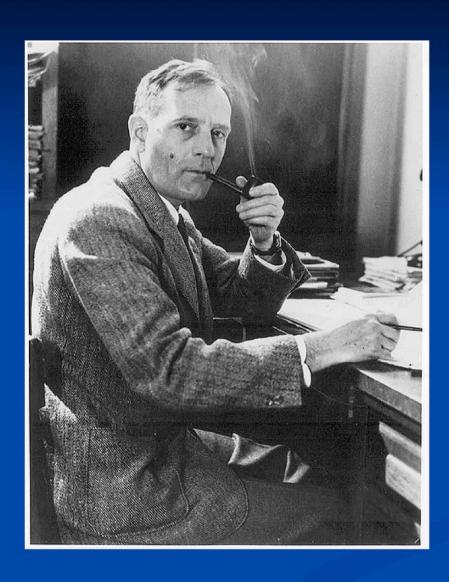


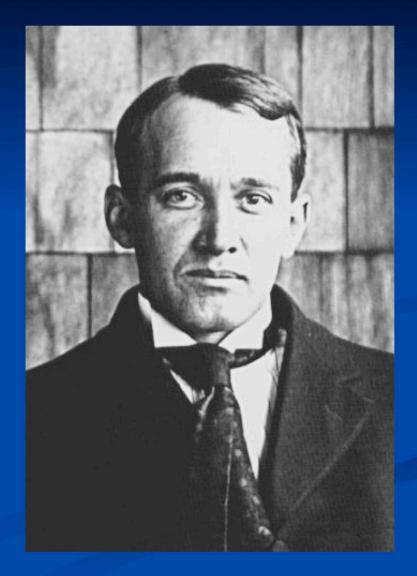
#### Definition: Redshift

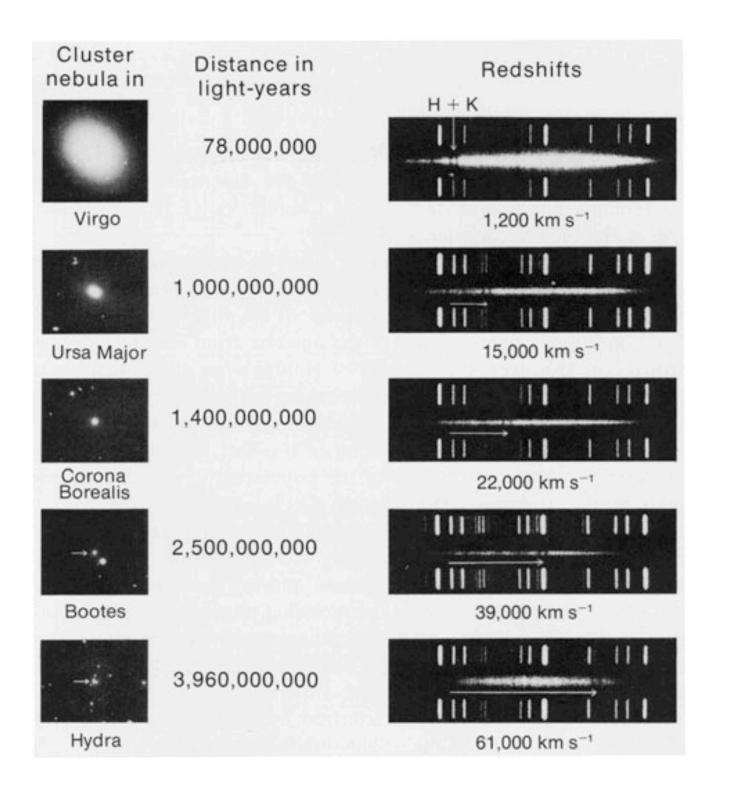
• The measure of the amount a spectral line is shifted in wavelength



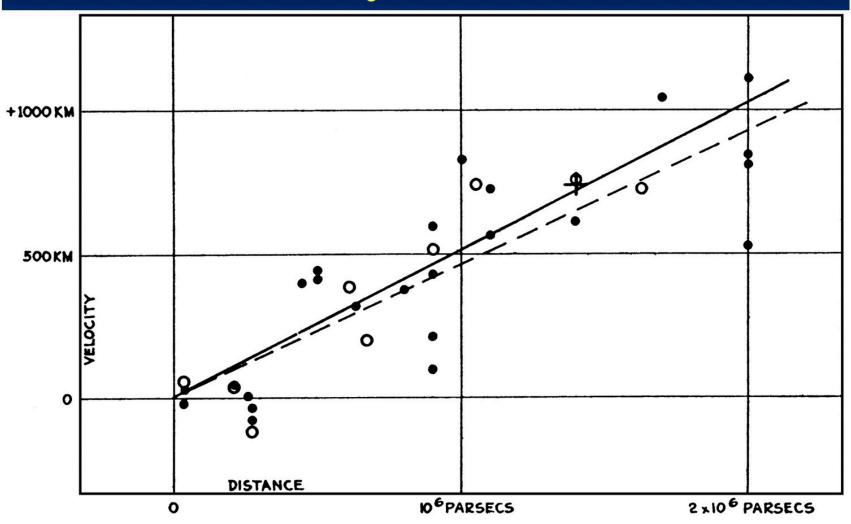
## Edwin Hubble & Vesto Slipher



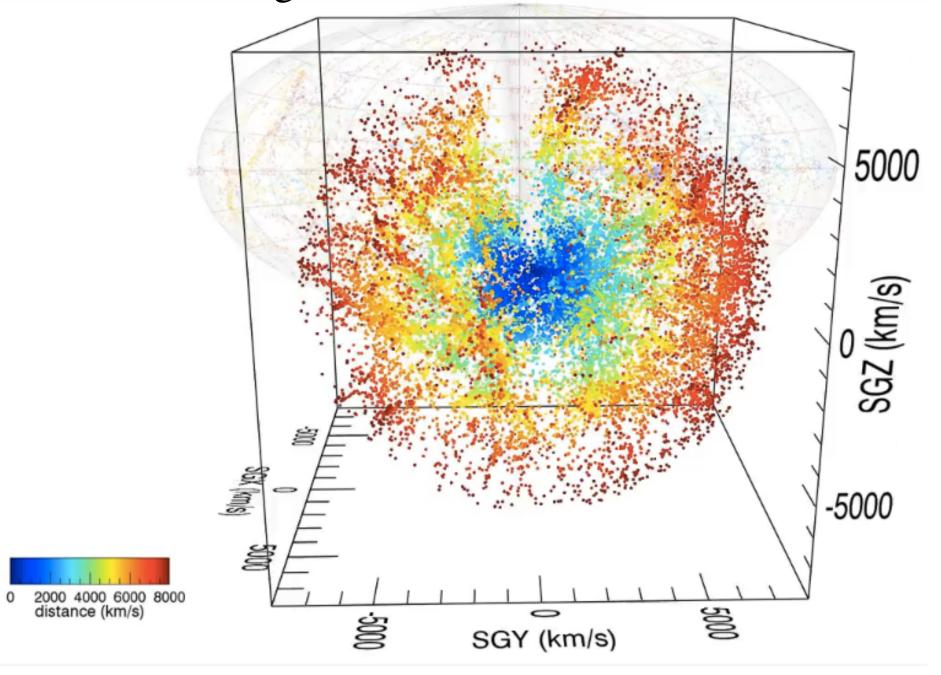




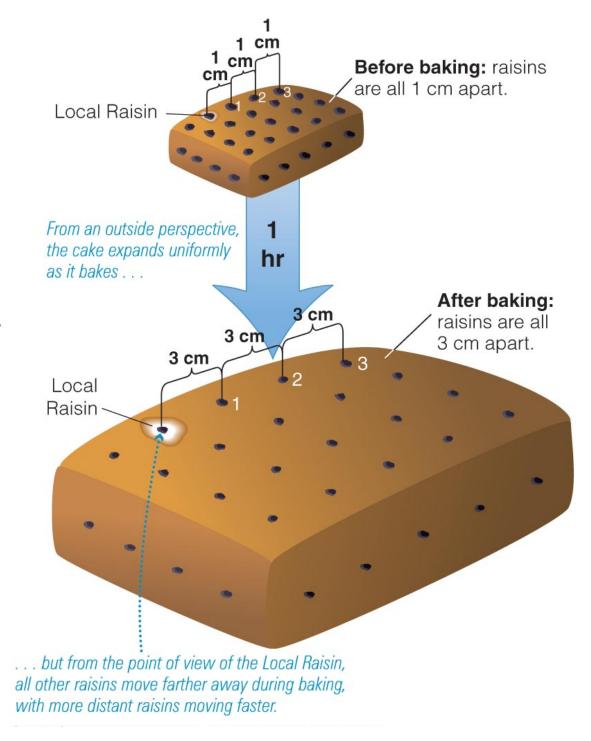
## Hubble Law - 1929 Originally $H_0 \sim 500$ km/s/Mpc



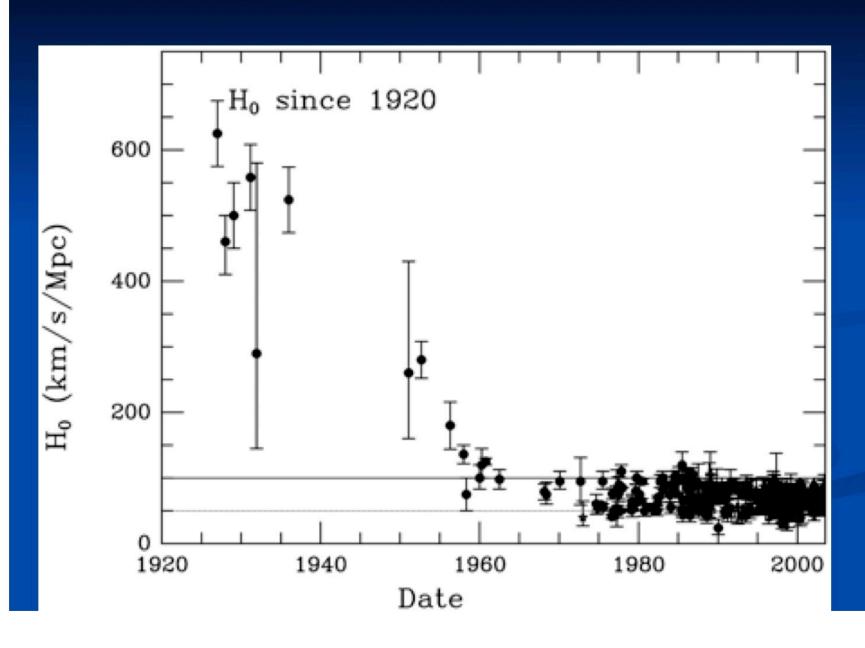
## Known galaxies within 8,000 km/s of us



- Galaxies are all moving away from each other, so every galaxy sees the same Hubble expansion, i.e there is no center.
- The cosmic expansion is the unfolding of all space since the big bang, i.e. there is no edge.
- We are limited in our view by the time it takes distant light to reach us, i.e. the universe has an edge in time not space.

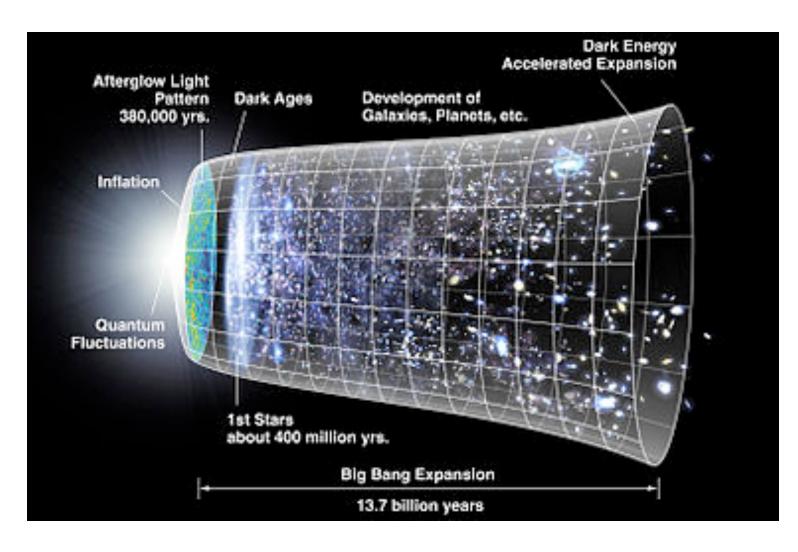


## **Hubble Constant Determinations**

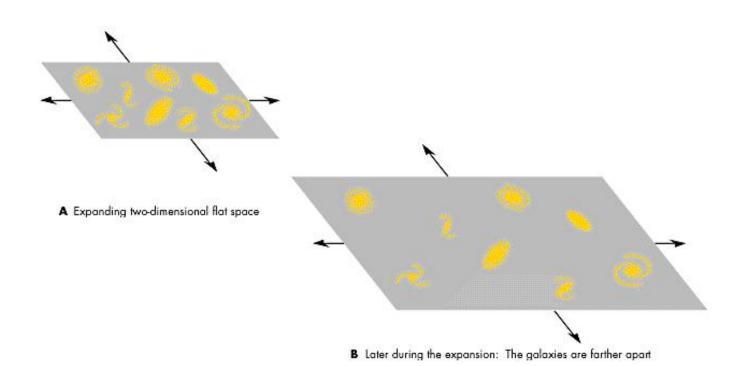


## Cosmology: What We Know

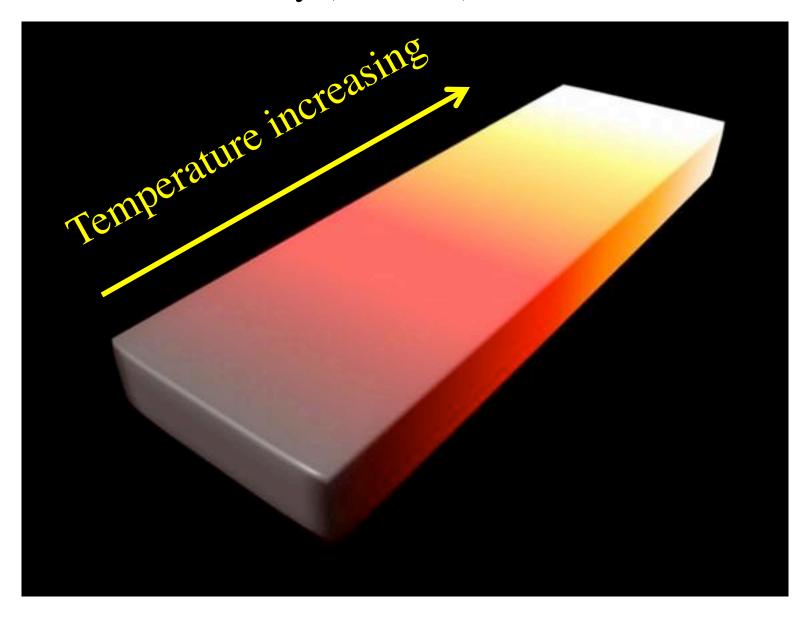
1. Redshift – it's cosmic expansion, *not Doppler* 



1. If the Universe is expanding, then reversing that expansion (going backwards in time) indicates that the Universe must have been smaller in the past.

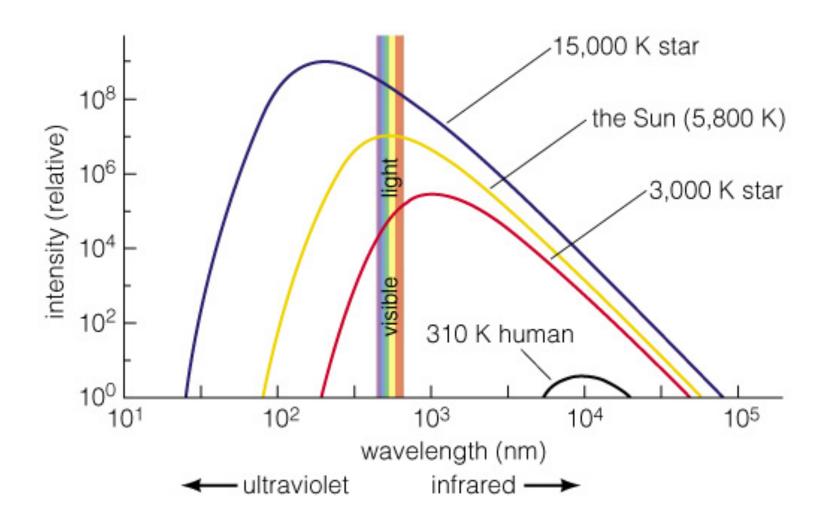


### Blackbody (Thermal) Radiation

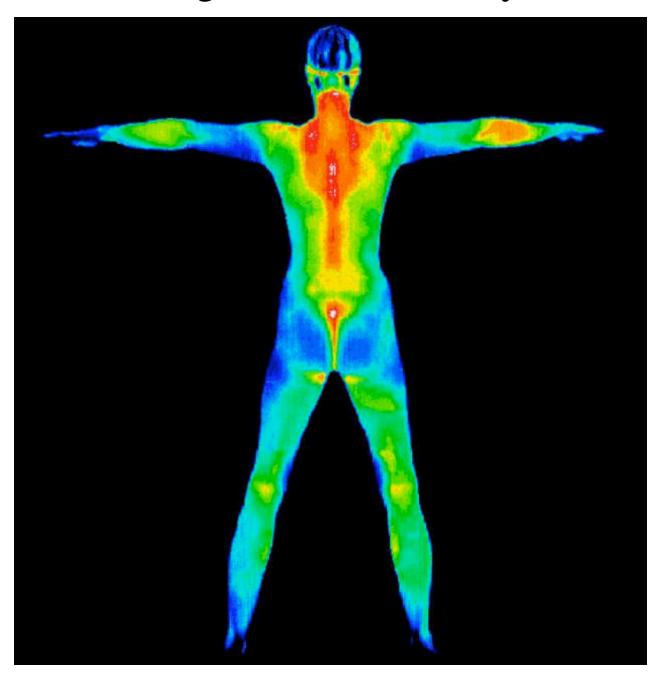


#### Two Properties of Thermal Radiation:

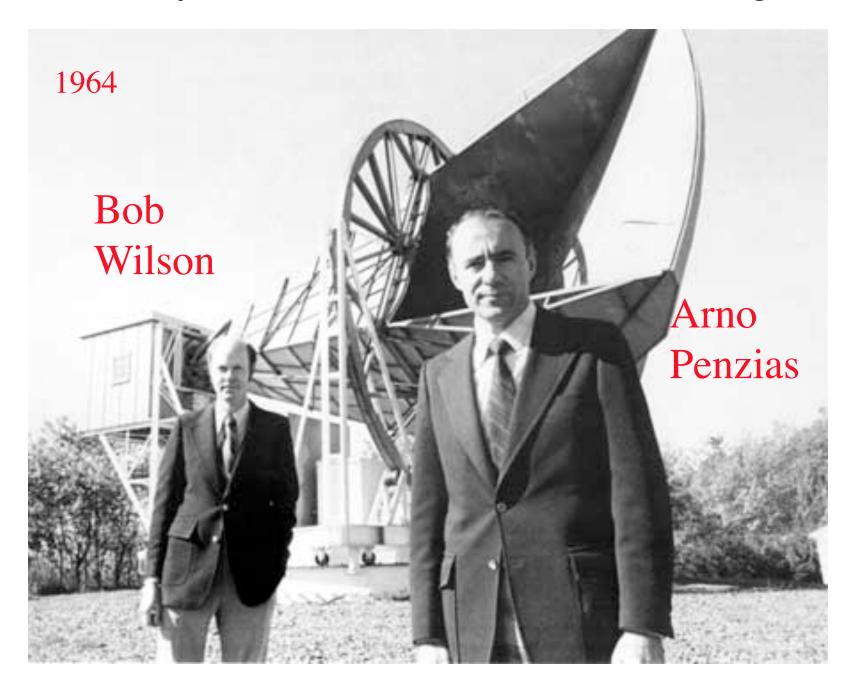
- 1. Hotter objects emit more light at all frequencies per unit area.
- 2. Hotter objects emit photons with a higher average energy.



## Infrared Light – Human Body Glows!

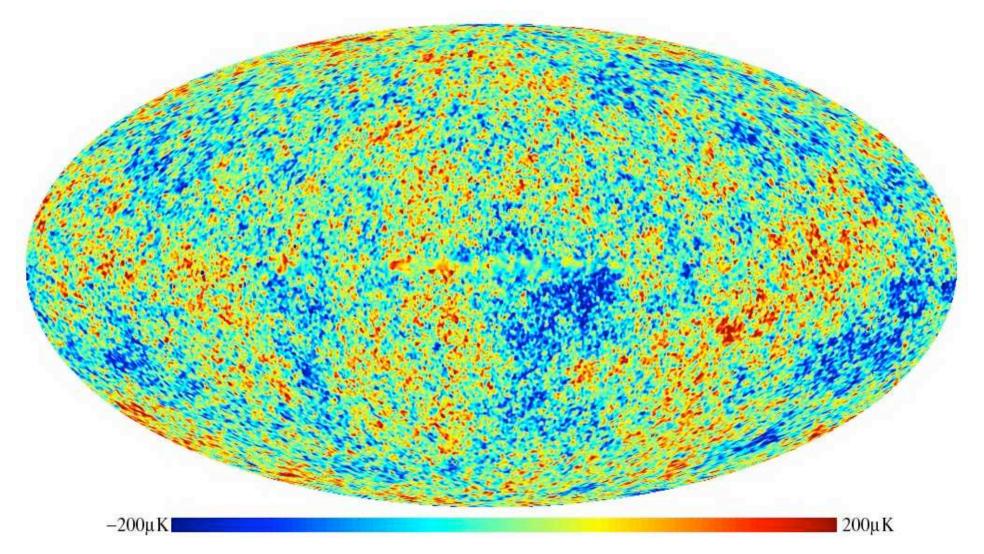


## 2. Discovery of the Cosmic Microwave Background

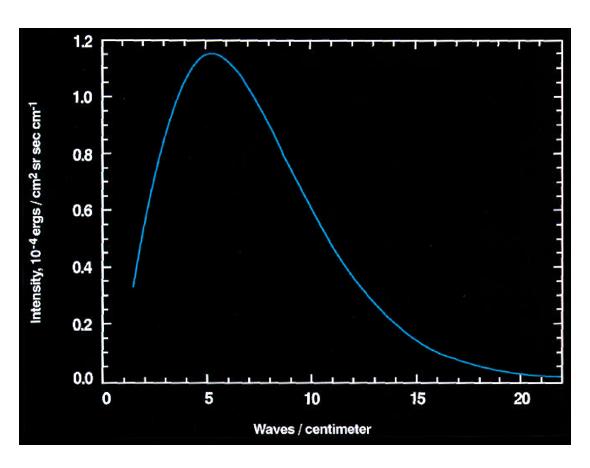


## Cosmic Microwave Background: The farthest we can see back...

Radiation signature from 300,000 years after the Big Bang

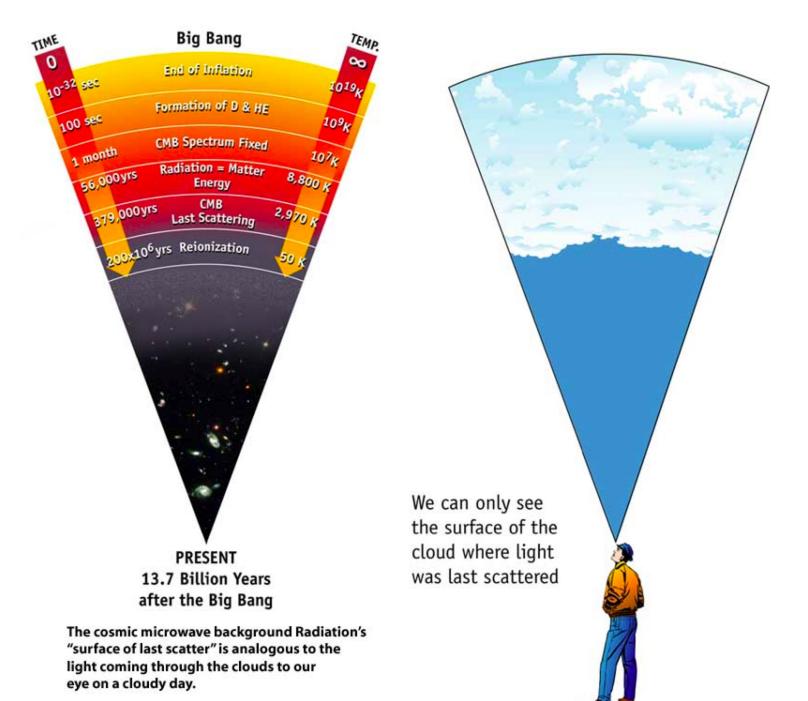


## Cosmology: What We Know

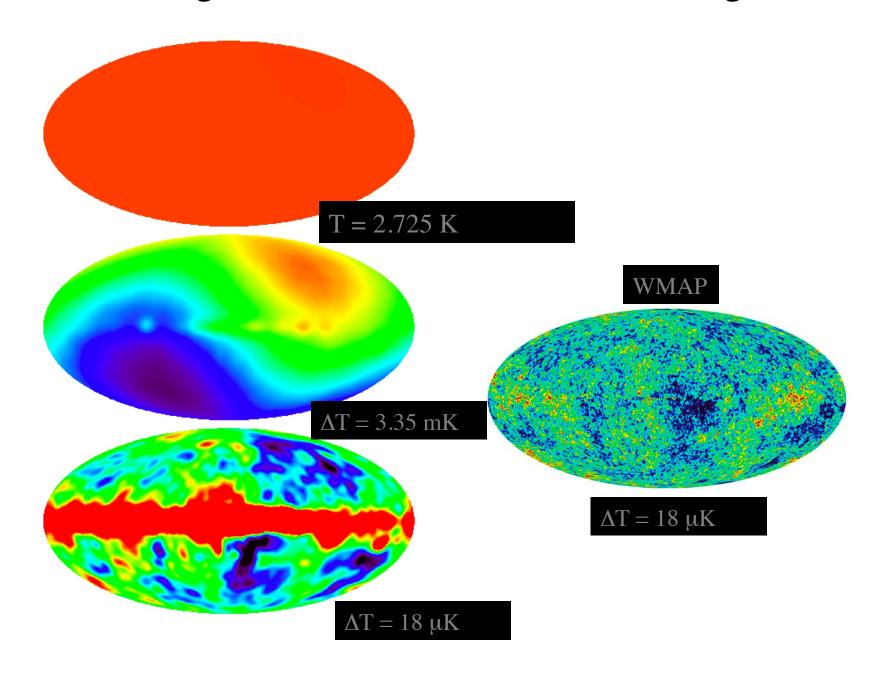


2. Background Radiation – thermal, at 2.73K

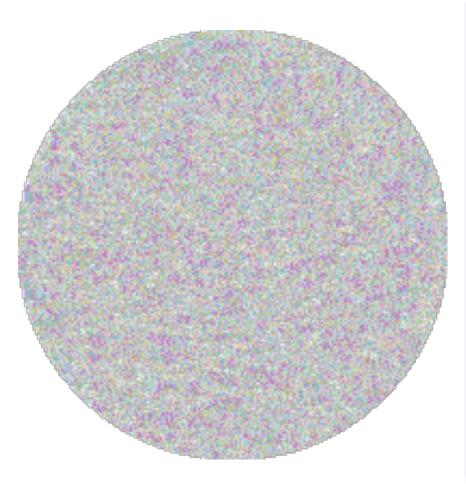
© 2005 Pearson Education I publishing as Addison-Wes

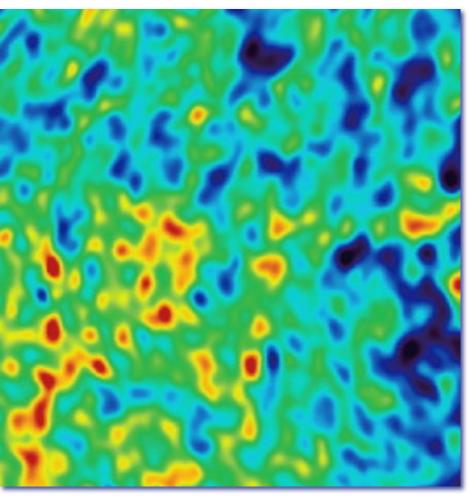


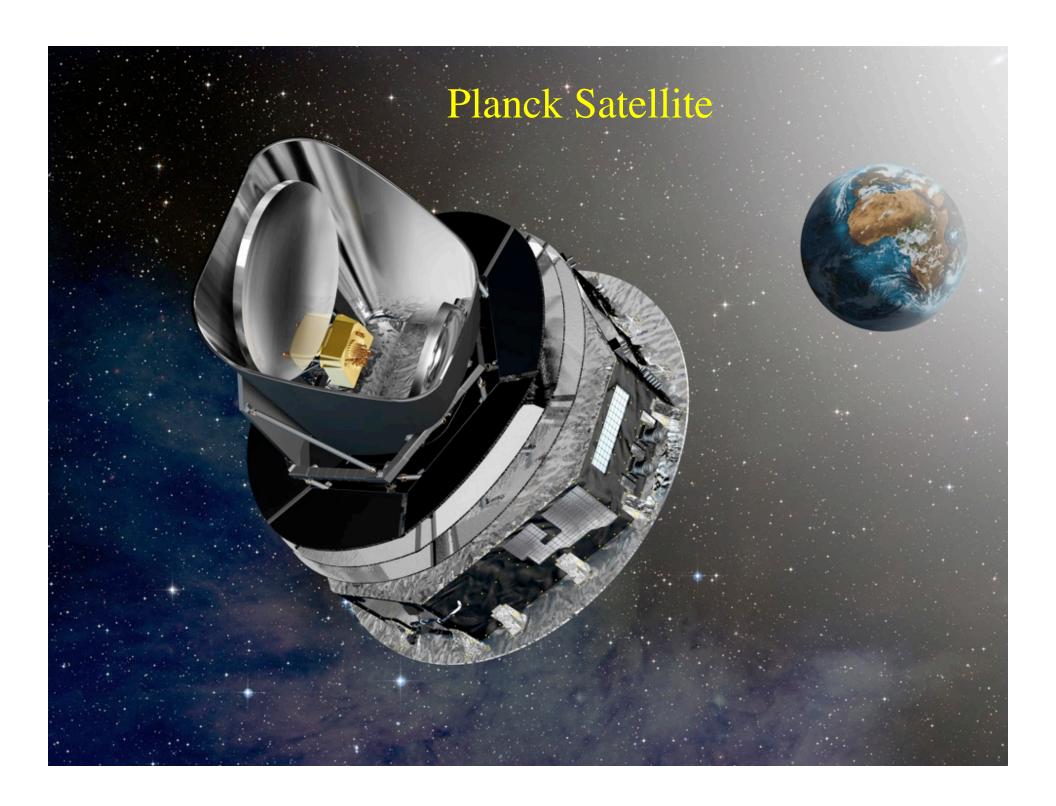
## Measuring the Cosmic Microwave Background



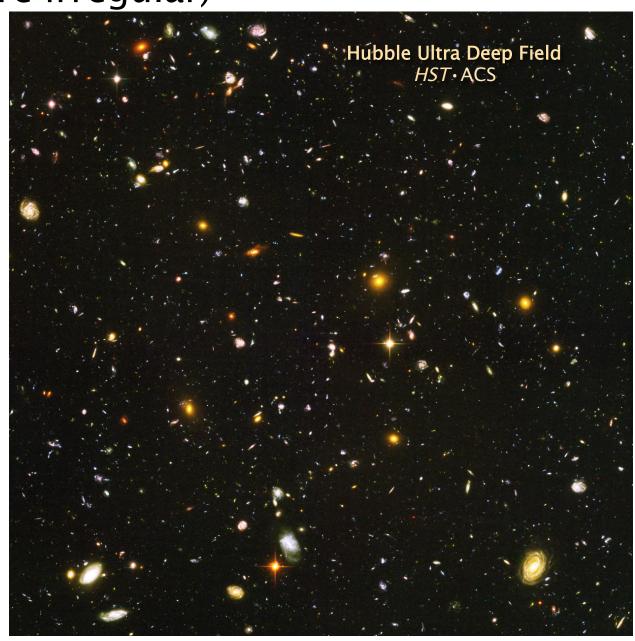
# An image of quantum fluctuations blown up to the size of the universe







3. Galaxies in past look younger (smaller and more irregular)



## Galaxy Formation Simulation

Courtesy Charlotte Christensen



# Interacting Galaxies Hubble Space Telescope • ACS/WFC • WFPC2

NASA, ESA, the Hubble Heritage (AURA/STScI)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University)

STScI-PRC08-16a

## 4. Abundance of the Lightest Elements

The lightest elements — hydrogen, helium, and a smattering of deuterium (heavy hydrogen isotope) and lithium — were from the big bang itself, produced by fusion in the first three minutes when the universe was as hot as the core of a star like the Sun!

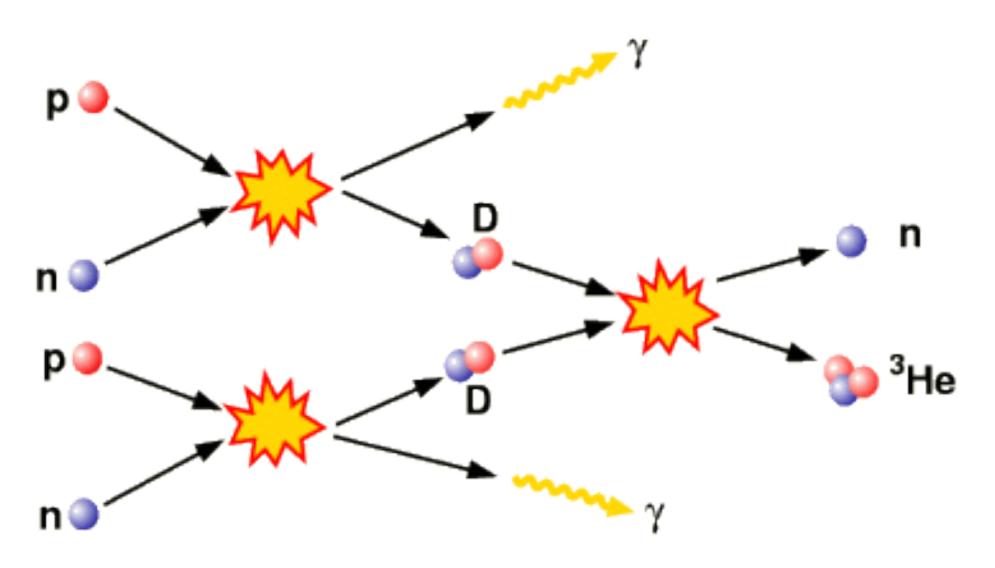
drogen 1 H 1.0079	. <del></del>		253	15 to	iá.	5	1,53,1	ē	utu.	55.	5.5.2		ē.52	<del>-</del>	£.52	5.5		helium 2 He 4.0026
lithium 3	eryllium 4												boron 5	carbon 6	nitrogen <b>7</b>	oxygen 8	fluorine 9	neon 10
l'i	Be												В	Č	Ň	Ô	F	Ne
															N		_	
941 so.	9.0122 magnesium												10.811 aluminium	12.011 silicon	14.007 phosphorus	15.999 sulfur	18,998 chlorine	20,180 argon
11	12												13	14	15	16	17	18
Na	Mg												ΑI	Si	Р	S	CI	Ar
22.990 potassium	24.305 calcium		scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	26.982 gallium	28.086 germanium	30.974 arsenic	32.065 selenium	35,453 bromine	39.948 krypton
19	20		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
K	Ca		Sc	Ti	V	Cr	MA	Fe	Ca	NI:	C	7.0	0-	0-	Λ -	Ca	D.	1/4
			00		V	CI	Mn	ге	Co	NI	Cu	Zn	Ga	Ge	As	Se	Br	Kr
39.098	40.078		44.956	47.867	50.942	51.996	54.938	55.845	58.933	58.693	63,546	65.39	69.723	72.61	74.922	78.96	79.904	83.80
39,098 rubidium <b>37</b>	500000000000000000000000000000000000000		44.956 yttrium	47,867 zirconium	1.7					1500515								83,80 xenon
rubidium	40.078 strontium		44.956	47.867	50.942 niobium	51.996 molybdenum	54.938 technetium	55.845 ruthenium	58.933 rhodium	58,693 palladium	63,546 silver 47	65,39 cadmium	69.723 indium	72.61 tin	74.922 antimony	78.96 tellurium	79,904 iodine	83.80
rubidium 37 <b>Rb</b> 85,468	40.078 strontium 38 Sr 87.62		44.956 yttrium 39 <b>Y</b> 88.906	47.867 zirconium 40 Zr 91.224	50.942 niobium 41 Nb 92.906	51.996 molybdenum 42 Mo 95.94	54.938 technetium 43 <b>TC</b> [98]	55,845 ruthenium 44 <b>Ru</b> 101.07	58.933 rhodium 45 <b>Rh</b> 102.91	58.693 palladium 46 Pd 106.42	63,546 silver 47 <b>Ag</b> 107,87	65.39 cadmium 48 Cd 112.41	69.723 indium 49 In	72.61 tin 50 <b>Sn</b> 118.71	74.922 antimony 51 Sb 121.76	78.96 tellurium 52 Te 127.60	79.904 iodine 53 1 126.90	83.80 xenon 54 <b>Xe</b> 131.29
rubidium 37 <b>Rb</b> 85,468 caesium	strontium 38 Sr 87.62 barium	57-70	44.956 yttrium 39 Y 88.906 lutetium	47.867 zirconium 40 Zr 91.224 hafnium	50.942 niobium 41 Nb 92.906 tantalum	51,996 molybdenum 42 Mo 95,94 tungsten	54,938 technetium 43 TC [98] rhenium	ruthenium 44 Ru 101.07 osmium	58.933 rhodium 45 Rh 102.91 iridium	58.693 palladium 46 Pd 106.42 platinum	63.546 silver 47 <b>Ag</b> 107.87 gold	65.39 cadmium 48 Cd 112.41 mercury	69.723 indium 49 In 114.82 thallium	72.61 tin 50 <b>Sn</b> 118.71 lead	74.922 antimony 51 Sb 121.76 bismuth	78.96 tellurium 52 Te 127.60 polonium	79.904 iodine 53 1 126.90 astatine	83,80 xenon 54 Xe 131,29 radon
rubidium 37 <b>Rb</b> 85,468	40.078 strontium 38 Sr 87.62	57-70 <del>*</del>	44.956 yttrium 39 <b>Y</b> 88.906	47.867 zirconium 40 Zr 91.224	50.942 niobium 41 Nb 92.906	51.996 molybdenum 42 Mo 95.94	54.938 technetium 43 <b>TC</b> [98]	55,845 ruthenium 44 <b>Ru</b> 101.07	58.933 rhodium 45 <b>Rh</b> 102.91	58.693 palladium 46 Pd 106.42	63,546 silver 47 <b>Ag</b> 107,87	65.39 cadmium 48 Cd 112.41	69.723 indium 49 In	72.61 tin 50 <b>Sn</b> 118.71	74.922 antimony 51 Sb 121.76	78.96 tellurium 52 Te 127.60	79.904 iodine 53 1 126.90	83.80 xenon 54 <b>Xe</b> 131.29
rubidium 37 <b>Rb</b> 85.468 caesium 55 <b>Cs</b> 132.91	40.078 strontium 38 Sr 87.62 barium 56 Ba 137.33	1907 - 31,1901	44,956 yttrium 39 Y 88,906 lutetium 71 Lu 174,97	47.867 zirconium 40 Zr 91.224 hafnium 72 Hf	50.942 niobium 41 Nb 92.906 tantalum 73 Ta 180.95	51,996 molybdenum 42 Mo 95,94 tungsten 74 W 183,84	54.938 technetium 43 TC [98] rhenium 75 Re 186.21	55.845 ruthenium 44 Ru 101.07 osmium 76 Os 190.23	58,933 rhodium 45 Rh 102,91 iridium 77 Ir	58,693 palladium 46 Pd 106,42 platinum 78 Pt 195,08	63,546 silver 47 <b>Ag</b> 107,87 gold 79 <b>Au</b> 196,97	65.39 cadmium 48 Cd 112.41 mercury 80 Hg 200.59	69.723 indium 49 In 114.82 thallium	72.61 tin 50 Sn 118.71 lead 82 Pb 207.2	74.922 antimony 51 Sb 121.76 bismuth 83	78.96 tellurium 52 Te 127.60 polonium 84	79,904 lodine 53 126,90 astatine 85	83.80 xenon 54 Xe 131.29 radon 86
Rb 85.468 caesium 55	40.078 strontium 38 Sr 87.62 barlum 56 Ba	1907 - 31,1901	44.956 yttrium 39 Y 88.906 lutetium 71 Lu	47.867 zirconium 40 Zr 91.224 hafnium 72 Hf	50.942 niobium 41 Nb 92.906 tantalum 73 Ta	51,996 molybdenum 42 Mo 95,94 tungsten 74	technetium 43 TC [98] rhenium 75 Re	ruthenium 44 Ru 101.07 osmium 76 Os	58,933 rhodium 45 Rh 102,91 iridium 77 Ir	58,693 palladium 46 Pd 106.42 platinum 78 Pt	63,546 silver 47 <b>Ag</b> 107,87 gold 79 <b>Au</b>	cadmium 48 Cd 112.41 mercury 80 Hg	69,723 indium 49 In 114.82 thallium 81	72.61 tin 50 <b>Sn</b> 118.71 lead 82 <b>Pb</b>	74.922 antimony 51 Sb 121.76 bismuth 83 Bi	78.96 tellurium 52 Te 127.60 polonium 84 Po	79.904 iodine 53	83.80 xenon 54 <b>Xe</b> 131.29 radon 86 <b>Rn</b>
Rb 85.468 caesium 55 Cs 132.91 francium 87	40.078 strontium 38 Sr 87.62 barium 56 Ba 137.33 radium 88	<del>×</del> 89-102	44,956 yttrium 39 Y 88,906 lutetium 71 Lu 174,97 lawrencium 103	47.867 zirconium 40 Zr 91.224 hafinium 72 Hf 178.49 rutherfordium 104	50.942 niobium 41 Nb 92.906 tantalum 73 Ta 180.95 dubnium 105	51,996 molybdenum 42 Mo 95,94 tungsten 74 W 183,84 seaborgium 106	technetium 43 TC [98] rhenium 75 Re 186.21 bohrium 107	55,845 ruthenium 44 Ru 101.07 osmium 76 OS 190.23 hassium 108	58,933 rhodium 45 Rh 102,91 iridium 77 Ir 192,22 meitnerium 109	58.693 palladium 46 Pd 106.42 platinum 78 Pt 196.08 ununnilium 110	63,546 silver 47 Ag 107.87 gold 79 Au 196.97 unununium 111	65.39 cadmium 48 Cd 112.41 mercury 80 Hg 200.59 ununbium 112	69,723 indium 49 In 114.82 thallium 81	72.61 tin 50 Sn 118.71 lead 82 Pb 207.2 ununquadium 114	74.922 antimony 51 Sb 121.76 bismuth 83 Bi	78.96 tellurium 52 Te 127.60 polonium 84 Po	79.904 iodine 53	83.80 xenon 54 <b>Xe</b> 131.29 radon 86 <b>Rn</b>
Rb 85.468 caesium 55 Cs 132.91 francium	40.078 strontlum 38 Sr 87.62 barlum 56 Ba 137.33 radium	*	44,956 yttrium 39 Y 88,906 lutetium 71 Lu 174,97 lawrencium	47.867 zirconium 40 Zr 91.224 hafinium 72 Hf 178.49 rutherfordium	50.942 niobium 41 Nb 92.906 tantalum 73 Ta 180.95 dubnium	51,996 molybdenum 42 Mo 95,94 tungsten 74 W 183,84 seaborgium	technetium 43 TC [98] rhenium 75 Re 186.21 bohrium	55.845 ruthenium 44 Ru 101.07 osmium 76 Os 190.23 hassium	58,933 rhodium 45 Rh 102,91 iridium 77 Ir 192,22 meitnerium	58.693 palladium 46 Pd 106.42 platinum 78 Pt 196.08 ununnilium 110	63,546 silver 47 Ag 107.87 gold 79 Au 196.97 unununium	65.39 cadmium 48 Cd 112.41 mercury 80 Hg 200.59 ununbium 112	69,723 indium 49 In 114.82 thallium 81	72.61 tin 50 Sn 118.71 lead 82 Pb 207.2 ununquadium	74.922 antimony 51 Sb 121.76 bismuth 83 Bi	78.96 tellurium 52 Te 127.60 polonium 84 Po	79.904 iodine 53    126.90 astatine 85    At	83.80 xenon 54 <b>Xe</b> 131.29 radon 86 <b>Rn</b>

\*Lanthanide series

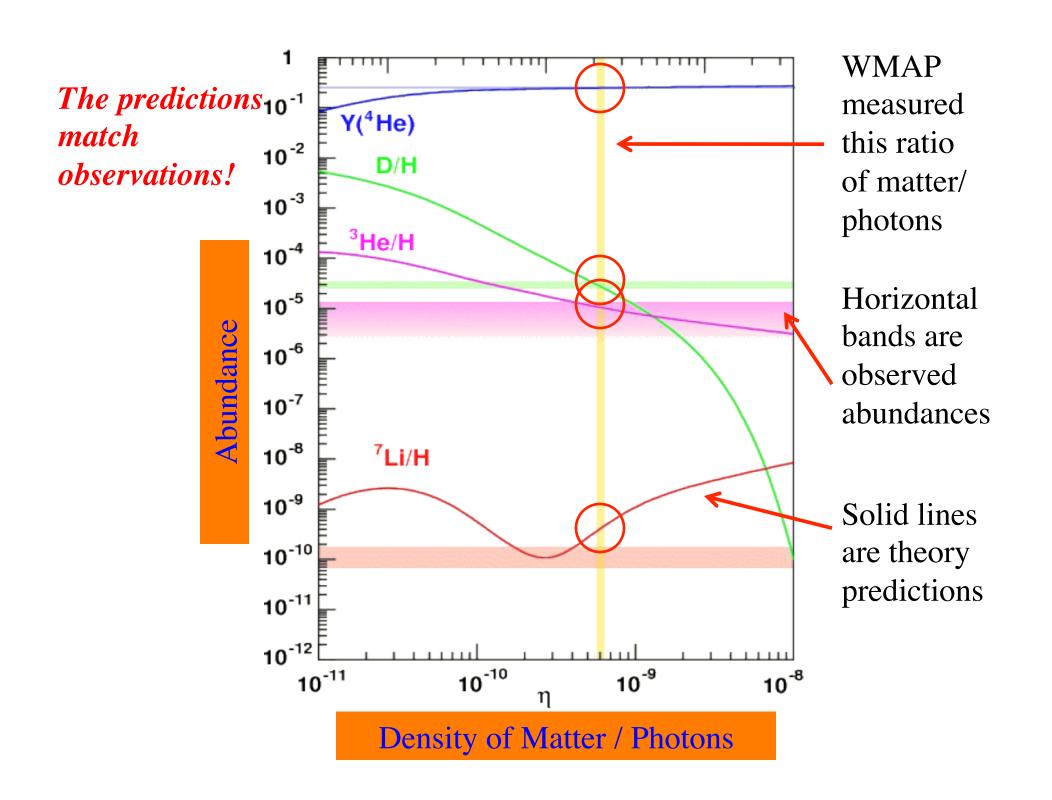
\* \* Actinide series

ı	lanthanum	cerium	praseodymium	neodymium		samarium	europium	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium
П	57	58	59	60	61	62	63	64	65	66	67	68	69	70
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Но	Er	Tm	Yb
-1	138.91	140.12	140.91	144.24	[145]	150.36	151.96	157.25	158.93	162.50	164.93	167.26	168.93	173.04
ſ	actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium
-1	89	90	91	92	93	94	95	96	97	98	99	100	101	102
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No
I	[227]	232.04	231.04	238.03	[237]	[244]	[243]	[247]	[247]	[251]	[252]	[257]	[258]	[259]

## **Big Bang Fusion**



Nuclear fusion in first 3 minutes



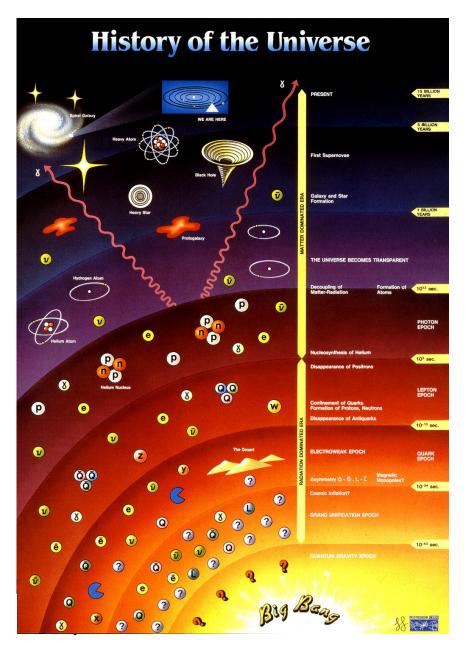
## Status of the Big Bang

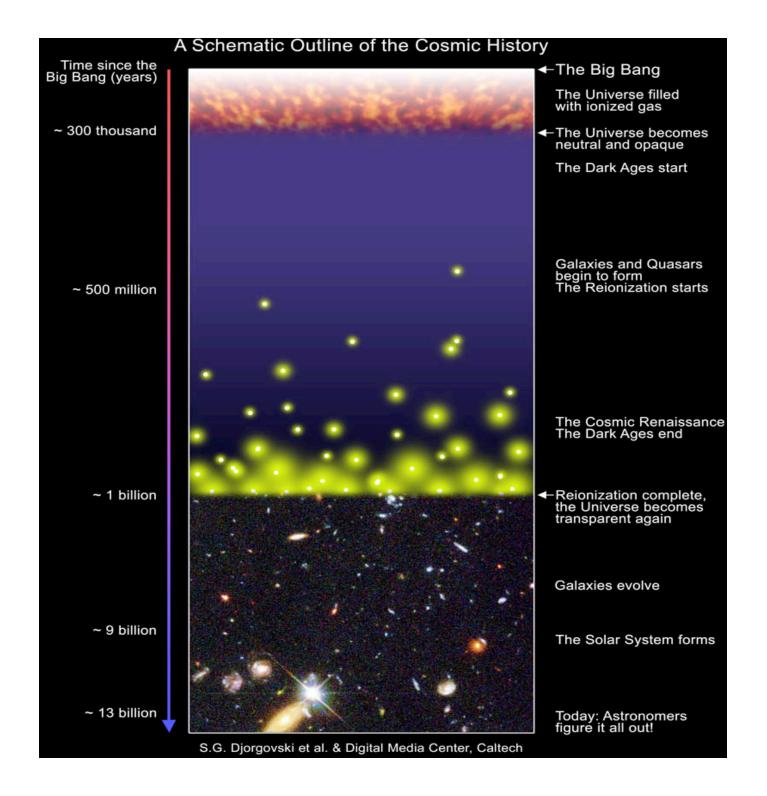
There is evidence for expansion, and the universe was hotter and denser in the distant past.

The microwave background and the helium abundance cannot easily be explained in any other way.

There are hundred of thousands of big bang photons in every breath you take: the big bang is all around us.

It is a theory, but a theory with a web of evidence to support it. The theory is mute about the cause of the cause.

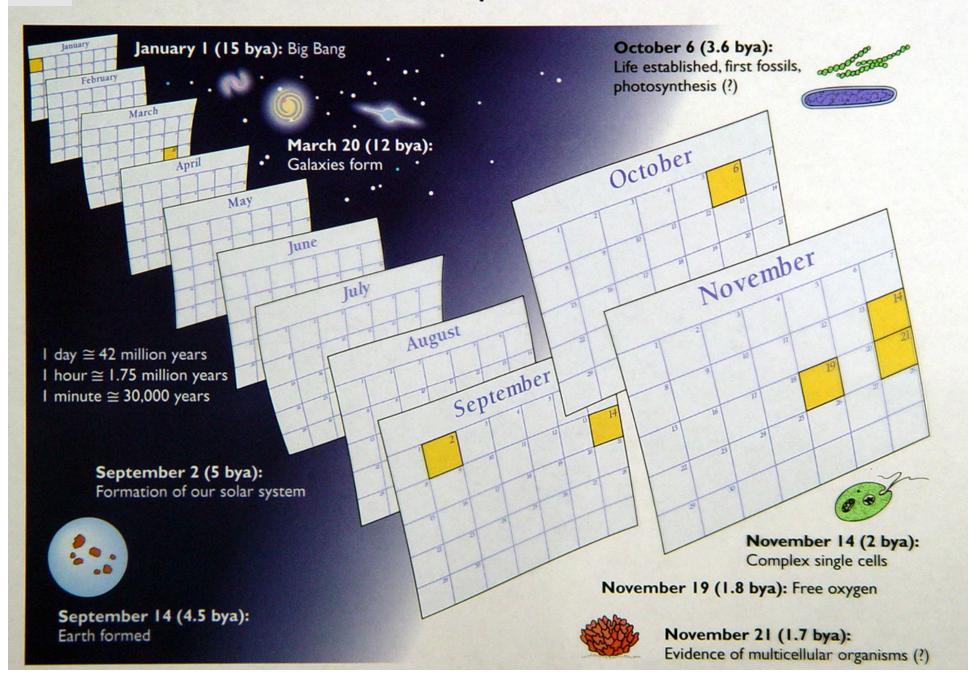




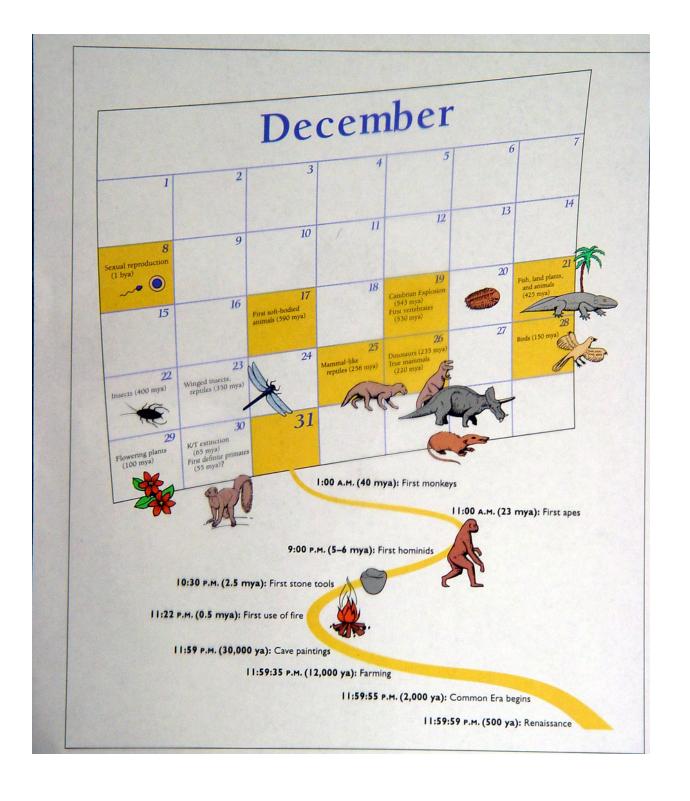
## How do our lifetimes compare to the age of the Universe?

- The Cosmic Calendar: a scale on which we compress the history of the universe into 1 year.
- This is a time scale model where 14 billion years equals 1 year, i.e. 14,000,000,000:1.
- Our lives would scale similarly, so 80 years goes down by a factor of 14 billion too.
- In the scale model, a human life is about 2 tenths of a second!

#### The Cosmic Calendar: January-November



Now home in on the more recent span of the history of life and of humans and civilization



## The Raw Material for Astrobiology

- **Space:** the potential habitable worlds around ten thousand billion billion stars; ours is just one.
- Time: a cosmic history of nearly 14 billion years; life took less than ½ billion years to start here.

"If they not be inhabited, what a waste of space."

Thomas Carlyle, Scottish Essayist (1795-1881)