

Nature's Design

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April 20 2004, Designing Matter, #13

Designing Matter Lecture Series:

Topics 1 - 12 span: atoms → humans → earth's surface
Topic 13 (this one): the rest of the Universe.....

In terms of size :

Topics 1-12

Topic 13



Outline

- 1) Design in Nature: the stage, actors and play.
- 2) Quick tour: from nuclei to distant galaxies.
- 3) Universe as a laboratory of extremes:
size/mass/time/power/density/temperature.
- 4) Constituents, and their construction/creation:
nuclei & atoms, particles, matter, forces.
- 5) Emergence of structure:
stars, galaxies, clusters/voids.
- 6) Origin of energy.

Shakespeare : "As You Like It"

Reflections on human life

"All the world's a stage,
And all the men and women merely players.
They have their exits and their entrances,
And one man in his time plays many parts,
His acts being in seven ages."

Deep Contents

- Space & Time (space-time)
- Matter (particles)
- Forces (act between particles)
4(5) : strong, electromagnetic, weak, gravity, (QM)
- Rules (quantum/classical physics)
(e.g. conservation laws, QED, QCD, GR)

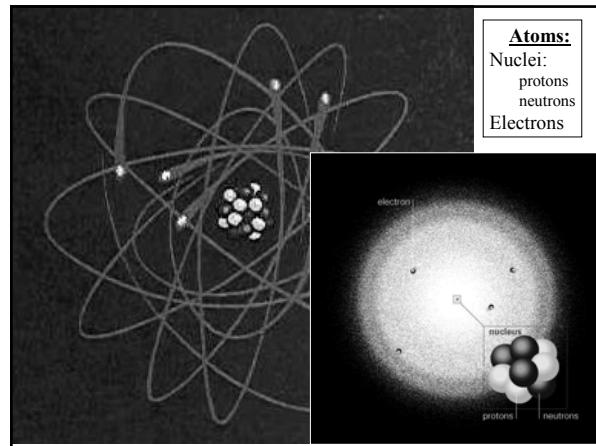
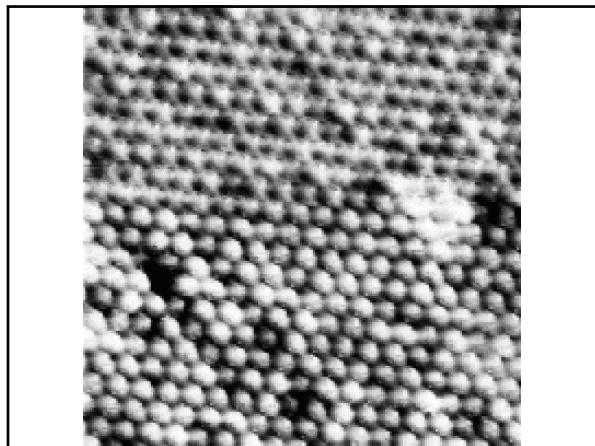
Together, these make four basic structures

Four Basic Structures

- Nuclei
- Atoms
- Stars/Planets
- Galaxies

<u>FORCES</u>
strong, EM, QM
EM, QM
gravity, EM, QM
gravity

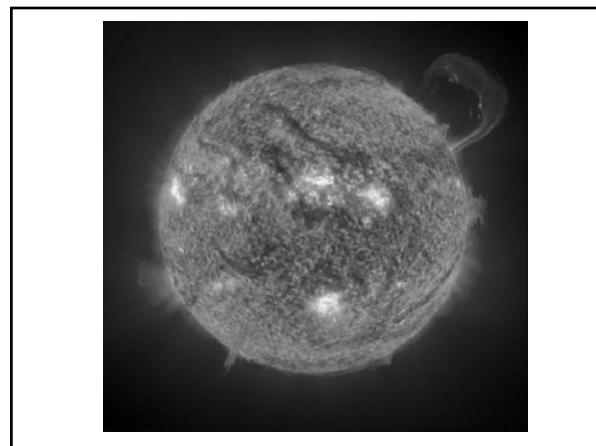
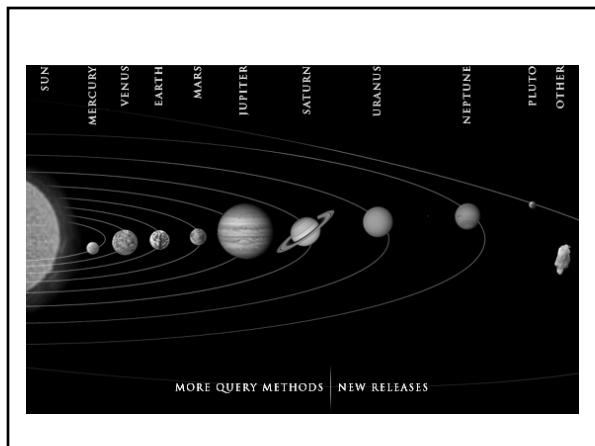
Lets begin our brief tour of these basic structures

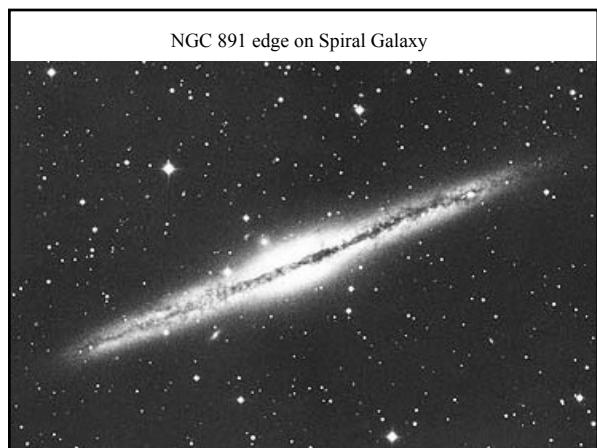
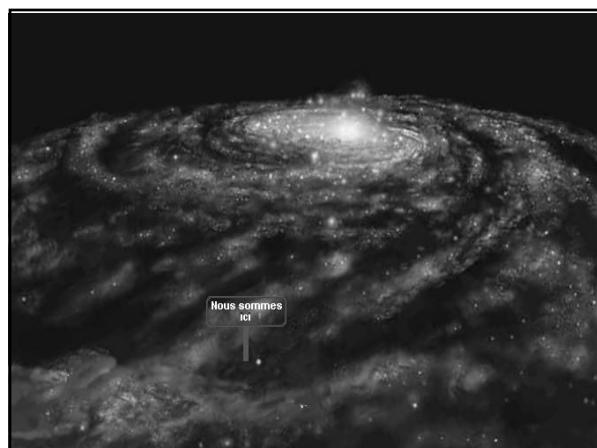
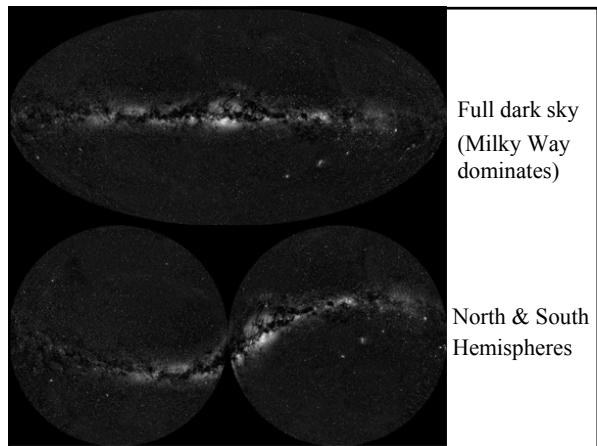
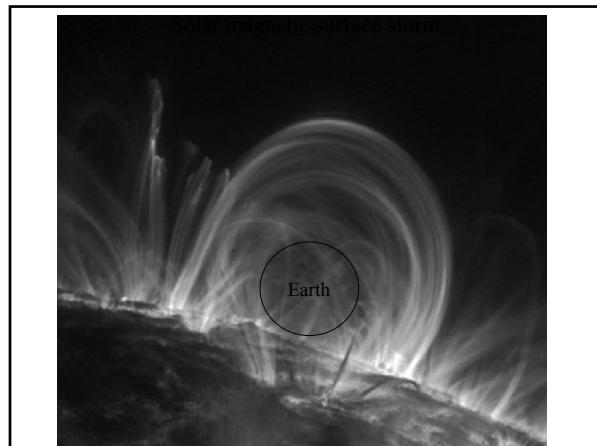


Periodic Table of the Elements

1	IA	2	IA	3	IIA	4	IIA	5	IIIB	6	IVB	7	VIB	8	VIB	9	VIIA	10	0																	
1	H	2	Li	3	Mg	4	Be	5	Ti	6	Sc	7	Y	8	Cr	9	Mn	10	He																	
11	Na	12	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	F	19	Ne																			
19	K	20	Ca	21	Sc	22	Ti	23	Y	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Zn	30	Ga	31	Ge	32	As	33	Se	34	Br	35	Kr			
37	Rb	38	Sr	39	Y	40	Zr	41	Zr	42	Nb	43	Mo	44	Tc	45	Ru	46	Rh	47	Pd	48	Ag	49	Cd	50	In	51	Sn	52	Sb	53	Te	54	Xe	
55	Cs	56	Ba	57	*La	58	Hf	59	Ta	60	W	61	Re	62	Os	63	Ir	64	Pt	65	Au	66	Hg	67	Tl	68	Pb	69	Bi	70	Po	71	At	72	Rn	
87	Fr	88	Ra	+Ac	Rf	89	Ha	104	105	106	107	108	109	110	109	110	106	107	108	109	110	106	107	108	109	110	106	107	108	109	110	106	107	108	109	110

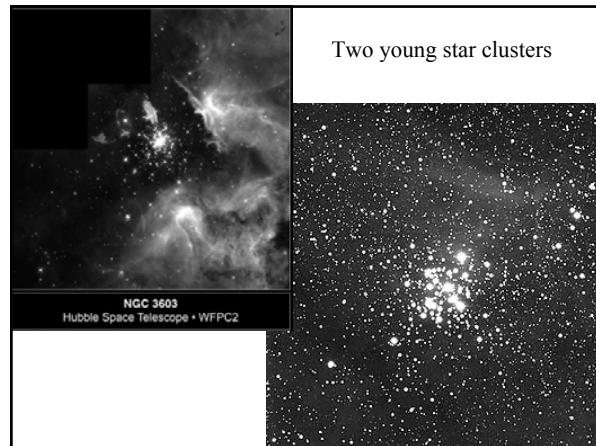
*Lanthanide Series + Actinide Series



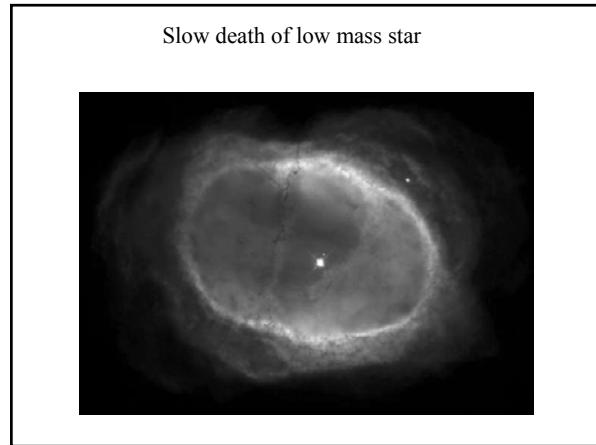
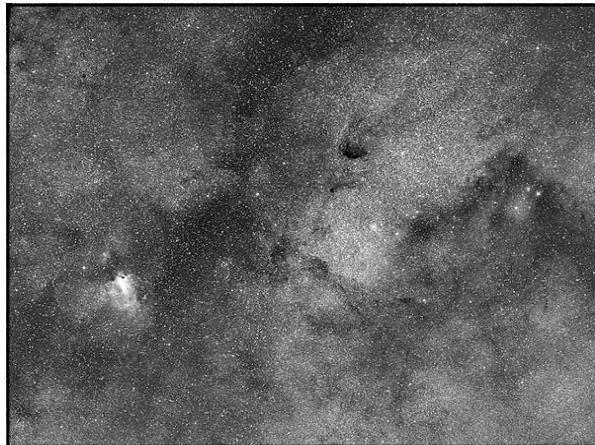




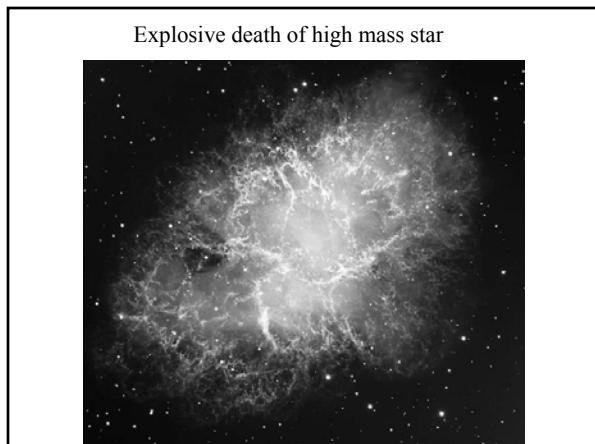
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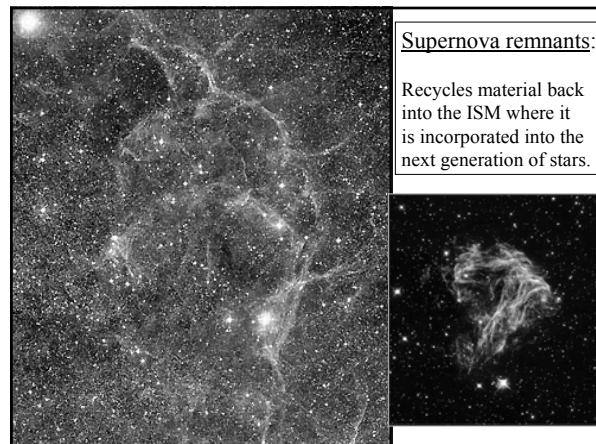
Two young star clusters

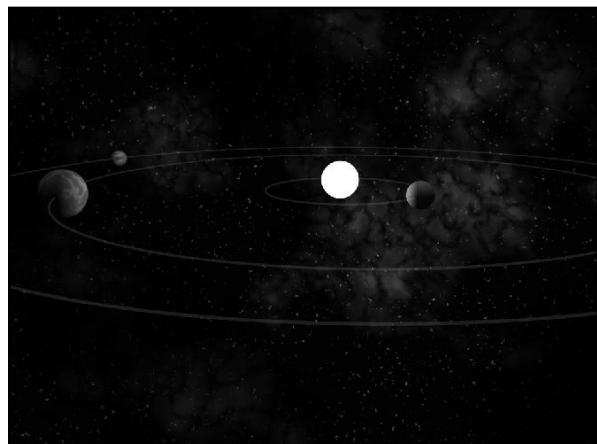
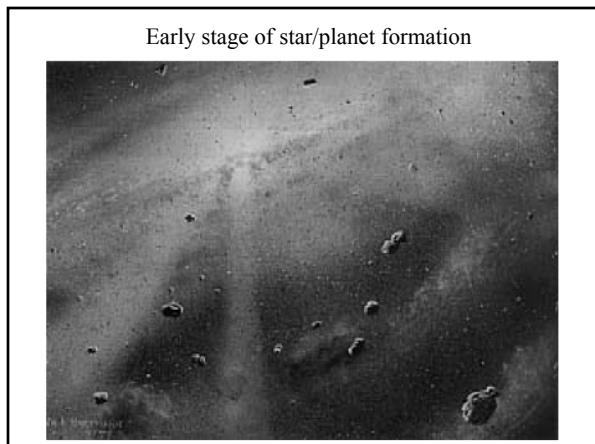
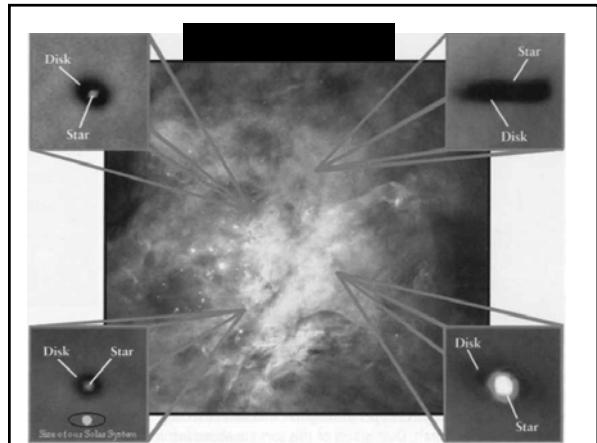
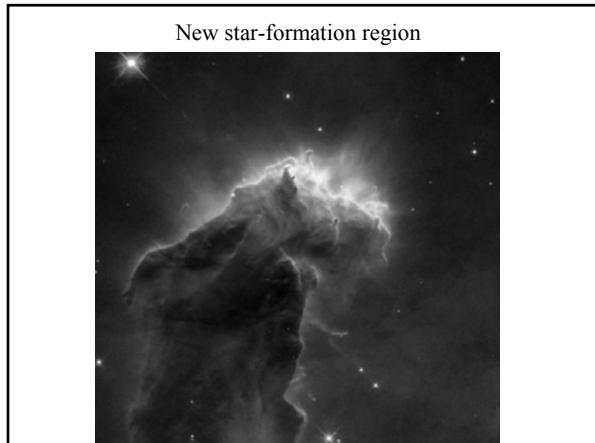
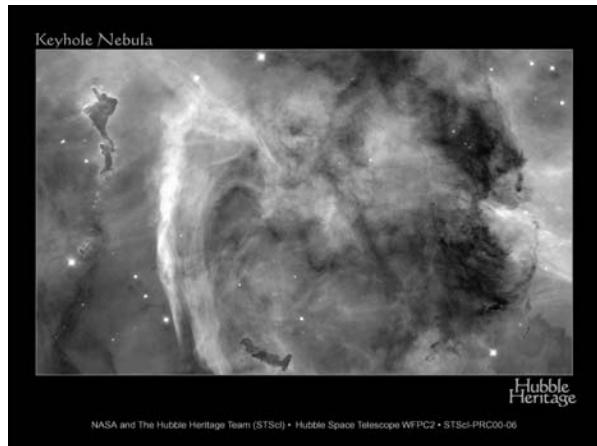
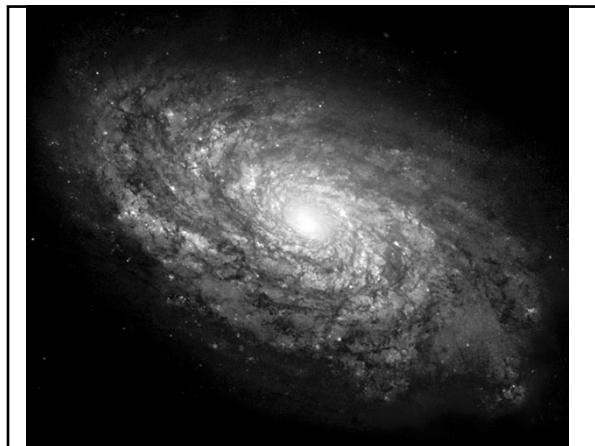


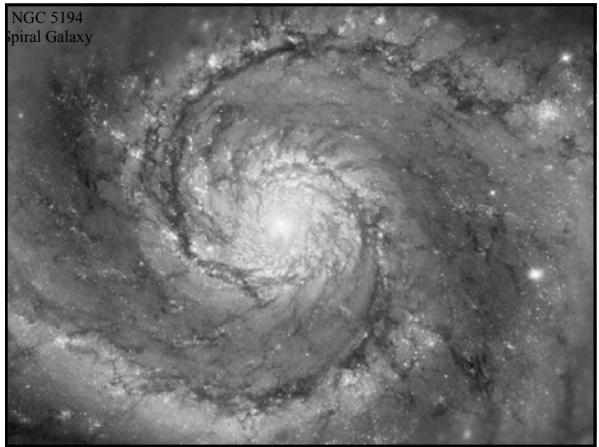
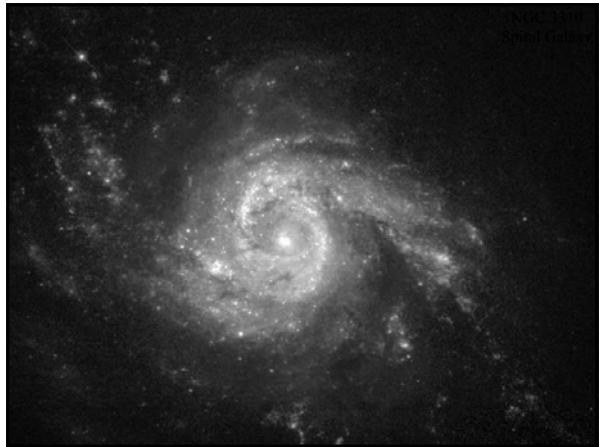
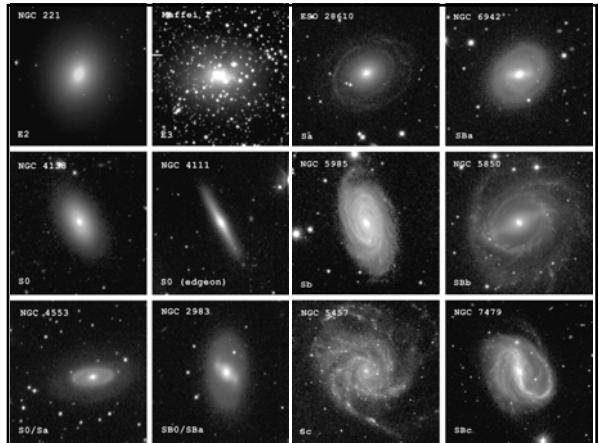
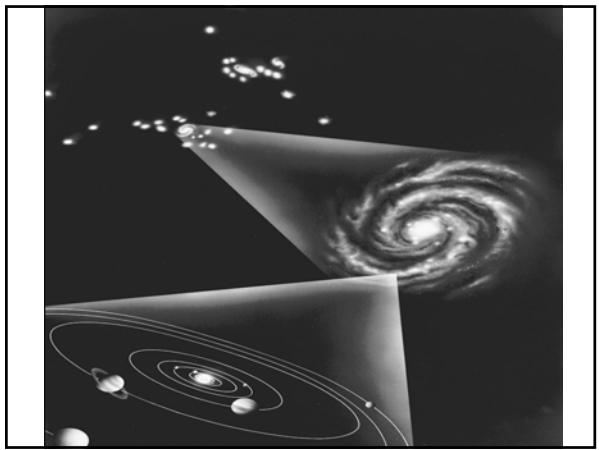
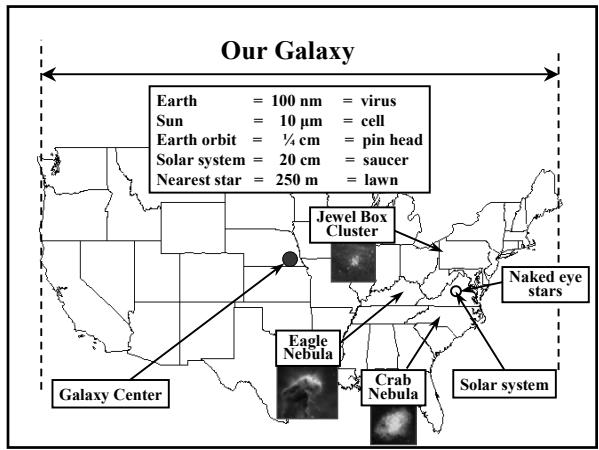
Slow death of low mass star

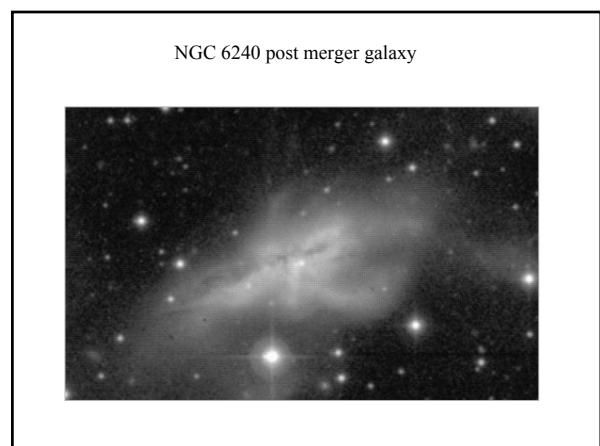
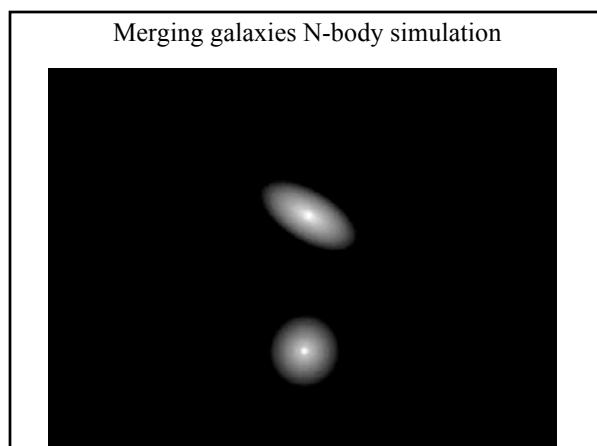
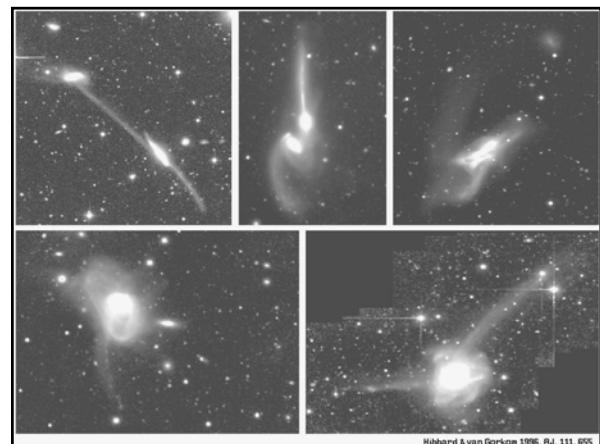
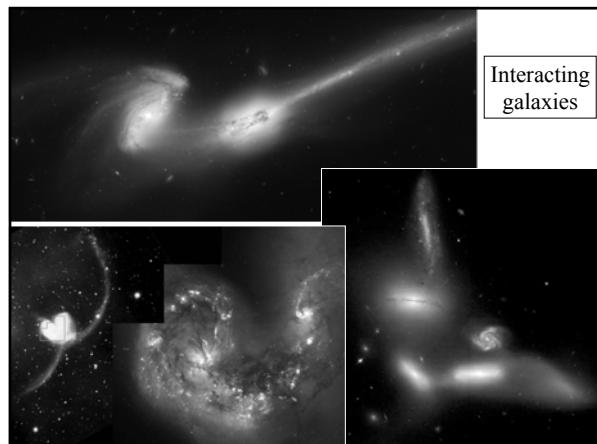


Explosive death of high mass star





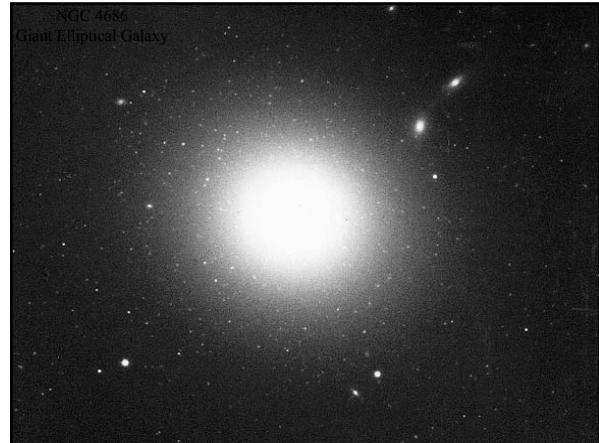




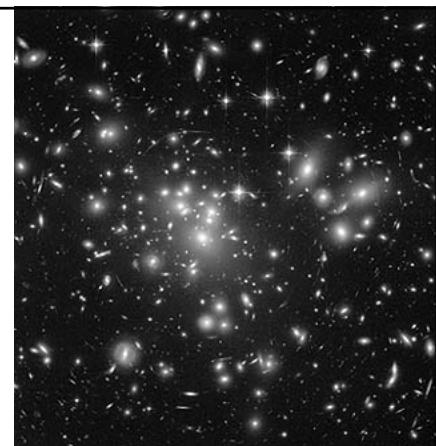
Merging group of galaxies



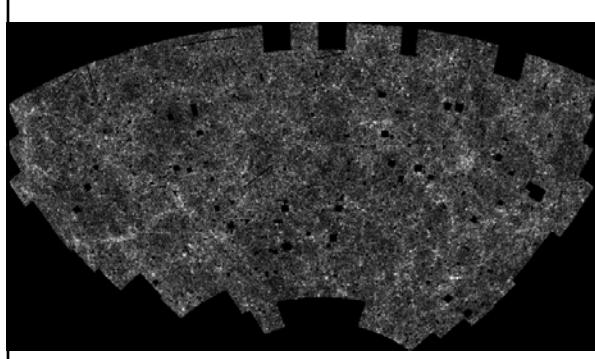
NGC 4686
Giant Elliptical Galaxy



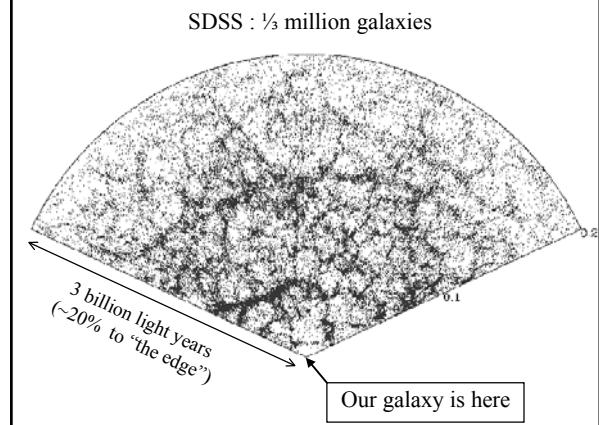
A 1689
Rich galaxy cluster
2 Gly distant
Gravitational lens

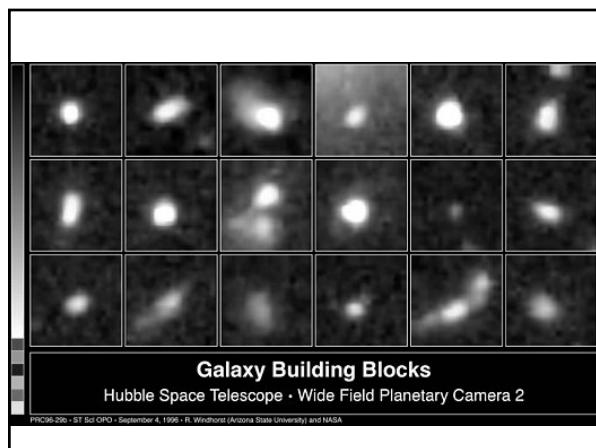
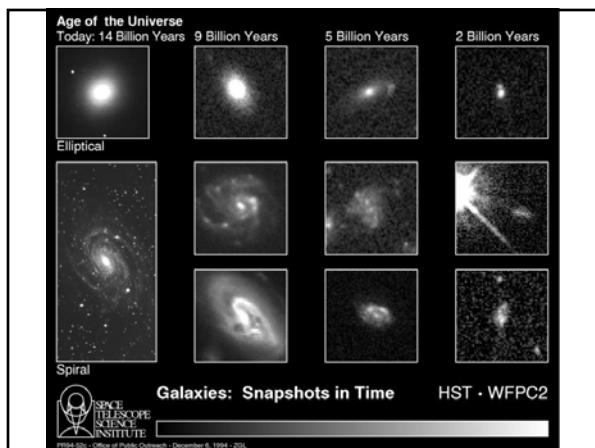
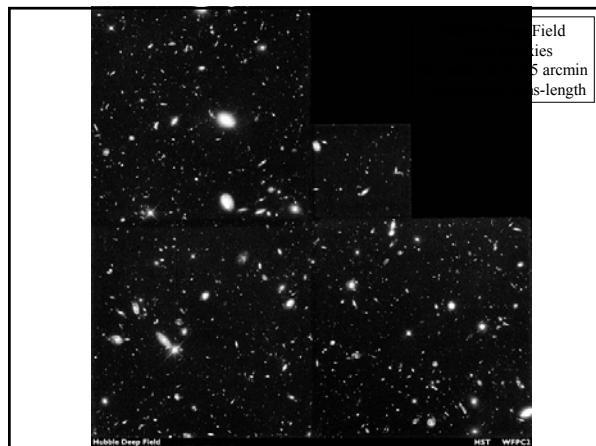
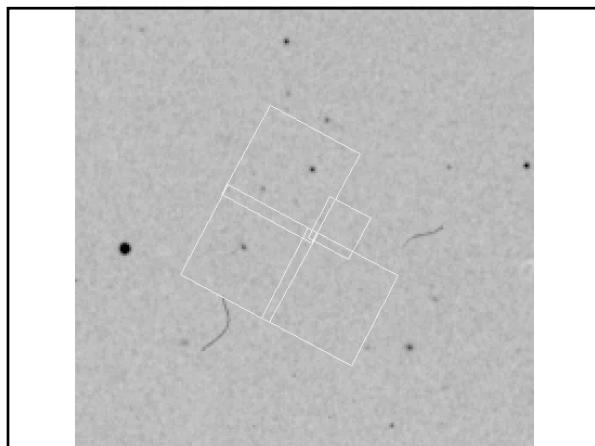
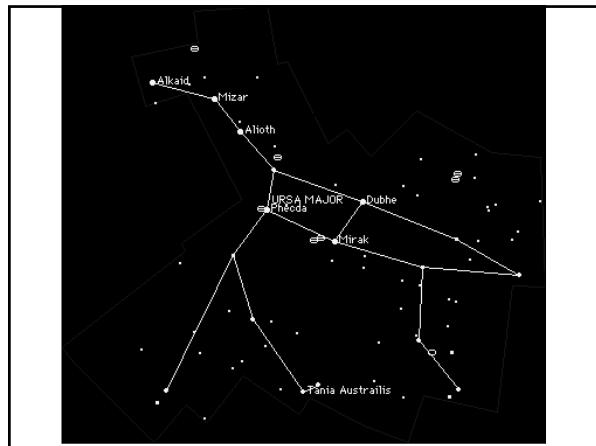
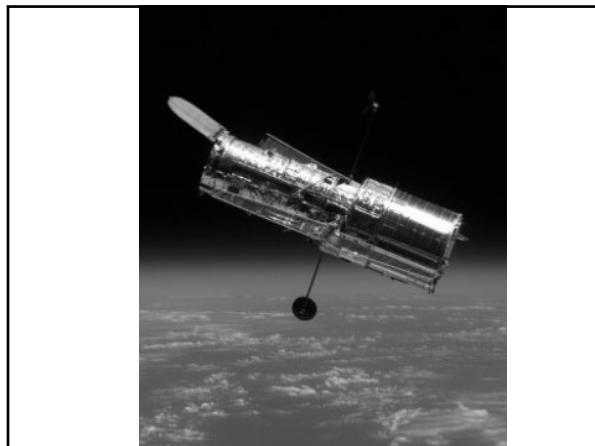


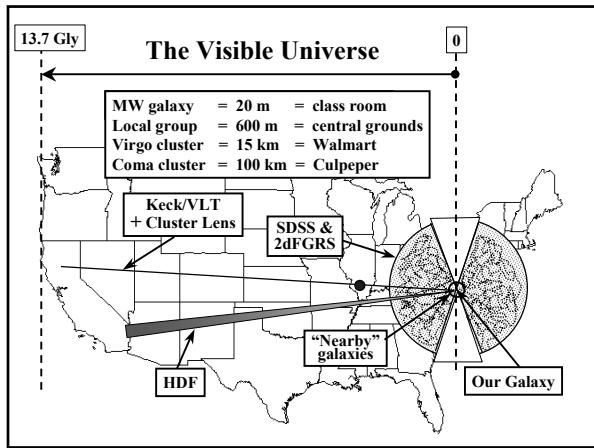
1 million galaxies
(stars removed, ~120 degrees of sky)



SDSS : $\frac{1}{3}$ million galaxies







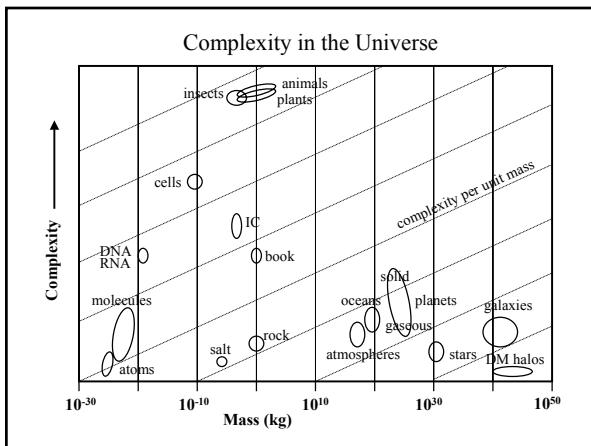
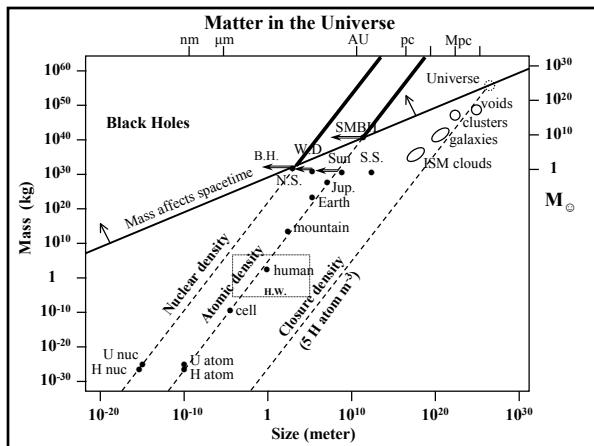
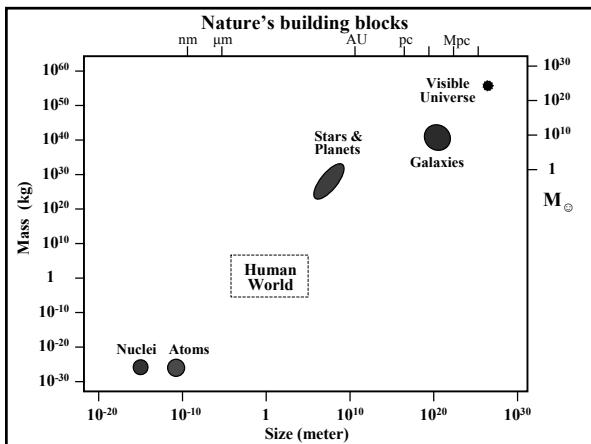
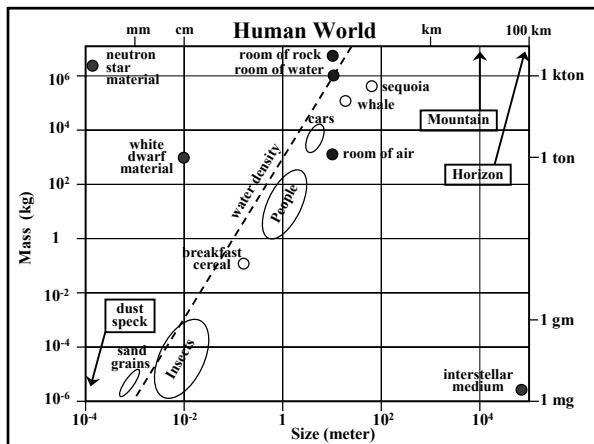
3. Universe as a creative laboratory

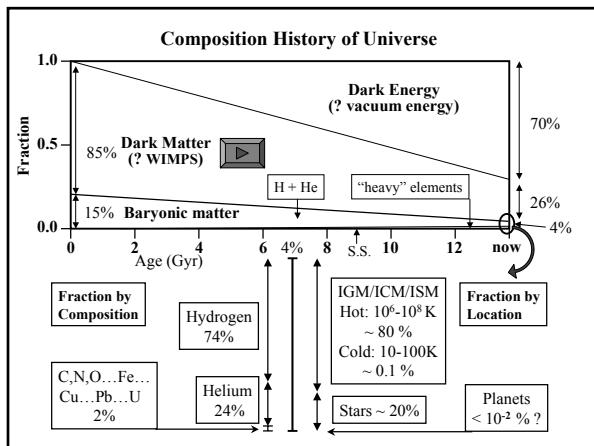
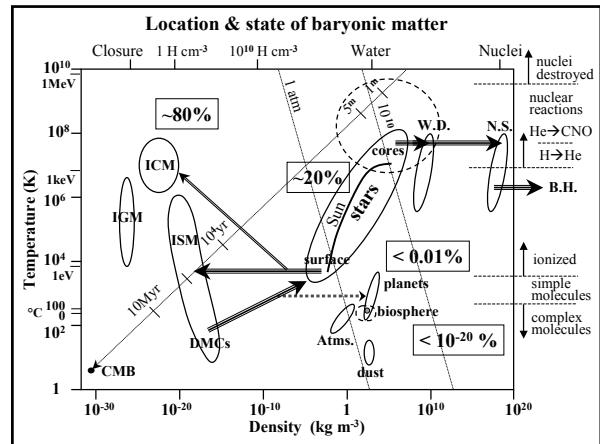
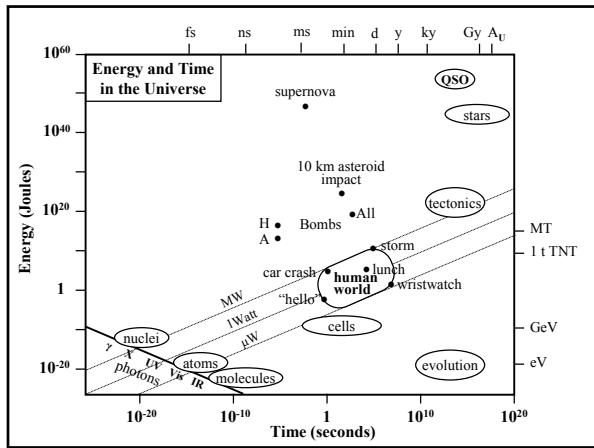
The Universe is a wild and wonderful place !

- it is vast, beyond imagination
- its building blocks are minute, beyond imagination
- Almost all of it is:
 - hotter or colder
 - denser or more rarified
 - more powerful or more delicate
 - evolves faster or more slowly
} than we can possibly imagine

Within such extremes, the Universe is highly creative

Lets try to locate our world amongst these properties, and identify where creativity arises, and why.....



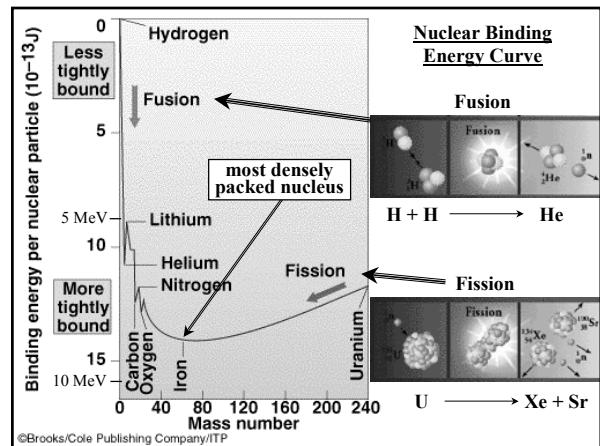
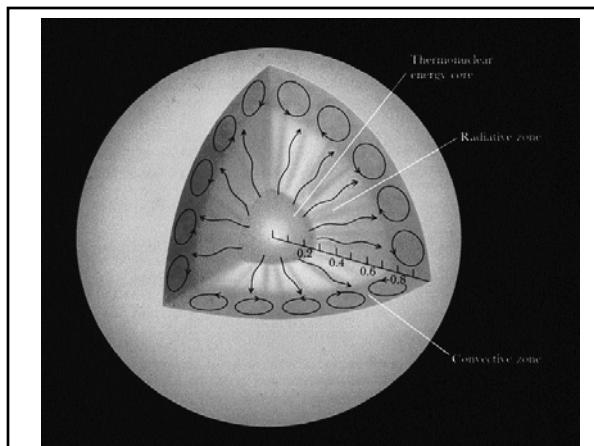


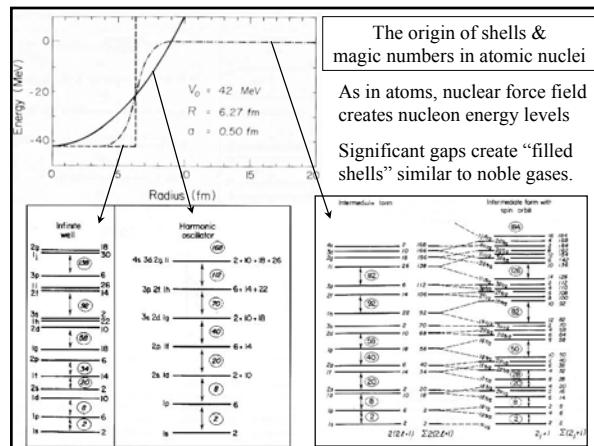
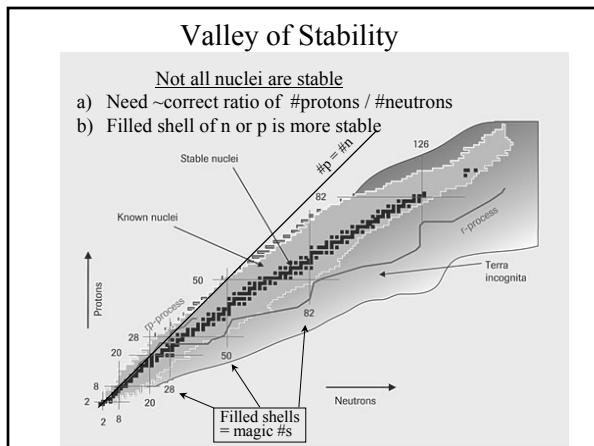
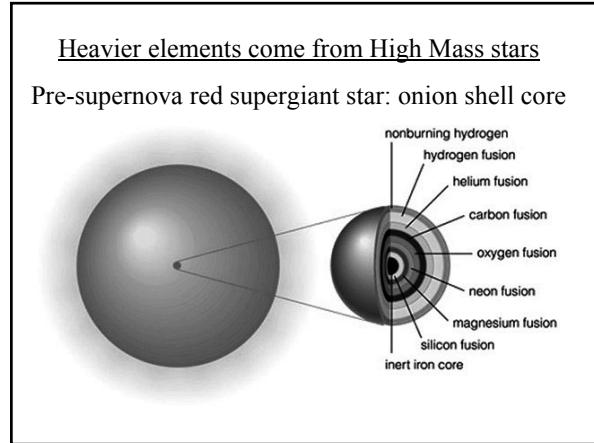
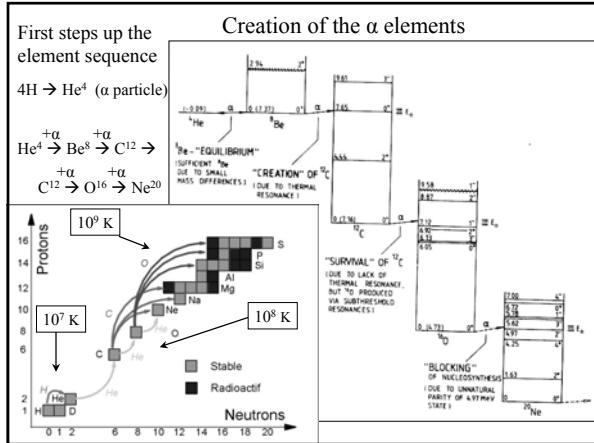
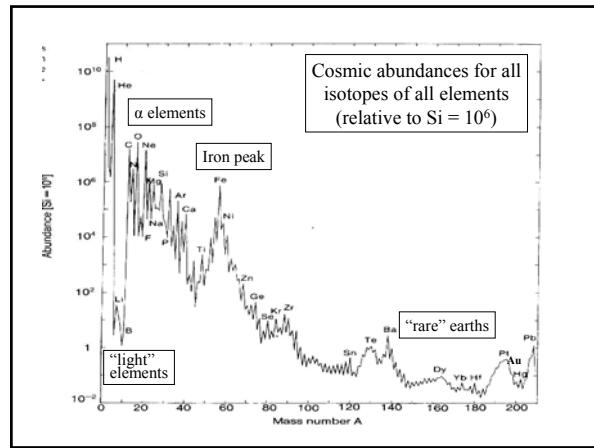
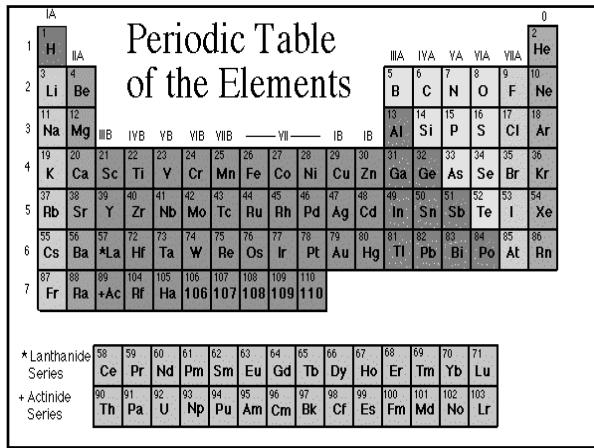
4. Creation of elements & particles

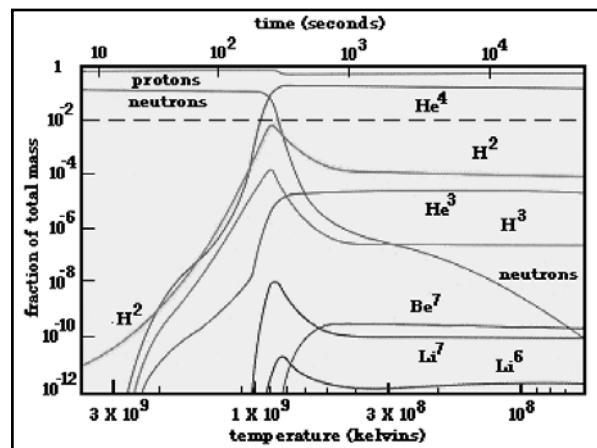
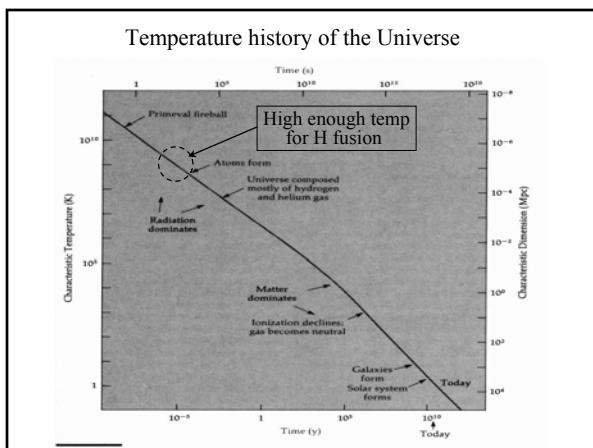
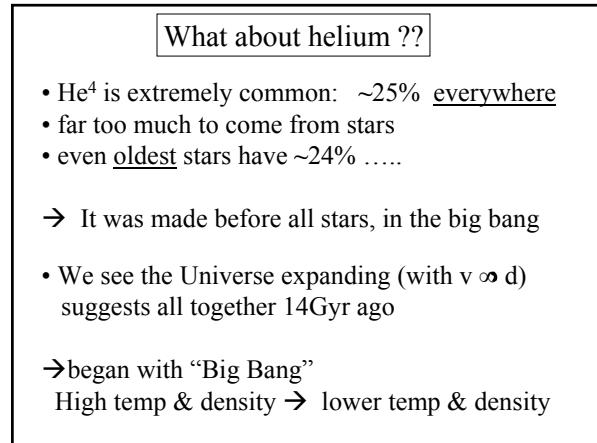
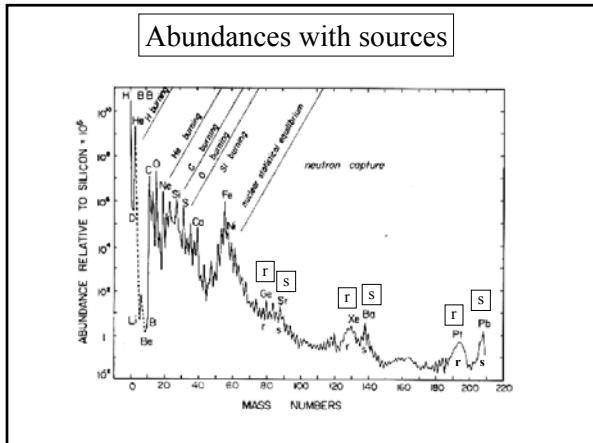
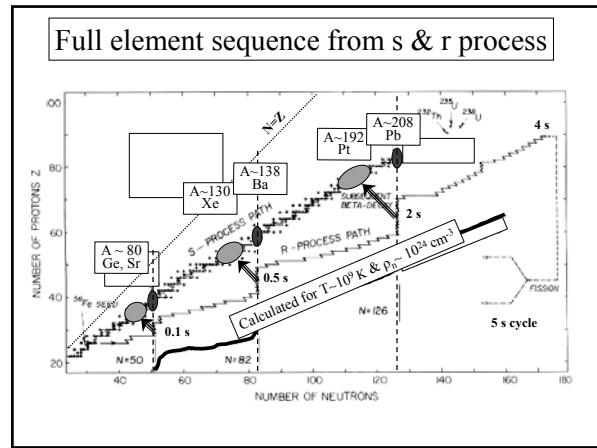
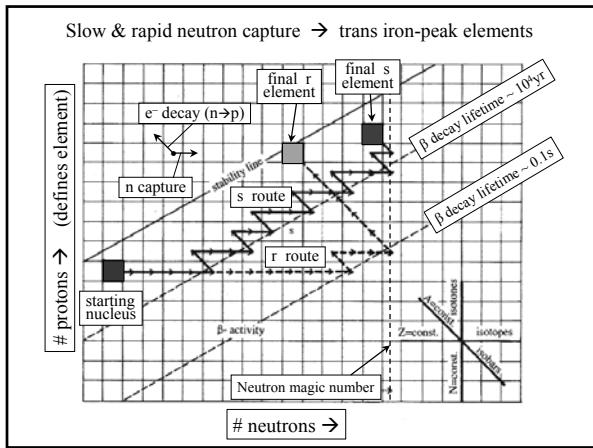
We must go inside stars and back to the Big bang.

We consider the creation of three things:

- 1) heavy elements (nuclei) in stars
- 2) helium in the Big Bang (1-5 mins).
- 3) protons/electrons in the Big Bang (< 1 sec)







What about protons & electrons ??

- were p, n, e^- made at some earlier time ?
- if so, how ?
- what about other particles (μ , ν , $q \dots$) ?
- what about anti-matter, was it also created ?
- must consider energy \leftrightarrow matter interchange
- must visit much earlier times
 - well-known physics: back to $\sim 1\mu s$
 - \sim known physics : back to $\sim 10^{-12}$ sec
 - \sim rough guesses : back to $\sim 10^{-35}$ sec
 - profound ignorance : before $\sim 10^{-43}$ sec

Energy / Matter Interchange

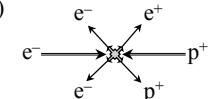
Matter is very concentrated energy : $E = mc^2$
 $1\text{kg} \equiv 10^{17}$ Joules = 100 megatons (big H bomb)

Examples of matter into energy:

In general: particle + anti-particle \rightarrow energy
 $e^- + e^+ \rightarrow 2\gamma$ ($\frac{1}{2}$ MeV photons created)

Examples of energy into matter:

In general: energy \rightarrow particle + anti-particle
 $2\gamma \rightarrow p + \bar{p}$ (need >1 GeV γ s)
KE can also create matter:
(need KE $> 2m_e c^2$
= threshold energy)



Energy / Matter Interchange

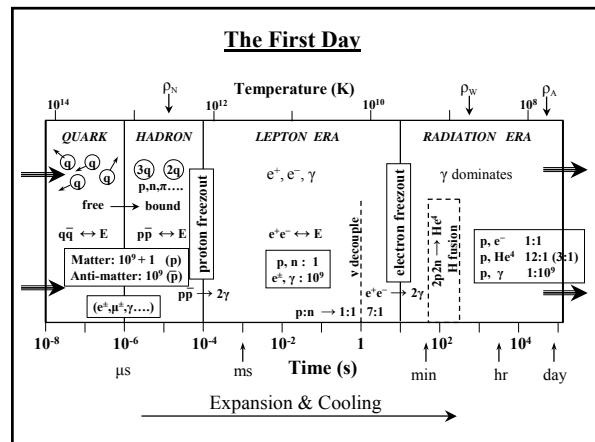
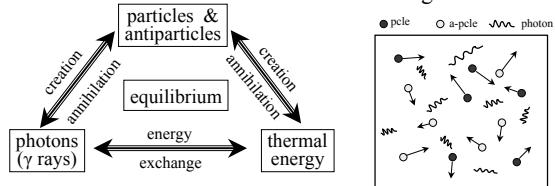
Consider extremes of temperature:

temperature = KE / particle ($E_{\text{pce}} = k \times T$)

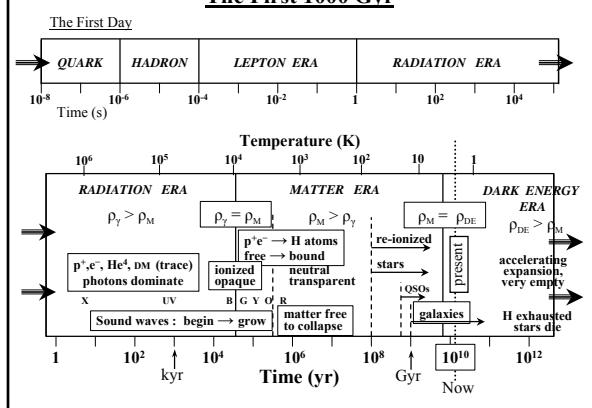
what happens when $E_{\text{pce}} >$ threshold energy ?

eg: 6×10^9 K (electron); 1.1×10^{13} K (proton)

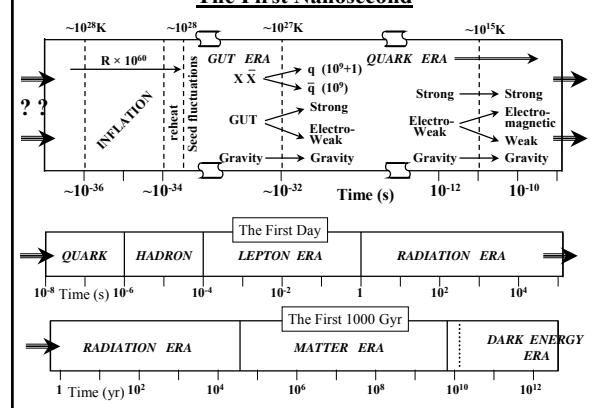
- matter/anti-matter created out of thermal energy
- new matter arises in the midst of existing matter



The First 1000 Gyr



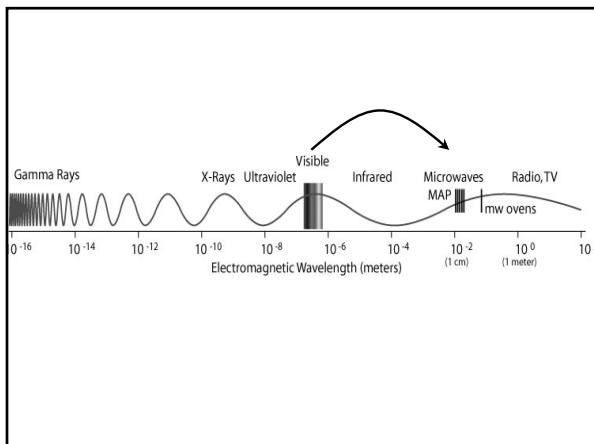
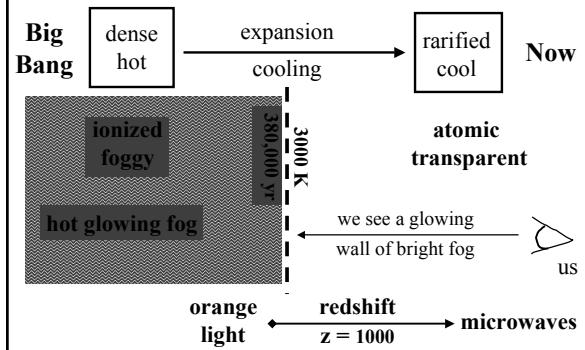
The First Nanosecond



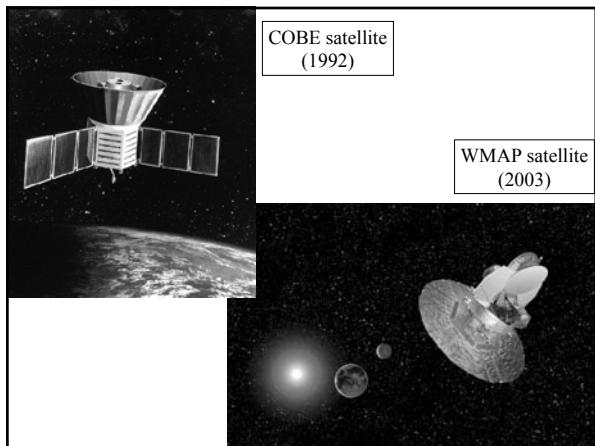
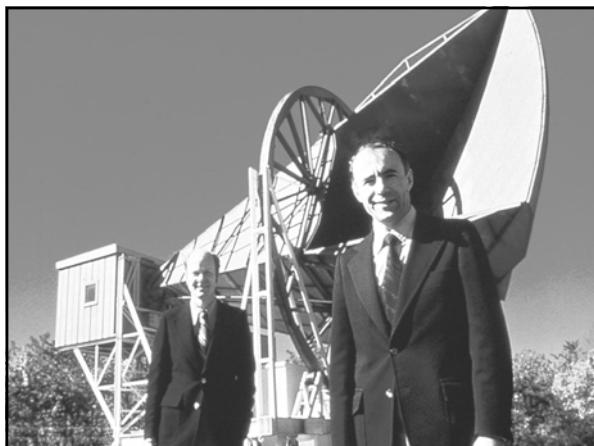
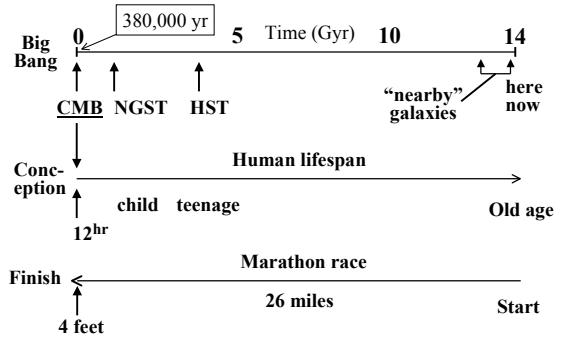
5. Origin of cosmic structures

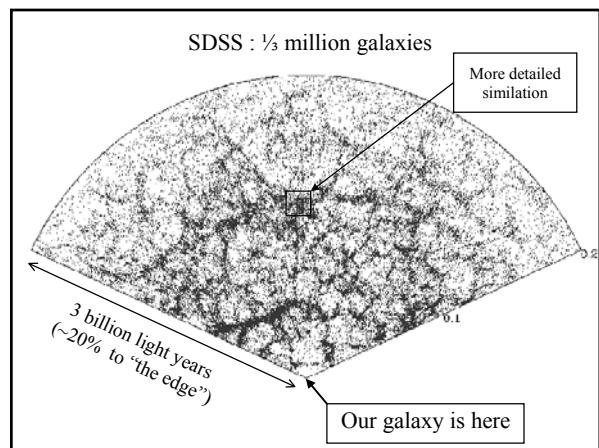
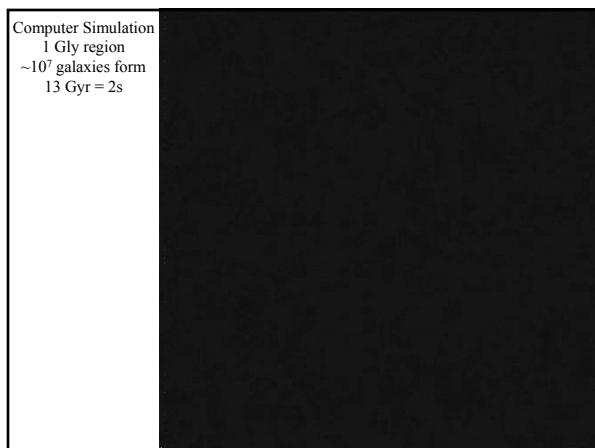
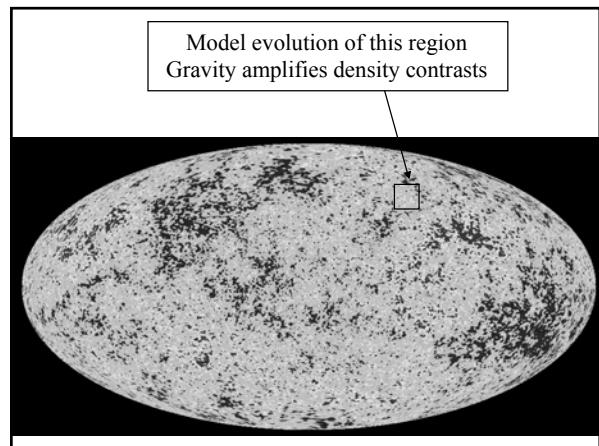
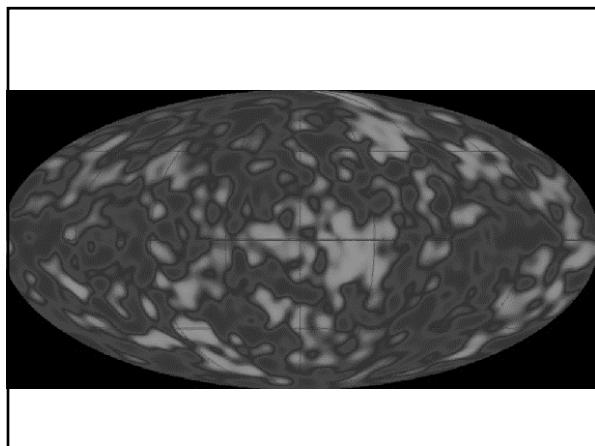
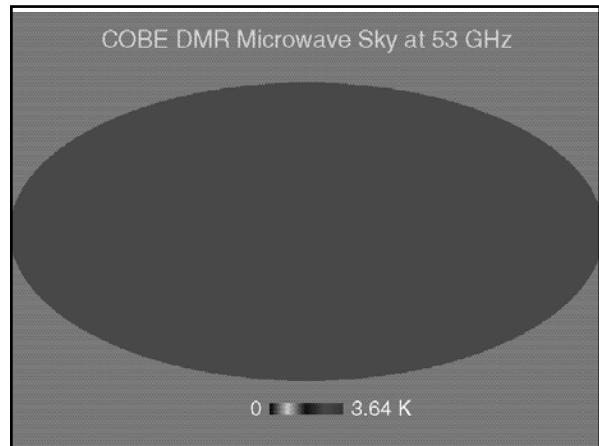
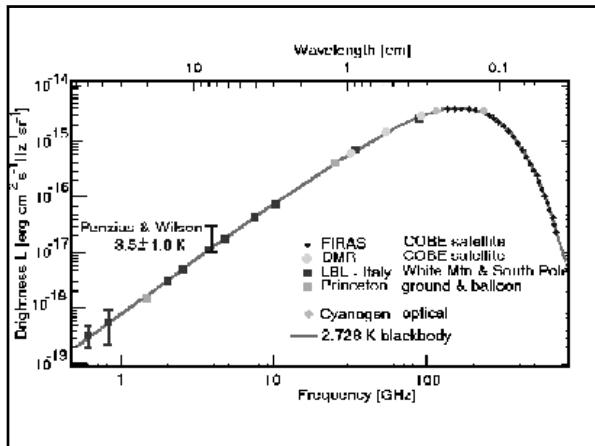
- Today's Universe is extremely lumpy
 - clusters, galaxies, stars, planets, people.....
 - with very very little in between
- But, the Universe started out smooth
- How did the structure arise ?
 - there must be initial variation/ripples
 - which are amplified (by gravity?)
- Observe the early Universe by looking far away
 → the Cosmic Microwave Background (CMB)

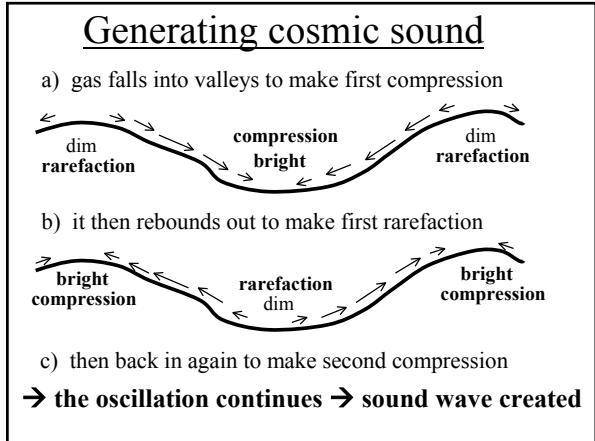
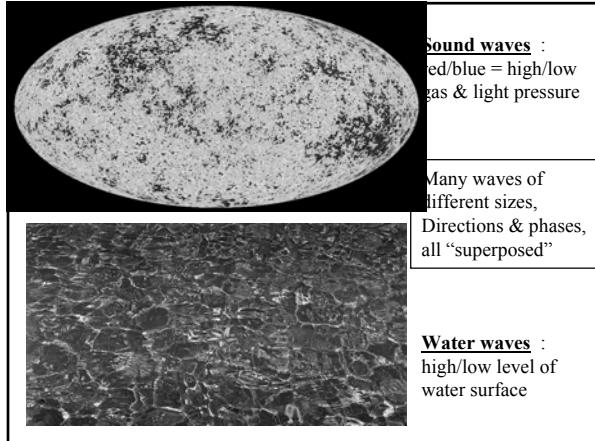
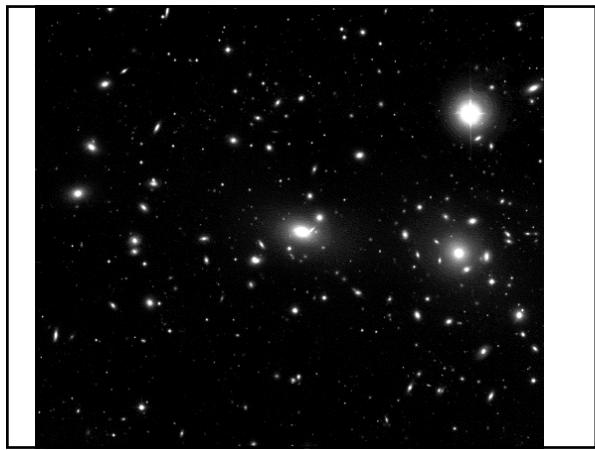
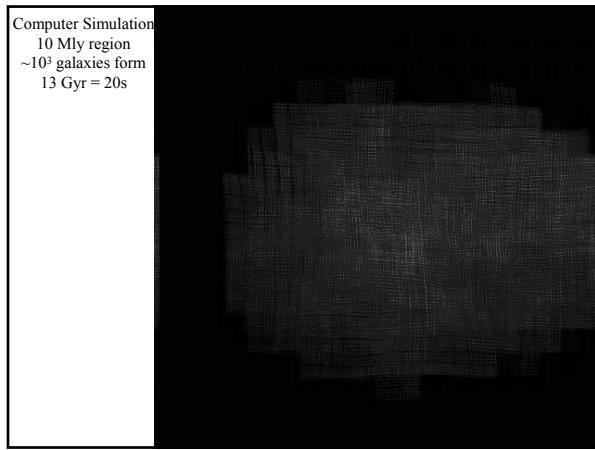
The Microwave Background



CMB is Young and Far

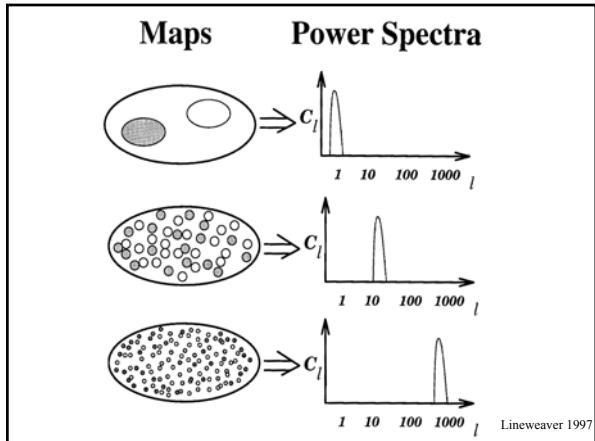


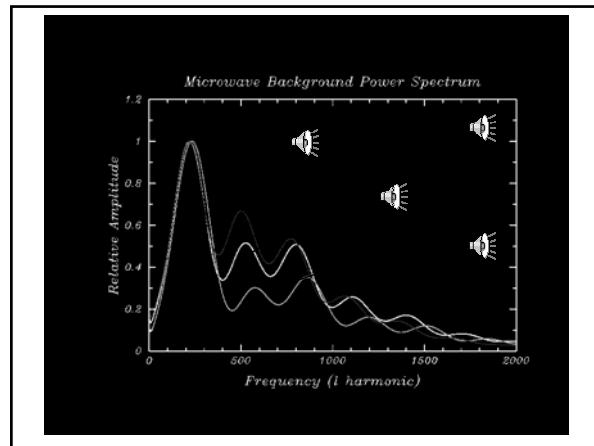
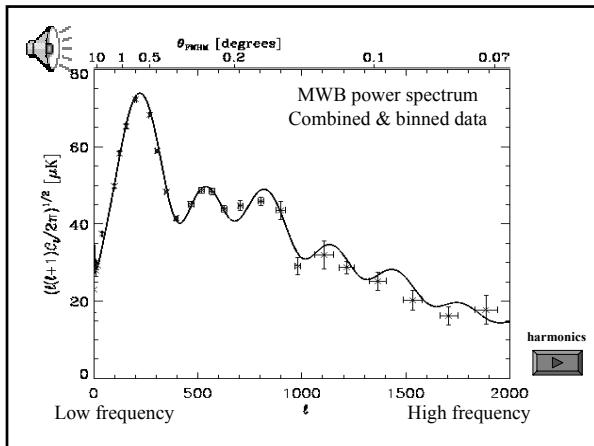




Nature of Cosmic Sound

- 1. Volume :**
pressure variations $\sim 1/100,000$
corresponds to about 90 dB
→ Loud but not cacophonous
- 2. Pitch :**
measured wavelengths $20,000 - 200,000$ lyr
pitch $10^{-12} - 10^{-13}$ Hz ($v \sim 0.6c$)
→ 48 – 52 octaves below concert A (440 Hz)
- 3. Quality :**
need to construct the “power spectrum”





Properties from the CMB

• Age of Universe	13.7 Byr	(2%)
• Flatness	1.02	(2%)
• Atoms	4.4%	(9%)
• Dark matter	23%	(15%)
• Dark energy	73%	(5%)
• Hubble constant (km/s/Mpc)	71	(6%)
• Photon/proton ratio	1.6x10 ⁹	(5%)
• Time of first stars	180 Myr	(50%)
• Time of CMB	380,000yr	(2%)

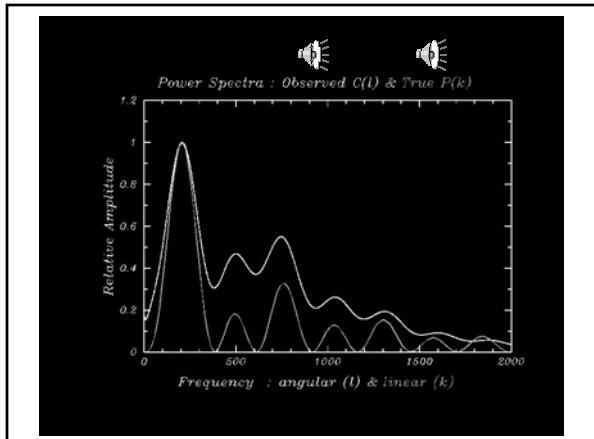
The cosmic concert hall

The universe is **not** a perfect concert hall
There is distortion en-route and local noise.

Similar to carpet+drapes in a concert hall
plus a noisy audience adding distractions.

Correct for these problems using detailed
computer calculations of the early Universe.

Observed : $C(l)$ → Pure : $P(k)$



Into the fog : yet earlier times

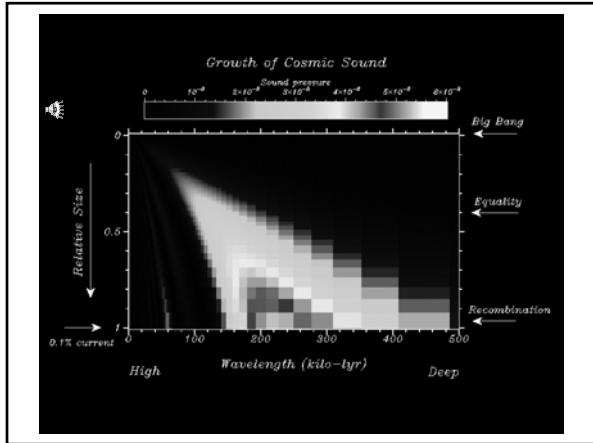
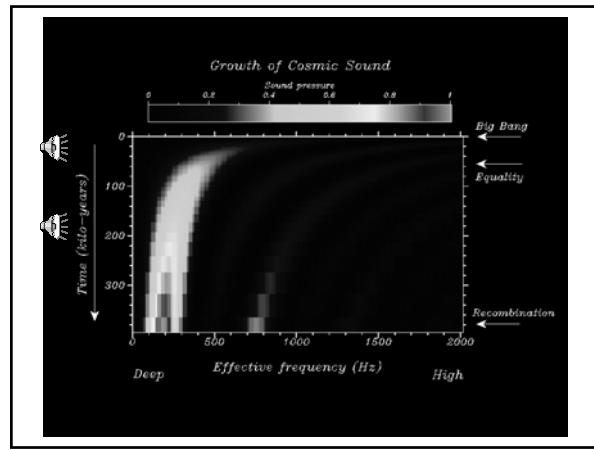
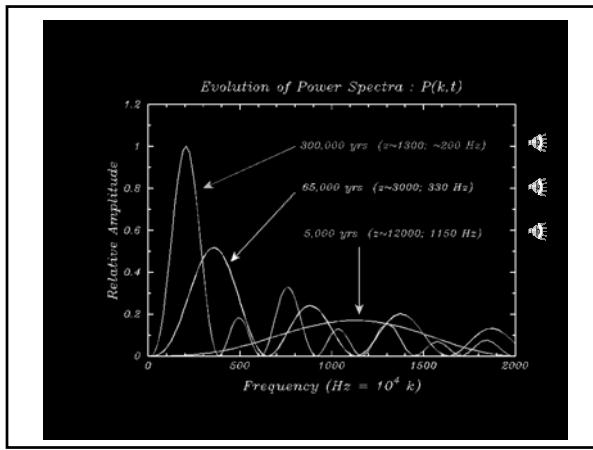
The CMB shows the sound at 380,000 yrs
What was the sound like **before** then ?

We can't see beyond the CMB foggy wall !
But computer models can take us there

Earlier times :

- Gas only had time to fall into **smaller** “valleys”
- Wavelengths are shorter, **frequencies higher**
- Amplitudes lower, sound is **quieter**

Examples :



The first sound : striking the bell

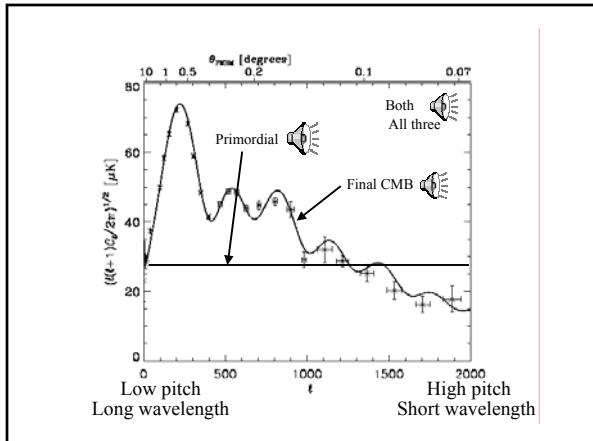
Although gravity amplifies sound, there must be initial irregularities, what caused these ?

Deep mystery, but recent progress :

- Quantum roughness in early universe
- Amplified by $\sim 10^{50}$ during inflation at $\sim 10^{-35}$ sec
- Inaudible quantum hiss made audible by inflation
- All structure in the universe due to quantum effects !

What did the quantum hiss sound like ?

- Its power spectrum is **flat** → “white noise”
- Gravity’s amplifier then distorts the sound to make the final power spectrum with its harmonics



From sound to structure

Gravity amplifies sound into structure, right?

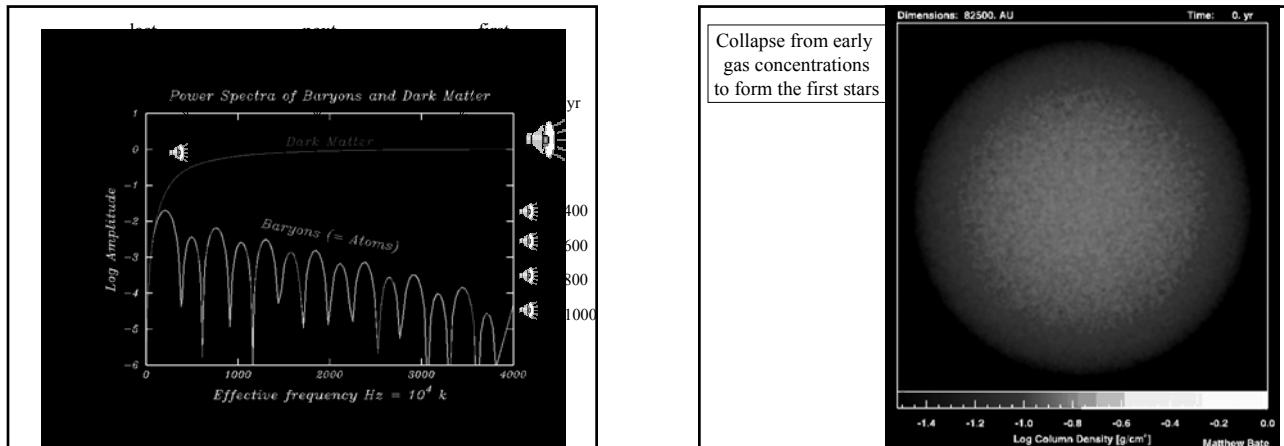
Wrong !! it is too **quiet**

at the CMB, the maximum fluctuations are $\sim 10^{-5}$ at the 1st peak (size $\sim 2 \times 10^5$ lyr), all others are weaker. This is too small to grow quickly into stars & galaxies.

- We need something else with greater variation ??

Dark matter comes to the rescue

- it feels no pressure
- it keeps collapsing from early times (no rebound)
- At CMB, fluctuations are large ($\sim 10^{-2}$)
- P.S. shows no harmonics, power at high frequencies



6. Origin of Energy

- In high school we learn:
 - many types of energy (heat/light/KE/chemical,nuclear..)
 - conversion from one type to another is possible
 - such conversions always conserve energy
 - energy can facilitate transformations: eg
 - sunlight drives/creates the biosphere
 - energy needed to purify and fabricate material things
- Where does all this energy ultimately come from ?

Origin of Energy (ii)

- All energy arises when particles “drop” down the potential associated with one of the four forces
- Examples:
 - chemical energy: electrons closer to nucleus
 - nuclear energy: protons/neutrons packed tighter
 - gravitational energy: released when objects fall
- Sometimes need one to enable another
eg : starlight (sunshine)
collapsing star (gravity) heats core (particle KE)
enabling protons to overcome repulsion and combine,
dropping down the (short range) nuclear potential

Origin of Energy (iii)

- Ultimately, then, energy arises because things are initially far apart, and then come closer.
- What separated everything initially ?
 - The Big Bang !!
 - specifically, inflation which drove expansion
 - inflation stored energy in all the force fields
 - to be released later, when circumstances allow
- Without fluctuations, gravity could never have begun the process, energy production would have ceased following He⁴ production & recombination



