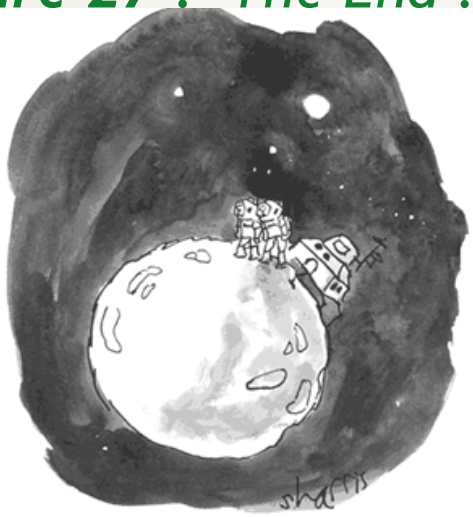
Lecture 27 : The End ?

- Alternatives to Inflation
- Are we here, because we can be here?
- Time
- Final musings



"Another one uninhabited. That's three down and several hundred billion to go."

Reading: Chapter 16-17 of text

FINAL EXAM

- *Friday, 15 May, 8:00-10:00*
- Exam is in this room
- Cumulative, but with emphasis on material after the midterm
- No notes or books allowed
- **Bring calculator**

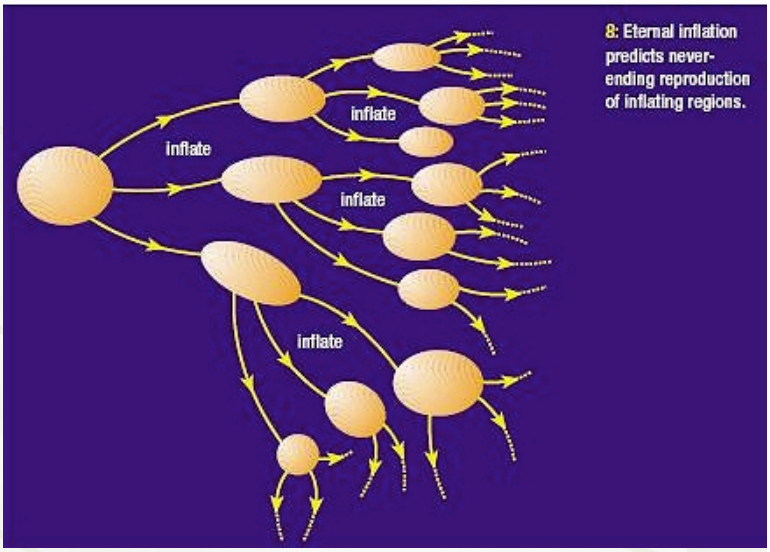
Please fill in your course evaluation!

- www.CourseEvalUM.umd.edu
- **We are at only 9% (4 people!)-**
- What did we do that you liked-disliked
- How can I improve?
- Help your fellow students and me.

Philosophical and scientific rationale for alternatives

- Competition is good for theories; it focuses attention on unresolved problems and flaws
- For some, chaotic inflation is a weasely way to explain things:
  - Inflation has fine-tuned parameters; why are they just right?
  - But *why* did inflation start 13.7 Gyr ago?
  - Is this all just luck in chaotic inflation? The strict anthropic principle* can't be tested (why not?), so can it be part of a *scientific* theory?
- And suddenly dark energy shows up without even a theoretical whisper that it might? This makes for three independent ideas: inflation, "normal" expansion, and dark energy acceleration. No matter how successfully they're stitched together, are these "epicycles?"
- anthropic principle- more later

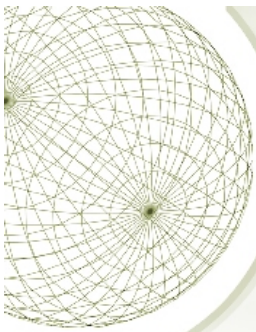
- Beyond the boundary of the little patch of the early universe that inflated to encompass the whole of our visible universe may lie many other such causally linked patches that can all undergo varying amounts of inflation
- http://ned.ipac.caltech.edu/level5/ESSAYS/Barrow/barrow.html



for an interesting discussion of the philosophical issues see http://harpers.org/archive/2011/12/the-accidental-universe/

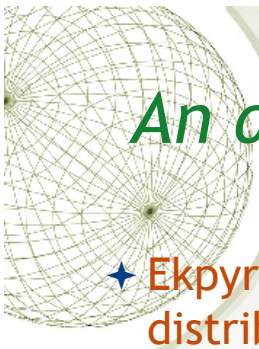
So it's settled?

- Well, no. It shouldn't be – it's science!
- Inflation has its problems
  - does not come 'naturally' out of string theory (which many believe is the basis for a grand unified theory)
  - No one knows what did the inflating. Theorists describe the 'force' as a field and give it a name — the inflaton — but the mystery remains. It is the same frustration as dark energy
  - Its not clear how to stop it !
  - Inflation is not a theory of how it all began, but a theory of how it all began just after the beginning.. a morning-after theory.
  - In eternal inflation an infinite number of bubbles form with an infinite variety of properties. Everything that can happen does happen in some bubble. *A theory that predicts everything cn happen predicts nothing.*



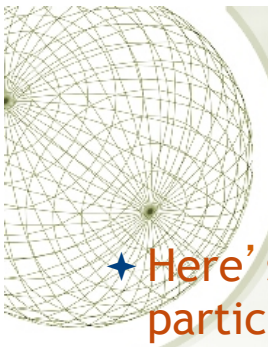
Dream: Use cosmology to constrain string theory

– given the energy scales,string theory will be studied first with early- universe measurements (and not with a particle-physics TeV experiment).



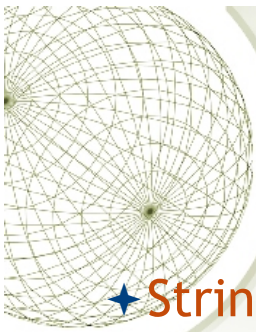
An alternative: the ekpyrotic proposal

- Ekpyrotic: the universe is created in a distributed and sudden burst of high but finite temperature-collision of 2 'branes'
- Ekpyrotic universes can be cyclical, helping solve the “why just then?” problem.
- This proposal uses superstring theory; here the Universe appears to be four dimensional, but the four are embedded in a larger 5-9 dimensional spacetime (with more dimensions curled up so we can’t easily see them)



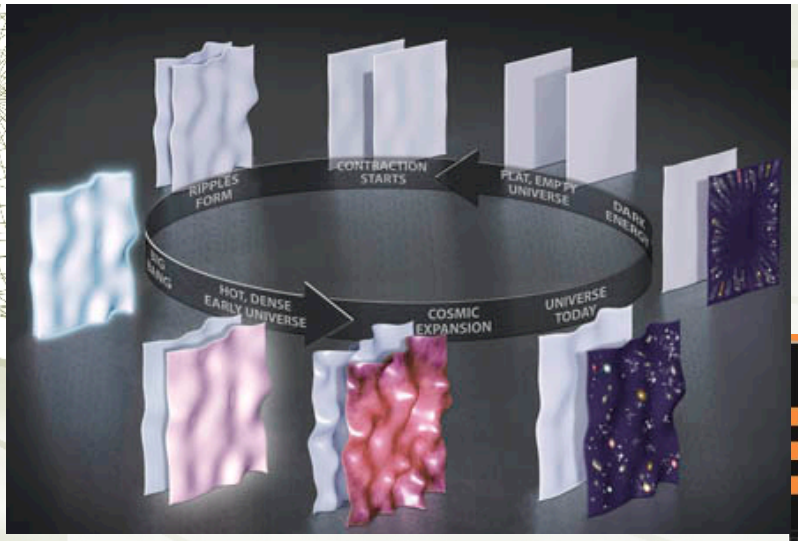
Brane universe

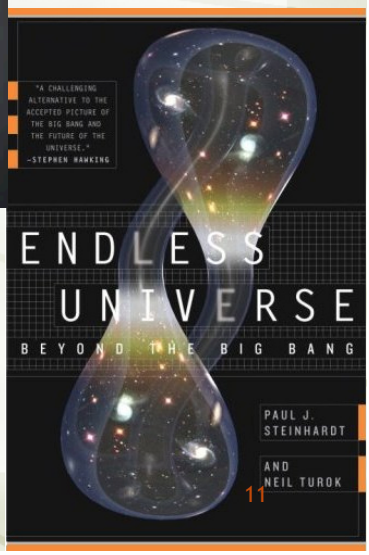
- Here's the idea: the Universe is a brane; particles move in a 3D brane
- They can't cross the extra dimension to neighboring branes; there's a little gap.
- The EM, strong, and weak force are also confined to the brane
- But gravity isn't; it can (weakly) couple neighboring branes



Strings and branes

- Strings are long and skinny, and particles are manifestations of string vibrations
- Branes (think membranes) have more dimensions


RIPPLES FORM
CONTRACTION STARTS
FLAT, EMPTY UNIVERSE
DARK ENERGY
BIG BANG
HOT, DENSE EARLY UNIVERSE
COSMIC EXPANSION
UNIVERSE TODAY


"A CHALLENGING ALTERNATIVE TO THE ACCEPTED PICTURE OF THE BIG BANG AND THE FUTURE OF THE UNIVERSE."
–STEPHEN HAWKING
ENDLESS UNIVERSE
BEYOND THE BIG BANG
PAUL J. STEINHARDT
AND
NEIL TUROK

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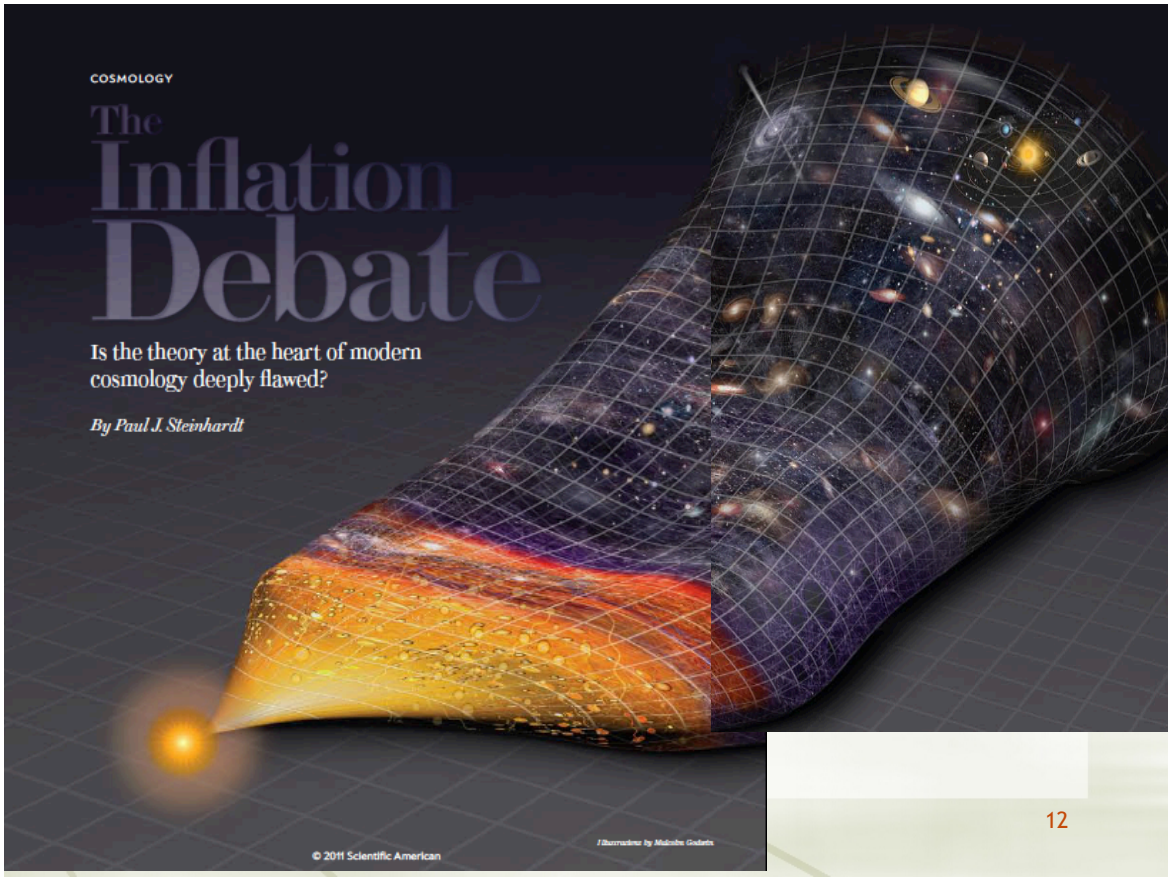
COSMOLOGY
The Inflation Debate
Is the theory at the heart of modern cosmology deeply flawed?
By Paul J. Steinhardt
© 2011 Scientific American

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So what's ekpyrotic about this?*

- Replace inflation by something quite different: the face-face collision of two neighboring branes.
- Dark energy stretches the branes ultra-flat before collision, but quantum fluctuations leave little wrinkles that later turn into structure (e.g. galaxies).
- The collision releases energy nearly simultaneously throughout the universe (ekpyrosis*!), and the branes bounce apart.
- Then the usual expansion of spacetime, temperature evolution, nucleosynthesis etc. runs on afterwards.
- the branes can collide cyclically.

*a Stoic belief in the periodic destruction of the cosmos by a great conflagration every Great Year. The cosmos is then recreated (palingenesis) only to be destroyed again at the end of the new cycle.

http://wwwphy.princeton.edu/~steinh/npr/

Features of this explanation

- Produces a homogeneous, isotropic, and flat universe without relic problems
- One story for the whole time development of the universe, includes dark energy
- Cyclical models allow many (maybe infinite) recurring "big bangs," answering the "why then, and just once?" question
- Dark matter could be the usual particles on nearby branes (or, just as well, dark matter particles in our brane)
- In cyclical models, can solve some entropy problems

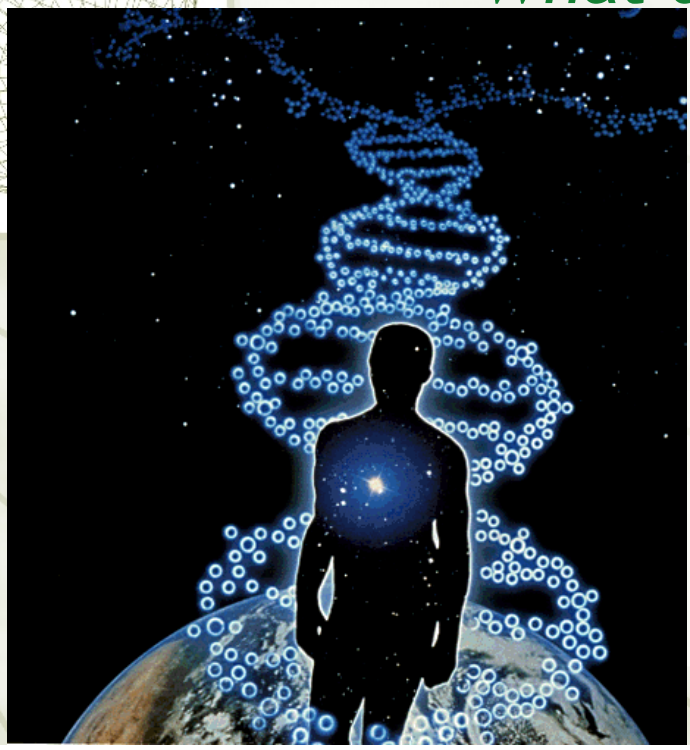
Cyclic Model

- The Cyclic Model was developed based on the three intuitive notions:
  - the big bang is not a beginning of time, but rather a transition to an earlier phase of evolution;
  - the evolution of the universe is cyclic;
  - the key events that shaped the large scale structure of the universe occurred during a phase of slow contraction before the bang, rather than a period of rapid expansion (inflation) after the bang.
- the cycles are tightly interlinked. The events that occurred a cycle ago shape our universe today, and the events occurring today will shape our universe a cycle from now.
- *It is this aspect that transforms the metaphysical notion of cycles into a* ***scientifically*** *testable concept- there are signatures in the CMB of the previous cycle (!) -being looked for*

Why are Things the Way that they are

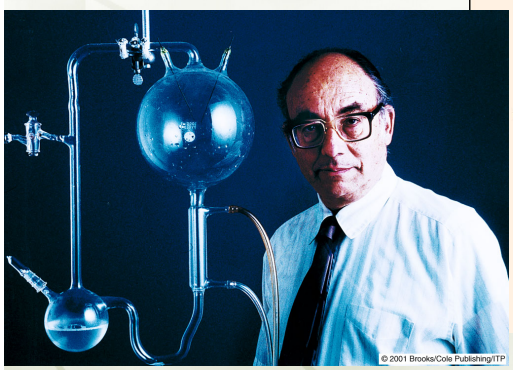
- By our very existence, we impose a sort of selection effect on the Universe. For example, in a Universe where just one of the fundamental constants that govern nature was changed - say, the strength of gravity - we cannot exist !
- Weak Anthropic Principle (WAP):
  - the observed values of all physical and cosmological quantities are not equally probable but they take on the values restricted by the requirement that there exist places where carbon-based life *can* evolve and by the requirement that the Universe be old enough for it to have already done so." (The Anthropic Cosmological Principle by John Barrow and Frank Tipler, p. 16)

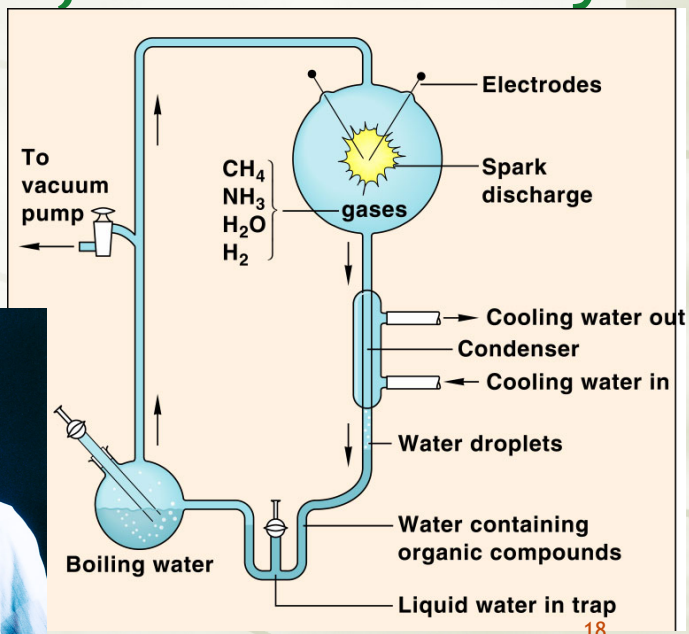
What about life?



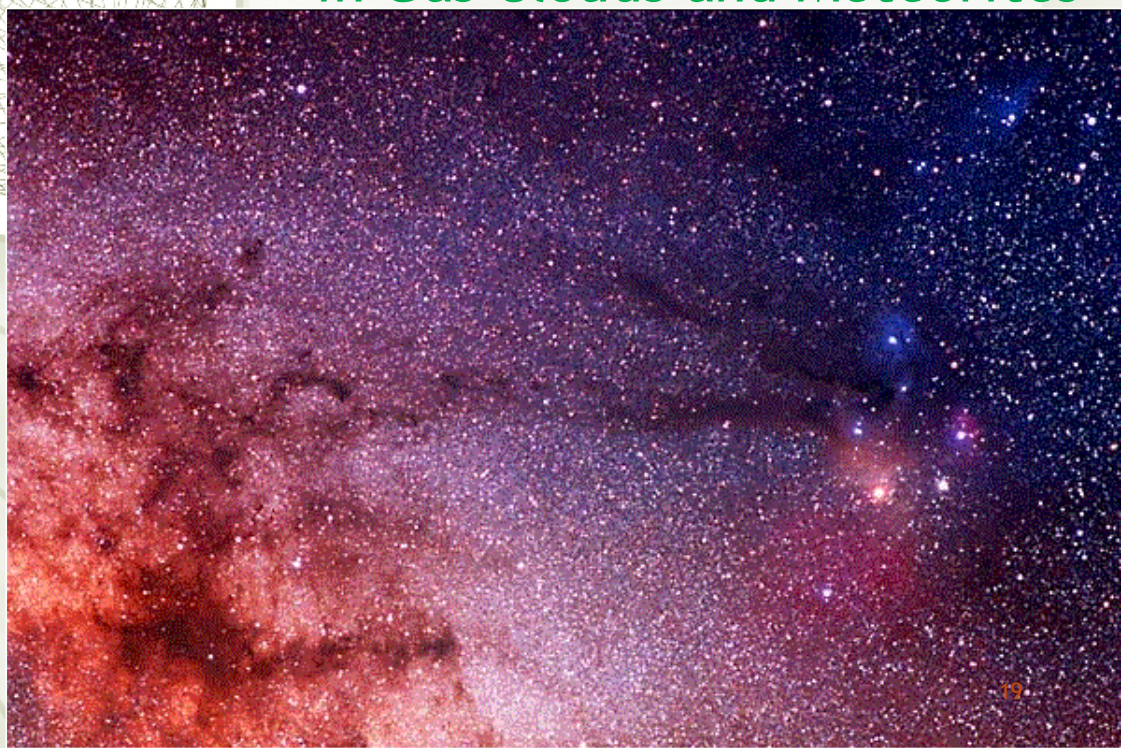
Urey-Miller experiment: amino acids formed naturally

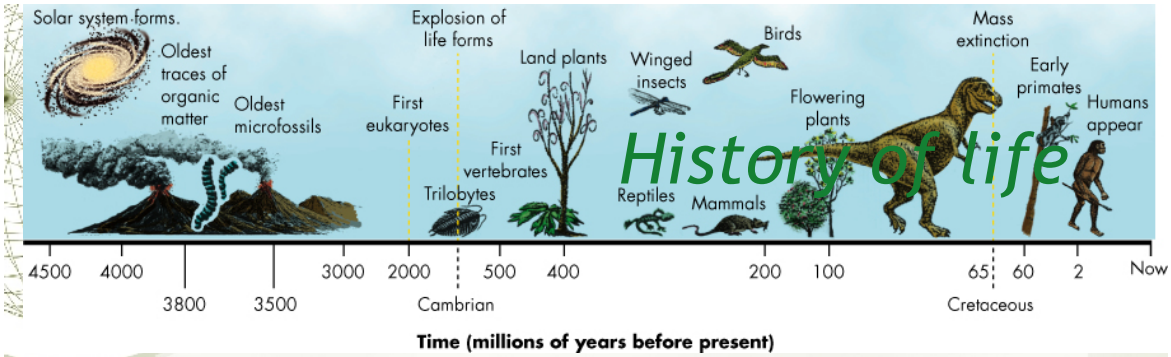
right conditions, in right place at right time





Universe 'Filled' with Organic Molecules in Gas Clouds and Meteorites

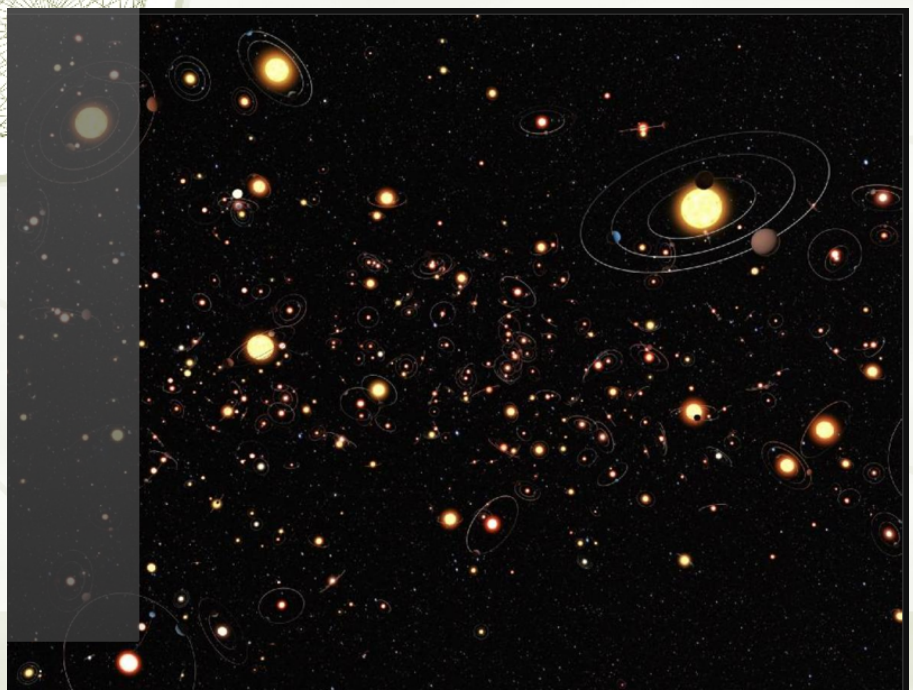




We now know that 'earth like' planets are not rare- Kepler results (The Milky Way's Two Billion Earthlike Planets: Kepler has uncovered 1,094 more potential planets - >3% of all stars have earthlike planets and the average star has one or more bound planets per Milky Way star from microlensing observations http://www.dailygalaxy.com/my_weblog/2011/12/the-milky-ways-two-billion-earthlike-planets-an-update.html)

MILKY WAYS 100 BILLION PLANETS

http://www.huffingtonpost.co.uk/2012/04/30/nasa-photos-of-the-week_n_1463810.html



Life On Earth: How Long it Took to Develop

Stage	Development	Elapsed time [Myr]
1	Microbial life	**<500**
2	Oxygen atmosphere	1000
3	Multicellular life	2000
4	Life on land	100
5	Animal intelligence	150
6	Human intelligence	.3-3?

Development of Complex Life

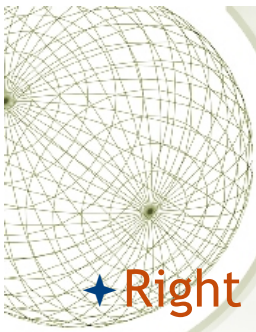
- Took more than 3 BILLION years after development of first microbial life
  - Using Earth as our guide, this suggests development of complex life may require an environment that remains hospitable for billions of years

Complexity

- Making a star is simple: gravity
- Making life has more steps, but not infinitely many more
- But need the right conditions- force of gravity, EM force right size ...

Things that had to be, or we wouldn't be here

- A star with just the right mass
  - Two times larger: its lifetime would be too short
  - Two times smaller: very small habitable zone
- A benevolent Jupiter
  - Shields us from many impacts (extinctions)
  - Bad Jupiters drive interior planets into star



Things that had to be, or we wouldn't be here

- Right place in Galaxy
  - Nearer nucleus, too many supernova, gamma ray bursters, AGN
  - In halo & globular clusters, few heavy elements
- Large Moon
  - Keeps tilt of Earth's axis relatively steady
    - Otherwise widely varying seasons

Things that had to be, or we wouldn't be here

- Planet with the right mass and composition, in "habitable zone"

Can this be coincidence?

- Yes
- Think properly: what is the chance that we find ourselves orbiting the Sun, one star out of 10^{10} in the galaxy, and that's just this galaxy
- Statistics can't be applied to individuals in a simple way!

Things that had to be, or we wouldn't be here

- **The right universe!**
  - Right kind and strengths of the four fundamental forces: Gravity, Electromagnetic, Strong, Weak
  - Favorable values for Ω and Λ

Some of the Necessary Qualities this needed Universe to create US:

- The Universe is "flat" - if more matter had been in the Universe then gravity would have collapsed the Universe before life began - if it had less matter everything would have been too far apart to interact properly to create life.
- The existence of matter - super-symmetry indicates that matter and anti-matter should have been created in equal amounts at the Big Bang - but there was ~1% less anti-matter created so that when matter and anti-matter annihilated each other there was some left to create us.
- If the mass of a neutron was 0.2% heavier, protons would collapse into them so creating no elements.
- The fine structure constant: if it had been slightly higher all early hydrogen would be turned into helium, preventing chemistry
- Carbon would be much rarer were it not for the triple-a nuclear fusion process in stars. If oxygen had a nuclear resonance a little lower, all the carbon would have rapidly changed to oxygen.
- stars were needed to create some of the heavier elements and to then eject it via supernovae to form new stars and planet systems. If the force of gravity and other constants hadn't been just right, no heavy element synthesis would occur.

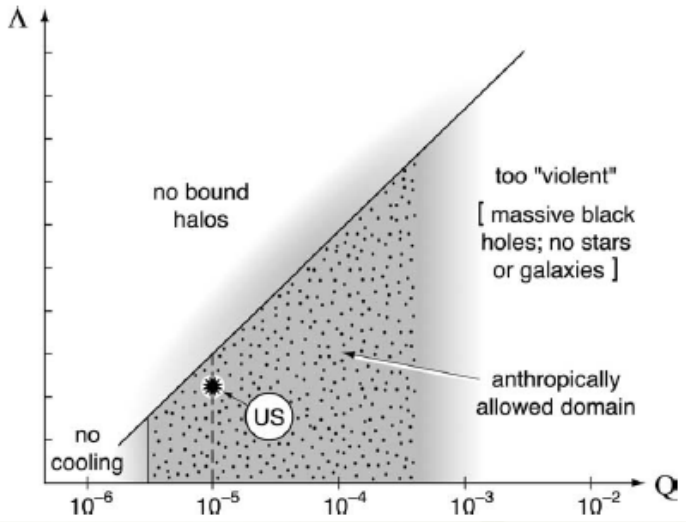
- http://www.hollowsun.co.uk/list-of-anthropic-coincidences-in-the-univers

- The premise of the fine-tuned universe assertion is that a small change in several of the dimensionless fundamental physical constants would make the universe radically different.

- "The laws of science, as we know them at present, contain many fundamental numbers, like the size of the electric charge of the electron and the ratio of the masses of the proton and the electron. ... The remarkable fact is that the values of these numbers seem to have been very finely adjusted to make possible the development of life."- Stephen Hawking

- Martin Rees (Astronomer Royal) formulates the fine-tuning of the universe in terms of the following 5 dimensionless constants :
  - ratio of the strength of electromagnetism to that of gravity
  - strength of the nuclear force
  - relative importance of gravity
  - cosmological constant
  - number of spatial dimensions (!!)
- if any of these differed **even a small bit** from the observed values we would not exist

- Rees 2004



Original lumpiness of universe

Figure 2. This shows in a two-dimensional parameter space Λ and Q. The upper and lower limits to Q are discussed by Tegmark and Rees (1998). The upper limit to Λ stems from the requirement that galactic-mass bound systems should form before the universe enters its accelerating de Sitter phase. Our universe (obviously) lies in the anthropically-allowed domain. But we cannot say whether it is at a typical location within that domain without a specific model for the probability distributions of Q and Λ in the ensemble.

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The Nature of Fundamental Theory-Rees 1993

- do we have a hope that someday physics will derive all the parameters of the universe from first principles

OR

- Will the anthropic concept be required?

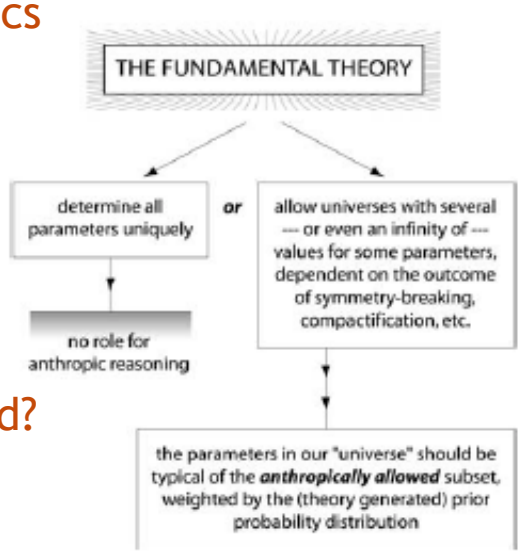
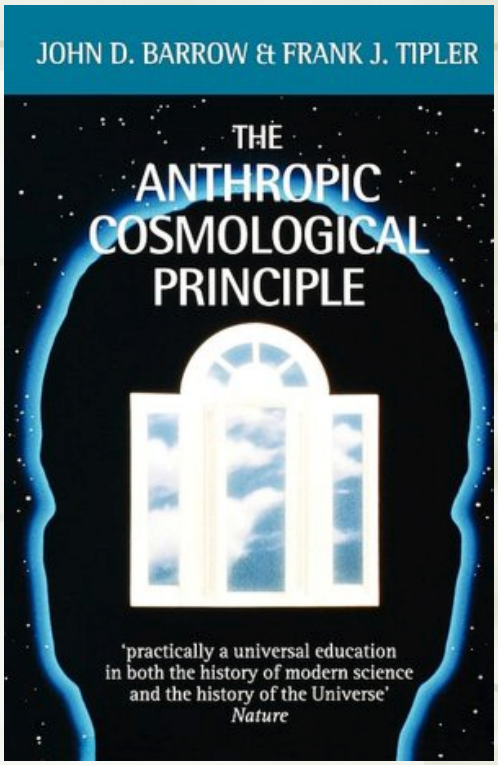


Figure 4. 'Decision tree'. Progress in 21-st century physics should allow us to decide whether anthropic explanations are irrelevant or, on the other hand, the best we can ever hope for.

- Anthropic Cosmological Principle: the existence of intelligent observers determines the fundamental structure of the Universe.
- Beware of the Completely Ridiculous Anthropic Principle e.g. is this simply a elaborate way of saying "if things were different, they would be different,"
- *If it is not testable or falsifiable, it is not a scientific statement but rather a philosophical one.*



So where are we?

- We understand a tremendous amount about the *characteristics* of our universe
  - Flat universe, expands forever.
  - Started with a rapid expansion of space and time.
  - Still expanding, even accelerating.
- For us:
  - We are not at the center of the universe.
  - Ordinary planet, star, galaxy, maybe universe.
  - Space and time depend on our point of view (reference frame).
  - Gravity is a puzzle.

- The topic of this Conference is so engaging and noteworthy, taxing many of humanity's greatest minds, precisely because of its monumental intellectual challenge.
- How can one know the ultimate origin of a thing in which one is irrevocably enmeshed? Is the attempt to grasp the how and why of cosmic origins beyond human capacity, like containing an ocean in a teacup? How have things progressed from the Big Bang (or the Big Bangs if the Multiverse is real) to the exquisite elegance of biospheres—including ourseves?

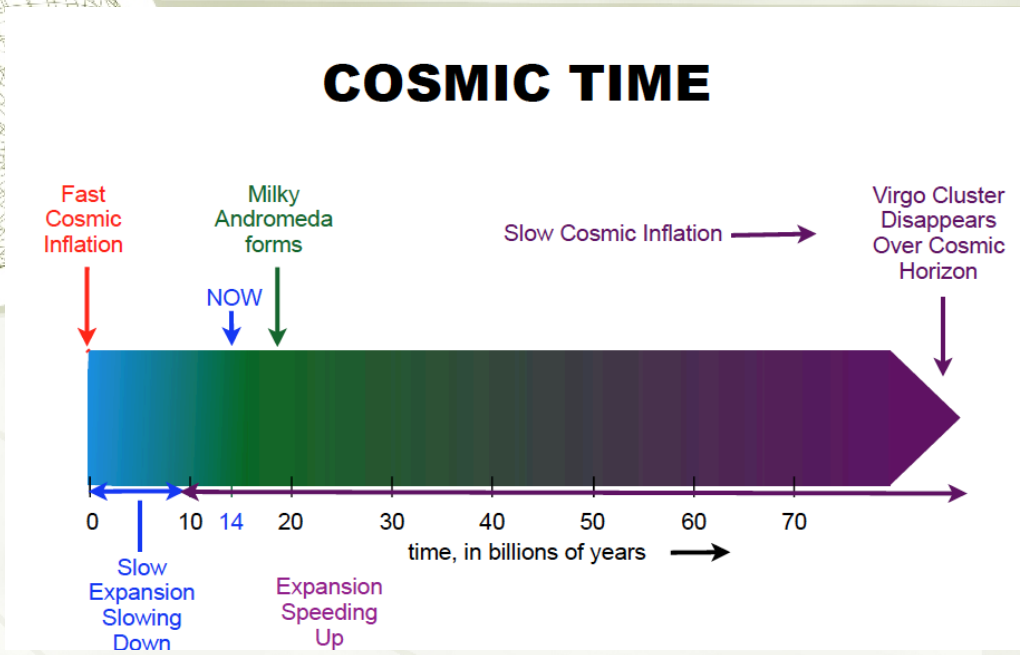
- http://whyisthereanything.org/public-lecture-8-oct

Time

- We live in a 4D universe: three spatial dimensions (*x*, *y*, *z*), and one of time (*t*)
- The four are mingled but space and time are not quite the same
  - Time always increases, but we can move freely in space
  - Distinct in invariant distance:

- *Almost* all Physics is symmetrical in time
- But time is one-way

Chapter 17



J. Primack

Should we even think in time?

- Maybe we should find something more *fundamental* than time to mark the development of the universe.
- What about the scale factor of the universe $R(t)$, or the temperature $T(t)$?
- Universal time, defined as observed from a frame at rest with respect to the universe as a whole, is difficult to deal with when the universe is so small that quantum effects are important.
- Temperature as a record is unambiguous: start at infinite temperature, approach zero temperature in the distant future.

Entropy

- Almost all Physics is reversible in time; entropy is a notable exception.
- Entropy is a measure of how fully a system occupies the states available to it, or of disorder.
- The Second Law of Thermodyamics: the entropy of a closed system never decreases.
- Unless some process is reversible, entropy always increases: a system becomes more "diffuse," occupying an increasing number of states. Disorder increases.
- Relating time to entropy, a concept from thermodynamics, makes sense. So the universe's temperature may be seen as more fundamental than time.

We actually do think of time in terms of entropy

- Organized systems become less organized
  - Life forms die and decompose
  - Pencils break
  - It's funny to watch movies running backwards

The universe's entropy

- A system that is disordered today has been more ordered yesterday
- So the initial conditions on entropy are more interesting than entropy itself: only this way do we see an increase of entropy
- Universe started with very low entropy- how/why
- Why was this? It must have something to do with the universe's quantum mechanical properties during the Planck era. Another reason to understand quantum gravity!

The origin

- Really hot, rapidly expanding ball of energy

The end

- No more stars: cold and dark
- Leftover black holes, cold stellar cores, freezing planets, eternally cryogenically preserved bugs…
- Rapidly-increasing separations of these husks due to ever-increasing acceleration by dark energy

We are Not done yet-Cosmic Coincidences -

- The Universe is balanced on a knife-edge of coincidence. It is apparently a coincidence that gravity and the strong force are as strong as they are, or that the Universe happens to be as old as it is. It is also a coincidence that all of these coincidences of physical constants and other phenomena of the Universe have happened together, making the Universe hospitable for intelligent observers like ourselves.

http://www.physics.sfsu.edu/~lwilliam/sota/anth/coincidence.htm

Its Turtles all the way down...

- Stephen Hawking's 1988 book "A Brief History of Time" begins with the following famous anecdote.

- A well-known scientist gave a public lecture on astronomy. He described how the earth orbits around the sun and how the sun, in turn, orbits around the center of a vast collection of stars called our galaxy. At the end of the lecture, a little old lady at the back of the room got up and said: "What you have told us is rubbish. The world is really a flat plate supported on the back of a giant tortoise." The scientist gave a superior smile before replying, "What is the tortoise standing on?" "You're very clever, young man, very clever," said the old lady. *"But it's turtles all the way down!"*

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So where are we?

- For us:
  - We are not at the center of the universe.
  - Ordinary planet, star, galaxy, maybe universe.
  - Space and time depend on our point of view (reference frame).
- We understand a tremendous amount about the *characteristics* of our universe
  - Flat universe, expands forever.
  - Started with a rapid expansion of space and time, a hot "Big Bang."
  - Still expanding, even accelerating.
  - Gravity is a puzzle.
  - Time itself is a puzzle.
- Conditions of our universe allow life and structure to exist
  - Structure, stars, galaxies
  - Life

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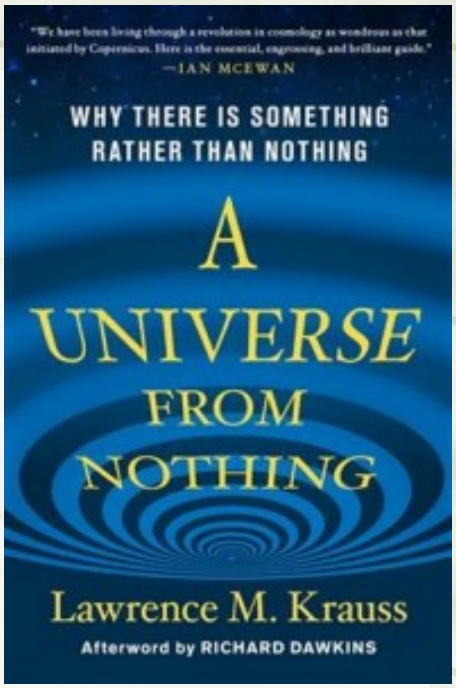
Next

- Review of the Class
- I will attempt to review the entire class and make sense of it



http://blogs.discovermagazine.com/cosmicvariance/2012/04/28/a-universe-from-nothing/