Astronomy 150:

Killer Skies

(Lecture 34):
The End of the Universe

Next Class:
Quasars

HW 11 due on Dec 5th

Exam 3: Dec 8th

Music: Until the End of the World – *U2*

Exam 3

Exam 3 is a little over 1 week away (Dec 8th). How many questions should be on the exam?

a) 25
b) 30
c) 35
d) 40
e) 45

Exam 3

- Exam 3 in this classroom on Dec 8th, regular time
- 40 Multiple choice questions
- Will cover material from Lecture 26 to last day.
- May bring 1 sheet of paper with notes
  - Both sides
  - Printed/handwritten/whatever.. I don't really care
- Major resources are lecture notes, in-class questions, and homeworks
- Created and posted a study guide (new one posted soon)

Online ICES

- Anonymous ICES forms are available online, so far 49/286 (~17%!) students have completed it.
- I **appreciate** you filling them out!
- **Please** make sure to leave **written** comments. I find these comments the most useful, and typically that's where I make the most changes to the course.

Question

Are you going to fill out an ICES form before the deadline of Dec 9th?

a) Yes, I did it already. I'm good.
b) Yes, sometime today
c) Yes, this weekend
d) Yes, I promise to do it before the deadline!
e) No, I don't want help you out (even after all you have done for me and my education) nor do I want to help out the students who will come after me. I prefer stagnation.

Question

What part of class did you like best?

a) Lecture
b) HW
c) Micro-meteorite experiment
d) Asteroid Lab
e) Night Lab

Question

What part of class did you like least?

a) Lecture
b) HW
c) Micro-meteorite experiment
d) Asteroid Lab
e) Night Lab

Question

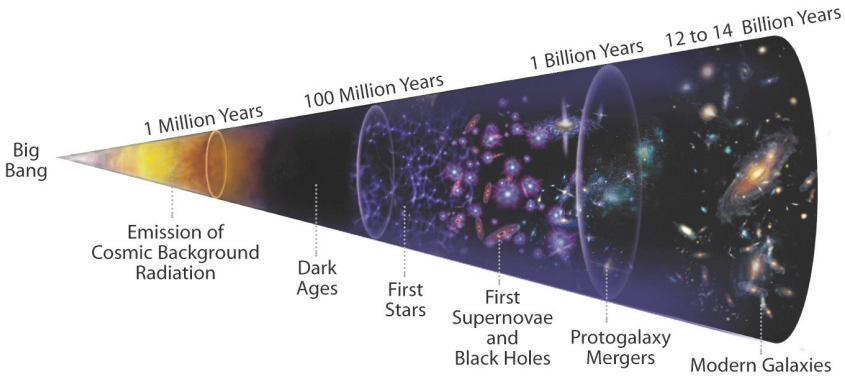
Your Exam grade is worth 58% of your total grade. Because of this, I am thinking about breaking it into 4 parts; 3 parts for Exams 1-3 and the 4th being your highest grade of the three. Should I do this?

a) Yes
b) No
c) I don't care

Outline

- The fate of the Universe
  - Big Crunch
  - Big Chill
  - Big Rip

Looking Back in Time



- After recombination came a period known as the Dark Ages
  - 380,000 to 200 million years
  - No light yet detected from this period
- Matter consists of warm clouds of hydrogen and helium
  - Too hot for star formation to occur
  - Gravity slowing drawing clouds together into bigger and bigger clumps
  - Proto-galaxies

http://www.darkages.com/

The First Stars

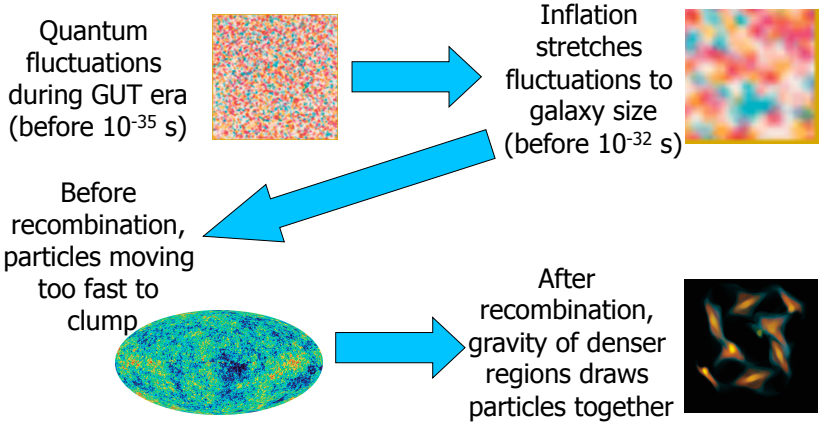
- We think the first stars began to form after about 200 million years after the Big Bang
- Proto-galactic clouds are slowly collapsing – no galaxies yet
- Remember mostly hydrogen gas with very few metals.

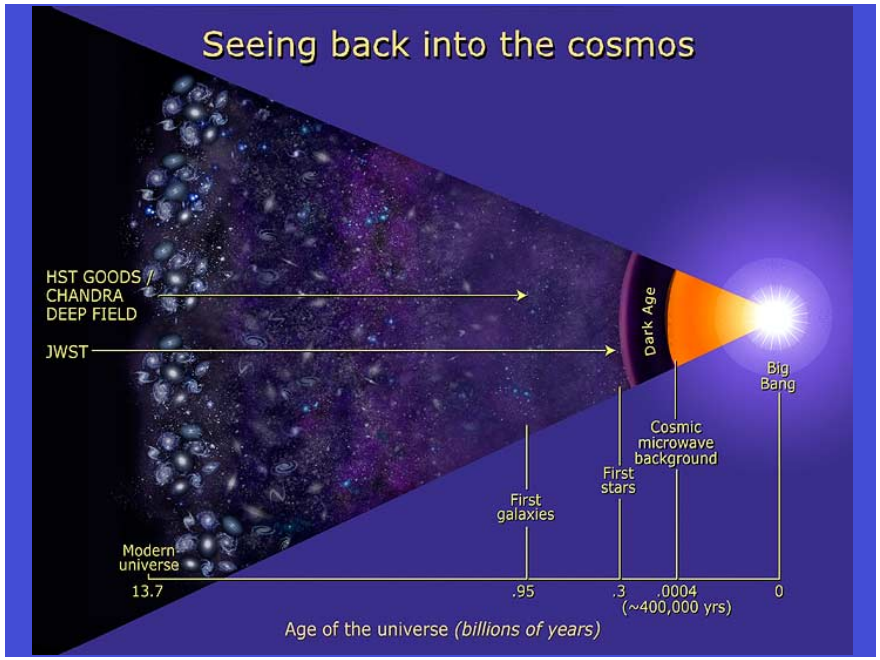
Question

A planet forms around one of the first stars in the Universe, which of the following is the most correct?

a) It will be a rocky planet.
b) It will be mostly made from hydrogen.
c) The life that forms on this planet will be very alien, likely using silicon instead of carbon.
d) It will be a reddish-blue color.
e) It will be made in the outer reaches of the Galaxy.

The Beginnings of Galaxies





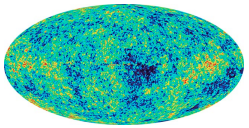
From the Home Office in Urbana, IL

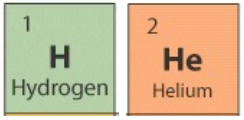
Top 3 Reasons We Believe in the Big Bang

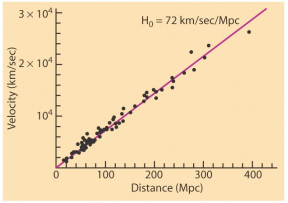
1. Cosmic Microwave Background
   - Big Bang working at about 380,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + Einstein's General Relativity

   = Expanding Universe with an age of 13.7 billion yrs







One of the most successful scientific theories of all time!

Question

Which of the following is not evidence of the Big Bang?

a) Hubble's law.
b) Big Bang Nucleosynthesis.
c) Olber's paradox.
d) Cosmic Microwave Background

The Universe: Timeline

- Big Bang: 13.7 billion years ago
- GUT era: $+10^{-35}$ second, energy and quarks
- Inflation: 10^{-35} to 10^{-32} seconds, Universe expands by more than 10^{50}!
- Quark confinement: 10^{-32} to 10^{-6} seconds, protons and neutrons form
- Matter vs. antimatter: 10^{-6} seconds, matter wins
- Big Bang Nucleosynthesis: 10^{-4} seconds to 3 mins, He and some other nuclei form.
- Era of Recombination: 380,000 years. Universe becomes transparent, CMB
- Dark Ages: 380,000 to 200 million years, gravity works on stuff
- Stars: 200 million years, first stars form, protogalaxies

What is the fate of the Universe?

Fire and Ice

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

-- Robert Frost

What is the Universe's Fate?

Today: Universe is expanding. What do you expect to happen next?

Competition: gravity vs inertia

Compare: Pop fly and rocket!

- Quantitative question
- Launch speed vs speed to escape Earth

or

?

What is the Universe's Fate?

For Universe it is still gravity vs speed.

- Gravity acts on mass of galaxies (pulling back)
- The speed is the speed of expansion

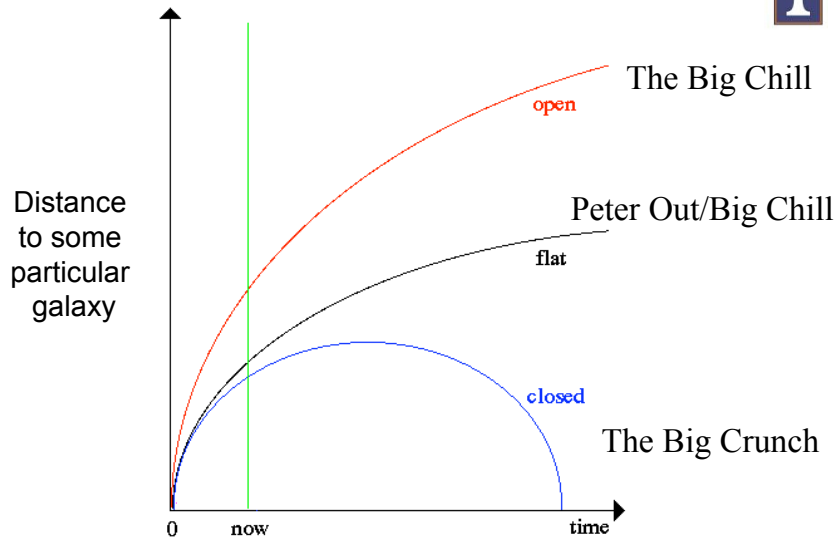
Both are observable!

or

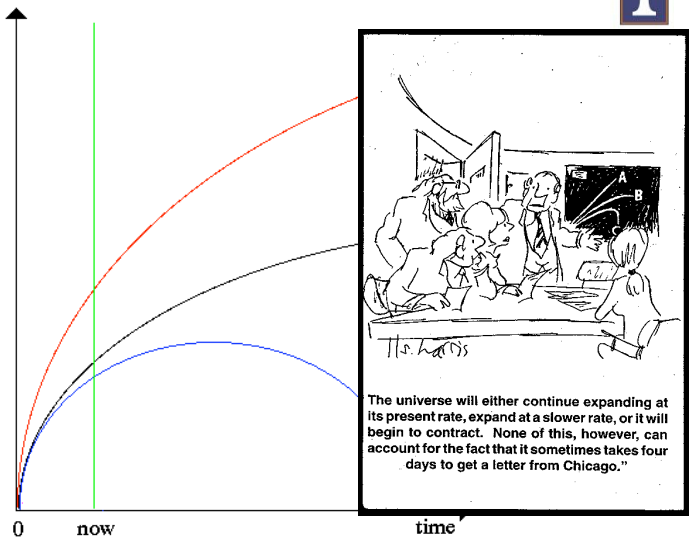
Our fate is a **quantitative** question :

- **If our mass is small enough we expand forever.**
- **If our mass is large enough expansion halts, and we collapse back.**

What kind of Universe do we live in?



What kind of Universe do we live in?



Big Chill/Big Crunch

- **Less mass:**
  An open or flat Universe will end in a **Big Chill**:
  - Galaxies exhaust their gas supply
  - No more new stars
  - Old stars eventually die, leaving only dust and stellar corpses
- **More mass:**
  A closed Universe will end in a **Big Crunch**:
  - Expansion will stop, and the Universe will re-collapse
  - Ends as it began, incredibly hot and dense

Question

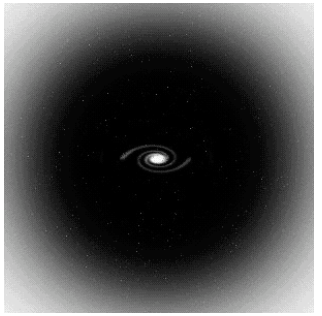
Our Universe could be one of three types: Open, Closed, or Flat. What would happen to a closed Universe?

a) No one else could get in.
b) It would expand forever.
c) It would just barely expand forever.
d) It would expand for a while, then eventually begin to re-collapse on itself.
e) It would expand, then slow down, then expand faster.

How Much Does the Universe Weigh?

- The first major component is luminous matter.
- The stuff we've been talking about all semester
  - You
  - Stars
  - Planets
  - Gas
  - Dust
  - Molecular clouds
  - White Dwarfs
  - Etc.

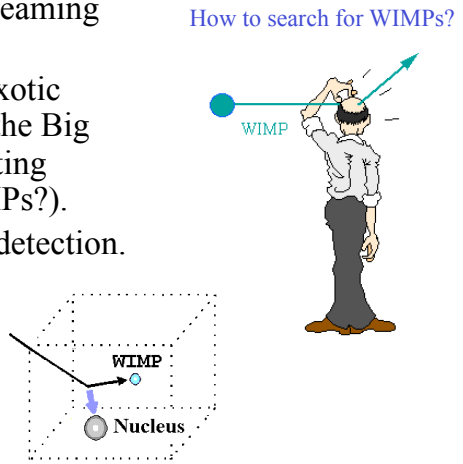
And Dark Matter



- The unseen mass in our Galaxy!
- Needed to explain stellar orbits.
- The dark matter in the Galaxy is in greatly extended halo
  - Up to 90% of the Galaxy's mass is dark matter!
- Most of our Milky Way is Dark Matter
  - We can't see it (only interacts via gravity)
  - We aren't sure what it is, but it is much more common than "normal matter"

Dark Matter

- Dark matter is likely streaming through us right now!
- Probably some heavy exotic particle created during the Big Bang. (Weakly Interacting Massive Particle– WIMPs?).
- Recent suggestion of a detection. Stay tuned!



http://www.shef.ac.uk/physics/research/pa/DM-introduction-0397.html

How Much Do We Weigh?

% of mass for closed Universe

22% Dark matter

Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter

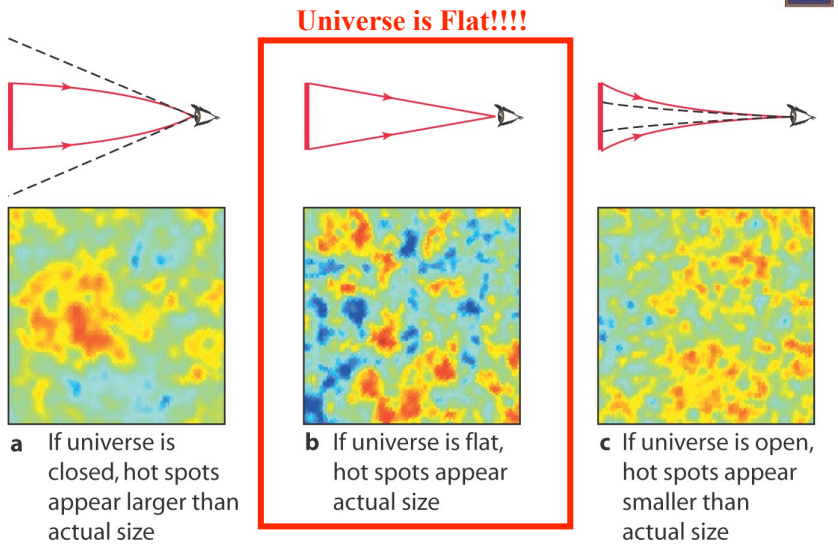
Made of protons, neutrons, and electrons

<1.5% Neutrinos

28% Total Not enough to close the Universe

So we live in an open Universe?

CMB Measurements



Peter Out/ Big Chill

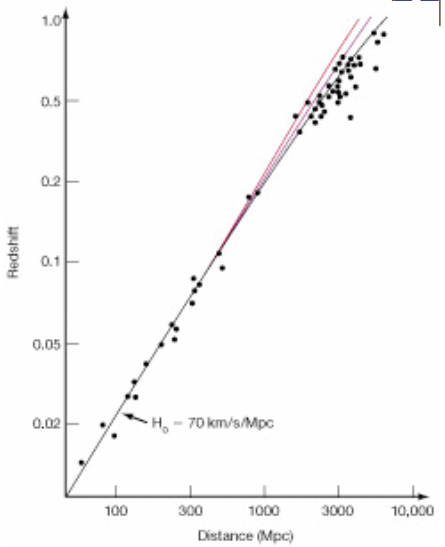
- The Universe will just barely expand forever, getting cooler and cooler.
- But if all of the mass, dark +regular, isn't enough, **then what's up?**
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe
  → $E = mc^2$

We must be missing some extra mass/ energy?

The Accelerating Universe!!!

The universe is not slowing down at all. In fact, it's speeding up!!! We live in an accelerating universe!

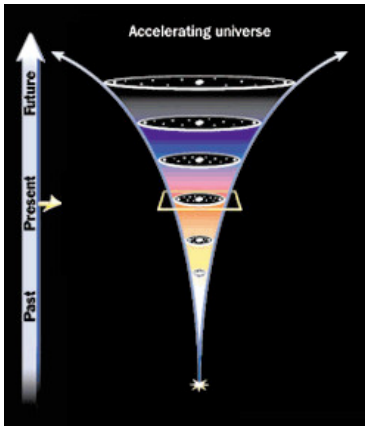
It's as if there's another force pushing the universe apart – a Cosmological Constant!!!

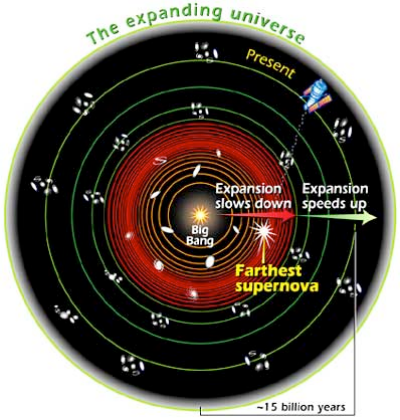


Dark Energy

- The matter census isn't enough to be flat and the expansion is accelerating!
- So, a new type of energy called ***dark energy*** must exists
  - Not related to dark matter
  - Acts as repulsive gravity, pushing apart.
- Dark energy is actually *accelerating* the expansion of the Universe!

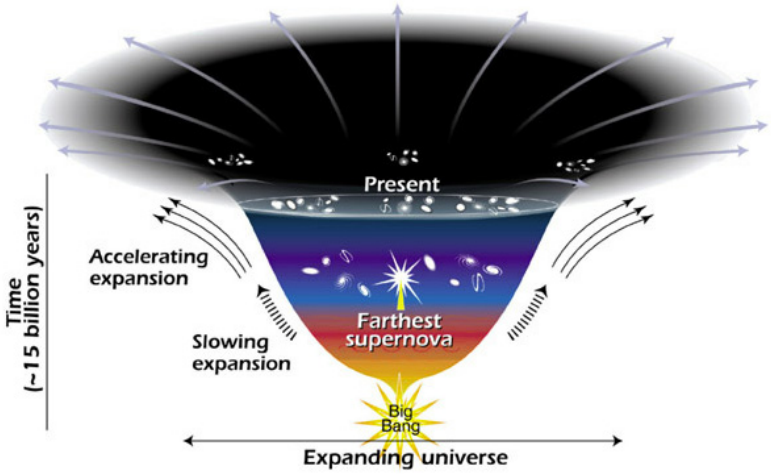
The Accelerating Universe!!!





Whatever this force is, we *think* that it is growing stronger as the universe evolves. The more empty space in the universe, the greater the acceleration – as if the vacuum of space has energy.

Effects of Dark Energy



http://www.lbl.gov/Publications/Currents/Archive/Apr-06-2001.html

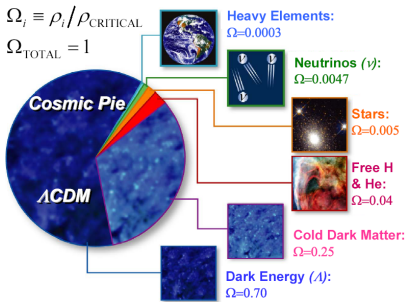
Question

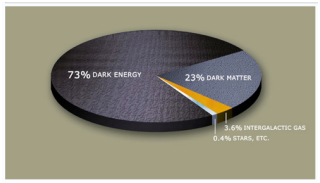
Based on measurement of the CMB, we live in a flat Universe. But there is not enough known mass to account for this. What's up?

a) We must be underestimating the amount of Dark Matter.
b) It would expand forever.
c) It would just barely expand forever.
d) We have something called Dark Energy.
e) It would expand, then slow down, then expand faster.

The Accelerating Universe!!!

The universe is 13.7 billion years old, and it is now dominated by dark energy.

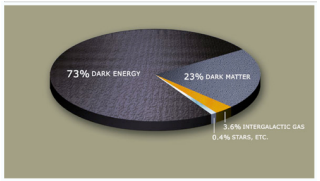




Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

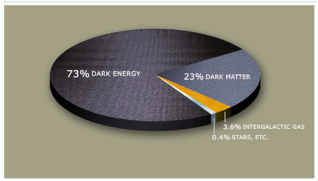
The Accelerating Universe!!!

- But, we are still in very speculative times here.
- How the Universe ends will depend on the nature of Dark Energy.
- If it really acts like a cosmological constant (go Einstein!), then we live in a flat Universe that will keep expanding forever, but if not, then we don't know yet.



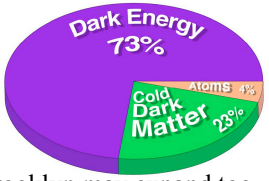
The Accelerating Universe!!!

- Understanding dark energy is one of the biggest questions for humankind today.
- There are many experiments underway to accomplish this. So we have to wait and see.
- But what are the options?



The Distant Future: The Big Rip

- Although this is not very popular, and the chances of it occurring is small, what if Dark Energy is not a cosmological constant?
- One extreme case is that it gets carried away, and rips the Universe apart.

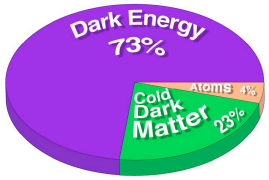


  - If repulsive force increases– Brooklyn may expand too.
  - Gravity/E&M forces can not hold Galaxies rip apart
  - Could rip the MilkyWay apart in ~1-100 billion years
  - Earth gets ripped apart soon after
  - You'd get ripped apart!

http://www.youtube.com/watch?v=oGVYG0ce1Ps

The Distant Future: The Big Crunch

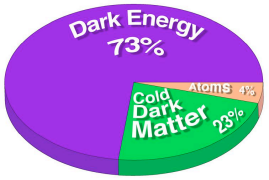
- Another extreme case, is if the nature of Dark Energy changes and we re-collapse afterall.
- The entire Universe falls back to a point.
- All atoms smashed into particles, then pure energy—very hot again.



- Perhaps this has happened before?
- Would take more than 14 billion years.

The Distant Future: The Big Chill

- From what we know right now, we think that the Peter Out/Big Chill is more likely.
- It is less exciting and slow, but an effective way to end the human race.
- Let's play with the stages of the end of the Universe.



- For an interesting read of these, try "The Five Ages of the Universe" by Adams and Laughlin.

Stelliferous Age: 10^8 to 10^{15} years

- Last stars to form will happen in a few hundred billion years.
- Stars age and die
- In about trillion years all Sun-like stars are gone from the Universe forever.
- Only stars left are low-mass red dwarfs (~0.1 solar masses), which can live for trillions of years
  - Lots of these stars and they get brighter with age, so Galaxy brightness doesn't change too much

Stelliferous Age: 10^8 to 10^{15} years

- In 7-8 trillion years, in our Galaxy (Milkomeda), the last red dwarf stops fusing, becoming a white dwarf.
- These tiny white dwarfs will stay hot for quite some time.
- Wait another few trillion years and they fade.
- So when the Universe is 100 trillion years old, the Universe goes dark.

Really Dark

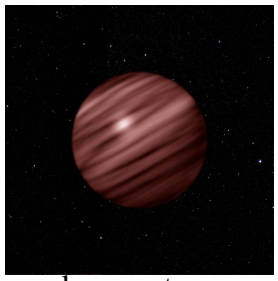
- If the Universe keeps expanding, it get worse for astronomers.
- The Galaxies we can see now, far away galaxies move out of our view.. Too far to see given the age of the Universe… out of our horizon.
  - The observable Universe is less and less
- The one giant elliptical galaxy (all that is left from our local group) is all that can be seen.
- The Universe appears empty!

Humans?

- We have 100 trillion years!
- Maybe longer, by smashing stars together to make fusion last longer.
- Won't last too long.
- When the Universe is slightly older than 100 trillion years old, the human race is out of fuel, out of stars, and out of luck.
- But the Universe isn't done!

The Degenerate Era: 10^{15} to 10^{40} years

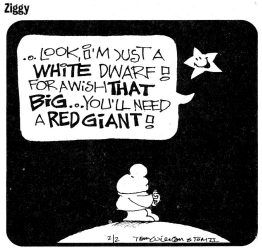
- Stellar corpses are all around the Galaxy.
- Every once in a while, a black hole will accrete a compact object, creating light again.
- Corpses may collide (remember we are talking 100 trillion years of time not the measly 13.7 billion of the Universe so far), and create new stars.



- Brown dwarfs, which did not have enough mass to fuse, can collide, making new stars.
- New life? Different Universe..

The Degenerate Era: 10^{15} to 10^{40} years

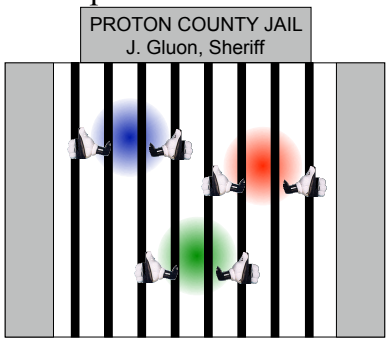
- But after a trillions, then quadrillions, and then quintillions of years, everything that can ever burn has happened.
- The Galaxy starts to lose weight.
  - Interactions with the stellar corpses, cause all the low-mass objects to be ejected from Galaxy.
  - High-mass objects fall to the center.
  - Supermassive Black Hole feeds!



- If the Earth still orbited the dead Sun (white dwarf) it is likely kicked out of the Sun and the Galaxy– a frozen dead planet in intergalactic space.

Proton Decay

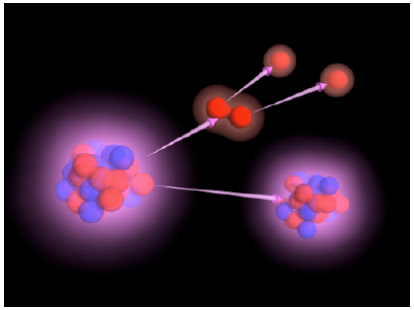
- Remember when quarks were imprisoned?
- We think that protons are radioactive.
- Except that they decay with a half-life of about 10^{37} years.
- Time is all that is left.



10^{31} years to life
Little chance of parole

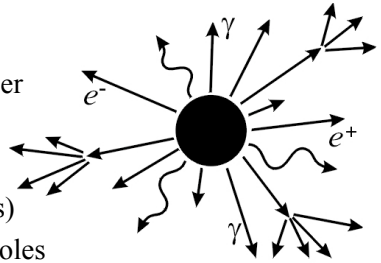
Proton Decay

- This proton decay creates heat again, feeble heat.
- What does non-proton life do?
- White dwarfs will evaporate
  - At -454 F, they are the hottest thing around!



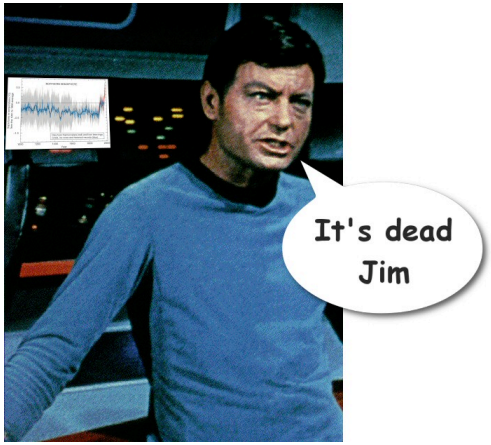
The Black Hole Era: 10^{40}-10^{92} years

- Black Holes survive.
  - Not made from matter, remember
- Galaxy is
  - The Supermassive Black Hole (1-10% of original Galaxy mass)
  - Trillions of stellar mass black holes
  - Lower mass stuff that was thrown out, so very far away.
- Hawking radiation is slow, but it will begin to evaporate the black holes
  - Slow, but lots and lots of time



The Dark Era: 10^{92}- Infinity

- 10^{92} is crazy!
- I mean really, really crazy!
- The weight of a single proton to the rest of the Universe is only 10^{79}!
- Still, at this point, the Universe is dead!
- Dead Jim!



The Dark Era: 10^{92}- Infinity

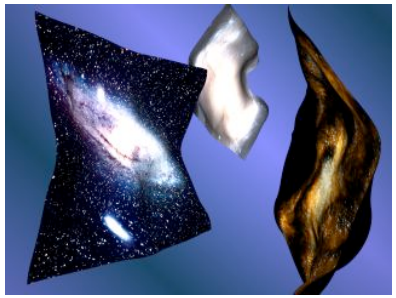
- Beyond this, two particles will once in a great while interact, but nothing will really happen.
- Universe is dead, randomized, and silent.
- Nothing really will ever happen again..
- Or will it?

The Dark Era: 10^{92}- Infinity

- Rebirth?
- We don't know what caused the Big Bang.
- Maybe it happens again?
- Maybe it already has?

Branes, Branes!

- One idea is that the Universe has 11 dimensions
  - Our 4 dimensional Universe floats around in this space
  - Other universes float there too (called branes, short for membranes)
  - Sometimes they collide
  - Violently disturbed, energy/matter heat up, expanding space
  - Sounds familiar..



Mitigation

- Are you kidding me?
- If humans live this long, they won't be anything we'd recognize as human.