Killer Skies

- HW 11 due next Monday
- Exam 3, Dec 11
- Last time: Big Bang
- Today: End of the Universe

Music: *Major Tom* – Peter Schilling

Hour Exam 3

Hour Exam 3 Wed, Dec 11th, in class

- information on course website
- 40 questions (cover material from Nov 4 to Dec 9: Lect 25-36)

May bring 1-page of notes

- both sides
- printed, handwritten, whatever

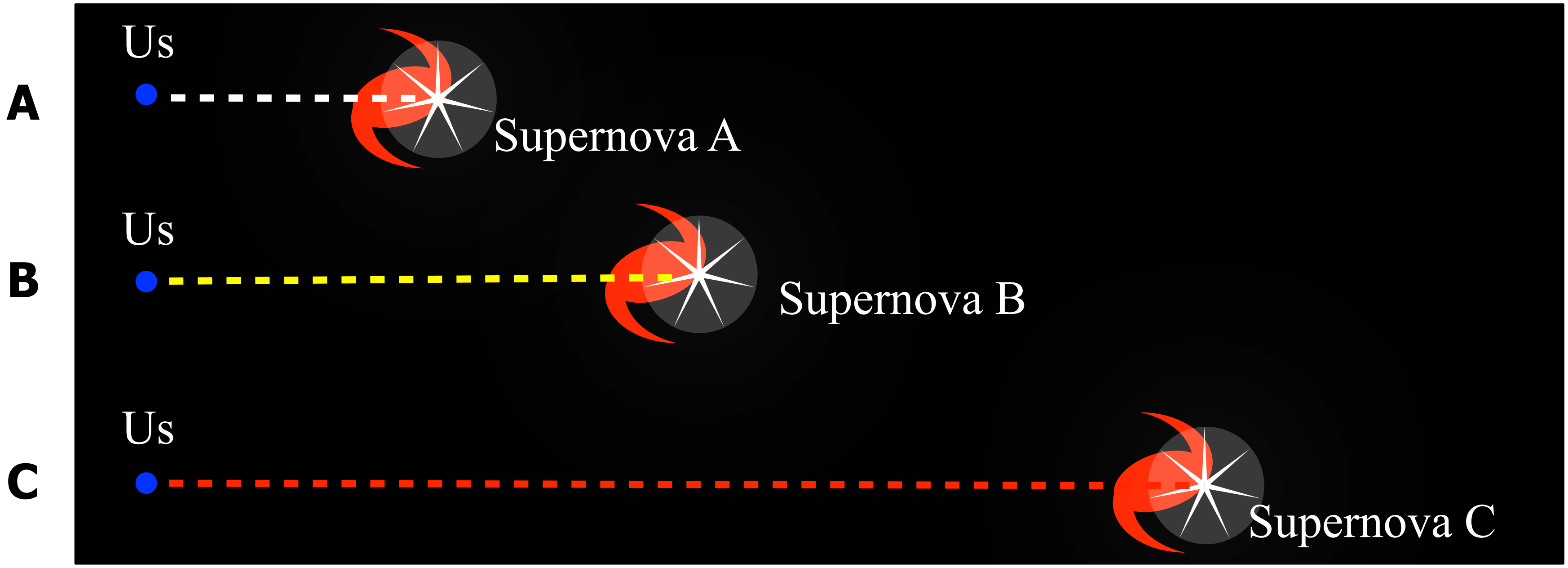
Most useful study materials

- class notes
- iClicker questions
- study guide
- homework questions
- old exam

Focus on concepts, main ideas

What if we measure our expansion?

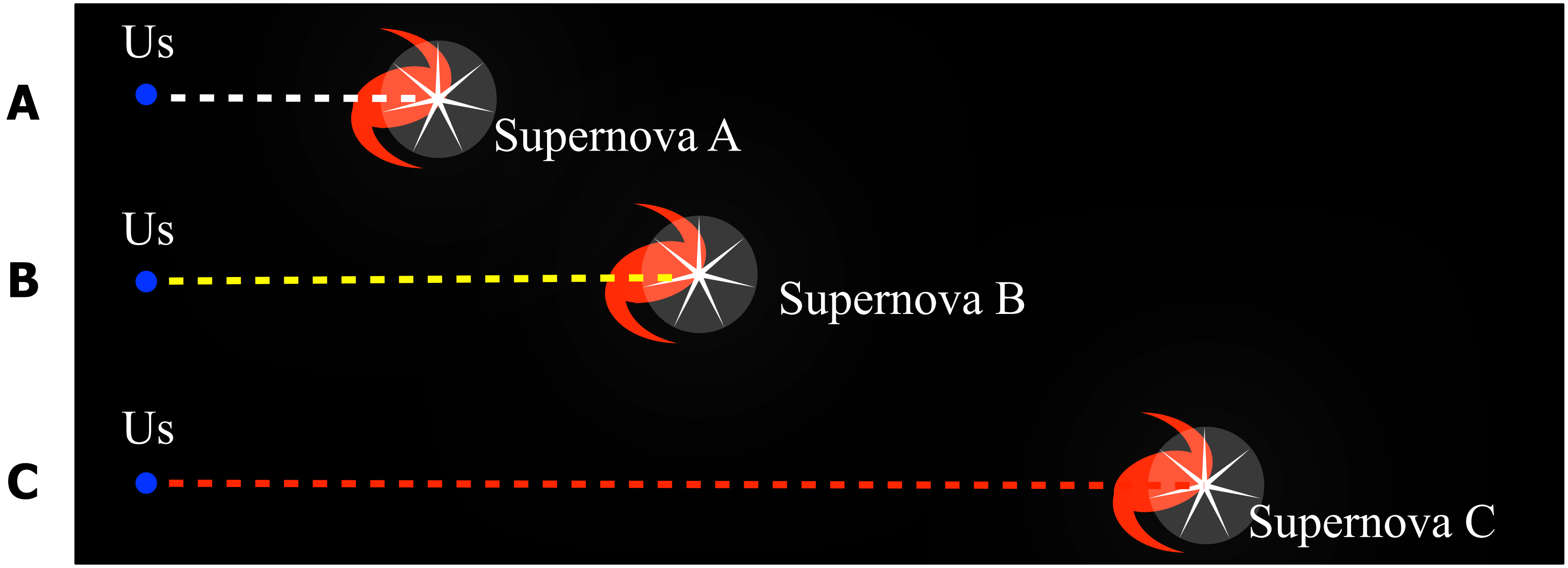
- Compare supernova distances with Hubble redshifts for distant galaxies
- Do they show difference from Hubble Law?
- We should be slowing down, right?



Measuring distances (using the brightness of the supernova) and redshifts (using the galaxy spectrum) can help us determine how the expansion of the universe is changing with time.

What if we measure our expansion?

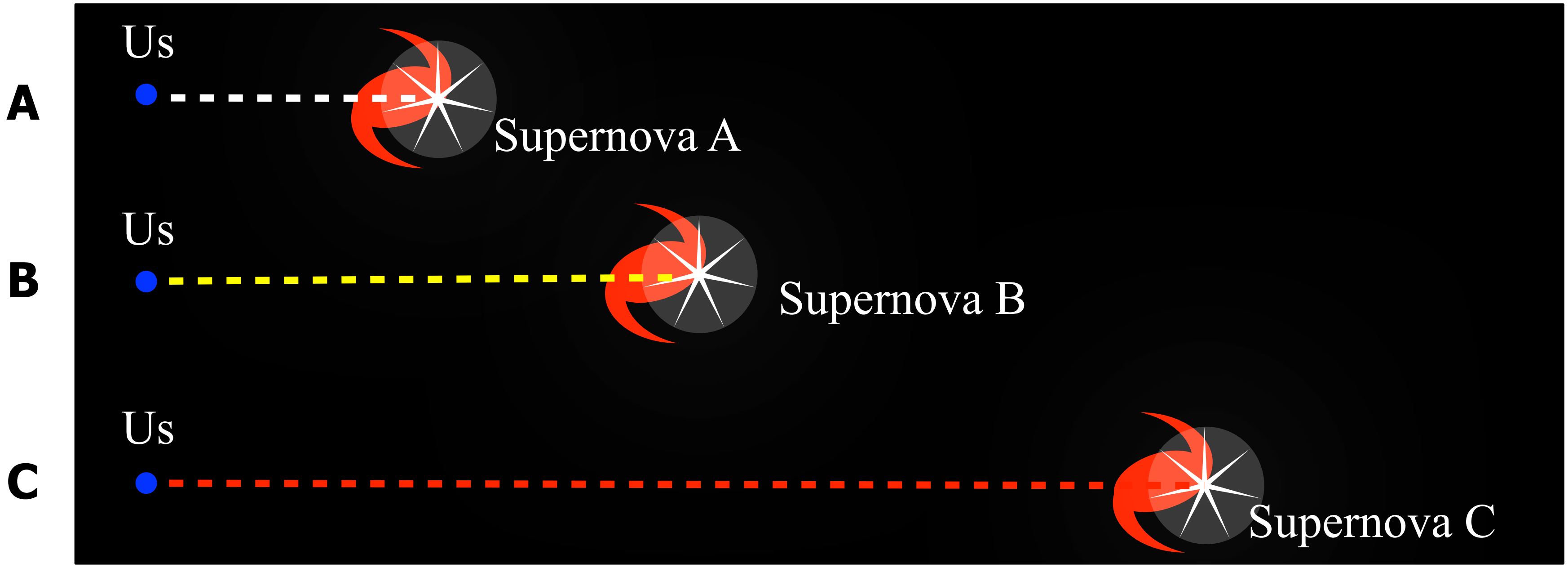
- Consider three supernovae: A, B, C
- Supernova B has twice the Hubble redshift of Supernova A
- Supernova C has four times the Hubble redshift of Supernova A



Measuring distances (using the brightness of the supernova) and redshifts (using the galaxy spectrum) can help us determine how the expansion of the universe is changing with time.

What if the rate of expansion were constant?

- Distance increases directly with redshift
- Supernova B is **twice** as far a Supernova A, and it has **twice** the redshift!
- Supernova C is **four** times as far Supernova A, and it has **four** times the redshift!



Gravity has no effect

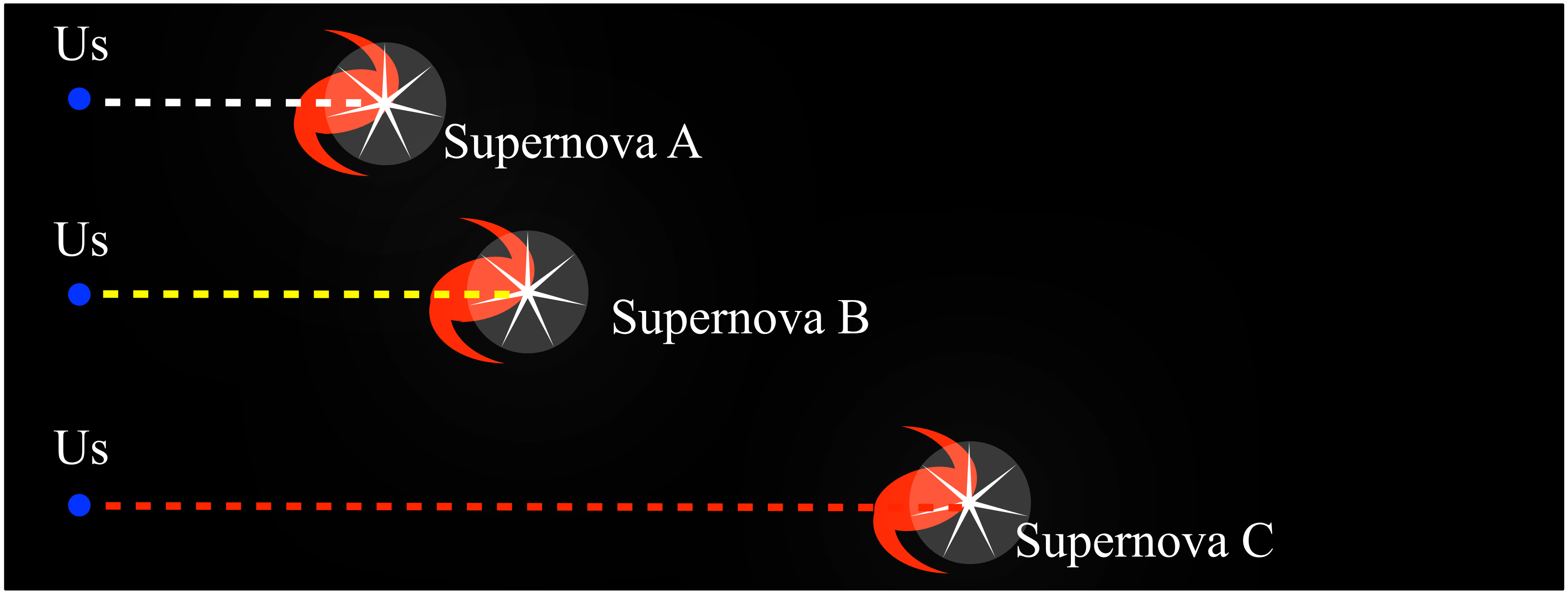
If the expansion is slowing down due to gravity

- The expansion was faster in the past
  - More redshift per distance traveled
  - Objects are closer than with constant expansion
- Supernova C is **three** times as far as Supernova A, but it has **four** times the redshift!

A

B

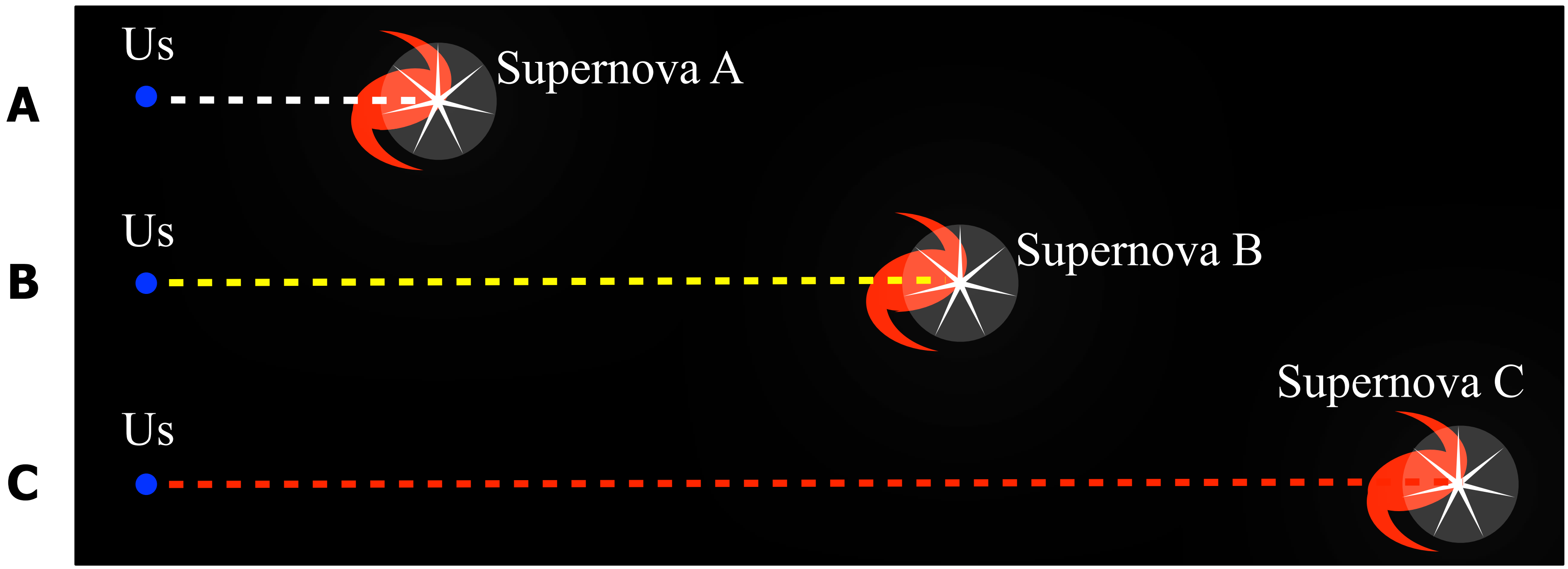
C



Galaxy C is closer than we expect, because Universe expansion is slowing down

What was observed?

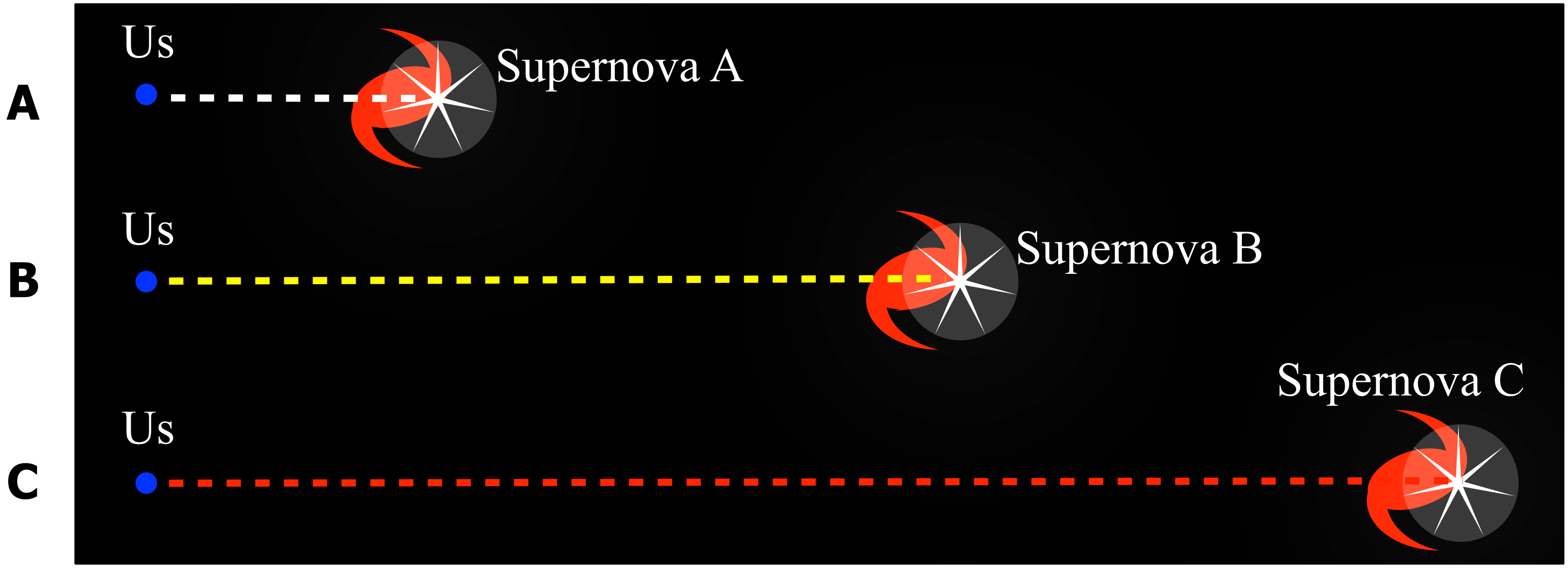
- Supernovae were **farther** than expected for a Universe with a constant rate of expansion!
- Supernova C is **five** times farther than Supernova A, but is only has **four** times the redshift!



Indicates that the expansion of the Universe isn't slowing down, it is speeding up!

What was observed?

- Indicates that the expansion of the Universe isn't slowing down, it is speeding up!
- Weird! This is the **opposite** of what was expected!

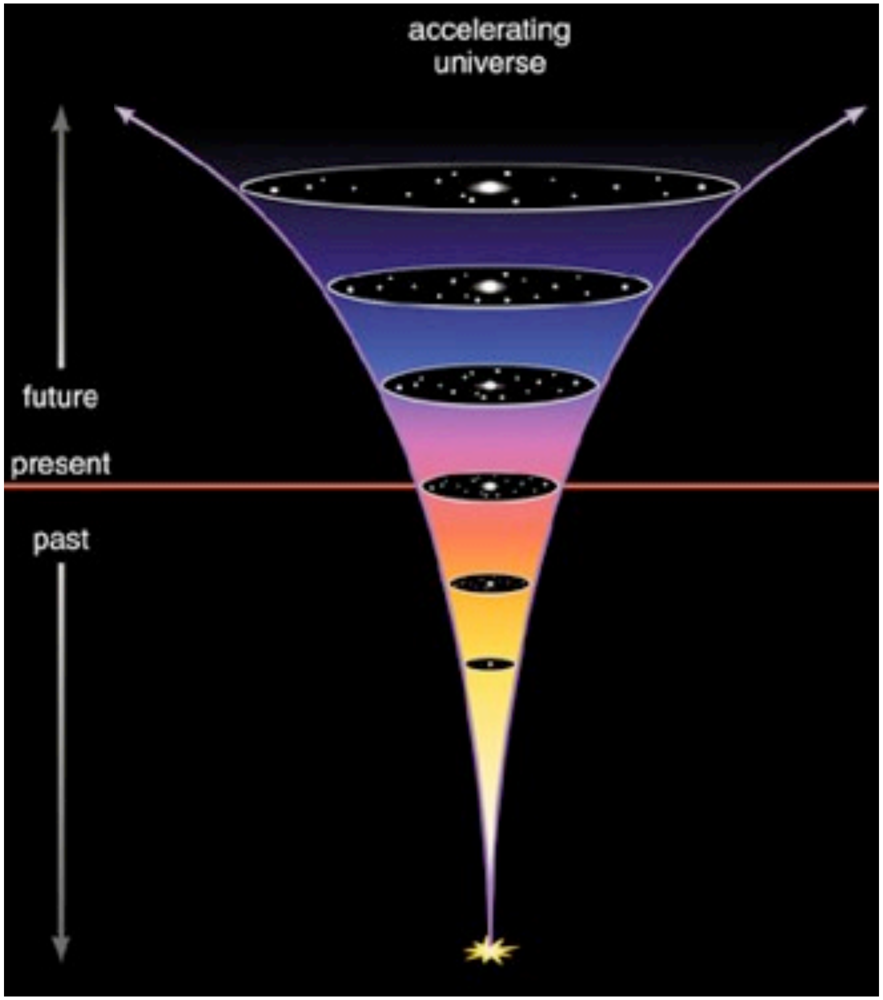


This is very weird!

Toss Newton's apple in the air and expect it to slow down as it goes up, but instead it rockets away! What is up?

Dark Energy

- If the expansion of the Universe is accelerating, then there must be a force of repulsion in the Universe
- We call this force **dark energy**
- Astronomers today are struggling to understand what it could be

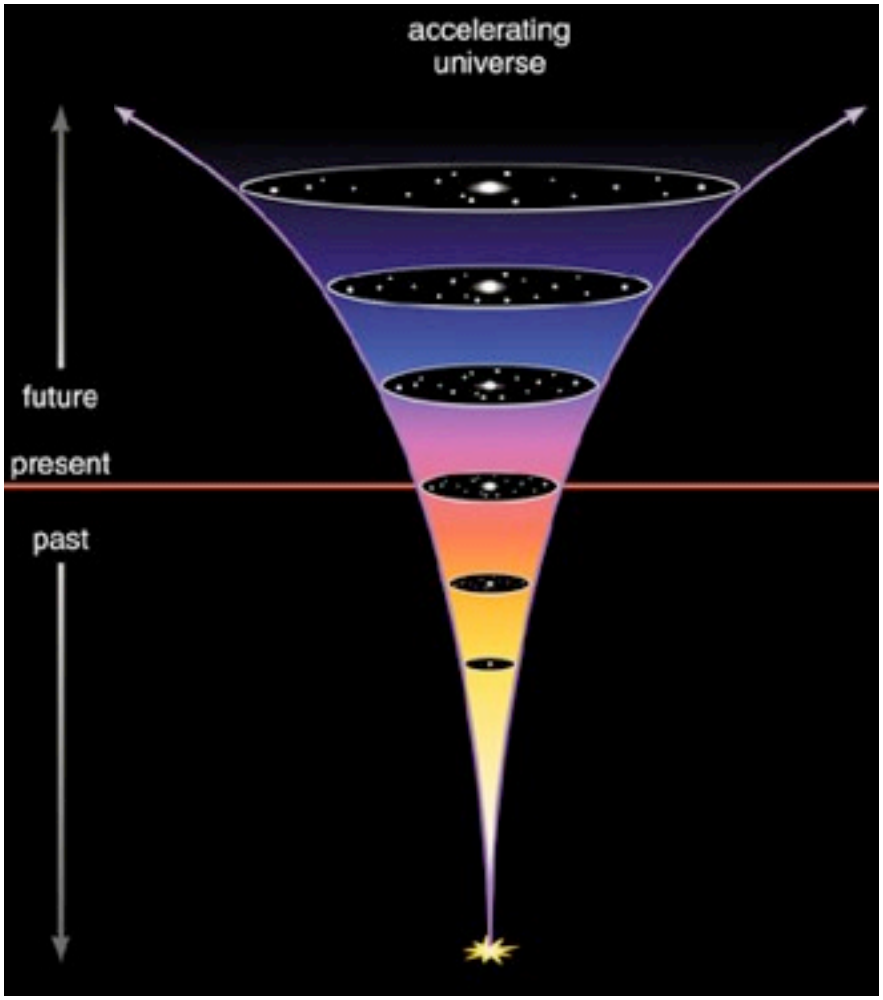


Dark energy drives the expansion <u>faster</u> with time

The observed acceleration is evidence that some form of energy is spread throughout space. Because we have no idea what it is, astronomers refer to this as dark energy. This energy drives the acceleration of the universe.
It, however, does not contribute to the formation of starlight or the CMB.

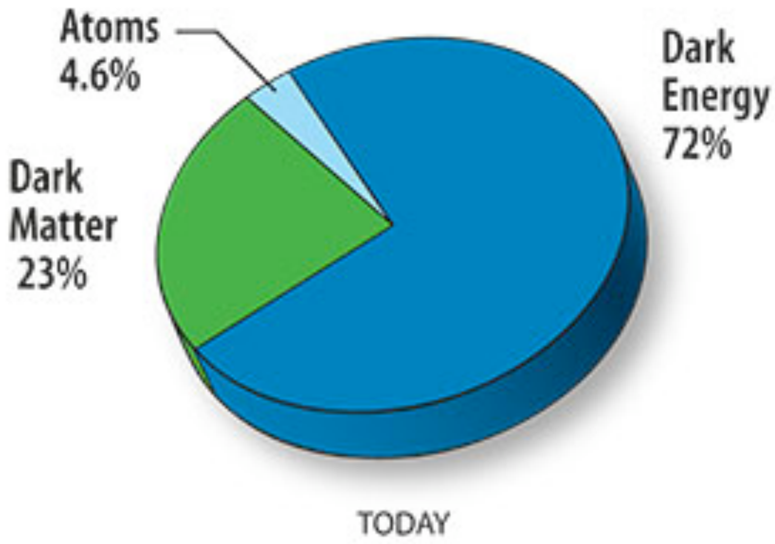
Dark Energy

- Spread throughout space
- Dark energy drives acceleration of the Universe today.
- This makes it the most abundant stuff in the Universe
- And we have NO idea what it is!!!!
- One of the greatest mysteries in science today!



Make-up of the Universe

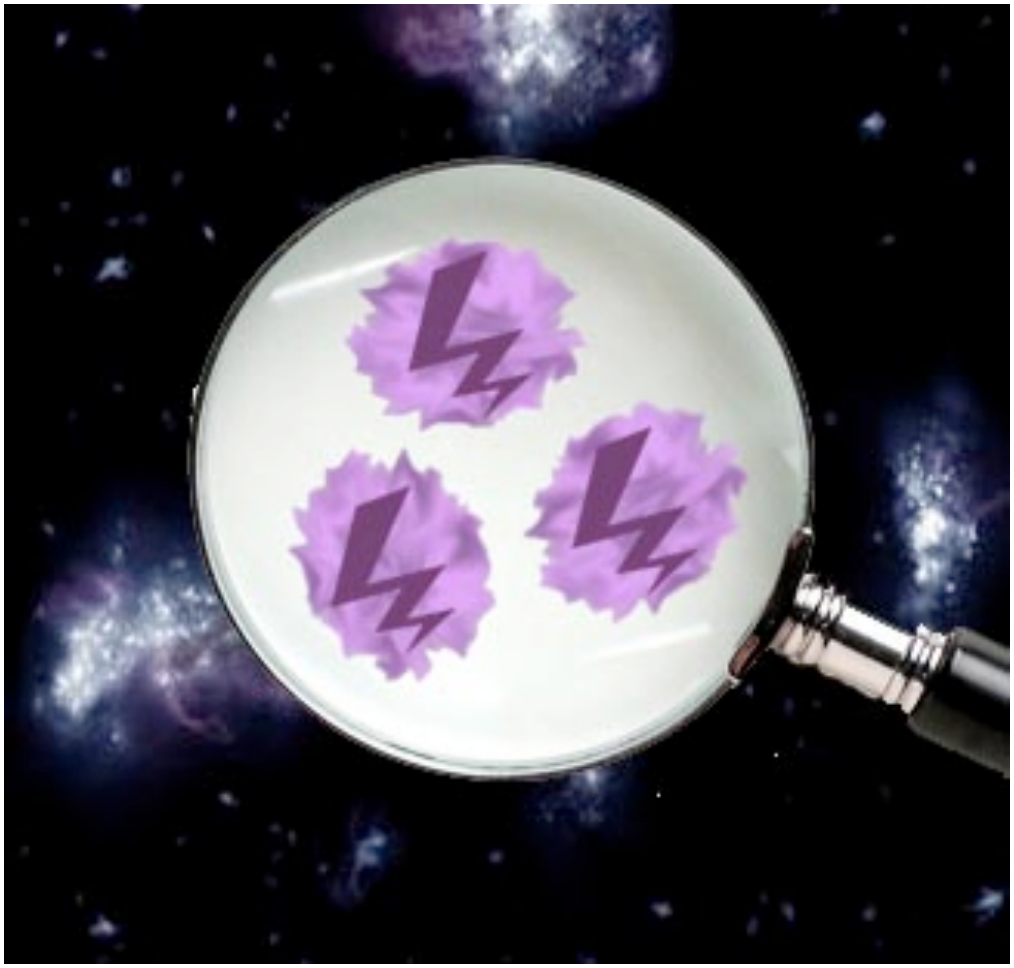
- The Universe is dominated by dark matter and dark energy
- About 4% is in form of normal matter (atoms)
- Only the normal matter can be directly detected with telescopes



The "stuff" that makes up our world is only a small fraction of all the stuff in the universe

Only the normal matter can be directly detected with telescopes, and about 85% of this is hot, intergalactic gas within rich galaxy clusters. Therefore, most of the universe is "unseen", only detected by it effects on other matter and the expansion of the universe.

Where is the dark energy?

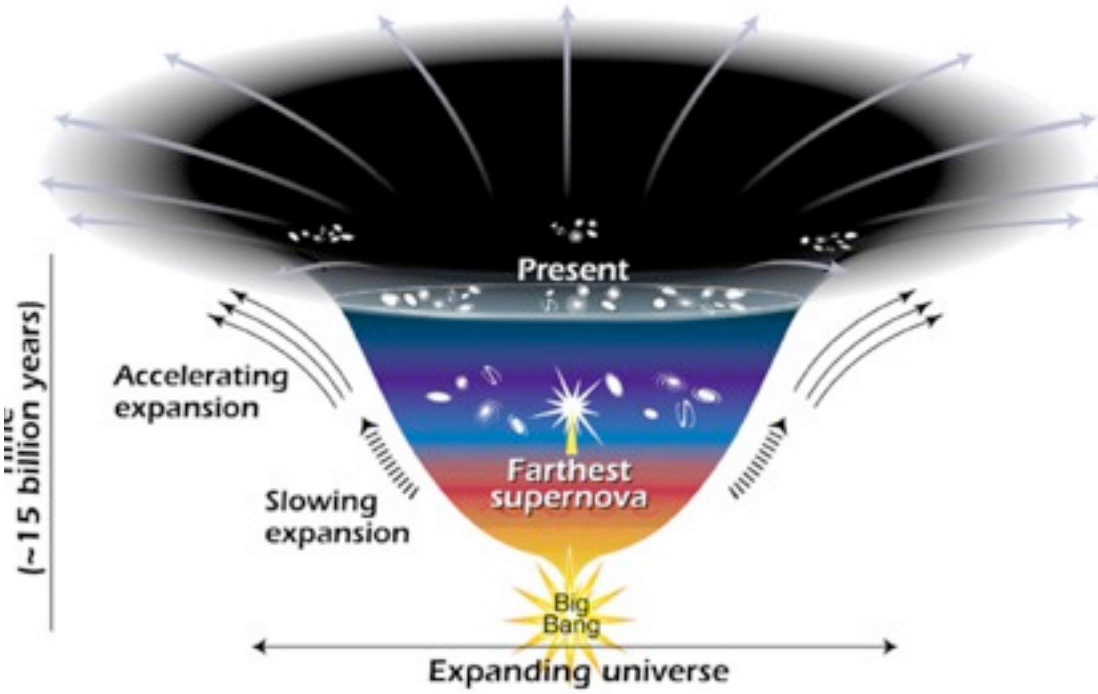


Dark energy is <u>everywhere</u> and is thought to be an inherent property of space itself

If Dark Energy is causing the Universe to expand, where is it? Dark energy is everywhere. Dark energy is thought to be an inherent property of space itself. However we don't notice dark energy mostly because it is an incredibly small amount of energy per volume. The effect is only seen acting on the universe as a whole, much like how we can feel a gust of wind, but cannot feel the individual particles in air.

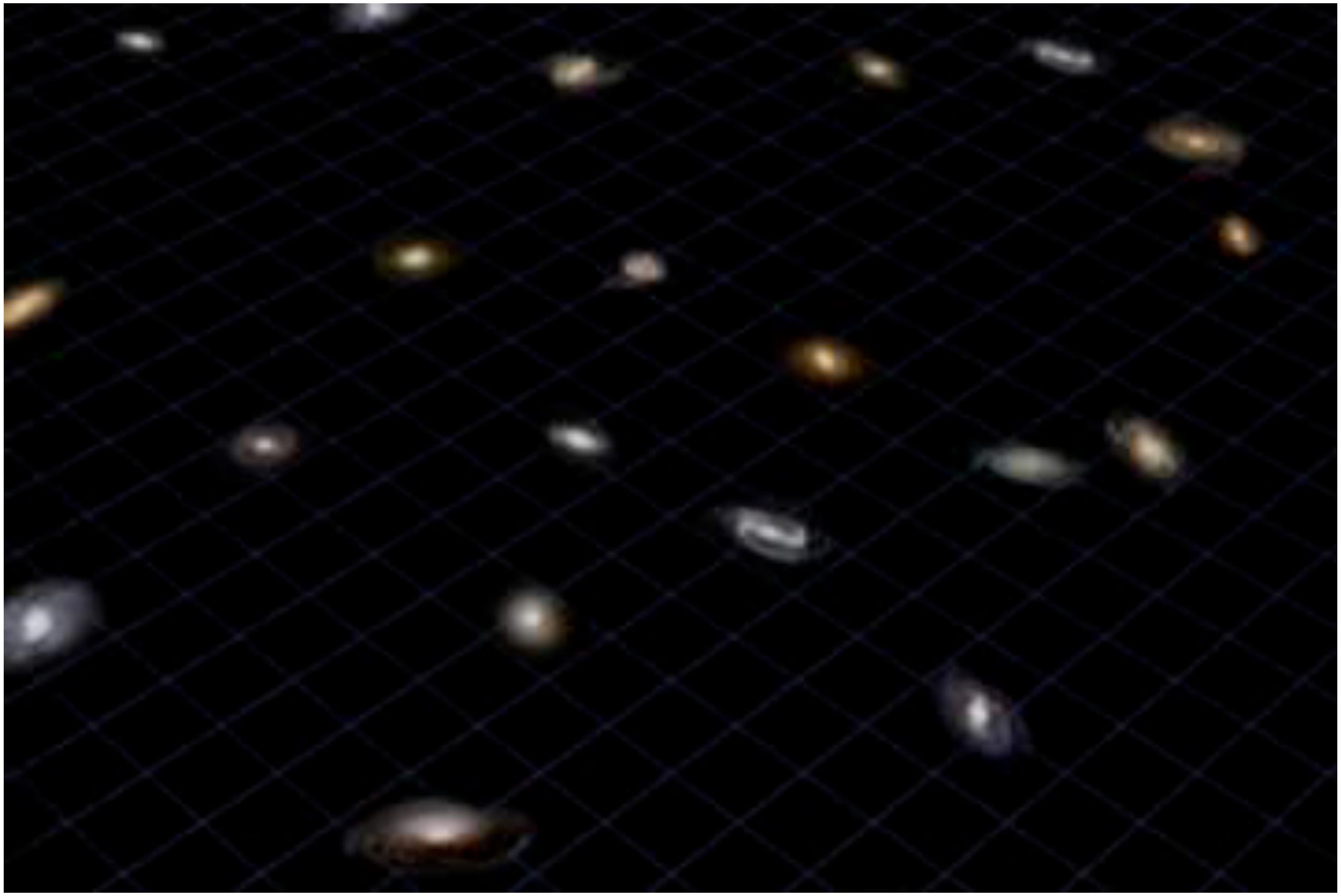
Deceleration, Acceleration

Observations further show that the Universe's expansion initially slowed down and started accelerating ~6 billion years ago



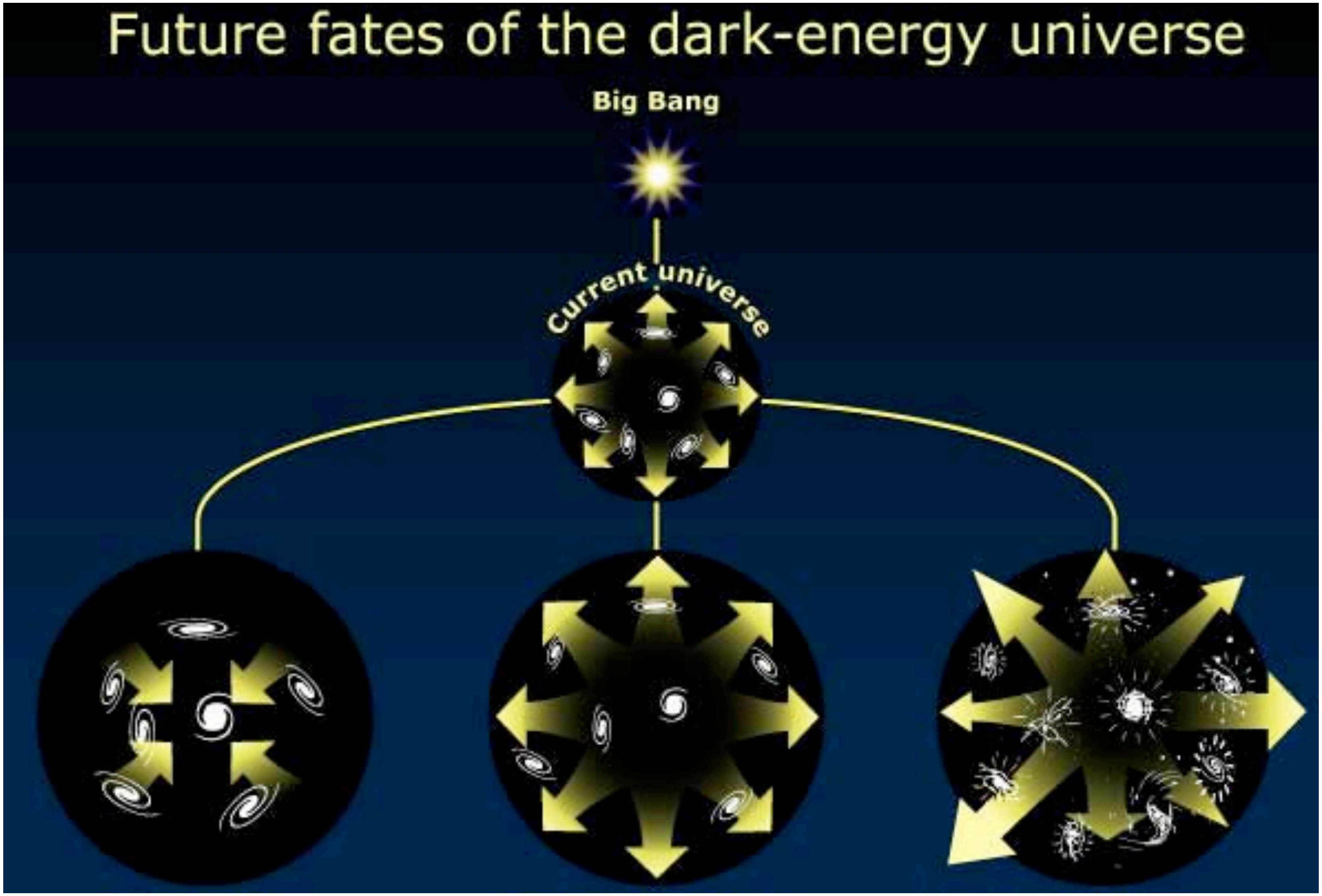
Observations of galaxies over 6 billion light years away show that the universe expansion initially slowed down—but shifted gears about 6 billion years ago and is now accelerating

The Effects of Dark Energy



The expansion history of the Universe

This animation shows the expansion history of the Universe by modeling the Universe as a two-dimensional grid of galaxies. The Big Bang, shown as a flash of light, is immediately followed by rapid expansion of the Universe. This expansion then slows down because of the gravitational attraction of the matter in the Universe. As the Universe expands, the repulsive effects of dark energy become important, causing the expansion to accelerate. For clarity, the size of the deceleration and acceleration has been exaggerated. The ultimate fate of the universe depends on the nature of dark energy.

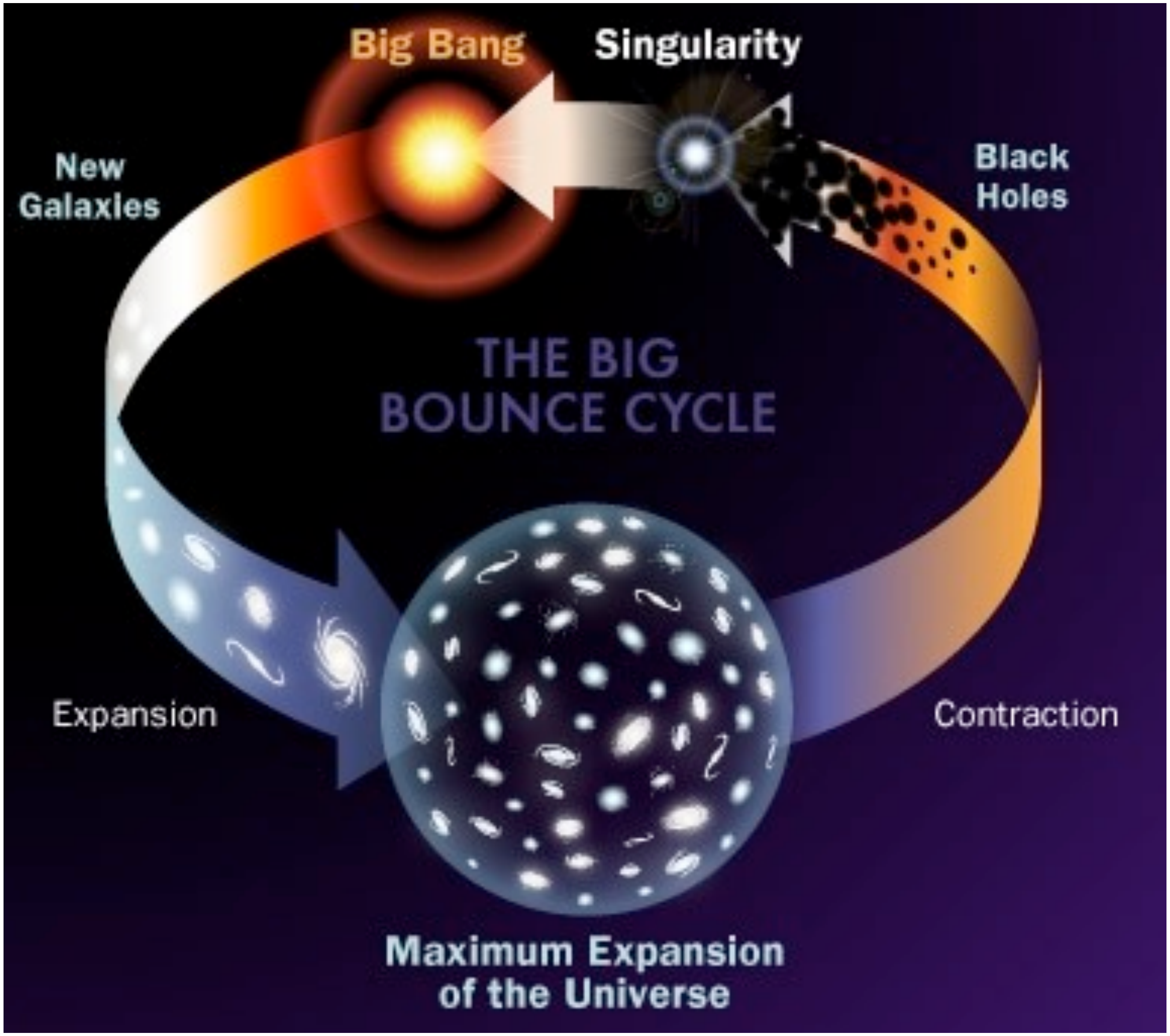


Big Crunch
Dark energy is unstable and reverses

Big Freeze
Dark energy is constant “energy of the vacuum”

Big Rip
Dark energy is unstable and increases with time

72% of the universe is dark energy, so the nature of dark energy greatly influences the ultimate fate of the universe. Three possible fates for the Universe: Expand forever, Big Rip, or Big Crunch



If dark energy is unstable, it could reverse the expansion and re-collapse the universe

According to some theorists, the Big Bang was simply the beginning of a period of expansion that followed a period of contraction. In this view, one could talk of a Big Crunch followed by a Big Bang, or more simply, a Big Bounce. This suggests that we might be living in the first of all universes, but are equally likely to be living in the 2 billionth universe (or any of an infinite other sequential universes).

Constant Dark Energy: Big Freeze

If dark energy is a constant "energy of the vacuum", it will expand forever

The galaxies will get farther and farther apart – we can no longer see galaxies beyond the local group in 2 trillion years due to accelerating expansion. Gas and dust to make new stars runs out within 100 trillion years, last stars die within 10 trillion years of that. Each galaxy will be isolated, burnt out, dark, and alone. This is the most likely scenario, according to observations

The Distant Future: The Big Rip

What if the density of Dark Energy increases with time?

- current data don't require this
- but also don't rule it out!

If so, the cosmic repulsion gets ever larger, eventually overcoming all other attractive forces in the Universe:

Result is to tear the Universe apart: "the Big Rip"

- If repulsive force increases–first, galaxy groups torn apart.
  - Andromeda galaxy yanked away from view
- Gravity/E&M forces can not hold--galaxies shredded
- Would rip MilkyWay apart into isolated stars after ~40 billion years
- Earth gets ripped apart soon after
- You'd get ripped apart!
- Yikes.

An instant before the end, our very atoms would be torn apart!

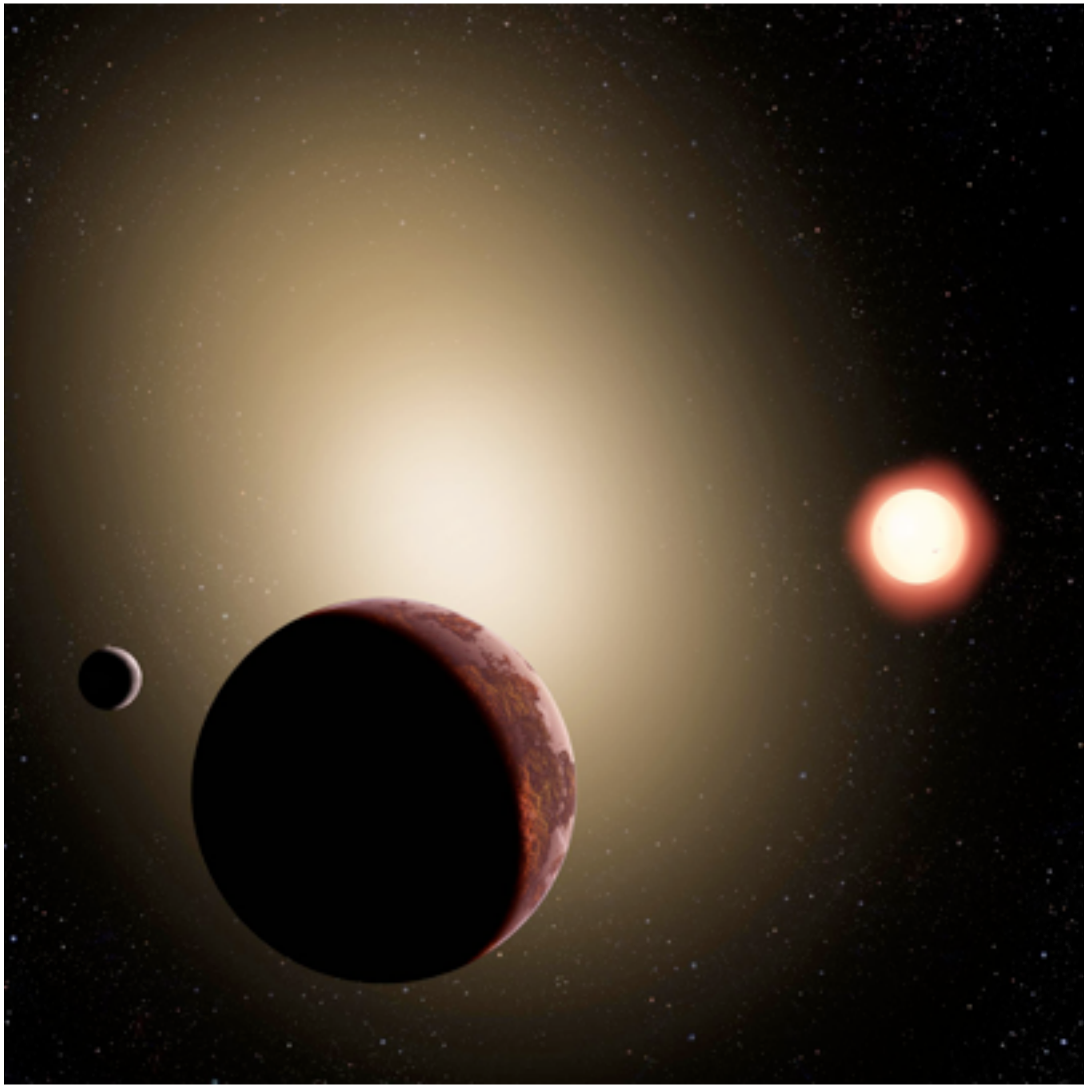
Though Question

Do you prefer the fate of the universe to be the Big Crunch, Big Freeze, or Big Rip?

A. I’m more comfortable with a universe that will end in recollapse someday in the future.
B. I like the idea that the universe had a definite beginning but will continue without end.
C. I’m cool with having my atoms ripped apart by the accelerating expansion of the Universe.
D. I don’t prefer one over the other.
E. Dude, you’re freaking me out!!!!

No right answer here...

2-5 billion years from today: Milky Way-Andromeda merger



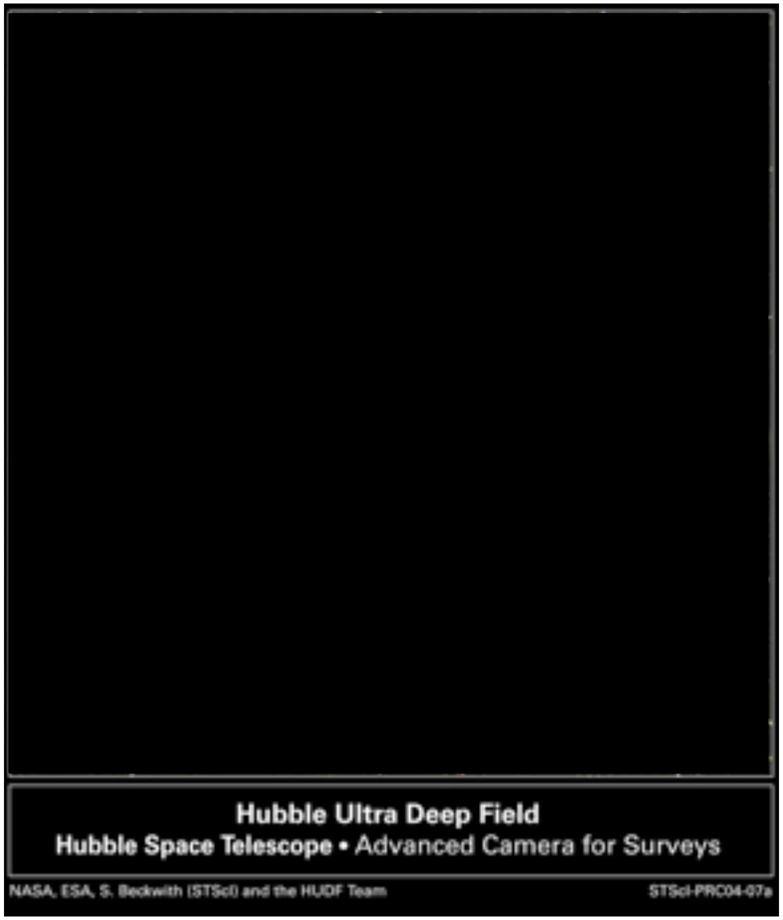
Astronomers estimate that in about three billion years, our Milky Way galaxy will be swallowed up by one of its nearest neighbors, a large galaxy named Andromeda that lies 2.2 million light-years away.

100 billion - 1 trillion years from today: Local Group Coalesces

The galaxies in the Local Group, the cluster of galaxies which includes the Milky Way and the Andromeda Galaxy, are gravitationally bound to each other. It is expected that between 10^{11} (100 billion) and 10^{12} (1 trillion) years from now, their orbits will decay and the entire Local Group will merge into one large galaxy.

~2 trillion years from now: Galaxies disappear from view

- Expansion of the universe continues to accelerate
- Eventually, distances between galaxies grows faster than speed of light!
- Light from galaxies beyond the Local Supercluster can no longer reach us!



For our distant descendants, a Hubble Deep Field would be empty!

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

Last stars to form will happen in in less than 100 trillion years.

Stars age and die

In 100 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 100+ 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.

Humans?

We have 100 trillion years!

Maybe longer, by smashing stars together to make fusion last longer.

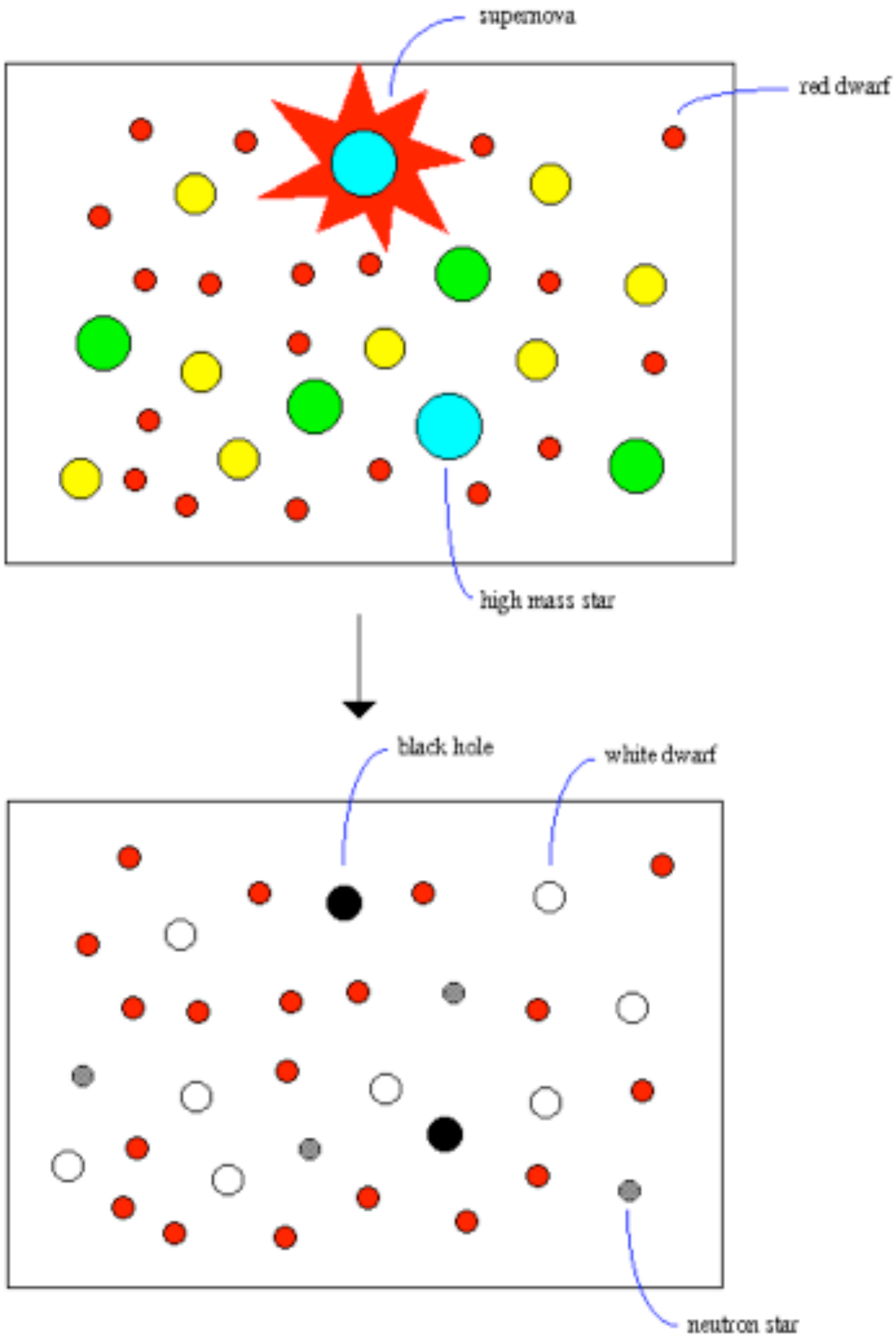
Won't last too long.

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!

10^{14}+ years: Degenerate era

- Last stars die out
- Universe dominated by *stellar corpses*
  - Black holes
  - Neutron stars
  - White dwarfs
  - Brown dwarfs
- Called the **degenerate era**

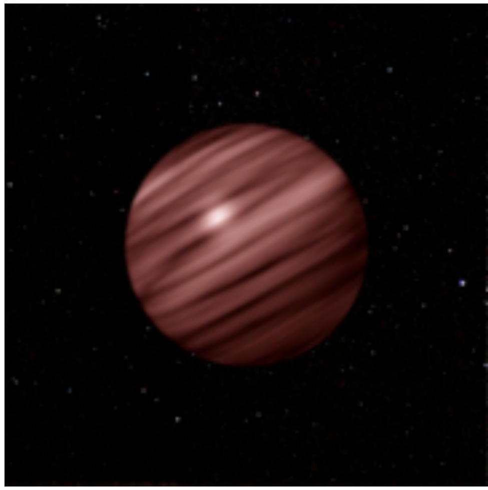


During this phase all stars are in the form of white or brown dwarfs, or neutron stars and black holes from previous explosions. White and brown dwarfs are degenerate in their matter, slowly cooling and turning into black dwarfs. Most of the mass of this collection, approximately 90%, will be in the form of white dwarfs. In the absence of any energy source, all of these formerly luminous bodies will cool and become faint. The universe will become extremely dark after the last star burns out. Occasional light from a white dwarf supernova (white dwarf binary spiraling into each other)

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 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

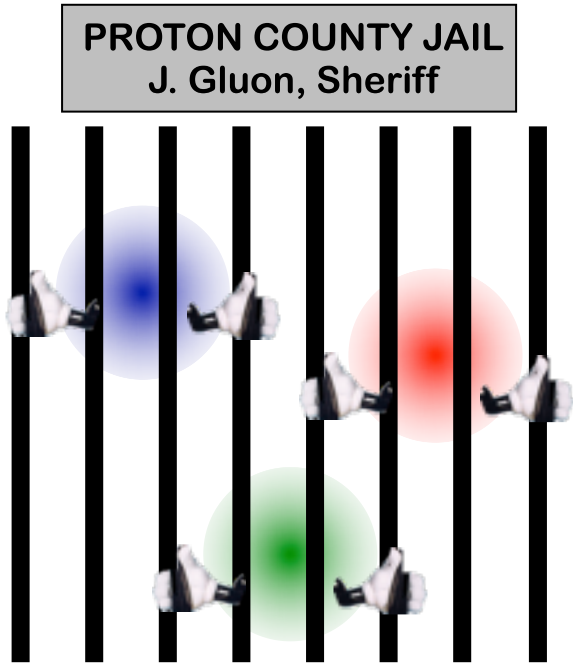
In very early universe:

- quarks condensed into protons and neutrons
- have appears to be stable ever sense

But we think that protons are ultimately unstable and 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

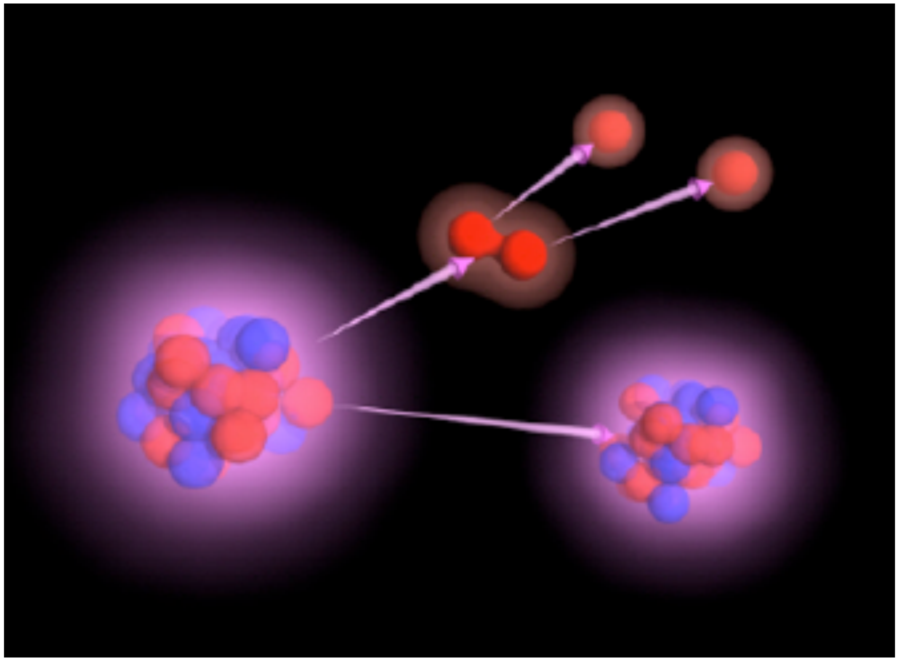
Proton Decay

This proton decay creates heat again, feeble heat.

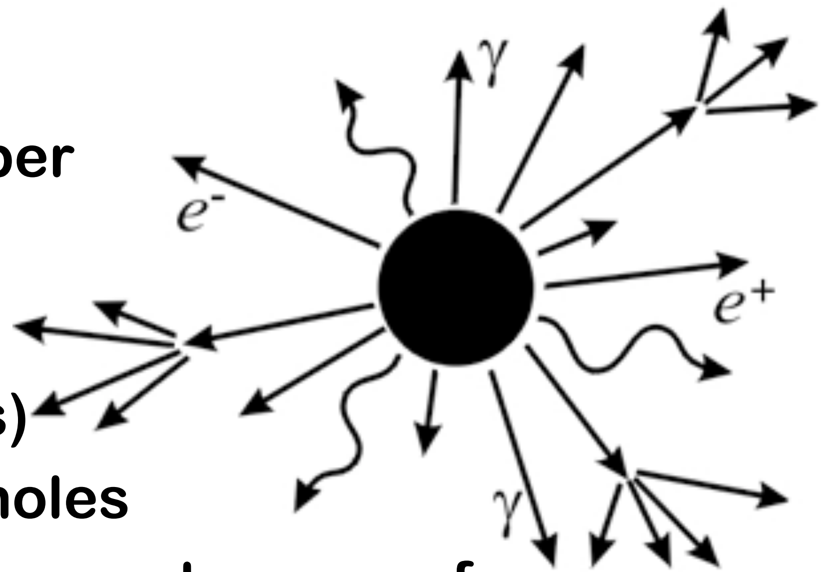
What does non-proton life do?

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.

But Stephen Hawking has shown that eventually even black holes "evaporate" into elementary particles

- Slow, but lots and lots of time on our hands!

well, not normal matter

The Dark Era: 10^{92} years- Infinity

10^{92} is crazy!

I mean really, really crazy!

The number of protons in the observable 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.

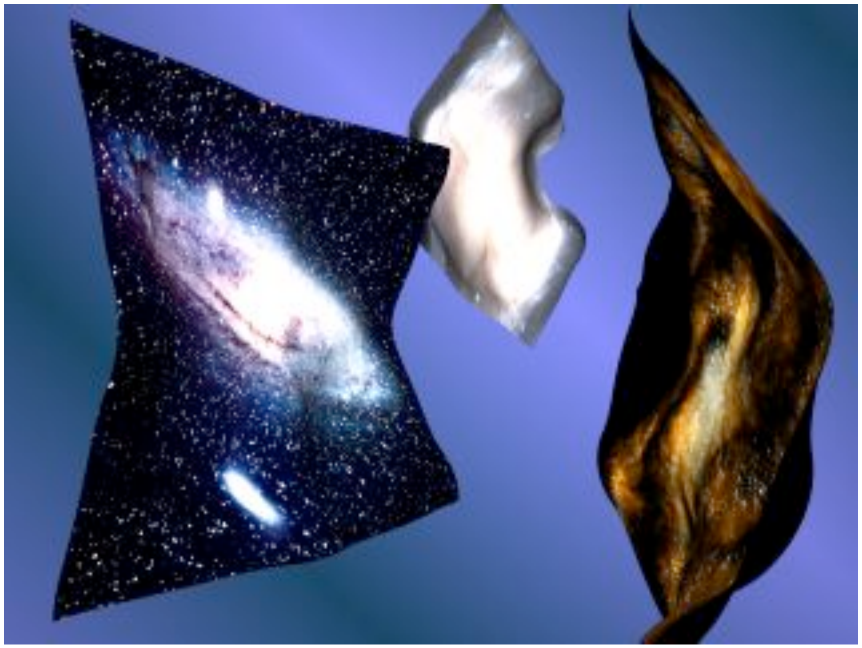
Maybe it happens again?

Maybe it already has?

Branes, Branes!

One idea is that the Universe has 11 dimensions

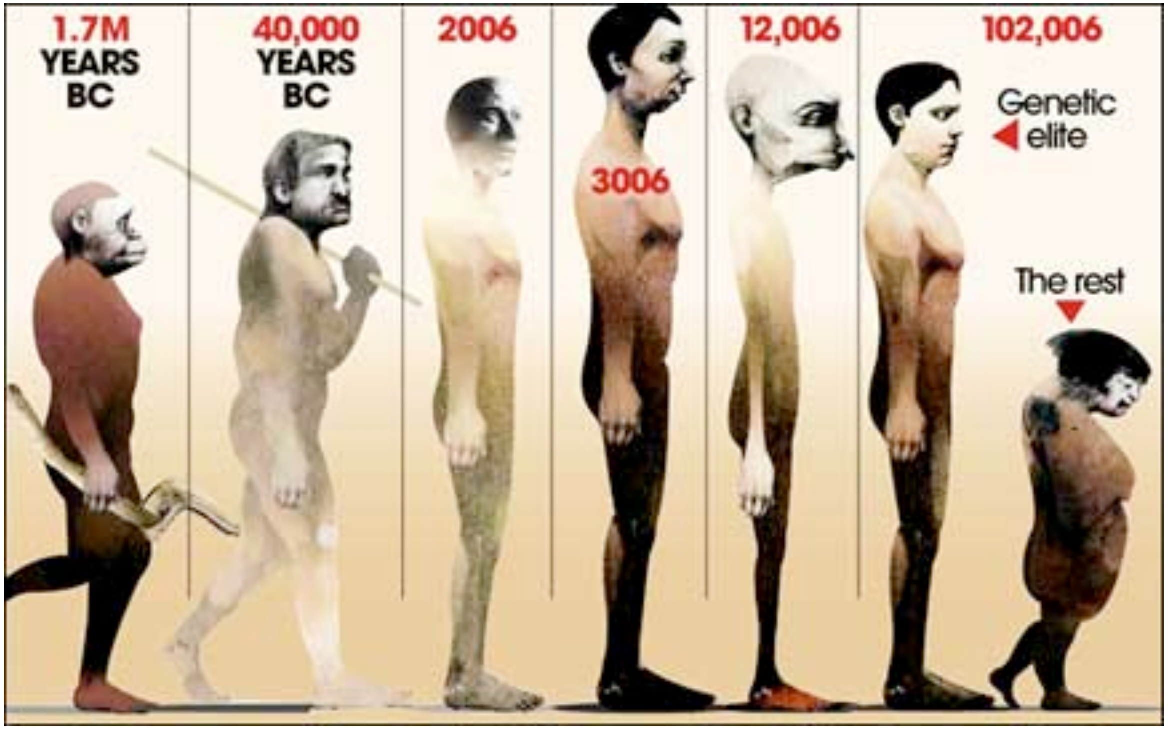
- Our 4 dimensional Universe floats around in this space
- Other universes float there too (called branes, short for membranes)
- Sometimes they collide
- Violently disturbed, energy/matter heat up, expanding space
- Sounds familiar..



Mitigation

Are you kidding me?

If humans live this long, they won't be anything we'd recognize as human.



Imagine

After getting flung a few billion years into the future by a spinning phone booth, everything seems normal.

Humans must have moved the Earth.

But something isn't right.

Suddenly, the stars disappear from view.

Then the outer planets, one by one: Pluto, then Neptune, and so on until Mars winks out of sight along with the Sun an inner planets

Then the Moon is gone

Next the Earth begins to rip in two!

And finally so do you!

As your body's atoms get ripped apart, you wonder why Leslie didn't mention how painful it would be, and you wish you had filled out your ICES form.

What Else

There are a lot of astronomical threats out there.... most are too far away for you to care probably....

But, what about an intelligent astronomical threat that could happen this afternoon?

Still very unlikely though.

Imagine

Astronomers notice something bright in gamma-rays moving into the Solar System.

The object is changing course!

Contact! But it isn't responding to our hails.

The object passes by the asteroid belt, but then starts to move out of the Solar System.

Excitement dies down, but a year later, an asteroid starts to change orbit and move toward Mars.

The asteroid has factories and "lands" on Mars.

Robotic spiders are building more and more factories, and with our orbiting spacecraft, we watch.

Imagine

Within a few years, the surface of Mars is picked clean, as micro-factories replicate huge numbers of alien robot-like organisms and spacecraft.

A year later, objects start to lift off from Mars, and they are coming toward Earth!

As they land, there is nothing we can do.

They begin to destroy the surface of the Earth, making more replicates of themselves.

As you are ripped apart for your heavy elements, you wonder why you didn't pay attention during the last day of Leslie's class.

Are We Alone?

- It's a great time to think about this question!
- In 1995, we knew of 9 planets. Now, in 2013, we know of 1050 confirmed exoplanets!!!

http://exoplanet.eu

- In the near future, NASA missions may find life on Titan or Europa, evidence of life of Mars, or image Earth-like planets around nearby stars.
- Can we answer arguably the biggest astronomical question of all time: Are we alone?

iClicker Poll

Do you think we are alone? Have we been visited by spacefaring aliens?

a) No: we are alone, there is no life elsewhere
b) Yes, there's life elsewhere, but we have not been visited
c) Yes, ET has been here!
d) Maybe, how am I supposed to know?!?

The Universe: Some Facts to Help you Live in it

Something like 100 billion galaxies, each with something like 100 billion stars-- that's 10^{22} stellar systems in the observable Universe. If only 1% of these stars have life and only 1% of those have intelligent life then there is still 10^{18} star systems with life! It's a big observable Universe!