Astronomy 150: Killer Skies
Lecture 36, April 27

Assignments:

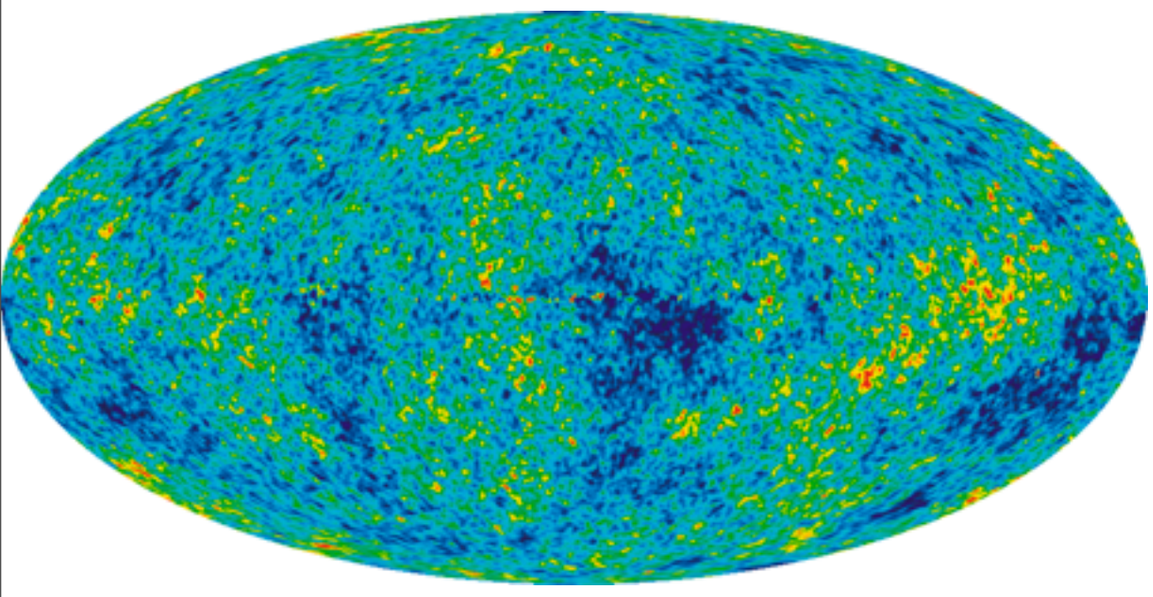
- ICES available online
- HW11 was due at beginning of class

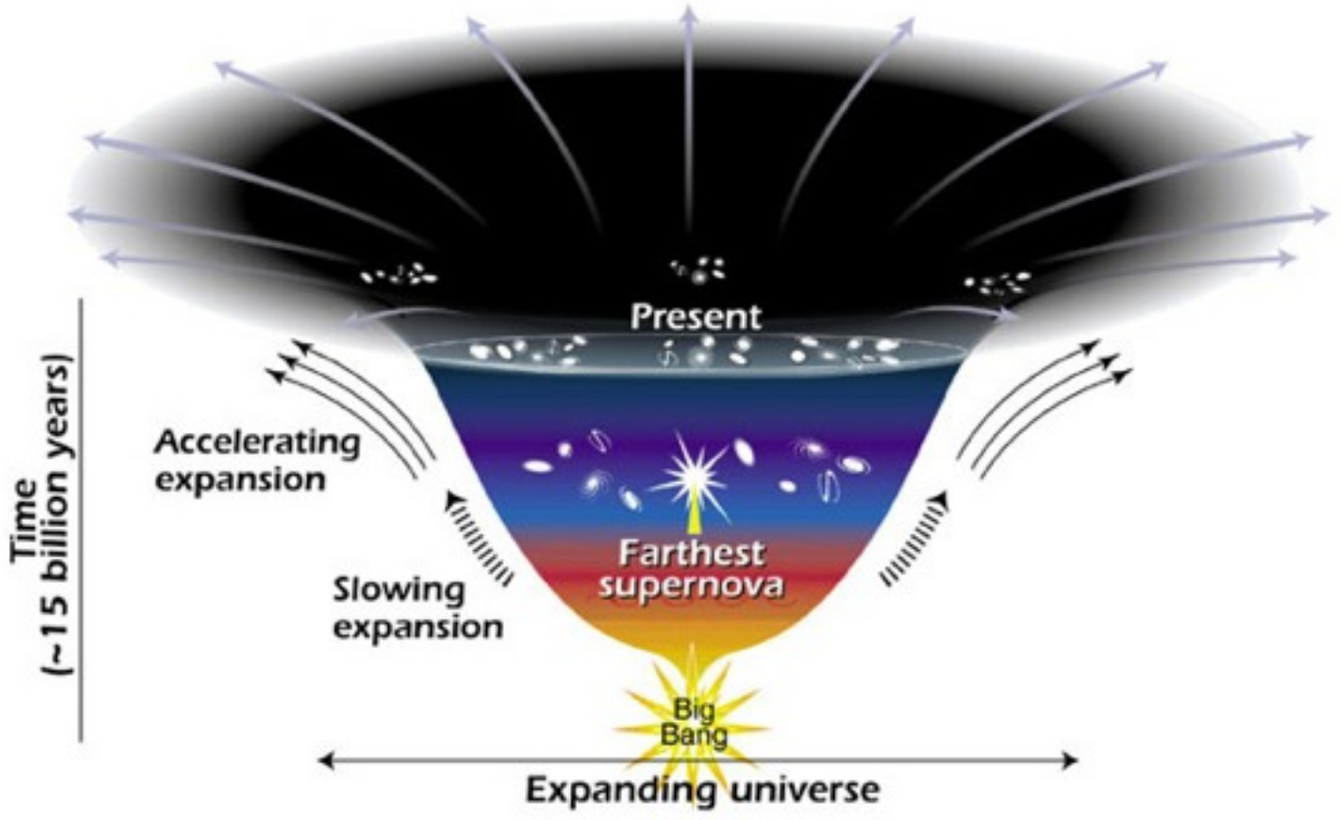
  no more homework!
- Hour Exam 3: next Wednesday, June 2, in class

  details on course website

Last time: The Early Universe

Today: Dark Energy, the Big Rip; to Infinity and Beyond





Music: The End by the Doors

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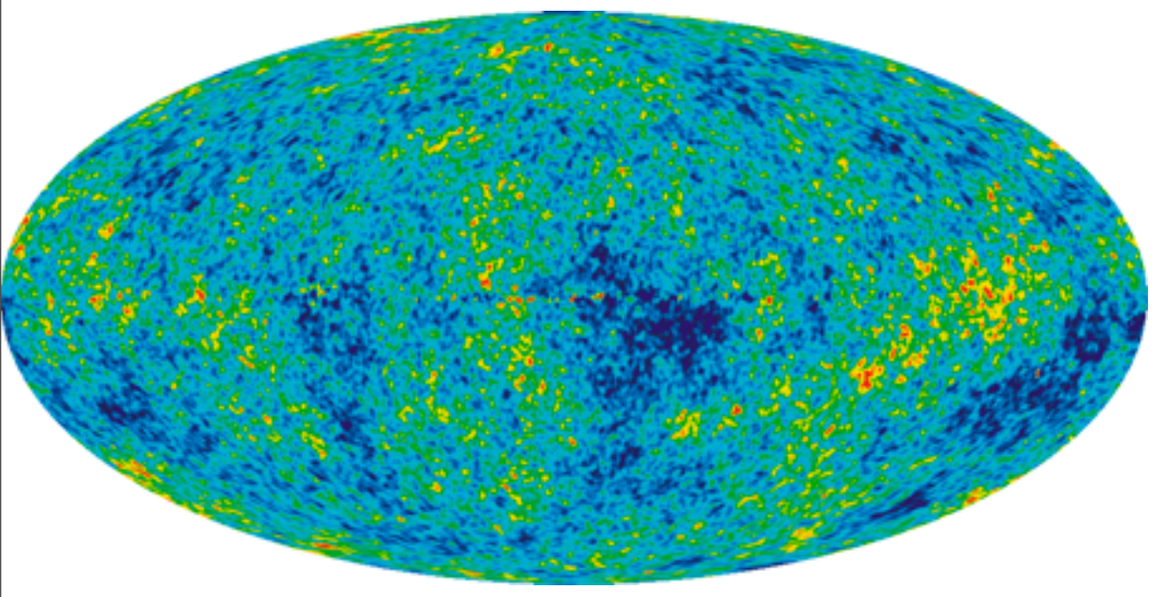

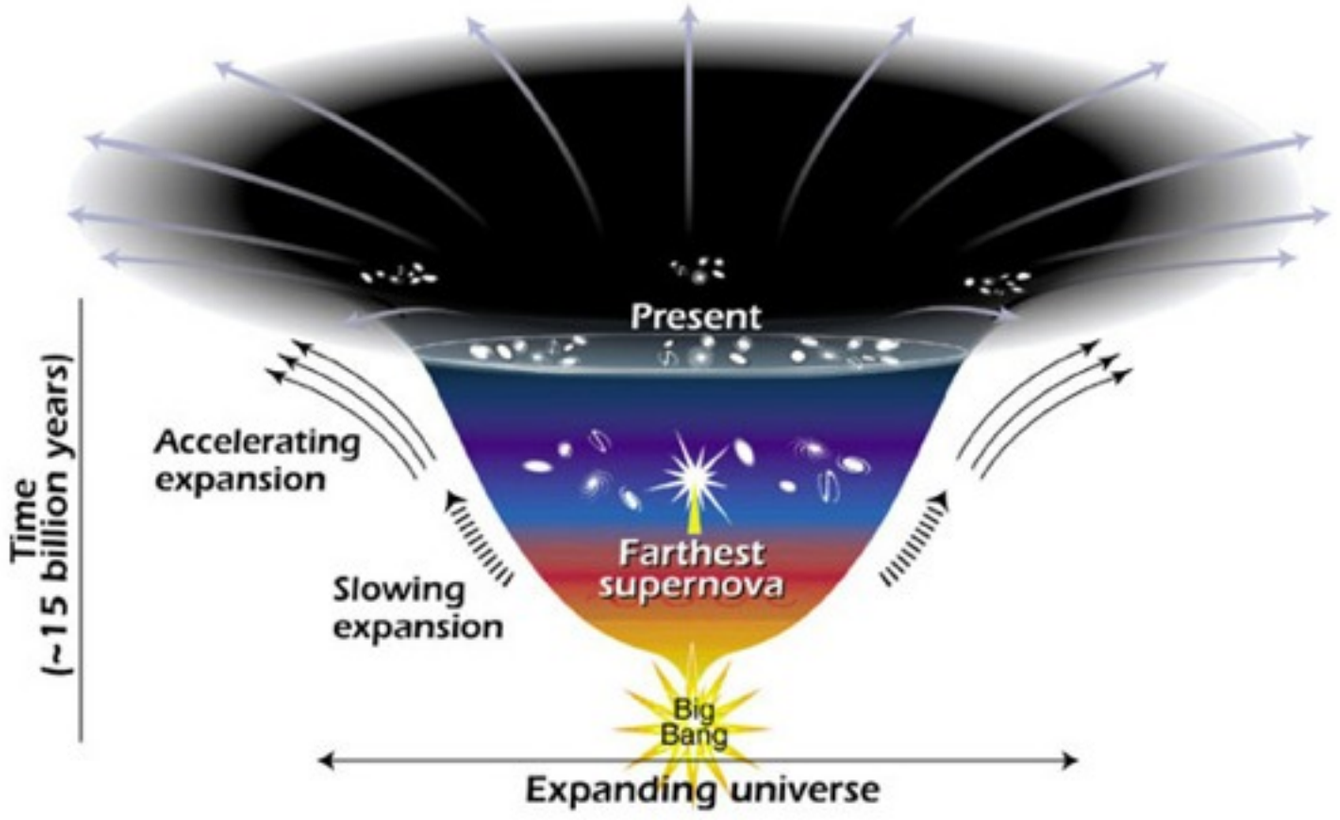

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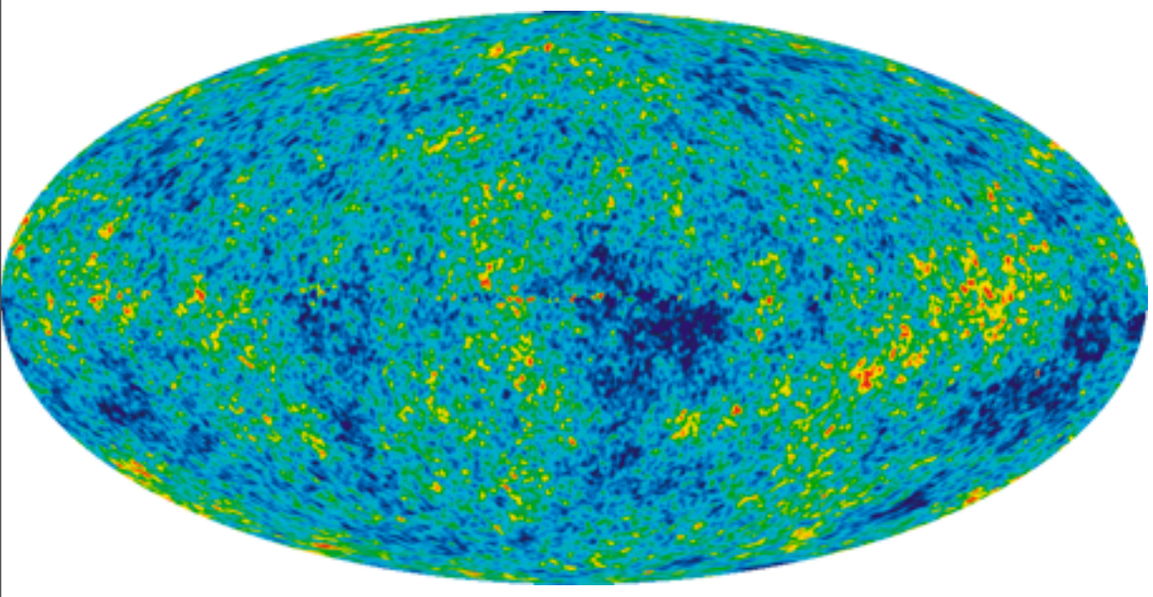
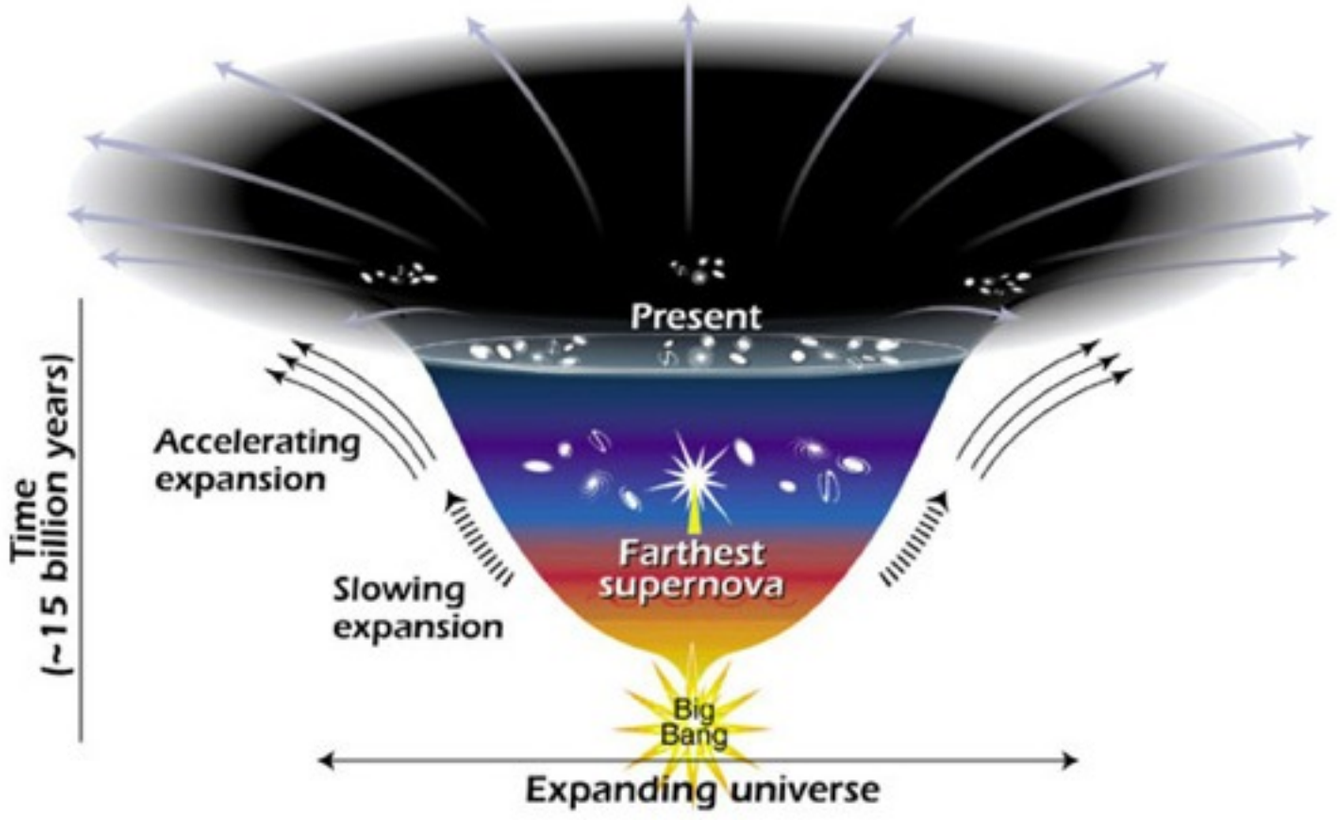
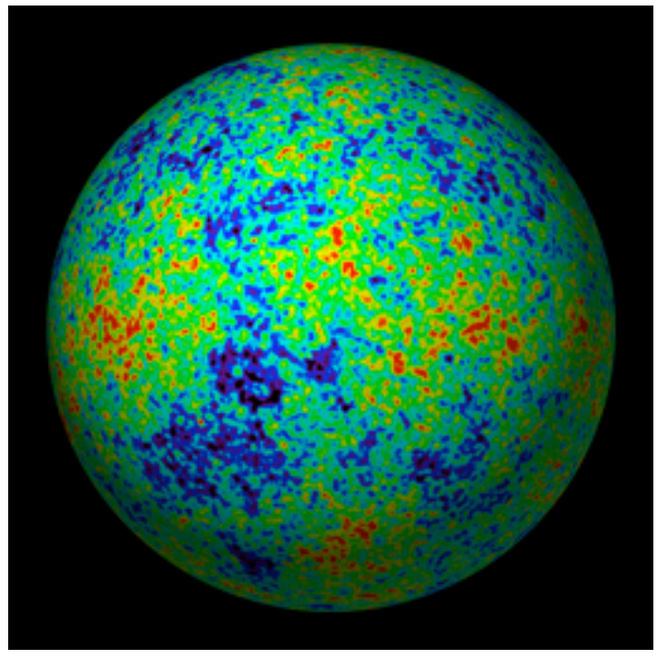




Music: The End by the Doors

Want More Cosmology?



After ASTR 150, you qualify for

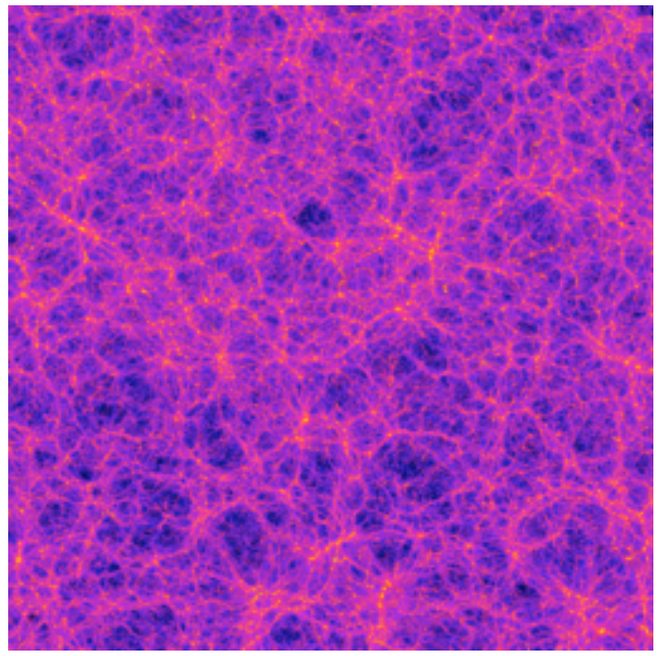
ASTR 350:

Introduction to Cosmology

- next semester: MWF 11-11:50am

Survey of modern cosmology, including

- special relativity
- general relativity
- primordial nucleosynthesis
- cosmic microwave background
- dark energy and cosmic acceleration
- inflation
- quantum cosmology
- formation of the first galaxies and stars



Prerequisite: ASTR 150 satisfies!

- no other Astronomy or Physics needed!

ICES

ICES course evaluation is now available, done online.

Please do it! I appreciate it!

- **Written comments are the most useful and important**
- **I do read the comments, and I do modify the course as a result.**
- **Note that this course is relatively new, so your comments will have a particularly large impact.**

iClicker Poll:
Hour Exam 3 Question Count

The exam will be multiple choice.

You will have the usual 50min of classtime:

no more, no less.

How many questions should be on the exam?

A. 20 each question: 5% of total score, avg time 2min 30sec
B. 25
C. 30 class choice for # questions on Exam 1
D. 35
E. 40 each question: 2.5% of total score, avg time 1min 15sec

just so we are totally clear...

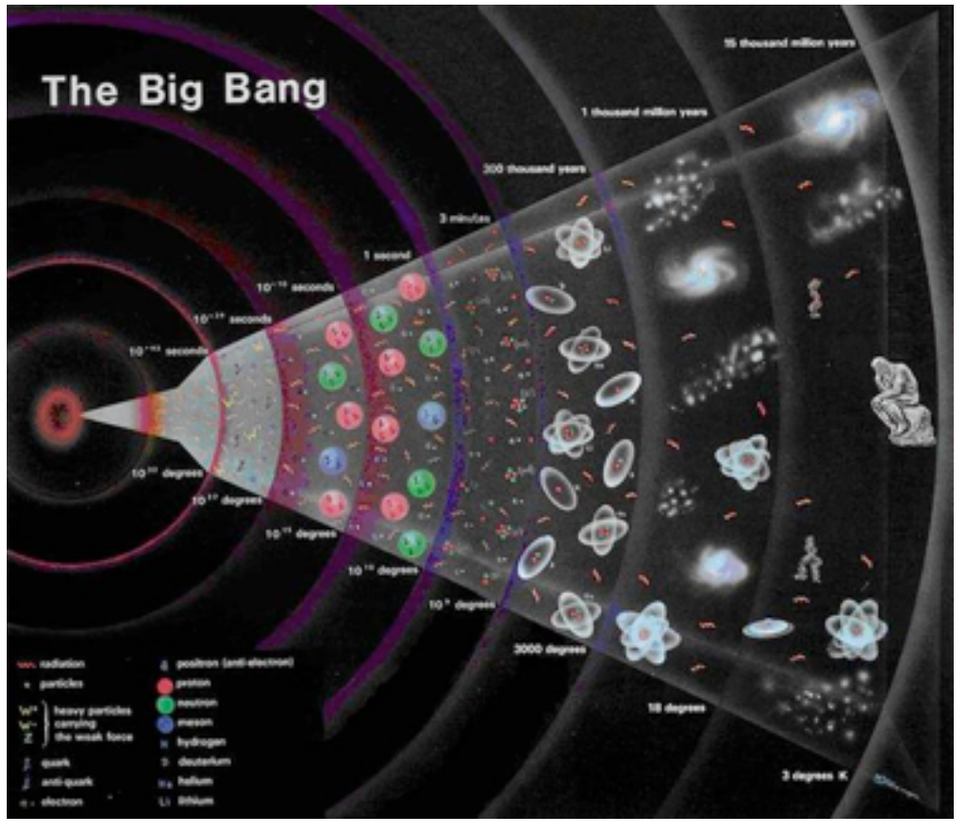
Hour Exam 3
in class
Wednesday!

This will conclude the course
Nothing during finals week

Recap: Cosmic Past

Today t = 13.7 billion years: Universe is expanding

- **as time goes on:**
  - **cools**
  - **gets less dense**



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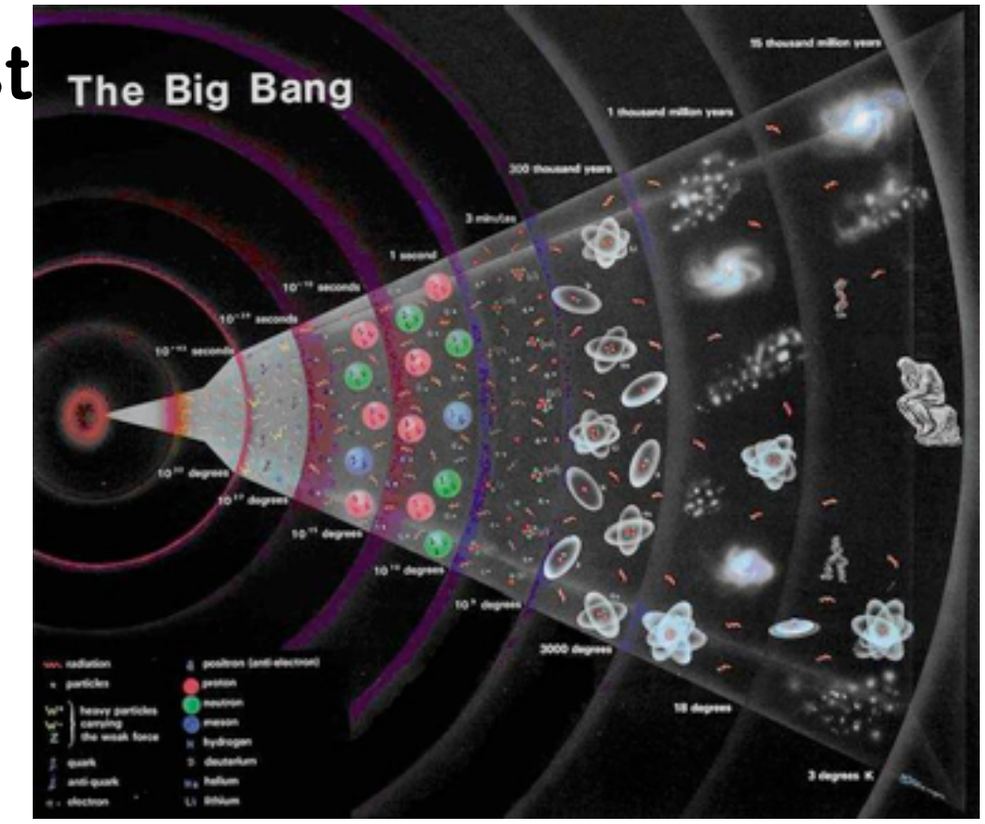
- **cosmic ingredients broken down into more and more basic parts**



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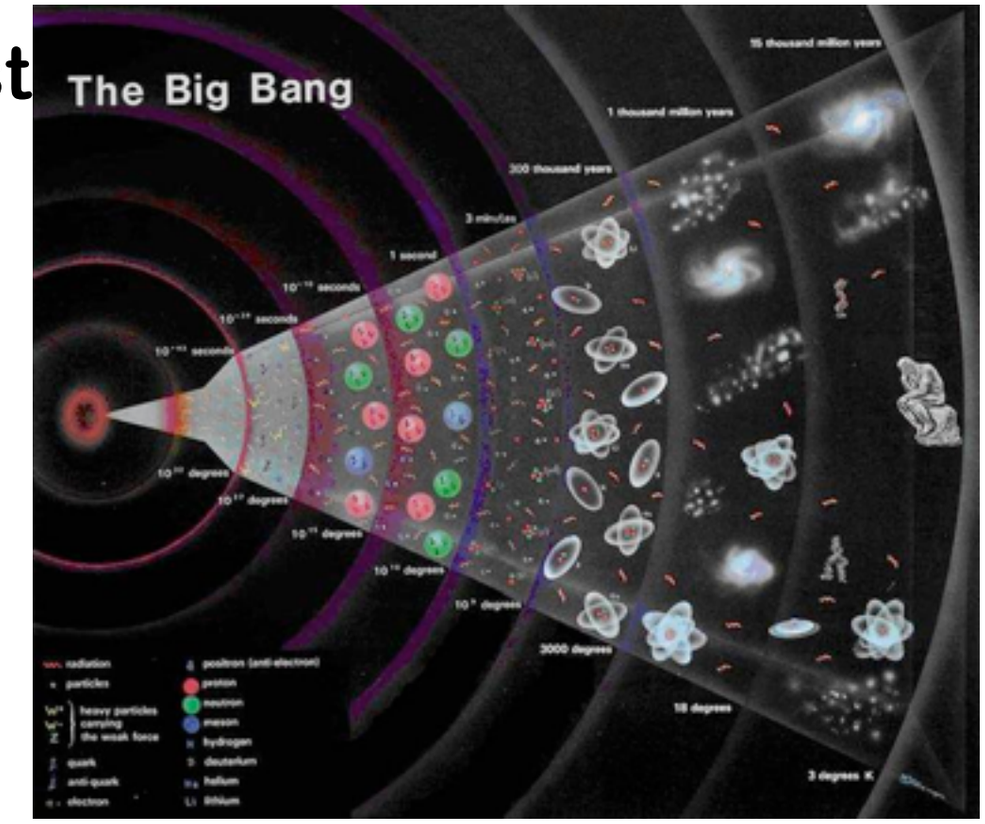

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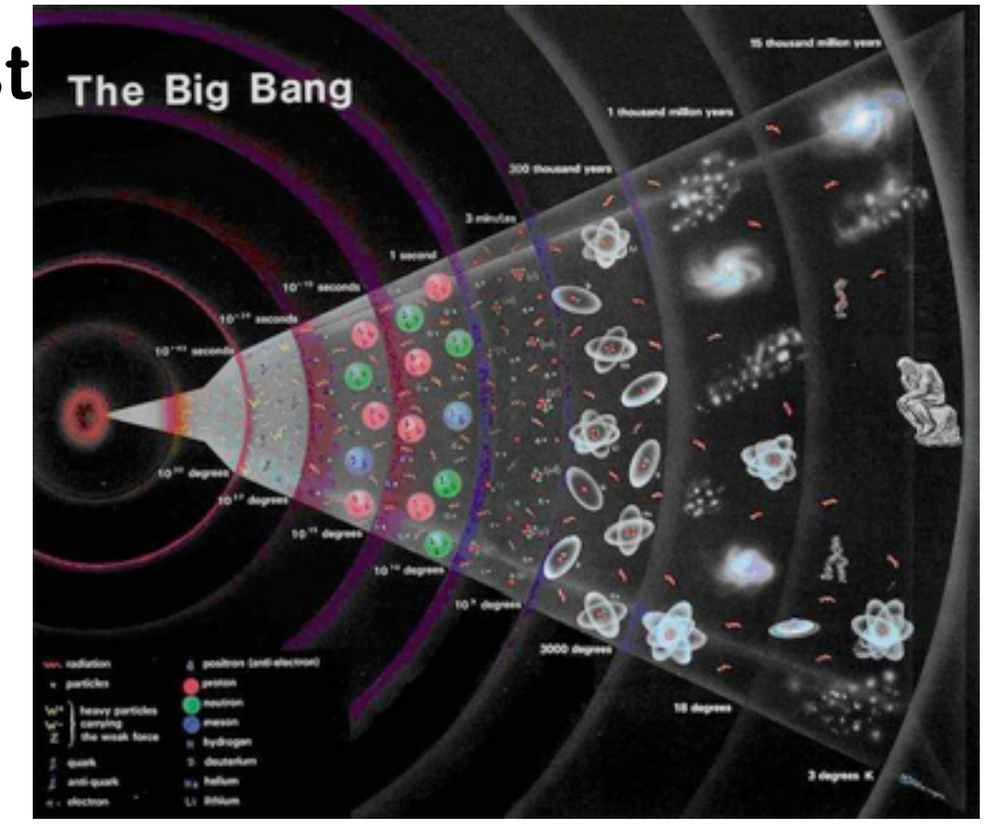

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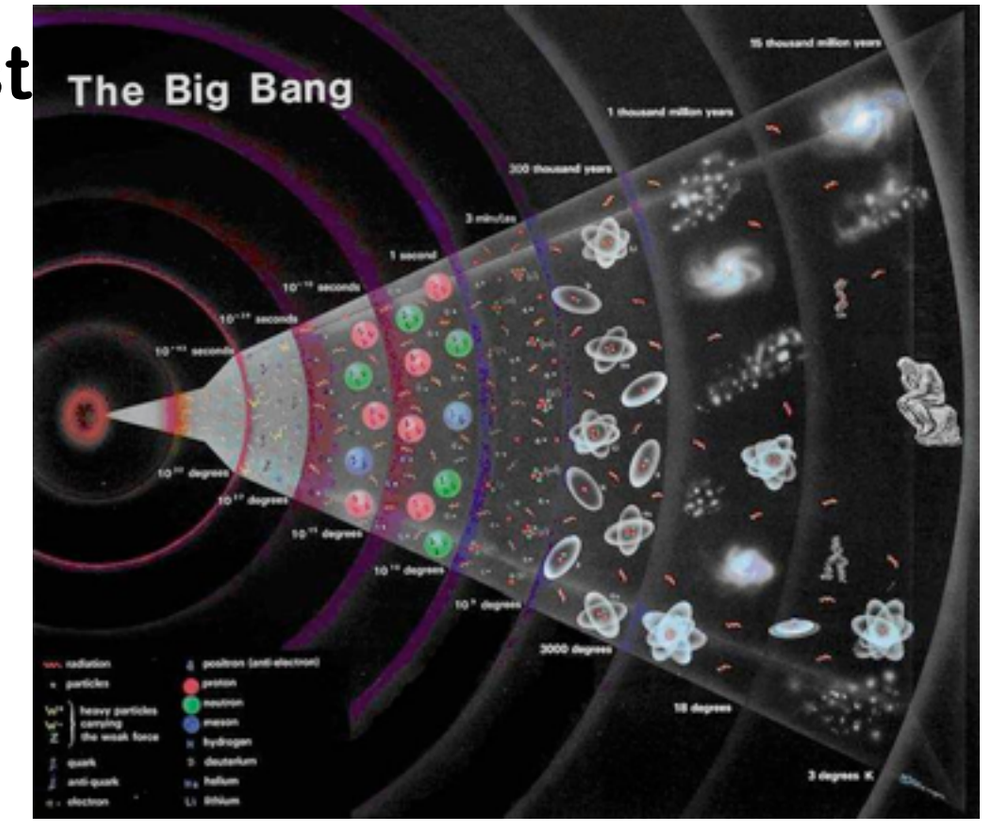

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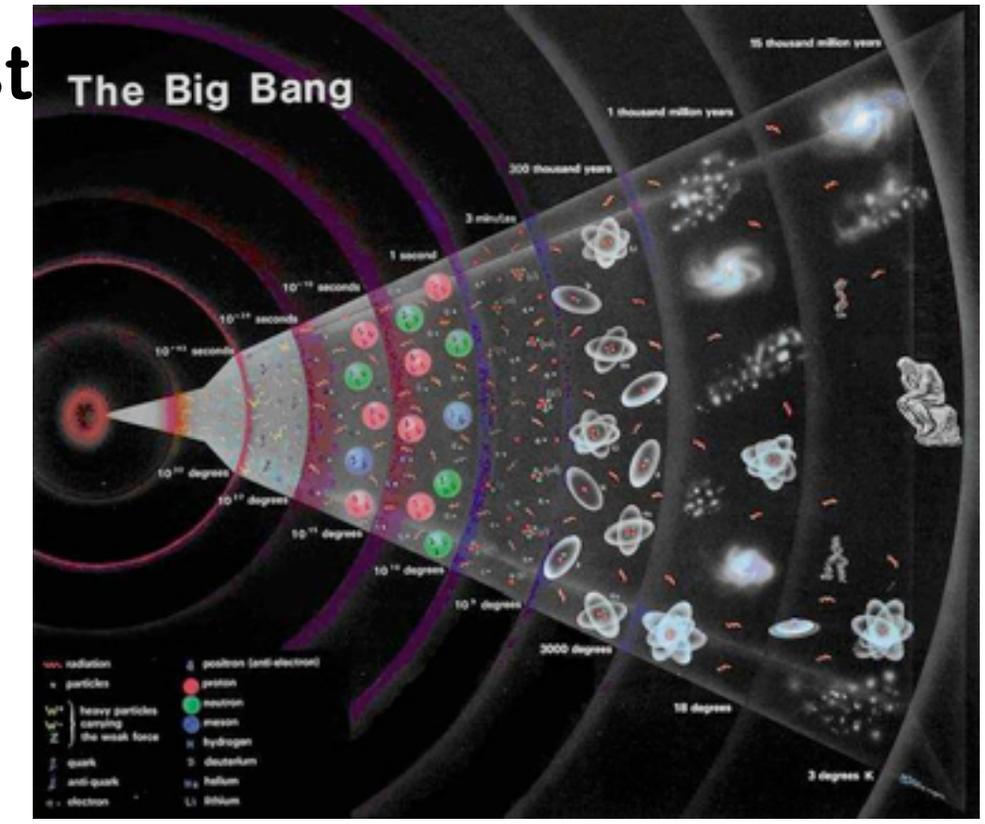

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- **t = 0: big bang**
  - conditions too extreme for currently available theories

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Future of Universe set by competition

- gravity: inward pull of galaxies, versus
- expansion: outward inertia

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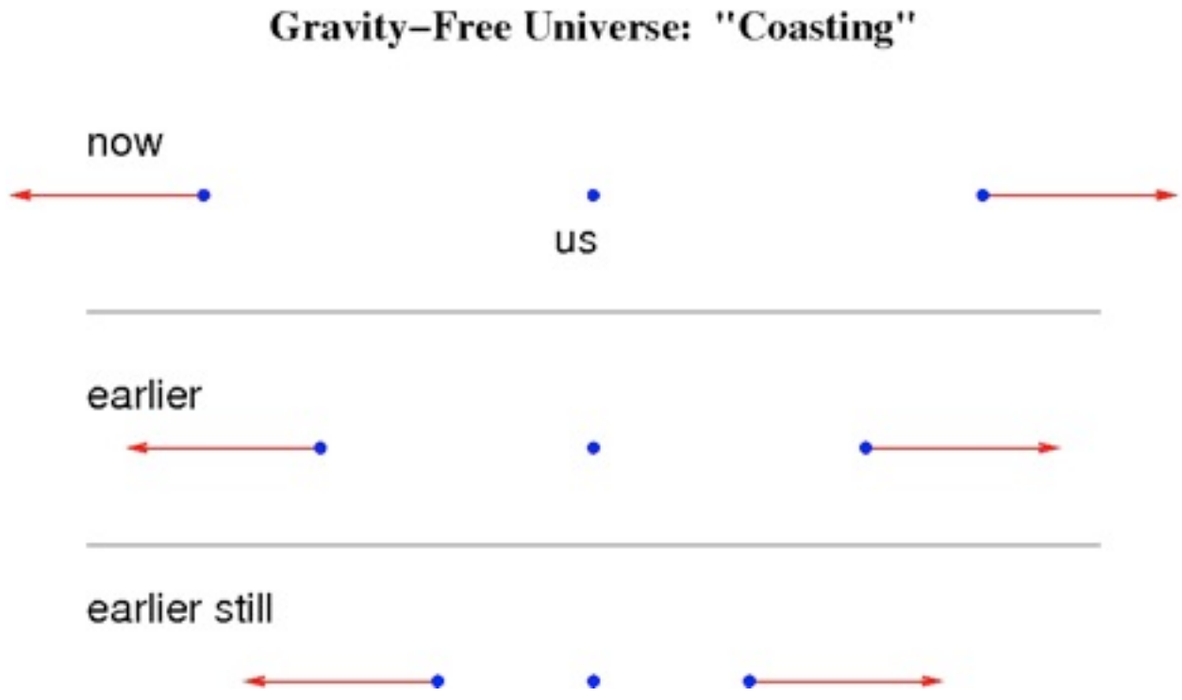

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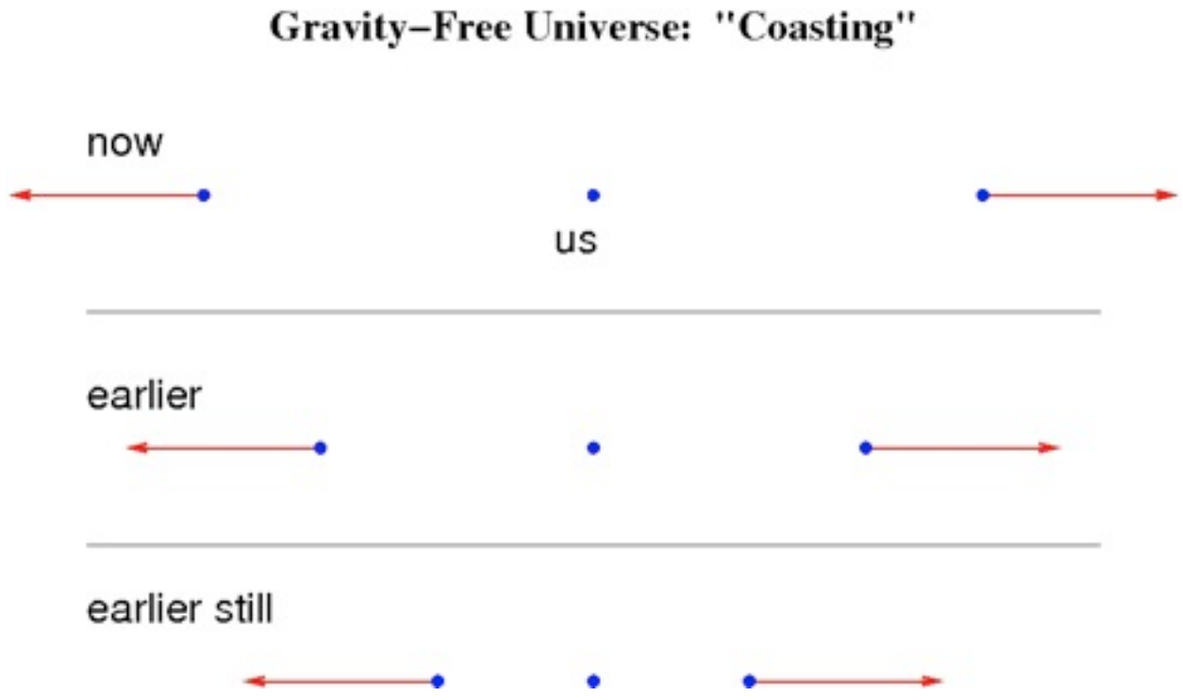

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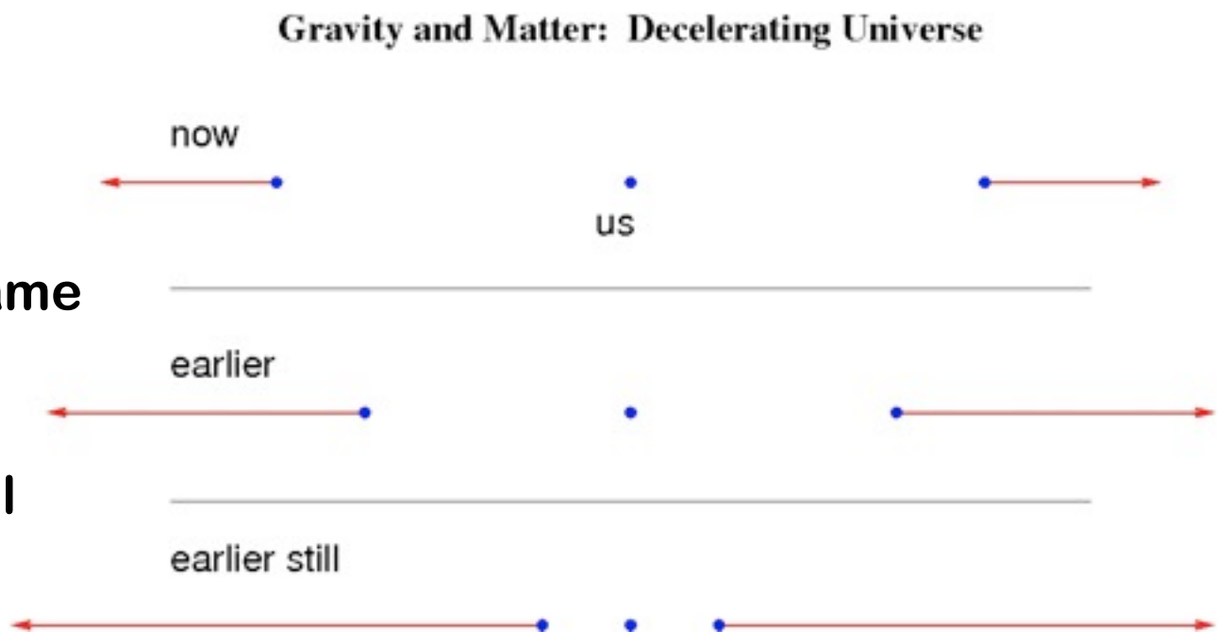
Expansion and Gravity

- if gravity "switched off": galaxies coast with same speed
  - expansion neither accelerated nor decelerated
- but with gravity: galaxy masses attracted by all other galaxy masses
  - pull of gravity should slow galaxies down
  - expect expansion to be faster in past, slower in future



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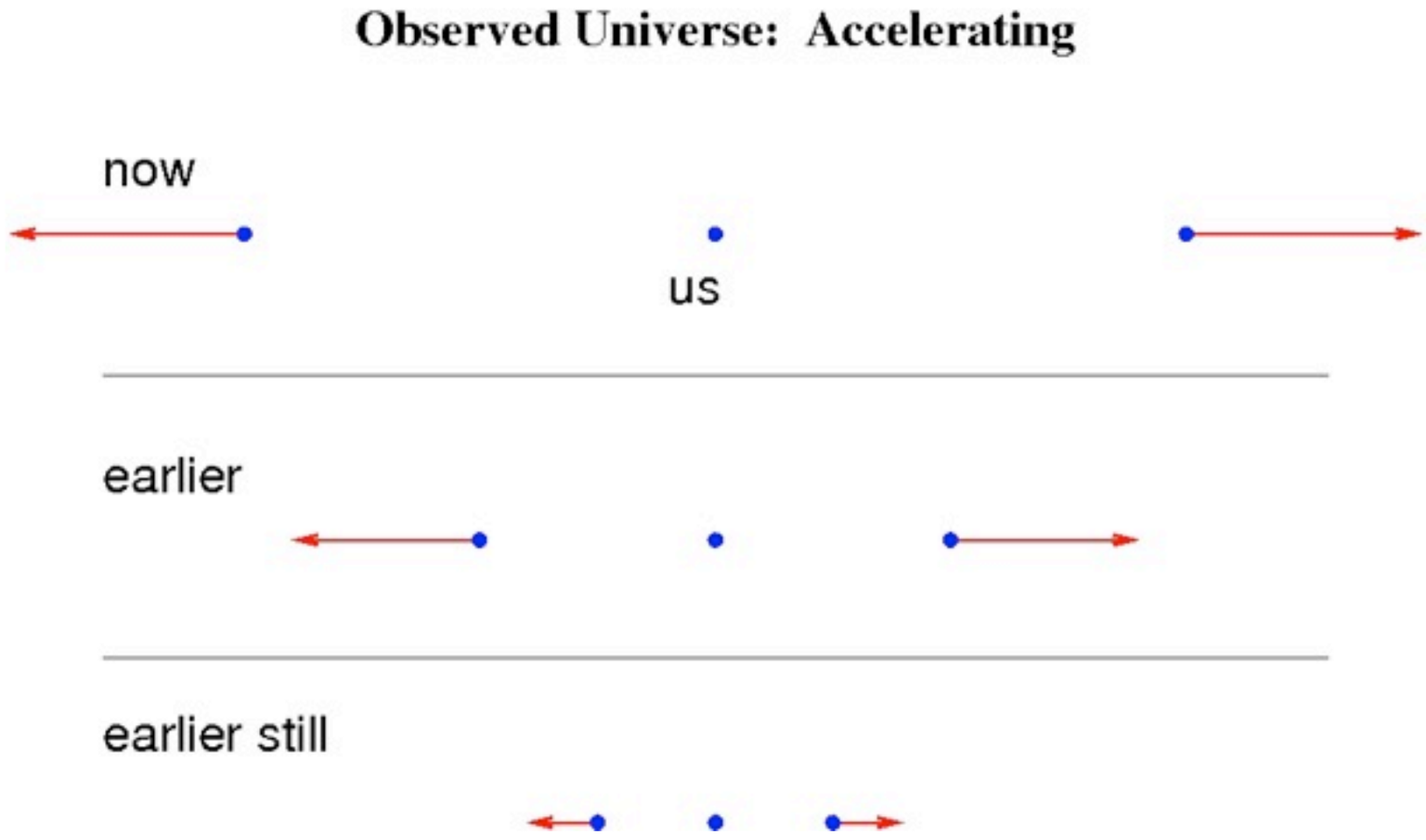

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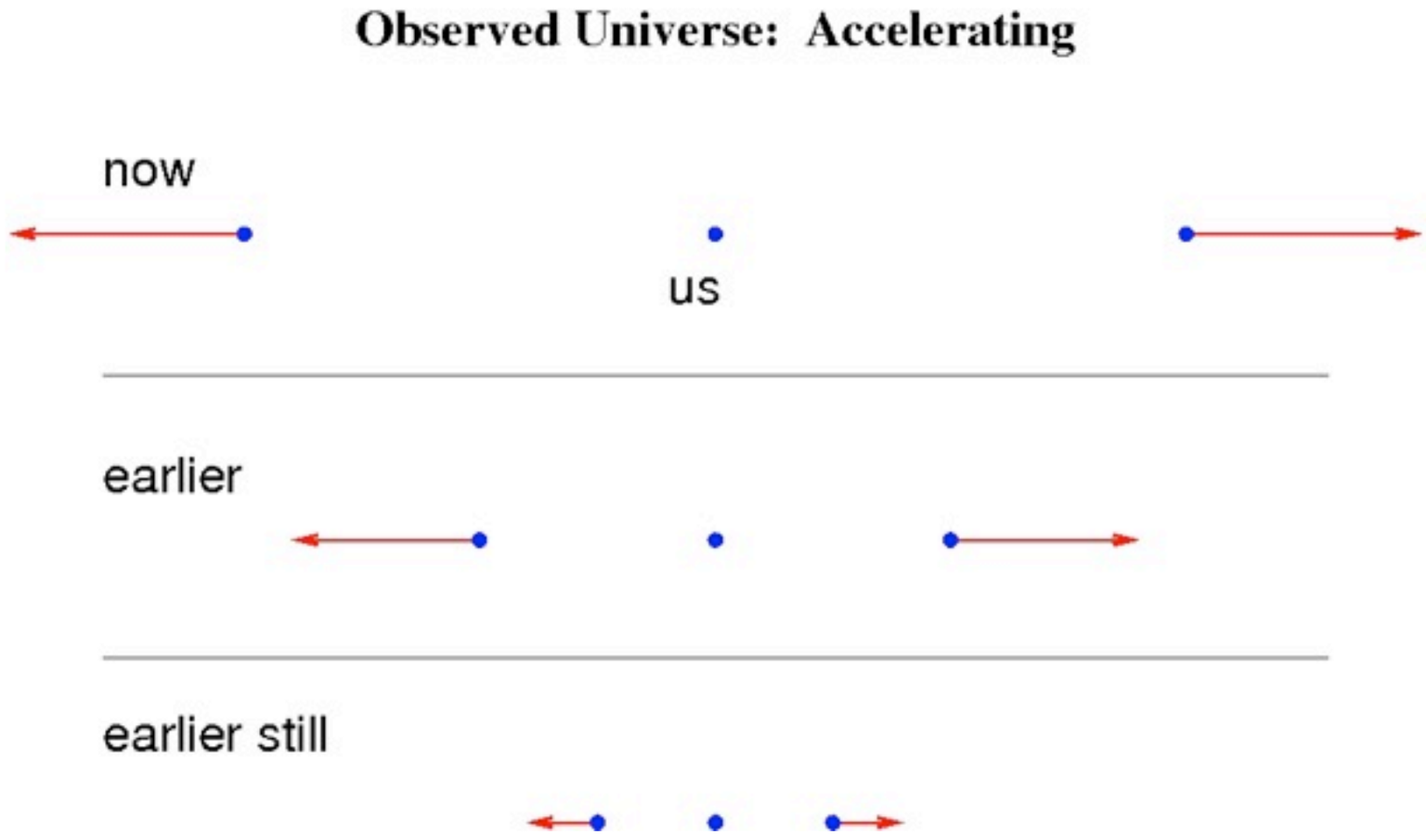
  like pop fly leaping out of your hand and away from Earth!?



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acceleration requires gravitational repulsion

- "antigravity"
- no known substance does this!
- but some energy fields expected to have this property

  ...fields similar to the Higgs field!
- this energy field must be dark or else we would have seen it already

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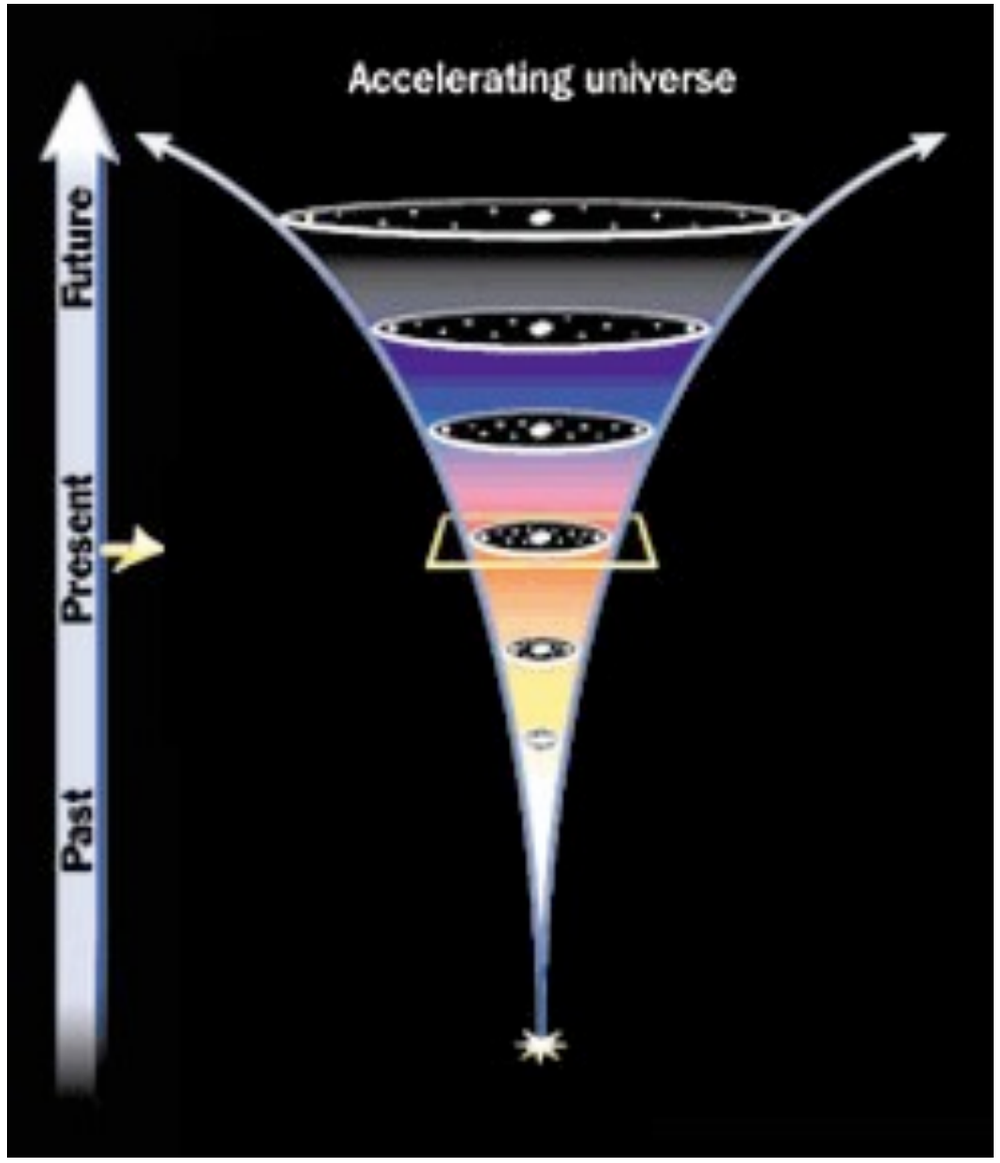
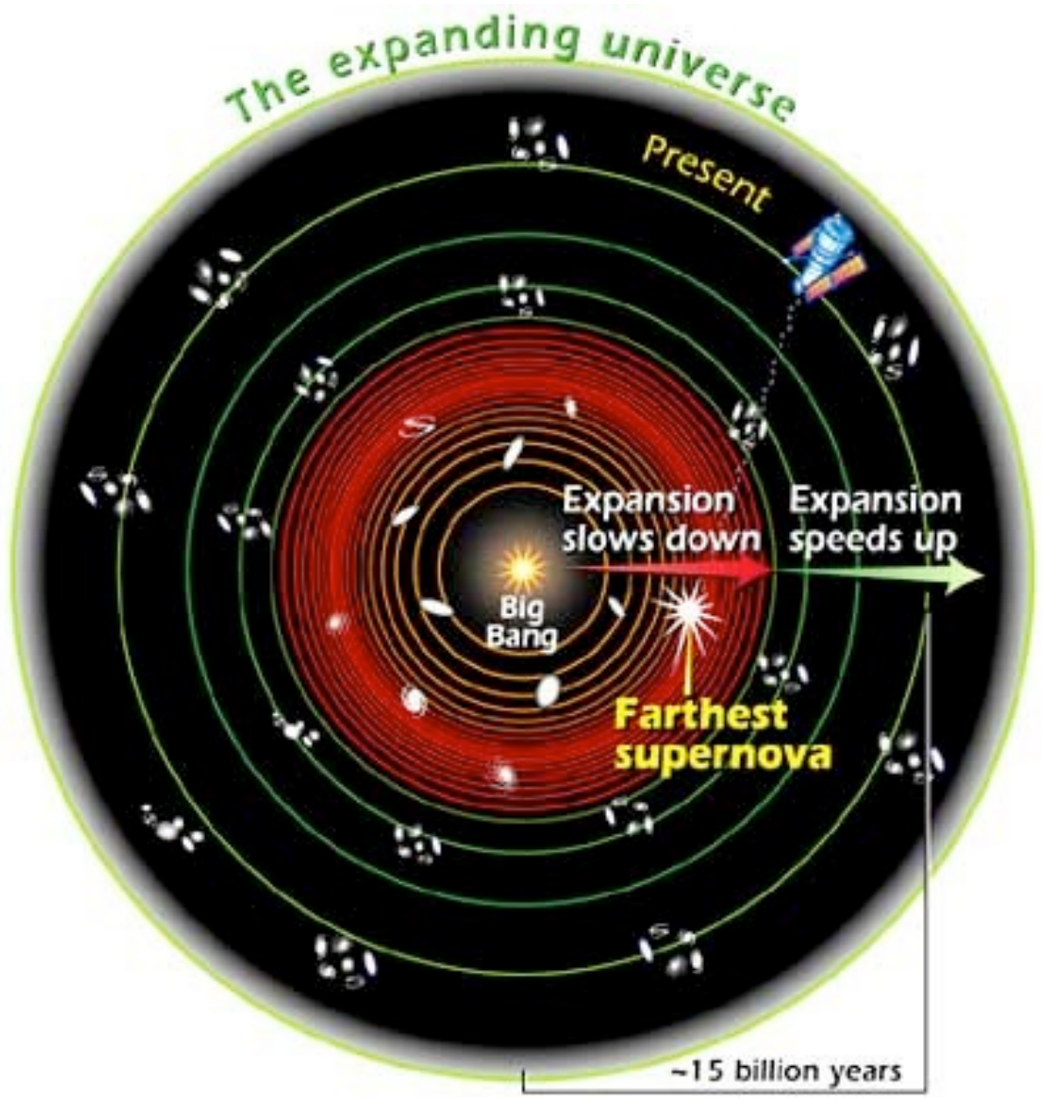
so acceleration seems to require an accelerant:

- dark energy

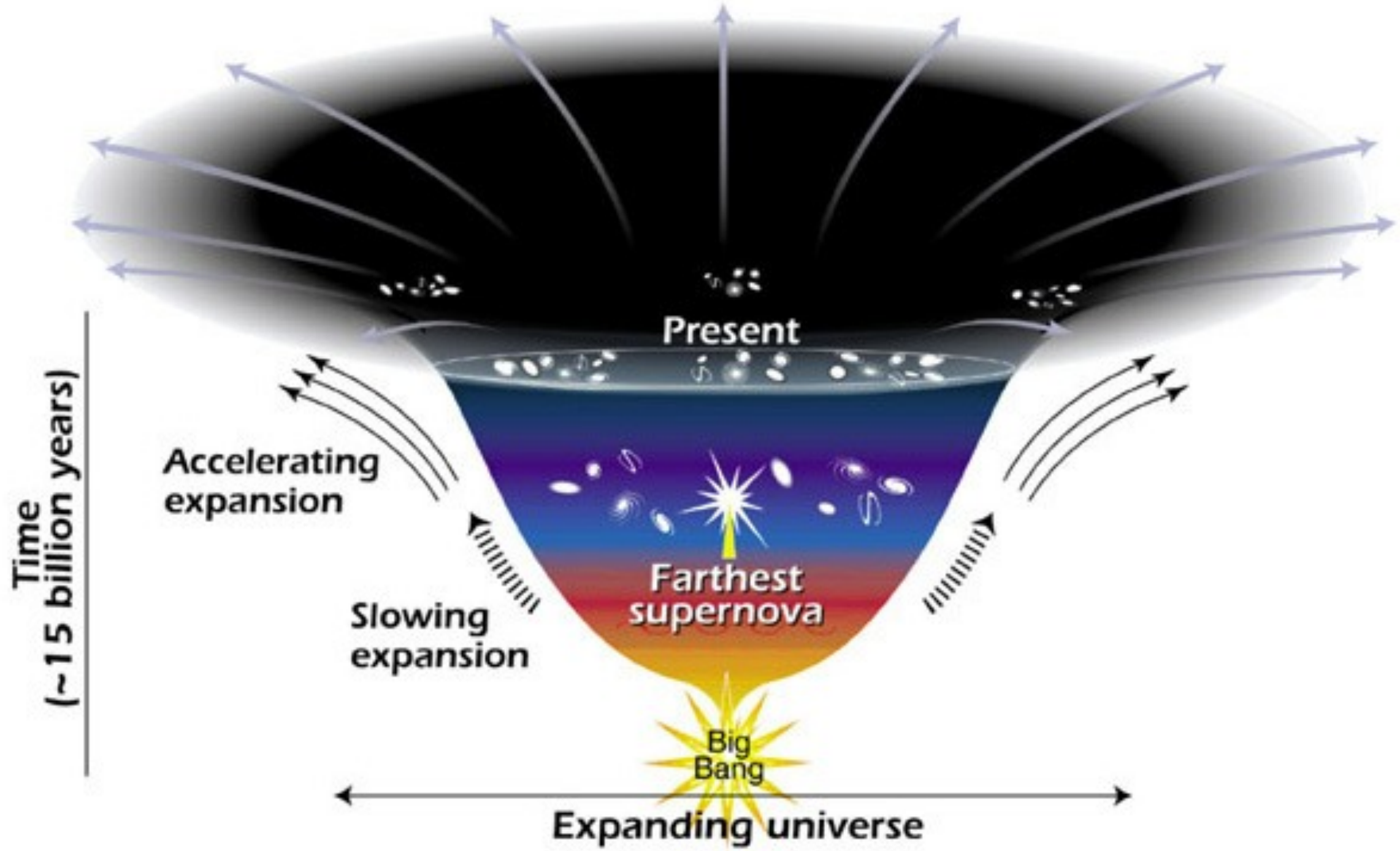
The Accelerating Universe!?!?





Whatever this repulsive Dark Energy is, its density appears to change very little as the universe expands (might even become stronger!). The more empty space in the universe, the greater the acceleration – as if the vacuum of space has energy (!).

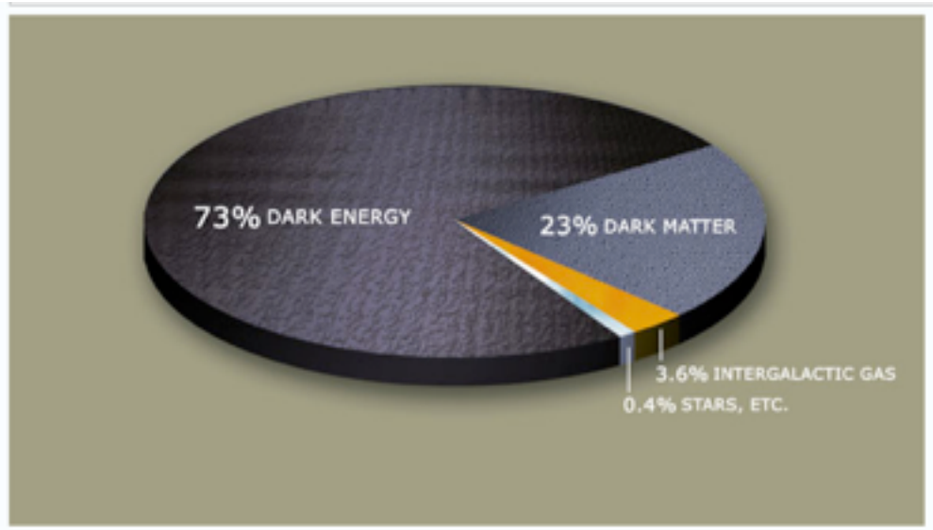
Effects of Dark Energy

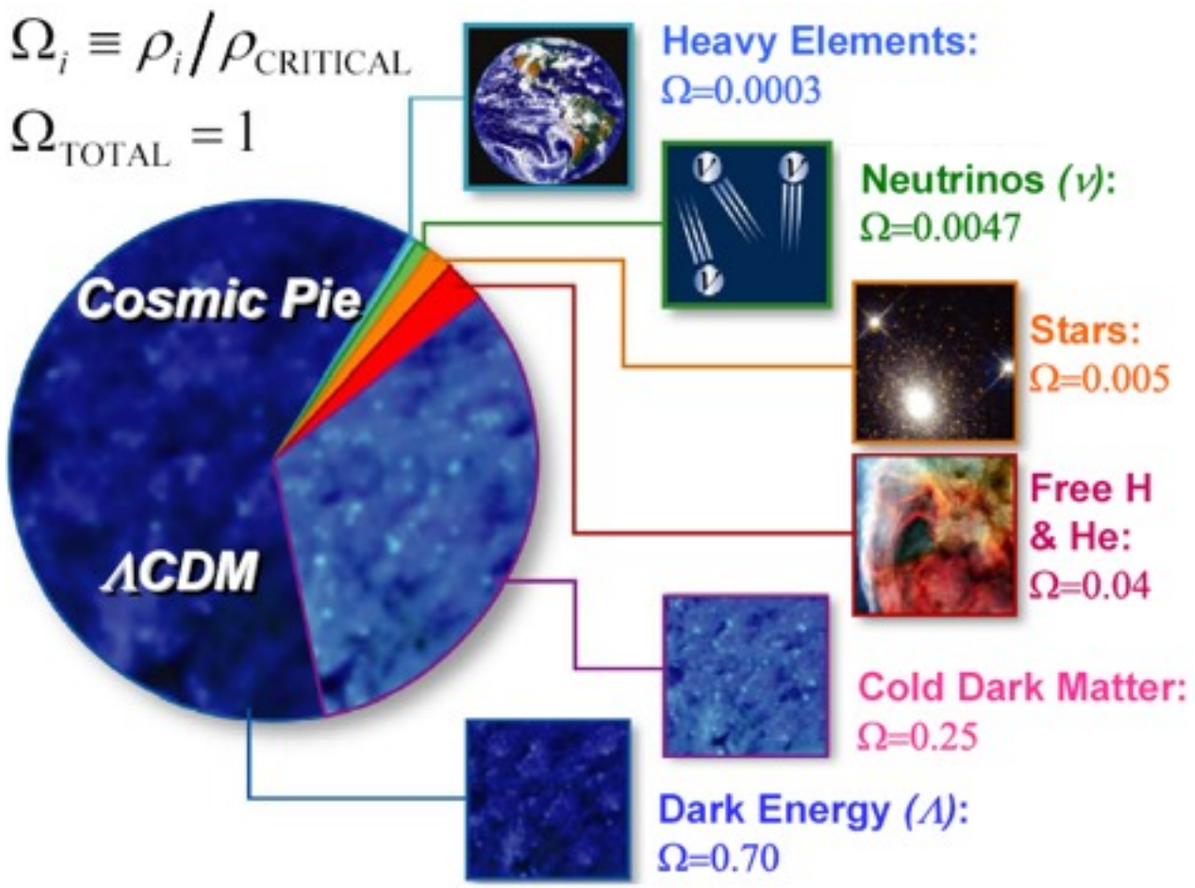


http://www.lbl.gov/Publications/Currents/Archive/Apr-06-2001.html

The Accelerating Universe!!!

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





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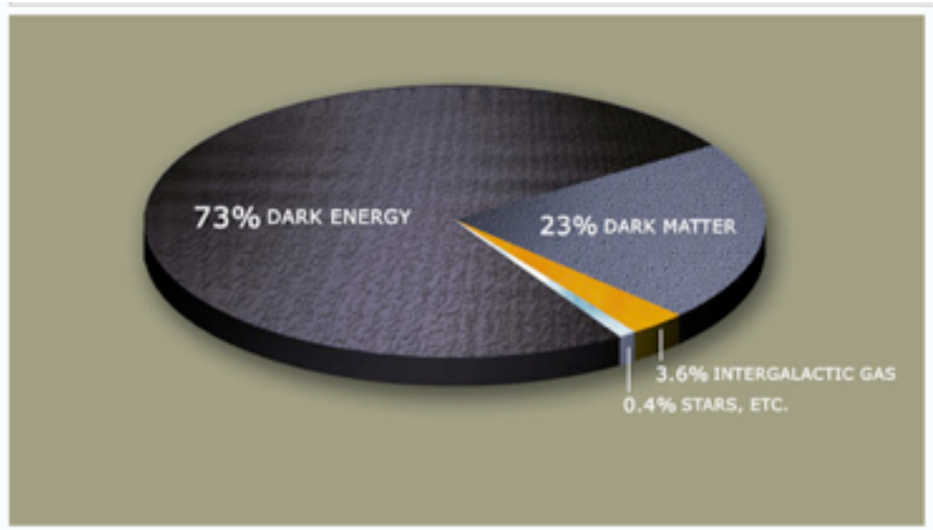
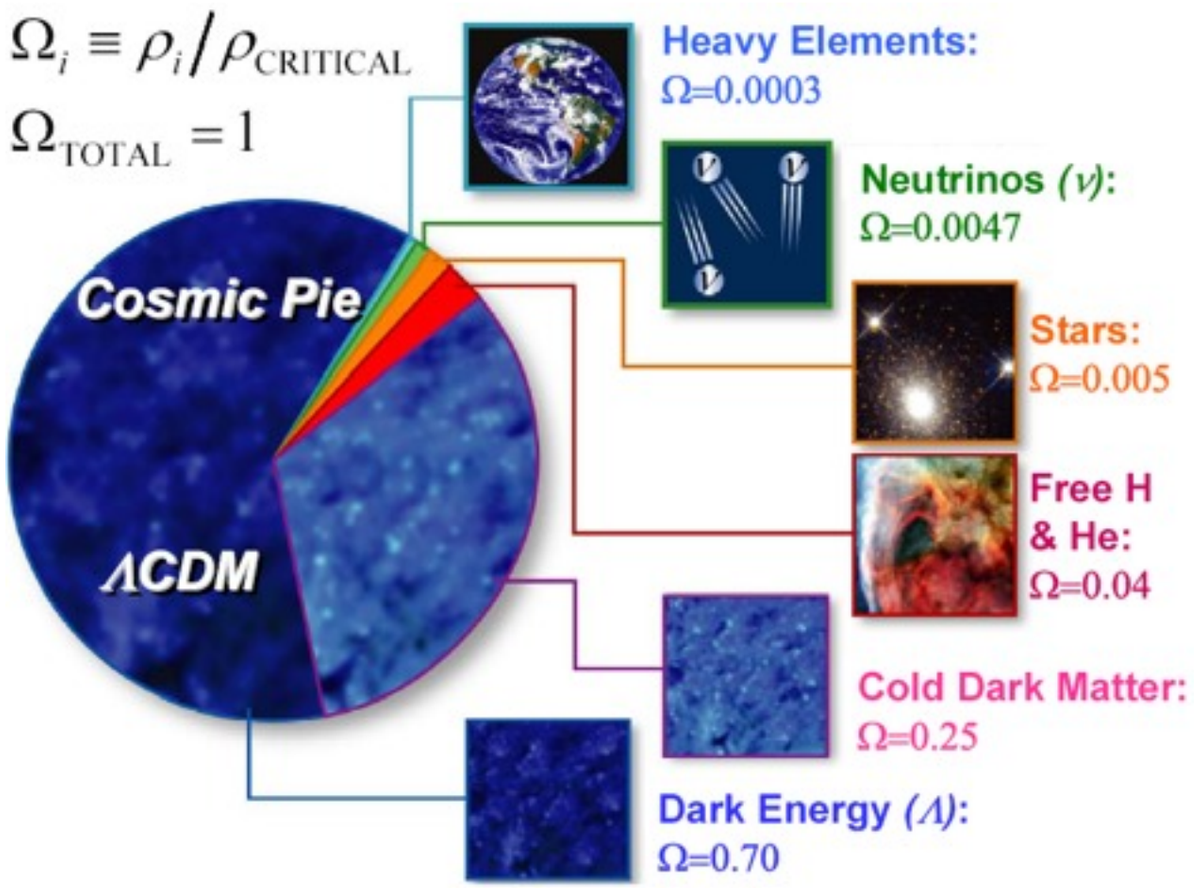
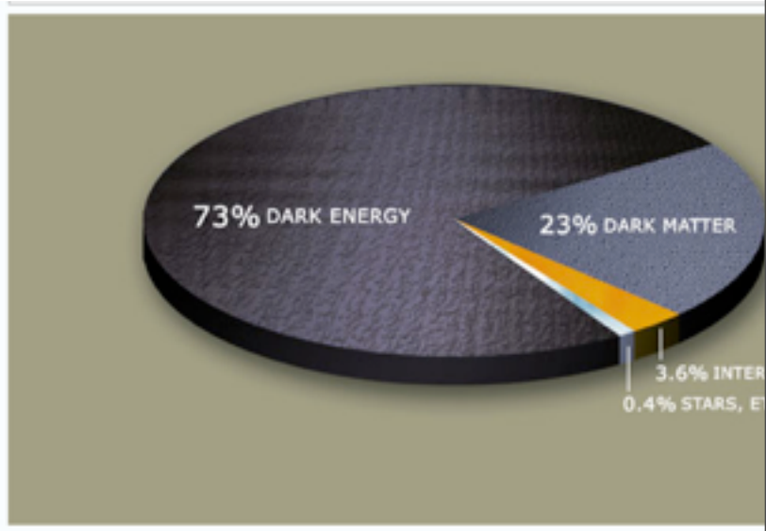




Dark Energy even dwarfs dark matter! Regular matter (atoms) are really insignificant. We really don't know anything about what's going on!!

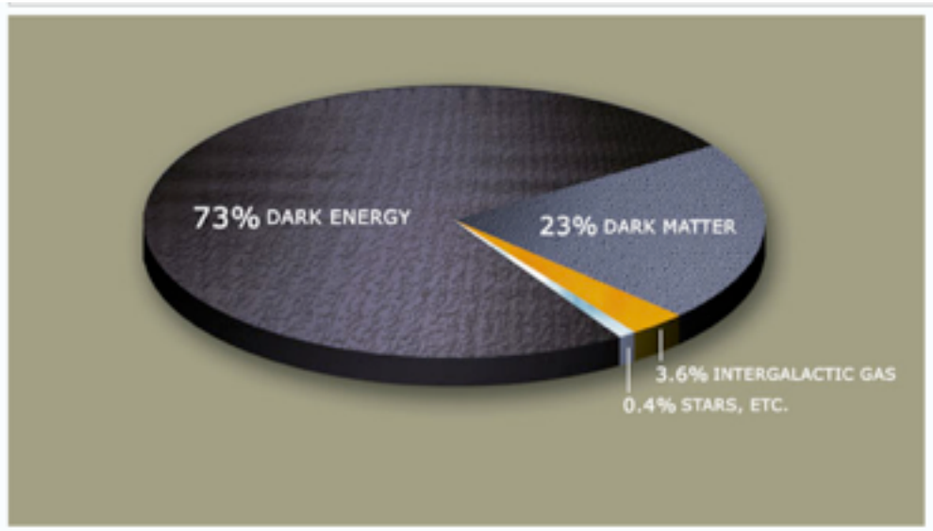
The Accelerating Universe!!!

- But, we are still in very speculative times here.
- How the Universe ends will depend on the nature of Dark Energy.
- If it really is constant as the universe expands, then we live in a 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

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- You'd get ripped apart!
- Yikes.

The Big Rip Foretold

Cosmologists Harold Ramis & Bill Murray

Ghostbusters (1984)

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

Cosmologist Woody Allen

Annie Hall (1977)

http://www.youtube.com/watch?v=3Pa34orcwwA

The Distant Future:
The Big Crunch

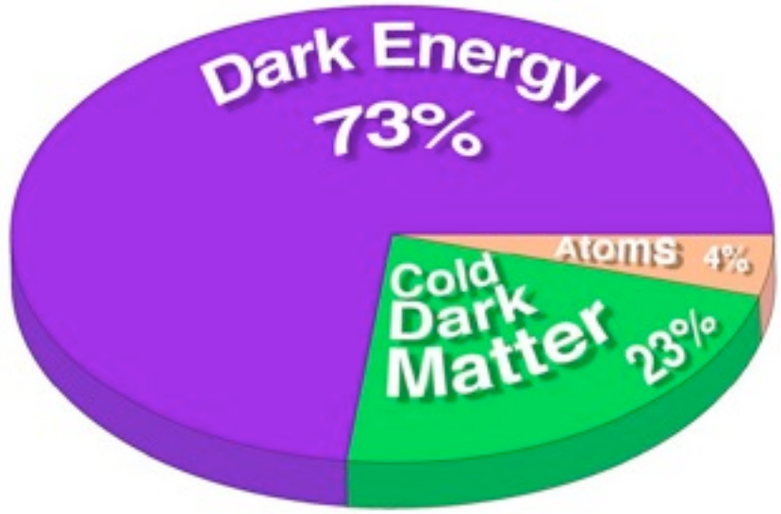
Another extreme case, is if the nature of Dark Energy changes and we re-collapse afterall.

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.



iClicker Poll:
Your Preferred Cosmic Fate

We have no control over the fate of the Universe

But if you could have a say:

What is your preferred cosmic fater?

A. Big Chill

B. Big Crunch

C. Big Rip

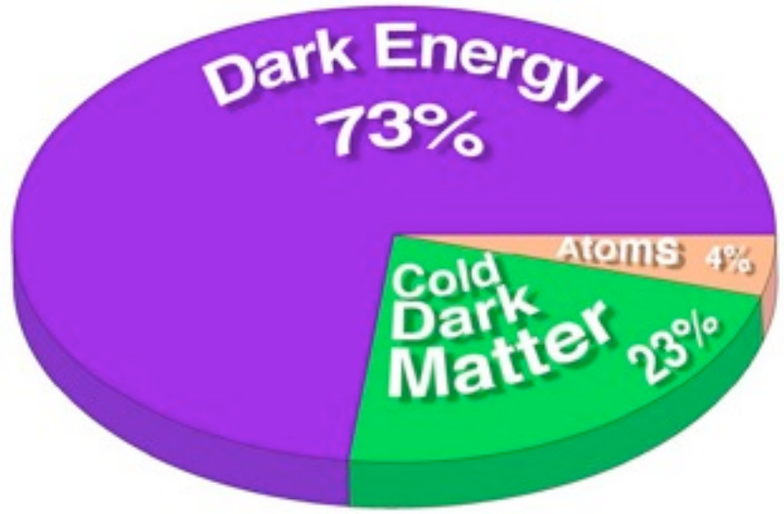
The Distant Future:
The Big Chill

From what we know right now, we think that the Big Chill fate is most likely.

The universe may well accelerate forever

A bleak but 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

The Age of Stars

- this includes now! ($t = 1.4 \times 10^{10}$ years)

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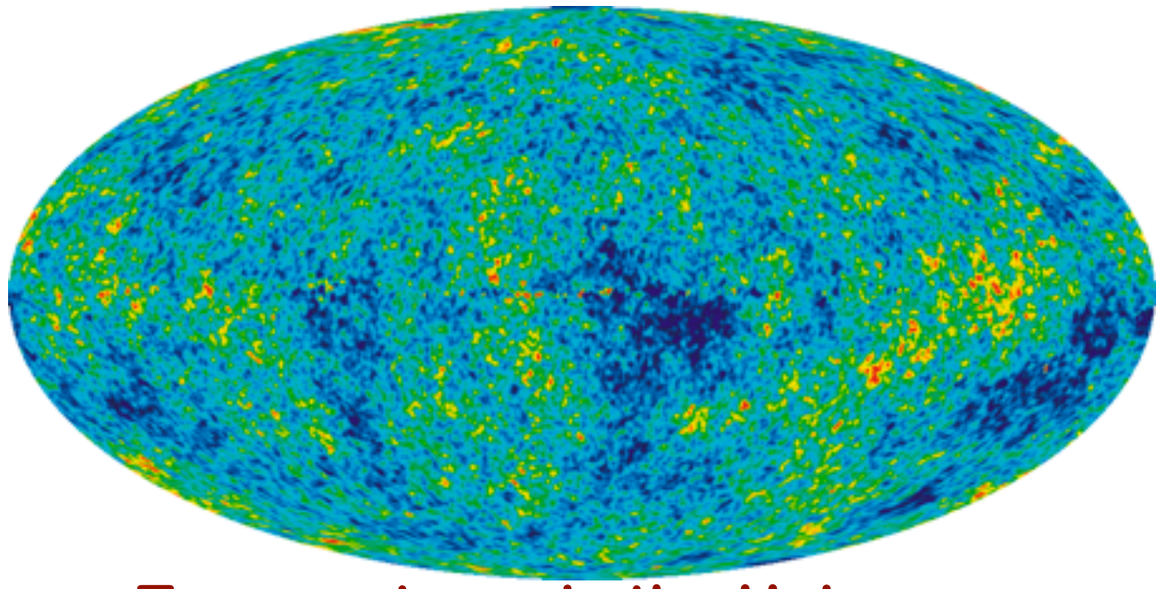

Temperatures in the Universe
t = 380,000 years
small fluctuations, ultrahigh contrast

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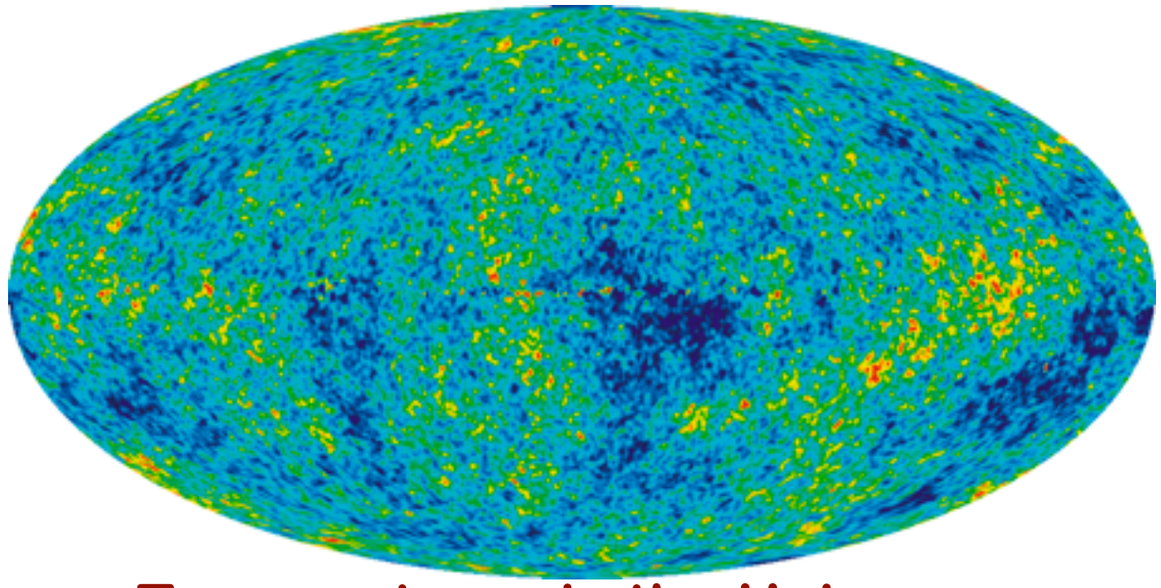

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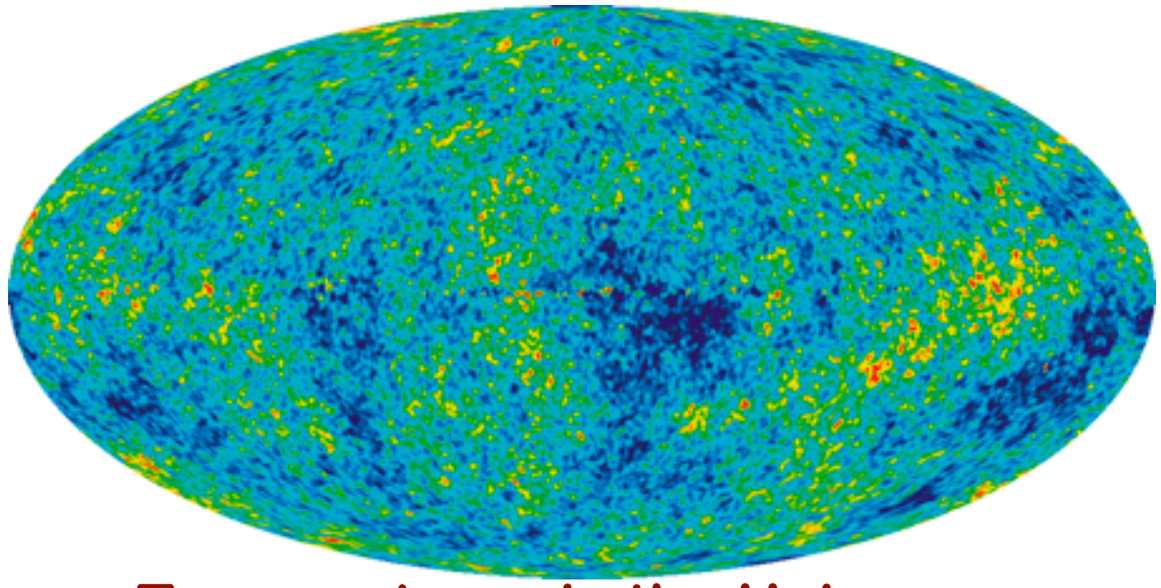

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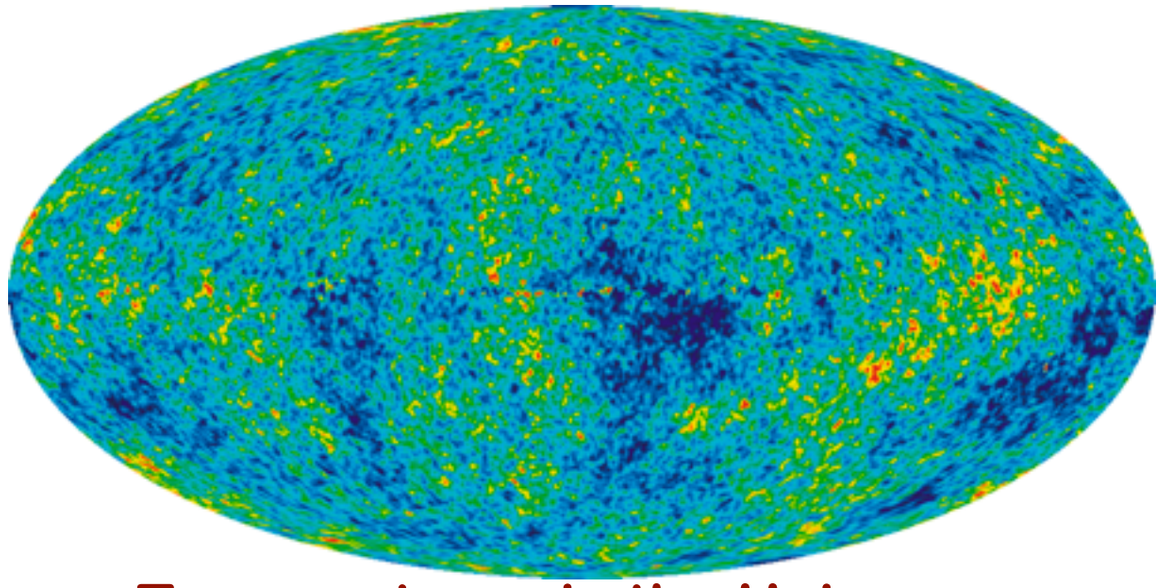

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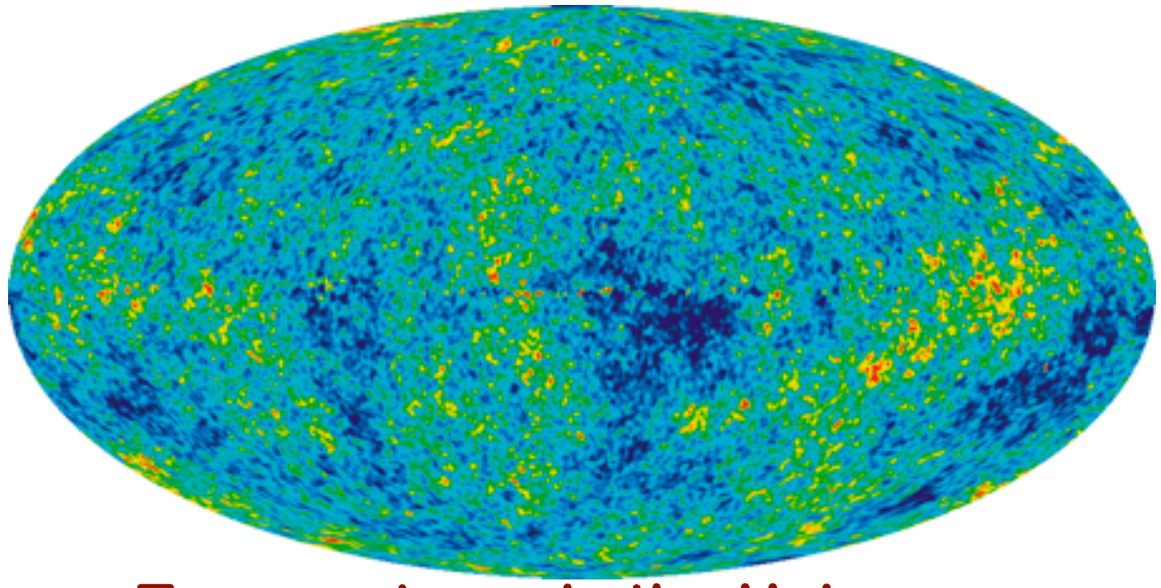

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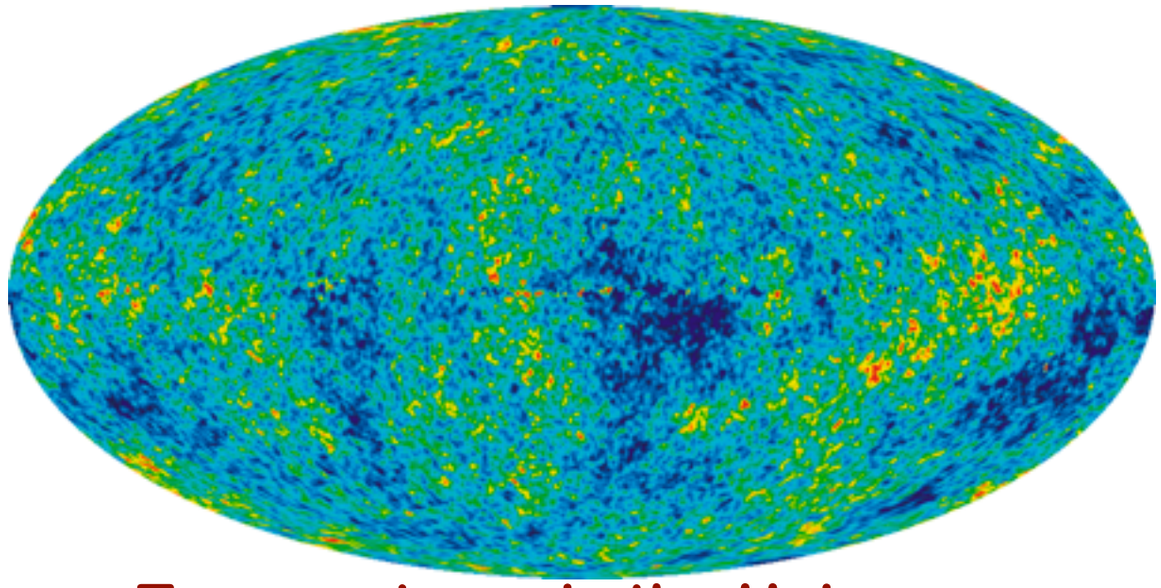
By today:

- small density fluctuations have become the small-scale lumpiness we see in the Universe today
- so temperature fluctuations in CMB are the "ancestors" of galaxies, stars, and us!



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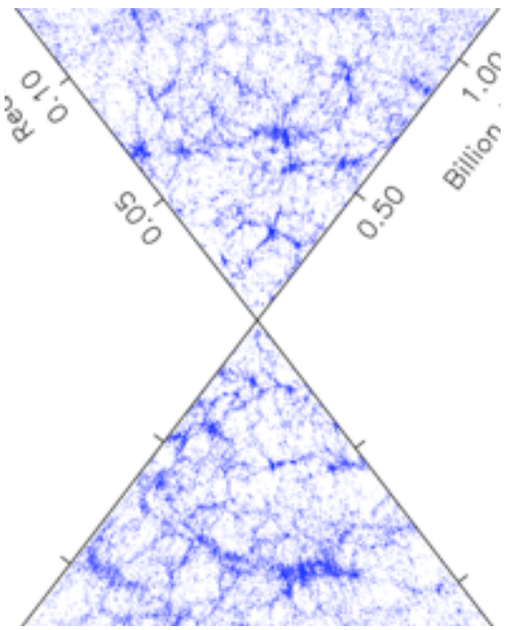


Map of the Universe today
t = 13.7 billion years
large fluctuations on small scales

The Cosmic Web

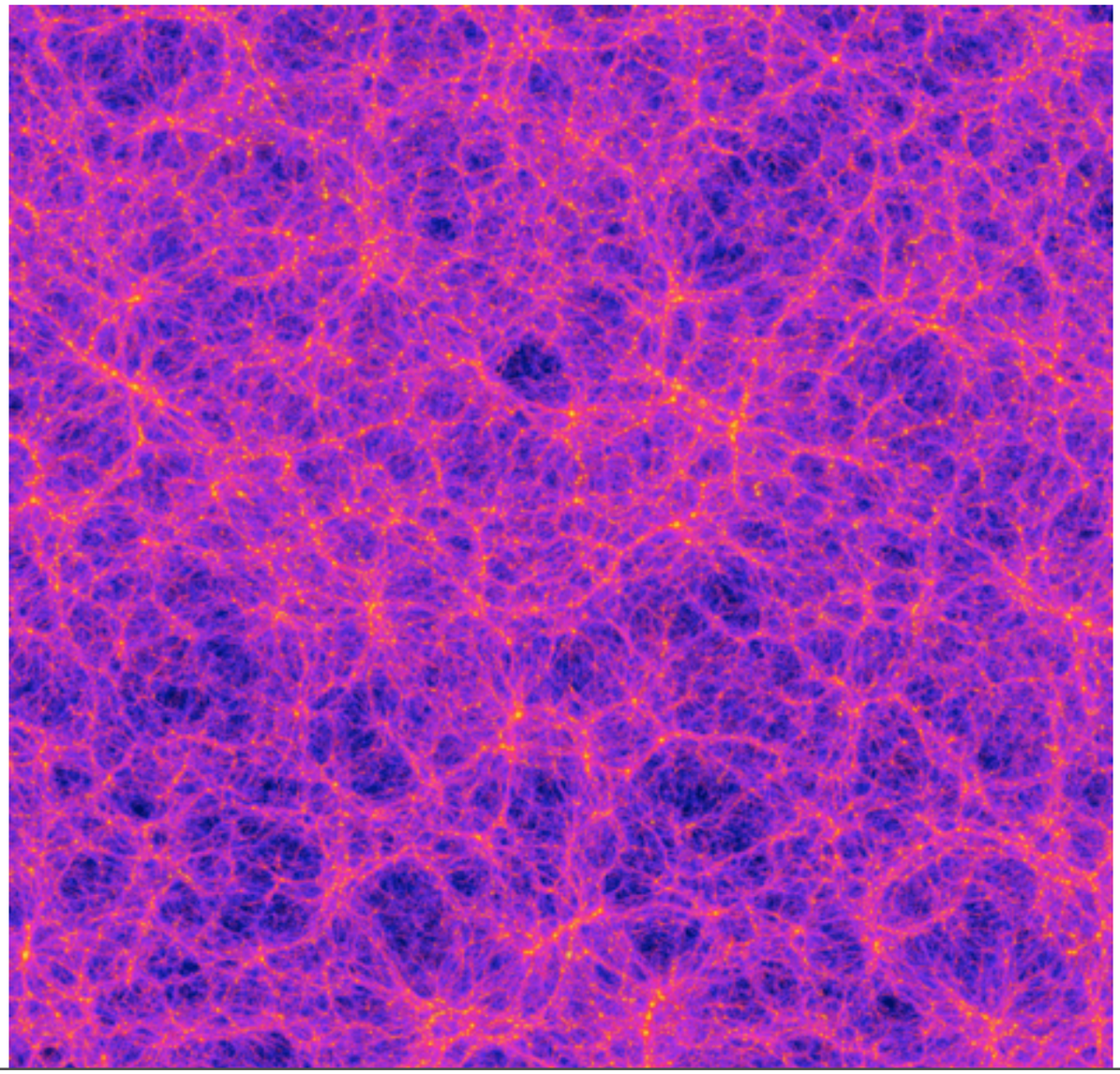
Simulations of the growth of structure and galaxies

- **Dark Matter only**

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

- **Dark Matter and ordinary matter (gas and stars)**

  http://vimeo.com/13816367



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 accelerating, 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 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.

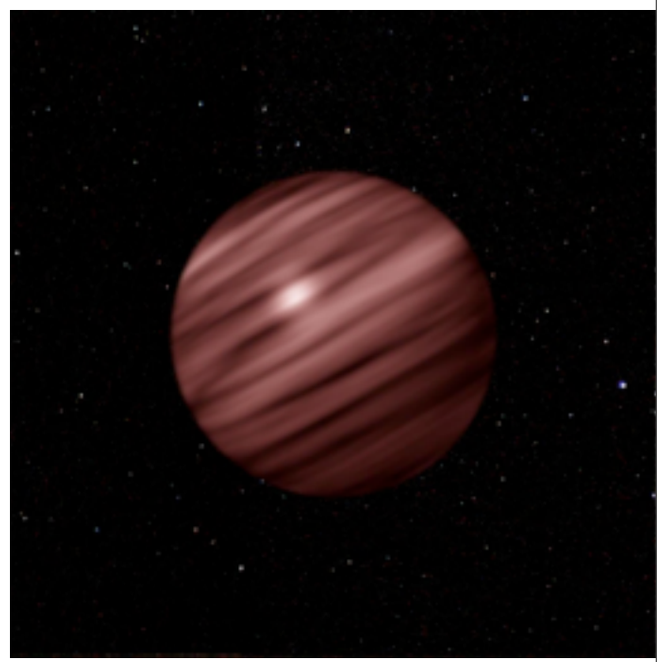
When the Universe is slightly older than 100 trillion years old, the human race is out of fuel, out of stars, and out of luck.

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.

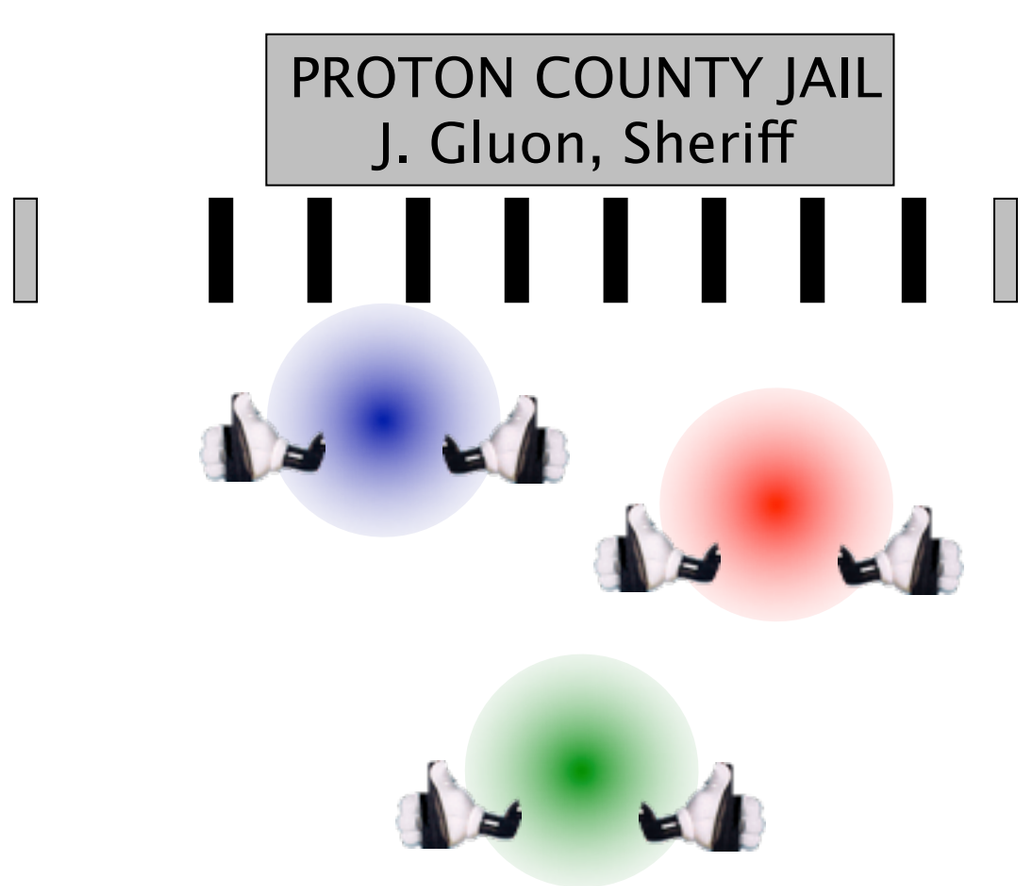
- **Interactions with the stellar corpses, cause all the low-mass objects to be ejected from Galaxy.**
- **High-mass objects fall to the center.**
- **Supermassive Black Hole feeds!**

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

In very early universe:

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



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Little chance of parole

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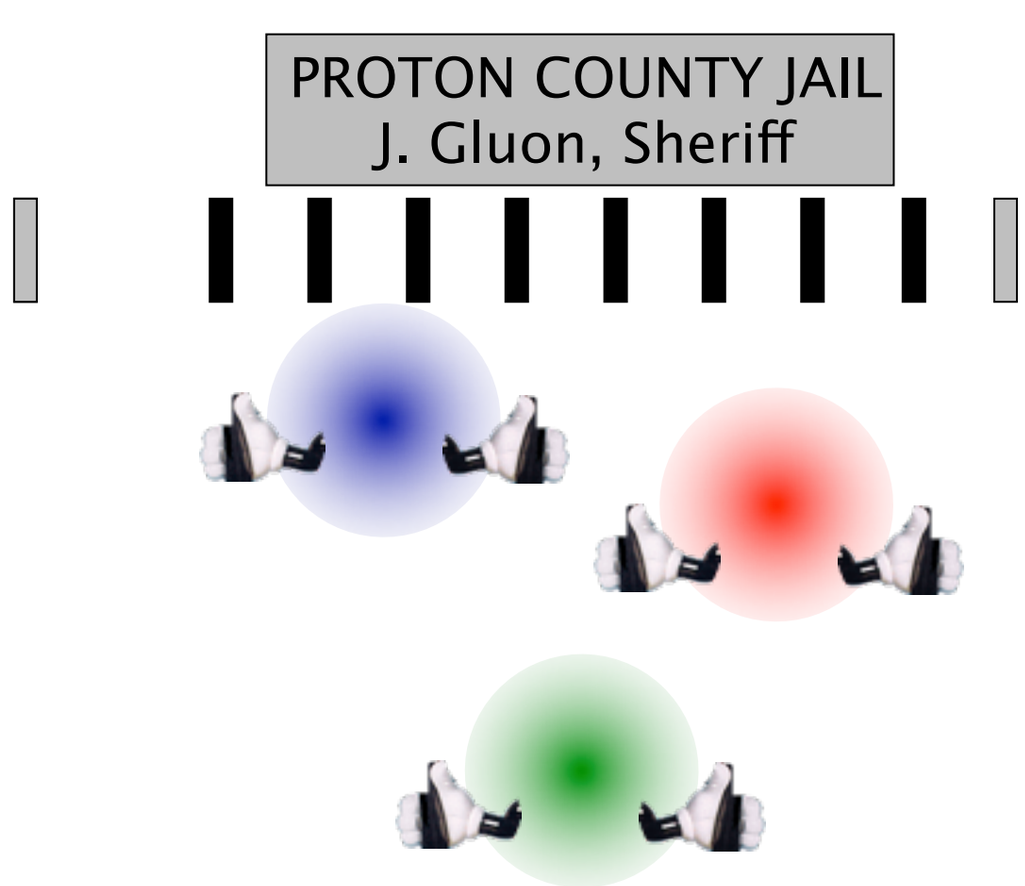

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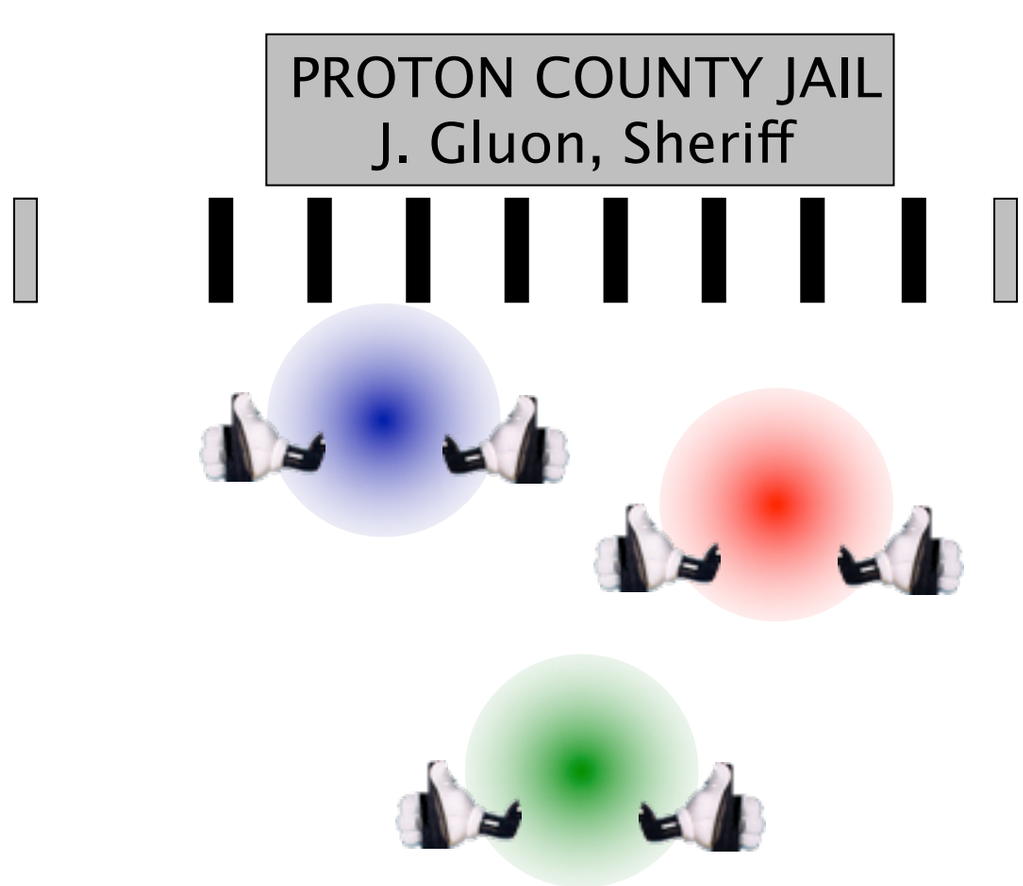

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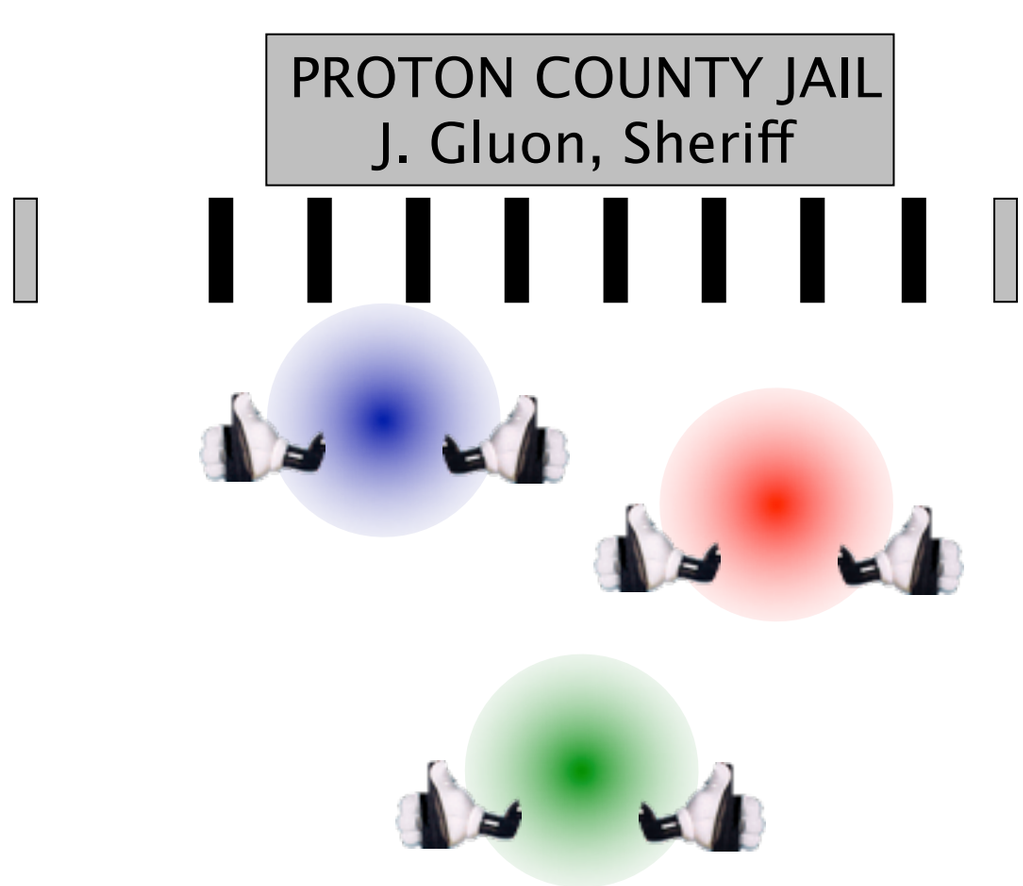
Time is all that is left.



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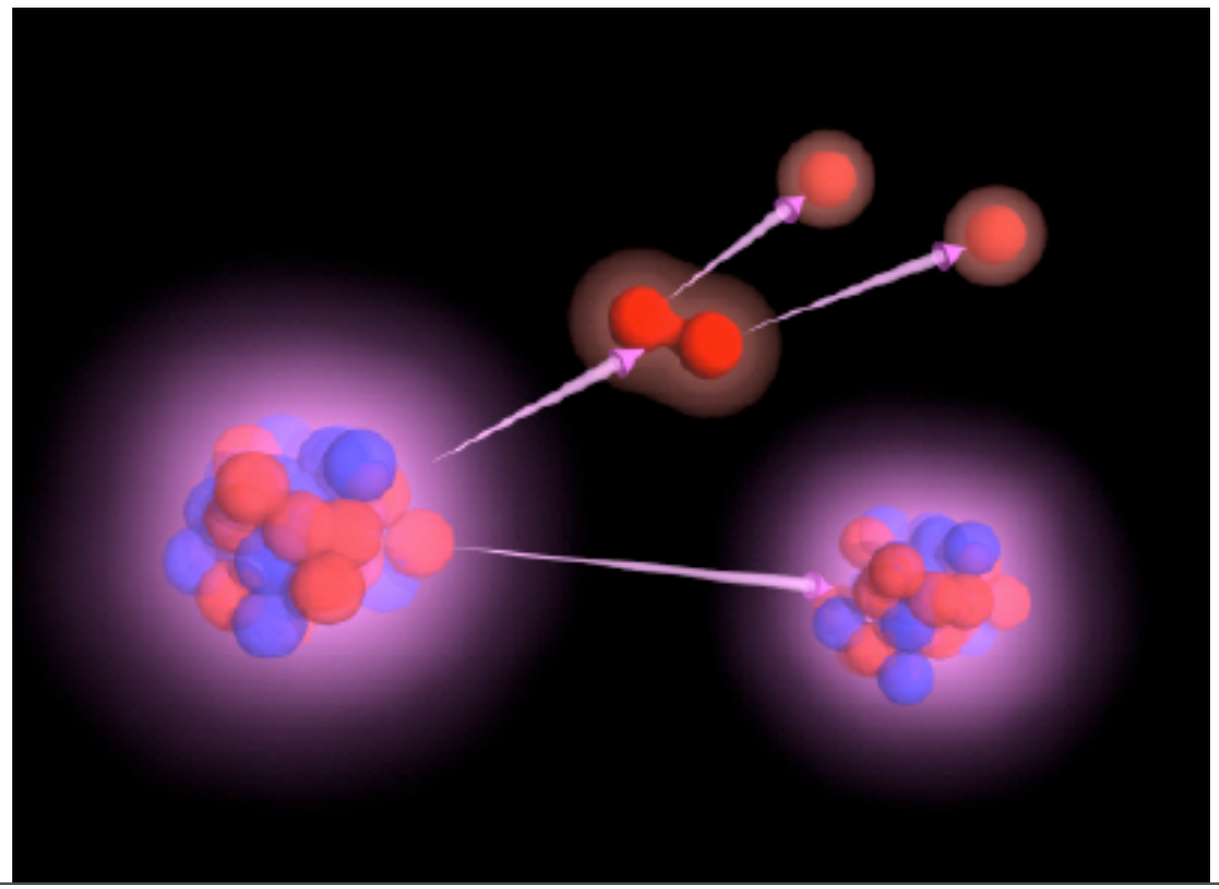
Proton Decay

This proton decay creates heat again, feeble heat.

What does non-proton life do?

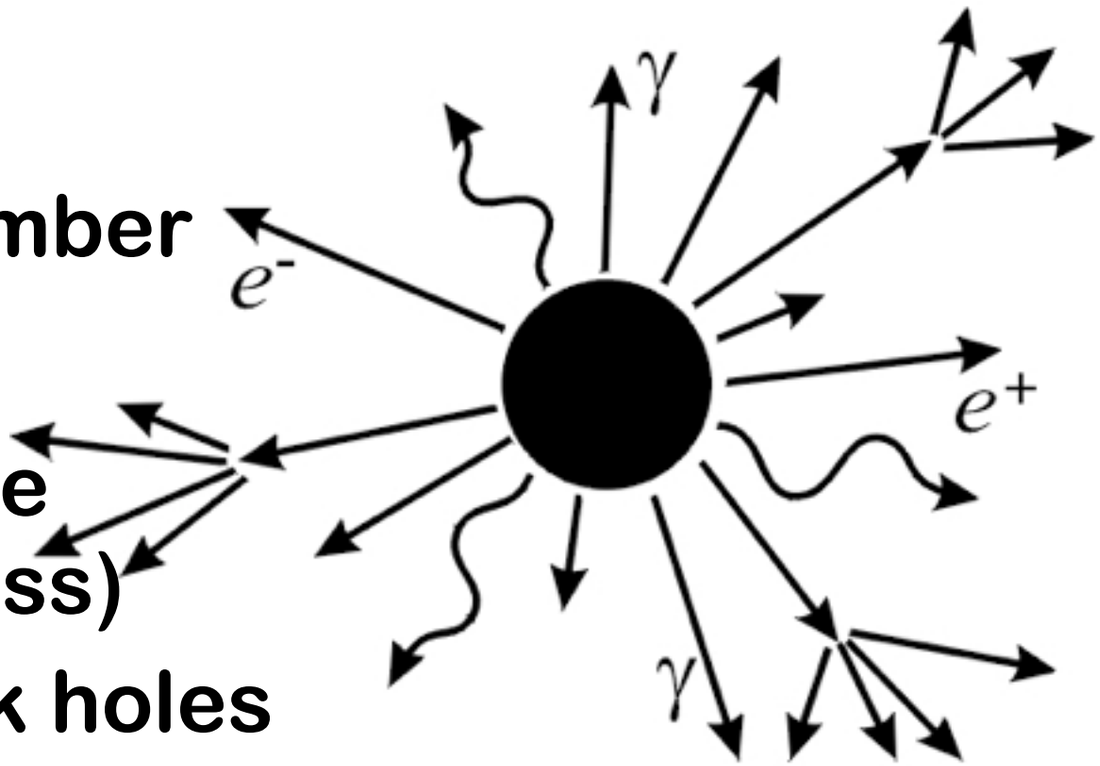
White dwarfs will evaporate

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

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

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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..

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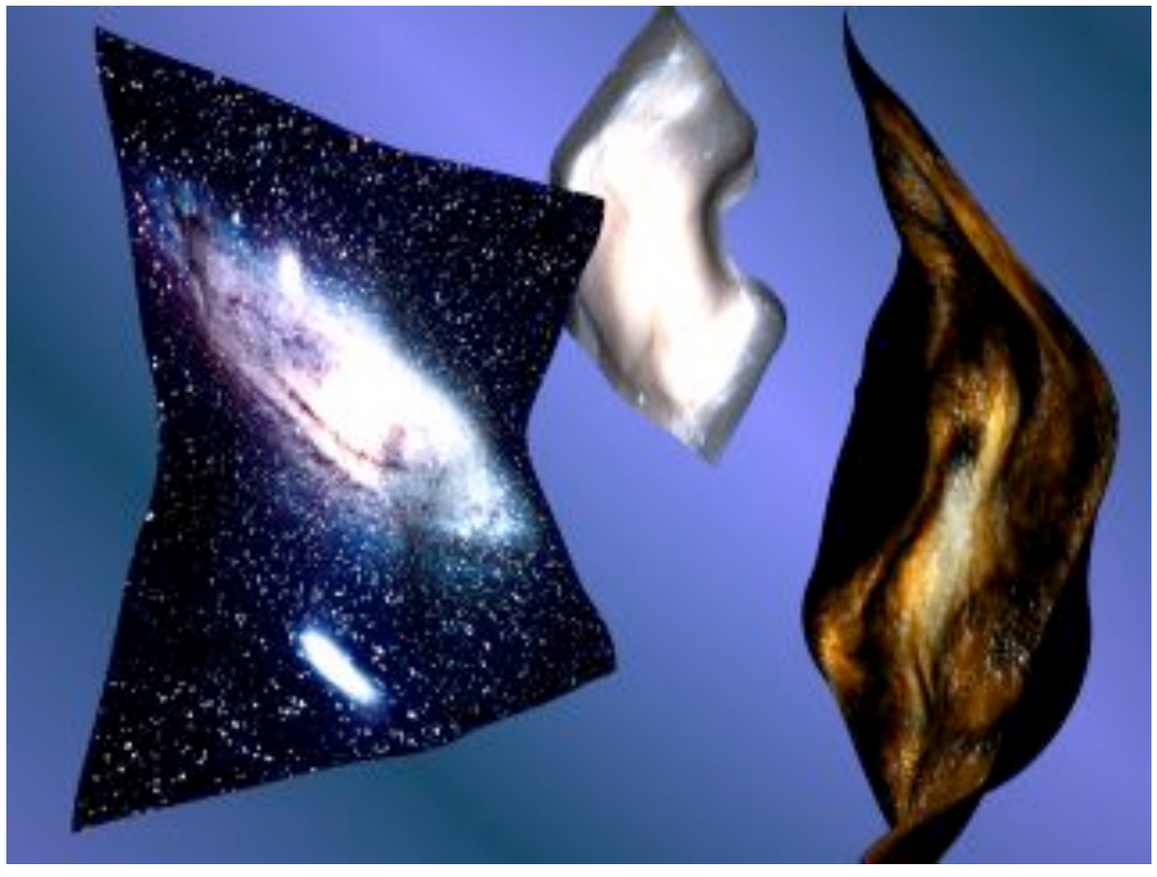

Mitigation

Are you kidding me?

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