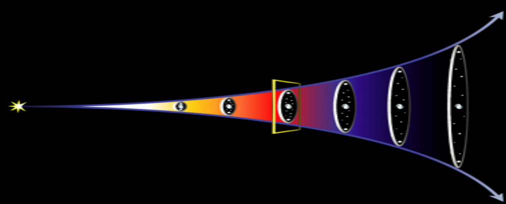
Lecture 45

"This is the way the World ends…"

The Future of Life in the Universe



Astronomy 141 – Autumn 2009

This lecture is about the future of life in the Universe as a whole.

The ultimate fate of an expanding universe is determined by the density of matter within it.

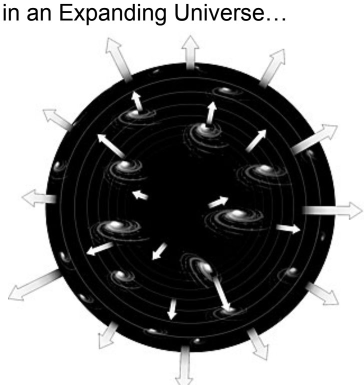
The best current data show that we live in a spatially flat Accelerating Universe.

In accelerating universe, galaxies get further apart, and it rapidly colder as time goes on.

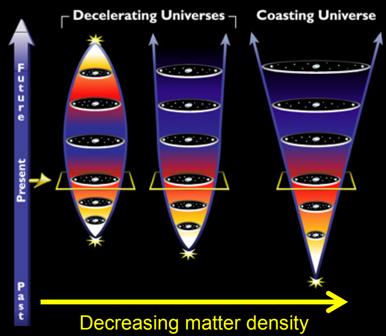
Can distinguish 5 distinct Eras in the Universe related to the physical processes active during those times.

End state of the Universe will be cold, dark, and disordered.

We live in an Expanding Universe…



The future of the Universe depends on the density of matter within it – “Density is Destiny”



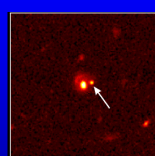
Distant Type Ia Supernova are excellent “standard candles” for measuring large cosmic distances.

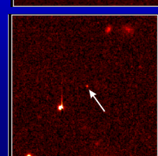
Exploding white dwarfs in binary systems.

Very luminous, so we can see them very far away.

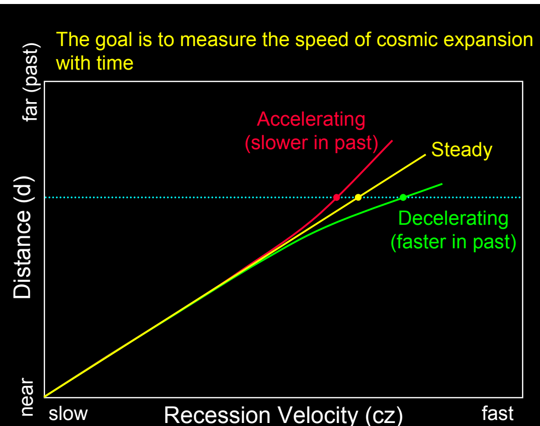
Have characteristic spectra that make them easy to identify.

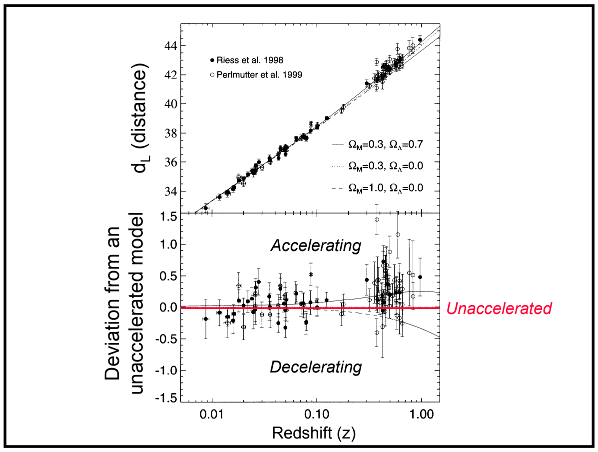
Our current best way to measure the greatest cosmic distances.





The goal is to measure the speed of cosmic expansion with time





The Type Ia supernovae results show that we live in a spatially flat accelerating Universe

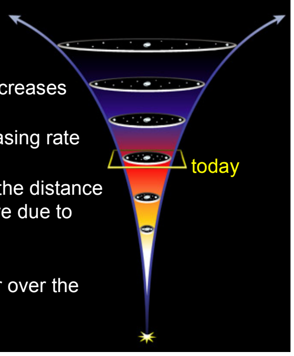
Expands at an increasing rate

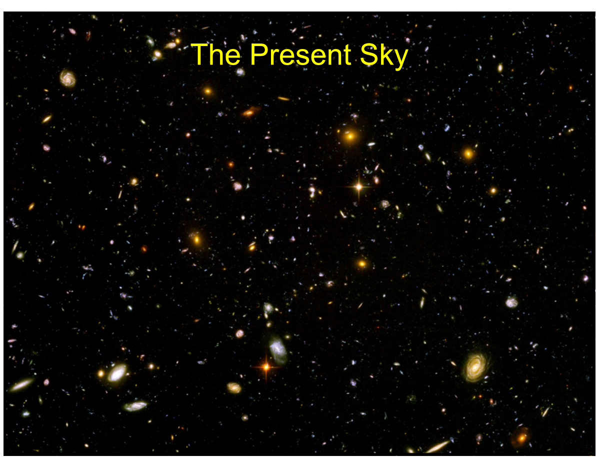
The space between galaxies increases

The Universe cools at an increasing rate

The “Cosmological Horizon” is the distance beyond which we can’t observe due to the finite speed of light

The nearest galaxies disappear over the Horizon after ~10^{11} years





The Future Sky

The Five Ages of the Universe

Primordial Era: Big Bang to 10^6 years

Stelliferous Era: 10^6 to 10^{14} years

Degenerate Era: 10^{14} to 10^{45} years

Black Hole Era: 10^{45} to 10^{100} years

Dark Era: > 10^{100} years

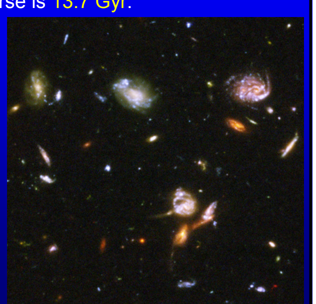
We live in the Stelliferous ("Star Bearing") Era: 10^6 to 10^{14} years since the Big Bang

The current age of the Universe is 13.7 Gyr.

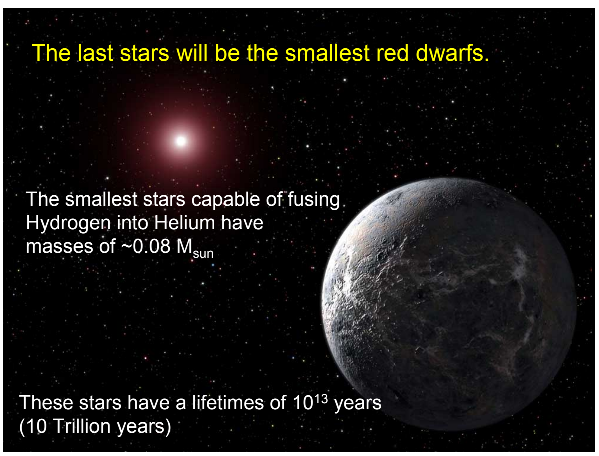
Star formation continues (~7 stars/year in our Galaxy)

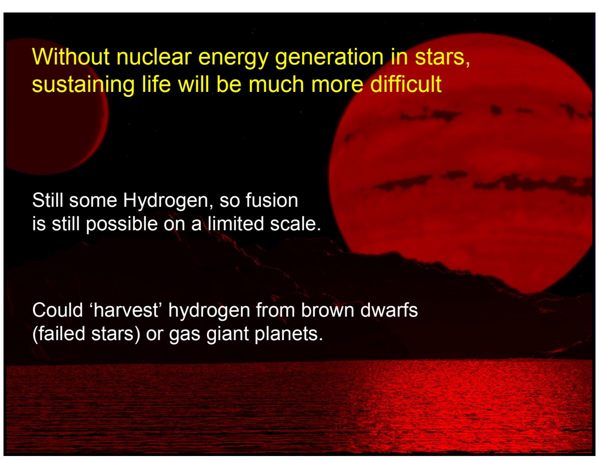
Only stars more massive than $0.8M_{sun}$ have had time to use up their Hydrogen

Some gas is returned, but a fraction is locked up in remnants (white dwarfs, neutron stars, & black holes)

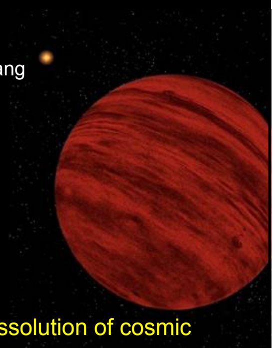



The End of Star Formation will occur when all of the free gas reserves in the Universe are depleted.
With each generation of stars, more and more matter gets locked up in stellar remnants
~10^{14} years after the Big Bang, the cycle of star birth & death will be broken:
No more nuclear fuel
Last red dwarfs burn out as low-mass white dwarfs.
The last stars fade slowly into a long night…


The last stars will be the smallest red dwarfs.
The smallest stars capable of fusing Hydrogen into Helium have masses of ~0.08 M_{sun}
These stars have a lifetimes of 10^{13} years (10 Trillion years)


Without nuclear energy generation in stars, sustaining life will be much more difficult
Still some Hydrogen, so fusion is still possible on a limited scale.
Could 'harvest' hydrogen from brown dwarfs (failed stars) or gas giant planets.

The death of the last red dwarf marks the start of the Degenerate Era



10^{14} to 10^{45} years after the Big Bang

Normal matter is locked up in:
- Brown dwarfs
- White dwarfs,
- Neutron Stars,
- Black holes

Essentially no energy generation

Begins the era of the dissolution of cosmic structures…

After 10^{15} years, Solar Systems begin to evaporate due to gravitational encounters with passing stars.

Gravitational encounters between stars are very rare, but 10^{15} years is enough time rare encounters to occur.

Planetary systems get disrupted by stellar encounters and their planets get scattered into space.

Binary star systems also get disrupted by encounters:

- Wide binary systems get broken apart.
- Close binary systems coalesce into single remnants.

After 10^{19} years, Galaxies begin to dissolve by accumulated star-star interactions

Stellar remnants in galaxies begin to interact over many many orbits.

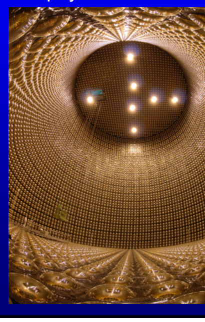
~90% of the remnants gain energy from the interaction and get ejected from the galaxy.

After 10^{24} years, others lose energy and sink towards the center of their galaxy.

After 10^{30} years the last 10% of stellar remnants at the center coalesce into *Supermassive Black Holes.*

After $10^{34\text{-}45}$ years, even matter itself may begin to dissolve as protons begin to decay.

Extensions of the Standard Model of particle physics predict that protons are unstable.



The Super Kamiokande experiment in Japan has set a lower limit on the proton half-life of $>6.6\times10^{33}$ years

Protons decay into electrons, positrons, and neutrinos.

All matter not in Black Holes would come apart.

Does the end of matter spell the end of Life?

Without nuclear energy generation, life as we understand it becomes effectively impossible

The only remaining sources of energy in the Universe are extremely weak background radiation and gravity.

Would have to learn how to harvest gravitational energy near black holes…

The Black Hole Era (10^{45} to 10^{100} years after the Big Bang) begins once matter dissolves

The only organized matter left is Black Holes

Stellar-mass black holes leftover from massive stars evaporate after 10^{67} years by emitting particles (Hawking Radiation).

Supermassive black holes in what used to be the centers of Galaxies evaporate after 10^{100} years…

End of the epoch of organized matter

The Dark Era begins 10^{100} years after the Big Bang when the last black holes have all evaporated away.

The Universe continues to cool off towards a radiation Temperature of absolute zero.

The only matter left is a thin, formless gas of electrons, positrons, and neutrinos.

The only radiation remaining is a few increasingly redshifted photons.

The end is cold, dark, and disordered...

The End of Life at long last?

In this final state, everything is at the same temperature and has the same entropy.

According to second law of thermodynamics, there are now no sources of energy.

Life – organized self-replicating systems that utilize energy – is now finally impossible.

"This is the way the world ends
This is the way the world ends
This is the way the world ends
Not with a bang but a whimper."

T.S. Eliot
The Hollow Men (1924)