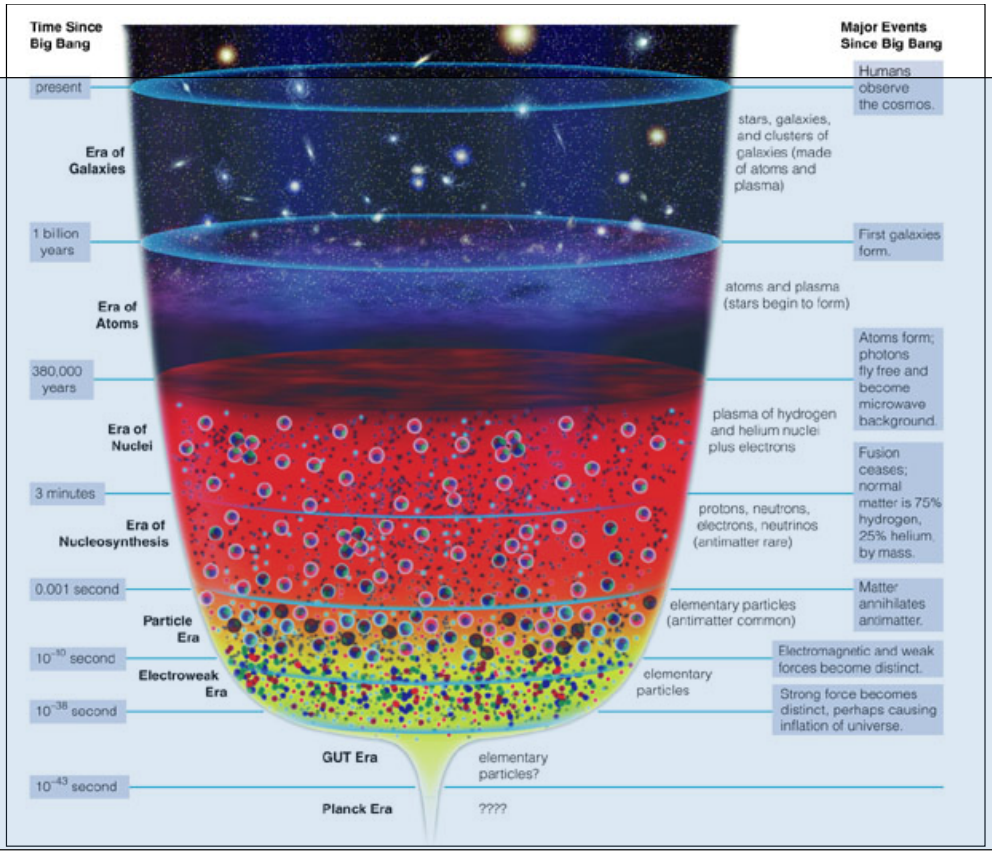
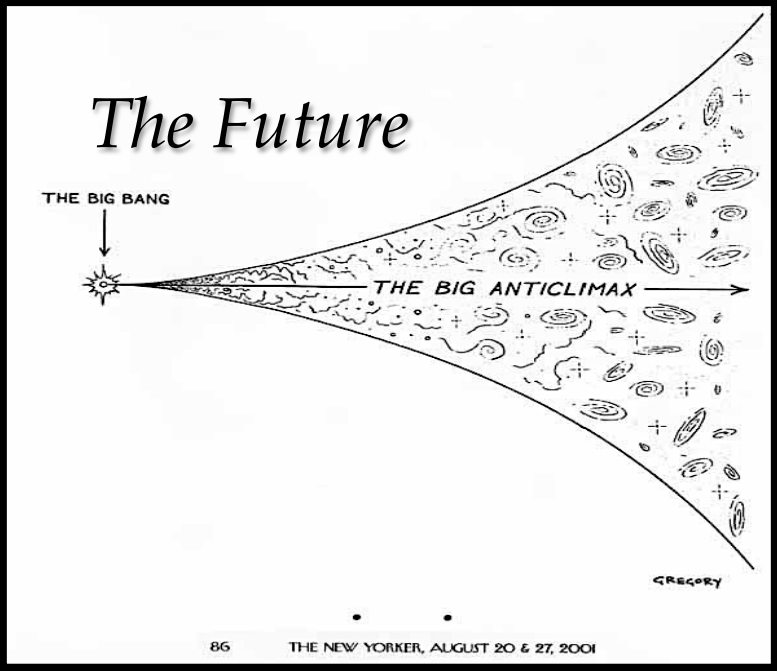
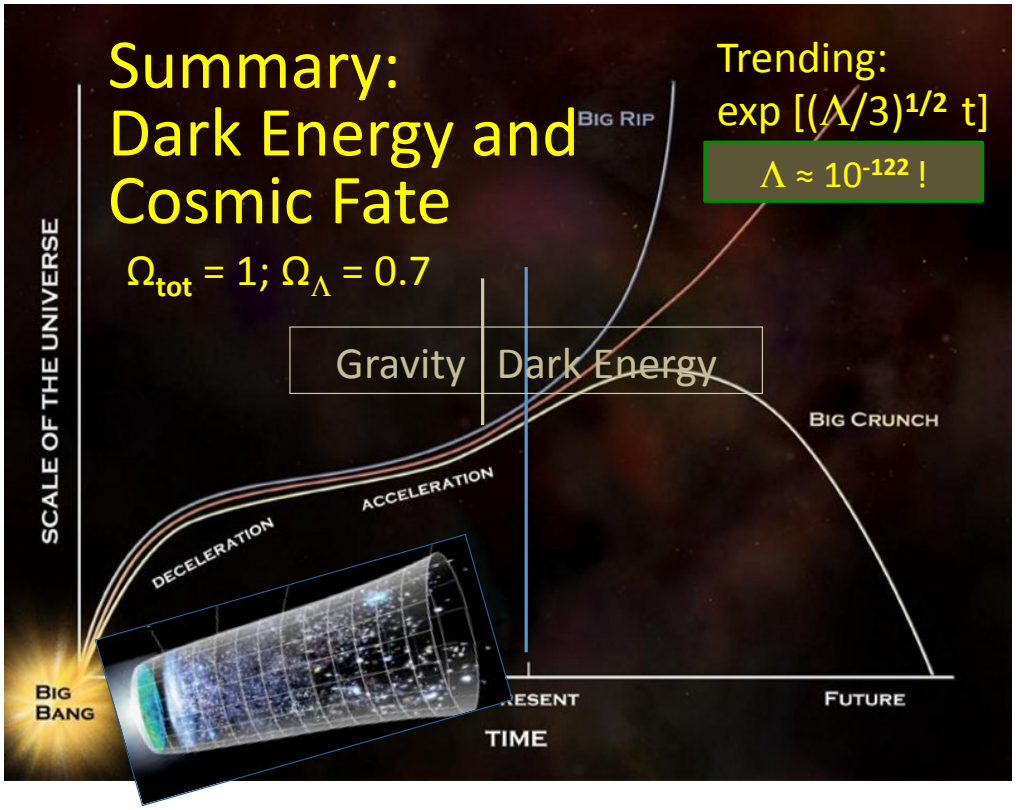
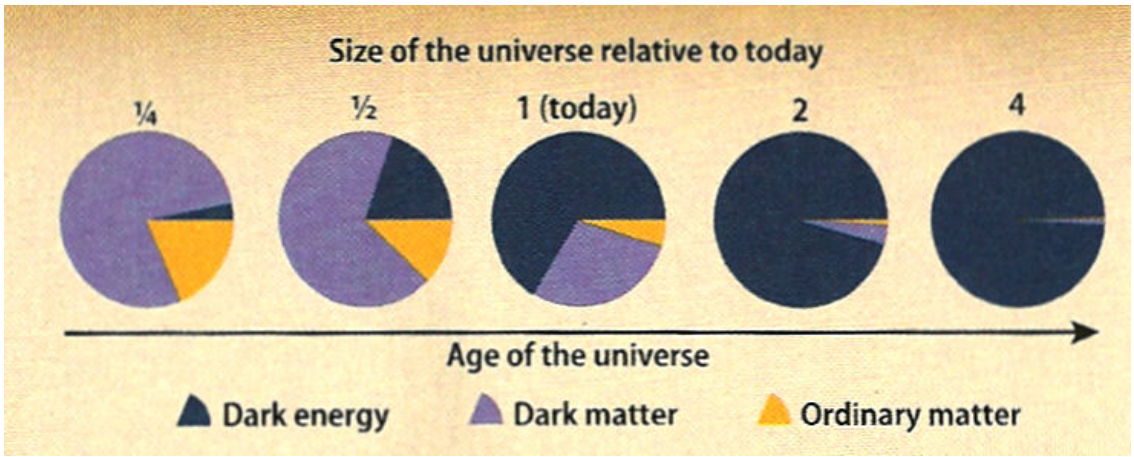

Time Since Big Bang
Major Events Since Big Bang
present
Humans observe the cosmos.
Era of Galaxies
stars, galaxies, and clusters of galaxies (made of atoms and plasma)
1 billion years
First galaxies form.
Era of Atoms
atoms and plasma (stars begin to form)
380,000 years
Atoms form; photons fly free and become microwave background.
Era of Nuclei
plasma of hydrogen and helium nuclei plus electrons
3 minutes
Fusion ceases; normal matter is 75% hydrogen, 25% helium by mass.
Era of Nucleosynthesis
protons, neutrons, electrons, neutrinos (antimatter rare)
0.001 second
Matter annihilates antimatter.
Particle Era
elementary particles (antimatter common)
10^{-10} second
Electromagnetic and weak forces become distinct.
Electroweak Era
elementary particles
10^{-38} second
Strong force becomes distinct, perhaps causing inflation of universe.
GUT Era
elementary particles?
10^{-43} second
Planck Era
????


The Future
THE BIG BANG
THE BIG ANTICLIMAX
GREGORY
86
THE NEW YORKER, AUGUST 20 & 27, 2001



Long-term Cosmic Outcomes

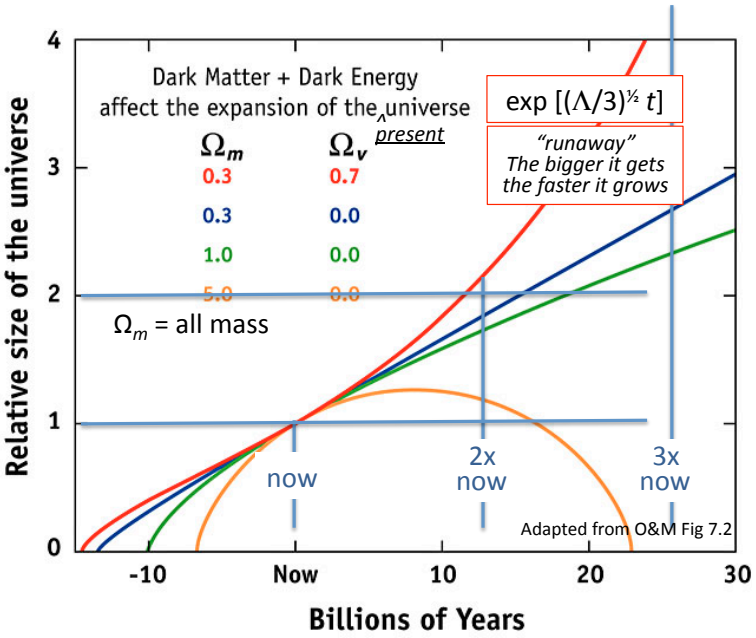
What do you expect?

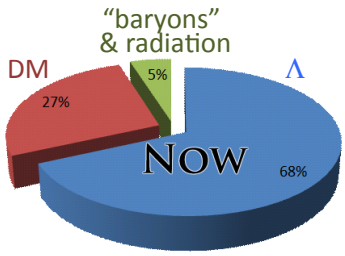


Dark Energy Will Rule!

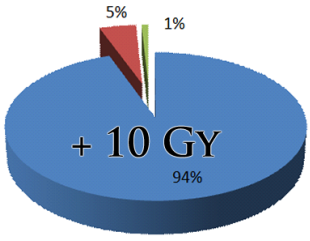
Before long mass will play an insignificant role in restraining the acceleration of space.

Long-term Cosmic Outcomes





Gravity now plays a minor role



Gravity won't matter much longer

The Universe doubles in size every 12 billion yrs

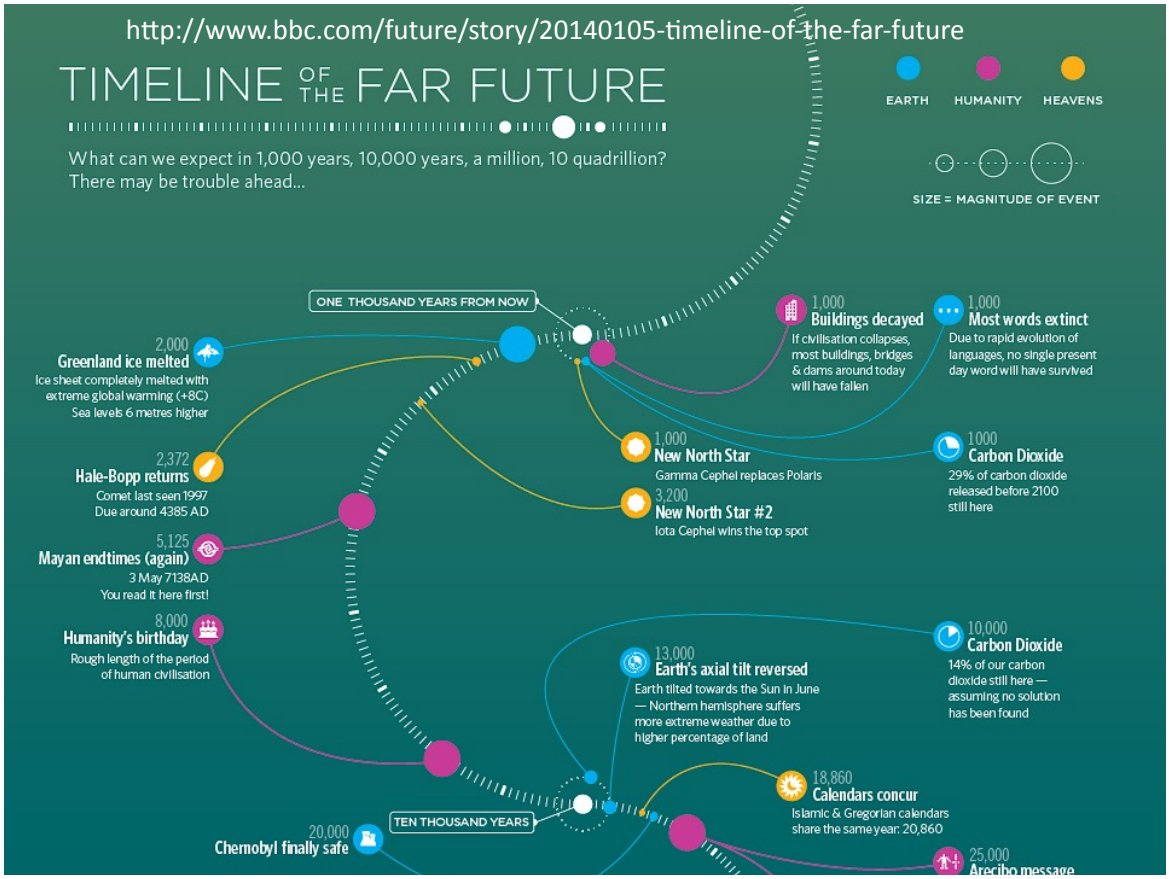
The Cosmic Future

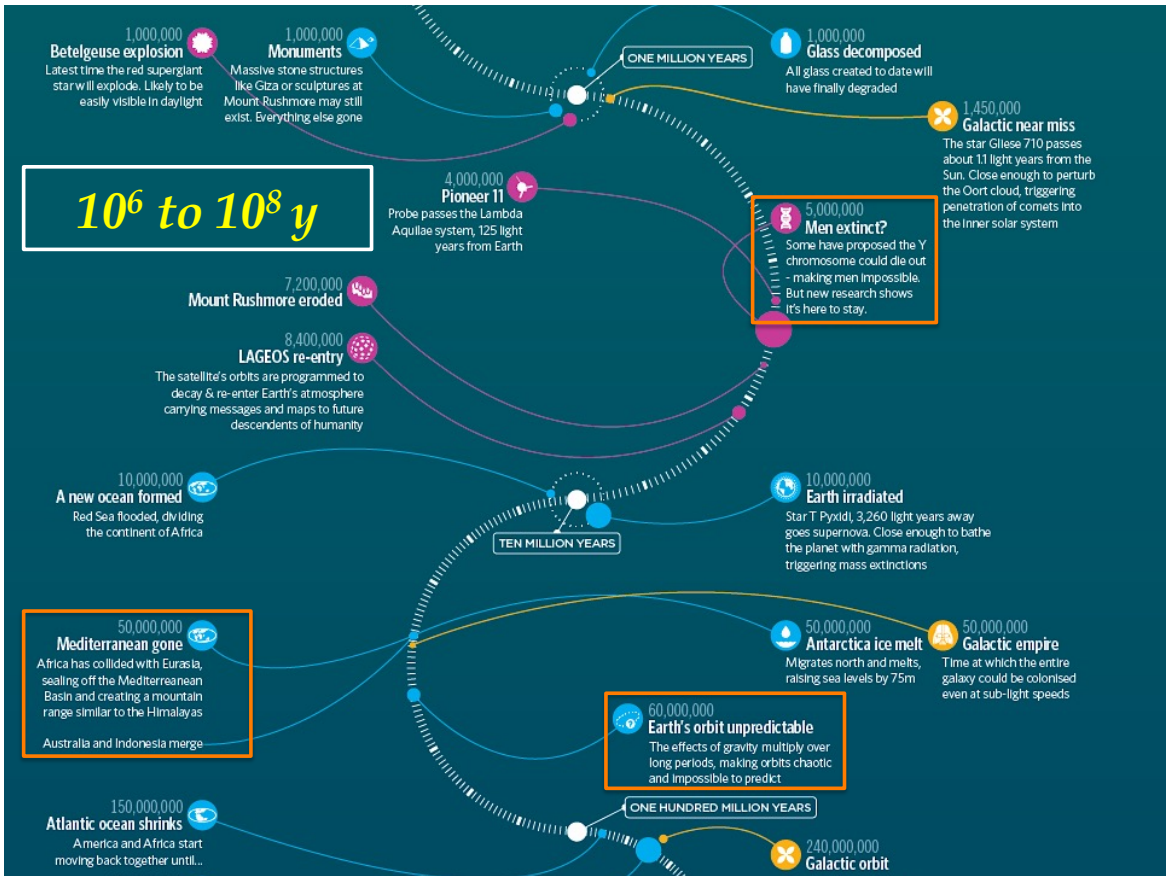
Short-Term Cosmic Forecast

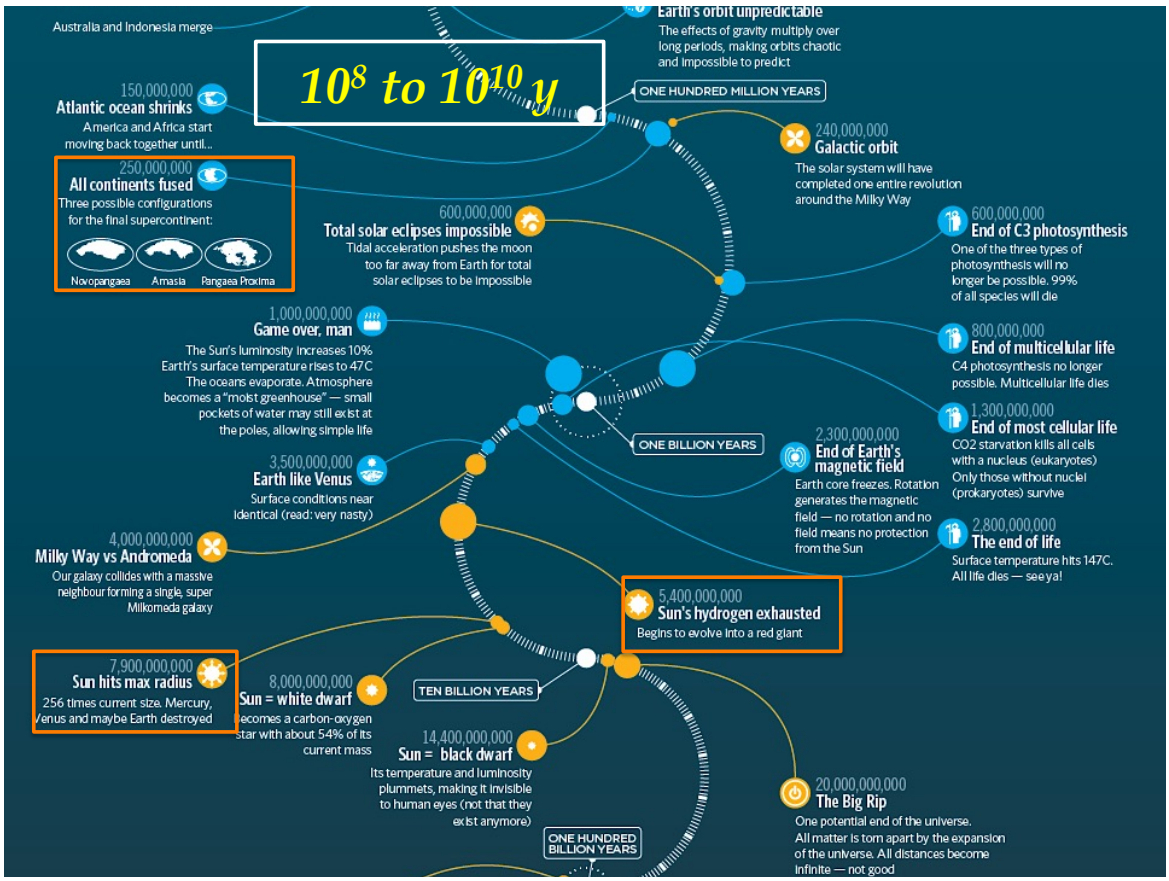
(< 100× present time)

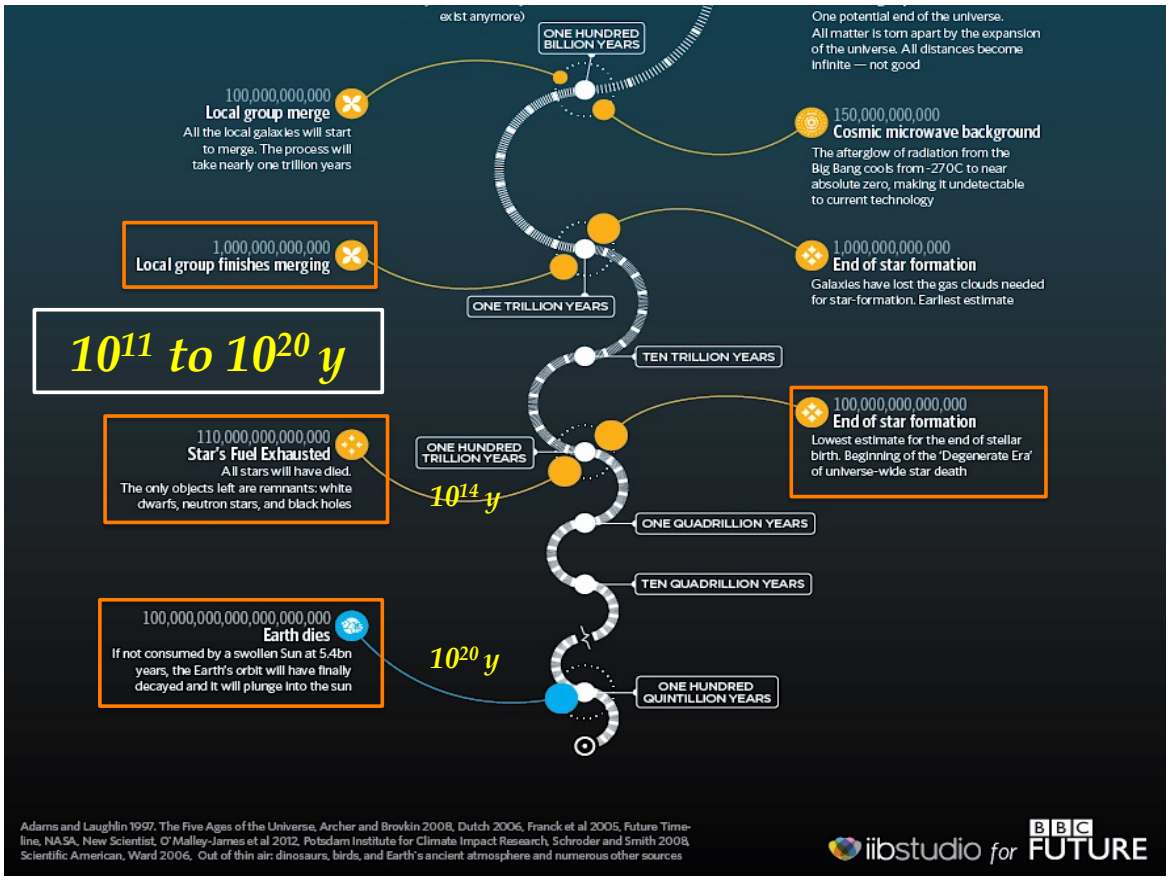
- ✧ Darker, colder, and less dense
- ✧ Existing gravitationally bound systems will persist (and slowly become even denser)
- ✧ High-mass star production will drop off. Supernova rate will go down, as will the production of most heavy elements.
- ✧ All star formation ends once the ISM is depleted
- ✧ White dwarfs and neutron stars will eventually deplete the reservoir of interstellar dust and gas.
- ✧ Friction results in the Earth's orbital death spiral

http://www.bbc.com/future/story/20140105-timeline-of-the-far-future






Australia and Indonesia merge
10^8 to 10^{10} y
Earth's orbit unpredictable
The effects of gravity multiply over long periods, making orbits chaotic and impossible to predict
ONE HUNDRED MILLION YEARS
150,000,000
Atlantic ocean shrinks
America and Africa start moving back together until...
250,000,000
All continents fused
Three possible configurations for the final supercontinent:
Novopangaea
Amasia
Pangaea Proxima
240,000,000
Galactic orbit
The solar system will have completed one entire revolution around the Milky Way
600,000,000
Total solar eclipses impossible
Tidal acceleration pushes the moon too far away from Earth for total solar eclipses to be impossible
600,000,000
End of C3 photosynthesis
One of the three types of photosynthesis will no longer be possible. 99% of all species will die
1,000,000,000
Game over, man
The Sun's luminosity increases 10% Earth's surface temperature rises to 47C The oceans evaporate. Atmosphere becomes a "moist greenhouse" — small pockets of water may still exist at the poles, allowing simple life
800,000,000
End of multicellular life
C4 photosynthesis no longer possible. Multicellular life dies
ONE BILLION YEARS
2,300,000,000
End of Earth's magnetic field
Earth core freezes. Rotation generates the magnetic field — no rotation and no field means no protection from the Sun
1,300,000,000
End of most cellular life
CO2 starvation kills all cells with a nucleus (eukaryotes) Only those without nuclei (prokaryotes) survive
3,500,000,000
Earth like Venus
Surface conditions near identical (read: very nasty)
2,800,000,000
The end of life
Surface temperature hits 147C. All life dies — see ya!
4,000,000,000
Milky Way vs Andromeda
Our galaxy collides with a massive neighbour forming a single, super Milkomeda galaxy
5,400,000,000
Sun's hydrogen exhausted
Begins to evolve into a red giant
7,900,000,000
Sun hits max radius
256 times current size. Mercury, Venus and maybe Earth destroyed
8,000,000,000
Sun = white dwarf
becomes a carbon-oxygen star with about 54% of its current mass
TEN BILLION YEARS
14,400,000,000
Sun = black dwarf
Its temperature and luminosity plummets, making it invisible to human eyes (not that they exist anymore)
20,000,000,000
The Big Rip
One potential end of the universe. All matter is torn apart by the expansion of the universe. All distances become infinite — not good
ONE HUNDRED BILLION YEARS


exist anymore)
ONE HUNDRED BILLION YEARS
One potential end of the universe. All matter is torn apart by the expansion of the universe. All distances become infinite — not good
100,000,000,000
Local group merge
All the local galaxies will start to merge. The process will take nearly one trillion years
150,000,000,000
Cosmic microwave background
The afterglow of radiation from the Big Bang cools from -270C to near absolute zero, making it undetectable to current technology
1,000,000,000,000
Local group finishes merging
1,000,000,000,000
End of star formation
Galaxies have lost the gas clouds needed for star-formation. Earliest estimate
ONE TRILLION YEARS
10^{11} to 10^{20} y
TEN TRILLION YEARS
100,000,000,000,000
End of star formation
Lowest estimate for the end of stellar birth. Beginning of the 'Degenerate Era' of universe-wide star death
110,000,000,000,000
Star's Fuel Exhausted
All stars will have died. The only objects left are remnants: white dwarfs, neutron stars, and black holes
ONE HUNDRED TRILLION YEARS
10^{14} y
ONE QUADRILLION YEARS
TEN QUADRILLION YEARS
100,000,000,000,000,000,000
Earth dies
If not consumed by a swollen Sun at 5.4bn years, the Earth's orbit will have finally decayed and it will plunge into the sun
10^{20} y
ONE HUNDRED QUINTILLION YEARS
Adams and Laughlin 1997, The Five Ages of the Universe, Archer and Brovkin 2008, Dutch 2006, Franck et al 2005, Future Timeline, NASA, New Scientist, O'Malley-James et al 2012, Potsdam Institute for Climate Impact Research, Schroder and Smith 2008, Scientific American, Ward 2006, Out of thin air: dinosaurs, birds, and Earth's ancient atmosphere and numerous other sources
iibstudio for BBC FUTURE

BEYOND THE HORIZON

BEYOND THE HORIZON

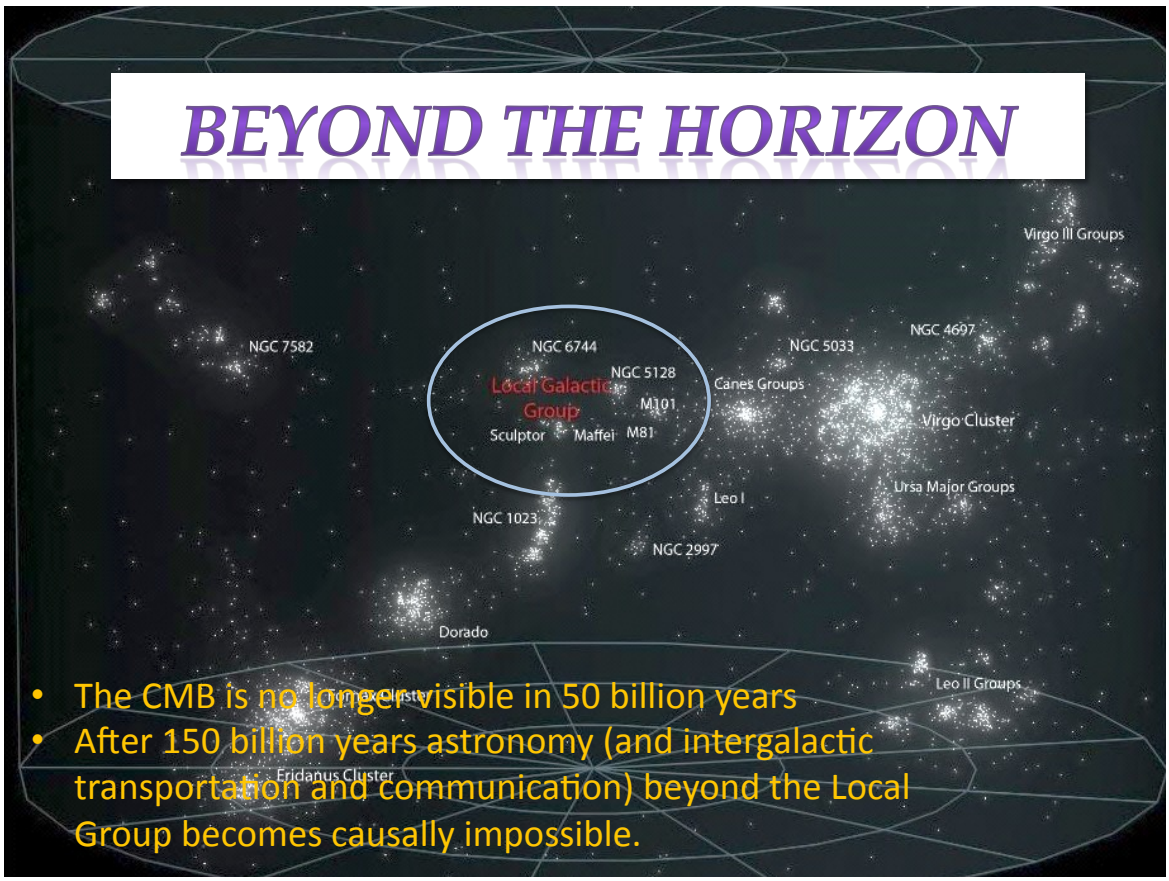
The Universe doubles in size every 12 billion yrs

- Suppose that the exponential expansion (runaway inflation) of space and time continues.
- Our horizon grows at the speed of light.
- But space-time expands even faster!

The speed of distant objects increases until, eventually, their apparent speed exceeds c. These objects disappear over the horizon and are never observable again.

https://en.wikipedia.org/wiki/Future_of_an_expanding_universe

BEYOND THE HORIZON



- The CMB is no longer visible in 50 billion years
- After 150 billion years astronomy (and intergalactic transportation and communication) beyond the Local Group becomes causally impossible.

The Cosmic Future

Medium-Term Cosmic Forecast

(10^4 × present time)

- **The "Cosmic Sprawl": Acceleration of the Cosmic Expansion (if it continues) makes everyplace lonely**
- **100 trillion (10^{14}) y: All ISM depleted**
  - **Star formation ends**
  - **The last red giant becomes a white dwarf**
  - **Occasional flares as brown dwarfs collide**
  - **Galaxies fade as their white dwarfs cool**
  - **All chemical and nuclear energy depleted**

The Cosmic Future

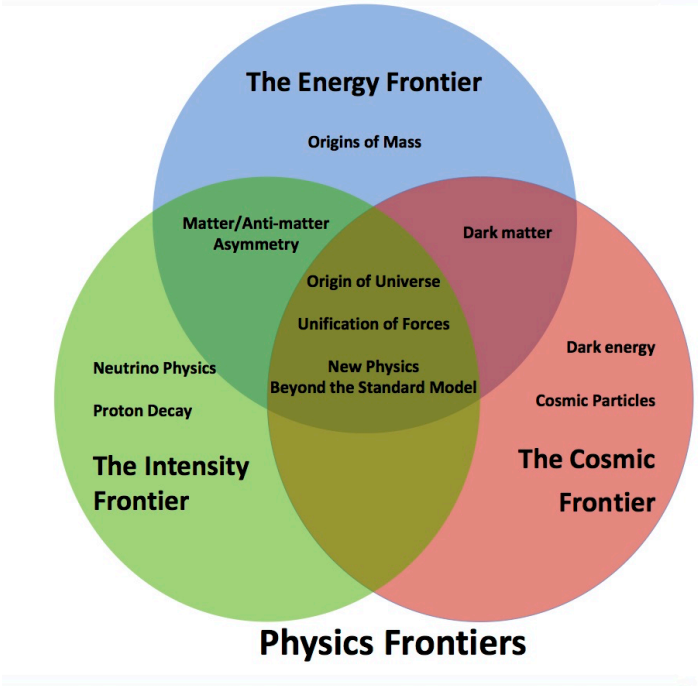
Ultimate Cosmic Forecast

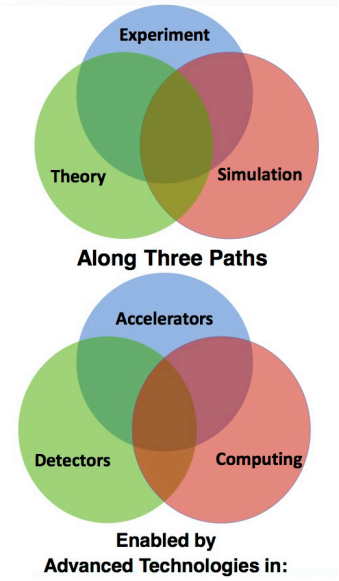
(>10^{10} × present time)

- 10^{39} y: white dwarfs die from proton decay and neutron stars decay from neutron beta decay
- > 10^{100} y: frigid and orderless 'ULTRA-LOW-density sea' of photons (sub radio energy) electrons, positrons.

The 2nd Law and local quantum effects rule!

Frontiers of Cosmology Research



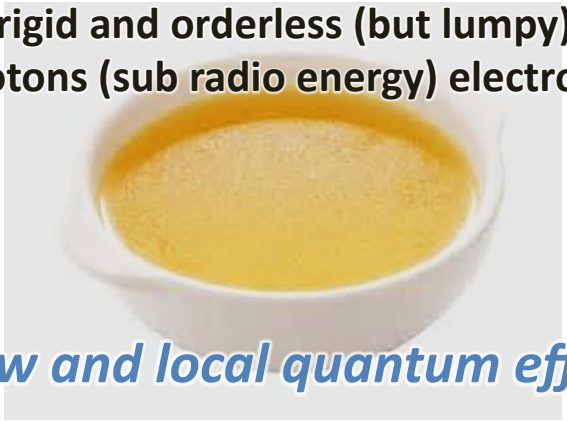


The Cosmic Future

Ultimate Cosmic Forecast

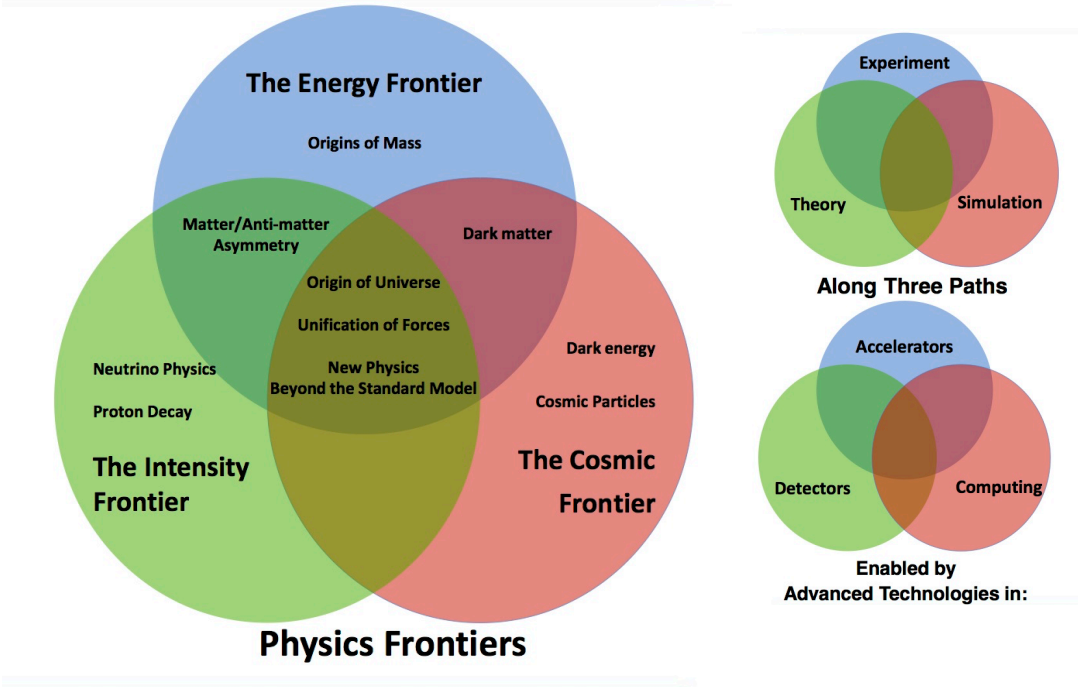
(>10^{10} × present time)

- **10^{39} y: white dwarfs die from proton decay and neutron stars decay from neutron beta decay**
- **> 10^{100} y: frigid and orderless (but lumpy) 'sea' of sparse photons (sub radio energy) electrons, positrons.**

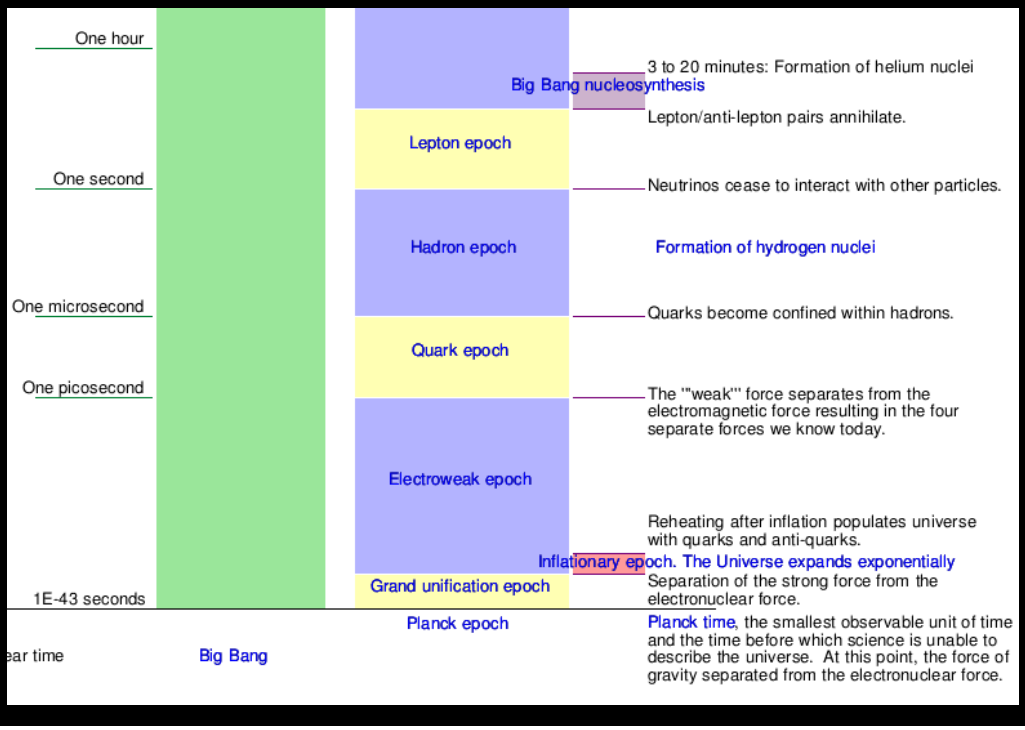


The 2nd Law and local quantum effects rule!

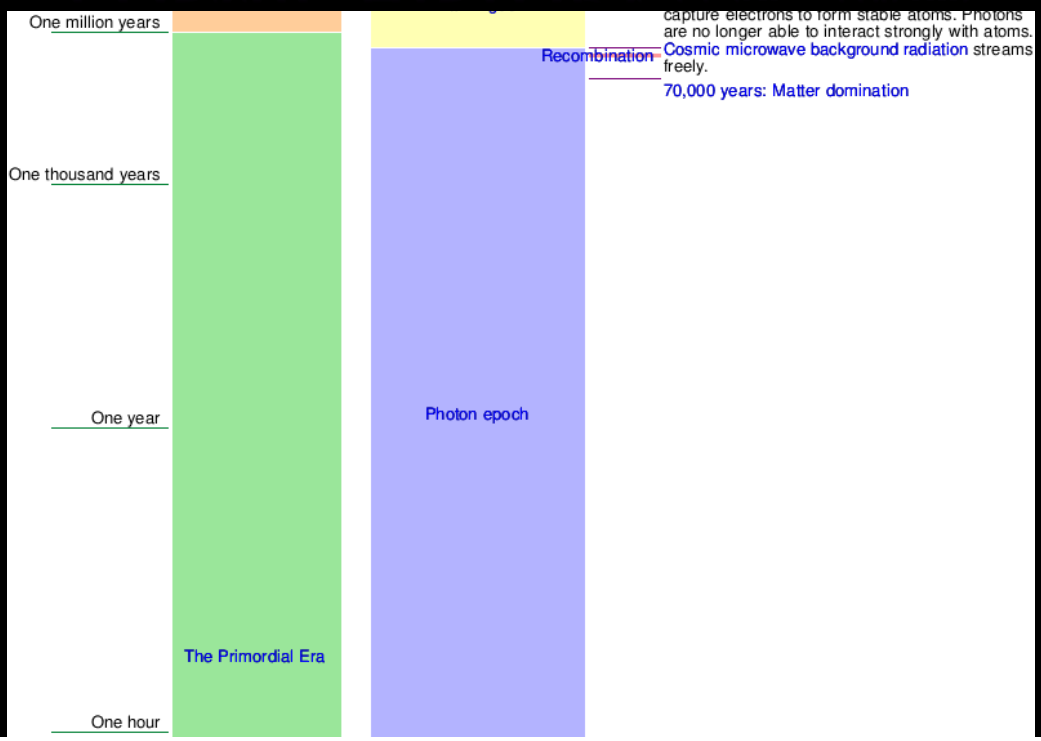
Frontiers of Cosmology Research



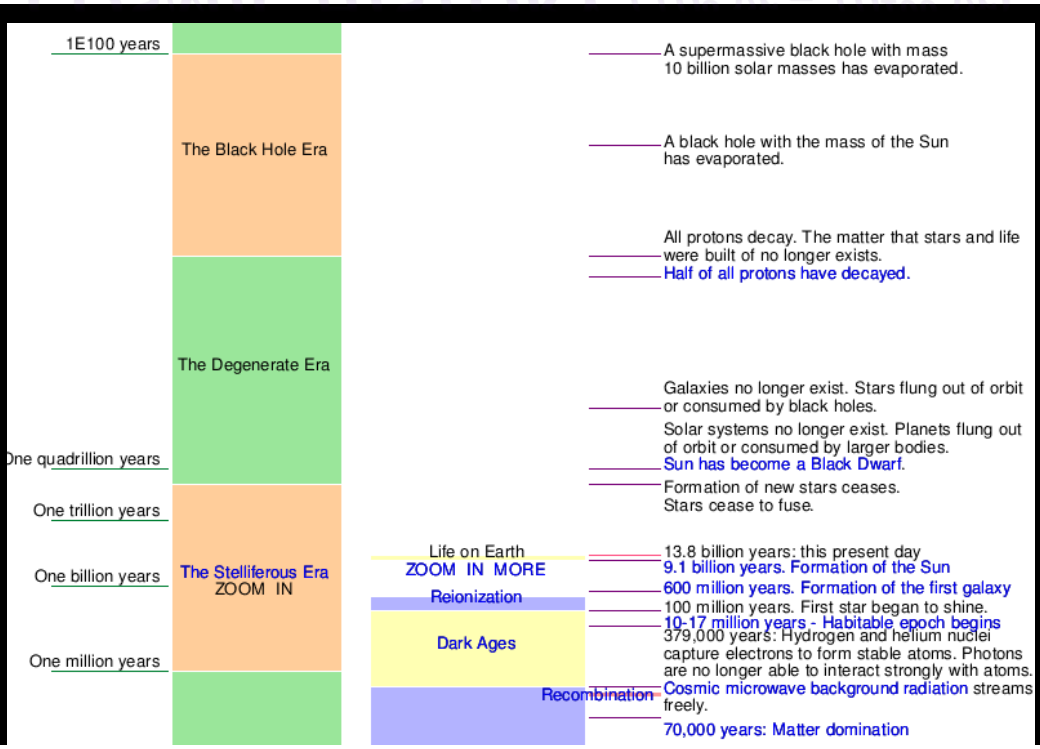
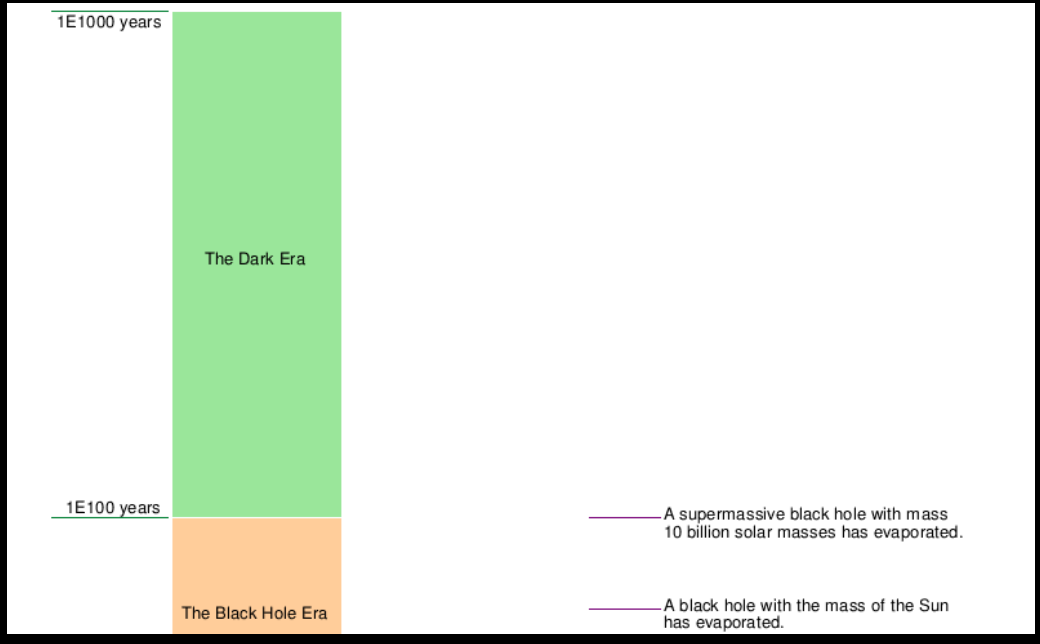
COSMIC HISTORY (10^{-43} s to 1 hr)



COSMIC HISTORY (1 hr – 10^6 yr)



COSMIC HISTORY (10^6 yr – 10^{100} yr)



COSMIC HISTORY (10^{100} yr – 10^{1000} yr)