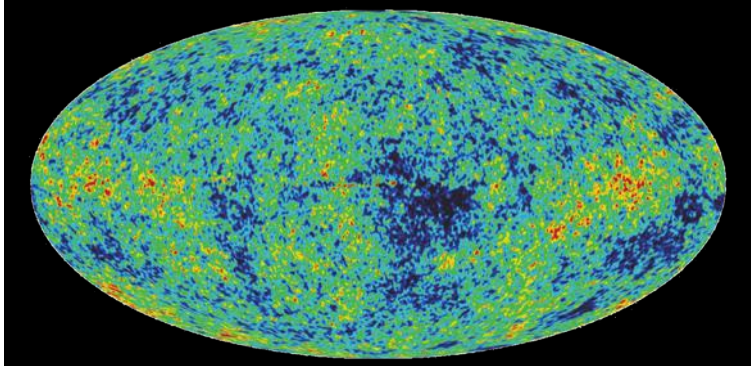
The Fate of the Universe



Multi-Dimensional Space

- ***multi-dimensional space*** is difficult to imagine
- it defies our *common sense* notions
- however, our *common sense* is *often* wrong!

DEMO: *Can you imagine something with* ***one side****?*

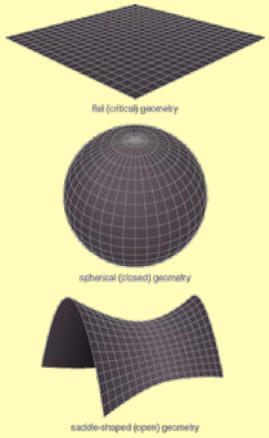
- *a Möbius strip; draw a line down the middle…*

DEMO: *2D paper & "ant"; curl paper into "U"*

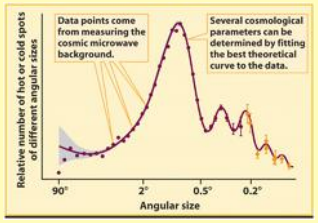
- *ant's "world" is 2D surface of the paper, which, if curved, requires 3D to describe (+1 dimension)*

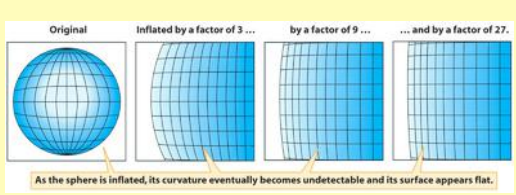
Shape of the Universe

- ***matter*** *curves* ***space***
- ***matter*** & ***energy*** are ***interchangeable***: $E=mc^2$
- *shape* of universe ***depends on amount of both***
- ***flat***, ***closed***, ***open***: by analogy to 3D shapes, but ***our universe is 4D*** (at least!)



- ***observations*** currently indicate a "***flat***" universe
- however, if universe has ***inflated***, it may just ***appear*** flat to us *on local scales* ***(eg)*** *Earth, visible universe*





DVD: Cosmos "Flatland"

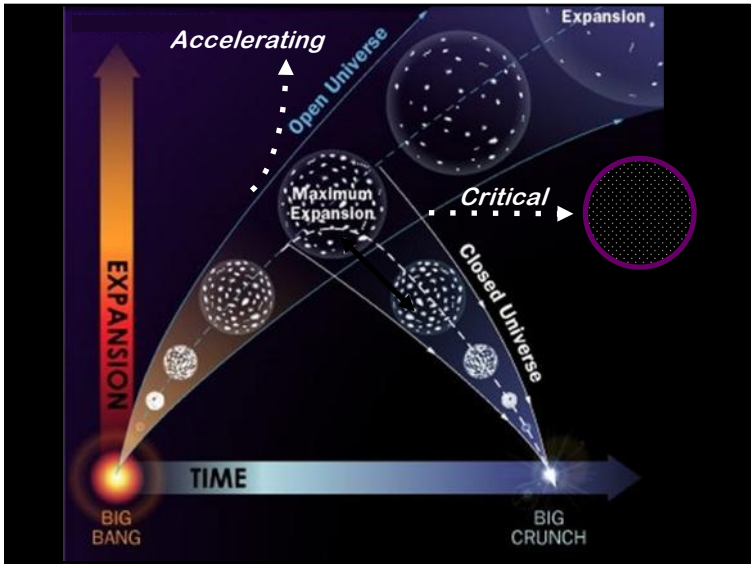
The Fate of the Universe

- ***matter & energy*** (***shape***) determines its ***fate***

- ***closed*****:** expansion ***reverses***, universe *collapses*
- "***Big Crunch***"

- ***critical*****:** expansion ***stops*** after *infinite time*
- ***open*****:** constant expansion ***continues forever***
- "***Big Chill***" or "***Heat Death***"

- ***accelerating*****:** expansion ***accelerates*** *with time*
- "***Big Rip***"



CLICKER*: Why did early astronomers expect the expansion of the universe to* ***slow****?*

(a) friction

(b) run out of energy after 14 billion years

(c) interactions with the non-observable universe

(d) gravitational pull of all matter & energy

Q: Which ***fate*** is ***most*** likely to occur?

- depends on *how strong* ***gravity*** *is*
i.e. *is there enough mass so that gravitational forces can* ***slow***, ***stop***, *or* ***reverse*** *the expansion?*

- need to estimate the ***density*** (ρ) of the *universe*

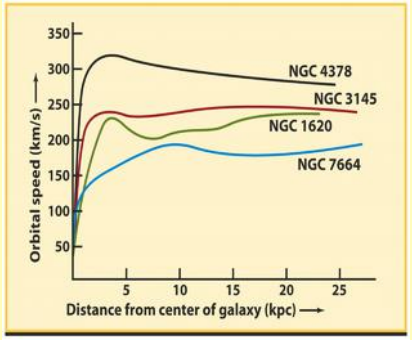
- compare to the "***critical density***" (ρ_c) required to *exactly* ***stop*** *the currently observed expansion*

- using current H_o, estimate $\rho_c \sim 10^{-29}$ ***g/cm***^{3}
(eg) *like a few H atoms in a typical closet*

- ***luminous matter*** (stars, galaxies, gas): $\rho << \rho_c$

Dark Matter

- "***rotation curves***"
- ***gravity should decrease*** with ***increasing*** distance…
- …but *speed of stars stays ~* ***constant beyond visible edge!***

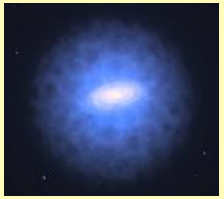


- from rotation speeds, $m_{MilkyWay}$ *~ a* ***trillion*** *Suns!*

Q: *How many stars do we* ***observe*** *in the* ***MW****?*
So what is the ***source*** *of this "extra"* ***mass****?*

- ~85% of galaxies are made of "***dark matter***"
- ***undetectable*** in ***any*** *part of the* ***EM spectrum***
- ***only*** detectable through ***gravitational effects***

- ***dark matter*** *~spherical* about ***galactic core***



- ***dark matter*** also appears ***between*** galaxies in clusters

MACHOs, Neutrinos & WIMPs (oh my!)

• ***Massive Compact Halo Objects*** include *you & I, planets, failed stars, very small dim stars…*

• ***neutrinos*** (*"small neutral ones"*)
• estimates of ***1 billion-to-1*** versus protons, etc.
• fast moving ⇒ *"**hot**" **dark matter***

• other, massive ***but as yet unknown*** particles?
• *Weakly Interacting Massive Particles* (*"**WIMPs**"*)
• slow moving ⇒ *"**cold**" **dark matter***

CLICKER: *The rotation curves of spiral galaxies implied to astronomers that*

(a) huge black holes existed in the spiral arms
(b) the gravity due to visible matter in galaxies was not enough to hold them together
(c) stars in galaxies were static and fixed in place
(d) galaxies spun more slowly than expected

• ***regular (luminous) matter*** yields $\rho \sim 5\%$ ***of*** ρ_c

• adding ***dark matter*** yields $\rho \sim 25\%$ ***of*** ρ_c

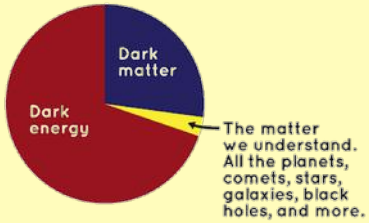
• $\rho << \rho_c$ indicates an ***open*** *universe*

• **BUT** ***we don't observe an "open" shape…***
• **…AND** a ***"flat"*** *universe* **requires** $\rho \sim \rho_c$

• to "***flatten***" ***the universe (as we observe)*** **requires** ***additional*** *"mass":* we use *ENERGY* (***~ 70% of*** ρ_c)

Dark Energy

• this *additional* energy is called *"**dark energy**"*, *"**quintessence**"* or *"**cosmological constant**"*



• ***we don't know what it is… may*** be source of a ***repulsive force*** exceeding ***gravity*** on ***largest scales***

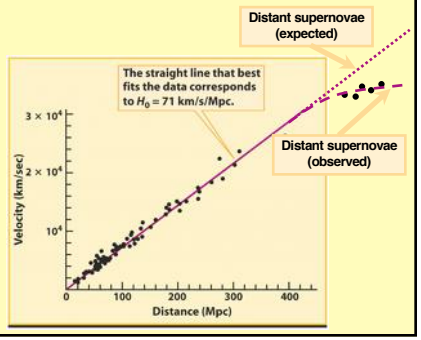
Q: *Evidence for existence of* ***dark energy****?*

• distant supernovae are ***dimmer*** than their ***redshift*** (***velocity***) implies ***ie.*** they are ***further away*** than we ***expect*** them to be based on ***Hubble's Law***

• slope tells us H_o (***i.e. expansion rate***) is ***changing over time***

• ***expansion*** *appears* to be ***accelerating***

• headed for ***Big Rip?***



***Review*: The Shape & Future of the Universe**

• "***How does the universe end?***"

• depends on how much "*stuff*" in universe

• ***matter*** & ***energy*** determine "shape" of universe

• ***Crunch, Chill, Heat Death*** or ***Rip***

• ***Big Rip*** looks most likely, but…

• …depends on ***Dark Matter*** & ***Dark Energy***