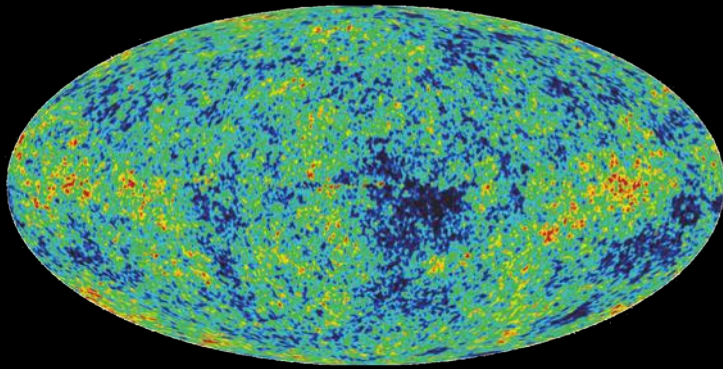


# The Fate of the Universe



## 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*?

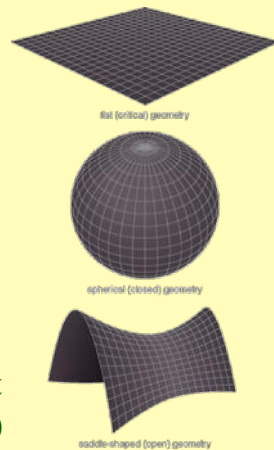
- a Möbius strip; draw a line down the middle...

**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)

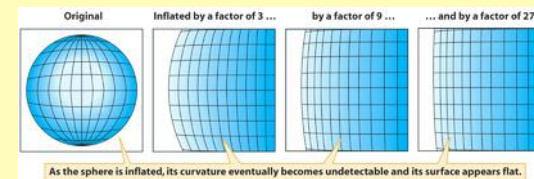
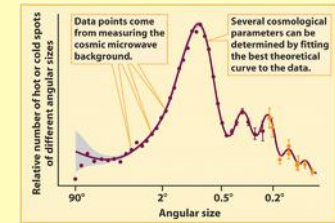
## Shape of the Universe

- **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!)

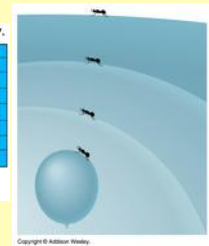


- **observations** currently indicate a **“flat”** universe

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

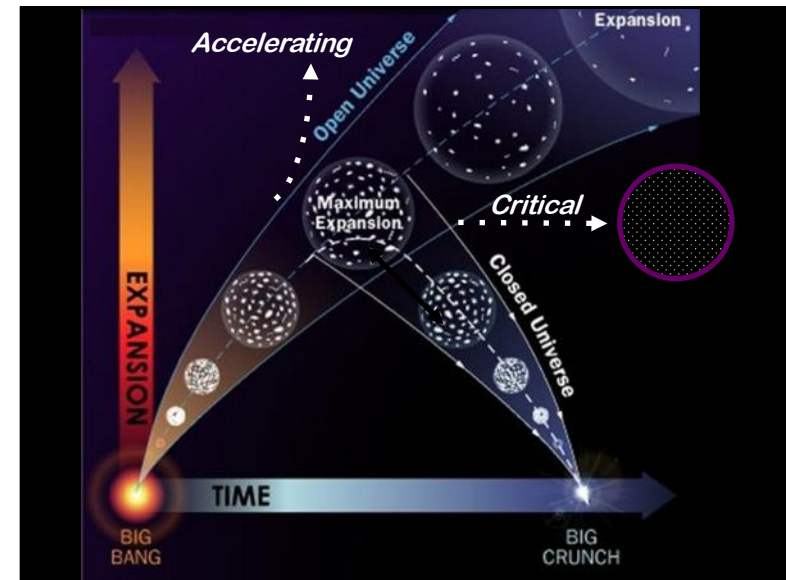


**DVD:** Cosmos “Flatland”



# The Fate of the Universe

- **matter & energy** (*shape*) determines its *fate*
- **closed**: "**Big Crunch**"
- expansion *reverses*, universe *collapses*
- **critical and open**: "**Big Chill**" or "**Heat Death**"
- expansion *stops* after *infinite time*
- constant expansion *continues forever*
- **accelerating**: "**Big Rip**"
- expansion *accelerates with time*



**CLICKER:** Why might astronomers expect the expansion of the universe to **slow down**?

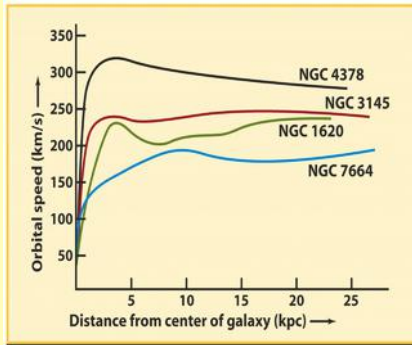
- (a) friction
- (b) run out of energy after 14 billion years
- (c) interactions with the non-observable universe
- (d) gravitational pull of all matter & energy

**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** ( $\rho$ ) of the *universe*
- compare to the "**critical density**" ( $\rho_c$ ) required to *exactly stop* the *currently observed expansion*
- using current  $H_o$ , estimate  $\rho_c \sim 10^{-29} \text{ g/cm}^3$   
(*eg*) like a few H atoms in a typical closet
- **luminous matter** (stars, galaxies, gas):  $\rho \ll \rho_c$

## Dark Matter

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



- from rotation speeds,  $m_{\text{MilkyWay}} \sim$  *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  $\Rightarrow$  “*hot*” *dark matter*
- other, massive *but as yet unknown* particles?
- *Weakly Interacting Massive Particles* (“*WIMPs*”)
- slow moving  $\Rightarrow$  “*cold*” *dark matter*

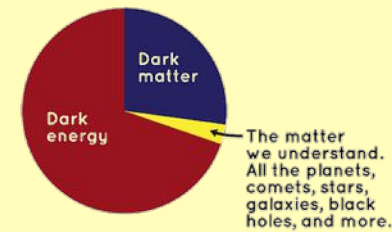
*CLICKER: When astronomers measured rotation curves of spiral galaxies they found*

- (a) *galaxies did not spin*
- (b) *gravity of the visible matter in galaxies was not enough to hold the galaxies together*
- (c) *stars moved back & forth, not really moving*
- (d) *galaxies rotated more slowly than expected*

- **regular (luminous) matter** yields  $\rho \sim 5\%$  of  $\rho_c$
- adding **dark matter** yields  $\rho \sim 25\%$  of  $\rho_c$
- $\rho \ll \rho_c$  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: ENERGY** ( $\sim 70\%$  of  $\rho_c$ )

## Dark Energy

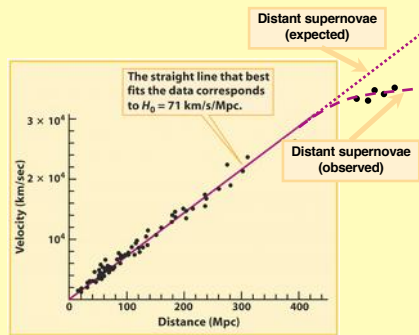
- this **additional** energy is called **"dark energy"**, **"quintessence"** or **"cosmological constant"**



- **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  **$H_0$**  (**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**