Modern Cosmology

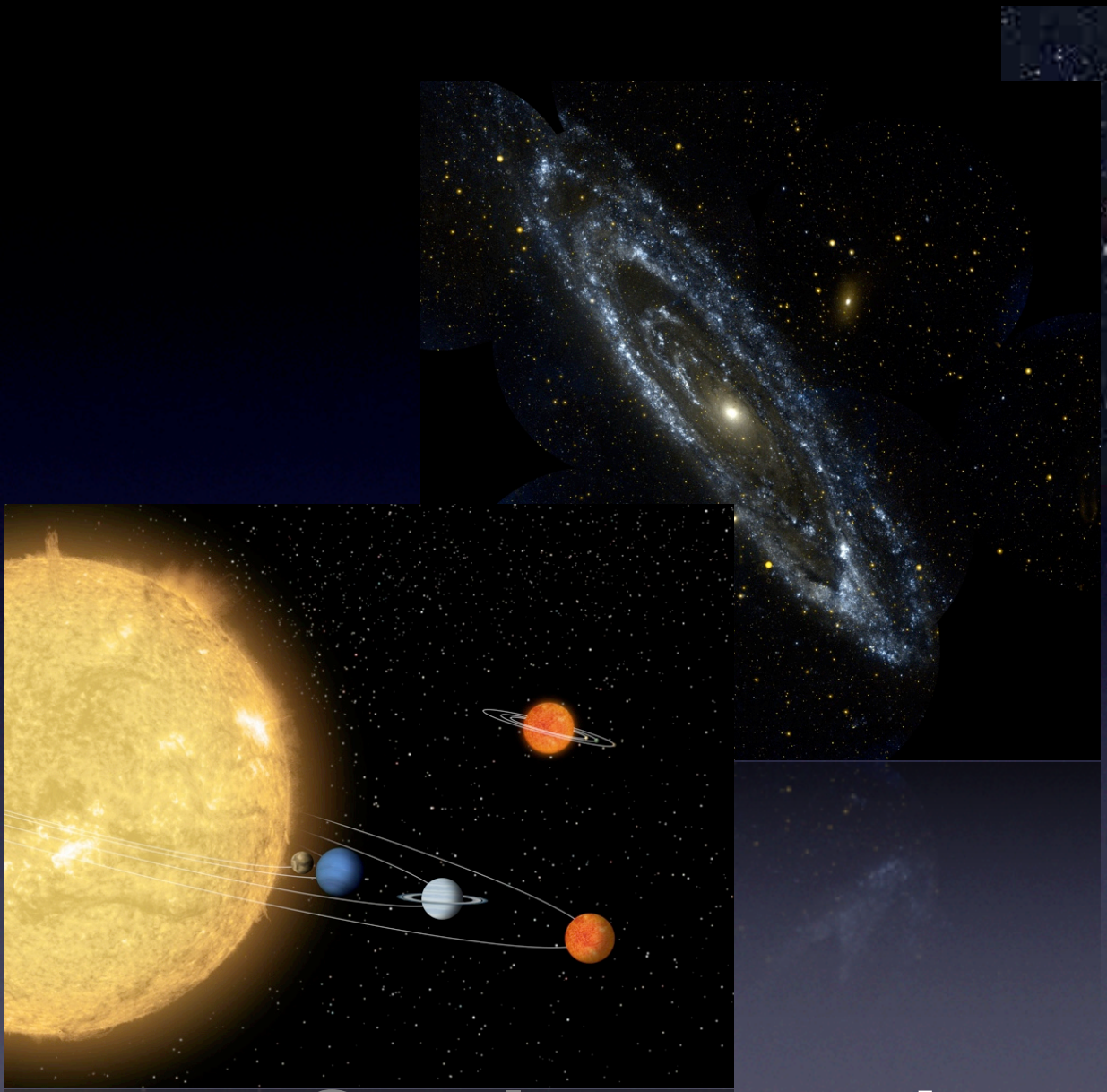
Norman Gray

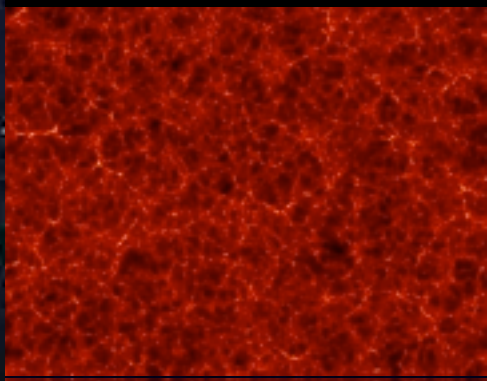
2006 November 25

Talk given at DACE Cosmologies day-school, University of Glasgow, 2006 November 25 (image credits at end)

Overview

- structure of the universe
- ‘history’ of western cosmologies
- cosmogeny





the universe: 3000Mpc

supercluster: 50Mpc

local group: 1Mpc=1000kpc

galaxy: 30kpc=6×10^9AU

solar system: 1AU=15×10^{10}m

Scales in the universe

Cosmologies

Cosmology is a two-millennium-long retreat from anthropocentrism

(and yes, modern science does have
an *extremely* Whiggish view of history...)

Plato

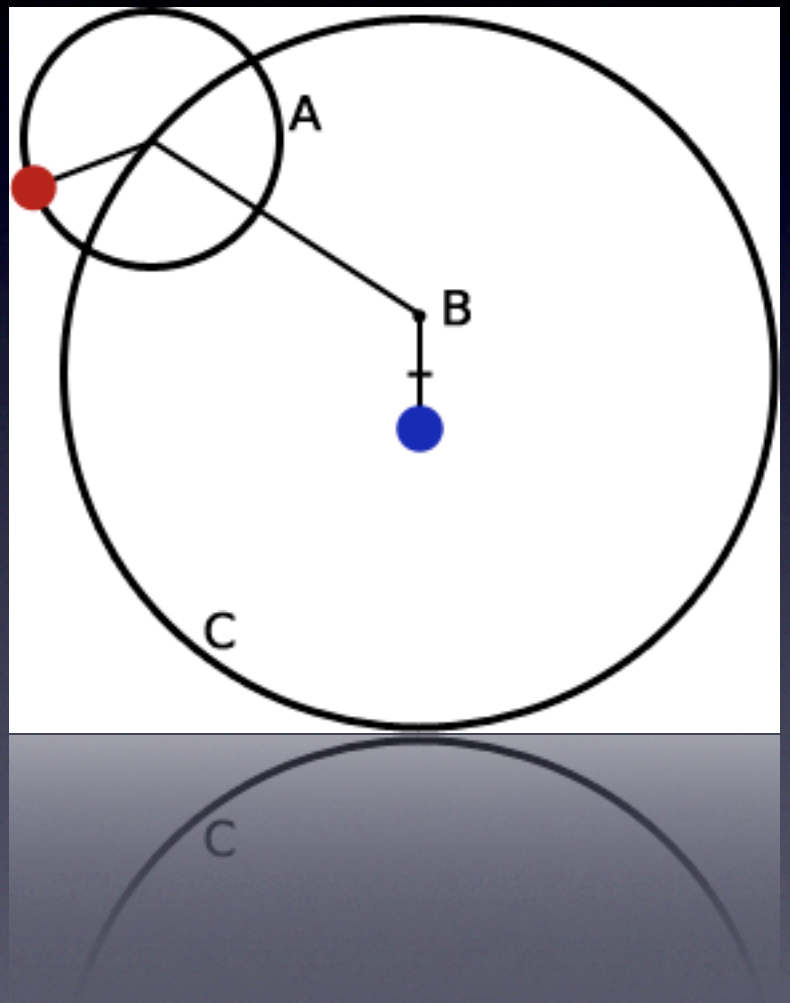
somewhat hostile to experimental science

"Let us concentrate on abstract problems, said I, in astronomy as in geometry, and dismiss the heavenly bodies, if we intend truly to apprehend astronomy"

The Republic

Ptolemy

geocentric
epicycles
usable for producing almanacs
sky-geometry, divorced from sky
four elements, plus quintessence



Copernicus

heliocentric
still lots of epicycles
no *better* at ephemerides

NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circu currens. In medio uero omnium residet Sol. Quis enim in hoc

I. Stellarum fixarum sphæra immobilis.
II. Saturnus anno. XXX. revolvitur.
III. Iouis. XII. annorum revolutio.
IIII. Martis bima revolutio.
V. Telluris
VI. Veneris nonemestris
VII. Mercurii
Sol.

pulcherimo templo lampadem hanc in alio uel meliori loco po neret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uo- cant. Trimegistus uisibilem Deum, Sophoclis Electra intuentē omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximā Luna cū terra cognationē habet. Concipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub hac

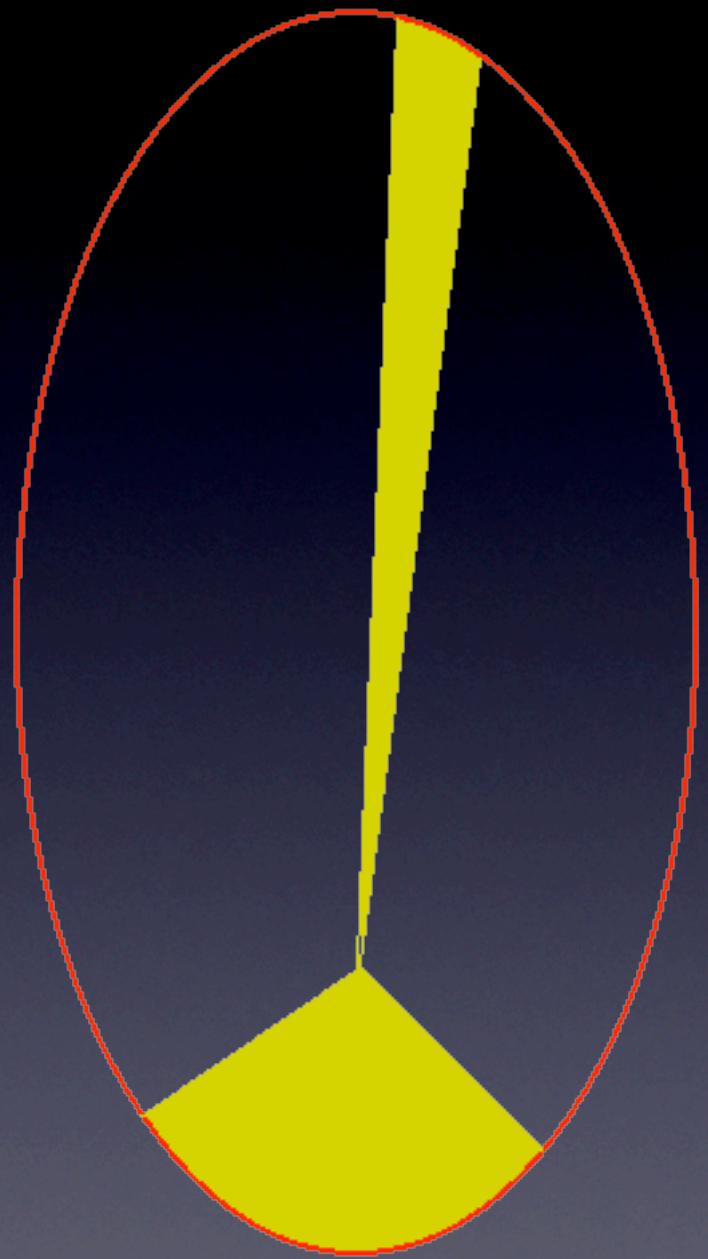
Kepler

ellipses!

Kepler's laws of planetary motion

better for ephemerides

simpler



Newton

calculus

The Law of Universal Gravitation

as above, so below

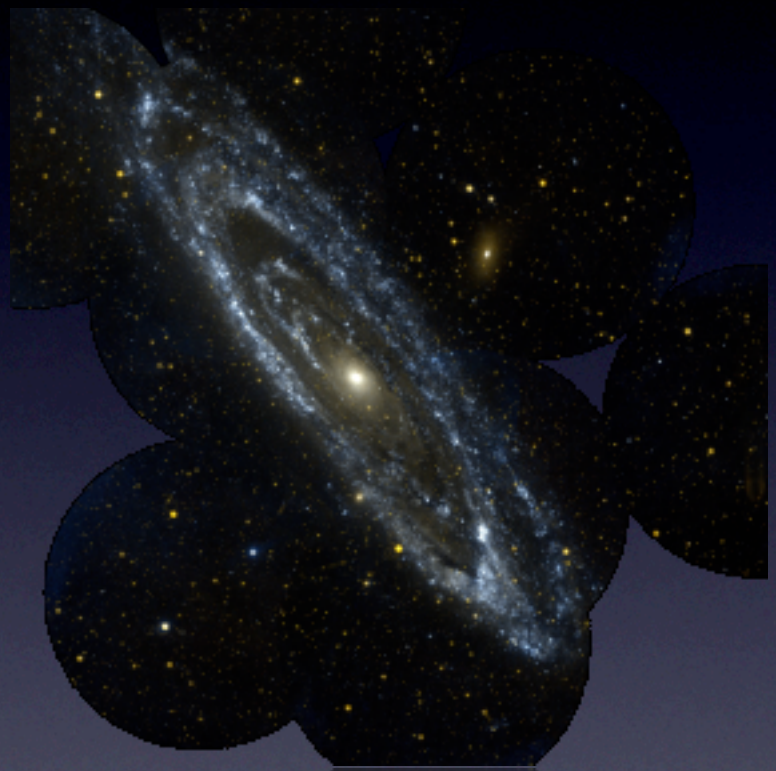
celestial mechanics

$$f = m\frac{\mathrm{d}v}{\mathrm{d}r}$$

$$f = \frac{Gmm'}{r^2}$$

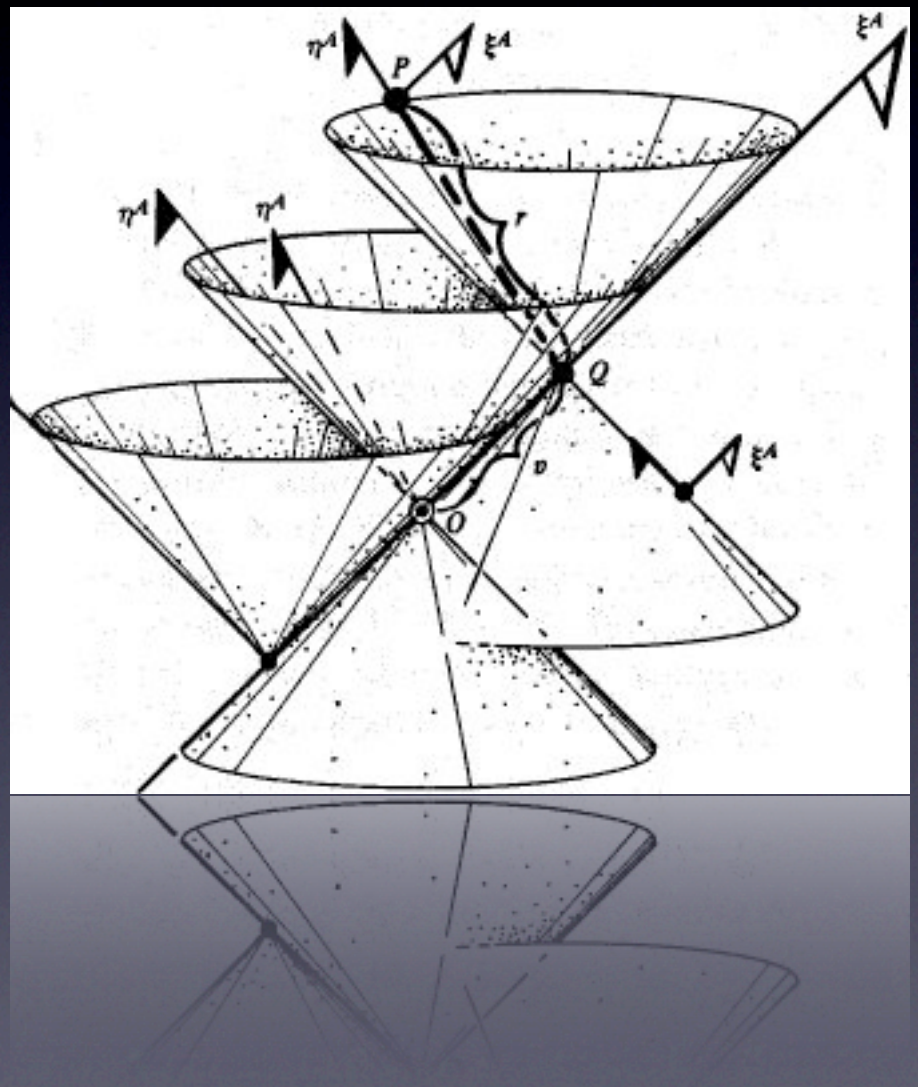
Hubble

distance to Andromeda
too far away to be in our galaxy
...but in our local group
...remoter galaxies are receding

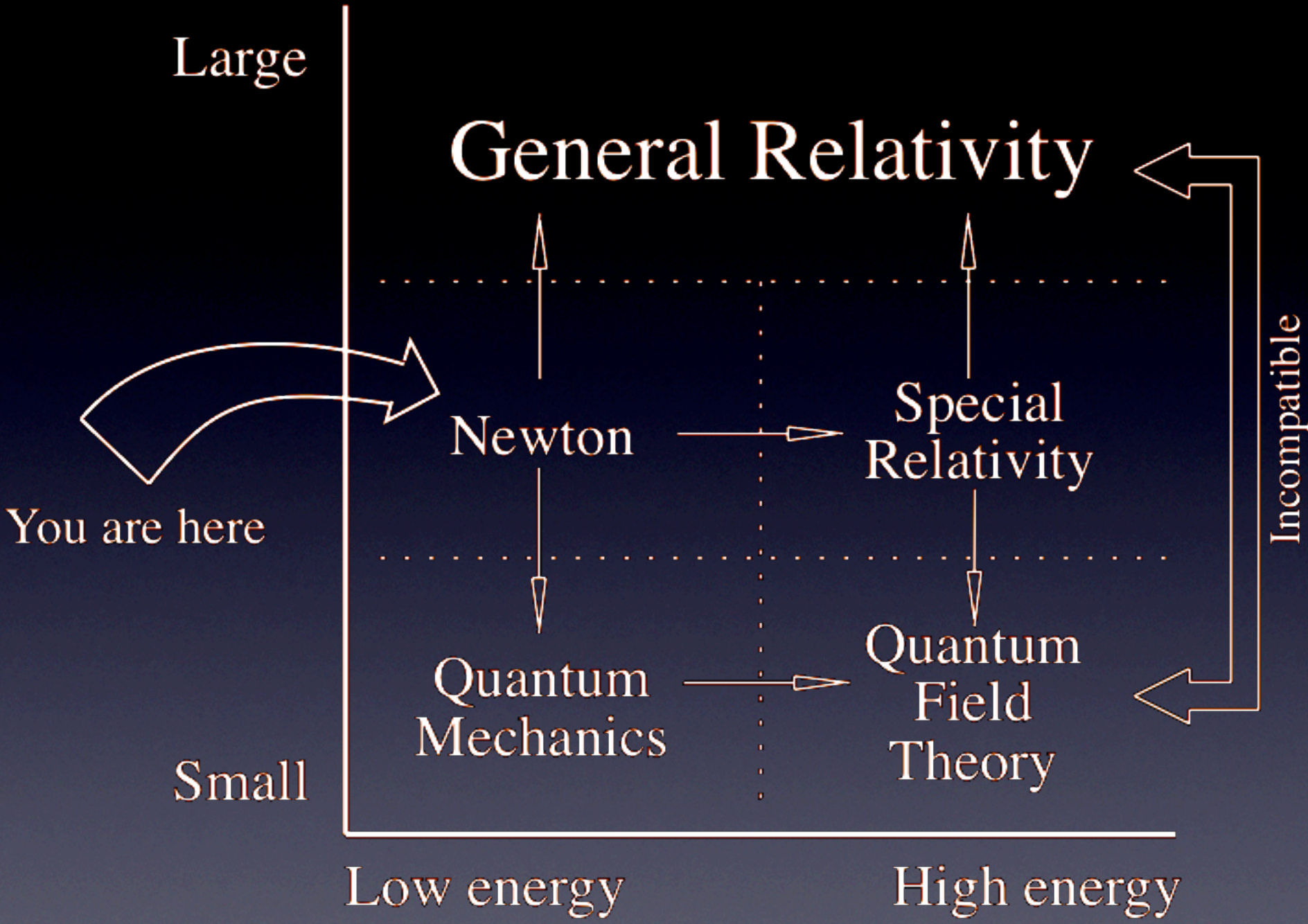


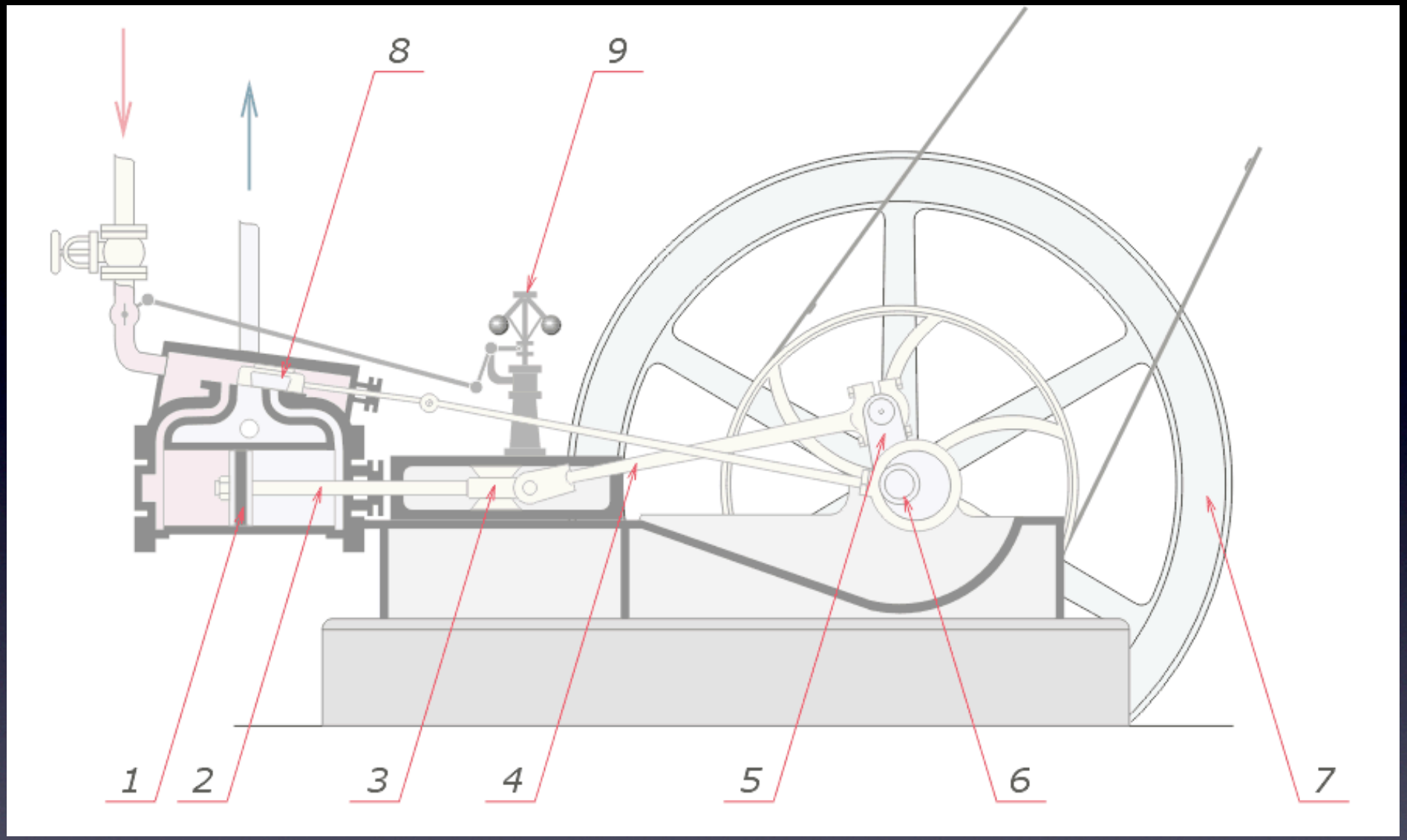
Einstein

geometry of spacetime
large-scale structure of spacetime
highly mathematical
...but still fundamentally simple!



The Standard Model


Large
General Relativity
Newton
Special Relativity
You are here
Incompatible
Quantum Mechanics
Quantum Field Theory
Small
Low energy
High energy



$$S = Ak_B c^3 / 4\hbar G$$

The particle zoo

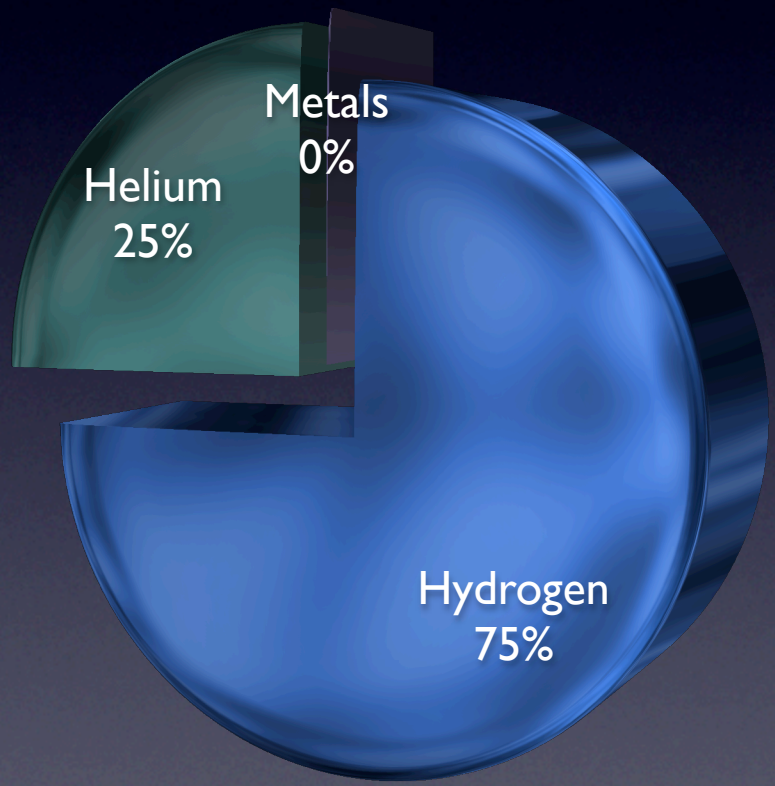
- **Electromagnetism –** This is the force that drives motors,comprises radio waves, keeps the electrons circling the nucleus, and stops us falling through the floor.
- **Weak nuclear force –** Responsible for radioactive decay,when a neutron decays into a proton, and electron, and a neutrino.
- **Strong nuclear force –** The strong nuclear force is the force that keeps nuclei firmly in one piece against the hugeelectrostatic repulsive force.

The particle zoo (2)

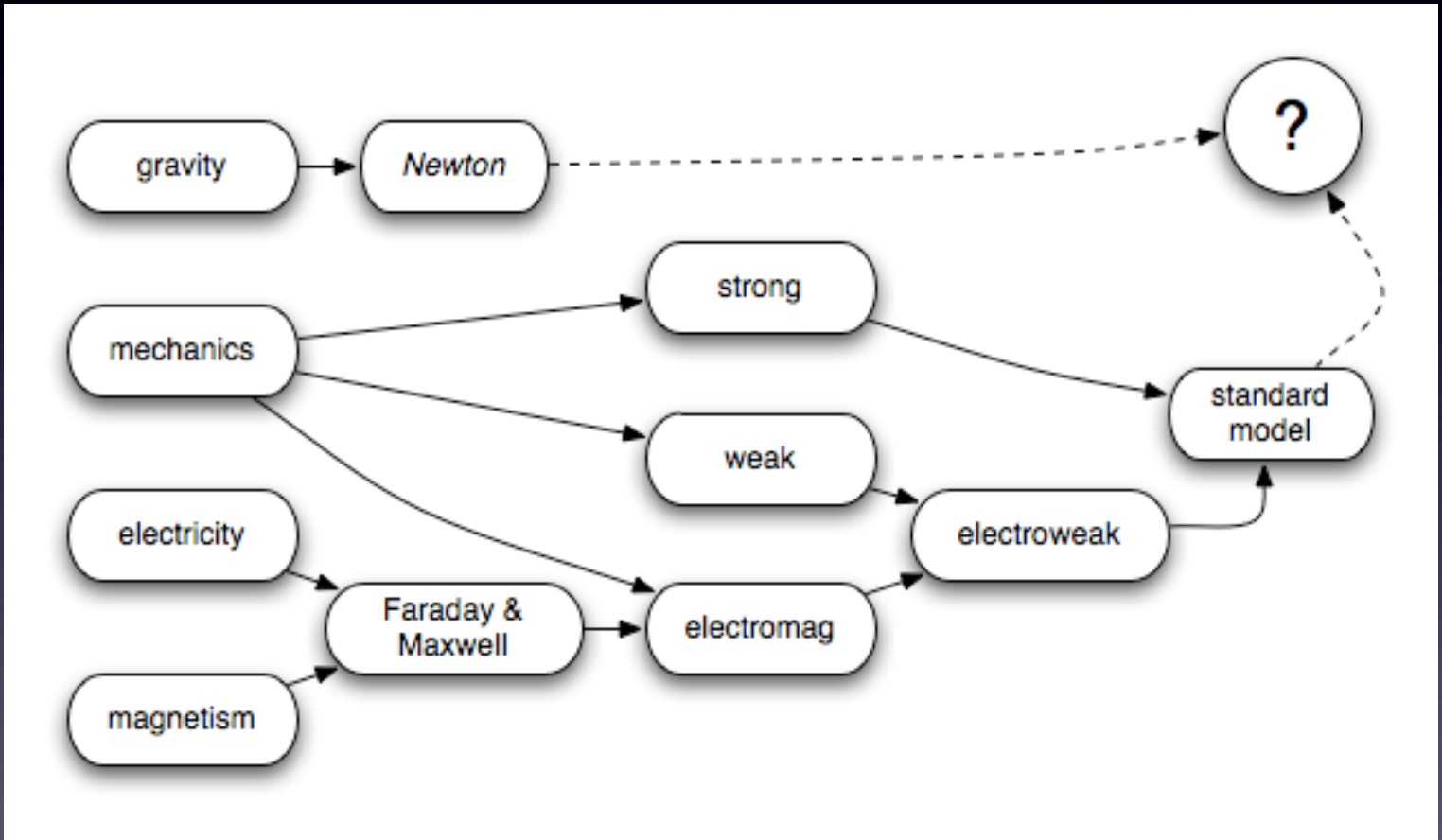
- **Gravity –** In this picture, gravity is the stage on which all of the rest of physics takes place, and in consequence *everything* feels its effects, even the massless photon. ‘Space tells matter how to move; matter tells spacehow to curve.’

Big bang nucleosynthesis

alpher-bethe-gamow paper



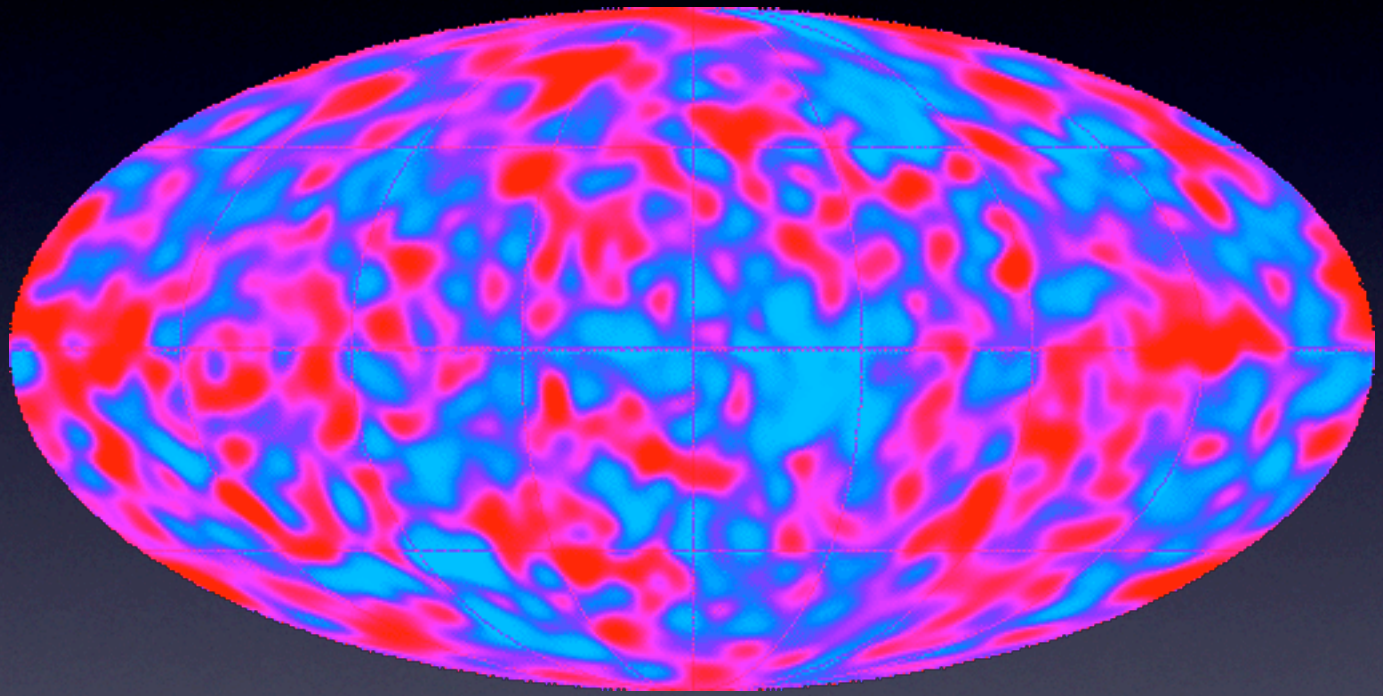
Unification

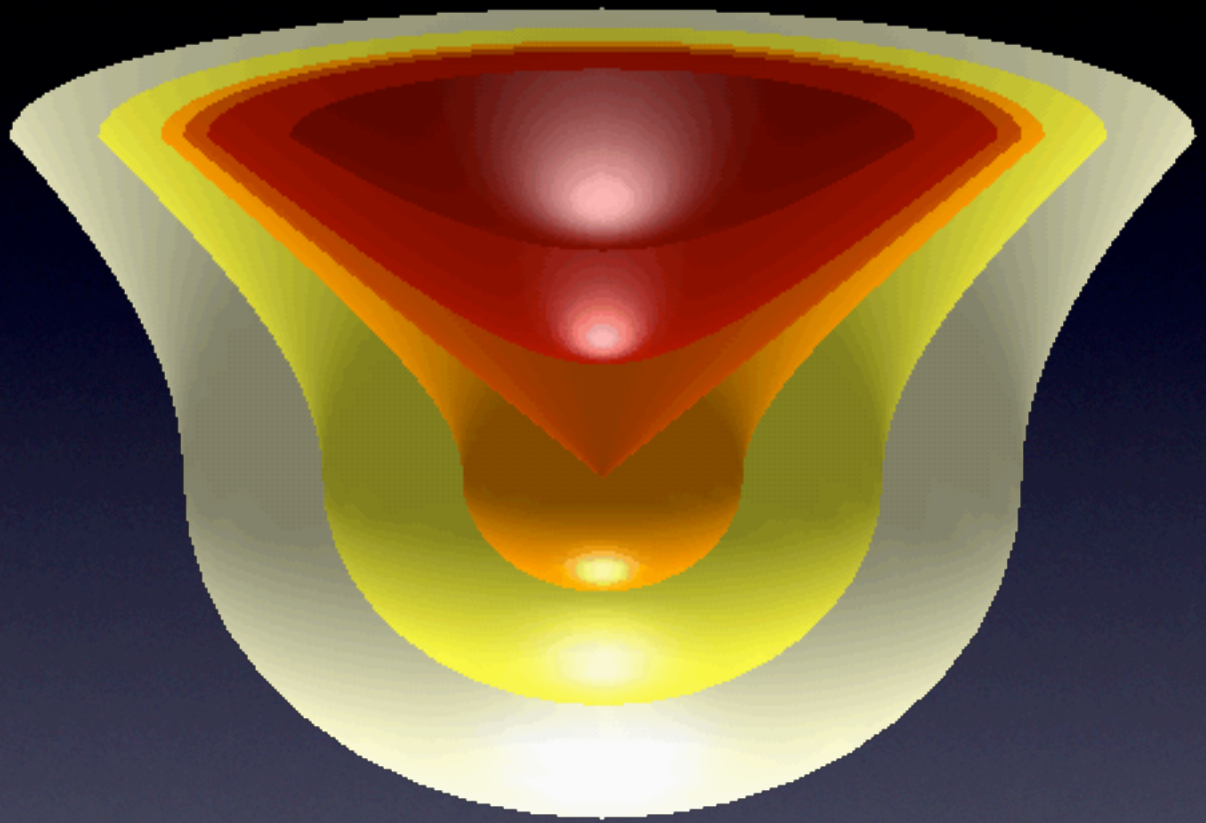


Cosmogeny

Big bang timeline

- 10^{-37}s – 10^{-35}s: inflation
- 10^{-35}s – 1s: particle physics
- 1s – 3min: nuclear physics, nucleosynthesis
- 3min – 300 000y: radiation, to the CMBR
- 100My: the first stars
- 100My – 10^{10}y: stars, planets, people, stuff





What drives inflation?

Symmetry breaking of an underlying field

...which is therefore an actor

73% dark energy

23% dark matter

4% matter

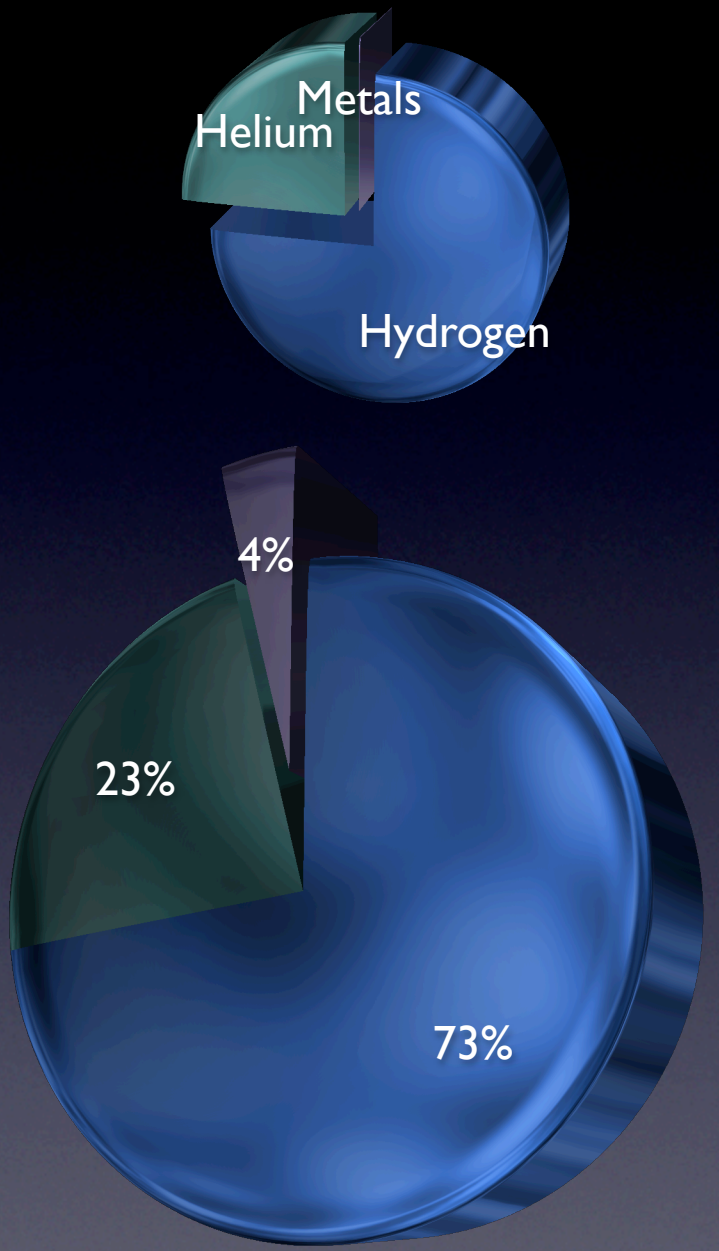


Image credits

- www.virgo.dur.ac.uk
- jpl.nasa.edu
- hubblesite.org
- wikipedia
- www.damtp.cam.ac.uk