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WHAT IS THE NATURE OF DARK ENERGY?

What is dark energy?

- A form of energy which permeates all of space, accounts for the majority of energy in the universe and causes the expansion of the universe to accelerate

How do we know dark energy exists?

- Calculations of the universe's overall energy density from the Cosmic Microwave Background compared with the total matter density of the universe
  - Matter only accounts for 25-35% of the universe's total energy density
- Observations of an accelerating universe using Type Ia supernovae

Background: Interesting properties of general relativity

- In going from Newtonian gravity to general relativity, the energy contained in a system replaces the mass contained in a system in describing gravitational force
- Pressure also determines the gravitational force strength in the form (E+3P), though the P term is generally negligible

How pressure affects gravity

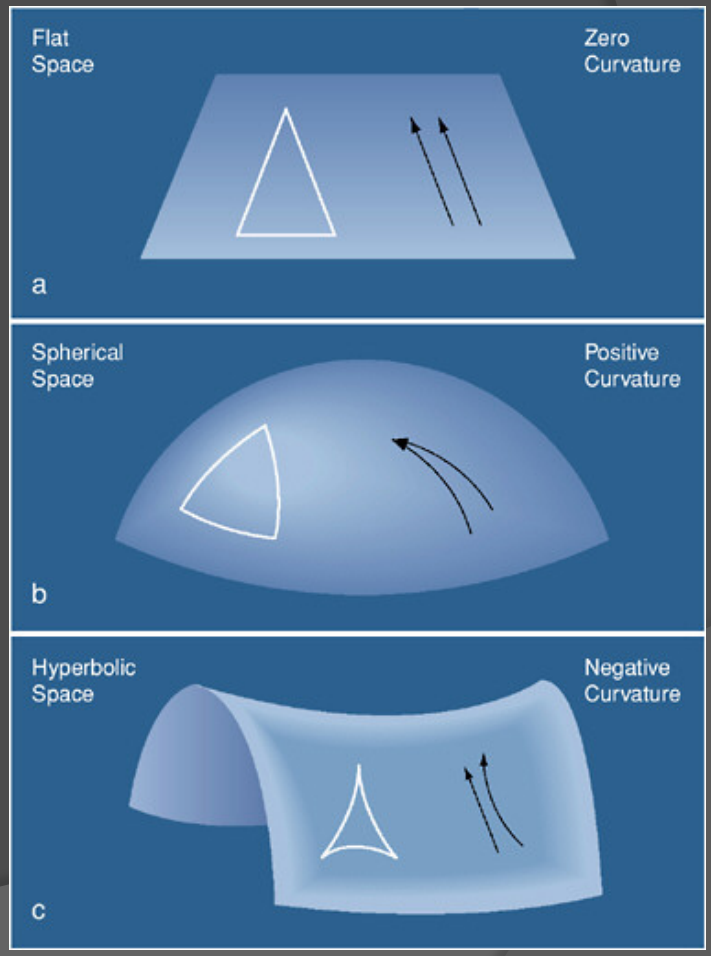
- Positive, outward pressure
  - Results in an attractive gravitational force
  - Hastens the collapse of black holes
- Negative, inward pressure
  - Results in a repulsive gravitational force
  - Only detectable when P is on the same order as E
    - The extent to which it has an effect is determined by the equation of state $w = p / \rho_E$; p = pressure, ρ_E = energy density)

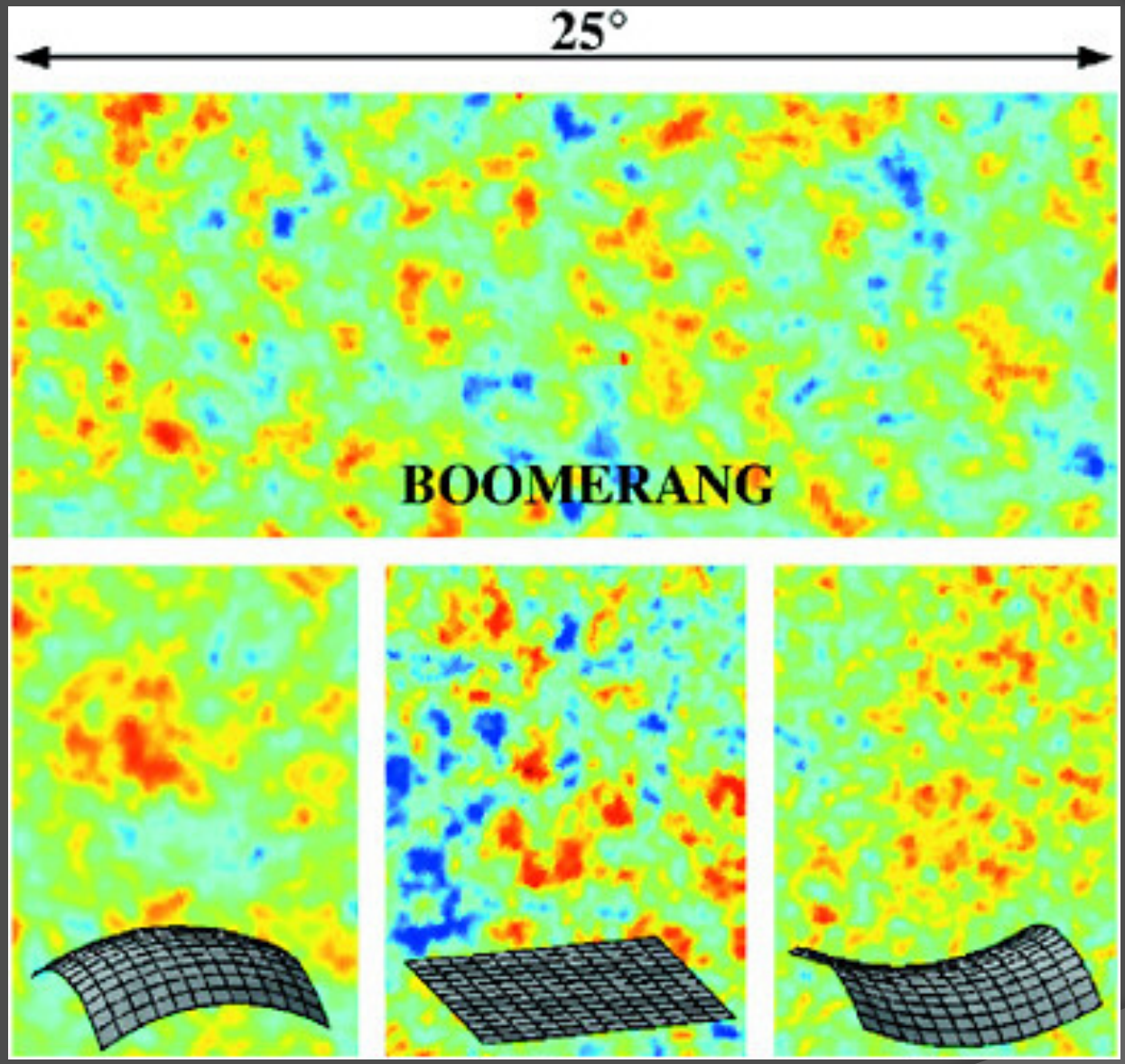
The cosmological constant

- Up to the early 20th century it was believed that the universe was static
- Einstein found that GR calculations of a homogeneous, isotropic universe made entirely of matter would collapse into itself
- Einstein introduced a constant, Λ, which represents an isotropic, homogeneous distribution of energy that utilizes the repulsive property of gravity to balance it's long-range attractive property
- After Hubble's discovery of the universe's expansion Einstein abandoned the constant

New evidence, the shape of the universe

- According to general relativity the universe can have one of three different shapes:
  - Flat – The universe has a flat geometry. This occurs if the energy density of the universe equals the critical density (critical).
  - Closed – The universe curves into itself. This occurs if the energy density of the universe is greater than the critical density (supercritical).
  - Open – The universe is saddle-like in nature. This occurs if the energy density of the universe is less than the critical density (subcritical)





Indicates the energy density of the universe is equal to the critical density, which is about 3-4 times greater than that of all the known matter in the universe.

Type Ia supernova

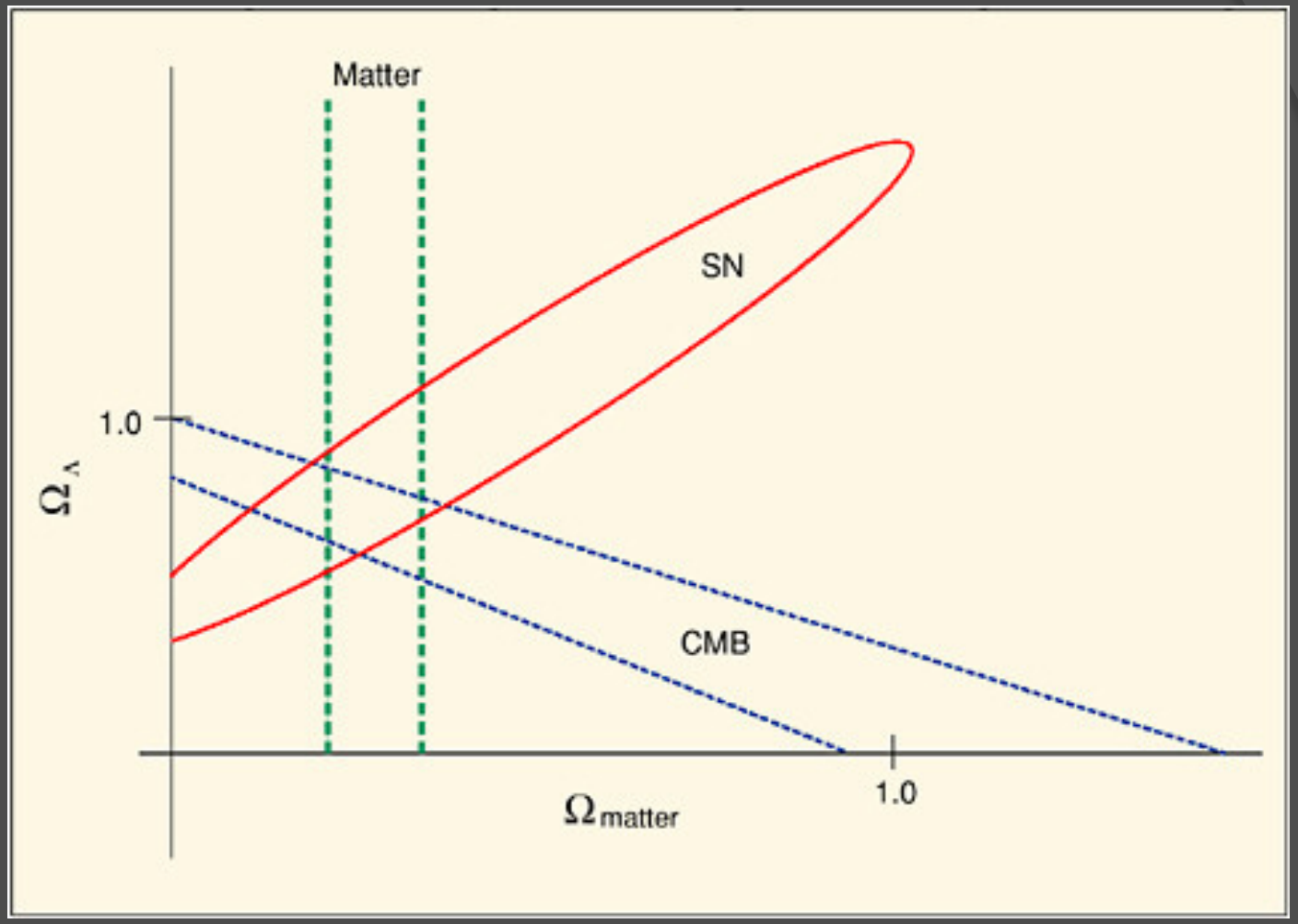
- Take place in binary systems with a white dwarf acreeting matter from its partner
- When correcting for pulselength, they have the same peak luminosity
  - Can determine distance with simple $1/r^2$ relation
- Characteristic spectrum allows measurement of redshift

Supernovae observation results

- Noticed that the events with a higher redshift were less luminous than predicted by Hubble's law ($v = H_0 d$)
- Determined the universe is accelerating outward
  - Implies a positive cosmological constant, a.k.a. dark energy

Possible systematic errors

- Grey dust
  - Dust could be falsely altering the luminosity of the distant supernovae, giving false results for their distances
- Composition of early supernovae
  - The more distant and therefore earlier supernovae may have taken place without the presence of heavier elements found in closer supernovae, calling for a possible alteration of our current models



The dark energy and matter densities of the universe as ratios of the critical density.

Current pursuit

- Better understand the equation of state of dark energy:
  - $w = p / \rho_E$
    - w = dimensionless constant
    - p = pressure
    - ρ_E = energy density