DARK ENERGY

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Cosmologia - Gravitació i astropartícules

- Introduction
- Equations
- Candidates

- DE -> Modern & unknown

- Universe expanding
  - Observational evidence from supernovae for an accelerating universe and a cosmological constant (A.Riess et al.) 1998
  - Measurements of omega and lambda from 42 high redshift supernovae. (S. Perlmutter *et al.*) 1999

DE ~ expansion

Beginnings

- Einstein wants a static universe.

    GR don't permit it (Matter attracts gravitionally)

    He added a term (<u>*cosmological constant*</u>) to arrange a static UNI

$$R_{\mu\upsilon} - \frac{1}{2} R g_{\mu\upsilon} \boxed{- \Lambda g_{\mu\upsilon}} = 8\pi G T_{\mu\upsilon}$$

- Hubble law -> expansion -> problem!

The standard cosmological model

- Cosmological principle: Universe is isotropic and homogeneous (on large scales)

- Metrics: equation which gives the distance between two points
  - SR -> Minkowsky metric

$$ds^2 = -c^2 dt^2 + dr^2 + r^2 d\Omega^2$$

  - GR -> Robertson-Walker metric

$$ds^2 = -c^2 dt^2 + a(t)\left[dr^2 + S_k(r)^2 d\Omega^2\right]$$

t: cosmic time

r: comoving coordinates

Dynamics: relations between curvature & content (a(t), k, R_0, ε(t) & P(t))

- # Friedmann equation. Rel. between a(t), k, ε(t) & R_0

$$H(t)^2 = \frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{kc^2}{R_0^2 a(t)^2}$$

- # Fluid equation. Rel. between a(t), ε(t) & P(t)

$$\dot{\varepsilon} + 3\frac{\dot{a}}{a}(\varepsilon + P) = 0$$

- # Acceleration equation. Rel. between a(t), ε(t) & P(t)

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\varepsilon + 3P)$$

- # Equation of state. Rel. between ε(t) & P(t)

$$P = \omega\varepsilon$$ where w < 1

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DARK ENERGY

W < -1/3

Λ

W = -1

Equations with lambda

- Friedmann equation. Rel. between a(t), k, ε(t) & R_0

$$H(t)^2 = \frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{kc^2}{R_0^2 a(t)^2} \boxed{+ \frac{\Lambda}{3}}$$

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Einstein wanted to find H=0. In a flat Universe $\Lambda = -\frac{8\pi G}{c^2}\varepsilon$

"New component"

- Λ ~ fluid

$$P_\Lambda = -\varepsilon_\Lambda = -\frac{c^2}{8\pi G}\Lambda$$

- Λ has a negative effective pressure.

  As UNI expands, work is done on Λ fluid.

  -> E_Λ remains constant

$$W = -\int P dV$$

-> Energy of the empty space (vacuum)

- Classical physics
  - ("Nothing can come from nothing." King Lear)
- Quantum physics

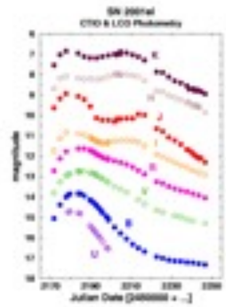
$$\Delta E \Delta t \geq h$$

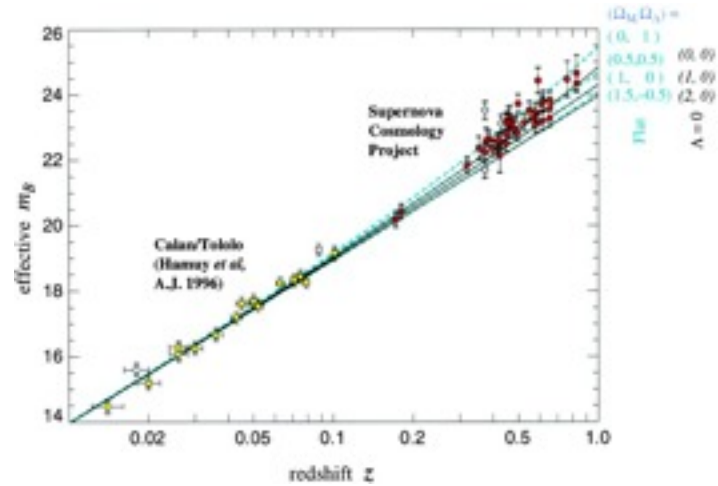
$$\varepsilon_{VAC} \sim \frac{E_P}{l_P^3} \approx 3 \times 10^{133}\, eV \times m^{-3} \boxed{\sim 10^{124}\, \rho_{critical}}$$

Theory and observations don't match

Evidences

- Observation of SNIa





Standarized standard candles

$$m - M \approx 43.17 - 5\log_{10}\left(\frac{H_0}{70\,km\times s^{-1}Mpc^{-1}}\right) + 5\log_{10} z + 1.086(1 - q_0)z$$

– The best model is

$\Omega_M \approx 0.3$

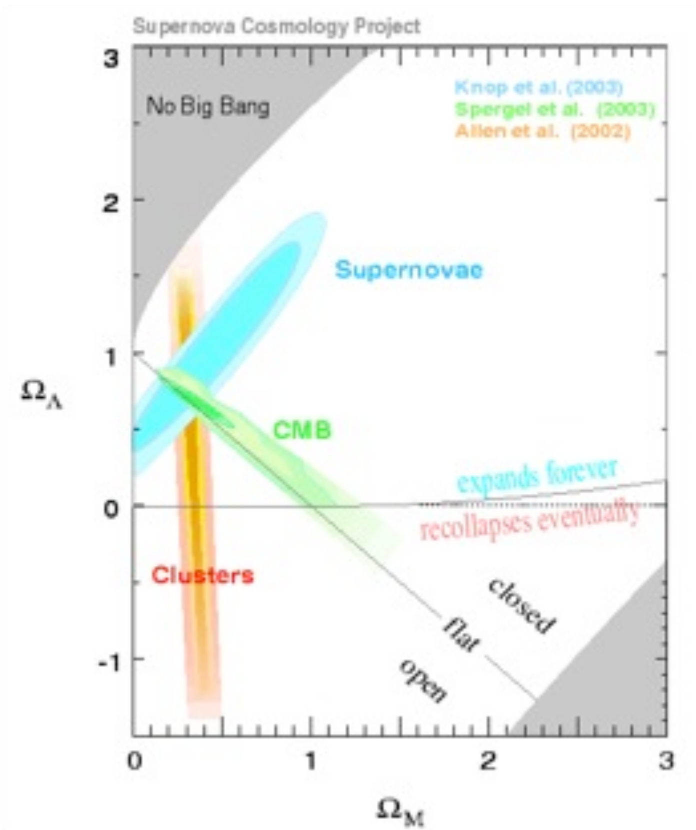
$\Omega_\Lambda \approx 0.7$

- Universe only with Λ (or Λ -dominated)

Friedmann equation $$\dot{a}^2 = \frac{8\pi G\varepsilon_\Lambda}{3c^2} a^2 \longrightarrow \boxed{a(t) = e^{H_0(t-t_0)}}$$

Universe exponentially expanding

Infinitely old, infinite horizon distance

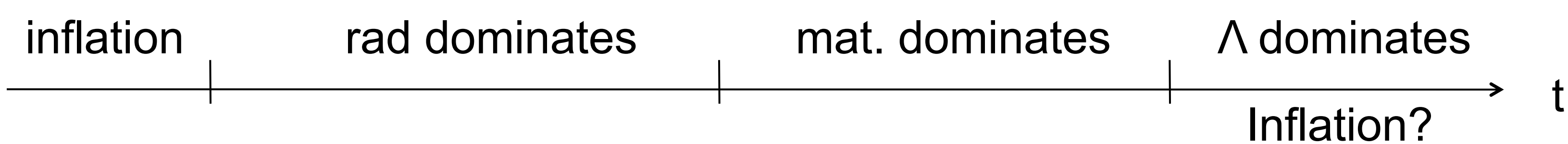


Inflation

- DE is fundamental in inflation (Guth 1981)

  Early period in the history of the Universe, when the expansion was accelerating outward

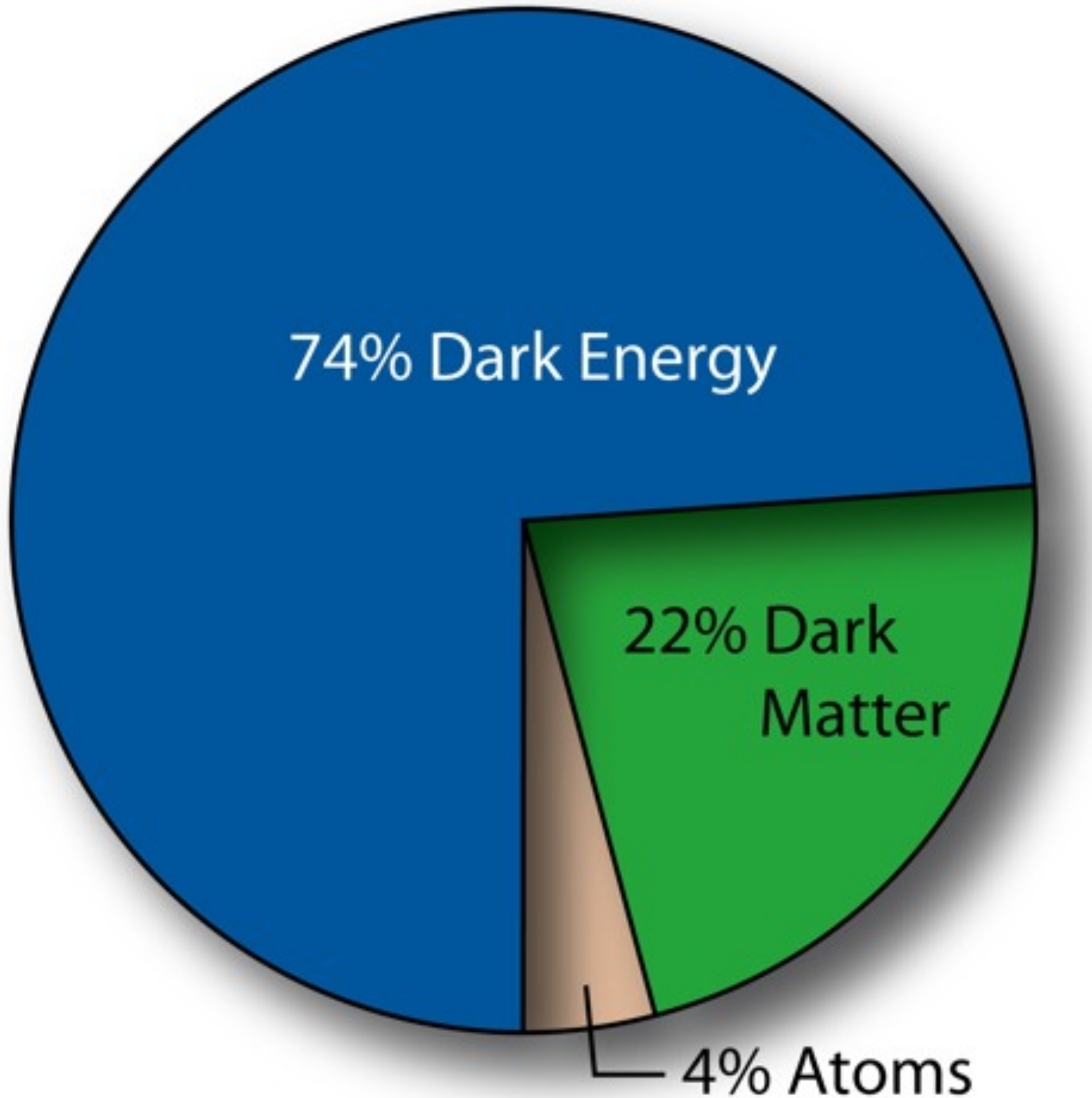
$$\ddot{a} > 0$$

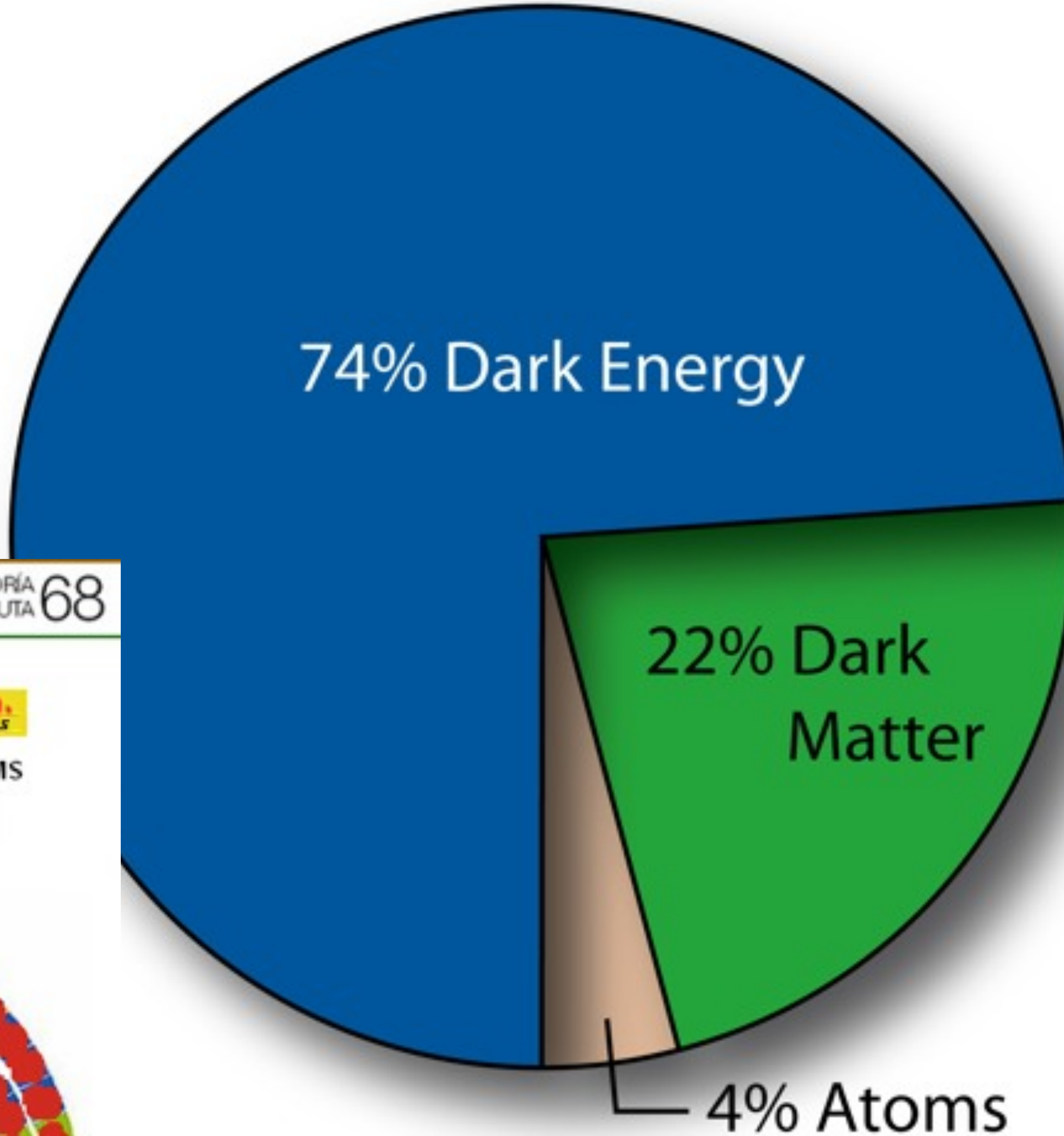


DE is not…

What can be DE?

- Transient phenomenon, which will disappear in the future
- Cosmological constant (ΛCDM model)
- Scalar field (quintessence). Λ is not constant, exhibits slow variation
- Modified gravity (Gauss-Bonet: extradimensions)


74% Dark Energy
22% Dark Matter
4% Atoms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LOS ESCAÑOS
TOTAL ESCAÑOS 135
MAYORÍA ABSOLUTA 68
ESCRUTADO: 100%
DARK ENERGY
100
DM
DARK MATTER
30
ATOMS
5