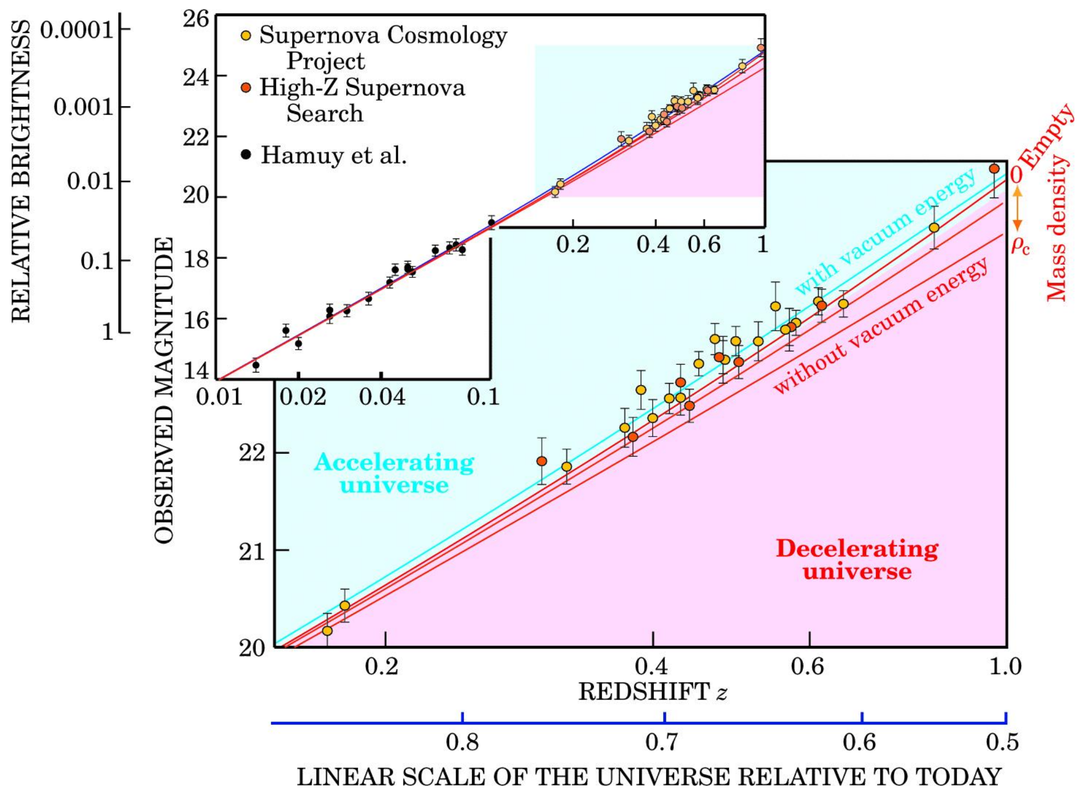
Lecture 37 : The Accelerating Universe

A surprising and startling discovery was made around the year 2,000 the universe is not only expanding, but the expansion is accelerating! In the first half of this lecture, how this great discovery was made is described. If the expansion is 'accelerating then it implies two things, (i) There must be a cosmic repulsion, and (ii) This cosmic repulsion must be dominating over the attractive gravity in the present epoch. What could this 'cosmic repulsion or 'repulsive gravity be due to? In the second part of this lecture, the present state of our understanding of this deep and intriguing question is discussed.



Observed magnitude versus redshift, for well-measured distant and (in the inset) nearby Type Ia supernovae. At redshifts beyond $z = 0.1$ (distances greater than about 109 light-years), the cosmological predictions (indicated by the curves) begin to diverge, depending on the assumed cosmic densities of mass and vacuum energy. The red curves represent models with zero vacuum energy and mass densities ranging from the critical density ρ_c down to zero (an empty cosmos). The best fit (blue line) assumes a mass density of about $\rho_c/3$ plus a vacuum energy density twice that large - implying an accelerating cosmic expansion.

Suggested Reading : S. Perlmutter, 2003, Phys.Today, 56 (4), 53   [The picture above is taken from this article.]

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Suggested Problems

1. Consider a flat universe in which the dark energy, cold pressure-less matter and radiation contribute 70.24%, 29.75% and 0.01% of the total energy density respectively.

   (a) At what redshifts is the energy density of matter equal to the energy density of radiation?

   (b) At what redshift is the contribution of matter to the energy density equal to that of dark energy in this universe?

   (c) Consider a universe with the same initial conditions as ours, but in which the matter particles have remained relativistic. How does the temperature of the CMB compare to that in our Universe when it is as old?

2. In an accelerating or decelerating Universe the redshift, $z = a(t_0)/a(t_e) - 1$, measured for a particular source (at rest in comoving coordinates), will slowly change over time t_0.

   (a) Show that the rate of change is -
   $$\frac{dz}{dt} = H_0(1+z) - H(z) \tag{1}$$
   where, $H(z) = \dot{a}/a$ is the Hubble constant at the time of emission.

   (b) How much does the redshift of a source at $z = 0.5$ change over 10 years, in $k = 0, \Omega_\Lambda = 0.73, \Omega_m = 0.27, H_0 = 71\ km.s^{-1}$ universe? Discuss the practicality of measuring this [High resolution optical spectroscopy of narrow quasar absorption lines produced by cold clouds can achieve a precision of $\delta\lambda/\lambda \sim 1/300,000$ ("1 km.s^{-1}1" resolution). You might also consider radio or submm measurements of HI or CO lines.]

3. Our universe became transparent at recombination, $z \sim 1088$. Suppose that the protons, electrons and helium nuclei in the universe had not recombined at $z \sim 1088$, but had remained fully ionized (e.g. by early-formed hot stars or accreting black holes). At what redshift $z(t)$ will expansion make such a universe transparent (for simplicity, neglect He, and assume the universe is made entirely of H)?

   Hints:

   1) the interaction between photons and free electrons is through Thomson scattering [the electric field of passing light accelerates each electron. Accelerated electrons radiate. The ratio of the luminosity radiated by the electron to the incident Poynting flux of radiation has units of area, and is called the Thomson cross-section, $\sigma_T = 8\pi/3(e^2/m_ec^2)^2 = 0.665 \times 10^{-24} cm^2$].

   2) The probability that a photon is scattered in traversing a physical distance $dl = c(dt/dz)dz$ is $n_e\sigma_T dl$, where n_e is the physical (not comoving) electron density.

   3) the comoving electron density, neglecting He, is $\Omega_{b,\rho_{c,0}}/m_H$, where $\rho_{c,0}$ is the present critical density, $\Omega_b = 0.045$ and m_H is the mass of a hydrogen atom.

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