# 1 Cosmological supernovae

Due to their high luminosity, SNe Ia are seen at very large, cosmological distances of thousands megaparsecs. They played a crucial role in the discovery of acceleration of the Universe in late nineties of the $20^{\text{th}}$ century for which Saul Perlmutter (Supernova Cosmology Project), Adam Riess and Brian Schmidt (High-z Supernova Search Team) have been awarded the Nobel prize in physics for 2011.

Simply put, if all SNe Ia have the nearly the same luminosity or absolute magnitude at maximum light, we can measure their apparent magnitudes and determine distances to their host galaxies. We know from Hubble's time that the Universe is expanding and the other quantity that we can measure are galaxies' redshifts $z$. Now, in cosmology we can define distance in multiple ways. If we use objects whose dimensions are know, the so-called "standard rods", and measure their angular dimensions, the distance obtained in this way is called angular-diameter distance $d_A$ and it can be shown that the Hubble's law for small $z$ takes the form

$$H_0\ d_A = \frac{c}{1+z}(z - \frac{1+q_0}{2}z^2 + \ldots), \tag{1}$$

where Hubble constant is $H_O$ and deceleration parameter $q_0$ is supposed to be positive if the Universe is decelerating, what we expect if the only relevant force is attractive – the gravity. If, on the other hand, we use "standard candles" like SNe Ia then we are talking about luminosity distances $d_L$ and the Hubble's law is

$$H_0\ d_L = c(1+z)(z - \frac{1+q_0}{2}z^2 + \ldots); \tag{2}$$

$$H_O\ d_L \approx c(z + \frac{1-q_0}{2}z^2 + \ldots). \tag{3}$$

In both cases, for local universe $z \to 0$, we obtain the well-known linear Hubble's law v = z $\cdot$ c = $H_0 d$.

Table 1: Data adopted from Ned Wright's page* (Riess et al. 2007 dataset).

| $z$ | $d_L$ |
|---|---|
| 0.015 | 0.063 |
| 0.033 | 0.142 |
| 0.071 | 0.321 |
| 0.207 | 1.007 |
| 0.322 | 1.635 |
| 0.423 | 2.338 |

`*http://www.astro.ucla.edu/~wright/sne_cosmology.html`

If we use data from Table 2 and perform least squares fit we obtain $H_0 \approx 73$ km $s^{-1}$ $Mpc^{-1}$ and $q_0 = 0.569$ – negative value suggesting the action of some repulsive force commonly known as cosmological constant $\Lambda$ or dark energy. Deceleration parameter can be expressed as

$$q = \frac{1}{2}\Omega_m + \Omega_r - \Omega_\Lambda, \tag{4}$$

where $\Omega_m$, $\Omega_r$ and $\Omega_\Lambda$ are mass-energy contributions from matter (including dark matter), radiation and dark energy, respectively. For the flat universe (curvature constant $k = 0$) we have

$$\Omega_m + \Omega_r + \Omega_\Lambda = 1, \tag{5}$$

and if further set $\Omega_r = 0$, the last two equations give us $\Omega_\Lambda \approx 0.71$ and $\Omega_m \approx 0.29$ which are close to the real values.