Peculiar velocities and Type Ia supernovae

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Advisor: dr. Anže Slosar

23. December, 2009

Outline

Overture

Different types of supernovae (SNe):

- Type II (H lines)

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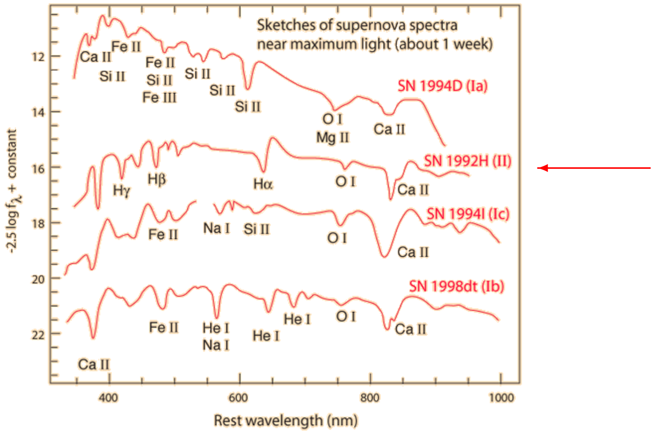

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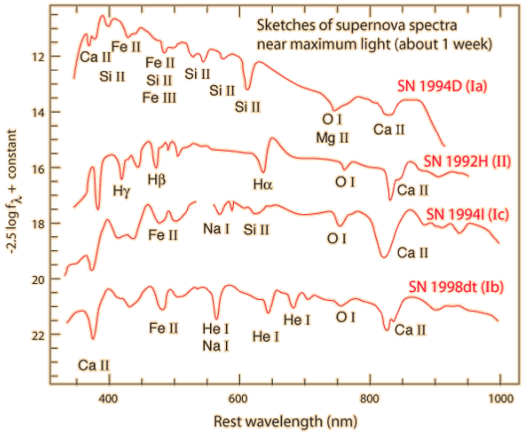

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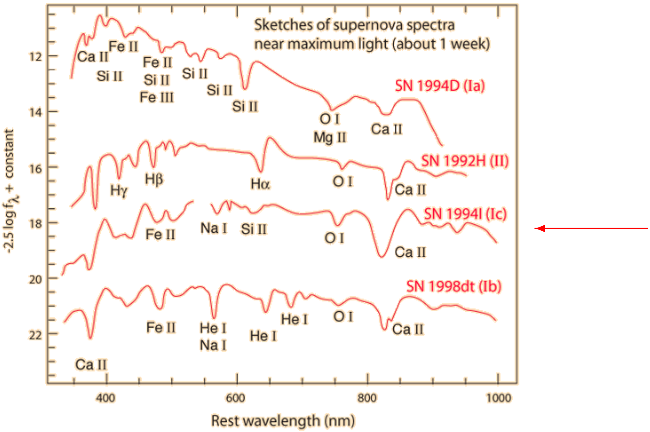

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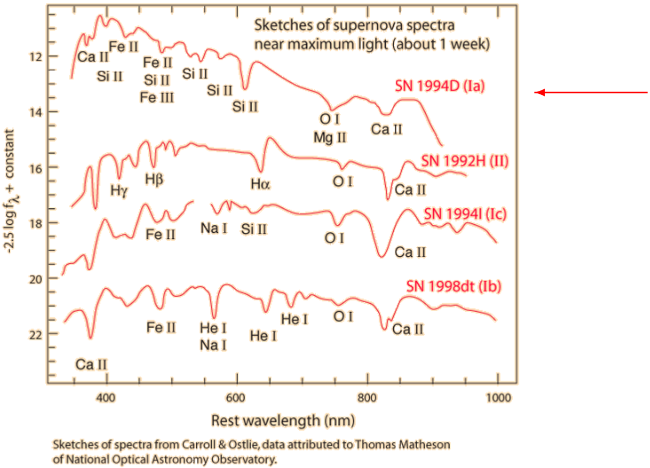

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$\longleftarrow$ $t \sim 10^9$ years, $M \leq 8\ \mathrm{M}_\odot$

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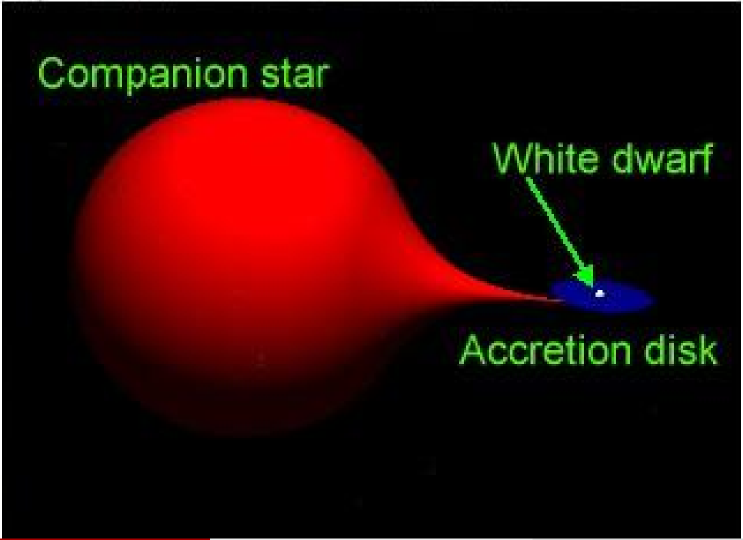

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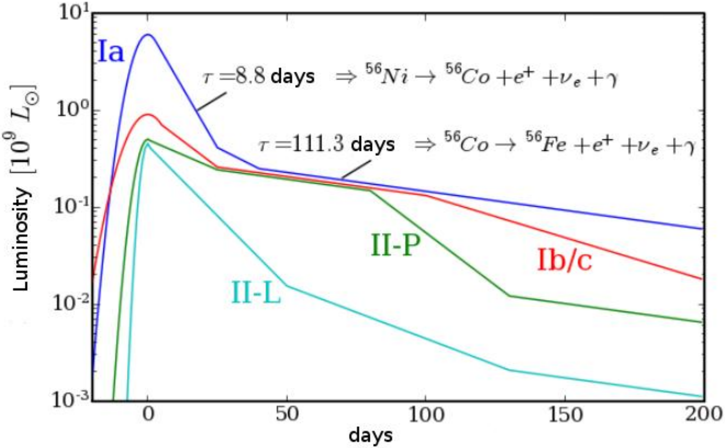

SNLS-3yr: http://www.physik.uni-bielefeld.de/igs/cosmology2009/guy.pdf (Nov 29., 2009)

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- peak luminosity of SN Ia depends on the mass of ^{56}Ni ejected (0.6 $M_\odot$)

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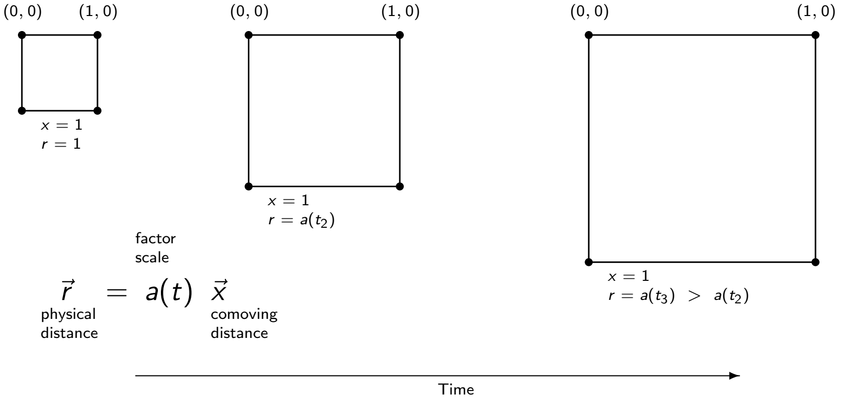
In 1990s two independent groups (SCP,HSST) announced surprising discovery using SNe Ia as standard candles $\rightarrow$ expansion of the Universe is accelareting (The results are consistent with some sort of 'dark energy', possibly Einstein's cosmological constant)

Data corrections

Uncorrected observations of SN Ia absolute magnitudes have an RMS scatter of ~ 40 %

- reduced via correlations between rate of decline,colour and intrinsic luminosity
- current standardization techniques normalize scatter to 15 % to 20 % (0.16 mag)
- Many popular methods (SALT(2),Stretch,(M)CLS(2k2),CMAGIC) enjoying similar level of success
- New method using flux ratios from a single flux-calibrated spectrum (0.12 mag) (arXiv:astro-ph/0905.0340)

Distances in cosmology



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- evolution of $a(t)$ derived from Einstein's field equation

Hubble rate $\longrightarrow$ $$H^2(t) \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$$ $\longleftarrow$ Geometrical curvator

$$\frac{\partial\rho}{\partial t} + 3\frac{\dot{a}}{a}(\rho + p) = 0$$

Geometrical curvator
- k $= 0 \rightarrow$ flat universe
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$\rho \leftarrow$ matter, dark energy, radiation, neutrions.

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Luminosity distance

The wavelength of light emitted from a receding object is stretched out so that the observed wavelength is larger than the emitted one. We define redshift (z) as

$$1 + z \equiv \frac{\lambda_{obs}}{\lambda_{emit}} = \frac{1}{a(t)}$$

It can be shown that the flux we observe is

$$F = \frac{L}{4\pi d_L^2}$$

Where we have introduced the luminosity distance d_L as

$$d_L = (1+z)\int_0^z \frac{dz'}{H(z')} \qquad \text{(in a flat universe)}$$

Cosmological parameters from SNe Ia

Transforming luminosity to magnitude we get

$$m - M = 5\log_{10}(d_L\ [\mathrm{Mpc}]) + 25$$

We seek minimum of χ^2 statistics

$$\chi^2(H_0, \Omega_m, \Omega_\Lambda, w) = \sum_i \frac{(m_i - m(z_i; H_0, \Omega_m, \Omega_\Lambda, w))^2}{\sigma_{m_i}^2 + \sigma_m^2 + \sigma_v^2}$$

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or maximum of probability L as

$$\log L \propto -\frac{1}{2}\chi^2 - \frac{1}{2}\sum_i \log(\sigma_{m_i}^2 + \sigma_m^2 + \sigma_v^2)$$

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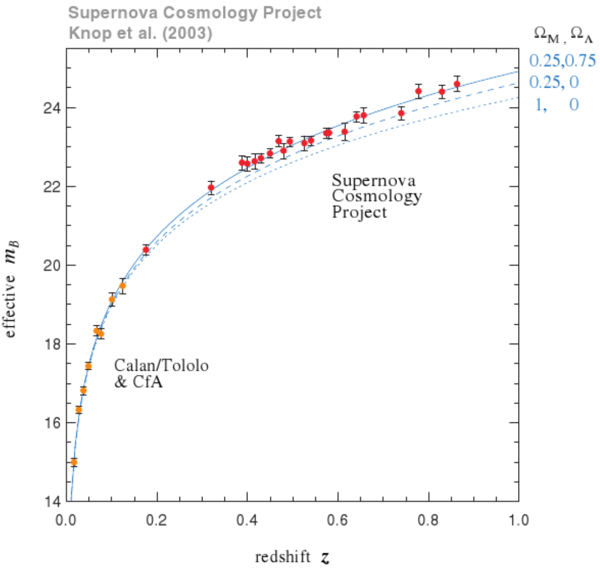

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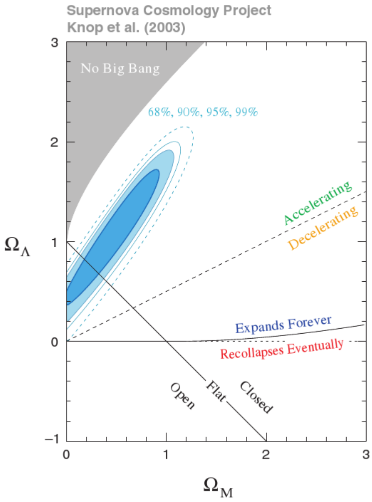

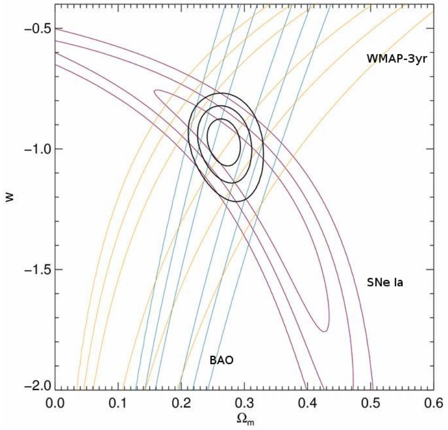

http://128.111.9.106/online/snovae c07/sullivan/pdf/Sullivan SnovaeConf KITP.pdf (Nov 29., 2009)

http://supernova.lbl.gov/ (Nov 29. 2009)

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$$\frac{\delta d_L}{d_L} = \frac{d_L^{me} - d_L^{th}}{d_L^{th}} = \hat{\mathbf{r}} \cdot \left(\mathbf{v} - \frac{(1+z)^2}{H(z) d_L} (\mathbf{v} - \mathbf{v}_o) \right)$$

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- the PV field can be derived $(\hat{\mathbf{r}} \cdot \mathbf{v}(\mathbf{r}))$

Correlation function #1

- PVs drawn from initial gaussian distribution $\rightarrow \langle(\mathbf{v}(\mathbf{r})\cdot\hat{\mathbf{r}})\rangle = 0$, $\langle(\mathbf{v}(\mathbf{r_i})\cdot\hat{\mathbf{r}}_\mathbf{i})(\mathbf{v}(\mathbf{r_j})\cdot\hat{\mathbf{r}}_\mathbf{j})\rangle \neq 0$

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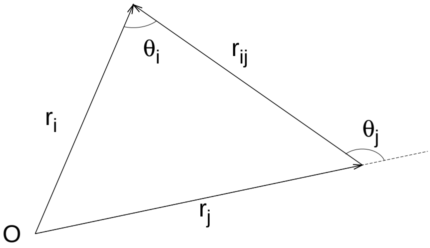

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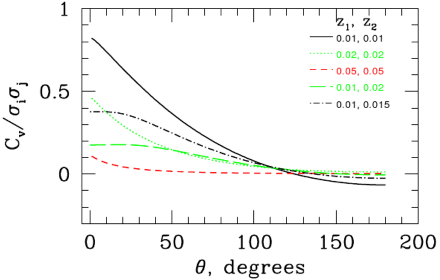
$$\xi(\mathbf{r_i},\mathbf{r_j}) \propto \int_0^\infty \frac{dk}{2\pi^2}P(k)K(k|\mathbf{r_{ij}}|)$$

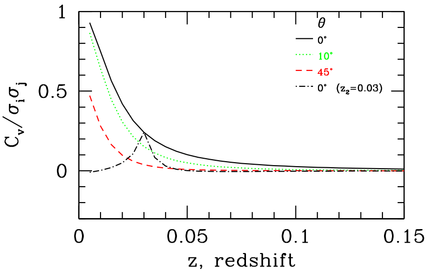
$$\langle(\mathbf{v}(\mathbf{r})\cdot\hat{\mathbf{r}})^2\rangle \propto \int_0^\infty P(k)dk$$

Correlation function #2

The PVs correlations lead to luminosity distance correlations and the covariance for the $\delta d_L/d_L$ for a pair of SN can be written as

$$C_v(i,j) = \left(1 - \frac{(1+z)^2}{H(z)d_L}\right)_i \left(1 - \frac{(1+z)^2}{H(z)d_L}\right)_j \xi(\mathbf{r_i}, \mathbf{r_j})$$





Slosar et al, arXiv:astro-ph/0705.1718v5

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- alternative approach $\rightarrow$ estimate the underlying density field from galaxy redshift surveys

Conclusion

- using SNe Ia data it has been proven that the expansion of the universe is accelerating
- indication of an unexpected gravitational physics $\rightarrow$ dark energy
- SNe Ia remain our best tool to constraint dark energy (precision and statistically significant samples)
- density inhomogeneities $\rightarrow$ deviation from Hubble flow: peculiar velocities
- in the limit of large data sets and small redshifts ($z \leq 0.1$) correlations between PVs contribute significantly to the overall error
- systematic uncertainties in relative distances due to: intervening dust, instrumental calibration and unknown evolution in z of SNe Ia luminosity $\leftarrow$ limiting factors
- without PV correlations we measure parameters (H_0, Ω_m, w), with PV correlations we probe $P(k)$ and measure other parameters as well ($\Omega_b, n_s, \sigma_8, \ldots$)