Indications for Anisotropy of the Hubble flow

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FLRW model and density parameter

Assuming isotropic and homogeneous perfect fluid being the content of the Universe we yield:

$$H^2 = \frac{8\pi G\rho}{3} - \frac{kc^2}{R^2} + \frac{\Lambda c^2}{3}$$

For present time we define the critical density of the Universe:

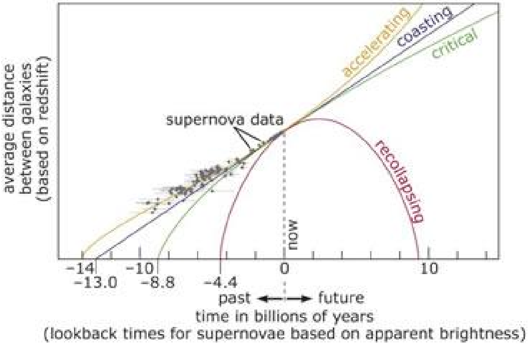
$$\rho_{tot,0} = \frac{3H_0^2}{8\pi G} = 1.9\cdot 10^{-29} h^2 g/cm^3$$

with $h = H_0/100$. We can rewrite Friedmann equation:

$$1 = \sum_i \frac{8\pi G\rho_i}{3H^2} = \sum_i \Omega_i$$

Accelerated expansion

$\Omega_m > 1,\ \Omega_\Lambda = 0$ $\Omega_m = 1,\ \Omega_\Lambda = 0$ $\Omega_m = 0.3,\ \Omega_\Lambda = 0$



- In 1998 the discovery of Supernovae Ia showed that the cosmic expansion is accelerating: flat ΛCDM with $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$

Cosmological analysis with JLA SNIa for a flat ΛCDM model w=-1

- $\mu_{obs} = m_B - M + \alpha\chi_1 - \beta c$

$$M = \begin{cases} M^1 \text{ if } \; M_{stellar} \leq 10^{10} M_{\odot} \\ M^1 + \Delta_M \;\; \text{otherwise} \end{cases}$$

  (Betoule et.al 2014)
  $\alpha = 0.141,\ \beta = 3.101,\ M^1 = -19.05$ and $\Delta_M = -0.07$

- $H(z) = H_0[\Omega_m(1+z)^3 + (1-\Omega_m)]^{1/2}$

- $d_L = c(1+z)\int_0^z \frac{dx}{H(x)}$

- $\mu_{\Lambda CDM}(z;\Omega_m) = 5\log d_L + 25\ (Mpc)$

- $\chi^2 = (\mu_{obs} - \mu_{\Lambda CDM}(z;\Omega_m))^\top C^{-1}(\mu_{obs} - \mu_{\Lambda CDM}(z;\Omega_m))$

JLA

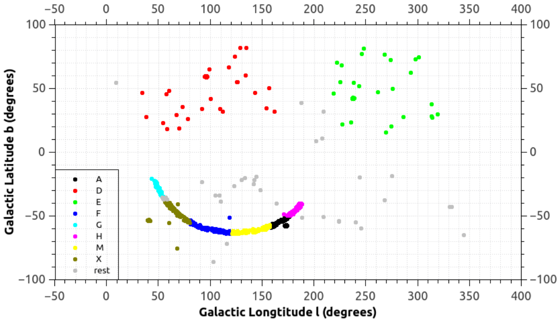
1. Low-z samples z$\leq$0.1
2. SDSS-II (Apache point observatory) 0.05$\leq$z$\leq$0.4
3. SNLS (Canada-France-Hawaii Telescope) 0.2$\leq$z$\leq$1
4. HST 0.7$\leq$z$\leq$1.4

Best fit for all data: $\Omega_m = 0.295 \pm 0.02$
Betoule et al. 2014: $\Omega_m = 0.295 \pm 0.034$
Planck: $\Omega_m = 0.308 \pm 0.012$

We choose SNIa with redshift $z > 0.02$ to avoid bulk flows (704 out of 740 SNIa events)

Test 1: Deriving SSMD for Ω_m

- We divide our sample of 704 SNIa into 9 spatially coherent groups
- For each group we constrain the **Ω_m within a flat ΛCDM model with a distance modulus approach**



Test 1: Deriving SSMD for Ω_m

- Given Ω_{m1} and Ω_{m2} best fit values for each group and the corresponding rest of the data, we define the quantity:

$$d\Omega_m = \Omega_{m2} - \Omega_{m1} \tag{1}$$

- For the $1-\sigma$ confidence levels we derive the σ_1 and σ_2 mean uncertainty range of each group and the rest of the data respectively, obtaining:

$$d\sigma = \sqrt{{\sigma_1}^2 + {\sigma_2}^2} \tag{2}$$

- Thus we have SSMD:

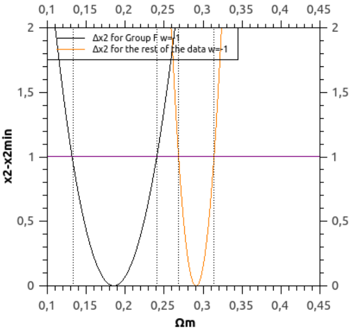
$$\beta = \frac{d\Omega_m}{d\sigma} \tag{3}$$

$-1 < \beta < 1 \rightarrow$ no significance
$\beta \in (-2,-1]$ or $\beta \in [1,2) \rightarrow$ moderate significance
$|\beta| \geq 2 \rightarrow$ strong significance

Test 1: Deriving SSMD for Ω_m

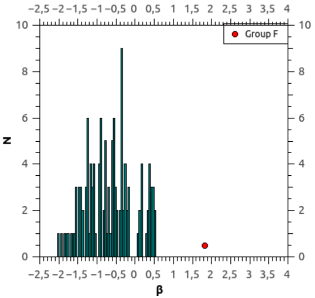
- A fairly significant SSMD for Group F consisting of 86 SNIa events $\beta = 1.8$

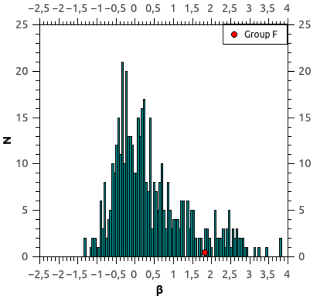
(Moderate significance due to possible outliers?)



Test 2: Distributions of SSMD

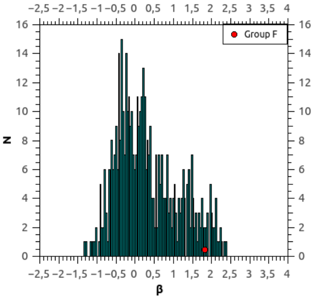
- Northern galactic hemisphere contains 182 SNIa events while southern 522
- We derive the distribution of SSMD for spatially coherent (as to I) groups of 60 SNIa members among the two galactic hemispheres (123 and 463 groups respectively)
- K-S test rejects the null hypothesis that the samples are derived from the same distrubution at a significance level greater than 99.99%
- Same pattern for large spatially coherent groups of 120 members





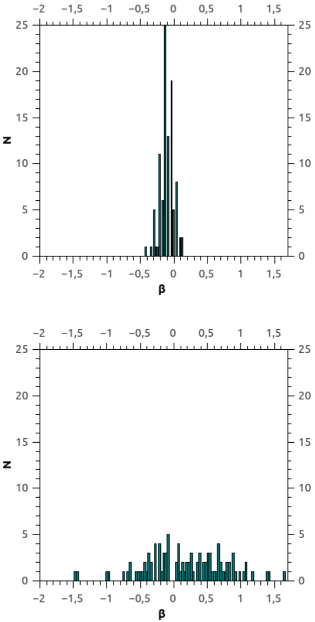
Test 2: Locate region of high SSMD

- The exclusion of two SNIa (SDSS15756 & SDSS14481) erases the tail in the distribution of high SSMD of the southern hemisphere
- The K-S test rejects the null hypothesis at significance level greater than 99.99%



Test 3: Distributions of SSMD

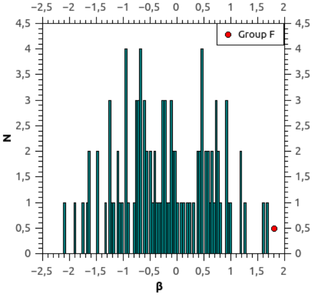
- Considering large groups of 180 random SNIa with boostrap sampling taken only from the northern or the southern hemisphere with the rest of the data. We repeat this procedure 100 times and we obtain the β distributions.
- K-S test rejects the null hypothesis at significance level greater than 99.99%

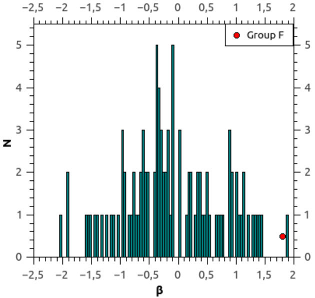


Test 4: Verifying the distinct distributions

- We take 100 random groups of 180 random SNIa with boostrap sampling from the whole data and see their β distribution. We apply the procedure twice to obtain 2 distributions
- With the K-S we cannot reject the null hypothesis at any significance level (p=0.55)

Suggests some anisotropy of the cosmic expansion within this model





Conclusions

- Considering either spatially coherent or random groups of SNIa among the two galactic hemispheres, we obtain statistically important distinct distributions. This possibly provides indication of anisotropy of the Hubble flow between them within this model or some unknown systematic uncertainties which we plan to investigate.

THANK YOU FOR YOUR ATTENTION