Peculiar velocities of SN Ia in clusters of galaxies: the impact on distance measurements

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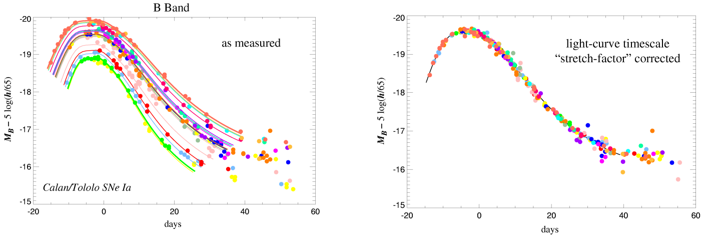
Introduction

Cosmology with SN Ia

- "luminosity distance-redshift" relation
- standardization of SN Ia (Rust 1974; Pskovskii 1977, 1984; Phillips 1993; Phillips et al. 1999; Riess et al. 1996; Perlmutter et al. 1997, 1999; Wang et al. 2003; Guy et al. 2005, 2007; Jha et al. 2007)

$$M = M_B - \alpha X1 + \beta C$$



Kim, *et al.* (1997)

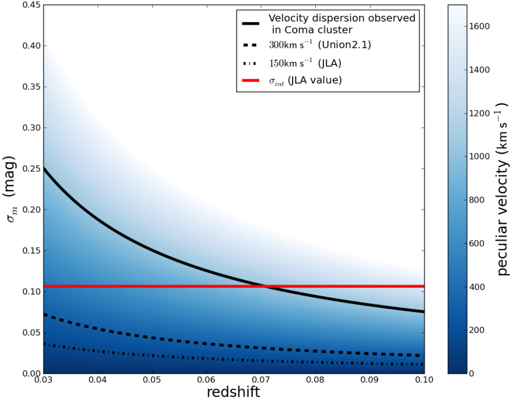
Introduction

Cosmology with SN Ia

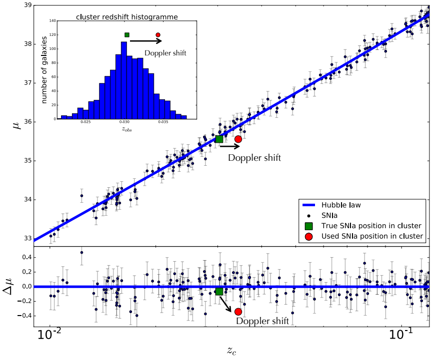
- Is the uncertainty on the redshift negligible?
  $(1 + z_{obs}) = (1 + z_c)(1 + z_d)$
- For low and intermediate redshifts ($z < 0.2$):
  - to remove all SNe with $z < 0.015$ from the Hubble diagram (Astier et al. 2006; Wood-Vasey et al. 2007)
  - high intrinsic velocity dispersion (300 km/s, Amanullah et al. 2010)
  - velocity maps of the nearby Universe (150 km/s, Hudson et al., 2004; Conley et al., 2011; Betoule et al., 2014)

Coma cluster

$$\sigma_V = 1038 \text{ km/s}$$
$$\sigma_m = \frac{5\,\sigma_V}{cz \ln 10}$$



SN Ia in clusters



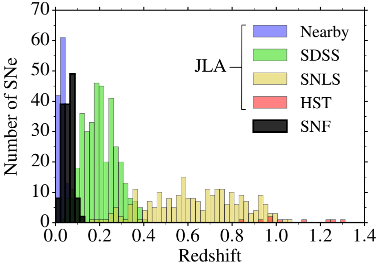
Blakeslee et al. 1999;
Radburn-Smith et al. 2004
(Virgo, Fornax)

How to estimate better the impact of peculiar velocities on the distance measurements?

- to match the host galaxies of SNe Ia with known clusters of galaxies
- to use the host cluster redshift instead of the host galaxy redshift

Nearby Supernova Factory data

- 145 SN Ia (2004 – 2009)
- The sample contains the objects with good final references and properly measured light-curve parameters, including quality cuts suggested by Guy et al. (2010).
- m_B^*, X_1, and C are estimated with the SALT2.4 lightcurve fitter (Guy et al. 2007, Betoule et al. 2014).



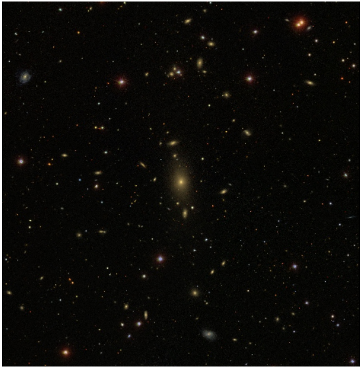
Galaxy clusters

Methods for identifying the clusters:

- over-density regions on the images
- red sequence method
- diffused X-ray emission
- Sunyaev-Zel'dovich effect

SIMBAD database

- only clusters of galaxies (exclude groups of galaxies)
- $d < 1$ Mpc
- $\Delta z < 0.01$



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Host clusters data

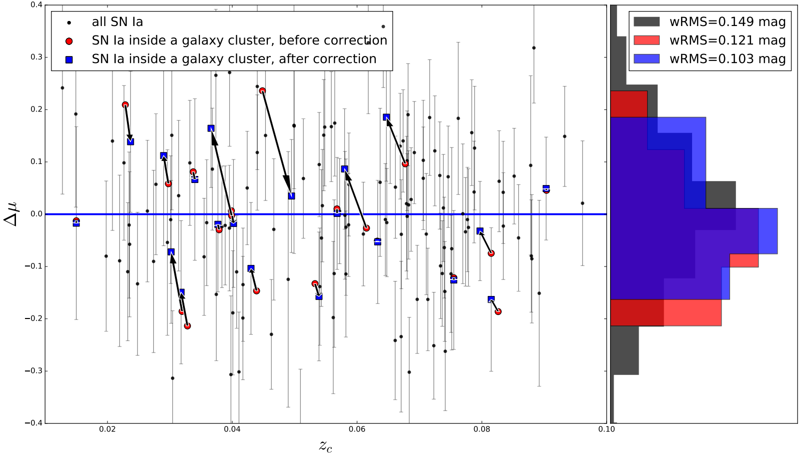
SN name	Galaxy cluster	MCXC name	$R_{200}\,(Mpc)$	z_{sn}	z_{cl}	z^{cl}_{er}	N_{gal}	Source
PTF09foz	A0087	in BAX	2.01	0.0533	0.0539	0.0003	62	SDSS
SN2004gc	WBL 113		1.24	0.032	0.0302	0.0010	8	[3-7]
SN2007nq	A0119	J0056.3-0112	1.43	0.0439	0.0430	0.0003	132	SDSS
SN2008ec	ZwCl 2259+0746		0.39	0.015	0.0150	0.0004	5	[14]
SN2009hi	A2589	J2323.8+1648	1.33	0.0399	0.0402	0.0003	58	[10]
SNF20051003-004	RXJ0228.2+2811	J0228.1+2811	0.92	0.0337	0.0340	0.0015	2	[19]
SNF20051113-000	[DEM94] 042751.5-174203		1.00	0.0826	0.0815	0.0012	4	[11]
SNF20060609-002	A2151a	J1604.5+1743	1.16	0.0399	0.0366	0.0002	175	SDSS
SNF20061020-000	A0076	J0040.0+0649	1.06	0.0379	0.0377	0.0009	7	[17]
SNF20061021-003	[WHL2012]J003555.3+071306		0.77	0.0615	0.0580	0.0013	2	[12]
SNF20061111-002	RXC J2306.8-1324	J2306.8-1324	1.08	0.0677	0.0647	0.0018	2	[18]
SNF20070403-001	[SPD2011] 27349		0.96	0.0815	0.0797	0.0002	23	SDSS
SNF20070417-002	[WHL2012] J132045.4+211627		1.27	0.0904	0.0903	0.0005	35	SDSS
SNF20070712-000	ZwCl 1743+5528		1.37	0.0298	0.0290	0.0016	4	[20]
SNF20080512-010	[WHL2012] J161104.1+522701		1.50	0.0632	0.0633	0.0002	30	SDSS
SNF20080514-002	RXC J1329.5+1147	J1329.5+1147	0.77	0.0229	0.0237	0.0002	46	SDSS
SNF20080612-003	RXC J1615.5+1927	J1615.5+1927	0.76	0.0328	0.0318	0.0010	3	[21]
SNF20080623-001	ZwCl8338	J1811.0+4954	1.17	0.0448	0.0495	0.0003	55	[10]
SNF20080731-000	ZwCl 1742+3306	J1744.2+3259	1.55	0.0755	0.0755	0.0026	2	[22]
SNF20080803-000	[YSS2008] 510		0.48	0.0568	0.0568	0.0007	14	SDSS

Calculation of cluster redshift:

- Red: z_{cl} and its dispersion are estimated as the average and the standard deviation of the redshift distribution of cluster members
- Blue: $\sigma_V \sim \sqrt{\frac{GM_{200}}{R_{200}}}, \sigma_V \sim 10R_{200}H_0 \Longrightarrow z^{cl}_{err} = \frac{\sigma_V}{\sqrt{N_{gal}}}$

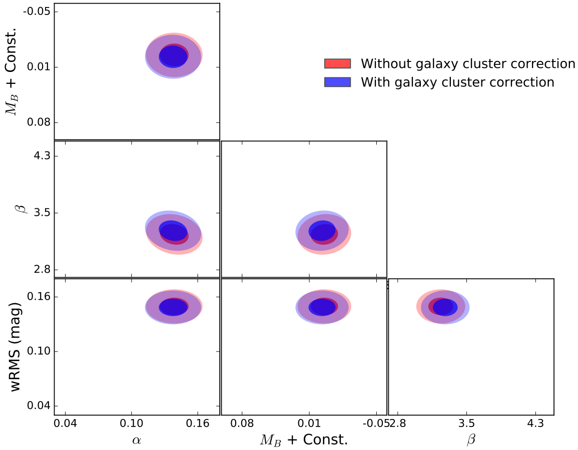
Hubble diagram

$wRMS = 0.150^m$ (without correction); $wRMS = 0.149^m$ (with correction)
The significance of improvement is 1.7-σ



} 2.4-σ

Confidence contours for nuisance parameters



Luminosity dispersion of SN Ia inside the galaxy clusters

The wRMS (0.121^m) for SNe inside the clusters even before correction is smaller than wRMS for the SNe outside the clusters (wRMS=0.153^m)

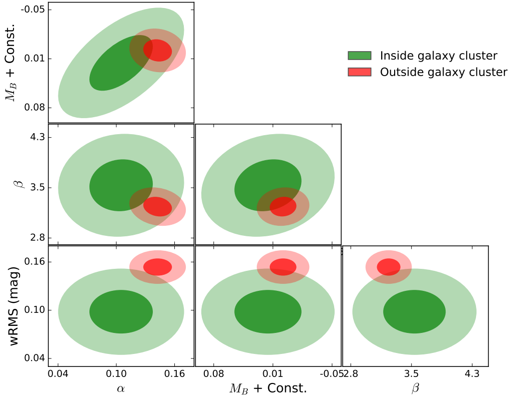
$\Downarrow$

Are SNe Ia inside the galaxy clusters more standard?

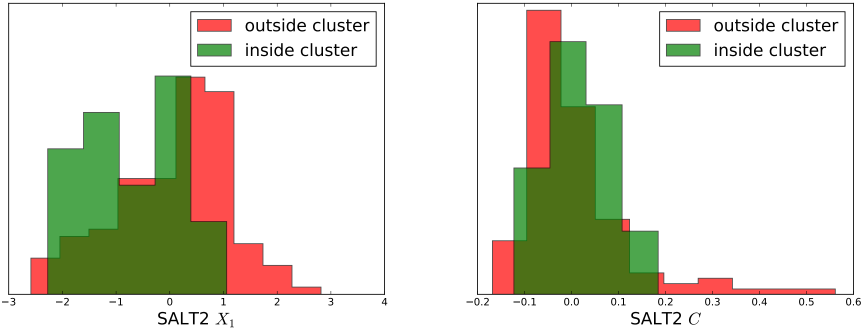
Luminosity dispersion of SN Ia inside the galaxy clusters

Two separate Hubble diagram fits

$wRMS = 0.098^m$ (in clusters); $wRMS = 0.154^m$ (outside clusters)



Stretch and color distribution



The environment of SN Ia

The influence of the environmental effects on the SN Ia intrinsic luminosity was proved in many works:

- host galaxy morphology and stellar population age (Hamuy et al. 1995,1996,2000; Riess et al. 1999; Sullivan 2003; Hicken et al. 2009; Hill et al. 2016; Henne et al. 2017)
- galocentric distance (Sullivan et al. 2003; Hill et al. 2016)
- star-formation rate (Sullivan et al. 2006; Neill et al. 2009; Lampeitl et al. 2010; Sullivan et al. 2010; Smith et al. 2012; Johansson 2013)
- local star-formation rate (1-3 kpc; Rigault et al. 2013; Roman et al. (in prep.))
- stellar mass of host galaxy (Kelly et al. 2010; Sullivan et al. 2010; Johansson 2013)
- host metallicity (Gallagher et al. 2005,2008; Howell et al. 2009)

The properties of host galaxies of SNe Ia in clusters

SN name	Host name	Host type	log(sSFR)	log($M_{stellar}$)
SNF20070403-001	2MASXJ10054419+1819037	Sbc	-10.07	11.01
SN2007nq	UGC 595	E	-12.57	12.12
SNF20080914-001	2MASXJ04572695-0004153	Sbc	-	-
SN2006X	M 100	Sc	-	-
SNF20080514-002	UGC 8472	S0	-9.722	11.12
SN2009hi	NGC 7647	E	-12.30	11.51
SNF20061020-000	2MASXJ00410521+0647439	Sab	-10.08	10.26
SNF20051003-004	NSFJ022743.32+281037.6	-	-10.33	9.005
SNF20060609-002	MCG+03-41-072	Sbc	-9.586	10.19
SN2008ec	NGC 7469	Sa	-10.04	10.84
SNF20080731-000	-	-	-12.22	10.14
SN2004gc	2MASXJ05214980+0640372	E-S0	-11.79	10.31
SNF20061111-002	-	-	-9.300	9.016
SNF20080803-000	2MASXJ17000690+2307533	Sab	-9.934	11.26
SNF20080623-001	WINGSJ181139.70+501057.1	-	-10.05	8.857
PTF09foz	2MASXJ00421192-0952551	S0	-11.34	10.49
SNF20070417-002	2MASXJ13205225+2119452	E	-11.03	10.85
SNF20080512-010	UGC 10261	E-S0	-12.26	11.51
SNF20051113-000	-	-	-8.839	7.506
SNF20061021-003	2MASXJ00361351+0710004	S	-8.890	11.17
SNF20080612-003	2MASXJ16152860+1913344	E	-9.348	10.17
SNF20070712-000	2MASXJ17461117+5516000	E	-10.61	10.05

Conclusions

- We studied how the peculiar velocities of SNe Ia in galaxy clusters affect the distance measurements by matching 145 SNFACTORY supernovae with known clusters of galaxies.
- The applied technique allowed to decrease the spread on the Hubble diagram. The *wRMS* is improved from 0.150^m to 0.149^m with 1.7-σ significance.
- For the SN Ia in clusters *wRMS* is improved from 0.121^m to 0.103^m with 2.4-σ significance.
- SNe Ia in clusters have smaller dispersion on the Hubble diagram than ones outside the clusters, i.e. represent more standard subclass of supernovae (1.8-σ significance). The separate fit of two subsamples shows the difference in α, β, and M_B parameters.
- The described effect influences the distance measurements in the nearby Universe ($z < 0.1$) and has to be taken into account in future cosmological surveys.

Merci pour votre attention !