The Dependence of Type Ia Supernova Luminosities on Their Local Environment

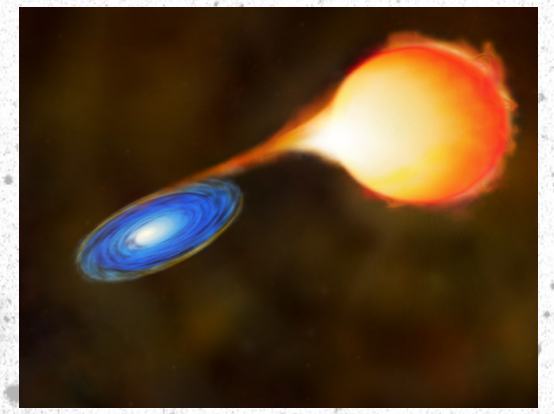
Matthieu Roman, Delphine Hardin, Marc Betoule

Standard candles

$$d_L(z) = (1+z)\frac{c}{H_0}\int dz \left(\Omega_m(1+z)^3 + \Omega_x \exp\left(\int_0^z dz' 3\frac{1+w(z')}{1+z'}\right)\right)^{-1/2}$$

Type Ia supernovæ

- ✓ Silicium features
- ✓ No helium, no hydrogen
- ✓ Single or double degenerate scenarios
- ✓ Rare: 1 per century per galaxy
- ✓ Short-lived: few months
- ✓ Luminous



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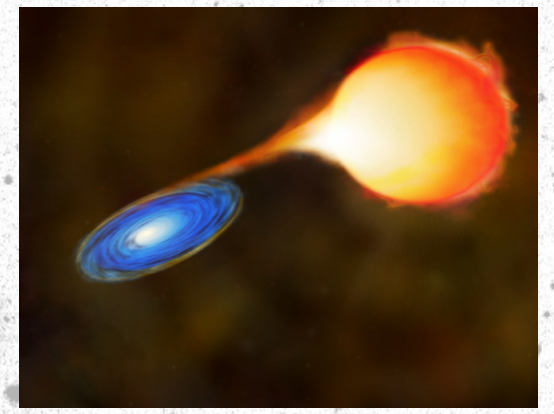
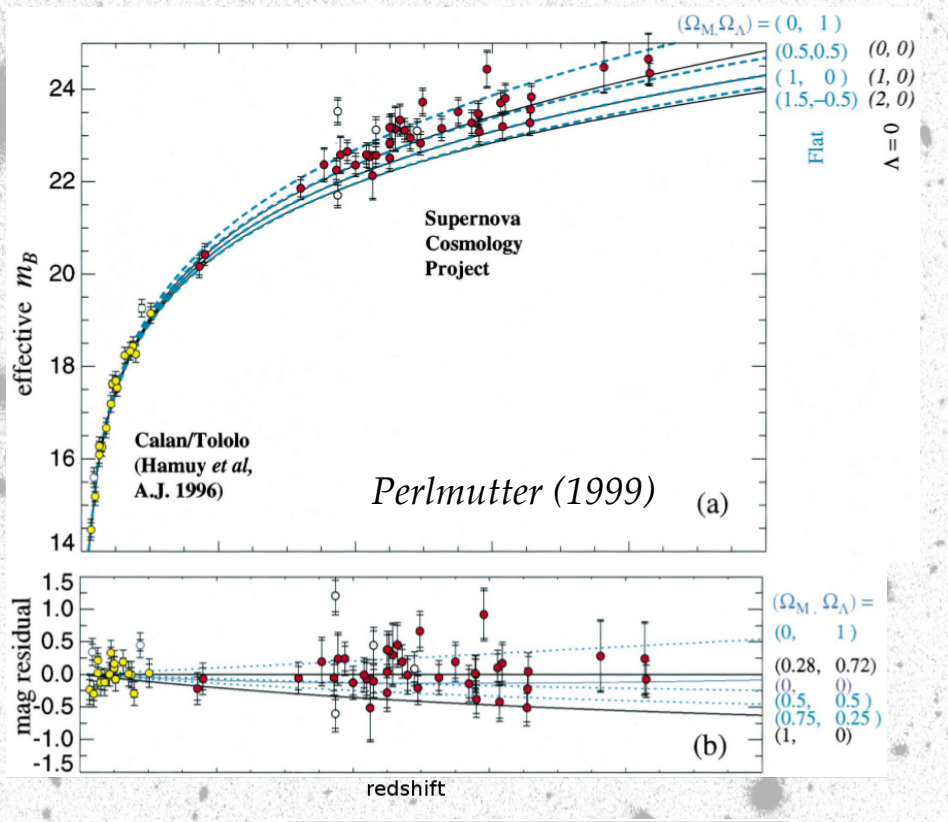
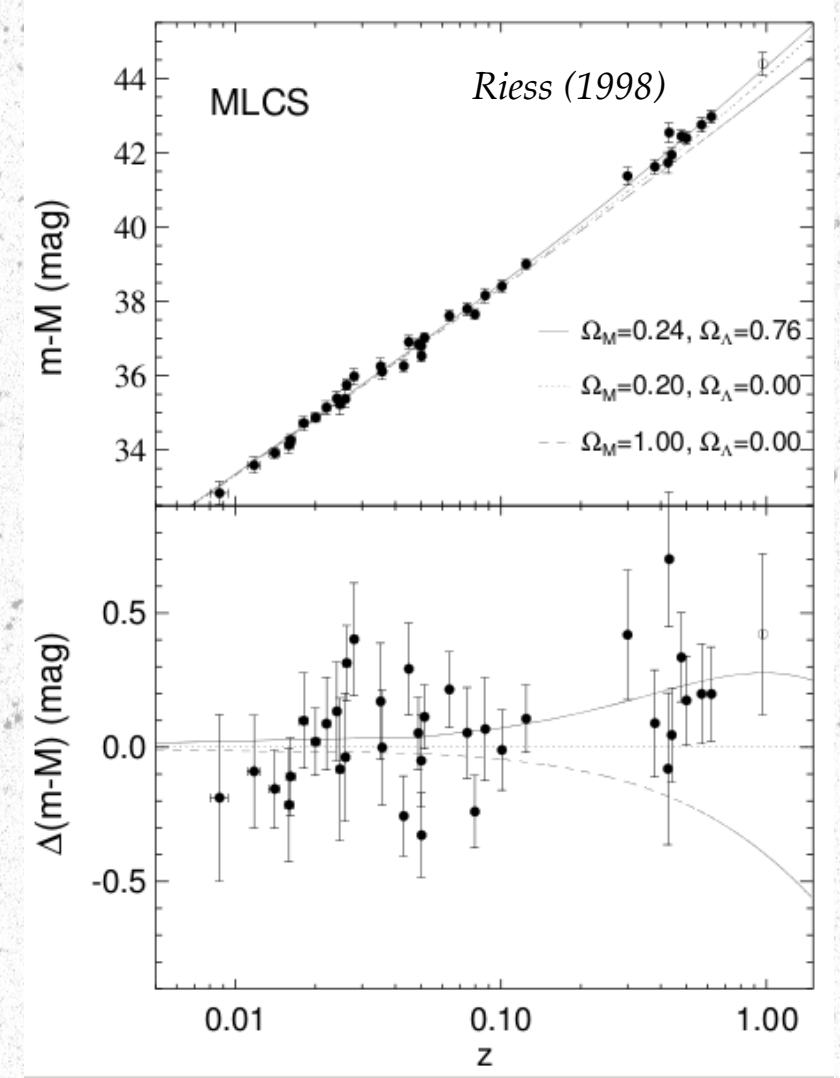


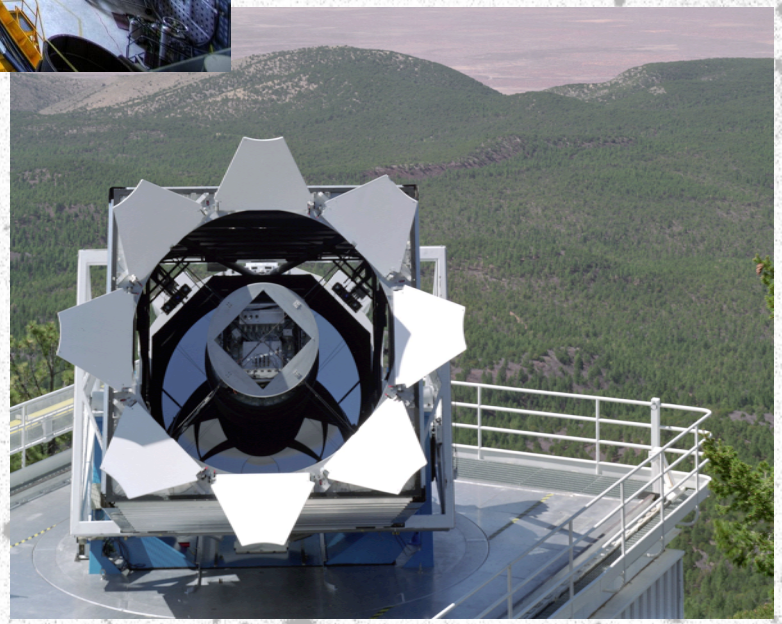
Flux measurement, calibration, unknown phenomenon, systematics

From SNIa to dark energy

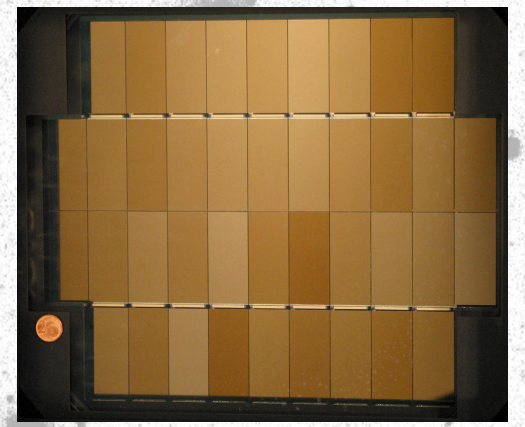




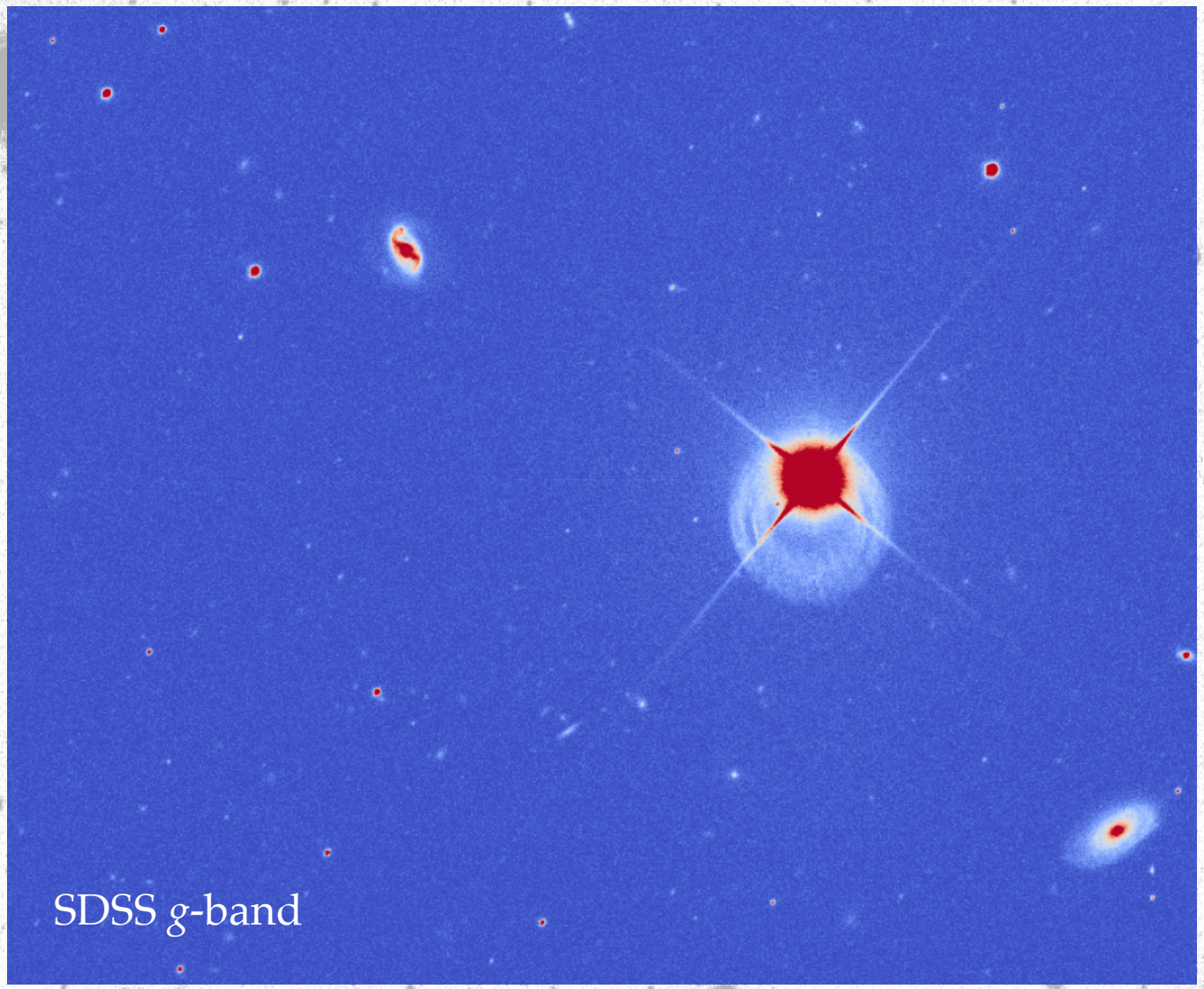
SNIa today



- Rolling search
- Matrices of CCDs
- SNLS
- SDSS



SNIa today



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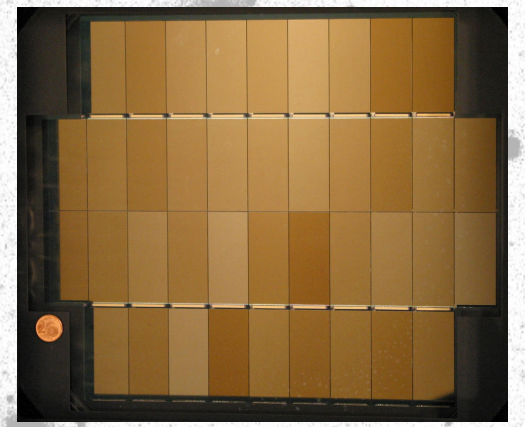

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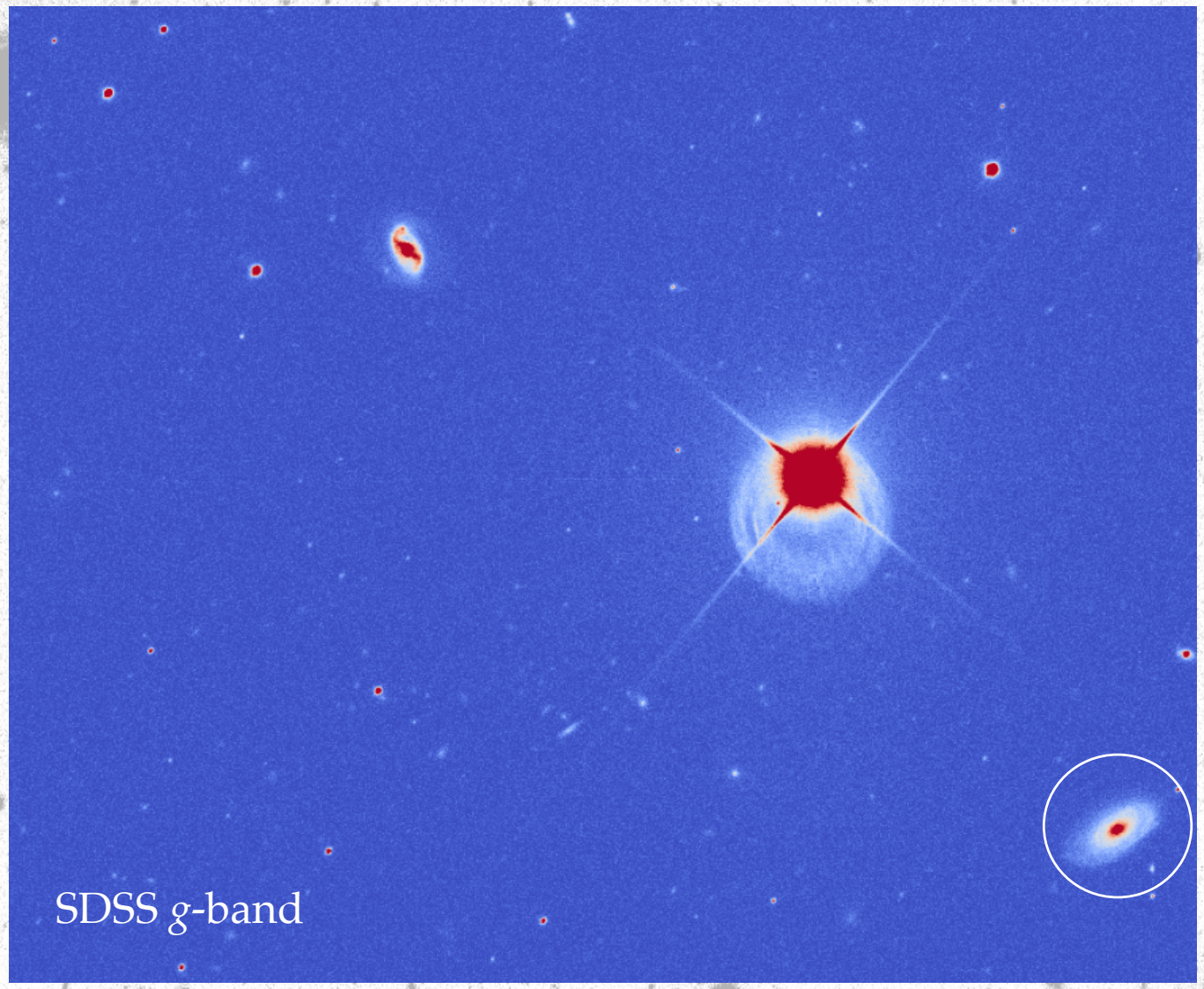

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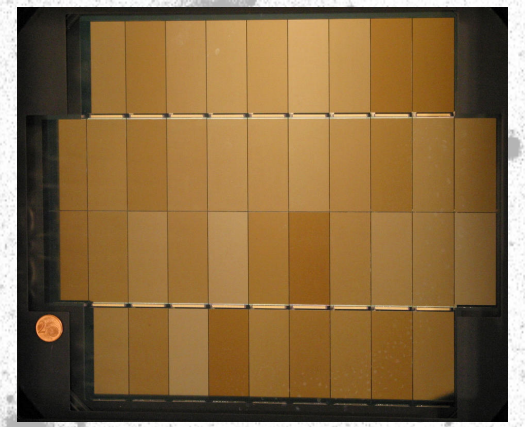

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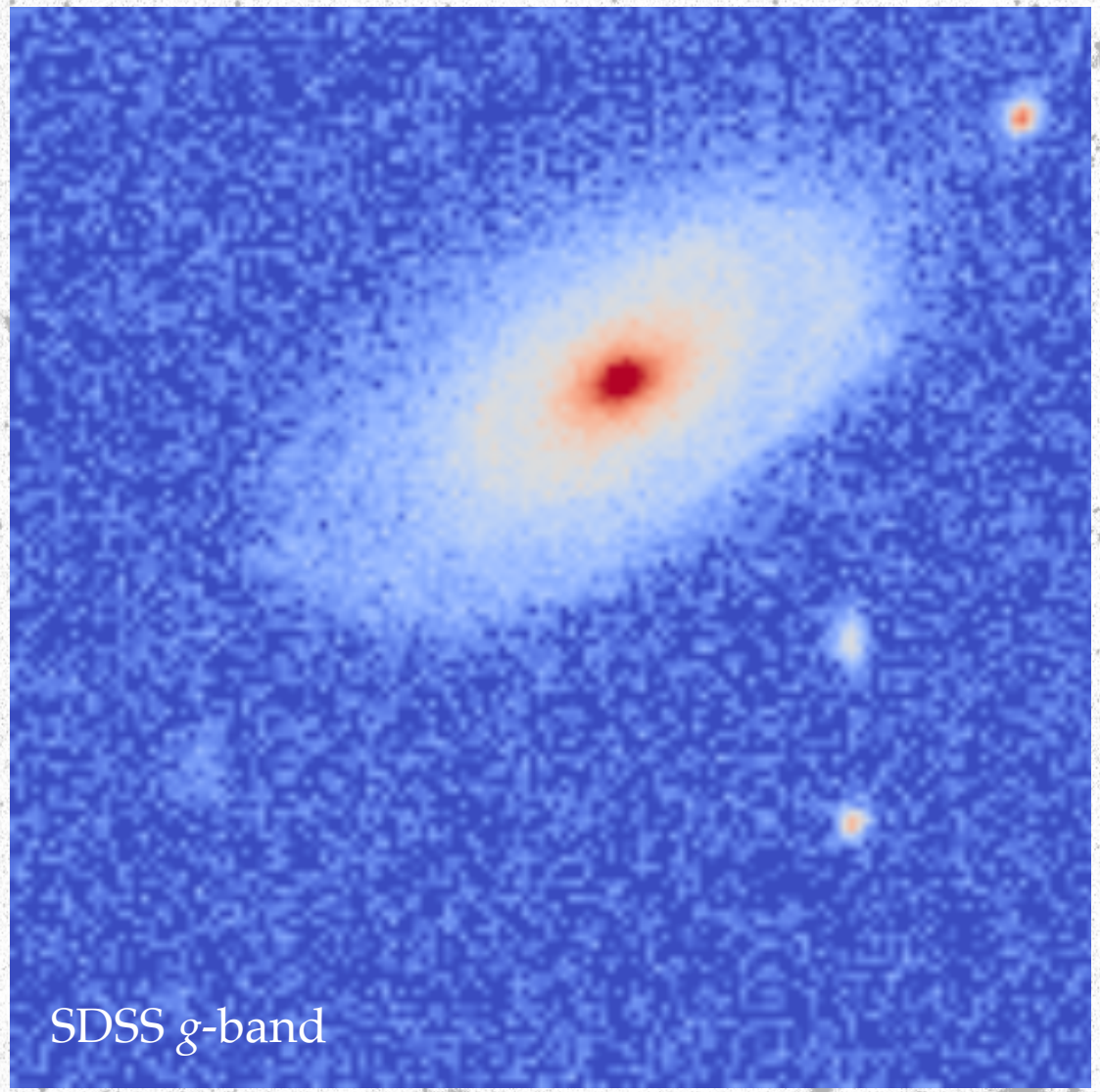
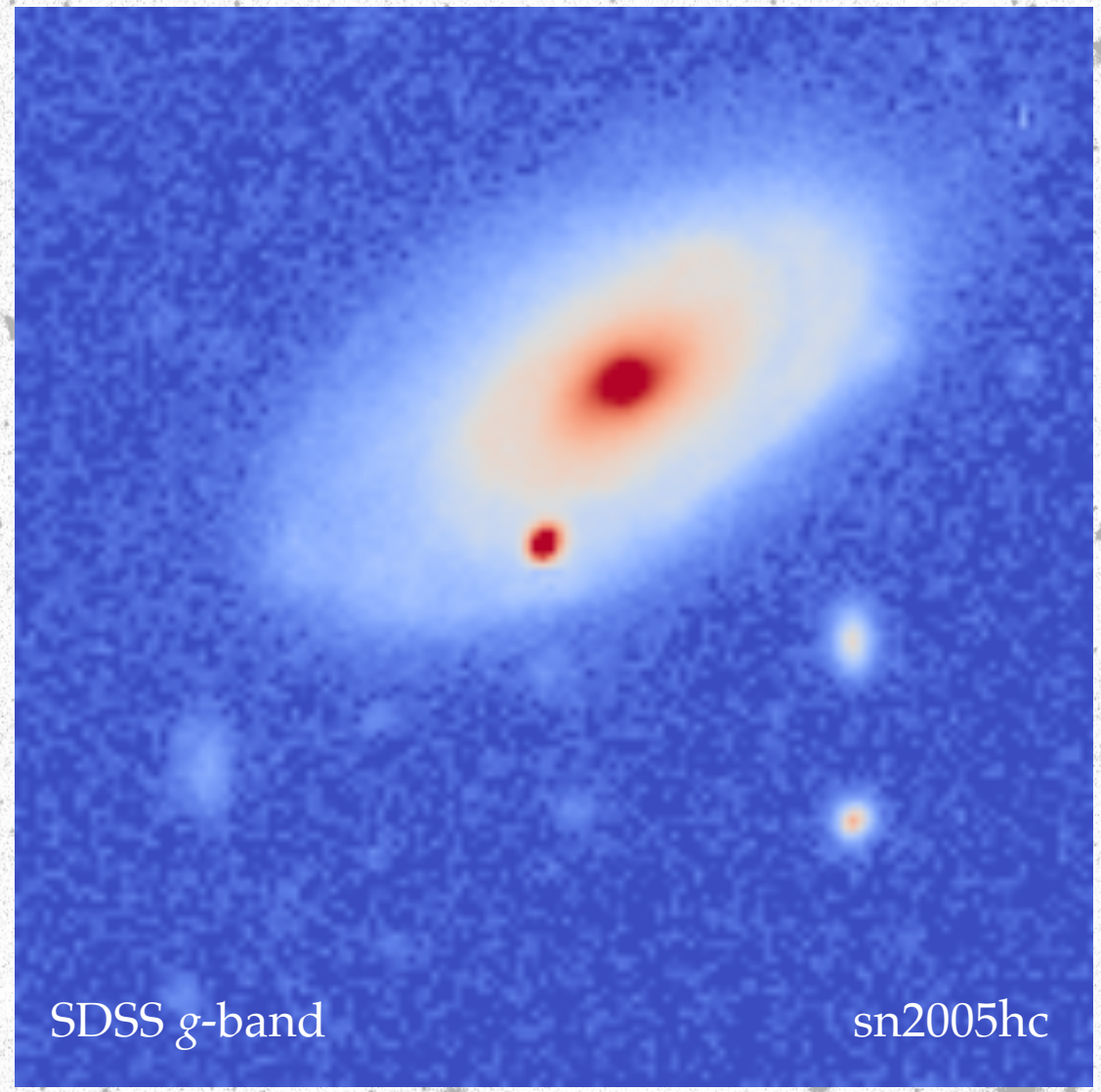
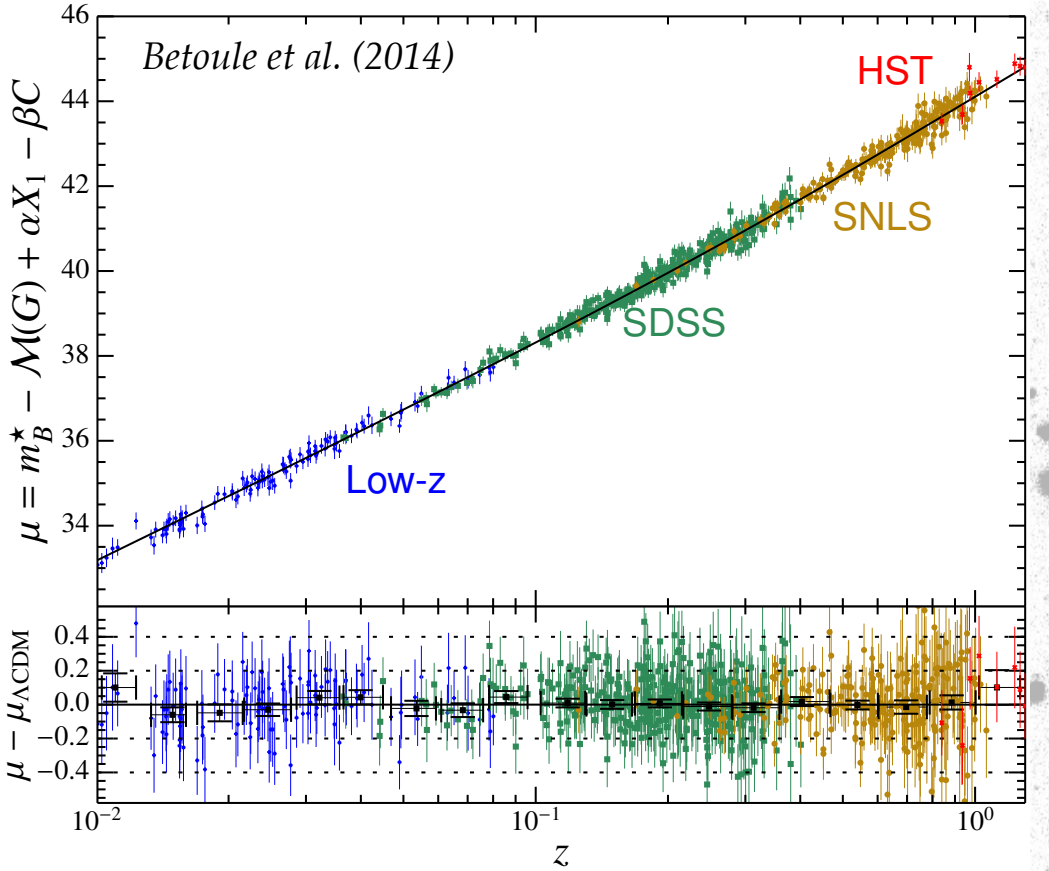


SNIa today



SNIa today

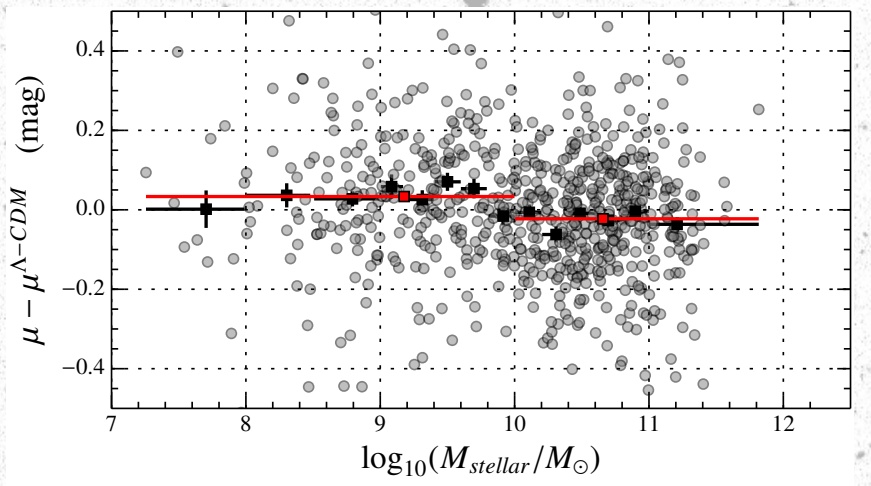
- Joint Light-curve Analysis (JLA)
- Improved calibration accuracy
- 0.15 mag dispersion
- 6% precision on w
- Going further in the standardization
  - SNIa environment
  - evolution



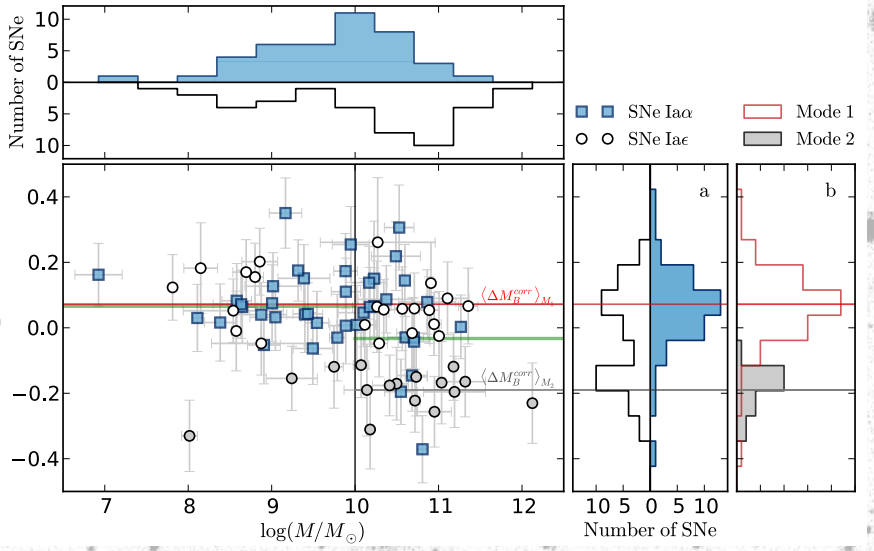
Global and local environment

- Stellar mass of the host galaxy
  - 5σ correlation with residuals
  - bimodality
- Local (1 kpc) H_α
  - traces stellar formation
  - can explain mass step

Betoule et al. (2014)

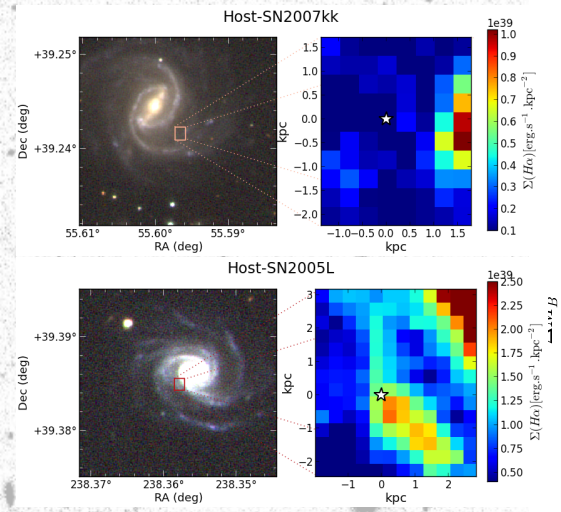


Rigault et al. (2013)

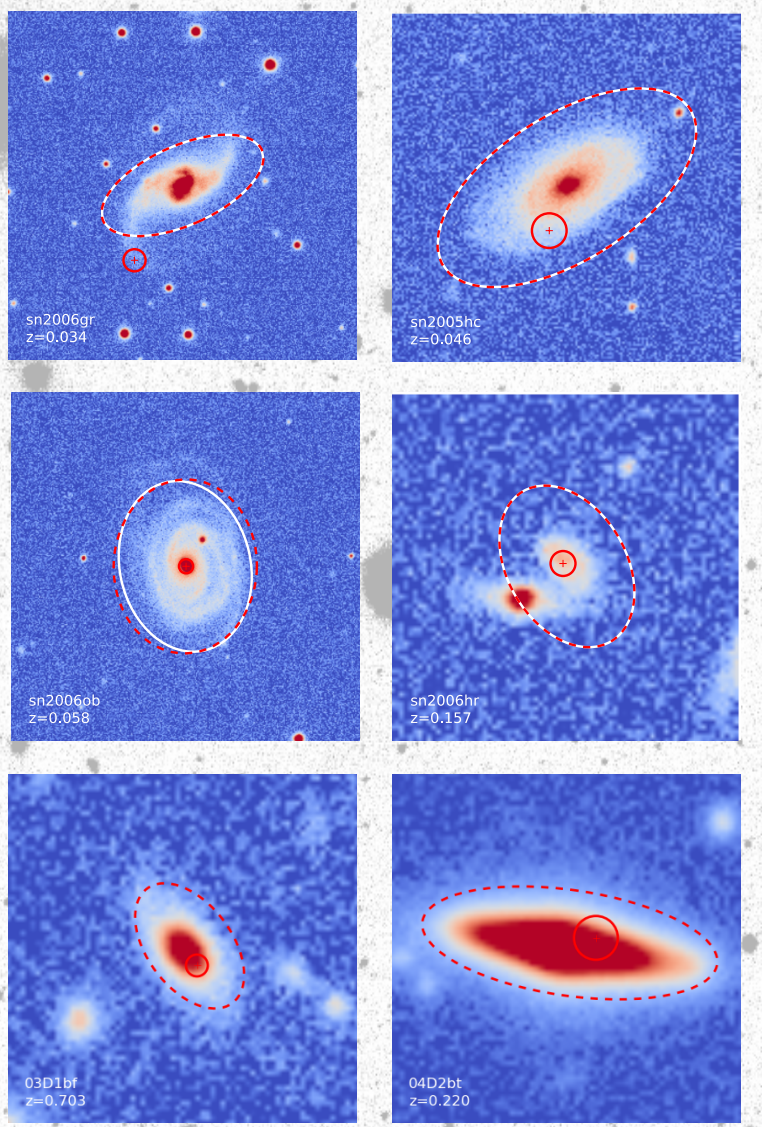


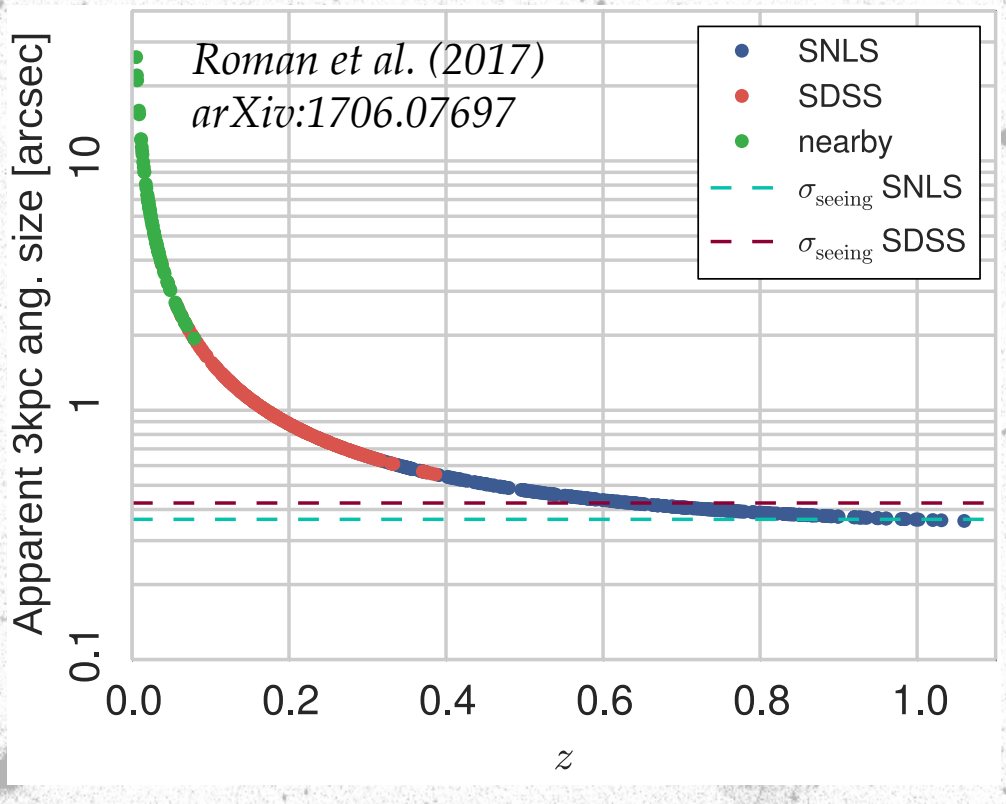
Supernova Factory
~60 low *z* SNIa

Rigault et al. (2013)



Local environment at ALL redshifts





- Local and global photometry of 882 host galaxies of SNIa at ALL redshifts
- 3 kpc local radius
- rest-frame U-V colors by interpolating fluxes

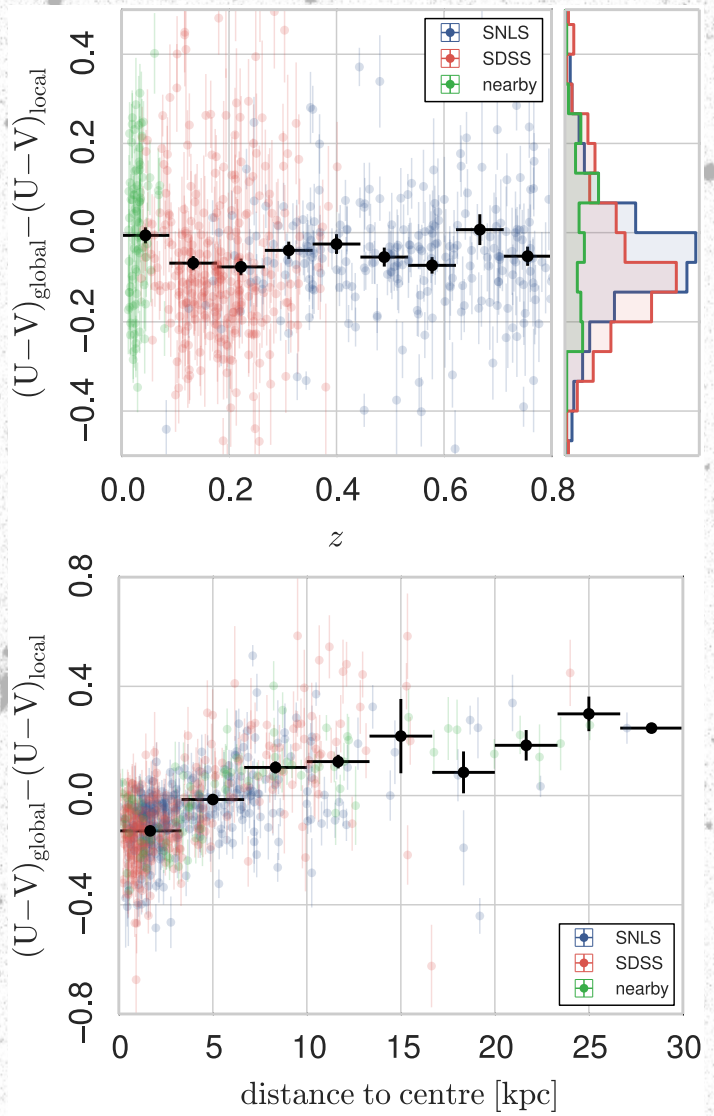
Demography

	SNIa	Host photometry	Reference	Filters/Instrument
CSP	19	7	SIMBAD	$ugriz$/SDSS & JHK/2MASS
CfAIII	84	55	SIMBAD	$ugriz$/SDSS & JHK/2MASS
CfAIV	53	34	SIMBAD	$ugriz$/SDSS & JHK/2MASS
SDSS	441	389	Sako et al. 2014	$ugriz$/SDSS
SNLS	397	397	Hardin et al. 2017	$ugriz$/MegaCam
Total	994	882	–	–

Requirement	CSP	CfAIII	CfAIV	SDSS	SNLS	All
Available host stellar mass	7/7	55/55	34/34	389/389	345/397	830/882
$+ \sigma_{\log_{10}\mathcal{M}} < 0.12$	6/7	51/55	31/34	338/389	309/345	735/830
$+ \sigma_{C_{\rm L}} < 0.12$	6/6	49/51	30/31	288/338	293/309	666/735

Difference between global and local

- On average different than zero
  - changes with redshift
  - mostly comes from intermediate redshifts
- Link with distance to galactic centre
  - locally redder than host: close to centre
  - locally bluer: outskirst

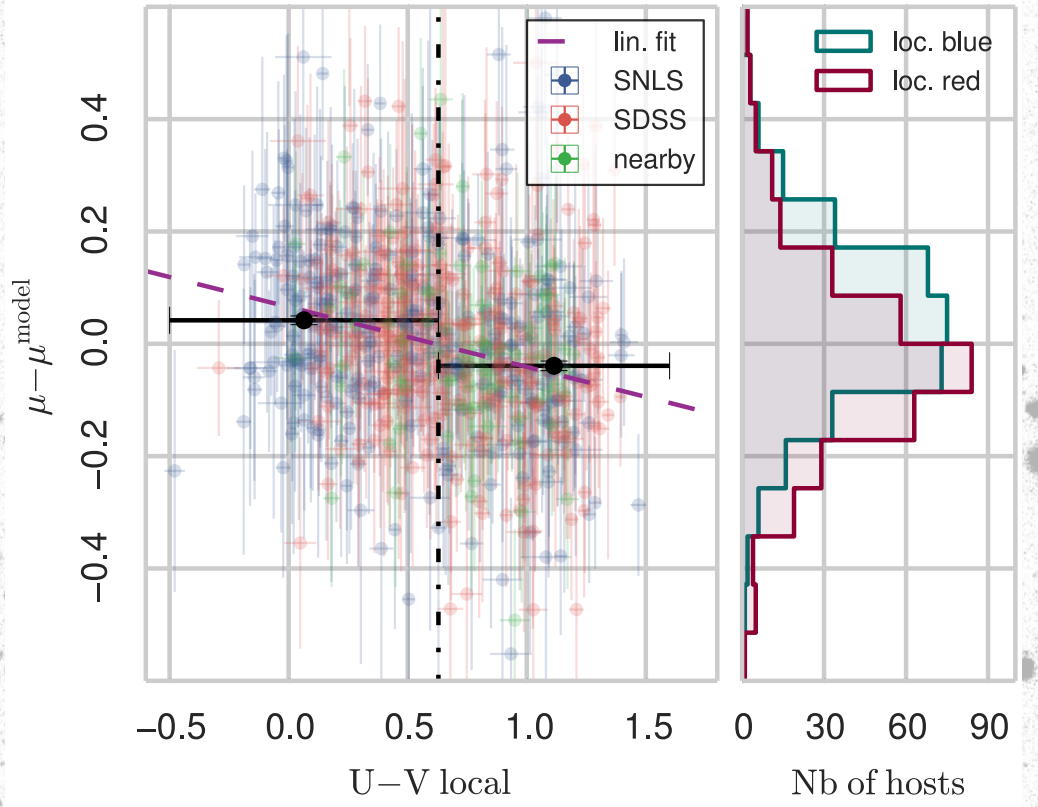


Roman et al. (2017)
arXiv:1706.07697

New standardization?

- Correlations with Hubble diagram residuals
  - bimodality
- Third standardization parameter
  - magnitude step of -0.091 ± 0.013 mag (7σ)
  - reduction of the dispersion: 0.14 mag
  - impact on dark energy: $\Delta w \sim 1\%$

Roman et al. (2017)
arXiv:1706.07697

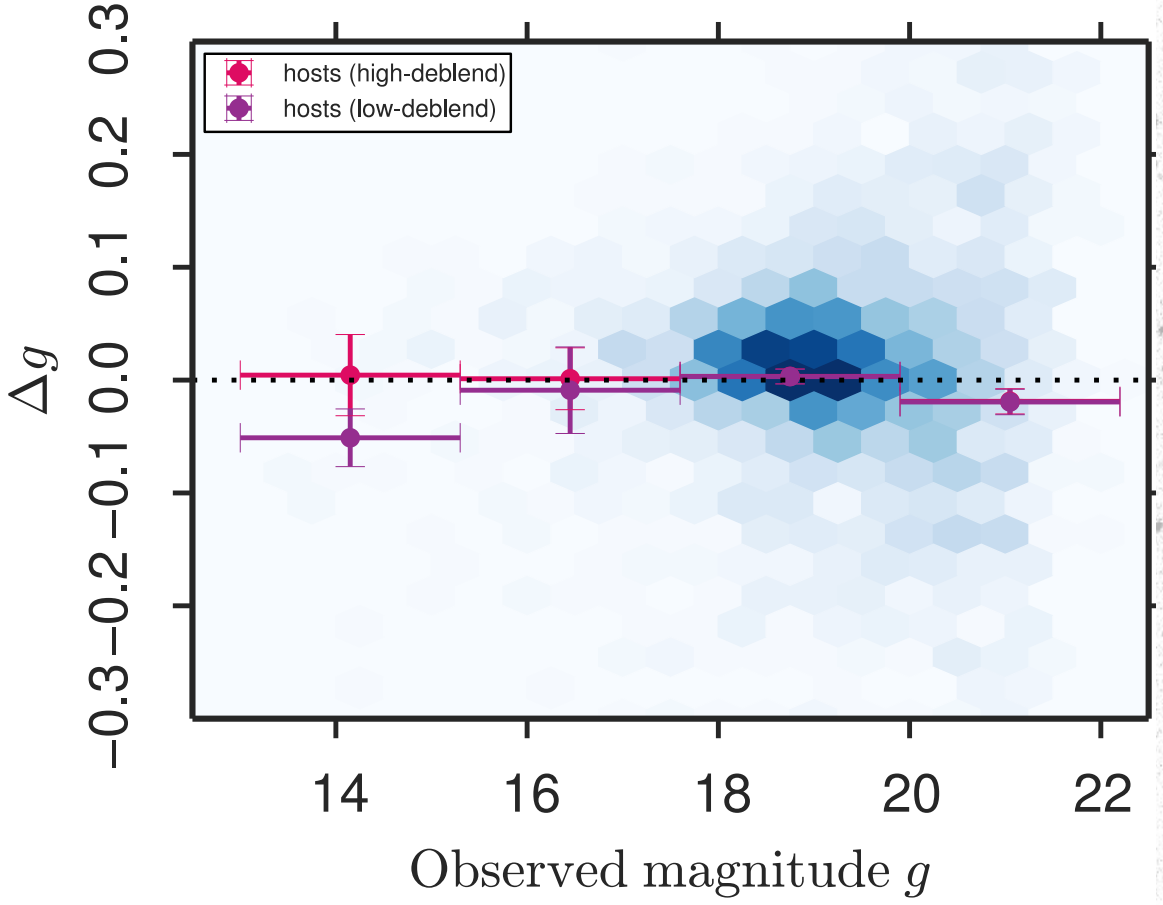


New standardization?

- Splitting the sample into
  - survey bins
  - redshift bins

	Nb of SNIa	ΔM_B Local color	ΔM_B Host color	ΔM_B Host stellar mass
Nearby	85	-0.0491 ± 0.0462 (1.1σ)	-0.0401 ± 0.0454 (0.9σ)	-0.0235 ± 0.0430 (0.5σ)
SDSS	288	-0.0877 ± 0.0189 (4.6σ)	-0.0526 ± 0.0190 (2.8σ)	-0.0604 ± 0.0188 (3.2σ)
SNLS	293	-0.0993 ± 0.0205 (4.8σ)	-0.0917 ± 0.0202 (4.5σ)	-0.0882 ± 0.0205 (4.3σ)
$z < 0.1$	123	-0.0534 ± 0.0323 (1.7σ)	-0.0119 ± 0.0313 (0.4σ)	-0.0260 ± 0.0310 (0.8σ)
$0.1 < z < 0.5$	350	-0.1172 ± 0.0171 (6.9σ)	-0.0975 ± 0.0171 (5.7σ)	-0.0834 ± 0.0168 (5.0σ)
$z > 0.5$	193	-0.0586 ± 0.0259 (2.3σ)	-0.0556 ± 0.0258 (2.2σ)	-0.0702 ± 0.0262 (2.7σ)
All	666	-0.0909 ± 0.0130 (7.0σ)	-0.0689 ± 0.0130 (5.3σ)	-0.0704 ± 0.0128 (5.5σ)

Photometry comparison



	low-deblending	
Band	Field galaxies	Host galaxies
u	-0.029 ± 0.309	-0.048 ± 0.307
g	0.007 ± 0.079	-0.003 ± 0.077
r	0.019 ± 0.077	0.014 ± 0.060
i	0.013 ± 0.086	0.009 ± 0.080
z	-0.004 ± 0.125	-0.027 ± 0.123

Roman et al. (2017)
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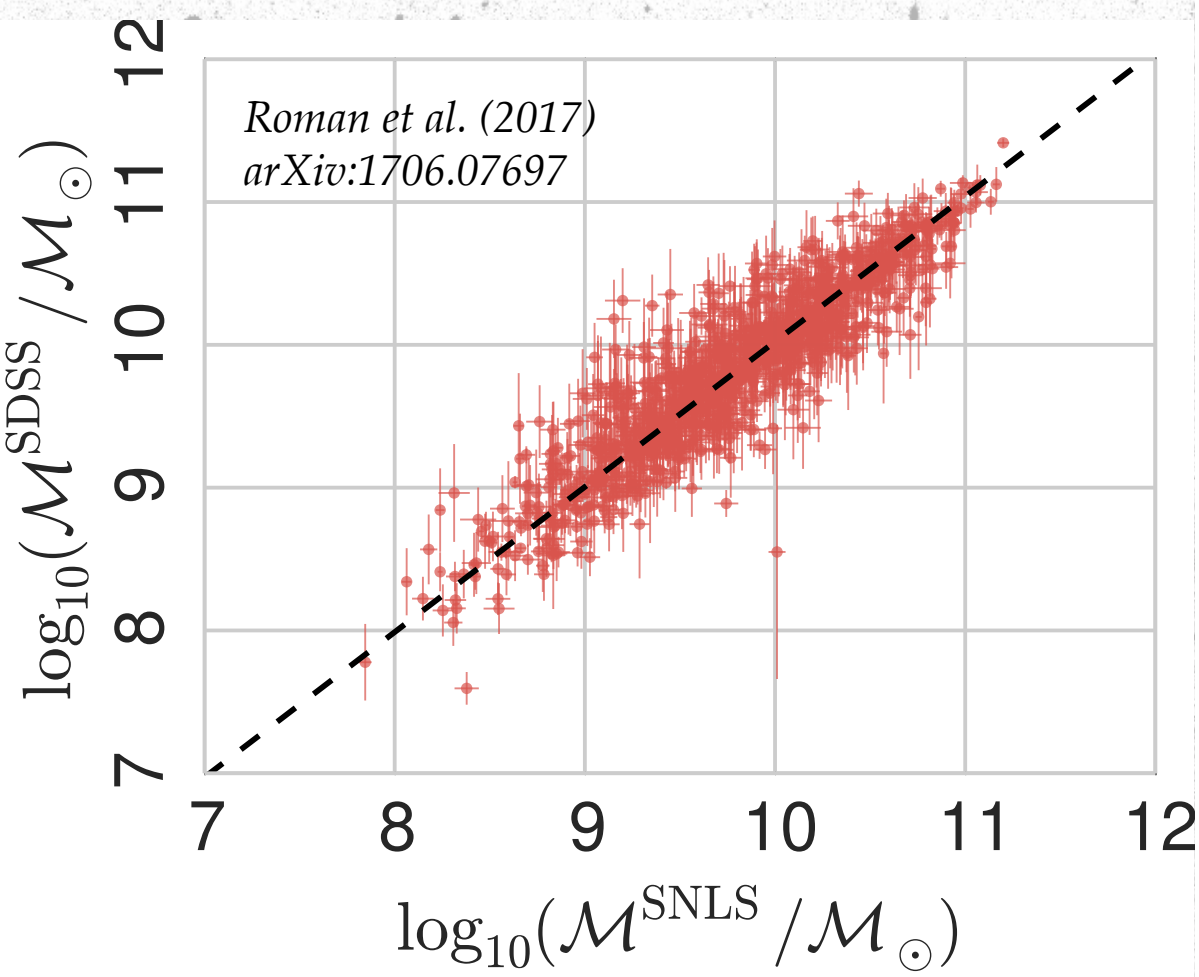
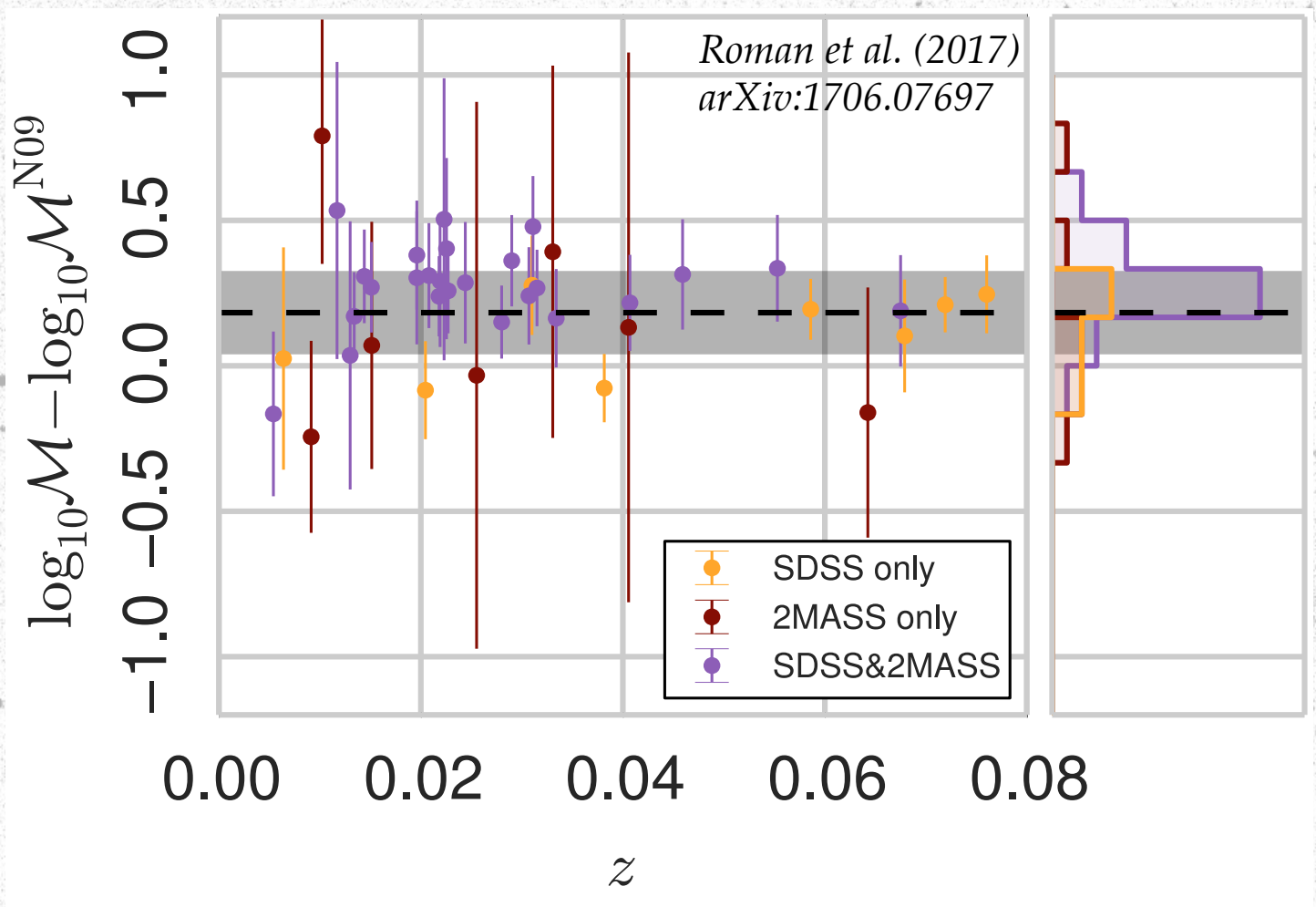
Catalog of host stellar masses

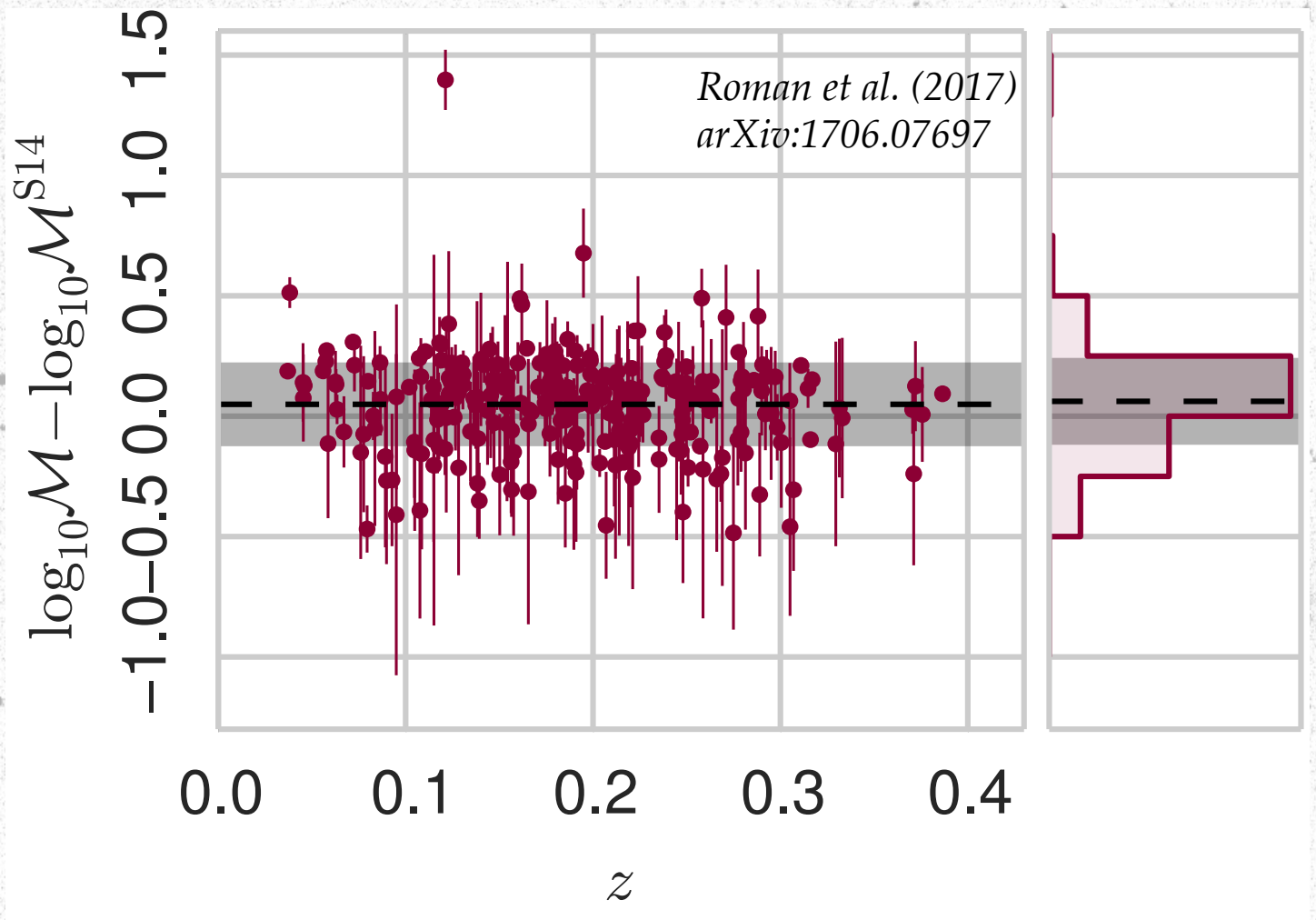
- Common objects between SNLS D3 field and SDSS
- Good correspondence between stellar masses estimated using both photometries
- No redshift dependence
- We also estimate masses using *K*-band magnitudes
  - relation mag_K-mass



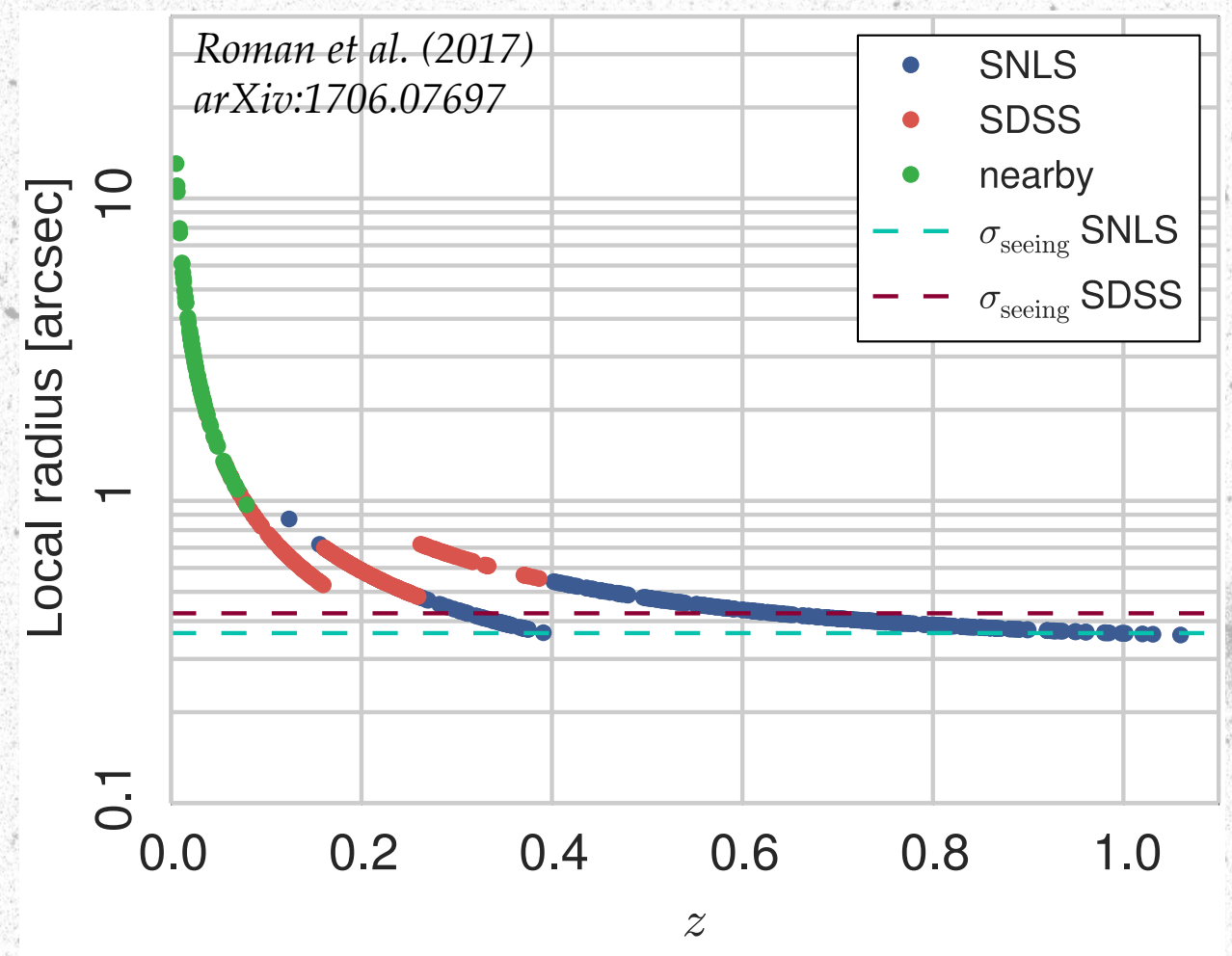
Comparison of host masses: Neill et al. 2009



Comparison of host masses: Sako et al. 2014



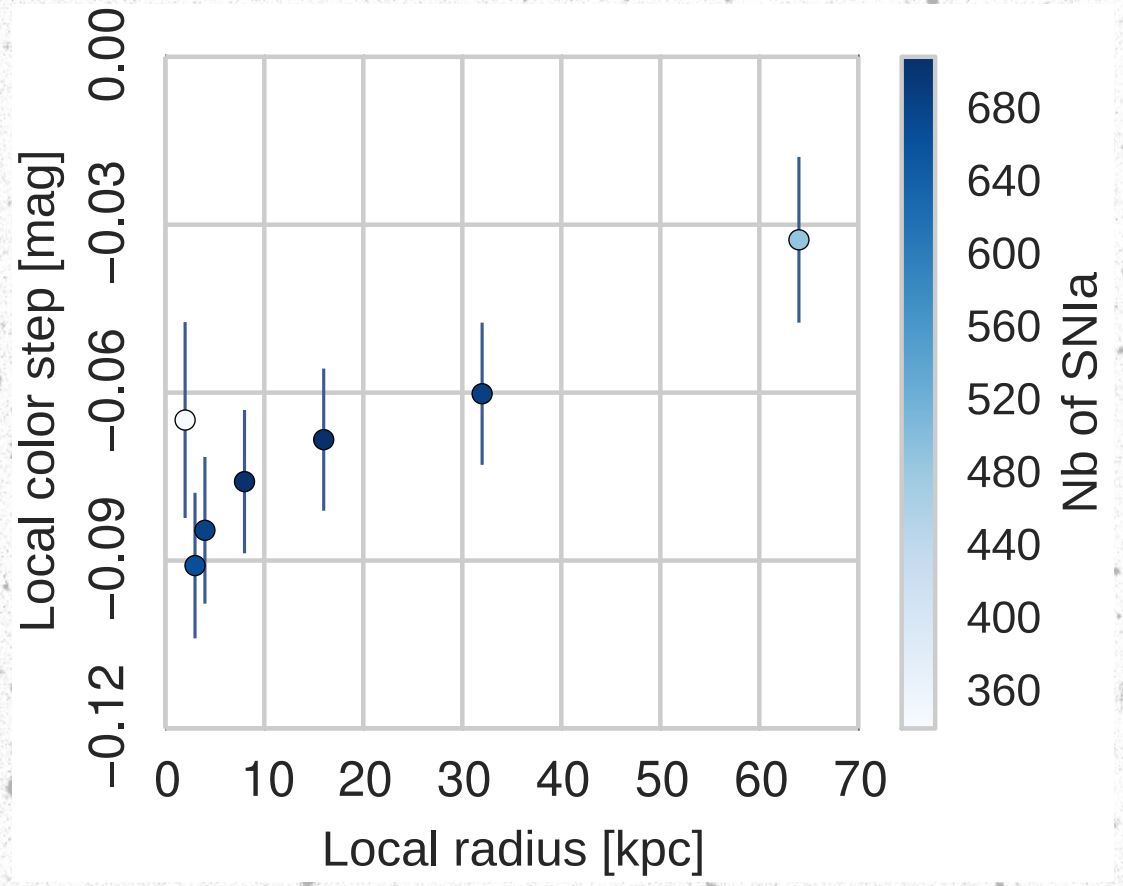
Getting more local



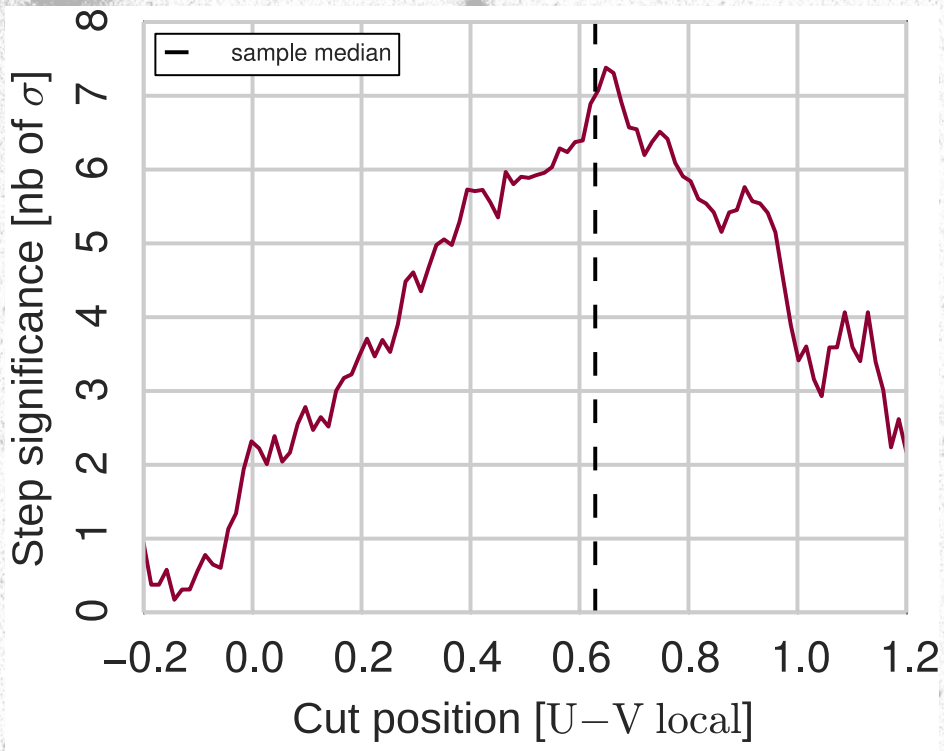
Comparable results to the 3 kpc case

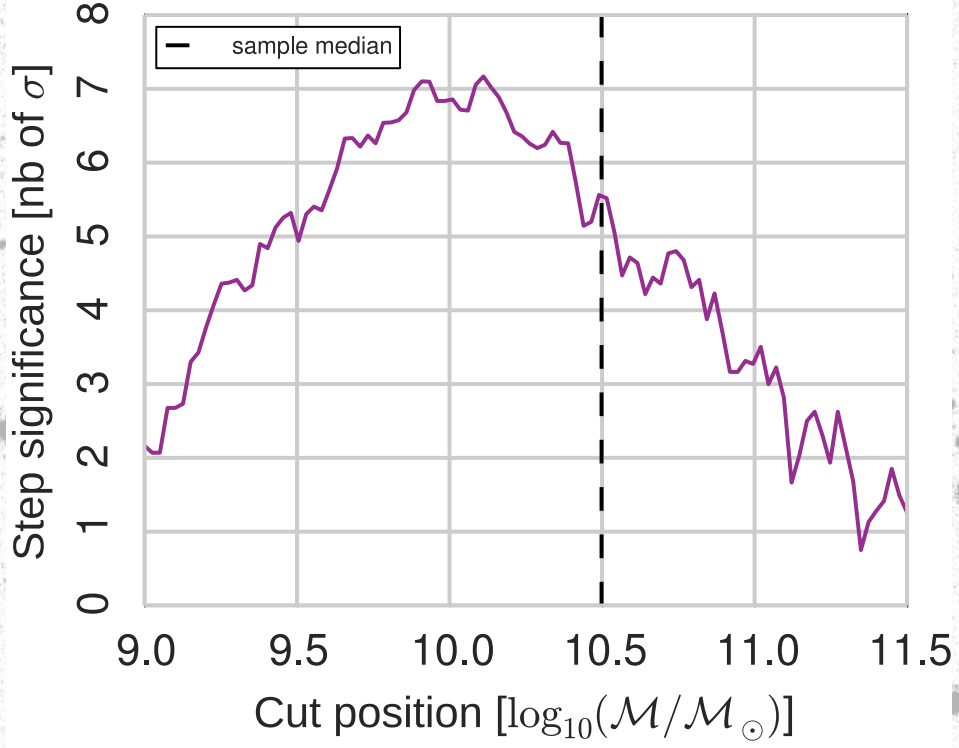
Step significance as a function of local radius

- Transition from local to global between 3 and 32 kpc
- r=2 kpc and r=64 kpc brings significantly less SNIa in the sample
  - sub-seeing radius: large error bars for local colors
  - too large radius:large error bars for local fluxes



Choice of the median

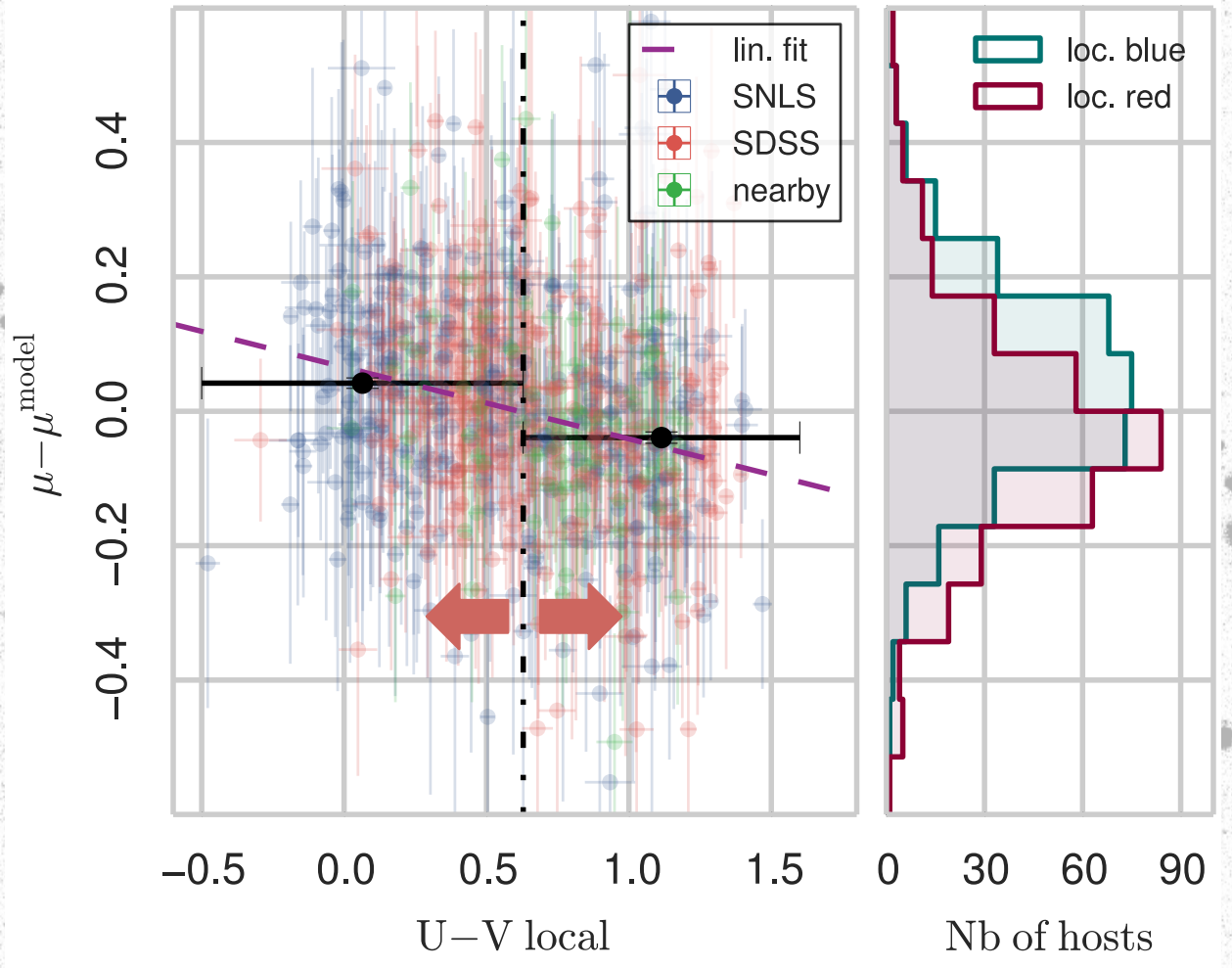




if we correct for the *maximum* local color step: the *maximum* remaining mass step is 3.8σ
if we correct for the *maximum* mass step: the *maximum* remaining local color step is 5σ

Why precise photometry?

- Numbers of SNIa within 1σ of the bin limit:
  - 52 for local color
  - 37 for mass
- MC simulation gives 1σ shift for steps:
  - 0.00391 mag for local color
  - 0.00383 mag for mass

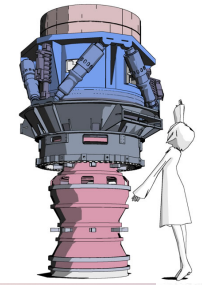


Perspectives

- Multiple surveys
- About 10^4 SNIa in 10 years
- Increasing analysis techniques
  - powerful probe of dark energy

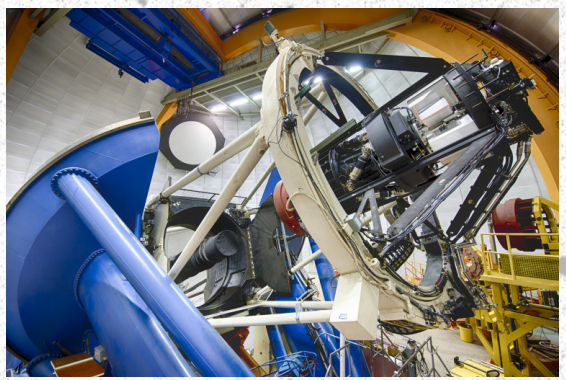
LSST

Subaru - HSC



ZTF

Dark Energy Survey



ASAS SN

Pan-STARRS

Backup