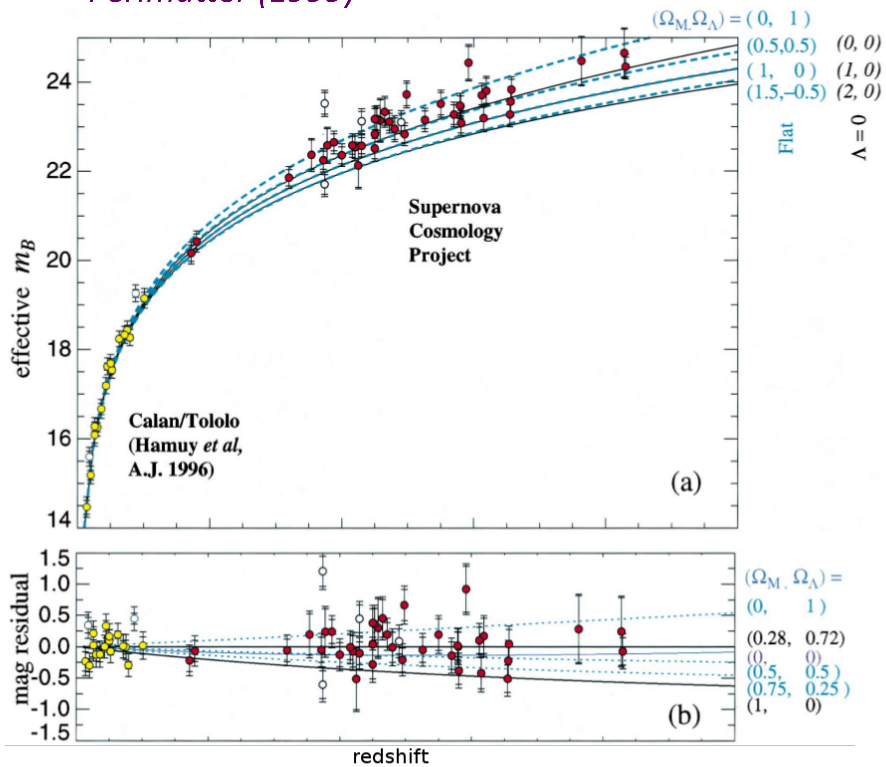
Local environment of SNLS5 Type Ia supernovæ

Matthieu Roman, Marc Betoule, Delphine Hardin

The discovery of the accelerated expansion

Perlmutter (1999)



Riess (1998)

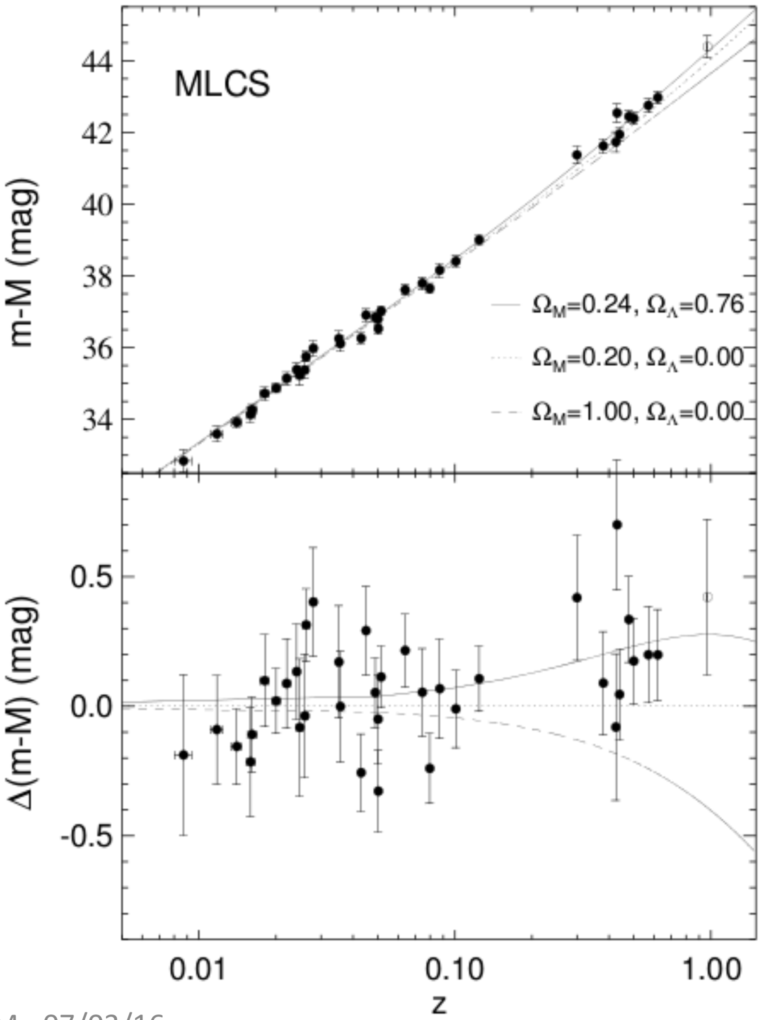


Photo: U. Montan Saul Perlmutter | Photo: U. Montan Brian P. Schmidt | Photo: U. Montan Adam G. Riess

The best standard candle available

- Basic hypothesis:
  - *supernovæ of same light-curve and lying in the same galactical environment have in average the same luminosity at all redshifts*

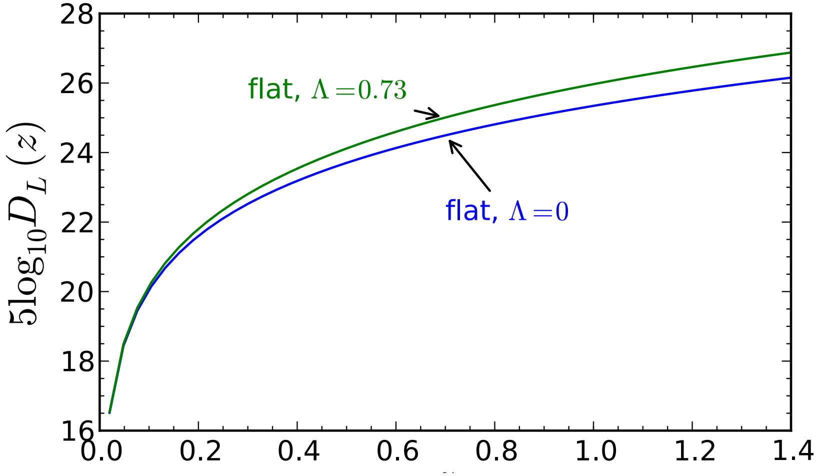
$$\begin{array}{ccccccc} m & = & \mathcal{M} & + & \mu & + & \delta\mathcal{M} \\ -2.5\log_{10} f & & -2.5\log_{10}(\mathcal{L}) & & 5\log_{10}(d_L/10\mathrm{pc}) & & \end{array}$$

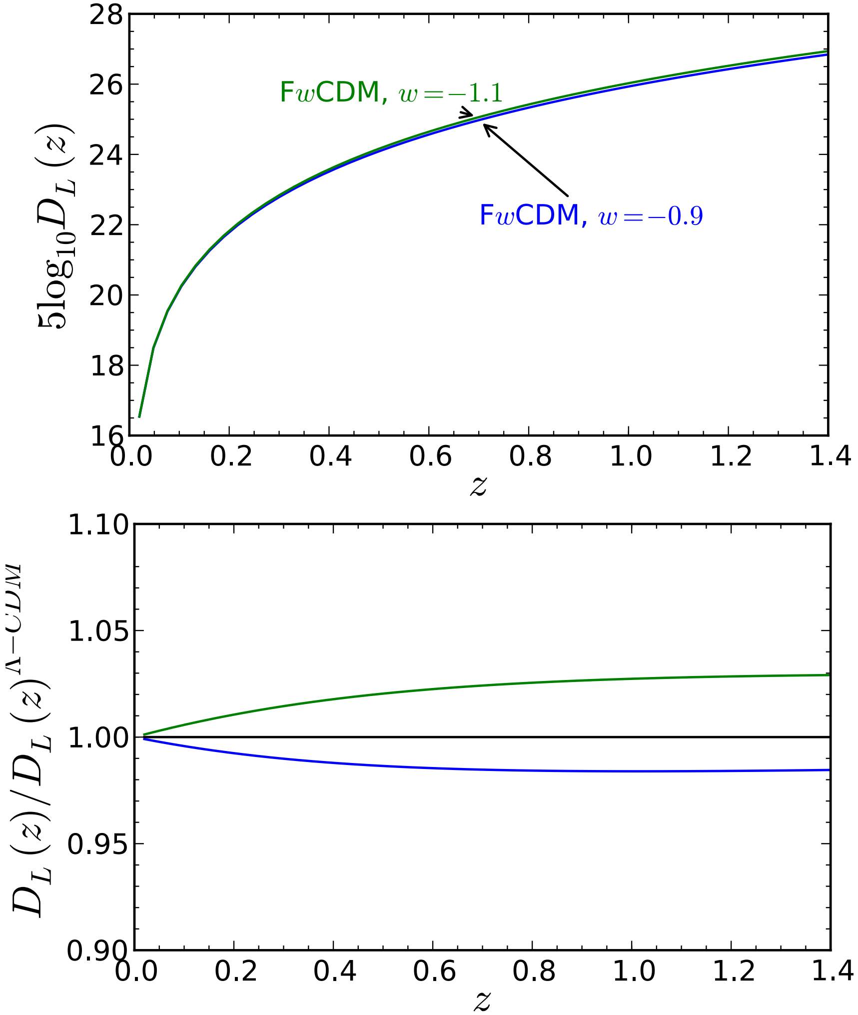
$$\sigma(\delta\mathcal{M}) \sim 0.14 \quad \rightarrow \quad \sigma(d_L) \sim 0.07$$

- Constrain luminosity distance ratios
  - determination of H_0 and reduced densities decouple
  - see Riess et al. (2011)

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

From the discovery of the accelerated expansion to the characterization of dark energy





- Current constraints on *w* around 6%
- Indistinguishable from a cosmological constant
- Need to measure luminosity distance with a precision of <3% at *z*=1

A difficult probe

- Difficult to gather sufficient statistics
  - rare events (1 per galaxy per century)
  - short-lived (few months)
  - random
  - but fortunately quite luminous
- Difficult to do the metrology:
  - precise flux measurement
  - modeling of a largely unknown phenomenon
- The effort is shared between:
  - improving statistics
  - improving the measurement

The Canada-France-Hawaï Telescope (CFHT) instrument

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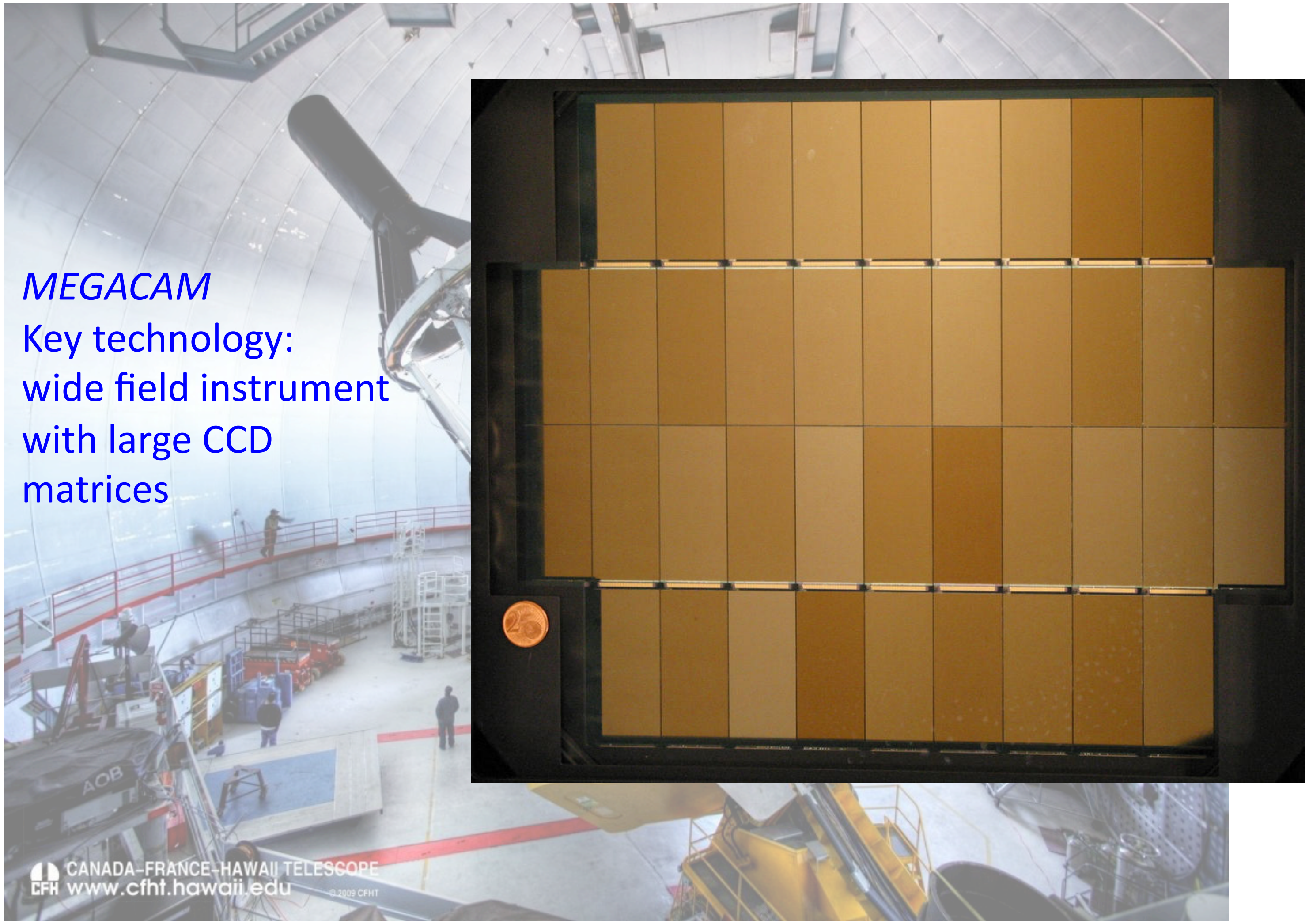
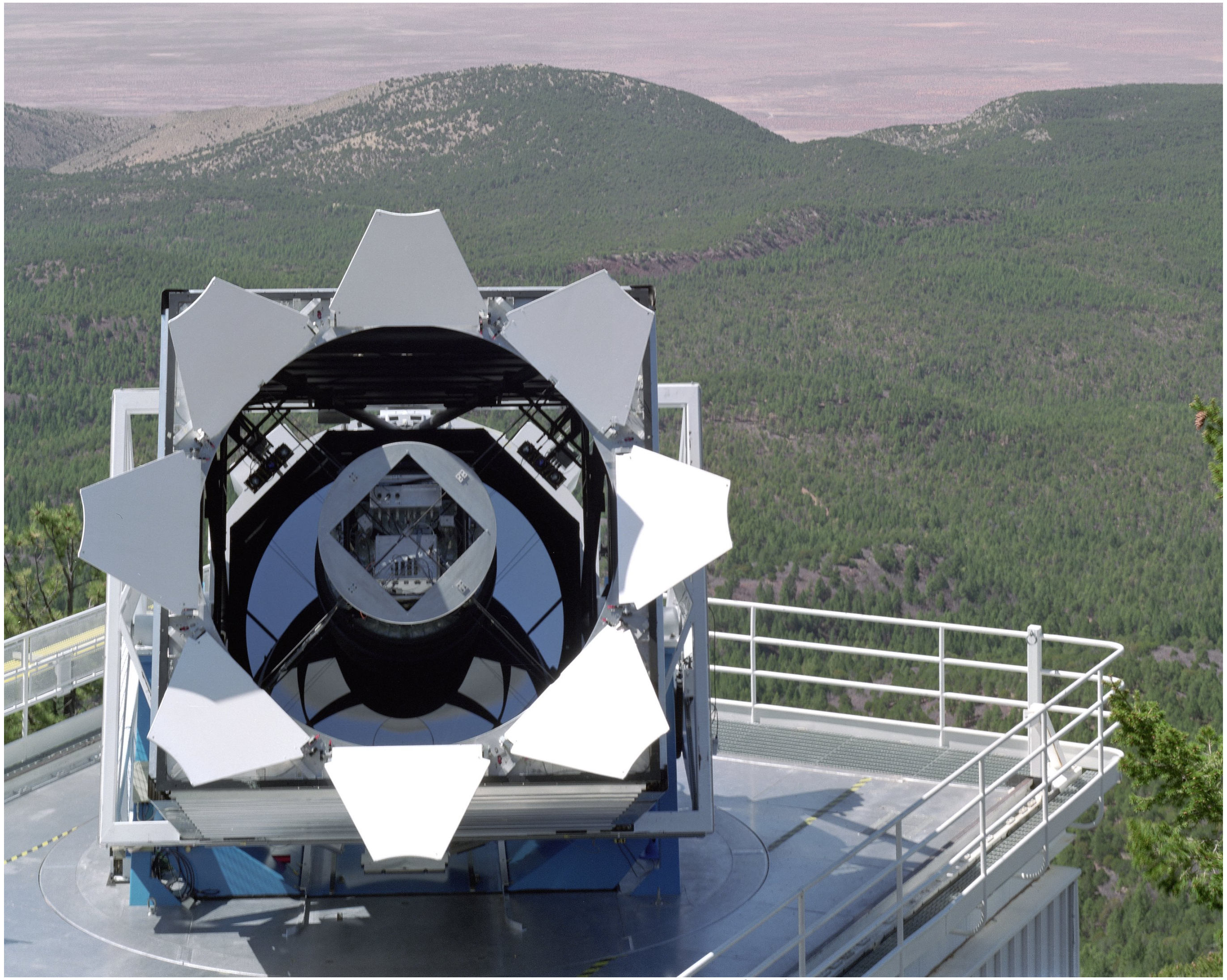
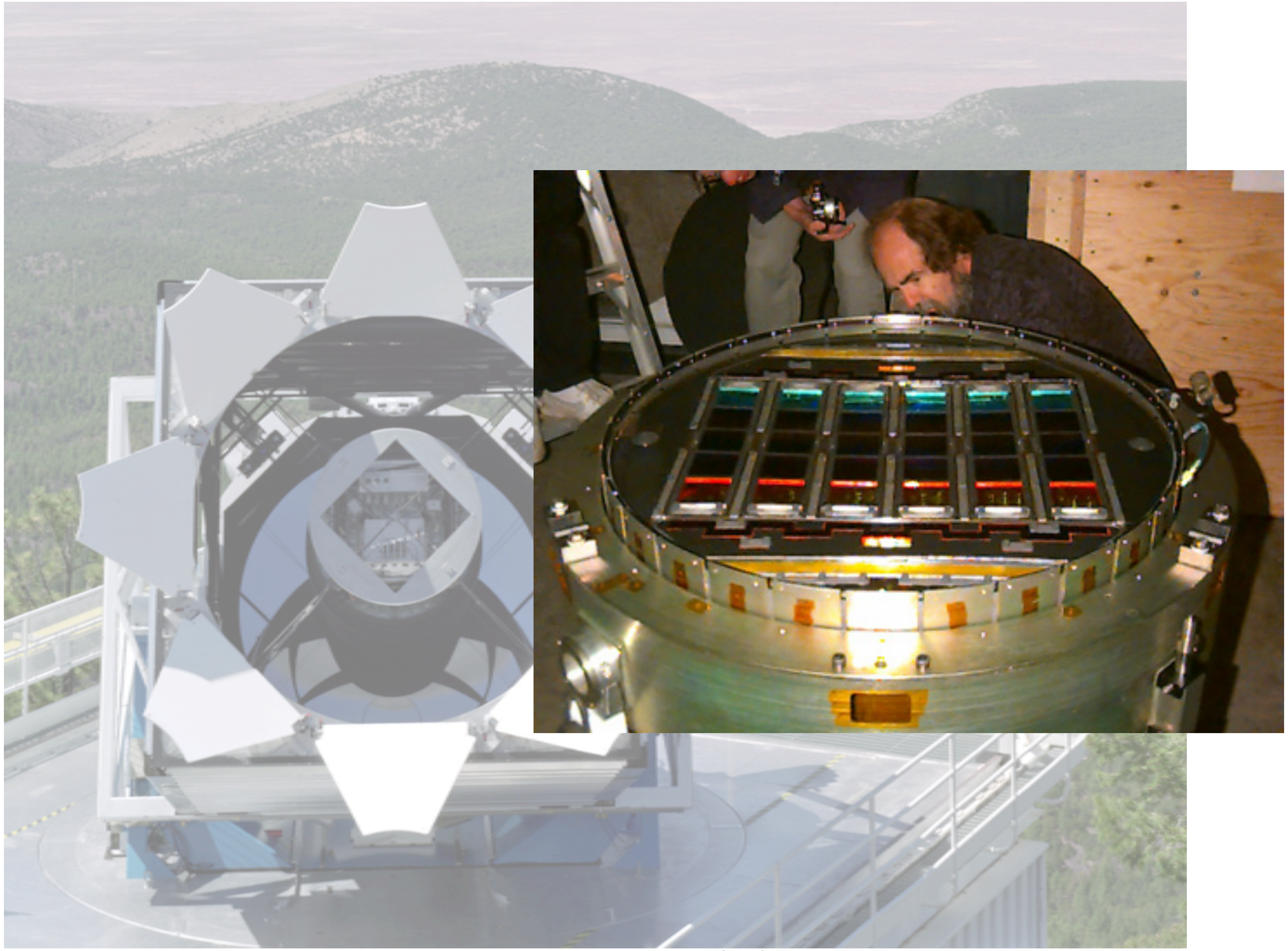


MEGACAM
Key technology:
wide field instrument
with large CCD
matrices

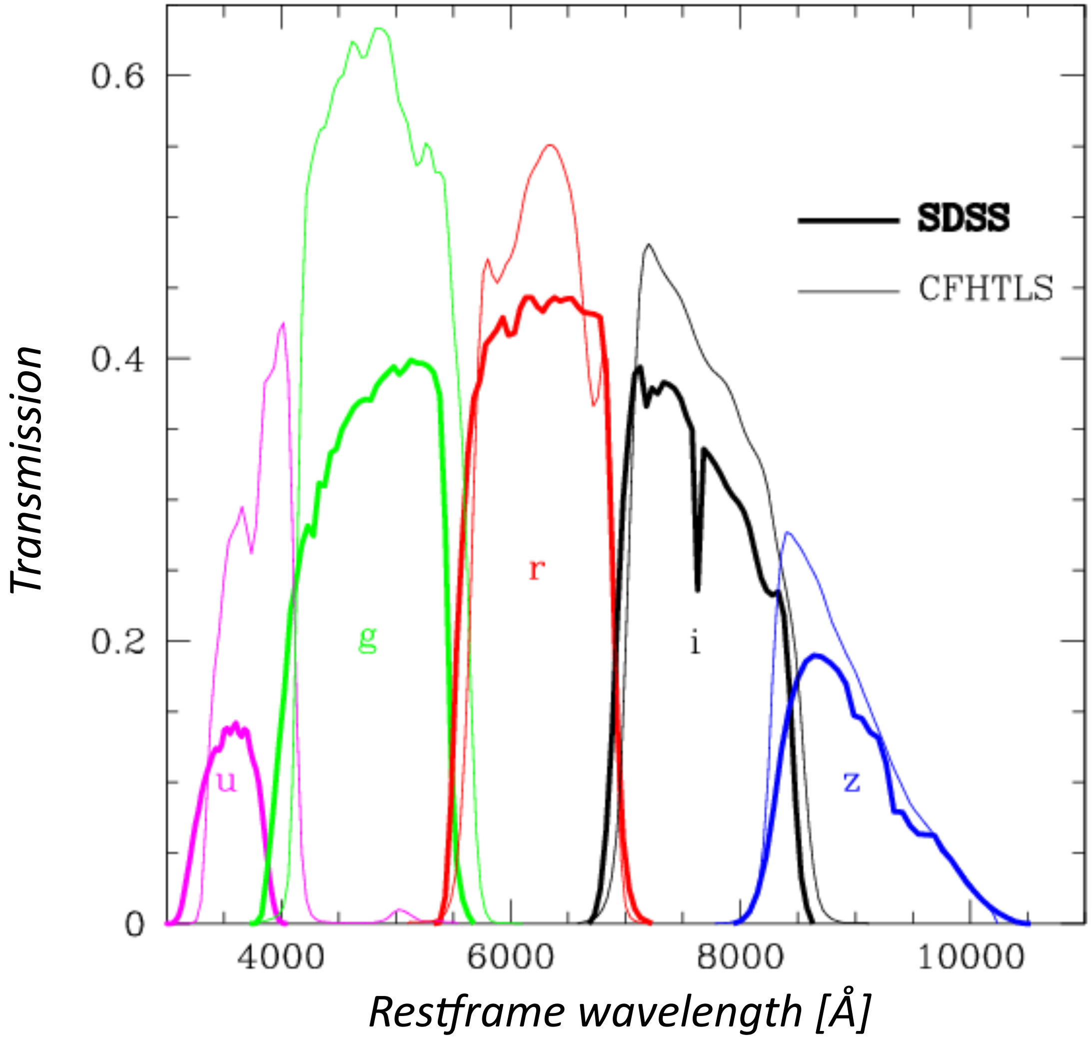
The SDSS instrument



The SDSS instrument

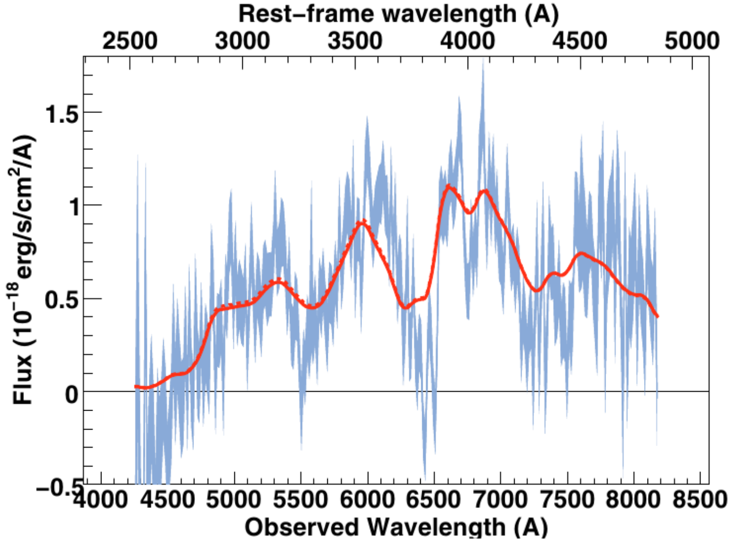


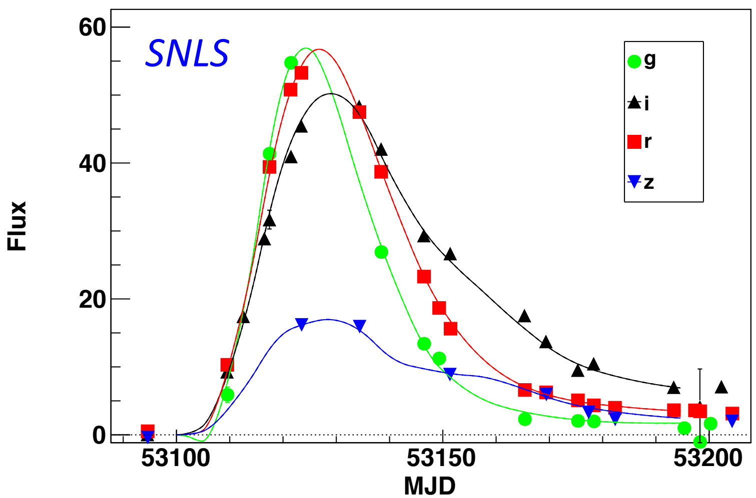
Comparison of filters transmission

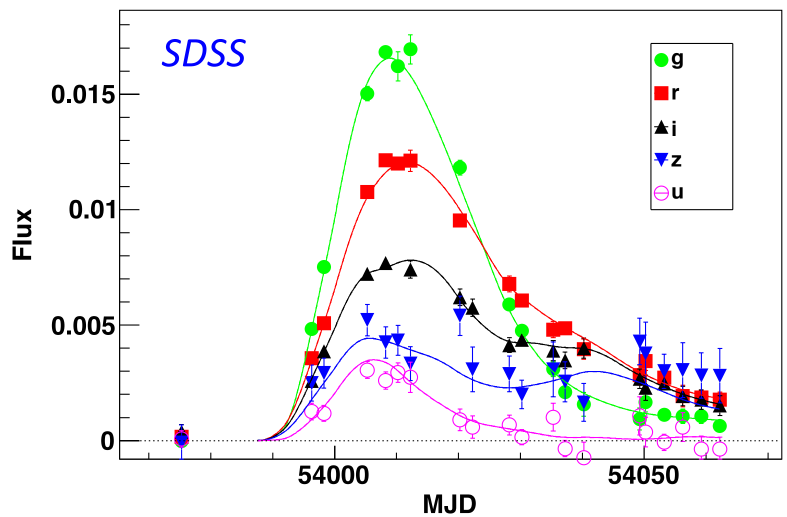


Light-Curves and Spectra

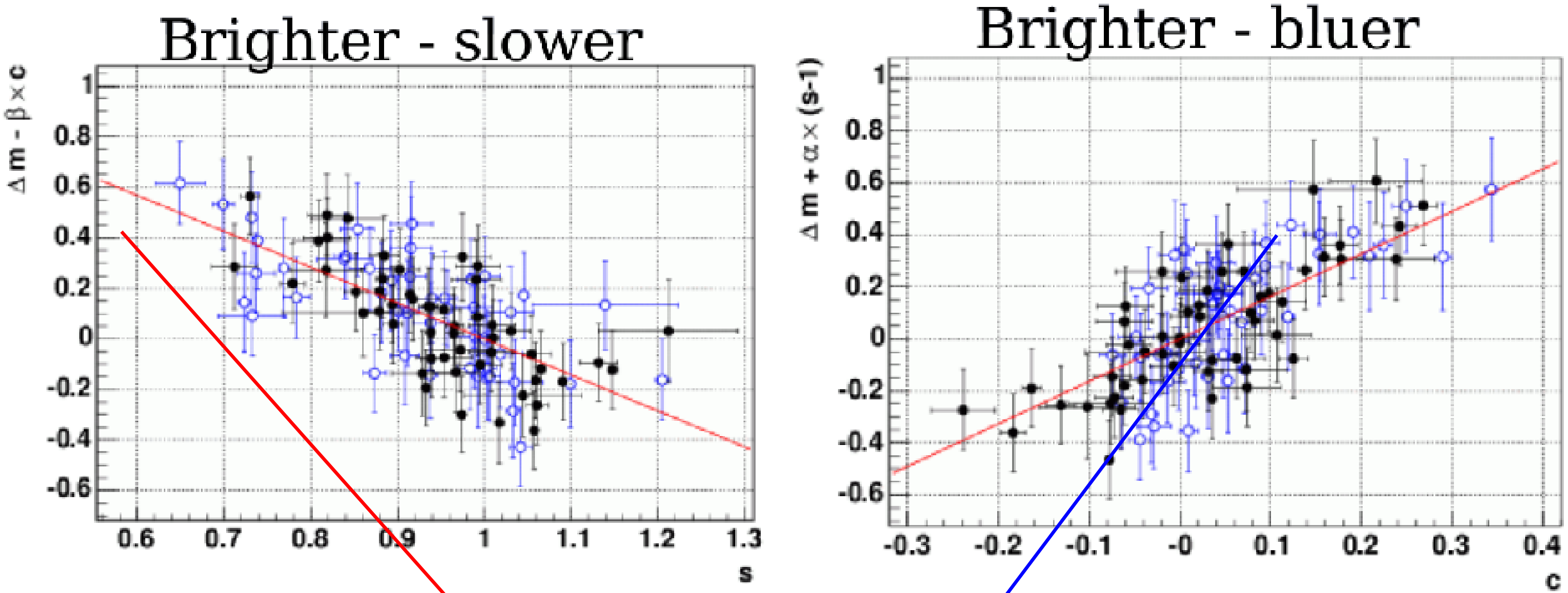
- Observables:
  - possibly redshift (spectrometry)
  - apparent flux (photometry)
- Identification







Standardization of the distance modulus



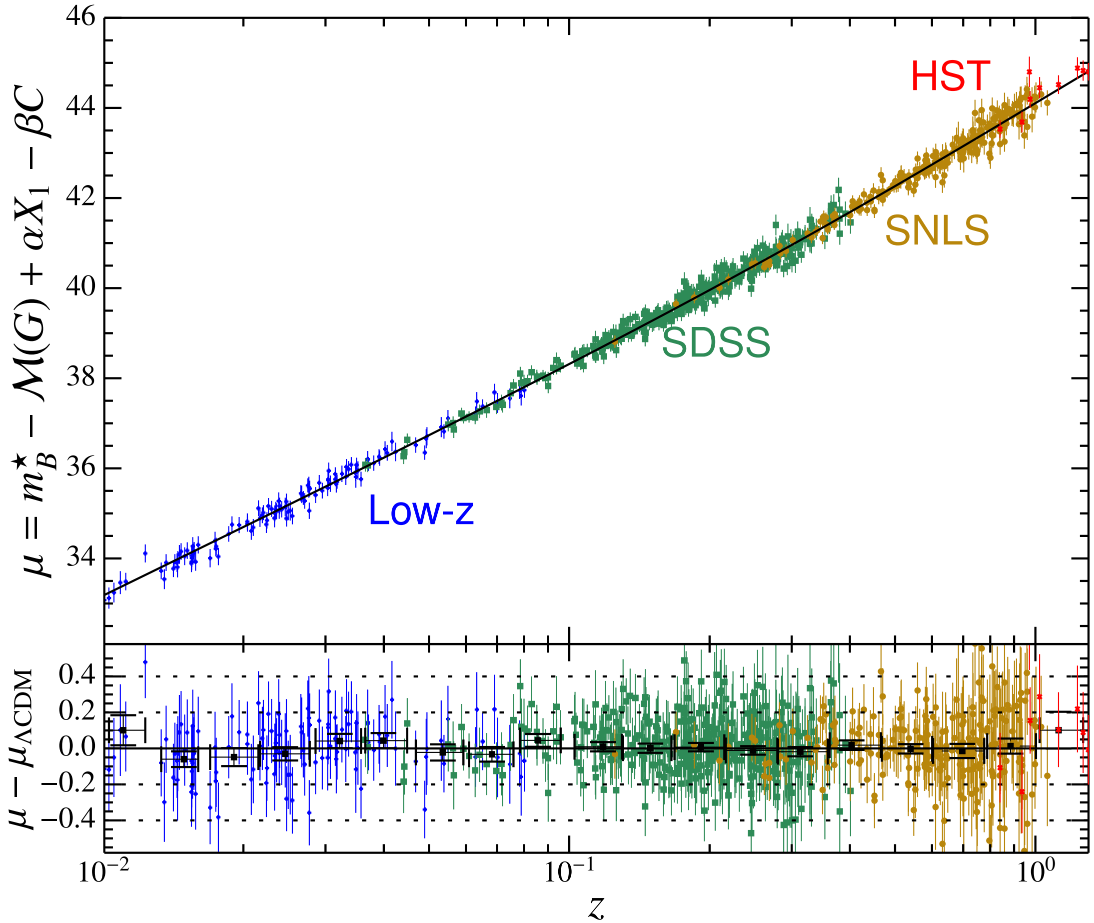
$$\mu_B = m_B^{\star} - \mathcal{M}_B + \alpha \times stretch - \beta \times color$$

El-Hage (2014)

Joint Light-Curve Analysis (JLA)

- Collaboration btw SNLS, SDSS and low-redshift surveys
  - improved calibration accuracy
  - statistic-limited Hubble diagram

Betoule et al. (2014)



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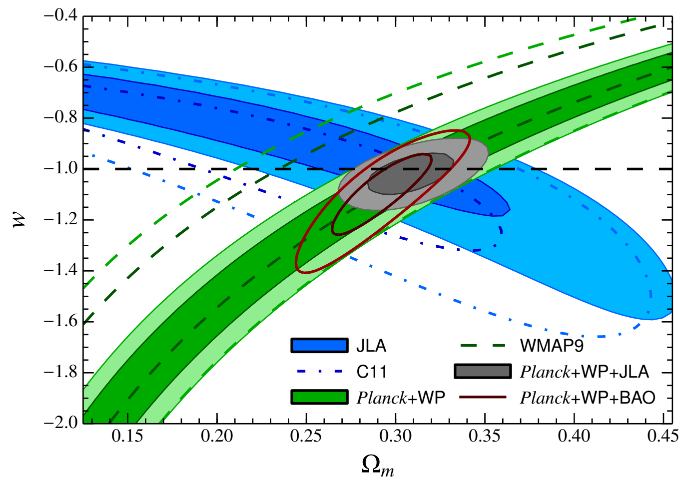
Planck+WP+BAO+JLA

w=−1.027±0.055

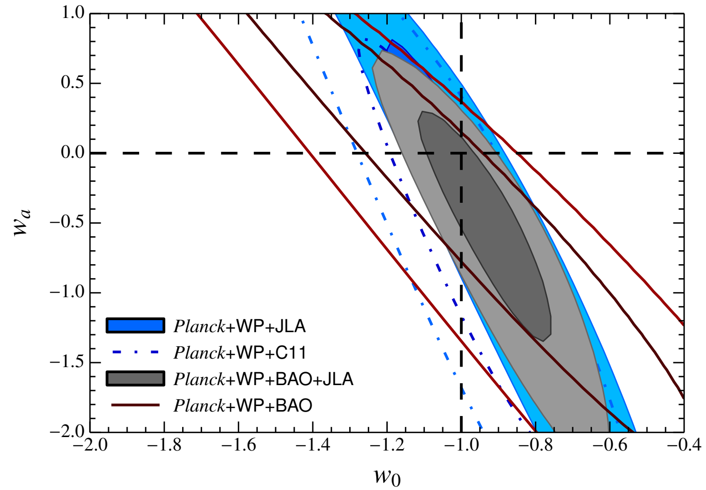
Ω_m=0.303±0.012



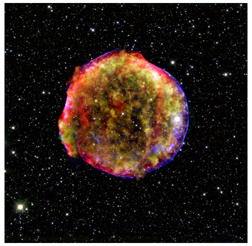
Planck+WP+BAO+JLA

w_0=−0.957±0.124

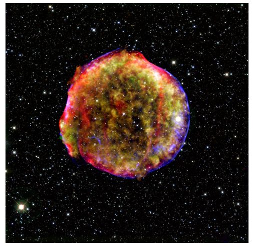
w_a=−0.336±0.552



We know that:



✓ Standardization of supernovæ is well-motivated but not perfect
✓ The missing information is most probably connected to host galaxy properties
✓ Explosion mechanism is poorly known
✓ It does not evolve with redshift (in principle), but the initial conditions do
✓ Age of progenitors can be involved



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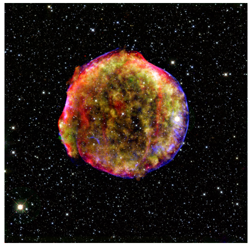

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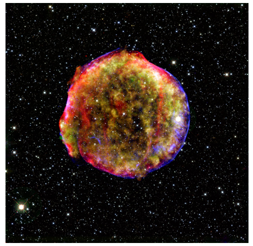


With the increase of survey statistics, we need to find new techniques to take those effects into account

Increasing the precision of standardization: looking for global or local properties

- Host stellar mass/star formation rate correlates to absolute magnitude/stretch factor

  (*Neill et al. 2009, Hamuy et al. 2010, Sullivan et al. 2011, Lampeitl et al. 2010, Johansson et al. 2013*)

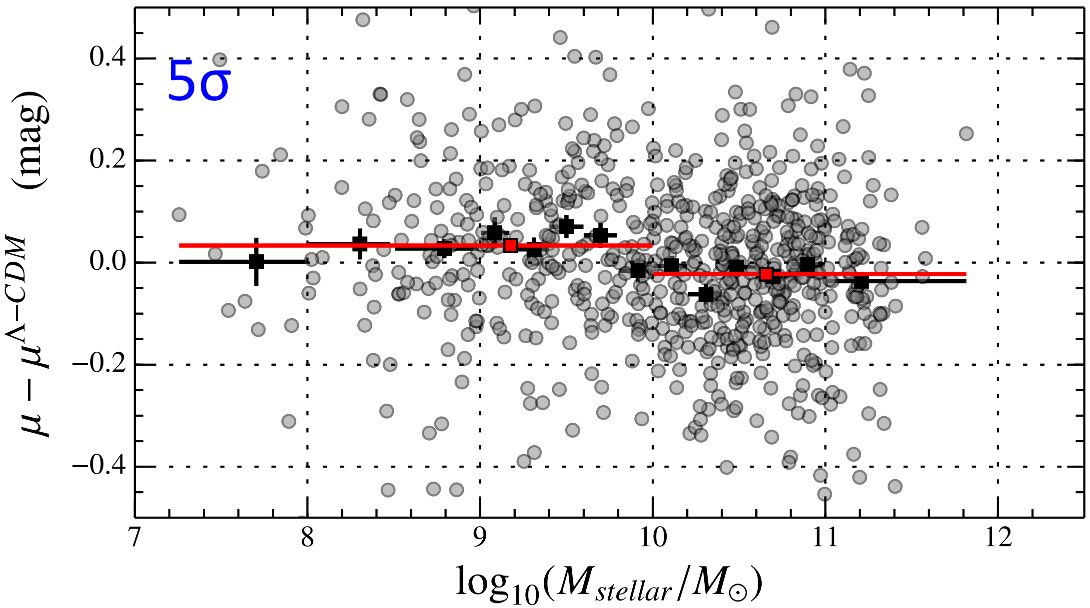
- Hubble diagram residuals correlate to global or local host properties

  (*Kelly et al. 2010, Sullivan et al. 2011, Gupta et al. 2011, Childress et al. 2013, Rigault et al. 2013 and 2015*)

Joint Light-Curve Analysis (JLA)

- There is ≈0.14 magnitude intrinsic luminosity variation after corrections are applied
- The stellar mass strongly correlates to HR residuals
- Mass-step for absolute magnitude

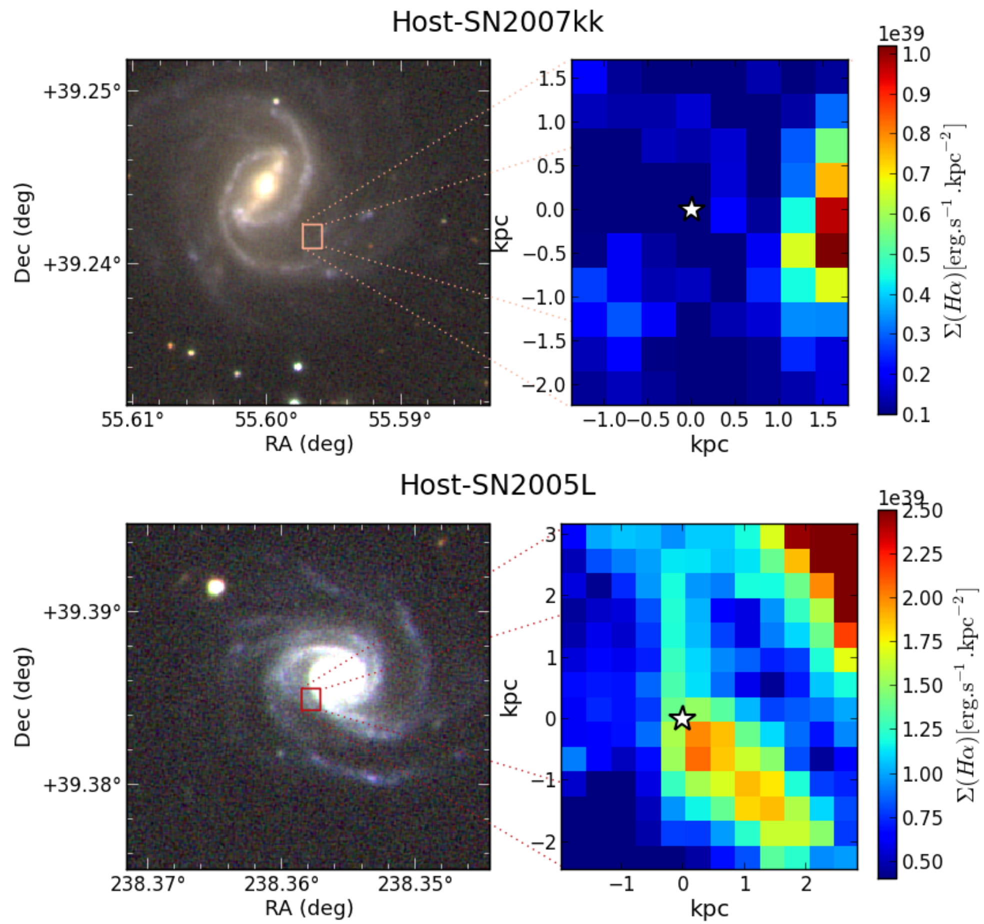
Betoule et al. (2014)



$$M_B = \begin{cases} M_B^1 & \text{if} \quad M_{\text{stellar}} < 10^{10}\ M_{\odot}, \\ M_B^1 + \Delta_M & \text{otherwise.} \end{cases}$$

A first look at local host properties

Rigault et al. 2013



Hα as a tracer of stellar formation

$\mathcal{O}(80)$ SNe

Nearby Supernova Factory

A first look at local host properties

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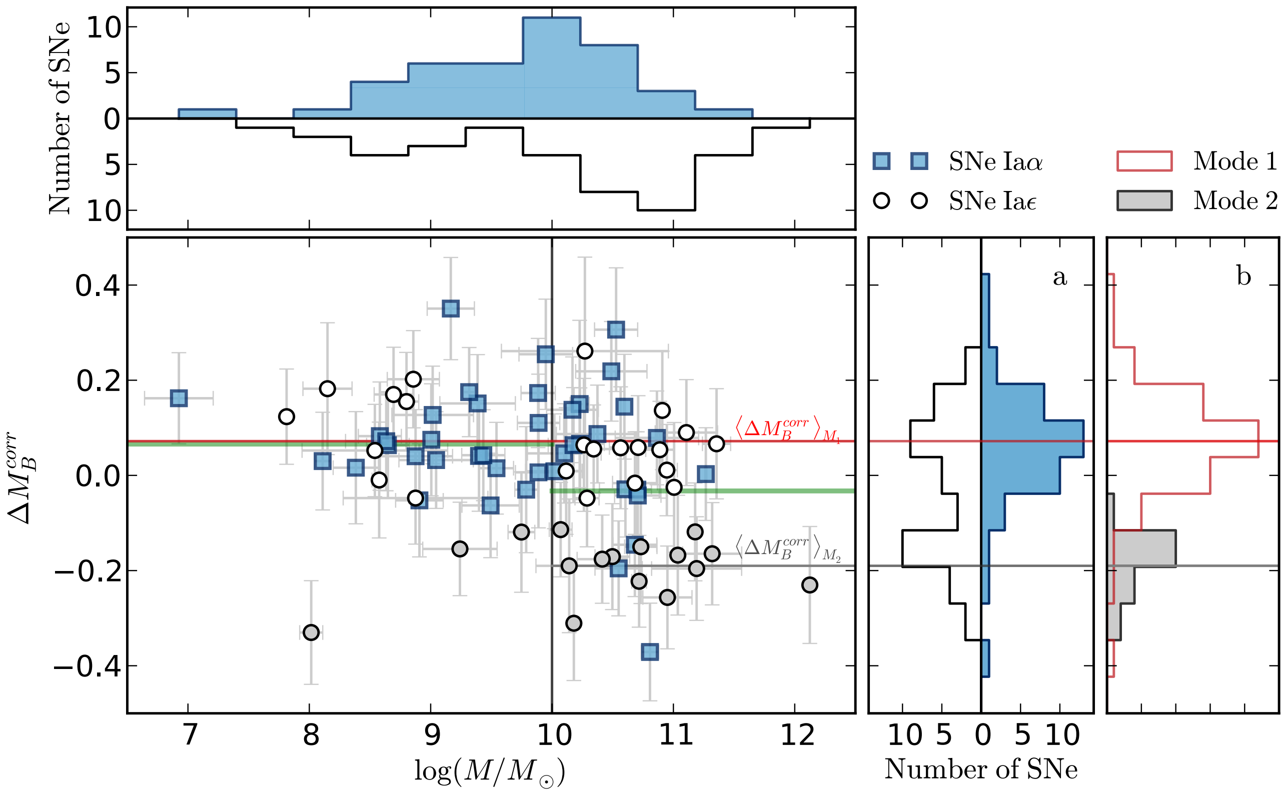
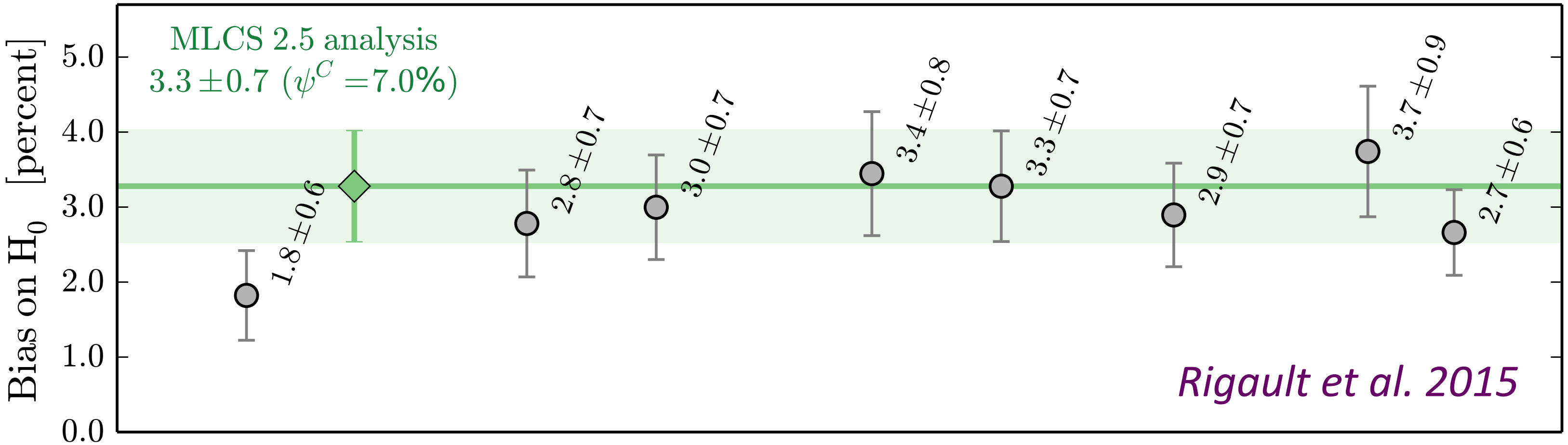


SNe in locally passive regions are brighter, causing the mass step

$\mathcal{O}(80)$ SNe

Nearby Supernova Factory

Re-determination of H_0



Hicken et al. 2009 sample + GALEX images

VS

RECONSIDERING THE EFFECTS OF LOCAL STAR FORMATION ON TYPE IA SUPERNOVA COSMOLOGY

David O. Jones[1], Adam G. Riess[1,2], Daniel M. Scolnic[3]

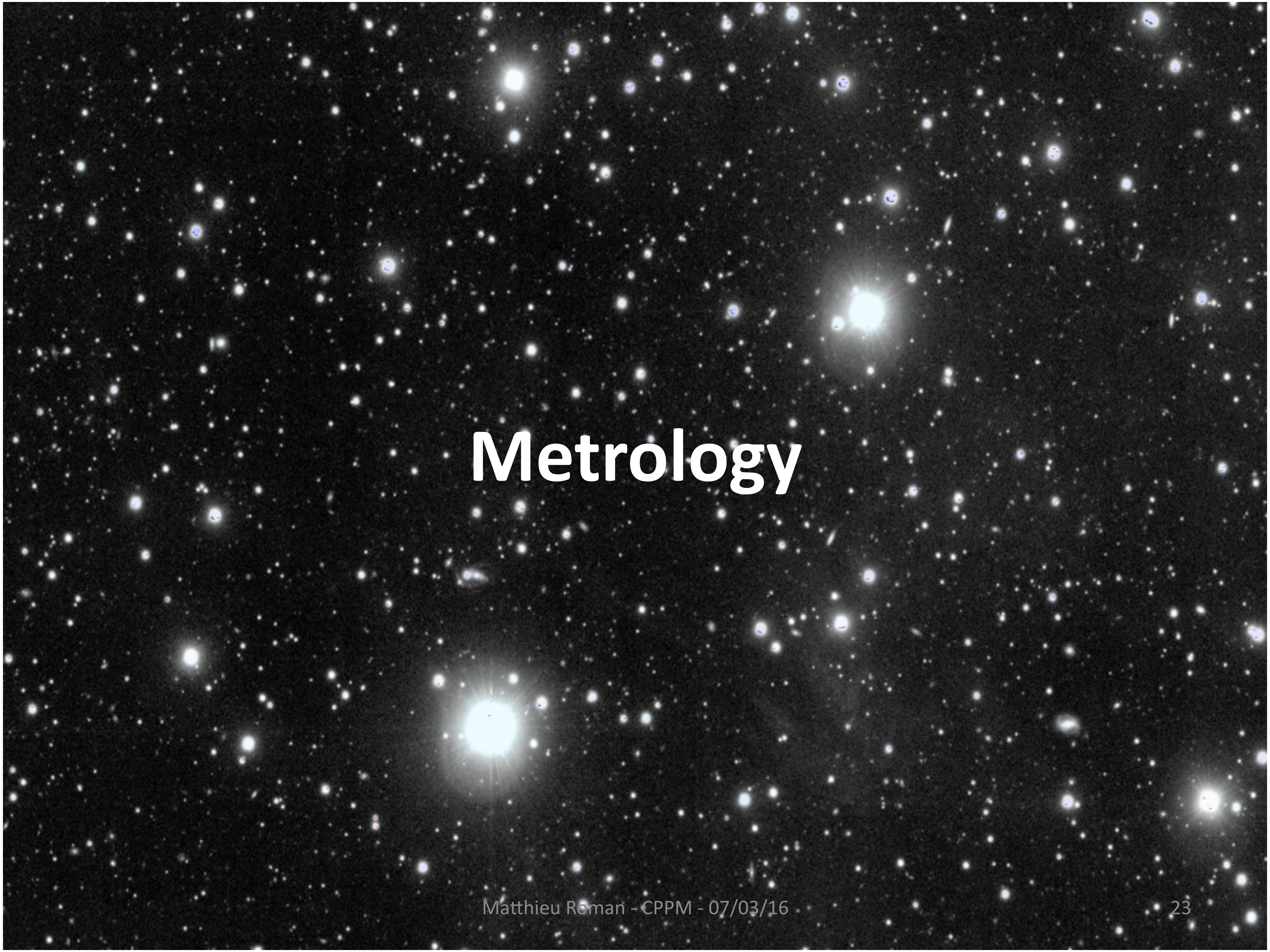
Draft version September 3, 2015

use of JLA sample, different selection criteria, GALEX images

Our challenge

We want to build a new tracer of local SN properties and perform precise measurements for the whole SNLS5 sample

Metrology



SNLS5 final data sample: hosts photometry

- we have global host galaxy photometry for most of the sample (83%)

Preliminary

	# SN	# Host photometry	Reference	Filters/Instrument
SNLS	392	346	Hardin et al. (in prep.)	$ugriz$/MegaCam
SDSS	330	291	Sako et al. 2014	$ugriz$/SDSS
low-z	137	117	SIMBAD	$ugriz$/SDSS & JHK/2MASS
Total	**859**	**754**	–	–

	# SN	# z match	# in SDSS	# in 2MASS	# only 2MASS	no photo
CSP	18	16	8	16	8	0
CfAIII	79	68	46	59	19	3
CfAIV	40	38	24	33	12	2
Total	**137**	**122**	**78**	**108**	**39**	**5**

http://simbad.u-strasbg.fr/simbad

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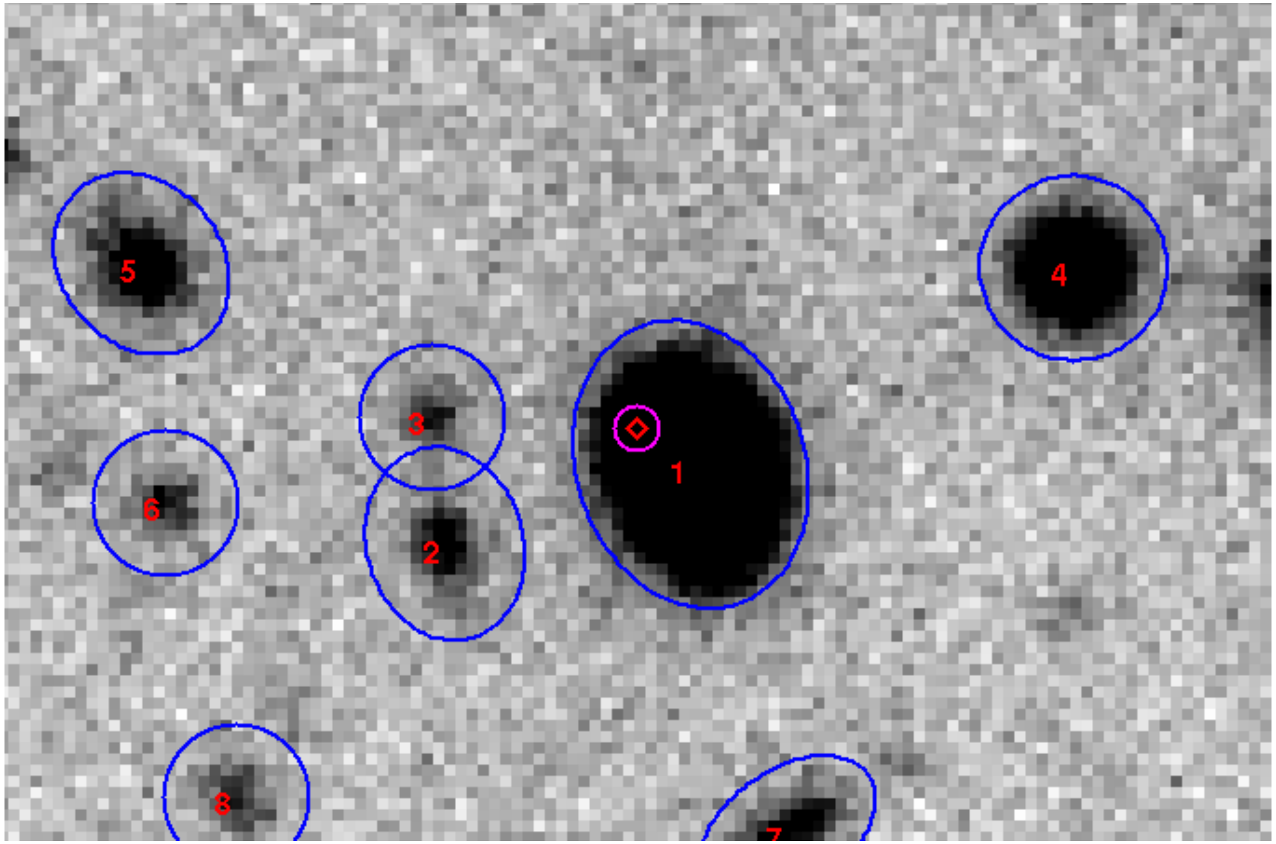
369 SNe

http://simbad.u-strasbg.fr/simbad

Host photometry for SNLS

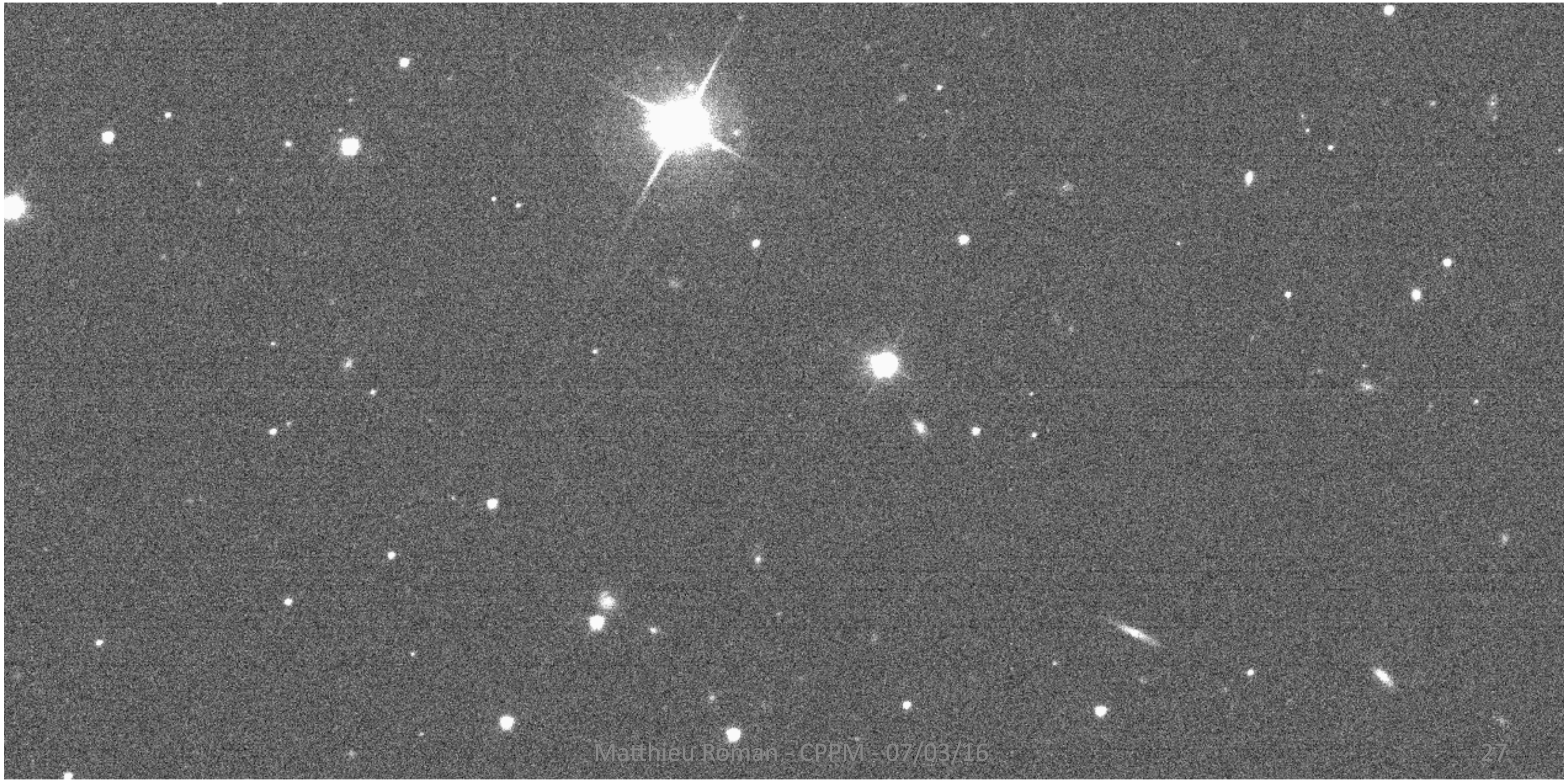
- Local: circular photometry with fixed radius (2-3 pixels) at SN position (violet circle)
- Global: corresponding host ellipse (blue)



Megacam (zoom)

Two kinds of SDSS images

- single-epoch images (DR12)
- coadded images of Stripe 82 (before fall 2005)



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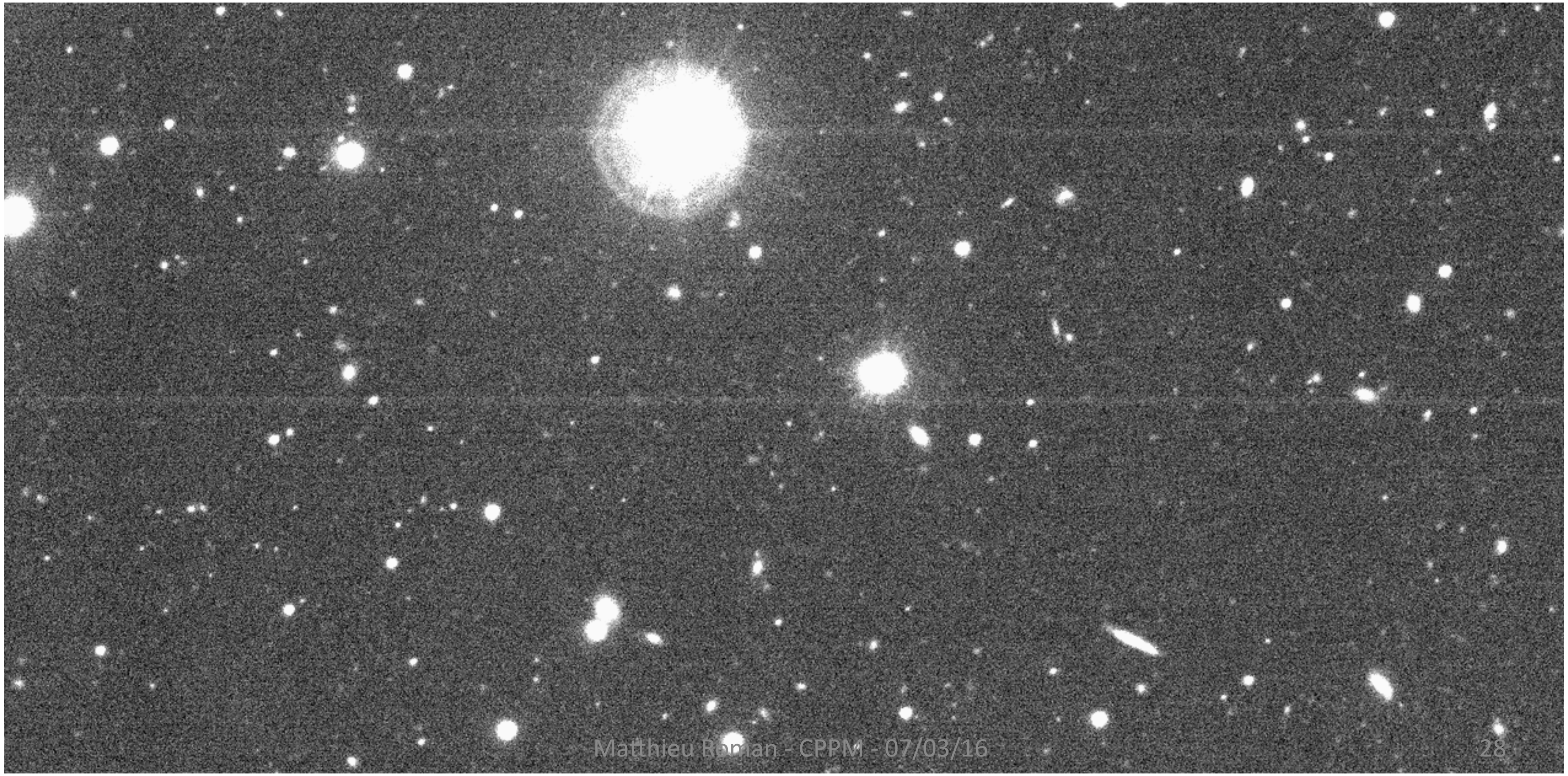

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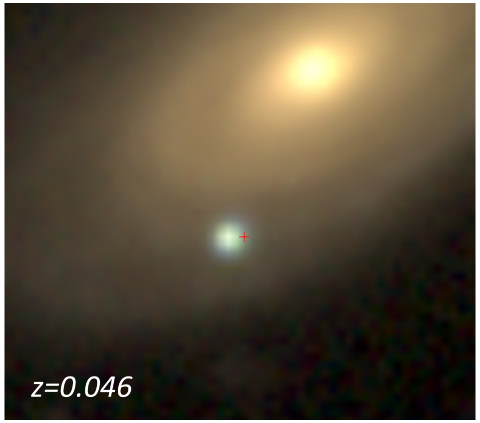
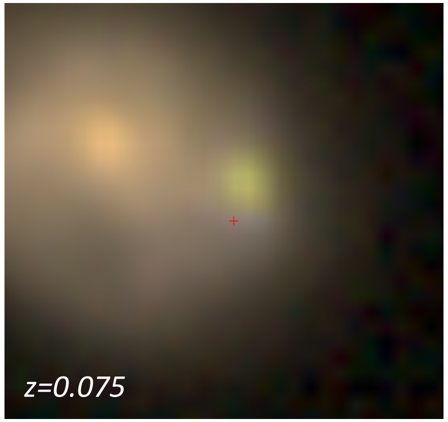
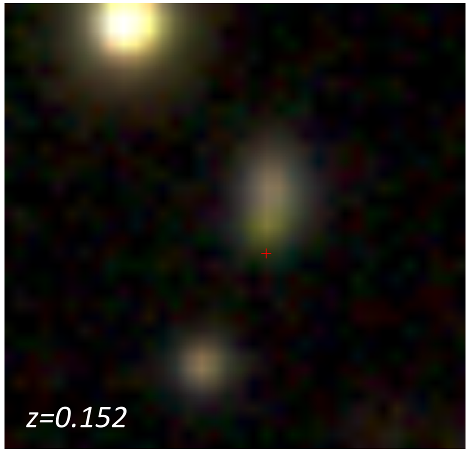
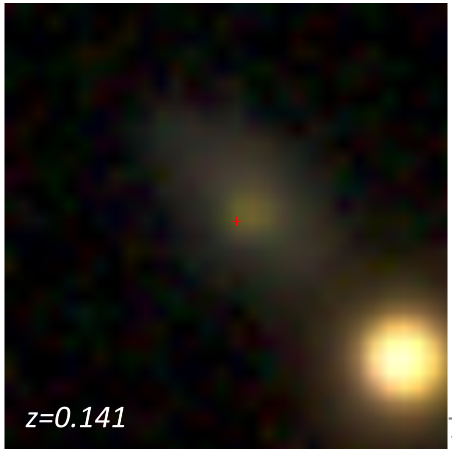


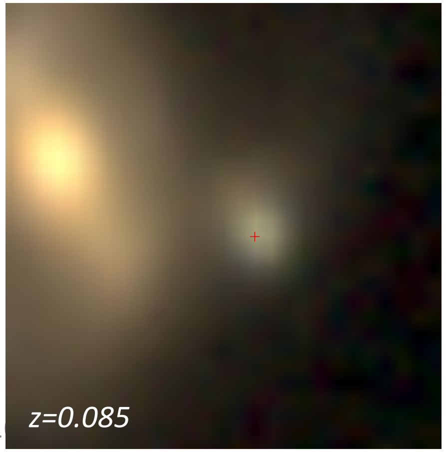


we do not consider contaminated stacks

RGB

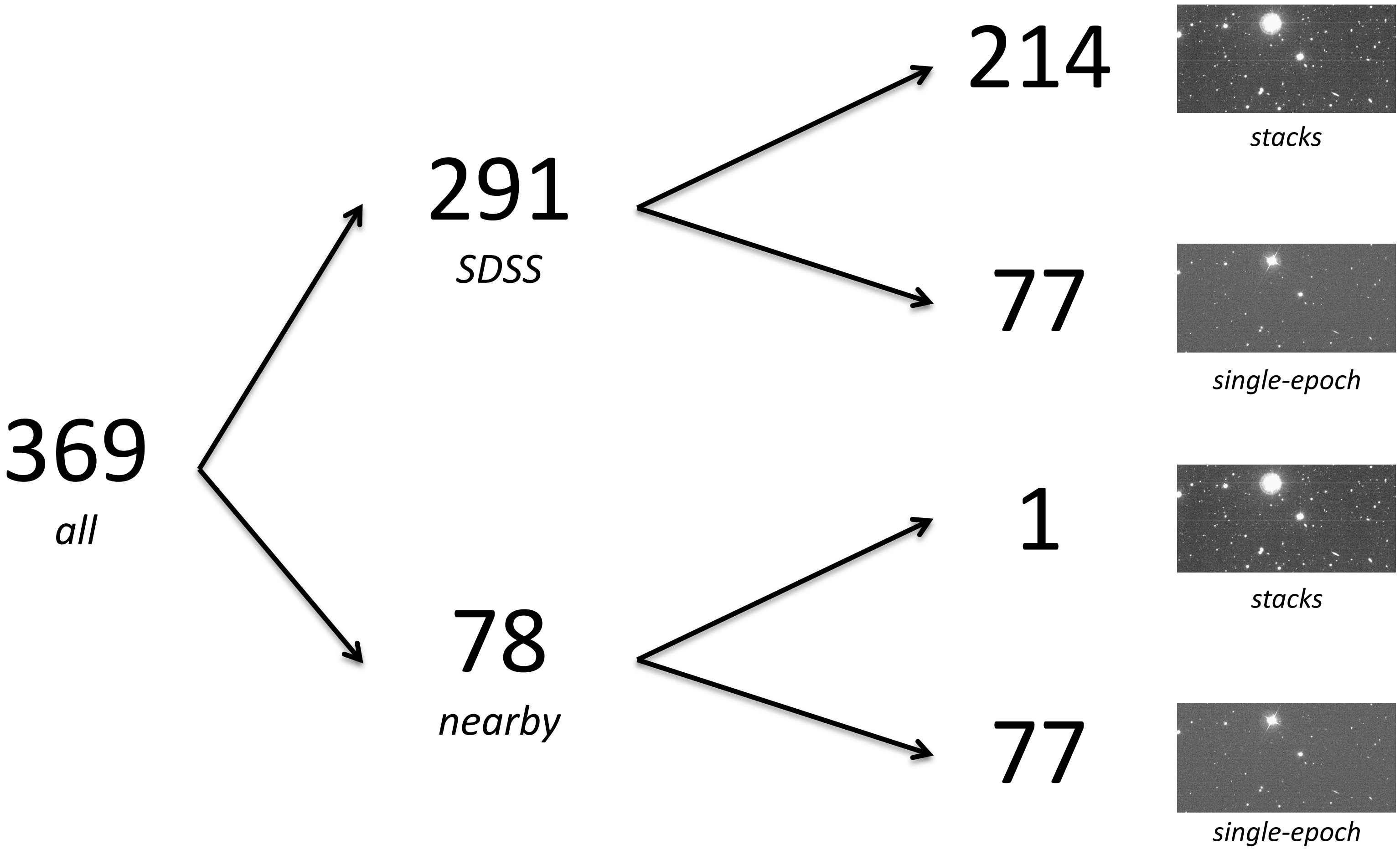






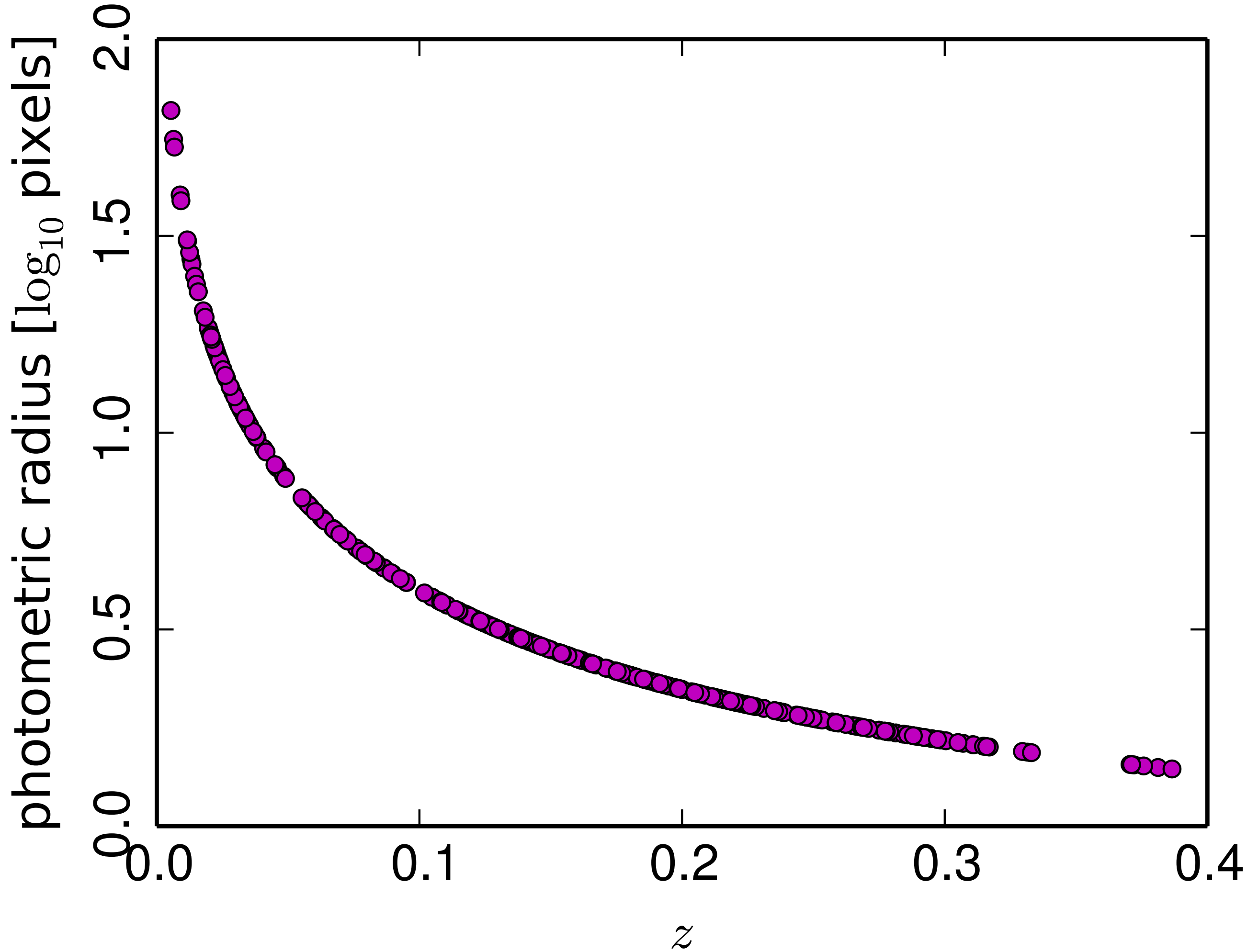
small position offset

Two kinds of SDSS images



Photometric radius

- we probe regions of radius 3kpc at all redshifts



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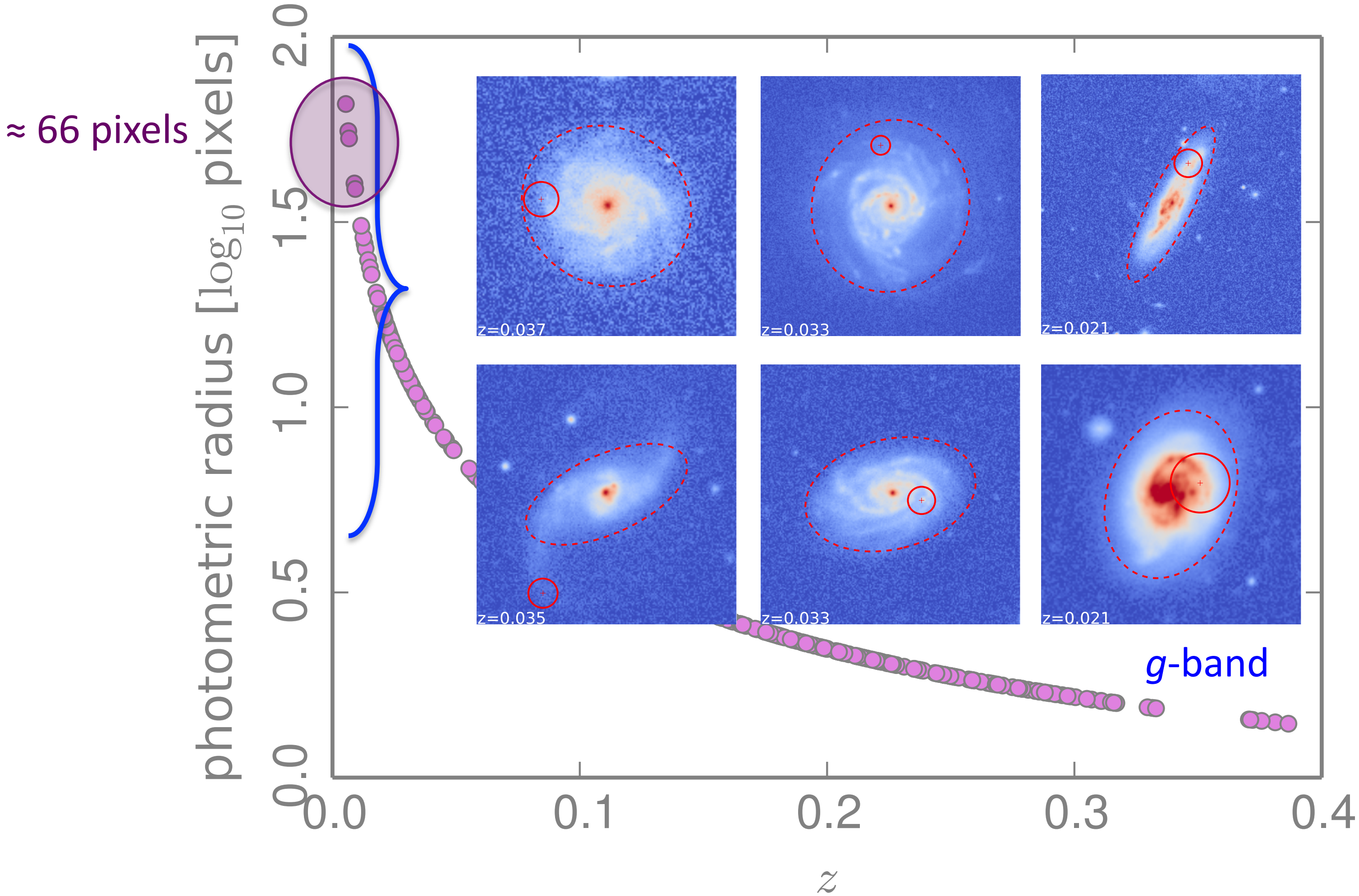

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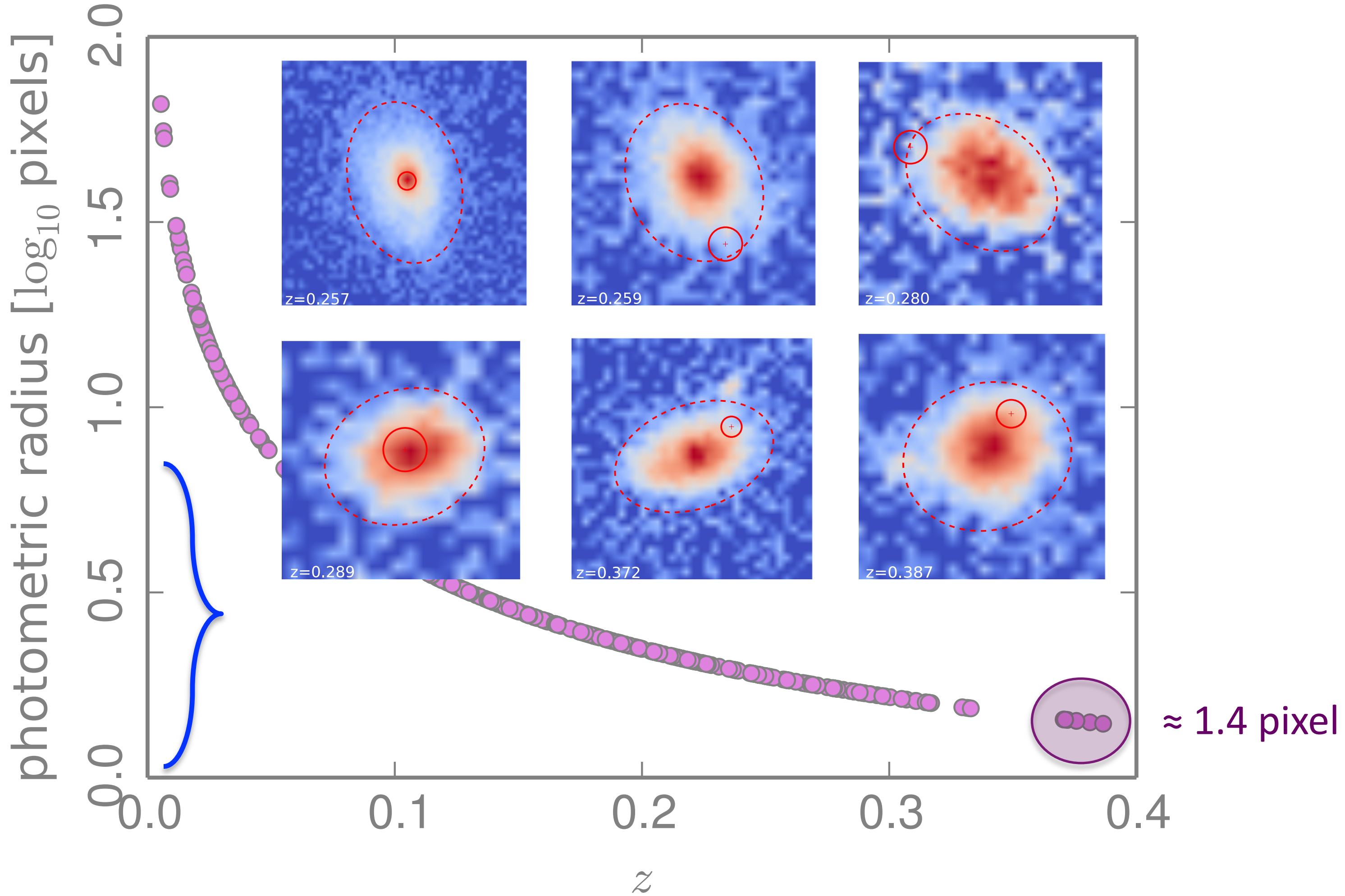
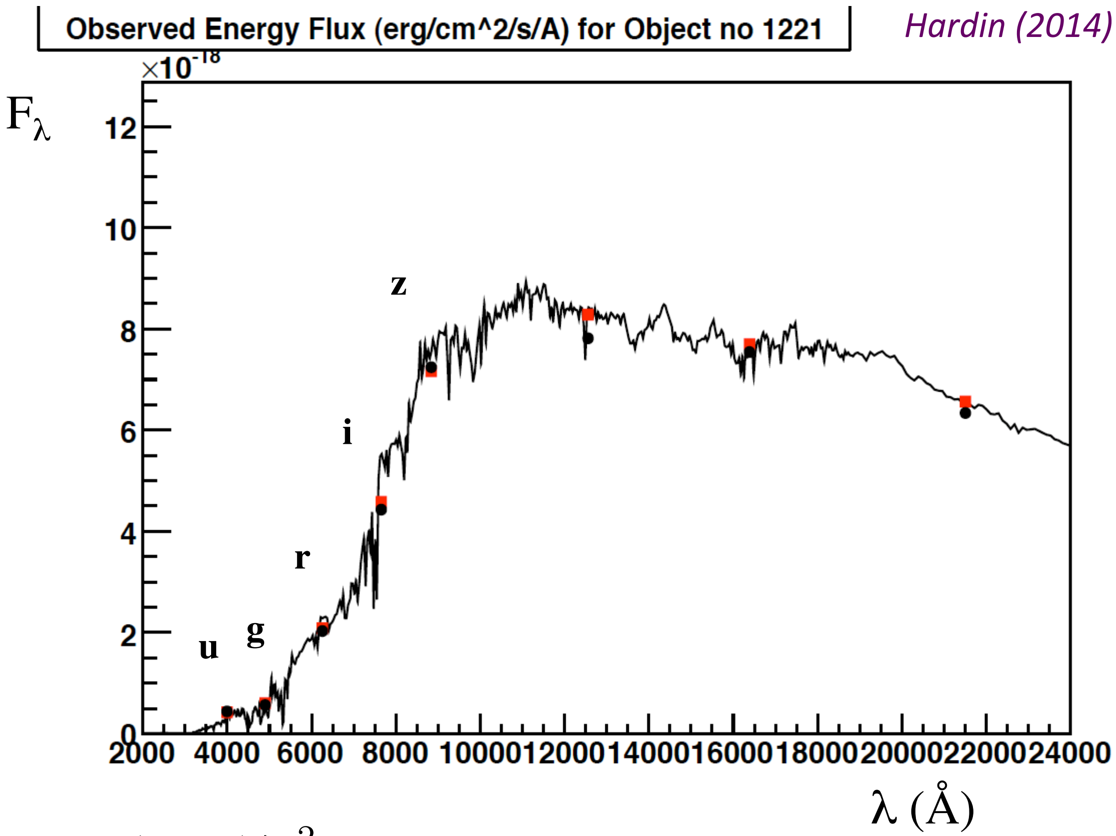


SED fitting (in a nutshell)

SED fitting

- How to compute stellar masses?
  - a spectrum is built from observed magnitudes m_f at redshift z and compared to the PEGASE library
  - a model spectrum M is found by minimizing

Hardin (2014)

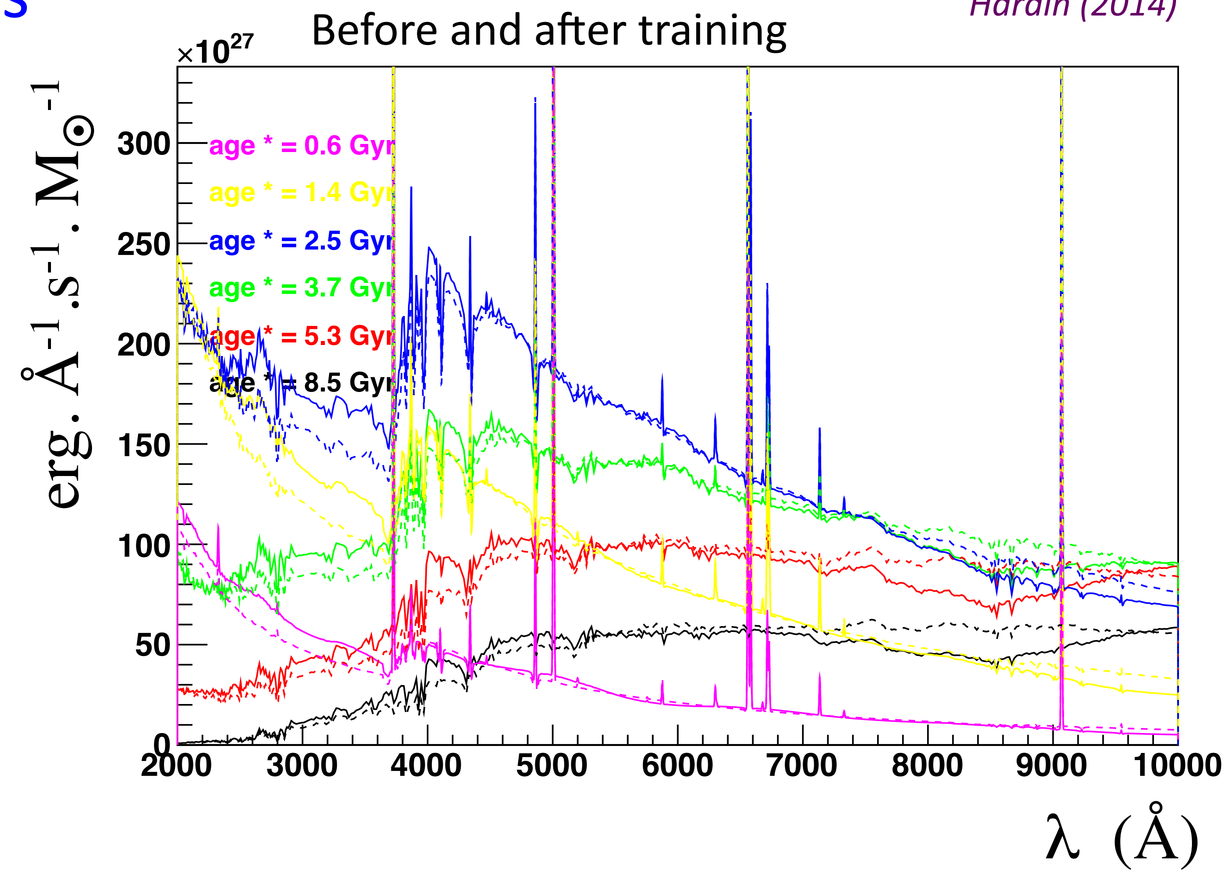


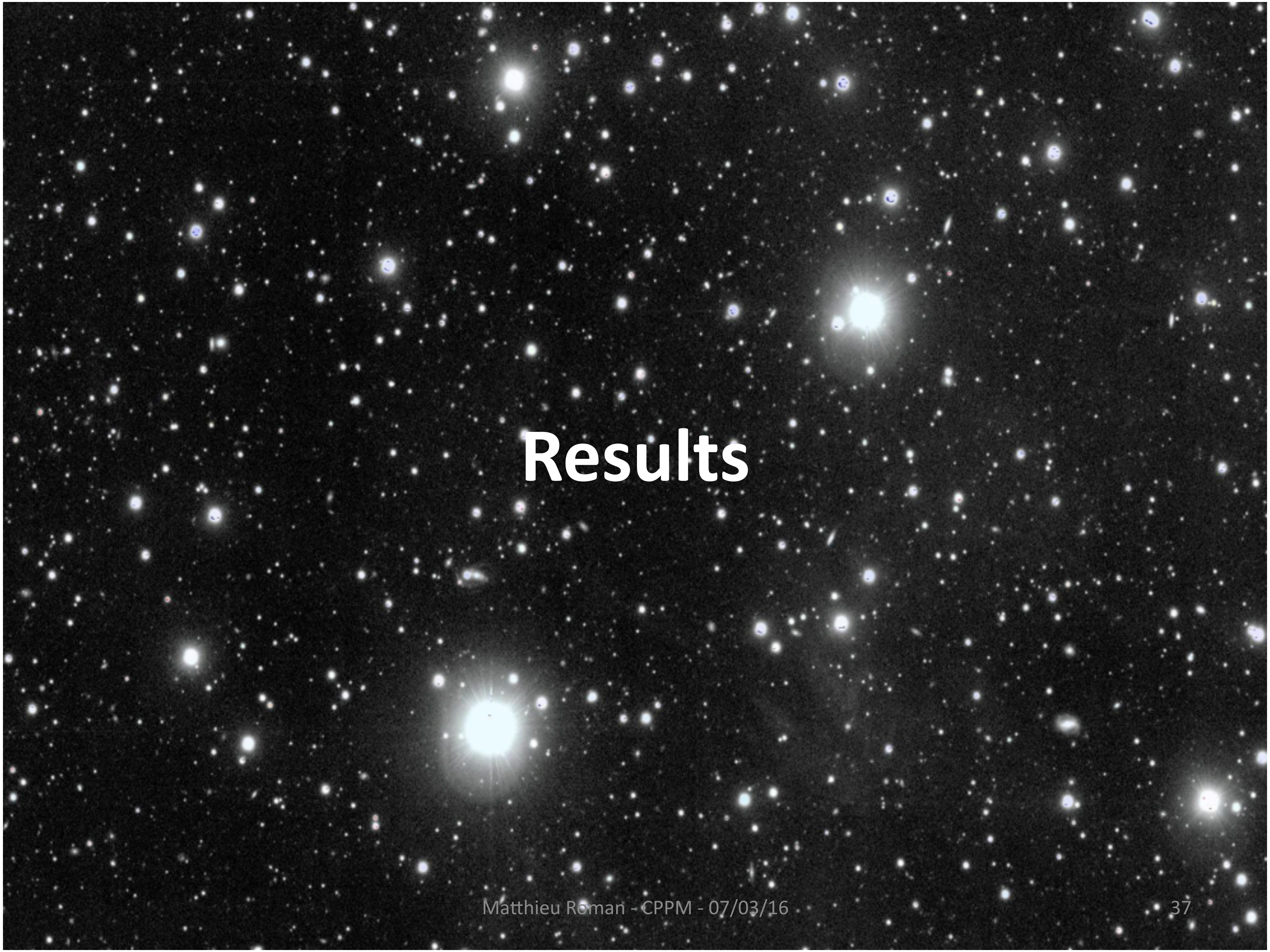
$$\chi^2(z, M) = \sum_{\text{filtres } f} \left(\frac{m_f(\text{obs.}) - m_f(z, M)}{\sigma_f} \right)^2$$

SED fitting: interpolator

- For rest-frame colors we use our own template library (EXPO)
  - starting from PEGASE spectra, a family of trained spectra is built (SNLS deep field)
  - up to 30% correction
  - by minimizing a χ^2 we find the corresponding photo-*z* and colors

Hardin (2014)





Results

SNLS+SDSS+nearby: cuts

- choice of SN cuts
  - well measured stretch $\sigma_{x_1} < 0.5$
  - not too distant $z < 0.8$
- choice of local photo cuts
  - reasonable error on local circular magnitude

$$\sigma_{\mathrm{mag,u}} < 1,\ \sigma_{\mathrm{mag,g}} < 0.5,\ \sigma_{\mathrm{mag,r}} < 0.5,\ \sigma_{\mathrm{mag,i}} < 0.5,\ \sigma_{\mathrm{mag,z}} < 0.5$$

- total of 441 (225+149+67) local photo measurements out of 715 (346+291+78) possible (62%)

Two kinds of SDSS images - update

- ~~369~~ 216 *all*
  - ~~291~~ 149 *SDSS*
    - ~~214~~ 118

      stacks
    - ~~77~~ 31

      single-epoch
  - ~~78~~ 67 *nearby*
    - 1

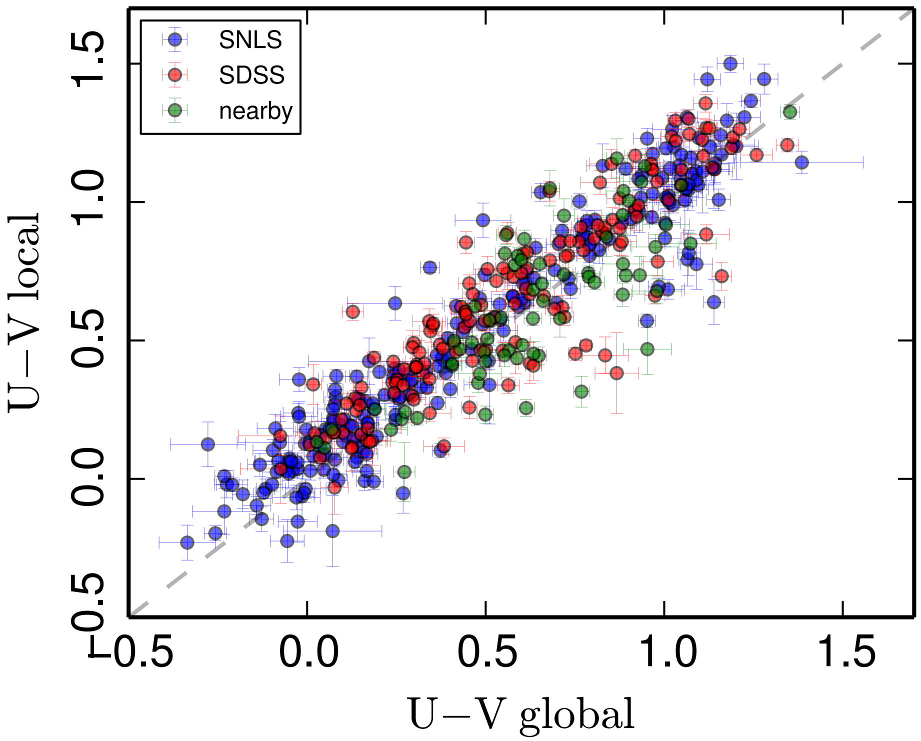
      stacks
    - ~~77~~ 66

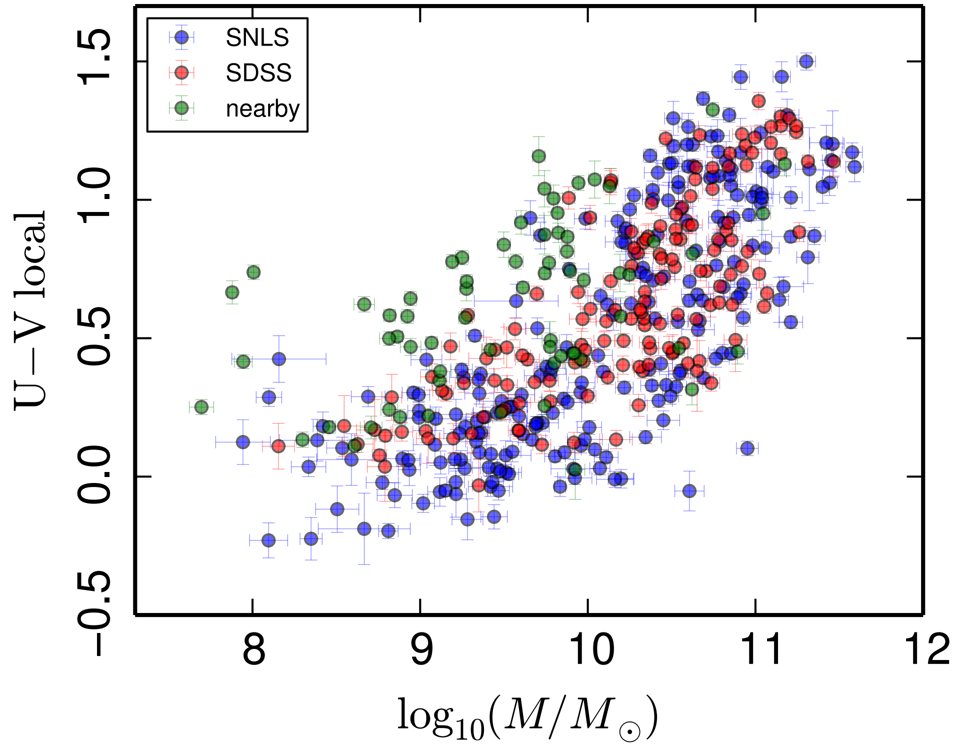
      

      single-epoch

SNLS+SDSS+nearby: local vs global properties

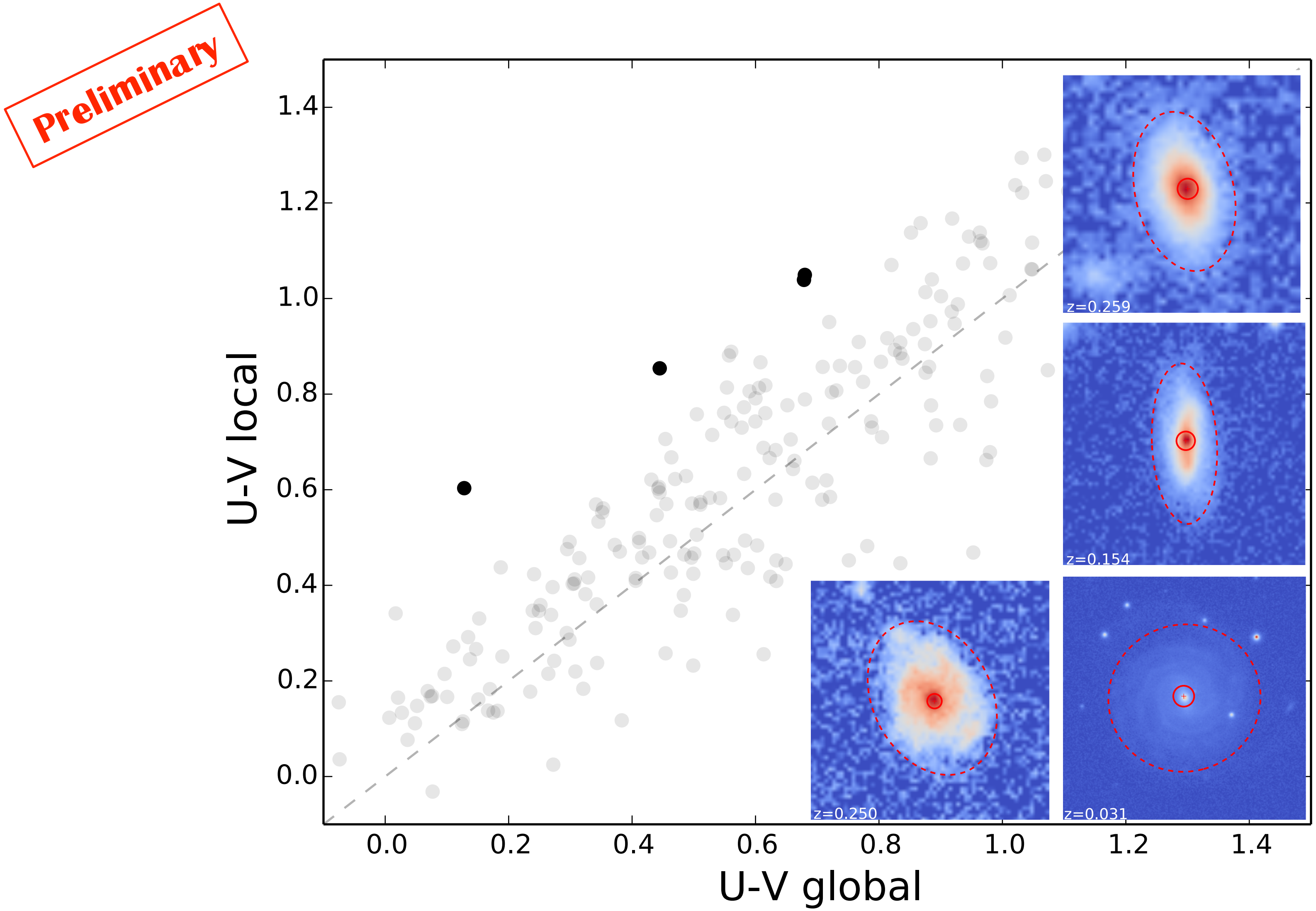
Preliminary





Interpolator: EXPO (with extinction)
Masses: PEGASE

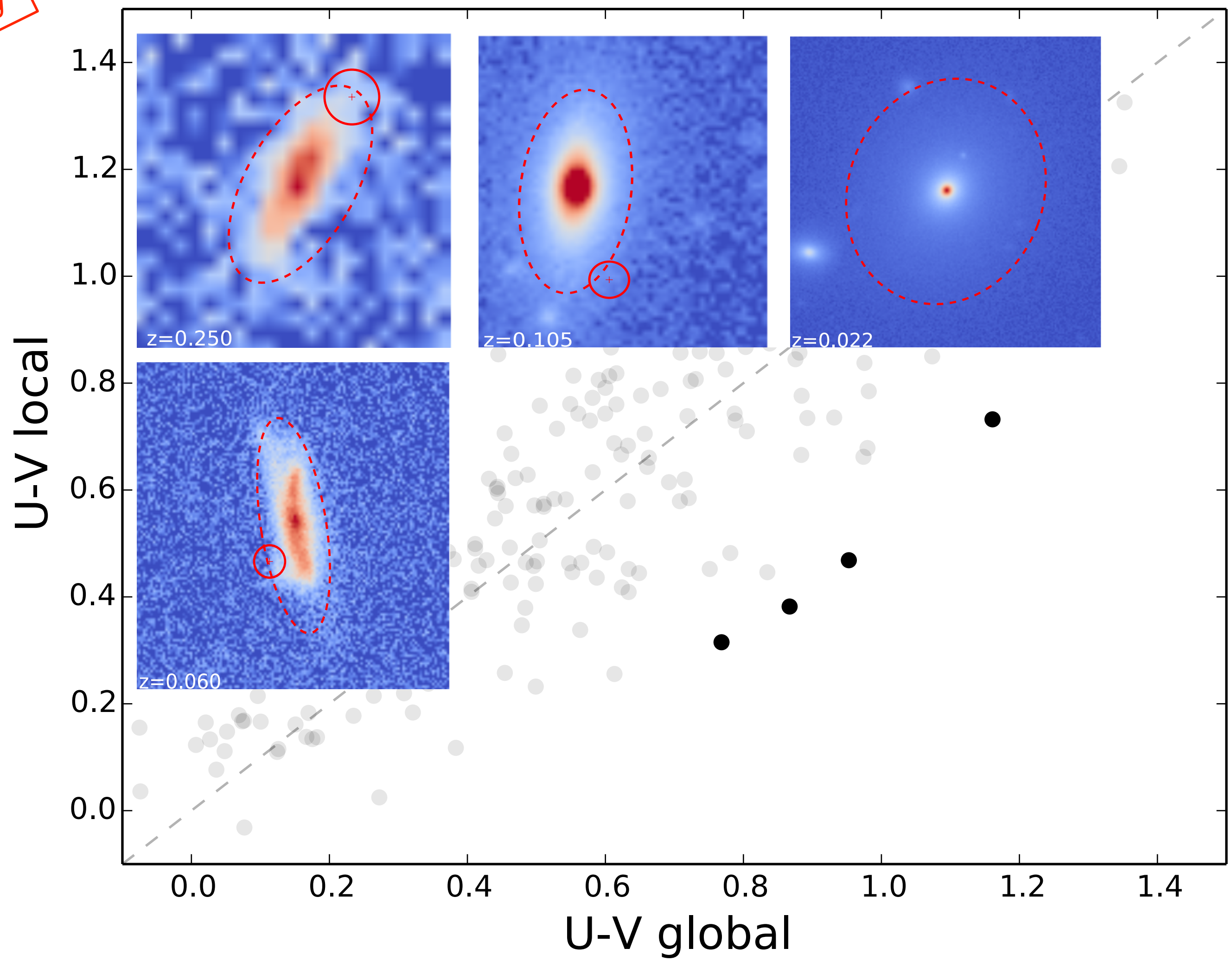
SDSS+nearby: local vs global properties



locally redder than the host; close from the galacitic centre

SDSS+nearby: local vs global properties

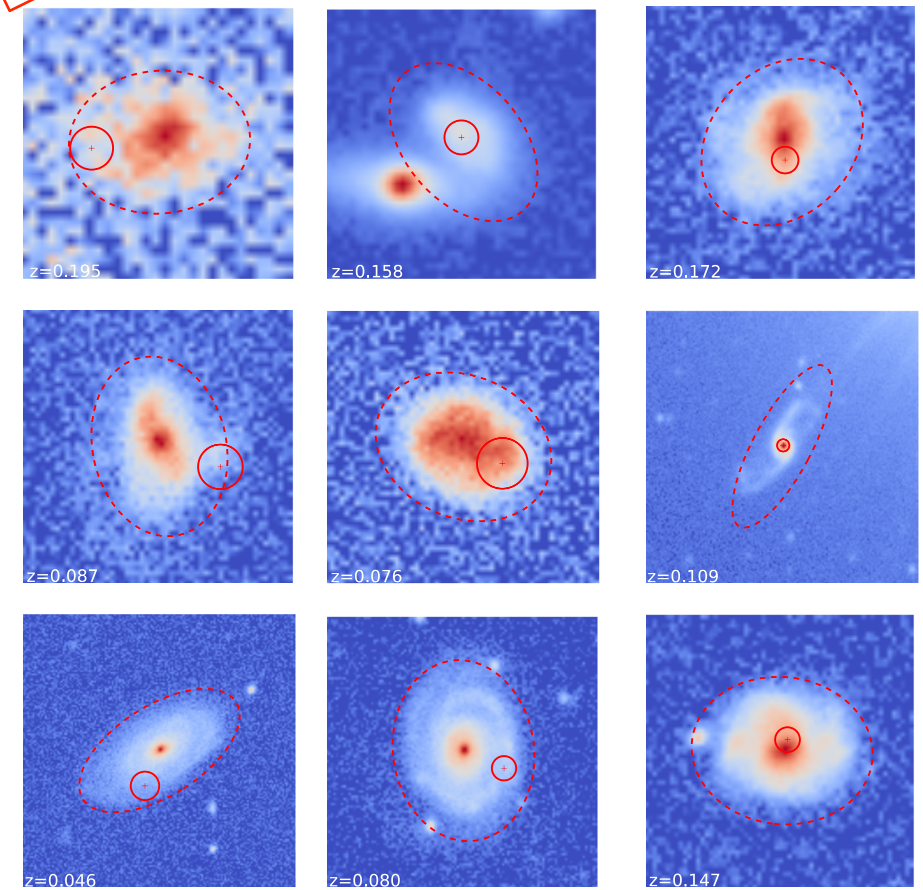
Preliminary

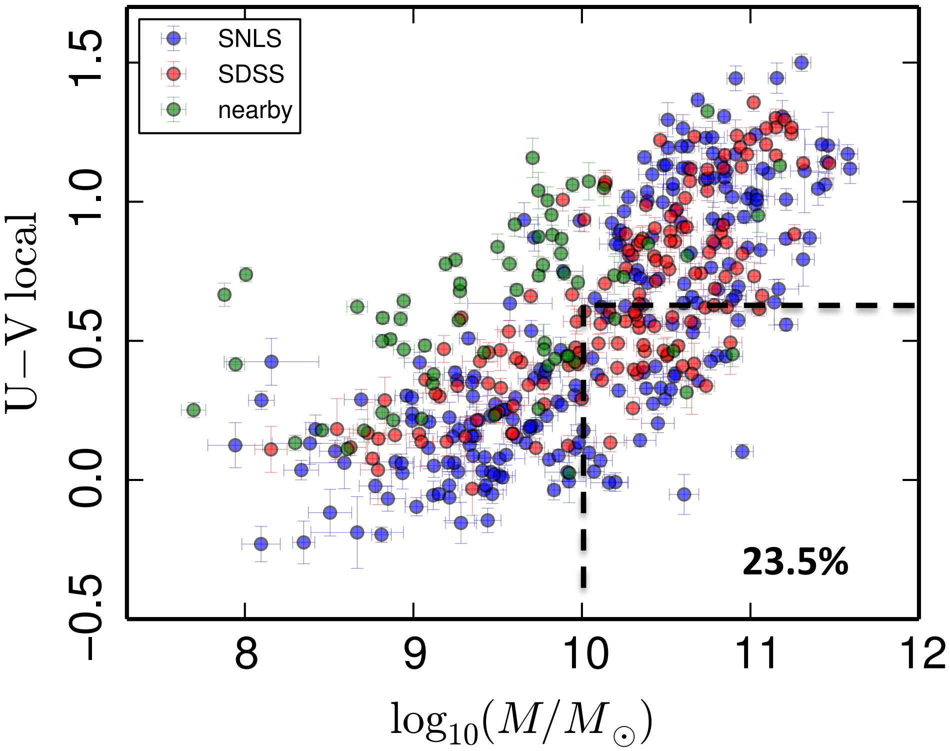


locally bluer than the host; further away from the galacitic centre

SNLS+SDSS+nearby: local vs global properties

Preliminary





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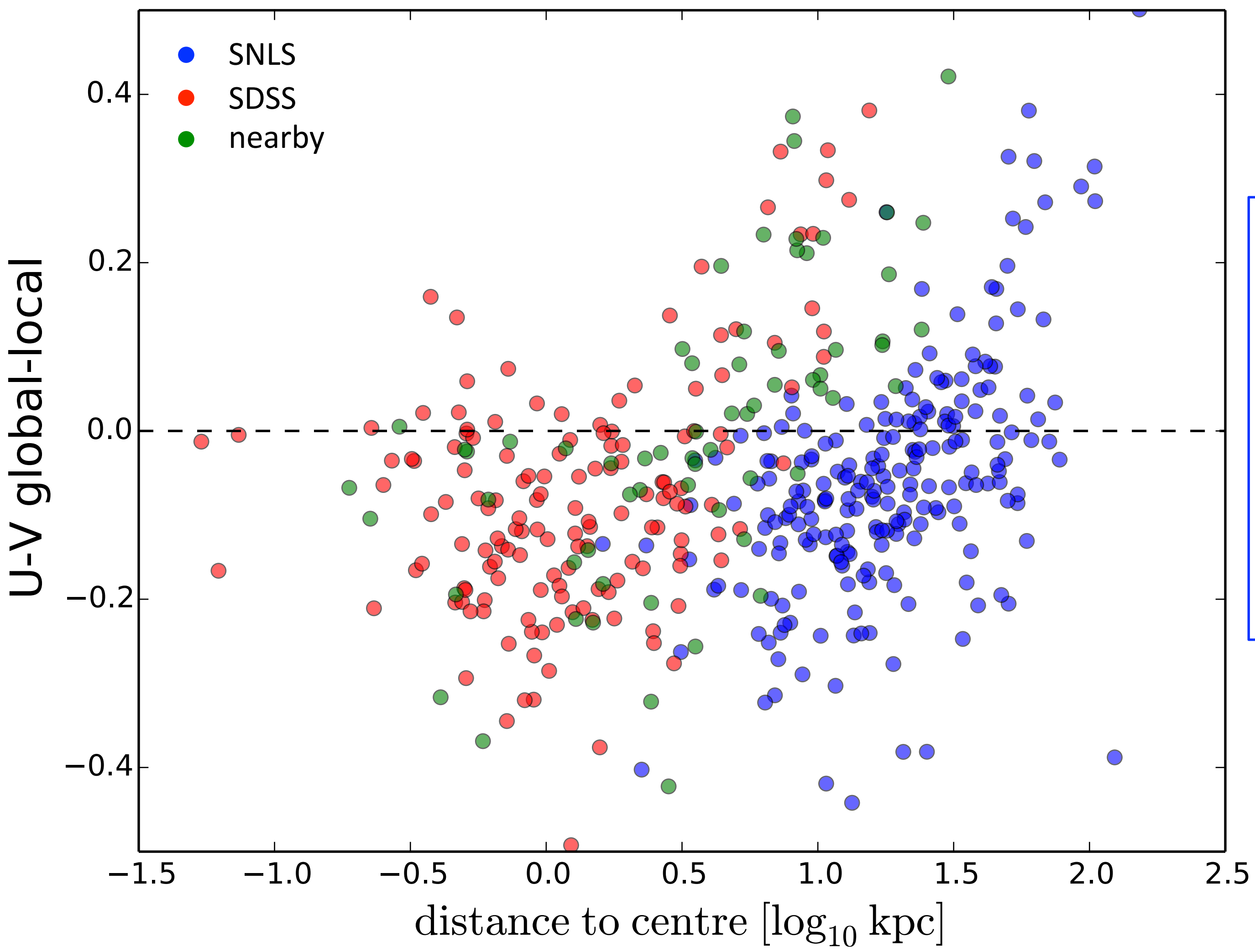
Preliminary

SNLS: local vs global properties

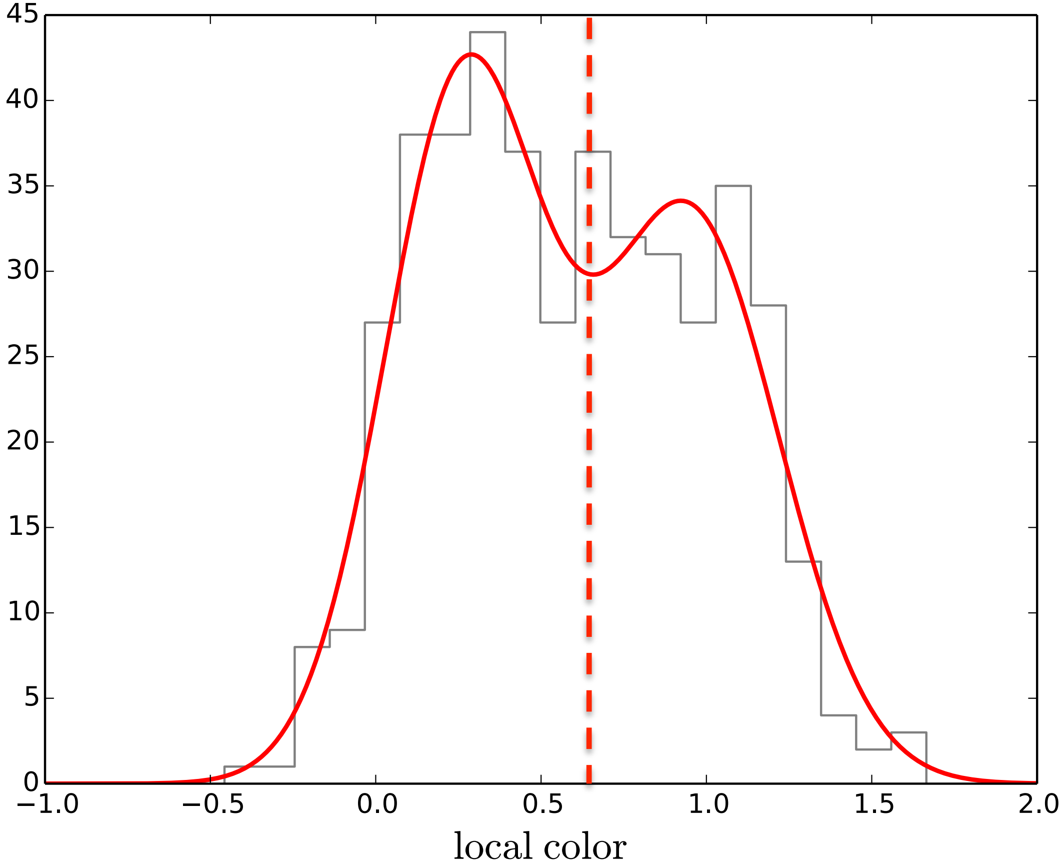


local measure bluer than global away from the centre, redder close to it

Interpolator: EXPO (with extinction)

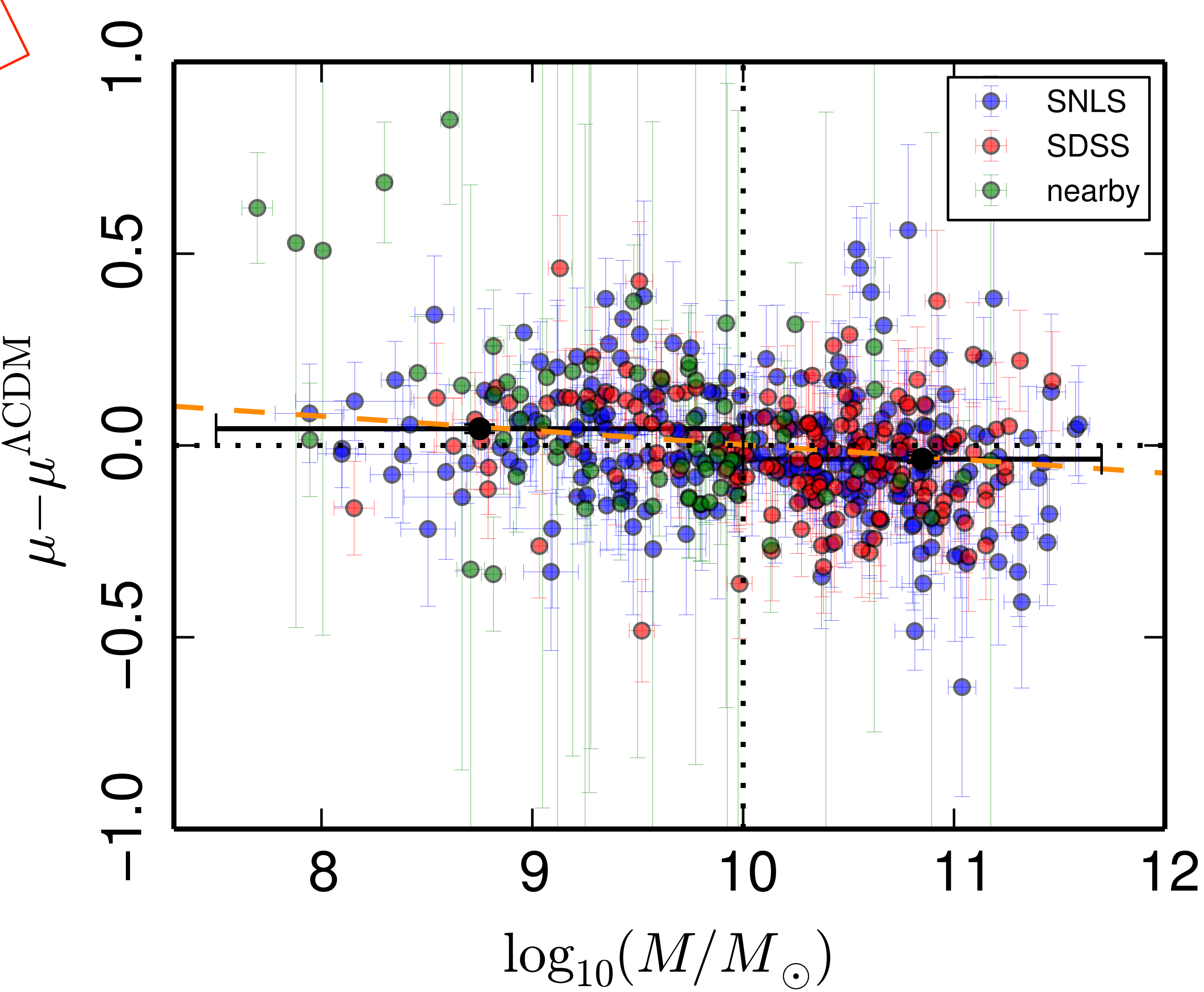
Bimodal color distribution

- fit the sum of two gaussian distributions
- find position of the trough between the peaks
- also works with global color, not with mass distribution
- $(U\text{-}V)_{local} \approx 0.65$
- $(U\text{-}V)_{global} \approx 0.67$



Correlations with residuals: stellar mass

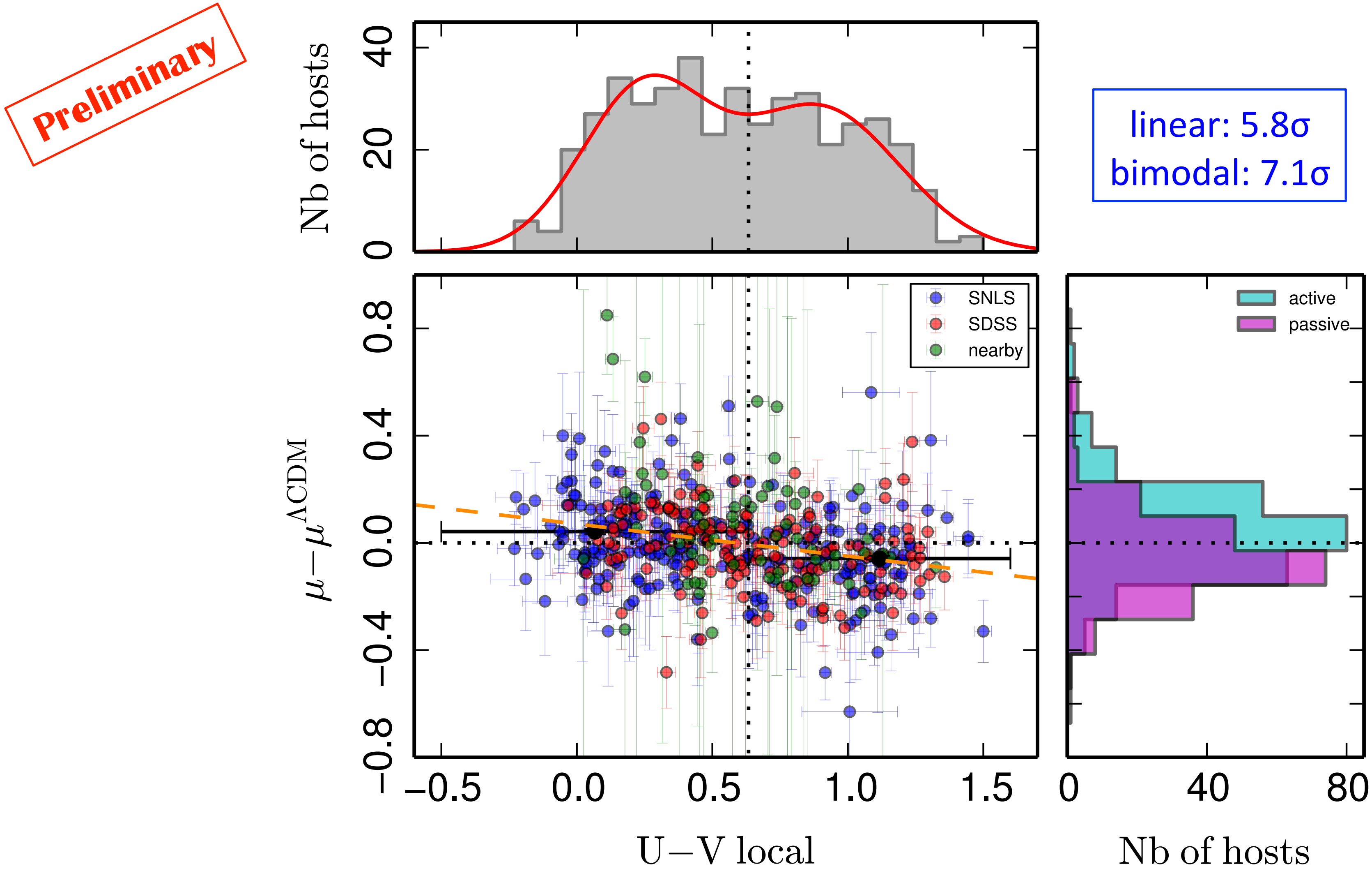
Preliminary



linear: 3.6σ
bimodal: 5.4σ

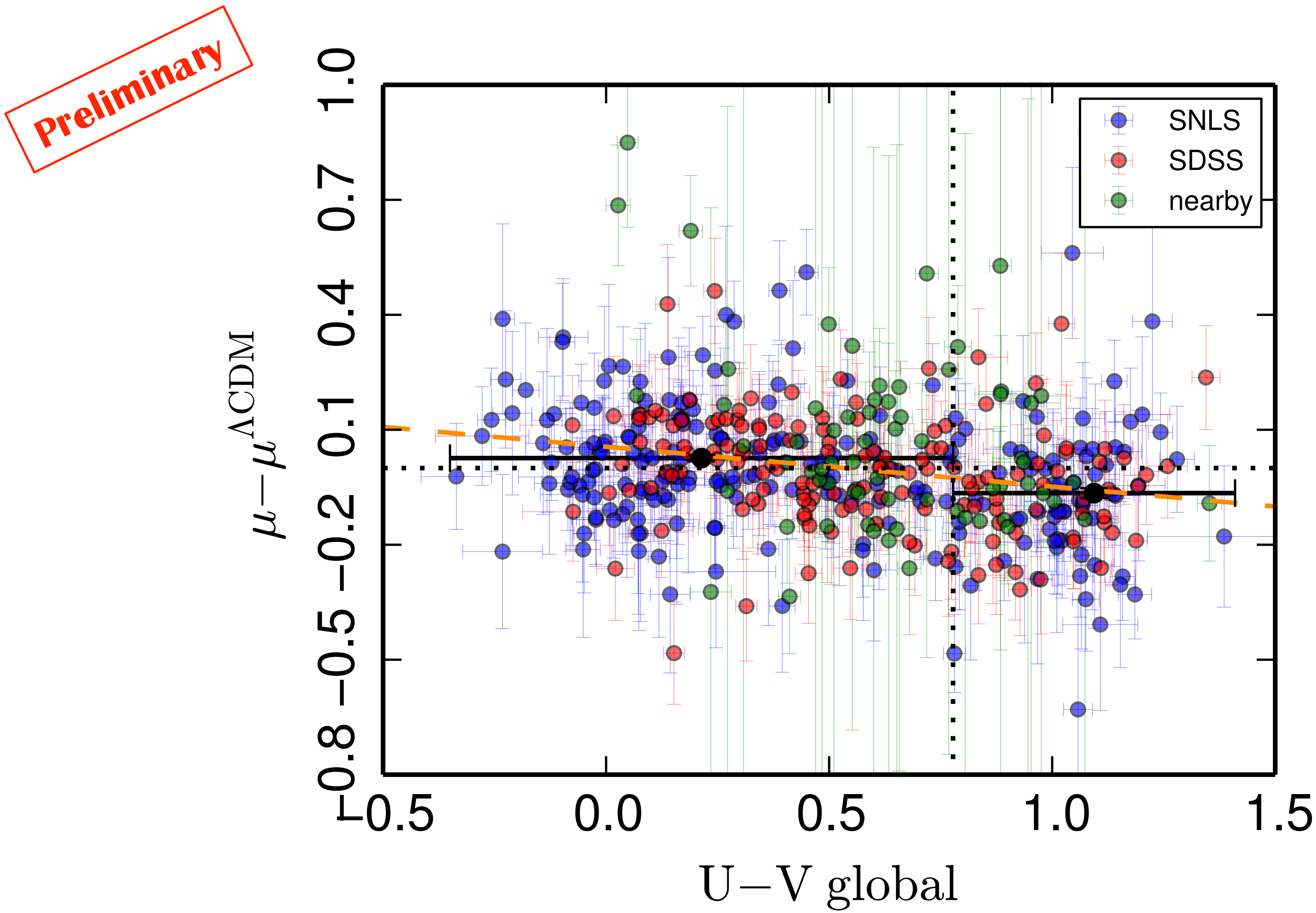
Masses: PEGASE

Correlations with residuals: local color



Interpolator: EXPO (with extinction)

Correlations with residuals: global color



linear: 5.0σ
bimodal: 5.8σ

Interpolator: EXPO (with extinction)

Conclusions & Perspectives

- We built a new technique to measure color in the local environment of SNLS5 supernovæ
- Local color is the most correlated variable to Hubble residuals in all samples
- Progress can be made:
  - with an increase of the local photometric sample (Pan-Starrs, how to deal with very low fluxes?)
- Next step:
  - impact on cosmology

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Thank you for your attention