Type Ia SNe standardization accounting for the environment

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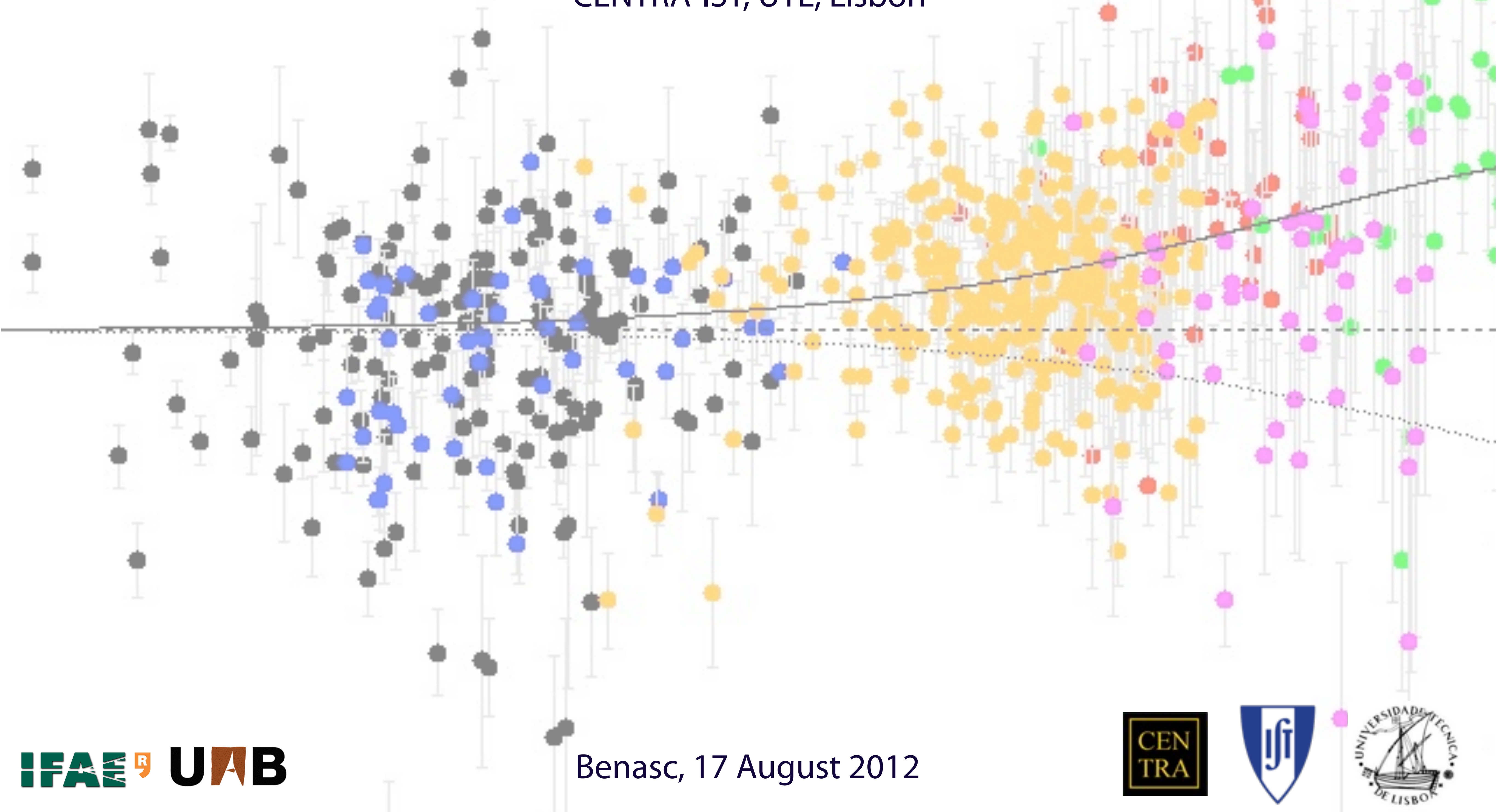

Benasc, 17 August 2012

Type Ia SNe as standard candles

- Used as a cosmological probes because of their bright peak luminosities: useful distance indicators
- Thermonuclear explosions of ~1.4 M_{SUN} C/O White Dwarfs: similar peak luminosity and homogeneous light-curves (LC).

$$\mu(z) = m(z) - M = 25 + 5\log_{10} d_L(z) \qquad d_L = \frac{c}{H_0}(1+z)\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \Omega_\Lambda}}$$

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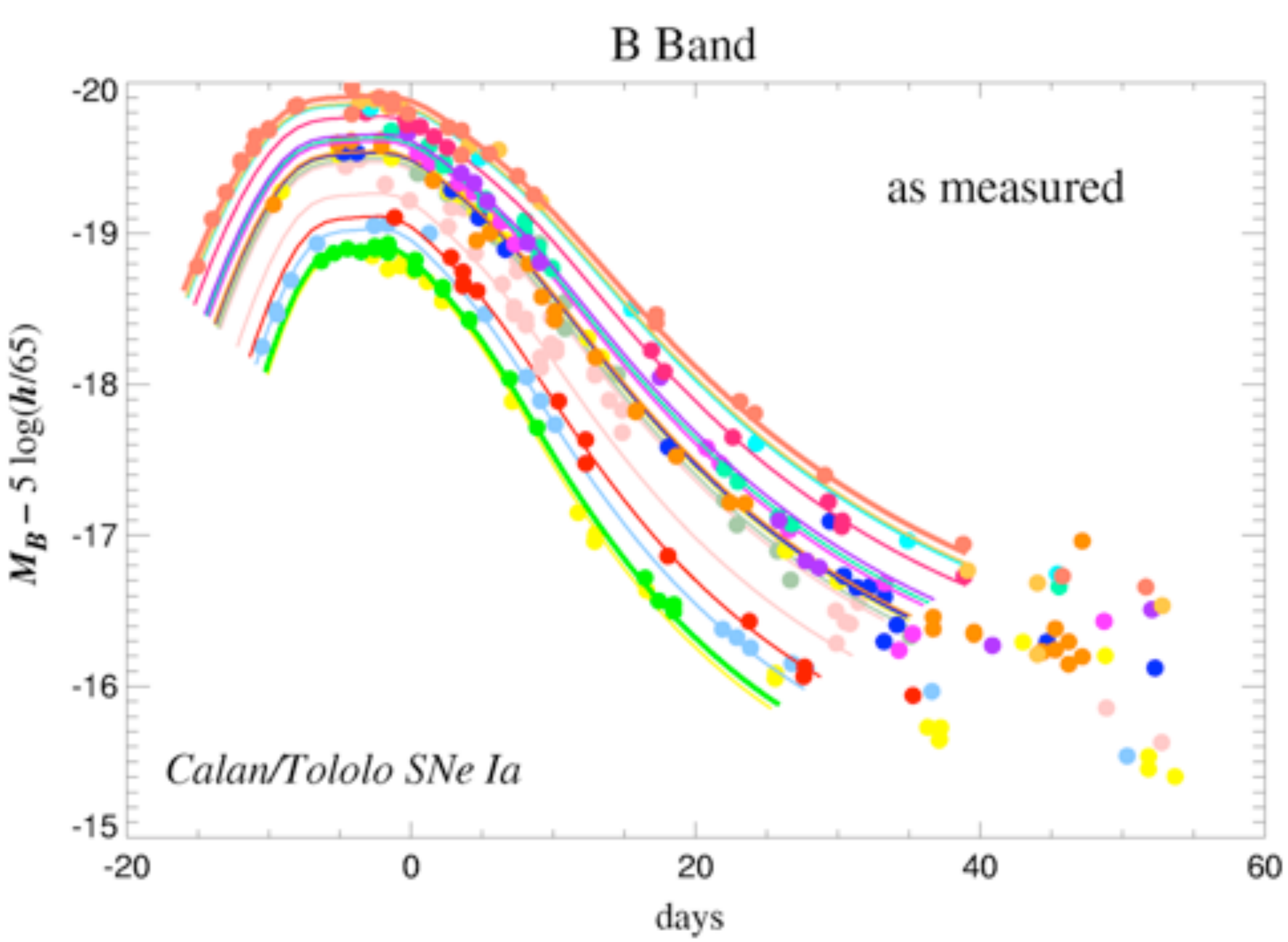


- Exact evolutionary scenario is unknown. Different populations may be present:

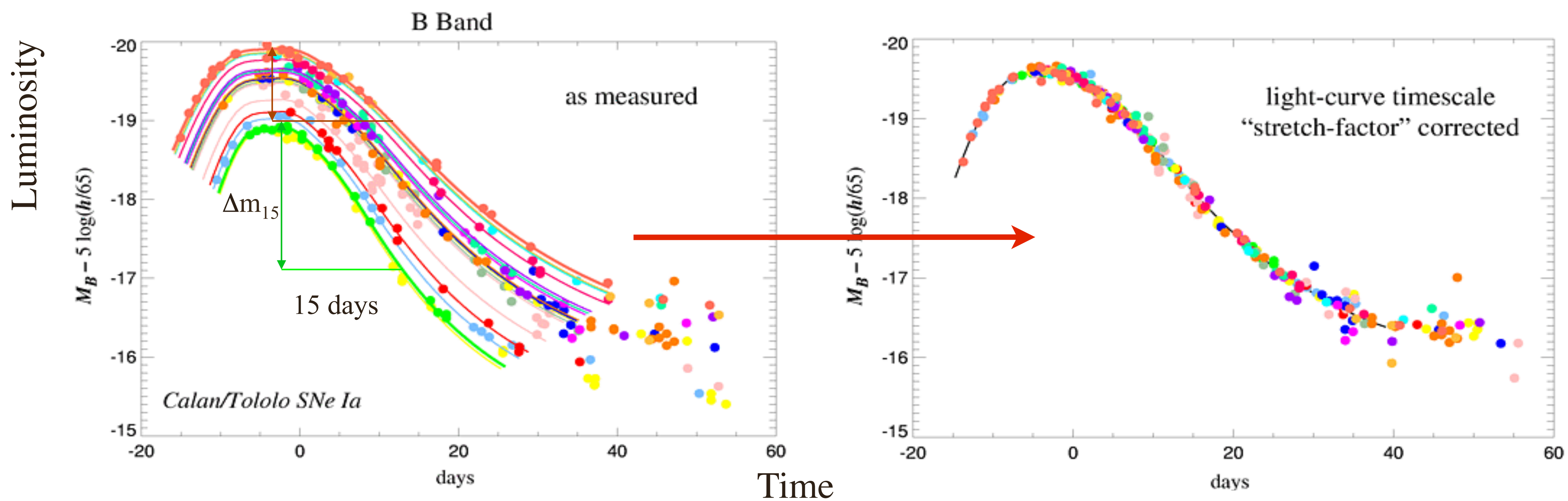
  2 channels: single degenerate (SD), double degenerate (DD)

  Details of the physics of the explosion: deflagration, detonation, velocity of the burning front, rotation...

- Progenitors can be studied only indirectly

Type Ia SNe as standard(izable) candles

- Empirical correlation between the SN peak luminosity and LC decline rate (Phillips 1993).



$$\mu(z) = m(z) - M \; +\Delta \; +A_\lambda$$

extinction

- dispersion on their corrected peak magnitude of 0.10–0.15 mag, corresponding to a precision of ~5%–7% in distance.

- Understanding systematic uncertainties in SN LC parameters can improve the determination of cosmological parameters

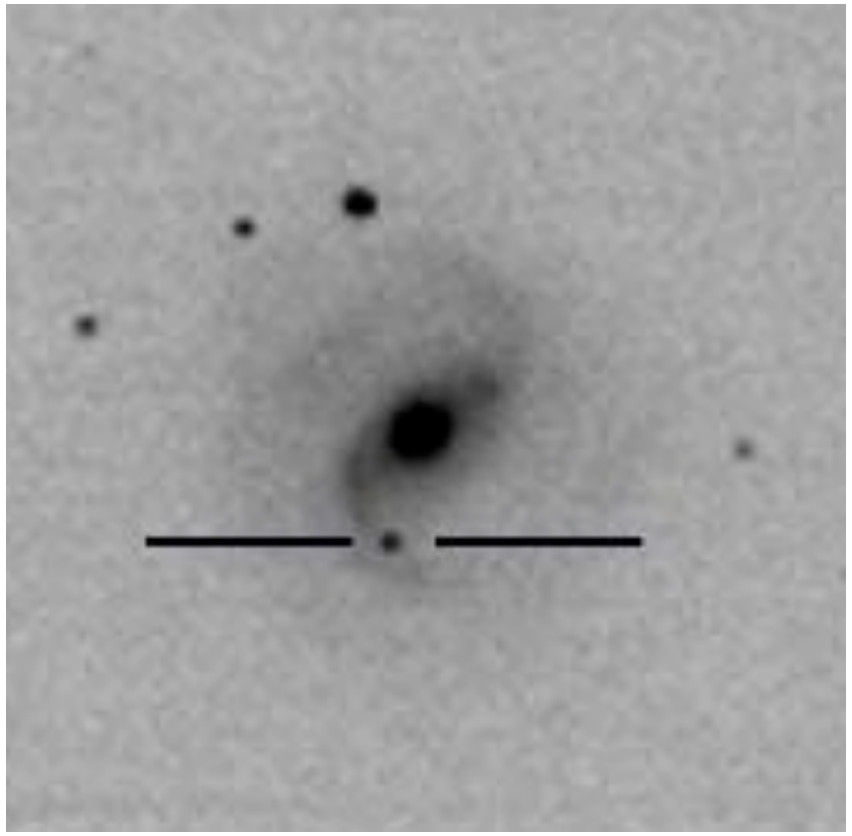
Second order corrections: Environment

Look for dependences of the SN properties on the host galaxy properties (focused on global characteristics of the host)

As they evolve with redshift, such dependences would impact the cosmological parameters

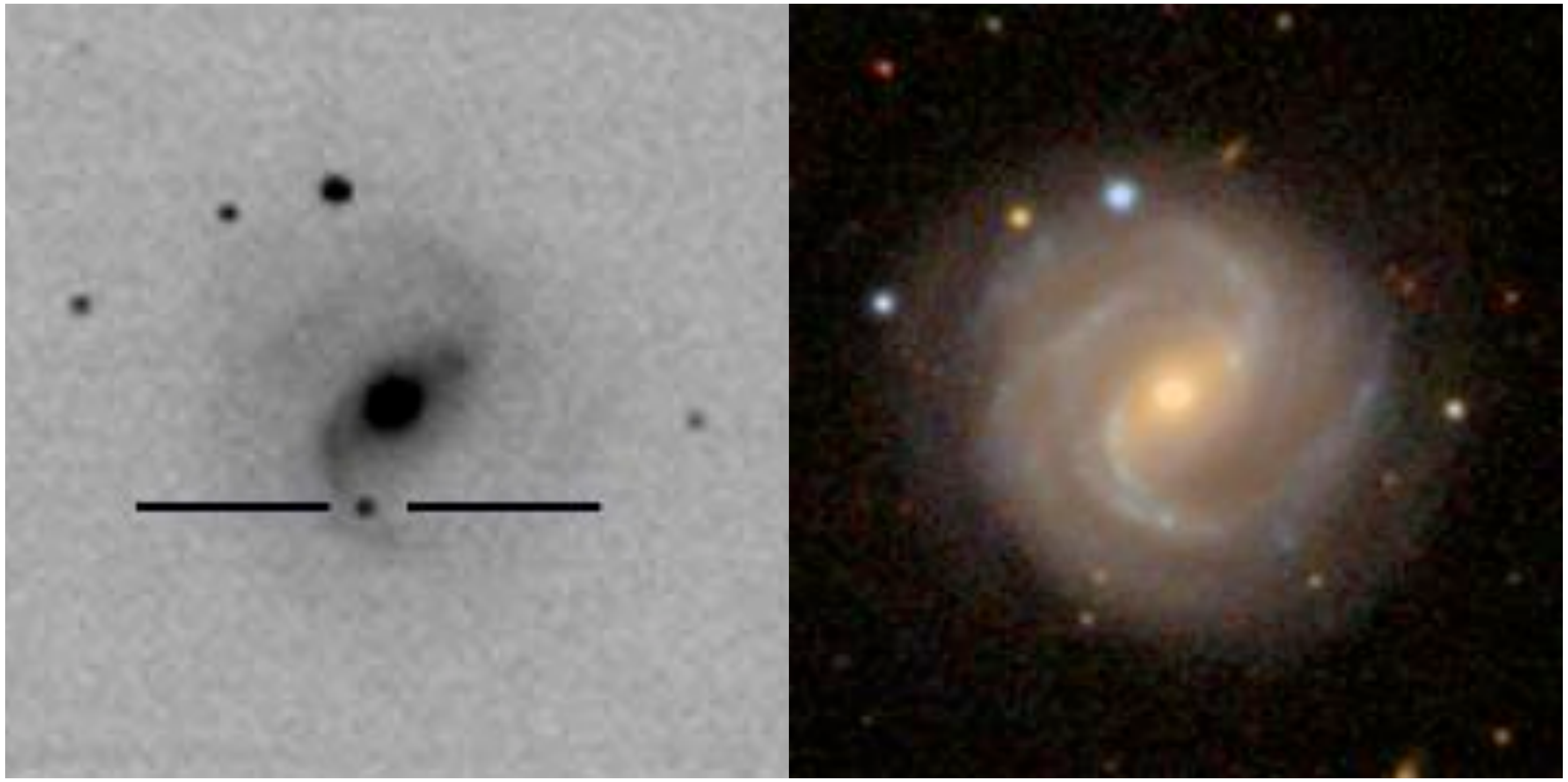
Hamuy et al. (1996)	Bright events occur preferentially in **young** stellar environments.
Hamuy et al. (2000)	Luminous SNe are produced in **metal-poor** neighborhoods
Gallagher et al. (2005)	**Age** is more likely to be the source of LC variability than **metallicity**
Sullivan et al. (2006)	Brighter events are found in systems with ongoing **star-formation**
Gallagher et al. (2008)	**Progenitor age** primarily determines the peak luminosity
Hicken et al. (2009)	SN Ia in **spiral** hosts are intrinsically fainter
Howell et al. (2009)	**more massive** progenitors give rise to more luminous explosions
Neil et al. (2009)	**Older** hosts produce less-extincted SNe Ia
Brandt et al. (2010)	Luminous SNe associated with recent **star-formation** and **young** prog.
Cooper et al. (2010)	SNIa are more luminous or more numerous in **metal-poor** galaxies
Sullivan et al. (2010)	SNIa are brighter in **massive** hosts (metal-rich) and with low **SFR**
Kelly et al. (2010)	SN Ia in physically **larger**, more **massive** hosts are ~10% brighter
Lampeitl et al. (2010)	introduce the stellar **mass** of the host in the parametrization
D'Andrea et al. (2011)	SNe are 0.1 mag brighter in **high-metallicity** hosts after corr.
Gupta et al. (2011)	**older** galaxies host SNe Ia that are brighter
Nordin et al (2011)	**passive** and **massive** galaxies host faint SNe
Konishi et al. (2011)	SNe in **metal-rich** hosts become brighter after corrections
Smith et al. (2012)	SNe rate is higher in **star-forming** galaxies

z=0.016



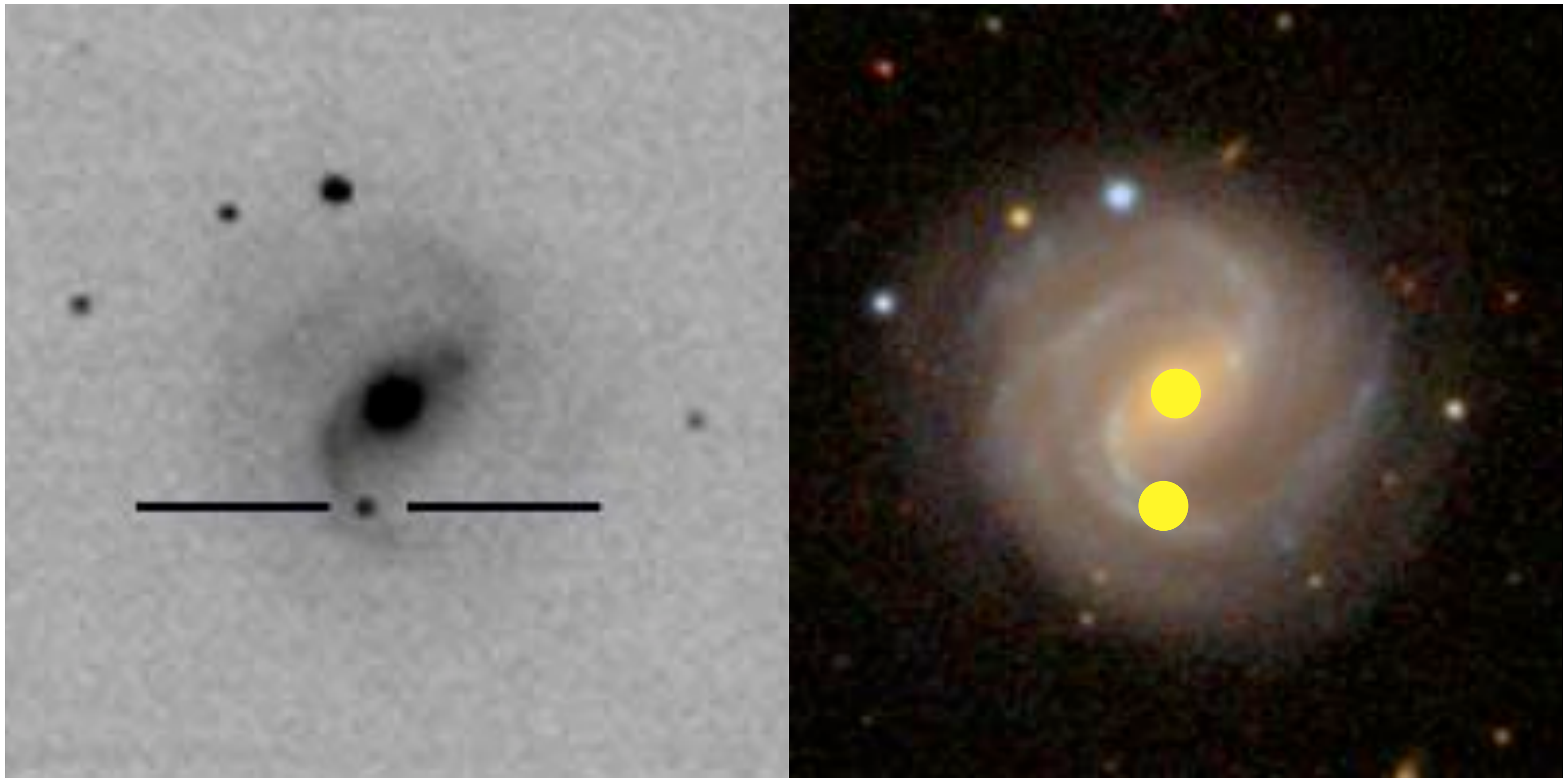
Broad-band photometry

z=0.016



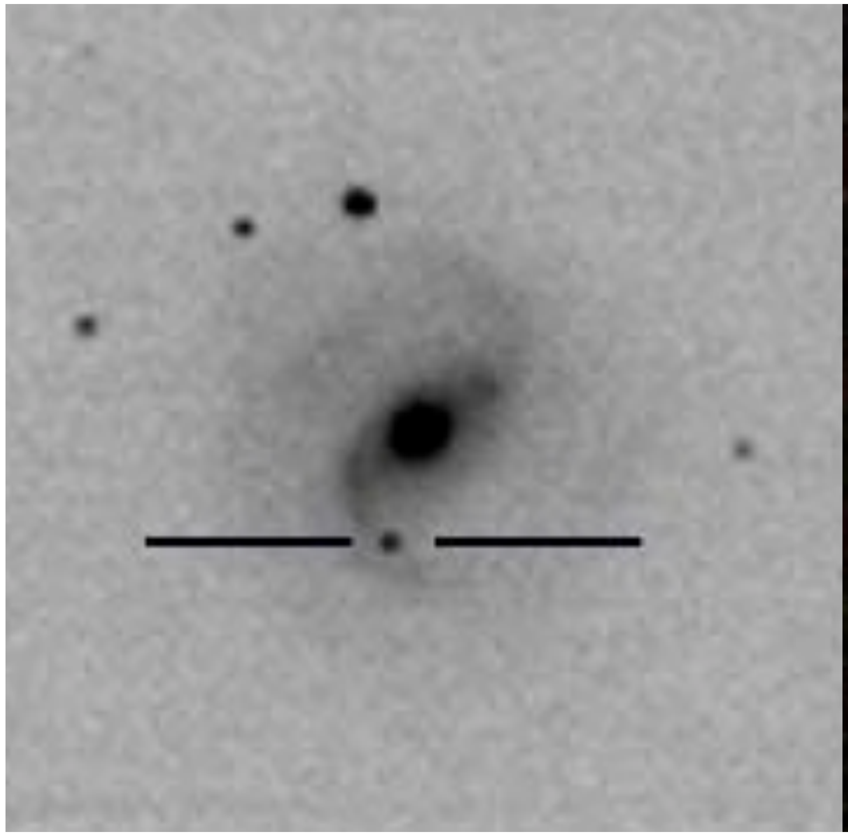
Broad-band photometry Fiber spectroscopy

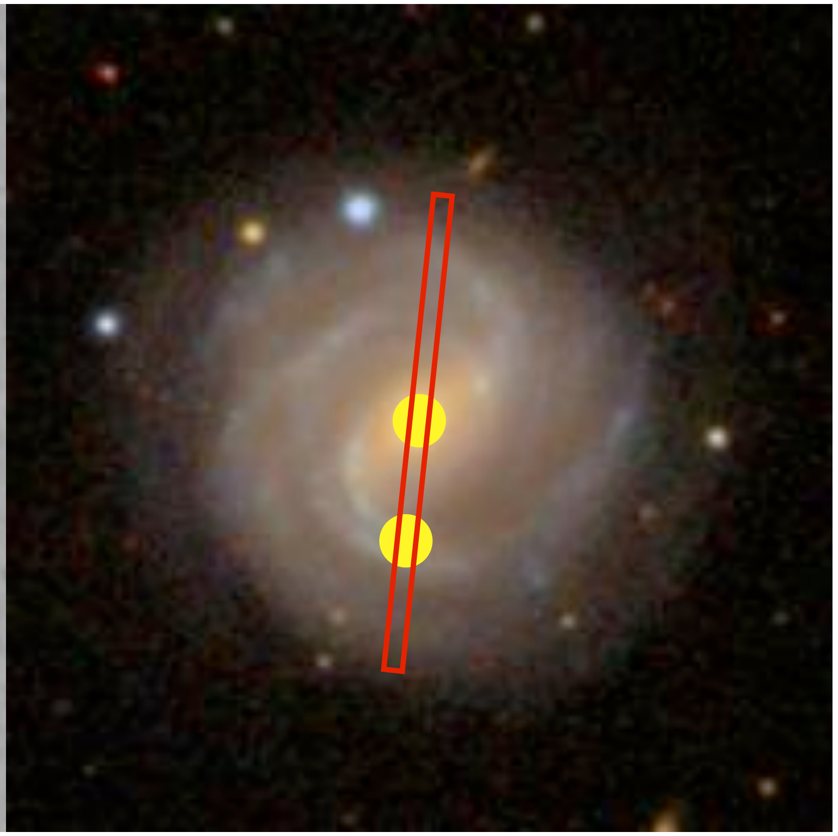
z=0.016



Broad-band photometry Fiber slit spectroscopy

z=0.016





Broad-band photometry Fiber slit spectroscopy

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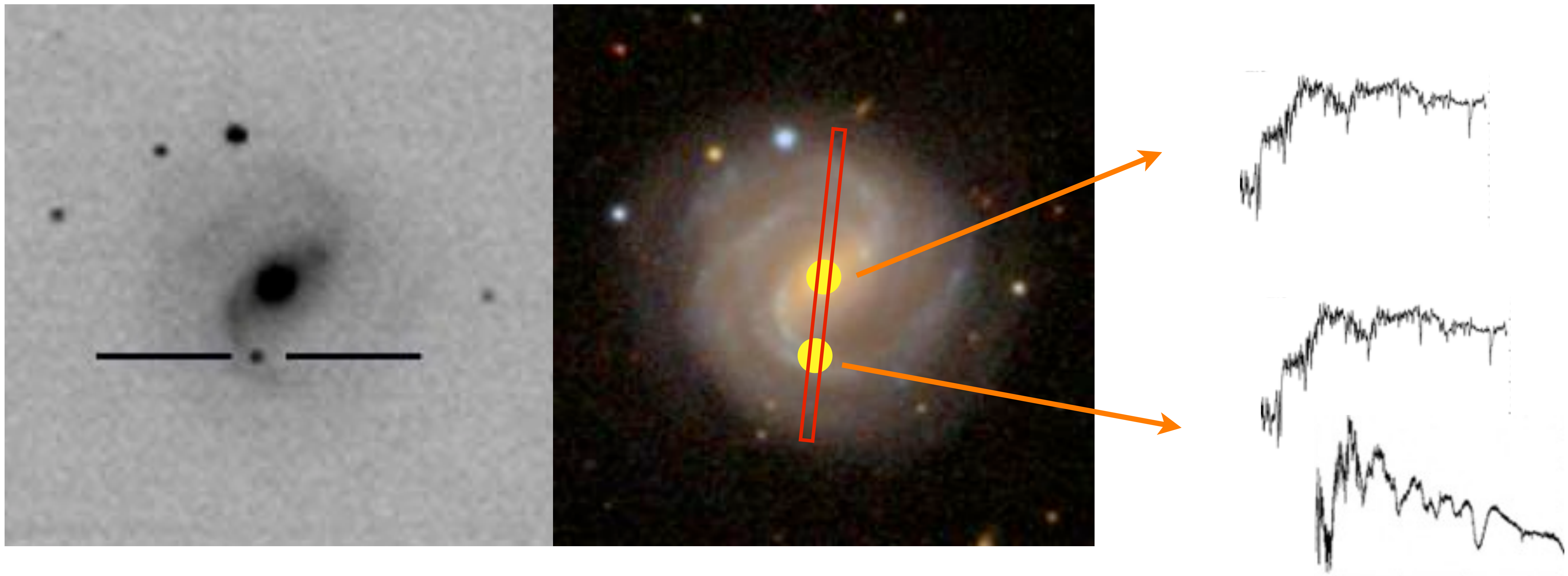
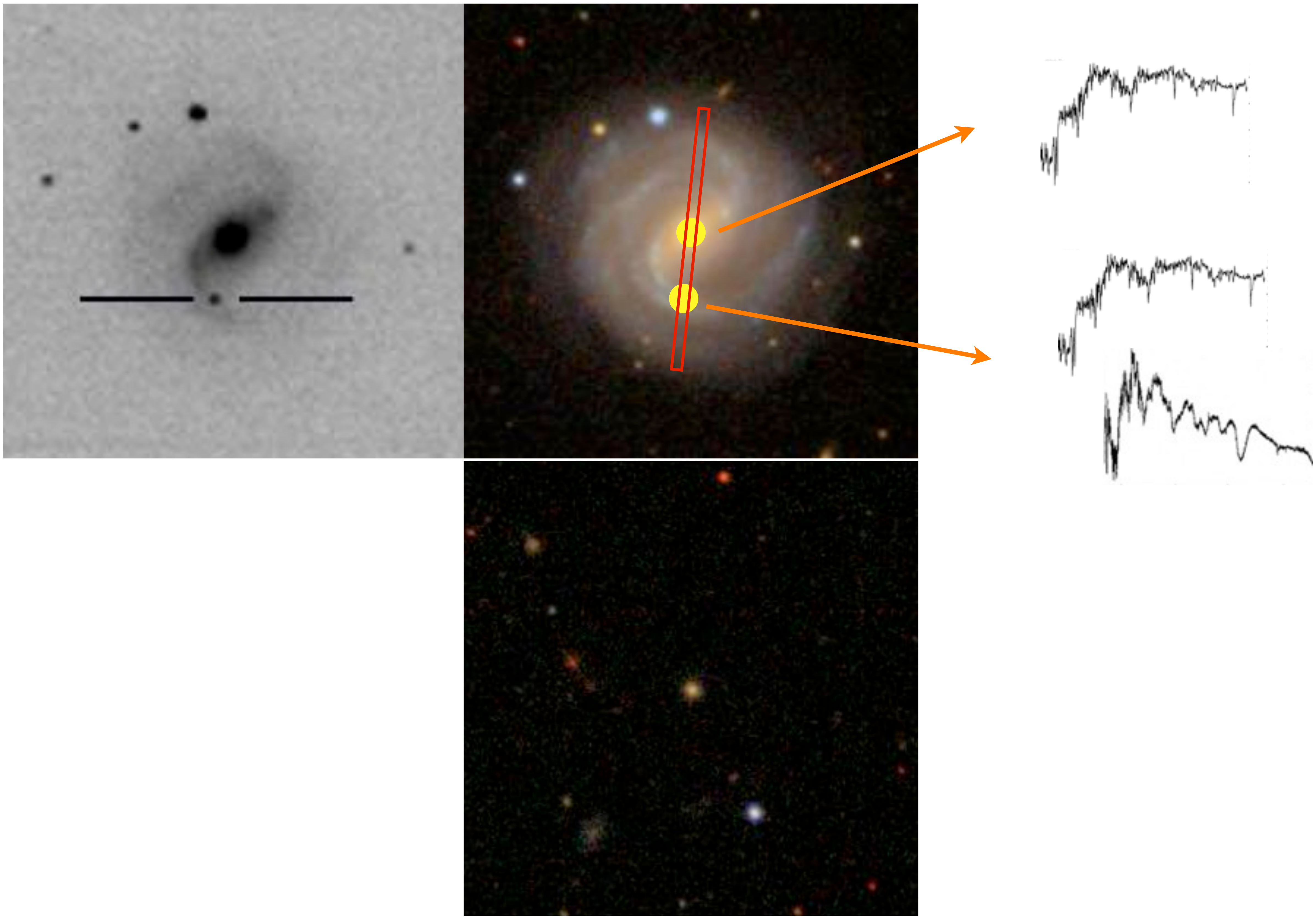
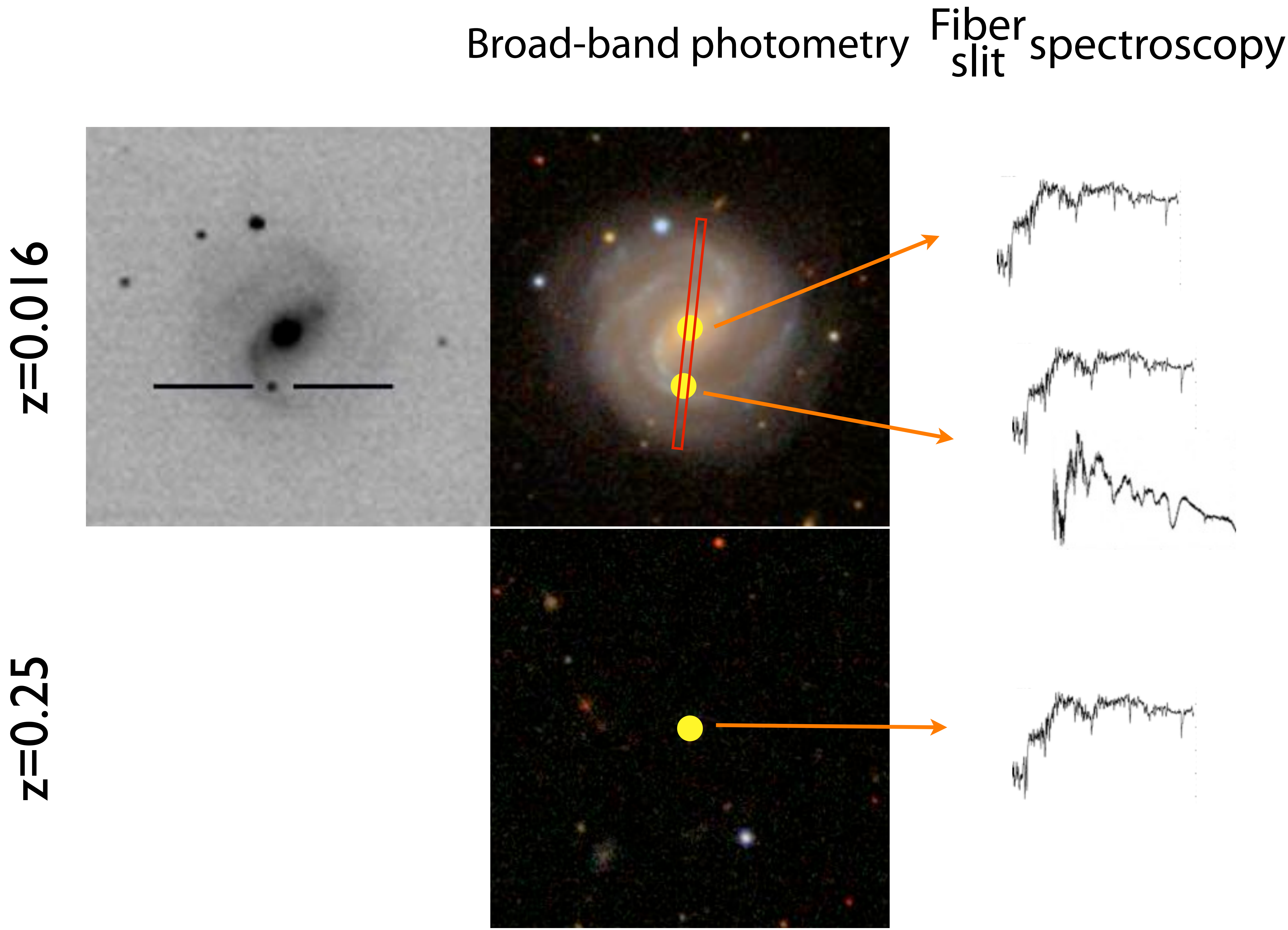


Broad-band photometry Fiber / slit spectroscopy

z=0.016

z=0.25




Broad-band photometry
Fiber
slit
spectroscopy
z=0.016
z=0.25

SNe Ia properties as a function of the GCD

The Astrophysical Journal, 755:1 (14pp), 2012 ??? doi:10.1088/0004-637X/755/1/1

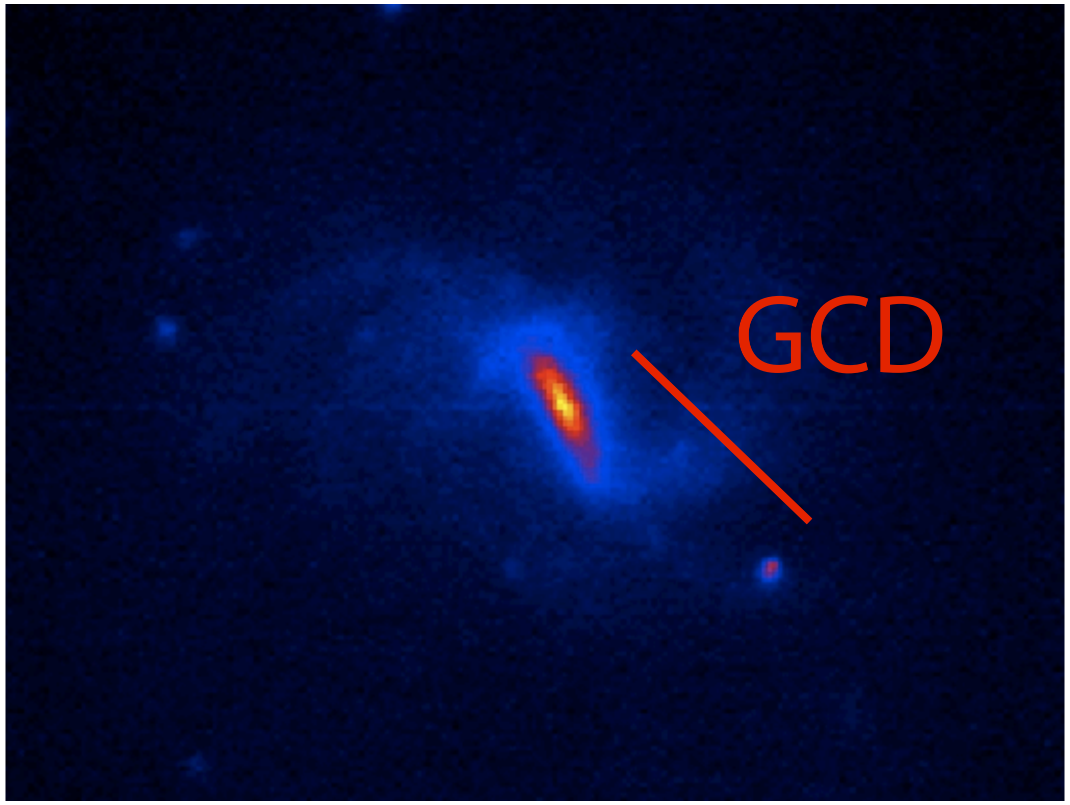
TYPE Ia SUPERNOVA PROPERTIES AS A FUNCTION OF THE DISTANCE TO THE HOST GALAXY IN THE SDSS-II SN SURVEY

Lluís Galbany[1,18], Ramon Miquel[1,2], Linda Östman[1], Peter J. Brown[3], David Cinabro[4], Chris B. D'Andrea[5], Joshua Frieman[6,7,8], Saurabh W. Jha[9], John Marriner[8], Robert C. Nichol[5], Jakob Nordin[10,11], Matthew D. Olmstead[3], Masao Sako[12], Donald P. Schneider[13,14], Mathew Smith[15], Jesper Sollerman[16], Kaike Pan[17], Stephanie Snedden[17], Dmitry Bizyaev[17], Howard Brewington[17], Elena Malanushenko[17], Viktor Malanushenko[17], Dan Oravetz[17], Audrey Simmons[17], and Alaina Shelden[17]

Galbany et al., 2012, ApJ, 755, 125

1206.2210

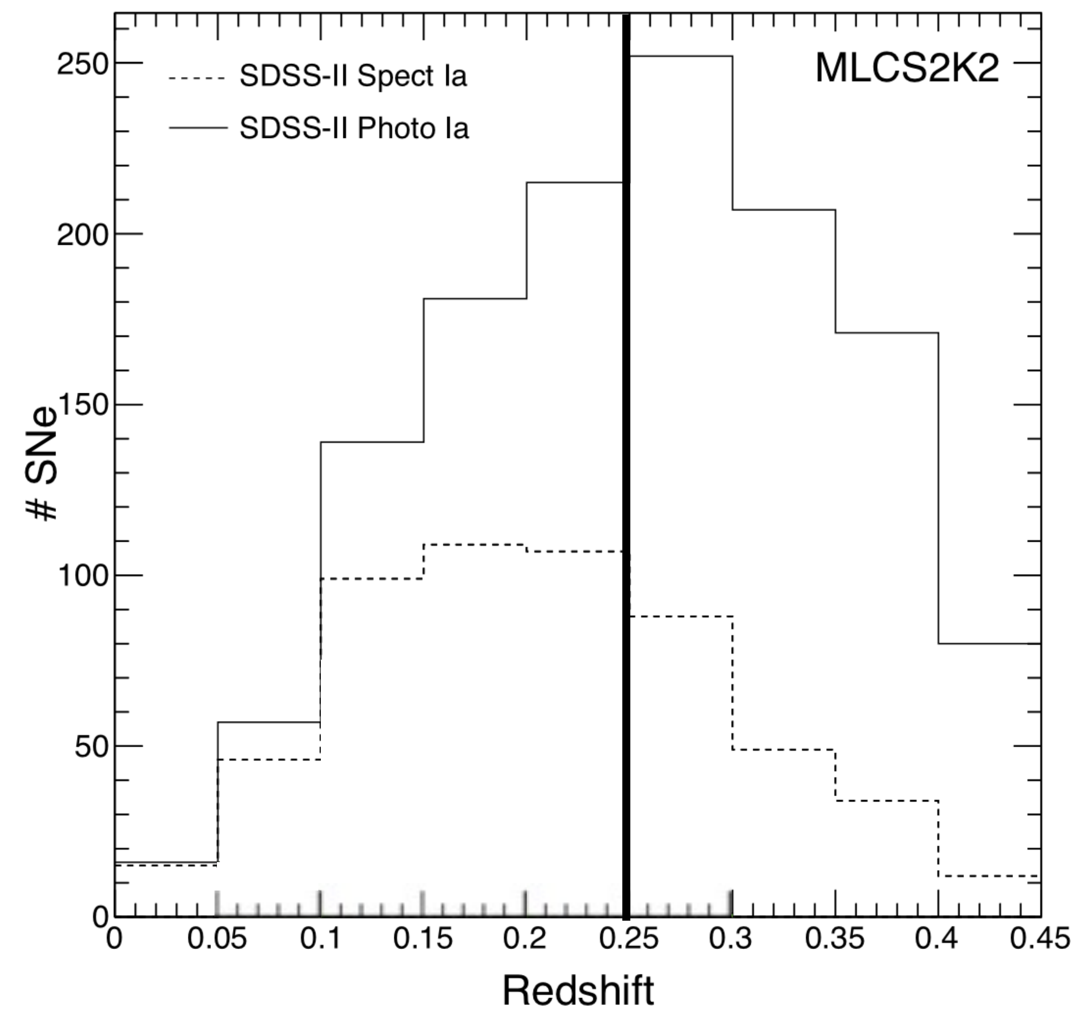
- Look for dependencies between SN Ia properties and its projected distance to the host galaxy center, using the distance as a proxy for **local** galaxy properties (star-formation rate, local metallicity, etc.).
- Use SDSS-II/SNe Survey 3-year sample
- Fit LCs using both MLCS2k2 and SALT2. Determine:
  - Color (A_V, c)
  - Decline rate (Δ, x_1)
  - Residuals in the fit to the Hubble diagram ($\delta\mu$).
- Correlate these parameters with several definitions of the distance of the SN to the center of the host galaxy



Sample

- The SDSS-II SN sample consists of 1318 SNe Ia in the range 0<z<0.45
  - 559 SNe Ia confirmed spectroscopically (*Spec-Ia* sample)
  - 759 SNe photometrically classified as Type Ia from their LCs (*Photo-Ia* sample)
- We restrict the sample to redshifts z<0.25 where the completeness is still relatively high
- The closest galaxy within an angular separation of 20" was matched using the SDSS DR7

17 no host



	Spec-Ia	Photo-Ia	Total
SN Ia sample ($z < 0.45$)	559	759	1318
Redshift < 0.25	376	232	608
Identified host galaxy	363	228	591

Light-curve fitters

- LC fitted through MLCS2k2 and SALT2. Parameters obtained:
  - LC shape (*Δ* and *x_1*)
  - SN color (*A_V* and *c*)
  - Hubble residual (μ_{MLCS} and $\mu_{SALT2}=m_B-M+\alpha x_1-\beta c$) ➞ $\delta\mu = \mu_{LC} - \mu_{TH}$

From full SDSS-II/SNe sample

$M = -19.41 \pm 0.04$
$\alpha = 0.131 \pm 0.052$
$\beta = 3.26 \pm 0.49$
ΛCDM: $\Omega_M = 0.274 = 1 - \Omega_\Lambda$

- We apply LC quality cuts *(MLCS, SALT2)*
  - 5 obs between $t_{max}-20<t_{obs}<t_{max}+$*70 (60)* days
  - 1 obs $t_{obs}<t_{max}-$ *2 (0)* days
  - 1 obs $t_{obs}>t_{max}+$*10 (9.5)* days
  - 1 obs with S/N > 5 in *gri*
  - Probability of LC fit > 0.001

- And Parameter cuts
  - $\Delta>-0.4$
  - $-4.5<x_1<2.0$
  - $-0.3<c<0.6$

	Spec-Ia		Photo-Ia		Total	
	MLCS	SALT2	MLCS	SALT2	MLCS	SALT2
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LC quality cuts	228	217	115	125	343	342
LC parameter cuts	203	209	110	111	313	320

Galactocentric distances (GCD)

- Measurement of the angular separation (θ) between the host galaxy center and the SN, and physical (projected) distance using z

$$d_A = \frac{c}{H_0}\frac{1}{(1+z_{host})}\int_0^{z_{host}}\frac{dz'}{\sqrt{\Omega_M(1+z')^3+\Omega_\Lambda}}$$

$$PGCD = d_A \times \theta$$

$$H_0 = 70.4 \pm 1.4 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

- Due to different sizes of the host galaxies we use 3 distance normalization methods to allow comparisons

  - Petrosian radius 50 (P50): radius of a circle that contains 50% of the galaxy flux
  - Sérsic profile (SER): distance to the center of the ellipse containing half the luminosity
    - de Vaucouleurs (DEV) profile (n=4, for ellipticals)
    - exponential (EXP) profile (n=1, for spirals)

$$I(r) = I_0 \exp\left[-a_n(r/r_e)^{1/n}\right]$$

  - Isophotal ellipse (ISO): distance to the center of the ellipse containing 25 mag/arcsec^2

- We then apply cuts on distance measurements:
  - $\sigma(\theta) < 0.5''$
  - $\sigma(PGCD) < 1$kpc
  - $\sigma(R) < 0.5''$
  - $\sigma(R)/R < 1$
  - NGCD ≡ θ/R < 10

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	MLCS	SALT2	MLCS	SALT2	MLCS	SALT2
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Distance cuts	171	177	95	94	266	271

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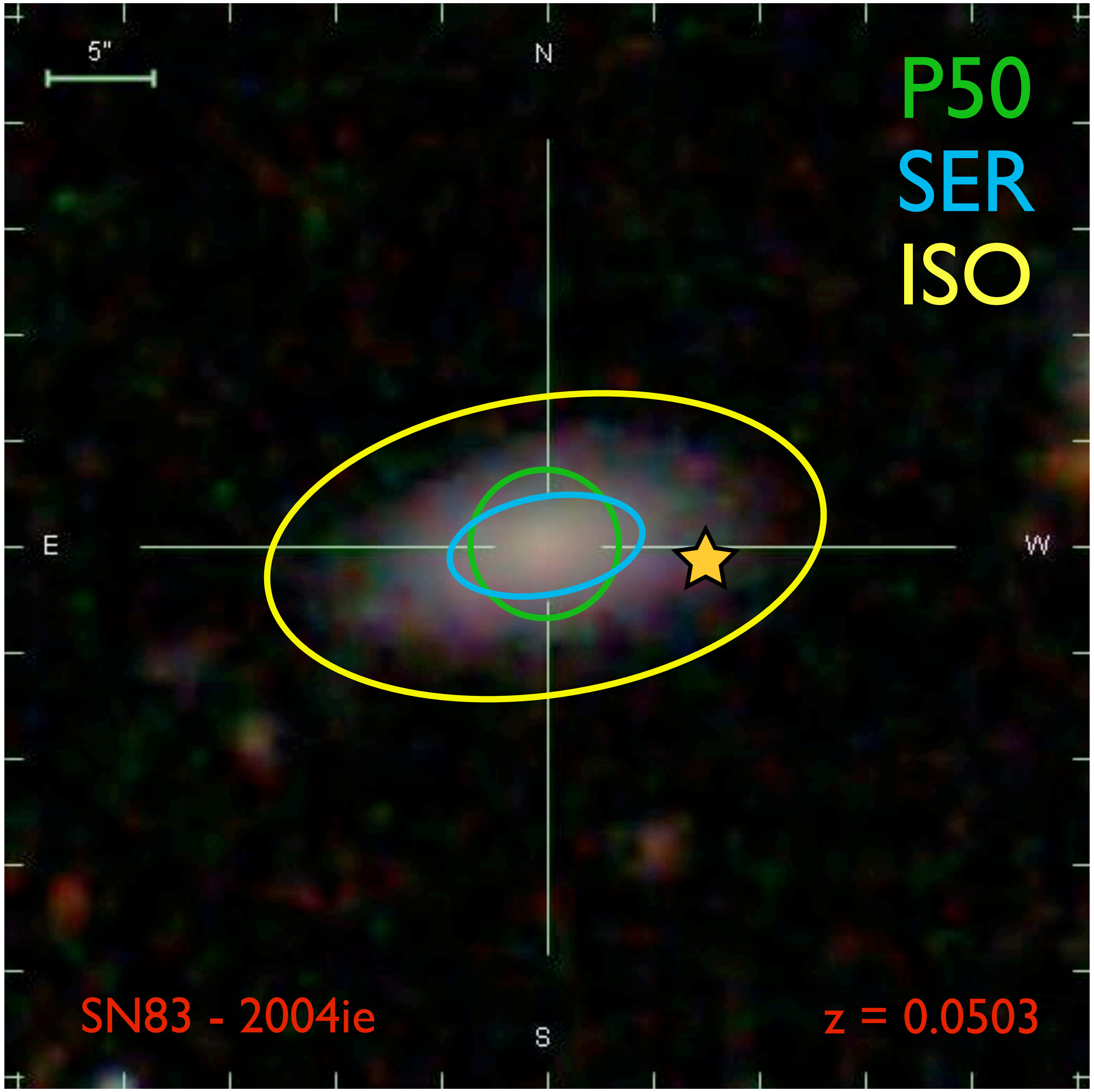
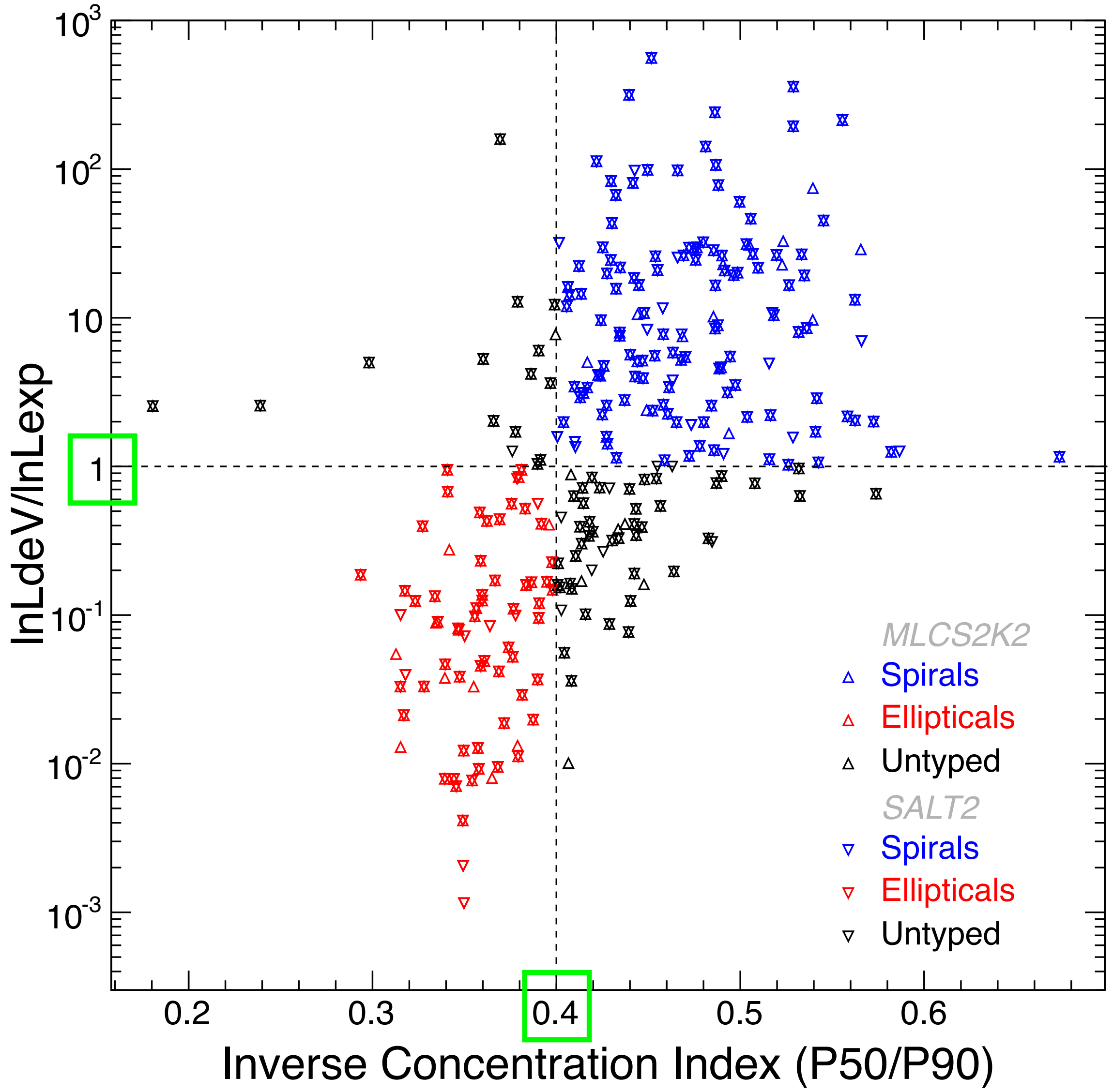


d_{kpc} = 7.293 ± 0.162
d_{P50} = 2.137 ± 0.032
d_{SER} = 1.754 ± 0.033
d_{ISO} = 0.307 ± 0.003

Host typing

- 2 criteria used in order to separate the hosts in elliptical and spiral
  - Inverse concentration index (P50/P90)
  - Best brightness profile fit (DEV/EXP)
- Selection made on agreement on both criteria



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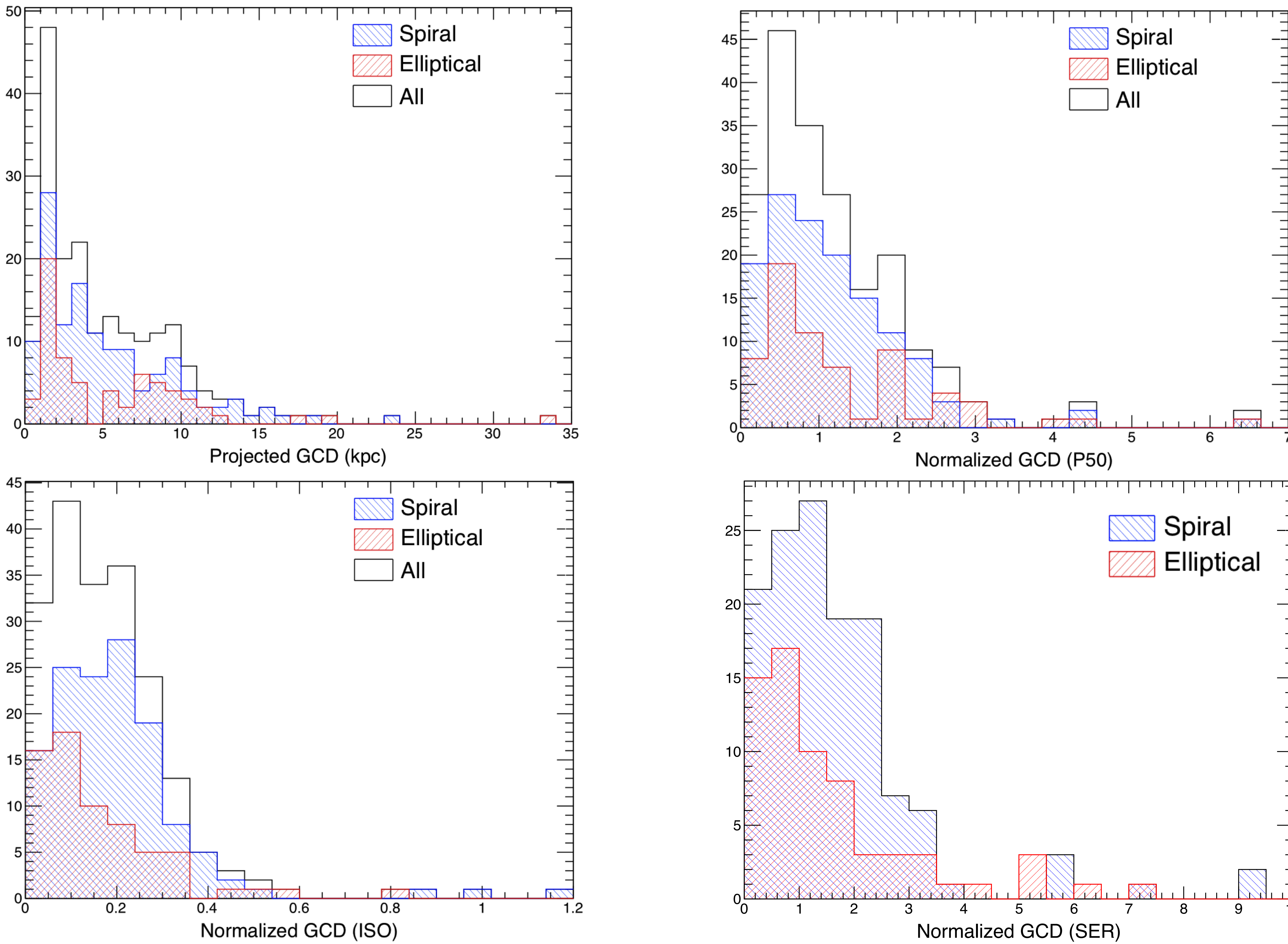
Consistent host type	128	132	64	65	192	197

MLCS: 127 spirals
65 ellipticals

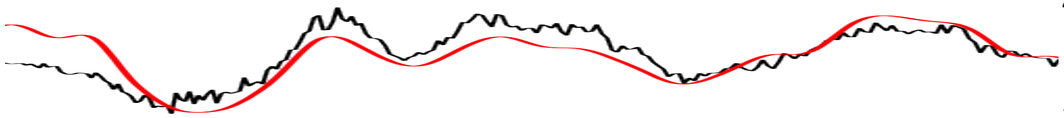
SALT2: 131 spirals
66 ellpiticals

GCD distributions

(SALT2 plots)



Distributions



- $\langle c\rangle_{ell} = 0.015 \pm 0.013$

  $\langle c\rangle_{spi} = 0.043 \pm 0.011$
- $\langle AV\rangle_{ell} = 0.252 \pm 0.031$

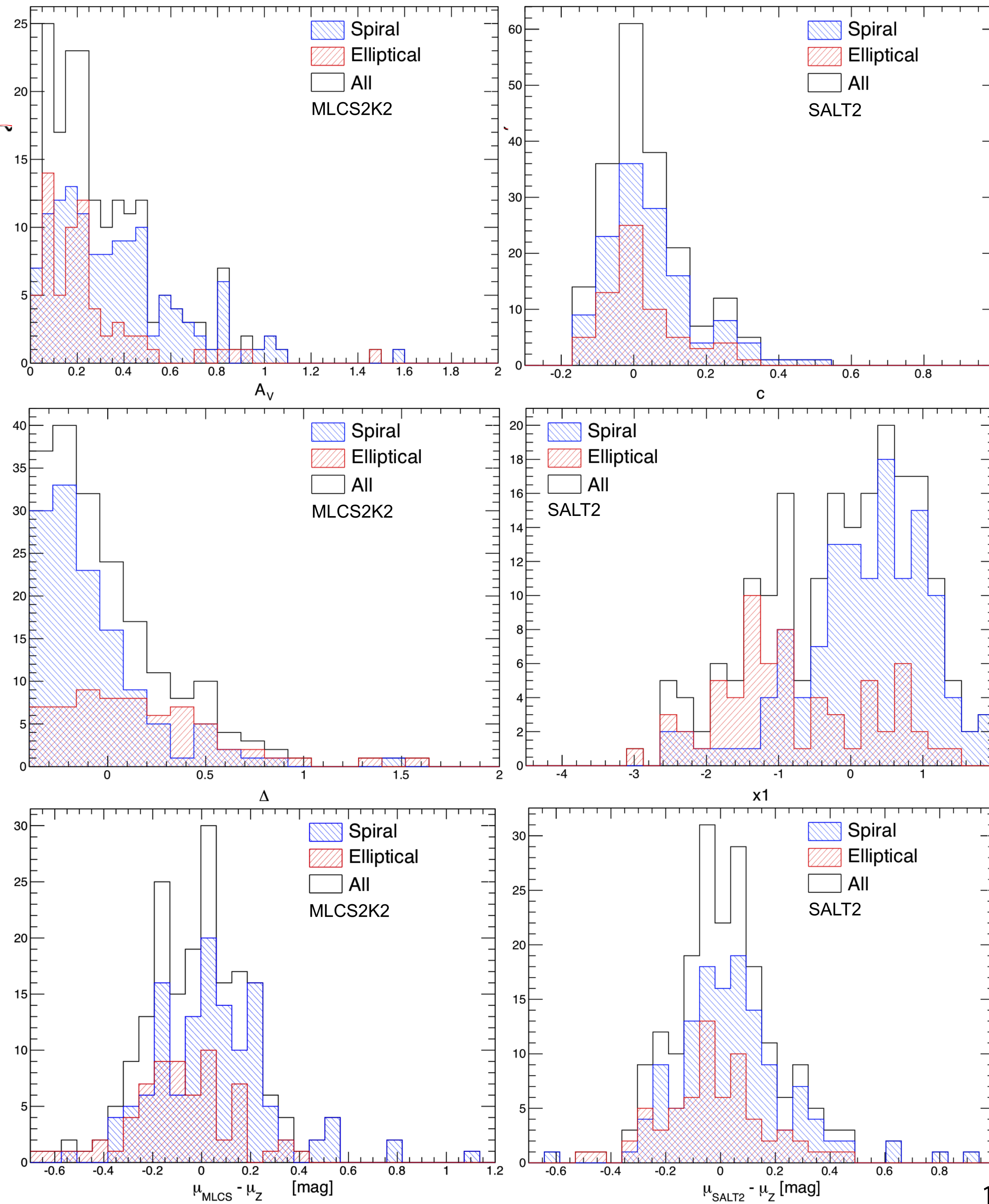
  $\langle AV\rangle_{spi} = 0.363 \pm 0.024$
- $\langle \Delta\rangle_{ell} = 0.162 \pm 0.049$

  $\langle \Delta\rangle_{spi} = -0.078 \pm 0.031$
- $\langle x1\rangle_{ell} = -0.780 \pm 0.129$

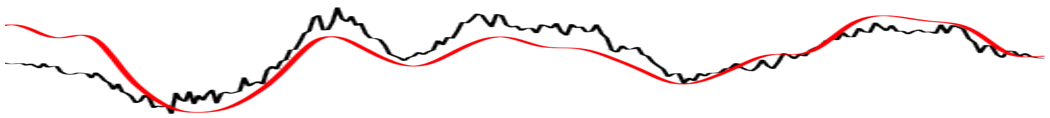
  $\langle x1\rangle_{spi} = 0.189 \pm 0.080$
- $\langle \delta\mu_{MLCS}\rangle_{ell} = -0.093 \pm 0.026$

  $\langle \delta\mu_{MLCS}\rangle_{spi} = 0.051 \pm 0.022$
- $\langle \delta\mu_{SALT2}\rangle_{ell} = -0.025 \pm 0.023$

  $\langle \delta\mu_{SALT2}\rangle_{spi} = 0.048 \pm 0.019$



Distributions



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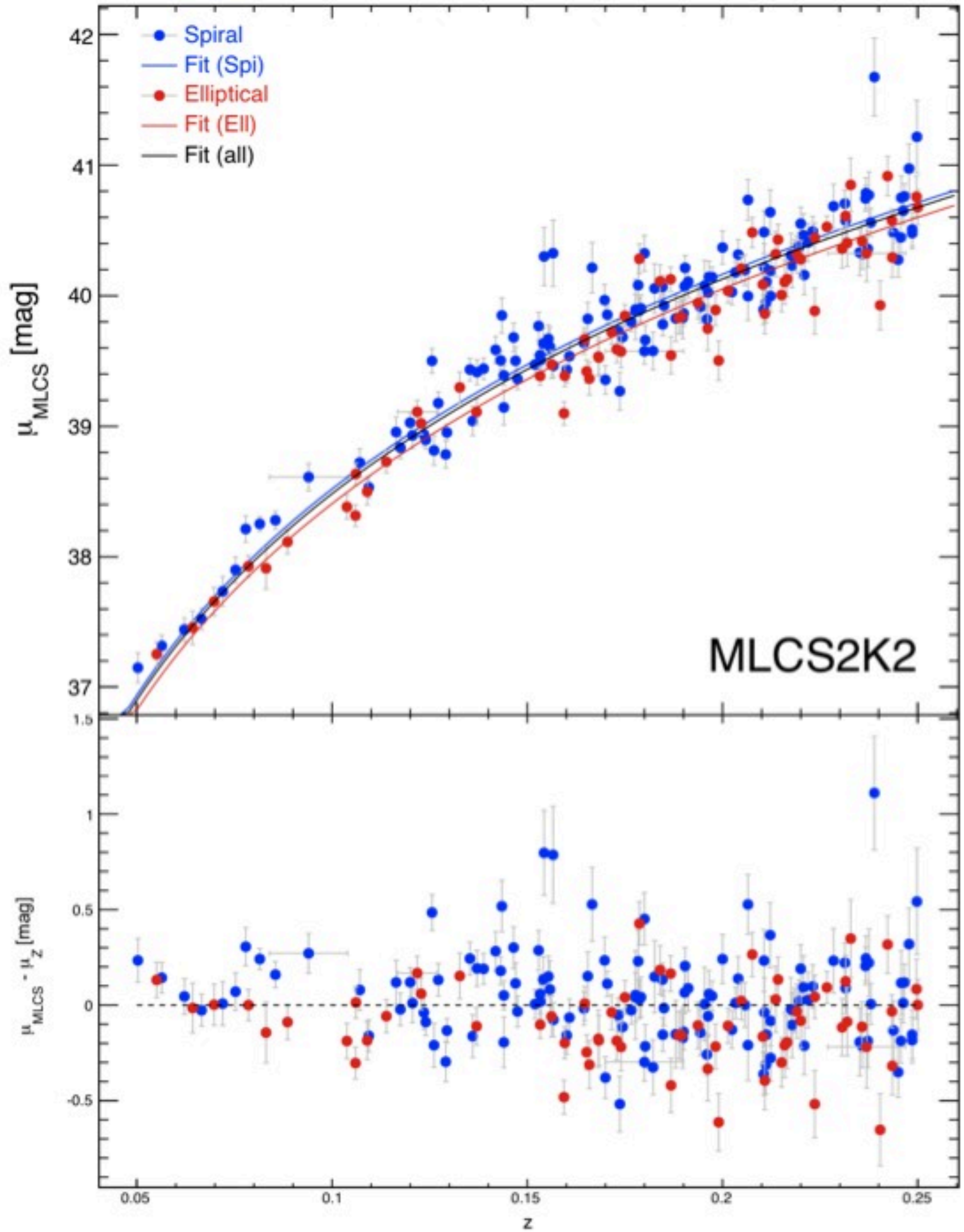


Analysis procedure

bin width	
PGCD	0.5 kpc
P50	0,25
SER	0,25
ISO	0,05

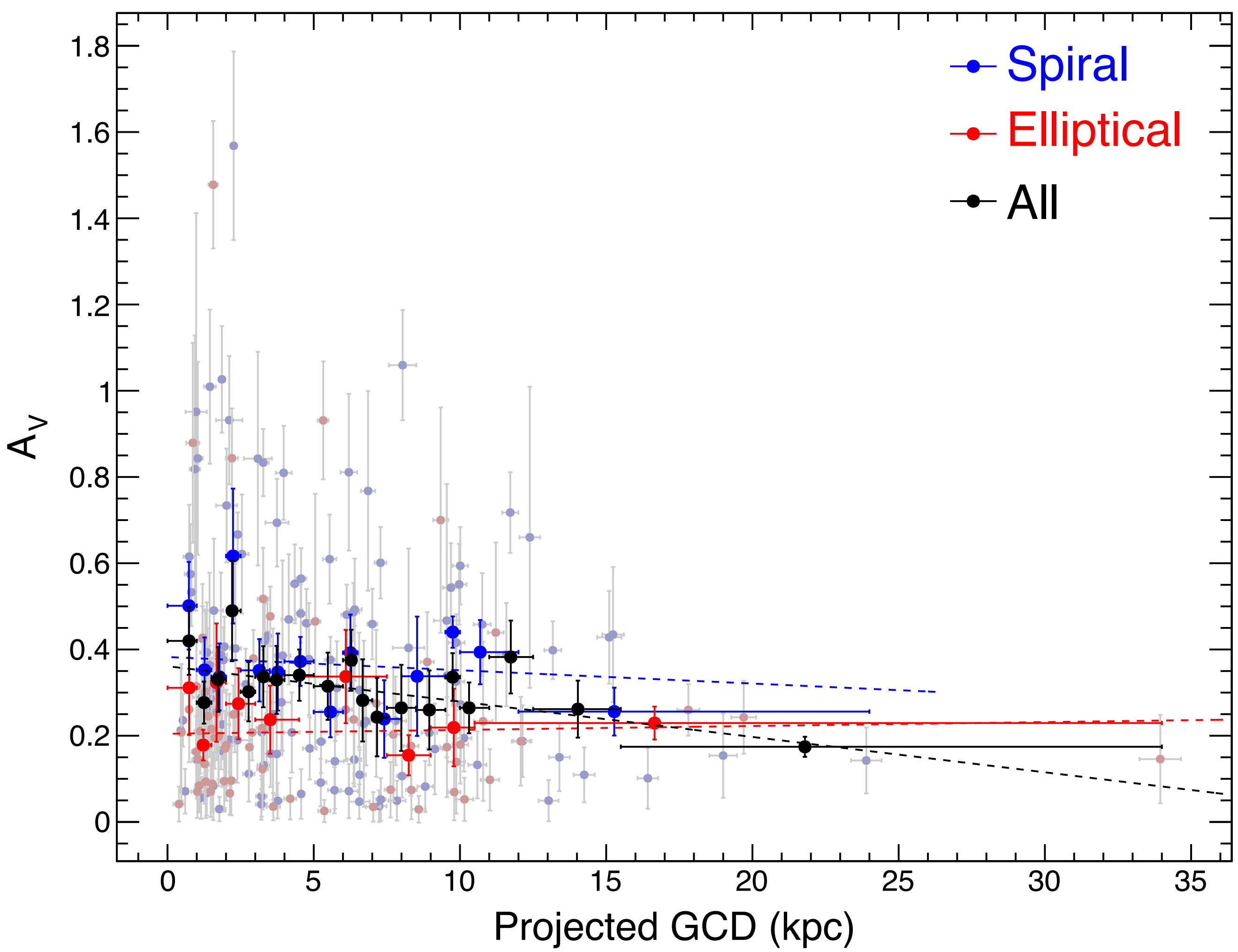
- We correlate A_V, Δ, c, x_1 and Hubble residuals with the PGCD and the 3 normalized distances

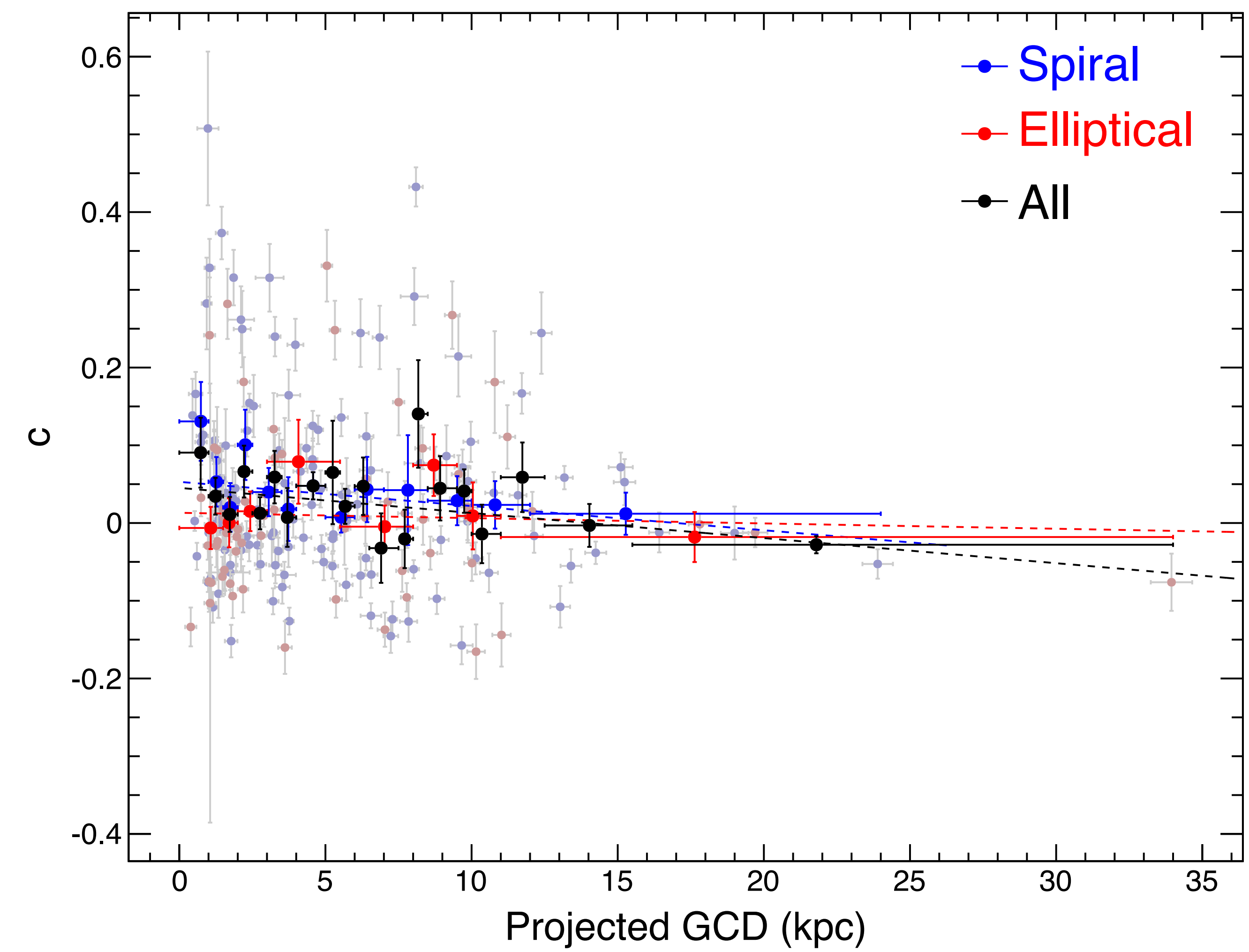
- For every combination of LC parameter and distance measurement, SNe are binned in distance (at least 5 SNe per bin, or joined), for all the SNe, and separating host types
  - Measurement of the mean value in each bin, for both LC parameter and distance
  - Linear fit of all the SNe, and separating host types
    - Compute reduced χ^2 and significance of the slope are calculated
  - We focus on results with slope different from 0 with more than 2σ significance and reduced $\chi^2 < 2$

- We also split the sample in 2 bins (Near-Far) with same #SNe in each bin
  - Measurement of the mean and the scatter, and calculate the significance in the difference between the 2 bins
  - We focus on results with a difference with more than 2σ significance

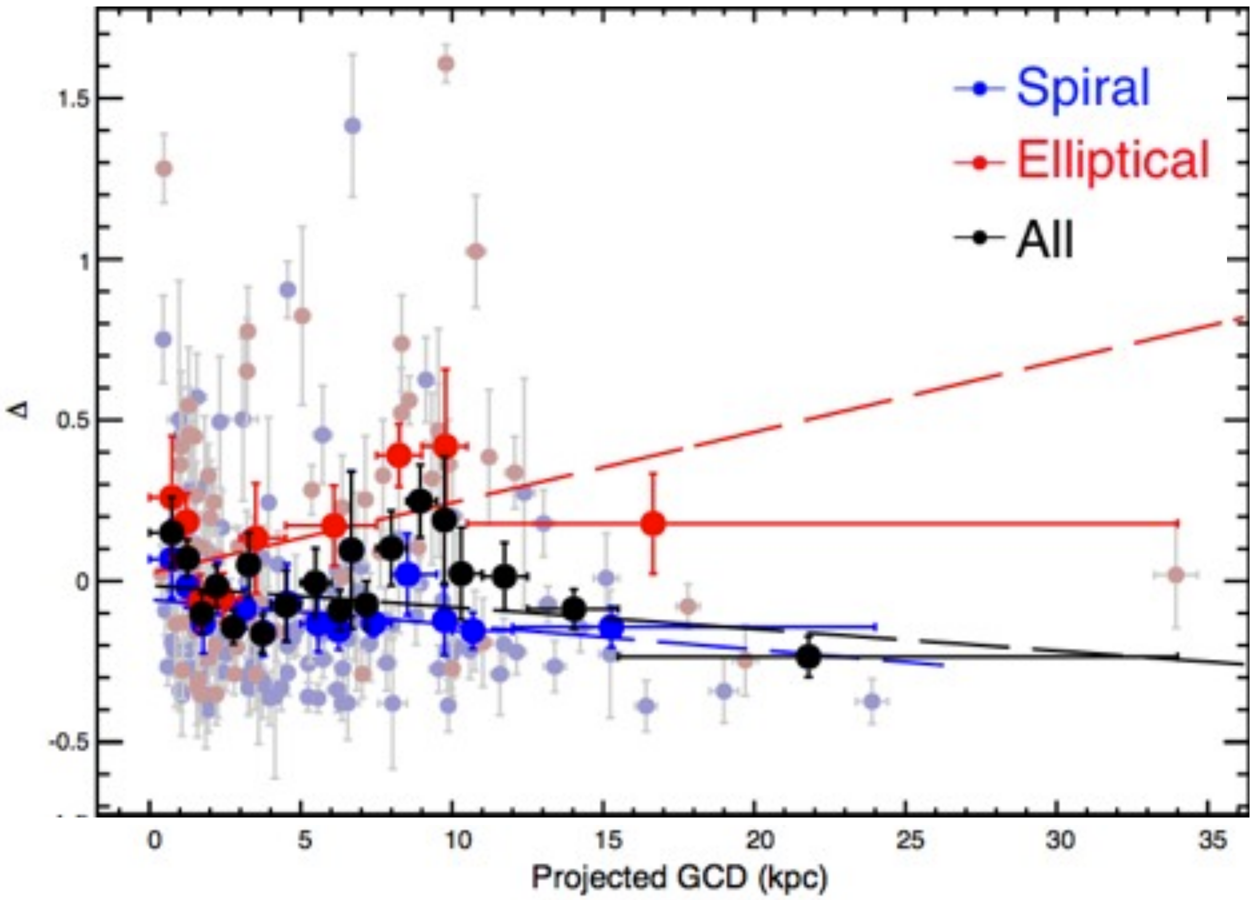
Results (I)

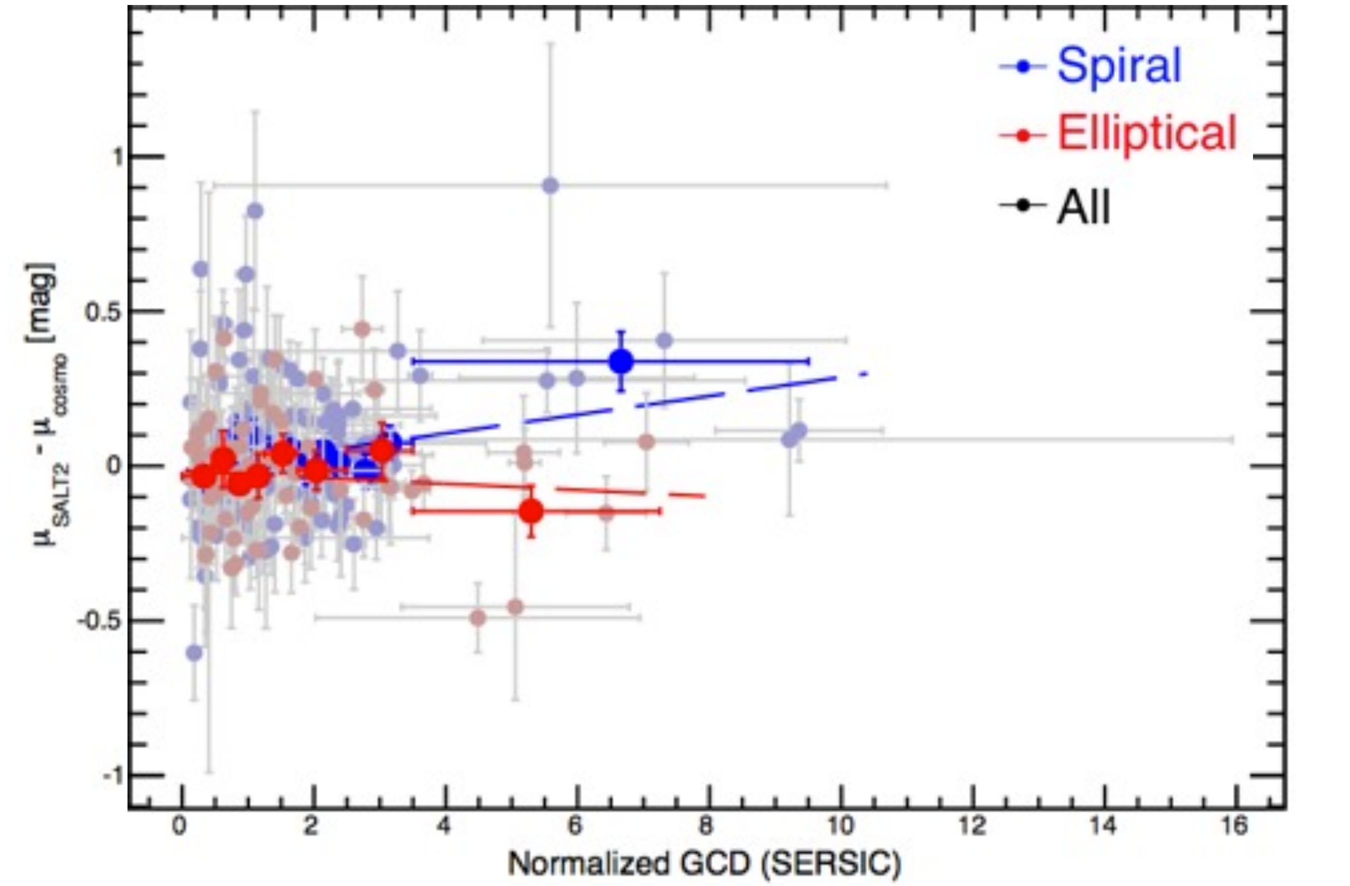
- We find 2 (related) trends with very high significance and good fit quality:
  - A_V and c decrease with physical GCD with significant slopes (4.9 and 4.4σ), and good reduced χ^2/dof (0.6 and 0.9), when consider the whole sample
- Av and c decreases with distance. Most extinguished explosions occur close to the center of the host galaxies





Results (II)





Linear fit: we find weak correlation in ellipticals, larger Δ (dimmer SNe) are found at large GCD

Distance unit	Host type	Slope	Sig.[a]	χ^2/dof
kpc	Elliptical	0.0220 ± 0.0092	2.4	2.1
P50	Elliptical	0.092 ± 0.050	1.9	0.7
ISO	Elliptical	0.81 ± 0.45	1.8	1.1
deV	Elliptical	0.103 ± 0.043	2.4	1.4

- Linear fit: we only find a weak correlation between $\delta\mu_{SALT2}$ and EXP normalization. $\delta\mu_{SALT2}$ in spirals increases with distance

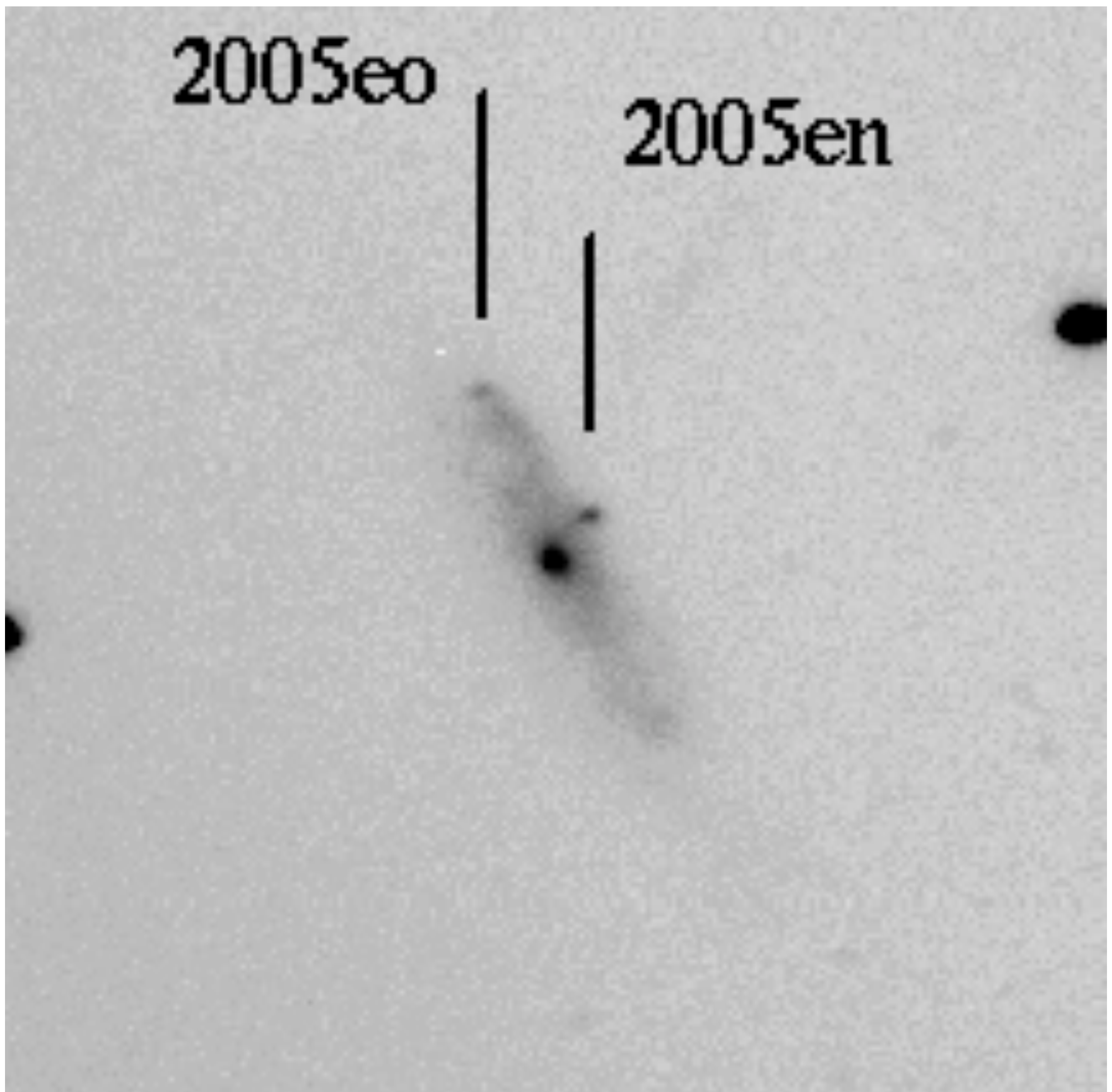
Distance unit	Host type	Slope	Sig.[a]	χ^2/dof
exp	Spiral	0.030 ± 0.014	2.2	1.1

Conclusion

- We find some indications that SNe in elliptical galaxies tend to have narrower LC (larger Δ, fainter SNe) if they explode farther from the galaxy core
  - This could be explained by the difficulty to detect faint SNe close to the galaxy center, where the galaxy light is stronger (selection effect)
- We find strong indications of a decrease in color with distance
  - If most of the variability in color is due to dust, and dust is expected to decrease with distance from the center, this would be expected
  - Due to the difficulty to observe faint SNe close to the galaxy center, we would expect fewer dust extincted SNe (with high A_V) at small distances. However, this is opposite of what we find, so maybe the selection effect is not too large
- We do not find any correlation between the Hubble residuals and the GCD
  - Since GCD can be used as a proxy for the local metallicity, this can be seen as an indication of a limited correlation between Hubble residuals and local metallicity.
  - This does not confirm a recent result (D'Andrea et al. 1110.5517, ApJ accepted), which finds a correlation between Hubble residuals and global metallicity

Forthcoming

do the correlations found from global galaxy properties hold when using the local ones?



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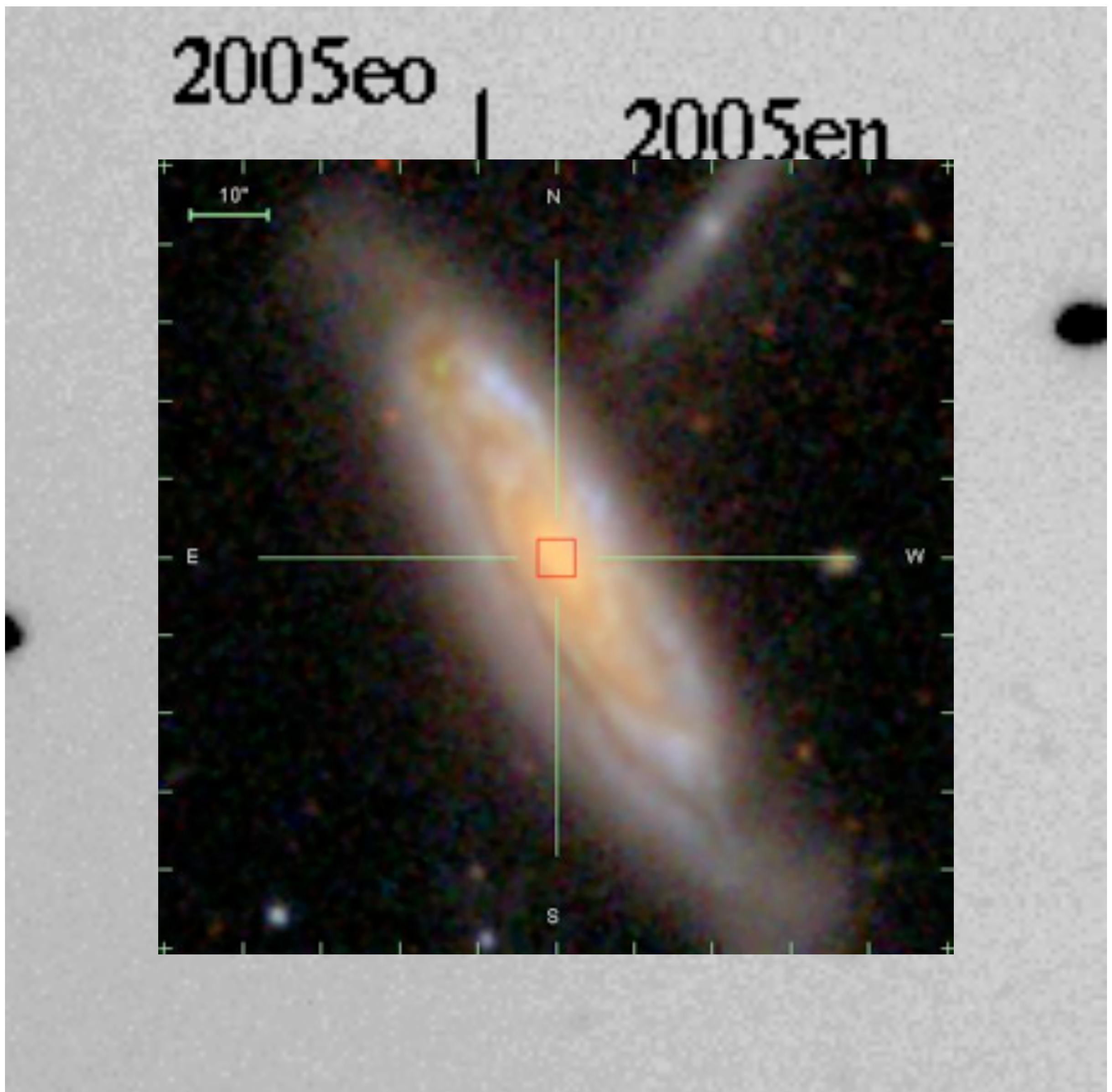

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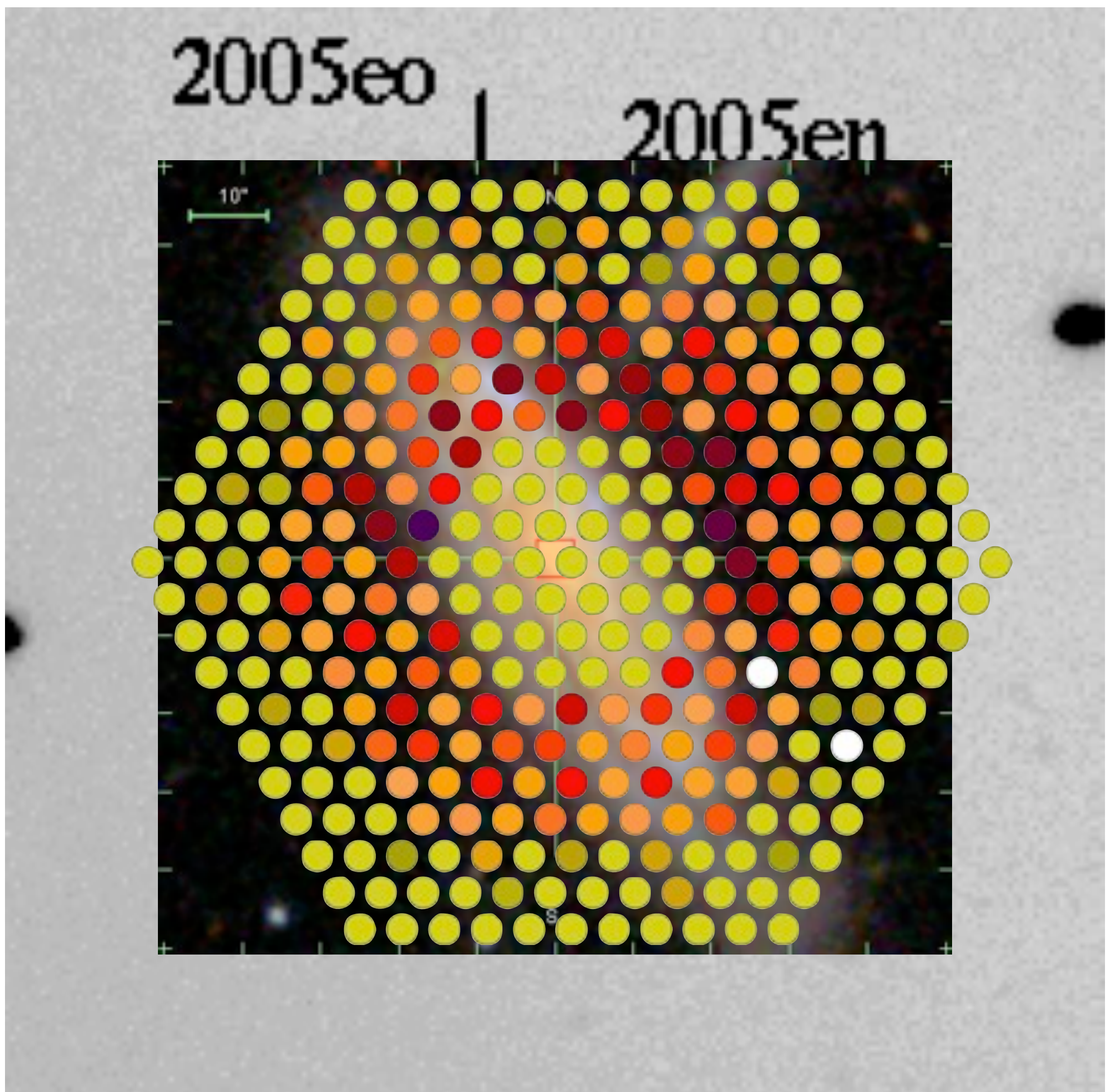
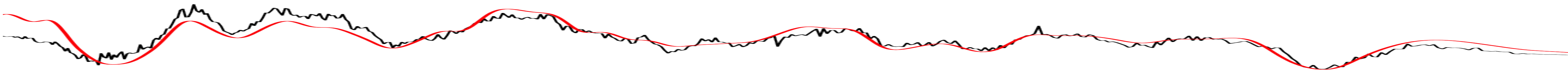
Integral spectroscopy



Forthcoming



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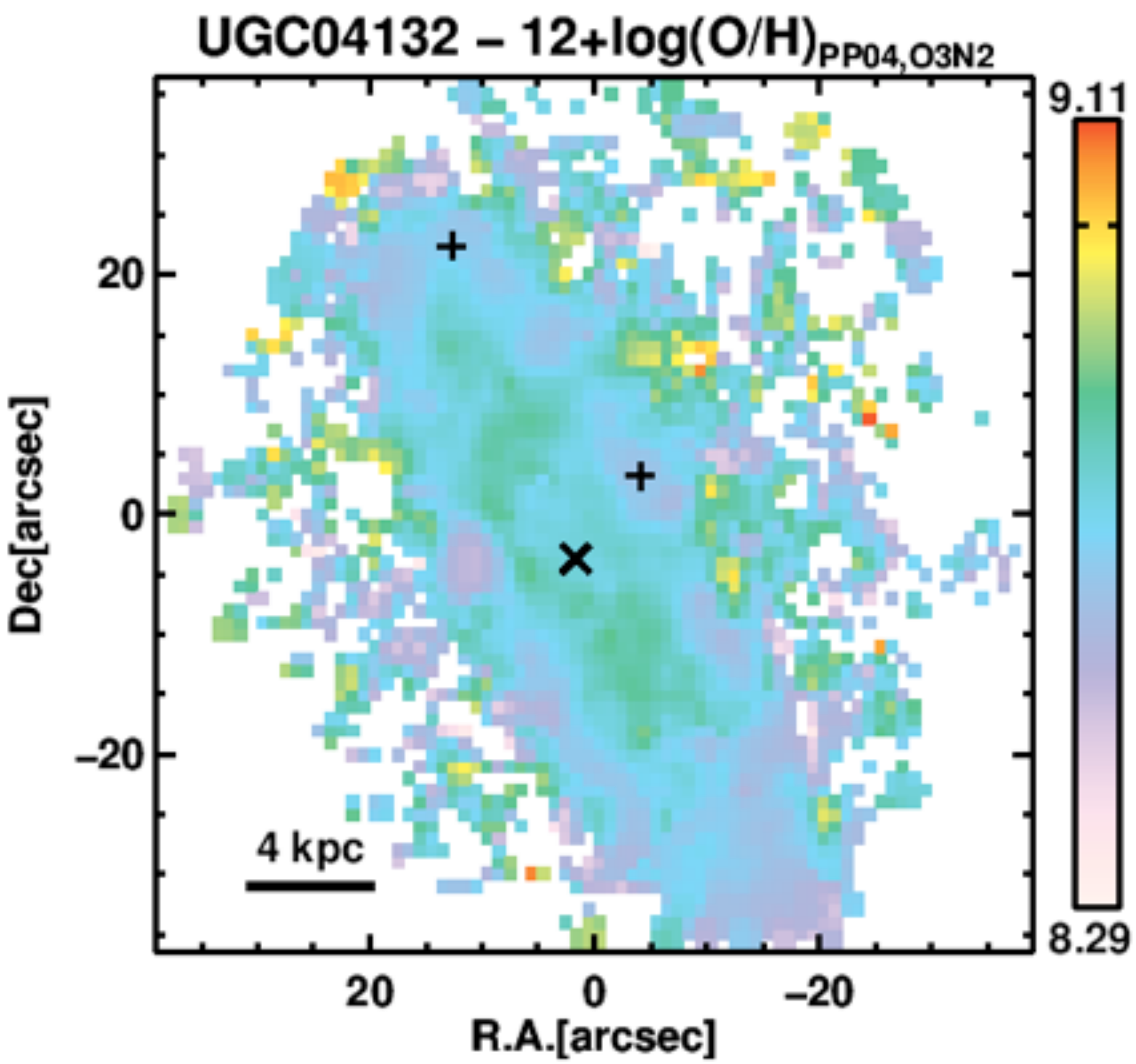
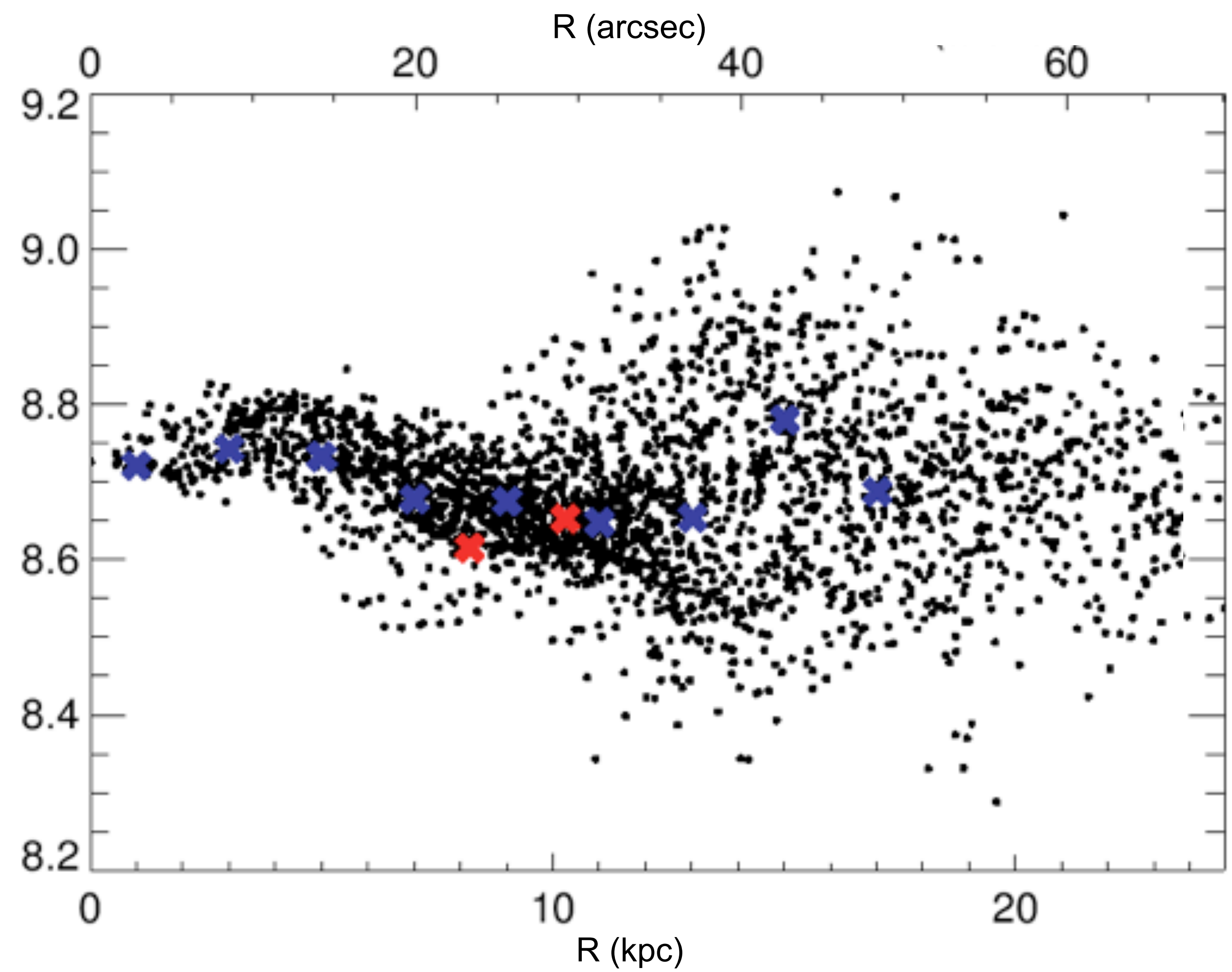
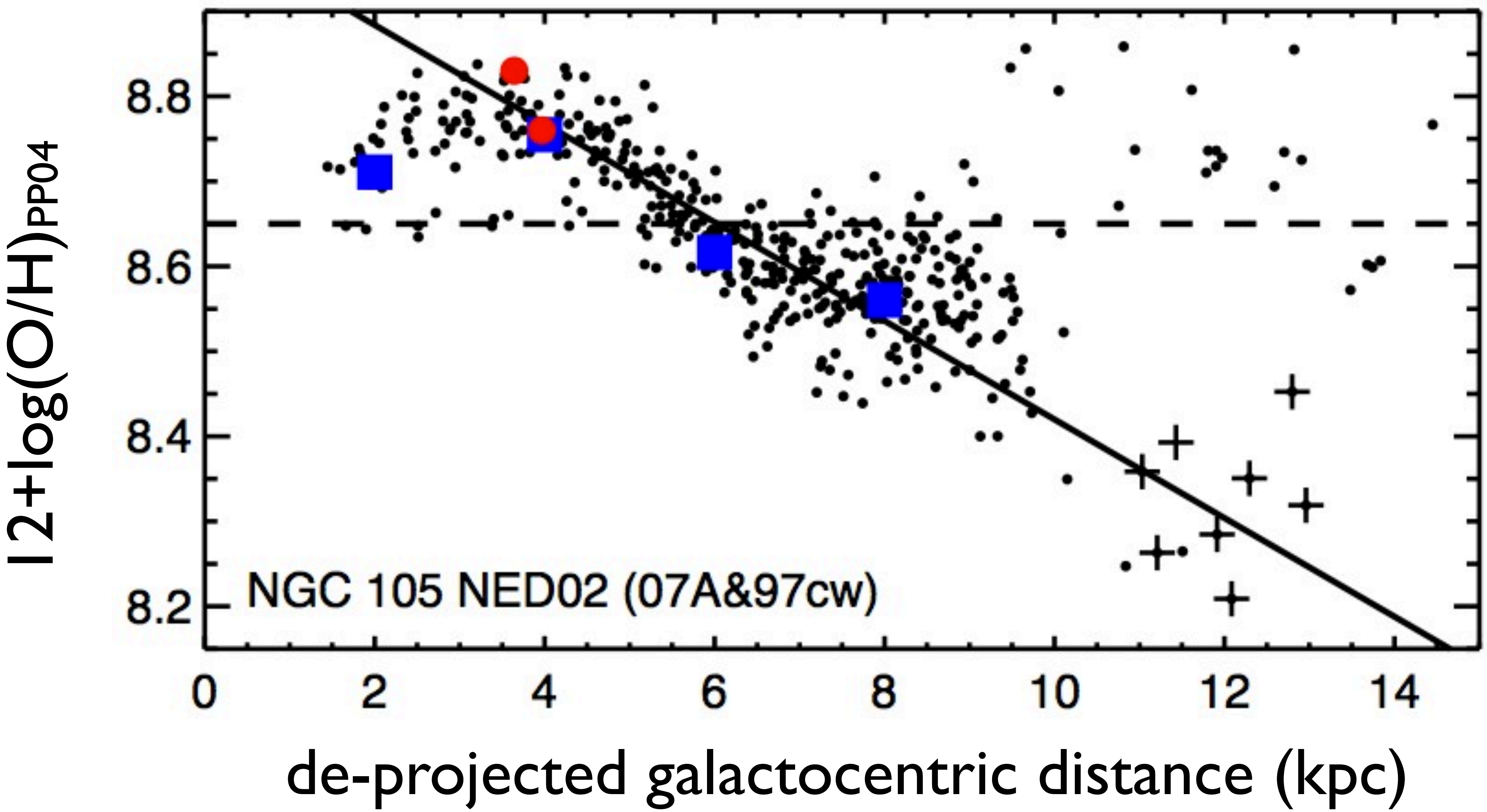





Thanks!



Stanishev et al., 2012, astro-ph:1205:5183