SF2A Montpellier 2013

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SuperNova Legacy Survey 5yrs

Final type Ia supernova spectroscopic sample

Flora CELLIER-HOLZEM

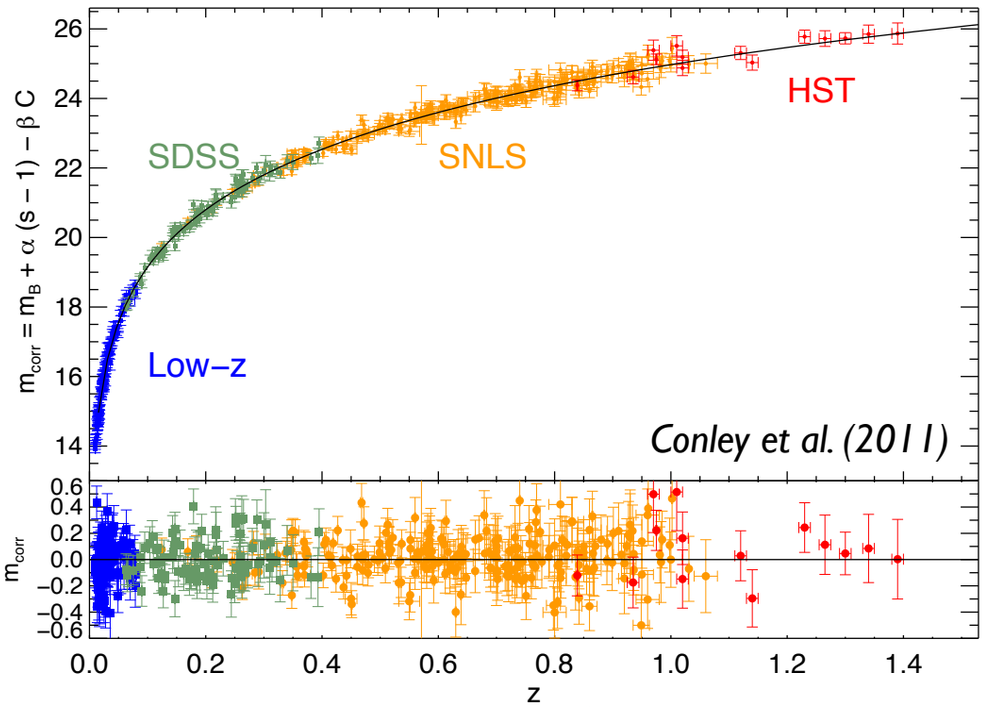
PhD student - LPNHE (Paris)

cellier@lpnhe.in2p3.fr

supervisor: Christophe BALLAND

The SuperNova Legacy Survey experiment

- **Aim** : measuring the luminosity distance to a large number of intermediate and high redshift SNeIa ($0.15 < z < 1.1$) in order to build a **Hubble diagram** to constrain the cosmological parameters
- **When ?** 2003-2008
- **Method :**



imaging survey

at the Canada-France Hawaii Telescope (CFHT) in Hawaii

➔ a rolling-search to detect new SN Ia candidates and to monitor their light-curves in several photometric bands

➔ more than 1000 light curves have been gathered

spectroscopic programs

at the Very Large Telescope (VLT), Gemini, Keck telescopes

➔ ~1500h of observation on 8-m telescopes over the course of the survey

➔ to confirm the nature of the SN Ia candidates

➔ to measure their redshift

Progress of the SNLS

- SNLS 3yrs cosmological analysis : ✓ published in Sullivan et al. (2011) & Conley et al. (2011)
- SNLS 3yrs recalibrated :

  ➔ **SNLS 3yrs photometry**

  - photometric calibration : **✓ done (Betoule et al. 2013)**
  - distance measurement of SNe Ia and cosmological constraints : **✓ paper in prep**

- SNLS 5yrs :

  ➔ **SNLS 5yrs photometry : on going**

  ➔ **SNLS 5yrs spectroscopy** ➔ **This talk**

  NEW

  - Full spectroscopic sample : **✓ ready for cosmological analysis**
  - Fundamental study for cosmology with SNe Ia : is there evolution of SNe Ia ? **✓ SNLS spectra contribution**

Telescopes for the SNLS spectroscopy

➔ SNLS spectroscopy on 8-10m class telescopes : ~ 1500h of observation


Gemini North

- **Gemini North & South telescopes (Hawaii & Chile)** : can observe the 4 SNLS fields

➔ ~60h per semester from August 2003 to May 2008

➔ **when possible observed preferentially highest redshifts candidates (z > 0.6)**

➔ measured ~35% of the SN Ia spectra

- 1st year : Howell et al. (2005)
- 2nd + 3rd years : Bronder et al. (2008)
- 4th + 5th years : Walker et al. (2011)


VLT

- **Very Large Telescope (Chile) :** the northernmost SNLS field D3 not observable

➔ ~60h per semester from June 2003 to September 2007

➔ **observed preferentially equatorial SNLS fields**

➔ measured ~45% of the SN Ia spectra

- first 3 years : Balland et al. (2009)
- 4th year : Cellier-Holzem et al. (in prep)


Keck I & II

- **Keck I & II (Hawaii) :** can observe the SNLS field D3

➔ ~30h per semester from May 2003 to April 2008

➔ **observed preferentially high latitude fields + detailed study of z~0.5 candidates**

➔ measured ~20% of the SN Ia spectra

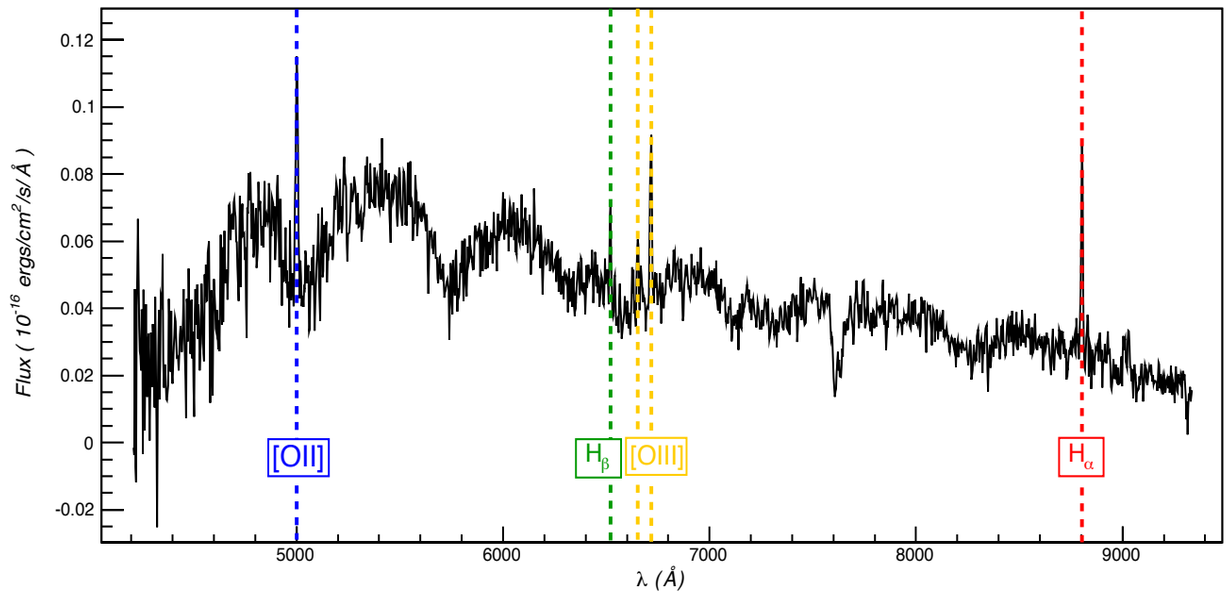
- first 2 years : Ellis et al. (2008)
- last 3 years : Fakhouri et al. (in prep)

First aim : z estimate

- **Host signal available : → z ± 0.001**

  determination based on host lines

  ↳ example : SN 07D1ah with z = 0.342 ± 0.001

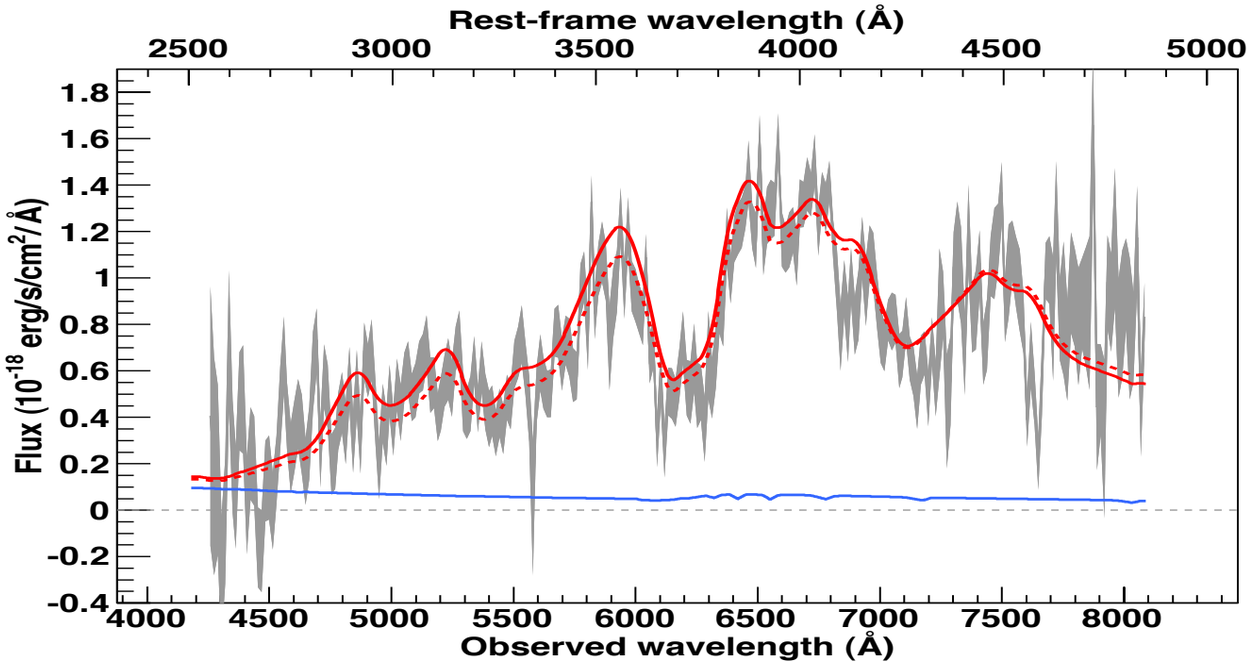


- **Do not have host signal : → z ± 0.01**

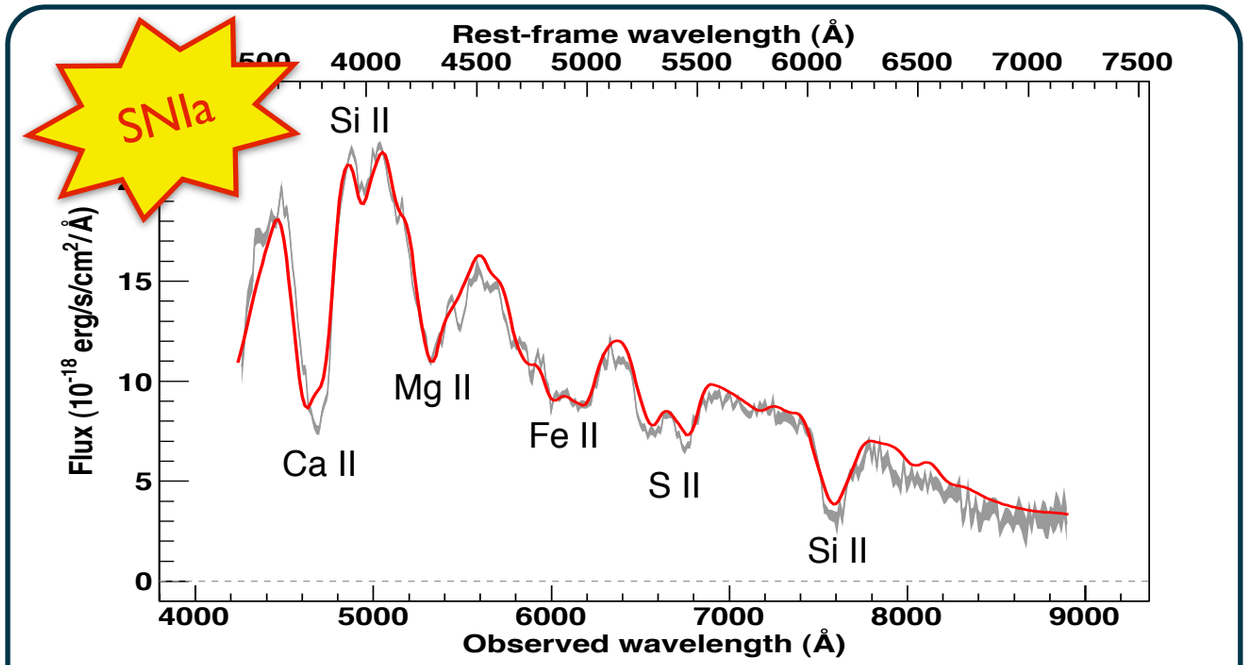
  → Estimate based on SN Ia features

  → Fit the spectrum + galaxy using a SN Ia spectro-photometric model with various host templates (**SALT2** developed by Guy et al. 2007)

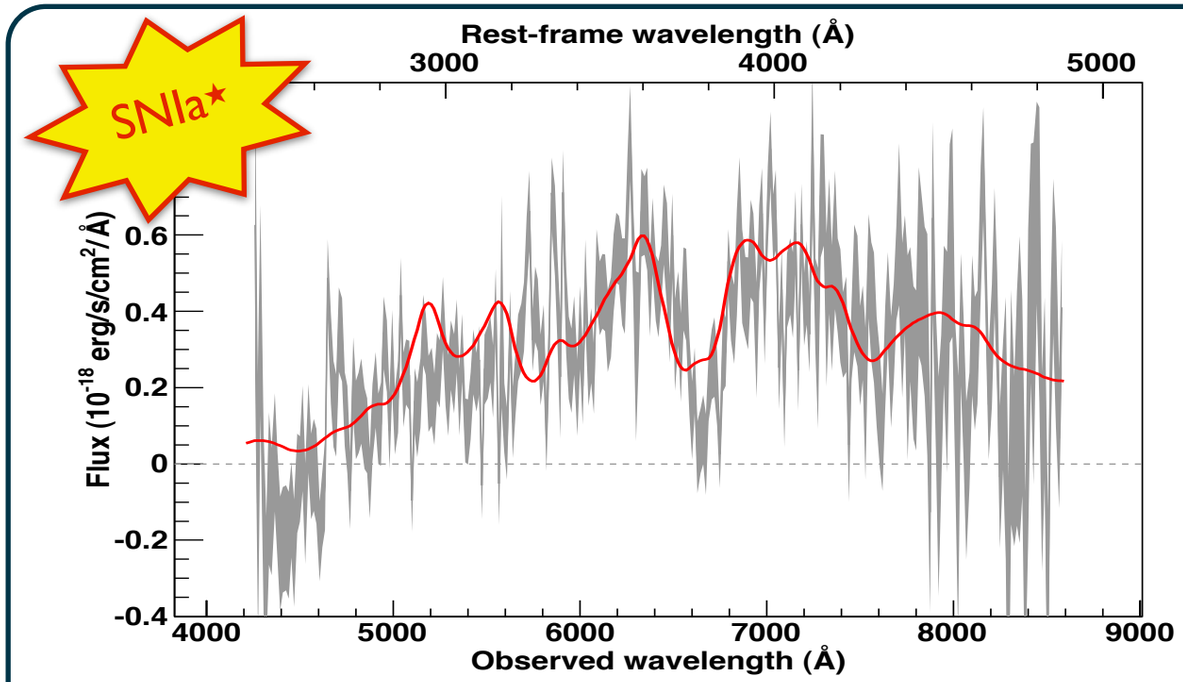
  ↳ example : SN 06D1ix with z = 0.65 ± 0.01



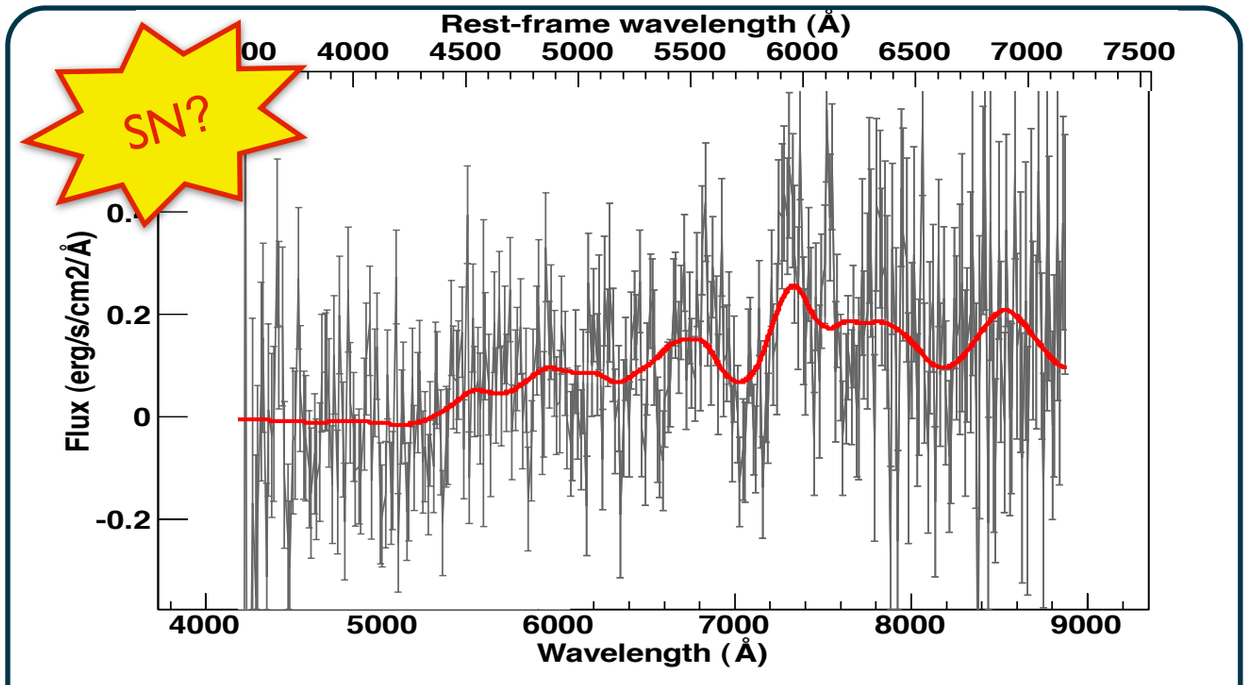
Second aim : SN Ia identification



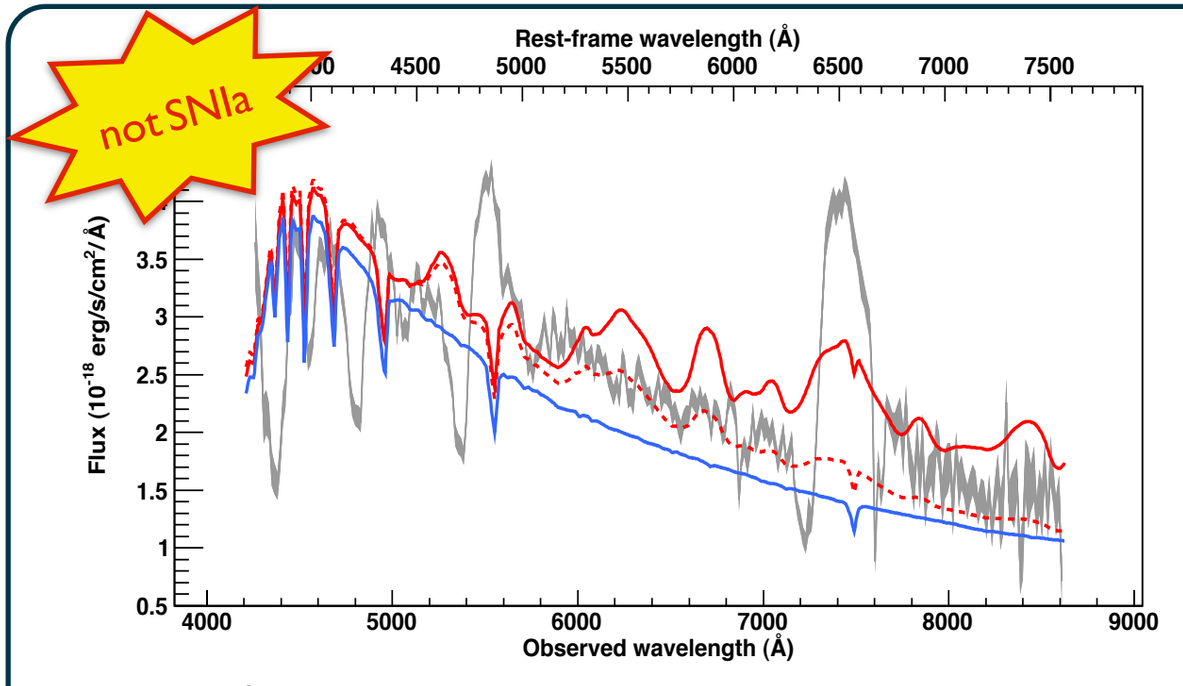
↳ SN 06D1du at maximum with z = 0.24 ± 0.01



↳ SN 06D4jt 3days after maximum with z = 0.76 ± 0.01

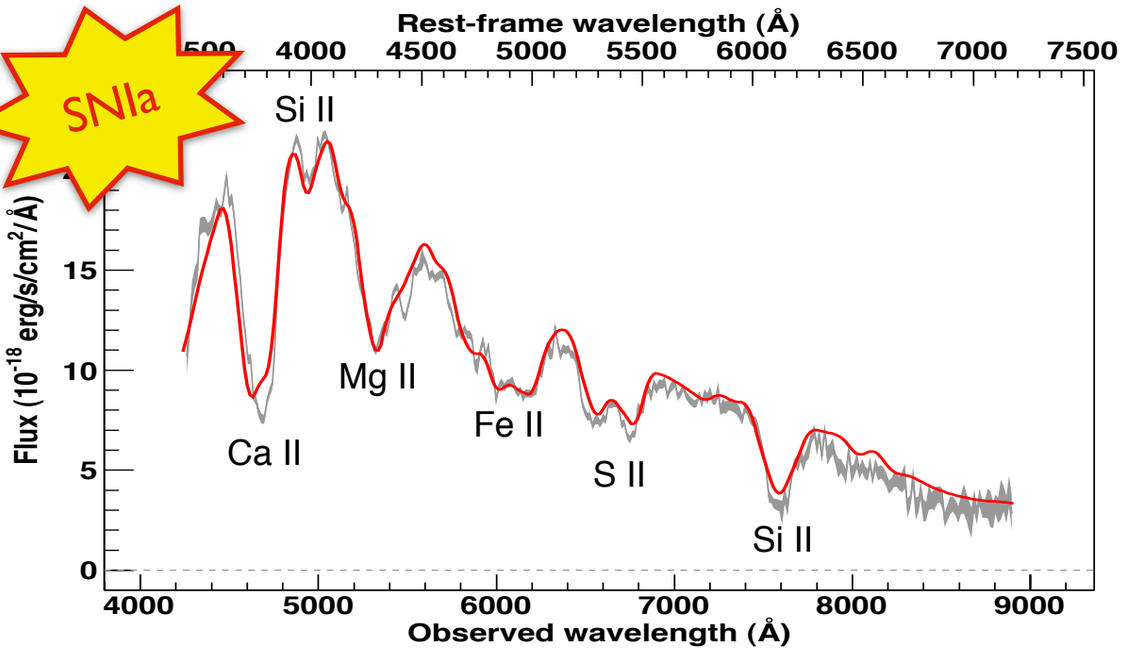


↳ SN 05D4he 11days after maximum with z = 0.87 ± 0.01



↳ SN IIp 06D1jx with z ~ 0.14 ± 0.01

Second aim : SN Ia identification



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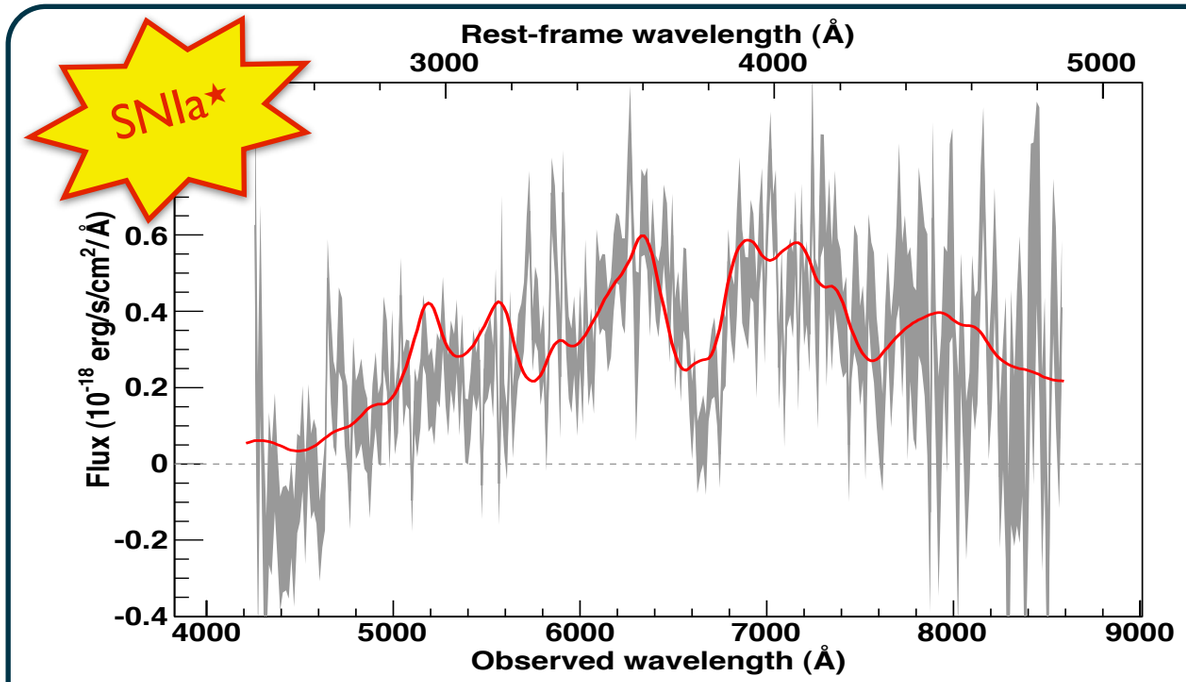

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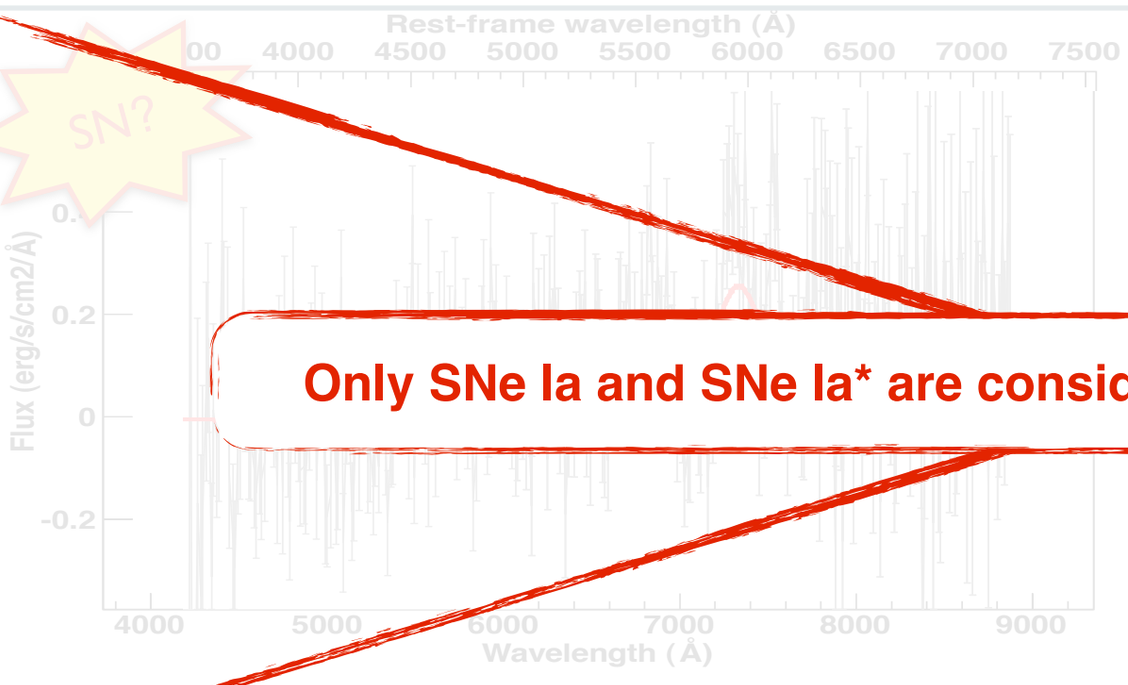

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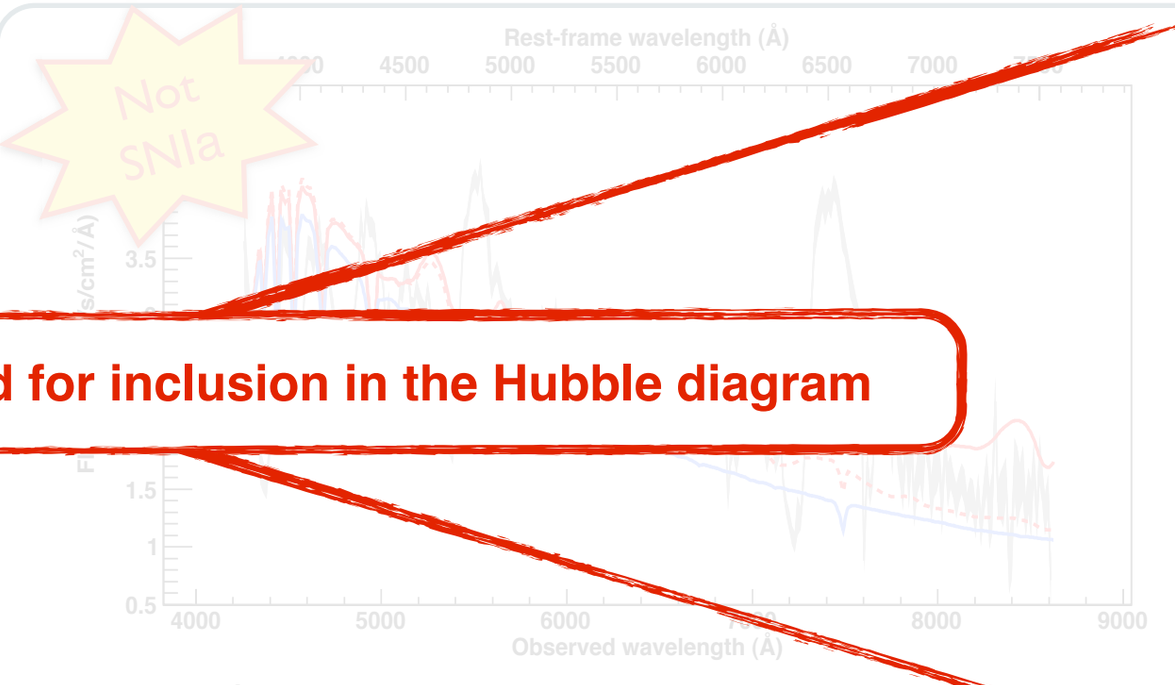


↳ SN IIp 06D1jx with z ~ 0.14 ± 0.01

Only SNe Ia and SNe Ia* are considered for inclusion in the Hubble diagram

Final spectroscopic sample of the SNLS

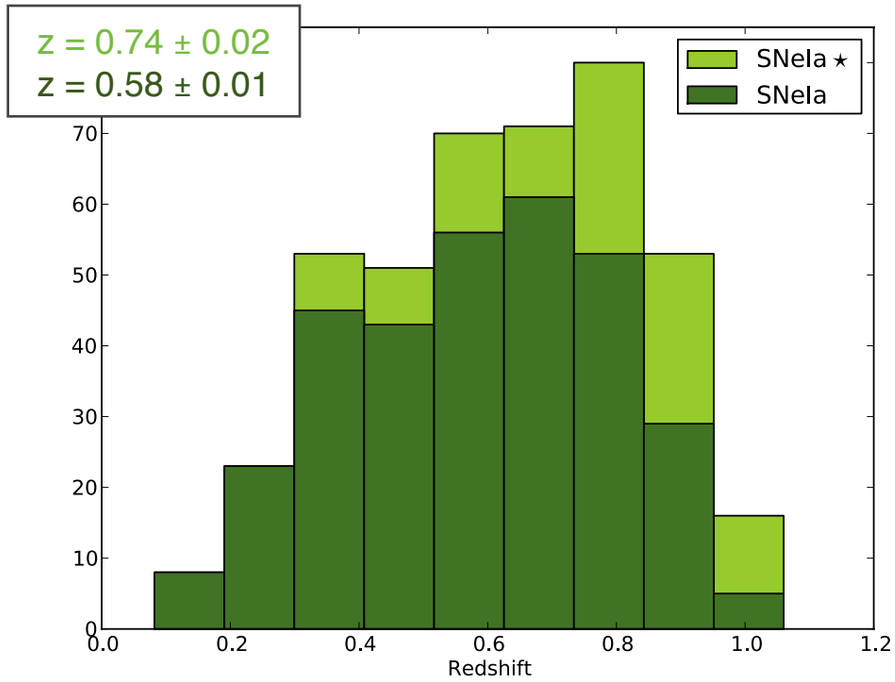
- **Final spectroscopic sample :**

  ➔ 426 type Ia supernovae

  ↳ 324 SNe Ia (76%) and 102 SNe Ia* (24%)

  ➔ Unique spectroscopic survey with ~1500h of observation on 8-10m telescopes

  ➔ Exceptional sample at intermediate and high z with relative good S/N spectra



- **Contamination of SNe Ia* by other types :**

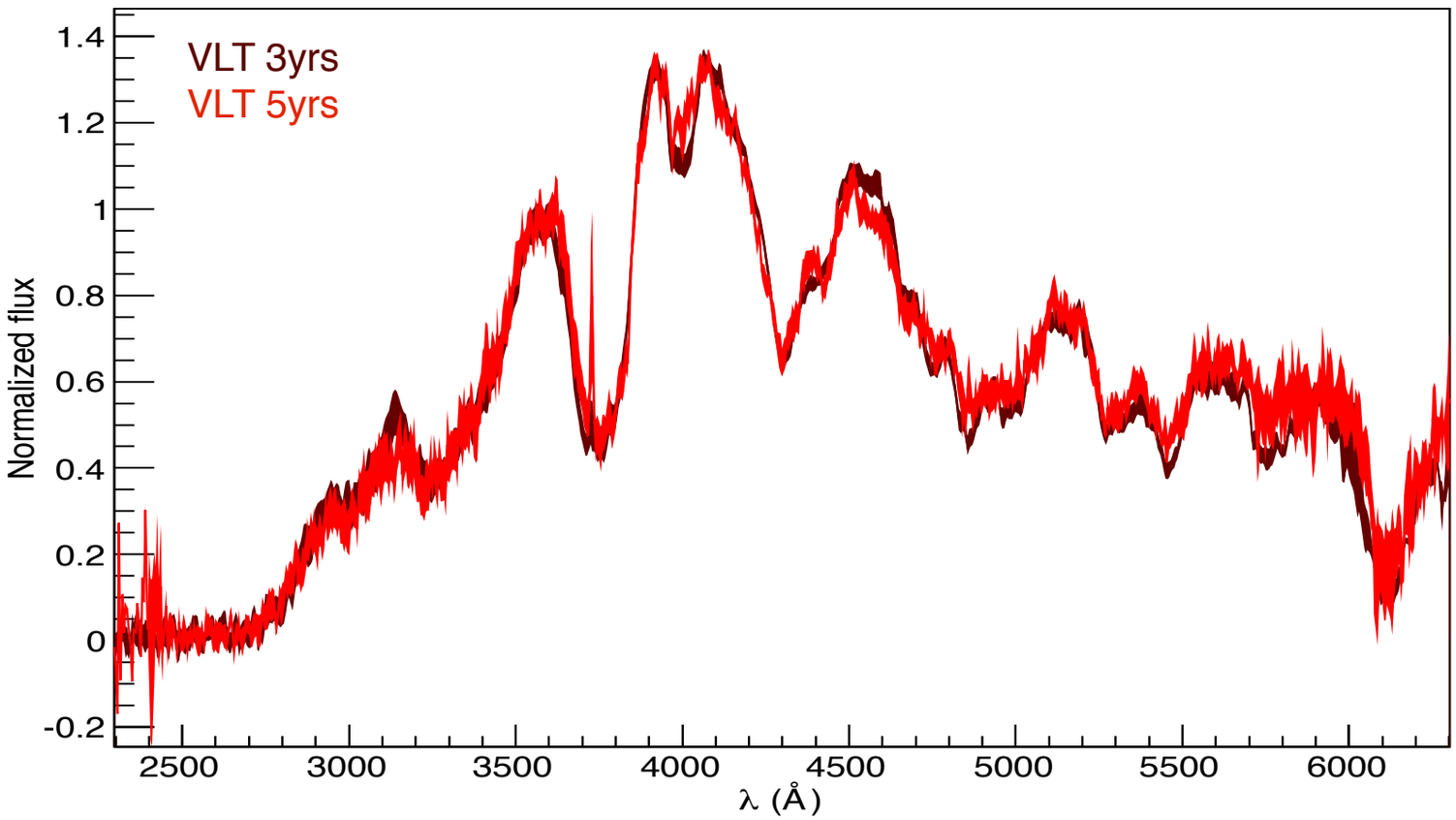
  ➔ Check that SNe Ia and SNe Ia* have the same distributions of the photometric parameters on average

  ↳ SNe Ia and SNe Ia* are the same population

  ➔ Pure SNe Ia sample without contamination on average

Comparison of the 3yrs and 5yrs VLT samples

- **VLT samples :** 2 independant sub-samples with 2 different extractions and without common SN Ia
  - ➔ VLT 3yrs (Balland et al. 2009)
  - ➔ VLT 5yrs (Cellier-Holzem et al. in prep)
- **Compare the raw data :** build mean spectrum for the 2 sub-samples (only SNe Ia)
  - ➔ Spectra are de-redshifted + rebinned to 5Å
  - ➔ Normalisation : same flux integral over 4000-4500Å
  - ➔ Average weighted flux + dispersion in each bin
  - ➔ Error : 1σ confidence level



➔ mean spectra of the 2 independent samples are remarkably similar

↳ SNe Ia of the 2 sub-samples are identical in average

↳ ~5% calibration between the 2 spectral sub-sample

Is there evolution ?

- **Key question for cosmology :** used SNe Ia over a large redshift range

  ↳ **do the SNe Ia population properties evolve with z ?**

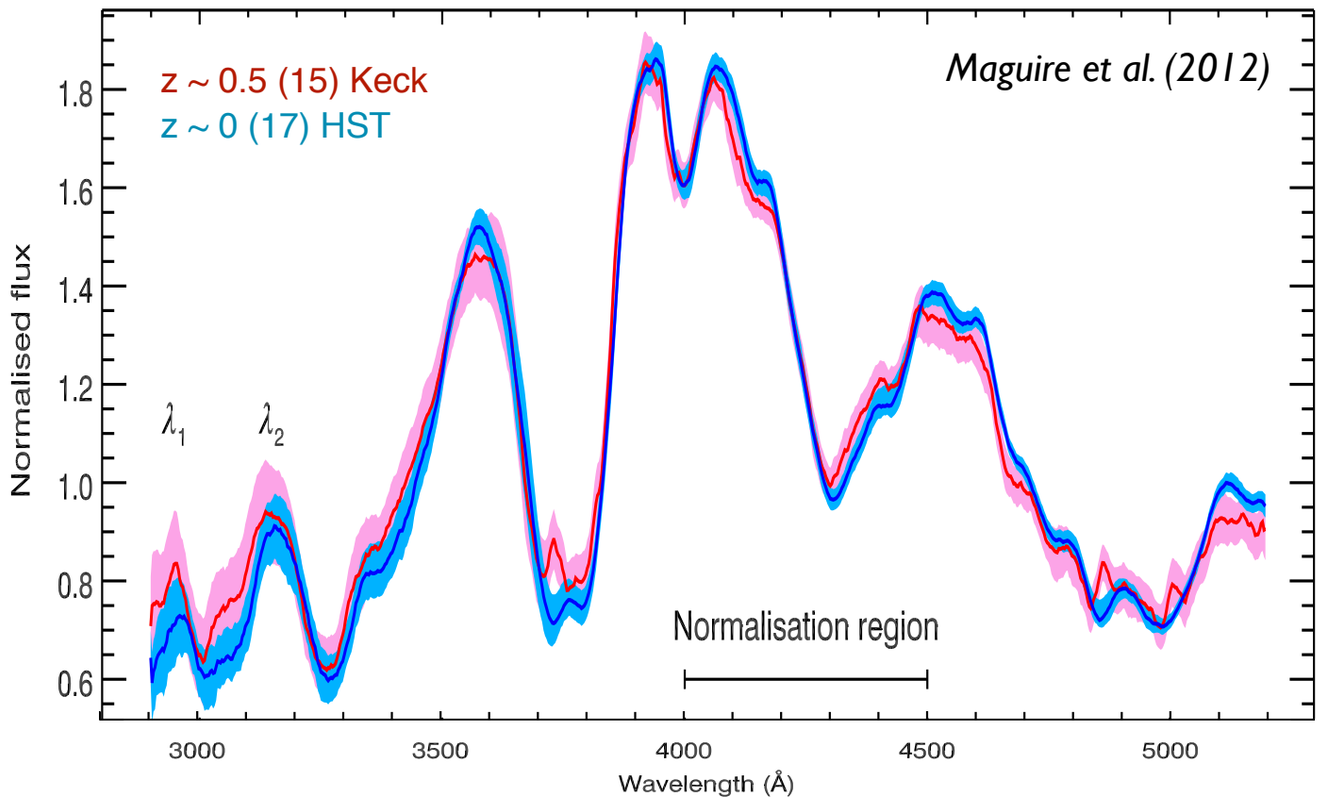
- **Investigation of the SN Ia evolution :** using spectral properties

  ➔ comparison of composite spectra built at low and high z around maximum light

  ↳ spectral differences exist in the UV part : low z have depressed flux compared to higher z

  ➔ **Interpretation :**
  - decrease in metallicity with increasing z in agreement with galaxy evolution (Maguire et al. 2012)
  - demographic evolution of the SN Ia population (Sullivan et al. 2009)

  ↳ **controversial question**



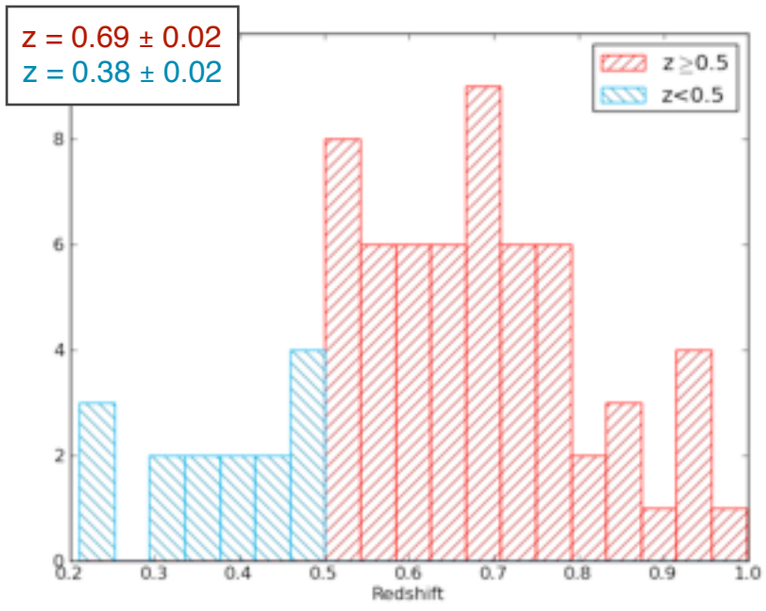
Is there evolution ?

- **New analysis using VLT spectra from SNLS 5yrs spectrsocopic sample :** Cellier-Holzem et al. (in prep)

➔ SN Ia samples :

- Phase cut : -4 < phase < 4 days
- Color cut : -0.2 < c < 0.2
- 2 redshift bins : z < 0.5 and z ≥ 0.5

low z : 15 spectra
high z : 56 spectra

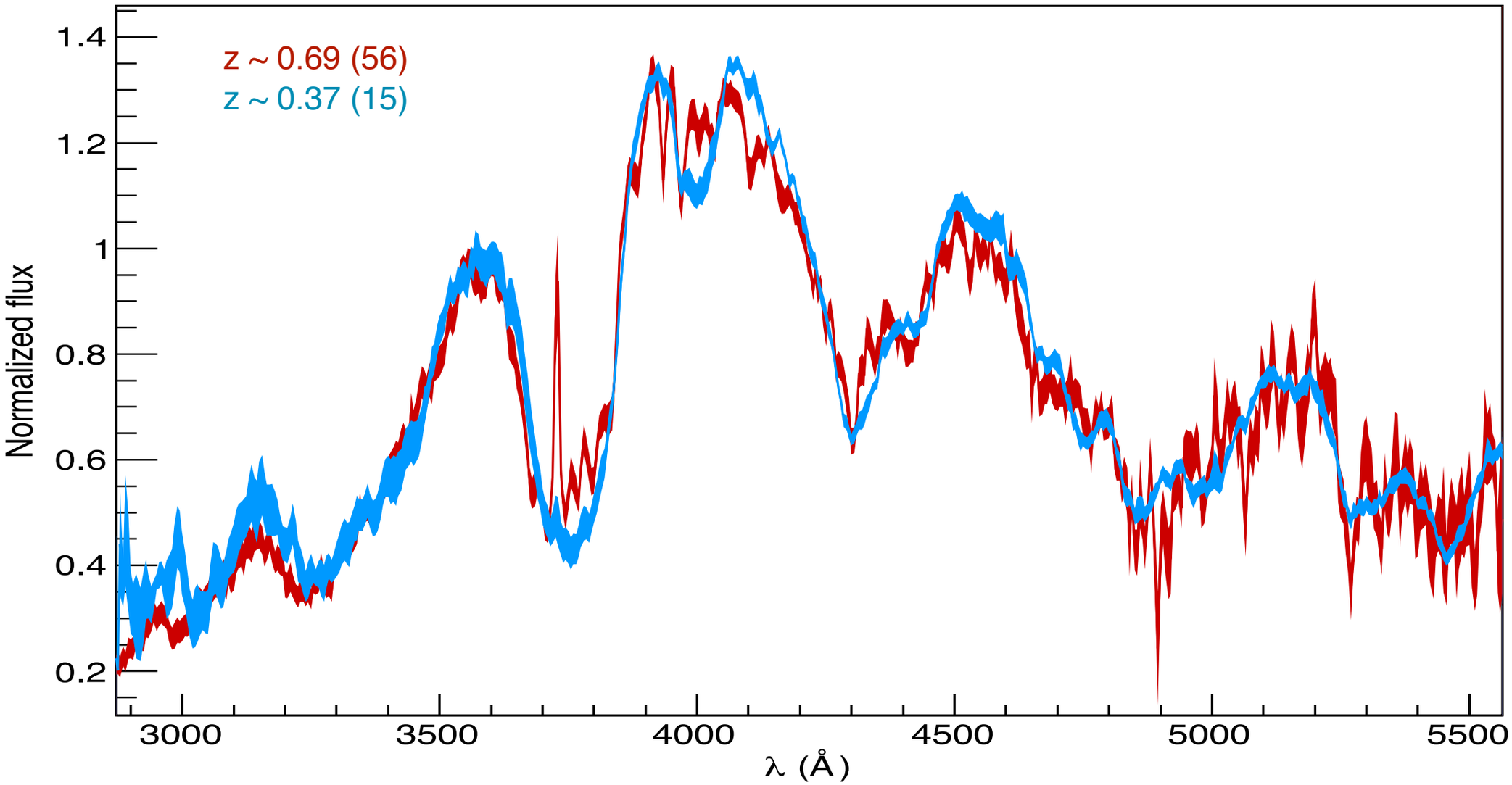


➔ SN Ia mean spectra :

- Spectra are de-redshifted + **color-corrected using the SALT2 color law (Guy et al. 2007)** + rebinned to 5Å
- Normalisation : same flux integral over 4000-4500Å
- Average weighted flux + dispersion in each bin
- Error : 1σ confidence level

Is there evolution ?

➔ **Spectral differences :**

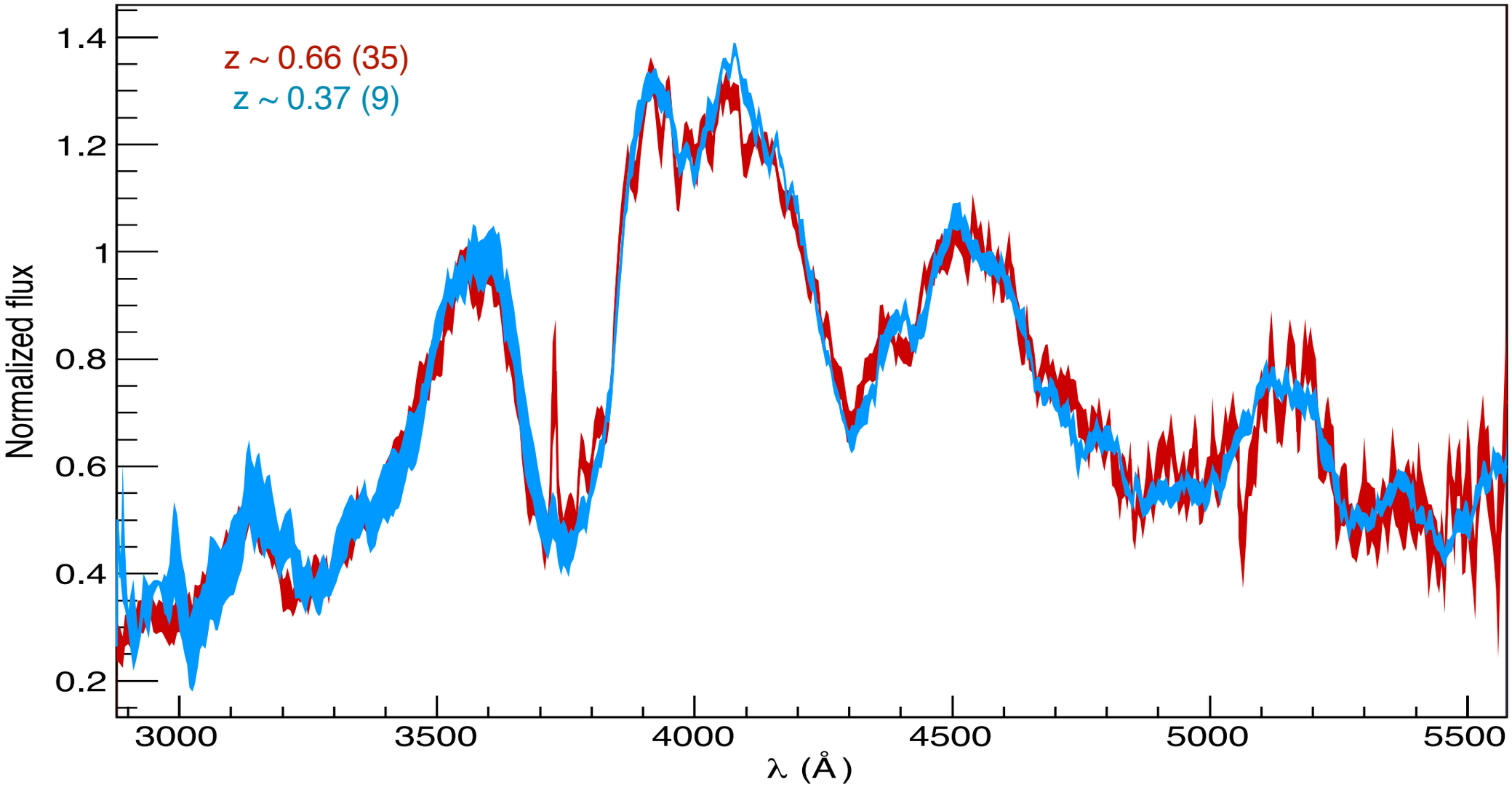


↳ Low z spectra : deeper absorption features due to intermediate mass elements (Ca II, Si II)

↳ Consistent with higher z SNeIa beeing bluer, brighter and hotter thus ionising more IMEs

Is there evolution ?

➔ **Compare comparable SNe Ia :** select 2 sub-samples with same distributions of photometric properties



↳ Differences are significantly reduced

↳ Consistent with a selection effect : selecting brighter (bluer and hotter) SNe Ia at higher z

➔ **We do not need to invoke a demographic evolution of SNe Ia (but it could be exist)**

Conclusion

- **Spectroscopy is essential to estimate z and assess the nature of the SN Ia candidates**

  ↳ large spectroscopic surveys in SNLS : ~1500h of observation on 8-10m class telescopes over the course of the survey

- **Final SNe Ia spectroscopic sample with 426 SNe Ia**

  ↳ large effort to estimate the redshift and assess the type

  ↳ pure SNe Ia spectroscopic sample at intermediate to high redshift

  ↳ The final SNLS cosmology analysis will rely on this full sample after further photometric cuts are made

- **SNLS spectra can be used to investigate the evolution of SNe Ia with z**

  ↳ differences between low and high z spectra

  ↳ no need demographic evolution : **➔ Selection effect**

➔ Legitimate the use of SNe Ia as «calibrated candles» for cosmological purposes

Backup

SNLS spectroscopy : pre-selection

➔ Observing time not sufficient to measure a spectrum for each photometric candidate

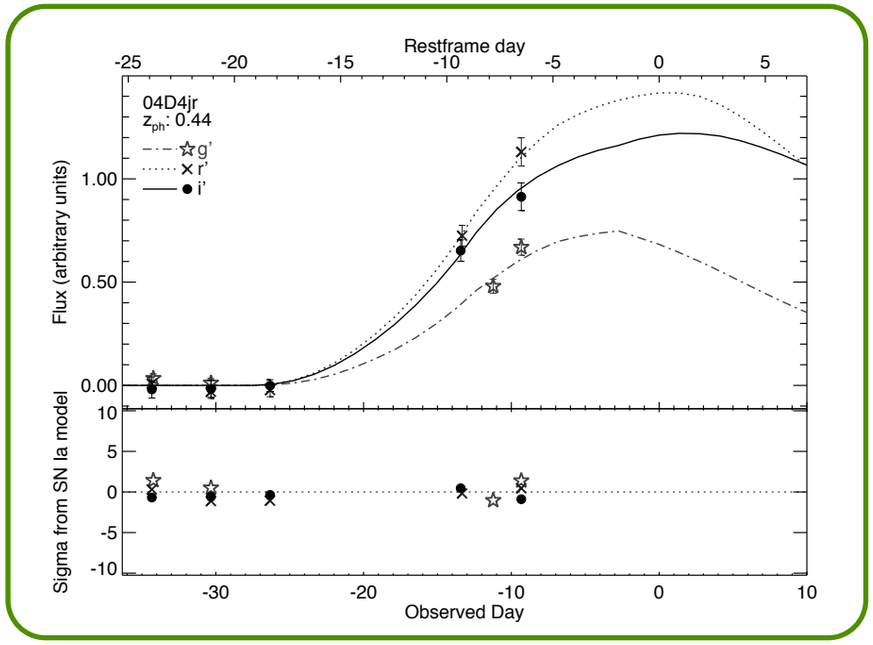
- Pre-selection for the spectroscopy (Sullivan et al. 2006, Perrett et al. 2010) :

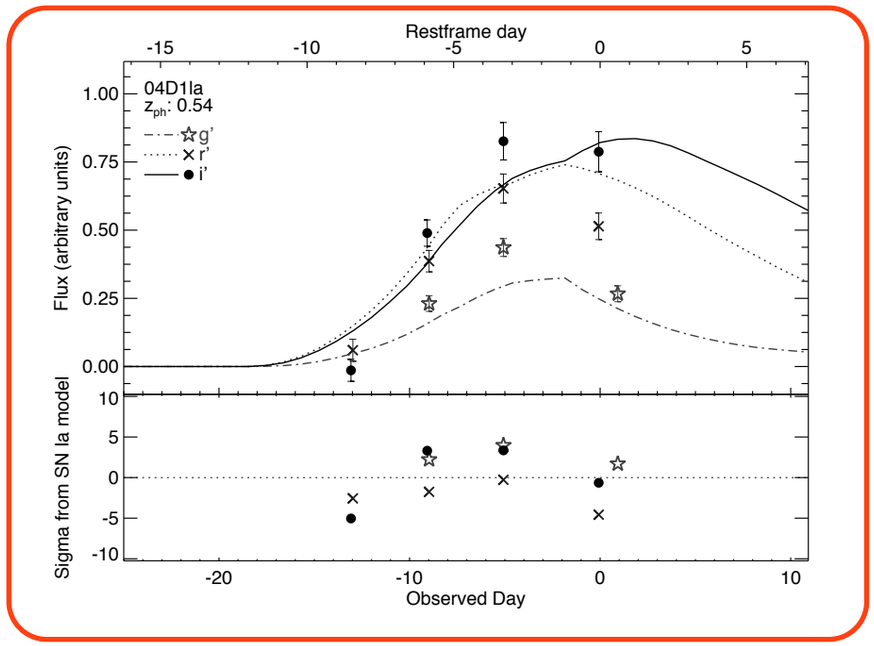
  ➔ Fit the first points of light-curves with a SN Ia model based on light-curve templates (Goldhaber et al. 2001 & Knop et al. 2003) and spectral templates (Nugent et al. 2002) using a χ^2 minimization procedure

  ➔ Output : best fitting parameters of redshift (precision of ~10%), phase (+/- 2-3 rest-frame days), stretch and optionally the color excess of the SN host galaxy E^{host}_{B-V}) + light-curve best fit

  ➔ differentiating SNe Ia from other variable sources by visual inspection of the best fit

✓ possible SN Ia





✗ SN Ib/c ?

- List of SN Ia candidates: candidates classed in order of priority to be send to the spectroscopic telescopes
- over the course of the survey : more than 500 photometric candidates have been spectroscopically observed