SNFactory: when spectra help standardizing type Ia supernovae

(artist's concept)

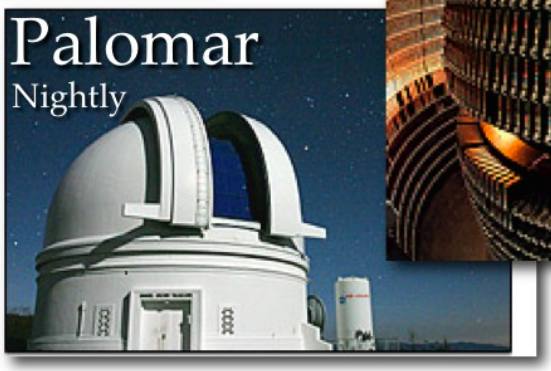
E. Gangler
For the SNFactory

G. Aldering, P. Antilogus, C. Aragon, S. Bailey, C. Baltay, S. Bongard, K. Boone, C. Buton, M. Childress, N. Chotard, Y. Copin, P. Fagrelius, H. K. Fakhouri, U. Feindt, M. Fleury, D. Fouchez, B. Hayden, A. Kim, M. Kowalski, S. Lombardo, J. Nordin, R. Pain, E. Pécontal, R. Pereira, S. Perlmutter, D. Rabinowitz, M. Rigault, K. Runge, D. Rubin, C. Saunders, R. A. Scalzo, G. Smadja, C. Sofiatti, N. Suzuki, C. Tao, R. C. Thomas, B.A. Weaver

Nearby Supernova Factory

Spectrophotometric time series

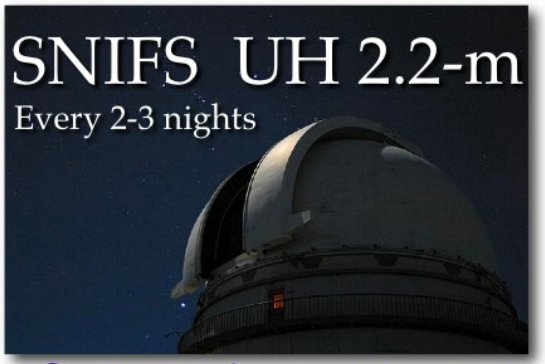
1. Discover



Hubble flow SN1a
0.03<z<0.07
~~Blind~~ Untargeted search

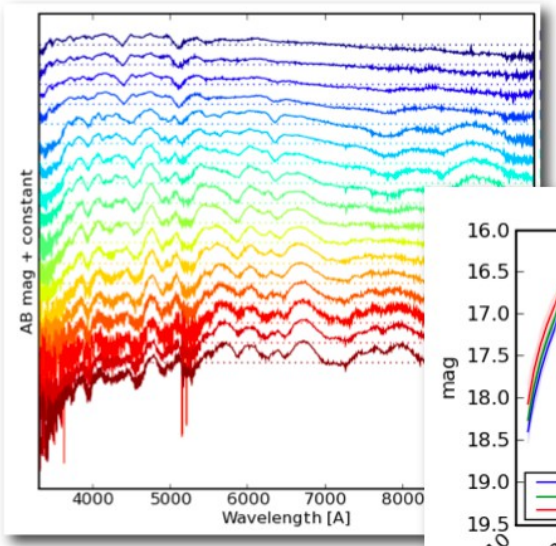
= ~10^{-7} of the area observed per night

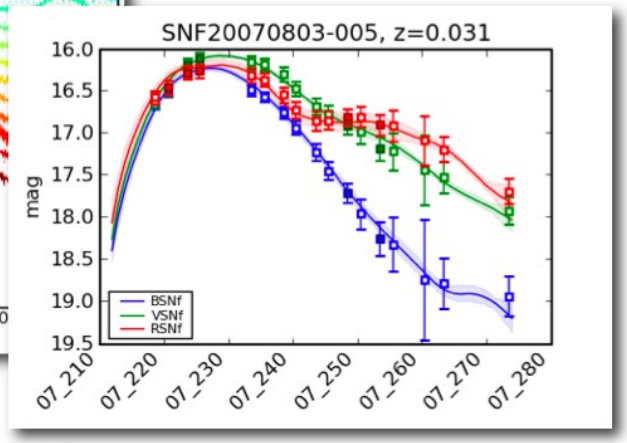
2. Observe



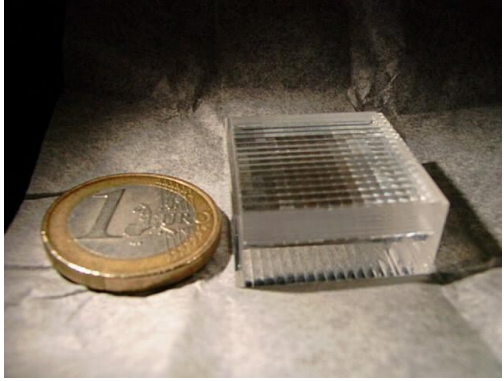
Custom, unique spectrometer designed for nearby SN obs

3. Analyze

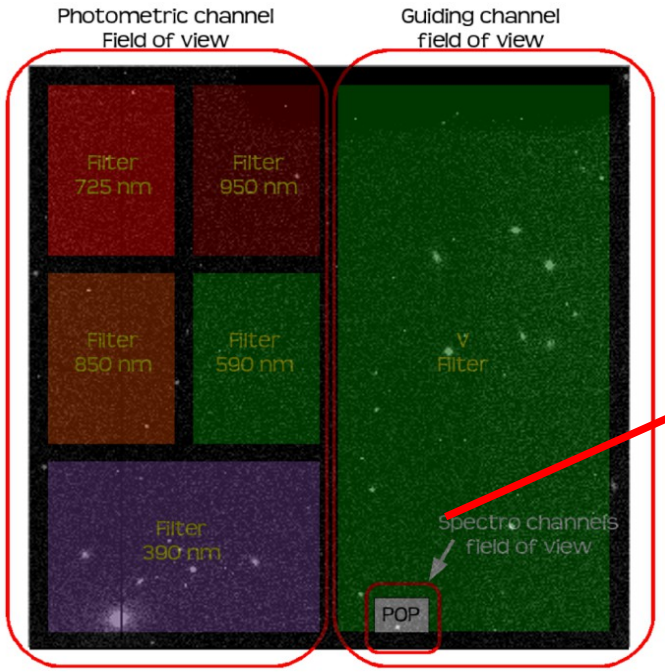




Principle of SNIFS instrument: data

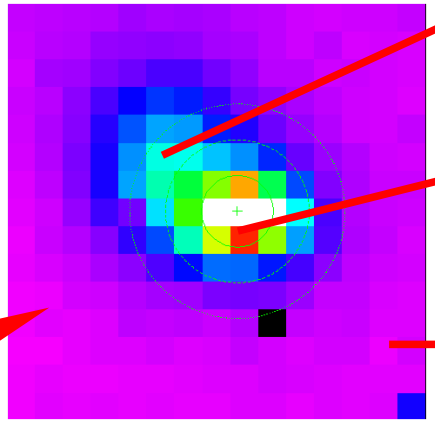


Photometric channel

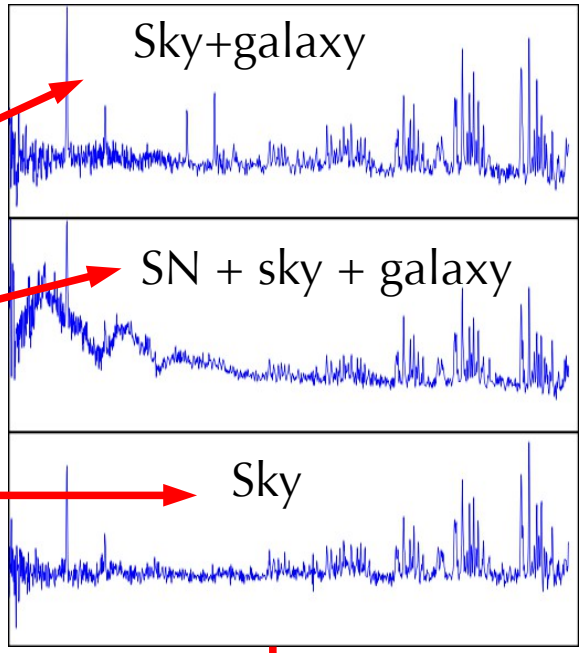


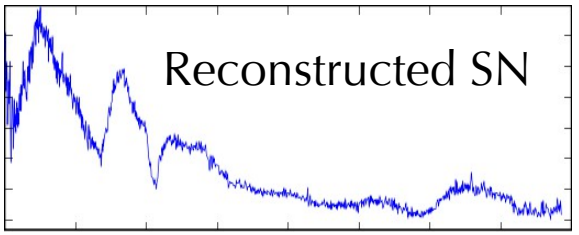
9.4'x9.4' FOV @ 0.14''/pix

IFU : 15x15=225 spectra



MLA : 2 channels
0.32 – 0.54 µm @ 2.4 Å
0.54 – 1.0 µm @ 2.9 Å
6''x6'' FOV @ 0.4''/spax





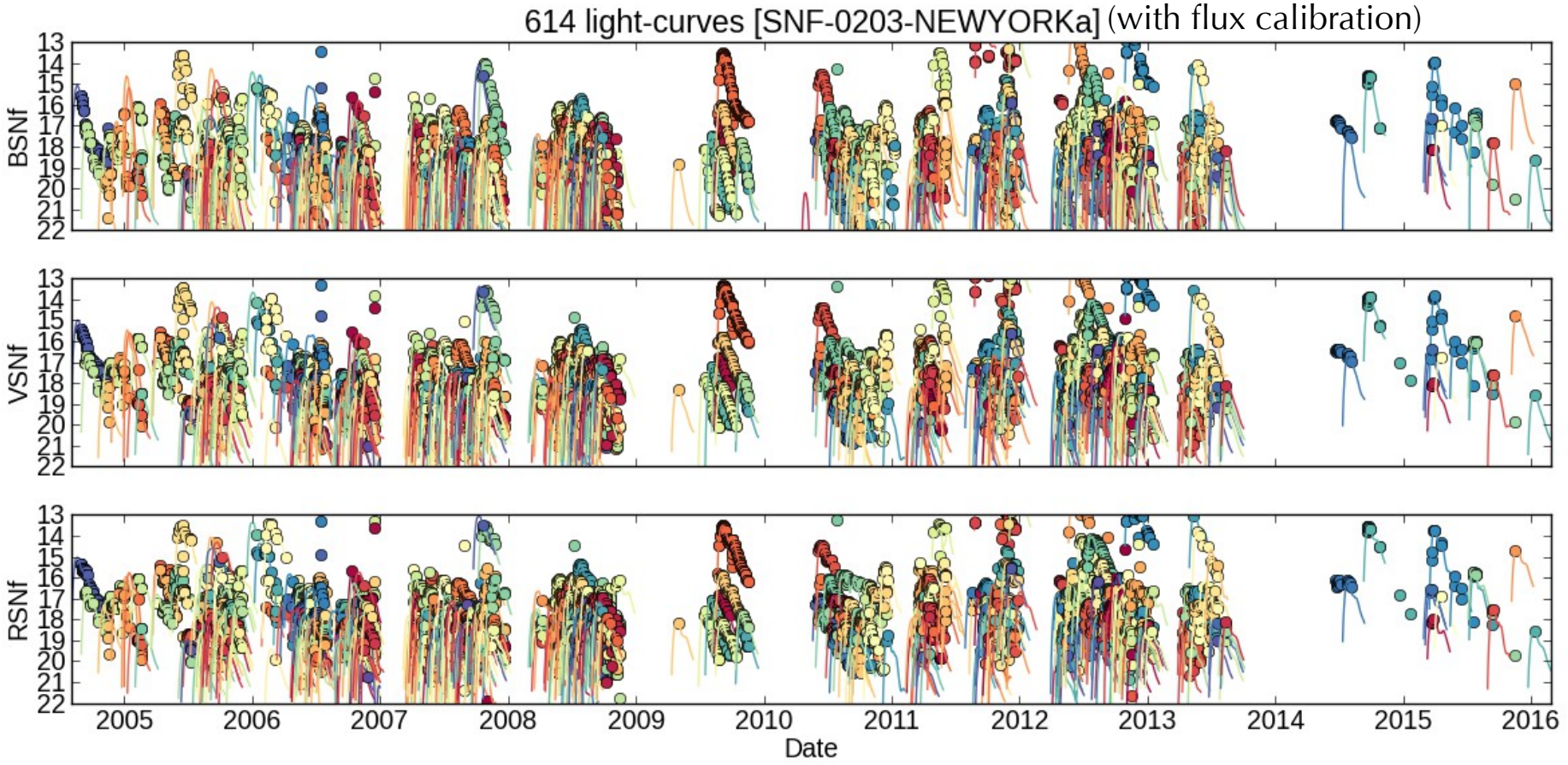
Observations every 2-3 days :
Spectrophotometric time series

On sky since 2004

The sample so far

Palomar/QUEST search over in 2008
→ untargeted search
SNF2 started 2011 with PTF SNIa and LSQ
Still running ...

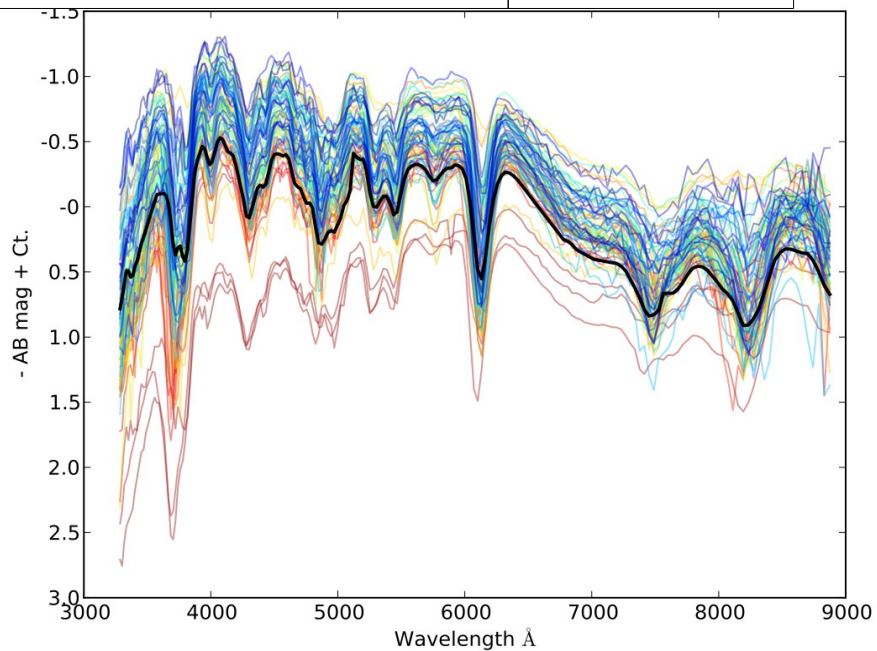
	Total
Spectred supernovae	1123

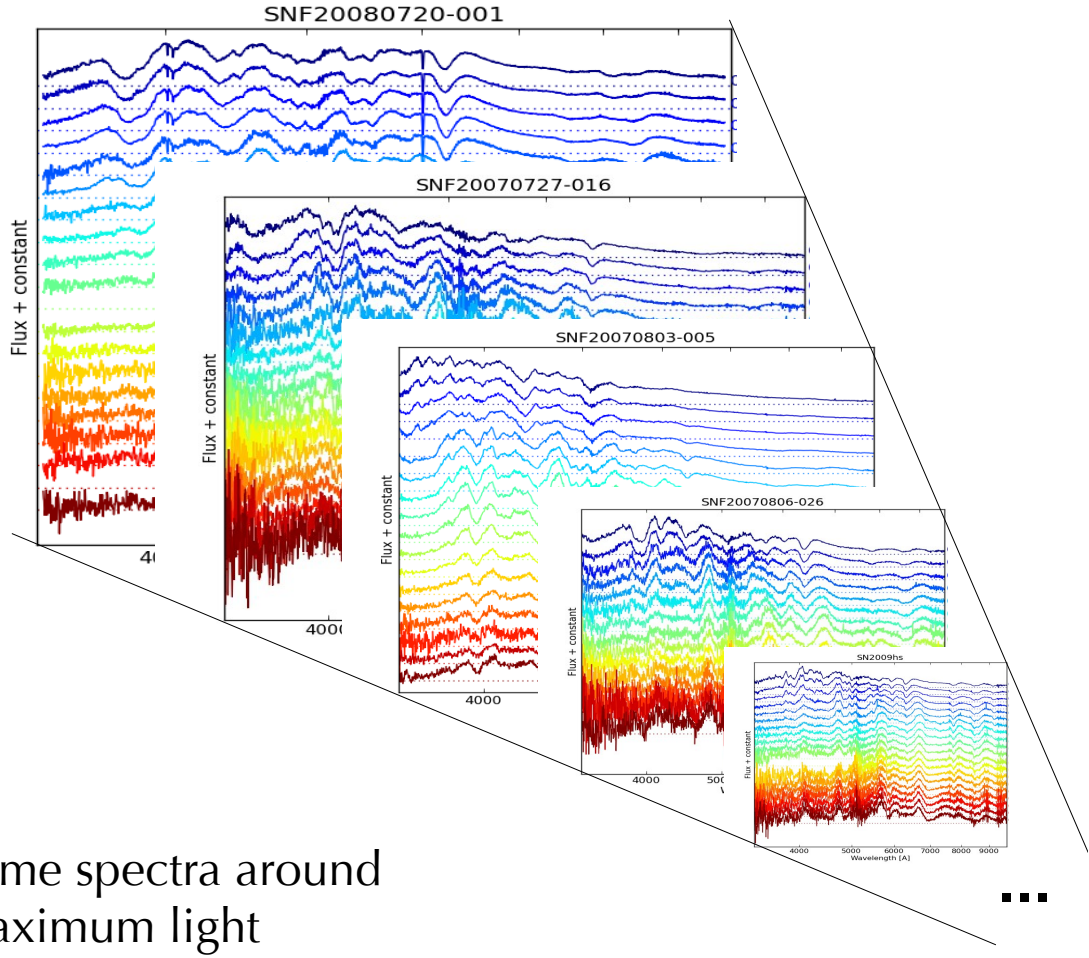


The sample so far

Palomar/QUEST search over in 2008
→ untargeted search
SNF2 started 2011 with PTF SNIa and others
Still running ...

	Total
Calibrated supernovae	614
>=4 epochs	287
Gold SNIa supernovae	**234**
Gold spectra	3503
Spectra / SN	**~15**



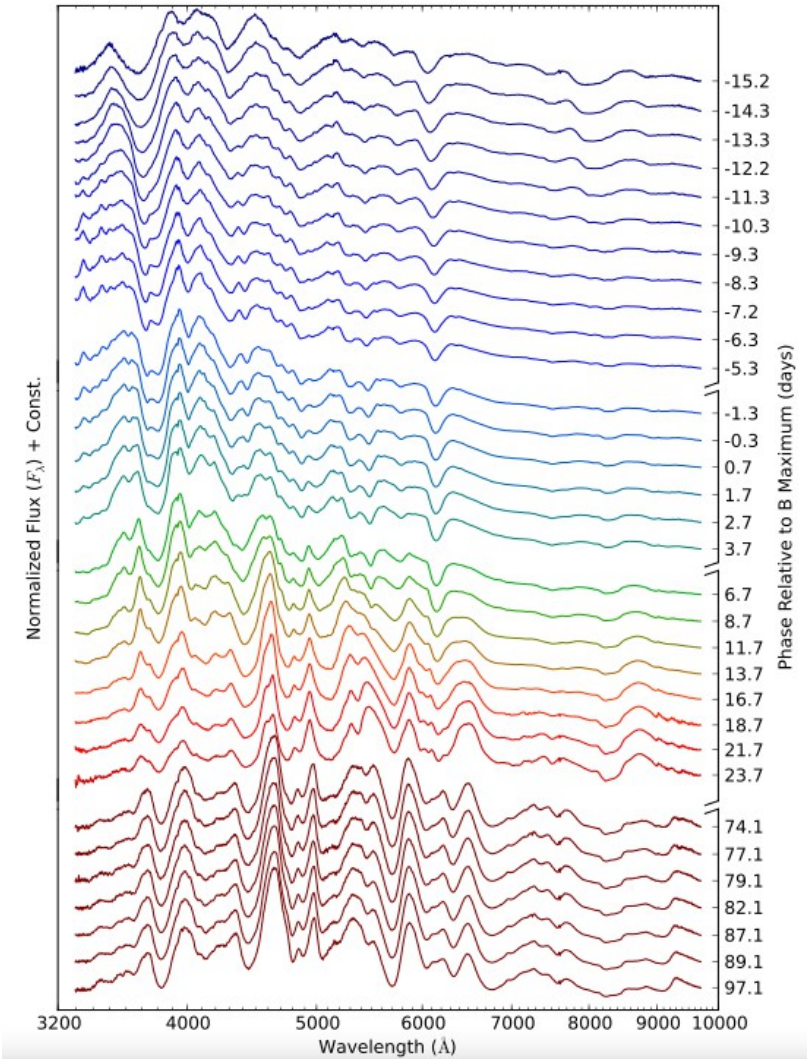


Some spectra around maximum light

...

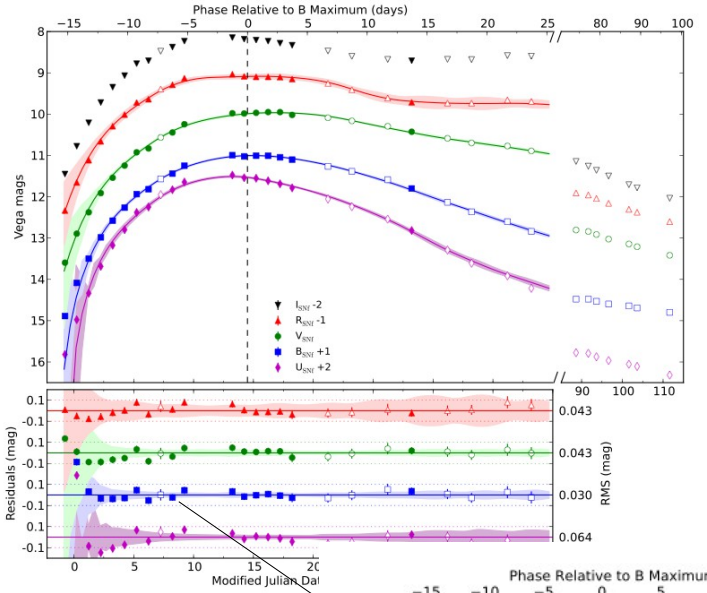
Example : SN2011fe

SN2011fe time serie

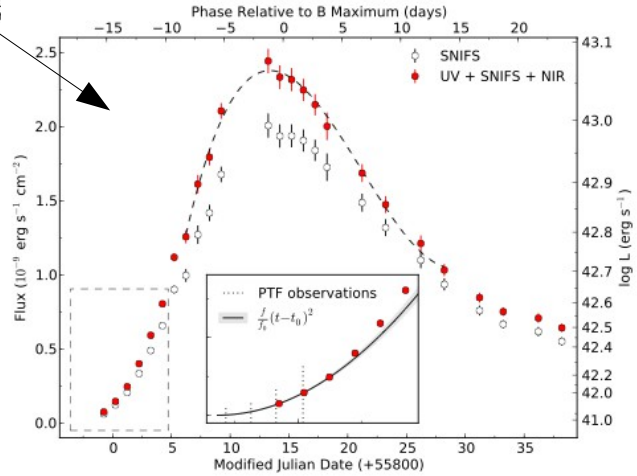


Pereira 2013

Synthetic photometry

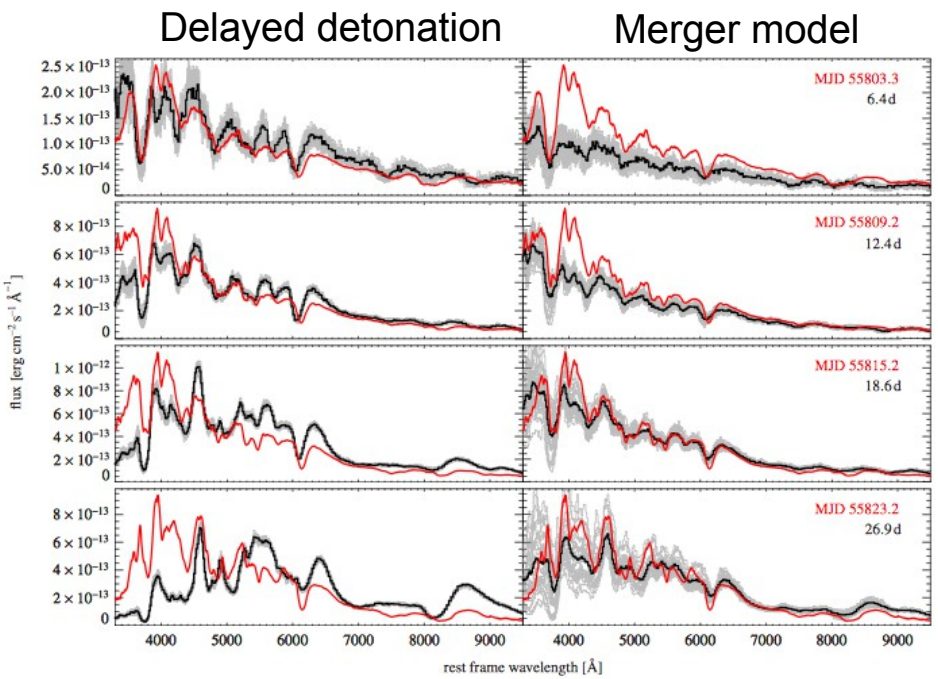


Bolometric light-curve



Some astrophysics results

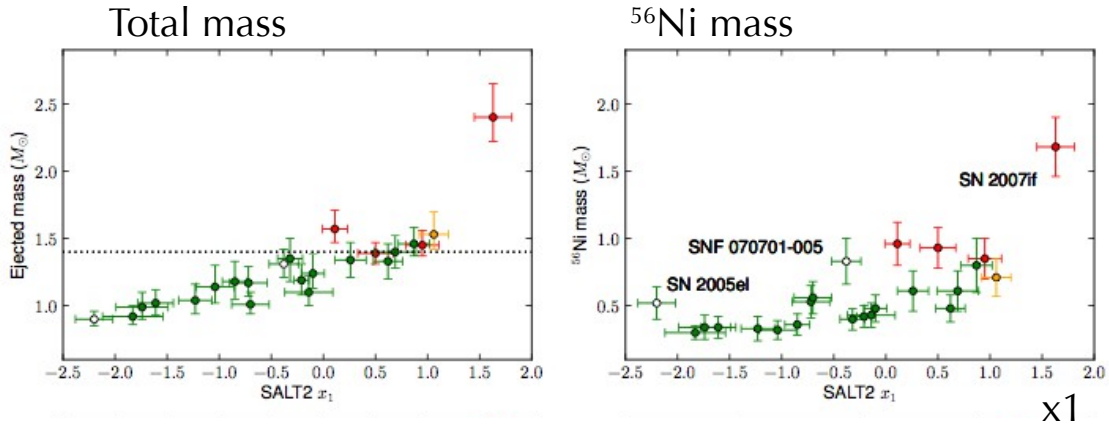
Comparison with explosion models

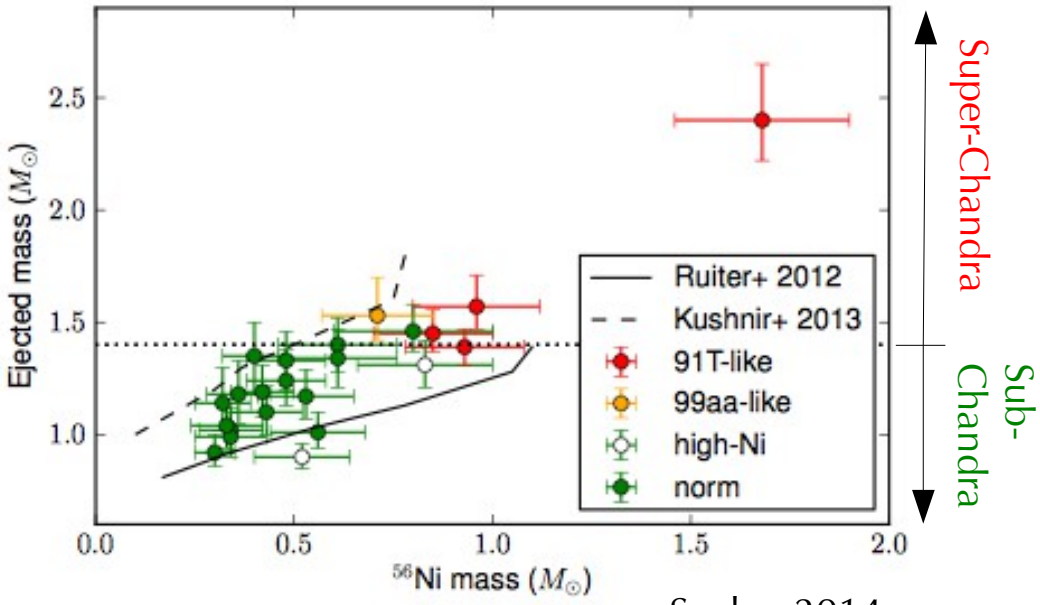


Röpke 2012

… see also Sasdelli 2015

Derivation of ejected mass

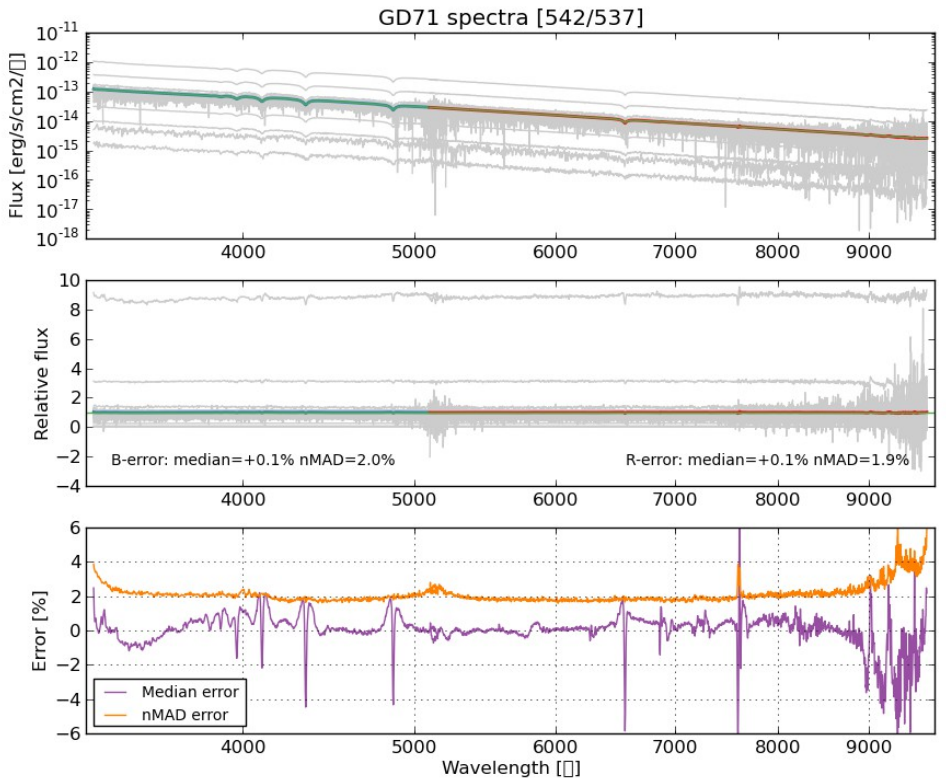




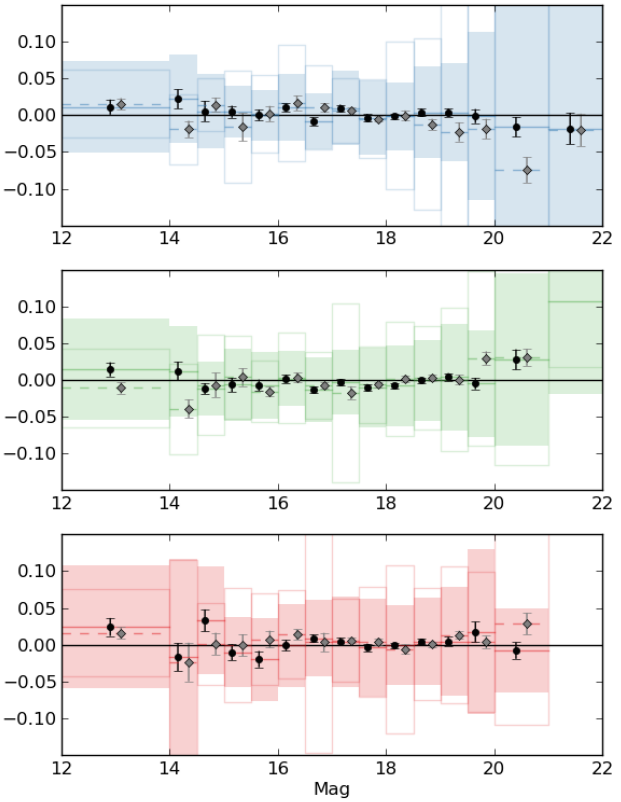
Scalzo 2014

Calibration accuracy

Given by repeated observations on
Standard Stars
~ 4700 observations of 28 Stdstars



Validation on Supernova
Departure from SALT2 model

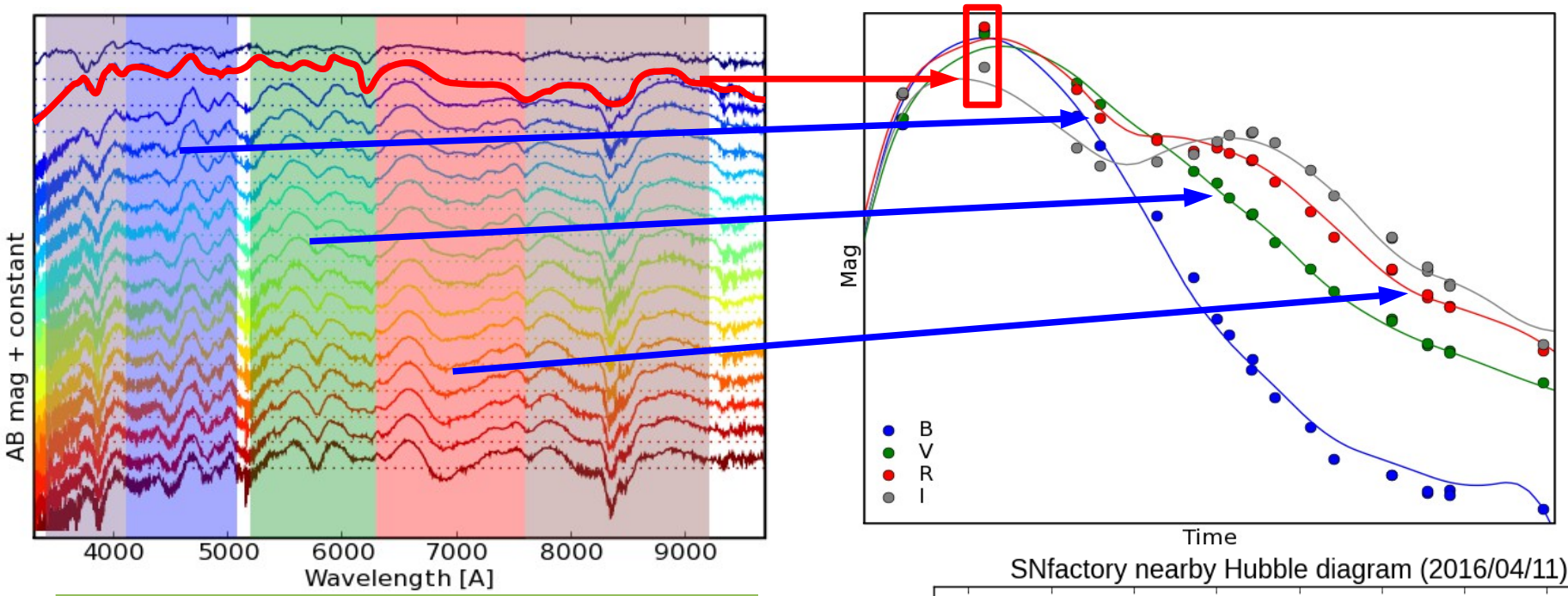


Achromatic scatter ~ 0.03

Zero-points and scatter under control

Color RMS 0.005 - 0.011 mag
→ calibration uncertainies correlated

SALT2 standardization from spectral series

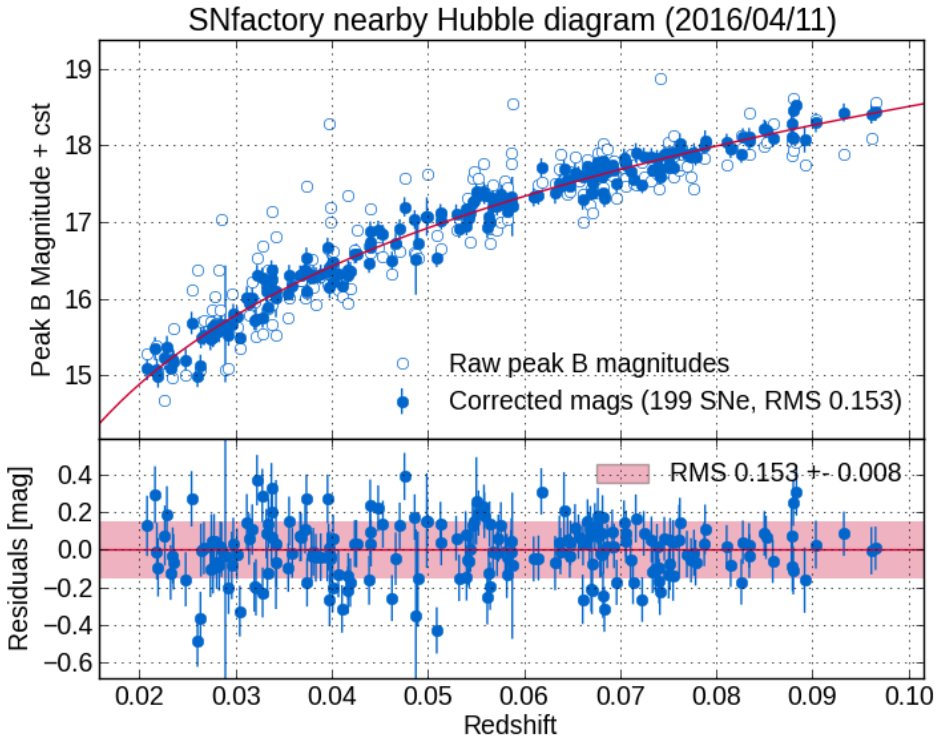


Integration on top-hat custom filters :
Minimal loss of flux
No band overlap
B,V,R SNf to fit x1,c

Standard Hubble diagram fit :

$$\mu = m_B^* - M + \alpha x1 - \beta c$$

Reduces residuals from 0.40 to 0.15 mag
Added magnitude dispersion
Low value for beta



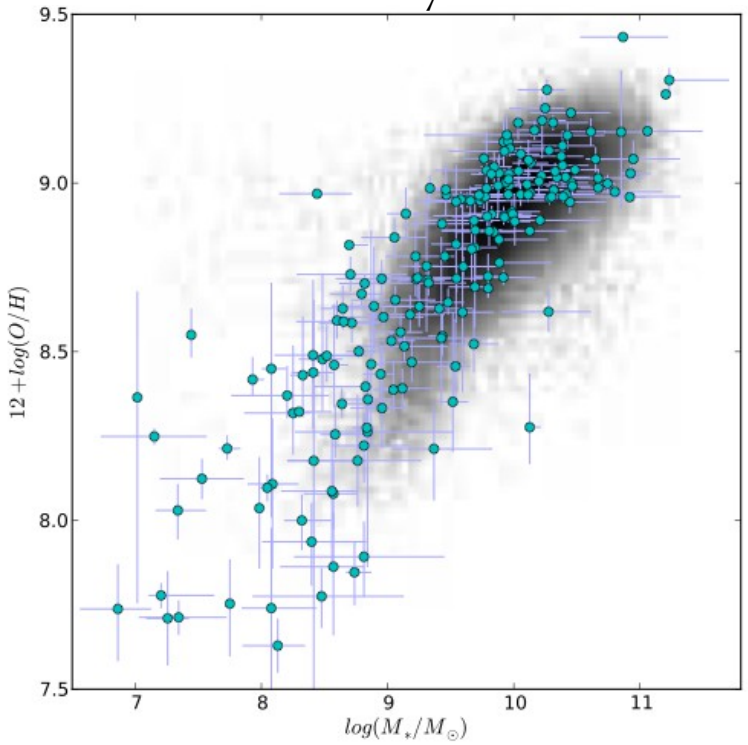
Beyond traditional SALT2

- Host studies
- SED model
- Twins

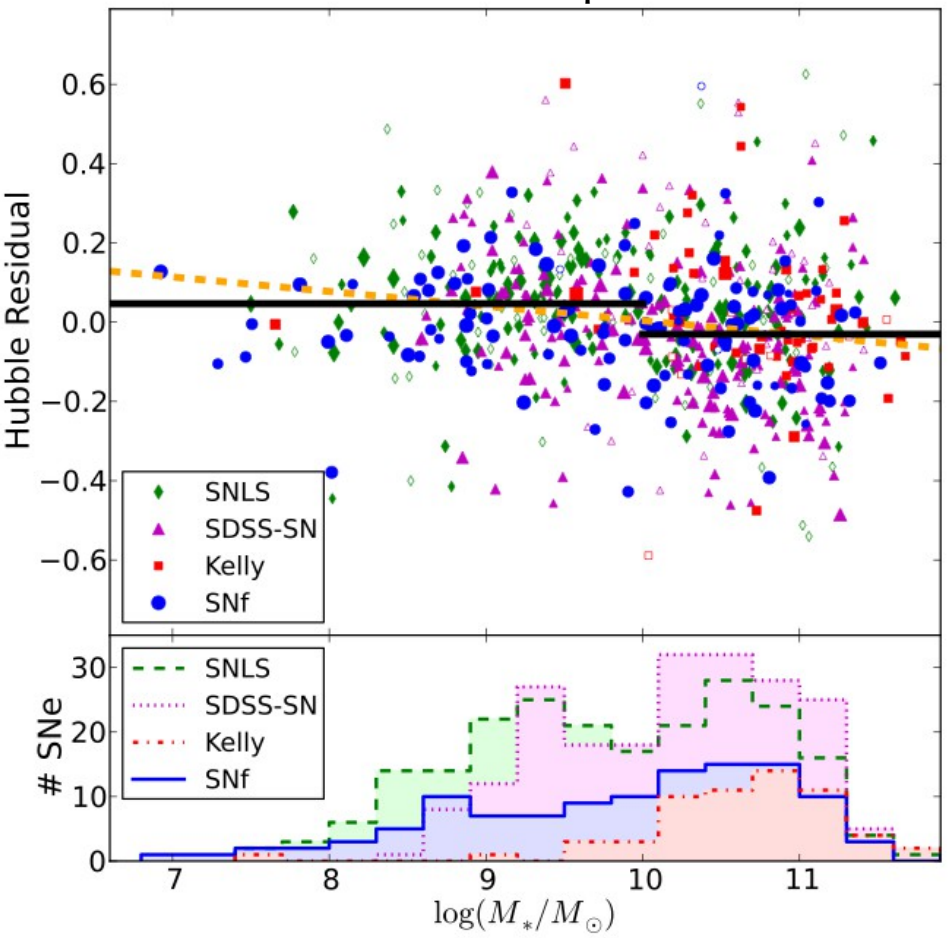
Global Host Analysis

Childress 2013

Mass-metallicity of SNF hosts



Mass Step



- SN hosts follow normal mass-metallicity relation
- Color-metallicity follows Hoeflich prediction
- Simple A+B model for host mass distribution
- Mass step comes from age and statistical properties, not metallicity

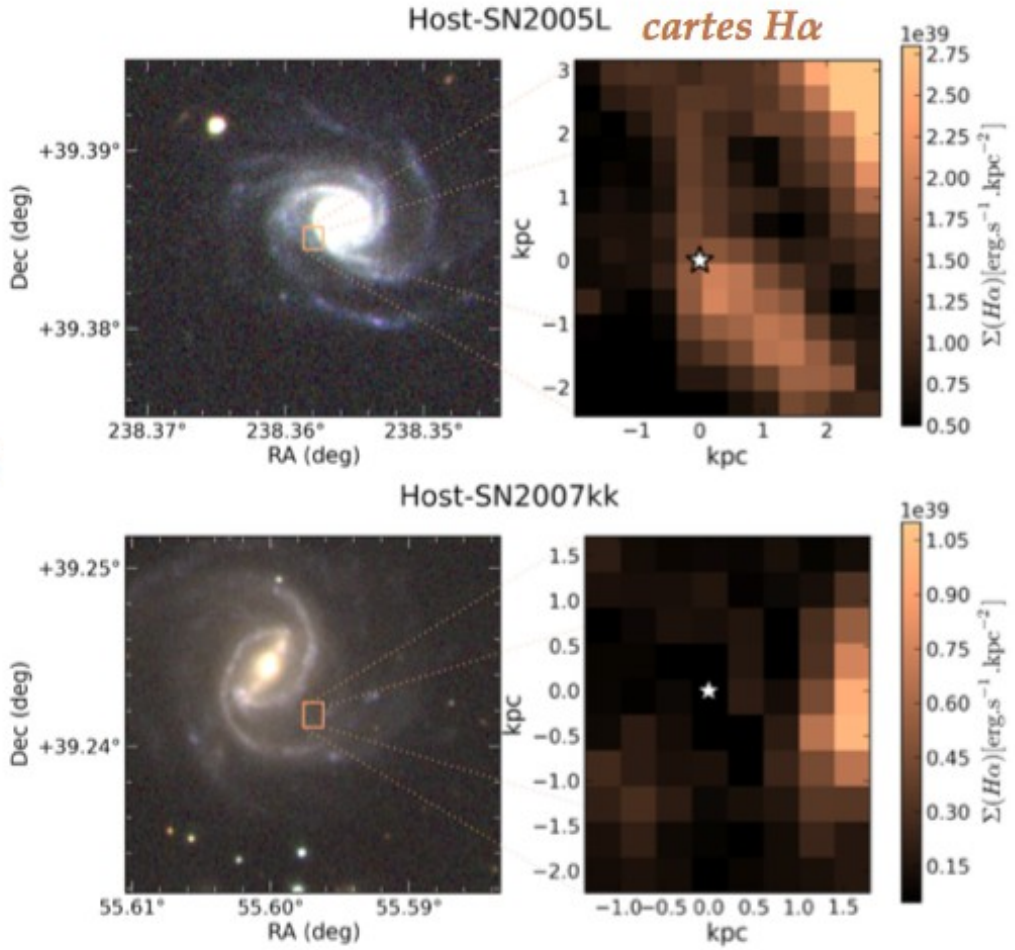
Local Host Analysis

Rigault et al. (2013, 2015)

GLOBAL

LOCAL

Spiral Star forming galaxies



Locally Star-forming

—

There is young stars

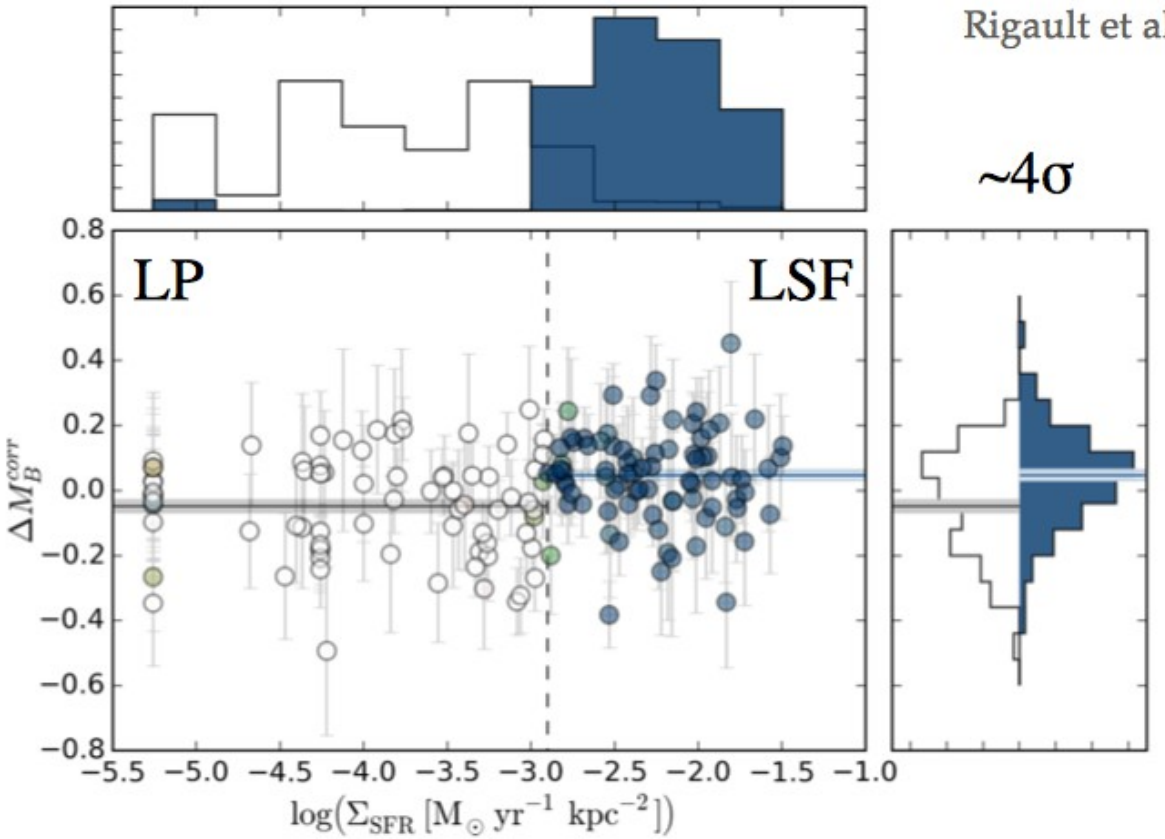
Locally passive

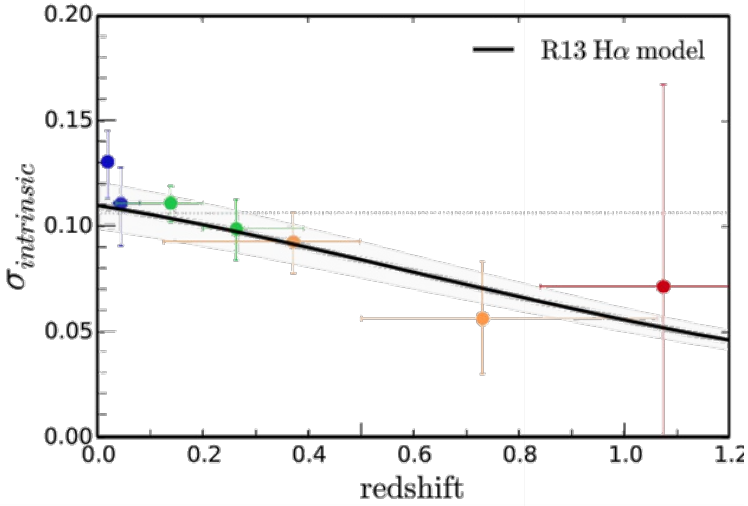
—

~No young stars

The Locally Star-forming bias

Rigault et al. 2013, 2015





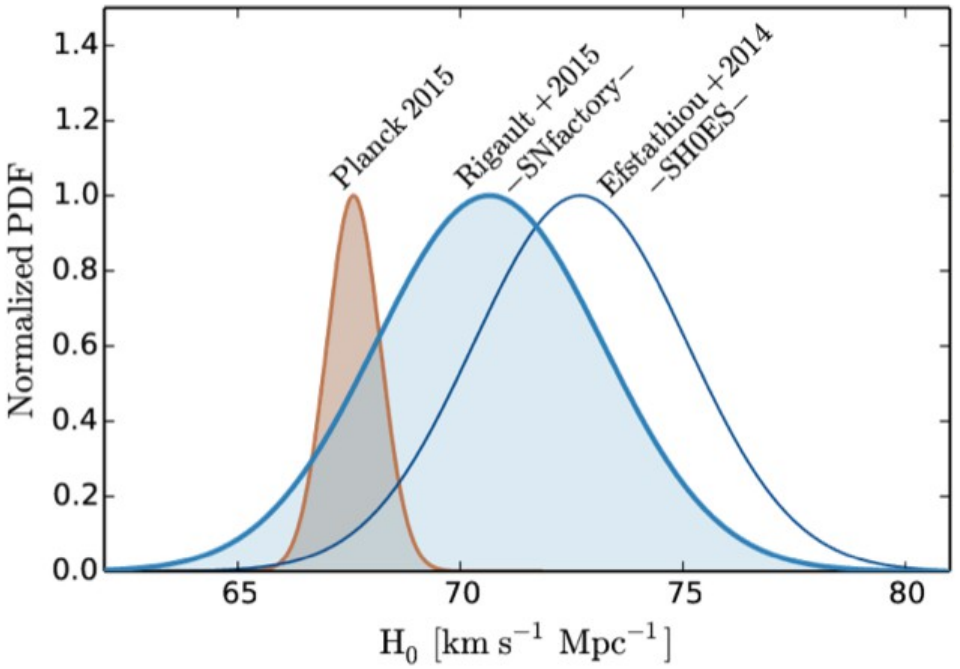
Bias the cosmology if the relative fraction of LSF changes (as a function of redshift and/or sample)

→ leads to similar analyzes in JLA sample

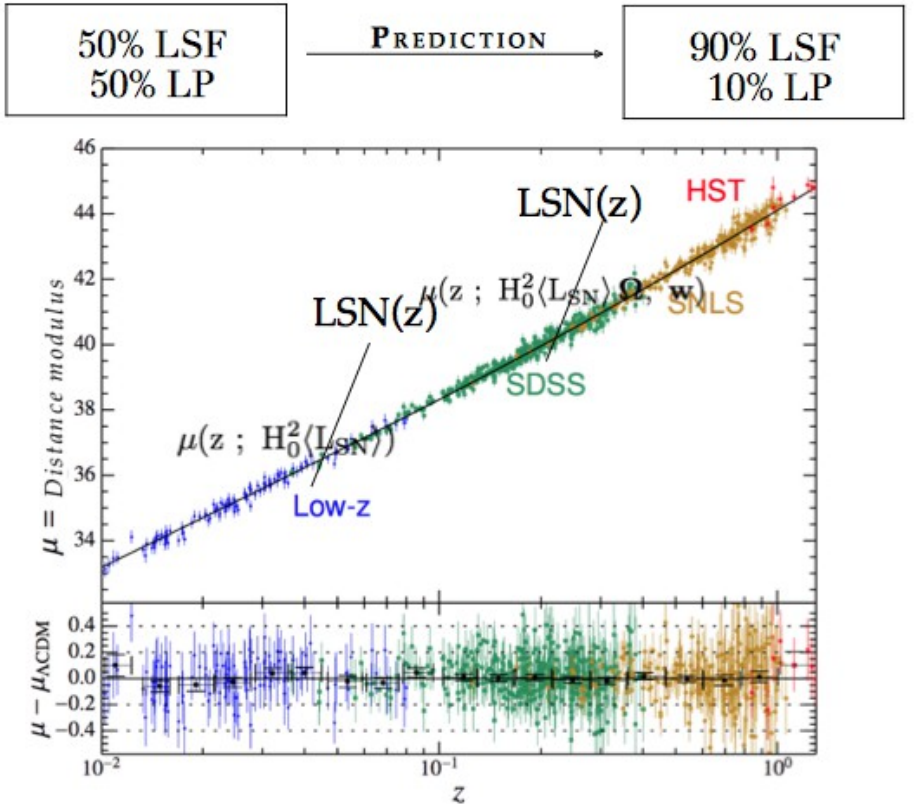
Bias due to local environment

Bias on H0

Cepheid-SN calibrators are from LSF environment while only 50% of the Hubble Flow SNe are



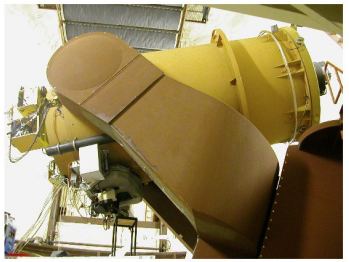
Bias on *w*



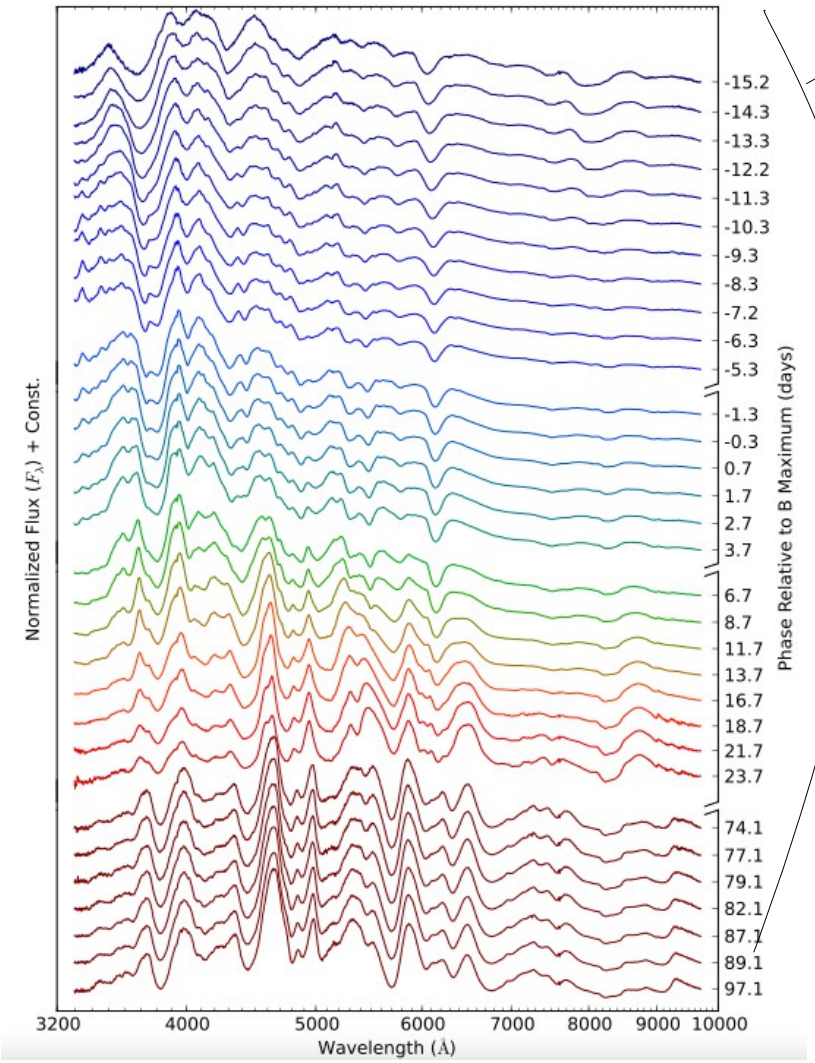
Could affect *w* by a few %

→ HST host observation campaign going on

Building an SED model



beyond **SALT2**



SN2011fe *(Pereira et al. 2013)*

SED

The **SUGAR** approach :

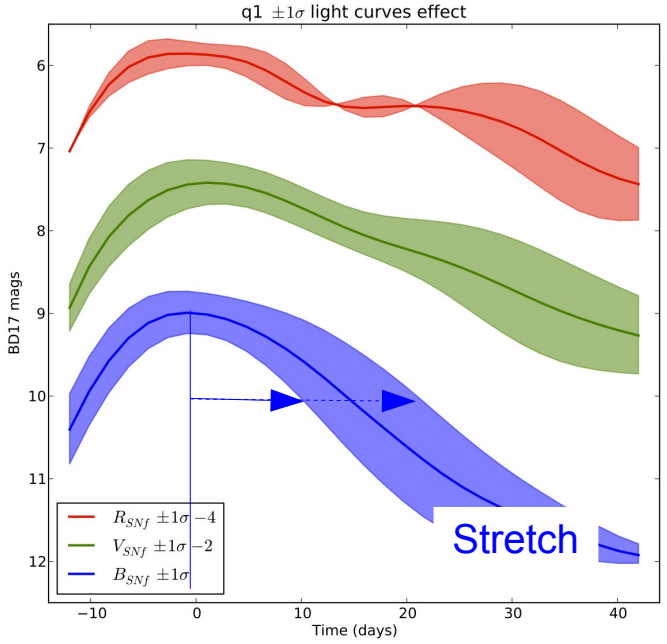
$$M(t;\lambda) = M_0(t;\lambda) + \sum_{i=1}^{i=3} \alpha_i(t;\lambda) q_i + A_V f(R_V;\lambda) + \Delta M_{grey}$$

3 intrinsic parameters
→ Physically inspired (derived from spectral indicators)

1 color
→ no a priori on color shape

There is also the **GP-based** approach
(Kim, Saunders)

SUGAR Spectral Energy Density model :

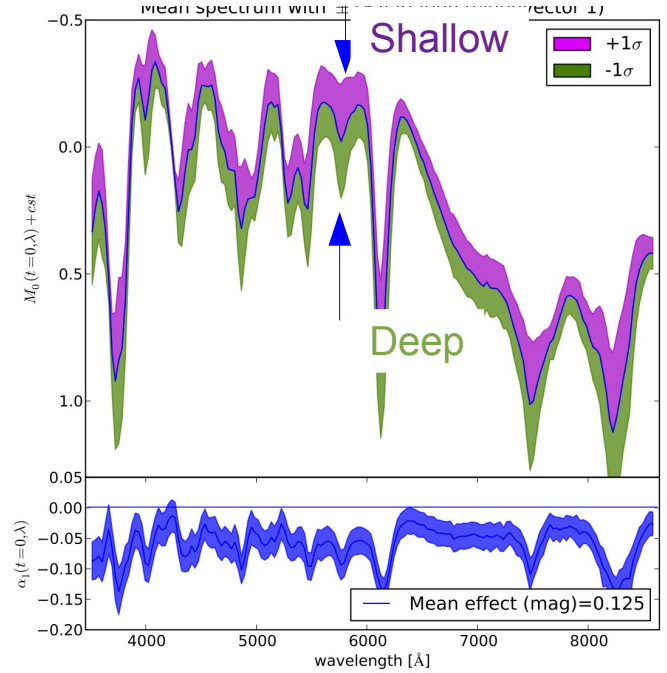


$$M(t;\lambda) = M_0(t;\lambda) + \sum_{i=1}^{i=3} \alpha_i(t;\lambda) q_i + A_V f(R_V;\lambda) + \Delta M_{grey}$$

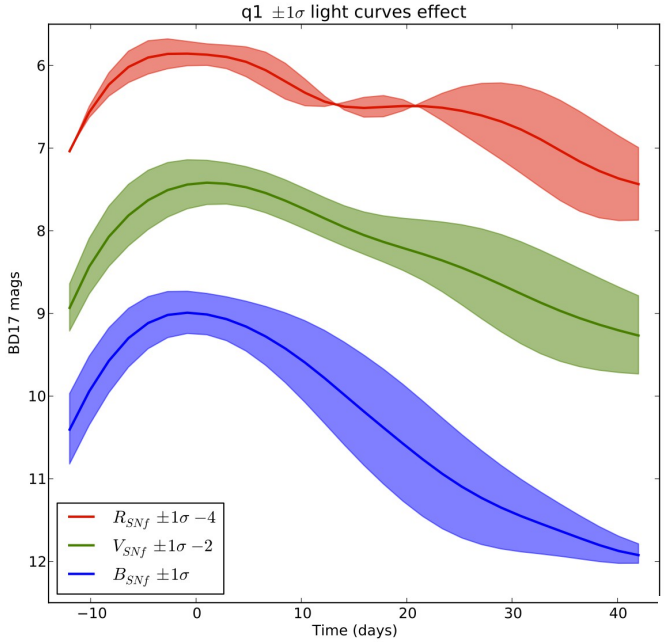
Model response :

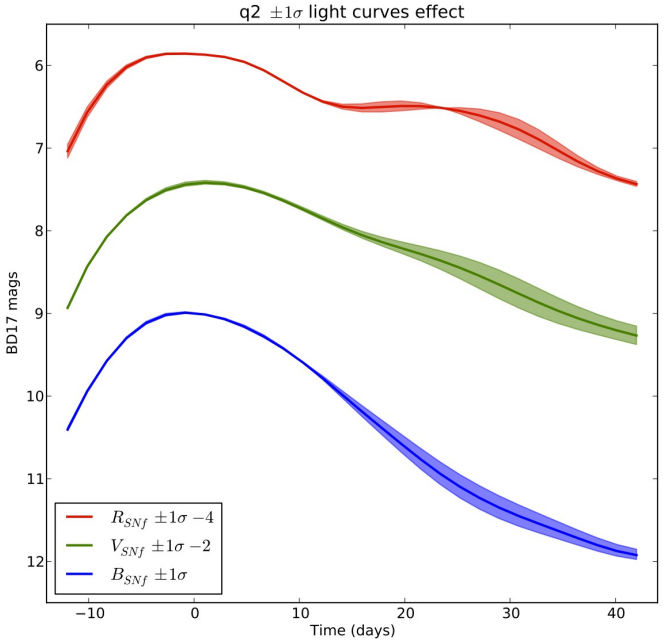
Average spectrum

Spectral vector 1 : (0.13 mag)
→ Brighter / Shallower
= stretch

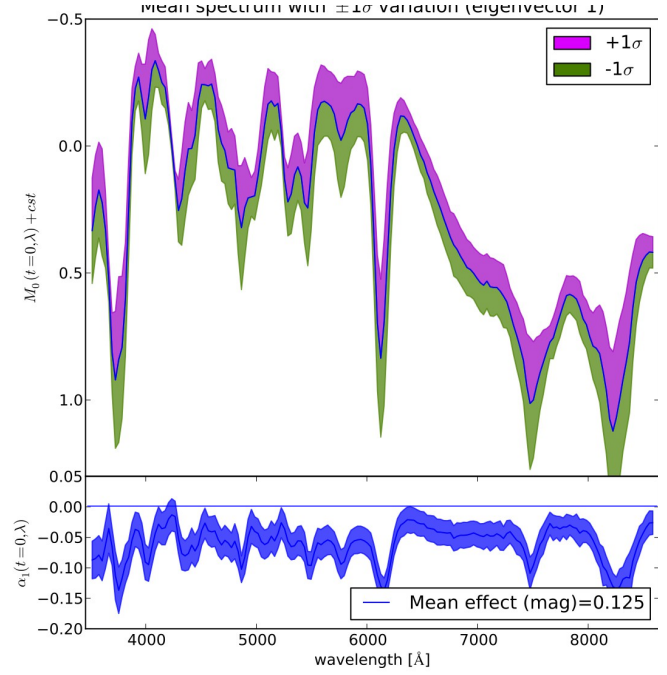


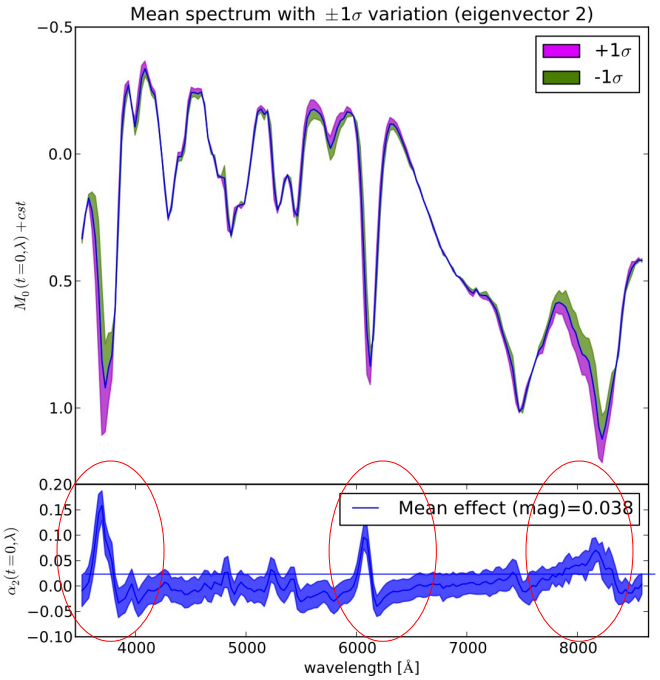
SUGAR Spectral Energy Density model :





$$t;\lambda)q_i + A_V f(R_V;\lambda) + \Delta M_{grey}$$





Model response :

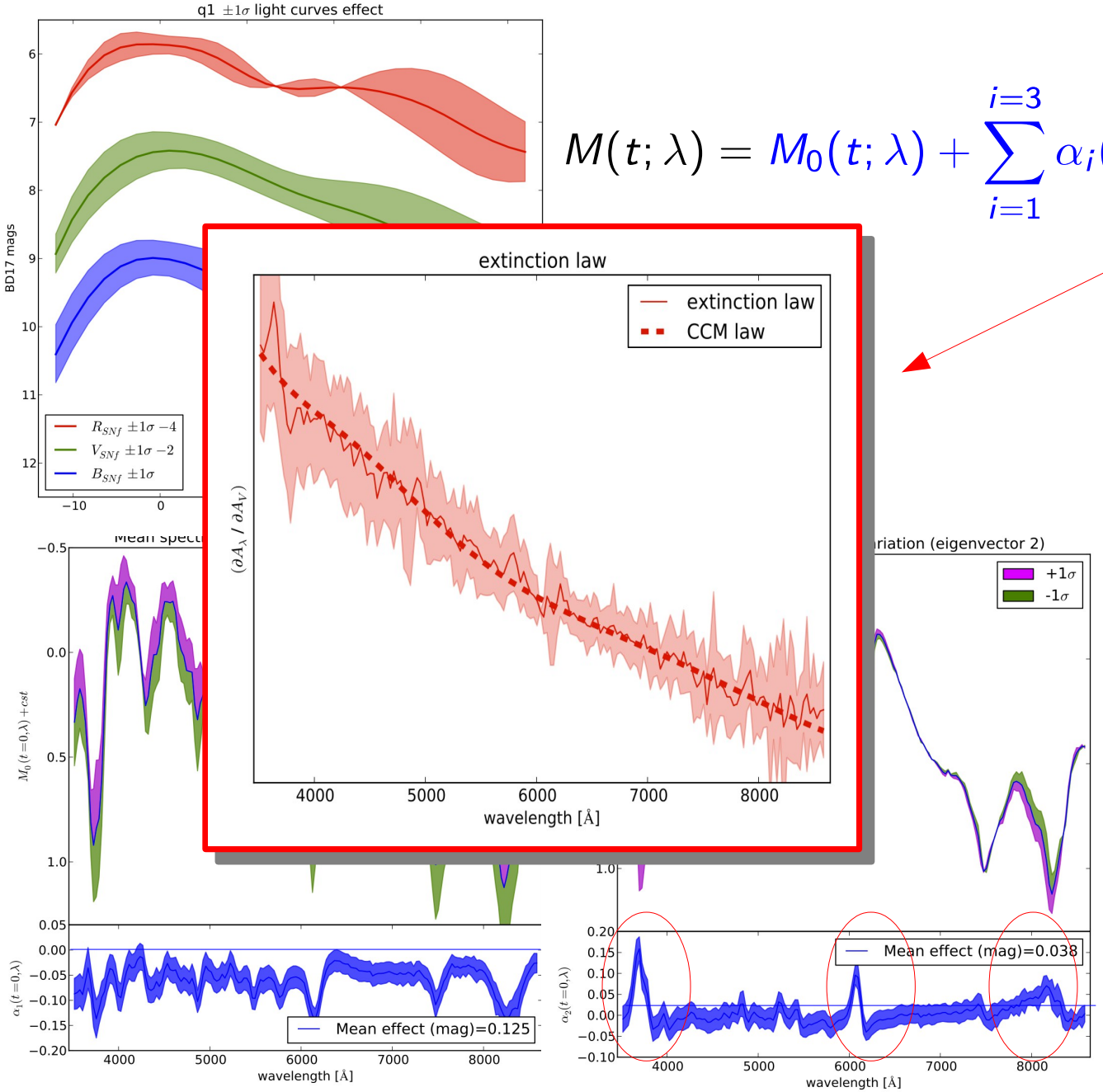
Average spectrum

Spectral vector 1 :(0.13 mag)
→ Brighter / Shallower
= stretch

Spectral vector 2 :(0.04 mag)
→ Ca / Si correlation
= marginal on LC

SUGAR Spectral Energy Density model :

$$M(t;\lambda) = M_0(t;\lambda) + \sum_{i=1}^{i=3} \alpha_i(t;\lambda) q_i + A_V f(R_V;\lambda) + \Delta M_{grey}$$



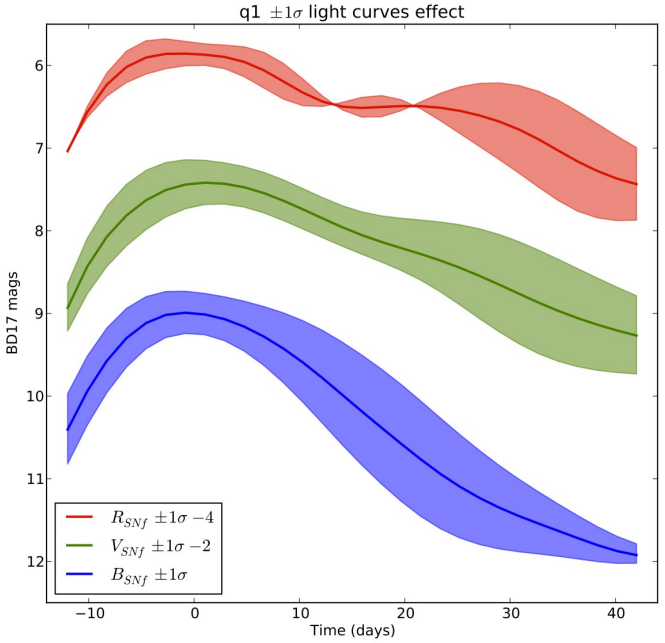
Model response :

Average spectrum

Spectral vector 1 :(0.13 mag)
→ Brighter / Shallower
= stretch

Spectral vector 2 :(0.04 mag)
→ Ca / Si correlation
= *not seen by SALT2*
Impact on color law

SUGAR Spectral Energy Density model :



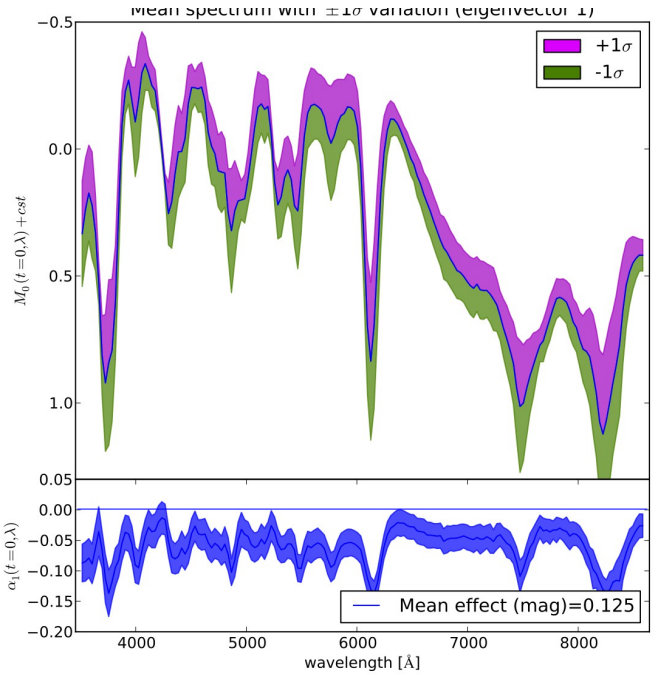
Model response :

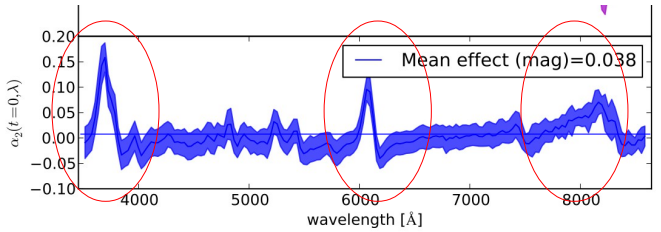
Average spectrum

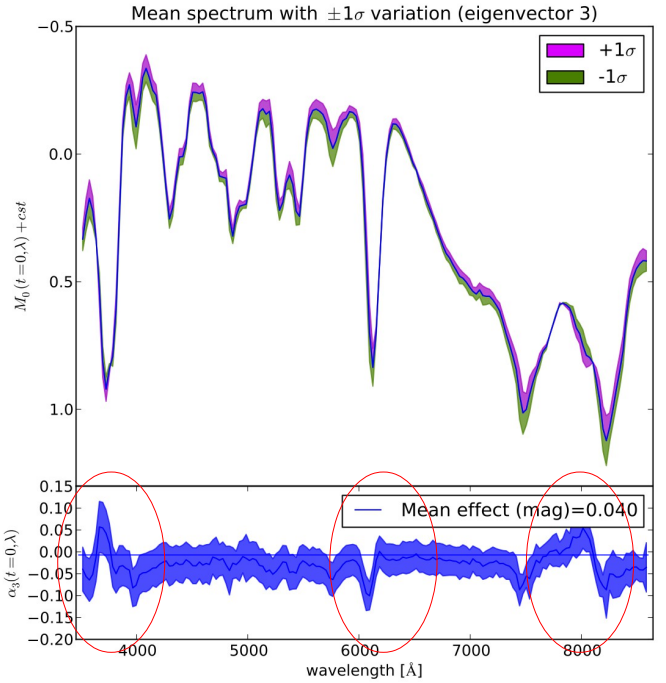
Spectral vector 1 :(0.13 mag)
→ Brighter / Shallower
= stretch

Spectral vector 2 :(0.04 mag)
→ Ca / Si correlation
Impact on color law

Spectral vector 3 : (0.04 mag)
→ Still Ca / Si influence
→ Global impact on LC

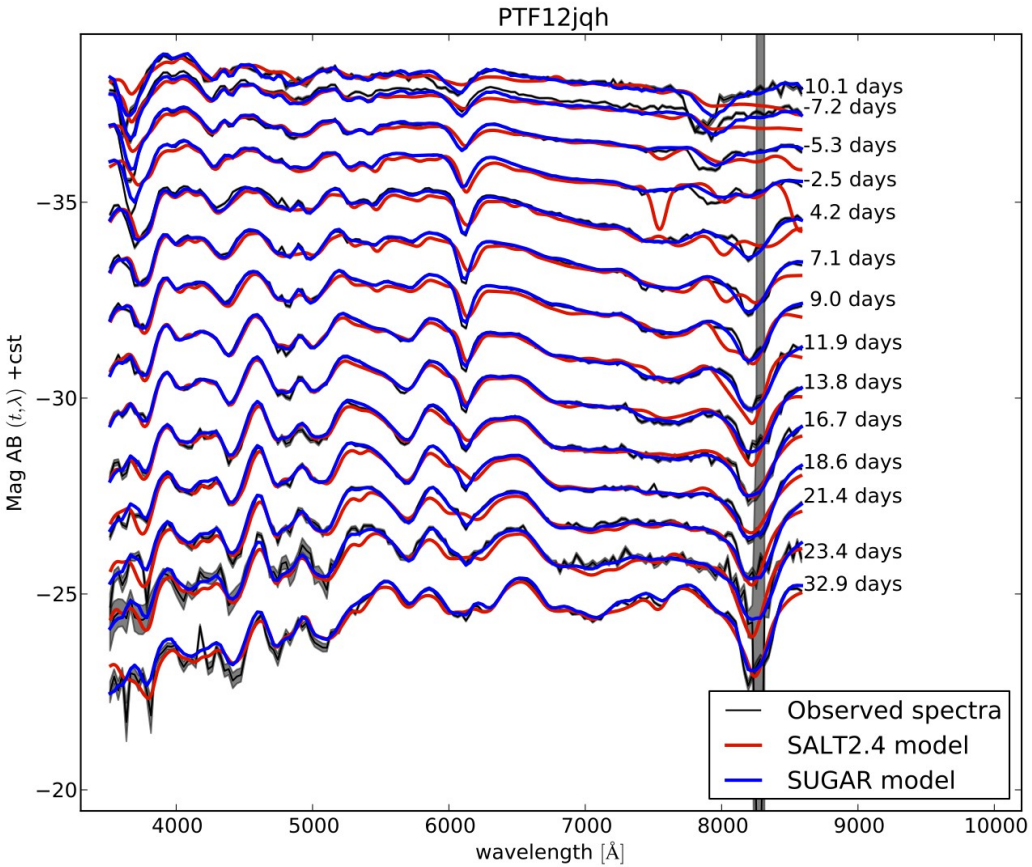




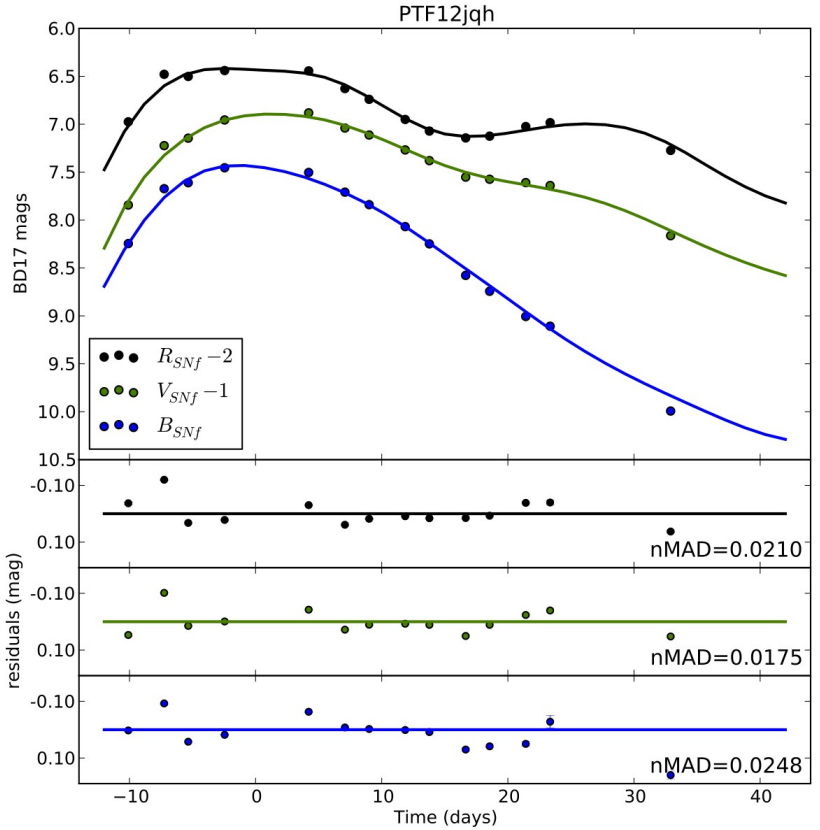


Using SUGAR as a fitter :

Spectral time serie view



Light-curve view



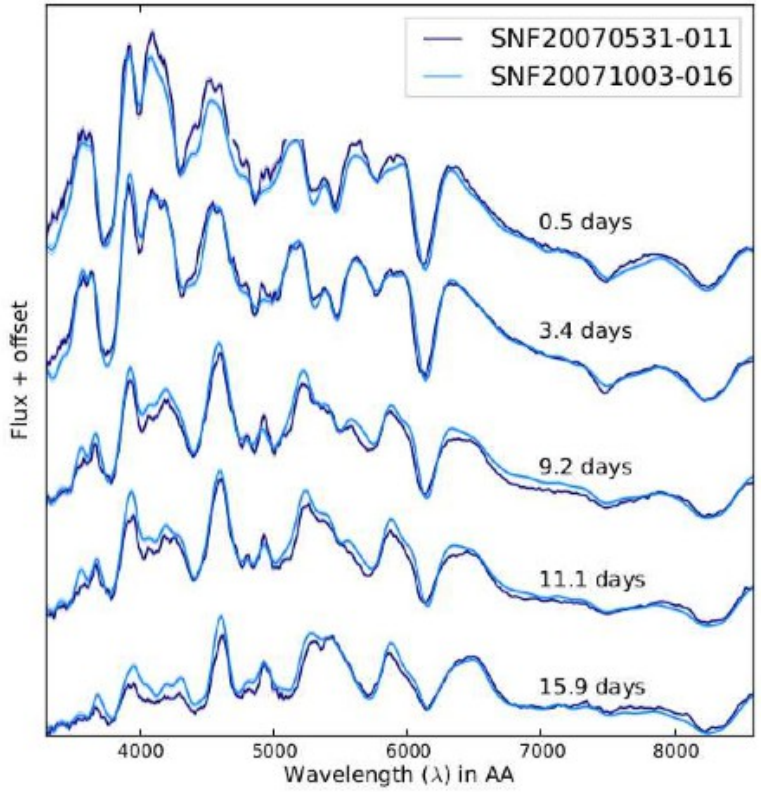
Pre-validation sample

nMAD	Bsnf	Vsnf	Rsnf
SALT2	0.073	0.051	0.056
SUGAR	0.053	0.035	0.037
Calib.	0.030	0.030	0.029

Spectral and Light-curve description improved

Standardization 0.13 mag

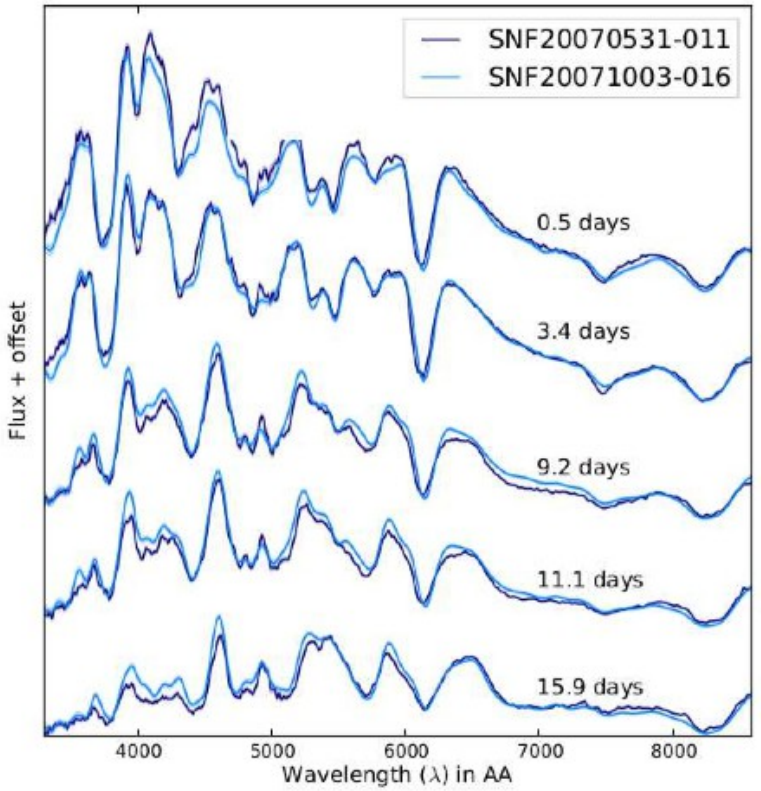
Another look at spectra : Twins



Some SN look very similar
(up to an extinction + offset)

Do they have the same flux ?

Another look at spectra : Twins



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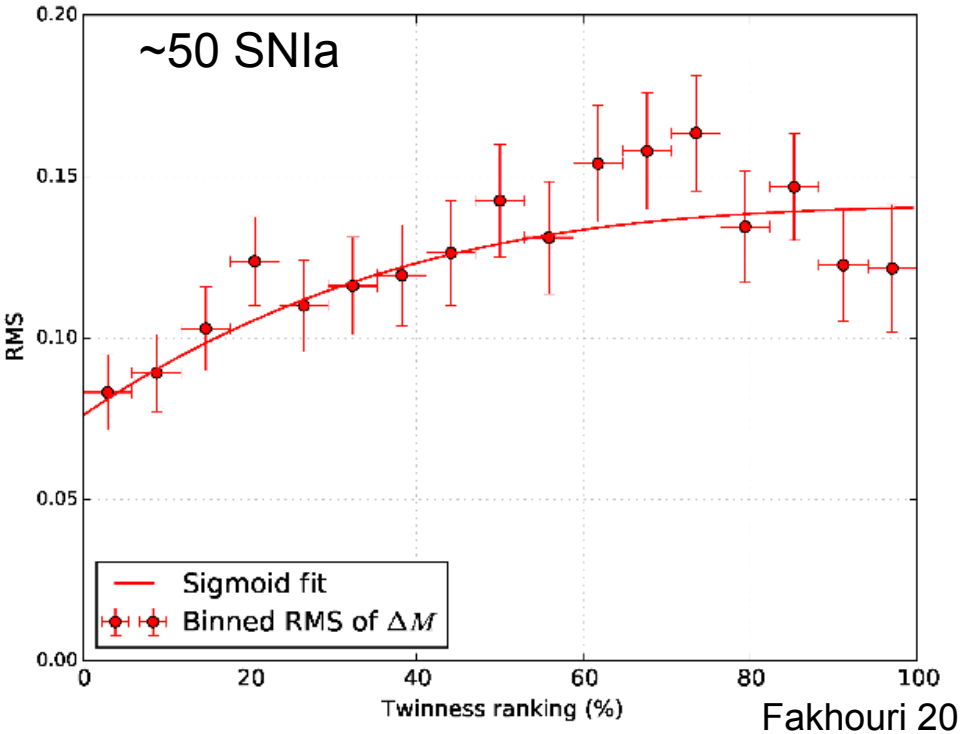
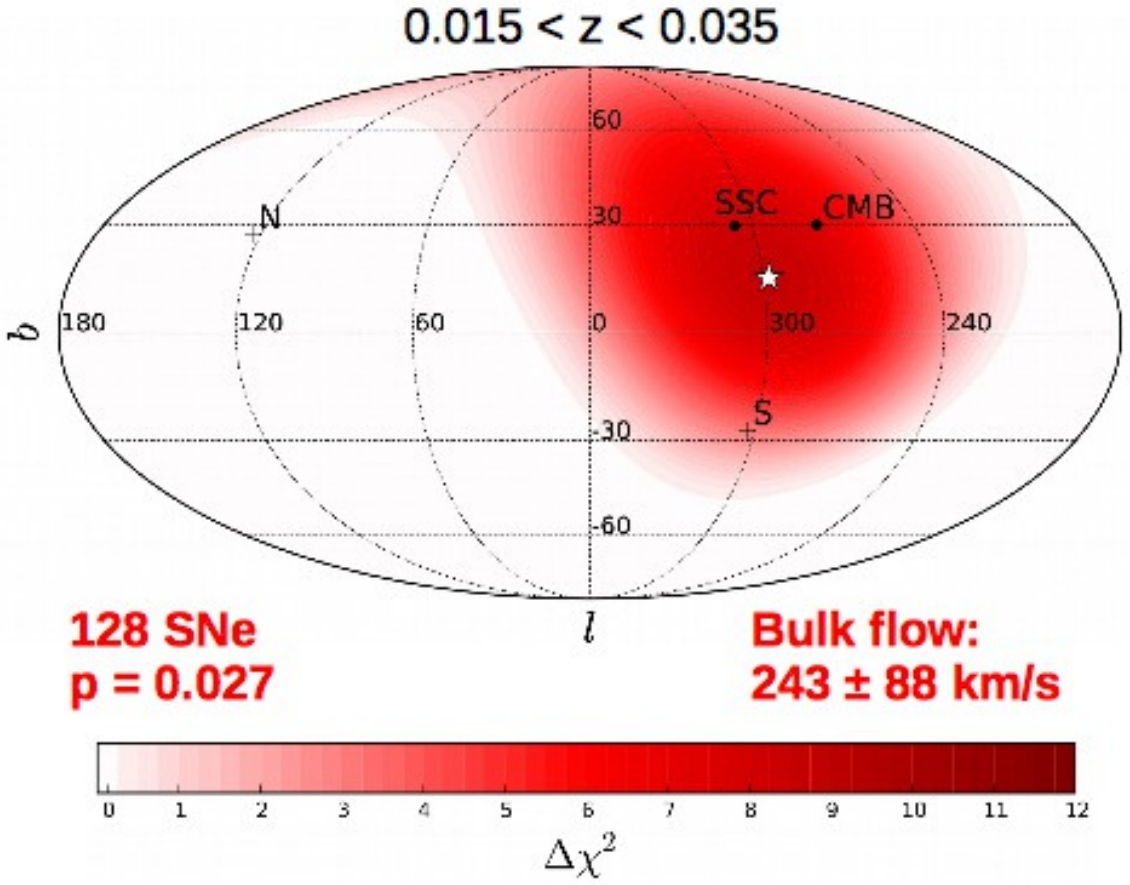


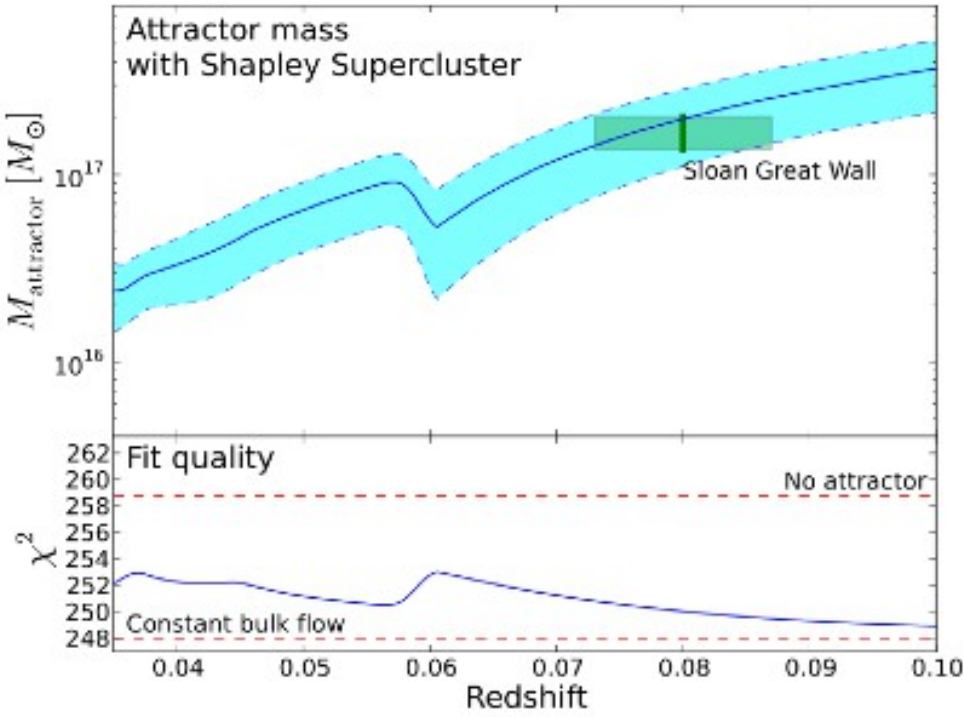
Fakhouri 2015

Analysis v2.0 in progress

Bulk flow studies

- No evidence for backside infall to Shapley
- Mass of Shapley supercluster insufficient to explain velocities
- Sloan Great Wall may explain remaining velocity





Feindt 2013

Conclusions

- SNIFS instrument *still alive and running* !
  - 5-10 nights/semester for calibration, SN screening,
  - would need refurbishing for more ambitious survey
- Data quality is *good enough for cosmological use*
  - **0.15 mag SALT2 dispersion** as other surveys
  - still some improvements going on : Stdstar network, non-linearity investigation, …
- *Improvement of standardization* techniques
  - **SED model,** multiband fit → 0.12-0.13 total dispersion easily achieved
  - *0.08 mag standardization achieved* on best twins SN…
- More analysis to come...