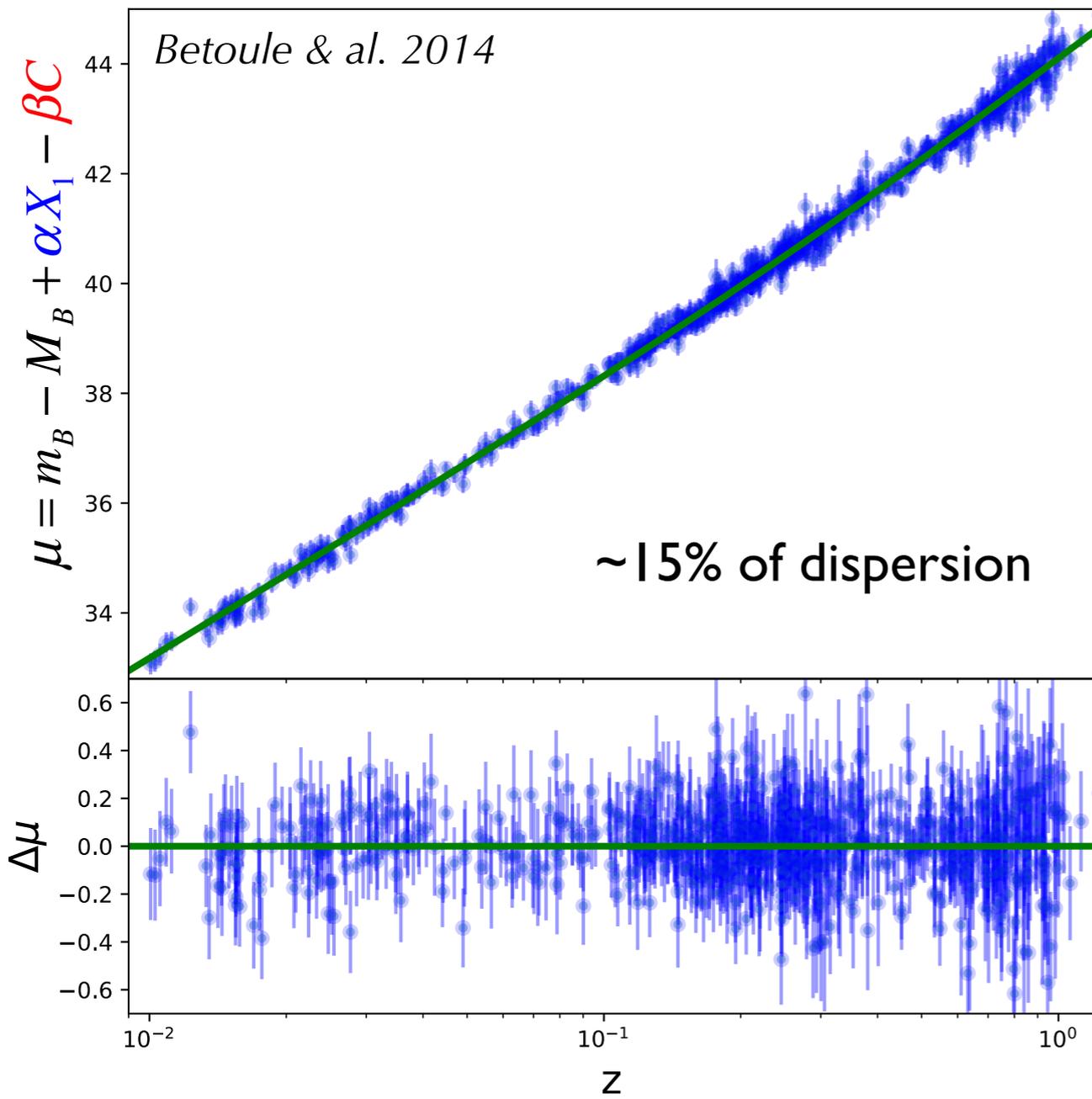


Improved description of SNIa variability for a better understanding of dark energy properties

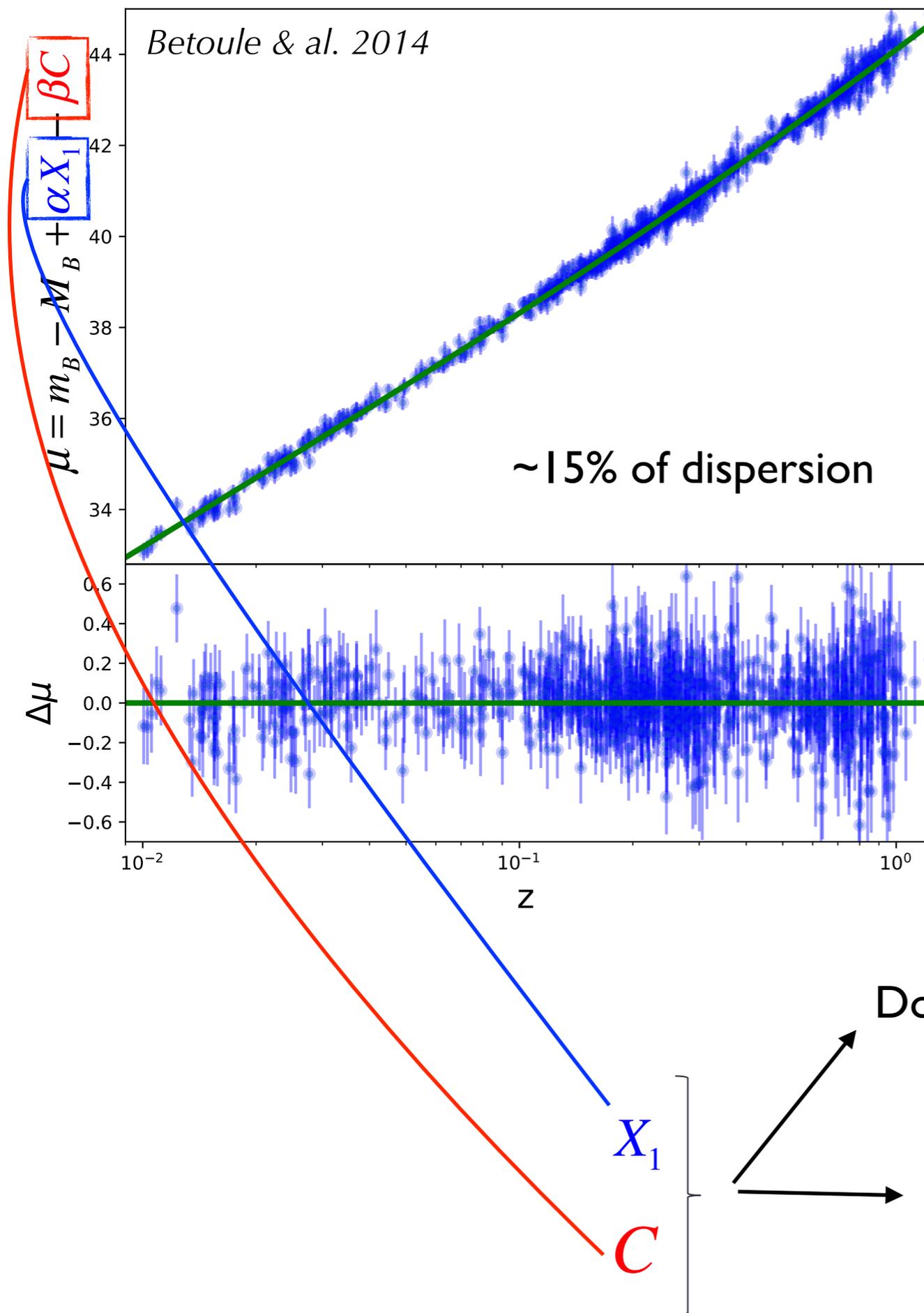
Pierre-François Léget
Postdoc @ LPNHE



Supernovae are quasi-standard candles:

Two main sources of variability:

1. **Stretch**: intrinsic variability
2. **Color**: extrinsic variability



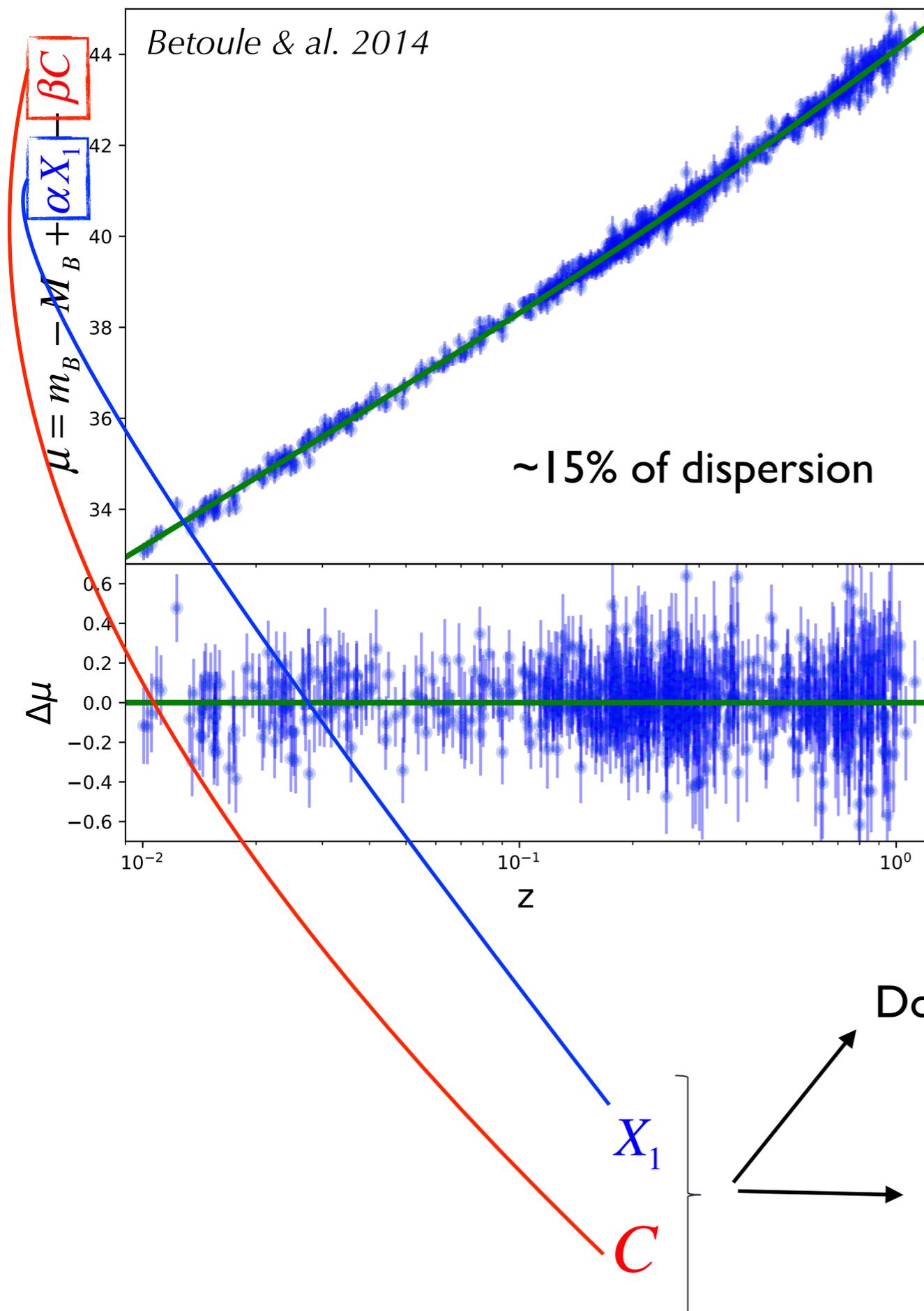
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Do those corrections are optimal ?

Do those corrections involve bias ?



Supernovae are quasi-standard candles:

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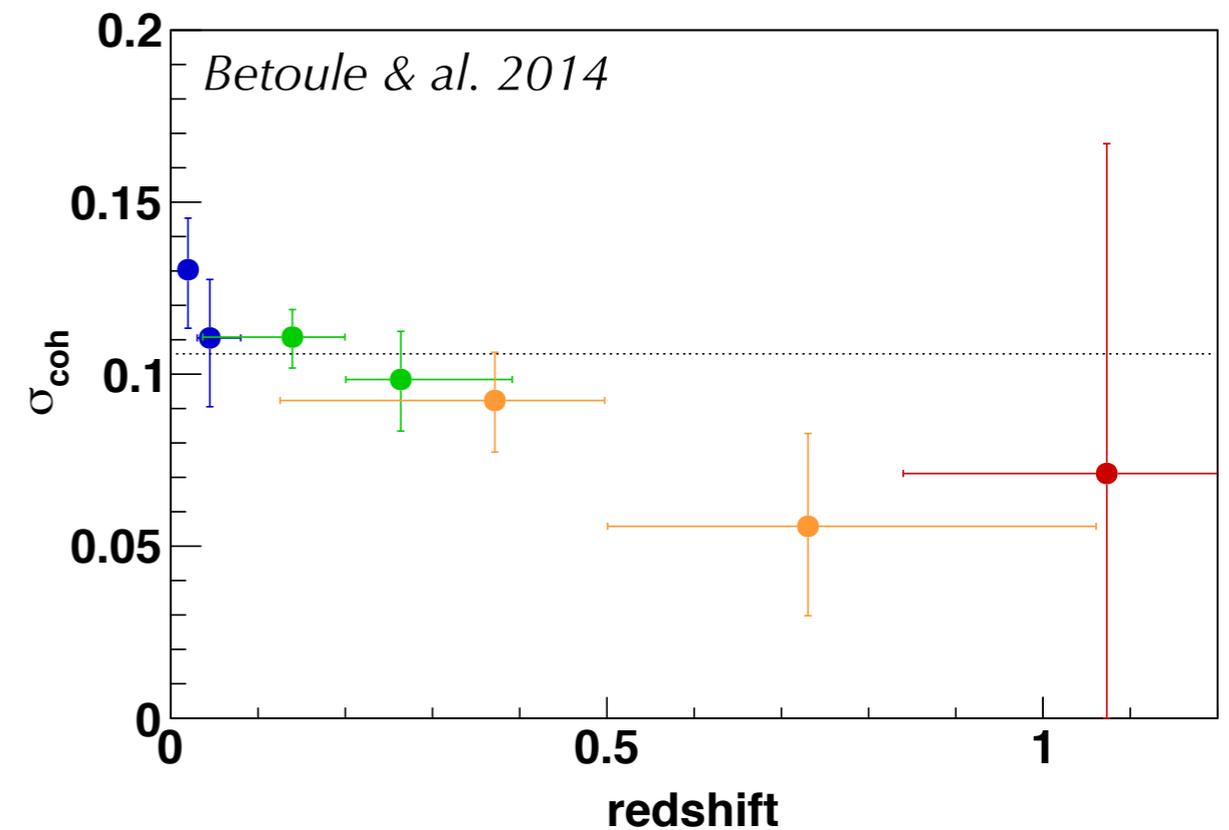
1. **Stretch**: intrinsic variability
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Do those corrections are optimal ? No ...

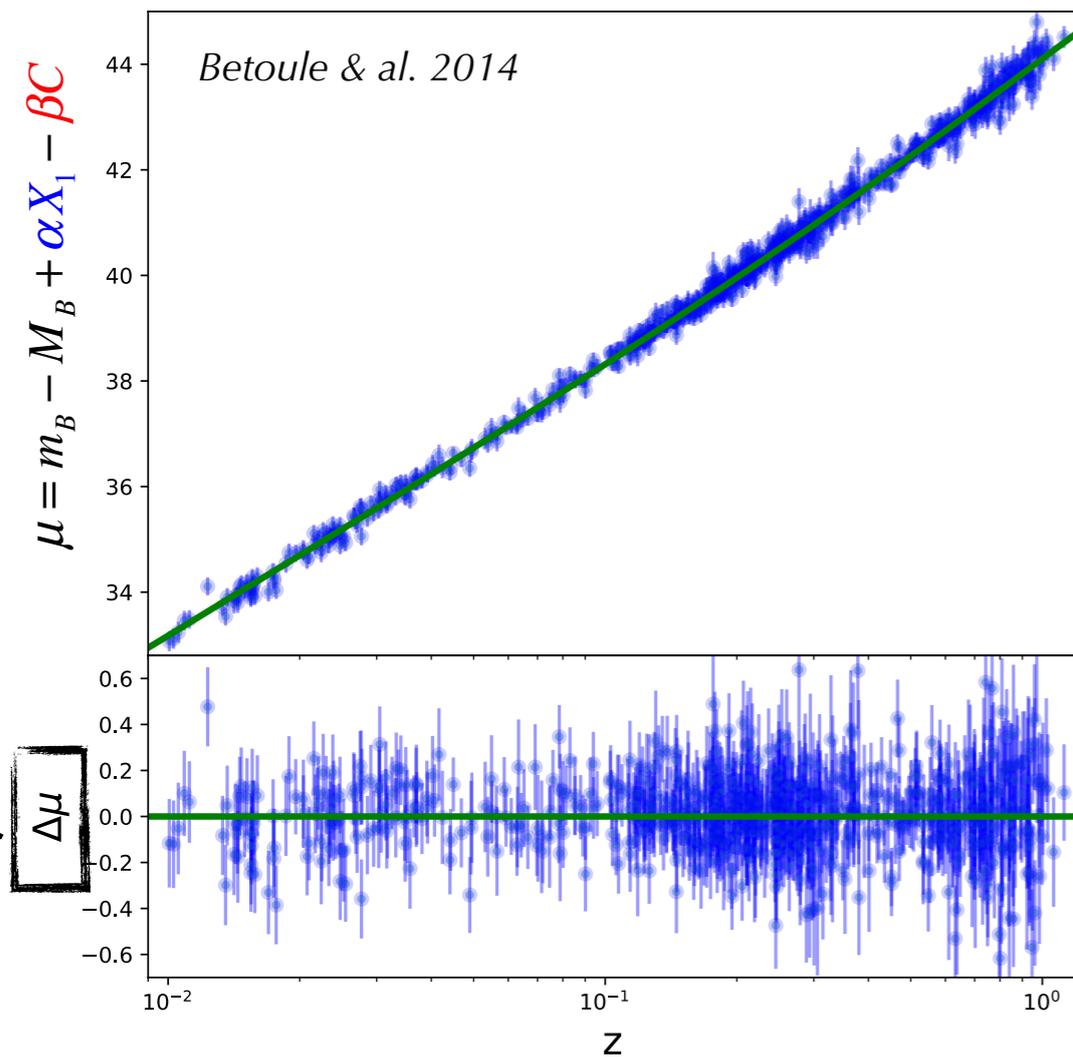
Do those corrections involve bias ? Yes ...

Do Stretch & Color corrections are optimal ?

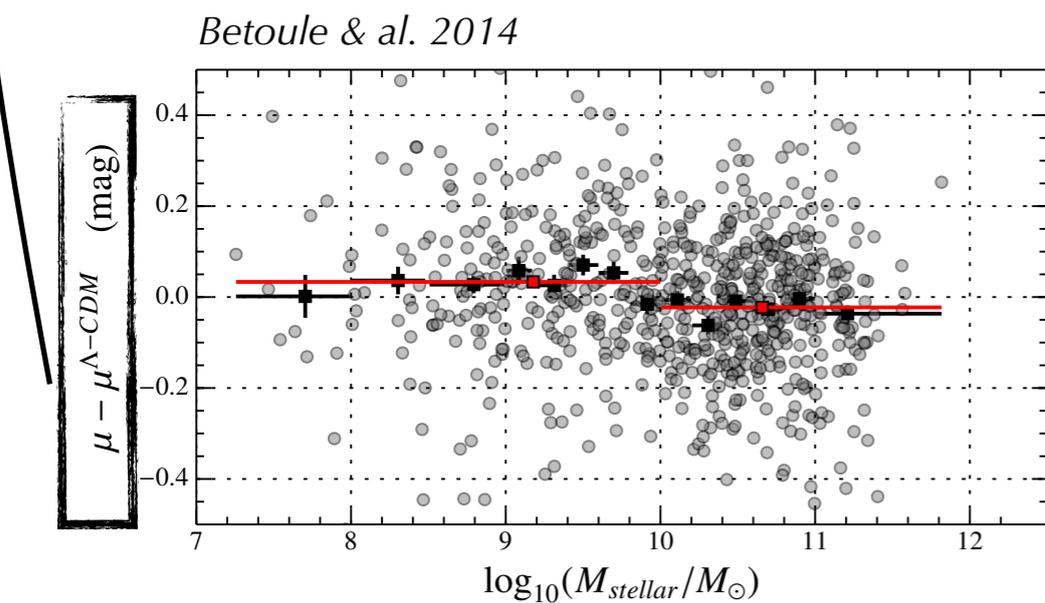
- Remaining scatter on Hubble Diagram:
 - Noise
 - Intrinsic scatter
- Intrinsic scatter: remaining variability of SNIa
- Non-zeros and evolves in terms of redshift
- Limits precision and could potentially bias cosmological analysis with SNIa



Do Stretch & Color corrections involve bias ?

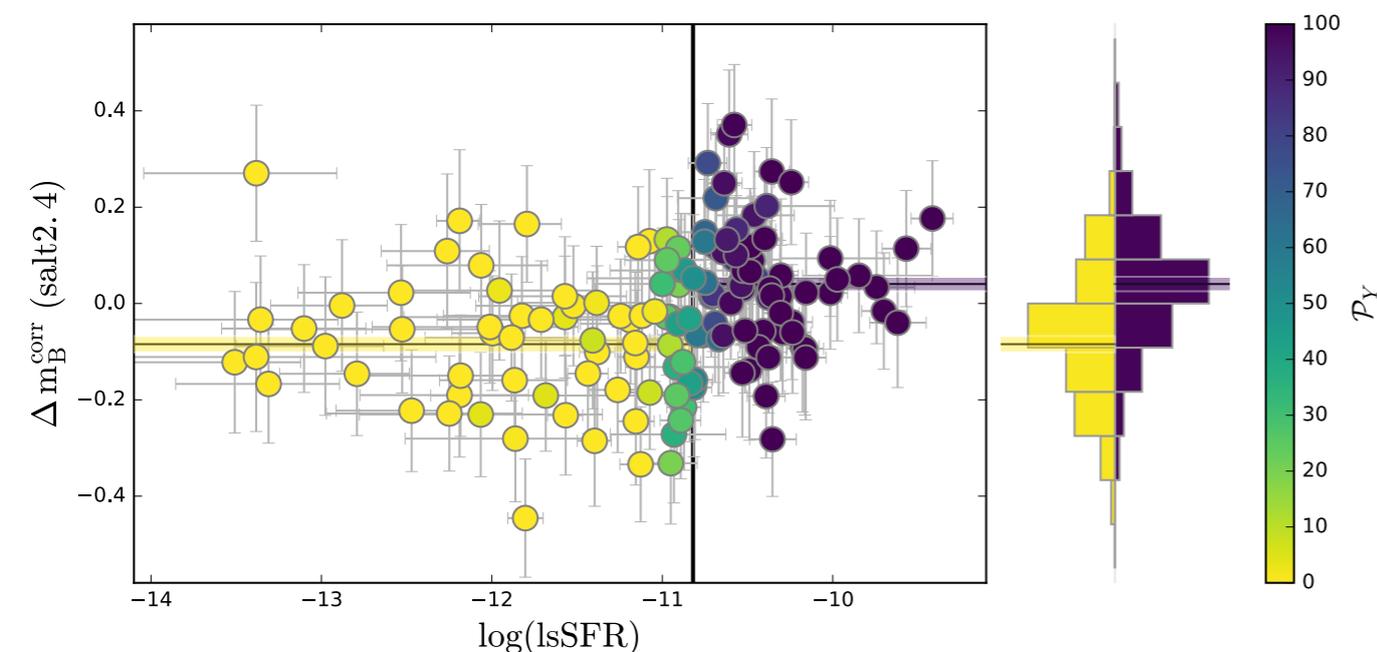


- Dependency of Hubble residuals after stretch & color with Host mass
- Called the « Mass-step »
- $\Delta M = -0.06 \pm 0.012 \text{ mag } (5\sigma)$



Do Stretch & Color corrections involve bias ?

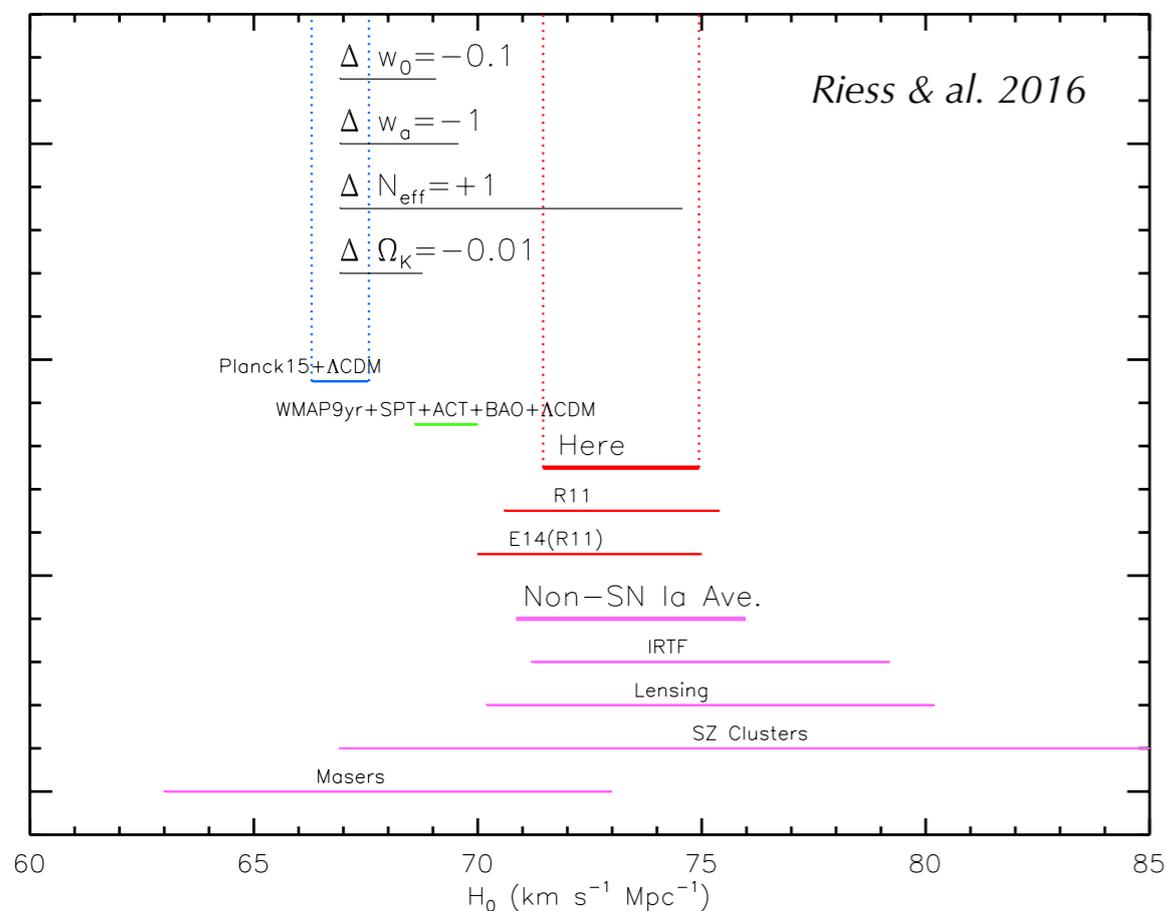
Rigault & al. 2018



- SNIa & Host from SNFactory
- Compute local sSFR (1 kpc radius)
- 141 SNe Ia
- Low z ($z < 0.1$)
- $\Delta M = 0.12 \pm 0.03 \text{ mag } (5.5\sigma)$

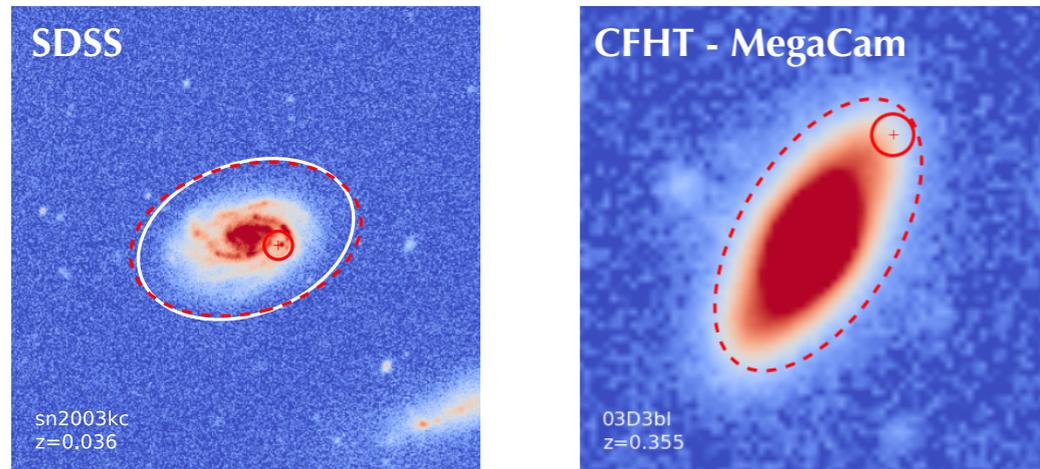


- Distance estimation are biased after stretch and color correction
- It demonstrates that something is missing in the description of SNIa
- May explain the tension of Hubble constant between local measurement and the CMB



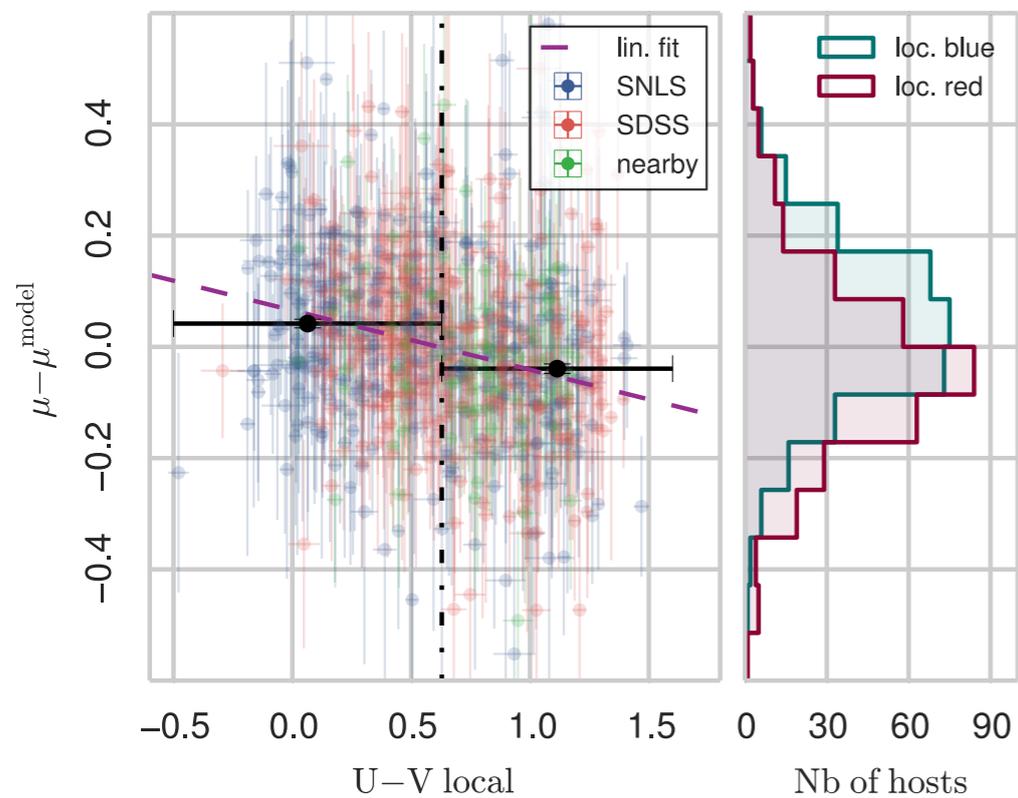
Do Stretch & Color corrections involve bias ?

Roman & al. 2017



- SNIa & Host from SDSS & SNLS
- Compute local U-V (3 kpc radius)
- 882 SNe Ia
- all range of redshift
- $\Delta M = -0.091 \pm 0.013 \text{ mag } (7\sigma)$

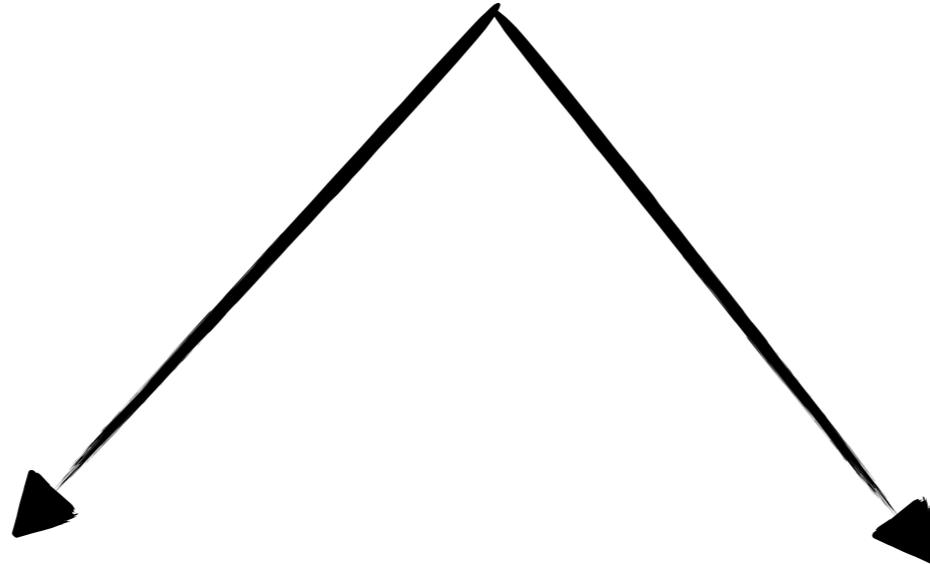
Roman & al. 2017



Residual dispersion
source of systematics



Different ways to improve
distance measurement



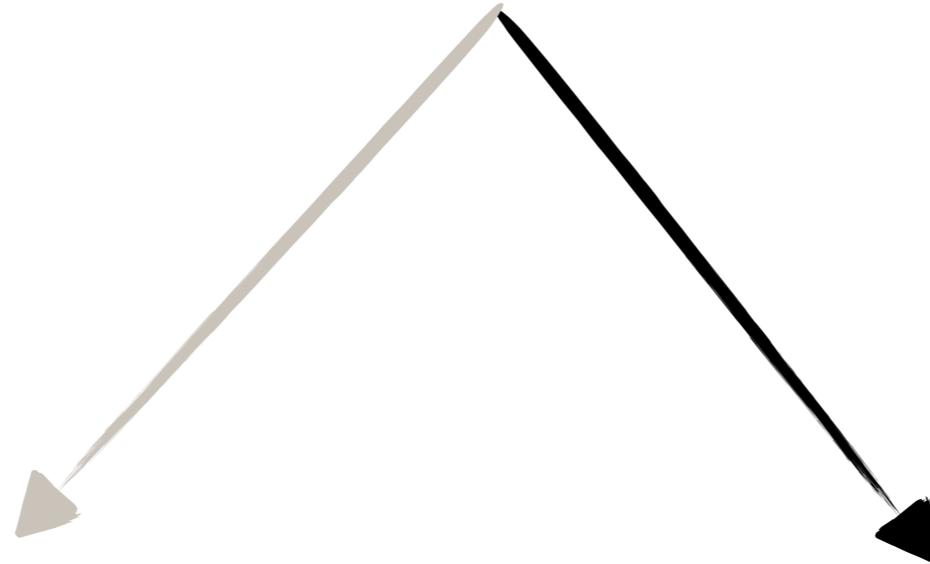
Studies host properties

New SNIa model

Residual dispersion
source of systematics



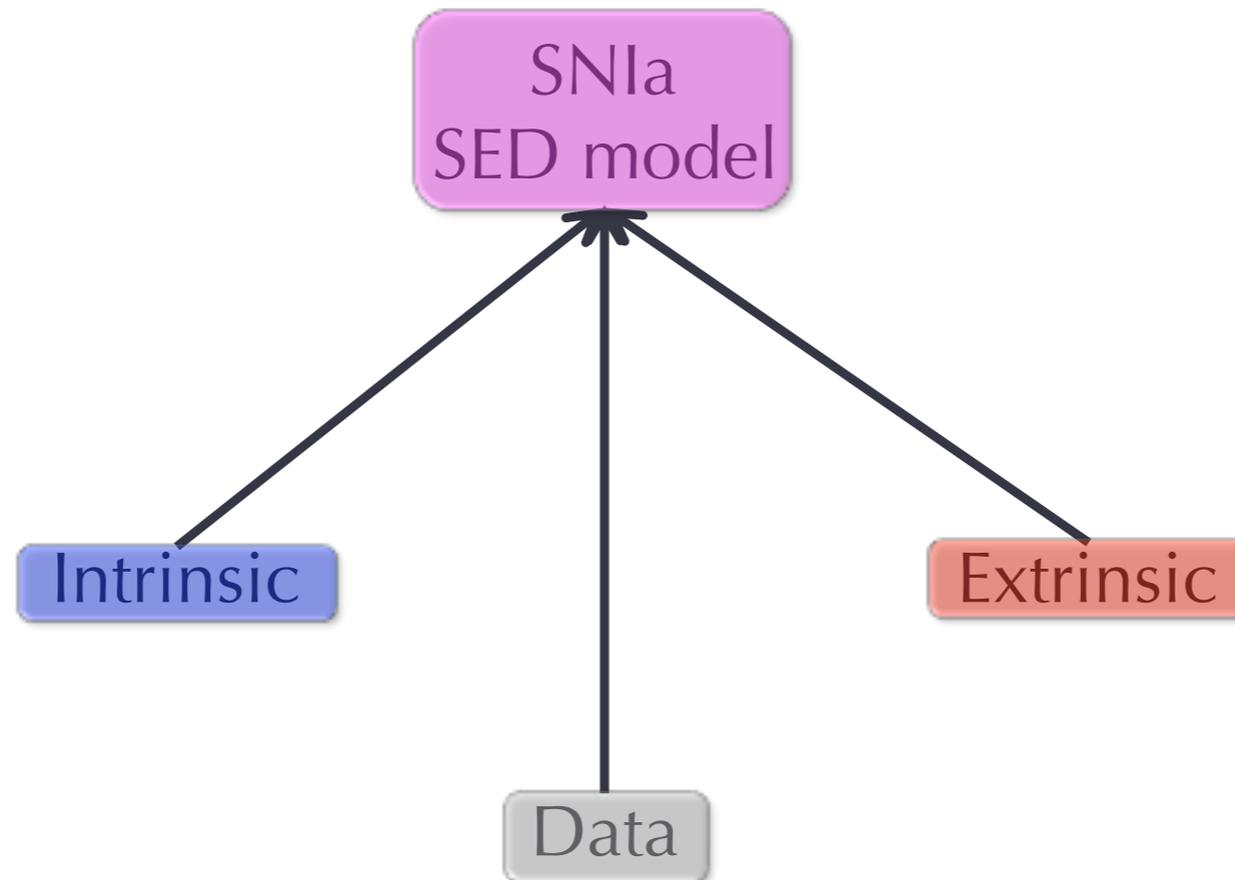
Different ways to improve
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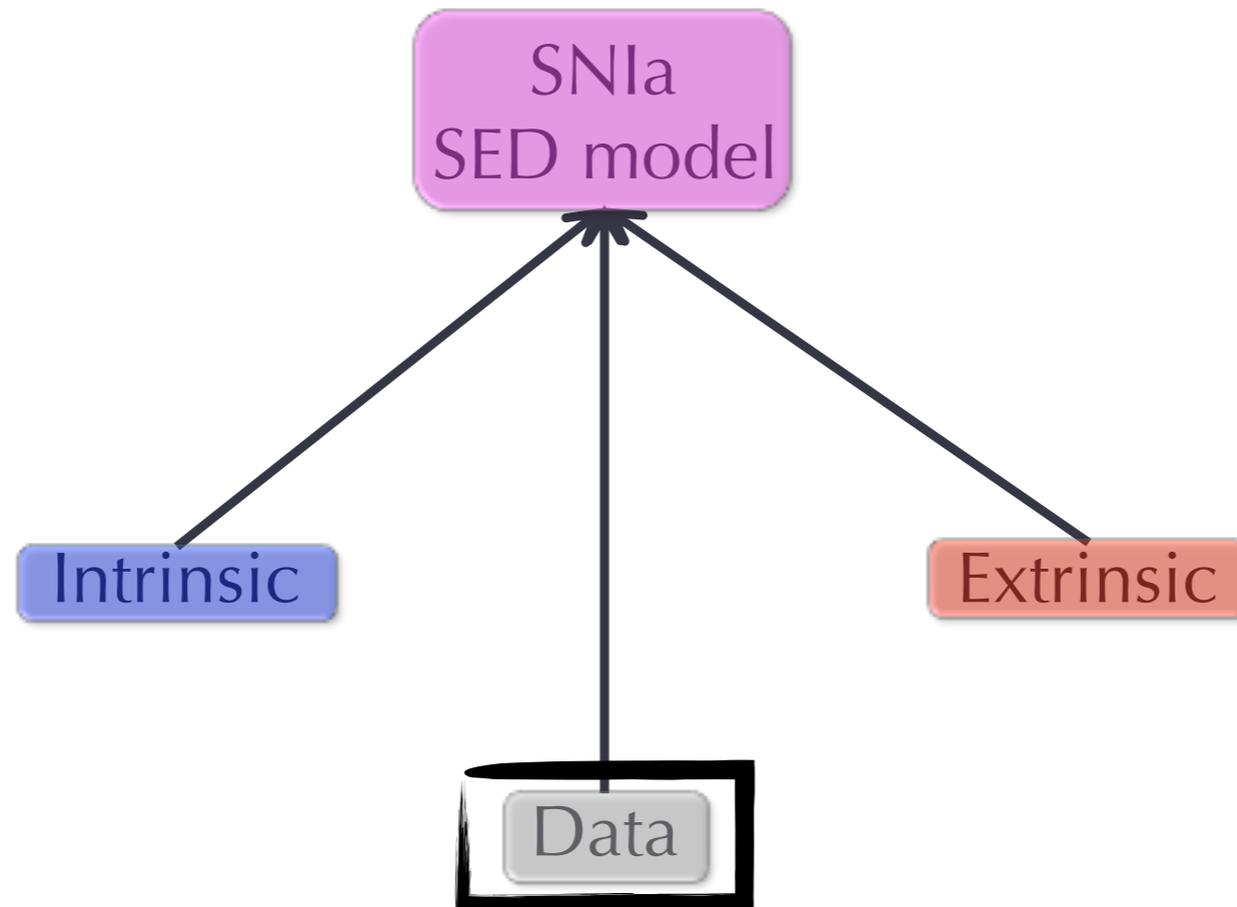
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New SNIa model

Go beyond : Describing the Spectral Energy Distribution



Go beyond : Describing the Spectral Energy Distribution



The Nearby Supernova Factory



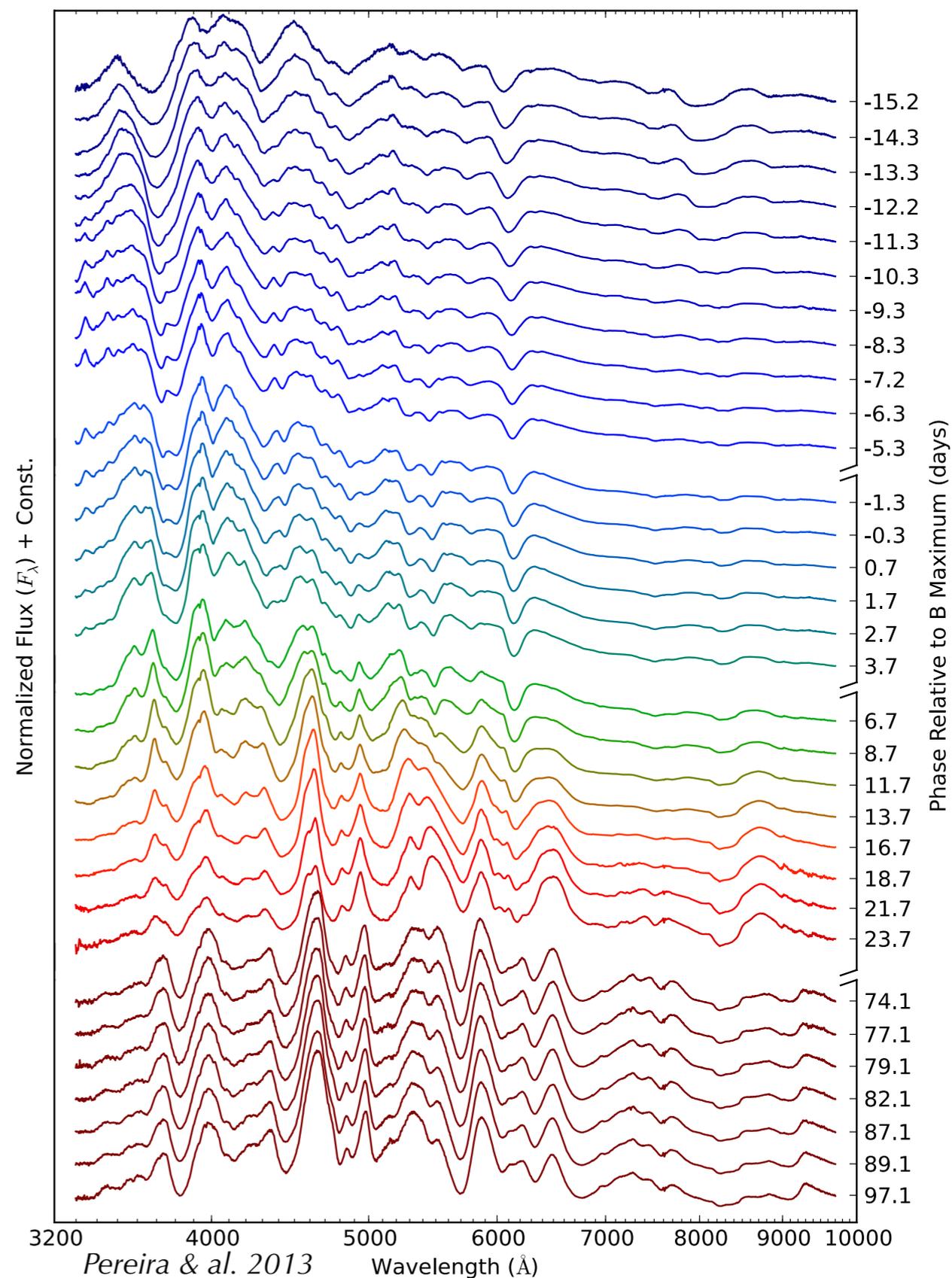
- UH88 + Supernova Integral Field Spectrograph (SNIFS)
- SNIFS Gives high quality spectrophotometry time series (Great example: SN2011fe, *Pereira et al. (2013)*)
- ~300 supernovae at low redshift ($z < 0.1$)
- Best data that provide tools to standardize SNIa or build empirical SED model



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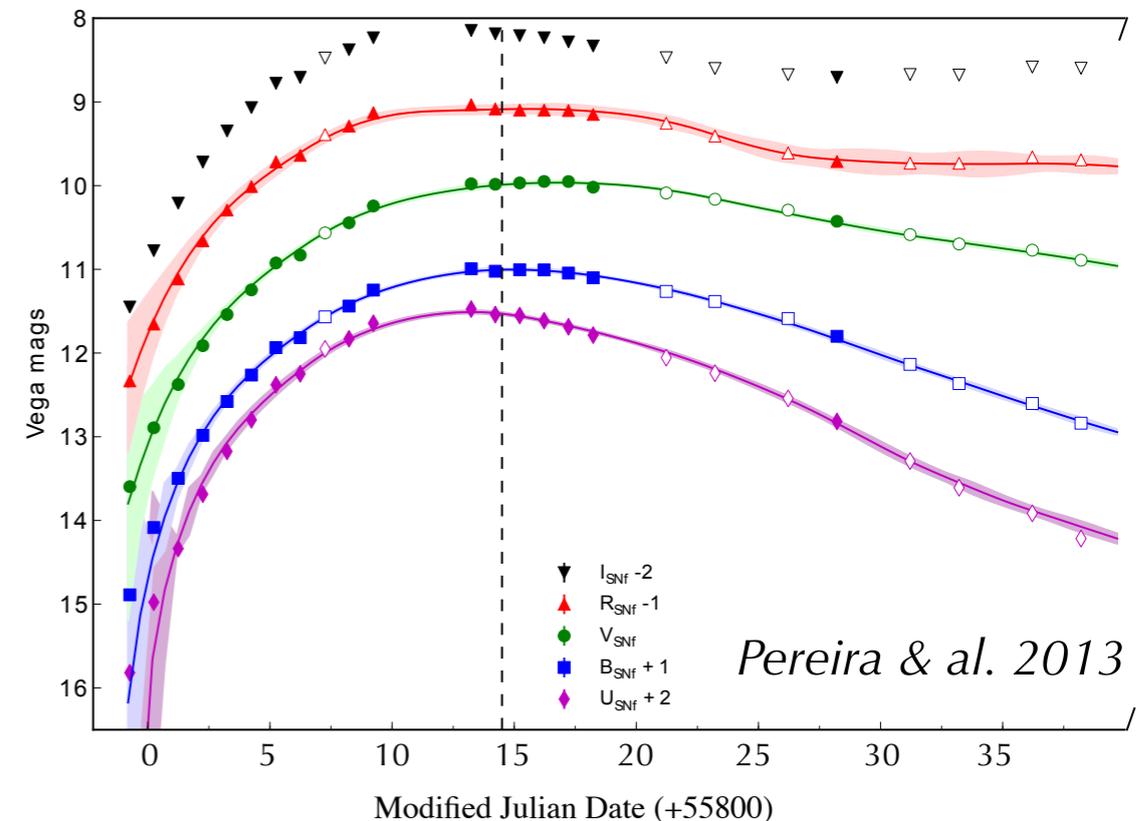
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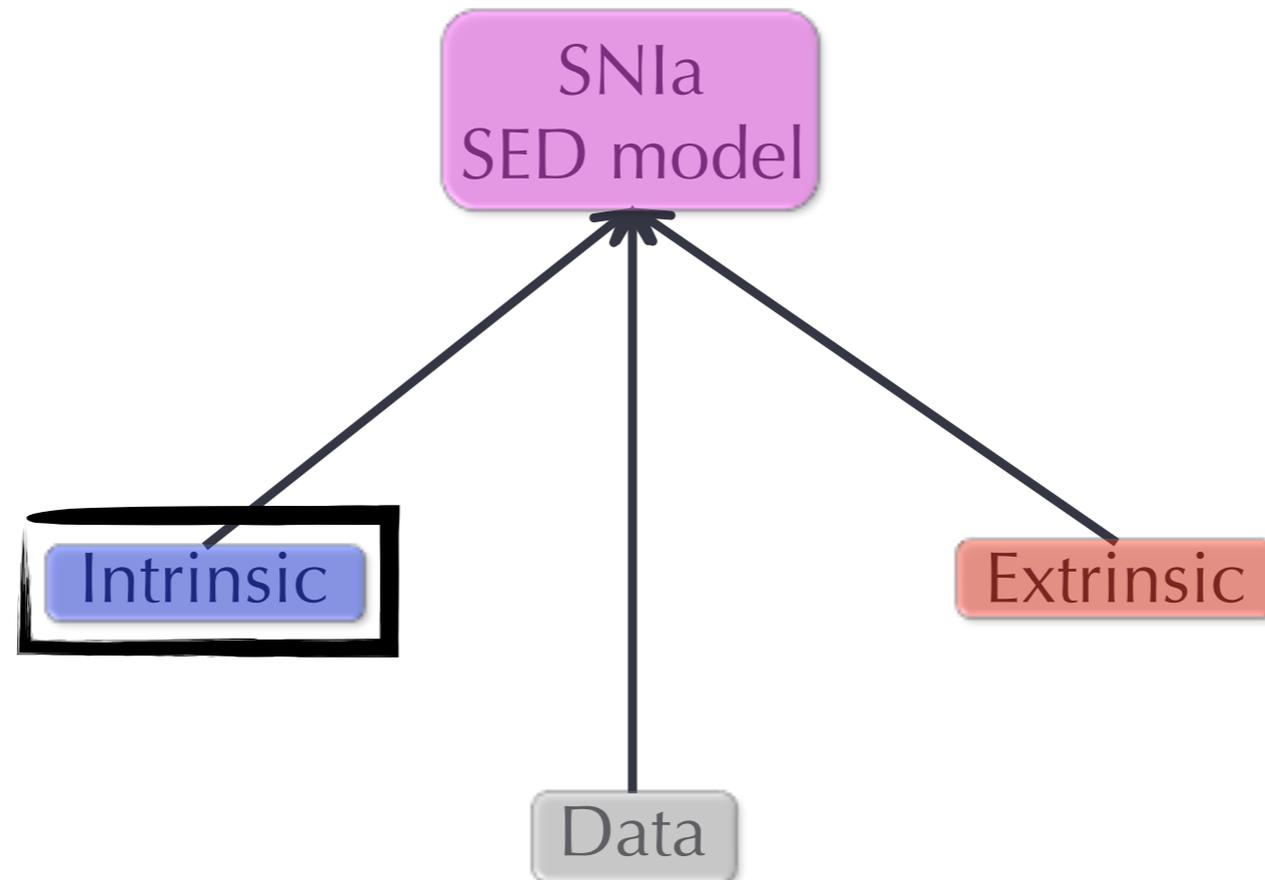
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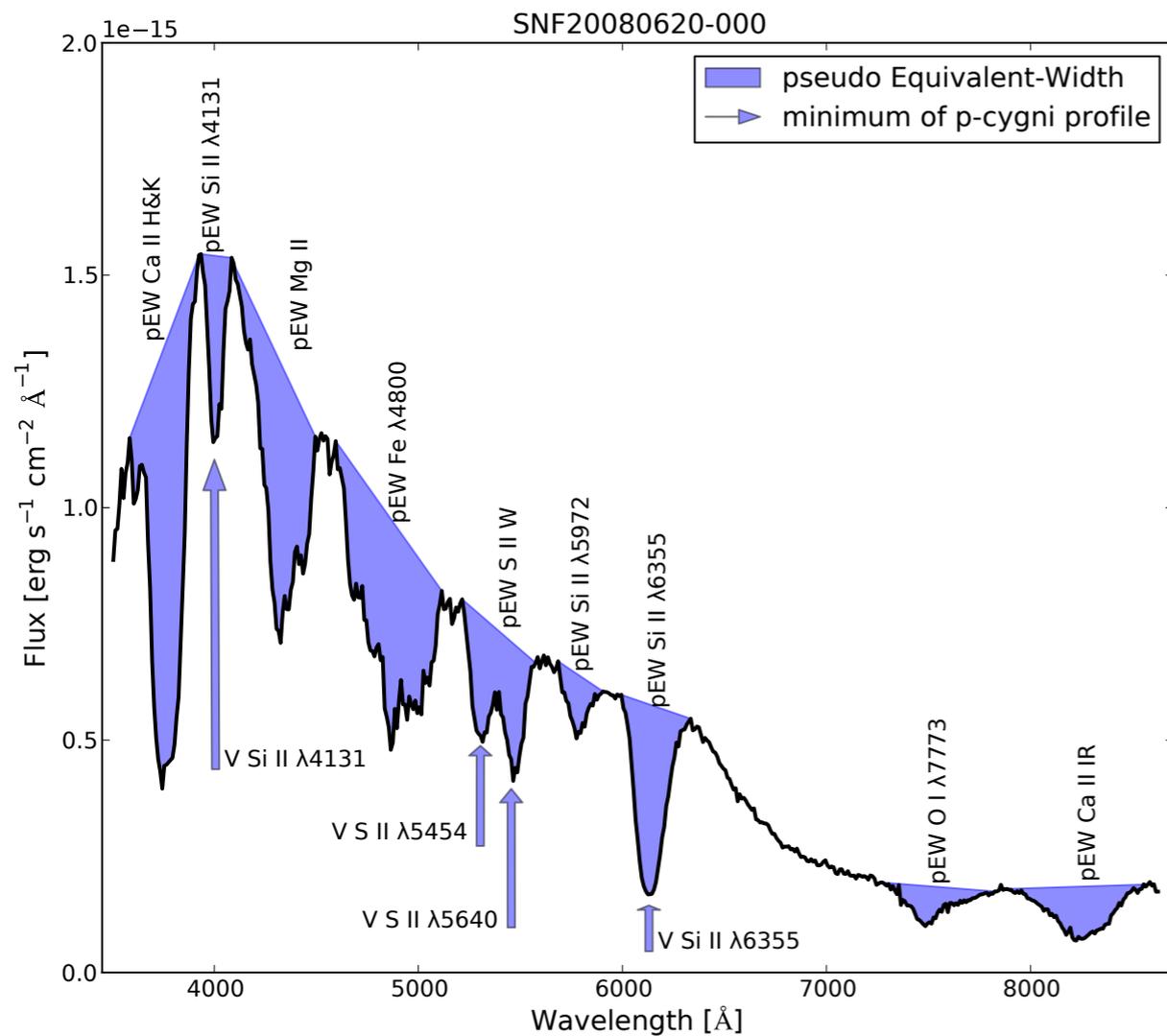
Go beyond : Describing the Spectral Energy Distribution



SUPernova Generator And Reconstructor (SUGAR)

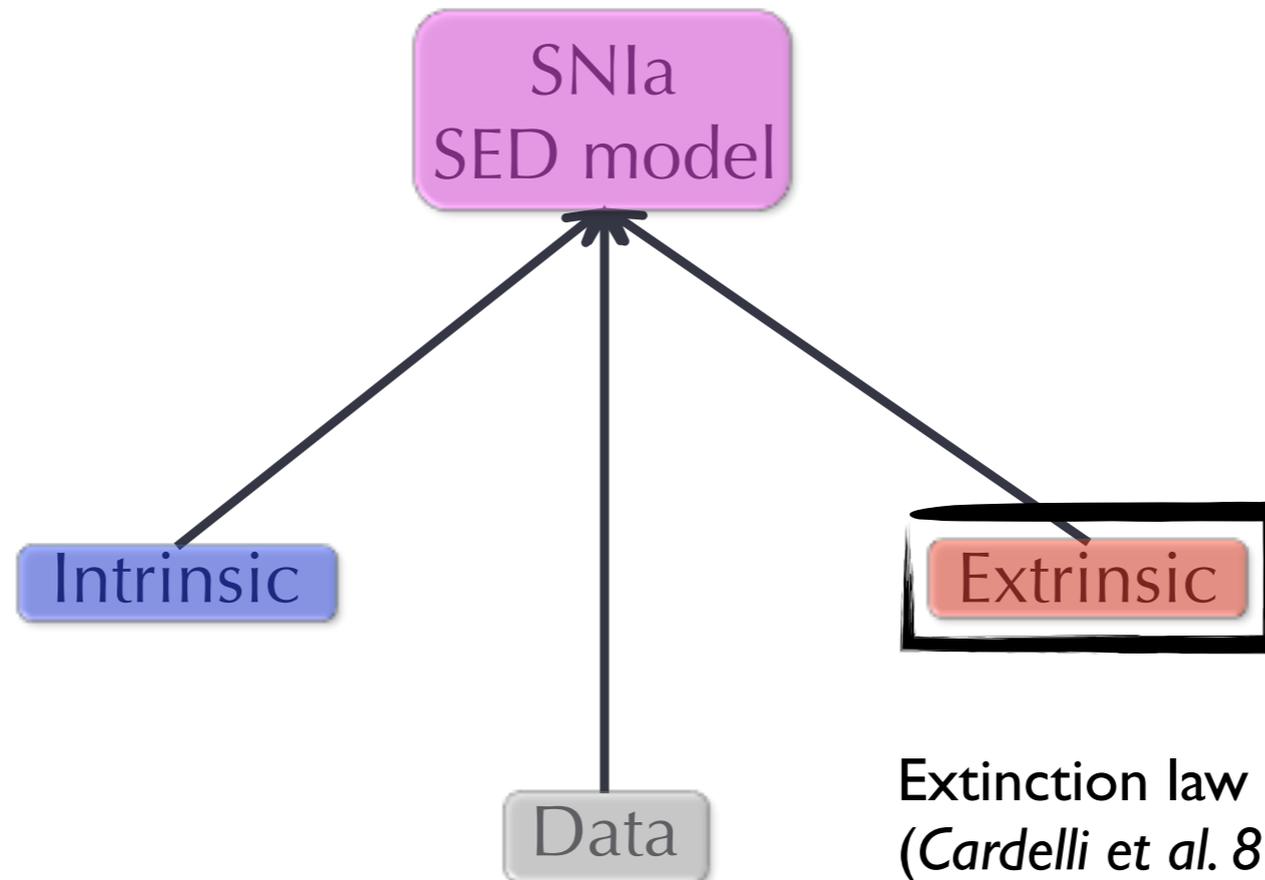
Léget & al. submitted

Basic idea of SUGAR modeling —> Used spectral features measured at maximum light in B-band to describe intrinsic variability of SNe Ia:



- Spectral features are related only to the physics of the explosion
 - * Pseudo-equivalent width
 - * Minimum position of p-cygni profile
- Do not depend on host dust
- Do not depend on distance
- 13 computed at maximum light and used to train the SUGAR model

Go beyond : Describing the Spectral Energy Distribution



Extinction law is the Cardelli law (*Cardelli et al. 89*) with one free parameter that represents dust properties (R_V)

SUpernova Generator And Reconstructor (SUGAR)

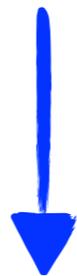
Léget & al. submitted

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

SUPernova Generator And Reconstructor (SUGAR)

Léget & al. submitted

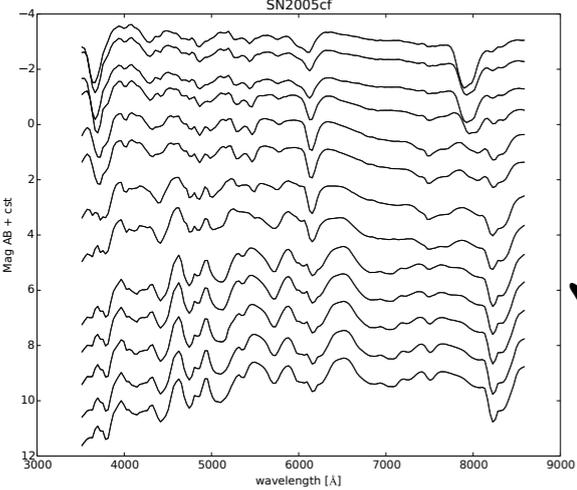
$$M(t; \lambda) = M_0(t; \lambda) + \sum_{i=1}^{1=3} \alpha(t; \lambda) q_i + A_V f(\lambda; R_V) + \Delta M_{grey}$$



**3 components
instead of 1 for SALT2**

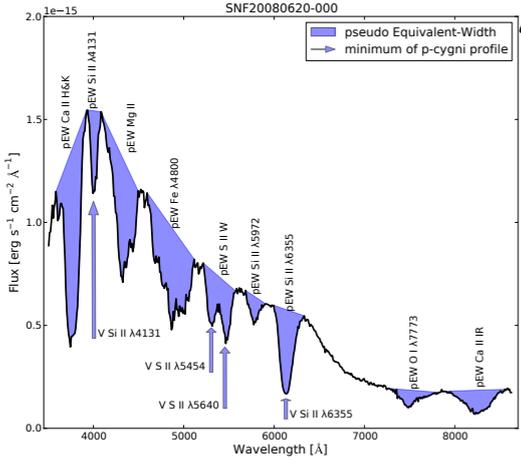
SUPernova Generator And Reconstructor (SUGAR)

Léget & al. submitted



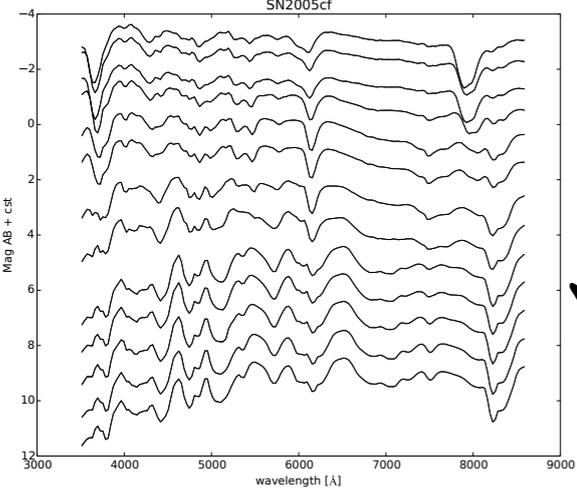
SUGAR TRAINING
(<https://github.com/PFLéget/sugar>)

SUGAR model



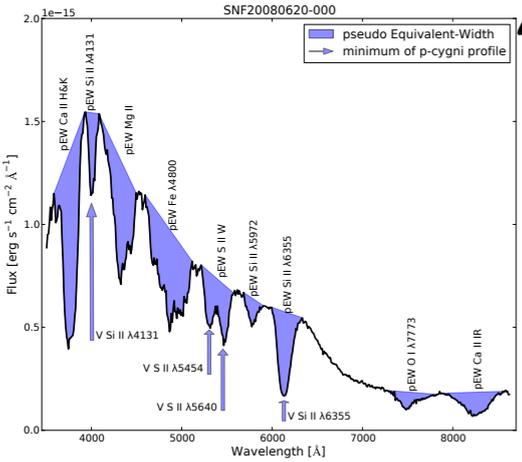
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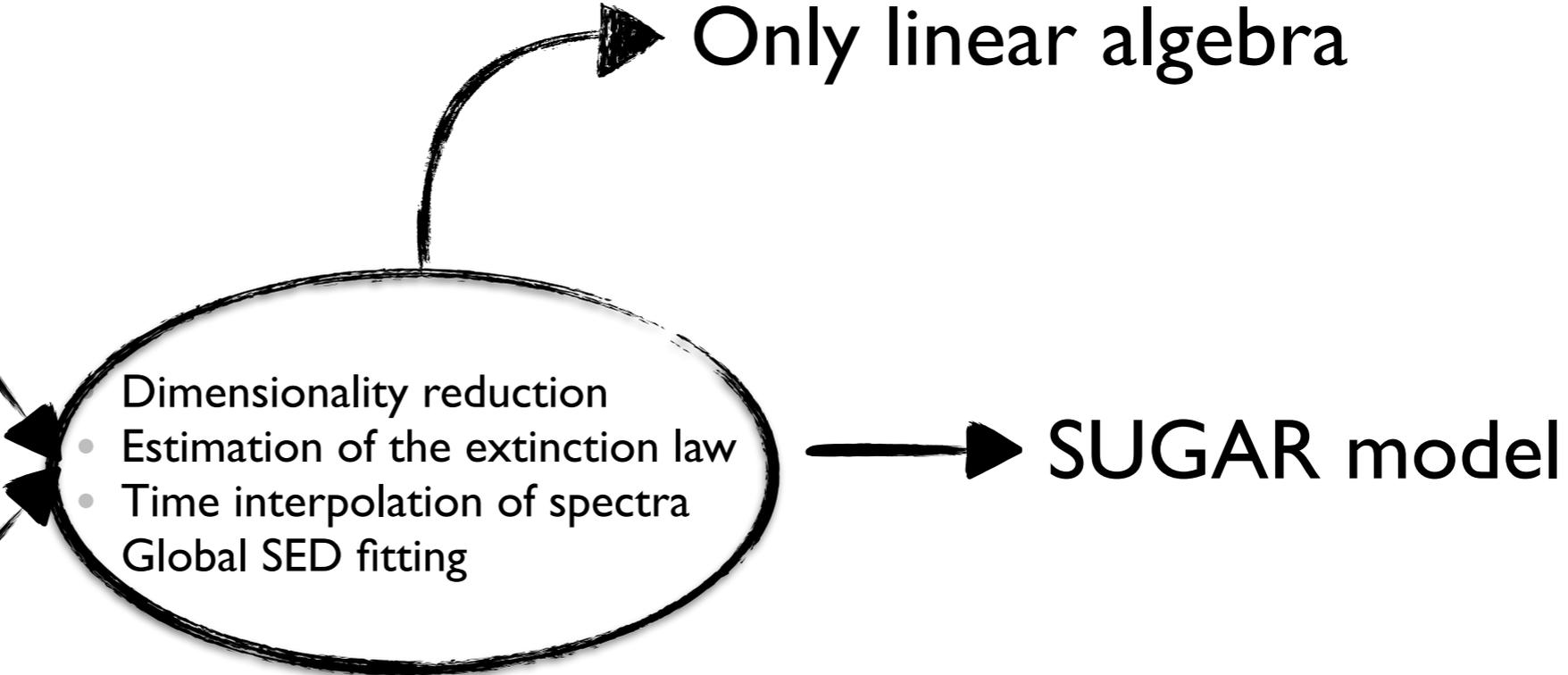
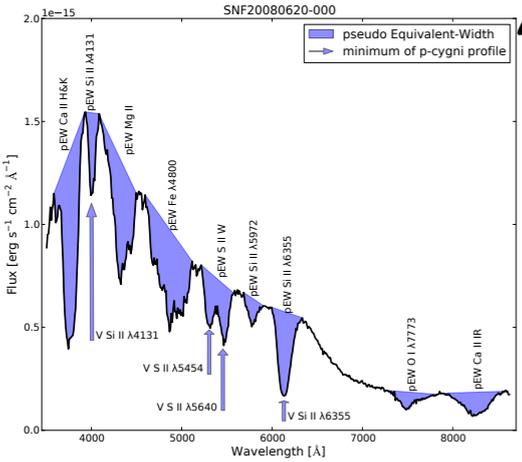
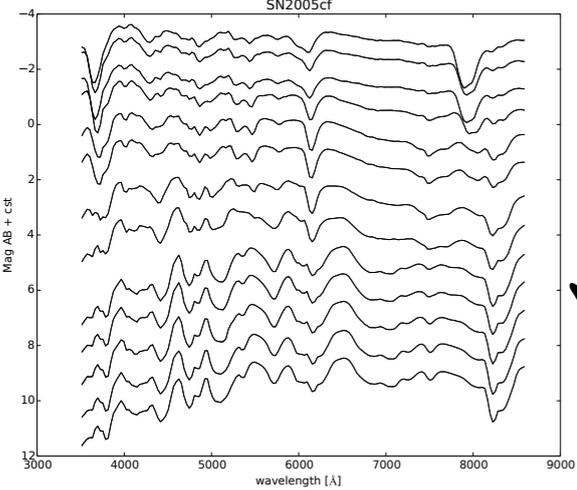
- Dimensionality reduction
- Estimation of the extinction law
- Time interpolation of spectra
- Global SED fitting

→ SUGAR model



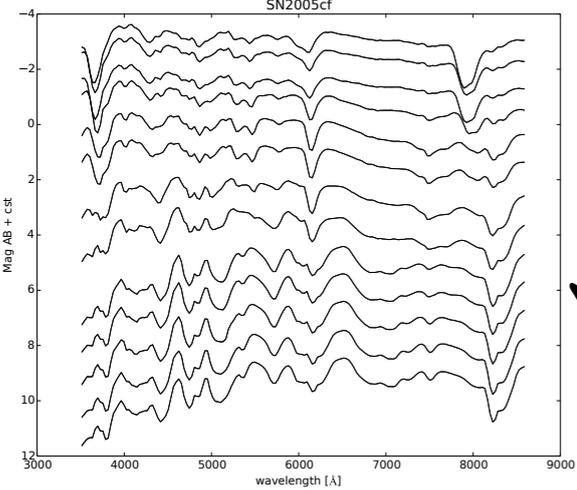
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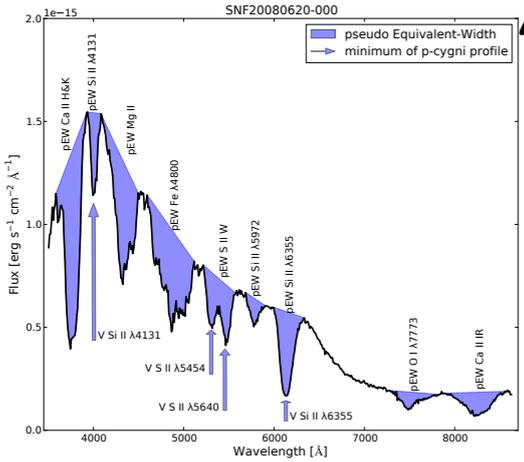
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Léget & al. submitted



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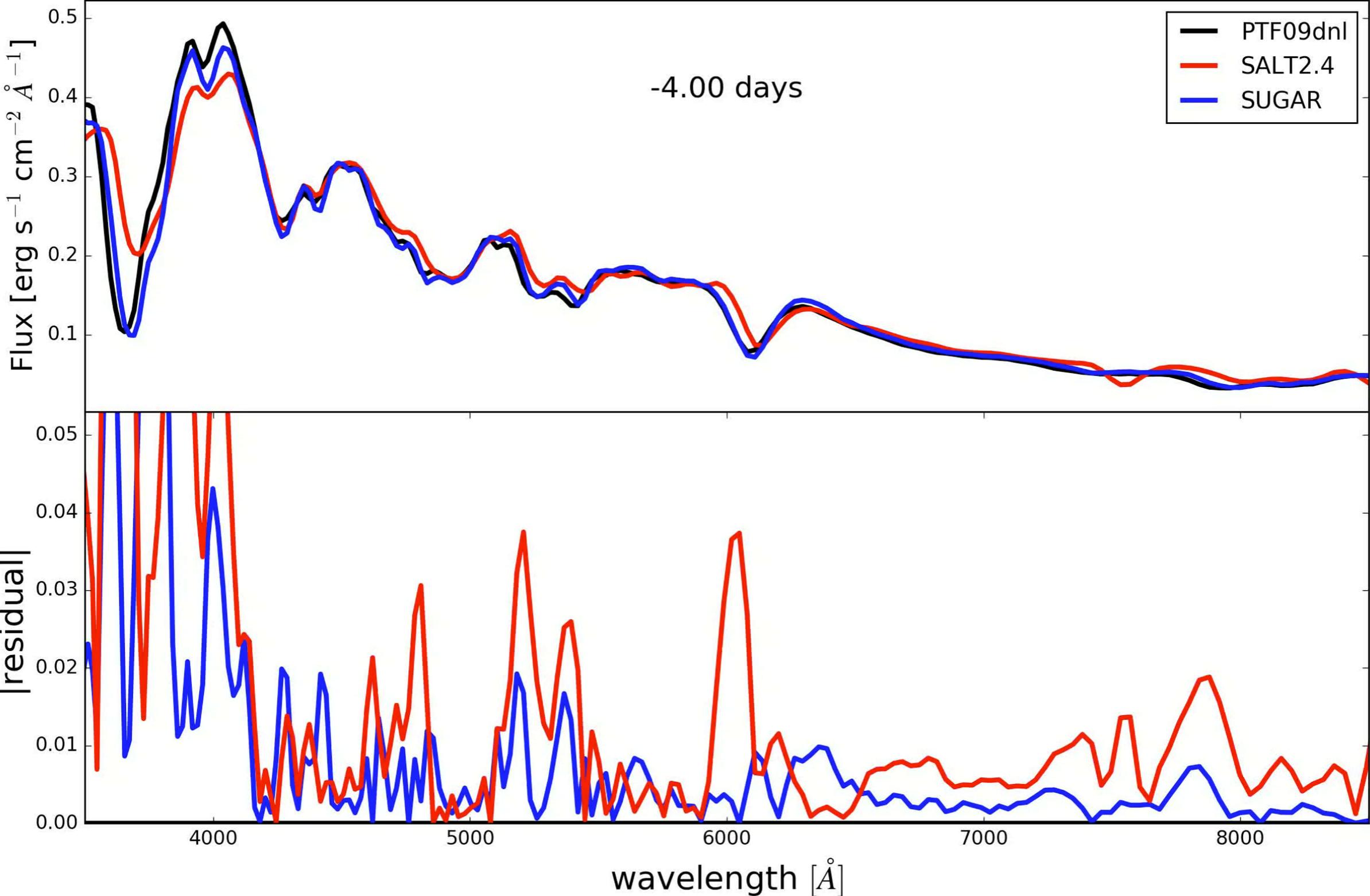
→ SUGAR model



~ 16 000 parameters to estimate
~ 1 hours on a laptop with good choice of matrix inversion

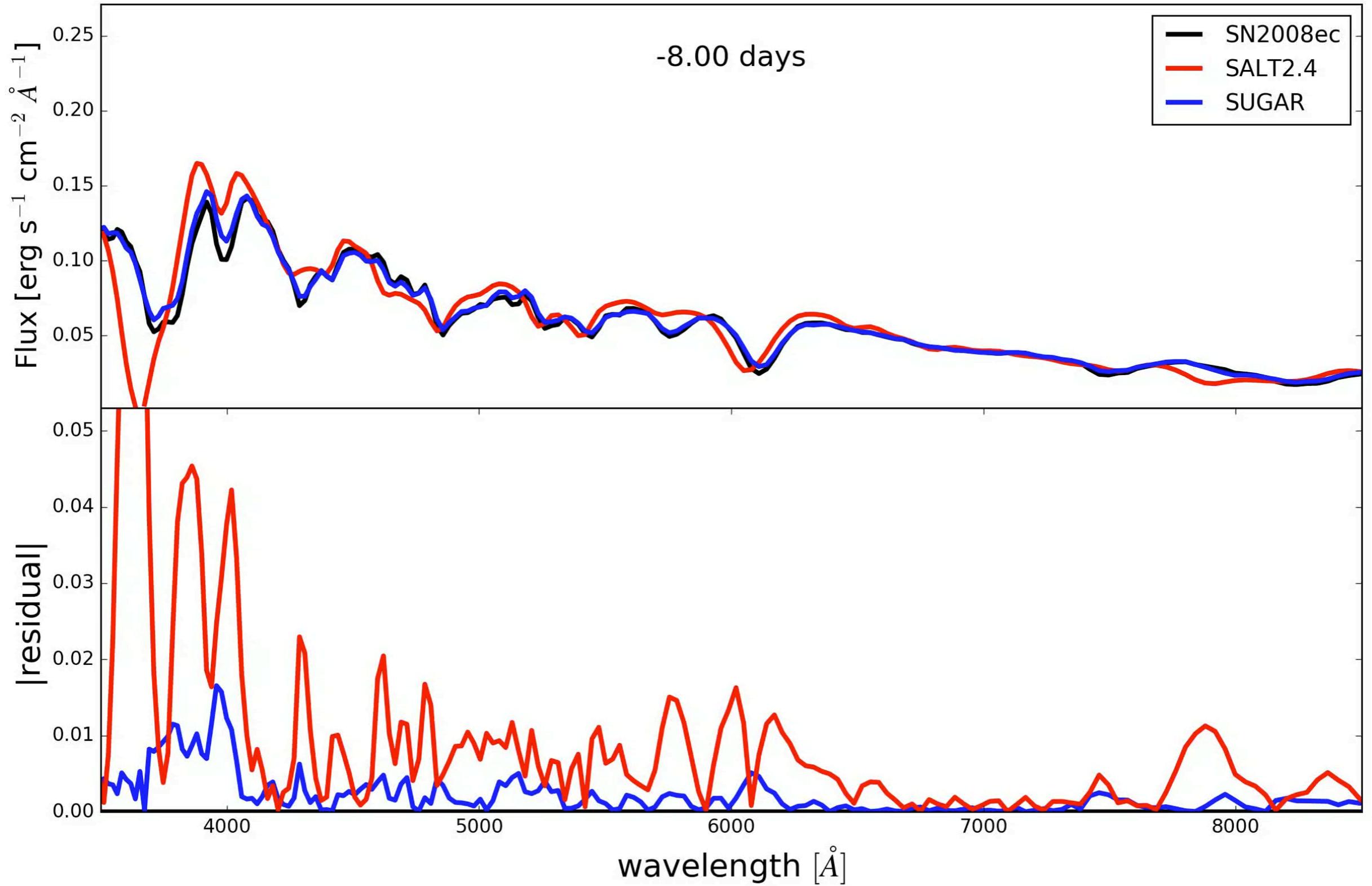
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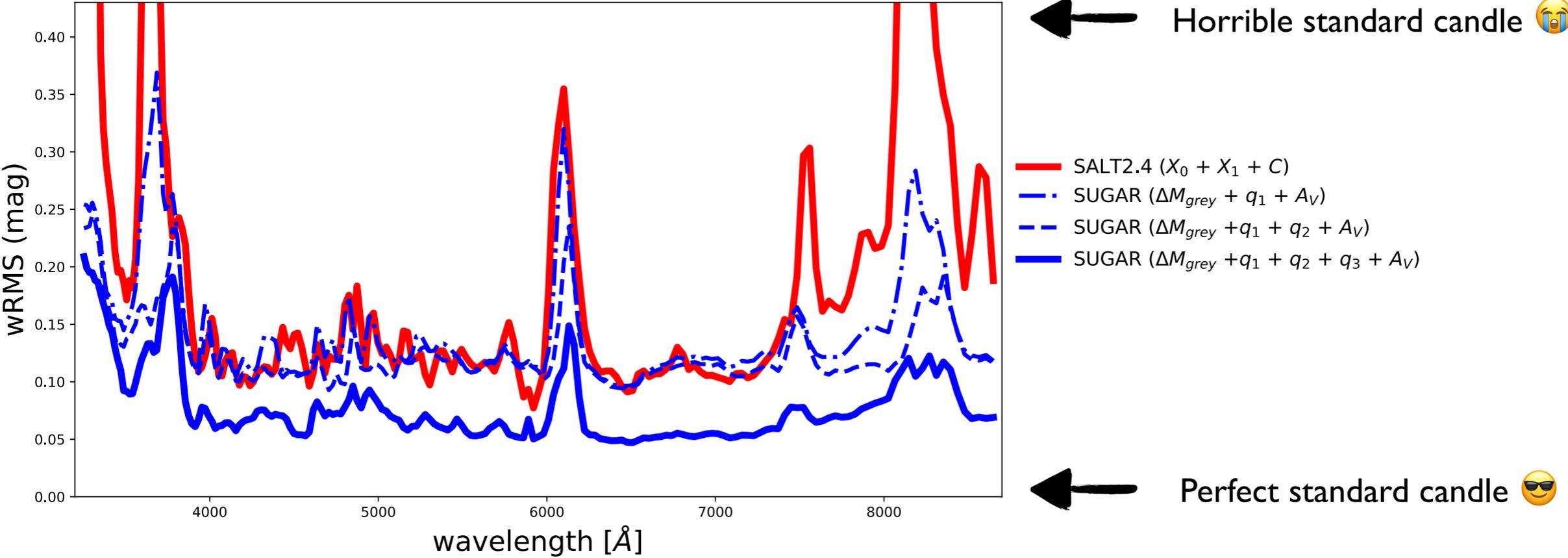
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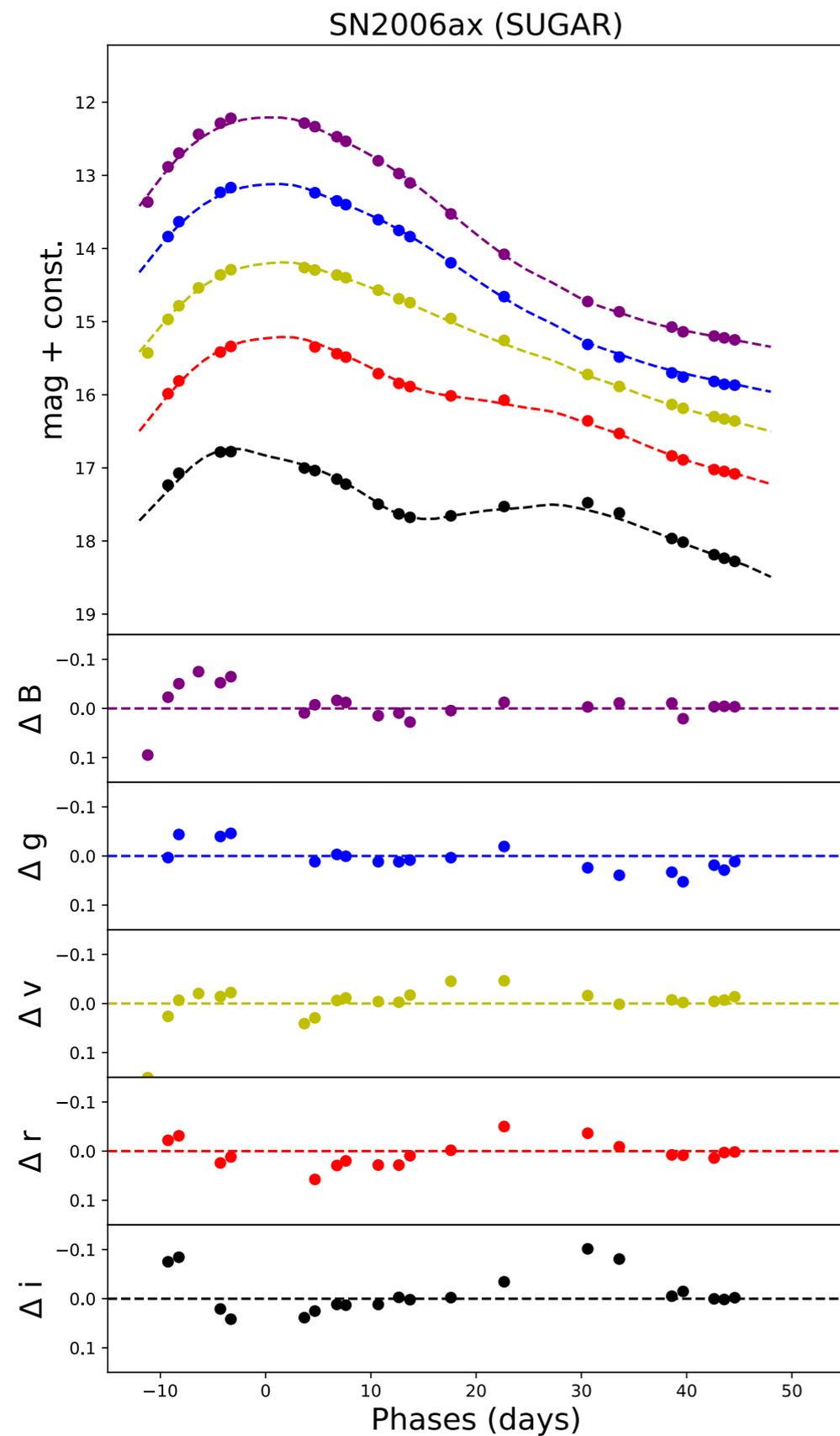
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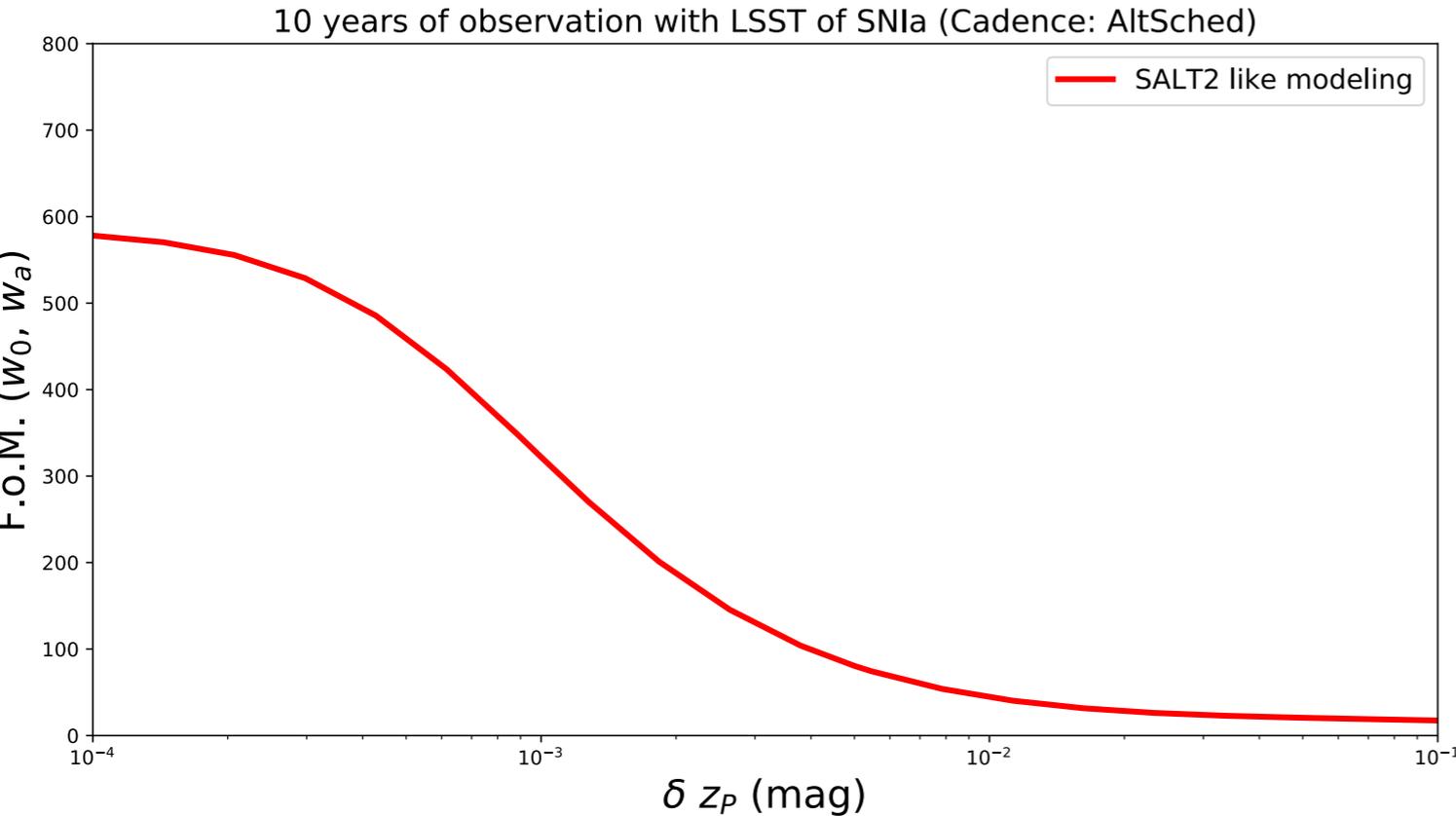
SUGAR improves SNIa spectral variability description in all spectral range!

Application on an external data set:



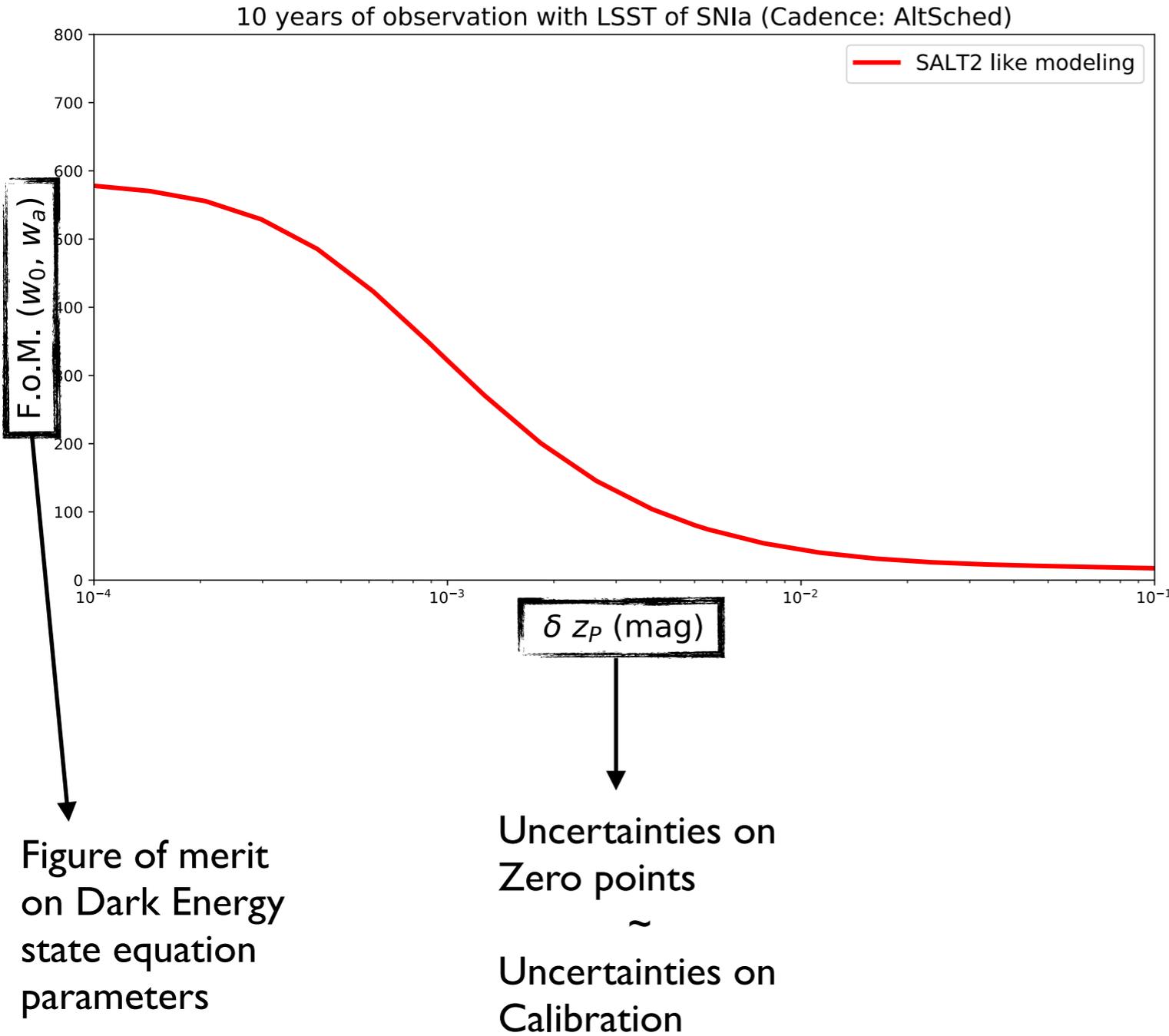
- SUGAR validated on external data set
- CSP III \rightarrow Purely photometric survey
- No spectroscopic information
- Intrinsic dispersion reduce by 20 % in comparaison of a Stretch & Color correction

Impact of SUGAR on LSST science:



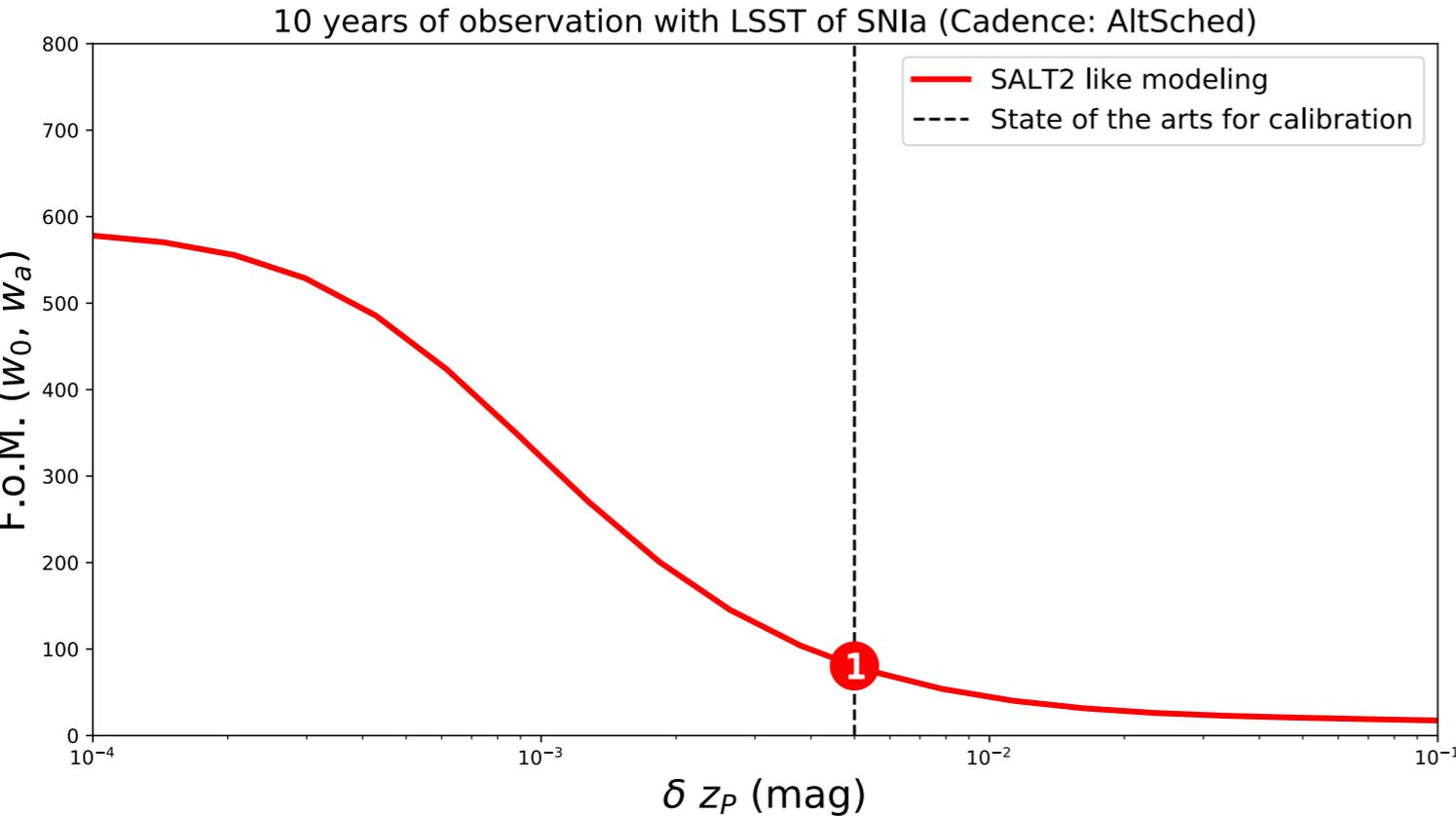
- LSST like survey for ten years
- Calibration of SNIa are one of the other main challenges
- Drive precision on Dark Energy state equation parameters

Impact of SUGAR on LSST science:

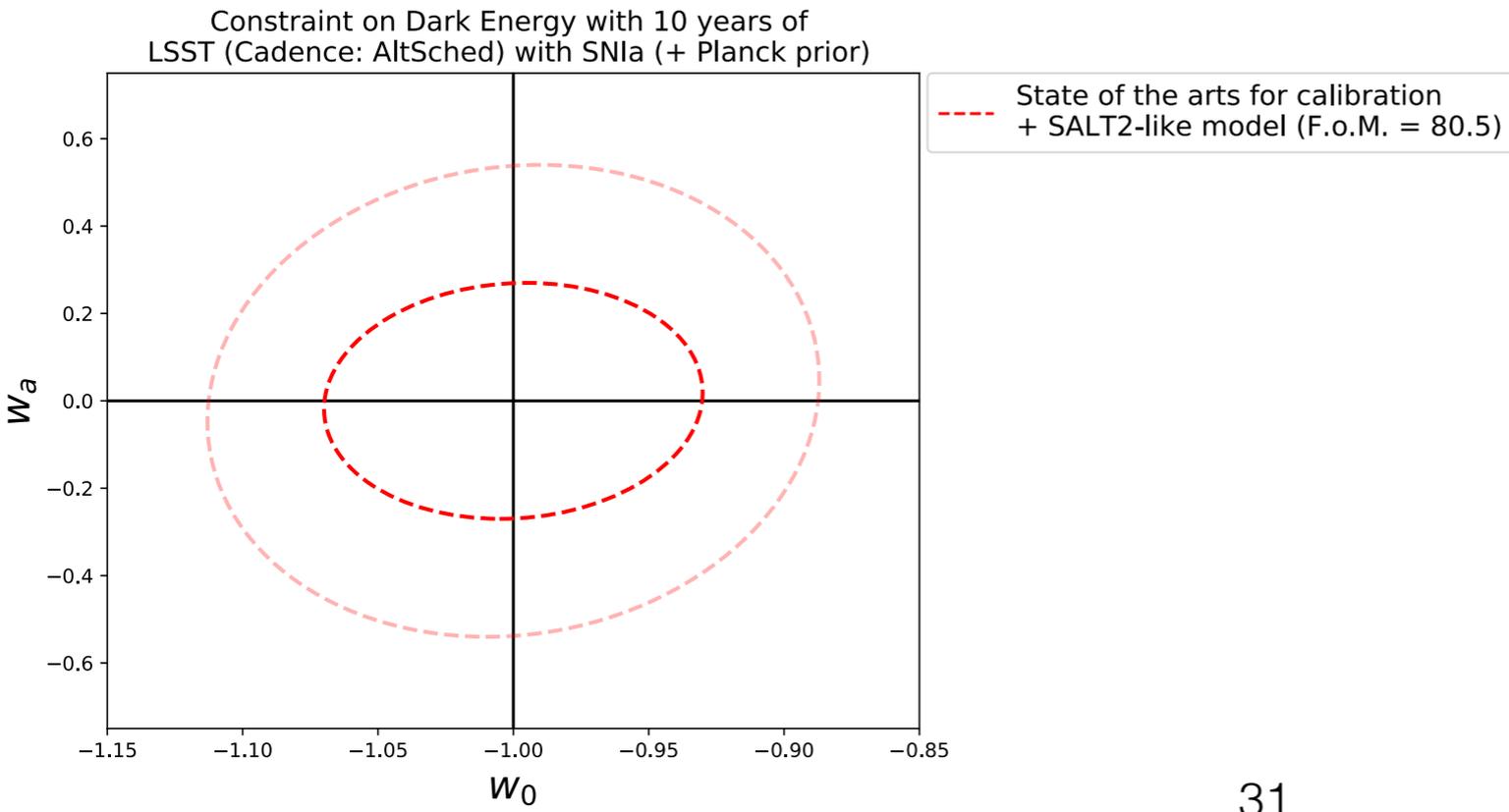


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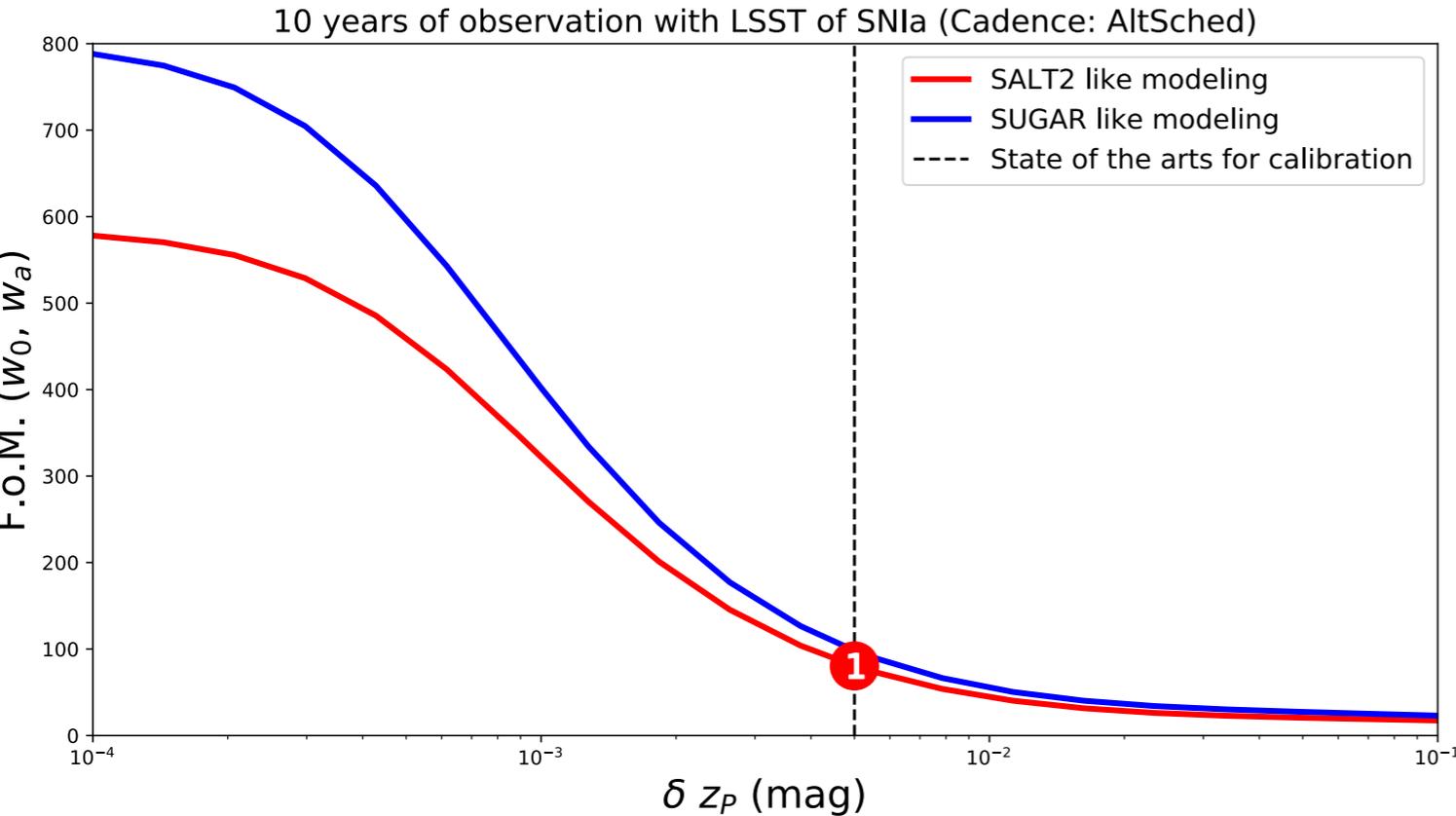
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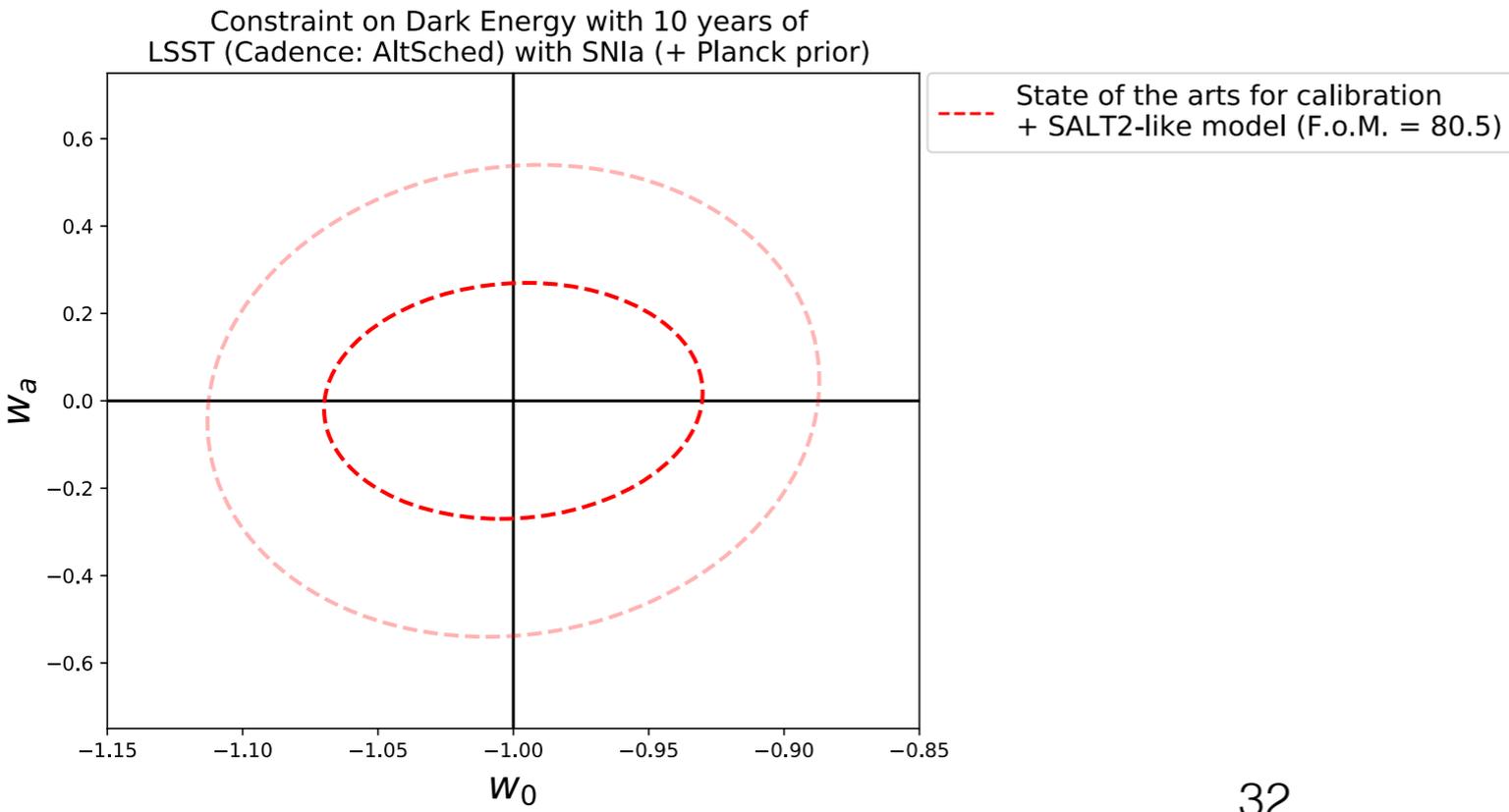
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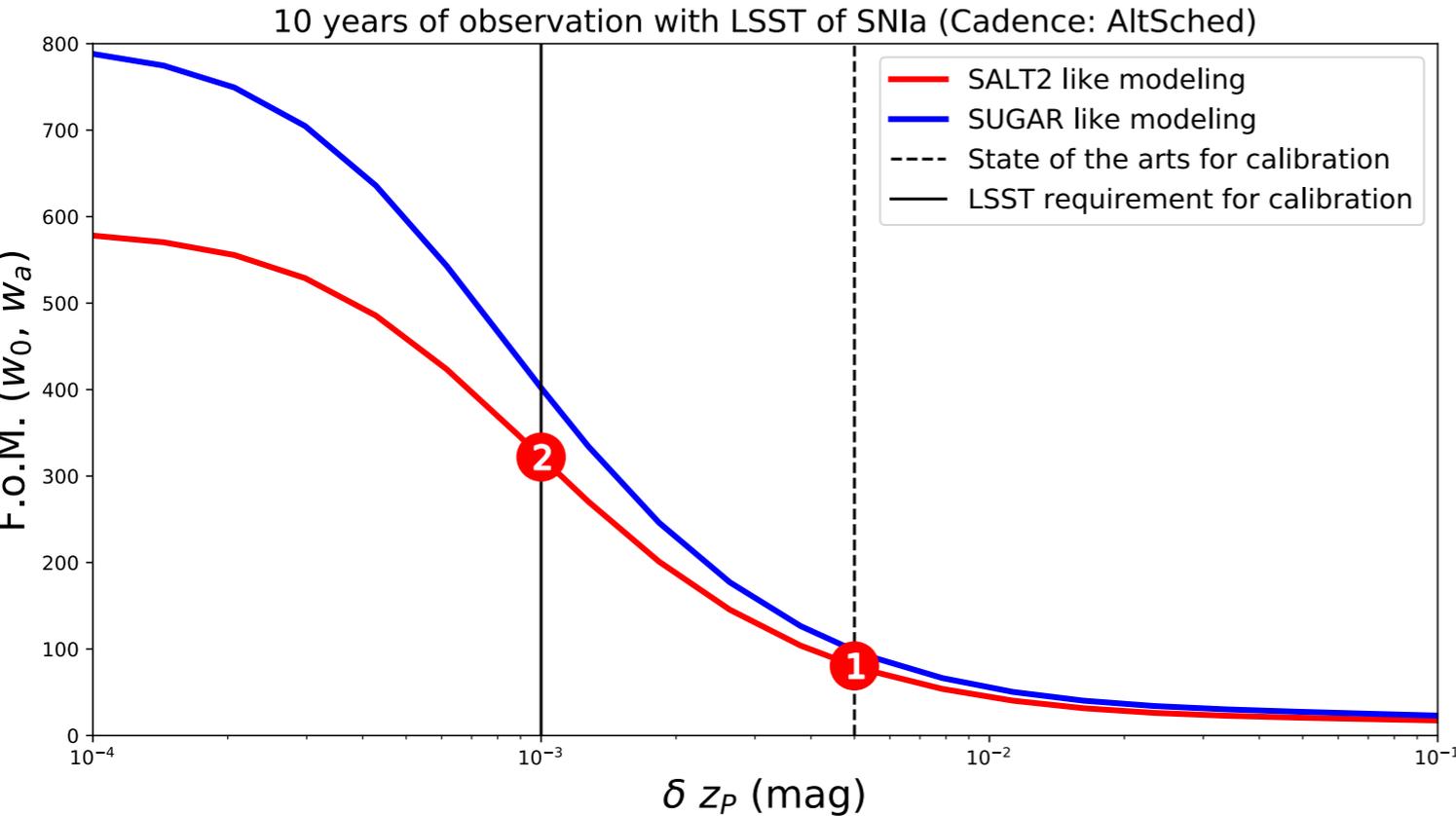
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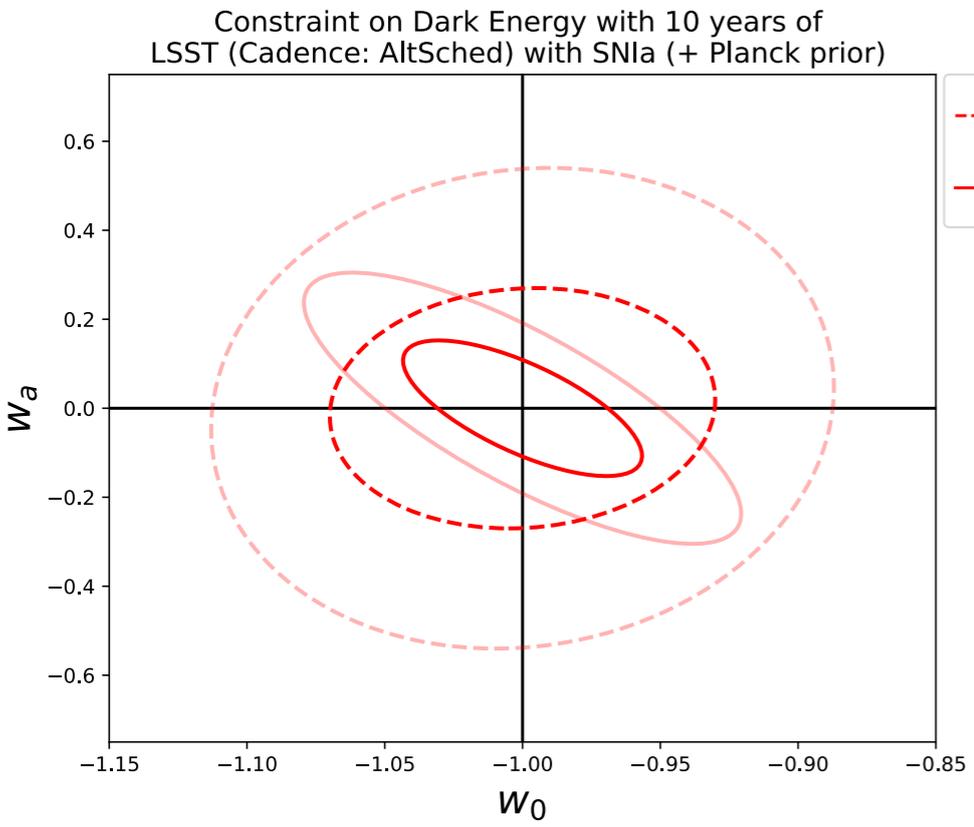
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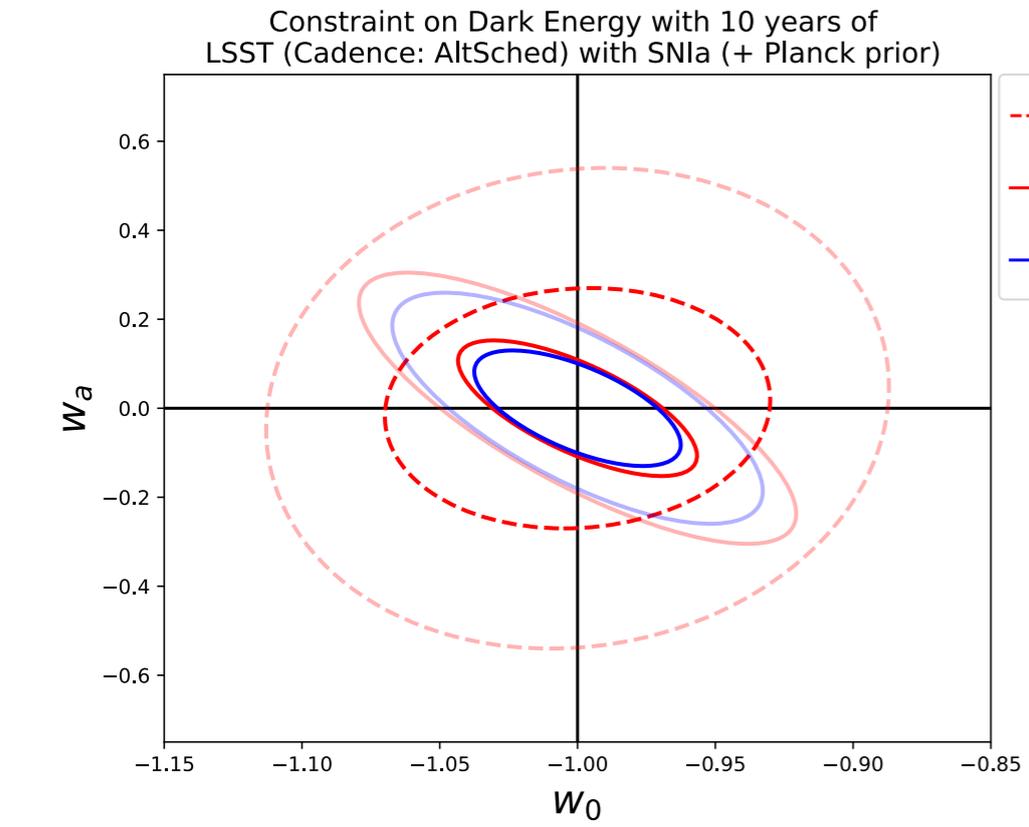
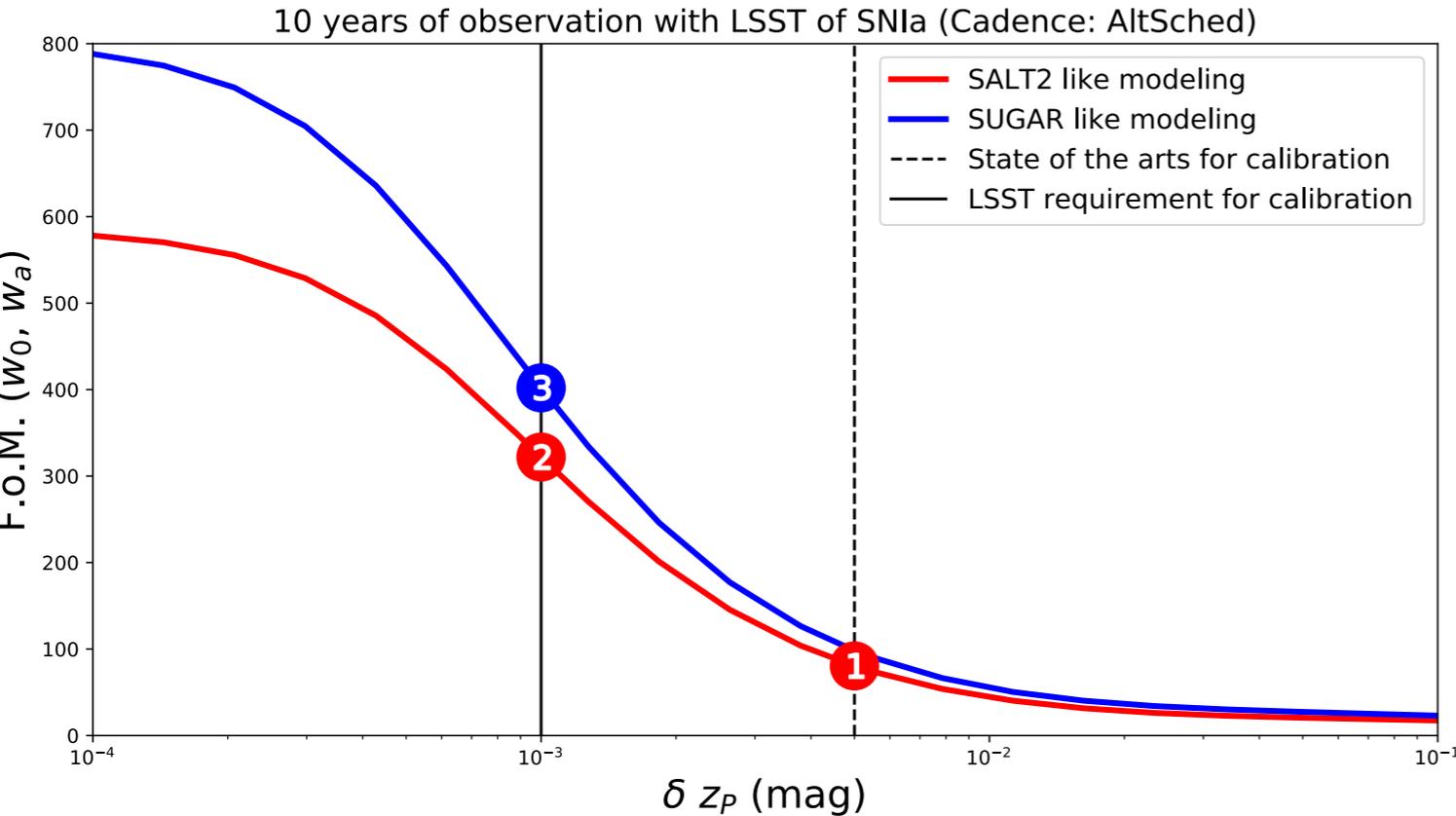
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- Expected Calibration for LSST + SALT2 give an improvement of 20% on w_0 and 45% on w_a



Impact of SUGAR on LSST science:



- LSST like survey for ten years
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- Drive precision on Dark Energy state equation parameters
- Adding SUGAR does not matter for the current state of the arts for calibration
- Expected Calibration for LSST + SALT2 give an improvement of 20% on w_0 and 45% on w_a
- Expected Calibration for LSST + SUGAR give a total improvement of 45% on w_0 and 50% on w_a

Conclusions:

- **New SED model: SUGAR**
 - 3 intrinsic components instead of the classical stretch effect
- **Model performances:**
 - Better spectral description
 - Intrinsic scatter reduced by $\sim 20\%$ on external data
 - Could improve by $\sim 20\%$ constraint on Dark Energy (compared to SALT2)
 - Reduce the problem of the correlation of Hubble residual & Host properties
- **New tools for cosmology analysis**
 - Need to be implemented for following experiment to get the best constraint on Dark Energy using SNIa!

Merci !