THE SNEMO MODEL

Clare Saunders, March 14, 2019, LPNHE Meeting of SSP

SNEMO = SuperNova Empirical MOdels

arXiv:1810.09476

snfactory.lbl.gov/snemo

Astrophysics > Cosmology and Nongalactic Astrophysics

SNEMO: Improved Empirical Models for Type Ia Supernovae

C. Saunders, G. Aldering, P. Antilogus, S. Bailey, C. Baltay, K. Barbary, D. Baugh, K. Boone, S. Bongard, C. Buton, J. Chen, N. Chotard, Y. Copin, S. Dixon, P. Fagrelius, H. K. Fakhouri, U. Feindt, D. Fouchez, E. Gangler, B. Hayden, P.-F. Léget, W. Hillebrandt, A. G. Kim, M. Kowalski, D. Küsters, S. Lombardo, J. Nordin, R. Pain, E. Pecontal, R. Pereira, D. Rabinowitz, M. Rigault, D. Rubin, K. Runge, G. Smadja, S. Perlmutter, C. Sofiatti, N. Suzuki, C. Tao, S. Taubenberger, R. C. Thomas, M. Vincenzi

(Submitted on 22 Oct 2018)

Type Ia supernova cosmology depends on the ability to fit and standardize observations of supernova magnitudes with an empirical model. We present here a series of new models of Type Ia Supernova spectral time series that capture a greater amount of supernova diversity than possible with the models that are currently customary. These are entitled SuperNova Empirical MOdels (\textsc{SNEMO}\footnote{this https URL}). The models are constructed using spectrophotometric time series from 172 individual supernovae from the Nearby Supernova Factory, comprising more than 2000 spectra. Using the available observations, Gaussian Processes are used to predict a full spectral time series for each supernova. A matrix is constructed from the spectral time series of all the supernovae and Expectation Maximization Factor Analysis is used to calculate the principal components of the data. K-fold cross-validation then determines the selection of model parameters and accounts for color variation in the data. Based on this process, the final models are trained on supernovae that have been dereddened using the Fitzpatrick and Massa extinction relation. Three final models are presented here: \textsc{SNEMO2}, a two-component model for comparison with current Type-Ia models; \textsc{SNEMO7}, a seven component model chosen for standardizing supernova magnitudes which results in a total dispersion of 0.100~mag for a validation set of supernovae, of which 0.087~mag is unexplained (a total dispersion of 0.113~mag with unexplained dispersion of 0.097~mag is found for the total set of training and validation supernovae); and \textsc{SNEMO15}, a comprehensive 15 component model that maximizes the amount of spectral time series behavior captured.

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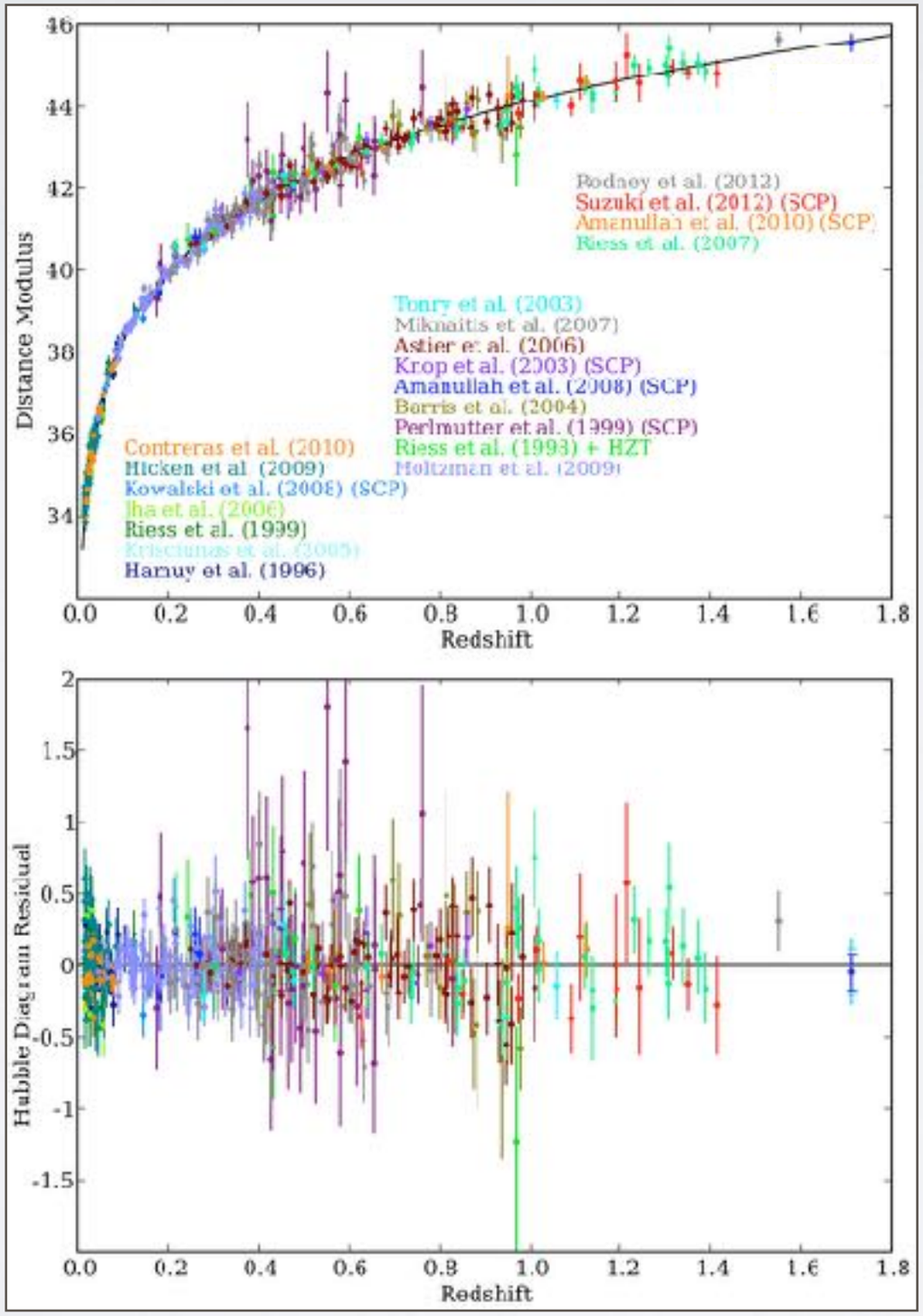
SNEMO: Type Ia Supernova Models from the Nearby Supernova Factory

SNEMO is a series of models trained on the spectrophotometric time series of Type Ia supernovae observed by the Nearby Supernova Factory. The training procedure and results are described in Saunders, et al. 2018 (link here). Three models are presented here:

- **SNEMO2: a two component model intended as means to directly compare the training data and method with other two-component SNIa models such as SALT2.**
- **SNEMO7: a seven component model chosen for standardizing supernova magnitudes**
- **SNEMO15: a comprehensive 15 component model that maximizes the amount of spectral time series behavior captured.**

CONSTRAINING COSMOLOGICAL PARAMETERS

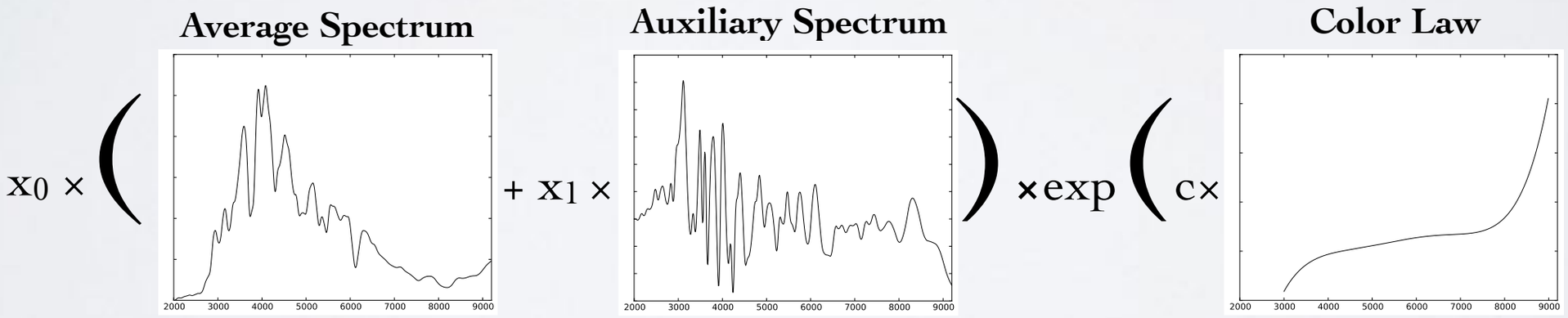


Rubin+2013

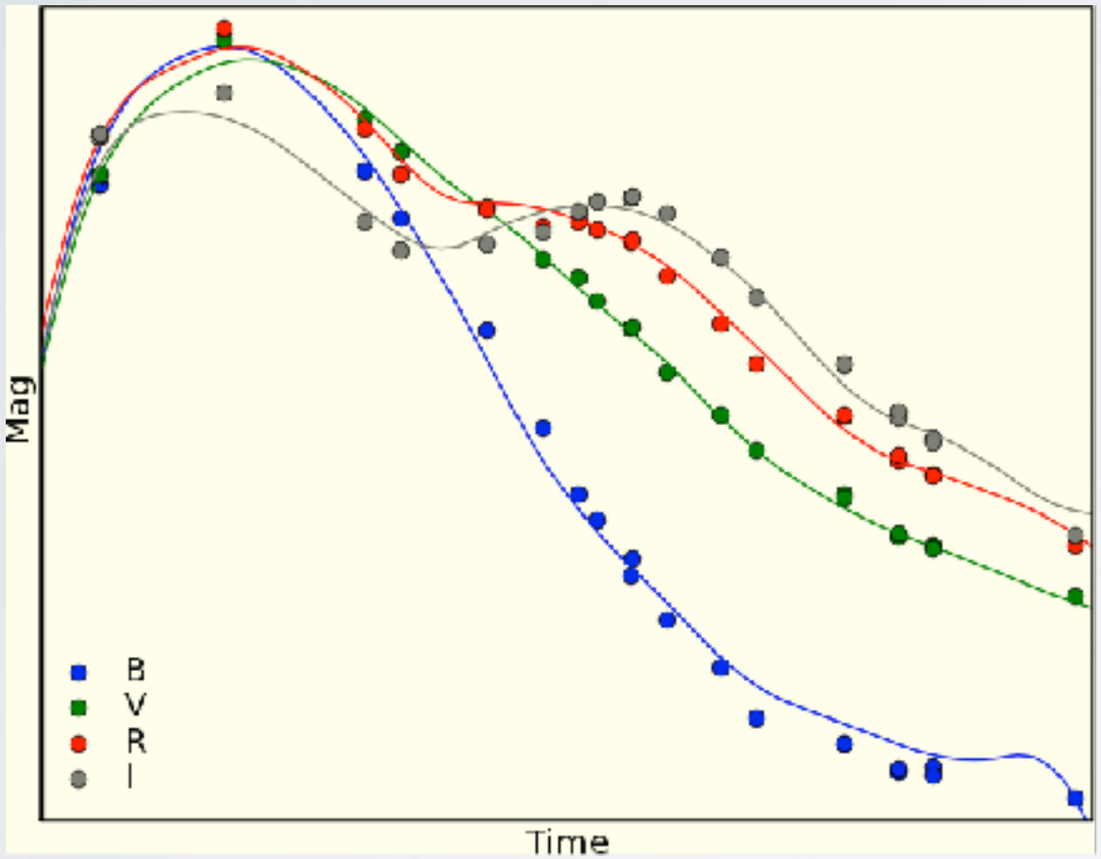
CURRENT STANDARDS

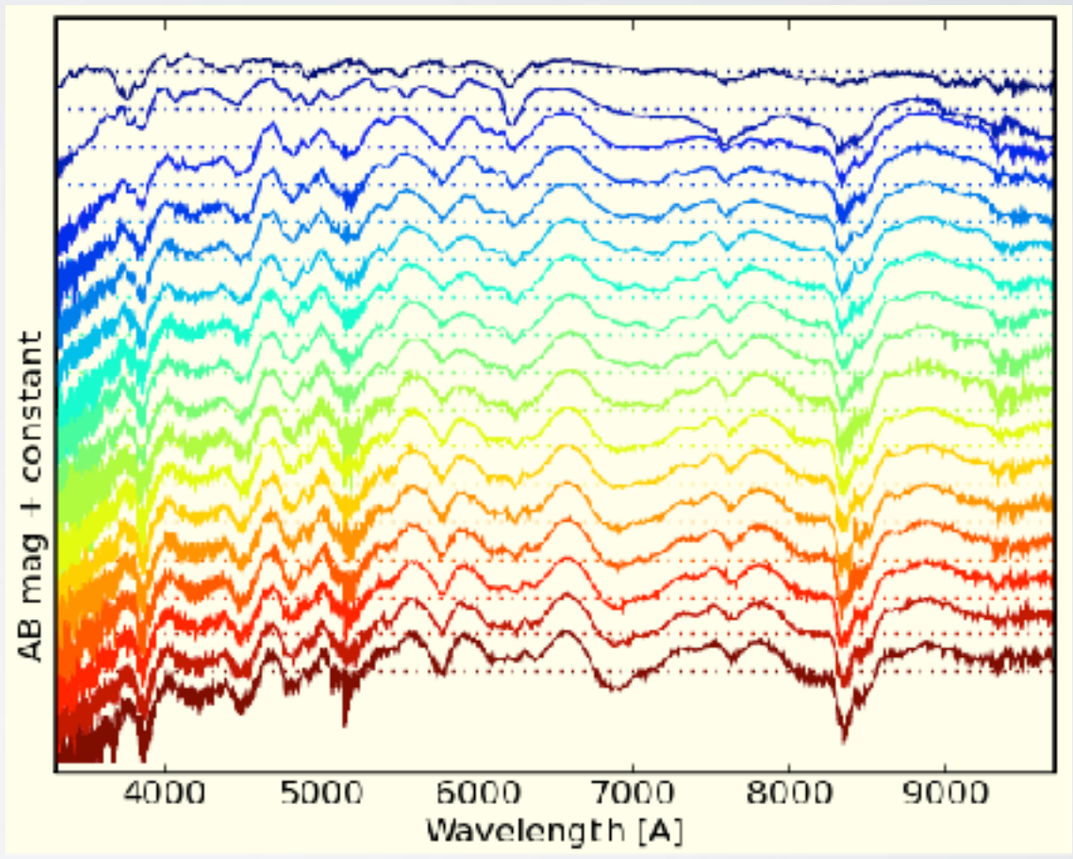
- SALT2, MLCS2k2 (not based on spectral time series templates)
- Simple, only a few degrees of freedom, trained mostly on photometry.

SALT2 model = flux(phase, λ) =



THE DATA


Mag
B
V
R
I
Time


AB mag + constant
4000
5000
6000
7000
8000
9000
Wavelength [A]

PLAN FOR MAKING A MODEL*

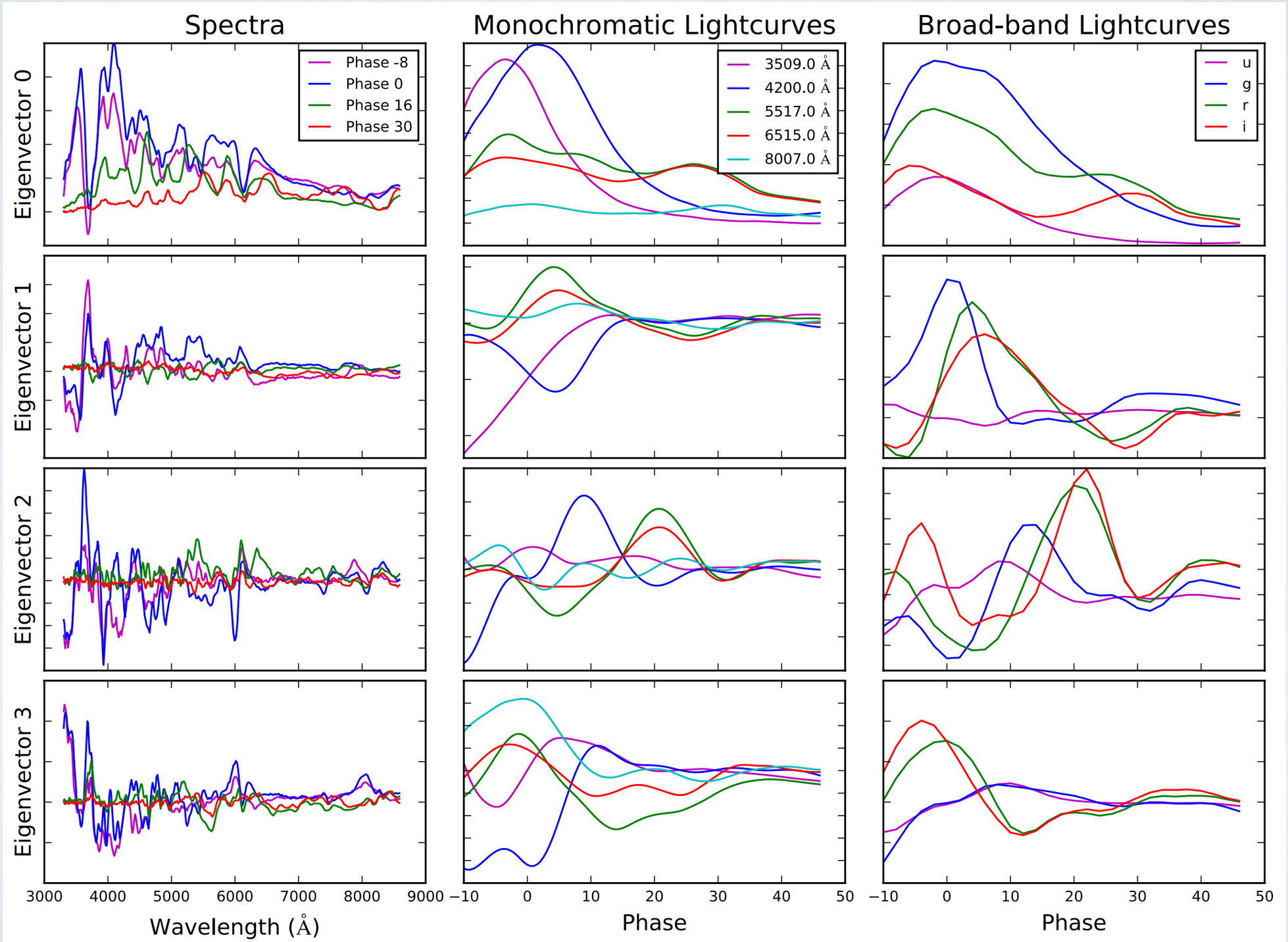
- Use data from SNfactory
- Do something like SALT2 -- linear spectral time series templates
- Add complexity to capture more of SNIa diversity
- Result: SNEMO = SuperNova Empirical MOdel

* See the next talk for a totally different method!

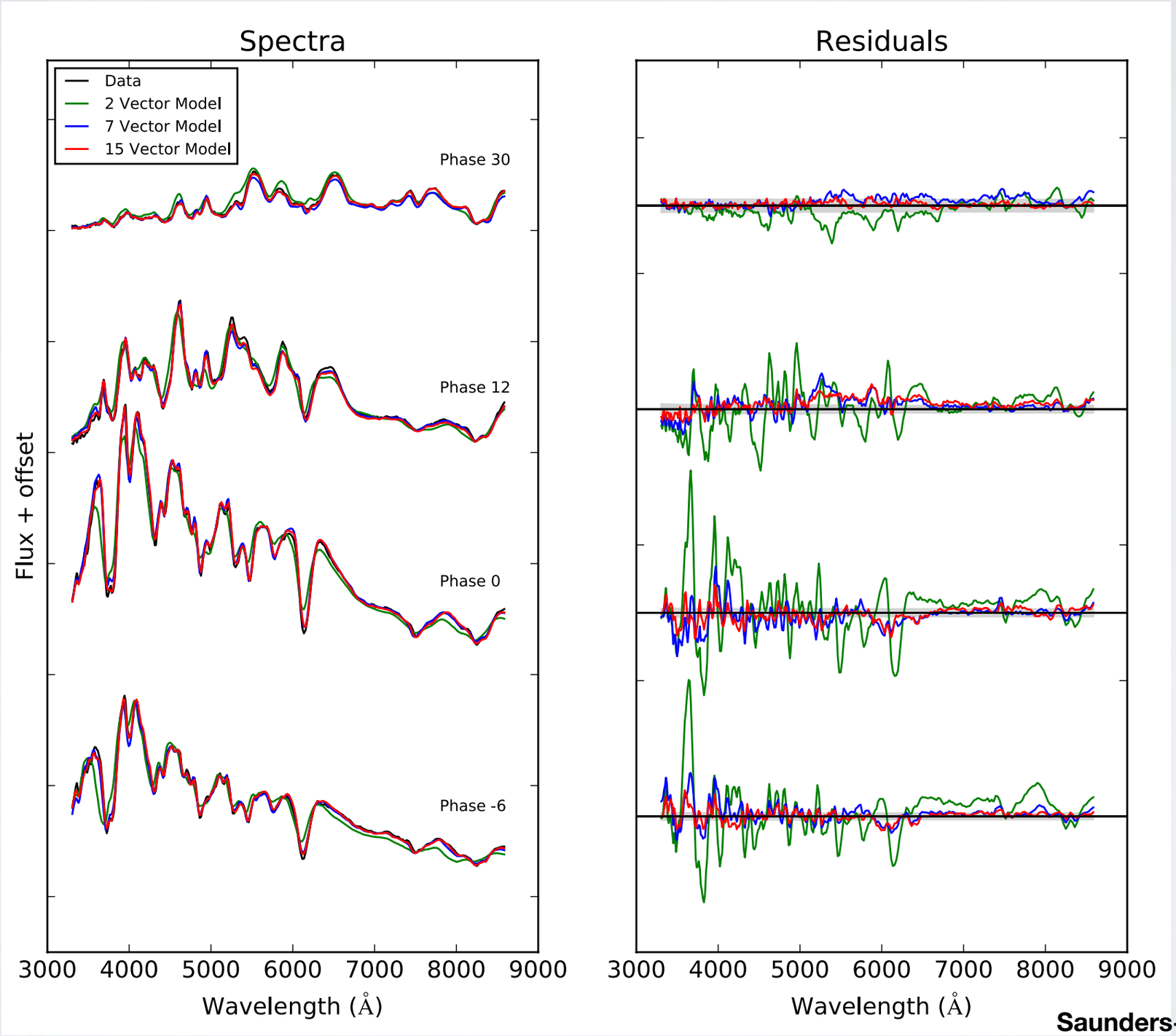
MAKING THE MODEL

- Use Gaussian Processes to model each individual SN
- (Optional) Deredden with a color relation
- Use EMFA (PCA-like process) to calculate model components
- Use K-fold cross-validation to determine model parameters:
    - What color relation to use
    - Model training set selection
    - Number of components in the final model

OUTPUT RESHAPED AS SPECTRAL TIME SERIES AND LIGHTCURVES

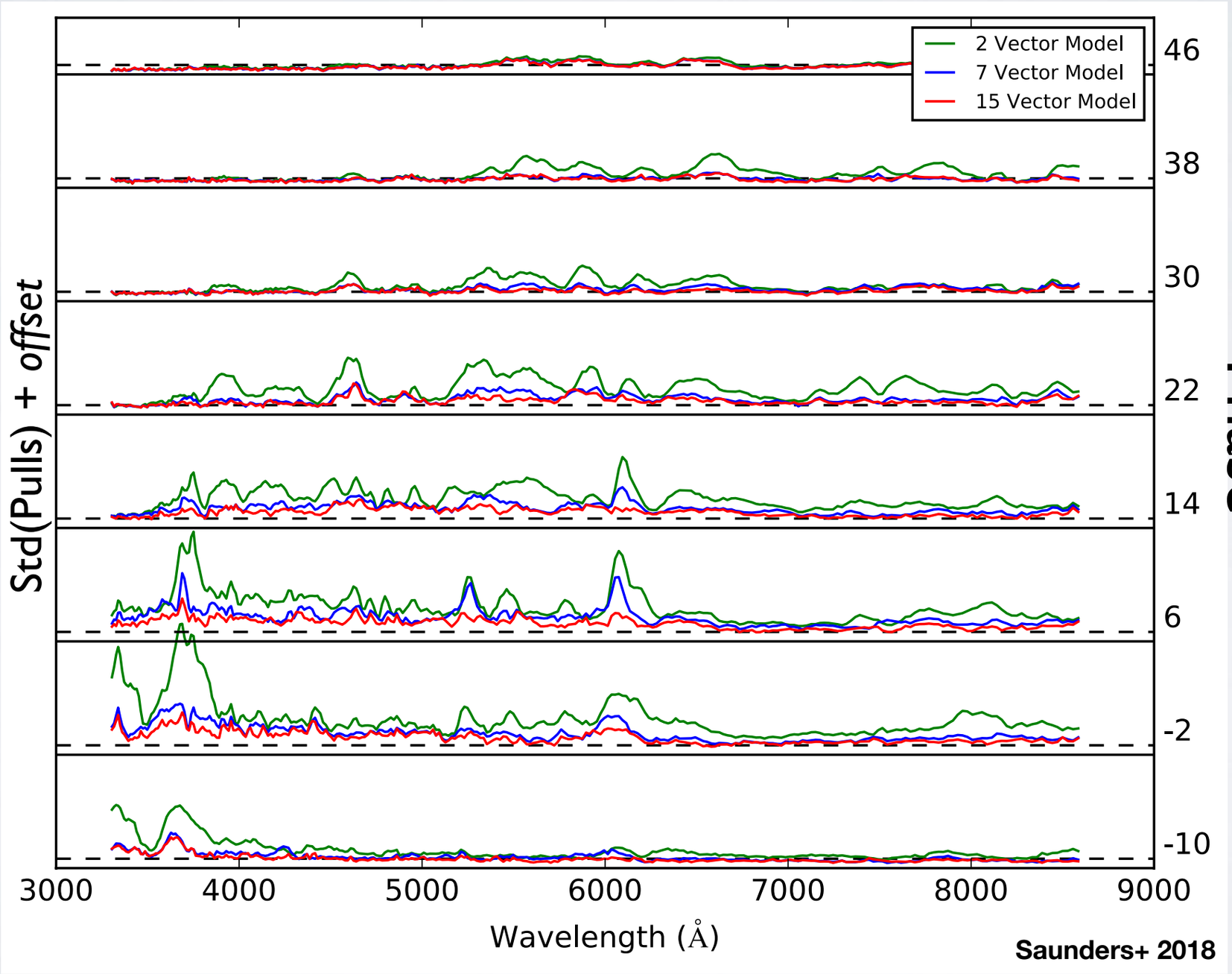


PERFORMANCE ON AN OUT-OF-SAMPLE SUPERNOVA



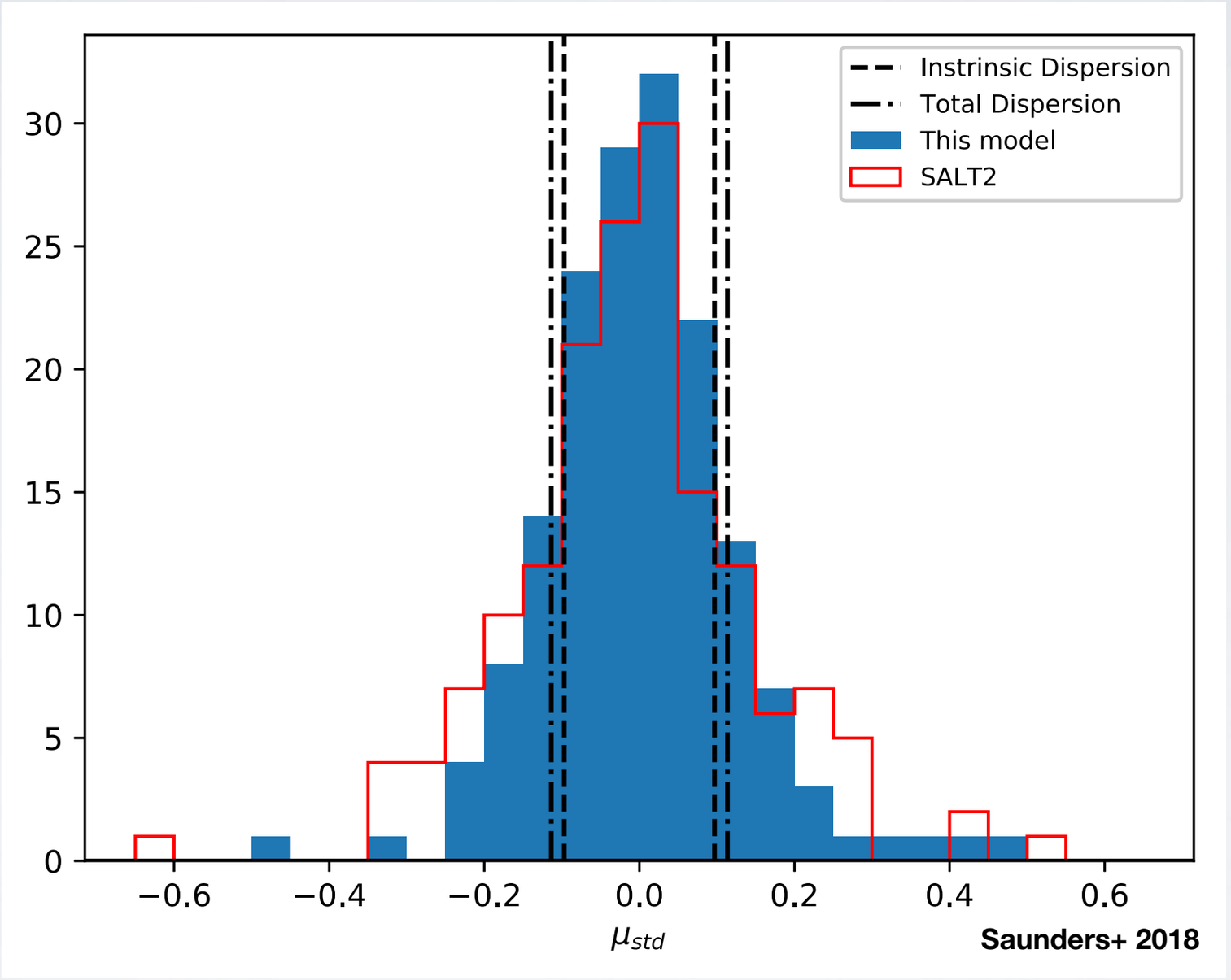
Saunders+ 2018

PERFORMANCE ON ALL OUT-OF-SAMPLE SUPERNOVAE



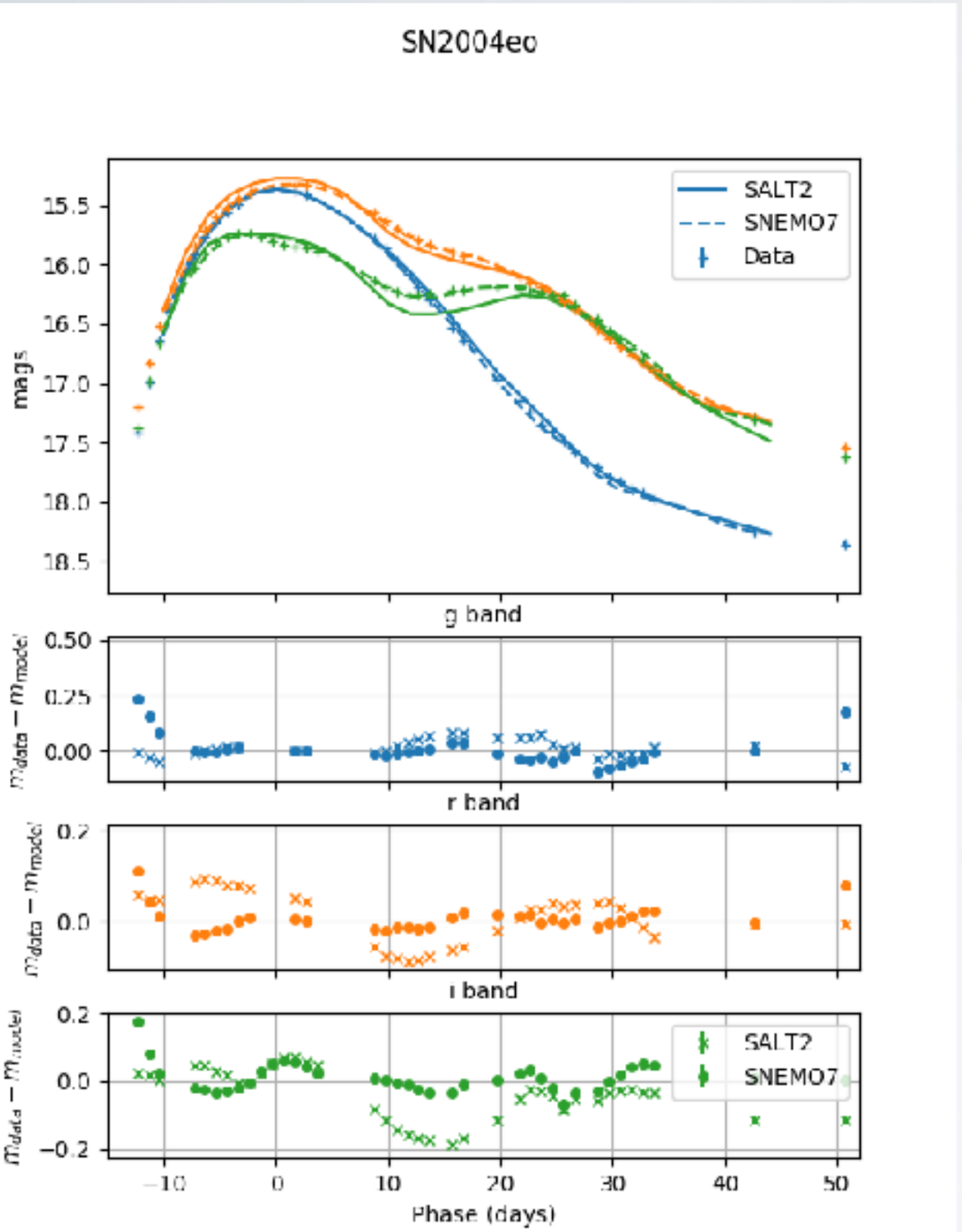
STANDARDIZED MAGNITUDES

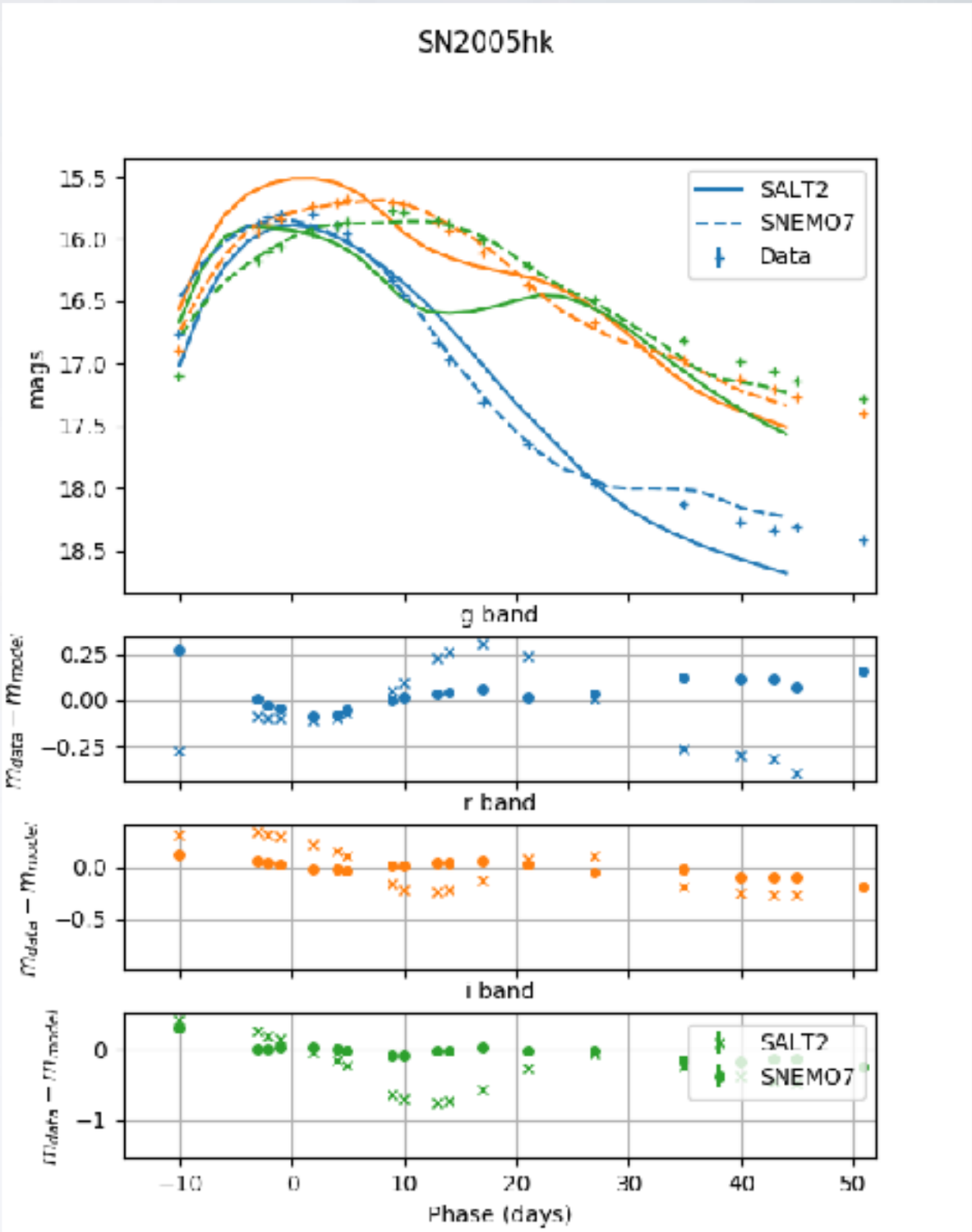
$$\mu_g = m_g^{std} - M_g = m_g + \sum_i \alpha_i \, c_i \; + \; \alpha_c \times A_S - M_g$$



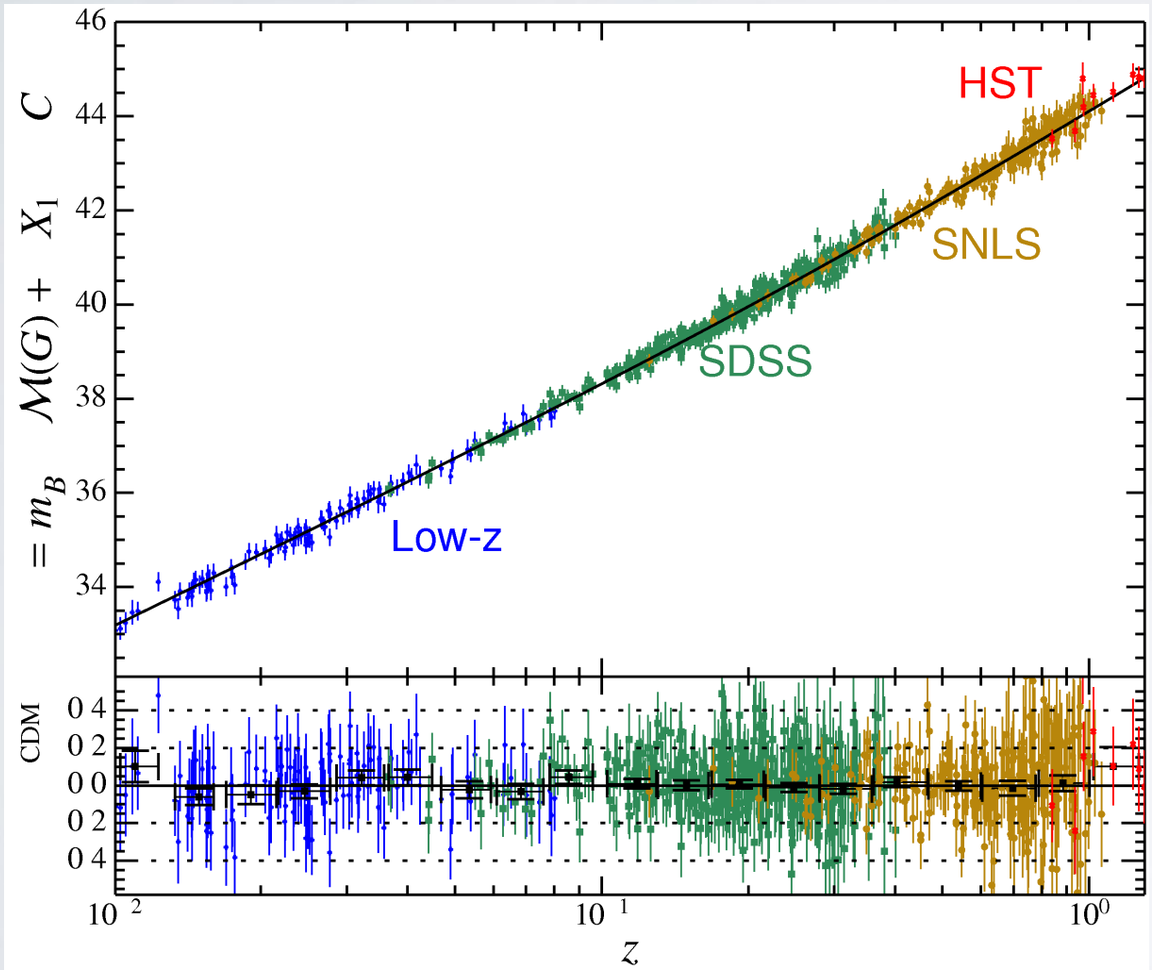
Total dispersion = 0.113 mags
Intrinsic Dispersion = 0.097 mags

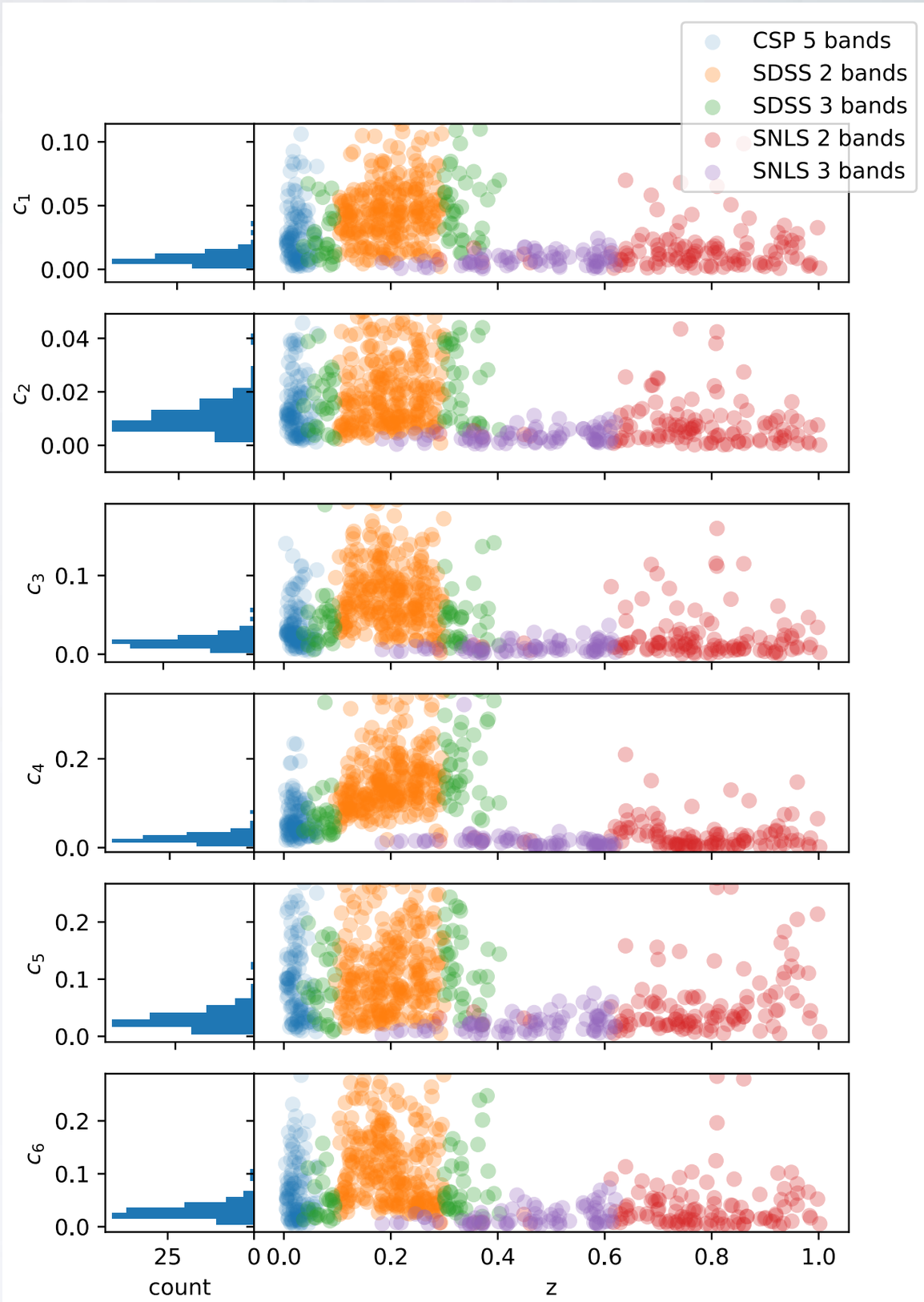
FITTING PHOTOMETRY



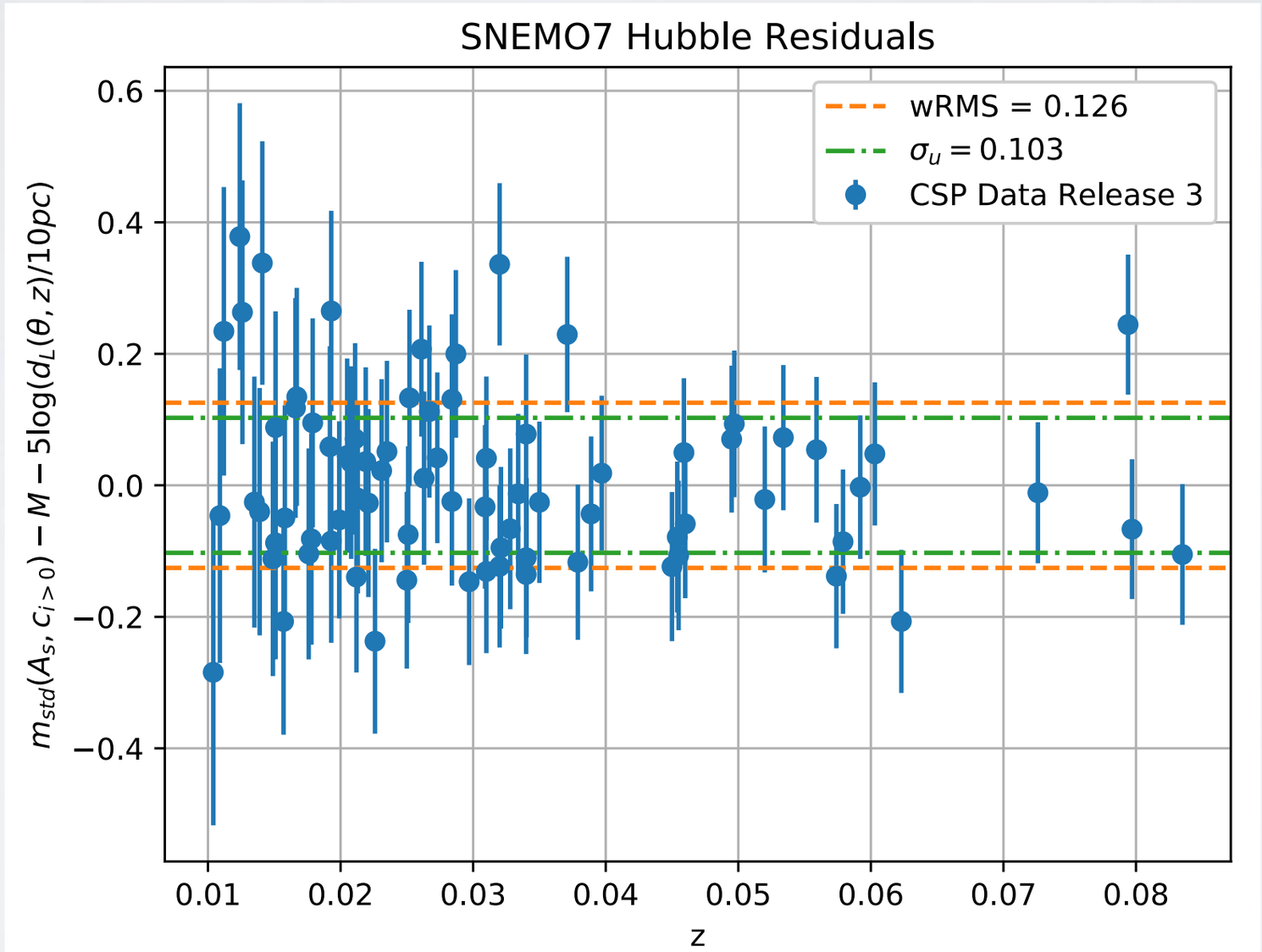


FITTING PHOTOMETRY



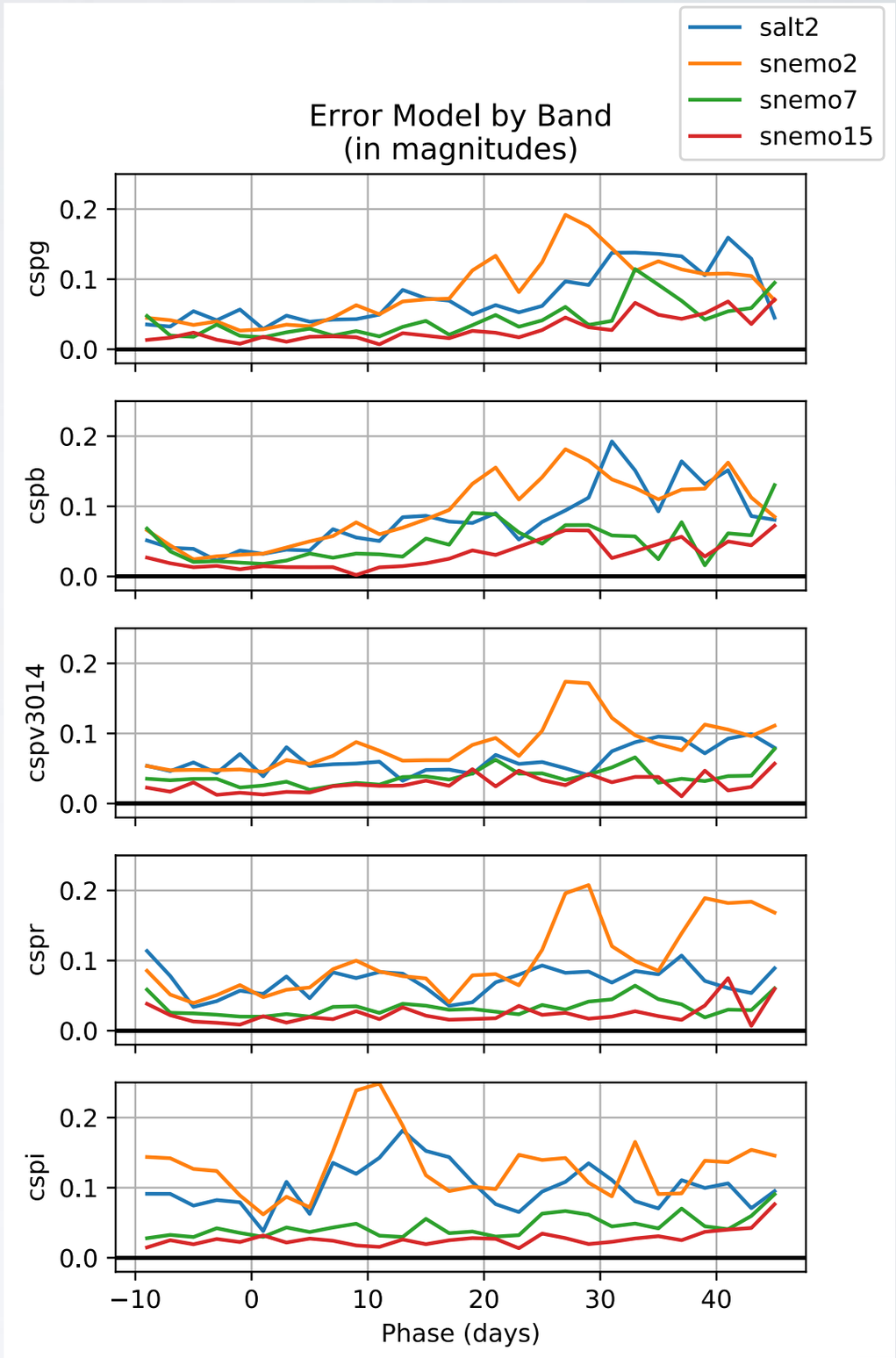


STANDARDIZATION WITH CSP DATA



DEVELOPING AN INDEPENDENT ERROR MODEL

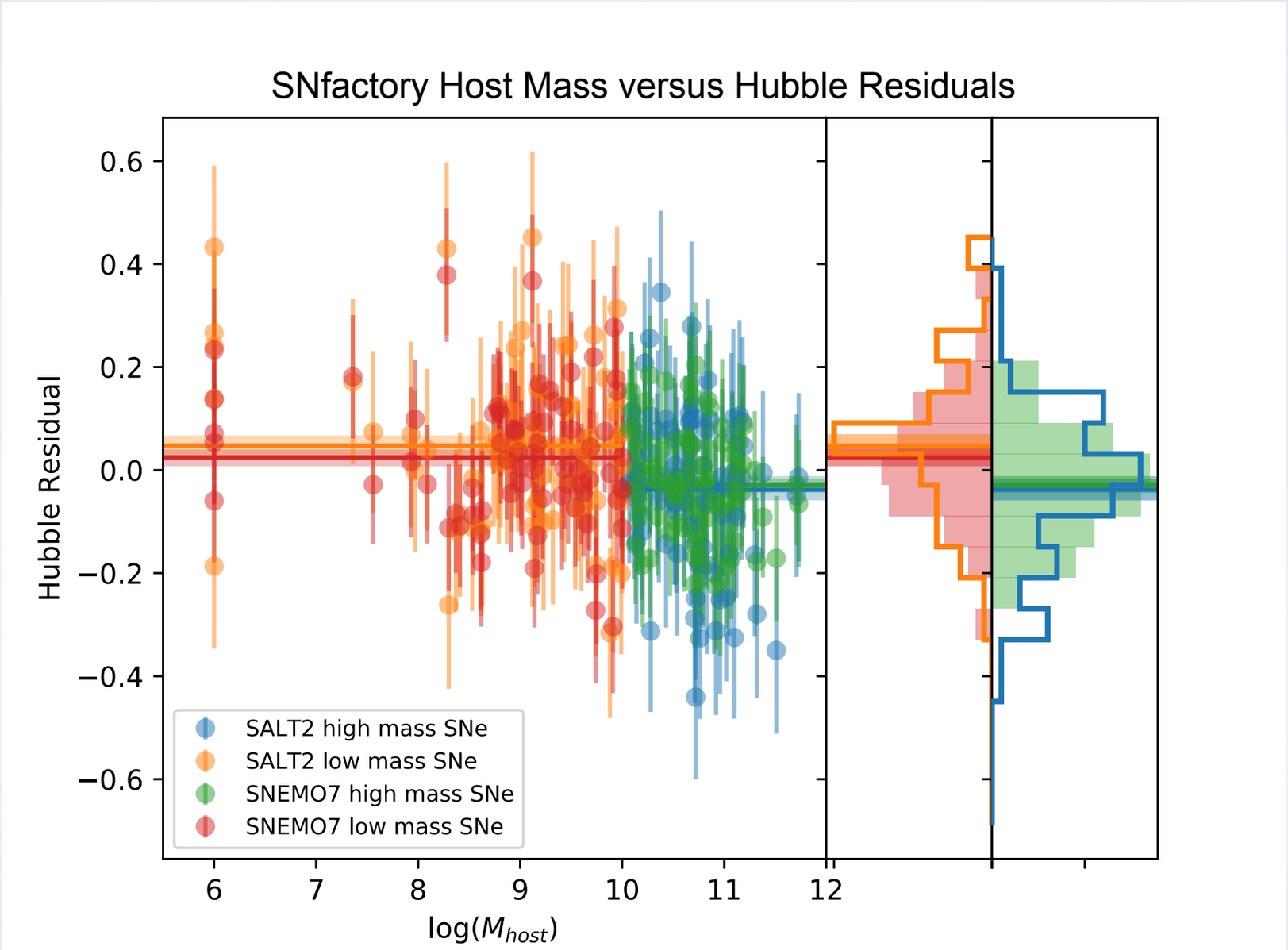
$$\sigma^2_{residual}(M_i, t) = \sigma^2_{model}(M_i, t) + \sigma^2_{phot}(M_i, t)$$



A REDUCED HOST-MASS STEP?

Host step with SNEMO7: 0.053 +/- 0.020 mag

Host step with SALT2: 0.086 +/- 0.026 mag



- SNEMO is available currently on the github version of sncosmo and will be in the next release.

- Publication of the error model to come.

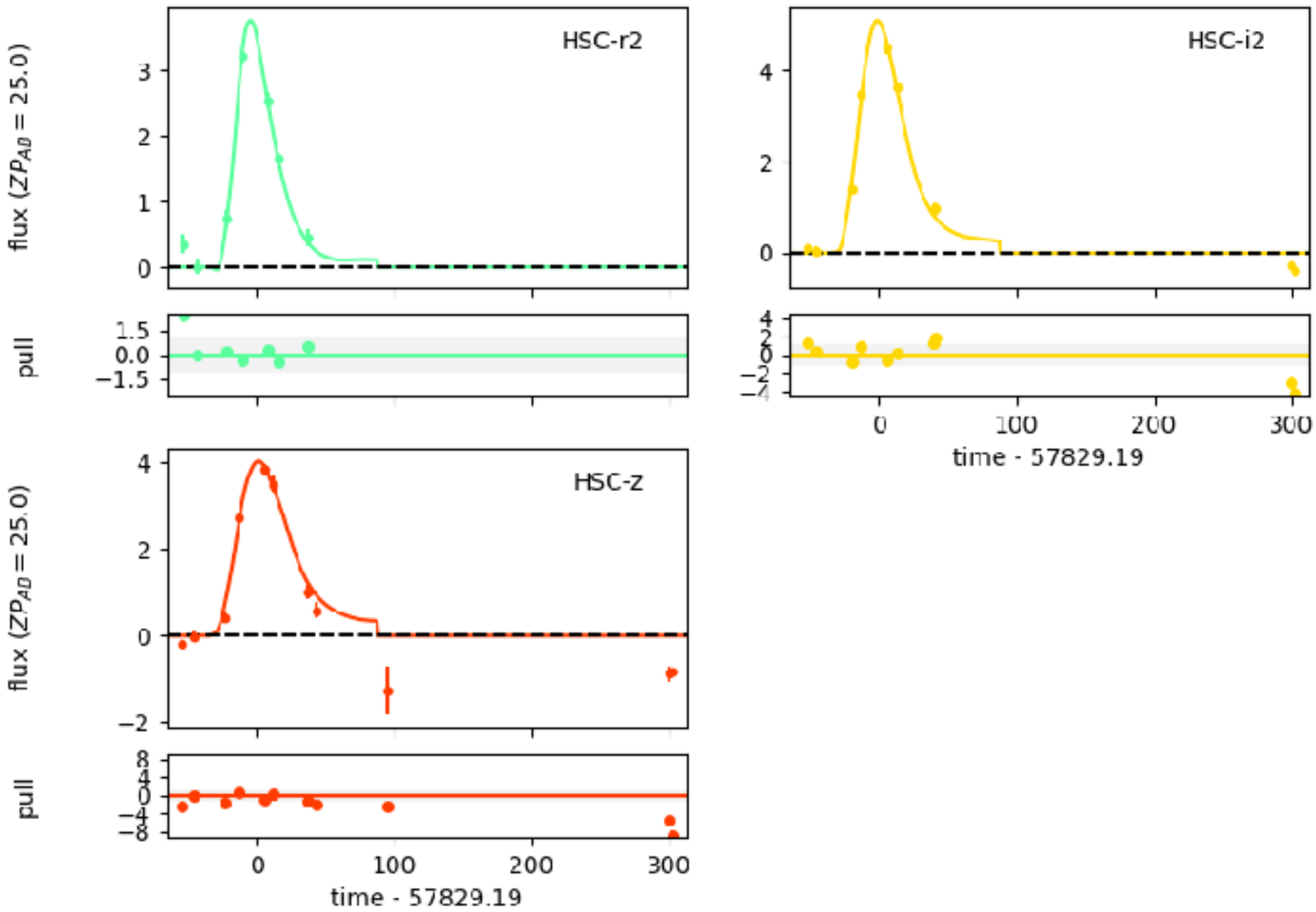
- Further improvements in wavelength and phase range to come…

THE PRELIMINARY-FINAL LIGHTCURVES PROMISED ON TUESDAY…

SSP2183

$z = 0.76248997$
$t_0 = 57829.19 \pm 0.21$
$x_0 = (4.723 \pm 0.087) \times 10^{-6}$
$x_1 = -0.17 \pm 0.22$

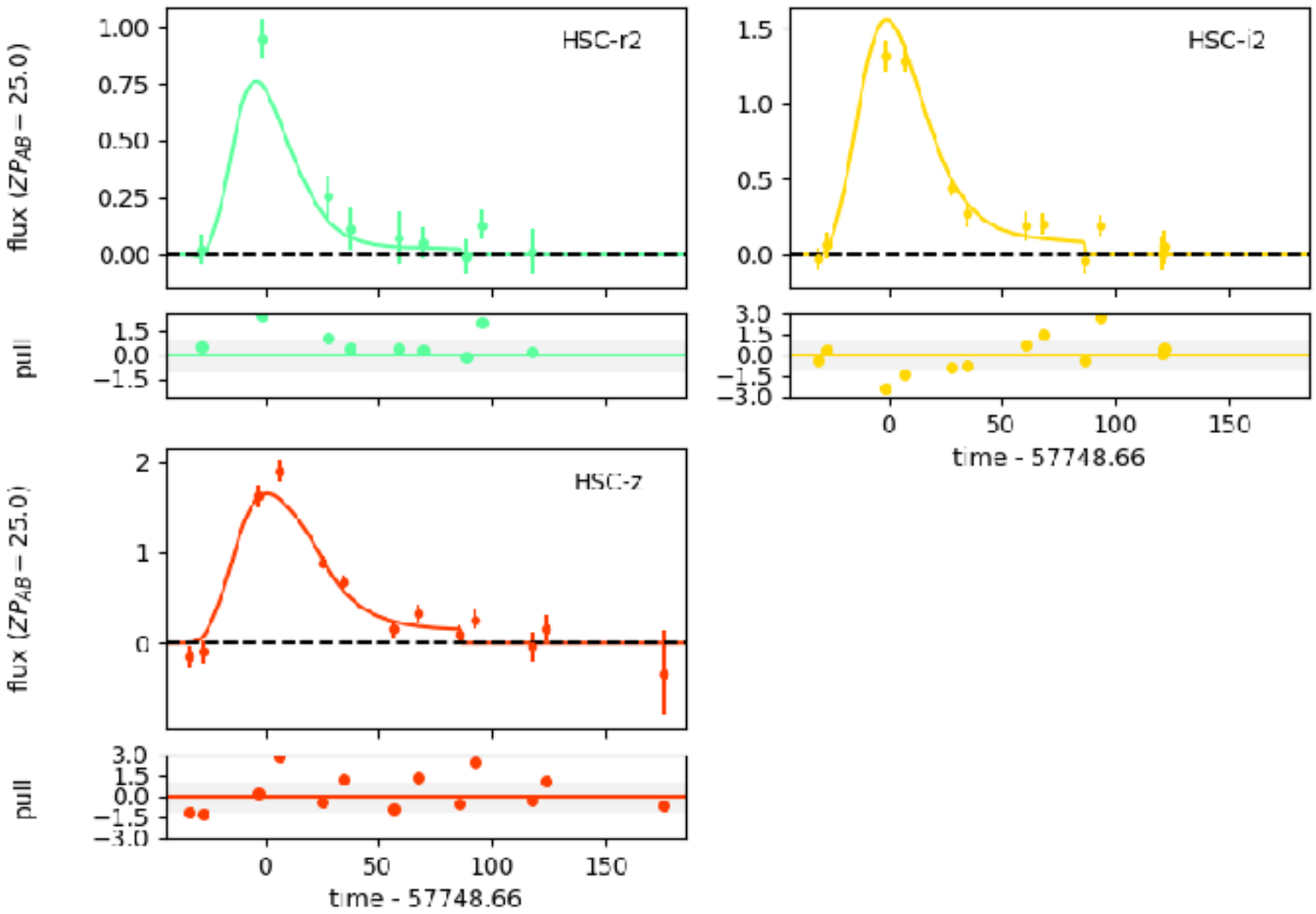
$c = -0.200 \pm 0.015$
mw $ebv = 0.016786992$
mw $r_v = 3.1000000$



SSP393

$z = 0.73200000$
$t_0 = 57748.6569 \pm 0.0026$
$x_0 = (1.458 \pm 0.054) \times 10^{-6}$
$x_1 = -0.41 \pm 0.46$

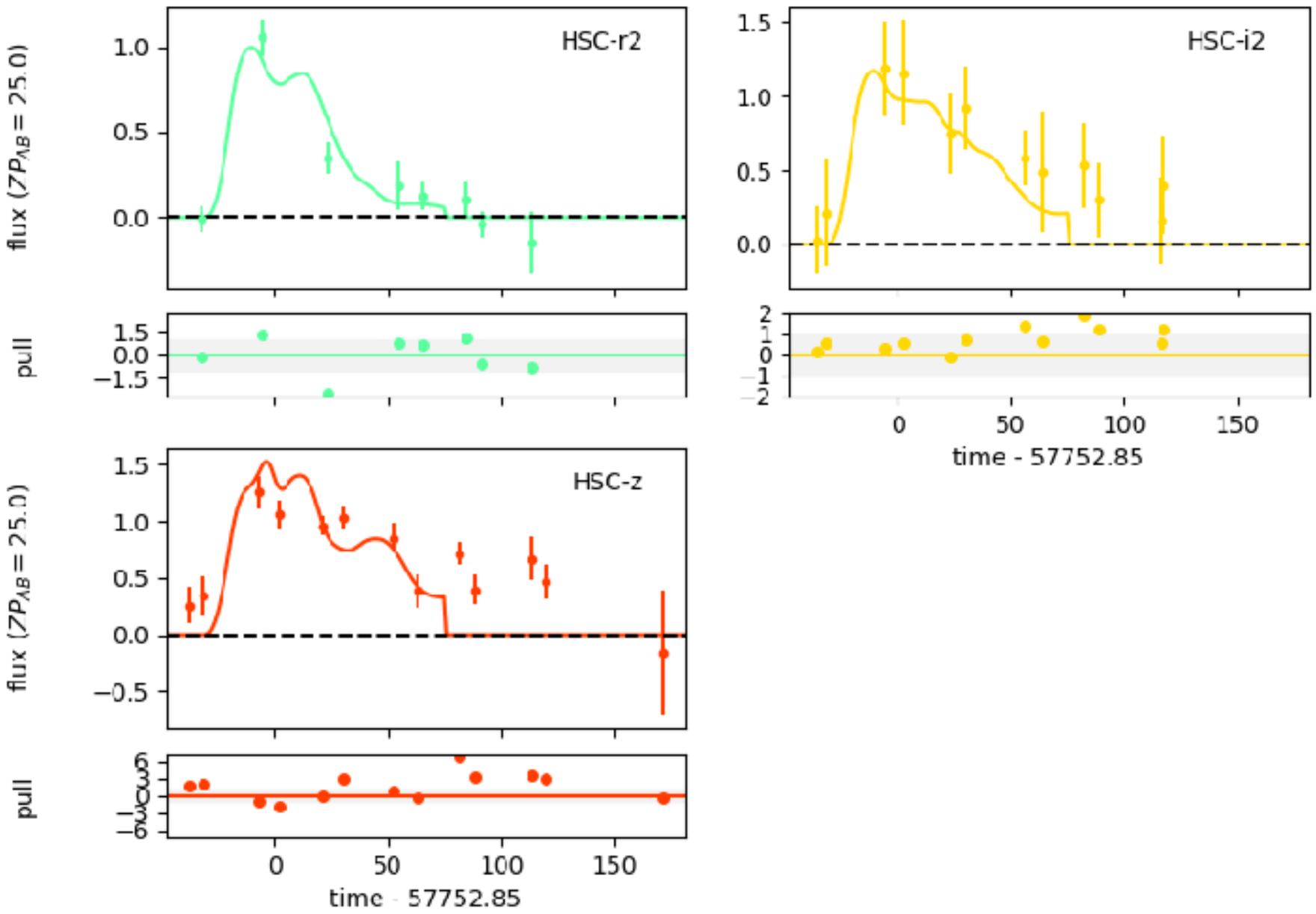
$c = 0.232 \pm 0.071$
mw $ebv = 0.014978450$
mw $r_v = 3.1000000$



SSP517

$z = 0.51665998$
$t_0 = 57752.8 \pm 1.2$
$x_0 = (9.7 \pm 1.2) \times 10^{-7}$
$x_1 = 7.6 \pm 2.0$

$c = 0.262 \pm 0.071$
mw $ebv = 0.017568477$
mw $r_V = 3.1000000$



SSP481

$z = 1.0420000$
$t_0 = 57739.25 \pm 0.66$
$x_0 = (1.497 \pm 0.090) \times 10^{-6}$
$x_1 = 0.06 \pm 0.50$

$c = -0.015 \pm 0.058$
mwebv = 0.013760679
mwr_v = 3.1000000