BayeSN-SED:
A Hierarchical Bayesian Model for SN Ia in the Optical and NIR

Cambridge Astrostatistics

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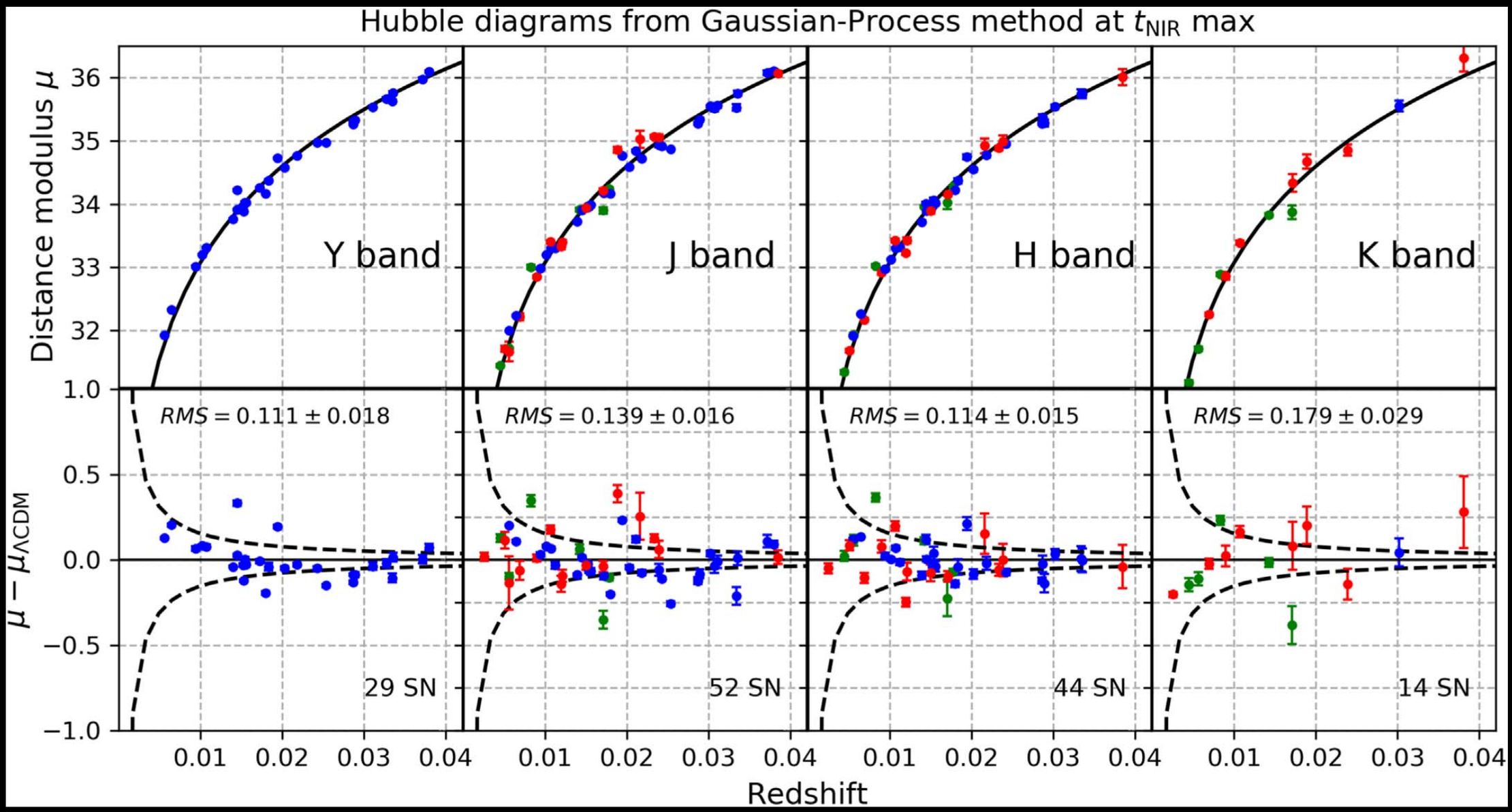
02 Oct 2019

Introduction

- SN Ia have attractive properties in rest-frame NIR (YJH, 1-1.6 μm)
  - Low Dispersion in Peak Magnitudes (Avelino+19)
  - Host Dust Extinction is diminished in NIR: A_J / A_B ~20%
- Conventional SALT2 SED model fitter only effective to ~ 7000 Å
- SN Ia LC fitters in the NIR [SNooPy, BayeSN (2011)] model LCs in discrete rest-frame photometric passbands; require K-corrections (mangling) to rest-frame bands
- **BayeSN-SED : a Bayesian continuous SED SN Ia model/fitter leveraging the properties of the NIR**

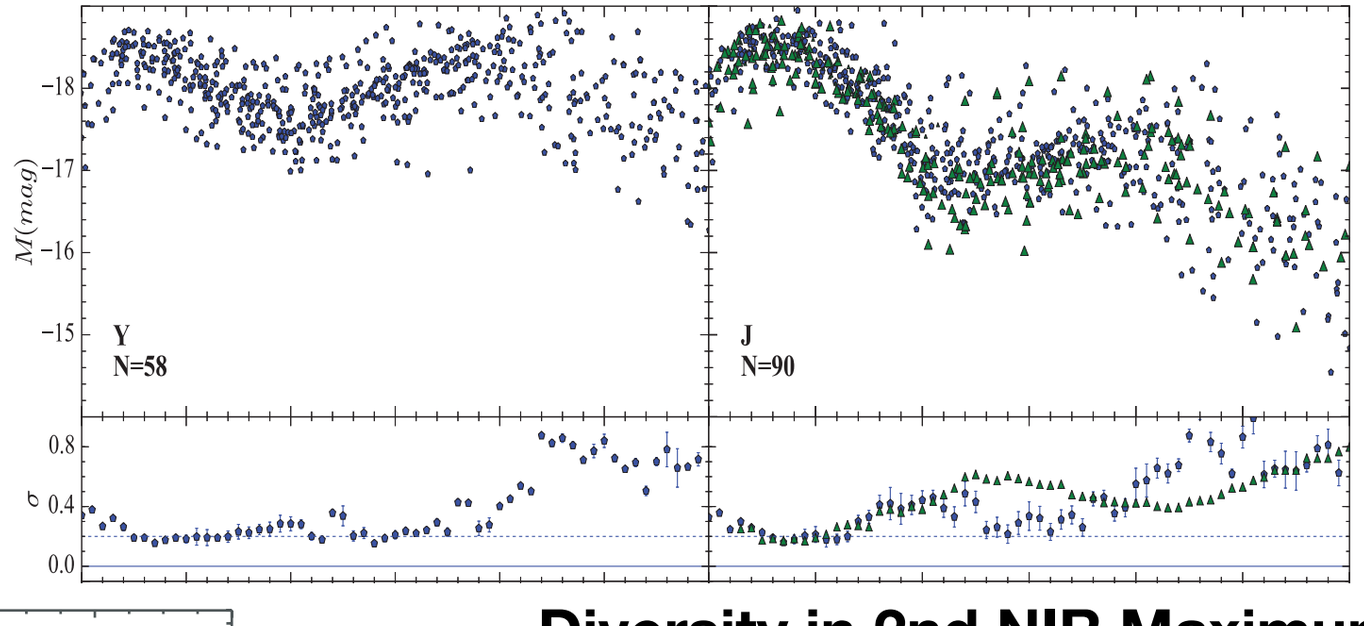
SN Ia in the NIR as standard candles: Avelino et al. 2019



dataset: compilation of
CSP (Krisciunas+17) & CfAIR2 (Friedman+15)
NIR low-z SN Ia samples

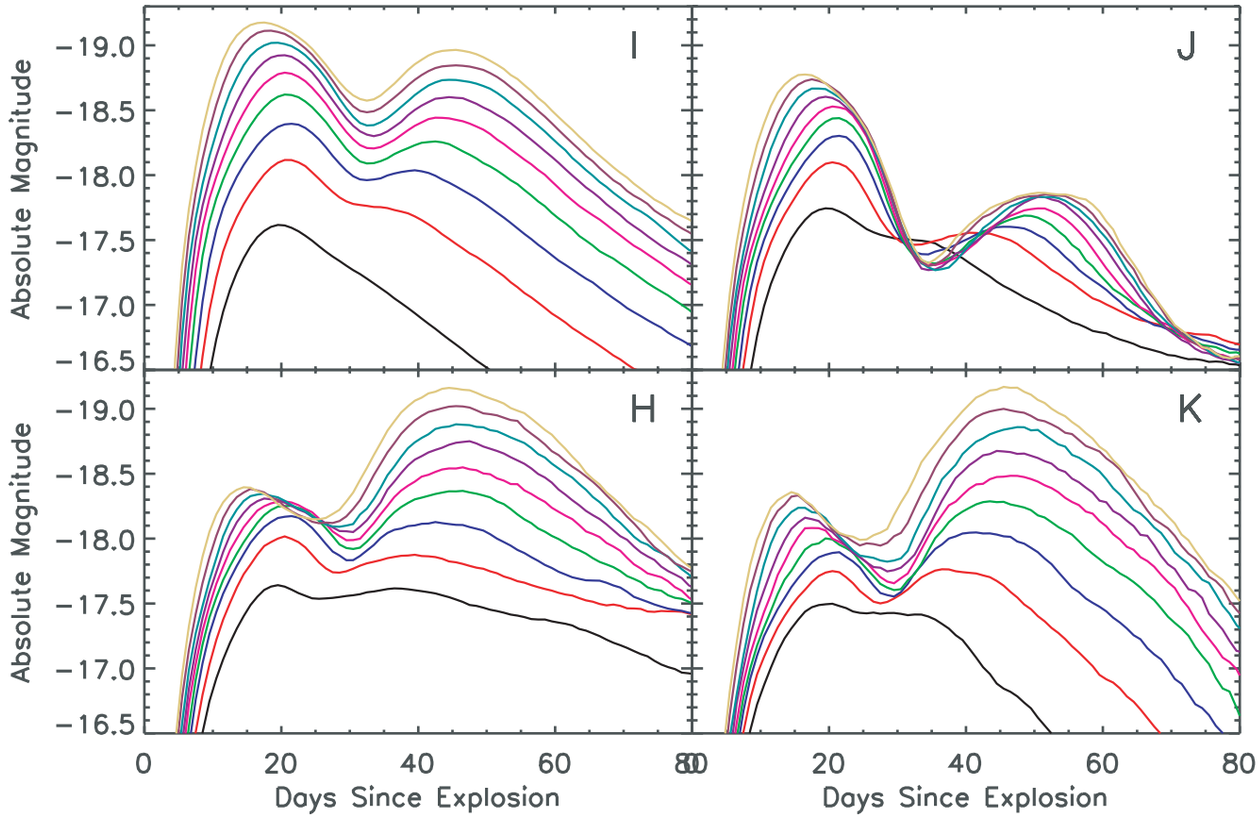
The NIR 2nd Maximum: a probe of SN physics

Dhawan+15



Diversity in 2nd NIR Maximum behaviour at 20-30 days

Effect of ^{56}Ni mass on NIR LCs (Kasen 2006)

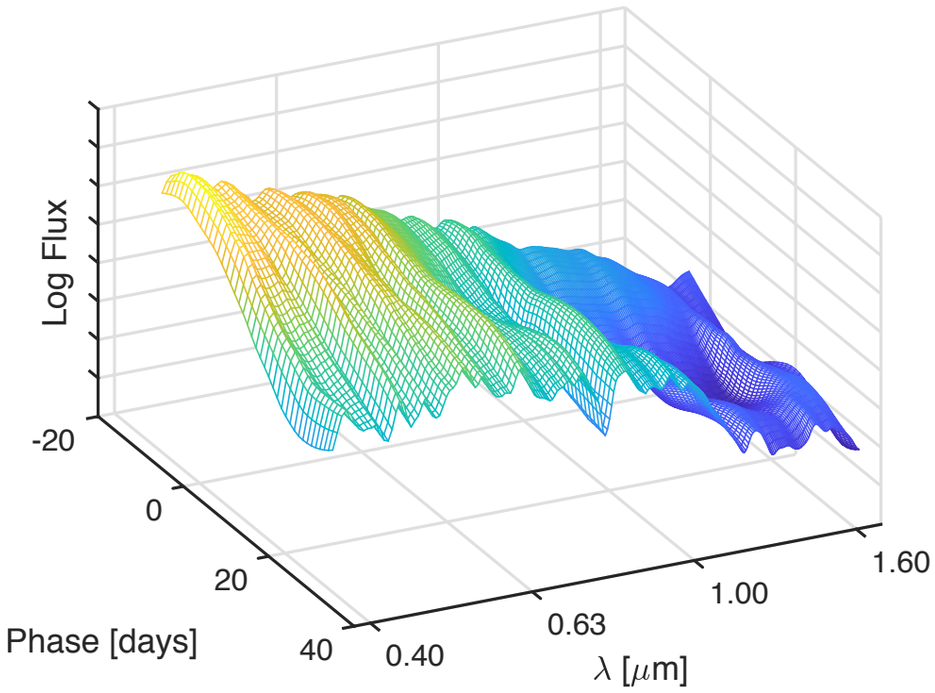


Luminosity and Timing of 2nd NIR max linked to the amount and ionisation evolution of Fe-group elements in ejecta (Kasen 2006)

. 10.—Effect of the mass of ^{56}Ni (M_{Ni}) on the NIR light curves. The model light curves demonstrate variations in M_{Ni} from 0.1 to 0.9 $M_\odot$ in 0.1 $M_\odot$ increments.

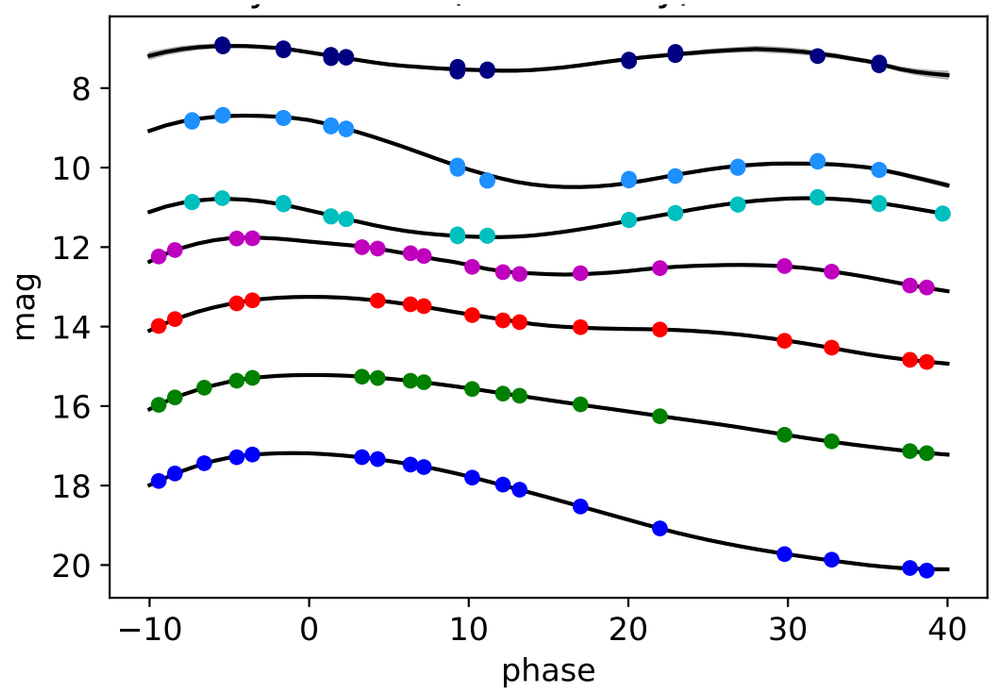
BayeSN-SED:
A Hierarchical Bayesian model for SN Ia Optical-NIR Spectral Energy Distributions (SED)

Most data in NIR are photometric LCs



Filters, Cadence, Noise

Inverse?



Latent Spectral Energy Distribution Function

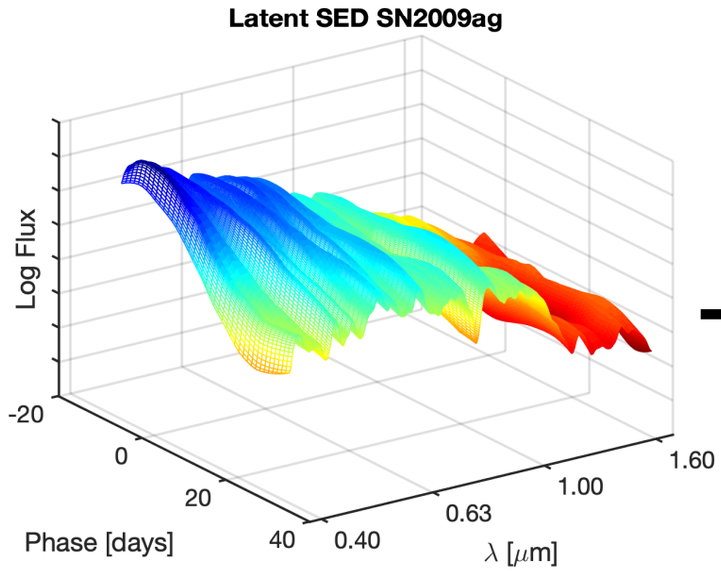
Optical and NIR Light Curves (BVriYJH)

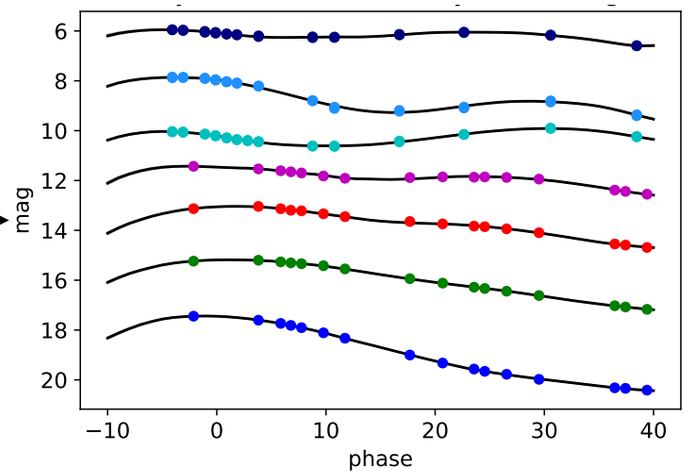
Goal: Model Distribution of SN Ia Optical-NIR SED(t,λ) functions

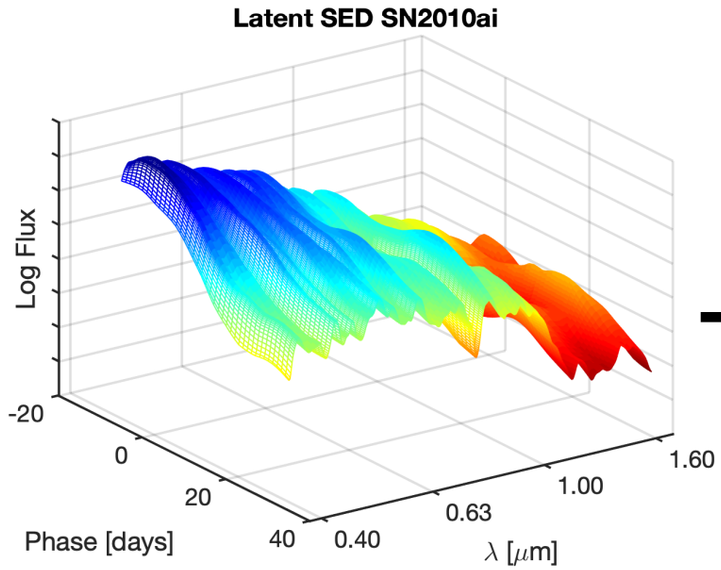
A Probabilistic Model Leveraging the Population

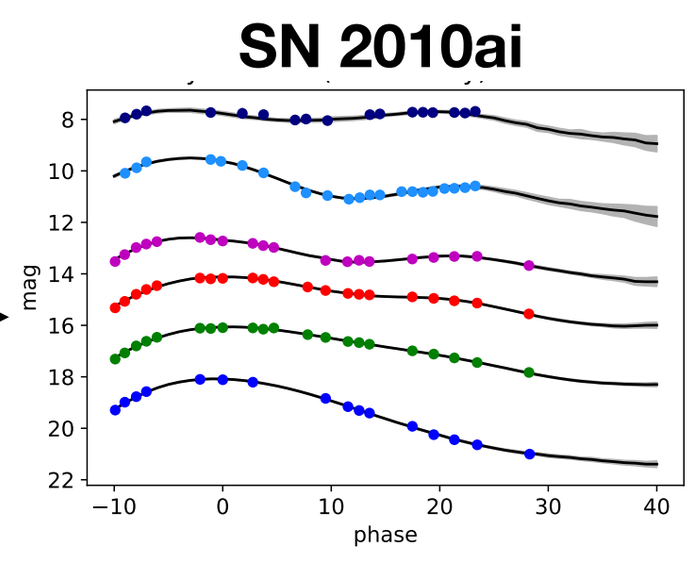
Population Distribution of SED(t, λ)s (Covariance Structure)

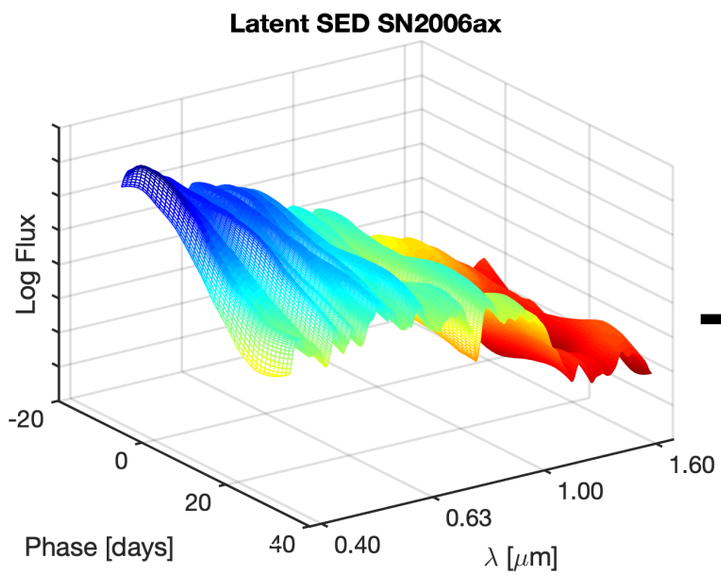
Goal: Solve Inverse Problem with Probabilistic *Effective* Model for Distribution of SN Ia Optical-NIR SED(t,λ) functions

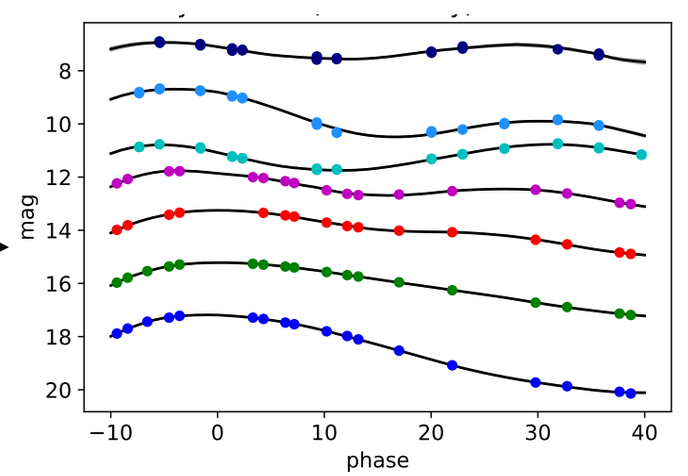






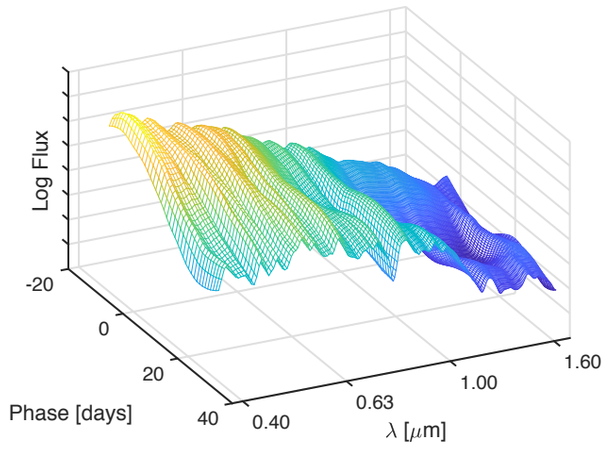






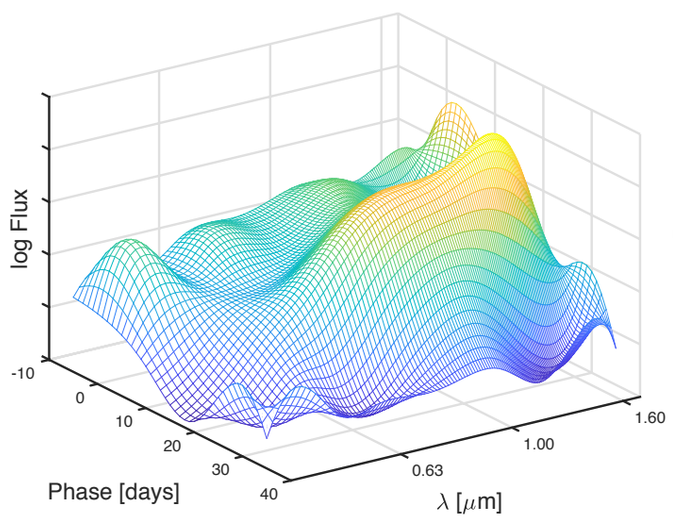
BayeSN Model Covariance Components

Mean Intrinsic SED (warped Hsiao template)



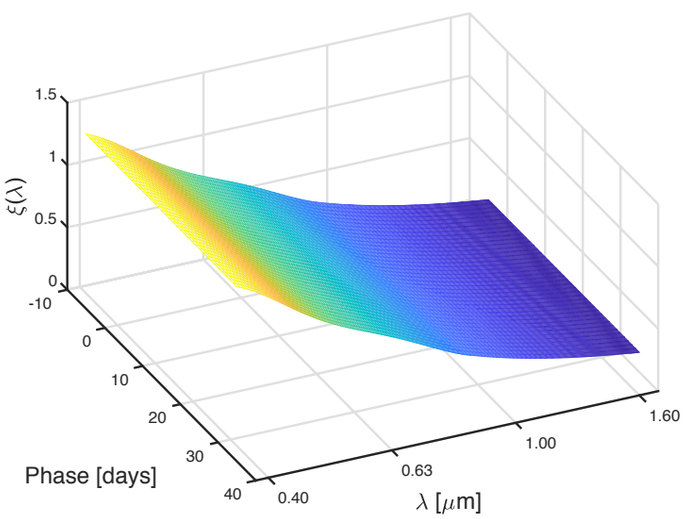
+ θ ×

Intrinsic Functional Component #1 (FC1)



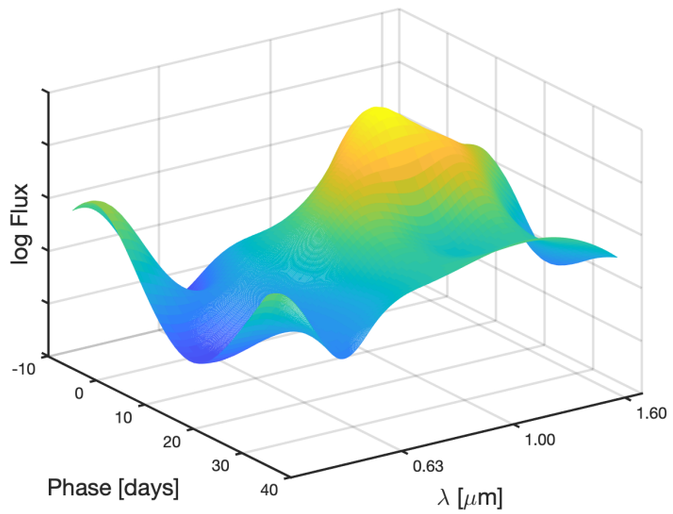
+ A_V ×

Dust Extinction Law (R_V)



+

Residual SED Perturbations



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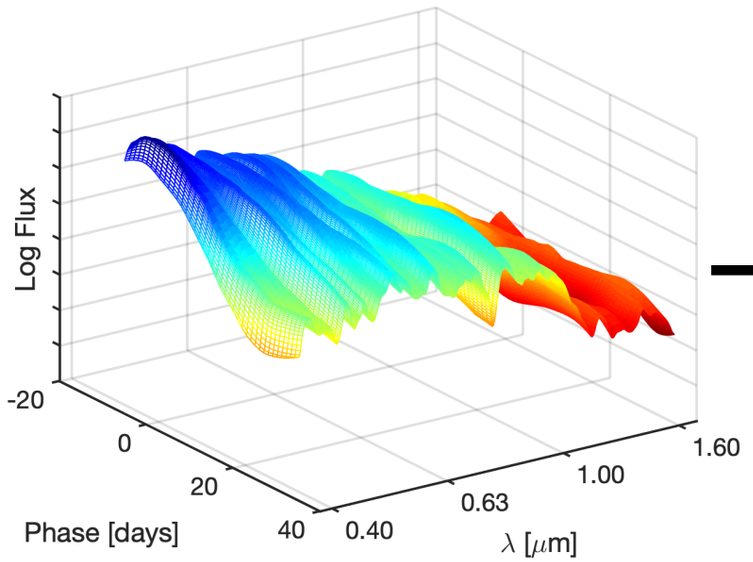
Latent SN SED



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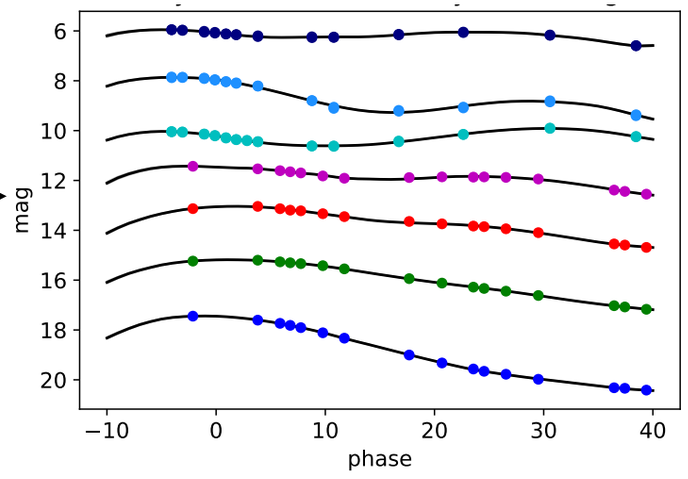
SN Ia Opt+NIR LCs



BayeSN-SED Probabilistic Graphical Model

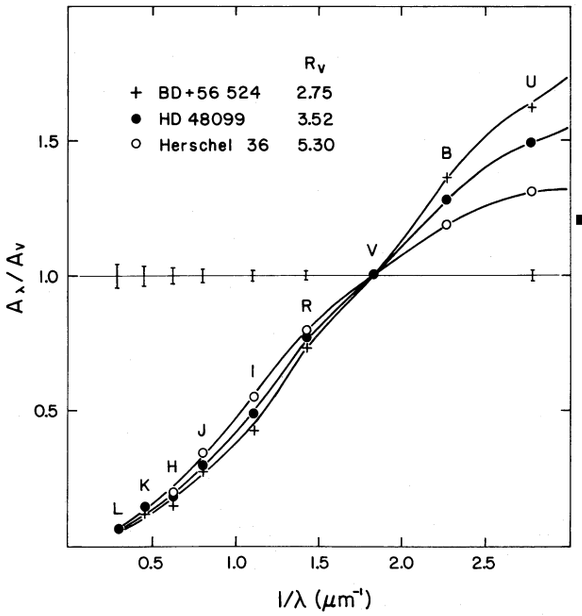
$\Omega_M, w, \ldots$

Population Distribution of host galaxy dust

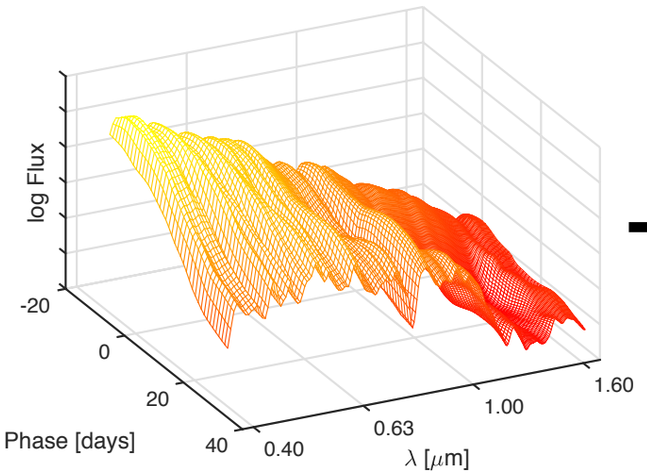
A_V^s, R_V^s

μ_s

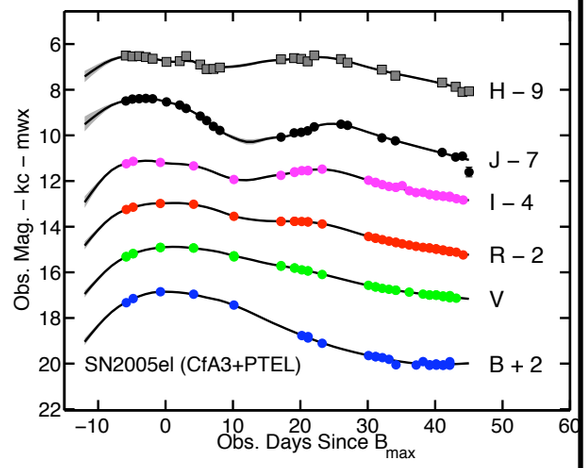
z_s



Dust Law(λ)

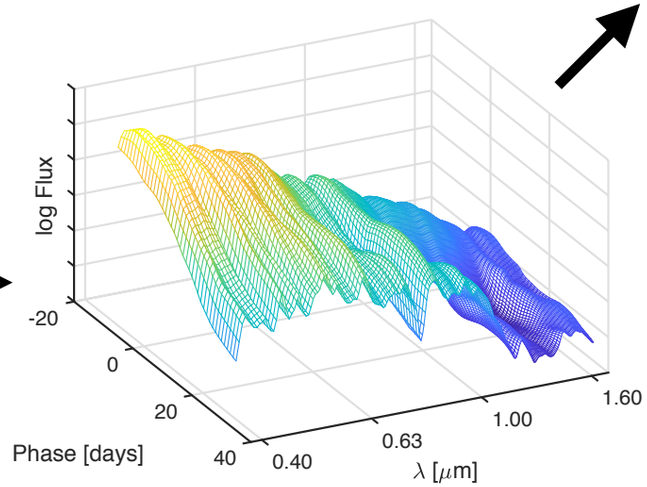


Apparent SED$_s$(t, λ)



Light Curves

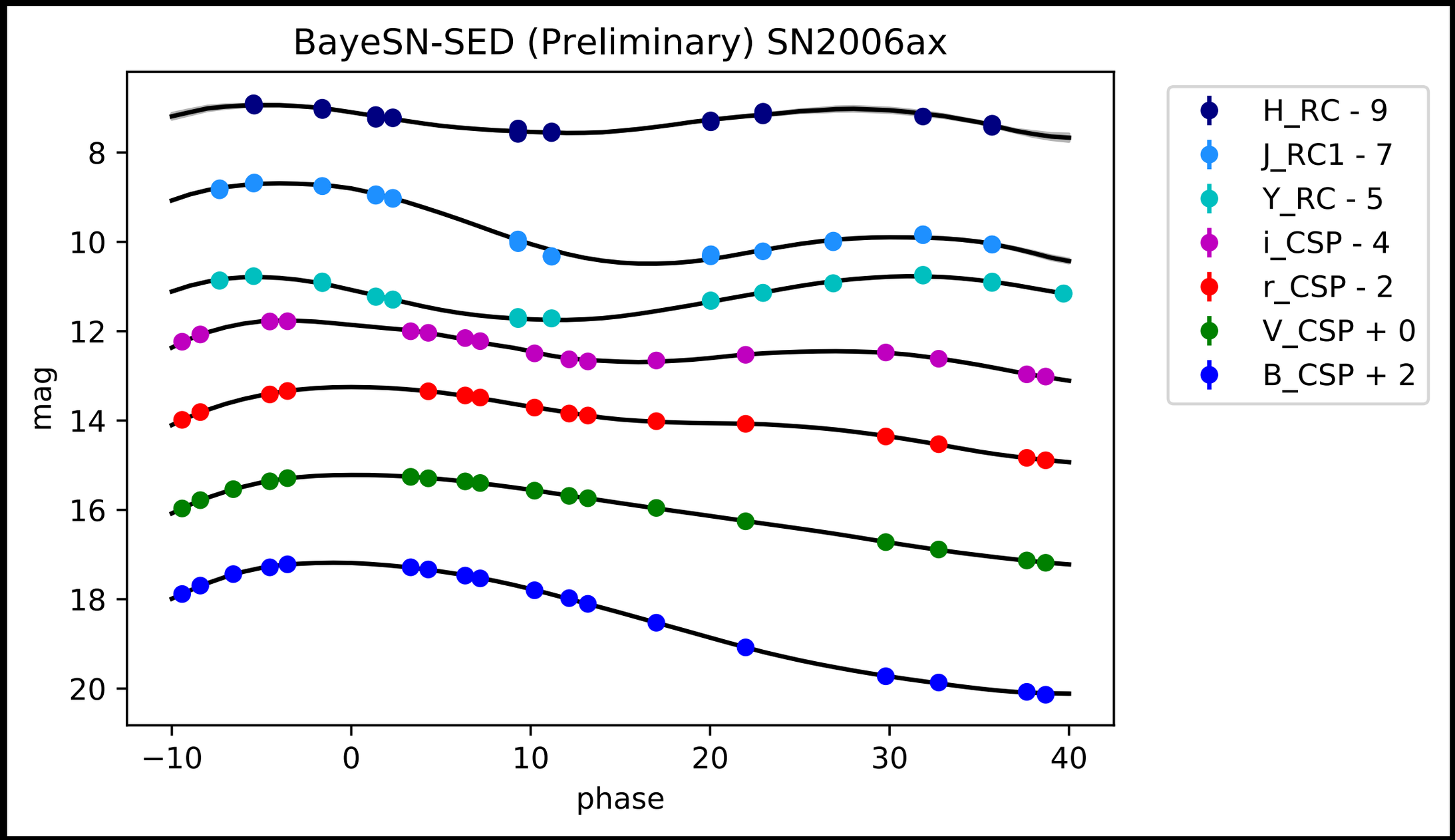
Population Distribution of SED(t, λ)s (Intrinsic Covariance)



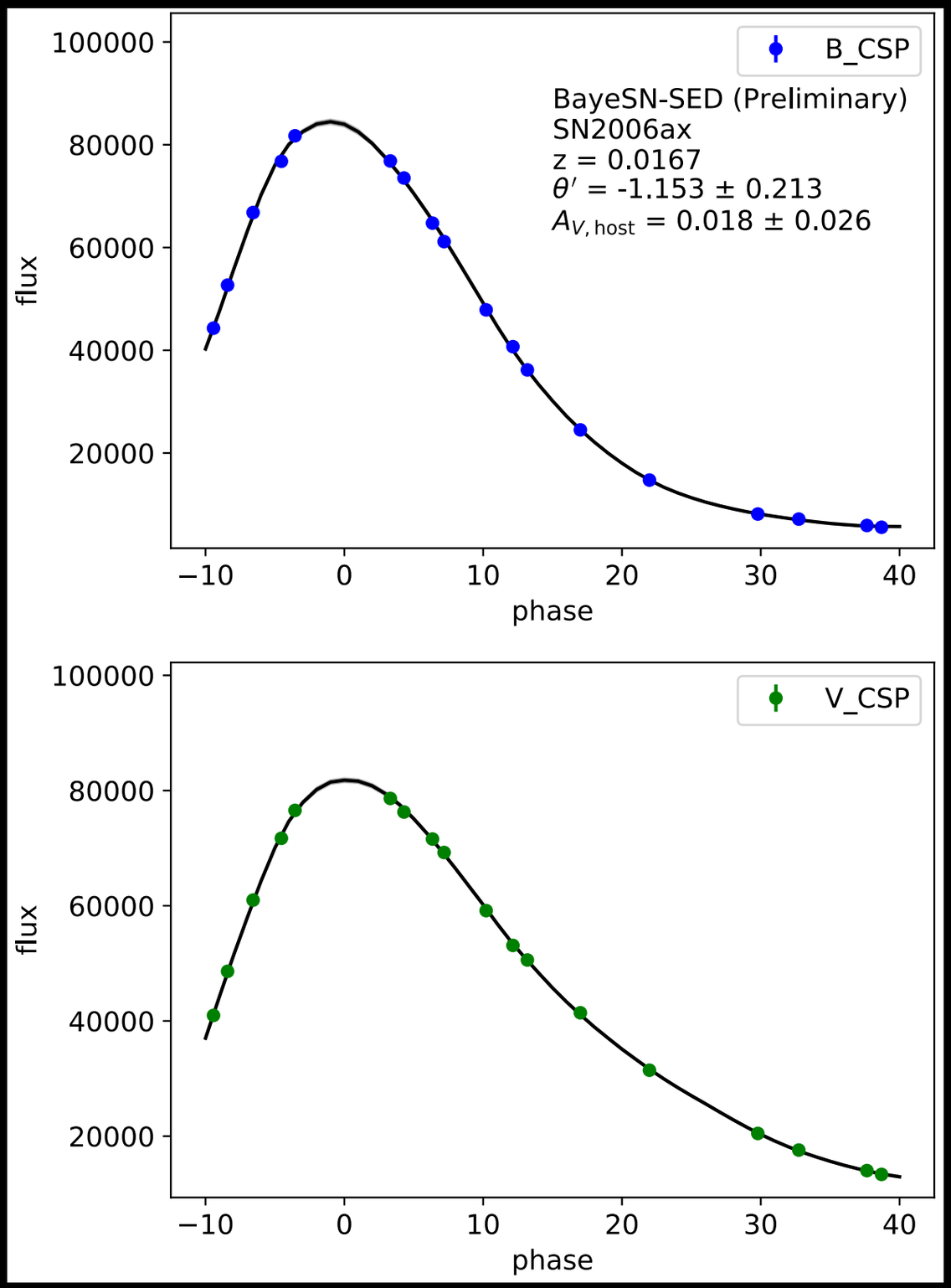
Intrinsic SED$_s$(t, λ)

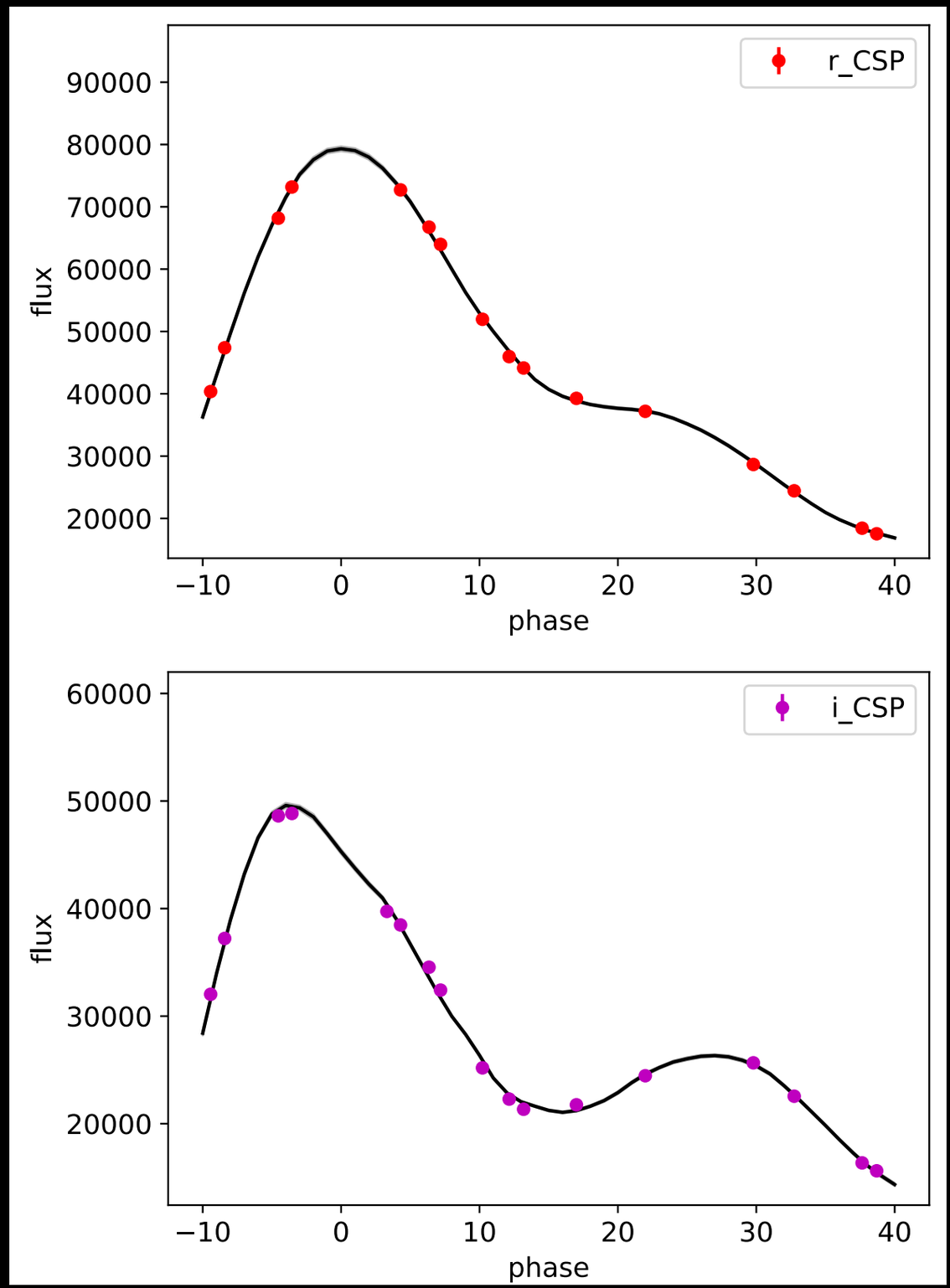
$s = 1 \ldots\ldots N_{SN}$

BayeSN Fit example: SN2006ax (CSP)



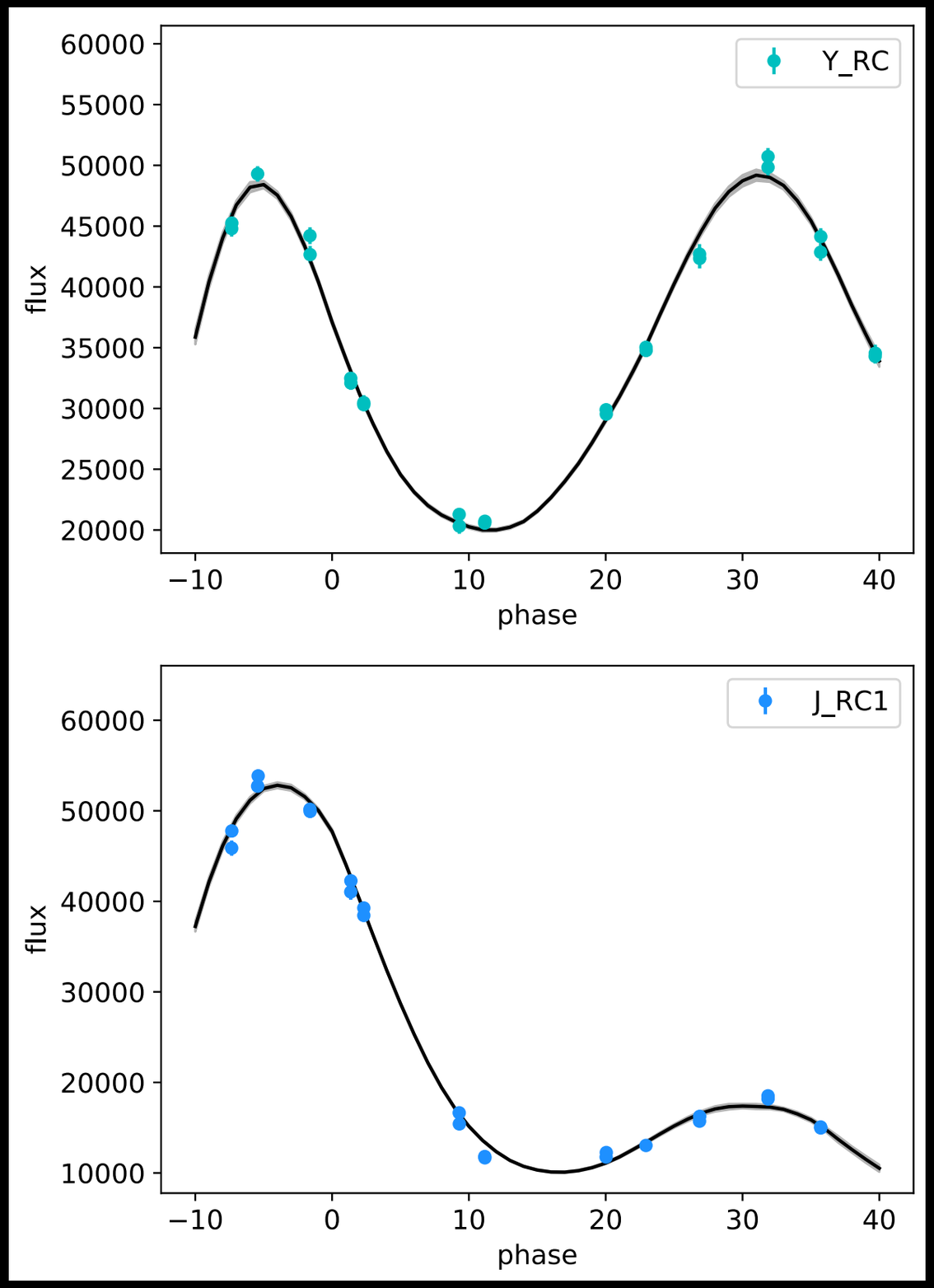
SN2006ax Flux LC fits BVri

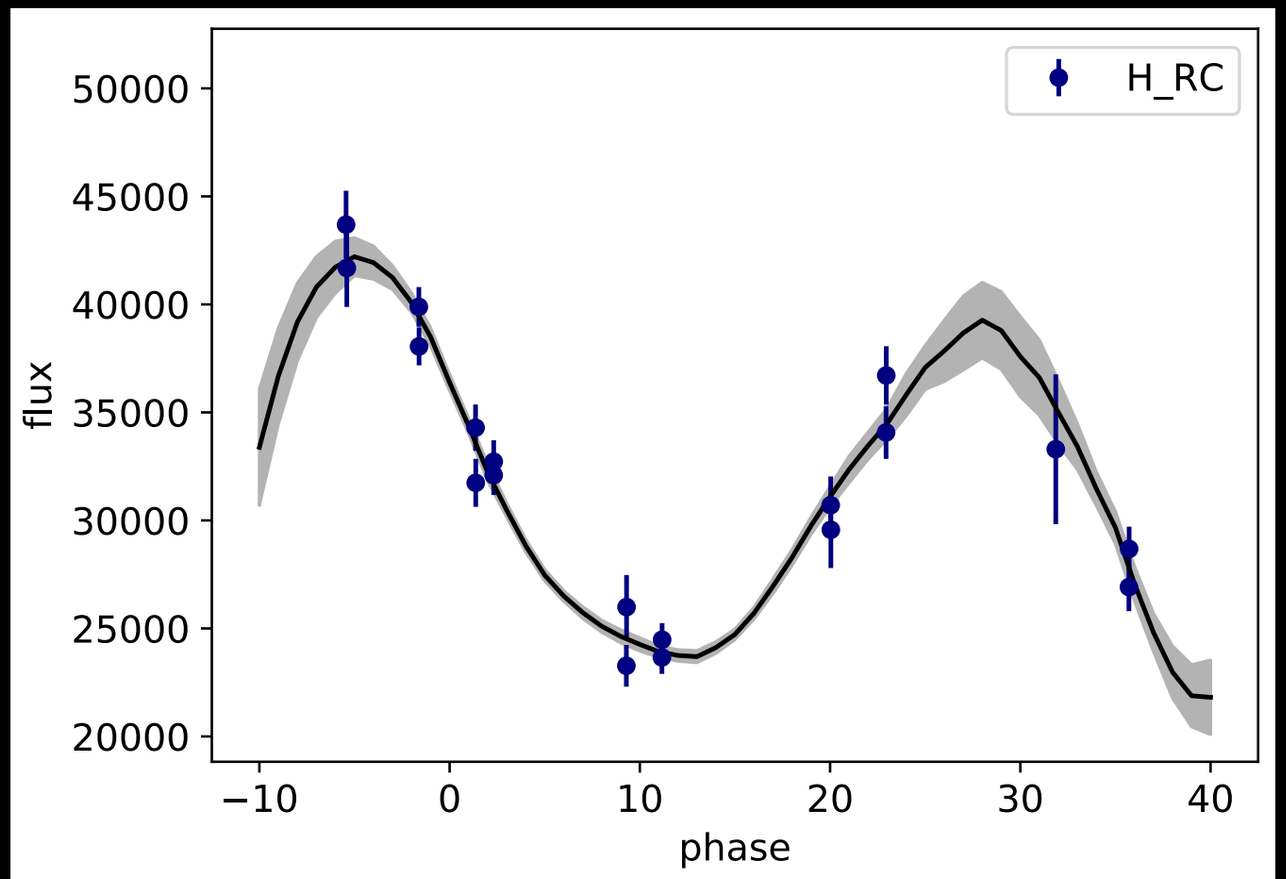




SN2006ax Flux NIR YJH LC fits

(Bands SALT2 does not fit!)

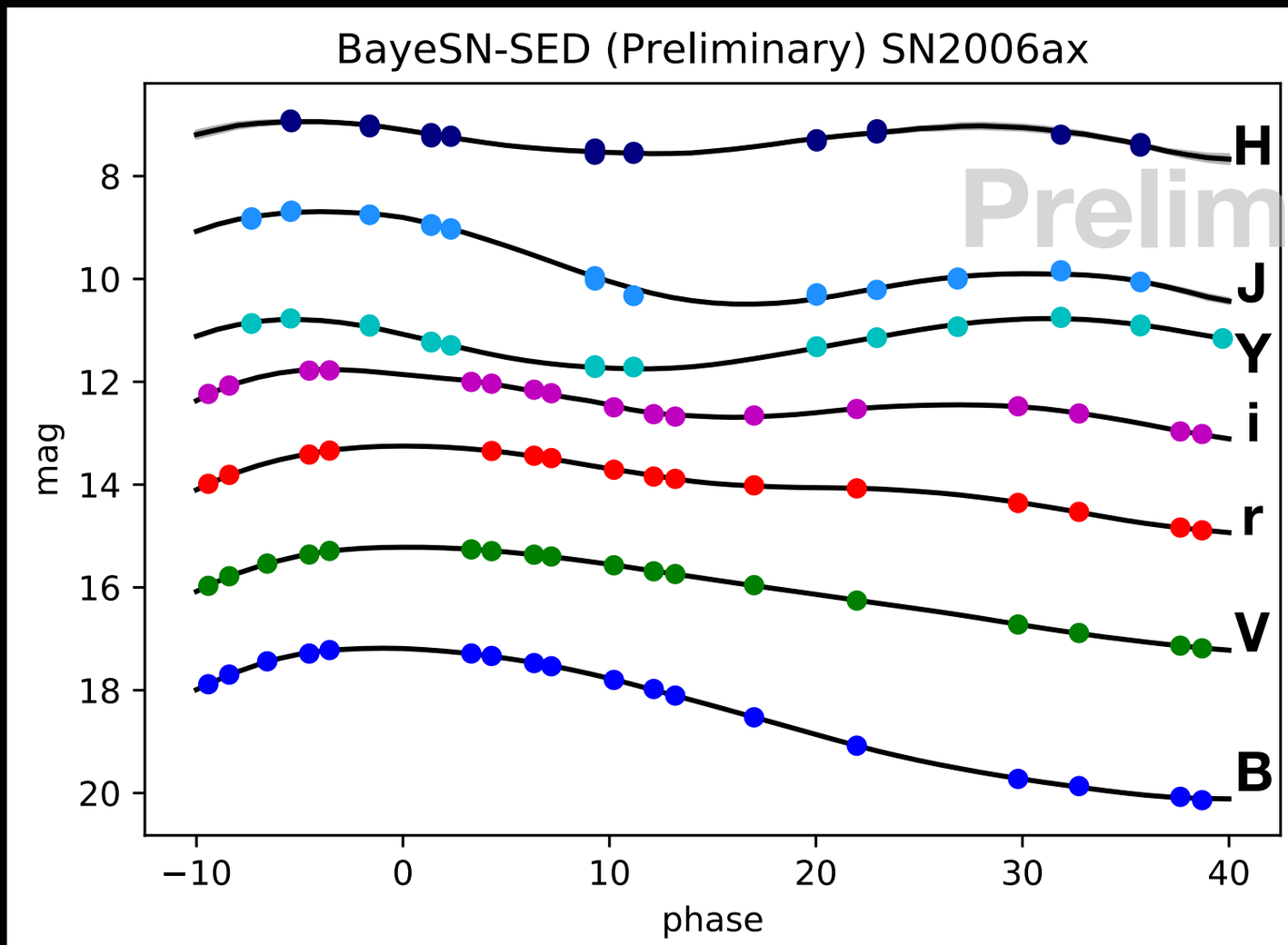


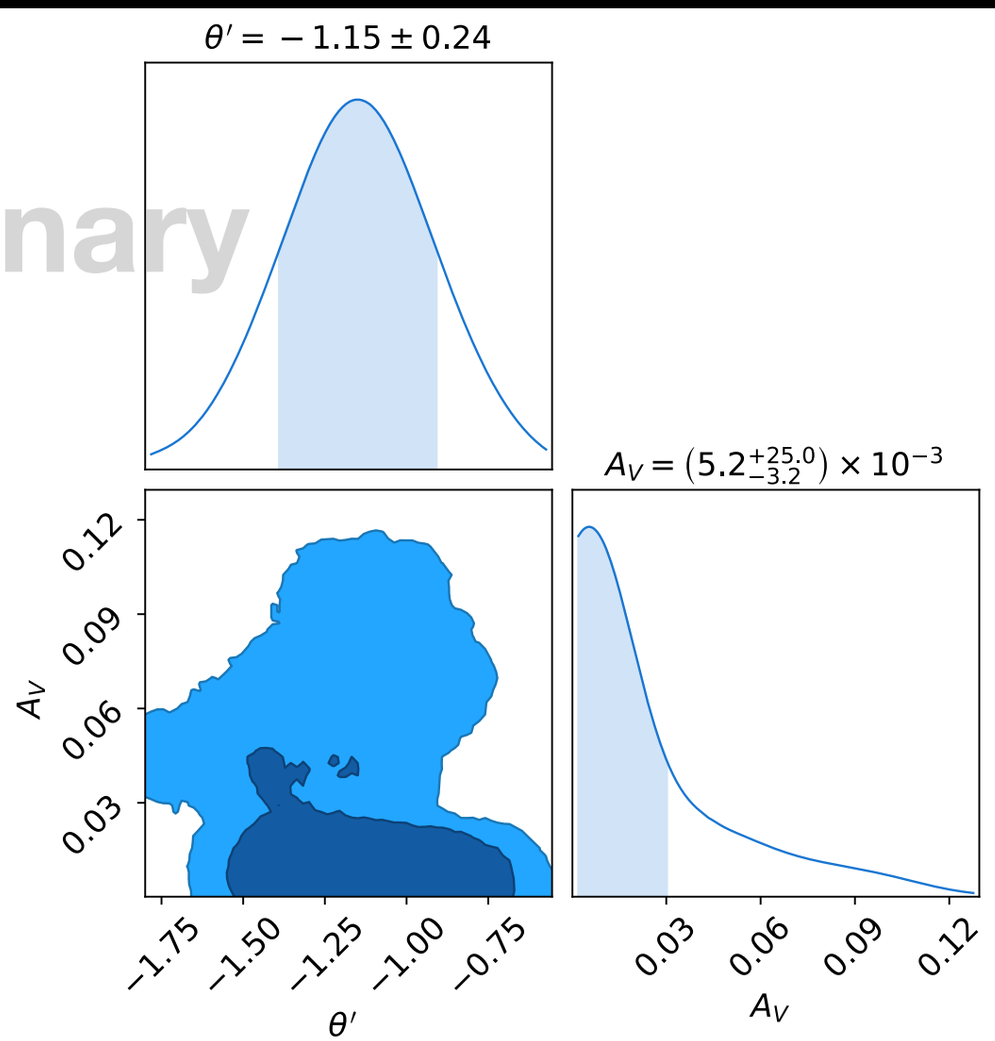


Inference for SN2006ax (CSP)

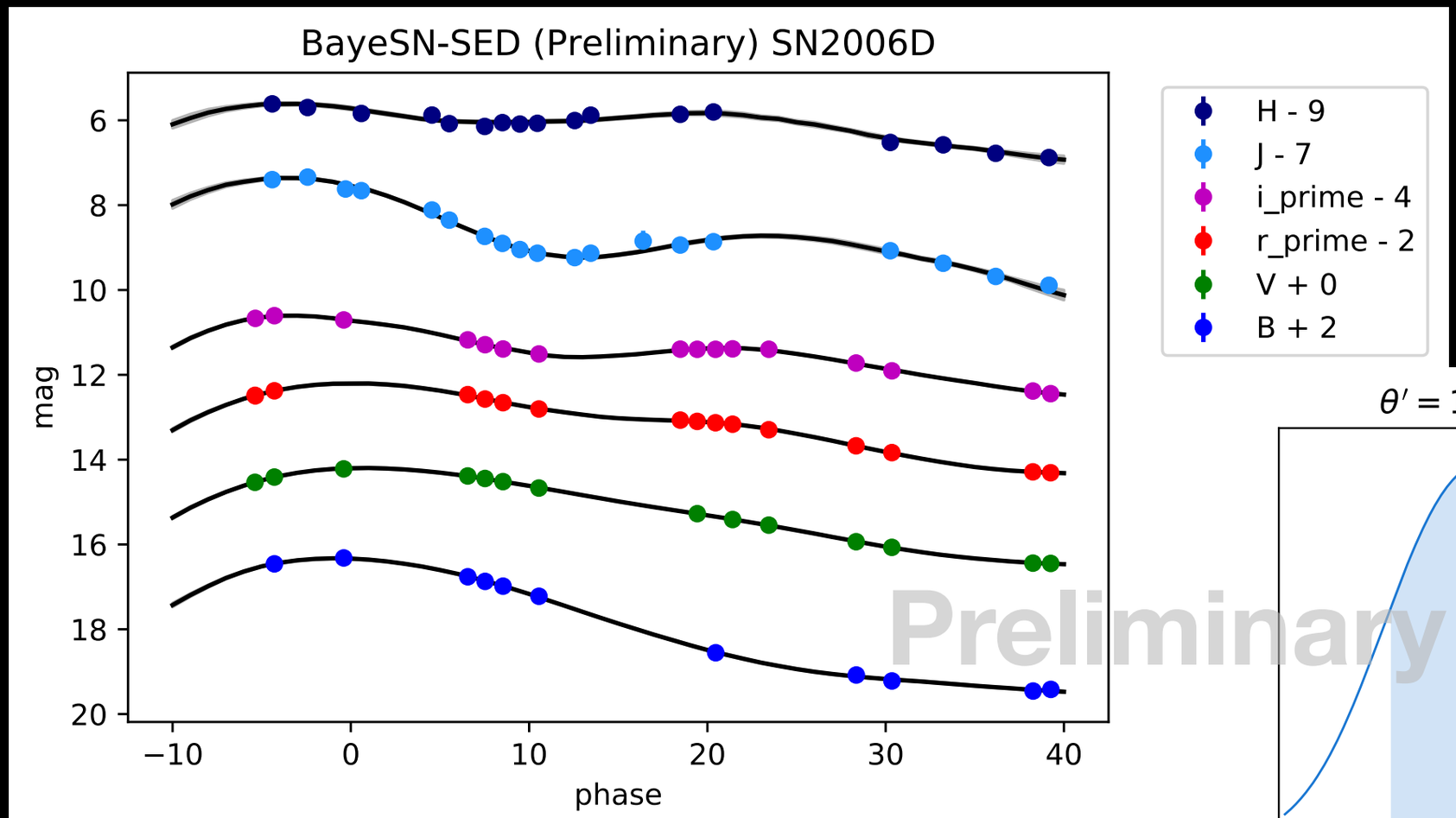
θ = coeff of Functional Component 1

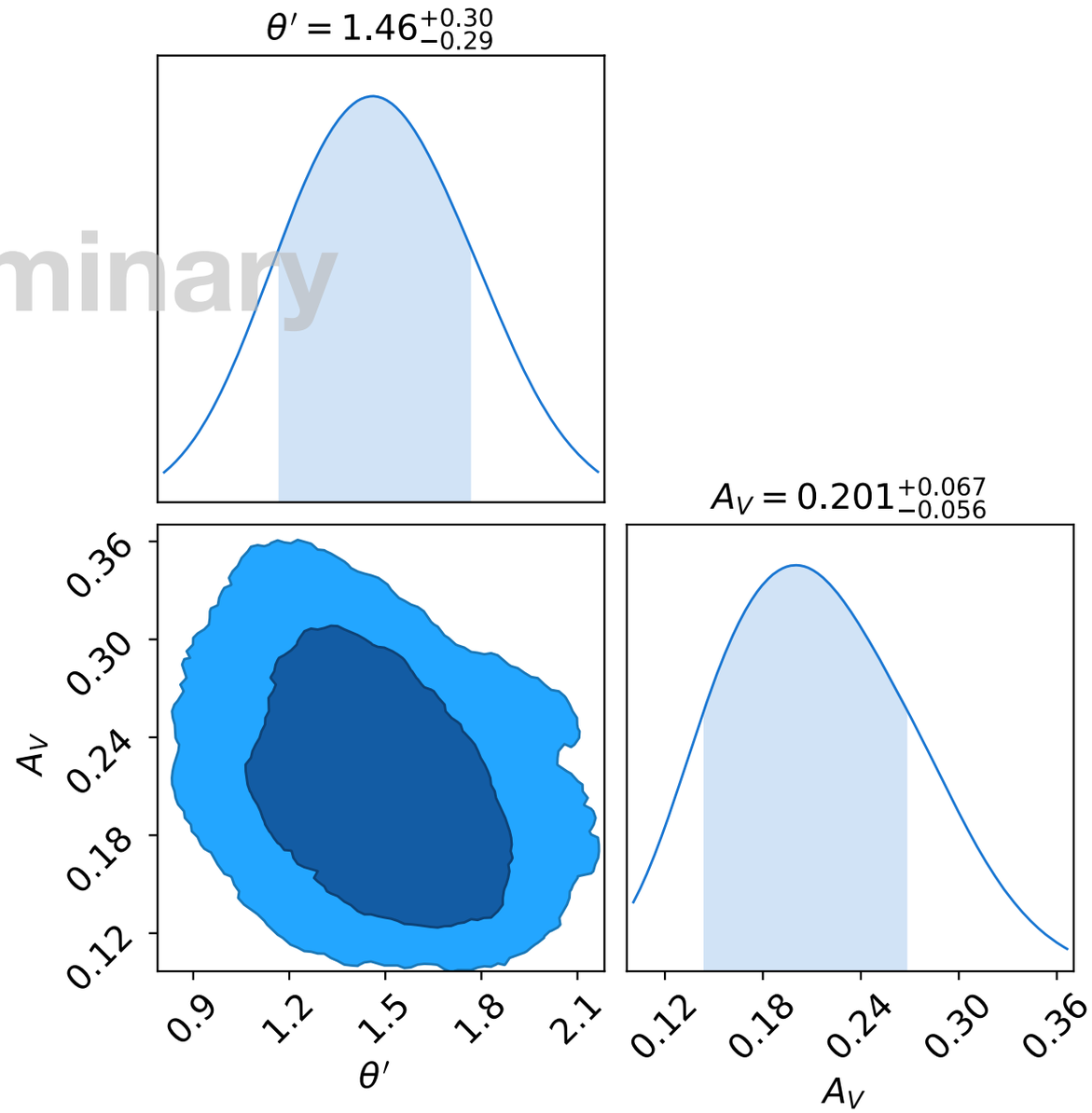
A_V = Dust Extinction





BayeSN Fit example: SN2006D (CfA)





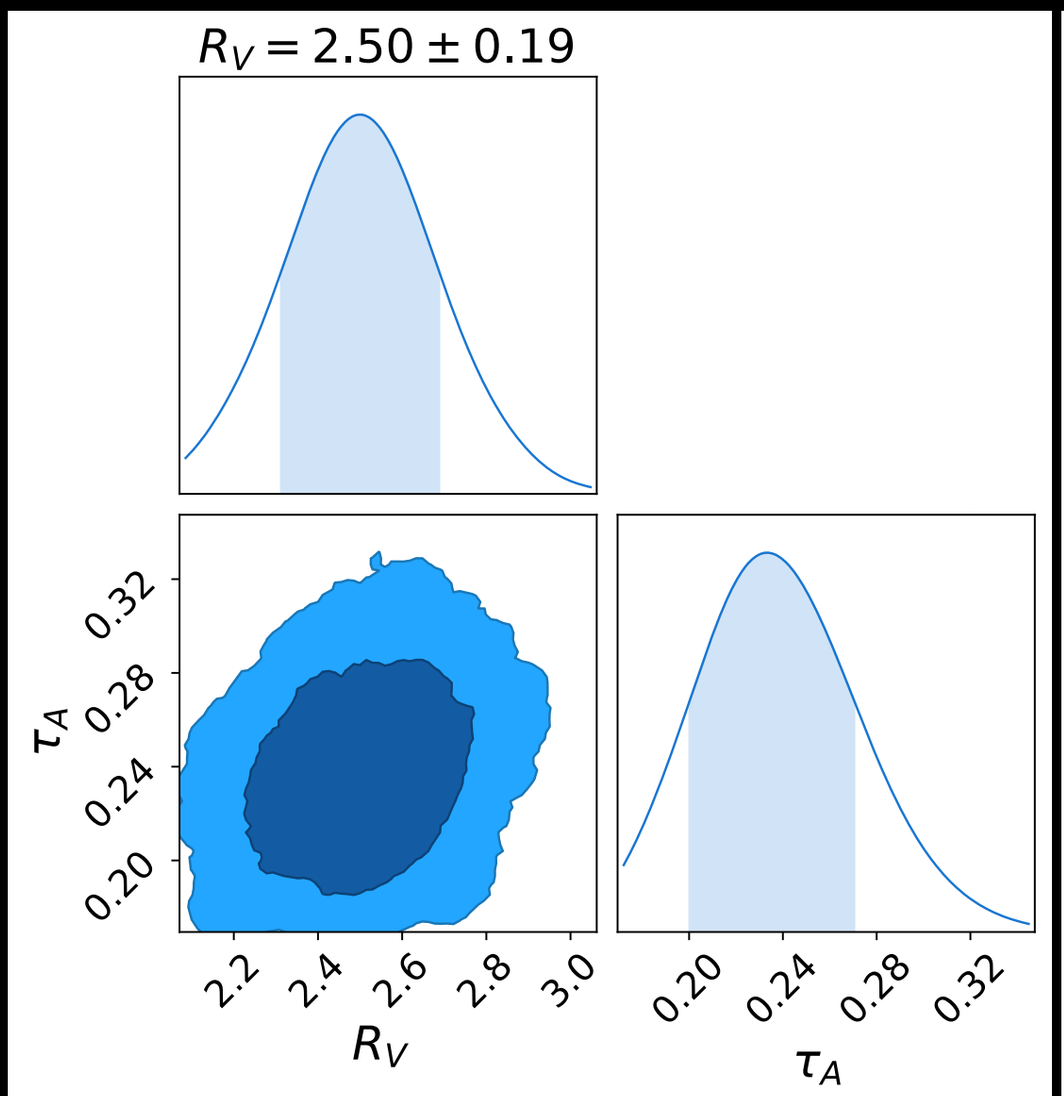
θ = coeff of Functional Component 1

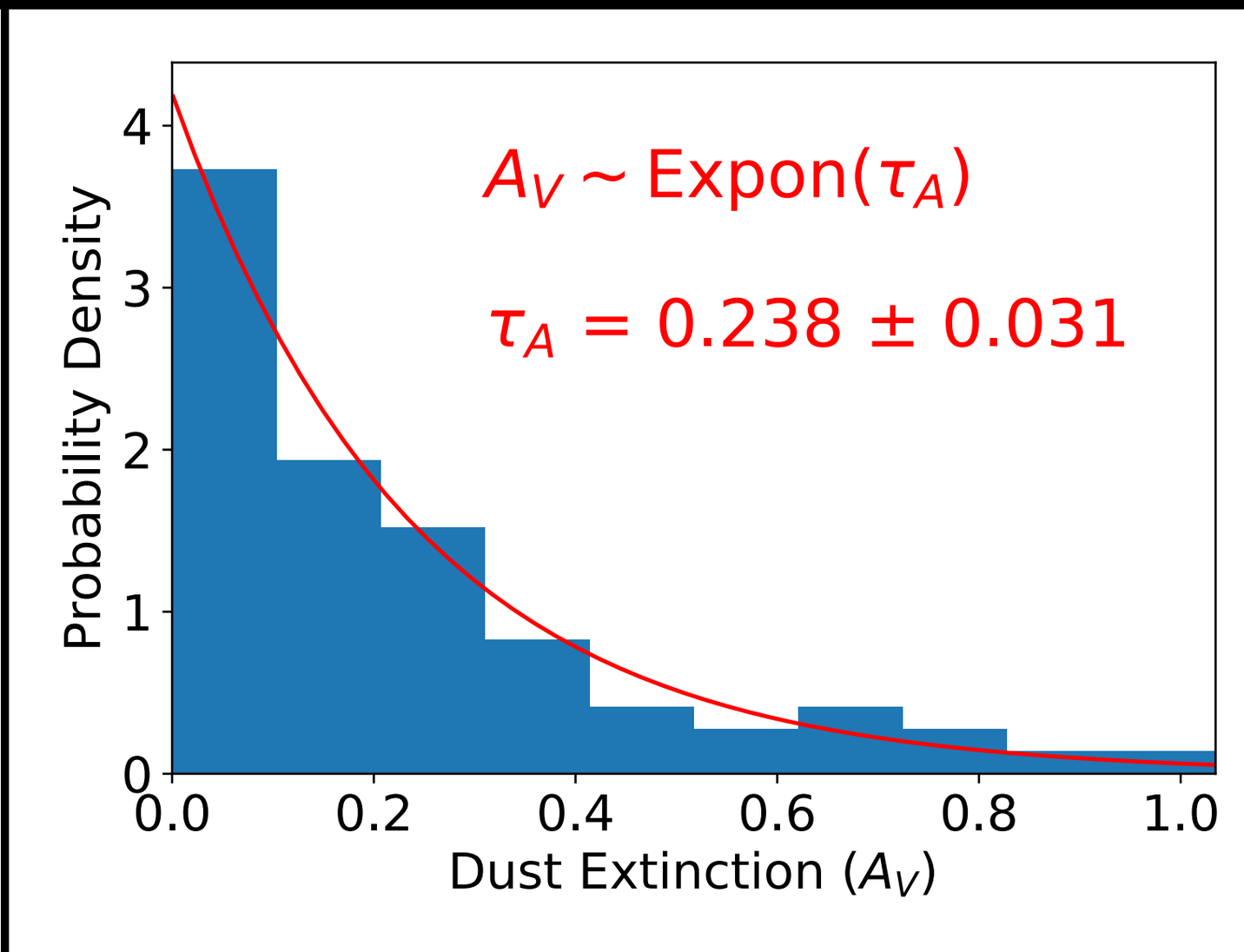
A_V = Dust Extinction

Dust Population Inference

τ_A = Population Mean Dust Extinction

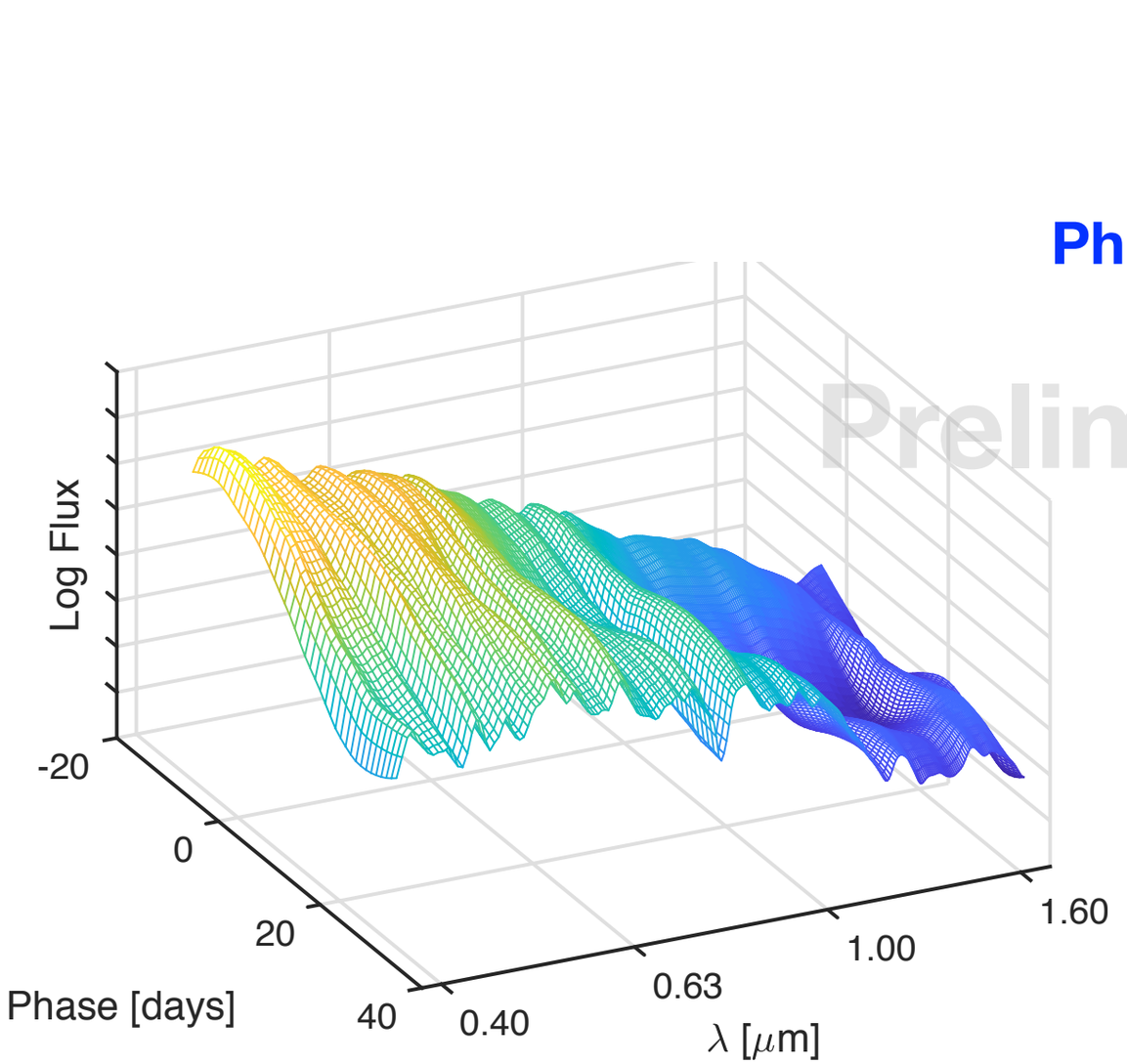
R_V = Slope of CCM Dust Extinction Law



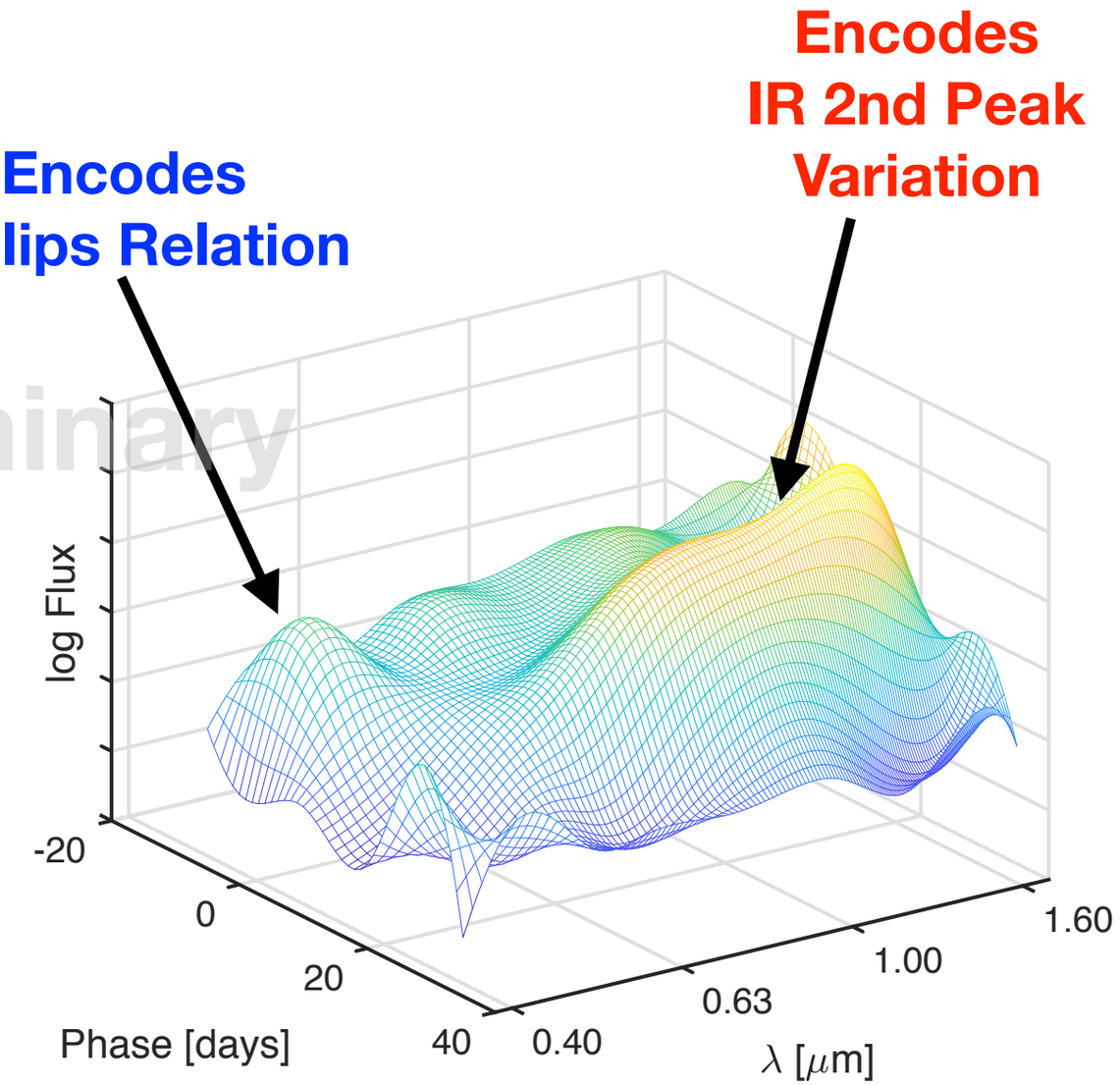


Rv = 2.5 ± 0.2 (cf. Mandel+2011, 2017)

Inferred of SED components:
An Effective Model of SED variations



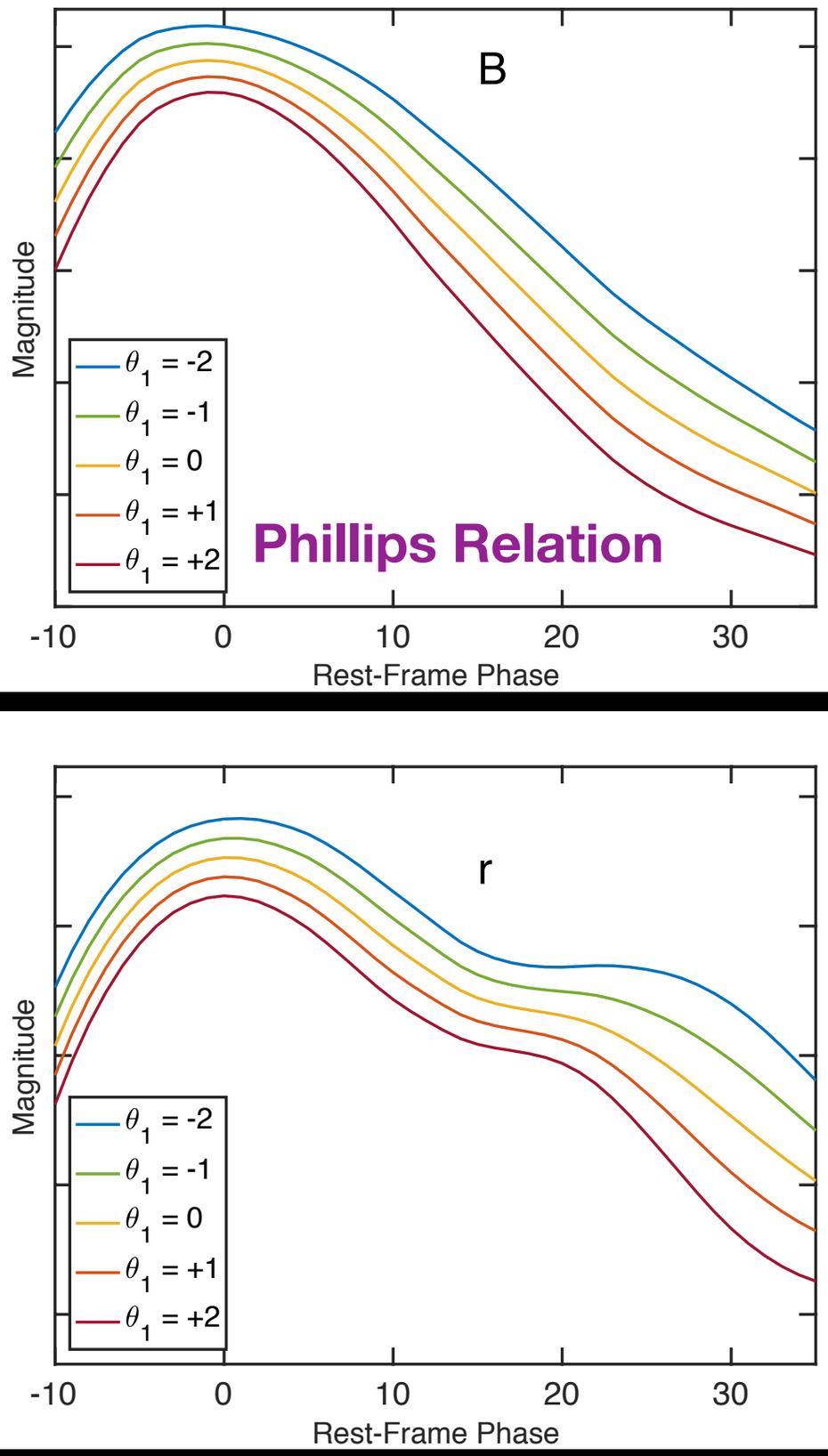
Mean Intrinsic SED
(Hsiao template broadly warped to mean intrinsic colours of sample)

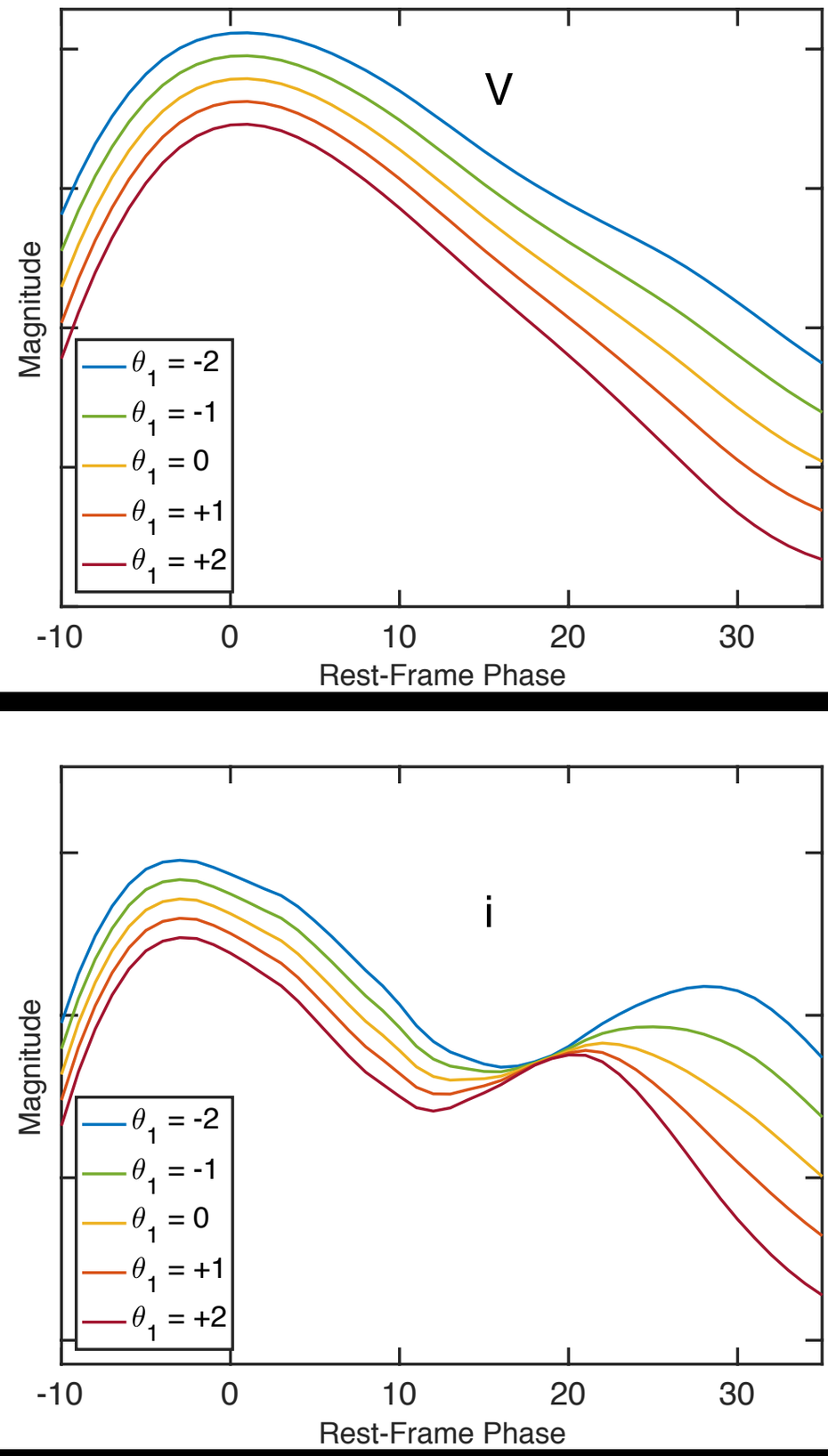


First Functional SED Component

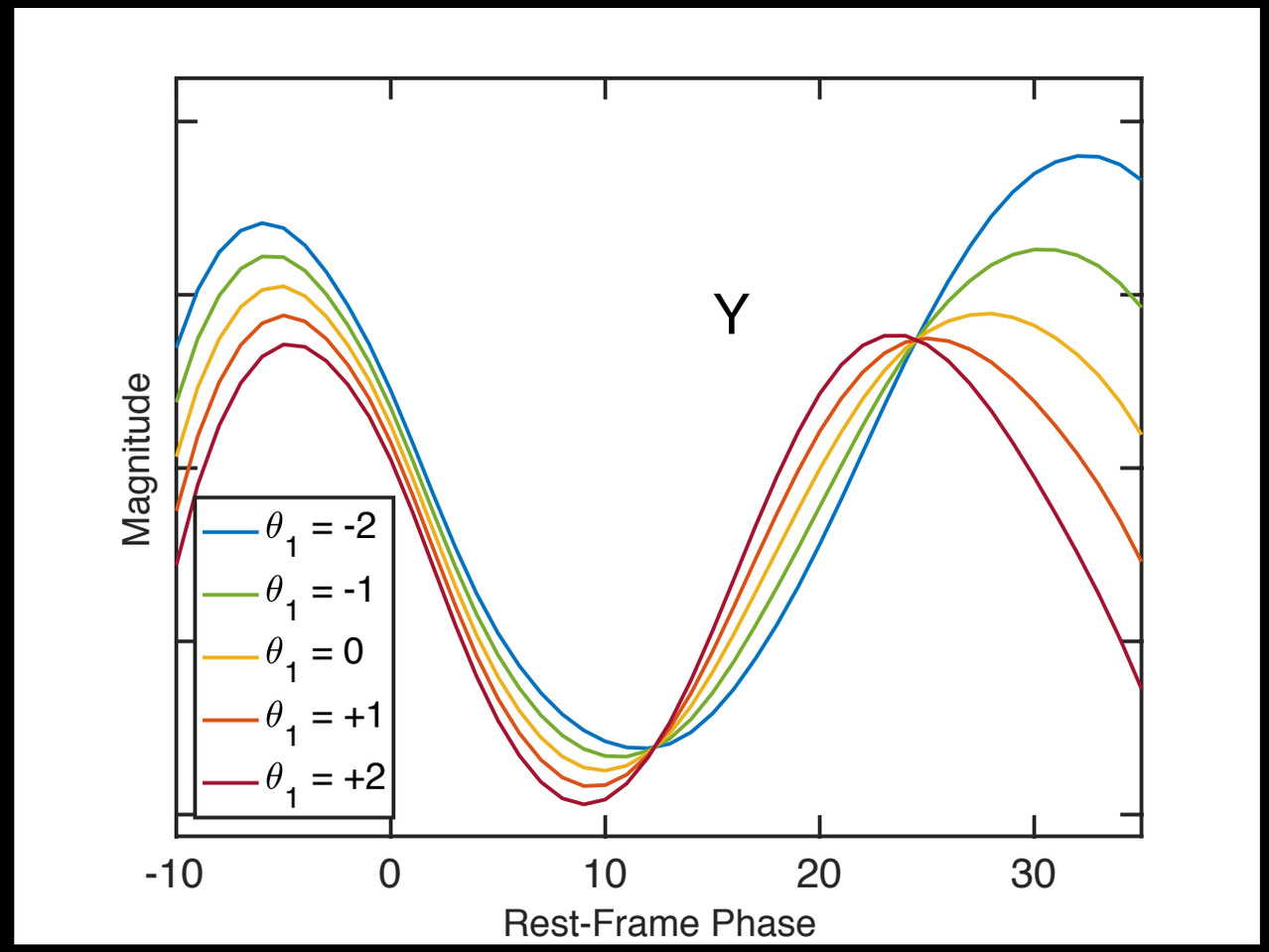
Preliminary

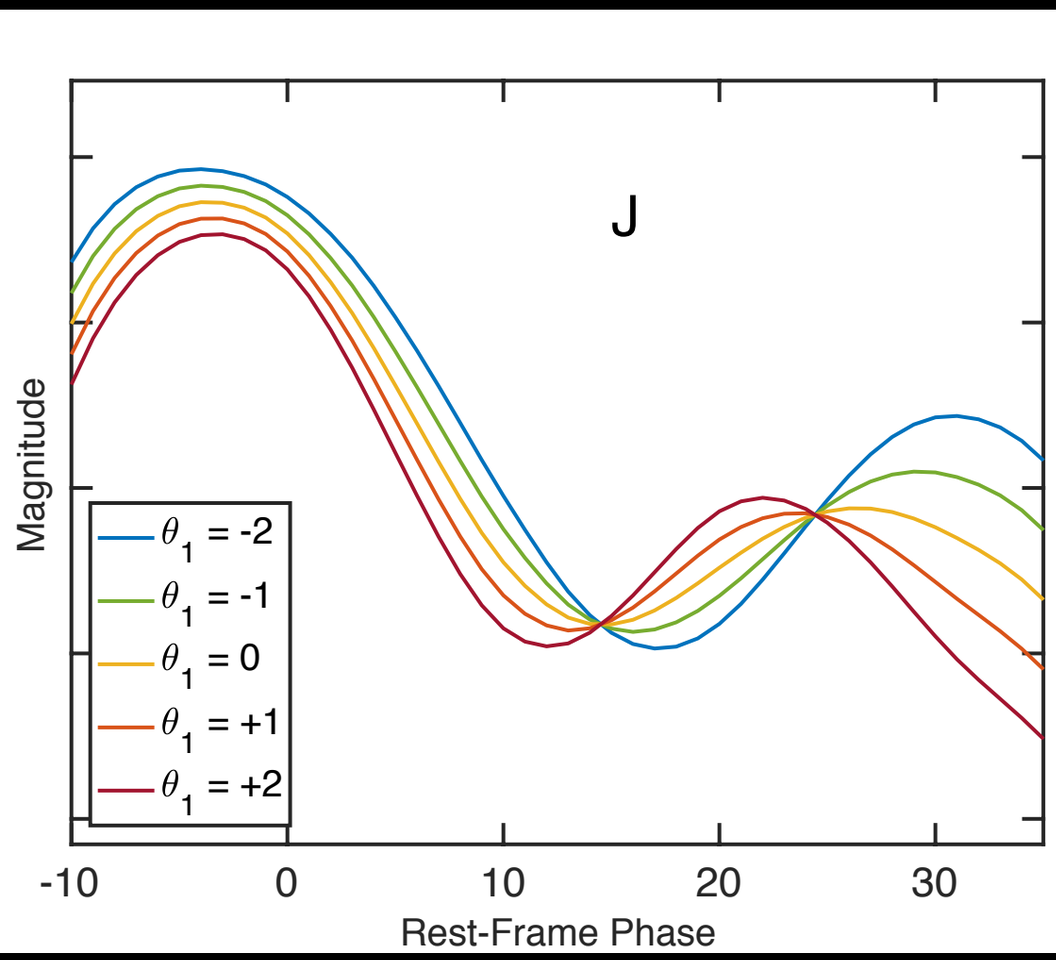
Effect of FC1 on BVri LCs

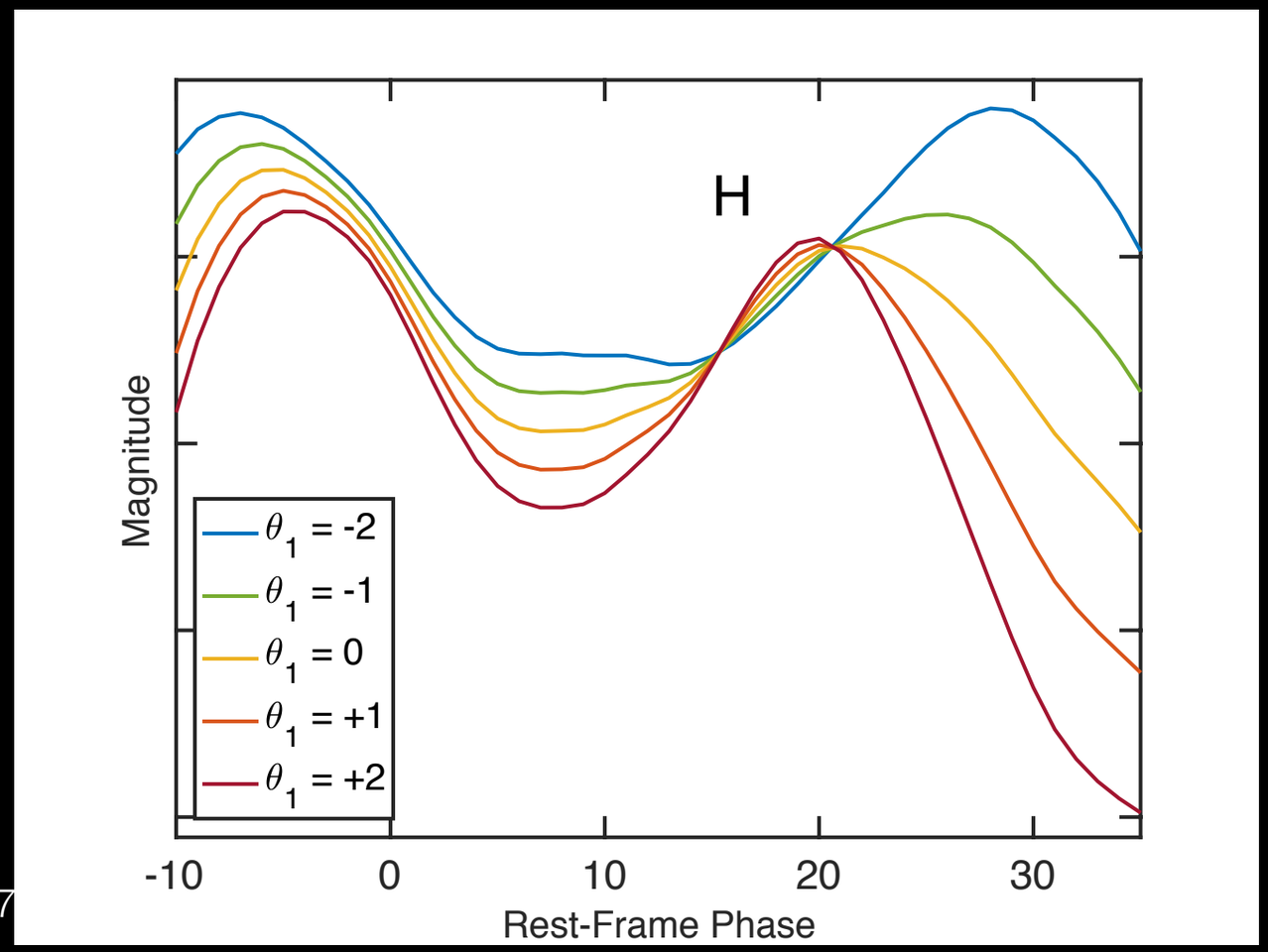




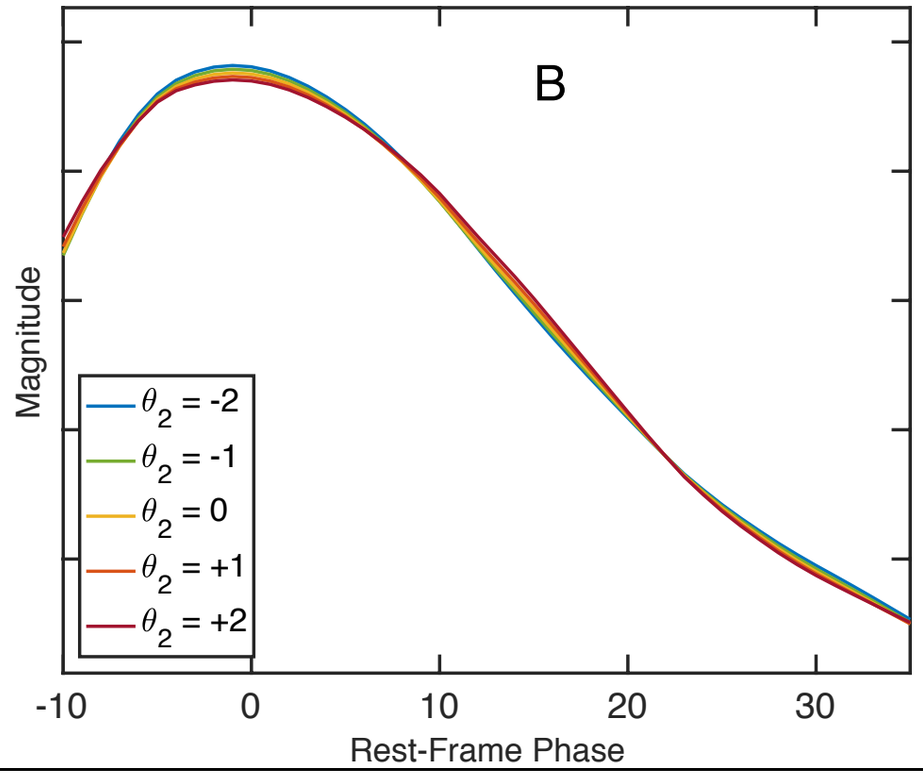
Effect of FC1 on NIR YJH LCs: Amplitude & Timing of 2nd NIR Peak

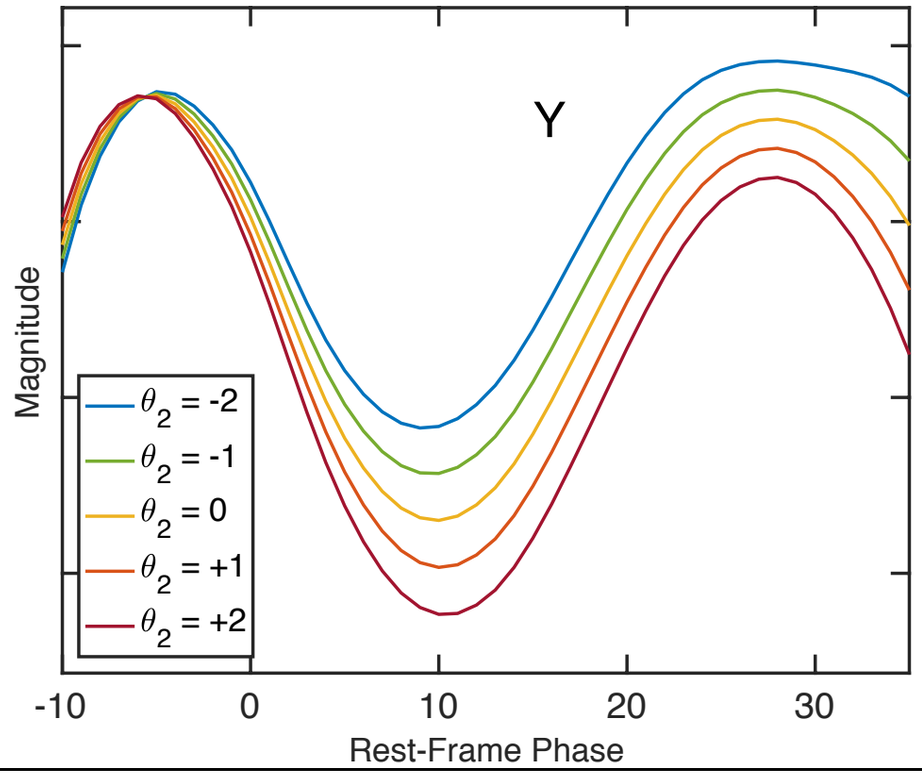


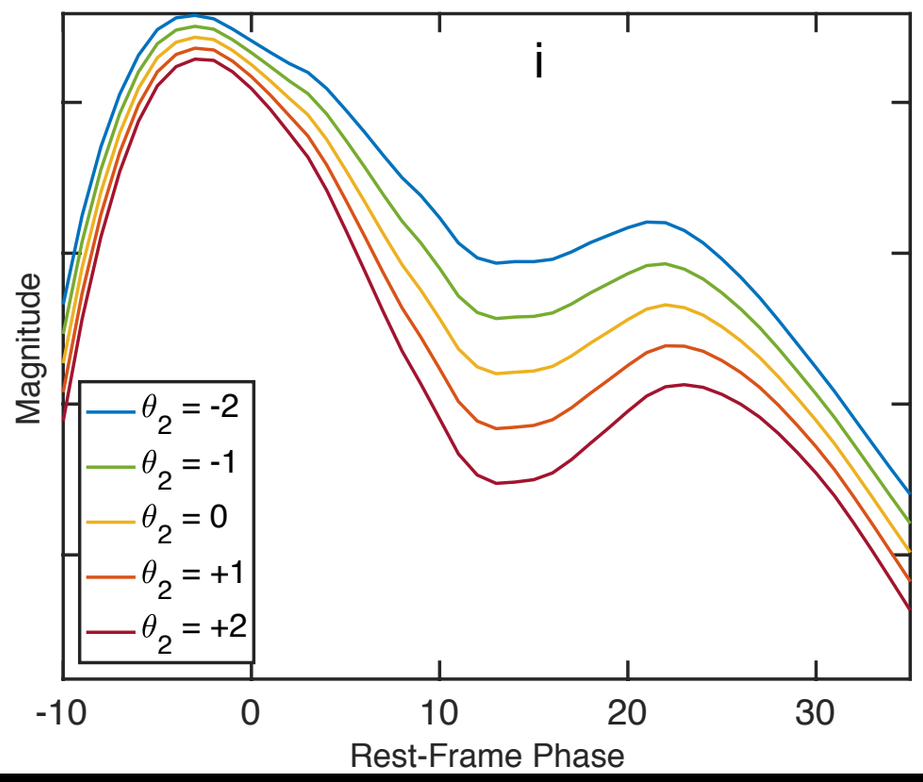


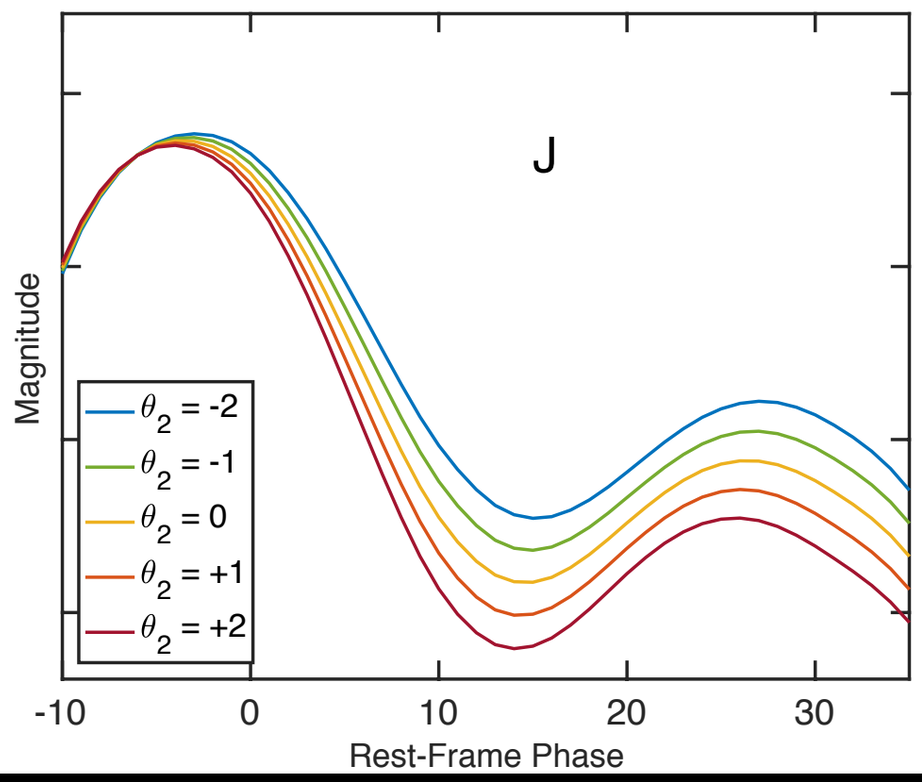


Preliminary: Extracting 2nd Functional Component $FC_2(t, \lambda)$ Modulates amplitude of IR 2nd Peak

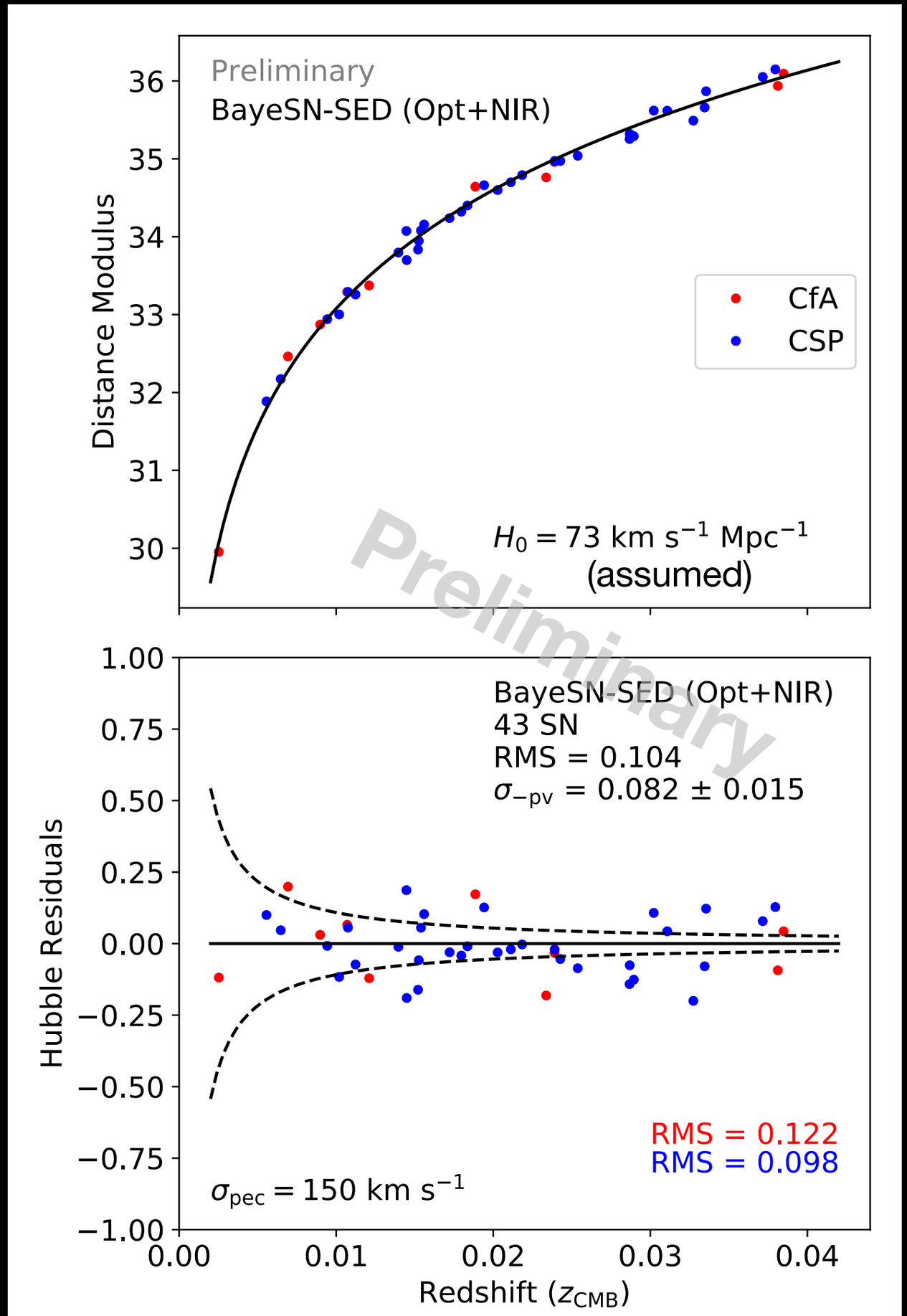




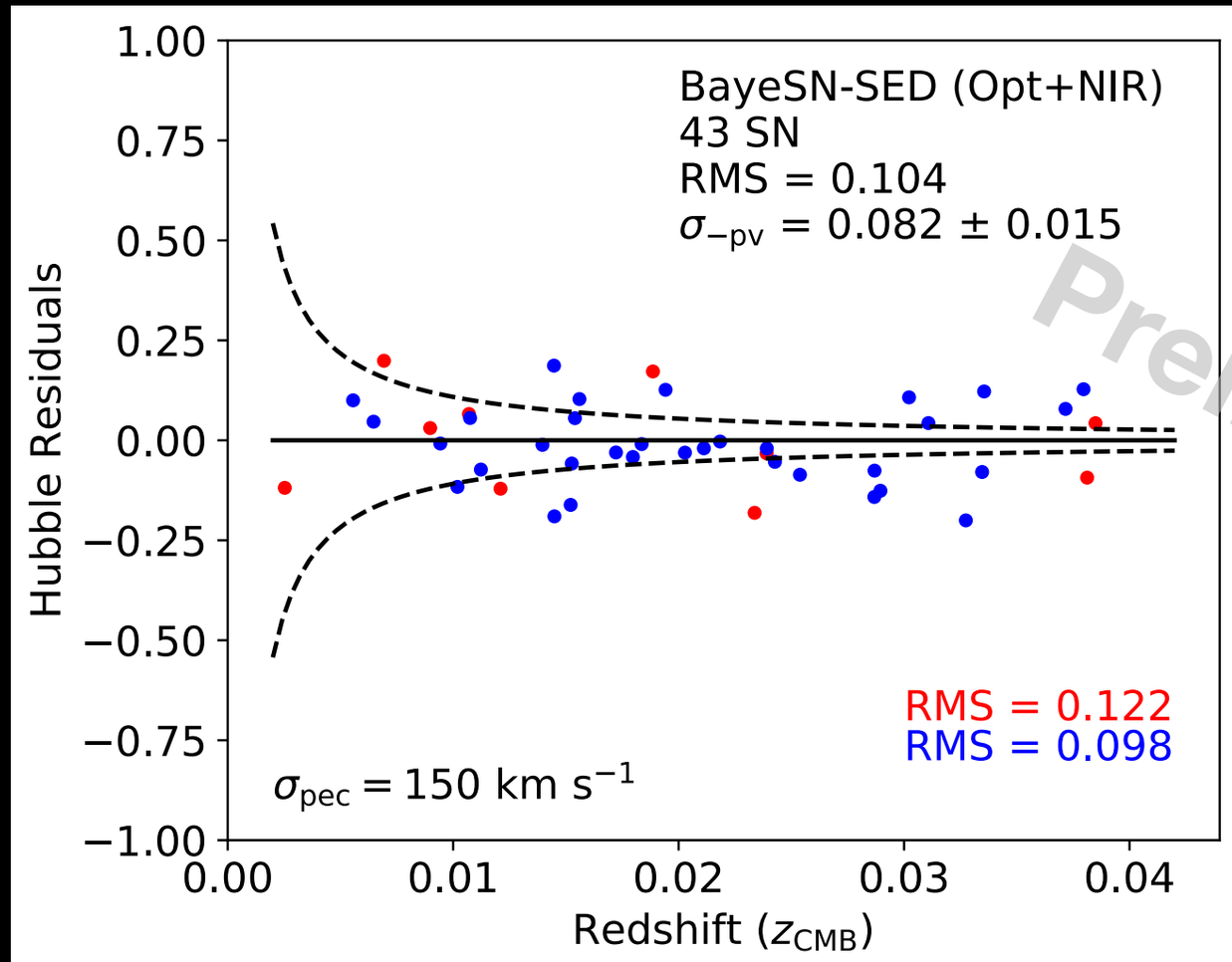


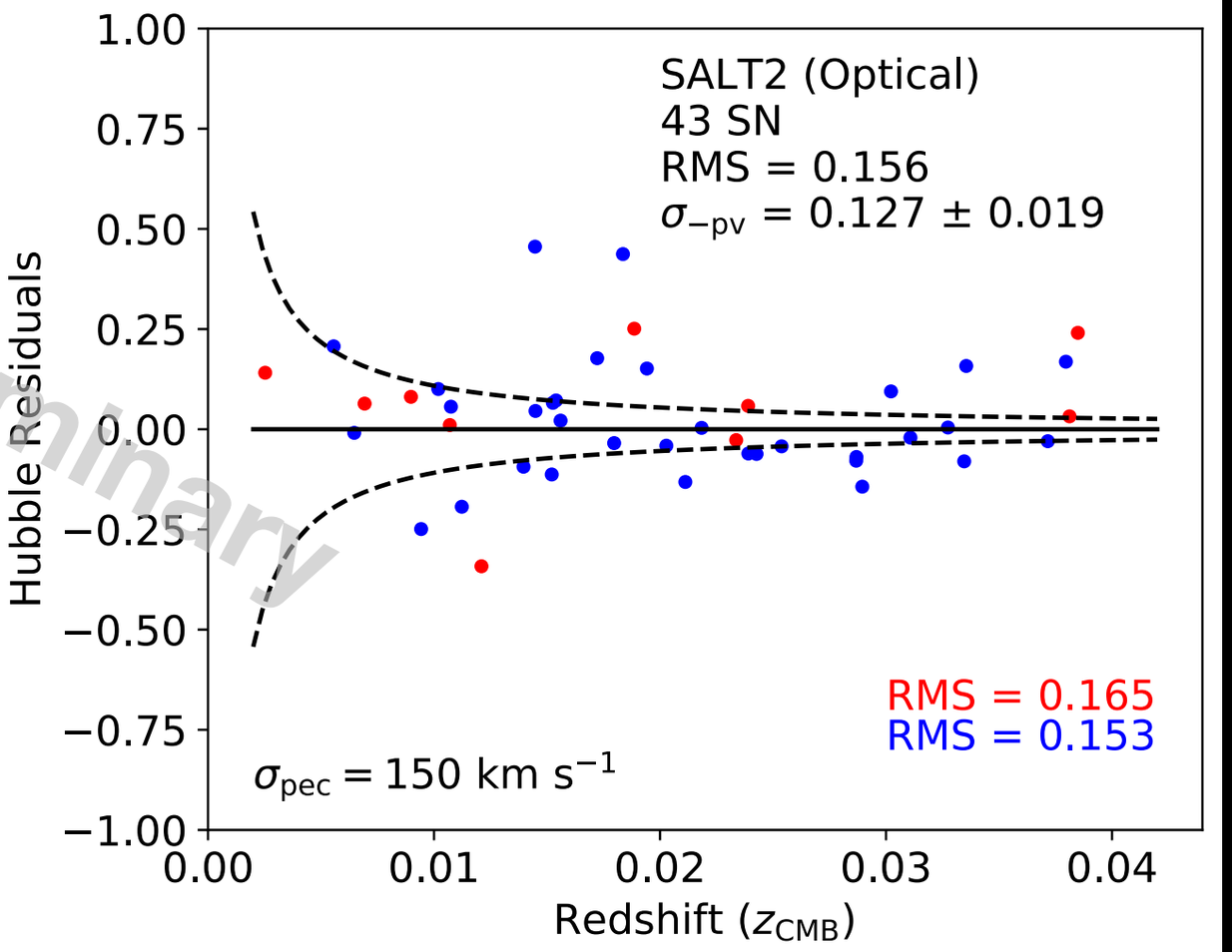


Hubble Diagram: Application of BayeSN to Avelino+19 sample with Optical+NIR [BVri(Y)JH] near max



Hubble Diagram comparison:
BayeSN Optical+NIR
vs.
SALT2 Optical





Preliminary

BayeSN-SED Probabilistic Graphical Model

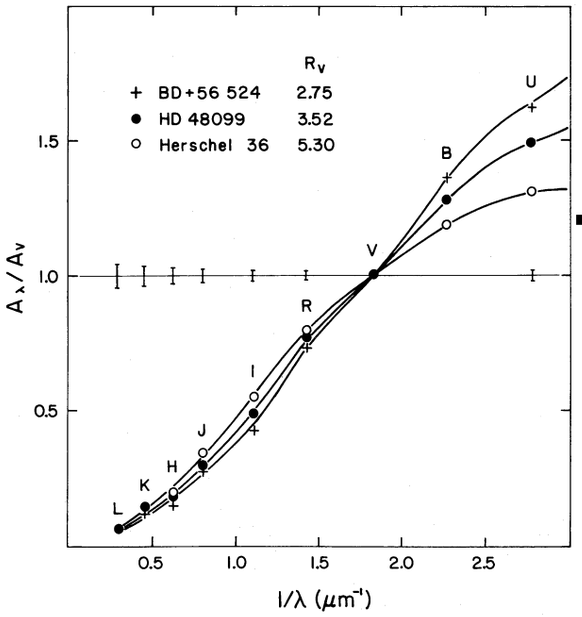
$\Omega_M, w, \ldots$

Population Distribution of host galaxy dust

A_V^s, R_V^s

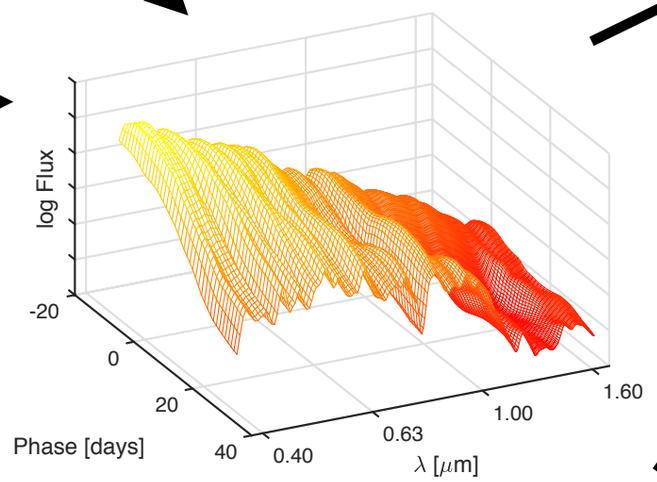
μ_s

z_s

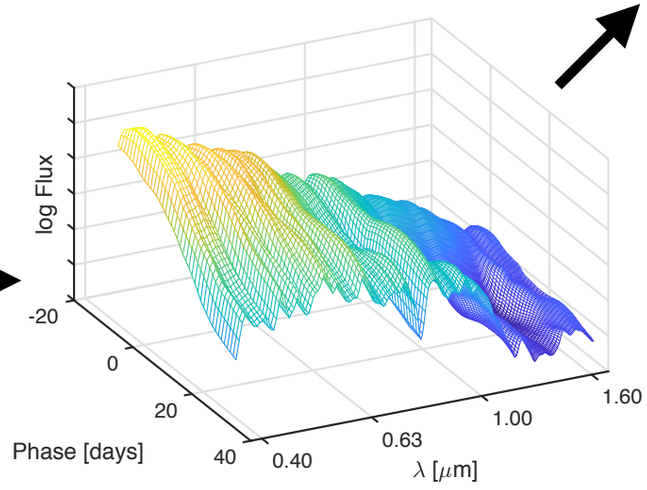


Dust Law(λ)

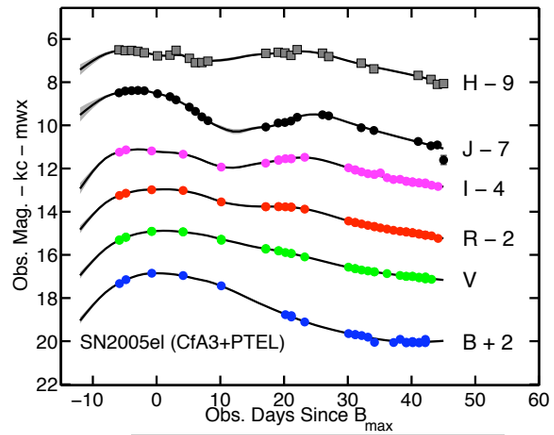
Population Distribution of SED(t, λ)s (Intrinsic Covariance)



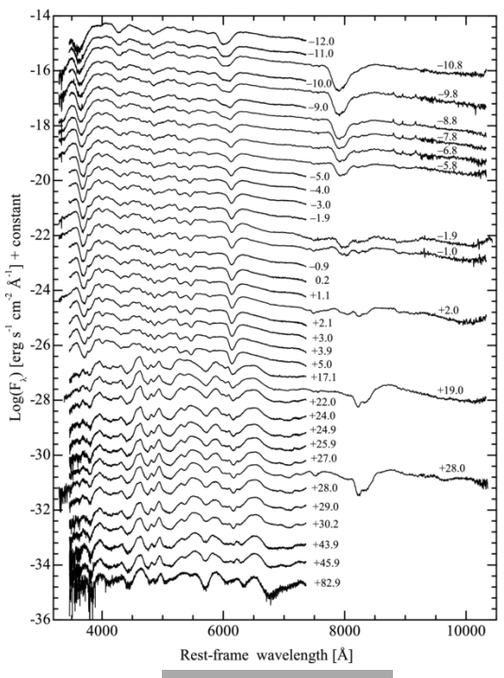
Apparent SED$_s$(t, λ)



Intrinsic SED$_s$(t, λ)



Light Curves



Spectra

$s = 1 \ldots\ldots N_{SN}$

Ongoing & Future Work

- Cross-Validation Tests : Sensitivity to the sample
- Training on additional photometric LCs and spectra to refine the spectral model (e.g. Foundation, Swope, Kaepora, …).
- Explore the diversity of host dust extinction laws (R_V)
- Incorporate and test dependence of SED(t, λ) against astrophysical parameters, e.g. host galaxy properties, ejecta velocities
- Applications to current and future NIR SN Ia programs (RAISIN, SIRAH, WFIRST)