Type Ia SN Light Curve Inference: Hierarchical Models for Nearby SN in the Rest-Frame Near Infrared (+Optical)

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Outline

- Statistical Inference with SN Ia Light curves
  - Hierarchical Framework for Constructing Probability Models for Observed Data
  - Describing Populations & Individuals
- Statistical Computation with Hierarchical Models
  - BayeSN (MCMC/Gibbs Sampling)
- Application to Nearby CfA NIR Data (PAIRITEL)

For more details:

Mandel, K. , W.M. Wood-Vasey, A.S. Friedman, R.P. Kirshner.
Type Ia Supernova Light Curve Inference: Hierarchical Bayesian Analysis in the Near Infrared.
2009, ApJ, in press (October).
preprint: arXiv:0908.0536

Collaborators:

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CfA Supernova Group

Statistical Learning from SN Ia is a complex inference problem

- Empirical statistical models are learned from the data
- Several Sources of Randomness & Uncertainty
  - Photometric errors (Observational Noise)
  - "Intrinsic Variation" = Population Distribution of SN Ia
    - Variations in light curve shape over time, intrinsic color and luminosity vs λ : intrinsic correlation structure of SN Ia observeables
  - Random Peculiar Velocities in Hubble Flow
  - Host Galaxy Dust: extinction and reddening.
- How to incorporate this all into a coherent statistical model?

Advantages of Hierarchical Models

- Coherently and simultaneously incorporate multiple sources of randomness & uncertainty: express complex probability models
- Hierarchically Model (Physical) Populations and Individuals simultaneously: e.g. SN Ia and Dust
    - Can model both intrinsic variations/correlations in color/luminosity/ light curve shape and dust reddening and extinction for populations and individuals
        - Explore & Marginalize over posterior trade-offs/joint distributions
- Get full probability distribution not just point estimates:
    - global, coherent quantification of uncertainties,
    - can compute complete marginalization over posterior uncertainties
- Modularity: Can incorporate additional statistical structure to parts of the global model & condition on additional information (e.g. host galaxy type/environment, dust laws)

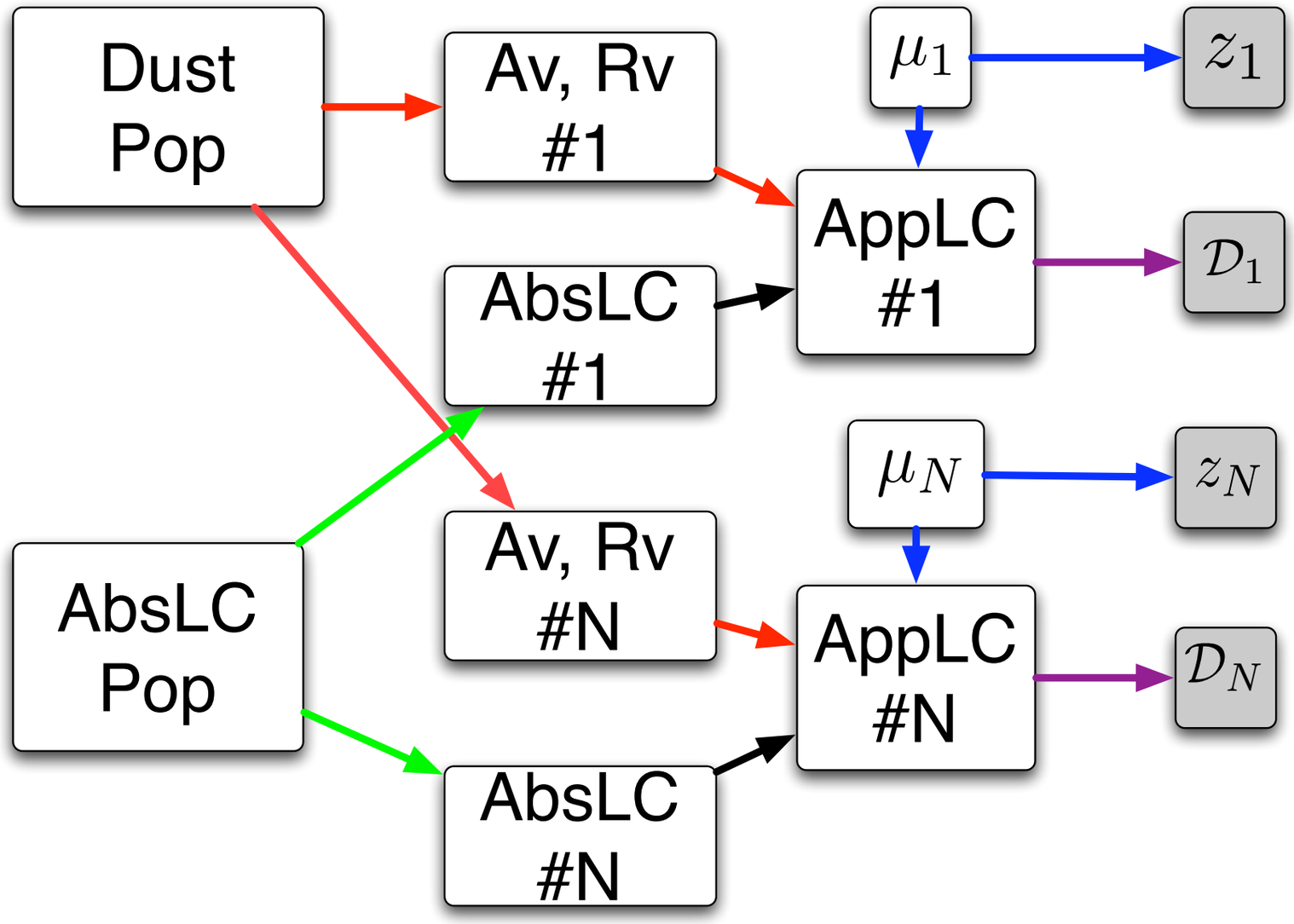
Directed Acyclic Graph for SN Ia Inference with Hierarchical Modeling

- Intrinsic Randomness
- Dust Extinction & Reddening
- Peculiar Velocities
- Measurement Error

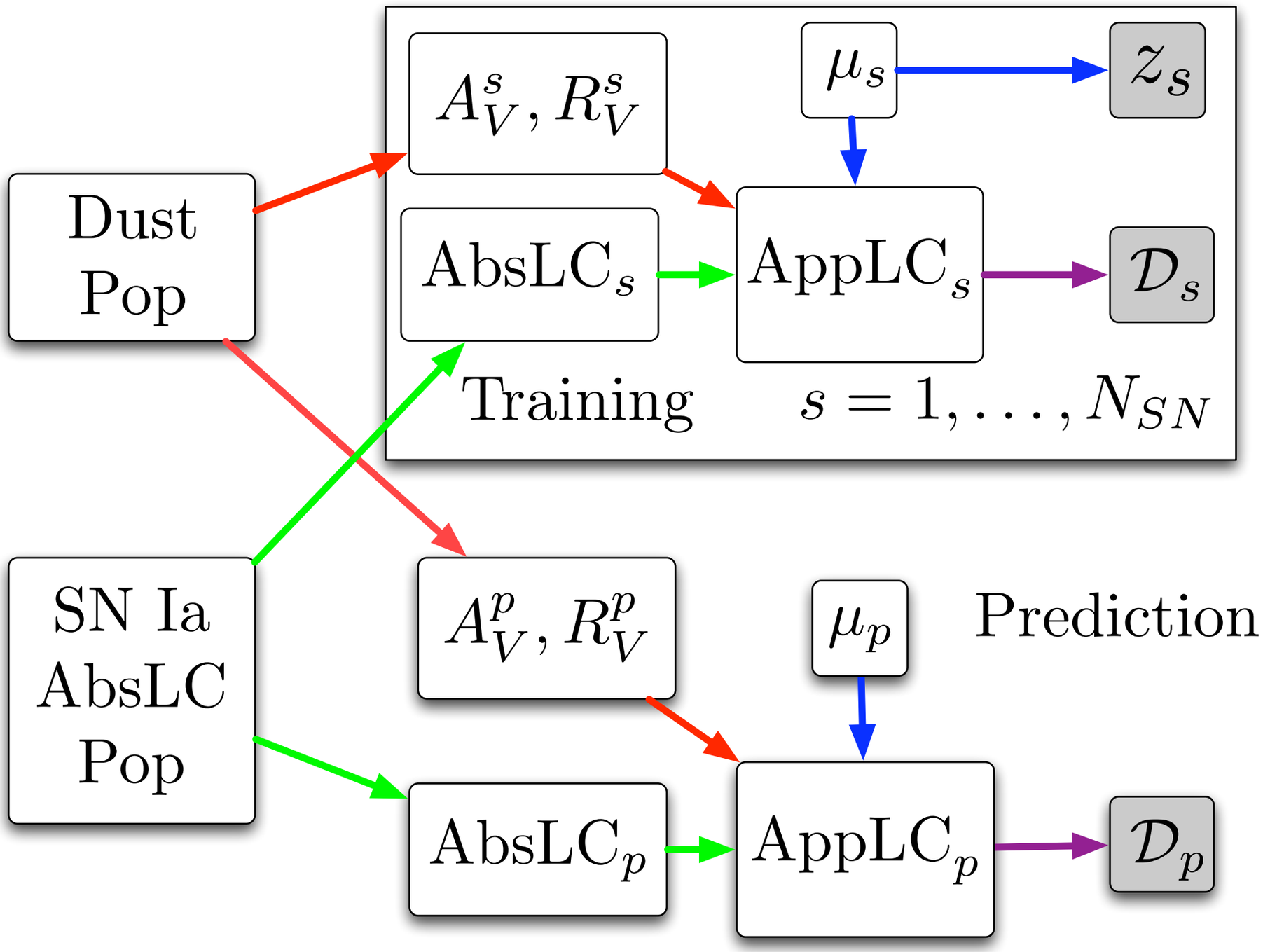
"Training" - Learn about Populations

Generative Model

Global Joint Posterior Probability Density Conditional on all SN Data



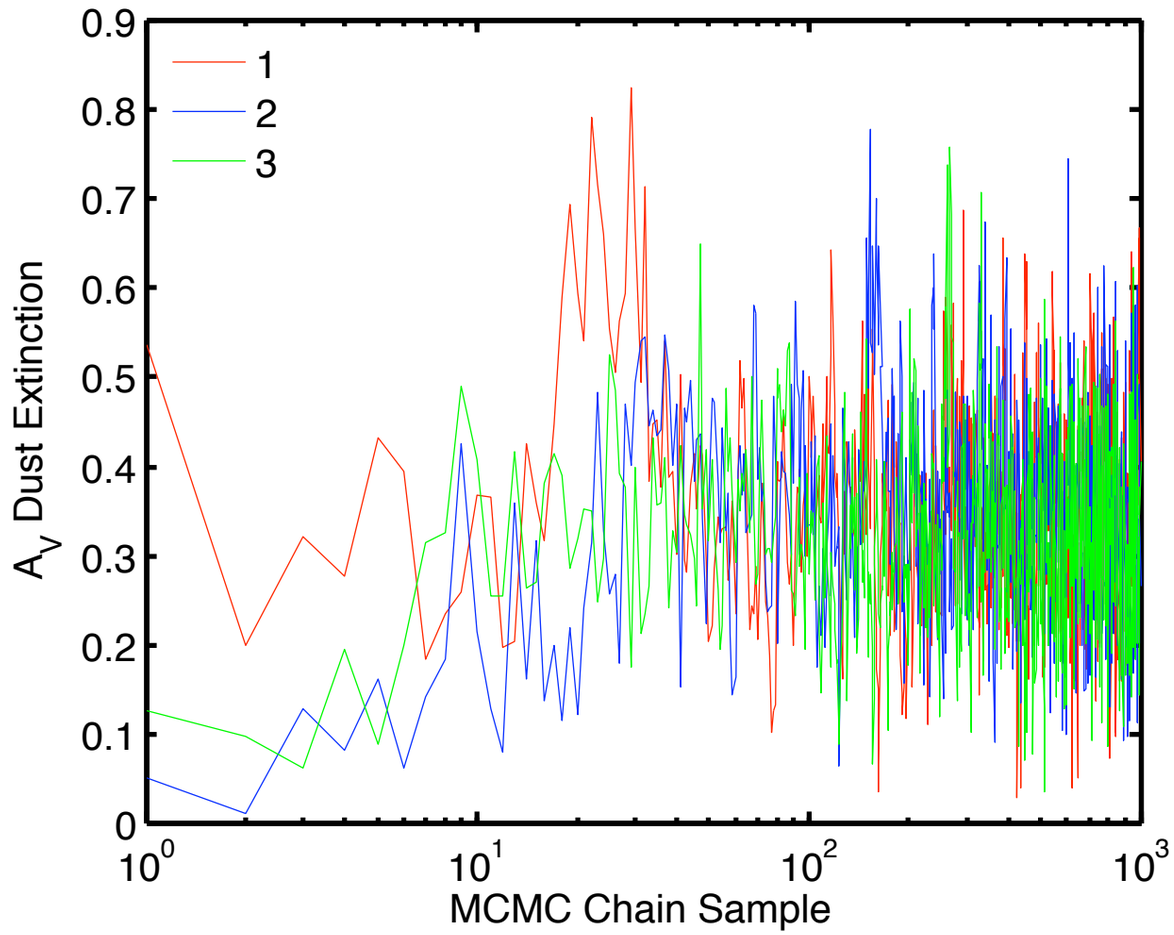
Directed Acyclic Graph for SN Ia Inference:
Distance Prediction



Statistical Computation with Hierarchical SN Ia Models: The BayeSN Algorithm

- Strategy: Generate a Markov Chain to sample global parameter space (populations & all individuals) using Gibbs Sampling => seek a global sol'n

- Chain explores/samples trade-offs/degeneracies in global parameter space for populations and individuals

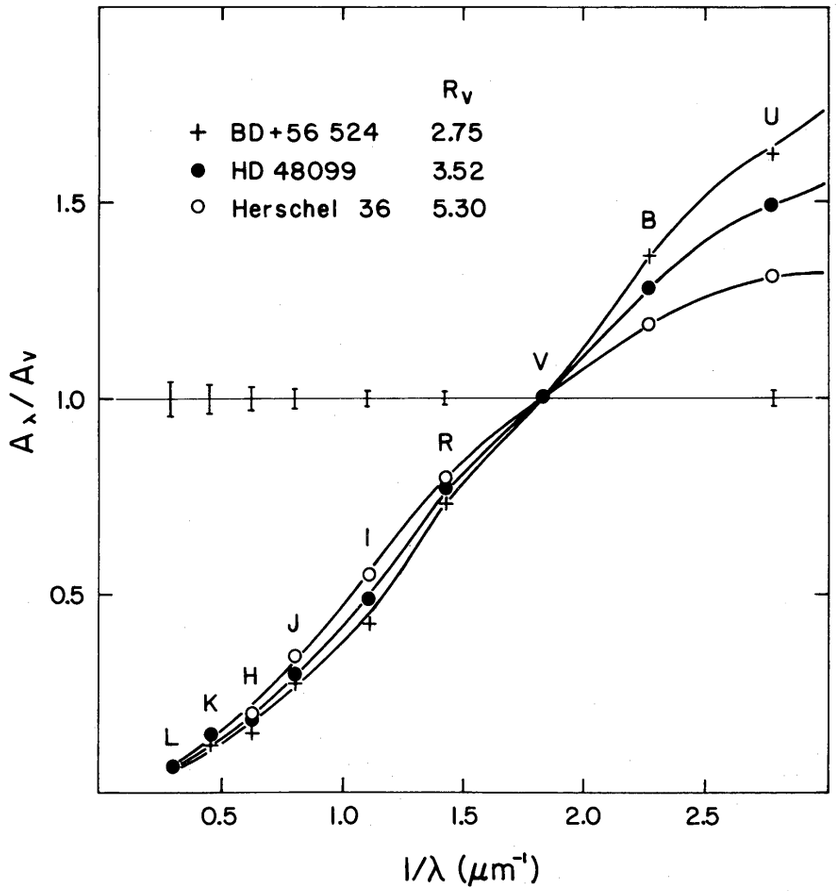


Multiple chains globally converge from random initial values

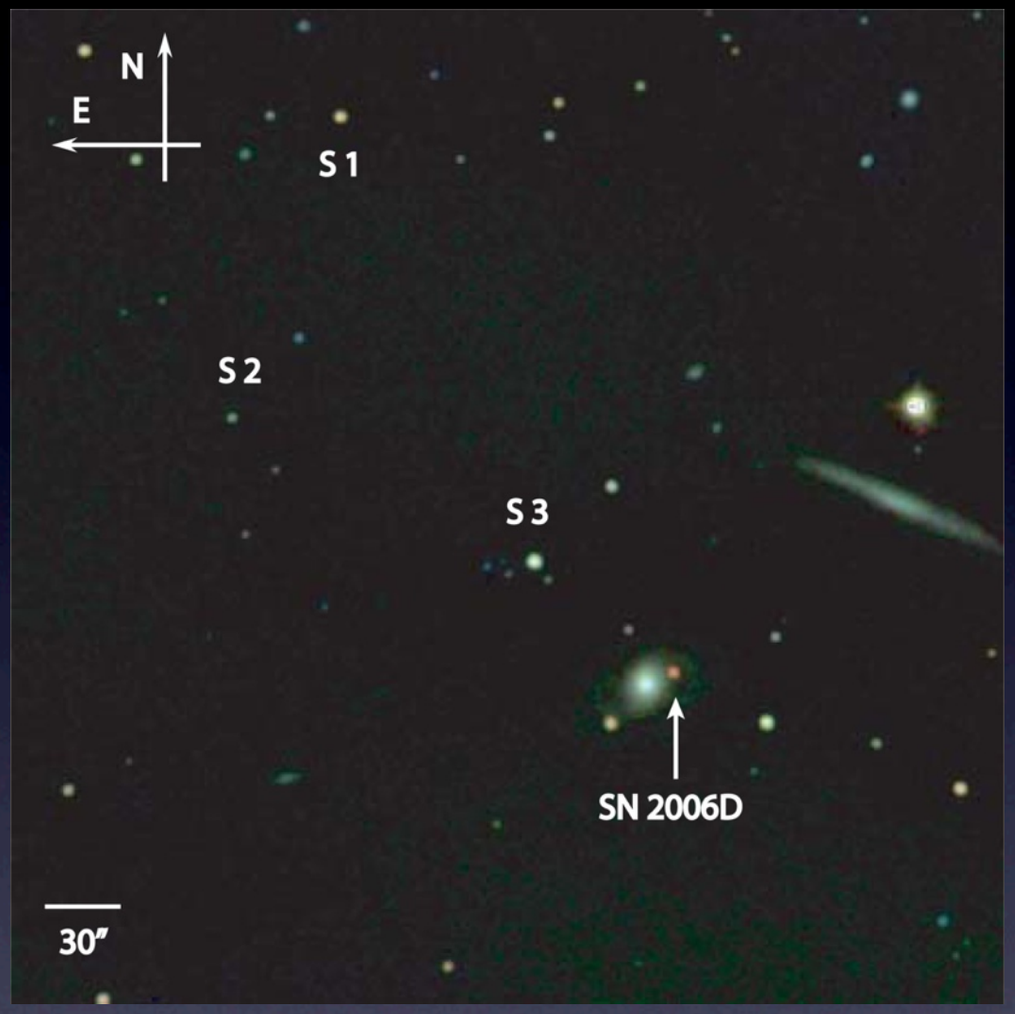
Practical Application of Hierarchical Model: NIR SN Ia

Why are NIR SN Ia interesting?

- Host Galaxy Dust presents a major systematic uncertainty in supernova cosmology inference
- Dust extinction has significantly reduced effect in NIR bands
- NIR SN Ia are good standard candles (Elias et al. 1985, Meikle 2000, Krisciunas, et al. 2004+, Wood-Vasey, et al. 2008, Mandel et al. 2009).
- Observe in NIR!: PAIRITEL /CfA



NIR Observations from



Observe in NIR bands

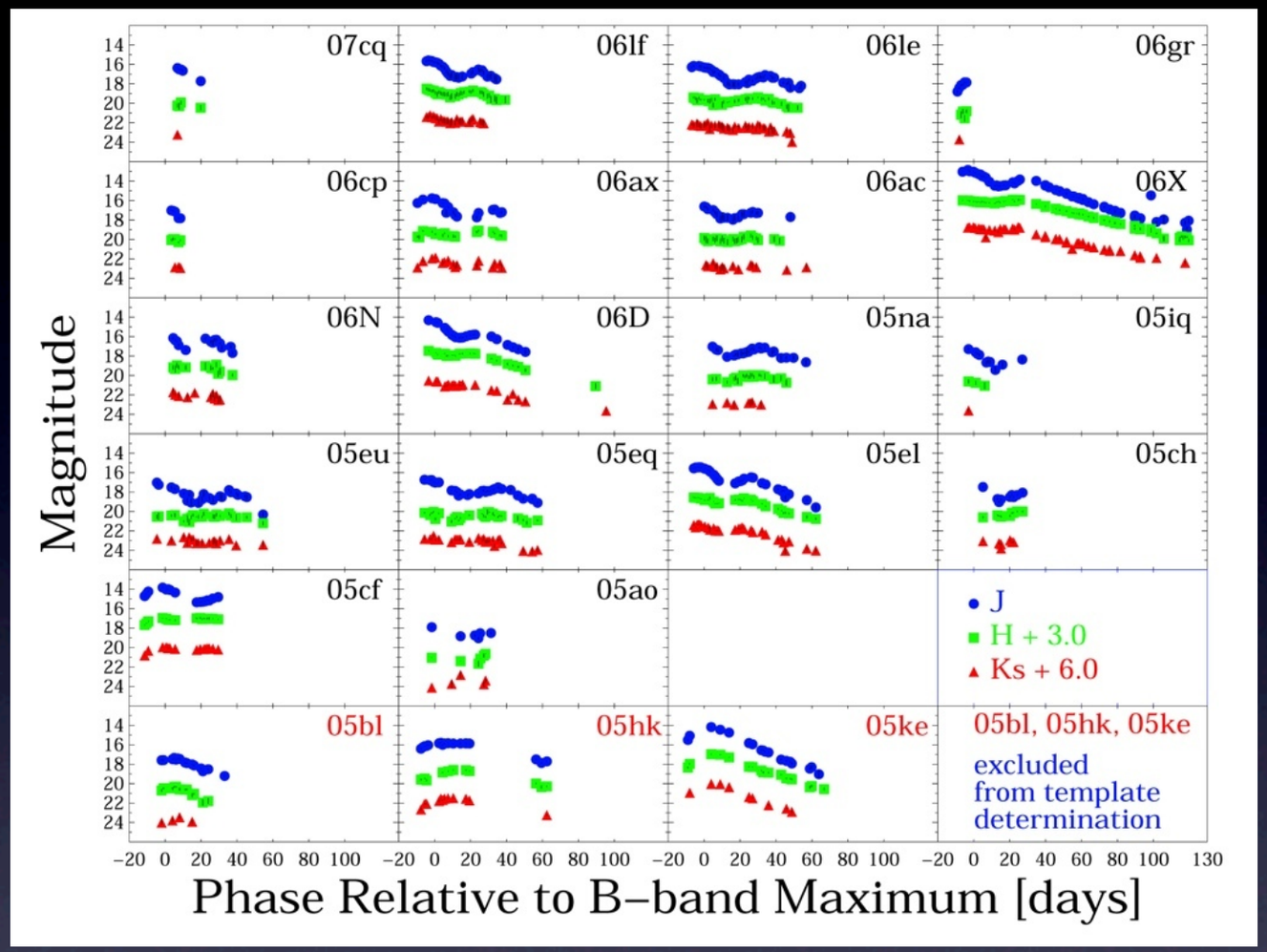
J (λ=1.2 μm)

H (λ=1.6 μm)

Ks (λ=2.2 μm)

Credit: Andrew Friedman

Nearby SN Ia in the NIR: The Training Data



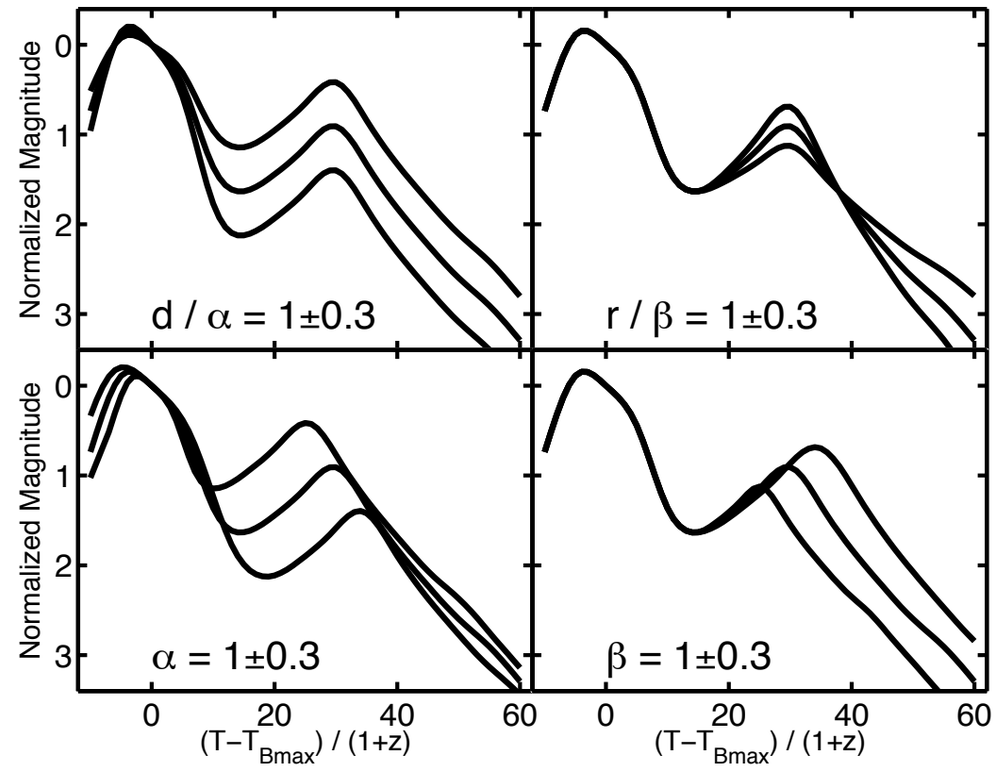
Credit: Michael Wood-Vasey, Andrew Friedman

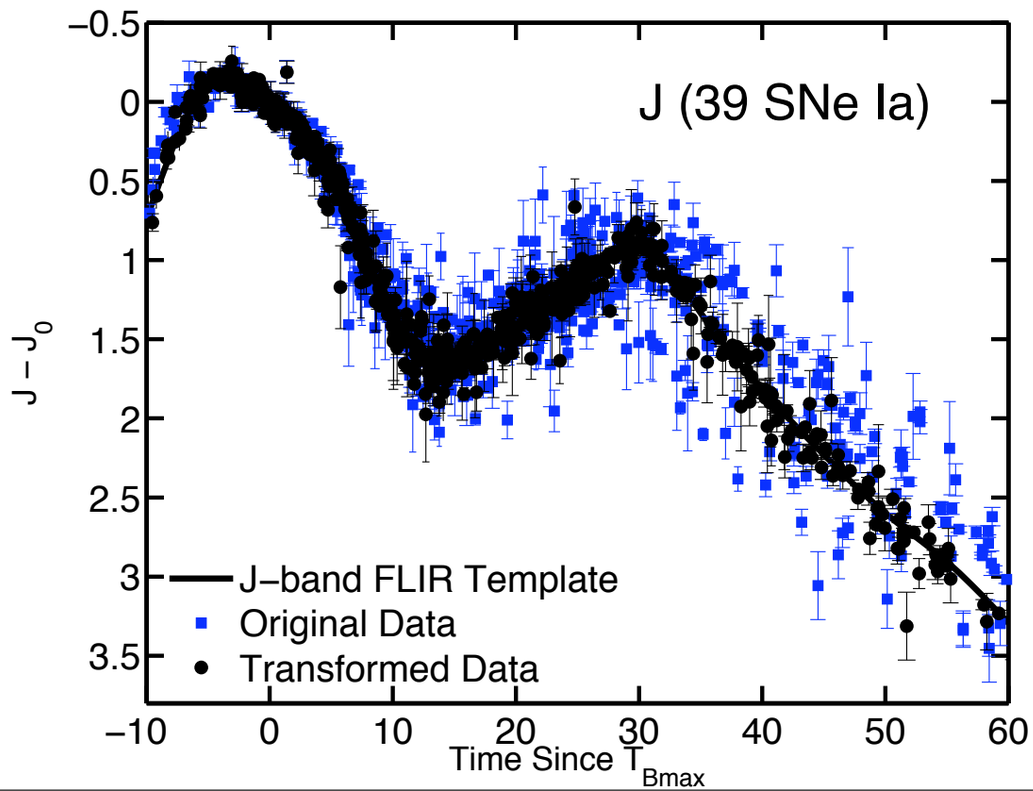
WV08 Data Set = PAIRITEL + Lit = 39 SN Ia in NIR

Working on 40-60 more SNe (Andy Friedman)

Light-curve shape variations in NIR

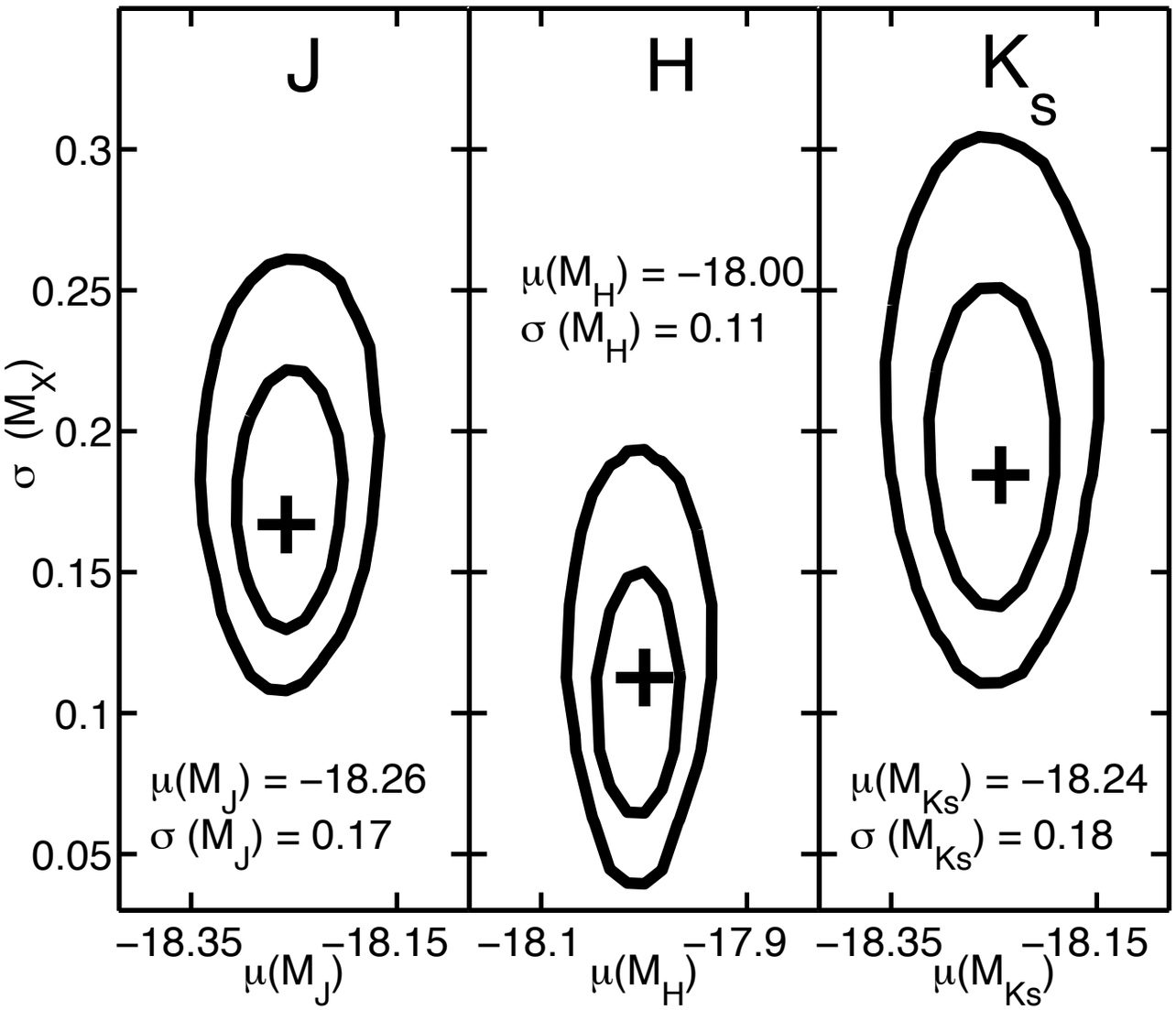
- Double-Peak light-curve structure seen in JHK bands
- Difficult to capture with one parameter
- J-band LC Model captures timescales and amplitudes of late-time NIR light curves (Mandel et al. 2009)





SN NIR Population Inference: Peak Absolute Magnitudes

Marginal Distributions of SN Ia NIR Population characteristics

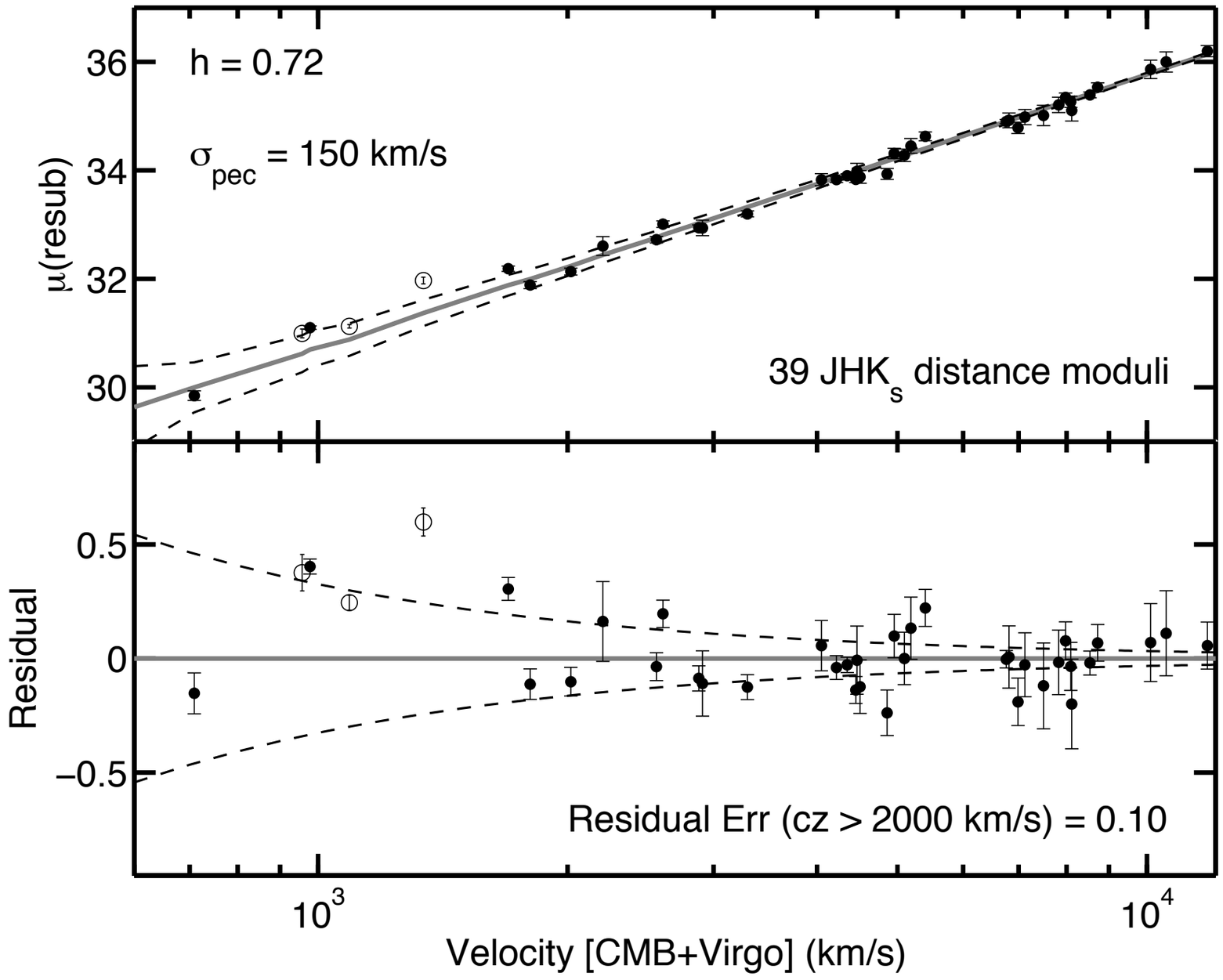


Mandel et al. 2009

- Marginal Estimate of Population Variance in H-band (1.6 μm) is $\sigma(M_H) = 0.11 \pm 0.03$ mag

- SN Ia in NIR are excellent standard candles!

Hubble Diagram with nearby NIR SN Ia



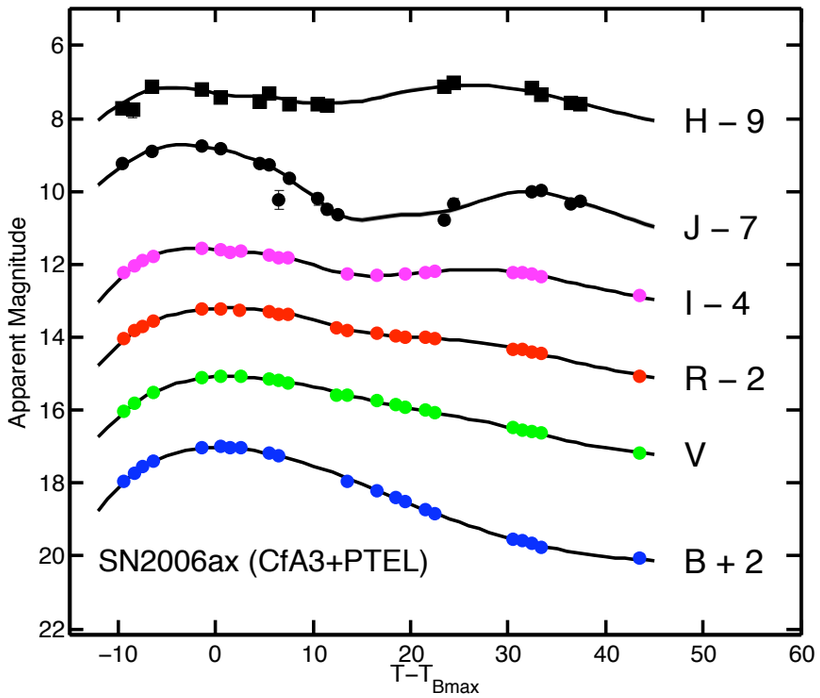
Mandel et al. 2009

Hubble Residuals of Hierarchical NIR SN Ia Model Fit

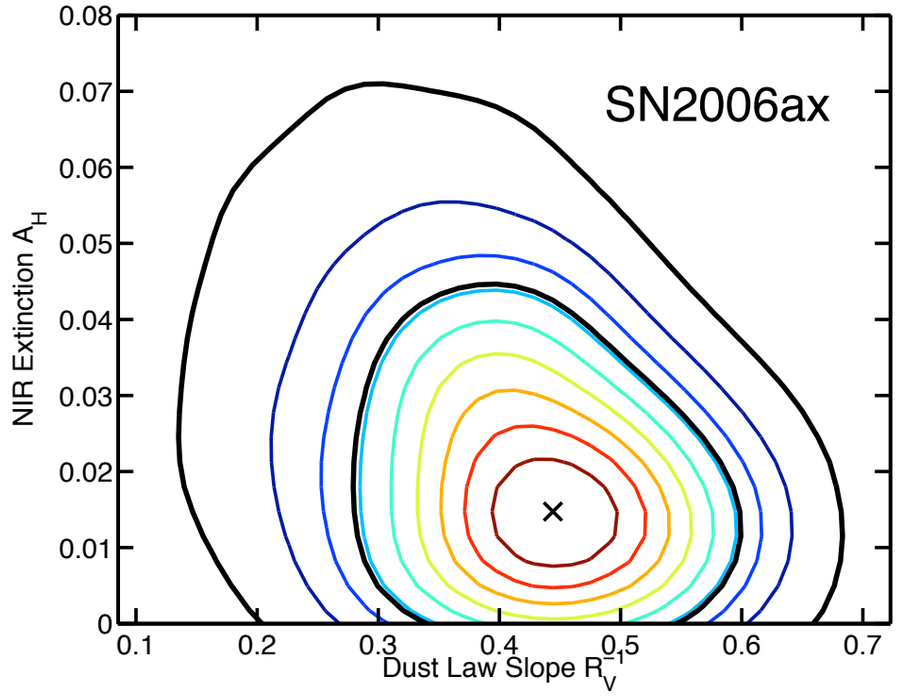
Bootstrap Cross-Validation:
To Estimate effect of finite sample size
~ 0.05 mag:
Need larger sample
(Friedman, Wood-Vasey)

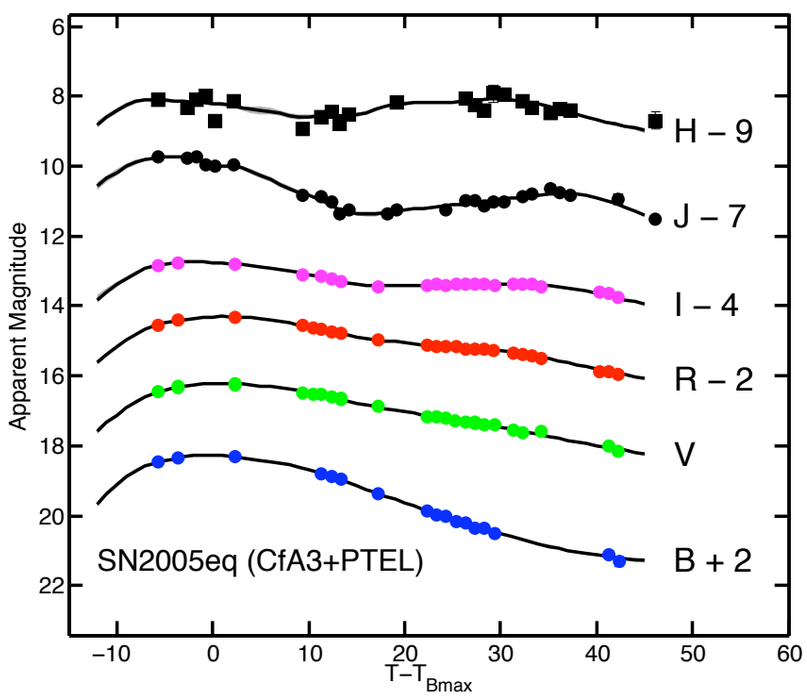
Preview: Optical+NIR Hierarchical Inference

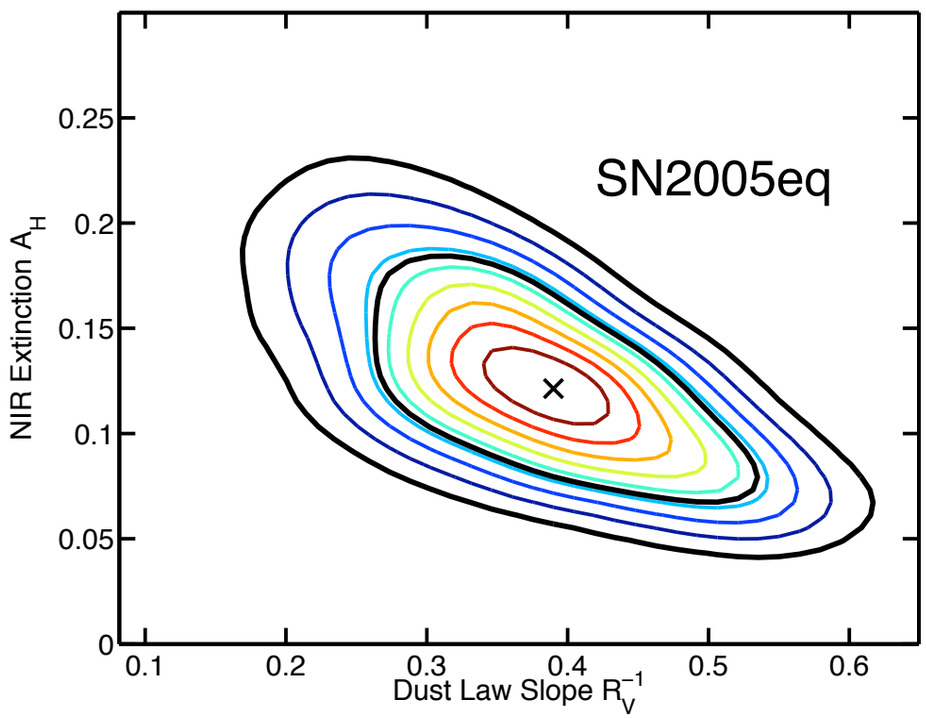
PTEL+CfA3 Light-curves



Marginal Posterior of Dust







(Preliminary)

Summary

- Hierarchical models are useful statistical constructions for incorporating multiple levels of randomness affecting SN Ia inference and modeling physical populations coherently
- BayeSN: an efficient MCMC/Gibbs Sampler for computing hierarchical models conditional on SN data
- NIR Light Curves give excellent distances less prone to dust extinction
- Use Optical with NIR to estimate dust and make Type Ia SN better standard candles (work in progress!)
- Rest-Frame NIR observations of SN Ia: consideration for JDEM