Hierarchical Bayesian Models for Type Ia SN Light Curves, Dust and Cosmic Distances

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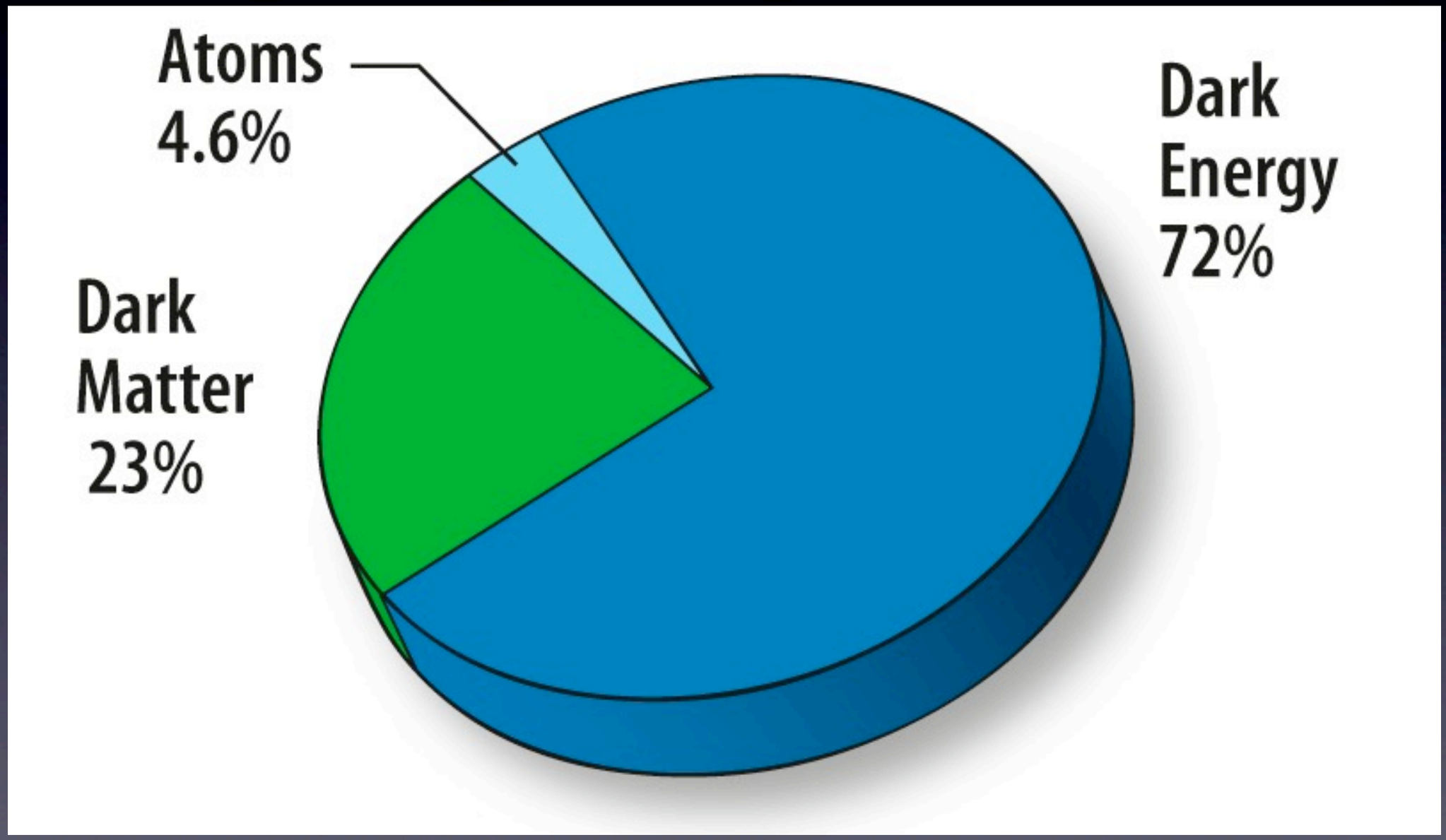
Hierarchical

Brings deep knowledge from data

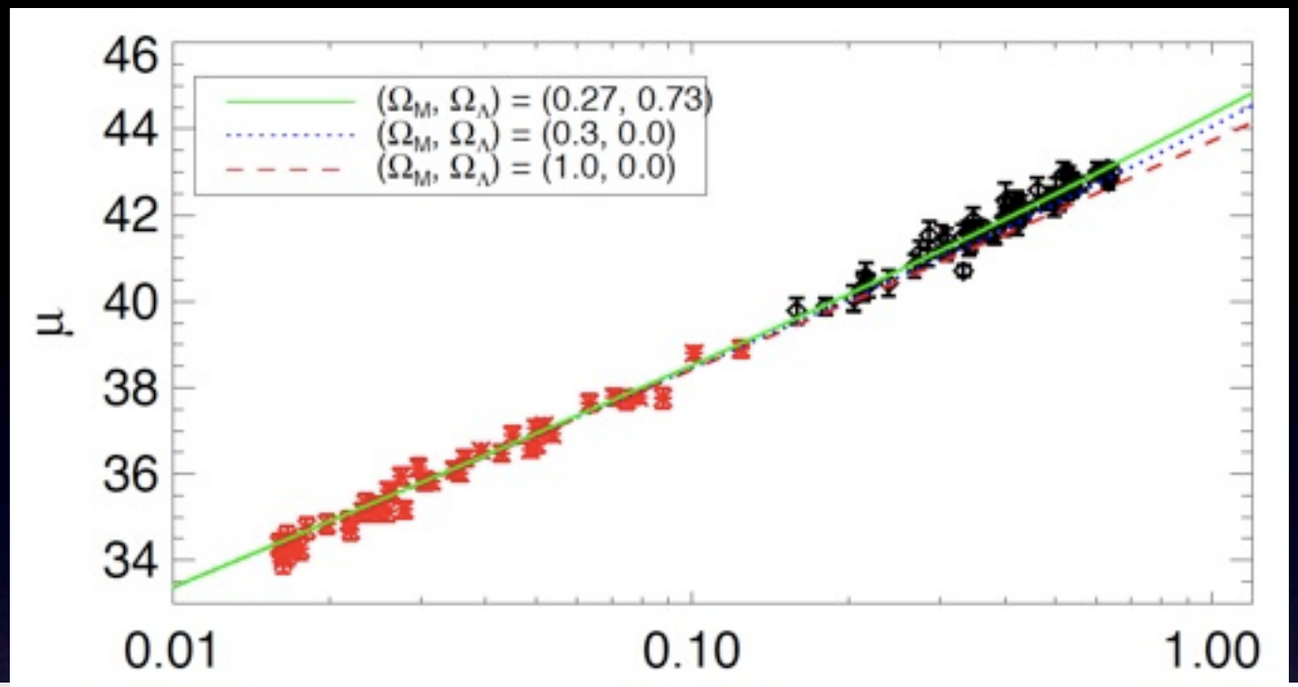
Distant star glows, fades.

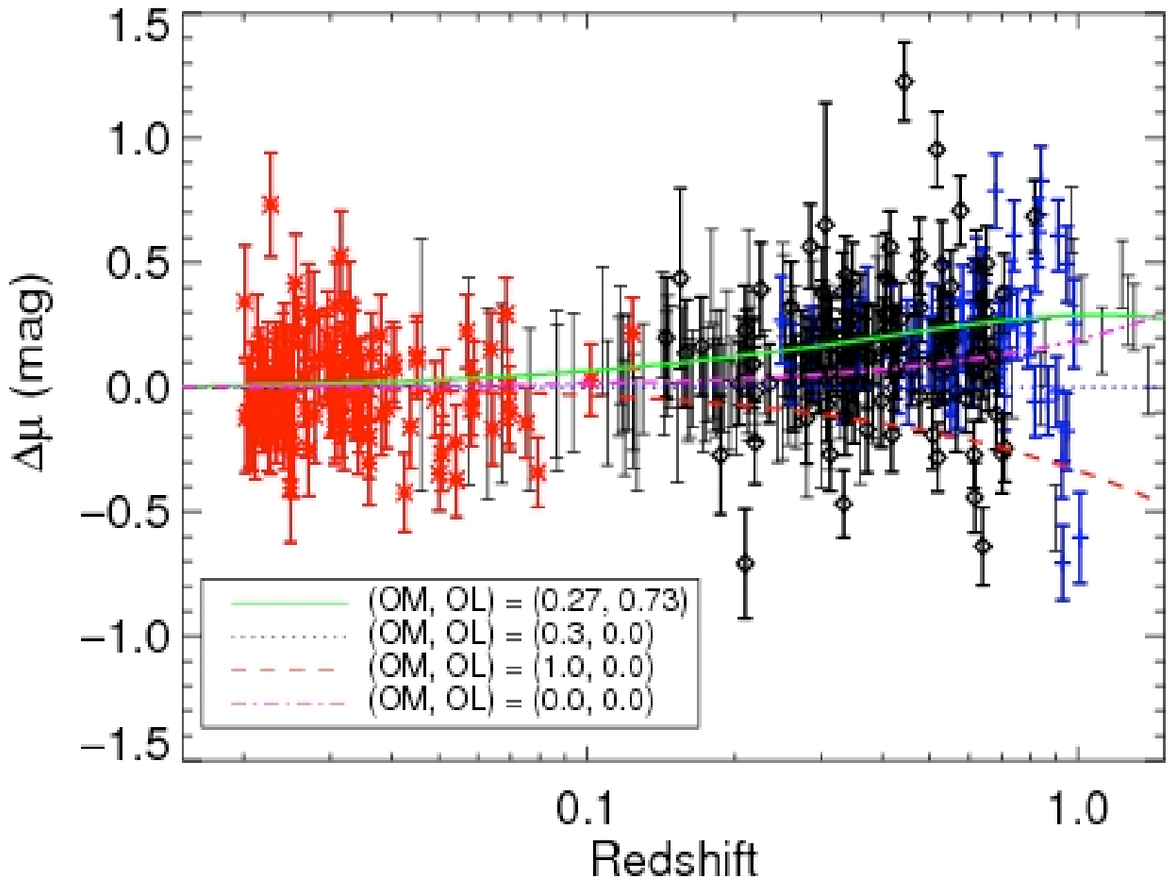
-Bob Kirshner

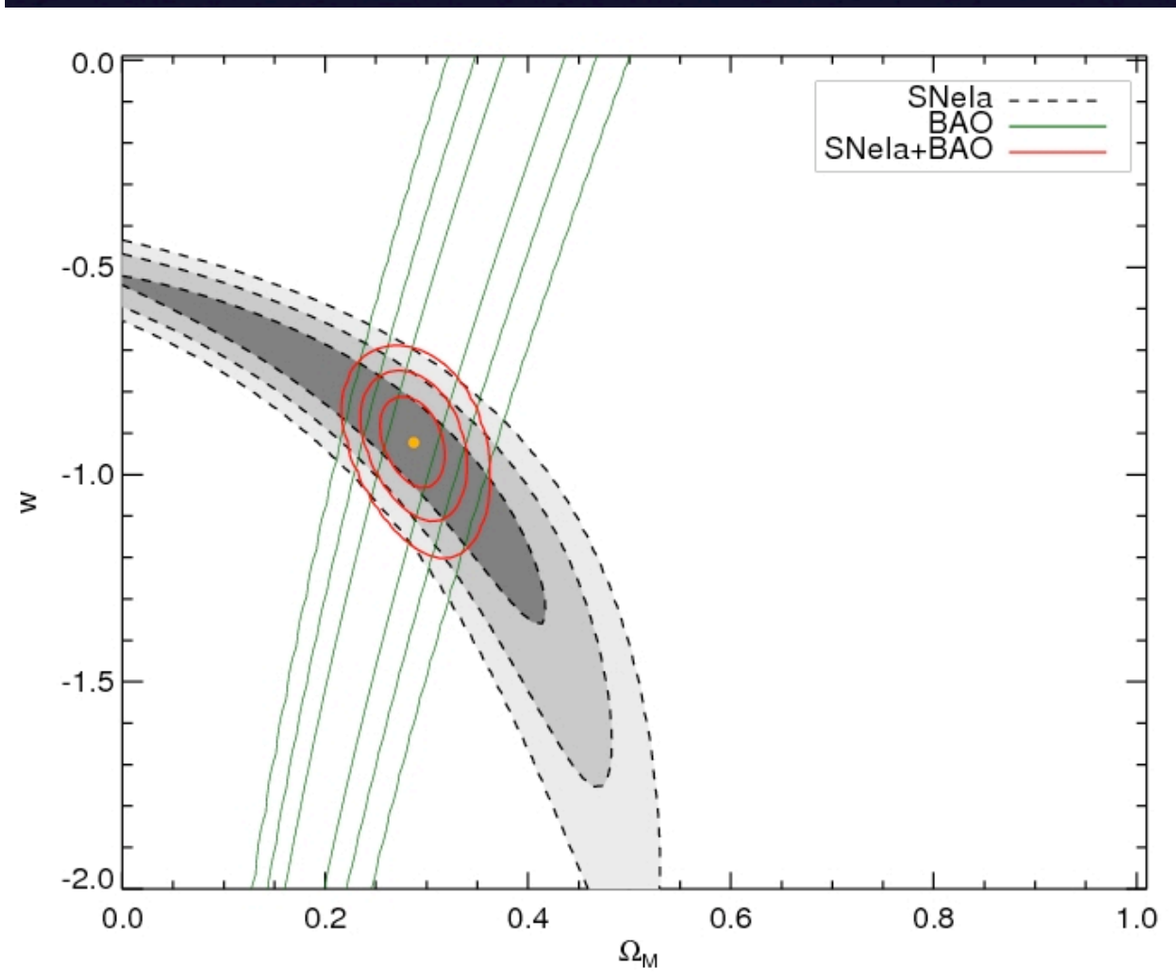
Cosmological Energy Content



Supernova Cosmology: Constraining Cosmological Parameters using Distance vs. Velocity







Standard Candle Principle

1. Know or Estimate Luminosity L of a Class of Astronomical Objects
2. Measure the apparent brightness or flux F
3. Derive the distance D to Object using Inverse Square Law: $F = L / (4\pi D)$

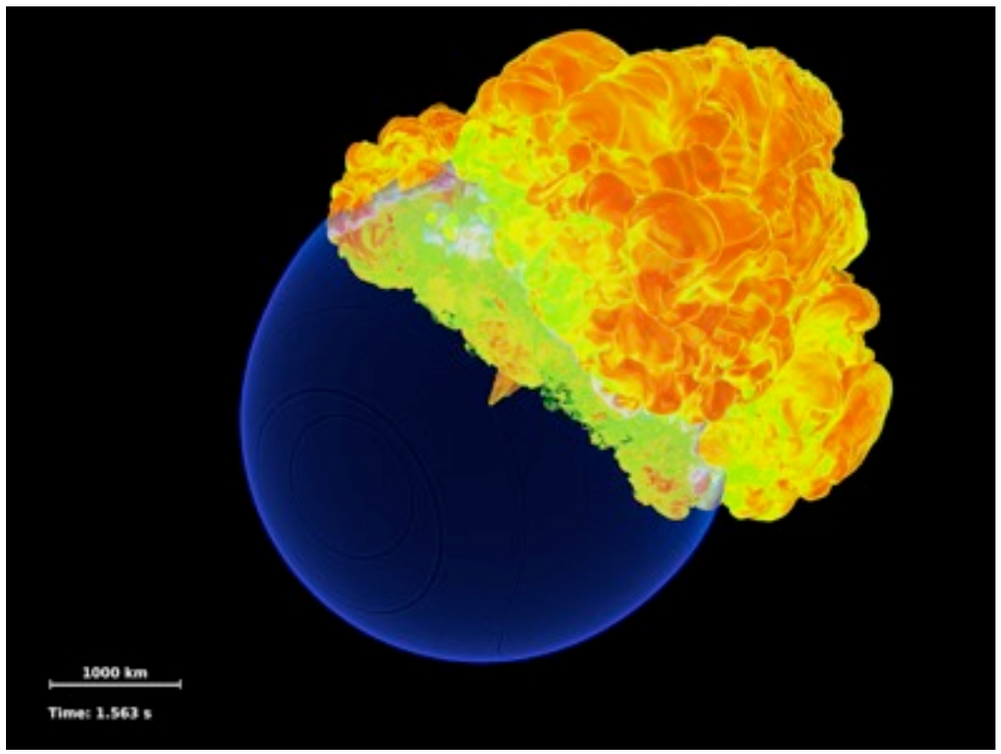
Type Ia Supernovae are Nearly Standard Candles

- Progenitor: C/O White Dwarf Star accreting mass leads to instability

- Thermonuclear Explosion: Deflagration/Detonation

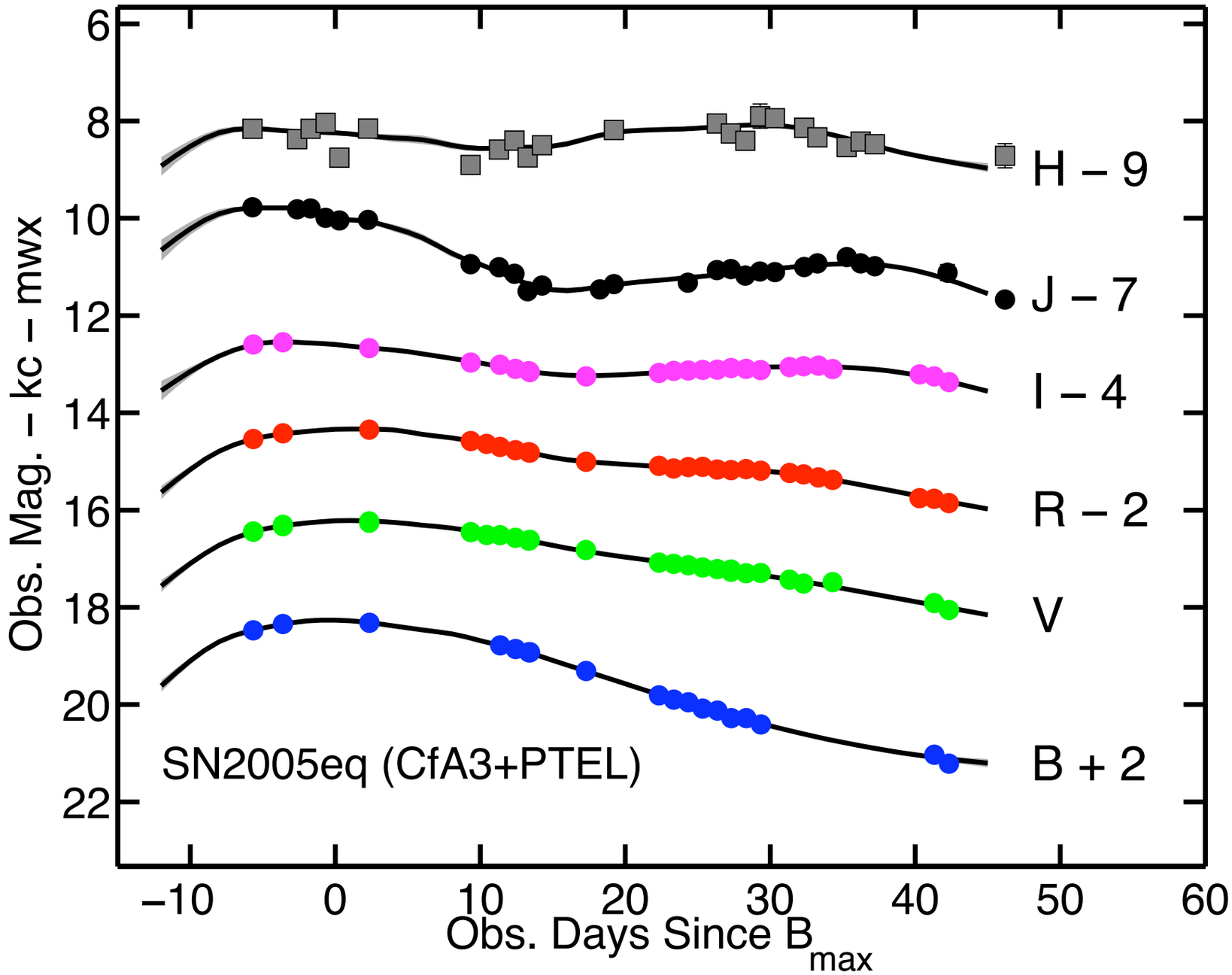
- Nickel to Cobalt to Iron Decay + radiative transfer powers the light curve

- SNe Ia progenitors have nearly same mass, therefore energy



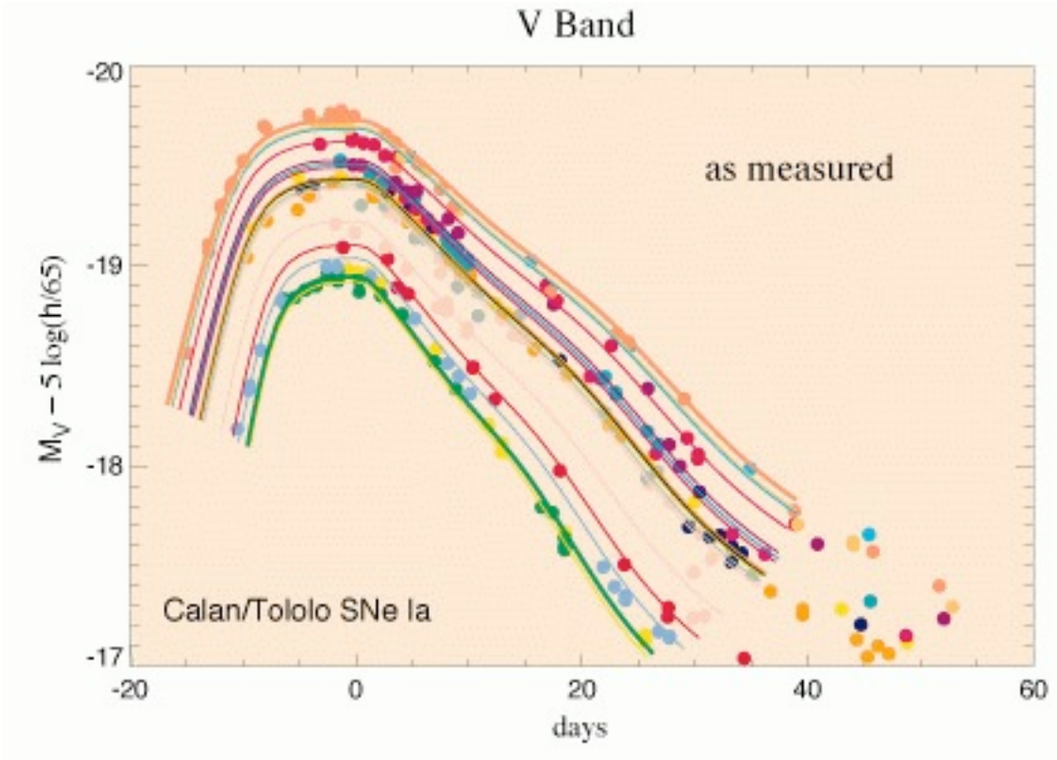
Credit: FLASH Center

Type Ia Supernova Apparent Light Curve



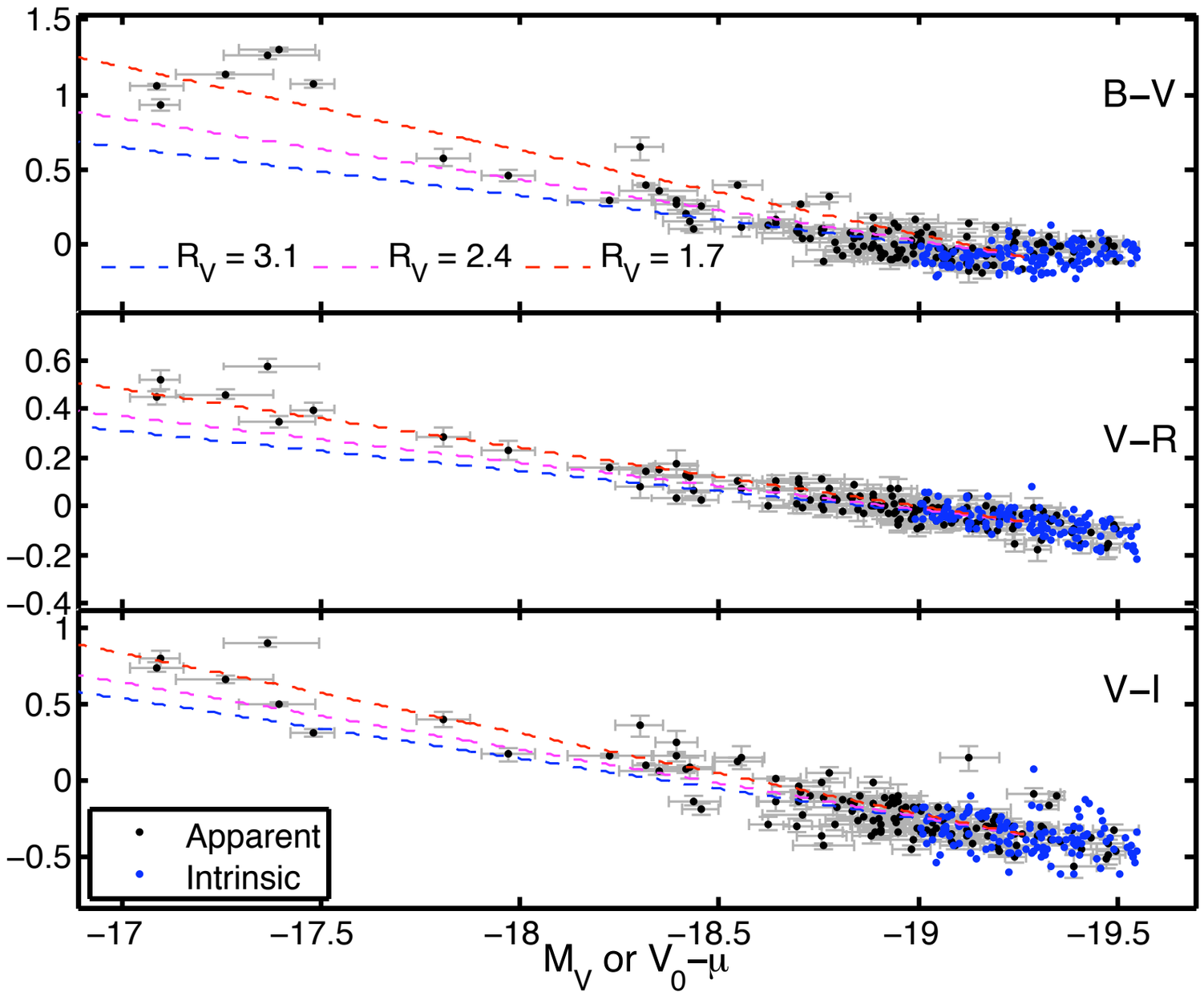
Reading the Wattage of a SN Ia: Empirical Correlations

- Width-Luminosity Relation: an observed correlation (Phillips)
- Observe optical SN Ia Light Curve Shape to estimate the peak luminosity of SN Ia more precisely: ~0.5 mag to ~0.2 mag error
- Color-Luminosity Relation



Intrinsically Brighter SN Ia have broader light curves and are slow decliners

I will show you fear in a handful of Dust

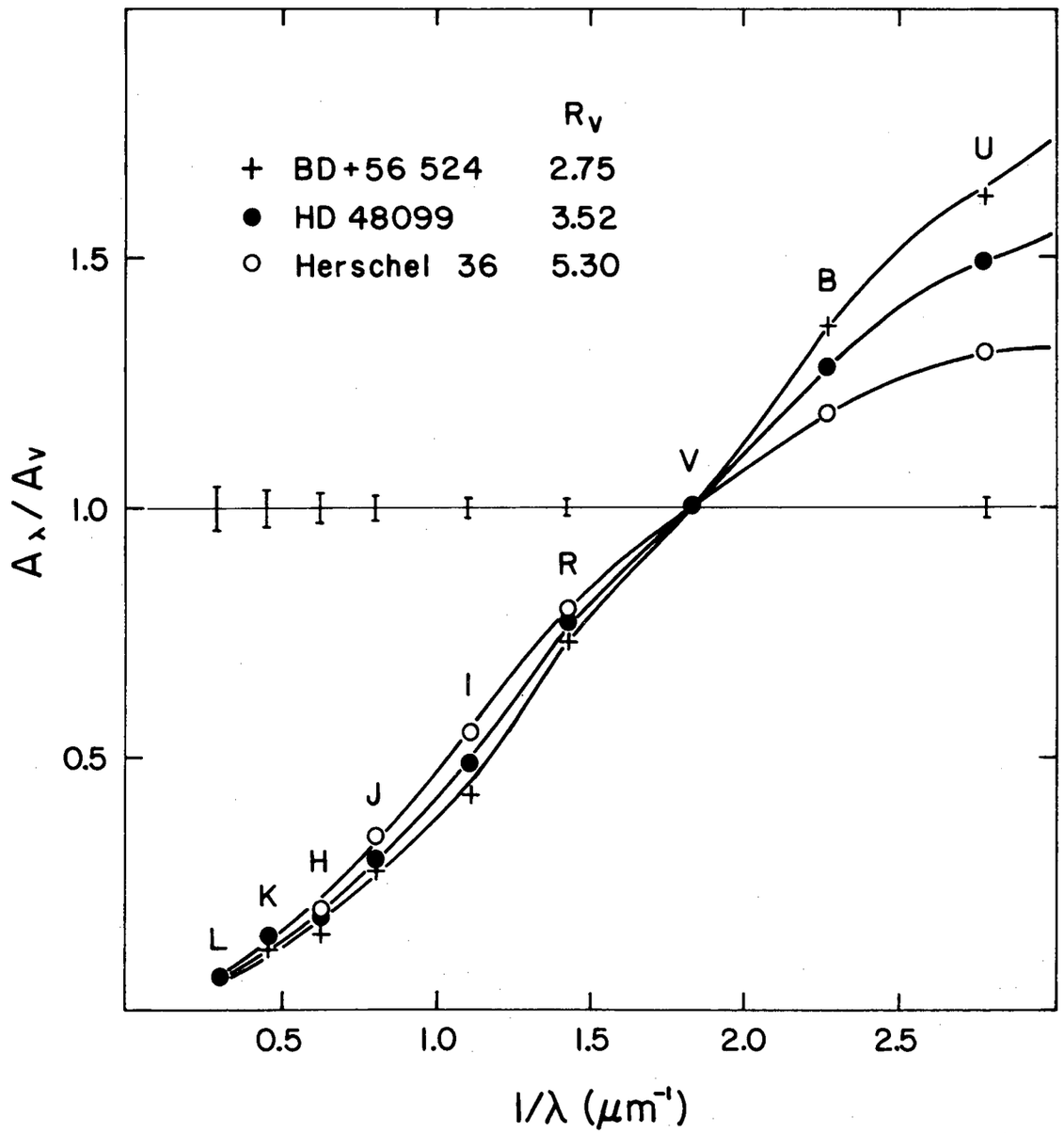


Random Dust Effects:

1. Redder
2. Dimmer

Observe in NIR to see through dust

- 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
- Observe in NIR!: PAIRITEL /CfA



Statistical inference with SN Ia

- SN Ia cosmology inference based on empirical relations
- Statistical models for SN Ia are learned from the data
- Several Sources of Randomness & Uncertainty

  1. Photometric errors
  2. Intrinsic Variation and Correlations between L, Light Curve Shape, Color = Population Distribution of SN Ia
  3. Random Peculiar Velocities in Nearby Hubble Flow
  4. Host Galaxy Dust: extinction and reddening.

- How to incorporate this all into a coherent statistical model? Hierarchical Bayesian Model!

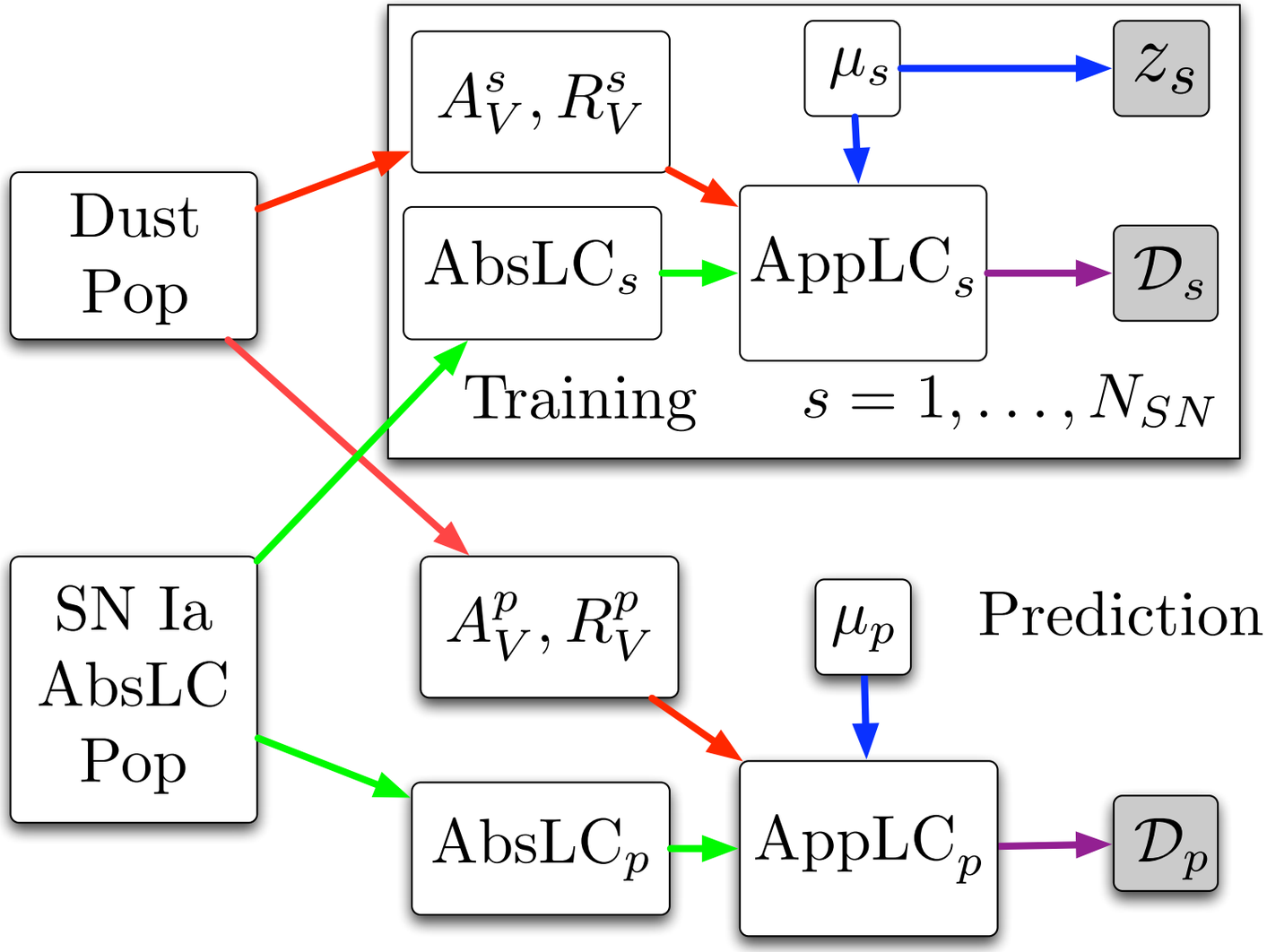
Directed Acyclic Graph for SN Ia Inference with Hierarchical Modeling

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

Generative Model

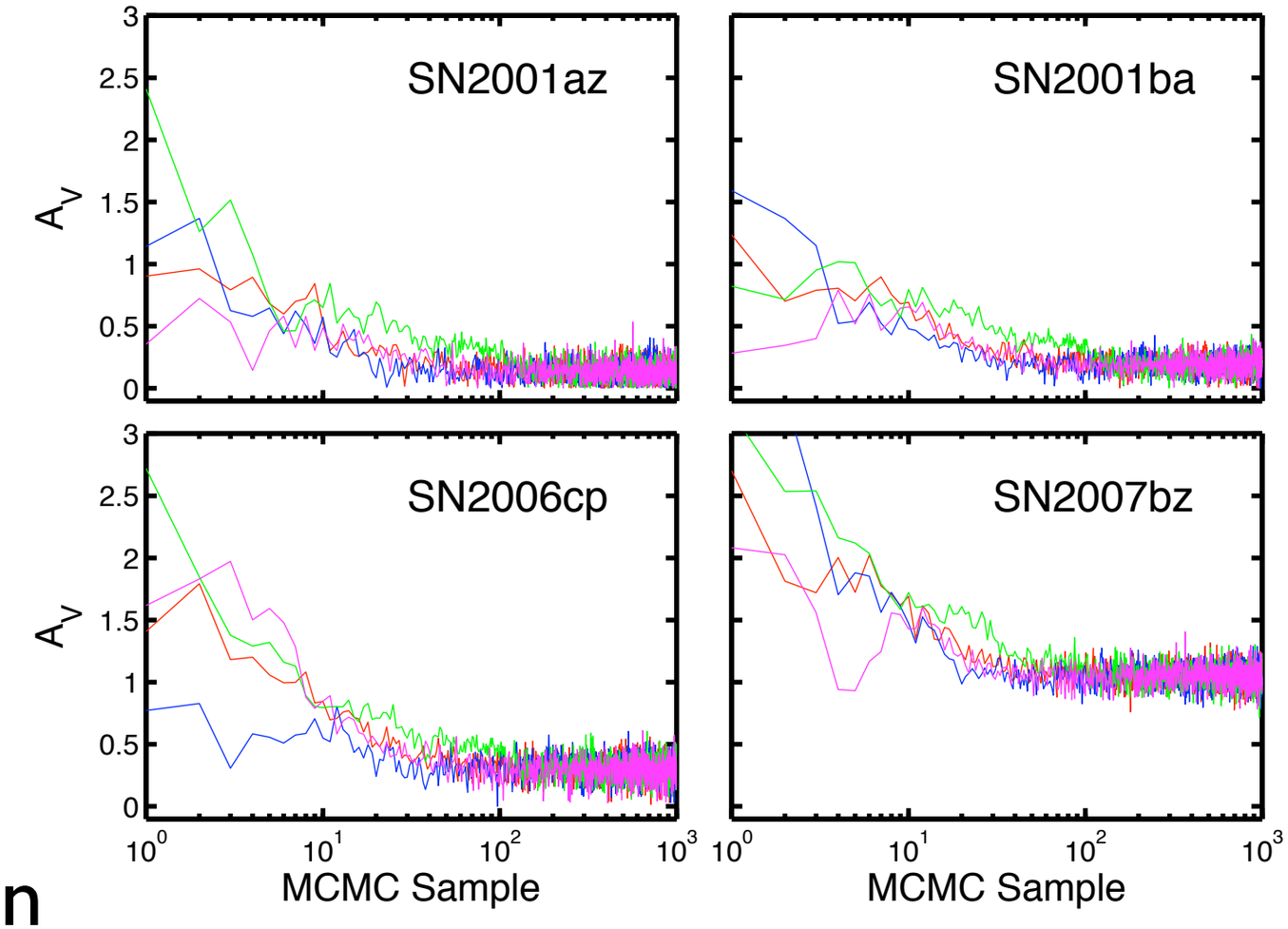
Global Joint Posterior Probability Density Conditional on all SN Data

"Training" - Learn about Populations



Statistical Computation with Hierarchical SN Ia Models: The BayeSN Algorithm

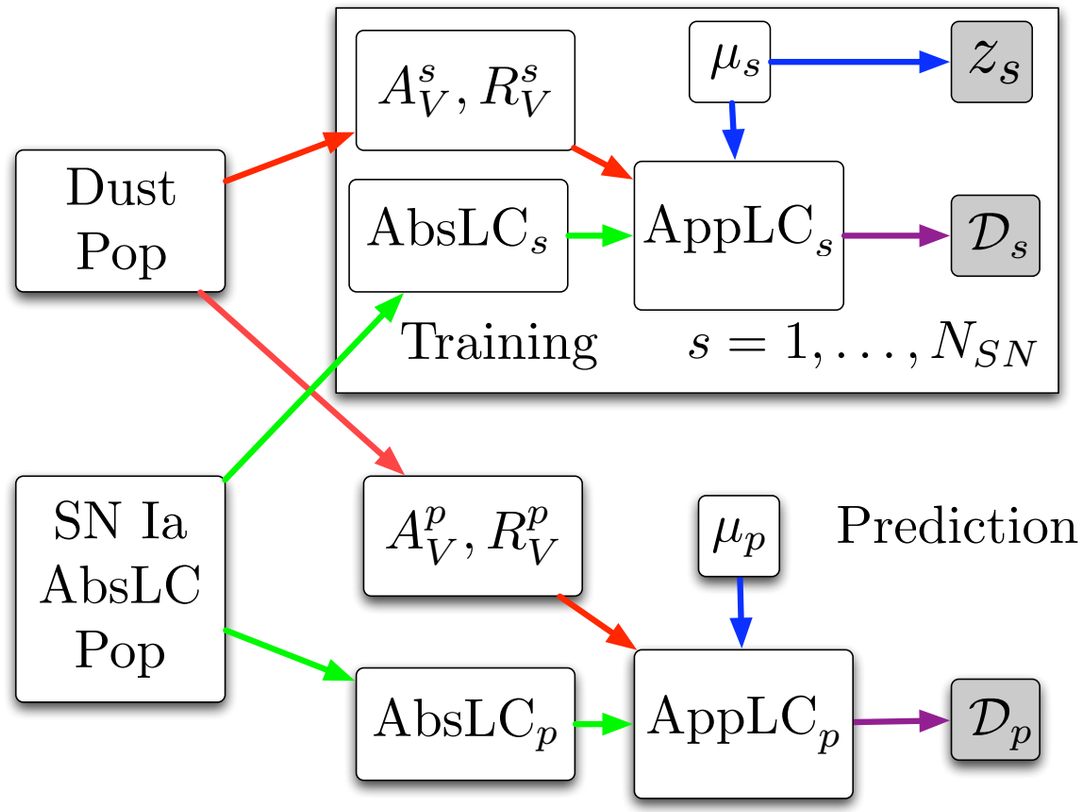
- Strategy: Generate a Markov Chain to sample global parameter space (populations & all individuals) => seek a global solution
- Chain explores/samples trade-offs/degeneracies in global parameter space for populations and individuals



Multiple chains globally converge from random initial values

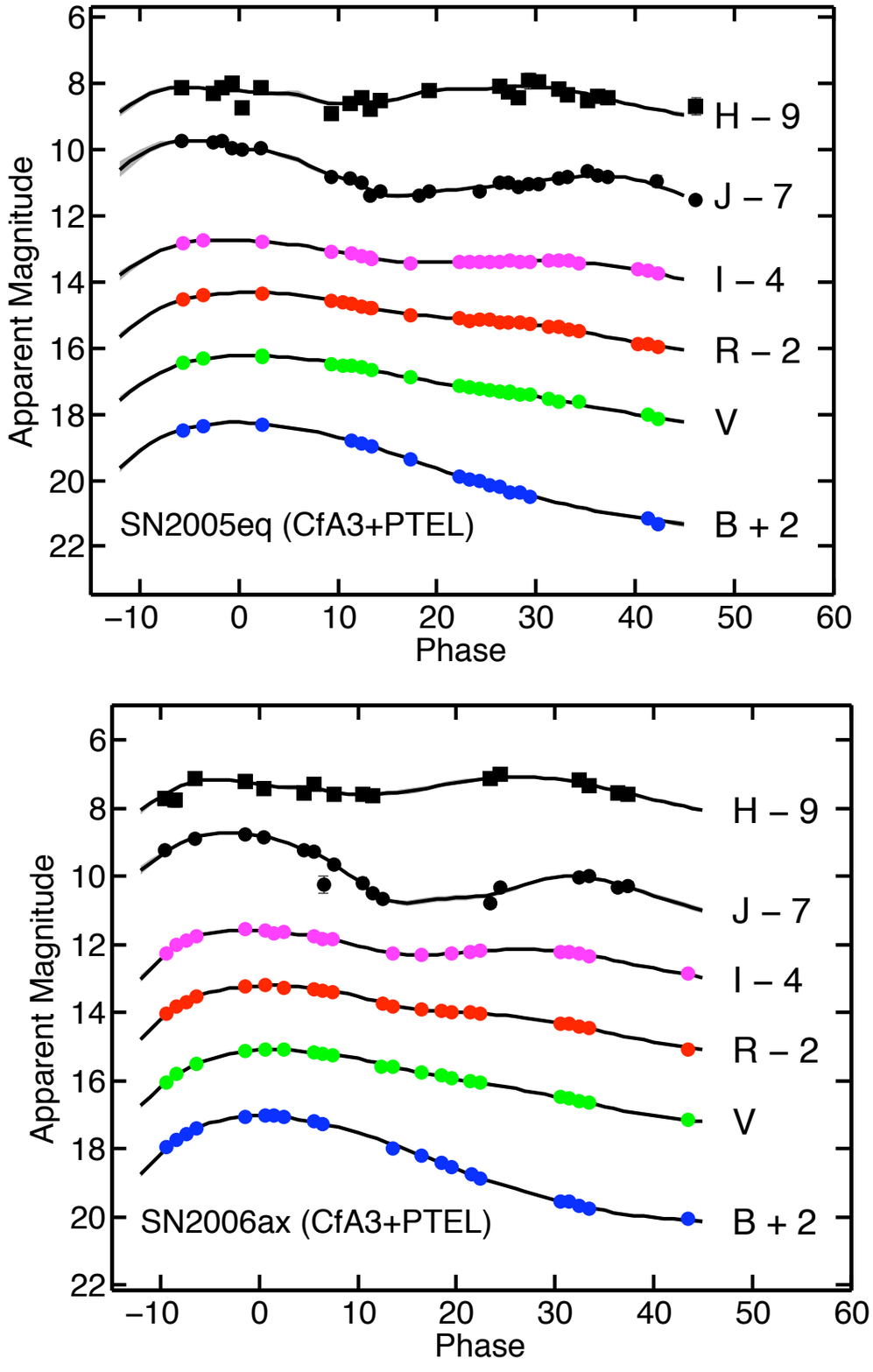
BayeSN MCMC strategy

- Gibbs Sampling
- Metropolis-Hastings
- Parameter Expansion
- Generalized Conditional Sampling
- Parallel chains to diagnose convergence

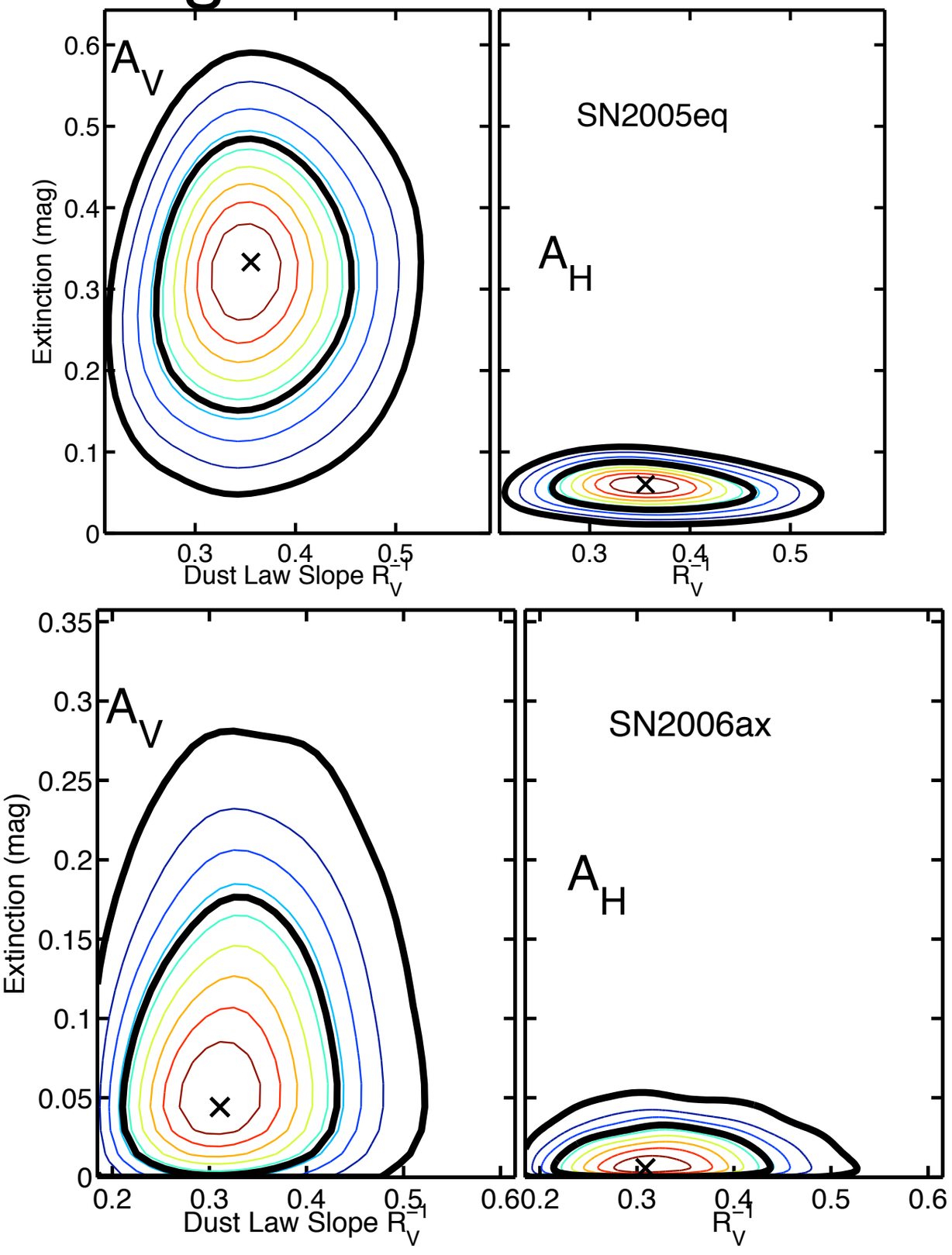


Results: Optical+NIR Hierarchical Inference

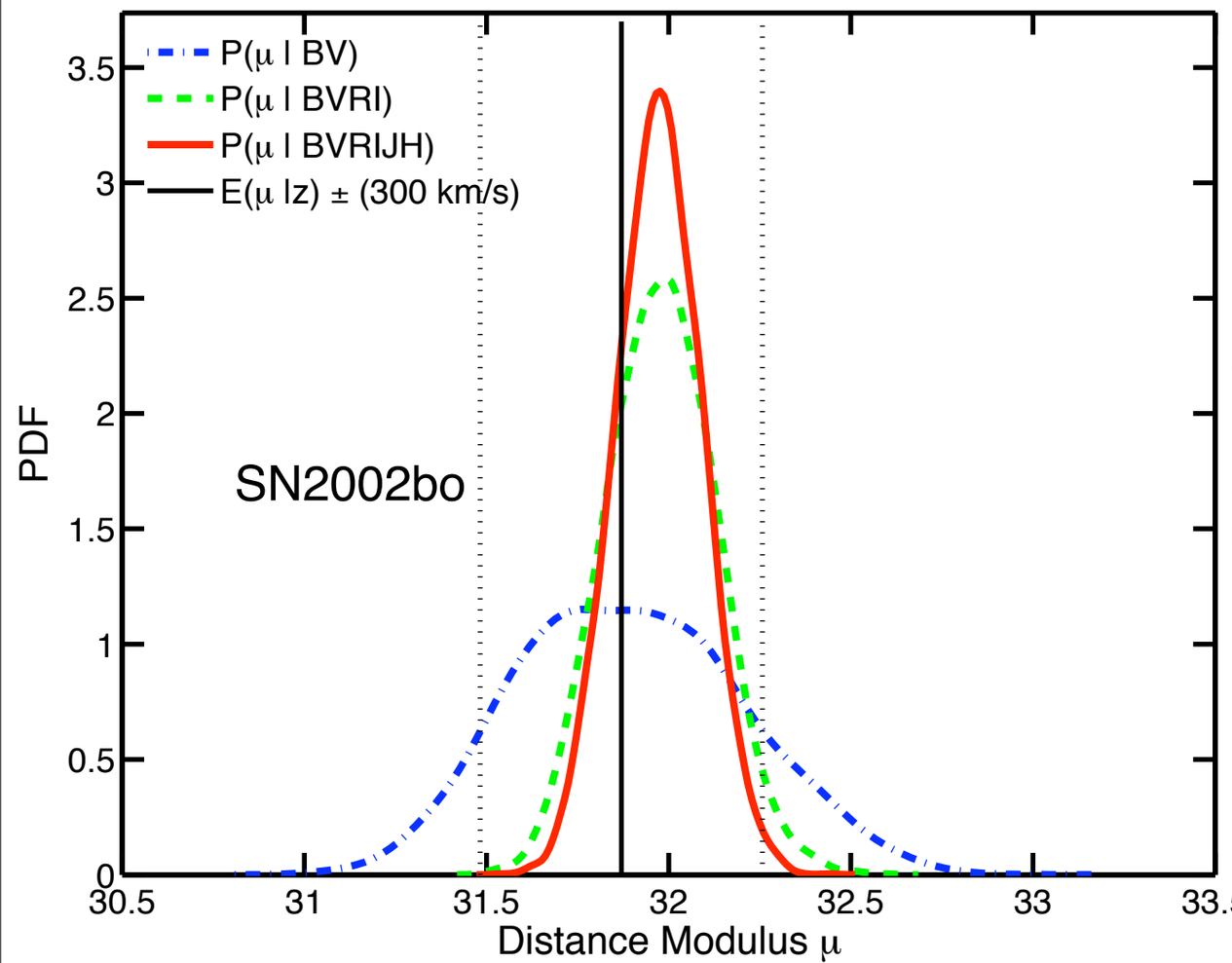
PTEL+CfA3 Light-curves

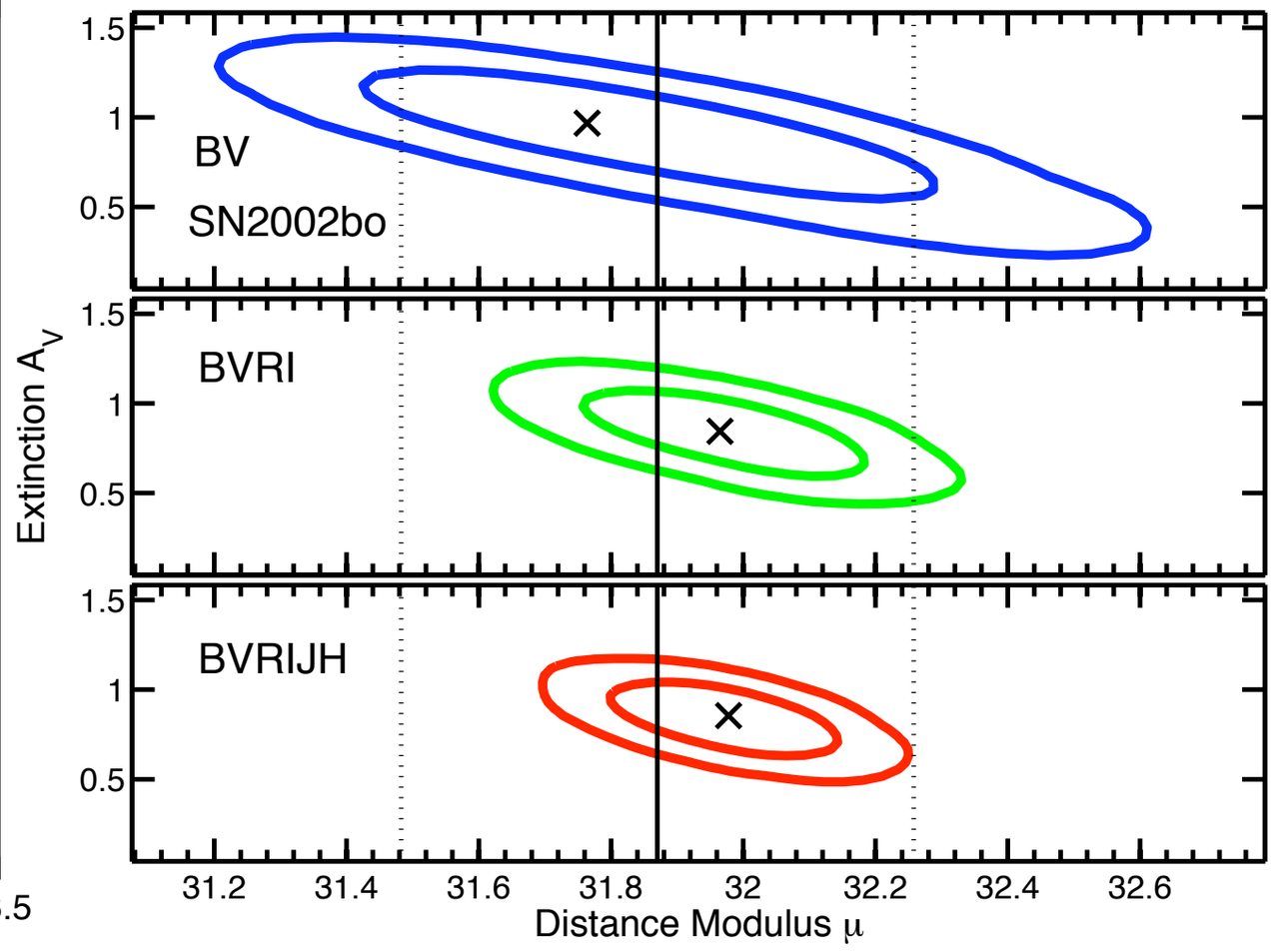


Marginal Posterior of Dust



Improved Constraints from Combining Optical with Infrared Light Curves





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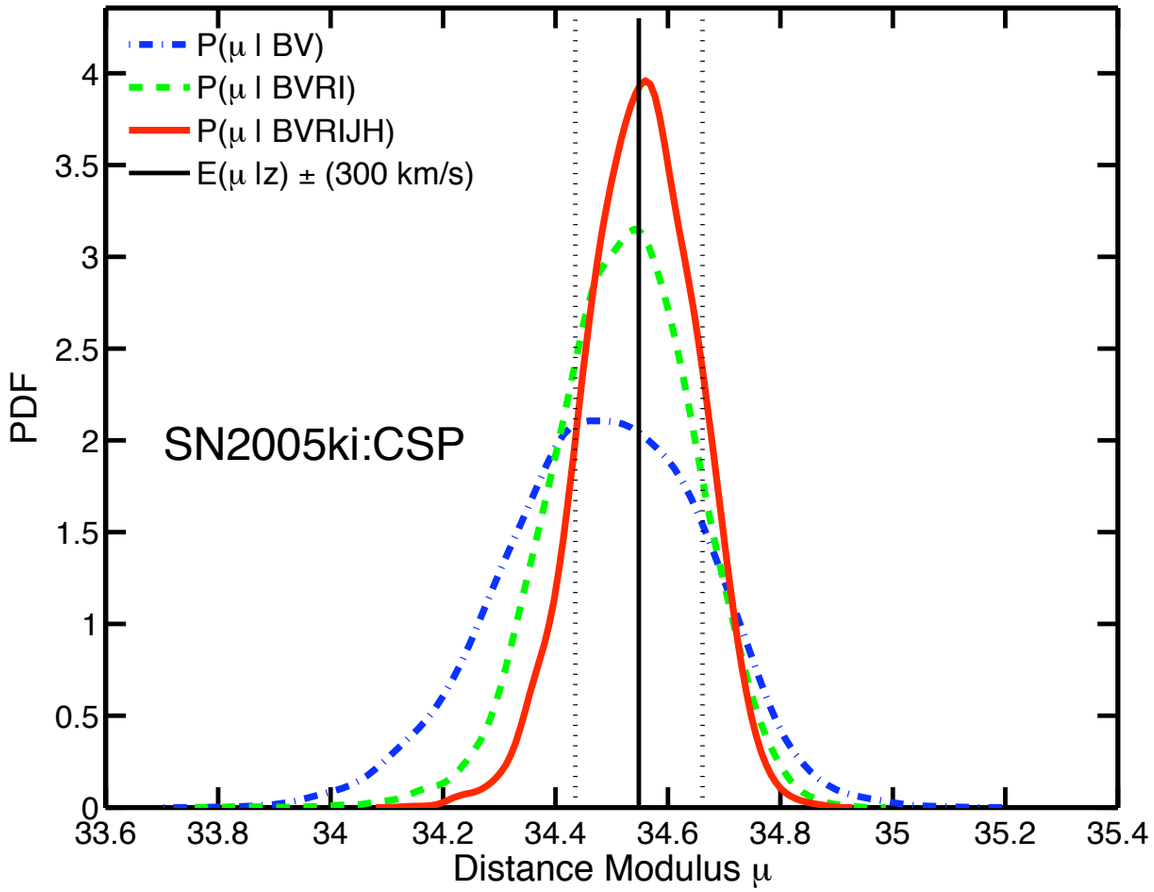
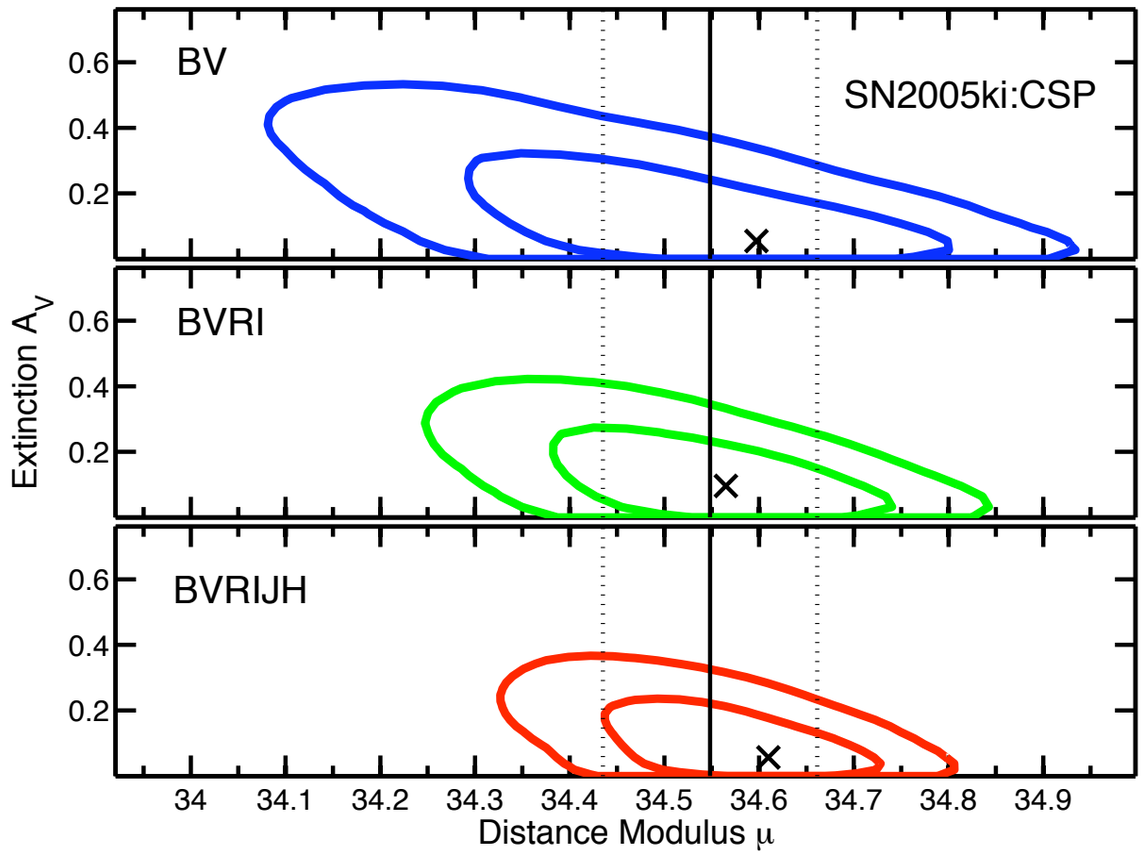
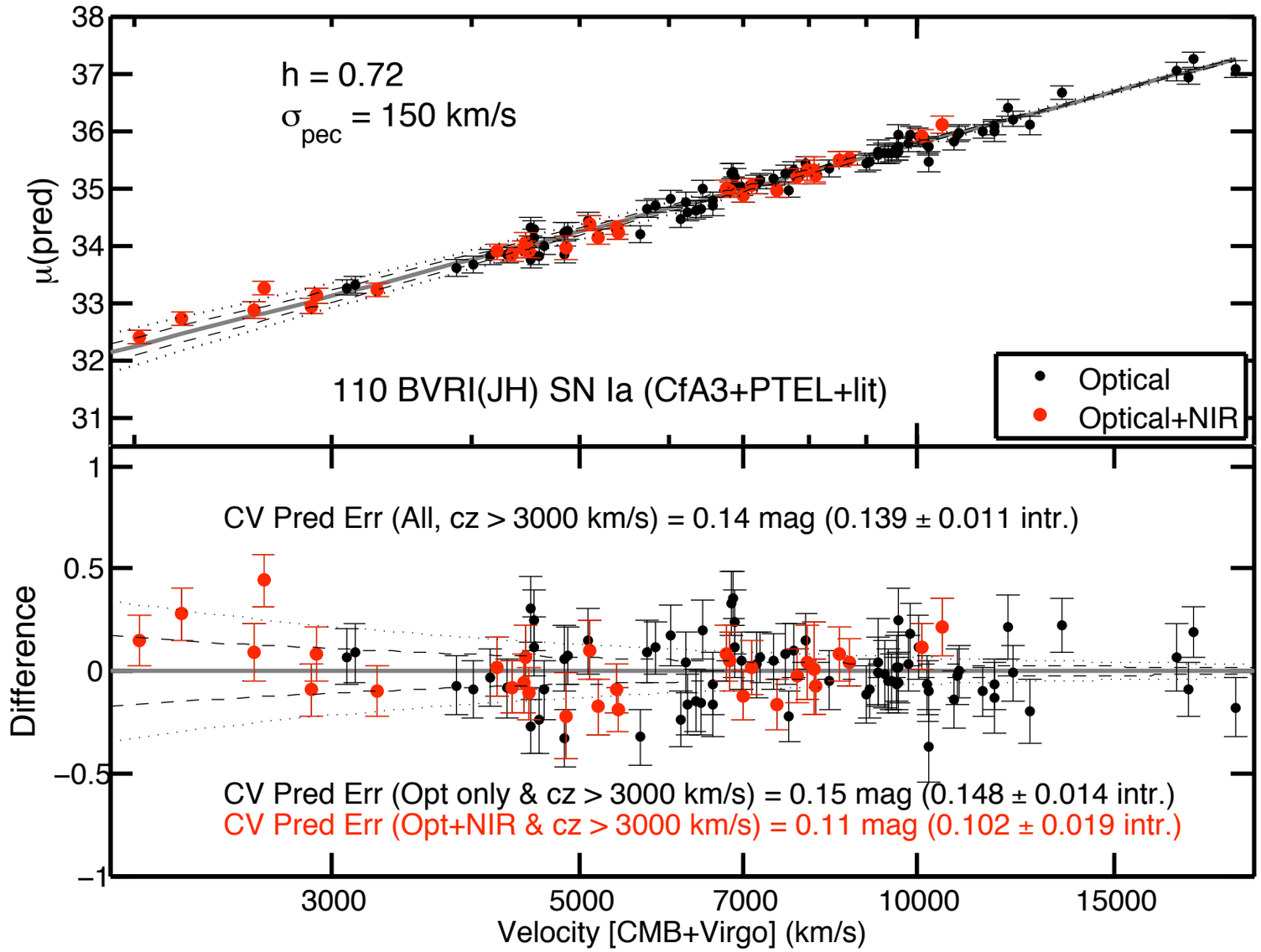




Nearby Optical+NIR Hubble Diagram



Cross-Validated Distance Predictions

(Opt+NIR) RMS Distance Prediction Error = 0.11 mag (5.5% in distance)

Summary

- Hierarchical models for SN Ia Light Curves, Dust, Distance
- BayeSN: MCMC for fitting hierarchical models for SN Ia
- SN Ia Optical+NIR: Constrain dust, predict distances better

References

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, 704:629-651

Mandel, K., G. Narayan, & R.P. Kirshner. Type Ia Supernova Light Curve Inference: Hierarchical Modeling in the Optical and Near Infrared. 2010, in prep.