Recent Results from the Nearby Supernova Factory

Stephen Bailey
LPNHE, Paris
for the Nearby Supernova Factory

Paris-Berkeley Cosmology Workshop 2009

(artist's concept)

G. Aldering[2], P. Antilogus[1], C. Aragon[2], S.B.[1], C. Baltay[3], S. Bongard[1], C. Buton[4], M. Childress[2], N. Chotard[4], Y. Copin[4], D. Fouchez[6], E. Gangler[4], M. Kowalski[7], S. Loken[2], P. Nugent[2], K. Paesch[7], R. Pain[1], E. Pecontal[5], R. Pereira[4], S. Perlmutter[2], D. Rabinowitz[3], G. Rigaudier[5], P. Ripoche[1], K. Runge[2], R. Scalzo[3], G. Smadja[4], H. Swift[2], C. Tao[6], R.C. Thomas[2], C. Wu[1] , J. Zylberberg[2]

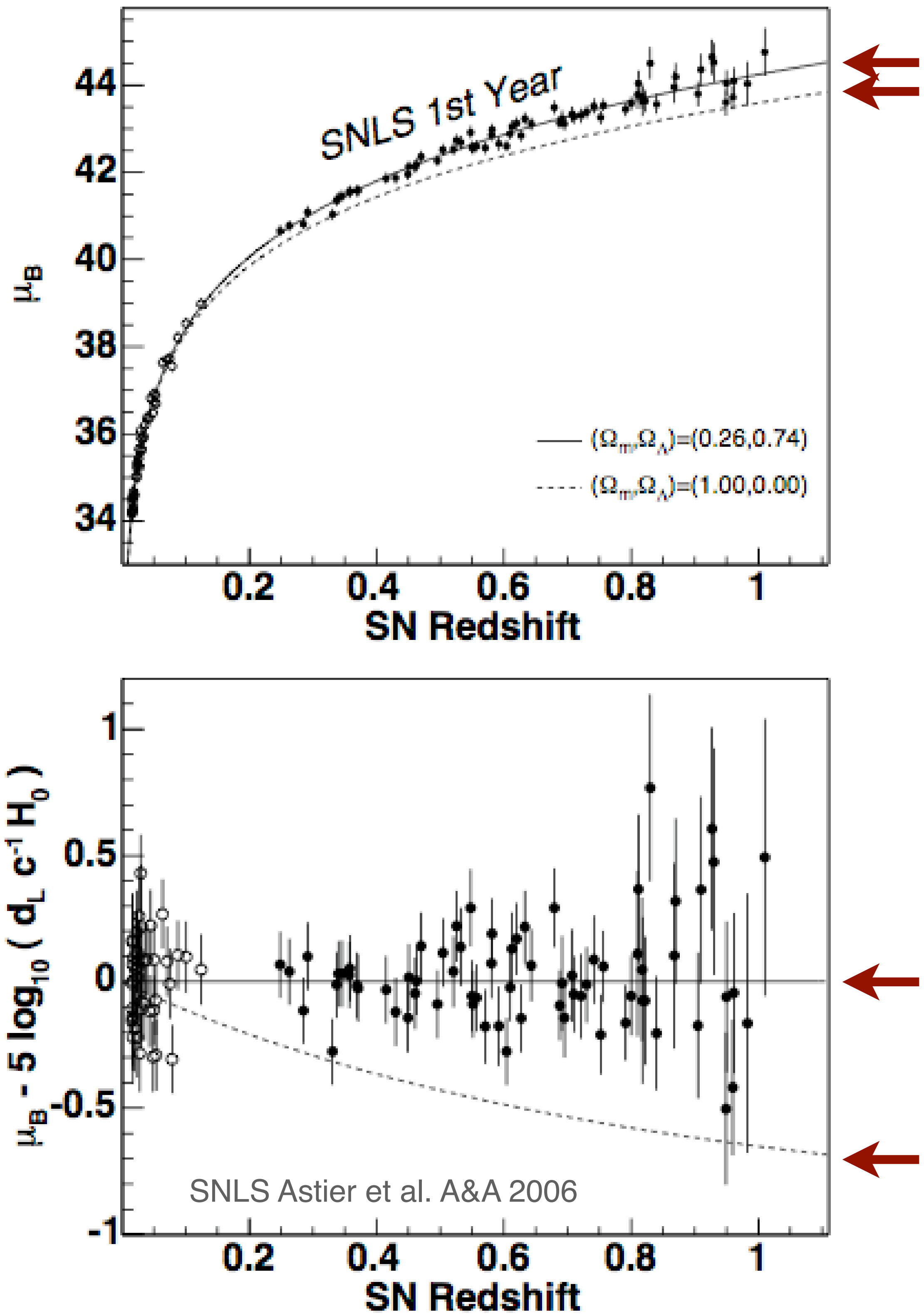
[1]LPNHE (Paris), [2]LBL (Berkeley), [3]Yale (New Haven), [4]IPNL (Lyon), [5]CRAL (Lyon), [6]CPPM (Marsaille), [4]Uni Bonn

Outline

- Why Nearby Supernovae?
  - Overview for non-SN folks
- The Nearby Supernova Factory
  - SN search
  - Followup instrument (SNIFS) and methodology
- Recent Results
- The Future

(artist's concept)

Why Nearby Supernovae?



- Cosmology differences are degenerate with absolute normalization of SNe Ia
- Low-z sample breaks this degeneracy
- Current systematics are limited by low-z sample and its intercalibration to high-z sample
  - Quality of current low-z data (esp. U-band)
  - Different filters and calibrations
  - SN models
  - Evolution
  - Bulk-flow and redshift range

Example Systematics

TABLE 8
SYSTEMATIC UNCERTAINTIES IN w FOR THE SALT–II ANALYSIS OF THE FwCDM MODEL, INCLUDING THE BAO+CMB PRIOR. +/− VALUES INDICATE ASYMMETRIC UNCERTAINTIES.

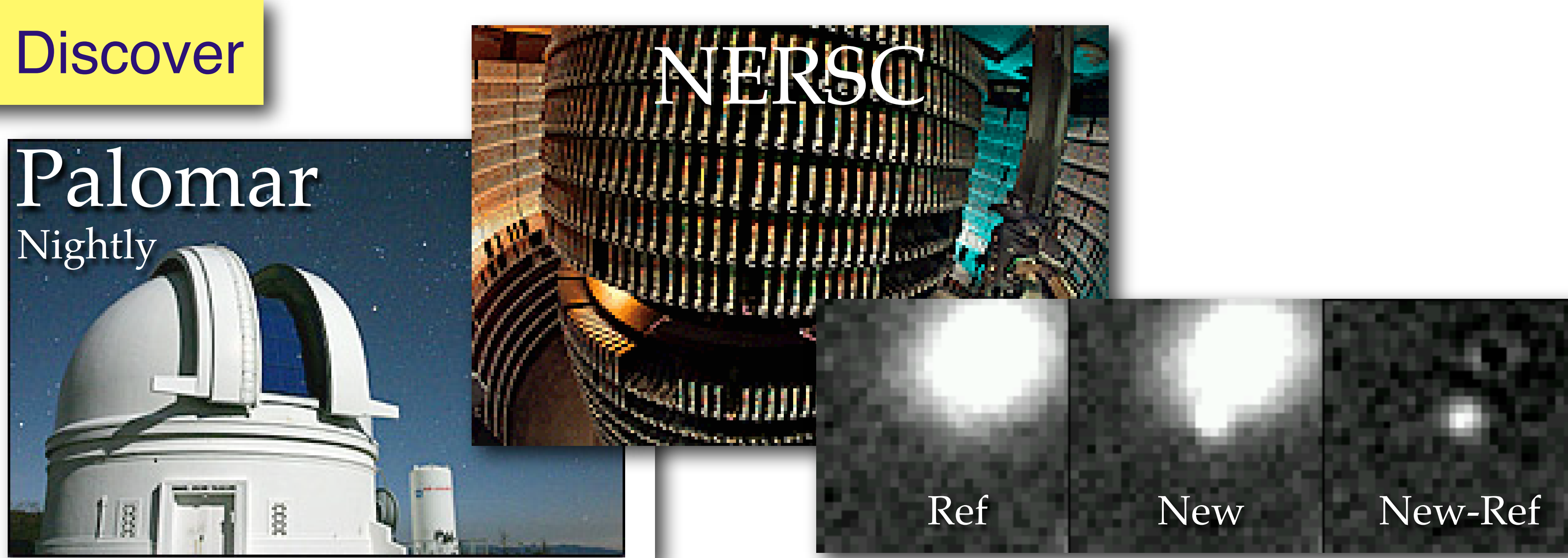
Source of Uncertainty	Uncertainty on w for Sample: a	b	c	d	e	f
Rest frame U-band	−0.100	0.104	−0.133	0.104	0.104	0.104
$z_{\rm min}$ cut for Nearby sample	0.050	0.030	0.050	0.030	0.030	0.030
Galactic Extinction	0.021	0.012	0.004	0.016	0.022	0.023
SALT–II SN Ia MODEL PARAMETERS						
retraining : include SDSS data	0.008	0.005	0.017	0.011	0.005	0.005
dispersions of SALT-II surfaces	0.001	0.003	0.002	0.006	0.006	0.004
β-variation with redshift	0.000	+0.073	0.000	+0.045	+0.013	+0.036
SELECTION EFFICIENCY						
simulated bias	0.020	0.011	0.009	0.002	0.001	0.012
CALIBRATION						
0.01 mag errors in U, B, V, R, I	0.029	0.030	0.027	0.022	0.020	0.022
shifted Bessel90 filters	0.000	0.000	0.015	0.010	0.008	0.013
vary SDSS AB offsets for g, r, i	0.018	0.037	0.031	0.015	0.016	0.000
vary ESSENCE $R - I$ color zeropoint	0.000	0.035	0.000	0.036	0.021	0.025
vary SNLS g, r, i, z zeropoints	0.000	0.057	0.000	0.046	0.030	0.043
vary HST zeropoints	0.000	0.000	0.000	0.000	0.015	0.000
Total	$^{+0.06}_{-0.12}$	$^{+0.15}_{-0.14}$	$^{+0.07}_{-0.15}$	$^{+0.13}_{-0.13}$	$^{+0.12}_{-0.12}$	$^{+0.13}_{-0.12}$

SDSS Kessler et al. (2009)

Fixable with a better low-z sample

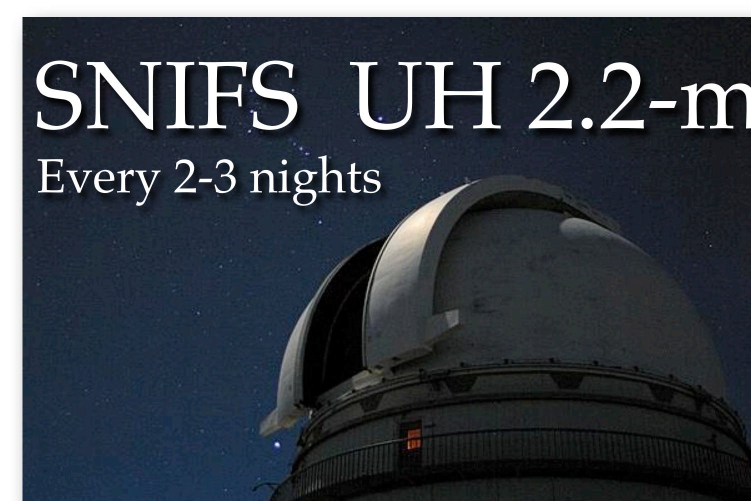
Nearby Supernova Factory

1. Discover



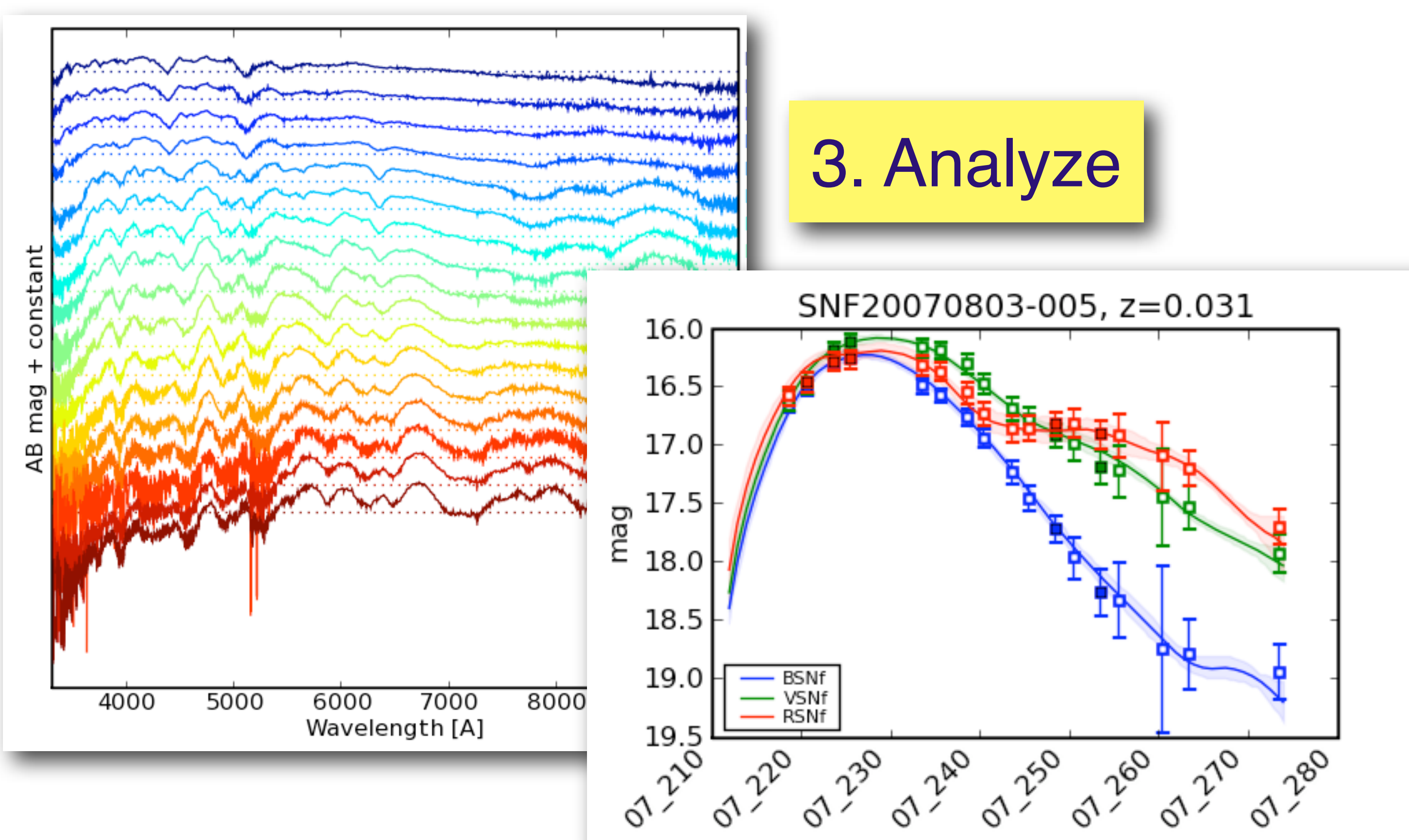
= ~10^{-7} of the area observed per night

2. Observe



Custom, unique spectrometer designed for nearby SN obs

3. Analyze

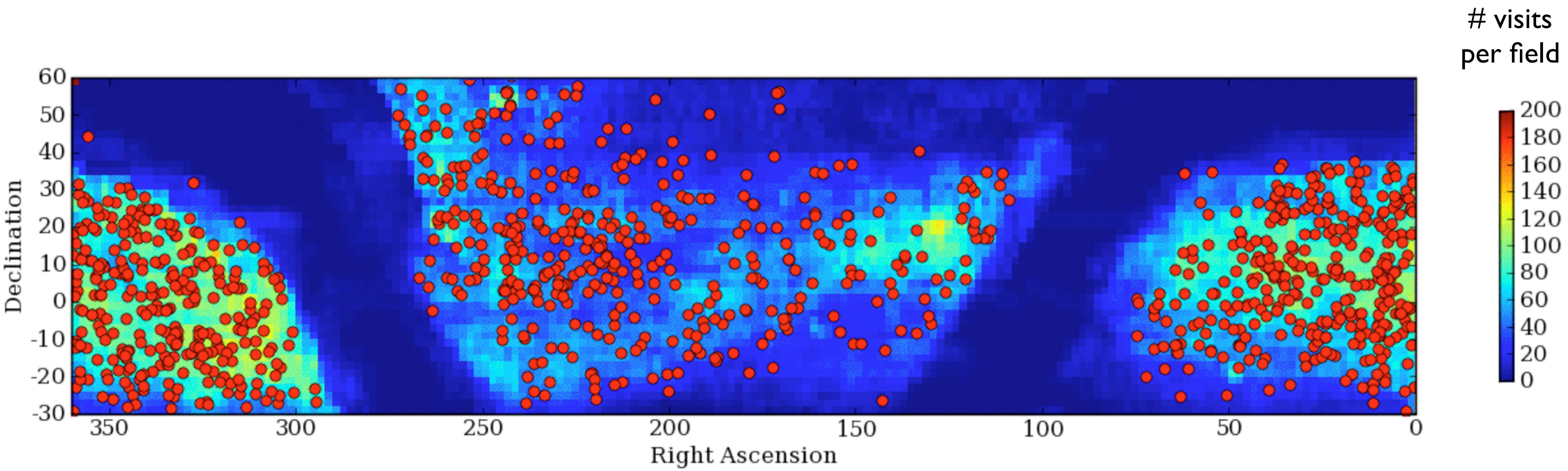


The Search

Image: Caltech Archives

- 28 months during 2005 – 2008
- Palomar Oschin 1.2m
  - 112 CCD QUEST-II camera
  - ~9 square degree field-of-view
  - Joint with asteroid / NEO searches
- Search low-z like high-z
  - Wide field impartial search
  - Representative distribution of host galaxy environments
- Pioneering work in large area, large data SN searches
  - PTF, PanSTARRS, LSST, ...
  - e.g. machine learning algorithms to identify SN candidates

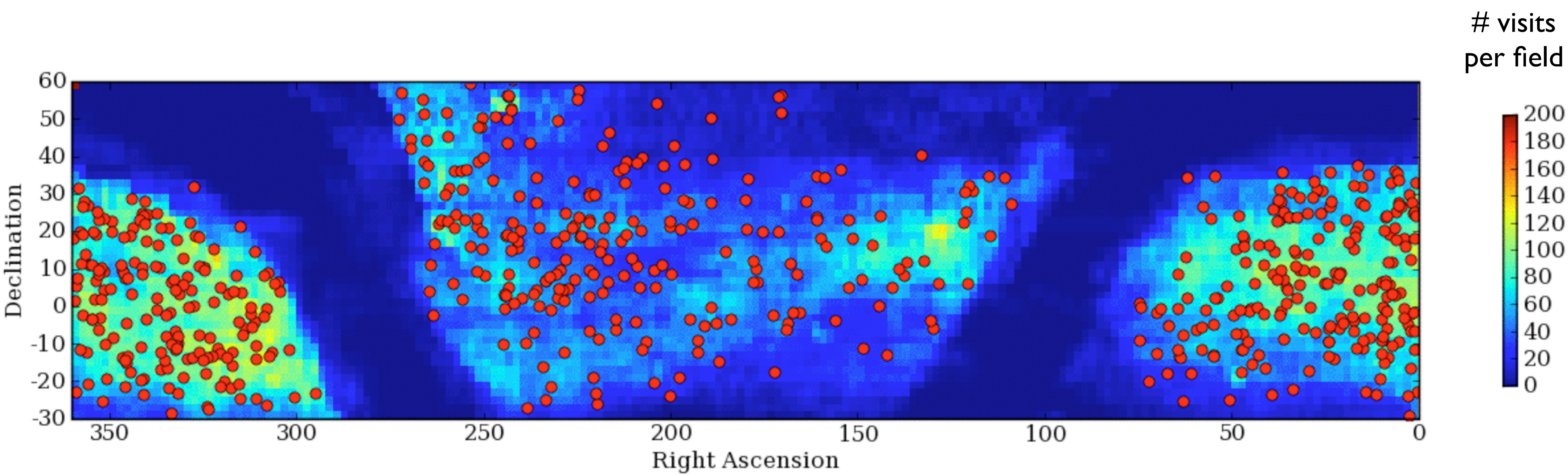
1000+ SN Discoveries



2π coverage

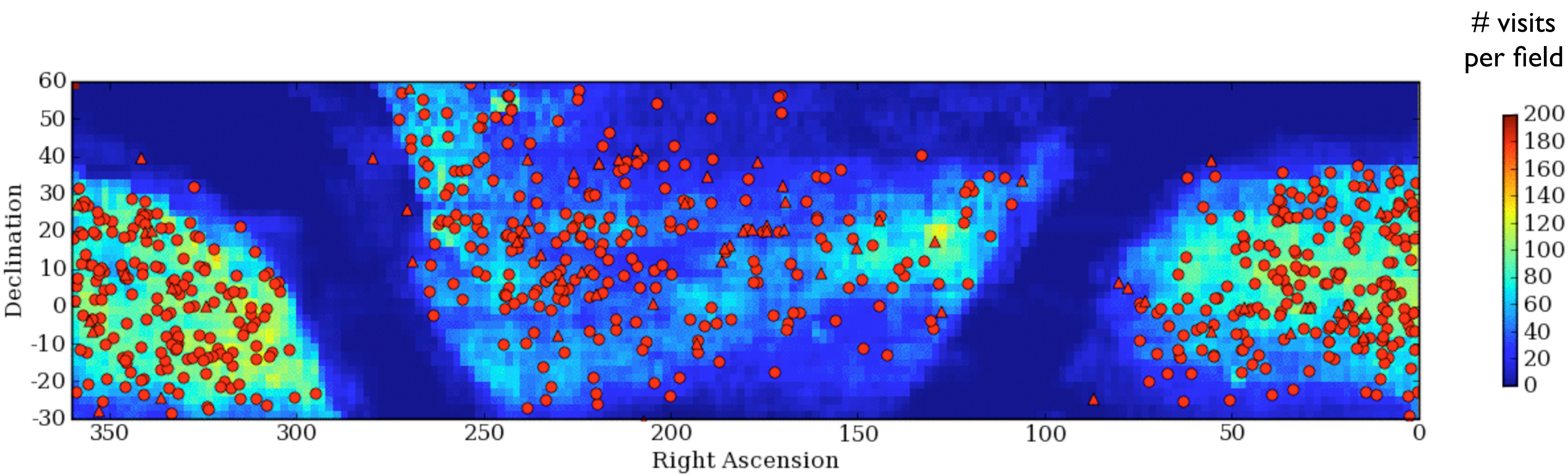
Over 1000 SN discoveries of all types

Classifications



	SNfactory	Others	Total
All Typed	**624**	71	695
SNe Ia	396	50	446
Follow-up	147	38	186
Processed	62	12	74

Classifications



	SNfactory	Others	Total
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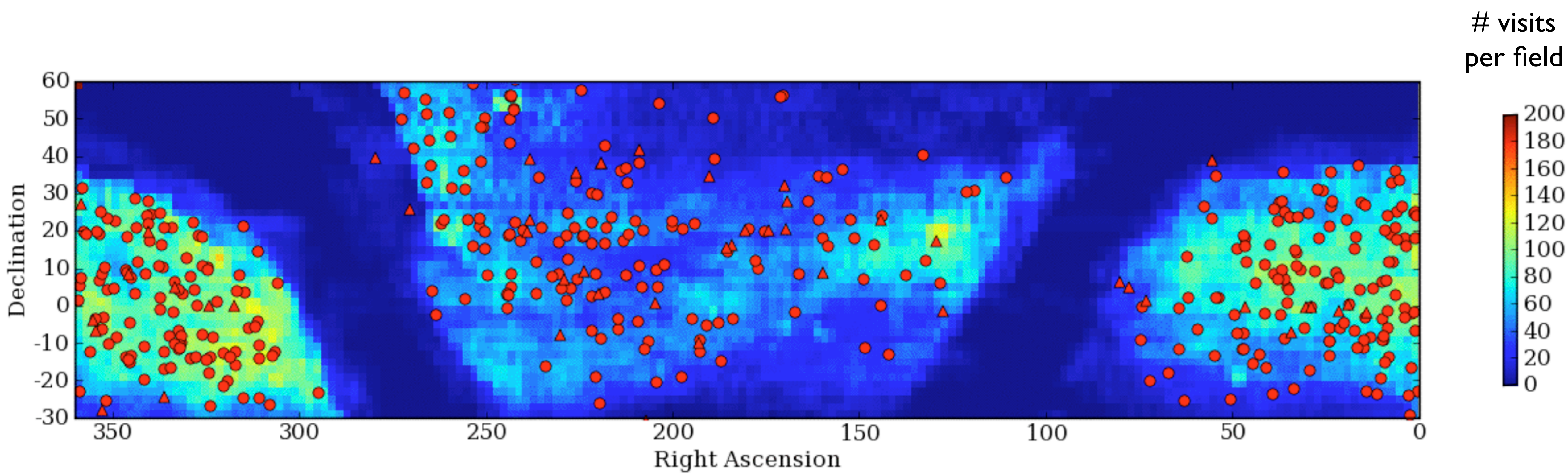
SNe Ia



	SNfactory	Others	Total
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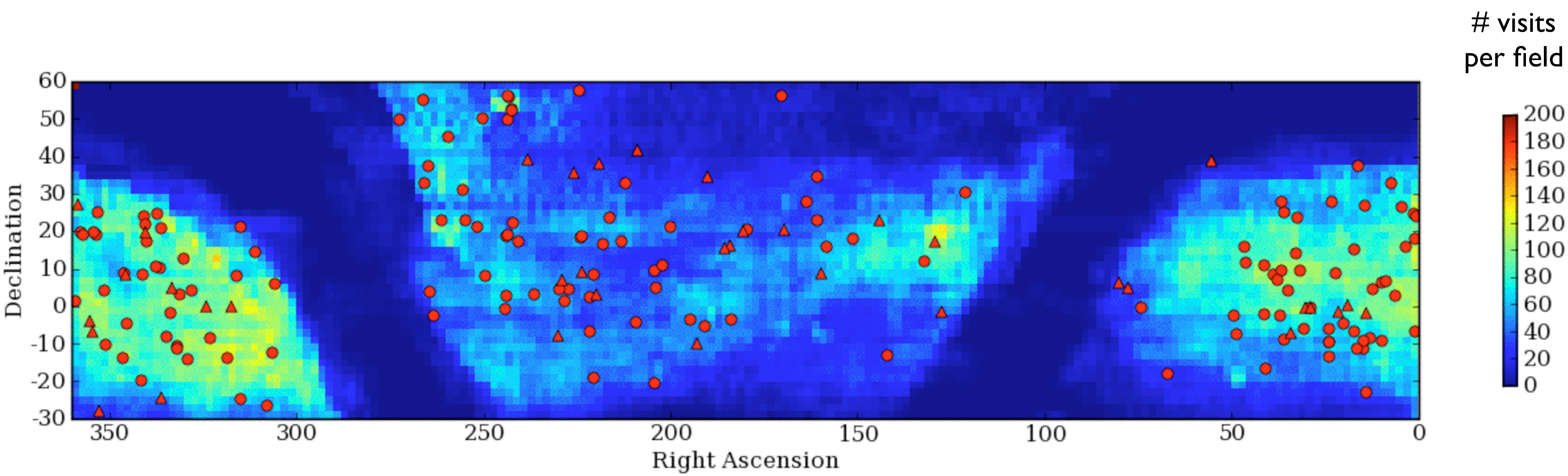
Detailed Followup



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All Typed	624	71	695
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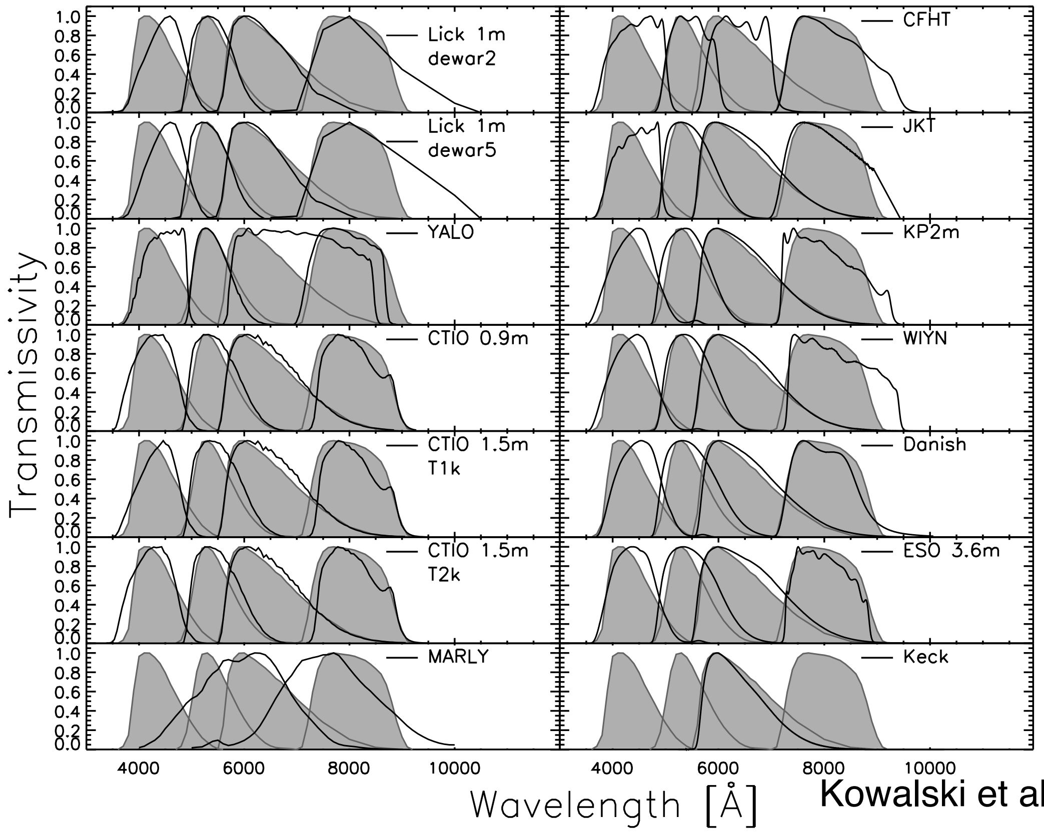
Followup Methodology

- Most SN programs:
  - Oriented toward broad-band photometry
  - Some spectroscopy, mainly for redshift and confirming Type Ia
  - Difficulties:
    - Inter-program calibrations (different filters and redshift coverage)
    - Model building with sparse non-flux calibrated spectra
- New Paradigm:
  - Flux-calibrated spectra = spectrophotometry
  - Spectrophotometry at every epoch
  - Benefits
    - Synthesize any filter/redshift range you want
    - Dense sample of spectra for model building and understanding SNe

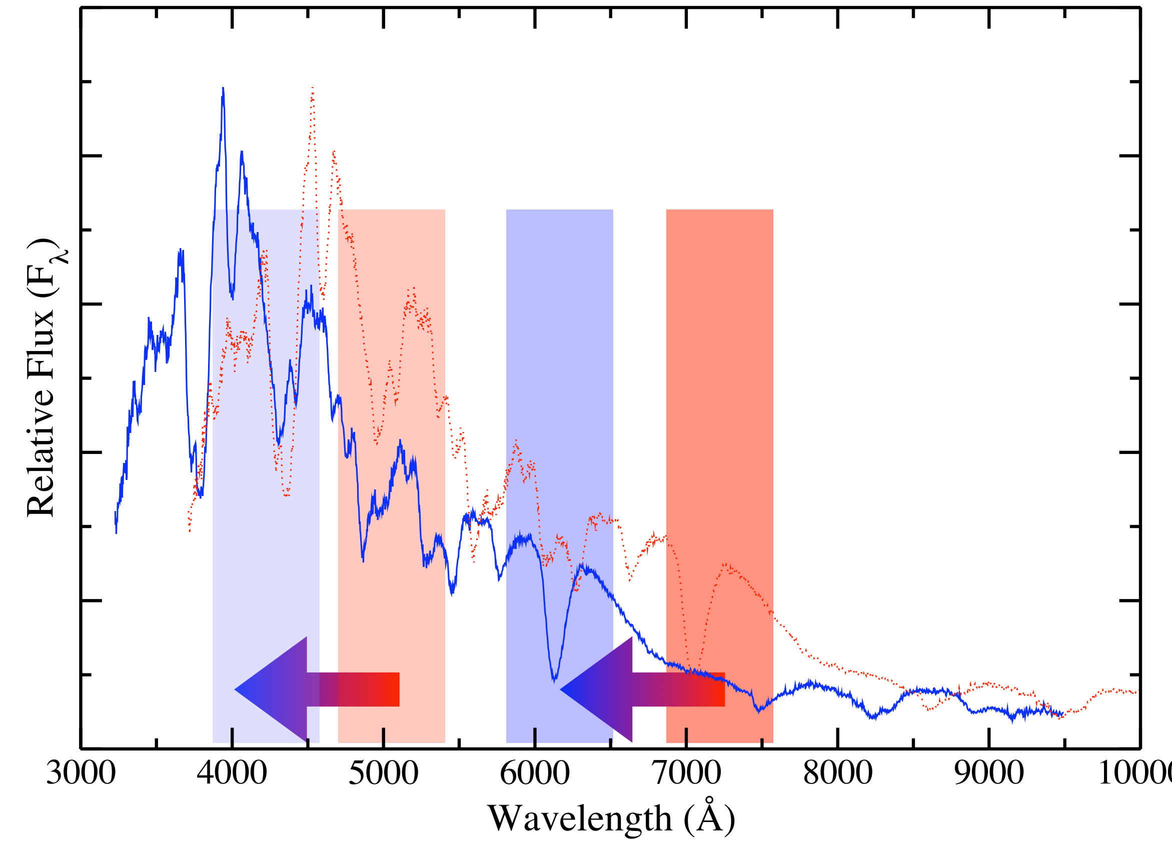
Motivations for Spectrophotometry

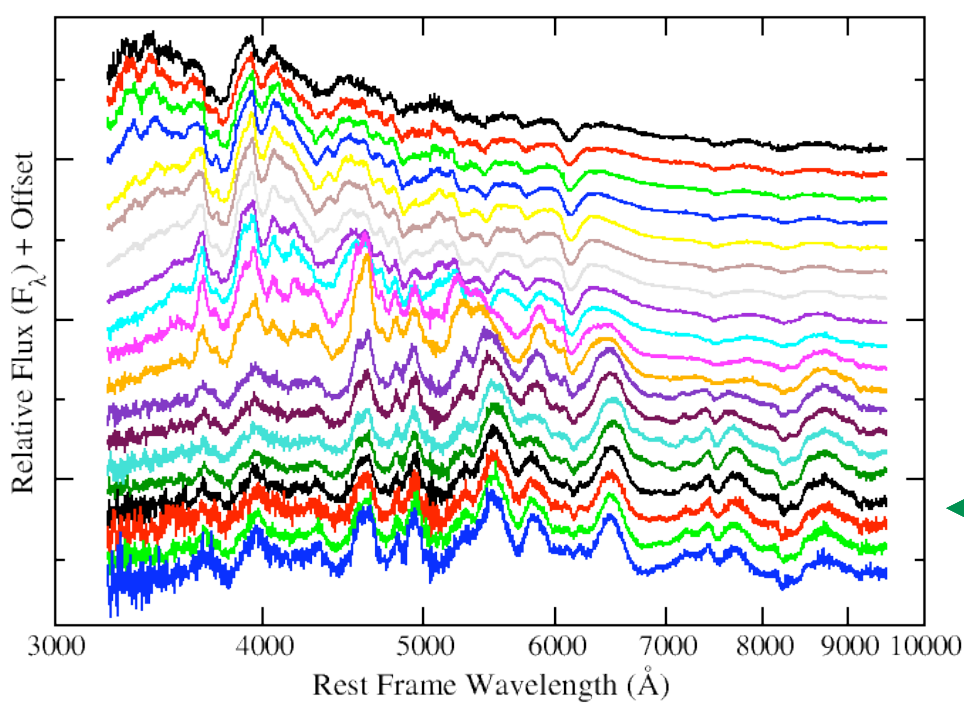
S-corrections



Kowalski et al 2008

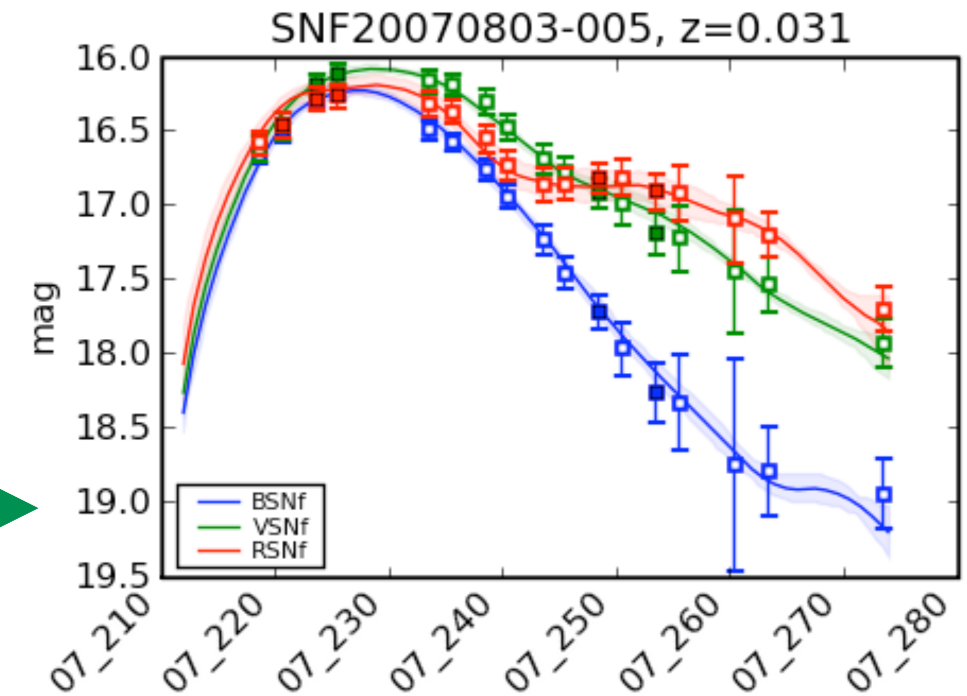
K-corrections





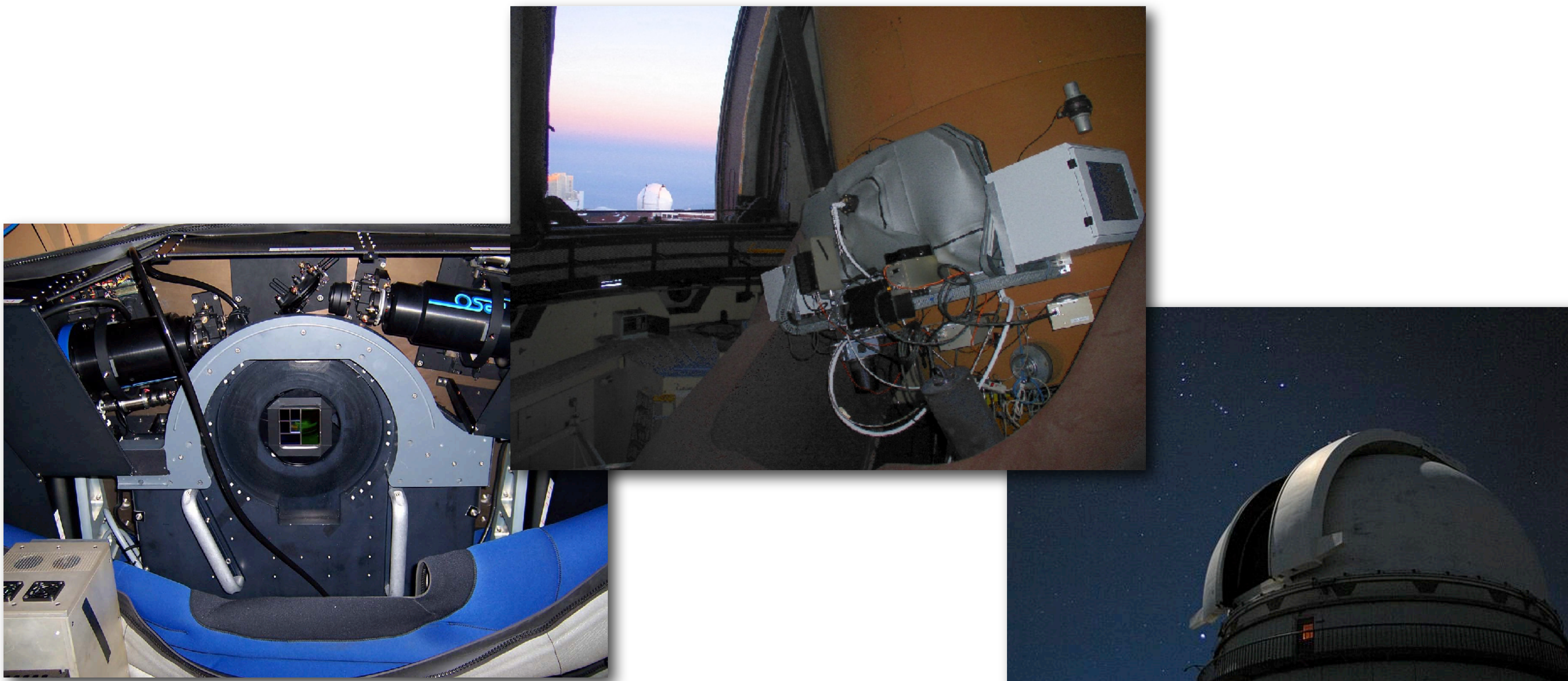
Info for models etc.

vs



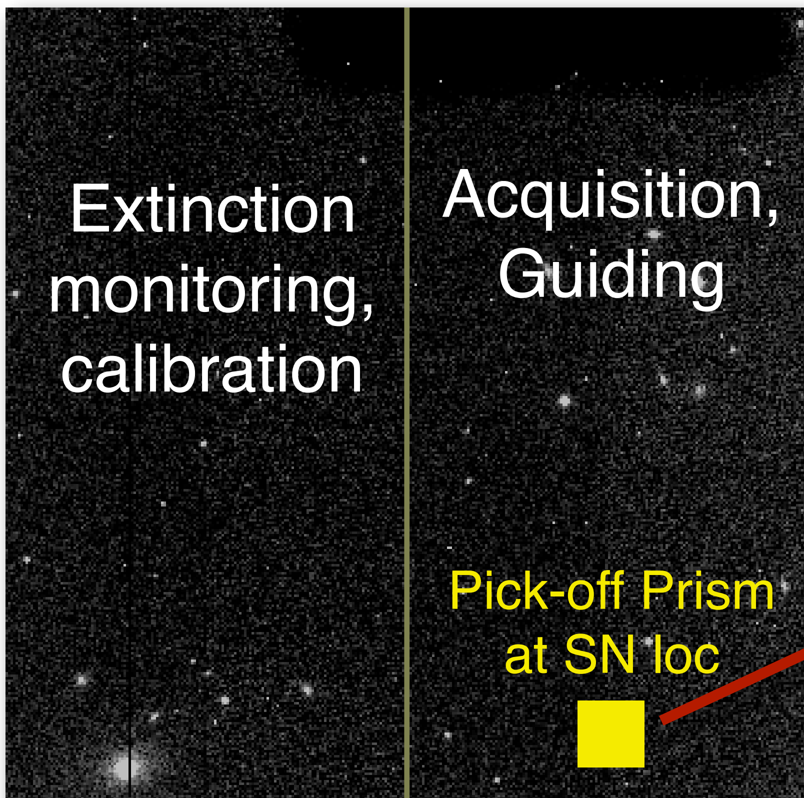
Followup Instrument

- SNIFS: SuperNova Integral Field Spectrometer
- Custom designed and built by SNfactory for nearby SNe
- Remotely operated every 2-3 nights
  on UH 2.2m on Mauna Kea



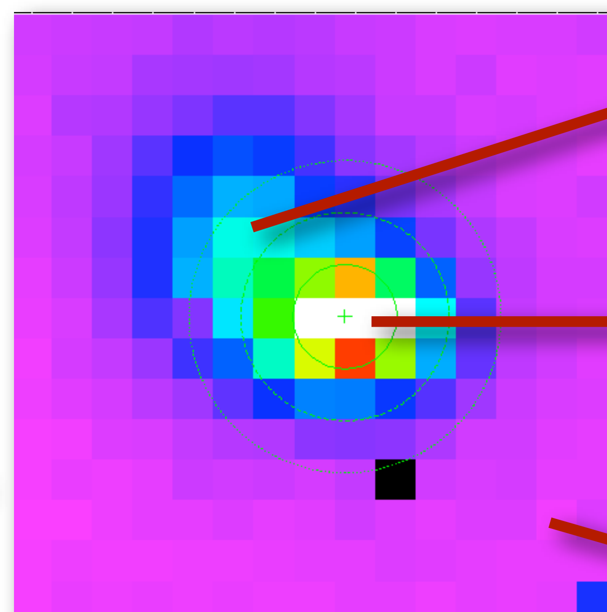
SuperNova Integral Field Spectrometer (SNIFS)

Photometric Channel



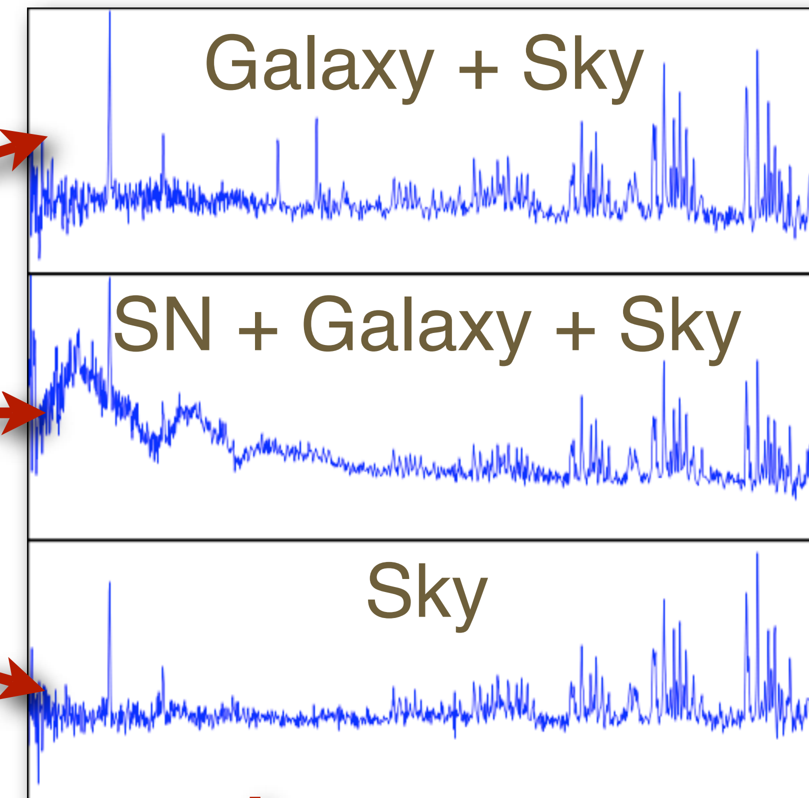
9.4' x 9.4' FOV; 0.14"/pix

Microlens array to two channel spectrograph 15x15 = 225 spectra

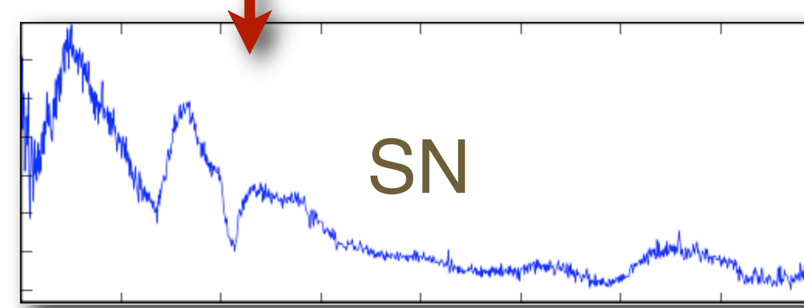


6" x 6" FOV; 0.4"/spaxel

R channel:



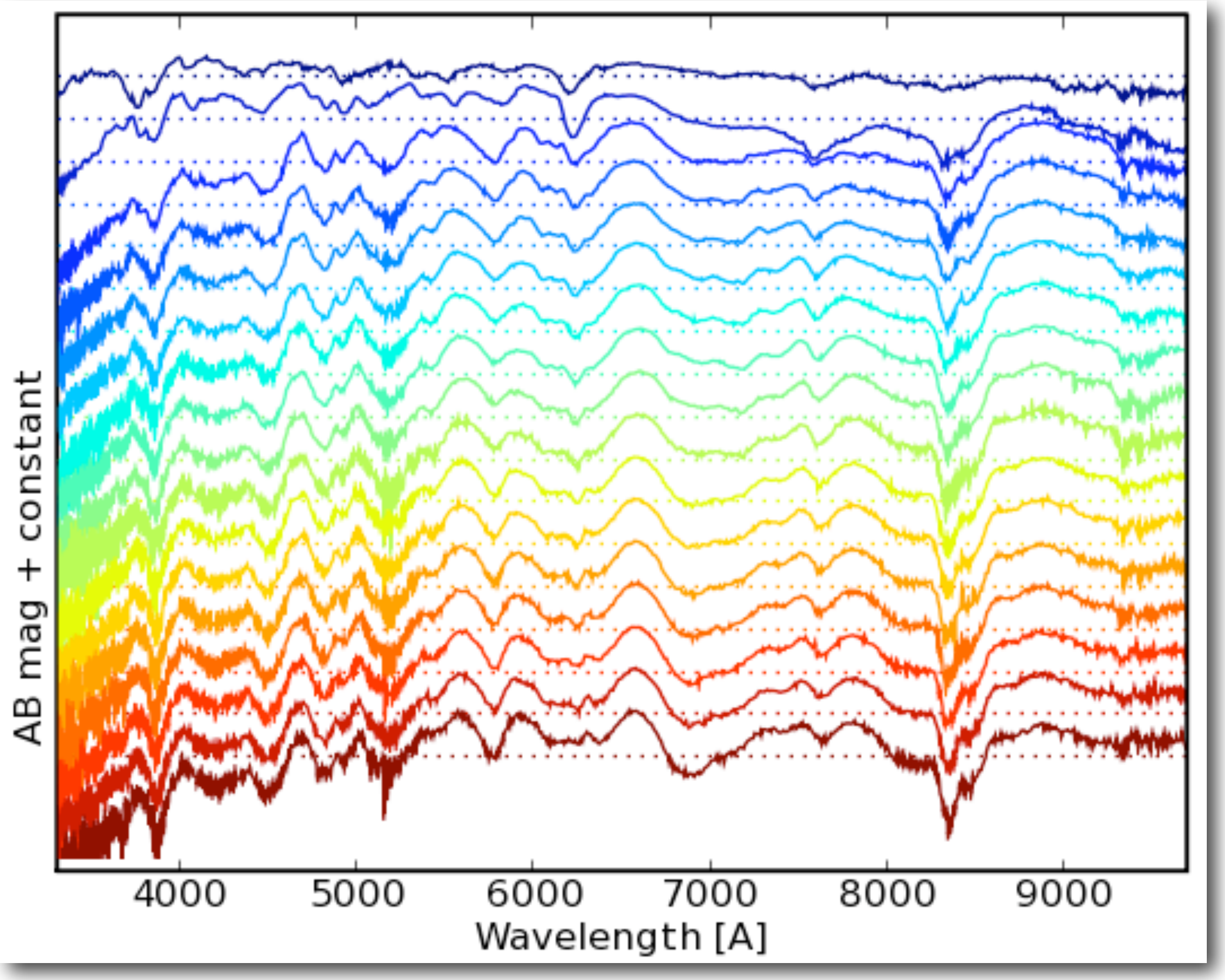
Hard work...



Every obs: flux calibrated spectra,
320 – 520, 510 – 1000 nm coverage

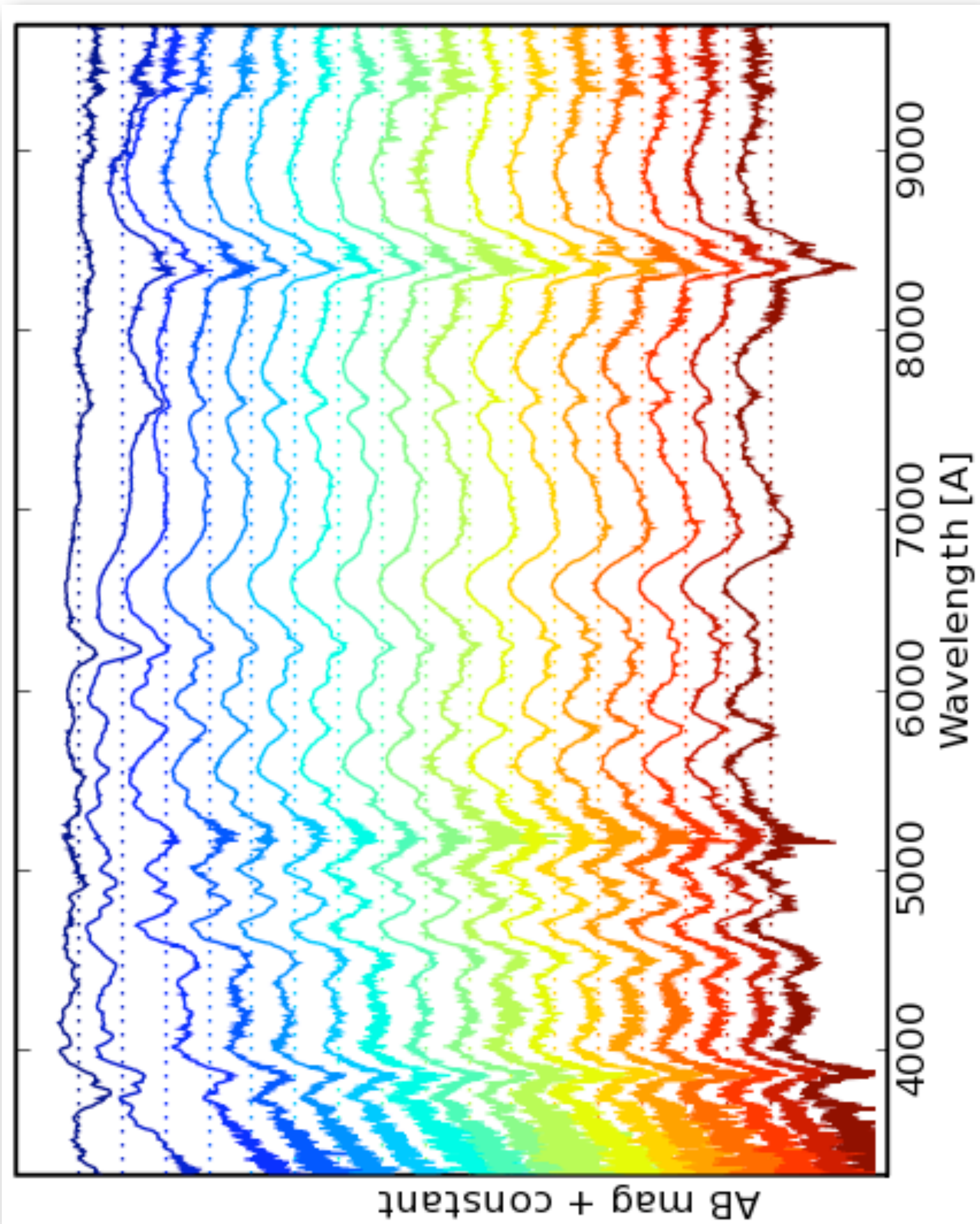
On UH 2.2m on Mauna Kea;
SNfactory every 2-3 nights for ~9 months/year

From Spectra to Lightcurves



Slides: Rui Pereira

From Spectra to Lightcurves



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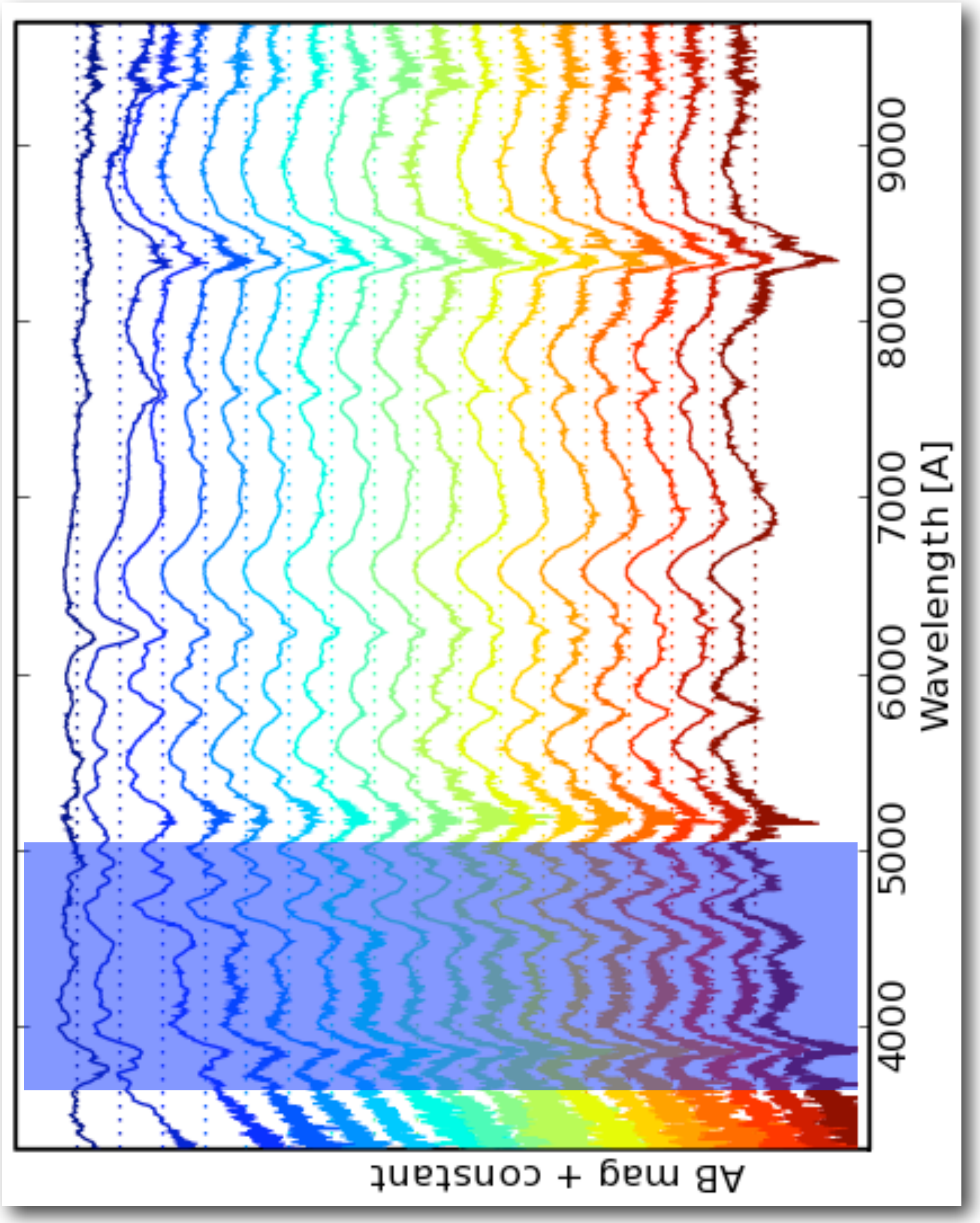
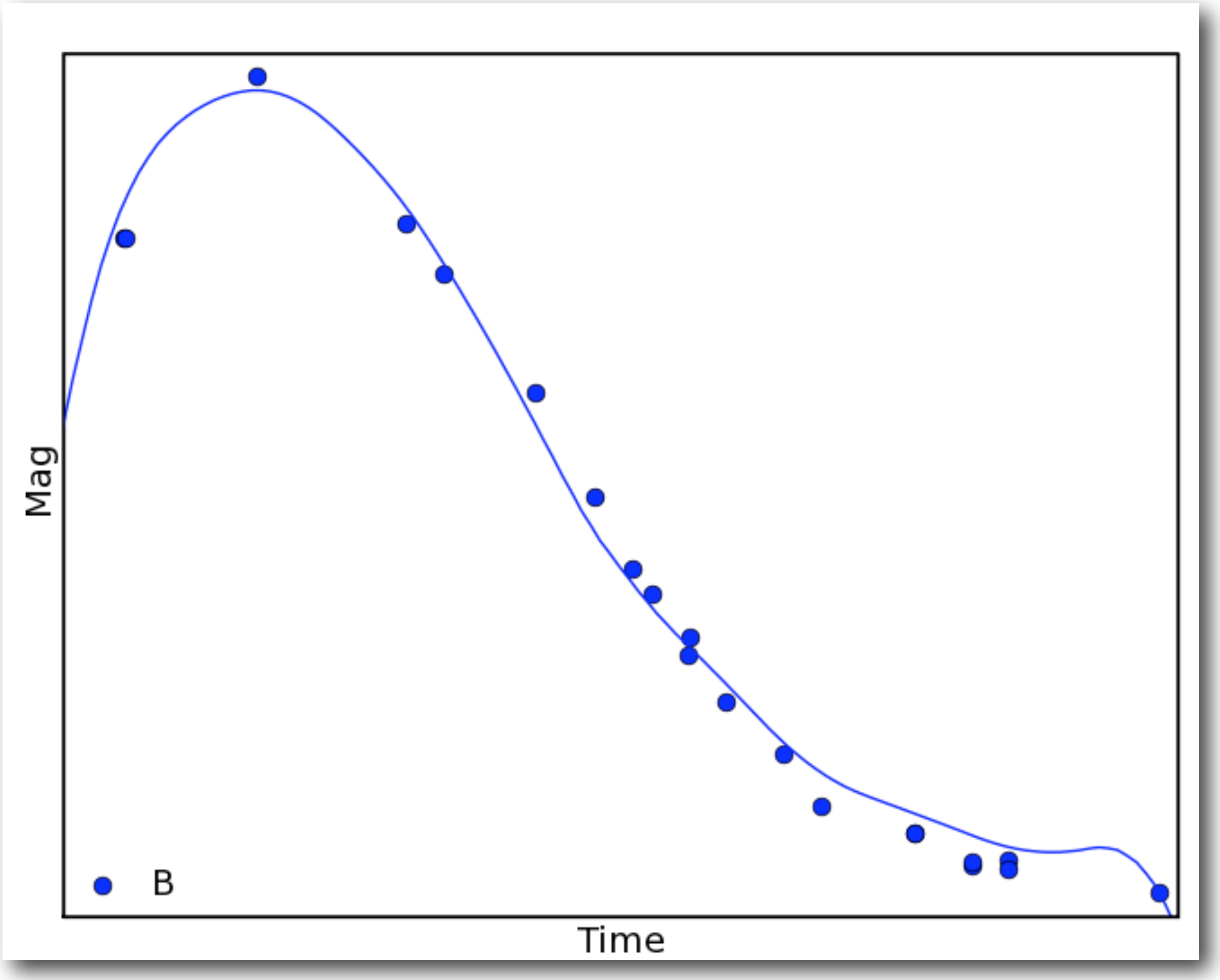
From Spectra to Lightcurves





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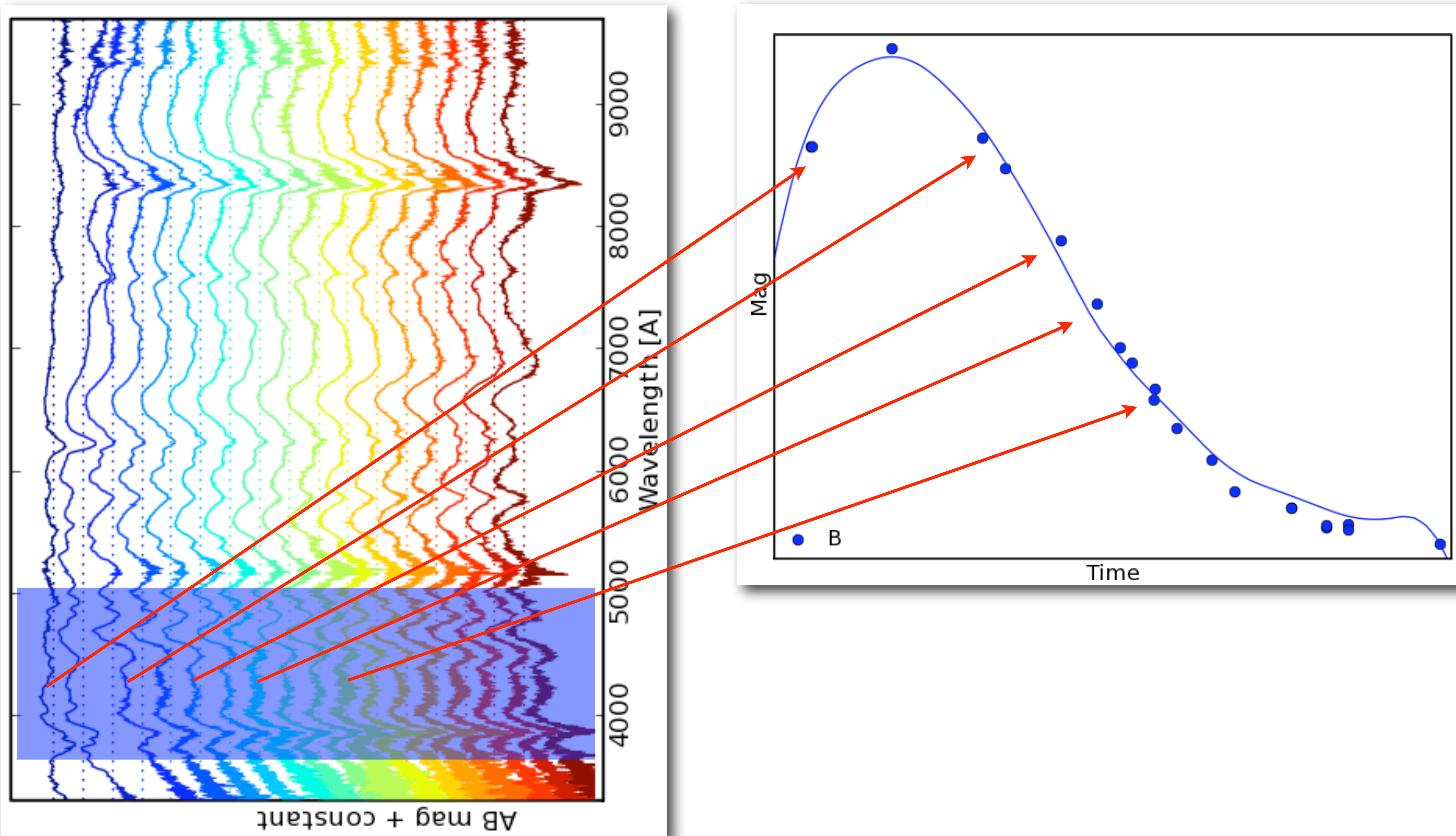

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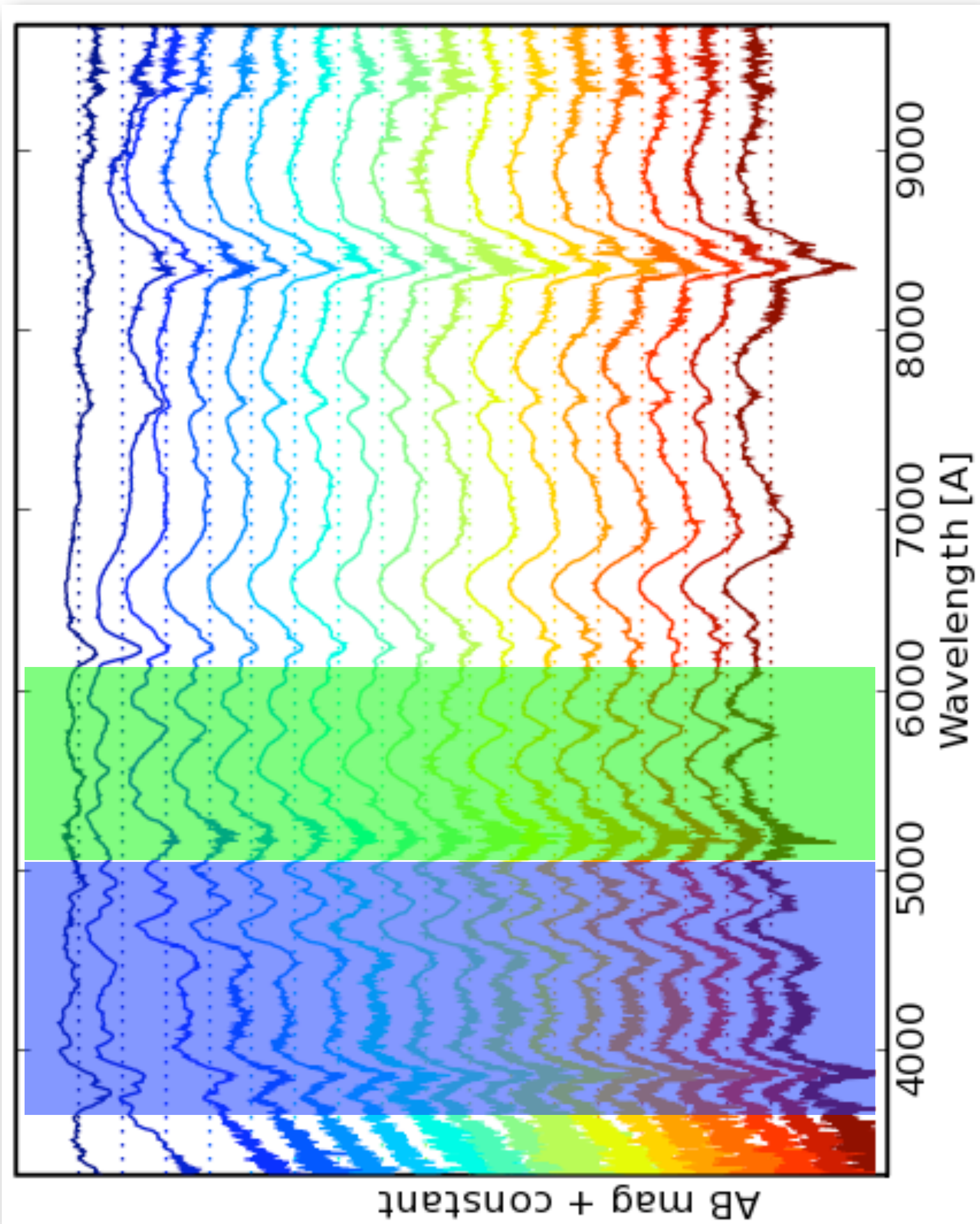

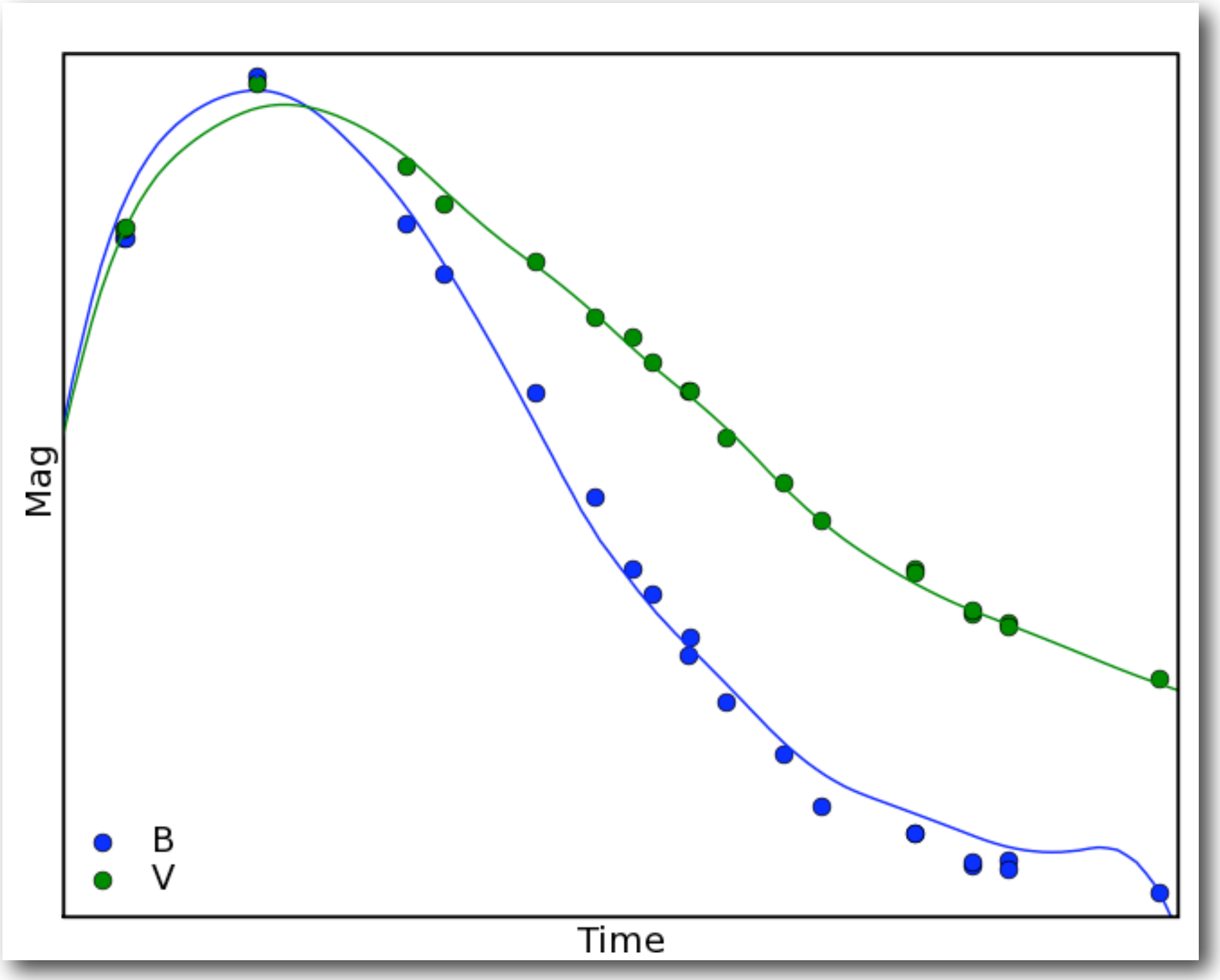

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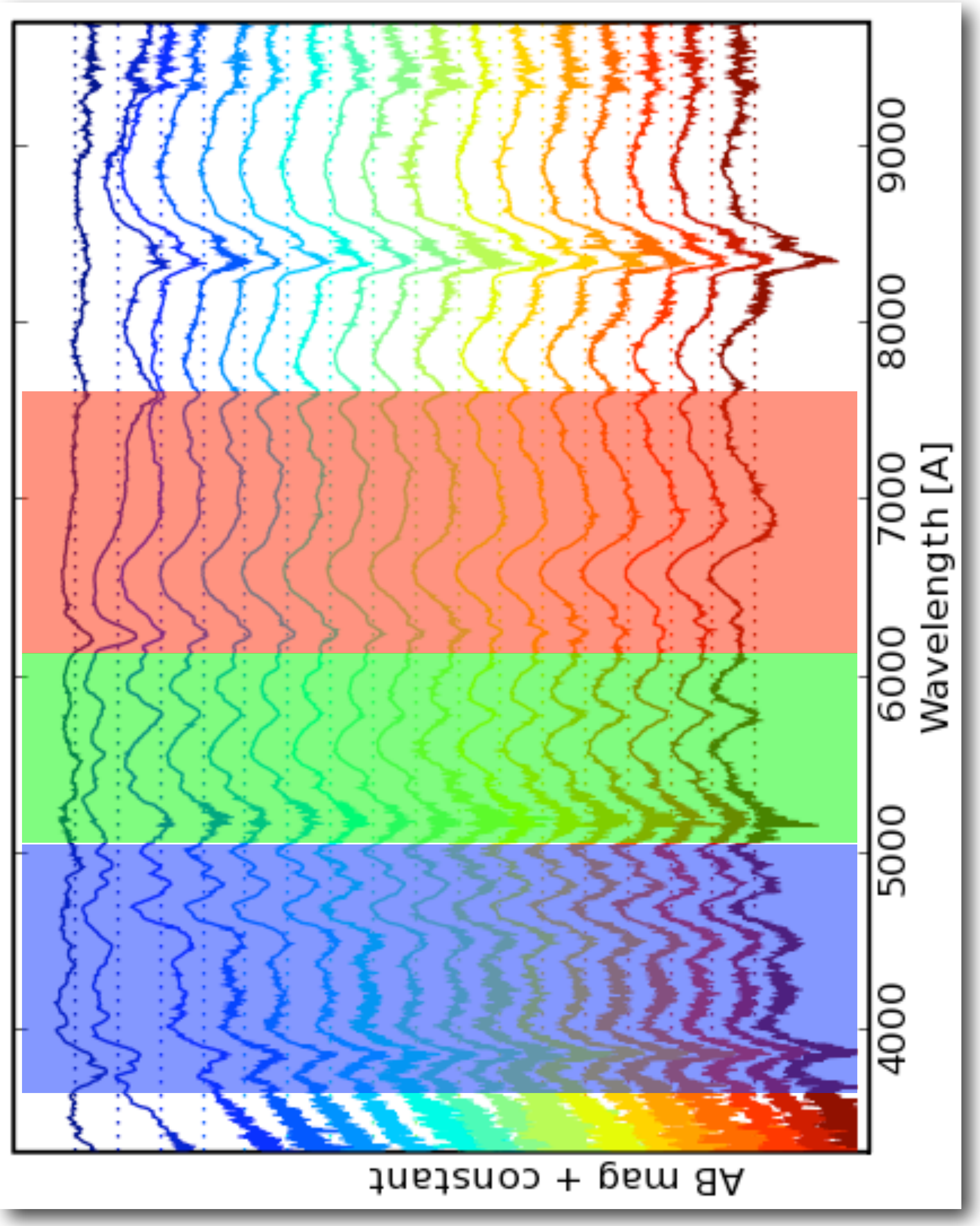

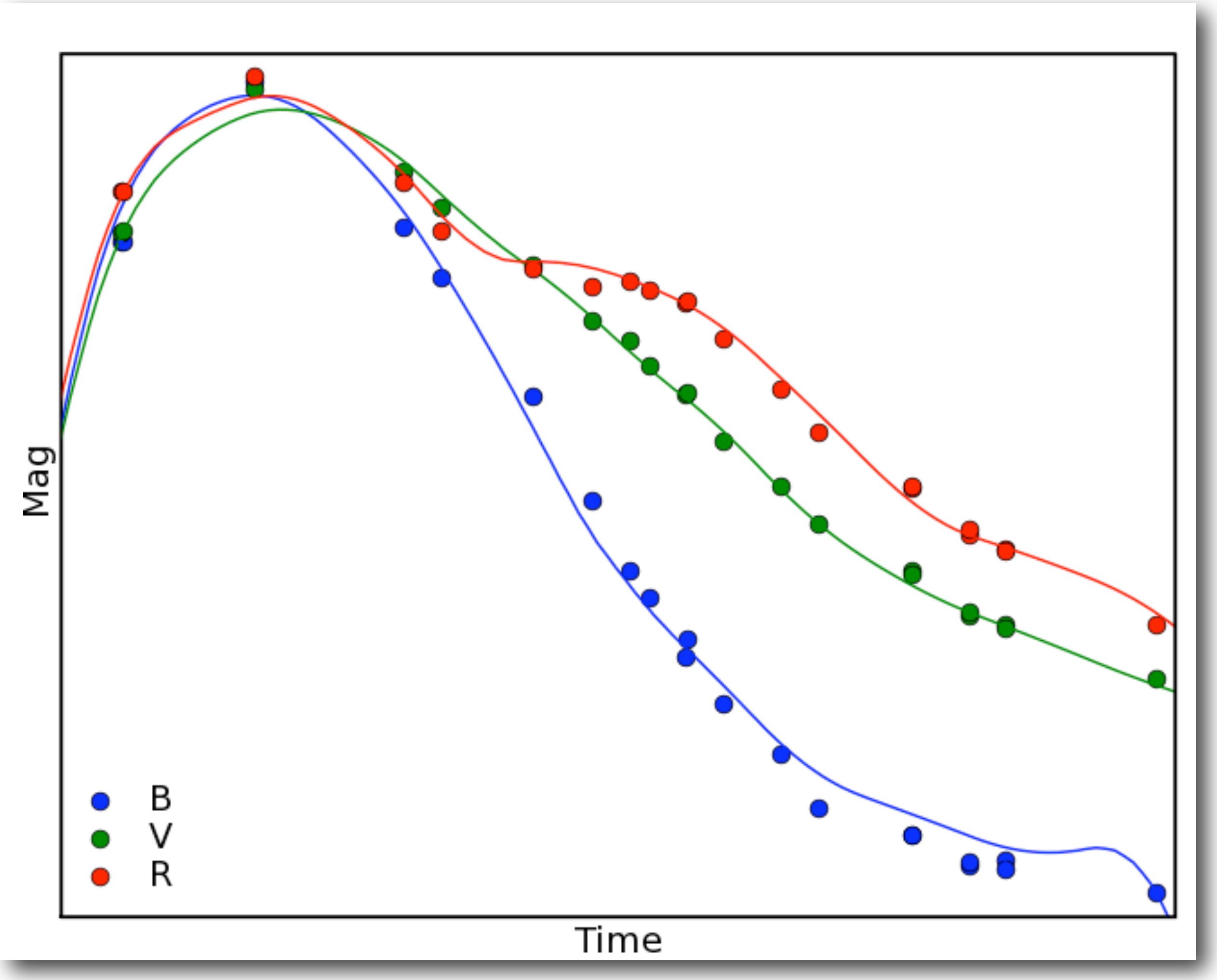

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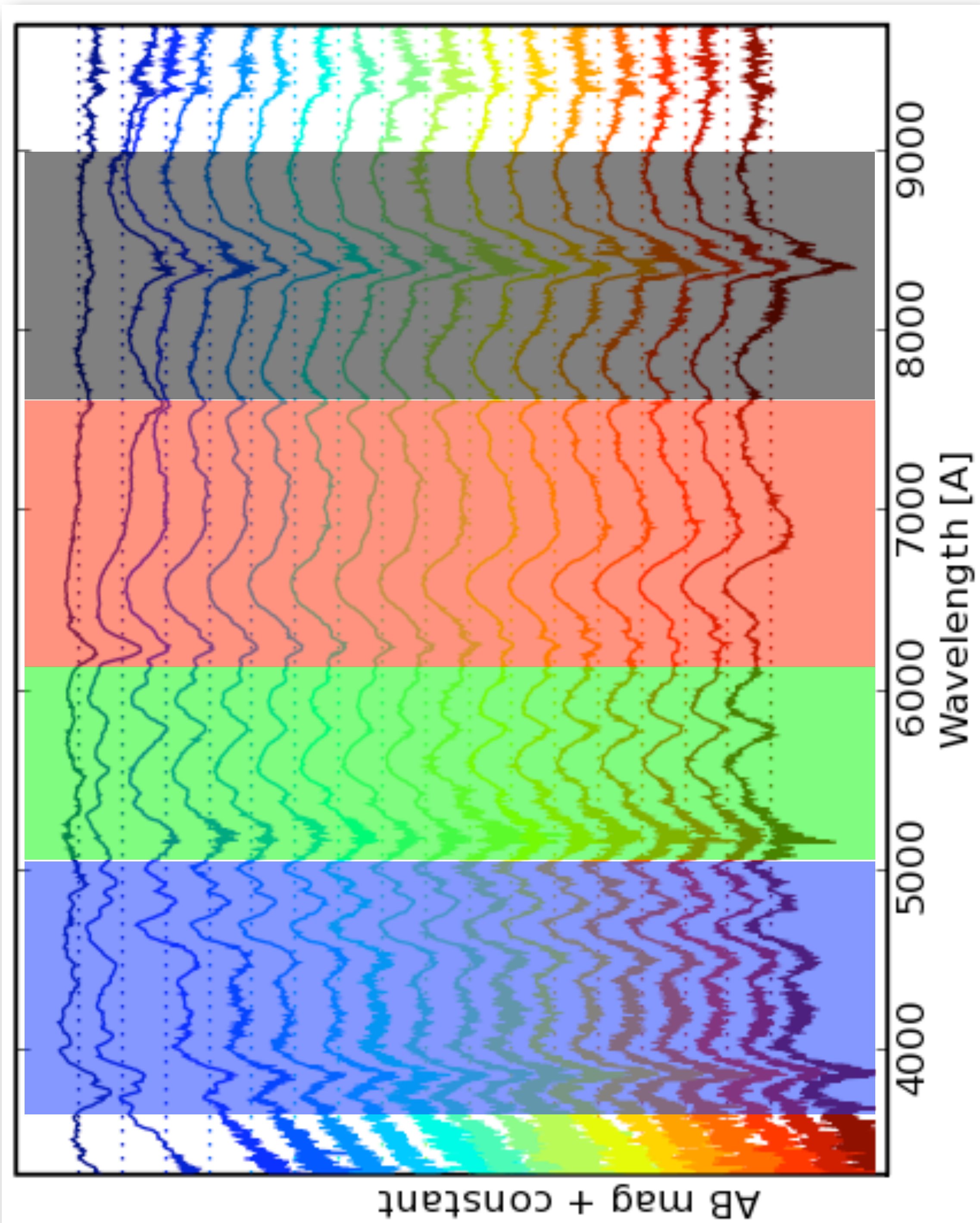
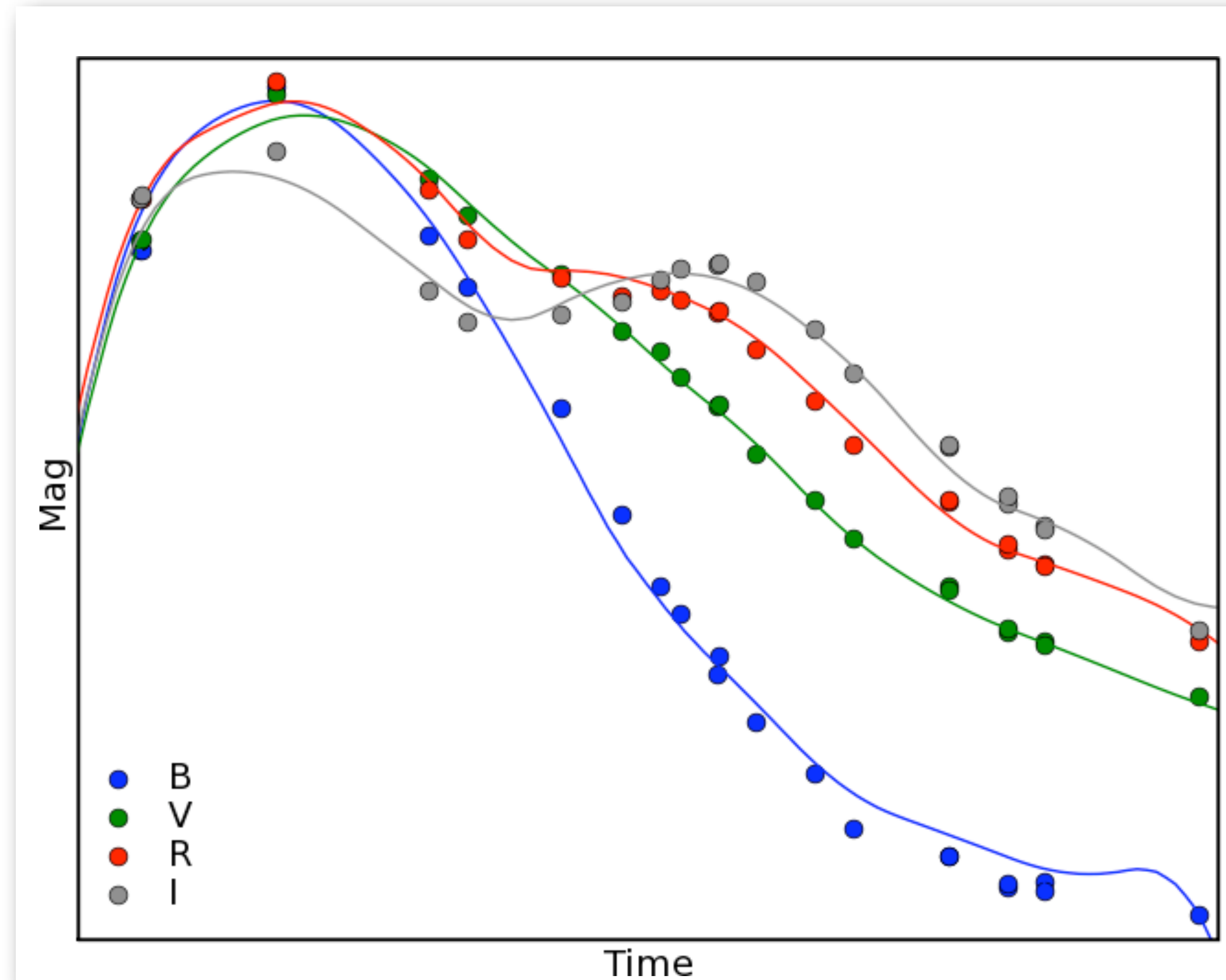
From Spectra to Lightcurves





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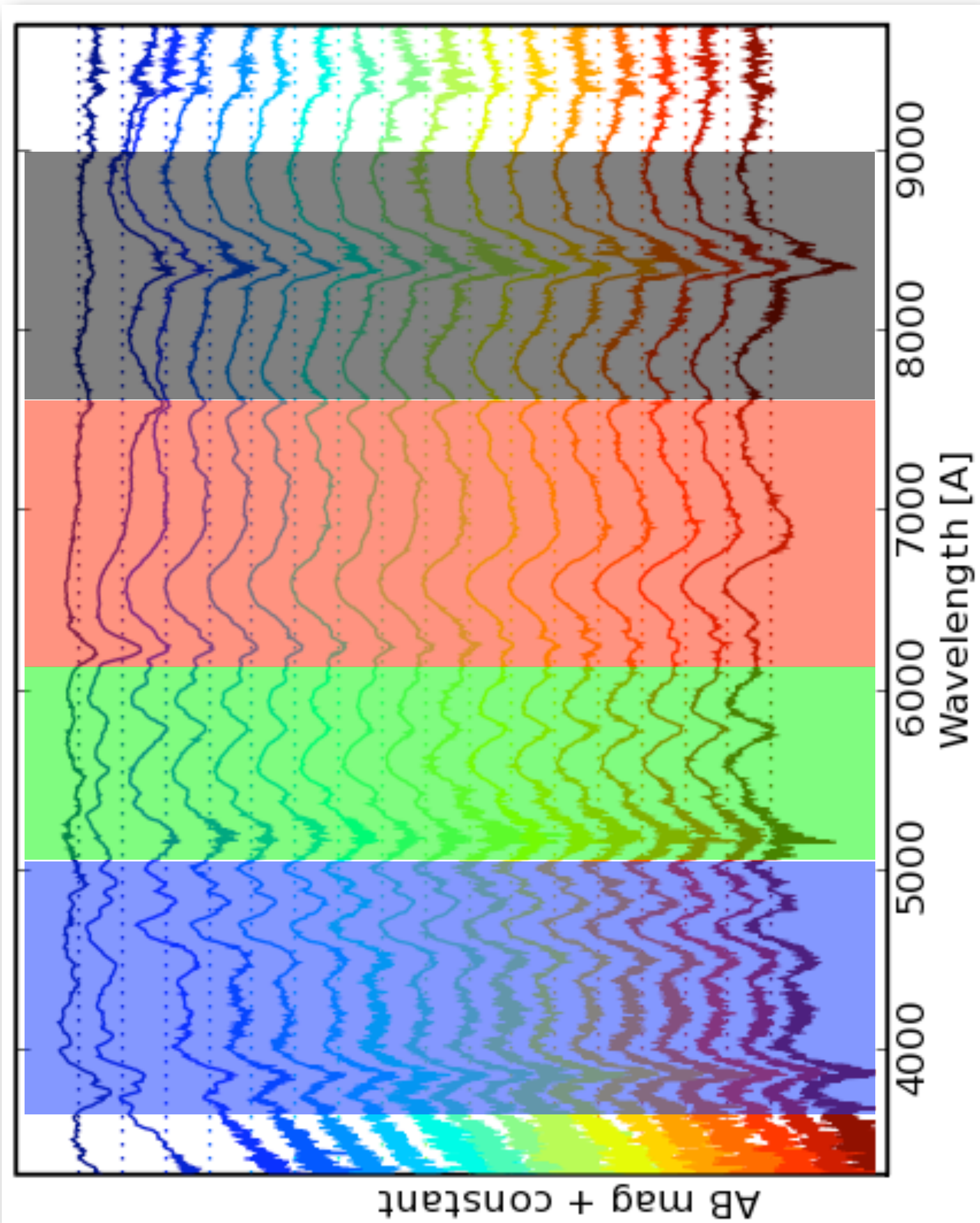
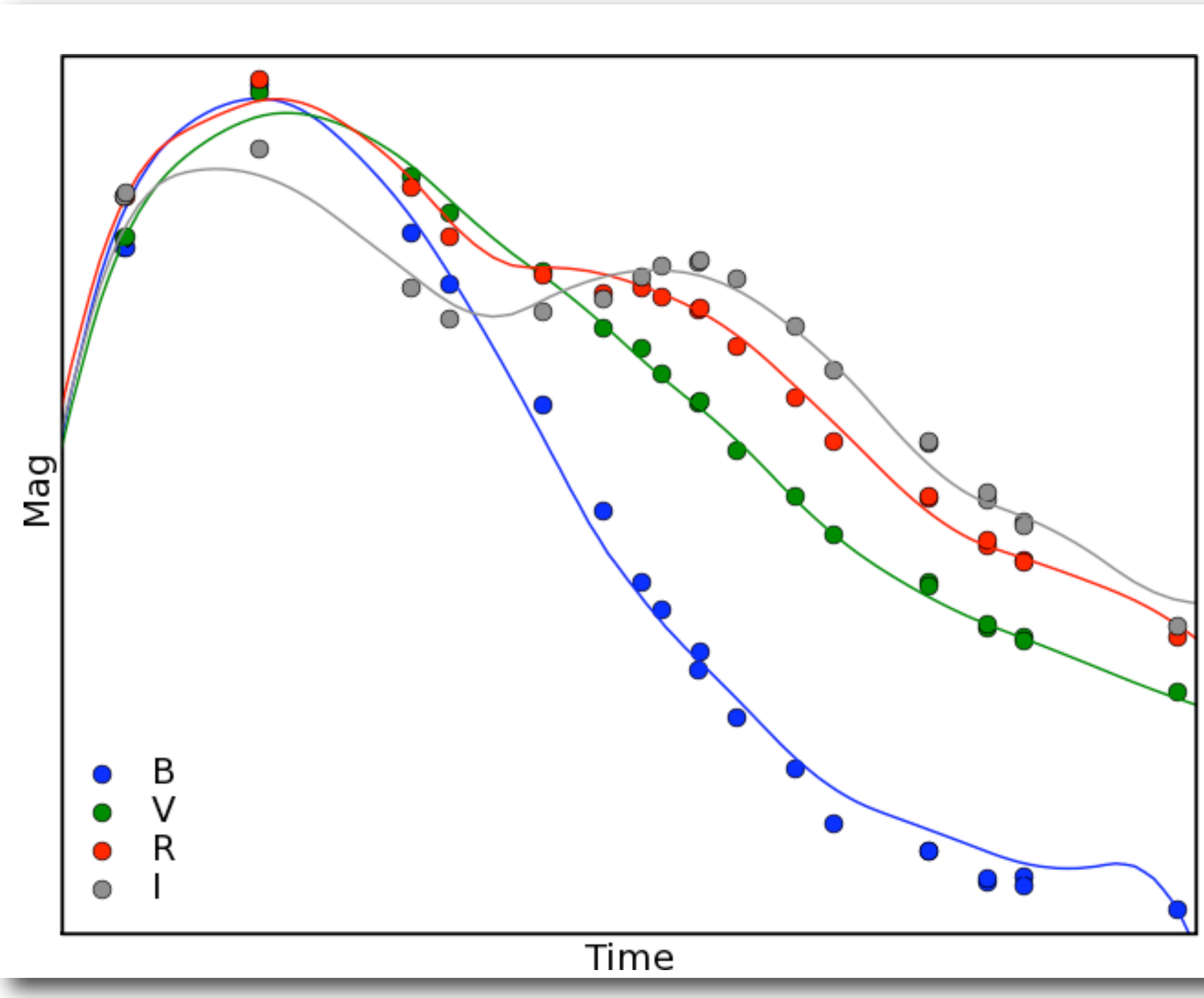
From Spectra to Lightcurves



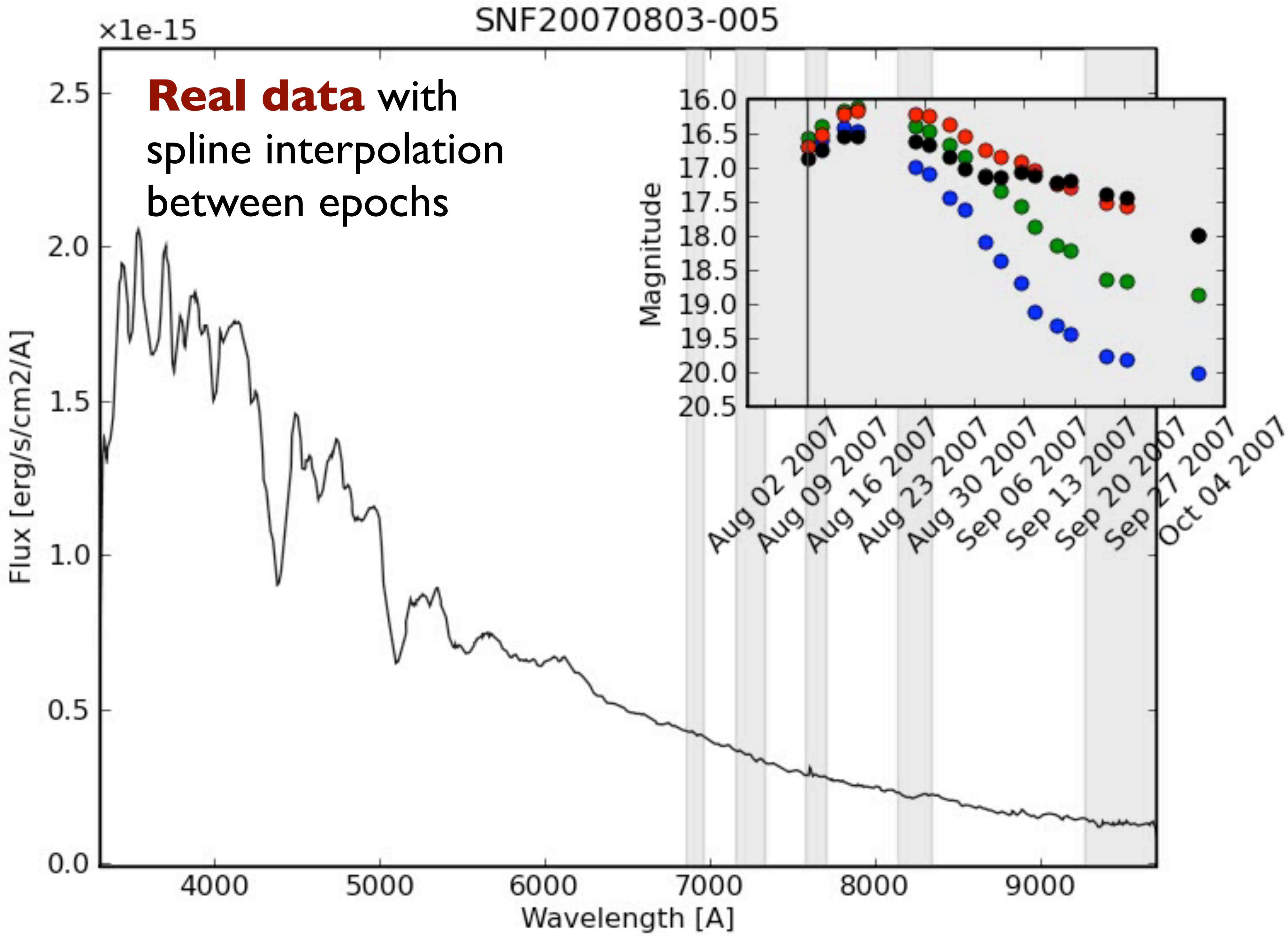


- One spectrum per point / night
- Synthesizable in any filter
- Lightcurves + spectral features

Slides: Rui Pereira

Each SN: Spectral Timeseries

Real data with spline interpolation between epochs



Animation: Yannick Copin

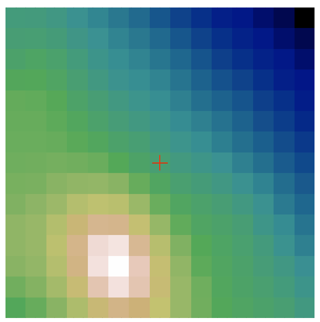
Calibration

- SNe calibrated to network of standard stars
  - CalSpec reference flux-calibrated spectra
  - Includes BD+174708 (fundamental calibrator for SDSS, SNLS3)
  - Allows nightly extinction solutions for airmass corrections
- Non-photometric nights
  - Photometric channel extinction monitoring corrections
- Primary difficulty
  - Extraction of SN from complicated host background structure

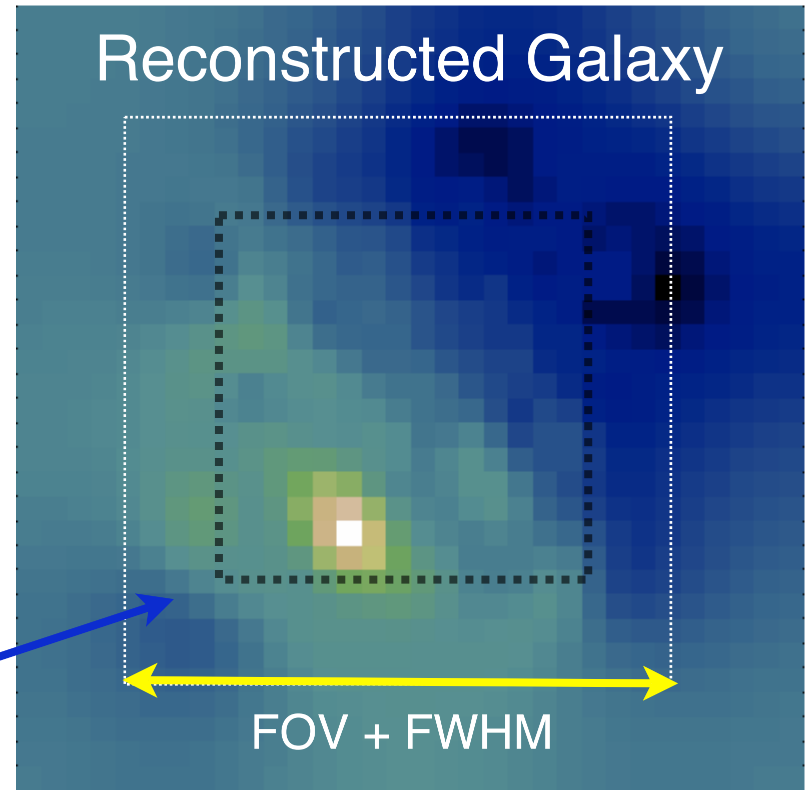
Galaxy Reconstruction

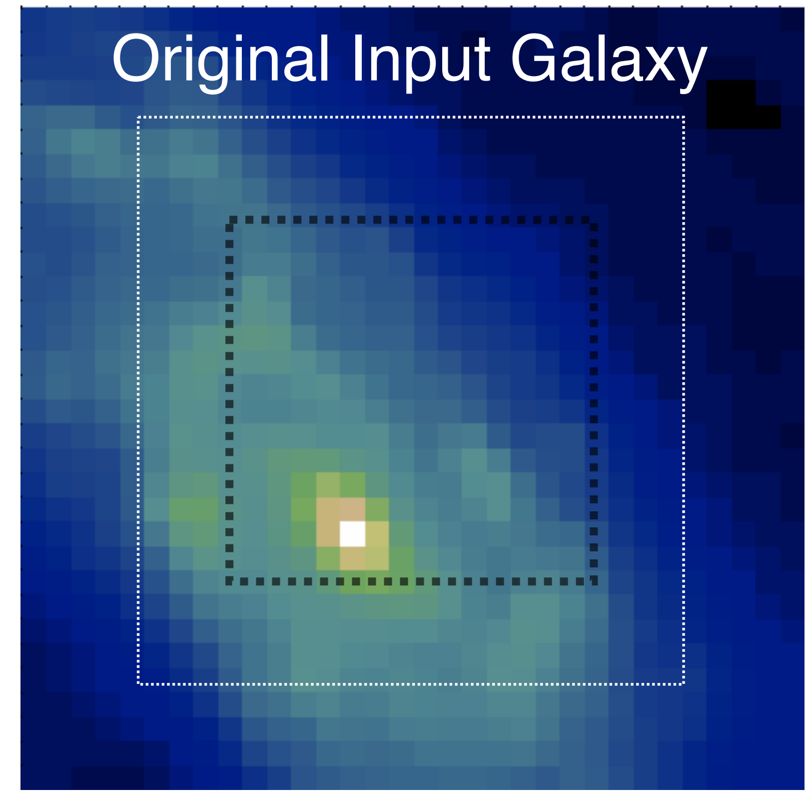
Simulated Data

Final Ref



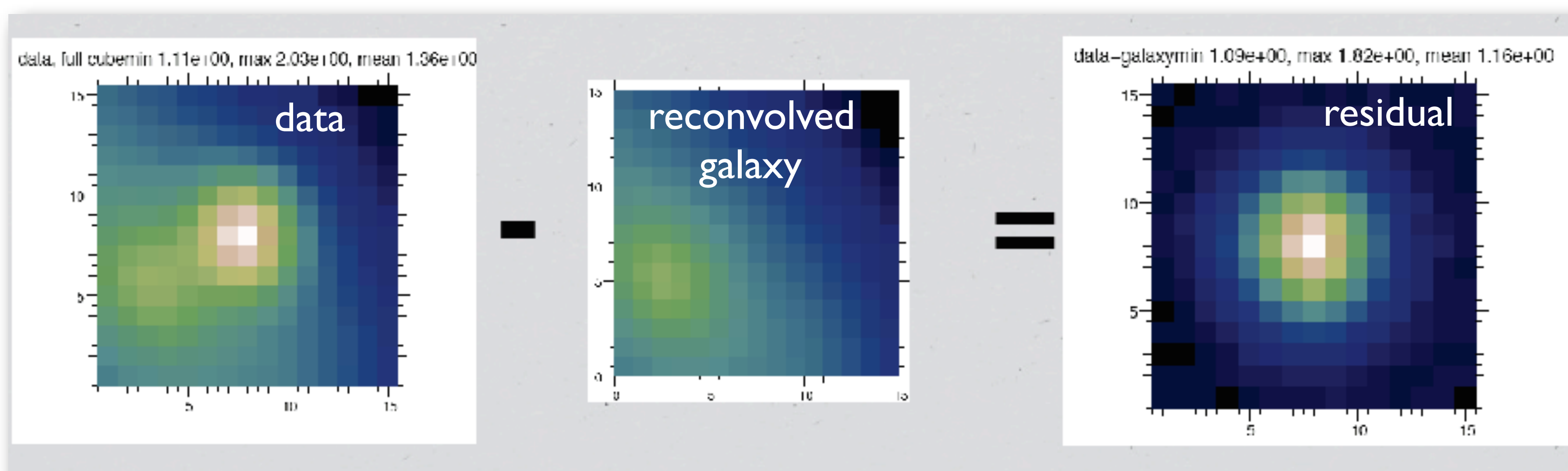
+ PSF model





Reconstruction outside of nominal spectral field of view

Subtract convolved galaxy from datacube with SN

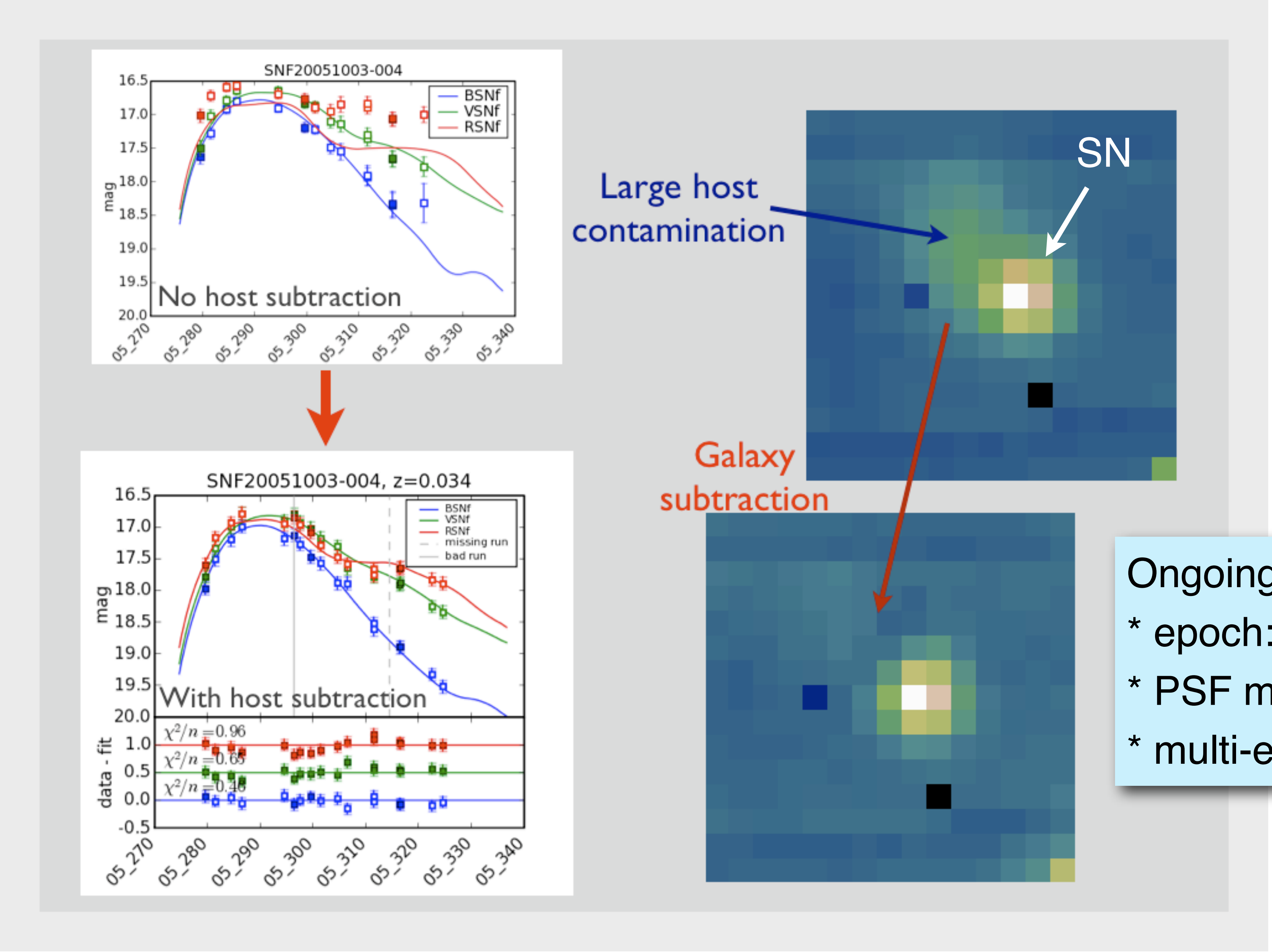


Analogous to photometry methods, but with spectra

Sébastien Bongard

Galaxy Reconstruction

Real Data



Ongoing work:

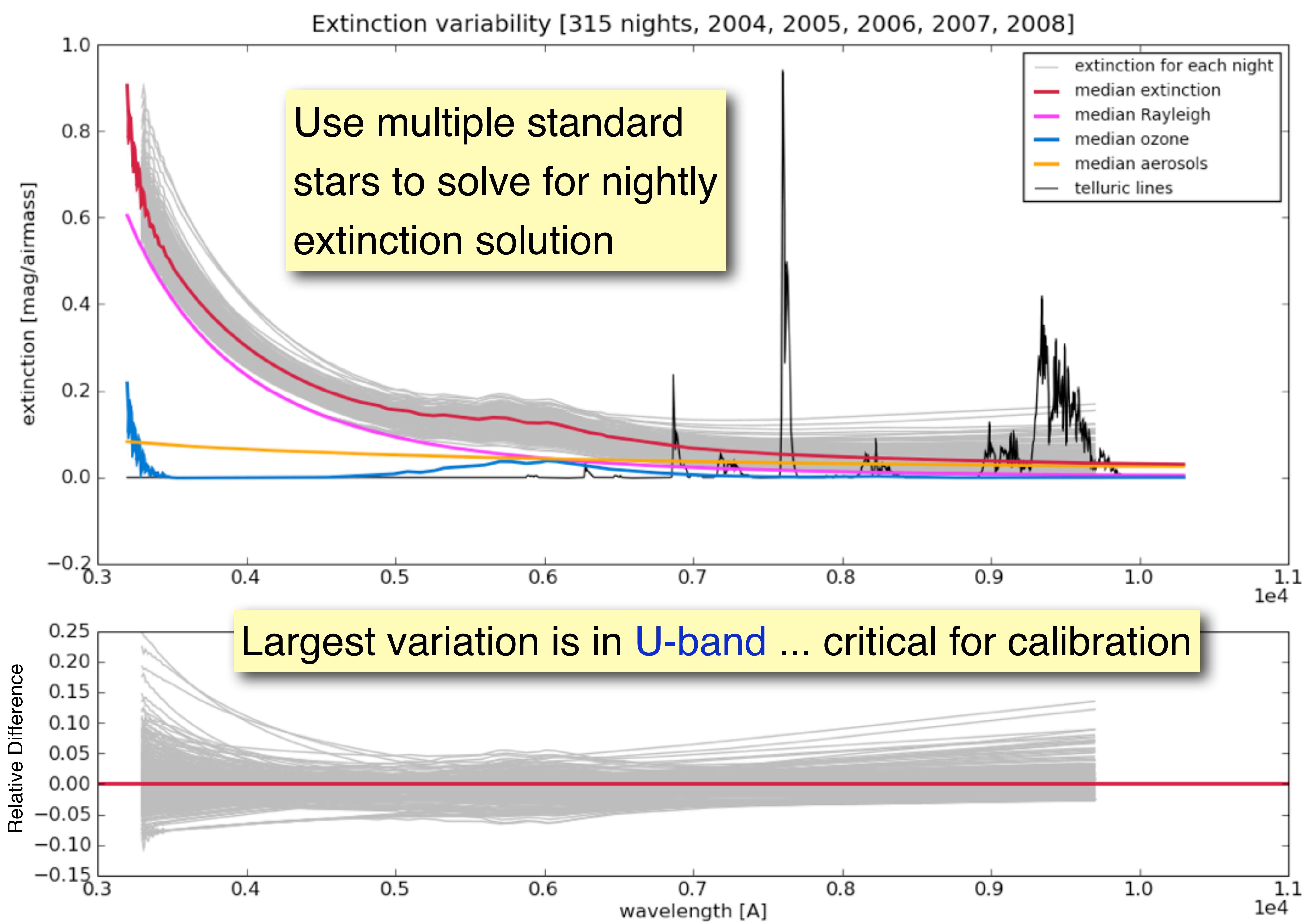
* epoch:epoch alignment

* PSF modeling

* multi-epoch simultaneous fit

Sébastien Bongard

Calibration: Nightly Extinction



Clément Buton

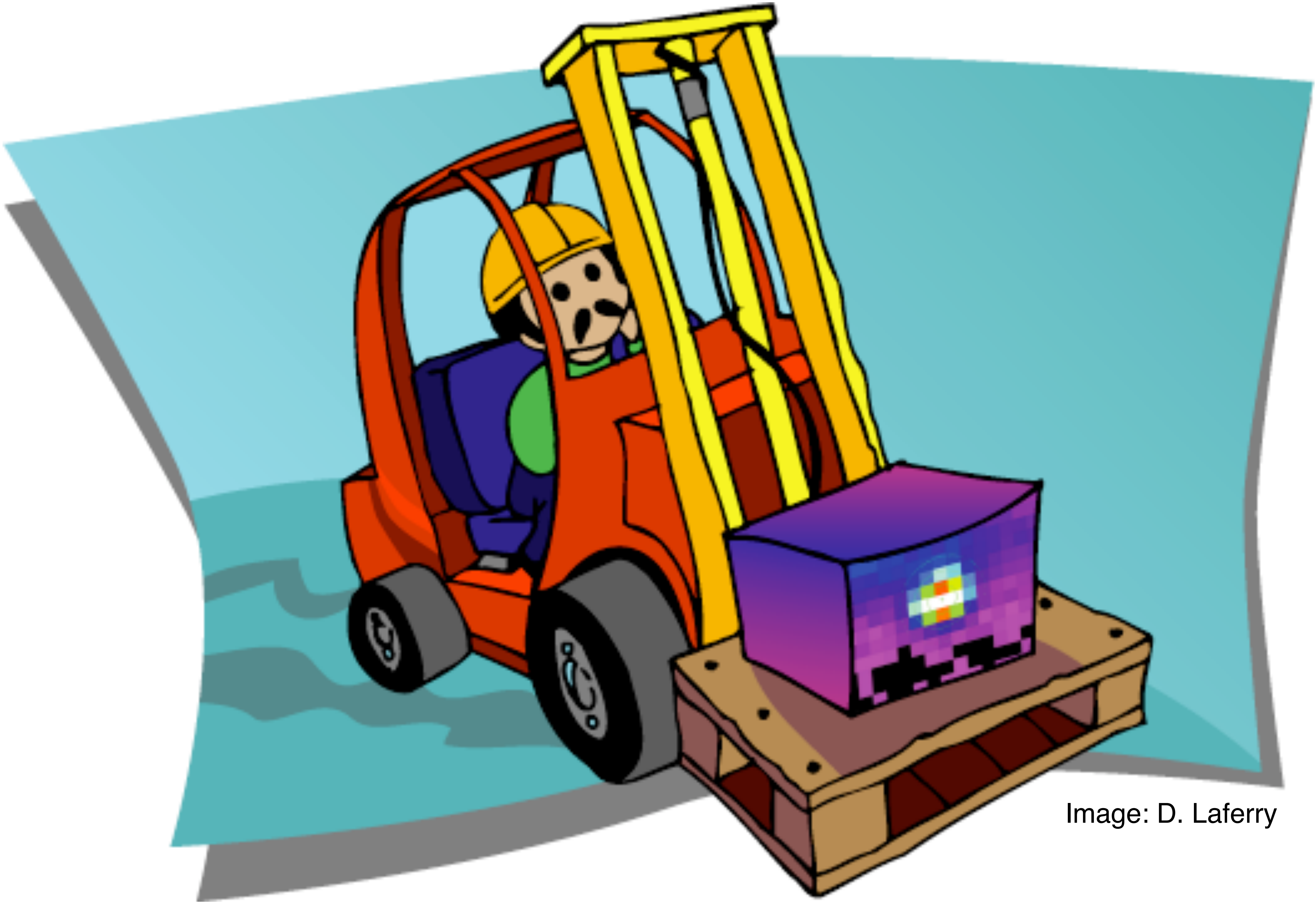
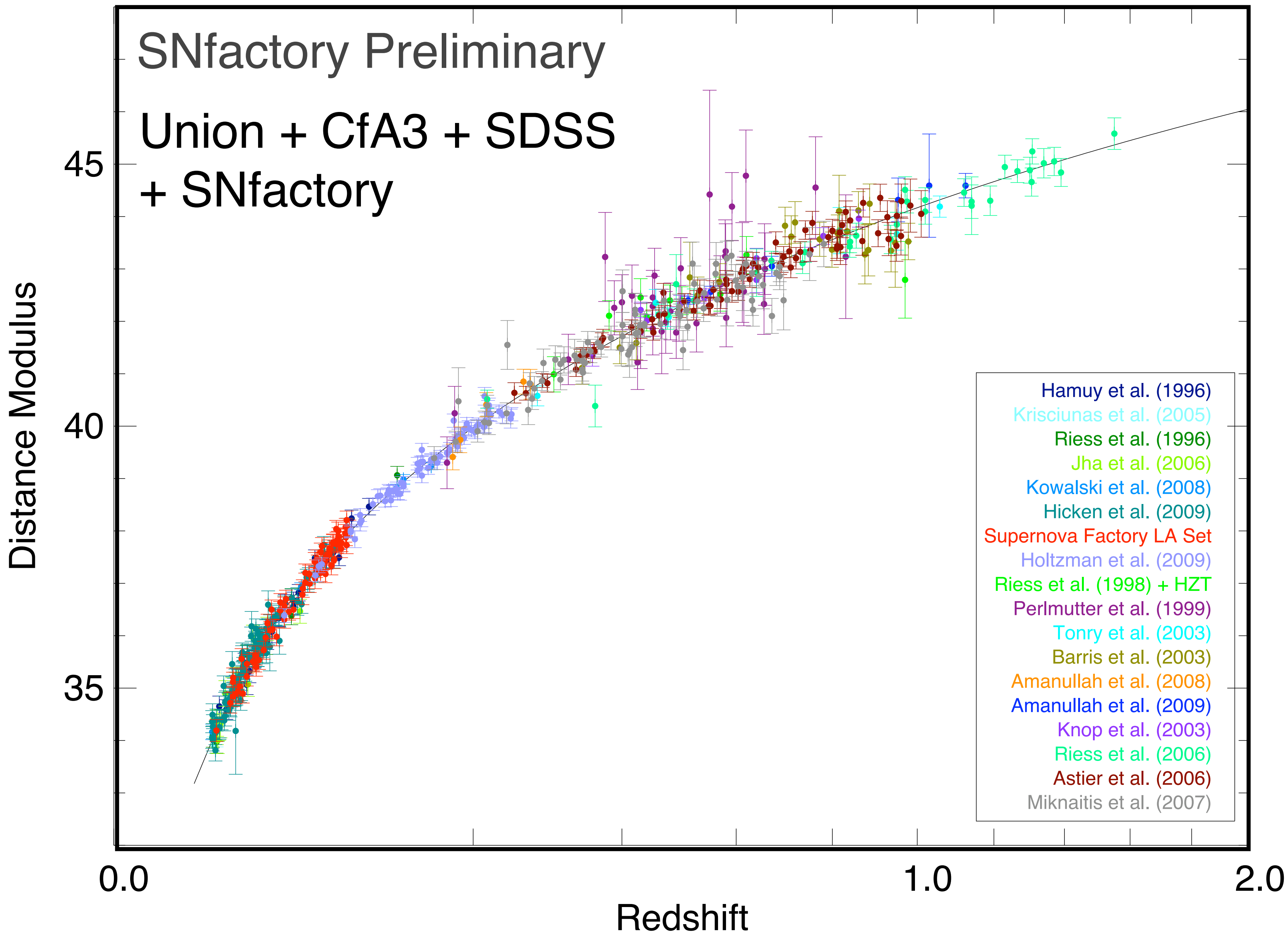


Image: D. Laferry

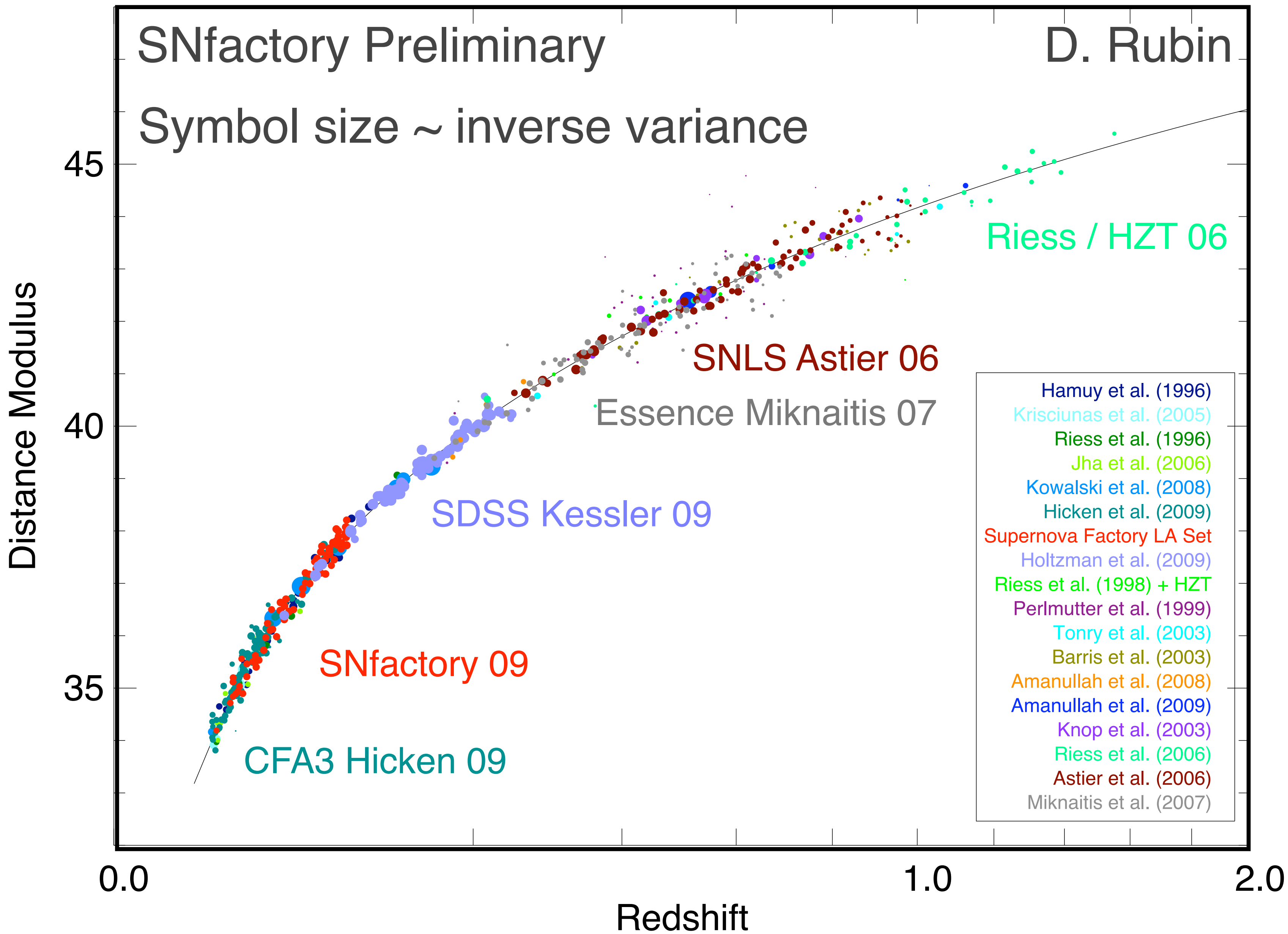
Hubble Diagram



Prepared by David Rubin using SALT2 and “Union” (Kowalski et al 2008) framework

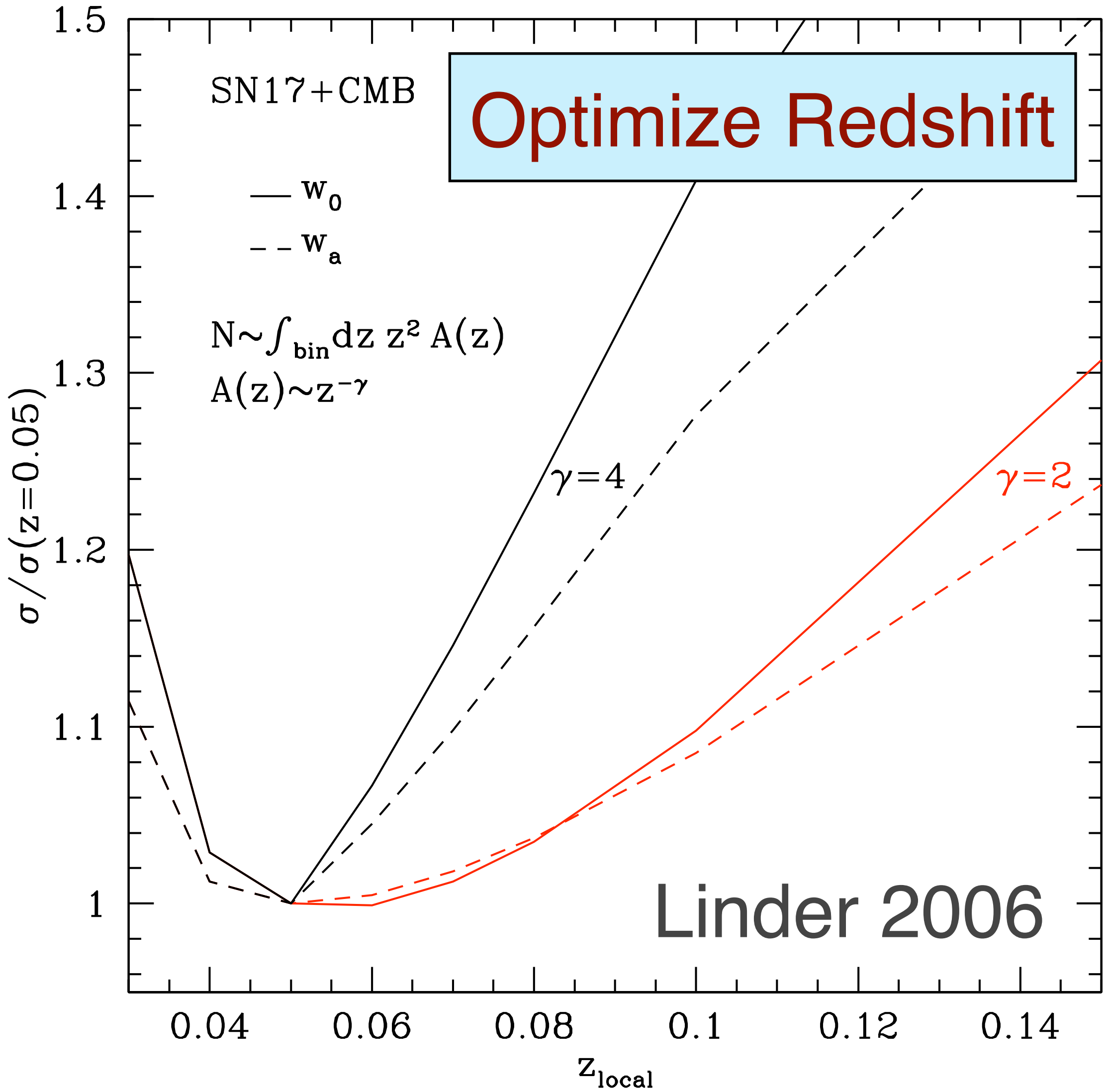
~40% of SNfactory followup sample

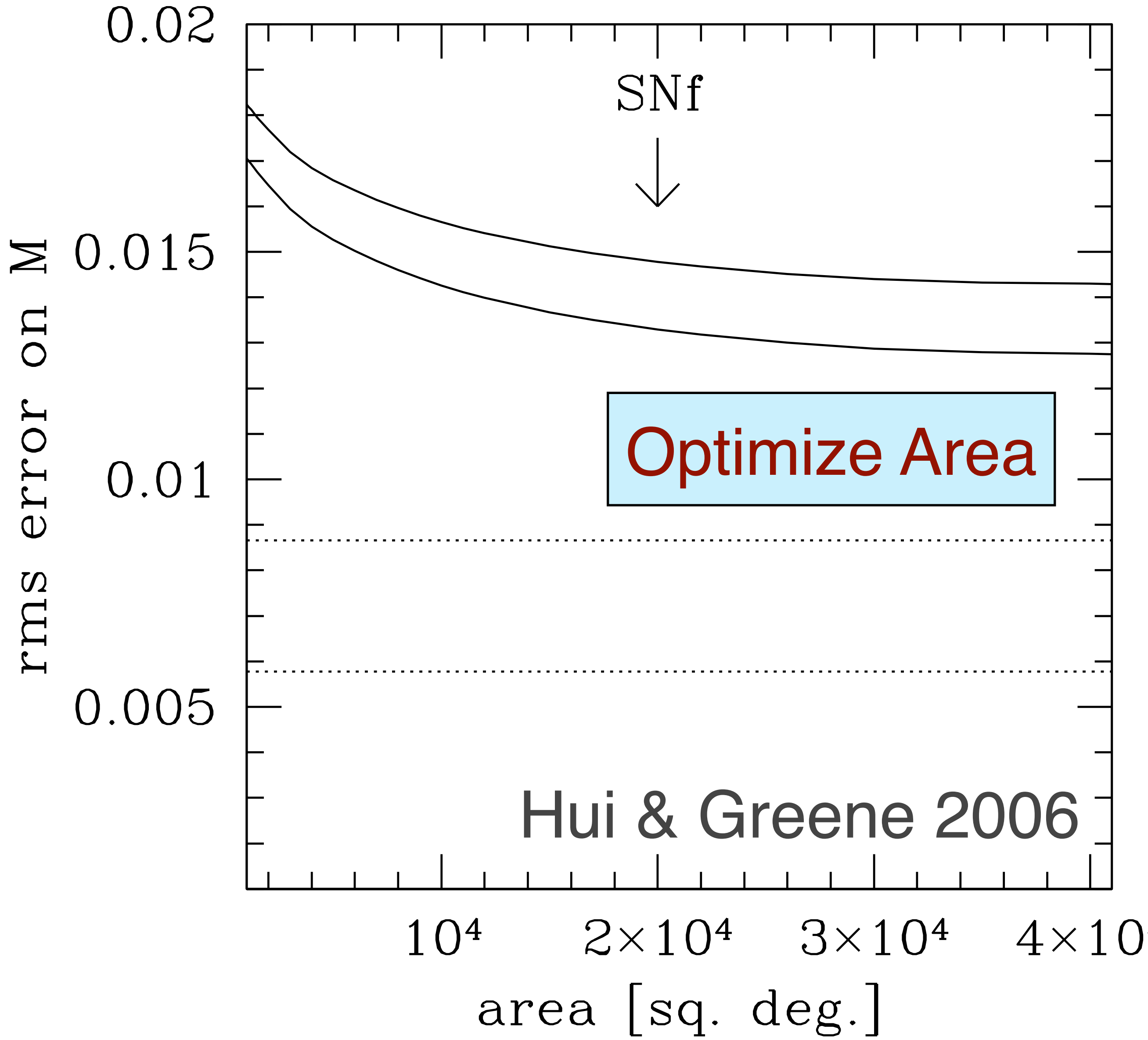
Hubble Diagram



Cosmology parameters still blinded ... work in progress ...

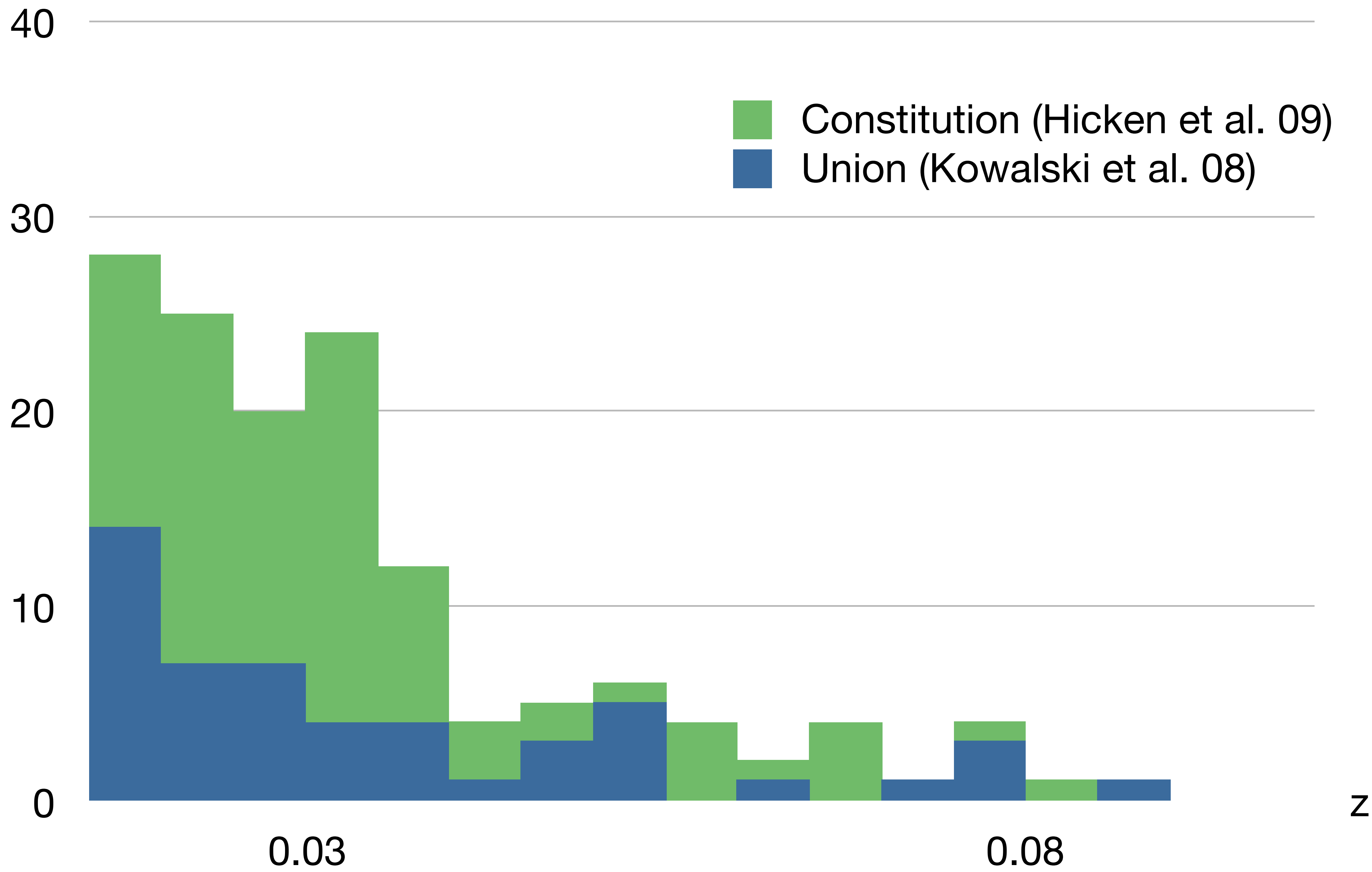
Bulk Flow Systematics





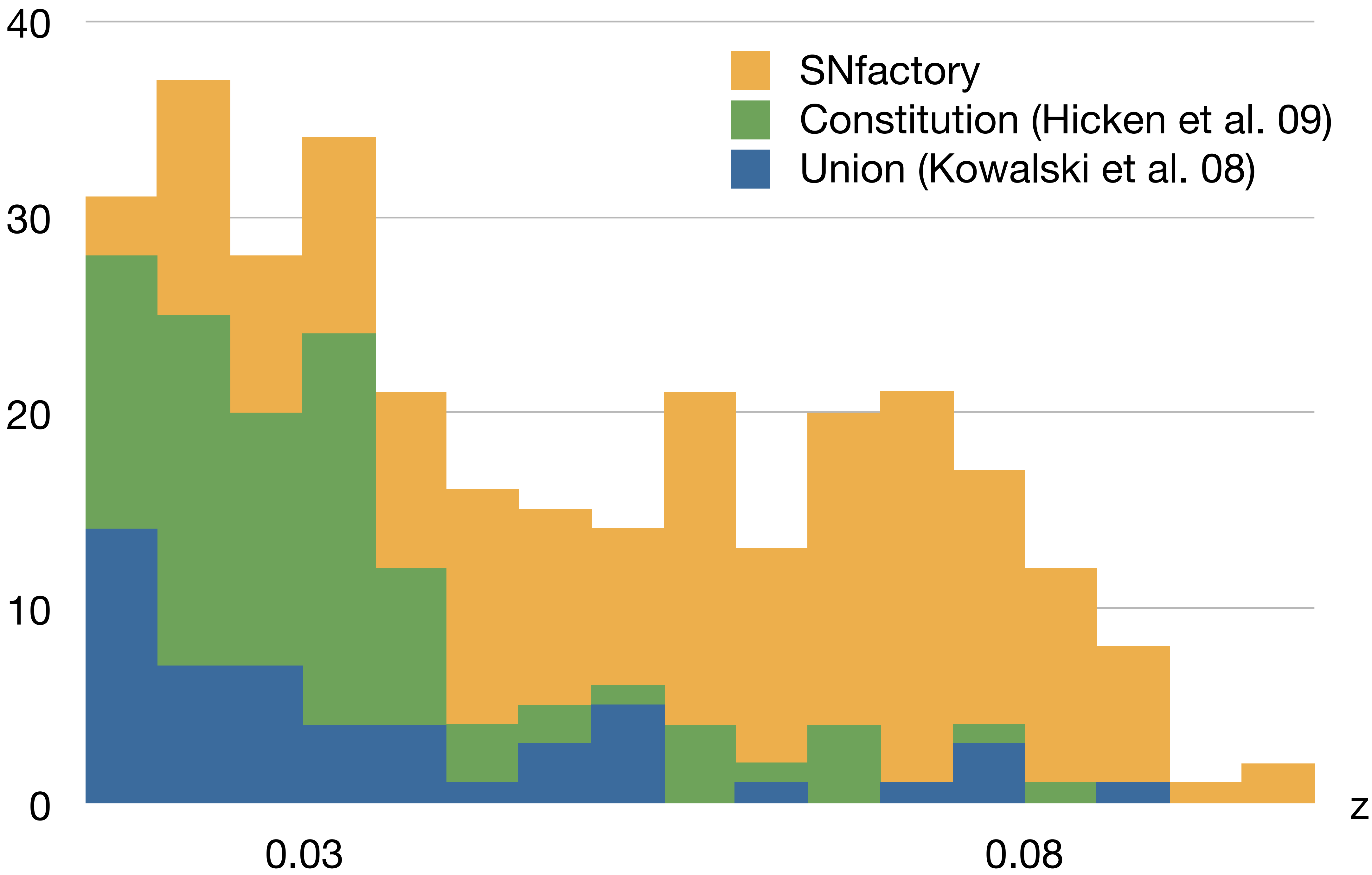
SNfactory sample optimizes balance between cosmological fit lever arm (z) and bulk flow systematic (volume of survey)

SNfactory Redshift Range



Histograms: Rui Pereira

SNfactory Redshift Range



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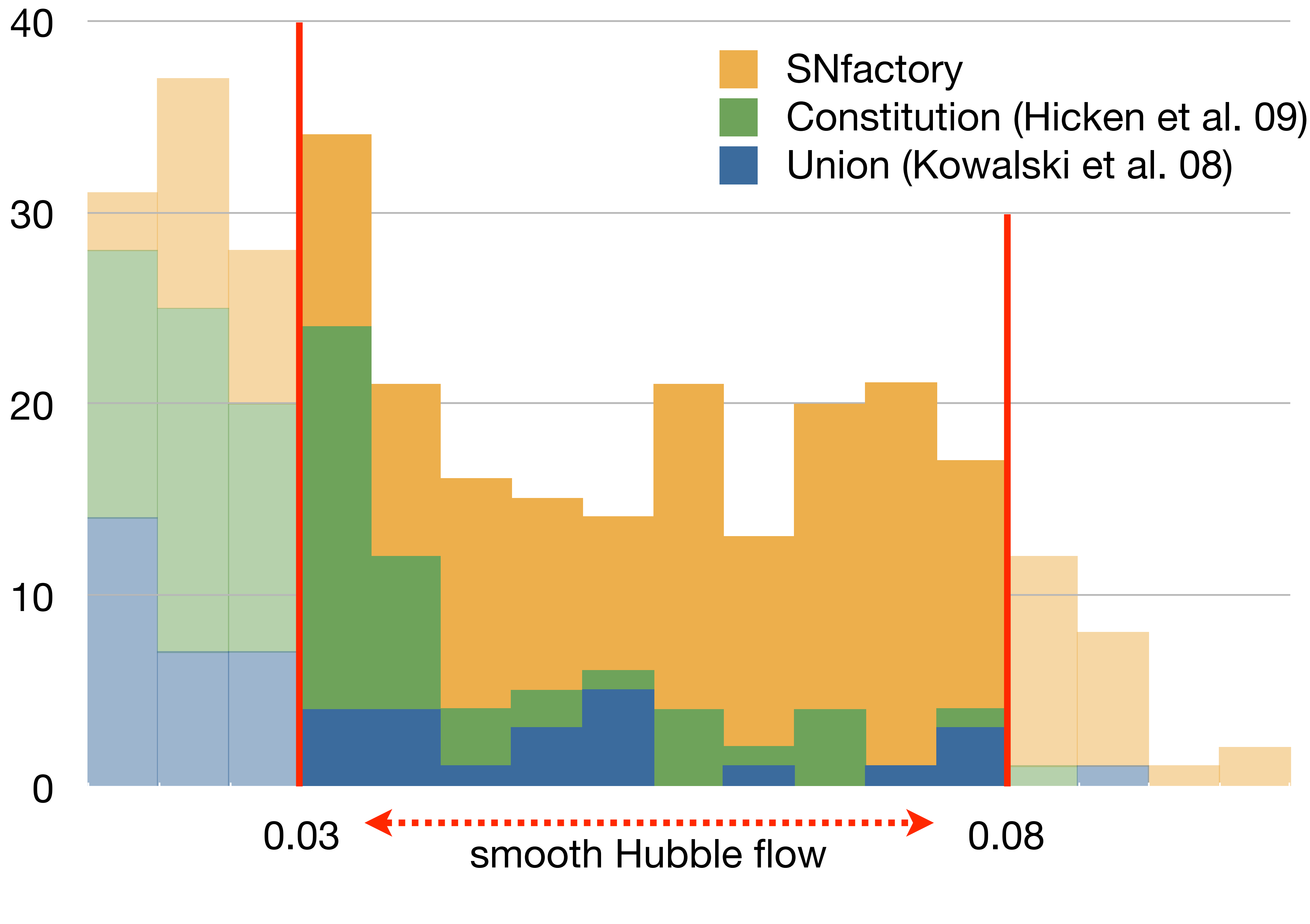


Histograms: Rui Pereira

Benefits from SNfactory Sample

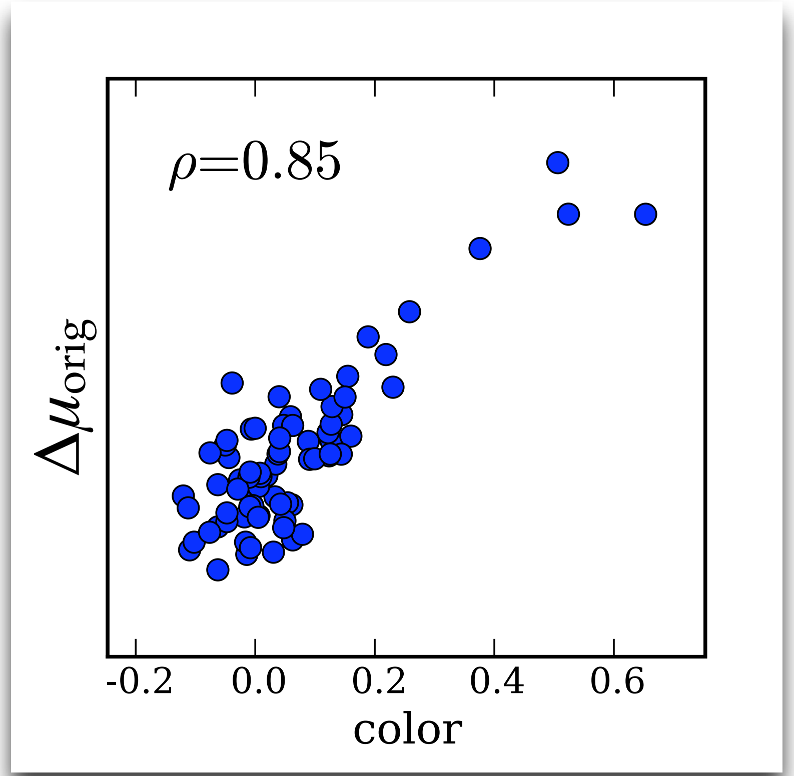
- Short Term
  - Bulk flow systematic
    - Redshift range and area covered optimizes fit lever arm vs. systematic from coherent bulk flows
  - Sample composition bias
    - Search is deeper than followup: less Malmquist bias (to be quantified)
    - Untargeted search: representative host sample diversity
  - Low/High-z sample inter-calibration
    - SNfactory sample directly calibrated to BD+174708
    - Ability to synthesize same filters as high-z samples
- Somewhat longer term
  - Full K-correctionless Hubble diagram fits
  - New SN spectral timeseries templates
  - Better understanding of SNe Ia ...

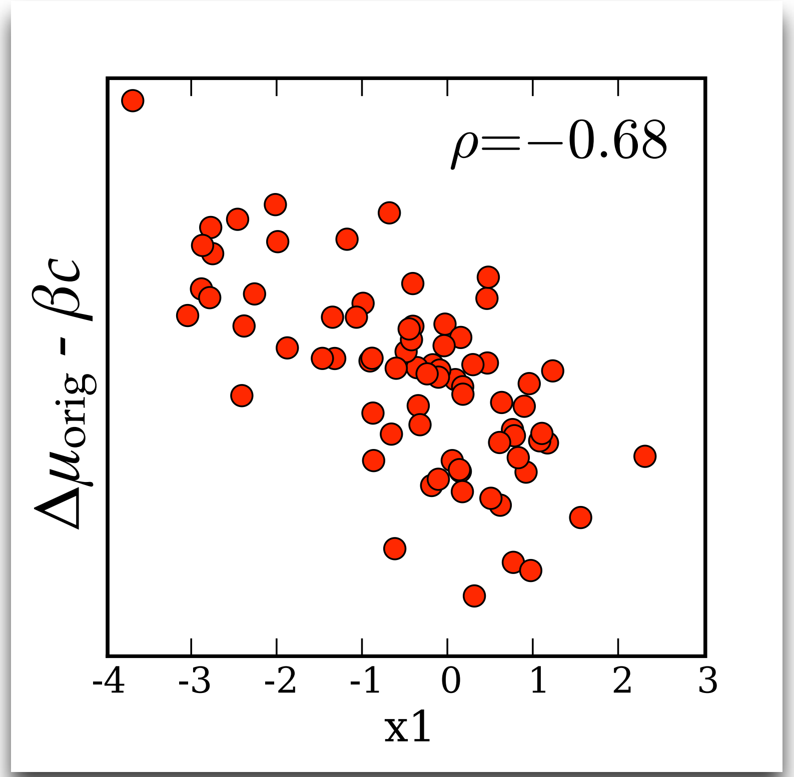
We get these benefits even if we just add our data to the Hubble diagram with standard methods

Discussed in working groups at this workshop

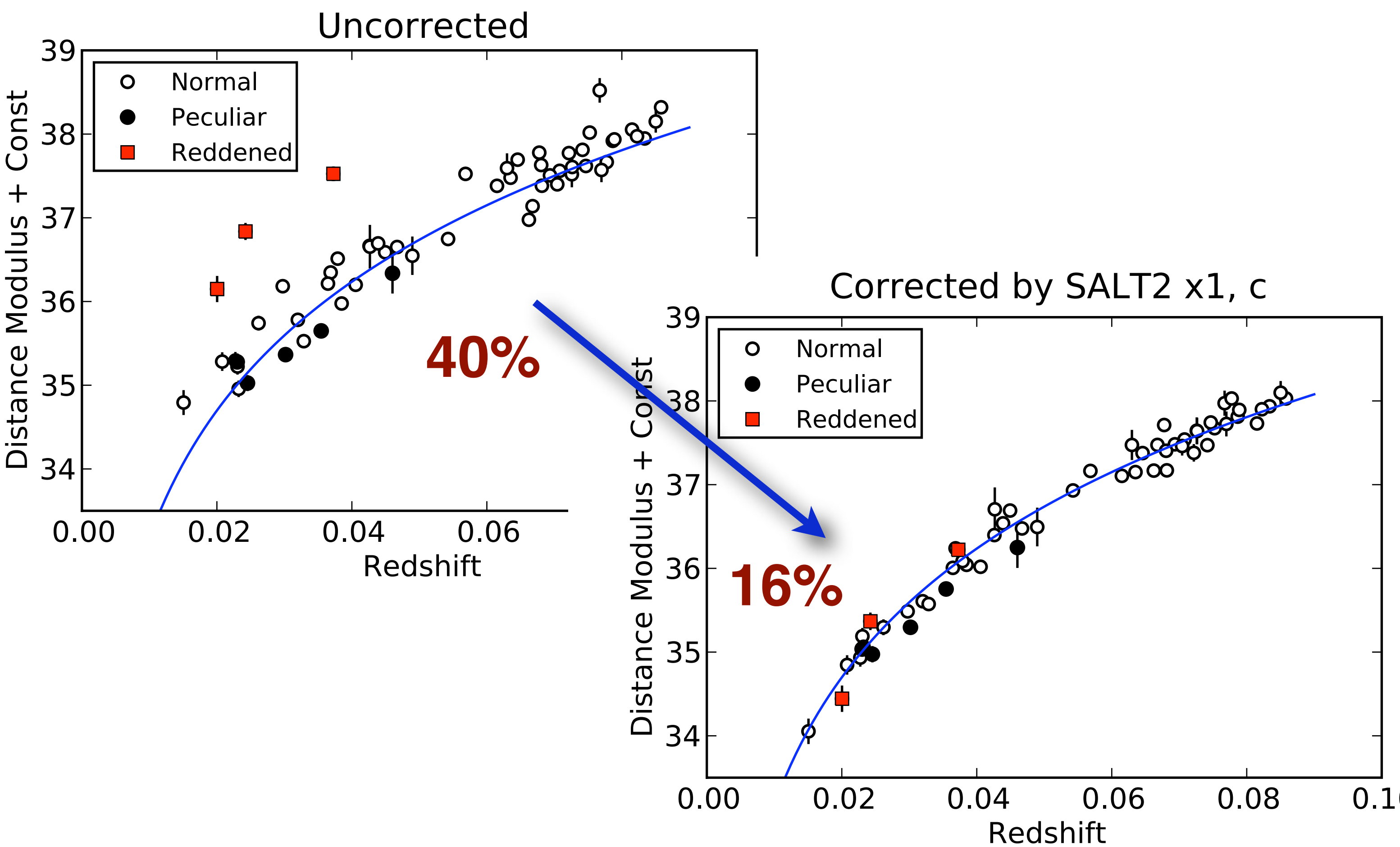
Unique dataset enables improvements beyond standard methods

Two Classic Corrections

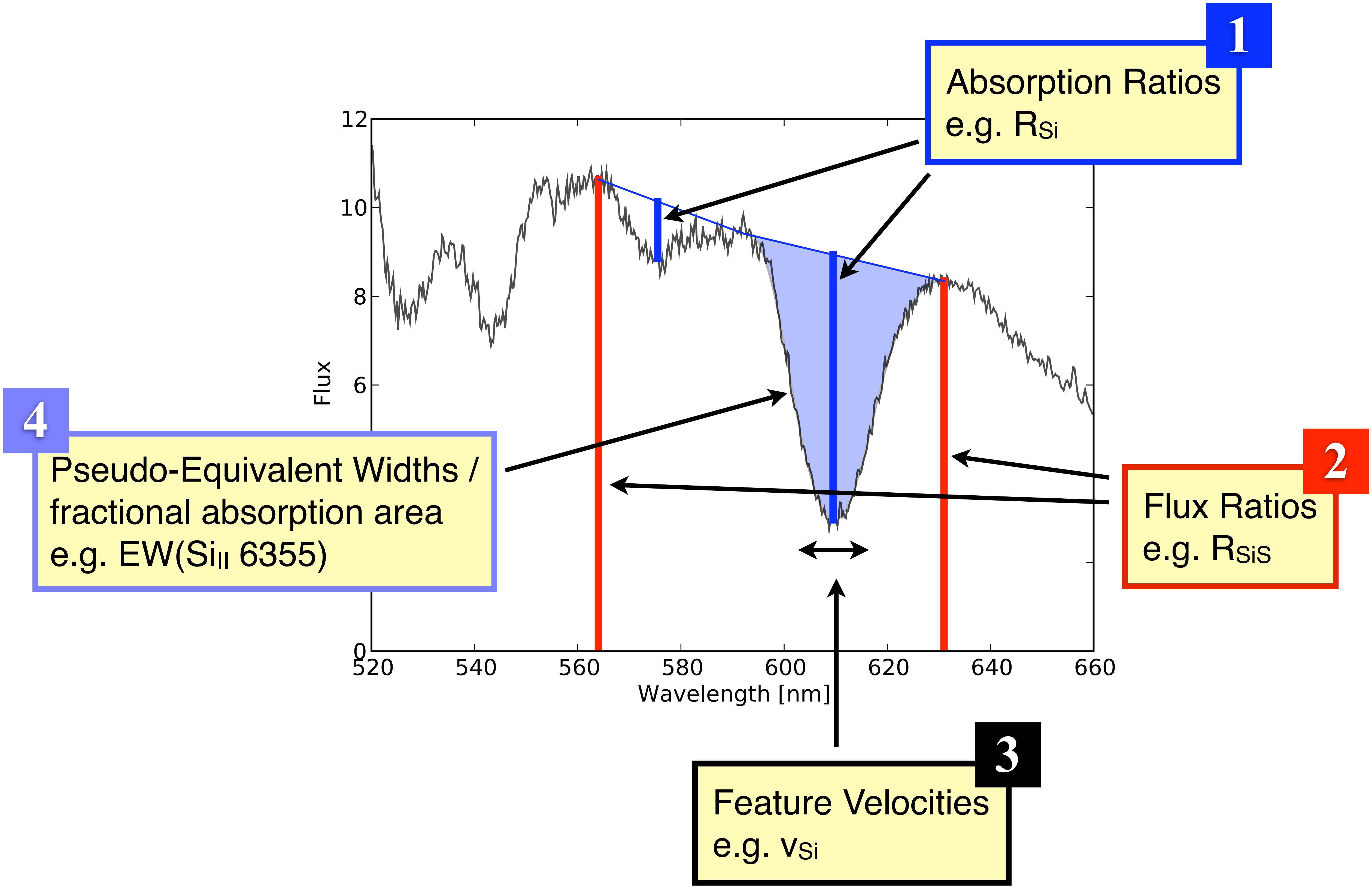




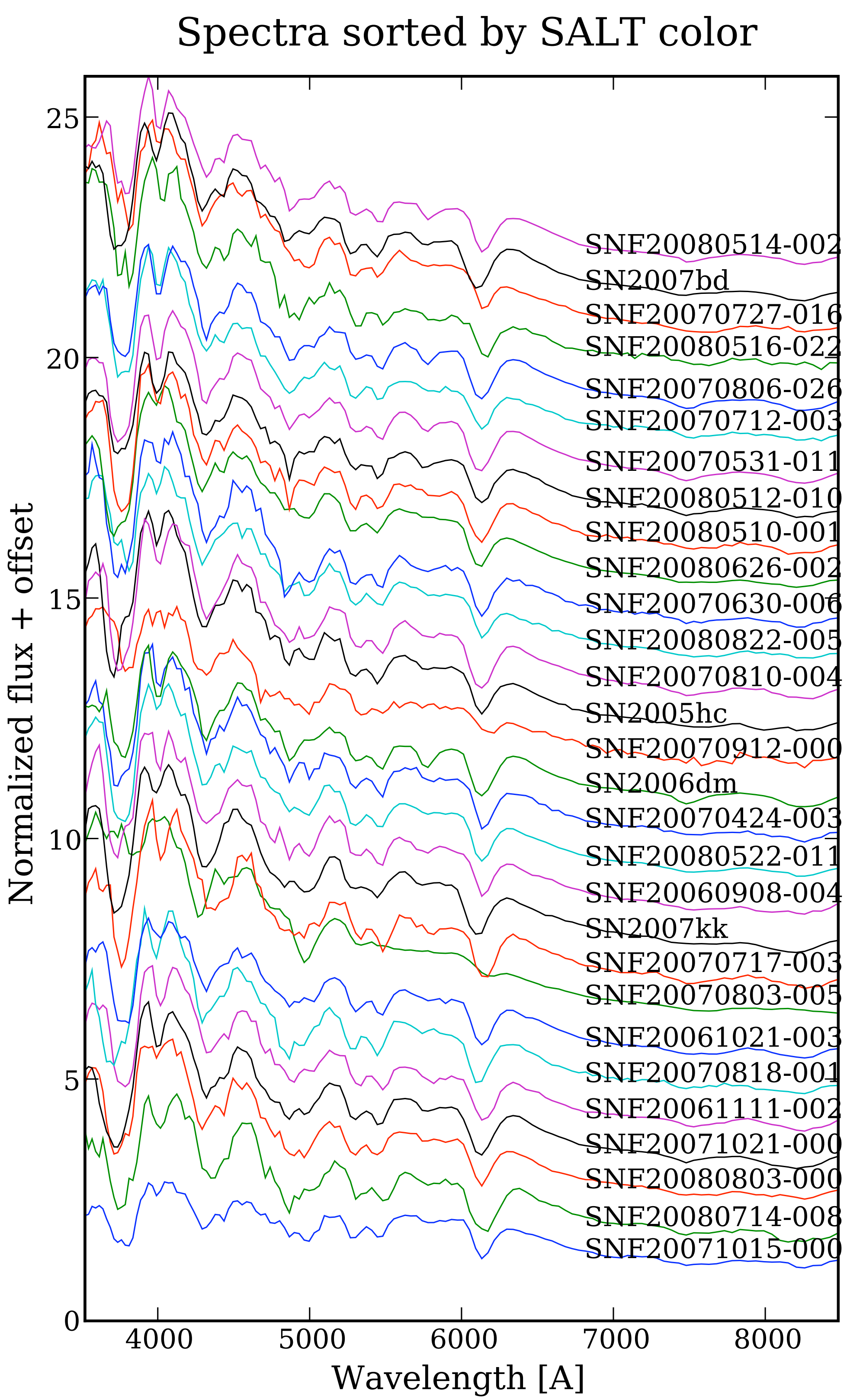
- Classic corrections
  - Color: Bluer = Brighter
  - Lightcurve shape: Broader = Brighter
- ~40% → ~16 – 20% scatter
- Can we do better with spectral info?
  - Search correlations of features with residuals



Previous Spectral Metrics

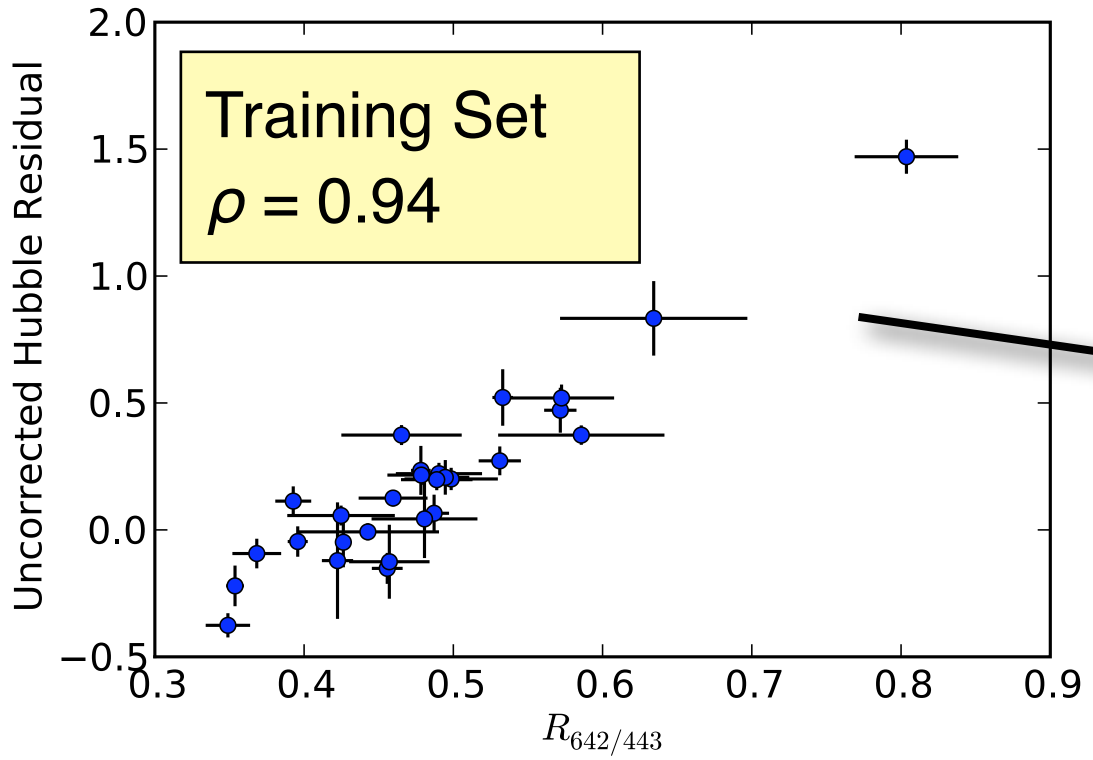


Generalized Flux Ratios

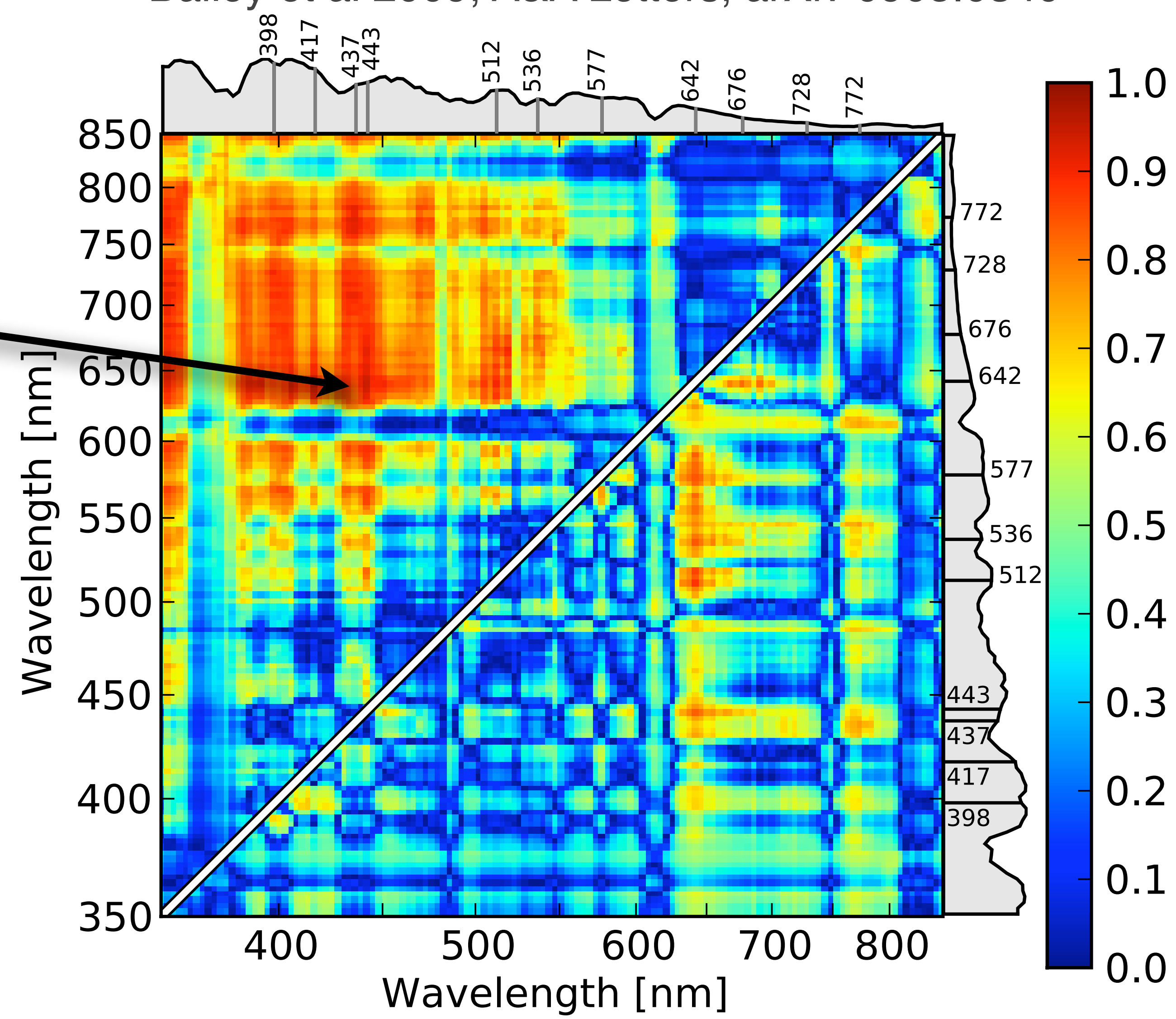


- Consider all flux ratio combos, not just ratios of known peaks
- Search for correlations with uncorrected Hubble residuals
- SNfactory spectra
  - Flux calibrated
  - Within ±2.5 days of peak brightness
- Training and Validation Datasets
  - Search with training set (28 SNe)
  - Cross check w/ validation set (30 SNe)
  - Minimizes bias and confirms results

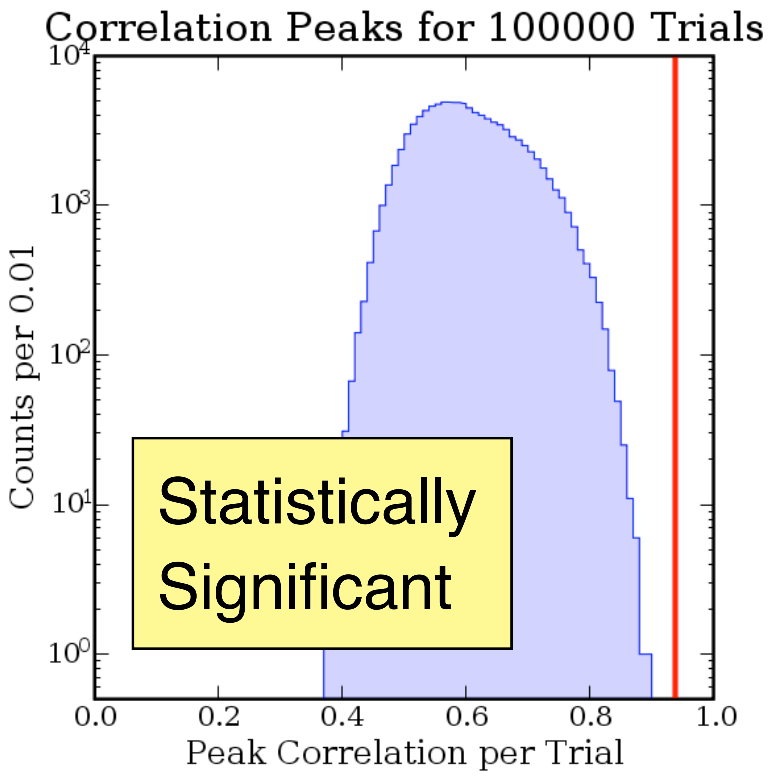
Flux Ratio Correlations



Bailey et al 2009, A&A Letters, arXiv 0905.0340

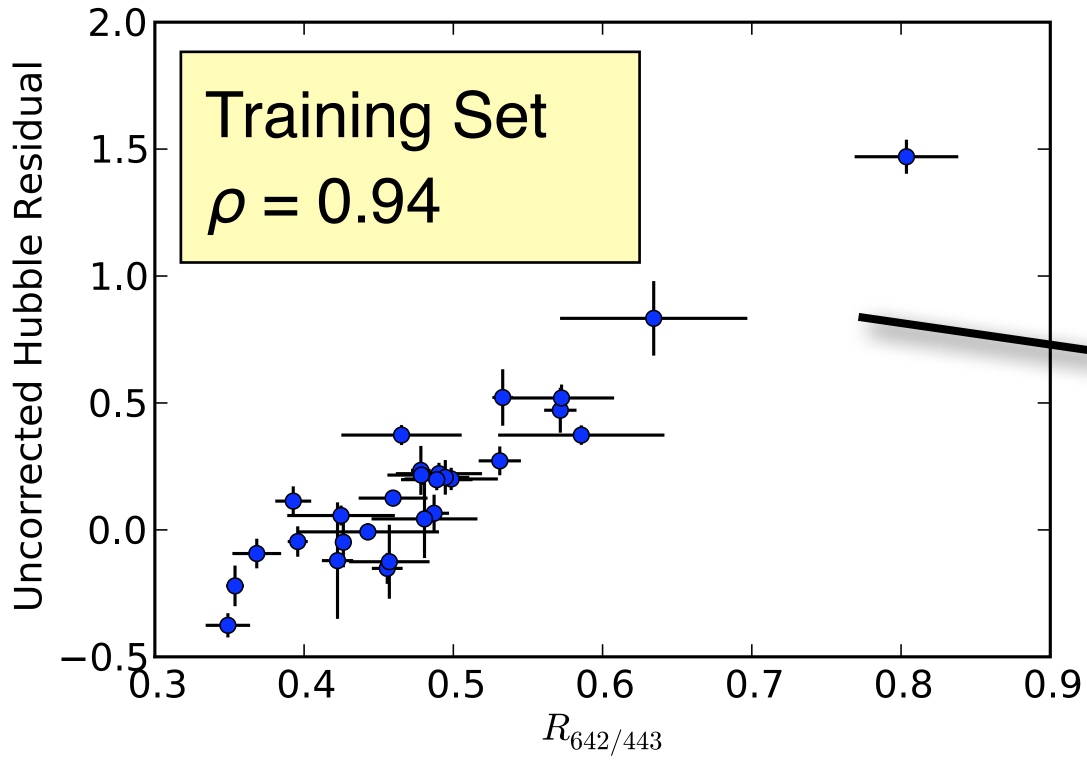


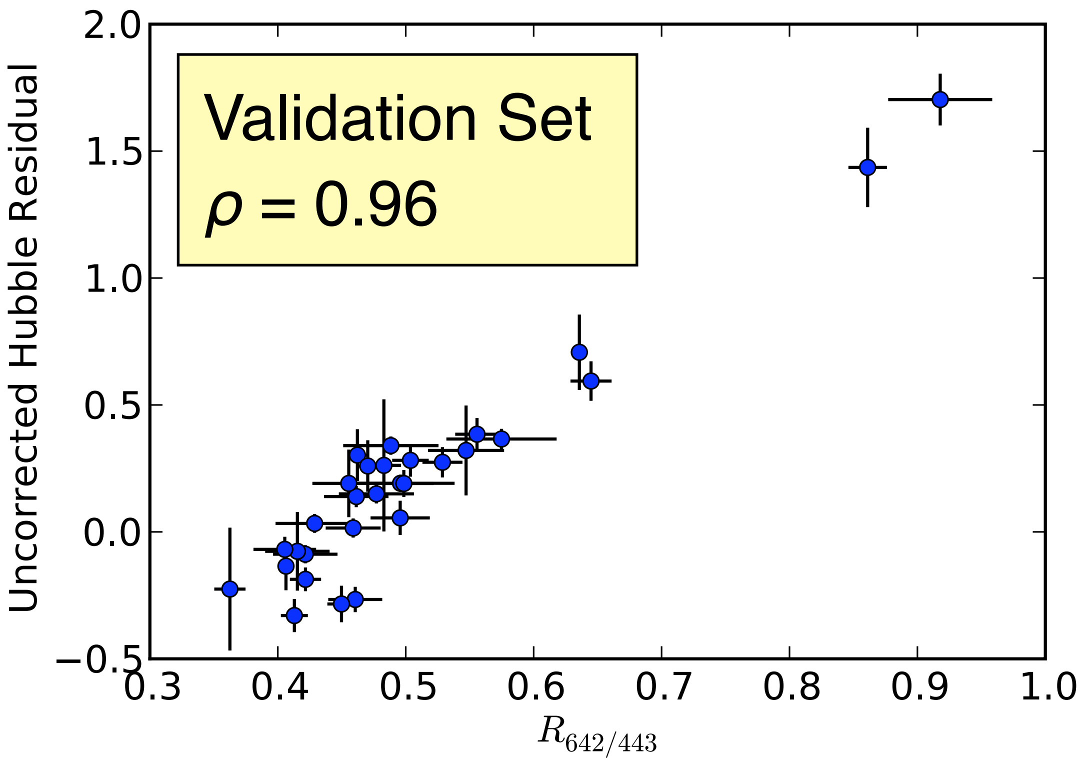
Lower diagonal: Decolor spectra before forming ratios



- Develop method and pick ratios based upon training sample
- Then look at validation sample

Flux Ratio Correlations





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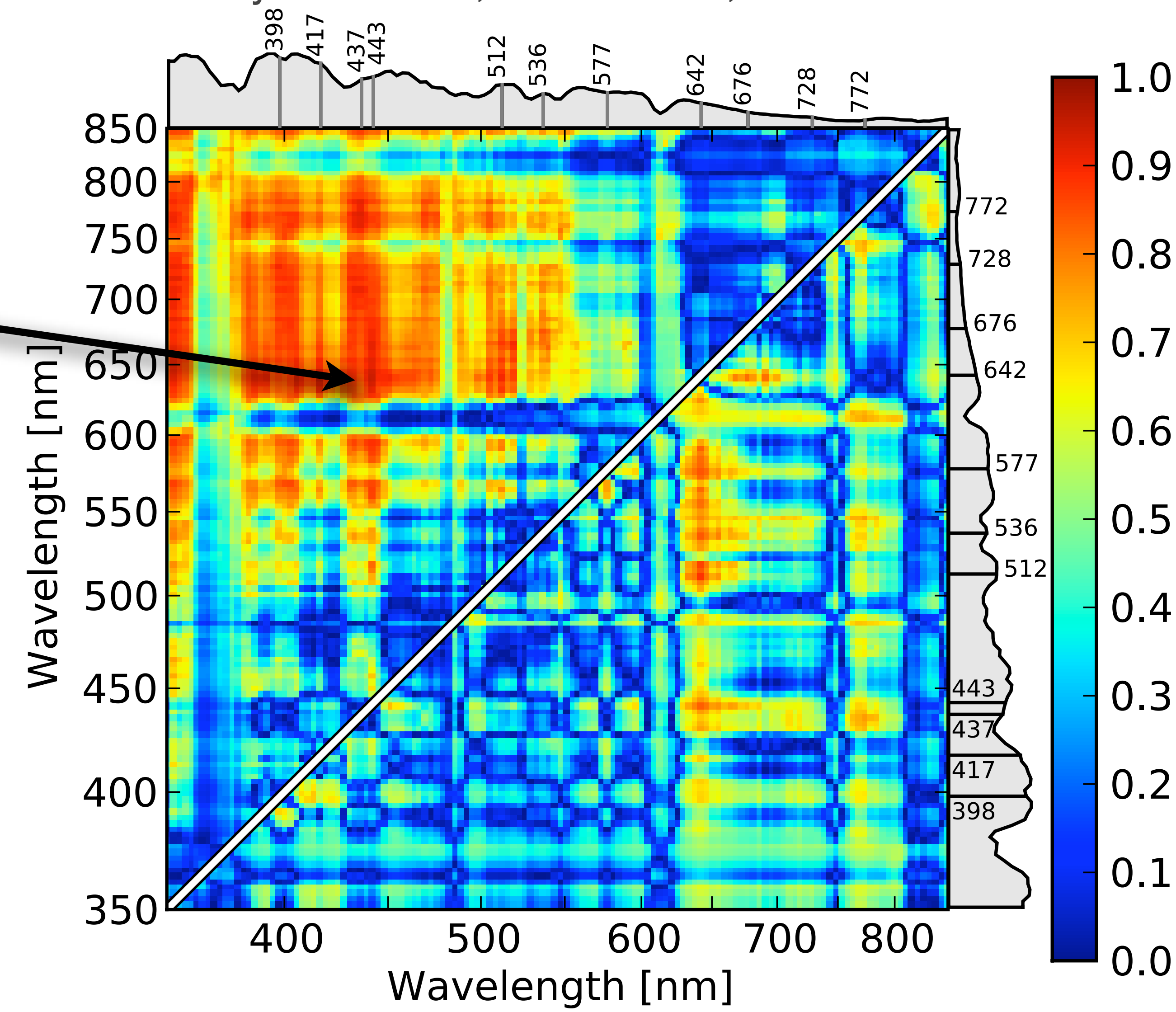
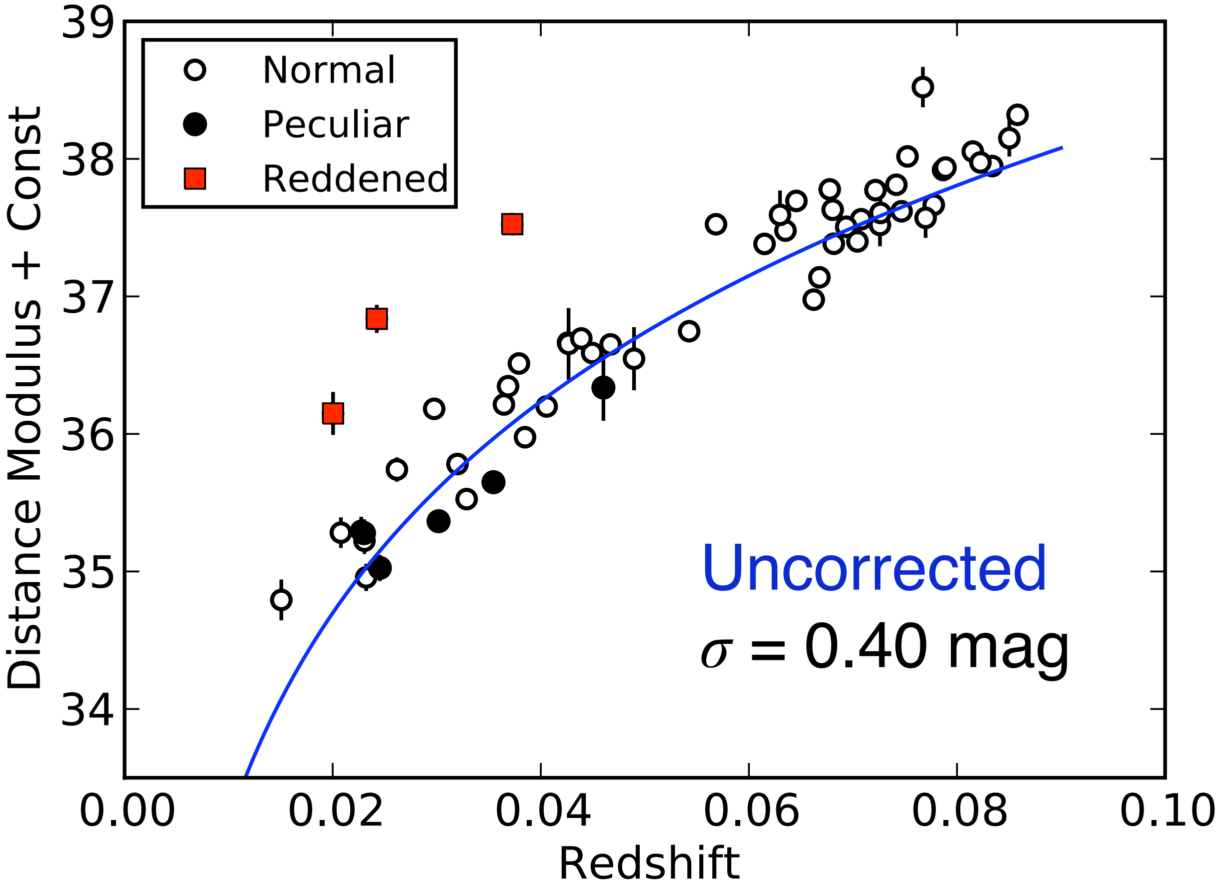


Lower diagonal: Decolor spectra before forming ratios

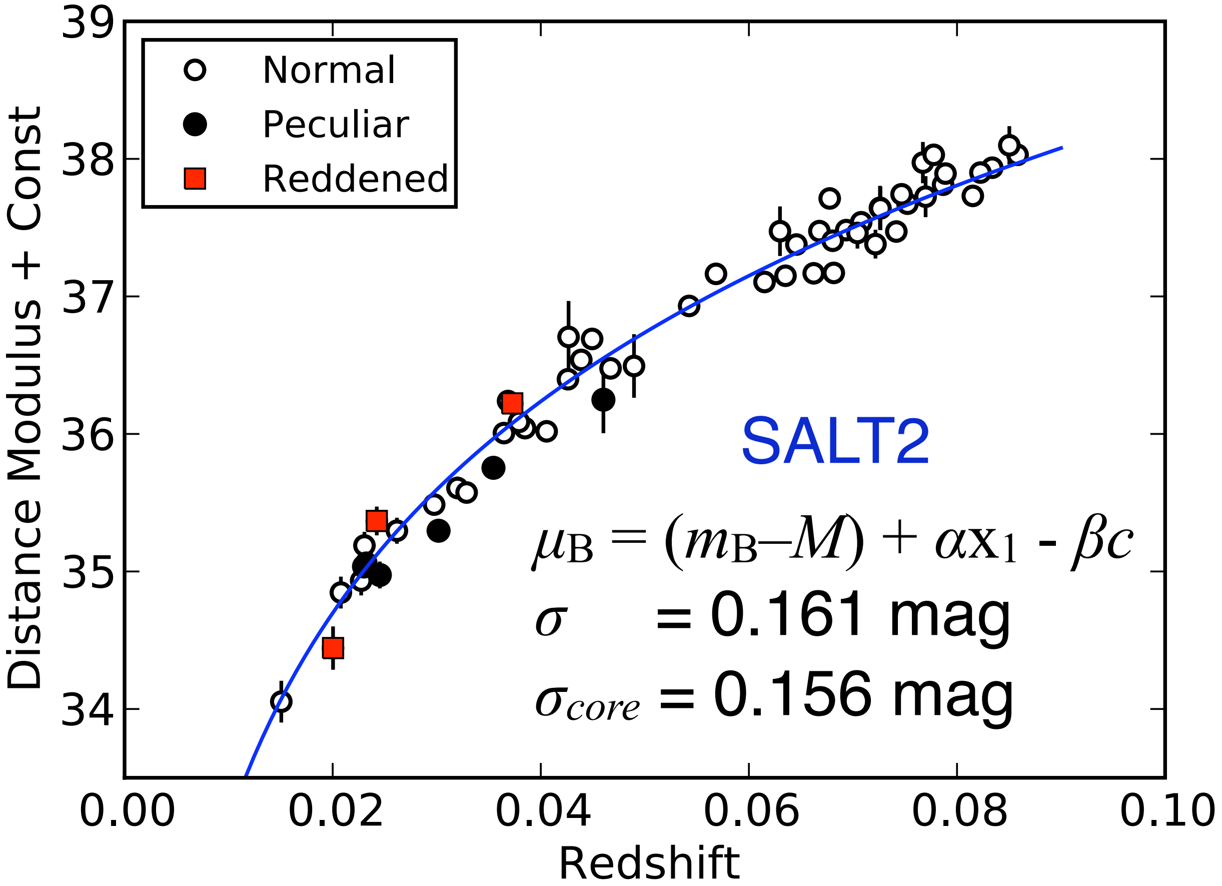
Correlations

- Stronger than color or stretch
- Selected only from training sample
- Confirmed by validation sample

Nearby Hubble Diagram



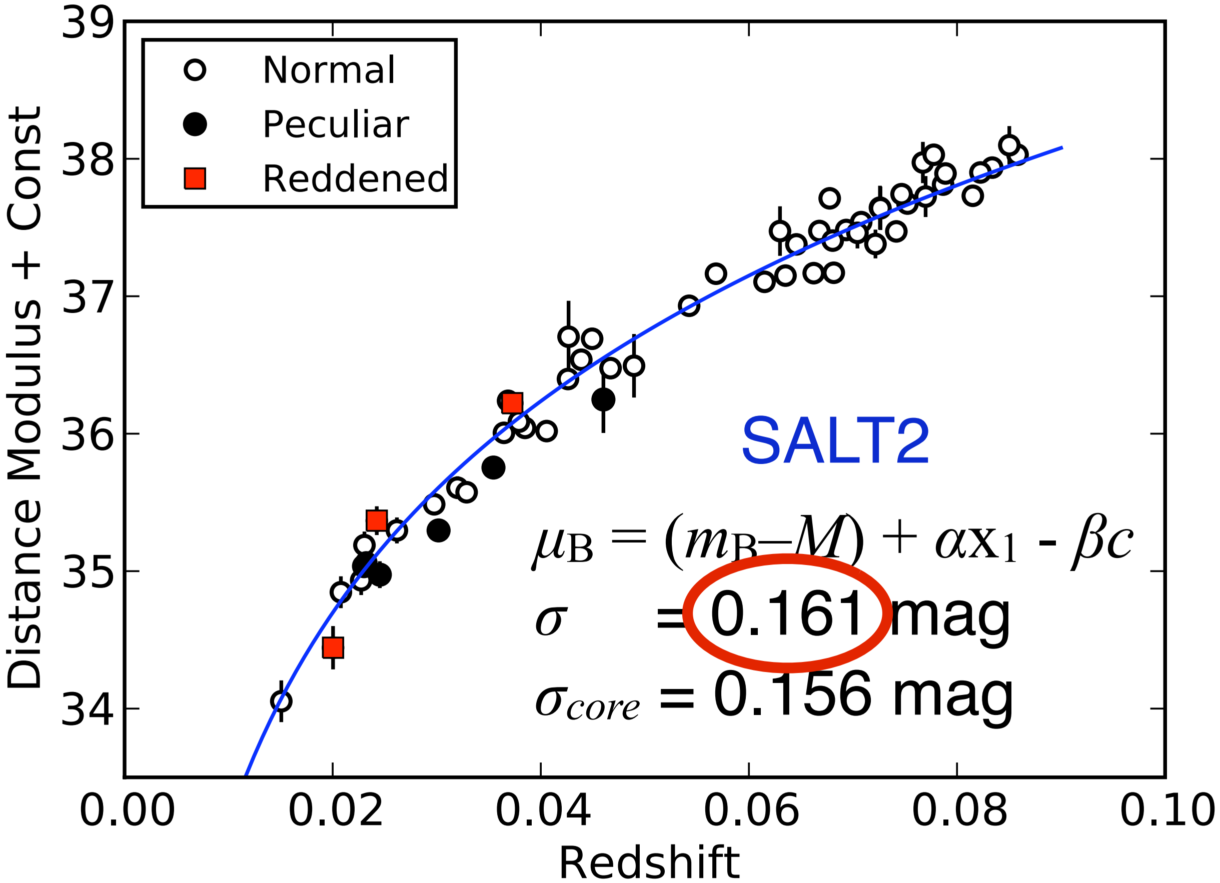
Nearby Hubble Diagram

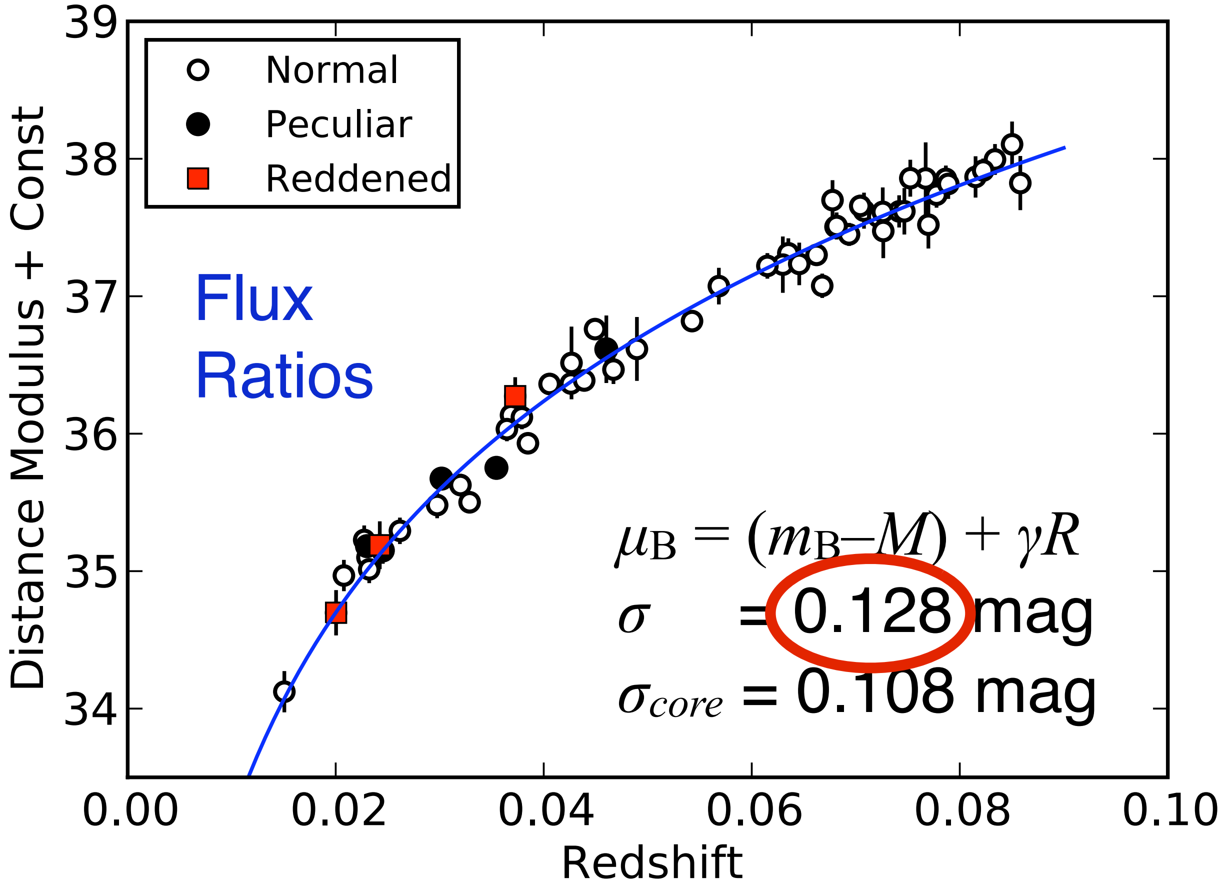


SALT2 corrects 0.40 → 0.16 mag

What if we fit with $R_{643/442}$ instead?

Nearby Hubble Diagram





Flux Ratios standardize SNe Ia better than x_1 and c combined

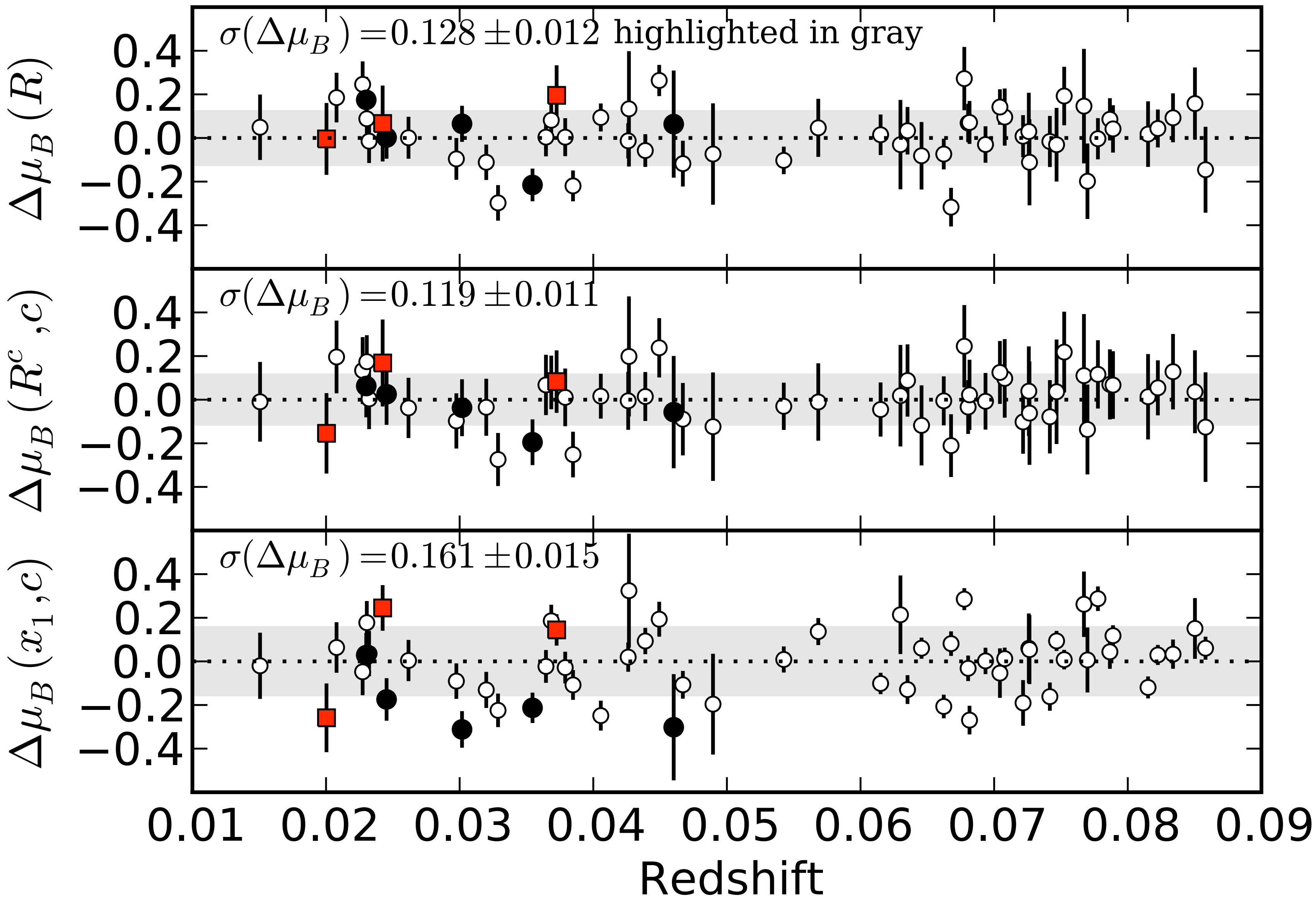
Bailey et al 2009
A&A Letters
arXiv: 0905.0340

Hubble Residuals

Sample	$R_{642/443}$	x_1, c
Training	0.130	0.154
Validation	0.134	0.171
All	0.128	0.161

Hubble Residuals

Bailey et al 2009, A&A Letters, arXiv 0905.0340



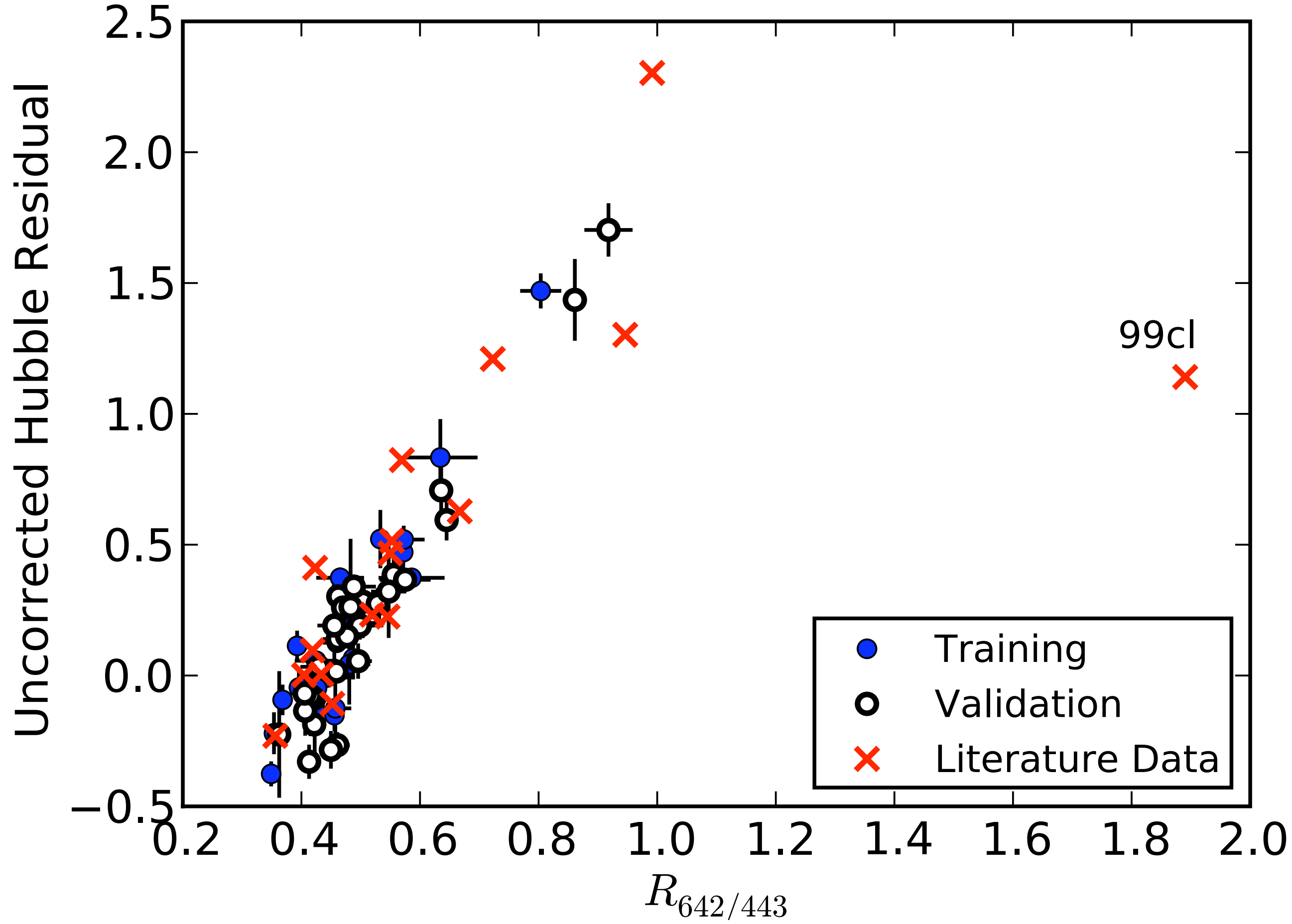
Single Flux Ratio:
$\sigma = 0.13$
Also better at correcting red and peculiar SNe

combined with color:
$\sigma = 0.12$

Traditional method (SALT2)
$\sigma = 0.16$

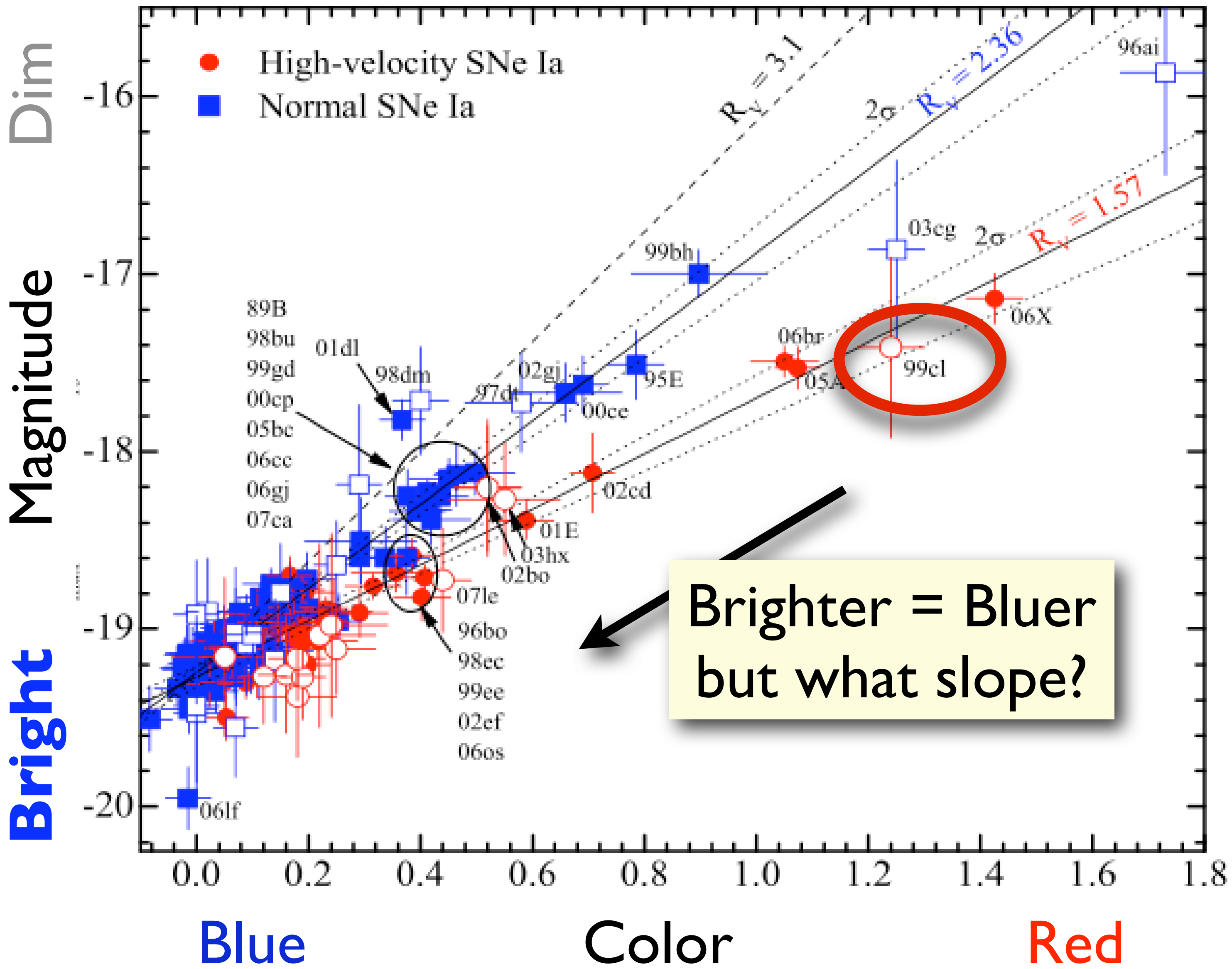
Literature SNe Comparison

Bailey et al 2009, A&A Letters, arXiv 0905.0340

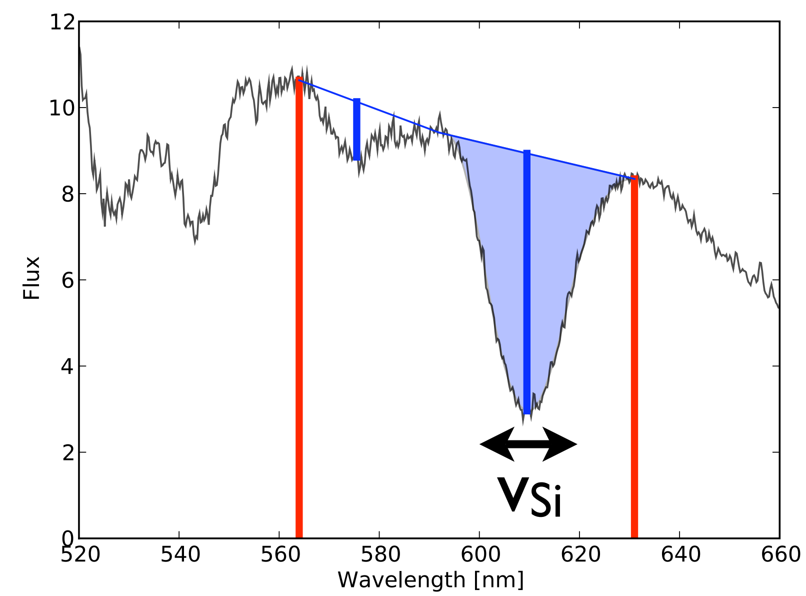


- Literature SNe from Matheson, with photometry from Jha and Hicken
- Overall, supports our results within the resolution of the data
- One outlier (99cl) known to be unusual:
  - Very heavily reddened
  - Time variable sodium absorption
  - Very low R_V value

Related Work: v_{Si} and Color



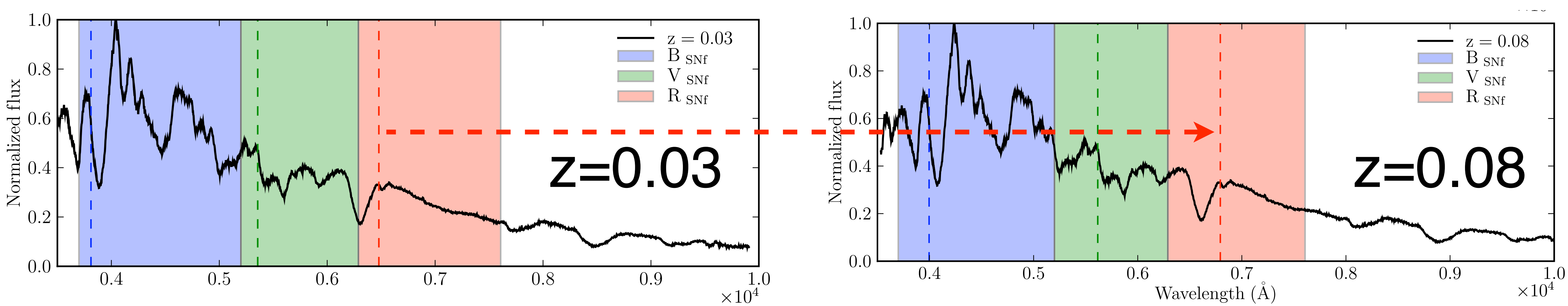
- Slope of color correction related to Si velocity v_{Si}
- Separating high/normal v_{Si} significantly improves scatter (0.178 → 0.125 mag)
- 99cl is in high v_{Si} set



X. Wang et al. 2009
ApJ Letters, arXiv:0906.1616
Improved distances to Type Ia Supernovae with Two Spectroscopic Subclasses

K-correctionless Hubble Diagram

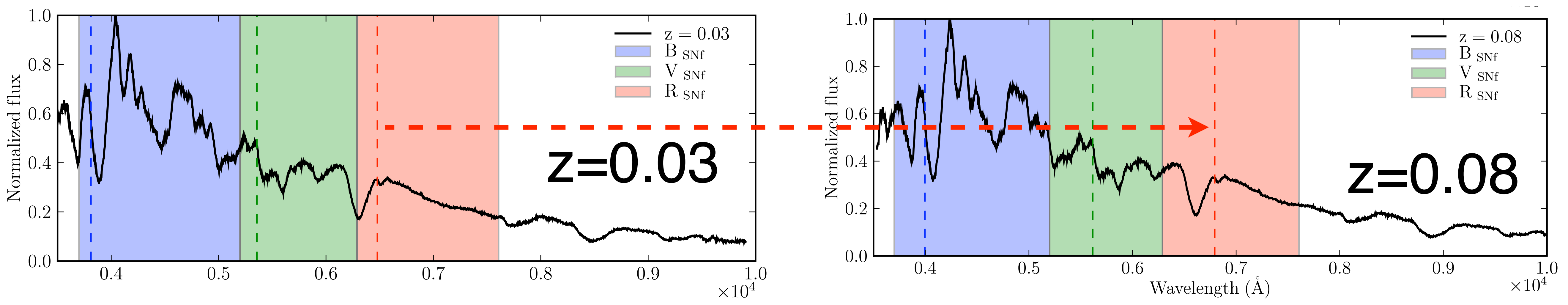
- Synthesize photometry on a redshift-dependent filter-set
- One filter integrates the same spectral range on all SNe
- Minimize systematic errors due to the light curve fitter spectral model (SALT2)



(74 SNe)	"standard" SALT2	no K-correction	$\sqrt{\Delta\sigma^2}$
σ_{core} (mag)	0.158	0.138	0.077
SNe Ia σ_{int} (mag)	0.131	0.110	0.071

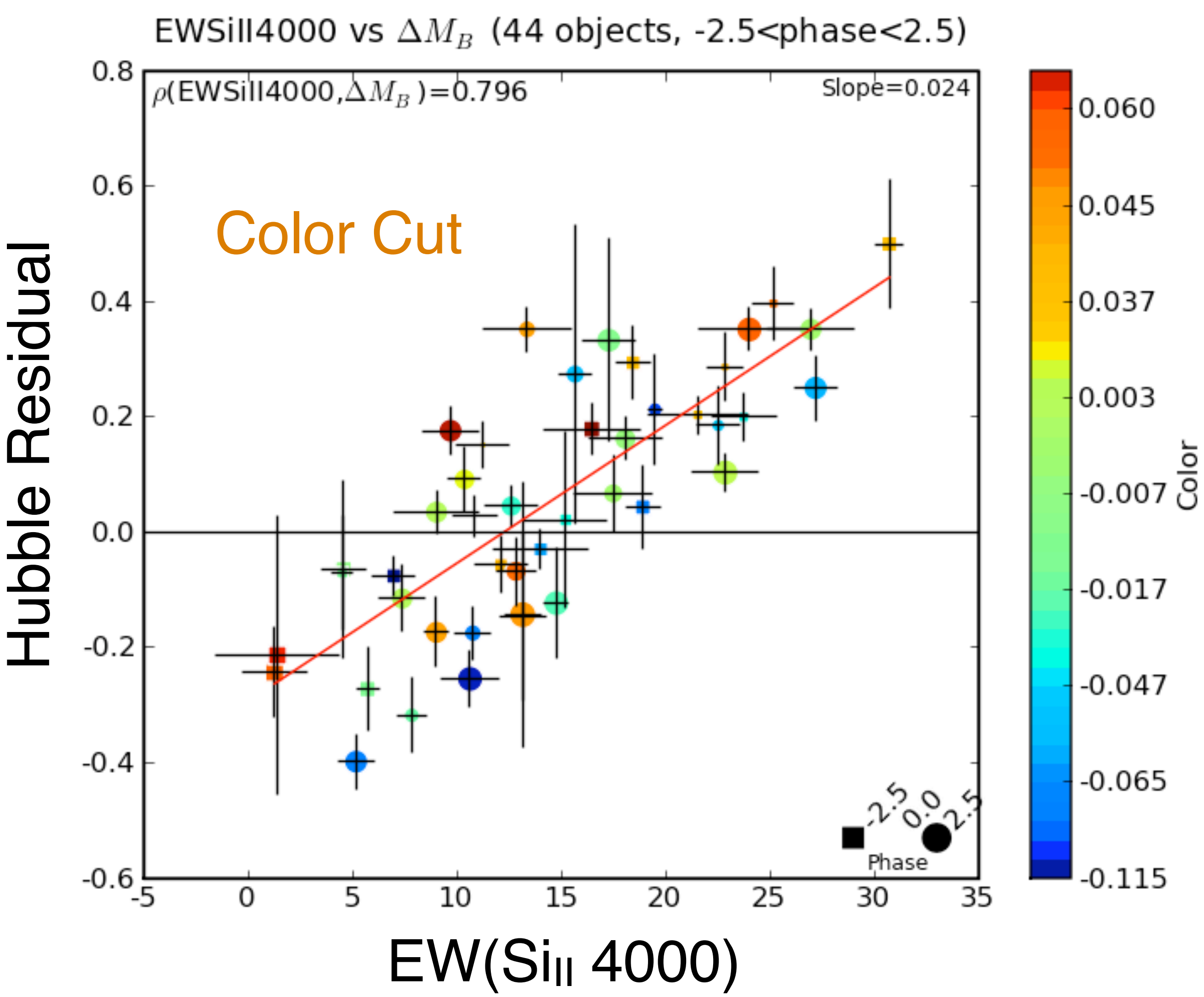
K-correctionless Cosmology

- Custom calibrate each high-z SN with low-z SNe using
  - same filters
  - same restframe wavelengths
- Apples-to-apples comparisons for cosmology
- Cancels many fit biases
- Work in progress...



Classic Metric Studies

- Complete study underway of classic metrics (R_{Si}, EW(4000), etc.)
  - Ability to standardize SNe Ia
  - Covariance with each other and with stretch and color
- Example: EW(Si_{II} 4000)



Color cut

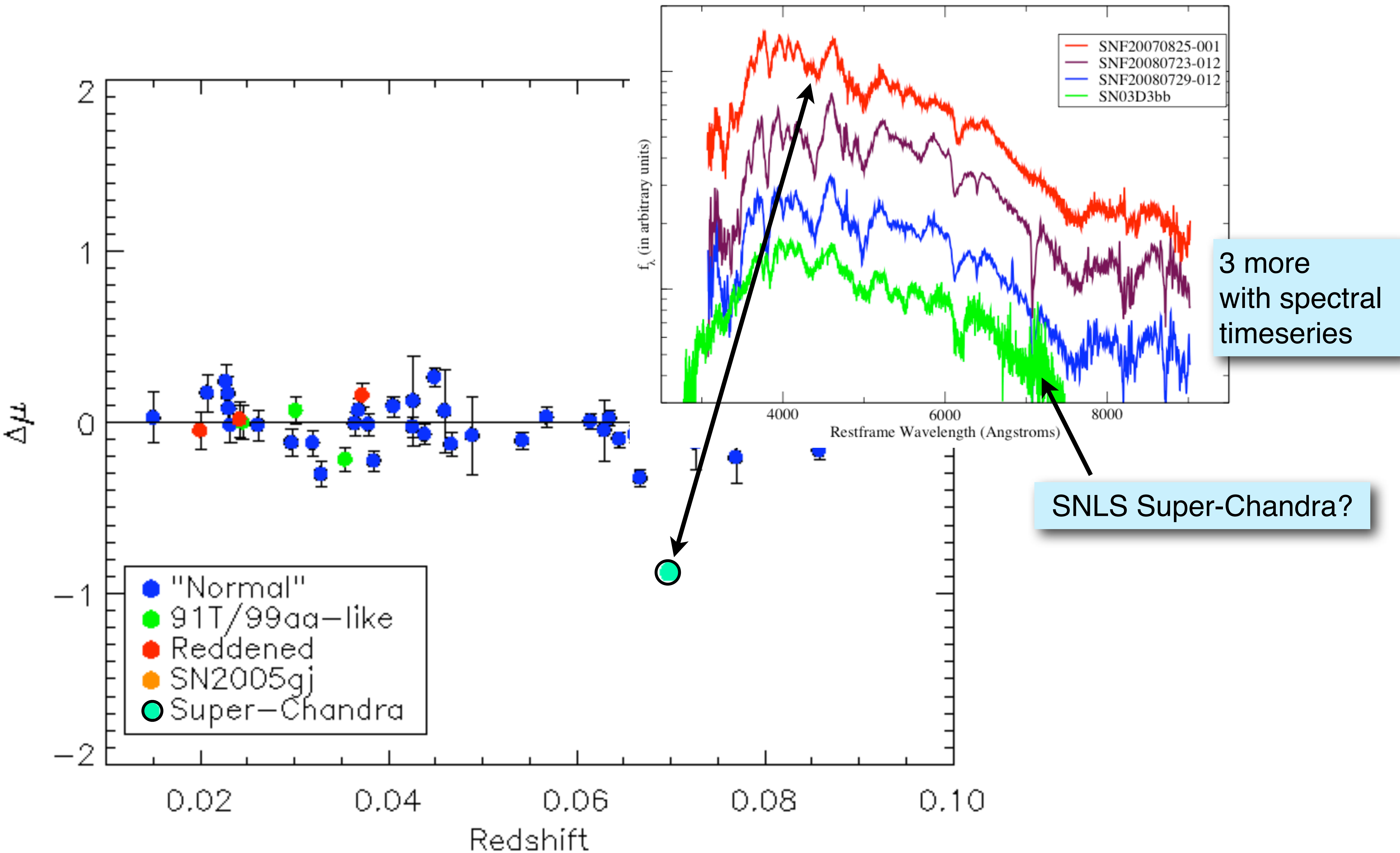
Correction	None	c & x1	c & EWSiII 4000	None	c & x1	c & EWSiII 4000
RMS	0.406	0.161	0.164	0.217	0.153	0.123
nMAD	0.264	0.159	0.177	0.243	0.139	0.148

Standard deviation and normalized median absolute deviation.

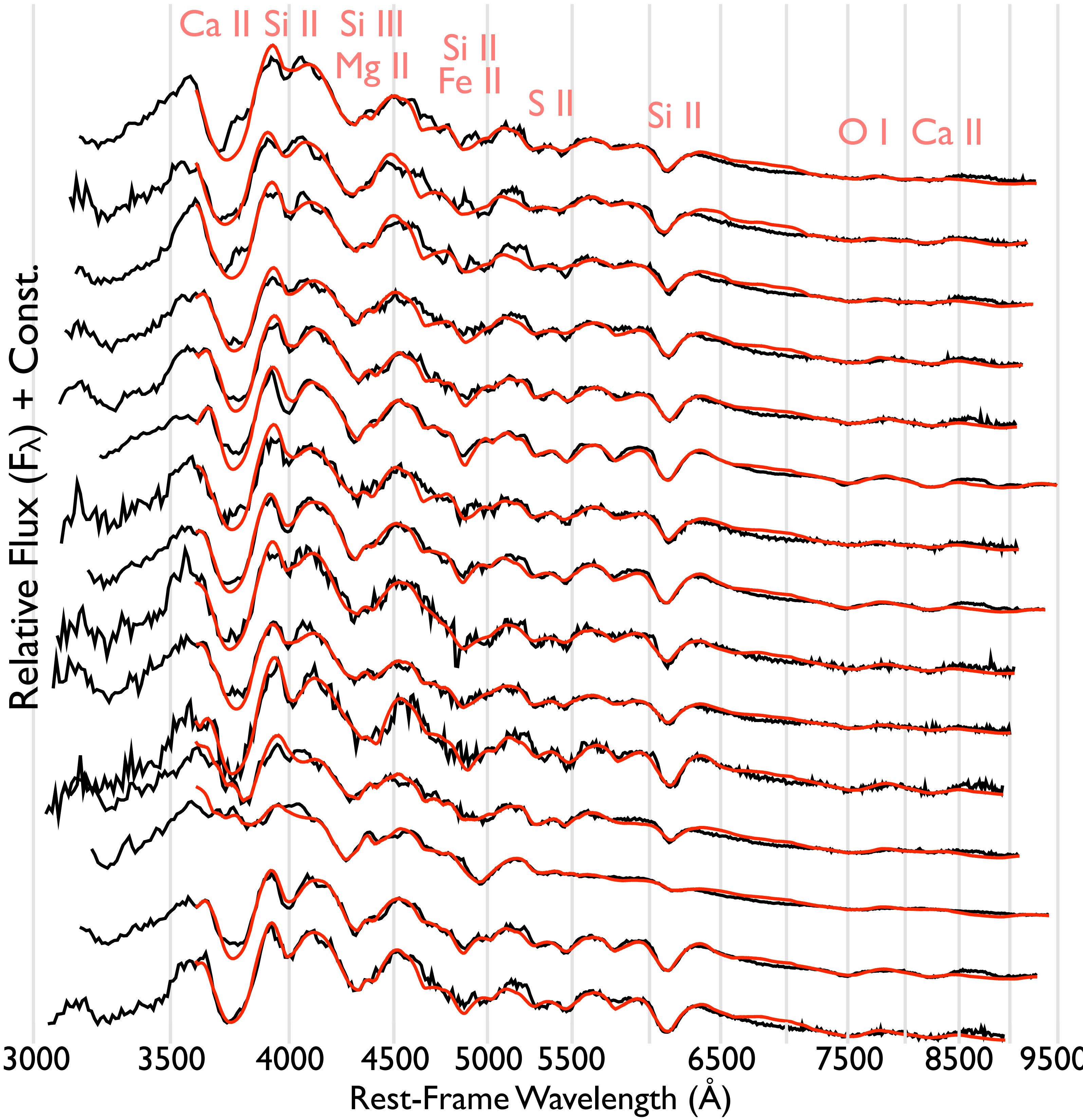
EW(Si_{II} 4000) + Color competitive with x1 + Color
(cp Bronder EW alone)

Nicolas Chotard

Double Degenerates?



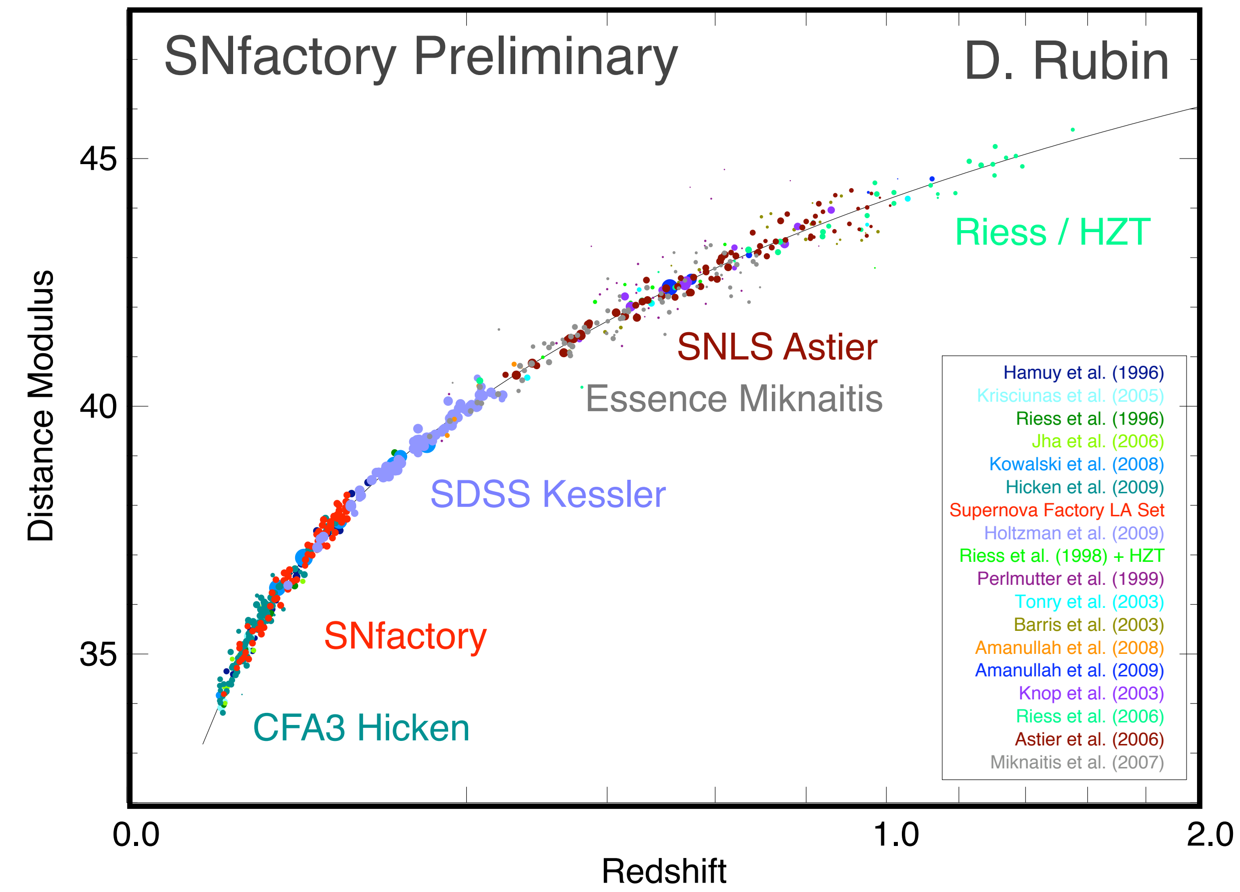
Modeling the Physics of SNe Ia



- Map underlying physics to observed features
  - Abundances, densities, KE
  - Stretch, color
  - Spectral features
- Data-driven modeling
  - New methods developed to handle the richness of data

Rollin Thomas

The Future



- Cosmology
  - Our highest priority
- Additional spectral metrics
  - Full study of classic metrics
  - New metric studies underway
- New SN spectral timeseries templates
- SN Modeling
- Studies of individual SNe
- and much more

From Taste to Facts

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  - Exactly how useful are spectra beyond typing and redshift?
  - Ariel: we need to do our homework
- SNfactory is doing that homework
  - *e.g.* Flux ratios are first quantitative evidence of how good spectra can outperform multi-color lightcurves on the same data
  - Just the first of multiple related analyses
    - Calibration methods: classic metrics, other new metrics
    - Likes-to-likes: calibrate SNe with other SNe that look most similar
    - Subsamples: split 91T-like from 91bg-like from normal from ...

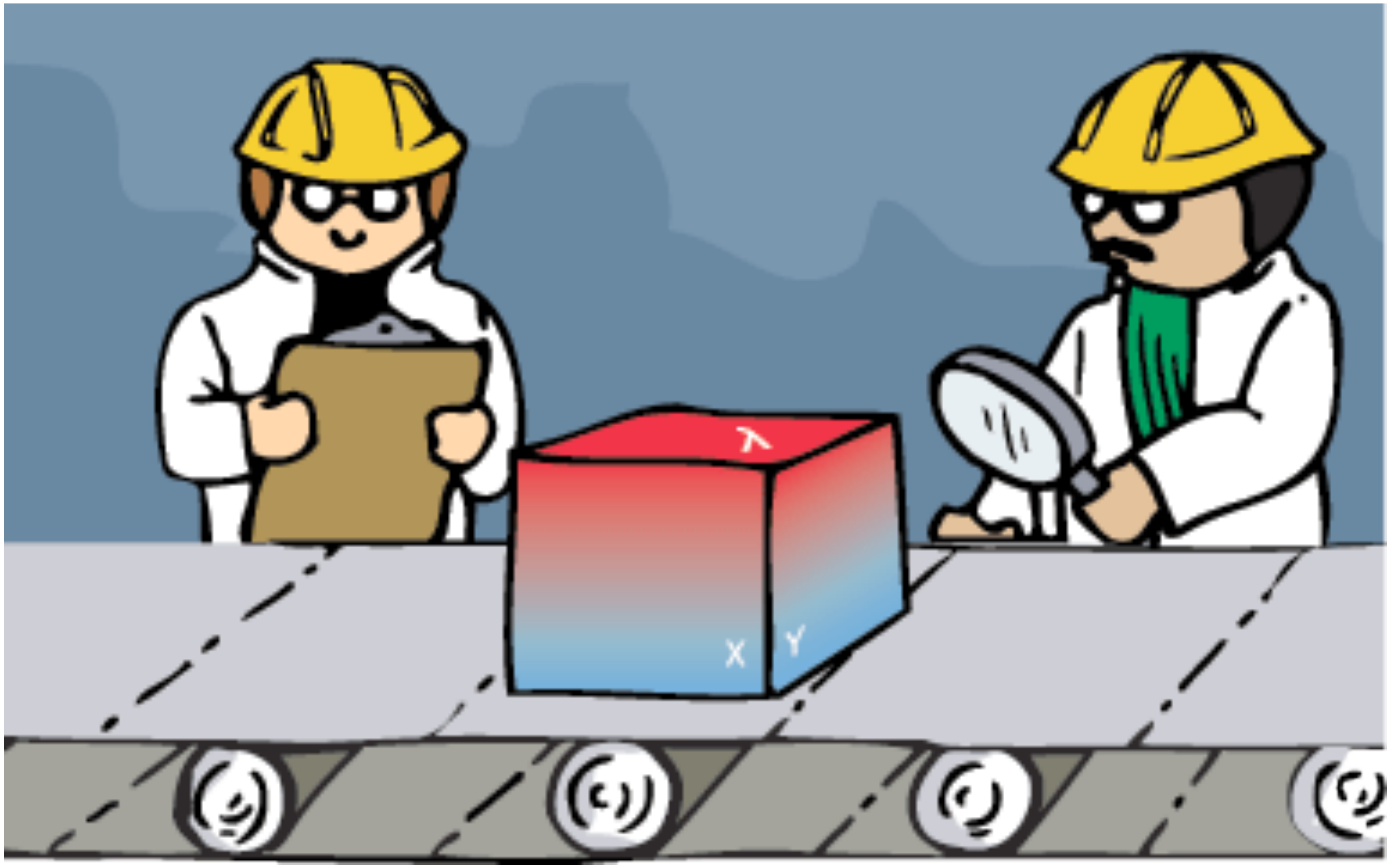

Image: D. Laferry