SDSS-II Photometrically-Classified Type Ia Supernova

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Thanks to all my collaborators in the SDSS II SN survey

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Outline

- Motivation
- Data – SDSSII SN survey and BOSS host z
- Photometric Classification
- Selection cuts: Choosing with Simulations
- Selection cuts: Data
- Hubble Diagram

Motivation

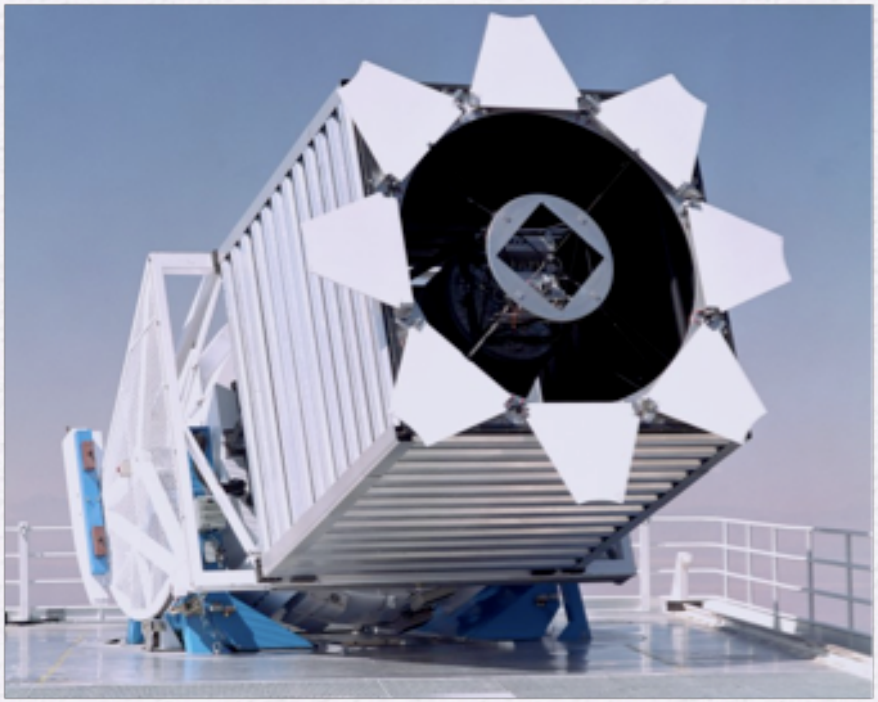
- How do we do SN surveys in the future?
- *SDSS + BOSS is a case study*
- Cosmology from a photometrically classified sample of hundreds of SNe
- *Also unbiased compare to spectroscopic surveys (good check of past results)*

Dark Energy Survey Camera

SDSS II Supernovae Project

- Ran for 3 seasons between 2005 and 2007
- *Regularly scanned "Stripe 82"*
- Database of 10,000s of transient objects
- *SDSS II SN survey 504 spec Ia*
- Cosmological analysis of the first year SDSS II data

The Sloan Telescope



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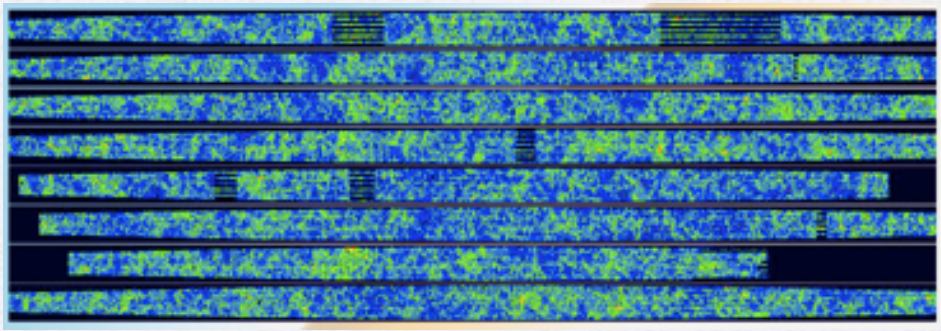
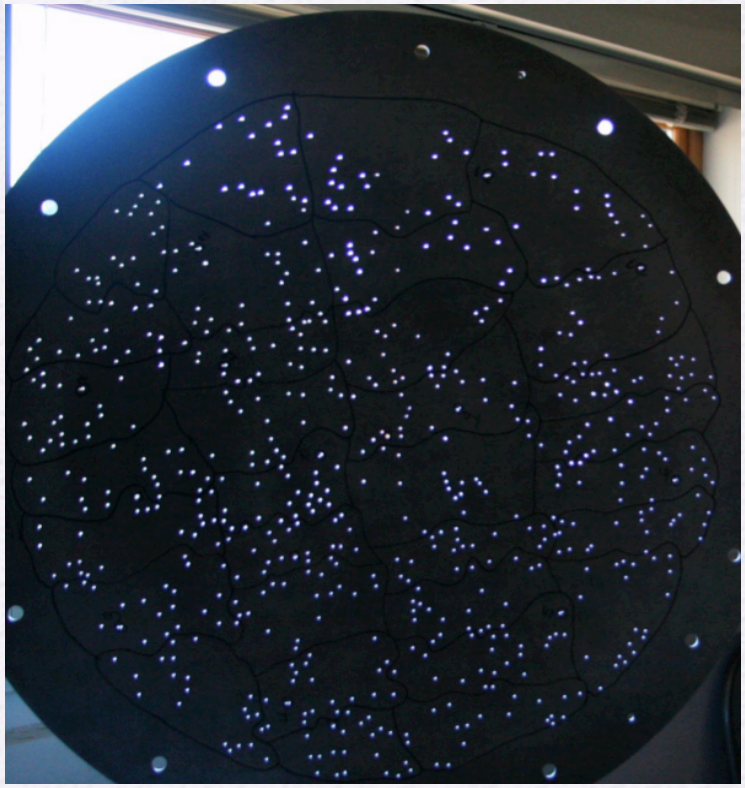
Stripes in Sloan



The SDSS observes the sky in stripes. Each of these eight long stripes contains millions of galaxies.

BOSS Host Galaxy Follow up

- *Spec z – Anchors SNe on Hubble diagram*
  – Improves classification & light curve fit



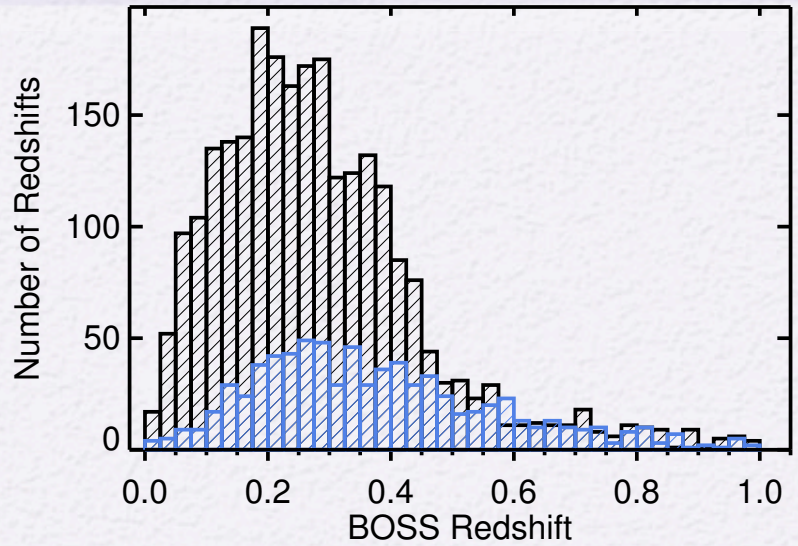
- Large sample of Host galaxy spectra: investigate intrinsic scatter

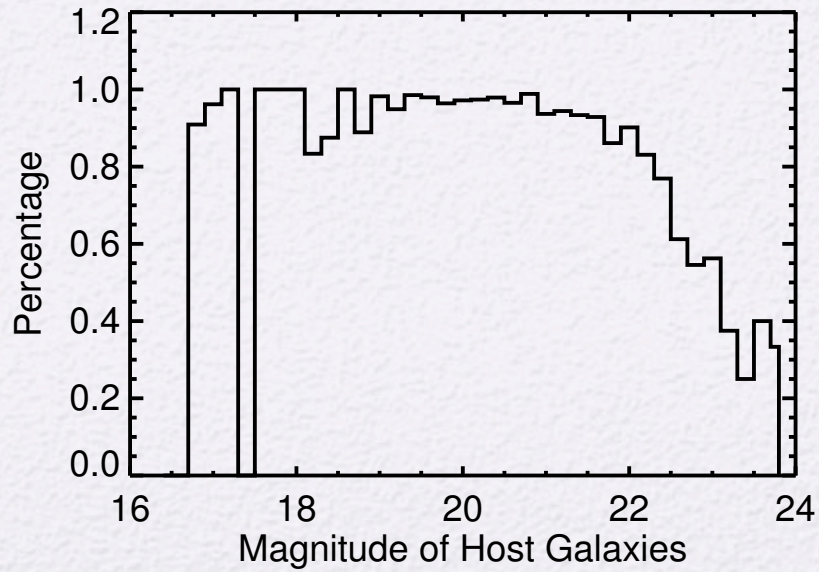
- *Plates drilled with 1000 holes*

- 3655 targets:
  1) Probability of being a SNe>0.2 (2654)
  2) Random sample of transients (1001)

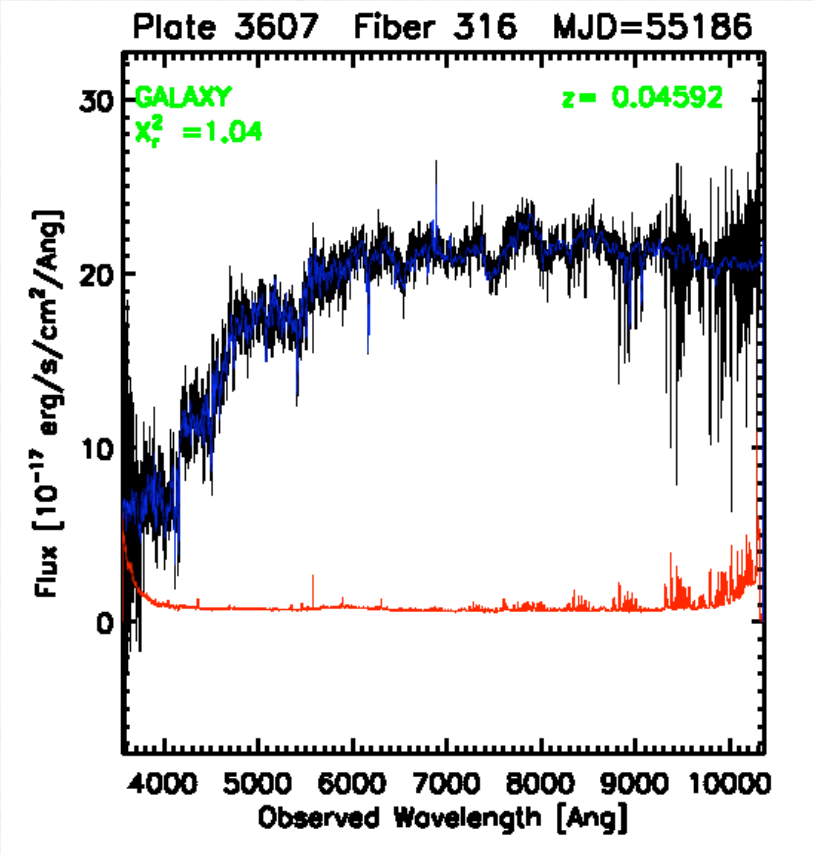
BOSS Host Galaxy Follow up

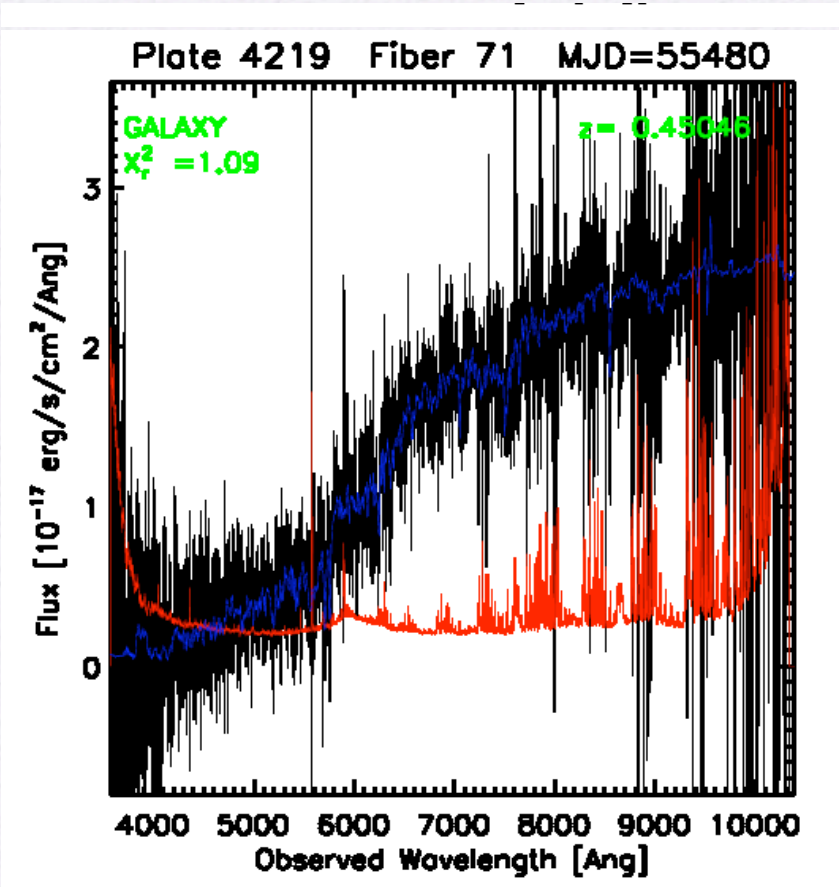
- 3392 galaxies with accurate redshifts (263 lost)
- 2433 from main sample (black)
- 959 from random sample (blue)
- Complete to 22 magnitude





BOSS Host Galaxy Spectra





PSNID Photometric Classification

$$E_{Ia} = \int P(z) e^{\frac{-\chi^2}{2}} dz dA_v dT_{max} d\Delta m_{15,B} d\mu,$$

$$P(z) = \frac{1}{\sqrt{2}\pi\sigma_z} e^{-(z-z_{ext})^2/2\sigma_z^2}.$$

$$P_{type} = \frac{E_{type}}{E_{Ia} + E_{Ibc} + E_{II}}$$

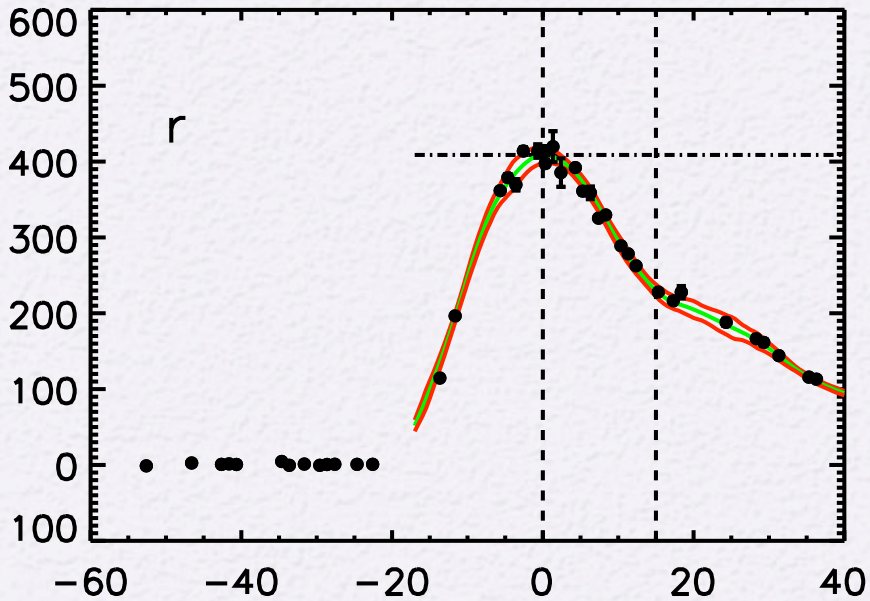
- Fits templates to the light curves to find lowest X^2
- *Host redshift used as a prior*
- Calculated Bayesian probabilities of the SN being a Type Ia, Type Ib/c or Type II

Data cuts and SALT

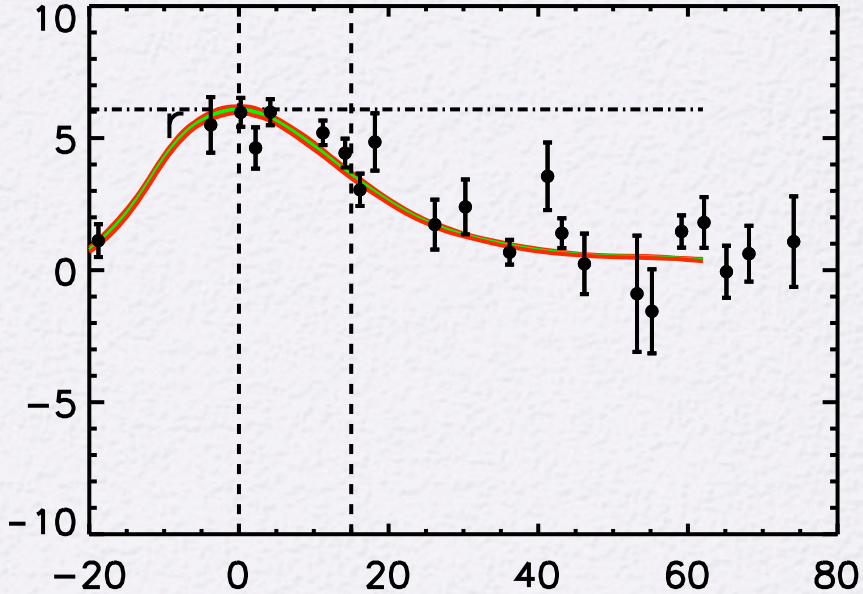
- Sako et al. classifier is good, but how do I make a cosmology sample?
- Data cuts quality
- Cuts on probability
- Cuts on salt parameters (really a 3D space)

SALT2 Light Curve Fitting

z=0.04592



z=0.45046



$$\mu = m_{*B} - M + \alpha X_1 - \beta c$$

$$m_{*B} = -2.5\log_{10}(X_0)$$

Simulations to Optimize Selection cuts

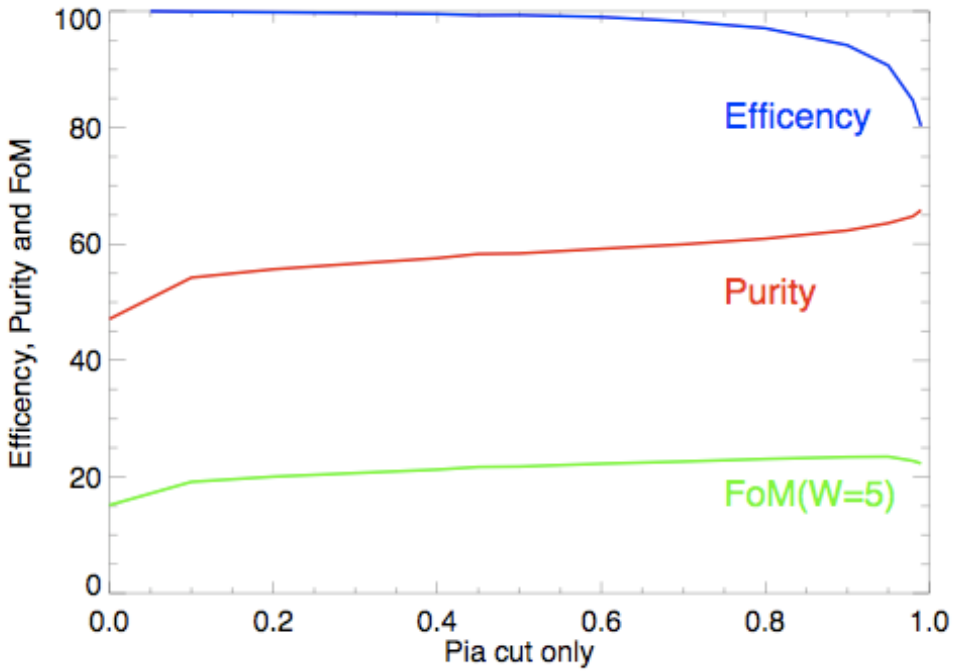
- Public SDSS SN Simulations (Kessler) created using SNANA
- *Redshift range and observing conditions to replicate SDSS SN survey.*
- 5018 Type Ia
- 7185 Non Ia
- *Run all simulated SN through classifier and fitted light curves*

$$E_{Ia} = \frac{N_{Ia}^{true}}{N_{Ia}^{cut}}$$

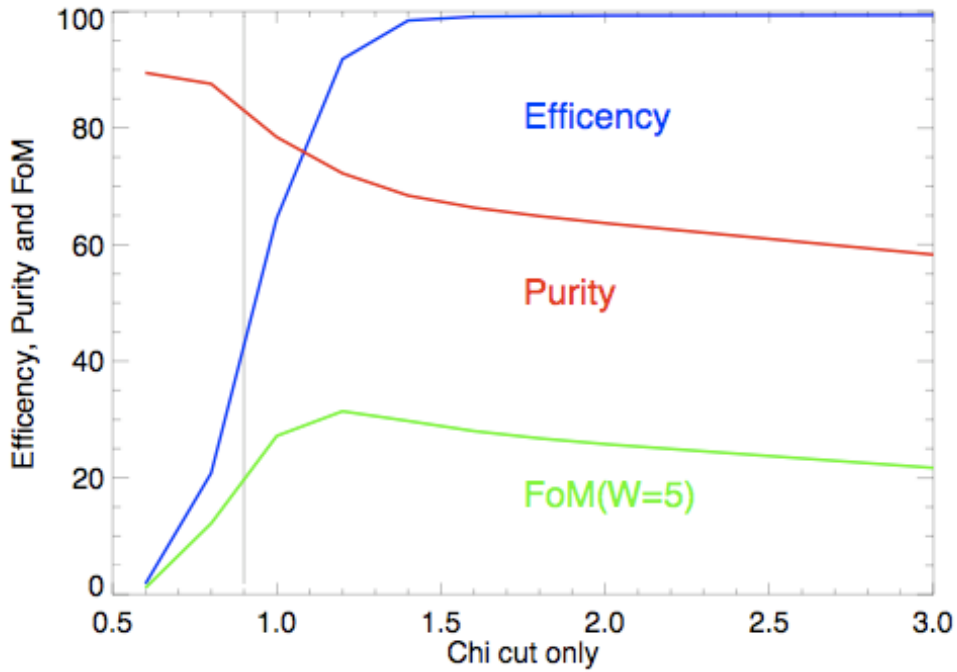
$$P_{Ia} = \frac{N_{Ia}^{true}}{N_{Ia}^{true} + N_{Ia}^{false}}$$

$$FoM(5)_{Ia} = \frac{N_{Ia}^{true}}{N_{Ia}^{cut}} \frac{N_{Ia}^{true}}{N_{Ia}^{true} + W_{Ia}^{false} N_{Ia}^{false}}$$

Selection cuts: Simulations Probability and X^2

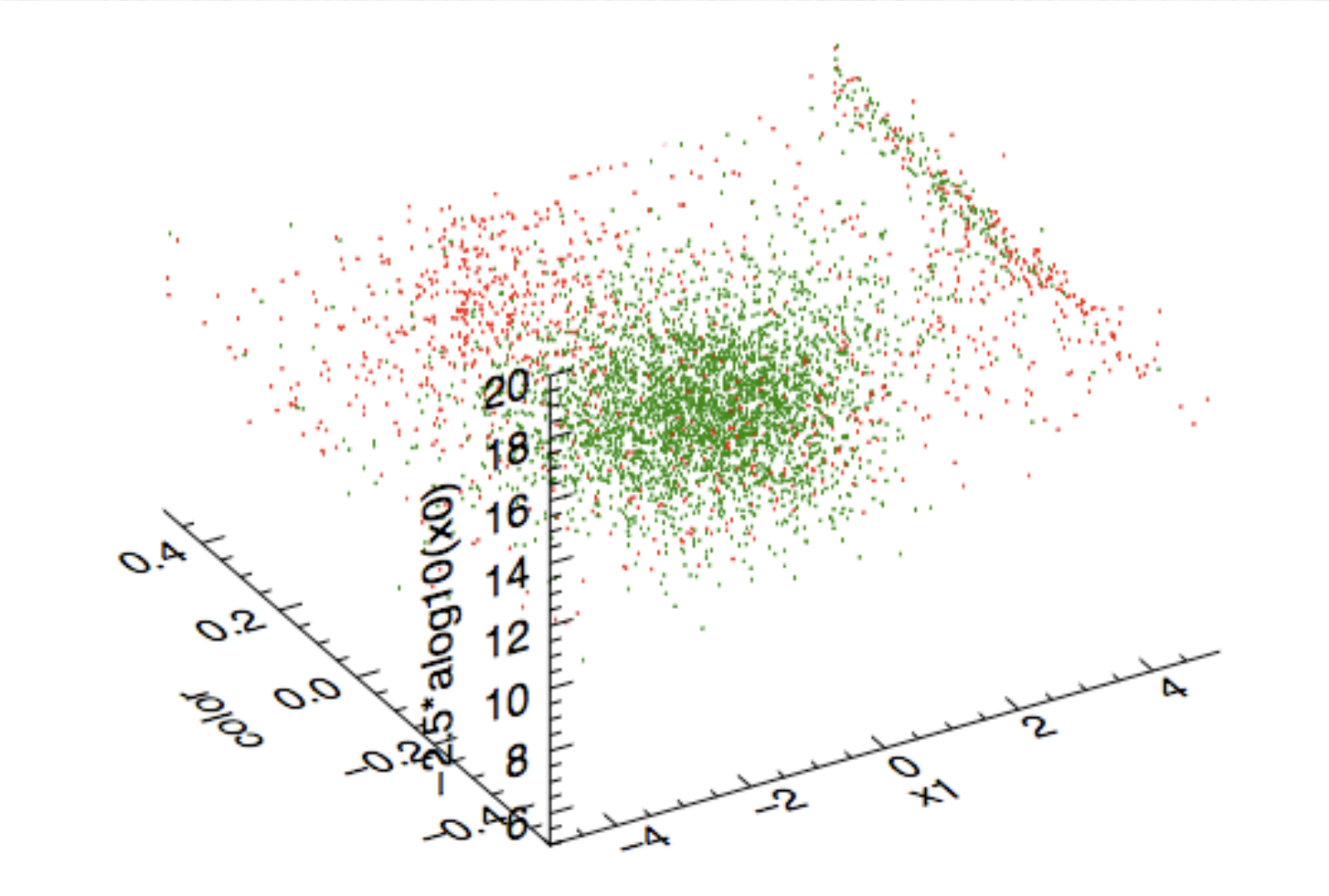


- Light curve quality cuts:
  - -5 < 1 epoch <+5
  - +5 <1 epoch <+15



- $P_{Ia} > P_{non}$ (inclusive)
- $X^2 > 1.2$ (peak of FoM)

Selection cuts: Simulations SALT2 Parameters 3D space



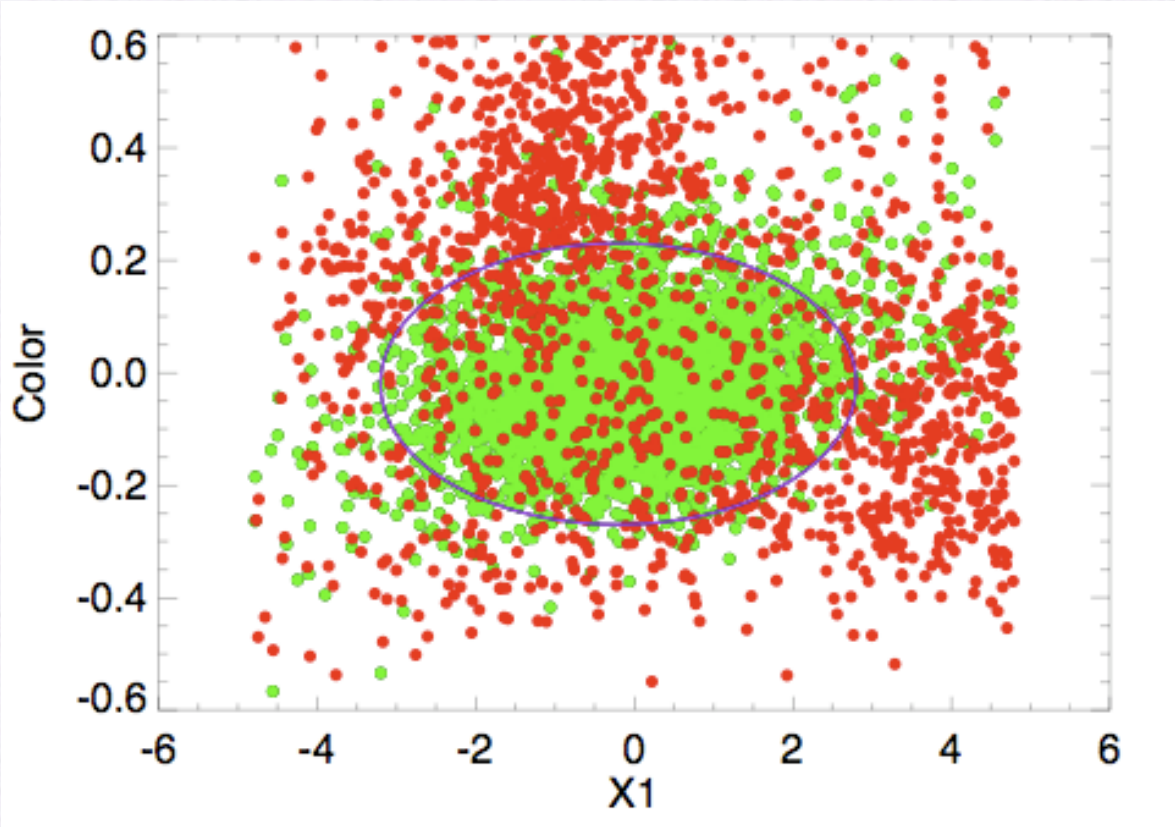
Selection cuts: Simulations SALT2 Parameters Color and X1

- Color and X1 cut an ellipse

$$\frac{y^2}{a^2} + \frac{(x+0.2)^2}{b^2} = 1 - 0.02$$

a = semi-major axis
= 3 (X1 axis)
b = semi-minor axis
= 0.25 (color axis)

Center at (-0.2,-0.02)



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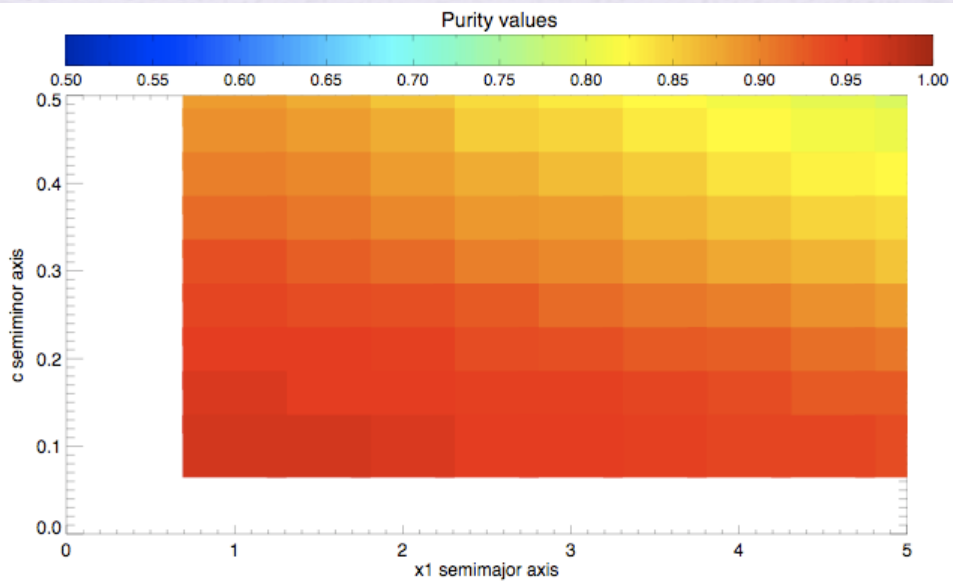
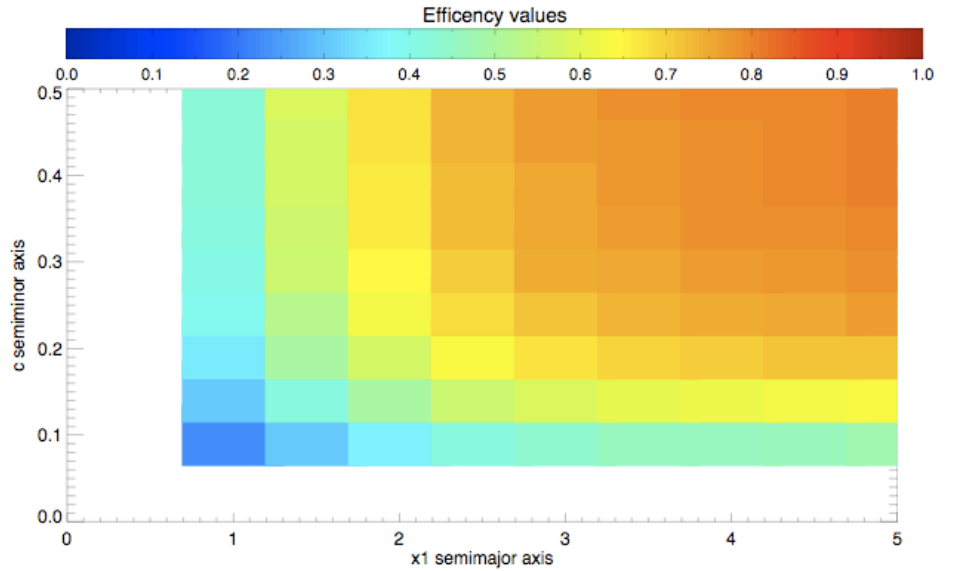
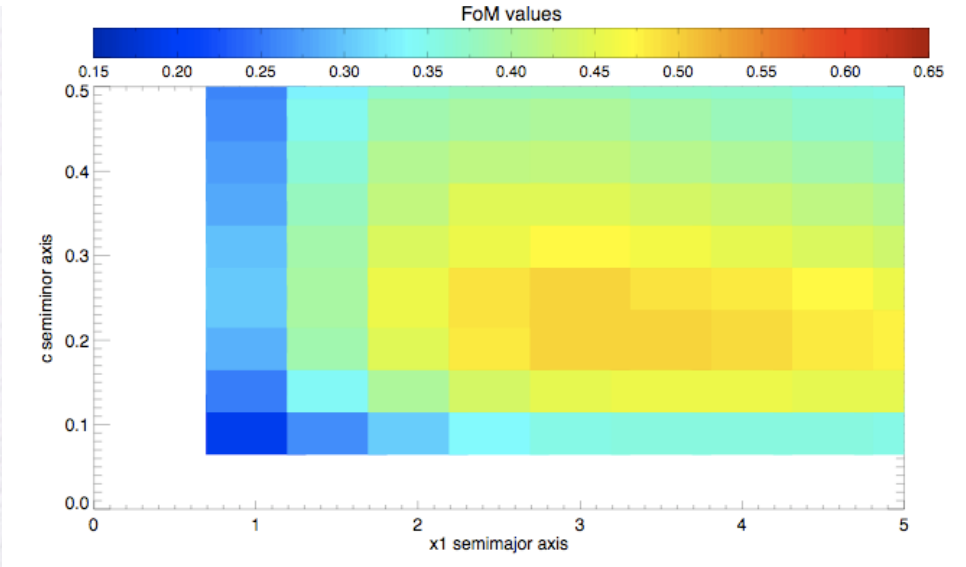
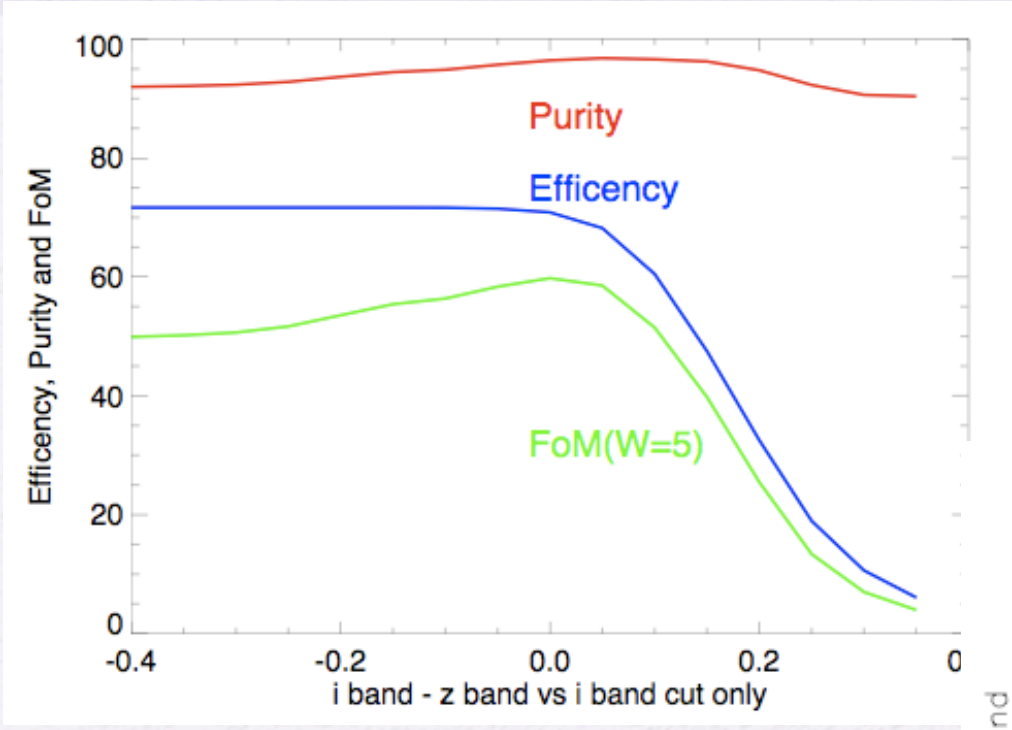


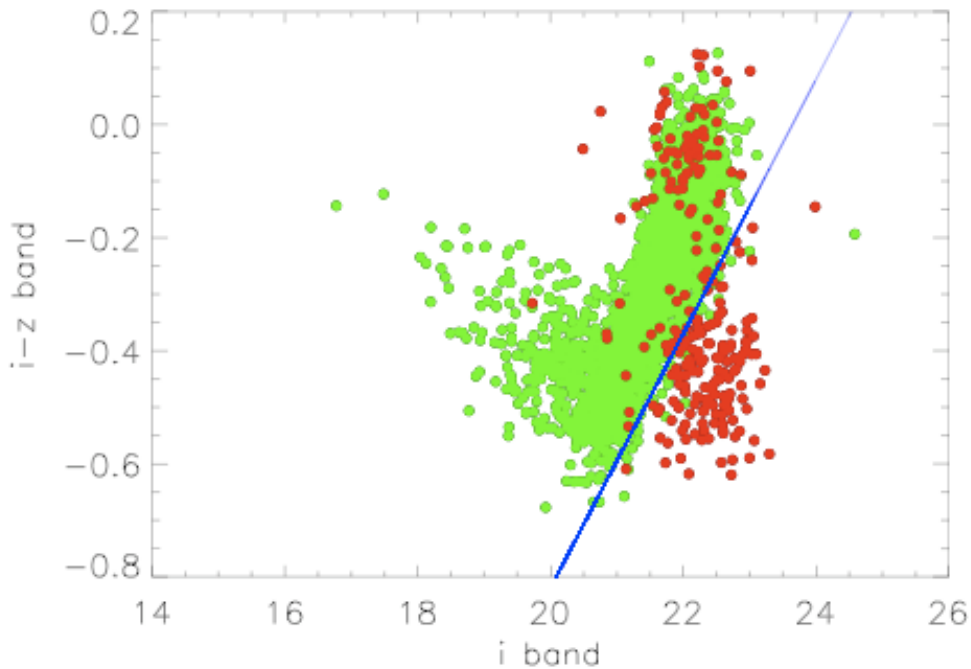




Selection cuts: Simulations
Color vs magnitude cut



- i-band – z-band vs i-band >blue line shown (peak of FoM)



Selection cuts: Simulations
All cuts summary

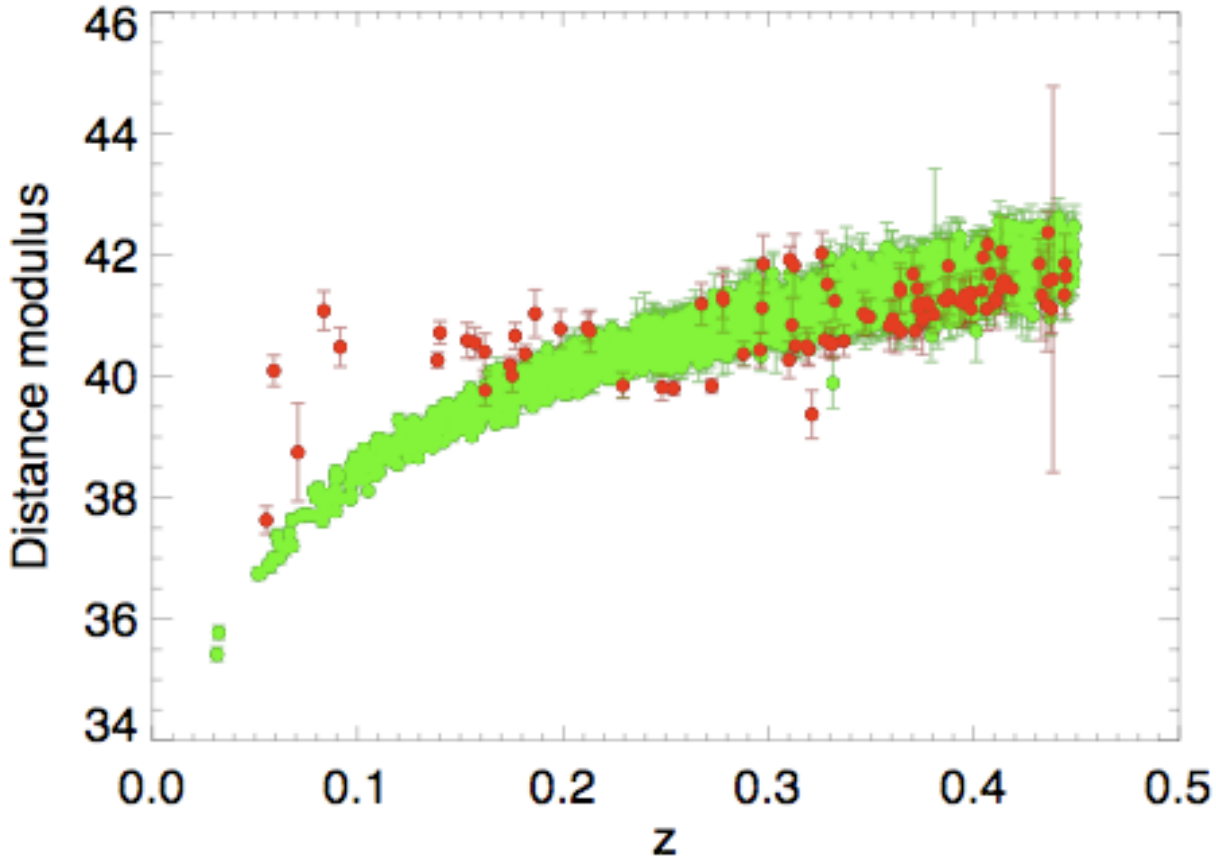
Selection cut	Contamination	Efficiency	FoM (W=5)
$P_{Ia} > P_{non}$	41.7%	99%	21.7%
$X^2 \geq 1.2$	27.8%	91.8%	31.4%
X1, color ellipse	8.1%	71.6%	49.6%
i-band – z-band vs i-band	3.7%	70.9%	59.8%

Selection cuts: Simulations
All cuts Hubble Diagram

After all cuts have:

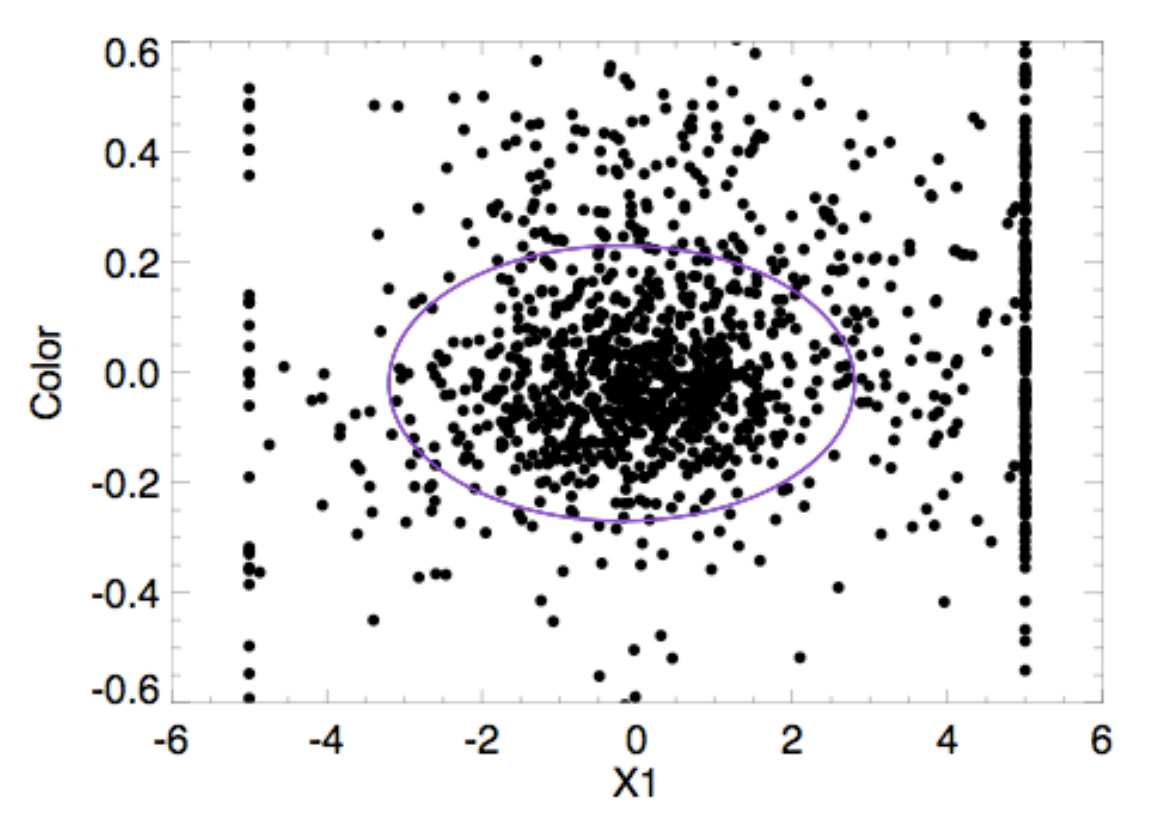
- *Purity= 96.3%*
- *Efficiency = 70%*
- *FoM(W=5)= 60%*

- 2644 Type Ia
- 98 non Ia



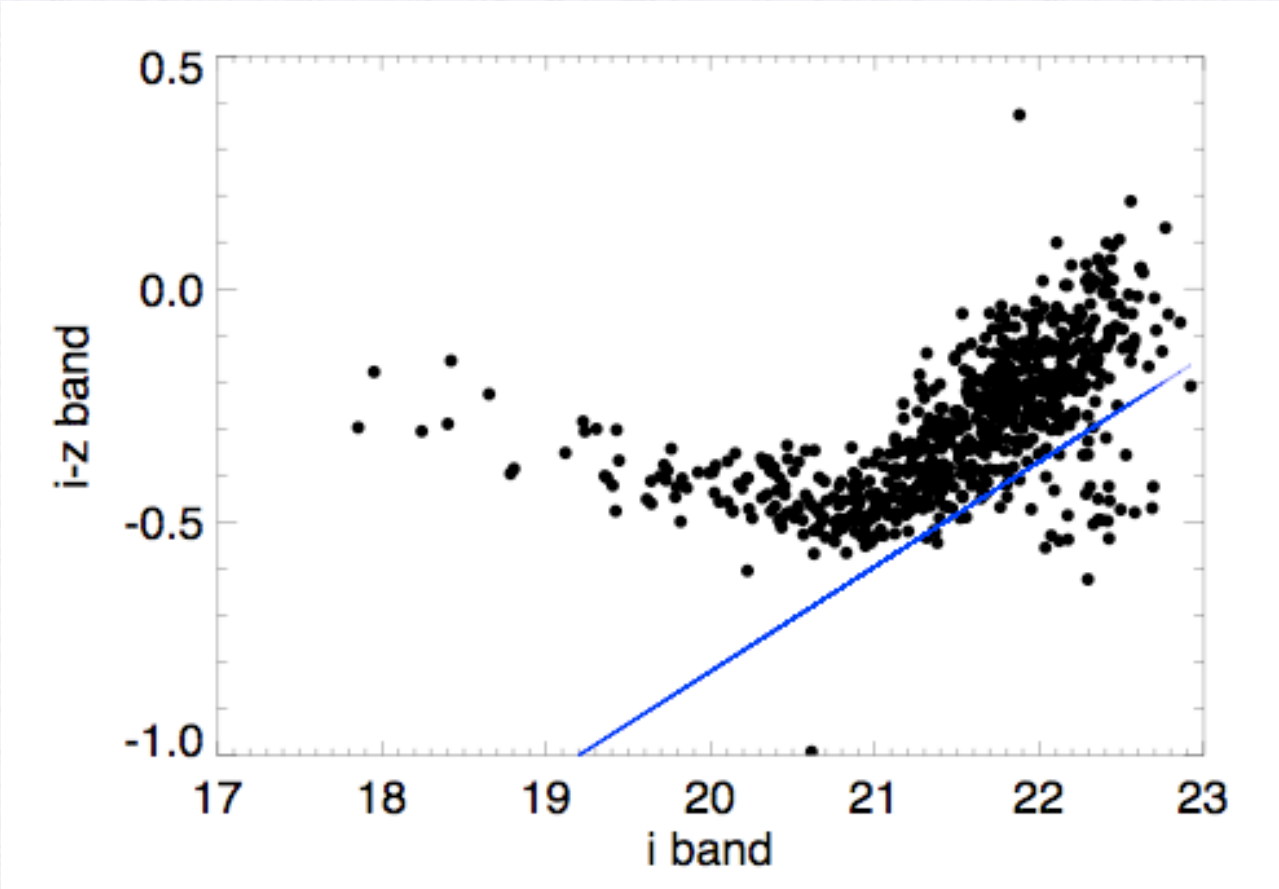
Selection cuts: Data Probability, X^2, Color and X1 ellipse

- Light curve quality cuts:
  - -5 < 1 epoch <+5
  - +5 <1 epoch <+15
- $P_{Ia} > P_{non}$
- $X^2 > 1.2$
- Color vs X1 ellipse



Selection cuts: Data Color vs Magnitude cut

- i-band –z-band vs i-band > blue line

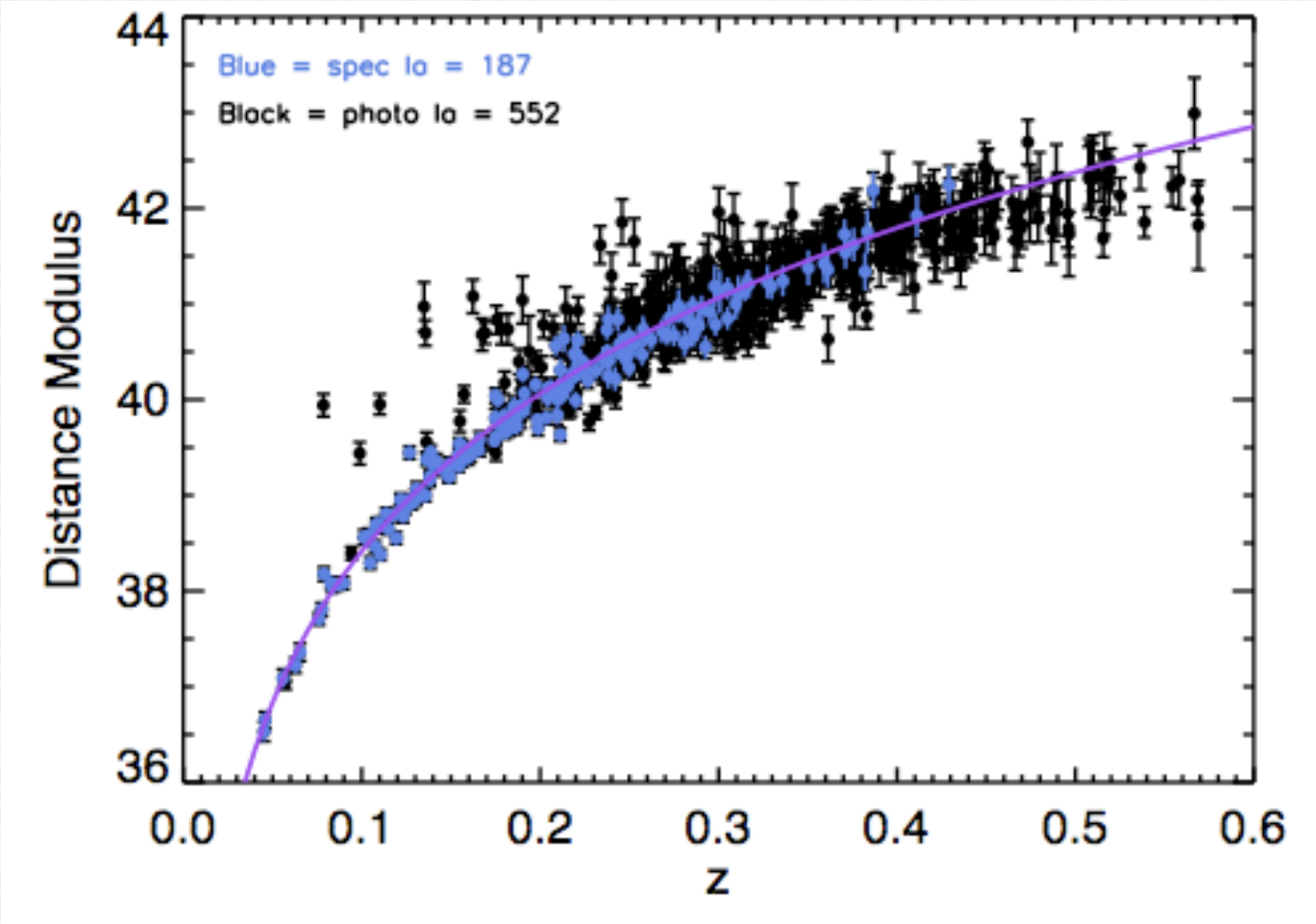


Selection cuts: Summary

Selection Cut	Number SNe removed	Number of SNe kept	Number Spec Ia
Accurate Redshift		3392	289
Quality	1429	2515	221
$P_{ia}>P_{non}$	552	1963	219
X^2	587	1376	213
Color and X1 cut	614	762	187
i-band – z-band vs i-band cut	23	739	187

Photometric Hubble Diagram

739 SN with host redshifts on Hubble Diagram



Can it get better?

- Cut on host distance
- Photoz
- Other color plane cuts

Steps to Cosmology

- Summary!
- Malmquist bias - simulations can help
- Host galaxy (We have all the spectra!)
- Systematic errors

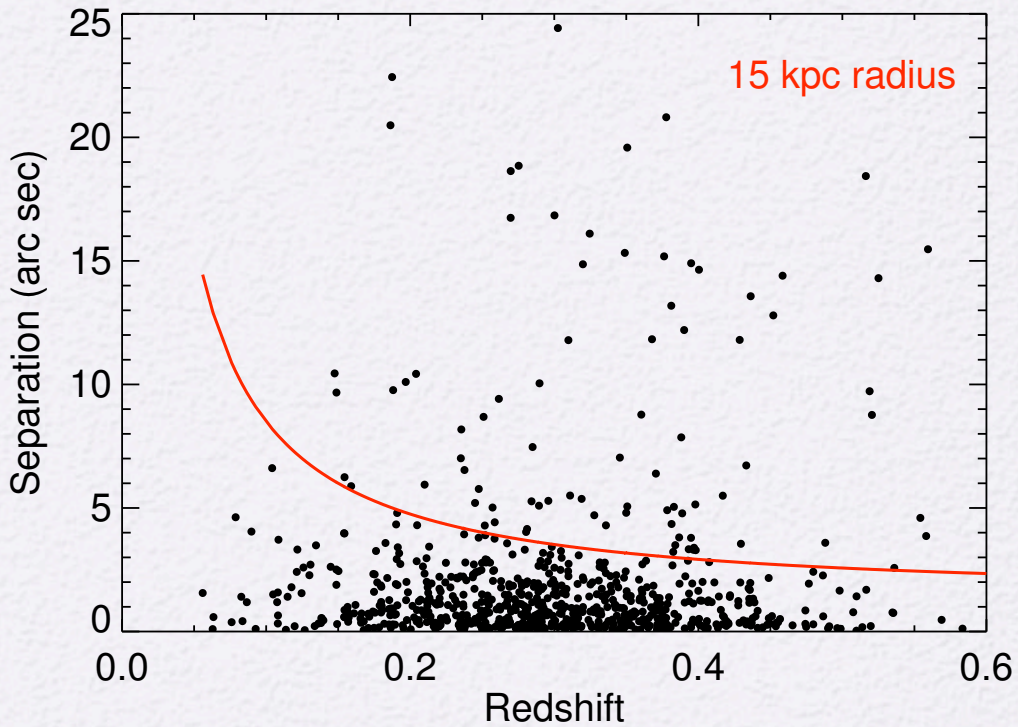
Summary

- 3394 reliable host galaxy redshifts
- Photometric classification of SNe, using host z as a prior.
- New Hubble diagram with 739 SN Ia (187 spec Ia, and 552 New)
- Very important for the next generation of SNe surveys

Extra slides!

Quality Criteria: Host galaxy cut

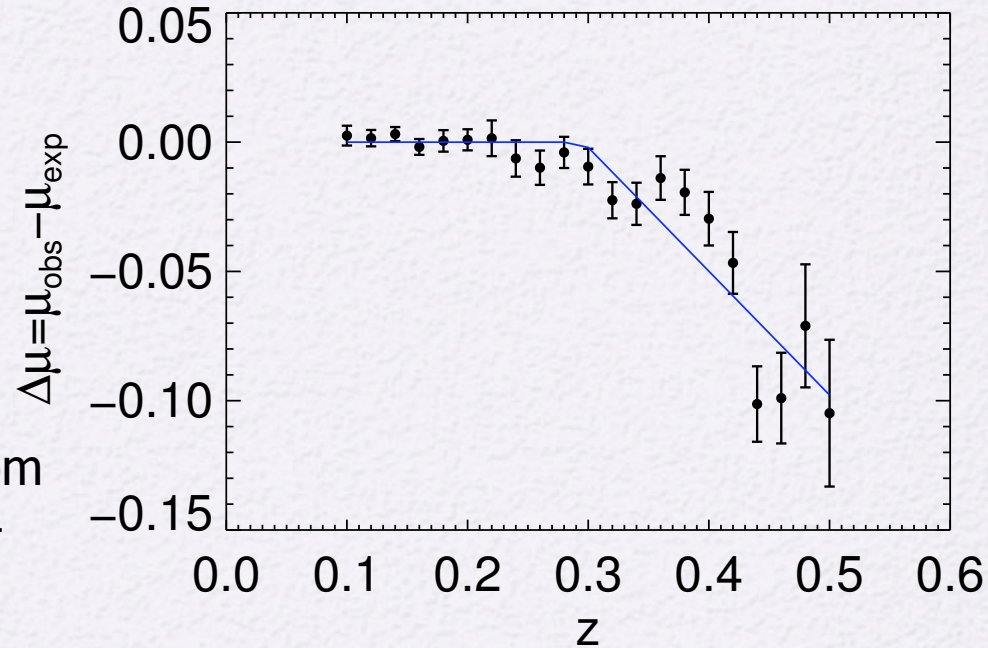
- Distance to Host Galaxy cut:
- If the separation between SNe and host galaxy is > 15kpc then candidate is removed



Bias Tests: Malmquist Bias

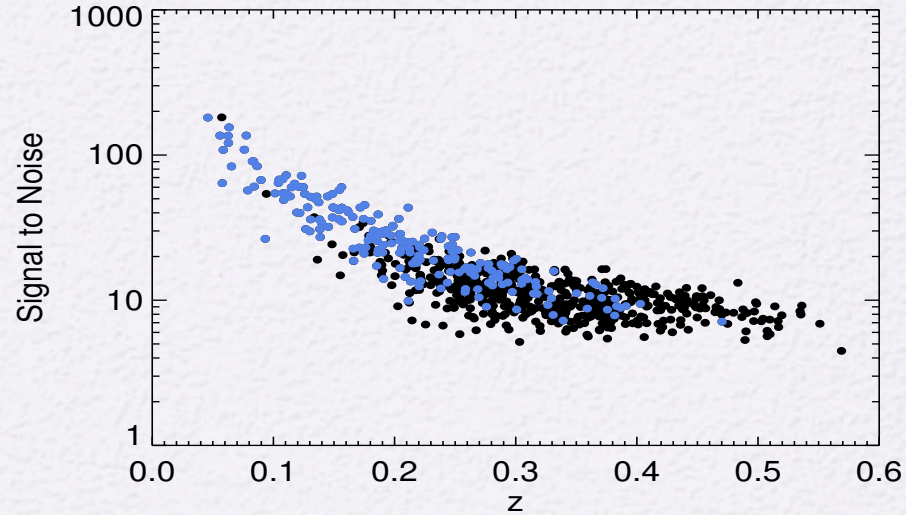
- 30,000 SNe Ia SNANA simulations
- Model for the Malmquist bias as a function of redshift.
- 10 random samples, size and z distribution of photometric sample
- Cosmological analysis with and without Malmquist Bias correction
- All samples were >> 2 σ away from input w without correction and <<1 σ when included.
- Checked correction not stretch or cosmology dependent

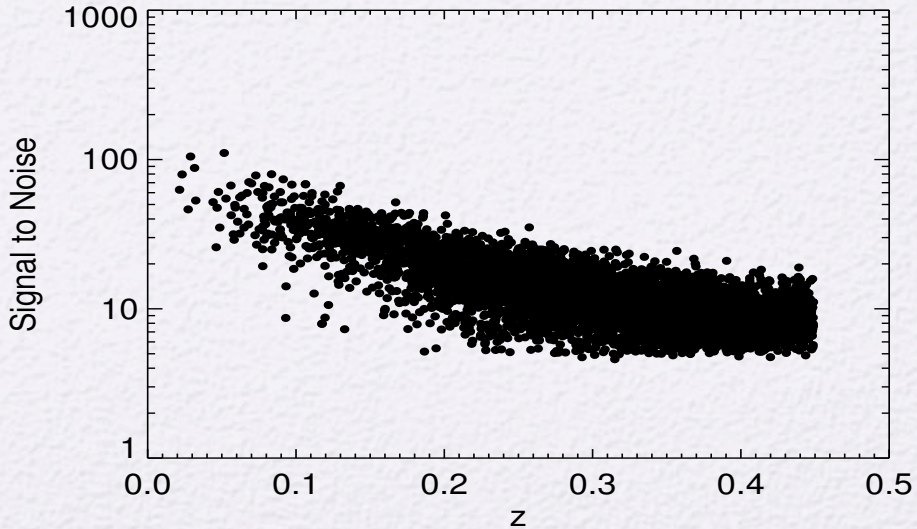
Malmquist Bias correction



Bias Tests: Malmquist bias

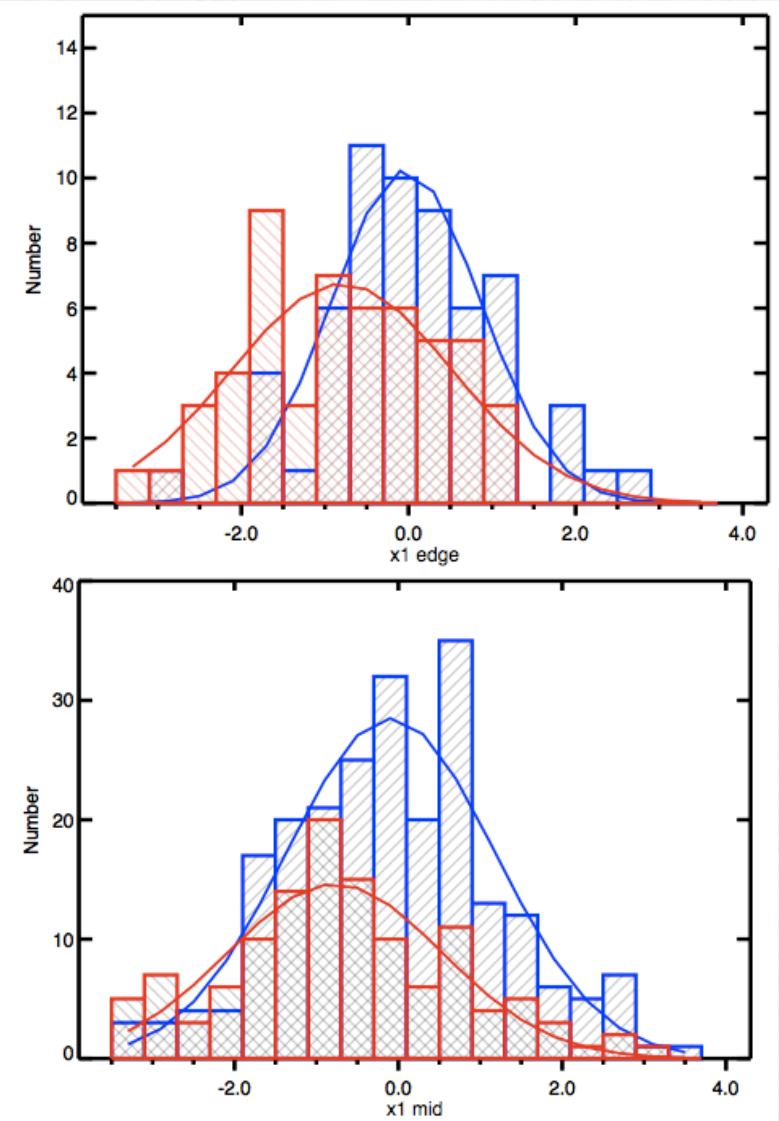
- Spec SNe Ia at a given redshift have systematically higher S/N than the photo Ias
- z > 0.3 we see effect of S/N> 5 selection cut, curtailing the distribution
- Leads to the "Malmquist bias"
- See same in simulations





Host Galaxy Correlations

- Have spectra for all hosts
- SALT2 X1 color distributions in Red/blue galaxies: SALT color same in both galaxies, X1 different, same relation at all distances from centre of galaxy
- Host masses form BOSS pipelines (cosmology corrected for the host galaxy mass correlation)



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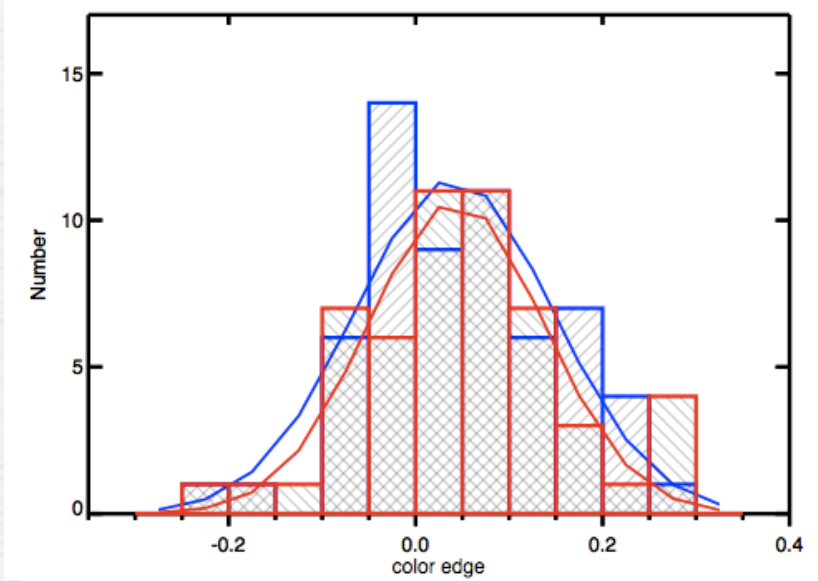

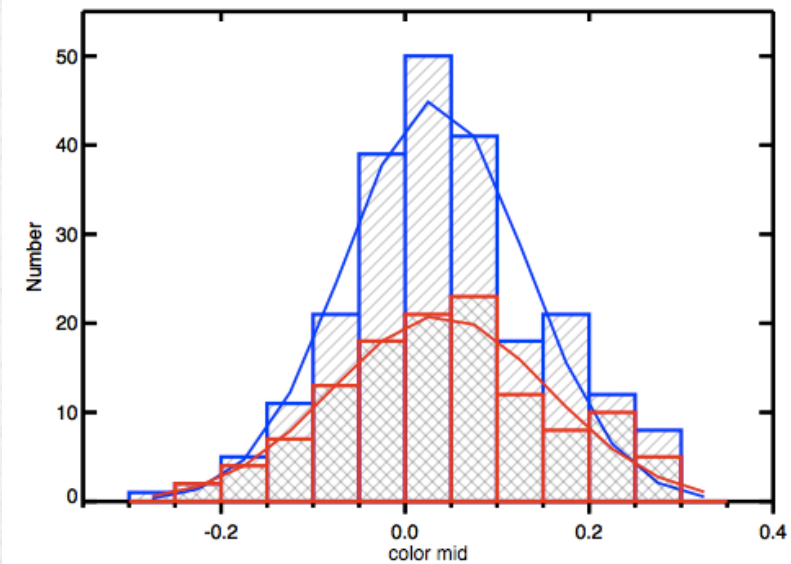

Systematic Errors

Instrumental:

- Photometric calibration
- Light curve fitting techniques

Astrophysical:

- Correlations with hosts galaxy properties
- SN lensing
- Peculiar velocities
- Galactic dust
- Possible SN evolution

Implications for DES

- Possible to use photometrically classified supernovae for cosmological analysis – Good for DES which can't follow up all Sne

- Host galaxy z are important for classification and Hubble diagram - minimum DES needs for each SNe
- Low contamination – appears to create no bias on cosmology
- Need to model the Malmquist bias for magnitude limited samples