Supernova Survey with WFIRST-AFTA

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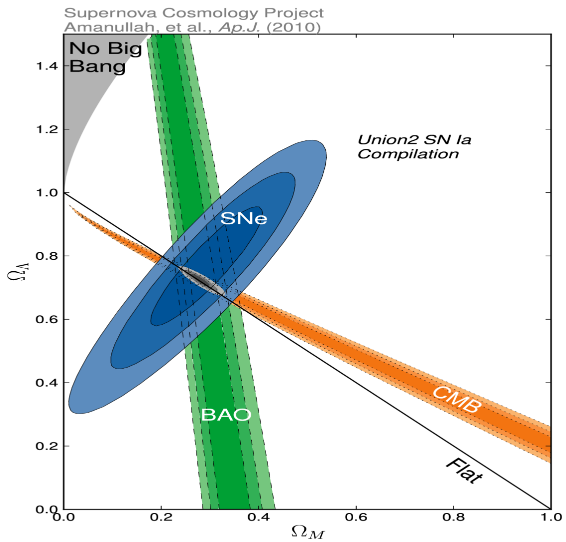
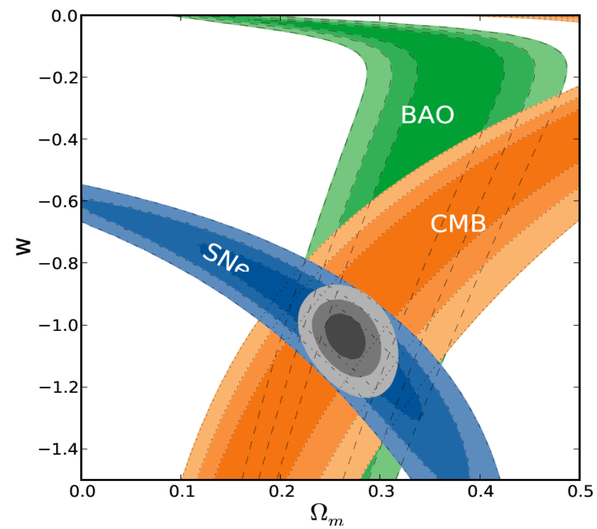
The Nature of Dark Energy

- Part of the mission of WFIRST-AFTA is the study of the nature of Dark Energy using all three techniques
  - Type Ia supernova (SNe)
  - Baryon Acoustic Oscillations (BAO)
  - Weak Lensing (WL)
- SNe and BAO both measure the expansion history of the Universe. They are complementary since their error ellipses or bands in various parameters intersect at different angles, giving much better constraints then either alone.
- Weak Lensing measures the growth of structure. Together with SNe and BAO a check on General Relativity is possible.
- The WFIRST Science Definition Team has simulated all of these techniques in great detail

Complementarity of Techniques



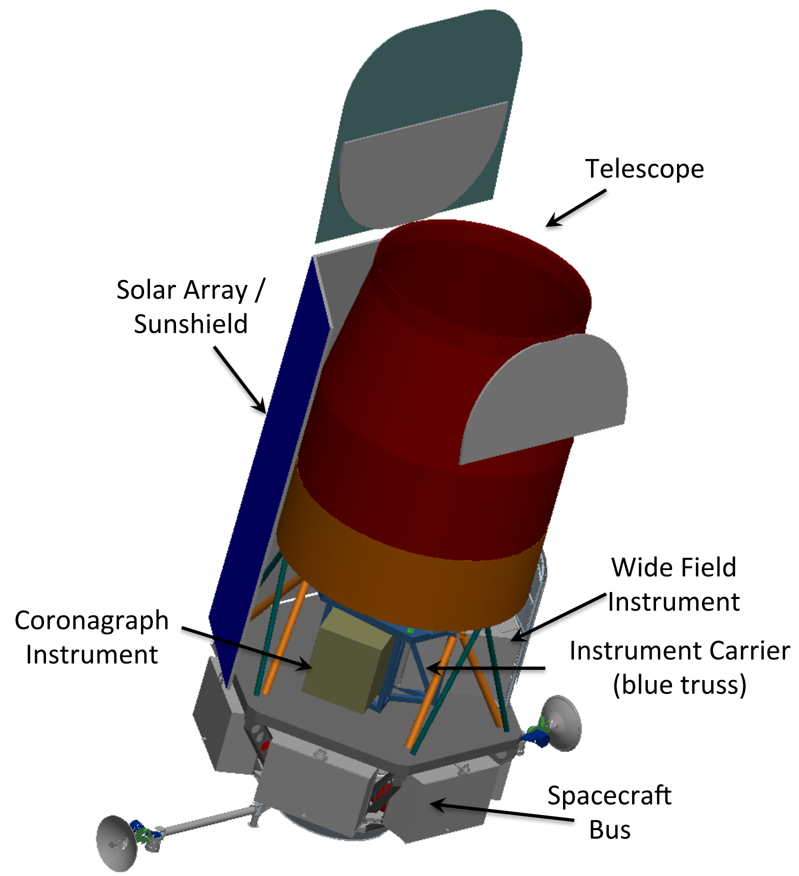


Results from Amanullah et al ApJ 2010

WFIRST –AFTA Baseline

Assume 6 months for Supernova Survey

- 2.4 m on axis mirror
- Imager with
  - 18 H4RG detectors (6x3)
  - 0.11 “/pixl
  - 0.28 sq degrees
- Filter wheel with
  - 4 filters.
- IFU Integral Field Spectrometer
  - R = 75 (150 per pixel)
- 2.0 micron λ cutoff



Supernova Survey Strategy

- Use the 0.28 sq degree imager to discover supernovae in two filter bands
- Use IFU spectra to get light curves with roughly a 5 day rest frame cadence
- 7 spectra on light curve from -10 rest frame days before peak to +25 rest frame days past peak, S/N = 3 per pixel (S/N = 15 per synthetic filter band)
- 1 reference spectrum after supernova has faded, for galaxy subtraction with S/N = 6 per pixel
- 1 deep spectrum near peak for subtyping, spectral feature ratios etc. with S/N = 10 per pixel

Supernova Survey Strategy

- Do a 3 tier survey, scanning different areas of sky for different redshift ranges

Tier	Z max	Sky Area Sq Degrees
1	0.4	27.44
2	0.8	8.96
3	1.7	5.04

Survey Cadence

- Plan to run supernova survey for 6 months spread over 2 years calendar time.
- Plan on supernova survey with a 5 day cadence, 30 hours per visit
- (2*365/5)*30 hrs/24 = 182 days = 6 months

IFU Spectrometer, Lightcurves from Spectra

Use imaging to discover supernovae in two filters with S/N>4 in each

Use IFU spectrometer to get points on the lightcurve with S/N=15 per synthetic band (S/N=3 per pixel). Get an additional deep spectrum (S/N=10)near peak for subtyping and line ratios and one reference spectrum with S/N = 6 per pixel

Mode	Low z z < 0.4 Area Time Hours	Medium z z < 0.8 Area Time Hours	High z z < 1.7 Area Time Hours	Time per visit
Imaging Discovery	27.44 15sec 0.8	8.96 75s 1.3	5.04 360s 3.6	6 hrs
Spectra for lightcurves	27.44 varies	8.96 varies	5.04 varies	11hrs
Deep+Ref Spectra	27.44 varies	8.96 varies	5.04 varies	13hrs

2.4m IFU Deep, Spectro Lightcurves, FoM=312

<Z>	SNe Low z	SNe Mid z	SNe Hi z	SNe Total	σ_{stat}	$\sigma/\sqrt{N}$	σ_{sys}	σ_{tot}
0.15	46	14	8	69	0.114	0.014	0.006	0.015
0.25	139	44	24	208	0.114	0.008	0.007	0.011
0.35	269	86	47	402	0.116	0.006	0.008	0.009
0.45	0	144	78	223	0.117	0.008	0.008	0.011
0.55	0	211	115	327	0.120	0.007	0.009	0.011
0.65	0	280	152	136	0.122	0.010	0.009	0.014
0.75	0	349	189	136	0.125	0.011	0.010	0.014
0.85	0	0	233	136	0.128	0.011	0.010	0.015
0.95	0	0	270	136	0.131	0.011	0.011	0.016
1.05	0	0	297	136	0.135	0.012	0.011	0.016
1.15	0	0	311	136	0.139	0.012	0.012	0.017
1.25	0	0	313	136	0.143	0.012	0.012	0.018
1.35	0	0	304	136	0.147	0.013	0.013	0.018
1.45	0	0	282	136	0.152	0.013	0.014	0.019
1.55	0	0	253	136	0.157	0.013	0.014	0.020
1.65	0	0	222	136	0.162	0.014	0.015	0.020

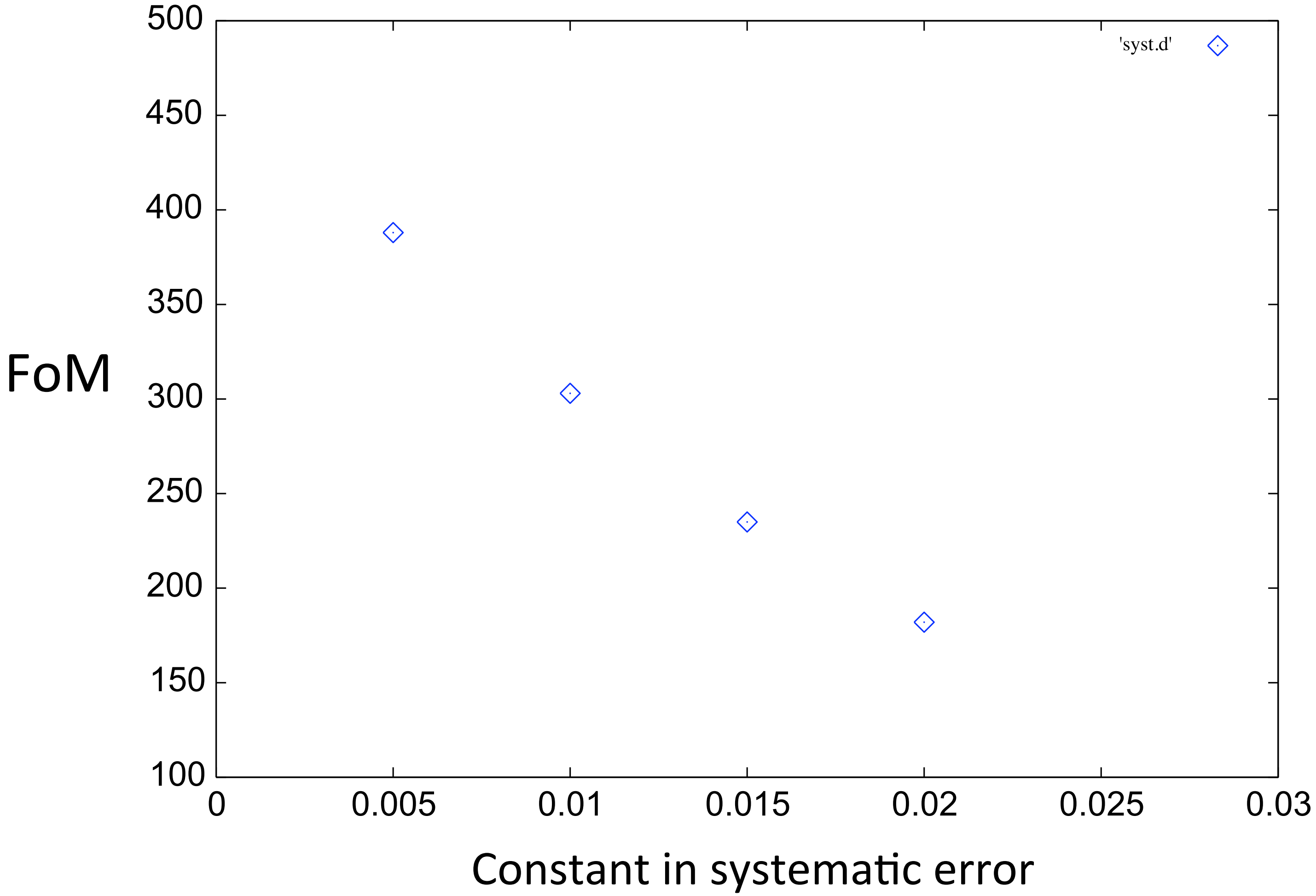
Figures of Merit

- For the Supernova Survey only FoM = 312
- Supernova with Stage III prior FoM = 582

FoM dependence on Systematic Error

IFU Deep Survey with spectroscopic lightcurves

σ_{sys} = constant x (1+z)/1.8

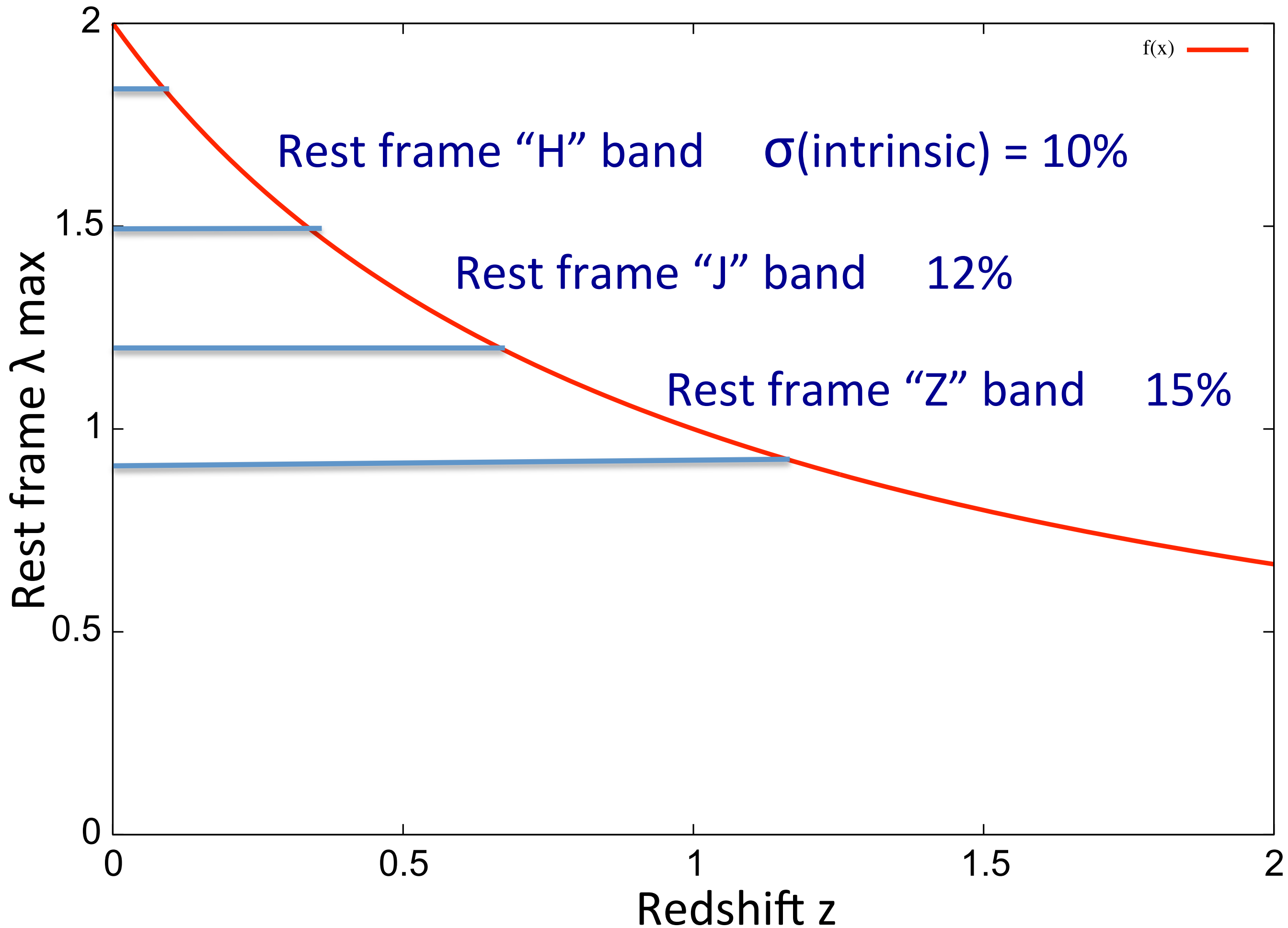


Importance of Systematic Errors

- With the superb statistics (2700 supernova in six months) allowed by the large 2.4 m mirror need to reduce systematic errors to match.
- There are several possible approaches:
  - Emphasize low redshifts to go further into the infrared in the supernova restframe
  - Obtain deep high quality spectra for each supernova
- After detailed simulations we find both methods effective but find deep spectra more powerful for reducing errors

Intrinsic Spread vs Restframe λ max

Rest frame λ max for an instrument λ max of 2.0 microns



Supernova Survey Strategy

- Do a three tier survey, scanning different areas of sky for different redshift ranges
- The three tiered survey does emphasize low redshifts but extends up to a redshift of 1.7

Tier	Z max	Sky Area Sq Degrees
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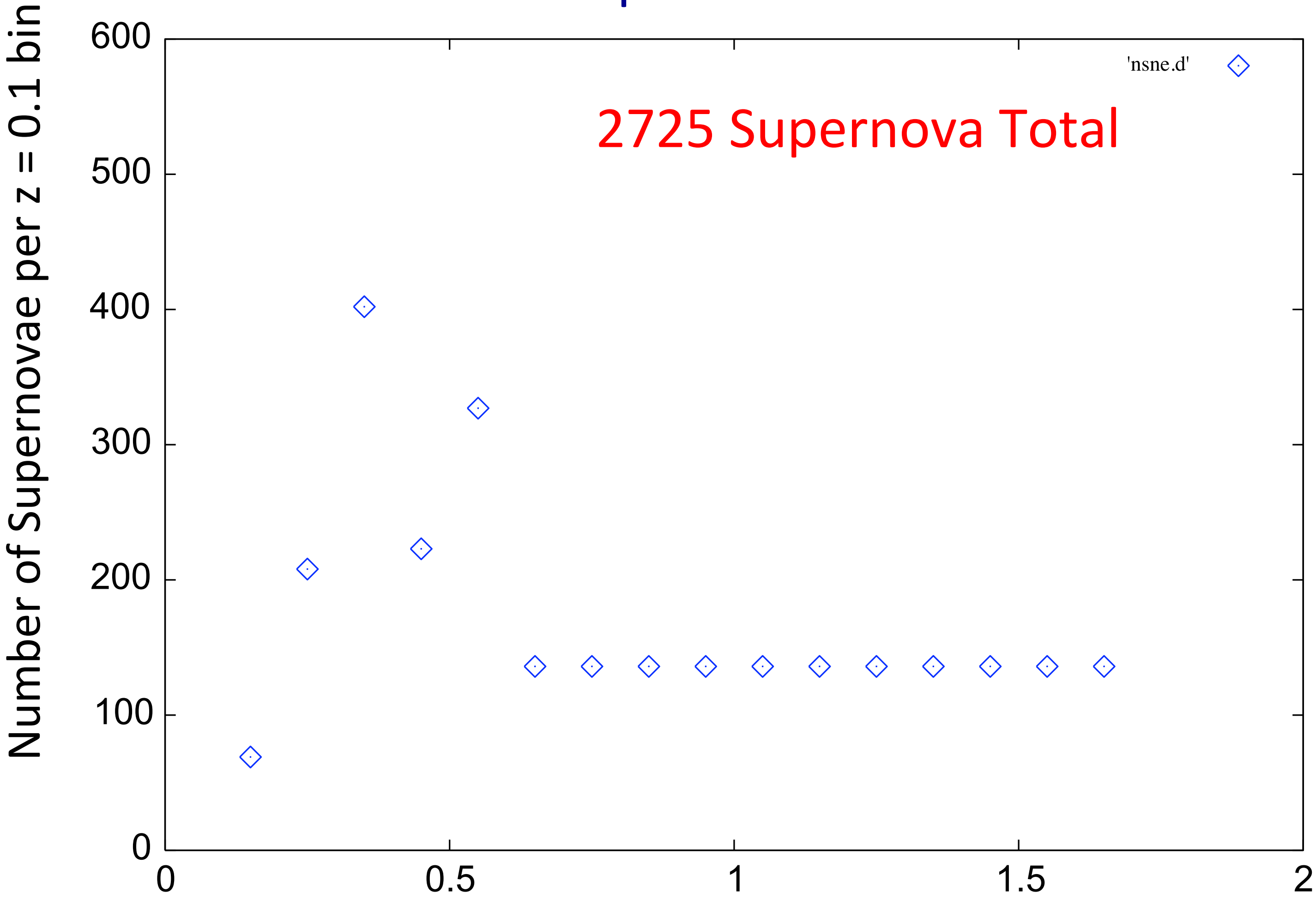
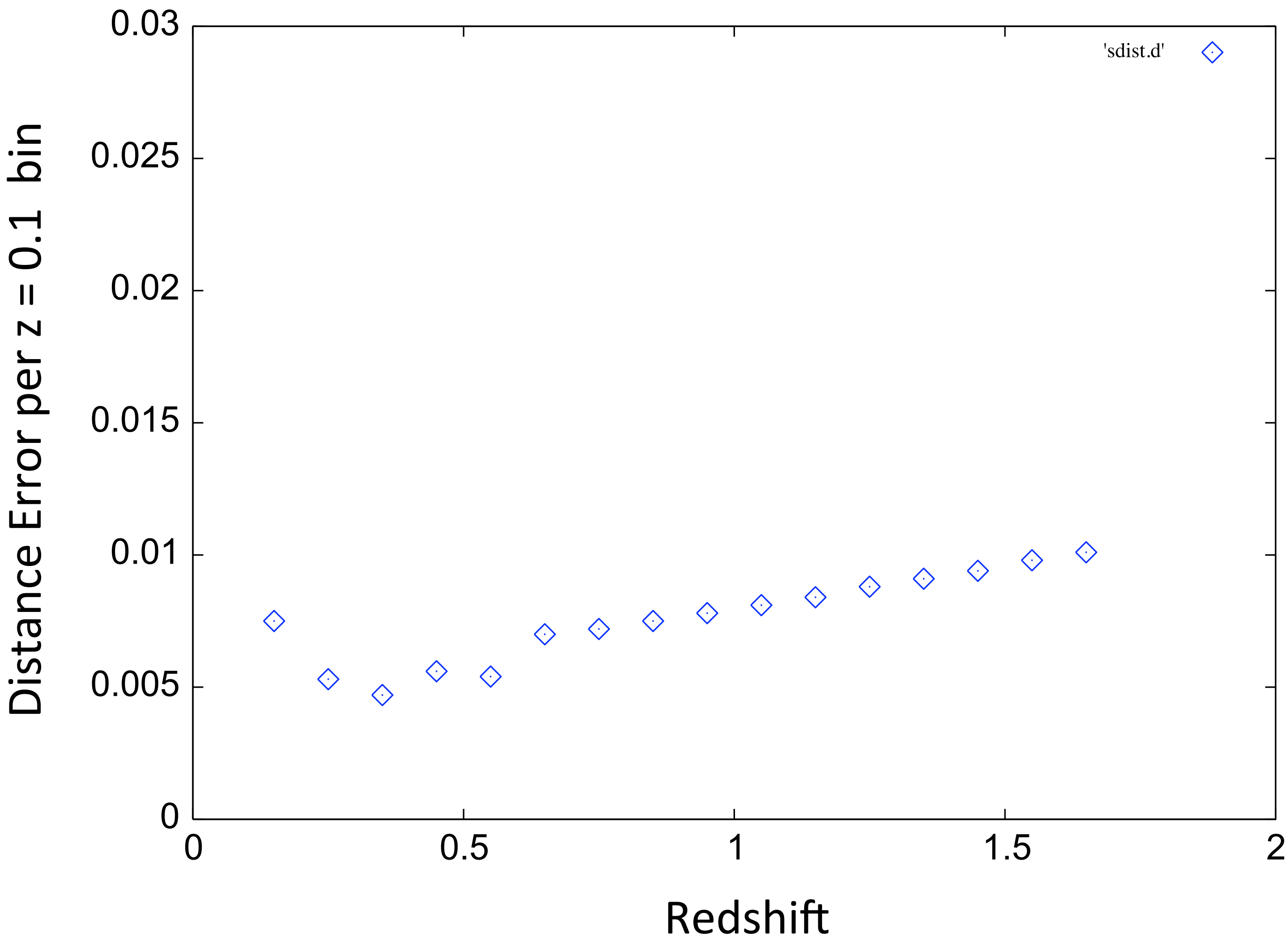
Numbers of Supernovae

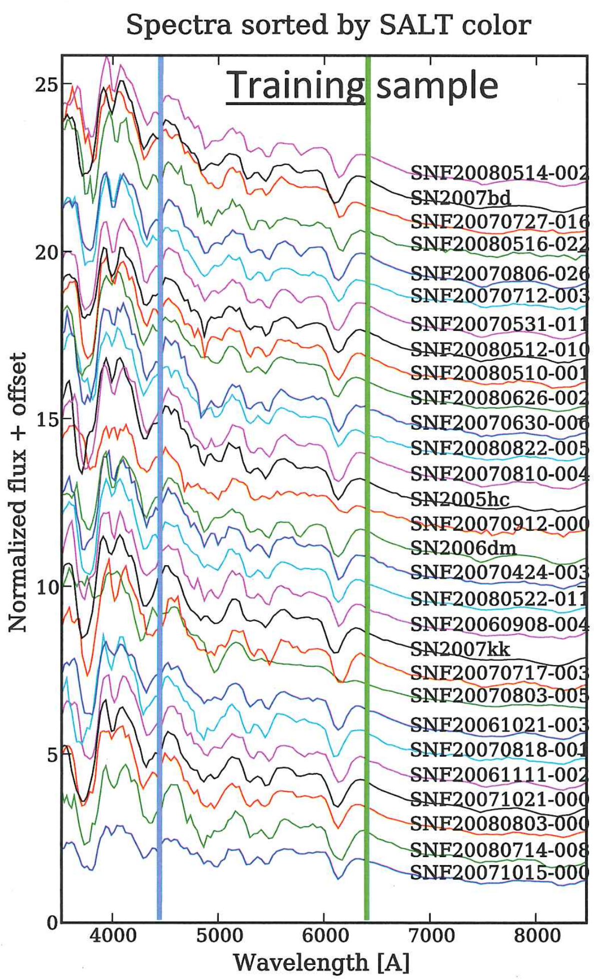
Three tiered survey does emphasize low redshifts but extends up to redshift of 1.7

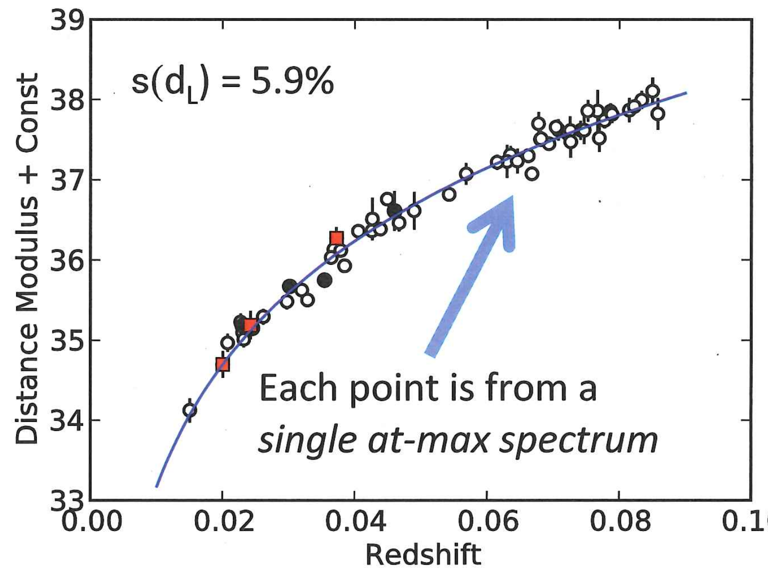


Error on Distance Measurement



Spectral Flux Ratio Standardization

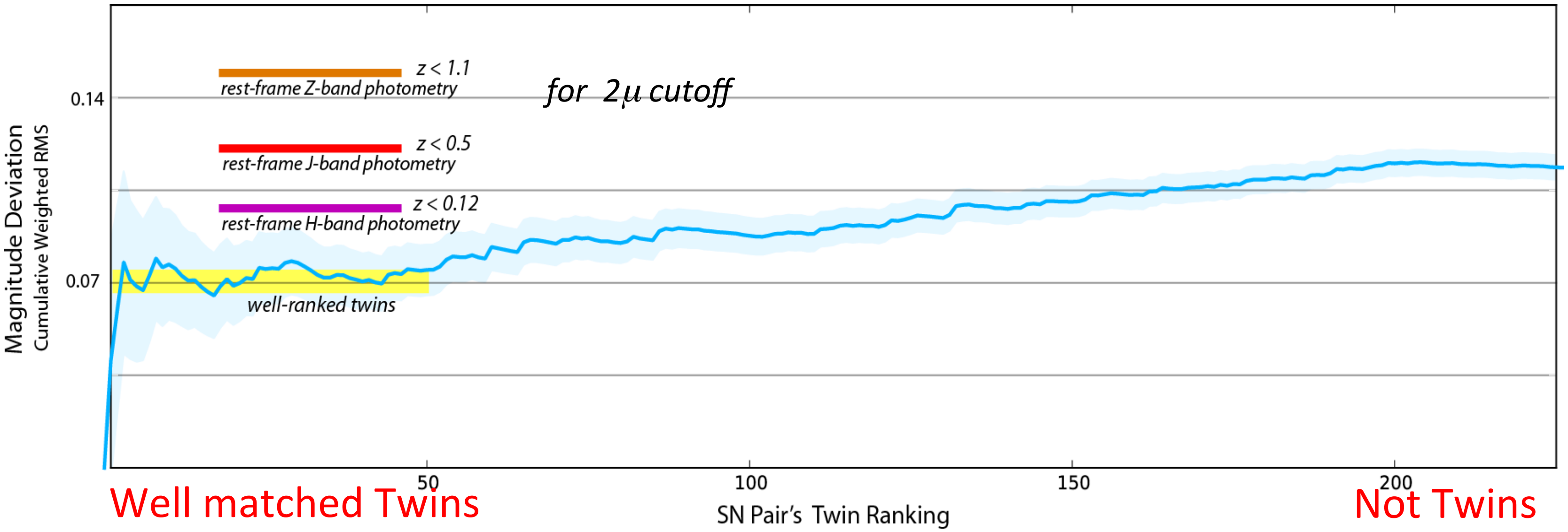


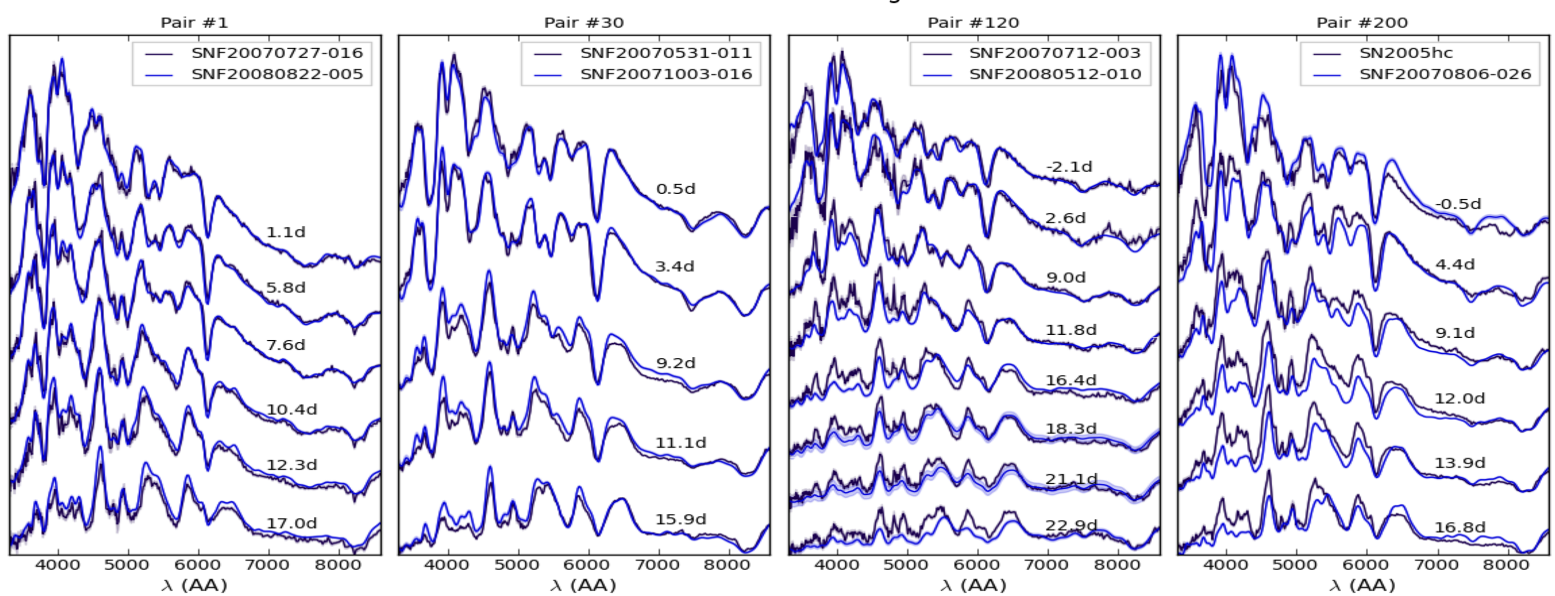


Using Correlations of ratios of spetroscopic feature strengths with peak brightness provide lower intrinsic spread of 11.8%

Bailey, et al., A&A (2009)

Supernovae with similar spectra (Twins) have much lower intrinsic spread





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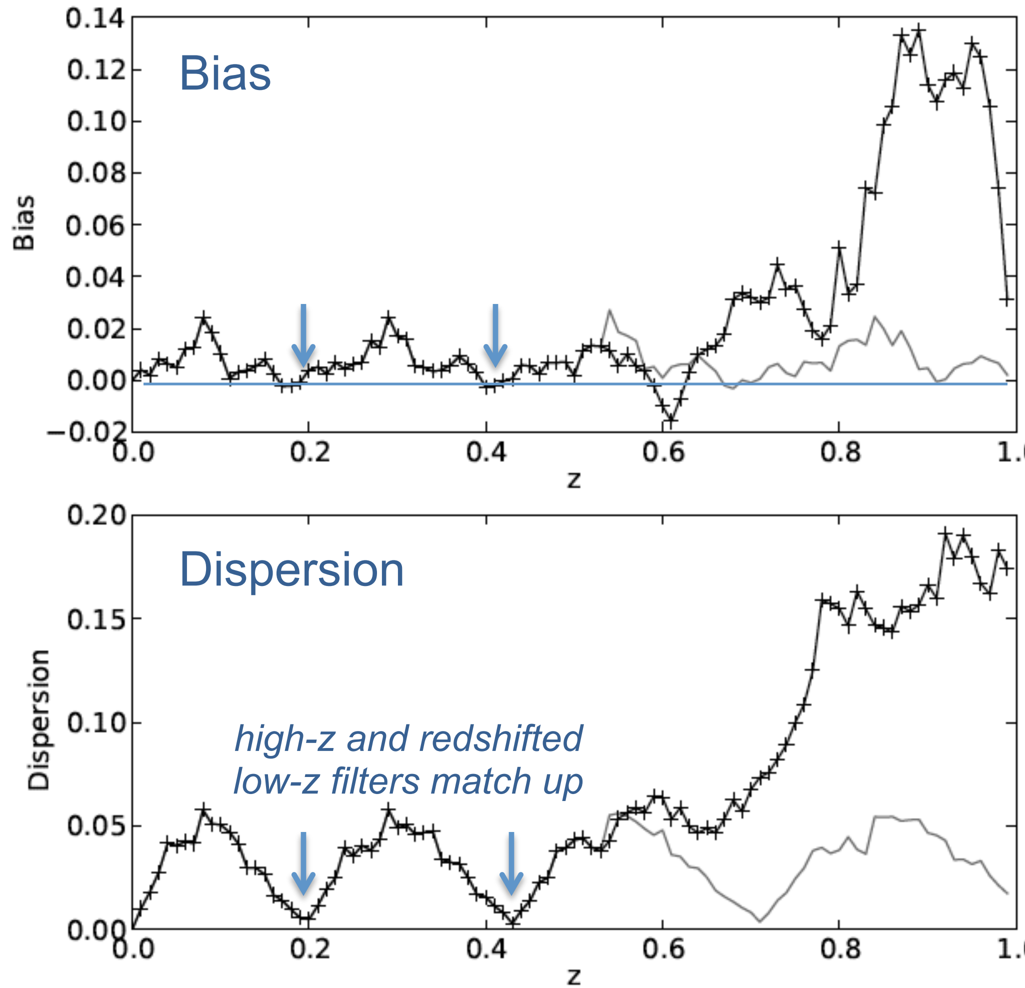
K Corrections

SNe Ia do not all show the exact same spectral time series, so the standard K corrections are not exact much of the time.

The distribution of K correction errors exhibits bias and dispersion whenever the high-redshift observations' filters don't exactly match the redshifted low-redshift observations' filters.

Average error and dispersion on K-correction for a best-case logarithmically-spaced infinite filter set and for a finite number of logarithmically-spaced filters (SALT-2 fitter is used here.)

For light curves from spectra we do not need K corrections



Saunders et al (submitted) **Nearby SN Factory**

In Conclusion

- WFIRST-AFTA with a 2.4 m mirror and an Integral Field Spectrometer (IFU) is a superb instrument for a powerful supernova survey out to redshift of 1.7
- WFIRST-AFTA Supernova survey unmatched by any other planned facility
- The purpose of the WFIRST Science Definition Team studies is to arrive at the most powerful and versatile mission design that enables a variety of approaches to many important measurements.
- Presumably at some later time there will be an Announcement of Opportunity (AO) for WFIRST, following which the most promising methods for the various measurements will be selected, using the best state of the art information at that time.

Backup Details

Parameters used in the Exposure Time Calculations

Parameter	Imaging	IFU Spectra
Signal to noise per band S/N	20/(1+z)	15
No of pixels npix	12.6	133
Zodi Bkgrd Z	0.36 cts/pix/sec	0.017 cts/pix/sec
Dark Current D	0.015 e/pixel/sec	0.010 e/pixel/sec
Read noise Single Read Floor	20.0 e/read 5 e	15.0 e/read 4 e
Pixel area Apix	(0.11)**2	(0.11)**2
Wavelength λ	Center of band	
Range admitted Δλ in zodi background	Width of filter band	< 0.02μ
Spectrometer Resolution		R = 75 (150/pix)

Read Noise Estimate

- Assume 5.24 sec/read, 10.48 sec/read pair
- m = (exp time)/10.48, the number of read pairs
- R = noise per read pair (20 for imaging)
- f = read noise floor (5 for imaging)
- Read Noise $=\{ [(R/\sqrt{m})*\sqrt{3}]^2 + f^2\}^{1/2}$

Error Model Used

- Statitical errors
  - Measurement error σ_{meas} = 8 % with S/N = 15 spectra per filter band 2 and one deep spectrum near peak with S/N=47 per filter band 2
  - Intrinsic spread σ_{int} = 8 % with IFU deep spectra
  - Gravitational lensing error $\sigma_{lens} = 0.07*z$
  - Statistical $\sigma_{stat} = [\sigma_{meas}^2 + \sigma_{int}^2 + \sigma_{lens}^2]^{½}/\sqrt{n}$
- Systematic errors
  - Systematic error $\sigma_{sys} = 0.01(1+z)/1.8$
- Total error per z bin
  - Total error $\sigma_{tot} = [\sigma_{stat}^2 + \sigma_{sys}^2]^{½}$