Enhancing LSST with WFIRST:
A few elements of a missing program

Saul Perlmutter

Cosmic Visions meeting
Berkeley Lab
November, 2017

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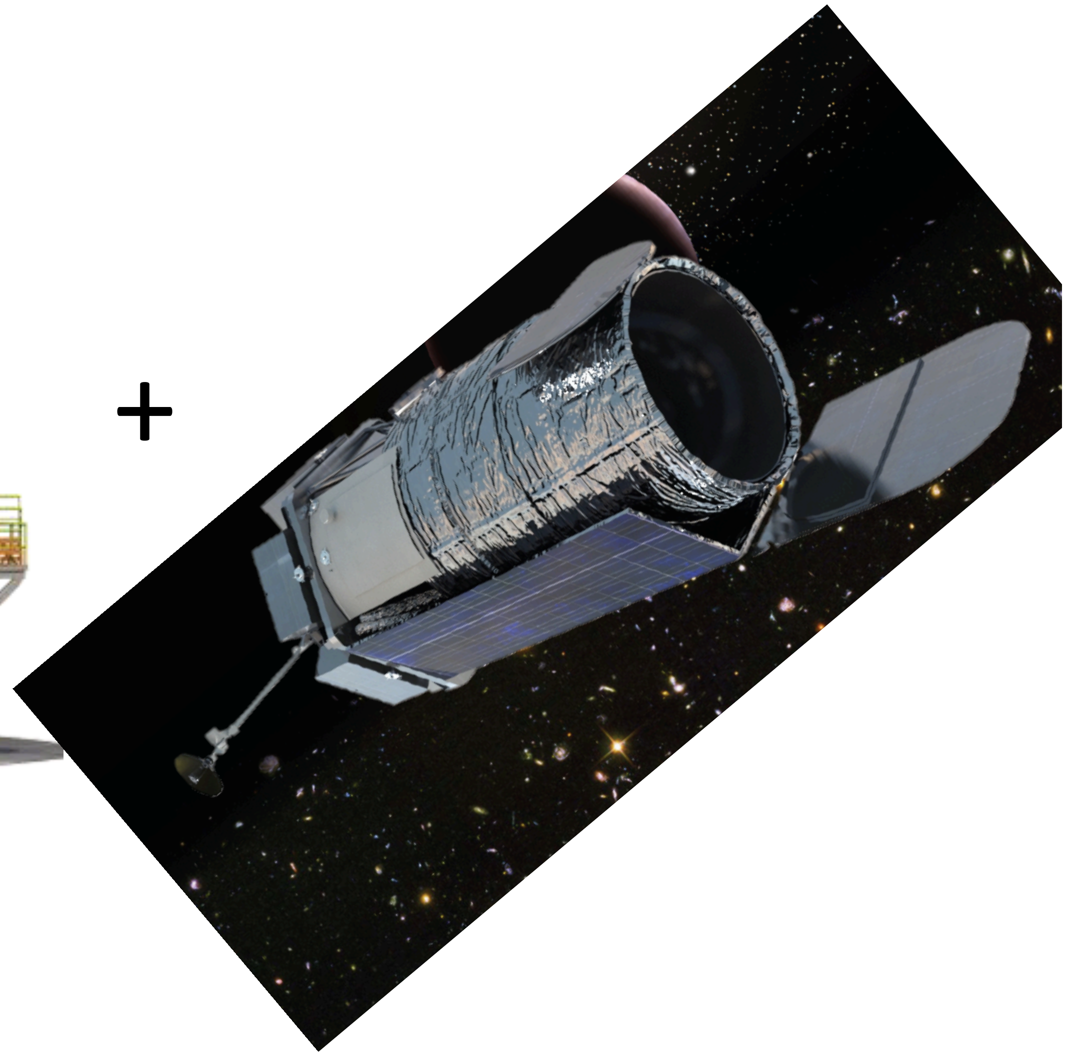


There is much to be gained if DOE can support a project effort that fills the gaps to make it possible to do the science that requires LSST + WFIRST:

1. WFIRST IFC galaxy spectroscopy to calibrate the photo-z's in parts of parameter space that are difficult/impossible from the ground (see previous discussion).

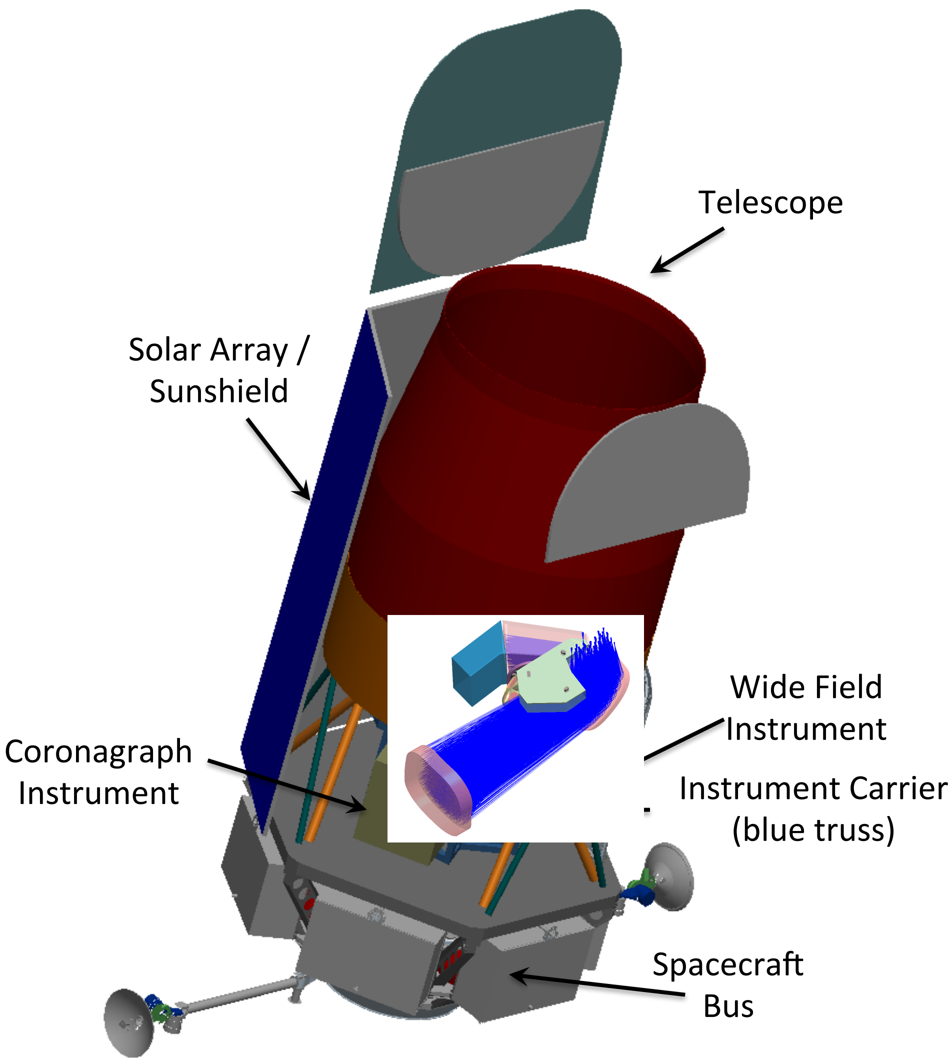
2. WFIRST WFC galaxy NIR photometry to build photo-z's, presumably by joint-pixel processing (see next discussion).

3. LSST cadenced SN discovery that can be followed with WFIRST WFC + IFC to provide NIR imaging and spectrophotometry data unavailable from the ground (see last discussion tomorrow morning on scheduling synergy).

4. WFIRST IFC SN spectrophotometry of ~2000 LSST SNe to train the photometry classifiers.

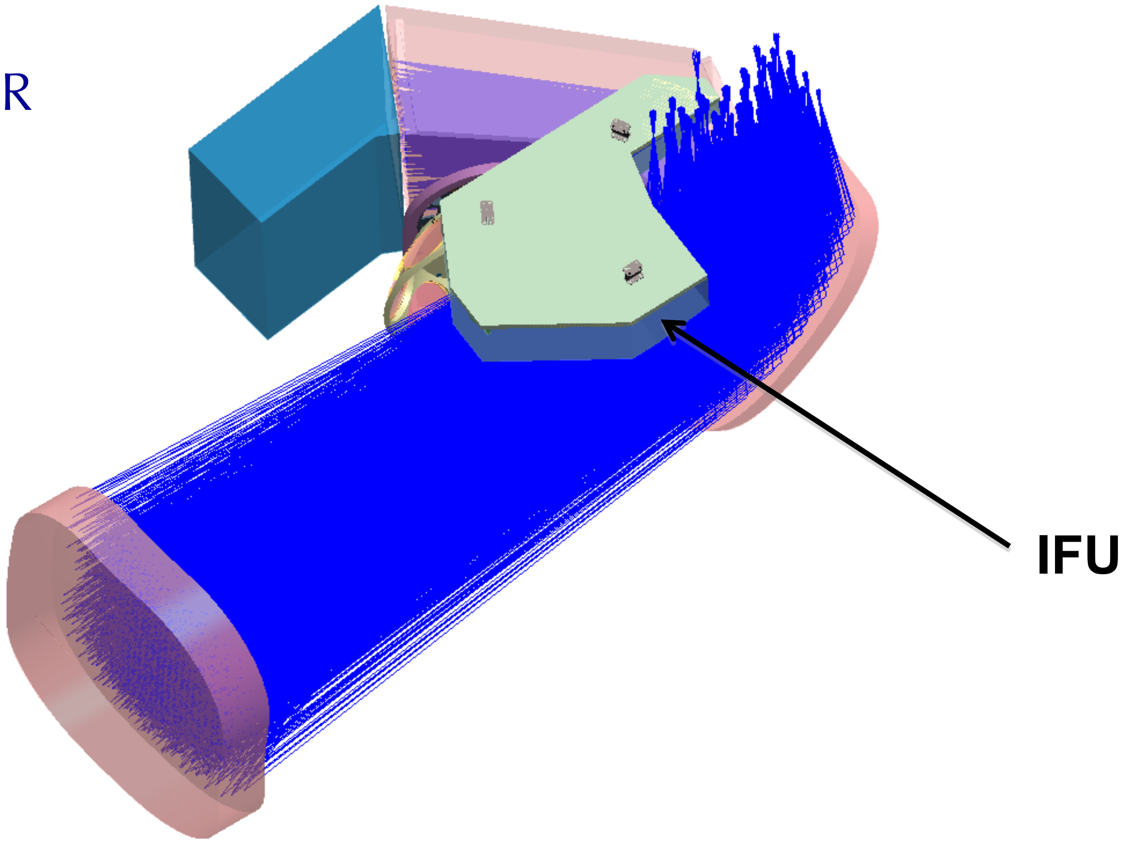
5. WFIRST IFC and WFC triggered follow-up of particular LSST transients (see first discussions tomorrow morning).

All of these require much planning and design, then pipeline building, execution, reduction, and analysis. Currently, not either DOE or NASA ownership.



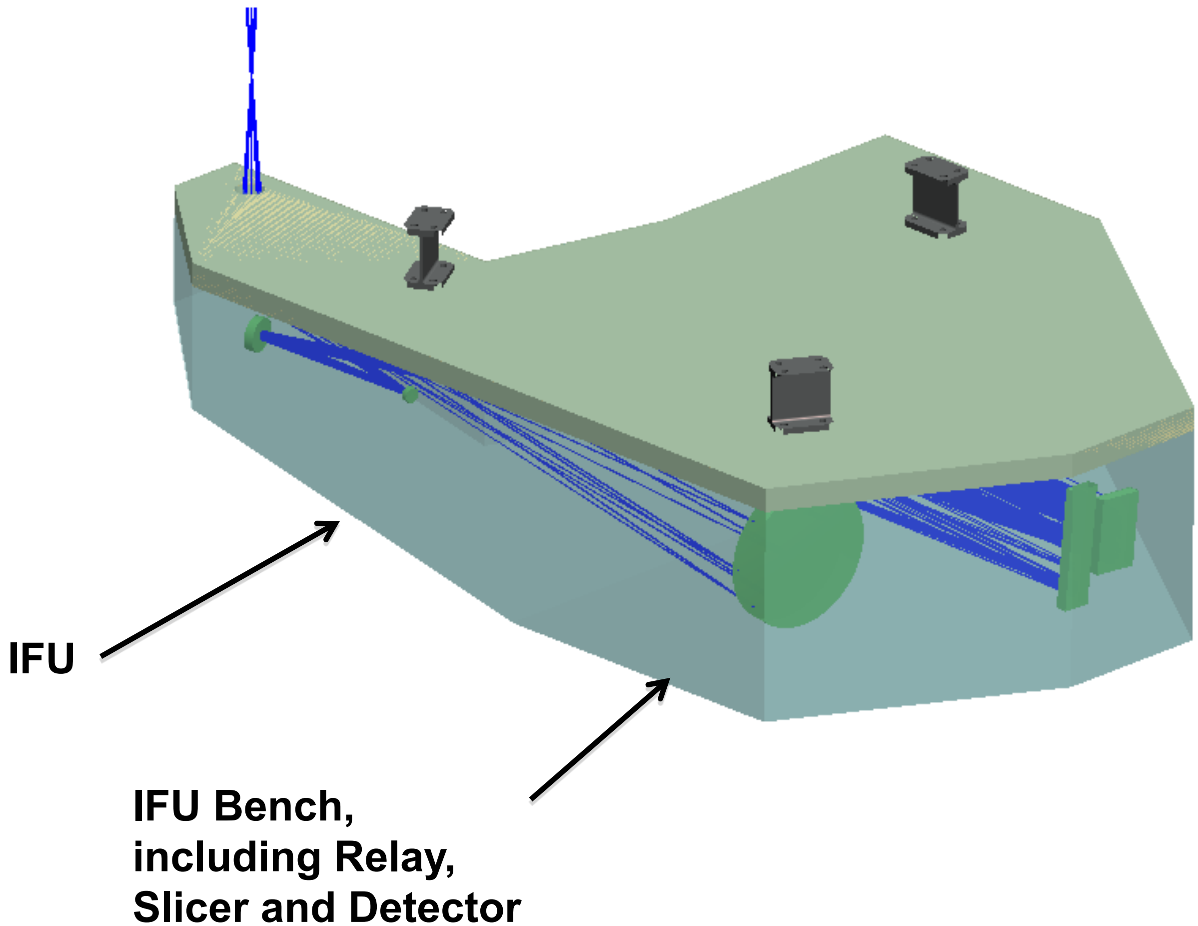
Telescope
Solar Array /
Sunshield
Wide Field
Instrument
Instrument Carrier
(blue truss)
Coronagraph
Instrument
Spacecraft
Bus

Use the 0.28 sq degree Wide Field Imager (with 0.11″ pixels) to follow supernovae in NIR bands.

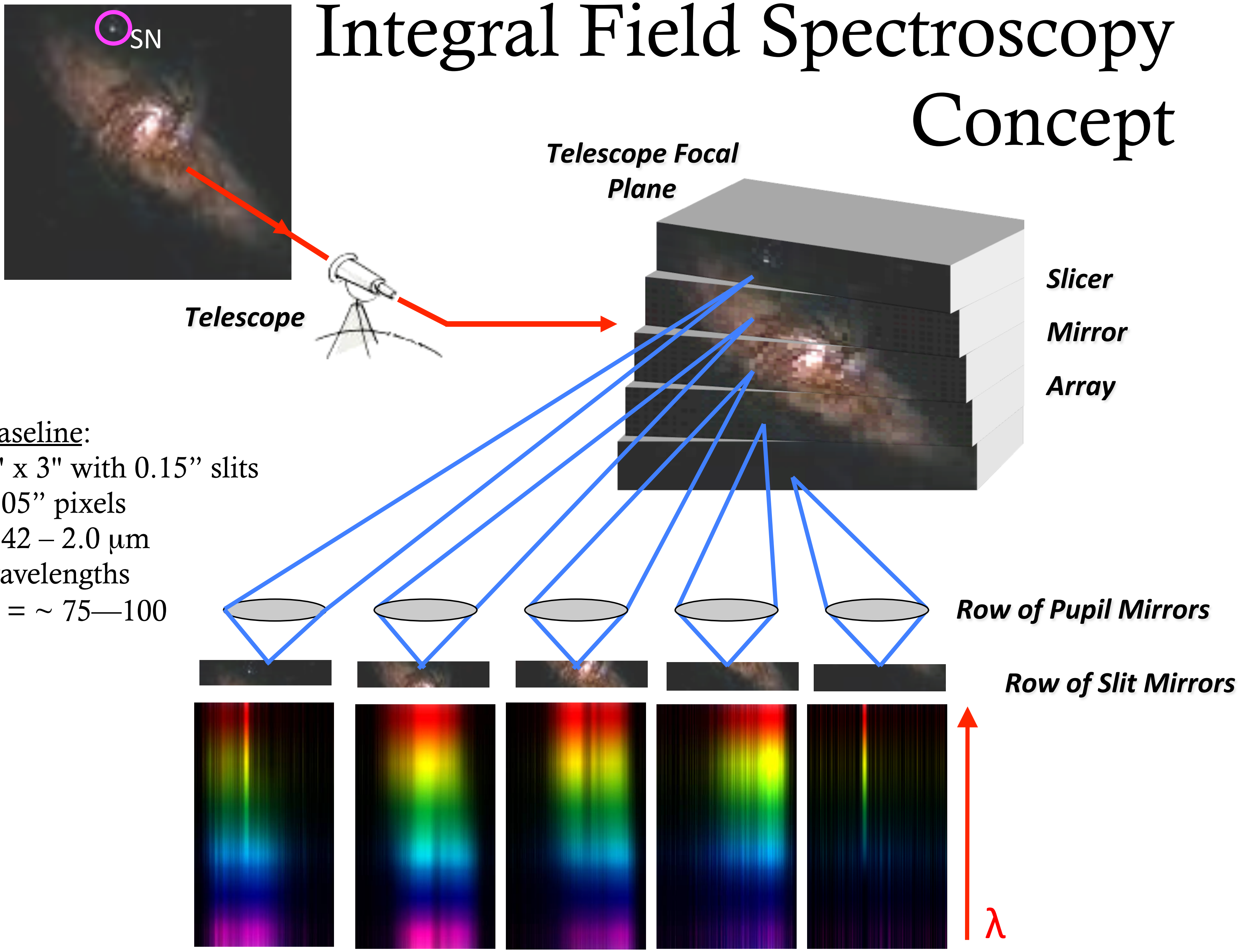


Small, compact assembly:

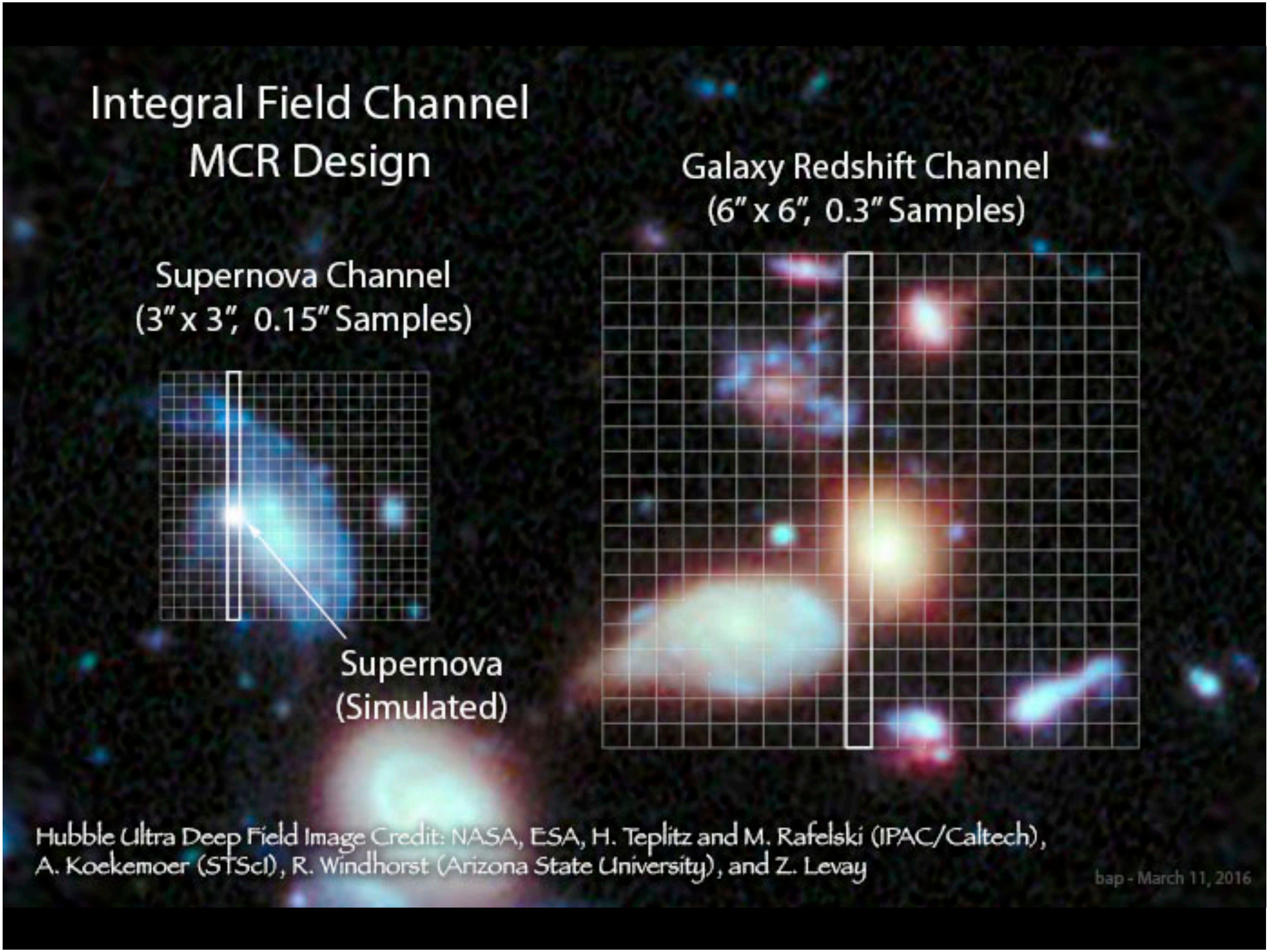
- ~ 6 to 7 kg
- 30 x 50 x 12.5 cm

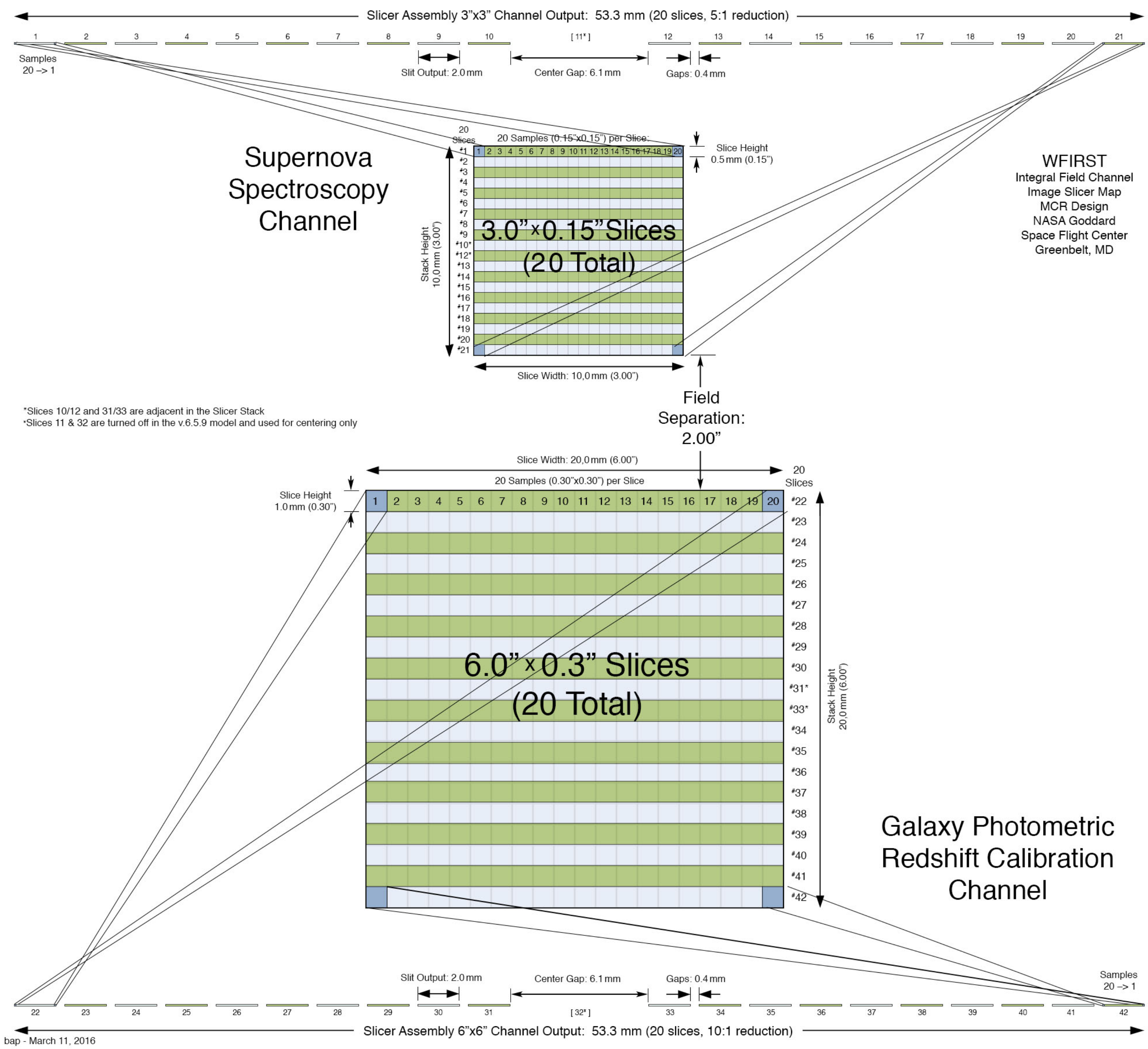


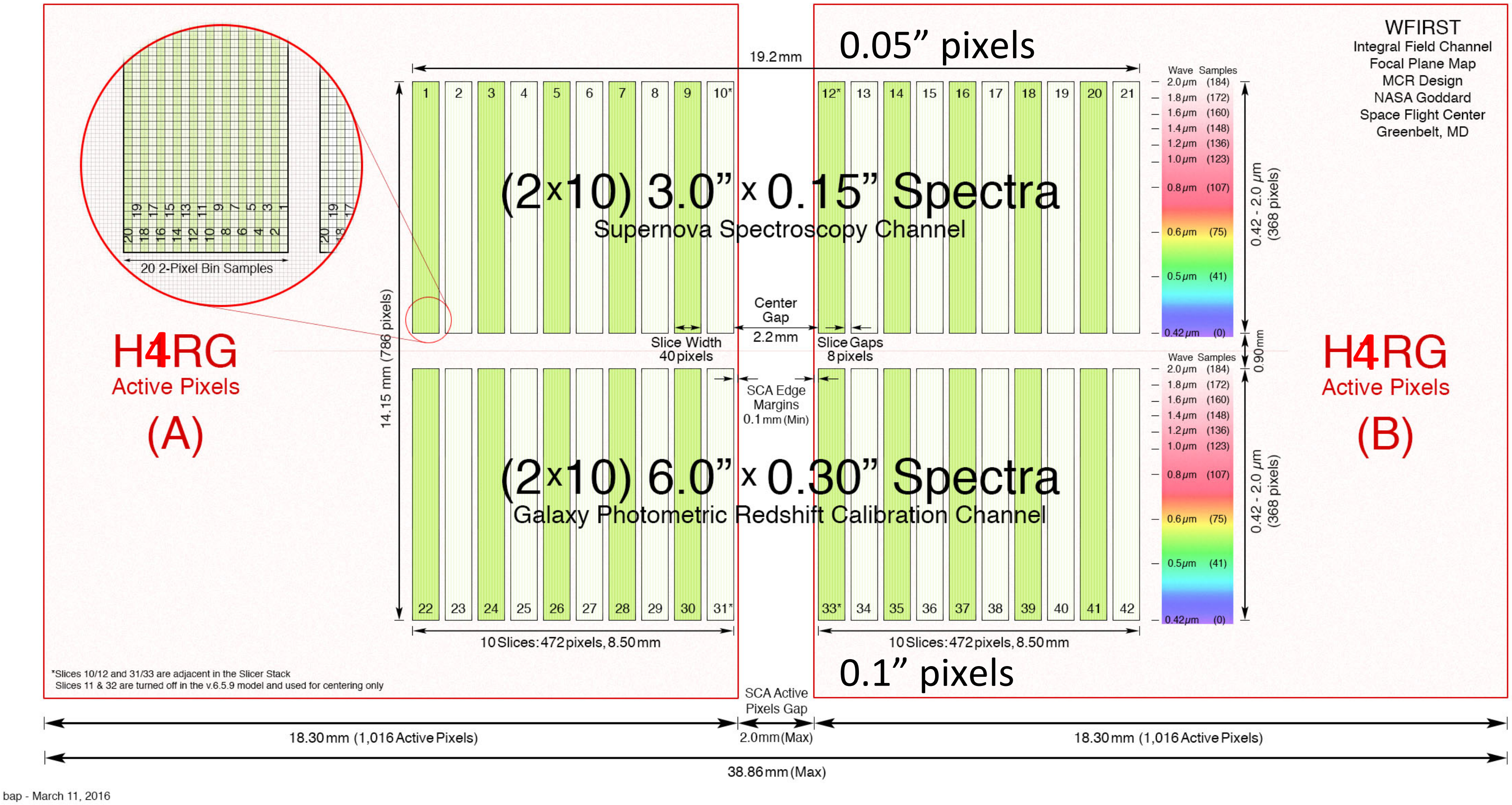
Integral Field Spectroscopy Concept



Baseline:
3" x 3" with 0.15" slits
0.05" pixels
0.42 – 2.0 μm wavelengths
R = ~ 75—100

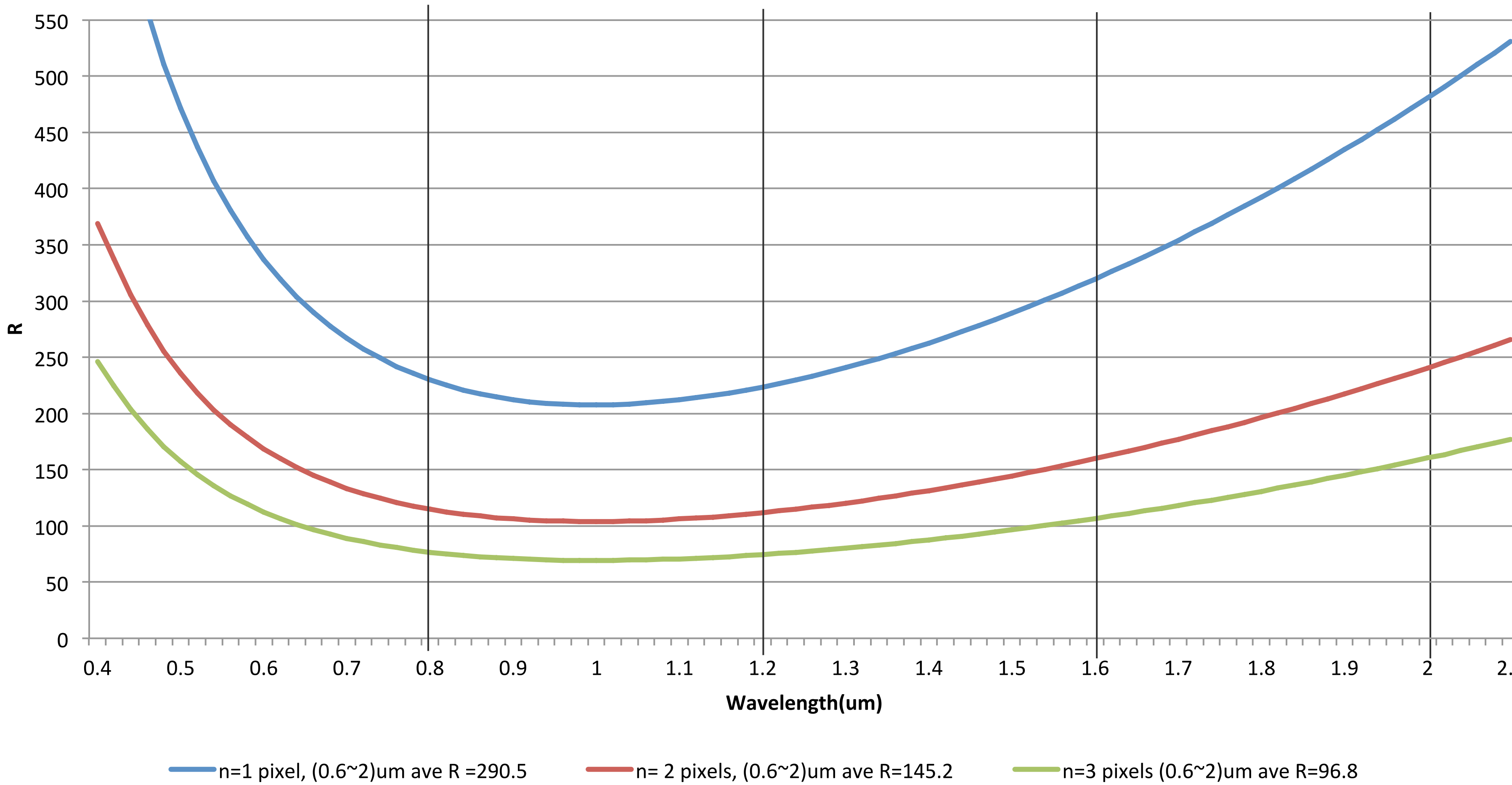

Integral Field Channel
MCR Design
Galaxy Redshift Channel
(6" x 6", 0.3" Samples)
Supernova Channel
(3" x 3", 0.15" Samples)
Supernova
(Simulated)
Hubble Ultra Deep Field Image Credit: NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech),
A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay
bap - March 11, 2016


Slicer Assembly 3"x3" Channel Output: 53.3 mm (20 slices, 5:1 reduction)
Samples 20 –> 1
Slit Output: 2.0 mm
Center Gap: 6.1 mm
Gaps: 0.4 mm
[11*]
Supernova Spectroscopy Channel
20 Slices
20 Samples (0.15"x0.15") per Slice
Slice Height 0.5 mm (0.15")
3.0" x 0.15" Slices (20 Total)
Stack Height 10.0 mm (3.00")
Slice Width: 10.0 mm (3.00")
WFIRST
Integral Field Channel
Image Slicer Map
MCR Design
NASA Goddard
Space Flight Center
Greenbelt, MD
*Slices 10/12 and 31/33 are adjacent in the Slicer Stack
*Slices 11 & 32 are turned off in the v.6.5.9 model and used for centering only
Field Separation: 2.00"
Slice Width: 20.0 mm (6.00")
20 Samples (0.30"x0.30") per Slice
20 Slices
Slice Height 1.0 mm (0.30")
6.0" x 0.3" Slices (20 Total)
Stack Height 20.0 mm (6.00")
Galaxy Photometric Redshift Calibration Channel
Samples 20 –> 1
[32*]
Slicer Assembly 6"x6" Channel Output: 53.3 mm (20 slices, 10:1 reduction)
bap - March 11, 2016


0.05” pixels
19.2 mm
WFIRST
Integral Field Channel
Focal Plane Map
MCR Design
NASA Goddard
Space Flight Center
Greenbelt, MD
(2x10) 3.0” x 0.15” Spectra
Supernova Spectroscopy Channel
(2x10) 6.0” x 0.30” Spectra
Galaxy Photometric Redshift Calibration Channel
20 2-Pixel Bin Samples
H4RG
Active Pixels
(A)
H4RG
Active Pixels
(B)
14.15 mm (786 pixels)
Center Gap
2.2 mm
Slice Width
40 pixels
Slice Gaps
8 pixels
SCA Edge Margins
0.1 mm (Min)
0.90 mm
0.42 - 2.0 µm (368 pixels)
Wave Samples
2.0µm (184)
1.8µm (172)
1.6µm (160)
1.4µm (148)
1.2µm (136)
1.0µm (123)
0.8µm (107)
0.6µm (75)
0.5µm (41)
0.42µm (0)
10 Slices: 472 pixels, 8.50 mm
0.1” pixels
*Slices 10/12 and 31/33 are adjacent in the Slicer Stack
Slices 11 & 32 are turned off in the v.6.5.9 model and used for centering only
SCA Active Pixels Gap
18.30 mm (1,016 Active Pixels)
2.0 mm (Max)
38.86 mm (Max)
bap - March 11, 2016

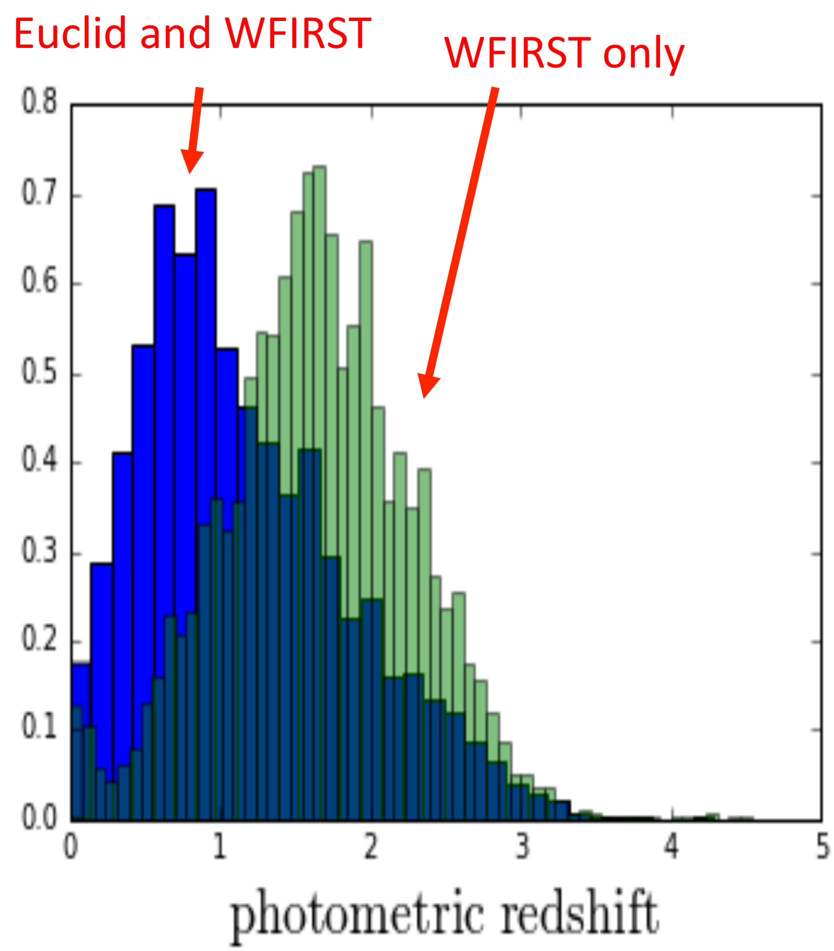
$$R = \frac{\lambda}{\Delta\lambda}$$

Where the spot distance of λ and $\lambda + \Delta\lambda$ on the FPA surface is n pixel (pixel size 10um).



Comparison of WFIRST and Euclid lensing sample

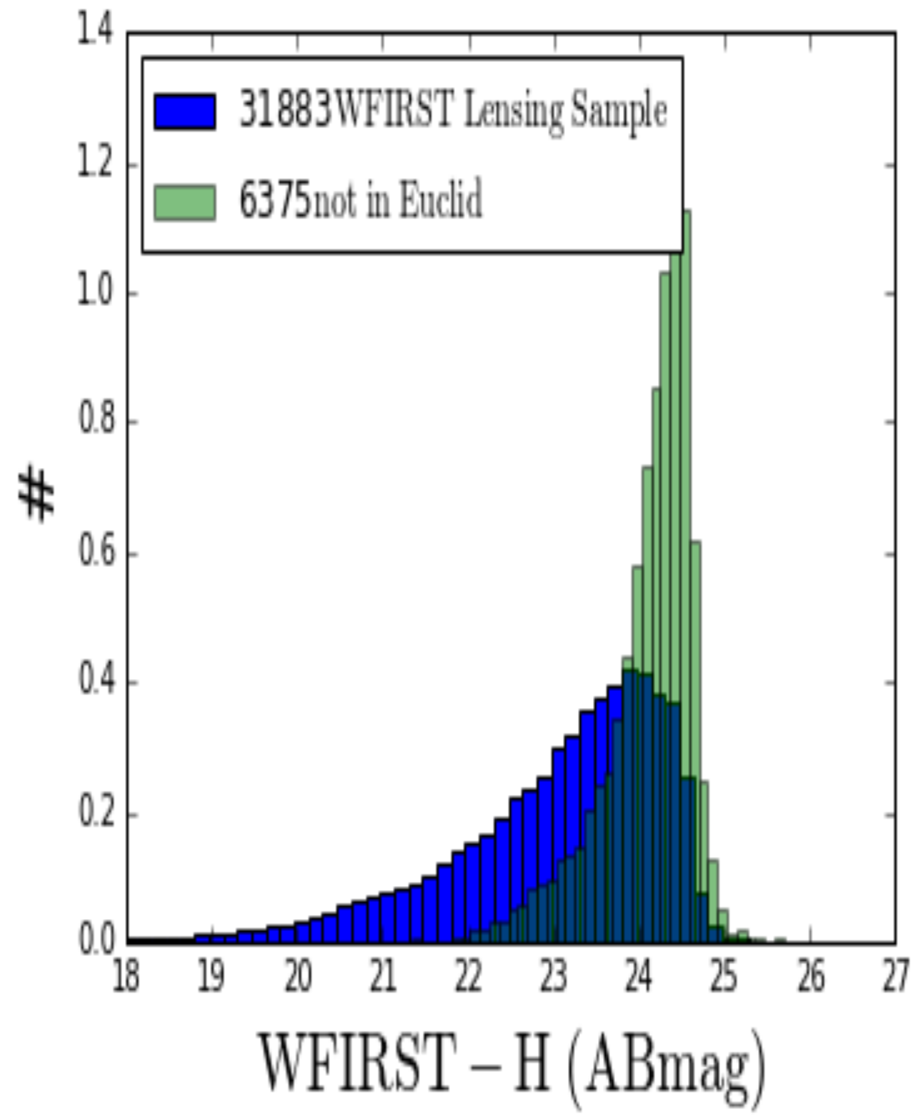
- Analysis based on CANDELS (HST) catalog
  - Converted to LSST + WFIRST colors
  - Nominal WFIRST shape cut
  - 31,883 total sources
- Full WFIRST lensing sample in blue+green, WFIRST faint sample (missed in Euclid sample) in green
- Here the “Euclid sample” is defined to be RIZ<25
  - 0.5 mag deeper than nominal Euclid
  - Depth being targeted for C3R2 spectroscopy
- WFIRST faint sample (6375 sources, ~20% of total) has higher mean redshift than full WFIRST lensing sample
  - Not a surprise
- Overall redshift range is similar



Dore, Capak, Hematti, and Masters

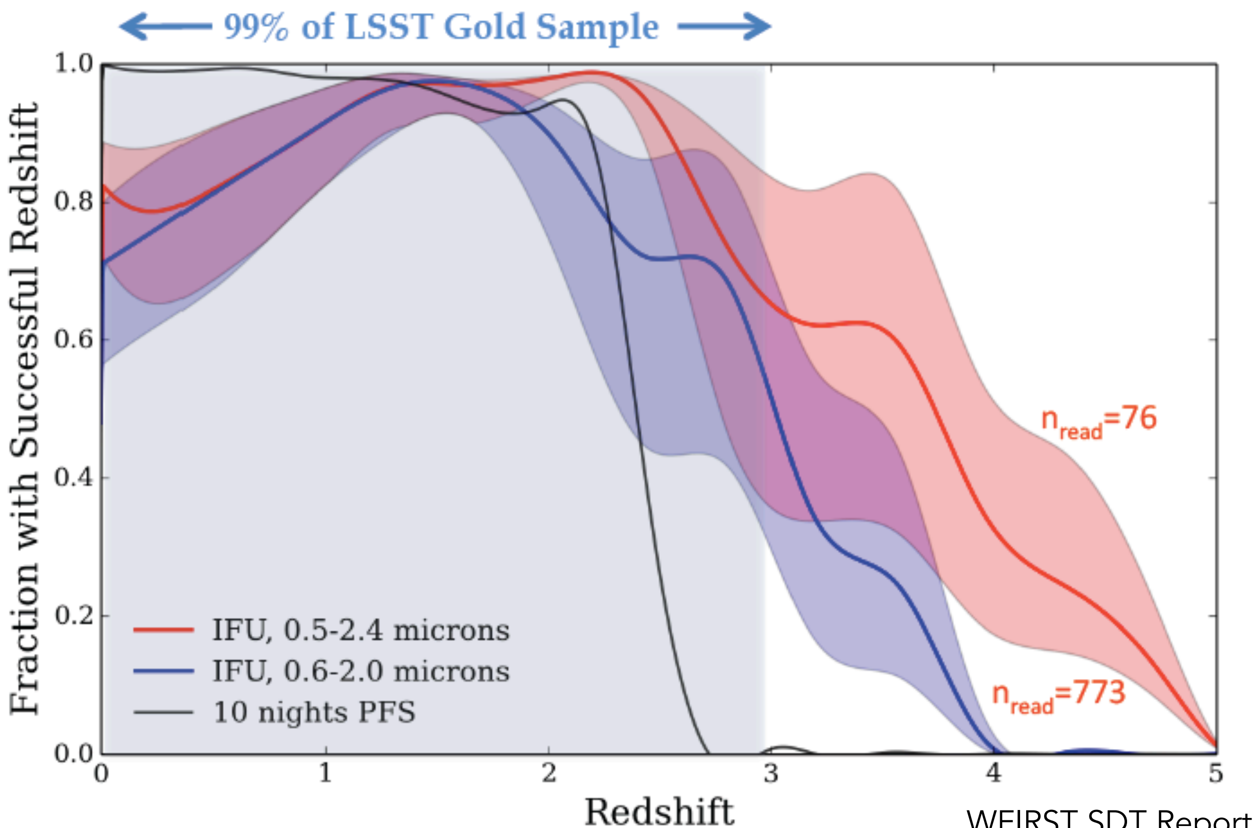
Comparison of WFIRST and Euclid lensing sample

- Significant number of galaxies not in the Euclid Sample
  - 20% of WFIRST sample have RIZ>25
- These will be hard to get spectra for from the ground
- What fraction don't have colors in the C3R2 sample?
  - *Complete Calibration of the Color-Redshift Relation* (C3R2, P. Capak and D. Stern, et al.), aims at taking spectra of ~10k galaxies to calibrate photo-z using the Keck, and also Magellan, VLT and the GCT.
  - Al collected ~5k spectra and will last about 1.5 more year.



Dore, Capak, Hematti, and Masters

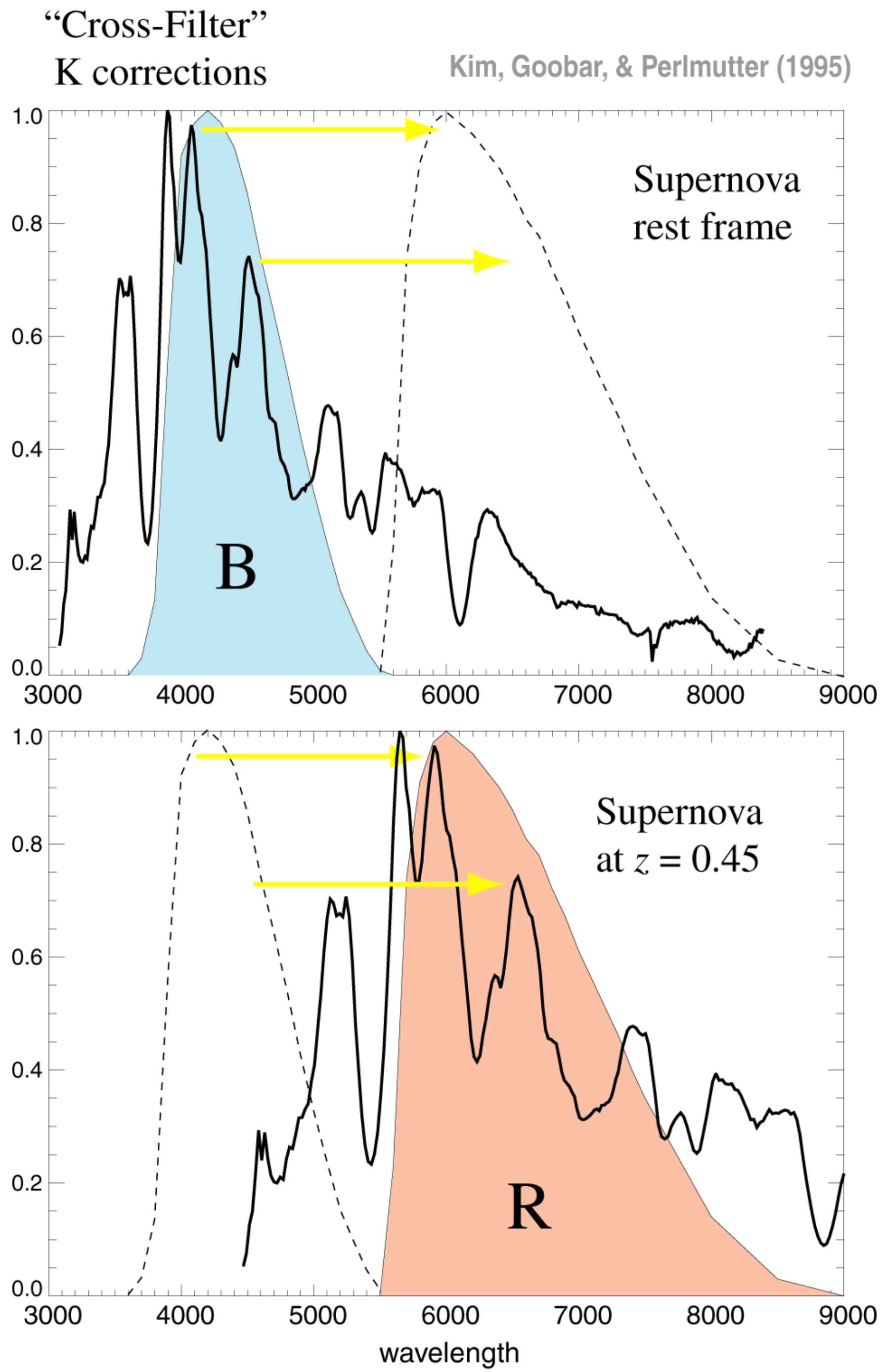
LSST-WFIRST photo-z calibration



WFIRST SDT Report

Figure 3: Predictions of the fraction of LSST weak lensing sample objects that would yield a secure (multiple-confirmed-feature) spectroscopic redshift, based either on 1440-second exposure time with *WFIRST* (colored regions) or 10 nights' open-shutter-time spectroscopy with the Subaru/PFS spectrograph (black curve) *WFIRST* IFU spectroscopy would provide training redshifts for objects at higher z than are easily accessible from the ground, particularly if read noise per pixel is small (the colored regions indicate a range of feasible scenarios). Longer exposure times (e.g., in supernova fields or by optimized dithering strategies) could enhance the success rate further.

LSST's SN program
starts out photometry-based

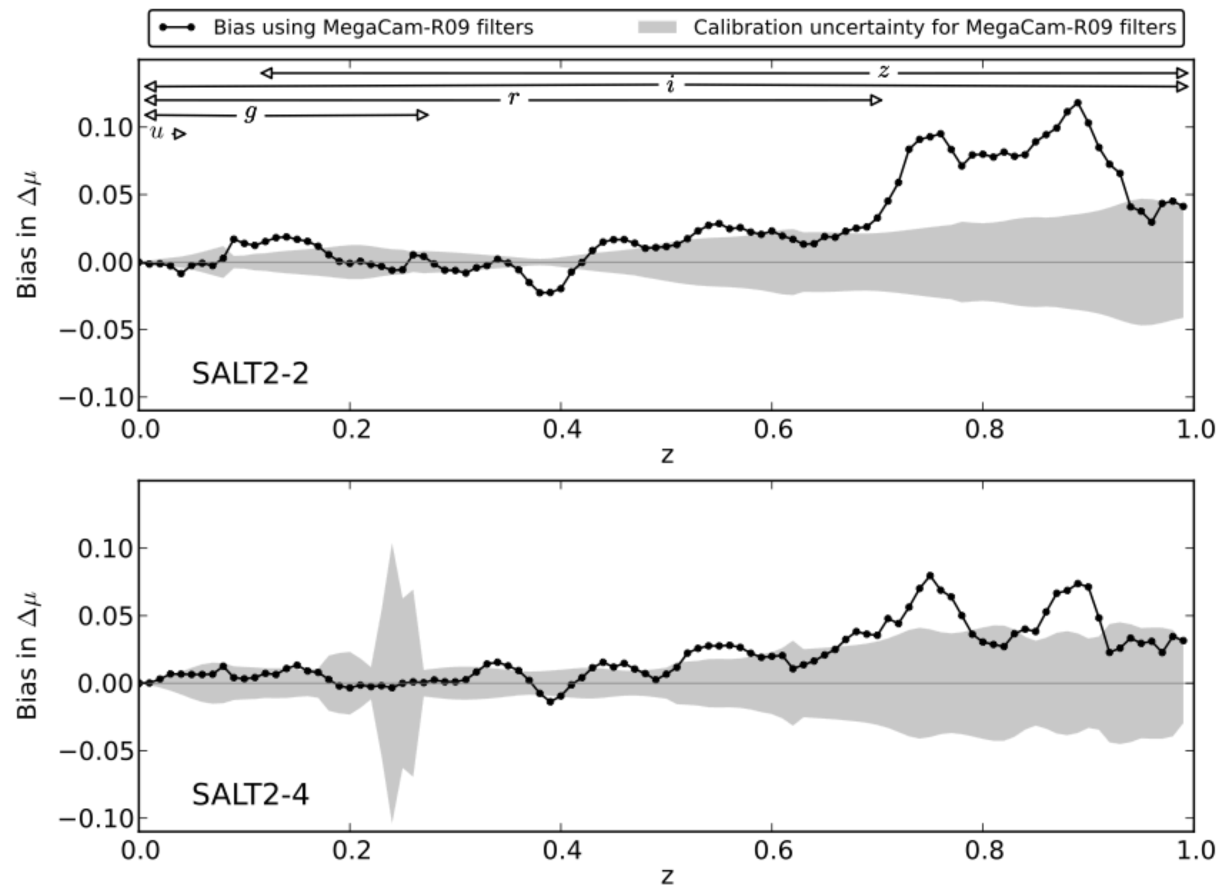


But when the filters don't match perfectly across redshift, this approach is accurate only to the extent that the spectral template family captures the distribution of SN Ia behavior – at both low and high redshift.

Average K-correction bias from a single-parameter spectral time series

Implied bias on current estimates of *w* is 0.03. This compares with overall error of 0.06

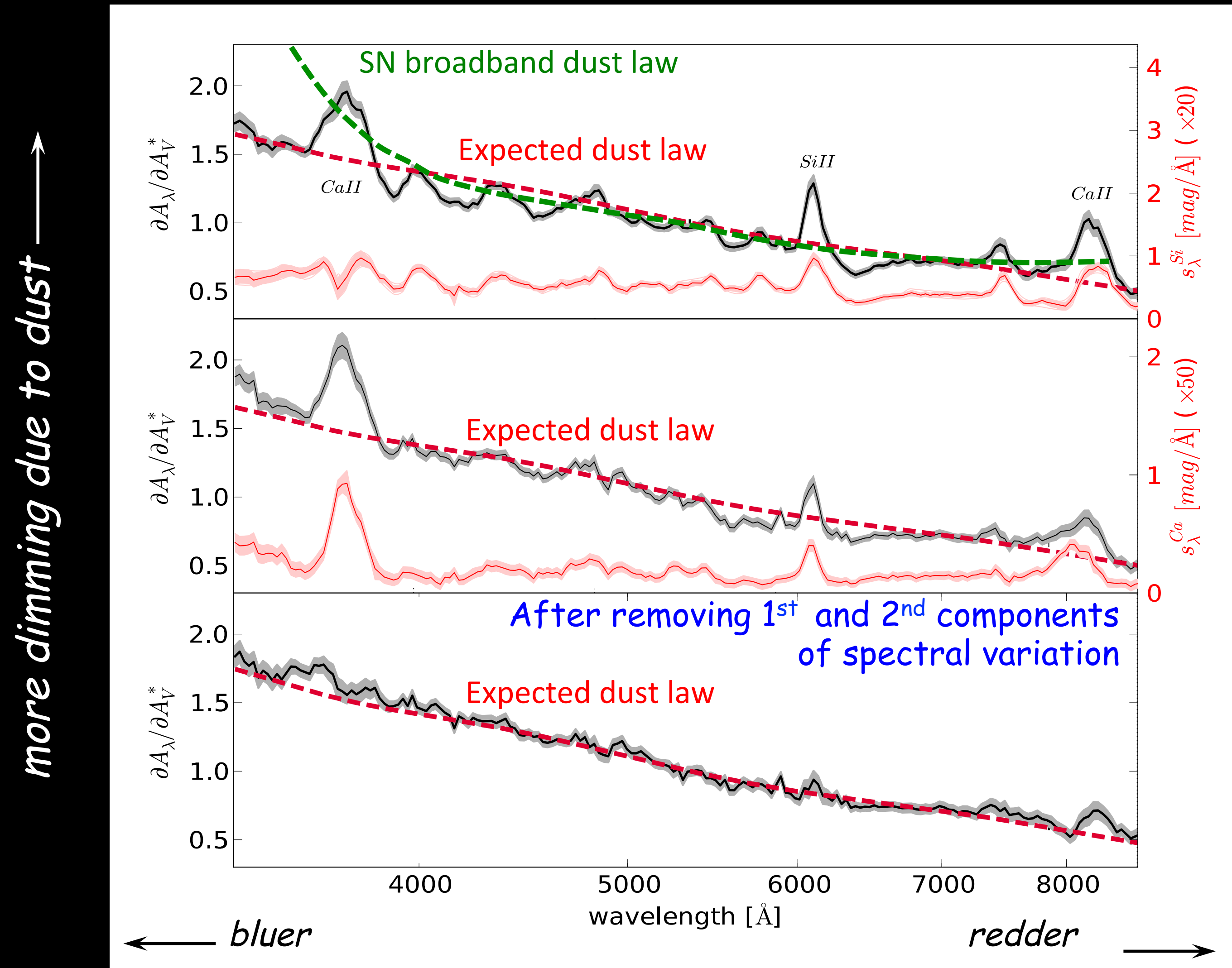
Bias on *w* in the range 0.03 – 0.06 if there is population drift, even if full spectral diversity is sampled with nearby SNe



Saunders+ (ApJ 2015)

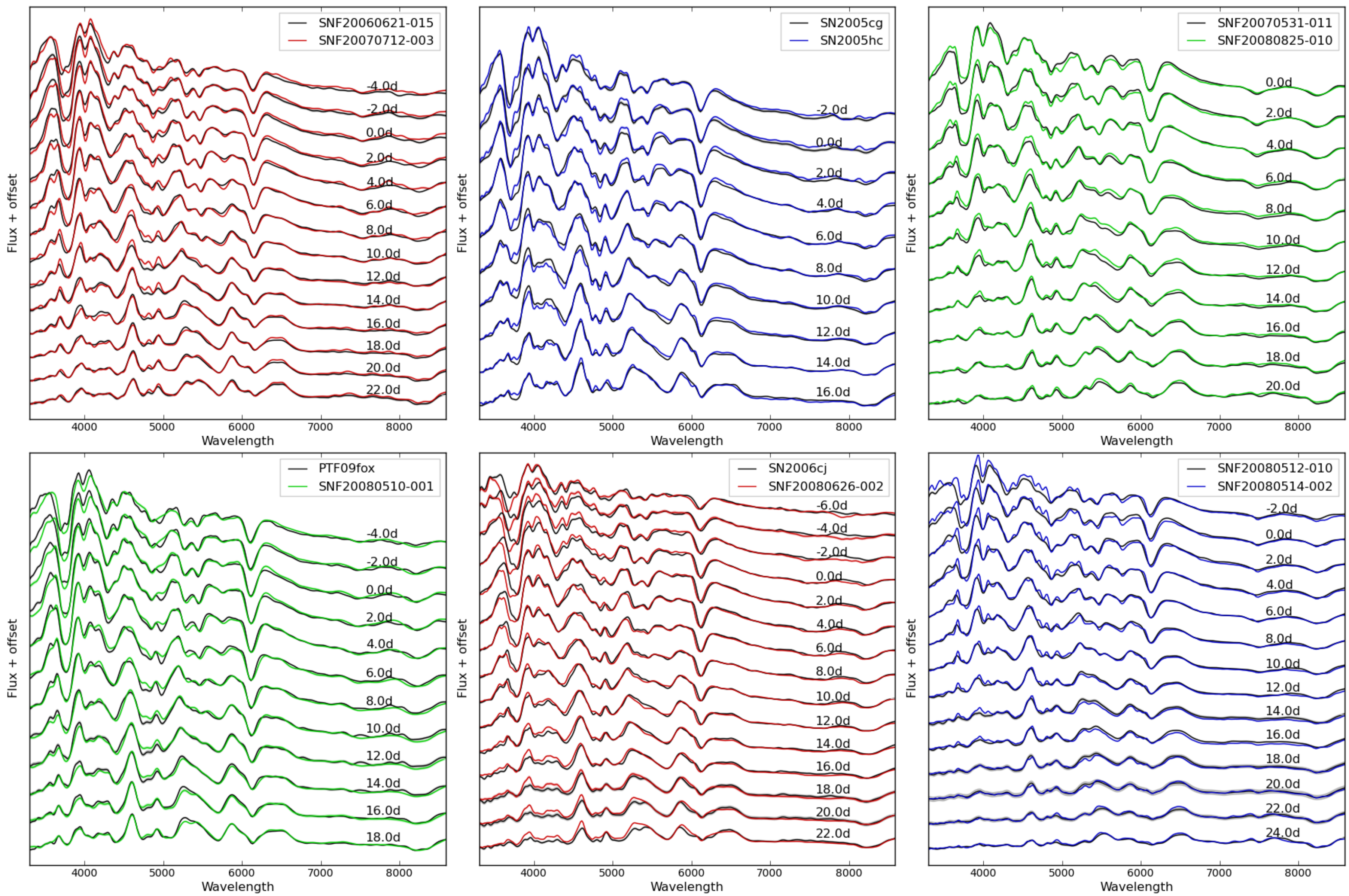
Nearby SN Factory

Dust Systematic: Spectral indicator distinguishes dust reddening from intrinsic SN color



Chotard et al 2011 (SNfactory)

Twins study from SN Factory spectral time-series

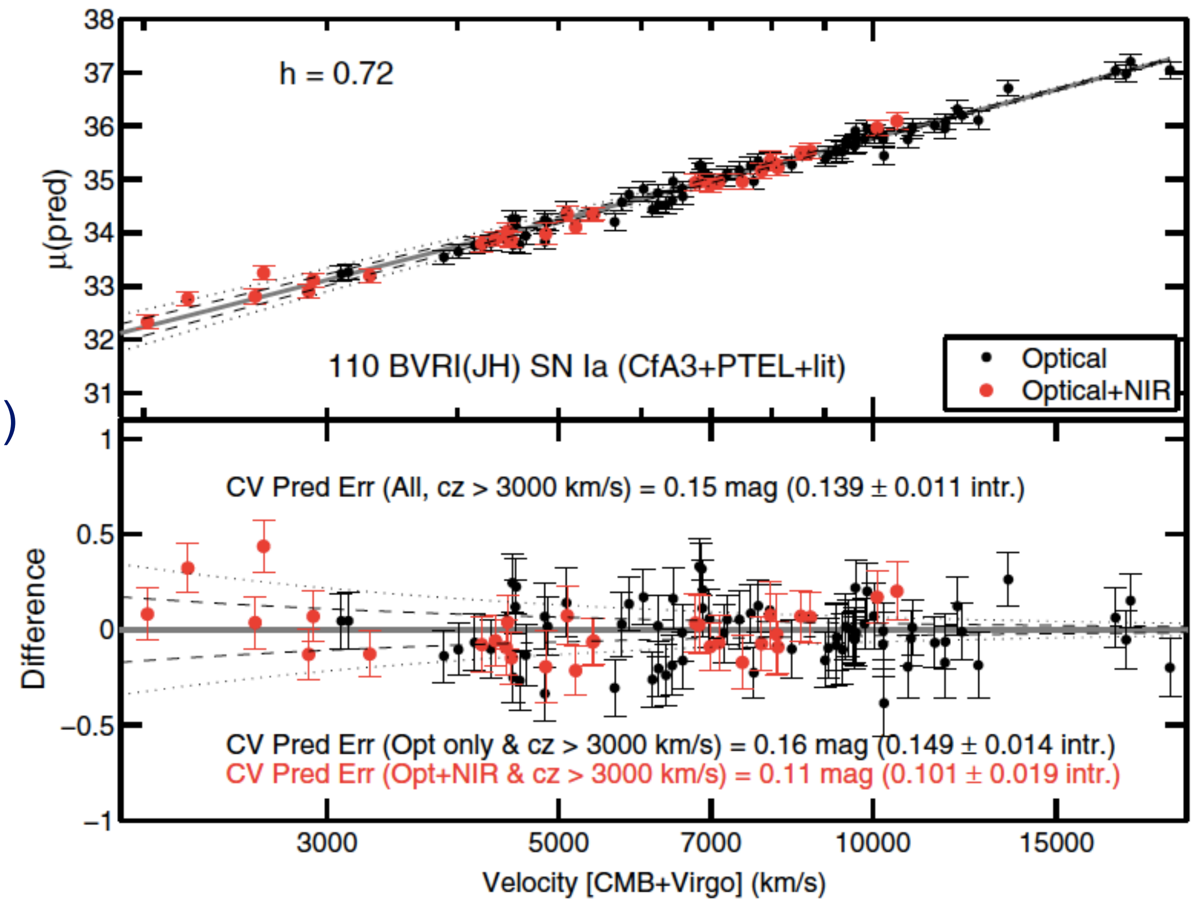


Fakhouri, Boone+ ApJ 2015

NIR Standardization

A route to better standardization:
Add J and H band.

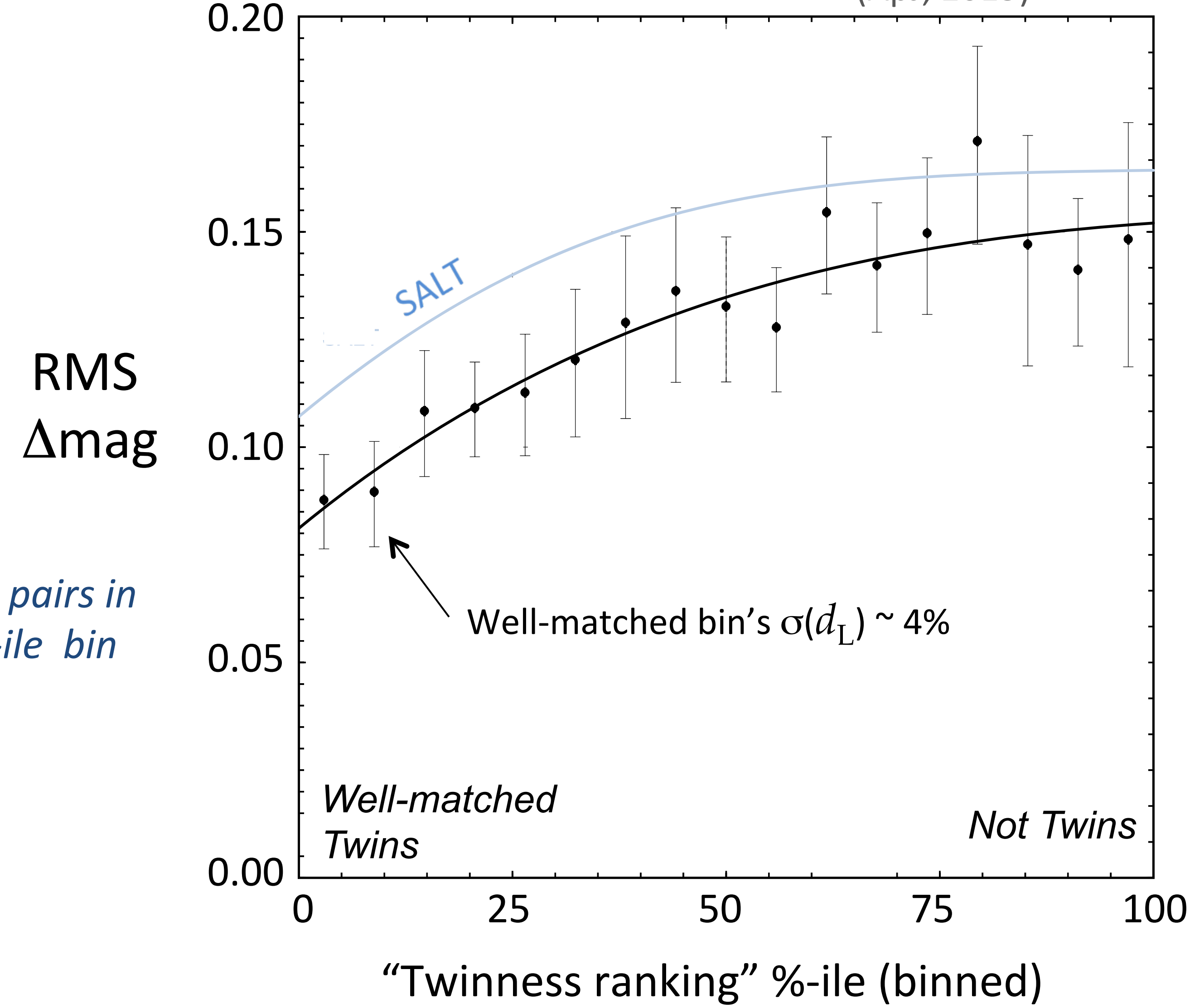
(J band is not as big an improvement as H band.)



Mandel et al (2011)

Twin SNe

Nearby SN Factory
Fakhouri, Boone, et al.
(ApJ, 2015)



for SN pairs in the %-ile bin

NB: Blind analysis methods used.

LSST’s SN program
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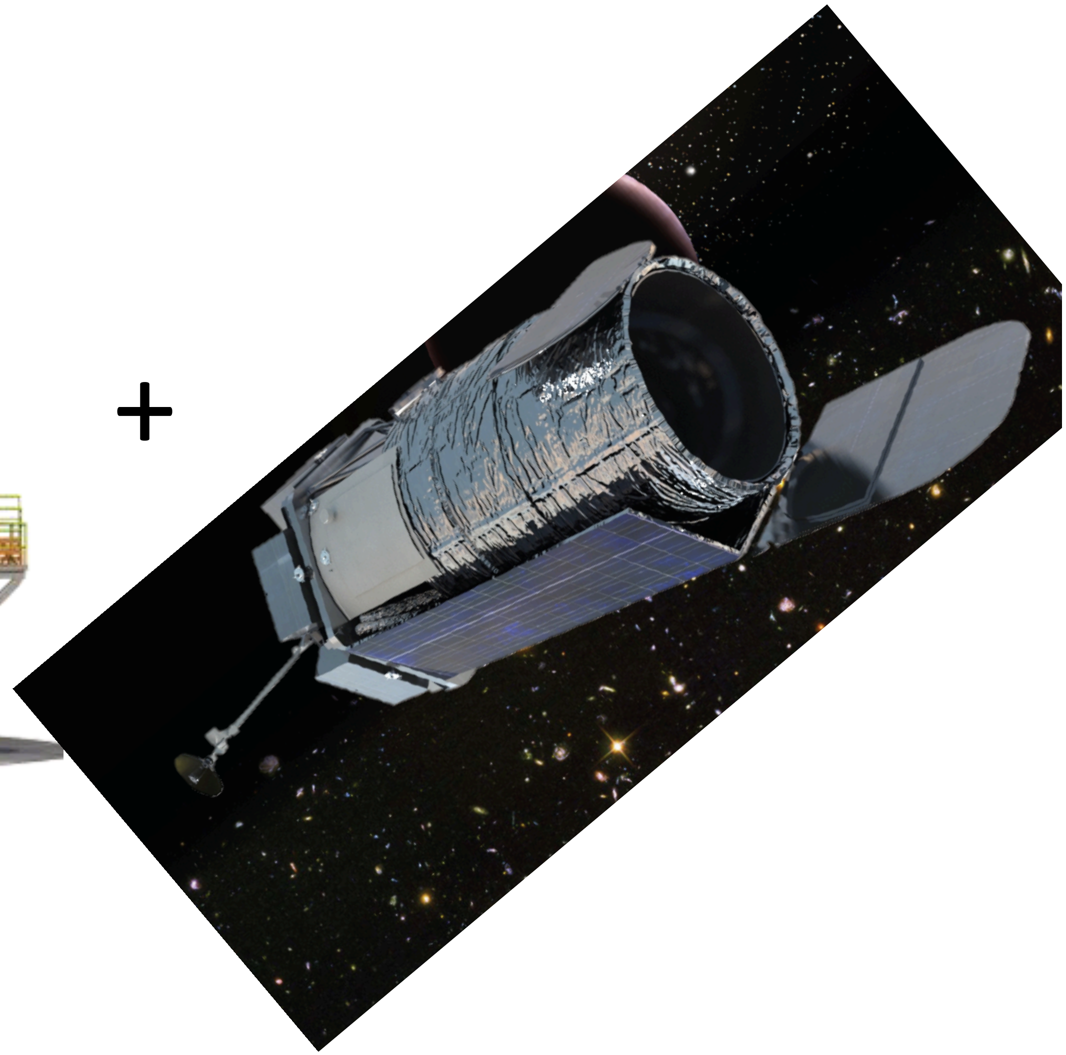
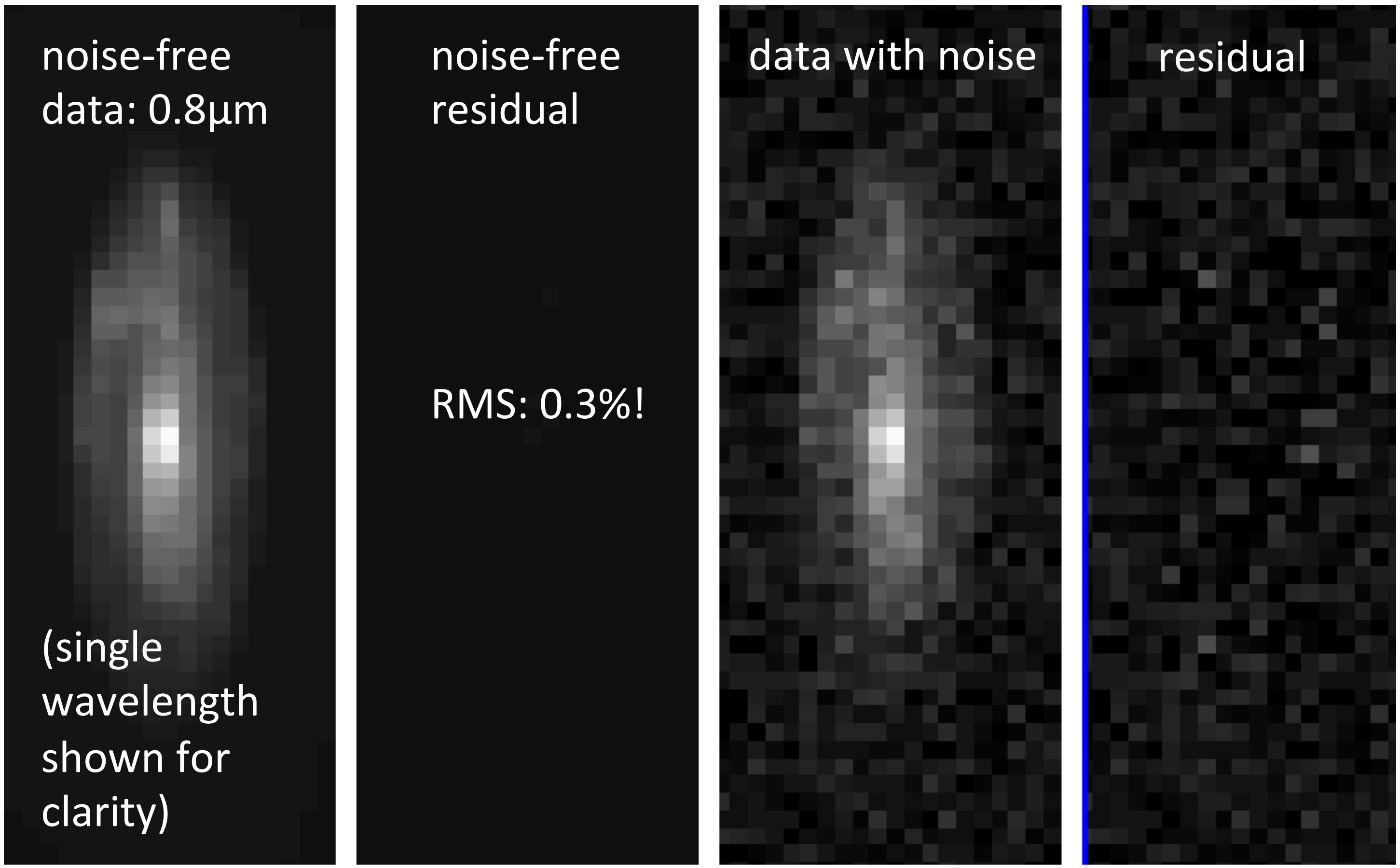


SN photometry uncertainty from IFC while **subtracting host** gal. light.

David Rubin

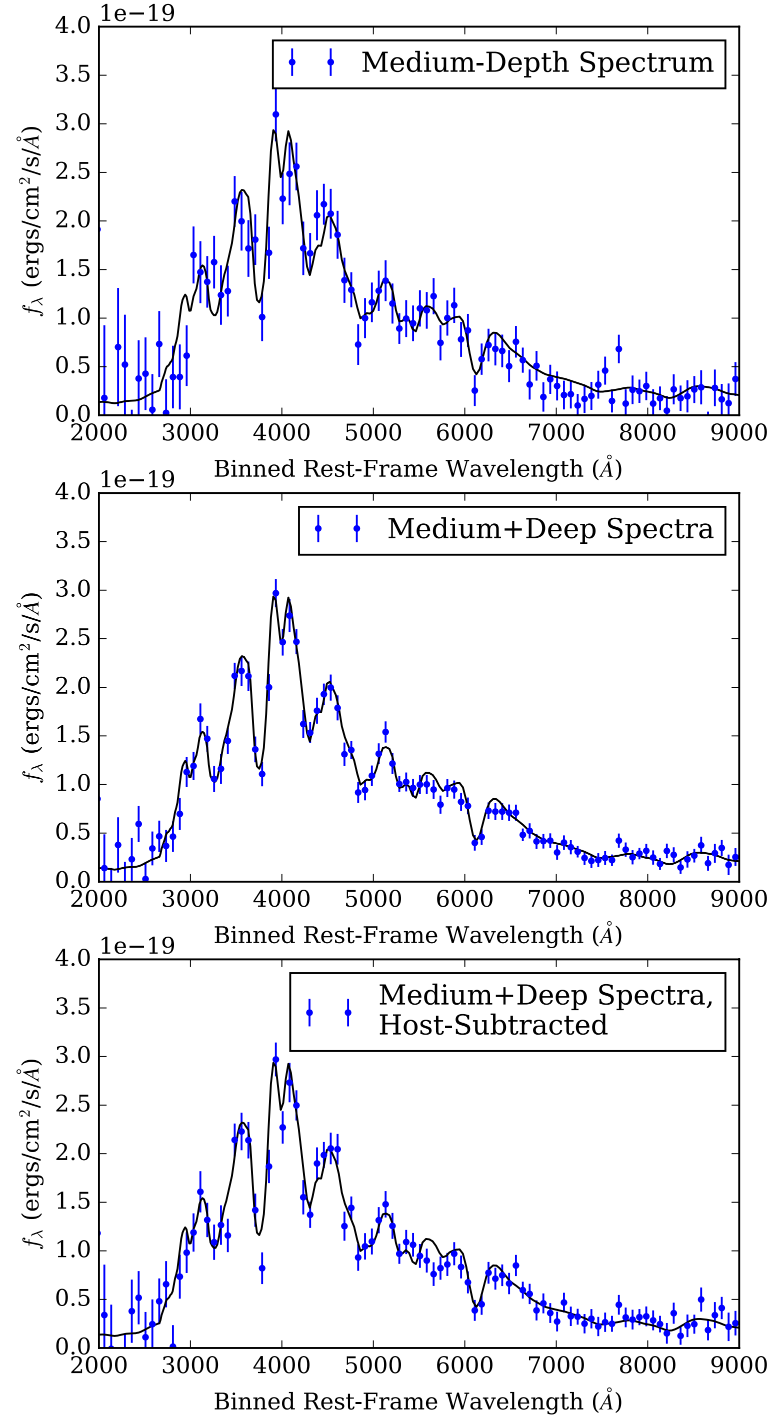


The final noise is dominated by sky and read noise,
not subtraction error

WFIRST Spectrophotometry

Two epochs near maximum with increasing S/N.

Reference epoch(s) after SN has faded.



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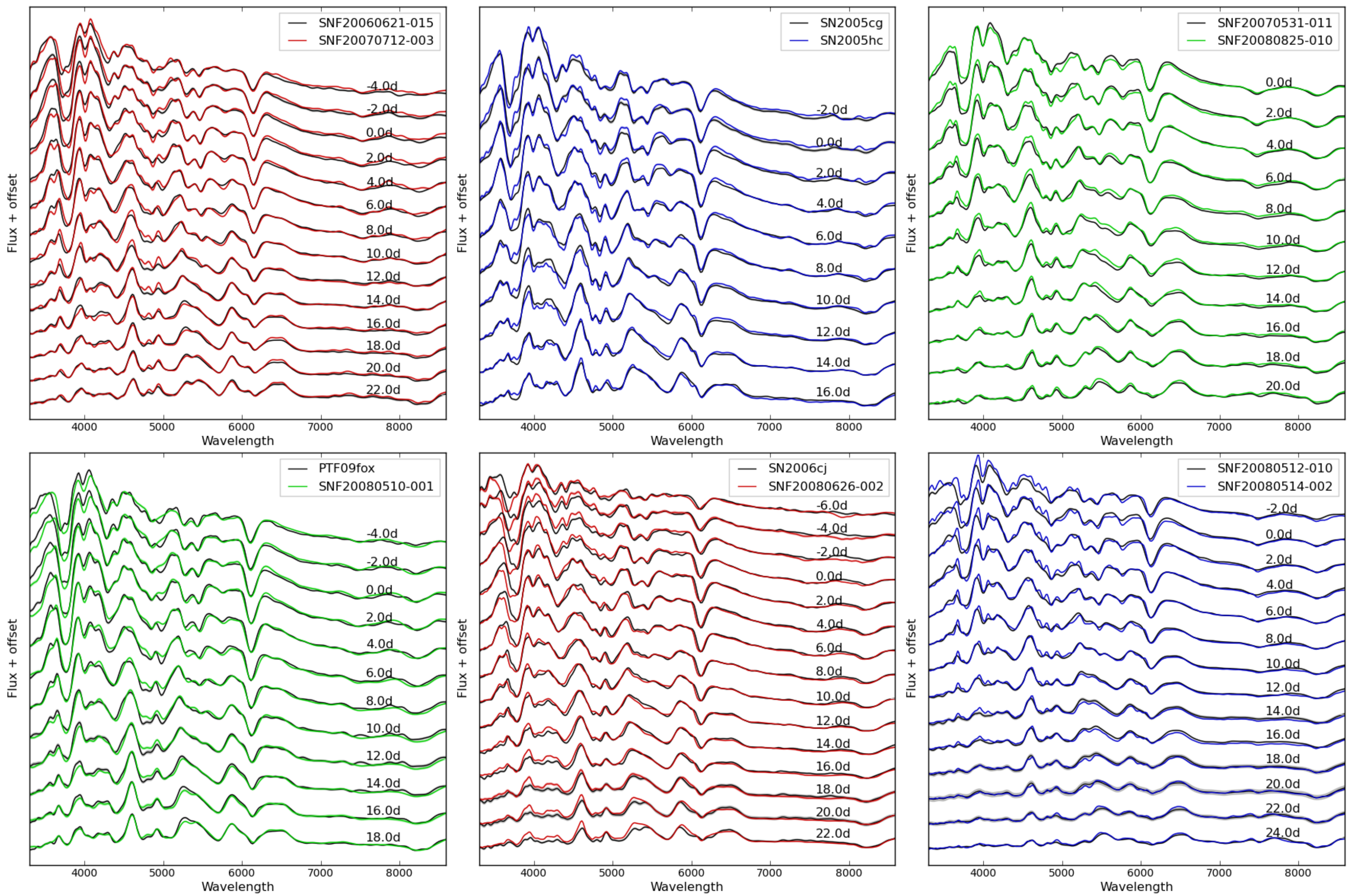
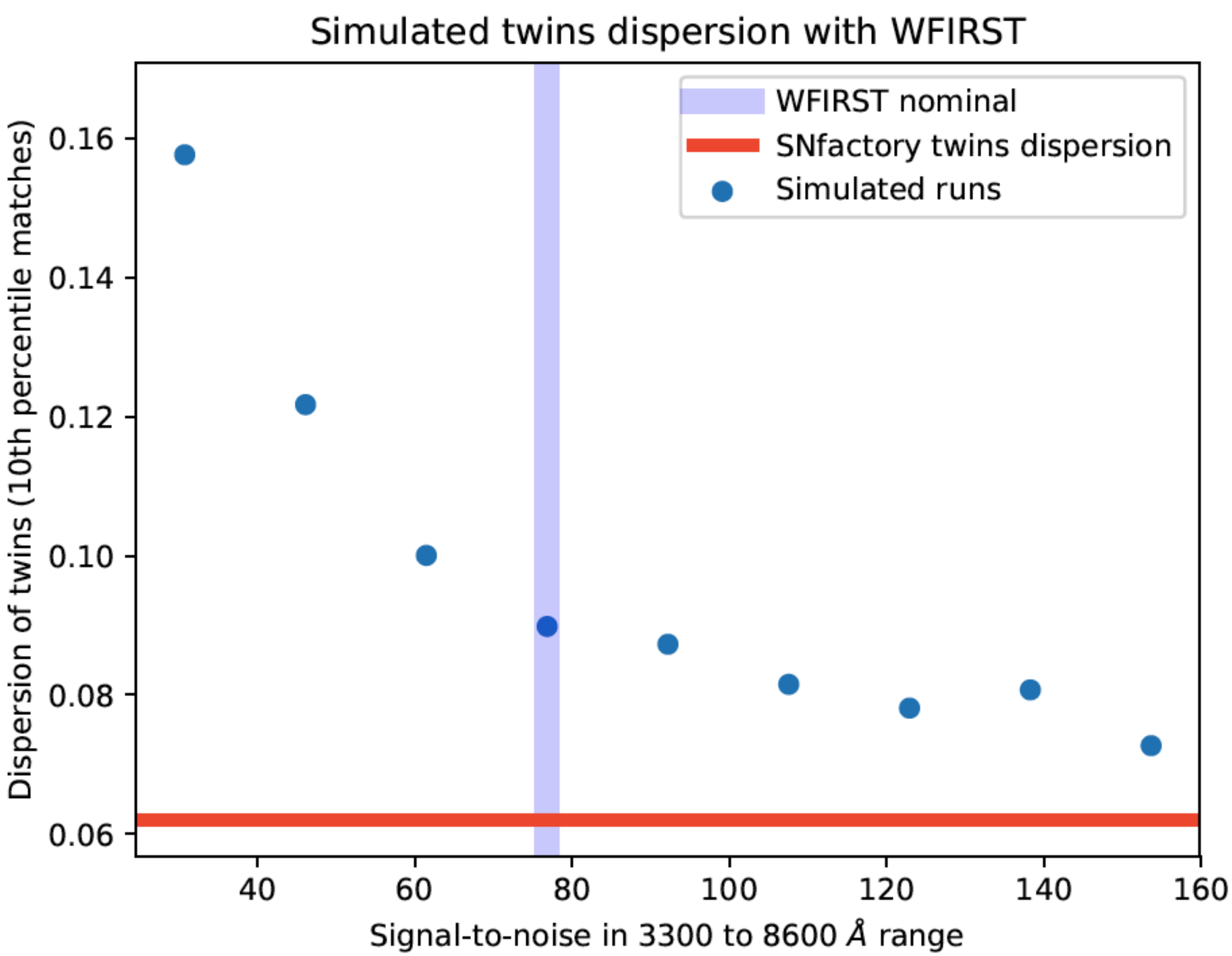


Fakhouri, Boone+ ApJ 2015

Spectral feature measurements and **twinning using IFC**, as fn. of S/N.

Kyle Boone



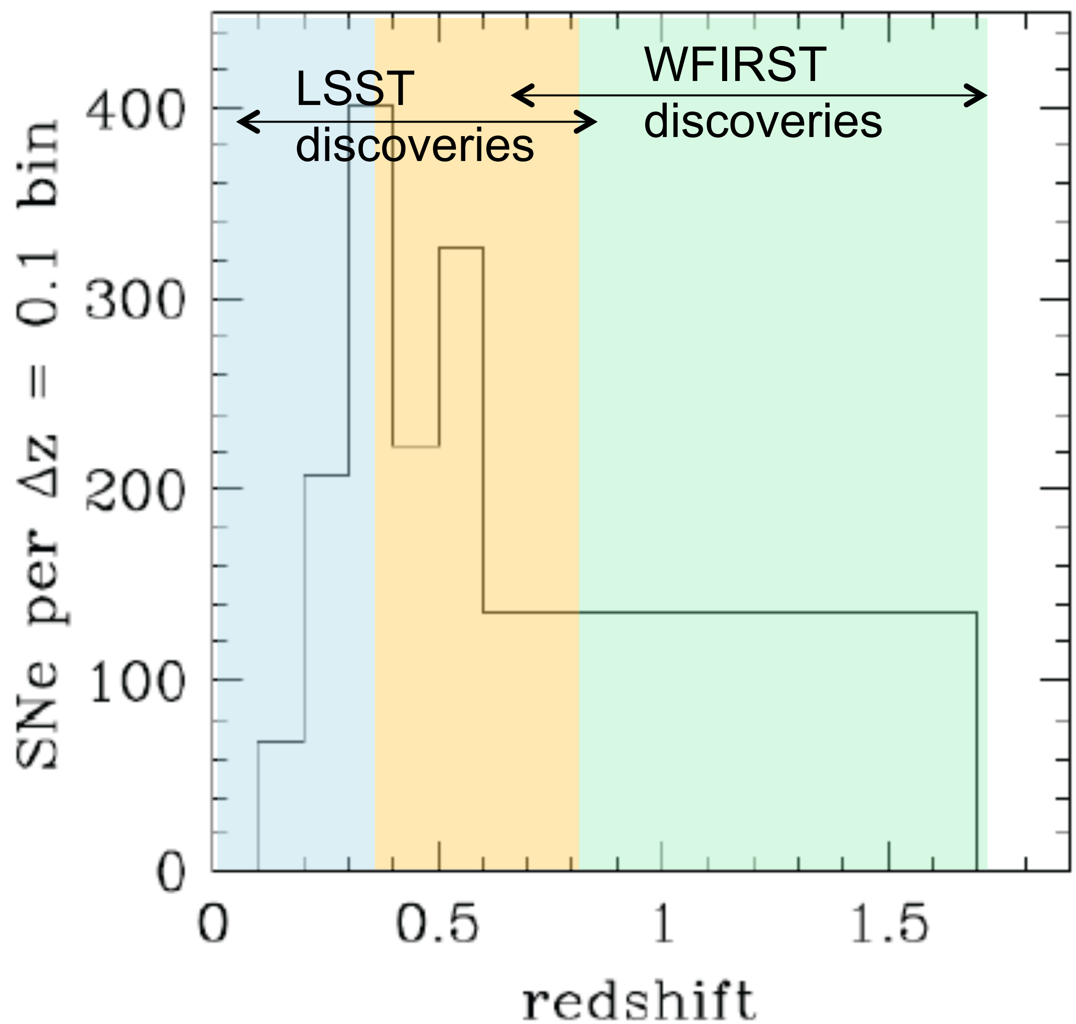
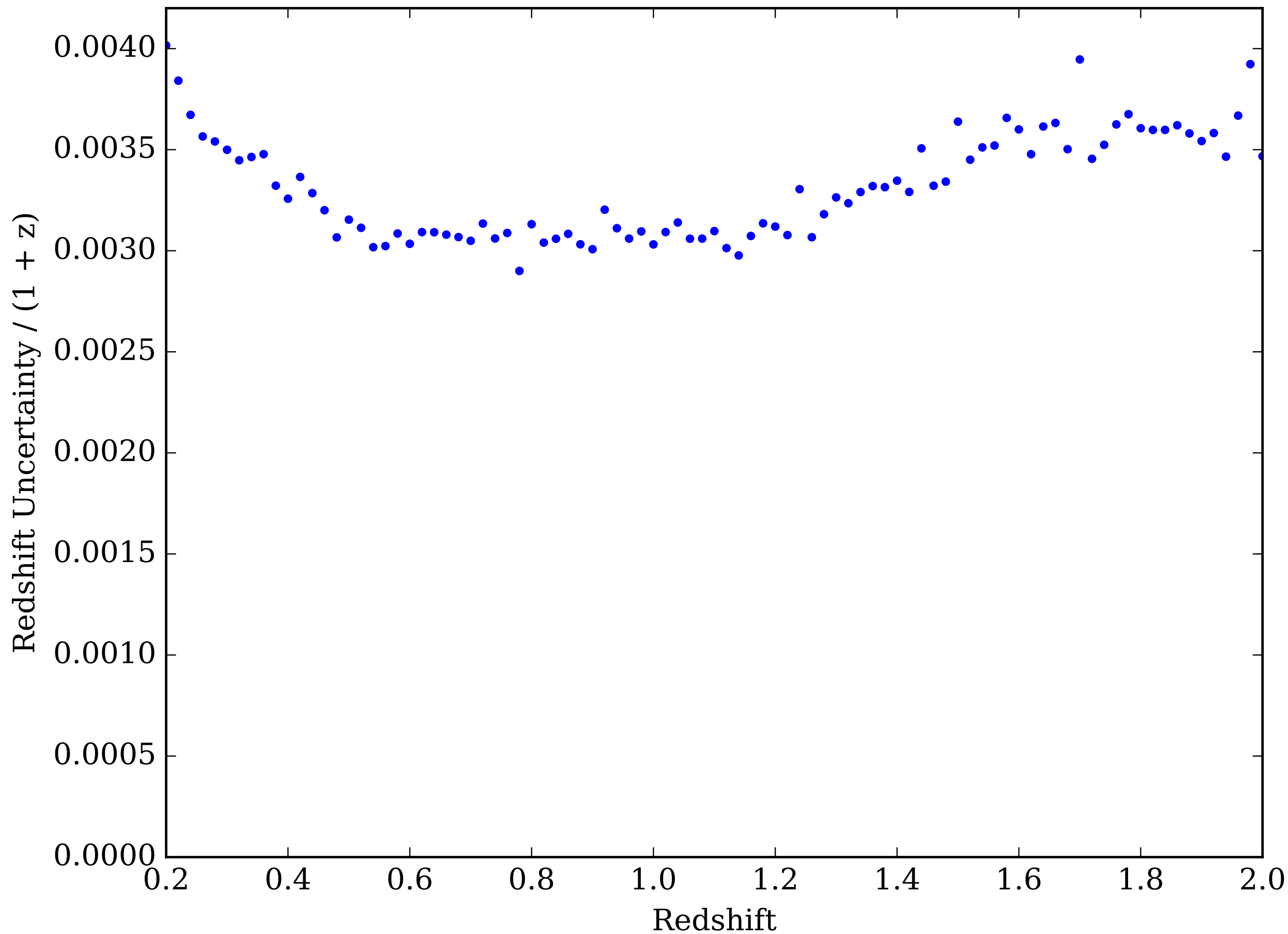


Figure 2-6: Expected number of Type Ia SNe to be followed in each $\Delta z = 0.1$ redshift bin. For $z > 0.6$ there are, by design, 136 SNe followed up with spectroscopic observations in each bin (from a larger number detected). The total number of SNe is 2725.

Redshift Precision
(from SN alone, before using host-galaxy)



(using > 3300A restframe)

This is a mutual LSST-WFIRST win-win:

Current SN program concepts with and without LSST discoveries at $z < 0.8$.

Program Concept	**Number of SNe**			**FoM** (±~10)	
z =	0.1--0.4	0.4--0.8	0.8--1.7	*Without Rv drift syst.*	*With the systematics*
2-band **WFIRST imaging discovery** and lightcurves. Spectrophotometric time series.	420	912	606	350	300
LSST & WFIRST imaging discovery and lightcurves. Spectrophotometric time series.	591	1,712	909	460	360

Note: These numbers are based on full simulations with more optimal exposure time/ redshift distributions, correlation-accounted systematics, host-galaxy light, and vetted ETCs, ***not*** *the straw-man SDT notional program.*

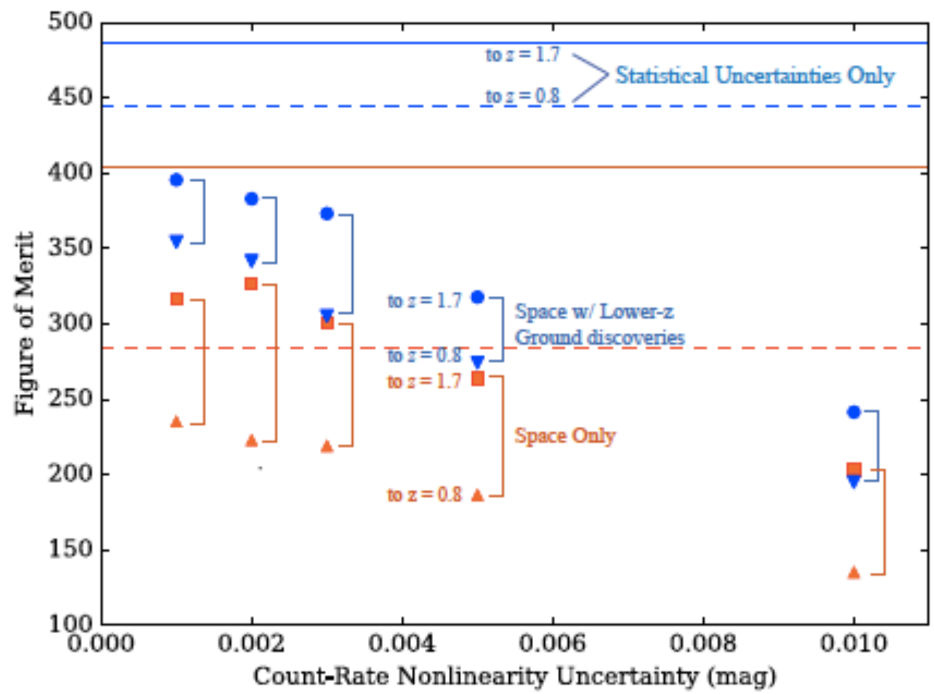


Figure of Merit
Count-Rate Nonlinearity Uncertainty (mag)
to z = 1.7
to z = 0.8
Statistical Uncertainties Only
Space w/ Lower-z
Ground discoveries
Space Only

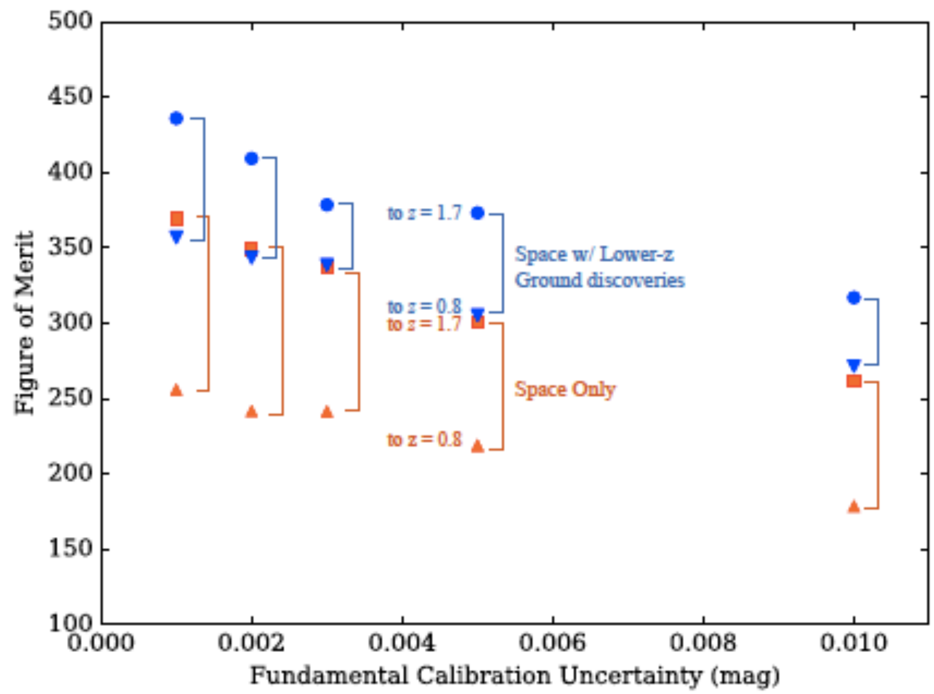
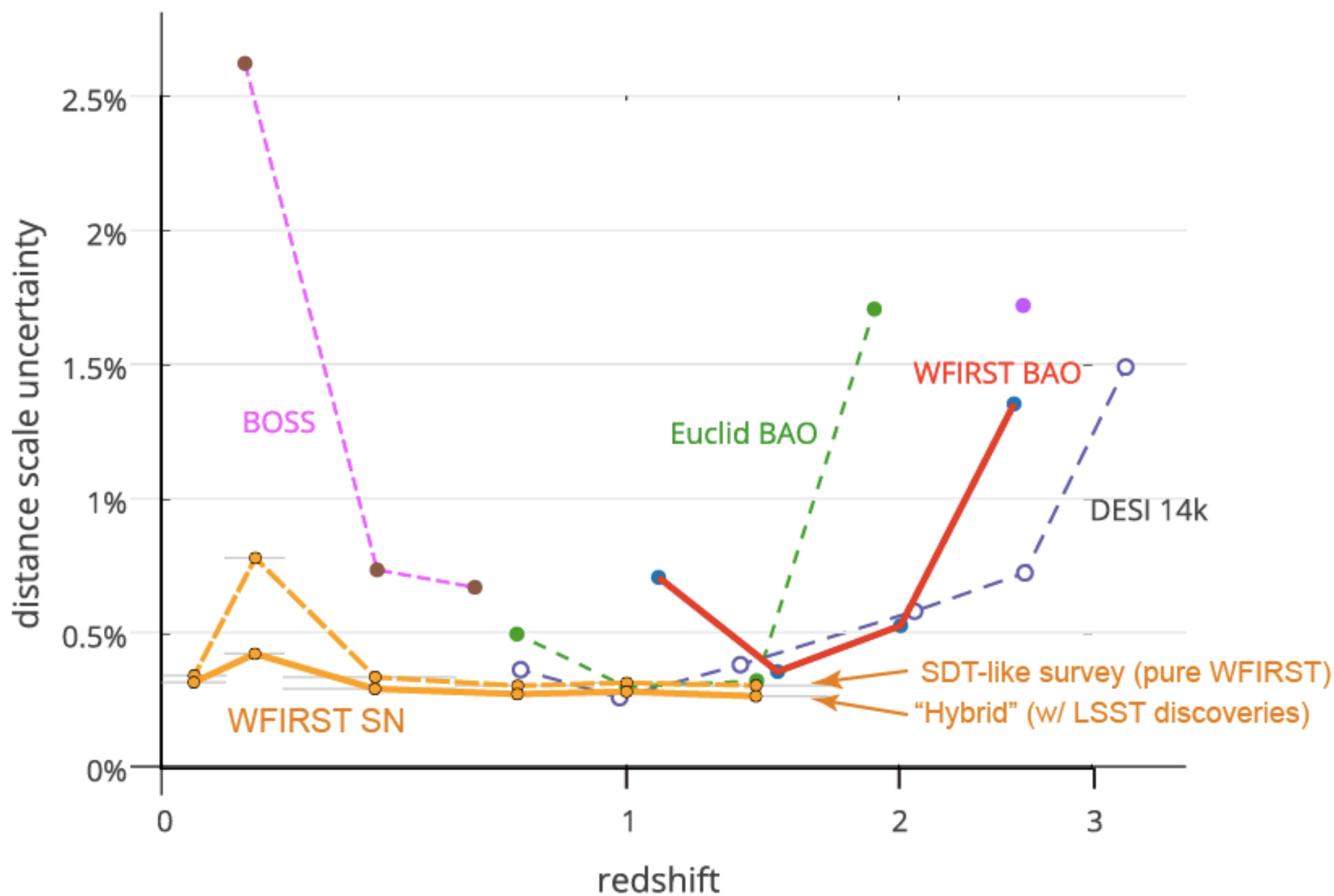


Figure of Merit
Fundamental Calibration Uncertainty (mag)
to z = 1.7
to z = 0.8
Space w/ Lower-z
Ground discoveries
Space Only

David Rubin



distance scale uncertainty
2.5%
2%
1.5%
1%
0.5%
0%
0
1
2
3
redshift
BOSS
Euclid BAO
WFIRST BAO
DESI 14k
WFIRST SN
SDT-like survey (pure WFIRST)
"Hybrid" (w/ LSST discoveries)

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Distance measurements improve as the number of nearby (z < 0.1) SNe is made comparable to the number of distant SNe

Projected WFIRST FoM as a function of number of low-z SNe Ia