Alternate design considered by the JDEM Interim Science Working Group (ISWG)

C Baltay

March 10-11, 2011

The JDEM ISWG

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Monthly Meetings December to April

- December 7, 8 2009 Johns Hopkins
- January 28, 29 2010 Johns Hopkins
- February 25, 26 2010 Berkeley LBNL
- March 25, 26 2010 Fermilab
- April 15, 16 2010 GSFC

The Function of ISWG

- JDEM Omega was on the table when we started
- Charge to ISWG:

  Develop a less expensive Probe-Class mission (650 M$ + Launch) that fulfills the JDEM Science Requirements
- We developed Design A2
  - Costed as 650 M$ + Launch by NASA Project Office
  - Total cost (including Launch) by ICE ~1 B$

Minimum Performance Requirements December Meeting

- What are the minimum Performance requirements that make a JDEM mission worthwhile?
  - The Dark Energy Task Force (DETF) minimum requirement of a Figure of Merit 10 times Stage II and 3 times Stage III is still valid
  - DETF estimated Stage II as FoM = 50 and FoMSWG estimated Stage III as FoM = 116
  - The panel therefore felt that we should aim for a minimum FoM = 500 with Planck + Stage III priors

Minimum Performance Requirements December Meeting

The DETF FoM is not the only relevant measure.

- JDEM should aim for a redshift reach complementary to what is possible from the ground.
- JDEM should enable at least two methods to investigate Dark Energy
  - Note that this is consistent with the DETF recommendation that the Dark Energy program have multiple techniques at every stage, at least one of which is a probe sensitive to the growth of structure in the form of galaxies and clusters of galaxies.

It is important not to look at JDEM in isolation but as a component of a coordinated world wide space and ground based Dark Energy program, to ensure that techniques not enabled by one mission are covered by some other component of the program, and that the different parts of the program help and complement each other.

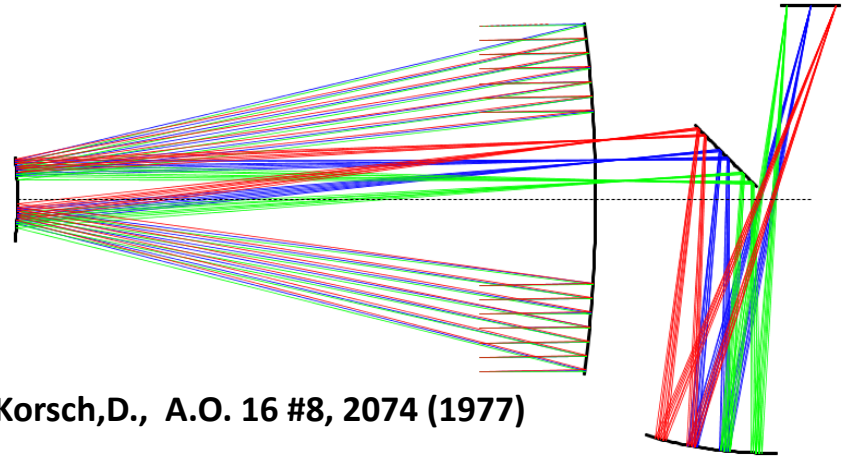
Three considerations that led to Design A

- Use a 1.1m unobstructed view mirror. This has the performance comparable to a 1.3 to 1.5 m convetional mirror
- Use a different Supernova strategy
  - Use the NIR mercatel imager to discover Supernovae
  - Use an IFU spectrometer to follow supernova, obtain lightcurves from the spectra
- Realized that you can not do a credible Weak Lensing measurement at a Probe class mission price. Rely on LSST and EUCLID to do Weak Lensing

(we also developed a Design B that could do all three Dark Energy techniques but was a lot more expensive)

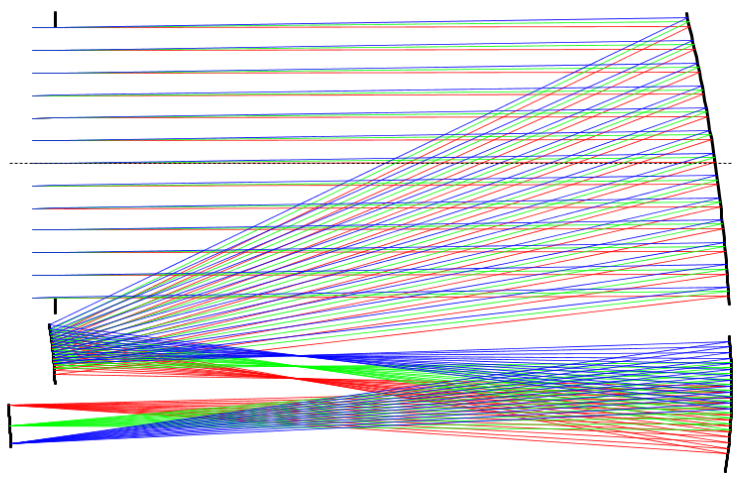
Obscured vs Unobscured TMAs

Obscured



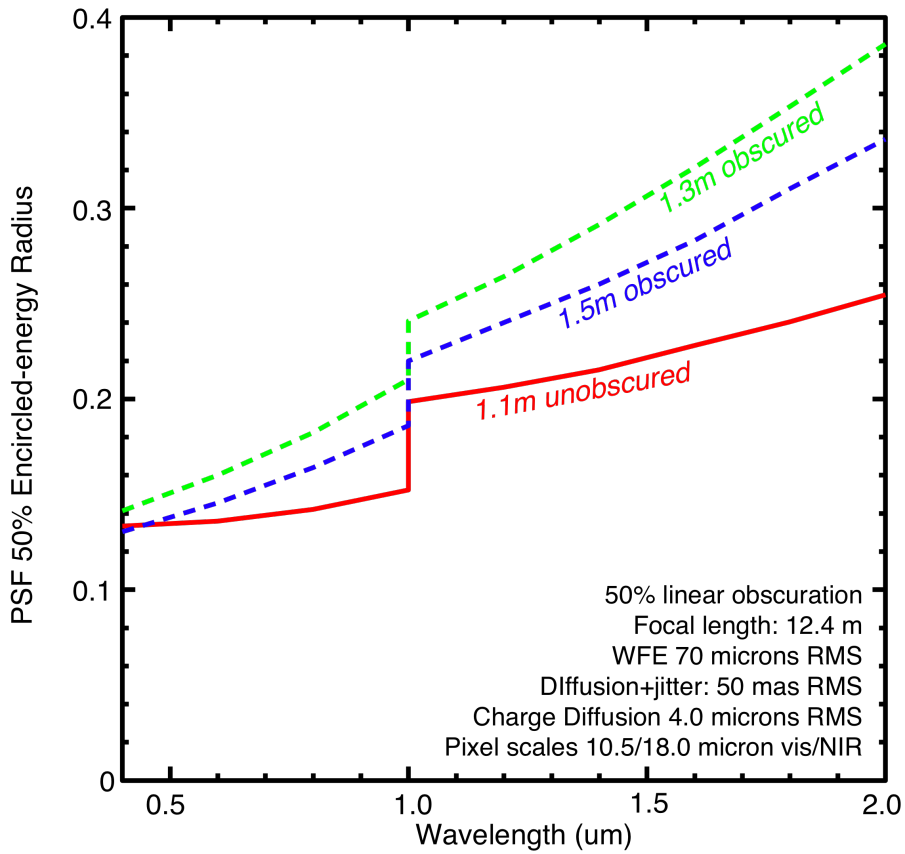
Korsch,D., A.O. 16 #8, 2074 (1977)

Unobscured



Cook,L.G., Proc.SPIE v.183 (1979)

50% Encircled Energy Radius



Advantages of the new SNe Strategy

- Lightcurves from a Rolling Search.
  - SNAP and DESTINY were planning to follow many supernovae in one field in a rolling search (SNAP with photometry, DESTINY with grism spectroscopy). With the large mirror apertures and fields of view this was very efficient.
  - All exposures had to be long enough to give precision lightcurve points for the highest redshift supernova at its faintest (early or late) epoch
- Lightcurves from IFU spectroscopy
  - Need one exposure for each lightcurve point of each supernova
  - Single exposures gets full wavelength range (instead of 9 filters in SNAP) i.e. we switch from spatial multiplexing to wavelength multiplexing. With the smaller apertures and fields of view we are considering here, this turns out to be much more efficient.
  - Exposure time can be tailored for the brightness of any given SNe
  - Better systematics—no need for K corrections, no filter transmission curves to calibrate, simpler flux calibration.
  - Needs more frequent interactions with the spacecraft after SNe discovery.

Design A2 for BAO and Supernovae

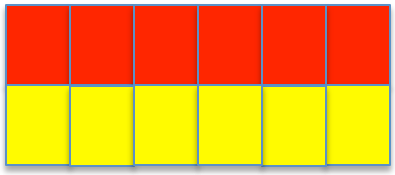
- Design A2 enables BAO + SN
  - PO Cost Estimate: Fits Probe Class
  - Imager with 12 NIR Detectors, 0.25”/pixel
  - BAO Spectrometer with 8 NIR Detectors, 0.45”/pixel
  - IFU or slit SNe Spectrometer, single arm, single detector 0.26”/pixel
  - 21 identical NIR detectors, 88 Megapixels, no moving parts!
  - Require a 3-year mission (if it lasts longer, so much more science)

Design A2 Schematic

1.1 m Mirror
Unobstructed
View

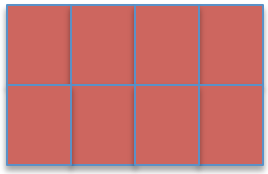
NIR Imager

12 Detectors 2Kx2K
0.25”/pix 0.25 sq deg
Two fixed filters



BAO Spectrometer

Prism Spect R=200
8 Detectors 2Kx2K
0.45”/pix 0.50 sq deg



Supernova Spectrometer

Integral Field Unit R=50
Single 2Kx2K Detector
0.26”/pix Single Object

Design A Performance

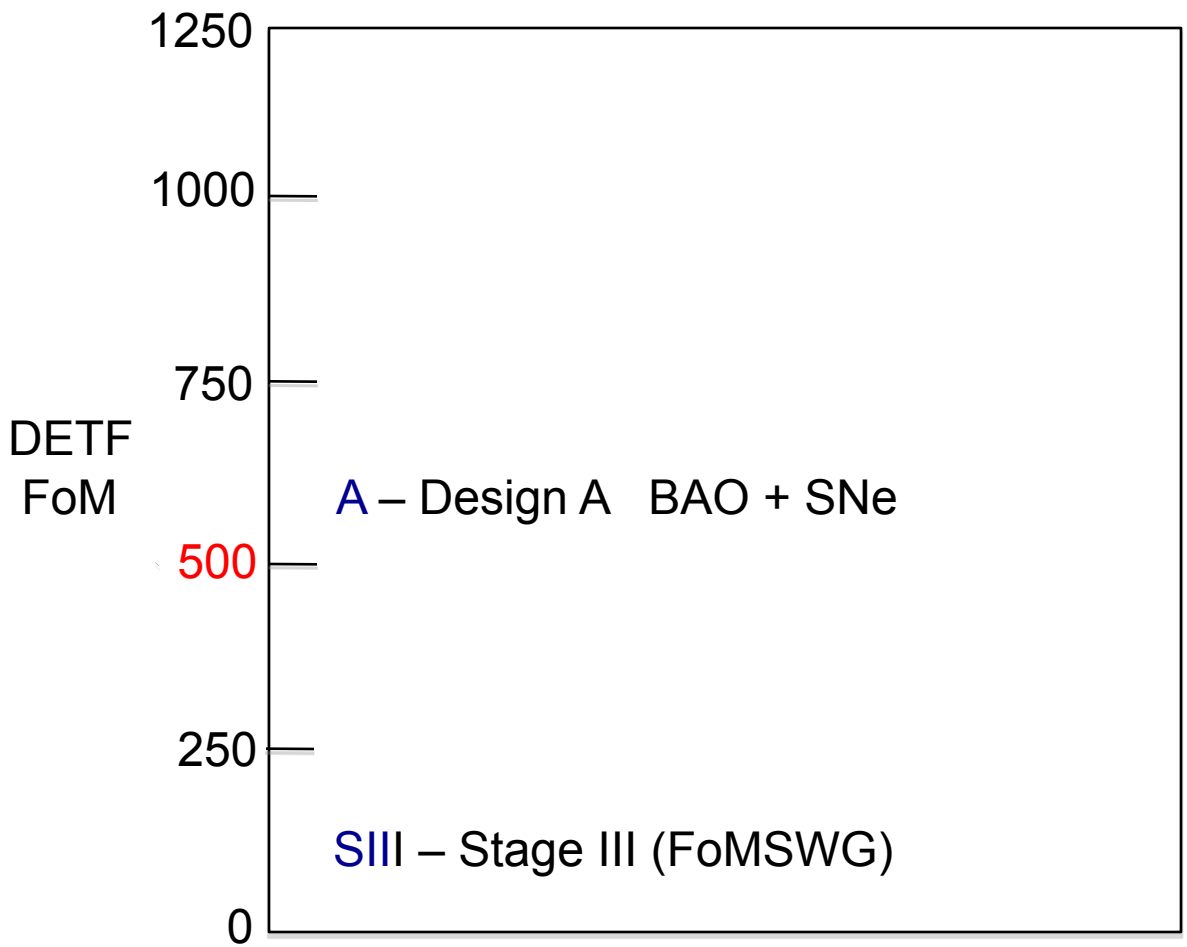
1.1 meter mirror, 3 year mission

- BAO
  - 16,000 square degrees in 1.5 yrs
  - Redshift range $1.3 < z < 2.0$
  - Depth limit 2×10^{-16} ergs/sqcm/sec, redshifts for 60 million galaxies
  - Redshift uncertainty $0.001(1 + z)$
- Supernovae
  - 1500 supernova to redshift of 0.2 to 1.5 in 1.5 yrs
  - Supernova discovery with JDEM imager
  - Assumes large sample of ground based nearby ($z < 0.1$) supernovae

Good performance for a 3 year mission, even better performance with a potential extended lifetime

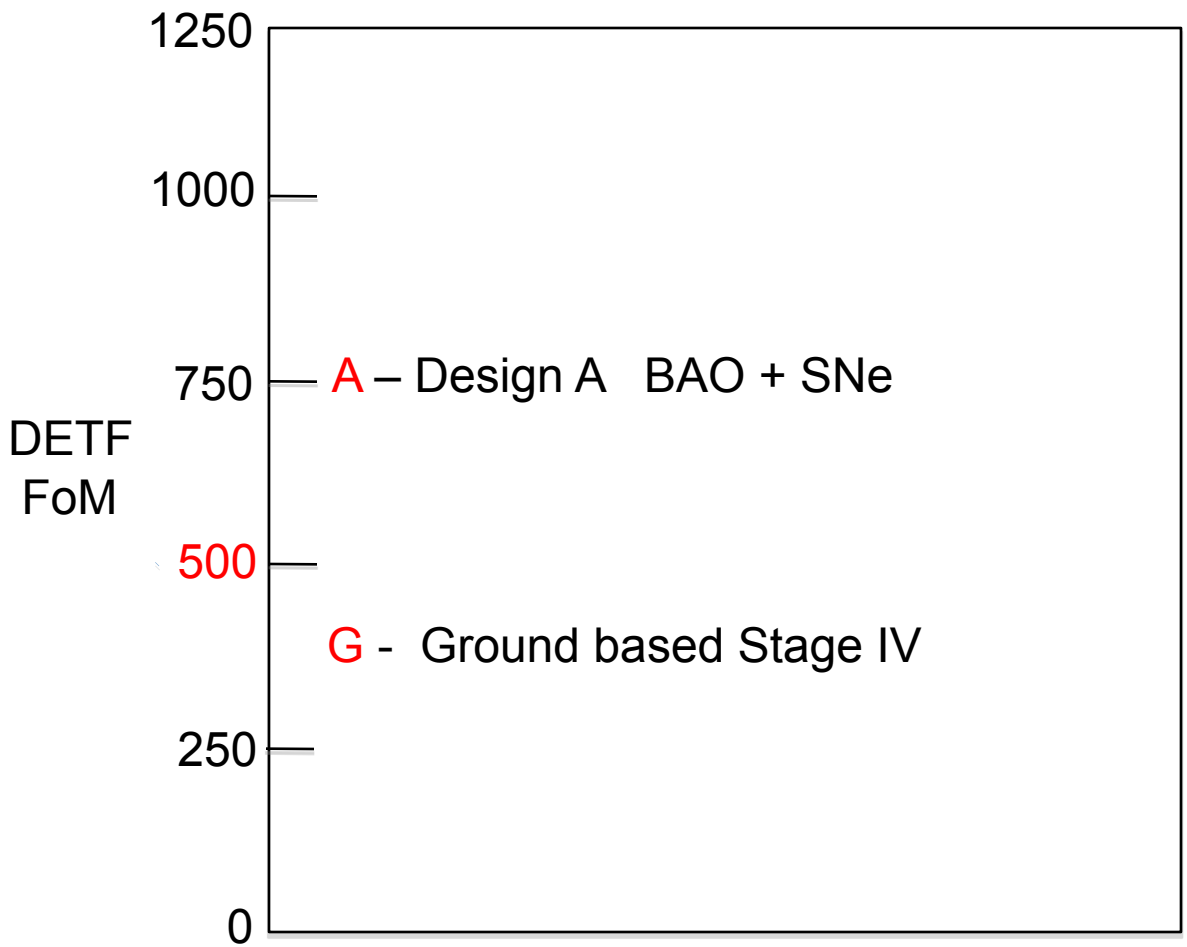
Design A Figure of Merit

Assuming only Stage III priors



Design A Figure of Merit

Assuming Maximal Stage IV Ground (24,000 deg^2 BigBOSS + LSST)



Design A BAO and Supernova Mission

- Nikhil Padmanabhan combined FoM's March 19 Nos.

- Planck plus Stage III priors (FoMSWG) FoM = 116
- Add BAO , JDEM Design A FoM = 190
  - Z range 1.3 – 2.0
  - Wavelength range 1.5 – 2.0
  - Depth limit 2.0 E-16
- Add JDEM Supernova, no BAO FoM = 365
  - IFU with single R = 50/2pixels, 0.26"/pixel
  - Dark current = 0.03 e/pixel/sec
  - Redshift range 0.1 to 1.5
- Both JDEM BAO + Supernova FoM = 564
- This satisfies DETF criteria for a worthwhile mission

What if BigBOSS happens?

- Planck + Stage III FoM = 116
- Planck + Stage III + BigBOSS(North) 183
- Planck + Stage III + BigBOSS(N + S) 279
- Planck + Stage III + BigBOSS (N + S) +
  JDEM (BAO + Supernova) 784

Redshift Space Distortions

- Redshift Space Distortions measure the velocities of galaxies with respect to the Hubble flow
  - Allows probes of growth of structure independent of WL by redshift surveys
- Significant improvements in DETF/ ϒ FoM when included
  - All scenarios (JDEM & ground) see ~50-100% increases in γ FoM and ~50% increases in DETF FoM when simplified RSD estimates are included.
- Combining RSD with WL enables new tests of GR not captured by existing FoM's
- Open issues :
  - Systematics not as well characterized
  - Further work needed on requirements, optimization

Comparison of Designs

Design	Mirror	Imager CCD	Imager NIR	Imager Area	BAO Spectr	Sne Spectr	Filter Wheel		
SNAP	1.9m	36 / 0.10	36 /0.18	0.70	No	Yes	No		
MPF Exoplt	1.1m	0	35/0.24	0.62	No	No	No		
DESTINY	1.8m	0	36/0.13	0.25	No	Yes	No		
ADEPT	1.5m	0			2	No			
JEDI	1.5m	0	20/0.15	0.14	Yes	Yes	No		
IDECS	1.5m	18 /0.14	9 /0.28	0.55	2	No	Yes		
Omega	1.5m	0	24 /0.18	0.24	2	No	Yes		
Euclid	1.2m	36 /0.10	16 /0.30	0.50	1	No	Yes		
ISWG- A	1.1U	0	12 /0.25	0.25	1	Yes	No		

Cost Reduction : Omega to ISWG-A

- Mirror: 1.5m to 1.1m (unobstructed View),
  similar performance due to unobstructed view
- Imager: 24 (with 0.18”/pixl, 0.24 sq degrees) to
  12 (with 0.25”/pixl 0.24 sq degrees)
- 2 BAO Spectrometers to 1 BAO Spectrometer
  Omega 6 NIR det each with 0.36”/pix for 0.24 sq deg each
  ISWG-A 8 NIR det with 0.45”/pix for 0.50 sq deg
- Eliminated Filter Wheel (fixed filters--no moving parts)
- Added Integral Field spectrometer to allow a more efficient supernova strategy (free French contribution?)

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Clearly, more pixels would be better, but will increase cost

Mission cost is probably correlated with likelyhood of mission and its launch date.

Comments on the Supernova Spectrometer

- Need a spectrometer for the supernova survey
  - Verify as Type Ia supernova
  - Measure redshift of supernova
  - Advantageous to get lightcurves from spectroscopy
  - High quality spectra can be used to "subtype" supernova and thus reduce their natural spread of luminosities
- Different types of spectrometers have been discussed
  - Slitless Grism spectrometers
  - Slit Spectrometers
  - Integral Field Units (IFUs)
- They all have their pros and cons—I assume a detailed study of this choice will be carried out by one of the working groups.

Pros and Cons of different Spectrometers

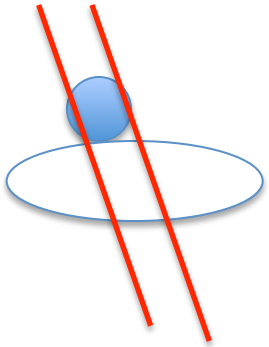
- Slitless Grism Spectrometer –
  - Simplicity--Single instrument, discovery and spectra in one operation, no feedback needed to telescope
  - Can get spectra of many SNe in one exposure
  - Need to set long exposure time for faintest SNe off peak
  - Background larger by an order of magnitude or more then is the case for Slit Spect or IFU, and thus lower Signal to Noise in reasonable exposure times, and thus harder to do supernova "subtyping"
- IFU or Slit Spectrometer
  - An additional instrument on board (but needs no Filter Wheel)
  - Take one spectra at a time
  - Can set exposure time suitable for each SNe (usually quite short)
  - Low background, can get high S/N, allows detailed "subtyping" and thus reduced intrinsic luminosity spread.

Pros and Cons of different Spectrometers

- Spacecraft roll orientation precision and repeatability required
  - To get precise lightcurves from spectra with uniform galaxy background subtraction, slit spectrometer and grisms need very precise spacecraft orientation and have to return to the same orientation for all repeated exposures of any given supernova. It is difficult to do this and still keep the same side to the sun etc.
  - Slit Spectrometer has to be very precisely set on target to get luminosity from spectra to the required accuracy
  - IFU can take exposures in any orientation since it can do a two dimensional galaxy background subtraction

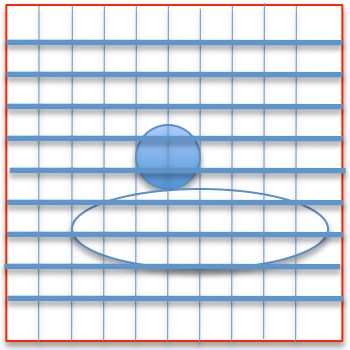
Spectrometer Comparison

Grism or Slit Spectrometer



- Requires constant roll angle for long periods
- Allows one dimensional galaxy Bkgrd subtracion
- Requires more time for post Sne reference spectra
- Slit Spectr requires extremely precise positioning on Sne

Integral Field Unit



- Easy positioning on Sne
- Variable roll angle not an issue
- Allows robust two dimensional galaxy bkgrd subtraction
- Less time for reference spectra

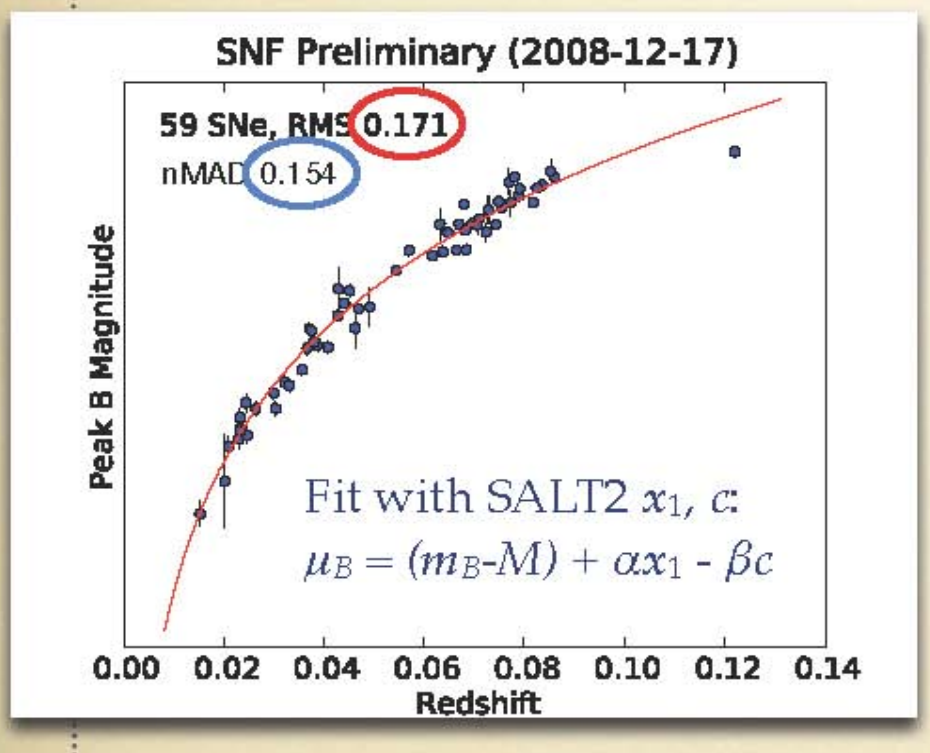
Reducing the natural spread of SNe Luminosities

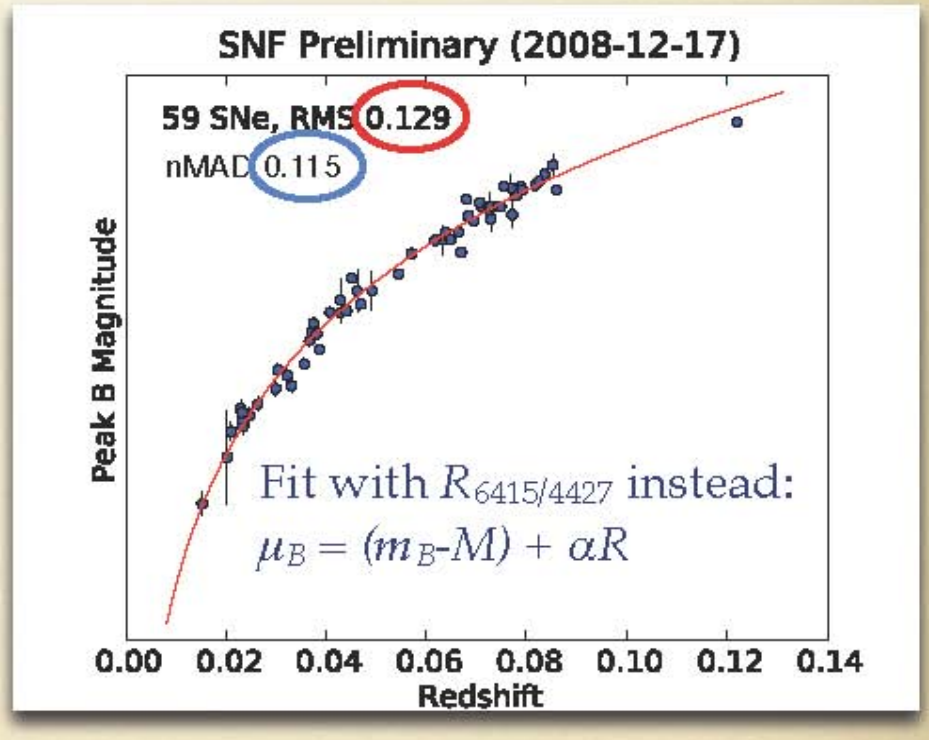
- Typically the peak luminosities of Type Ia are standardized by making a stretch correction. This produces a natural spread of ~17% in the peak luminosity
- High signal to noise spectra can be used to reduce this natural spread (subtyping). As an example, the Supernova Factory (S. Bailey et al) has shown that using the ratio of spectroscopic features at 6415 and 4427 A instead of the stretch factor can reduce the natural spread to ~13%
- Spectra with an IFU can get good enaugh signal to noise in a reasonable exposure time for this to work. Not so clear with grism spectra.
- Reducing errors is crucial to get high Fig of Merit

Reduced Natural Spread of Peak Luminosities

Data from the Supernova Factory Project, S. Bailey et al

Nearby Hubble Diagram



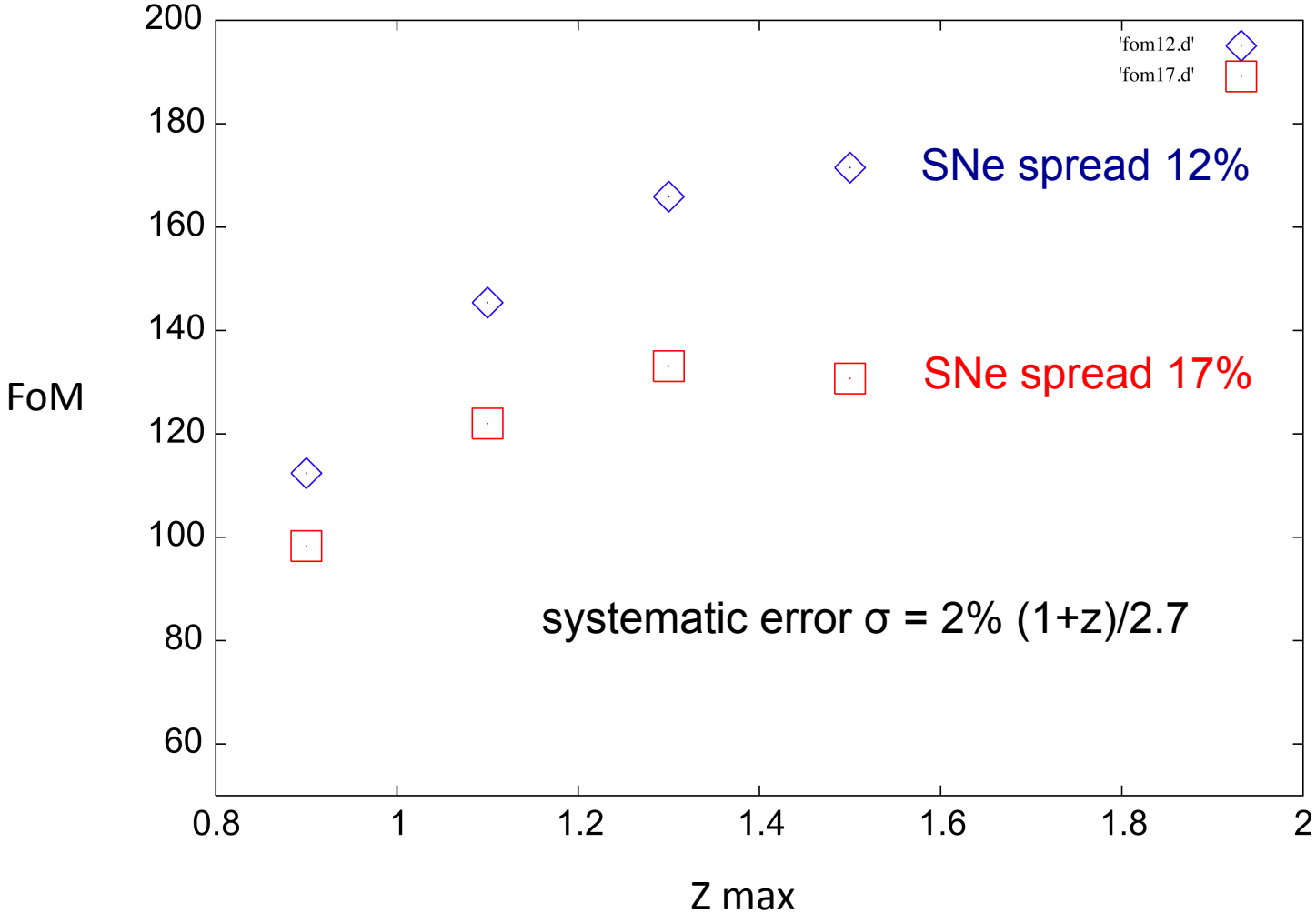


Redshift Reach

- For a fixed Supernova survey time, say 1 year, higher z_{max} means fewer supernova per bin
- Divide z range from 0 to z_{max} into bins of 0.1

z_{max}	SNe/bin
0.9	792
1.1	366
1.3	190
1.5	100

Fig of Merit depends on errors assumed

Supernova Figures of Merit

FoM's for 347 days shutter open time for spectroscopy, single resolution IFU spect R=50,plate scale 0.26"/pixel, dark current = 0.03 e/pixel/sec