JDEM-ISWG Report
To NASA HQ & DOE HQ

May 4, 2010

Report to HEPAP
C. Baltay
June 3, 2010

Charter for the DOE and NASA Joint Dark Energy Mission (JDEM)
Interim Science Working Group (ISWG)
December 3, 2009

Purpose
The JDEM ISWG is being constituted by NASA HQ and DOE HQ (hereafter the Agencies) to provide scientific assistance during JDEM pre-phase A activities and will inform the Agencies on their findings. A near-term study is requested by the Agencies. Further studies may be requested in the future.

Study Request
The Agencies' near-term request to the ISWG is to provide science requirements, key mission parameters and any other scientific studies needed to support a process to design an optimized Probe-class space mission concept(s) for the study of dark energy, subject to budget constraints ($650M in FY2009 dollars, not including the launch vehicle). To aid their studies, the ISWG may review past mission concepts developed, including the concepts presented to the National Research Council's Astro2010 panel, and the families of low-cost Probe-class concepts currently under development by the Project Office (PO), as well as other studies and reports. Justification for going to space should be included.

Concept Development
The JDEM Project Office (PO) is at Goddard Space Flight Center (GSFC). The DOE Lawrence Berkeley National Laboratory (LBNL) Project Office works in coordination with GSFC.

The PO will be responsible for actual mission concept development, based on input and/or comment from the ISWG, and costing studies, eventually followed by independent cost estimates. One, or at most two, concepts shall be defined by April 15 2010 in sufficient detail for Independent Cost Estimates. Cost estimates shall be completed by June 15 2010.

Organization
The ISWG and the PO are independent of each other, but need to work in close coordination. They will iterate on science requirements and the mission concepts that flow from these and will share results with each other in a two-way exchange.

The ISWG may ask the PO to study particular mission concept(s), trades or other studies, including variations of concepts already studied or new concepts.

Comments on the ISWG Process

Purpose: Provide scientific assistance during pre-Phase A activities. Proceed in two phases

- First phase — through Spring 2010
  - Develop one or two best designs for JDEM with the fiscal constraint of 650 2009 M$ + Launch (as costed by the GSFC Project Office) i.e. a Probe Class Mission
  - This phase has been completed, we presented our report the the NASA and DOE Headquarters on May 4

Comments on ISWG Process (continued)

- Expect new information over the next few months
  - Costing by Independent Cost Estimate (ICE)
  - Report from the Decadal Survey
  - Status of plans for new ground based programs
  - Input from the broader scientific community
- Second phase to follow later
  - Reexamine JDEM mission design with possibly new constraints based on new information
  - Continue the present joint scientific and engineering efforts

The JDEM ISWG

Warren Moos (Co-chair)
Charlie Baltay (Co-chair)

Dominic Benford
Gary Bernstein
Wendy Freedman
Chris Hirata
Alex Kim
Rocky Kolb
Sangeeta Malhotra
Nikhil Padmanabhan
Jason Rhodes
Gregory Tarle

Neil Gehrels (Ex Officio)
Michael Levi (Ex Officio)

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

Working Groups

- BAO Working Group
  - Padmanabhan, Moos, Hirata, Malhotra
- SNe Working Group
  - Kim, Baltay, Tarle, Benford, Freedman
- Weak Lensing Working Group
  - Bernstein, Rhodes, Hirata, Gehrels, Levi
- Calibration Working Group
  - Tarle, Benford, Gehrels, Levi
- Redshift Space Distortions
  - Padmanabhan ,Moos, Bernstein, Hirata, Gehrels

The Project Offices and the Working Groups worked very well together. A significant amount of work was done between each of the ISWG meetings.

Three techniques to study Dark Energy

- Type 1a Supernovae use standard candles

$$d_L = (c/H_0)(1+z)\int(1/E(z))dz$$

where $E(z) = (\Omega_m(1+z)^3+\Omega_{DE}(1+z)^{3(1+w)})^{½}$

- Baryon Acoustic Oscillations use standard ruler

$$d_A = (c/H_0)(1/(1+z))\int(1/E(z))dz$$

where $E(z) = (\Omega_m(1+z)^3+\Omega_{DE}(1+z)^{3(1+w)})^{½}$

- Weak Lensing measure growth of structure

$$\ddot{g} + 2H_0E(z)\dot{g} = 4\pi G\rho_m g$$

where $E(z) = (\Omega_m(1+z)^3+\Omega_{DE}(1+z)^{3(1+w)})^{½}$

- These are related by General Relativity via $E(z)$.

Comparing the results of the different techniques provides a check on General Relativity

The Importance of Measuring w

Equation of state parameter $p = w\rho$

- The value of w distinguishes between
  - The Cosmological Constant $w = -1$
  - Some other form of Dark Energy $w = \leq -\frac{1}{3}$
- Is w a constant or a function of time

  $w = w_0 + w_a(1-a)$

  Measurement of w_a distinguishes between different models of Dark Energy
- w governs the development of the energy density of the universe and therefore its age and future

  $\rho = \rho_0 a^{-3(1+w)}$

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

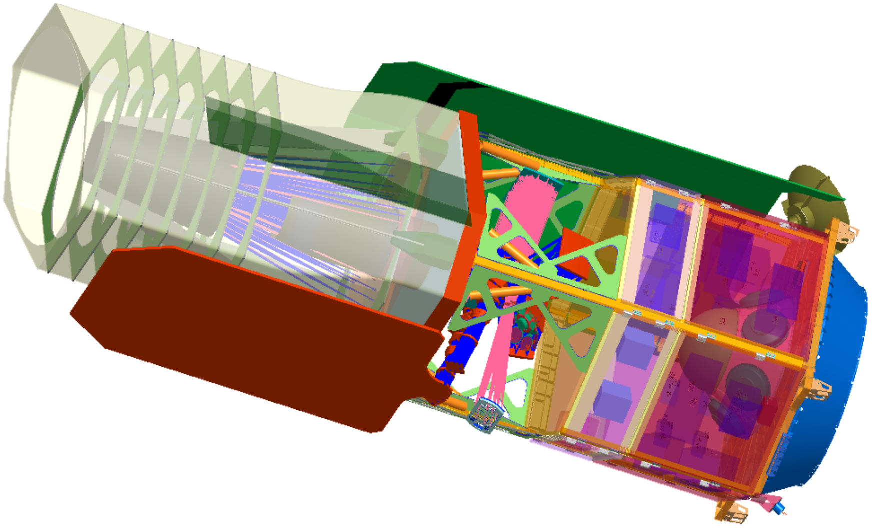
The DETF FoM is not the only relevant measure.

- 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 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.

The JDEM ISWG relied heavily on the families of Probe Class missions developed by the Project Offices at GSFC and LBL

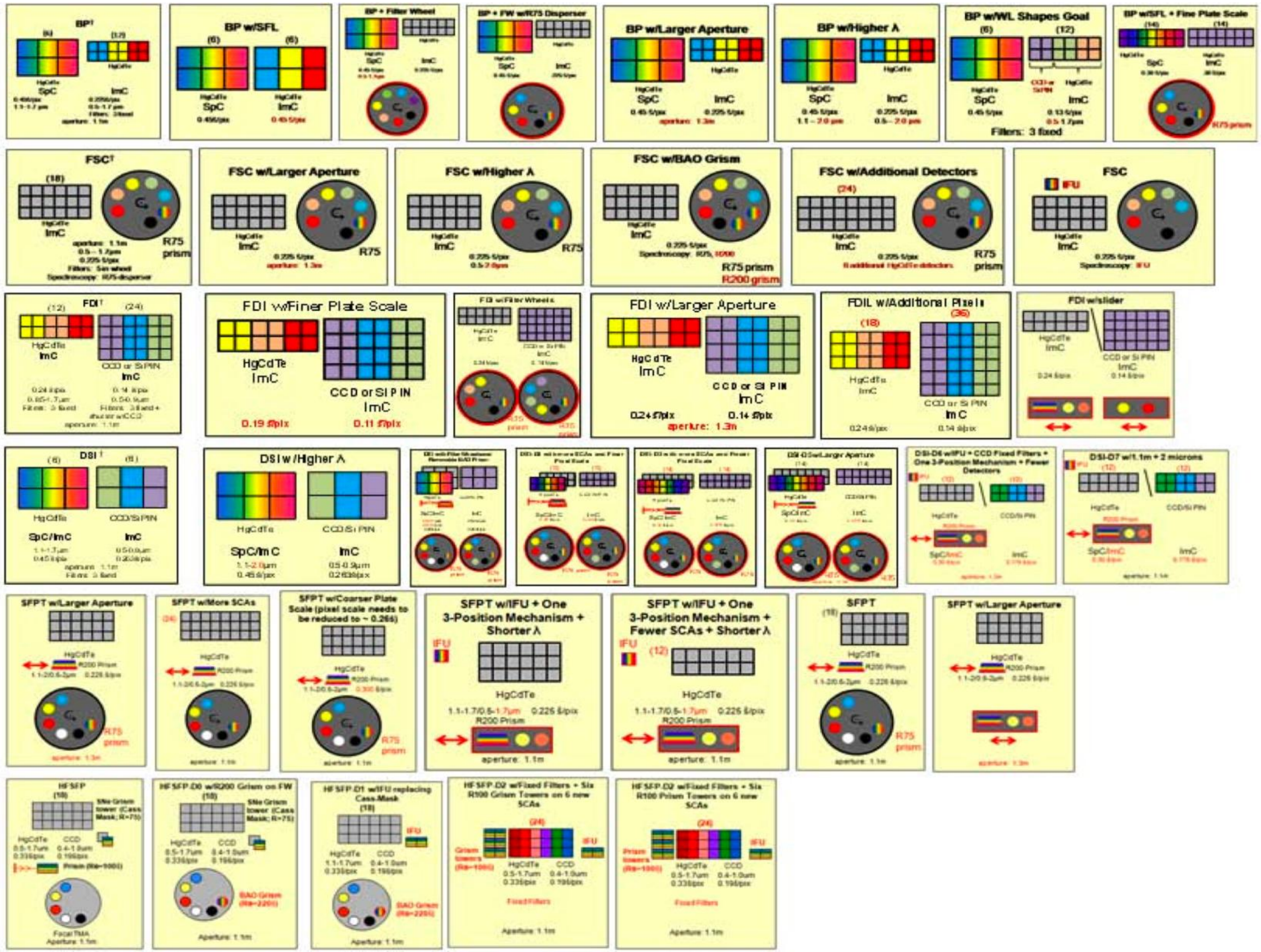
JDEM Probe Study Status



January 28, 2010

Started out with 60 different Mission Concepts

1. Benchmark Probe **(7 of 18 cases shown)**
2. Focal Single Channel Imagers **(7 of 11 cases shown)**
3. Focal/ Dichroic Imagers **(6 of 10 cases shown)**
4. Dichroic Spec/Imager **(8 of 10 cases shown)**
5. Single Focal Plane Transformer **(7 of 7 cases shown)**
6. Heterogeneous Focal Single Focal Plane **(5 of 5 cases shown)**



Process of Narrowing down the concepts

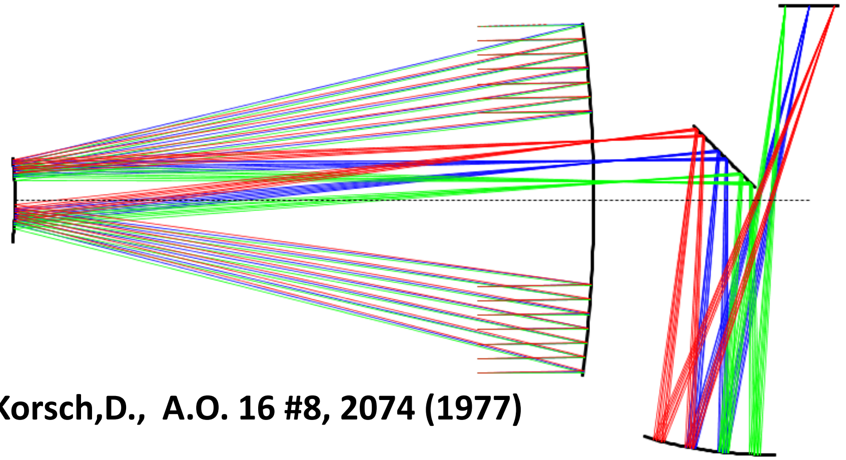
- At the February meeting narrowed it down to three designs
  - BAO + Supernovae
  - Weak Lensing + Supernovae
  - Weak Lensing + BAO
- At the March meeting narrowed it down to two designs
  - BAO + Supernovae
  - Weak Lensing + BAO + Supernovae

Important New Design Considerations

- Several significant new design considerations emerged from these studies that allowed a breakthrough in cost effective designs
  - Technical: Unobstructed view telescope. A 1.1 meter unobstructed view telescope has a performance similar to a 1.3 to 1.5 m conventional telescope (the enhanced psf improves S/N significantly).
  - New survey strategies: Supernova survey for example
    - In previous designs, SNAP for example, supernova light curves were built from photometric measurements with a large area, fine plate scale imager with 9 filters. Spectrometer was used to take a single spectrum for each supernova for typing.
    - New survey strategy uses a small area wide field imager for discovery and a high quality spectrometer to generate photometric lightcurves. The imager is not used for precision photometry and can have a coarse plate scale and only two broadband filters. The spectrometer provides the requisite spatial and wavelength resolution for the lightcurves.

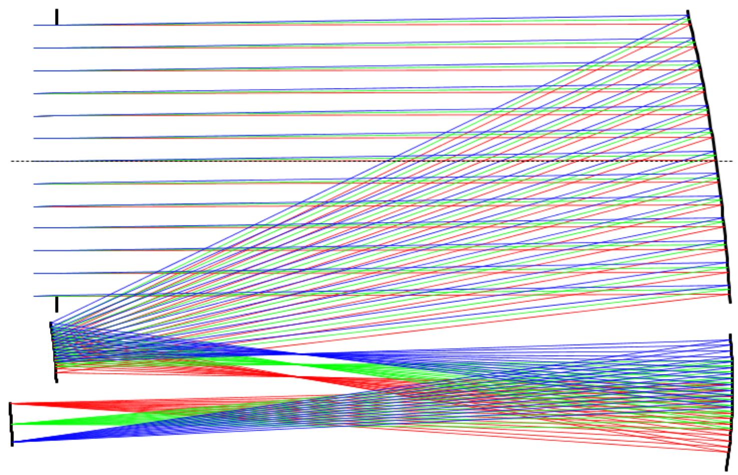
Obscured vs Unobscured TMAs

Obscured



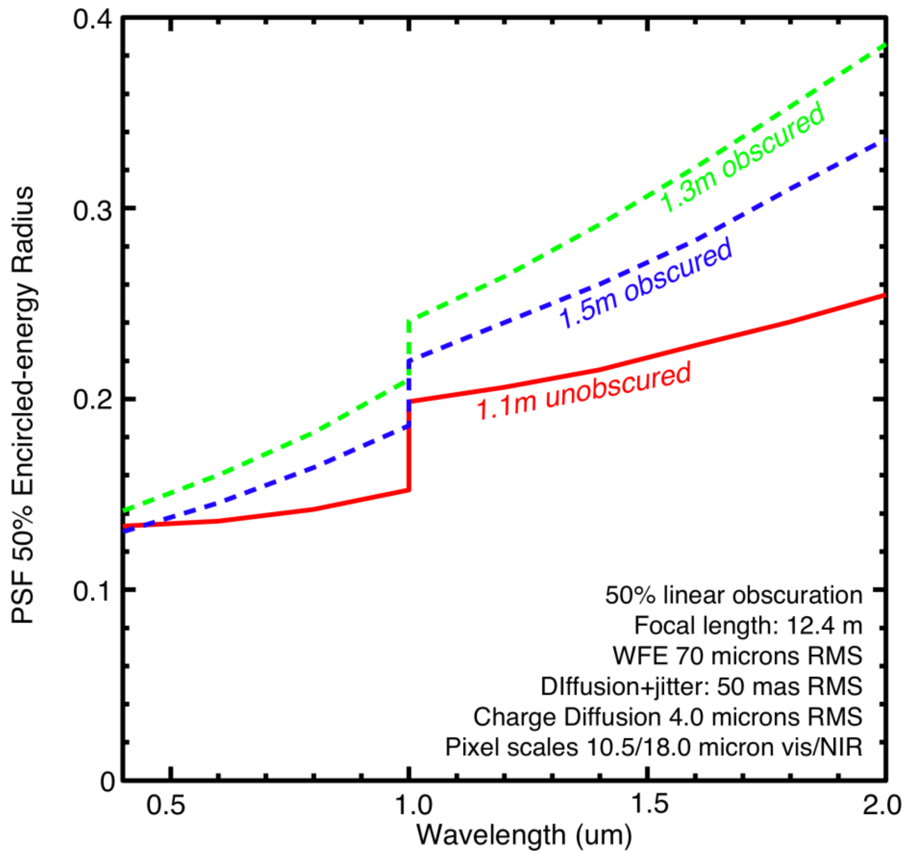
Korsch,D., A.O. 16 #8, 2074 (1977)

Unobscured



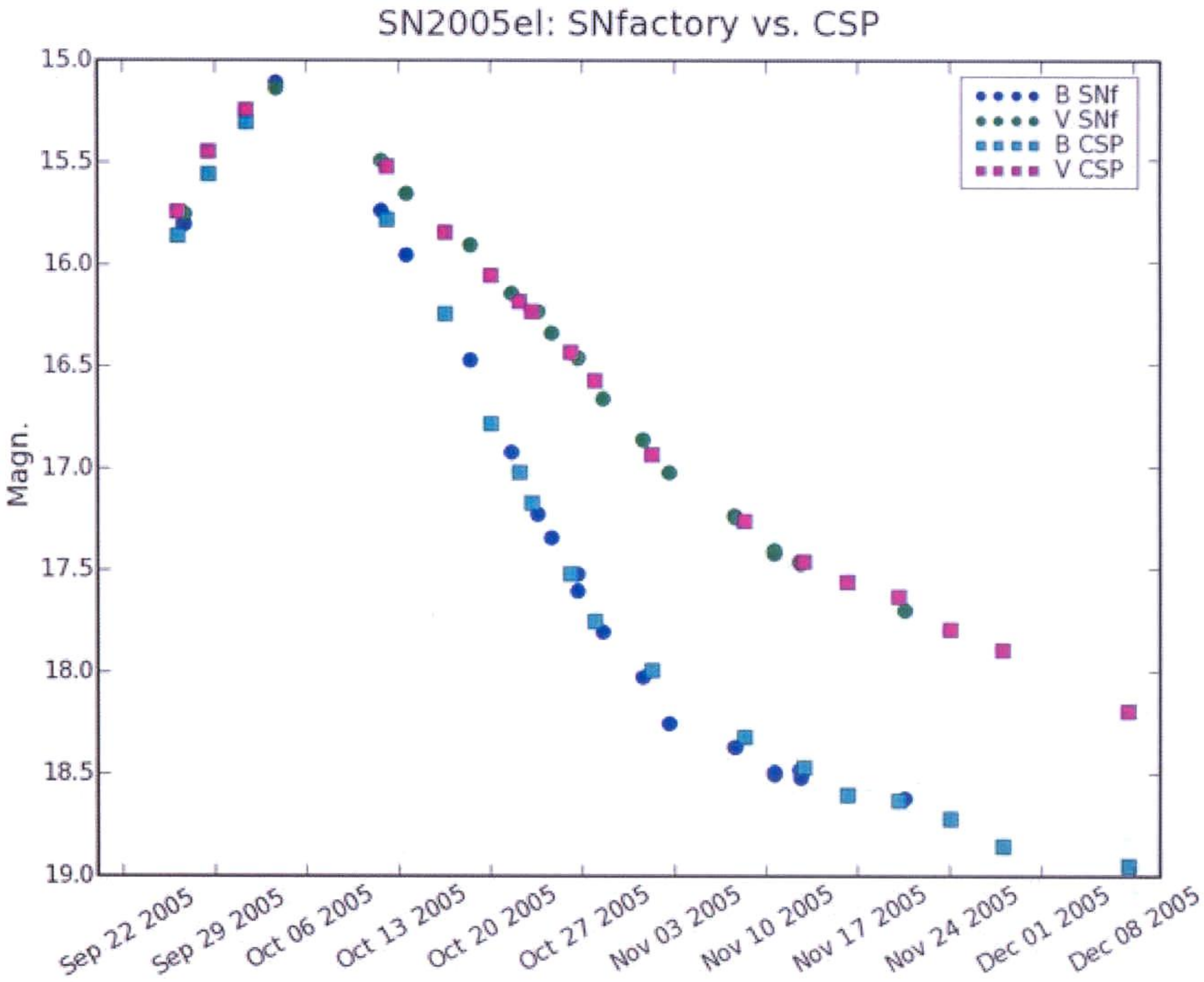
Cook,L.G., Proc.SPIE v.183 (1979)

50% Encircled Energy Radius

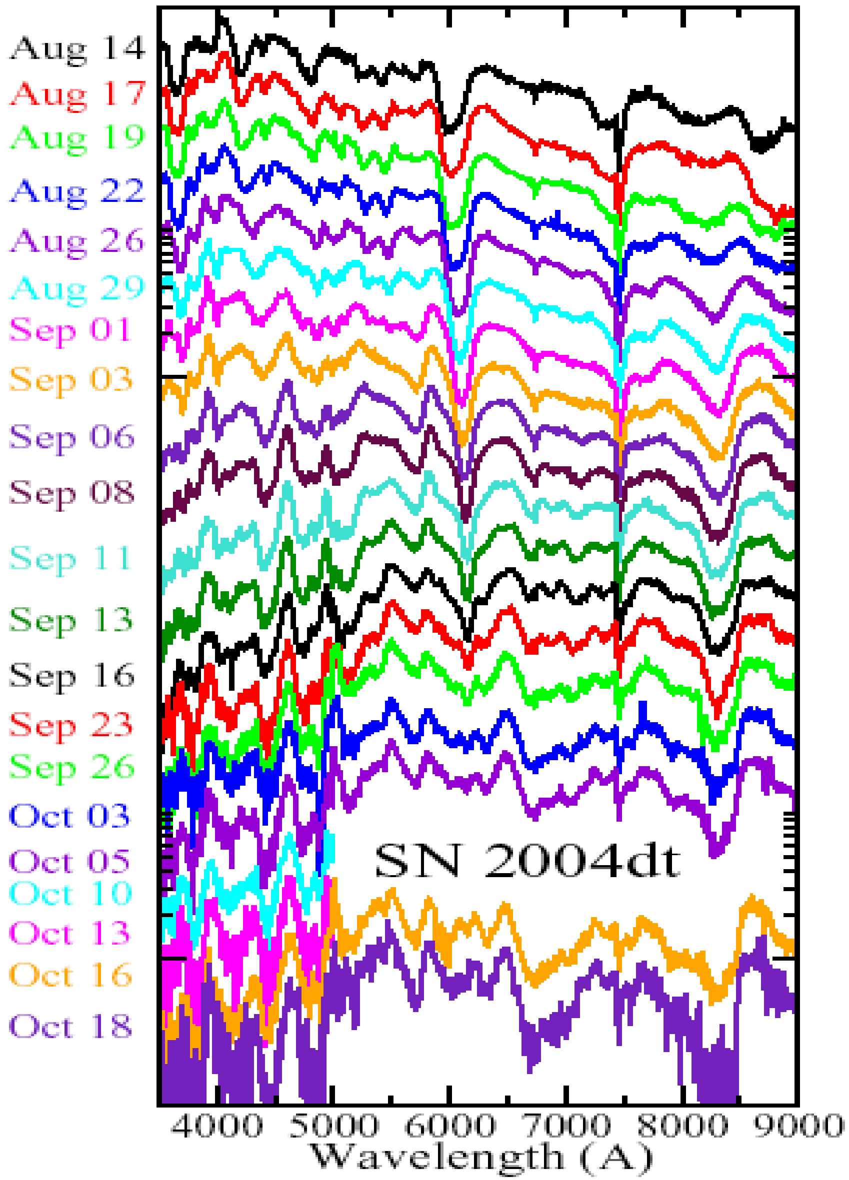


Advantages of the new SNe Strategy

- Lightcurves from a Rolling Search.
  - SNAP and Destiny were planning to follow many supernovae in one field in a rolling search. 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 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.



Lightcurve SNf Type Ia supernova 2005 el from spectrophotometry



Aug 14
Aug 17
Aug 19
Aug 22
Aug 26
Aug 29
Sep 01
Sep 03
Sep 06
Sep 08
Sep 11
Sep 13
Sep 16
Sep 23
Sep 26
Oct 03
Oct 05
Oct 10
Oct 13
Oct 16
Oct 18
SN 2004dt
4000
5000
6000
7000
8000
9000
Wavelength (A)

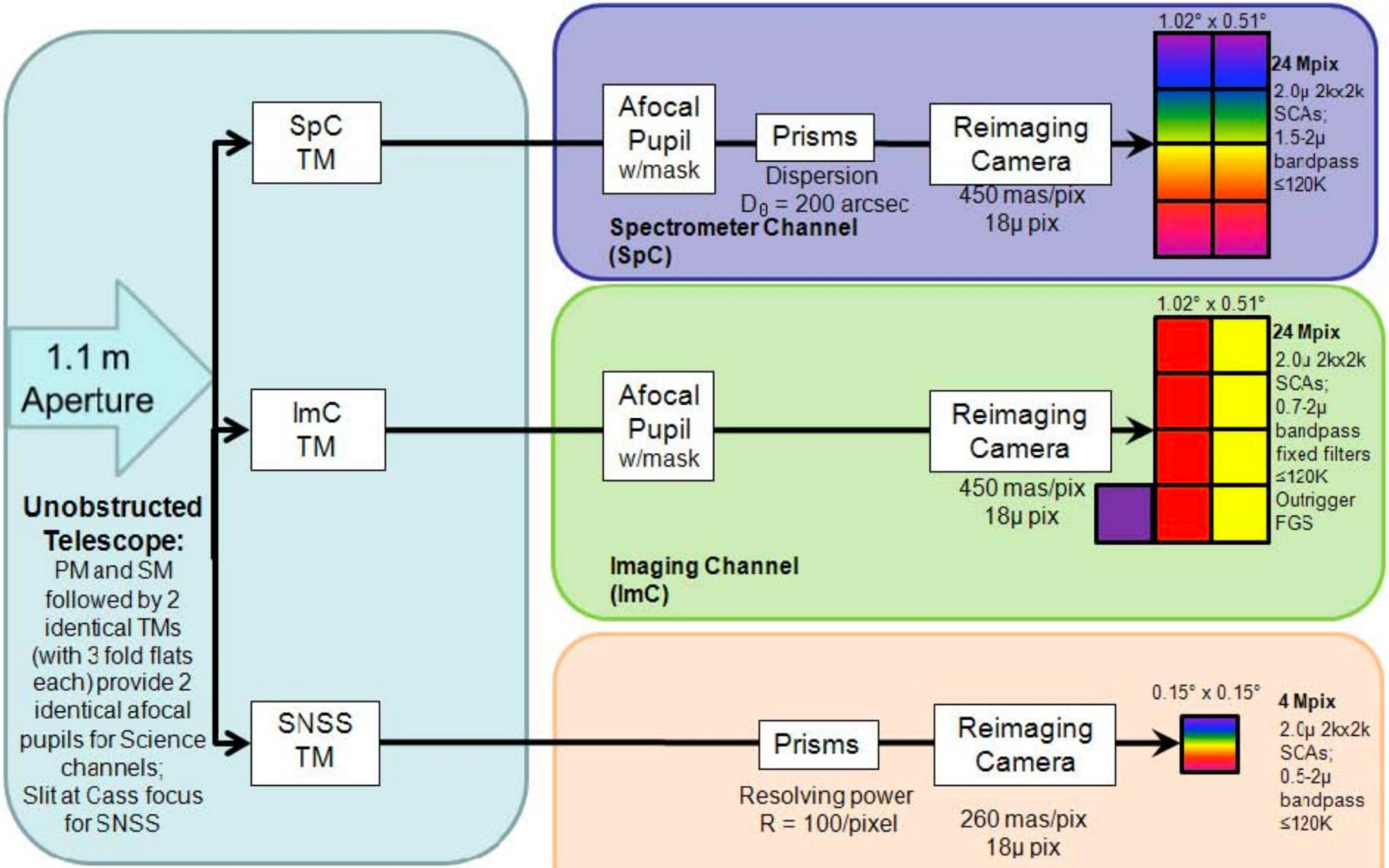
Significance of the New Considerations

- Unobstructed View Telescope enables BAO, WL, and Supernova Surveys with a 1.1 meter telescope
- New Supernova Survey Strategy
  - Instead of a large number of detectors with fine plate scale and many filters, can use either of the wide-field imagers required by the BAO or Weak Lensing surveys with fewer detectors and larger plate scales
  - This makes a supernova survey compatible with BAO or WL
  - The supernova survey is now an easy add-on to any Weak Lensing or BAO mission, requiring only an IFU or slit spectrometer which is relatively inexpensive

Two 3-Year Mission Concepts

- Design A enables BAO + SN
  - PO Cost Estimate: Fits Probe Class
  - Imager with 8 NIR Detectors, 0.45”/pixel
  - BAO Spectrometer with 8 NIR Detectors, 0.45”/pixel
  - IFU or slit SNe Spectrometer, single arm, single detector 0.26”/pixel
  - 17 identical NIR detectors, 68 Megapixels, no moving parts!
- Design B enables Weak Lensing, BAO, and Supernova Surveys
  - PO Cost Estimate: Does not fit into a Probe Class Mission but has greater science reach (less mature at this time than Design A)
  - For example:Imager with 18 CCD’s, 0.175”/pixel, 18 NIR’s, 0.30”/pixel
  - Photo z Calibration Spectrometer
  - BAO Spectrometer
  - Supernova spectrometer
  - Optimized for Weak Lensing, but allows a flexible mission strategy
  - For example, a 3 year mission can do two of the three techniques, a 4 year mission can do all three.

Design A for BAO and Supernova Surveys



FGS = Fine Guidance Sensor
SNSS = Supernova Slit Spectrometer

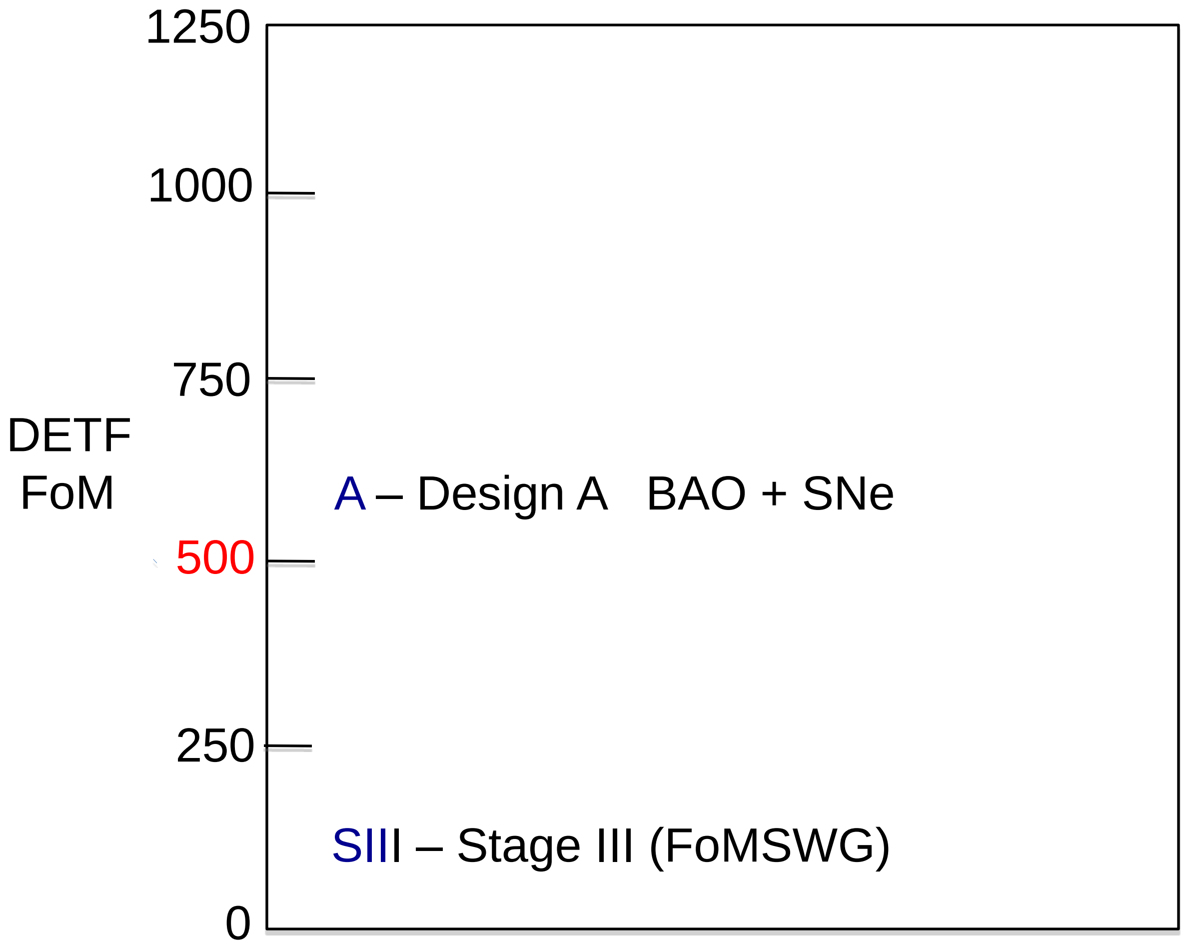
Design A Performance

- BAO 1.1 meter mirror, 3 year mission
  - 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

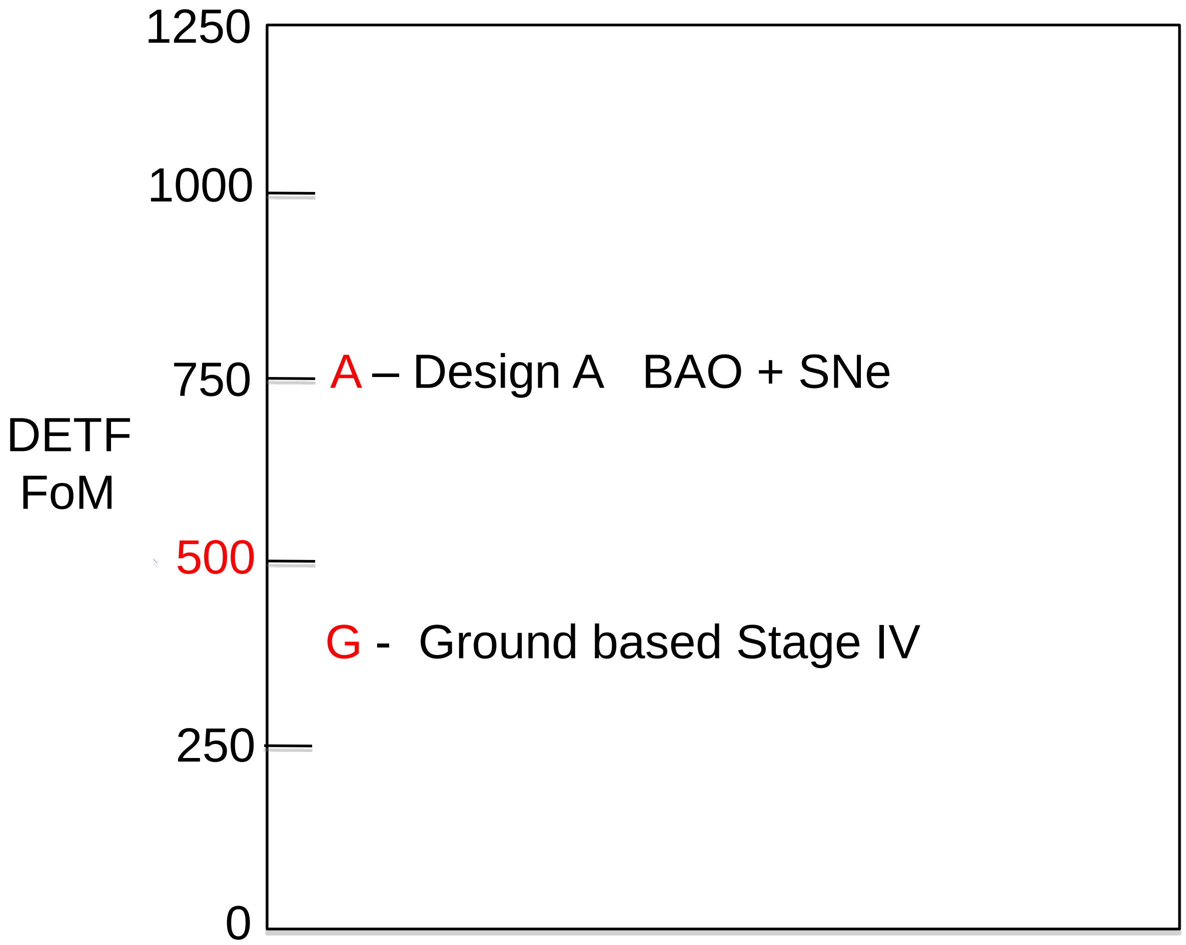
Design A Figure of Merit

Assuming only Stage III priors

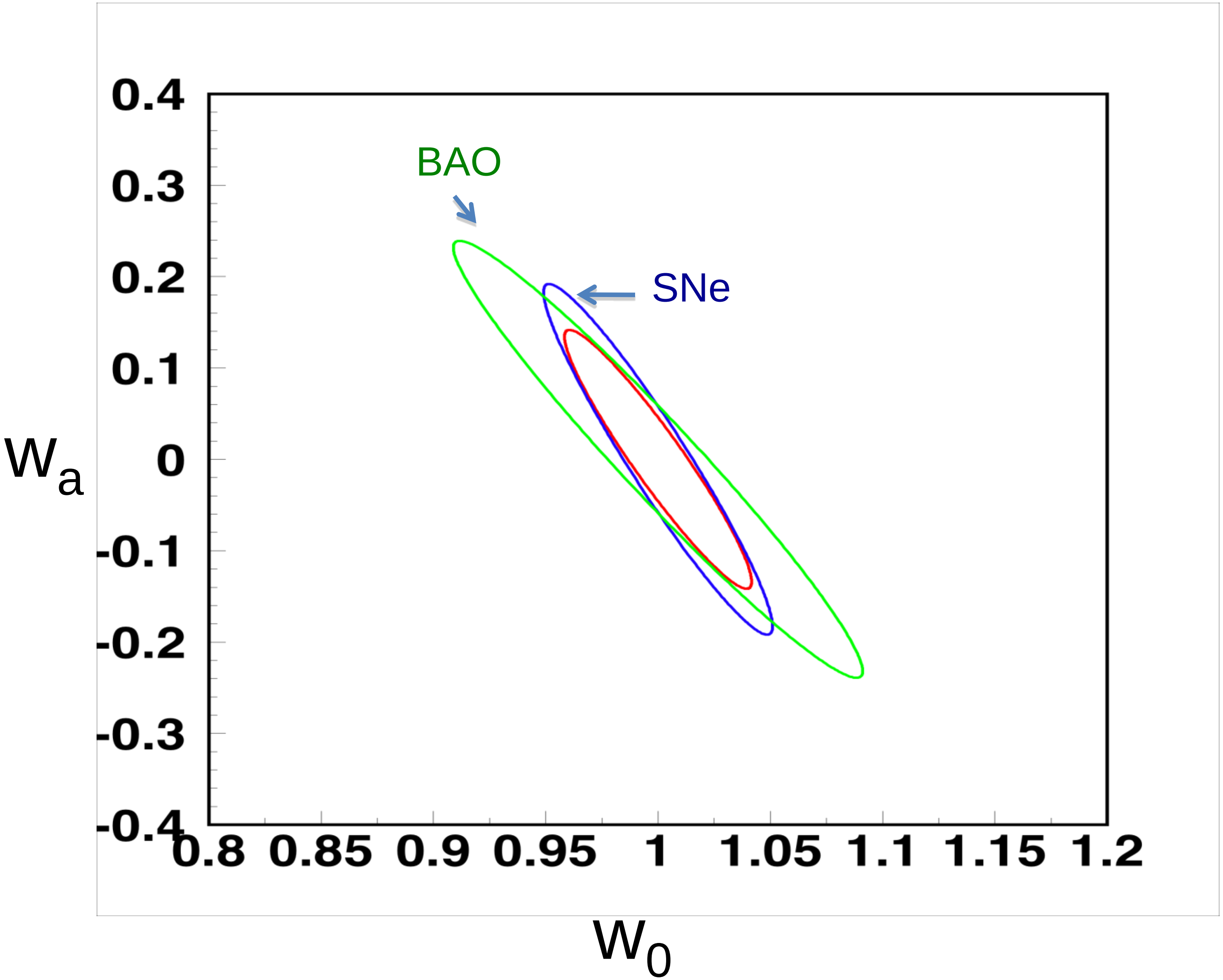


Design A Figure of Merit

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



BAO and Supernova Error Ellipses



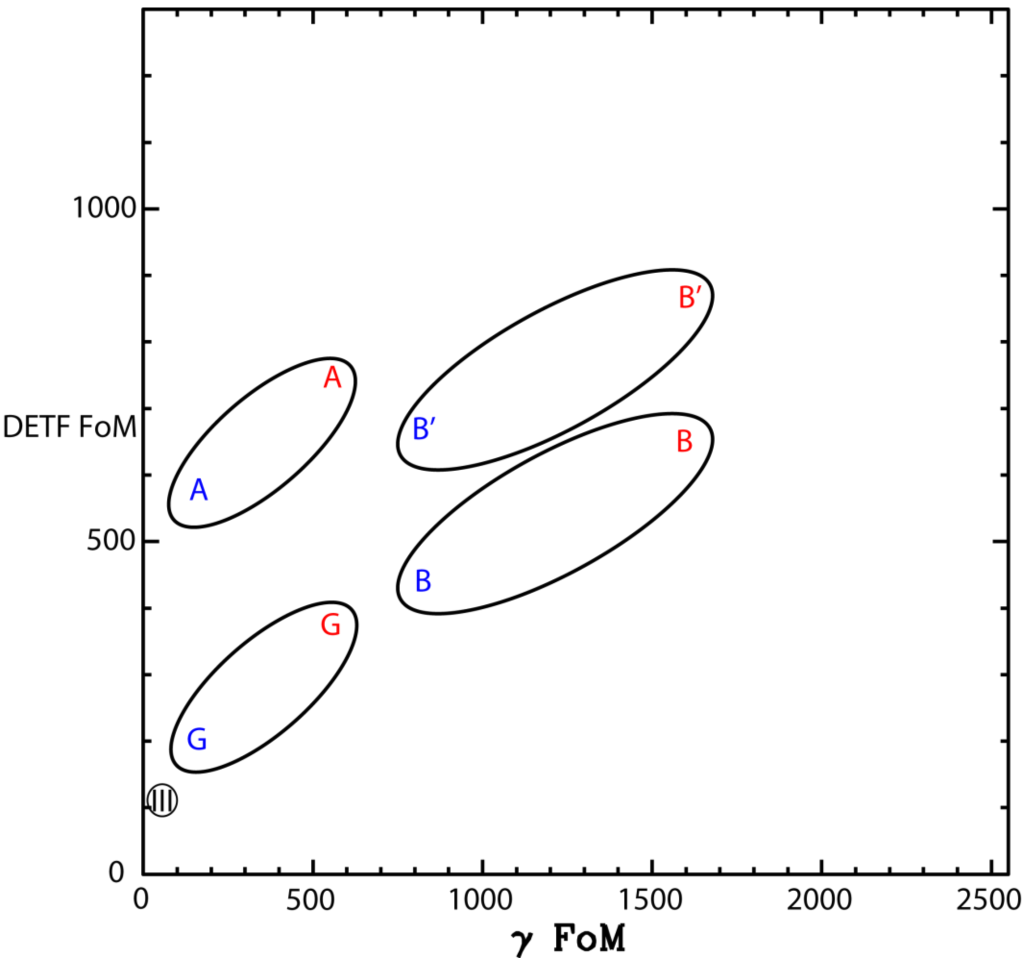
Design B Performance

- Weak Lensing
  - 10,000 square degrees
  - 30 Galaxies/ square arcminute
  - 100,000 spectra for photo z calibration
  - Assumes ground based visible 10,000 square degree survey to complete Photo-z measurements
- BAO and Supernovae
  - Similar performance to Design A per unit time

Comments on the FoM Summary Plot

- The DETF FoM characterizes the expansion history of the universe i.e. the growth of geometry, while the γ FoM characterizes the growth of structure.
  - The two are related by General Relativity and thus a measurement of both provides a check on GR.
  - The strength of Weak Lensing is the sensitivity to the growth of structure. The BAO survey has some sensitivity to the growth of structure through the measurement of Redshift Space Distortions (RSD) but is not as sensitive as Weak Lensing.

Figure of Merit Summary



III is FoMSWG Stage III FoM

A and B stand for Designs A and B
G is for Ground Based

B is WL and BAO only
B′ includes Supernovae

Blue for minimal ground program
Stage III + Double DES + u band

Red is for a maximal Stage IV
Ground program including
BigBOSS(24,000 sq deg) and
LSST

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

An adequately funded archival program will return the full scientific value of the investment.

- JDEM can furnish valuable data sets which can be used for non-Dark Energy science, for example:
  - 60 million emission-line galaxy redshifts,
  - infrared images with an associated catalog containing ~10^9 objects
  - 1500 SN spectral photometric time series
  - Ten square degrees imaged down to a magnitude of 28.5 in two filters
  - a complete redshift survey of 100,000 galaxies to 25^{th} magnitude
- The data products may need to be enhanced in order to be useful for a broad range of science other than DE. These new analyses likely will in turn improve the quality of the Dark Energy measurements.
- This may require enhancements to the data pipeline, a good archive, support manuals and a help desk
- Continued studies of low cost modifications to the mission which would improve ancillary science performance and, as appropriate, dialogs with the broad community will be useful.

Findings

- The ISWG and the Project Offices have developed two JDEM mission designs to investigate the nature of Dark Energy. Two new design innovations, unobstructed view telescope optics and alternative survey strategies, enable cost effective designs with a 1.1 meter telescope.

Findings

- Design A : The ISWG and the Project Offices arrived at a mission concept that satisfies the criteria for a compelling space mission and is estimated by the GSFC Project Office to fit within the cost cap of a Probe class mission.
  - This design enables BAO and Supernova Dark Energy surveys in a 3 year mission
  - The design does not enable a Weak Lensing survey.

Findings

Design B The ISWG and the Project Offices are considering mission concepts with an enhanced science capability for testing GR modifications as the source of the acceleration of the universe. These designs were estimated by the GSFC Project Office to be more expensive than a Probe class mission.

- This design enables Weak Lensing, BAO, and Supernova techniques
- Optimized for Weak Lensing, but allows a flexible mission strategy
- For example, a 3 year mission can do two of the three techniques, a 4 year mission can do all three.

Findings

The ISWG finds that the following would be valuable:

– Continued joint study by the ISWG for science performance and by the Project Offices for engineering design and cost optimization of the two designs. One goal of this study is to better understand the science performance and cost differential of the two designs.
– A more detailed analysis of Redshift Space Distortions by the ISWG
– Additional studies based on the new information coming in the next few months

Comparison of Designs

Design	Mirror	Imager CCD	Imager NIR	Imager Area	BAO Spectr	Sne Spectr			
SNAPClassic	1.9m	36 / 0.10	36 /0.18	0.70	Yes	Yes			
SNAP Lite	1.4m	20 /0.10	12 /0.18	0.32	Yes	Yes			
IDECS	1.5m	18 /0.14	9 /0.28	0.55	2	No			
Omega	1.5m	0	24 /0.18	0.24	2	No			
Euclid ??	1.2m	36 /0.10	18 /0.30	0.84	1	No			
Design A	1.1U	0	8 /0.45	0.50	1	Yes			
Design B	1.1U	18 /0.175	18 /0.30	1.02	1	Yes			

Performance Comparisons

Design	No of SNe	Sne z max	BAO Area	BAO z range	WL Area	WL galxs/sqar cmin
SNAPClassic	2000	1.7	10,000	0.7 – 1.6	10,000	65
SNAPLite	1200	1.3	4700	0.7 – 1.6	4,700	55
IDECS	1500	1.3	20,000	0.7 – 2.0	10,000	30
Omega	1500	1.3	20,000	0.7 – 2.0	10,000	30
Euclid	0	0	?	?	?	?
Design A	1500	1.5	16,000	1.3 – 2.0	----	---
Design B	1500	1.5	16,000	1.3 – 2.0	10,000	30