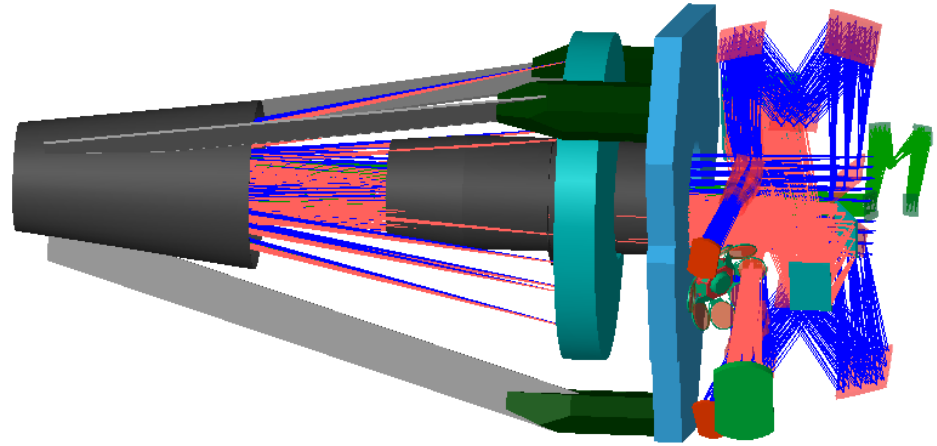
Unobscured Telescope Trade

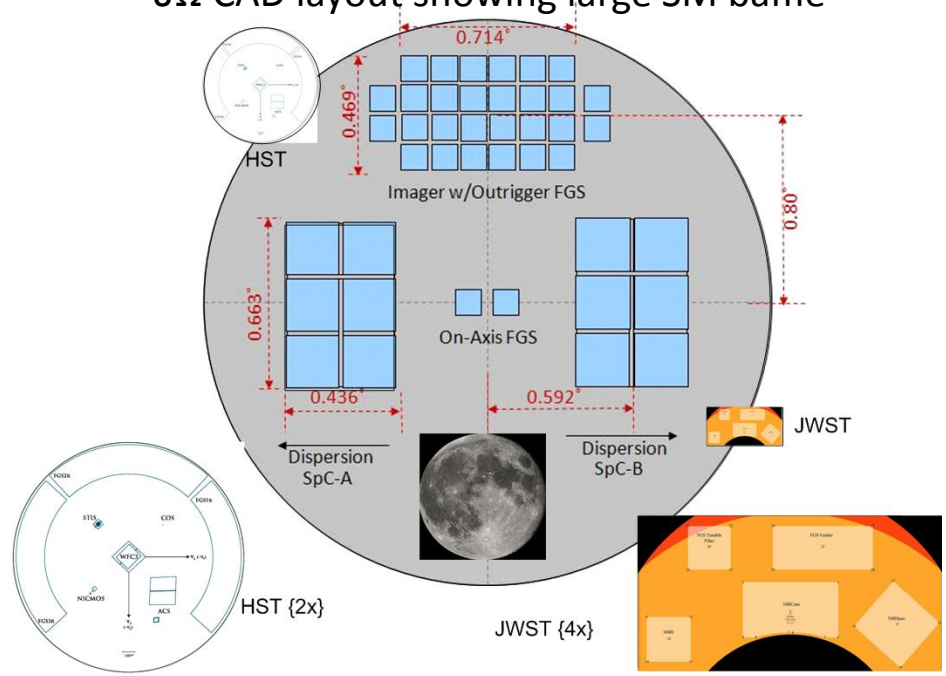
- Outline
  - Issues and liens on JDEM-Ω
  - Pros and cons for unobstructed aperture telescope
  - Review of trade space among various unobscured 3-mirror anastigmat (uTMA) options that we have explored
  - Example design: focal imager, three channel, unobscured analog to J-Ω
    - Field layout
    - Performance: field area, imaging quality, mass/volume
    - Packaging
    - Comparison table
  - Trade space remaining for optimization
- Backup: Cold Masking comparison; uTMA heritage charts; throughput

Issues & Liens on Omega

- Large secondary baffle reduces MTF and throughput
- On axis form requires large field bias to get beam clearance at intermediate focus
- Residual errors still a substantial fraction of total error budget
- Long axes of fields not aligned; complicates sky tiling schemes
- Spider diffraction increases confusion in crowded fields
- Additional throughput loss if pupil mask needed to keep stray light and thermal radiation out of instrument



JΩ CAD layout showing large SM baffle

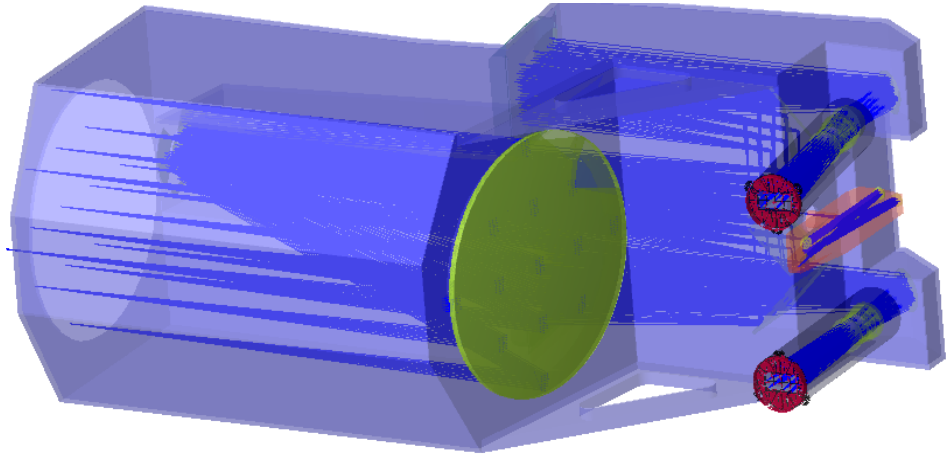


JΩ Field layout and comparison w/ HST, JWST, Moon

Probe work suggested uTMA as alternate

- During the Probe exercise we realized many of these issues could be alleviated using an unobstructed aperture
- Probe design closed on 1.1m uTMA
- Discussions with vendors suggested 1.3m aperture as upper limit for the WFIRST cost range
- Equivalent cost to 1.5m oTMA

- 1.3m uTMA has equivalent throughput to 1.5m oTMA
- Resolution is roughly equivalent – lower resolution and higher MTF
- Sampling is closer to Nyquist at 0.18”/pixel



Probe “A1” CAD layout, 1.1m uTMA

Pros and Cons

Pros for uTMA

- Beam clearance simpler
  - Instrument packaging simpler
- No spider diffraction
- Overall lower integration time for same limiting flux
- Tiling improved for galaxy surveys
- Simpler pupil mask if needed, less throughput loss
- Shorter baffle
  - Lower payload volume
- Can use lower field bias angles

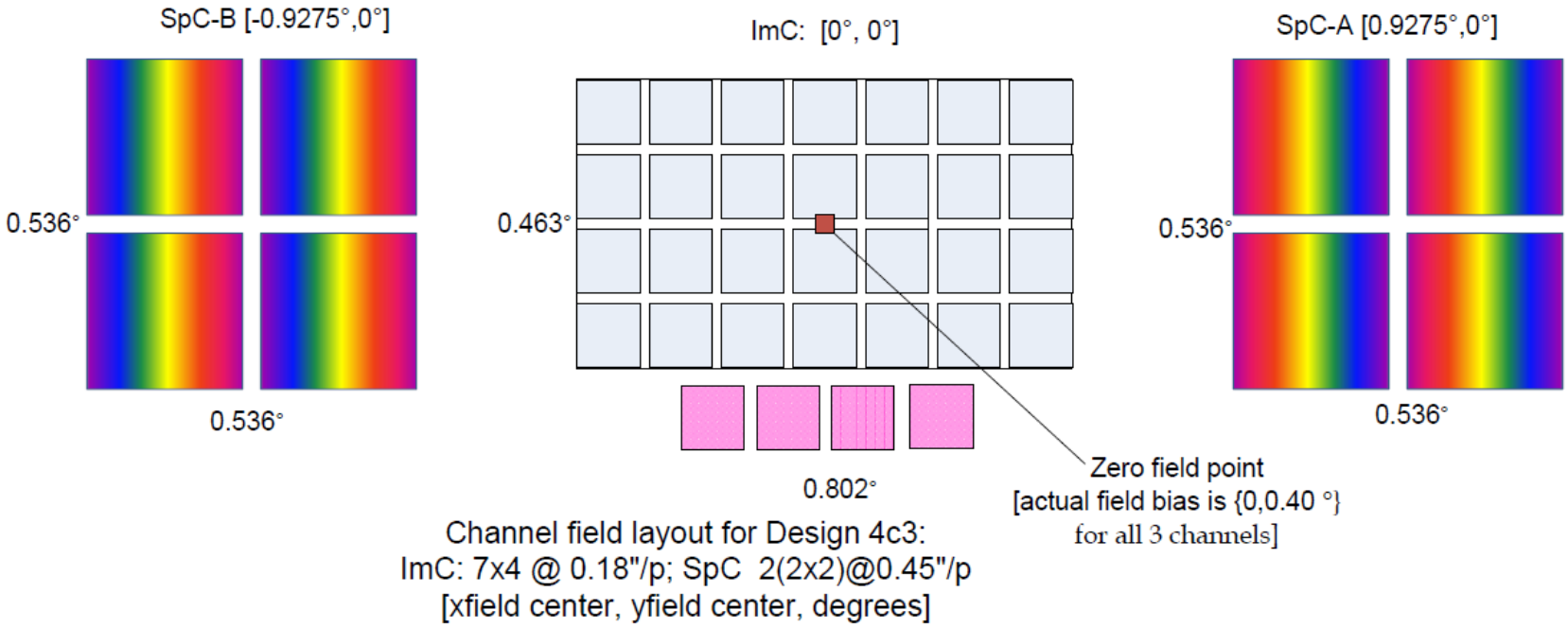
Cons for uTMA

- Some tolerances may be tighter
- Need to slow down PM to keep asphericity w/in fabrication limits
- Less flight experience than oTMA

uTMA trade space

- Starting in ~Nov2010 we explored >12 options including variables such as
- Telescope form: imager/ spectrometer Focal/Focal, afocal/ afocal, focal/afocal [aka hybrid], respectively
- 1 or 2 spectrometer channels
- Reflective & refractive cameras for afocal case
- Fixed or adjustable dispersion direction on the sky
- Previously presented several examples of these to SDT:
  - SDT1: afocal 2 channel, 2 reflective cameras
  - SDT2: afocal 3 channel, refractive SpC cameras
- Some options had good imaging but not shown for packaging or lens size reasons
  - Adjustable dispersion direction
  - Focal spectrometer with focal reducer before focal prism
- Focal imager strongly preferred for simplicity and stability

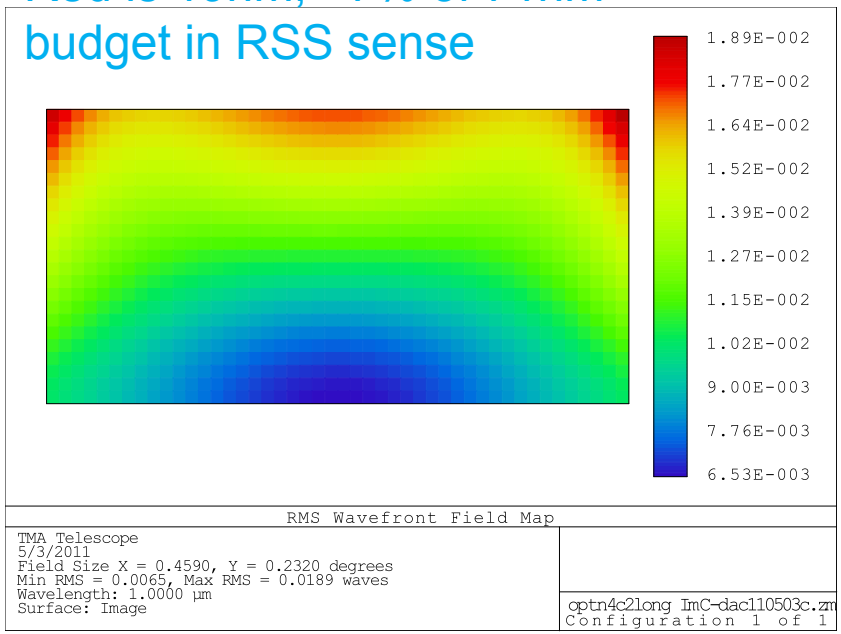
Example design "4c3": 3 channels, all focal

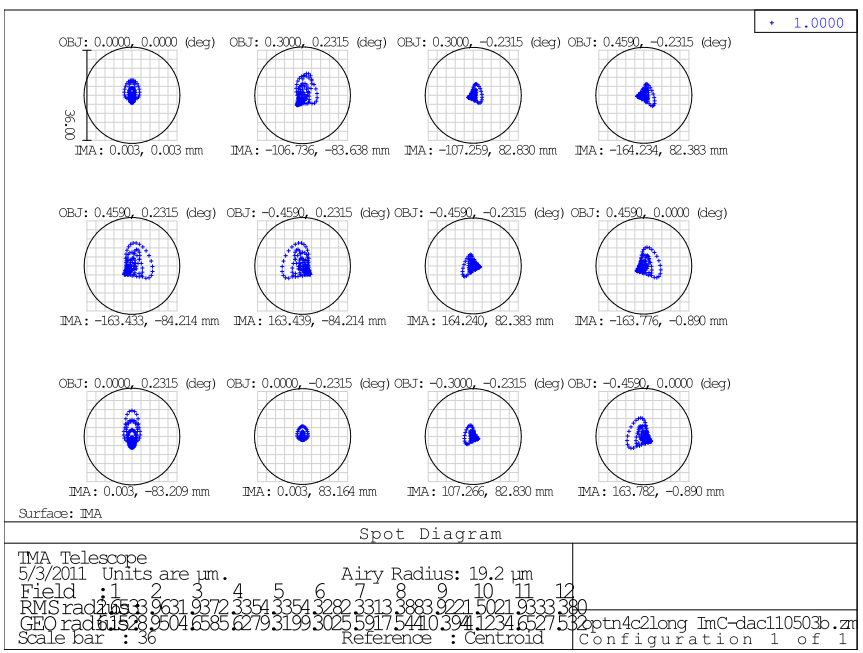


- Focal imager, two copies of spectrometer
- Imager layout 7x4 H2RG at 0.18" plus 4 outrigger H2RG for fine guidance system
  - 1/6th more field than J-Ω ImC
- Spectrometers each 2x2 at 0.45"/pixel
  - Same field as J-Ω SpC's
- Two working examples with hybrid (afocal SpC) and all focal (SpC uses focal prisms)
- Tightest budget channel (ImC) is focal, minimum # powered mirrors

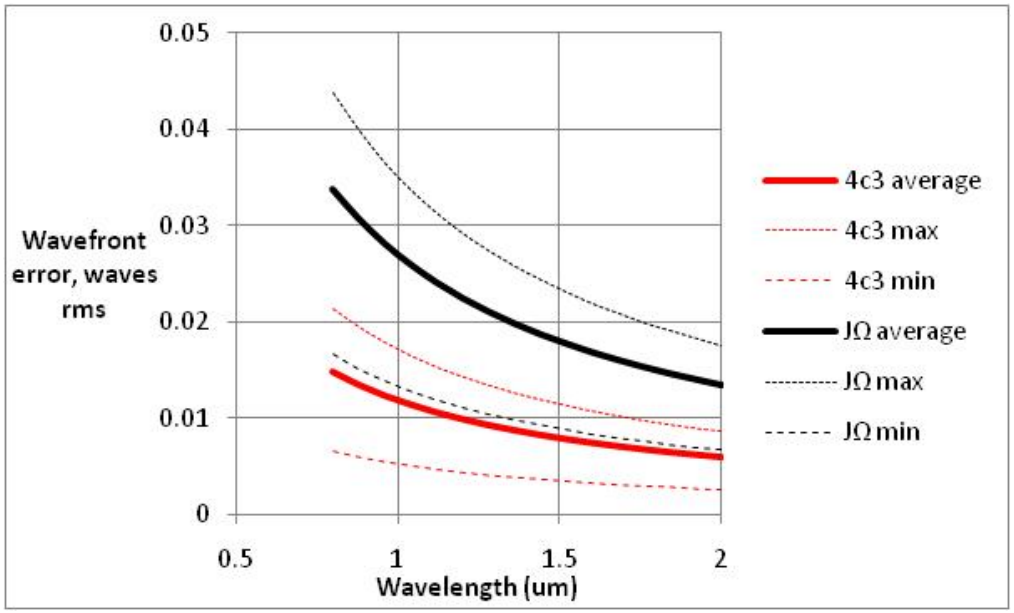
ImC performance

Red is 19nm, ~7% of 71nm budget in RSS sense





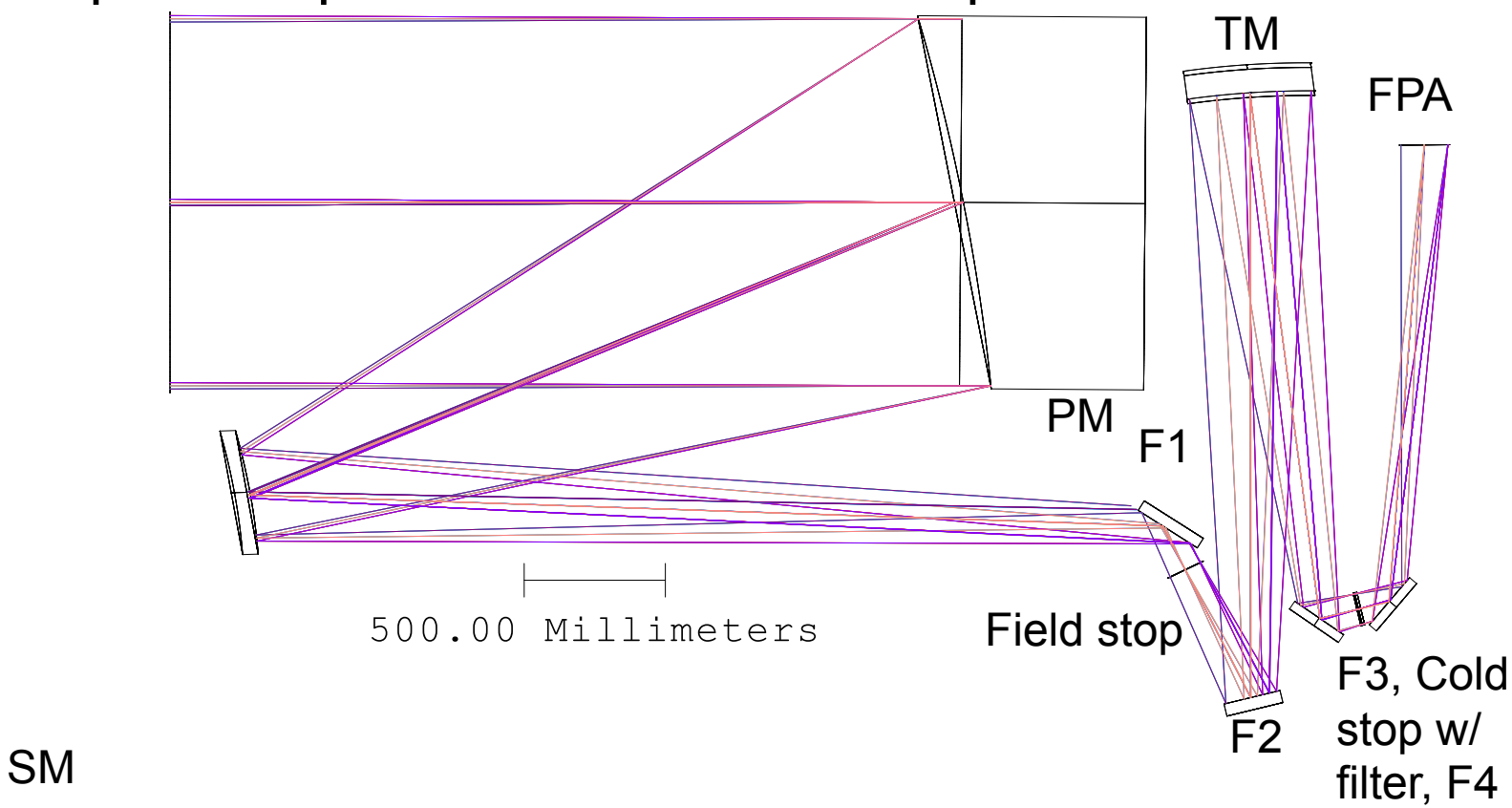
- Field map at 1um
- Spot diagram
- Rms vs wavelength
  - Export to excel/overlay w/ Omega to show improvement
- Eccentricity map if we can get that done



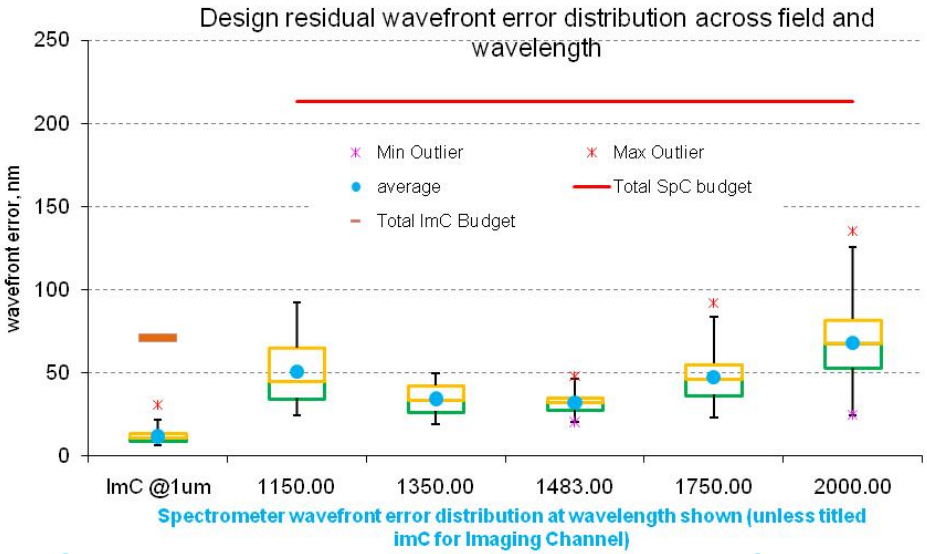
Wavefront comparison – Red: 4c3; Black: JΩ

ImC layout

- Pupil size is 116 mm diam.
- Filters designed as 8mm thick plano CaF2 substrates
- 4 fold mirrors
- Focal plane is placed close to radiator position

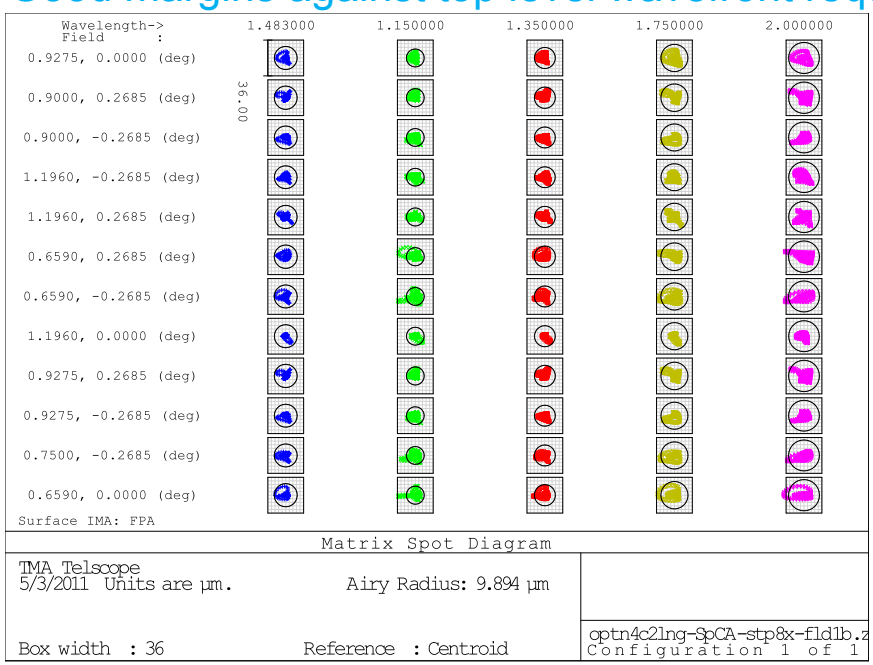


SpC performance

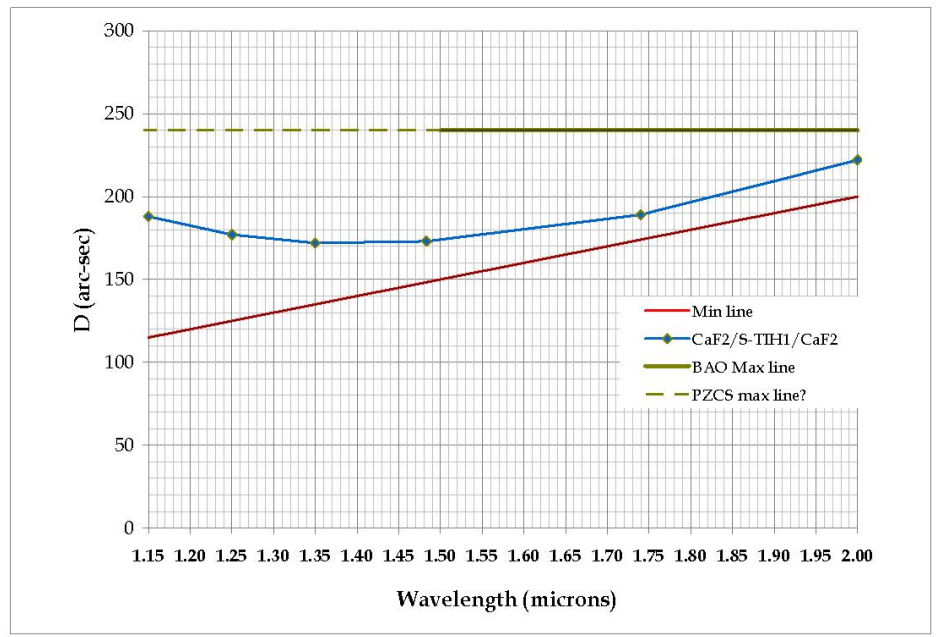


Good margins against top level wavefront requirements

- Box plot comparison to JΩ
- Spot diagram
- Dispersion plot



Diffraction limited across band of use

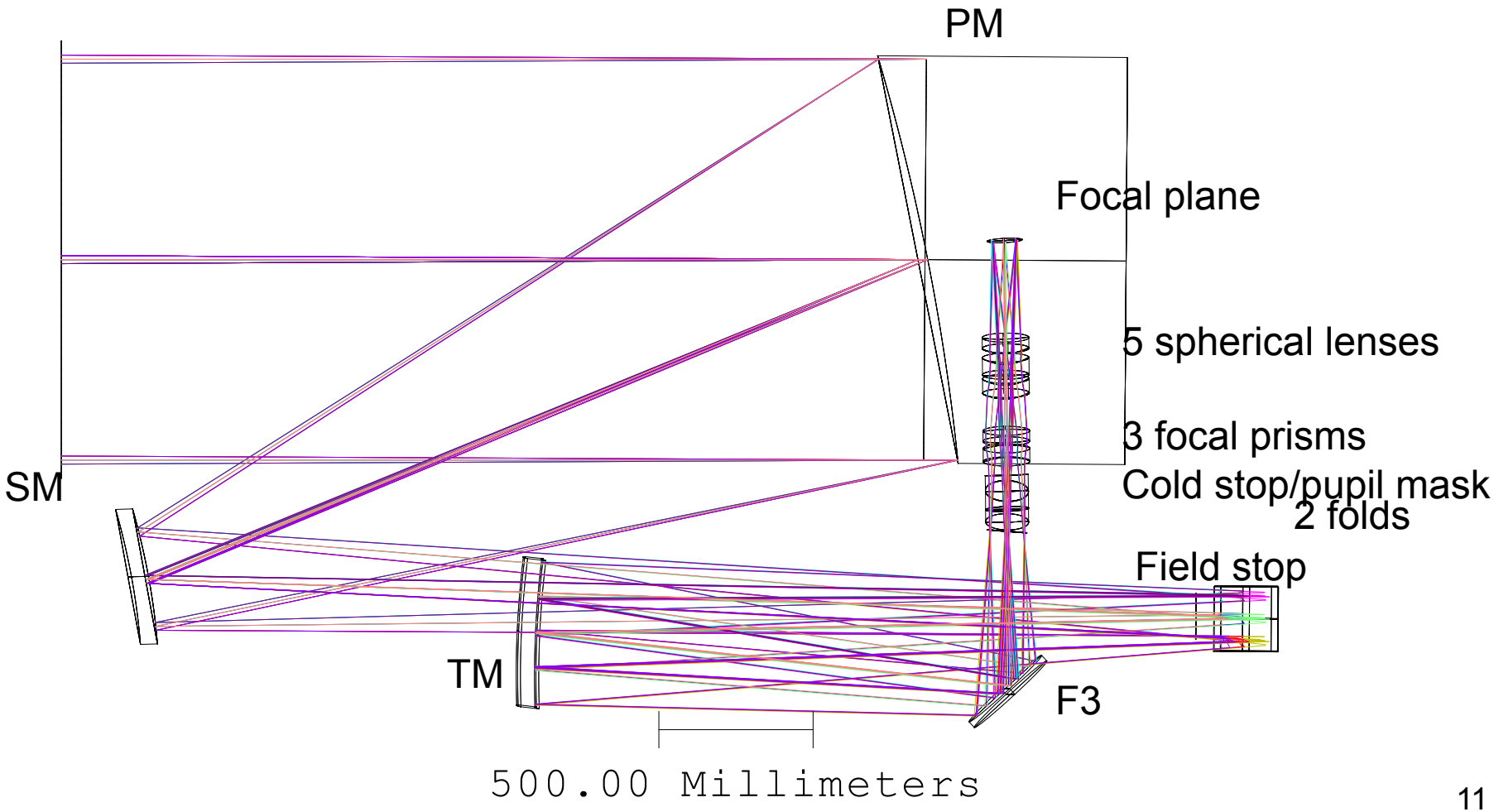


Dispersion is within range across band

SpC layout

- Pupil size is ~116 mm diam.
- prisms designed as focal prism triplet CaF2/S-TiH1/CaF2
  - 1st prism input side has mild conic; last prism output side has slight toroid
  - 140mm diameter aperture
  - We would need to rad-hard qualify S-TiH1 [Ohara analog to rad-hard Schott glass but with better NIR transmission]
- 3 fold mirrors
- 5-lens focal reducing system to adjust to 0.45”/pixel; 152mm diameter aperture
- Focal plane is placed as close to cold side as layout permits

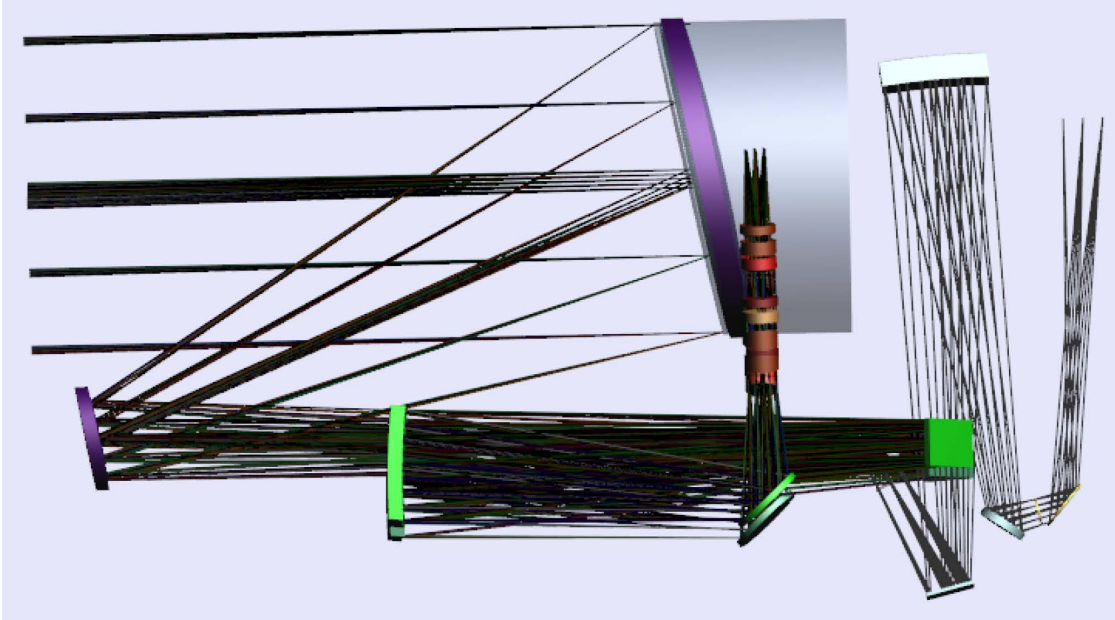
SpC layout

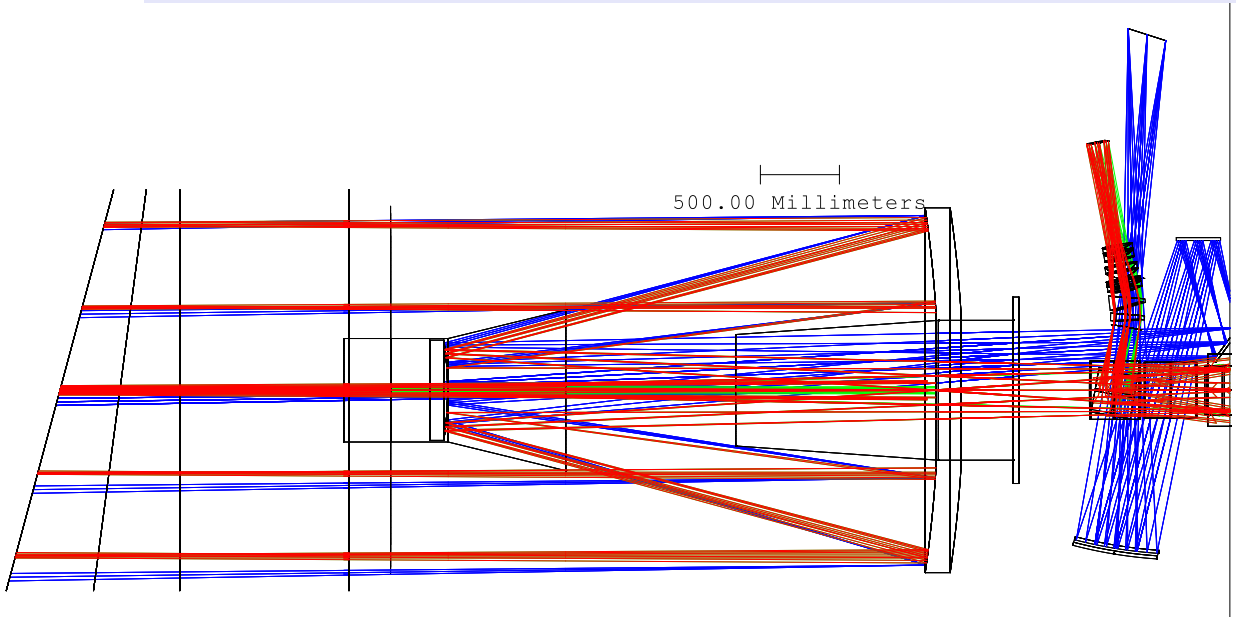

PM
Focal plane
5 spherical lenses
3 focal prisms
Cold stop/pupil mask
2 folds
Field stop
SM
TM
F3
500.00 Millimeters

To-Scale optical layout comparison w/ Omega

Cold side is toward top of page;

Plane of view is Imager plane of symmetry





Comparison table

- 1st column is JΩ as used in RFI
- 2nd column just shows update to project basis for optics weight estimates, consistent w/ WFIRST options
- Other columns are concepts shown at previous SDT meetings
- Weight is ~10kg more
- ImC residual lower, SpC similar
- More compact volume
- 2 fewer components

design name	unit	JΩ	JΩ	1c	3ao	4c3
Aperture diam/type	m/xTMA	1.5/o	1.5/o	1.3/u	1.3/u	1.3/u
# SpC's		2	2	1	2	2
# SCA's ImC/SpC		24/12	24/12	24/8	24/12	28/8
ImC pixel scale (")/FOV area (sq		0.18"/0.25	0.18"/0.25	0.18"/0.25	0.18"/0.25	0.18"/0.29
deg.)		0.37"/0.52	0.37"/0.52	0.45"/0.52	0.416"/0.67	0.45"/0.52
#Tel components for ImC Feed		5R	5R	5R	6R	6R
# ImC components		1T	1T	3R+1T	3R+1T	1R+1T
total # ImC optical train		6	6	9	10	8
#Tel components for SpC Feed not incl. common PM/SM		5R	5R	4R	4R	4R
# components ea. SpC		7T	7T	3R+1T	6T	8T
total # ea SpC optical train		14	14	10	12	12
total # components, single counting		30	30	17	30	28
total optics mass	kg	**232.5**	**132.4**	**106.2**	**143.6**	**142.2**
telescope optics mass	kg	209.2	106.6	75.0	89.7	93.7
ImC optics mass	kg	3.5	3.5	20.3	27.6	6.2
Ea. SpC optics mass	kg	10.5	10.5	9.5	12.5	20.4
ImC top level budget	nm rms	71	71	71	71	71
residual	nm rms	32.3	35	35	35	20.9
SpC top level budget	nm rms	213	213	213	213	213
residual	nm rms	108	108	107	107	108.2
Component allocation ratio ImC/SpC		**2.07**	**0.51**	**0.31**	**0.33**	**0.43**
design name		**JΩ**	**JΩ**	**1c**	**3ao**	**4c3**
Dimensions & Bounding Volume						
z (view direction)		4.2	4.2	2.8	5.1	4.5
x	m	2.5	2.5	1.6	2.5	2.0
y (off axis direction)	m	2.7	2.7	2.8	2.4	2.4
Volume	**m^3**	**27.1**	**27.1**	**12.1**	**31.3**	**22.2**

Work still to be done

- Packaging vs wavefront error and I&T complexity
  - May be able to move TM & FPA of imager down at modest cost to wavefront margin
- Placement of back focus and distribution of magnification in telescope for robust tolerances for both alignment & stability
- Complexity vs. # of focal reducer lenses [currently 5 spheres]; try for 4 with minimum # conics or aspheres
- Adjustment of SpC design residual wavefront errors against flowdown of requirements (wavelength weighting)
- SN spectroscopy focal prism
  - element on ImC filter wheel
- Auxiliary guiding capability when ImC doing SN spectroscopy
- Alternate Hybrid SpC option "14c3": 3-mirror collimator after PM-SM telescope front end; plano prisms, and refractive or reflective camera [for ea. SpC] – *nearly completed*
  - Imager is focal, same layout as 4c3, minor differences vs. ImC shown here

Summary

- This option provides:
  - The same geometric area as JΩ
  - Better psf and MTF than JΩ
  - Therefore lower integration time to same depth
  - 17% larger field at same 0.18”/pixel sampling in imaging channel [7x4 vs. 6x4]
  - Same FOV in 2 slitless Spectroscopy channels (2 (2x2) at 0.45”/pixel)
  - Same science pixel count as JΩ
  - Smaller payload volume
  - Improved wavefront error margin
  - Likely smaller payload mass
  - Superior stray light rejection
    - Easier to expand field of regard, at least for stray light
  - Lower throughput loss for pupil mask
  - Improved tiling efficiency
- uTMA does have lower heritage but we consider this engineering, NOT technology development
  - Probe ICE agreed with this for 1.1m uTMA
- We request you consider it for the baseline for the DRM

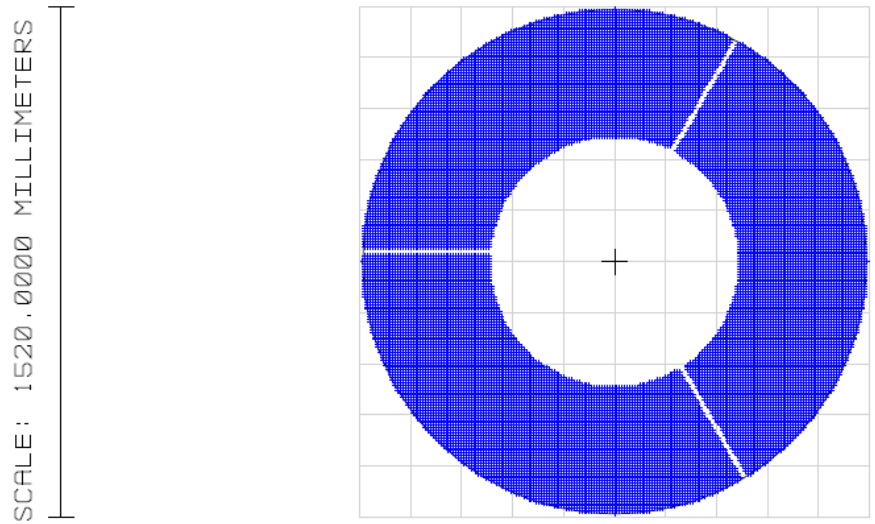
Backup charts

- Pp 17-22: Cold Masking comparison
- Pp 22-41: uTMA examples
- Pp. 41-46 JΩ & 4c3 throughput estimate including pupil masking

This & next 4 slides show results of careful masking of JΩ; similar analysis for 4c3 then added on last pg.

WFIRST Omega Cold Mask Study

- Cleaned up pupil definitions in 090618 Omega optical designs
  - 3 arm spider ahead of secondary mirror, 21.2 mm arms
  - 1500 mm diameter outer Stop in contact with Primary Mirror
  - 748 mm diameter inner Stop in contact with Primary Mirror
  - No other baffles in telescope affect the beam transmission



APERTURE DIAMETER: 1500.0000 % RAYS THROUGH = 73.76%

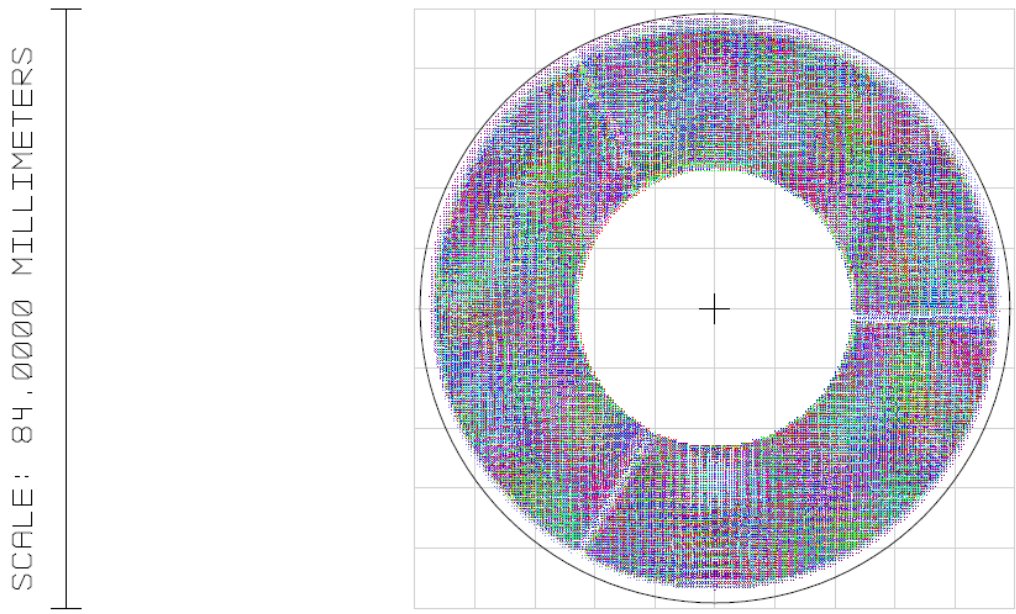
FOOTPRINT DIAGRAM

OMEGA_6X4_H_1H_PKG
4/13/2011
SURFACE 11: ENTRANCE PUPIL
RAY X MIN = -750.0000 RAY X MAX = 750.0000
RAY Y MIN = -750.0000 RAY Y MAX = 750.0000
MAX RADIUS= 750.0000 WAVELENGTH= 1.0000

OMEGA_090618_H_IMC_PUPIL_MASK_110411.ZMX
CONFIGURATION 1 OF 1

1st of 4 stages: find exact ImC pupil location

Optimized the tilt and focus of the exit pupil for the Imaging Channel



APERTURE DIAMETER: 82.5564 % RAYS THROUGH = 73.76%

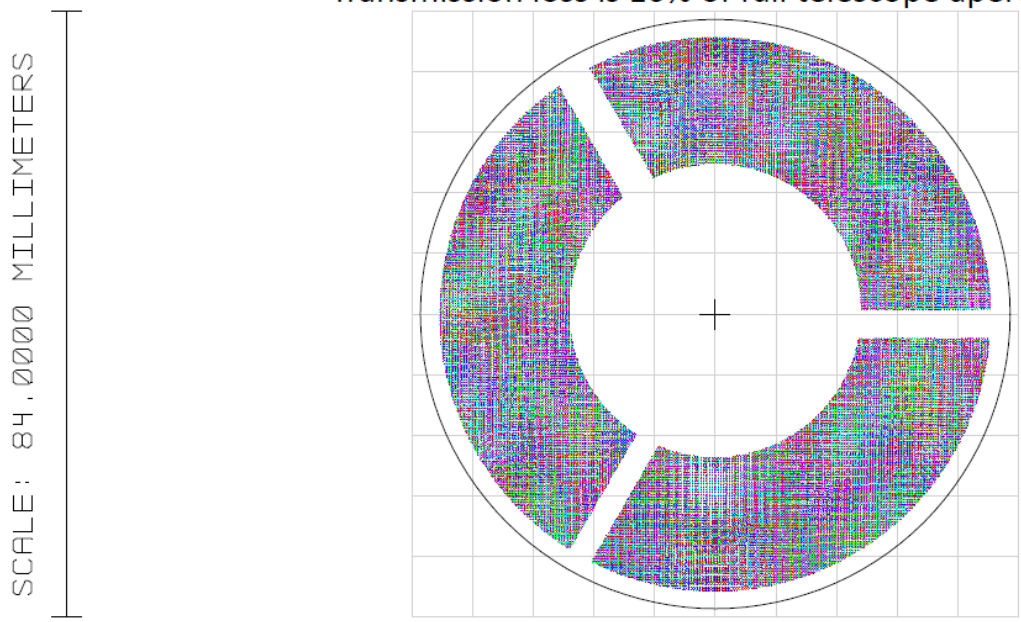
FOOTPRINT DIAGRAM

OMEGA_6X4_H_1H_PKG
4/13/2011
SURFACE 28: EXIT PUPIL
RAY X MIN = -40.0129 RAY X MAX = 40.0129
RAY Y MIN = -39.4403 RAY Y MAX = 40.9122
MAX RADIUS= 41.1350 WAVELENGTH= 1.0000

OMEGA_090618_H_IMC_PUPIL_MASK_110411.ZMX
CONFIGURATION 1 OF 1

2nd of 4 stages; elliptical inner & outer ImC pupil masks

Added separate inner and outer elliptical masks, and 3 rectangular spiders.
0.25 mm alignment margin on all apertures.
Transmission loss is 10% of full telescope aperture.



APERTURE DIAMETER: 81.6745 % RAYS THROUGH = 63.80%

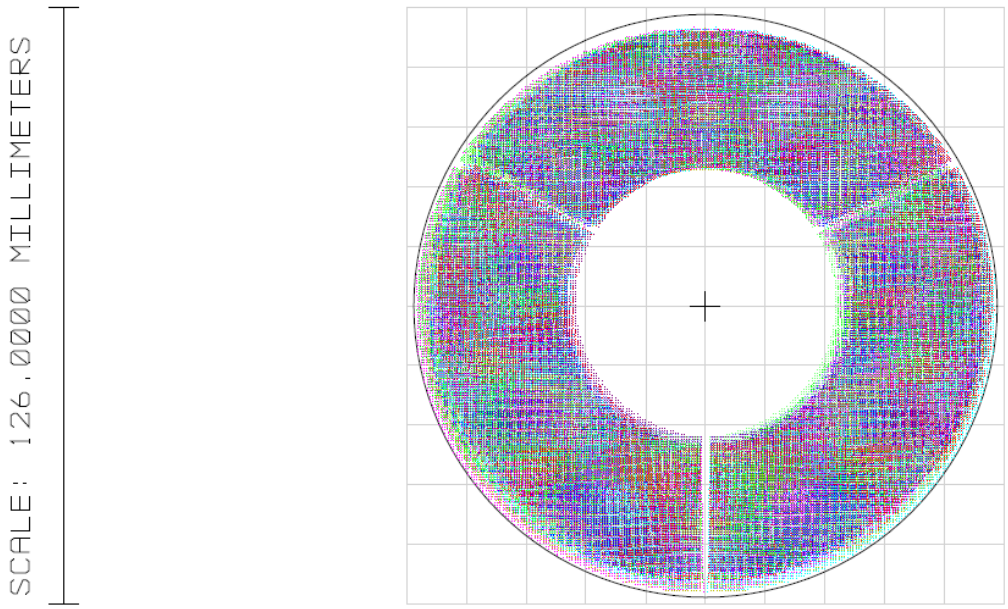
FOOTPRINT DIAGRAM

OMEGA_6X4_H_1H_PKG
4/13/2011
SURFACE 32: COLD MASKED
RAY X MIN = -38.1356 RAY X MAX = 38.1131
RAY Y MIN = -38.3767 RAY Y MAX = 38.4020
MAX RADIUS= 38.4367 WAVELENGTH= 1.0000

OMEGA_090618_H_IMC_PUPIL_MASK_110411.ZMX
CONFIGURATION 1 OF 1

3rd of 4 stages, do same as stage 1 for SpC

Optimized only tilt of the exit pupil for the Spectrograph Channel
(optimal focus collides with prism)



APERTURE DIAMETER: 122.9478 % RAYS THROUGH = 73.77%

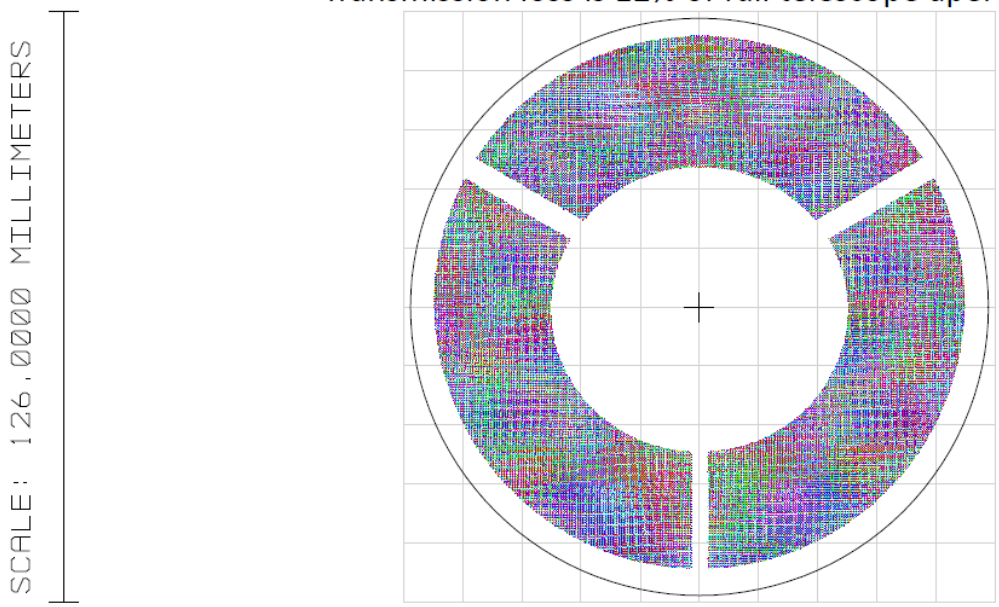
FOOTPRINT DIAGRAM

OMEGA_6X4_H_SPC_PKG1H
4/13/2011
SURFACE 40: EXIT PUPIL
RAY X MIN = -61.2669 RAY X MAX = 61.2669
RAY Y MIN = -60.2302 RAY Y MAX = 58.7957
MAX RADIUS= 61.4604 WAVELENGTH= 1.5500

OMEGA_090618_H_SPC_PUPIL_MASK_110411.ZMX
CONFIGURATION 1 OF 1

4th of 4: same as stage 2 for SpC

Added separate inner and outer elliptical masks, and 3 rectangular spiders.
0.25 mm alignment margin on all apertures.
Transmission loss is 12% of full telescope aperture.



APERTURE DIAMETER: 122.9478 % RAYS THROUGH = 61.79%

FOOTPRINT DIAGRAM

OMEGA_6X4_H_SPC_PKG1H
4/13/2011
SURFACE 44: COLD MASKED
RAY X MIN = -56.3963 RAY X MAX = 56.3963
RAY Y MIN = -55.7134 RAY Y MAX = 57.6922
MAX RADIUS= 57.7193 WAVELENGTH= 1.5500

OMEGA_090618_H_SPC_PUPIL_MASK_110411.ZMX
CONFIGURATION 1 OF 1

Summary of masking results

- JDEM-Omega:
  - ImC:
    - SM baffle and spiders lose 26.24%, 100%-> 73.76%
    - Inner & outer pupil elliptical masks and spiders lose 9.96%, 73.76%->63.80%
  - SpC:
    - Spiders & SM baffle: 73.77%
    - Inner & outer pupil elliptical masks and spiders lose 11.98%, 73.77%->61.79%
- 4c3:
  - ImC: outer pupil elliptical mask loses 5.08%, 100%->94.92%
  - SpC: {preliminary} can mask w/ losses ≤ 9.57%

- I will generate updated <u>masked</u> throughput files for each as I can

Examples of unobstructed aperture space telescopes

D. Content/ WFIRST optics lead

- LDCM OLI [Landsat data continuity mission, operational land imager]
  - 0.7m largest mirror
  - Built by BATC on contract to NASA GSFC
- Worldview [1 & II]
  - 0.6m aperture
- EO-1
  - 0.46m largest mirror
  - Built by SSG on contract to NASA GSFC
- [JPL direct experience] SIM Brassboard Optical Beam Compressor
- None encountered alignment or stability problems

- Finally I add here a tolerance comparison between two TMAs
  - Comparing PM-SM 6 DOF positioning stability
  - JDEM-Ω imager
  - “4” [focal 3 channel] imager

Example 1 of unobstructed aperture space telescopes

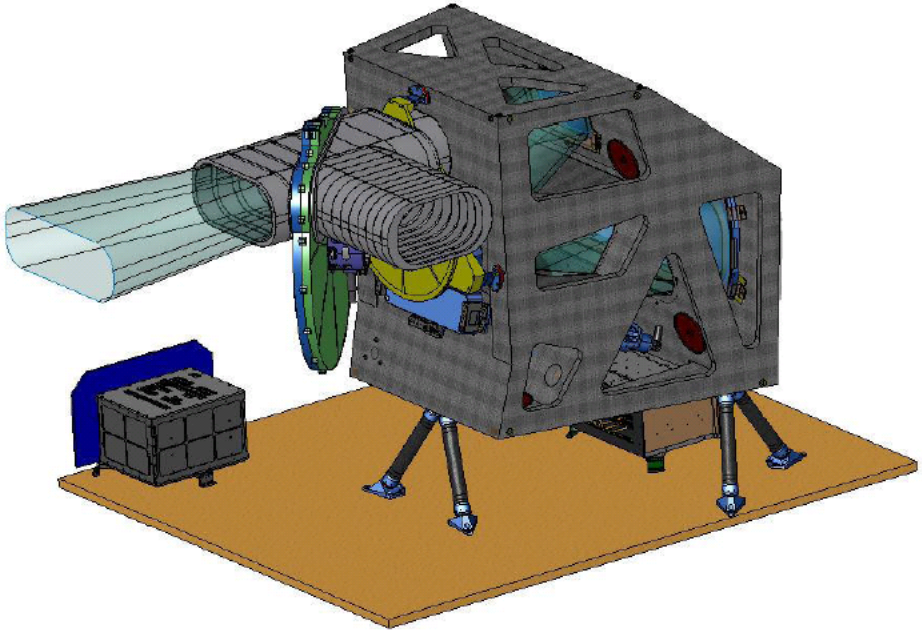
- LDCM OLI [Landsat data continuity mission, operational land imager]
  - Designed by M. Dittman/Ball [also initiated design of Omega on contract to GSFC JDEM project]
- OLI is built and ready to deliver, will launch in 2012
- 4-mirror camera system
  - Largest mirror 0.7m
  - Similar materials & temperatures to WFIRST
  - Some tighter requirements [visible operating band]
- Assembly and alignment went very smoothly

Operational Land Imager (OLI)

Contract awarded to Ball Aerospace Technical Corp. (BATC) July 2007

Critical Design Review Completed Oct. 2008

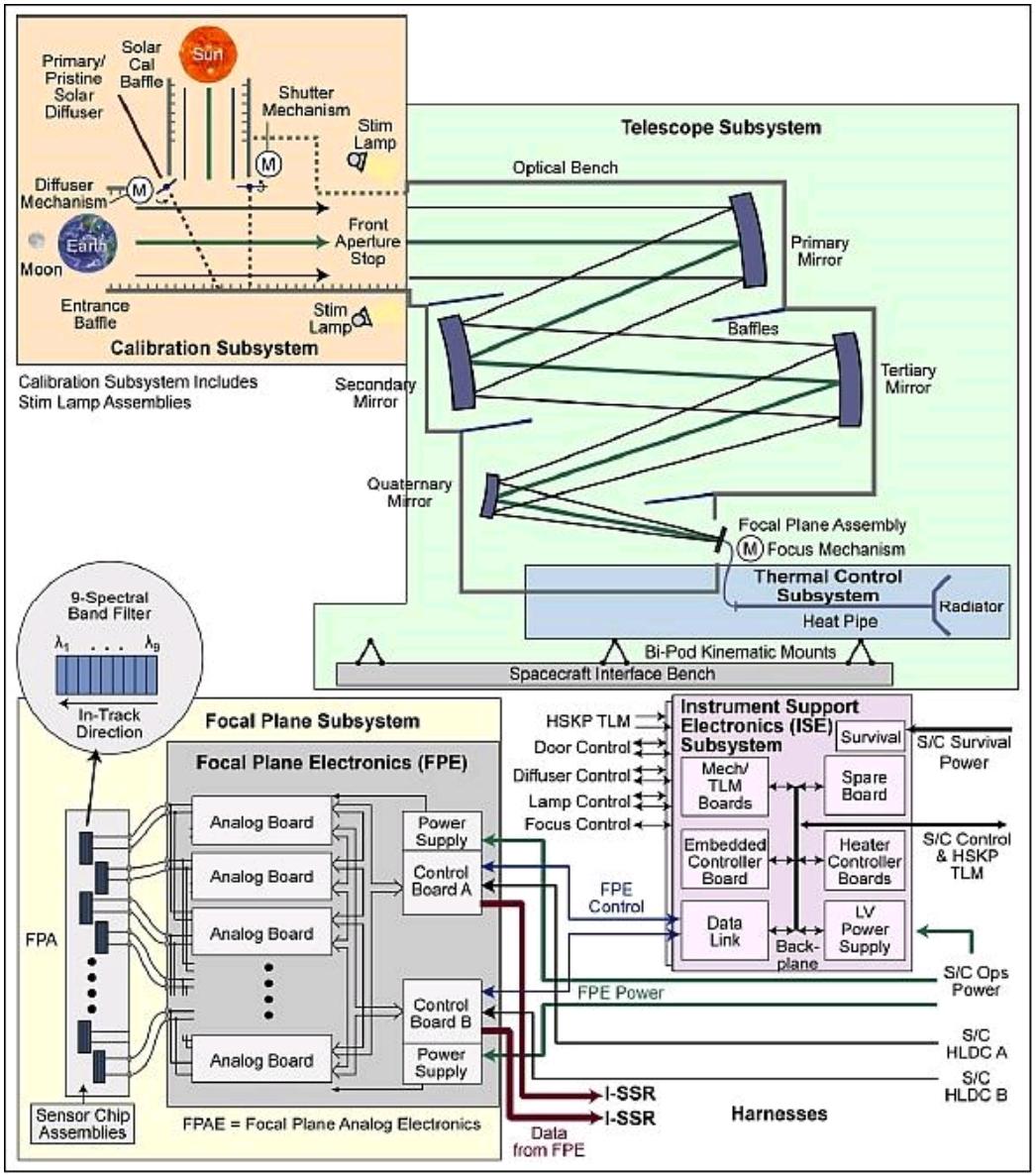
- **Pushbroom VIS/SWIR sensor** 15° cross track FOV
- **Four-mirror telescope with front aperture stop**
- **FPA consisting of 14 sensor chip assemblies, passively cooled**
- **Aperture 135 mm**
- **F number 6.4**
- **36 um / 18 um detectors (MS / Pan)**



Courtesy of BATC

http://download.ittvis.com/groups/VISualize_2010/VISualize_JIrons.pdf

Block diagram shows schematic of optical path



http://events.eoportal.org/presentations/129/10001248.html

Built performance matches design

Figures taken from SPIE2010 paper:

OLI telescope post-alignment optical performance

Michael G. Dittman, Brenda Firth
Ball Aerospace and Technologies Corp., 1600 Commerce St., Boulder, CO, USA 80306

- OLI alignment was uneventful and completed in less time than budgeted [1]; mechanical accuracy placement and gang alignment against computer models of field aberrations was used
- Top row of top figure is MTF model before alignment; Top row of bottom figure is as-built MTF, matching model

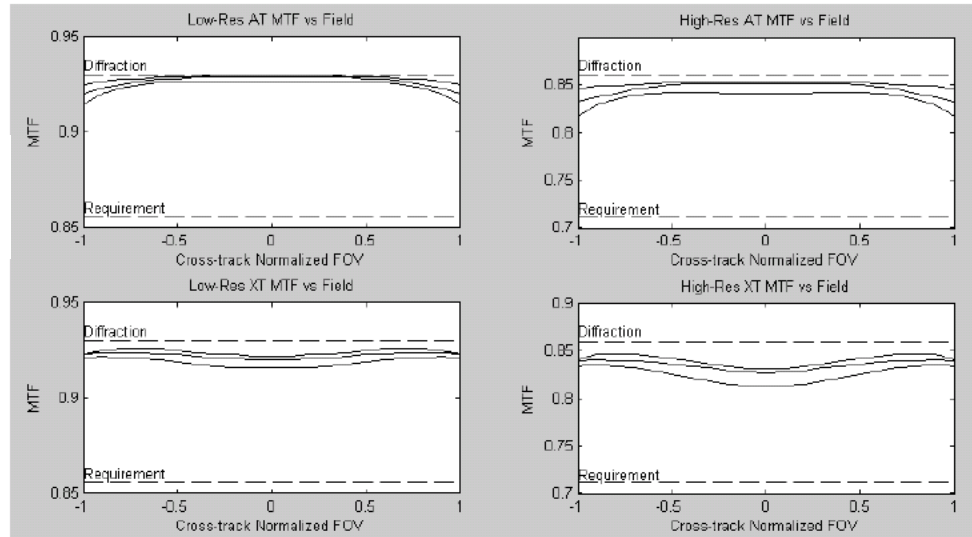


Figure 2. As-Designed MTF of the OLI Telescope.

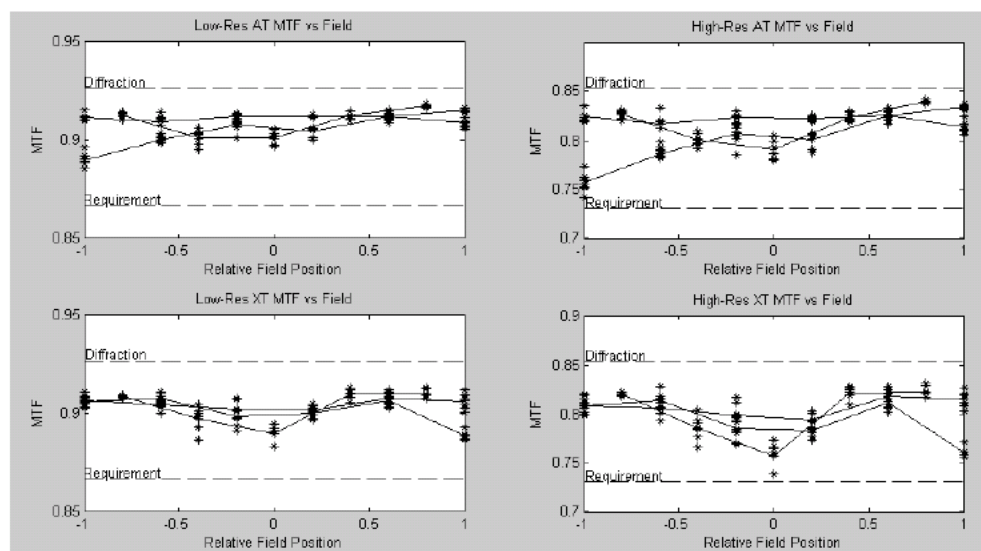


Figure 3. As-Built MTF of the OLI Telescope.

- [1] M. Dittman, personal communication (2010).

OLI Status

2nd example – WorldView1&2

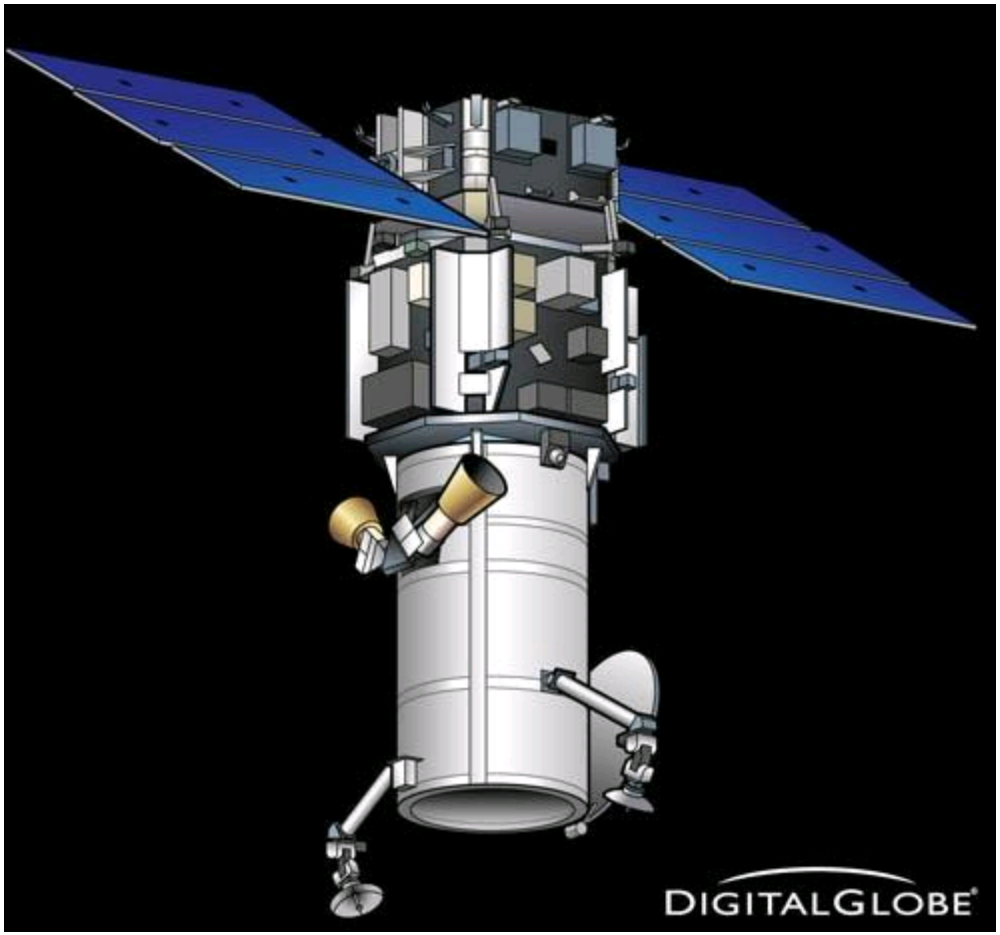
- The optical subsystem, mounted on an optical bench (with sunshield and internal baffling to suppress stray light), is of Ball design (telescope aperture of 60 cm diameter, lightweight structure, focal length of 8.8 m, f/14.7, the telescope mass is 138 kg, telescope size: 115 cm x 141 cm x 195 cm), providing a FOV (Field of View) of 2.12º, obtained with an **unobscured off-axis three-mirror-anastigmatic (TMA) optical form**. A fourth mirror is used to fold the light bundle for compact telescope packaging.

- Aperture size is 60cm

BATC photo of WorldView1

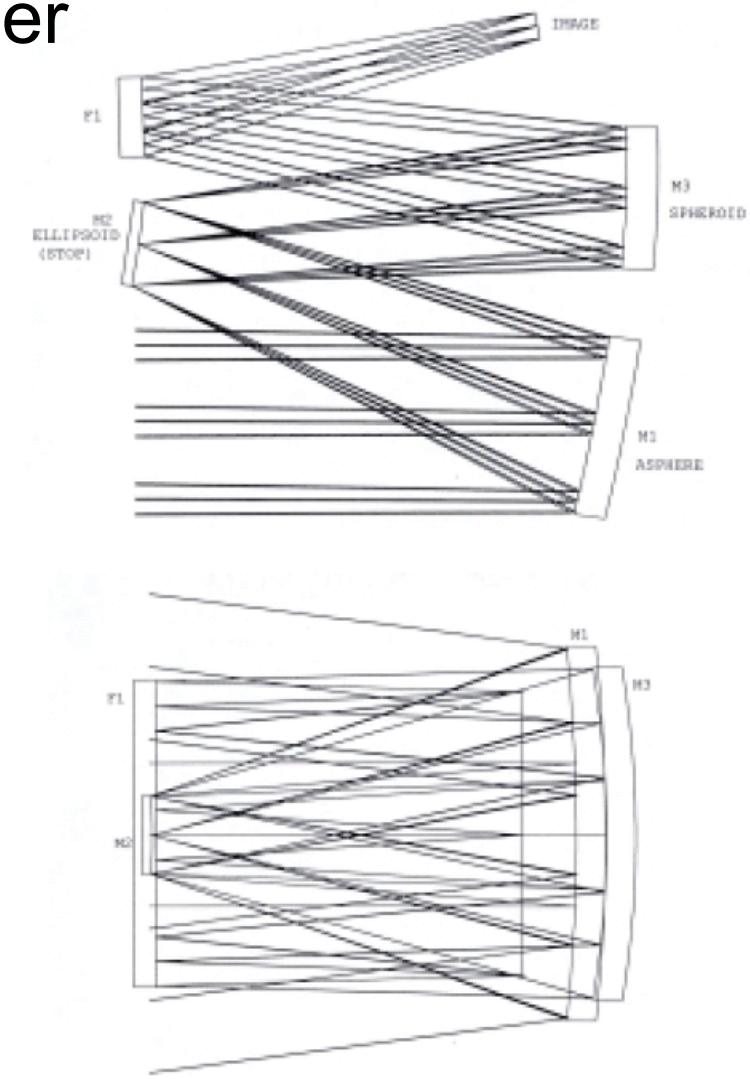
This system also met specs and is still operating in space – 'Google Mapping' commercial remote sensors

- DigitalGlobe [Wordview 1] delivered its first sample set of high-resolution images on Oct. 15, 2007
- 2nd instrument launched in 2009
- Both are still operating
- Ball personnel who designed and executed the alignment plan for these assured us it went well and we could expect the same for WFIRST.



3rd example --Earth Observer-1 [EO-1] Advanced land imager

- Reflective Cooke triplet form
- Off-axis aperture
  - Off-axis in field also
- Wide field: 1.3x15°
- No intermediate image
- Aperture stop on secondary
- Near telecentric
- Flat image plane
- Low distortion
  - PM: CC general asphere; SM CX ellipsoid; TM: cc sphere

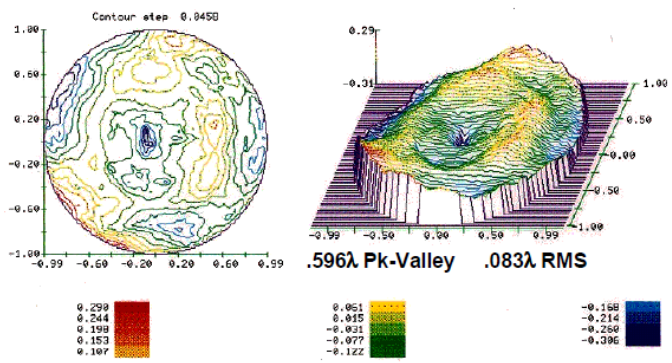


ALI Raytrace

SSG
Precision Optronics, Inc.

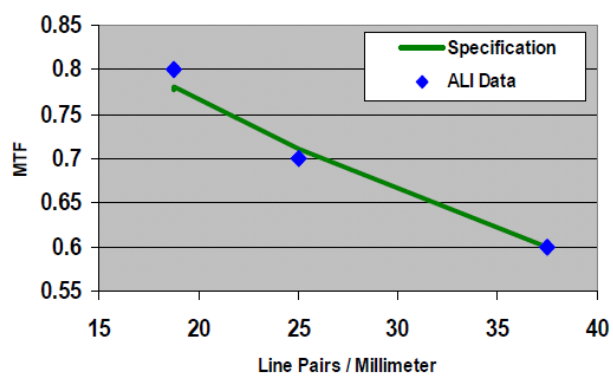
Performance met requirements

Optical Performance Summary (Image Quality)



On Axis, system level WFE

- **System Level Wavefront Error**
  - WFE derived from MTF specification using Code V
  - Required system WFE (@ temp) < 0.15 λ RMS (@ 0.63 μm)
  - 12 Field points tested, System WFE (@ temp) 0.089 - 0.148 λ RMS (@ 0.63 μm)



MTF spec and performance

- **System Level MTF**
  - MTF performance projected from wavefront maps input specification using Code V
  - System meets or exceeds spec at 18.75 and 37.5 lp/mm

SSG Precision Optronics, Inc.

EO-1 Mission was launched on a Delta II rocket from Vandenberg Air Force Base on November 21, 2000

- The mission had a design life of 18 months and a nominal life of 12 months.
- It is still operational

Telescope features

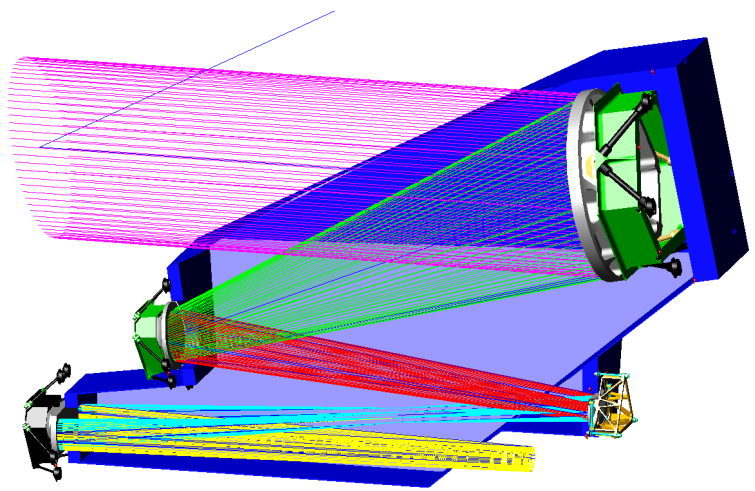
- **12.5 cm entrance pupil**
- **15° x 1.26° field-of-view**
- **Telecentric, f/7.5 design**
- **Unobscured, reflective optics**
- **Silicon carbide mirrors**
- **Wavefront error = 0.11 λ RMS @ 633 nm**

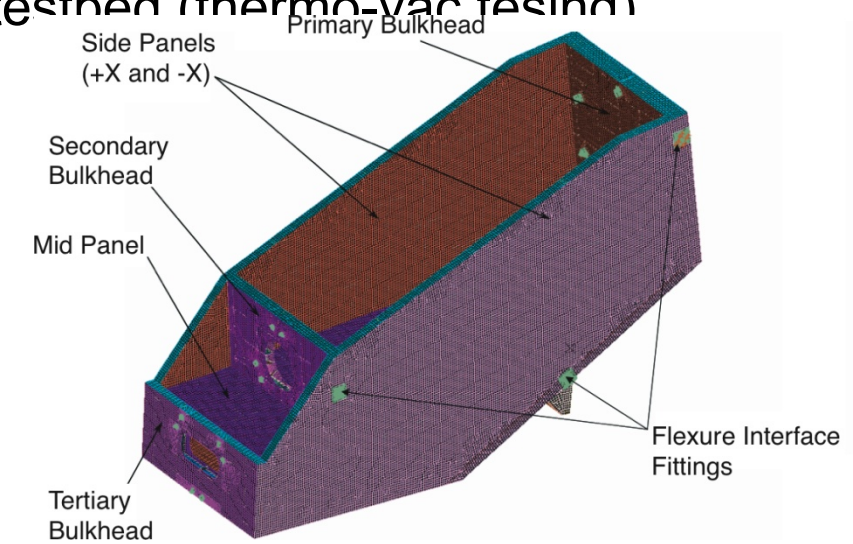
SIM Brassboard Optical Beam Compressor

- presented by Renaud Goullioud/WFIRST JPL telescope lead
  - Worked on these SIM milestone tests, direct experience with uTMA alignment

SIM Brassboard Optical Beam Compressor

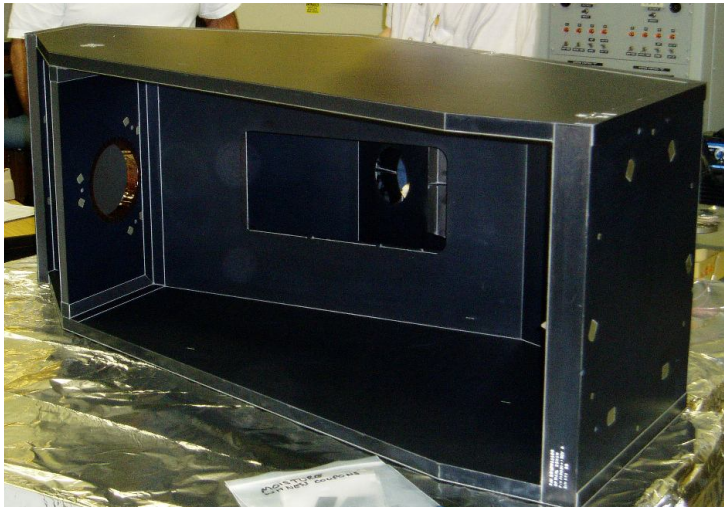
- Developed by JPL for SIM Technology Milestone 8.
- Unobscured Afocal TMA (with fold mirror), 350mm clear aperture, 7:1 compression ratio.
- Fixed Primary Mirror, 6 degrees of freedom mounts on M2, M3 and Fold.
- Once the optics were installed in their mounts, optical alignment took less than 2 weeks using SSG deterministic approach.
- Built a Finite Element Model (bench, M1,M2): ~526,000 nodes.
- Conduct model validation in TOM3 testbed (thermo-vac tesing)



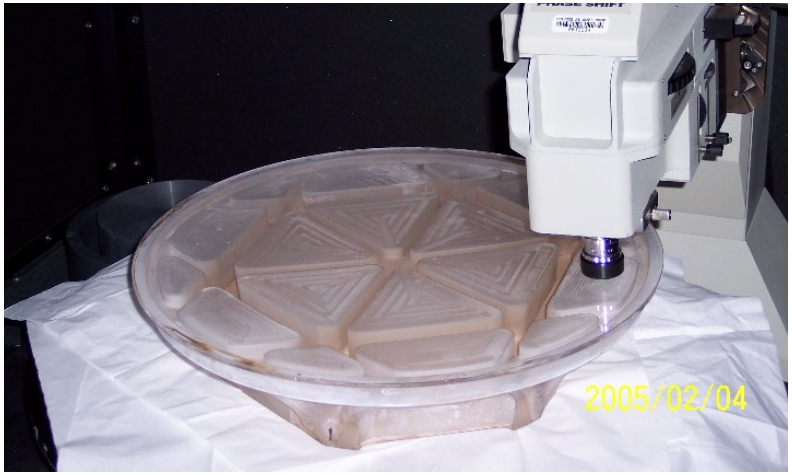


SIM Beam Compressor Development

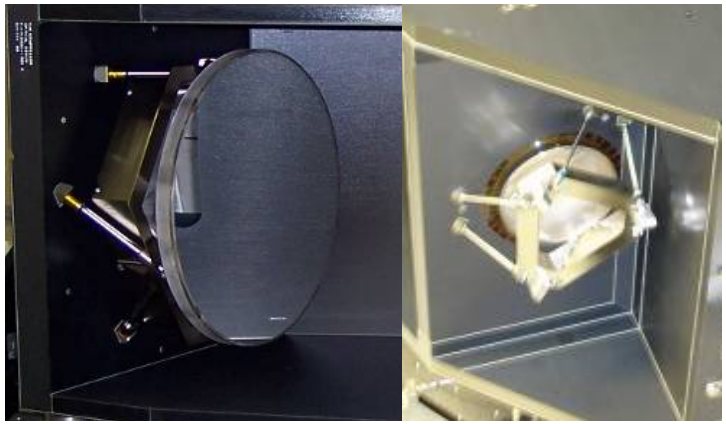
Composite bench built by ATK



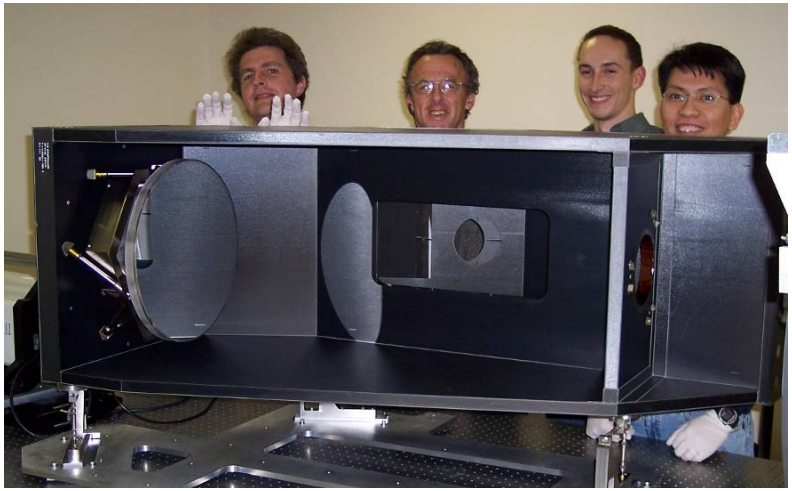
Optics built by Tinsley



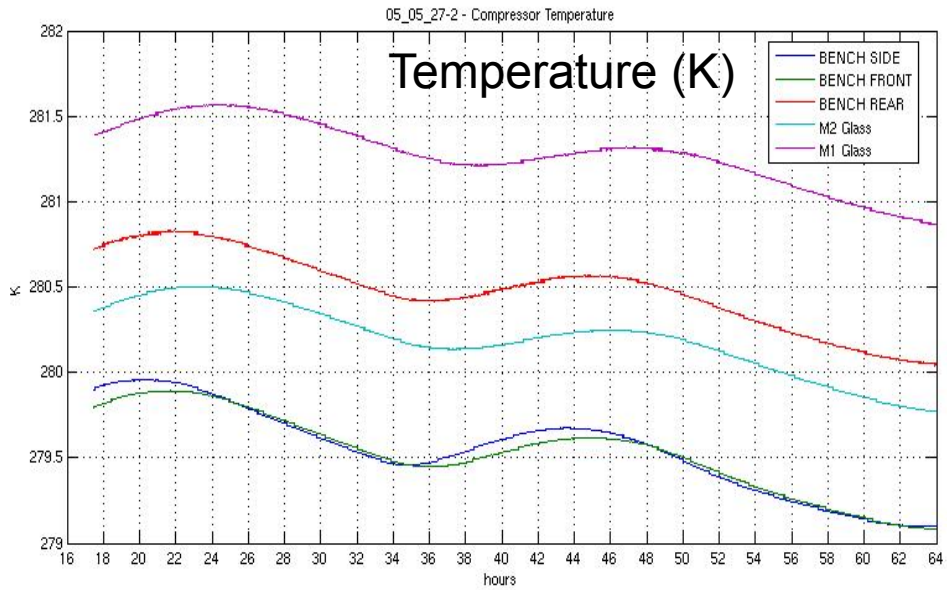
Mirror mounts built at JPL

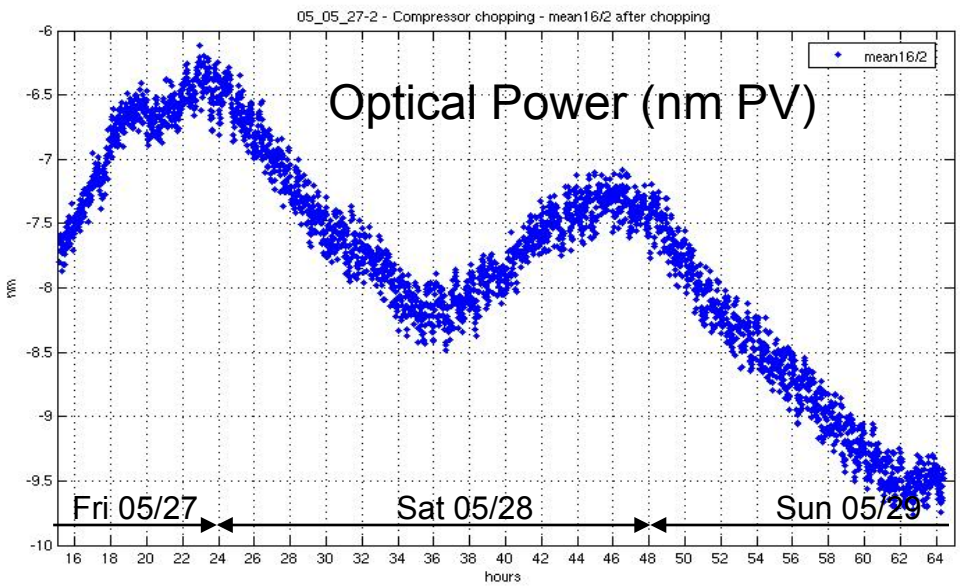


Telescope Alignment done by SSG

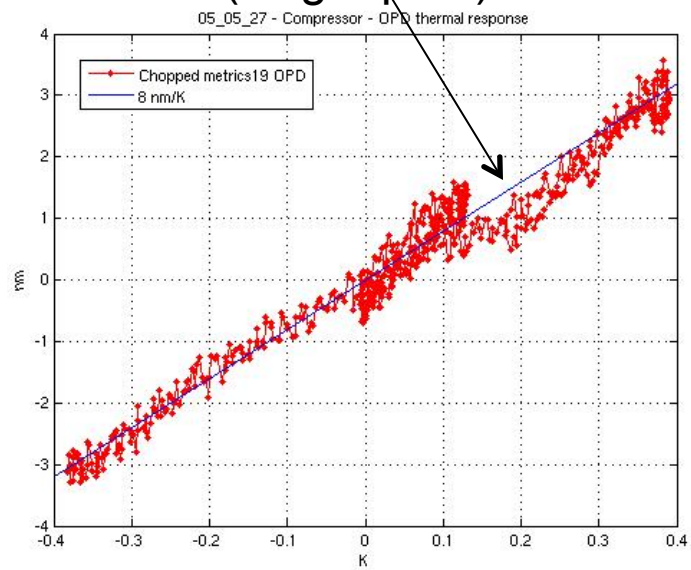


TMA Compressor Optical Tests in Thermo-Vac chamber





Compressor thermal response:
Best fit is 8nm PV/K (double-path),
4 nm PV (single-path).

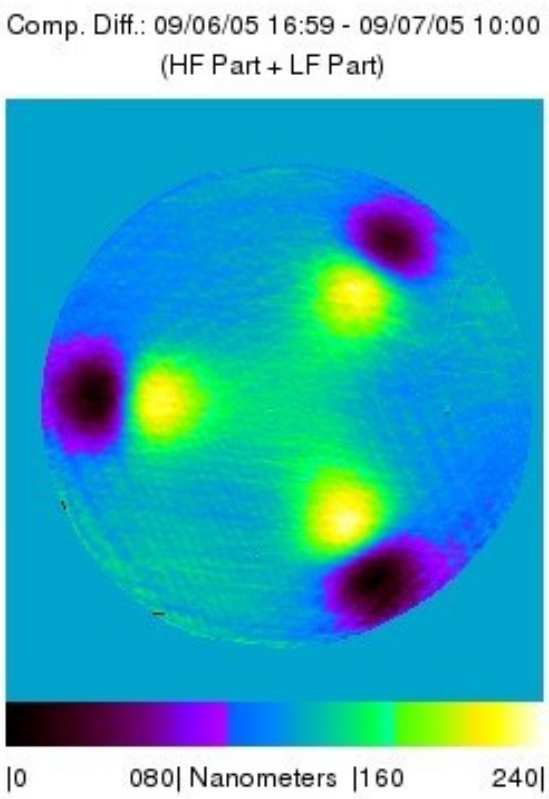


Model prediction for single-path optical power change was 4.98 nm/K

Primary mirror optical distortion due to mechanical mount stress

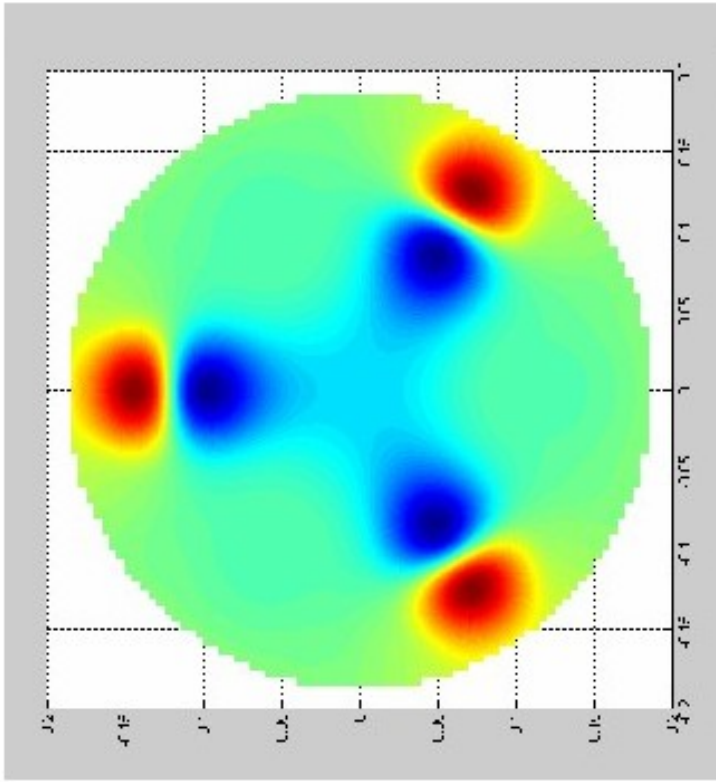
Measured Results

P-V = 14.3 nm/^{o}K



Analytical Results

P-V = 14 nm/^{o}K



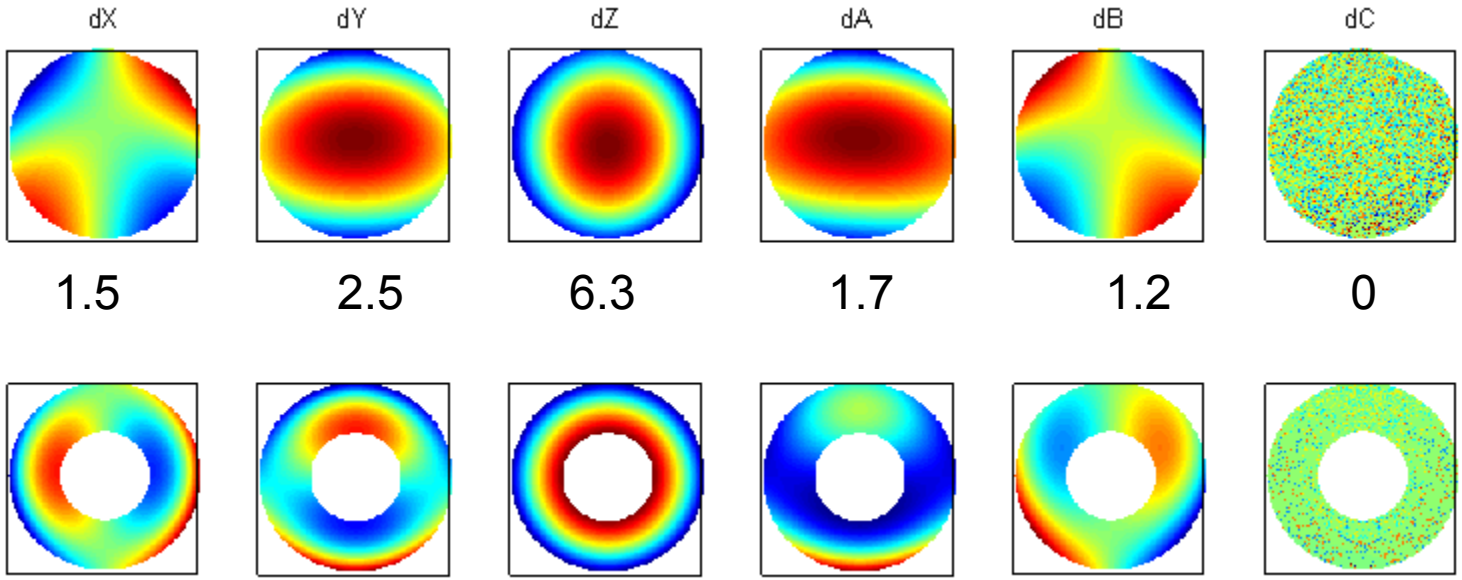
Secondary Mirror Wavefront Stability Sensitivities (No Boresight)

This is for an older version of design “4” [2(2x2) SpC@0.477”/pixel, 7x4 ImC @ 0.18”/pixel]

Larger is worse, ie more wavefront error per unit perturbation

Z = axis of SM

Linear positioning stability | Angular positioning stability



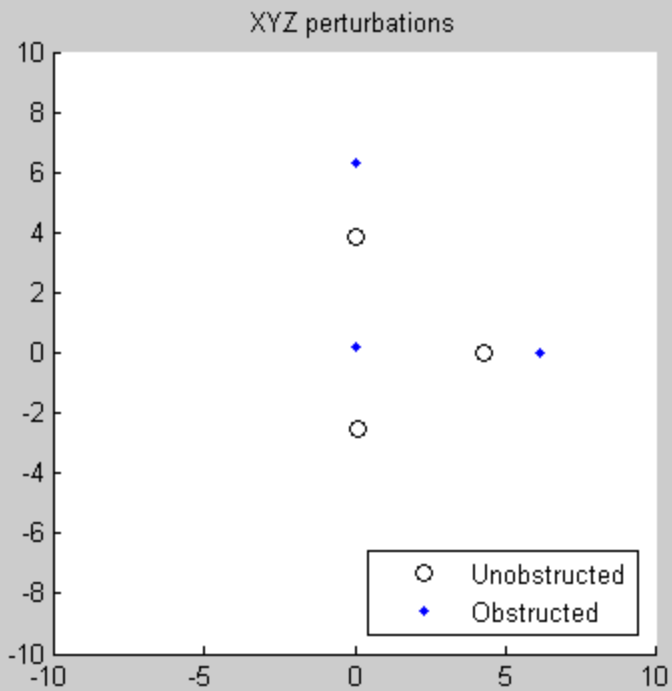
	dX	dY	dZ	dA	dB	dC
Unobstructed 1.3m “4” Coefficient:	1.5	2.5	6.3	1.7	1.2	0
50% Obstructed 1.5m Omega Coefficient:	0.60	0.61	8.8	0.68	0.63	0

Units = nm wfe/um perturbation OR um wfe/urad perturbation

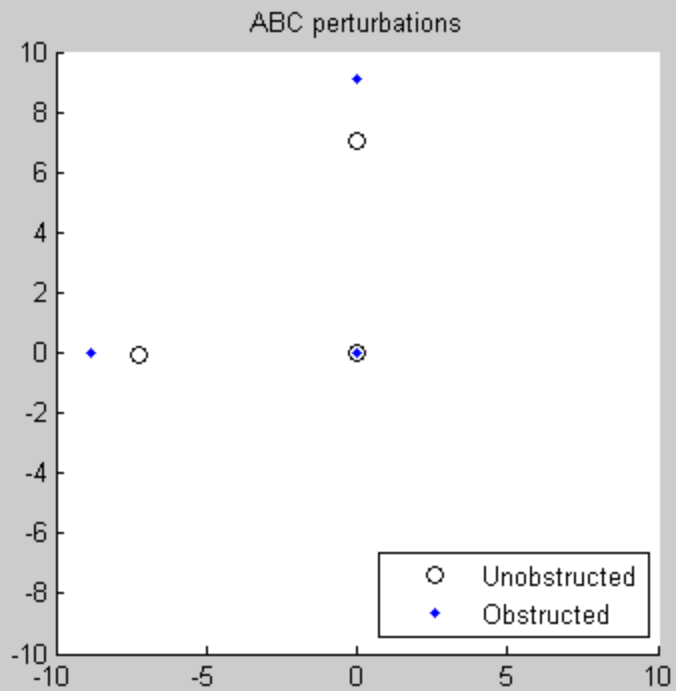
*Unobstructed is ~ 2x to 4x **more** sensitive (RMSWE metric); harder*

Chief Ray Sensitivities
(i.e. Boresight)

SM position errors



SM angular errors



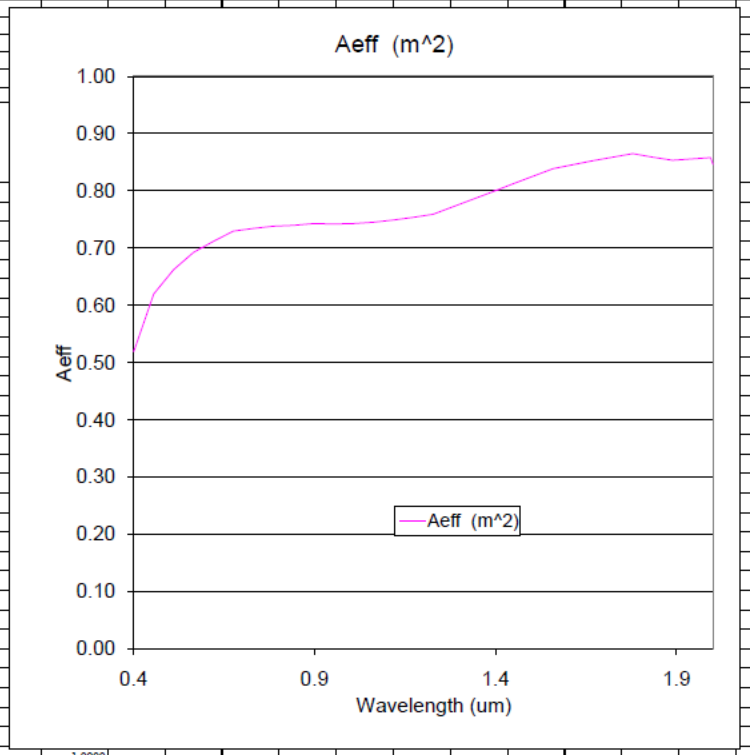
Units = m/m m/rad

Unobstructed 1.3m “4” is **less** sensitive than 1.5m 50% obstructed Omega (~ 20% less for tilts) ...

Likely due to SM having less magnification for Unobstructed.

Updated JΩ throughput w/ pupil mask - ImC

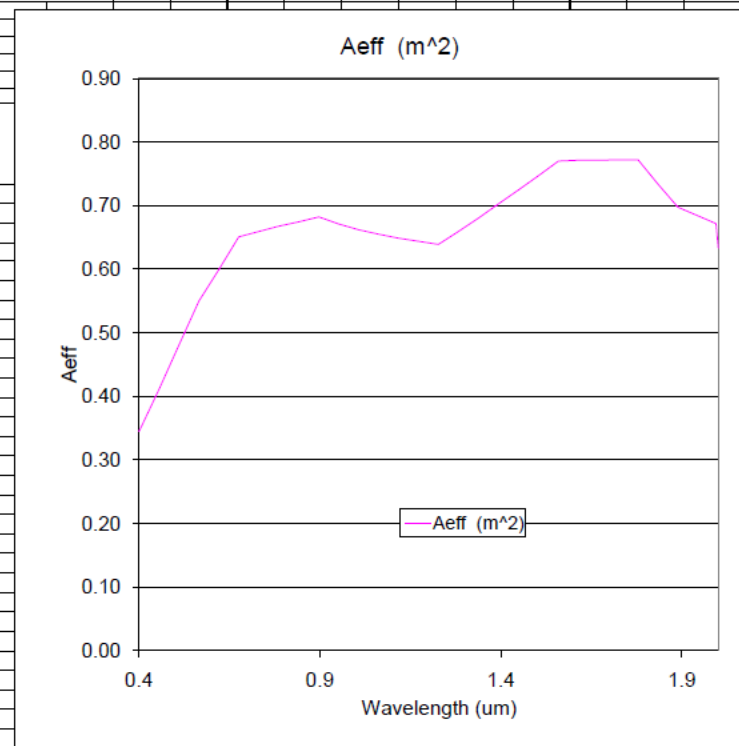
Effective Area Analysis					configuration title:	NIRI								
D. Content														
Min wavelength		um	0.4			Mirror diameter		m		1.5	mirror geometric area			
Max wavelength		um	2			# mirrors				5		Area (m^2)	1.767	
Mirror coating		pAg or pAu	pAg			# refractive elements (lens/prism/filter)				1	illuminatated aperture		1.1609	
filter name						linear obscuration ratio (HST=0.33)				0.5				
bandpass filter center, w0		um	n/a			area fraction lost to SM vanes				0.0245				
fraction width of bandpass, R			n/a			area fraction lost to pupil mask				0.0996				
wavelength spacing		um	0.055172			Contamination loss at EOL				0.02				
Rel. bandpass			1.3333			Dichroic T/R, #			T	0				
assumed max bandpass efficiency			0.9500							m^2				
wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	throughput	Aeff (m^2)			
0.4	0.9446	0.9340	1	1.0000	0.6560	0.7519	0.8724	0.98	0.6956	0.447	0.519			
0.4552	0.9766	0.9340	1	1.0000	0.7749	0.8883	0.8724	0.98	0.7024	0.533	0.619			
0.5103	0.9819	0.9481	1	1.0000	0.8205	0.9127	0.8990	0.98	0.7091	0.570	0.662			
0.5655	0.9831	0.9623	1	1.0000	0.8503	0.9183	0.9260	0.98	0.7159	0.597	0.693			
0.6207	0.9828	0.9717	1	1.0000	0.8659	0.9171	0.9442	0.98	0.7226	0.613	0.712			
0.6759	0.9819	0.9811	1	1.0000	0.8788	0.9129	0.9626	0.98	0.7294	0.628	0.729			
0.7310	0.9809	0.9823	1	1.0000	0.8761	0.9079	0.9650	0.98	0.7362	0.632	0.734			
0.7862	0.9797	0.9835	1	1.0000	0.8728	0.9023	0.9673	0.98	0.7429	0.635	0.738			
0.8414	0.9780	0.9847	1	1.0000	0.8673	0.8945	0.9696	0.98	0.7497	0.637	0.740			
0.8966	0.9766	0.9859	1	1.0000	0.8632	0.8881	0.9719	0.98	0.7564	0.640	0.743			
0.9517	0.9754	0.9835	1	1.0000	0.8540	0.8829	0.9673	0.98	0.7632	0.639	0.741			
1.0069	0.9748	0.9811	1	1.0000	0.8473	0.8802	0.9626	0.98	0.7699	0.639	0.742			
1.0621	0.9747	0.9788	1	1.0000	0.8427	0.8796	0.9580	0.98	0.7767	0.641	0.745			
1.1172	0.9749	0.9764	1	1.0000	0.8397	0.8807	0.9534	0.98	0.7835	0.645	0.748			
1.1724	0.9755	0.9741	1	1.0000	0.8380	0.8832	0.9488	0.98	0.7902	0.649	0.753			
1.2276	0.9761	0.9717	1	1.0000	0.8367	0.8862	0.9442	0.98	0.797	0.654	0.759			
1.2828	0.9769	0.9741	1	1.0000	0.8441	0.8897	0.9488	0.98	0.8037	0.665	0.772			
1.3379	0.9776	0.9764	1	1.0000	0.8513	0.8929	0.9534	0.98	0.8105	0.676	0.785			
1.3931	0.9783	0.9788	1	1.0000	0.8587	0.8963	0.9580	0.98	0.8173	0.688	0.798			
1.4483	0.9791	0.9811	1	1.0000	0.8661	0.8997	0.9626	0.98	0.824	0.699	0.812			
1.5034	0.9797	0.9835	1	1.0000	0.8731	0.9026	0.9673	0.98	0.8308	0.711	0.825			
1.5586	0.9804	0.9859	1	1.0000	0.8803	0.9057	0.9719	0.98	0.8375	0.723	0.839			
1.6138	0.9809	0.9847	1	1.0000	0.8805	0.9081	0.9696	0.98	0.8443	0.729	0.846			
1.6690	0.9813	0.9835	1	1.0000	0.8803	0.9101	0.9673	0.98	0.851	0.734	0.852			
1.7241	0.9818	0.9823	1	1.0000	0.8802	0.9121	0.9650	0.98	0.8578	0.740	0.859			
1.7793	0.9821	0.9811	1	1.0000	0.8795	0.9137	0.9626	0.98	0.8646	0.745	0.865			
1.8345	0.9819	0.9741	1	1.0000	0.8660	0.9127	0.9488	0.98	0.8713	0.739	0.858			
1.8897	0.9821	0.9670	1	1.0000	0.8542	0.9135	0.9351	0.98	0.8781	0.735	0.853			
1.9950	0.9831	0.9599	1	1.0000	0.8464	0.9185	0.9215	0.98	0.891	0.739	0.858			
2	0.9832	0.9529	1	1.0000	0.8340	0.9186	0.9079	0.98	0.8916	0.729	0.846	1.0000		
average	0.9782	0.9733	1.0000		0.8493	0.8960	0.9475	0.9800	0.7938	0.6617	0.7682			
RMS	0.0070	0.0143	0.0000		0.0429	0.0302	0.0276	0.0000	0.0598	0.0686	0.0796			
min	0.9446	0.9340	1.0000		0.6560	0.7519	0.8724	0.9800	0.6956	0.4472	0.5191			
max	0.9832	0.9859	1.0000		0.8805	0.9186	0.9719	0.9800	0.8916	0.7452	0.8651			
Avg 0.9-2	0.9789	0.9770	1.0000	1.0000	0.8579	0.8988	0.9546	0.9800	0.8243		0.8048			



Updated JΩ throughput w/ pupil mask – SN prism in ImC

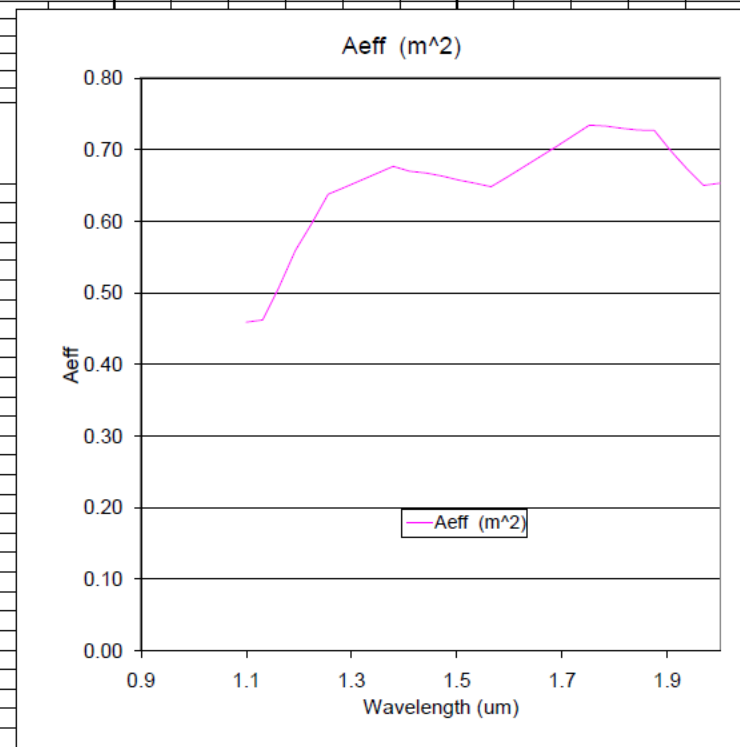
Effective Area Analysis					configuration title:	NIRI					
D. Content											
Min wavelength		um	0.4			Mirror diameter		m		1.5	mirror geometric area
Max wavelength		um	2			# mirrors				5	Area (m^2) 1.767
Mirror coating		pAg or pAu	pAg			# refractive elements (lens/prism/filter)				4	illuminatated aperture 1.1609
	filter name					linear obscuration ratio (HST=0.33)				0.5	
bandpass filter center, w0		um	n/a			area fraction lost to SM vanes				0.0245	
fraction width of bandpass, R			n/a			area fraction lost to pupil mask				0.0996	
wavelength spacing		um	0.055172			Contamination loss at EOL				0.02	
Rel. bandpass			1.3333			Dichroic T/R, #		T		0	
assumed max bandpass efficiency			0.9500							m^2	

wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	throughput	Aeff (m^2)
0.4	0.9446	0.9340	1	1.0000	0.4355	0.7519	0.5791	0.98	0.6956	0.297	0.345
0.4552	0.9766	0.9340	1	1.0000	0.5144	0.8883	0.5791	0.98	0.7024	0.354	0.411
0.5103	0.9819	0.9481	1	1.0000	0.5961	0.9127	0.6531	0.98	0.7091	0.414	0.481
0.5655	0.9831	0.9623	1	1.0000	0.6752	0.9183	0.7352	0.98	0.7159	0.474	0.550
0.6207	0.9828	0.9717	1	1.0000	0.7290	0.9171	0.7949	0.98	0.7226	0.516	0.599
0.6759	0.9819	0.9811	1	1.0000	0.7839	0.9129	0.8587	0.98	0.7294	0.560	0.651
0.7310	0.9809	0.9823	1	1.0000	0.7872	0.9079	0.8670	0.98	0.7362	0.568	0.659
0.7862	0.9797	0.9835	1	1.0000	0.7899	0.9023	0.8754	0.98	0.7429	0.575	0.668
0.8414	0.9780	0.9847	1	1.0000	0.7906	0.8945	0.8838	0.98	0.7497	0.581	0.674
0.8966	0.9766	0.9859	1	1.0000	0.7925	0.8881	0.8923	0.98	0.7564	0.587	0.682
0.9517	0.9754	0.9835	1	1.0000	0.7729	0.8829	0.8754	0.98	0.7632	0.578	0.671
1.0069	0.9748	0.9811	1	1.0000	0.7559	0.8802	0.8587	0.98	0.7699	0.570	0.662
1.0621	0.9747	0.9788	1	1.0000	0.7410	0.8796	0.8424	0.98	0.7767	0.564	0.655
1.1172	0.9749	0.9764	1	1.0000	0.7277	0.8807	0.8263	0.98	0.7835	0.559	0.649
1.1724	0.9755	0.9741	1	1.0000	0.7158	0.8832	0.8105	0.98	0.7902	0.554	0.643
1.2276	0.9761	0.9717	1	1.0000	0.7044	0.8862	0.7949	0.98	0.797	0.550	0.639
1.2828	0.9769	0.9741	1	1.0000	0.7210	0.8897	0.8105	0.98	0.8037	0.568	0.659
1.3379	0.9776	0.9764	1	1.0000	0.7378	0.8929	0.8263	0.98	0.8105	0.586	0.680
1.3931	0.9783	0.9788	1	1.0000	0.7550	0.8963	0.8424	0.98	0.8173	0.605	0.702
1.4483	0.9791	0.9811	1	1.0000	0.7726	0.8997	0.8587	0.98	0.824	0.624	0.724
1.5034	0.9797	0.9835	1	1.0000	0.7901	0.9026	0.8754	0.98	0.8308	0.643	0.747
1.5586	0.9804	0.9859	1	1.0000	0.8082	0.9057	0.8923	0.98	0.8375	0.663	0.770
1.6138	0.9809	0.9847	1	1.0000	0.8026	0.9081	0.8838	0.98	0.8443	0.664	0.771
1.6690	0.9813	0.9835	1	1.0000	0.7967	0.9101	0.8754	0.98	0.851	0.664	0.771
1.7241	0.9818	0.9823	1	1.0000	0.7908	0.9121	0.8670	0.98	0.8578	0.665	0.772
1.7793	0.9821	0.9811	1	1.0000	0.7846	0.9137	0.8587	0.98	0.8646	0.665	0.772
1.8345	0.9819	0.9741	1	1.0000	0.7397	0.9127	0.8105	0.98	0.8713	0.632	0.733
1.8897	0.9821	0.9670	1	1.0000	0.6984	0.9135	0.7646	0.98	0.8781	0.601	0.698
1.9950	0.9831	0.9599	1	1.0000	0.6622	0.9185	0.7210	0.98	0.891	0.578	0.671
2	0.9832	0.9529	1	1.0000	0.6242	0.9186	0.6796	0.98	0.8916	0.545	0.633
average	0.9782	0.9733	1.0000		0.7265	0.8960	0.8098	0.9800	0.7938	0.5669	0.6581
RMS	0.0070	0.0143	0.0000		0.0871	0.0302	0.0880	0.0000	0.0598	0.0868	0.1007
min	0.9446	0.9340	1.0000		0.4355	0.7519	0.5791	0.9800	0.6956	0.2969	0.3446
max	0.9832	0.9859	1.0000		0.8082	0.9186	0.8923	0.9800	0.8916	0.6648	0.7718
Avg 0.9-2	0.9789	0.9770	1.0000	1.0000	0.7473	0.8988	0.8317	0.9800	0.8243		0.7002



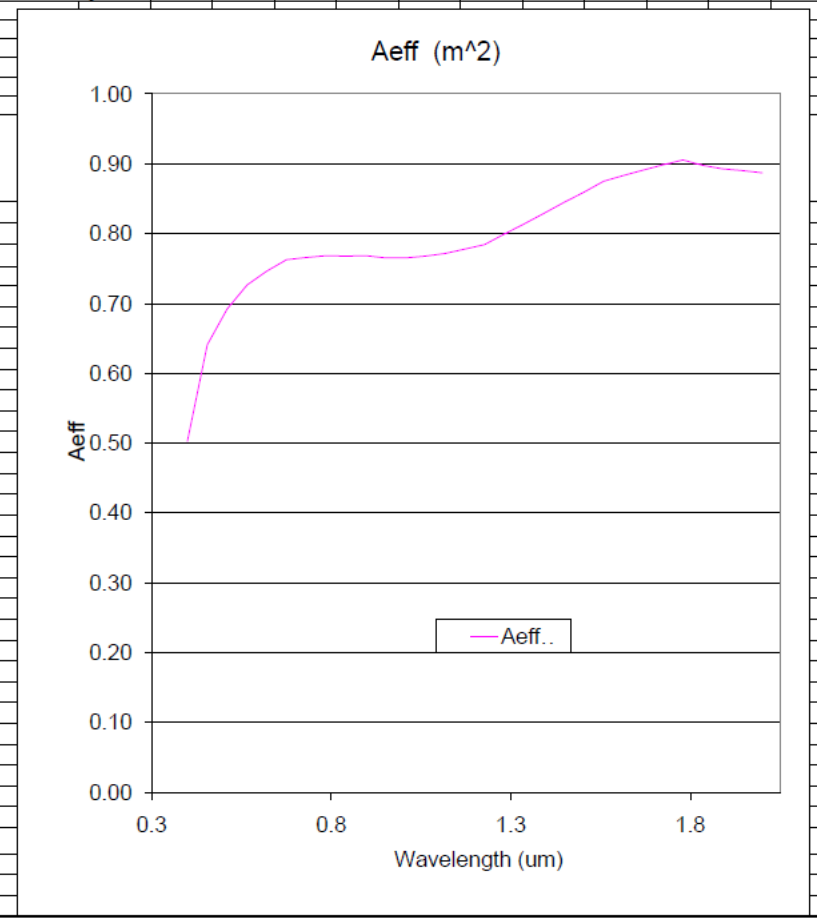
Updated JΩ throughput w/ pupil mask - SpC

Effective Area Analysis					configuration title:	NIRS							
D. Content													
Min wavelength		um	1.1				Mirror diameter	m		1.5	mirror geometric area		
Max wavelength		um	2				# mirrors			7	Area (m^2)	1.767	
Mirror coating		pAg or pAu	pAg				# refractive elements (lens/prism/dichroic))			7	illuminatated aperture	1.134	
	filter name						linear obscuration ratio (HST=0.33)			0.5			
bandpass filter center, w0		um	1.55				area fraction lost to SM vanes			0.0245			
fraction width of bandpass, R			1.72				area fraction lost to pupil mask			0.1198			
wavelength spacing		um	0.031034				Contamination loss at EOL			0.02			
Rel. bandpass			0.5806				Dichroic T/R, #		T	0			
assumed max bandpass efficiency			0.9500							m^2			
wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	throughput	Aeff (m^2)		
1.1	0.9749	0.9713	0.95	1.0000	0.5284	0.8367	0.6316	0.98	0.7814	0.405	0.459		
1.1310	0.9751	0.9713	0.95	1.0000	0.5293	0.8381	0.6316	0.98	0.7852	0.407	0.462		
1.1621	0.9754	0.9774	0.95	1.0000	0.5795	0.8398	0.6900	0.98	0.789	0.448	0.508		
1.1931	0.9757	0.9836	0.95	1.0000	0.6343	0.8419	0.7534	0.98	0.7928	0.493	0.559		
1.2241	0.9761	0.9877	0.95	1.0000	0.6742	0.8441	0.7987	0.98	0.7966	0.526	0.597		
1.2552	0.9765	0.9918	0.95	1.0000	0.7166	0.8466	0.8464	0.98	0.8004	0.562	0.637		
1.2862	0.9769	0.9923	0.95	1.0000	0.7241	0.8493	0.8526	0.98	0.8042	0.571	0.647		
1.3172	0.9773	0.9928	0.95	1.0000	0.7313	0.8516	0.8588	0.98	0.808	0.579	0.657		
1.3483	0.9778	0.9933	0.95	1.0000	0.7390	0.8543	0.8650	0.98	0.8118	0.588	0.667		
1.3793	0.9781	0.9938	0.95	1.0000	0.7463	0.8566	0.8713	0.98	0.8156	0.596	0.676		
1.4103	0.9782	0.9928	0.95	1.0000	0.7358	0.8569	0.8588	0.98	0.8194	0.591	0.670		
1.4414	0.9790	0.9918	0.95	1.0000	0.7294	0.8617	0.8464	0.98	0.8232	0.588	0.667		
1.4724	0.9794	0.9908	0.95	1.0000	0.7213	0.8646	0.8342	0.98	0.827	0.585	0.663		
1.5034	0.9797	0.9897	0.95	1.0000	0.7124	0.8664	0.8222	0.98	0.8308	0.580	0.658		
1.5345	0.9801	0.9887	0.95	1.0000	0.7040	0.8687	0.8104	0.98	0.8346	0.576	0.653		
1.5655	0.9804	0.9877	0.95	1.0000	0.6955	0.8709	0.7987	0.98	0.8384	0.571	0.648		
1.5966	0.9807	0.9887	0.95	1.0000	0.7072	0.8726	0.8104	0.98	0.8422	0.584	0.662		
1.6276	0.9810	0.9897	0.95	1.0000	0.7190	0.8745	0.8222	0.98	0.846	0.596	0.676		
1.6586	0.9812	0.9908	0.95	1.0000	0.7306	0.8757	0.8342	0.98	0.8498	0.608	0.690		
1.6897	0.9815	0.9918	0.95	1.0000	0.7427	0.8774	0.8464	0.98	0.8536	0.621	0.705		
1.7207	0.9818	0.9928	0.95	1.0000	0.7550	0.8791	0.8588	0.98	0.8574	0.634	0.719		
1.7517	0.9820	0.9938	0.95	1.0000	0.7671	0.8804	0.8713	0.98	0.8612	0.647	0.734		
1.7828	0.9821	0.9933	0.95	1.0000	0.7625	0.8815	0.8650	0.98	0.865	0.646	0.733		
1.8138	0.9819	0.9928	0.95	1.0000	0.7558	0.8801	0.8588	0.98	0.8688	0.643	0.730		
1.8448	0.9819	0.9923	0.95	1.0000	0.7501	0.8799	0.8526	0.98	0.8726	0.641	0.728		
1.8759	0.9821	0.9918	0.95	1.0000	0.7458	0.8811	0.8464	0.98	0.8764	0.641	0.726		
1.9069	0.9820	0.9887	0.95	1.0000	0.7138	0.8808	0.8104	0.98	0.8802	0.616	0.698		
1.9379	0.9823	0.9856	0.95	1.0000	0.6847	0.8827	0.7757	0.98	0.884	0.593	0.673		
1.9690	0.9831	0.9825	0.95	1.0000	0.6588	0.8873	0.7425	0.98	0.8878	0.573	0.650		
2	0.9831	0.9825	0.95	1.0000	0.6592	0.8878	0.7425	0.98	0.8916	0.576	0.653	1.0000	
average	0.9796	0.9885	0.9500		0.7018	0.8656	0.8102	0.9800	0.8365	0.5762	0.6535		
RMS	0.0026	0.0061	0.0000		0.0622	0.0162	0.0657	0.0000	0.0335	0.0635	0.0720		
min	0.9749	0.9713	0.9500		0.5284	0.8367	0.6316	0.9800	0.7814	0.4046	0.4589		
max	0.9831	0.9938	0.9500		0.7671	0.8878	0.8713	0.9800	0.8916	0.6474	0.7342		



4c3 throughput w/ mask - ImC

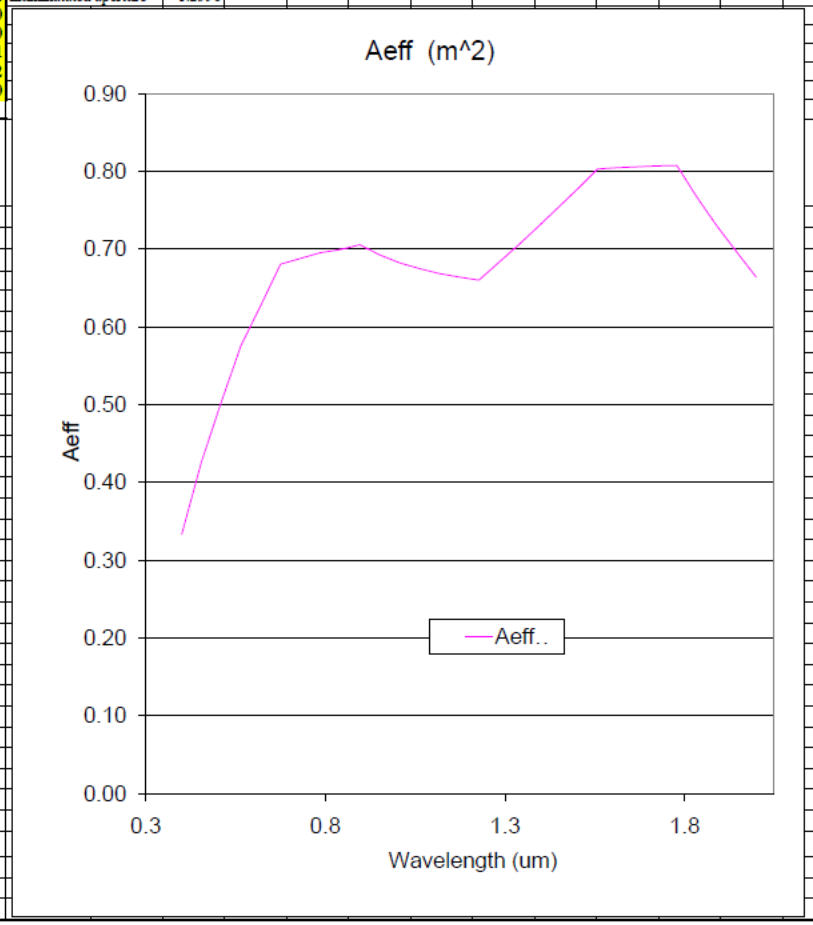
Effective Area Analysis					configuration title:		WFIRST 4c3 ImC							
D. Content														
Min wavelength		um	0.4				Mirror diameter		m	1.3	mirror geometric area			
Max wavelength		um	2						# mirrors	7		Area (m^2)	1.327	
Mirror coating		pAg or pAu	pAg				# refractive elements (lens/prism)			1	illuminatated aperture		1.260	
filter name							linear obscuration ratio (HST=0.33)			0				
bandpass filter center, w0		um	n/a				area fraction lost to SM vanes			0				
fraction width of bandpass, R			n/a				area fraction lost to pupil mask			0.051				
wavelength spacing		um	0.055172				Contamination loss at EOL			0.02				
Rel. bandpass			1.3333				Dichroic T/R, #		R	0				
assumed max bandpass efficiency			0.9500							m^2				
wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	Aeff (m^2)				
0.4	0.9446	0.9340	1	1.0000	0.5853	0.6709	0.8724	0.98	0.6956	0.503				
0.4552	0.9766	0.9340	1	1.0000	0.7390	0.8472	0.8724	0.98	0.7024	0.641				
0.5103	0.9819	0.9481	1	1.0000	0.7910	0.8799	0.8990	0.98	0.7091	0.692				
0.5655	0.9831	0.9623	1	1.0000	0.8218	0.8875	0.9260	0.98	0.7159	0.726				
0.6207	0.9828	0.9717	1	1.0000	0.8364	0.8859	0.9442	0.98	0.7226	0.746				
0.6759	0.9819	0.9811	1	1.0000	0.8473	0.8802	0.9626	0.98	0.7294	0.763				
0.7310	0.9809	0.9823	1	1.0000	0.8429	0.8735	0.9650	0.98	0.7362	0.766				
0.7862	0.9797	0.9835	1	1.0000	0.8377	0.8660	0.9673	0.98	0.7429	0.768				
0.8414	0.9780	0.9847	1	1.0000	0.8295	0.8555	0.9696	0.98	0.7497	0.768				
0.8966	0.9766	0.9859	1	1.0000	0.8232	0.8470	0.9719	0.98	0.7564	0.769				
0.9517	0.9754	0.9835	1	1.0000	0.8125	0.8400	0.9673	0.98	0.7632	0.765				
1.0069	0.9748	0.9811	1	1.0000	0.8052	0.8364	0.9626	0.98	0.7699	0.765				
1.0621	0.9747	0.9788	1	1.0000	0.8006	0.8357	0.9580	0.98	0.7767	0.768				
1.1172	0.9749	0.9764	1	1.0000	0.7981	0.8371	0.9534	0.98	0.7835	0.772				
1.1724	0.9755	0.9741	1	1.0000	0.7973	0.8404	0.9488	0.98	0.7902	0.778				
1.2276	0.9761	0.9717	1	1.0000	0.7972	0.8443	0.9442	0.98	0.797	0.784				
1.2828	0.9769	0.9741	1	1.0000	0.8056	0.8490	0.9488	0.98	0.8037	0.799				
1.3379	0.9776	0.9764	1	1.0000	0.8136	0.8533	0.9534	0.98	0.8105	0.814				
1.3931	0.9783	0.9788	1	1.0000	0.8219	0.8579	0.9580	0.98	0.8173	0.829				
1.4483	0.9791	0.9811	1	1.0000	0.8302	0.8624	0.9626	0.98	0.824	0.844				
1.5034	0.9797	0.9835	1	1.0000	0.8380	0.8664	0.9673	0.98	0.8308	0.859				
1.5586	0.9804	0.9859	1	1.0000	0.8461	0.8706	0.9719	0.98	0.8375	0.875				
1.6138	0.9809	0.9847	1	1.0000	0.8472	0.8738	0.9696	0.98	0.8443	0.883				
1.6690	0.9813	0.9835	1	1.0000	0.8477	0.8764	0.9673	0.98	0.851	0.891				
1.7241	0.9818	0.9823	1	1.0000	0.8484	0.8792	0.9650	0.98	0.8578	0.898				
1.7793	0.9821	0.9811	1	1.0000	0.8484	0.8813	0.9626	0.98	0.8646	0.905				
1.8345	0.9819	0.9741	1	1.0000	0.8349	0.8800	0.9488	0.98	0.8713	0.898				
1.8897	0.9821	0.9670	1	1.0000	0.8238	0.8810	0.9351	0.98	0.8781	0.893				
1.9448	0.9826	0.9599	1	1.0000	0.8148	0.8843	0.9215	0.98	0.8848	0.890				
2.0000	0.9832	0.9529	1	1.0000	0.8061	0.8879	0.9079	0.98	0.8916	0.887				
average	0.9782	0.9733	1.0000		0.8131	0.8577	0.9475	0.9800	0.7936	0.7980				
RMS	0.0069	0.0143	0.0000		0.0492	0.0394	0.0276	0.0000	0.0595	0.0883				
min	0.9446	0.9340	1.0000		0.5853	0.6709	0.8724	0.9800	0.6956	0.5026				
max	0.9832	0.9859	1.0000		0.8484	0.8879	0.9719	0.9800	0.8916	0.9054				



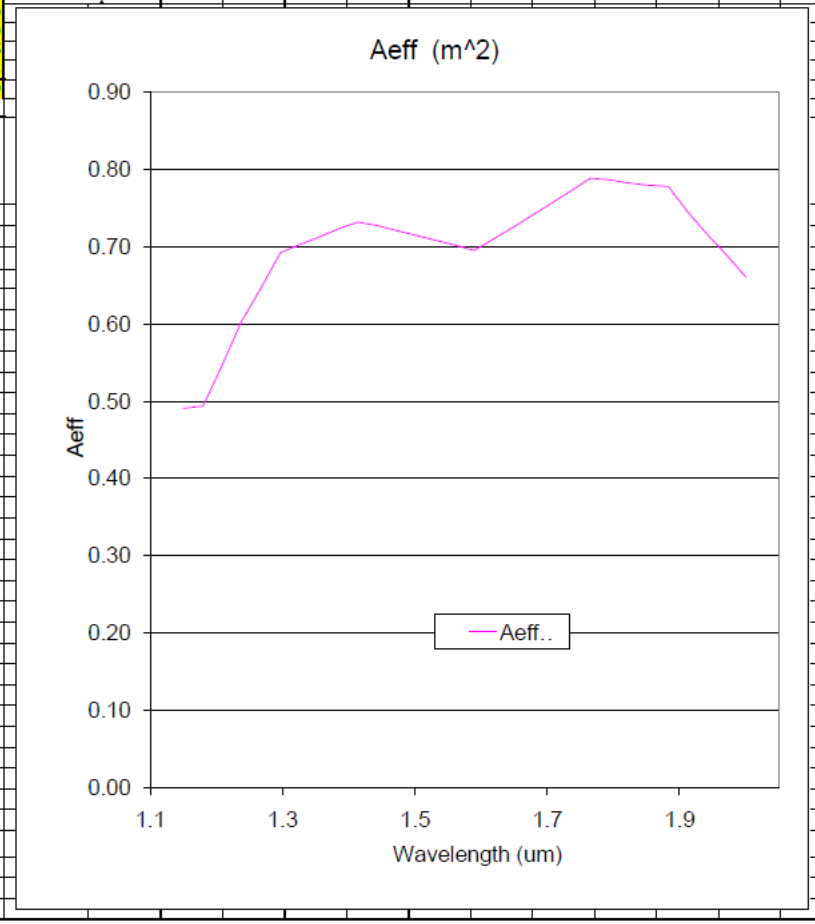
4c3 ImC w/ SNe prism

Effective Area Analysis					configuration title:		WFIRST 4c3 Sn prism in ImC filter whee			
D. Content										
Min wavelength		um	0.4				Mirror diameter	m	1.3	mirror geometric area
Max wavelength		um	2				# mirrors		7	Area (m^2) 1.3273
Mirror coating		pAg or pAu	pAg				# refractive elements (lens/prism)		4	illuminatated aperture 1.2596
	filter name						linear obscuration ratio (HST=0.33)		0	
bandpass filter center, w0		um	n/a				area fraction lost to SM vanes		0	
fraction width of bandpass, R			n/a				area fraction lost to pupil mask		0.051	
wavelength spacing		um	0.055172				Contamination loss at EOL		0.02	
Rel. bandpass			1.3333				Dichroic T/R, #	R	0	
assumed max bandpass efficiency			0.9500						m^2	

wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	Aeff (m^2)
0.4	0.9446	0.9340	1	1.0000	0.3885	0.6709	0.5791	0.98	0.6956	0.334
0.4552	0.9766	0.9340	1	1.0000	0.4906	0.8472	0.5791	0.98	0.7024	0.425
0.5103	0.9819	0.9481	1	1.0000	0.5747	0.8799	0.6531	0.98	0.7091	0.503
0.5655	0.9831	0.9623	1	1.0000	0.6525	0.8875	0.7352	0.98	0.7159	0.577
0.6207	0.9828	0.9717	1	1.0000	0.7042	0.8859	0.7949	0.98	0.7226	0.628
0.6759	0.9819	0.9811	1	1.0000	0.7559	0.8802	0.8587	0.98	0.7294	0.681
0.7310	0.9809	0.9823	1	1.0000	0.7573	0.8735	0.8670	0.98	0.7362	0.688
0.7862	0.9797	0.9835	1	1.0000	0.7581	0.8660	0.8754	0.98	0.7429	0.695
0.8414	0.9780	0.9847	1	1.0000	0.7561	0.8555	0.8838	0.98	0.7497	0.700
0.8966	0.9766	0.9859	1	1.0000	0.7558	0.8470	0.8923	0.98	0.7564	0.706
0.9517	0.9754	0.9835	1	1.0000	0.7353	0.8400	0.8754	0.98	0.7632	0.693
1.0069	0.9748	0.9811	1	1.0000	0.7182	0.8364	0.8587	0.98	0.7699	0.683
1.0621	0.9747	0.9788	1	1.0000	0.7039	0.8357	0.8424	0.98	0.7767	0.675
1.1172	0.9749	0.9764	1	1.0000	0.6916	0.8371	0.8263	0.98	0.7835	0.669
1.1724	0.9755	0.9741	1	1.0000	0.6811	0.8404	0.8105	0.98	0.7902	0.664
1.2276	0.9761	0.9717	1	1.0000	0.6712	0.8443	0.7949	0.98	0.797	0.660
1.2828	0.9769	0.9741	1	1.0000	0.6881	0.8490	0.8105	0.98	0.8037	0.683
1.3379	0.9776	0.9764	1	1.0000	0.7051	0.8533	0.8263	0.98	0.8105	0.705
1.3931	0.9783	0.9788	1	1.0000	0.7227	0.8579	0.8424	0.98	0.8173	0.729
1.4483	0.9791	0.9811	1	1.0000	0.7406	0.8624	0.8587	0.98	0.824	0.753
1.5034	0.9797	0.9835	1	1.0000	0.7584	0.8664	0.8754	0.98	0.8308	0.778
1.5586	0.9804	0.9859	1	1.0000	0.7768	0.8706	0.8923	0.98	0.8375	0.803
1.6138	0.9809	0.9847	1	1.0000	0.7722	0.8738	0.8838	0.98	0.8443	0.805
1.6690	0.9813	0.9835	1	1.0000	0.7672	0.8764	0.8754	0.98	0.851	0.806
1.7241	0.9818	0.9823	1	1.0000	0.7623	0.8792	0.8670	0.98	0.8578	0.807
1.7793	0.9821	0.9811	1	1.0000	0.7568	0.8813	0.8587	0.98	0.8646	0.808
1.8345	0.9819	0.9741	1	1.0000	0.7132	0.8800	0.8105	0.98	0.8713	0.767
1.8897	0.9821	0.9670	1	1.0000	0.6736	0.8810	0.7646	0.98	0.8781	0.730
1.9448	0.9826	0.9599	1	1.0000	0.6375	0.8843	0.7210	0.98	0.8848	0.696
2.0000	0.9832	0.9529	1	1.0000	0.6034	0.8879	0.6796	0.98	0.8916	0.664
average	0.9782	0.9733	1.0000		0.6958	0.8577	0.8098	0.9800	0.7936	0.6838
RMS	0.0069	0.0143	0.0000		0.0871	0.0394	0.0880	0.0000	0.0595	0.1081
min	0.9446	0.9340	1.0000		0.3885	0.6709	0.5791	0.9800	0.6956	0.3336
max	0.9832	0.9859	1.0000		0.7768	0.8879	0.8923	0.9800	0.8916	0.8077



4c3 throughput: SpC

Effective Area Analysis					configuration title:		WFIRST 4c3 SpC			
D. Content										
Min wavelength		um	1.15				Mirror diameter	m	1.3	mirror geometric area
Max wavelength		um	2				# mirrors		6	Area (m^2) 1.327
Mirror coating		pAg or pAu	pAg				# refractive elements (lens/prism/dichroic))		8	illuminatated aperture 1.200
	filter name						linear obscuration ratio (HST=0.33)		0	
bandpass filter center, w0		um	1.575				area fraction lost to SM vanes		0	
fraction width of bandpass, R			0.5397				area fraction lost to pupil mask		0.096	
wavelength spacing		um	0.0293				Contamination loss at EOL		0.02	
Rel. bandpass			0.5397				Dichroic T/R, #	T	0	
assumed max bandpass efficiency			0.9500						m^2	

wavelength (um)	Mirror reflectivity (Protected Ag)	Lens Antireflection coating transmission, per surface	Bandpass filter trans-mission	Dichroic	Optical Through-put	combined reflectivity of mirrors	combined transmission of lenses & prisms	Contami-nation loss	detector QE	Aeff (m^2)
1.15	0.9753	0.9733	0.95	1.0000	0.5300	0.8604	0.6160	0.98	0.7875	0.491
1.1793	0.9755	0.9733	0.95	1.0000	0.5309	0.8619	0.6160	0.98	0.791	0.494
1.2086	0.9759	0.9790	0.95	1.0000	0.5843	0.8636	0.6766	0.98	0.795	0.546
1.2379	0.9763	0.9847	0.95	1.0000	0.6430	0.8657	0.7427	0.98	0.798	0.604
1.2672	0.9767	0.9886	0.95	1.0000	0.6858	0.8679	0.7901	0.98	0.802	0.647
1.2966	0.9771	0.9924	0.95	1.0000	0.7311	0.8700	0.8404	0.98	0.805	0.692
1.3259	0.9774	0.9928	0.95	1.0000	0.7384	0.8719	0.8469	0.98	0.809	0.702
1.3552	0.9778	0.9933	0.95	1.0000	0.7459	0.8740	0.8534	0.98	0.813	0.713
1.3845	0.9782	0.9938	0.95	1.0000	0.7536	0.8763	0.8600	0.98	0.816	0.723
1.4138	0.9782	0.9943	0.95	1.0000	0.7592	0.8760	0.8666	0.98	0.820	0.732
1.4431	0.9790	0.9933	0.95	1.0000	0.7512	0.8803	0.8534	0.98	0.823	0.727
1.4724	0.9794	0.9924	0.95	1.0000	0.7418	0.8827	0.8404	0.98	0.827	0.721
1.5017	0.9797	0.9914	0.95	1.0000	0.7318	0.8843	0.8276	0.98	0.831	0.715
1.5310	0.9800	0.9905	0.95	1.0000	0.7221	0.8861	0.8149	0.98	0.834	0.708
1.5603	0.9804	0.9895	0.95	1.0000	0.7126	0.8881	0.8024	0.98	0.838	0.702
1.5897	0.9806	0.9886	0.95	1.0000	0.7025	0.8891	0.7901	0.98	0.841	0.695
1.6190	0.9809	0.9895	0.95	1.0000	0.7149	0.8909	0.8024	0.98	0.845	0.710
1.6483	0.9811	0.9905	0.95	1.0000	0.7268	0.8919	0.8149	0.98	0.849	0.725
1.6776	0.9814	0.9914	0.95	1.0000	0.7395	0.8936	0.8276	0.98	0.852	0.741
1.7069	0.9817	0.9924	0.95	1.0000	0.7520	0.8948	0.8404	0.98	0.856	0.757
1.7362	0.9819	0.9933	0.95	1.0000	0.7646	0.8959	0.8534	0.98	0.859	0.773
1.7655	0.9821	0.9943	0.95	1.0000	0.7775	0.8972	0.8666	0.98	0.863	0.789
1.7948	0.9822	0.9938	0.95	1.0000	0.7723	0.8980	0.8600	0.98	0.866	0.787
1.8241	0.9819	0.9933	0.95	1.0000	0.7648	0.8961	0.8534	0.98	0.870	0.782
1.8534	0.9819	0.9928	0.95	1.0000	0.7589	0.8961	0.8469	0.98	0.874	0.780
1.8828	0.9821	0.9924	0.95	1.0000	0.7540	0.8972	0.8404	0.98	0.877	0.778
1.9121	0.9821	0.9895	0.95	1.0000	0.7198	0.8971	0.8024	0.98	0.881	0.746
1.9414	0.9824	0.9866	0.95	1.0000	0.6889	0.8992	0.7661	0.98	0.884	0.716
1.9707	0.9831	0.9838	0.95	1.0000	0.6601	0.9027	0.7313	0.98	0.888	0.689
2	0.9832	0.9809	0.95	1.0000	0.6303	0.9031	0.6980	0.98	0.892	0.661
average	0.9798	0.9892	0.9500		0.7096	0.8851	0.8014	0.9800	0.8395	0.7015
RMS	0.0024	0.0058	0.0000		0.0661	0.0132	0.0702	0.0000	0.0316	0.0777
min	0.9753	0.9733	0.9500		0.5300	0.8604	0.6160	0.9800	0.7875	0.4908
max	0.9832	0.9943	0.9500		0.7775	0.9031	0.8666	0.9800	0.8916	0.7889