Wide Field Infrared Survey Telescope [WFIRST]: Telescope design and simulated performance

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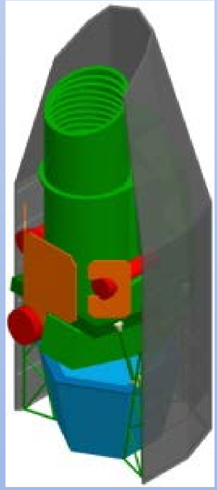

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Outline

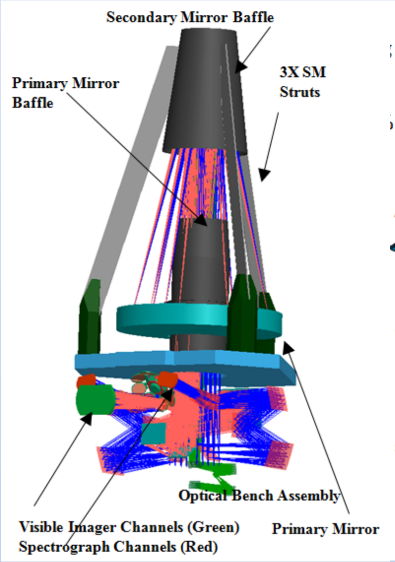
1. Introduction & Science Overview
2. IDRM design
   - Field Layout & Ray trace
   - Design Performance
3. IDRM Modeling and Analysis
   - Telescope Models
   - Mirror Surface Distortion Maps
   - Secondary Mirror Compensation
   - Thermal Stability
4. Conclusion

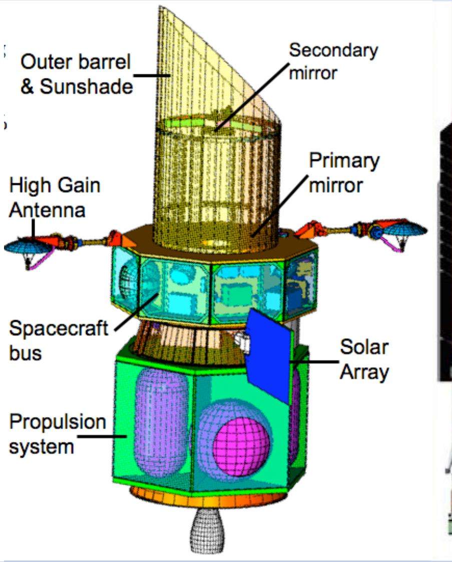
Note – not a science talk, very brief science section. More information in the following paper:

The Wide Field Infrared Survey Telescope: WFIRST, James C. Green, Univ. of Colorado at Boulder (USA) and The Wide Field Infrared Camera Science Definition Team (USA) . . . . [8442-27]

1. Introduction – Astro2010 Decadal Survey

- <u>Multiple</u> missions with NIR focal planes and 3 mirror wide field telescopes in the 1.5m aperture range.
  - <u>None</u> of them would have won as standalone missions
- WFIRST is a combination of these missions, created by Astro 2010 committee.
  - WFIRST Science Definition Team (SDT) tasked to examine the design.
  - Project team is a GSFC-JPL-Caltech collaboration.
  - This interim mission design is a result of combined work by the project team with the SDT.

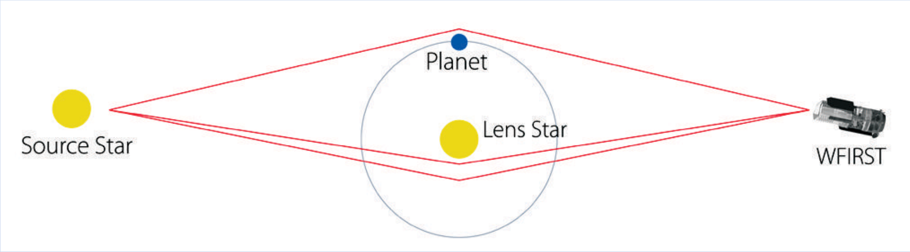




	units	JDEM/ Omega	MPF	NIRSS
Aperture diameter	m	1.5	1.2	1.5
aperture type		oTMA	oTMA	oTMA
# channels		3	1	1
# science H2RG		36	35	36
imager pixel scale	arcsec/ pixel	0.18	0.24	0.25
spectral bandpass	µm	0.4-2.0	0.6-1.7	1.0-4.2
spectroscopy channels		2	0	0

WFIRST – IDRM Summary

Schematic of exoplanet microlensing



❖ WFIRST top level science:

- Complete the statistical census of Galactic planetary systems using micro-lensing.
- Determine the nature of the dark energy that is driving the current accelerating expansion of the universe.
- Survey the NIR sky for the science community.

❖ Earth-Sun L2 orbit, 5 year lifetime.

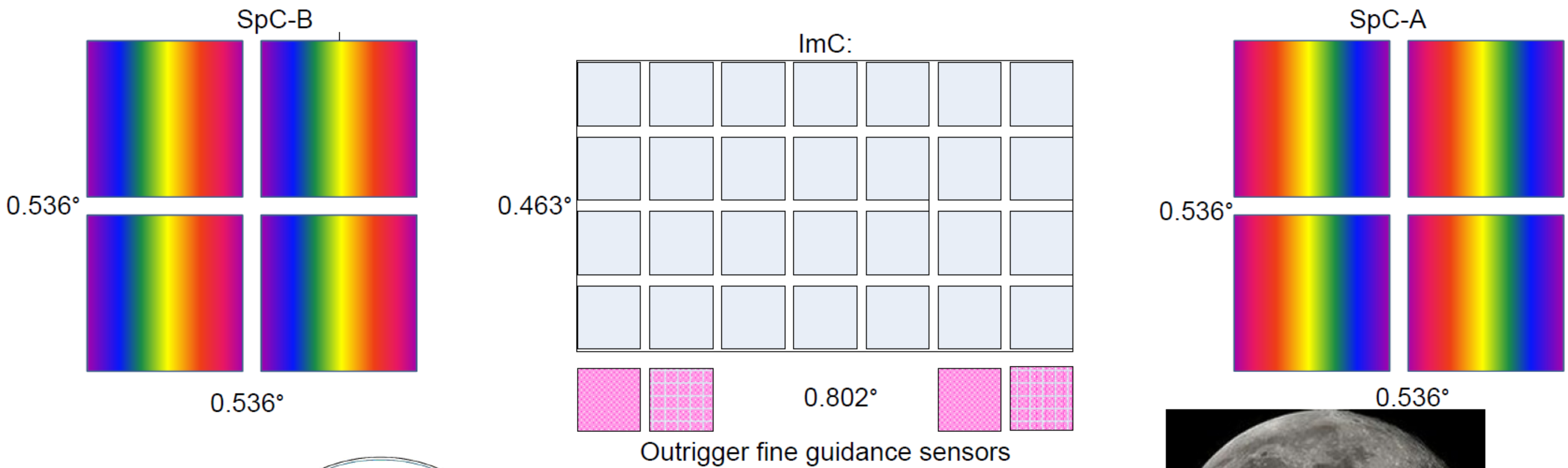
❖ Interim Design Reference Mission:

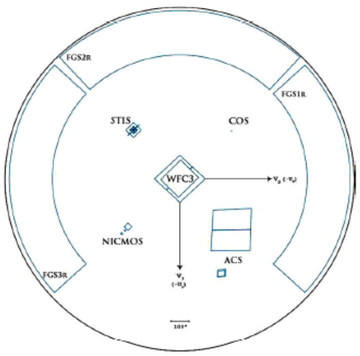
- 1.3 m unobstructed Three Mirror Anastigmatic telescope
- Imager Instrument: 7x4 HgCdTe 4-Mpix NIR detector arrays
- 2 Slit-less Spectrometer instruments: 2x2 HgCdTe 4-Mpix NIR detector arrays

❖ Current status is pre-phase A, waiting funding to move into phase A

2. IDRM design – Field Layout

- FOV layout with HST, JWST, Moon to scale
- Much wider field area, but with coarse pixels (0.18”/pixel imager)
- Appropriate for wide surveys



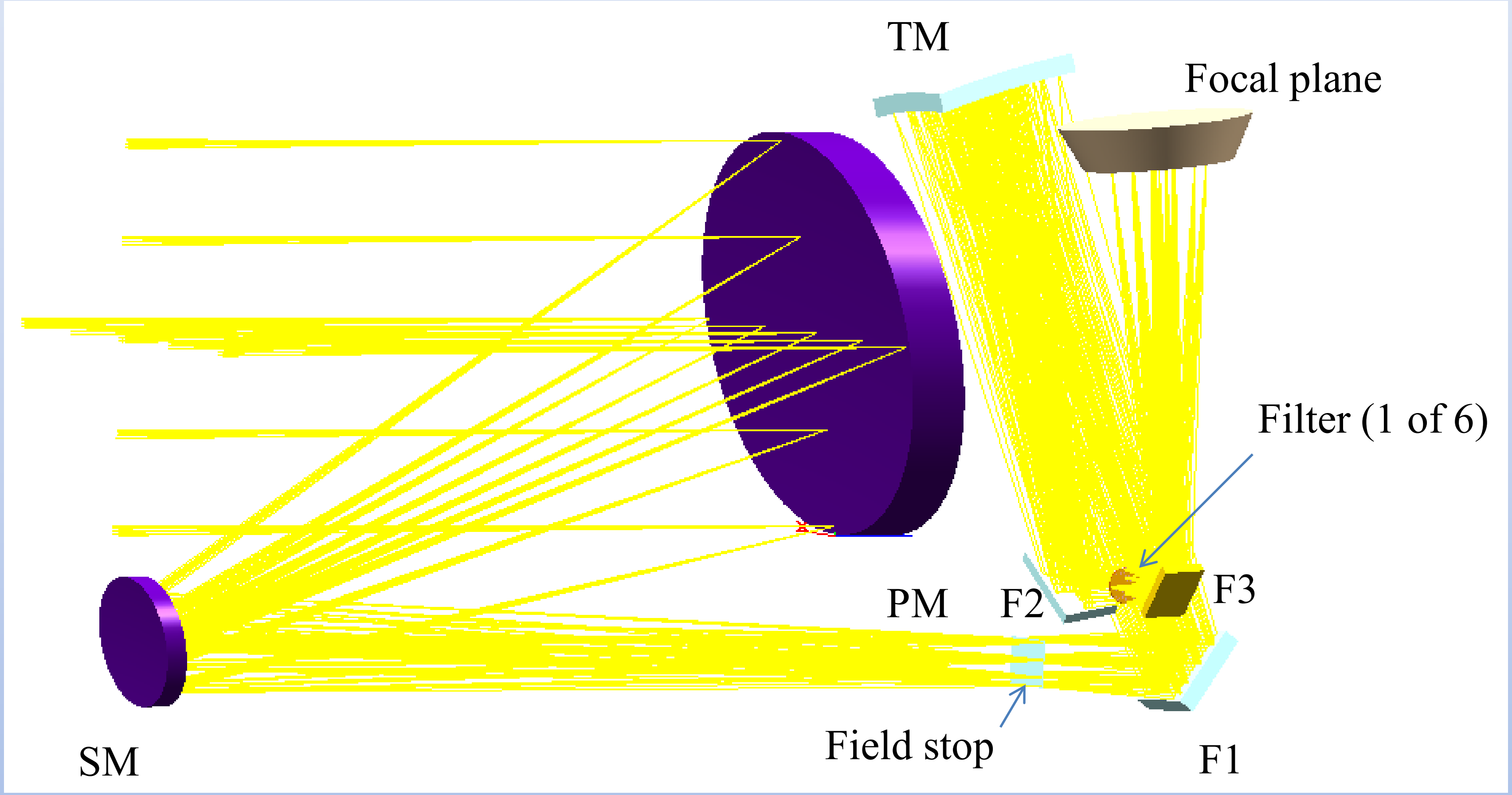


HST [all instruments]

JWST [all instruments]

Moon (average size seen from Earth)

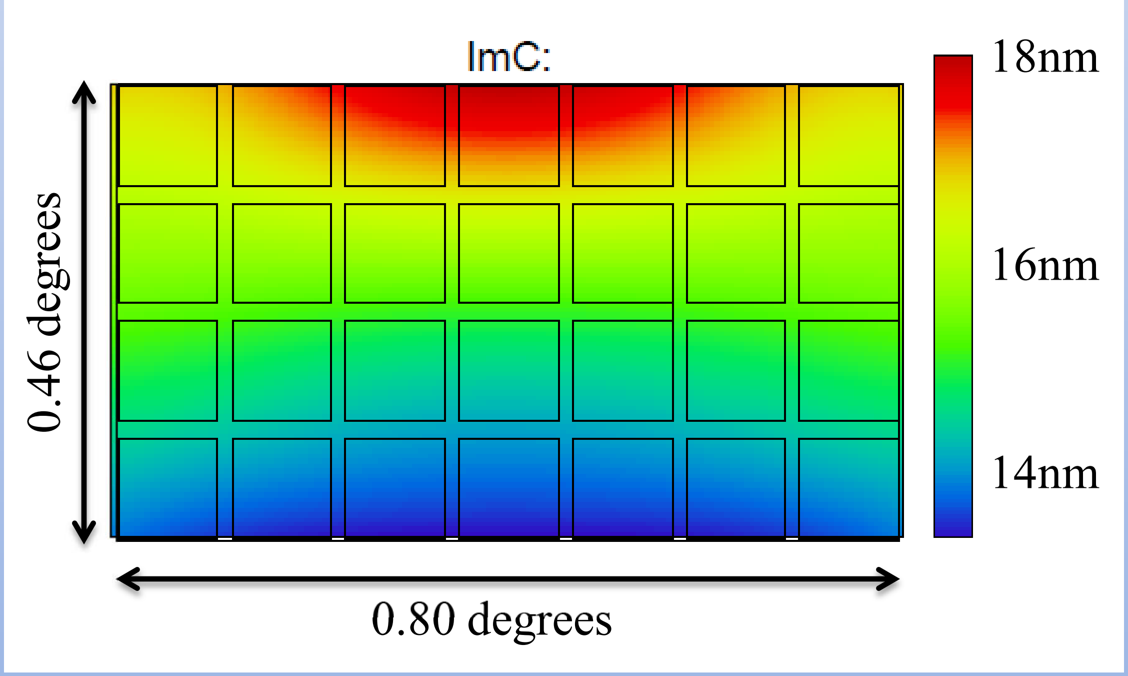
Imaging Channel Ray Trace



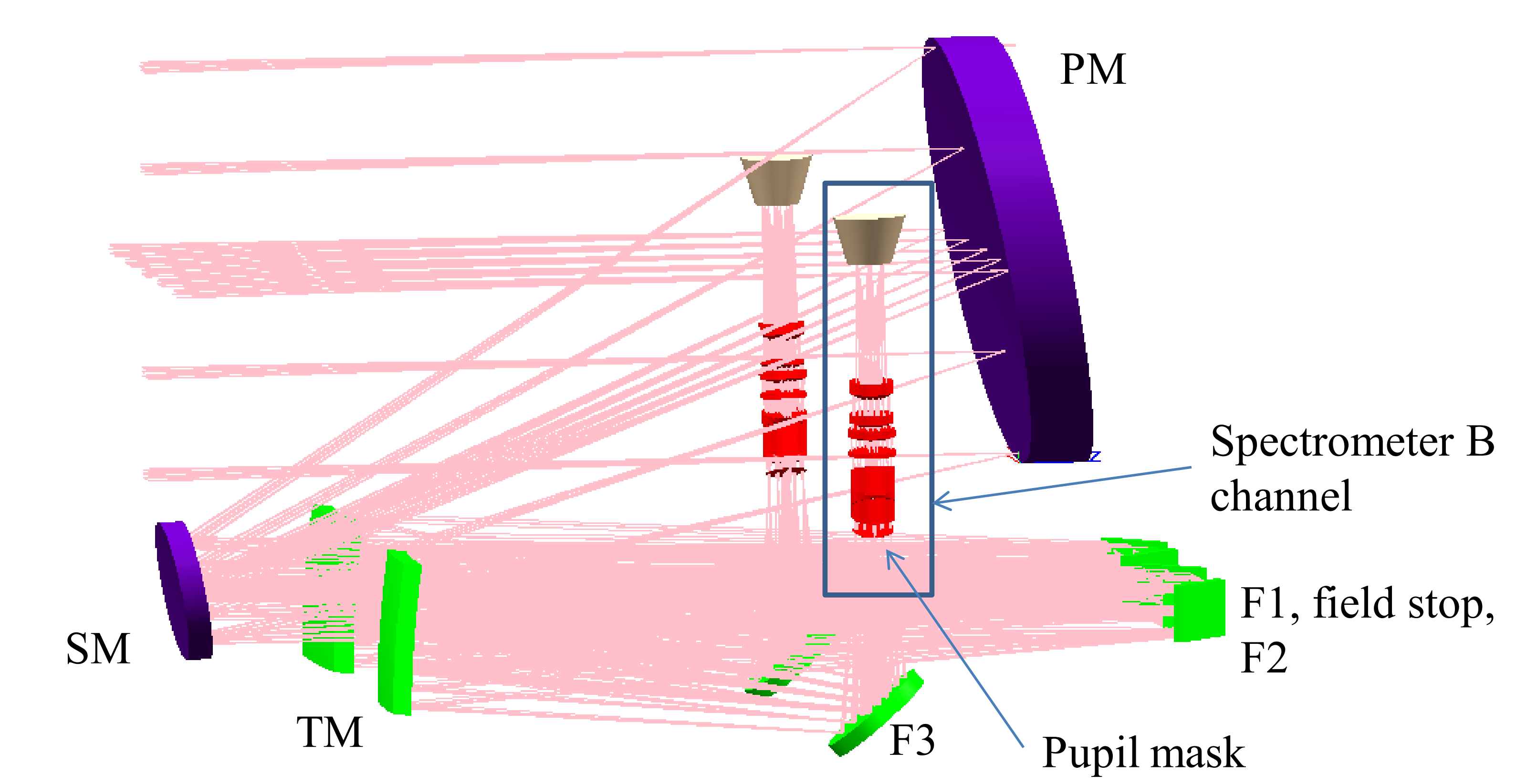
Ray trace of the Imaging Channel. ImC is an unobscured 1.3m three mirror anastigmat with a single fold between the intermediate focus and the tertiary, and two additional fold mirrors on either side of the exit pupil. The feed optics (non common telescope fold mirrors and tertiary mirror) and instrument (pupil mask, filter, and fold mirror) are packaged behind the primary mirror for stability.

Imager Optical Design performance

- Imaging Channel: Error map at R;
  - Dominant terms in residual error are coma and astigmatism.
  - Combined errors 13 to 18 nm rms vary slowly over field.
  - Error is achromatic.
  - Map of design residual wavefront error:

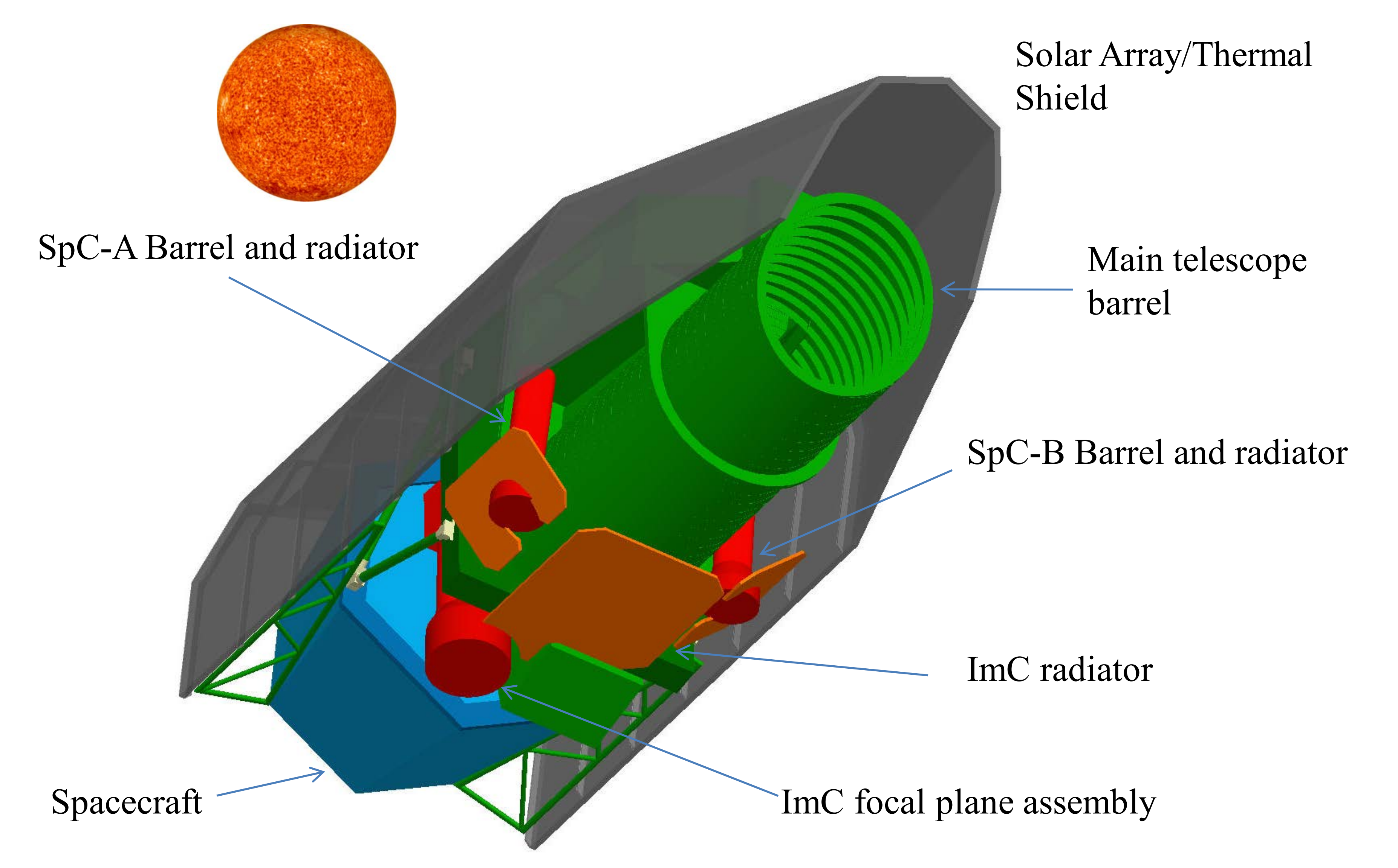


Spectrometer Channel Ray Trace



Ray trace of the spectroscopy channels. SpC use two folds on either side of the intermediate focus and a third fold before the exit pupil to allow the instrument barrel to be located outside the telescope main barrel with the focal plane on the cold side of the observatory. The two channels A (far side) and B (near side) are mirror images.

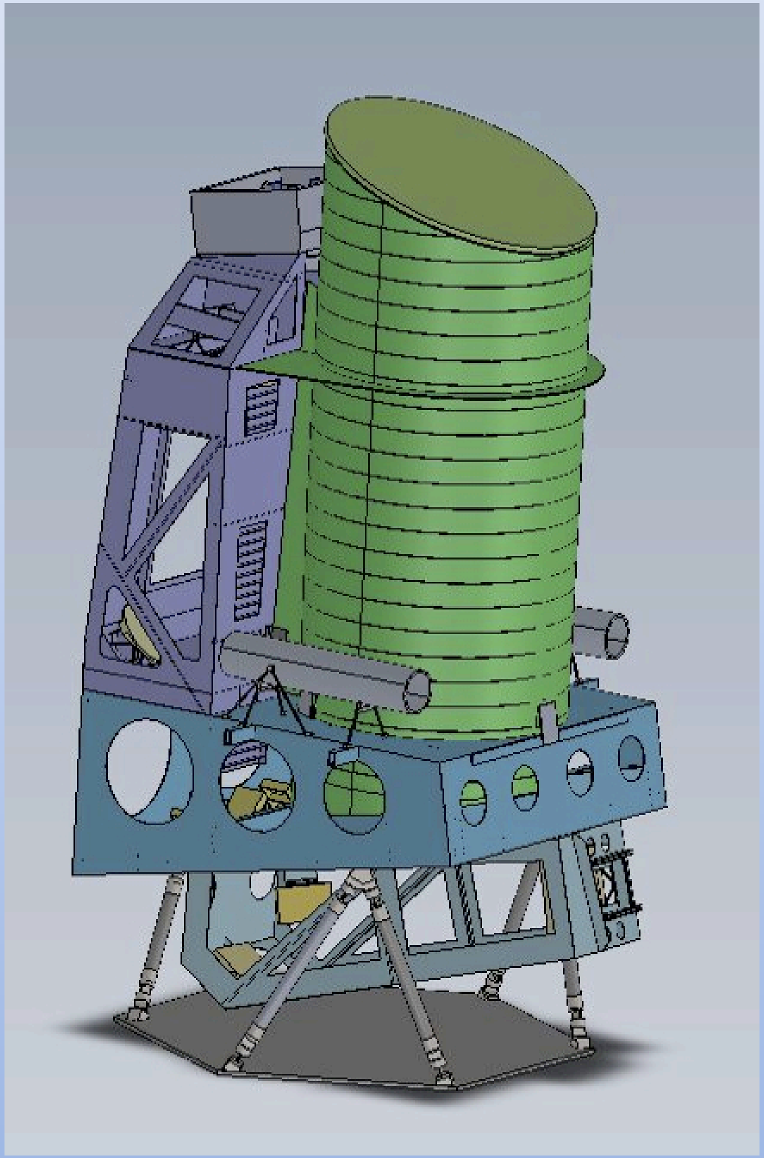
IDRM design – Observatory CAD view



3. IDRM Modeling and Analysis Telescope Modeling Status

- Completed detailed CAD model.
- Completed Thermal model.
- Completed Finite element model.
- Competed Optical Tolerancing model.
- Modeled Ground Alignment of Telescope:
  - Requires 5 DoF on Secondary Mirror (SM) and tip/tilt of ImC Fold mirror
  - Requires tip/tilt of SpC Fold F2 and tip/tilt/piston of SpC TM
- Modeled Ground to On-orbit Gravity shift:
  - Gravity shift can be taken out by the SM mechanism 5 DoF.
- Modeled Ground to On-orbit Thermal Distortion:
  - Alignment shift and mirror figure distortion can be taken out by the SM mechanism 5 DoF.
- Modeled On-orbit Thermal Distortion versus S/C attitude:
  - Wavefront Error change is below 1nm rms.

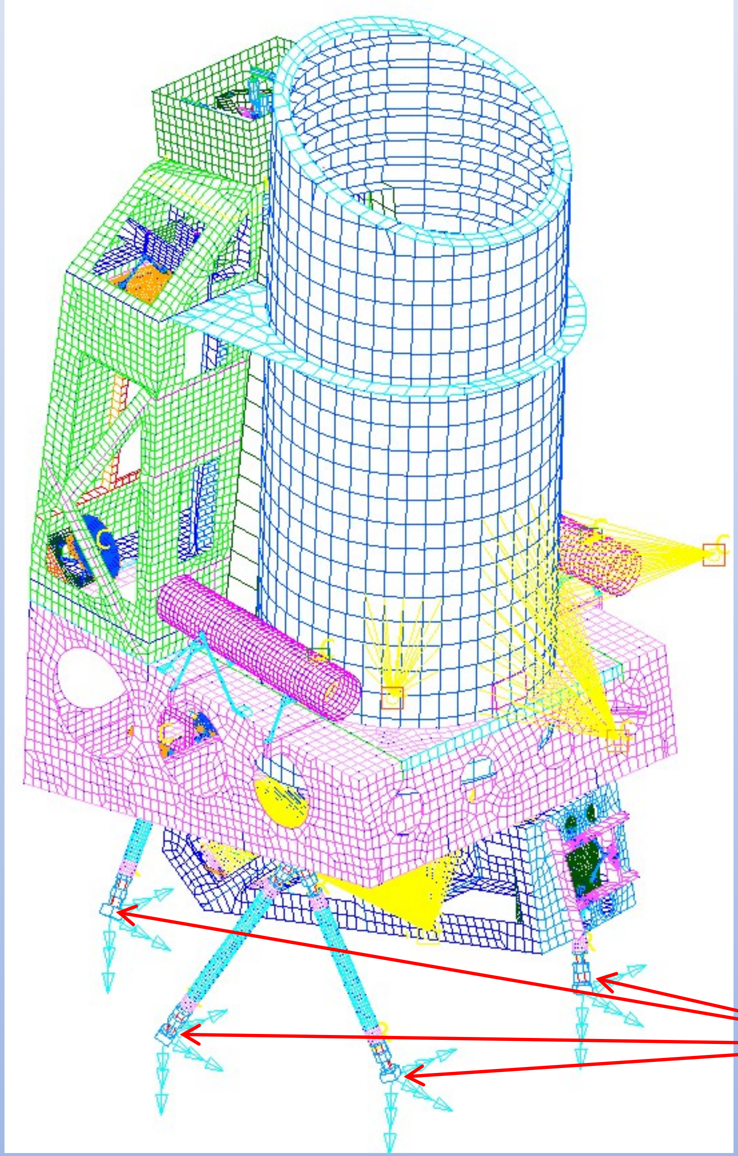
IDRM – Telescope CAD Model



Telescope Mass Breakdown

Mass Breakdown by material:	**kg**
M55J (composite structures, tubes)	375.3
Titanium (mirror mounts)	21.8
Stops and cans (Aluminum)	2.8
OTA mount	53.6
ULE (mirrors)	127.4
Mechanical (mechanisms)	18.8
MLI (thermal blankets)	19.8
Kapton (heaters)	13.9
PRTs (thermal sensors)	0.7
Telescope electronics (chassis+boards)	16.4
Cabling	39.0
Instruments (one Imager, two Spectrometers)	154.3
Radiators	34.3
Contingency	282.3
TOTAL	**1160.2**

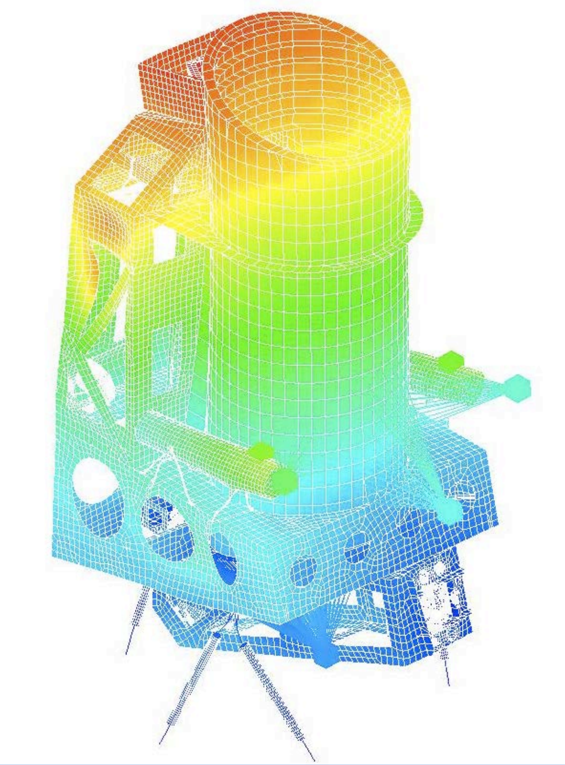
Telescope Finite Element Model



Node count: 103,219
Element count: 209,748
Mass: 1,139.0 kg

Element type:
- CBAR: 305
- CHEXA: 16,776
- CONM2: 14
- CPENTA: 6,798
- CQUAD4: 91,648
- CTETRA: 81,790
- CTRIA3: 12,115
- CTRIA6: 202
- RBAR: 8
- RBE2: 69
- RBE3: 23

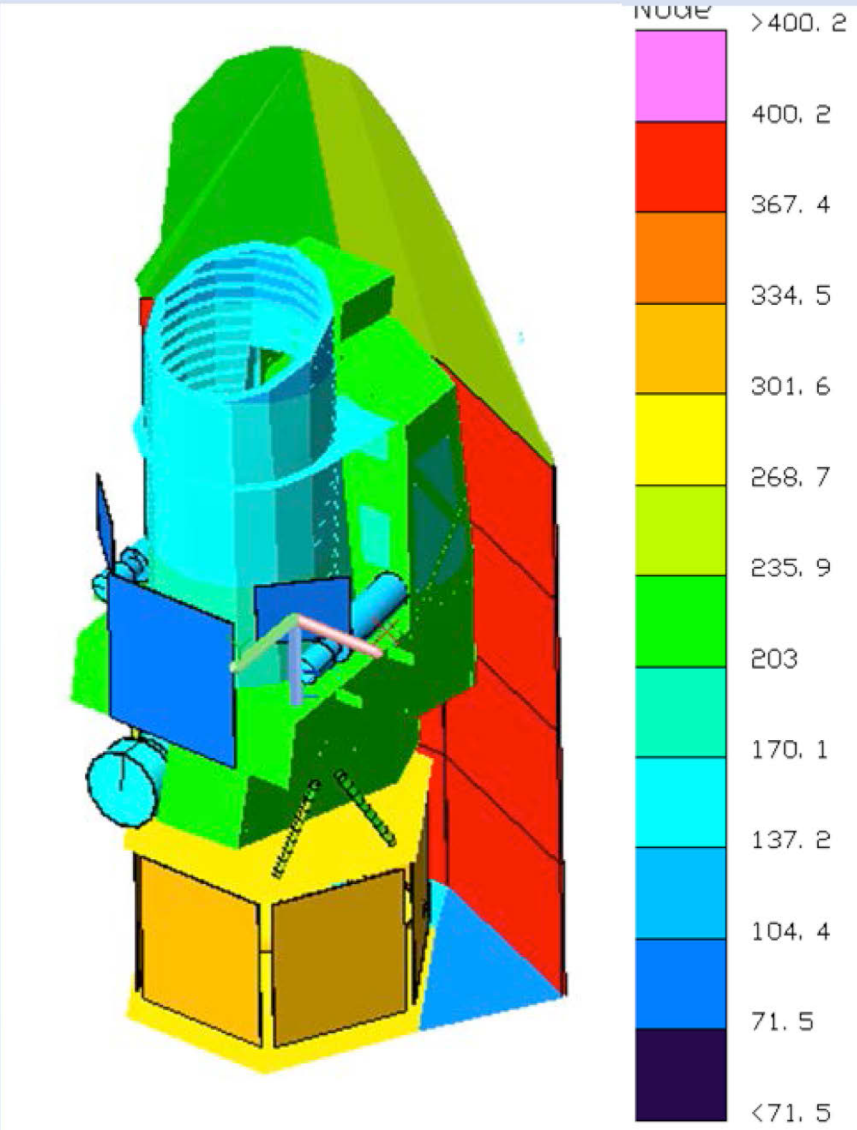
Mode 1



17.78 Hz, Telescope moves from side to side

Boundary conditions: ends of the 3 bipods fixed

Thermal Model

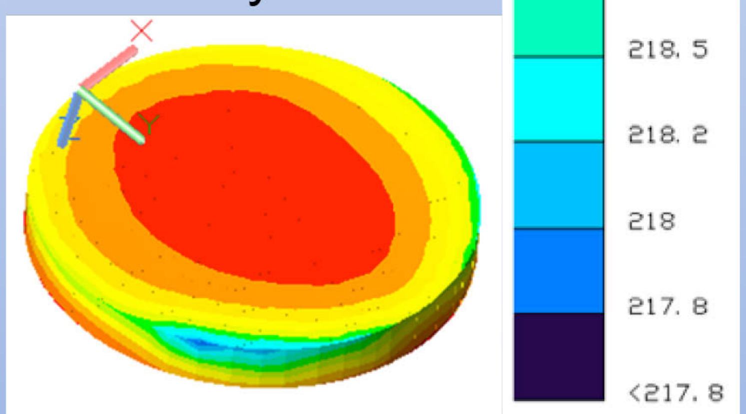


9006 TD/RC Nodes
23 User Nodes
8 boundary (SC at 313.2K)
3538 MLI (non graphical)

Surfaces
8675 planar elements
413 surfaces

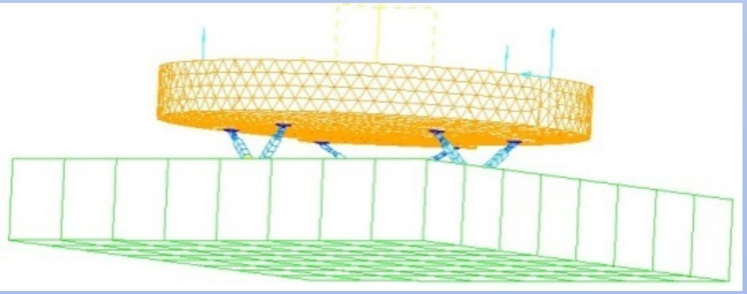
50 heaters

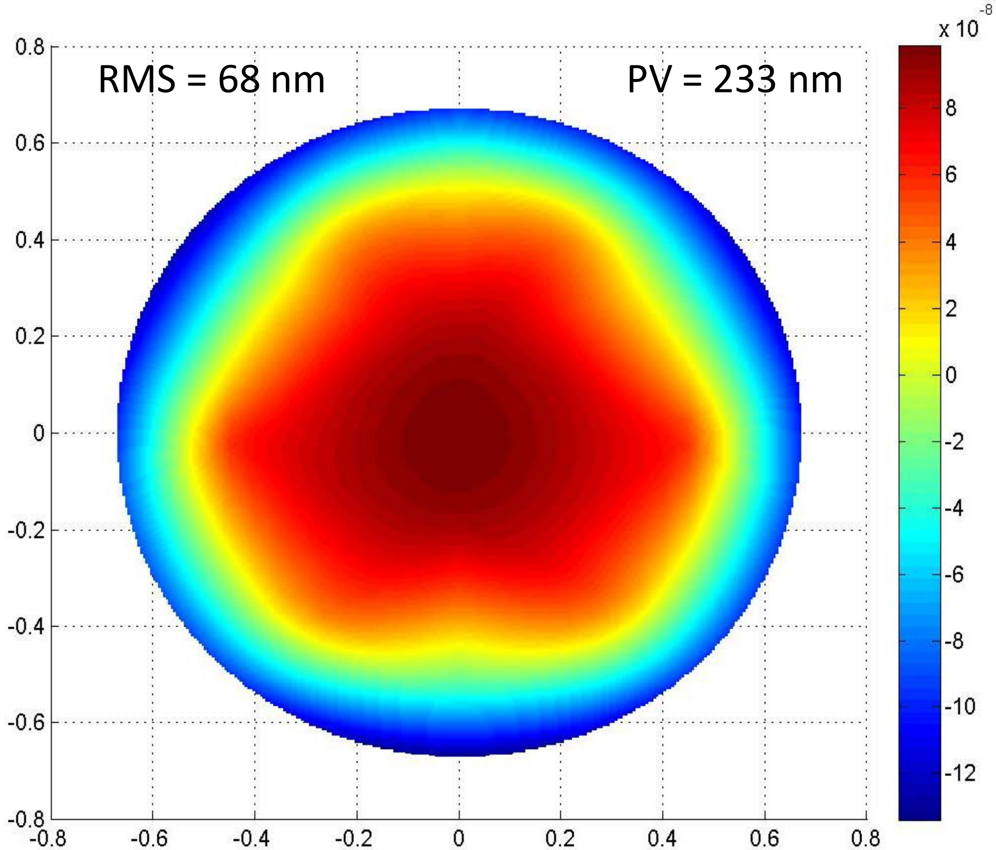
Primary mirror



Primary Mirror Surface error map

- ULE Honeycomb mirror, similar to Kepler primary mirror
- Assembled at room temperature
- Flight Temperature:~220K
- 6 Invar pads on mirrors
- 3 Titanium bipods
- M55J structure
- Adhesive CTE = 110 ppm/ ⁰K

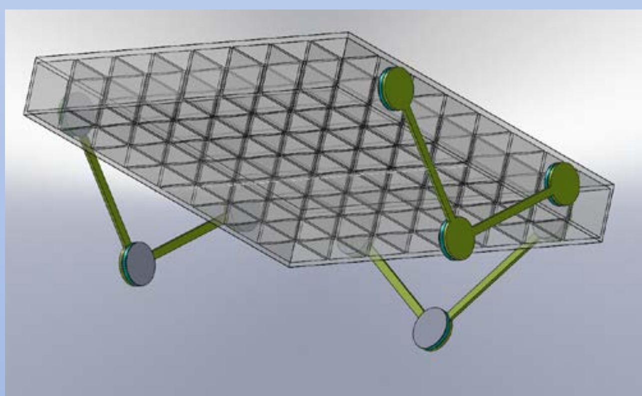




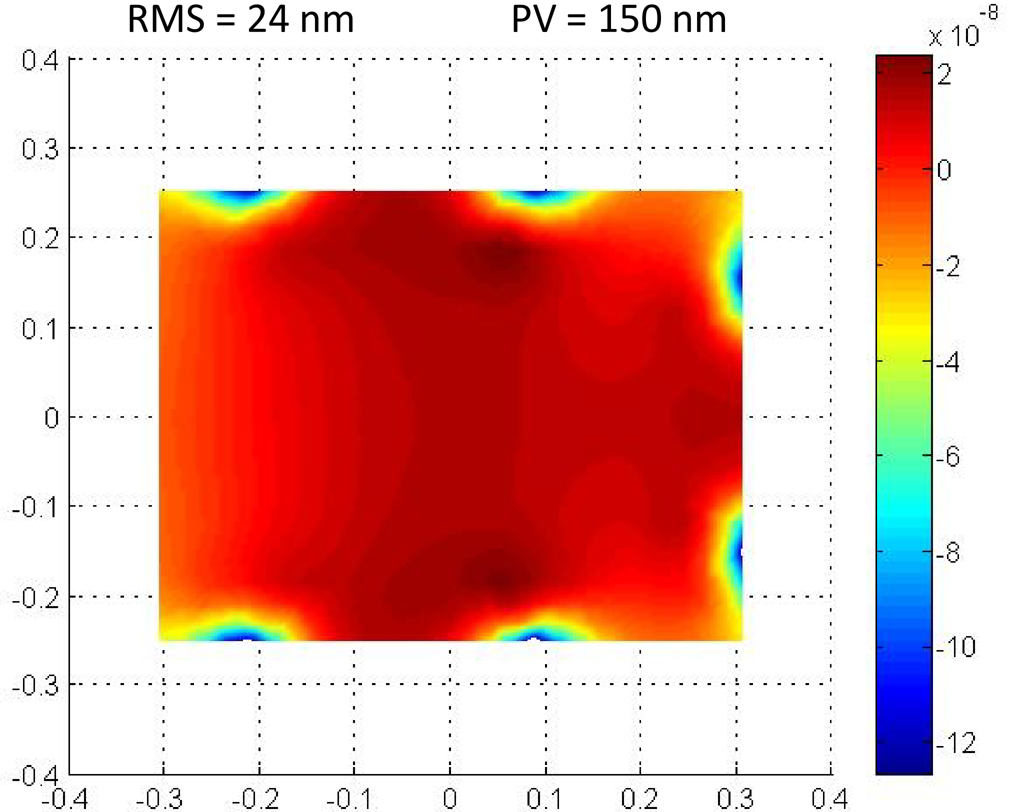
RMS with defocus removed = 13 nm

Imager Ch. Tertiary Mirror Surface error map

- ULE Honeycomb mirror
- 615mm X 505mm X 90mm
- Assembled at room temperature
- Flight Temperature:~220K
- 6 Invar pads
- 3 Titanium bipods
- M55J Structure
- Adhesive CTE = 110 ppm/^{o}K



Surface Error over the entire mirror
RMS = 24 nm PV = 150 nm

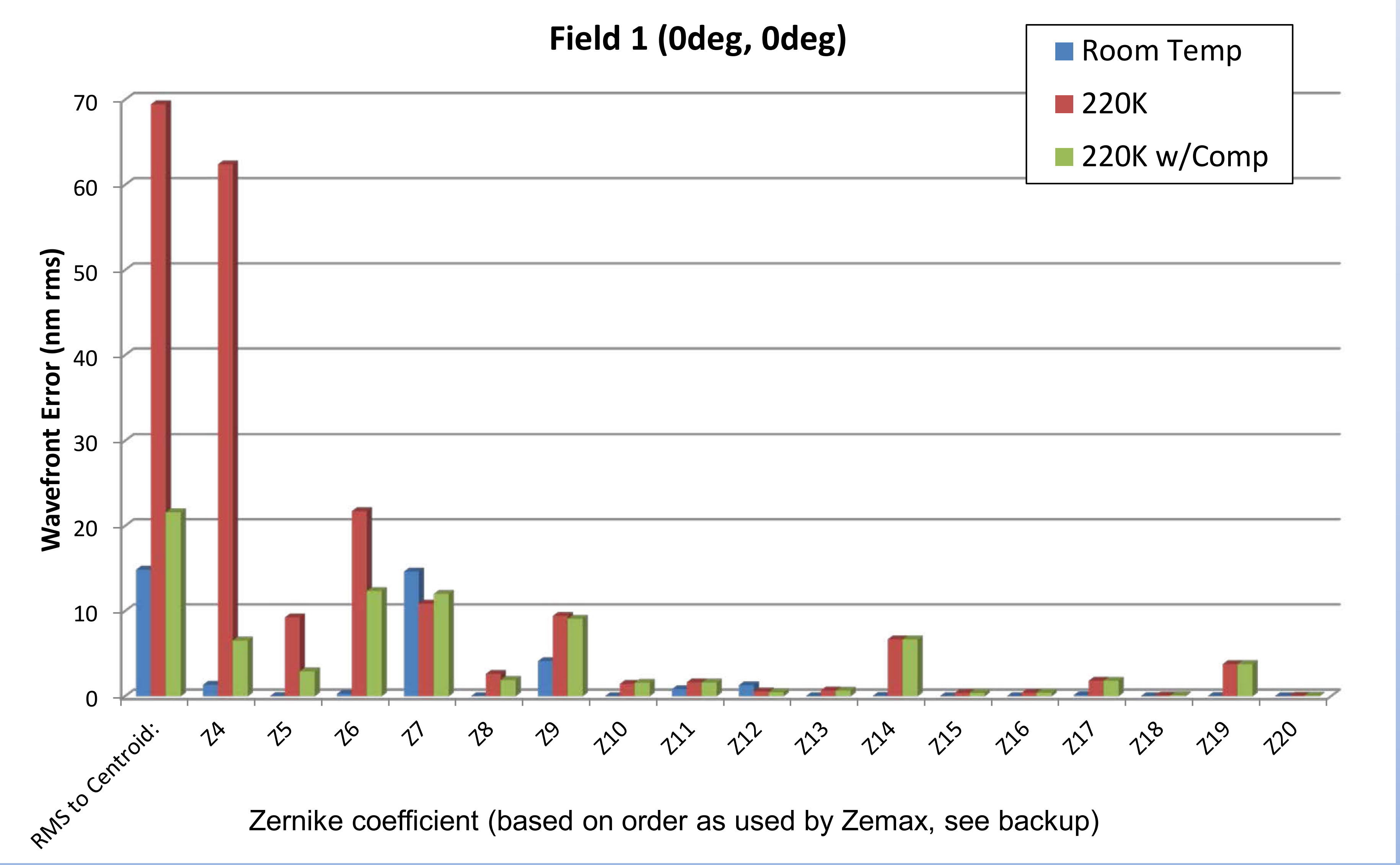


Surface Error over the Clear Aperture
RMS = 12 nm PV = 72 nm

Thermoelastic Surface Deformation Analysis Procedure

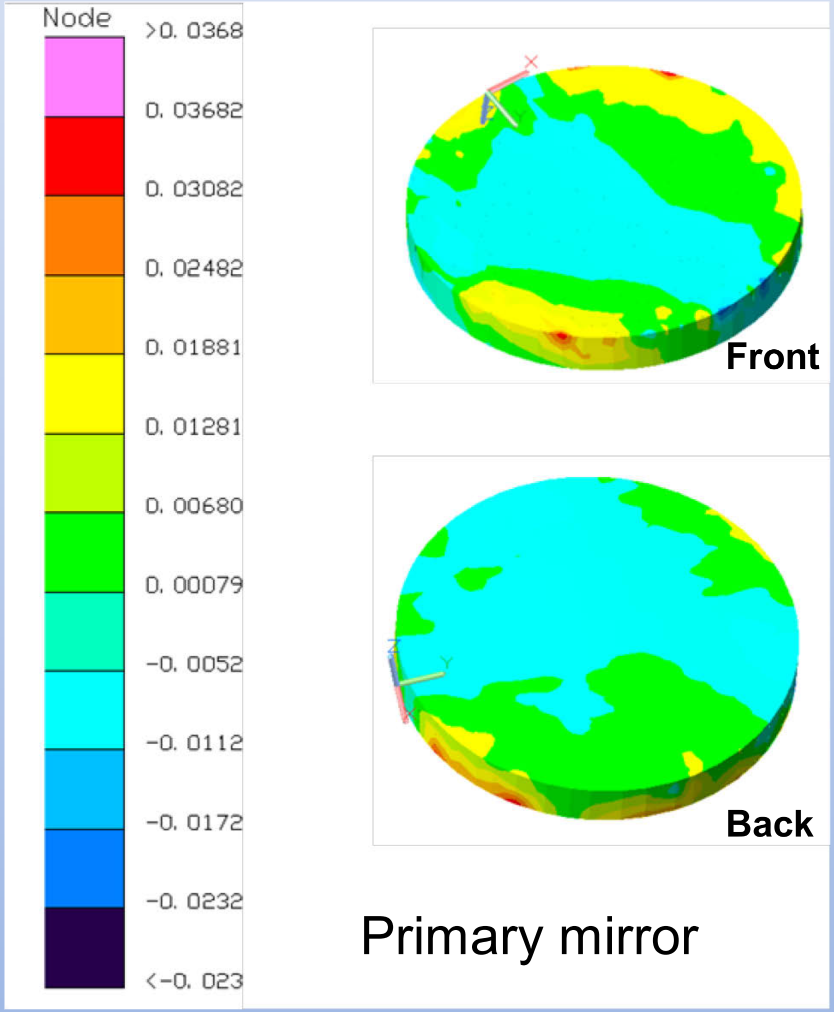
- Compute WFE at Room Temp:
  - No surface deformation, ideal alignment
  - WFE averaged over all fields
- Compute WFE at 220 deg K:
  - Apply surface deformation to each optic
  - Convert thermoelastic deformation data to Zernike decomposition
  - WFE averaged over all fields
- Compute WFE at 220 deg K with Secondary Mirror compensation:
  - Optimize Secondary Mirror motion (5 DOF) to minimize WFE
  - WFE averaged over all fields

Optical WFE with Zernike Decomposition



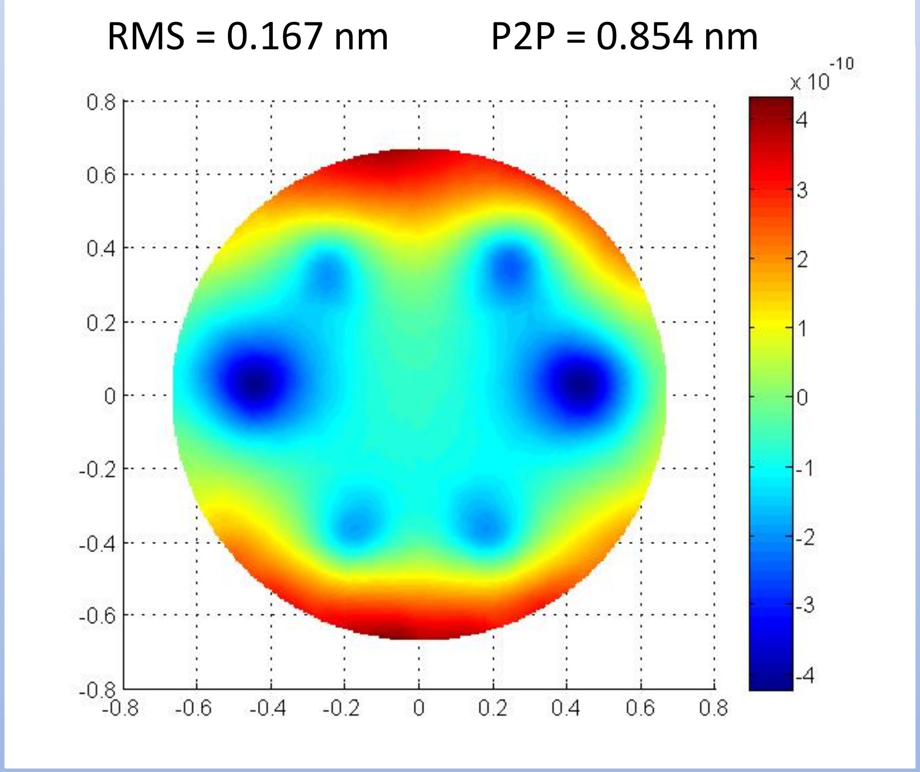
Temperature Change vs. Orientation
Delta_T (T_nominal – T_10deg_Roll_&_36deg_Pitch)

Temperature difference



Primary mirror

Contour map of mirror surface displacement



Conclusion

- WFIRST science is exciting and broad
- IDRM concept design and analysis well advanced
- IDRM performs well with “warm telescope design”
- NO new technology required
- We are ready to move into next phase towards building WFIRST

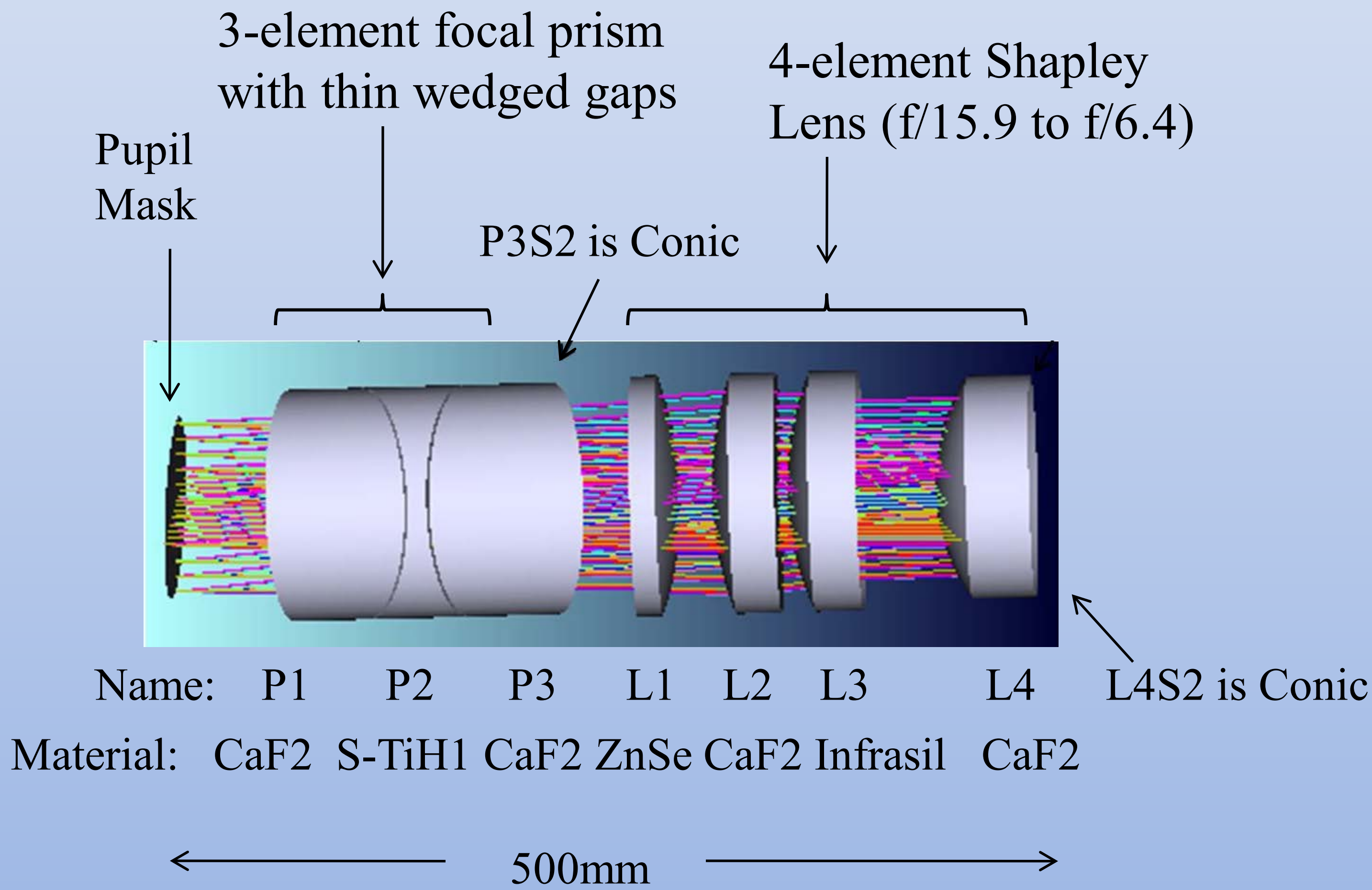
Acknowledgements

The research described in this presentation was performed at the Jet Propulsion Laboratory of the California Institute of Technology, under contract with the National Aeronautics and Space Administration, in close collaboration with the WFIRST project team at the NASA Goddard Space Flight Center.

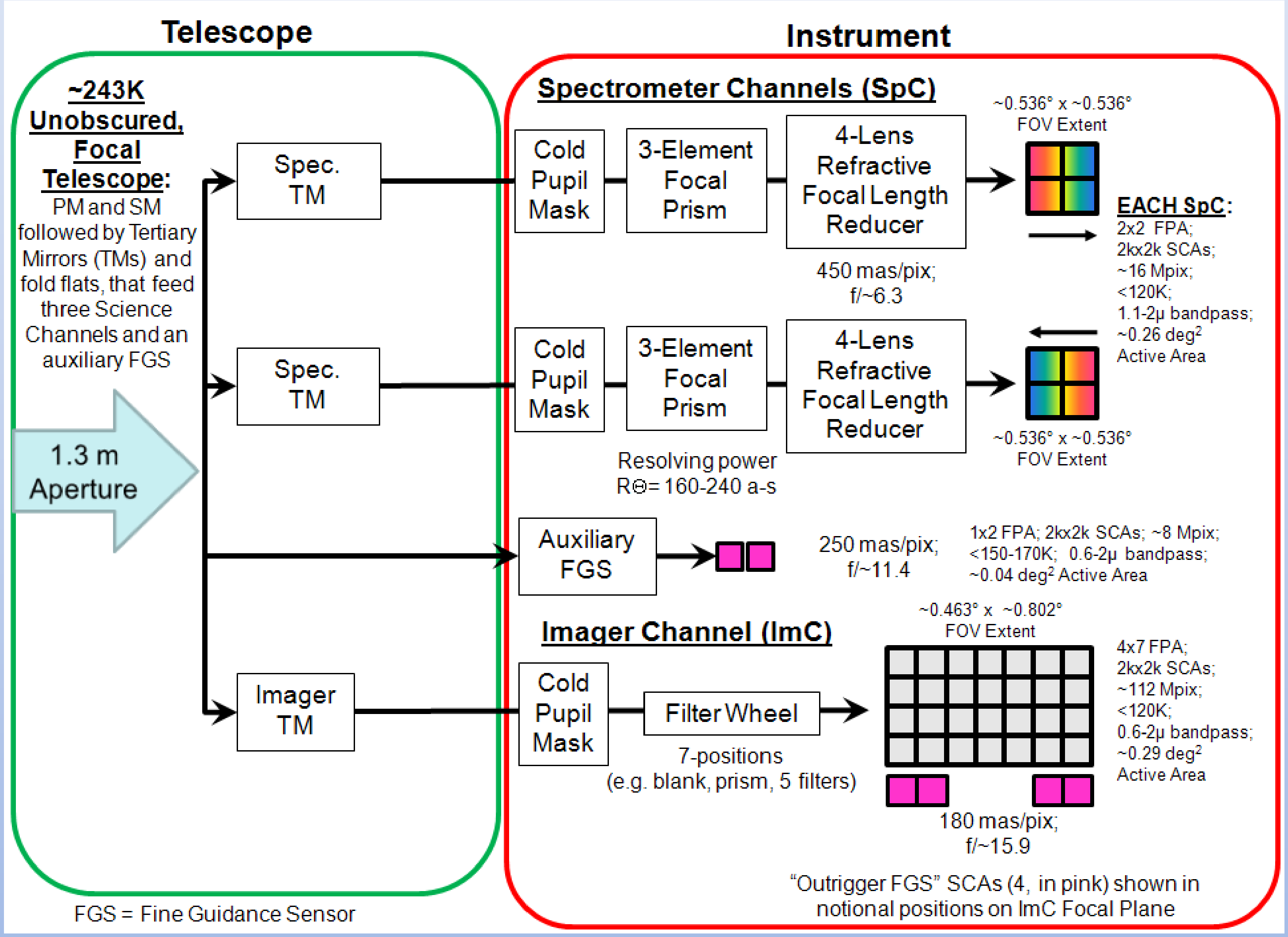
Backup charts

Spectrometer Detail

- Detail of spectroscopy channel, showing the prism and Shapley lens groups. 14 surfaces, 12 spheres, 2 conic



IDRM Block diagram



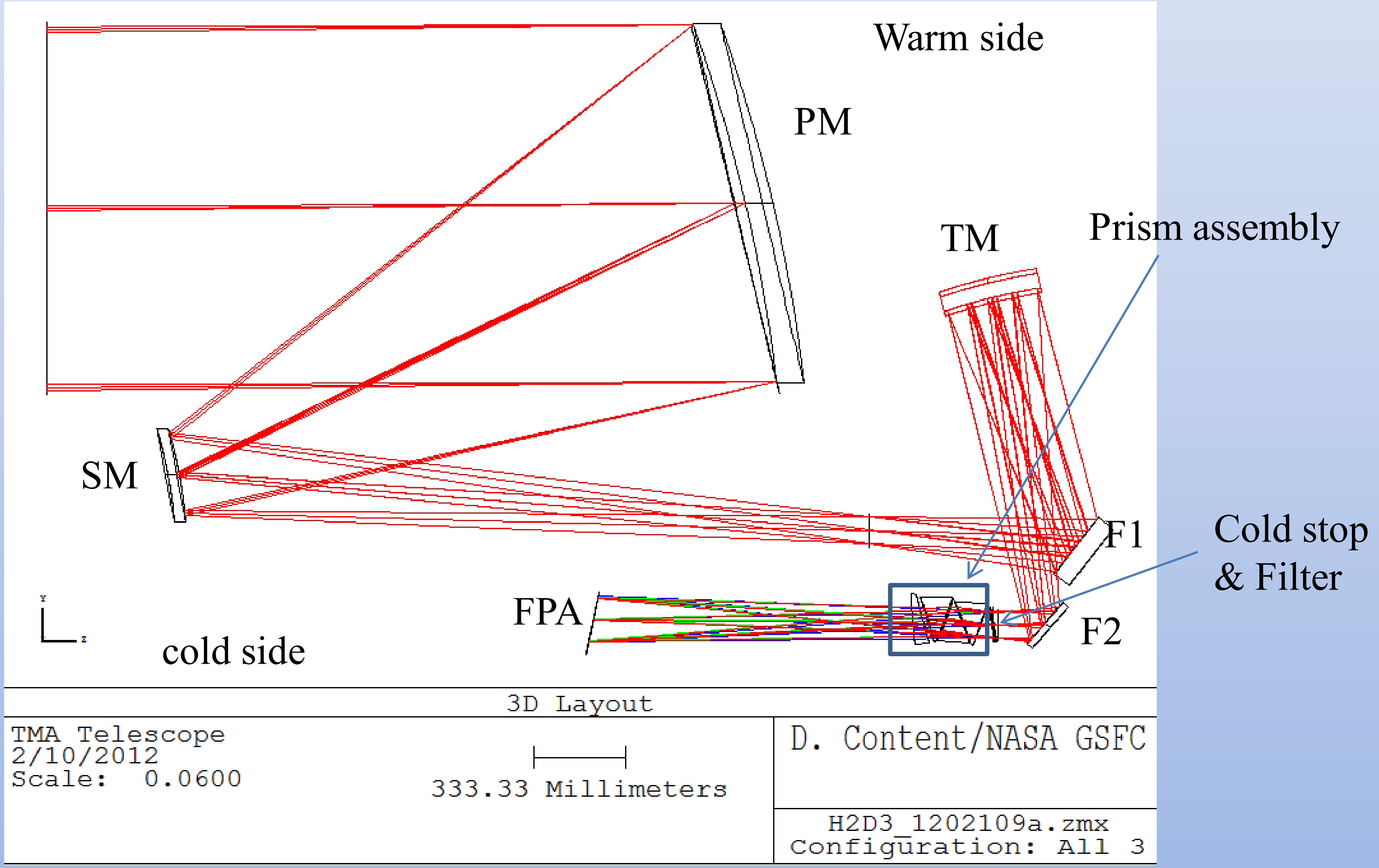
Block diagram of the IDRM. This shows the interfaces, optical elements, and temperature zones of the payload.

WFIRST DRM1 design summary

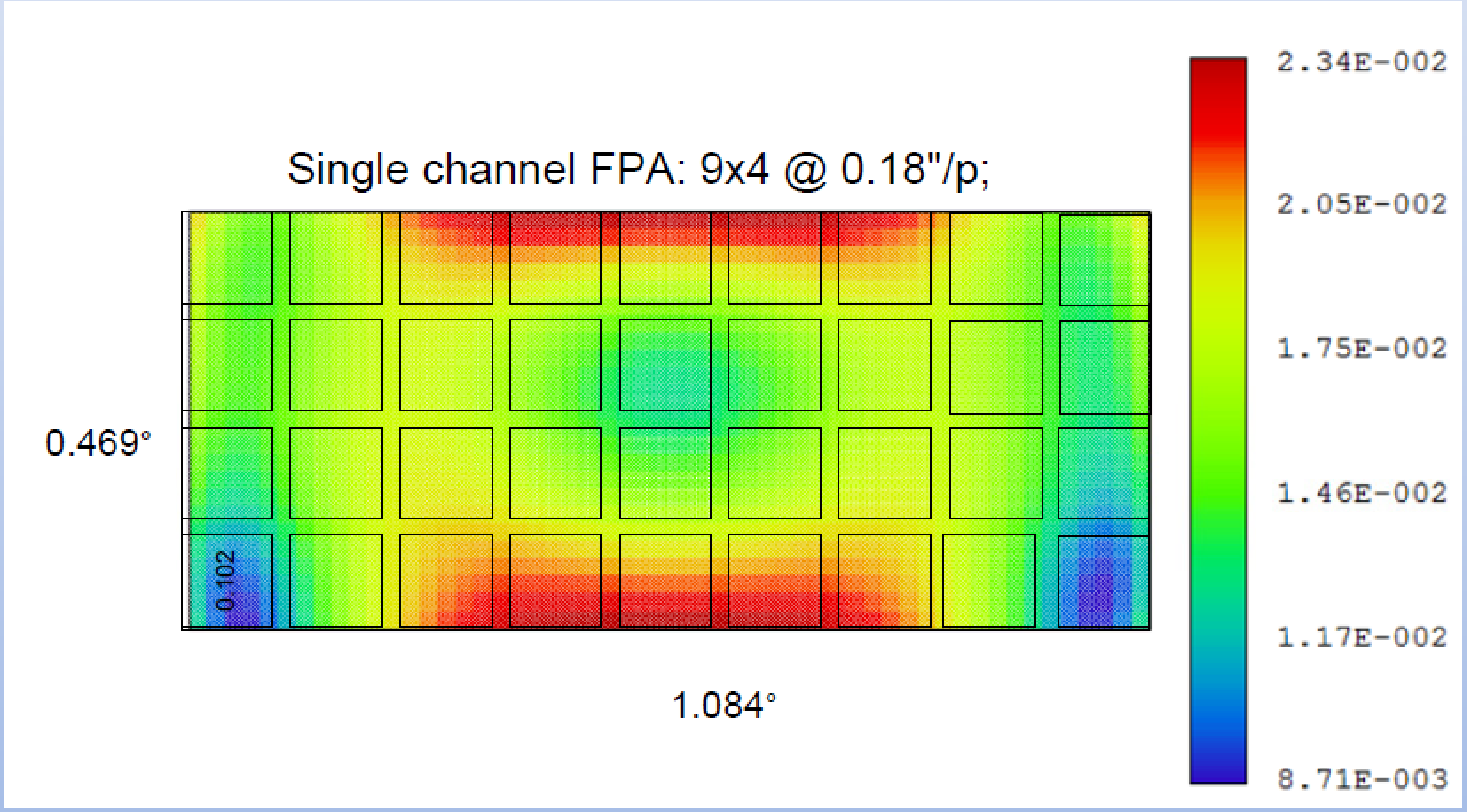
- DRM1 is based on a 9x4 H2RG layout focal plane array
  - 0.18”/pixel, ie same focal length and f/# as ImC on IDRM1
  - Same detector and pixel count as IDRM1
  - 0.356 sq deg active pixels, 20% gaps
  - Auxiliary fine guider for guiding during spectroscopy modes
  - Outrigger fine guider for guiding during imaging modes
  - 0.387 IDRM ImC AΩ < this AΩ < 0.690 IDRM SpC AΩ [m^2deg^2]

title	DRM1 H2D3 1.3m 9x4 single channel			
filled		ImC/SpC	outrigger FGS	Aux FGS
npix		2040	2040	2040
pixel size	mm	0.018	0.018	0.018
pixel scale	"/p	0.180	0.18	0.208
nx		9	1	1
ny		4	1	1
total x	deg	1.081	0.102	0.118
total y	deg	0.469	0.102	0.118
total area/channel	deg^2	0.507	0.010	0.014
total active area	deg^2	0.375	0.021	0.014
focal length	m	20.62664	20.62664	17.84997
aperture	m	1.3	1.3	1.3
system f/#		15.867	15.867	13.731
obscured fraction		0.000	0.000	0.000
A	m^2	1.327	1.327	1.327
A - omega est.	m2deg2	0.497	0.028	0.018
Mpix		149.8	8.3	4.2
field size x	mm	389.232	36.72	36.72
field size y	mm	168.912	36.72	36.72
x gap angle	deg	0.0204	0.0204	0.0236
y gap angle	deg	0.0204	0.0204	0.0236
chip size	mm	36.72	36.72	36.72
chip angle	deg	0.102	0.102	0.118
# science SCA	36			

DRM1 ray trace



DRM1 ImC error residual map, 1um

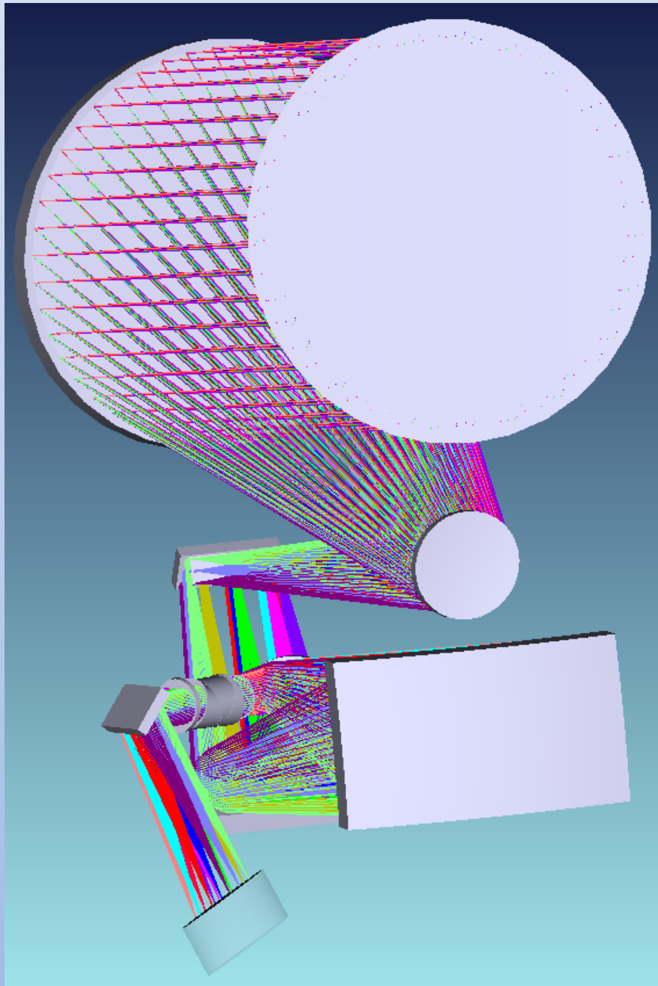


WFIRST DRM candidate design summary – DRM2

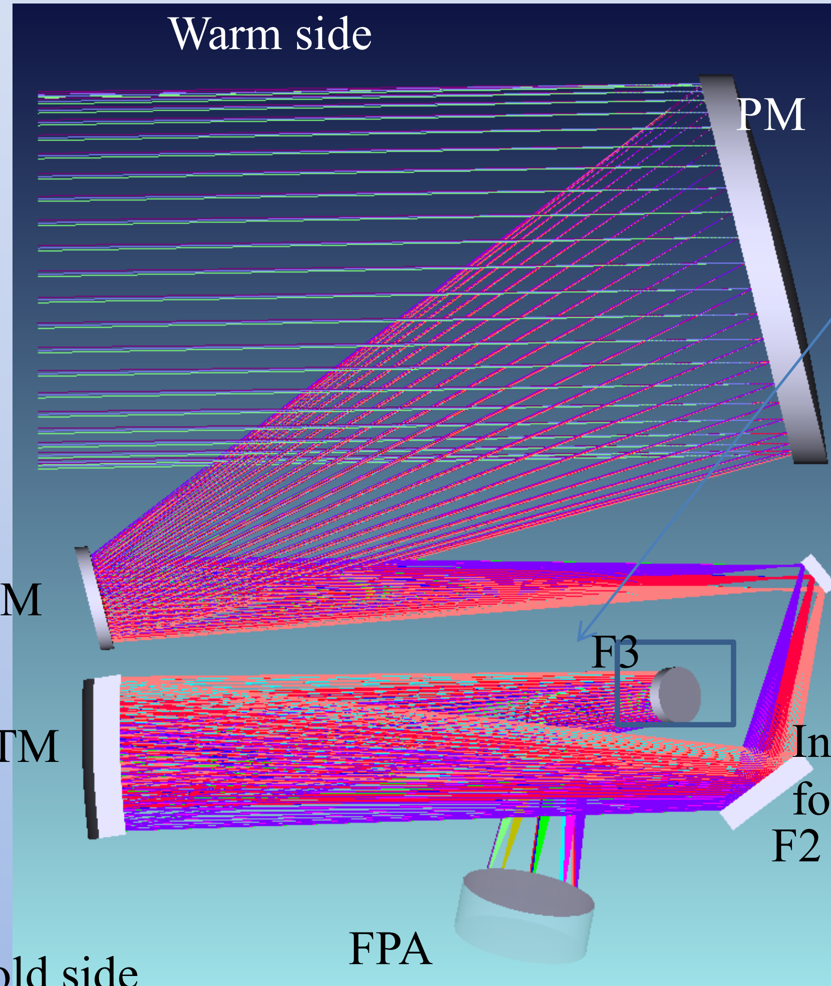
- DRM2 is based on a 7x2 H4RG(-10) layout focal plane array
  - 0.18”/pixel, ie same focal length as ImC on IDRM1 and DRM1
  - 0.585 deg^2 active pixels
  - 0.387 IDRM ImC AΩ < this AΩ < 0.690 IDRM SpC AΩ [$m^2 deg^2$]
  - Auxiliary fine guider for guiding during spectroscopy modes
  - Instead of outrigger fine guider, imaging mode fine guiding will be done using science focal plane using internal guide windowing function

packed		ImC/SpC
npix [1 side of SCA]		4088
pixel size	mm	0.01
x gap size	mm	4.00
y gap size	mm	4.00
pixel scale	"/p	0.1800
nx		7
ny		2
active x	deg	1.431
active y	deg	0.409
total x	deg	1.551
total y	deg	0.429
active area	deg^2	0.585
total area/channel	deg^2	0.665
focal length	m	11.45924
aperture	m	1.1
system f/#		10.417
A - omega est.	m^2deg^2	0.556
Mpix		234.0

DRM2 ray trace



Oblique view view

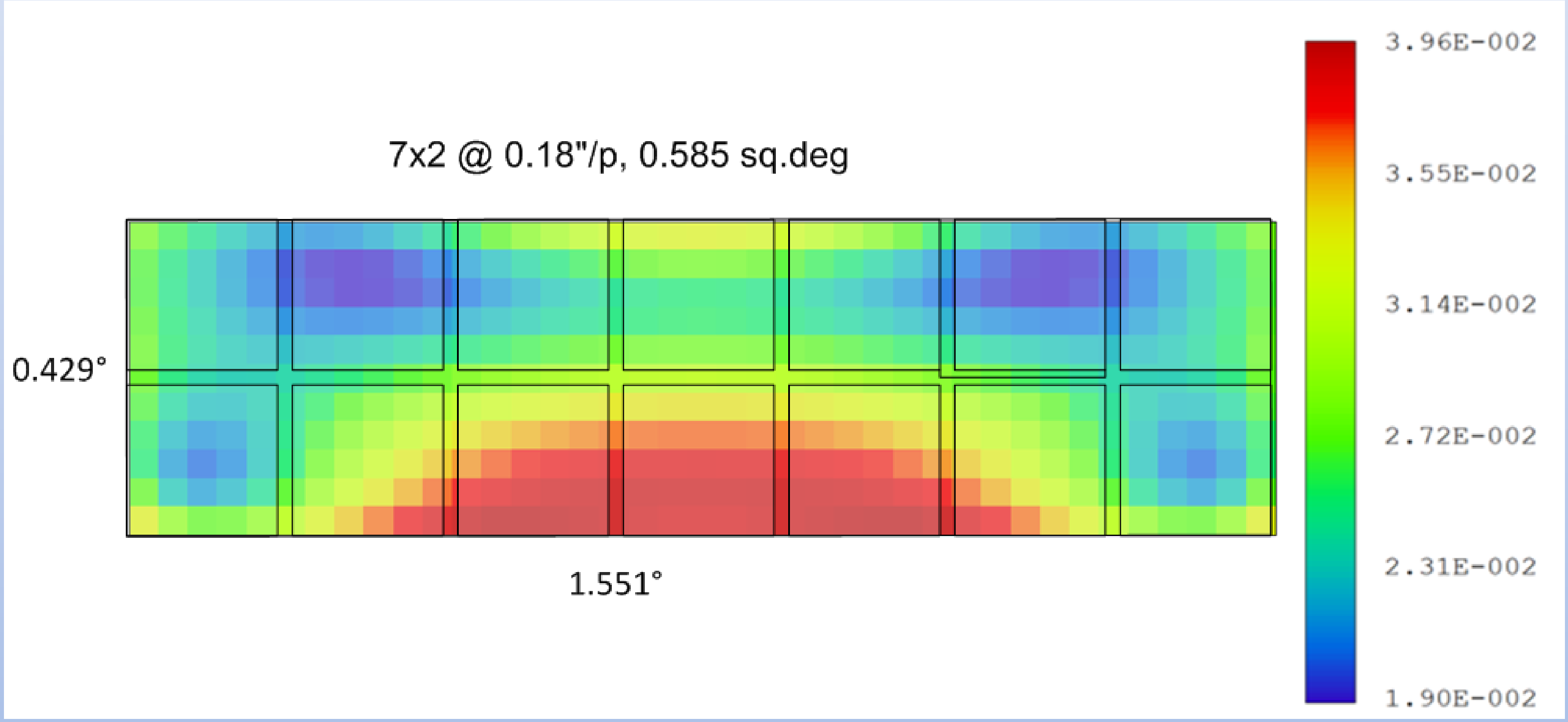


Cold stop &
Filter wheel,
Prism wheel,
behind F3

Intermediate
focus; field stop

Side view

DRM2 ImC error residual wavefront error map, 1um



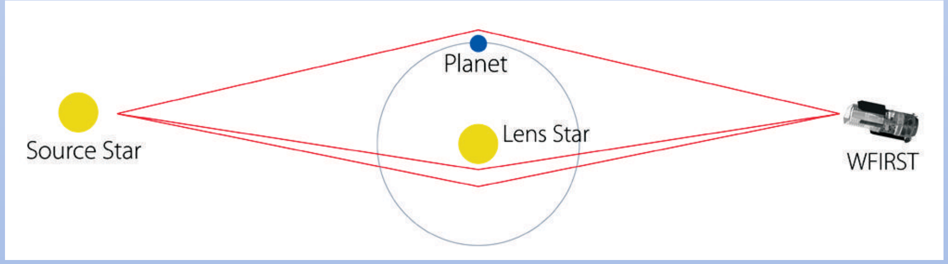
Thermal Results Summary

Component	Nominal				Roll 10, Pitch 36			
	Max. T, °K	Min. T, °K	Avg. T, °K	Heater Power at 220K, W	Max. T, °K	Min. T, °K	Avg. T, °K	Heater Power at 220K, W
Baffle	215.8	126.0	163.4	--	215.8	123.8	162.5	--
Primary mirror	220.1	217.8	219.8	27.2	220.1	217.7	219.8	27.5
Rear Encl.	226.0	189.4	215.9	73.3	226.2	188.9	215.7	71.2
Secondary mirror	220.1	219.5	219.9	4.2	220.1	219.5	219.9	4.2
Tertiary 1	220.1	217.9	219.3	0.9	220.1	217.9	219.3	0.9
Tertiary 2	220.1	218.0	219.4	0.9	220.1	218.0	219.4	0.9
Fold mirror 1	220.0	218.7	219.4	7.0	220.0	218.7	219.4	7.3
Fold mirror 2	220.0	218.8	219.3	7.5	220.0	218.8	219.3	7.7
Strongback	222.8	197.2	216.1	58.1	222.7	196.9	216.0	64.6
Rooftop mirror 1	220.1	219.0	219.5	0.4	220.1	219.0	219.5	0.4
Rooftop mirror 2	220.1	218.4	219.4	0.5	220.1	218.4	219.4	0.5
Rooftop mirror 3	220.2	218.5	219.5	0.5	220.1	218.4	219.5	0.5
Rooftop mirror 4	220.0	219.1	219.5	0.4	220.0	219.0	219.5	0.4
Feed Structure	220.4	215.2	218.5	24.5	220.4	215.1	218.4	25.2
Imager mirror	216.5	216.0	216.3	--	216.4	215.8	216.1	--
Imager tertiary	218.4	217.4	217.8	--	218.4	217.4	217.8	--
Imager fold mirror	218.7	217.5	218.1	--	218.7	217.4	218.1	--
			Total	205.4			**Total**	211.7

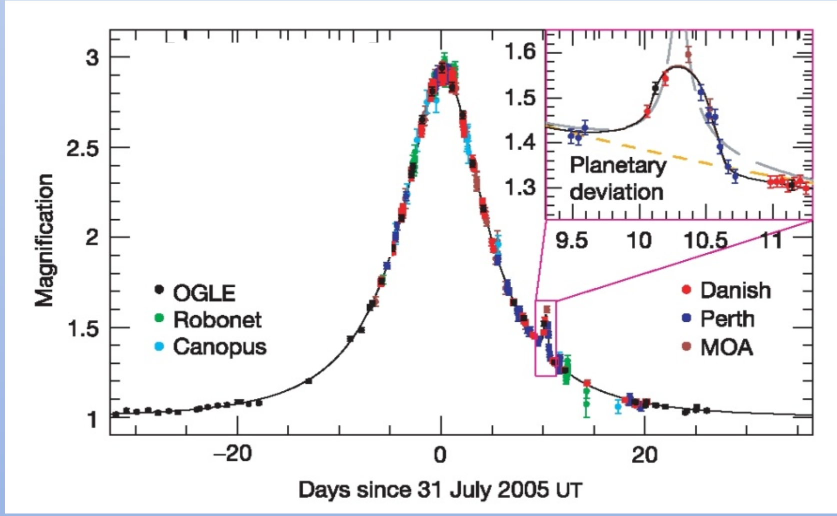
§2: Science Overview (1 of 3) – **exoplanet microlensing**

- Monitor Galactic bulge in NIR
- Detect microlensing events of background stars by foreground stars + planets
- Also detects free-floating planets
- Complementary to transit techniques (such as Kepler)

- Objective: Complete the statistical census of planetary systems in the Galaxy, from habitable Earth-mass planets to free floating planets, including analogs to all of the planets in our Solar System except Mercury.



Above: exoplanet microlensing geometry (not to scale);
Right: Example exoplanet microlensing discovery light curve



Science Overview 2 of 3–
IR survey

- Identify ≥100 quasars at redshift $z>7$
- Obtain broad-band NIR spectral energy distributions of ≥1e9 galaxies at z>1 to extend studies of galaxy formation and evolution
- Map the structure of the Galaxy using red giant clump stars as tracers

- Objective: Produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at z>10.

Data Set Rqts include:

✓High Latitude data from Imager and Spectrometer channels during BAO/RSD and WL Surveys;
- Image 2500 deg^2 in 3 NIR filters to mag AB=25 at S/N=5

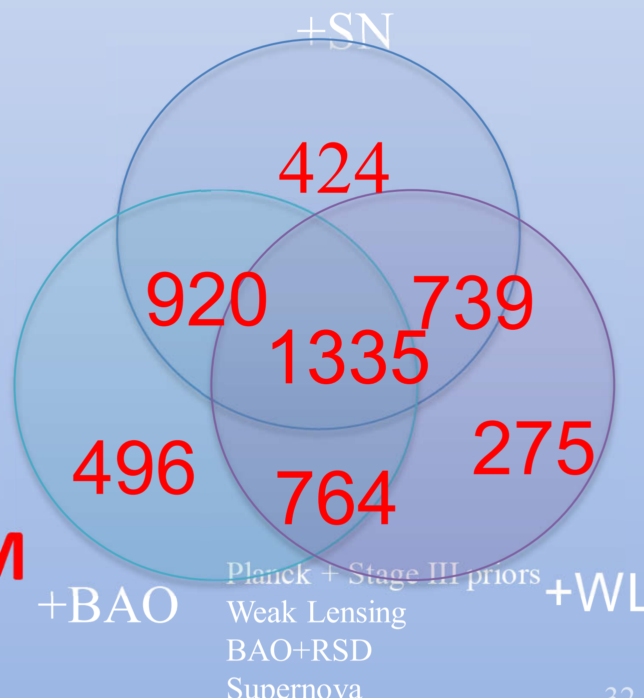
✓Galactic Plane Survey (~0.5 yr, per EOS Panel);
- Image 1500 deg^2 of the Galactic Plane in 3 NIR filters

✓Guest Investigator observations (~1 yr, per EOS Panel) will supplement

Science Overview, 3 of 3–
Dark Energy

- Baryon Acoustic Oscillations (BAO)/Redshift Space Distortion (RSD): ... "WIDE" survey mode
  - 11,000 deg^2/dedicated year
  - Redshift errors $\sigma_z \leq 0.001(1+z)$, over redshift range $0.7 \leq z \leq 2$
- Weak Lensing: ... "DEEP" survey mode
  - 2700 deg^2/dedicated year
  - Effective galaxy density $\geq 30/amin^2$, shapes resolved plus photo-zs
- Supernova type 1a (SNe) Survey:
  - >100 SN per $\Delta z = 0.1$ bin for most bins $0.4 < z < 1.2$, per dedicated 6 months
  - Redshift error $\sigma_z \leq 0.005$ per supernova

- Objective: Determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity.



Optimistic FoM calculations