Progress on 1.5m Aperture Telescope and Instruments: Solar UV, Visible and near IR Telescope (SUVIT)

Y. Suematsu, Y. Katsukawa (NAOJ), K. Ichimoto (Kyoto), T. Shimizu (ISAS)
and Solar-C/Chromosphere sub-WG

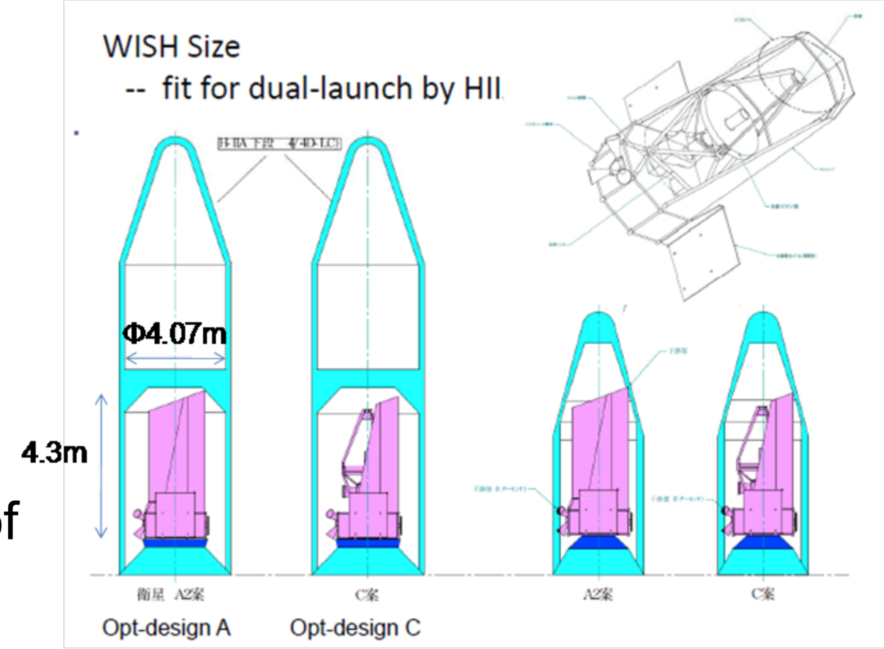
Solar Optical Telescope

space	Ground -based
SOT Φ1.5 m (planned 1980) resolve photon mean-free-path scale in the photosphere OSL Φ0.8 m （planned late 1980s) Spacelab 0.3 m	
Hinode/SOT Φ0.5 m (2006～） need more photons and resolution!	NST Φ1.6 m (2009～） GREGOR Φ1.5 m (2010?～）
Solar-C/Plan-B	ATST Φ4 m (2018?～）

Heritage of developments of Hinode/SOT and large-aperture ground based telescope.
→ Technology is getting mature enough to build 1.5-m class space-borne telescope.

Basic requirements to the instrument

- Telescope aperture and length
  - 1.5mϕ
  - Fit within the H-IIA nose fairing
- Spatial resolution
  - 0.1" in UV
  - 0.16" in Vis/NIR (Diffraction limit of 1.5mϕ at 1μm)
- FOV
  - ~200" x 200" to cover a medium size AR with 4kx4k detector
- Wavelength coverage (250 – 1100 nm)
  - Shortest ~250 nm to observe Mg II h/k.
  - Longest ~1100 nm to observe He I 10830.
- I/F between the telescope and the focal-plane instrument
  - Collimated beam with ~ϕ60mm exit pupil to relax the tolerance of alignment.



Primary Mirror

Monolithic light-weight mirror for 1-1.5 m aperture are feasible

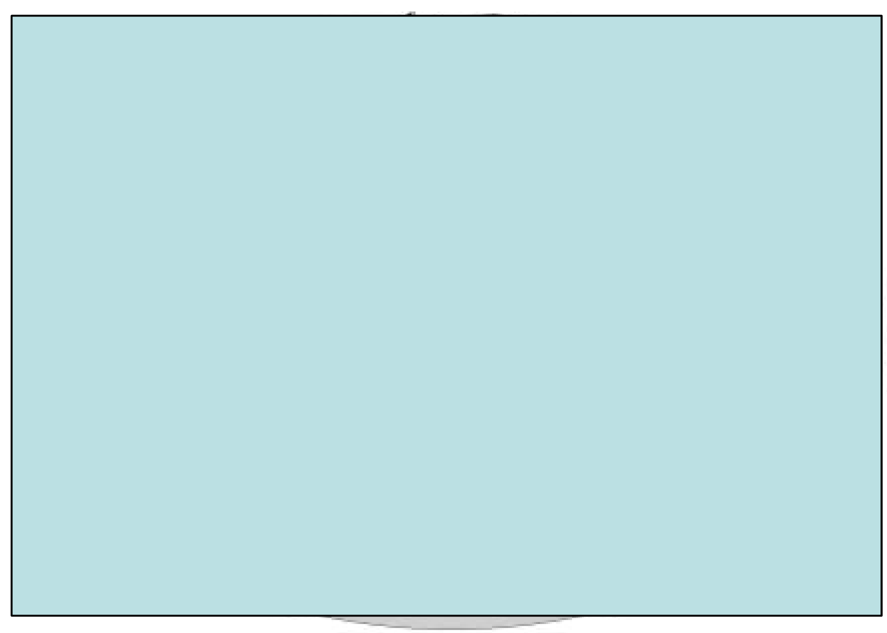
- 90% light-weighting: 100 – 150 kg (weight budget)
- Small gravity effect in horizontal configuration

    WFE < 35 nm rms (optical performace)

    coma < 4 nm rms (alignment)

Coating chamber can be accommodated with 1.5 m mirror

Structure model of the Sunrise 1-m aperture primary

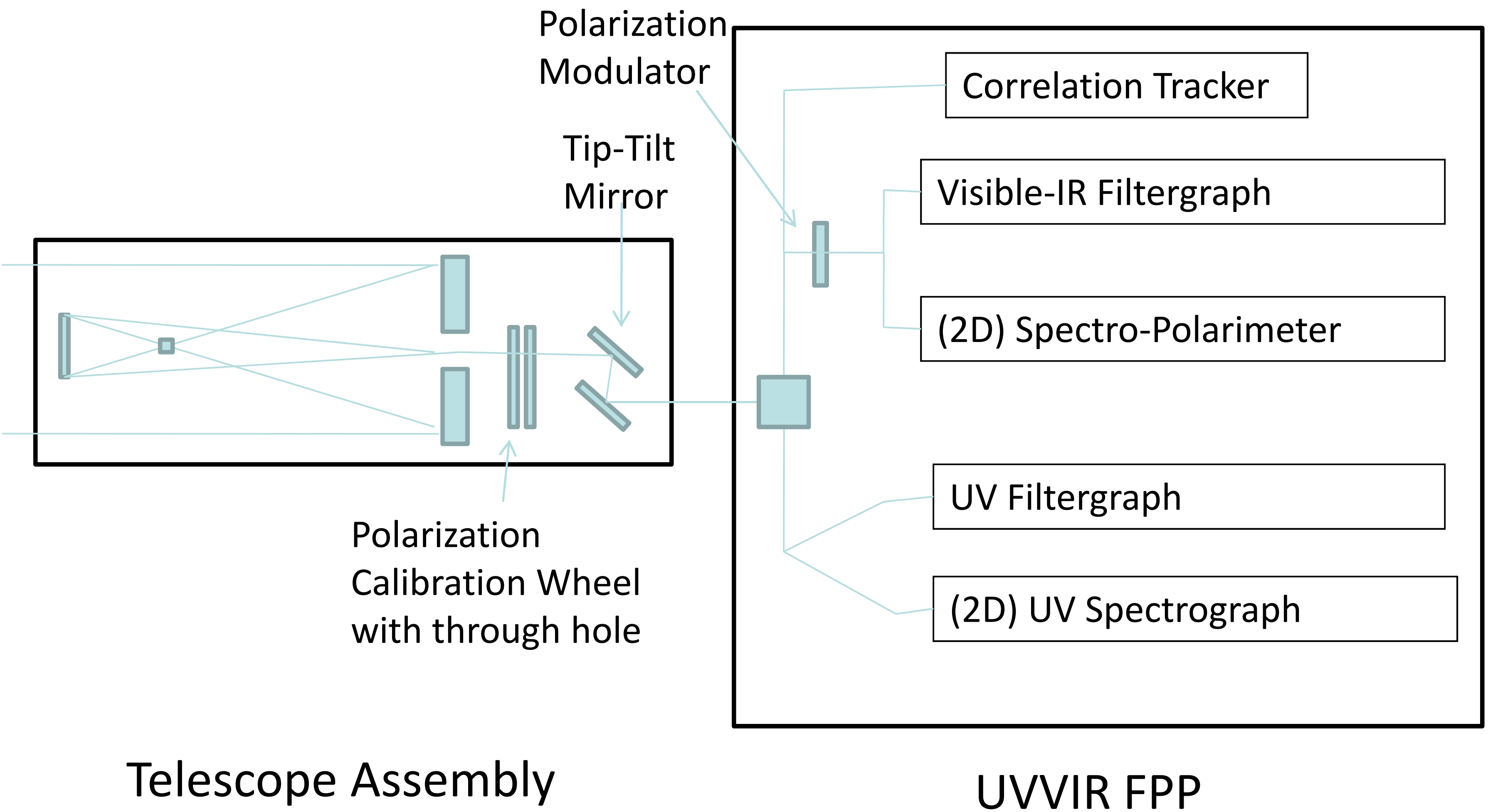


Telescope Structure

Hinode/SOT truss structure of CFRP (CTE < 0.1 ppm/K)

Thermal stability (ΔT=5 deg) in focus accommodate 1.5 m aperture and 3 m M1-M2 length Gregorian.

Conceptual Design for SUVIT



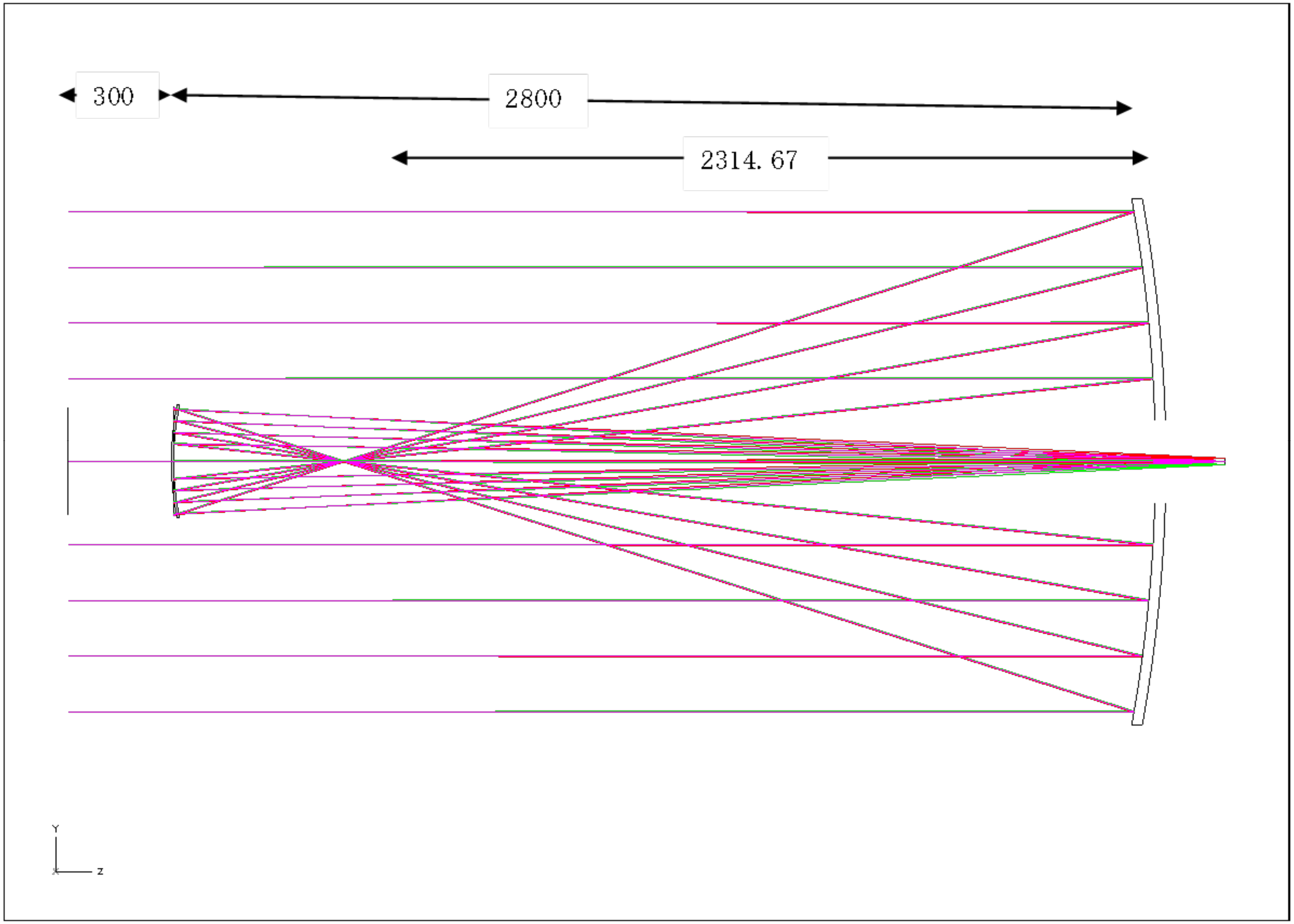
Positional Tolerance Study of φ1.5 m Gregorian

M1-M2 (cm)	300	280	250	220	OTA 150
f1 (cm)	246.6 (F1/1.64)	231.467 (F1/1.54)	208.467 (F1/1.39)	185.167 (F1/1.23)	116.9617 (F1/2.34)
f2 (cm)	45.7633	41.775	35.9961	30.4184	26.247
Defocus 1μ A20 (Strehl)	0.0367 (0.983)	0.0415 (0.980)	0.0508 (0.968)	0.0636 (0.951)	0.0178 (0.997)
Defocus 3μ A20		0.1245 (0.832)	0.1522 (0.748)		0.057 (0.967)
Decenter10μ A31	-0.0359 (0.994)	-0.0432 (0.991)	-0.0588 (0.983)	-0.0831 (0.966)	-0.0125 (0.999)
Decenter50μ A31		-0.216 (0.791)	-0.294 (0.653)	-0.4156 (0.4267)	-0.0625 (0.98)
Tilt 10" B31	0.0908 (0.960)	0.0996 (0.952)	0.1161 (0.936)	0.1379 (0.910)	0.01897 (0.998)
Tilt 50" B31	0.454 (0.362)	0.498 (0.289)	0.581 (0.190)		0.0948 (0.955)

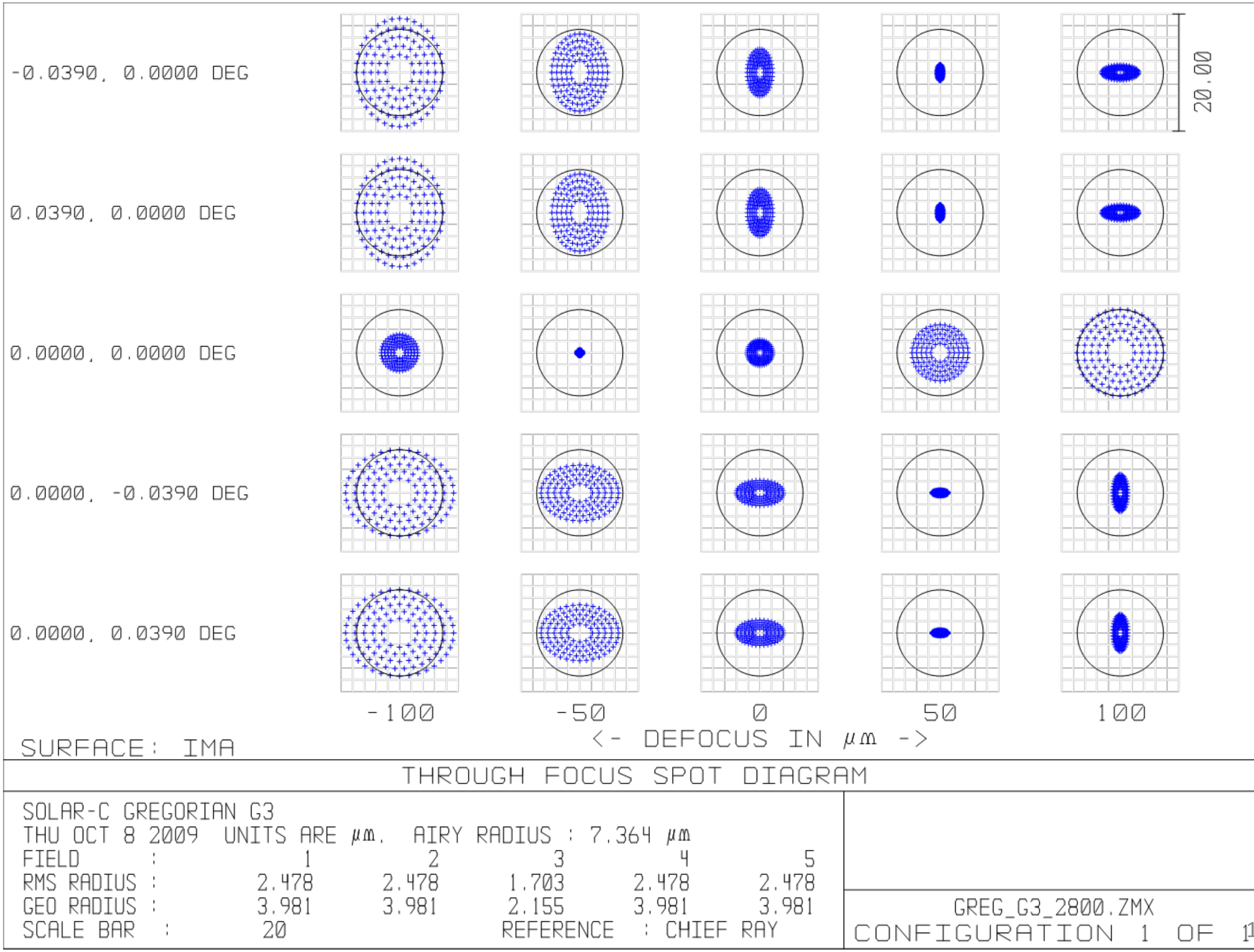
Baseline Optical Parameters

	SOT-OTA (SOLAR-B)	SUVIRT-OTA (SOLAR-C)
Entrance pupil (mm)	500	1500
M1-M2 distance (mm)	1500	2800 (<4500)
M1 outer diameter (mm)	560	1580
clear aperture	509	1513
radius (focal)	2339.4 (1169.7)	4629.34 (2314.67)
conic const.	-0.9706	-0.990927
M2 outer diameter (mm)	159	340
clear aperture	147	320.5
radius (focal)	524.94 (262.47)	835.494 (417.747)
conic const.	-0.3996	-0.548155
HDM outer diameter (mm)	32.83	48.37

Baseline Telescope Design



Spot Diagram

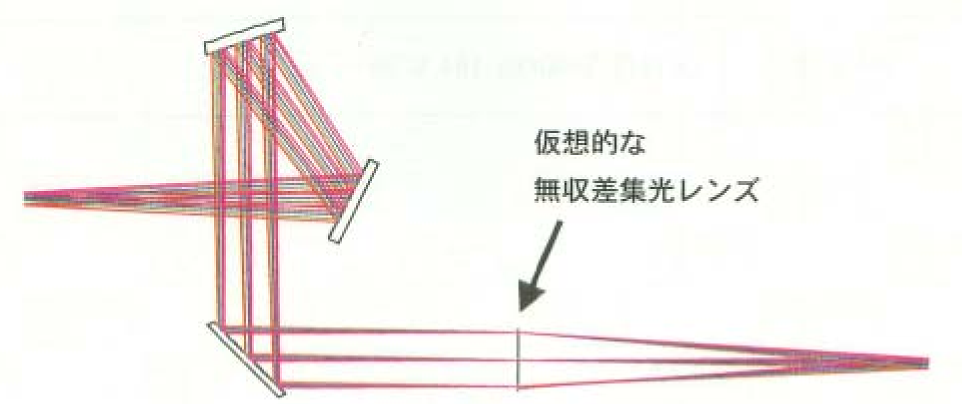


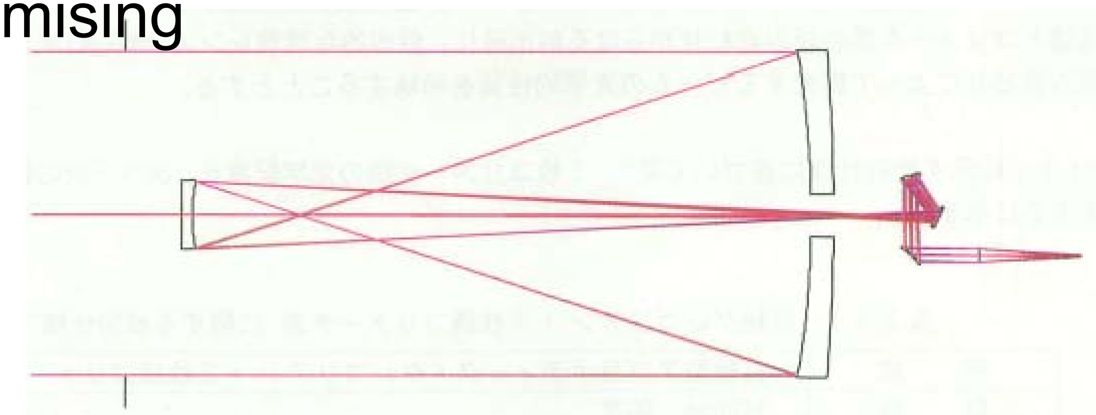
Collimating Optics

Trade off study among
1. All reflective
2. Lens (SiO_2, CaF_2)
3. Composite lens-Cassegrain design

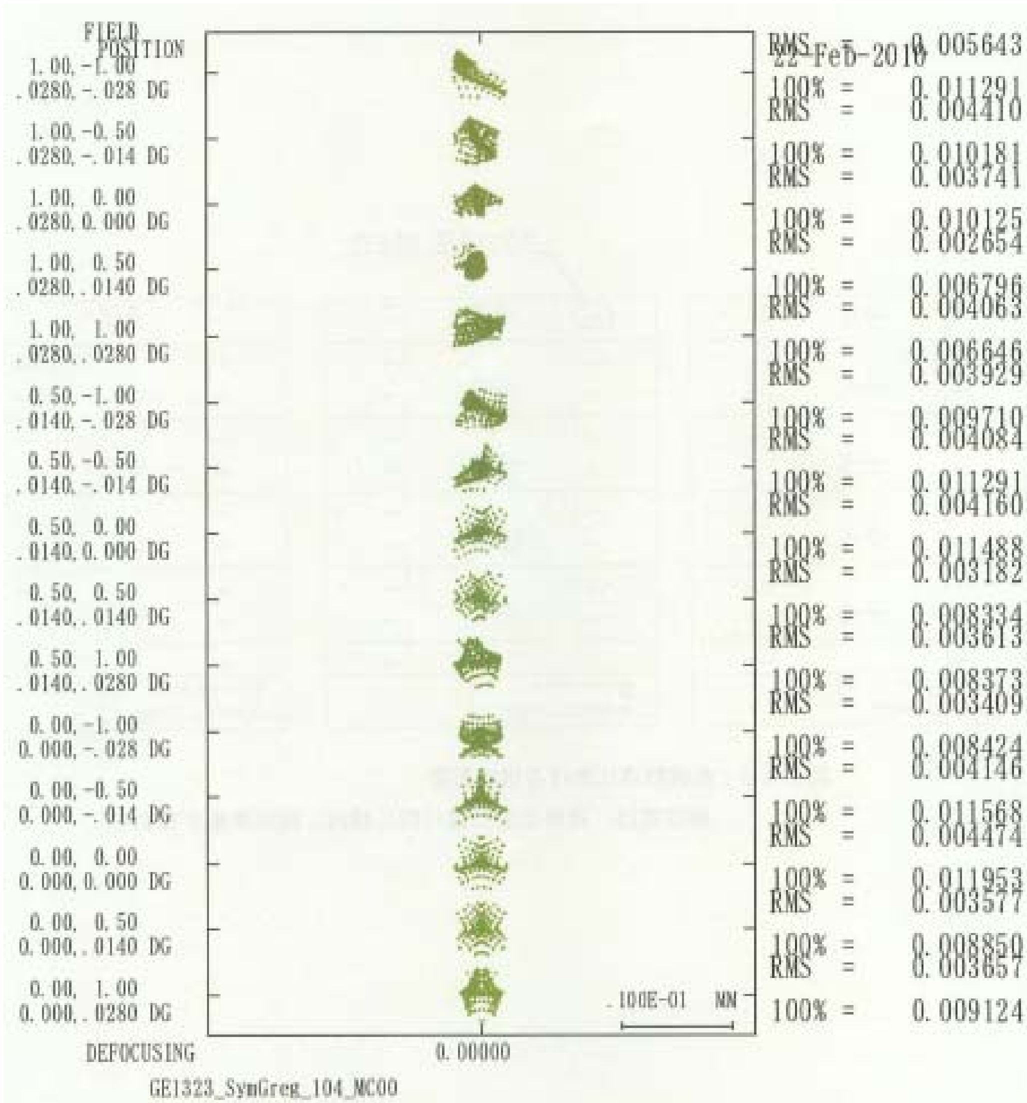
・Chromatic aberration
・Thermal stability in focus

All reflective option is promising

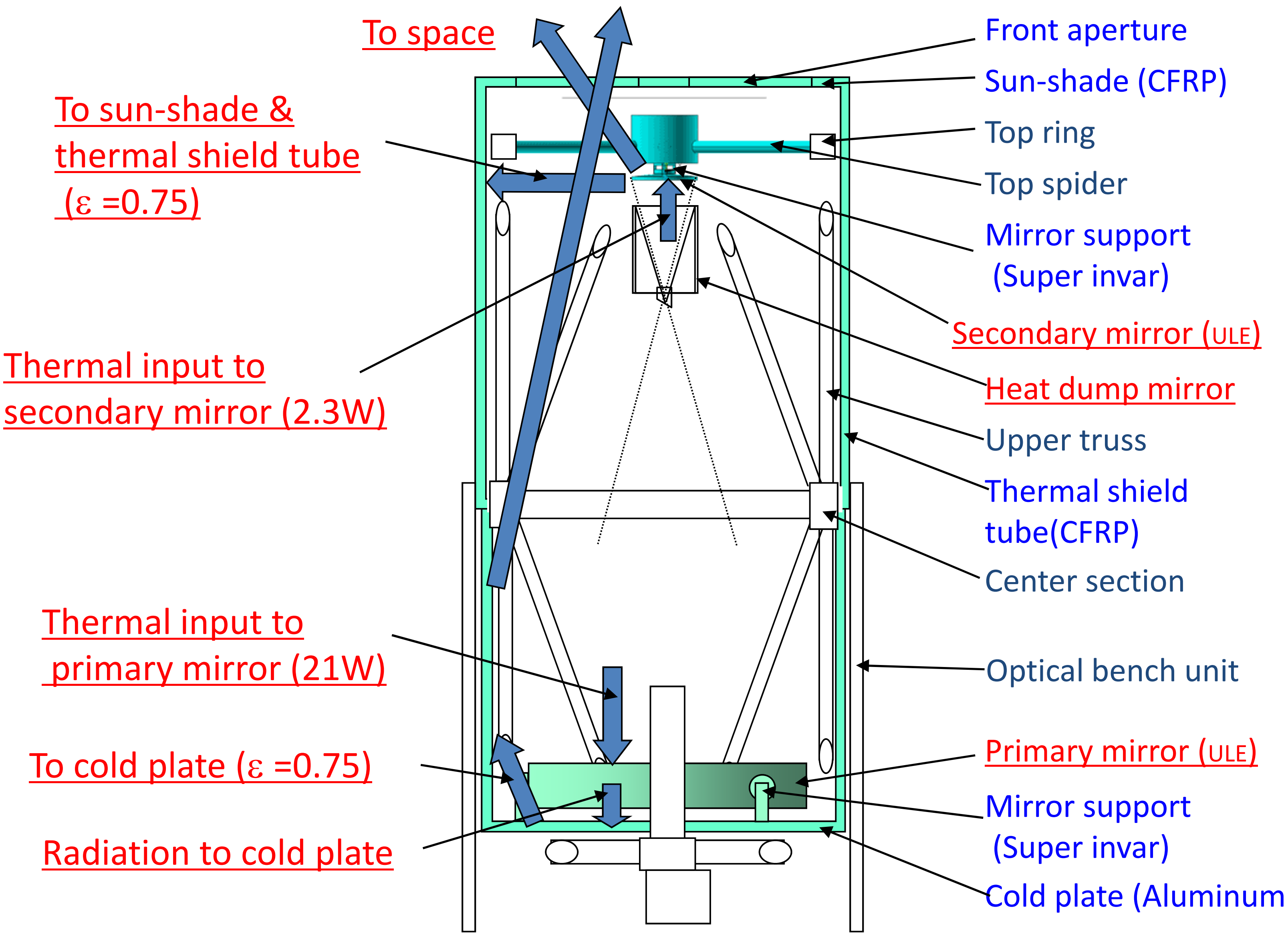




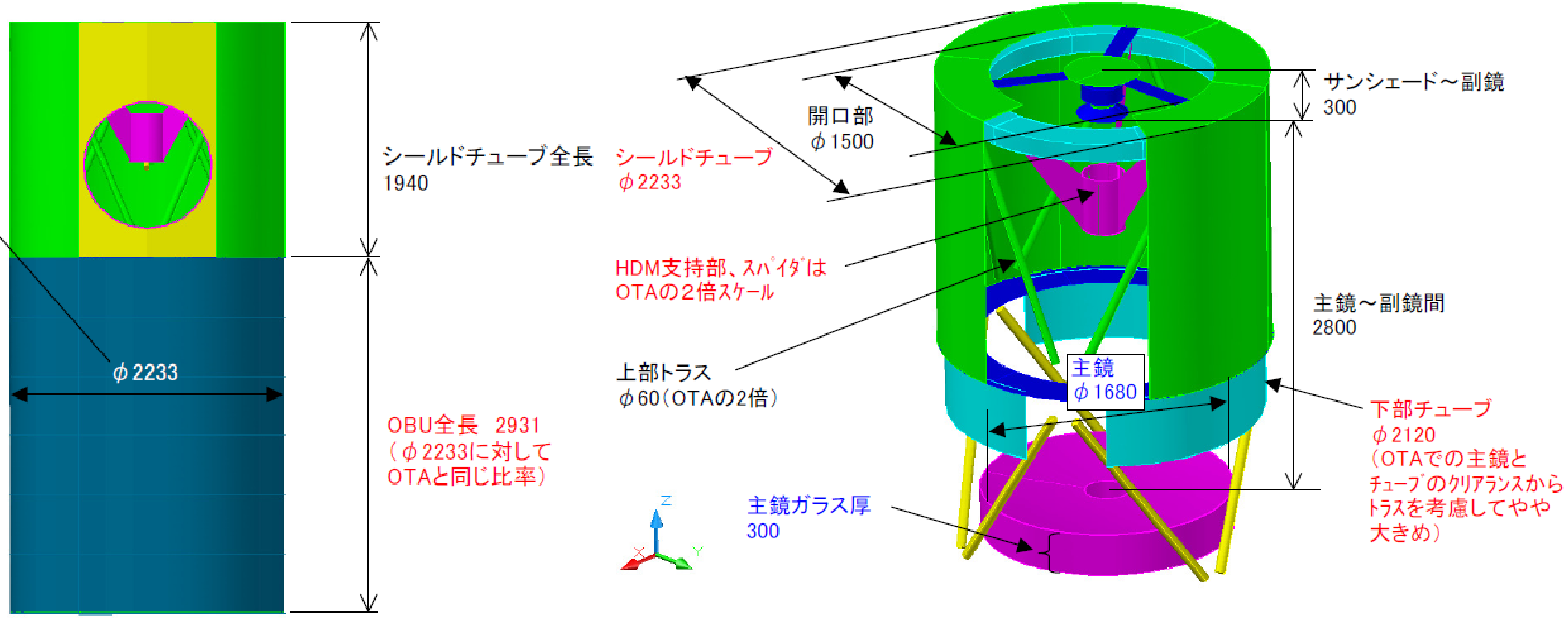
Spot diagram for Gregorian + 3-mirror collimator



Heat dump path from M1 and M2 in case of Solar-B OTA



Structure Model of φ1.5 m Telescope: Scaled-up model of OTA



Termal properties of surfaces are of end-of-life except for M1 and M2.

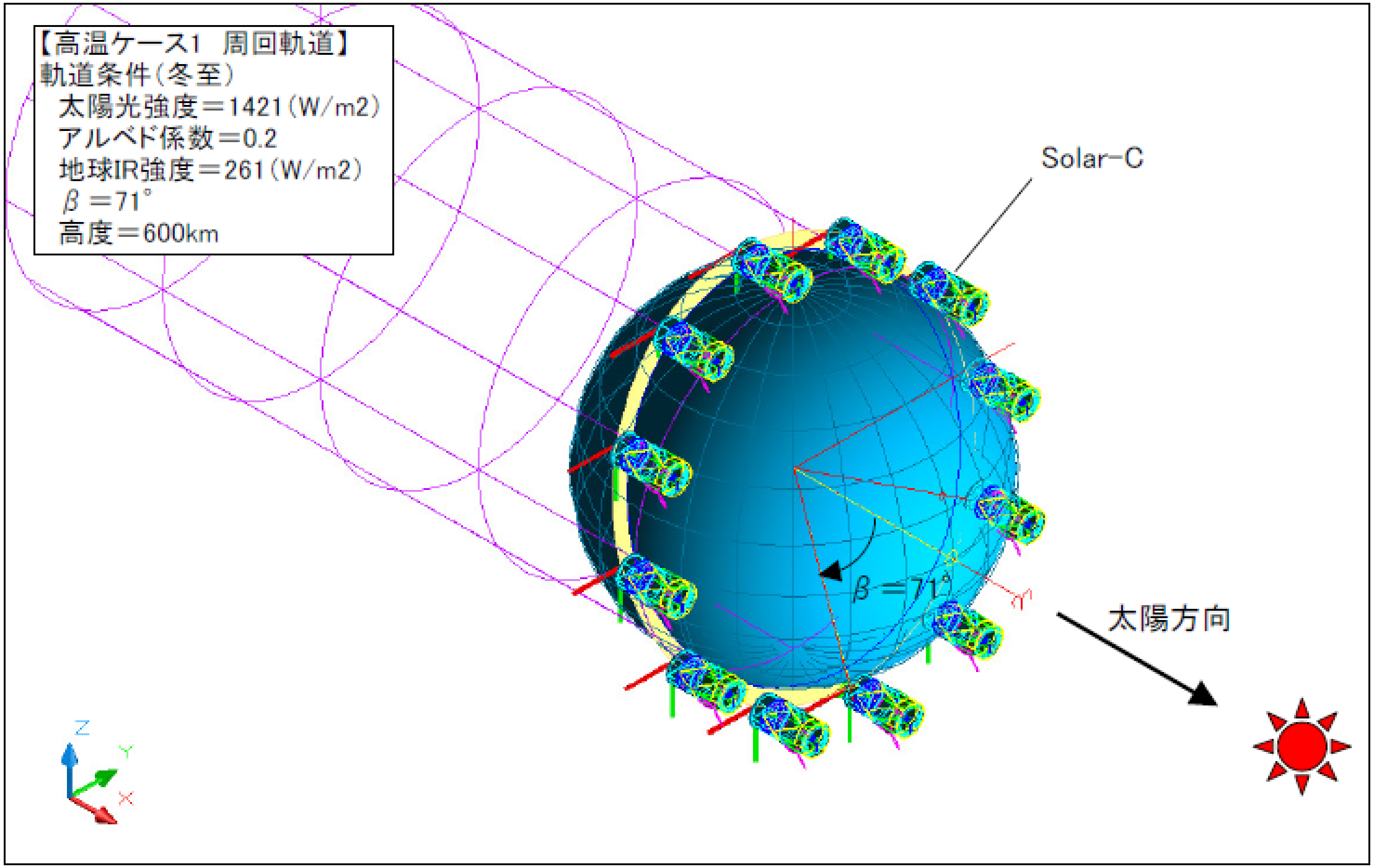
名称	吸収率α		入射量(W)	吸収量(W)
主鏡	α1	0.118	2074.9	244.8
排熱鏡	αH	0.1	1830.1	175.4
副鏡	α2	0.118	76.2	9.0
コリメータ	α3	0.11	19.4	2.1 改訂
			合計	431.4

※αの値はICDパッケージより抜粋（中間報告と異なる）

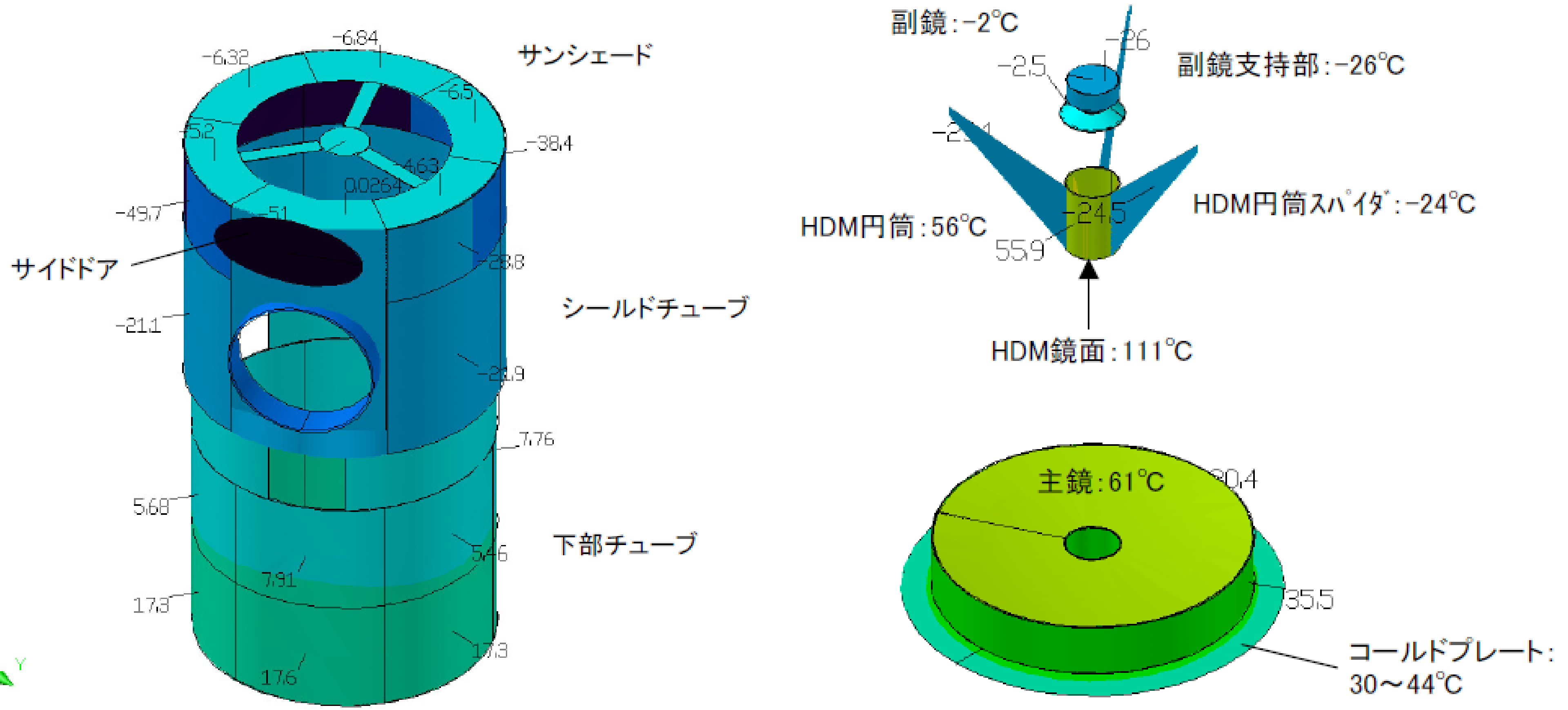
OTA　α	OTA吸収量(W)
0.1	22.3
0.15	27.2
0.1	2
TBD	0.5
合計	52

※OTA熱設計中間報告より

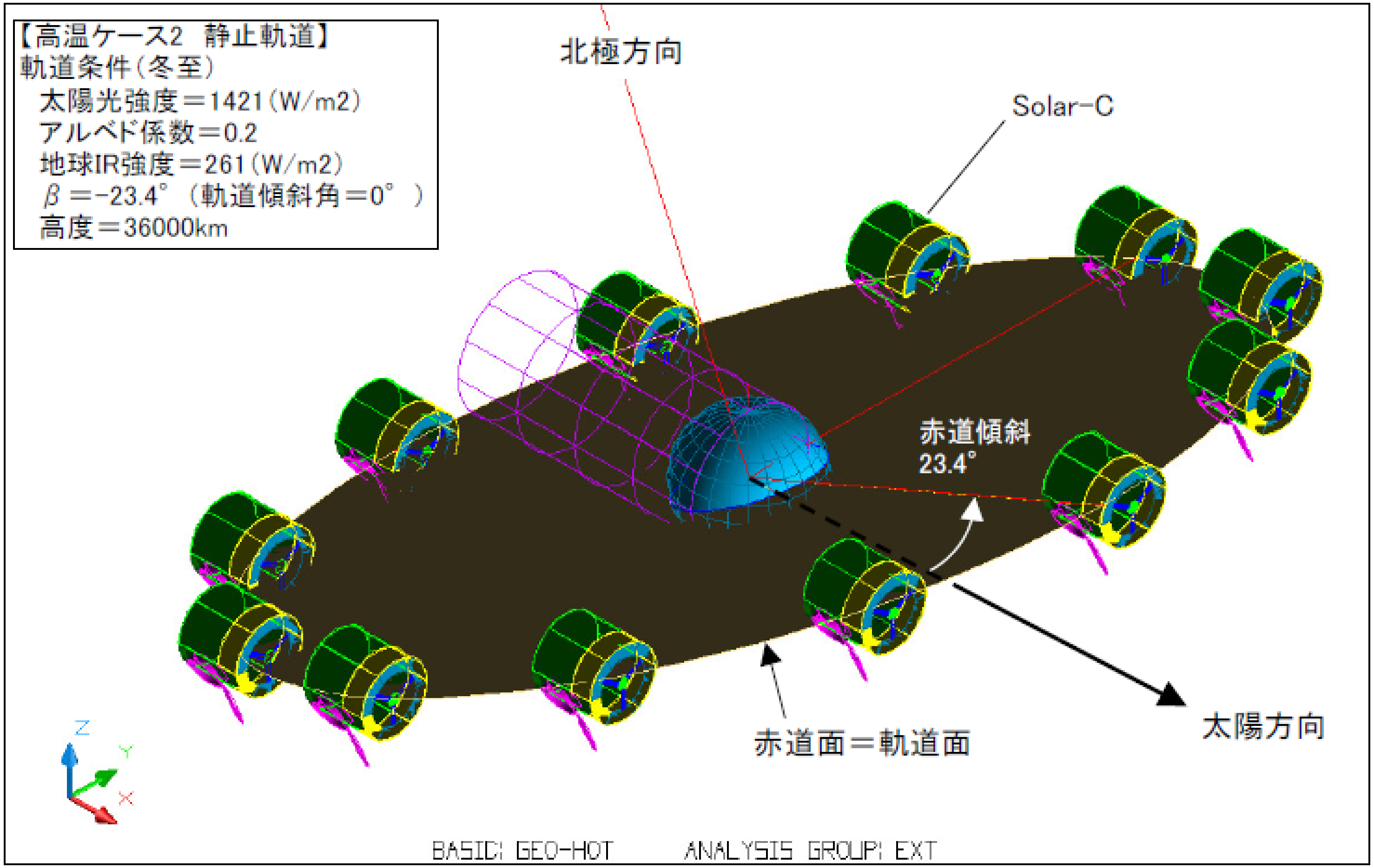
Solar-C Solar Synchronous Polar Orbit same as Hinode



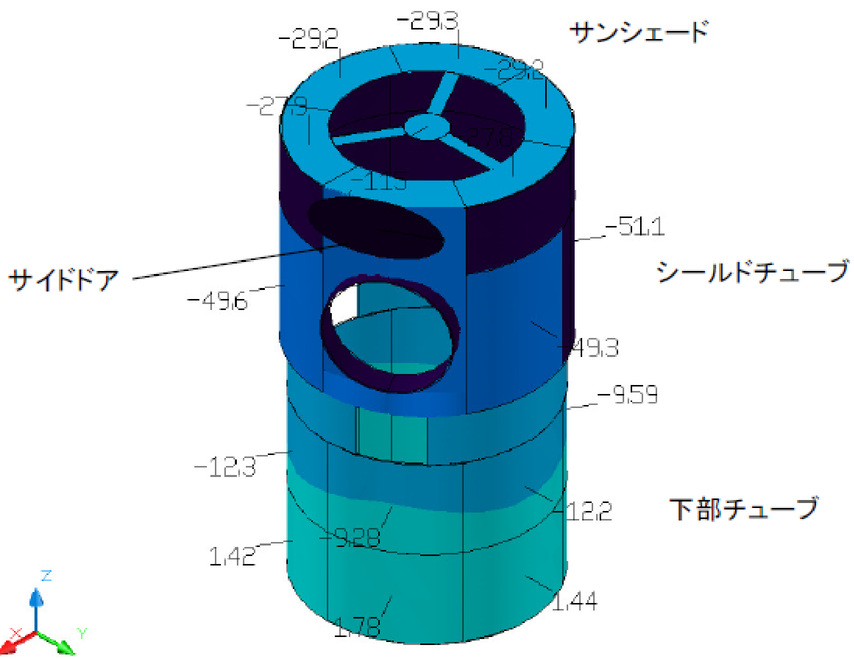
Temperatures for Polar Orbit

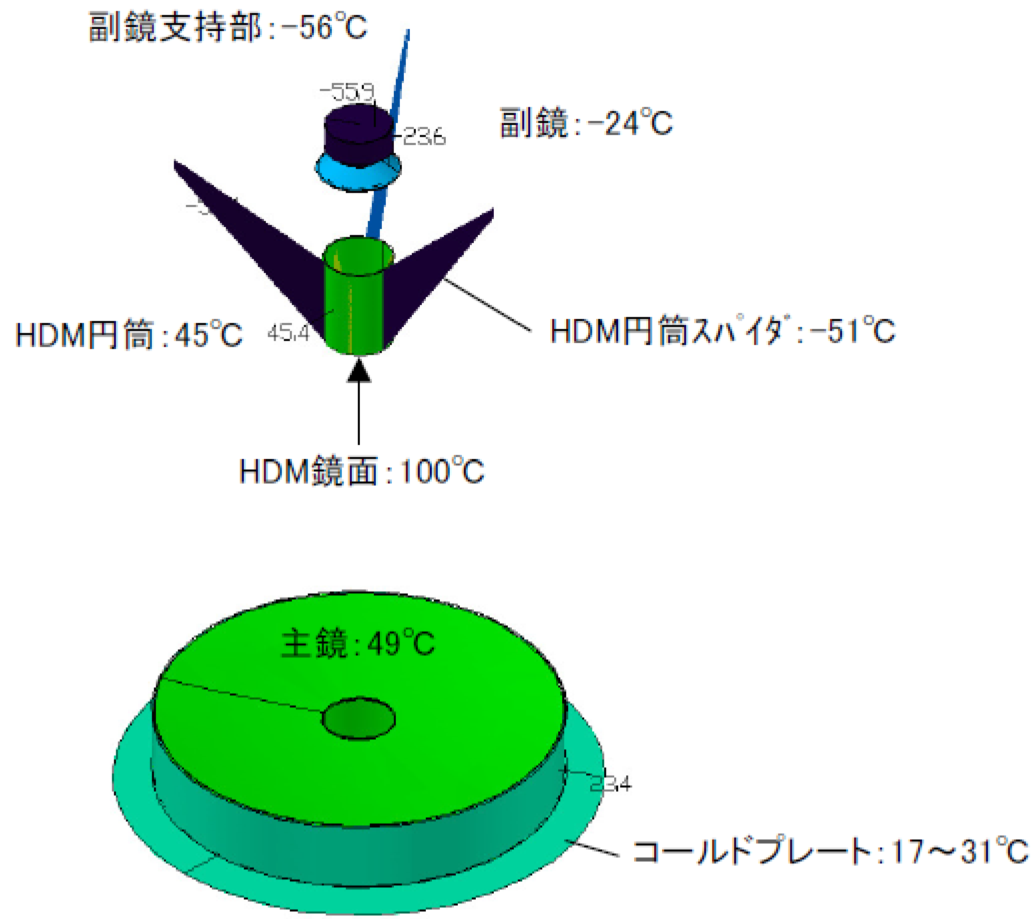


Solar-C Geosynchronous Orbit



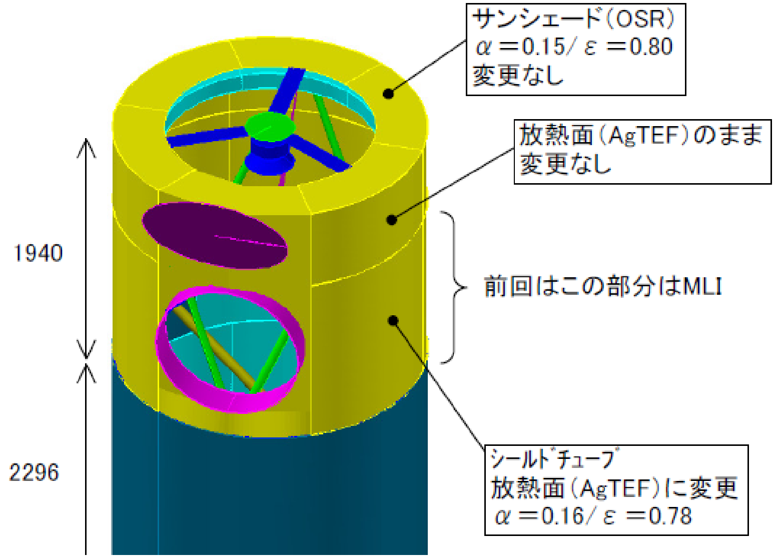
Temperatures for Geosynchronous Orbit





Sensitivity study with radiator area modification

1) Mod-1 Expand radiator area at Shield Tube



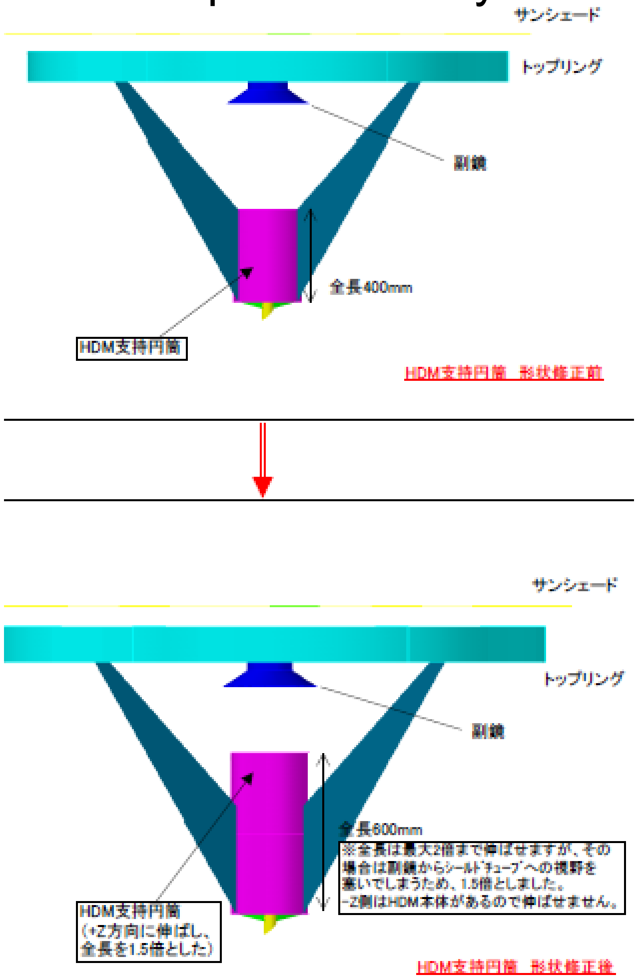
2) Mod-2 Enhance conduction at HDM inner spider

AlBe (210W/mK) x 3 spiders

↓

AlBe (210W/mK) x 6 spiders

3) Mod-3 Expand HDM cylinder

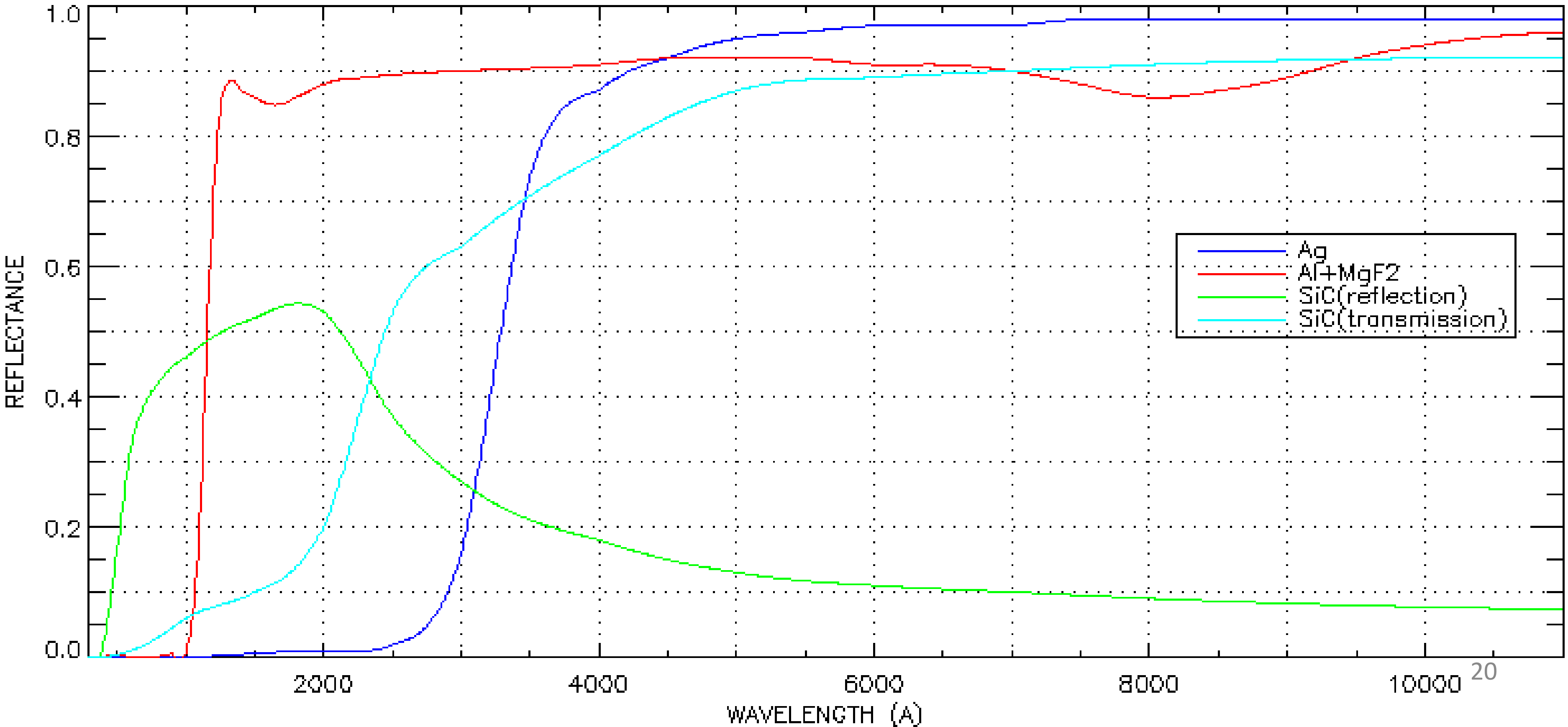


Mirror Coating Issue

Hinode/OTA: M1 and M2 have a protected Ag coat（solar light absorption α～ 6.5%) which is not suitable for UV observation (not capable of reflecting UV light shorter than 360 nm).

A typical coating for UV is Al+MgF2. However, The coating has a large α of ～ 12% and overall reflectivity in visible and IR is Lower than the Ag coating.

→ The development of UV-reflective and low solar absorption coating is under study.



Degraded (EOL) Reflectivity for Al+MgF2 Coating

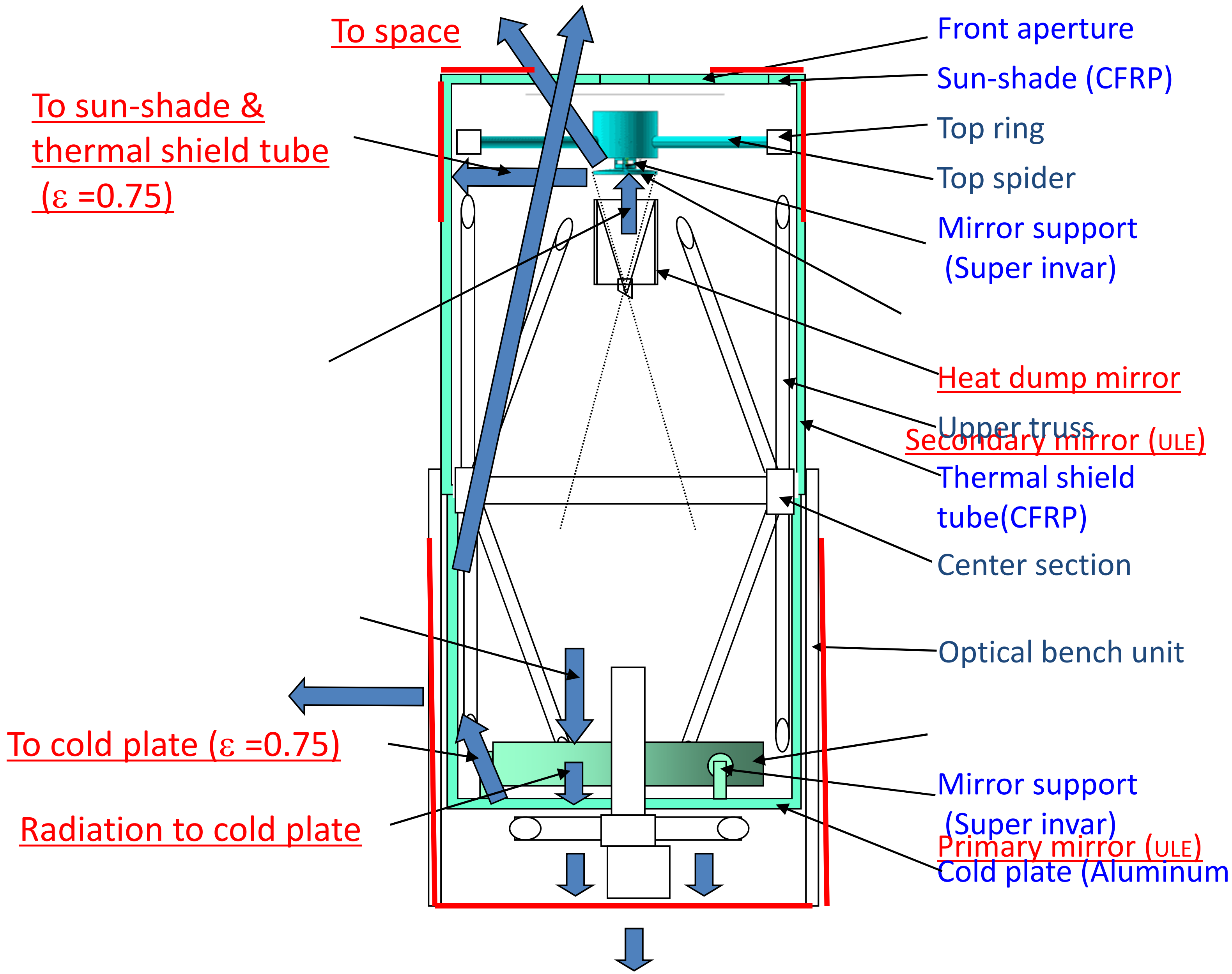
Assume that the solar absorption α incease by 0.05 in the end of life (EOL).

名称	吸収率α		入射量(W)	吸収量(W)	変更前
主鏡	α1	0.168	2074.9	348.6	245
排熱鏡	αH	0.1	1726.3	165.4	175
副鏡	α2	0.168	71.9	12.1	9
コリメータ	α3	0.11	18.6	2.0	2.1
			合計	528.2	431

Predicted temperatures for optics

T (degC)	Polar orbit	Geosync. orbit	Polar orbit with Mod-1	Polar orbit with Mdd-1 and Mod-2	Polar orbit with Mod-1 and Md-2 and Mod-3	Polar orbit +Mod-1 α+0.05 @M1& M2	Geosync +Mod-1 α+0.05@ M1&M2
M1 surface	61	49	52	52	52	80	70
M2 Surface	-2 ～ -7	-24	-12 ～-8	-12 ～-8	-12 ～-7	0～4	-17～-16
HDM surface	109～111	100	103～104	77～78	60～61	63～64	51
CLU	34 - 37	22-24	24 - 27	24 - 27	24 - 26	41	29

Heat dump path from M1 necessary



Off-axis Gregorian

Pro

・no central obscuration, lower scattered light, higher contrast images

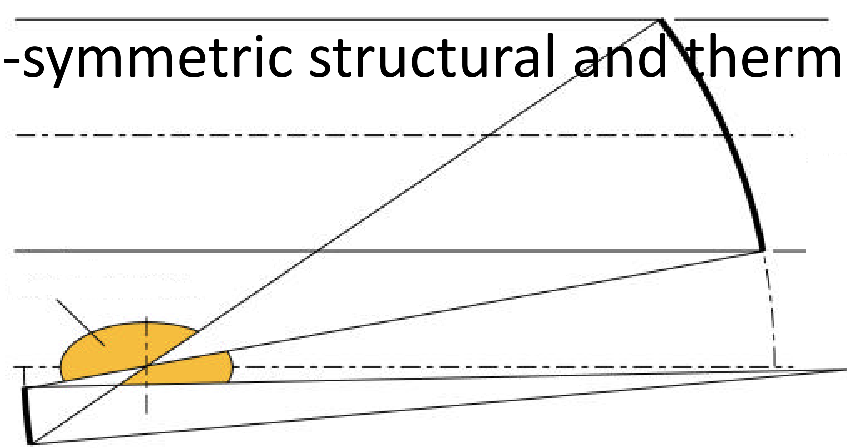
・more freedom in designing HDM at primary focus, direction of reflected light and cooling method

Con

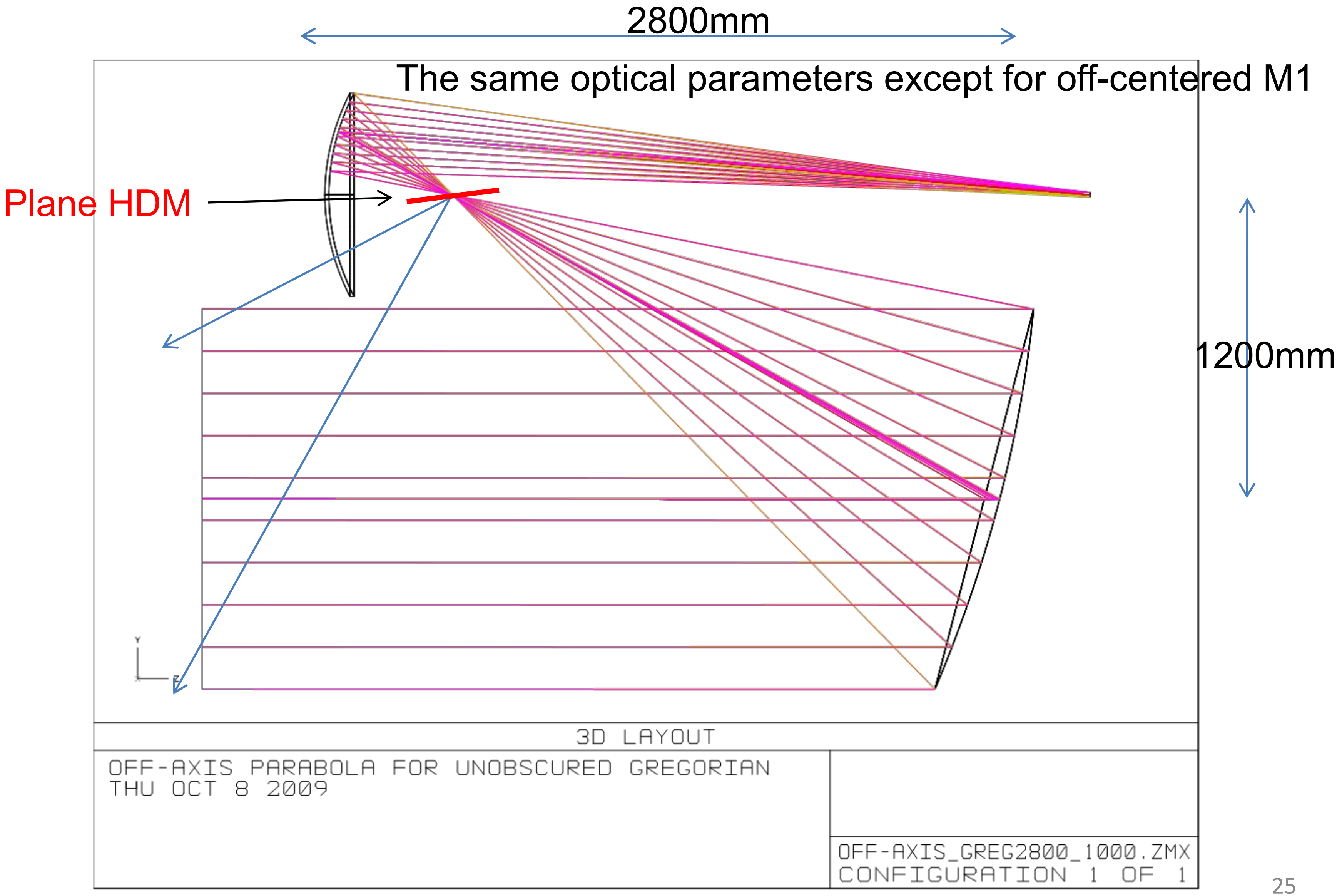
・largerer intrumental polarization (may be calibrated with continuum and sunspot obs.)

・harder to fabricate and validate M1 and M2 mirrors alignment

・higher non axi-symmetric structural and thermal deformation of telescope



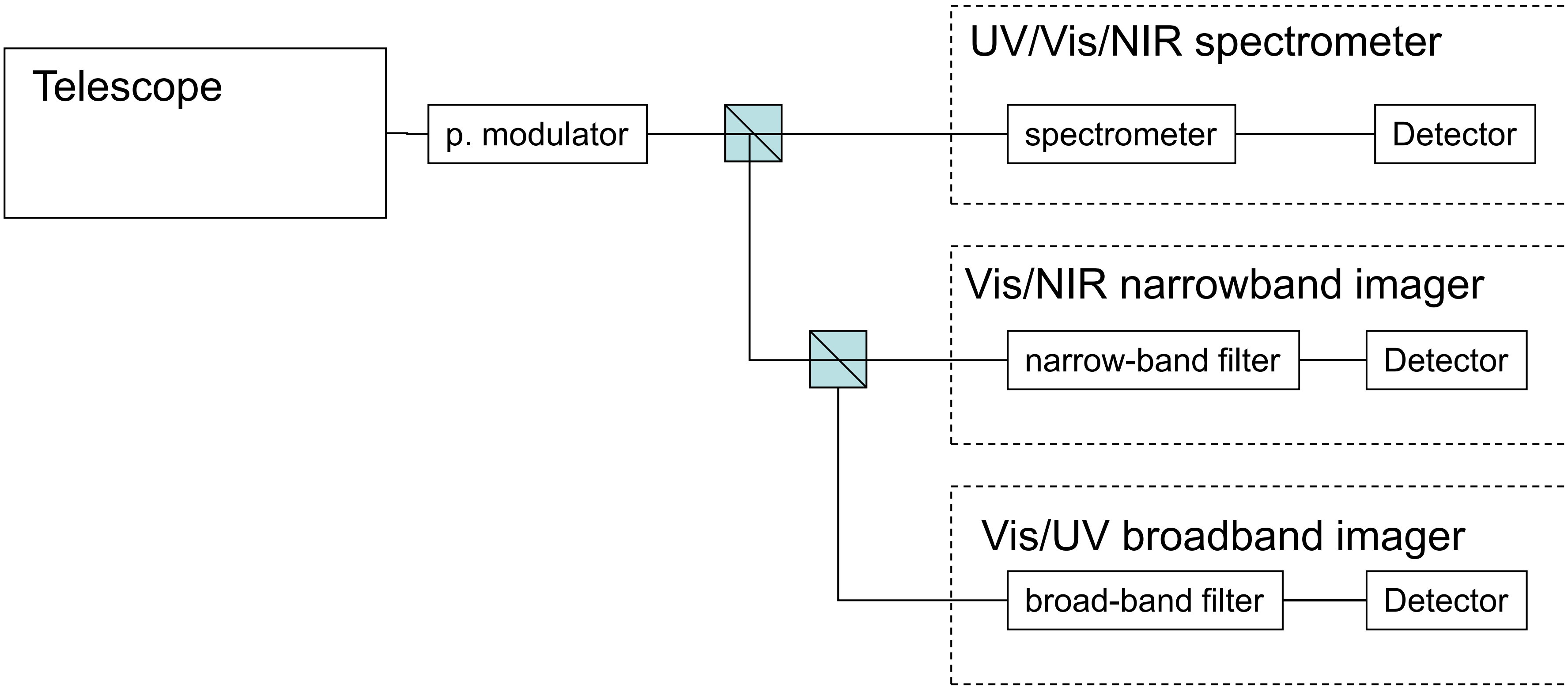
Off-Axis Gregorian



Preliminary choices of spectrum lines (most deluxe configuration)

Instrument	Spectrum line	wavelength	Purpose
Vis/UV broadband imager	UV continuum	~250nm	High res. Img of photospehre
	Mg II h/k	280nm	High res img of chromosphere
	CN band	388nm	Granules and magnetic elements
	G-band	*430nm*	*Granules and magnetic elements*
Vis/NIR narrowband imager +He D3	Mg Ib2	512nm	Low chromosphere V and B
	Fe I	525nm	Photosphere B
	Na ID1 (D2)	589nm	Low chromosphere V and B High photosphere
	Hα	656nm	High chromosphere V
	Ca II IRT	854nm	High chromosphere T, V and B
UV/Vis/NIR spectrometer +Ca II IRT weaker line	Mg II h/k	280nm	High chromosphere T and V
	Ca II IRT	854nm	High chromosphere T, V and B
	He I	1083nm	High chromosphere V and B

Block diagram of the optical configuration



Pixel size and FOV of the instruments

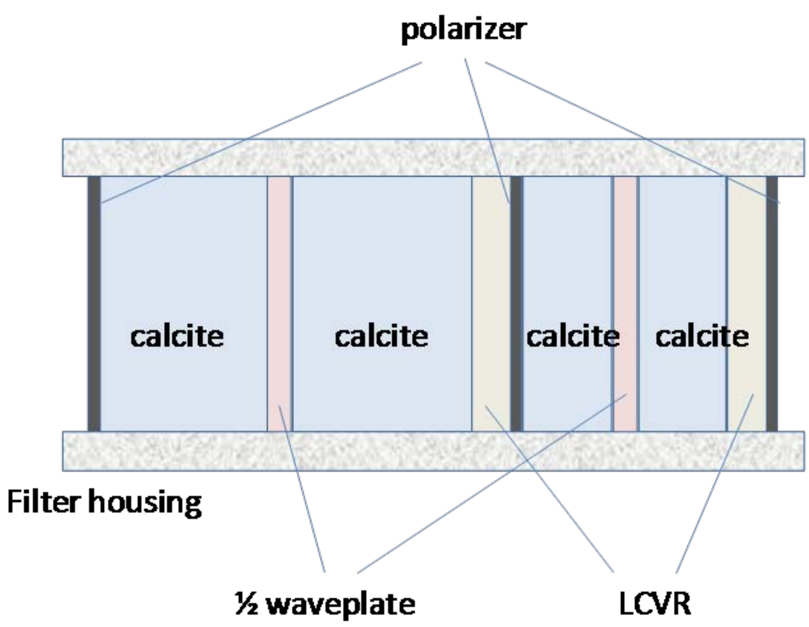
		FOV	Pixel size	Exposure	Note.
UV-Vis-NIR telescope	Broad band	164" x 164"	0.04"	< 1sec	• 2.5 pix sampling of **0.1"** res. • 4Kx4K detector
	Narrow band	246" x 246"	0.06"	< 1sec	• 2.5 pix sampling of **0.16"** res. • 4Kx4K detector
	Spectrometer	246" x 246"	0.06"	1sec (S/N~ 1600)	• 2.5 pix sampling of **0.16"** res. • 4K pix along slit
			0.12"	10sec (S/N~ 10^4)	

Basic requirements on TF (preliminaily)

- Wavelength range	TBD (a possibility 5000 – 8700A)
- band width (FWHM)	~100mA (50~70mA)
- Strehl	>0.9
- FOV	~200 arcsec w/ϕ1.5m (TBR)
- free spectral range	>5A
- tuning range	+/- 5A
- tuning speed	<50ms
- tuning resolution	<5mA
- repeatability	<2mA
- uniformity	
wavelength	5mA (TBD)
transmission	5%
- stability	
wavelength	5mA /day
transmission (flat)	1% /day
- Parastic light	<2%
- Ghost	<1%
-	

Choice of tunable filter

Lyot filter vs. Fabry Perot



Need Bubble-free design!
All elements can be attached with index matching oil?.

	Lyot filter	Fabry Perot
F (Speed of incident beam)	F~ 40	F ~ 200 (air space) ~ 90 (LiNb)
Necessary diameter of filter (D=1m, FOV=3’)	~40mm	~180mm, ~80mm
Transmission	~ 5%	~ 70%
Simultaneous 2-polarization	impossible	possible
Simultaneous multi wavelen	(in principle possible)	impossible
Structure	Complex	High accuracy
Oil	Necessary	Free
Control device	Rot. waveplate or liquid crystal	Piezo or LiNb
Past experience	SOT/Hinode	LASCO C1/SoHO
Concern	- Contact of opt. elem.s (avoiding bubble) - Mounting calcites - Outgas - Calcite availability	- Mount and control for high accuracy surfaces (thermal/mech. stress) - Endurance of coaring - Stability of inhomogeneity

Filter diameter, L_{min} = image size = F*D*(W/60/180*π) = 0.0003*F*D*W (cm, Telecentric)

D: aperture, cm、 W: FOV, arcmin、 F: F-ratio

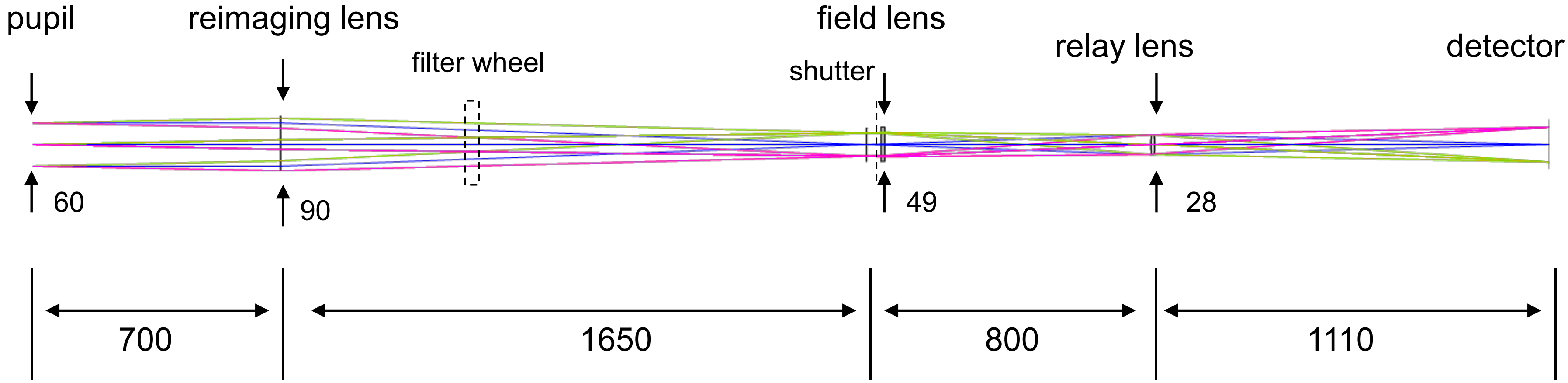
Need of 2-dimensional spectroscopy

- Rapid motion of chromospheric materials are ubiquitously seen associated with eruptions, jets, and wave propagation.

- There are several options under investigation to achieve the 2D spectroscopy in SOLAR-C.
  - Double pass spectrograph
    - Slot spectroscopy with medium wavelength dispersion
  - Tunable filter-type instruments with rapid wavelength tuning
    - Fabry-Perot or Lyot
  - Integral field spectroscopy
    - Fiber-optics bundle or image slicer

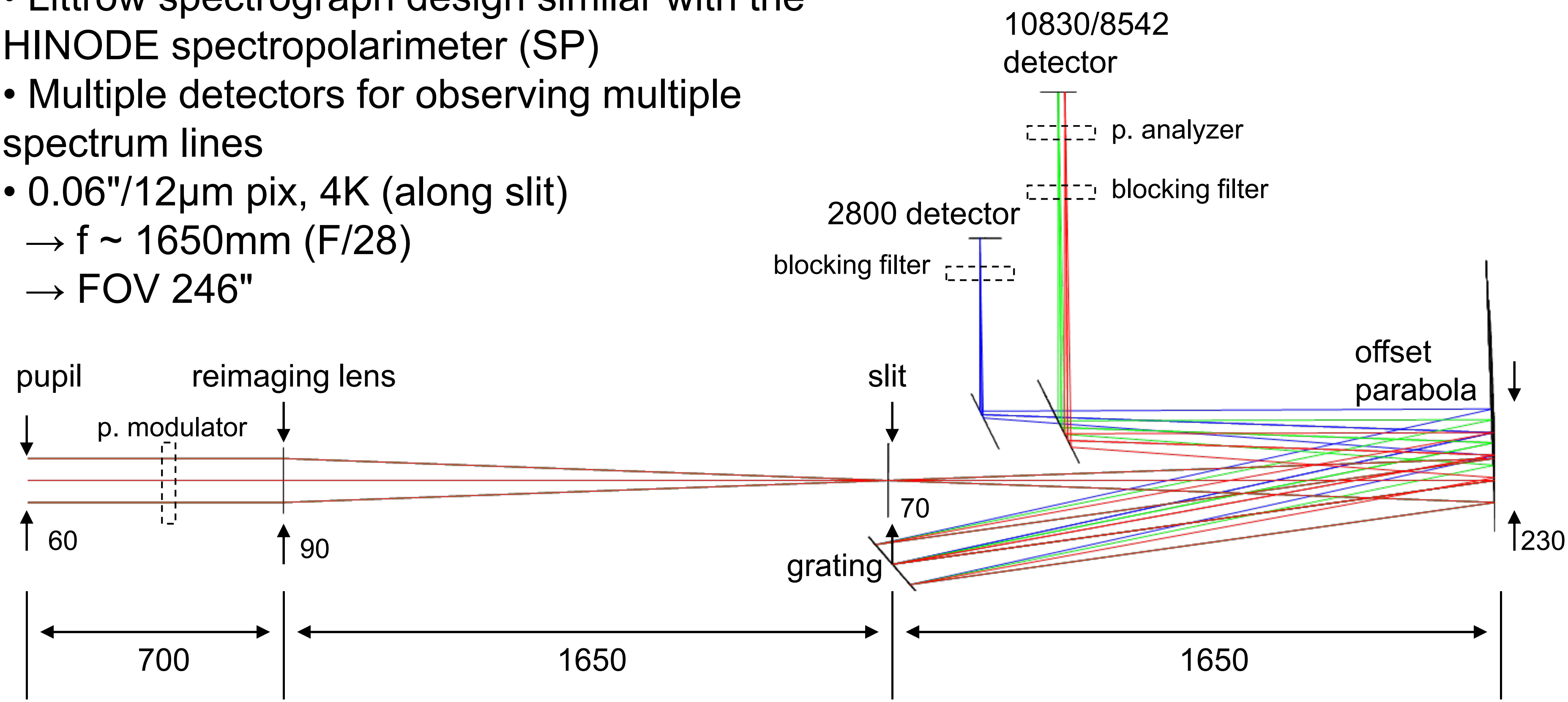
Broadband imager layout

- Similar design with the HINODE broadband filter imager (BFI).
- The rotating shutter is located near the focal plane
- 0.04"/12μm pix, 4Kx4K
  → f ~ 2470mm (F/41)
  → FOV 164"



Spectrograph layout

- Littrow spectrograph design similar with the HINODE spectropolarimeter (SP)
- Multiple detectors for observing multiple spectrum lines
- 0.06"/12μm pix, 4K (along slit)
  → f ~ 1650mm (F/28)
  → FOV 246"

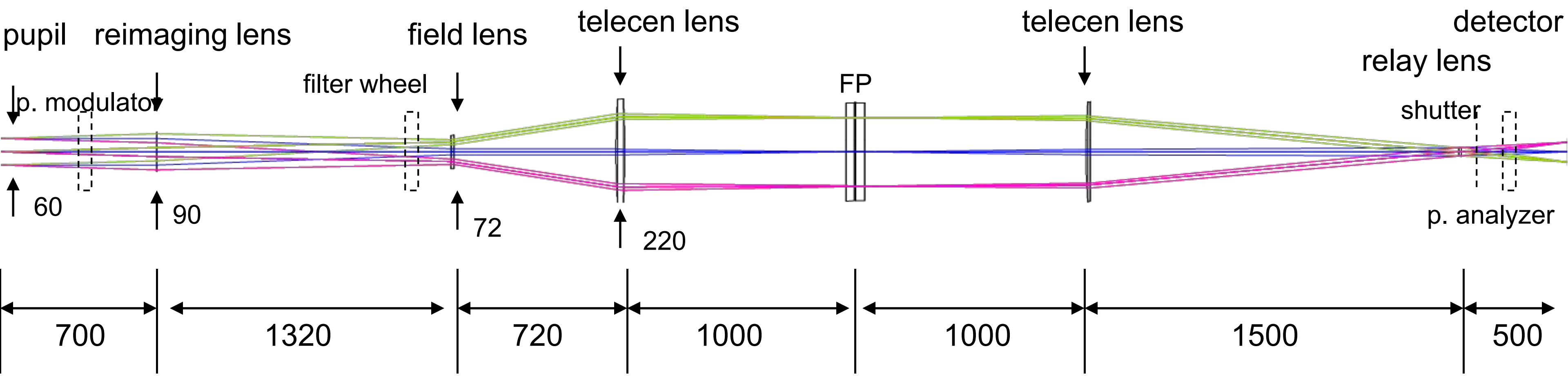


blaze angle	56°
groove	80lines/mm

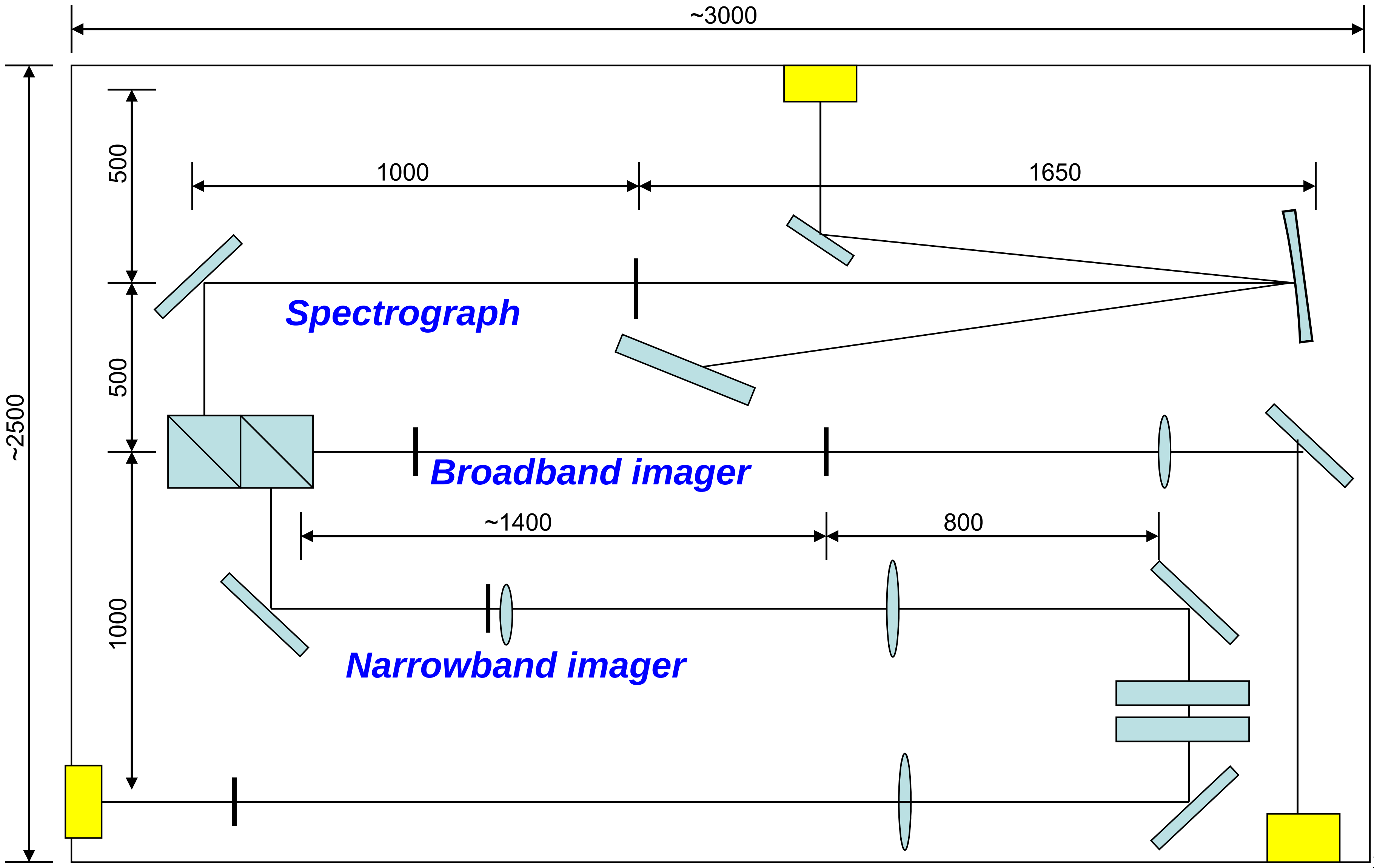
λ	Order	dispersion
2800A	73	7.0mÅ/12μm
8542A	24	21mÅ/12μm
10830	19	27mÅ/12μm

Narrowband imager layout

- Telecentric configuration to have uniform wavelength over FOV.
- Large F (F>150) at the Fabry-Perot etalon.
- The shutter is located near the exiting-pupil.
- 0.06"/12µm pix, 4Kx4K
  → f ~1650mm (F/28)
  → FOV 246"



Strawman layout of the focal-plane package



Items to be further studied

- **Priority of the spectrum lines** (wavelength coverage)
  - Either spectrograph or filtergraph for each line

- Telescope thermal design
  - Radiator configuration for cooling M1
  - Development of UV-reflective and low solar absorption coating
  - Axi-symmetric vs. off-axis design

- Configuration of the narrowband filtergraph
  - Fabry-Perot or Lyot (telecentric or collimated)
- Configuration of the spectrograph
  - Multi-slit (or image slicer) or IFU (integral field unit) spectrograph to achieve high time res.
  - Multi-wavelength simultaneous obs. or multi-wavelength obs by switching filters (and tilting a grating).
- Availability of large format detectors
  - IR detector for He I 10830
  - UV enhanced detector for Mg II h/k