Doc MagAOX-001
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MagAO-X PDR
2.1 Optical Mechanical Design Overview

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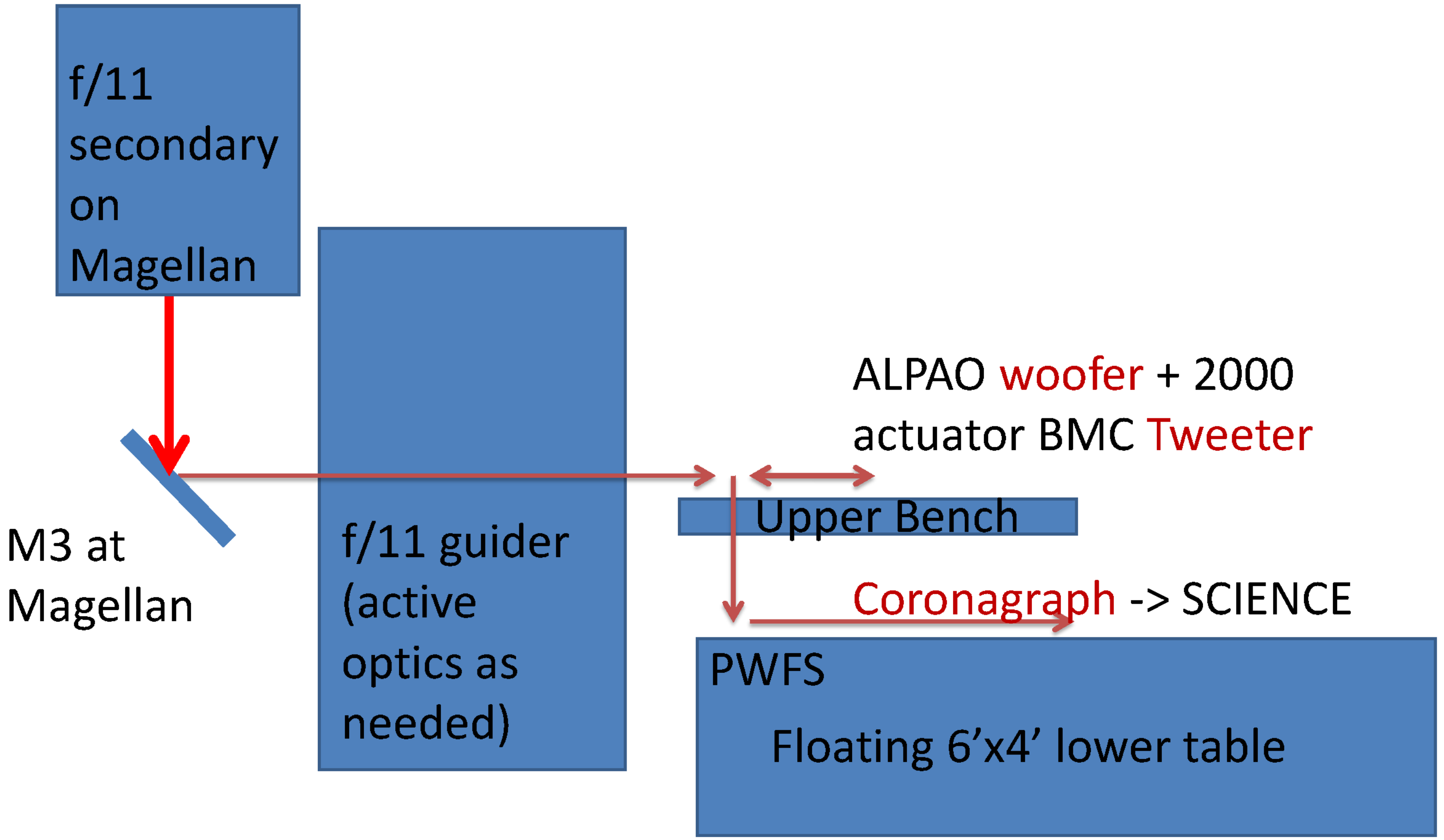
MagAO-X OptoMech Design Philosophy

The MagAO-X PDR design is based on our experiences with 5 years of high-contrast AO at Magellan and lessons learned from the current generation of ExAO systems (like SECxAO)

1. MINIMIZE FLEXURE and NCP VIBRATIONS: The design almost eliminates issues with NCP vibrations through use of a stiff floating optical table. It is gravity invariant. Our LOWFS should track and mitigate any NCP vibrations that are missed by the PWFS.
2. MINIMIZE NCP WAVEFRONT ERRORS: The design limits NCP errors by building the PWFS feed deep into the heart of the instrument. Also post-coronagraphic errors can be sensed with our flexible LOWFS concept which is common path with almost all the powered optics.
3. MINIMIZE OPTICAL AND CHROMATIC ERRORS: All reflective (silver) optics design with very tight polishing specs. Use an advanced triplet ADC design without on-axis ghosts.
4. MINIMIZE MISALIGNMENT ERRORS: Use all 2inch (or smaller) stainless steel mounts on Stainless table to minimize temperature effects (which are small at Magellan). Automatic pupil sensing and correction. Automatic re-alignment of masks and wheels.
5. MINIMIZE DUST CONTAMINATION: Use completely sealed instrument that doesn't need to be opened during regular observations
6. MINIMIZE INSTALLATION AND CALIBRATION COMPLEXITY: Must be able to work with either the f/11 facility secondary or the MagAO f/16 ASM. Must be able to have internal interaction matrices that can be made in daytime at scope (internal, deployable fiber source).
7. ALLOW DIFFERENT CORONAGRAPHS AND LOWFSs TO BE TESTED: we have 2 focal plane wheels and 2 pupil plane wheels allowing a wide range of coronagraphs to be remotely deployed (From Simple vAPPs to PIAACMCs systems).
8. ALLOW DIFFERENT SCIENCE CAMERAS AND SPECTROGRAPHS: while the initial science camera is a pair of EMCCD SDI cameras there is room (post coronagraph) to deploy fiber fed spectrographs like RHEA or MKIDs cameras.
9. SHIPPING SHOULD BE ROUTINE: The instrument must be safe and easy to pack and unpack.

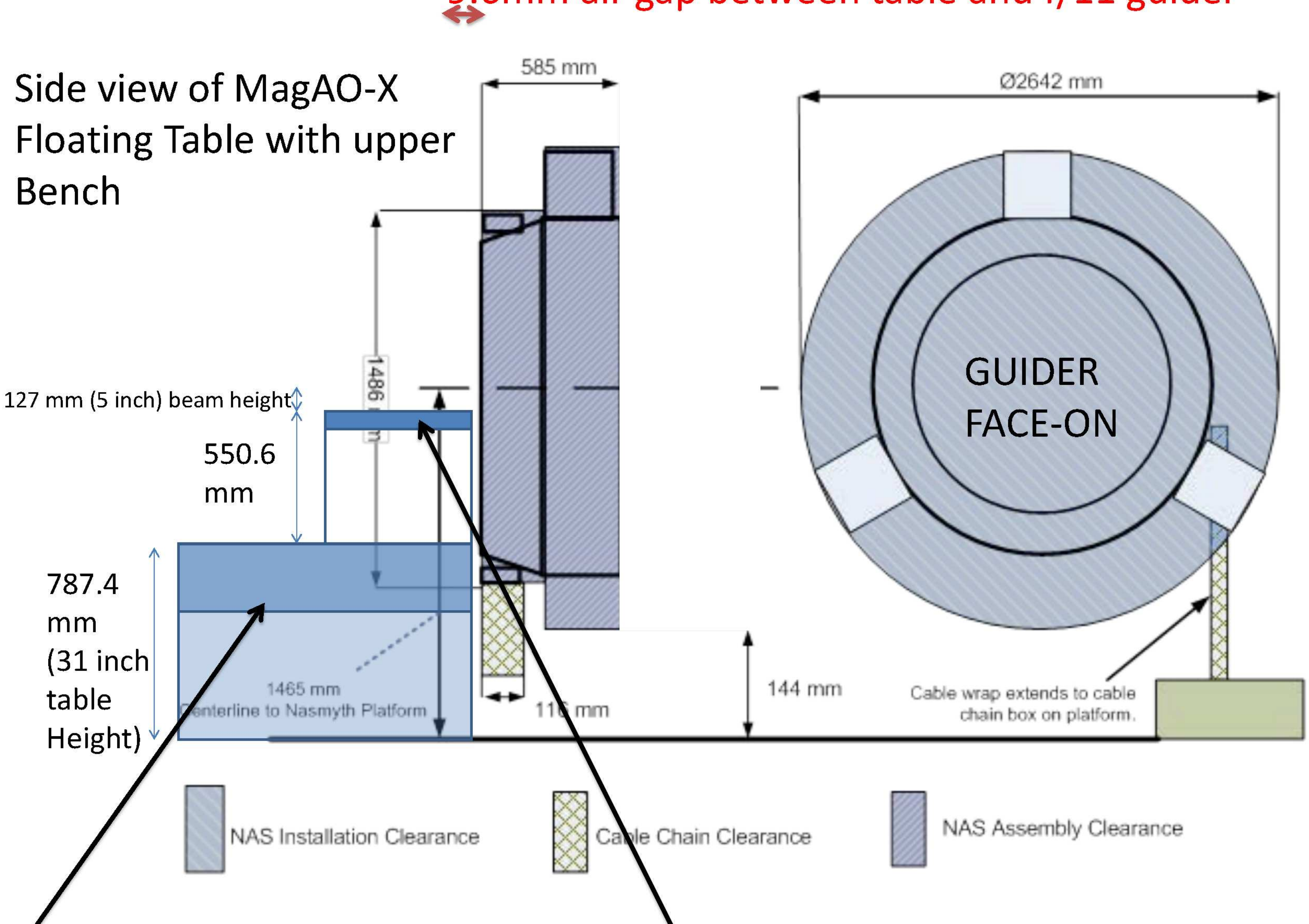
Conceptual design of f/11 MagAO-X optics with Coronagraph



MagAO-X Summary:

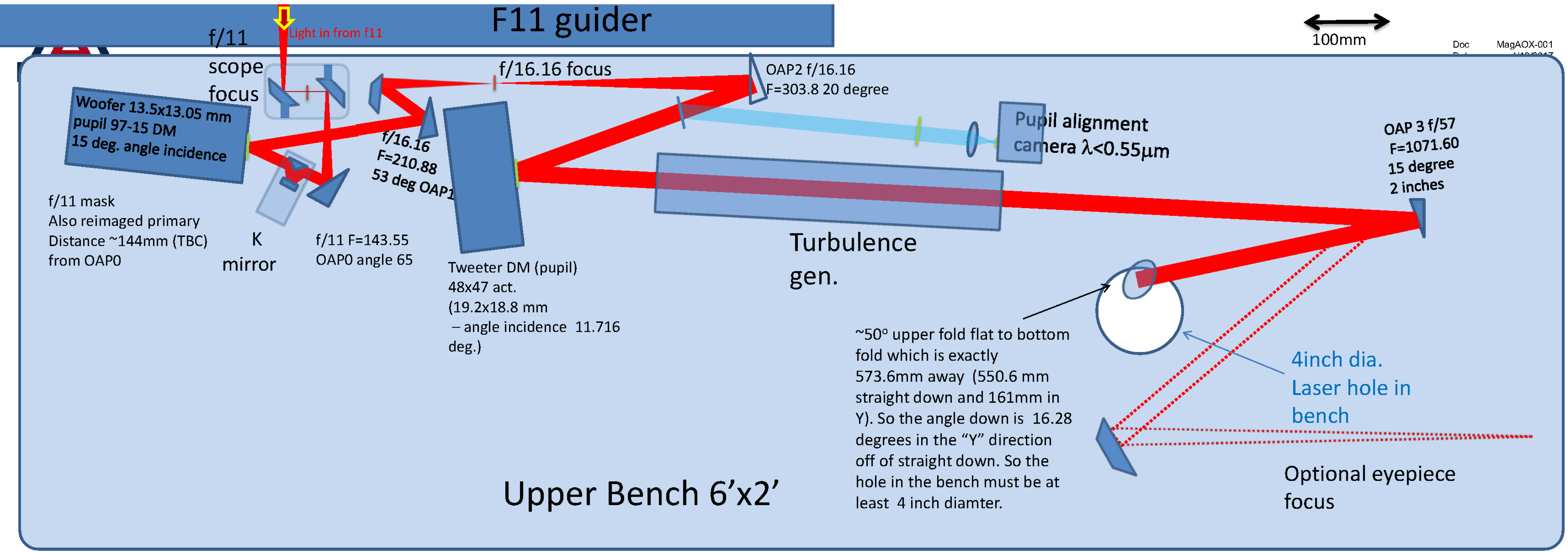
~80% Strehl at 0.65 microns + PIAACMC coronagraph with **Contrasts of 10^{-5}- @50 mas and 10^{-6} @150 mas** on a 5th mag star in median conditions.
Also can feed MKID or RHEA IFS R=60,000 (PI Ireland)

9.6mm air gap between table and f/11 guider

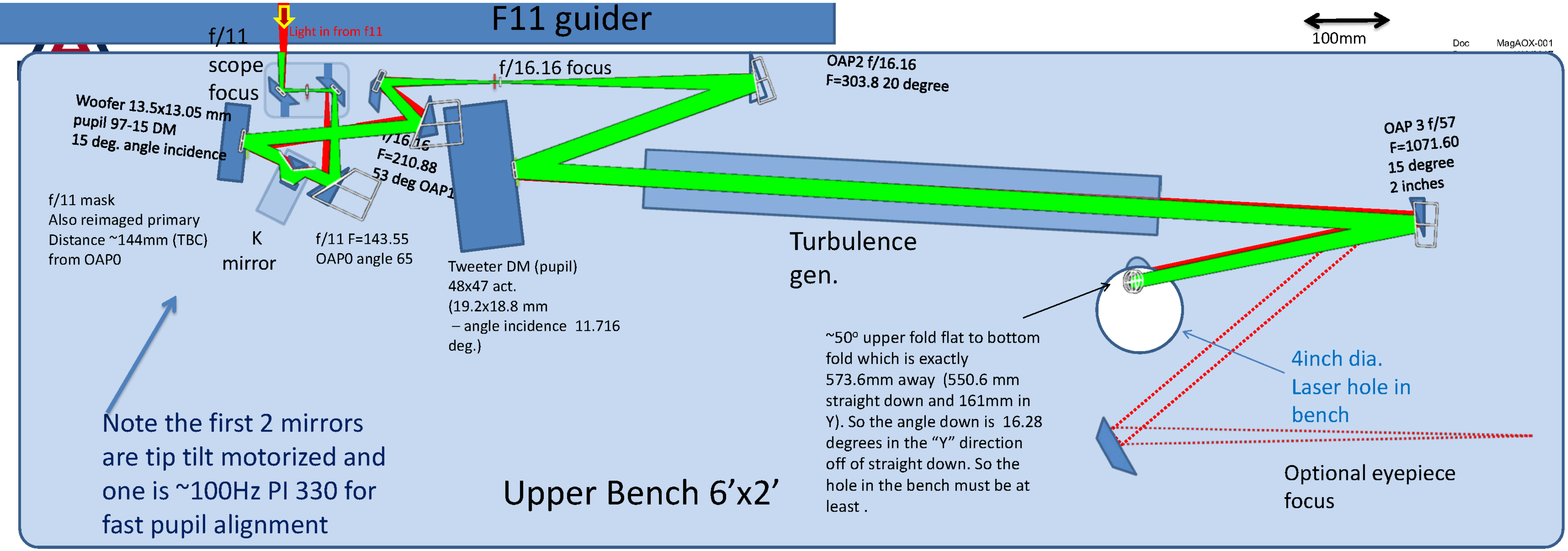


Lower 6’x4’x1’ TMC research grade optical top

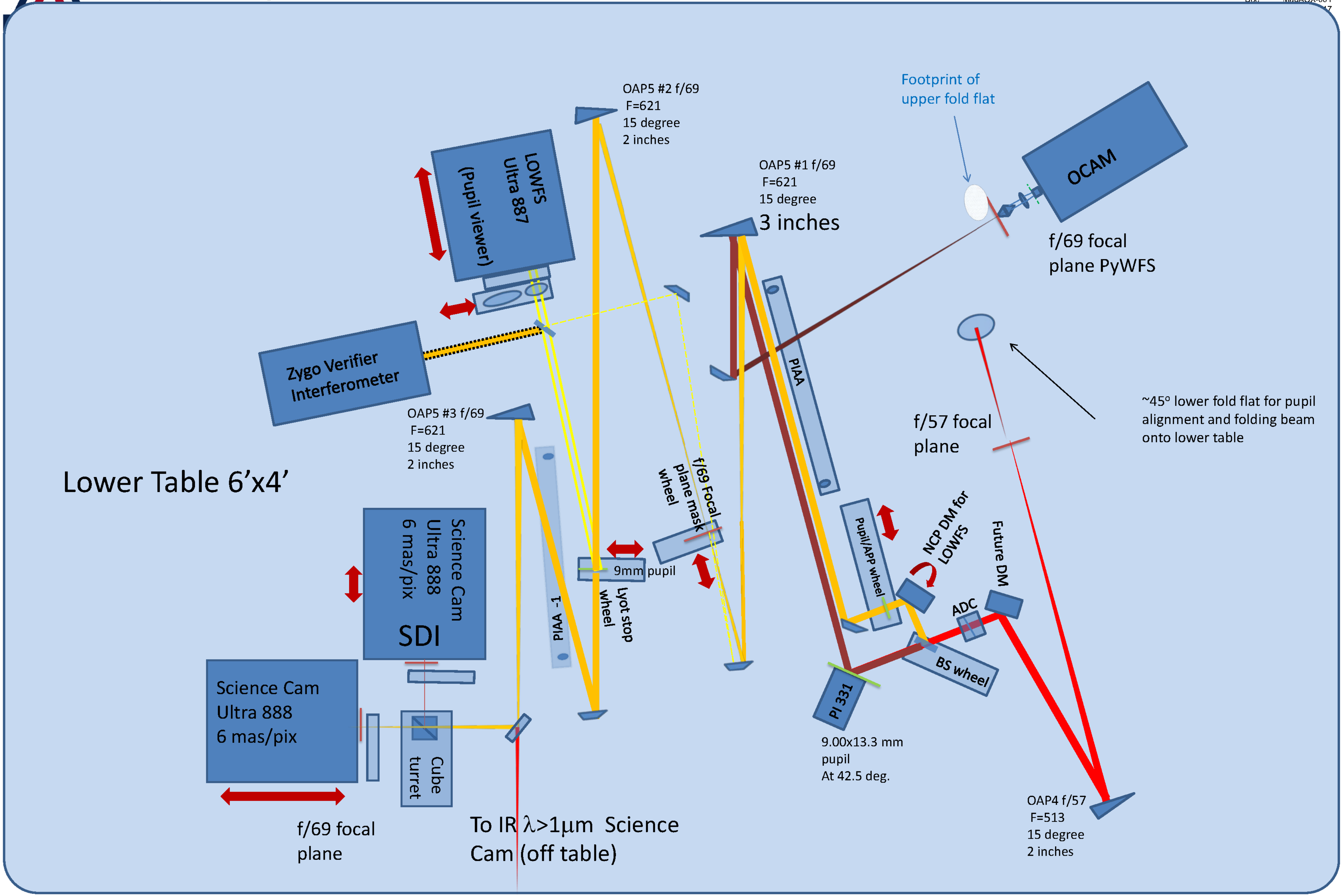
Upper 2’x6’x4” TMC research grade optical breadboard (aligned with Table)



Analytical concept of the f/11 feed to the Woofer and Tweeter on the upper bench



Zemax design in Green – agrees with our analytical optical design, OAPs and pupils correct in ZEMAX.


Lower Table 6'x4'
OAP5 #2 f/69 F=621 15 degree 2 inches
LOWFS Ultra 887 (Pupil viewer)
Zygo Verifier Interferometer
OAP5 #1 f/69 F=621 15 degree 3 inches
Footprint of upper fold flat
OCAM
f/69 focal plane PyWFS
PIAA
~45º lower fold flat for pupil alignment and folding beam onto lower table
f/57 focal plane
OAP5 #3 f/69 F=621 15 degree 2 inches
f/69 Focal plane mask wheel
Science Cam Ultra 888 6 mas/pix
SDI
PIAA -1
9mm pupil
Lyot stop wheel
Pupil/APP wheel
NCP DM for LOWFS
Future DM
ADC
BS wheel
PI 331
9.00x13.3 mm pupil At 42.5 deg.
OAP4 f/57 F=513 15 degree 2 inches
Science Cam Ultra 888 6 mas/pix
Cube turret
f/69 focal plane
To IR λ>1μm Science Cam (off table)

Selected Key MagAO-X Components

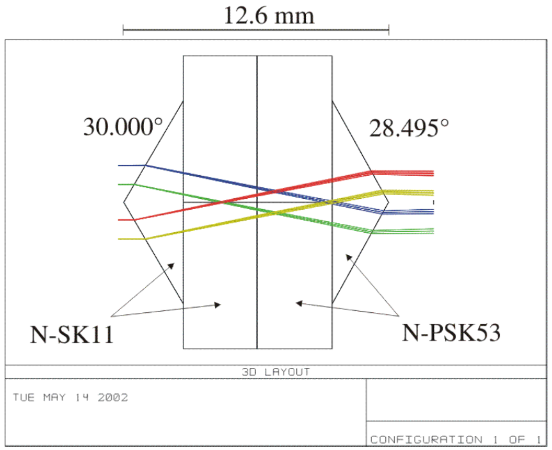
Based on our experiences with MagAO we could identify “tried and tested” sets of controllers/motors/gears/wheels/pinons that already perform well at Magellan for many years maintenance free.

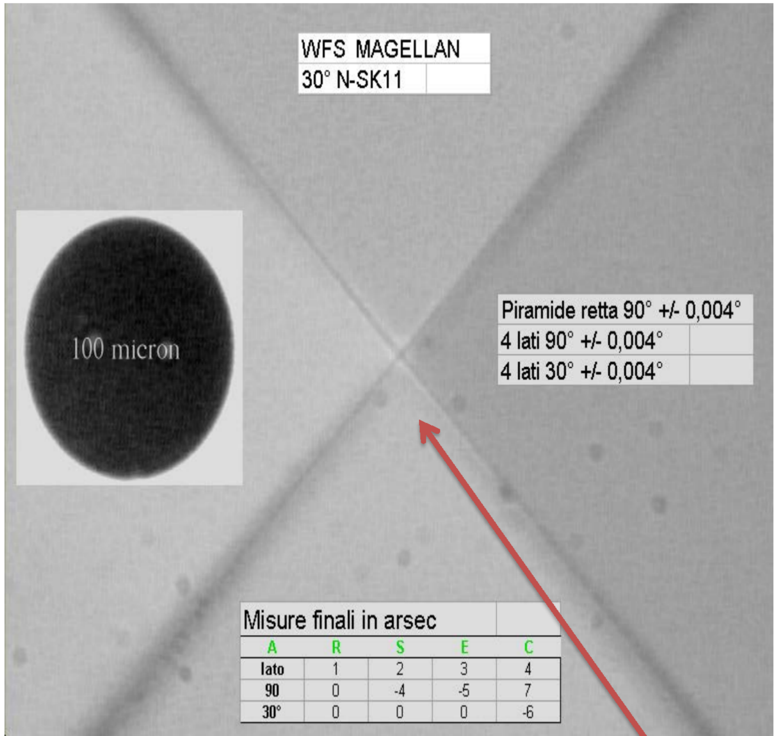
We have also identified long lead time optics (such as the pyramid optic for the PWFS) and have that fabricated ahead of time.

We also identified a series of low thermal drift stainless steel optical mounts, that were also low stress for our flats and OAPs.

Also we have identified a vendor with excellent coatings for our SDI differential Hα camera. Moreover we will feed the 2 SDI cameras at 90 degrees through a dichroic beamsplitter cube. Hence we should be able to image at Ha and the continuum simultaneously with around ~95% transmission of the Ha photons (this is a large improvement over MagAO’s ~20% transmission of its current SDI optics).

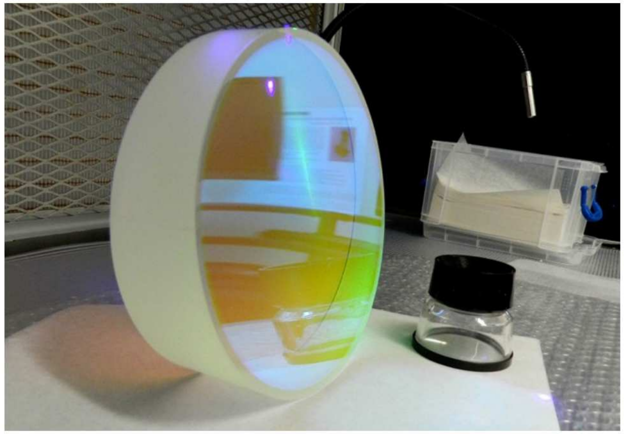
Pyramid Optics for PWFS: In Hand



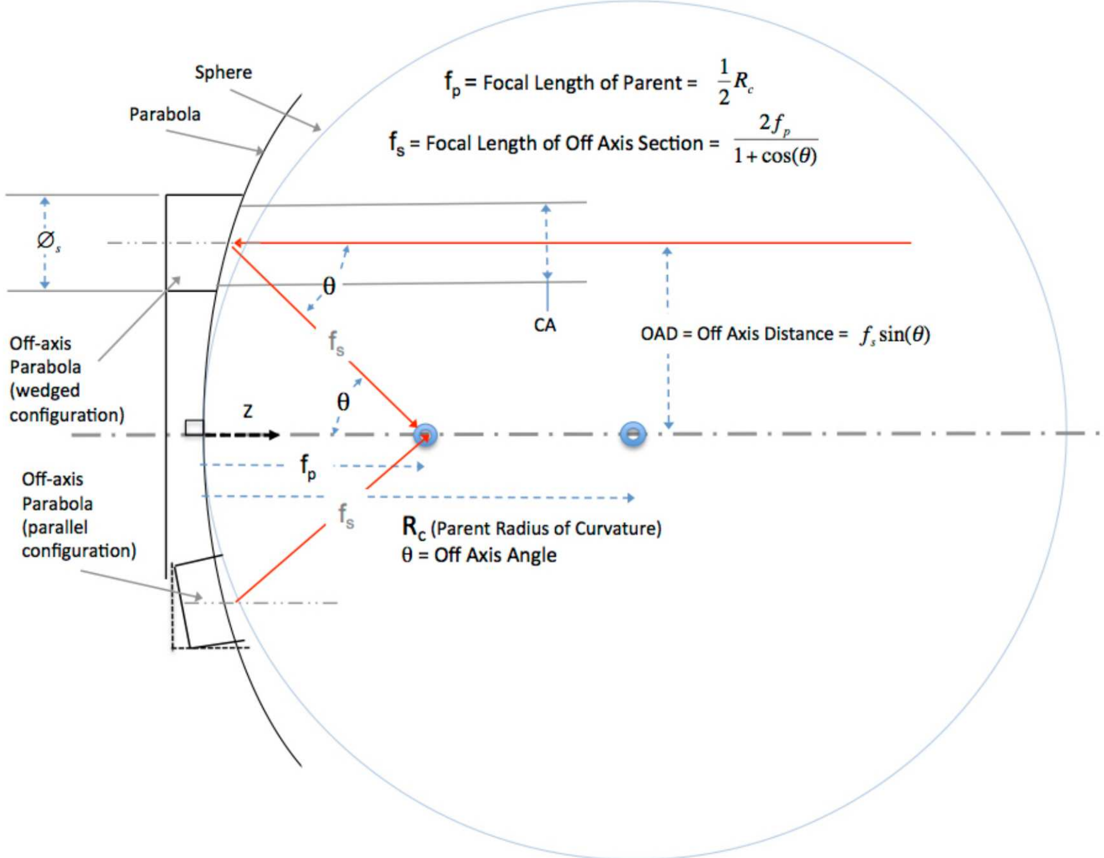


Very high quality tip

All powered Optics are OAPs

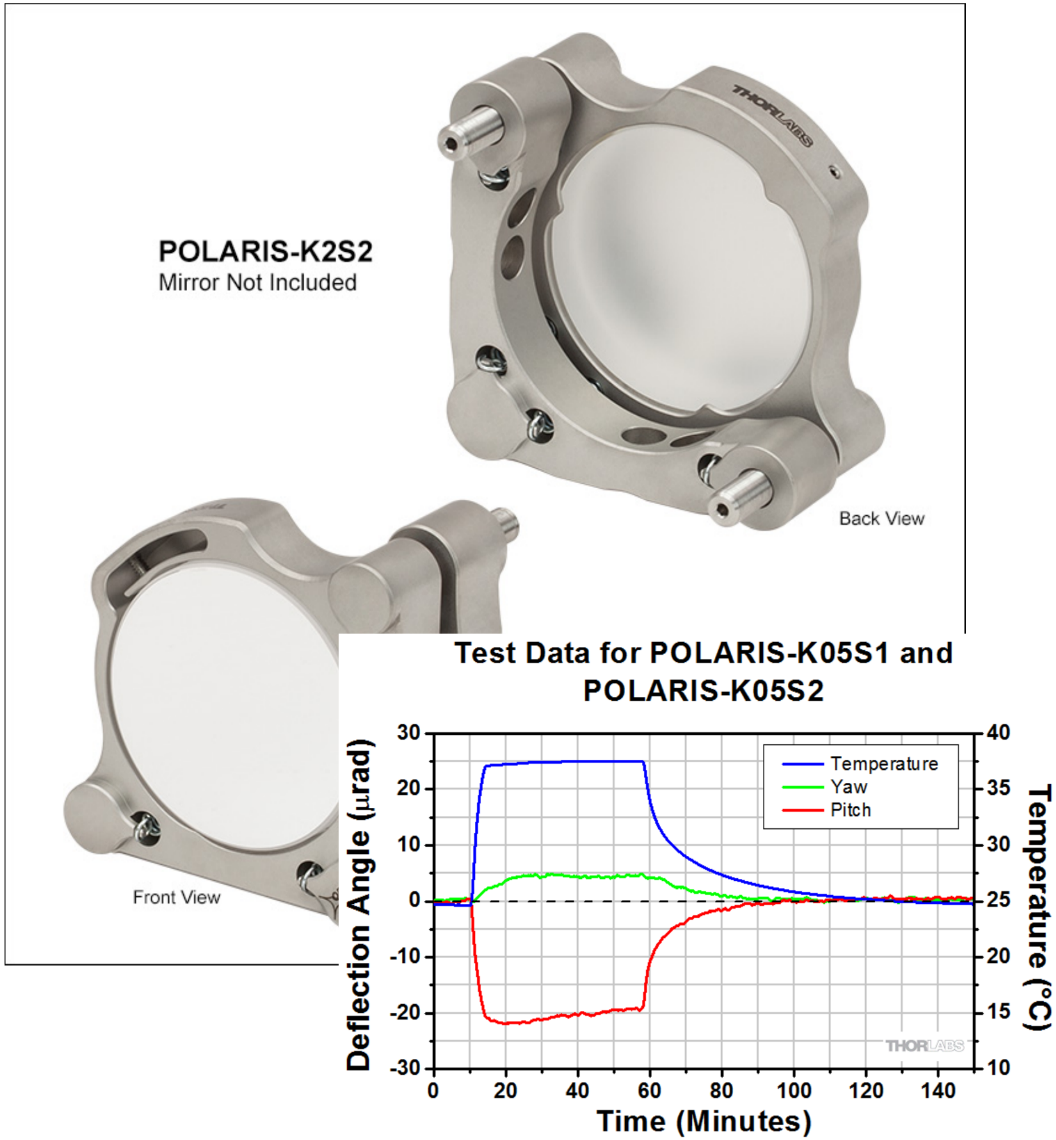


Aperture Optical Sciences (AOS) OAP



Main Paramerters of AO Design **								
AO ASM f/ratio	dia. of 48 act tweete	weeter to have 47 act dia	Second f/#	dia. of Corono beam	Final f#	f11 f/#	dia. of Woofer	Ang. Inc. on woofer
16.16	19.2	11.716	57	9	69	11.02	13.5	15
FS (vertex focus) mm	theta (deg)	FP (parent focus) mm	Off Axis Dist. OAD	OAD to inner edge of 2in	effective f/	optic size	name	
143.7007616	65	102.2154911	130.2372804	104.8372804	11.02	2inch	OAP0 f/11 collimates 13.05mm pupil	
210.7263437	53	168.7721295	168.2938153	142.8938153	16.16	2inch	OAP1 makes f/16.16 focus	
303.8078076	20	294.6468388	103.9086229	78.50862292	16.16	2inch	OAP 2 -- f/16 collimator to 18.8mm twe	
1071.599321	15	1053.342306	277.3509467	251.9509467	57	2inch	OAP3 -- makes f/57 focus	
513	15	504.2599338	132.7744735	107.3744735	57	2inch	OAP4 collimates 9mm pupil	
621	15	610.4199199	160.7269942	135.3269942	69	2inch	OAP5 x3 for Corono	

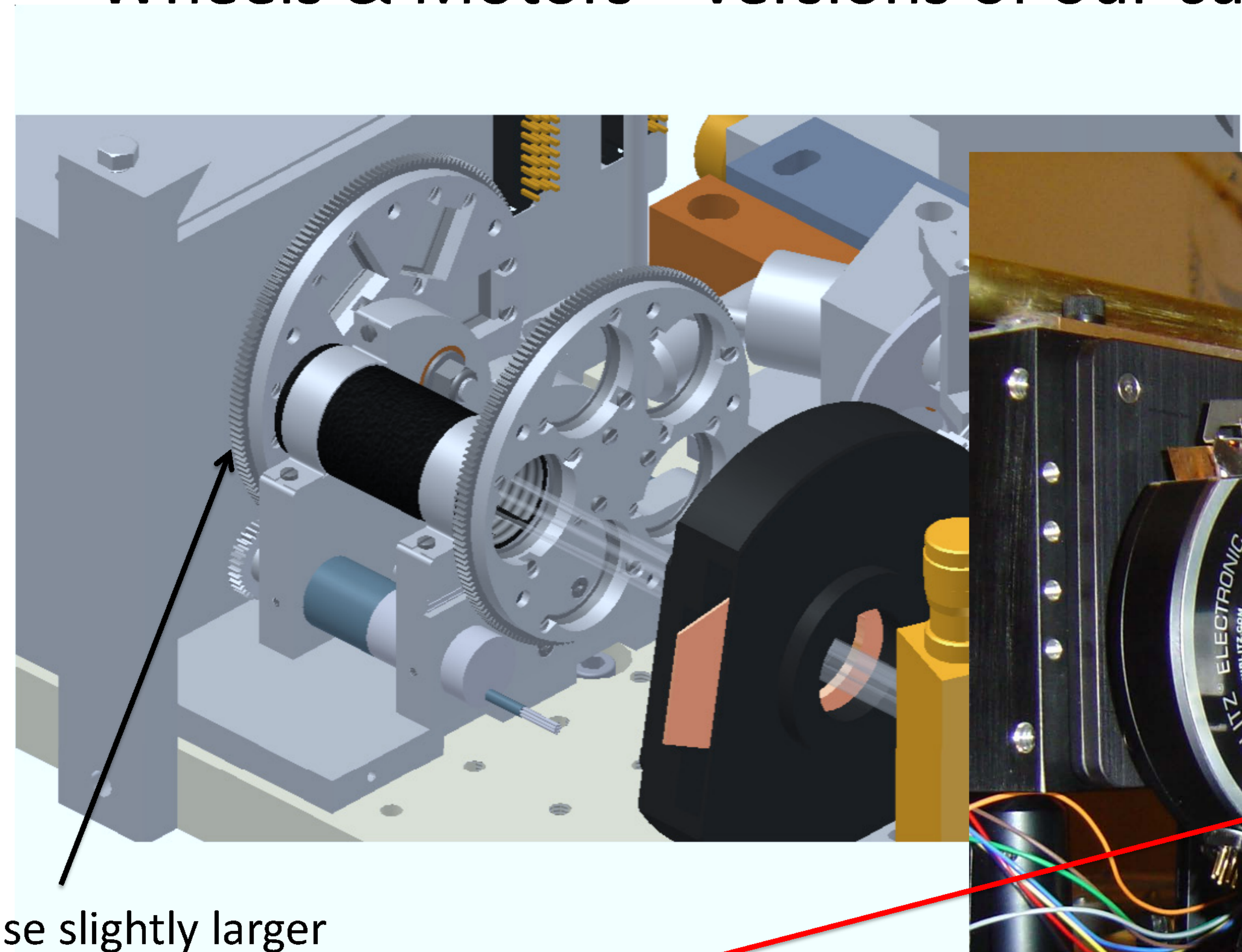
2inch OAP & Fold Mirror Mounts

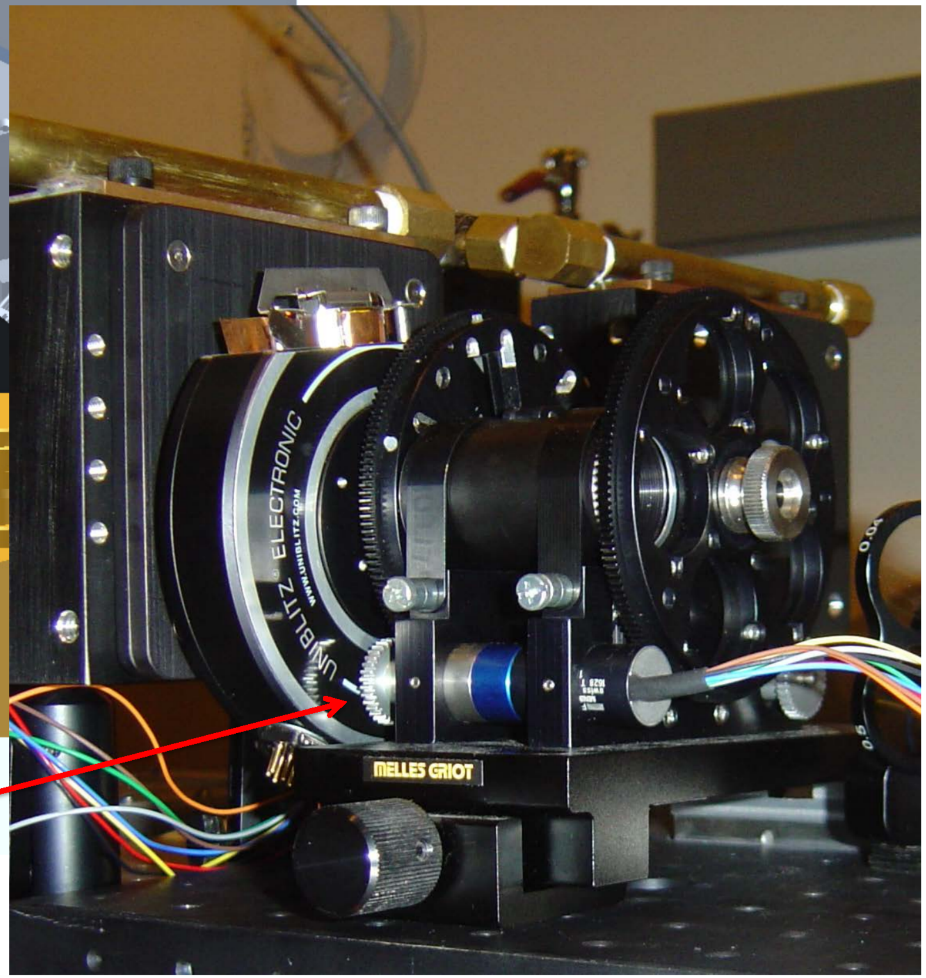


--Monolithic and Spring Flexure Arms Provide Highly Stable Mirror Retention
--Matched Actuator Threading Minimizes Drift and Backlash
--Heat Treating Stainless Steel Minimizes Temperature-Dependent Hysteresis
--Sapphire Seats Ensure Long-Term Stability

HOW MUCH TILT DUE TO TEMP CHANGES?
--in one MagAOX night only expect 5C change hence only 4µrad of tilt
-- 4µrad/night of tilt is 57µm over the whole 8.2m pathlength which is just over a pixel/night of drift (open loop)
-- with the loop closed it is only 0.6m of NCP path -and so just 4 µm / night.
-- This very slow motion can easily be completely corrected by stacking the SDI images post-detection.

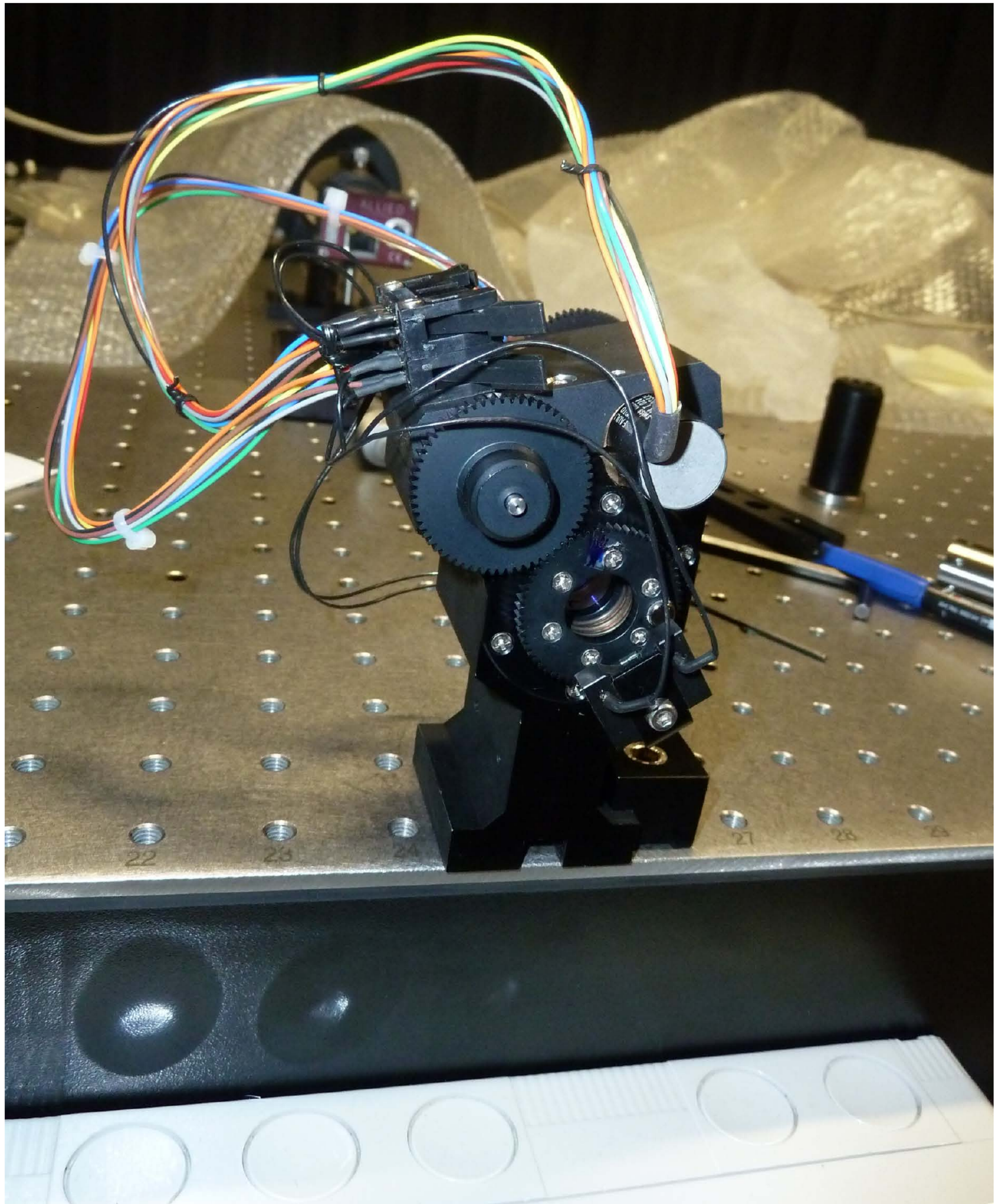
Wheels & Motors --versions of our current VisAO wheels



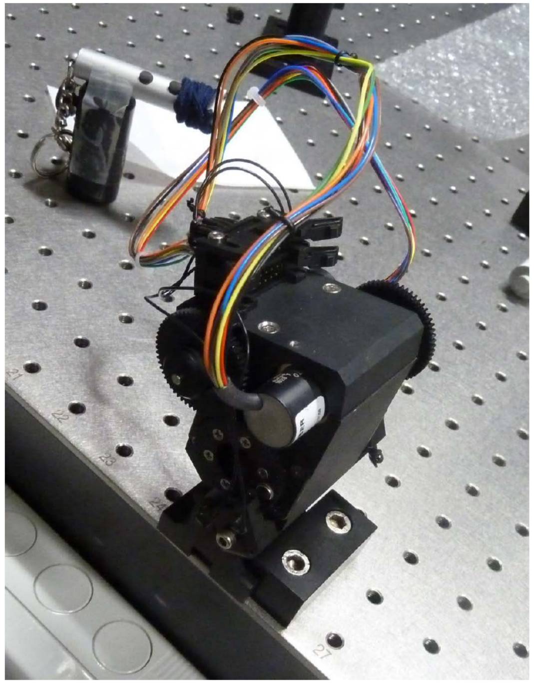


Use slightly larger version with spring loaded pinon and Faulhaber motors with 1:66 gear reducers

ADC (modified version of MagAO ADC)



- Very Compact
- Well understood optomech design
- Same motors



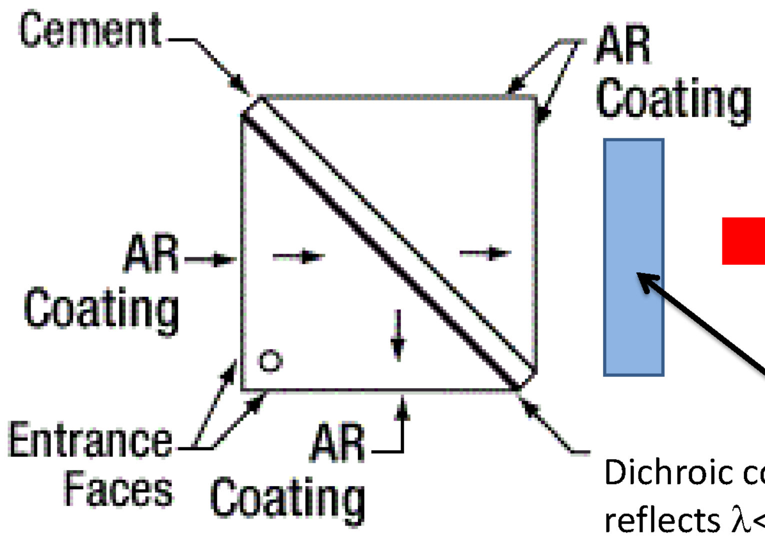
Linear Stages

PI M-406 Precision Linear Stage
Cost-Effective With High Guiding Accuracy –high load crossed bearings
Can Drive the LOWFS and Main Utra 888 EMCCDs 150 mm for phase diversity and focus uses

PI N-565 Linear Positioner with the Highest Precision
NEXACT® Piezo Stepping Drive with Subnanometer Encoder Resolution
will drive all the Pupil & mask wheels by up to 13mm with no vibration or heat when powered off.

SDI Beamsplitter (Hα, also r' & i' SDI)

In-coming f/69 beam, 15x15mm



Transmitted "continuum" Beam:
666-670nm
Greater than 90% of original beam transmitted

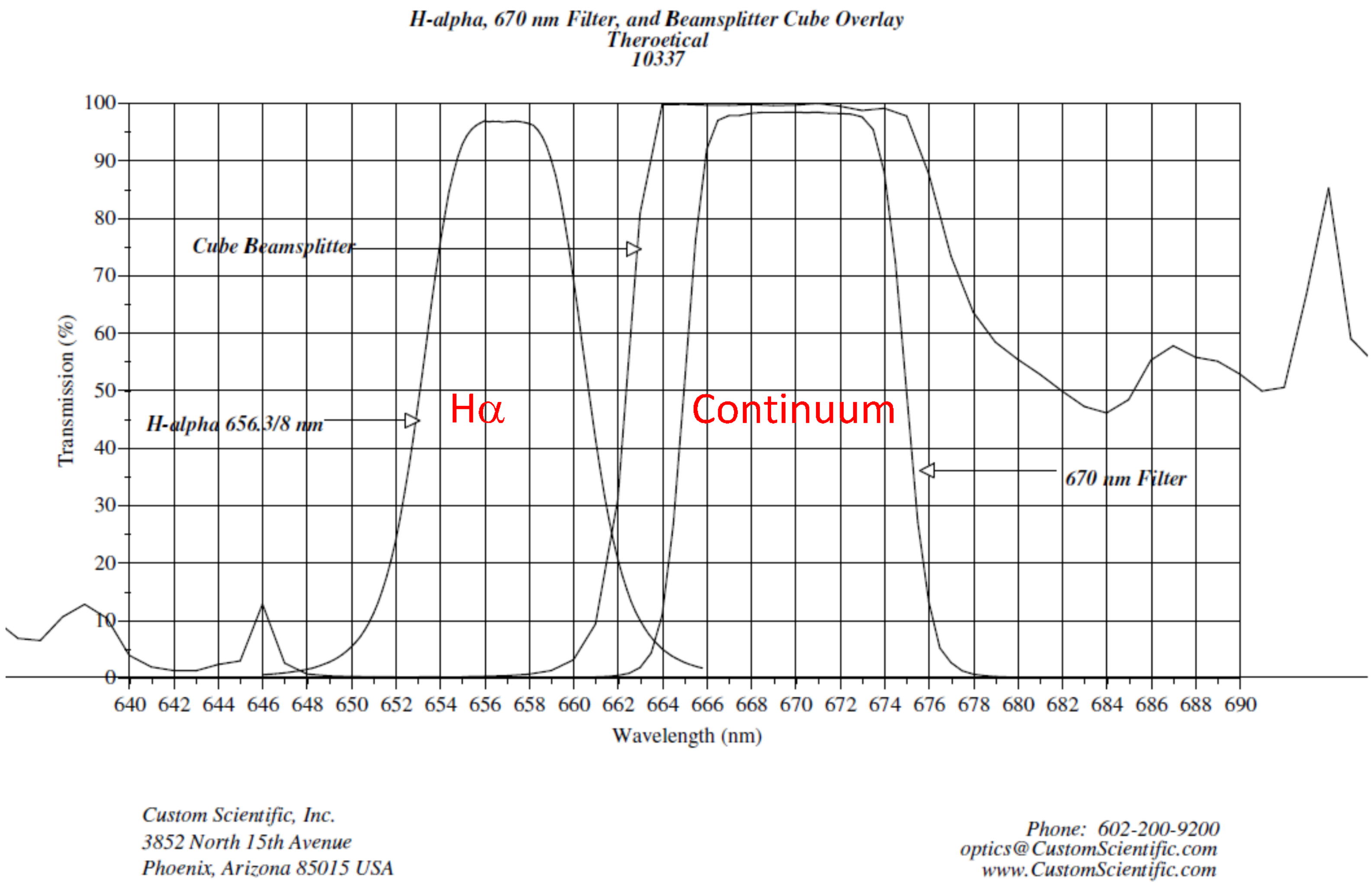
Dichroic coating reflects λ<659 Transmits λ> 666 nm

Narrowband 666-700 nm single substrate filter

Reflected "H-alpha" Beam:
654.3-658.3nm
Greater than 90% of original beam reflected

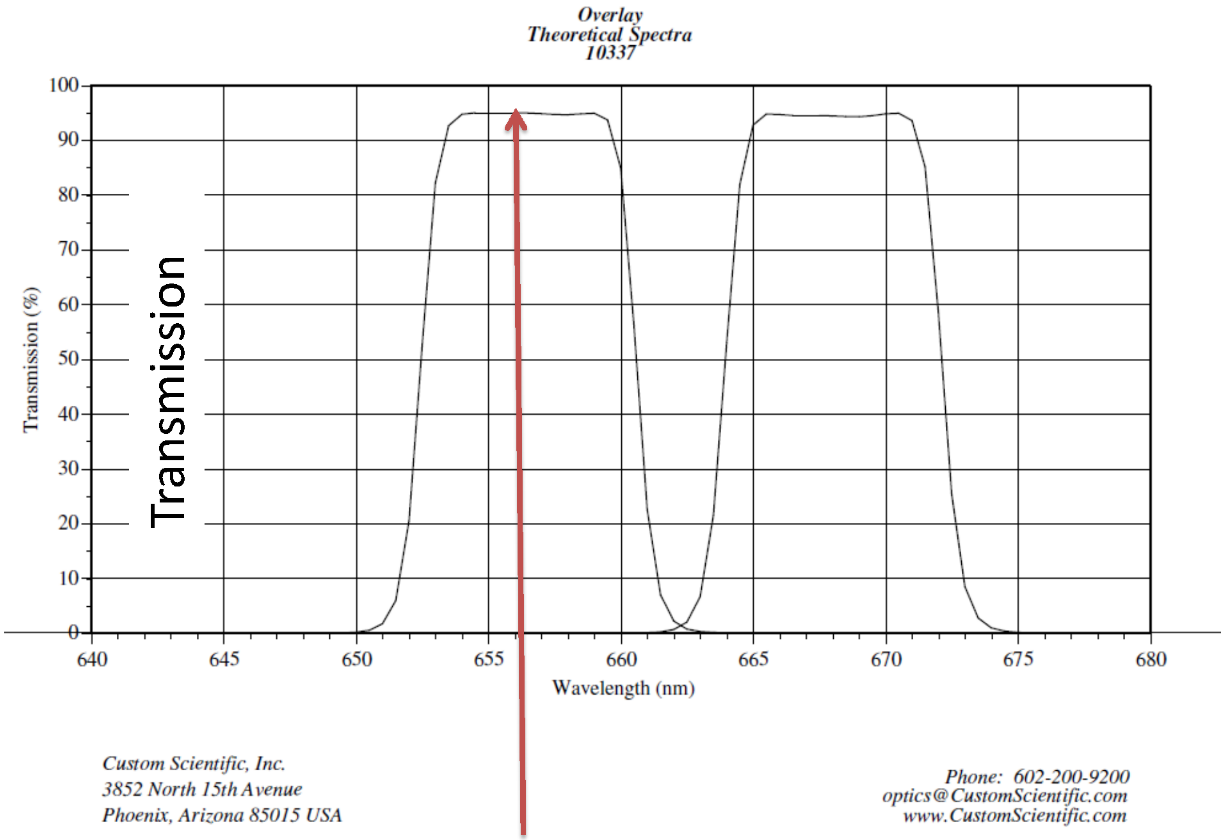
Narrowband 654.3-658.3nm single substrate filter

Halpha SDI design with ~95% Throughput



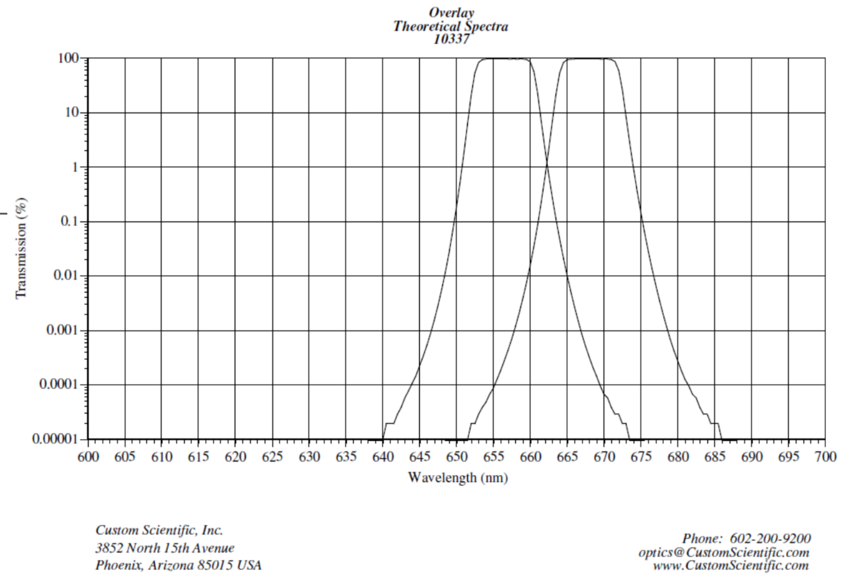
Doc MagAOX-001
Date: 4/18/2017
Status:Draft v. 21

SDI Hα (656nm) and (668 nm) Continuum Cube Filters



Hα at 656.3 nm
at >95% Transmission

Blocking <0.01% leak at Hα



OPTICAL DESIGN

- Zemax design by Oli Durney (Senior Optical Engineer Steward Observatory) from initial analytical design
- The design is all reflective (save the ADCs)
- All the powered optics are OAPs (eliminates ghosts and chromaticity)
- The ADC design is diffraction-limited from 1-2 airmasses and from 0.6 to 1.8 microns. The ADC is commonpath with the PWFS and the science cameras.
- The design was first analytically done by Laird Close and then done with zemax by Oli Durney. Both designs are in excellent agreement.
- The true aperture stop (the primary mirror) is relayed to the Woofer pupil to the Tweeter pupil to the first coronagraphic pupil to the Lyot stop.
- The first coronagraphic focal plane is f/67 and is the location of the coronagraphic mask
- The final focal plane is after the Lyot stop and is also f/67 yielding a 6mas/pixel platescale on the Ultra 888 science camera.
- The optical quality of the on-axis beam has a Strehl 100% (with perfect optics) over any broad band astronomical filter that we would use (such as r’,i’,z’,J, H).

Doc MagAOX-001
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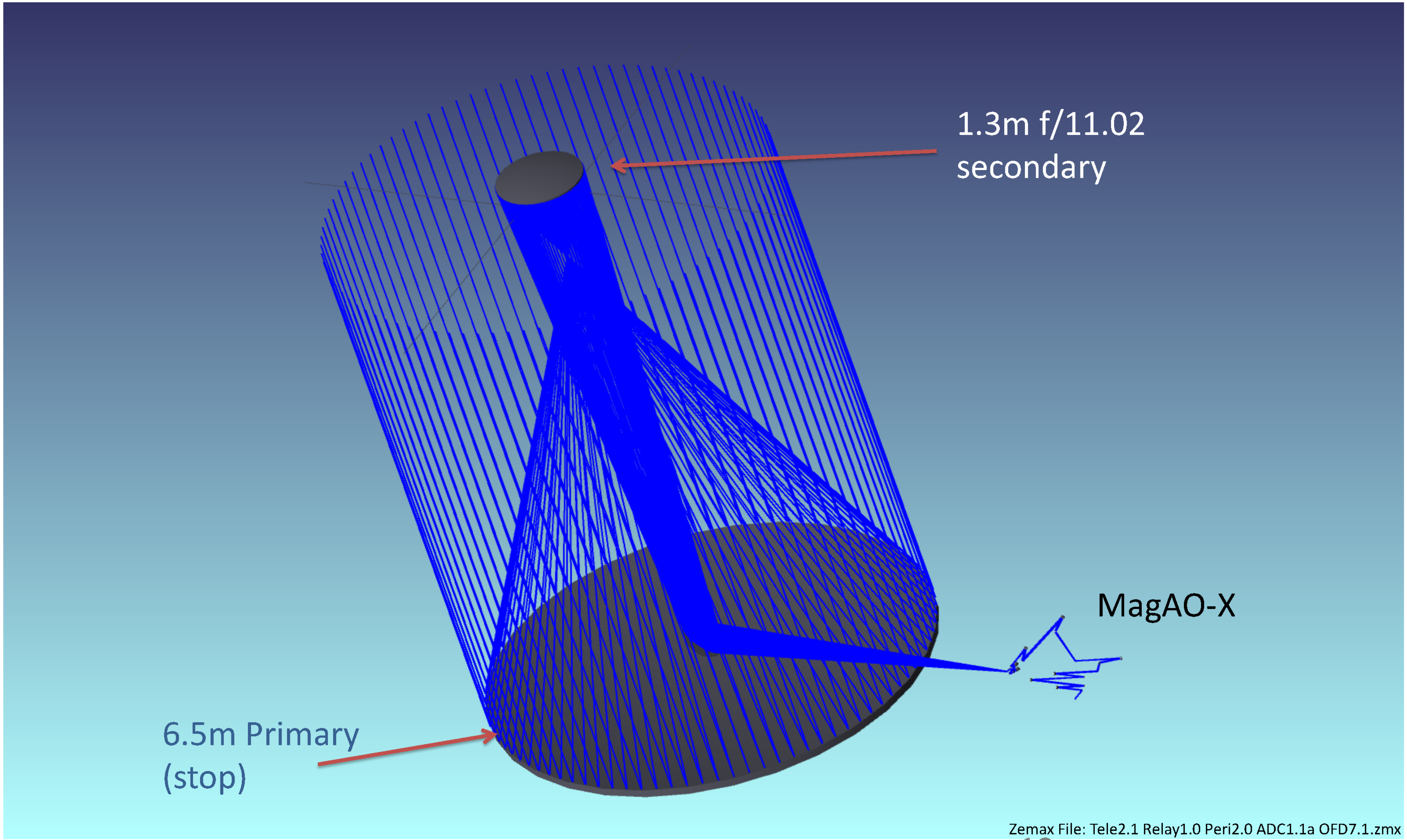
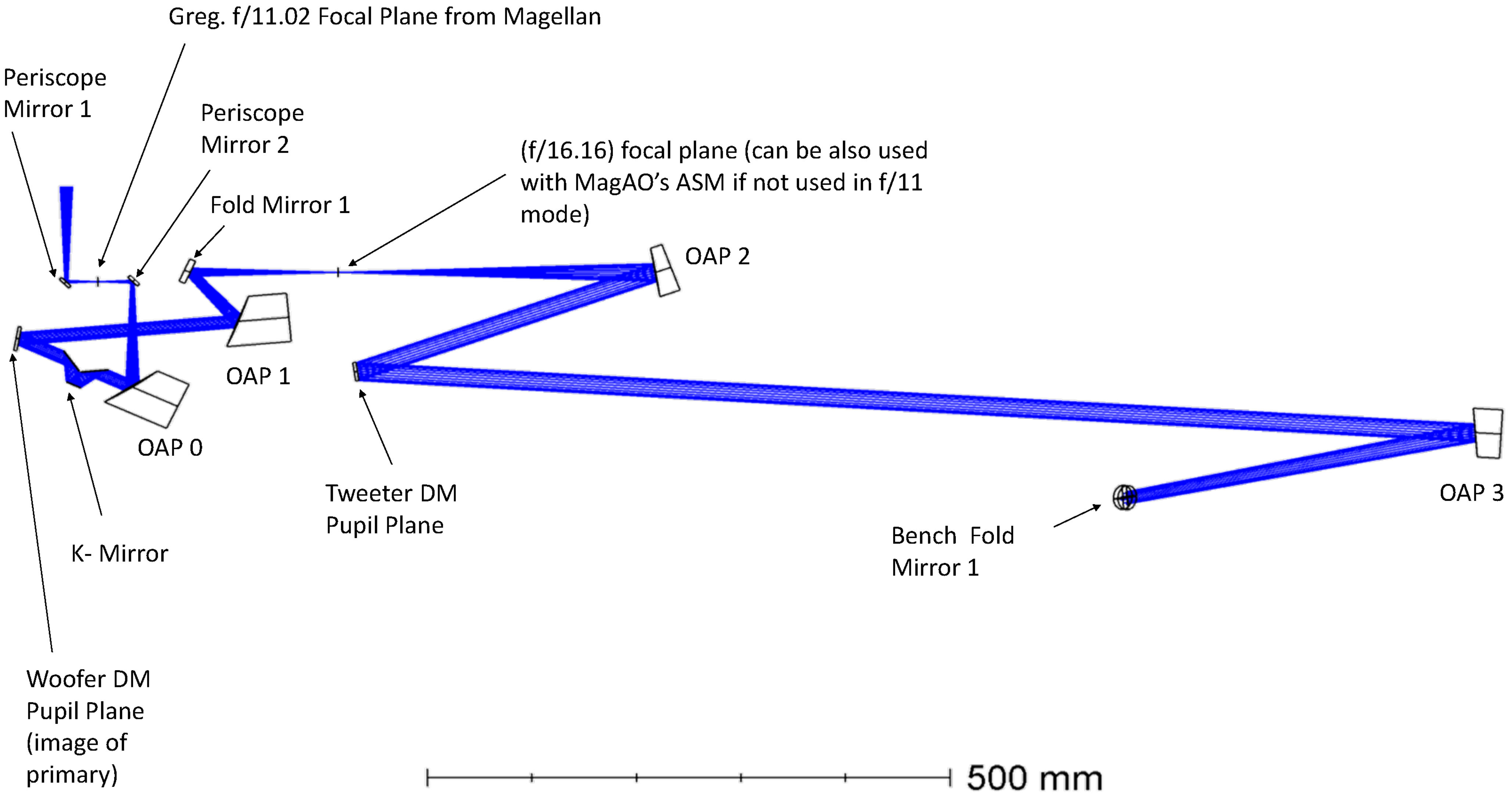
Shaded Model of f/11 + MagAO-X



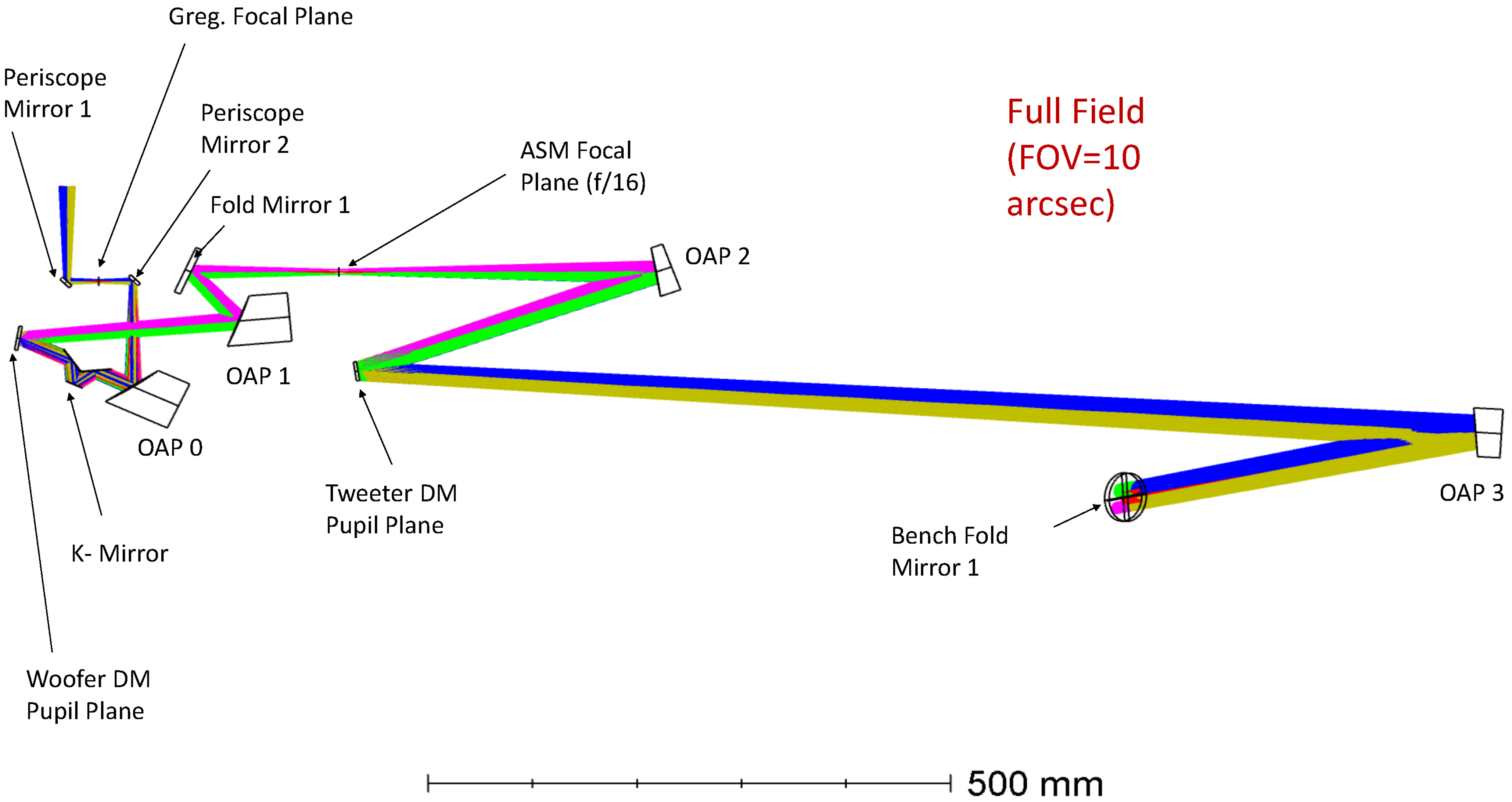
Upper Bench Optical Design (on-axis)



Zemax File: Tele2.1 Relay1.0 Peri2.0 ADC1.1a OFD7.1.zmx

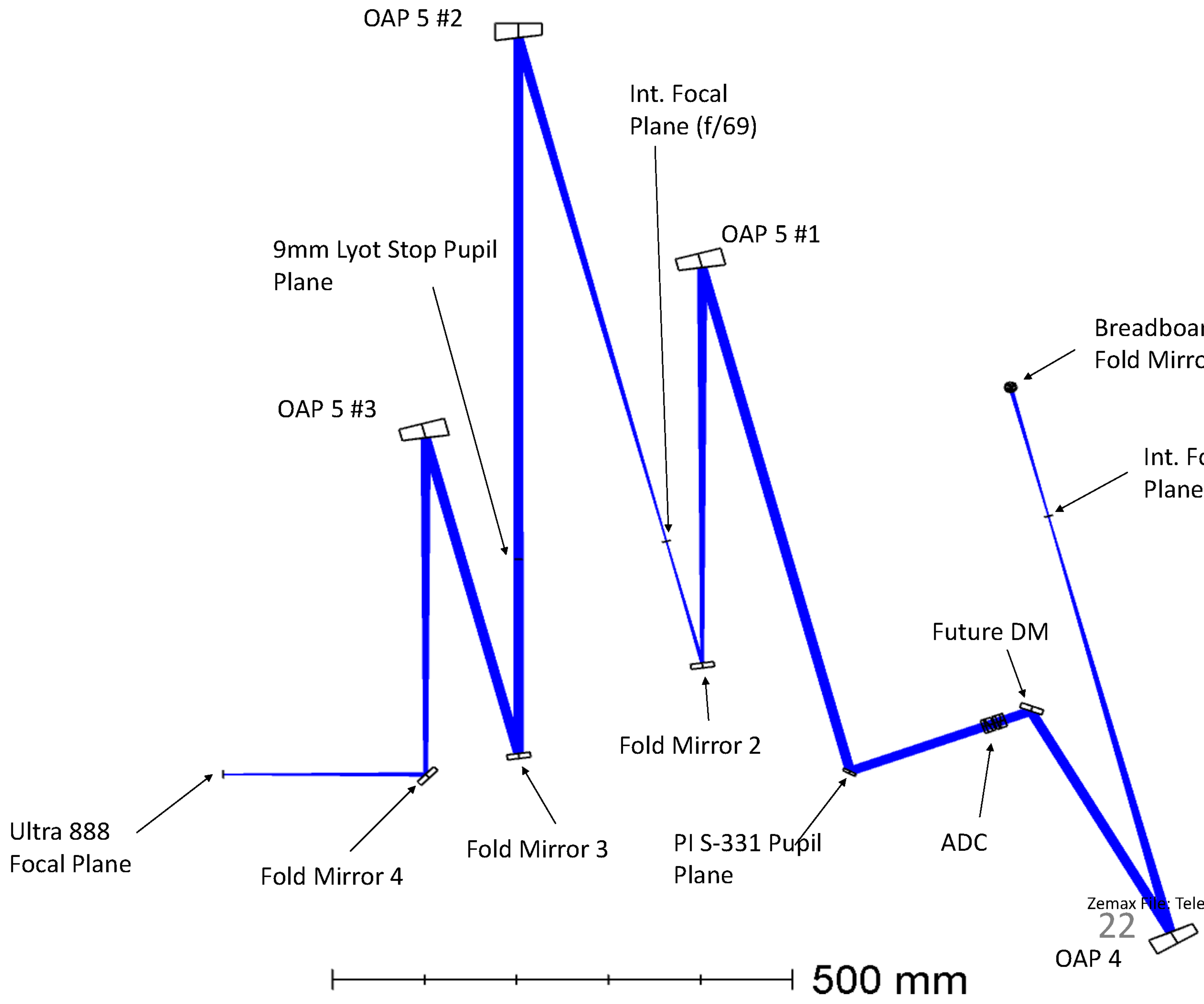
Doc MagAOX-001
Date: 4/18/2017
Status:Draft v. 21

Upper Bench Optical Design (10” FOV)



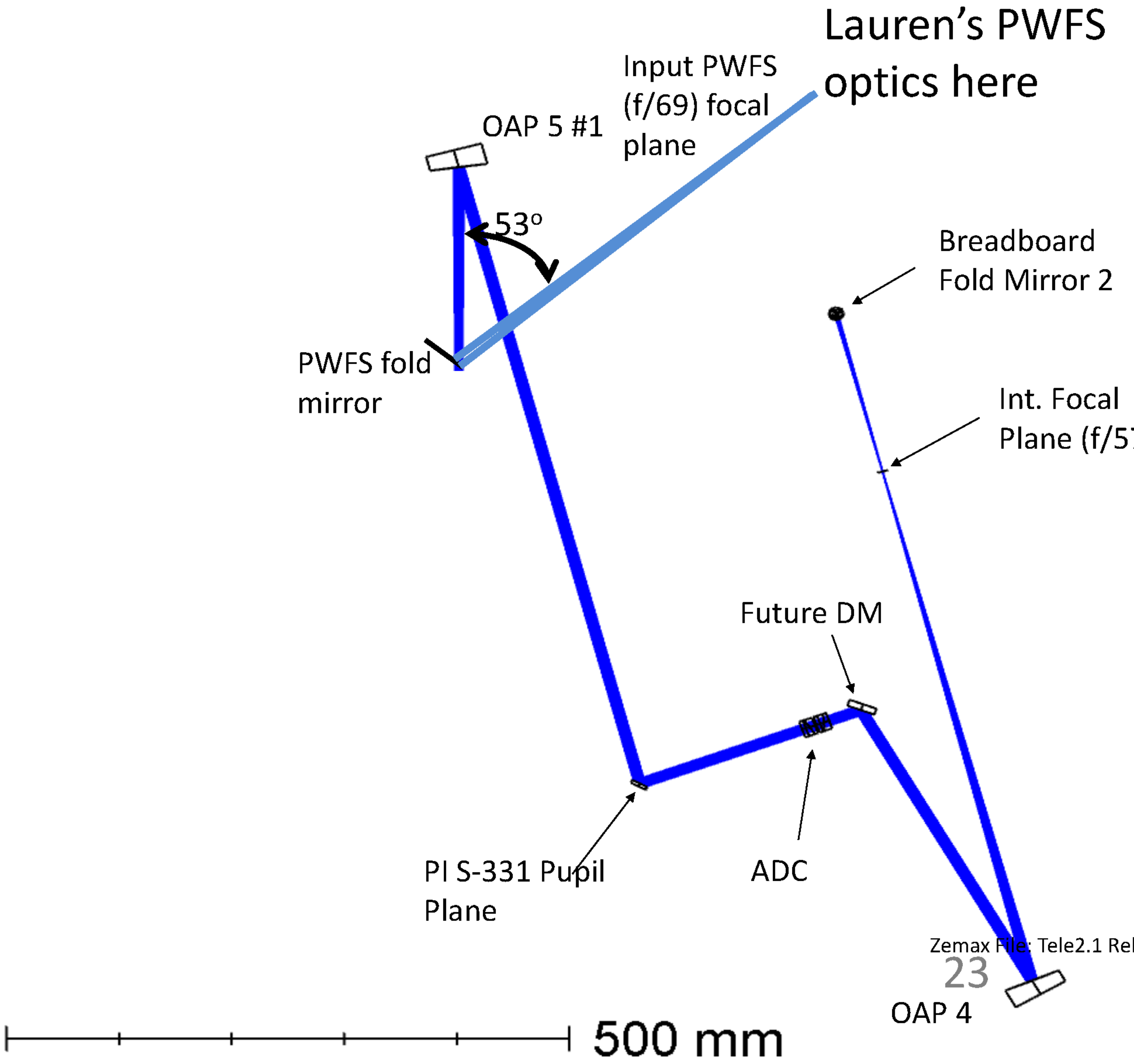
Zemax File: Tele2.1 Relay1.0 Peri2.0 ADC1.1a OFD7.1.zmx

Lower Table Optical Design On-Axis



Zemax File: Tele2.1 Relay1.0 Peri2.0 ADC1.1a OFD7.1.zmx

Lower Table Optical Design with PWFS



Zemax File: Tele2.1 Relay1.0 Peri2.0 ADC1.1a OFD7.1.zmx

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Date: 4/18/2017
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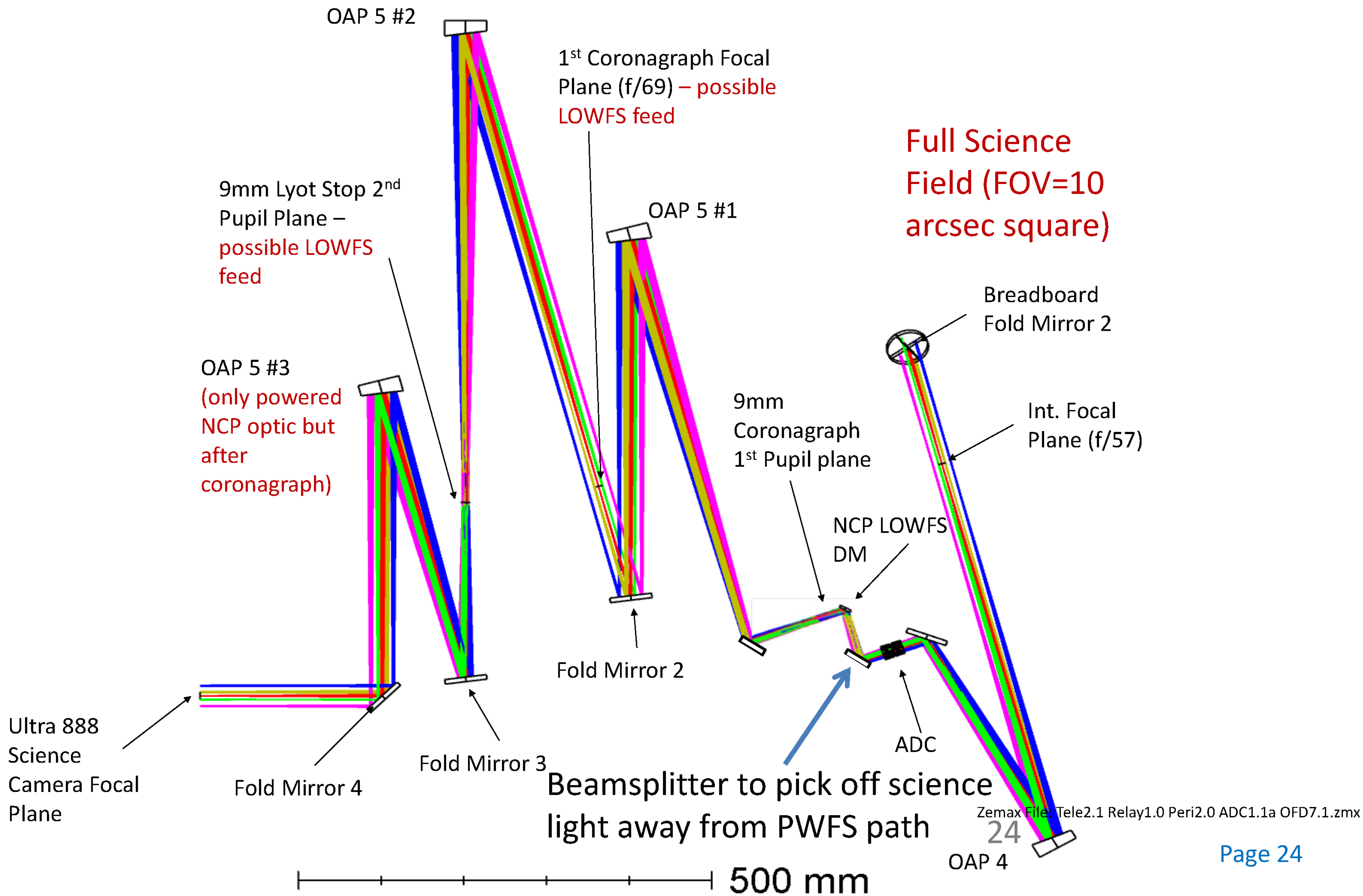
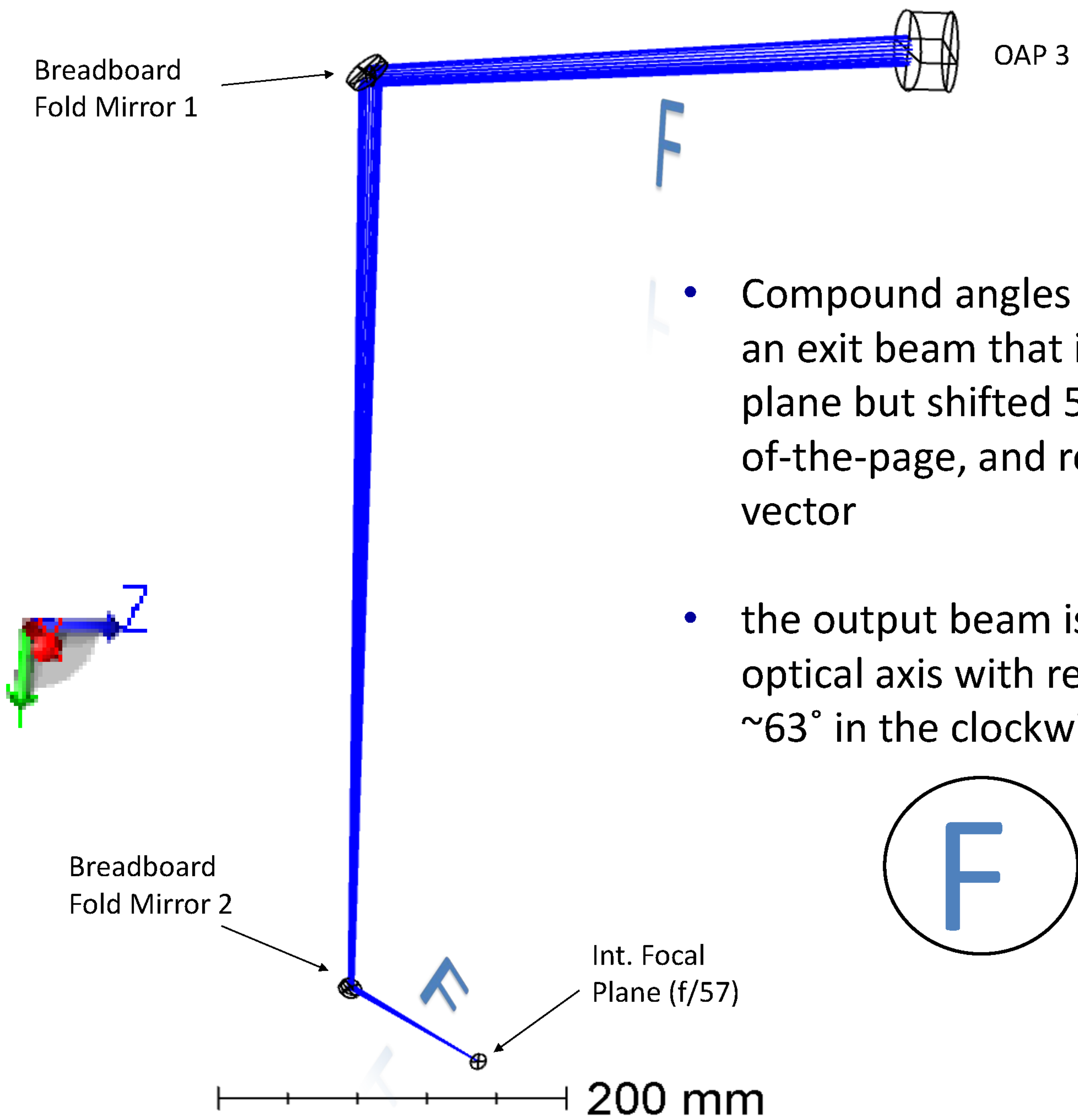
Lower Table Science Full FOV

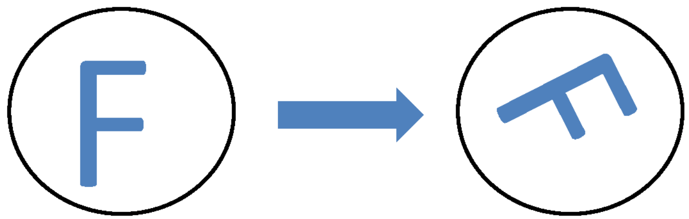


Bench to Table Periscope



- Compound angles for both BBFM1 & 2 result in an exit beam that is parallel with the input beam plane but shifted 550.6 mm lower, 161 mm out-of-the-page, and rotated in its output direction vector

- the output beam is also rotated about the optical axis with respect to the input beam by ~63˚ in the clockwise direction.



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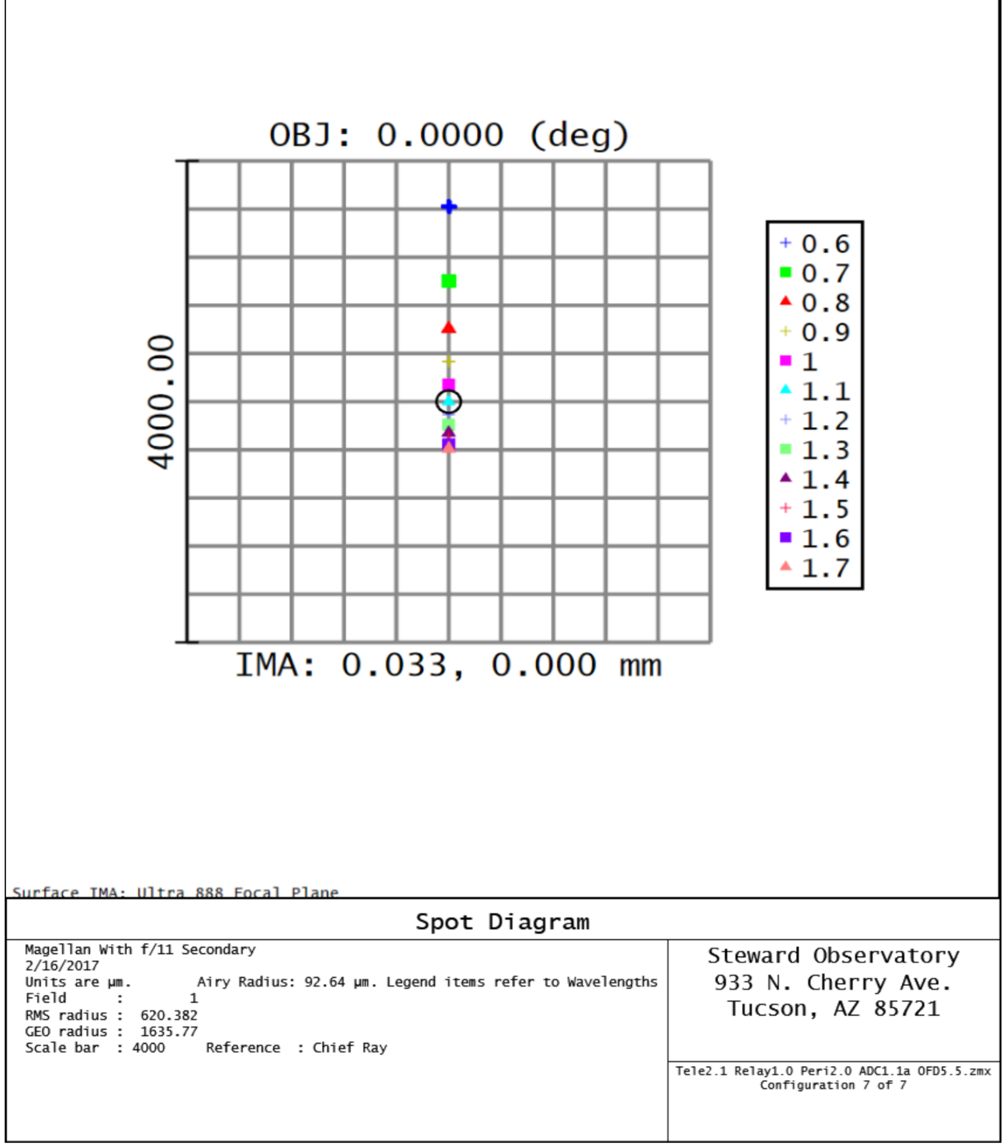
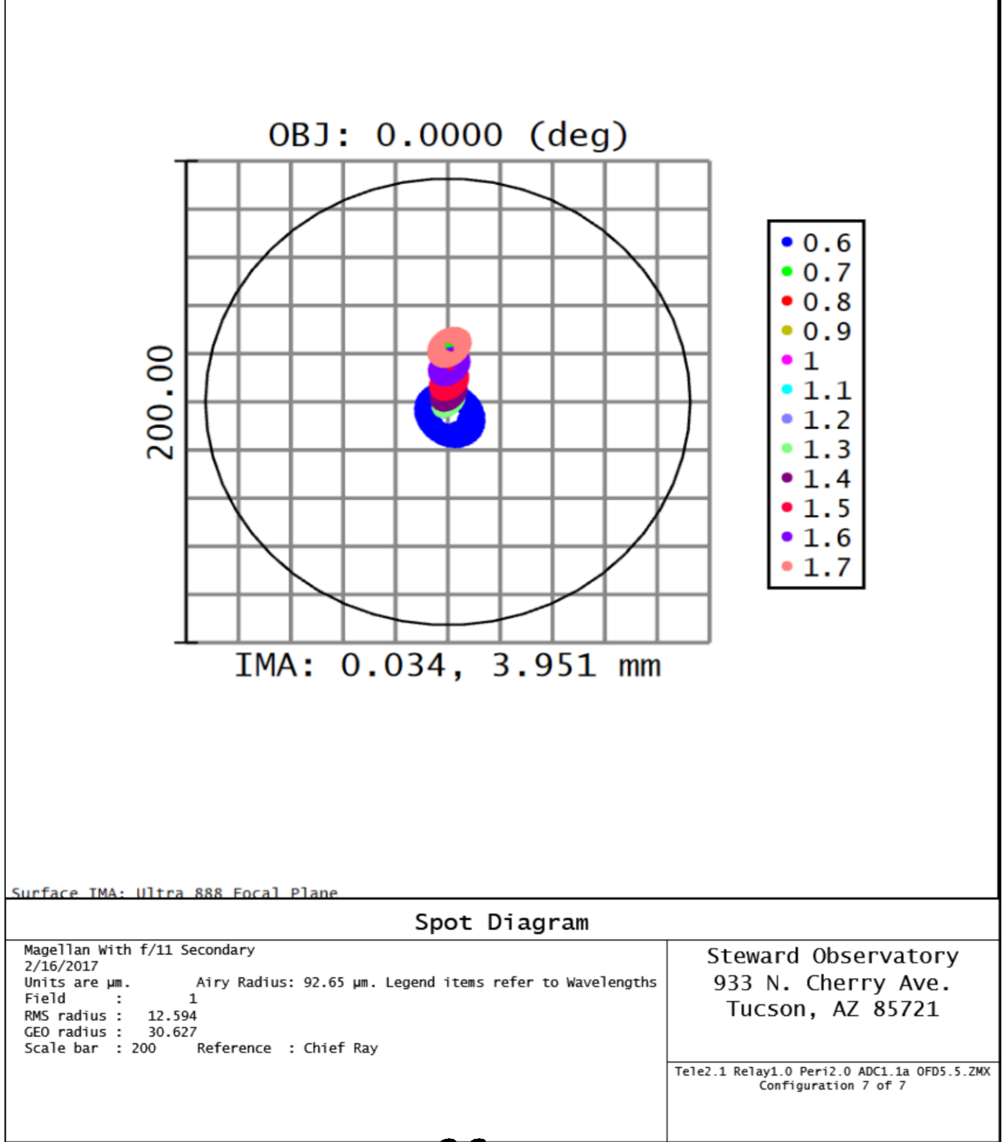
Spot Diagrams for Zenith Z=40° w/ ADC

No ADC Correction



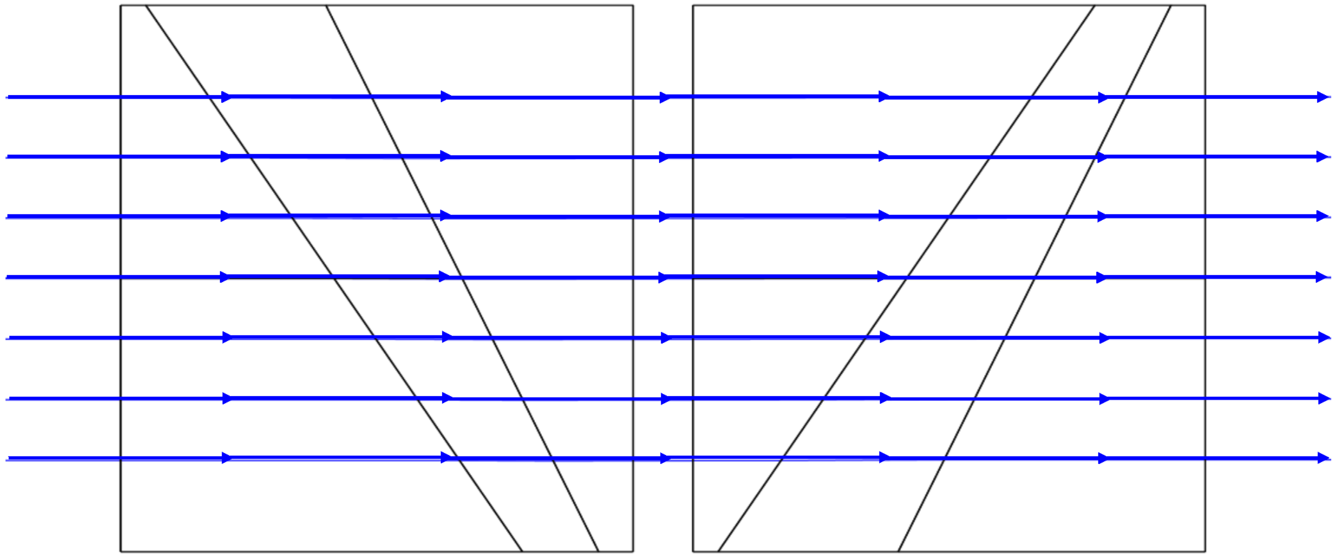
ADC Correction (Current Design)



ADC Prism Design Layouts

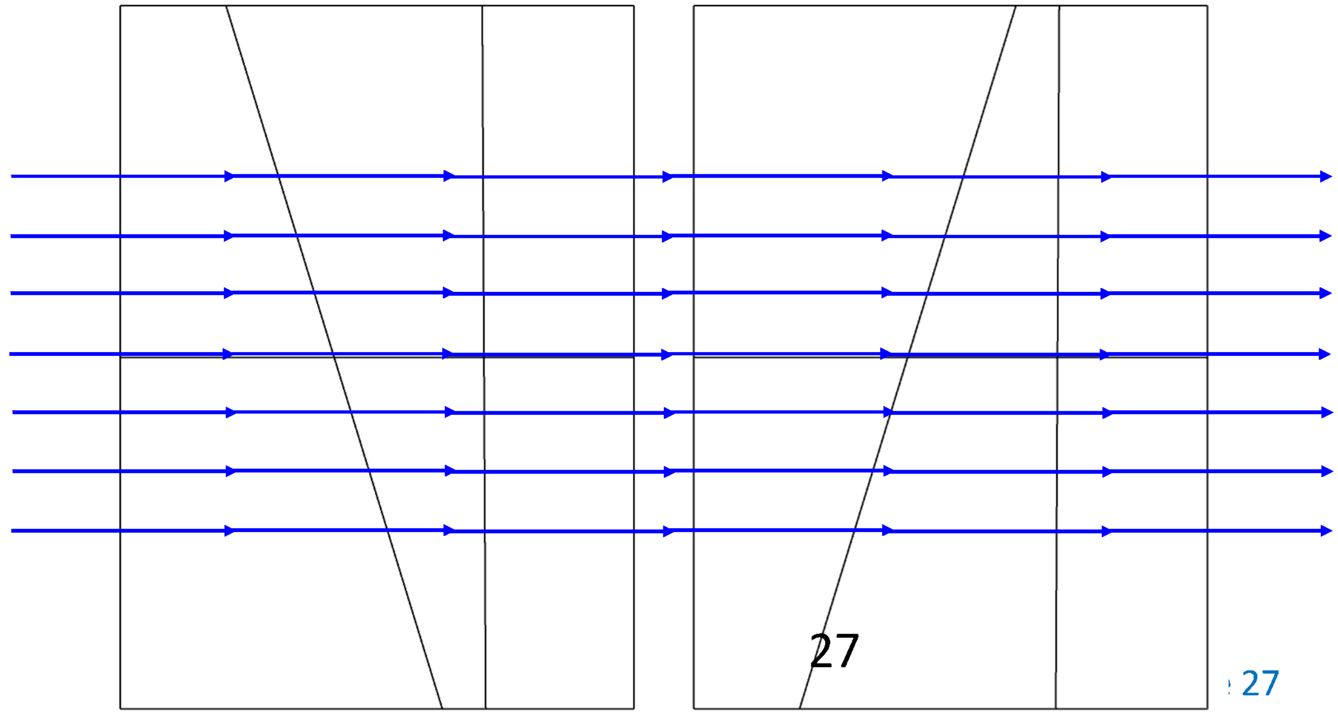
Current ADC Design

- ϕ = 14 mm
- S-PHM53, S-TIM8, N-KZFS4
- CT = 5.0, 3.0, 4.0 mm
- θ = 57.785°, 65.474°



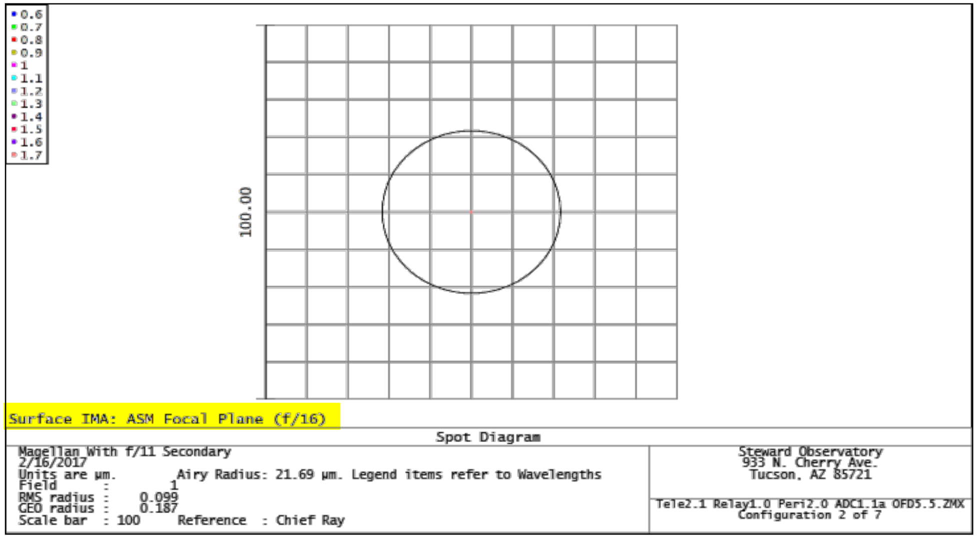
New ADC Design

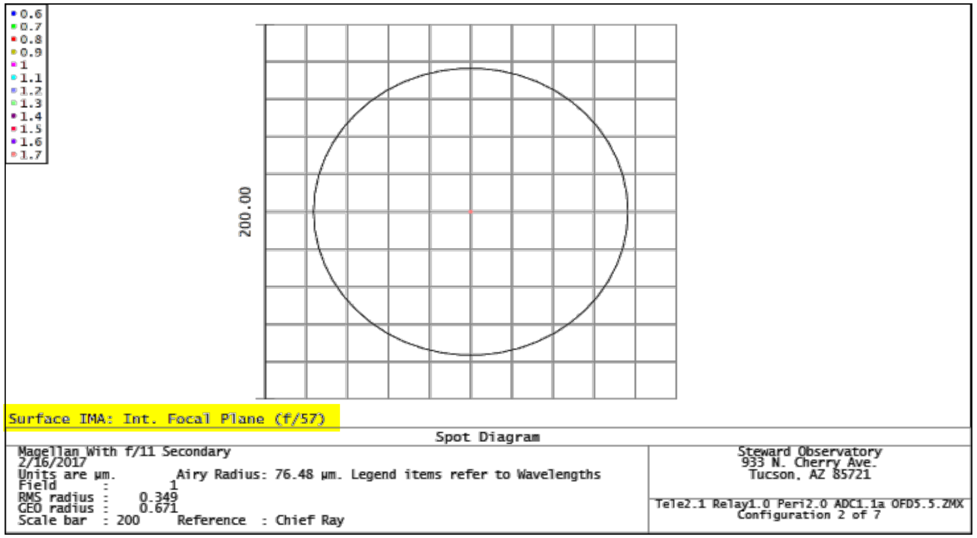
- ϕ = 18 mm
- S-PHM53, S-TIM8, N-KZFS4
- CT = 5.0, 3.5, 3.5 mm
- θ = 73.687°, 0.260°

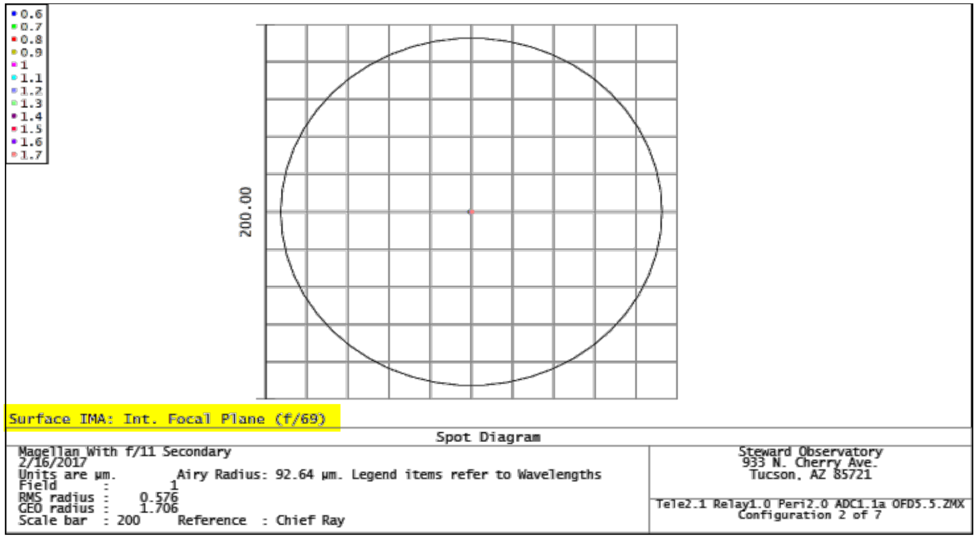


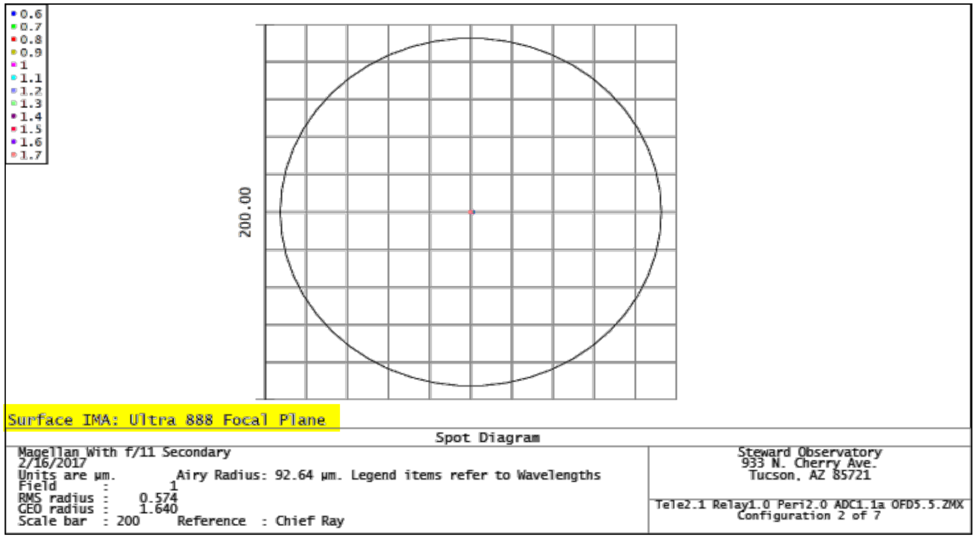
27

Spot Diagrams at Focal Planes

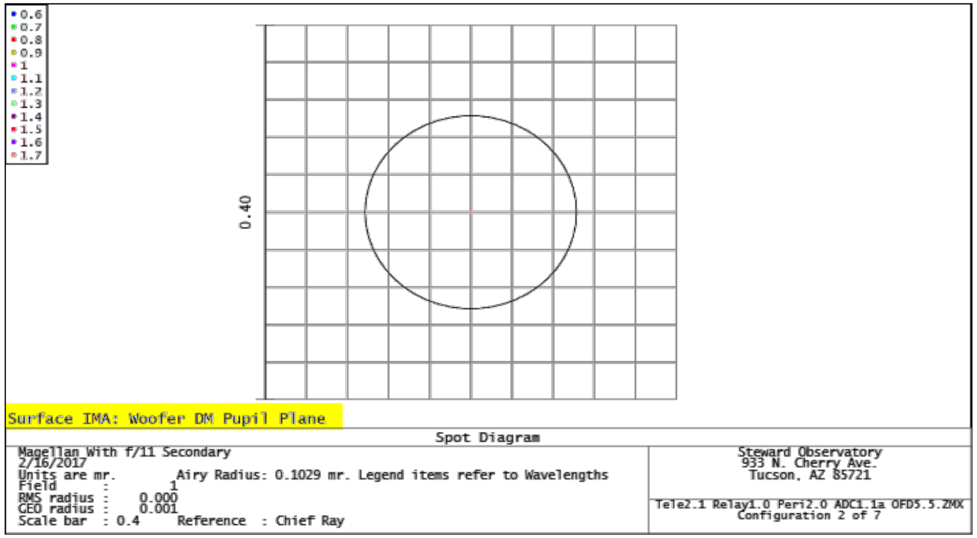


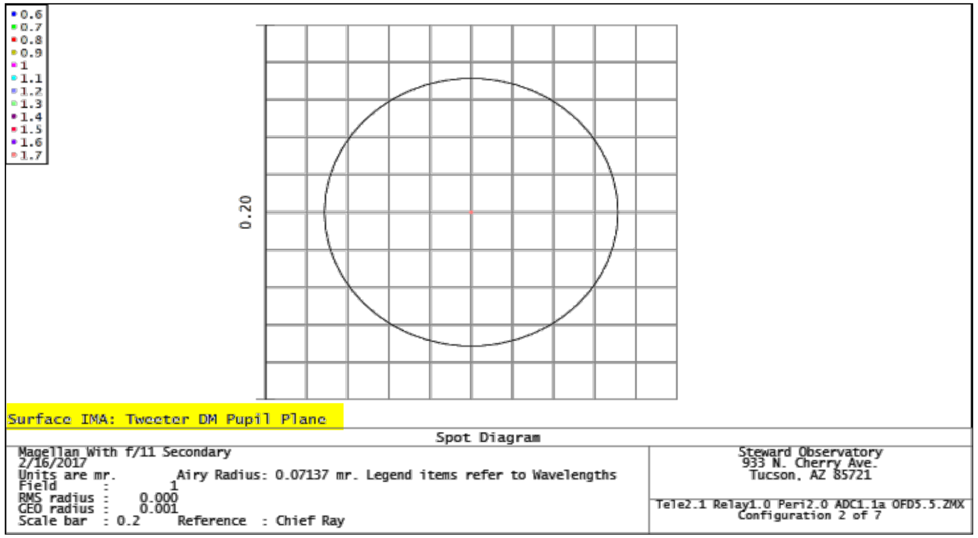


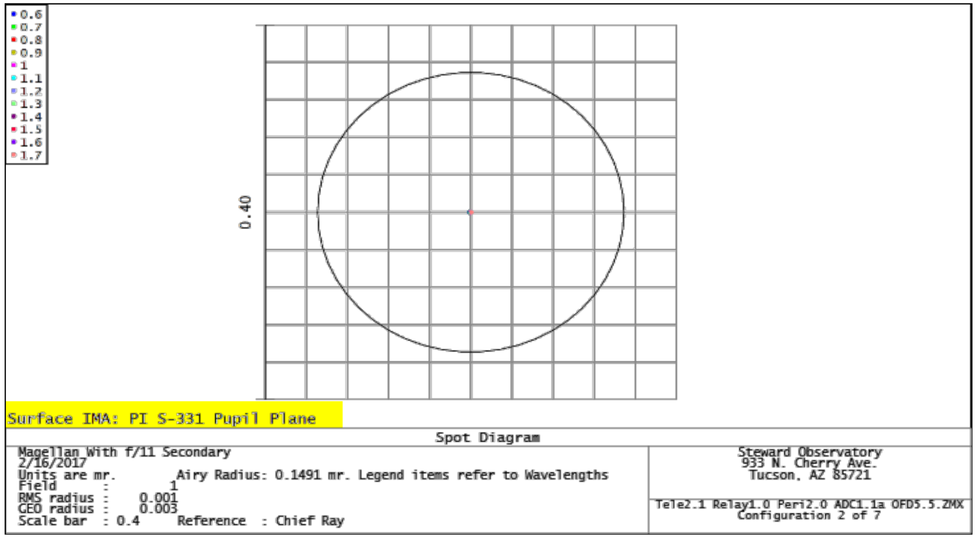


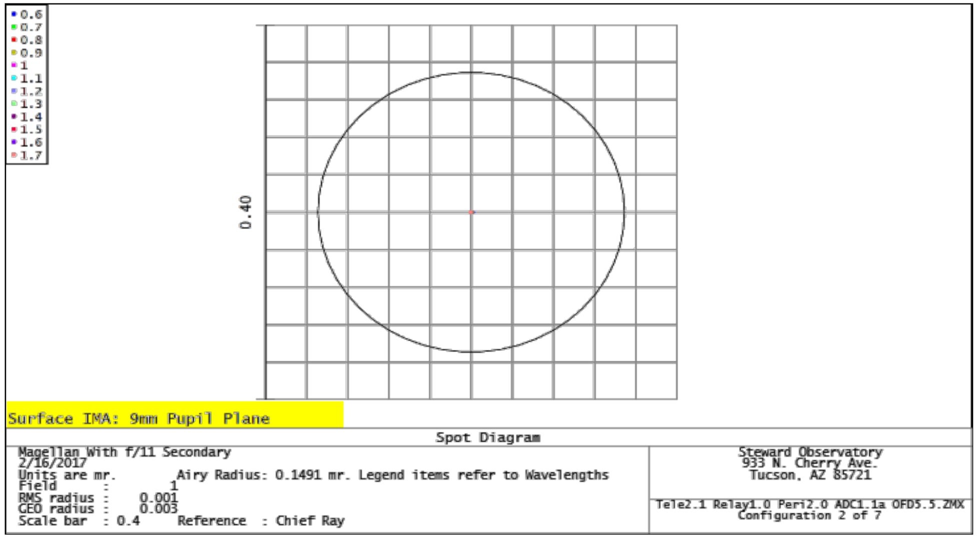


Spot Diagrams at Pupil Planes

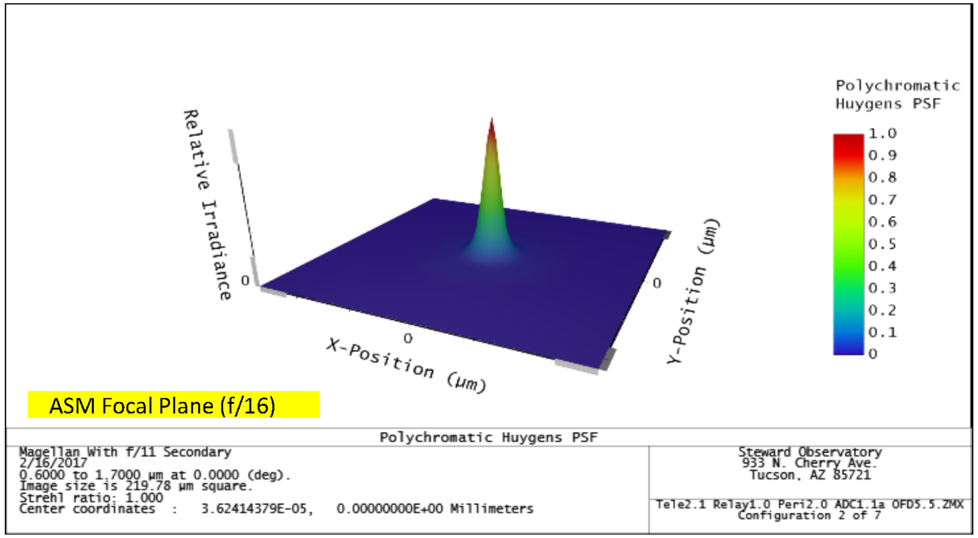


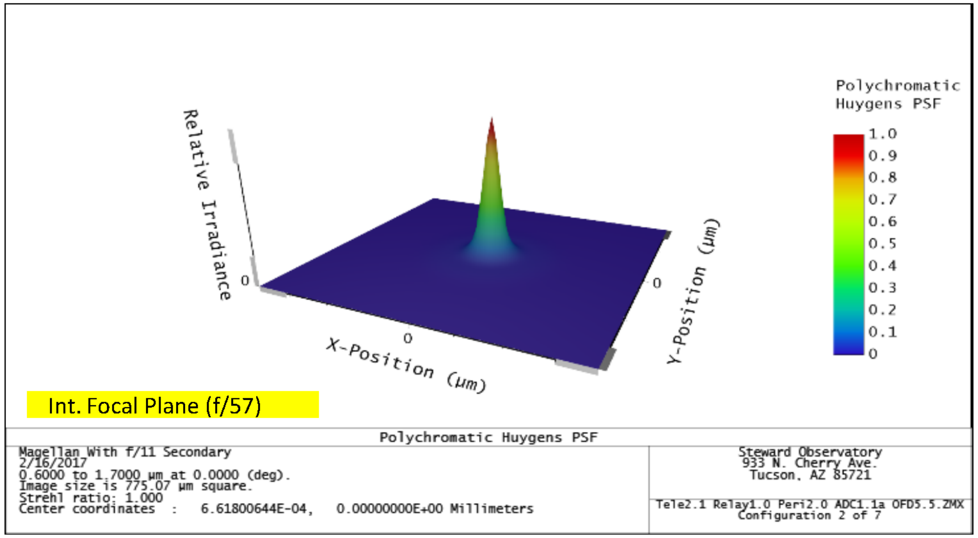


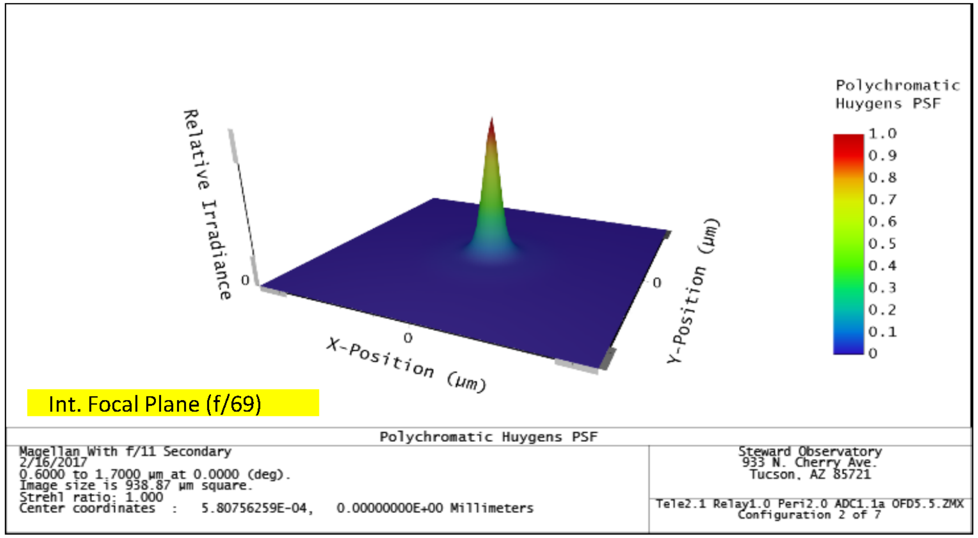


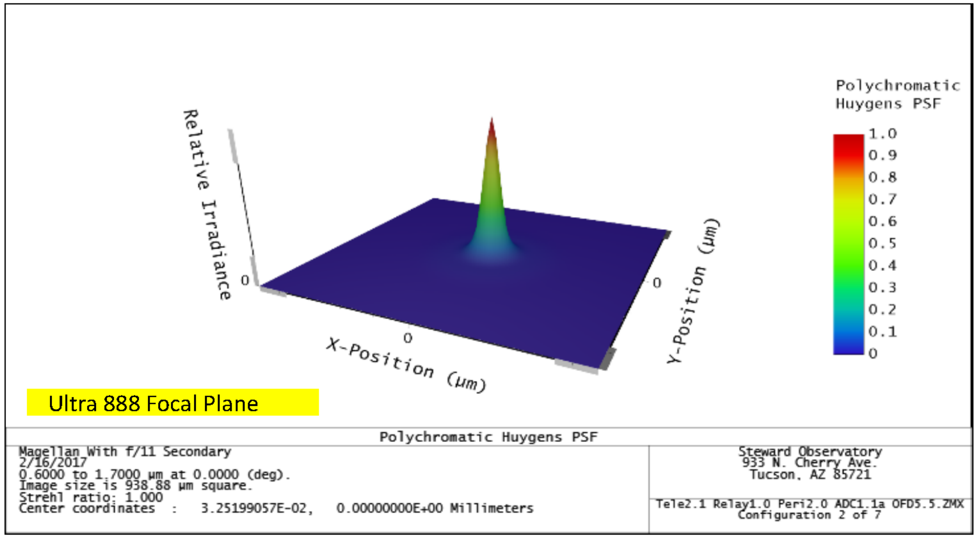


PSF at Focal Planes

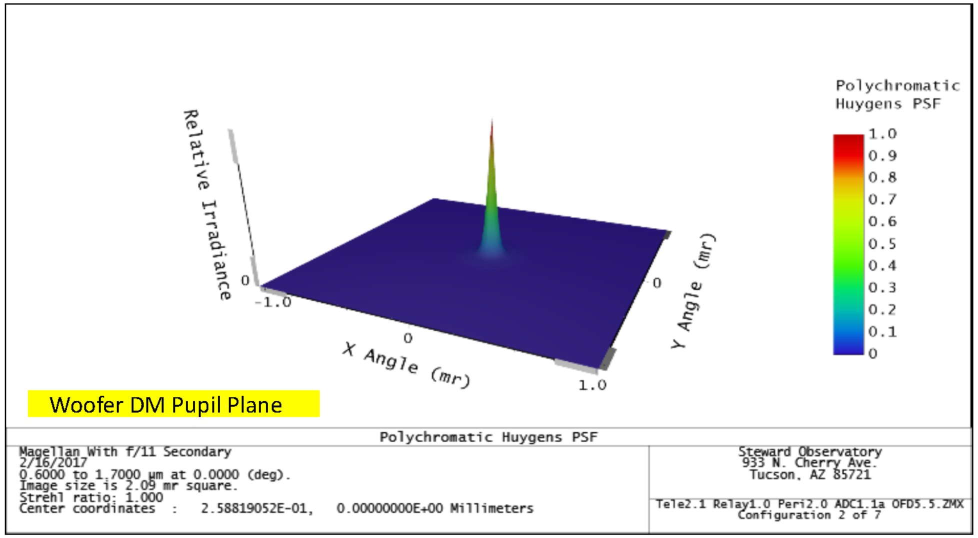


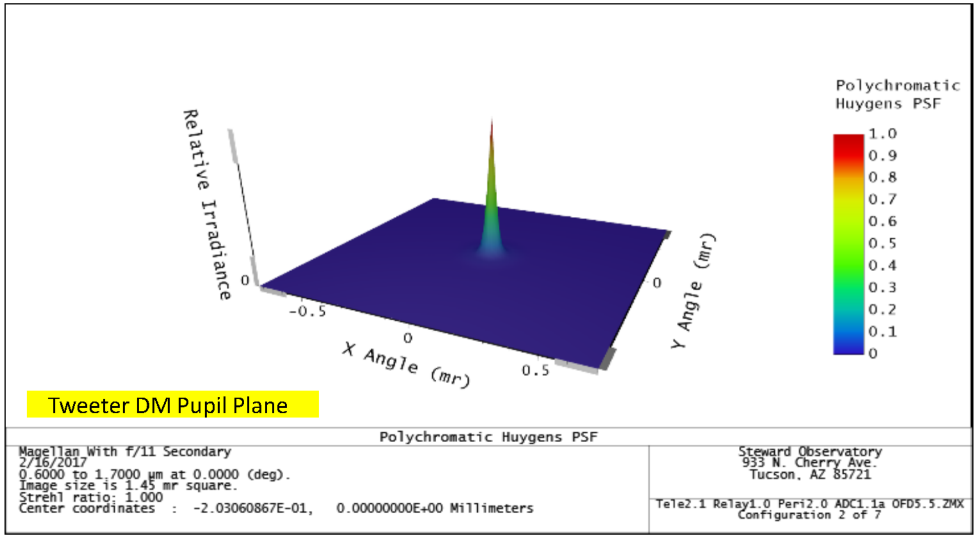


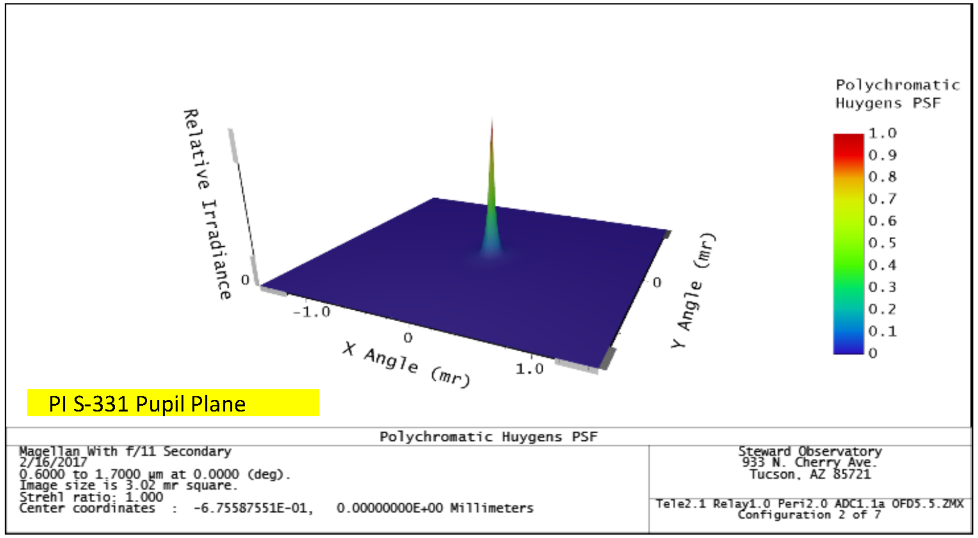


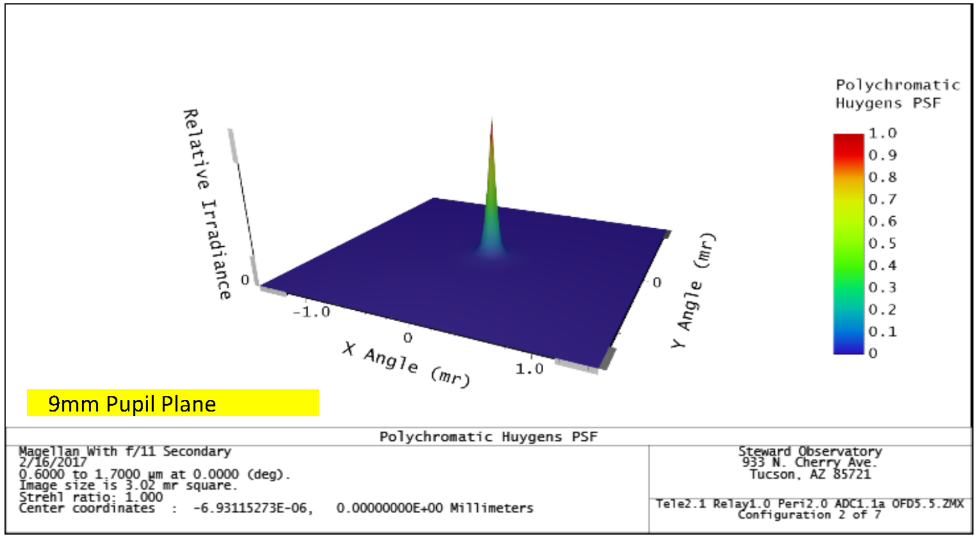


PSF at Pupil Planes





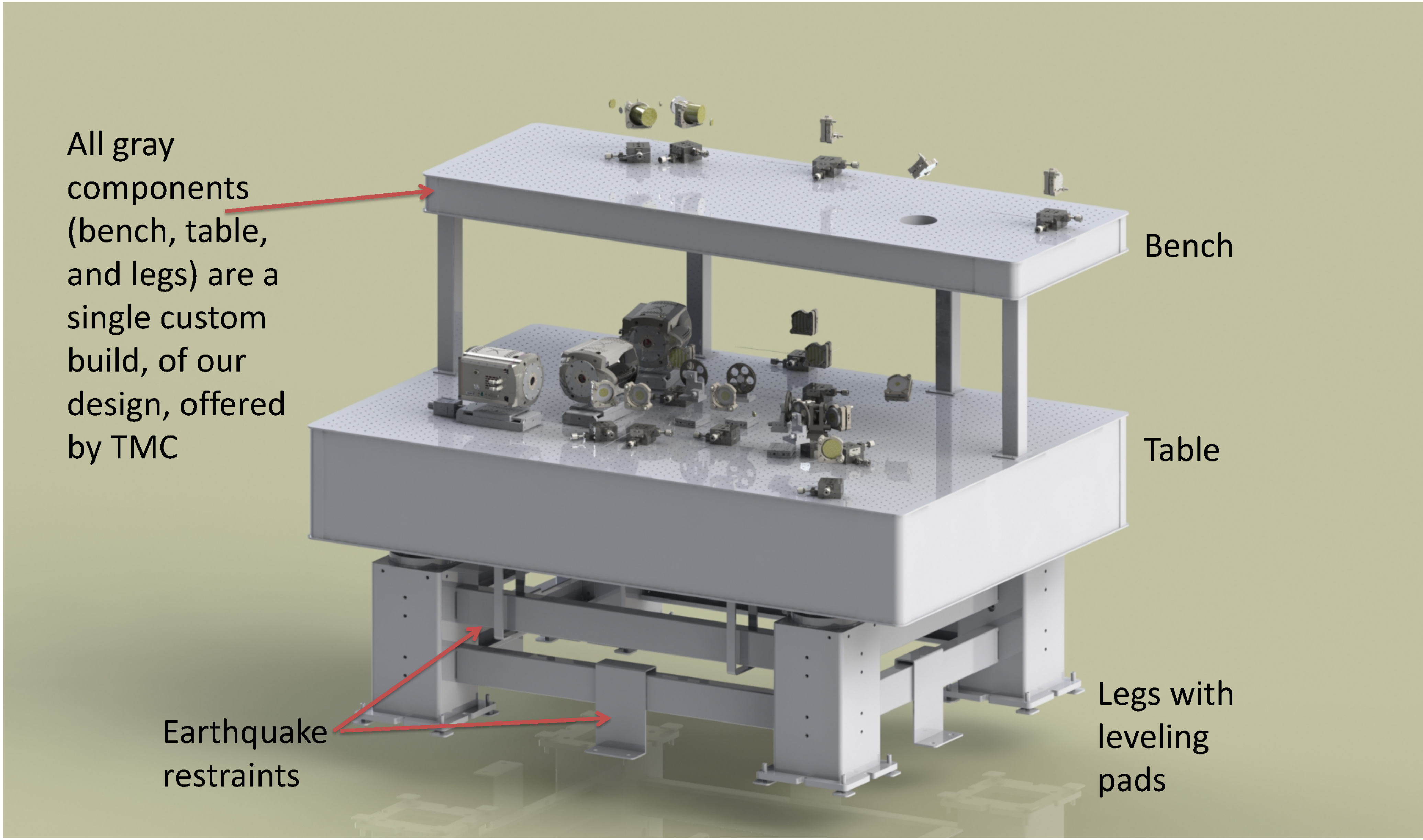




Mechanical Solid Model

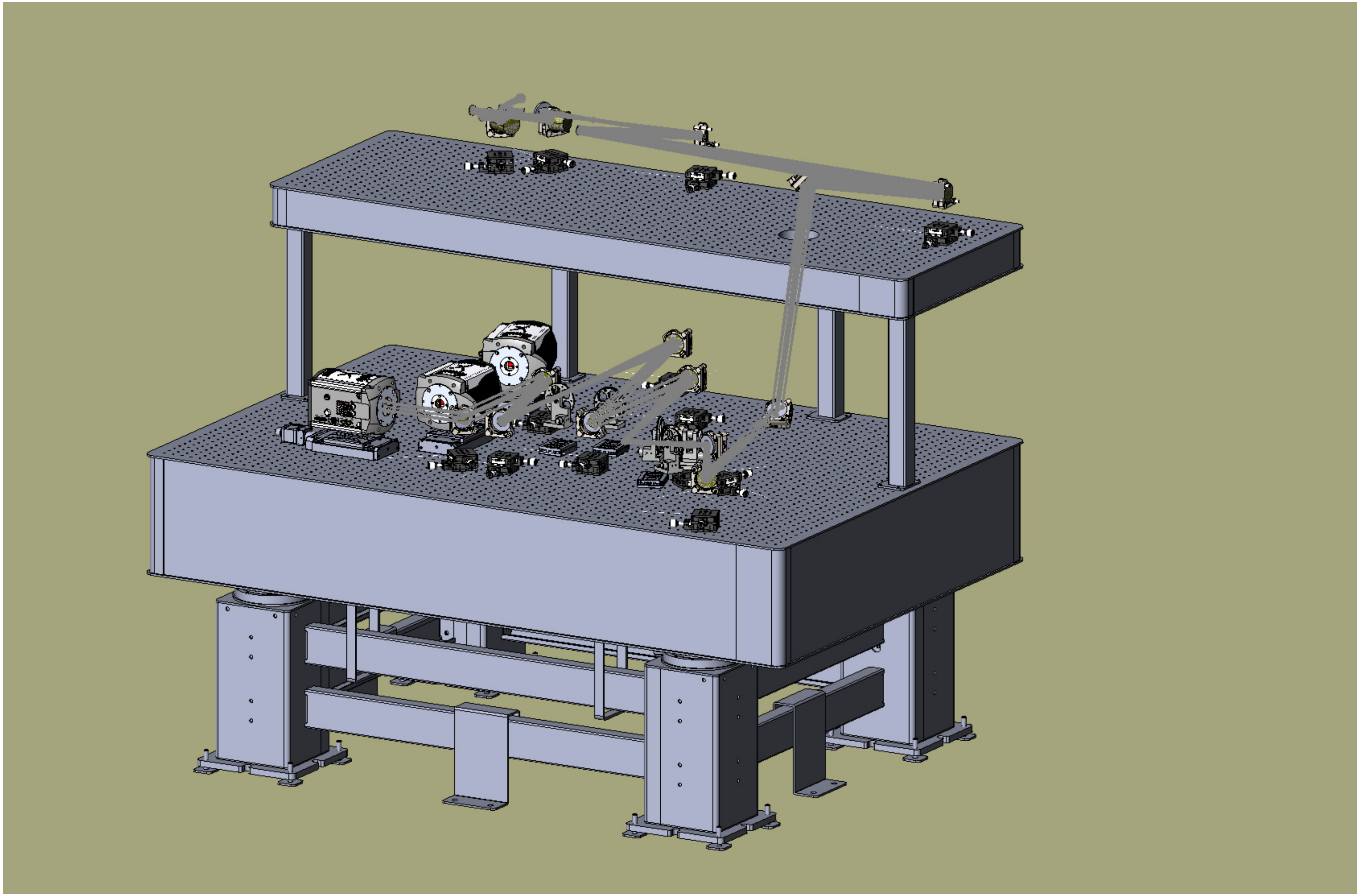
Solid works design by Corwynn (Cork) Sauve, Steward Observatory

Mechanical Solid Model With TMC Table



Full Science FOV (10”) Rays

Doc MagAOX-001
Date: 4/18/2017
Status:Draft v. 21



10” Rays

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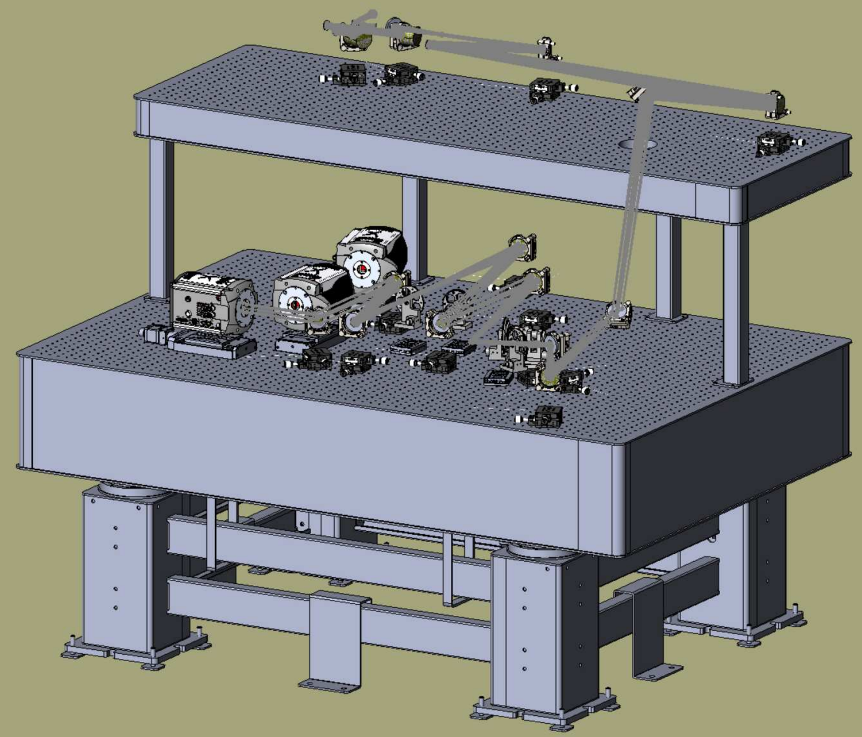
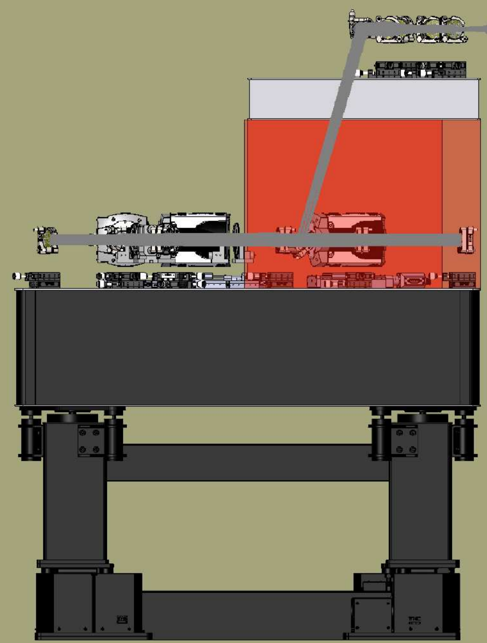
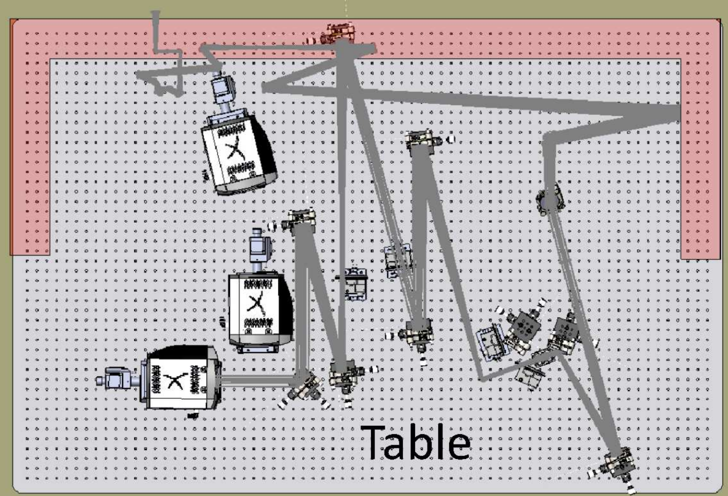
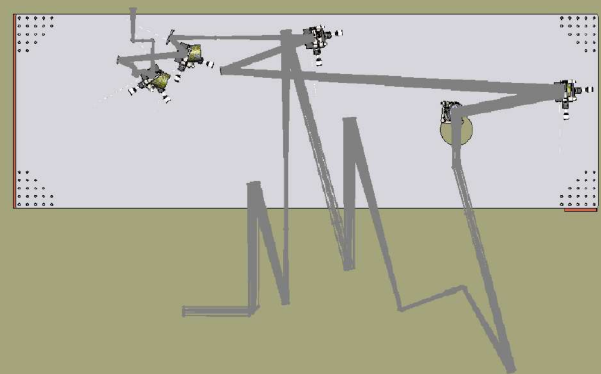




5 inch b
height
through



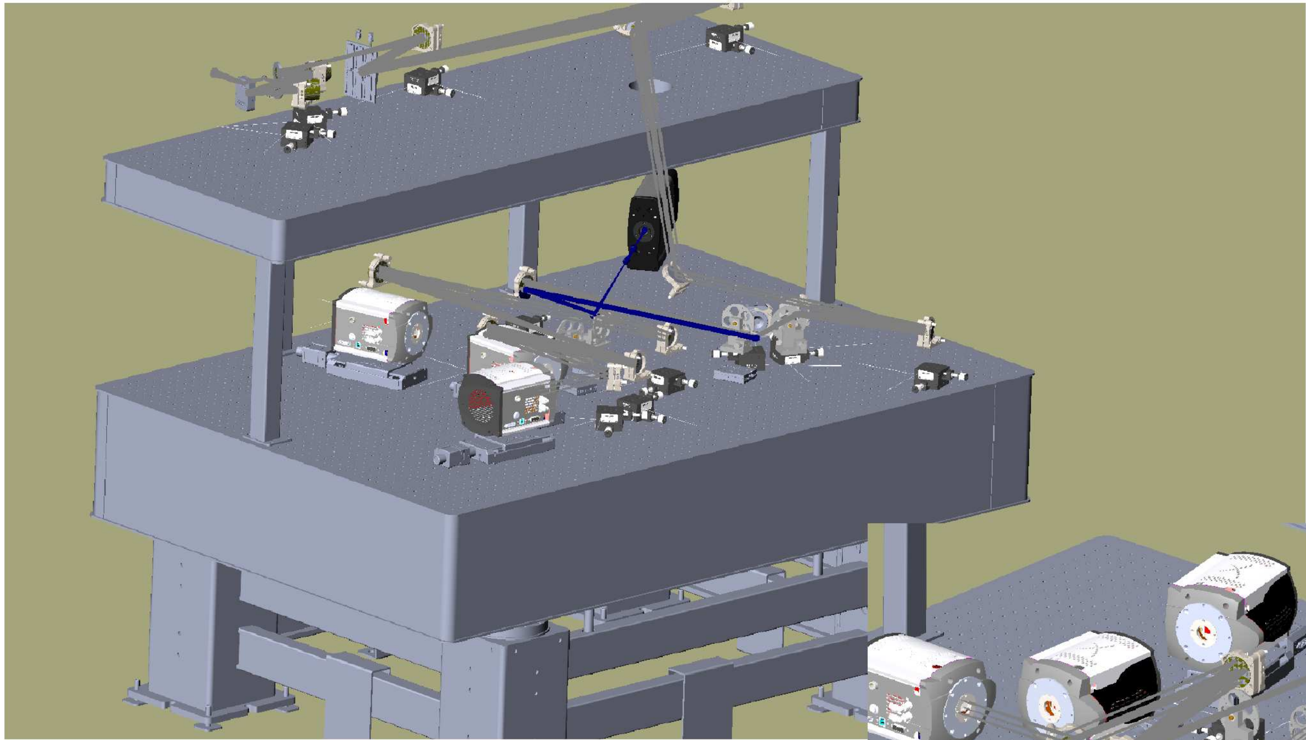
All the optics, mounts, and cables fit on the bench and Table

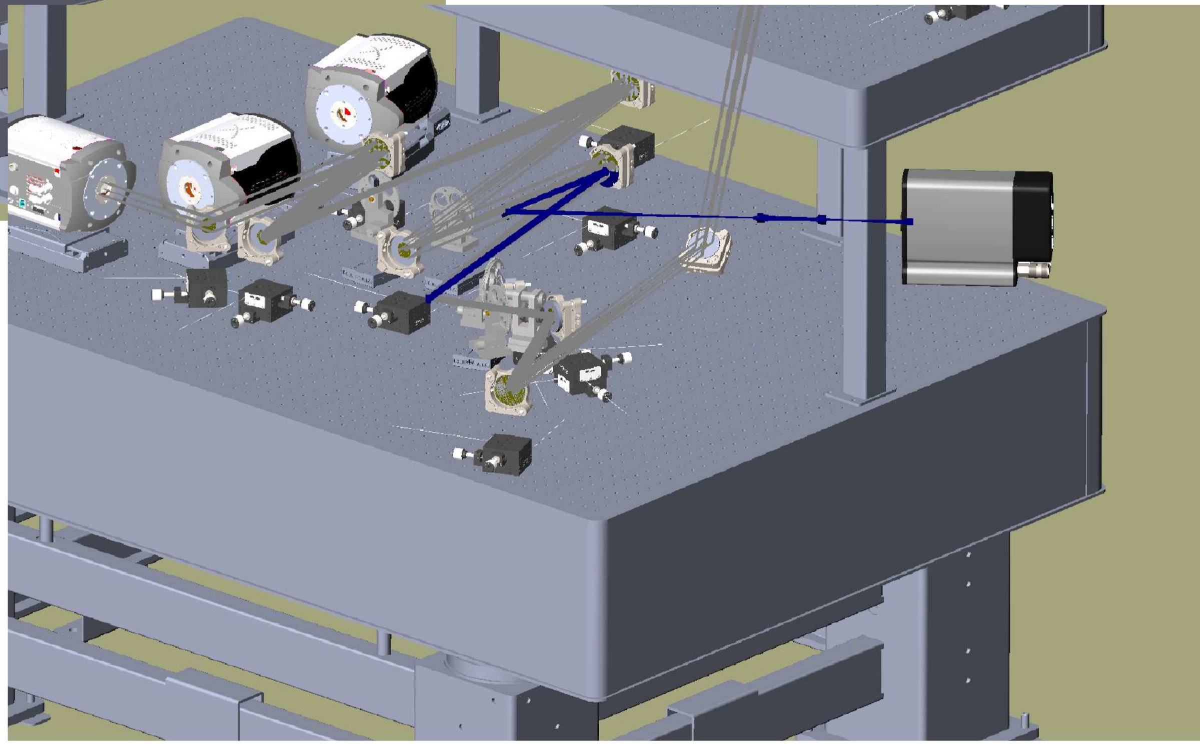


Bench

With PWFS

NCP rays for PWFS in blue





With PWFS

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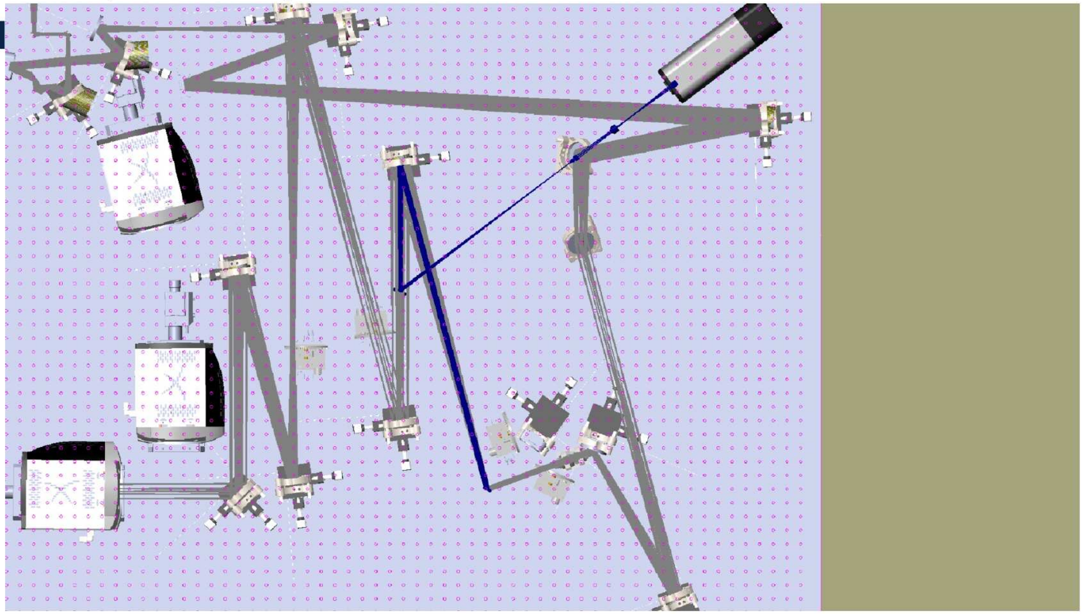
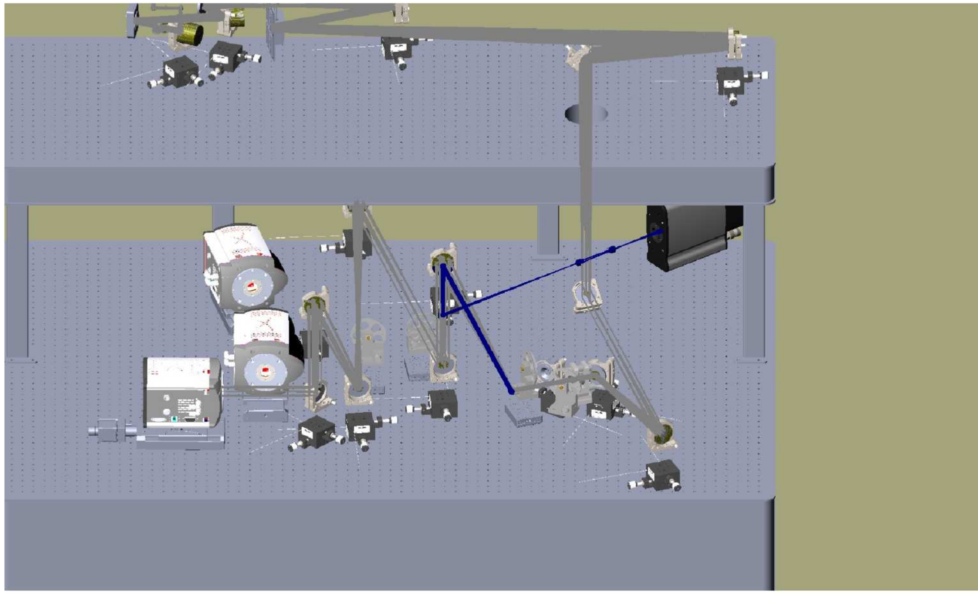
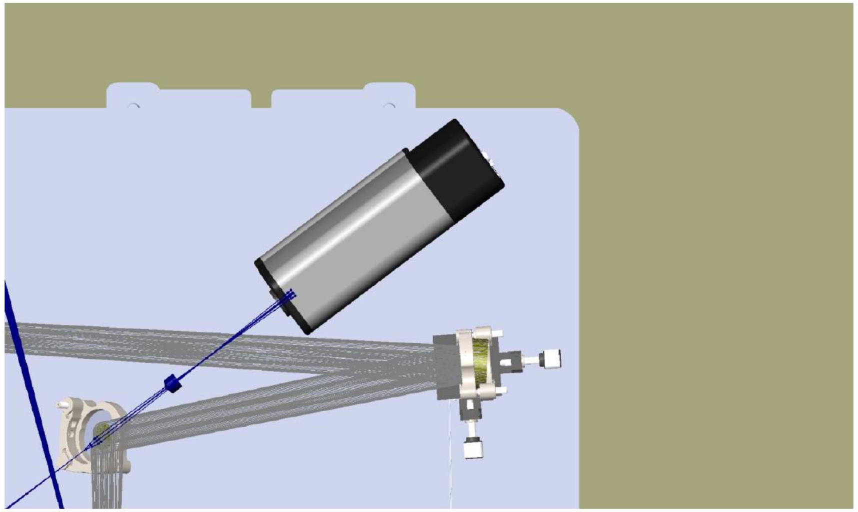
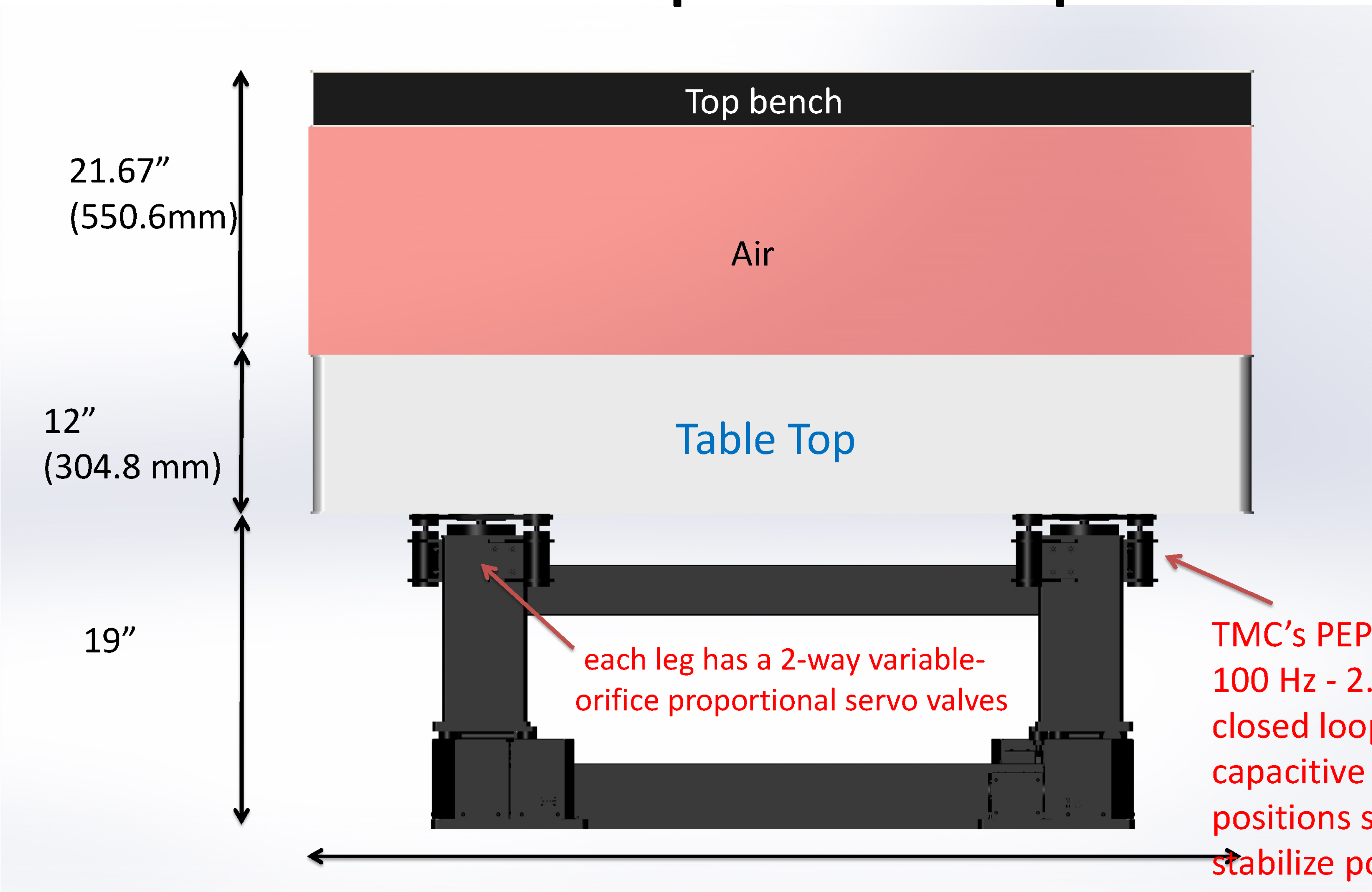


NCP rays for PWFS in blue



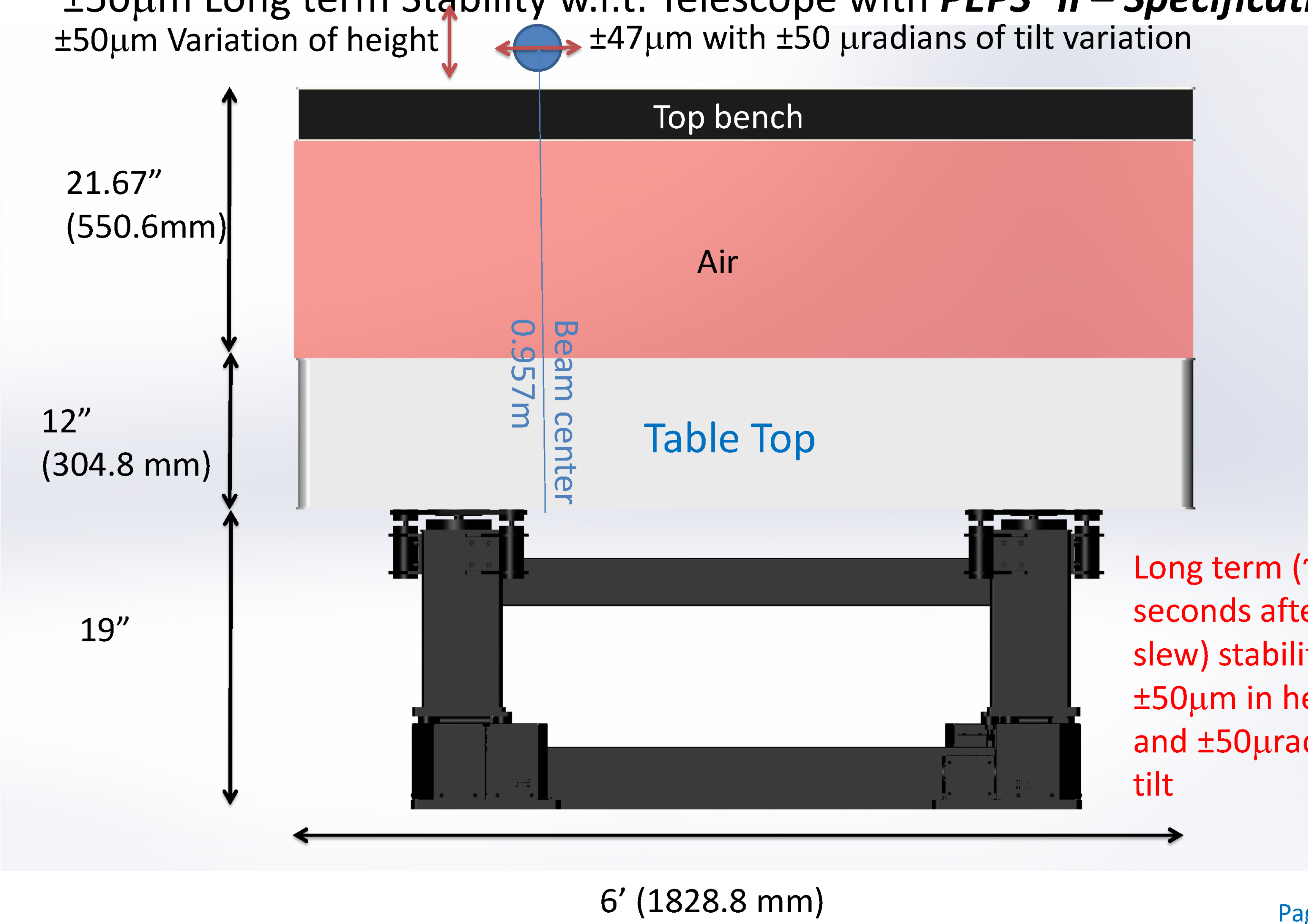


The Closed-loop Air Damped Table



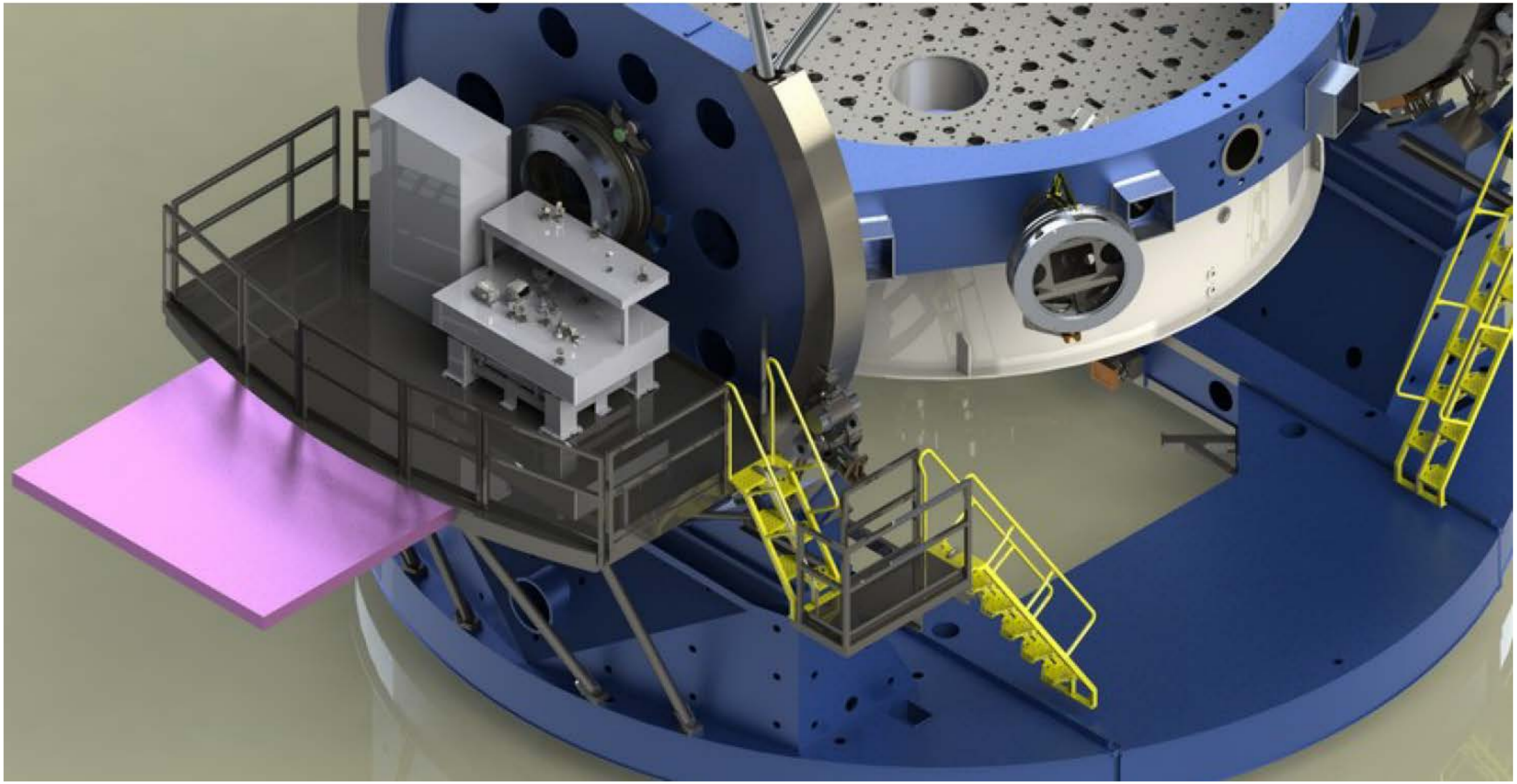
TMC's PEPS II 100 Hz - 2.0 KHz closed loop capacitive positions sensors stabilize position of floating table w.r.t. table legs

±50μm Long term Stability w.r.t. Telescope with ***PEPS® II – Specifications***

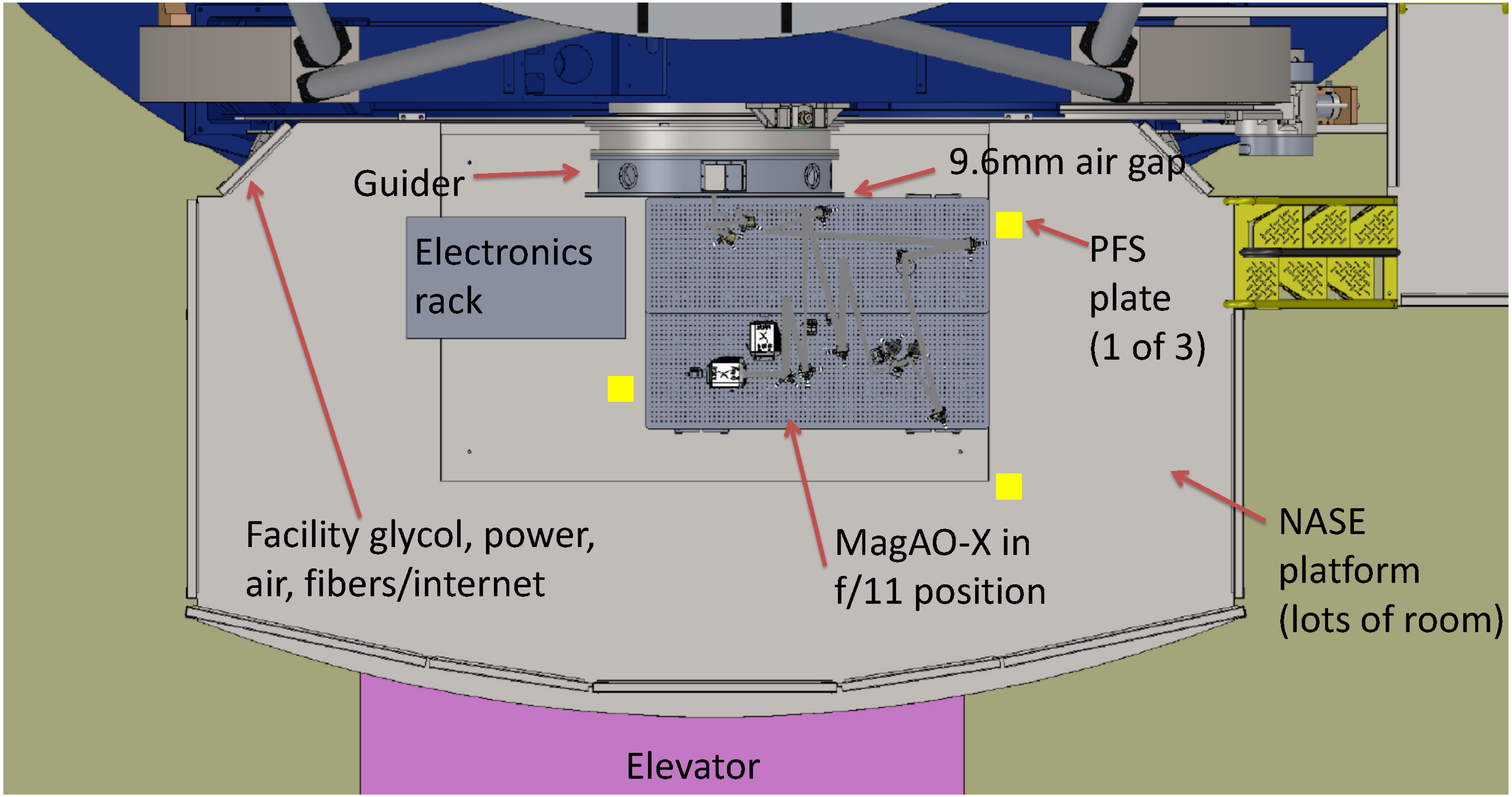


Long term (~1-2 seconds after slew) stability is ±50μm in height and ±50μrads in tilt

Completed Design At Magellan



MagAO-X fits on the NASE



Unpacking and Alignment at Telescope

START: Use the Iszu truck to move the shipping box to the lift gate at summit, then hand truck to elevator, then:

1) hand truck shipping box to telescope observing floor off of the elevator

2) Independently, position our legs (on their casters) to the correct X position of the legs w.r.t. the guider center of the NASE platform. So all that is needed is a straight push (in Y) towards the guider, rotate the casters in the Y direction.

(Note: we could use a simple piece of angle bar bolted to the hatch to guarantee the casters motion in Y only once the Table is attached- TBD)

3) lift up the 5 sided top of the shipping box -- rotate dome and place beside Table.

4) pull bench out of shipping box base with overhead jib crane and lifting triangle

5) lower the Table onto the legs with crane, remove Triangle.

(NOTE: the Table/Legs alignment is guaranteed with alignment pins (that slide into the tiebars on legs) that are bolted onto in the tapped holes for earthquake brackets -- these pins are already attached when we are shipping the bench)

6) Now slowly push the whole assembly on the casters towards the guider until the air gap is 9.6mm then stop.

7) Carefully engage all 16 leveling pads (disengaging the casters)

8) remove alignment pins and add the missing 2 upper earthquake brackets.

9) Add the lower earthquake brackets

10) cable up the system, etc.

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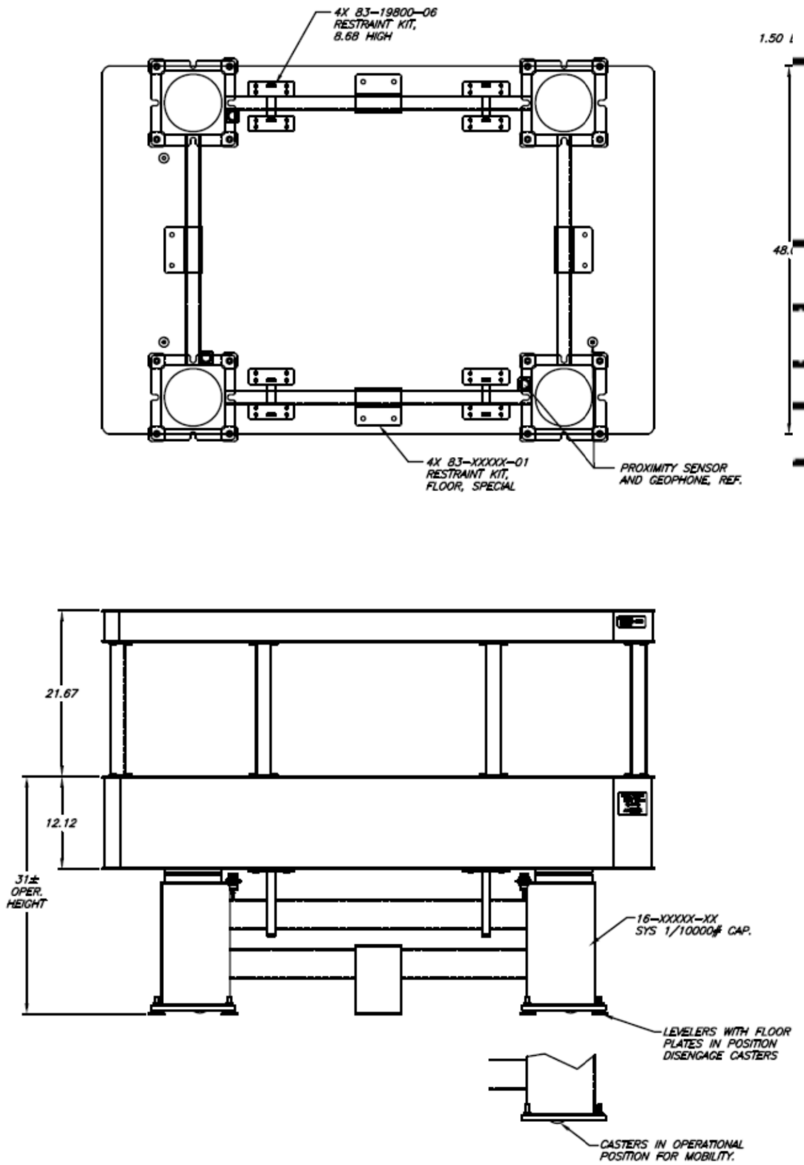
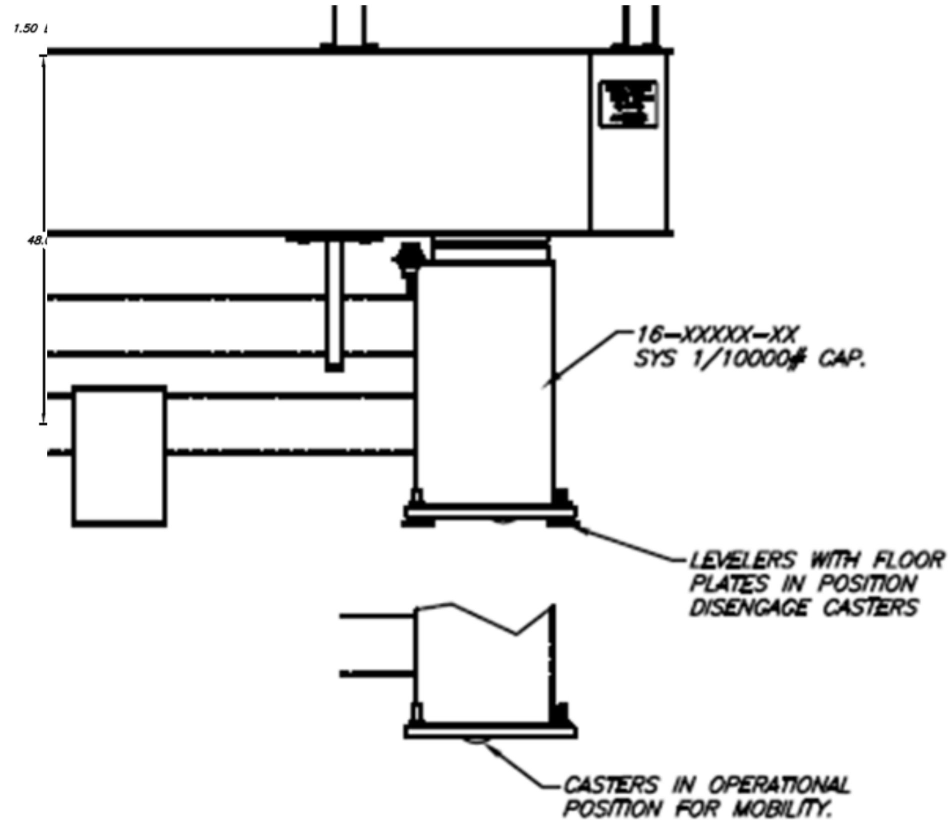
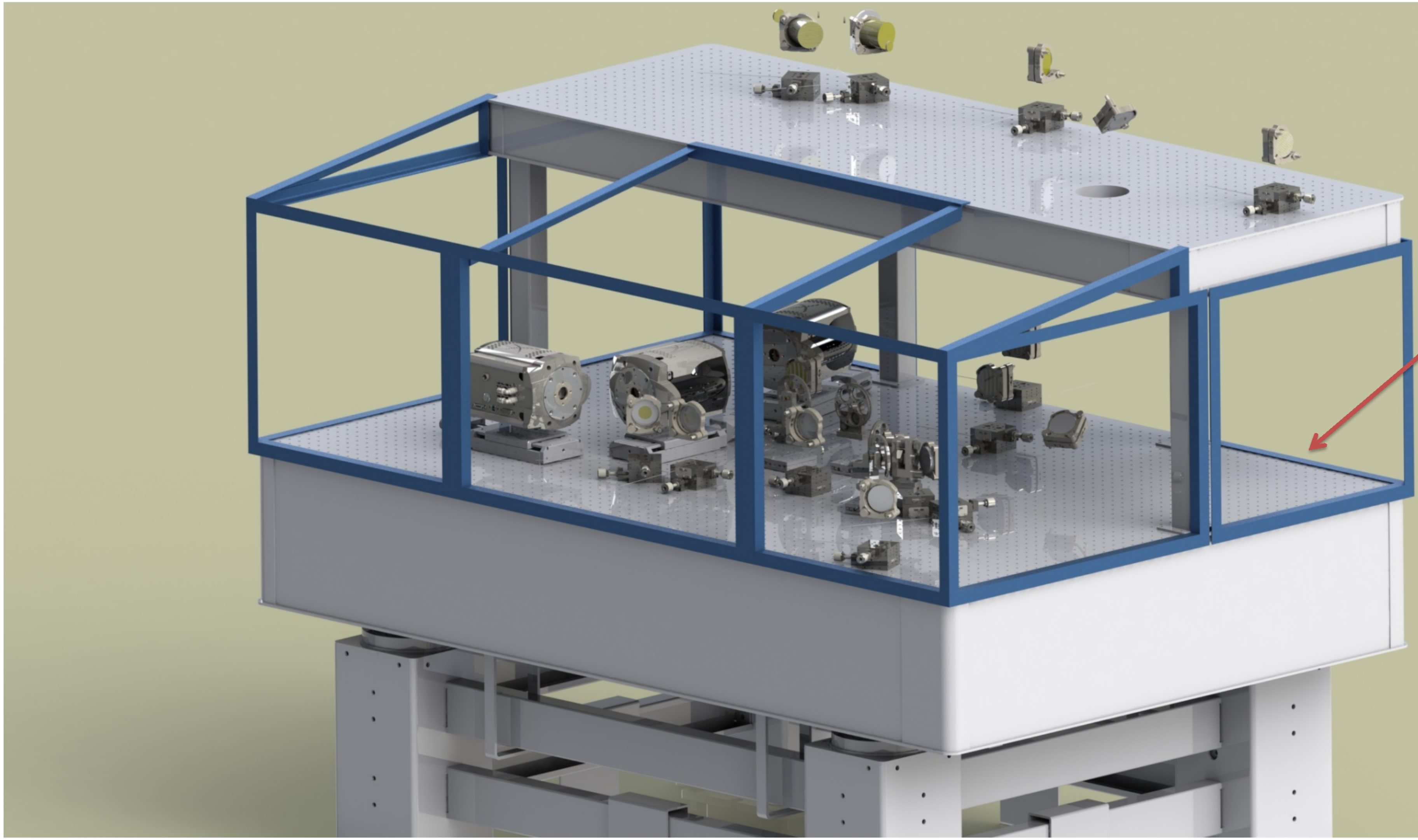
Unpacking and Alignment at Telescope





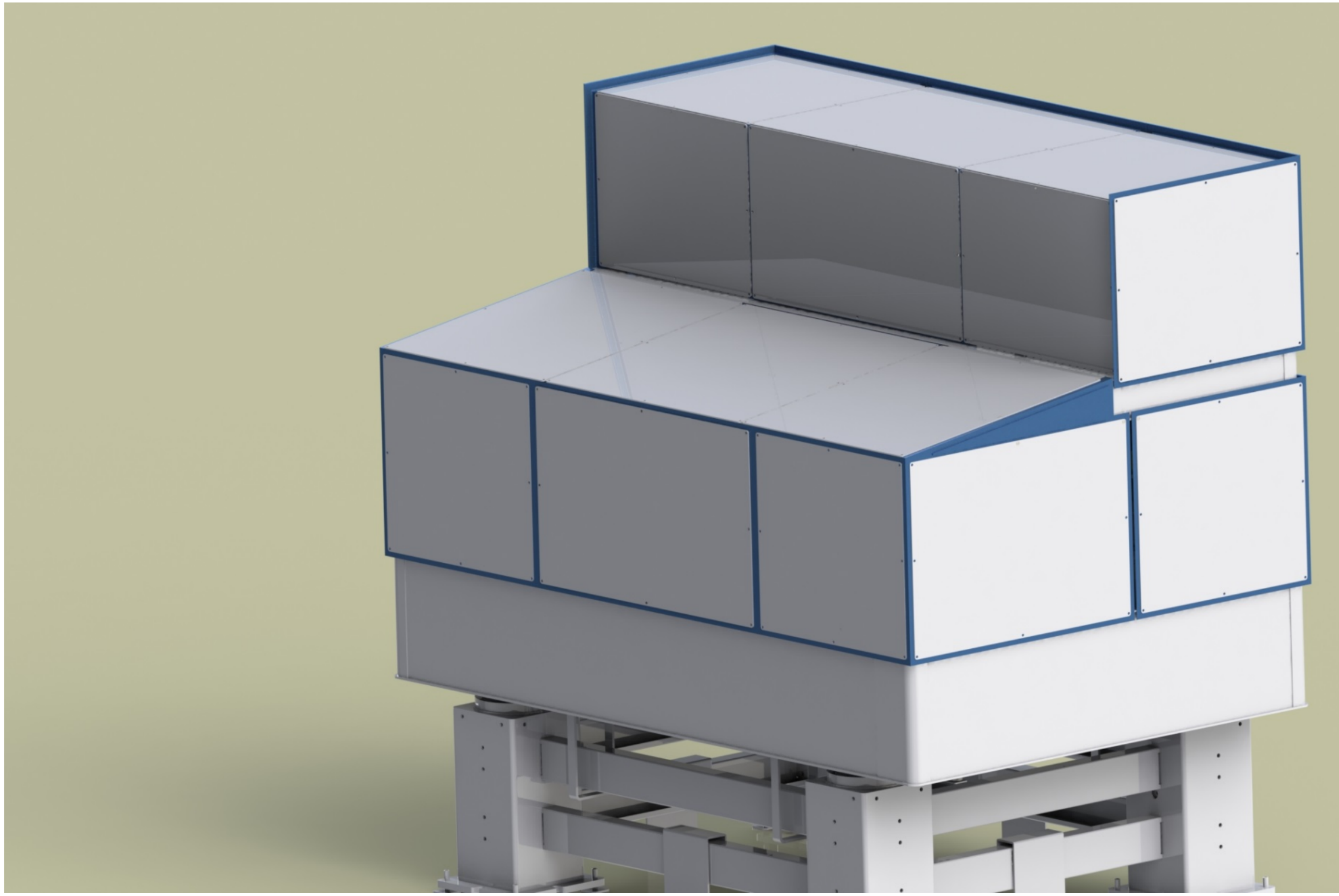
CASTERS ALLOW TABLE TO BE FINELY ALIGNED EVEN UNDER FULL LOAD

Wind/dust screen



This "backside" of panels is proud by ~5mm past edge of the current table, hence final air gap is 4.6 mm.

Wind/dust screen



MagAO-X as it will appear for observing (or shipping) with dust covers attached