ERIS Memo on VLT Pupil Geometry and HCI Pupil Mask Sizes

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v2.0

Introduction

This is an ERIS Memo detailing the pupil geometry required for coronagraphic masks in ERIS.

Reference Documents

The reference documents (RDs) are:

RD Number	Doc. Nr.	Doc. Title	Issue	Date
RD1	ERIS Memo OAA-17-001	Shape of Cassegrain Pupil at VLT-UT4	2	07/07/2017
RD2	VLT-SPE-ERI-14402-2009	ERIS-NIX Pupil Masks Requirements Specification v1.0	1.0	07/04/2017
RD3	VLT-TRE-ERI-14401-3103	VLT optical prescription for the ERIS focal station	1.0	23/03/2017
RD4 (in RD1)	VLT-DWG-AES-11310	M2-spiders general assembly		15/01/1994

Two pupil masks are required for ERIS coronagraphy - a mask for the APP180 and a Lyot mask for the Vortex coronagraph. Both masks are not in the reimaged pupil plane of ERIS, but are a distance of 4.40mm out of this plane.

The APP-180 requires a pupil mask to ensure that only light from the pupil enters the APP coronagraph optic. The steps needed to determine this are detailed in RD2. After this document was released, it was noted that a pupil image from VISIR shows warm thermal emission from not only the secondary mirror and its supports, but also a surrounding light baffle on M2, and from M3 when it is fixed in its stow position - this was detailed in RD1.

We combine the results from these documents into this document to provide a single reference for the justification we have on the masks and provide a Python computer code that generates a binary mask that masks out the warm optical elements in the VLT optical beam.

The geometry of the VLT pupil

An engineering drawing from the VLT shows the location of the secondary support structures and the secondary hub with respect to the optical centre of the mirror. There are a list of critical radii concerned with determining the VLT UT4 pupil listed in Table 1.

Radius (mm)	Relevant optical component	Reference	Notes
4219.7	Secondary support crossing coordinate system of primary mirror in drawings	RD4	Used for fixing where the spider arm crosses the axes
4092	M1 radius	RD4	David Henry email to MAK 12/1/2018
4060	ERIS Entrance Pupil (M2 projected onto M1)	RD3	Confirmed David Henry email to MAK 12/1/2018
775	M2 sky baffle		
646.5	DSM wind screen external diameter on UT4	RD1	Screen is emissive and needs blocking
558	M2 mirror diameter		

Table 1: Relevant radii of optical components in ERIS and the VLT.

We define a coordinate system centred on the middle of the primary mirror. The spider arms are tilted at an angle of 5.5 degrees with respect to the axes of this coordinate system, and they all cross at a radius of 4219.7mm. The Python code used to generate the pupil masks defines a square image whose size equals 2 times 4219.7mm, marking the point where the spiders cross the coordinate axes of the primary mirror as at the midpoint of each side of the square.

The radius of the primary is at 4092mm.

ERIS follows the design of many IR instruments and so the mirror M2 is undersized with respect to M1, and the projected radius of M2 is 558mm, which when reprojected onto M1 is a diameter of 4060mm.

The diameter of 4060mm is the defined pupil of ERIS, and this dimension is used in simulations and raytracing through to the location of the pupil in ERIS.

The geometry of the ERIS pupil

The L/M camera optics in ERIS are referred to as 'Camera 3' with a 13mas/pix scale at the camera focal plane. This is a large oversampling of the PSF but it is necessary due to the large sky background in ERIS and is required to prevent saturation of the detector.

The optics are refractive lenses, and so the image of the pupil formed at the location of the coronagraphs is blurred by a few tens of microns. To ensure all light from the pupil and no light from thermal emission of nearby warm telescope components, the pupil is undersized for two effects - the reimaging out of pupil plane of the pupil, and for the alignment and flexure budget of ERIS.

Two movable wheels are on either side of the pupil location in ERIS. The Optical interface is shown in the Figure below. In this figure, light from the telescope comes from the right, passes through a tilted filter, then the Pupil plane has a fixed cold aperture of 13mm in place, and then the pupil wheel where the gvAPP optic will be located.

6 Optical Design Description

6.1 Optical Interface

Figure 15 shows the location and orientation of the optical elements placed in the PFW for the example of the Lyot stop together with a ND filter in the PWA and a colour filter in the FWA.

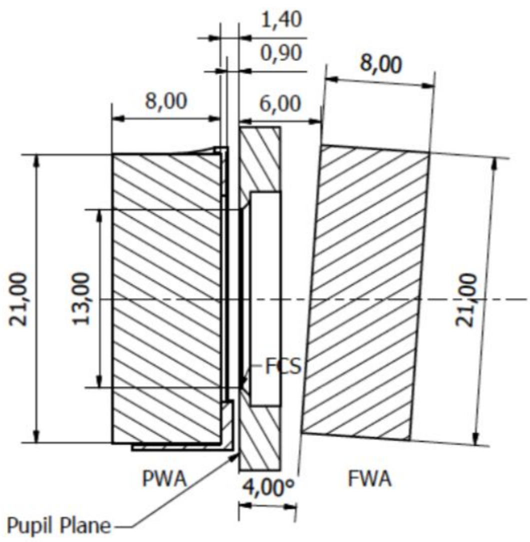
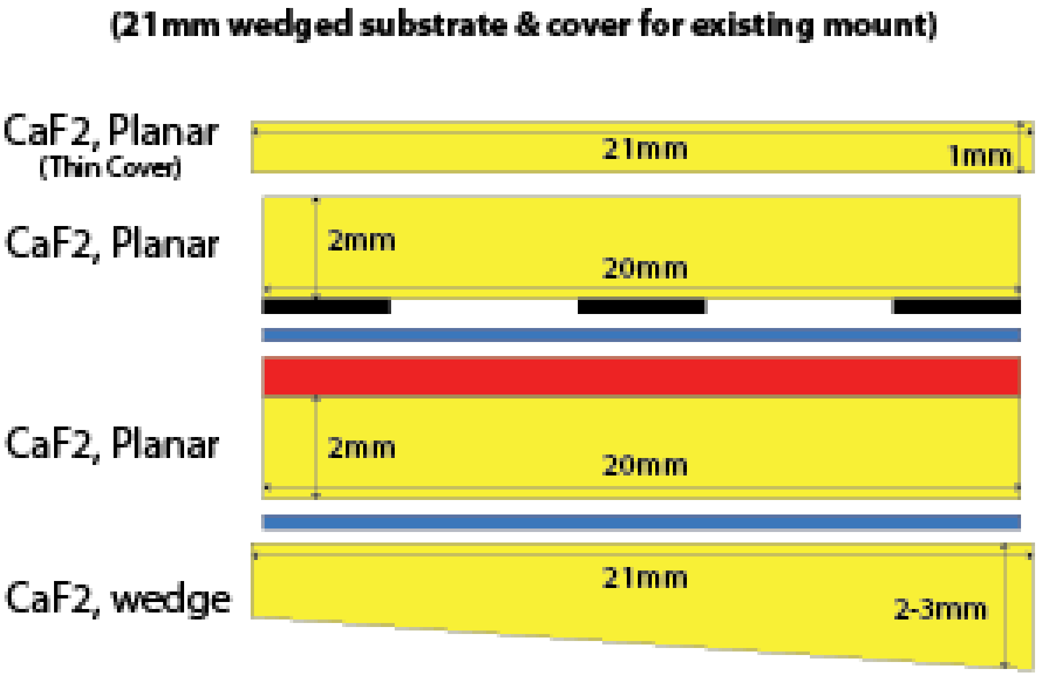


Figure 15 – Optical interface of the PFW for filter elements placed in both wheels and a pupil mask placed behind the fixed cold stop. Note that not all functions of the PFW require all these elements in the science beam.

For other functional modes, not all elements are necessarily placed in the beam.

The geometry of the gvAPP for ERIS is shown in the figure below - sent by Jason Kekas in 2018 Jan 18 email. [Matt K local link]



Size of the pupil in the pupil plane

The image of the outer edge in the pupil plane is not a sharp transition, but goes from 100 to 0 percent transmission from 5.8mm to 6.3mm. We define the radius of the pupil image in ERIS Camera 3 to be 6.025mm, by visual inspection of Figure 5 of RD2 for the half power point of the L band curves (see Figure 1).

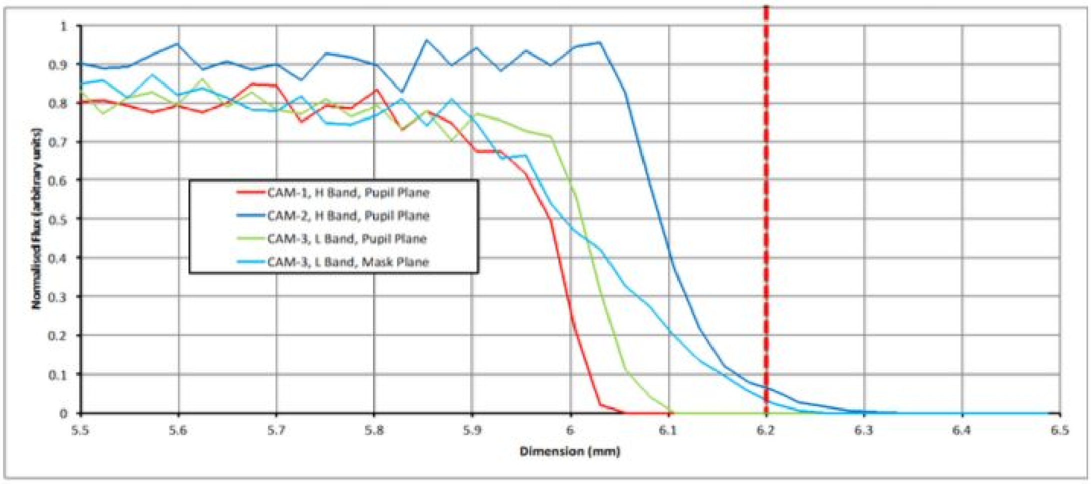


Figure 5 - Outer radius determination

Figure 1: Figure 5 from RD2 showing a radial cut through the raytraced pupil image.

The 6.025mm was checked in ZEMAX and found to be 6.009mm. The 6.025mm number was kept for the rest of the calculations.

Size of the pupil in the plane of the gvAPP pattern

There are three effects that reduce the effective area of the illuminated pupil. First is the mechanical and alignment tolerances within ERIS and the VLT. The second is the blurring due to the optical train, and the change in pupil position as a function of field position because the optic is no longer at the pupil plane. The third is that the pupil plane is in a converging beam, and so the pupil image becomes smaller out of the pupil plane.

The distance from pupil plane in ERIS to the gvAPP pattern is 1.40mm from the pupil plane to the mechanical interface, and 3.00mm from the gvAPP surface to the gvAPP pattern, meaning that there is d=4.40mm from the ERIS pupil plane to the gvAPP pattern, all in a converging beam.

A ZEMAX file with the details of the ERIS optical design called ERIS-NIX 205.zar from David Henry on 2018 Jan 17 (Matt K local link) was used to calculate the size and blurring effects of the pupil.

Demagnification of the pupil

The pupil scales down by 0.977427 from 6.025mm to 5.89mm at the location of d=4.40mm behind the ERIS pupil, and these calculations are detailed in a spreadsheet. (From David Doelman on 18 Jan 2018: a spreadsheet detailing the pupil image geometry ERIS_Pupil_alignment_tolerances.xlsx: (Matt K local link)

Pupil movement as a function of field position

The gvAPP is not in the pupil plane, so there is a lateral shift of the pupil image for different field positions. The gvAPP is used in a beamswitching capacity, between two positions that are 5 arcseconds either side of the centre of the field of view. These calculations are detailed in the spreadsheet above, and this leads to a reduction of the pupil structures by 110 microns.

Tolerances of ERIS alignment

There is an additional amount of uncertainty in the location of the ERIS pupil image in the pupil wheel, due to flexure and reattachment tolerances in the design, estimated in Table 2. This adds another 154 microns of blurring to the resultant pupil mask.

Item	Error +- (microns)	Type of error
PFW asembly	50	random
NIX internal static alignment	15	random
NIX flexure	20	flexure
NIX mounting interface	20	random
ERIS flexure	50	flexure
ERIS mounting interface	20	random
Telescope pupil movement	100	random
Pupil hole drill tolerance	25	random
Linear combination	300	
Quadratic combinaton of random	119	
Linear combination of flexure	70	
Quadratic plus half of linear	154	

Table 2: Contributions to the error budget in the location of the telescope pupil in ERIS.

Additional warm structures in the VLT pupil

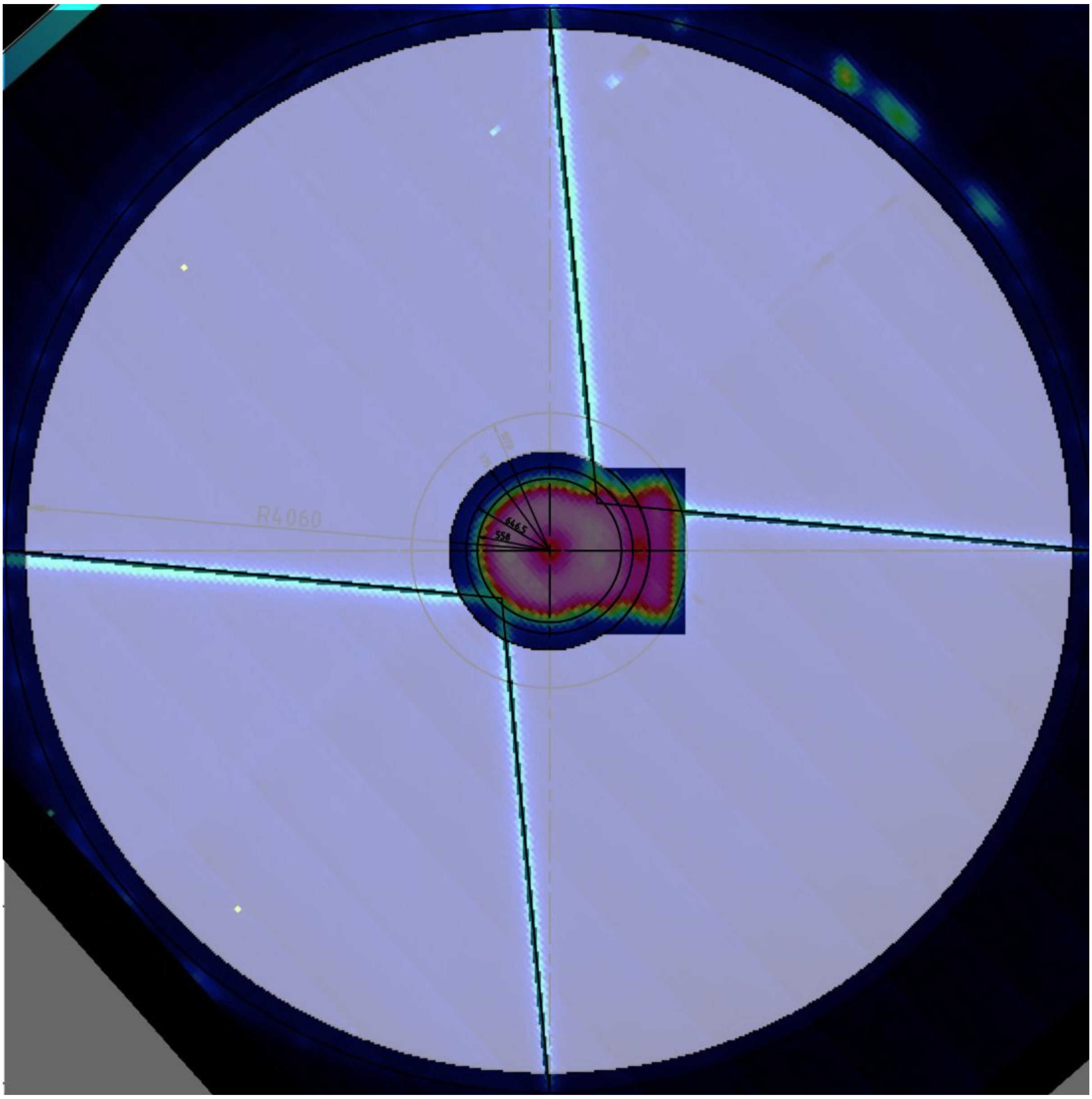
The thermal infrared image of UT4 as taken by VISIR shows the presence of the stowed M3 mirror and a wind baffle at M2.

The Deformable Secondary Mirror will replace M2 in the future, and its diameter is listed in the table above. The M3 mirror in stow can be masked with the addition of a rectangular mask extending out to one side of the M2 circular obstruction.

The width of the spider arms are 40mm.

Light from the sky can go past the side barrel of M2 and go directly into wide field visible wavelength instruments, adding to the sky background. This is an issue for instruments such as MUSE, and to prevent this direct line of sight propagation, a sky baffle is added around the barrel of M2. This baffle is uncooled, and appears as a warm emissive surface in the field of view of ERIS at thermal wavelengths.

The radius of this baffle is 775mm.
An overlay of the pupil generated in A is shown overlaid on the VLT VISIR pupil image. It can be seen that the ERIS pupil matches the secondary support structure, the M3 baffle and the expected radius of the M2 sky baffle.



Code to generate the gvAPP pupils

The Python code ERIS_pupil_tight_ZEMAX_corrected_SkyBaffle.py generates three pupil masks based on the discussions above. They are labelled

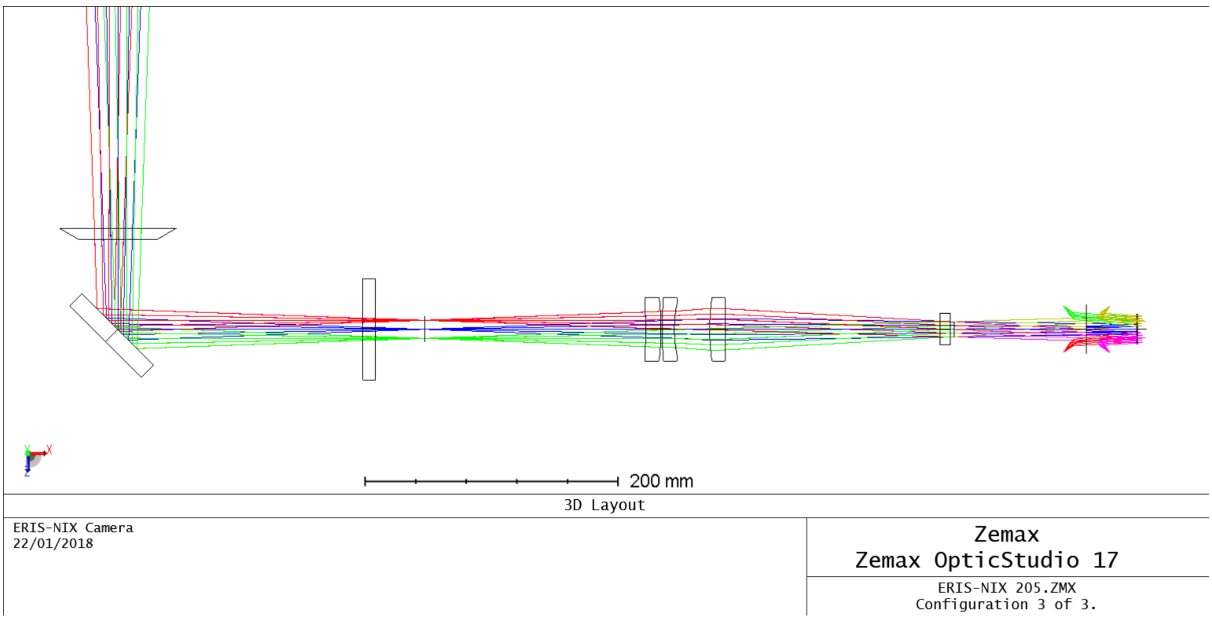
VLT_ERIS_pupil_X_*.fits

...where X is a letter A, B, or D. These are described in the table below. We use D for the design of the gvAPP ERIS pupil. All masks produce the mask with a pixelsize of 5 microns. The demagnification is currently hard-coded in the pixelsize in the code, so it is inconsistent with the real pixelsize. The box and sky baffle are slightly demagnified but the kernel convolution overwhelms this demagnification factor.

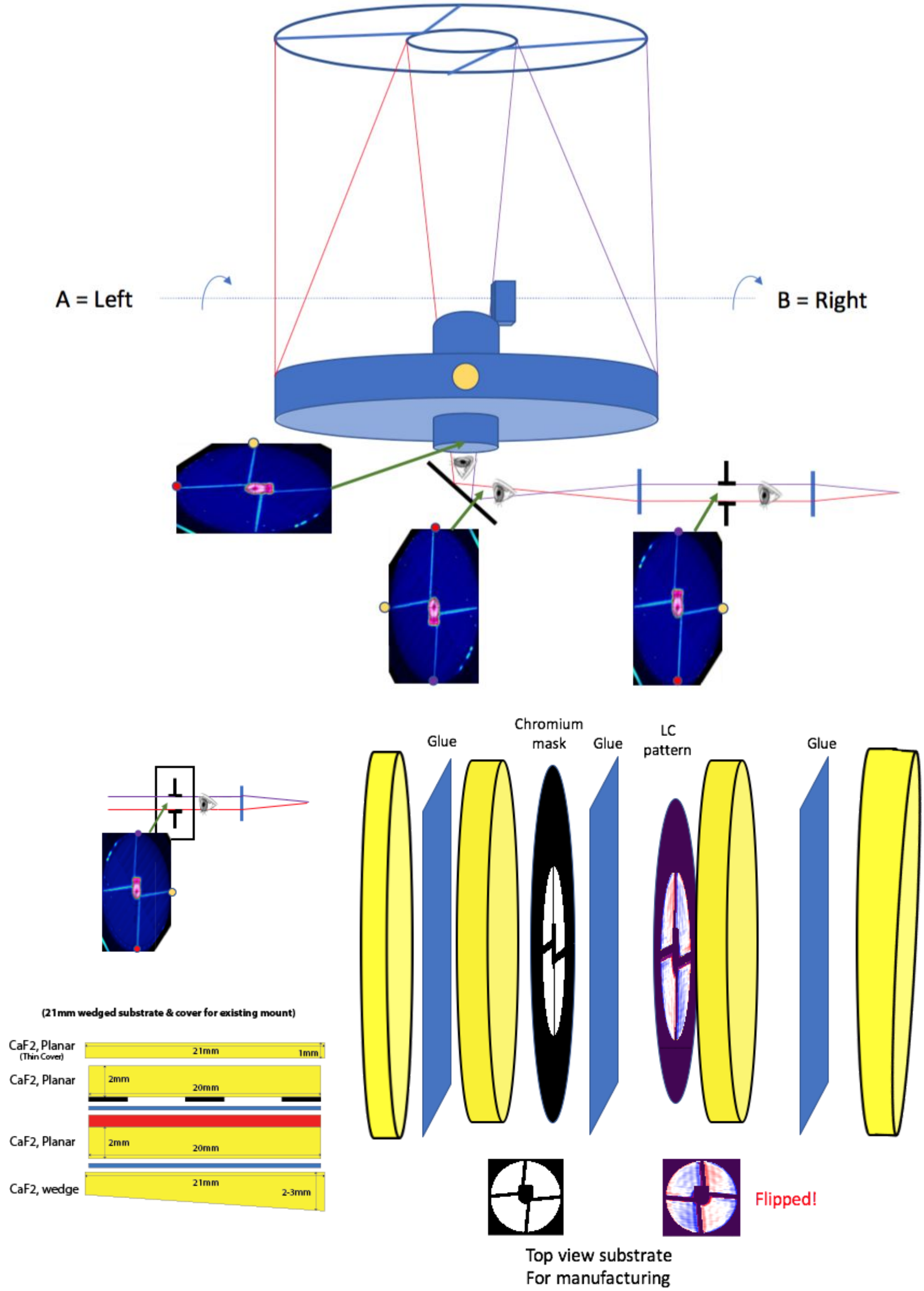
Pupil mask	Comment
VLT_ERIS_pupil_A_entrance_pupil_SkyBaffle	A is the with the sky baffle but no blurring at all at d=4.40mm plane with CaF2 substrate for a thickness of 3.00mm.
VLT_ERIS_pupil_B_undersized_out_of_pupil_plane_SkyBaffle	B is blurred by the kernel for out of pupil plane field dependencies with +/- 5 arcsec field of view (110 microns total kernel size).
VLT_ERIS_pupil_D_tightly_undersized_ZEMAX_corrected_SkyBaffle	D is convolved with an additional 154 micron kernel for the flexure and combination of alignment tolerances. This is the mask that should be used.

Orientation of mask with respect to the optical path

The addition of the M3 baffle to mask out the M3 baffle means that the symmetry of the mask is broken, and the orientation with respect to the gvAPP glass subtrates needs to be determined. We use a ZEMAX drawing of ERIS optics with Camera 3 in the beam, and photos of UT4 to derive the orientation of the masks. The python code generates the pupil to be consistent with the VISIR orientation and needs to be rotated by 90 degrees to match the orientation of the chromium pupil mask shown below.



This is an image of the raytraced ZEMAX configuration for ERIS.



The appropriate configurations for the mask substrate and the liquid crystal substrate are shown in the bottom figure.