# ERIS Memo on VLT Pupil Geometry and HCI Pupil Mask Sizes

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v1.0

## 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 0.9mm 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 |
| 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 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 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.

The image of the outer edge 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).

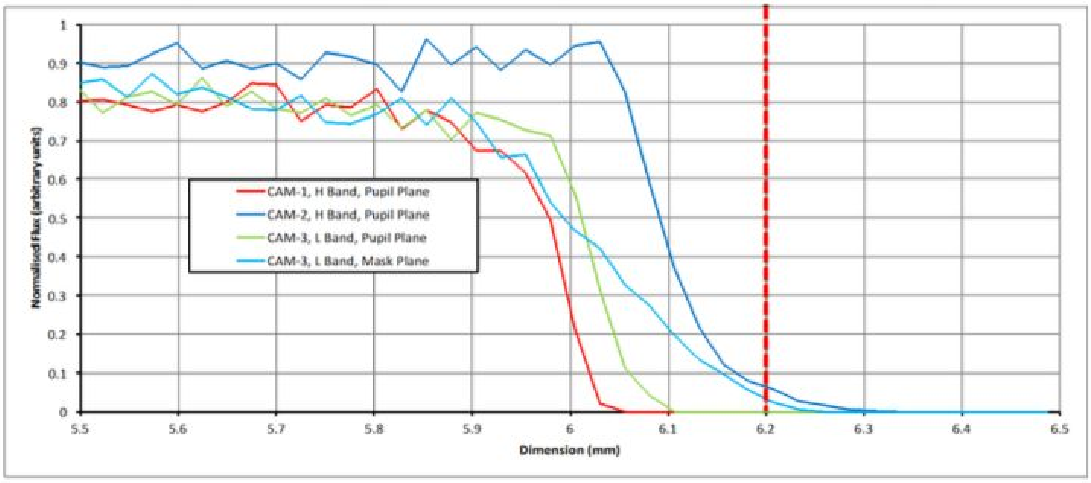



**Figure 5 - Outer radius determination**

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

We then take 100% transmission to be at 5.9mm, leading to a blurring of 125 microns due to the out of plane location and camera optics.

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 300 microns of uncertainty to the calculation but results in a very conservative 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.

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

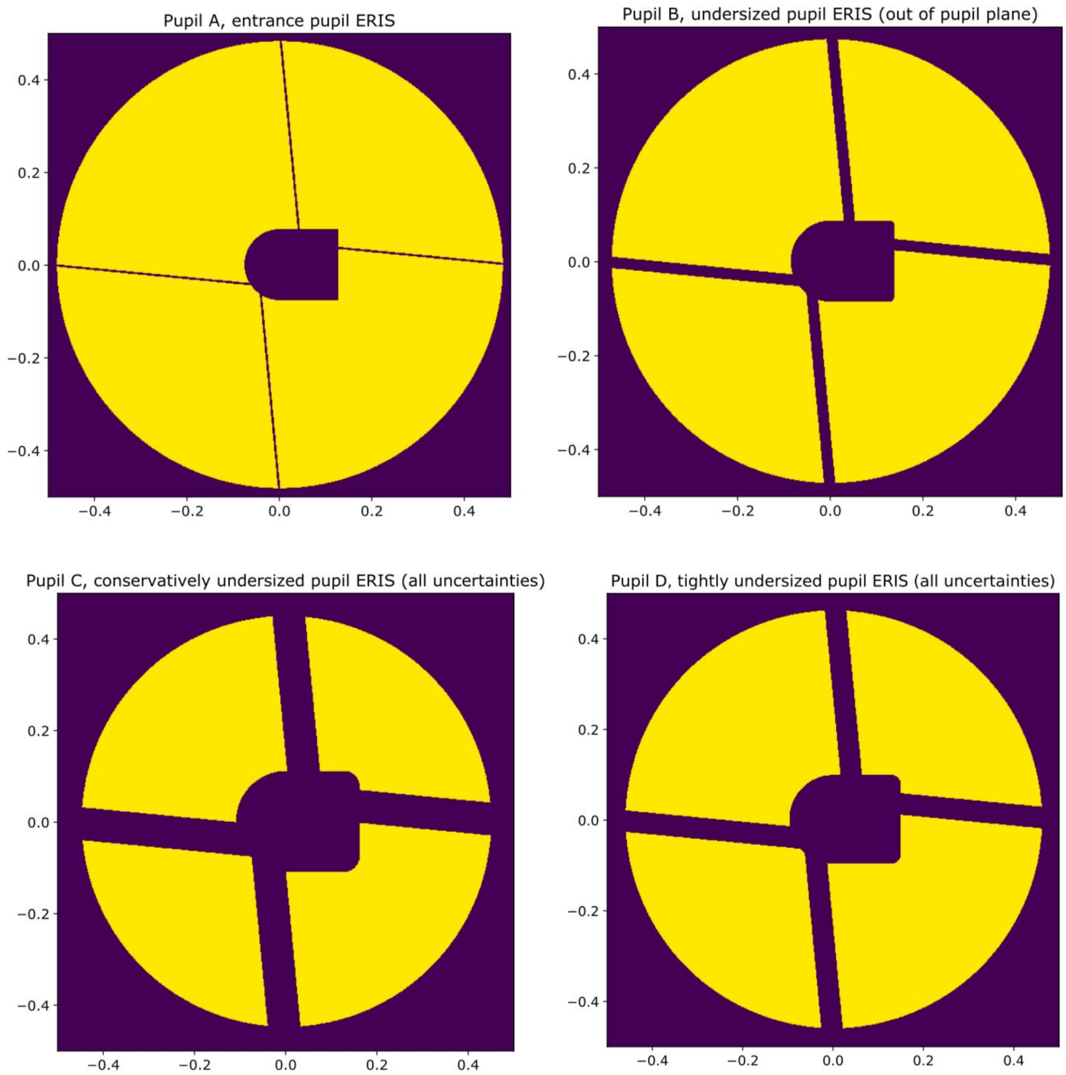
The Deformable Secondary Mirror will replace M2 in the future, and its diameter is listed in the table above. The M3 mirror in stow can be masked with the addition of a rectangular mask extending out to one side of the M2 circular obstruction.

The width of the spider arms are 40mm.

Two computer programs generate four pupil masks based on the numbers and blurring factors listed above.

We recommend that the VLT_ERIS_pupil_D_tightly_undersized_all_uncertainties.fits is used for the ERIS APP and for the Vortex Lyot mask.

| Pupil mask | Comment |
|---|---|
| VLT_ERIS_pupil_A_entrance_pupil | Geometric pupil shadow masking all warm telescope components. |
| VLT_ERIS_pupil_B_undersized_out_of_pupil_plane | 125 micron blurring due to out of plane image and camera optics for Camera 3. |
| VLT_ERIS_pupil_C_conservatively_undersized_all_uncertainties | 125 micron blurring and 300 microns for conservative blurring |
| VLT_ERIS_pupil_D_tightly_undersized_all_uncertainties | 125 micron blurring and 150 microns for tight blurring |


Pupil A, entrance pupil ERIS
Pupil B, undersized pupil ERIS (out of pupil plane)
Pupil C, conservatively undersized pupil ERIS (all uncertainties)
Pupil D, tightly undersized pupil ERIS (all uncertainties)
0.4
0.2
0.0
−0.2
−0.4

# 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.

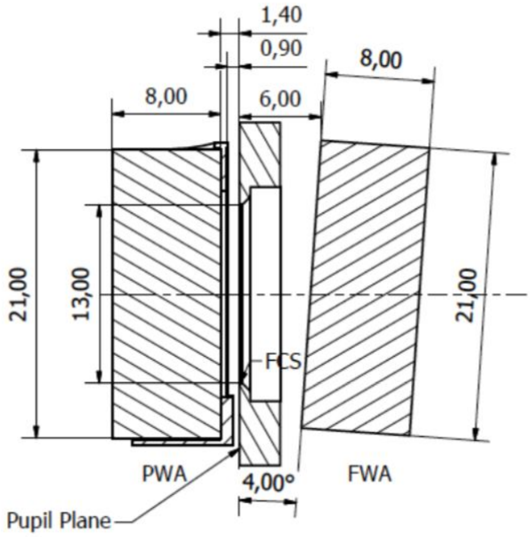



**Figure 15 – Optical interface of the PFW for filter elements placed in both wheels and a pupil mask placed behind the fixed cold stop. Note that not all functions of the PFW require all these elements in the science beam.**

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