Design of the low incidence dichroic

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	Name	Date

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CHANGE RECORD

Issue	Date	Section/ Paragraph Affected	Reasons / Remarks	Name
1.0	before 10/07/2012	All	Created	Bonaglia
1.1	10/07/2012	All	Removed fold mirror spec	Bonaglia
1.2	12/07/2012	All	Revision	Busoni
1.3	25/09/2012	All	Hill's review	Antichi
1.4	02/10/2012	All	Woodruff's review	Antichi
1.5	03/10/2012	All	Revision Specs removed and attached as AD6	Bonaglia
1.6	15/10/2012		Synchronisation with AD6	Bonaglia
1.7	19/10/2012		Correction of typos in Sections 5.1 and 5.2. Insertion of Section 8.3.	Antichi

1 Scope

The document desribes the delta-FDR design of the ARGOS dichroic unit for both the optical and mechanical productions of the elements shaping this subsystem.

2 Applicable documents

No. - Title	**Number & Issue**
AD1 - LUCIFER FDR_TRE-09_Optics	1.0 31/01/2002
AD2 - CAN 650s002	
AD3 - Dich_low_inc_F15_120523.zmx	
AD4 - Dich_low_inc_F15+LGS_WFS_v46_120710.zmx	
AD5 - M120220_LBT-ARGOS.	
AD6 - ARGOS_SoW_102_Low_inc_dichroic_specs_v1.5	1.5 04/10/2012
AD7 - ARGOS_FRD_015a_DichoricDesign	
AD8 - ARGOS_PDR_005_SysDesign	
AD9 - ARGOS_PDR_008_WFS	
AD10 – ARGOS_FDR_003_TLR	
AD11 – ARGOS_FDR_015b_WFS	

3 Introduction

A new design of the ARGOS dichroic is mandatory to address overlooked issues at FDR and others arisen after that milestone. At the FDR the issued problem was related to the differential path experienced by the beam crossing different parts of the dichroic according to the FOV, being the optic tilted with respect to the LUCIFER optical axis and lying in a convergent F/15 beam with its entrance pupil at finite position above the telescope. The new ARGOS dichroic addresses this issue and all relatives to the injection of static aberrations in the LUCIFER beam due to a dichroic. Moreover it face with those ones concerning the motion of the imaged FOV across the dichoric surface, arising once the transmistted beam is field stabilized for LUCIFER. These issues were noticed after the FDR and have been fully taken into account in this delta-FDR design.

The major changes with respect to the FDR layout are:

- dichroic incidence angle 15 deg << 40.5 deg proper to the FDR layout
- dichroic wedge angle 0.08 deg << 0.5 deg proper to the FDR layout
- dichroic center thickness 20 mm << 40 mm proper to the FDR layout.
- dichroic 1st and 2nd surfaces are both flat while in the FDR layout the 2nd was cylindrical.

The mechanical design is schemed too and and the major changes onto the LGS WFS path assembly are described hereafter.

3.1 Issues encountered with the FDR dichroic

At ARGOS PDR the dichroic option to separate the laser light from the scientific light (600-2450nm) has been adopted.

The laser beam has to be deflected towards the LGS wavefront sensor, while the sky ligth has to be transmitted towards LUCIFER and the Pyramid WFS unit for tip-tilt and truth sensing. Figure 1 shows the arrangement of the dichroic and of the LGS-WFS as proposed and accepted at the ARGOS FDR. The dichroic is mounted on a motorized cart that allows to insert the optic in the telescope optical path and to remove it when ARGOS is not in use or when the LUCIFER calibration unit is needed. The LUCIFER calibration unit is parked on top of the rotator gallery (just outside Figure 1 on top) and may be deployed in the beam in front of LUCIFER. To avoid collisions, the dichroic cart and the LUCIFER calibration unit are interlocked.

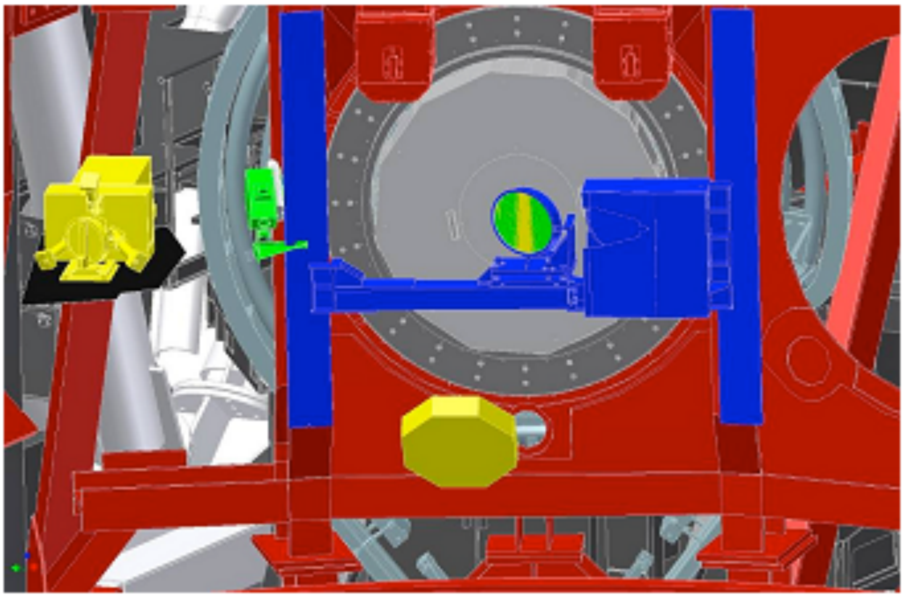

Figure 1: Rendering of the ARGOS dichroic and LGS WFS system as at FDR. In blue the dichroic unit. In yellow on the left side of the picture the LGS WFS.

The FDR dichroic is a 40mm thick INFRASIL wedged plate with a flat reflecting surface and a cylindrical back surface, working at 40.5° in the F/15 beam. The flat surface was at 970mm from the F/15 focal plane. The plate shape was designed to compensate the static aberrations introduced on the transmitted beam by the thick, tilted window itself. The beam quality on LUCIFER (after proper alignment of the hexapod and the application of a small static coma on the ASM) was practically unaffected by the presence of the dichroic plate. The polishing of the surfaces was specified to assure minimal static aberrations on the WFS path and the thickness of the plate, as well as the mounting frame, was designed in such a way that the displacement and the bending of the plate when the telescope elevation is changed were negligible. However, at the time of the FDR, two main issues were unnoticed. These issues are both related to the motion of the beam footprints on the dichroic surface: during the tracking, the on-axis field is kept fixed on the derotator axis while the off-axis fields moves on the non-derotated dichroic on circular trajectories. The unnoticed issues are the following:

1. The principal ray angle arrives on the F/15 plane tilted by 7mrad. This corresponds to a pupil shift of 10% of the pupil diameter. This is per se marginally acceptable, but since the tilt is introduced by the transmission through the dichroic, the pupil shift appears to rotate on the derotated instrument. This has an impact on both LUCIFER and on the FLAO board.
    a. On the FLAO board, the pupil rerotator vignettes the beams that are tilted more than 0.7mrad, so the principal ray tilt should be a factor of 10 smaller. If not the Pyramid WFS cannot be used as ARGOS Truth Sensor. On the FLAO technical viewer arm the tilted beam is not vignetted, so the ARGOS TT WFS can be used, with a loss of flux coupled in the fibers due to the 10 % pupil shift.
    b. On LUCIFER the pupil shift causes a vignetting on the cold stop placed in front of the grating/mirror. It can be compensated using the remotely controlled fold mirrors M1 and M4 (0.4° and 0.2° respectively). Note that these mirrors are already used for flexures compensation so that only a reduced stroke could be available for the pupil shift compensation. Moreover the compensation will have to be rotator-dependent. This approach is discouraged by the fact that these motors are not meant to operate continuously.

2. The tilted dichroic breaks the axial symmetry and introduces differential aberrations that are not axial-symmetric. The distortion is negligible for the fields that intersect the dichroic on its sagittal plane while his maximum for the fields lying on its tangential plane. The spot size is not huge, amounting to approx. 1arcsec on-sky for the extreme LUCIFER off-axis field (2.82 arcmin in the LUCIFER imaging mode). This problem was issued at the FDR. However, the broken axial symmetry causes a problem on the derotated focal plane: in fact, the object moves on the derotated focal plane along a circular trajectory whose diameter changes across the FOV. The resulting effect is that a point-like source is imaged, in the limit of a very long exposure, to a ring-like PSF with a diameter increasing linearly from 0 (at the center of the field) to 1arcsec at the outmost LUCIFER field. Note that because of the symmetry of the system, a 180° rotation of the sky produces a complete-circle on the derotated focal plane. Simulated long exposure PSF using the FDR layout model are shown in Figure 2.

These 2 issues impose unacceptable limitations for the ARGOS operations in both wide-field GLAO and small-field DL.

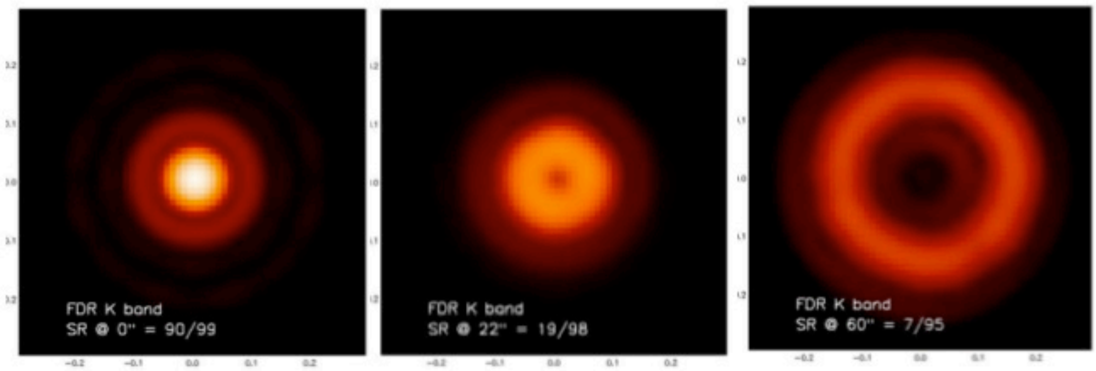

Figure 2: Long exposure PSFs with the FDR dichroic: on-axis (left), 22arcsec off-axis (middle), 60arcsec off-axis (right). The differential aberration introduced by the dichroic causes an annular shape on the derotated focal plane. SR values in each picture correspond to the long exposure (full rotation)/short exposure (no rotation) values.

More generally, a tilted window placed in the converging beam will impact also on other important characteristics of the transmitted and reflected beams that have to be taken into account for the design of the new dichroic unit:

3. Pointing offset: the dichroic shifts the transmitted beam. The point of the sky pointed by telescope (around which the sky rotates) is not imaged on the rotator axis. To correct the pointing offset it is possible to either a) correct the mount pointing or b) rotate the M1 and M2 around a common point (e.g. the centre of M3). The solution a) is not viable in binocular mode. Solution b) is limited by the stroke of M1 and M2 hexapods. In any case the pointing correction introduces a tilt of the focal plane that must be limited to prevent damaging the off-axis performances.
4. Chromatic aberration: the tilted dichroic introduces a chromatic dispersion. The amount of dispersion is field independent, but its orientation on the derotated F/15 plane is obviously rotator-dependent. The filters used in Lucifer are reported in Table 1.
5. Chromatic differential pointing: even if the chromatic aberration is corrected in the individual bands, still the R-band is imaged in a different position with respect to the IR image. Separation between R-image and IR-image is constant but the orientation varies with the rotator angle. The TT WFS will lock the R-star in a fixed position of the derotated focal plane and the IR image will follow a circular trajectory around the R image. This effect can be corrected in several ways: a)

adding signal offsets to the TT WFS, b) moving the motorized stages on which the TT WFS is mounted in a suitable way to maintain the IR image fixed in the field.

6. Bending of the substrate: this is in the first approximation negligible for the transmitted beam, but it introduces non-common path aberration in the reflected beam resulting in elevation-dependent offsets in the LGS WFS. The truth sensor can dynamically correct this effect.
7. Vibrations: the added optical element in the optical path can introduce some jittering due to mechanical vibrations of the supporting arm. In the dichroic case, this effect can impact on the LGS WFS performance.
8. Light losses: the added optical surfaces reduce the throughput of the system. The dichroic must have a very high transmittivity in the thermal infrared, to avoid reflecting the dome thermal background into LUCI. The dichroic coating must be optimized for that.
9. Ghosts: multiple reflections inside the dichroic can cause the superposition on the focal plane of a bright off-axis star on the weak on-axis target. The shape of the dichroic plays a role in this effect as well as its thickness.

The fact that aberrated spot size on the LUCIFER focal plane scales linearly with the glass thickness and with the 3rd power of the angle of incidence, indicates that a good option for a new optical design consist to lower the angle of incidence and to make the substrate thinner with respect to the FDR dichroic layout.

4 Delta-FDR Optical design

The rationale behind the optical design of the new dichroic is to reduce the angle of incidence of the rays onto the dichroic surface. In this case a second mirror, hanged over the telescope M1, has to be coupled to the dichroic to direct the LGS light toward the LGS WFS, as depicted in Figure 3.

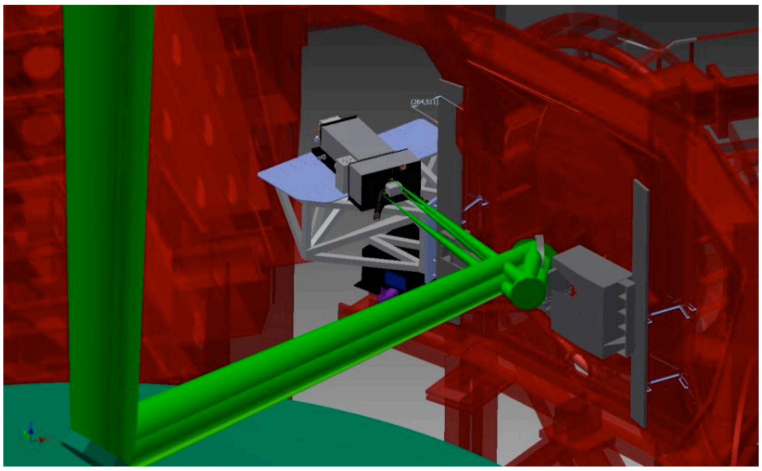

Figure 3: Rendering of the new arrangement of the ARGOS dichroic. The angle of incidence of the rays is reduced tilting the dichroic towards the LBTI focal station. A flat mirror is then hanged over M1 to direct the laser light toward the LGS WFS.

4.1 Requirements

The dichroic unit must satisfy two different observing modes: the wide-field (4arcmin x 2.5arcmin FOV) GLAO mode (LUCIFER in Multi Object Spectroscopy) and a small-field (30 x 30arcsec^2 FOV) diffraction limited mode (LUCIFER in Long Slit Spectroscopy). In the following we refer to the term PSF unaberrated PSF i.e. the image of a point source through a perfectly corrected atmosphere: this includes the effect of off-axis telescope aberrations and all kind of aberrations induced by the dichroic. A distinction is made between instantaneous or short-exposure PSF, defined as the PSF obtained at a instantaneous rotation angle, and long-exposure PSF, obtained over a full 360° sky rotation that integrates the effect of the differental aberrations and the chromatic aberration of the dichroic.

Designing the new dichroic arrangement the following requirements have been considered:

1. General requirement: the contribution to the telescope PSF due to the dichroic aberration must negligibly affect the best expected GLAO PSF. Supposing a GLAO corrected atmospheric PSF of 150mas FWHM, we require the presence of the dichroic to impact on the telescope long exposure PSF in GLAO mode (large FOV) in less than 30mas FWHM.
2. High Strehl Ratio on the Diffraction Limited FOV. On the small 30arcsec FOV, high values of Strehl ratio must be reached. We consider acceptable a minimum SR value in the small FOV (22" max. radial distance) of: 80% in J, 90% in H, and 95% in K. This requirement is the most demanding for the correction of the chromatism.
3. Chromatism in R band: this has an impact on TT WFS performance.
4. Loss of spatial resolution: during a long exposure the telescope PSF can move in the F/15 plane <100mas.

5. A pupil shift of <1% is considered acceptable: it causes no vignetting in the pyramid WFS and an acceptable one in LUCIFER.
6. The pointing offset (distance between the on-axis star and the derotator center, when the telescope is collimated for the no-dichroic case) must be corrected with a rotation of the optical train (e.g. M1-M2 around M3 vertex, M3 vertex around the focal station selection angle). Considering the plate scale of LBT equals 0.6mm/arcsec, a pointing offset of 10mm corresponds to 16.67arcsec. Such pointing offset is considered acceptable in terms of optical quality degradation of the on-axis PSF induced by the curved focal delivered to the F/15 focus. Pointing offset can be then corrected within the available movement ranges of the M1 hexapod (0.18 mm) and the M2 hexapod (0.68 mm) both smaller than the hexapod stroke.
7. This is due to the fact that ARGOS M2 is pre-compensated to deliver the highest SR onto LUCIFER when considering static aberrations only. Imposing and aberration budget to the dichroic of 36nm RMS, the PWFS dynamic range is more or less preserved. On the LGS WFS path, such pre-compensation of M2 inject another amount of static aberrations that are acceptable for the GLAO WFE error budget if they hare lower than 1000 nm.
8. The bending of the dichroic plate due to off-plane forces like gravity load or wind must have a negligible effect on the LGS WFS. A sag of 2um on a plate working at a 40° incidence angle affects the slopes PTV of 0.1arcsec. Bigger deflections can in principle be tolerated since the Truth sensor will remove them, provided that the deflection occurs on a very slow time-scale (<0.1Hz).
9. Emissivity of the plate must not impact on operations in K-band.

These requirements are resumed in Table 2 together with the performance of the FDR dichroic and the performance of the new unit described in this document.

4.2 Method

A Zemax model including the LBT telescope up to the F/15 focal plane has been created. The model includes the atmospheric dispersion, the deformable M2, a pointing correction obtained by rotation of M1 and M2 around the M3 vertex, the rotating sky and the derotated F/15 plane. LUCIFER window is not included in the model. The geometry is properly set to simulate the front bent oGregorian focal station. Atmospheric dispersion is simulated to provide a comparison with the dichroic chromatism, but the new dichroic design has been optimized at zenith. The definition of the LUCIFER filters has been derived by the LUCIFER documentation [AD1] and is shown in Table 1.

Filter	20%	50%	100%	50%	20%
R	0.60	0.68	0.75	0.82	0.90
J	1.12	1.17	1.25	1.33	1.38
H	1.48	1.53	1.65	1.77	1.82
K	2.00	2.03	2.22	2.42	2.45
zJ	0.98	1.10	1.40	1.70	1.80
H+K	1.40	1.50	1.90	2.30	2.45

Table 1: Definition of filters used in the Zemax optimization of the new dichroic.

The telescope collimation has been optimized independently for each filter by allowing a change in pointing offset (M1-M2 rotation), a correction of the selection angle with M3 and by applying a static focus, astigmatism Z6 and coma Z7 to M2.
The fact that the pointing offset is adjusted for each filter is a way of taking into account in the simulation an ideal correction of the R-IR pointing offset: indeed it is a way of supposing that the TT WFS is applying slope offset perfectly calibrated to null the shifting of IR focal plane.

Polychromatic long Exposure PSFs are computed integrating the polychromatic Huygens PSF for several (72) values of the rotator angle in the full 360° range. The integration is done by shifting and adding each short-exposure Huygens PSF (corresponding to a single value of the derotator) accordingly to the actual position of the centroid of the PSF in the focal plane. PSFs are computed with a pixel scale of 10mas/px and recentering is also done in 10mas steps. The long exposure procedure takes into accounts the effects of both chromatic aberrations and rotation-dependent distortion in the PSFs. Since the Huygens PSFs are properly normalized, the long exposure Strehl Ratio can be measured simply as the maximum of the long exposure PSFs.

4.3 Design layout

The new optical layout of the dichroic unit and LGS WFS is shown in Figure 4. The dichroic is tilted by 15 deg to reflect the beam in the direction of the LBTI focal station and a flat circular mirror is then used to direct the laser beams toward the LGS WFS. The flat mirror is at 600mm distance from the dichroic center. This flat mirror is tilted by 22.5° and the LGS WFS is placed directly on the light path from this mirror, at 1785mm distance.

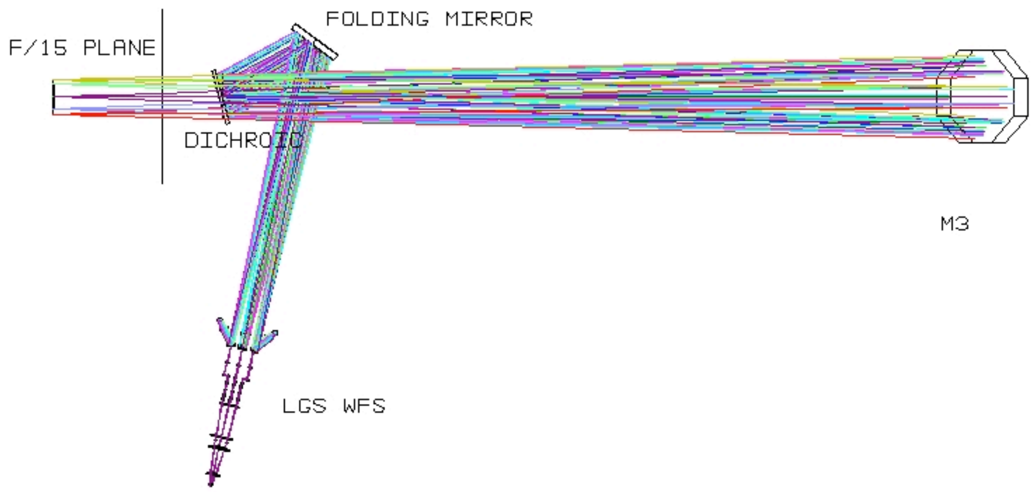

Figure 4: View of the low-incidence dichroic solution

The dichroic is a circular element working at an incidence angle of 15 deg. The optical footprint is 320mm diameter. This is mandatory to allow the GLAO acquisition phase to work with a 5x5arcmin^2 FOV. This scientific footprint is 280 mm and corresponds to 4x4arcmin^2 as required to the LUCIFER Imaging mode. The first element is the dichroic made of 2 planar surfaces (hereafter S1 and S2) wedged of 0.08°. The thicker edge is on the LBTI side while the thinner one is facing the LGS WFS as shown in Figure 6.

The second element is a circular and flat folding mirror of 304mm (12 inch) diameter. This mirror is placed at 600mm distance from the dichroic S1 and it is used to fold the laser light toward the LGS WFS that in this new arrangement is placed almost perpendicular to the LUCIFER focal station axis.

The footprints of the 3 LGS on the first surface of the fold mirror are shown in Figure 7. Figure 8 resumes the technical details of the selected optic

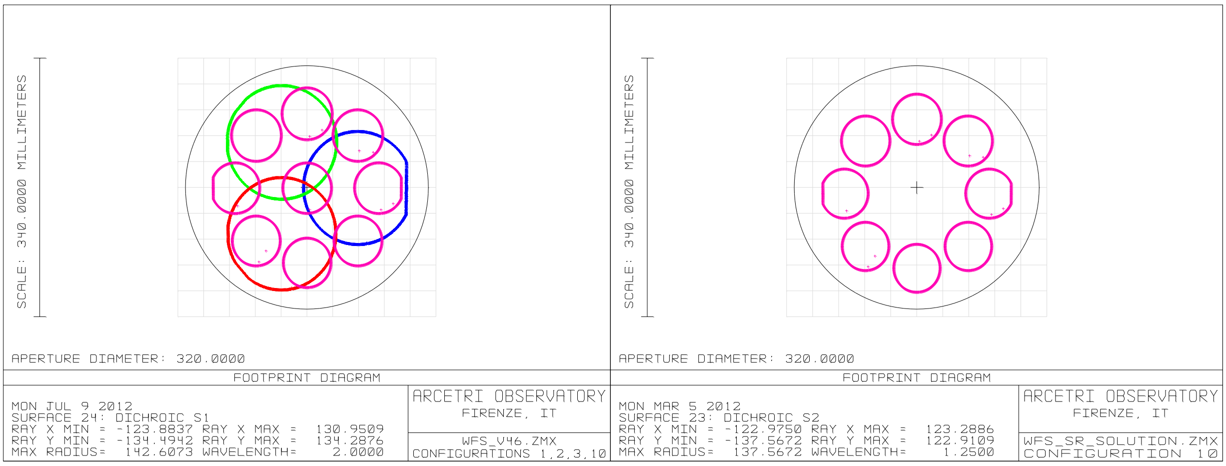

Figure 5: Footprints of the 3 LGS beams and of 9 NGS on dichroic S1 optical area (left). The natural stars footprints are arranged at the edge of the scientific FOV that is transmitted by the dichroic. Footprints of the 9 NGS beams on the dichroic S2 optical area (right). The beams are shifted by 7mm in the Y direction. Vignetting is due to the fixed size of LBT. Physical diameter of a single NGS beam is 65 mm. Physical diameter of a single LGS beam is 150 mm. Angular on-sky position of a single NGS beam is 2·√2 arcmin. Angular on-sky position of a single LGS beam is 2arcmin.

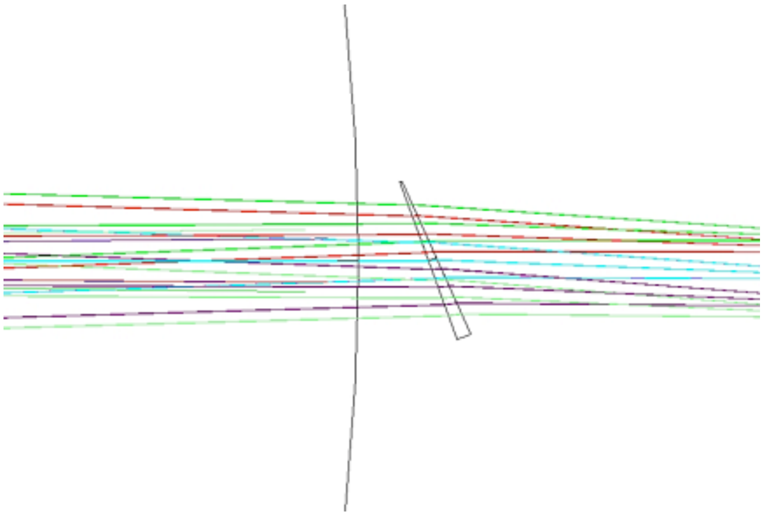

Figure 6: Layout of the low incidence dichroic. The thicker edge is facing the LBTI side. Wedge angle is enhanced by a factor 100 to better show the wedge direction.

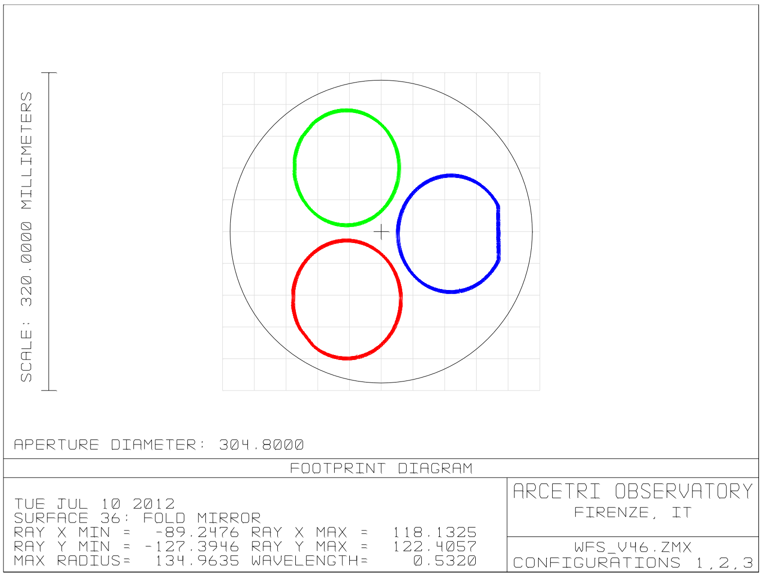

Figure 7: Footprints of the 3 LGS on a 12 inch circular fold mirror. Vignetting is due the M3 fixed size.

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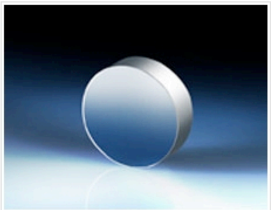

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Diameter (mm)	304.80
Diameter Tolerance (mm)	+0.0/-1.0
Thickness (mm)	38.10
Thickness Tolerance (mm)	±2.5
Surface Accuracy (λ)	1/10 @ 632.8nm
Surface Quality	60-40
Substrate	Fused Silica
Coating	Enhanced Aluminum
Typical Energy Density Limit	0.2 J/cm2 @ 532nm, 10ns
RoHS	Exempt

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Figure 8: Specifications for the Edmund 12 inch flat mirror to be used as fold mirror for the LGS WFS.

4.4 Performance

The performances of this new design are evaluated accordingly to the requirements expressed in section 4.1 and they are resumed in Table 2. These values have been computed using the Zemax model of AD3.

Requirement	Units & spec	FDR	New
Thickness	*mm*	*40*	*20*
Wedge	*deg*	*-0.59*	*0.08*
Angle of incidence	*deg*	*-40.5*	*15.0*
Field distortion at 2.35'	60um	879	50
Field distortion at 15"	10um	130	8
Chromatism (R)	60um	3	7
Chromatism (J)	15/30um	1	3
Chromatism (H)	11/30um	1	5
Chromatism (K)	10/30um	0	9
Chromatism (zJ)	60um	3	11
Chromatism (HK)	60um	1	17
Pupil shift	0.7mrad	7.4	0.7
Pointing offset	15arcsec	7	2
Pointing offser (R-K)	60um	4	21
Long exposure SR (J)	80%	10	92
Long exposure SR (H)	90%	14	94
Long exposure SR (K)	95%	19	92
Short exposure SR (J)	80%	95	96
Short exposure SR (H)	90%	97	98
Short exposure SR (K)	95%	98	97

Table 2: Summary of the optical performance of the new dichroic, compared with the FDR ones. SR values are evaluated at the corner of the 30arcsec FOV.

5 Tolerance analysis

The tolerance analysis has been realized using a merit function in which the various terms described in Table 2 are set in a “thresholding way”: the cost of each term is 0 if it stays in the range defined in Table 2. Otherwise it is set to an extremely high value. This creates a merit function landscape with very steep walls surrounding the region where the parameters are “good enough”. This approach eases the finding of a “sufficiently good” minimum when, like in this case, the various terms of the merit function are not homogenous. To ensure that all the terms are inside their allowed ranges, we allow a tiny departure of the merit function from 0 to the tolerance algorithm.

5.1 Substrate size, thickness, wedge and material

The physical dimensions and the clear aperture of the dichroic have been evaluated looking at the envelope of the 3 LGS and 9 NGS at the edges of the LUCIFER FOV. Figure 5 shows that the all are inscribed well in a circle of 320 mm diameter and that the footprints of the 9 NGS correspond is 280 mm and corresponds to $4x4arcmin^2$ i.e. the FOV requested to the LUCIFER imaging mode.

Taking into account for the FOV requested in the ARGOS LGS WFS acquisition phase: $5x5arcmin^2$, this FOV translates into a 320 mm footrprint onto the dichoric S1, see Figure 9. Hence, we decided to consider as dichroic subtrate size 320 mm, and to consider as dichroich clear aperture size 300 mm. In this way we let 20 mm safety circular annulus as margin for builging the subtrate and for the coating deposit refinements.

Finally, the circular geometry instead of the elliptical one has been chosen to ease the blank cutting process and to reduce differential bending of the substrate.

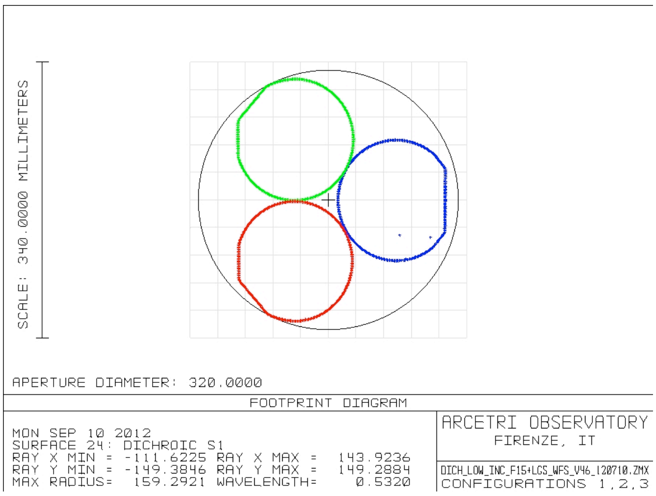

Figure 9: Footprints of 3 LGS corresponding to the WFS area requented during the ARGOS acquisition phase $5x5arcmin^2$. These footprints fix the physical size of the dichroic substrate to be 320 mm.

5.2 Subtrate thickness

The dichroic has been designed to have a 20mm central thickness. Tolerance anaalysis of the thickness indicates that 1 mm is acceptable: a tichkness wider than 21 mm makes the K band chromatism out of specifications, while a thickness smaller than 19 mm gives better performances but is a priori dangerous because of the major risks of bending and brittleness of the substrate.

Oper #	Type	-	Nominal	-	-	Comment
1 (TTHI)	TTHI	22	-20.000000	-1.363970	20.000000	Dichroic central thickness

Figure 10: Maximum thickness error for the dichroic evaluated in Zemax. At 21.36970mm thickness the K band chromatism hits the threshold value.

5.3 Substrate wedge

The same approach has been used to evaluate the tolerance on the 0.08° wedge. Slighter wedges (below 0.07°) bring the K band color above the threshold level while larger wedges (over 0.09°) cause a principal ray tilt larger than the accepted 0.7mrad. This seems to be the tighter tolerance (±6arcmic) for the dichroic production and for sure it is the one most affecting the performance of the optic.

Oper #	Type	-	Nominal	-	-	Comment
1 (TUTX)	TUTX	23	0.080000	-0.010346	9.302827E-004	Wedge angle

Figure 11: Tolerated error for the dichroic wedge angle evaluated in Zemax.

5.4 Substrate material

The dichroic should transmit light from 620 nm to 2400 nm with the maximum efficiency in order to have negligible effect onto the LUCIFER trasmission budget. To accomplish with this task the substrate of the dichroic will is made of INFRASIL 301/302 or SUPRASIL 3001/3002. Both quartz have excellent transmission of on the wavelength window of LUCIFER.

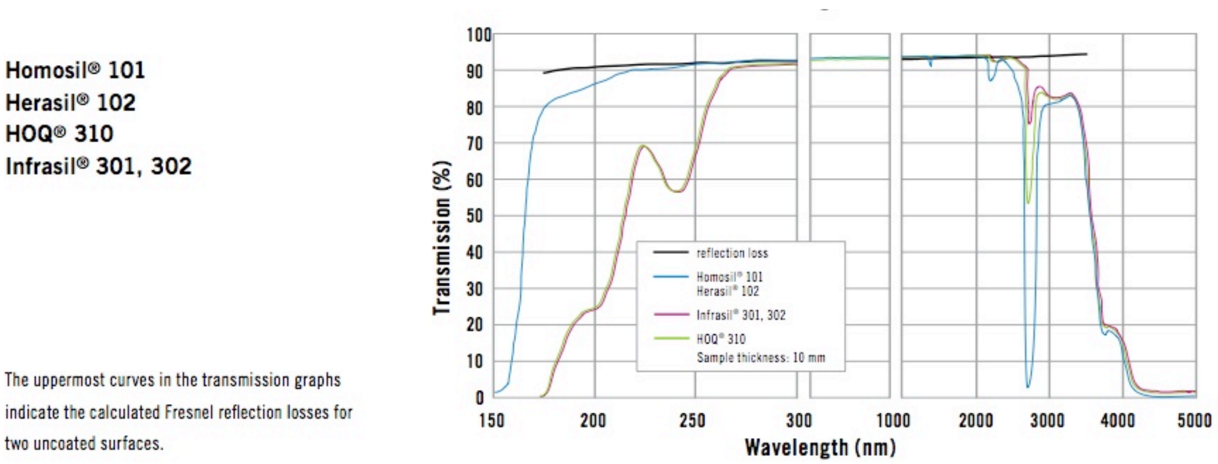

Figure 12: Transmission of INFRASIL 302 is well above 90% in the LUCIFER wavelengths window.

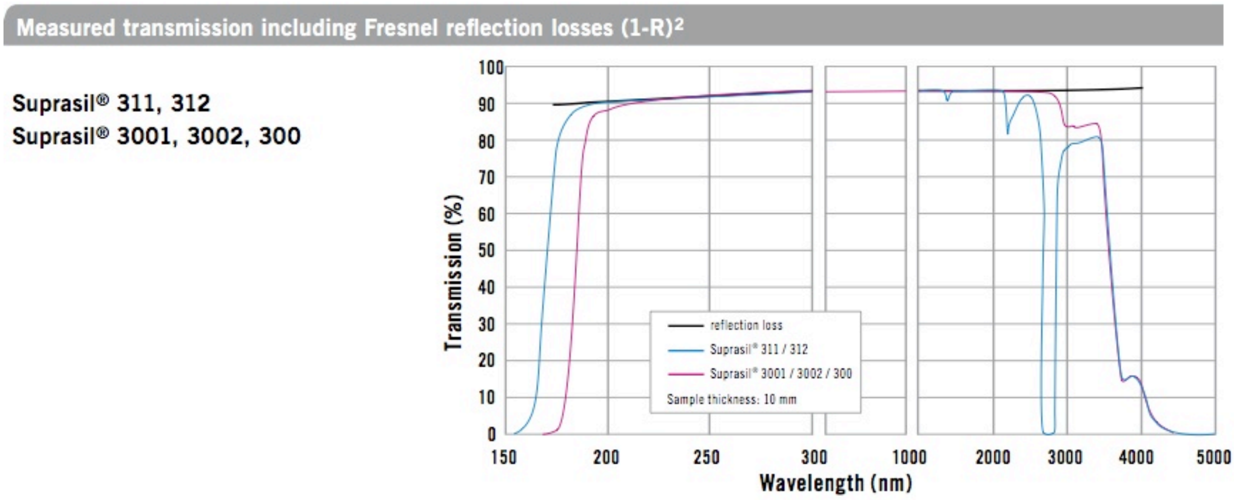

Figure 13: Transmission of SUPRASIL 3002 is well above 90% in the LUCIFER wavelengths window.

6 WFE budgets

6.1 Budget in reflection

The local tilt of the dichroic surface S1, measured on the area of a single SH-WFS subaperture (equivalent to 10mm) must be low enough to not displace the correspondent spot on the LGS focal plane by more than a small fraction of the WFS dynamic range (1/25 as baseline, 1/50 as goal). Considering the diagonal the FOV of the LUCIFER Multi Object Spectroscopy mode (2.35arcsec radius), the telescope plate scale (0.66mm/arcsec at the F/16.6 LGS plane) and the distance between dichroic and focal plane (2385mm) the acceptable average tilt of the dichroic S1 over a patch of 10mm corresponds to a maximum derivative of 26nm/mm.

The quality of the wavefront reflected by the the dichroic surfaces (since the optic symmetry we expect the dichroic S1 and S2 to be exchangeable) must be better than 100nm rms over the 10mm subaperture footprint. This is needed to ensure that the WFS is able to produce good quality spots on the LGS WFS focal plane. So the specification for the dichroic S1 and S2 optical quality is a maximum surface error of 50nm rms measured on patches of 10mm diameter.

6.2 Budget in transmission

The total wavefront error budget in transmission must allow a SR > 90% in infrared bands over the NGS footprints. This requirement is equivalent to measure a maximum RMS wavefront error of 48nm on patches of 66mm diameter (set by the major axis of the NGS footprint) distributed on the whole optical area of the dichroic. Dividing this budget is 3 mains components:

1. WFE due to surface roughness
2. WFE due to refraction index homogeneity
3. WFE due to dichoric residual static aberrartions.

Knowing that the amount of residual static aberrations is 36 nm, and fixing a homogeneity class H4 that introduce 10 nm WFE for 20 mm thickness of the subtrate, the total budget for the WFE due to the surface error is 30 nm at working angle of 15 deg. To ensure that the transmitted beams are not displaced by surface local tilts, the sum of the low order aberrations over an NGS footprint must result in a tilt low enough to maintain star image within LUCIFER slit width. Considering also that the instrument field rotates during the observation while the dichroic is fixed this requirement sets the maximum tilt that can be introduced in the transmitted wavefront. Since the LUCIFER slit width is equivalent to 0.125arcsec on-sky, the maximum tilt introduced on a 66mm diameter beam has to be less than 0.015arcsec to avoid the above-described effect. This requirement means that the average wavefront tilt in transmission on any circular patch of 66mm diameter, after the global tilt removal, must be smaller than 9nm/mm.

These requirements constrain the optical quality obtainable on the instrument focal plane and should be measured at at angle of incidence equals 15 deg.

7 Specifications and SoW

The specifications for the low incidence dichroic manufacturing, polishing and coating are detailed in AD6. This document constitutes the ARGOS Statement of Work (n. 102) and it has been distributed to several vendors asking for a Rough Order of Magnitude independent quotation for both polishing and coating.

8 Quotes discussion

We resume here the offers received and the results of the procurement campaign accomplished so far.

Vendor	Polish/Coating	Offer	Notes
LZH	Coating	11000€	3 units, curves in Figure 14
Layertec	Coating	??	curves in Figure 15
Zygo	Polishing	60000$	
SESO	Pol & Coating	150000	
Gooch & Housengo	Polishing	43000	
Sagem	Pol & Coating	200000	
Materion Barr	Pol & Coating	125000	
Torc	Polishing	28000	

8.1 Coating curves from LZH

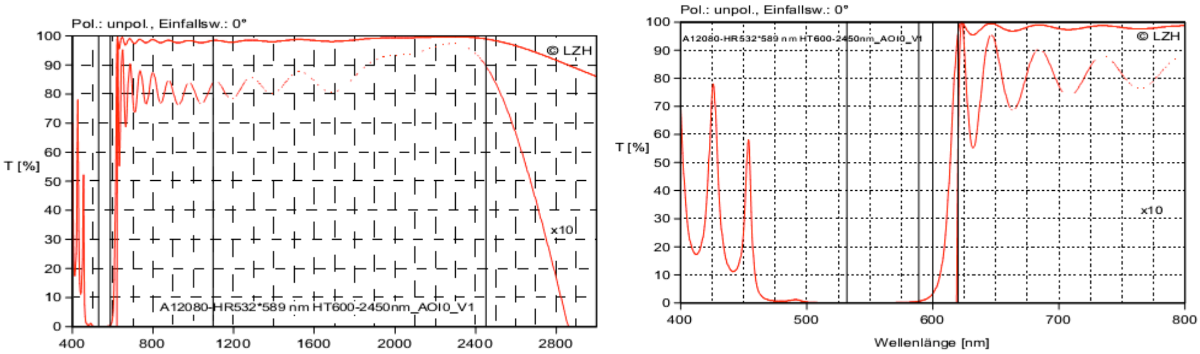

Figure 14: Transmission curves received from LZH, Left: full spectral range between 0.4 and 2.8um, rigth: detail of the high reflectivity range.

8.2 Coating curves from Layertec

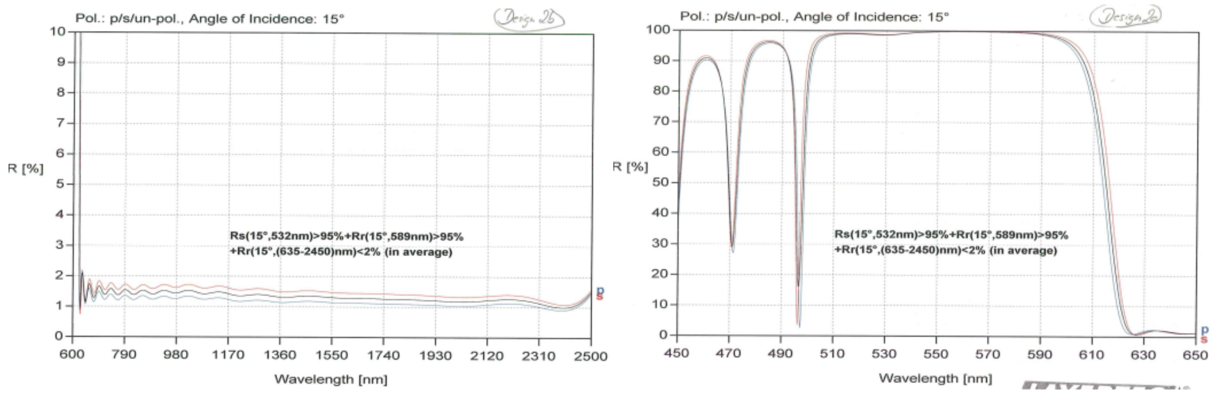

Figure 15: Detail of the reflectivity curves obtained from Layertec. Left: high transmission range, rigth: high reflectivity range.

8.3 Coating curves from Materion Barr

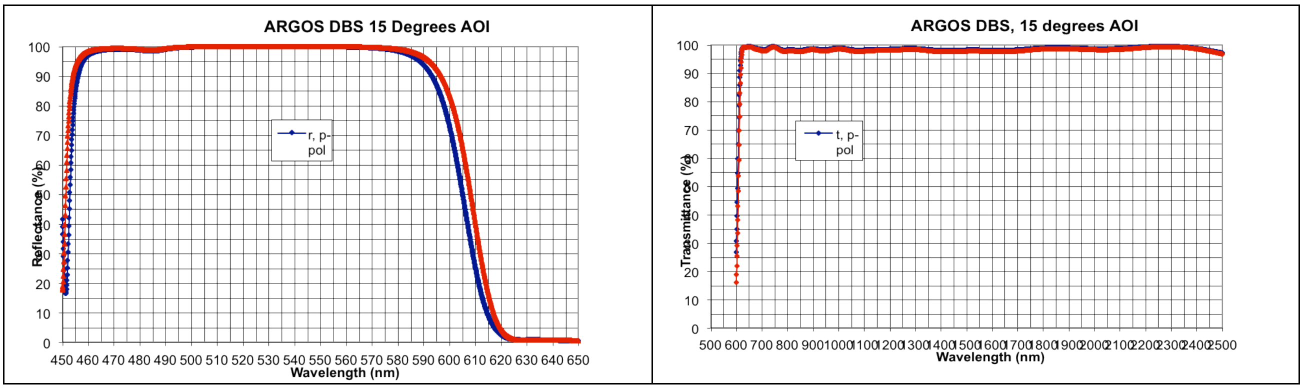

Figure 16: Detail of the reflectivity curves obtained from Materion Barr. Left: high reflectivity range, rigth: high transmission range.

9 Mechanical design

To install and operate the low incidence ARGOS dichroic system at the telescope major changes must be applied to the mechanics defined at the FDR. A detailed discussion of the FDR dichroic mechanics is available in AD5.
The new system is made by 2 elements: the dichroic itself and the fold mirror, hanged over the primary mirror by a deployable arm. So the contract with TOMELLERI srl will be extended to account for re-designing the mechanics accordingly to the new optical design and produce the units. The price will increase from 80000 euro to 139000 euro.

9.1 Change in the dichroic volume allocation

The volume allocated for the ARGOS dichroic assembly needs to be extended. Figure 17 shows the area that will be obstructed by the new dichroic hardware when the system is in use. In yellow it is highlighted the allowed area as indicated in AD2.

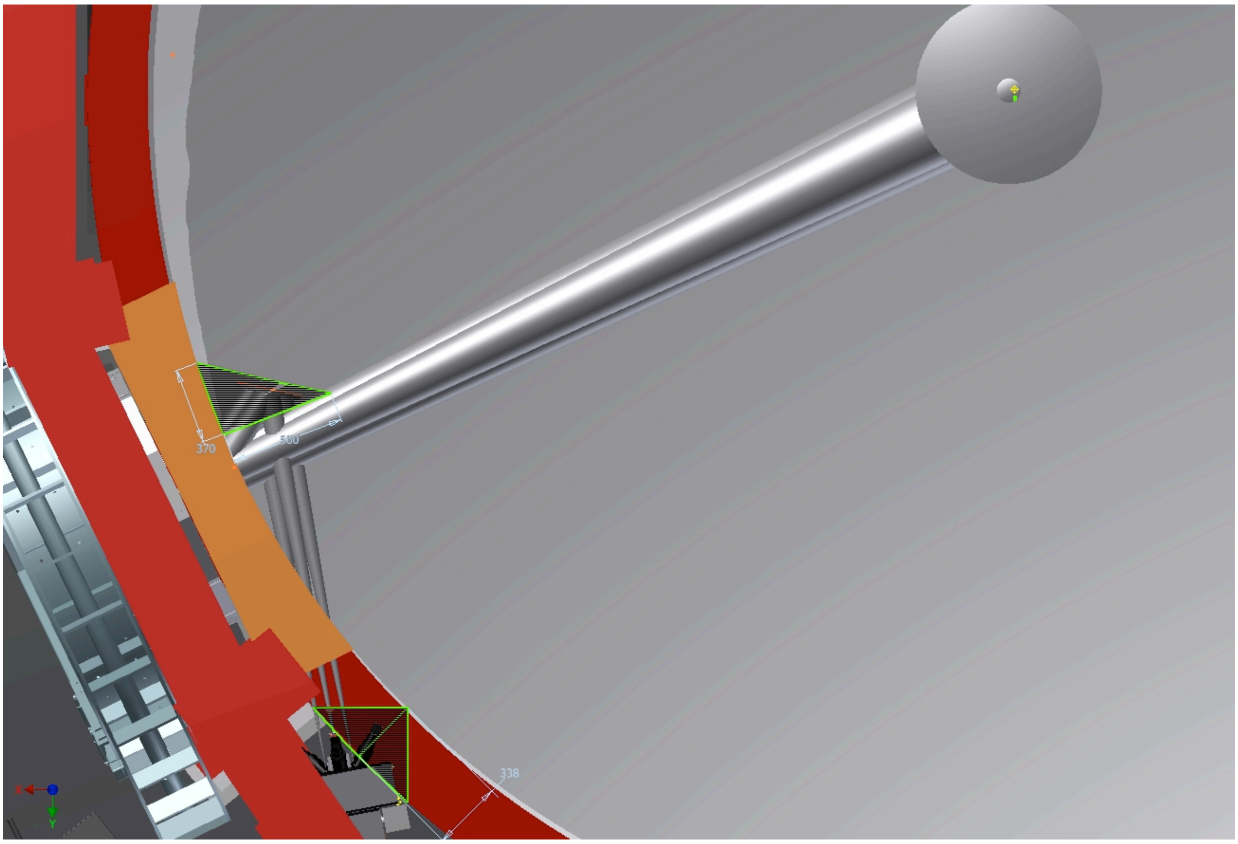

Figure 17: Sketch of the area that will be obstructed by the new dichroic hardware and the consequent repositioning of the LGS WFS. The obstructed are of the LBT primary mirror during the opeation of the LGS WFS of ARGOS is a triangle with an area equals to 0.2% of the area of M1. This is equivalent to a 4mm decreament of the M1 size. These numbers are small enough to consider useless a trade-off between mechanical assembling and dichroic optical layout due to the technical specfications imposed to the dichroic on one side and the variation of telescope collenting area and spatial resolution on the other side.

When in their park position the deploying mechanisms are able to put the 2 optics within the volume allowed as described in AD2 (see Figure 18).

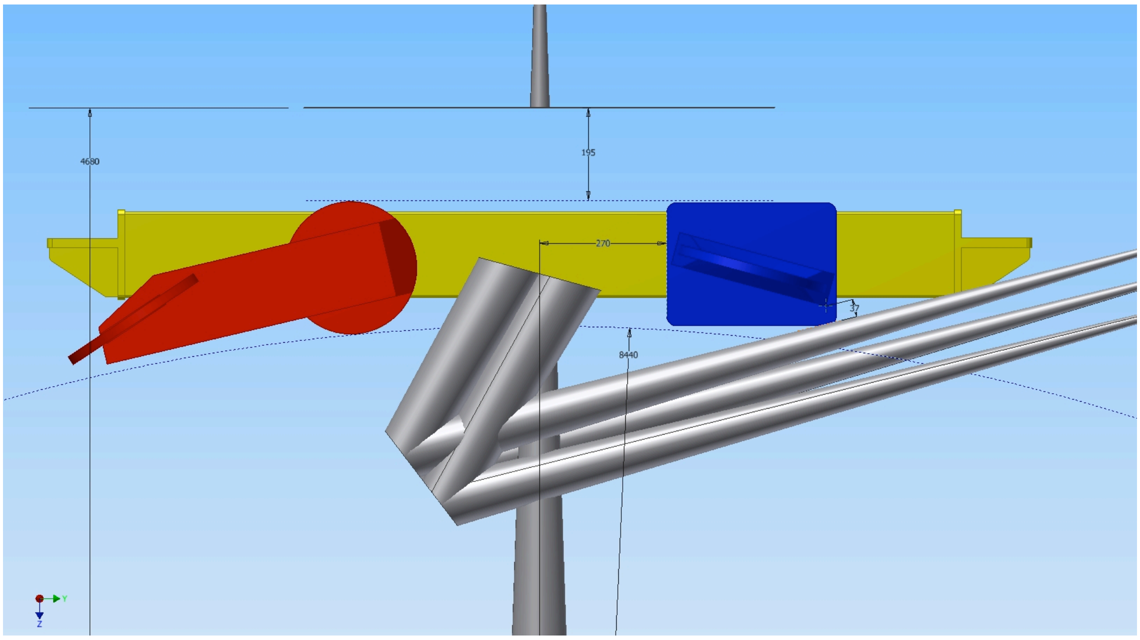

Figure 18: Sketch of the dichroic and fold mirror deployment system as proposed by TOMELLERI srl.

9.2 Specifications

We evaluated the specifications for the production of the dichroic and fold mirror support mechanics considering different conditions:

1. When ARGOS works in close loop, the stiffness of the optic mounts must ensure that the LGS light reflected by the 2 optical elements stays inside the LGS WFS FOV.
2. The repeatability of the 2 optical elements deployment mechanisms must be high enough to allow placing the ARGOS calibration sources (deployed at prime focus) within the LGS WFS FOV. Note that for the alignment, the only remotely adjustable component is the M2 hexapod.
3. After M1 aluminization, no manual realignment of the optical elements should be needed.

9.2.1 Stability specifications

The following values have been evaluated in Zemax, looking at the field position on the F/16.6 LGS focal plane

Tip-Tilt: A tip-tilt flexure of the mounts of 0.010° is sufficient to shift the focus position of 1mm on the LGS focal plane. Since the dichroic and folder flexures sum up we specify a 0.005° stability in tip-tilt for both mounts.

Decenter XY and Z shift: in the dichroic case a ±1mm error gives a ±0.6mm (=±1arcsec) shift on the F/16.6 plane. In the folder mirror case, the same error gives a ±0.8mm (=±1.2arcsec) shift on the F16.6 plane. Since the dichroic and fold decenter errors sum up we specify a ±0.5mm tolerance on the XYZ direction for stability.

Sag: a flexure of the glass substrate introduces an astigmatism component in the reflected WF because of the incidence angle on the 2 mirrors. Notice that this flexure induced astigmatism should be slowly varying and it can be corrected by the truth WFS. So the main concern about flexure is mainly to not saturate the

LGS WFS. Sag of 15um corresponds to a RoC of the reflecting surfaces of the 2 optics less than 750m. We evaluated in Zemax that this RoC causes a WF error of less than 100nm rms (see Figure 19).

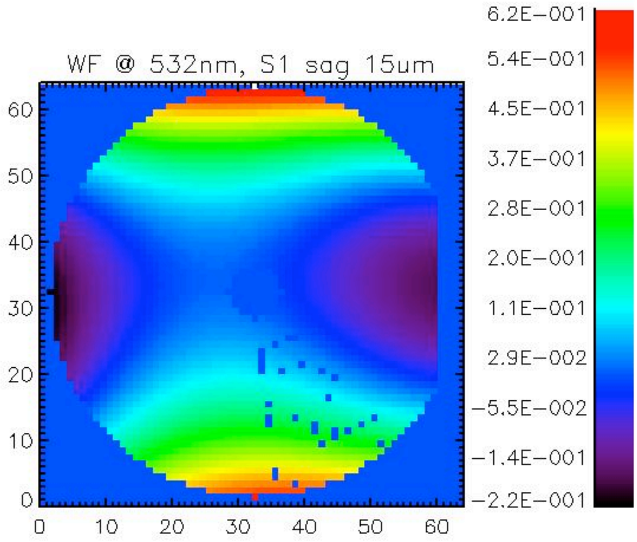

Figure 19: WFE introduced in the LGS WFS when a 750m RoC is applied to dichroic or fold mirror S1 surfaces. This value constrains the maximum sag that can be introduced in this optic by the variation of the wind or gravity forces.

9.2.2 Repeatability specifications

We describe here 2 different use-cases regarding deployment repeatability of the dichroic unit.

In the first case, during use with on-sky lasers, the deployment repeatability must ensure that the light falls at least within the LGS WFS Patrol Cameras FOV (60arcsec diameter). This ensures that the position of the laser beacons LGS can be measured and the lasers can be re-pointed to enter the WFS FOV (5arcsec). This is done without using any of M2 and M3 degrees of freedom in such a way that the telescope collimation giving the best image on LUCIFER is maintained.

The second case is the use with the calibration sources at prime focus. In this case there is no possibility to independently adjust the position of the sources that are fixed on the calibration swing arm. The only adjustable element is the M2 hexapod that can be used to steer the 3 calibration sources images on the F/16.6 focal plane. To properly recenter the calibration unit off-axis sources within the WFS FOV a coma free movement must be applied to M2. A tip-tilt error of 0.1° in the mount repeatability, when corrected with the M2 hexapod, produces a slopes variation of 0.05arcsec RMS on the LGS WFS.

The repeatability of the swing arm unit is 1 mm x,y.z.

9.2.3 Alignment DoF

The dichroic position must be adjusted to allow laser light to reach the LGS WFS. At the same time this adjustment should not degrade the optical quality obtainable on the F15 plane.

To evaluate the maximum range of adjustments available in the alignment procedure we performed a tolerance analysis in Zemax allowing a maximum increase of 5% in the WFE rms. This corresponds to a decrease of ~1% in the on-axis SR evaluated at R band.
The tolerance analysis results are resumed in Figure 20. The allowed movement of the dichoric along the optical axis, and in the perpendicular xy plane, can be as large as +/-5mm. The incidence angle can be increased up to ~16deg. A +/-3deg of tilt around the sliding direction is tolerable.

Oper #	Type	-	-		Nominal	-	-	Comment
29 (TOFF)	TOFF	-	-	-	-	-	-	
30 (TUTX)	TUTX	21	-	-	15.000000	-5.000000	0.915174	Tilt about vertical axis
31 (TUTY)	TUTY	21	-	-	0.000000	-2.833336	2.824599	Tilt about horizontal axis
32 (TUDX)	TUDX	21	-	-	0.000000	-5.000000	5.000000	Decenter in the sliding direction
33 (TUDY)	TUDY	21	-	-	0.000000	-5.000000	5.000000	Decenter in the vertical direction
34 (TTHI)	TTHI	19	0	-	-4330.000000	-5.000000	5.000000	Shift along the optical axis

Figure 20. Results of the tolerance analysis performed in Zemax to evaluate the adjustment range available in the dichroic alignment DoF.

9.3 Mechanical layout

A first sketch of the dichroic and fold mirror deploying mechanism is shown in Figure 21. The red arm is needed to hold the fold mirror over the primary mirror to allow folding the laser light toward the LGS WFS. The blue chart, sliding over the yellow support structure, is almost the same structure designed to hold and deploy the FDR dichroic.

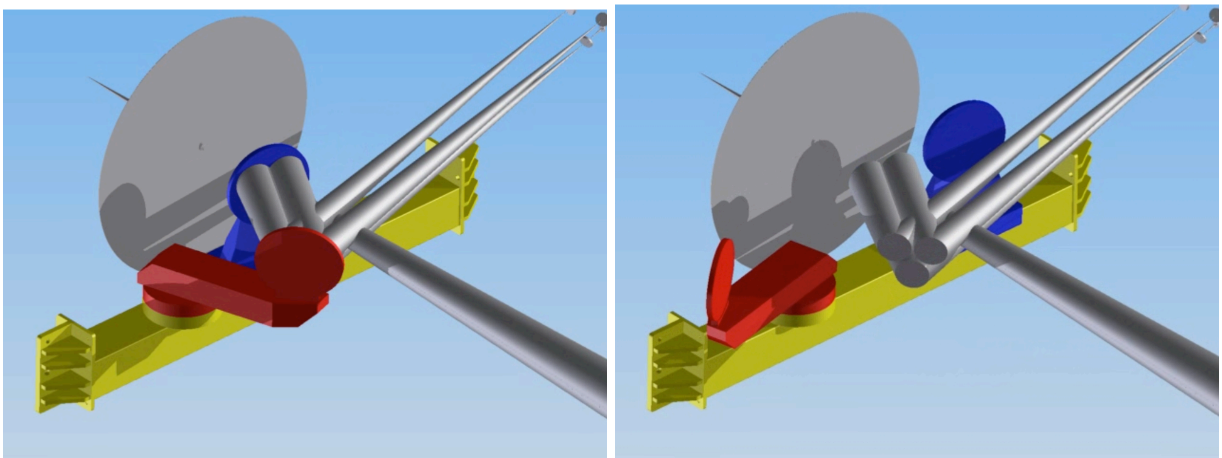

Figure 21: First sketch of the dichroic and fold mirror deploying mechanism. Left: the 2 units are in their working position. Right: the units are parked.

9.4 Electronics

The dichroic unit is now using 2 motors instead of 1. The 2 motors will be of the same vendors and the 2 controllers will be of the same vendors and possibly of the same family to ease software development.
Space for another controller must be found in the WFS rack. From a point of view of interfaces, note that the interlocking mechanism with the LUCIFER calibration unit must be updated to prevent the motion of both motors when the LUCIFER Cal Unit is not in parking position.

10 The LGS WFS layout

The proposed design for the new dichroic unit requires a new arrangement of the LGS WFS. A view of the new arrangement is shown hereafter for both sides of the telescope. The 3D model of the region of the telescope where the WFS are located (between the C-ring and the instrument gallery) is not accurate enough for our purposes, and this has already caused some difficulties during the installation of the WFS tables. We recently refined the model by taking some rough measurements of the telescope structure referring to the dichroic interfaces already installed by Tomelleri on the instrument gallery. The position of these interfaces referred to the rotator axis and LUCIFER flange is known with high accuracy (1mm). At the moment we consider to have measured the critical parts of the telescope with an accuracy of approx. 50mm, which is comparable with the clearance around the WFS.

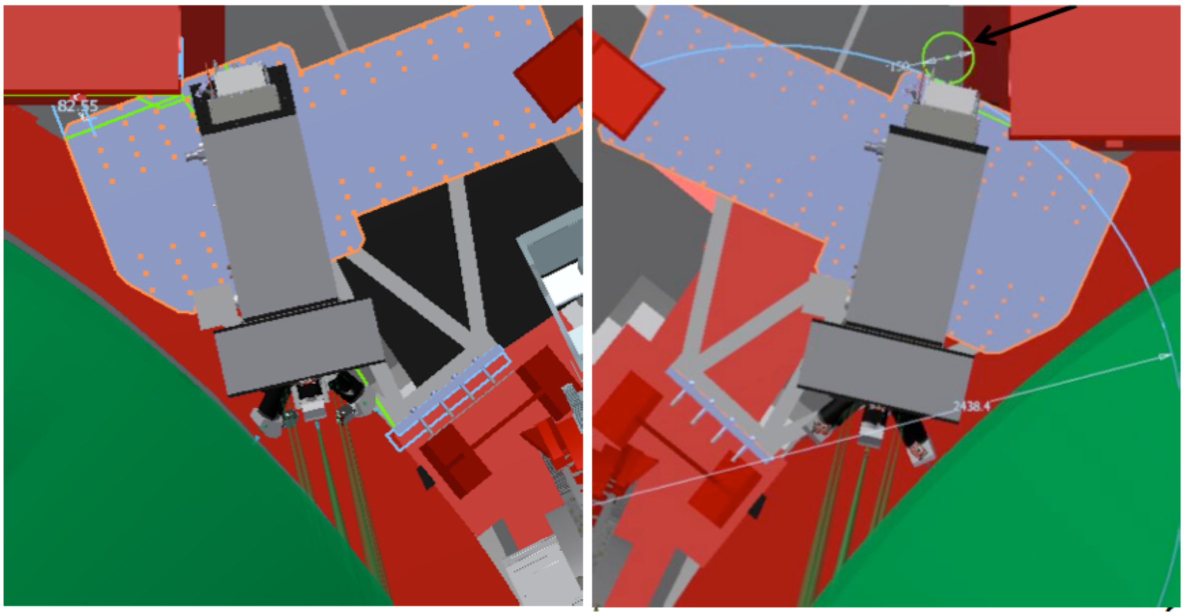

Figure 22 Top view of the arrangement of the LGS WFS for sx and dx side. The WFS tables in this picture are the old ones, and they will have to be modified for the new arrangement. The optical designs are symmetric, so the location of the WFS referred to the LUCIFER optical axis is the same on both sides, but

To critical aspect here can be explained in this way: to arrange the WFS in a position that ensures more clearance one should push the WFS CCD away from the C-ring extension. Since we need to prevent vignetting of the incoming beams on the gallery structure, one should increase the angle of the folding mirror in the dichroic unit and, more important, one should move the folder mirror away from the dichroic, “consuming” some optical path that has to be recovered by shifting the WFS toward the folder. This last step is constrained by the vignetting of the WFS over M1 and by the collision of the WFS patrol camera with the instrument gallery.

The consequence of this argument is that any possible adjustment of the WFS location during the alignment phase can be critical. We are still working in the direction of making ourselves confident that the WFS can be fitted in the new location with a safe margin.

10.1 Modification to the telescope

On the right side, the LGS WFS will collide with a cooling pipe routed along the C-ring extension. At a first glance, it seems possible to re-route the pipe to gain approx. 30cm that will solve these interference.

10.2 WFS table

The WFS table will have to be modified to support the WFS in its new location. The design of the new WFS table is still to be done. The requirement of accommodating the interferometer for M2 calibrations will be taken into account. The new WFS location is closer to the primary mirror, possibly causing problems during aluminization. We'll provide a way (with pins or the like) to allow for dismounting the all unit and remounting it without the need of a new manual optical alignment.

10.3 WFS paint and tape

The paint should be medium grey primer and the wrapped with low emissivity black tape.

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