ARIEL Consortium Phase A Payload Study

Dichroic Study Results and Dichroic Development Plan

ARIEL-DIAS-PL-PL-006

Issue 1.0

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DOCUMENT CHANGE DETAILS

Issue	Date	Page	Description of Change	Comment
0.1	25/01/17	All	New document draft created based on ARIEL Dichroic Technical Note: ARIEL-RAL-PL-TN-003 Issue 0.4	
1.0	15/2/17	All	First issue for MSR	

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1 PREAMBLE

1.1 Scope and Applicable Documents

This document describes the outcome of discussions with potential suppliers of the ARIEL Dichroics as regards feasibility of their manufacture and the need for any further studies to ensure their technical readiness level. These dichroics are to be procured by the Dublin Institute for Advanced Studies (DIAS) as a member of the ARIEL consortium led by UCL & RAL Space. The plan is based on the ARIEL Baseline Telescope Optical Prescription (ARIEL-RAL-PL-TN-001) and the higher level requirements and description of the design as set out in the ARIEL Payload Requirements Document (ARIEL-RAL-PL-RS-001) and ARIEL Payload Design Description (ARIEL-RAL-PL-DD-001) respectively. An additional source of information is the ARIEL Dichroic Background Information (ARIEL-RAL-PL-TN-003) technical note that describes the dichroic requirements in detail.

1.2 CONTEXT

ARIEL uses a number of dichroics (Ds), a short-pass filters (SPF) and long-pass filters (LPFs) to spectrally split the incident light into different spectrometer and photometer channels covering 0.5 – 8μm. This document describes how the performance requirements of these optical elements may be met after discussions of their feasibility with potential suppliers.

As context (see also ARIEL-RAL-PL-TN-003), Figure 1 shows how the dichroics D1 and D2 are used to split the light between the FGS and AIRS. The figure also shows the SPF (SP1) required for AIRS. The next figure (Figure 2) illustrates D3, D4 and D5 and the LPFs (LP1 and LP2) within the FGS.

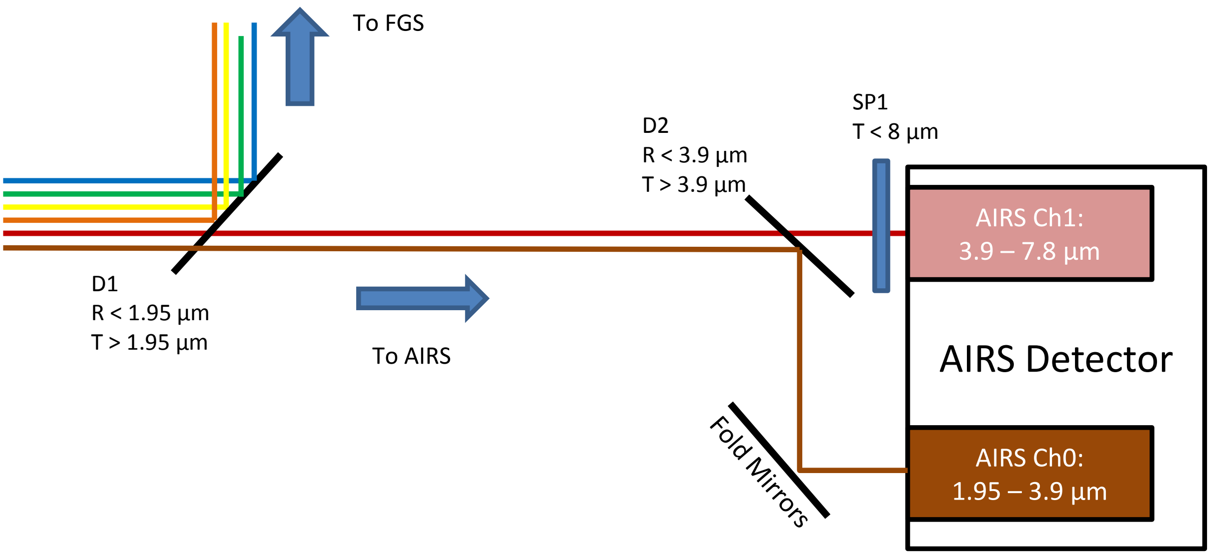


Figure 1: Schematic of dichroic splitting of channels between the FGS and AIRS. AIRS short-pass filter also shown

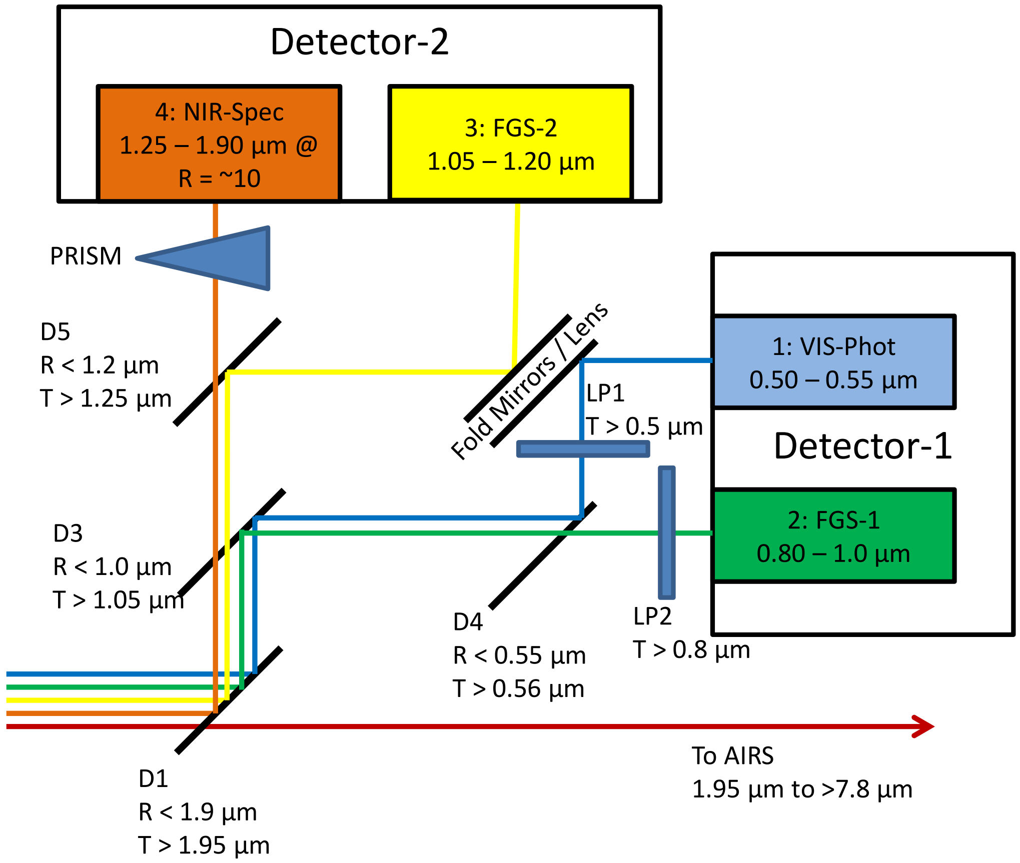


Figure 2 Schematic of dichroic splitting of channels within the FGS. FGS long-pass filters (LP1 and LP2) also shown

2 DICHROICS, SHORT AND LONG PASS FILTERS

2.1 D1 & D2

In what follows, R and T refers to the unpolarised reflectance and transmittance respectively. The Transition wavelength is the wavelength at which R, T = 0.5 and the Transition region is the waveband between the upper end of the R≥0.9 band and the lower end of the T≥0.9 band.
Here we describe the outcome of discussions in connection with the procurement of D1 and D2 that were had with Dr Gary Hawkins of the University of Reading, Infrared Multilayer Laboratory. Table 1 summarizes the requirements on D1 and D2.

Dichroic	Purpose	Reflectance λ (μm)	Transition λ (μm)	Transmission λ (μm)
D1	Division of FGS from Spectrometer Channels Definition of short wavelength edge of AIRS Ch0 Definition of long wavelength edge of NIR-Spec	<0.50 – 1.90	1.95	2.0 – >7.8
D2	Sub-Division of Spectrometer Definition of short wavelength edge of AIRS Ch1 Definition of long wavelength edge of AIRS Ch0	<1.95 – 3.8	3.9	4.0 – >7.8

The manufacturing of D1 and D2 will be done by depositing a suitable multi-layer onto a substrate. In connection with D2 note that:

1. As a result of reflective interference from the thin-film design, the spectral reflectivity performance inevitably contains some Fabry-Perot fringing structure (as shown for example in below in the 2.0-2.5μm region). Thus the specified 90% reflectance should be considered the average integrated energy across the band (for which the D2 is compliant) and a tolerance band above and below this average needs to be set.
2. There are a number of choices for the substrate such as Ge, ZnS, or ZnSe. As an example ZnSe was used exclusively for the Earth Cloud, Aerosol and Radiation Explorer mission (EarthCARE) Multispectral Imager (Hawkins et al. 2014) and for the shorter wavelengths (< 17 μm) filters in the Mid-Infrared Instrument (MIRI) on JWST (Hawkins and Sherwood 2008).
3. There is a large tolerance to the chosen angle of incidence (AOI) but note that this does not help suppress the reflective interference fringing and, in fact, only marginally shifts the entire structure in wavelength. This is illustrated in Figure 3 for an AOI of 45^0 and normal incidence.

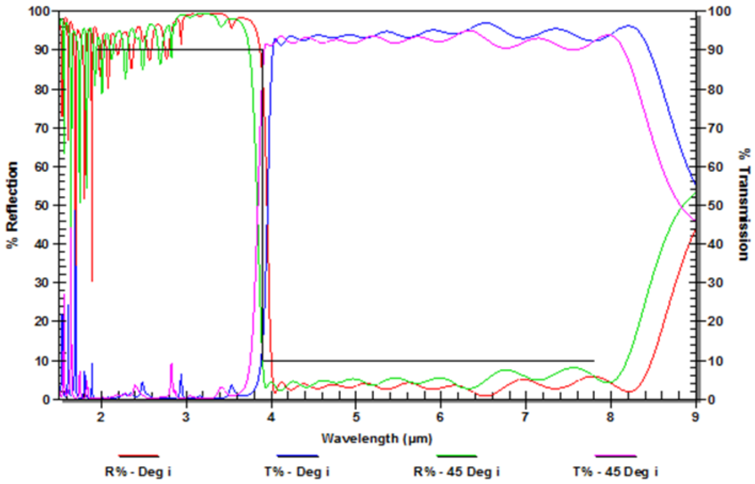
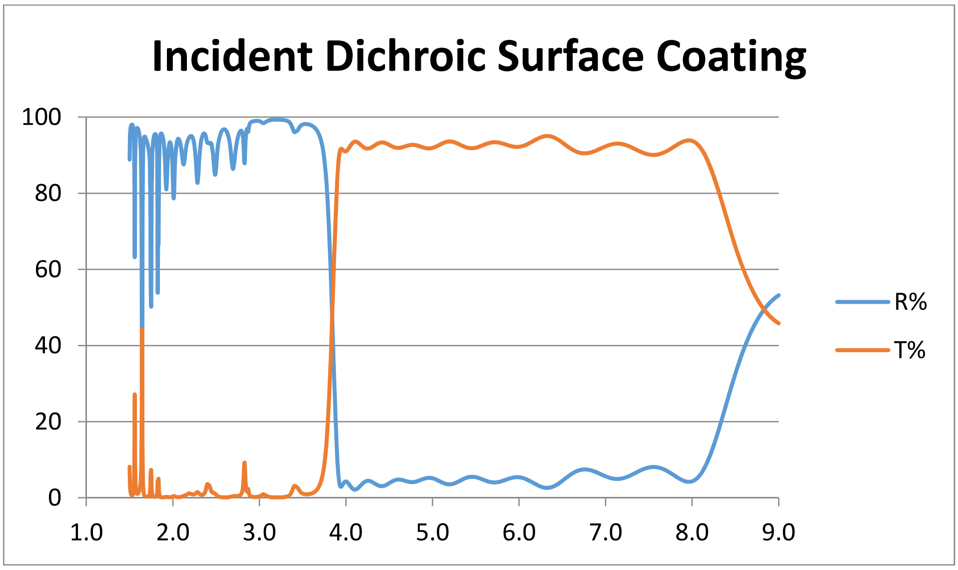


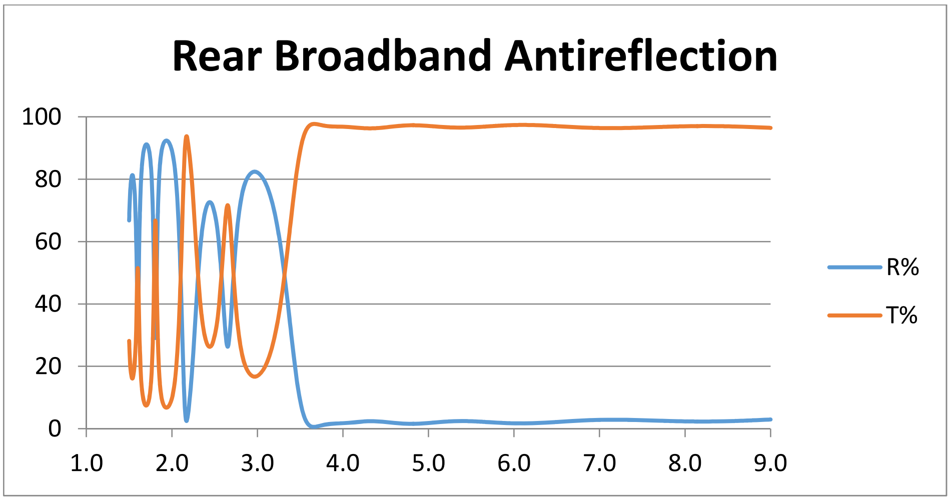
Figure 3 Preliminary design for D2 on ZnSe at 0o and 45o incidence, and at a temperature of 50K

Figure 4 shows 3 sets of simulations with data comprising the pure incident dichroic coating (a), antireflection coating (b) and double-sided coated performance (c). In all cases an operating temperature of 50K is assumed and an AOI of 45^0.

The Infrared Multilayer Laboratory has also looked into the design and manufacture of D1 which, for a number of reasons that will now be described, is somewhat more challenging than D2. The optimum solution appears to be the deposition of ZnS and BaF_2 (or YF_3) layers onto a ZnS substrate (see Figure 5). BaF_2 was incidentally used extensively as a single antireflection outer layer on the MIRI CdTe dichroics. Its deposition however within an embedded multilayer structure (~50 layers) is considerably more complex than in the case of the MIRI dichroics. This is particularly the case as many of the layers are exceptionally thin (50 – 100 nm), and of low refractive index in order to provide the visible wavelength high-reflectivity.

Current manufacturing capability at the Infrared Multilayer Laboratory cannot deposit the necessary thin layers with sufficient precision, and they require an alternative optical monitoring apparatus that can operate in the visible and NIR wavelengths. In particular, monitoring would require the combination of a new detector, monochromator grating, chopping





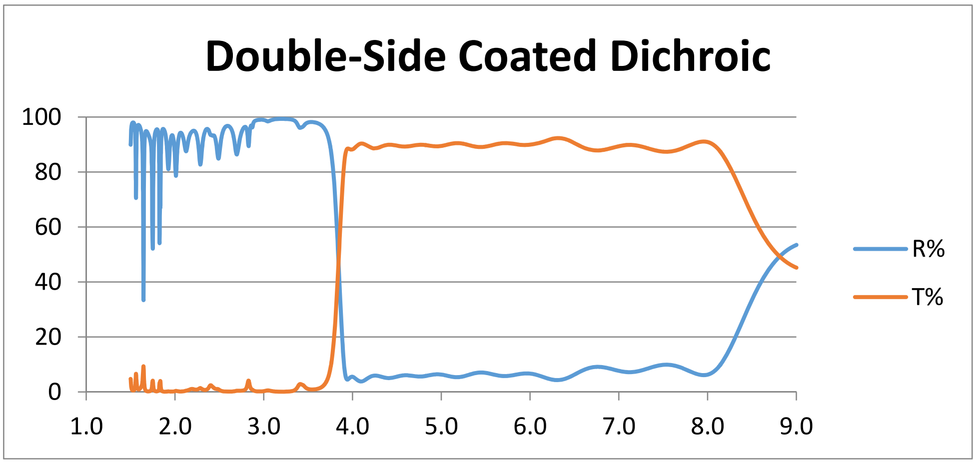


Figure 4 shows 3 sets of simulations for R and T comprising the incident dichroic coating (Top), antireflection coating (Middle) and double-sided coated performance (Bottom).

regulator, light source and UV-VIS blocking filters. The proposed approach however could be of future potential in broadband dichroic development.

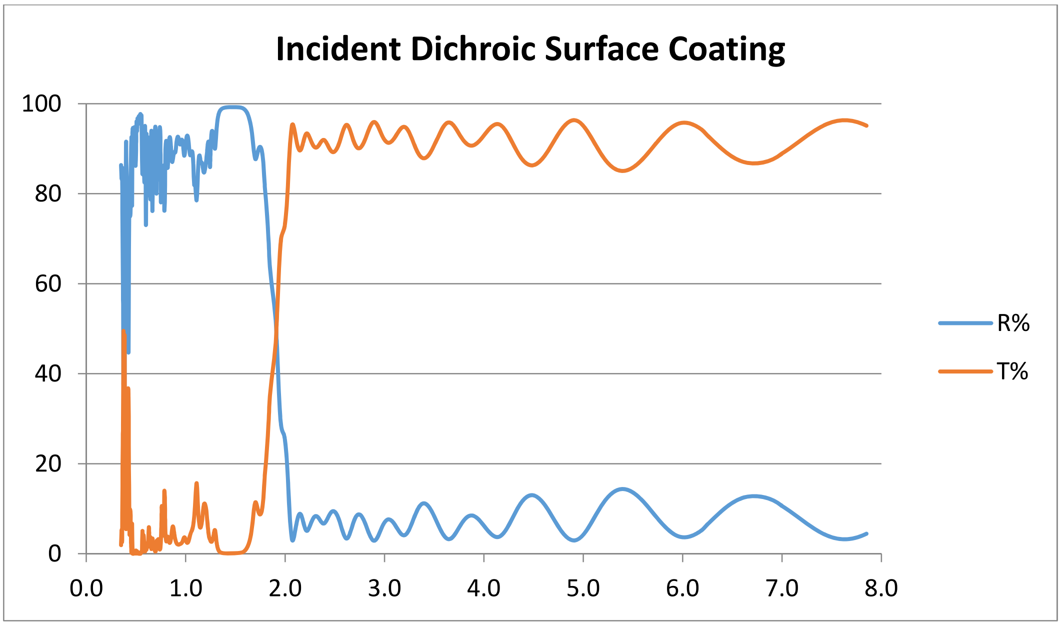


Figure 5 shows simulations for R and T using the preliminary D1 design and assuming an operating temperature of 50K and an AOI of 450.

With these ideas in mind, DIAS are funding the Infrared Multilayer Laboratory to carry a detailed theoretical and practical study (i.e. develop prototype coatings) to assess whether the material combination and spectral performance for D1 is potentially attainable and then identify areas where the deposition coating technology is deficient. If it is found that the environmental integrity and deposition performance is satisfactory, but accuracy of layer monitoring is poor, then we shall use additional funding sources (available in Ireland and the UK) for the required equipment and resources. The strategy is that at this stage it would then be possible to claim success with initial proof-of-concept results.

More precisely the Infrared Multilayer Laboratory will carry out over the next two months (March and April 2017) the following work plan:

1. Theoretical multilayer designs shall be developed for the wavelengths described as proposed within the outline specification (ARIEL-RAL-PL-TN-003). These designs shall comprise long-wave pass dichroic filter sub-modules. Each proposed design shall use spaceflight qualified infrared materials with known optical constants to arrive at provisional coating solutions.

2. Identification of areas in the spectral design where compliance margins are constrained, or where desired performance is technologically challenging to achieve shall be highlighted.

3. Thin-film calculations using appropriate spectral parameters derived from the design proposals will be used to simulate predicted performance throughput to demonstrate compliance and deviations.

4. Prototype fabrication of proposed coating type sub-modules and materials shall be attempted in depositions representative of the proposed coatings. These shall be deposited on standard ex-stock double-side polished optical substrates. The prototype filter manufacture shall be used to assess the spectral and environmental performance integrity of the thin-film materials.

5. Assessment of the feasibility to manufacture the entire coating and identify areas where technical deficiencies exist, or alternative deposition procedures are necessary.

6. Environmental testing including adhesion, abrasion and humidity assessment shall be performed on prototype coatings for determination of coating durability and stability.

7. A technical report will be written and provided as a deliverable, containing spectral design calculations of potential multilayer solutions, together with the results of spectral performance measurements and environmental results achieved from the prototype trials.

2.2 D3, D4 & D5

The required study on the feasibility of manufacturing D3, D4 and D5 was carried out by the Thin Film Coatings Department of CILAS, Aubagne. CILAS have carried out similar filter manufacturing, using Dual Ion Beam Sputtering (DIBS) technology, for the IRDIS instrument of Sphere on the VLT (Dohlen et al. 2008).

For these dichroics, it was noted very quickly by CILAS that the angle of incidence (AOI) is critically important. In particular at an AOI of approximately 45° both S and P polarisations are spectrally shifted and the "transition region" requirements are not reachable (see Figure 6). For this reason, it is proposed to work at an AOI of 15°.

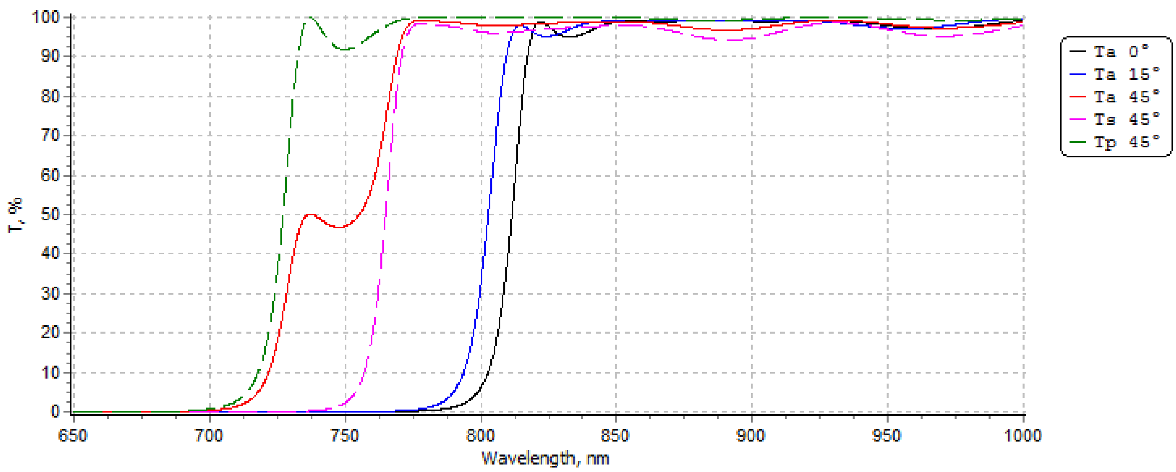
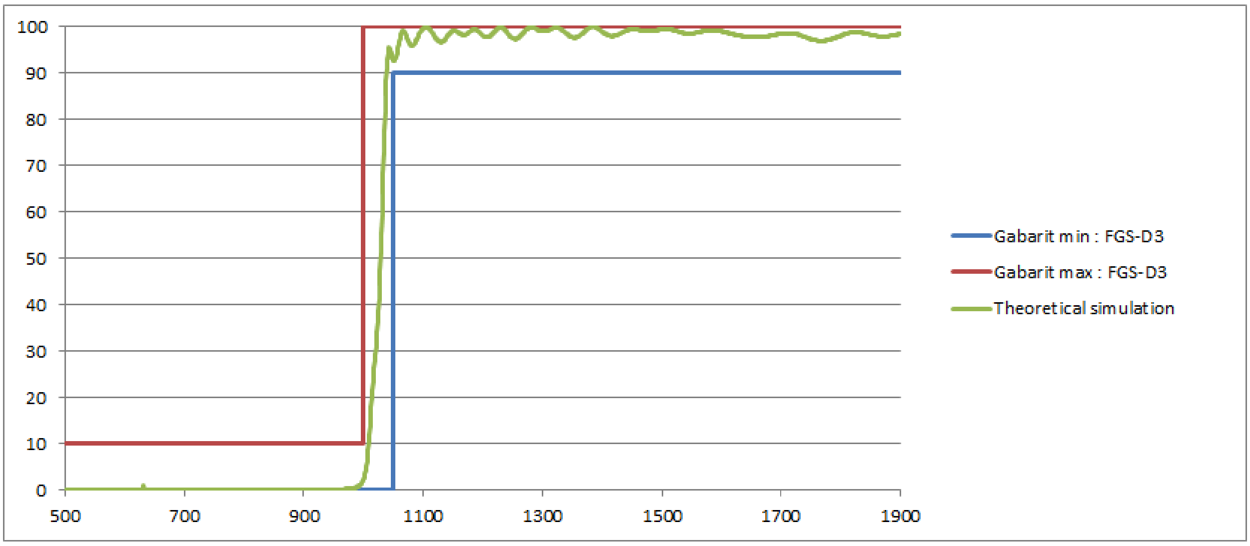
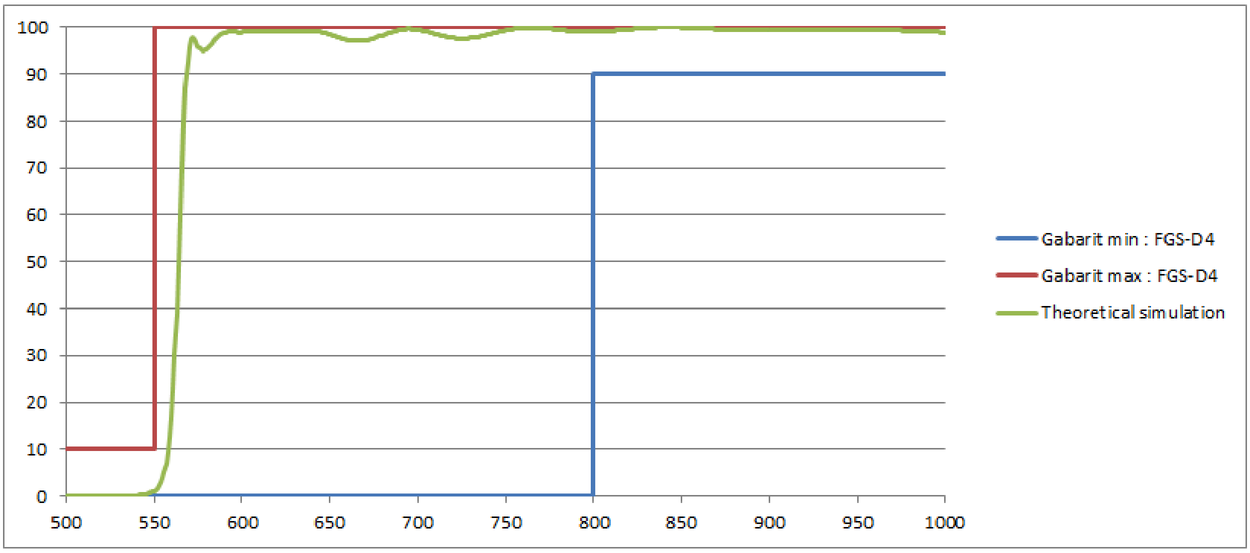


Figure 6. The effect on the Transmission properties of varying the AOI showing separation of the S and P polarizations.

As an example of the type of filters made by the CILAS DIBS facility, Figure 8 shows a low-pass filter designed and manufactured using multi-dielectric coatings based on low-pass functions. It was intended that the filter transmit in the 900-1700nm spectral range and reject from1800-2500nm. Meeting the specification required a relatively large number of layers (~75) and a physically thick stack (~22µm). Particular attention was paid when designed to smooth out ripple in the transmission zone by adding few non-quarter-wave layers at the extremities of the stack. One can see the spectral performances were compliant with the theoretical design. It has also to be noted that rejection measurement is limited by the noise of the spectrophotometer in the range 1800-2500nm.

The question arose as to the performance of these filters at the expected cryogenic temperatures of Ariel. Certainly such filters have been used for some time at operating temperatures of 140K to 77K in Sphere without any obvious deterioration. Nevertheless with this question in mind, CILAS forwarded in January 2017, 4 representative samples (Reference DF9_101B037_H2, DF55_111B064, N10_131B029-7 and N08_131B029-5) for testing in the cryogenic facilities in Cardiff at 4K. Note that these tests, which are expected to be complete by the end of February, will only check the transmission properties of the filters and not their reflectivity.





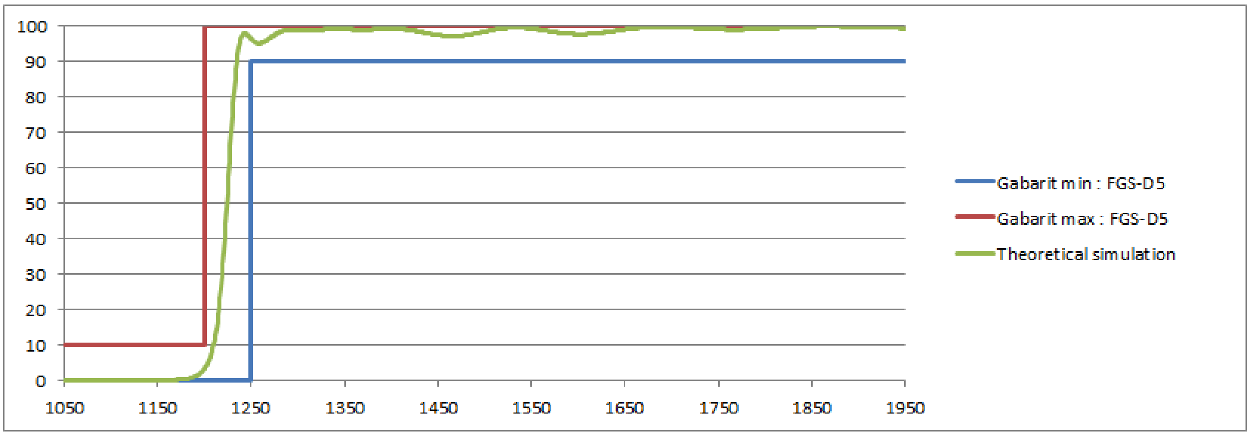


Figure 7. Specification templates (gabarit) minimum and maximum (blue and red respectively) and theoretical simulations (green) for D3 (Top), D4 (Middle) and D5 (Bottom).

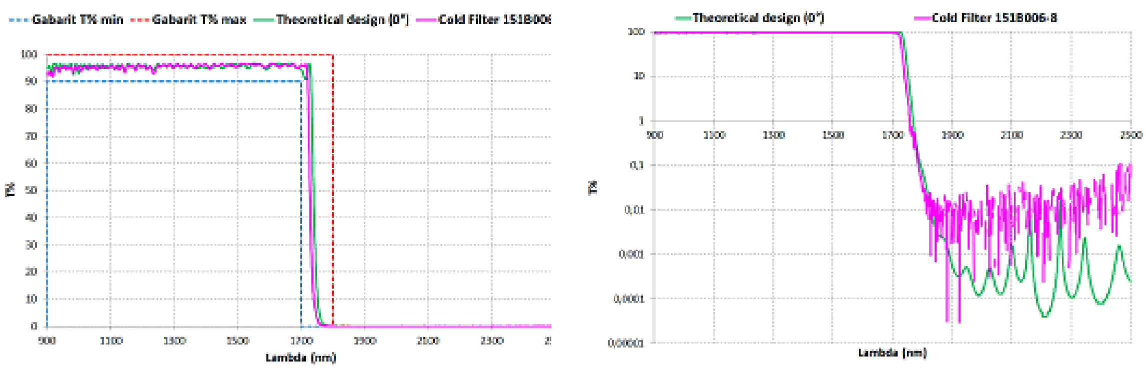


Figure 8. Spectral response measurement of a Low-pass Filter in the 900-2500nm range manufactured with DIBS coating technology. Transmission is shown on a linear scale (left) and on a logarithmic scale (right). Note that rejection measurements are limited by the noise of the spectrophotometer.

2.3 SP1, LP1 AND LP2

Northumbria Optics Coating Limited in Tyne and Wear, were consulted regarding the manufacturing of the Short Pass filter SP1. Figure 9 shows what they expect to achieve and when we requested information on space heritage, we were told that space heritage that while there was nothing documented that they could disclose, they have manufactured and delivered many similar filters to different organisations where they had to carry out tests at cryogenic temperatures.

The long pass filter LP1 specification is based on an off-the-shelf filter (Thorlabs FELH0500), data for which is shown in Figure 10.

The specification for the second-long pass filter, LP2, is also based on an off-the-shelf filter (Thorlabs FELH0800), data for which is shown in Figure 11.

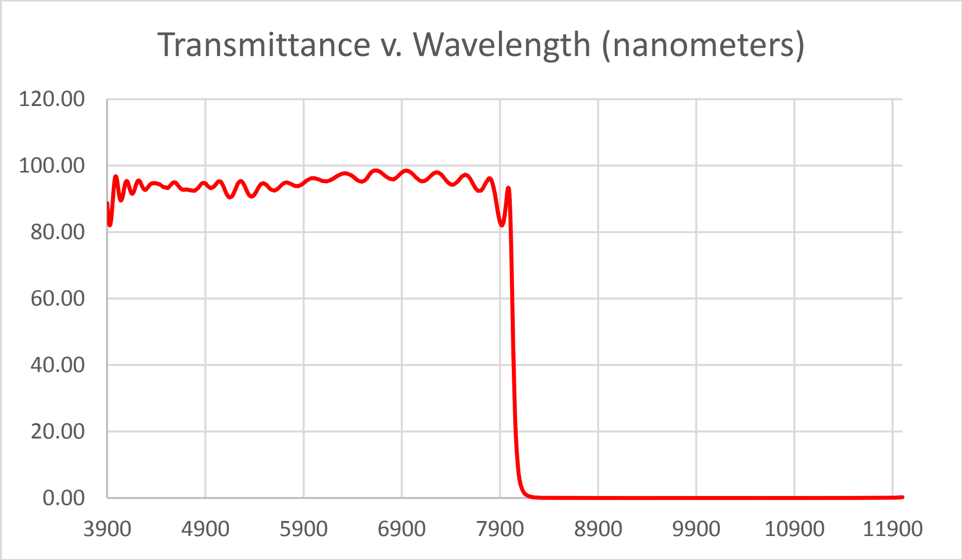


Figure 9. Transmittance v. wavelength for the short pass filter SP1

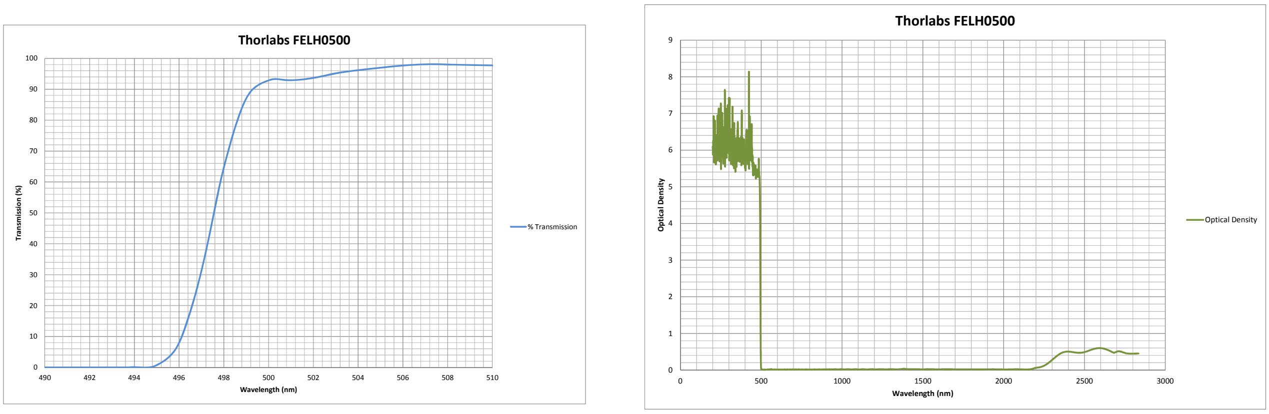


Figure 10. Transition region (Left) and optical density (Right) of the Thorlabs FELH0500 (500nm LPF) filter. Data courtesy of Thorlabs.

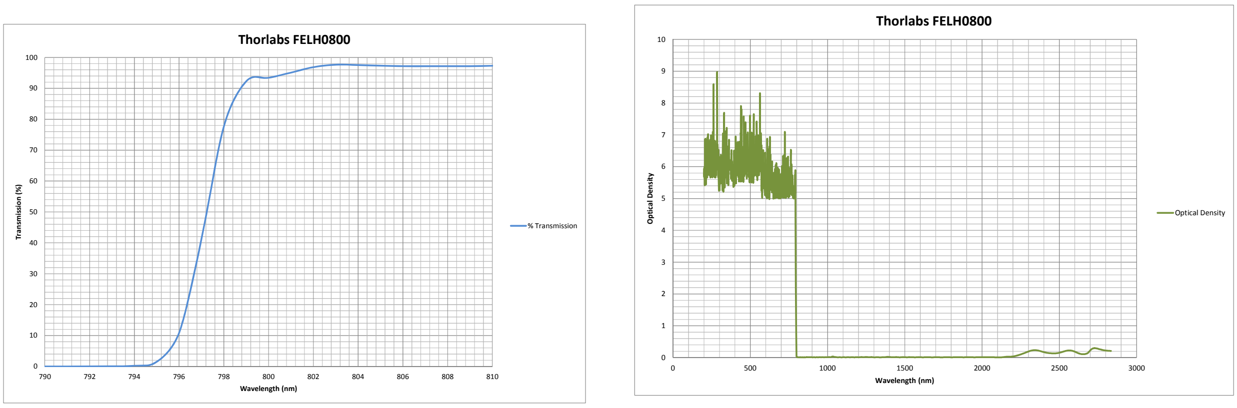


Figure 11. As Figure 10 but for the Thorlabs FELH0800 (800 nm LPF) filter. Data courtesy of Thorlabs.

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