

NewAthena reference telescope design: geometric prescription, predicted performance, and translation into implementation requirements

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ABSTRACT

NewAthena is ESA's next-generation X-ray observatory and a large-class mission of the Cosmic Vision programme. The mission will investigate the formation and evolution of hot baryonic structures, the growth of supermassive black holes, matter under extreme conditions, and energetic and transient phenomena. Its scientific capability relies on a large-aperture X-ray telescope based on Silicon Pore Optics, operated with a Wide Field Imager and a high-resolution X-ray Integral Field Unit.

This paper presents the current NewAthena reference telescope design and the methodology used to predict optical performance from individual Mirror Modules to the complete Mirror Assembly. The 13-row baseline comprises 492 Mirror Modules arranged in six petals, while compatibility is retained for a possible 15-row configuration with 600 modules. A detailed geometric model defines the dimensions, positions and orientations of the optical elements and provides the basis for calculating the expected performance in terms of effective area, vignetting, point spread function and straylight.

The analysis is conducted in two stages. The optical throughput and field response are first calculated from the prescribed geometry at row level using ray tracing. These results are then combined with measured or parametrised Mirror Module point spread functions and with integration, thermoelastic, gravity-related and pointing perturbations to predict the telescope response. For the current 13-row configuration, the predicted in-space mirror performance provides an on-axis effective area of approximately 1.03 m^2 and a half-energy width of approximately 8.96 arcsec at 1.49 keV . The paper also describes the row-dependent manufacturing and acceptance requirements for the forthcoming implementation contracts.

Keywords: NewAthena, Silicon Pore Optics, X-ray telescope, Optical modelling.

1. INTRODUCTION

1.1 Mission introduction

NewAthena, the New Advanced Telescope for High-Energy Astrophysics, is ESA's next-generation X-ray observatory and a large-class mission of the Cosmic Vision programme, following JUICE and LISA. It addresses the Hot and Energetic Universe science theme and is designed as a general-purpose observatory for high-energy astrophysics and was proposed in 2013 [1]. Its principal science objectives are to determine how large-scale hot-gas structures formed and evolved, trace the growth of supermassive black holes and their influence on their environments, investigate matter under extreme conditions, and explore energetic and transient phenomena across cosmic time.

The observatory combines a single large X-ray telescope with two complementary focal-plane instruments. The Wide Field Imager provides imaging and spectroscopy over a field of view of approximately $40 \times 40 \text{ arcmin}$, while the X-ray Integral Field Unit provides spatially resolved, high-resolution spectroscopy using transition-edge-sensor detectors operated at approximately 50 mK . A movable and tilting mechanism directs the telescope beam towards the selected instrument. The current mission requirements include approximately 1.1 m^2 effective area at 1 keV , 9 arcsec on-axis half-energy width at 1 keV and a 12 m focal length.

1.2 Mission status

Following suspension of the previous Mission Adoption Review in 2022 of the Athena mission, the mission entered reformulation to reduce cost and complexity while preserving its flagship scientific capability [2]. The reformulation – called NewAthena – included updates to the angular-resolution, effective-area and spectral-resolution requirements, parallel spacecraft industrial studies, continued instrument development, maturation of the optics and cryogenic technologies, and a revised Payload Compartment concept based on passive thermal solutions. A successful intermediate review was held in June 2025.

NewAthena is now entering the Mission Adoption Review process. The review has begun in September 2026, with the main activities taking place during Q4 2026 and continuing into early 2027. Subject to a successful review, the mission is targeted for adoption by the ESA Science Programme Committee in mid-2027. For the X-ray optics, the review requires a coherent and traceable connection between the scientific objectives, the telescope design, Mirror Module production requirements and the performance expected from the integrated telescope in flight.

1.3 Telescope

The telescope is based on Silicon Pore Optics (SPO), a technology which has greatly matured since its inception in 2005 supported by a large industrial consortium funded by ESA. The industrial context and the MM production status are described in [4,5]. SPO enables the combination of a large collecting area with low areal mass and a modular production approach. Processed silicon wafers are assembled into Mirror Modules that can be characterised and accepted before integration into the Mirror Assembly (MA).

The final telescope response depends not only on the ideal geometry, but also on coating response, manufacturing variability, the accepted Mirror Module population, integration alignment, thermoelastic distortion, gravity-related differences between ground and flight configurations, contamination and telescope-to-instrument alignment. The reference-design methodology therefore uses a controlled two-stage calculation. The optical response of the prescribed geometry is calculated first. The resulting throughput and field-response products are then combined with analytical or measured Mirror Module point spread functions and with the relevant integration and operational perturbations to predict the complete Mirror Assembly response. This paper presents the geometry/design, analysis sequence, effective-area, vignetting, point-spread-function and straylight predictions, and their translation into row-dependent manufacturing and requirements for the implementation phases.

2. REFERENCE TELESCOPE DESIGN

The current baseline contains 13 populated rows and 492 MMs. Rows 14 and 15 are presently represented by mass dummies, while the architecture remains compatible with a possible 15-row, 600-MM telescope. The present work reports the 13-row configuration as the baseline and retains the 15-row performance as a future option.

2.1 Mirror Module configuration

Each baseline MM contains two primary-secondary double-reflection X-ray Optical Units (XOUs), corresponding to four SPO stacks mounted in a common bracket. Each stack contains 38 plates, of which 36 contribute to nominal focused effective area because the innermost and outermost plates are assumed to be baffled - Figure 1. Plate 19 is the reference plate for each XOU and defines the optimum grazing geometry for an on-axis source. The XOUs are located on a Wolter-Schwarzschild (W-S) sphere with a radius equal to the focal length (12 m).

The primary plates are conical, and the secondary plates are hyperbolically corrected [6]. The plate thickness is 775 μm , including a 110 μm membrane and nominal 665 μm pore height [1]. The current assumed coating is a Cr/Pt/C trilayer for all rows.

The rib pitch is around 1.86 mm (but it is row dependent and can be as low as 1.63 mm for some configurations [3]), with a rib thickness of around 170 μm . The adopted inner to outer XOU radial spacing is 665 μm (equal to pore height - h_{pore}), and the primary-secondary stack distance is 600 μm .

The reference design adopts the technologically most feasible wedge configuration ($-1/+1$). This removes primary-secondary pore mismatch while preserving the required 2α difference between primary and secondary slopes, so that rays receive the desired 4α deflection, where α is primary plate incident angle for an on-axis ray (grazing angle), as in Figure

1. The plate length is defined using the reference plate (ref) and pore height (h_{pore}), according to $L_i = L_{ref} = h_{pore} / \tan(\alpha_{ref})$. Introducing a small axial curvature can eliminate blurring associated with the conical approximation [5]. The MM manufacturing process introduces hyperbolic curvature to secondary stacks to get closer to the true Wolter geometry.

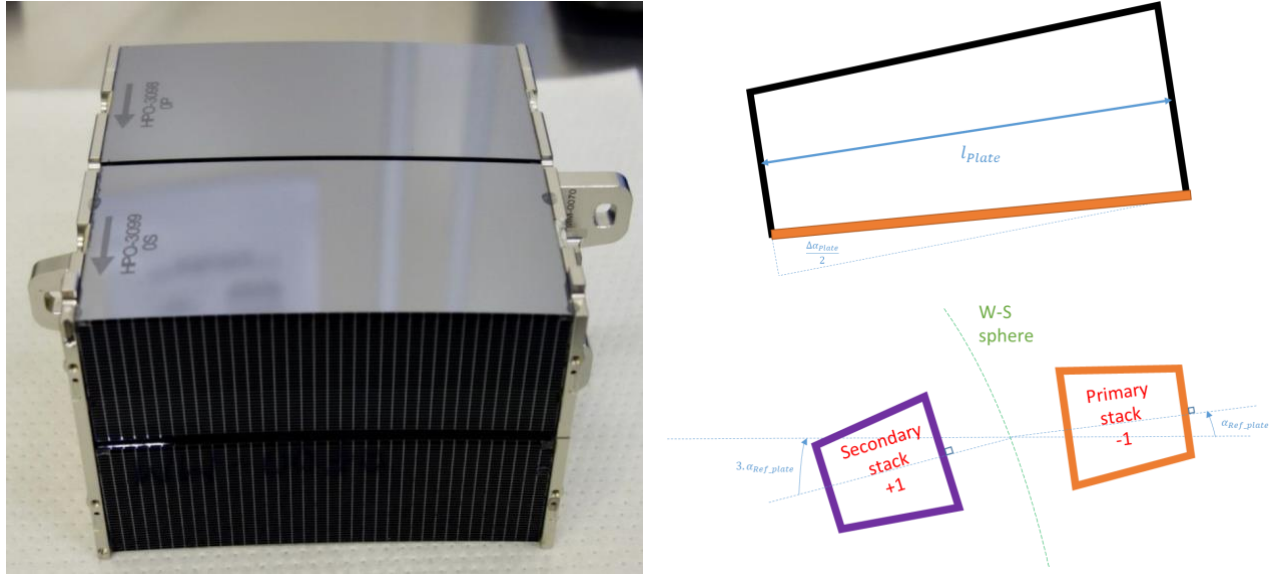


Figure 1: [Left] Assembled SPO Mirror Module MM-0070 with 4 SPO stacks of 38 plates (2 primary + 2 secondary), viewed from the exit side [5]. [Top right] Trapezoidal shape of a wedged SPO Plate (the reflective side is shown in orange). Half of the wedge angle, $\Delta\alpha_{plate}/2$, is defined by the reference plate and is introduced to both sides of the plates within the stack. [Bottom right] Wedging configuration (-1/+1).

2.2 Mirror Assembly and possible 15-row configuration

The baseline MA has 13 populated concentric rows with six-fold symmetry. The MM count by row is 24, 24, 24, 30, 30, 36, 42, 42, 42, 48, 48, 48, and 54, giving 492 MMs. Spacing between rows has been fixed to ensure the necessary spacing for structural, thermal, manufacturing constraints [5]. Rows 14 and 15 can each accommodate 54 additional MMs, giving 600 MMs in the 15-row option.

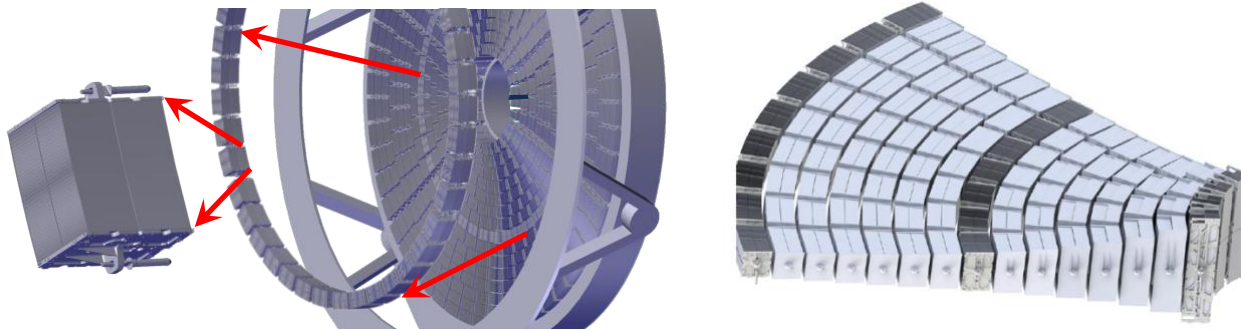


Figure 2: [Left] Modular concept. Each row (concentric ring) has MMs of the same type and the MA consists of different rows. [Right] Representation of the geometry of MMs in a 15-row petal (note that each row has a different geometry, length of the MMs being driven by grazing angle, height being driven by the number of plates and width being driven by accommodation constraints).

2.3 Remaining potential future changes

2.3.1 Composite stacks

Composite High-Performance Optics (CHPO) are being investigated as a possible future Mirror Module configuration. In this concept, the two primary stacks are bonded to form a single primary optical element, while the two secondary stacks are similarly combined into a single secondary element - Figure 3. A Mirror Module could therefore be assembled by aligning one primary composite stack with one secondary composite stack, rather than by co-aligning two separate X-ray Optical Units comprising four individual stacks. CHPO is not included in the reference configuration or in the performance predictions presented in this paper. Its impact on optical performance is expected to be limited, while the reduction in the number of elements requiring alignment could significantly simplify the Mirror Module assembly process. Adoption of the CHPO concept will require demonstration of the expected manufacturing benefits, preservation of the required optical performance, and compatibility with coating, metrology, environmental verification and the complete production chain [3] [4].



Figure 3: Example row-15 CHPO consisting of two bonded SPO stacks. Reproduced from the attached MM-development paper [4].

2.3.2 Multilayer coatings

A possible future evolution of the telescope is the introduction of optimised Pt/C multilayer coatings on the outer Mirror Assembly rows, while retaining the baseline Cr/Pt/C trilayer coating for rows 1 to 5. The current concept considers a row-specific multilayer recipe, comprising several Pt/C bilayers, for rows above row 5 to improve the reflectivity and effective area around 6.5-7 keV, where the larger grazing angles of the outer rows limit the performance achievable with the trilayer coating. Current studies are investigating both a 20-bilayer design [7] and simplified configurations with approximately six bilayers to reduce the impact on coating time and production schedule.

3. PERFORMANCE SPECIFICATION

The NewAthena optical-performance framework provides traceability from the prescribed optical design to the predicted in-space performance of the complete Mirror Assembly (MA). Level 1 describes the ray-traced design, Level 2 the Mirror Module (MM) population and Level 3 the integrated MA. The suffix “a” identifies an applicable requirement, while “b” identifies a margin-inclusive input used for the next analysis level or for downstream simulations.

3.1 Level 1: optical-design performance

Level 1 is generated with from the detailed plate, stack, MM and MA geometry. It includes the effects represented explicitly in the ray tracing, such as coating reflectivity and roughness, pore geometry, obscuration and primary-to-secondary spacing. Its main products are effective area, vignetting and geometrical off-axis broadening. Level 1 is a design and diagnostic reference, rather than an industrial acceptance requirement.

3.2 Level 2a: Mirror Module requirements

Level 2a is applicable to the MM contractor through the MM User Requirements Document. It is derived from Level 1 by including allocated MM manufacturing, coating, contamination and other MM-level losses. Effective area is specified both for the aggregated accepted population and through row-level distributions, allowing production performance to be monitored while retaining controlled trading between rows. The row-level limits are deliberately less stringent than the aggregate requirement and therefore permit compensation between rows, while aggregate compliance remains mandatory (more details in section 5).

3.3 Level 2b: input for Mirror Assembly analysis

Level 2b is obtained from Level 2a by applying the MM-level margin. It is not an additional contractor requirement, but the conservative MM input used by the spacecraft prime for MA analysis. Similarly to the L2a specification, this specification is also provided with a row dependence. For the current 13-row population, the aggregate Level 2b effective areas are approximately 12,276 cm² at 1.49 keV and 1,493 cm² at 7 keV, about 2% below the corresponding Level 2a requirements. The current aggregate Level 2b PSF has a Half Energy Width (HEW) of 8.124 arcsec at 1.49 keV before MA-level effects are added.

3.4 Level 3a: Mirror Assembly requirements

Level 3a defines the required performance of the integrated MA and is intended to become applicable to the spacecraft prime through the System Requirements Document. It is calculated by combining the Level 2b MM population with integration errors, thermoelastic deformation, gravity-related differences between ground and flight, and allocated operational and line-of-sight effects. For the current 13-row configuration, the Level 3a on-axis values at 1.49 keV are approximately 10,684 cm² effective area and a HEW below 8.852 arcsec.

3.5 Level 3b: Predicted in-space performance

Level 3b is the margin-inclusive MA prediction supplied for instrument and science simulations; instrument effects are not included. Its products include effective area versus energy and field angle, two-dimensional PSFs, encircled-energy functions, HEW, vignetting and off-axis performance. For the 13-row configuration, the predicted on-axis values are approximately 10,269 cm² effective area and 8.964 arcsec HEW at 1.49 keV, and approximately 1,213 cm² effective area at 7 keV (more details in section 6).

Table 1: Summary of the NewAthena performance-specification levels

Level	Scope and derivation	Use	Representative aggregate values
L1	Ray-traced optical design, including the effects explicitly represented in SPORT.	Design information and basis for MM specifications.	Effective area, vignetting, off-axis response and straylight versus energy and field angle.
L2a	L1 plus allocated MM manufacturing, coating, contamination and other MM-level losses.	Requirement applicable to the MM contractor.	$A_{\text{eff}} > 12,525 \text{ cm}^2$ at 1.49 keV; $A_{\text{eff}} > 1,523 \text{ cm}^2$ at 7 keV; HEW < 8 arcsec at 1.49 keV.
L2b	L2a with MM-level margin; row-dependent A_{eff} , vignetting and PSF.	Input to spacecraft-prime MA analysis.	$A_{\text{eff}} \approx 12,276 \text{ cm}^2$ at 1.49 keV; $A_{\text{eff}} \approx 1,493 \text{ cm}^2$ at 7 keV; HEW = 8.124 arcsec at 1.49 keV.
L3a	L2b plus integration, thermoelastic, gravity-related and operational effects.	Requirement applicable to the spacecraft prime.	At 1.49 keV: $A_{\text{eff}} \approx 10,684 \text{ cm}^2$; HEW < 8.852 arcsec.
L3b	Integrated MA response with additional MA-level margin; excludes instruments.	Input to instrument and science simulations.	At 1.49 keV: $A_{\text{eff}} \approx 10,269 \text{ cm}^2$ and HEW $\approx 8.964 \text{ arcsec}$; at 7 keV: $A_{\text{eff}} \approx 1,213 \text{ cm}^2$.

4. PERFORMANCE ANALYSIS SEQUENCE

4.1 First stage: ray-traced optical response

The first stage uses SPORT, the Silicon Pore Optics Ray-Tracer [8]. The reference geometry, coating, photon energy, and field direction are supplied to the ray tracer. SPORT calculates for a representative MM of each row: the effective area, the radial and azimuthal MM vignetting functions, and the geometric off-axis broadening. Additional MM manufacturing, coating, and contamination loss factors are applied to the ray-traced effective area to establish the L2a prescription. A further MM-level margin produces L2b, which is the input used for MA propagation.

4.2 Second stage: MM population and MA perturbations

The second stage uses NewAthena_E2E_PSF [9], a Python-based end-to-end PSF simulation and analysis toolkit developed for the NewAthena Mirror Assembly. The software uses a configured Excel workbook as the authoritative input description. The workbook contains the MM positions and row assignments, effective-area weights, PSF parameters, vignetting data and perturbation terms associated with alignment, gravity offload, thermal distortion and additional observing conditions. A graphical configuration application can be used to generate or update the workbook, while the main Python analysis engine reads the configured workbook, performs the calculations and exports the resulting performance products.

For each MM, the tool constructs a two-dimensional PSF at the corresponding focal-plane centroid. The intrinsic MM PSF may be represented analytically as a rotated Gaussian or as a separable two-dimensional pseudo-Voigt profile with independent radial and azimuthal widths and mixing parameters. Alternatively, a measured PSF can be loaded directly as a FITS image. This allows the same aggregation framework to be used during early design phases, when parametric PSFs are required, and during later verification phases, when measured MM responses become available.

The centroid assigned to each MM includes the combined effects of alignment, gravity offload, thermal deformation and additional off-axis or defocus terms. Translational and rotational perturbations are combined for each MM, and axial displacement is projected onto the focal plane using the MM position and the 12 m focal length. Off-axis and energy-dependent PSF degradation is introduced through row-dependent lookup tables (based on the SPORT results). The radial and azimuthal PSF widths are broadened in quadrature using the applicable off-axis contribution and are subsequently scaled using the selected photon energy.

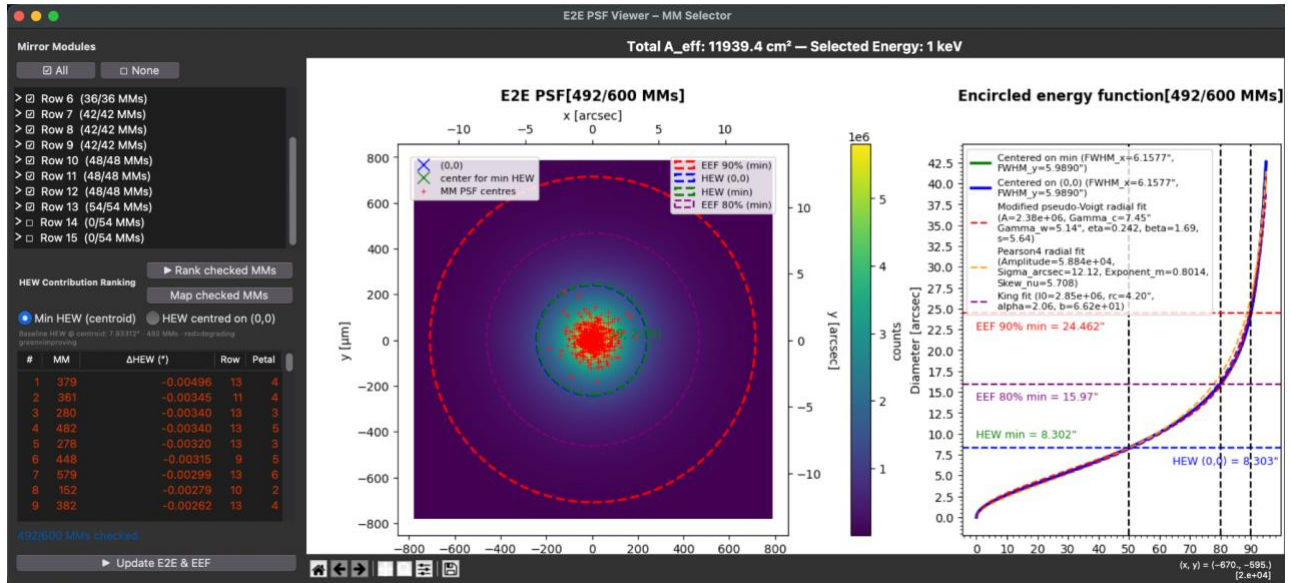


Figure 4: Screenshot of the NewAthena_E2E_PSF MM Selector and viewer. The interface displays selected rows and MMs, aggregate effective area, the two-dimensional PSF, EEf, fitted profiles, and HEW-contribution ranking.

The complete MA PSF is obtained by co-adding the individual MM PSFs. Each PSF is shifted to its perturbed centroid, rotated as required and weighted by the corresponding effective area after application of the appropriate vignetting factor.

In mathematical form, the aggregate response is the weighted sum of the individual PSFs, with the effective area providing the relative normalization of each MM contribution. The analysis can be applied to the complete MM population or to a selected subset of rows, petals or individual MMs.

After aggregation, the focal-plane position that minimizes the HEW is determined numerically. The tool then calculates an azimuthally averaged radial intensity profile and its cumulative encircled-energy function. The diameters enclosing 50%, 80% and 90% of the total energy are derived from this function, providing the HEW, EEf-80 and EEf-90 metrics. One-dimensional marginal profiles are also used to calculate directional FWHM and half-energy widths. The aggregate radial profile can be fitted with a modified pseudo-Voigt, a Pearson type-IV or a King model.

The principal outputs are the two-dimensional MA PSF, the encircled-energy function, HEW and other EEf metrics, radial-profile fits, effective area before and after vignetting, and machine-readable data products. Results can be exported as figures, EEf data tables, aggregated Excel workbooks and FITS files. Batch processing supports systematic calculations over combinations of photon energy, off-axis angle and defocus, while coarse and fine modes provide different computational resolutions. The interactive MM Selector additionally allows the user to include or exclude individual MMs and immediately recompute the aggregate PSF and EEf - Figure 4.

The sequence is therefore deliberately asymmetric. SPORT establishes the physics-based throughput, vignetting and geometrical off-axis broadening. NewAthena_E2E_PSF then uses these products to construct the population-level image response and to propagate effects that are most naturally represented as MM PSF shapes, effective-area weights, centroid displacements, rotations and measured response maps.

This hybrid approach avoids a full plate-error ray trace for every MM, which would require accurate knowledge of the figure errors of all individual plates. These errors cannot be determined reliably after stacking. Traceability from the row-level optical calculations to the predicted MA performance is nevertheless maintained.

5. MIRROR MODULE MANUFACTURING AND ACCEPTANCE REQUIREMENTS

The plan for the forthcoming MM implementation contract is to translate the Level 2a prescription into measurable manufacturing, verification and acceptance criteria for the SPO Mirror Module (MM) population. Level 2a is the contractual MM-level performance after the allocated manufacturing, coating and contamination losses have been applied to the ray-traced optical design. Compliance is controlled at two complementary levels: an aggregate requirement for the complete accepted flight population and row-dependent distributions that permit progressive verification during production. The aggregate requirement remains governing, while the row limits allow controlled trading between rows.

For effective area, the accepted 13-row flight population aggregate requirement was mentioned earlier in section 3.2 (more 12,525 cm² on axis at 1.49 keV and more than 1,523 cm² at 7 keV). At 1.49 keV, the principal row-dependent requirements apply to rows 5–13; at 7 keV, the driving row requirements apply to rows 1–4. Each row is specified by a required population mean μ , a standard deviation σ and a minimum individual-MM value $\mu-2\sigma$ (Table 2). Effective area is measured after environmental testing, with the measurement and post-processing method to be agreed with ESA.

Table 2: L2a row-dependent effective-area acceptance values for MMs in the 13-row flight population

Energy	Rows	Mean Ae _{eff} per MM per row, μ (cm ²)	σ (cm ²)	Minimum individual Ae _{eff} per MM, $\mu-2\sigma$ (cm ²)
1.49 keV	5–13	23.35–28.35	1.17–1.42	21.02 - 25.52
7 keV	1–4	9.68–14.08	0.48–0.70	8.71 - 12.67

For imaging performance, HEW is the contractual PSF metric. The effective-area-weighted aggregate of the accepted MM population shall have an on-axis HEW below 8 arcsec at 1.49 keV, assuming coincident MM PSF barycenters. For rows 5–13, the prescribed mean HEW increases from 7.01 to 7.98 arcsec with a row standard deviation of 1 arcsec; the maximum individual-MM values, defined as $\mu+2\sigma$, therefore range from 9.01 to 9.98 arcsec. The row limits are intentionally less stringent than the aggregate requirement and correspond to an aggregate HEW of approximately 8.4 arcsec, allowing row-to-row trading while retaining mandatory compliance with the 8-arcsec aggregate requirement. Separate 7-keV PSF requirements apply to the inner rows, for which the high-energy response is most relevant.

Table 3: L2a row-dependent HEW acceptance values for the 13-row flight population.

Energy	Rows	Mean HEW per row, μ (arcsec)	σ (arcsec)	Maximum individual HEW, $\mu+2\sigma$ (arcsec)
1.49 keV	5–13	7.01–7.98	1.00	9.01 - 9.98
7 keV	1–4	16.43–18.01	2.00	20.43 - 22.01

The prescribed row variability is also used to test the population-level performance before flight production is complete. In the current approach, synthetic MM populations are generated in NewAthena_E2E_PSF using truncated shifted-gamma distributions, with row-dependent means and limits and iterative adjustment until the target aggregate performance is reached. Each simulated or measured MM PSF is then weighted by its effective area and combined with the other MMs. This verifies that the proposed row distributions and permitted production variability remain compatible with the Level 2a aggregate requirements. During implementation, the synthetic distributions can progressively be replaced by measured PSFs, including FITS images, and measured post-environmental effective areas.

Acceptance also requires traceable performance data for each MM. The contractor shall provide an individual performance data package before acceptance, a validated representation of each accepted PSF reproducing the measured encircled-energy function within 1.5% over 40 arcmin (WFI FoV) centered on best focus, and evidence that the absolute HEW change between pre- and post-environmental verification does not exceed 0.2 arcsec. Coating verification is performed on representative plates or samples from each coating run at critical energies including 1.49 and 7 keV, linking coating control directly to the effective-area acceptance process.

6. MIRROR ASSEMBLY PREDICTED PERFORMANCE

6.1 Effective Area at MA-level

The L3b MA-level on-axis effective area values are displayed in Table 4 and Figure 5. The reference design aims to maximise on-axis effective area at 1 keV.

Table 4: L3b Aeff in cm² (input for science/instrument community). 1.49 keV (Al) and 4.51 keV (Ti) are expected to be the energies to be used for the verification/acceptance.

	Energy (keV)										
	0.2	0.5	1	1.49	2	4	4.51	6.4	7	10	12
13 rows	13087.32	10465.70	11222.69	11004.77	9241.90	3476.38	2917.07	1492.13	1213.26	404.54	93.65
15 rows	17781.05	13214.37	14847.02	13433.55	10646.90	3494.21	2919.94	1492.13	1213.26	404.54	93.65

L3b Effective Area Curve of NewAthena

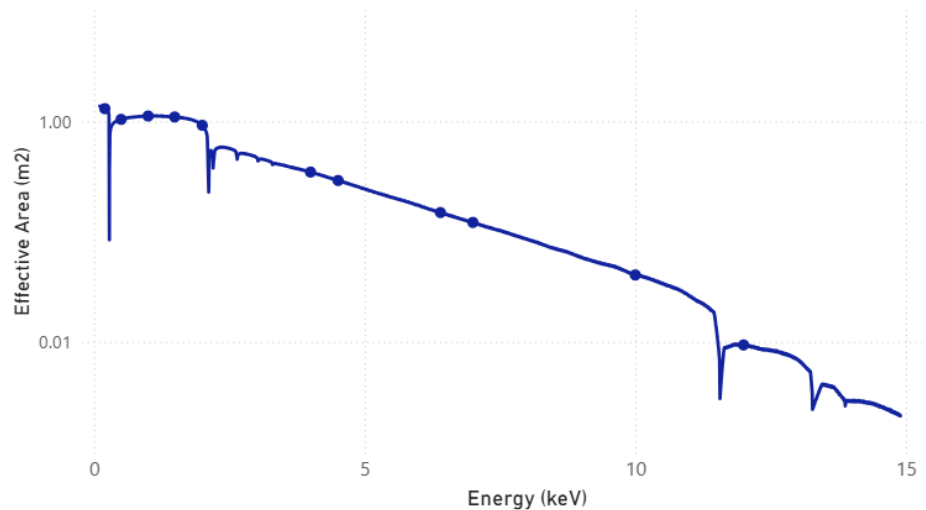


Figure 5: L3b effective area curve for NewAthena 13-row configuration (input for science/instrument community). Note the absorption lines of Silicon, Platinum and Carbon. ESA reference energies are marked.

6.2 Vignetting at MA-level

MA-level vignetting factors at different energies are tabulated in Table 5 and displayed in Figure 6. The MA axisymmetric layout leads to an overall axisymmetric vignetting curve. L3 vignetting curves monotonically decrease with off-axis angle, with steeper decreases at higher energies.

Table 5: L3 vignetting functions for a 13-row configuration at ESA reference energies. See Figure 6 for the vignetting plot. Curves are monotonically decreasing with angle – with steeper decreases for higher energies.

	Energy [keV]										
Off-axis [arcmin]	0.2	0.5	1	1.49	2	4	4.51	6.4	7	10	12
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.5	0.9978	0.9981	0.9975	0.9978	0.9973	0.9955	0.9958	0.9927	0.9914	0.9864	0.9825
1	0.9906	0.9914	0.9899	0.9905	0.9891	0.9839	0.9841	0.9775	0.9746	0.9585	0.9541
2	0.9700	0.9720	0.9690	0.9707	0.9659	0.9525	0.9519	0.9312	0.9275	0.8874	0.8723
3	0.9444	0.9451	0.9423	0.9444	0.9364	0.9124	0.9088	0.8730	0.8659	0.7957	0.7700
5	0.8829	0.8799	0.8788	0.8787	0.8648	0.8167	0.8047	0.7373	0.7208	0.6020	0.5512
7	0.8133	0.8093	0.8089	0.8065	0.7866	0.7145	0.6942	0.5982	0.5704	0.4292	0.3683
10	0.7087	0.7041	0.7049	0.6989	0.6694	0.5665	0.5375	0.4155	0.3834	0.2415	0.1922
15	0.5770	0.5693	0.5733	0.5665	0.5224	0.3944	0.3600	0.2359	0.2091	0.1081	0.0804
20	0.4190	0.4090	0.4102	0.4000	0.3495	0.2286	0.1986	0.1115	0.0940	0.0373	0.0223
28	0.2584	0.2497	0.2504	0.2403	0.1969	0.1117	0.0927	0.0411	0.0306	0.0054	0.0016

L3 Vignetting Curve

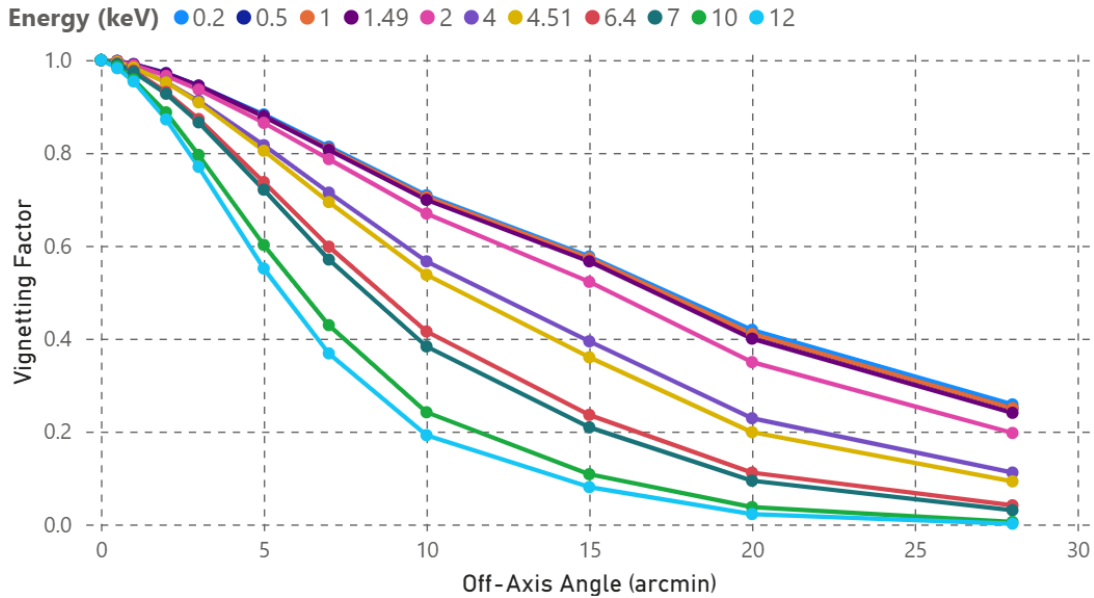


Figure 6: L3 vignetting curve for reference energies. Note that this curve is symmetric.

6.3 PSF Performance at MA-level

The L3b PSF is the best guess of the final in-space performance of the mirror without instrument effects. The L3b PSF is generated by assuming an on-axis HEW $\leq 8.964''$ at MA-level including MM-level losses and margins, and MA-level losses and margins. This is slightly less than the 9'' mission requirement, leaving 0.8'' allocation for the instrument

pixelation (to be added in RSS). The L3b PSFs have been fitted with modified pseudo-Voigt, Pearson4 and King functions, as in Figure 7. The King profile appears to provide the best fitting performance for most configurations and is therefore recommended if the raw encircled-energy function cannot be used and a fit is required.

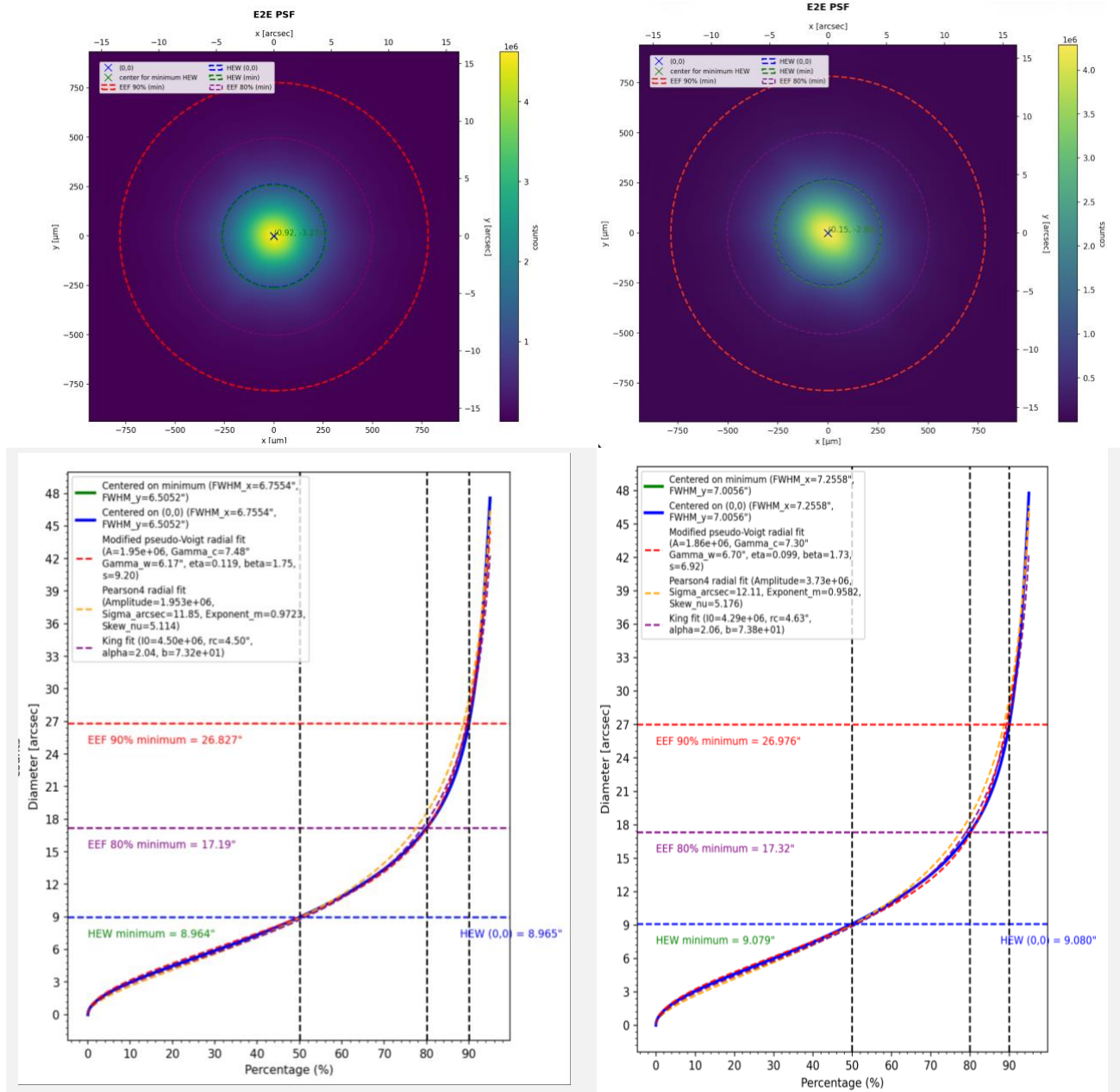


Figure 7: (Left) PSF image (top) and E2E function (bottom) of the L3b PSF on axis at 1 keV and comparison with 3 different PSF fittings; Modified pseudo-Voigt, Pearson4, and King.

(Right) PSF image (top) and E2E function (bottom) of the L3b PSF 20 arcmin off axis (the incidence angle is 45 deg wrt. the x axis) at 1 keV and comparison with 3 different PSF fittings; Modified pseudo-Voigt, Pearson4, and King. The off-axis PSF is elliptical and has a slightly larger HEW by 0.115", relative to the on-axis configuration.

Figure 8 depicts HEW performance per energy and off-axis angle. There is negligible off axis HEW degradation for energies below 6.4 keV. Above 6.4 keV, noticeable HEW degradation only occurs above 15 arcseconds off axis.

L3b HEW as a function of Off-Axis Angle

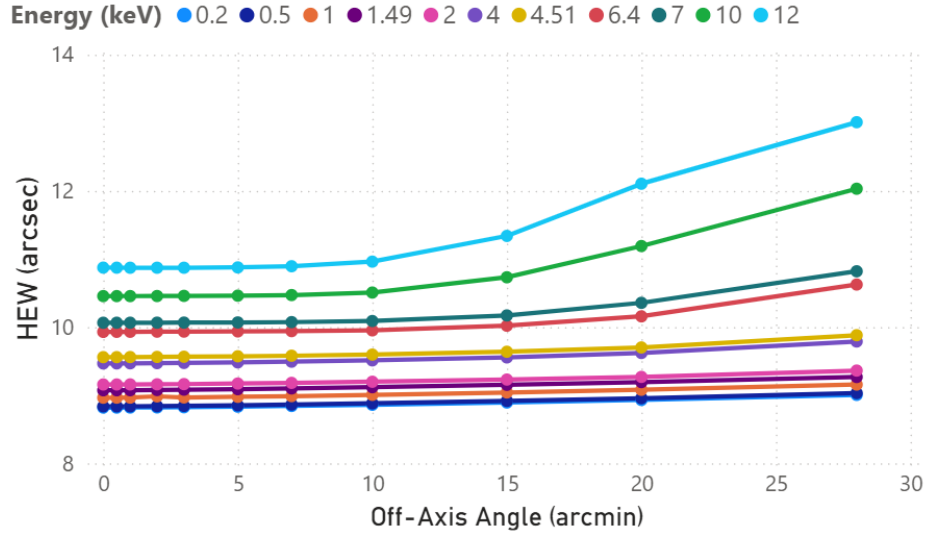


Figure 8: HEW [arcsec] vs. off-axis angle [arcmin] for different energies (given in keV). HEW has little degradation off axis due to Wolter-Schwarzschild optical design of SPO.

6.4 Straylight Performance

When performing X-ray observations with a Wolter telescope, the presence of bright off-axis sources can introduce unfocused rays, known as straylight, which contaminate the detector. This chapter identifies two categories of straylight affecting NewAthena. The first, plate straylight, arises primarily from photons that undergo a single reflection rather than the nominal double reflection, producing the pattern as in Figure 9. The second, gap straylight, describes photons that pass directly through the gaps between MMs and the mirror structure (MS). Both categories of straylight were modelled using SPORT with 100,000 photons.

The geometric contribution of straylight, independent of any energy dependence, was calculated within the WFI focal plane. From Figure 10, the plate straylight flux peaks at an off-axis angle of 50 arcminutes, reaching 47 cm². The gap straylight flux remains relatively constant at 5 cm² between off-axis angles 60 and 330 arcminutes.

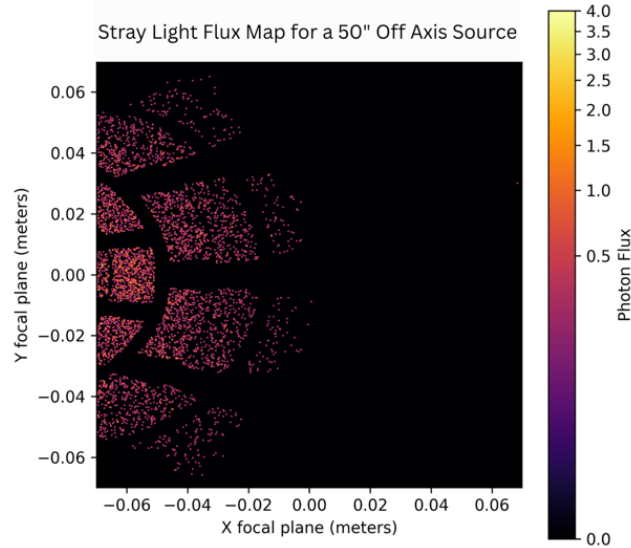


Figure 9: Example for plate straylight image within the WFI focal plane. Only photons originating from an off-axis source that singly reflect off the secondary plate reach the detector.

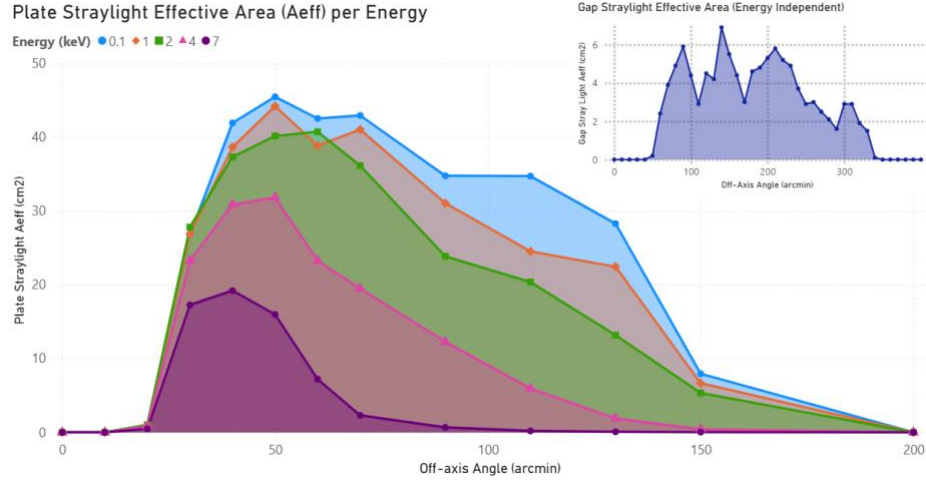


Figure 10: Plate straylight effective area from a bright point source outside the WFI field of view, which reaches the WFI detector. The flux peaks between 40 - 50 arcminutes for all energies and is zero beyond 200 arcminutes. The insert on top depicts gap straylight. The latter is energy independent as it does not undergo reflection before hitting the detector.

Figure 10 shows the energy dependence of plate straylight effective area. The effective area peak occurs between 40 - 50 arcminutes for all energies and averages approximately 40 cm² below 2 keV. Gap straylight effective area is independent of energy since the photons do not undergo reflection before reaching the detector. In Table 6, the on-axis focused effective area is compared to maximum straylight. For a source of the same flux, straylight effective area is 0.4%-1.4% of focused light.

Table 6: Aeff of straylight compared to the focused on-axis Aeff at energies 1, 4, 7 keV. Straylight calculations are confined to the WFI focal plane. A point source at 50'' off-axis was chosen as it is the position of maximum total straylight below 2keV.

Straylight type	Energy		
	1 keV	4 keV	7 keV
Focused On-Axis Aeff (cm ²)	11,223	3,476	1,213
Plate straylight at 50'' (cm ²)	44	32	16
Gap straylight at 50'' (cm ²)	1	1	1
Ratio of straylight to focused	0.004	0.009	0.014

These straylight figures seem relatively negligible, especially taking into consideration that the plate straylight is distributed over the detector as shown in Figure 9. Still, mitigation measures are currently being explored to reduce the gap straylight since this component will have a clear spatial concentration and roughly extends until up to angles of 6 deg (Figure 10).

7. CONCLUSIONS

The NewAthena reference telescope design provides a coherent and traceable framework connecting the Silicon Pore Optics geometry, Mirror Module production requirements and predicted in-space performance of the complete Mirror Assembly. The current baseline comprises 492 Mirror Modules arranged in 13 rows and six petals, while preserving compatibility with a possible future extension to 15 rows and 600 modules.

The performance methodology combines two complementary analysis stages. SPORT calculates the row-dependent effective area, vignetting, off-axis response and straylight from the prescribed optical geometry. NewAthena_E2E_PSF then combines these results with parametrised or measured Mirror Module PSFs and propagates manufacturing variability, integration errors, thermoelastic deformation, gravity-offload differences and pointing effects to Mirror Assembly level.

This hybrid approach avoids the need for unavailable post-stacking plate-figure information while maintaining traceability from the optical design to telescope-level performance.

For the 13-row configuration, the predicted in-space mirror performance provides approximately 1.12 m² effective area and 8.96 arcsec HEW on axis at 1 keV. The Wolter-Schwarzschild design also limits off-axis PSF degradation over most of the field, while the predicted straylight contribution remains small relative to the focused effective area.

The same framework translates the high level prescriptions into aggregate and row-dependent manufacturing and acceptance requirements for the forthcoming Mirror Module implementation contract. It can progressively incorporate measured PSFs and effective areas as production advances. Future options, including CHPO, multilayer coatings and population of rows 14 and 15, can consequently be assessed and introduced within the same configuration-controlled performance chain.

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