# Manufacturing process for the WEAVE Prime Focus Corrector optics for the 4.2m William Herschel Telescope

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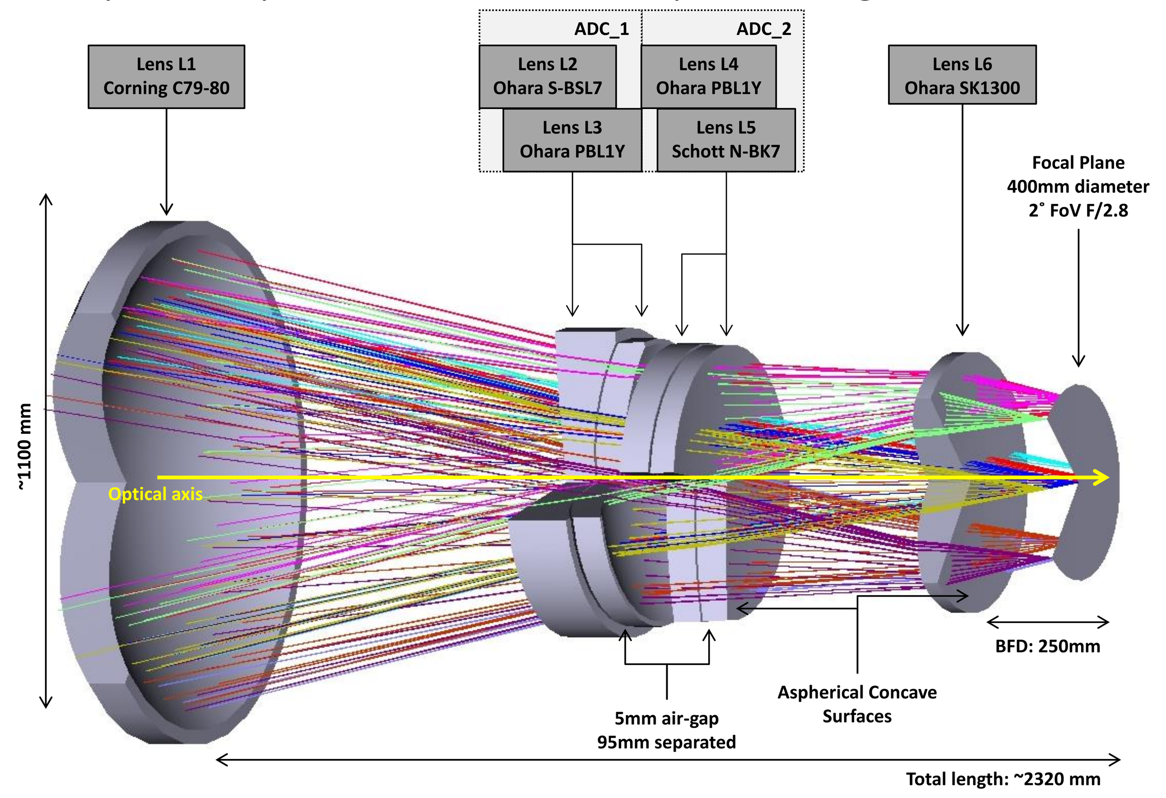
## INTRODUCTION

WEAVE (WHT Enhanced Area Velocity Explorer) is the next-generation wide-field Multi-Object Spectroscopy facility for the 4.2m William Herschel Telescope at the Roque de Los Muchachos observatory on La Palma in the Canary Islands. The instrument will provide unique capabilities in the Northern hemisphere for scientific exploitation of European-led surveys (Gaia, LOFAR…).

This poster presents the process for delivering the six PFC lenses, from the optical design prescriptions, through the manufacturing trade-offs for the blanks and lenses, to the as-built design re-optimisation. The optical testing is also detailed and a description of the lens mounting and alignment philosophy is outlined.

## OPTICAL DESIGN CHARACTERISTICS

As the new Prime Focus Corrector (PFC) will be located at the prime focus of the 4.2-meter diameter parabolic mirror of the WHT, the main purpose of the PFC is to correct for the geometrical aberrations in the two-degree field-of-view. The PFC also includes an Atmospheric Dispersion Corrector (ADC) consisting of a pair of counter-rotating and air-separated doublets which compensate for atmospheric dispersion whilst the telescope is moving in elevation.




**The WEAVE PFC is a unique and innovative optical system, based on non-standard lenses:**

- The lens L1 is a 230kg meniscus of 1.1m diameter.
- The large diameter of lens L2 and the long radius of curvature of its convex surface (~6m) make the lens wedge difficult to measure.
- The lenses L3 and L4 are wedged lenses with both surfaces tilted with respect to the PFC optical axis.
- The concave surface of lenses L5 and L6 is aspherical.
- The ADC doublets are air-separated (5mm).

**Characteristics of the PFC image quality:**

- Better than 1-arcsec diameter (80% encircled energy)
- Field-of-view diameter of 2 degrees
- Wavelength range of [370-1000]nm
- Telescope altitude from Zenith up to 65 degrees
- Thermal environment ranging from -5˚C to +25˚C

## MANUFACTURING TRADE-OFFS FOR THE BLANKS AND LENSES

**Manufacturing specifications for the blanks:**

- **Choice of material.** The greatest challenge was the production of high-quality glass blanks with a high homogeneity of refractive index of 10 ppm PV (class 2 according to the ISO 10110 standards).
  - ⇒ Lenses L1 and L6: made from fused silica as this material offers excellent glass properties.
  - ⇒ Lenses L2 to L5: correcting for atmospheric dispersion requires a combination of a crown and a flint glasses. To achieve the required homogeneity grade for such large amorphous glasses, two annealing processes were required.

- **Size of the blanks.** The diameter and thickness of each blank were calculated to ensure that just enough material was available to manufacture the lens. The following margins, on top of the lens clear aperture diameter, were taken into account:
  - Optical design re-optimisation of the as-built lens radii of curvature
  - Polishing roll-off, coating area and room for mounting pads
  - Flat annulus and chamfer for safe handling and supporting

- **Shape of the blanks.** While the five blanks B2 to B6 were manufactured as plano-cylinders, the blank B1 was slumped very close to the final shape of the lens, avoiding a heavy grinding process.

- **Homogeneity of the substrate.** The glass homogeneity of the six blanks was measured by sub-aperture interferometry and stitched OPD maps were delivered, indicating where local polishing of the lens surfaces is required.

**Trade-offs for the specifications of the lenses:**

- No coating will be applied to the lens L1 as it was not guaranteed to meet the specification of uniformity on such a steep lens.
- The strategy to manufacture the ADC lenses is to tilt only one surface while during assembly the lens will be further tilted.
- The aspherical surfaces (on L5 and L6) are on the concave side of the lenses, easing its testing.

## RE-OPTIMISATIONS OF THE OPTICAL DESIGN

**As-built blank parameters:**

- Inputs: refractive index measured for 8 spectral lines covering the instrument wavelength range (B1 and B6 as per catalogue)
- Outputs: updated set of lens prescriptions for L2 to L5 (radii of curvature, axial separations, wedges, aspherical parameters…)

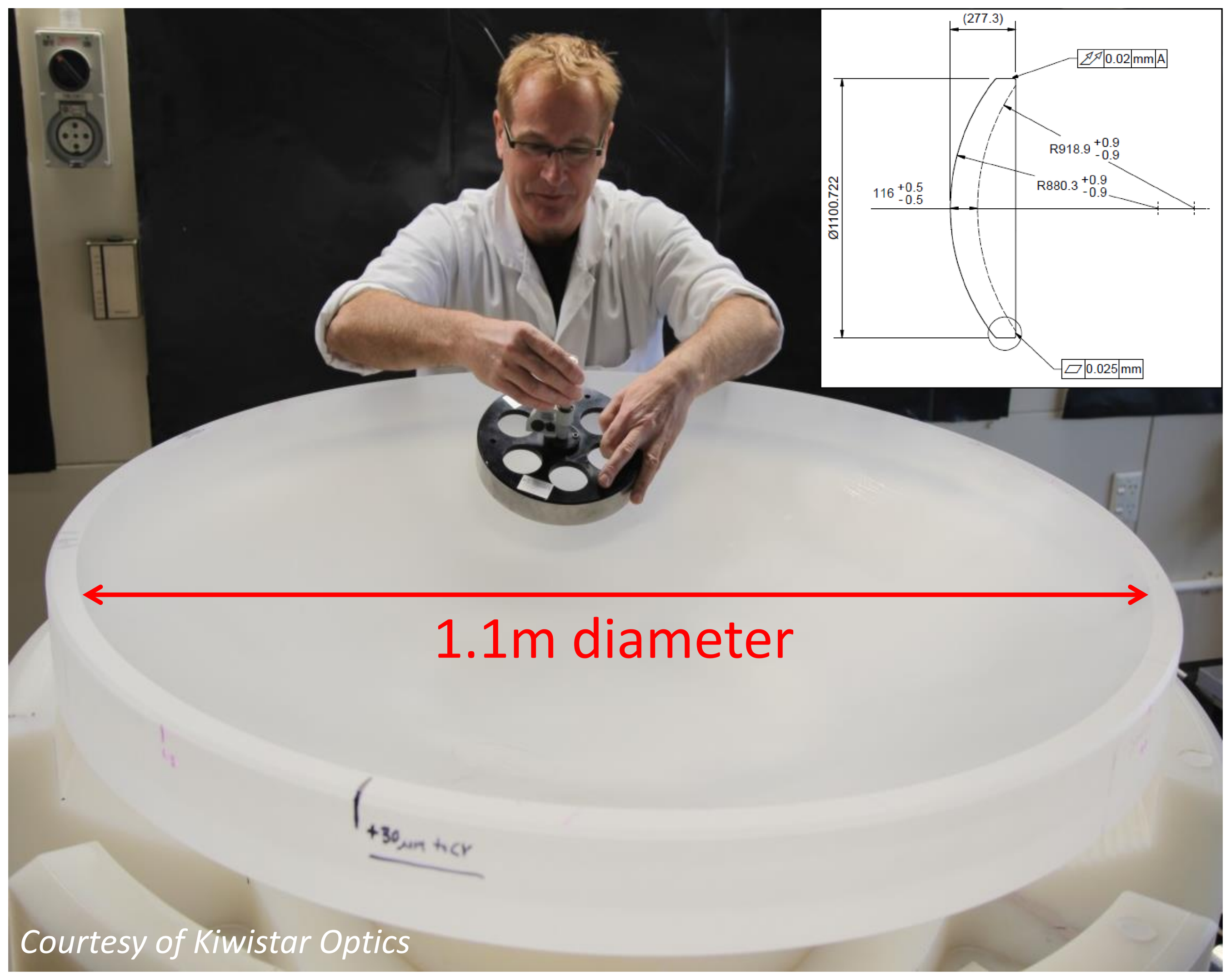
**As-built lens parameters:**

- Inputs: final dimensions of the lenses (radii of curvature, central thicknesses, wedges…)
- Outputs: updated axial separations WHT/M1-L1, L1-L2 and L5-L6

## LENS POLISHING, OPTICAL TESTING AND COATING

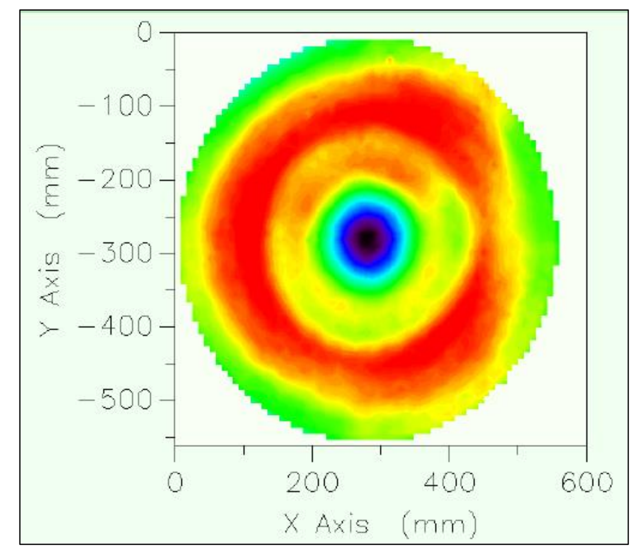
The four main steps for manufacturing the lenses are **(1)** milling and lapping, generating the final shape of the lens, **(2)** polishing of the two lens optical surfaces, **(3)** optical testing of the polishing and correction of errors and **(4)** application of an anti-reflection coating.

On arrival, the physical dimensions of the blank are checked on a Coordinate Measuring Machine and data are used to mill the optical surfaces plane-parallel to each other and perpendicular-cylinder to within the specified tolerance. The blank is mounted on a milling machine and the concave surface is milled first, then it is lapped with different grit sizes down to 5um. For the two aspherical lenses L5 and L6, the concave surface is lapped to the best-fit sphere before being asphericised. Then the lens is turned over and the convex surface is milled and lapped however during this stage central thickness and wedge are tightly controlled.




**The total surface irregularities for lens L4 concave surface (562mm clear aperture Ø):**

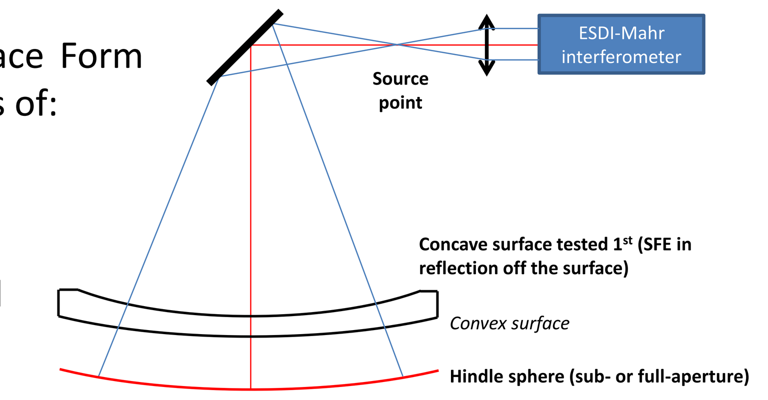
- The results have been fitted to the standard Zernike coefficients (Z5 to Z190) with the residual fitting errors.
- Tilt, focus, and mount-induced astigmatism have been subtracted (residual focus is from averaging of multiple OPD files).
- PV = 214.8nm, RMS = 32.2nm (the colour scale runs from black to red).




KiwiStar Optics have developed a dedicated test tower to measure the optical Surface Form Errors from the concave surfaces and the transmitted wavefront of each lens. It consists of:

- A test tower made of large aluminium rails
- A Mahr-ESDI interferometer and its auxiliary optics
- A lens holder fitted with the required degrees of freedom
- The Hindle spheres (acting as a return mirror) lying underneath the lens being tested

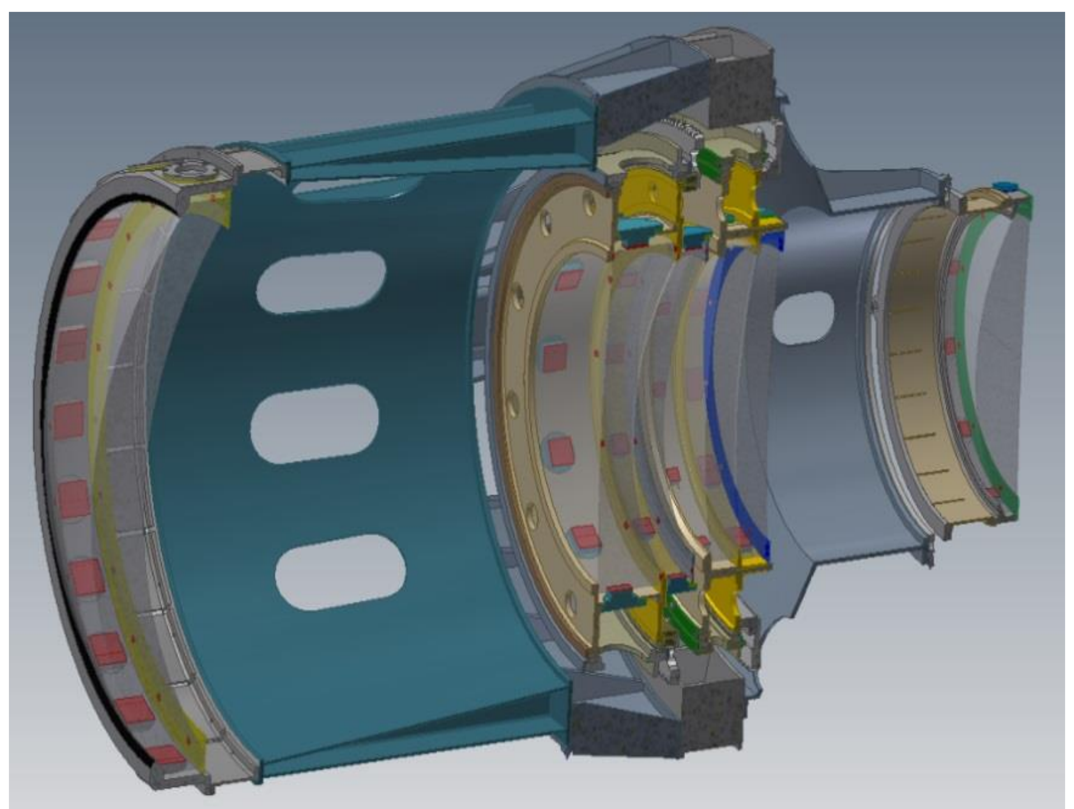
$$TWFE = \sqrt{WFE\_irreg.^2 + WFE\_homo^2 + WFE\_stress^2 + WFE\_striae^2}$$




## LENS MOUNTING & ALIGNMENT PHILOSOPHY

**STEP 1.** Each lens is secured into a cell using a number of discrete radial and axial RTV mounting pads, providing an athermal mounting arrangement. The RTV pads are initially cast and then glued in place following a technique which involves rotatory tables.

**STEP 2.** The cylindrical edge of the lens is concentrically aligned with the bore of its cell. The cell of L3 is manufactured with a bore decentre with respect to the cell of L2. The bore of cell L4 is tilted with respect to the cell of L5.



**STEP 3.** The outer diameters of all the lens cells are aligned to be concentric with the PFC optical axis by means of lasers, targets, and alignment markers. The physical position of each lens is measured against the specified tolerance budget.

**STEP 4.** The aligned PFC unit will be shipped to the observatory where it will be integrated into the WEAVE top-end, and then the whole assembly will be aligned onto the WHT optical axis.

## CONCLUSION

The manufacturing process for the WEAVE Prime Focus Corrector optics is a great technical challenge due to the large size, demanding high quality optical performance, and specific characteristics of the six lenses. Thanks to a flexible and well-controlled budgeted optical design, the as-built data of the blanks and lenses are accounted in the design re-optimisation processes. Several trade-offs were necessary to ensure the manufacturability of the PFC within acceptable time, risks, and costs while achieving the best image quality for the success of the instrument.