Modular Cross-Dispersion Spectrometer MOBIUS for Large Binocular Telescope

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Abstract: MOBIUS is a modular optical system designed to fit within the focal plane mask frame of the LUCI spectrograph. MOBIUS provides cross-dispersion, allowing spectra to be recorded covering all four near-infrared bands.

1. MOBIUS (Mask-Oriented Breadboard Implementation for Unscrambling Spectra)

The Large Binocular Telescope (LBT) is equipped with the LUCI (LBT Utility Camera in the Infrared) instruments shown in Fig.1, that are a pair of near infrared ($0.9 - 2.4$ μm) imagers and spectrographs. The LUCI instruments are installed at the front Bent-Gregorian f/15 focal stations and have exchangeable cryogenic focal plane masks. Currently, both LUCIs can be used together to observe spectra covering the zJHK bands (zJ and HK) at a spectral resolution of R~2300. [1]

A modular cross-disperser, MOBIUS (Mask-Oriented Breadboard Implementation for Unscrambling Spectra), is being developed to produce a simultaneous zJHK spectrum with a single LUCI. A key design boundary condition for MOBIUS is that there would be no modifications to the existing LUCI instruments. [2] This is achieved by housing MOBIUS inside of a LUCI slit mask frame and using the MOS-Unit (Multi-Object Spectrograph Unit) to deploy it in the telescope focal plane as depicted in Fig. 1 (right). With an 0.25 arcsecond wide slit and LUCI's rapid guide and collimate mode, MOBIUS will produce spectra with a spectral resolution of R~1800 using only one LUCI. The available slit length of each of the two spectrographs is limited to ~2.3 arcseconds. This is driven by the limited space available for the collimated beam in the mask frame as well as the dispersing power of the Strontium Titanate ($SrTiO_3$) prism. [3]

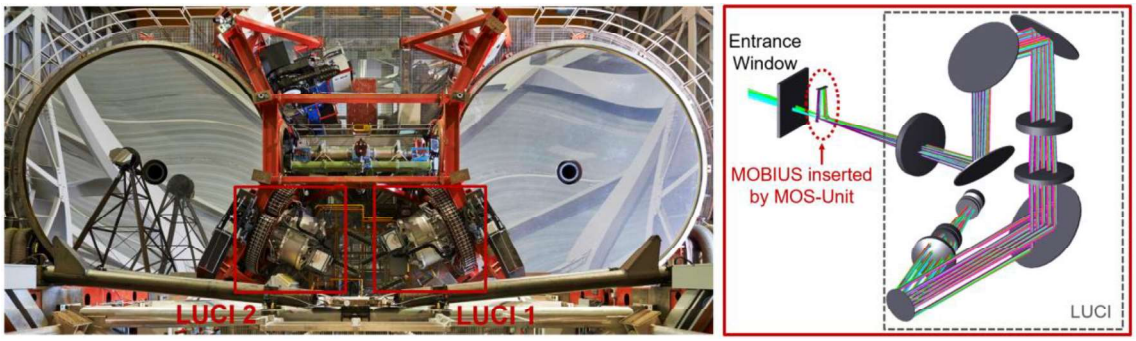

Fig. 1. (left) Two 8.4 m diameter primary mirrors on the Large Binocular Telescope and the two LUCI instruments in the red boxes (right) Modular optical design of MOBIUS between the LUCI instrument and the entrance window. The MOBIUS is located at the telescope (i.e., the primary, secondary, and tertiary mirror) focal plane of LBT. By substituting a standard slit mask with MOBIUS, LUCI produces cross-dispersed zJHK spectrum without any modifications to the current instrument.

2. Modular optical design of MOBIUS

The 3-dimensional optical design view of MOBIUS featuring two identical mini spectrographs to provide sky subtraction by dithering is shown in Fig. 2 (left). Because MOBIUS needs to fit within a limited space (150 × 150 × 12 mm), the maximum size of optical components is limited by the slit mask frame shown in Fig. 2 (middle). Also, the total mass of MOBIUS had to be kept to no more than 20 grams over that of a standard slit mask frame so it can be inserted by the MOS-unit robot. Finally, it must survive and maintain its optical quality and alignment when cooled to the cryogenic temperatures (~77 K) of LUCI.

The MOBIUS optical components include a folding (i.e., right-angle) roof mirror made of Zerodur with gold coating (i.e., 100 nm thickness Au), a spherical collimating mirror (180 mm radius of curvature), made of aluminum-coated Zerodur, and a dispersing prism made of Strontium Titanate with a return silver coating on the back prism surface. The roof mirror is located at the focal point of the LBT. It folds the incident beam into the mask plane and also re-directs the returning dispersed light into the LUCI instrument. The spherical mirror collimates the input beam and directs it to the Strontium Titanate dispersing prism, as well as re-focuses the

dispersed beam and directs it back to the roof mirror. The apex angle of the prism is 19° and the prism is used in a double-pass configuration using retroreflection from the rear surface silver mirror coating. The dispersed beam heads back to the spherical mirror and is re-focused near the other side of the roof-mirror. As a result, the input beam from the LBT is pre-dispersed in the orthogonal direction of the LUCI grating dispersion. At the final science camera focal plane, a cross-dispersed spectrum covering the zJHK bands is acquired. [2]

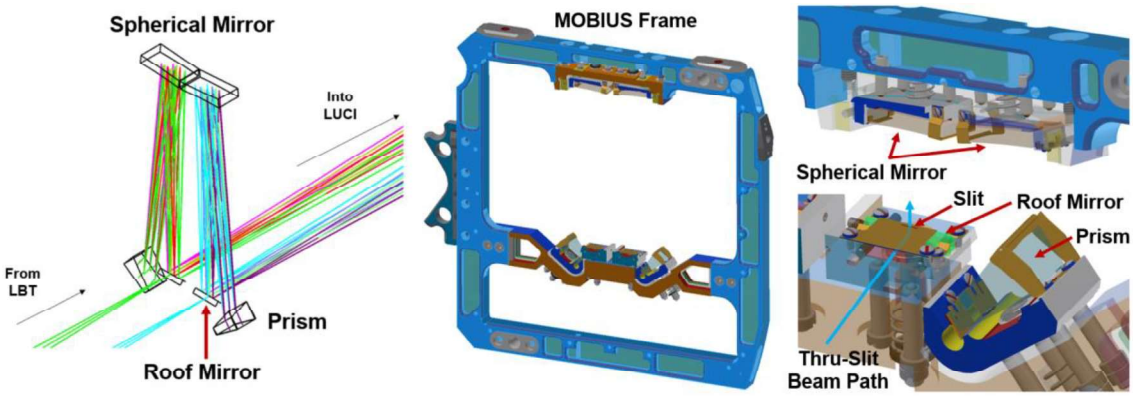

Fig. 2. (left) Optical path through MOBIUS with two spectrograph units located side by side for sky subtraction by dithering. (middle) The MOBIUS optical components mounted on a frame interchangable with the original slit masks in the MOS-Unit. (right) Zoom-in view of the opto-mechanical mounts allwoing a precision integration and alignment of the MOBIUS optics.

3. MOBIUS integration and performance testing

Without MOBIUS, the footprint of the different orders from the LUCI grating overlap, requiring the use of order-sorting filters. In contrast, MOBIUS generates perpendicular pre-dispersion that gives spectra without overlap. Also, the twin cross dispersers produce sets of zJHK spectra, one for the science target and the other for sky subtraction. MOBIUS is assembled and optically aligned as shown in Fig. 3 (left). MOBIUS was assembled, aligned, and tested at room temperatures using an incandescent light source followed by f/15 telescope beam emulator. The focused beam footprint with and without MOBIUS was measured as compared in the Fig. 3 (middle). Also, the width of the pre-dispersed footprint was measured along the profile (red dashed line in the middle) and the measured ~1800 µm spectra width was well matched to the optical simulation value.

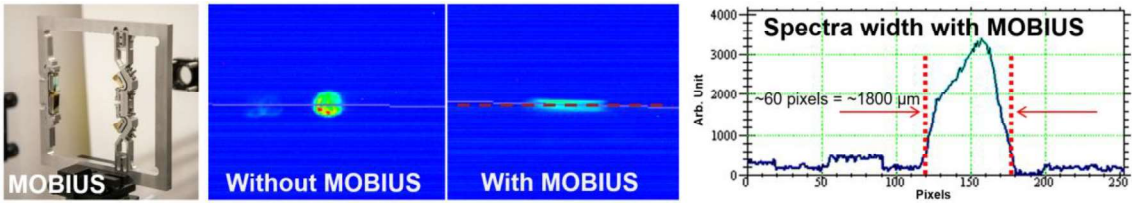

Fig. 3. (left) Assembled MOBIUS optical components and test frame. (middle) Measured footprint of the f/15 beam focal spot with and without MOBIUS. The red dashed line repsents the profile analysis line. (right) The mesaured spectrum profile from the MOBIUS assembly with a test light source (limited bandwidth).

4. Conclusion

The MOBIUS slit mask based cross dispersing unit has been successfully assembled and tested. Because MOBIUS follows an identical form-factor as the current mask frames it does not require any modification to the current instrument. MOBIUS enables zJHK spectroscopy in a single exposure. Paired with one MODS (Multi-Object Double Spectrograph) in binocular observing mode, a MOBIUS-equipped LUCI can provide spectra from the UV atmospheric cut-on at 0.32 microns to 2.4 microns in the NIR. This simultaneity over a broad wavelength range allows study of transient phenomena such as rotating asteroids or early phase (super)novae or gamma ray bursts, or otherwise interesting objects such as quasars where the redshifts may be unknown.

5. References

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