SCALES Slenslit Design Status

R. Deno Stelter[a], Renate Kupke[a], Cyril Bourgenot[b], David Bramall[b], Jürgen Schmoll[b], Andrew J. Skemer[c], and Stephanie Sallum[d]

[a]UC Observatories, Santa Cruz, CA, USA
[b]Durham Precision Optics, Durham, UK
[c]UC Santa Cruz, Santa Cruz, CA, USA
[d]UC Irvine, Irvine, CA, USA

ABSTRACT

We report on the design and status of the slicing unit of SCALES (Slicer Combined with an Array of Lenslets for Exoplanet Spectroscopy), which sits behind the lenslet array and produces a pseudoslit suitable for higher dispersion than is achievable with a lenslet alone. Typical lenslet-based integral field spectrographs achieve high spatial resolution (but at the expense of spectral resolution), and slicers can achieve high spatial and spectral resolution (but at the expense of field of view), and additionally require extreme care in design and fabrication to avoid introducing aberrations through the slicer and spectrograph optics that can reduce the overall performance. Our 'slenslit' (SLiced LENlet pseudoSLIT) combines the benefits of the lenslet array, which samples the field of view, and the slicer, which rearranges the field of view, to produce diffraction-limited, high spatial resolution spectra of exoplanets. SCALES' diffraction-limited integral field spectrograph operates from 1 to 5 microns behind the W.M. Keck Observatory's AO system, and coronagraphic masks unlock the high contrast needed to observe and characterize exoplanets. The SCALES slenslit opens up new parameter space heretofore untapped by rearranging a small patch of lenslets into a pseudoslit before being dispersed at moderate spectral resolution (R$\sim 2500 - 7500$) over the SCALES bandpass while preserving the spatial resolution offered by the Keck AO system. The slenslit is being built in collaboration with the University of Durham's Centre for Advanced Instrumentation.

Keywords: slenslit, high-contrast, instrumentation, exoplanets, thermal infrared, adaptive optics, integral field spectroscopy

1. INTRODUCTION

SCALES is well into its assembly, integration, and verification phase (see Stelter, et al, this proceedings, Paper 13096-45, and references therein). The optical design of SCALES[1] is a lenslet array-based integral field spectrograph, shown in Figure 1. The slenslit optics will be fabricated by the University of Durham's Centre for Precision Optics, with whom we are working with closely to finalize the design. They have implemented several changes to the opto-mechanical design in order to make it more fabricable.

In this proceedings we give an overview of the design and discuss the current design of the SCALES slenslit, which is now in its pre-manufacturing stage. The expected delivery date to UCSC is late Summer 2025, where it will then be integrated into SCALES.

2. DESIGN AND CURRENT STATUS

One of the key modules in SCALES is the slenslit,[2] which takes a rectangular subarray of 17×18 lenslets and geometrically rearranges them into a pseudoslit, as shown in Figure 2.

Further author information: (Send correspondence to R.D.S.)
R.D.S.: E-mail: deno@ucolick.org, Telephone: 1 831 459 1832

Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation VI,
edited by Ramón Navarro, Ralf Jedamzik, Proc. of SPIE Vol. 13100, 1310049

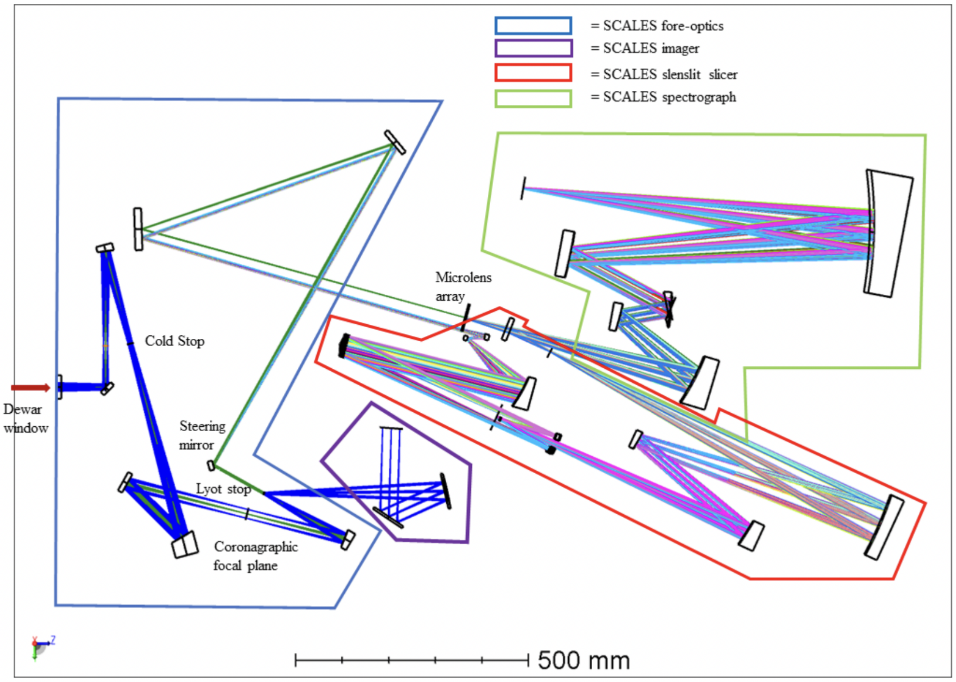

Figure 1. SCALES optical design.

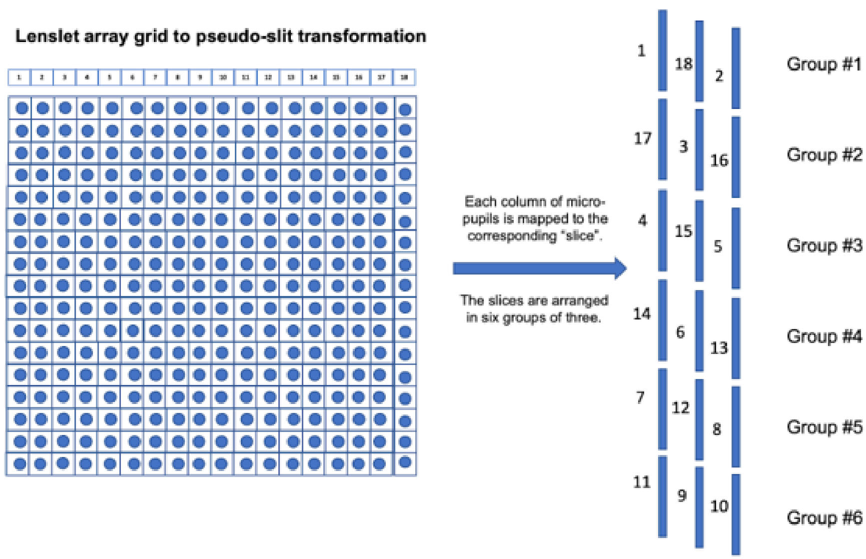

Figure 2. SCALES slenslit input and output. The 18 lenslet micro-pupil columns of 17 rows each are rearranged into a staggered pseudoslit by the slicing optics, and then reintroduced into the SCALES spectrograph ready to be dispersed.

2.1 Design starting point

Unlike typical slicers (e.g., GNIRS[3] or MUSE[4]), the SCALES slenslit does not see a contiguous field of view. Because of this, the SCALES pseudoslit can be thought of as three sparsely-filled pseudoslits, staggered in the spatial direction, such that the spacing between nearest lenslet micro-pupil images is $\sim 113\mu$m, or 6 science pixels.

The 6 science pixel separation between nearest micro-pupils was chosen to match the low-resolution mode's spaxel separation. A 6 science pixel separation is wide enough that cross-talk is low, leading to easier spectral extraction.

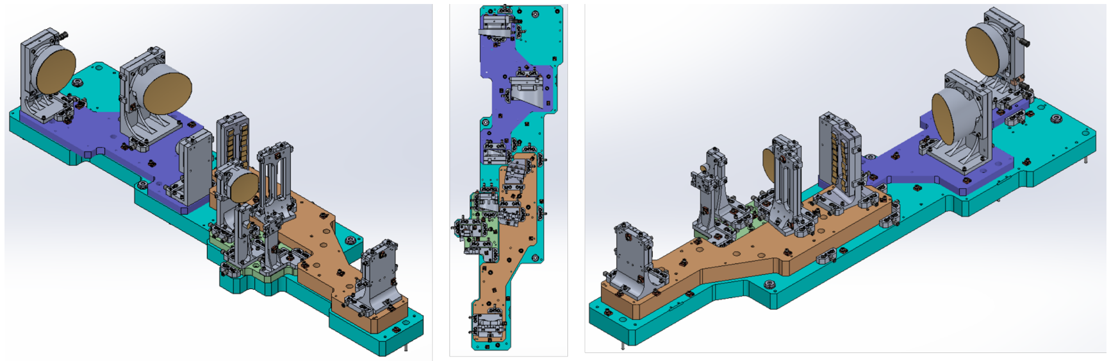

Figure 3. 3 views of the SCALES slenslit opto-mechanical design. The teal bench is the main slenslit bench. It supports the input relay (light green), slicing optics (orange), and output relay (dark blue).

The slenslit itself has three modules each on their own sub-bench as shown in Figure 3: 1) an input relay, consisting of a three-mirror anastigmat (TMA); 2) a Content-style set of slicing optics[5] (slicer, pupil, and field or slit mirrors); and 3) an output relay that is also an anistigmat.

The input relay takes the output of the lenslet array (e.g., a regular grid of micro-pupil images) at f/8 and reimages it onto the slicer, which has one slice for every column (a total of 18). The input relay optics are fairly standard, lightly aspheric off-axis conics (the only non-zero polynomial aspheric term is the 8th). The input relay also magnifies the beam from f/8 (the lenslet output beam speed) to f/64; slicers, having powered optics at the focal and pupil planes, can introduce geometric aberrations, and a slower beam speed minimizes the third-order and higher aberrations by allowing smaller angles.

The slicer mirror array is at the output focal plane of the input relay. All optics in the slicer module are simple spheres, although each has unique tips, tilts, and radii of curvature. Each slicer mirror is paired with a pupil and field mirror, much like all other slicing IFUs. To mitigate the atelecentricity introduced by the slicer and pupil mirrors, we power the surfaces of the field mirrors. The pupil mirrors are laid out in 2 columns of 9 mirrors each. Because we have a staggered pseudoslit with 3 'super-columns' of 6 lenslet subarray columns each, the field mirrors are narrow and closely spaced. The beam reflects off the field mirrors and passes through the 2 pupil mirror columns. Overall, the slicing optics demagnify the beam, going from f/64 to f/32 at the field mirror array.

The output relay is, as stated above, a TMA. It reimages the telecentrically-corrected pseudoslit and places it at a plane confocal with the lenslet array, further demagnifying the beam from f/32 to f/8 (matching the lenslet array output beam speed). As with the input relay, the output relay mirrors are lightly aspheric off-axis conics, and are fairly standard. A flat fold mirror returns the beam to the spectrograph, which is none the wiser that light has taken a 'scenic detour' through the slenslit optics, allowing us to reuse the spectrograph mirrors and use 1st order gratings to enable higher-resolution, diffraction-limited, coronagraphic spectroscopy of exoplanets and brown dwarfs.

2.2 Modifications for fabricability

U Durham suggested several sensible modifications to the opto-mechanical design of the slenslit optics, which we will go through below.

The input and output optics started with simple mushroom stem designs meant to isolate the mirror surface from print-throughs or distortion from the bolts holding the mirror substrate to the mount. A better approach (in terms of stiffness and light-weighting) was proposed by U Durham that involved a milling out pockets in the backs of each of the larger mirrors, followed by careful wire-EDM cuts leaving three symmetric thin sections supporting the mirror, as shown in Figure 4. The thin sections are not flexure blades, and maintain good stiffness from self-weight and transient accelerations (such as from earthquakes). To help increase the stiffness of the mounts, the gussets across all the mirrors were thickened, and large-radius fillets added where possible.

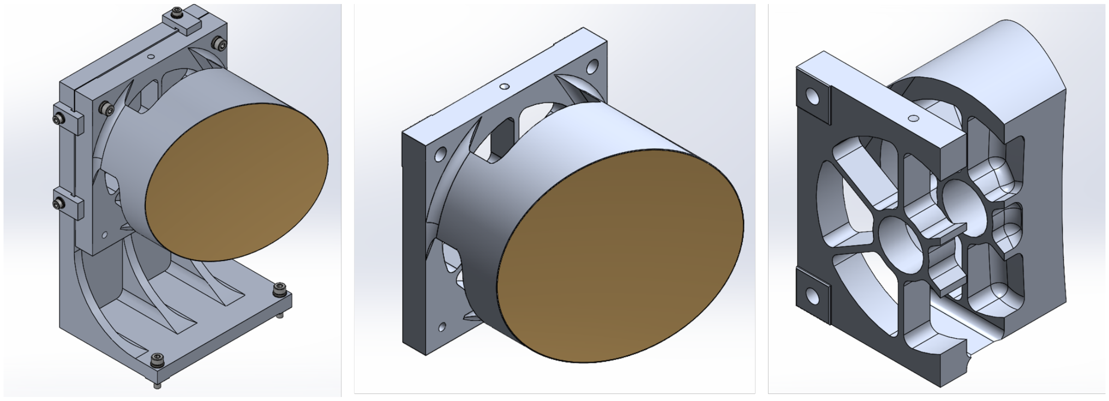

Figure 4. Output Relay Mirror 1. Left: The mirror on its mount. Center: Detail of the mirror, showing the thin sections and lightweighting of the substrate. Right: A rear view of the mirror and section cut, showing the lightweighting in more detail.

Due to how the slicer mirrors will be diamond-turned, we split the slicer mirror into two substrates that share a common mount. The pupil mirrors were originally split across two substrates, and a separate mount. The current design now has two mirror arrays that alternate in the vertical direction of which substrate each mirror is a part so that the mirrors are interlaced. The pupil mirror mount was originally a separate piece from the pupil mirror arrays and is now combined with one of the mirror arrays; the other mirror array will mate to it. This should reduce alignment errors by reducing the number of interfaces. The pass-through has been made more substantial to minimize vibrations during machining.

The field mirrors are, by necessity, narrow and closely spaced. U Durham suggested adding drafts to thicken the mirror substrates in the narrow direction. T This helps maintain mechanical stiffness without vignetting the beam as it passes from the slicer mirror array to the pupil mirror array. We also thickened the outer vertical supports, resulting in a stiffer structure.

The last modification is the adjustability of the last mirror in the output relay shown in Figure 5 . In order to have adjustability in focus and position of the output beam into the spectrograph, U Durham added features to allow us to move ORM 3 (output relay mirror 3) with high precision as part of a pointing-centering pair; the other mirror involved is the flat fold mirror in the mode selecting mechanism. The mirror can be precisely rotated about its center and translated vertically with the knobs on the top and bottom, respectively. Translation parallel to the bench plane and rotation about the vertical axis is handled by using fine-threaded ball-end screws in the ‘nudger blocks’ that are bolted to the output relay bench.

3. CONCLUSION

We have given an update of the slenslit opto-mechanical design. The slenslit has 60 mirrors that will be diamond-turned at the Centre for Advanced Instrumentation starting this Fall, with delivery slated for early Fall 2025.

ACKNOWLEDGMENTS

We are grateful to the Heising-Simons Foundation, the Alfred P. Sloan Foundation, and the Mt. Cuba Astronomical Foundation for their generous support of our efforts. This project also benefited from work conducted under NSF Grant 1608834 and the NSF Graduate Research Fellowship Program. In addition, we thank the Robinson family and other private supporters, without whom this work would not be possible.

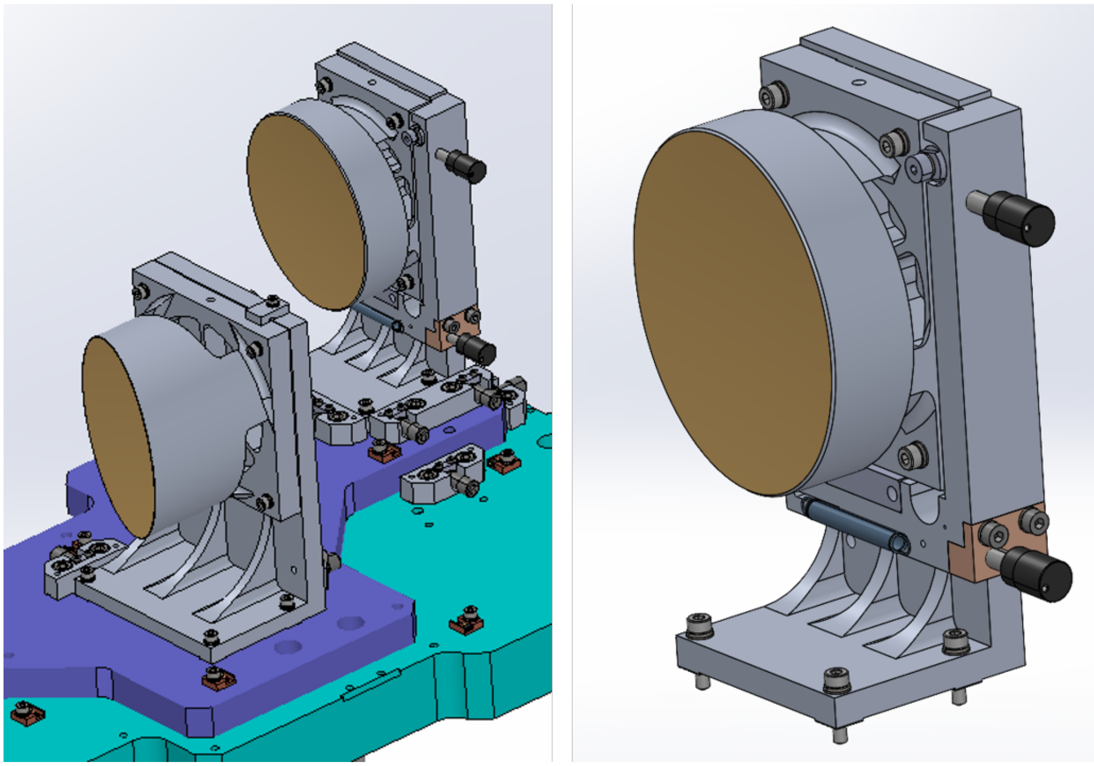

Figure 5. Output Relay Mirror 3. Left: The mirror in context on the slenslit bench and the output relay sub-bench. Right: An isolated view of the mirror, mount, and adjusters.

REFERENCES

[1] Kupke, R., Stelter, R. D., Hasan, A., Surya, A., Kain, I., Briesemeister, Z., Li, J., Hinz, P., Skemer, A., Gerard, B., Dillon, D., and Ratliff, C., "SCALES on Keck: optical design," in [*Ground-based and Airborne Instrumentation for Astronomy IX*], Evans, C. J., Bryant, J. J., and Motohara, K., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **12184**, 121844A (Aug. 2022).

[2] Stelter, R. D., Skemer, A. J., Kupke, R., Bourgenot, C., Martinez, R. A., and Sallum, S. S., "Weighing exo-atmospheres: a novel mid-resolution spectral mode for SCALES," in [*Ground-based and Airborne Instrumentation for Astronomy IX*], Evans, C. J., Bryant, J. J., and Motohara, K., eds., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **12184**, 1218445 (Aug. 2022).

[3] Allington-Smith, J. R., Content, R., Dubbeldam, C. M., Robertson, D. J., and Preuss, W., "New techniques for integral field spectroscopy - I. Design, construction and testing of the GNIRS IFU," *Monthly Notices of the Royal Astronomical Society* **371**, 380–394 (Sept. 2006).

[4] Laurent, F., Henault, F., Renault, E., Bacon, R., and Dubois, J.-P., "Design of an Integral Field Unit for MUSE, and Results from Prototyping," *Publications of the Astronomical Society of the Pacific* **118**, 1564–1573 (Nov. 2006).

[5] Content, R., "New design for integral field spectroscopy with 8-m telescopes," in [*Optical Telescopes of Today and Tomorrow*], Ardeberg, A. L., ed., *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series* **2871**, 1295–1305 (Mar. 1997).