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Fiber Link Design of the NASA-NSF extreme precision Doppler spectrograph concept WISDOM

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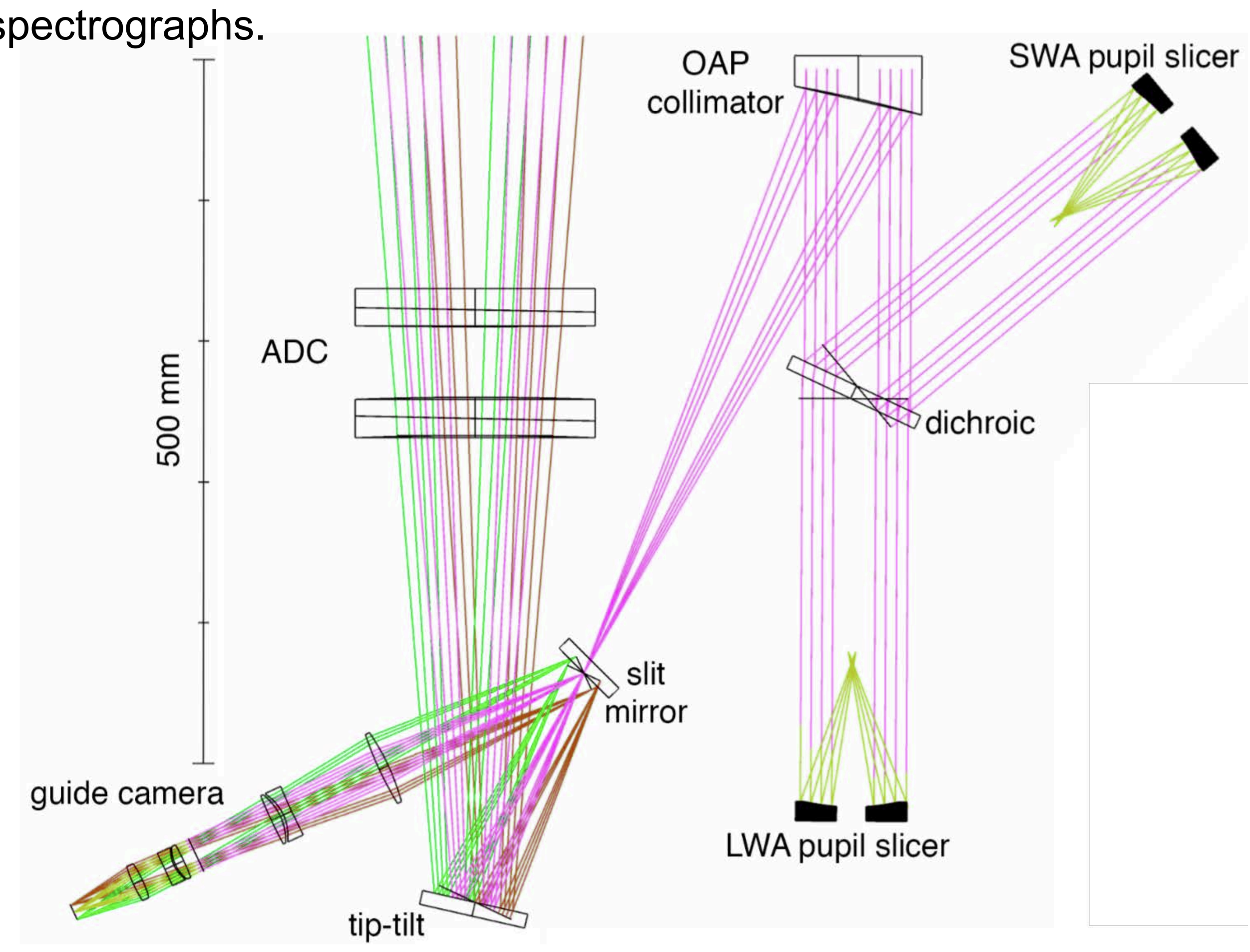
MIT KAVLI INSTITUTE

OVERVIEW

The WISDOM (**WI**YN **S**pectrograph for **DO**ppler **M**onitoring) instrument concept was developed at MIT as part of a NASA-NSF funded study to equip the 3.5m WIYN telescope with an extremely precise radial velocity spectrometer. (See talk/paper 9908-41 for more details.)

The WISDOM optical design offered R=110k spectral resolution for the 380-1300nm VIS-NIR coverage (see poster 9908-247) using a "Long" and "Short" passband spectrograph. Each channel was designed to be fed by its own fiber link, simultaneously illuminated at the telescope front end after a dichroic (at 750nm) split before the fiber feeds. An **atmospheric dispersion compensator** and a **tip-tilt mirror** assures maximum throughput and improved pupil illumination of the spectrographs.



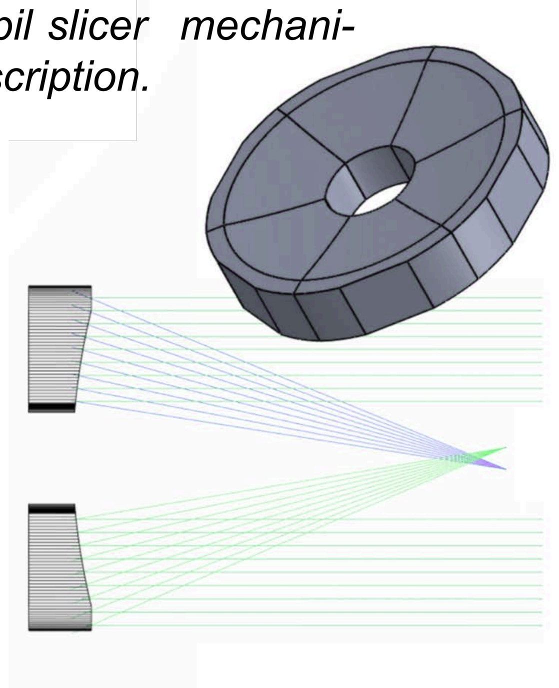
The **pupil slicer** couples light into a set of **custom drawn octagonal fibers** for improved near-field scrambling, and a **ball-lens scrambler** evens out the far-field. Then **3-3 fibers are spliced onto a rectangular fiber** of 3:1 aspect ratio to decrease modal noise. After a low FRD **vacuum feed-through** the rectangular fibers form a 2-component slit with a calibration fiber in-between them. For the evaluation and characterization of the fiber link we designed and built a **comprehensive fiber test setup**, which is now available to the astronomical instrumentation community through Polymicro.

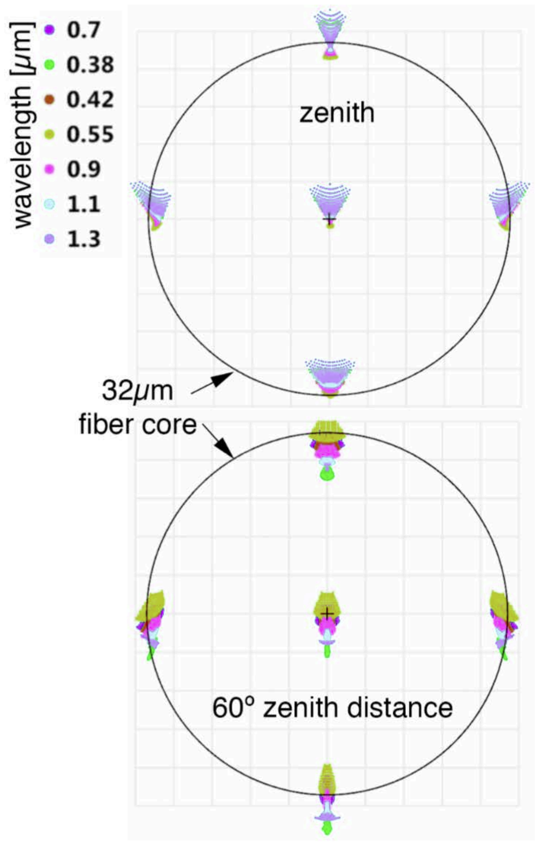
PUPIL SLICER

It is well known that for a given slit width / spectral resolution the size of a spectrograph (the diameter of the collimated beam) linearly scales with the size of the telescope. Due to space constraint at the WIYN Observatory we chose to slice the pupil, which allowed to design an instrument that offers what HARPS does but in less than ¼ volume.

We chose **a macroscopic pupil slicer design that allows for high throughput and well controlled machining/alignment**. It consists of a fast parabolic mirror that is conjugated to the telescope primary. It is physically sliced 6-ways, and the segments are pushed inward to cross the refocused telescope beam(s) and couple those into 6 fibers. This effectively decreases the telescope size and for a given slit/collimated instrument beam diameter **offers a factor of 2.3 resolution boost**.

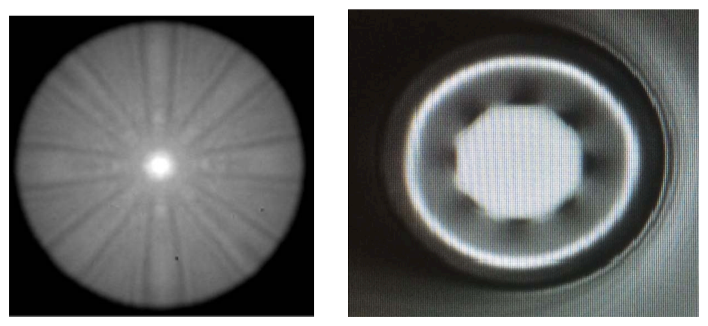
See poster 9912-183 for the pupil slicer mechanical description.



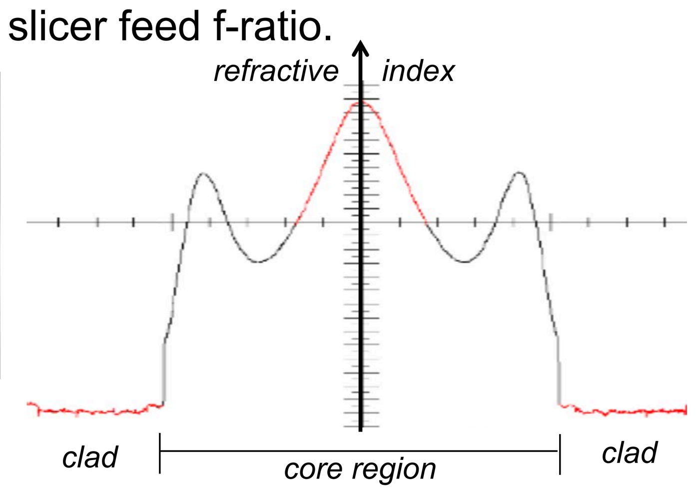


CUSTOM OCTAGONAL FIBER

Octagonal fibers are widely used in PRV spectrographs by now. Since pupil slicing on a 3.5m telescope requires a 32μm core size, we needed a thick clad fiber for mechanical strength. However, we wanted to avoid cladding modes, a known issue polluting the near/far fields of dual clad fibers (Avila, 2012). Thus we opted for a custom, thick but single clad fiber, also prescribing a custom numerical aperture (NA=0.17; f/3) to minimize FRD by matching the pupil slicer feed f-ratio.



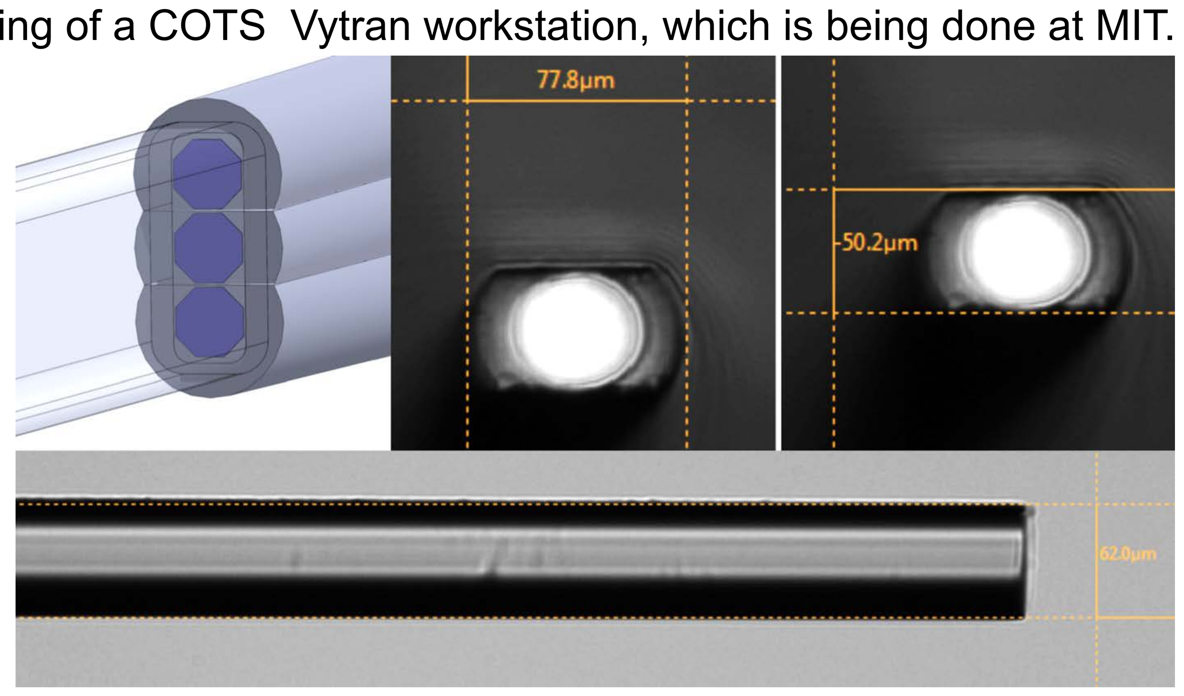
"dual clad" octagonal fiber (Avila, 2012) *"single clad" octagonal fiber (WISDOM)*



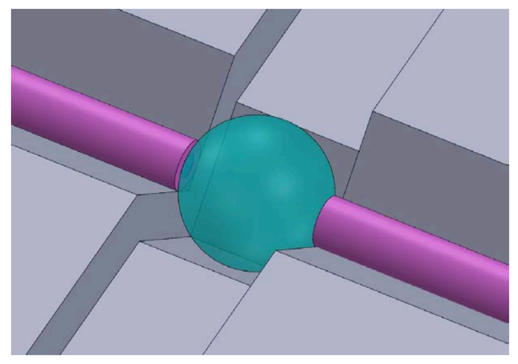
As it turns out the long and heat-intensive deposition of a thick cladding causes the dopant of the clad to diffuse into the core, essentially creating a dual clad index profile, one without a clear definition of an NA value. Also, depositing thick Flourine doped cladding makes the fiber preform *very expensive*, while the mechanically implemented dual clad is much cheaper – and apparently the performance does not differ much (without some mode stripping).

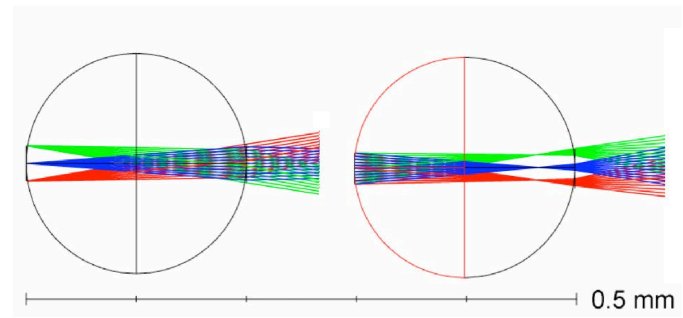
3-to-1 FIBER SPLICING

The 3-to-1 fiber splicing requires to closely bring together the cores of the thick clad fibers. We worked with FiberTech Optica to side-polish fibers in a slight taper, allowing to splice 3 individual fibers onto a 3:1 elongated rectangular fiber. The splicing experiments require special tooling of a COTS Vytran workstation, which is being done at MIT.

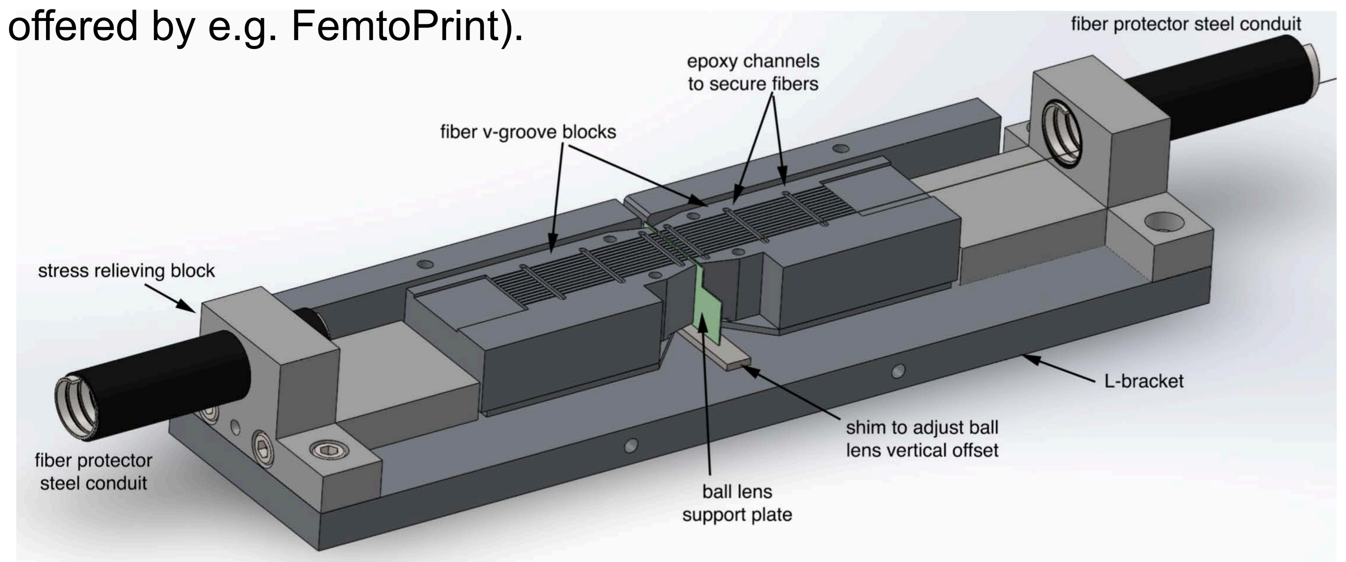


BALL LENS DOUBLE-SCRAMBLER



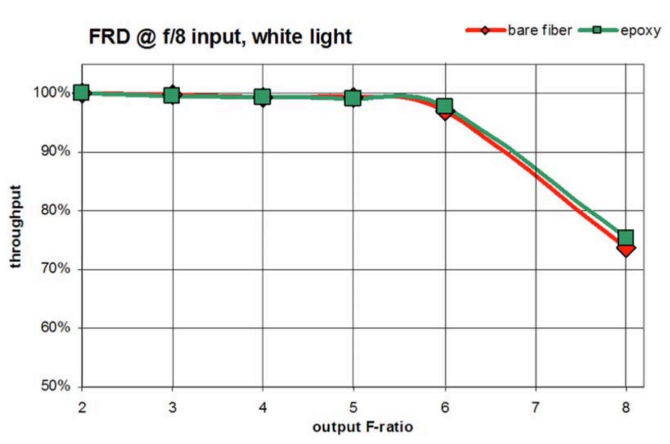


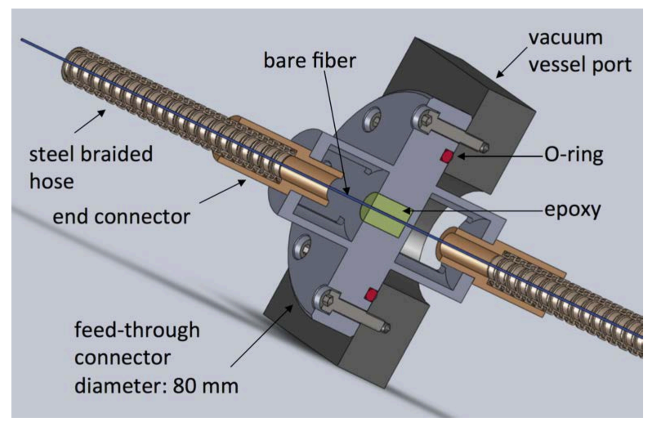
The single ball lens scrambler has recently been re-discovered, thanks to the availability of high index glasses that allow for simple alignment, as the fibers can be simply butted against the ball lens, leaving a simple radial alignment between the components (Halverson et al., 2015). For the WISDOM prototype we used a small, 200μm ball lens that could not be made of the typically soft high index glasses. Thanks to the small size, however, we could use cubic zirconia as we were not restricted by the low blue transmission of that material. The COTS lenses were supplied by Swiss Jewel and AR coated(!) by Deposition Sciences, which is a must at n=2.2 to maintain high throughput. For the alignment fixture we used invar v-blocks and precision shims, all machined in a single setup kinematic fixture, made by FiberTech Optica. We note that micron precision radial alignment can also be achieved using custom fused silica fixtures machined by photo-assisted chemical etching (as offered by e.g. FemtoPrint).



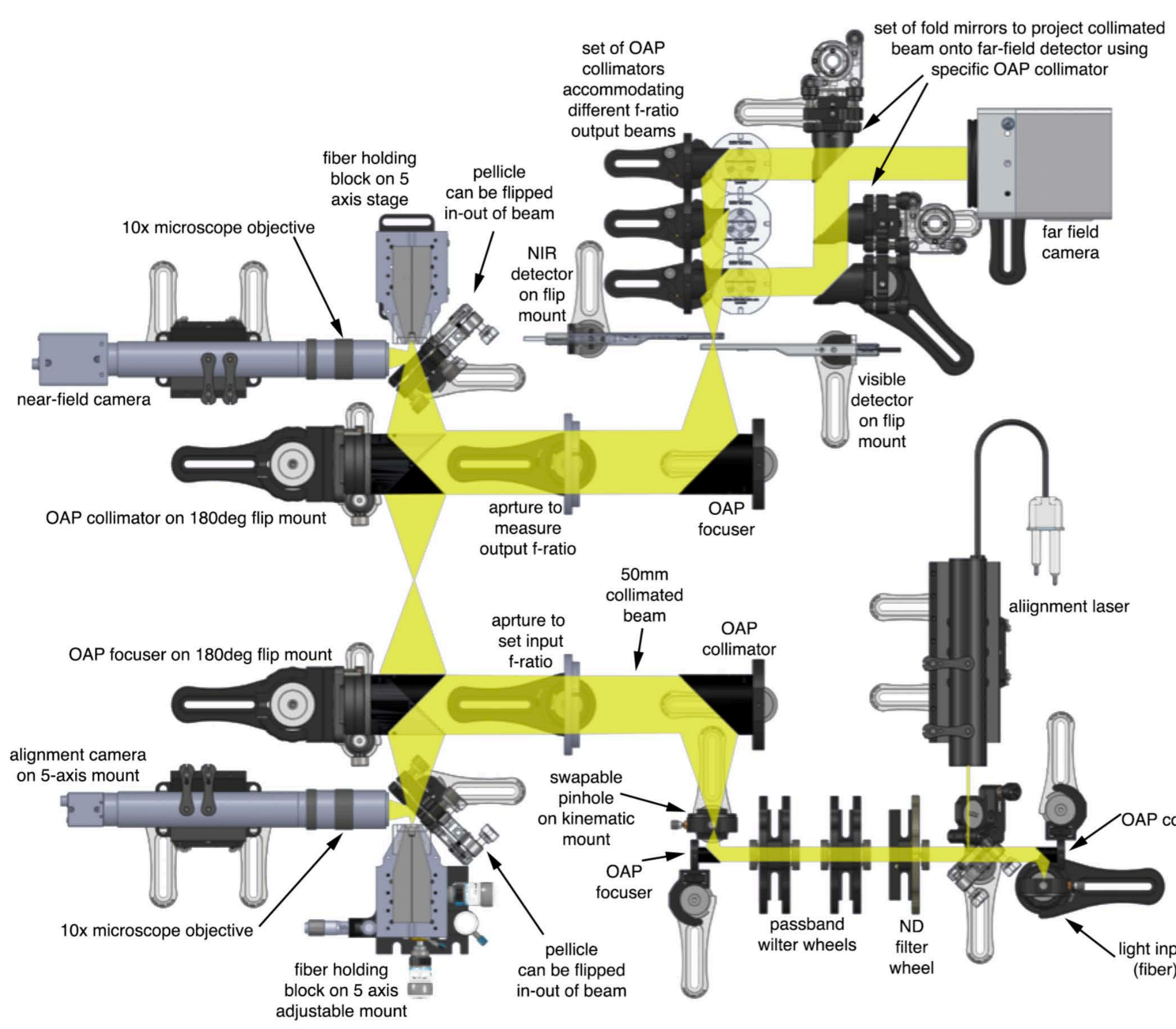
VACUUM FEEDTHROUGH

To maximize throughput and minimize FRD at the vacuum vessel interface we adopted the G-CLEF prototype feed-through design.

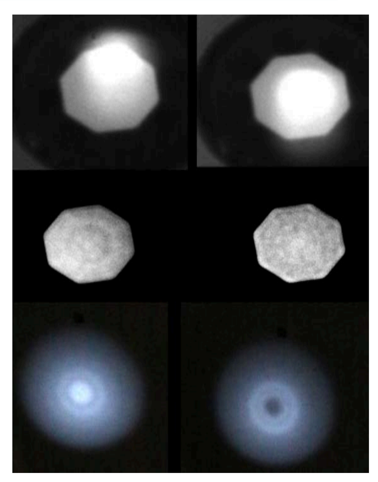


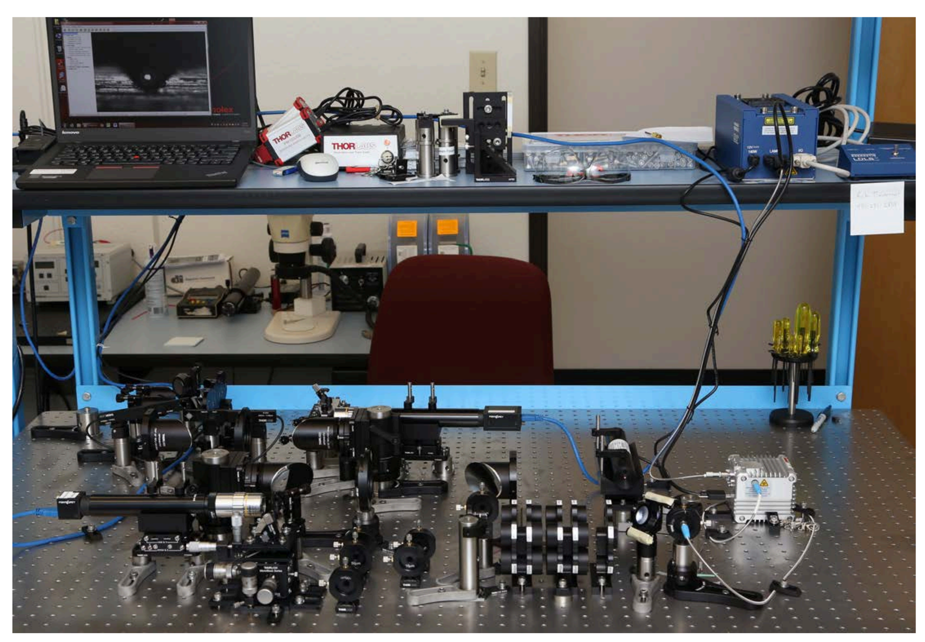


COMPREHENSIVE FIBER TESTING



We designed a fiber test bench that simultaneously can measure near- and far field patterns, FRD, absolute throughput and also characterize modal noise/patterns. The layout of the system can be seen on the left, the actual realization at the bottom, while some fiber feed / near- / far-field (from top-down) samples are shown on the right. This system is now owned by the U.S. fiber manufacturer Polymicro, and thus anyone can order characterization tests/measurments from them (see a sample FRD chart at the bottom right corner, from Polymicro).





Date:	2/18/2016	
Fiber Type:	FBPI100120140 Lot AOET01B	
NA	**f#**	**Matched Input/Output Loss**
0.20	**2.5**	**0.2%**
0.16	**3.0**	**1.0%**
0.12	**4.0**	**4.5%**
0.08	**6.0**	**9.4%**
Note: all data measured on 5m fiber long bare fiber (no connectors, stress-free v-groove mounting, cleanly cleaved end preparation free of stress fractures), using a flat, broadband Xe light source, visible (400nm-1100nm) silicon photodetector and fully achromatic optics.		