IR-FOBOS: A Near-IR Multi-object Spectrograph Enabled by the FOBOS Focal Plane

K. Bundy, K. Westfall

1. Background

The Fiber-Optic Broadband Optical Spectrograph (FOBOS) is an instrument concept for the Keck II Telescope that completed its conceptual design phase in July 2021. FOBOS provides medium resolution ($R \sim 3500$) spectroscopy from 0.31–1.0 μm with suitable multiplex capacity for follow-up of the upcoming large-scale imaging surveys undertaken by new ground-based (Rubin/LSST) and space-based (Euclid, Roman) facilities (cf. 2016 Keck Scientific Strategic Plan). The core technology that enables this is FOBOS's flexible focal-plane system: FOBOS deploys up to 1629 single-fiber apertures, or up to 42 integral-field units (IFUs), over the full 20-arcmin field-of-view of the Keck II Nasmyth port. Apertures are robotically positioned on the field plate using the Starbugs technology pioneered by Australian Astronomical Optics (AAO). The FOBOS focal-plane module is connected to its bank of fixed-format spectrographs by a short ($\sim$15m) fiber run.

In its current design, the FOBOS focal-plane module (FFPM) is a dedicated instrument system, exclusively used to feed FOBOS's optical spectrographs. However, the FFPM can usefully serve as a platform for multiple fiber-based instruments: With specific design foresight (and/or instrument retrofits), the FFPM can become a module that *also* feeds spectrographs that are sensitive in the near-infrared, have higher spectral resolution, or both. We believe that a near-IR spectroscopic capability served by the FOBOS platform would be particularly compelling and set WMKO apart in the mid-to-late 2030s.

2. IR-FOBOS Motivation

Motivated by the Jan 2021 "Keck Future IR Spectroscopy Workshop," we developed an initial concept we refer to as IR-FOBOS. We summarize that concept here and can provide additional material we developed to sketch a possible design upon request. The IR-FOBOS concept was well received in the Jan 2021 workshop, especially since its K-band sensitivity and use of an adaptive secondary mirror (ASM) would make it unique and extremely compelling compared to other instrument concepts on other telescopes. Not surprisingly, a significant concern was cost. Workshop attendees speculated that if funding were somehow available, IR-FOBOS could rise to become a major long-term priority for WMKO.

The reason for this enthusiasm stems from IR-FOBOS's ability to address three core science goals that were identified at the workshop as critical to progress in the mid 2030s. The first is a new generation of high-z surveys that can provide *rest-frame* spectral diagnostics for large samples of galaxies out to $z \sim 5$. VLT-MOONS and Subaru-PFS will be limited by their lack of K-band and their 8m aperture. They will also be unable to benefit from the enhanced seeing and additional depth provided by an ASM.

The second science area is resolved galaxy formation at high redshift. Here the ASM is critical because it provides access to physically-relevant spatial scales over a large field of view, enabling IR-FOBOS to deploy multiple integral field units and perform MaNGA-like studies at $z \sim 2$. The larger samples at modest spatial resolution would be highly complementary to WMKO's ability to "zoom in" with Liger and obtain high-resolution observations for targeted samples. The thousands of resolved IR-FOBOS galaxies would also provide high-value targets for followup with ELT instruments, like TMT-IRIS.

Finally, IR-FOBOS can provide valuable spectral signatures of resolved stars in crowded regions that are inaccessible without a ground-layer AO correction. Because these regions are nearby, they subtend large angles on the sky, making it important that IR-FOBOS be optimized for the widest fields possible. The dust-obscured Central Molecular Zone of the Milky Way is a prime example where a number of mysterious phenomenon with important implications for galaxy formation, extreme environment star formation, and AGN behavior really require an instrument like IR-FOBOS to make meaningful progress.

3. IR-FOBOS Concept

Given the competitive landscape of the mid-2030s when an IR-FOBOS might come on sky, core metrics for success are: (1) a bandpass that covers the K-band, (2) overall sensitivity in the JHK bands that is competitive with MOSFIRE, and (3) an adaptive-optics correction such as ground-layer AO (GLAO). These capabilities would provide transformative scientific opportunities for both single-fiber configurations, with approximately 1000 apertures patrolling a GLAO-corrected field, and ∼25 multiplexed IFUs providing 2 kpc resolution for target galaxies at $z \sim 2$.

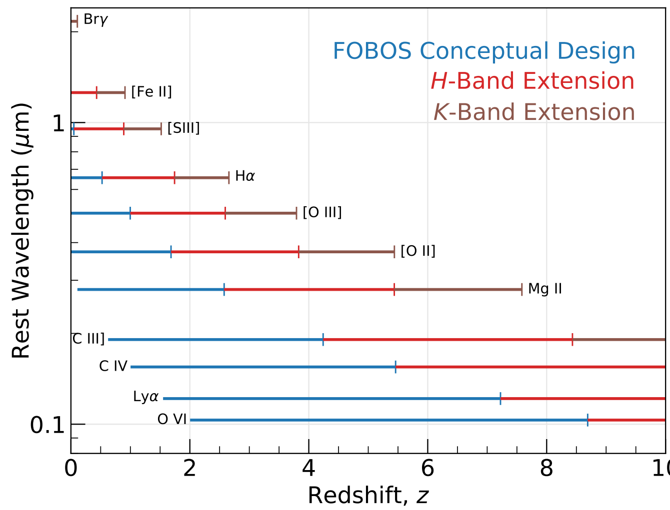

Figure 1. Redshift coverage of various spectral features in FOBOS (*blue*), an H-band extension (*red*), and a K-band extension (brown). Extension of FOBOS-like MOS+Multi-IFU spectroscopy in the K-band enables access to rest-frame optical features (particularly Hα) at intermediate redshift.

K-band. Where previous fiber-based instruments have been limited to wavelengths less than 1.8 μm, rapidly developing fiber technologies (especially Fluoride-based glasses) now provide excellent throughput in the 1.0–2.5μm band (and beyond). Indeed, such a fiber is already deployed in the Keck KPIC instrument.

High Throughput. The fiber-based Subaru-PFS and VLT-MOONS instruments are forecasting instrumental throughput above 30% in the near-IR (roughly 90% of the throughput of MOSFIRE). This performance will be verified as these instruments come online in 2022-2023.

Wide-Field AO. Finally, new actuator technology shows great promise for enabling a more robust and less expensive Keck adaptive secondary design (Keck-ASM). A regular GLAO mode at Keck with a ∼10 arcmin corrected field may be easier to realize by 2030 than was previously thought.

> *Recommendation.* Fund a series of initial trade studies needed to verify particular design specifications for a future IR-FOBOS, especially so that they can be enabled by ongoing FOBOS development. The most critical are the bandpass, ASM system coupling, and format of deployable IFUs. Determine technology readiness and cost of K-band fibers, detectors, and cooling requirements.