Keck Science in the FOBOS Era

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Summary. The Astro2020 Decadal Survey's top recommendation for sustaining ground-based astronomy includes a major investment in highly multiplexed spectroscopy. The report specifically calls out Keck-FOBOS as a next generation instrument that can help "achieve a large fraction of the main science goals" prioritized in separate Astro2020 panel reports on Cosmology, Stars, Galaxies, and Compact Objects and Energetic Phenomena, especially as a way to "maximize return on investment for the large-area imagers coming online in the 2020s." Earlier this year, FOBOS completed its Conceptual Design (July 2021) and is planned for commissioning in 2029. Beyond its 1st-light capabilities, FOBOS's flexible, Starbugs-enabled focal plane and modular design offers new and unique scientific and strategic opportunities for WMKO in the mid-2030's. These include advanced operational modes and data services as well as synergies with new instrumentation technologies that can dramatically enhance WMKO's observing capabilities.

1. Enhancing Observing & Scientific Output

1.1. **Operations.** FOBOS era observing will likely involve multiple programs carried out simultaneously, with PI's and observing teams coordinating to optimally share apportioned FOBOS fibers. Supported by Observatory and instrumentation software, this integration of programs can grow the community of WMKO users and stakeholders and increase scientific breadth. FOBOS's always-ready IFU and dynamic target allocation makes it attractive for time domain followup, while pre-defined background programs will be possible anywhere on the sky thanks to targets selected from Rubin/Roman imaging and prioritized in "fiber clearing houses."

> *Recommendation.* Define shared-observing models within the Keck Data Services Initiative (DSI) framework that enable program combination. Establish protocols for shared focal plane assignment and instrument control across WMKO stakeholders. Determine requirements for dynamic response and the interface to pre-defined target clearing houses (e.g., managed by NOIRLab).

1.2. **Data & Science Platform.** The vast size of FOBOS data volumes will make robust data handling and reduction pipelines critical and opens an opportunity for community-sourced analysis packages that deliver high-level data products using open-source platforms. Making high-level products available dramatically shortens the path to science and amplifies the ability of small teams to produce high-impact results.

> *Recommendation.* Support community-sourced development of data pipelines and tools for producing high-level data products. Coordinate stakeholders including: FOBOS instrument team; WMKO pipeline support; PypeIt and related efforts; databases held at KOA and NOIRLab; major surveys and related facilities (e.g., LSST/Roman). Support development of an open-source science analysis platform along the lines of SDSS tools (e.g., MaNGA-Marvin).

2. Synergies with New Instrumentation

2.1. **"Enhanced-Seeing" with an Adaptive Secondary Mirror.** From an instrumentation perspective, FOBOS offers a number of highly compelling upgrades and synergies. Chief among these is combining FOBOS with "enhanced seeing" from GLAO provided by an adaptive secondary mirror (ASM). Beyond the S/N boost from a more concentrated PSF and the increase of observing efficiency thanks to more "good seeing" nights, an ASM would enable unprecedented access to resolved spectroscopy of large samples of galaxies in the high-z universe. Combined with Liger, this capacity will uniquely position WMKO in the 2030s to engage with and support super-resolution studies of complementary but smaller samples observed with AO-fed instruments on ELTs. A second area of unique scientific territory opened up by FOBOS+ASM is the study of crowded fields that suffer from source confusion in natural seeing. This includes our own galaxy's Central Molecular Zone, the disk and bulge of M31, and other local group galaxies.

> *Recommendation.* Support development of a combined ASM+FOBOS concept, including studies of potential WFS technologies (e.g., fiber lantern WFS) that could deploy at the focal plane and sample natural, instead of laser, guide stars. Determine wide-field AO performance opportunities at bluer wavelengths (500 nm) and wider fields (10–20′). Estimate year-on-year efficiency gains and improvements to FOBOS image quality with an ASM.

2.2. **IR-FOBOS.** FOBOS's flexible focal plane makes it easy to deploy additional sets of Starbugs that position fibers which feed additional spectrographs. Particularly compelling would be a near-IR capability, a concept we refer to as IR-FOBOS (a separate IR-FOBOS White Paper was submitted as part of the Keck IR Futures Workshop in Jan 2021). 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 $\sim$25 multiplexed IFUs providing 2 kpc resolution for target galaxies at $z \sim 2$. Multiplexed IFS again is particularly complementary to Keck-Liger and higher resolution but single-object ELT capabilities.

> *Recommendation.* A concept study for an IR-FOBOS to define science requirements, required technologies, and impact on the FOBOS design. Especially important are new fiber glass materials (e.g., Fluoride-based, as used in KPIC) that now provide excellent throughput at 1.0–2.5μm band (and beyond). As the FOBOS design matures, can we ensure that a future IR capability can be realized?

2.3. **From Multiplex to "Polyplex".** IR-FOBOS provides a concrete example of how FOBOS provides a focal plane platform that can serve multiple instruments and enable "polyplex," the ability not only to observe multiple objects on the focal plane simultaneously, but to observe them with different kinds instruments all run simultaneously. For any instrument that can be fiber fed, polyplex represents a vast set of opportunities for increasing observing efficiency. Separate instruments used to require separate nights, but many kinds of different spectroscopic observations of different target classes can be usefully combined. There is community interest in adding $R \sim 30,000$ spectral resolution multi-object spectroscopy to the FOBOS platform. Meanwhile, astrophotonic technologies are rapidly evolving (Gatkine et al. 2019) and may one day offer a substantial increase in the spectroscopic data volume that FOBOS could serve.

> *Recommendation.* Seek community participation in future instrument designs that utilize FOBOS as a platform for polyplex and study requirements for polyplex operational modes (§1.1). Ensure that the FOBOS design maximizes future instrumentation potential.