Instrumentation capabilities

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MAIN QUESTION #2

What critical instrumentation capabilities should Keck Observatory develop or maintain on 10 to 15-year timescales? Are there combinations (e.g., deep imaging + multiplexed spectroscopy) of instrumentation where the combination is more impactful than the sum of the parts? If so, what are they?

SUMMARY

Since its inception, Keck has been a leader in deep spectroscopy, as a result of its superior aperture, adaptive optics, and innovative and dedicated work by the Keck community. Although these areas should remain a focus, the next generation of 30m-class facilities will perform far better, resulting in a need to investigate other areas of priority and impact. Reviewing facilities operating at all other wavelengths (radio through gamma-ray) and particle and gravitational wave messengers, a move to wide-field instrumentation has been, by far, the most dominant focus. In addition, the need for optical wide-field imaging and spectroscopy has been the focus of major ground- and space-based facilities.

Wide-field imaging and spectroscopic instruments on 4m-class telescopes have been the premier instruments of their type and the highest in demand. They have kept 4m-class telescopes relevant in the 8m-class era, playing a crucial role for the larger aperture telescopes. Although Keck will continue to perform well in the 30m-class era, wide-field imaging and spectroscopy are essential to help maintain Keck leadership fulfil an essential role for larger aperture telescopes. Finally, Maunakea's high transmission at blue wavelengths is unique to observatory sites, including 30m-class telescope sites. As as result, instruments like the Keck Wide-Field Imager are promising direction for Keck to maintain leadership.

THE PREVIOUS 10–15 YEARS

Over the last 10–15 years, new facilities and efforts at wavelengths other than optical include wide-field Square Kilometre Array Pathfinders (ASKAP, MeerKAT, MWA), wide-field South Pole Telescope (mm/sub-mm), wide-field HXMT, NICER, Astrosat (UV/X-ray), wide-field HESS (Cherenkov gamma-ray detection), wide-field Pierre Auger Observatory and HAWC (ultra-high-energy particles), the all-sky IceCube neutrino detector, and the all-sky LIGO, Virgo, and KAGRA gravitational wave detectors and work toward a fifth detector, LIGO-India. As a result, the vision over the last 10–15 years at all other wavelengths has been focused on wide-field astronomy.

The two existing wide-field imagers on 4m-class telescopes have helped those facilities 'punch well above their weight' compared to similar telescopes. The CFHT (3.6m) MegaCam performed the CFHT Legacy Survey that included the Supernova Legacy Survey (SNLS). SNLS made a significant impact on cosmology and remains the highest performing program for high redshift type Ia supernovae. MegaCam has helped keep CFHT very high on the publications per telescope list. CFHT will be decommissioned to make way for the Maunakea Spectroscopic explorer. The CTIO Blanco (4m) Dark Energy Camera (DECam) in the Southern Hemisphere has led the world with the Dark Energy Survey, gravitational wave follow up, and ground-breaking science programs in nearly every area of astronomy. The Subaru (8.2m) Hyper-SuprimeCam (HSC) is the only deep (m $\sim$ 27–28) wide-field optical imager to date (however it has no blue sensitivity or rapid ToO capability). HSC has helped the NAOJ community lead the world with the HSC-SSP survey, Lyman-α emitter science, crucial transient host galaxy localizations, and many other programs. Finally, wide-field imagers are the highest demand instruments and vital for nearly every area of astronomy, including non-optical wavelengths (e.g., source localization, host galaxies, etc.).

Looking forward 10–15 years

Keck has been a leader in deep spectroscopy and adaptive optics. However, 30m-class telescopes will perform significantly better. As a result, Keck should continue to progress these areas, including their use as test beds for 30m-class telescopes, but importantly, Keck should lead the world in wide-field astronomy and blue science that 30m telescopes cannot do. In 10–15 years, we will witness the launch of the wide-field Roman and Euclid Space Telescopes. In addition, the next generation mega-facilities are wide-field facilities and include the Square Kilometre Array, Cherenkov Telescope Array (gamma-ray), LHAASO and SWGO wide-area GeV and PeV facilities, existing gravitational wave facilities with sensitivity advances and improved localizations, and progress on the next-generation Cosmic Explorer, Einstein Telescope, and space-based LISA. Finally, wide-field spectrographs, such as the Subaru Prime Focus Spectrograph and the Maunekea Spectroscopic Explorer, will necessitate a very high-density of targets, including faint targets, over ~1.2–1.5 degree fields, and JWST and TMT will demand $m > 27$ targets and interesting, rare, and lensed sources, only found with extremely deep, wide-field imaging.

The extreme depths ($m \sim 28$–30), wide field, and blue sensitivity of KWFI will enable high-impact discovery, resolve long-standing problems in astrophysics, and achieve science that cannot be done at any other facility, not even 30m-class telescopes. Examples include detecting Lyman continuum from the sources responsible for cosmic reionization and mapping ionized regions with neutral gas mapped by the Square Kilometre Array, and, as the only > 2m wide-field imager in the Northern Hemisphere for the foreseeable future capable of rapid transient follow-up, KWFI will probe much deeper volumes to detect > 90% of all kilonovae missed by existing and future wide-field optical search facilities. Finally, a deployable secondary mirror would provide a powerful capability. For example, wide-field deep KWFI imaging, rapid (minutes) image reduction and source detection with KWFI's fast pipeline, secondary mirror deployment and rapid spectroscopy with the future FOBOS or other Keck spectrographs will enable detection and follow up of fast evolving sources, optimization of observing time, and new science.

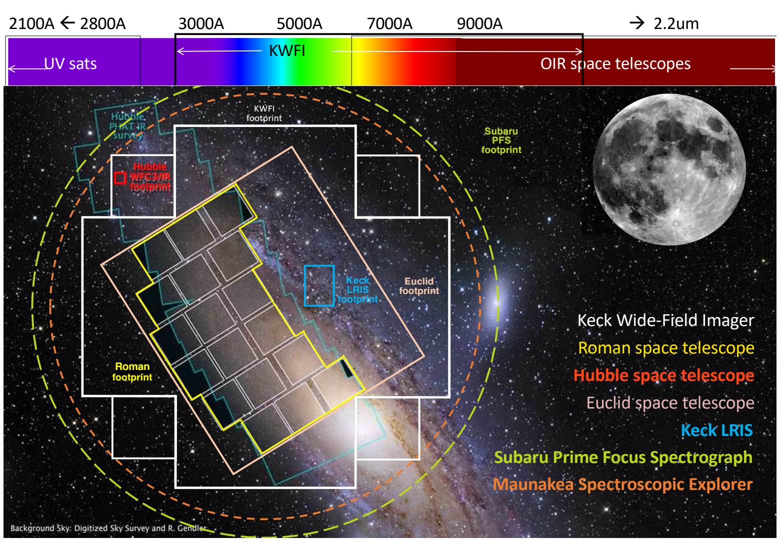

Figure 1: Fields of view. Existing deep imagers LRIS (cyan) and *HST* WFC3 (red) have small fields of view. The upcoming Roman (yellow) and Euclid (pink) infrared space missions will have wide-fields of view, cover ~5500Å – 2.4μm (top bar), and will perform large area surveys to $m \sim 28$–30. Potential UV space missions will cover the ~2100–2800Å wavelength range (top bar). KWFI will be the only facility that can cover wide fields to $m \sim 28$–30 over 3000–5500Å necessary for photometric redshifts, $z \sim 1.5$–4.0 galaxies, type Ia supernovae, and many other space mission main science cases. In addition, the upcoming Prime Focus Spectrograph (green) and Maunakea Spectroscopic Explorer (orange) are ~2000-4000 fiber spectrographs will require high-density targets to deep magnitudes over wide fields of view. Finally, extremely deep, wide-field imaging is essential for rare, lensed, and faint targets for TMT and JSWT and source and host galaxy localization for upcoming mega-facilities, such as the Square Kilometre Array, Cherenkov Telescope Array, particle detectors, and gravitational wave facilities.