OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jul **Proposal type:** short-term

UKIRT/WFCAM Survey of the Subaru/HSC Deep Fields

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CoI(s): Xiaohui Fan (SO), and the Steward/UKIRT team (SO)

Abstract of Scientific Justification

Hyper Suprime-Cam (HSC) is a new CCD mosaic camera on the Subrau Telescope, which provides a wide field of view (FOV) of a D=1.5 deg circular area, unprecedented for an 8m-class telescope. By taking advantage of the fast mapping speed and great depth afforded by the combination of Subaru and HSC, the HSC team will perform three types of surveys (HSC-Wide, HSC-Deep, and HSC-Ultradeep) with a variety of scientific goals. Here, we request 96 hours of open-shutter time (estimated to require $\sim$12 nights) with UKIRT/WFCAM to obtain J-, H-, and K-band images (2 hr/pixel depth) of the E-COSMOS field, one of the four fields targeted by the HSC-Deep Survey. This field currently dose not have any near-infrared imaging data, which will severely limit the scientific potential of the obtained HSC data in the long run. In 2014B, we were awarded 140 hours of UKIRT observing time to image the other target field, DEEP2-3, and the observations are about to start (Oct 2014). The proposed program will help Steward researchers get involved in the HSC-Deep survey, and will likely help us build a path toward our involvement in the future Subaru/PFS survey.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling: Optimal	Scheduling: Acceptable	Sharing: Poss.	Sharing: Adv.
1	UKIRT		WFCAM			12	bright	Feb–Apr	Jan–Jun	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*:

no text past this line

A $\star$ appended to the proposal type indicates a continuation proposal; a $\star$ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a $*$ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	E-COSMOS	10:00:29	+02:12:21	Four WFCAM 0.75 deg^2 FOVs outside
2				the central COSMOS field.

Approval for Instrument Use from PI: _____

*(have instrument PI signature appear on, or attach PI e-mail to, **all** copies)*

Graduate students *(provide the following information for **each** student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on **all** submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

Subaru/Hyper Suprime-Cam (HSC) and Its Extragalactic Survey

Hyper Suprime-Cam (HSC) is Subaru's new prime-focus camera with a wide field of view (FOV) of a D=1.5 deg circular area, which is unprecedented for an 8m-class telescope. Subaru will allocate ∼300 nights of observing time over the next 5 years to conduct a large extragalactic survey with three components: Wide (1400 deg^2; $r \simeq 26$ AB mag), Deep (27 deg^2; $r \simeq 27$ AB mag), and Ultradeep (3.5 deg^2; $r \simeq 28$ AB mag). Scientifically, these programs will address the following most pressing problems in modern cosmology and astrophysics: the origin of the acceleration of the Universe's expansion (Wide), the properties and evolution of galaxies from $z \simeq 7$ to today (Deep), and the nature of cosmic reionization (Ultradeep). HSC had a successful first light last year (fall 2013), and has just started science observations this spring.

For the success of such a large ambitious survey, it is essential to ensure a good multi-wavelength coverage for the targeted fields. For the near-infrared coverage, the HSC survey benefit from wide-field surveys like UKIRT/UKIDSS and VISTA/VIKING. In fact, the HSC survey systematically targets those sky areas where these wide-field near-infrared imaging data exist. Although the near-infrared coverage is fairly good for the Wide and Ultradeep fields, the situation is not as complete for the Deep fields. Table 1 shows the HSC-Deep fields and the existing near-infrared coverage. The XMM-LSS and ELAIS-N1 fields have been imaged by the UKIDSS Deep Extragalactic Survey (UKIDSS-DXS), and the central 2 deg^2 area of the COSMOS field has been imaged by a variety of programs with UKIRT, CFHT, VISTA. However, the Extended COSMOS field (E-COSMOS) outside the central 2 deg^2 and DEEP2-3 field still lack a near-infrared coverage. In other words, for the total HSC-Deep area of ∼26.9 deg^2, near-infrared imaging data exist only for 14.5 deg^2 (∼50%). This will severely limit the scientific potential of the obtained HSC data in the long run.

Proposed Program: UKIRT/WFCAM *JHK* Imaging of HSC-Deep Fields

Here, we propose to observe with UKIRT/WFCAM one of the HSC-Deep fields, E-COSMOS, in 2015A. HSC-Deep will obtain g, r, i, z, y broad-band images with 5 σ limiting magnitudes (2" aperture; 0.7" seeing) of 27.5, 27.1, 26.8, 26.3, and 25.3 mag (AB), respectively. Narrow-band images will also be obtained with the NB387, NB816, and NB921 filters, sampling Lyα emitters at z=2.2, 5.7, and 6.6.

With WFCAM, we will integrate for 2 hours/pixel, achieving 5 σ limiting magnitudes of $J = 23.6$, $H = 23.2$, and $K = 23.1$ mag (AB), respectively (from the WFCAM ETC with 0.9" seeing and D=2" aperture). These depths are comparable to those of the existing UKIDSS-DXS data for the other two HSC-Deep fields, and are sufficiently deep to allow a variety of scientific investigations. To maximize the scientific/legacy value of the obtained data set, it is important to achieve a deep uniform near-infrared depth over the full HSC-Deep fields, whose large area coverage is unprecedented for such a deep survey. To ensure a good image quality, we request a maximum acceptable FWHM of 0.8". Data obtained under a thin cirrus condition would be acceptable as long as the final fully coadded images achieve the targeted depths.

Figure 1 shows the HSC area coverage of the DEEP2-3 and E-COSMOS fields. As the figure shows, 6 WFCAM fields are required to cover DEEP2-3, which currently does not have any near-infrared data, while 4 WFCAM fields are required to image the outerparts of E-COSMOS. Each WFCAM field consists of 4 separate pointings to fill a 0.75 deg^2 area, and we will obtain J, H, and K images for each field. So, the requested open-shutter time for E-COSMOS is 96 hours (= 2 hr/pointing × 4 pointings/field × 4 fields × 3 filters). With the two target fields combined, our Steward/UKIRT program will image a total of 7.5 deg^2.

Although the scientific merit of completing the near-infrared coverage for the HSC-Deep fields is many (e.g., significant improvement with photometric redshifts and stellar-mass estimates), one particularly interesting application is the detection and study of optically-faint red galaxies that are difficult to study with the HSC optical data alone. We are therefore submitting a research project proposal to the HSC collaboration with the goal of conducting a survey of optically-faint near-infrared-bright sources using the Steward/UKIRT data. Such red sources will include, (1) **Bright high-redshift dropout galaxies:** Using the y-band data, which is the reddest HSC band, we can look for y dropouts, some of which may be z∼8 galaxies. Although the expected number of z∼8 y-dropouts above the bright detection limit of the UKIRT data is small even with such a large area coverage, the excitement of conducting such a large survey is to look for the unexpected; (2) **Near-infrared-bright Lyman-alpha emitters at high redshift:** Many of high-redshift Lyman-alpha

emitters are expected to be too faint to be detectable with the UKIRT near-IR data. However, the proposed survey may be wide enough to pick up a small number of high-redshift Lyman-alpha emitters that are exceptionally bright in the near-infrared, whether it is intrinsically or due to gravitational lensing. In collaboration with the HSC-Deep narrow-band survey team, we will look for such exceptional sources; (3) **Extremely Red Objects (EROs):** EROs are often defined with red optical-near-infrared colors such as $R - K$ and $r - K$. The resultant population is usually a mixture of passively-evolving galaxies and dusty star-forming galaxies at $z \sim 1 - 3$. The proposed 7.5 deg^2 survey will allow us to sample the brightest of such sources. Especially interesting are the most massive galaxies, which are rare by definition and need wide-field data to produce a large sample. The evolution of the most massive galaxies is one of the most exciting areas of galaxy science because it involves a number of interesting phenomena such as the mass assembly, size growth, morphological transformation, and quenching; (4) **Late-type stars:** Although our primary science is extragalactic, this survey will discover a substantial number of late-type stars as a by-product, which may include such exotic objects as free-floating brown dwarfs; (5) **Near-IR transients/variables:** Although the Steward UKIRT program is not optimized for the detection of transients/variables in any specific way, we may discover such sources serendipitously.

Why should we invest so much Steward UKIRT time in this program?

Assuming 8 hours of science observing time per night on average, the proposed program will require about one month ($\sim$30 nights) of UKIRT observing time in total. Why should we invest so much Steward UKIRT time in this program?

1. **Getting Steward researchers involved in the HSC-Deep survey** — In return for providing the UKIRT/WFCAM data, we will be able to obtain a membership in the HSC-Deep collaboration, which can open up the possibility of conducting a variety of science investigations for the Steward participants. We are currently in the process of finalizing the MOU, and we expect it to be accepted by both parties soon (see below for more detail).

2. **Building a path toward getting involved in the Subaru/PFS survey** — Following the HSC survey, Subaru will conduct a similarly ambitious spectroscopic survey with the Prime Focus Spectrograph (PFS). PFS is a multi-fiber spectrograph that can target 2400 sources within a D=1.3 deg field of view, providing a spectral coverage of 0.38 μm - 1.3 μm with an average resolving power of 3000. For the PFS survey, deeper near-infrared imaging data will be needed for target selection, and this will likely provide a window of opportunity for us to get involved in the PFS survey if we can collect more near-infrared imaging data by operating UKIRT beyond the first two years. Supporting the PFS survey this way will also provide a strong justification for us to request funding for upgrading WFCAM for a better survey efficiency.

Current status of our negotiation with the HSC team

At the HSC team meeting in Japan in late August, Egami presented a close-to-final MOU draft that has been worked on since spring. It incorporates comments from people on both the HSC and Steward sides. It was well received, and was basically considered acceptable by the HSC team. Subsequently, the draft was discussed at the HSC Executive Board meeting in September, and was regarded as acceptable.

The draft was also presented at a meeting at Steward in September. We are currently in the process of incorporating some final comments from the Steward participants, including those from the Steward Director Buell Jannuzi. Buell is ready to accept the MOU once all these last modifications are incorporated, and after his final approval, the final draft will be submitted to the HSC board again for their votes. The HSC survey coordinator Michael Strauss (Princeton) says that the votes will be taken by email (since no issue was raised during the board meeting), and therefore the decision will be swift. Considering all this, we expect the MOU to be approved by both sides by the end of Oct 2014. Anticipating this decision, we plan to start our 2014B observations from the beginning of October since the target field DEEP2-3 is already transiting around the midnight.

Table 1: HSC-Deep fields and existing near-infrared coverage

Field	RA (J2000)	DEC (J2000)	Area (deg^2)	Existing NIR data
XMM-LSS	02:25:00	−04:30:00	5.3	UKIDSS-DXS
E-COSMOS	**10:00:29**	**+02:12:21**	7.2	UKIRT/CFHT/VISTA (central 2 deg^2)
ELAIS-N1	16:10:00	+54:00:00	7.2	UKIDSS-DXS
DEEP2-3	**23:30:00**	**+00:00:00**	7.2	None

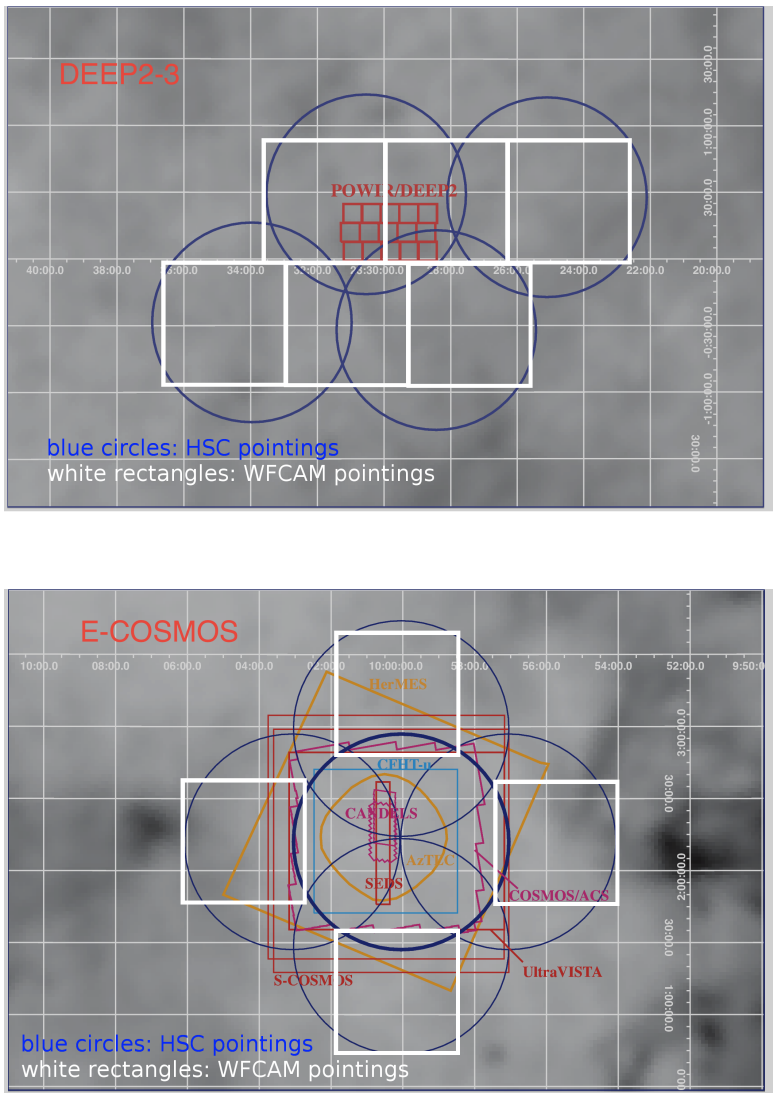

Figure 1: The planned field coverage with WFCAM (white squares) and HSC (blue circles) for the DEEP2-3 field (top) and E-COSMOS field (bottom).

Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science.* ***(up to one page)***

With WFCAM, we will integrate for 2 hours/pixel, achieving 5 σ limiting magnitudes of $J = 23.6$, $H = 23.2$, and $K = 23.1$ mag (AB), respectively (from the WFCAM ETC with 0.9" seeing and D=2" aperture). These depths are comparable to those of the existing UKIDSS-DXS data for the other two HSC-Deep fields, and are sufficiently deep to allow a variety of scientific investigations.

Figure 1 shows the HSC area coverage of the DEEP2-3 and E-COSMOS fields. As the figure shows, 6 WFCAM fields are required to cover DEEP2-3, which currently does not have any near-infrared data, while 4 WFCAM fields are required to image the outerparts of E-COSMOS. Each WFCAM field consists of 4 separate pointings to fill a 0.75 deg^2 area, and we will obtain J, H, and K images for each field. So, the requested open-shutter time for E-COSMOS is 96 hours (= 2 hr/pointing $\times$ 4 pointings/field $\times$ 4 fields $\times$ 3 filters). Assuming 8 hours of science observing time per night on average, this translates into 12 nights of UKIRT observing time.

To ensure a good image quality, we request a maximum acceptable FWHM of 0.8", which is roughly a median seeing on Mauna Kea. However, this condition could be softened somewhat if the progress of observing turns out to be slower than expected. Data obtained under a thin cirrus condition would be acceptable as long as the final fully coadded images achieve the targeted depths.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in.* ***(up to one page)***

(1) This is the second time we are submitting a proposal for this program. The program was allocated 140 hours of observing time in 2014B, and we are requesting here another 96 hours of open-shutter time, which corresponds to $\sim$12 nights. In the MOU with the HSC team, we are promising a total of 240 hours of open-shutter time ($\sim$ 30 nights) to complete the proposed J, H, K coverages for the E-COSMOS and DEEP2-3 fields.

(2) & (3) The proposed program is part of the large HSC-Deep survey. Regarding the proposed near-infrared imaging program with UKIRT, Egami and Fan will take the lead, and will try to get involved other Steward researchers as well, following the collaboration agreement between the HSC team and us. The actual terms of collaboration is currently under discussion with the HSC team (see Scientific Justification for more detail).

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

The following is a list Steward time allocations obtained by PI Egami and his student/postdoc:

- ⋆ Magellan/MMIRS 2012A (PI: G. Walth; 2 nights allocated; $\sim$1 night usable)
- ⋆ MMT/SWIRC 2012A (PI: E. Egami; 2 nights allocated; no data due to snow)
- ⋆ LBT/Lucifer 2012B (PI: M. Rex; 2 nights allocated; 2 nights observable)
- ⋆ LBT/MODS 2013A (PI: E. Egami; 2 nights allocated; 2 nights observable)
- ⋆ Magellan/IMACS 2013B (PI: E. Egami; 2 nights allocated; 1 night observable)

Status of the Observations

LBT/Lucifer: Five clusters have been successfully observed to-date, with the reduction currently underway (with a pipeline developed by M. Rex and G. Walth, based on the Carnegie/Magellan COSMOS package). Results from selected sources will be included in Egami et. al. (2014, in prep).

Magellan/IMACS: Observations were very successful in 2010B, with clear weather and no technical difficulties. Two clusters observed with data reduced and redshifts determined. The results have been published in the following papaer:

"Disocvery of Warm Dust Galaxies in Clusters at $z \sim 0.3$: Evidence for Stripping of Cool Dust in the Dense Environment?"
Rawle, T. D., et al. 2012, ApJ, 756, 106

Although the weather was not great for the 2013B run, we did manage to obtain some useful data, including the detection of Lyα line from a $z = 5.66$ galaxy (B. Clement, 2014, in prep).

Magellan/MMIRS: These observations constitute part of G. Walth's Ph.D. thesis project. The data reduction has mostly been done.

LBT/MODS: The data are currently being analyzed. Egami et al. presented these results at the recent STScI workshop (May 2013) on lensing clusters, and B. Clement is currently drafting a paper.