OBSERVING REQUEST
University of Arizona Observatories

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

Beijing-Arizona Sky Survey (BASS): A New Legacy Survey of the Northern Galactic Cap

P.I.: Xiaohui Fan (SO; *fan@as.arizona.edu*; 520-360-0956)

CoI(s): Ed Olszewski, Branda Frye, Ian McGreer, Mike Lesser, Buell Jannuzi, Eduardo Rozo (SO), Xu Zhou, Hu Zuo, Zhaoji Jiang, Jun Ma, Tianmeng Zhang, Zhimin Zhou, Jundan Nie, Shude Mao (NAOC), Arjun Dey (NOAO), David Schlegel, Peter Nugent (LBNL)

Abstract of Scientific Justification

We propose to carry out the Beijing-Arizona Sky Survey (BASS), an ambitious wide-field multicolor survey of 5000 deg^2 of the Northern Galactic Cap using the 90prime imager on the Bok Telescope, as a four-year collaboration between Steward and China. The survey will use 400 nights, covering SDSS g, r, and z bands, reaching limiting AB magnitude of 24.4, 24.0 and 23.4, respectively. BASS will cover half of the SDSS extragalactic footprint at 1.2 to 2.9 magnitude deeper. It will produce a new legacy wide-field imaging dataset, with scientific impact comparable to the original SDSS imaging survey as the leading imaging survey of the Northern Galactic Cap for the foreseeable future. It will provide unique science opportunities in a wide range of topics in galactic and extragalactic astronomy, including Galactic structure, near-field cosmology, AGN evolution, high redshift quasars, large scale structure of the universe and time-domain astronomy, and produce high impact results in many of these areas. The survey will follow the successful SCUSS model with strong participations and support from both China and US teams and produce high level science products for the general astronomical community. In addition, the survey data will allow effective target selection for the DESI dark energy spectroscopic survey project in the survey area, and be used as in-kind contribution for both Steward and the Chinese community to joining DESI project. Funding has been identified for the project and it is subject to final approval by Steward, NAOC and DESI Directors.

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	90’	PF	90Prime			90	dark/grey	Jan - June	Jan - June	yes	no

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

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ 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	Northern Galactic Cap	8h - 16h	30 deg - 60 deg	SDSS/DESI high DEC region

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

A New Legacy Photometric Survey in the Northern Hemisphere

SDSS, with its unique combination of wide-field spectroscopic and imaging surveys, has made revolutionary discovery in a wide range of areas in astronomy and cosmology, from dark energy, the most distant quasars, to near-field cosmology and cool dwarfs. However, the SDSS imaging survey was carried out more than a decade ago. SDSS only reaches $r \sim 22$, sensitive to low-redshift galaxies, luminous quasars and only the tip of iceberg of the Galactic halo substructure. There is a glaring gap between what is available now in photometric data, and what LSST can offer; this is even more acute in the Northern hemisphere, as most of the new, deeper imaging survey being planned in the south (e.g. SkyMapper, KIDS, LSST); note that PanStarrs is no deeper than SDSS except in z band.

To fully exploit the existing spectroscopic data also needs deeper imaging. The SDSS/BOSS surveys contain 2.8 million spectra, including 300,000 stars, 700,000 galaxies at $z < 0.2$, 500,000 galaxies at $0.2 < z < 0.5$, 1 million galaxies at $z > 0.5$, 100,000 QSOs at $z < 2$, and 200,000 quasars at $z > 2$. SDSS-IV/eBOSS (2014-2020) will add another 600,000 galaxies at $0.6 < z < 1$ and 750,000 quasars at $z > 0.9$. Although SDSS-I spectroscopy is relatively shallow, BOSS and eBOSS are pushing to the limit of the original SDSS photometry (Dawson et al. 2013). The existing imaging data is merely sufficient for target selection. We lack precise photometry, size measurements, morphology, and any detailed information of the galactic environment that are needed to study galaxy properties in addition to the large scale structure and cosmology. By imaging 2 magnitudes fainter in three optical bands, we will increase the number of $z > 0.5$ by close to two order of magnitude. In addition, SDSS-IV/eBOSS has demonstrated that using g, r, and z band with the addition of WISE, we can efficiently isolate $z > 0.5$ galaxies, measure stellar mass and select AGNs at high redshift.

BASS imaging will offer unique opportunities in a wide-range of areas ranging from Galactic structure and near-field cosmology, to galaxy clustering and high-redshift quasars, to time-domain astronomy. As a natural successor of the SDSS imaging survey, it will have board impact in galactic and extragalactic astronomy prior to the LSST era. By providing photometry 2 magnitude deeper in the three most critical optical bands over almost half of the original SDSS footprint, BASS will enable qualitative new imaging science, and at the same time greatly enhance the scientific reach of existing spectroscopy.

The Milky Way Halo and Near-Field Cosmology

The SDSS revolutionized our view of the Milky Way, especially its halo and environment. SDSS has found numerous stellar halo streams and has doubled the number of dwarf galaxies. BASS data will reach more than a factor two further into the halo, and when combined with the equatorial data from the approved NOAO/DECam survey, will increase the volume probed by close to an order of magnitude. We will sue these data to study:

- Galactic Structure through proper motion
- Searching satellite dwarf galaxies of the Milky Way
- Searching substructures or tidal streams in the Galactic halo

AGN evolution and high-redshift quasars

The evolution of galaxies is tightly linked to the growth of their central super-massive black holes. Quasars might represent a key transitional phase in the evolution of massive galaxies. SDSS provided the most comprehensive view of AGN evolution so far, and opened the window of studies of high-redshift quasars close to the end of reionization. BASS will create an unprecedented sample of photometrically selected AGNs (a few million) over a wide range of redshift, AGN type, and AGN/galaxy luminosity. It also leverages the upcoming eROSITA all-sky survey, which will make a near-complete catalog of X-ray bright AGN over the last 8 Gyr. At the proposed depths, we will identify 97% of AGN (95% type 2 AGN), dramatically improving our ability to compile cross-identification of AGN across the electromagnetic spectrum. The AGN sample will allow us to study AGN clustering as a function of redshift which will provide strong tests

to the model of AGN evolution and black hole/galaxy co-evolution and to study how the overall SED of AGN, correlate with redshift, luminosity, host galaxy properties and environment.

Because of the increased survey volume and depth, BASS will be especially suitable for the studies of the rarest types of AGNs and quasars. A key limiting factor of the SDSS quasar survey is the shallow z-band data. BASS will reach more than 2 magnitude deeper in z, comparable to the stripe 82 z-band data. BASS data, combined with the full depths WISE data, will allow the discoveries of large number of quasars at the redshift up to 6.5. We estimate that the survey will produce 5 times more $z > 6$ quasars compared to SDSS, providing key reionization probes as well as mapping the detailed luminosity function of faint quasars which provides key constraints on early growth of supermassive black holes.

Galaxy clustering and dark matter halo

The relationship between the physical properties of galaxies and the dark matter halos in which they reside is a key problem in galaxy evolution. The contents (and shapes) of galaxy dark matter halos can be revealed from the cross-correlation of spectroscopic and imaging maps. These methodologies benefit substantially from deeper imaging. Our proposed depth of z = 23 will increase these samples by factors of 15 or more from SDSS. Cross-correlation studies use angular correlations to tie deep photometric catalogs to overlapping spectroscopic maps, measuring the mean environments and clustering of galaxies and AGN with great accuracy. The proposed survey will extend this to far larger spectroscopic and photometric samples at high redshift, measuring the satellite distributions around the central galaxies as a function of redshift, luminosity, stellar mass, color and other physical properties.

Evolution of galaxy clusters

SDSS has obtained redshifts of 1.5 million massive galaxies. These are often the central and brightest galaxies in groups and clusters; however, current imaging often cannot detect their satellites. The proposed imaging will significantly improve stellar mass models for these galaxies and enable a sensitive search for cluster members around them. We will construct volume-limited cluster catalogs out to z = 0.7, with richer systems detected to yet higher redshifts ($z >= 1$), providing key cosmological probes.

DESI Spectroscopic Target Selection

BASS proposed here will not only create the deepest survey of the northern SDSS footprint, but also be sufficient for identifying the primary LRG, ELG and QSO targets for the Dark Energy Spectroscopic Instrument (DESI) Key Project and for any possible public access time on the instrument. DESI, a 5000-fiber spectrograph destined for the Kitt Peak Mayall telescope, will undertake a spectroscopic survey an order of magnitude larger than SDSS, measuring spectra and redshifts for 20 million emission line galaxies (ELGs), 4 million luminous red galaxies (LRGs) and 2 million QSOs. The survey is designed to probe the expansion history at $0 < z < 3.5$ using the baryon acoustic oscillation scale, and to map the dark matter and gravitational growth through redshift space distortions. DESI will have revolutionary capabilities for broad investigations on the origin and evolution of galaxies, Galactic structure, rare-object discovery, and result in one of the most complete high-z AGN catalogs to date.

BASS will find a large number of rare classes objects, including halo and cool white dwarfs, to cool L/T brown dwarfs, to carbon stars, gravitationally-lensed quasars, high-z quasars etc. It will produce large and valuable dataset for spectroscopic follow-up observations. DESI spectroscopic survey will provide a key follow-up facility: DESI will have a wide range of ancillary fibers as part of the science operation, and DESI bright time allocation is expected to be focused on relatively bright galaxies and stars, with millions of fibers, all in the BASS survey area.

BASS is being used as the main component of in-kind contribution for both Steward and China (organized as the Chinese Participation Group) to join DESI as full institutional members, which will allow both Steward and Chinese community to have full access to both DESI imaging and spectroscopic data.

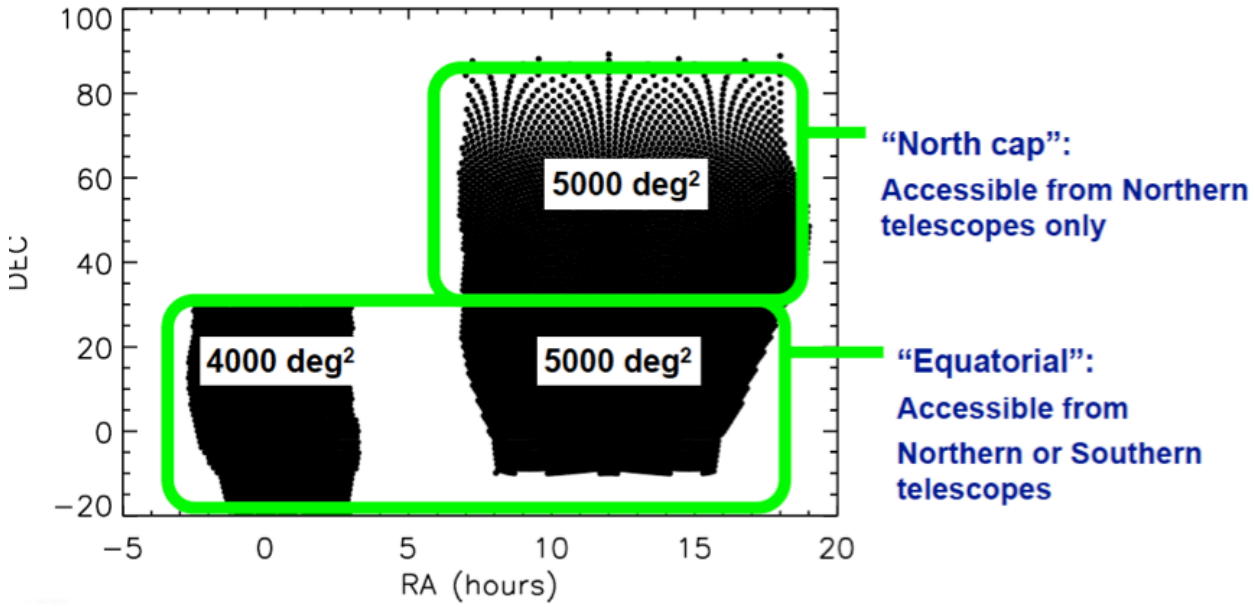

Figure 1: SDSS footprint. BASS will cover the northern 5000 deg^2 to 2 magnitude deeper

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)***

We will use the Bok Telescope on Kitt Peak, with the 90Prime 8kx8k CCD camera that covers 1 deg^2. For BASS g and r band survey, we will use the existing blue-sensitive CCD, which we plan to have a number of minor improvements on CCD controller and computer. For BASS z band survey, the Steward Observatory, in collaboration with LBNL, is constructing a new Dewar equipped with four 4kx4k complete depletion red sensitive CCDs, which will be ready from late 2015 and on the sky from the second year of our survey. The new red camera will improve z-band observing efficiency by a factor of three.

Figure 1 shows the entire SDSS photometric and spectroscopic footprint, which covers the high-galactic latitude sky accessible in the Northern hemisphere. Our goal is to create a legacy photometric dataset that is about 2 magnitude deeper than the SDSS. For BASS, we focus on the northern 5000 deg2 that can only be reached by a Northern telescope. Meanwhile, NOAO has approved a survey project using DECam on the 4m Blanco telescop at CTIO which will survey the equatorial region to a depth similar to BASS; the DECam data will be publicly available without proprietary period.

BASS will obtain data in 3 SDSS bands (g, r, and z); this is the minimum number of bands needed for (a) color selection of galaxies by types and redshift; (b) obtaining photometric parallax of main sequence stars, and (c) color selection of AGNs. We choose the depth by requiring: (i) g-r-z color selection of sub-L* galaxies at $z \sim 1$; (ii) high signal-to-noise data for the measurement of structural parameters of galaxies with known redshifts on the faintest z = 20 mag eBOSS galaxy targets; (iii) color-separating main sequence turnoff stars in distant halo (80kpc), (iv) detections of nearly 100% of the WISE sources for AGN selection. These requirements translate to a 5-σ point source depths of g, r, z = 24.4, 24.0, 23.4 AB mag. We find that BASS will need:

– g and r band survey: 200 nights for 5000 deg^2, using 90prime+blue dewar, m_lim = 24.4 and 24.0 (5-σ). When including overhead and weather, we find that we need 75 scheduled nights (2/3 usable) in g and 105 nights in r to cover 5000 deg^2.

– z-band survey: 200 nights for 5000 deg^2, using 90prime+red dewar, m_lim = 23.4 (5-σ). The observing efficiency is estimated following the same procedure as for g and r bands, expect now we are scaling the CCD response curve from the current Bok CCDs (blue sensitive) to those of the LBL thick devices, which are the same as those installed in DECam.

Timeline of the survey:

- 2014: survey planning, starting construction of the new red dewar
- 2015: BASS survey starts with g, r bands
- 2016: completion of new red Dewar, observing in all three bands
- 2017: routine survey observation, data release I for the first two years
- 2018: completion of BASS observing
- 2019: data release of the entire BASS survey

Request for 2015A

In 2015A, we are requesting 90 nights to start the g and r band survey. We will start our survey from low-DEC regions which also has partial overlap with the DESI DECam survey and work our way towards higher DEC. We will use the same planning software as SCUSS survey for our survey planing. Because we are observing in g and r, we will need dark and grey nights. *In addition, the BASS collaboration is offering to carry out limited service observing during our nights for other 90Prime observers. This will both allow time domain observations on Bok, and help optimize observing scheduling on the telescope.* BASS observing will start in Jan and run every dark run until June.

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)***

This is a long-term collaboration between Steward, NAOC and DESI project. BASS will use 400 nights (200 dark/grey nights for g and r bands and 200 grey/bright nights in z band). For a four-year survey, we will need 100 nights per year, or about half of the available nights between Jan and June. This survey is subject to final approval by Steward Director, NAOC Director and DESI Director regarding in-kind contributions and telescope availability.

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**)*

pastuse In past two years. Fan is PI of the following programs:

- 2014B: two nights on MMT/MAESTRO for quasar IGM spectroscopy. Instrument throughput issue. Data are useful for engineering only.
- 2014A: two nights on Magellan/FIRE for $z \sim 5$ quasar follow-up. One paper published, one ready to submit.
- 2014B etc. ToO proposal for high-redshift GRBs on LBT, no triggers yet.
- 2013B: three nights on MMT for PS1 quasar follow-up. Eight new PS1 quasars at $z \sim 6$. One paper published,two more in preparation.
- $\star$ 2013B, 15 nights on Bok for deep u-band imaging for SDSS-IV target selection, observations completed. Data reduction finished and incorporated into SDSS target selection. Data will be released with all SCUSS data. Several papers already published by SCUSS team.
- 2013A, 2012AB, six nights on LBT/LUCI for $z \sim 7$ galaxy spectroscopy. One paper published, one paper submitted.