OBSERVING REQUEST
University of Arizona Observatories

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

Exploring the Low Surface Brightness Universe

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Abstract of Scientific Justification

We propose to begin developing a set of novel techniques using the suite of Steward small telescopes to increase the precision of low surface brightness (LSB) measurements. Quantitative measurement of LSB features in galaxies probe the accretion history and are essential to establishing the full baryon census of dark matter halos.

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	61		Mont4K			3	dark	Aug-Jan	Sep-Jan	yes	no

Scheduling constraints and unusable dates *(up to 4 lines)*: DZ is away until Aug. 10, between Sept 13 and 20 (ISSI conference), Sept. 20 and 21 (Magellan Council), Sept 30 to Oct. 4 (GMT science conference), Oct 20-24 (AZ has a review panel meeting), DZ and AZ away after Dec 19.

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	TBD			We propose blank field observations
2				so we can accommodate any RA,DEC.

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
Matt Kirby	Dennis Zaritsky		no	no

Scientific Justification

The key to understanding the development of structure in the Universe is unraveling the processes responsible for how baryons distribute themselves within dark matter halos. The first step in this exercise is to measure the distributions of baryons and dark matter. The distribution of dark matter is relatively well understood both empirically, from dynamics (within individual galaxies from the study of satellite dynamics (Zaritsky and White 1994), within clusters from the dynamics of member galaxies (Geller, Diaferio, and Kurtz 1999), from gravitational lensing (Mandelbaum et al. 2006; Clowe et al. 2006), and from the thermodynamics of a hot plasma (Awaki et al. 1994; Allen, Schmidt, & Fabian 2001), and theoretically (Navarro, Frenk & White 1997). Ironically, we know less about the complete distribution of baryons. Here we propose a first step in extending existing techniques and developing new ones to extend observations of the low surface brightness components of galaxies and collections of galaxies.

With the measurement of intracluster light (ICL; stars unbound to the cluster galaxies), we have a reached a nearly complete accounting of baryons in systems with $M > 5 \times 10^{13} M_{\odot}$. The fascinating result is that the star formation efficiency drops with increasing mass, making it conceptually challenging, but not impossible, to create the more massive systems from those of lower mass in our standard picture of hierarchical growth (McCarthy, Bower, & Balogh 2007). We need to extend this type of analysis to lower mass systems so that we have a more complete picture of the results of the hierarchical growth of structures.

Nonlinear evolution is highly effective at erasing history. This makes it challenging to construct detailed tests of models of the merger (comparable mass added) and accretion (much smaller mass added) history of halos. Mergers and accretion events are numerous and come in a wide range of mass ratios across cosmic time. To emphasize the complexity of this process, we reproduce in Figure 1 a theoretical merger tree diagram for a brightest cluster galaxy from the study of De Lucia & Blaizot (2007). The challenge of testing this model in detail is obvious.

Many investigators have aimed to test the model merger histories by counting mergers or the relics of mergers identifiable as substructues (cf. Lavery & Henry 1988; Abraham et al. 1996 Lotz et al. 2011). Setting aside the difficulty in identifying such systems, the more fundamental problem in this approach comes from the unknown lifetime of such substructure. We propose forsaking the potential (but unrealized) temporal resolution provided by merger/accretion signatures for the robustness of utilizing the integrated "debris" from the merger/accretion history. The measurement of stars thrown out either into the halo of an individual galaxy or between the galaxies in groups and clusters, provided one has a full accounting of this debris, requires no additional assumptions or interpretation - it is an unambiguous benchmark that the models will need to reproduce. The difficulty is that this debris is sparse and therefore has very low surface brightness.

Reaching the surface brightness levels of the ICL required drift scanning, superb flat fielding, modeling of the time variable sky, and careful masking. We now seek to go even beyond that level of precision. Note that the ICL work was done with a 40inch telescope and < 10 minutes of effective exposure time. All published LSB observations are limited by systematics, not by the telescope aperture or exposure time. Here we propose to do a first test of the suitability of our smaller telescopes (because telescope aperture is not the limiting factor of these studies our access to a suite of small telescopes provides a competitive advantage). There are various aspects of the problem that require testing and new approaches.

The challenges include:

• Flat Fielding : The inherent sensitivity variations of the CCDs must be measured and accounted for. Approaches used to mitigate the effect of these variations include drift scanning and intensive sky flats. Neither is complete because of residual (real) fluctuations in the presumed flat (uniform) image. We propose to use and test both approaches, but to add a new approach involving the combination of data from various telescopes. The difficulty in achieving higher precision is that small positive fluctuations in apparent sensitivity could arise either from actual pixel sensitivity variations (which we need to remove) or to unresolved background sources that contaminate the flat field. A sky flat image obtained with a different detector system, on the same area of sky, will allow us to resolved this degeneracy and better calibrate both systems. Furthermore, because the image pixels in data from the two telescopes are likely to correspond to different

spatial scales, we should be able to confirm or refute that the fluctuations are on the sky because the signal will scale with area (larger areas will average over larger portions of the sky and be closer to the DC value).

• Light thrown to large radii : Regardless of the baffling of a telescope, there is always some level of scattered light and the point spread functions of stars deposit a low level of light far from the stars as well. Again, we will explore the role that having observations taken at multiple telescopes of the same field can play to address these concerns. We will use the fact that the different telescopes will have different scattered light properties to aid us in removing this contamination.

• Sky Variations : Temporal and spatial variations in the atmospheric emission are a principal limiting factor in LSB work. These are usually addressed using multiple exposures over a significant length of time. The coherence of temporal variations is not well known and we propose to explore this question. Depending on the time scale of coherent sky variations, we may be able to define our exposure times to optimize our chances of getting some of our frames to have only darker sky (by rejecting those that have higher sky emission). The gain from such a scheme will depend both on the magnitude of the variations and their timescale, neither of which is well known. We will also explore the degree to which filter choices can affect this. Eventually (not in this cycle) we would design optimized filters to minimize sky emission.

• Diffuse emission : There are astrophysical sources that contribute large scale backgrounds (for example, scattering from the same dust responsible for IR Cirrus). We propose using existing far infrared data to help identify that contribution to the background. We will avoid regions with an above a to-be-determined threshold of IR emission and remove an appropriately scaled version of that IR emission in the remaining regions. The latter approach in particular is something new to LSB work and we will be aiming to determine the optimal application.

• Unresolved sources : Most LSB analyses mask any detected sources before quantifying the LSB component. Undetected sources contribute noise to the LSB measurement and, in particular, make it difficult to determine if there is structure within the LSB component. Multiwavelengh analysis (for example using WISE data) can help identify missed sources (in this example, very red sources could be identified in the WISE data and not in the optical data). Maximizing the use of ancillary data at other wavelengths would also be an innovation in this type of measurement. We have shown that at least to the depth of SDSS data (which is deeper than most LSB data) there are many sources identified in WISE images that are not detected in the SDSS data.

In summary, we envision an analysis that attempts to decompose the emission at any location in the sky into a constant (the term of interest) + a time variable term (atmospheric emission) + a telescope variable term (scattered light, psf, detector sensitivity variations) + a wavelength variable term (cirrus, atmospheric emission). By obtaining data from a variety of telescopes and combining with archival data at other wavelengths we are proposing an innovative approach to the LSB measurement problem. Here we propose for time on the 61inch telescope, but we also plan to obtain data using the CSS 60 and 40 inch systems, Superlotis (24-inch) and the Phillips (24 inch). The requested allocation represents the first steps in developing a better understanding of what is possible with our small telescopes, particularly once they are robotized (some, such as Superlotis and the Phillips 24-inch are already).

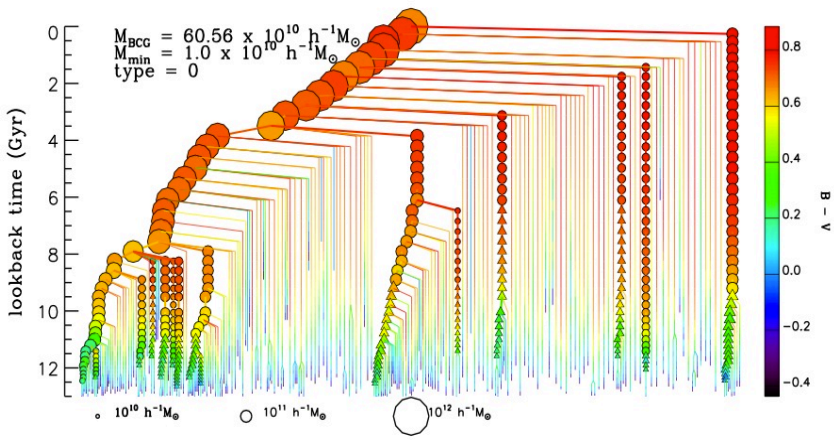

Figure 1: *(verbatim figure caption from De Lucia & Blaizot) "BCG merger tree. Symbols are colour-coded as a function of $B - V$ colour and their area scales with the stellar mass. Only progenitors more massive than $10^{10} M_\odot h^{-1}$ are shown with symbols. Circles are used for galaxies that reside in the FOF group inhabited by the main branch. Triangles show galaxies that have not yet joined this FOF group."*

References

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Awaki, H. , et al. 1994, PASJ, 46, 65L
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Lavery, R., Henry, J.P. 1988, ApJ, 330, 596
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Navarro, J., Frenk, C.S., & White, S.D.M. 1997, ApJ, 490, 493
Zaritsky, D. & White, S.D.M. 1994, ApJ, 435, 599

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 currently do not have a target object and a specific S/N needed to achieve a science objective. There are various previous studies that set the precision limit that we will ultimately need to surpass (signifincatly) if we are to pursue this work. It is typical in that work that neither the telescope aperture nor exposure time are large. For example, in the Gonzlez et al. work on the ICL, we used a 40-inch telescope and a total effective exposure time of less than 10 minutes. Therefore, progress can be achieved rather easily, IF we can control for the various systematic problems. We are proposing to obtain data with which to determine the precision that we can expect for super sky flats (including data from various telescopes), to determine how well scattered light can be removed, to explore whether scaling far IR emission works to further flatten images, and to determine the nature of sky fluctuations. We will be obtaining a string of images of a region of the sky for which there are relatively deep images that can serve as truth tests. We will optimize the field depending on when we are assigned time. We require stable photometric and dark conditions for these tests. As such we ask for a set of three nights to maximize the chances that we have several night's worth of data with which to undertake these tests.

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 the first request for this program. This could develop into a large program, but for now we are testing the possibilities. We are not obtaining any non-UA time for this program.

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**)*

Zaritsky, with D. Just, and G. Rudnick (Kansas) - Magellan IMACS observations of distant clusters (2 nights, March 2012, 3 nights March 2013). Data obtained are of high quality but ancillary data is still in the works.

Zaritsky is a co-I on the large AZTEC program. Observations are ongoing but a number of papers from various team members have already resulted.

Zaritsky, Zabludoff, Gonzalez, de Maio, and Mulchaey - Magellan LDSS3 observations of groups and clusters (1.5 nights, Aug 2014). Some data obtained, analysis ongoing.