OBSERVING REQUEST
University of Arizona Observatories

Year: 2017 **Term:** Jul–Dec **Proposal type:** short-term

Super-helium-rich giant stars in dwarf galaxies

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Abstract of Scientific Justification

Super-helium-rich (SHR) stars are believed to reside in the Milky Way (MW) and external giant galaxies, and their origin and implications have been a hot topic of investigation. Our pioneering observation with the Subaru 8.2-m telescope using the *hk* index as a metallicity indicator hinted at such SHR stars dwelling in dwarf galaxies as well. In particular, we found for the first time that many of *hk*-strong (i.e., metal-rich) horizontal-branch (HB) stars in MW satellite galaxies are way too blue (i.e., hot) in optical colors, which may indicate their highly elevated helium content. Direct high-resolution helium abundance measurement for stars in dwarf galaxies is extremely challenging, but evidence indicates that SRH stars are born with enhanced Na and N contents. We thus propose medium-resolution spectroscopy for the Lick indices of *hk*-strong HBs in the Draco dwarf galaxy to delve into their Na, N, and other metal abundances. Moreover, the post-HB evolution depends critically on helium abundance; SHR HB stars, because of their small mass, avoid the asymptotic-giant phase and evolve directly into a white dwarf stage. Thus we further propose to measure the Na and N abundances of red- and asymptotic-giant stars to see whether Na- and N-enhanced stars are indeed lacking on the asymptotic-giant branch. If confirmed, it will mark the first detection of SHR stars in dwarf galaxies, suggesting enhanced helium enrichment is a common feature across all type (from spiral to elliptical galaxies) and size (from globular clusters, dwarf to giant galaxies) of stellar systems. The data will enable to address the chemical evolution of dwarf galaxies and their causal connection to the MW. To this aim, we require four half nights of the MMT/Hectospec for the Draco dwarf galaxy. We ask it to be between Aug. and early Sep. considering the airmass of the target.

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	MMT	f/5	Hectospec			2	dark	Aug–Aug	Aug–Sep	no	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	Draco dSph	17:20:12.40	+57:54:55.0	giant stars in Draco, V=17.0–22.0

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 if student is PI on the cover page or if this is a 2nd-year or Thesis program. Send confirmation email to TAC chair in place of signature.)*

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

Scientific Justification

Super-helium-rich giant stars & their Lick indices as helium tracers: Anomalous super-helium-rich (SHR) stars are believed to reside in the Milky Way (its bulge and globular clusters) and in external giant elliptical galaxies (their halo and globular clusters) (e.g., Renzini 1994; Kaviraj et al. 2007; Nataf & Gould 2012; Chung et al. 2011, 2013; Lim et al. 2015). SHR stars are the products of elevated helium (He) enrichment, characterized by the parameter dY/dZ (the ratio of the increase in He to the increase in metallicity). Since it has long been assumed that dY/dZ is a universal constant (dY/dZ $\sim$ 1.5 when derived from the Sun), the origin and implications of the highly enhanced dY/dZ (= 5 $\sim$ 50) are hot topics of investigation. Direct, high-resolution spectroscopic He line detection of stars in dwarf galaxies is extremely challenging and time-demanding at their distances. An alternative method of inferring He content is through the observation of particular elements like Na and N, because their enrichment mechanism (i.e., p-capture productions) is known to be responsible for the He enrichment. Recent high resolution spectroscopic studies on stars in the Milky Way globular clusters successfully detected He lines, albeit for a small sample, showing that the Na- and N-rich stars are highly He-rich too (Dupree et al. 2011; Gratton et al. 2011). Therefore the discovery of Na- and N-rich stars in dwarf galaxies indicates the presence of SHR stars.

To this aim, we propose to obtain medium-resolution optical spectra of giant stars (i.e., red-giant-branch (RGB), horizontal-branch (HB), and asymptotic-giant-branch (AGB) stars) in the Draco dwarf spheroidal galaxy using the Hectospec on the MMT. The Draco provides a good testbed for the SHR giant stars in dwarf galaxies as it exhibits well-developed RGB, HB, and AGB (Figure 1). We will measure, as tracers of SHR stars, the Lick line-absorption indices, CaII H & K lines, and CN band representing Na and N as well as C and Ca (Table 1).

Our objectives are twofold:

(1) HB giant stars in the Draco dwarf galaxy: We have recently launched a chemo-structural study of dwarf galaxies in the Local Group using 8.2-m Subaru (S12B-067; S14A-03; S15A-070; PI: S.-J. Yoon) and 2.5-m Du pont telescopes (Han et al. 2015). Thanks to the deep Ca and strömgren *by* photometry in conjunction with V, I archival data, we successfully selected member stars in dwarf galaxies including Draco, Sculptor, Fornax, Sextans, Andromeda II, and Canes Venatici I. The *hk* index, defined as (Ca-*b*)-(*b*-*y*), is very sensitive to the abundance of Ca and other heavy elements (Anthony-Twarog et al. 1991), and can be used as a good metallicity discriminator for the member stars.

Figure 1 shows color-magnitude diagrams (CMDs) of stars in the direction of Draco dwarf spheroidal observed by Subaru/Suprime-Cam. We examined the HB morphology in V-I, governed mainly by metallicity, by carefully identifying *hk*-strong and *hk*-weak HB stars in the *hk* CMD. Surprisingly, many of the blue (i.e., hot) HB stars in V-I are *hk*-strong (i.e., metal-rich). This phenomenon cannot be explained by stellar populations with normal He content, and our model prediction (Joo et al. 2013) shows that strong He enrichment is needed (dY/dY $>$ 5). We stress that this is the first clue of the presence of SHR populations in dwarf galaxies. Therefore we will make use of the Lick absorption-line indices and other lines for the HB stars in order to delve into their metal and He abundances.

(2) AGB/RGB stars in the Draco dwarf galaxy: The final three stages of a low-mass star's evolution are from RGB via HB to AGB phases. It is well established by stellar evolution theories that if HB stars have a thin enough hydrogen envelope ($<$ 0.02 $M_\odot$), they fail to evolve into the AGB phase. But instead they evolve directly into a white dwarf stage following the AGB-manqué track (e.g., Landsman et al. 1996; Charbonnel et al. 2013). Recently, Campbell et al. (2013) found an extremely high 'AGB failure' rate in a Galactic globular cluster, NGC 6752, by showing that there are no Na-enhanced stars on the AGB (Figure 2).

On the theoretical and observational basis shown above, we propose to examine the stellar Lick absorption-line indices and other lines of the Draco and compare the number of Na- and N-rich stars between the RGB and AGB stages. According to our calculation for a typical cool giant ($T_{\rm eff} = 4662$, $\log g = 1.83$, and $[{\rm Fe/H}] = -1.35$), the increased Na abundance by 0.3 dex leads to 28% increase in the NaD (5895 Å) absorption strength. Similarly, the increased N abundance by 0.3 dex results in 142% increase in the CN1 (4161 Å) strength. This implies that using medium-resolution MMT Hectospec spectroscopy data, we expect to detect abundance difference between RGB and AGB stars.

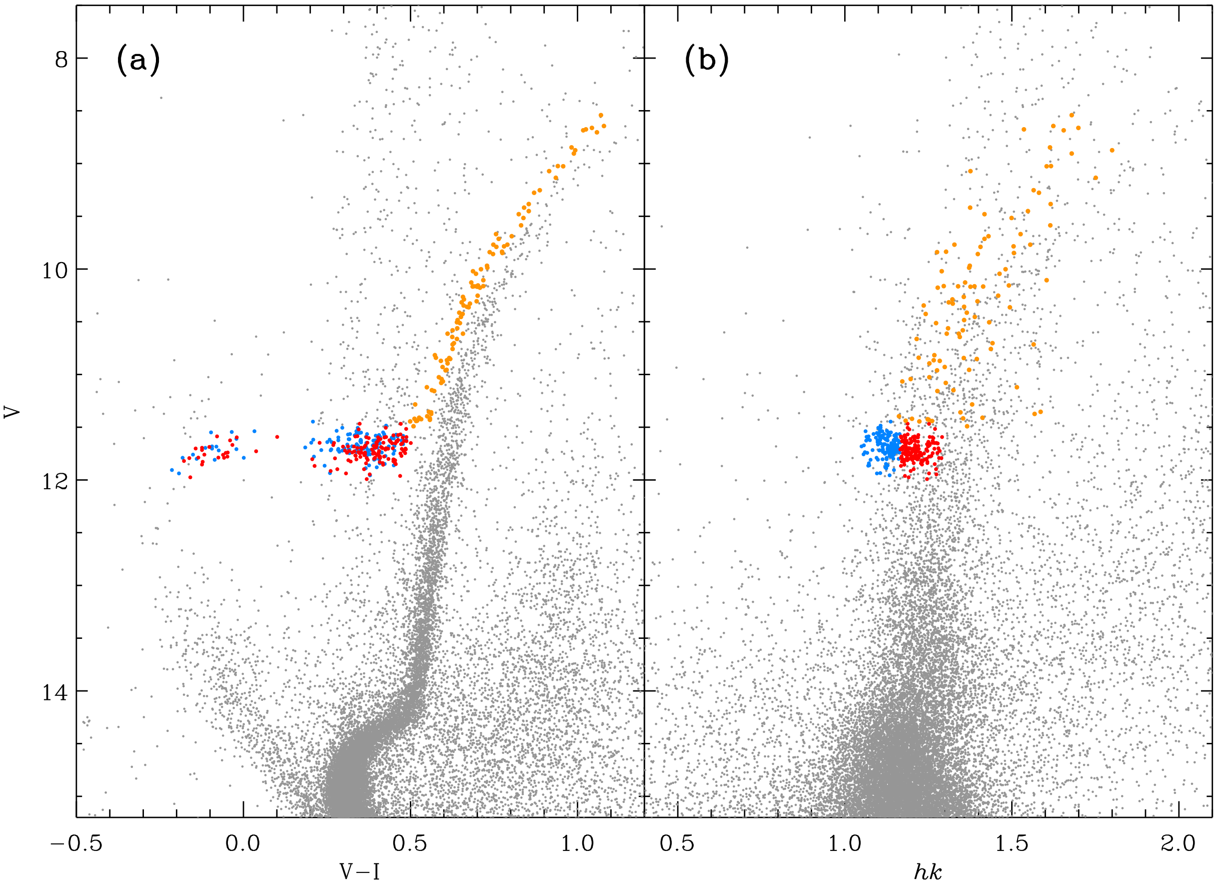

Figure 1: (a) V-I color-magnitude diagram and (b) *hk* index vs. V mag diagram for stars in the direction of the Draco dwarf spheroidal. The red and blue dots are the candidate HB stars, divided by the *hk* strength as a photometric metallicity indicator. Note that the *hk*-strong HB stars (red dots) in (a) are hot and blue in V-I in (b), which cannot be explained by populations with normal helium content. The orange dots are the candidate AGB stars. The spread of AGB stars in (b) demonstrates the power of of the *hk* index as a metallicity indicator. The RR Lyrae variable stars are taken out for clarity.

Table 1: The expected variation, ΔI, in terms of the index responses when the α-elements are increased by 0.3 dex for a giant star with ($T_{\rm eff}$, $\log g$, [Fe/H]) = (4662 K, 1.83, −1.35)

Lick index	α-element	I_0	I_{new}	$\Delta I(increment)$	unit
CN1 (4161Å)	N	−0.021	0.009	0.3 (142%)	mag
Ca4227 (4227Å)	Ca	0.149	0.346	0.197 (132%)	Å
G4300 (4300Å)	C	7.853	8.257	0.404 (5%)	Å
NaD (5895Å)	Na	0.580	0.742	0.684 (28%)	Å

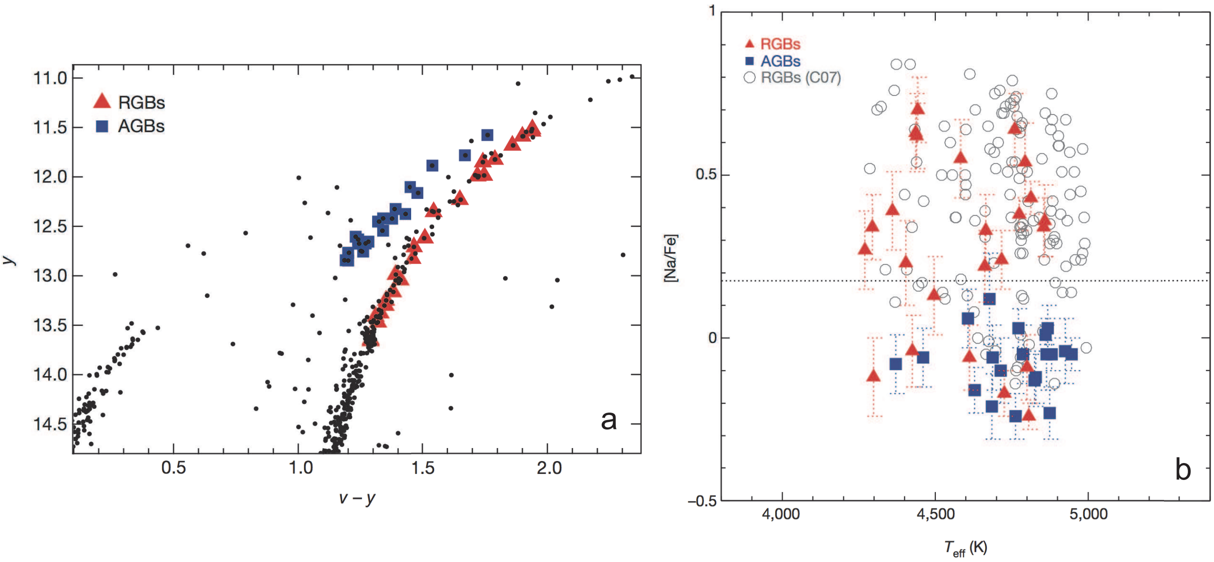

Figure 2: (a) The AGB and RGB stars in the strömgren *vy* CMD of NGC 6752 and (b) their Na abundance difference. The figure is from Figure 1 and 2 of Campbell et al. (2013). In both (a) and (b), red triangles are RGB stars and blue squares are AGB stars in NGC 6752. In (b), compared to the wide spread of the RGB stars along the $[\mathrm{Na/Fe}]$, the AGB stars are located only below $[\mathrm{Na/Fe}] = 0.18$. This implies that there is no Na-enhanced AGB stars in NGC 6752. Grey open circles are from Carretta et al. (2007). The horizontal dotted line marks the upper boundary of the AGB values, dividing the Na-rich and Na-poor stars.

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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)***

Our main goal is to search for the very first evidence of super-helium-rich stellar populations in the Local Group dwarf galaxies. To this aim, we propose to observe giant stars (HB, RGB, and AGB stars) in the Draco dwarf spheroidal galaxy using the Hectospec with the 270 line mm^{-1} grating. This configuration provides 3650 – 9200 Å wavelength coverage with a spectral resolution of ~ 6 Å, allowing us to measure all the Lick absorption-line indices, CaII H & K lines (~ 3950 Å), and CN band (~ 3883 Å). The measurements of the lines will enable us to find highly Na- and N-enriched stars (i.e., super-helium-rich stars) by comparing the Na and N abundances at given Ca, CN, Mg and Fe abundances.

Since the Draco exhibits well-developed RGB, HB, and AGB, it provides a good testbed for enhanced He enrichment in dwarf galaxies. We have already performed Ca and strömgren *by* photometry for the Draco using Subaru 8.2-m telescope. The resultant *hk* CMD shows that many of blue (i.e., hot) HB stars are *hk*-strong (i.e., metal-rich), which hints at their highly elevated He enrichment.

As the Hectospec provides simultaneous spectroscopy of up to 300 objects over a 1 degree field of view (FOV), we have carefully selected ~ 1000 candidate giant stars in the Draco from our Subaru/Suprime-Cam observations (FOV $\sim 40' \times 30'$). The V band magnitude of our target stars ranges between 17.0 and 22.0. We divide the target stars into three groups (bright, intermediate, faint) by V band magnitude. Based on exposure time calculator assuming a seeing of $0.7''$ and airmass of 1.2, we estimate the total integration time to be 600 s, 3600 s, 18000 s to obtain high quality spectra (S/N ≥ 30) for the bright, intermediate, and faint groups, respectively. We will use a total of four fiber configurations for our target stars, and take 6×600 s exposures for the bright group, and 14×3600 s exposures each for the intermediate and faint groups. The best time to observe our target field during the 2017B season is rather strictly in August considering the airmass. For this program, we request four half nights including overhead time between August and very early September.

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***)

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**)*

Other Information *Provide any additional program-related information including, for example, relation of current program to externally funded research, to the development of expanded capabilities for UA telescopes, or to individual timescales (e.g. PI is finishing postdoc appointment and this request would complete program). (**up to one page**)*