OBSERVING REQUEST
University of Arizona Observatories

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

Spectral properties of red supergiant stars in very low-metallicity dwarf irregular galaxy IC 1613

P.I.: Sang-Hyun Chun (Seoul National University; *shyunc.m@gmail.com*; 82-10-4597-0973)

CoI(s): Sung-Chul Yoon (Seoul National University), Young-Jong Sohn (Yonsei University), Hyun-Jin Bae (Yonsei University), Heeyoung Oh (Seoul National University)

Abstract of Scientific Justification

We propose a multi-object spectroscopic observation of red supergiant stars (RSGs) in the dwarf irregular galaxy IC 1613 using MMIRS on MMT in order to investigate the physical properties of RSGs in a very metal poor environment. RSGs provide important information to understand galaxy formation and evolution as well as to test the stellar evolution theory. In particular, the temperature variations with respect to metallicity is a matter of great debate. Our recent work with stellar evolution models indicates that the efficiency of convective energy transport in the hydrogen-rich envelope should depend on metallicity to explain the effective temperatures of RGS in nearby galaxies. However, this result is based on the limited metallicity range from Small Magellanic Cloud (SMC) to M31 values. Observational studies for a wider metallicity range are needed to obtain firm evidence for our finding. The dwarf irregular galaxy IC 1613 has a lower metallicity ($Z \approx Z_{\odot}/20$) than that of SMC, and RSGs of this galaxy have never been systematically studied. From this observation, we plan to infer the fundamental stellar parameters of RSGs including effective temperatures, surface gravity, and chemical abundances. This will provide observational constraints for RSG models at the lowest metallicity domain ever investigated and a critical insight into the formation and evolution, as well as the star-formation history of IC 1613.

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	MMIRS	*		1	grey	Sep–Oct	Sep–Nov	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: None

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	T22435	01:04:03.25	02:02:23.71	$K_s = 16.51$, Low limit of Right Ascension
2	T21625	01:04:07.51	02:01:05.09	$K_s = 16.66$
3	T20450	01:04:16.38	02:06:17.10	$K_s = 16.39$
4	T19926	01:04:19.77	02:01:18.98	$K_s = 16.73$
5	T12930	01:04:44.43	01:57:49.61	$K_s = 16.18$
6	T09278	01:04:53.09	02:03:33.41	$K_s = 16.00$
7	T09160	01:04:53.43	02:00:55.19	$K_s = 15.98$
8	T08651	01:04:54.82	02:00:40.90	$K_s = 16.77$
9	T08568	01:04:55.08	02:05:17.02	$K_s = 16.82$
10	T07788	01:04:57.33	02:19:21.90	$K_s = 16.74$, Upper limit of Declination
11	T07197	01:04:58.87	02:05:17.09	$K_s = 15.91$
12	T06077	01:05:02.30	02:06:27.68	$K_s = 15.56$
13	T05836	01:05:03.02	01:55:18.91	$K_s = 15.64$
14	T05086	01:05:05.97	01:55:03.39	$K_s = 15.84$, Low limit of Declination
15	T02012	01:05:22.71	02:12:57.71	$K_s = 15.86$
16	T01639	01:05:25.91	02:16:53.51	$K_s = 14.79$
17	T01600	01:05:26.22	02:12:36.22	$K_s = 15.48$
18	T00464	01:05:36.45	02:05:31.60	$K_s = 16.25$
19	T00125	01:05:38.69	02:06:15.52	$K_s = 15.91$
20	T00025	01:05:39.33	02:04:02.71	$K_s = 14.48$
21	T00012	01:05:39.53	02:06:16.88	$K_s = 16.54$, Upper limit of Right Ascension
22	A01203	01:04:43.24	02:15:14.06	$H = 14.00$, example of alignment star
23	A00015	01:05:02.17	02:10:16.02	$H = 15.40$, example of alignment star
24	A00113	01:05:05.75	02:04:54.66	$H = 15.87$, example of alignment star
25	A00020	01:05:36.87	02:08:22.14	$H = 14.93$, example of alignment star.
26	H116886	23:41:33.51	10:12:57.00	$V = 9.91$, A0V, example of telluric star. See the footnote.[1]

Approval for Instrument Use from PI: See attached e-mail from Dr. Brian McLeod.

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

Approval request for using MMIRS on MMT (KGMT2017B)

받은편지함 x

천상현 <shyunc.m@gmail.com> 15:43 (19시간 전)
bmcleod에게

Dear Dr. Brian McLeod

I am Sang-Hyun Chun, and a post-doctoral fellow in Seoul National University in South Korea.
I am writing to you to ask for approval of MMIRS on MMT.

We are planning to observe the red supergiant stars (RSGs) in dwarf irregular galaxy IC 1613 in order to investigate the physical properties of RSGs at low metallicity environments.
Recent our stellar evolutionary models reveal that a larger mixing length parameter of alpha=2.5 is necessary to explain the RSGs with super solar metallicity. However, the metallicity range in this study was limited on SMC, LMC, Milky Way and M31. Thus the investigation of RSGs in much lower metallicity environments is essential to get observational constraints in input parameters of model calculations. IC 1613 has low metallicity of Z=0.001, which is much lower than SMC, and the RSGs of this galaxy have never been studied. We will determine the fundamental stellar parameters of RSGs and investigate their physical properties using J-band spectra obtained by MMIRS.
The temperature variation by metallicity and galaxy evolutions/star formation of this galaxy will be explored.

MMIRS is PI instrument, thus we need your approval for using MMIRS in observing request proposal.
We are looking forward to your good response.

Sincerely yours,

Sang-Hyun Chun

McLeod, Brian 20:34 (15시간 전)
나에게

영어 > 한국어 메일 번역

Approved.

...

Brian McLeod

On Tue, Mar 21, 2017 at 2:43 AM, 천상현 <shyunc.m@gmail.com> wrote:

Dear Dr. Brian McLeod

I am Sang-Hyun Chun, and a post-doctoral fellow in Seoul National University in South Korea.
I am writing to you to ask for approval of MMIRS on MMT.

We are planning to observe the red supergiant stars (RSGs) in dwarf irregular galaxy IC 1613 in order to investigate the physical properties of RSGs at low metallicity environments.
Recent our stellar evolutionary models reveal that a larger mixing length parameter of alpha=2.5 is necessary to explain the RSGs with super solar metallicity. However, the metallicity range in this study was limited on SMC, LMC, Milky Way and M31. Thus the investigation of RSGs in much lower metallicity environments is essential to get observational constraints in input parameters of model calculations. IC 1613 has low metallicity of Z=0.001, which is much lower than SMC, and the RSGs of this galaxy have never been studied. We will determine the fundamental stellar parameters of RSGs and investigate their physical properties using J-band spectra obtained by MMIRS.
The temperature variation by metallicity and galaxy evolutions/star formation of this galaxy will be explored.

MMIRS is PI instrument, thus we need your approval for using MMIRS in observing request proposal.
We are looking forward to your good response.

Sincerely yours,

Sang-Hyun Chun

Scientific Justification

Backgrounds: Resolved massive stars in nearby galaxies provide important clues not only for the study of galaxy formation and evolution but also for testing the stellar evolution theory. Among various massive star populations, red supergiant stars (RSGs) with their initial masses between $9M_{\odot}$ and $30M_{\odot}$ are excellent sources to attempt such studies because of their unique physical properties. They can be relatively easily resolved in fairly distant galaxies given their high luminosities ($L > 10^4 L_{\odot}$). They are mostly younger than ~ 50 Myr, and can be used for the probe of the metallicities of star-forming regions of their host galaxies. RSGs are also known to have large radii and extended atmospheres with complex phenomena of turbulent convection, and strong mass loss [20]. These processes are considered in stellar evolution models with free parameters, and their effects on RSGs evolution are still subject to great uncertainty. For example, whether all RSGs evolve to a Type IIP supernova (SN IIP) or not is still not known, and the so-called red supergiant problem (a low maximum mass of the RSGs as SN IIP progenitors) [17, 18] is a controversial issue. For all these reasons, it is important to further investigate the physical properties of RSGs in nearby galaxies.

The previous observational studies on RSGs have focused on the galaxies in the Local Group with a limited range of metallicity: RSGs in Milky Way (Z=0.02) [11], the Magellanic Clouds (Z=0.004 and 0.007) [12], and M31 (Z=0.04) [13]. Investigations of RSGs in other galaxies in/beyond the Local Group have started only recently [3, 15].

In these studies, a curious issue regarding the effective temperatures of RSGs has emerged. The RSG temperatures are typically measured by the model fitting to TiO absorption bands in optical spectra [11, 12]. The temperatures obtained from this method show a correlation with metallicity [11, 12]: higher temperatures at lower metallicities, which is consistent with the prediction from current several evolutionary models. However, recent studies of RSGs [5, 6, 7, 15] suggested that the effective temperatures of RSGs obtained from J-band spectra [5] do not have any dependence on metallicities. To the contrary, these studies imply a single temperature range for all the RSGs. Davies et al. (2013) [6] recalculated the surface temperatures of RSGs in the Magellanic Clouds. They found that the temperatures from TiO lines are systematically lower than those obtained from the line-free continuum region or integrated flux. They concluded that TiO lines are not a good indicator for effective temperatures of RSGs and their temperatures are higher than previously thought. The higher temperatures of RSGs favor more compact radii of RSGs by 20% - 30%, and this is in line with the recent result from several studies on Type II-P supernova light curves. Dessart et al. (2013) explored the Type II-P supernova light curves resulting from various RSGs models and suggested that RSG progenitors should have a much smaller radius than the predicted values by stellar evolution models [8].

To resolve this discrepancy between the observation and theoretical predictions, we need to have a good understanding of the convective energy transport in the hydrogen-rich envelope. This physical process determines the radii of RSGs, hence their effective temperatures [10]. Recently we investigated how the convective energy transport depends on metallicity using a new grid of stellar evolution models (Sang Hyun Chun et al., in preparation [4]). Interestingly, we find that the energy transport efficiency in RSGs of M31, which has a super-solar metallicity, is systematically higher than in those of Magellanic Clouds and our galaxy. This finding leads us to question whether the physical processes in RSGs would also have a distinct feature in very metal poor environments.

Uniqueness of IC 1613: The dwarf irregular galaxy IC 1613 is an excellent target among the several nearby galaxies to address this question. This galaxy is a gas-rich dwarf irregular galaxy, isolated and known to have no interaction with other galaxies. The metallicity of this galaxy is about $Z = 0.001$ [2], which is lower than that of SMC. An observational study on RSGs of this galaxy would provide important observational constraints for physical properties of the RSGs for the lowest metallicity ever investigated. However, the majority of studies on stellar populations in this galaxy have focused on the asymptotic giant stars (AGBs) [2, 16] or a small number of Wolf-Rayet stars [19]. Only two RSG stars in IC 1613 were

[1] We have 103 RSG candidates in $21' \times 21'$ of IC 1613. Here we just list 21 RSGs including the examples of alignment star and telluric standard star. The full targets are indicated in attached list in last page. The telluric star is found at Gemini Telluric Standard Search. The full ranges in RA and DEC are RA-01:04:03.25~01:05:39.53 and DEC-01:55:03.39~02:19:21.90.

explored recently [1]. Chun et al. (2015), P.I. of this proposal, investigated the AGBs in IC 1613 and in this study they also identified about 250 RSGs of this galaxy using optical (gi) and near-infrared (JHK) photometric data (See Figure 2).

Objectives: Given the large sample of the identified RSGs in IC 1613, we plan to systematically investigate their properties using near-infrared spectra with MMIRS at MMT, for the first time. We will infer the fundamental stellar parameters such as effective temperatures, luminosities, and extinctions for a large sample of the RSGs in IC 1613. The obtained stellar parameters would make it possible to get constraints for the energy transport process in the convective envelope and the sizes of SN IIP progenitors in metal poor environments. This would eventually allow us to address the issue of the metallicity dependence of RSG effective temperatures. We also expect to derive the abundances of the RSGs in IC 1613 using J-band spectra with low-resolution as demonstrated by Davies et al.(2010) [5], which will serve as a critical information on the metallicity gradient across the galaxy and the evolution of the galaxy.

In summary, we propose a spectroscopic survey of RSG candidates in IC1613 with MMIRS/MMT in multi-slit mode. This study aims at investigating the physical properties of RSGs in IC 1613 using near-infrared (J-band) spectrum. Main goals of this observation are 1) to measure the fundamental stellar parameters of RSGs in IC 1613, 2) to get constraints for the energy transport process and size of SN IIP progenitors, 3) to confirm the metallicity dependence of RSG effective temperature, and 4) to obtain the information about the formation and evolution as well as the star formation history of IC 1613.

References

[1] N. E. Britavskiy, A. Z. Bonanos, A. Mehner, D. Garca-lvarez, J. L. Prieto, & N. I. Morrell 2014, A&A , 562, 75

[2] S.-H. Chun, M. Jung, M. Kang, J.-W. Kim, & Y.-J. Sohn, 2015 A&A , 578, 51

[3] S.-H. Chun, Y.-J. Sohn, M. Asplund, & L. Casagrande 2017, MNRAS , 467, 102

[4] S.-H. Chun, M.-K. Jung, D. Kim, J. Kim, & S.-C. Yoon in preparation

[5] B. Davies, R.-P. Kudritzki, & D. F. Figer 2010, MNRAS , 407, 1203

[6] B. Davies, R.-P. Kudritzki, B. Plez, S. Trager, A. Lanon, Z. Gazak, M. Bergemann, C. Evans, A. Chiavassa 2013, ApJ , 767, 3

[7] B. Davies, R.-P. Kudritzki, Z. Gazak, B. Plez, M. Bergemann, C. J. Evans, & L. R. Patrick 2015, ApJ , 806, 21

[8] L. Dessart, D. J. Hillier, R. Waldman, & E. Livne 2013, MNRAS , 433, 1745

[9] R. M. Humphreys, & K. Davidson 1979, ApJ , 232, 409

[10] R. Kippenhan & A. Weigert 1990, Stellar structure and Evolution (Berlin: Springer)

[11] E. M. Levesque, P. Massey, K. A. G. Olsen, B. Plez, E. Josselin, A. Maeder, & G. Meynet 2005, ApJ , 628, 973

[12] E. M. Levesque, P. Massey, K. A. G. Olsen, B. Plez, G. Meynet, & A. Maeder 2006, ApJ , 645, 1102

[13] P. Massey, D. R. Silva, E. M. Levesque, B. Plez, K. A. G. Olsen, G. C. Clayton, G. Meynet, & A. Maeder 2009, ApJ , 703, 402

[14] G. Meynet & A. Maeder 2000, A&A 361, 101

[15] L.R. Patrick, C.J. Evans, B. Davies, R.-P. Kudritzki, J. Z. Gazak, M. Bergemann, B. Plez, & A. M. N. Ferguson 2015, ApJ , 803, 14

[16] L. F. Sibbons, S. G. Ryan, M. Irwin, & R. Napiwotzki, 2015 A&A , 573, 84

[17] S. J. Smartt 2009, ARA&A , 47,64

[18] S. J. Smartt 2015, PASA, 32, 16

[19] F. Tramper, G. Grfener, O. E. Hartoog, H. Sana, A. de Koter, J. S. Vink, L. E. Ellerbroek, N. Langer, M. Garcia, L. Kaper, & S. E. de Mink 2013, A&A , 559, 72

[20] T. Verhoelst, N. van der Zypen, S. Hony, L. Decin, J. Cami, & K. Eriksson 2009, A&A , 498, 127

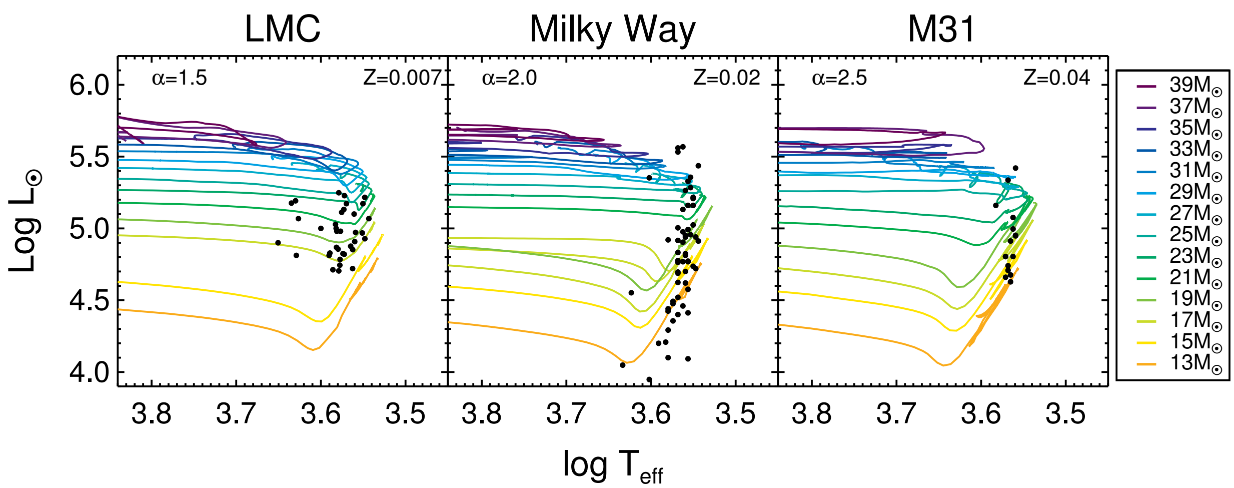

Figure 1: The H-R diagrams of RSGs in LMC [12], Milky Way [11] and M31 [13] with evolutionary tracks of several initial masses calculated by MESA model [4]. The adopted values of mixing length (α) varies for the RSGs with different metallicities (Z).

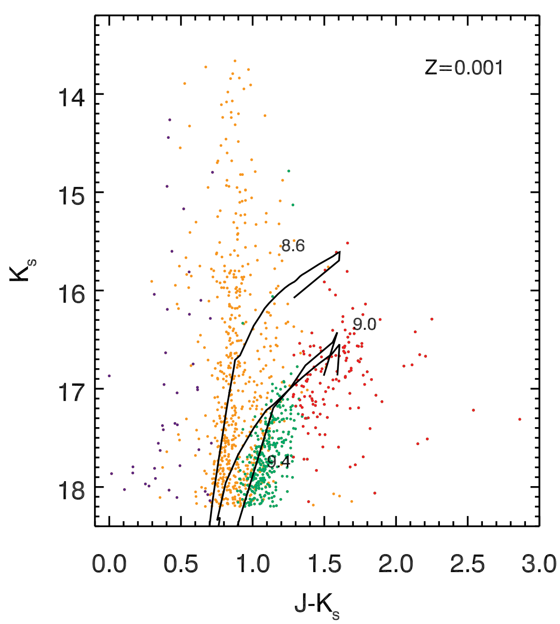

Figure 2: $(J - K_s, K_s)$ color-magnitude diagram of stars brighter than $K_s = 18.2$ with the theoretical isochrones of $\log(t_{yr}) = 8.6, 9.0$, and 9.4 with $Z = 0.001$. The green and red dots indicate the M-giant stars and C star in AGB stars, respectively. The red supergiant stars in IC 1613 are indicated by orange dots.

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)***

Sample selection: The sample selection for the RSGs of IC 1613 is motivated by our recent study of AGBs of this galaxy [2]. We note that the RSGs in IC 1613 have never been studied, and thus the RSG candidate catalogue of IC 1613 is not available yet in the literature. However, we already studied the stellar populations in $21' \times 21'$ area of IC 1613, and successfully classified them into the foreground Milky Way stars, RSGs, AGBs, and red giants stars by comparing the color-magnitude diagrams (CMDs) with several optical and near-infrared bands. In this work, about 250 RSGs candidates with magnitude range between 14 and 18 in K_s were finally identified (the orange-color dots in Figure 2), and we plan to obtain J-band spectra with at least S/N=50 for 103 bright RSGs ($K_s < 17$) in our RSGs catalogue using the MMIRS on MMT in this observation. The S/N of 50 is the minimum requirement to identify and measure the reliable atomic lines (e.g., Fe I-1.16108, 1.16414, 1.19763μm, Ti I-1.18299μm, and Mg I-1.18314, 1.20869μm) in J-band spectra as demonstrated by Davies et al. (2010) [5].

Technical Description: MMIRS on MMT is a powerful instrument to achieve our observation requirement and scientific goal. First, IC 1613 is located at a distance of 730 kpc, thus the observation using $6-8$m telescopes is necessary to obtain high signal-to-noise ratio in one or one and half hour exposure. Since the effective temperatures of RSGs obtained from near-infrared spectra are more reliable than those from optical region, near-infrared spectroscopy (more precisely J-band spectra with low resolution of $R \sim 2000$) of MMIRS is suitable for our study. Furthermore, we have 103 RSGs candidates displayed over $21' \times 21'$ sky, and multi-object spectroscopy with a wide-field view is essential. Given that the MMIRS has a capability of multi-slit spectroscopy in $4' \times 7'$ field of view, 6 masks are needed to get a statistically meaningful sample of RSGs across the region of IC 1613. We will use the J-grism, the zJ filter and created masks with $0''.5 \times 6''$ slits in this observation. This combination provides a spectral wavelength between $0.95 - 1.50\mu m$, which contains several atomic lines we are planning to analyse including Fe I, Ti I, and Mg I with an average spectral resolution of $R \sim 2000$. Based on the exposure time calculator, SNMMIRS, the required S/N~ 50 at $K_s < 17$ can be achieved with a total exposure of 3600 sec using $0''.5 \times 6''$ slit and in 0.7 arcsec seeing condition.

Analysis: The obtained spectroscopic data will be reduced by using the MMIRS data reduction pipeline. Then we will determine the fundamental stellar parameters including metallicity, effective temperature, and surface gravity. The spectral absorption line strengths of Fe I, Ti I, and Mg I in the wavelength range of $1.15 - 1.23\mu m$ will be measured by IRAF and compared with those of synthetic spectra derived from MARCS model atmospheres. The MARCS model is the most frequently used atmospheric model in RSGs studies, and is computed in local thermodynamic equilibrium with spherical symmetry for a range of stellar parameters. The best fitting model to these values would provide the stellar parameters of the RSGs in IC 1613.

The obtained effective temperatures would give the most valuable information on the energy transport process in the convective envelopes of RSGs. We will compare the temperatures of the RSGs in IC 1613 to those in other galaxies of various metallicities in order to more fully access temperature dependence by metallicity than in the previous work. In addition, the temperatures will be compared to our RSGs evolutionary models with different values in mixing length, overshooting, and semiconvection parameters at IC 1613 metallicity. Our previous study suggested that the mixing length parameter needs to be lowered with decreasing metallicity [4]. Therefore, we will be able to test if this trend can be extended to the IC 1613 metallicity.

Finally, the average metallicity and metallicity variations across the galaxy will be investigated in this study. The derived metallicities could be compared with those from blue supergiants, H II region measurements, and AGB. This will provide a crucial insight into the formation and evolution as well as the star formation history of IC 1613.

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**)*

We aims at obtaining at least S/N$\sim$ 50 with the spectra of RSGs with $K_s < 17$ for 103 RSG candidates in the field area $21' \times 21'$ of IC 1613, using MMIRS on MMT. We examined sky positions of RSGs and appropriate alignment stars, and then selected 6 mask fields to maximize the number of RSG targets and alignment stars. The sky positions of our targets and alignment stars are based on the 2MASS catalogue. In addition, telluric standard stars of A0V will be secured during the observation in order to calibrate the telluric absorption features and to perform a relative flux calibration.

We will use the J-grism, the zJ filter and masks with $0''.5 \times 6''$ slits. We plan to use the recommended four dithering patterns with +1.6, -1.2, +1.2, -1.6 arcsec offsets along the slit, and a 300 sec exposure in each dithering position. This means that we need 3 observation runs for one mask field to satisfy the total exposure time of 3600 sec. We will take a calibration frame (argon arc lamp and flat frame) before the mask field observation, and telluric standard stars will be taken after one mask field observation. In this observation plan, the observation time for one mask is 89 min (10 min for acquisition and mask alignment, 5 min for calibration frames, 60 min for target field - 3×4 dithering points$\times$300 sec, 4 min for readout and dithering time, and 10 min for telluric standard star). Therefore we request 8.9 hours for 6 masks (89 min$\times$ 6 masks) in total. The grey or bright time is preferred, and we wish this observation will proceed in the condition of airmass$<$ 1.5 to minimize the differential atmospheric refraction during the period between September and October.

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**)*

Attachment of Target list

#	Object	RA	DEC	mag, comment
1	T22435	01:04:03.25	+02:02:23.71	K_s=16.5113
2	T22177	01:04:04.59	+02:14:46.61	K_s=15.6453
3	T21737	01:04:06.92	+01:58:59.48	K_s=13.8373
4	T21625	01:04:07.51	+02:01:05.09	K_s=16.6573
5	T21541	01:04:08.23	+02:02:51.00	K_s=13.6633
6	T21488	01:04:08.69	+02:04:35.18	K_s=15.5943
7	T21429	01:04:09.07	+02:11:03.52	K_s=16.8693
8	T21381	01:04:09.41	+01:57:17.50	K_s=16.0513
9	T21375	01:04:09.44	+02:13:06.38	K_s=15.4303
10	T21274	01:04:10.13	+02:05:54.20	K_s=16.7363
11	T21049	01:04:12.03	+02:02:29.11	K_s=15.8653
12	T21051	01:04:12.03	+01:55:53.29	K_s=16.2843
13	T20917	01:04:12.98	+02:02:18.60	K_s=16.8293
14	T20450	01:04:16.38	+02:06:17.10	K_s=16.3903
15	T20393	01:04:16.86	+02:09:00.90	K_s=16.9403
16	T20352	01:04:17.14	+02:13:15.10	K_s=14.6803
17	T20161	01:04:18.37	+02:17:08.92	K_s=16.6463
18	T20076	01:04:18.92	+01:56:35.92	K_s=16.5823
19	T20035	01:04:19.15	+01:57:26.60	K_s=14.4593
20	T20001	01:04:19.40	+02:16:56.10	K_s=16.9213
21	T19926	01:04:19.77	+02:01:18.98	K_s=16.7313
22	T19713	01:04:20.98	+02:11:24.11	K_s=16.1603
23	T19654	01:04:21.28	+02:06:35.71	K_s=16.7843
24	T19583	01:04:21.70	+02:17:00.31	K_s=15.8023
25	T19466	01:04:22.40	+02:06:34.81	K_s=15.7533
26	T19442	01:04:22.49	+02:09:45.11	K_s=16.4433
27	T19176	01:04:23.82	+02:02:17.48	K_s=14.8783
28	T19077	01:04:24.34	+02:03:24.01	K_s=16.8733
29	T18954	01:04:24.92	+02:07:33.82	K_s=16.3763
30	T18945	01:04:24.95	+01:58:31.12	K_s=15.7983
31	T18520	01:04:27.12	+02:13:09.01	K_s=16.1403
32	T18397	01:04:27.65	+02:17:11.00	K_s=15.2483
33	T18235	01:04:28.35	+02:16:31.40	K_s=16.7403
34	T18203	01:04:28.46	+02:06:35.71	K_s=16.2863
35	T18169	01:04:28.65	+01:58:02.60	K_s=15.0913
36	T17970	01:04:29.60	+02:03:41.29	K_s=16.2503
37	T17190	01:04:32.67	+01:55:25.61	K_s=15.9723
38	T17154	01:04:32.80	+02:14:35.48	K_s=16.0043
39	T16892	01:04:33.74	+02:02:02.11	K_s=15.9713
40	T16715	01:04:34.47	+02:05:29.40	K_s=16.6363
41	T16668	01:04:34.64	+01:58:19.81	K_s=16.4103
42	T16177	01:04:36.18	+01:55:46.81	K_s=15.5113
43	T16163	01:04:36.24	+02:17:02.11	K_s=16.0673
44	T16139	01:04:36.34	+02:18:32.18	K_s=16.0153
45	T15637	01:04:37.79	+02:11:05.60	K_s=16.9883
46	T15127	01:04:39.26	+02:10:57.79	K_s=16.9013
47	T15050	01:04:39.46	+02:00:07.99	K_s=14.2013
48	T13470	01:04:43.20	+02:15:10.30	K_s=14.9523
49	T13400	01:04:43.36	+02:17:45.89	K_s=15.0833
50	T12930	01:04:44.43	+01:57:49.61	K_s=16.1763
51	T11399	01:04:47.92	+02:09:05.69	K_s=16.6893
52	T09933	01:04:51.44	+02:14:35.81	K_s=16.6653
53	T09915	01:04:51.48	+02:15:29.59	K_s=16.4353
54	T09906	01:04:51.50	+02:03:22.79	K_s=14.9983
55	T09770	01:04:51.84	+01:57:55.58	K_s=16.8303
56	T09327	01:04:52.96	+02:10:15.20	K_s=16.0723
57	T09278	01:04:53.09	+02:03:33.41	K_s=16.0033
58	T09160	01:04:53.43	+02:00:55.19	K_s=15.9823

59	T08651	01:04:54.82	+02:00:40.90	K_s=16.7673
60	T08568	01:04:55.08	+02:05:17.02	K_s=16.8213
61	T08139	01:04:56.32	+02:01:53.29	K_s=13.7933
62	T08095	01:04:56.44	+02:00:23.62	K_s=15.1883
63	T07921	01:04:56.91	+02:15:38.30	K_s=16.8923
64	T07788	01:04:57.33	+02:19:21.90	K_s=16.7383
65	T07429	01:04:58.26	+02:19:18.98	K_s=16.9523
66	T07253	01:04:58.74	+02:14:34.58	K_s=14.6003
67	T07197	01:04:58.87	+02:05:17.09	K_s=15.9083
68	T06792	01:05:00.09	+02:14:53.02	K_s=13.8433
69	T06758	01:05:00.23	+02:15:11.92	K_s=15.4203
70	T06616	01:05:00.60	+02:15:56.70	K_s=16.1823
71	T06299	01:05:01.55	+02:15:22.21	K_s=15.9753
72	T06077	01:05:02.30	+02:06:27.68	K_s=15.5613
73	T05836	01:05:03.02	+01:55:18.91	K_s=15.6363
74	T05328	01:05:05.02	+02:01:57.90	K_s=14.2403
75	T05086	01:05:05.97	+01:55:03.40	K_s=15.8663
76	T04630	01:05:07.81	+02:17:30.52	K_s=15.8243
77	T04598	01:05:07.94	+02:12:57.49	K_s=16.6793
78	T04501	01:05:08.37	+01:58:44.51	K_s=14.9403
79	T04399	01:05:08.89	+02:07:18.08	K_s=15.8183
80	T04378	01:05:09.00	+02:08:48.80	K_s=15.8623
81	T04025	01:05:10.64	+02:09:50.11	K_s=16.7703
82	T04003	01:05:10.71	+02:08:52.58	K_s=16.1603
83	T03705	01:05:12.28	+02:17:31.60	K_s=16.5483
84	T03098	01:05:15.44	+02:06:18.22	K_s=16.3333
85	T02984	01:05:16.17	+02:04:49.91	K_s=15.8363
86	T02890	01:05:16.70	+02:11:15.40	K_s=13.9083
87	T02820	01:05:17.11	+02:09:18.22	K_s=16.7613
88	T02785	01:05:17.31	+02:02:32.60	K_s=15.1033
89	T02467	01:05:19.41	+02:04:37.99	K_s=15.8003
90	T02401	01:05:19.87	+02:00:48.82	K_s=16.0213
91	T02347	01:05:20.18	+02:03:42.01	K_s=15.9223
92	T02338	01:05:20.23	+02:00:18.29	K_s=13.9803
93	T02298	01:05:20.50	+02:15:04.10	K_s=16.8563
94	T02105	01:05:21.97	+02:03:28.01	K_s=16.3683
95	T02012	01:05:22.71	+02:12:57.71	K_s=15.8623
96	T02011	01:05:22.71	+02:04:58.91	K_s=16.8463
97	T01672	01:05:25.52	+02:14:13.42	K_s=14.9793
98	T01639	01:05:25.91	+02:16:53.51	K_s=14.7903
99	T01600	01:05:26.22	+02:12:36.22	K_s=15.4813
100	T00464	01:05:36.45	+02:05:31.60	K_s=16.2563
101	T00125	01:05:38.69	+02:06:15.52	K_s=15.9143
102	T00025	01:05:39.33	+02:04:02.71	K_s=14.4843
103	T00012	01:05:39.53	+02:06:16.88	K_s=16.5473
104	A01203	01:04:43.24	+02:15:14.06	H=14.00, e.g. Alignment star
105	A00015	01:05:02.17	+02:10:16.02	H=15.50, e.g. Alignment star
106	H116886	23:41:33.51	+10:12:57.00	V=9.91, e.g. Telluric star