SCIENTIFIC AIM AND RATIONALE

SCIENTIFIC RATIONALE

Symbiotic stars are interacting wide binaries, consisting of an evolved giant transferring mass to a hot compact object (in most cases a white dwarf). A substantial fraction of the mass flow can be accreted on the compact object via a slow stellar wind. The wind accretion process with a high-accretion rate makes them as possible Type Ia supernovae progenitors, which is one of paramount issues in astrophysics and cosmology (Dimitriadis et al. 2014, Mikołajewska 2013, Dilday et al. 2012).

The heterogenous environment in the symbiotic binaries includes the nebular region photoionized by strong far-UV radiation from the hot source and the dense neutral region around the giant, providing an excellent laboratory to study Raman-scattering by H I. If a far-UV photon with wavelength shorter than Lyα is incident on a H I atom in the ground state, it can be inelastically scattered to emit a photon with a lower energy. This Raman scattering process by H I was noted by Schmid(1989), who proposed that the broad emission features at 6825 Å and 7082 Å in many symbiotic stars are the result of Raman-scattering of O VI $\lambda\lambda$1032 and 1038.

Also Raman-scattered He II features are formed blueward of hydrogen Balmer lines, if the far-UV He II lines with a slightly shorter wavelength than Lyman series are incident on H I atoms. A He II λ 1025 photon, arising from a $6 \rightarrow 2$ transition, interacts with an H I atom in the ground state, to produce an optical photon at 6545 Å with a de-excitation of the H I atom to the 2s state. Similar processes with He II λ 972 and 949 photons give rise to Raman features at 4850 Å and 4332 Å, respectively. The scattering cross sections range from 10^{-21} to 10^{-20}cm^2, enabling one to probe a neutral region with H I column density of $10^{20} - 10^{21}$cm^{-2} and thereby to study the mass loss process characteristic of evolved giants (Jung & Lee 2004; Lee 2012). Observationally the Raman-scattered He II features have been detected in a number of symbiotic stars and planetary nebulae (Péquignot et al. 1997; Groves et al. 2002; Lee et al. 2006; Kang et al. 2009).

The main parameters to affect the strength of Raman He II features include the H I column density $N_{H\ I}$ and the covering factor of the scattering region. By performing Monte Carlo simulations the Raman conversion efficiencies can be computed as a function of $N_{H\ I}$ and the covering factor. However, one serious issue of using a Raman He II 6545 feature is that it is blened with the strong forbidden emission [N II] λ6548, preventing an unambiguous isolation of the Raman feature. Therefore, a clear detection of Raman He II features at 4850 Å and 4332 Å is essential to investigate the mass loss processes in symbiotic stars. These two Raman He II features are approximately 5 times fainter than Raman He II 6545 feature, a large telescope is therefore needed to achieve our goal.

SCIENTIFIC AIM

We propose deep high-resolution spectroscopy of 11 southern symbiotic stars and 2 planetary nebulae with the MIKE at the Magellan-Clay telescope, in order to secure Raman He II features at 6545 Å, 4850 Å and 4332Å blueward of Hα, Hβ and Hγ, respectively. Combined with Monte Carlo simulations, this observation will provide strong constraints on the kinematics and the mass of the H I region and extend our understanding of mass loss process in symbiotic stars.

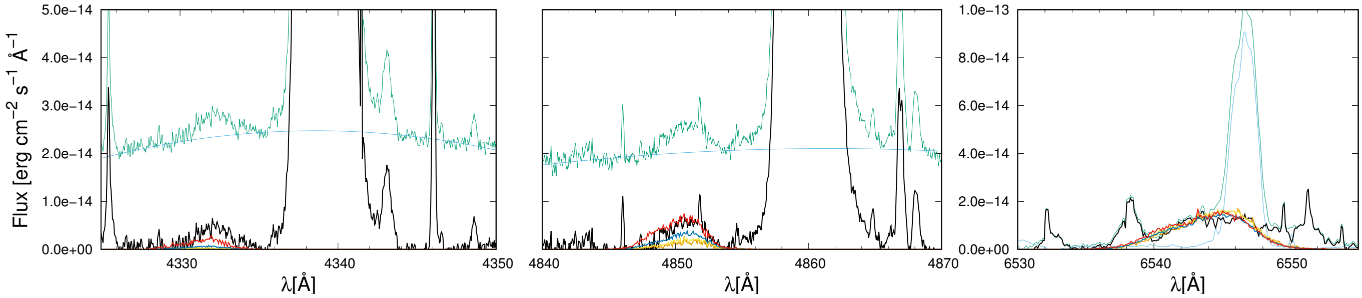

Figure 1: Raman-scattered He II features at 4332 Å (left panel), 4850 Å (middle panel) and 6545 Å (right panel) of the symbiotic star RR Tel obtained with the MIKE in July 2016. The data were combined with 3×1500 sec exposures. Our preliminary simulation results are shown by the red, blue and yellow lines for column densities of $N_{H\ I} = 10^{20}, 10^{21}$ and 10^{22} cm^{-2}, respectively. It appear that the observed data are consistent with the H I column density $N_{H\ I} > 1 \times 10^{22}$ cm^{-2} (Heo et al. in preparation).

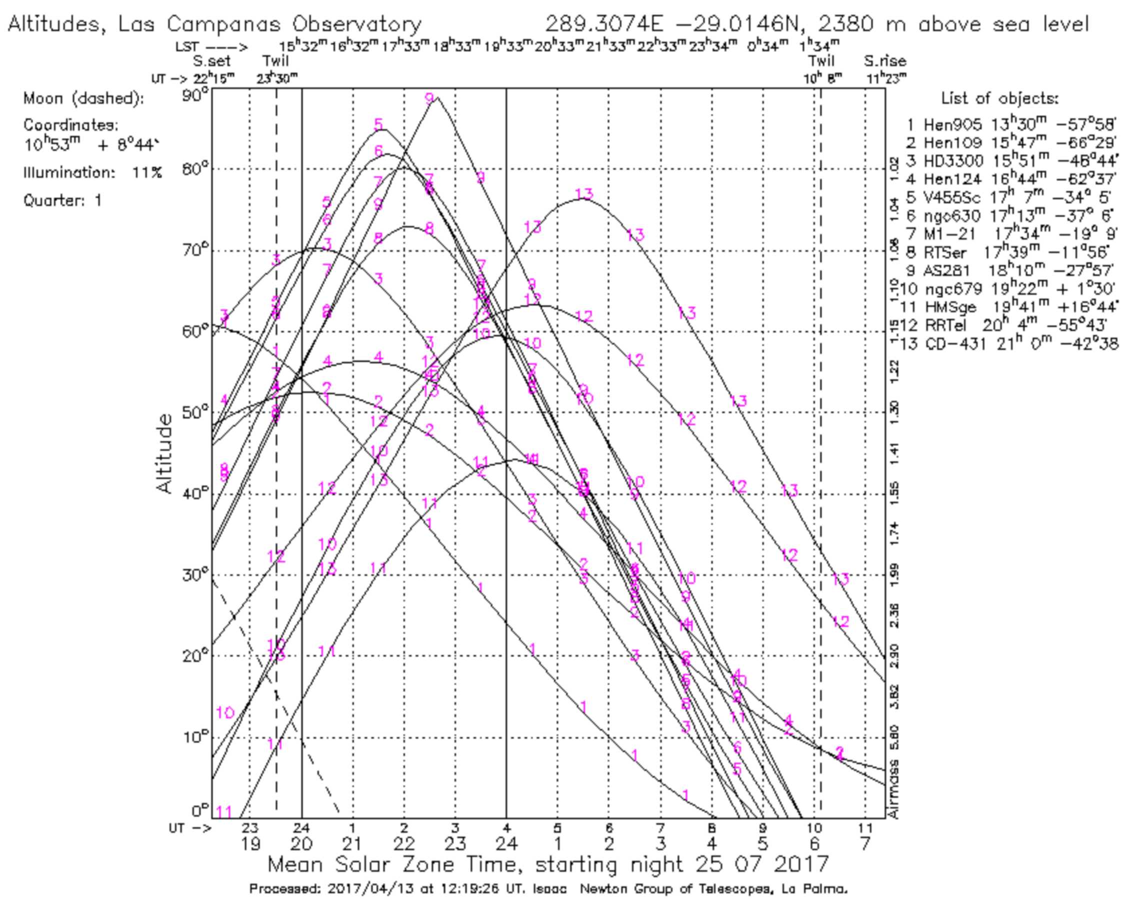

Figure 2: Target visibility for the night of July 25 from Las Campanas Observatory

Name	α	δ	Epoch	Mag.	
Hen 905	13 30 37.16	-57 58 20.2	J2000	V=12.5	SS
Hen 1092	15 47 10.50	-66 29 16.2	J2000	V=11.6	SS
HD330036	15 51 15.93	-48 44 58.5	J2000	V=11.28	SS
Hen 1242	16 44 35.47	-62 37 14.0	J2000	V=11.38	SS
V455 Sco	17 07 21.73	-34 05 14.5	J2000	V=14.00	SS
ngc 6302	17 13 44.339	-37 06 10.95	J2000	V=10.10	PN
M1-21	17 34 17.22	-19 09 23.0	J2000	B=14.0	SS
RT Ser	17 39 51.98	-11 56 39.0	J2000	V=10.6	SS
AS 281	18 10 43.86	-27 57 50.1	J2000	V=13.6	SS
ngc 6790	19 22 56.966	+01 30 46.46	J2000	V=10.45	PN
HM Sge	19 41 57.086	+16 44 39.94	J2000	V= 11.10	SS
RR Tel	20 04 18.54	-55 43 33.2	J2000	V=10.81	SS
CD-43 14304	21 00 06.36	-42 38 44.9	J2000	V=11.0	SS

Table 1: Target list

References

Dilday, B., Howell, D.A., Cenko, S.B., et al. 2012, Sci, 337, 942

Dimitriadis, G., Chiotellis, A. & Vink, J. 2014, MNRAS, 443, 1370

Groves, B., Dopita, M., Williams, R.E. & Hua, C.-T. 2002, PASA, 19, 425

Jung, Y.-C., & Lee, H.-W. 2004, MNRAS, 355, 221

Kang, E.-H., Lee, B.-C. & Lee, H.-W. 2009, ApJ, 695, 542

Lee, H.-W., Jung, Y.-C., Song, I.-O. & Ahn, S.-H. 2006, ApJ, 636, 1045

Mikołajewska, J. 2013, IAUS, 281, 162

Péquignot, D., Baluteau, J.-P., Morisset, C. & Boisson, C. 1997, A&A, 323, 217

Schmid, H. M. 1989, A&A, 211, 31

CURRENT STATUS OF THE PROJECT

This proposal is part of the recently started 3-year project entitled *"High Resolution Spectroscopic Study of Wind Accretion and Mass Loss in Stellar Systems Involving White Dwarfs"*, completely funded by the Korea Astronomy and Space Science Institute (KASI) with the explicit goal of fostering collaborative research between Korean and Chilean astronomers. The official webpage of the project is at `http://korea-chile.com`.

In the framework of this collaboration, last two semesters we were awarded half a night on July 30, 2016 (CN 2016B-82) and 1 night on March 10, 2017 (CN 2017A-143) with MIKE at Magellan-Clay telescope. The data reduction of 2016B observation has been completed and data analysis is currently in progress (Chang et al. 2017 submitted to ApJ, Heo et al. in preparation).

Publications

Ahn, S.-H. & Lee, H.-W. 2015, JKAS, 48, 195: *Polarization of Lyman α Emergent from a Thick Slab of Neutral Hydrogen*

Bach, K. & Lee, H.-W. 2015, MNRAS, 446, 264: it Accurate Lyα scattering cross-section and red damping wing in the re-ionization epoch

Angeloni, R., Ferreira Lopes, C. E., Masetti, N., et al. 2014, MNRAS, 438, 35: *Symbiotic stars in OGLE data - I. Large Magellanic Cloud systems*

Chang, S.-J., Heo, J.-E., Lee, H.-W. et al. 2017, submitted to ApJ *Formation of Resonantly Scattered Hα and Lyβ in Hot and Optically Thick Media*

Chang, S.-J., Heo, J.-E., Di Mille, F., et al. 2015, ApJ, 814, 98: *Formation of Raman Scattering Wings around Hα, Hβ, and Paα in Active Galactic Nuclei*

Heo, J.-E. & Lee, H.-W. 2015, JKAS, 48, 105: *Accretion Flow and Disparate Profiles of Raman Scattered O VI λ1032, 1038 in the Symbiotic Star V1016 Cygni*

Heo, J.-E., Angeloni, R., Di Mille, F., et al., 2016, ApJ, 833, 286 *A Profile Analysis of Raman-scattered O VI Bands at 6825 Å and 7082 Å in Sanduleak's Star*

Lee, H.-W. 2013, ApJ, 772, 123: *Asymmetric Absorption Profiles of Lyα and Lyβ in Damped Lyα Systems*

Lee, H.-W., Heo, J.-E. & Lee, B.-C. 2014, MNRAS, 442, 1956: *Raman-scattered Ne VII λ973 at 4881Å in the symbiotic star V1016 Cygni*

Lee, Y.-M, Lee, D.-S., Chang, S.-J., et al., 2016, ApJ, 833, 75 *A Monte Carlo Study of Flux Ratios of RamanScattered O VI Features at 6825 Å and 7082 Å in Symbiotic Stars*

TECHNICAL DESCRIPTION

The measurement of the line centers and strengths of the Raman He II features requires high resolving power exceeding 30,000. In consideration of the weakness of Raman scattered He II features, the huge resolving power of MIKE combined with the large collecting area of Magellan-Clay telescope is essential to accomplish our aim.

Additionally MIKE covers the wide wavelength range from 3200 to 10000 Å, allowing us to obtain many optical He II emission lines at 4340, 4686, 4859, 6527 and 6560 Å simultaneously. With the case B recombination theory, these He II lines can be used to deduce the fluxes of far-UV incident 1025 Å , 972 Å and 949 Å in a fairly reliable manner. A theoretical modeling adopting a Monte Carlo technique can be performed to infer the Raman conversion efficiencies as a function of the H I column density and the covering factor of the scattering region.

With this proposal, we request 1 night of high-resolution spectroscopy with the MIKE at the Magellan-Clay telescope to secure high quality spectra showing clear Raman He II features. Our target list includes 11 symbiotic stars and 2 planetary nebulae, which are carefully selected by previous observations. Those objects are known to exhibit the Raman He II or potential candidates having these features.

According to our previous experience with the instrument (Fig. 1) and the tabulated zero points, a count rate of 5 e-/pixel at 6000 Å is obtained for V$\sim$13 mag when we assumed 0.8 arcsec seeing and airmass 1. In order to reach S/N$\sim$100 per pixel we need an overall time on target of 2,000 seconds that, given the brightness distribution of our targets, can be considered as an averaged estimate. Also we need additional spectra with short exposures of 1, 5 and 10 seconds to obtain the profiles of strong emission lines (e.g, H and [O III] lines) without being saturated. With this in mind, our strategy is to collect 1$\times$10 sec and 4$\times$500 sec exposures for each target. For the flux calibration it is required to observe standard objects at least three times at night. Taking into account the overheads including readout time with 'slow, low-noise mode' (160 sec), we estimate that it will take 40 min on average for 1 object. For a total of 13 objects, 9 hours is required and we thus request 1 night of MIKE telescope time.