Raman He II in Young PNe

Hee-Won Lee, Seok-Jun Chang

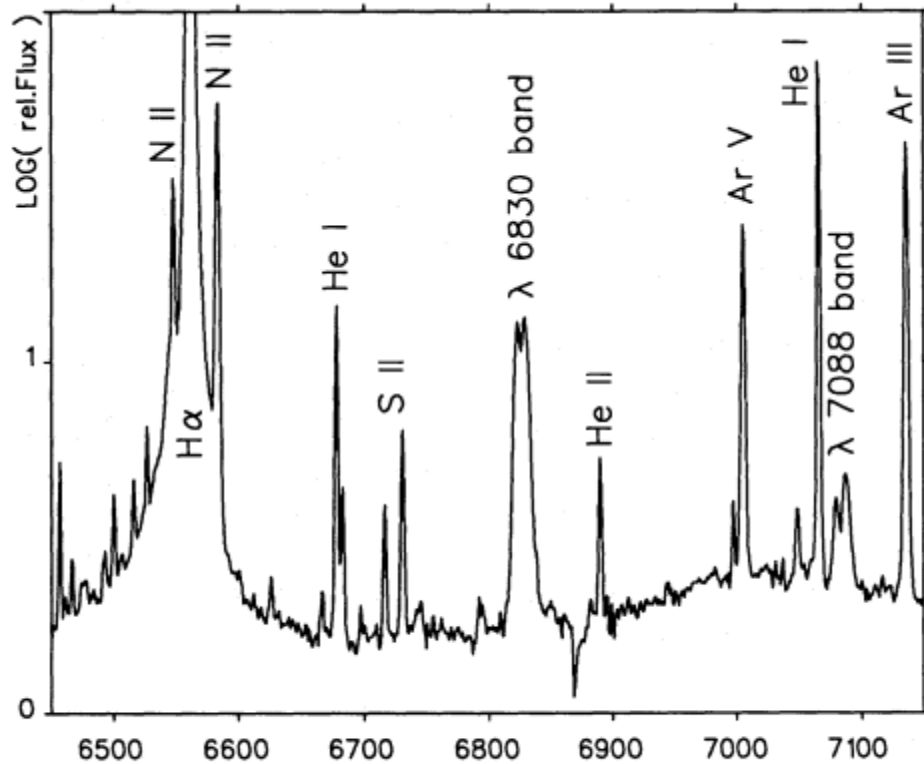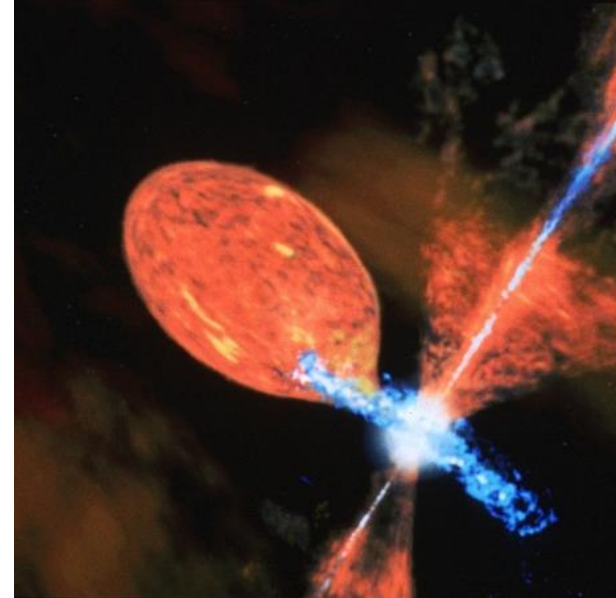Sejong University

Discovery of Raman Scattered Lines

Fig.1. Raman scattered emission bands in the symbiotic star V1016 Cyg. The spectrum was obtained on the 1.93m telescope at the Observatoire de Haute Provence.

Symbiotic Star
composed of
hot white dwarf and
cool red giant

- Raman scattered lines are relatively broader than other emission lines.
- Schmid (1989) identify Raman Scattered O VI at 6825 Å and 7082 Å in V1016 Cyg.
- The incident photons are O VI λ1032 and λ1038.
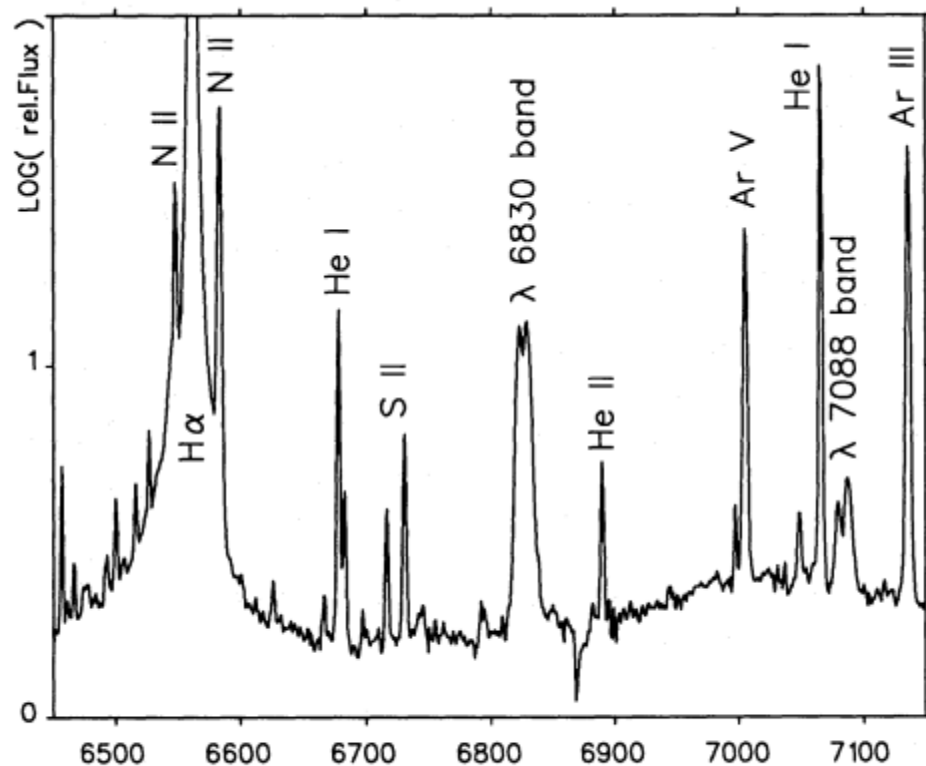
Discovery of Raman Scattered Lines

Fig.1. Raman scattered emission bands in the symbiotic star V1016 Cyg. The spectrum was obtained on the 1.93m telescope at the Observatoire de Haute Provence.
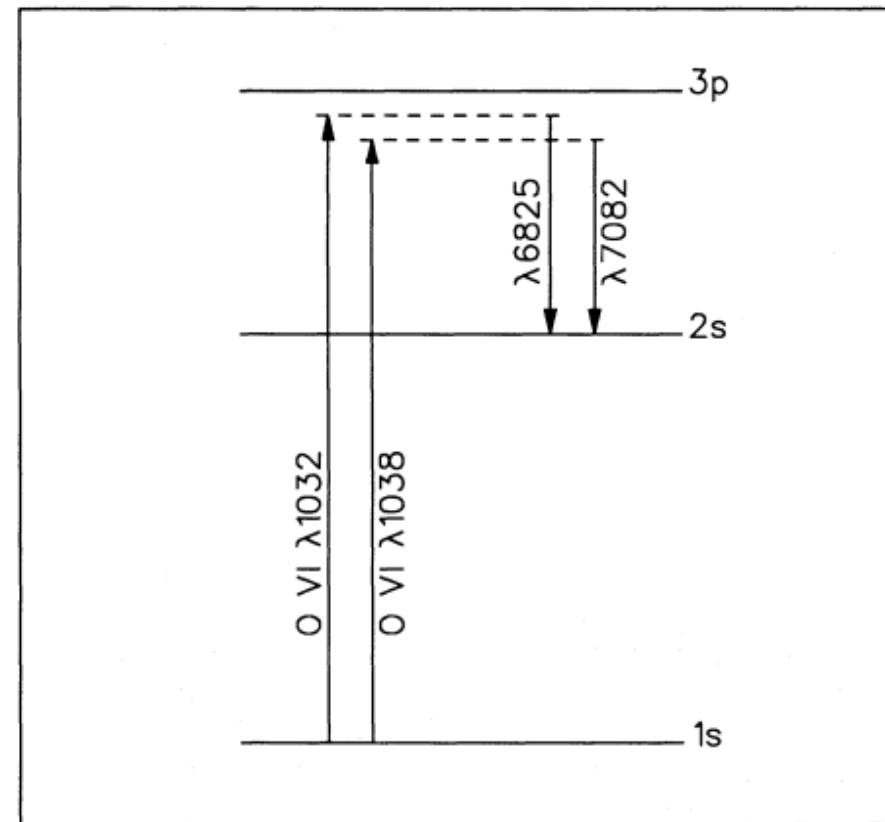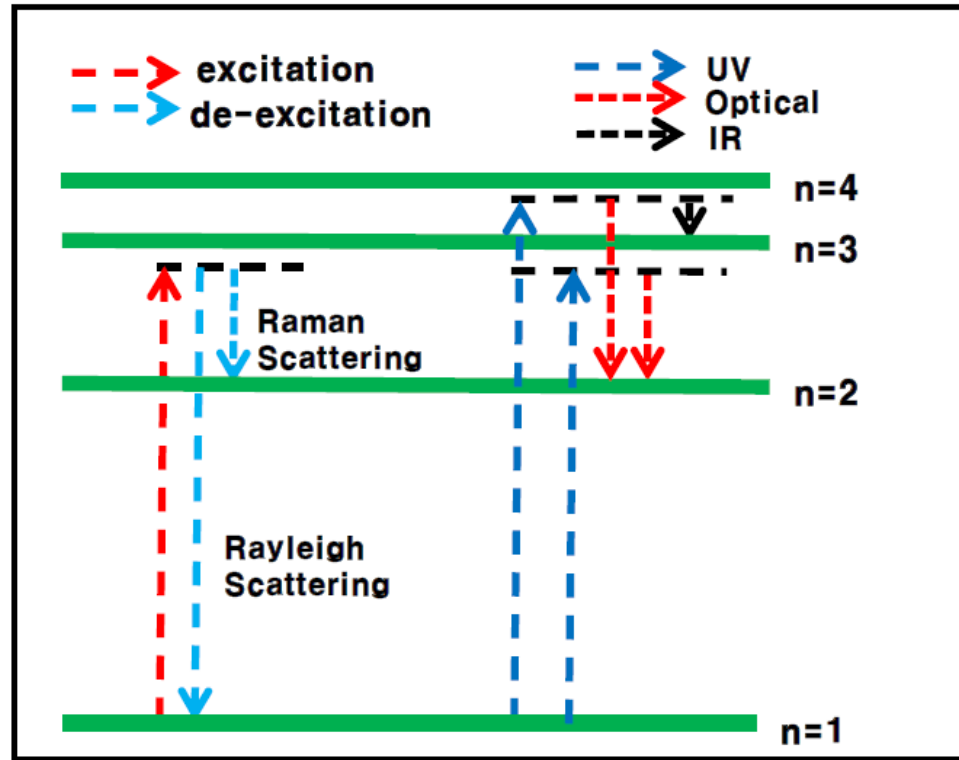

Fig.2. Schematic energy level diagram for Raman scattering of OVI photons by neutral hydrogen.

- Raman scattered lines are relatively broader than other emission lines.
- Schmid (1989) identify Raman Scattered O VI at 6825 Å and 7082 Å in V1016 Cyg.
- The incident photons are O VI λ1032 and λ1038.

Line Broadening by Raman Scattering

Hydrogen Atomic Level

Energy Conservation

$$E_i = E_s + E_{Ly\alpha}$$

$$h\nu_i = h\nu_s + h\nu_{Ly\alpha}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda_s} + \frac{1}{\lambda_{Ly\alpha}}$$

Derivation

$$\frac{1}{\lambda_i^2} d\lambda_i = \frac{1}{\lambda_s^2} d\lambda_s$$

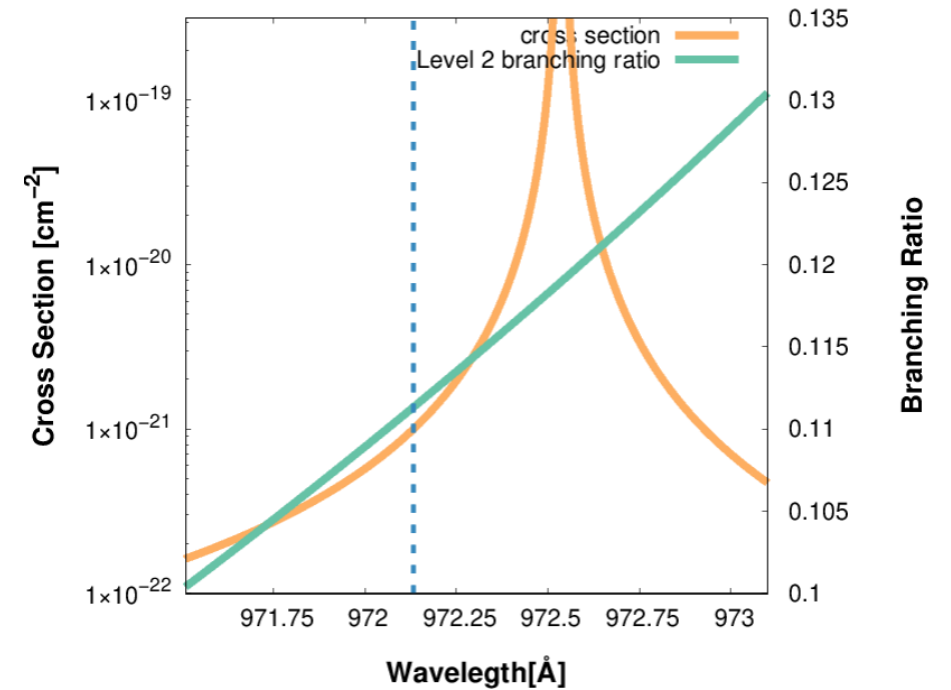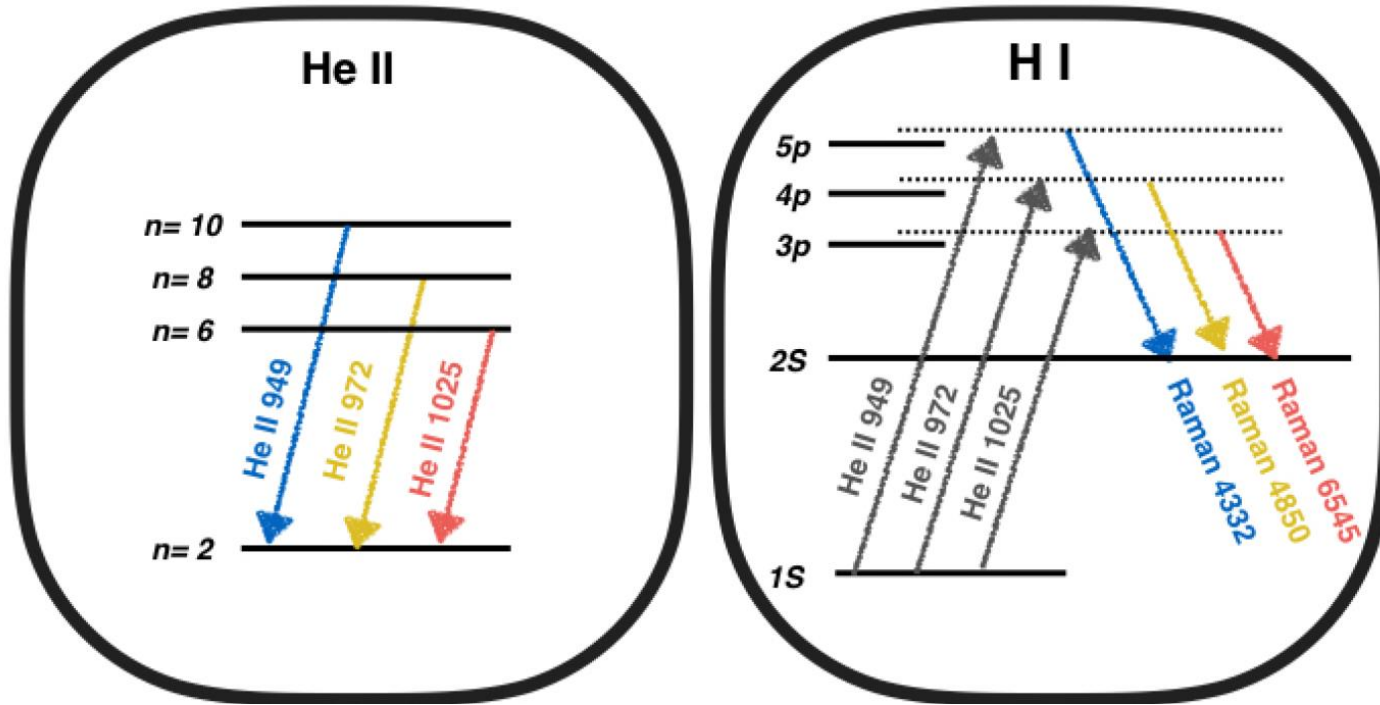$$\frac{d\lambda_s}{d\lambda_i} = \frac{\lambda_s^2}{\lambda_i^2}$$

Wavelength Broadening

$$\frac{d\nu_s}{d\nu_i} = \frac{\lambda_s}{\lambda_i}$$

Velocity Broadening

- When far-UV photons are Raman scattered by an atomic hydrogen, the lines are broadened.

- This broadening factor are considered as the photon scatter in the non-static medium.

Raman He II Lines

The cross section and the branching ratio to 2s state near Lyγ

- He II is hydrogenlike atom.

- The wavelength of He II Balmer lines are slightly shorter than H I Lyman lines.

- The wavelength of Raman He II lines are short shorter than H I Balmer Lines.
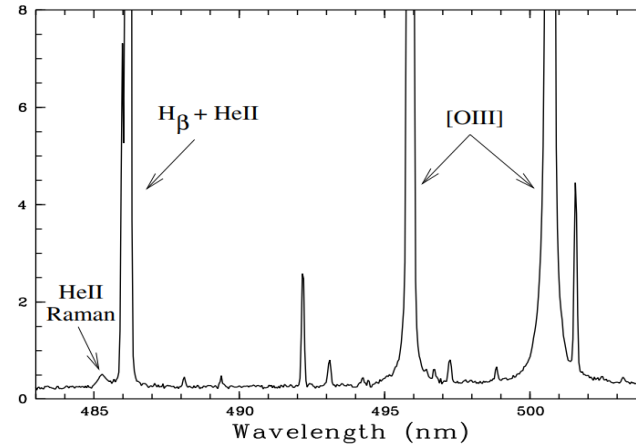
Raman Scattered Lines in Young PNe
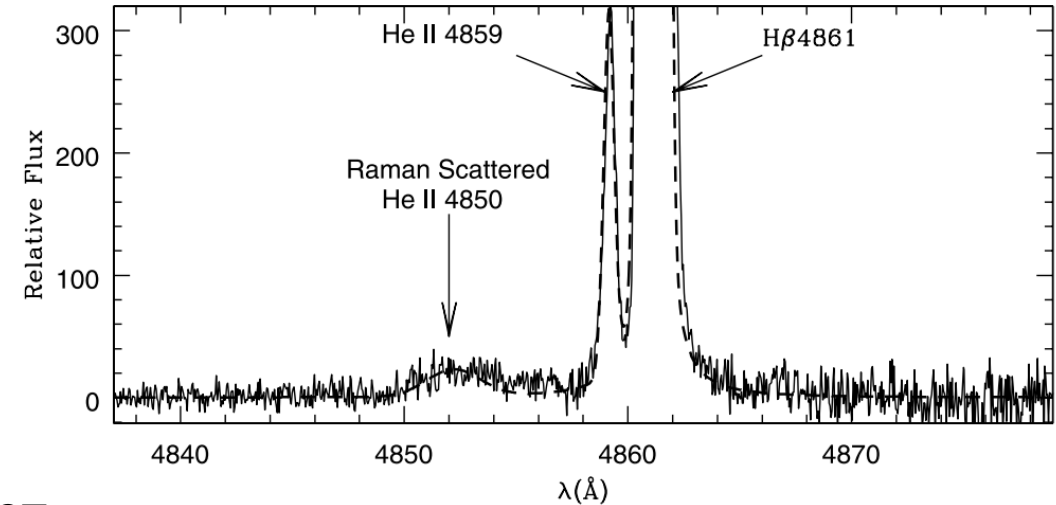

Planetary Nebula
(NGC 7027)
End Stage of
the stars of which
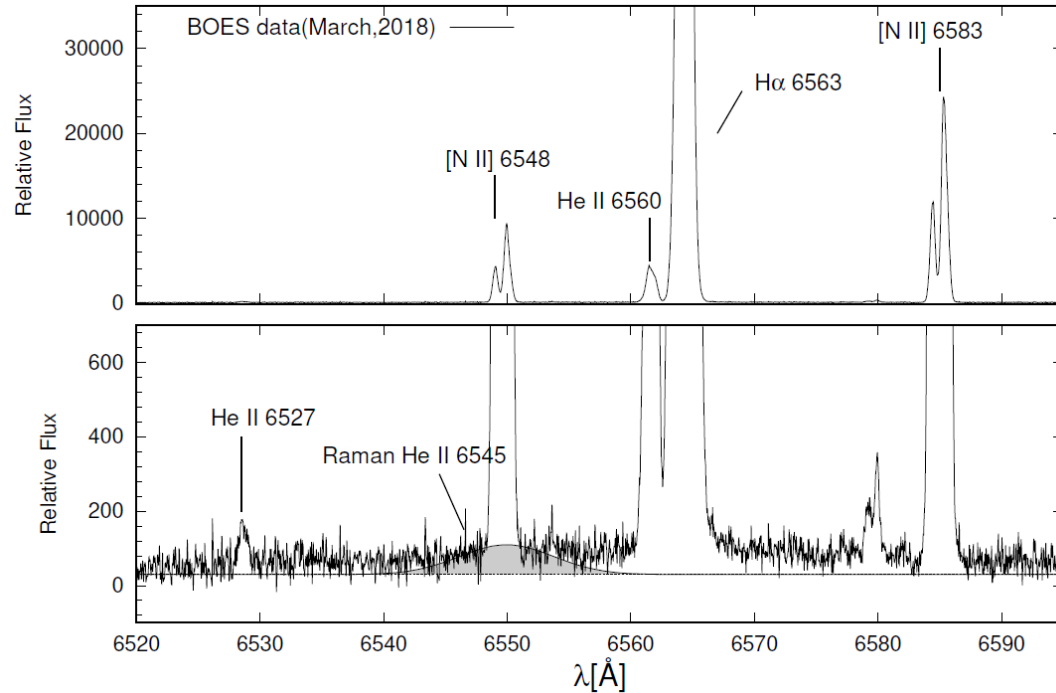$M_* < 8M_{sun}$

Raman He II 4850 in PN, NGC 7027
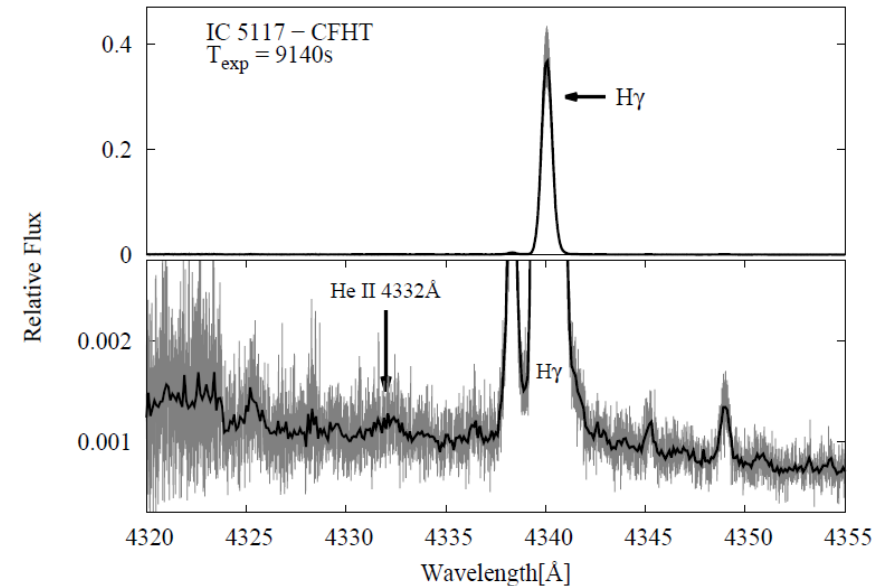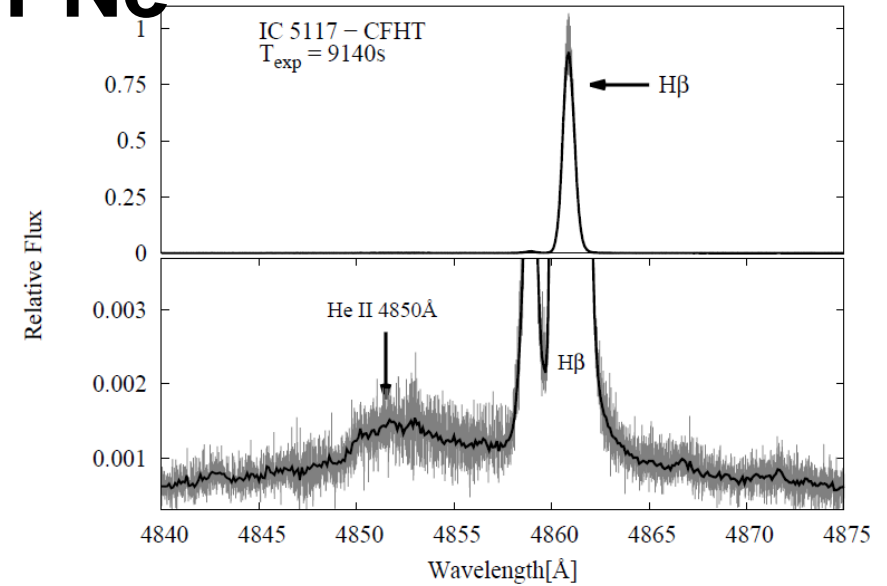**(Pequignot et al 1997)**

Raman He II 4850 in PN, IC 5117
(Lee et al 2006)

- The spectra of Young PNe have Raman scattered lines.
- Pequignot et al 1997 reveals Raman He II in NGC 7027 first time.
- Raman He II lines are discovered in NGC 6302 (Groves et al. 2002), IC 5117 (Lee et al. 2006) and NGC 6790 (Kang et al. 2009).
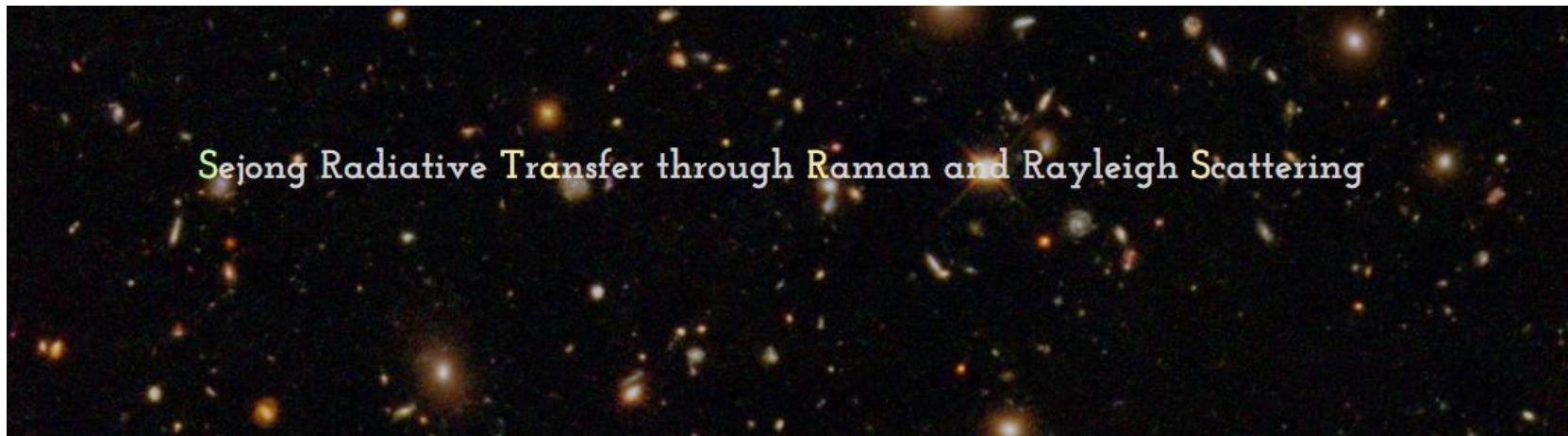
Raman Scattered Lines in Young PNe

Raman He II 6545 in J900
(BOES data)

Raman He II 4850 and 4332 in IC 5117
(CFHT data)

Monte-Carlo Radiative Transfer Code : STaRS

Sejong Radiative Transfer through Raman and Rayleigh Scattering

STaRS is the code for Radiative Transfer through Raman and Rayleigh Scattering with atomic hydrogen.
This code is 3D grid based Monte Carlo simulation tracing each generating photon packet.
The information of the photon packet include wavelength, position, and polarization.

The paper for STaRS is accepted for publication in JKAS.
The link for the manuscript in astro-ph
https://arxiv.org/abs/2012.03424

The link of Github for STaRS
https://github.com/csj607/STaRS

Publication List using STaRS

- Bo-Eun Choi, Hee-Won Lee, 2020, ApJL, 903, L39, **Discovery of Raman-scattered He II λ6545 in the Planetary Nebulae NGC 6886 and NGC 6881**
- Bo-Eun Choi, **Seok-Jun Chang**, Ho-Gyu Lee, and Hee-Won Lee, 2020, ApJ, 899, 12C, **Line Formation of Raman-scattered He II λ 4851 in an Expanding Spherical H I Shell in Young Planetary Nebulae**