Raman-scattered He II feature at 6545 in the D-type Symbiotic Star H1-36

Symbiotic stars, weird novae and related embarrassing binaries,
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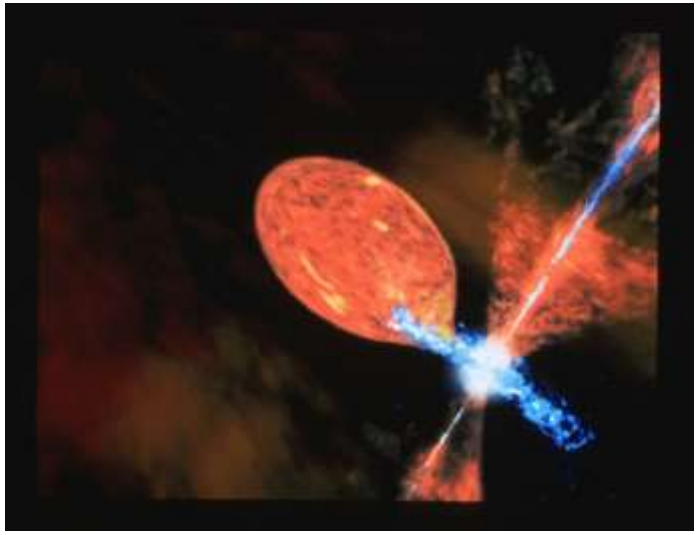
Introduction

- Symbiotic stars are classified into S-type and D-type based on the IR spectral energy distribution.
- The orbital parameters of D-type symbiotics are poorly known.
- Raman-scattered 6830 and 7088 features are useful spectroscopic identifier of a symbiotic star.
- Raman spectroscopy is useful to investigate the emission nebula and the thick neutral component in a symbiotic star.
- The ionization potential of He II higher than 50 eV implies that He II emission is formed near a hot WD.



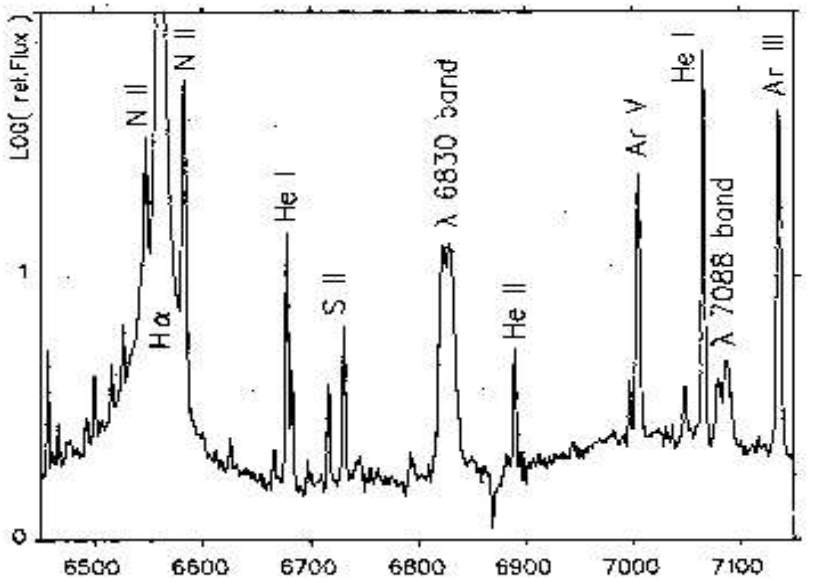
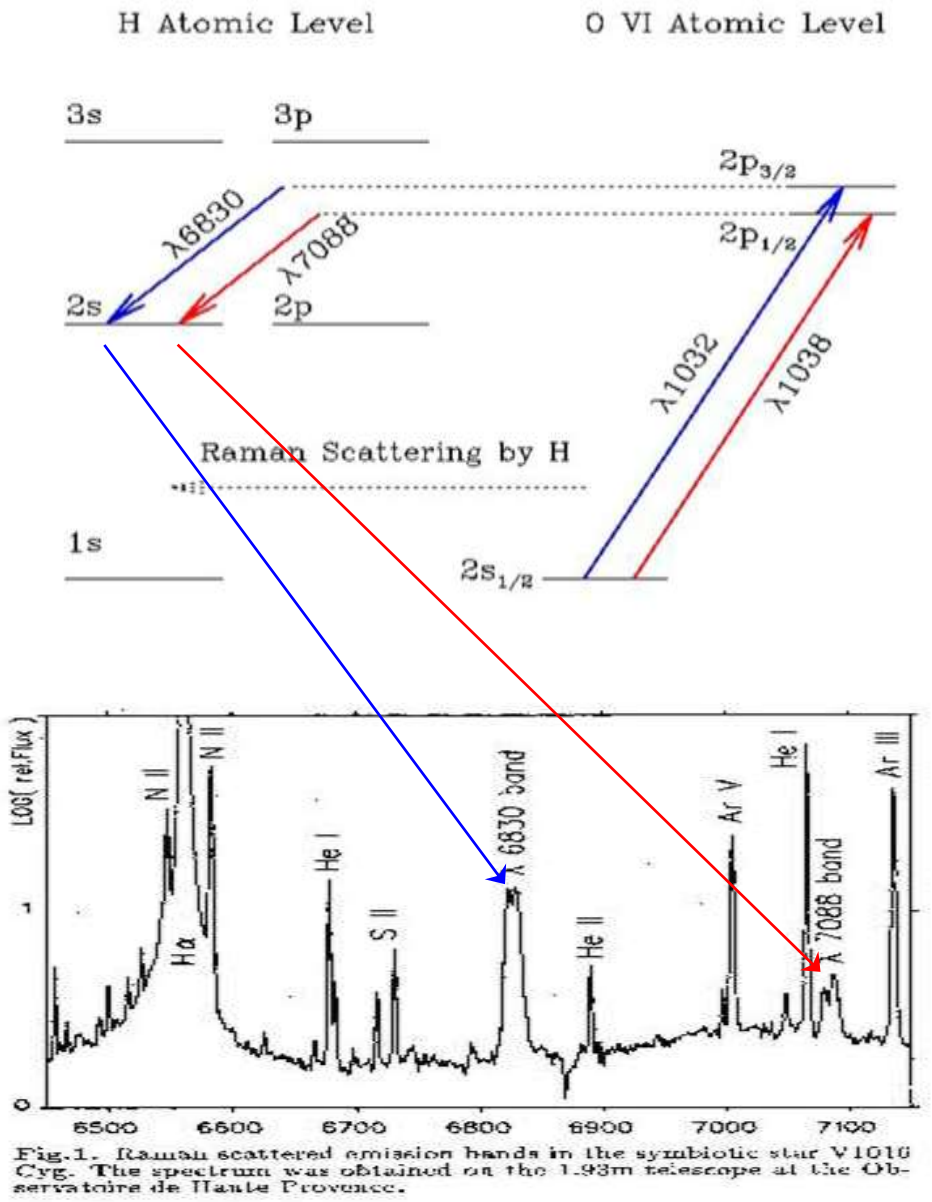


Fig.1. Raman scattered emission bands in the symbiotic star V1016 Cyg. The spectrum was obtained on the 1.93m telescope at the Observatoire de Haute Provence.

V1016 Cygni (Schmid 1989)

Raman scattering with atomic hydrogen

- When a far UV photon is incident on a hydrogen atom in the ground state, Raman scattering ocurrs if the final de-excitation is made to excited 2s state.
- O VI 1032 is Raman scattered to form a broad feature near 6830 (Schmid 1989).



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V1016 Cygni (Schmid 1989)

Mechanical Analog of Raman Scattering

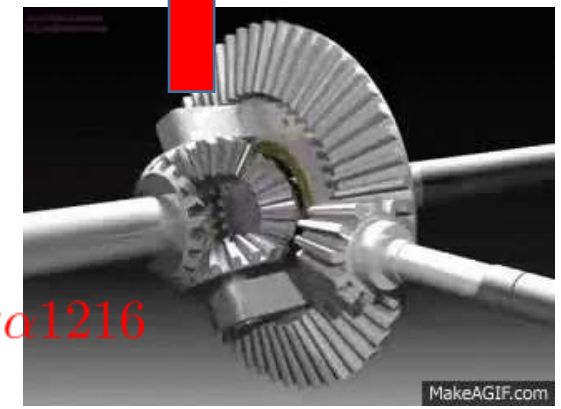
One may invoke the epicycle rotation or differential rotation as the physical origin of fluorescence and Raman scattering.

radiation by the differential
= Raman scattering

$\Delta\omega =$ Raman O VIλ6830

Rayleigh scattering

$\omega_{\rm Ray} =$ O VIλ 1032



$\omega_{\rm inc} =$ O VIλ 1032

$\omega_1 =$ Lyα1216

The left wheel of the hydrogen atom rotates with the fixed frequency of Lyman alpha, while the right wheel is driven by O VI 1032.

The differential rotates with the frequency that is equal to the difference of O VI and Ly alpha.

Hydrogen Atom Driven by O VI 1032

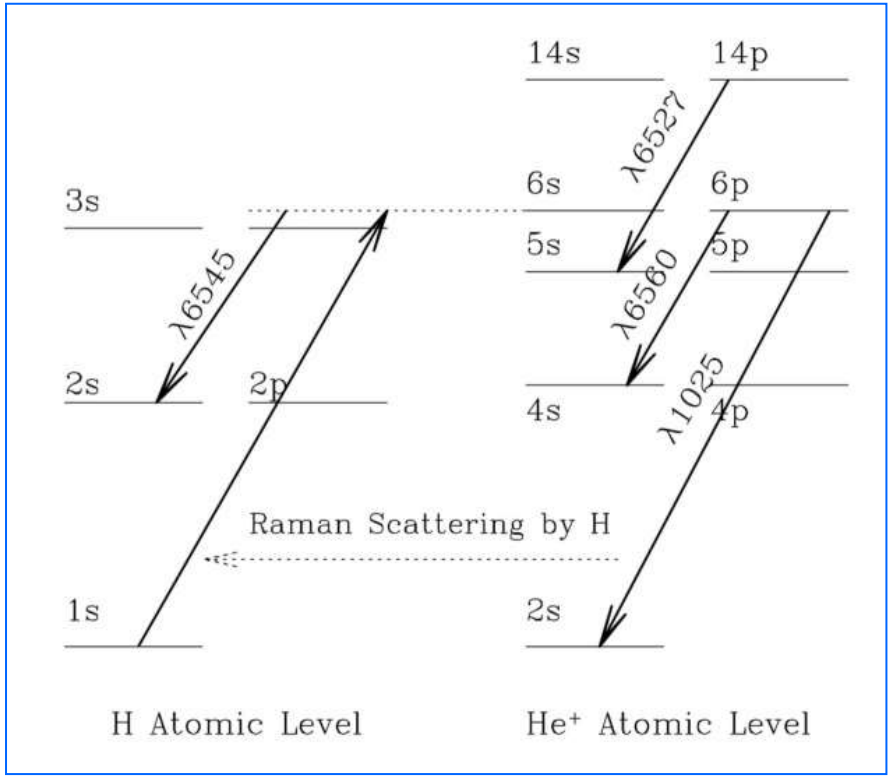
Raman Scattering of He II

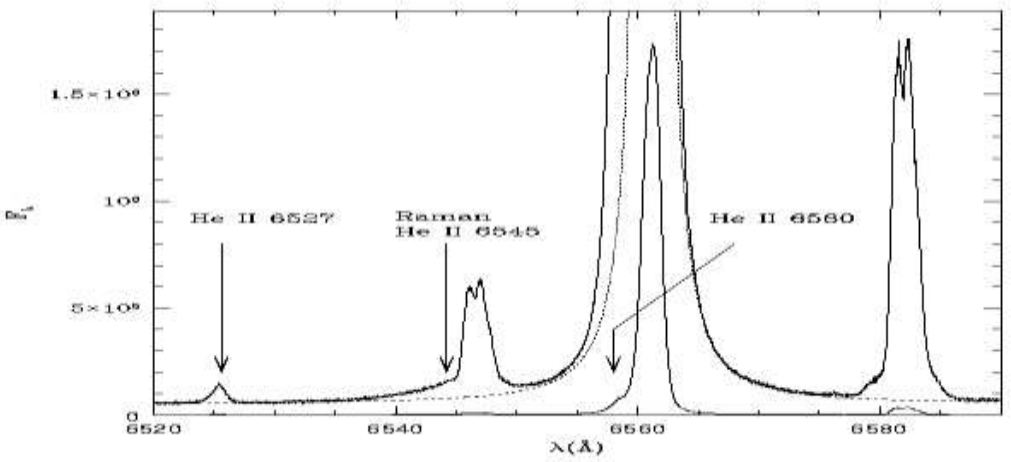
- He II is also a single electron atom like H.
- 2n →2 He II transition has almost same wavelength as H Lyman n→1 transition. The small difference is due to that of the reduced mass of the two-body system.

- He II 1025 ->6545 (Blueward of H alpha)
- He II 972 → 4850 (Blueward of H beta)
- He II 949→ 4330 (Blueward of H gamma)

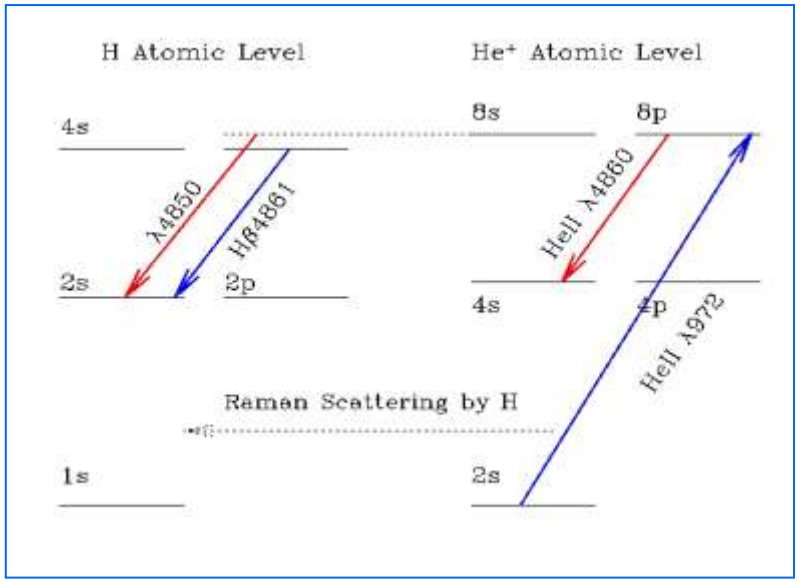
Note that there are two optical He II lines near Hα at 6560 (6→4) and 6527 (14 →5).

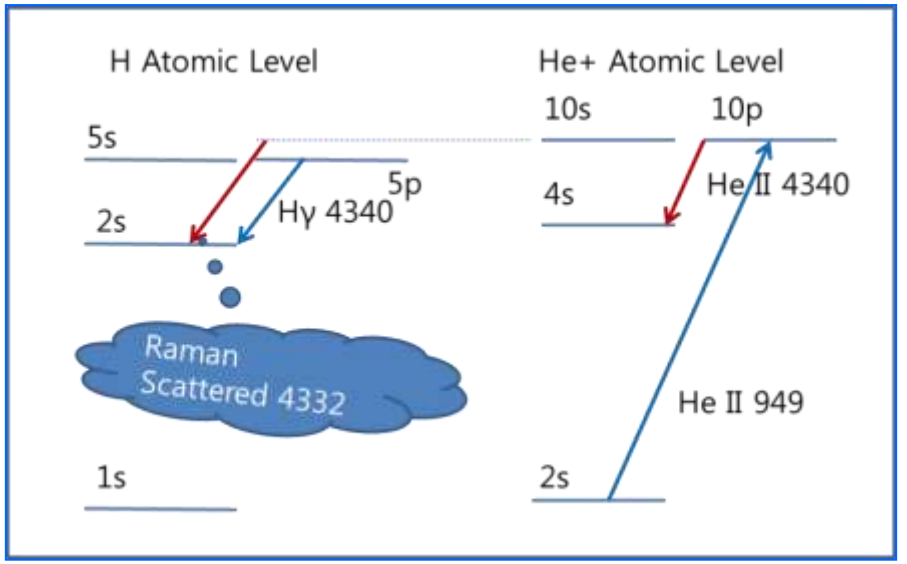
Note that Raman He II at 6545 is severely blended with [N]II 6548.

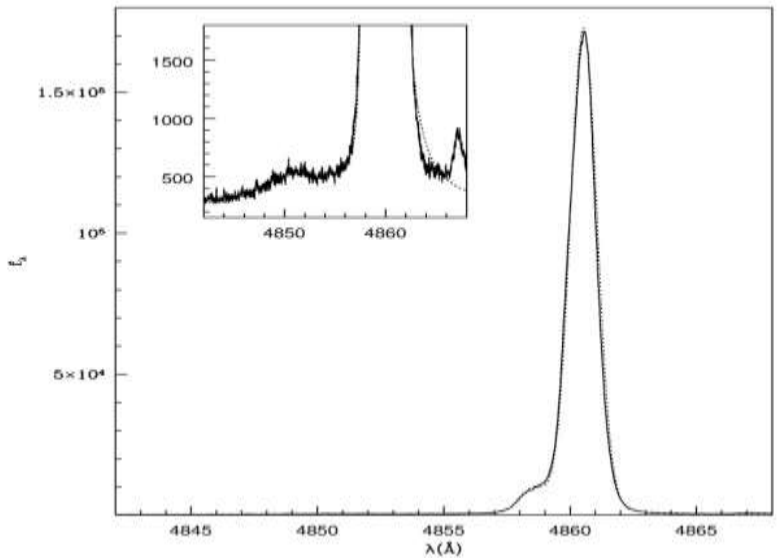


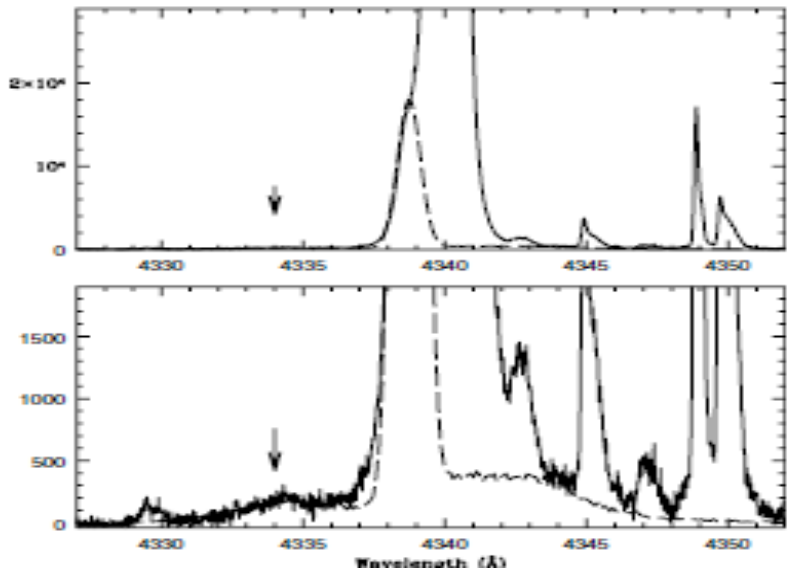


He II Raman Scattering around H β and Hγ





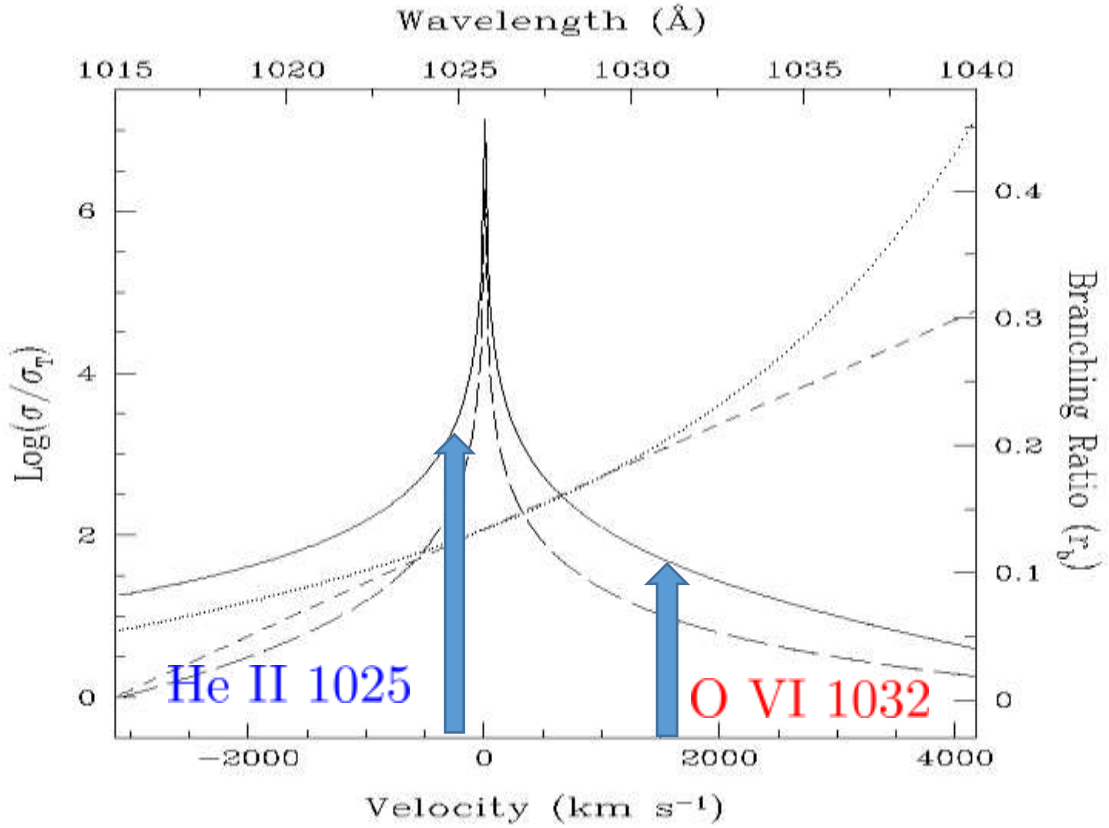




Cross Sections for Raman Scattering

- **The scattering cross section can be computed from the 2nd order perturbation theory in quantum mechanics.**

$\sigma=10^{-22}$ cm^2 for O VI 1032
$\sigma=10^{-20}$ cm^2 for He II 1025



Rayleigh Scattering

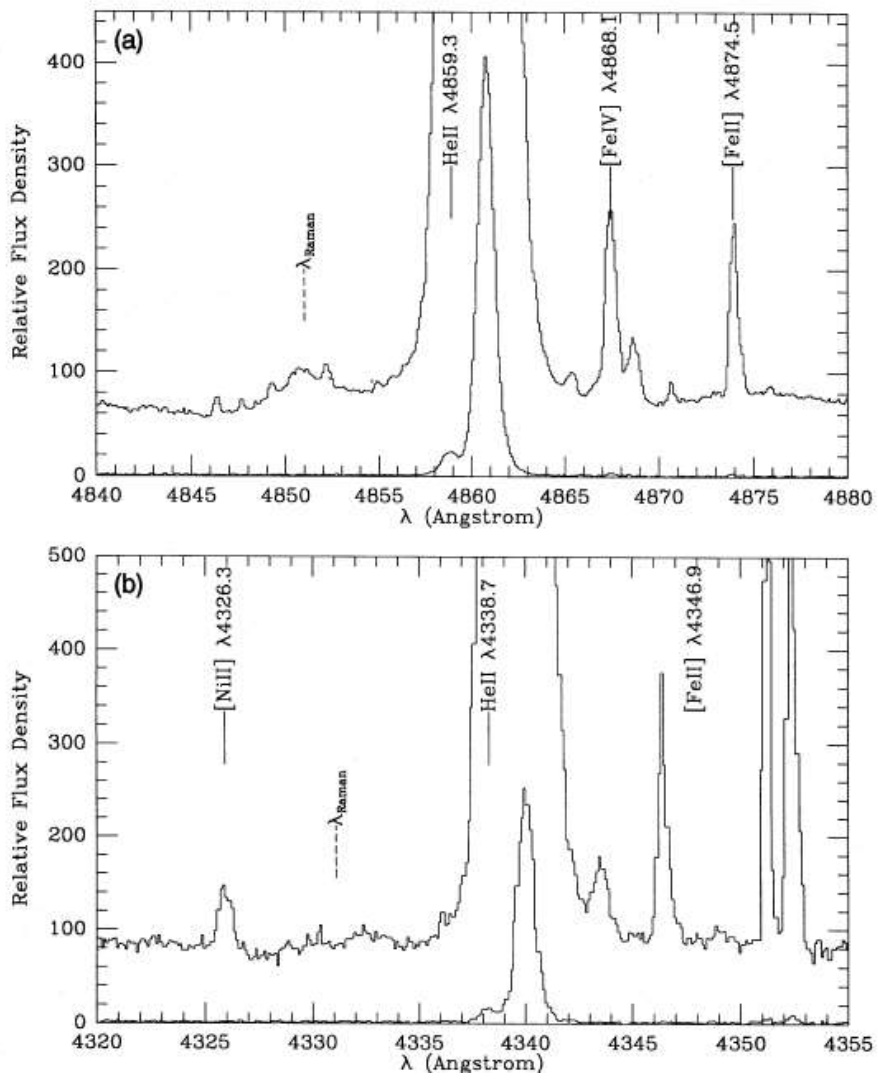
$$\left(\frac{d\sigma}{d\Omega}\right)_{Ray} = r_0^2 \left| \frac{1}{m\hbar} \sum_I \left(\frac{\omega(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{AI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{IA}}{\omega_{IA}(\omega_{IA}-\omega)} - \frac{\omega(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{AI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{IA}}{\omega_{IA}(\omega_{IA}+\omega)} \right) \right|^2 ,$$

Raman scattering

$$\left(\frac{d\sigma}{d\Omega}\right)_{Ram} = r_0^2 \left(\frac{\omega'}{\omega}\right) \left| \frac{1}{m\hbar} \sum_I \left(\frac{(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{BI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{IA}}{\omega_{IA}-\omega} + \frac{(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha})_{BI}(\mathbf{p}\cdot\boldsymbol{\epsilon}^{\alpha'})_{IA}}{\omega_{IA}+\omega'} \right) \right|^2 ,$$

In terms of cross section, He II lines are much more favorable to form Raman-scattered features than O VI.

Raman-scattered He II in D-type Symbiotic Stars

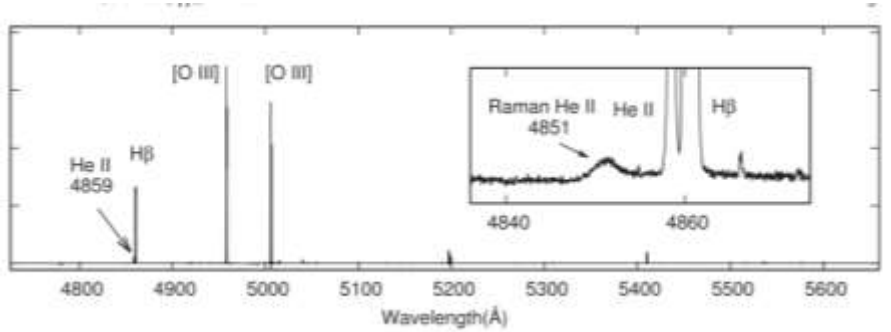


RR Tel (van Groningen 1993)

Object	Raman He II	Observation
RR Tel	4850, 4332	Van Groningen (1993) [ESO]
RR Tel	6545	Lee et al. (2001) [CTIO]
He 2-106	6545	Lee et al. (2001) [CTIO]
V1016 Cyg	6545	Lee et al. (2003) [CFHT]
V1016 Cyg	6545, 4851	Birriel (2004) [Kitt Peak]
HM Sge	6545, 4851	Birriel (2004) [Kitt Peak]
V1016 Cyg	4332	Lee (2012) [BOAO]
H1-36	6545	This presentation

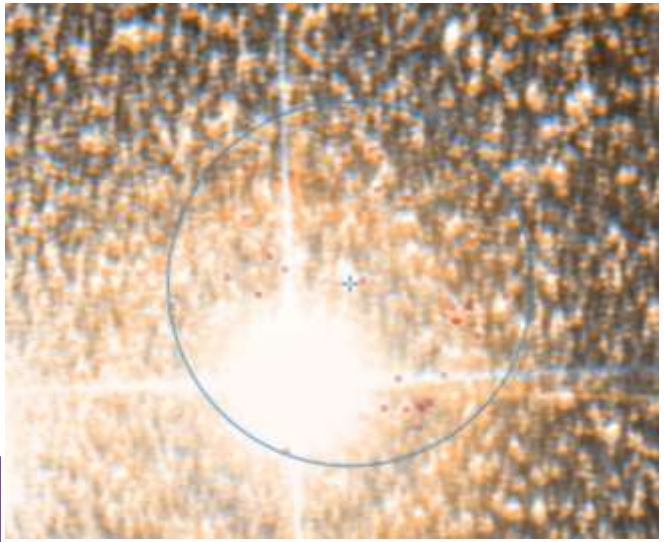
Raman scattering of He II in Young Planetary Nebulae

Planetary Nebula	Raman-scattered He II	Observer
NGC 7027	4851	Pequignot et al. (1997) [Observatoire de Haute Provence]
NGC 6302	4851, 4332	Groves et al. (2002) [Siding Springs Obs.]
IC 5117	6545, 4851	Jung et al.(2006) [CFHT]
NGC 6790	6545	Kang et al. (2009) [BOAO]
NGC 6881	6545	Choi & Lee (2020) [BOAO]
NGC 6886	6545	Choi & Lee (2020) [BOAO]
NGC 6884	6545	in preparation [BOAO]
NGC 6741	6545	in preparation [BOAO]

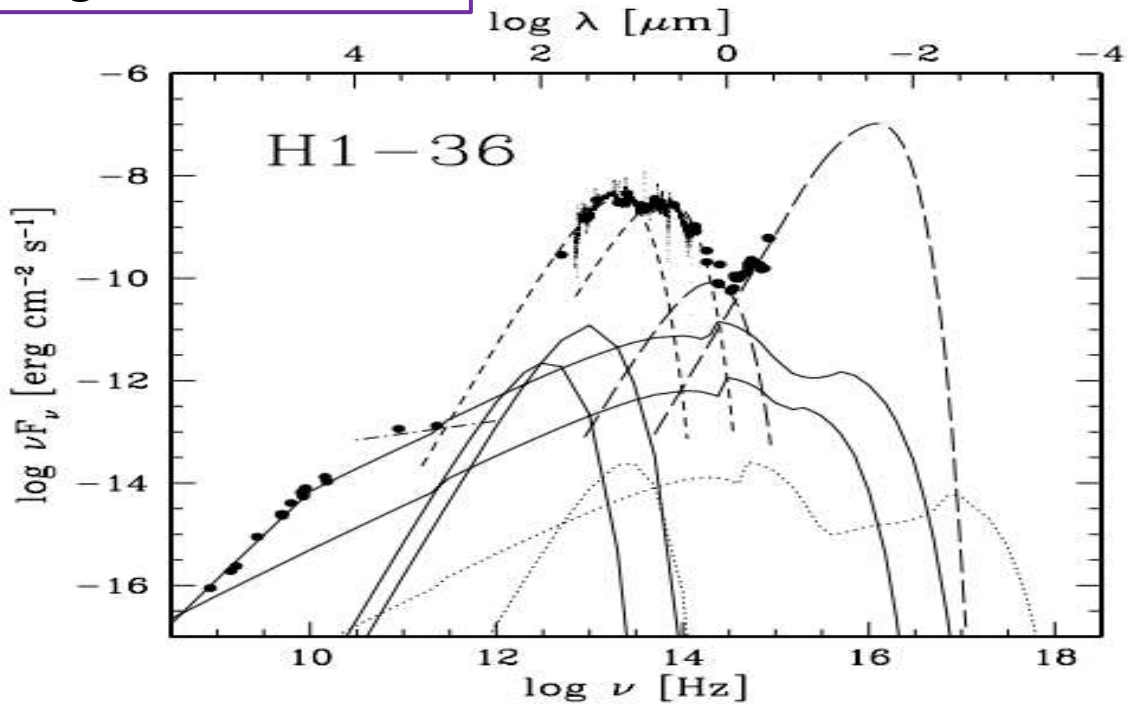


The D-type Symbiotic Star H1-36

- Discovered by Haro from his objective prism survey in 1952.
- Once thought to be an optical counterpart of the Uhuru source 3U 1746-37.
- Established as a D-type symbiotic by Allen (1983).
- The cool component is heavily embedded in its own thick dust shell.
- Distance ~ 4.5 kpc (Allen 1983)
- The high resolution spectrum available in ESO Science Portal obtained by Zamanov & Radoslav in 2004.

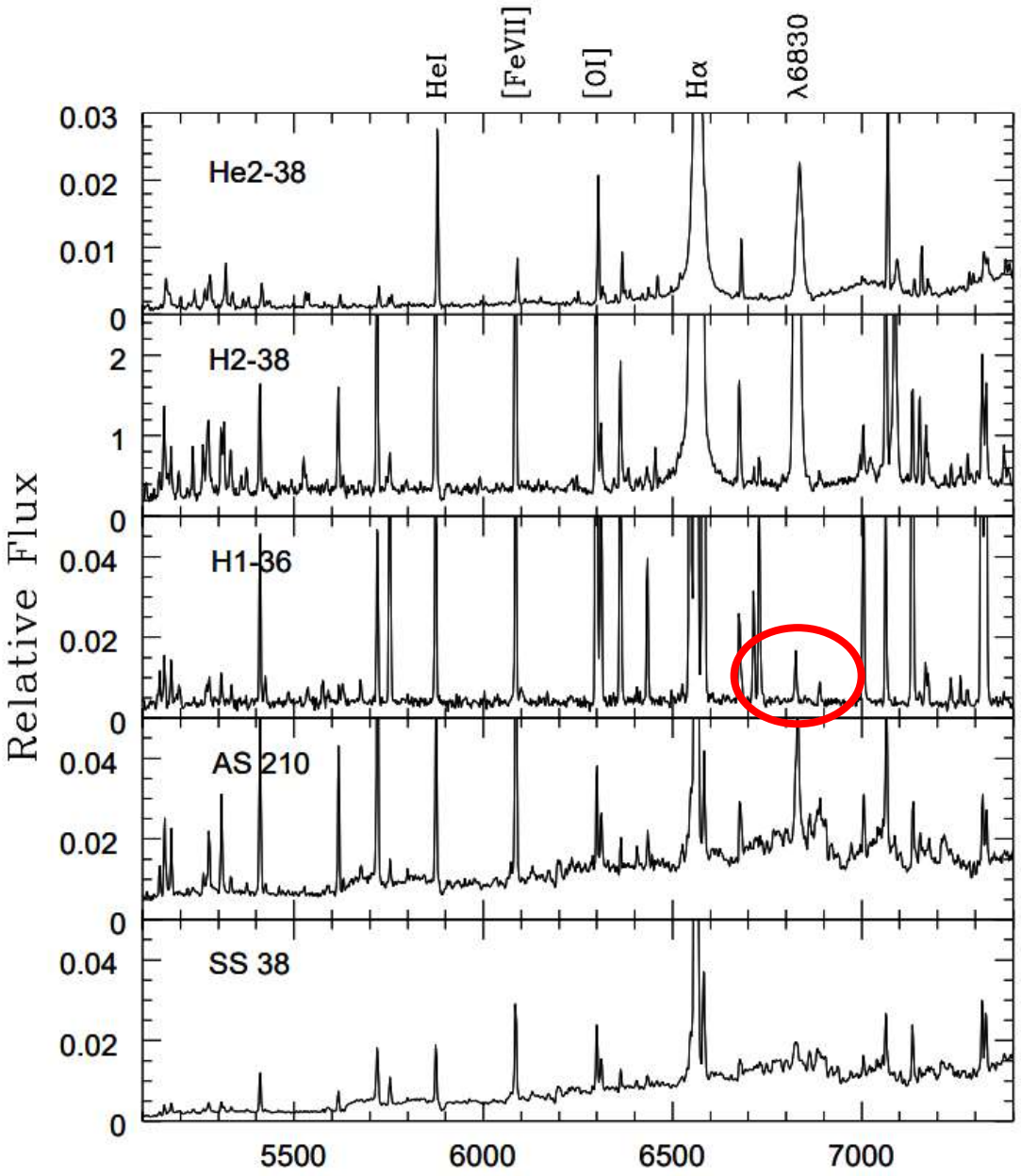


Spectral Eenergy Distribution of H1-36 [R. Angeloni et al. 2007]



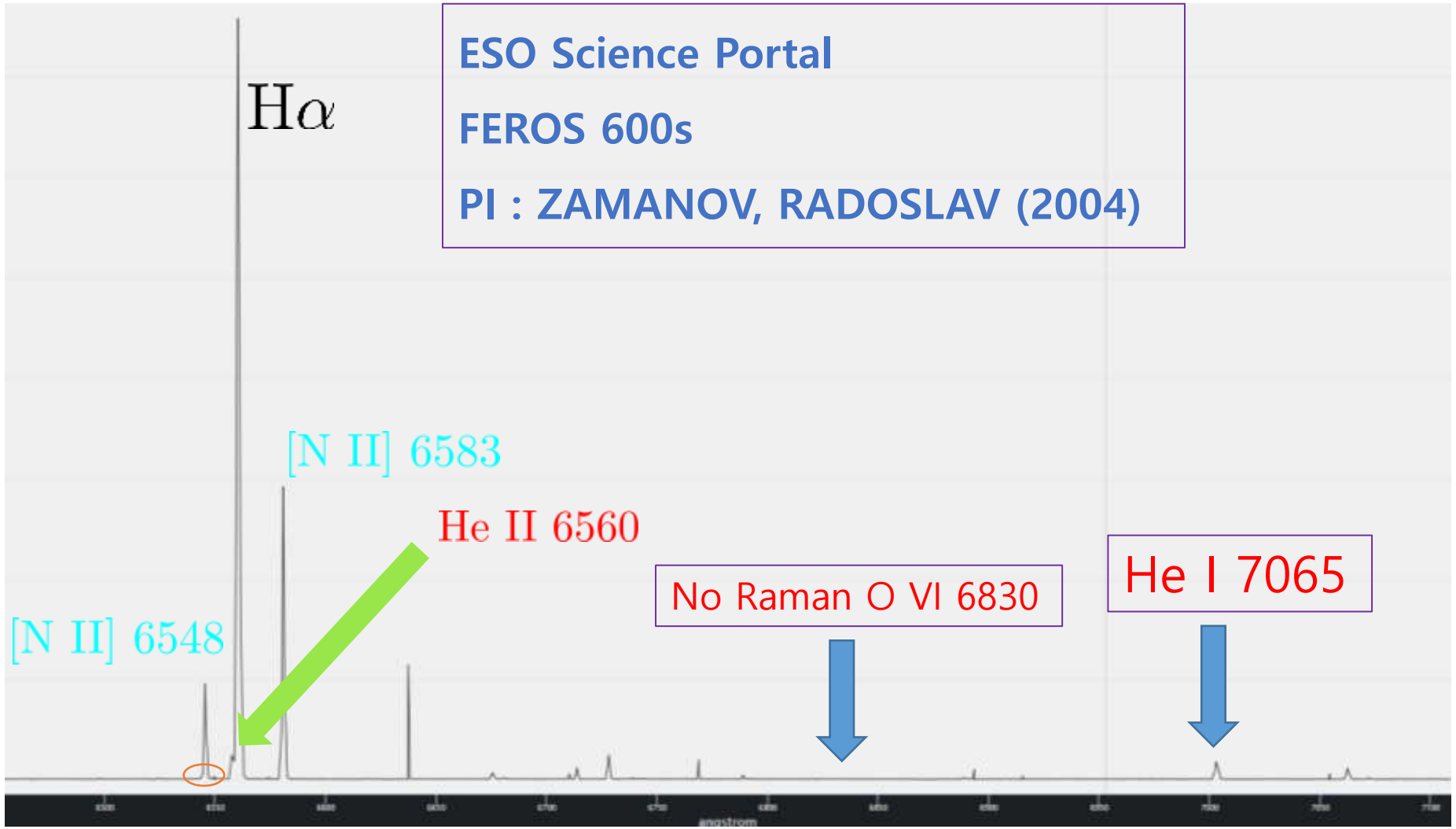
Emergence of Raman O VI in H1-36

- Pereira, Landaberry & Junqueira (1998) reported the emergence of Raman O VI 6830 in their observations using 1.52 m telescope of ESO.
- Allen (1983) reported no presence of Raman O VI 6830 even though he measured weak He II 6527 in his observation in 1978.



Pereira et al. (1998)

Raman-scattered He II in H1-36



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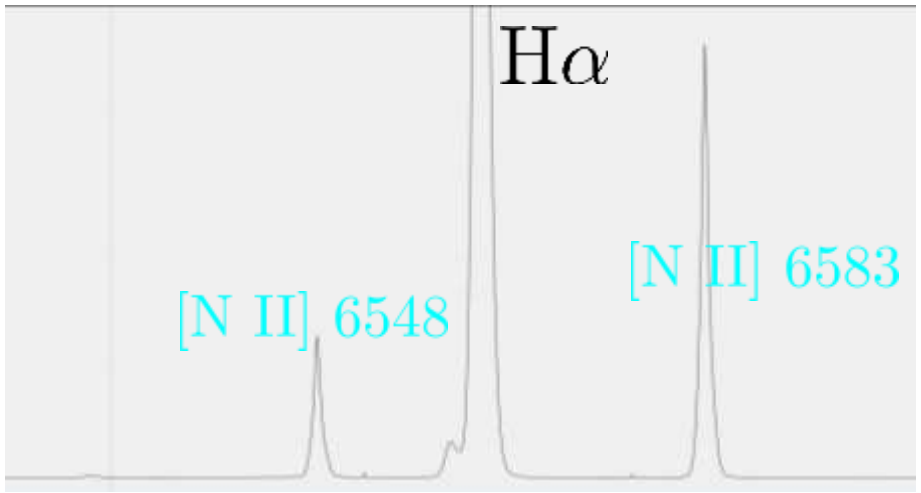
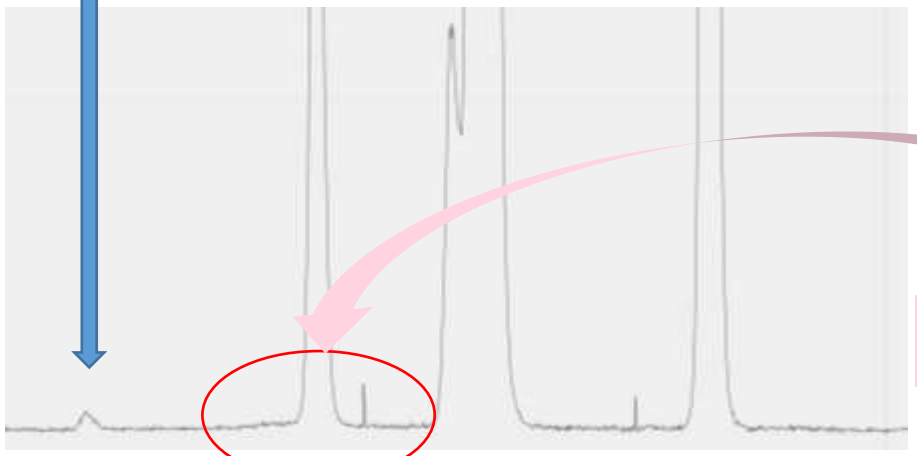
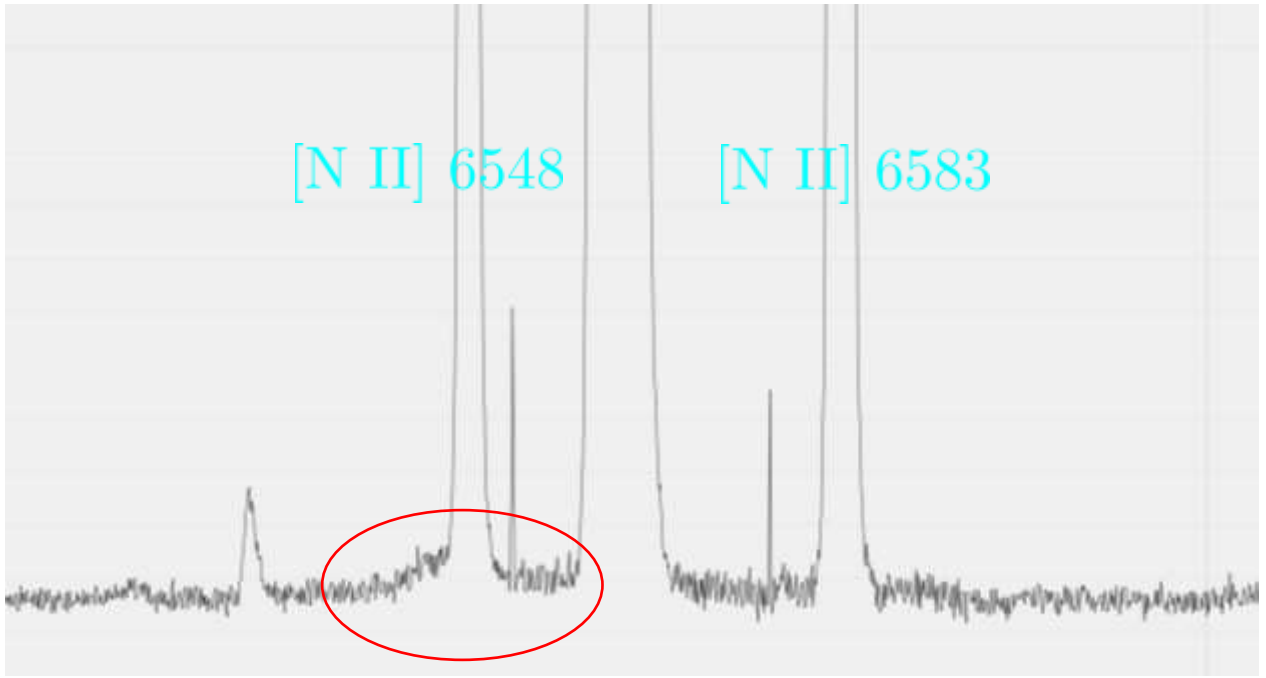


He II 6560



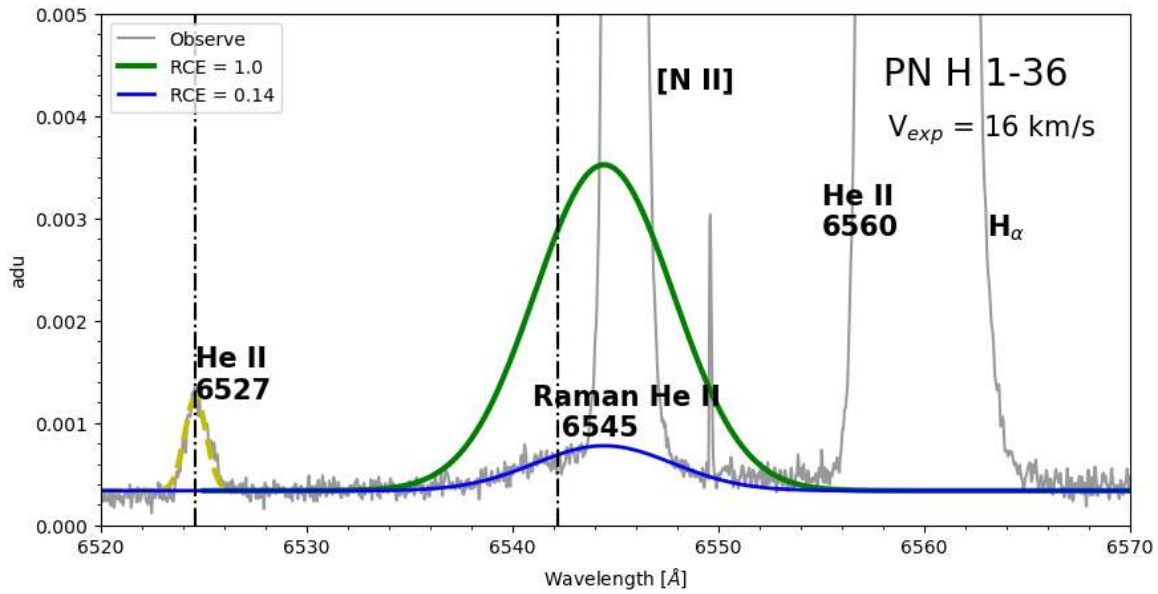
He II 6527



Raman – scattered He II 6545

Recombination Theory and Raman Conversion Efficiency

- How strong is He II 1025?
- Due to heavy interstellar extinction, He II 1025 may not be observable. One needs to infer the strength of He II 1025 from observed He II 6560.
- CASE B Recombination → The nebula is opitcally thick to Lyman transitions.
- The flux ratio of He II 6560 and He II 1025 is around 0.19.
- One may deduce the maximum flux of Raman He II 6545 from the Case B recombination assumption.



1. The green line is a fit to Raman He II 6545 under the assumption that He II 1025 is fully Raman-scattered with H I.
2. The blue line is a fit to the observed Raman He II 6545.
3. The Raman conversion efficiency is 0.14.

Discussion

- Why do we see Raman-scattered He II more rarely than Raman O VI in symbiotic stars?
- In young planetary nebulae, Raman O VI has not been confirmed whereas Raman He II features have been found in 6 objects. 5 out of 6 are northern objects, so that it will be interesting to **search in the southern sky**.
- O VI is one of major coolants in emission nebulae ionized from accreting compact objects like symbiotic stars and quasars.
- Will be interesting to **search Raman He II in S type symbiotics**.

Thank you for your attention.