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Raman mapping of atomic hydrogen in the Orion Bar and Orion South

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Abstract

I show that the broad Raman-scattered wings of Hα can be used to map neutral gas illuminated by high-mass stars in star forming regions. The near wings ($\Delta\lambda \approx \pm 10$ Å) trace neutral columns Absorption features in the pseudo-continuum at 6634 and 6663 Å correspond to neutral oxygen far-ultraviolet absorption lines at 1027.43 Å and 1028.16 Å.

Keywords: Atomic physics; Radiative transfer; Photodissociation regions

1. INTRODUCTION

Raman scattering is the inelastic analog of Rayleigh scattering by atoms or molecules. Both processes begin with a radiation-induced transition of an electron to a virtual bound state (non-eigenstate)

non-resonant scattering Recently, Dopita et al. (2016) identied Raman scattering wings to the Hα line in the Orion Nebula and a number of H II regions in the Magellanic Clouds.

Dopita et al. (2016) propose that the Raman wings form at the transition zone near the ionization fronts in H II regions. However, the total neutral hydrogen column through the ionization front can be no more than about $10/\sigma_0 \approx 2 \times 10^{18}$ cm^{-2}, where $\sigma_0 \approx 6.3 \times 10^{-18}$ cm^2 is the ground-state hydrogen photoionization cross section at threshold (Osterbrock & Ferland 2006). The Raman scattering cross section at wavelengths responsible for the observed wings is much lower than this: $\sigma_{\mathrm{Raman}} \sim 10^{-22}$ cm^2 (Chang et al. 2015), meaning that the Raman scattering optical depth through the ionization front is only of order 0.0001. A vastly larger column density of neutral hydrogen is available in the photodissociation region outside the ionization front, so it is more likely that Raman scattering will occur there instead, so long as there is sufficient far ultraviolet radiative flux in the vicinity of the Lyman β line (1025 Å).

2. OBSERVATIONS

MUSE (Bacon et al. 2010) observations of the Orion Nebula (Weilbacher et al. 2015; Mc Leod et al. 2015).

Keck HIRES spectra described in Henney & O'Dell (1999) and Bally et al. (2000). The spectrum I use is of HH 529 base region in Orion South. Published results from these data have concentrated on strong nebular lines, but here I use a small section of the spectrum in the range 6660 Å to 6670 Å for reasons which will become apparent.

Table 1. Wavelength bands used for extracting Raman-scattered light

Figure 1. Spatial distribution of Raman-scattered wings in Hα

3. DISCUSSION

The effective resolving power of the optical spectrograph is multiplied by 6.4 for the FUV domain.

The O I lines should be in absorption in the spectrum seen by the Raman scatterers.

Salgado et al. (2016) had found low dust cross-section in Orion Bar PDR, but there are loopholes. First, they assume plane-parallel geometry with exactly edge-on viewing angle, while in reality it is a roughly cylindrical filament. Second, they ignore scattering, see Watson et al. (1998).

Geometry of bar: in Henney et al. (2005) I pointed out that a diverging cylindrical geometry is necessary to explain the sharp peak in the [N II] emissivity seen at the ionization front. It has been apparent since O'Dell & Yusef-Zadeh (2000) that the nebula contains many bar-like features.

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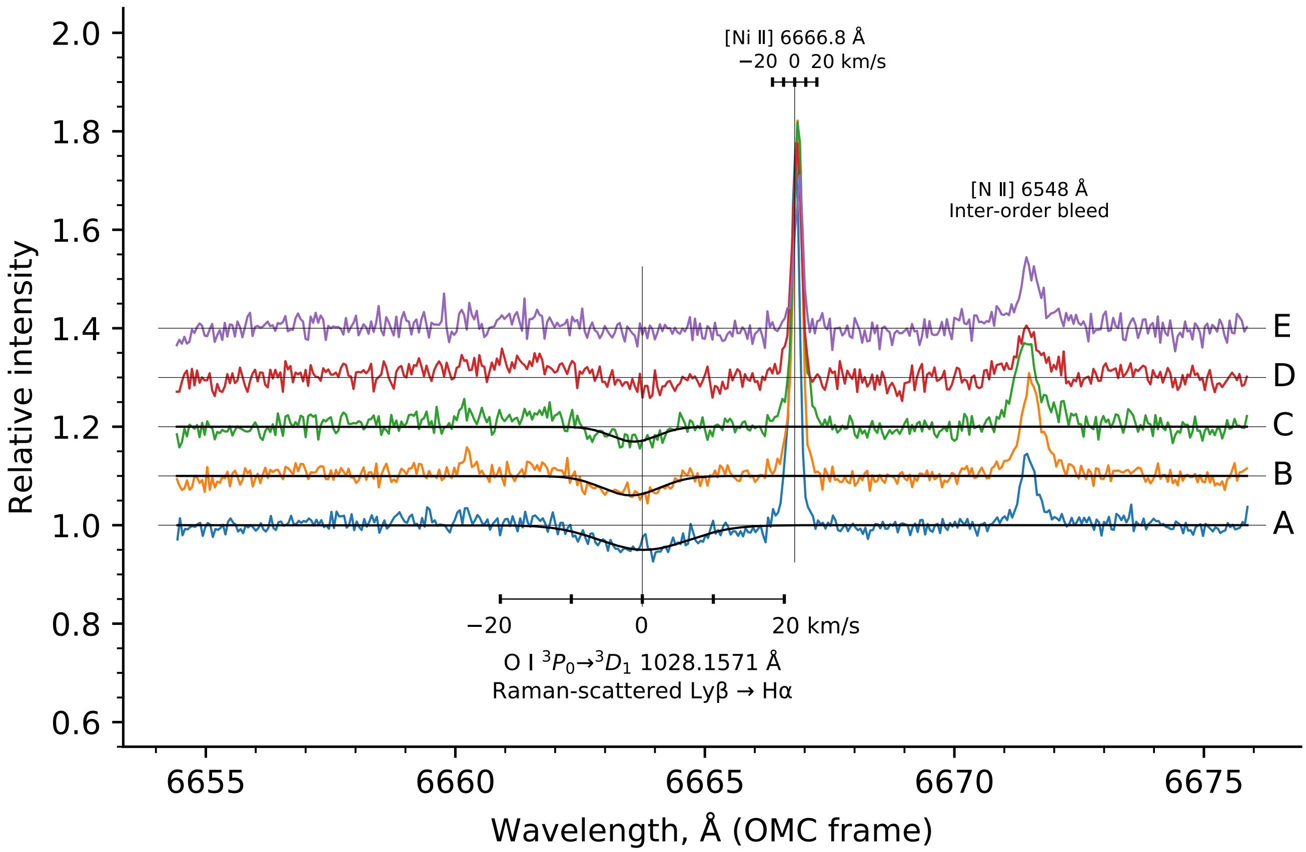

Figure 2. Keck HIRES spectra of Raman-scattered O I absorption line for five regions in Orion South. Wavelengths are given on an air scale and in the rest-frame of the Orion Molecular Cloud, as defined by the peak velocity of ^{13}CO.

Table 2. FUV/optical wavelength equivalencies for Raman scattering

Transition	A	B	C	D	E
H I {1,2}s → 3p	1025.72220	97492.283	0.000	6564.553248	6562.7406
O I J = 0 → 1	1028.15729	97261.383	−230.900	6665.5868	6663.7469
O I J = 1 → 1	1027.43139	97330.100	−162.183	6635.1951	6633.3630
O I J = 1 → 2	1027.43077	97330.159	−162.124	6635.1691	6633.3370
O I J = 2 → 1	1025.76339	97488.369	−3.914	6566.2400	6564.4269
O I J = 2 → 2	1025.76276	97488.429	−3.854	6566.2141	6564.4010
O I J = 2 → 3	1025.76170	97488.530	−3.753	6566.1706	6564.3575

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