PDRs in Star Forming Regions

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Abstract

The molecular gas can be photodissociated if it is exposed to intense far-ultraviolet (FUV) radiation. Intermediate and high mass stars generate enough flux in the FUV range to produce a significant photodissociation region (PDR) around them. In order to characterize the PDR that forms near these regions high resolution infrared and centimeter wavelength observations are required. Current centimeter-wave telescopes/interferometers offer the required spatial resolution to detect and to study in detail the PDRs in star forming regions. We present a short review of observations of PDRs and discuss the particular case of G111.61+0.37.

KEYWORDS: *ISM: HII regions, clouds – Radio lines: ISM – ISM: Individual objects: G111.61+0.37*

1. Introduction

Young massive stars not only form HII regions but also create significant photodissociated regions and the radiation field excites various transitions in the surrounding molecular material. In the last 25 years many theoretical works were done on PDRs (e.g. Hill & Hollenbach, 1978; Roger & Dewdney, 1992; Bertoldi & Draine, 1996; Hollenbach & Tielens, 1997; Díaz-Miller et al., 1998; Gorti and Hollenbach, 2002). PDRs of young massive stars are simply the intermediate region between the HII region and the quiescent molecular gas. For better illustrate the PDRs produced by young massive stars a simple diagram is shown in Fig. 1. The ionizing photons form an HII region close to the star, while the photodissociating photons penetrate more into the cloud generating, first, a zone where the hydrogen is neutral (HI zone), and then a molecular excited zone. The carbon is ionized deeper than the HI zone into the cloud. The PDR ends when all the oxygen is contained in O_2 and CO molecules (for details about PDRs see the review of Hollenbach & Tielens, 1997).

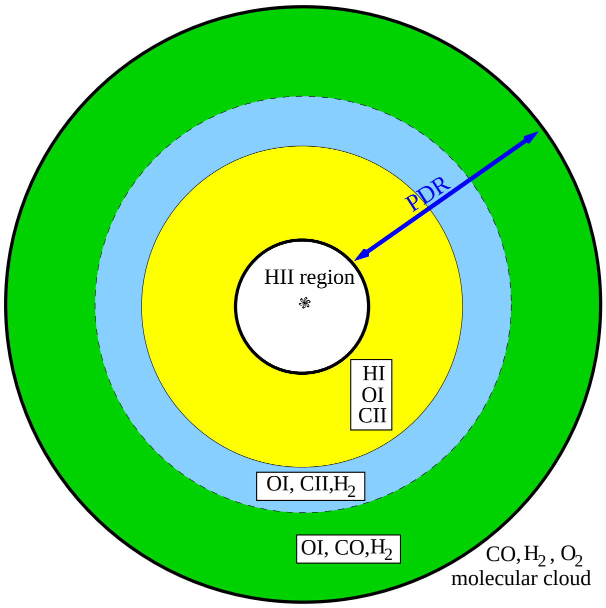

Figure 1: Diagram of a photodissociated region formed around a young massive star that also forms an HII region. The PDR starts with the HI zone where the hydrogen is in neutral phase, carbon is ionized and oxygen neutral. The zone of ionized carbon (CII) extends deeper into the cloud where the hydrogen is already molecular but the oxygen is still neutral. The last zone corresponds to the neutral oxygen (OI), that goes even deeper into the cloud, where the carbon is already contained in CO molecules. The PDR ends when all the oxygen is contained in O_2 and CO molecules.

The main coolants of the PDRs are [CII] 158 μm, [OI] 63 μm lines, CO rotational lines, flourescent H_2 lines, dust continuum emission and PAH features. The FIR and millimetric emission of PDRs are used to determine their physical parameters (e.g. Liu et al., 2001; Vastel et al., 2001). Because of the low angular resolution of FIR telescopes ($\sim$1 arcmin), it is not possible to study in detail the kinematic and the spatial distribution of PDR in compact sources (e.g. star-forming regions). Although the main coolants are in the IR band, PDRs also emit in the cm wavelength range.

The radio emission of PDRs is detected in the 21 cm HI line, and also in carbon recombination lines (e.g. Wyrowski et al., 1997; Lebrón & Rodríguez, 1997; Gómez et al., 1998; Wyrowski et al., 2000). The lines at cm wavelengths are weaker than the IR lines, but with the high spatial and spectral resolution that can be achieved with radio telescopes/interferometers, the observation of radio lines are a valuable tool for studying the kinematics of PDRs in compact sources. An example of a detailed study of the neutral region of the PDR in a star-forming region was done in G111.61+0.37 (Lebrón et al., 2001). The compact HII region G111.61+0.37 was studied in the HI 21cm line (that traces the neutral region of the PDR), ammonia transitions (1,1) and (2,2) (that trace the dense molecular gas) and the recombination line H92α (that traces the HII region) with the VLA interferometer.

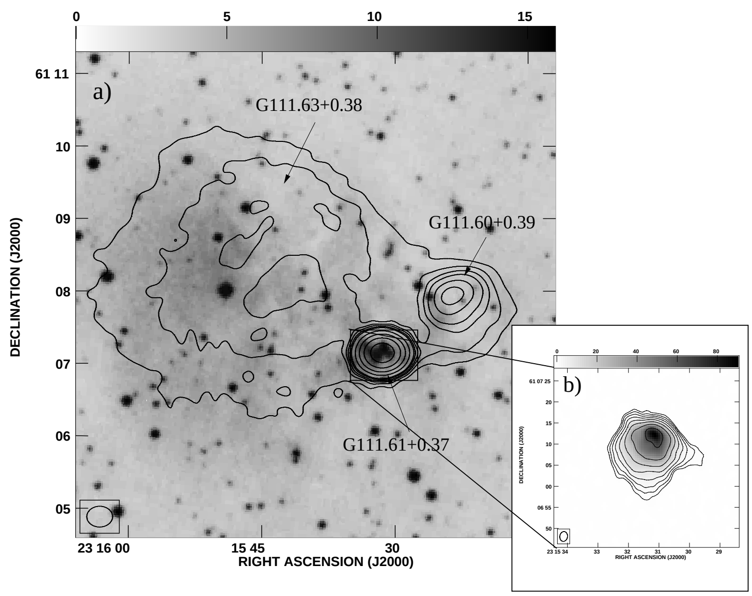

Figure 2: (**a**) 1.4 GHz continuum emission in Sharpless 159 (contours). G111.61+0.37 is located in the center of the map. The background image is the red POSS plate of the region. (**b**) 3.6 cm continuum emission of G111.61+0.37. The continuum emission shows a cometary shape distribution.

2. The PDR in G111.61+0.37

G111.61+0.37 (hereafter called G111.61) is a compact HII region in the Sharpless 159 region at a distance of 3.1 kpc (Brand & Blitz, 1993). Fig. 2a shows a continuum map at 1.4 GHz (contours) of the Sharpless 159 region. G111.61 is the brightest source in the region and is associated with the IR source IRAS 23133+6050. The cometary shape of the continuum emission in G111.61

(see Fig. 2b) is due to a champagne flow of the ionized gas (Lebrón et al., 2001; Kurtz et al., 1994).

The photodissociated region in G111.61 was detected in the 21cm line of HI. The HI spectra of G111.61 shows absorption and emission features (see Fig. 3), being the absorption ones the most prominent. Nevertheless, the emission feature is of our particular interest.

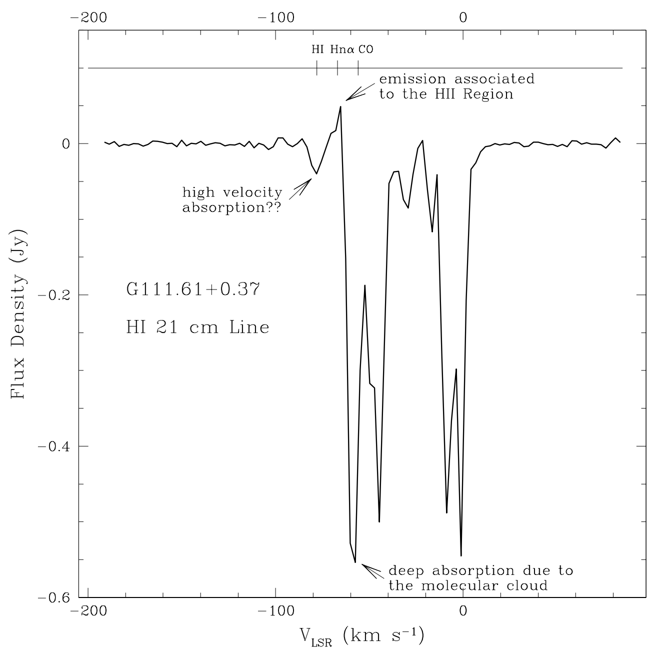

Figure 3: HI 21cm line spectrum of G111.61+0.37.

A contour map of the integrated HI emission between -58 and -67 km s^{-1} (emission feature) is shown in Fig. 4. The HI in emission (continuous line contours) is compact ($25'' = 0.4$ pc) and located next to G111.61. The HI in emission appears to the SE of G111.61. This asymmetry in the emission distribution is interpreted as a consequence of density gradients in the molecular gas. Sizes of PDRs have strong dependence on the density of the molecular gas (Díaz-Miller et al., 1998).

In the case of G111.61 we found dense molecular gas (density $> 10^6$ cm^{-3}), located to the NW of the HII region (see Fig. 5). This dense gas is confining the

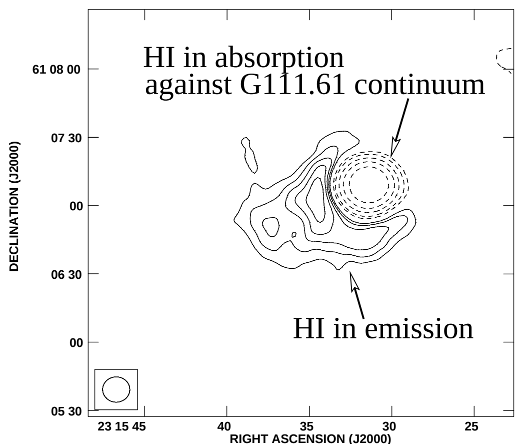

Figure 4: HI 21cm velocity-integrated map of G111.61+0.37. The line emission was integrated between -58.6 to -68.9 km s^{-1}. The continuous line contours show the HI in emission, while the dashed-line contours show the HI in absorption. The contour levels are -100, -50, -25, -12, -9, -6, -4, 4, 5, 6, 7, 8, and 9 $\times$ 1.1 mJy beam^{-1}.

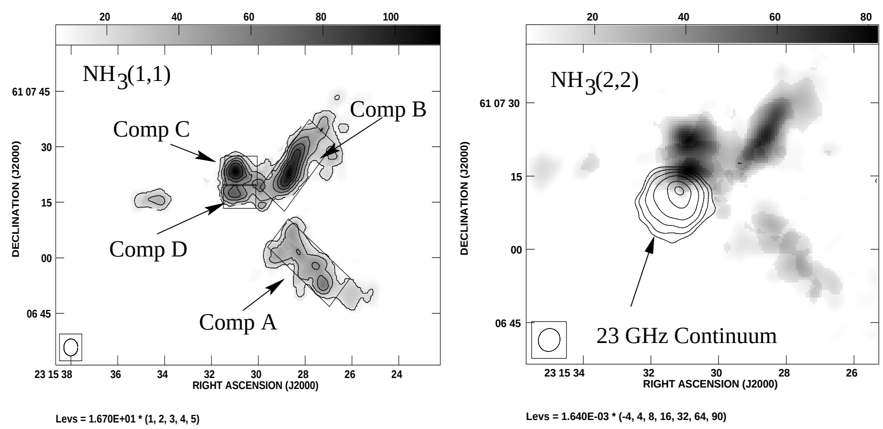

Figure 5: NH_3(1,1) and (2,2) velocity-integrated line maps (grey scale) and 23 GHz continuum map of G111.61+0.37 (contours on right panel). Component D is located near the HII region and is hotter than the other ammonia clumps. Clump D is confining the HII region and the PDR in the NW direction.

HII region in the NW direction (Lebrón et al., 2001). The expected size for a PDR that developes in a medium of density greater than 10^5 cm^{-3} is <0.03 pc

(Díaz-Miller et al., 1998). Such small structures could not be detected with the HI observations dicussed here. No PDR was detected between the HII region and the dense molecular gas (traced by ammonia), but a prominent HI zone extends into the low density molecular gas.

The HI emission observed in G111.61 is a clear example of the neutral region of a PDR in a massive star-forming region. The structure of the PDR is also shaped by the molecular environs like the HII region. The determined column density and mass of the HI emission are 5.9×10^{20} cm^{-2} and 0.8 $M_{\odot}$, respectively (a T_{ex} of 300 K was assumed).

3. Conclusions

In this paper we presented the results of the HI 21 cm line observations of the star-forming region G111.61+0.37. The neutral zone of the PDR is bigger than the HII region. The spatial distribution of the HI emission also suggests a density gradient in the molecular gas. This result is confirmed by ammonia observations. The spatial resolution that can be obtained in the cm wavelength range permits the study the PDRs in compact sources.

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