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EXPANDING SHELLS OF NEUTRAL HYDROGEN AROUND COMPACT H II REGIONS

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RESUMEN

Mediante una comparación de las velocidades radiales de regiones H II brillantes a radiofrecuencias con sus espectros de absorción en H I hemos descubierto cáscaras de hidrógeno neutro en expansión alrededor de ellas. Estas cáscaras se manifiestan por la absorción de la emisión de radiocontinuo proveniente de las regiones H II a velocidades que indican distancias mayores que la velocidad radial observada. Creemos que estas cáscaras son zonas chocadas en las orillas de las regiones ionizadas en expansión.

ABSTRACT

By comparing radial velocities of radio-bright compact H II regions with their H I absorption spectra, we have discovered expanding shells of neutral hydrogen around them. These shells are revealed by absorption of the radio continuum emission from the H II regions at velocities indicating greater distances than the observed radial velocity. We believe that these shells are shock zones at the outer edges of the expanding ionized regions.

Key Words: **CIRCUMSTELLAR MATTER — H II REGIONS**

1. THE SAMPLE OF COMPACT H II REGIONS

In order to investigate absorption profiles of compact H II regions we have looked at all unresolved ($\Theta \ll 1'$) outer Galaxy ($v_{\rm LSR} < 0.0\,{\rm km\,s^{-1}}$) sources within the area of the Canadian Galactic Plane Survey (CGPS; Taylor et al. 2003) ($l = 75°$ to $145°$ and $b = -3.5°$ to $+5.5°$) bright enough to be absorbed by foreground H I ($S \geq 250\,{\rm mJy}$). The resulting sample consists of 26 sources. We compared their H I absorption spectra with their radial velocity determined from either associated molecular material or recombination line measurements. We found that all but three of this sample show at least one additional absorption line at a more negative velocity than the source's systemic velocity. A flat rotation model for the Galaxy would indicate that these components are located behind the H II regions. Two example profiles are displayed in Figure 1.

2. A SIMPLE MODEL FOR EXPANDING H I SHELLS

From our results we can conclude that the absorbing H I, which creates the additional absorption line, is located between the H II regions and us and it is moving towards us relative to other material at its distance. Since almost all of the sources show this additional absorption line we can assume that it is a common phenomenon related to compact H II regions. Thus the most likely explanation is a symmetrically expanding shell of atomic hydrogen around those compact H II regions.

Models of the photodissociation of molecular clouds surrounding newly formed O and early B type stars (Roger & Dewdney 1992) show that the resulting H I exists in a layered structure surrounding the star (see Figure 2, left panel). A dissociation front (DF) will first move rapidly through the molecular cloud (H_2) forming a broad H I region (H). As the H II region (H^+) expands, a layer of shocked H I (H^*) will form just outside the ionization front (IF). Eventually, the faster moving IF will catch up with the DF and all of the H I will be found in the shocked layer. The time when the IF and DF merge ranges from $\sim 10^5$ to 10^6 years depending upon the spectral type of the star and the density of the surrounding molecular material.

The dissociated and ionized material created by the DF and IF are not moving and thus cannot be responsible for the additional absorption lines. However, the thin layer of shocked atomic hydrogen is expanding with the IF. To investigate the characteristics of this expanding H I shell we assume a systemic velocity of $-40\,{\rm km\,s^{-1}}$ for a compact H II region with an IF expanding at $10\,{\rm km\,s^{-1}}$ (see Fig. 2, right panel). The receding part of the shell would be shifted to a velocity of $-30\,{\rm km\,s^{-1}}$. By observing the absorption profile of the H II region, we would

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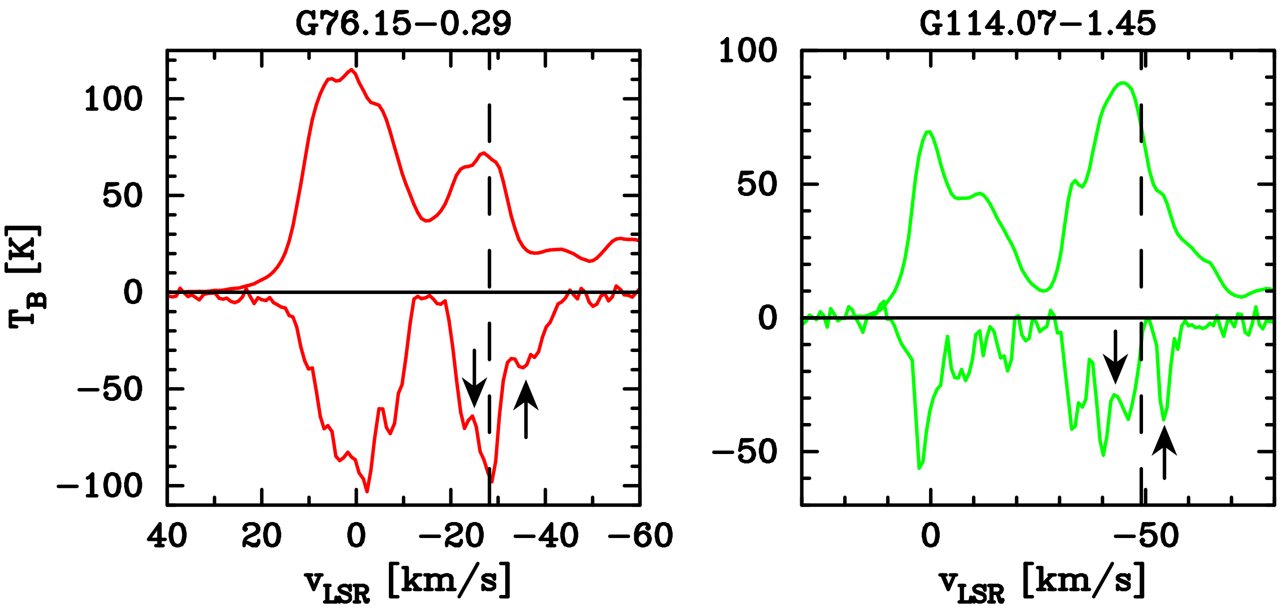

Fig. 1. Sample absorption profiles (below 0) from our sample of compact H II regions together with the background emission characteristics (above 0) interpolated for their position. The dashed line indicates the systemic velocity of the H II regions. The upwards pointing arrow indicates the additional absorption line and the downwards pointing one the probable position of the receding shell.

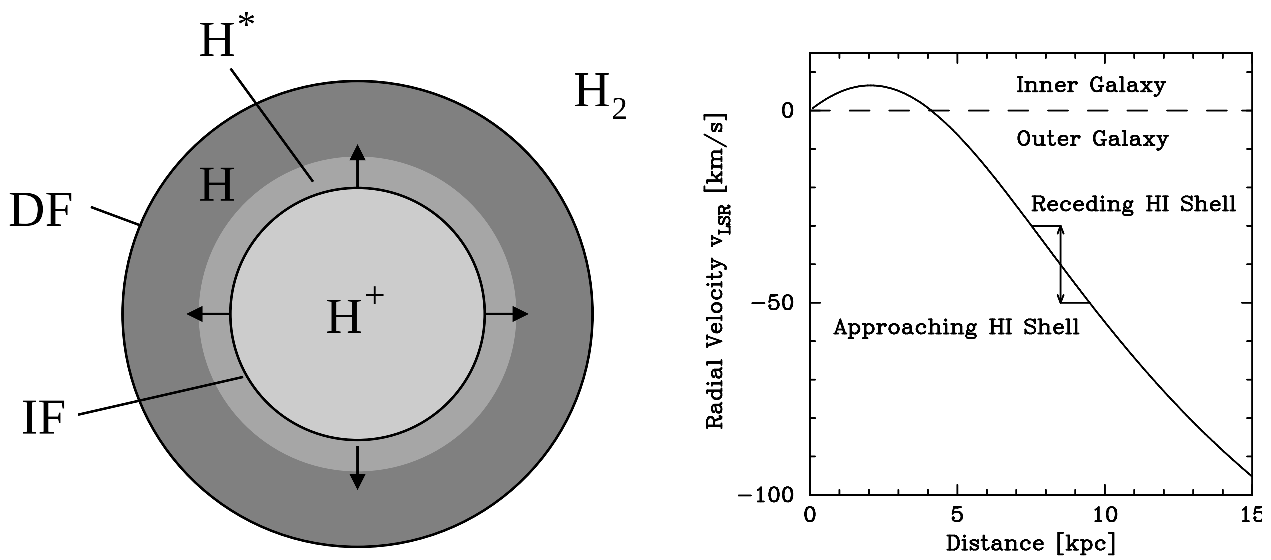

Fig. 2. Left: A sketch of a compact H II region (H^+) with an expanding layer of shocked neutral hydrogen (H^*). The dissociation front (DF) and ionization front (IF) are indicated, as is the layer of the unshocked H I (H). Right: A diagram of the radial velocity as a function of the distance from the Sun at a longitude of 76° for a flat rotation model with $v_\odot = 220\,\mathrm{km\,s^{-1}}$ and $R_\odot = 8.5\,\mathrm{kpc}$. Velocity shifts of an expanding shell with $v_{\rm exp} = 10\,\mathrm{km\,s^{-1}}$ for an H II region with a radial velocity of $v_{\rm d} = -40\,\mathrm{km\,s^{-1}}$ are indicated.

find the emission line of the receding part superposed on the foreground absorption structure, where it is difficult to detect. The approaching shell, however, would be shifted to a velocity of $-50\,\mathrm{km\,s^{-1}}$ and thus create an additional absorption line that seems to arise from "behind" the H II region.

3. THE NATURE OF THE ADDITIONAL ABSORPTION LINES

The Roger & Dewdney (1992) model gives us constraints on characteristics of the expanding shell of shocked atomic hydrogen. The maximum expansion velocity of the IF is about $11\,\mathrm{km\,s^{-1}}$ and the maxi-

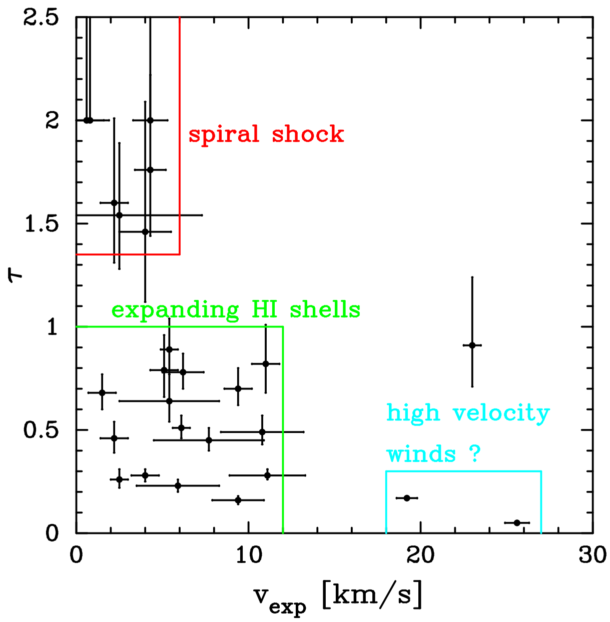

Fig. 3. Diagram with calulated τ values for all H II regions as a function of the expansion velocity. Three groups of sources with possible different origin for the additional absorption line are marked.

mum H I column density of the shocked layer is about $10^{21}\,\mathrm{cm}^{-2}$, which translates to a maximum optical depth of $\tau_{\max} = 1$.

In Figure 3 we have plotted the optical depth τ of each additional component found in the absorption spectra as a function of its implied expansion velocity. Apparently, most of the components satisfy the constraints laid out for the expanding shells of shocked atomic hydrogen, as indicated in the lower left corner. There are also some high-velocity components, which are most likely high-velocity winds or jets that just happen to be expanding in our direction.

There is another group of sources with low $v_{\rm exp}$ and very high τ. We believe that these absorption features indicate a possible distance ambiguity in the Perseus spiral arm. According to Roberts (1972) the spiral shock causes the radial velocity to drop by 20 to $30\,\mathrm{km\,s^{-1}}$ at the beginning of the Perseus arm and slowly rejoins the flat rotation curve after about 1 kpc. This creates a velocity inversion inside the Perseus arm. Thus inside the arm the distance is increasing with increasing radial velocity as opposed to the flat rotation curve. The density in the closer part of the Perseus arm is significantly enhanced by the spiral shock which would explain the high τ values we obtained.

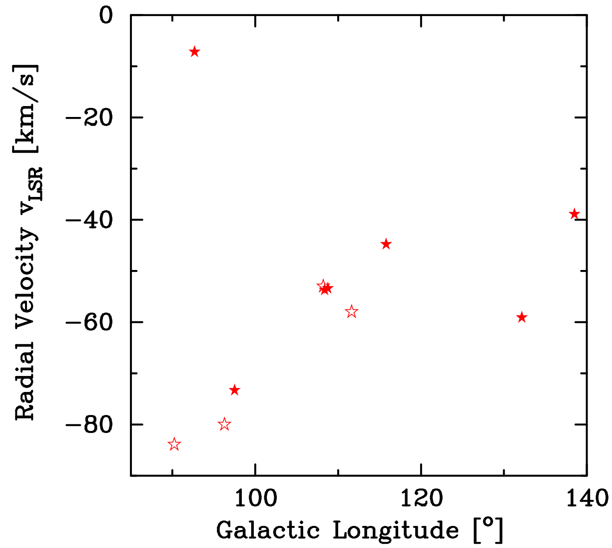

Fig. 4. Diagram of radial velocity as a function of Galactic longitude for sources with high calculated τ values.

For this interpretation, we would expect a strong dependence of the radial velocity of this absorption line on Galactic longitude caused by the changing viewing angle to the Perseus arm. To examine this dependence we plotted the $v_{\rm LSR}$ at the center of the absorption lines as a function of Galactic longitude, for the components with high opacities in Figure 4. The velocity dependence of the component is obvious. There is only one source far away from the others in the upper left corner of the diagram. For this component the expansion velocity would be $0.8 \pm 2.5\,\mathrm{km\,s^{-1}}$. It is most likely a local source with a dense foreground cloud.

REFERENCES

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