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Neutral Hydrogen Absorption Toward H II Regions in the Perseus Arm

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Abstract. Canadian Galactic Plane Survey H I data are used to examine the flow and evolution of material through the Perseus spiral arm, with particular reference to the 'two arm spiral shock' (TASS) model of Roberts (1972). Evidence for multiple shock regions is found.

1. Introduction

It has been known for a long time that velocities of the interstellar medium (ISM) and young stellar objects located in the Perseus spiral arm in the second quadrant of the Galaxy are systematically blueshifted from the velocities predicted by circular Galactic rotation. Further, there exist absorption lines in stellar spectra at more negative velocities than the stellar velocity (Münch 1957) indicating a reversal in the projected velocity field at the Perseus Arm location. Both these observations were very successfully modeled by the two arm spiral shock (TASS) model of Roberts (1972) wherein the ISM streams into the potential well of a stellar density wave and a large-scale shock develops. The shock leads to a compression of the atomic ISM; the young stellar objects retain the velocity of the compressed ISM from which they formed. A schematic overview of the TASS model at $l = 110$–115^o is shown in Figure 1. Crudely, the flow of the atomic ISM through the Perseus Arm can be envisioned to go from left to right in Figure 1, with the material gradually returning to circular rotation as it emerges from the shock. Strong contributions to the H I 21-cm emission line come from two major sources – (1) the density enhancement at the location of the shock and (2) a 'substantial amount of rarefied gas integrated over the top of the velocity hill' (Roberts 1972), where the projected v_{lsr} changes slowly with distance. Only the former of these two contributions (which generate comparable H I line intensities) comes from a surface density enhancement.

The Canadian Galactic Plane Survey data (Taylor et al. 2002), including high resolution panoramic spectral line images of both H I from DRAO and ^{12}CO (J=1–0) from the FCRAO Outer Galaxy Survey (OGS; Heyer et al. 1998) provide an excellent opportunity to examine the TASS model in some detail. In this contribution, we present an overview of the results of H I emission and absorption measurements toward H II regions located in the Perseus Arm at $l \sim 110^o$ that support, with modifications, the overall TASS picture. The absorption source sample, including extragalactic 'control' sources is summarized in Table 1. We have partitioned the sample into three groups for study, separated by horizontal

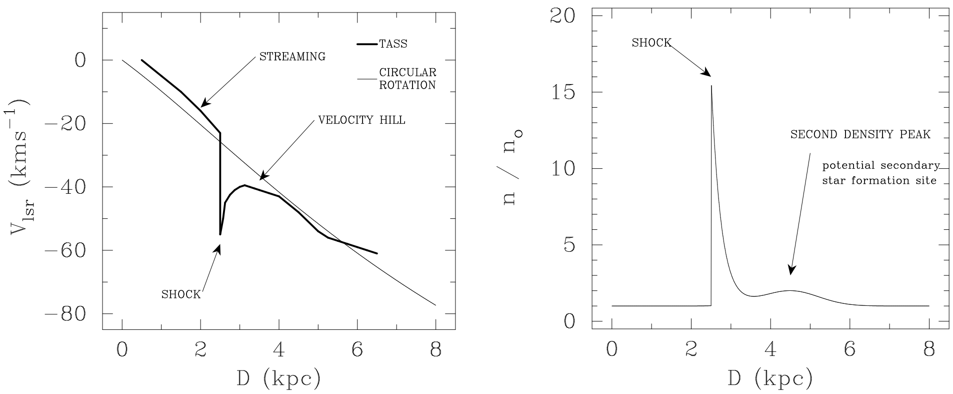

Figure 1. Schematic representation of Roberts' TASS model for l = 110 - 115 deg. We have attempted to adjust the overall pattern to the reference frame of circular rotation with R_o=8.5 kpc, v_o=220 km s^{-1} from the Schmidt model used by Roberts (1972). Actual distances and velocities are thus uncertain, but the overall pattern is reproduced.

lines. Distances of H II regions and velocities of associated molecular material are taken from Brand & Blitz (1993) and Bronfman et al. (1996).

Table 1. Absorption Source Sample

Source	l (deg.)	b (deg.)	v_{lsr} (km s^{-1})	D (kpc)	Notes.
Sh 148/9	108.36	–1.05	–53.1 (CO)	5.4 ± 1.7	H II region
Sh 152	108.76	–0.95	–50.3 (CS)	3.6 ± 1.1	H II region
E1	107.95	–1.50			extragalactic
Sh 156	110.10	+0.05	–52.1 (CS)	6.4 ± 2.0	H II region
Sh 157	111.28	–0.65	–44.1 (CS)	2.5 ± 0.4	H II region
E2	110.77	–0.88			extragalactic
Sh 158	111.52	+0.81	–56.1 (CO)	2.8 ± 0.9	H II region
Sh 159	111.61	+0.37	–56.3 (CS)	3.1 ± 1.2	H II region
E3	111.37	+0.53			extragalactic

2. Results and Discussion

Prototype emission and absorption spectra are shown in Figure 2 for Sh 152 and E1. All measurements contain, with some variations, the basic structures shown in Figure 2. The shock signature is interpreted as the presence of a major source of H I opacity at more negative v_{lsr} than the parent molecular gas from which the H II region formed. The H I optical depths are an order of magnitude greater than those seen in expanding shells around H II regions (Kothes & Kerton 2002). In the TASS model, the molecular material is downstream (at greater distance and more positive v_{lsr}) from the compressed atomic material. The FCRAO OGS shows no CO emission peak associated with the H I absorption peak, in accord with Heyer & Terebey (1998) who showed that the material entering the arm is predominantly atomic. The molecular material thus forms directly from the compressed atomic gas, and is observed at less negative v_{lsr} having moved downstream during the time taken to generate observable CO abundances. Lack of

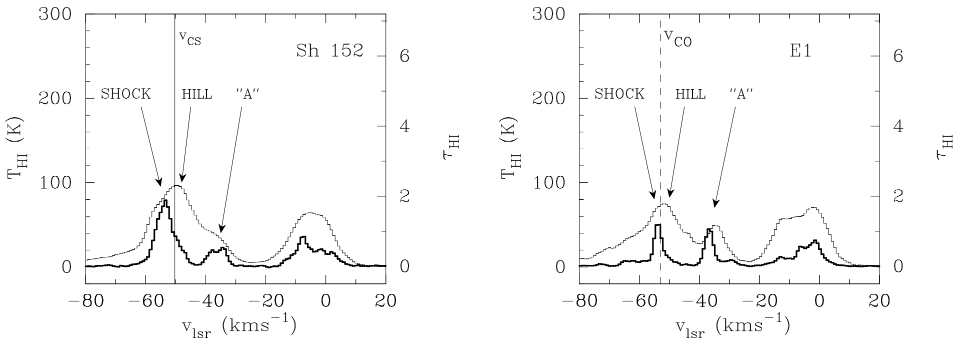

Figure 2. 'Prototype' absorption ($\tau_{\mathrm{H\,I}}$; heavy lines) and emission ($T_{\mathrm{H\,I}}$; lighter lines) toward Sh 152 and E1. Velocities of molecular emission are indicated by vertical lines.

absorption toward the peak of H I emission indicates low-opacity, warm material. The TASS model places this component in the 'velocity hill' downstream from the shock, but (1) Roberts' TASS model is isothermal and (2) the physical location of this component is ambiguous on purely empirical grounds. The observed v_{lsr} of the velocity hill is more negative than expected from Figure 1; see also this discrepancy in Roberts (1972). A direct evolutionary link between material in the shock and material in the 'velocity hill' must involve heating and/or expansion of the compressed cooled material (potentially having evolved through a partially- or wholly molecular stage). The induced star formation may play a role in this. Toward both Sh 152 and E1 there is an additional ("A") absorption signature. The existence of these "A" components is not explicitly represented in the TASS model and they are extremely unlikely to occur (see Figure 1). Material at these velocities would occur at a distance of $\sim$ 3 kpc if it is in circular rotation, but it is difficult to envision how some material avoids the streaming and shock motions entirely. Alternatively, this material may be related to material in the 'velocity hill' (if the H II region lies in the secondary density enhancement) *or* arise from minor shocks as material streams into the arm. The results below are in support of this latter hypothesis. Emission and absorption spectra for all sources are shown in Figure 3. All sources show a shock signature (at varying v_{lsr}) and lack of absorption toward the emission peak, and the presence of and/or v_{lsr} of "A" components is highly variable. Each group of three sources is discussed individually below.

Sh 152, Sh 148/9, E1 : The H II regions are associated with the same molecular cloud and are likely at a common distance, suggested also by the similarity of their absorption spectra.

Sh 156, Sh 157, E2 : Sh 157 is very likely at a closer distance than Sh 156, and while Sh 157 does show a shock signature at $v_{lsr} \sim$ –47 km s^{-1}, the second source of major H I opacity seen toward Sh 156 at $v_{lsr} \sim$ –60 km s^{-1} is not seen in Sh 157 in absorption but *is* seen in emission. This strongly suggests the presence of two major compression zones in the vicinity of Sh 156 and Sh 157.

Sh 158, Sh 159, E3 : The H II regions are associated with the same molecular cloud and are likely at a common distance of D $\sim$ 3 kpc which places them directly behind the shock in the TASS model. The "A" components seen here

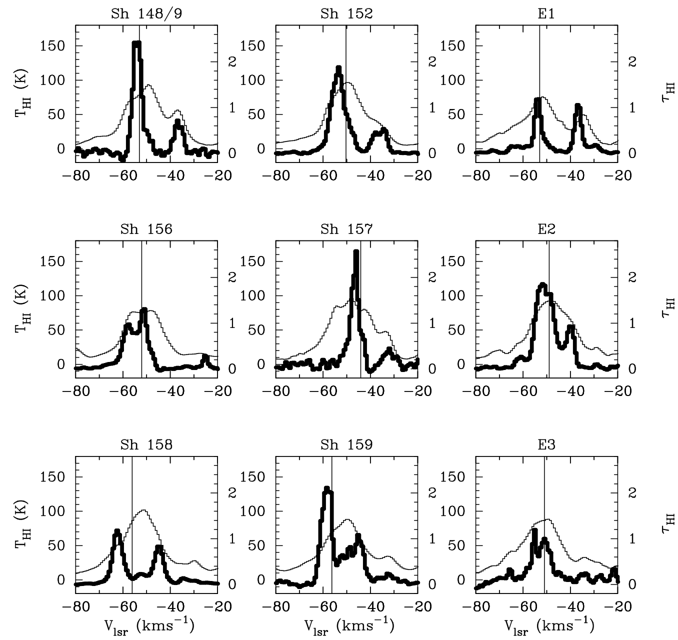

Figure 3. Absorption and emission toward all sources.

are thus near the shock at D $\sim$ 2.5 kpc, and not related to the 'velocity hill'. In this case, and perhaps also toward the other sources, the "A" components very likely arise from minor shocks of material as it enters the arm under variable conditions, since the observed v_{lsr} of the "A" components would place them behind the H II regions if the "A" material was in circular rotation.

In summary, all sources show a definite shock signature, with considerable variability in v_{lsr} which probably arises from variation in local shock conditions. Variations in absorption spectra between nearby sources are very pronounced. The inflowing gas is primarily atomic, and the molecular gas must form directly from the compressed atomic material. Near Sh 156/Sh 157 there are two compression zones that have led to the production of enough molecular material to form stars. The existence of additional absorption components which are inconsistent with being in circular rotation at their deduced distances suggests that numerous compression events occur under highly variable conditions as material enters the arm. The TASS model must be updated, at the very least, to account for inhomogeneous and non-isothermal atomic gas.

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