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H I TAILS FROM MOLECULAR CLOUDS NEAR HD 17603 AND WOLF-RAYET 5

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RESUMEN

Reportamos la detección de colas largas y delgadas de H I que provienen de nubes moleculares en el brazo de Perseo de la Galaxia. La hipótesis de que éstas están impulsadas por los vientos estelares de una o ambas de las estrellas masivas HD 17603 y WR 5 impone restricciones rígidas sobre el ambiente de los vientos estelares: encontramos que es necesario tener una burbuja de viento fuertemente cargada de masa.

ABSTRACT

We report the detection of long, thin H I tails emanating from molecular clouds in the Perseus Arm of the Galaxy. The hypothesis that they are driven by stellar winds from one or both of the massive stars HD 17603 and WR 5 places strong constraints on the stellar wind environment: we find that a heavily mass-loaded wind bubble is required.

Key Words: **ISM: BUBBLES — ISM: KINEMATICS AND DYNAMICS — STARS: WINDS, OUTFLOWS — STARS: EARLY-TYPE — STARS: WOLF-RAYET**

1. INTRODUCTION

The observational data which forms the basis of this work comes from the Canadian Galactic Plane Survey (CGPS), a large ongoing collaborative project pursued by a consortium of Canadian and international researchers. This project is imaging, at one arc minute resolution, the major components of the interstellar medium over a large section of the northern Galactic plane. The most important data products of the CGPS are the unique high resolution spectroscopic maps of Galactic H I 21 cm line emission which come from the Synthesis Telescope and 26 m single dish telescopes at the Dominion Radio Astrophysical Observatory in Penticton (Landecker et al. 2000). Using this data, we have discovered a system of what appear to be long, narrow H I tails emanating from molecular clouds located about 2 kpc away towards the outer Galaxy in the direction of the Perseus Arm (Figure 1). The main tail appears to stream away from a molecular cloud of mass $400\,M_\odot$ at radial velocities between 5 and $20\,\mathrm{km\,s^{-1}}$. This tail appears to have narrow parallel substructures. A second very narrow tail lies somewhat to the north of but parallel to the main tail. It is not so clear that the second tail is associated with molecular gas (these molecular gas observations come from the reprocessed FCRAO Outer Galaxy Survey CO data). This system of tails points toward the luminous stars HD 17603, which is an O-type supergiant, and the Wolf-Rayet star WR 5. These are the two most luminous stars known to lie in this general direction. Both stars are thought to be at a distance of about 2 kpc, which agrees with the probable kinematic distance of the CO clouds. The tails have a fairly well-defined radial velocity gradient in the direction along the tails, suggestive of a possible acceleration along their length.

2. STELLAR WIND-DRIVEN TAILS

We propose that the H I tails are gas dissociated from the molecular clouds and accelerated away in the wind of one or perhaps both of the stars. Under this assumption, we can derive the physical and kinematic parameters of the H I flow. The total mass of H I in the tails is $1700\,M_\odot$, which is roughly four times the mass in the associated molecular clouds. The mass-weighted mean flow radial velocity with respect to the CO clouds is $(12/\cos i)\,\mathrm{km\,s^{-1}}$, where i is the unknown angle of the H I flow direction with respect to the line of sight. The tails are several tens of parsecs long and the dynamical timescale is a few million years, which is of order the main sequence lifetime of the massive stars which evolved to become HD 17603 and WR 5. If one or both of these stars drive the H I tails, it must have occurred while they were on the main sequence. If the tails are entrained by a stellar wind, it is conceivable that shocks dissociate the gas to produce the H I. Alternatively, the dissociation may be caused by the stellar radiation

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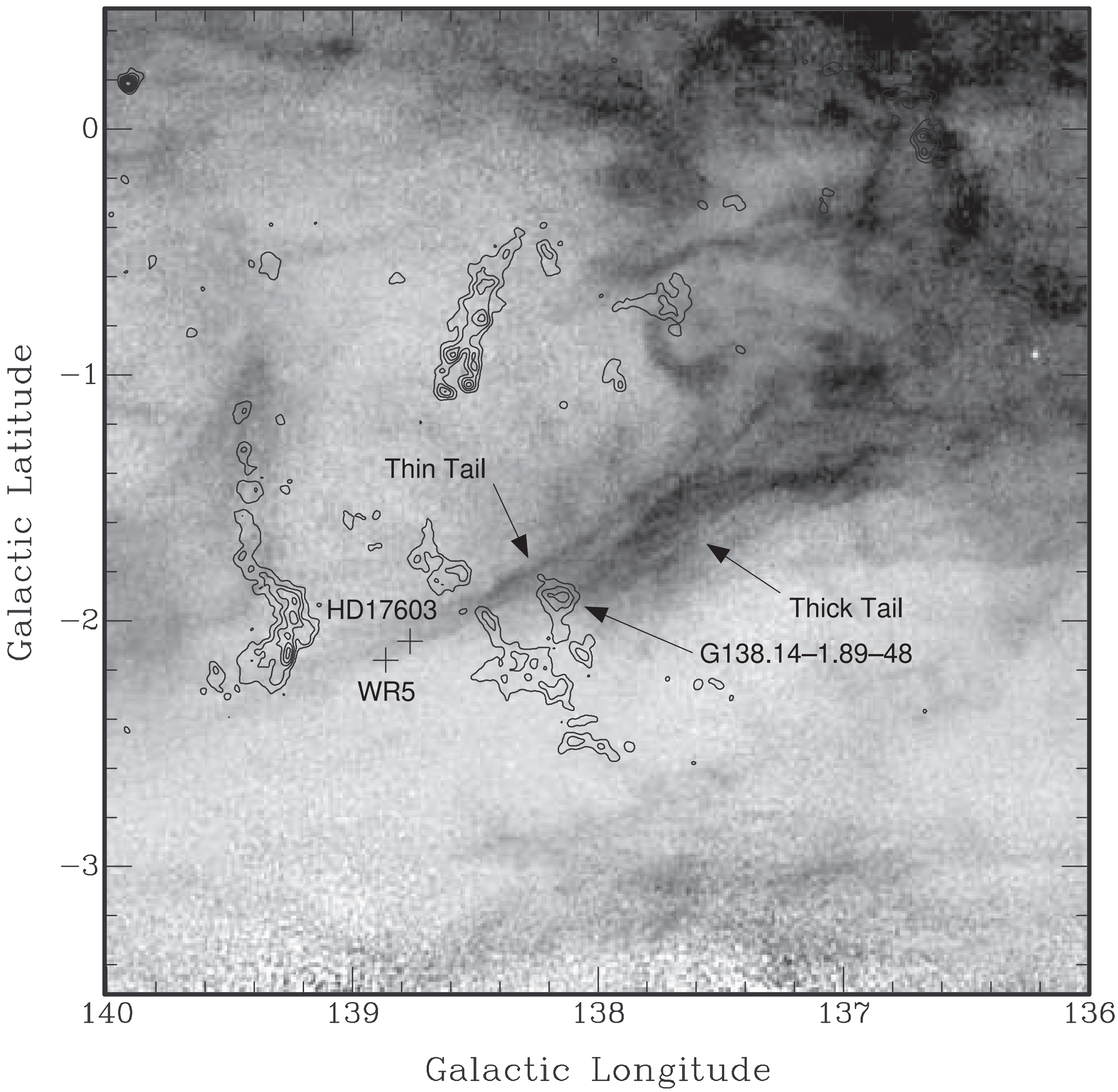

Fig. 1. H I data (greyscale) showing tails emanating from CO clouds (contours). The thick tail points towards the CO cloud G138.14−1.89−48. Both point towards the stars HD 17603 and WR 5.

field(s). There is, however, no evidence for the effects of photoionization in this system. The relative narrowness of the tails suggests that the Mach number in the driving wind is not very large (perhaps at most only mildly supersonic).

3. MASS LOADING IN A WIND BUBBLE

The kinematic parameters of the H I flow place tough constraints on the external wind flow. Using the phenomenological analytic theory developed by Hartquist et al. (1986), we can use the observed cloud mass-loss rate into the tails in order to derive the required momentum flux in the external driving wind. The results are somewhat sensitive to the unknown value of the system inclination and to the exact value of a free parameter in the theory, but a reasonable estimate for the external momentum density is $n_{\rm wind} v_{\rm wind} \approx 40\,{\rm cm^{-3}\,km\,s^{-1}}$. Extrapolating over the solid angle of a sphere for a spherically symmetric wind, this implies that a total of $\sim 10^{51}\,{\rm erg}$ of available kinetic energy (i.e., not in the form of thermal energy) must have

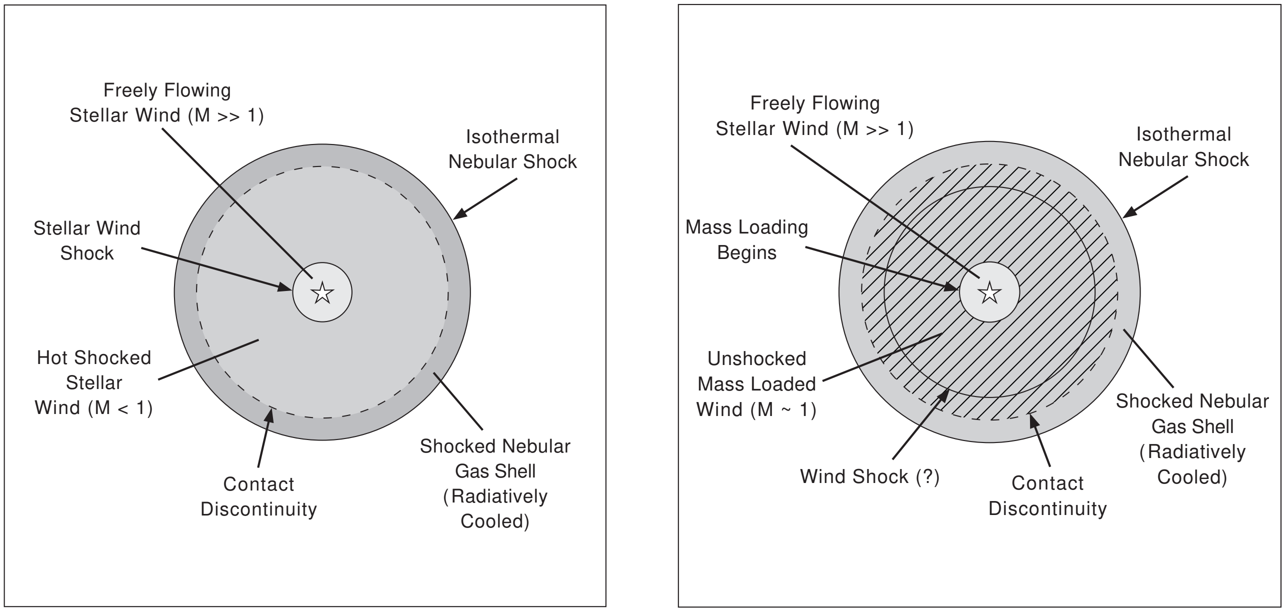

Fig. 2. Left: The basic adiabatic stellar wind bubble model. The high Mach number stellar wind goes through a global shock very near the star. Right: Stellar wind bubble with heavy mass loading (hatched region) near the star. There is no global shock near the star, but there may be a weaker one much further out near the edge of the bubble.

been supplied by the wind over the lifetime of the H I tails. This is a severe constraint, since in the basic theory of adiabatic stellar wind bubbles, only a tiny fraction, $\sim 1\%$, of the total energy in the wind ($E_{\rm tot} \sim 10^{51}$ erg) is in the form of kinetic energy within the shocked stellar wind region which takes up the majority of the volume of the wind bubble (Figure 2). The basic stellar wind bubble model cannot account for the acceleration of the H I tails. However, work done by Dyson and collaborators (cf. Pittard, Hartquist, & Dyson 2001) has shown that mass loading of an initially supersonic wind from mass sources distributed smoothly throughout the region around the star can reduce the Mach number of the wind without having the wind going through a global shock near the star (Fig. 2). If the mass loading is sufficiently heavy ($m_{\rm load}/m_{\rm wind} \sim 10$, where $m_{\rm load}$ is the mass loaded into the wind and $m_{\rm wind}$ is the mass of the wind injected by the star), a large fraction of the stellar wind energy ($> 50\%$) will remain in the form of kinetic energy instead of thermal energy. A heavily mass-loaded wind can thus, in principle, account for the very large amount of momentum required in our scenario. We suggest that a heavily mass-loaded wind may be driving the H I tails. Apart from accounting for the very high kinetic energy content in the driving wind and its apparent low Mach number, it also accounts for another feature of the interstellar environment of HD 17603 and WR 5. Heavy mass loading greatly reduces the mass of the swept-up bubble of ambient gas around the wind bubble, and for HD 17603 and WR 5 we see no evidence for a detectable swept-up shell.

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