AN UNUSUAL SYSTEM OF $\text{H} \, \text{I}$ FILAMENTS NEAR WR 5 AND HD 17603

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ABSTRACT

We report the discovery of a system of unusual $\text{H} \, \text{I}$ filaments that appear to be associated with molecular clouds in the Perseus spiral arm of our Galaxy. We investigate the hypothesis that this system is the result of a directed flow of dissociated gas from clouds trapped within an extended wind flow from massive stars. The Wolf-Rayet star WR 5 and the O Ib(f) star HD 17603 are identified as candidate driving sources. However, an examination of this hypothesis within the context of the theory of mass-loaded winds shows that these two stars alone cannot account for the energetics and kinematics of the required spherically symmetric wind flow. Unless the apparent association between $\text{H} \, \text{I}$, molecular gas, and stars is an accidental one, we suggest that other as yet unidentified stars must have contributed to driving the filaments.

Subject headings: ISM: bubbles — ISM: clouds — ISM: kinematics and dynamics — stars: individual (HD 17603, WR 5) — stars: winds, outflows

1. INTRODUCTION

Massive O-type stars, including the progenitors of Wolf-Rayet stars, inject enormous quantities of energy into the interstellar medium (ISM) in the form of dissociating and ionizing radiation and winds. The radiation fields create circumstellar/interstellar $\text{H} \, \text{I}$ and $\text{H} \, \text{II}$ regions into which winds blow, creating large-scale swept-up expanding shells of gas known as stellar wind bubbles (Dyson & de Vries 1972; Koo & McKee 1992a, 1992b). There are numerous analytical and numerical studies on the formation, structure, and evolution of stellar wind bubbles (SWBs), but there are few convincing observations of $\text{H} \, \text{I}$ bubbles around Wolf-Rayet stars and massive O stars. The VIIth Catalogue of Galactic Wolf-Rayet Stars indicates that only $\approx 15\%$ are associated with $\text{H} \, \text{I}$ bubbles (van der Hucht 2001). Surveys are incomplete, but many of these proposed bubbles are not securely established.

The interstellar environment of massive stars is observed to be extremely complex and is likely to be the combined result of inhomogeneous initial conditions and the influence of the stars. Our understanding of the physics of astrophysical flows in inhomogeneous media is incomplete (Hartquist & Dyson 1993). In particular, the effects of conduction, diffusion, turbulence, magnetism, and mixing and mass-loading processes are all poorly understood. Therefore, in the observational study of SWBs and the environment of massive stars it is important to remain open to the possibility of phenomena not predicted by standard SWB models.

In this paper we present one possible example of such a phenomenon. We investigate the nature of a large-scale system of neutral atomic hydrogen filaments that apparently emanate from compact molecular clouds located in or near the Perseus arm of our Galaxy. We investigate the possibility that these $\text{H} \, \text{I}$ “tails” are the result of molecular cloud mass loading within the wind flow of massive stars.

The observations and data processing are briefly outlined in § 2. Section 3 describes the observational results. In § 4 we consider possible driving sources, and in § 5 we take a closer look at the environment of the two main candidates. The discussion follows (§ 6), in which we first consider the kinematics and timescales involved (§ 6.1) and then present an analysis within the framework of a mass-loaded flow model (§ 6.2). Our conclusions follow in § 7.

2. OBSERVATIONS AND DATA PROCESSING

The data discussed in this paper were obtained as part of the Canadian Galactic Plane Survey (CGPS), a long-term multi-wavelength imaging survey of the ISM of the northern Galactic plane (Taylor et al. 2003). Table 1 summarizes the main parameters of the relevant CGPS data. The principal observational components of the CGPS are arcminute-resolution mosaics of 21 cm (in all Stokes parameters) and 74 cm (right-hand circular polarization) radio continuum and 21 cm $\text{H} \, \text{I}$ line emission, all observed with the Synthesis Telescope (Landecker et al. 2000) at the Dominion Radio Astrophysical Observatory of the Herzberg Institute of Astrophysics.

Complementary data produced as part of the CGPS include mosaics of dust emission created using Infrared Astronomical Satellite (IRAS) data processed using the HIRES algorithm (Cao et al. 1997; Kerton & Martin 2000) and of $^{12}\text{CO}(J = 1-0)$ emission from the Five College Radio Astronomy Observatory (FCRAO) Outer Galaxy Survey (OGS) (Heyer et al. 1998). The CGPS CO mosaics are the result of a reprocessing of the original OGS data, wherein correlated noise between pixels caused by the observing method was suppressed and faint contaminating
emission found in the reference positions of the survey was removed (Brunt et al. 2000). The reprocessed data were resampled and projected into the CGPS mosaic system.

3. RESULTS

3.1. Neutral Atomic Hydrogen

A mean brightness temperature H i image, averaged between local standard of rest (LSR) radial velocities $-53.4$ and $-66.6$ km s$^{-1}$, is shown in Figure 1. Prominent in this image is a linear H i structure 1'8 long, running at an angle $\sim 20^\circ$ north of west relative to the Galactic plane. In the extreme southeast this structure is a relatively narrow ($\sim 2'$ wide) filament beginning near $(l, b) = (138^\circ 7, -2^\circ 0)$. Near $(138^\circ 2, -1^\circ 9)$, the narrow filament is joined by a broader ($\sim 0'5$) structure that runs parallel and to the south of it. This structure continues to broaden toward the northwest, reaching a maximum width of $0'8$. Its northwest extremity lies near $(136^\circ 7, -1^\circ 0)$, where it blends into larger scale H i structures in the Galactic plane. The approximate center of the linear structure is at $(l, b) \approx (137^\circ 7, -1^\circ 6)$; we designate it HI G137.7$-1.6$ and for brevity refer to it as HI G137 in this paper.

The radial velocity width of HI G137 is 15 km s$^{-1}$, and there is a distinct velocity gradient along its length: velocities become more negative toward the northwest. This velocity gradient clearly separates HI G137 from the Galactic H i emission to the northwest (Fig. 2). Individual channel maps (Fig. 3) hint at the existence of linear substructures, resulting in the overall impression that HI G137 is composed of several parallel filaments. We can detect no clear velocity structure in the direction transverse to the length of the filaments: this may be due to a combination of sensitivity and angular resolution limitations for individual filaments and confusion between them.

We are unable to make a direct measurement of the distance to HI G137. There are no known H ii regions in the direction of the filaments, and there are large discrepancies between kinematic and photometric distances in the Galactic plane in this region in the sense that kinematic distances can be greatly overestimated compared to the latter (Foster & Routledge 2003).

3.2. Carbon Monoxide

The CGPS CO data were searched for molecular clouds having positional and/or velocity coincidences with HI G137. We found no CO emission near HI G137 within the velocity range of the H i structure. Widening the velocity range of our search revealed an irregular chain of CO clouds in the southeast of HI G137 at $-44$ km s$^{-1} \leq v \leq -50$ km s$^{-1}$ extending $\sim 1'$ in a direction perpendicular to the length of the H i structure. Of these, the cloud with the brightest peak CO line brightness ($T_R = 4.0$ K), which we dub CO G138.1$-1.9$ (CO G138 for brevity), lies at the convergence point of the broad-structured component of HI G137 (Fig. 4). The velocity difference between CO G138 and HI G137 ranges between 5 and 20 km s$^{-1}$.

The northern narrow filament of HI G137 appears to emerge from between a gap in the chain of CO clouds. Within this gap

| Parameter          | Value     |
|--------------------|-----------|
| H i 21 cm Line     |           |
| Spectral resolution| 1.32 km s$^{-1}$ |
| Channel width      | 0.82 km s$^{-1}$ |
| Angular resolution | 64$''$    |
| $^{12}$CO$(J = 1-0)$ Line |           |
| Spectral resolution| 0.98 km s$^{-1}$ |
| Channel width      | 0.82 km s$^{-1}$ |
| Angular resolution | 100$''$   |

Fig. 1.—Mean H i brightness temperature image of HI G137, averaged between LSR radial velocities $-53.4$ and $-66.6$ km s$^{-1}$.
there is a faint (1.3 K) compact cloudlet at −47 km s⁻¹ embedded within very faint (∼0.5 K) diffuse CO emission.

4. SEARCH FOR DRIVING SOURCES

The positional association between the molecular clouds and the convergent point of the H i filaments suggests that HI G137 might be the result of a directed flow of dissociated gas from the molecular clouds. If HI G137 is associated with the CO clouds at ∼48 km s⁻¹, its distance is \( D \approx 2 \) kpc, the approximate distance to the Perseus arm at this longitude. The source(s) of the radiation and/or winds driving HI G137 will be at the same distance. The former would have to be located on the sky such that the H i filaments point toward them and the CO clumps lie between them and the filaments in a more or less collinear fashion. The SIMBAD database was used to search for O, B, and Wolf-Rayet–type stars within 0°5 of (\( l, b \)) = (138°5, −2°0) (Table 2). Of the resulting 10 stars, the Wolf-Rayet star WR 5 and the O-type supergiant HD 17603 currently have substantial stellar winds and ionizing radiation. These two therefore merit closest attention.

4.1. Wolf-Rayet 5 and HD 17603

WR 5 (HD 17638) is a Wolf-Rayet star of spectral type WC6 (van der Hucht 2001). It has a reddening of \( E_{B-V} = 0.96 \) (\( A_V \approx 3 \)) and a photometrically derived distance of 1.91 kpc (van der Hucht 2001).

HD 17603 is an O7.5 Ib(f) star (Walborn 1973) located 7°5 northwest of WR 5. Stars of type O(f) are thought to be precursors of Wolf-Rayet stars. The available \( UBV \) photometry for this star (Haug 1970) is consistent with a reddening \( E_{B-V} = 0.93 \) (\( A_V \approx 3 \)). The absolute magnitudes of O(f) stars are not well determined; however, assuming that this star has \( M_V \approx -6.3 \) (Garmany et al. 1982), it lies at a distance \( D \approx 2.2 \) kpc.

Both WR 5 and HD 17603 satisfy the positional criteria to be considered candidate driving sources. In addition, both are hot, luminous objects with strong winds. For both stars, the apparent alignment of H i–CO–star is very good, and these stars are likely to be the most luminous and energetic of those we have identified. Finally, their approximate distances are consistent with that proposed for HI G137. Stellar wind parameters for both stars are listed in Table 3.

A final consistency check on the stellar and CO cloud distances can be made by integrating the H i line profiles toward the stars from zero velocity to the velocity at which an H i column corresponding to \( E_{B-V} \approx 1 \) is found. For the WR 5 and HD 17603 sight lines, reddening implies an H i column of \( N \approx 4.5 \times 10^{21} \) cm⁻². Our H i data show that this column density is reached when the line profiles are integrated from zero velocity out to \( \approx -50 \) km s⁻¹, consistent with the radial velocity of CO G138.

4.2. The B Stars

In addition to the Wolf-Rayet and O Ib(f) stars discussed above, there are eight B stars within ∼0°5 of the tip of HI G137. Among them is EO Per, a rapidly varying B0 supergiant. A B0 supergiant has a mass of roughly 30 \( M_\odot \), and so is approximately type O7.5 while on the main sequence. According to Howarth & Prinja (1989), such a star has a wind terminal velocity of 2300 km s⁻¹,
Fig. 3.—Eight $\text{H} \downarrow$ channel maps of HI $\text{G137.7} - 1.6 - 60$ showing filamentary substructures. The positions of WR 5 and HD 17603 are indicated. Each velocity channel spans $0.82 \text{ km s}^{-1}$. The gray scale runs from 0 (white) to 75 K (black).
slightly lower than the lower bound quoted for both WR 5 and HD 17603, and a mass-loss rate of $10^{-6.7} \ M_\odot/\text{yr}$, an order of magnitude smaller than the lower bound for the other two stars. At present, this star is likely to have a higher mass-loss rate but much lower wind terminal velocity than WR 5 and HD 17603, as well as a lower ionizing flux.

The remaining seven candidates have very limited observational data on which to base determination of their type and distance. If we assume they are located at $D \approx 2$ kpc and lie behind an extinction of $A_V = 3$, then all these stars have photometry

![Figure 4: Contours of $^{12}\text{CO}(J=1-0)$ at $-46.81 \ \text{km s}^{-1}$ at 0.75, 1.25, and 2.0 K superimposed on a gray scale of the H I at $-58.35 \ \text{km s}^{-1}$. The northern narrow H I filament appears to emanate from a faint CO cloudlet within a gap in a chain of brighter CO clouds. The thicker southern part of the H I tails appear to emanate from CO G138.](image)

**TABLE 2**

| Name       | Spectral Type | Galactic Longitude | Galactic Latitude |
|------------|---------------|--------------------|-------------------|
| WR 5       | WC6           | 138.87             | -2.15             |
| HD 17603   | O7.5 Ib(f)    | 138.77             | -2.08             |
| EO Per     | B0 Iab:e      | 138.50             | -1.89             |
| CDS 314    | B             | 138.50             | -1.89             |
| BD +56°722 | B             | 138.57             | -2.14             |
| ALS 7516   | B             | 138.80             | -2.08             |
| ALS 7523   | B             | 138.87             | -2.04             |
| ZZ Per     | B             | 138.84             | -2.19             |
| ALS 7453   | B             | 138.22             | -2.32             |
| ALS 7470   | B             | 138.16             | -1.75             |

**Notes:**
- Compiled using the SIMBAD database. Unless otherwise noted, the information in this table is that listed in SIMBAD.
- van der Hucht (2001).
- Walborn (1973).
- Listed R.A./decl. differ slightly for these two stars.

**TABLE 3**

| Parameter                      | WR 5     | HD 17603 |
|--------------------------------|----------|----------|
| Spectral type                  | WC6$^a$  | O7.5 Ib(f)$^b$ |
| $v_w$ (km s$^{-1}$)            | 2365$^c$ | 2500$^d$ |
| $M$ ($M_\odot$ yr$^{-1}$)     | $10^{-4.3e}$ | $10^{-6.79f}$ |
| $L_w$ (ergs s$^{-1}$)          | $8.9 \times 10^{37}$ | ... |
| MS spectral type               | O5       | O5       |
| MS $v_w$ (km s$^{-1}$)         | 2800     | 2800     |
| MS $M$ ($M_\odot$ yr$^{-1}$)   | $10^{-5.7}$ | $10^{-5.7}$ |
| MS $L_w$ (ergs s$^{-1}$)       | $4.5 \times 10^{36}$ | $4.5 \times 10^{36}$ |
| MS lifetime (Myr)              | 3.7      | 3.7      |
| MS wind energy (ergs)          | $5 \times 10^{39}$ | $5 \times 10^{39}$ |

**Notes:**
- The main-sequence (MS) spectral types were estimated from the evolutionary tracks by Maeder (1990). WR 5 would have had a zero-age main sequence (ZAMS) mass of $40 M_\odot$ yr$^{-1}$ or more, which corresponds to an MS spectral type of O6.5 or earlier. The type O5 was chosen to give a rough estimate of the energies involved. Masses quoted for O7.5 Ib stars are on the order of $60 M_\odot$ yr$^{-1}$, implying an MS type of O5 or earlier. Again, the type O5 was chosen to give a rough estimate of the energies involved. Their stellar wind parameters were calculated from the empirical relations of Howarth & Prinja (1989). Their MS lifetime is from Chiosi et al. (1978).
- van der Hucht (2001).
- Walborn (1973).
- Rochowicz & Niedzielski (1995). Values found in the literature range from $1600 \ \text{km s}^{-1}$ (Koesterke & Hamann 1995) to $2800 \ \text{km s}^{-1}$ (Torres et al. 1986).
- Bieging et al. (1989), based on comparison with other stars.
- Koesterke & Hamann (1995).
- Bieging et al. (1989), based on empirical relations by Garmany & Conti (1984).
5. THE INTERSTELLAR ENVIRONMENT OF WR 5 AND HD 17603

Based on low-resolution (9') observations, Arnal (1992) proposed that WR 5 is associated with an ovoid H i deficiency, interpreted as a cavity, at velocities around $-14$ km s$^{-1}$. We note that integrating out to $-14$ km s$^{-1}$ in the H i line yields a column density only $\sim 1.5 \times 10^{19}$ cm$^{-2}$, corresponding to $E_{B-V} \approx 0.3$, which is too small to be consistent with the observed reddening to the two stars. WR 5 and HD 17603 are well beyond the distance corresponding to that gas velocity and thus cannot be associated with the ovoid structure. Our high-resolution (1') observations show that the H i distribution is highly structured in both morphology and velocity, and the “cavity” is by no means clearly distinguishable. In addition, regions of depressed H i brightness within this cavity correspond in position and velocity with much of the CO emission seen around $-14$ km s$^{-1}$, which suggests that the relative lack of H i emission is due at least in part to the hydrogen being in molecular rather than atomic form.

For the velocity range within which we associate WR 5 and HD 17603 ($-53.5 \lesssim v \lesssim -42.0$ km s$^{-1}$), our H i data do not show any convincing evidence for an H i shell surrounding a cavity. However, it is possible that a gas shell does exist but is not clearly visible in the H i observations because of its low contrast or because parts of it are molecular. The clear anticorrelation between the CO clouds and the H i brightness distribution in the $-53.5$ to $-42.0$ km s$^{-1}$ velocity range and the relative lack of CO emission within $-40'$ of the stars lend some support to the latter possibility.

Marston (1996) cited evidence from IRAS Skyflux images for a 1.35 diameter dust shell around WR 5. Such a shell is not obvious in the HIRES-processed 12, 25, 60, and 100 $\mu$m mosaics. To investigate further, we used the 60 and 100 $\mu$m data to produce dust temperature and optical depth images. The scattered dust concentrations interpreted by Marston as a shell correlate much better with the velocity-integrated CO data than with the velocity-integrated H i data, some with CO emission in the velocity range around $-14$ km s$^{-1}$ and others with the CO around $-48$ km s$^{-1}$. This suggests that what was interpreted as a shell is in fact the result of projection effects.

We inspected H$\alpha$ data for this region from the Virginia Tech Spectral-line Survey (VTSS, Dennison et al. 1998) and the Wisconsin H$\alpha$ Mapper (WHAM) Northern Sky Survey (Haffner et al. 2003). The VTSS has an angular resolution of $\approx 1.6$ but does not provide velocity information. The WHAM H$\alpha$ data have a velocity resolution of 12 km s$^{-1}$ but a lower angular resolution of $\approx 1''$. The VTSS data suggest that WR 5 and HD 17603 both lie within a region relatively devoid of H$\alpha$ emission. The morphology of this “void” and thus its possible association with the stars is uncertain because a comparison of the VTSS image with velocity-integrated CO emission suggests that absorption by the dust in molecular clouds strongly influences the observed H$\alpha$ brightness distribution.

We conclude that there is at present no conclusive evidence for an H i or dust shell/cavity structure around WR 5 or HD 17603, although the stars appear to lie in regions relatively free of molecular, neutral atomic, and ionized gas. Any gas shell surrounding this region would have to be of low contrast or be rather inhomogeneous in its composition and structure: the latter implies a “leaky” shell within which a hot wind bubble might not be maintained.

6. DISCUSSION

The morphological relationships between the H i tails, the CO clouds, and the stars raises the question of whether all these are physically related. The possibility of a simple coincidence cannot be ruled out, but an explanation for the morphology and velocity structure of the H i tails would still be needed. In the remainder of this paper we investigate the possibility that winds from massive stars could be responsible for driving long, narrow H i tails from compact molecular clouds in their vicinity.

A viable physical model of HI G137 must be consistent with all the observational data that we have presented above. Obviously, we need a stellar mechanism for converting molecular to neutral atomic hydrogen and accelerating the H i away from the molecular clumps in long narrow tails at a velocity of $\sim 5$–$20$ km s$^{-1}$. WR 5 and/or HD 17603 must be able to supply momentum and energy at the rates required over a time comparable to the dynamical timescale. The molecular clumps must also be able to survive within the environment of the star(s) for this time.

One question that immediately arises is the association of H i tails with only some of the CO clouds in the $-44 \lesssim v \lesssim -50$ km s$^{-1}$ velocity range. Standard Galactic rotation curves predict a slope of the distance-velocity relationship at this location in the Galaxy of $\sim 150$ pc (km s$^{-1}$)$^{-1}$. The above velocity range thus potentially covers a line-of-sight range of $\approx ^1$ to $^1$ kpc, and the velocity resolution of our CO data (0.98 km s$^{-1}$) corresponds to $\sim 150$ pc. The empirical rotation curve of Brand & Blitz (1993) suggests that the slope may be even steeper. Given the potentially very wide range of distances for the CO clouds, only a small subset of the observed clouds may be within the range of influence of the tail-driving source(s). Additionally, H i flows from other CO clouds may be subject to confusion if they have relatively low radial velocities.

6.1. Kinematics and Timescales

Determining the mass of extended H i structures is always subject to wide uncertainties, not least because of confusion with unrelated emission. This is particularly acute for structures having large velocity dispersions. We determined the mass of HI G137 by first removing an estimate of the background H i emission on a channel-by-channel basis. This background was calculated by a linear interpolation anchored to velocity channels bracketing the velocity range of HI G137 that were judged to be free of emission from the latter. The background-subtracted cube was then integrated over a polygonal region enclosing HI G137. The solid angle of this region was 1.1 deg$^2$, and the mean H i column density derived was $N = 1.2 \times 10^{19}$ cm$^{-2}$. The total H i mass is $330D^2 M_\odot$, and the total mass, assuming a hydrogen mass fraction of 0.77, is $M = 425D^2 M_\odot$. The uncertainty in the mass estimate is at least 25%. The physical length of HI G137 projected onto the plane of the sky is $\sim 30D$ pc.

Assuming $D = 2$ kpc for HI G137, this yields a total mass of the structure of $M = 1700 M_\odot = 3.38 \times 10^{46}$ g. Assuming a systemic radial velocity of the mass reservoir of $-47$ km s$^{-1}$, the linear momentum contained in HI G137 is $P = P_0/cos(i) = 1.05 \times 10^{42} D/cos(i) = 4.20 \times 10^{42}/cos(i)$ g cm s$^{-1}$, where we have assumed that the space velocity of the flow can be deprojected from the radial velocity by using an inclination angle to the line of sight $i$. The mass-weighted mean outflow velocity is then $12.4/cos(i)$ km s$^{-1}$, and the kinetic energy is $E = P_0/cos^2(i) = 6.67 \times 10^{42}/D/cos(i) = 2.67 \times 10^{42}/cos(i)$ ergs. The driving source(s) presumably have injected momentum and energy isotropically into the ISM. The observed opening angle of HI G137 is $\theta \approx 20^\circ$, assuming that the three-dimensional structure is
conical and viewed at an inclination $i$, the true opening angle is $\theta \sin(i)$, and HI G137 subtends a fraction $f = \{1 - \cos[\theta \sin(i)/2]\}/2$ of a sphere. Therefore, $f \leq 7.6 \times 10^{-3}$ ($\leq 0.1$ sr), the maximum value occurring when $i = 90^\circ$ (when the outflow axis lies in the plane of the sky). Over the lifetime of HI G137 (discussed below), the driving source(s) have supplied a total (isotropic) momentum and kinetic energy of, respectively, $P_* = P/(f \epsilon P)$ and $E_* = E/(f \epsilon E)$, where the $\epsilon$-factors represent the efficiency of the transfer of momentum and energy to the H $i$.

The minimum values of $P_*$ and $E_*$ are obtained by minimizing the following two expressions with respect to $i$:

\[
\frac{\epsilon P_*}{P_0} = \frac{1}{f \cos^2(i)} \{1 - \cos[\theta \sin(i)/2]\} \cos^2(i),
\]

\[
\frac{\epsilon E_*}{E_0} = \frac{1}{f \cos^2(i)} \{1 - \cos[\theta \sin(i)/2]\} \cos^2(i).
\]

For $\theta = 20^\circ$, the minimum values are $P_{*, \min} = 342 P_0/\epsilon P = 1.43 \times 10^{45}/\epsilon P$ g cm s$^{-1}$ (when $i \approx 55^\circ$) and $E_{*, \min} = 526 E_0/\epsilon E$ ergs (when $i \approx 45^\circ$). A simple conical outflow model yields for the flow timescale $\tau = \tau_0/\tan(i) = 2.36 \times 10^6/D\tan(i)$ yr, where we have used the mass-weighted mean outflow radial velocity 12.4 km s$^{-1}$ and the mass-weighted mean angular extent 1.72. We have noted above the presence of a strong uniform radial velocity gradient along the H $i$ tails. If this were a manifestation of velocity sorting rather than continuous acceleration, $\tau$ might be more accurately estimated using the maximum outflow radial velocity observed ($\sim 20$ km s$^{-1}$) rather than the mean velocity, resulting in a factor of 2 decrease in $\tau$. We argue below that the velocity gradient is more likely to be the result of a steady acceleration of the tails, in which case the use of the mean velocity is approximately correct.

Using the dynamical timescale, we can estimate the rate at which the driving source(s) deliver (isotropically) momentum and energy to the HI G137. The minimum values of $P_*$ and $E_*$ are obtained by minimizing the following two expressions with respect to $i$:

\[
\frac{\epsilon P_*\tau_0}{P_0} = \frac{\sin(i)}{f \cos^2(i)} \{1 - \cos[\theta \sin(i)/2]\} \cos^2(i),
\]

\[
\frac{\epsilon E_*\tau_0}{E_0} = \frac{\sin(i)}{f \cos^2(i)} \{1 - \cos[\theta \sin(i)/2]\} \cos^2(i).
\]

We find $P_{*, \min} = 341 P_0/(\epsilon P \tau_0) = 9.6 \times 10^{40}/\epsilon P$ g cm s$^{-2}$ (when $i = 35^\circ$) and $E_{*, \min} = 405 E_0/(\epsilon E \tau_0) = 7.2 \times 10^{36}/\epsilon E$ ergs s$^{-1}$ (when $i = 30^\circ$). Figure 5 shows plots of the dependence of $P_*$, $P_0$, $E_*$, and $E_0$ on $i$ for the simple conical outflow model. The uncertainty in the values of the kinematic and energetic parameters is dominated by our lack of knowledge of the inclination angle, affecting in particular the value of the kinematic timescale. In our discussions below we assume that $i$ most likely lies within the range $30^\circ \leq i \leq 60^\circ$. Our estimates of the physical parameters of the H $i$ tails are summarized in Table 4.

### 6.2. Mass-loaded Flow Model

The lowest velocity shift discernible between the CO and H $i$, limited by background confusion, is $\sim 5$ km s$^{-1}$, which is roughly comparable to the sound speed in neutral atomic hydrogen. The systematic radial velocity gradient of HI G137 could be interpreted in terms of curvature along the line of sight or of expansion. However, if HI G137 is the result of a flow from the CO clouds, it is reasonable to assume that the H $i$ filaments are radially directed away from the driving source and are thus approximately linear. The velocity gradient would then reflect a continuous acceleration of gas along the filaments, leading to the picture of a flow embedded within an extended wind region. This picture of long, flowing tails from dense clouds driven by an external wind is similar to the situation described analytically by Dyson et al. (1993) and numerically by Falle et al. (2002) of the quasi-steady hydrodynamic mixing and entrainment of dense clump gas by a diffuse subsonic or transonic wind. We propose that the neutral atomic tails are created in the dissociation and entrainment of molecular clouds enveloped within a strong stellar wind or winds. The wind ablates and entrains cloud gas and accelerates it away from the cloud in long, narrow tails as a

### Table 4

**Physical Parameters of the H $i$ Tails**

| Parameter                               | Notation | Value          |
|-----------------------------------------|----------|----------------|
| Average H $i$ column density in HI G137 | $N$      | $1.2 \times 10^{20}$ cm$^{-2}$ |
| Total mass of HI G137                   | $M$      | $1700 M_\odot$ |
| Flow timescale for HI G137              | $\tau$   | $4.7 \times 10^{4}/[\tan(i)]$ yr |
| Linear momentum in HI G137              | $P$      | $4.2 \times 10^{4}/[\cos(i)]$ g cm s$^{-1}$ |
| Kinetic energy in HI G137               | $E$      | $2.7 \times 10^{40}/[\cos^2(i)]$ ergs |
| Minimum total kinetic energy from driving sources | $E_{*, \min}$ | $1.4 \times 10^{35}/[\epsilon E]$ ergs |
| Minimum total momentum from driving sources | $P_{*, \min}$ | $1.4 \times 10^{45}/[\epsilon P]$ g cm s$^{-1}$ |
| Minimum rate of kinetic energy delivery | $E_{*, \min}$ | $7.2 \times 10^{36}/[\epsilon E]$ ergs s$^{-1}$ |
| Minimum rate of momentum delivery       | $P_{*, \min}$ | $9.6 \times 10^{40}/[\epsilon P]$ g cm s$^{-2}$ |
mass-loaded flow. Given the positional associations noted above, the source of the wind(s) is likely to be in the vicinity of WR 5 and HD 17603.

We note that it is very unlikely that these H i filaments are cometary tails caused by shadowing of radiation in a low-density H ii region. The flaring of the tails away from the axis of symmetry with increasing distance from the apex is inconsistent with H i observations (Morarit-Schieven et al. 1996; Heyer et al. 1996) and models (Bertoldi & McKee 1990; Cantó et al. 1998; Pavlakis et al. 2001) of cometary clouds. The dynamical timescale of HI G137, a few million years, is far longer than the timescale for complete photoionization of the tails (Pavlakis et al. 2001). This leaves the wind-driven model, but in order to establish the plausibility of this model there are several questions that must be addressed. Can the molecular clouds survive a few million years inside a stellar wind region? What must be the conditions inside this region in order to account for the observed cloud mass-loss rate and entrained gas acceleration, and how realistic are they? Are the energetics plausible? What are the mechanisms by which the entrained gas may be dissociated? We address these questions in the following sections.

6.2.1. Cloud Survival

For the proposed model to be feasible, the molecular clouds must survive their initial impact with the stellar wind before settling down to a quasi-steady entrainment phase within the wind. Klein et al. (1994) have performed an analytic and numerical study of the interaction between a fast, steady, planar shock and a dense, isothermal, nonmagnetic, spherical, cold cloud. More recently, Poludnenko et al. (2002) have extended numerical studies to the case of shocks encountering multiple clouds in which cloud-cloud interactions can occur. As summarized in both these papers (we follow the formulation of Poludnenko et al. [2002] in this paper), a key timescale is the “cloud-crushing time” $t_{cc}$, which is the time required for the internally transmitted shock to cross the cloud, $t_{cc} \equiv 2a_0/v_{cs}$. Here $a_0$ is the initial cloud radius and $v_{cs}$, the forward velocity of the shock through the cloud, is

$$v_{cs} \approx \frac{v_s}{\chi^{1/2}} (F_{c1} F_{at})^{1/2},$$

where $F_{c1}$ is the ratio of the pressure just behind the cloud shock to that at the stagnation point and $F_{at}$ is the ratio of the pressure at the stagnation point to that in the far upstream wind. Both these quantities have values of roughly unity (Klein et al. 1994; Poludnenko et al. 2002). The velocity of the external shock is $v_s$, and the density contrast $\chi = \rho_{ic}/\rho_{ic}$ is the ratio of the initial cloud density to that of the external medium. In the numerical simulations of Klein et al. (1994) and Poludnenko et al. (2002), the cloud destruction time $t_{dest}$ (defined as the time at which the mass of the surviving cloud core is reduced to $\sim 0.5$ of its initial value) was typically found to be $t_{dest} \sim 2 t_{cc}$. The numerical simulations of Mac Low et al. (1994) suggest values of $t_{dest} \sim 4 t_{cc}$ with the inclusion of dynamically significant magnetic fields.

The molecular clouds at the apex of the H i tails have a total mass $\sim 440 M_\odot$. Their current radii are $a \approx 2$ pc, and they have H$_2$ number densities $n_{H_2} \approx 150$ cm$^{-3}$. At their present stage of evolution, the clouds have gravitational virial parameters $\alpha \approx 5 \sigma^2 a / G m_c \approx 80-150$, indicating that they are not bound by their self-gravity ($\sigma$ is the observed cloud velocity dispersion, $\sim 3.3$ km s$^{-1}$, and $m_c$ is the cloud mass). If we assume that the total mass of the H i tails was originally in the molecular clouds, we find that the clouds have been reduced from their initial mass by a factor of about 5: according to the formal definition of $t_{dest}$ above, these clouds would be classified as largely destroyed.

If we set $t_{dest} \equiv \zeta t_{cc}$, the cloud destruction time is

$$\frac{t_{dest}}{\text{yr}} \sim 1 \times 10^6 \zeta^{1/2} \left( \frac{a_0}{\text{pc}} \right) \left( \frac{v_s}{\text{km s}^{-1}} \right)^{-1}.$$

For shock velocities $v_s \sim 100$ km s$^{-1}$ and an initial density contrast $\chi > 100$ (with $a_0$ a few parsecs and $2 \leq \zeta \leq 4$), the clouds will survive for times of the order of a few times $10^6$ yr, long enough for them to become enveloped by the wind. We conclude that the molecular clouds can survive the passage of the initial shock, after which they are gradually destroyed while mass loading the surrounding flow.

6.2.2. Conditions in the Mass-loading Region

The mass loading of flows by embedded clouds has been discussed in a series of papers by Dyson and collaborators (Hartquist et al. 1986; Dyson & Hartquist 1987, 1994; Charnley et al. 1988; Arthur et al. 1993, 1994; Dyson et al. 1993). For an initially pressure-confined cloud that becomes immersed in a wind flow, the pressure gradients across the cloud surface cause a lateral expansion of the cloud that mixes cloud gas into the wind. Hartquist et al. (1986) show that the mass-loss rate from the cloud is

$$\dot{m}_c = \begin{cases} \alpha M^{4/3} (m_c C_c)^{2/3} \left( \frac{\rho_w v_w}{M_c} \right)^{1/3} & \text{for } M \leq 1, \\ \alpha (m_c C_c)^{2/3} \left( \frac{\rho_w v_w}{M_c} \right)^{1/3} & \text{for } M \geq 1, \end{cases}$$

where $C_c$ is the isothermal sound speed in the cloud, $\rho_w$ and $v_w$ are the wind density and velocity, respectively, and $M = v_w/C_c$ is the Mach number in the wind. In this expression, $\alpha$ is a constant of order unity for which Hartquist et al. (1986) provisionally assign a value $\frac{1}{2}$. Assuming that the wind and cloud parameters (except $m_c$) are roughly constant over the cloud lifetime, the cloud mass-loss rate averaged over the entire cloud lifetime is $\langle \dot{m}_c \rangle \approx \dot{m}_{c0}/3$, where $\dot{m}_{c0}$ is the maximum mass-loss rate corresponding to the initial mass $m_{c0}$ of the cloud. Therefore,

$$\frac{\langle \dot{m}_c \rangle}{\text{g s}^{-1}} \approx 3.41 \times 10^{18} M_c^{4/3} \left( \frac{m_{c0}}{M_c} \right)^{2/3} \left( \frac{C_c}{\text{km s}^{-1}} \right)^{2/3} \times \left( \frac{n_w}{\text{cm}^{-3}} \right)^{1/3} \left( \frac{v_w}{\text{km s}^{-1}} \right)^{1/3},$$

where $n_w$ is the number density of the cloud (we have assumed a mean mass per particle of $\mu = 2.17 \times 10^{-24}$ g).

For simplicity, we assume that the initial cloud mass (the current molecular cloud mass plus the mass in the H i tails) was contained within a single cloud, thus $m_{c0} \approx 2100 M_\odot$. The relative fraction of the initial mass in the tails and the clouds indicates that $\tau \approx 0.4 t_{cc}$, where $\tau$ is the cloud lifetime predicted by integrating the cloud mass-loss rate. We thus appear to be observing the clouds near the halfway point in their destruction process. The mass-loss rate averaged over this time period (the dynamical timescale $\tau$) is $\langle \dot{m}_c(\tau) \rangle \approx 2 \dot{m}_{c0}/3$, roughly twice $\dot{m}_c$. Using our value of $m_{c0}$, we obtain

$$\langle \dot{m}_c(\tau) \rangle \approx 1.13 \times 10^{21} \left( \frac{C_c}{\text{km s}^{-1}} \right)^{2/3} \left( \frac{n_w}{\text{cm}^{-3}} \right)^{1/3} \left( \frac{v_w}{\text{km s}^{-1}} \right)^{1/3},$$

where we have assumed $v_w \approx C_c$ (i.e., $M \approx 1$). We have observed a value $\langle \dot{m}_c(\tau) \rangle \approx 1.3-3.9 \times 10^{22}$ g s$^{-1}$ (for $30^\circ \leq i \leq 60^\circ$),

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which implies that we can match the theoretically predicted mass-loss rate if
\[
1.5 \times 10^3 \leq \left( \frac{C_c}{\text{km s}^{-1}} \right)^2 \frac{n_w}{\text{cm}^{-3}} \frac{v_w}{\text{km s}^{-1}} \leq 4.2 \times 10^4.
\]

In the theory of Hartquist et al. (1986), the isothermal sound speed \(C_c\) is better identified as the characteristic speed at which the dense cloud can supply mass to the wind-cloud mixing region. Thus, we assume that the effective value of \(C_c\) is \(c_s \approx 3.3\ \text{km s}^{-1}\). Then the above condition becomes
\[
140 \leq \frac{n_w}{\text{cm}^{-3}} \frac{v_w}{\text{km s}^{-1}} \leq 3800
\]
and has a value of \(\approx 730\) when \(i = 45^\circ\). The wind velocity experienced by the dense clouds cannot be less than the maximum velocity observed in the H I tails (\(\sim 25–40\ \text{km s}^{-1}\), depending on \(i\)). The maximum possible wind speed is, however, much larger: the winds of massive main-sequence stars can have terminal velocities \(\approx 3000\ \text{km s}^{-1}\) (cf. Table 3). If \(v_w \approx 3000\ \text{km s}^{-1}\), the mass-loading model predicts \(0.05 \leq \frac{n_w}{\text{cm}^{-3}} \leq 1.4\). Such large values of \(n_w\) rule out the possibility that the tails are produced in the mass loading of clouds immersed in a freely expanding bare stellar wind. Direct momentum driving of the tails by a wind is also ruled out: the total isotropic linear momentum supplied by the wind of a 40–85 \(M_\odot\) star during its main-sequence lifetime of a few times \(10^8\ \text{yr}\) is approximately \(10^{42}–10^{43}\ \text{g cm}^{-1}\) s\(^{-1}\) (Schaerer et al. 1996), which is at least 2 orders of magnitude smaller than \(P_w^{\text{min}}\).

The isotropic momentum flux predicted by the mass-loading model is
\[
\dot{P} = 4\pi r^2 \rho_w v_w^2 = \left[ (9.2–83) \times 10^{24} \right] v_w \ \text{g cm s}^{-2},
\]
where substituting our adopted range of values of \(n_w v_w\) leaves only one factor of \(v_w\). (The separation between the driving source[s] and the CO clouds is \(r = r_0/\sin \theta\), where we have assumed \(r_0 = 25\ \text{pc}\).) Equating \(\dot{P}\) with our observed value of \(9.6 \times 10^{40}\ \text{g cm}^{-2}\) s\(^{-1}\) \(\leq \dot{P} \leq 1.7 \times 10^{42}\ \text{g cm}^{-2}\) s\(^{-1}\) we see that wind speeds in the mass-loading region greater than \(v_w \approx 10^4\ \text{cm s}^{-1}\) (\(\sim 10\ \text{km s}^{-1}\)) would be sufficient to account for the momentum flux. Given that velocities in HI G137 may be as high as \(\sim 40\ \text{km s}^{-1}\), \(v_w\) must be significantly higher than the limit of \(\sim 10\ \text{km s}^{-1}\) that we have obtained. We note that the predicted value of \(n_w v_w\) in the mass-loading theory is very sensitive to the value of the “mixing efficiency” \(\alpha (n_w v_w \propto \alpha^{-3})\). The mixing efficiency may well be smaller (Cantó & Raga 1991; Arthur & Lizano 1997). Lowering the value of the mixing efficiency by a factor of 2 or 3 would increase the required wind speeds in the mass-loading region by a factor of \(\sim 10\), to \(\approx 100\ \text{km s}^{-1}\). Using this higher value, the mass-loading theory predicts a wind density in the mass-loading region of \(n_w \sim 1–40\ \text{cm}^{-3}\).

We conclude that the mass-loading scenario is workable in the context of the main-sequence stellar winds from massive O stars if the fast low-density stellar wind is significantly loaded with mass and greatly slowed before interacting with the dense cloud. The low inferred wind velocity is consistent with the relative narrowness of the H I tails, as predicted theoretically (Dyson et al. 1993) and found numerically (Falle et al. 2002) for the case of mass loading by a mildly supersonic (transonic) wind. A related point concerns the apparent complete mixing of mass injected into the wind before encountering the CO clouds: in contrast, the H I filaments clearly do not completely mix over a large distance. Mixing may be greatly enhanced in a highly inhomogeneous medium having numerous clumps that are close enough together for wind-driven interactions to occur (Poludnenko et al. 2002; García-Arredondo et al. 2002). In contrast, the CO clouds associated with the H I filaments are likely to be the dominant mass concentrations in their vicinity and so are not subject to mixing driven by cloud-cloud interactions.

Our model still requires that the wind transfer very large amounts of kinetic energy to the H I tails: several times \(10^{36}\ \text{ergs s}^{-1}\), which is the same order of magnitude as the mechanical luminosity of the main-sequence wind of a massive \(O\) star. This is a severe constraint, since in the basic theory of adiabatic stellar wind bubbles, only a tiny fraction, \(\sim 1\%\), of the energy is in kinetic form within the bubble, the bulk being in the thermal energy of hot shocked gas and in the kinetic energy of the swept-up shell. Therefore, a very small fraction of the energy is available to drive mass loading of clouds trapped inside.

Much higher efficiencies of energy conversion into kinetic form are possible if the stellar wind is itself significantly mass loaded. Arthur et al. (1994) have shown that mass loading of an initially highly supersonic wind by 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. If the mass loading is sufficiently heavy (\(m_{\text{load}}/m_{\text{wind}} > 10\), where \(m_{\text{load}}\) is the mass loaded into the wind and \(m_{\text{wind}}\) 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 within the wind region (Pittard et al. 2001). Therefore, stellar winds that are heavily “preloaded” with mass may be able to provide the kinetic energy required to drive flows from larger scale mass concentrations. It also may potentially explain the low wind velocities and high wind densities that we infer. In this regard, a scaled-up version of the scenario modeled numerically by García-Arredondo et al. (2002), the mass loading of the wind from the Trapezium cluster by proplyds, may be relevant. García-Arredondo et al. (2002) showed that mass loading could have very significant dynamical effects on the wind, including increased wind density and low Mach numbers at large radii. However, even with a high efficiency of momentum transfer to the H I filaments, the momentum input of the winds of WR 5 and HD 17603 integrated is too low by at least an order of magnitude. It would seem then that our scenario requires the wind input from a group of many more O stars in addition to these two.

We have not been able to identify such a grouping of stars. Since massive O stars form in OB clusters, short-lived stars such as WR 5 and HD 17603 do not have time to travel far from their birthplaces (unless they are runaway stars ejected from a binary during the supernova explosion of the other component). Although it is not satisfactory to have to posit the existence of an unseen group of OB stars, the apparent close proximity of WR 5 and HD 17603 to each other makes this idea more plausible. Given the effects of visual extinction (and possible anomalous extinction) in a direction toward a major spiral arm and the difficulties of finding, classifying, and obtaining distance estimates, it is perhaps not unlikely that such a group of stars could have escaped detection. Given the dynamical timescale of the H I filaments, it is quite possible that the parent molecular cloud in which the group formed has been largely destroyed by now and some of its members no longer exist after having gone supernova. (We could speculate that supernova explosions might have contributed to the flow driving.) Such a remnant grouping of stars might be very difficult to identify.
6.2.3. Dissociation

There are two plausible mechanisms for dissociating the molecular gas that forms the H I tails: photodissociation and shock dissociation. Stars like WR 5 and HD 17603 produce very large fluxes of ionizing photons (\(\geq 10^{49} \text{s}^{-1}\)), and thus the ionized skins of the molecular clouds may be observable in H\alpha. The H\alpha brightness can be estimated using, e.g., equation (13) of López-Martín et al. (2001), where we assume a cloud radius of 2 pc, a ratio of ionized skin thickness to cloud radius of 0.1, and a source of ionizing photons \(\sim 7.5 \times 10^{49} \text{s}^{-1}\) located 25 pc from the cloud. The latter was estimated using equation (1) in Greiner et al. (1999). The resulting H\alpha surface brightness observed from the Earth, assuming no extinction, corresponds to a photon specific flux of \(\sim 3.6 \times 10^{-7} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}\). This is comparable to the surface brightnesses of the fainter photoevaporating cometary knots observed in the Helix nebula by O'Dell et al. (2000). If the clouds suffer a similar extinction as WR 5, the H\alpha emission will be further attenuated by a factor of \(\sim 10\). The large \((A_{V} \sim 3)\) and patchy visual obscuration may make detection of H\alpha emission from the clouds difficult (see discussion in § 5). There is no evidence for radio continuum emission from ionized hydrogen from the CGPS 1420 MHz continuum data. Any H II region must thus be of very low radio surface brightness: a 100 pc path length through a 1 cm\(^{-3}\) H II region would produce only a few tenths of a kelvin brightness temperature, which could not easily be distinguished from the general Galactic background of several kelvins.

Hot massive stars produce photons capable of dissociating molecular hydrogen at rates comparable to the ionizing photon rates (Diaz-Miller et al. 1998). A rough evaluation of the possibility that the tails are photodissociated can be made by comparing the photodissociating rate into the solid angle of the photosphere, \(n_{\text{H}} f \delta_{\text{P}}\), to the dissociation rate implied by our observations. Here \(\delta_{\text{P}} \sim 10^{49} \text{s}^{-1}\) is a typical stellar photodissociating photon rate for a very massive O star, \(p \approx 0.15\) is a probability that an absorption will lead to dissociation (Diaz-Miller et al. 1998), and \(f = \text{the fractional solid angle subtended by the tails}\). We find that the two rates are roughly equal at \(\sim 10^{60}\) dissociations when integrated over a period of a few times \(10^6\) yr. Photodissociation thus appears to be a plausible dissociation mechanism for the tails.

The other possibility is that shocks driven into the molecular clouds by the stellar wind(s) may be capable of dissociating the H\(_2\), J-type shocks, in which the shock velocity \(v_{\text{sh}}\) is sufficiently high to preclude the existence of a magnetic precursor, are the most effective at dissociating molecular gas. In a strong J-type shock with \(v_{\text{sh}} \approx 50 \text{ km s}^{-1}\) moving into molecular gas with a preshock H\(_2\) number density \(n \approx 100 \text{ cm}^{-3}\), about 90% of the H\(_2\) will be dissociated (Hollenbach & McKee 1980). For \(\chi < 10^5\) and a wind velocity \(v_{\text{w}}\) of the order of a few hundred km s\(^{-1}\), shock velocities will be of the order of 40–50 km s\(^{-1}\), which is sufficient to result in very significant dissociation. The energy required to shock dissociate the molecular gas is roughly an order of magnitude smaller than that required to accelerate it to the velocity of the tail. However, shock velocities of this magnitude may reduce the cloud destruction time to values \(< 10^6\) yr, which is a problem for the scenario that we are proposing.

We conclude that photodissociation is the most workable mechanism for dissociating the molecular gas swept into the H I filaments.

7. SUMMARY AND CONCLUSIONS

We have discovered an unusual system of H I “tails” composed of a number of linear or quasi-linear thin filaments, which, if projected along their length, appear to have a common origin. The feature, which we dub H I G137.7–1.6–60, has dimensions of \(1.8 \times 0.8 \times 15 \text{ km s}^{-1}\) (length \(\times\) width \(\times\) velocity), although its width varies along its length.

Located at one end of the filaments is a chain of molecular clouds that lie at a distance of approximately 2 kpc. Despite the molecular material being displaced from the atomic by \(\sim 10–30\) km s\(^{-1}\), we propose that the molecular clouds and H I feature are located at the same distance and are dynamically related. The lack of a traditional head-tail morphology and the lack of any evidence of ionization along the leading edge of the molecular clouds lead us to reject the possibility that this system is simply a cometary cloud; instead, we propose that the H I feature is made up of material dissociated from the molecular clouds and entrained in the outflowing wind as a mass-loaded flow.

Given the velocity difference between the atomic and molecular material, we estimate the dynamical age of the system to be of the order of a few times \(10^6\) yr. The velocity gradient observed along the H I feature is, in our model, explained by continuous acceleration of the entrained material by the stellar wind.

A search for driving sources for the H I filaments identified the Wolf-Rayet star WR 5 and the (O(f)) star HD 17603 as candidates. Both these stars are located near the apparent origin of the filaments, are approximately at the same distance as the molecular clouds, and have main-sequence lifetimes comparable to the dynamical age of the system. However, even with the high efficiency of momentum transfer predicted for a heavily mass-loaded wind, WR 5 and HD 17603 are incapable on their own to drive the filaments: we are forced to speculate that other, unidentified stars and/or old supernova explosions must also have been involved. We cannot, of course, discount the possibility that the positional associations between H I, O, and stars are simply accidental. But assuming that stellar winds (or explosions) have shaped the gaseous structures that we have observed, we suggest that anisotropic H I structures similar to HI G137 should be searched for in the environments around massive stars (and supernova remnants).

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