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RECENT DEVELOPMENTS IN THE STUDY OF HERBIG-HARO OBJECTS

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RESUMEN

La aparición de CCDs de gran formato y de mosaicos de este tipo de detectores ha revolucionado el estudio de flujos visibles de estrellas jóvenes. Sus grandes campos han permitido ver que muchos flujos Herbig-Haro (HH) alcanzan tamaños de parsecs y tiempos dinámicos comparables al tiempo de acreción de las estrellas jóvenes. De esta forma, los flujos nos proveen de un registro "fósil" de los eventos de pérdida de masa que ocurrieron durante el nacimiento de sus estrellas fuente. Las imágenes de gran campo también nos han permitido ver una nueva clase de objetos HH, los cuales están siendo iluminados por campos radiativos externos. Cuando estos flujos se encuentran fotoionizados, sus propiedades físicas pueden ser determinadas usando los diagnósticos de plasma habituales. Las curvaturas y las asimetrías en el brillo entre jets y contra jets (externamente irradiados) son diagnósticos poderosos de la eyección y propagación de los jets estelares.

ABSTRACT

The advent of large format CCDs and mosaics has revolutionized the study of optically visible outflows from young stars. Their large fields of view led to the recognition that many Herbig-Haro outflows attain parsec-scale dimensions and dynamical time scales comparable to the accretion time of young stars. Thus, outflows provide fossil records of the major mass-loss events that have occurred during the birth of their source stars. Wide-field images have also revealed a new class of Herbig-Haro objects lit up by external radiation fields. When ionized, their physical properties can be readily determined using the nebular diagnostics of photoionized plasmas. C-shaped bends, brightness asymmetries, and jet/counter-jet velocity ratios in irradiated jets provide powerful diagnostics of the launch, collimation, and propagation of stellar jets.

Key Words: **HYDRODYNAMICS — ISM: HH OBJECTS — ISM: INDIVIDUAL: ORION NEBULA — ISM: JETS AND OUTFLOWS — STARS: PRE-MAIN-SEQUENCE**

1. INTRODUCTION

Herbig-Haro (HH) objects are the optical manifestations of the outflows powered by young stars during their formation. Many outflows from young stellar objects (YSOs) are highly collimated, frequently taking the form of bipolar jets emerging orthogonal to an accretion disk. In addition to visual wavelength emission lines, many outflows also emit in the near infrared lines of H_2 and [Fe II], and frequently produce extended lobes of high-velocity molecular gas visible in millimeter wavelength lines of species such as CO. Some jets and Herbig-Haro objects also produce radio continuum and maser emission.

In low-mass stars, jets and outflows appear to be launched primarily by magnetohydrodynamic processes, either from the region where the stellar magnetosphere interacts with the inner edge of the accretion disk (e.g., Shu et al. 1994a,b), or from the inner portions of the accretion disk by pinched open field lines (Uchida & Shibata 1983; Pudritz & Norman 1986; Königl & Pudritz 2000). While the launch of outflows is likely to be dominated by processes within 1 AU of the central star, collimation into a jet is likely to occur at distances of more than 10 AU. Several mechanisms may collimate initially wide-angle winds produced near the central star into a jet. The hoop stress of a wrapped-up magnetic field anchored in a rotating circumstellar disk can exert a confining pressure that redirects the outflow towards the rotation axis of the disk. The infall of gas from an extended envelope that feeds the accretion disk can also interact with the outflow, forming a nozzle that can result in the production of a jet.

During the formation of high-mass stars, radiation pressure and the heating effects of soft-UV irradiation and Lyman continuum photo-ionization can also contribute to outflow acceleration. While some powerful outflows from high luminosity sources such as OMC1 in Orion ($\sim 10^5 L_\odot$) are only poorly collimated, other such sources power highly collimated jets (e.g., HH 80/81, Martí, Rodríguez, &

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TABLE 1

TYPICAL OUTFLOW PARAMETERS

Parameter	Low M^{a}	High M^{b}	Units
$V_{\rm jet}$	100–300	100–1000	km s^{-1}
$\dot{M}$	10^{-9}–10^{-5}	10^{-6}–10^{-2}	$M_\odot$ yr^{-1}
Mass, M	0.001–10	1–1000	$M_\odot$
Age	10^3–10^6	10^3–10^5	years
Length	0.1–10	0.1–20	parsecs
Energy	10^{43}–10^{47}	10^{46}–10^{50}	erg
$L_{\rm mech}$	0.001–1	0.1–1000	$L_\odot$

[a] $M < 5\,M_\odot$. [b] $M > 5\,M_\odot$.

Reipurth 1995). However, most such collimated outflows are driven by sources having luminosities considerably lower than OMC1. Some giant low velocity ($\sim$ 10 km s^{-1}) molecular outflows such as those produced by DR 21 (3000 $M_\odot$) and Mon R2 (200 $M_\odot$) may be powered collectively by an entire cluster of stars and collimated by large scale density gradients in the parent cloud (Russell et al. 1992).

The HH flows from low-mass YSOs are far more abundant and tend to be less obscured than those from high-mass YSOs. Table 1 shows the characteristic range of physical properties of the outflows associated with low and high-mass YSOs.

Outflow production appears to be episodic. During the approximately 10^5 to 10^6 year duration of the main accretion phase of a typical low-mass star, dozens of large eruptions, possibly associated with FU Orionis outbursts of the source, drive a chain of ejecta into the inflating outflow cavity and collide with each other or with the ambient medium. There is evidence that outflows are most powerful during the Class 0 phase of protostellar evolution, which lasts about 10^4 years. During this highly embedded early phase, the ratio of the mechanical luminosity of the outflow divided by the bolometric luminosity of the source can exceed 0.1 and $\dot{M}$ can be larger than $10^{-5}\,M_\odot$ yr^{-1}. However, most outflows from Class 0 sources are too obscured to produce spectacular HH objects; they are best seen in the NIR lines of H_2 or [Fe II] or in millimetric tracers such as CO or SiO (e.g., HH 211, McCaughrean, Rayner, & Zinnecker 1994, and HH 212, Zinnecker, McCaughrean, & Rayner 1998). As the source enters the roughly 10^5 year duration Class I phase, accretion and outflow activity abate with mechanical to bolometric luminosity ratios ranging from less than 0.001 to 0.01 and $\dot{M} \sim 10^{-7}\,M_\odot$ yr^{-1}. By this time, many outflows have punched out of their parent cores, and the oldest ejecta have moved many parsecs, often into regions of low obscuration. It is during this phase that the most spectacular HH objects are produced. During the subsequent Class II and III T-Tauri phases of pre-main sequence stellar evolution, both accretion and outflow production decline even more. However, there is growing evidence that feeble outflow activity and HH object production persist at the level of $\dot{M} \sim 10^{-9}\,M_\odot$ yr^{-1} for several million years in some sources (e.g., Grady et al. 2000).

HH flows provide fossil records of the mass ejection histories of their parent protostars. Some flows record abrupt changes in outflow orientation that may indicate that the source YSOs have suffered violent dynamical interactions with companion stars (Reipurth 2000).

The kinetic energy and momentum that outflows inject into the surrounding interstellar medium can dissociate molecules, ionize the resulting atoms, and stir their host cloud. Outflows are a major source of turbulent motions and may play a fundamental role in the self-regulation of star formation. Their powerful shocks may contribute to the chemical rejuvenation of molecular clouds by fully dissociating molecules, evaporating grain mantles, and even disrupting refractory grains. Shocks may be one source of the widespread species such as C I, C II, and CH^+. Furthermore, by preventing chemical 'aging', HH objects may be partly responsible for keeping the CO/H_2 ratio in star-forming molecular clouds relatively constant.

Of the roughly 500 objects now catalogued, the majority are "classical" HH objects that trace shocks where outflowing stellar ejecta collide with either previously launched lower-velocity material (internal working surfaces) or with the ambient medium (terminal working surfaces). Internal working surfaces indicate that the flow ejection velocity is variable. Bends in outflow lobes indicate that the flow orientation is also variable. Additionally, the mass loss rate and degree of collimation may be time-dependent.

While shock fronts are sometimes visible as filaments of pure Balmer line emission, the extended post-shock cooling layers are bright in the forbidden emission lines such as the [S II], [N II], and [O I] optical lines. The complex non-linear physical processes occurring in shocks and the hard-to-determine ionization fractions in the radiating plasma make it very difficult to estimate outflow parameters such as the fluid density, mass-loss rate, flow momentum, and energy from optical emission alone. Estimates of these parameters are easier to obtain from infrared or millimeter wavelength observations.

Recently, a new category of "irradiated" HH flows have been found inside H II regions and near late B stars. Irradiated HH flows are rendered visible by the UV radiation fields of nearby massive stars and do not require shocks for their excitation (Reipurth et al. 1998; Cernicharo et al. 1998; Bally & Reipurth 2001) although shocks are equally present in irradiated jets. Their physical parameters can sometimes be determined from the nebular diagnostics used to probe fully ionized plasmas. Furthermore, the external radiation fields often illuminate the entire outflow.

In the next two sections, we discuss the two most recent developments in HH research; parsec scale flows and irradiated jets.

2. PARSEC-SCALE FLOWS

The advent of large-format CCDs and mosaics during the middle 1990s ushered in the recognition that many HH flows have parsec-scale dimensions. Over two dozen outflows from low-mass YSOs have been found to extend more than a parsec from their sources and some flows from low-mass stars are over 12 pc long (e.g., Bally & Devine 1994; Ogura 1995; Reipurth, Bally, & Devine 1997; Reipurth, Devine, & Bally 1998). Many molecular clouds are pockmarked with cavities produced by flows that entrained the surrounding gas and punched out of their parent cores (Bally et al. 1999). Outflows may be one of the key mechanisms by which star formation is self-regulated.

Many well-known Herbig-Haro jets such as HH 1/2 (Hester et al. 1996), HH 34 (Devine et al. 1997), and HH 111 (Reipurth et al. 1997) are merely the inner parts of such giant flows. Images of these jets show dozens of internal working surfaces whose individual post-shock cooling zones overlap to form the nearly continuous body of the jet. The proper motion data make it clear that the knots in jets are internal working surfaces in the body of the jets. They are *not* standing shocks or Kelvin-Helmholtz instabilities in the flow. These knots move with the fluid and trace either the shock or the post-shock cooling layers.

The *Hubble Space Telescope* (*HST*) has enabled the determination of accurate proper motions on time scales short compared with the cooling time, making it possible to separate the brightening and fading of different parcels of gas from true motions. The highest velocities are usually observed within the jets and along the flow axes that they define. In the HH 1 and 2 bow shocks, the fastest speeds are measured at the bow shock tips which lie along the jet axis. The average flow velocity tends to decline with increasing distance from this axis. HH 1 and 2 show very complex sub-structure indicating that instabilities have caused the fluid to fragment. Within the envelope of a large bow, smaller bow shocks surround clumps. Some small-scale bows face forward while others face backwards. There is a general trend in HH 1 and 2 that forward facing bow shocks have large proper motions with projected velocities of order 200 to 350 km s^{-1} while the reverse bow shocks move with speeds well under 200 km s^{-1}. The flow pattern orthogonal to the jet axis suggests that a variable-velocity jet is propagating through a more slowly moving wide angle flow. However, it is not clear from the existing data whether this slower, wide angle flow represents a separate flow component, or material entrained from the ambient medium by the passage of previous shocks powered by the axial jet.

Clumps in the medium into which a shock is propagating are evident in the detailed *HST* images of HH 29 in L1551 (Devine et al. 2000), the nearest bright interstellar shock in the sky. The actual shock front is traced by a Balmer filament (Hα emission and no forbidden lines) while the complex post-shock cooling layer emits both in Hα and [S II]. A cluster of 10 to 100 AU-scale clumps of dense and slow-moving gas are being overtaken by a faster ($\sim$ 200 km s^{-1}) lower density fluid. The clumps must have formed prior to the passage of the currently visible shock. It is possible that the slow-moving lumpy fluid is the cool remnant of a shock that has long since faded from view.

The spacing of internal shocks tends to increase with increasing distance from the source until the gaps that separate them cease to be a continuous luminous fluid. Discrete and well separated bow shocks are often found downstream from jets. The complex internal structures of these flows provide a fossil record of the flow velocity variations and variations in the ejection direction.

The increasing gap size between successive shocks with distance from the source implies that large variations in the outflow speed occur over long time intervals (centuries to millenia) while small velocity variations occur much more frequently (years to decades). Thus the overall spectrum of flow velocity variations appears to follow a $1/f$ noise process.

Many parsec-scale flows have S-shaped symmetry, indicating that the outflow axis has meandered over time (e.g., HH 34, Devine et al. 1997; PV Ceph, Reipurth et al. 1997). In some cases, the flow axis changed abruptly (e.g., HH 199, Bally et al. 1995). These bends may be a signature of violent interac-

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tions between protostars and their disks with nearby companions in dense groupings and clusters. Periastron passage in eccentric multiple star systems may alter the disk and jet orientation. It has been proposed that such interactions may lead to the disintegration of triple star systems. The resulting disk perturbations may trigger major mass accretion events that may be associated with the production of the spectacular HH jets found in many parsec-scale flows (Reipurth 2000).

At least one giant flow (HH 366 in Barnard 5; Bally, Devine, & Alten 1996) has C-shaped symmetry, indicating either flow deflection by a wind or, more likely, motion of the source through the surrounding cloud.

3. IRRADIATED JETS AND MICROJETS

Most stars in the sky form in OB associations. Within OB associations, most stars form in dense transient clusters such as those near the Trapezium and the somewhat older stars near σ Orionis (Walter, Wolk, & Sherry 1998), which has been dated to be 2 to 4 million years old. Thus, the discovery of jets from four low-mass stars in the σ Ori group (Reipurth et al. 1998) was a surprise. These jets are powered by visible stars located far (more than several parsecs) from known molecular clouds. They are ionized and rendered visible by the radiation fields of massive stars rather than by shocks within the jet. If the age estimates for the σ Ori group are correct, then jet production may appear and reappear over millions of years. Additional irradiated jets have been reported by Bally & Reipurth (2001) in the outskirts of the Orion Nebula and near late B stars in the NGC 1333 region of the Perseus molecular cloud.

In addition to these arcminute scale irradiated jets, the *Hubble Space Telescope* has revealed a class of sub-arcsecond scale jets emerging from protoplanetary disks. Nearly two dozen such irradiated microjets have been identified within the Orion Nebula on *HST* images (Bally, O'Dell, & McCaughrean 2000). The identification of these flows required the high angular resolution of *HST* since many are only about $0.1''$ wide and are therefore lost against the nebular background in most ground-based images. Most of the Orion irradiated jets are powered by stars embedded within the proplyds but are made visible by the radiation fields of the Trapezium cluster of massive stars. Some of the high-velocity features detected in high-resolution spectra of the Orion Nebula have turned out to be irradiated jets crossing the spectrograph entrance slit.

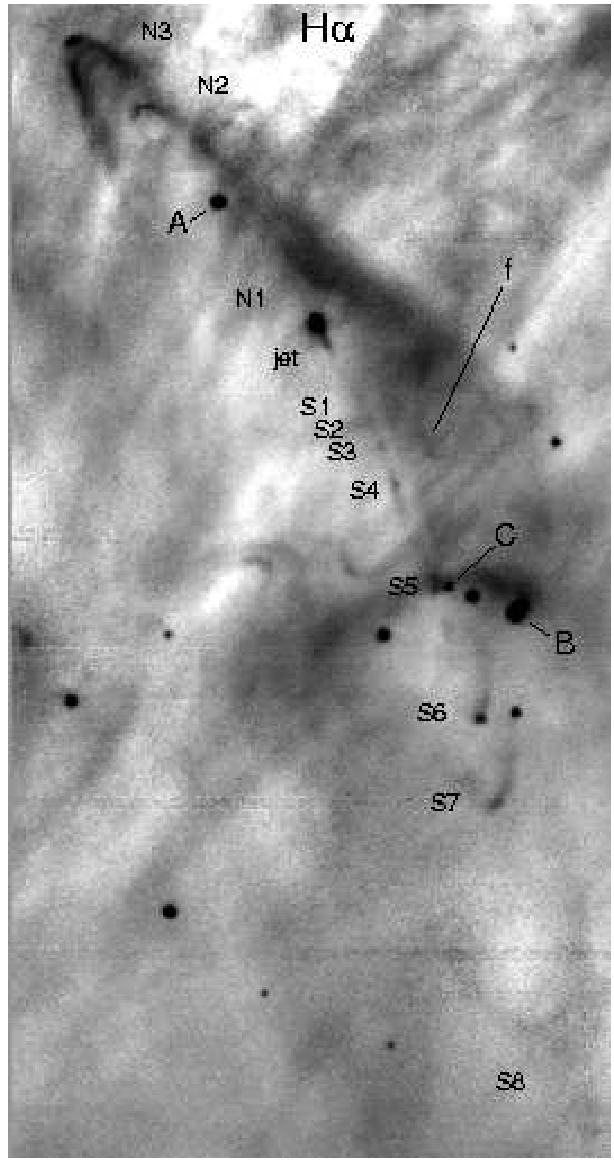

Fig. 1. The HH 502 irradiated jet in the southern portion of the Orion Nebula seen through an 80Å wide Hα filter.

The physical properties of irradiated jets, such as their densities, temperature, velocity fields, and spatial structure can be readily determined from standard recombination-line theory. In non-irradiated HH objects, the estimation of densities and other physical parameters is very difficult since the emission lines are produced in shocks and the estimation of densities from the line intensities requires a complete shock model. Mass-loss rates for irradiated jets can be directly estimated by converting the Hα surface surface brightness to an emission measure, and using the measured width and velocity of the plasma. This method is easier to apply than the more ro-

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bust [S II] doublet ratio method since the Hα line is typically about an order of magnitude brighter than the [S II] line in a photoionized plasma. The typical mass-loss rates of the Orion Nebula irradiated jets are only about $\dot{M} \approx 10^{-9} M_{\odot}\,\mathrm{yr}^{-1}$. Although the σ Ori jets (HH 444 through 447) have about an order of magnitude larger mass-loss rates they are still very weak compared to most classical HH flows. Thus, these irradiated jets are one to two orders of magnitude weaker than the spectacular Herbig-Haro jets such as HH 34, HH 46/47, and HH 111.

A curious feature of most irradiated jets is that many are predominantly one-sided. In the σ Ori region, all four irradiated jets have beams aimed away from σ-Ori that are about 10 times brighter than the beam facing towards the O star. Spectra show that the brightness asymmetry may be related to an underlying kinematic asymmetry; the fainter counter beam to HH 444 has a radial velocity about 2 to 3 times higher than the brighter beam.

Irradiated jets may provide clues about the physics of jet acceleration, collimation, and the entrainment of the ambient medium. The surface brightness of emission lines is proportional to the emission measure, $EM = n_e^2 l$ where l is the path length of the line of sight through the emission region. In an ionized jet, the EM depends on the rate at which the jet spreads orthogonal to the flow axis.

There are three plausible models for explaining brightness asymmetries in irradiated jets (Fig. 2):

- First, for a bipolar jet with unequal speeds but the same mass-loss rates into each beam and *the same jet opening angle*, the *faster* beam will appear *fainter* by a factor $(v_{\mathrm{f}}/v_{\mathrm{s}})^2$ at a given distance from the source (the subscripts refer to the fast and slow beams).

- Second, if the jet speeds are unequal but each beam spreads laterally at the same speed, then the beams will have different opening angles. This is the case if the sound speed, c_{s}, in each beam is the same, as might be expected if it is regulated by the external radiation field. In this case, the faster beam will have a narrower opening angle given by $\theta = 2c_{\mathrm{s}}/v_{\mathrm{f}}$ and will appear *brighter* by a factor of $v_{\mathrm{f}}/v_{\mathrm{s}}$ at a given distance from the source than the slower beam, a prediction opposite to that expected for a constant opening angle jet.

- Third, it is possible that the shaded beam will be colder, and hence have a smaller Mach angle. Assuming that the jet and counter-jet *have the same speed*, the *shaded side* will be denser at a given distance from the source and will therefore be *brighter* by a factor $(v_{\mathrm{t,s}}/v_{\mathrm{t,f}})^3$ where $v_{\mathrm{t,s}}$ is the transverse spreading speed in the slow beam and $v_{\mathrm{t,f}}$ is the transverse spreading speed in the fast beam. Determination of the jet opening angle, velocity, and brightness can be used to distinguish between these models.

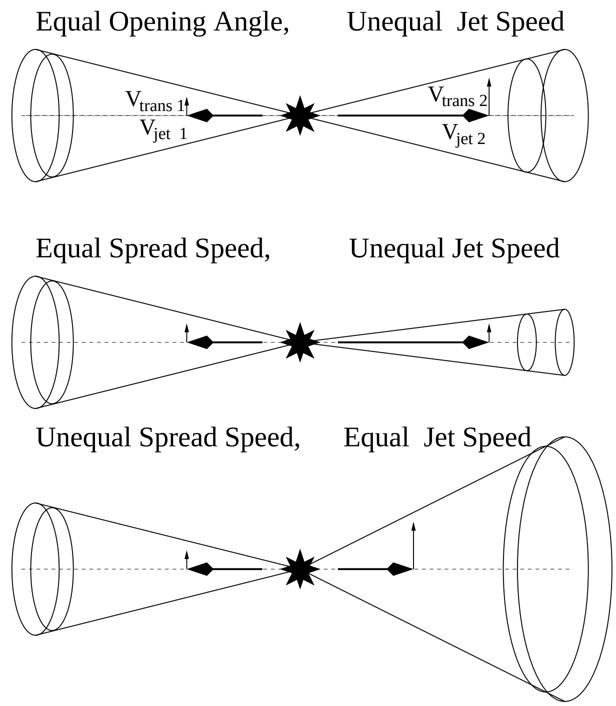

Fig. 2. Three possible models that produce brightness asymmetries in irradiated jets.

In HH 444, spectra provide evidence that the slower and brighter beam has entrained and accelerated material from the environment on the shaded side of a circumstellar disk presumed to exist around the source star. Within about 5″ of the source, the spectra reveal a flow component that accelerates from the rest velocity of the star to the jet speed seen farther away; in the same region, there is a decelerating component. The former feature is presumably associated with gas being entrained from the YSO environment while the latter feature traces the outflow that is being decelerated by the interaction (Solf 1987). Thus, the asymmetries may be a consequence of increased mass loading on the shadowed side of the disk (Bally & Reipurth 2001). In this case, the first model discussed above appears to apply.

On large scales, many irradiated outflows exhibit C-shaped symmetry. Three of the larger irradiated HH jets in the Orion Nebula (HH 502, 503, and 506) are bipolar but exhibit C-shaped symmetry with the jet beams and bow shocks bending *away* from the

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core of the Orion Nebula by as much as 20° (Fig. 1; Bally & Reipurth 2001). An outflow from the nebular interior must be deflecting these jets. The analysis of such jet bends can be used to constrain both the jet physical properties and those of the deflecting medium.

The core of the NGC 1333 star forming region contains nearly a half-dozen irradiated jets that are exposed to the soft UV radiation fields of late B stars in the region. Oddly, some of these jets exhibit C-shaped bending *towards* the cluster core, a result opposite to that seen in the Orion Nebula. Bally & Reipurth (2001) argue that the sources of these jets were probably recently ejected from the NGC 1333 cluster core by three-body interactions. Such interactions may be the result of the dynamical re-arrangement of non-hierachical and unstable triple star systems in which the lightest member is ejected while the most massive members form a tight binary (Reipurth 2000), or three body interactions between unbound cluster stars in which the lightest member is ejected while the remaining stars become more tightly bound to the cluster.

The Orion Nebula also contains an additional dozen outflows rendered visible by bow-shaped nebulae facing the Trapezium stars. Gull & Sofia (1979) first found a parabolic arc of emission facing the bright core of the nebula surrounding the young star LL Ori. Recent *HST* images (Bally et al. 2000) show the LL Ori bow shock in unprecedented detail. A chain of small high proper motion knots and small bows move parallel to the surface of the bow-shaped envelope seen on the ground based images. Fifteen other stars in the Orion Nebula are surrounded by smaller and fainter parabolic arcs facing the Trapezium stars (Bally et al. 2000; Bally & Reipurth 2001). These LL Ori shocks may be produced when wide-angle T-Tauri stellar winds powered by young stars near the foci of the parabolic arcs that have mass-loss rates of order $\dot{M} \approx 10^{-9}$ to $10^{-8}\,M_\odot$ yr^{-1} and wind velocities of about 500 km s^{-1} collide with a mildly supersonic (~ 20 km s^{-1}) outflow of plasma from the core of the nebula. However, Masciadri & Raga (2001) have successfully reproduced the LL Ori type arc, LL2, surrounding the one-sided irradiated jet HH 505, with models in which a jet propagates into a low velocity side wind. Thus, it is possible that the other LL Ori type bow shocks in the Orion Nebula are indirect manifestations of the interactions of otherwise invisible jets with the outflow of plasma in the nebular interior.

Finally, proper motions measured with *HST* have led to the discovery of dozens of irradiated HH objects within the Orion Nebula whose sources either remain unidentified, or are buried within background molecular cloud (Bally et al. 2000). A group of HH objects (HH 205 to 210) are associated with the powerful OMC1 outflow that has produced a large number of shock excited 'fingers' of H_2 emission (Allen & Burton 1993). HH 201 through 204 appear to trace at least two distinct large scale outflows from the OMC1-S core that lies some 90″ south of the OMC1 core. HH 269, recognized from ground based proper motion determinations, also originates from this core (Cudworth & Stone 1977). The recent *HST* proper motion studies have revealed at least three additional outflows originating here, including HH 528, 529, and 530. Thus, at least 6 distinct major HH flows are bursting out of the OMC1 cloud core.

Many other moving features criss-cross the Orion Nebula. Perhaps the most spectacular is the giant low-velocity redshifted bow shock (HH 400) that extends to the southeast from a distance 0.7 to 1.5 pc from the Trapezium. This giant bow has an axis of symmetry indicating a point of origin near the OMC1 core (Bally et al. 2001). If so, HH 400 traces the photoionized portion of a parsec scale outflow from an embedded source.

Thus, there are many sub-categories of irradiated HH flows, including large scale jets (HH 444, HH 502), small scale micro-jets (HH 514), collimated outflows that consist of chains of bow shocks (HH 203/204, HH 529), and large isolated bow shocks (HH 201, 202, and HH 400). Additionally, the LL Ori bows that wrap around their source stars indicate interactions between either wide-angle T-Tauri winds or possibly collimated jets and a side wind.

The large numbers of irradiated HH flows in H II regions such as the Orion Nebula implies that they may make a substantial contribution to the supersonic motions within such nebulae. However, an analysis of the kinetic energy budget within the Orion Nebula (Bally et al. 2000), indicates that the heating and acceleration of freshly ionized plasma at the main ionization fronts of the H II region dominates the rate at which kinetic energy is injected into the nebula. The 'normal' stellar winds of the massive Trapezium O stars are likely to inject an amount of kinetic energy comparable to the most powerful YSO outflows. Thus radiation induced motions are likely to dominate subsonic and mildly supersonic motions while protostellar outflows are likely to make a major contribution to the highly supersonic motions in young H II regions such as the Orion Nebula.

4. CONCLUSIONS

Outflows and jets from young stars are ideal laboratories in which the hydrodynamics of collimated supersonic flows in the presence of strong cooling (and possibly magnetic fields) can be studied. These objects are close enough to the Sun that their time evolution can be directly measured using high angular resolution instruments such as *HST*. These outflows provide fossil records of the mass-loss histories of their source stars. But in addition to being interesting objects in their own right, protostellar outflows play fundamental roles in determining the properties of the surrounding interstellar medium and in the self-regulation of star formation.

Outflows churn their host clouds. They create parsec-scale cavities surrounded by swept-up shells of accelerated molecular or atomic gas. Their shocks dissociate molecules and produce UV radiation which can alter the physical and chemical state of the medium. The repeated passage of shocks that dissociate molecules contributes to the stability of the CO/H_2 ratio and may be a source of species such as C I and C II. The complex non-linear evolution of HH shocks are a major source of turbulent motions in the dense and cold phase of the interstellar medium surrounding star forming regions.

The recognition of irradiated flows within H II regions and near late B stars has provided us with new and powerful tools that can be used to diagnose outflow properties, to probe the region in which jets are launched and collimated, and to study the interactions with surrounding media. The large number of irradiated HH objects in clustered star forming regions such as the Orion Nebula indicate that protostellar outflows may substantially perturb the medium, making large contributions to the frequently observed highly supersonic motions seen within H II regions.

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