1. PROTOSTELLAR OBJECTS

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JETS FROM YOUNG STARS

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Abstract

Recent optical observations have shown that many young stars are capable of generating highly-collimated bipolar flows. Such flows are evident from narrow emission-line jets extending over 0.01-1 pc and having opening angles of a few degrees. Their measured radial velocities reach values of up to 400 km/s. For most known jets the "driving stars" are T Tauri stars or IR-sources of low to moderate luminosity (1-100 $L_\odot$). The typical velocities, Mach numbers, particle densities, and mass fluxes of these jets are estimated to be 200-400 km/s, 10-40, 15-150 cm^{-3}, and 10^{-10}-10^{-7} $M_\odot$/yr, respectively. The estimated mass fluxes and velocities are consistent with our present knowledge of T Tauri star wind properties.
The emission-line spectra of the jets are the same as observed in Herbig-Haro (HH) objects. Furthermore, the brightest parts of some jets (hot spots) are known as HH objects, having often been discovered many years before their associated jet. Thus, both phenomena are highly related and in both cases the emission lines are very probably formed in the cooling regions of shock waves with velocities of 50-100 km/s. There are a variety of mechanisms, which can in principal excite internal (oblique) shockwaves in these jets. Examples of likely excitation mechanisms are fluid dynamical instabilities or pressure gradients in the ambient medium.
A model is proposed in which HH objects are representing the locations of the most strongly radiating (internal)shock waves in these jets. For those HH objects being located at the end of the jet the observational data strongly suggest that they are tracing the working surface of the jet. This idea is consistent with the observed proper motions of these HH objects, the typical densities near the edges of their associated molecular clouds, and with the jet parameter given above. For a more detailed discussion of these jets the reader is refered to the review articles listed below.

Mundt, R. 1985, in "Protostars and Planets II", eds. D. Black and M. Matthews, University of Arizona Press, Tucson, in press
Mundt, R. 1985, in "Nearby Molecular Clouds" ed. G. Serra, Lecture Notes in Physics, Springer Verlag, in press
Mundt, R., 1986, in "Jets from Stars and Galaxies", Can. J. Phys., in press
Mundt, R., Brugel, E.W., and Bührke, T. 1986, in preparation

Discussion

SHU:

1. Of the highly collimated sources, what fraction are T Tauri stars and what are infrared sources? Also, what are the visual extinctions to the T Tauri stars?
2. Can you eliminate the possibility that the ultimate jet sources are all infrared sources and that the observed T Tauri stars are simply companions to the true source?

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MUNDT:

1. About half of the sources have optical counterparts and for nearly all of them we have optical spectra which show that they are T Tauri stars or Herbig Ae/Be stars. A_V values have been estimated for only few stars and range from a few magnitudes up to 7 mag.
2. IR speckle observations of DG Tau, HL Tau, R Mon don't show indications for IR companions. By such observations one can detect only companions being a few magnitudes fainter than the main component and being separated from it by not less than about 0.1 arcsec.

ICKE:

1. You say that if you don't see the jet, it is there but it is "free". What observational evidence prevents me from saying the jet simply is not there?
2. Your criticsm of the Königl-Blandford-Rees model that $t_{cool} << t_{dyn}$ may not be valid if interaction between the jet and its suroundings keeps the jet gas hot.

MUNDT:

1. Observationally it can't be totally ruled out that the flow is switched on and off over destinct time intervals. However, it would require in several cases very unusual time variations of the flows.

2. If you keep the matter hot that way you may run into energy problems, since we need a mechanism which tranforms a large fraction of the wind energy into the jet (say about 10 %).

SHU:

I would like to support the notion that magnetic fields do play an important role in driving the T Tauri winds. After all, they are observed to have strong chromospheric activity - indeed they are defined by this property - and no one knows how to produce such activity without magnetic fields.

MUNDT:

I fully agree that magnetic fields are probably very important for all their activity including the wind. However, the question is what fraction of the magnetic field is carried along the jet and how important is it there for the jet dynamics. Let me make a comment on the pressure confinement of the jets. From what we know about magnetic fields in molecular clouds it is suggested that they may contribute significantly to the confinement.

LAGO:

I come back to the question someone asked before: What about magnetic fields? They are bound to the important in the jets since we know they are important for driving the winds in T Tauri stars, and the presence of a magnetic field will change the velocity and density structure in the jets as well as the confinement requirements.

MUNDT:

As mentioned before magnetic fields close to the stellar surface (where they are probably very important) and at several 10^4 stellar

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radii (in the jets) are two different issues. Magnetic fields may be important for the pressure confinement, but we have no (observational) indication yet that magnetic fields are important for the jet dynamics (e.g. the structure of their internal shock waves).

NORDLUND:

I would like to make a somewhat philosophical remark concerning magnetic fields in astrophysical plasmas: I think we must accept that magnetic fields are generic in most of the astrophysical systems considened at this meeting (like protostellar objects, convecting stars, accretion discs, AGN's, neutron stars, ...). In situtations where there is a flow of kinetic energy and/or heat through the system, magnetic fields (with complex topologies) develop. Typically these fields have field strengths of dynamical importance in small, localized parts of the system. Only in very simple (highly symmetric) cases may we expect magnetic fields to be unimportant. The fact that, in many cases, we cannot observe magnetic fields, should not be taken as an argument for simple models.

OPHER:

In your talk you did not mention the possible importance of magnetic fields in the formation of the jets. On the other hand, at the beginning of your talk you refered to extragalactic jets where magnetic fields have been observed and calculations indicate that they can be dominant in the formation and collimation. Can you comment on the possible importance of magnetic fields in the formation and collimation of the jets.

MUNDT:

see answers to questions by F. Shu and T. Lago

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