JET INTERACTIONS WITH MOLECULAR CLOUDS: C-SHOCK MODELS

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ABSTRACT. Molecular hydrogen emission lines are associated with collimated outflows from young stellar objects. They have been measured near Herbig-Haro objects within jets as well as at the jet termination. Similarly to HH objects, the lines are produced from radiative shocks which may be in the form of oblique internal jet shocks or bow shocks. A J-shock can only be invoked in a dynamical model context since the H_2 lines are often wide (> 30 km s^{-1}). The alternative is the MHD C-shock in which the ionisation level is sufficiently low so that the magnetic field and ions interact weakly with the neutrals. We have investigated C-shock flows by employing approximate forms for the ion-neutral drag, cooling and other processes with the following results.

(1) C-shock regimes are found for H_2 and H_2O cooling with density, magnetic field, ionisation fraction and shock velocity as separate parameters. We display how dissociation, self-ionisation and J-shocks limit these regimes. Breakdown velocities can be much smaller than 40 - 50 km s^{-1} although this range covers the maximum possible values.

(2) Line profiles for shocks have been calculated for LTE conditions ($n > 10^6$ cm^{-3}). Planar shocks produce H_2 lines < 40 km s^{-1} wide for H_2 dominant cooling (i.e. H_2O abundances < 2 10^{-4}). The n^2-cooling of H_2O results in narrow profiles, < 20 km s^{-1}. Profile shapes vary greatly being single peaked, double peaked, triangular or flat-topped according to the upper energy level. Simple but stringent line ratio tests are provided which demonstrate that the recent data for OMC-1 cannot be interpreted by a single planar C-shock.

(3) Bow shocks are now being investigated in the form of an accumulation of planar shock elements with a uniform external magnetic field. Line profiles are single peaked and narrow. This is due to the emission being dominated by the warm gas before the gas has been greatly decelerated in contrast to commonly observed atomic lines. Moreover the emission from the far tails of a bow shock (taken as a parabola or spherical cap) is highly peaked near the pre-shock velocity. Line widths are thus limited to < 35 km s^{-1} (full width at 10% maximum, resolved to 3 km s^{-1}). However the line intensities for OMC-1 can be reproduced by a C-shock bow shock.

R. Beck et al. (eds.), Galactic and Intergalactic Magnetic Fields, 332.