HYPERSONIC JETS FROM YOUNG STARS IN MOLECULAR CLOUDS

Hans-Joachim Blome, Inst. f. Theoretische Physik (SFB 301), D-5 Köln 41
Wolfgang Kundt, Inst. f. Astrophysik, D-53 Bonn 1

ABSTRACT. We argue that the narrow jets which are sometimes seen to escape from YSOs into an ambient molecular cloud consist of $e^{\pm}$-plasma which can be created in stellar magnetospheric discharges and subsequently centrifugally post-accelerated. This high-pressure pair plasma is squeezed into two jets which ram cocoons into the molecular cloud, observed in the form of molecular lobes (outflows).

## 1. JET SPEED

Twin-jets from stars and galactic nuclei are often thought to be caused by a similar mechanism (Königl 1982, Kundt 1984). Arguments have been given that jets from AGN consist of relativistic pair plasma (Kundt & Gopal-Krishna 1980). Here we estimate the temperature of the medium that fills the high-pressure cavities (lobes, outflows - which we interpret as cocoons). The estimates are based on the pressure needed to blow the cavities, the high required sound speed, the usual invisibility of the flow heads and the condition that a cocoon is filled through its jet. We thus arrive at almost relativistic jet velocities:

| Observed fact | Inferred lobe temperature/ jet speed |
|---|---|
| lobe pressure = $\rho_a v^2 \lessapprox 10^{-8}$ dyn cm$^{-2}$, no H II region | $T \gg 10^4$ K |
| piston subsonic (consisting of shocked jet) | $T > 10^7$ K |
| power liberated by piston is unseen (at X-rays) | $T \gtrsim 10^8$ K |
| flow heads are only seen in some 5% of all BFs | $T \gg 10^8$ K |
| particle number conservation: lobes are filled through jets | $\beta_{jet} \approx 1$ |
| jet near obj. 50 has been seen 'illuminated' | $\beta_{jet} \approx 1$ |

A young star is unlikely to blow off its envelope at almost relativistic speeds. Instead, we expect relativistic charges to be created in localized discharges inside the corotating magnetosphere. These charges will produce relativistic $e^{\pm}$-pairs on collision with stellar photons if their energy exceeds the necessary thresholds.

## 2. GENERATION OF PAIR PLASMA NEAR A YSO.

We assume that a star forms at the center of a massive disk. The (proto-) star's convective layer is likely to generate equipartition magnetic fields of order ($v_t$ = turbulent velocity):



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$$B \lessapprox (8\pi\varrho v_t^2)^{1/2} \approx 10^{6.5} v_6 \text{ Gauss.}$$

Magnetospheric discharges can accelerate charges up to an energy

$$E = e\int(\vec{B} \times \vec{B})\cdot d\vec{x} \approx eB\,GM/c^2 = B_4\,(M/M_\odot) \text{ erg}$$

near the speed-of-light cylinder. Electrons and positrons are created during collision of these charges with stellar photons when their Lorentz factors exceed $2m_e c^2/h\nu$, i.e. when B exceeds 10 kG. The injected number rate of pair plasma can be estimated both from the pressure near the end of the jet, of cross-sectional area A, and from the loss of stellar rotational energy:

$$\dot{N}_{e\pm} = nAc = \dot{E}_{rot}/\gamma m_e c^2 \approx 10^{42}\ s^{-1}/\gamma_1 ,$$

where the average Lorentz factor $\gamma$ has been inserted in units of 10.

## 3. JET AND COCOON

The ramming of a jet through the ambient molecular cloud (of mass density $\varrho_a$) can be described as a succession of explosions taking place along the jet path. For a hypersonic beam of width 2b propagating along the z-axis, the shape of the bowshock can be derived from momentum conservation in z-direction and energy conservation (Sedov-Taylor-wave) transverse to it: $r/a = \sqrt{z/a}$ with $a \approx b\,\sqrt[4]{(\varrho_j/\varrho_a)}$. This law describes both the bowshocks of young bipolar flows and of certain extragalactic radio sources (3C 33 S).

In the cocoon, the shocked relativistic pair plasma emits both synchrotron radiation at low radio frequencies and inverse Compton radiation at UV frequencies which heat the ionized and neutral component of the ambient molecular cloud, cf. Clark & Laureijs. The jet itself consists of light relativistic pair plasma streaming inside heavy 'walls' of thermal plasma which emit Coulomb-Bremsstrahlung (Snell, Bally & Strom).

The (invisible) power of the jet is related to the rotational energy of the YSO:

$$\int L_{jet}\,dt \approx E_{rot} \approx E_{grav} \approx 10^{48} \text{ erg } \left(\frac{M}{M_\odot}\right)^2\left(\frac{R_\odot}{R}\right).$$

It is worth mentioning that the boundary of the cocoon is Rayleigh-Taylor stable as long as its pressure decreases with time.

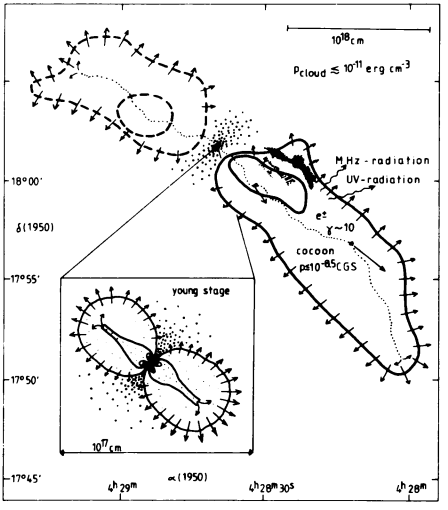


Fig. 1 displays our interpretation of the bipolar flow L 1551/IRS 5!

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