SHOCK EXCITATION OF EMISSION LINES AND THE RELATION TO GPS SOURCES

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1. Radio Lobes in Dense Environments

Gigahertz Peak Spectrum (GPS) and Compact Steep Spectrum (CSS) sources have attracted a large amount of attention in recent years since they occupy a surprisingly large fraction of the extragalactic radio source population. In this paper we summarise a theory which attempts to unify the optical emission line and radio properties of these sources. In outline the theory is as follows: The bow shock preceding the radio lobe driven into the ISM by a powerful radio jet ionizes the ISM producing both optical line emission and a free-free absorbing screen. The free-free absorption can explain the relationship between size and turnover frequency (Stanghellini et al., 1995) and the prediction of the line emission is in accord with the observation for a small sample of sources for which optical data are available.

Begelman (1995) has proposed a model of Compact Symmetric Objects (CSOs) in which a "dentist drill jet" (Scheuer, 1982) drives an overpressured lobe. Using Begelman's model, the shock velocity of the expanding lobe is

$$V_{\rm sh} = 2500\,\zeta^{\frac{1}{6}} \left[\frac{F_{E,45}}{(8-n)\,n_0\,(x_0/{\rm kpc})^2}\right]^{\frac{1}{3}} \left(\frac{x}{x_0}\right)^{(n-2)/3} {\rm km\,s^{-1}} \qquad (1)$$

where x is the distance of the hot-spot from the core, n_0 is the number density at $x_0 = 1$ kpc and $\rho \propto r^{-n}$. When $n = 2$, the value favoured

R. Ekers et al. (eds.), Extragalactic Radio Sources, 469–470.

by Begelman, the shock velocity is independent of distance. Emission line modelling carried out so far indicates that $500 < V_{\rm sh} < 1000\,{\rm km\,s^{-1}}$. This is consistent with the typical GPS line widths $\Delta V \sim 750\,{\rm km\,s^{-1}}$ reported by Gelderman (these proceedings). This constraint implies that for jet energy fluxes $\sim 10^{45}{\rm ergs s^{-1}}$ the confining medium is quite dense: $4 \lesssim n_0 \lesssim 30{\rm cm^{-3}}$.

The ionized gas, both post-shock and precursor, contribute to the free-free optical depths of post-shock and precursor regions and these are given by:

$$\tau_{\nu,{\rm ps}} \approx 3.9 \times 10^{-4}\, n_0\, T_{e,4}^{-1.35}\, \nu_9^{-2.1} \left(\frac{V_0}{500\,{\rm km\,s^{-1}}}\right)^{3.6} \left(\frac{x}{x_0}\right)^{\frac{0.6n-7.2}{3}} \tag{2}$$

$$\tau_{\nu,{\rm pc}} \approx 2.4 \times 10^{-4}\, n_0\, T_{e,4}^{-1.35}\, \nu_9^{-2.1} \left(\frac{V_0}{500\,{\rm km\,s^{-1}}}\right)^{2.66} \left(\frac{x}{x_0}\right)^{-\frac{0.34n+5.32}{3}} \tag{3}$$

The turnover frequency is given by approximately twice the frequency at which the optical depth becomes unity. For jet energy fluxes $\approx 10^{44} - 10^{46}$ ergs s^{-1} a good fit to the turnover frequency–size data of Stanghellini et al. (1995) is obtained.

2. Emission line luminosity

The software routine MAPINGSII gives for the $H\beta$ luminosity,

$$L(H\beta) = 7.4 \times 10^{-6}\, n_H \left[V_{\rm sh}/100\,{\rm km\,s^{-1}}\right]^{2.41} A_{\rm sh}\,{\rm ergs\,s^{-1}} \tag{4}$$

(Dopita and Sutherland, 1995) where n_H is the ambient Hydrogen number density and $A_{\rm sh}$ is the shock surface area. For $n = 2$ the dynamics of the expanding bubble imply that $\rho_a V_{\rm sh}^3 A_{\rm sh} \approx 0.13 F_E$ and we take $F_E = \kappa^{-1} L_{\rm radio}$ with $\kappa \approx 0.1$. For a cutoff frequency $\sim 10\times$ the reference frequency, $\nu_0 =$ 5 GHz, $L_{\rm radio} \approx 7.8 \nu_0 P_{\nu_0}$ and $L(H\beta)/\nu_0 P_{\nu_0} \approx 0.03\,(V_{\rm sh}/500\,{\rm km\,s^{-1}})^{-0.59}$ The geometric mean of the small number of sources we have examined (1345+125, 1934-638, 2352+495, 1718-649) is 0.03, encouraging examination of a larger sample.

The predicted amount of gas could be $\sim 10^{11} - 10^{12} M_\odot$ within 10 kpc. The detection of significant amounts of HI in 3 out of 4 GPS sources (J. Conway, these proceedings) is in substantial agreement with this prediction.

References

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