Extended Radio Emission from BAL Quasars

The outflows associated with broad absorption line (BAL) quasars are expected to drive a shock wave in the surrounding interstellar medium. The outflow speed of ~ 5000 km s^{-1} is similar to that of supernova remnants, which show synchrotron emission from a population of non-thermal electrons that are accelerated in the surrounding shock front. A strong ($v_{\rm shock}/c_{\rm sound} \gg 1$) non-relativistic ($v_{\rm shock} \ll c$) shock is expected to endow the accelerated electrons with equal amount of energy per logarithm of electron energy E, namely $E^2(dN/dE)$ =const. This is predicted theoretically (e.g., Blandford & Eichler 1987), and observed in some supernova remnants (e.g. Aharonian et al. 2005; Brogan et al. 2005). Observations indicate that about a percent of the supernova explosion energy is transferred to accelerated electrons.

Let us assume, conservatively, that the magnetic field encountered by the relativistic population of accelerated electrons on kpc scales is provided by the compressed interstellar medium without it being amplified to higher values at the shock front. In that case the magnetic field strength behind the shock front (where the interstellar gas density is enhanced by a factor of 4 and the magnetic field is amplified by a factor of $4^{2/3} = 2.5$ if its flux is frozen) will be of order $B \sim 1\mu$G. In that case, observations at a radio frequency of $\sim$ 1GHz are observing the synchrotron frequency of electrons with a Lorentz factor $\gamma = (E/m_e c^2) = 2 \times 10^4$. The synchrotron cooling time of these electrons is,

$$t_{\rm syn} = 10^9 \ {\rm yr} \left(\frac{B}{1\ \mu{\rm G}}\right)^{-3/2} \left(\frac{\nu}{1\ {\rm GHz}}\right)^{-1/2} . \tag{1}$$

Since the synchrotron cooling time is much longer than the time it takes the outflow to cross the host galaxy, $t_{\rm cross} \sim (1\ {\rm kpc}/5\times 10^3\ {\rm km\ s^{-1}}) = 2\times 10^5$ yr, the total radio luminosity at an observed frequency of 1 GHz can be estimated as follows,

$$\nu L_\nu \approx \frac{(1\% \times E_{\rm BAL})}{\ln \gamma_{\rm max} t_{\rm syn}} = 10^{40}\ {\rm erg\ s^{-1}} \left(\frac{E_{\rm BAL}}{10^{60}\ {\rm ergs}}\right) \left(\frac{\nu}{1\ {\rm GHz}}\right)^{1/2} \left(\frac{B}{1\ \mu{\rm G}}\right)^{3/2} . \tag{2}$$

where $\gamma_{\rm max} \sim 10^8$ is the maximum Lorentz factor of accelerated electrons (for which the radiative loss time equals the acceleration time). The energy associated with the BAL outflow can be estimated as follows,

$$E_{\rm BAL} \sim L_{\rm kin,BAL} \times t_{\rm cross} = 0.6 \times 10^{60}\ {\rm ergs} \left(\frac{L_{\rm kin,BAL}}{10^{47}\ {\rm erg\ s^{-1}}}\right) \left(\frac{t_{\rm cross}}{2\times 10^5\ {\rm yr}}\right) . \tag{3}$$

Detection of this extended radio emission can be used to calibrate the fraction of all quasars which possess BAL outflows, to image the BAL outflow geometry (radius and opening angle), and to calibrate the outflow parameters (energy, shock speed). For specific redshifts of BAL quasars, we can evaluate the detectability of the expected radio flux from a ring of radius ~ 1 kpc around these quasars.