RADIATIVE ACCELERATION OF ASTROPHYSICAL JETS: LINE-LOCKING IN SS 433

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ABSTRACT

Observations of SS433 are consistent with the view that the Doppler-shifted line emission originates in a pair of oppositely-directed, precessing jets in which a gas outflow is maintained at the remarkably time- and space-invariant speed of 0.26c. A radiative acceleration mechanism is described for the jets and a detailed, numerical, relativistic flow calculation presented which explain this terminal velocity as the result of "line-locking". The "line-locking" mechanism suggested here for SS433 may be important as well in extragalactic radio sources in which the radio luminosity is similarly weak compared with the kinetic energy and optical luminosities.

Measurements of the Doppler-shifted line emission from SS433 indicate that the outflow velocity has been constant to within roughly five per cent of 0.26c since the discovery of the moving lines. From the line widths, we know that the velocity is quite uniform in direction and magnitude across the jet (in the frame of the jet), as well. This has a very natural explanation (Milgrom 1979) if the following conditions are met: (1) A continuum radiation flux exists which is strong enough to accelerate gas away from the compact central object; (2) The dominant momentum transfer is through Lyman-line absorption by some hydrogenic ion; and (3) The continuum flux is sharply reduced at lab frame frequencies above the Lyman edge. In that case, the flow can accelerate only until the velocity is high enough to Doppler-shift the Lyman edge to the Ly-α frequency. This occurs when γ $(1-\beta) = 3/4$, or $v = 0.28c$. Thereafter, the flow speed is constant and described as "line-locked".

A detailed numerical calculation of this process has been performed which solves the relativistic flow equations, including matter-

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radiation coupling, radiative transfer, ionization balance, and the atomic level population equilibrium. We have assumed that the flow is steady-state, spherically symmetric, supersonic (ie. gas pressure is ignored), and isothermal, that special relativistic effects must be calculated exactly to all orders, but that gravity is Newtonian. Our first detailed results are of a pure hydrogen gas. We find that line-locking can be achieved and with rates of mass outflow within the range inferred for SS433 from observation, for a gas with $T \sim 10^4$K, as long as the gas is highly clumped (e.g. $\propto$ (Mach number)^2). For example, if initial radius, luminosity, temperature, and central object mass are 10^{12}cm, 10^{38} erg s^{-1}, 10^4K, and 1 $M_\odot$, respectively, then a 10^{17}gm s^{-1} outflow will achieve line-locking by roughly 3 x 10^{12}cm. In general, the maximum outflow is limited by the condition $(1/2)\dot{M}\beta^2c^2 \lesssim \beta L$.

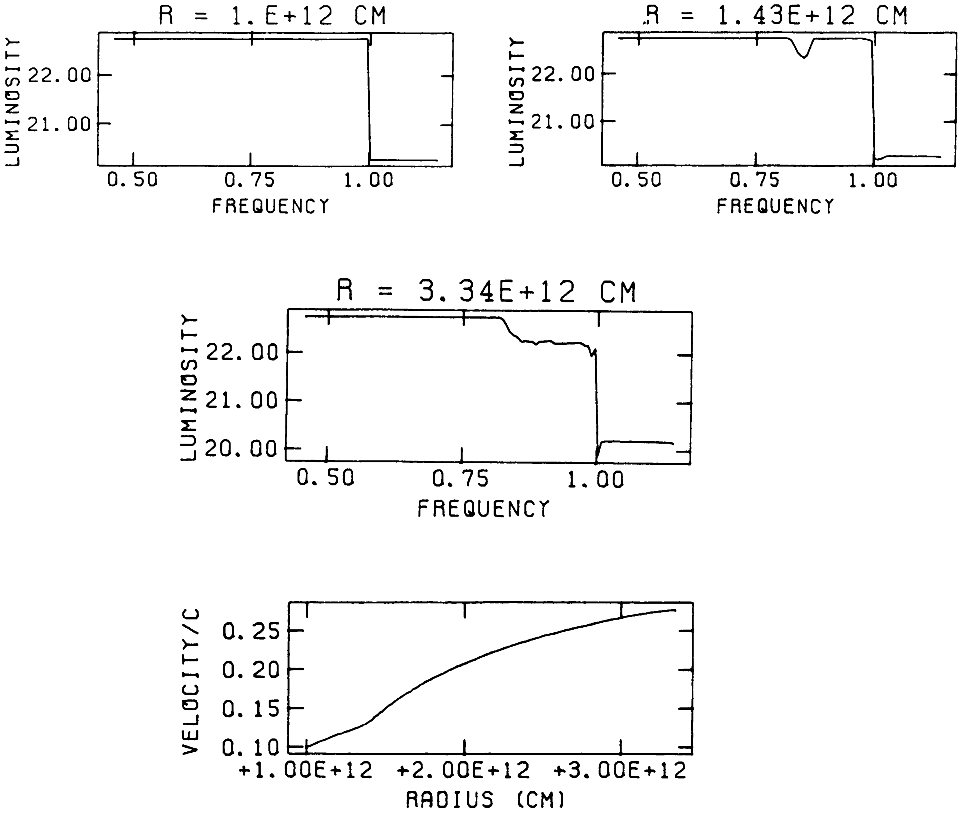

Figure 1. Results for illustrative case mentioned in text. Luminosity is $\log_{10}(dL/d\nu)$. Frequency is in units of $\nu_{Ly-edge}$.

REFERENCE

Milgrom, M. 1979, Astron. Astrophys., 78, L17.