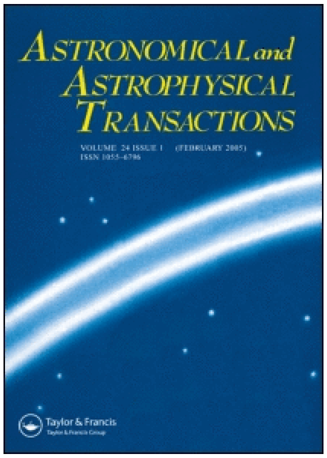

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DRAG ACTION ON THE MHD WINDS

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The effects of radiation drag force on particle acceleration are considered within the one-fluid MHD approximation. It is shown that for most Active Galactic Nuclei the photon density is too low to disturb the ideal MHD outflow. For cosmological gamma-bursters the density of photons is too large for the Poynting dominated outflow to be formed.

KEY WORDS Particle acceleration – MHD

Magnetohydrodynamic (MHD) models are now being intensively developed in the theory of and cosmological gamma-bursts. Unfortunately, up to now ideal MHD acceleration and the action of external photons have been considered independently. Only in the paper by Li, Begelman and Chiueh (1992) was the first step made to combine them. But within their approximation of the given poloidal magnetic field it was impossible to analyze the effects of radiation drag on the position of the fast magnetosonic surface and the properties of the outflow outside this surface. The main goal of our work is to determine more carefully the radiation drag effects on the magnetically dominated outflow.

To describe analytically the radiation drag effects we consider the axisymmetric stationary outflow of a two-component (e^+e^- or e^-p) plasma from the magnetosphere of a rotating body with a split monopole magnetic field. In the hydrodynamic approximation the flow structure is described by the set of Maxwell's equations and the equations of motion: $(\boldsymbol{v}^{\pm}\nabla)\boldsymbol{p}^{\pm} = \pm e(\boldsymbol{E} + \boldsymbol{v}^{\pm} \times \boldsymbol{B}/c) + \boldsymbol{F}^{\pm}_{\rm drag}$. Clearly, only the isotropic component of the photon field $U_{\rm iso}$ contributes substantially to the drag force $F^{\pm}_{\rm drag} = (4/3)(m_{\rm e}/m_{\pm})^2\sigma_{\rm T}U_{\rm iso}(\gamma^{\pm})^2$. This isotropic component can be produced, first, by the outer part of the accretion disk, and, second, by the external media. Here we assume $U_{\rm iso} = U(R_{\rm L})(r/R_{\rm L})^{-n} + U_{\rm h}$, where $R_{\rm L} = c/\Omega$ and $n \approx 3$.

As a zeroth approximation we use the analytical solution for the ideal MHD outflow (Beskin, Kuznetsova and Rafikov, 1998). Then, we introduce small deflecting functions over the zeroth approximation. Substituting these corrections into the Maxwell's equations and the equations of motion, one can obtain a linearized system of equation. This linearized system contains three integrals corresponding to the total energy flux and to the angular momentum fluxes separately for electrons and protons (or positrons). This allows us to obtain analytical expressions for the key parameters describing the outflow in the one-fluid approximation. It is noteworthy that, in comparison with the paper by Li *et al.* (1052), the disturbance of the magnetic surfaces was included into the consideration self-consistently.

As a result, the characteristics of the flow are determined by two main parameters, namely by the compactness parameter $l_{\rm A} = (4/8)(\sigma_{\rm T} U(R_{\rm L})/(m_{\rm e} c\Omega)$ and the magnetization parameter $\sigma = (\Omega e B_0 R^2)/(4\lambda m_{\rm p} c^3)$. Here $m_{\rm p}$ is the mass of a positively charged particle, and $\lambda = n_{\rm e}/n_{\rm GJ}$. For a dow enough photon density $l_{\rm A} < (m_{\rm p}/m_{\rm e})\sigma^{n/3}$ the position of the fast magnetosonic surface $r_{\rm F}$ and the particle energy $m_{\rm p}c^0\gamma(r_{\rm F})$ remain the same as without drag, e.g. $\gamma(r_{\rm Z}) \approx \sigma^{4/5}\sin^{2/3}\theta$ and $r_{\rm F} \approx R_{\rm L}\sigma^{1/3}$. On the other hand, if the photon ddnsity is high enough so that $l_{\rm A} > l_{\rm cr}$ (where $l_{\rm cr} = (m_{\rm p}/m_{\rm e})\sigma^{(n-2)/3}$ for $n < 3$ and $l_{\rm cr} = (m_{\rm p}/m_{\rm e})\sigma^{1/3}$ for $n > 3$), the particle energy outside the fast magnetosonic surface increases up to $\gamma_{\rm max} \approx \gamma(r_{\rm F})(l_{\rm A}/l_{\rm cr})^{(n-2)/n}$, and the disturbance of magnetic surfaces increases with $l_{\rm A}$. But a large enough disturbance of monopole magnetic surfaces ~ 1 can be realized only for a very high photon density $l_{\rm A} > (m_{\rm p}/m_{\rm e})\sigma^{n/3}$ when the drag force substantially diminishes the total energy flux of the flow.

Further, inside the fast magnetosonic surface the drag force does not disturb the particle energy. Here the action of the drag results in a diminishing of the Poynting flux, not the particle flux. Finally, outside the fast magnetosonic surface ($r > r_{\rm F}$ for $l_{\rm A} < l_{\rm cr}$ and $r > r_{\rm F}(l_{\rm A}/l_{\rm cr})^{2/n}$ for $l_{\rm A} > l_{\rm cr}$) particles become free so that the drag force decelerates them efficiently.

For AGNs ($M \sim 10^9 M_\odot$, the total luminosity $L_{\rm tot} \sim 10^{45}$ erg/s, $B_0 \sim 10^4$ G) the compactness parameter is $l_{\rm A} \approx 30 M_9^{-1}(\Omega R/c)L_{45}$. As to the magnetization parameter σ, the main uncertainty is in the multiplication parameter λ. If the density of the hard gamma-quanta in the very vicinity of the central engine is high enough, the direct pair creation $\gamma+\gamma \to e^+ + e^-$ results in an increase of the particle density up to $n_{\rm e} \gg n_{\rm GJ}$. It gives $\sigma \sim 10 - 10^3$. If the hard photon density is not large, then the multiplication parameter will be small enough: $\lambda \sim 10 - 100$, so that $\sigma \sim 10^9 - 10^{12}$. Thus, for most AGNs the photon density is too low to disturb substantially the MHD parameters of the Poynting dominated outflow. Only for $L_{\rm tot} \gg 10^{45}$erg/s and for e^+e^- outflow can one propose the additional acceleration of particles outside the fast magnetosonic surface.

For cosmological gamma-bursters ($M \sim M_\odot$, $L_{\rm tot} \sim 10^{52}$ erg/s, $B_0 \sim 10^{15}$ G) the compactness parameter is extremely large: $l_{\rm A} \sim 10^{16}(\Omega R/c)L_{52}$. Hence, even for $B_0 \sim 10^{15}$ G the magnetization parameter σ is small: $\sigma < 1 - 10$, because the magnetic field itself is secondary and its energy density cannot exceed the plasma energy density. Thus, for cosmological gamma-bursters the density of photons is too large for a Poynting dominated outflow to be formed.

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