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ELECTRIC DISCHARGES ONTO A BLACK HOLE AND X-RAY TRANSIENT PERIODIC VARIABILITY IN AGN

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RESUMEN

Presentamos un mecanismo para producir variaciones periódicas transitorias de rayos-X en NAG. La dispersión de Compton en el plasma que cae en un agujero negro puede inducir una carga eléctrica en la singularidad. Los procesos de carga y descarga pueden afectar la luminosidad en rayos-X del NAG.

ABSTRACT

We present a mechanism to produce X-ray transient periodic variations in AGN. This mechanism is triggered off by Compton scattering in the infalling plasma into a black hole, which can induce an electric charge in the singularity. The charging and discharging processes can affect the X-ray luminosity of AGN.

Key Words: **BLACK HOLE PHYSICS — GALAXIES: ACTIVE — GALAXIES: INDIVIDUAL (IRAS 18325-5926) — QUASARS: INDIVIDUAL (3C 273) — X-RAYS: GALAXIES**

1. INTRODUCTION

The high energy radiation field generated in the inner edge of an accretion disk can increase the separation between electrons and protons in the infalling plasma by Compton scattering, allowing a few electrons (approximately, one out of 10^{25}) to escape through the inner funnel and reach the disk corona. These electrons will be supported in the corona by radiation pressure from the disk. A small net charge is induced in the black hole by the excess protons, and it will eventually increase enough to reduce the accretion rate. This, in turn, will reduce the radiation pressure until the electrons can no longer be supported in the corona and fall to the black hole, thus neutralizing its charge. This process can be repeated, producing low amplitude quasiperiodic or even strictly periodic variations in the X-ray luminosity originated in the accretion disk, which may be superposed to other components of the X-ray luminosity.

2. COMPTON SCATTERING ON THE FREE FALL MATTER

For the infalling plasma, embedded in a radiation field with very high energy photons, the force due to Compton scattering on electrons and the gravitational force on protons are so strong, that they can occasionally overcome the electron-proton Coulomb force in the accreting plasma. The electric charge in the infalling plasma is shielded in a distance called Debye's wavelength: $\lambda_D = \sqrt{\epsilon_0 kT/(n_e e^2)}$. For a black hole of $10^8\ M_\odot$ accreting at the Eddington rate, the characteristic particle density near the horizon is 10^{11} cm^{-3} (Begelman, Blandford, & Rees 1984), and the electron temperature ranges from 10^5 to 10^7 K. The binding energy for the electron-proton pairs in the infalling plasma is given by $E = e^2/(4\pi\epsilon_0\lambda_D)$, which is of the order of 10^{-24} J. The maximum kinetic energy of the "struck" electron after a Compton scattering process is given by

$$K_{max} = \frac{h\nu_0}{1 + 1/2\alpha}, \qquad \text{with} \qquad \alpha = \frac{h\nu_0}{m_e c^2} \ . \tag{1}$$

where ν_0 is the frequency of the incident photon and α is the ratio between the energies of the incident photon and the electron in its rest frame. For UV and soft X-rays, $\nu_0 \sim 10^{16}$ Hz, the electron can acquire an energy of the order of 10^{-21} J, which is at least 3 orders of magnitude larger than the electric energy with the proton field. In normal conditions, after a Compton scattering occurs in a plasma, a nearby electron replaces the scattered one and scattering has negligible effects. However, near the black hole horizon, the infalling plasma containing the unbalanced proton produce a net positive charge in the black hole.

3. FORCE BALANCE AND ELECTRIC DISCHARGE

Once the decoupled electrons have reached the disk corona, the radiation pressure will prevent their infall until the black hole reaches a critical electric charge and the accretion rate decreases. Neglecting magnetic effects, only gravitational, Coulomb, and radiation pressure forces act on *isolated* particles, and they are proportional to R^{-2}, where R is the distance from the central source. This allows a simple treatment of the problem, independent of R. The conditions for accretion will be

$$f_{g,e} + Q f_e - f_{r,e} > 0 \ , \qquad f_{g,p} - Q f_e - f_{r,p} > 0,$$

where the first subindex denotes gravity (g), radiation (r) and electric (e), and the second subindex denotes proton (p) and electron (e). Q denotes the number of free elementary charges. The f terms are defined as

$$f_{g,x} = GMm_x \ , \qquad f_{r,x} = L\frac{\sigma_x}{4\pi c} \ , \qquad f_e = \frac{e^2}{4\pi\epsilon_0} \ . \tag{2}$$

where L is the luminosity, and σ_x is the classical cross section of the particle (x indicates the particle).

The accretion rate is proportional to the infalling velocity (v). Thus, this velocity may be expressed as a function of the distance R to the singularity, and the acceleration a on the infalling particles: $v = \sqrt{2Ra}$. As the luminosity is directly proportional to the accretion rate, it will also be proportional to the square root of a, and therefore, to the square root of the forces acting on the infalling particles.

Expressing the maximum luminosity emitted in the inner region in terms of the Eddington luminosity ($L \leq \kappa L_E$), and neglecting the radiation pressure on the proton, we can express the luminosity in a given moment as a function of the forces acting on the proton

$$L = \kappa L_E \sqrt{\frac{f_{g,p} - Q f_e}{f_{g,p}}} \ , \qquad \text{where} \qquad L_E = \frac{4\pi c GMm_p}{\sigma_e} \ .$$

Substituting in this expression equation (2)

$$GMm_e - \kappa GMm_p \left[\frac{GMm_p - Qe^2/(4\pi\epsilon_0)}{GMm_p}\right]^{1/2} + \frac{Qe^2}{4\pi\epsilon_0} > 0 \ .$$

Rearranging the equation, it can be written as

$$-X^2 - bX + d > 0 \ , \qquad \text{where } b = \kappa\sqrt{GMm_p} \ , \qquad d = GM(m_p + m_e) \ , \qquad X = \left(GMm_p - \frac{Qe^2}{4\pi\epsilon_0}\right)^{1/2} \ .$$

Solving the quadratic equation for X, the critical number of elementary charges Q allowed before the free electrons begin to fall into the black hole is $Q_{crit} = (GMm_p - X^2)\, 4\pi\epsilon_0/e^2$. The time required by the black hole to reach the critical number of charged particles Q_{crit} depends on the accretion rate, $\dot{M}$, and the efficiency ε of the process

$$\frac{dQ}{dt} = \frac{\dot{M}\varepsilon}{m_p} \ .$$

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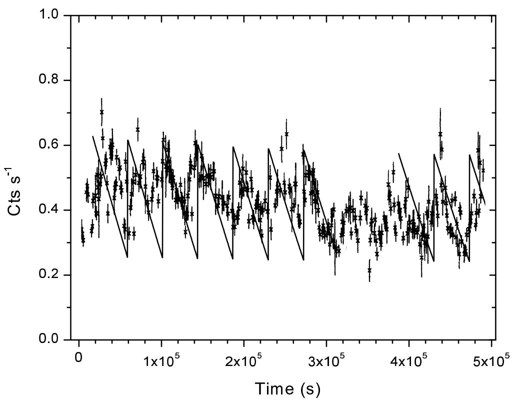

Fig. 1. IRAS 18325–5926 X-ray light curve from Iwasawa et al. (1998). Overlapped, the model fit (see main text for explanation).

Substituting $\dot{M} = L/\eta c^2$, where $\eta \approx 0.4$ is the accretion radiating efficiency, and integrating from zero to Q_{crit}, we obtain the necessary time, τ, to get the critical black hole charge

$$\tau = \frac{\sigma_e \epsilon_0 \eta m_p c}{\kappa \varepsilon e^2} \left[2 - \left(2\kappa^2 - 2\kappa\sqrt{4+\kappa^2} + 4 \right)^{1/2} \right] . \tag{3}$$

Finally, we consider the luminosity variation produced by this process. We define the index of variability as the ratio between the maximum and the minimum luminosities, L_{max} and L_{min} respectively. The luminosity may have an underlying, constant term (L_c), that can be expressed as $L_c = \chi L_E$, and we obtain

$$R_L = \frac{L_{max}}{L_{min}} = \frac{2(\chi + \kappa)}{2\chi + \kappa(\sqrt{4+\kappa^2} - \kappa)} . \tag{4}$$

Note that this model does not require of any mechanism to enhance the variable component of the luminosity, and that it needs *only three* free parameters: the efficiency η of the mass-energy conversion for the accretion process, the total X-ray and greater frequencies luminosity, and the efficiency ε of the decoupling process.

4. AN EXAMPLE: IRAS 18325-5926

IRAS 18325–5926 was observed by *ASCA* for 5 days (March 27–31 1997; Iwasawa et al. 1998). The data shows a periodicity of 5.8×10^4 s in the $0.5 - 10$ keV band. Allowing a super Eddington luminosity by a factor of 2, κ and χ are adjusted to produce the observed variability. The critical charge is $eQ_{crit} = 2.5 \times 10^9$ coul and the efficiency of the process is $\varepsilon = 6.5 \times 10^{-26}$. In Figure 1 we include both the observed light curve from Iwasawa et al. (1998) and the expected variability of the X-ray luminosity from our model. Note the lag in the fitting results in Figure 1 from approximately 3×10^5 to 3.8×10^5 s, where the periodical pattern is lost. The pattern is recovered at 3.8×10^5 s, but with a different phase. This behavior can be explained if, due to instabilities, some electrons fall into the central object before global neutralization occurs.

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