RANDOM PRECESSING JET AND ACCRETION DISK AT THE GALACTIC CENTER

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As a mechanism to generate asymmetric radio features in the central 50 pc of the Galaxy (Sofue and Fujimoto 1987), we consider a gaseous jet from the tilted accretion disk at the center and the interaction of the jet with ambient gas on the galactic plane. It is shown schematically in figure 1 that the magnetic torques $\boldsymbol{N}_{1,2,3}$ exert on a gaseous element $\rho h \Delta s \Delta r$ of a ring to change its tilted orbital plane,

$$\boldsymbol{N}_1 = \frac{\gamma_1 B^2 r \Delta r \Delta s \boldsymbol{e}_1}{4\pi}, \tag{1}$$

$$\boldsymbol{N}_2 = \frac{\gamma_2 B^2 h \Delta r \Delta s \cos^2\phi \sin\theta \, \boldsymbol{e}_2}{4\pi}, \tag{2}$$

and

$$\boldsymbol{N}_3 = \frac{\gamma_3 B^2 r \Delta r \Delta s \sin^2\phi \, \boldsymbol{e}_3}{8\pi}, \tag{3}$$

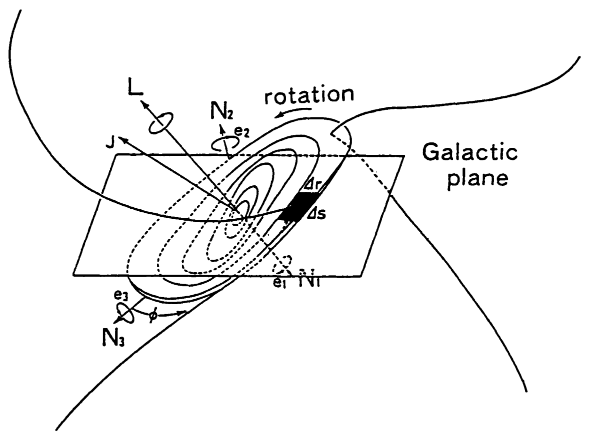

Figure 1. Two typical field lines are given in a tilted accretion disk and halo around it. The curvature radii of the field lines in and close to the disk are taken as h for estimating the magnitude of $\boldsymbol{N}_1$ and as r for $\boldsymbol{N}_2$, where r and h are respectively the orbit radius of the disk element and its thickness. The torque $\boldsymbol{N}_3$ is estimated from the magnetic pressure difference between above and below the disk.

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where $\gamma_{1,2,3}$ are constants of a factor of unity and $\boldsymbol{e}_{1,2,3}$ unit vectors. The azimuthal angle ϕ is measured along the rotation from the lowest part of the ring below the galactic plane. The orbital plane is tilted against the galactic plane by the angle θ. The change of the angular momentum of the disk element $\boldsymbol{L} = \rho h \Delta s \Delta r \, \boldsymbol{r} \times \boldsymbol{v}$ is,

$$\frac{d\langle \boldsymbol{L} \rangle}{dt} = \langle \boldsymbol{N}_1 \rangle + \langle \boldsymbol{N}_2 \rangle + \langle \boldsymbol{N}_3 \rangle, \tag{4}$$

where $\langle \rangle$ means the average over one rotation period T or over $\phi = 0$ to 2π in equations (1) to (3).

Since the magnetic energy in the disk would be much smaller than the rotation energy, the torques $\langle \boldsymbol{N}_1 \rangle$, $\langle \boldsymbol{N}_2 \rangle$, and $\langle \boldsymbol{N}_3 \rangle$, orthogonal each other, are regarded as perturbation on the circular rotation of the disk element, and thus their dynamical effects can be explained separately: $\boldsymbol{N}_1$ dissipates the orbital angular momentum $\boldsymbol{L}$; $\boldsymbol{N}_2$ makes $\boldsymbol{L}$ precess around the symmetry axis of the Galaxy; $\boldsymbol{N}_3$ tilts the vector $\boldsymbol{L}$ secularly toward the galactic plane, because $\boldsymbol{N}_3$, $\boldsymbol{L}$ and the symmetry axis are on the same plane. When the disk element contracts homologously, equation (4) is solved to give the rate of inclination of the orbital plane of radius r,

$$\begin{aligned} \frac{d\theta}{dt} &= T \left| \frac{\langle \boldsymbol{N}_3 \rangle}{\langle \boldsymbol{L} \rangle} \right| \\ &\sim 0.6^\circ \textit{ to } 6^\circ \ (r/\mathrm{pc})^{-3/2} / 10^5 \ \mathrm{yr} \end{aligned}$$

where we have assumed that the mass of the central blackhole is $10^6 M_\odot$, $h/r = 0.1$, and $c_A^2/v^2 = 10^{-3}$ to 10^{-2} with c_A and v the Alfvén and the rotation velocities of gas in the accretion disk. The time scale of the disk inclination is thus 10^6, 3×10^4 and 10^3 yr respectively when $r = 1$, 0.1 and 0.01 pc. Since the jet, $\boldsymbol{J}$ in figure 1, is ejected normal to the accretion disk at its final collapse to the central object and such collapse will take place from time to time, many tilted beams of gas will be ejected sporadically within the time scale of $\leq 10^6$ yr. The collisions of the jets with the ambient gas on the galactic plane would generate the asymmetric radio features in the central 50 pc.

Reference

Sofue, Y. and Fujimoto, M. (1987) *Astrophys. J.* **319**, L73-L76.