PHYC 581: High Energy Astrophysics
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Accretion Columns:

If the compact object at the center is strongly magnetized, the disk will not extend all the way down to the stellar surface. The radial infall will be disrupted some distance away from the star in this case. This is intuitively expected as the magnetic field tends to whirl the particles around.

The magnetic field may be quite complex near the surface of the compact object. However, all of the multipole moments higher than the dipole fall off very rapidly away from the star. It is therefore sufficient to keep the contribution from the magnetic dipole moment $\vec{m}$, which results in:

$$\vec{B} = \frac{3\hat{n}\,(\hat{n}\cdot\vec{m}) - \vec{m}}{r^3}$$

On the horizontal plane, where the disk is located, we have:

$$B(R) = B_* \left(\frac{R_*}{R}\right)^3$$

Here B_* is the magnetic field at the polar cap ($R = R_*$), and R denotes radius in the equatorial plane.

A simple criterion for the dominance of the magnetic field is that the energy density in the magnetic field becomes larger than the gravitational potential energy on the disk:

$$\frac{1}{8\pi} B^2 \gtrsim \frac{GM\rho}{R}$$

From previous lectures, we have:

$$\rho \sim \frac{\dot{M}}{12\pi} \frac{1}{\zeta\alpha} \left(\frac{\mu}{R_g T}\right) \left(\frac{GM}{R^3}\right)^{\frac{1}{2}}$$

The magnetic radius R_m is then found to be:

$$R_m \simeq B_* R_*^3 \left(\frac{R_g T}{\mu}\right)^{3/4} \frac{1}{GM} \left(\frac{3}{4}\alpha\right)^{\frac{1}{2}} \dot{M}^{-\frac{1}{2}}$$

It can be written in a useful form:

$$R_m \simeq (30\,\text{km})\, \alpha^{\frac{1}{2}} \left(\frac{B_*}{10^{12}\,G}\right) \left(\frac{R_*}{10^6\,\text{cm}}\right)^3 \left(\frac{T}{10^6\,K}\right)^{3/4} \left(\frac{M_\odot}{M}\right) \left(\frac{\dot{M}}{10^{16}\,\text{g s}^{-1}}\right)^{-\frac{1}{2}}$$

For a neutron star, when parameters take their natural values used in the above normalization, we find $R_m \sim 3 R_*$. This suggests that the radial flow of material and the disk are disrupted relatively far away from the surface of the star.

Once the gas reaches the magnetic radius, $R \sim R_m$, it is funneled toward the polar caps of the star along the magnetic field lines. This is the only possibility for motion when the magnetic field is very strong. This cropping of the disk is indeed seen in both systems where the compact object is a magnetized white dwarf (Cataclysmic Variable) or a neutron star (pulsar). The physical conditions in the latter are much more extreme ($B_* \sim 10^{12}$ G, and gravitational free-fall velocities $\sim \frac{c}{2}$ at R_*), and hence more difficult to model. Magnetic cataclysmic variables, in which the

the primary is a magnetized white dwarf, are better understood than X-ray pulsars (their neutron star counterparts). This is because not only the physical modeling is more straightforward for the former, but also there is more observational evidence available for making comparisons with theoretical predictions. Next, we will discuss the accretion columns in magnetic cataclysmic variables (m-CVs) and, briefly, X-ray pulsars.