Feeding Compact Objects: Accretion on All Scales
Proceedings IAU Symposium No. 290, 2012
C. M. Zhang, T. Belloni, M. Méndez & S. N. Zhang, eds.

doi:10.1017/S174392131202039X

Jet and kHz QPO-Accreting Pulsar and Bottom Magnetic Field

Yuanyue Pan and Chengmin Zhang

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
zhangcm@bao.ac.cn

Abstract. The bottom magnetic fields of neutron stars (NSs) in LMXBs are found to be proportionally related to their accretion rate, i.e. Z (Atoll) source with Eddington (less Eddington) rate is associated with a stronger value of about B $\sim 10^9$ G (B $\sim 10^8$ G). We discuss the relation between the jet formation of NS and its bottom magnetic field strength, and pointed out that the accretion powered millisecond pulsar will not exclude the jet production, furthermore the appearance of kHz QPOs may be also coexistence with the jets. The observer's viewing angle to the NS rotating axis may be a significant factor for observing the jet, pulsar or kHz QPO.

Keywords. Accretion: accretion disks, X-rays: binaries, stars: outflows, star: neutron

---

1. NS bottom magnetic field, jet, pulsar and kHz QPO

Jets are the popular phenomena in the galaxies of universe (Fanaroff & Riley (1974)). Jets in microquasars are widely discussed (Belloni 2009, Belloni 2010). Their formations in compact + accretion disk systems, black holes (BH) or neutron stars (NS) accreting matter from their companions, attract much attentions. The jet condition in NS binary system is recently proposed by Massi and Bernado (2007), where they take the magnetosphere radius comparable to the stellar radius as a criterion of NS jet production. However, above NS jet condition is also the condition for the formation of bottom magnetic field of NS, which is derived from a accretion induced field decay model (Zhang & Kojima 2006), where the accretion induced magnetic-field evolution is obtained analytically with the initial field $B(t=0)=B_0$,

$$B = \frac{B_f}{(1-[C\ exp(-y)-1]^2)^{\frac{7}{4}}}. \tag{1.1}$$

Here, $y = \frac{2\Delta M}{7M_{cr}}$ with $\Delta M = \dot{M}t$ and $M_{cr} \sim 0.2M_\odot$ is the crust mass, $C = 1+\sqrt{1-x_0^2} \sim 2$ with $x_0^2 = (\frac{B_f}{B_0})^{4/7}$, and B_f is the bottom magnetic-field defined by the NS magnetosphere radius matching the star radius, i.e., $R_M(B_f) = R$. $R_{\rm M}$ is defined as $R_M = \phi R_A$, where the $Alfv\acute{e}n$ radius R_A reads, $R_A = 3.2\times10^8(cm)\dot{M}_{17}^{-2/7}\mu_{30}^{4/7}m^{-1/7}$, and ϕ is a parameter of about 0.5. $\dot{M}_{17}$ is the accretion rate in units of 10^{17} g/s, μ_{30} is the magnetic moment in units of 10^{30} Gcm^3, and mass $m = M/M_\odot$. So, from $R_M(B_f) = R$, the bottom field reads,

$$B_f = 1.32\times10^8(G)(\frac{\dot{M}}{\dot{M}_{18}})^{\frac{1}{2}}m^{\frac{1}{4}}R_6^{-\frac{5}{4}}\phi^{-\frac{7}{4}}, \tag{1.2}$$

where $\dot{M}_{18} = \dot{M}/10^{18}g/s$ and $R_6 = R/10^6cm$. Three observational consistent conclusions can be obtained: (1). the field decay is inversely related to the accreted mass, (2). the bottom field strength is about 10^8 G, and (3). the bottom field strength is proportionally related to the X-ray luminosity. This means that Z source with Eddington accretion can be a stronger magnetic field about $\sim 10^{8.5-9}G$ if the convenient parameters are chosen;

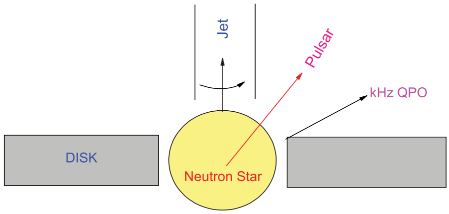

Figure 1. Illustration of the NS accreting system, where it is shown that the appearance of jet, pulsar and kHz QPO depends on the viewing angle of the observers.

then for Atoll source with 1% Eddington rate, its field should be about one magnitude order less than that of Z source.

While, the kHz QPOs have been detected in thirty-five Z and Atoll sources. It is pointed out by the kHz QPO model of Keplerian frequency and Alfven wave excited frequency for twin kHz QPOs (Zhang 2004) that the QPO emission position is very close to NS surface, at about 20 km. This implies that the appearance of kHz QPO is also related to bottom field of NS. Then an interesting question arises that in what condition we can observe jet, pulsar and kHz QPO simultaneously? As shown in FIG.1, the viewing angle to the NS rotation axis should be a significant factor. (1) If the disk environment is too thick, e.g. Z source, the pulsar will be difficult to view, since the NS polar cap may be blocked the the accreting matter around, where the jet and kHz QPO can be observed in a convenient direction. (2) If the disk environment is mediate thin/thick, e.g. Atoll, the pulsar can be detected if its beaming to earth, and kHz QPOs can be detected as well. Then the jet may be observed in high accretion state, and difficult to view in low accretion state. (3) If the disk environment is too thin, e.g. millisecond accretion powered pulsar, the accretion power is too weak to provide sufficient energy to ignite the Jet and kHz QPOs.

2. Overview and Conclusion

To answer when will an accreting neutron star become a microquasar, an X-ray pulsar and a kHz QPO source ? We propose a criterion condition that the NS accreting system should enter a bottom magnetic field state, where the magnetosphere radius is approaching NS surface. Three cases are classified to appear as jet, pulsar and kHz QPO. (a) For Eddington rate, jet and kHz QPO occur but no pulsar; (b) For 0.1 Eddington rate, jet, pulsar and kHz QPO can occur simultaneously if the convenient viewing angle exists; (c) For 0.01 Eddington rate or less, only pulsar can be observed, since the accretion power is to weak to ignite jet and kHz QPO.

References

Belloni, T. M. 2010, in: Ian F Corbett (ed.), *"Astrophysical Outflows and Associated Accretion Phenomena"*, To appear in Highlights of Astronomy, Vol. 15, Proc. of the XXVIIth IAU General Assembly, Rio de Janeiro, Brazil, Cambridge University Press, (arXiv:1001.0742)

Belloni, T. M. 2009, in: Belloni, T. M.(ed.), *The Jet Paradigm: from Microquasars to Quasars*, Lecture Notes in Physics (Heidelberg: Springer), in press (arXiv:0909.2474)

Fender, R. P., Belloni, T., & Gallo, E. 2004, *MNRAS*, 355, 1105

Fanaroff, B. L. & Riley, J. M. 1974, *MNRAS*, 167, 31

Liu, Q. Z., van Paradijs, J., & van den Heuvel, E. P. J. 2007, *A&A*, 469, 807

Massi, M. & Kaufman, Bernado, M. 2007, *AA*, in press, arXiv:0709.4287

Zhang, C. M. & Kojima, Y. 2006, *MNRAS*, 366, 137, astro-ph/0410248

Zhang, C. M. 2004, *A&A*, 423, 401

https://doi.org/10.1017/S174392131202039X Published online by Cambridge University Press