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On the structure of quasi-Keplerian accretion discs surrounding millisecond X-ray pulsars

ISAAC HABUMUGISHA[1,2,*], SOLOMON B. TESSEMA[3], EDWARD JURUA[1] and SIMON K. ANGUMA[4]

[1]Department of Physics, Mbarara University of Science and Technology, Mbarara, Uganda.
[2]Department of Physics, Kabale University, Kabale, Uganda.
[3]Astronomy and Astrophysics Research and Development Department, Entoto Observatory and Research Center, Addis Ababa, Ethiopia.
[4]Department of Physics, Muni University, Arua, Uganda.
E-mail: hisaac08@yahoo.co.uk

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Abstract. In this study, we investigated the time-independent dynamics (disc structure, forces and torques) of a quasi-Keplerian disc around a millisecond pulsar (MSP) with an internal dynamo. We considered the disc around a MSP to be divided into the inner, middle and outer regions. By assuming that the disc matter flows in a quasi-Keplerian motion, we derived analytical equations for a complete structure (temperature, pressure, surface density, optical depth and magnetic field) of a quasi-Keplerian thin accretion disc, and the pressure gradient force (PGF). In our model, the MSP-disc interaction results into magnetic and material torques, such that for a given dynamo (ϵ) and quasi-Keplerian (ξ) parameter, we obtained enhanced spin-up and spin-down torques for a chosen star spin period. Results obtained reveal that PGF results into episodic torque reversals that contribute to spinning-up or spinning-down of a neutron star, mainly from the inner region. The possibility of a quasi-Keplerian disc is seen and these results can explain the observed spin variations in MSPs like SAX J1808.4-3658 and XTE J1814-338.

Keywords. 97.80.Jp X-ray binaries—97.60.Gb pulsars—97.10.Gz accretion and accretion discs.

1. Introduction

The study of accretion-powered millisecond pulsars was inaugurated in the 1970s by the discovery of the 4.8 s X-ray pulsations from Centaurus X-3 (Cen X-3) (Giacconi *et al.* 1971). Over a period of time, Cen X-3 showed peculiar spectral structures and was found to be a source of variable energy emissions. Thereafter, observations of shorter period pulsations (1.2 s) were observed from Hercules X-1 (Her X-1) (Tananbaum *et al.* 1972) and on the millisecond-scale, a 2.494 ms pulsation was observed for SAX J1808.4-3658 (in 't Zand *et al.* 2001). Because of this rapid period change, pulsars are both theoretically and observationally puzzling astronomical objects in ascertaining their spin periods (Camenzind 2007). They are believed to be old, rapidly rotating neutron stars which have been spun up or recycled back as radio pulsars through accretion of matter from a companion star in a close binary system (Alpar *et al.* 1982; Bhattacharya & van den Heuvel 1991; Wijnands & van der Klis 1998).

Accretion powered MSPs (APMSPs) are known to have magnetic surface field of the order of 10^8–10^9 G (Backer *et al.* 1982), which is less than that of a typical X-ray pulsar. Consequently, the ionized gas in the pulsar magnetosphere is brought into corotation closer to the stellar surface (Psalts & Chakrabarty 1999) and is channeled along field lines to the polar caps, releasing its potential and kinetic energy, mostly in X-rays (Shapiro & Teukolsky 2004). As a result of the energy released, the accretion disc temperature reaches such a high temperature that gas pressure is far less than radiation pressure. They therefore behave

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