Accretion onto Magnetic Degenerate Stars – Final Report

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1. Grant Information

This grant, **NAG 5 – 3082**, LSU Prop # 6757, was awarded as a result of a proposal submitted in the summer of 1995 by Ganesar Chanmugam as PI and Juhan Frank as Co–PI in response to NRA 95-OSS-02 for the Astrophysics Theory program. The project was funded at a level of $58,000 per annum, starting on October 1, 1995. The PI Chanmugam passed away in March 1996, and the Co-PI Frank was appointed PI in April of the same year. This grant was originally awarded for three years and extended once at no-cost, expiring finally on September 30 1999. The grant provided partial summer salary for the PI and support for three graduate students at various times: Erik J. Young (Oct. 1995 – Aug. 1998), Patrick McCormick (Feb. 1997 – Jun. 1998), and Patrick Motl (Jul. 1998 – Jan. 1999).

2. Introduction

The original objectives of the proposal included the study of radiative processes in magnetic cataclysmic variables (CVs) and the evolution of neutron star magnetic fields. Significant progress under the support provided by this grant has occurred in the following areas:

- Irradiation–driven mass transfer cycles in cataclysmic variables and low–mass X–ray binaries.
- Propeller effect and magnetic field decay in isolated old neutron stars.
- Erik Young's dissertation research.
- Numerical (Finite Difference Hydrodynamics [FDH]) simulations of mass transfer in binary stars.

Further details are provided below. The review and introductory material included below is given without explicit references. The bibliography only includes references to the work done by our research group.

3. Mass Transfer Cycles

Cataclysmic variables (CVs) are semi-detached binary stars with orbital periods of a few hours ($\lesssim .5$ days) containing an accreting white dwarf and a companion or mass donor star which the stability of irradiated main sequence companions was given in King, Frank, Kolb & Ritter (1996), and extended to evolved companions in King, Frank, Kolb & Ritter (1997a). Some of the astrophysical consequences of the irradiation instability for LMXBs and XRTs were explored in King, Frank, Kolb & Ritter (1997b) and in Kolb, King, Ritter & Frank (1997).

The stability criterion for irradiation–driven cycles developed in King, Frank, Kolb & Ritter 1997a, indicates that LMXBs with hydrogen–rich companions and similar systems containing black holes should be stable, whereas those with sub–giant companions should be violently unstable. Because the instability in the latter case would result in the transfer of almost all the envelope, such systems should not be observed. The reason we do in fact observe systems with such companions is that they are transient, their duty cycle is relatively small and therefore the irradiation instability is quenched (King, Frank, Kolb & Ritter 1997a, 1997b). These systems are transient probably because the accretion rate is low enough to make their accretion disks vulnerable to the disk instability.

The orbital evolution of cataclysmic variables in which the companion is illuminated by a fraction of the accretion luminosity therefore consists of irradiation–driven limit cycles on thermal timescales, superimposed on a secular evolution toward shorter periods due to systemic angular momentum losses. The PI and graduate student Patrick McCormick (who was initially supported by another grant) have conducted extensive numerical simulations of the evolution of CVs and LMXBs under the effects of illumination and consequential angular momentum losses (CAML) with the help of a code developed by McCormick. The first results obtained with McCormick's bi–polytropic code including irradiation and CAML were presented at the XIIIth North American Workshop on CVs in Jackson Hole in the summer of 1997 (McCormick 1998; McCormick & Frank 1998a). A detailed account of these simulations is now published in The Astrophysical Journal (McCormick & Frank 1998b).

Further work on irradiation-enhanced cycles in the mass transfer of catalysmic variables is still in progress, funded by other grants, but some preliminary results were obtained with support from NAG5-3082 and were reported at the Austin AAS meeting in January 1999 (McCormick & Frank 1999).

4. Isolated Neutron Stars

In a recent paper (Livio, Xu & Frank 1998) we examined the discrepancy between the theoretically expected number of detectable isolated old neutron stars (IONs) (10^2–10^3), and the actually detected number of candidates (2–3). We argued that this discrepancy is explicable in terms of the suppression of accretion from the interstellar medium onto the old neutron stars. We showed that for such a suppression to occur, a specific pattern for the magnetic field evolution in neutron stars is required. High magnetic fields ($B \gtrsim 10^{12} G$) are required to decay rapidly, while fields of the order of $10^{10} G$ are required to remain constant in the absence of accretion. The surface magnetic field of a young neutron star was detailed, and this was used to conclude that with existing data it was unclear whether pulsars were born with strong surface fields or whether these fields were generated after birth (Chanmugam, Rajasekhar and Young 1995).

Later he included the effects of Hall drift into the field evolution of magnetized neutron stars. The results demonstrate that the dominant dipole magnetic field may be significantly altered late in the star's life through interaction with higher order poles of lower strength if both poloidal and toroidal components are present. These changes may alter the expected characteristics of the graveyard population of pulsars. Additionally, he has incorporated the general relativistic effects of space curvature and gravitational redshift in the strong gravitational field of a neutron star into calculations of Ohmic field decay. The results show a decrease in the rate of magnetic field decay that we would measure. The magnitude of this decrease is dependent on both the neutron star model used and the depth to which the field penetrates the star.

Finally, these advances in the theory of neutron star magnetic field evolution were coupled with the accretion simulations first explored in Young & Chanmugam (1995). This provided a more complete picture of the possible avenues available to a magnetic neutron star that is undergoing accretion, and its subsequent magnetic evolution after mass transfer halts. These results were detailed in Young's PhD dissertation, which was completed in the Spring of 1998. This thesis won an award as the "Best 1998 Dissertation in Basic Sciences at LSU".

6. FDH Simulations of Mass Transfer in Binaries

Patrick Motl is a graduate student who was supported for the first 4 years on a LSU Chancellor's Fellowship and who has received support from this grant in order to conduct simulations of the onset and stability of mass transfer in binary stars. He began developing in 1996 a large-scale 3D finite-difference hydrodynamics (FDH) code coupled to a Poisson solver designed to tackle a variety of astrophysical fluid dynamics problems including both external and self-gravity in cylindrical geometry. This code was then adapted to the study of the onset and stability of mass transfer in polytropic binaries with the aim of applying the results to the interpretation of certain observations of cataclysmic variables and binaries of the Algol type.

After an initial development stage we realized that the scope of the research and numerical development needed to tackle our goals required more support than the current grant could provide. This led us to submit in 1998 a new ATP proposal specifically designed to address the more long term goals of this research. This proposal was funded in May 1999 (NAG5-8497) and is being currently pursued vigorously. Preliminary results of the numerical simulations were presented in January 1999 at the 193th Meeting of the American Astronomical Society in Austin, TX, and select examples are available on the web at http://www.phys.lsu.edu/astro/movie_captions/motl.binary.html. Three papers are currently in preparation which will acknowledge partial support from NAG5 3082 and NAG5-8497: The first

* McCormick, P. and Frank, J. 1999, BAAS, 31, 1399: Irradiation and Enhanced Magnetic Braking in Cataclysmic Variables, 193th Meeting of the AAS, Austin, TX.

* Motl, P.M., Frank, J. and Tohline, J.E., BAAS, 31, 1402: Numerical Simulations of Dynamical Mass Transfer in Binaries, 193th Meeting of the AAS, Austin, TX.

Young, E.J. & Chanmugam, G. 1995, ApJ, 442, L53: Postaccretion Magnetic Field Evolution of Neutron Stars.

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While the original objectives of this research program included the study of radiative processes in cataclysmic variables and the evolution of neutron star magnetic fields, the scope of the reported research expanded to other related topics as this project developed. This final report therefore describes the results of our research in the following areas:

1) Irradiation-driven mass transfer cycles in cataclys mic variables and low-mass X-ray binaries; 2) Propeller effect and magnetic field decay in isolated old neutron stars; 3) Decay of surface magnetic fields in acreting neutron stars and pulsars; 4) Finite-Difference Hydrodynamic simulations of mass transfer in binary stars.

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