Populations of High Energy Sources in Galaxies
Proceedings IAU Symposium No. 230, 2005
E. J. A. Meurs & G. Fabbiano, eds.

doi:10.1017/S1743921306007927

Optical observations of *IGR J00291+5934* in the post outburst phase

M. T. Reynolds[a], P. Elebert[a], P. J. Callanan[a], B. Field[a], P. Tuite[a], M. A. P Torres[b], D. Steeghs[b], P. M. Garnavich[c], D. M. Terndrup[d], A. V. Filippenko[e], R. J. Foley[e] & E. T. Harlaftis[f]

[a]Department of Physics, University College Cork, Ireland
email: m.reynolds@ucc.ie
[b]Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
[c]Department of Physics, University of Notre Dame, Notre Dame, IN 46556-5670, USA
[d]Department of Astronomy, The Ohio State University, Columbus, OH 43210, USA
[e]Astronomy Department, University of California, Berkeley, California 94720, USA
[f]National Observatory of Athens, PO Box 20048, Athens 11810, Greece

Abstract. We present optical observations of the newly discovered accretion powered millisecond pulsar *IGR J00291+5934*, undertaken in the weeks following its outburst on 2^{nd} December 2004. The decay to quiescence is seen to be highly variable with no indication of a modulation on the ∼2.46 hr orbital period apparent in the data, consistent with a system at low inclination. We also have a single *Keck LRIS* spectrum of the companion to *IGR J00291+5934* taken 10 days after outburst. Strong hydrogen and helium emission lines are observed confirming the identity of the counterpart.

Keywords. X-rays: binaries, pulsars: individual (IGR J00291+5934).

1. Introduction

IGR J00291+5934 was discovered by *INTEGRAL* on 2004 December 2*nd* (Shaw *et al.* 2005). The optical counterpart was identified two days later and was found to have a magnitude R ≈ 17.4 (Fox *et al.* 2004). It was quickly identified as the 6*th* member of the class of accretion powered millisecond X-ray pulsars to be discovered. It has the fastest spin period yet observed in this class $p_{spin} \sim 1.7$ms and the second longest orbital period ∼2.46hr. We present here the first optical study of its outburst and decay.

2. Photometry

Two nights of R-band data were obtained on 2004 December 9*th* and 18*th* at the 1.3m MDM telescope at KittPeak and the 4m WIYN telescope respectively (see Fig. 1). We also obtained 2 nights of white light observations from the 1.2m telescope at the Kryoneri observatory in Greece. The resulting lightcurves were phased to the ephemeris of Markwardt *et al.* (2004). The lightcurves are observed to be highly variable with no significant modulation at the orbital period evident (Fig. 1). The observed fading is consistent with that observed by Bikmaev *et al.* (2005). The IR counterpart was first observed on December 8*th* (see Steeghs *et al.*, 2004), 6 days after the onset of the outburst.

3. Spectroscopy

In an effort to confirm the identification by Roelofs *et al.* (2004), a single 300s *LRIS* spectrum of the proposed optical counterpart was obtained 10 days post outburst (Filippenko *et al.*, 2004), Fig. 1. We observe broad (FWHM = 1200 km/s) emission lines of Hα 656 nm, Hβ 486 nm, and HeI 667.8 nm, as well as narrow (FWHM = 300 km/s),

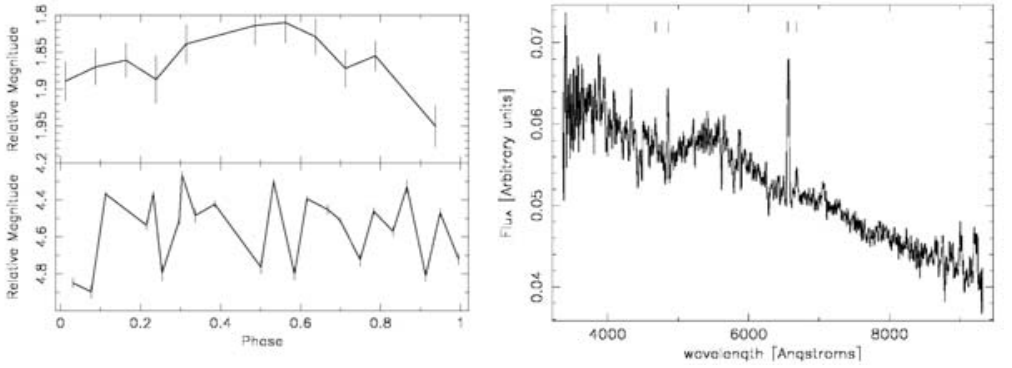

Figure 1. LEFT: The R-band light curve. The top panel is from 9.12.04 with the bottom panel obtained 9 days later. RIGHT: *Keck LRIS* spectrum of the optical counterpart taken on 12.12.04. The markers indicate, from left to right, the positions of the HeII 468.6 nm (EW = 0.06 nm), $H\beta$ 486 nm (EW = 0.54 nm), $H\alpha$ 656 nm (EW = 0.96 nm) & HeI lines 667.8 nm (EW = 0.1 nm).

very weak HeII 468.6 nm emission. The lines are superposed on a blue continuum. These are classic hallmarks of an X-ray transient in outburst and hence they firmly establish the counterpart of the accreting X-ray pulsar.

4. Discussion

IGR J00291+5934 is the 6*th* member of the class of accretion powered millisecond X-ray pulsars to be discovered and the third 'long' orbital period system. The decay of *IGR J00291+5934* is the fastest yet observed in this class of binary, with an e-folding time $\tau_e = 5.5$ days. In comparison, the e-folding time for *SAX J1808.4-3658* was $\sim$14 days. This may be due to the relatively small accretion disk present in these systems, because of (i) the short orbital period (and small system size), and (ii) the truncated inner disk due to the magnetosphere of the neutron star: this is similar to what happens during outbursts of intermediate polars (Angelini *et al.*, 1989). Recently Burderi *et al.* (2005) suggested that *IGR J00291+5934* could be a high inclination system; however the absence of any clear modulation in our data is inconsistent with this.

Acknowledgements

The data presented in this paper was obtained at the following observatories; *WIYN, MDM, Kryoneri, PAIRITEL & Keck I.*
MTR, PE & PJC wish to acknowledge financial support from Science Foundation Ireland. The authors wish to dedicate this paper to the memory of Emilios T. Harlaftis, who passed away in tragic circumstances earlier this year.

References

Angelini, L. & Verbunt, F., 1989, MNRAS, 238, 697
Bikmaev, I., Suleimanov, V., Galeev, A. & 7 co-authors, 2005, ATel, 395
Burderi, L., Di Salvo, T., Riggio, A. & 6 co-authors, astro-ph/0509224
Filippenko, A.V., Foley, R.J. & Callanan, P.J., 2004, ATel, 366
Fox, D.B. & Kulkarni, S.R., 2004, ATel, 354
Markwardt, C.B., Galloway, D.K., Chakrabarty, D. & 2 co-authors, 2004, ATel, 360
Roelofs, G., Jonker, J.G., Steeghs, D., Torres, M.A.P. & Nelemans, G., 2004, ATel, 356
Shaw, S.E., Mowlawi, N., Rodriguez, J., Ubertini, P. & 7 co-authors, astro-ph/0501507
Steeghs, D., Blake, C., Bloom, J.S., Torres, M.A.P., Jonker, P.G., & Starr, D., 2004, ATel, 363
Vanderspek, R., Morgan, E., Crew, G., Graziani, C., & Suzuki, M., 2005, ATel, 516

https://doi.org/10.1017/S1743921306007927 Published online by Cambridge University Press