UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

Department of Astronomy, FM-20

August 17, 1987

Dr. L. Kaluszienski
Code EZ
600 Independence Ave.
NASA Headquarters
Washington, D.C. 20546

Subject: Final Technical Report – NASA Grant NAGW 805

I. Overview

During the funding period for NAGW 805 we established a working collaboration with Profs. Satio Hayakawa and Fumiaki Nagase at Nagoya University. Our joint program involves the analysis and interpretation of observations of X-ray pulsars made with X-ray detectors aboard Japanese and U.S. scientific satellites. Both the Nagoya group and we at the University of Washington in collaboration with Prof. Fred Lamb at the University of Illinois have pursued this research topic with the goal of better understanding the physical processes associated with matter accretion onto neutron stars.

By careful measurements of the fluctuations in pulsar pulse periods on time scales of days and longer, we have determined that these fluctuations are caused by changes in the rotation rate of the stellar crust apparently arising from matter accretion. The study of these fluctuations is a particularly promising way to determine the properties of accreting pulsars, because stellar rotation is relatively simple in comparison to much other X-ray source physics and can be investigated in detail. Moreover, rotation rates can be determined very precisely with the combined capabilities of modern X-ray detectors and data analysis techniques. Thus, a direct, quantitative confrontation between theory and observation is possible.

II. Research Completed

The collaboration with the group at Nagoya University grew out of an arrangement made several years ago which allowed Dr. Noriaki Shibazaki to first visit us at the University of Washington for several months, and then Prof. Fred Lamb and his colleagues at the University of Illinois. Dr. Shibazaki brought with him the Hakucho observations of Vela X-1, allowing us to begin a joint analysis of these data while he was at the University of Washington. In the course of this work, we were lead to discuss and compare our methods and philosophies of pulse timing with those used by the group at Nagoya University, which also examined this same data set. They express a specific interest in seeing the software we developed for our pulse timing studies. Funded by NAGW 805, we were able to visit Japan for a month in the summer of 1985 and continue these discussions.

An important element of this visit was a workshop held September 4-6 at Inuyama (near Nagoya) attended by us and Japanese astrophysicists interested in pulse timing. Each of us gave two talks at this meeting, and the Japanese contributed about ten presentations.

(NASA-CR-181195) [ANALYSIS AND INTERPRETATION OF X-RAY PULSARS] Final Technical Report (Washington Univ.) 3 p
Avail: NTIS HC A02/MF A01 CSCL 03B
N87-27571
Unclas
G3/90 0087896

J.E.D. gave an introductory talk on the uses of the harmonic representation for folded pulses, a fundamental aspect of our approach to pulse timing. This representation is the natural setting for discussion noise in pulse shape which does not have the character of white noise (flat power spectrum), and explaining how noise in pulse shape propagates into uncertainty in pulse phase. Using the harmonic representation, we have also been able to investigate and resolve questions such as the optimum resolution of the pulse shape for the purpose of precise timing. In a second talk, J.E.D. discussed the effect of red noise in pulsar rotation on the precision of parameters (such as the orbital parameters) estimated from pulse timing. This included a description of the method we used to reduce the effect of red noise in rotation on the estimated orbital parameters for Vela X-1.

P.E.B. followed with two presentations. In the first talk, he discussed the sources of noise which affect the precision of pulse timing of X-ray pulsars and of results based on such pulse timing. Not only is there noise in pulse shape arising from the discreteness of photon detection events ("counting statistics"), but there can also be noise both in pulse shape and pulse phase intrinsic to the pulsar. The key point in this distinction is that the "counting statistics" noise in pulse shape can be reduced by increasing the area of the detector and hence the counting rate, while the noise sources intrinsic to the pulse formation process can not be similarly reduced. Thus there seems to be an fundamental constraint to the improvement in pulse timing which can be obtained merely by increasing the area of the X-ray detector, at least for strong sources.

In his second talk, P.E.B. showed that such a conclusion is unnecessarily pessimistic. Using the methods we have developed for dealing with non-white shape noise, it is possible to substantially improve the precision of pulse timing even in the presence of excess noise in pulse shape inherent to the pulse formation process. From an understanding of the statistical aspects of this problem has emerged a relationship between the spectrum of the pulse shape and the spectrum of noise in pulse shape which may be used to predict noise limitations on the observations of a given pulsar. Under certain rather general conditions the filtering technique we have developed will allow indefinite improvement in pulse timing precision with increasing detector area. Thus, pulse timing projects for certain high count-rate pulsars which depend on reducing the counting-statistics noise are feasible with large area detectors, such as Astro-C, XTE, and the 100 m^2 XLA proposal. The problem is to determine which pulsars have favorable properties for noise suppression through filtering.

Three of these talks were subsequently written up as papers, and submitted to the Astronomical Journal for publication. Preprints of these papers wee previously submitted to NASA headquarters.

Another major portion of our effort in 1985 was the introduction of the group at Nagoya University to our approaches of dealing with noise in pulse shape and pulsar rotation. This included a successful installation of part of our software on the computer used by the Department of Astrophysics at Nagoya University.

During our visit in 1985, Profs. Hayakawa and Nagase proposed to two Japanese foundations for grants to sponsor return visits in 1986. We were fortunate to have both grants awarded. The Japanese Society for the Promotion of Science provided a grant for a one month visit by P.E.B., while the Yamada Science Foundation funded a three month stay by J.E.D. This trip was actually extended to over four months (July 15 to November 24), while the visit by P.E.B. covered the period from August 15 to September 24.

The major activity during our 1986 visit was the unification of our earlier, separate analyses of the Vela X-1 data from the Hakucho and Tenma satellites into a single, joint paper (Deeter *et al.* 1987 - see attached copy). In this paper, we show that the method of pulse filtering significantly improves the precision of pulse timing, particularly for the Tenma data. We also report on updated mean orbit for Vela X-1, based on all available pulse-timing studies covering a 10-year interval. In addition, we present the local frequency record for Vela X-1 for the Hakucho and Tenma data, and compute a power density spectrum of fluctuations in the derivative of the pulse frequency on analysis frequencies between 0.5 and 80 days. These results support the phenomenological hypothesis that unresolved fluctuations in the angular acceleration of the neutron star, describable as random noise, are responsible for the entire history of the observed variation in pulse frequency of Vela X-1 on all time scales longer than a few days.

Submitted by:

Paul E. Boynton
Prof. of Physics and Astronomy
Dept. of Astronomy FM-20
University of Washington
Seattle, WA 98195

John E. Deeter
Research Associate
Dept. of Astronomy FM-20
University of Washington
Seattle, WA 98195