passband has been divided into channels of 140 kHz and again there was no post-detection smoothing so that each intensity point has 2 degrees of freedom.

Interstellar scattering of the emission from PSR 1749 - 28 (DM = 50.88 cm$^{-3}$ pc) limits the best time resolution to about 10 μs at 408 MHz. This is because the coherent bandwidth is in effect the width of one scintillation fringe. Nine pulses from PSR 1749 - 28 were analyzed. Since the nine pulses had signal to off-pulse noise ratios near unity little could be done with single pulses. However auto-correlation functions were calculated and averaged over seven of the pulses. The average auto-correlation function of the power spectrum is shown in Figure 3. This shows a number of features. The broad feature extending from 0 to 35 kHz is interpreted as due to the interstellar scintillation. (The seven pulses occurred within 20 seconds and so have a common scintillation pattern with a fringe spacing of about 200 kHz.) The feature extending to about 4 kHz corresponds to a microstructure pattern with a fringe spacing of about 200 kHz.) The feature extending to about 4 kHz corresponds to a microstructure time scale of 250 ± 50 μs. This is because in the AMN model there is a Fourier relationship between the modulating function and structure in the spectrum. Similarly the significant peak at 9 kHz implies a 110 μs periodicity.

I thank Dr P. M. McCulloch and Dr M. I. Large for assistance with the observations and helpful discussions. The project received financial support from the Radio Research Board and I received a Commonwealth Postgraduate Award.


### Comparison of the X-Ray Sources CIR X-1, GX301-2 and 2SO535-668

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#### Introduction

There is reasonably strong evidence to suggest that the periodic X-ray, radio and optical variable Cir X-1 is a highly eccentric orbit (e ~ 0.8), binary system comprising an OB supergiant primary and a compact object, probably a neutron star (Whelan et al. 1977; Haynes, Lerche and Murdin 1980). It is believed that the observed periodic phenomena are caused about the time of periastron passage (every 16.6 days) by a greatly increased rate of mass transfer from primary to secondary at this time. We may regard Cir X-1 as defining a
new class of object whose characteristics including those observed and those inferred from the model of Haynes, Lerche and Murdin (1980) (hereafter referred to as the HLM model) are briefly summarized as follows.

(i) X-ray, optical and radio flux density modulated with a period of a few tens of days;
(ii) high orbital eccentricity;
(iii) system becomes an effective contact binary at periastron when $\phi \sim 0$.
(iv) radio flaring at phase $0 < \phi < 0.15$;
(v) associated with an early type supergiant primary;
(vi) existence of a nearby SNR, possibly associated with the formation of the compact secondary.

Two further objects have now become possible candidates for this class. Kelley et al. (1979) have examined X-ray pulse arrival times from the source GX301-2 (4U1223-62, Wray 977) and have concluded that it has an orbital period of 35 days and a high eccentricity of 0.44. Secondly, Johnston et al. (1980) report that 2S0535-668 (A0538-66) is a recurrent transient X-ray source possessing a probable period of 16±7 between outbursts. The orbital elements of GX301-2 and the temporal behaviour of 2S0535-668 bear considerable similarity to the corresponding properties of Cir X-1.

In order to decide whether these two sources are in fact members of the Cir X-1 class more should be known about them, particularly with regard to periodic phenomena at other then X-ray wavelengths. In this paper we compare all three objects with an emphasis on radio properties. Some of the general characteristics of the sources are given in Table I.

**Table I**

<table>
<thead>
<tr>
<th>Source Comparison</th>
<th>Cir X-1</th>
<th>GX 301-2</th>
<th>2S 0535-668</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (days)</td>
<td>16.59</td>
<td>34.99</td>
<td>16.67</td>
</tr>
<tr>
<td>Distance (kpc)</td>
<td>10</td>
<td>2.3</td>
<td>60</td>
</tr>
<tr>
<td>Peak $L_x$ (erg sec$^{-1}$)</td>
<td>$\sim 10^{38}$</td>
<td>$\sim 10^{39}$</td>
<td>$8 \times 10^{38}$</td>
</tr>
<tr>
<td>Nearby SNR</td>
<td>G 321.9 - 0.3</td>
<td>?</td>
<td>N63A</td>
</tr>
<tr>
<td>Primary spectral type</td>
<td>OB supergiant</td>
<td>B1.5Ia</td>
<td>B</td>
</tr>
<tr>
<td>Primary mass</td>
<td>&gt; 20</td>
<td>&gt; 30</td>
<td>?</td>
</tr>
<tr>
<td>Primary radius ($R_\odot$)</td>
<td>20</td>
<td>45</td>
<td>?</td>
</tr>
<tr>
<td>Periastron separation ($R_\odot$)</td>
<td>20</td>
<td>70</td>
<td>?</td>
</tr>
<tr>
<td>Periastron Roche lobe size ($R_\odot$)</td>
<td>16</td>
<td>55</td>
<td>?</td>
</tr>
<tr>
<td>$S$(quiescent, $\lambda = 2$ cm) / Jy</td>
<td>0.1</td>
<td>&lt;0.04</td>
<td>?</td>
</tr>
<tr>
<td>$S$(flare)/$S$(quiescent), $\lambda = 2$ cm</td>
<td>2-20</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

We have examined, modulus the 35$^\circ$ orbital Period, some 2 cm wavelength radio data obtained at Parkes during a survey of X-ray source positions prior to the determination of the orbital parameters (Duldig et al. 1979). Observations were made with the 64 m telescope during 1977 June 13-18, 1977 August 18-20 and 1978 April 19-28. A 2 cm cryogenically cooled, Dicke switched receiver with a bandwidth of about 500 MHz and a system noise temperature of 90 K was used. The receiver was tuned to 14.7 GHz for the 1977 observations and to 14.4 GHz in 1978.

We made observations in the direction of GX301-2 on six separate occasions and found an extended radio source whose position was in good agreement with a Parkes 6 cm survey source (Haynes et al. 1978) and with one identified with GX301-2 by Seaquist (1977). It is clear however that this source is centred at 4$^\circ$ arc south of Wray 977, the optical counterpart of GX301-2, and cannot be directly associated with the X-ray source. Seaquist (1977) reported flux densities of about 1 Jy at 3.5 and 6 cm wavelength giving a spectrum consistent with that of an HII region. The Parkes 6 cm survey peak flux density is 650 mJy. We have not been able to accurately determine the integrated flux density at 2 cm but our peak flux density of 80 ± 15 mJy may indicate that the spectrum is not as flat as previously thought and that a non-thermal source origin is a possibility. If GX301-2 is similar to Cir X-1 it would not be surprising to find an SNR located nearby (see Table I). Clearly, a more detailed study of this extended source is warranted.

The confusion caused by this source made observations of the actual X-ray position difficult and we cannot claim to have detected any associated point radio source at the position of Wray 977. Our measurements are shown in Table II together with their orbital phases using the solution A ephemeris. The first measurement was made on the peak of the extended source while the remainder were at the X-ray position. However the extended source was still in the beam, resulting in the positive flux densities obtained. The apparent variability is difficult to interpret as we cannot be sure that in all measurements the offset beam was centred on the same point of the
any large increase in the measured flux density near orbital phases $0 < \phi < 0.15$ would almost certainly indicate behaviour similar to Cir X-1. However, Table II shows that only one observation was made in this phase interval. Although this flux density observed is slightly greater than the others measured on the X-ray source position, it is clear that the data are inconclusive and that further observations should be made within the critical phase window, preferably at higher angular resolution in order to reduce confusion. At 2 cm wavelength we place an upper limit of 40 mJy (rms) for any point source resolution in order to reduce confusion. At 2 cm wavelength we place an upper limit of 40 mJy (rms) for any point source coincident with the X-ray position.

2SO535-668:
This recurrent transient source exhibits 16.7 day periodic X-ray flaring which reaches a peak corresponding to a luminosity of $8 \times 10^{36}$ erg s$^{-1}$; assuming that the source is located in the LMC (Johnston et al. 1979). A candidate B type star within the 25" arc radius 90% confidence error box has been demonstrated to be variable, but there are yet insufficient observations to permit any correlation with the X-ray period. The X-ray source is located near the SNR N63A which at 5 GHz has a flux density of 1.15 Jy. (McGee and Newton 1972) A 1.4 GHz Fleurs synthesis observation of this field (Haynes and Turtle — private communication) failed to detect a radio source at the X-ray position, although a $5 \sigma$ source of 42 mJy at R. A. (1950) = 05°35'29.78±0’.26, Dec. (1950) $=-66°53'50''.6\pm3''.2$ was found about 1’ arc away in right ascension from 2SO535-668.

Discussion
In the HLM model for Cir X-1, the radio flaring is caused following the generation of highly relativistic electrons in shock fronts which are produced when Roche lobe overflow causes the mass accretion rate near periastron to exceed the critical value corresponding to the Eddington limiting luminosity. Such effects occur near the periastron passage time (phase 0). Practically all the GX301-2 observations in Table II were at predicted quiescent phases (i.e. $\phi = 0$) and in the absence of reliable flare time observations, we will use the available measurements to set limits to Cir X-1 type behaviour in GX301-2.

The quiescent flux density of Cir X-1 at $\lambda = 2$ cm is $\sim 100$ mJy. If Cir X-1 were not at 10 kpc (Whelan et al. 1977) but were located at the distance of GX301-2, i.e. 2 to 3 kpc (Vidal 1976; Thomas et al. 1979) the quiescent source would appear at a level of 1 to 2 Jy. Our results therefore indicate that at $\lambda = 2$ cm, GX301-2 is intrinsically weaker than Cir X-1 by a factor of at least 25 (assuming a minimum detectable 2 cm flux $\sim 40$ mJy from GX301-2).

It is difficult for us to estimate how the radio flux density depends on orbital eccentricity, periastron separation and mass transfer rate in Cir X-1 type systems. A critical dependence involving a threshold effect at the attainment of the Eddington limit mass accretion rate is certain. Kelley et al. (1979) show that Roche lobe overflow near periastron is a possibility in GX301-2 (see Table I). However, the fact that its peak X-ray luminosity during active states $\sim 10^{37}$ erg s$^{-1}$ is at least an order of magnitude below both that of Cir X-1 and the Eddington limit, may indicate that insufficient mass is accreted to generate the luminosity-driven shocks which are required for radio emission.

The absence of so-far detected radio emission makes GX301-2 dissimilar to Cir X-1, although we cannot discount the possibility that it differs only in the magnitude of emission. We think this unlikely due to the switch or threshold action of the Eddington limit. Nevertheless, further radio monitoring of GX301-2 during possible flare times, i.e. $0 < \phi < 0.15$ and during X-ray active states should be valuable. For example, if its quiescent radio flux density were undetectable at $\sim 5$ mJy and an enhancement by a factor $\sim 10$ occurs during flares (similar to Cir X-1), the flare peak of $\sim 50$ mJy should be easily detectable. Finally, we suggest further studies of the nearby extended sources shown in the Parkes 6 cm survey maps of the GX301-2 region, with a view to ascertaining whether any are SNRs. The presence of an SNR near the X-ray source would strengthen any similarity with Cir X-2.

The same arguments may be applied to 2SO535-668. Assuming a distance of 60 kpc, a system identical to Cir X-1 would possess a quiescent flux density $\sim 3$ mJy at $\lambda = 2$ cm, below the present level of detection. However a 30 mJy flare may be just detectable. The flare X-ray luminosity $\sim 8 \times 10^{38}$ erg s$^{-1}$ is sufficiently high to permit the formation of luminosity-driven shocks and radio flares. Furthermore the

### Table II

<table>
<thead>
<tr>
<th>Epoch JD 2443000 +</th>
<th>Orbital phase*</th>
<th>Flux density ± rms Beam Centre</th>
<th>(1950.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>311.6</td>
<td>0.99</td>
<td>77 ± 15</td>
<td>12 24 00.7 -62 33 45</td>
</tr>
<tr>
<td>312.3</td>
<td>0.01</td>
<td>70 ± 3</td>
<td>12 23 40 -62 29 40</td>
</tr>
<tr>
<td>374.2</td>
<td>0.78</td>
<td>17 ± 9</td>
<td>12 23 40 -62 29 40</td>
</tr>
<tr>
<td>377.1</td>
<td>0.86</td>
<td>58 ± 11</td>
<td>12 23 40 -62 29 40</td>
</tr>
<tr>
<td>377.2</td>
<td>0.86</td>
<td>66 ± 10</td>
<td>12 23 40 -62 29 40</td>
</tr>
<tr>
<td>626.5</td>
<td>0.99</td>
<td>35 ± 6</td>
<td>12 23 40 -62 29 40</td>
</tr>
</tbody>
</table>

* $\phi = 0$ corresponds to periastron.*
Further Studies of the Cosmic Ray Flare of November 22, 1977

A. J. Fenton, K. B. Fenton and J. E. Humble, Physics Department, University of Tasmania

Introduction
The ground level event (GLE) observed on November 22, 1977, is of interest because of the spread of onset times observed by various cosmic ray neutron monitors. Previous reports (Fenton, Fenton and Humble 1978, 1979) have discussed this matter without being able to reach definite conclusions. We have now obtained data from a further seven neutron monitors, and also some from the Imp 8 spacecraft. These data combine to suggest that the event may have been more complex than we initially supposed.

Table I summarises the neutron monitor data which we now have available. The solar flare which has been assumed to be responsible for the event was observed optically at the location 23°N, 40°W. It commenced at 0945 UT, reached maximum at 1007 UT and ended at 1105 UT (Solar Geophysical Data, 1977). GOES satellites observed an X-ray enhancement which had a similar time-profile (loc. cit.).

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The direction of maximum flux
As a result of extensive calculations of the trajectories of charged particles in the geomagnetic field, Shea et al. (1979) have shown that for solar particle GLEs having maximum rigidities of 15 GV the asymptotic directions for vertically incident particles can be used to characterise the effective response of a neutron monitor. This confirms and extends an earlier statement by McCracken (1962), who showed that for low altitude, high latitude, neutron monitors, whose effective cut-off of ~ 1.1 GV is determined by atmospheric absorption, the mean asymptotic direction of viewing for a flare-type spectrum is close to the asymptotic direction of a 1.8 GV particle vertically incident at the station. We have used this simplification in the present analysis.

We showed in our 1979 paper that the percentage increases of intensity observed by five high-latitude neutron monitors near the time of maximum of the event were reasonably linearly related to the angles between the mean directions of viewing of the monitors and the mean direction assumed for the quiet time interplanetary magnetic field. This result suggested that the maximum flux was approaching the earth from a range of directions centred on the ‘garden-hose’ direction.

We have now extended this analysis by assuming a number of different possible directions of maximum intensity, and by incorporating data which have recently become available to us from four additional high latitude neutron monitors. As in the initial analysis we have restricted our attention to neutron monitors having vertical cut-off rigidities ~ 1.1 GV, and located at or near sea level, in order to avoid complications of atmospheric origin. The best linear fit (correlation coefficient r = -0.971) obtained to these data is shown in Figure 1. It corresponds to a direction of maximum intensity (~ 15°, 330°), and is significant at a level better than 0.1%.

The high correlation coefficient does not necessarily imply high precision in the coordinates obtained for the source direction. The sensitivity of the correlation coefficient to variations in assumed source direction is shown in Figure 2, in