A parsec scale X-ray extended structure from the X-ray binary Circcinus X−1

P. Soleri,1★ S. Heinz,2 R. Fender,1,3 R. Wijnands,1 V. Tudose,1,4,5 D. Altamirano,1 P. G. Jonker,6,7 M. van der Klis,1 L. Kuiper,6 C. Kaiser3 and P. Casella1

1Astronomical Institute 'Anton Pannekoek', University of Amsterdam, Kruislaan 403, 1098 SJ Amsterdam, the Netherlands
2Department of Astronomy, University of Wisconsin-Madison, 475 N. Charter St, Madison, WI 53705, USA
3School of Physics and Astronomy, University of Southampton, Hampshire, SO17 1BJ
4Astronomical Institute of the Romanian Academy, Cattalul de Argint 5, RO-040557 Bucharest, Romania
5Research Center for Atomic Physics and Astrophysics, Atomistilor 405, RO-077125 Bucharest, Romania
6SRON, Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA, Utrecht, the Netherlands
7Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

Accepted 2008 October 12. Received 2008 September 22; in original form 2008 May 30

ABSTRACT

We present the results of the analysis of two Chandra observations of Circcinus X−1 performed in 2007, for a total exposure time of ~50 ks. The source was observed with the High Resolution Camera during a long X-ray low-flux state of the source. Cir X−1 is an accreting neutron star binary system that exhibits ultra-relativistic arcsec-scale radio jets and an extended arcmin-scale radio nebula. Furthermore, a recent paper has shown an X-ray excess on arcmin-scale prominent on the side of the receding radio jet. In our images, we clearly detect X-ray structures on both sides of the receding and the approaching radio jet. The X-ray emission is consistent with a synchrotron origin. Our detection is consistent with neutron star binaries being as efficient as black hole binaries in producing X-ray outflows, despite their shallower gravitational potential.

Key words: ISM: jets and outflow – stars: individual: Cir X−1 – X-rays: binaries.

1 INTRODUCTION

Cir X−1 is an exotic X-ray binary discovered by Margon et al. (1971) which shows flares with a period of 16.55 d, observed first in the X-ray band (Kaluzienski et al. 1976) and then in the infrared (Glass 1978, 1994), radio (Haynes et al. 1978) and optical bands (Moneti 1992); this fact is interpreted as enhanced accretion close to the periastron passage of a highly eccentric binary orbit (e ∼ 0.8, Murdin et al. 1980; Nicolson, Glass & Feast 1980). Beyond variability at the 16.55 d orbital period, the source shows dramatic evolution of its X-ray luminosity, spectra and timing properties on time-scales from milliseconds to decades (Shirey, Bradt & Levine 1999; Parkinson et al. 2003). The evidence that the system harbours a neutron star comes from the detection of type I X-ray bursts (Tennant, Fabian & Shafer 1986a,b), confirmed by the recent detection of twin kilohertz quasi-periodic oscillations in the X-ray power density spectra (Boutloukos et al. 2006). Based on the properties of the type I X-ray bursts, Jonker & Nelemans (2004) estimated a distance to the source of 7.8–10.5 kpc; according to a different measurement of the Galactic absorption, Iaria et al. (2005) derived a lower distance of 4.1 kpc (but see Jonker, Nelemans & Bassa 2007).

Cir X−1 is the most radio-loud neutron star X-ray binary (Whelan et al. 1977; Haynes et al. 1978; Cyg X−3 and SS433 are brighter in radio but their nature is unclear) showing extended structures both at arcmin and arcsec scale. The arcmin-scale structure has been extensively studied by Stewart et al. (1993) and Tudose et al. (2006): the source shows two radio jets (south-east and north-west direction) embedded in a large scale, diffuse radio nebula. There is a general agreement that this nebula is the result of the radio lobe inflated by the jets over several hundred-thousand years. Arcmin-scale jets are curved which might be due to an interaction with the interstellar medium (ISM) or a precessing jet. The arcsec-scale structure has been investigated for the first time by Fender et al. (1998) and later studied by Fender et al. (2004), that reported a one-sided highly variable jet (for a detailed study of the arcsec-variability evolution over 10 yr, see Tudose et al. 2008), the most relativistic one detected so far within our Galaxy, with a bulk Lorentz factor ≥10.

The X-ray light curve of Cir X−1 is highly variable and characterized by bright flares and periods of very low X-ray flux (Parkinson et al. 2003). On 2005 June 2, Cir X−1 was observed with the High-Energy Transmission Gratings (HETGS) onboard Chandra for 50 ks during one of its long-term X-ray low-flux states (an example of X-ray light curve with long periods of low flux is reported in Fig. 1). Analysing the HETGS observation, Heinz et al. (2007) found
Figure 1. RXTE/ASM daily-average light curve from 2005 March 31 to 2007 November 29. The vertical dashed lines correspond to two Chandra/HRC-I observations, the vertical dash-dotted line corresponds to the HETGS observation analyzed in Heinz et al. (2007).

Evidence for an arcmin-scale X-ray structure prominent on the side of the receding radio jet. While for black hole candidates extended X-ray jets have already been detected with Chandra and XMM–Newton in a number of sources (e.g. XTE J1550−564, Corbel et al. 2002; 4U 1755−33, Angelini & White 2003; H1743−322, Corbel et al. 2005), this is the first detection of X-ray structures in a secure neutron star system, showing that neutron stars can be as efficient as black holes in producing X-ray outflows.

Here, we present recent Chandra observations of Cir X−1 where we clearly detect an extended X-ray structure both on the side of the approaching and the receding radio jet, confirming and extending the detection of Heinz et al. (2007).

2 OBSERVATION AND DATA ANALYSIS

Cir X−1 was observed with the High Resolution Camera (HRC; Zombeck et al. 1995; Murray et al. 1998) onboard the Chandra X-ray Observatory on 2007 April 21 (43 ks) and 2007 May 16 (7 ks), during an exceptionally long interval of very low X-ray flux that occurred from approximately 2007 February until approximately 2007 August. Fig. 1 shows the X-ray light curve of Cir X−1 taken with the All Sky Monitor (ASM) instrument onboard the Rossi X-ray Timing Explorer (RXTE) satellite for the period 2005 March – 2007 November, where several episodes of low flux can be identified. Two vertical dashed lines correspond to our two HRC-I observations (hereafter observation A and observation B, respectively).

2.1 X-ray jets

Images from observations A and B are reported in Fig. 2. The images have been rebinned and smoothed using a Gaussian kernel of three pixels in radius and contour lines have been applied. A visual inspection of the images clearly reveals the presence of an extended X-ray structure around the source up to ~arcmin scale, visible in the south-east and in the north-west quadrant (i.e. aligned with the south-east–north-west direction), both consistent with the results recently reported by Heinz et al. (2007) and with the alignment of Cir X−1 with the receding radio jet.

Figure 2. (a) Top left-hand panel: HRC-I image of observation A. (b) Top right-hand panel: HRC-I image of observation B. (c) Bottom left-hand panel: image of the merger of observations A and B, adaptively smoothed. (d) Bottom right-hand panel: image of the residuals obtained after fitting the source image (observation A) with a Gaussian function and a constant using the PSF image as the convolution kernel. In all the panels, we marked the source location with a cross.
the arcmin-scale jet observed by Stewart et al. (1993) and Tudose et al. (2006); this issue will be discussed in Section 2.2.

The extended emission is detected both in observations A and B and the two images (note the different exposure in the two observations), at a visual inspection, are consistent: the X-ray emission around the central source, in both of them, elongates along the same axis and furthermore, it presents similar structures in the north-west quadrant and a similar spike-like structure in the northern quadrant (although there are differences specially in the south-east quadrant, due to different sensitivity limits).

Since the two images are consistent, we can merge them to have an image with a higher equivalent exposure, using the standard ciao 4.0 analysis tools (Fruscione et al. 2006). We adaptively smoothed the image obtained from the merging with an average significance of 8.3σ per smoothing length (the minimum smoothing length is 6 pixels, the maximum one corresponds to the image size) and we applied contour levels. The resulting image is plotted in Fig. 2 (panel c), where a diffuse X-ray emission elongated along the south-east–north-west direction is evident, extending up to ∼1 arcmin from the point source. Other structures might look real from an analysis of this image (e.g. a circular excess in the south-west quadrant) but they will not be discussed since an inspection of the residuals obtained after fitting the point spread function (PSF) suggests that they are noise features (see next part of this paragraph).

Fig. 3 shows two profile cuts (for observation A), one extracted on a region aligned with the X-ray excess and one along the perpendicular axis, showing an excess along the south-east–north-west axes and supporting the evidence that there is an X-ray extended structure aligned with a privileged direction.

From Fig. 2 (panels a, b and c) and Fig. 3, the presence of an extended X-ray structure around the central source is evident but to make our detection more robust, an analysis of the PSF is needed. We simulated a monochromatic PSF at 1 keV (from Heinz et al. 2007, we expect the X-ray excess emission to peak at this energy) using CHART (Carter et al. 2003), considering the same number of counts as detected from the source and we projected it in the detector plane using the MARX ray tracing (Wise 1997). Since the PSF wings depend on the position on the detector, for the PSF analysis we used only the observation A: even if the image from the merging has a higher equivalent exposure, the PSF extracted from that image might contain artefacts (the source position on the detector is not the same for observations A and B) that we want to avoid. For the PSF analysis, the SHERPA 3.4 tools (Freeman, Doe & Siemiginowska 2001) have been used.

In Fig. 2 (panel d) we show the image of the residuals obtained after fitting the source image with a Gaussian function and a constant using the PSF image as the convolution kernel. The presence of an extended X-ray structure aligned with the south-east–north-west axes is evident, at a distance from the central source between ∼25 and ∼50 arcsec (the lower limit is inferred by inspecting both the residuals image and the radial profile image in Fig. 3). The X-ray excess on the side of the receding radio-jet (north-west quadrant, hereafter ‘receding X-ray jet’) lies at position angle (PA, measured counterclockwise from due north from the point source) intervals 286°–295° and 307°–324°. A knot appears also at PA ∼10° and its identification will be discussed in the next section. On the side of the approaching radio jet (south-east quadrant), we see one main X-ray blob in a PA interval 88°–152° (elongated along a north-east–south-west direction, hereafter ‘approaching X-ray jet’) at a distance from the point source between 28 and 38 arcsec. Other minor blobs appear in the residuals image: all of them are located in the south-east quadrant and are consistent with being knots of the approaching X-ray jet.

2.2 Comparison with previously detected X-ray extended structure and the radio jet

The radio nebula and the relativistic radio-jets of Cir X−1 have been investigated during multiple epochs of radio observations, both on arcmin and arcsec scale (Stewart et al. 1993; Fender et al. 1998, 2004; Tudose et al. 2006, 2008). From those papers, we estimate the corresponding PAs for the arcmin-scale jets: 303° ± 9° and 310° ± 15° for the jets in Stewart et al. (1993) and Tudose et al. (2006), respectively, and 320° ± 4° for the ultra-relativistic jets in Fender et al. (2004). All these angles are consistent with the PAs of the X-ray jets in our HRC-I observations and fall between the two X-ray filaments detected by Heinz et al. (2007) in the HETGS image.

Fig. 4 shows an overlay of the residuals image [the same as Fig. 2 panel (d), grey-scale], the X-ray contours from Fig. 2 panel (c) and the jet emission from fig. 1 of Heinz et al. (2007). Also shown are the radio contours from fig. 3 of Tudose et al. (2006) and the limits on the PA for the arcsec-scale jet (Fender et al. 2004). The X-ray jets detected in the HRC-I images are broadly consistent with the X-ray excess of Heinz et al. (2007). Besides the X-ray knot that we detected at PA 10°, the consistency between the X-ray and the radio jets is clear on both the sides (approaching and receding): what we see in the HRC-I images appears as the X-ray counterpart of the radio jets from Cir X−1.

3 DISCUSSION AND CONCLUSIONS

The analysis of our two HRC-I observations of Cir X−1 clearly showed X-ray jets both on the side of the receding and the approaching radio jet, consistent with being the X-ray counterpart of the arcmin-scale radio jets (Tudose et al. 2006). Heinz et al. (2007) proposed two possible alternative explanations for the origin of the X-ray excess: synchrotron emission and thermal bremsstrahlung. We now investigate whether these two mechanisms can still explain the X-ray jets as observed by HRC-I.

Synchrotron emission. HRC-I does not have the energy resolution necessary to allow for spectral fitting, instead we calculate the jet.
emission takes place. Considering the jet length to be roughly that we are observing the surface of a conical volume where the energy associated with the source. The morphology of the jet suggests following Longair (1994) and Fender (2006) to estimate the minimum energy associated to both on the receding and the approaching side. Under these assumptions, the minimum jet energy is \( E_{\text{min}} \approx 6 \times 10^{44} \text{ erg} \), again following Longair (1994) and Fender (2006), we can calculate the magnetic field \( B_{\text{min}} \) associated to \( E_{\text{min}} \), the Lorentz factor \( \gamma \) of the energetic electrons emitted by synchrotron and their gyro-radius \( r_g \): \( B_{\text{min}} = 8.2 \mu G, \gamma = 2.3 \times 10^5 \) and \( r_g = 1.6 \times 10^{-2} \text{ pc} \). The energy of these electrons is \( E_e = 1.2 \times 10^{14} \text{ eV} \) and their energy-loss rate is \( R \sim 2300 \text{ eV s}^{-1} \); considering that we have no evidence for reacceleration taking place, the lifetime \( t_{\text{syn}} \) of these electrons is \( t_{\text{syn}} \approx 1600 \text{ yr} \). Following Tudose et al. (2006), we assume that the jets are injected mainly during the flare states (duty cycle \( \sim 6 \text{ per cent} \)): the resulting minimum jet power is \( W_{\text{syn}} \gtrsim 2 \times 10^{35} \text{ erg s}^{-1} \).

**Thermal bremsstrahlung.** In this case, the X-rays would originate from the shock driven into the ISM by the propagation of the jets. Here, we use a model developed for extragalactic jet sources by Castor, McCray & Weaver (1975), Kaiser & Alexander (1997) and Heinz, Reynolds & Begelman (1998). We assume the temperature of the thermal gas to be \( k_B T_{\text{shock}} = 2.2 \text{ keV} \) (\( k_B T_{\text{shock}} = 2.2 \times 10^7 \text{ keV} \) and \( N_H = 5.4 \times 10^{22} \text{ cm}^{-2} \) are obtained by Heinz et al. 2007 fitting the jet spectrum with an absorbed thermal model), the electron density to be \( n_e \approx 10 \text{ cm}^{-3} \) (as used in Heinz et al. 2007; since the temperature \( T_{\text{shock}} = 25.5 \text{ MK} \), we assume an ionization fraction \( x = 1 \): all the hydrogen is ionized) and the length of the shock region (considering both receding and approaching side) \( L_{\text{shock}} \approx 2.2 \text{ pc} \). Such length and the used density give an emitting mass gas of \( 0.02-0.4 M_\odot D_{\text{shock}}^2 / \sin i \): uncertainties are due to different possible measures of the thickness of the shock region. Following Kaiser & Alexander (1997) and balancing the interior pressure exerted by the jets and the ram pressure of the shocked ISM, the jet lifetime is \( t_{\text{th}} = \frac{1}{2} \frac{D_{\text{shock}}}{V_{\text{sys}}} \approx 1700 \text{ yr} \) (\( V_{\text{sys}} \) is the velocity of the shock-compressed particles, obtained from the shock temperature \( k_B T_{\text{shock}} = 2.2 \text{ keV} \)) and the jet power is \( W_{\text{th}} \approx 6 \times 10^{37} \text{ erg s}^{-1} \).

**Discussion.** In the synchrotron case, the jet lifetime \( t_{\text{syn}} \) is smaller than the time expected for the jet to inflate the large-scale radio lobe \((10^4-10^5 \text{ yr}, \text{Tudose et al. 2006})\) and this suggests that the X-ray emission could come from the jet itself rather than from the inflated radio nebula. Furthermore, the gyro-radius of the electrons responsible for the X-rays is smaller than the size of the jet \((r_g < l_{\text{jet}})\) and this implies that those electrons can be confined in the jet region. Our jet power value is consistent with the estimate of Tudose et al. (2006) \((W_{\text{jet},\text{Tudose}} \approx 10^{35} \text{ erg s}^{-1})\), which, however, could be up to two order of magnitude higher) and one order of magnitude smaller than the jet power calculated by Heinz et al. (2007) \((W_{\text{syn},\text{Heinz}} \gtrsim 5 \times 10^{36} \text{ erg s}^{-1})\). The magnetic field associated to the emitting electrons is again consistent with the value reported in Tudose et al. (2006) \((B_{\text{min},\text{Tudose}} = 6.3 \mu G)\) making \( W_{\text{syn}} \) a robust estimate of the jet power, sufficient to inflate the radio nebula. \( W_{\text{syn}} \) is \( \gtrsim 0.1 \% \) of the Eddington luminosity \((L_{\text{eddd}} = 1.8 \times 10^{38} \text{ erg s}^{-1})\) for a 1.4 M\(_\odot\) neutron star: Cir X–1 is only slightly super-Eddington and this would imply a jet-production efficiency \( \eta \gtrsim 0.01 \% \), consistent with what obtained by Heinz et al. 2007 \((\eta \gtrsim 0.5 \% \))

In the thermal bremsstrahlung case, we calculated a jet power \( W_{\text{th}} \approx 6 \times 10^{37} \text{ erg s}^{-1} \), two orders of magnitude larger than \( W_{\text{syn}} \) and possibly not consistent with the values estimated by Heinz et al. (2007) \((W_{\text{th},\text{Heinz}} = 5 \times 10^{36} \text{ erg s}^{-1})\). Furthermore, \( W_{\text{th}} \) is a significant fraction \((\sim 33 \% \)) of the Eddington luminosity \((L_{\text{eddd}} = 1.8 \times 10^{38} \text{ erg s}^{-1})\) for a 1.4 M\(_\odot\) neutron star and this would be an extremely high jet-production efficiency \( \eta \approx 3 \% \), even for an accreting black hole. Taking an Eddington-limit mass accretion rate \( M = 10^{18} \text{ g s}^{-1} \) and even considering that all the accreted mass is ejected in an outflow, the time required to inflate the jets would be \( \approx 2.7 \text{ Myr} \), much bigger than \( t_{\text{th}} \approx 1700 \text{ yr} \), suggesting that the emission cannot come from the jet itself. Therefore, thermal bremsstrahlung appears as an unlikely emission mechanism (especially compared to the synchrotron case) for the X-ray jets.

**Acknowledgments**

The authors thank Harvey Tananbaum for scheduling the DDT observations and Alessandro Patruno and Dave Russell for very useful help. The data analysis was done using the {	t w3pmms} software tool.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image.png}
\caption{Radio-X-ray overlay. Grey-scales: X-ray residuals image (Fig. 2d); green contours: adaptively smoothed image of observations A and B merged (Fig. 2c); red contours: adaptively smoothed, normalized, PSF subtracted image (from Heinz et al. 2007); dark blue contours: 1.4 GHz surface brightness (adapted from Tudose et al. 2006, levels increase by \( \sqrt{2} \) between contours, outermost contour: 11.2 mJy beam\(^{-1}\)) and light blue lines: estimated allowed range of PAs from high-resolution radio observations of approaching radio jet (Fender et al. 2004). The crossing of these two lines identifies the source position.}
\end{figure}

1 http://heasarc.nasa.gov/Tools/w3pmms.html
comments and discussion. PS would also like to thank Nanda Rea, Simone Migliari and the Chandra Help Desk for very useful suggestions on the Chandra data analysis. PS and PGJ also acknowledge support from NWO.

REFERENCES

Angelini L., White N. E., 2003, ApJ, 586, L71
Boutloukos S., van der Klis M., Altamirano D., Klein-Wolt M., Wijnands R., Jonker P. G., Fender R. P., 2006, ApJ, 653, 1435
Carter C., Karovska M., Jerius D., Glotfelty K., Beikman S., 2003, in Payne H. E., Jedrzejewski R. I., Hook R. N., eds, ASP Conf. Ser. Vol. 295, Astronomical Data Analysis Software and Systems XII. Astron. Soc. Pac., San Francisco, p. 477
Castor J., McCray R., Weaver R., 1975, ApJ, 200, L107
Corbel S., Fender R. P., Tzioumis A. K., Tomskick J. A., Orosz J. A., Miller J. M., Wijnands R., Kaaret P., 2002, Sci, 298, 196
Corbel S., Kaaret P., Fender R. P., Tzioumis A. K., Tomskick J. A., Orosz J. A., 2005, ApJ, 632, 504
Fender R., 2006, in Lewin W., van der Klis M., eds, Compact Stellar X-ray Sources. Cambridge Univ. Press, Cambridge, p. 381
Fender R., Spencer R., Tzioumis T., Wu K., van der Klis M., van Paradijs J., Johnston H., 1998, ApJ, 506, L121
Fender R., Wu K., Johnston H., Tzioumis T., Jonker P., Spencer R., van der Klis M., 2004, Nat, 427, 222
Freeman P. E., Doe S., Siemiginowska A., 2001, in Starck J.-L., ed., SPIE Conf. Ser. Vol. 4477, Astronomical Data Analysis. SPIE, Bellingham, p. 76
Fruscione A. et al., 2006, in Silva D. R., ed., SPIE Conf. Ser. Vol. 6270, Observatory Operations: Strategies, Processes and Systems. SPIE, Bellingham, p. 60
Glass I. S., 1978, MNRAS, 183, 335
Glass I. S., 1994, MNRAS, 268, 742
Haynes R. F., Jauncey D. L., Murdin P. G., Goss W. M., Longmore A. J., Simons L. W. J., Milne D. K., Skellern D. J., 1978, MNRAS, 185, 661
Heinz S., Reynolds C. S., Begelman M. C., 1998, ApJ, 501, 126
Heinz S., Schulz N. S., Brandt W. N., Galloway D. K., 2007, ApJ, 663, L93
Iaria R., Spanò M., Di Salvo T., Robba N. R., Burderi L., Fender R., van der Klis M., Frontera F., 2005, ApJ, 619, 503
Jonker P. G., Nelemans G., 2004, MNRAS, 354, 355
Jonker P. G., Nelemans G., Bassa C. G., 2007, MNRAS, 374, 999
Kaiser C. R., Alexander P., 1997, MNRAS, 286, 215
Kaluzienski L. J., Holt S. S., Boldt E. A., Serlemitsos P. J., 1976, ApJ, 208, L71
Longair M. S., 1994, High Energy Astrophysics. Cambridge Univ. Press, Cambridge
Margon B., Lampton M., Bowyer S., Cruddace R., 1971, ApJ, 169, L23
Moneti A., 1992, A&A, 260, L7
Murdin P., Jauncey D. L., Lerche I., Nicolson G. D., Kaluzienski L. J., Holt S. S., Haynes R. F., 1980, A&A, 87, 292
Murray S. S., Chappell J. H., Kenner A. T., Kraft R. P., Meehan G. R., Zombeck M. V., 1998, in Bely P. Y., Breckinridge J., eds, SPIE Conf. Ser. Vol. 3356, Space Telescopes and Instruments V. SPIE, Bellingham, p. 974
Nicolson G. D., Glass I. S., Feast M. W., 1980, MNRAS, 191, 293
Parkinson P. M. S., Tourner D. M., Bloom E. D., Focke W. B., Reilly K. T., Wood K. S., Ray P. S., Wolff M. T., Scargle J. D., 2003, ApJ, 595, 333
Shirey R. E., Bradt H. V., Levine A. M., 1999, ApJ, 517, 472
Stewart R. T., Caswell J. L., Haynes R. F., Nelson G. J., 1993, MNRAS, 261, 593
Tennant A. F., Fabian A. C., Shafer R. A., 1986a, MNRAS, 219, 871
Tennant A. F., Fabian A. C., Shafer R. A., 1986b, MNRAS, 221, 279
Tudose V., Fender R. P., Kaiser C. R., Tzioumis A. K., van der Klis M., Spencer R. E., 2006, MNRAS, 372, 417
Tudose V., Fender R. P., Tzioumis A. K., Spencer R. E., van der Klis M., 2008, MNRAS, 390, 447
Whelan J. A. J. et al., 1977, MNRAS, 181, 259
Wise M., 1997, Chandra News, 5, 22
Zombeck M. V., Chappell J. H., Kenter A. T., Moore R. W., Murray S. S., Fraser G. W., Serio S., 1995, in Siegmund O.-H., Vallerga J. V., eds, SPIE Conf. Ser. Vol. 2518, EUV, X-Ray, and Gamma-Ray Instrumentation for Astronomy VI. SPIE, Bellingham, p. 96

This paper has been typeset from a TeX/LaTeX file prepared by the author.