The changing X-ray period of the Seyfert galaxy IRAS18325–5926

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ABSTRACT
We report on two observations of the Seyfert galaxy IRAS18325-5926 made in 1997 December and 1998 February with the Rossi X-ray Timing Explorer (RXTE). We find evidence for periodicities in the resulting X-ray lightcurves which are shorter than the 58 ks period found from data of the source taken in 1997 March with the imaging satellite ASCA. It is therefore likely that IRAS18325-5926 has a quasi-periodic oscillation (QPO) similar to, but at a much longer period than, the QPO seen in some Galactic Black Hole Candidates. The power spectrum of the February data has several peaks, the second highest of which is consistent with a monotonic decrease in the X-ray period. The period change is then consistent with that expected from two massive black holes spiralling together due to the emission of gravitational radiation. This possibility is very unlikely but mentioned because of its potential importance.

Key words: galaxies: individual: IRAS 18325–5926 – galaxies: Seyfert – X-rays: galaxies

1 INTRODUCTION

We recently discovered a 16 hr X-ray periodicity in the Seyfert galaxy IRAS18325-5926 using data from ASCA (Iwasawa et al 1998). Nearly 9 cycles of the oscillation were observed, with a total amplitude of about 15 per cent. The active nucleus has similar properties to that of Seyfert 1 galaxies, except that the power-law continuum is slightly steeper than most (photon index $\Gamma \sim 2.1$) and there is moderate absorption by a column density of $\sim 10^{22}$ cm$^{-2}$. There is also a broad iron line in the X-ray spectrum (Iwasawa et al 1996) which indicates the presence of an accretion disk in the X-ray emission region, viewed at moderate inclination (40–50 deg). The periodicity is plausible for Keplerian motion at 10–20 gravitational radii around a black hole of mass $2 \times 10^8 - 2 \times 10^7 M_\odot$. It also scales well with quasi-periodic oscillations (QPO) seen from some Galactic Black Hole Candidates (BHC; Belloni et al 1997). The cause of the oscillation in IRAS 18325-5926, or indeed in any BHC, is unknown.

In order to determine whether the variation is exactly periodic or a QPO, we observed IRAS 18325-5926 with the Rossi X-ray Timing Explorer in 1997 December 25–27 and 1998 February 21–23. We report here the light curves and power spectra of those observations, which also show oscillations, but of different periods. We conclude that the AGN has a clear QPO signal and note that our results are consistent with the exciting possibility that 2 black holes are rapidly spiralling together.

2 OBSERVATIONS

RXTE Proportional Counter Array (PCA) light curves were extracted from stretches of data in which the number of Proportional Counter Units (PCUs) on were consistent (e.g. light curves during observations in which only 3 PCUs were on were extracted separately from light curves during times when all 5 PCUs were on). We combined these to produce the final light curve by scaling up to the level of 5 PCUs all those light curves with less than 5 PCUs on. Due to the potential urgency to report our results we have used realtime data for the analysis of the February data; production data are used for the December data.

Good time intervals were selected to exclude any Earth occultations or South Atlantic Anomaly (SAA) passage and to ensure stable pointing. We generated our background data using PCABACKEST v1.5 in order to estimate the internal background caused by interactions between the radiation or particles and the detector or spacecraft at the time.

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of observation. This was done by matching the conditions of observations with those in various model files. The model files that we chose were constructed using the VLE rate (one of the rates in PCA Standard 2 science array data that is defined to be the rate of events which saturate the analog electronics) as the tracer of the particle background.

Fig. 1 shows the background subtracted PCA light curve in the 4–10 keV band for both observations in 1997 December and 1998 February.

3 POWER SPECTRA

In the same manner as for the analysis of the ASCA data, we used the Lomb algorithm (Lomb 1976; Press et al 1992) to determine the power spectra of the RXTE lightcurves (Fig. 2). There is a clear peak in the first power spectrum, at $2.52 \times 10^{-5}$ Hz (11.0 hr) in December 1997 and several peaks in February 1998. The highest of these is at $2.48 \times 10^{-5}$ Hz (11.2 hr), very close to the December peak. The total amplitude of the signal is strong, being about 50 per cent (see Fig. 3 and 4 for folded light curves).

The arguments used in our previous work (Iwasawa et al 1998) for a periodicity in each dataset being a real property
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We note that the power spike around $1.7 \times 10^{-4}$ Hz seen in the spectrum of the February data is at the orbital period of the satellite, and unlikely to be due to the source. We have examined the satellite housekeeping and other available data and can find no explanation for the main peaks in the power spectrum. The power spectrum of a 10 day long RXTE observation of MCG–6-30-15 in August 1997 shows no distinct peaks (it shows much red noise, as expected).

Table 1. Mean flux and period for X-ray observations of IRAS 18325-5926. The Ginga data are reported by Iwasawa et al (1995). The error bars indicate the period change over which the power drops by a factor of two from the peak. 1998a and b refer to the highest and next highest peaks in the February power spectrum, respectively.

| Detector   | Flux (4–10 keV) erg cm$^{-2}$ s$^{-1}$ | Period ks |
|------------|-------------------------------------|-----------|
| Ginga 1989 | $1.5 \times 10^{-11}$               | $> 30$    |
| ASCA 1994  | $5.6 \times 10^{-12}$               | $> 80$    |
| ASCA 1997  | $1.0 \times 10^{-11}$               | $58.0^{+2.6}_{-1.7}$ |
| RXTE 1997  | $2.6 \times 10^{-11}$               | $38.7^{+1.2}_{-1.4}$ |
| RXTE 1998a | $2.1 \times 10^{-11}$               | $40.3^{+1.5}_{-1.7}$ |
| RXTE 1998b | $2.1 \times 10^{-11}$               | $28.2^{+2.0}_{-1.4}$ |

4 DISCUSSION

The X-ray emission from IRAS 18325-5926 oscillates in a manner similar to that seen in BHQ QPO. Such a large clear oscillation from matter around a black hole may suggest that we are detecting the fundamental frequency of some space-filling corona above the disk. This may be possible if the corona has a proton temperature close to the virial value and a lower electron temperature (see e.g. Di Matteo, Blackman & Fabian 1997). Of course this must happen over a very restricted range of radii in order that a single dominant oscillation is seen. Perhaps it corresponds to the radius where the surface emission from the disk peaks (i.e. $\sim 7$ Schwarzschild radii for a non-spinning hole). The variation of period with flux (Fig. 5) is similar to that seen in some QPO.

Otherwise, as mentioned by Iwasawa et al (1998), it could be due to the Bardeen-Petterson effect if the angular momentum vectors of the black hole and accreting matter...
are not aligned. A range of radii are then selected over which the accretion disk tilts over to match the equatorial plane of the black hole. (The disk is not actually precessing in this case; Markovic & Lamb 1998.) Reflection/obscuration by blobs of gas in the tilt zone might then lead to observed flux variations, especially if the inclination is fairly high (as for the binary pulsar). The rate of period change orbital energy loss by the emission of gravitational waves from a priori a lower mass black hole captured by a central black hole is likely initially to have a highly eccentric orbit (Sigurdsson 1997). When the eccentricity $e$ is high, the above estimates for $\dot{P}$ are dramatically increased (Shapiro & Teukolsky 1983), for example by a factor of 100–1000 when $e \sim 0.8 – 0.9$, respectively. This allows $M_2$ to be much lower than estimated above for a circular orbit (it can be as low as about 100 $M_\odot$). The overall temporal behaviour of the system is then more complex ($e$ decreases with time). It may be difficult for a low mass black hole to modulate the observed X-ray emission greatly; this problem is offset by the enhanced probability of such an event occurring.

We stress that this last, exciting, interpretation involving an in-spiralling black hole is unlikely and depends upon the identification of the second highest power peak in the February 1998 data with the orbital period of the second black hole. It does not explain the other peaks in the power spectrum nor why some peaks expected in the lightcurve do not occur. We discuss it here only because of its potential importance of an eccentric orbit. ACF and ACF are grateful to Jean Swank for approving the February TOO observation and to Steinn Sigurdsson for pointing out the potential importance of an eccentric orbit. ACF and D and KI thank Royal Society and PPARC, respectively, for support. JCL thanks the Isaac Newton Trust, the Overseas Research Studentship programme (ORS) and the Cambridge Commonwealth Trust for support. CSR acknowledges support from the NSF under grant AST9529175 and NASA under grant NAG5-6337 and WNB support from NASA grant NAG5-6852.

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Figure 6. The peak period displayed against time in days, measured backwards from the February 1998 observation. Error bars show where the peak power has decreased by about a factor of 2. The line shows the best-fitting relation $P = 6203.(t + 63.5)^{3/8}$ s.

For the February data we plot both the period with the peak power and the longer one which had slightly less power.

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