DISCOVERY OF A NEW X-RAY TRANSIENT IN SCORPIUS

GRO J1655–40 ≡ X-ray Nova Scorpii 1994

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Abstract. A bright transient X-ray source, GRO J1655–40 (X-ray Nova Scorpii 1994) was discovered with BATSE (the Burst and Transient Source Experiment) in late July 1994. More recently, the source also became a strong radio emitter, its rise in the radio being approximately anti-correlated with a decline in the hard X-ray intensity. High-resolution radio observations subsequent to this symposium showed evidence for superluminally expanding jets. Since the hard X-ray emission extends to at least 200 keV and we find no evidence of pulsations, we tentatively classify the source as a black-hole candidate. However, its hard X-ray spectrum is unusually steep (power-law photon index $\alpha \simeq -3$) relative to most other black-hole candidates. In this regard, it resembles GRS 1915+105, the first galactic source to show superluminal radio jets.

1. Introduction

GRO J1655–40 (also designated X-ray Nova Sco 1994) was first detected with BATSE (Zhang *et al.* 1994a) on 27 July 1994 and located initially to within about 0.3° using Earth occultation imaging (Zhang *et al.* 1993). A candidate optical counterpart was found by Bailyn *et al.* (1994) and confirmed spectroscopically by Della Valle (1994). Subsequently, we used additional BATSE data to produce an improved location (Wilson *et al.*

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1994), with a precision of about 0.1°, which agreed well with the optical counterpart.

The radio counterpart to GRO J1655–40 was first detected on 6 August by Campbell-Wilson & Hunstead (1994a) who used the Molonglo Observatory Synthesis Telescope (MOST). From its initial intensity of 370 mJy at 843 MHz, the source continued to flare, reaching more than 5 Jy on 15 August (Campbell-Wilson & Hunstead 1994b). It quickly became apparent that this radio source was unusually bright in comparison with other X-ray transients. The radio spectrum during most of the rise was consistent with optically-thick synchrotron emission (Hjellming 1994a). The early radio observations are described in more detail in an accompanying paper (Hunstead *et al.* 1995).

Subsequent to this symposium, the radio intensity peaked at ~7 Jy around 17–18 August and the spectrum became optically thin (Hunstead *et al.* 1994). The source was the subject of an intensive campaign of interferometric radio observations. The initial observations showed a double source with the components moving apart (Hjellming 1994b). At an estimated distance of ~3.5 kpc (McKay & Kesteven 1994), the apparent separation velocity is superluminal (Reynolds & Jauncey 1994; Hjellming & Rupen 1994a). BATSE observed further X-ray outbursts in September (Paciesas *et al.* 1994) and November (Zhang *et al.* 1994b,c), with associated radio activity (Hjellming & Rupen 1994b,c,d). The hard X-ray, radio and optical behavior of X-ray Nova Sco 1994 is summarized elsewhere (Harmon *et al.* 1995; Hjellming & Rupen 1995; Tingay *et al.* 1995; Bailyn *et al.* 1995).

2. Observations

The early history of GRO J1655–40 was remarkable for its unusually fast rise. Fig. 1 shows the hard X-ray intensity derived from Earth occultation measurements using BATSE. We show data from individual source rises and sets in order to provide the best possible time resolution using this technique. The first clear detection of the source occurs around the end of 27 July and the turn-on occurs in less than 0.5 days, and may be as short as 0.25 days. There is a weak indication of emission for several days prior to the turn-on, but this may be a systematic effect, possibly due to interference from nearby sources such as the variable X-ray pulsar OAO 1657–415.

The occultation geometry for several days around the turn-on of GRO J1655–40 was particularly unfavorable for separation of this source from the OAO pulsar. The latter had been detected in a bright state since mid-June by the BATSE daily epoch-folding search. However, the midpoint of its binary eclipse occurred on 27 July and pulsations were not detected by BATSE on either that day or the following day. Furthermore,

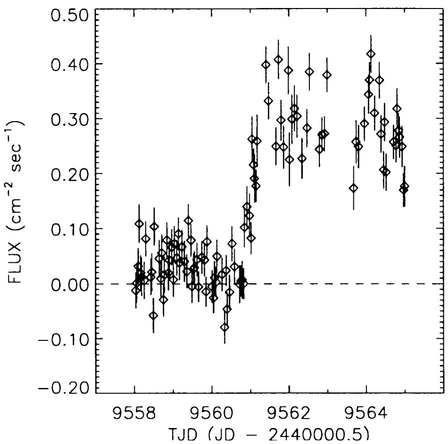

Figure 1. The early intensity history of GRO J1655–40 derived from individual occultation steps. The energy range is 20–430 keV. The rise begins around the end of Truncated Julian Day (TJD) 9560 (27 July) and the turn-on to essentially full intensity occurs in less than 0.5 day.

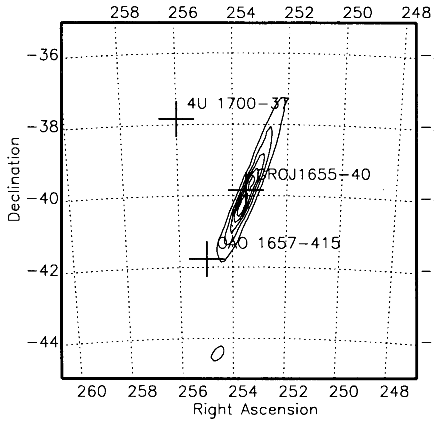

Figure 2. Occultation transform image for 30 July showing the region surrounding GRO J1655–40. The dominant emission is clearly distinct from the nearby X-ray pulsar OAO 1657–415. Due to the unfavorable occultation geometry the contours are severely elongated along the direction of the Earth's limb.

occultation images of the region showed that the new source was clearly distinct from the OAO source. Fig. 2 shows one such image for 30 July. The effect of the unfavorable occultation geometry is evident in the elongated contours. The OAO source is not visible in the image even though it was detected on this day by the BATSE epoch-folding and Fast Fourier Transform (FFT) searches which are more sensitive than the occultation method for detecting pulsed sources.

The lack of any significant unidentified peaks in the FFT search allows us to place an upper limit of $\sim$10% on the pulsed fraction in the 20–100 keV band at maximum intensity, indicating that the new source is likely to be a black-hole candidate. We also generated power spectra of the data during the times when the source was visible to look for excess red noise or flickering. No obvious evidence of flickering was detected; however, a more detailed investigation is in progress (Crary *et al.* 1995).

The intensity history of GRO J1655–40 as of the time of this symposium is shown in Fig. 3. Here we have averaged the data in intervals of up to one day and we have omitted data from days when the interference from OAO 1657–415 was most severe. In contrast to most other such transients, the light curve of this source is erratic, showing no clear trend until the rather fast intensity drop around 13 August. Superimposed on Fig. 3 we also show the radio intensity, which increased spectacularly around the time

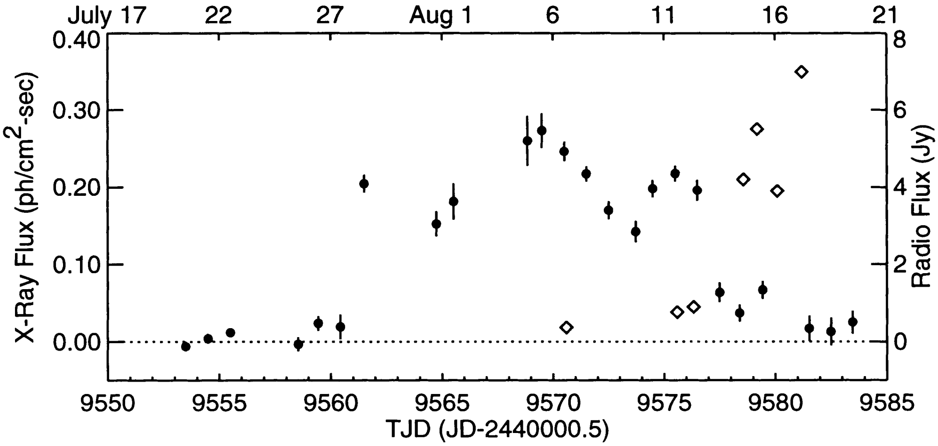

Figure 3. **The intensity history of the entire initial outburst of GRO J1655–40. The energy range is 20–100 keV and the data points (solid circles) are one-day averages. The indicated errors are statistical only. Diamonds show the radio intensity at 843 MHz (Campbell-Wilson & Hunstead 1994a,b; Hunstead *et al.* 1994).**

of the hard X-ray drop.

Preliminary analysis showed that the GRO J1655–40 hard X-ray spectrum was fit adequately with a single power law, with some evidence for hardening with time. We obtained values of the photon index $\alpha = -3.38 \pm 0.07$ ($\chi^2 = 18.1$ for 18 d.o.f.) during 1–4 August and $\alpha = -2.95 \pm 0.06$ ($\chi^2 = 66.8$ for 38 d.o.f.) during 4–8 August. We find no evidence for the high-energy cut-off typically seen in the spectra of black-hole candidates (Sunyaev *et al.* 1991). In fact, nearly contemporaneous observations using the OSSE instrument on CGRO detect emission to at least 600 keV (Kroeger *et al.* 1994) and in comparison with the BATSE results suggest a spectral flattening at higher energies. In the OSSE energy range ($E > 50$ keV), Kroeger *et al.* (1994) measured $\alpha = -2.7$ on 4 August and $\alpha = -2.4$ on 9 August.

3. Discussion

Although it is tempting to classify GRO J1655–40 as a black-hole candidate, it is somewhat unusual among unpulsed hard X-ray transients and classification may be premature. The combination of fast rise time, soft power-law spectrum with no high-energy cut off, lack of flickering, and highly variable light curve is not typical of the black hole candidates observed with BATSE (Paciesas *et al.* 1995). Superluminal radio emission has been observed in only one other galactic source, GRS 1915+105 (Mirabel & Rodriguez 1994) which previously had been recognized as unusual among X-ray transients

(Harmon *et al.* 1994). Except for its slow rise, the latter source strongly resembles GRO J1655–40 in hard X rays. More careful inter-comparison of these two sources may be useful in understanding their nature.

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