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Ariel V Sky Survey: X-ray variability of NGC 5128

A. Lawrence, J. P. Pye and M. Elvis *X-ray Astronomy Group, Department of Physics, University of Leicester, Leicester LE1 7RH*

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Summary. Long-term monitoring of the X-ray source associated with the nucleus of NGC 5128 has produced the most complete light curve in any frequency band for this peculiar active galaxy. The X-ray data indicate activity on at least two timescales: (i) a slow outburst with a timescale of 4–7 yr, (ii) superimposed flares with a timescale of 20–50 day.

This pattern of behaviour is related to other X-ray active galaxies: specifically NGC 4151 (Seyfert) and MKN 421 (BL Lac). Some similarities are noted.

1 Introduction

The nucleus of the active galaxy NGC 5128 (Cen A) has been detected from $\sim 10^9$ to $\sim 10^{26}$ Hz; it is a source of radio, infrared, X- and gamma-radiation (see, e.g. Grindlay 1975, and references therein), but is obscured by dust at visible frequencies. Previous authors have shown the X-ray emission to be variable; in this paper we present the results of long-term monitoring of the X-ray source (3U 1322 − 42, 2A 1322 − 427) in NGC 5128 with the *Ariel V* Sky Survey Instrument (SSI) (Villa *et al.* 1976; Cooke *et al.* 1977) and produce a composite X-ray light curve spanning nine years (1968–77).

Previous observations, summarized by Grindlay *et al.* (1975) and Stark, Davison & Culhane (1976) are shown in Fig. 1 as 2–6 keV luminosities (assuming a distance of 5 Mpc, Burbidge & Burbidge 1959). Even allowing for uncertainties in calibration between different instruments, the published fluxes (converted to this uniform energy range using the spectral and calibration details quoted in each paper) show a clear upward trend by a factor ~ 4 from 1971 to 1973 April (Fig. 1 points 2, 3a, b). A rapid increase by a further factor 1.8 ± 0.2 over six days in 1973 April (Fig. 1 points 3b, c) (Winkler & White 1975), implies a compact source of dimension $\lesssim 1.6 \times 10^{16}$ cm, supporting the implication of the low-energy X-ray spectral cut-off (Tucker *et al.* 1973; Perola & Tarenghi 1973) that the X-ray emission originates in the galactic nucleus. The recent *SAS-3* positioning of the X-ray source to within 15 arcsec of the nucleus (Schnopper & Delvaille 1977) gives further support for this view.

Although there is no strong evidence for changes in the 2–10 keV spectrum with intensity variations (Winkler & White 1975; Grindlay *et al.* 1975; Stark *et al.* 1976), the long-term flux increase (1970–73) appears to be greater at 10–50 keV (Winkler & White 1975).

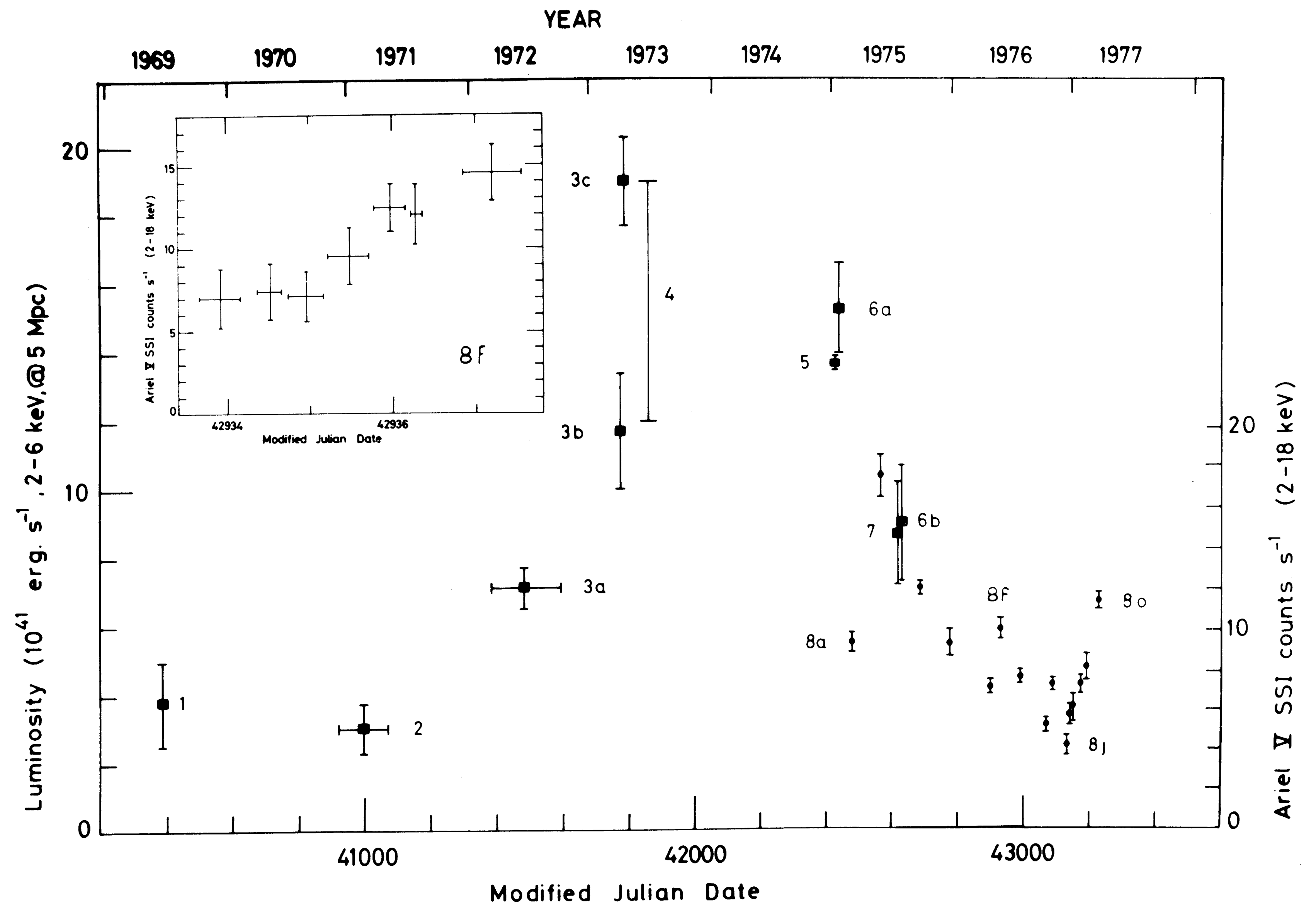

Figure 1. Light-curve of the X-ray source (3U 1322 – 42) associated with the nucleus of the active galaxy NGC 5128. The filled circles (●), numbered 8a–o, denote the *Ariel V* SSI measurements reported here. The other numbered and lettered data points are from previously reported observations, namely (with spacecraft name): (1) Bowyer *et al.* (1970, rocket), (2) Tucker *et al.* (1973, *Uhuru*), (3) Winkler & White (1975, *OSO-7*), (4) Davison *et al.* (1975, *Copernicus*), (5) Stark *et al.* (1976, *Ariel V*, Experiment C), (6) Grindlay *et al.* (1975, *ANS*), (7) Stark *et al.* (1976, *Copernicus*). *Inset, Ariel V* SSI: measured X-ray flux from NGC 5128 during the continuous observation of 1976 June 4–8 (8f), averaged over ≈ 0.5-day intervals. Error bars are ± 1σ.

2 Observations with the SSI

The *Ariel V* SSI measurements from 1975 March to 1977 March are also shown in Fig. 1. Each plotted point is a summation of data over 2–6 day; $\pm 1\sigma$ error bars from counting statistics apply to the SSI count/s scale. Counting rates are related to luminosities by:

Luminosity (erg/s, 2–6 keV) = 0.59×10^{41} (*Ariel V* SSI count/s, 2–18 keV)

derived from the known spectral response of the SSI, the spectrum by Stark *et al.*, and a distance of 5 Mpc to the source.

All sightings at a collimator transmission less than 0.4, with statistical significance $<3\sigma$, or those possibly affected by confusion with nearby sources, are omitted from Fig. 1. Regular observations of well-known 'steady' X-ray sources such as the Coma cluster (see, e.g. Elvis 1976), Cas A and the Crab nebula confirm that the sensitivity of the SSI has remained constant since launch.

From the SSI observations, variability is evident on several timescales:

(i) A downward trend, from $\sim 1 \times 10^{42}$ erg/s in mid-1975 (in good agreement with the nearby *Copernicus* (point no. 7) and *ANS* (point no. 6b) measurements), to $\sim 3 \times 10^{41}$ erg/s in 1976 December – the discovery and *Uhuru* level. with an *e*-folding time ~1 yr.

(ii) Variations on timescales of weeks to a few months, indicated by the scatter of points 8a–8o. Least-squares fits of points 8b–8i to linear and exponential trends yield reduced $\chi^2 = 16$ and 14, and standard deviations 2.2 and 1.8 SSI counts/s, respectively.

(iii) An approximately linear rise from 4.2 ± 0.5 SSI count/s on 1976 December 18 to 11.4 ± 0.4 SSI count/s on 1977 March 26 (points 8j–8o). These data are well fitted by a linear trend with slope 0.07 SSI count/s (day).

(iv) To search for variability on still shorter timescales, the SSI data have been subdivided in intervals of ≈ 0.5 day. For each data set (i.e. each SSI data point in Fig. 1) we have then performed least-squares fits of both a constant intensity and a linear trend. Systematic errors were monitored by simultaneous observations of known constant sources. One observation (point 8f) taken from 1976 June 4 to 8 (i.e. MJD 42933.6 to 42937.6), shown in the higher-resolution plot of Fig. 1 inset, displays an intensity increase similar to that reported by Winkler & White, though slightly faster. Averaging over one-day intervals centred on MJD 42934.06 and 42936.03 gives 'base' and 'peak' fluxes of 6.7 ± 1.2 and 12.1 ± 1.1 SSI count/s respectively, an increase of 1.8 ± 0.4 in about 2 day. Since the flux had decreased to 7.6 ± 0.3 SSI count/s by MJD 42990, it is evident that the whole 'flare' lasted $\gtrsim 2$ day and $\lesssim 56$ day. For the remaining data sets, intensity variations are $\lesssim 58$ per cent (at about the 2σ limit, for timescales of 0.5–6 day). Thus, since only one rapid flux increase is seen in a total of 46 day, we may estimate very roughly that such variations occur at a mean frequency $\lesssim 8$/yr.

3 Interpretation of the light curve

The SSI observations reported here clearly confirm the general fall suggested by Stark *et al.* and show that indeed the flux declined to the pre-1972 state by the end of 1976 December, followed by an increase over the next three months. In addition, we have observed a second example of a rapid intensity increase on a timescale of a few days.

It is clearly of interest to attempt to establish any characteristic timescales of the light curve. The sparse data-sampling limits the justification of any speculation; however, linear interpolation between data points produces an unlikely step shape and the interpolation we put forward is shown in Fig. 2, a 'slow outburst' with superimposed 'flares'. Alternatively

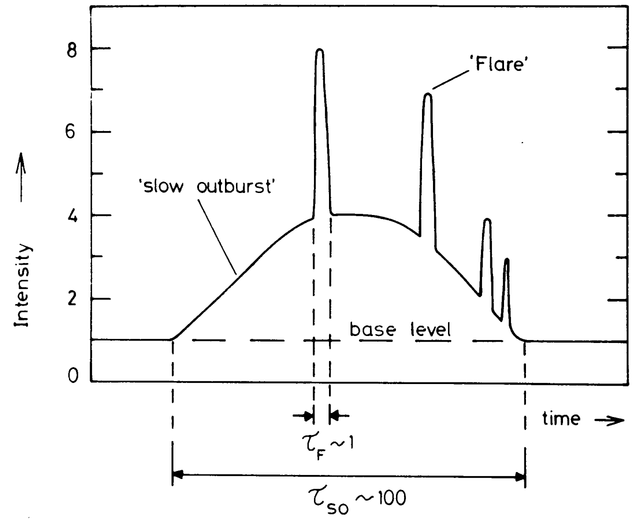

Figure 2. Schematic light-curve for variations of active galaxy X-ray sources. The axes are marked in arbitrary units. The number of 'flares' shown is not intended to be significant.

our light curve may be interpreted as a series of flares superimposed on a constant base level, the apparent envelope being a sampling accident. A quantitative evaluation is difficult, but this seems an unlikely hypothesis.

(a) *Slow outburst.* The light curve exhibits an apparent envelope from point 2 through 8j – a 'slow outburst' of total 'rise and fall' timescale given by $4 < \tau_{SO} < 7$ yr. The *e*-folding decay time is ~1 yr.

(b) *Flaring activity.* Short rise-times of the order 5 day are observed (Winkler & White 1975; this paper, Fig. 1 inset). That activity on such a short timescale is common is evidenced by the scatter of points 8a–j. Unfortunately, no *complete* rise or fall is observed by one experiment. However, an idea of the total timescale involved, τ_F, may be obtained by identifying points 5–6a–8a with such a flare:

(i) point 5 is 2 day long with no significant variability at 29 per cent (3 σ upper limit, Stark *et al.*). Point 6a (Grindlay *et al.*) is consistent up to 11 day after this. If, then, point 5 was preceded by an intensity rise similar to that reported by Winkler & White, or in this paper (Fig. 1 inset), $\tau_F \gtrsim (2+11+6) = 19$ day;

(ii) point 8a is 30 day after point 6a, so $\tau_F \lesssim 50$ day.

Thus 19 day $< \tau_F <$ 50 day if this flare is a typical example. The *e*-folding decay time is $\lesssim$ 40 day.

While flaring activity implied here is of smaller amplitude than earlier examples, the increase relative to 'outburst level' is about the same (~ a factor 2). If real, such a correlation would imply a physical association between the sources of the slow outburst and the flares. More sensitive and frequent observations over the next few years will be needed to determine whether flares occur only during a slow outburst, or are a normal feature of the source's behaviour.

4 Discussion

Five of the six sources which are active galaxies not in clusters, but which are bright enough for variability to be detected with contemporary satellites, display rapid variability. For 3C 390.3 (Charles, Longair & Sanford 1975) and 3C 273 (White, Ricketts & Lloyd, in

Table 1. Summary: variable extragalactic X-ray sources.

Source	Timescale (day) 'Slow outburst' (τ_{SO})	Timescale (day) 'Flare' (τ_F)	Increase over 'normal' flux 'Slow outburst'	Increase over 'normal' flux 'Flare'	Increase over 'normal' flux Total	Total energy (erg) 'Slow outburst'	Total energy (erg) 'Flare'	
NGC 5128	~2000	~20	4	1.6	7	3×10^{50}	1×10^{47}	Radio galaxy
Mkn 421*	~30	1	6	2.5	16	2×10^{51}	3×10^{49}	BL Lac object
NGC 4151†‡	>1400	~10	2	1.7	3.4	$>10^{50}$	5×10^{47}	Seyfert galaxy

* Ricketts *et al.* (1976).
† Elvis (1976).
‡ Ives *et al.* (1976).

preparation), little more can be said than that they vary on a timescale of 1–2 yr. However, for NGC 4151 (Ives, Sanford & Penston 1976; Elvis 1976) and Mkn 421 (Ricketts, Cooke & Pounds 1976), a comparison with NGC 5128 is possible.

The identification of the BL Lac object Mkn 421 with the 'transient' X-ray source 2A 1101 + 384 is strengthened by a new error box from the *Ariel V* High Galactic Latitude Survey (Cooke *et al.* 1977). Its light-curve (Ricketts *et al.* 1976) shows a division into 'slow outburst' and 'flare', with some suggestion of a second flare in the slow-outburst decline. Both τ_{so} and τ_F are ~ 1/100 of their values for NGC 5128. Since an absorption-line redshift from the underlying galaxy is available (Ulrich *et al.* 1975; Wills & Wills 1974), we can give estimates of the total energy in the slow outburst and flare for this and the other two objects (Table 1). The X-ray energy in the one-day flare in Mkn 421 is some 300 times that in the ~10-day flares in NGC 5128 and 4151, suggesting an inverse relation between timescale and energy content.

NGC 4151 has been less well studied but appears to fit the same scheme, doubling its flux in the two years between the *Uhuru* (Giacconi *et al.* 1974) and the *Ariel V* observations (Ives *et al.* 1976), during which it revealed at least one flare (Elvis 1976), on a timescale of a few days. The mean level of the source has not, as yet, been seen to decay to its *Uhuru* value.

Discrimination between radiation mechanisms has proved inconclusive but we note that, for synchrotron emission, identification of our decay time with the electron lifetime, and use of the radio self-absorption data suggested by Grindlay (1975); Perola & Tarenghi (1973) and Mushotzky *et al.* (1976), implies a magnetic energy density much less than the photon energy density, in which situation Compton Losses would dominate. This is not rigorous, because our 'measured' decay times are upper limits. However, we note that no 'rapid fall' has yet been observed.

Finally, we note that if the 'slow outburst' were caused by the tidal disruption and accretion of a star of one solar mass by a massive black hole (*cf.* Fabian *et al.* 1976), then the energy released as 2–10 keV X-rays would require a conversion efficiency of only 10^{-4}. Because the X-ray spectrum is hard and extends at least up to 2 MeV (Haymes 1975; Grindlay 1975), we should increase this estimate by a factor ~ 5. Nevertheless, the mass required to be converted into energy to explain *all the emission* (slow outburst, flares and base level) is still small.

5 Conclusions

Extended X-ray observations of the NGC 5128 nucleus have shown large intensity-variations over widely differing timescales. Observations in a narrow spectral band are sensitive only to a restricted range of the physical conditions in the source and will probably not determine the emission mechanism or origin of the energy; however, it seems likely that X-ray emission arises in the innermost regions of active galaxies close to the (unknown) seat of energy. It is interesting to note that, with the assumption of energy release by accretion of matter on to a massive black hole, the accretion rate and conversion efficiency required are plausibly small.

Some common features of variable X-ray sources in active galaxies have been noted. The best established of these is the existence of at least two characteristic timescales in each such source. This now relies on three examples and seems worthy of further study.

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