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ABSTRACT

The Ariel-V satellite has monitored the X-ray light curve of A1524-62 almost continuously from 40 days prior to maximum light until its disappearance below the effective experimental sensitivity. The source exhibited maximum light on ~ 4 December 1974, at a level of 0.9 the apparent magnitude of the Crab Nebula in the energy band 3-6 keV. Although similar to previously reported transient sources with a decay time constant of ~ 2 months, the source exhibited an extended, variable pre-flare on-state of ~ 1 month at a level of $\gtrsim$ 0.1 maximum light. The four bright (> 0.2 of the Crab Nebula) transient sources observed during the first half-year of Ariel-V operation are indicative of a galactic disk distribution, a luminosity at maximum in excess of 10^{37} ergs-sec^{-1}, a frequency of occurrence which may be as high as 100 year^{-1}, and a median decay time which is < 1 month.

INTRODUCTION

The Ariel-V satellite was launched into a low, near-circular equatorial orbit from the San Marco platform in the Indian Ocean on 15 October 1974. It contains a complement of six separate X-ray astronomy experiments, including an UHURU-type Sky Survey Instrument (SSI) which views in the satellite equatorial plane, and an All-Sky Monitor (ASM) which observes more than 3π steradians of the celestial sphere each orbit. The object of the latter experiment is the continuous measurement of strong sources for anomalous intensity variations, and the detection of new transient sources.

Shortly after launch, a strong new X-ray source appeared in the constellation Triangulum Australis near the highly variable source Cir X-1. It was first reported to be at maximum on 22 November 1974 from the SSI by Pounds (1974), when it was out of the field of view of the ASM. The presently reported observations of the ASM and SSI indicate that the 22 November 1974 maximum was only a precursor to a prolonged transient source which was above the ASM level of detectability ($\sim$ 100 UHURU counts-sec^{-1}) for several months. While its decay phase is quite similar to that of the previously reported transient sources Cen X-2, Cen X-4, and 3U1543-47, it apparently has an extended, variable low phase prior to maximum light which was not observed in these earlier sources.

Because all but one of the pre-Ariel-V transients had decay times $>$ 1 month, such long-lived sources have been considered typical of the phenomenon. New results from Ariel-V, however, indicate that experimental bias may have favored the discovery of such prolonged sources relative to a more numerous population of shorter-lived transients.

II. EXPERIMENTAL RESULTS

The ASM consists of a pair of 1 cm^2 pinhole cameras which utilize one-dimensional position-sensitive proportional counters to image the X-ray sky in spacecraft latitude. The $\sim$ 10 rpm spacecraft rotation carries the camera fan beam response around in longitude, so that the entire sky can be covered (with the exception of dead spots near the spacecraft poles and a dead band at the equator). Data storage restrictions limit the ASM to 512 discrete data words per orbit, so that the sky can be divided into approximately $10^0 \times 10^0$ elements if no differential energy resolution or temporal resolution finer than the ~ 100 minute orbit time is attempted. The energy acceptance window is well-defined, however, with an efficiency of ~ 60% in the band 3-6 keV which is relatively independent of source spectral form. The duty cycle for the observation of any source in the sky with the pinhole camera is ~ 1%. A detailed description of the ASM may be found in Holt (1975).

The SSI consists of a set of proportional counters viewing out from the side of the spinning spacecraft and divided into two pairs, each pair being associated with one arm of the X-shaped field of view. Each arm of the collimator has FWHM angles of 44 arc mins and 10.6 degrees, with a separation between the arms of 50 degrees. The effective area (behind the collimator) of each detector pair is 290 cm^2, with one pair covering the energy range 1.2 - 5.8 keV and the other pair the range 2.4 - 19.8 keV. Limitations in the capacity of the on-board data store require a trade-off between the arc of sky covered and the spectral detail obtained from any one orbit observation. Most of the present results were obtained in the '180^0 sector mode', in which a selected $180^0 \times 20^0$ band of sky in the spin plane of the satellite (the galactic plane in this case) is monitored by both pairs every second orbit, the complementary 180^0 sector being observed in the intervening orbits. A more detailed description of the SSI may be found in Pounds et al. (1975). It is important to note that the complementary fields of view of the SSI and ASM are mutually exclusive, so that they do not simultaneously view the same parts of the sky.

Figure 1 shows the overall 3-6 keV X-ray light curve constructed for A1524-62 via the ASM (points) and SSI (solid curve), the decline phase of which is reminiscent of the earlier transient sources Cen X-4 (Evans et al., 1970) and 2U1543-47 (Matilsky et al., 1972). This phenomenology is characterized by an apparent plateau region lasting about 3 weeks where the source is relatively constant at ~ 80% of the peak intensity, followed by a gradual decay back to the unobservable pre-flare state with an e-folding time of ~ 2 months. A significant feature not observed in the earlier transients is the prolonged and variable low-level activity, including at least one pronounced precursor peak, prior to the onset of the main flare. After its discovery by the SSI, a search of earlier ASM data revealed a possible presence of A1524-62 as early as day 301, if Cir X-1 (with which it may be confused in the ASM) was truly < 50 UHURU counts-sec^{-1} at this time. Observations of the SSI over the period day 314-337 find Cir X-1 at a level of < 10 UHURU counts-sec^{-1} and, in fact, Cir X-1 has not been positively detected by any experiment since the launch of Ariel-V.

In Figure 2 data from the SSI are plotted differentially in time, with the upper trace the ratio of the low to the high energy counting rates, and the lower trace their sum. Clearly, the ratio implies a spectral softening of the source up until the maximum of 22 November 1974, after which the ratio measurements are consistent with spectral stability following this precursor peak. Four channel pulse-height spectra were obtained during days 328 through 330, which were not fittable with an optically thin isothermal source. They were, however, each consistent with the same power-law approximation to the source spectrum $\frac{dN}{dE} = (5.2 \pm 0.8)\ E^{-(2.5 \pm 0.1)} cm^{-2}\ sec^{-1}\ keV^{-1}$, with no measurable absorption by cold interstellar material at a 1σ upper limit of 1.4 keV.

III. DISCUSSION

The existence of an extended early on-state in the evolution of transient X-ray sources would appear to rule out models which are characterized by a lack of substantial X-ray emission prior to a critical instability which flashes the source. Such models include the thermonuclear shell flash mechanism proposed by Van Horn and Hansen (1974), as well as X-ray analogies to the optical nova model of Rose (1968).

Amnuel et al. (1974) have suggested that transient sources are generically similar to the bright, variable X-ray sources in the galaxy, in the sense that the site of X-ray emission is the compact member of a binary system. In contrast to the bright sources, however, the transients may have primaries which are dwarfs of spectral class later than F rather than giants or supergiants. These sources may be expected to appear as weak, relatively constant X-ray emitters prior to outburst, but could still supply a flare lasting several months at $> 10^{37}$ ergs-sec^{-1} with a mass transfer rate of $\sim 10^{15}$ gm-sec^{-1} ($\sim 10^{-11}\ M_{\odot}$ year^{-1}) over $\sim 10^{4}$ years. We note that the difference between a "flare" in a known source as a new "transient" source may be a strong function of detector threshold. Unlike the factor of ~ 3 increase in Cyg X-1 (Gursky et al., 1975; Holt et al., 1975a) or even the order-of-magnitude increase in Aquila X-1 (Buff, J., 1975; Holt et al., 1975b) recently detected, A1524-62 had to increase by more than two orders of magnitude to be reconcilable with its absence from the UHURU catalog.

The spectral data are not inconsistent with a binary system interpretation of the source geometry, as well-established binaries such as Cyg X-1 and Her X-1 are characterized by spectra which are well-fit by power law approximations over this energy range. This does not imply that the production of X-rays is necessarily non-thermal; in fact, such spectra may be synthesized by a thermal gradient in the source in combination with photon transport effects (cf. Davidson, 1974). We suggest that the spectral softening observed prior to the precursor peak may be a manifestation of the lessening of the optical thickness of circumstellar matter, as expected from models (cf. Pringle, 1973) in which transient sources result from a <u>decrease</u> in the mass accretion rate to the compact member, with the source emergence a consequence of the depletion of the optically thick blanket of accreting matter which previously smothered the X-ray output.

Additional information concerning the galactic distribution of the transient sources is emerging from Ariel-V observations. A total of four major transient sources (> 20% of the apparent magnitude of the Crab Nebula) have now been observed from the spacecraft, all within 5° of the galactic plane. Furthermore, no new sources exceeding this flux and lasting longer than a few days have been detected by the ASM outside the plane. Silk (1973) elegantly demonstrated the galactic origin of transient sources, but found the pre-Ariel-V transients to be reconcilable with a halo distribution. The new sources clearly favor a Population I distribution at distances $\gtrsim$ 1 kpc. With apparent magnitudes in X-rays comparable to the Crab Nebula, therefore, their maximum luminosities may be as high as the Eddington-limited $\gtrsim 10^{38}$ ergs-sec^{-1} of the strongest galactic sources.

If the transient sources all have comparable intrinsic luminosities and occur uniformly in the galactic plane, the four sources with luminosity at maximum $> 10^{-8}$ ergs-cm^{-2}-sec^{-1} over the first half-year of Ariel-V operation imply an average peak luminosity $\gtrsim 10^{37}$ ergs-sec^{-1} if there are $\lesssim$ 100 of these sources occurring in the galaxy each year (after Silk, 1973). It is formally possible to constrain the scale height of the transient source disk by demanding that the upper limit to a galactic ridge be consistent with present measurements (cf. Holt et al., 1974), but this approach is meaningful only if many unresolvable sources are "on" at the same time. In this regard, an important difference between the presently reported source and others recently detected by Ariel-V is one of decay timescale. A1118-61 was reported with a decay time of ~ 1 week (Ives, Sanford and Bell-Burnell, 1975), and A0535+26 had a decay time of ~ 19 days (Kaluzienski et al., 1975). Earlier, the other UHURU source positively identified as a transient, 3U1735-28, was found to have a similarly short decay time (Giacconi et al., 1974). It would appear, then, that the "typical" decay time of ~ 2 months for A1524-62 may actually be quite atypical.

The relative paucity of UHURU transients is a clear indication that long-lived sources of the type reported here with absolute luminosities at maximum $\gtrsim 10^{37}$ ergs-sec^{-1} certainly cannot have a frequency of occurrence as large as 10 year^{-1} in the plane without contributing a significant ridge component, or conflicting with the UHURU results (as their detection would require coverage of a large fraction of the plane in a time $\lesssim$ 1 week). The sensitivity of the ASM is not good enough to detect them all (especially in source-confused regions), but over the anticipated ~ 2 year lifetime of Ariel-V we may expect the catalog to grow sufficiently to allow a first determination of the transient source frequency, timescale and luminosity distributions.

REFERENCES

Amnuel, P. R., Guseinov, O. H. and Rakhamimov, Sh. Ju. 1974, Astrophys. Space Sci. 29, 331.

Buff, J. 1975, IAU Circular No. 2788.

Davidson, K. 1973, Nature Phys. Sci. 246, 1.

Evans, W. D., Belian, R. D., and Conner, J. P. 1970, Ap. J. (Letters) 159, L57.

Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Koch, D., and Tananbaum, H. 1974, Ap. J. Suppl. No. 237, 27, 37.

Gursky, H. et al. 1975, IAU Circ. No. 2778.

Holt, S. S. 1975, Proc. Cospar Symp. Fast Transients X- and Gamma-Ray Astronomy, Astrophys. Space Sci. (in press).

Holt, S. S., Boldt, E. A., Kaluzienski, L. J., and Serlemitsos, P. J. 1975, Nature (in press).

Holt, S. S., Boldt, E. A., Serlemitsos, P. J., Murray, S. S., Giacconi, R., Kellogg, E. M., and Matilsky, T. A. 1974, Ap. J. (Letters) 188, L97.

Holt, S. S., Kaluzienski, L. J., Boldt, E. A. and Serlemitsos, P. J. 1975, in preparation.

Ives, J., Sanford, P. W., and Bell-Burnell, S. J. 1975, Nature 245, 578.

Kaluzienski, L. J., Holt, S. S., Boldt, E. A., and Serlemitsos, P. J. 1975, Nature (in press).

Matilsky, T. A., Giacconi, R., Gursky, H., Kellogg, E. M., and Tananbaum, H. D. 1972, Ap. J. (Letters) 174, L53.

Pounds, K. A. 1974, IAU Circ. No. 2729.

Pounds, K. A., Cooke, B. A., Ricketts, M. J., Turner, M. J., Page, C., and Watson, M. 1975, M. N. R. A. S. (in press).

Pringle, J. E. 1973, Nature 243, 90.

Rose, W. K. 1968, Ap. J. 152, 245.

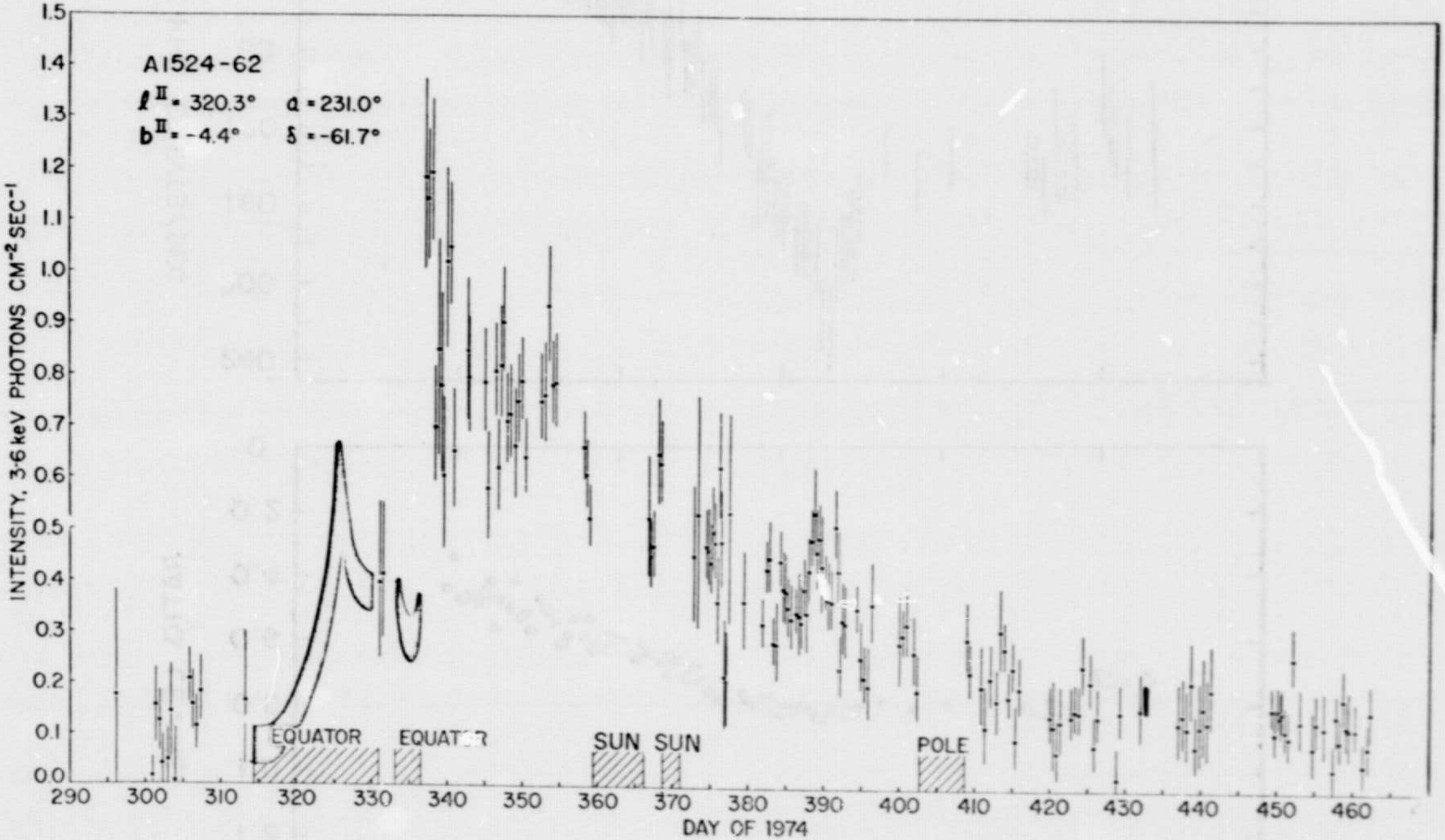
Silk, J. 1973, Ap. J. 181, 747.

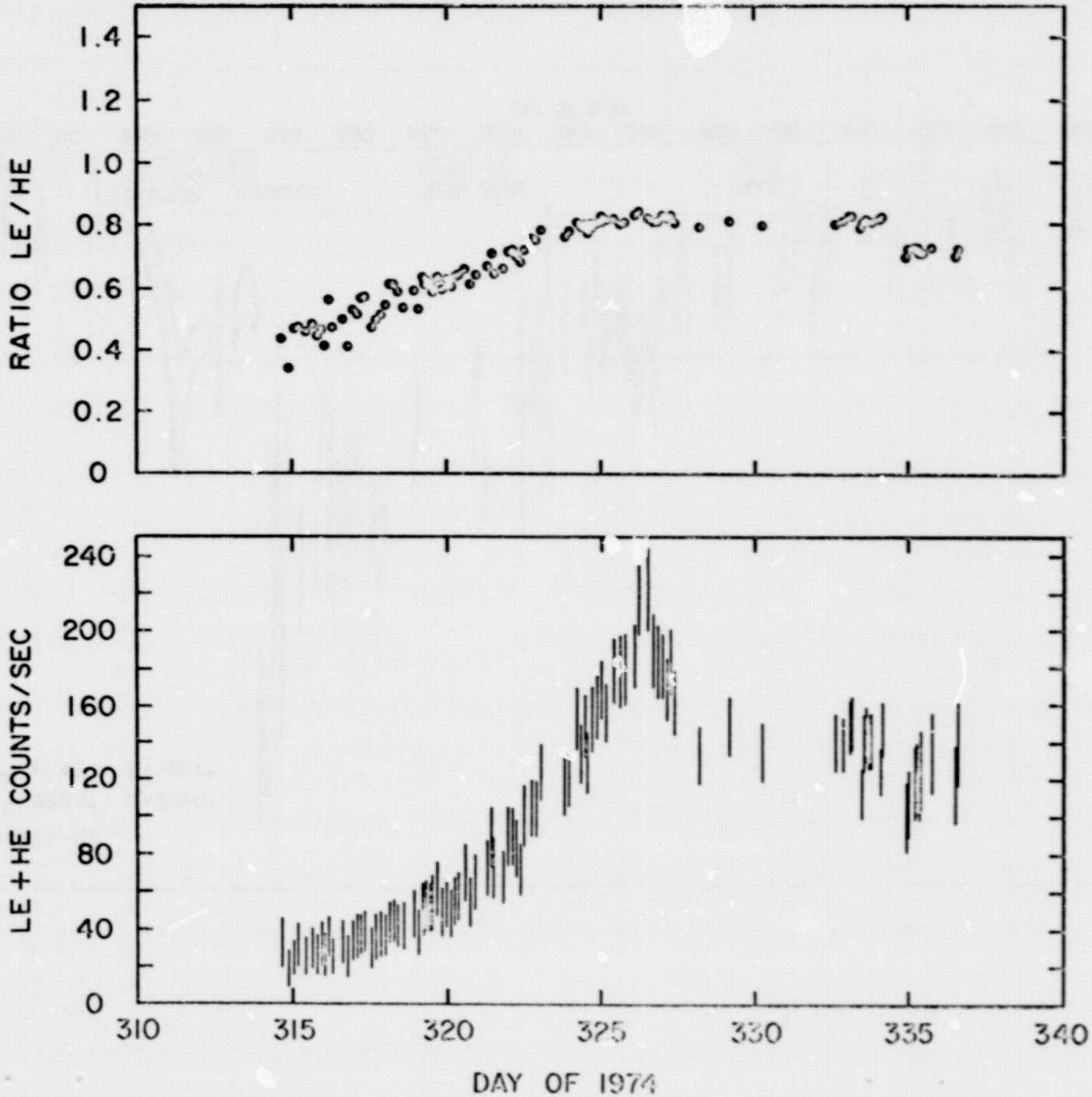
Van Horn, H. M. and Hansen, C. J. 1974, Ap. J. 191, 479.

FIGURE CAPTIONS

1. The 3-6 keV X-ray light curve of A1524-62. The points are data from the ASM accumulated over 3-7 orbits (~ 4.5-10.5 hours). The solid trace is a representation of the SSI data displayed in Figure 2, normalized to the natural ASM ordinate using the response of both experiments to the Crab Nebula (1.4 $cm^{-2}sec^{-1}$ in the 3-6 keV band). The shaded regions indicate where the source is out of the field of view of the ASM. SSI data in addition to those taken over days 314-337 consist of a single measurement on day 433 (displayed in the Figure), and an upper limit of 0.07 $cm^{-2}sec^{-1}$ on day 294 (not displayed).

2. The detailed history of the precursor peak from the SSI. The lower trace is the sum of the 1.2-5.8 keV (LE) and 2.4-19.8 keV (HE) count rates, and the upper trace is their ratio. The Crab Nebula has a total SSI count rate of 510 sec^{-1}.


A1524-62
ℓ^{II} = 320.3° α = 231.0°
b^{II} = -4.4° δ = -61.7°
INTENSITY, 3-6 keV PHOTONS CM^{-2} SEC^{-1}
EQUATOR
EQUATOR
SUN
SUN
POLE
DAY OF 1974



RATIO LE / HE
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
LE + HE COUNTS/SEC
240
200
160
120
80
40
0
310
315
320
325
330
335
340
DAY OF 1974

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