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APOLLO GALACTIC X-RAY ASTRONOMY OBSERVATIONS

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APOLLO GALACTIC X-RAY ASTRONOMY OBSERVATIONS
Preliminary Science Report

by

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CONTENTS

ILLUSTRATIONS

TABLE

APOLLO GALACTIC X-RAY ASTRONOMY OBSERVATIONS
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Introduction

The objectives of the galactic x-ray observations are a detailed study of the temporal behavior of pulsating x-ray sources. About a hundred sources of x-ray emission have been discovered beyond the solar system. They include a large variety of unusual objects such as supernova remnants, energetic external galaxies, quasars and a large number in our galaxy which cannot be associated with any previously known class of objects. Several of these are detectable as emitters of radiowaves or can be seen as faint stars but their emission occurs predominantly at x-ray frequencies. Understanding the nature of these x-ray sources is truly one of astrophysics' prime objectives. NASA's first x-ray astronomy satellite "UHURU" (Explorer 42) has recently discovered fast time variability or pulsations in the output from several sources.[1,2] The fast time variability occurs on a time scale of minutes, seconds, and less implying that the emitting regions are very small in size, much smaller than the Sun although they are emitting about a thousand times more power. Because it is such an unusual phenomenon, the fast time variability may provide the clue that is needed to understand the mechanisms which drive these sources. The objectives of the Apollo observations are to record the emission from several objects continuously for a period of about an hour. Apollo's capability for observing time variations is unique because the spacecraft can be pointed at the source for the entire time. On the other hand, "UHURU" can observe only for about a minute or two per sighting. Consequently, Apollo has the capability for determining whether there exists periodicities in the range 10^1 - 10^3 seconds.

Two powerful x-ray sources observed by Apollo 15, Scorpio X-1 and Cygnus X-1, can also be seen on the earth in other regions of the electromagnetic spectrum. Sco X-1 is detectable in both visible light and radio emission and Cyg X-1 in radio. We know that the visible light and radio emissions are also variable, but we do not yet know how the light or radio variability correlates with the x-ray variability. Particluar models for these x-ray objects make rather specific predictions concerning the relation of x-ray and other variability ranging from no correlation to complete correlation. Consequently, in order to broaden the scope of the investigation arrangements were made for ground based observatories to monitor the visible and radio emission simultaneously with Apollo 15. The Apollo observations were made during Houston daylight hours which is not a favorable situation for observatories in North America. Fortunately, observatories located at more easterly points where it was night were able to acquire Sco X-1 and Cyg X-1 simultaneously with Apollo 15. The optical flux from Sco X-1 was observed by the Crimean Astrophysical Observatory in the U. S. S. R. with a time resolution of 20 seconds and the Wise Observatory in Israel with a time resolution of 4 minutes. Radio emission from Sco X-1 and Cyg X-1 was observed by the Westerbork Observatory in the Netherlands.

The specific objectives of the first phase of the analysis will be to fourier analyze all these data.

Theory

The observation of rapid time variations in several galactic x-ray sources is rather conclusive evidence that they are highly compact objects. Significant variations in intensity in a time of a few seconds or less indicates that the diameter of the x-ray emitting region is comparable to the Earth's or smaller, although it is emitting energy at a rate of a thousand suns. Phenomenologically, the behavior of the pulsating x-ray sources is rather remarkable and not easy to explain. The simplest approach would be to try to associate these sources with strange objects that are previously known. Their small size is consistent with the x-ray source being a white dwarf, neutron star, or the hypothesized black hole. However, there are rather formidable problems in associating the pulsating x-ray source with either of these three objects and in explaining how so much energy can be radiated. The most common of the three are white dwarfs. However, no white dwarf has been observed to either radiate energy so copiously, emit x-rays, or to vary on such a rapid time scale. If the pulsating x-ray sources are white dwarfs they represent a rather unique sub-group. Neutron stars, the super dense core remnant of a supernova explosion would be a posible explanation if it were not for the fact that there is no nebulosity surrounding the x-ray source to suggest that a supernova explosion has taken place. It is possible for the x-ray source to be an old neutron star remnant in which the surrounding nebulosity has dissipated. However, the older known neutron stars do not emit x-rays and their radio emissions show a rather stable well defined period. Black holes are the hypothesized infinitely dense remnant of a supernova explosion of a massive star. It has been suggested that although the intense gravitational field of a black hole does not allow it to emit radiation of its own, the accretion of matter from a nearby neighbor onto the black hole would result in an irregularly varying x-ray source. In fact, according to some viewpoints this is the only way in which a black hole can be detected.

One important objective is determining the mechanism that causes such a small object to radiate energy so copiously. The x-rays presumably come from either the thermalization of high velocity matter accreting onto a small object, or from the dissipation of rotational or vibrational mechanical energy contained in the object itself. We hope that from a study of the time variability this question can be answered. Each mechanism would predict a frequency spectrum.

An explanation based on the dissipation of rotational energy may result in the variability being rather regular. Vibrational energy or matter accretion as the source would predict a different kind of time variability.

It is possible to study the time variability as a function of x-ray energy. The x-ray detectors are sensitive to the range 1 - 3 Kev. The presence of filters over two of the three detectors allows us to subdivide this range into effectively three parts for the analysis.

The bright x-ray source Sco X-1 is an especially interesting candidate for the Apollo studies because it is detectable as a 12th magnitude blue star in visible light, is observable in infrared radiation, and is also a radio source. Thus, the observational power of a broad range of astronomical disciplines can be brought to bear upon a study of this object. An understanding of the mechanisms driving Sco X-1 may provide a basis for understanding many galactic sources. No fast time variability has been detected from Sco X-1. However, Apollo is able to observe Sco X-1 in a new time regime, and look for variability of the order of a few minutes.

Instrumentation

Apollo x-ray astronomy observations utilize the same instrumentation as the x-ray fluorescence studies of the lunar surface chemical composition. A detailed description of the instrument has been given in the section on the surface composition studies.

The field of view of the detectors is limited to an angular acceptance of 30 deg. x 30 deg. (full width at half maximum) by mechanical slat collimators. A cosmic source reaches the counters as a perfectly parallel beam and is seen at maximum intensity when its direction is normal to the plane of the counters. Off axis the intensity is reduced by the cosine effect and shadowing effect of the collimators. When the source's angle exceed 60 deg. off axis no counts are detected. Variation of the angle will cause an apparent variation in the intensity of an otherwise steady source.

The nature of the x-ray emission from two of the Apollo 15 targets, Sco X-1 and Cyg X-1 and most cosmic x-ray sources is such that the unfiltered detector counts much more strongly than the other two. Most of the useful data on cosmic sources will come from that detector although the other two taken with the first provide important information regarding the time variability as a function of energy. The time resolution of the Apollo 15 instrument is eight seconds, the minimum integration time. This allows us to detect periodicities down to about five seconds and random variability of the order of about 10 seconds.

Deployment and Operation of the Instrumentation

The instrument is hard mounted in the SIM bay of the service module. It is used for the galactic x-ray astronomy observations during the trans-Earth coast of the mission by pointing the instrument at a cosmic x-ray source and continuously counting for a sustained period. The spacecraft is required to hold the pointing position accurately to within about a degree for the entire time of observation which is about one hour. The integrated count output of each of the three counters is recorded for successive eight second periods. Signals are divided into eight channels of pulse amplitude. A summary of the observing schedule is given in Table I. Two of the objects, Sco X-1 and Cyg X-1, were observed simultaneously in radiowaves by the Westerbork Observatory (the Netherlands) and Sco X-1 was observed simultaneously in visible light by the Crimean Astropysical Observatory (U. S. S. R) and the Wise Observatory (Israel). The x-ray spectrometer can be operated in either a normal gain mode in which the pulse height or energy channels is concentrated on the region 0.7 - 3 Kev or an attenuate mode in which all energies are doubled. For all but the first pointing position the instrument was in the normal gain mode. The x-ray source observed in the first pointing position is known to be deficient in photons below 3 Kev. Consequently, the instrument was placed in the attenuate mode for that position.

Table I

Apollo 15 X-ray Astronomy Schedule

Source	GET Start	Observation Time	GMT
1 Cen	226:28	1:05	5 Aug 0^{hr} 02^{min}
2 MGL	237:15	0:50	5 Aug 10^{hr} 49^{min}
3 Sco X-1	245:45	0:35	5 Aug 19^{hr} 19^{min}
4 Cyg X-1	246:35	0:55	5 Aug 20^{hr} 09^{min}
5 SGP	261:50	0:55	6 Aug 11^{hr} 24^{min}
6 NGP	274:15	0:30	6 Aug 23^{hr} 49^{min}
7 GPA	275:00	1:00	7 Aug 0^{hr} 34^{min}

The field of view of the instrument is 30° x 30°, or about one steradian of solid angle. This is rather large, so large that if the instrument were pointed directly at Sco X-1 and Cyg X-1 other neighboring sources would be in the field of view at the same time. To avoid these potential confusion difficulties pointing positions were intentionally chosen to be several degrees off the source. As a result these sources were not observed at their full intensity.

There exists a rather strong component of diffuse cosmic x-rays whose origin is still unknown. The flux contained one steradian which is actually greater than that of all but a few discrete sources. One of the outstanding questions of x-ray astronomy is whether this flux is truly isotropic, or whether there is increased emission from relatively nearby clusters of galaxies. If it is isotropic to a high degree the flux originates from sources at very large distances, possibly at the edge of the universe. The diffuse flux should not show any time variability. Several of the pointing positions, Number 2, 5, 6 and 7, did not include discrete sources, only diffuse x-ray background. There were two reasons for which we wished to devote some of the time to observing the diffuse flux: one, to determine the degree of isotropy, and two, to provide a control for our ability to determine time variability. If variability is observed in these positions, it is an indication of extraneous systematic effects in the instrument, the data transmission, or the method of analysis.

Results

Preliminary results have been obtained for Sco X-1 and Cyg X-1 from analysis of the quick look or "thrift data". There are indications of variability in the count rate. However it has been mentioned that the apparent intensity of a source is a function of the angle with which it is viewed. A change in angle of one degree will cause an apparent intensity change of 1.5 per cent. Consequently, spurious variations in the intensity of a source are induced by spacecraft motion. Records of the spacecraft attitude during the pointing positions were not available for this report. Thus, we have no definite notion as to whether observed variability effects are intrinsic to the source.

Figure 1 shows the count rate as a function of time for Sco X-1. Data is not included for several intervals of time because of the appearance of calibration sources. In the final data analysis the contribution of the calibration sources will be subtracted and the missing intervals will be filled in. X-ray data is shown for two intervals of energy 1 - 3 Kev and $>$3 Kev. The former is the sum of all the events in channel 1 - 7 and the latter is channel 8. Qualitatively two features are seen in the data: there is a weak quasi-cyclical variation in intensity for three periods of about five minutes duration and there is a very pronounced increase in the x-ray counting rate at the end of the Apollo observations. Both features appear in both energy intervals. These effects are statistically significant and if they are not due to changes in spacecraft attitude it would be the first indication that Sco X-1 is varying rapidly.

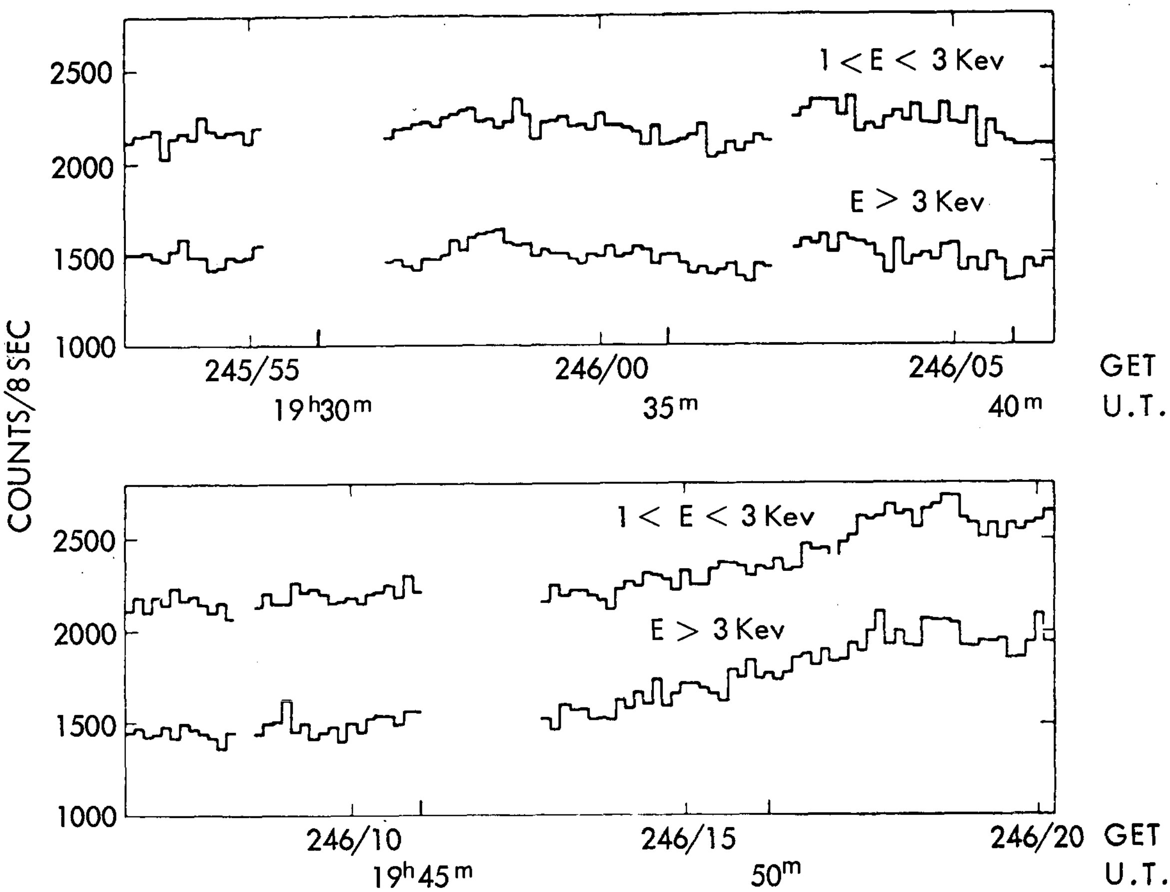

Figure 1. X-ray counting rate of Sco X-1 in two energy bands vs time as observed on Apollo 15. Data has been omitted during periods when a calibration source appears.

Figure 2 shows data from simultaneous optical observations by the Crimean Astrophysical Observatory of the U.S.S.R. Sky background has been subtracted. The statistical precision of these data is about 1 - 2% smaller than the apparent variations in optical density. However, systematic effects that could lead to variations have not been investigated. Ignoring possible corrections for systematic errors a decrease in optical intensity is seen at the same time that the x-ray intensity increases.

Several minutes of data from Cyg X-1 is shown in Figure 3. The large peak is the appearance of a calibration source. The 8 second time resolution of the instrument is not sufficient to bring out the very rapid time variations that are described in reference 1. However a statistically significant rise and fall in intensity occurs starting at about GET 246/57 and ending at about 247/03. In this case too, it is not known if spacecraft motion is a factor.

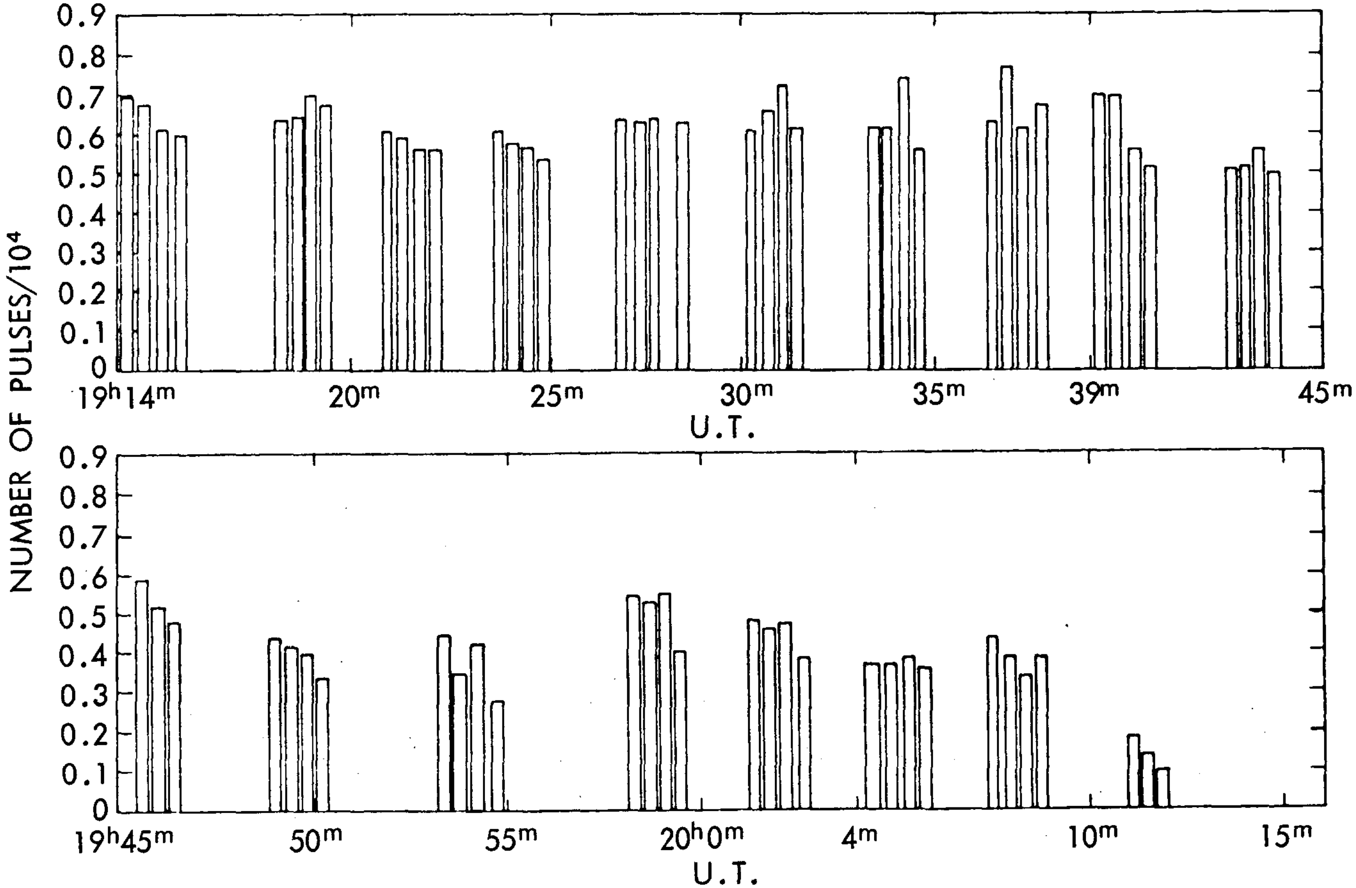

Figure 2. Optical flux of Sco X-1 at the time of the Apollo 15 x-ray observation. The sky background has been subtracted. These data were obtained by the Crimean Astrophysical Observatory, U.S.S.R.

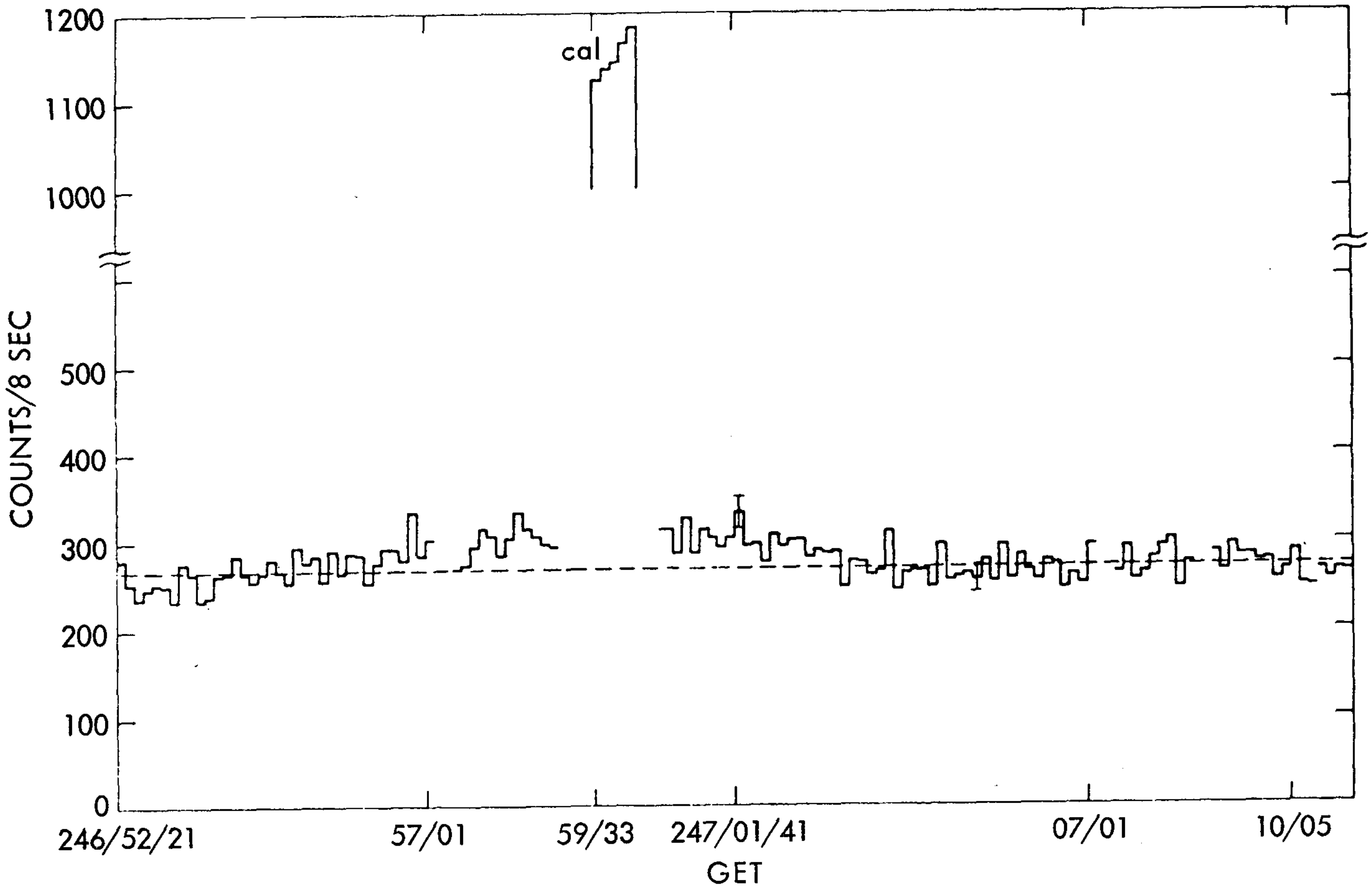

Figure 3. X-ray flux of Cyg X-1 during thirteen minutes of one hour observation by Apollo 15. A dashed horizontal line representing a constant intensity is shown for reference. The large peak is the effect of a calibration source.

Discussion and Conclusions

Apollo 15 successfully pointed at three pulsating x-ray sources and four locations dominated by the diffuse x-ray flux. During the observation period the count rate from Sco X-1 and Cyg X-1 did show statistically significant changes of about 10% in intensity in a time of several minutes. However, possible changes in spacecraft attitude might account for the variations. Simultaneous optical observations of Sco X-1 by the Crimean Astrophysical Observatory tentatively indicates an anticorrelation between changes in x-ray and optical intensities during the final few minutes of the Apollo observations. If the increase in flux of Sco X-1 observed by Apollo 15 turns out not to be a result of changes in spacecraft attitude it will be the most rapid change in the x-ray intensity of Sco X-1 yet seen.

Final analysis of the Apollo data will necessarily involve a comparison with "UHURU" results which cover different time regimes. UHURU has superior fast time resolution than Apollo, 0.1 second as compared to 8 seconds. It being an orbiting satellite allows it to observe over a period of several days although only for several tens of seconds at a time. Apollo's ability to monitor variations continuously for about an hour will fill an important gap in our observation of the pulsating sources.

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2. R. Giacconi, H. Gursky, E. Kellogg, E. Schreier and H. Tananbaum 1971, Ap. J. (Letters) 167, L67.