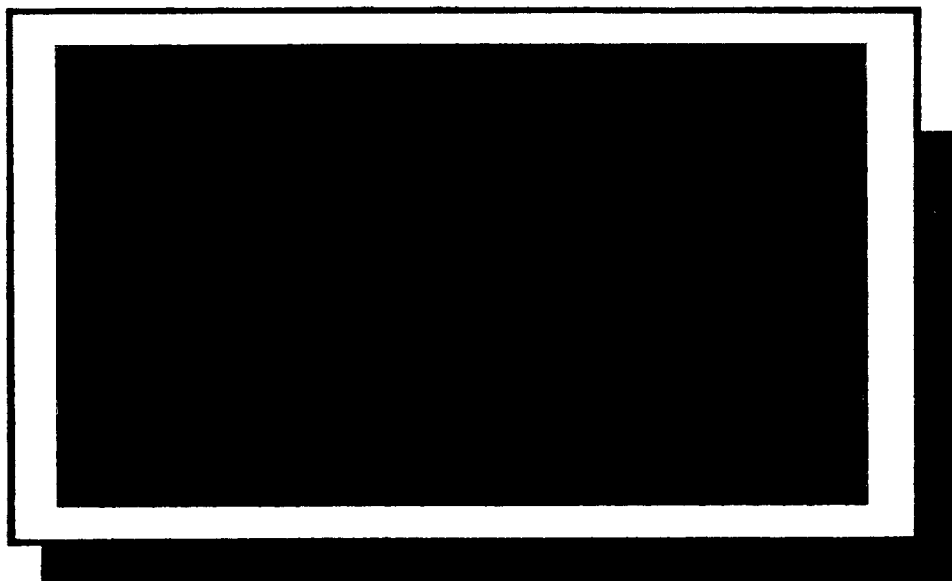


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A Limit on the Angular Size  
of Cyg XR-1<sup>†</sup>

by

Franklin W. Floyd

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<sup>†</sup> This work was supported in part by NASA grant NGL 22-009-015

# A Limit on the Angular Size of Cyg XR-1<sup>†</sup>

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Both nebular and stellar objects have been identified as discrete sources of cosmic x-rays. Representative of the first is the Crab Nebula, the size of which has been measured to be 1 to 2 arc minutes in the energy range 1-6 keV according to observations during a lunar occultation<sup>(1)</sup> and with a modulation collimator<sup>(2)</sup>. This size is comparable to the optical size of the nebula. Representative of stellar sources is Sco X-1, the x-ray size of which has been shown to be less than 20 arc seconds by a measurement with a modulation collimator, also in the energy range 1-6 keV<sup>(2)</sup>. The optical counter part of Sco X-1 is an irregularly variable blue star<sup>(3)</sup>. No other discrete x-ray source has been observed with equipment capable of measuring sizes less than 10 arc minutes. However the tentative identifications of Cas XR-1 with the supernova remnant, Cas A<sup>(4)</sup>, and of several other x-ray sources with blue stars (Cyg X-2<sup>(5)</sup>, Cen XR-2<sup>(6)</sup>) obviously suggest that these particular sources can be assigned to the nebular and the stellar classes, respectively.

The bright x-ray source Cyg XR-1 presents a specially interesting problem for size measurement because it has a

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hard "power-law" x-ray spectrum extending to 100 keV and beyond<sup>(7)</sup> like the Crab Nebula, and is apparently highly variable<sup>(8)</sup> like Sco X-1. Moreover, no optical counterpart of Cyg XR-1 has been identified. Thus a direct measurement of its x-ray size may be the only way to determine whether it is a variable x-ray nebula or a stellar object emitting x-rays with a power law spectrum extending beyond 100 keV.

The purpose of this note is to report an observation that places an upper limit of 1.4 minutes of arc on the angular diameter of the x-ray source Cyg XR-1 in the energy range from 25 to 100 keV. This result is based on data obtained in a balloon experiment carried out on 16 July 1968 with an instrument comprising a pair of x-ray telescopes with gyro-stabilized modulation collimators.

The collimators are similar to the one used by Oda et al.<sup>(2)</sup> in a rocket measurement of the angular diameter of the Crab Nebula in the 1-6 keV range. Each collimator consists of two parallel grids of 10 mil gold wires mounted 35 inches apart in a cylindrical tube. When an x-ray source passes across the field of view along an arc perpendicular to the wires, the transmitted intensity is modulated with a period of 2.0 arc minutes and an amplitude that depends on the angular diameter of the source. For a point source the modulation is nearly one hundred per cent, and for a source much larger than 2 arc minutes it is nearly zero. A slow and steady source scan is achieved by an inertial stabilization system. Two rate integrating gyroscopes are

used to stabilize the collimators against random motions of the balloon gondola while rotating them at a uniform rate of several arc minutes per minute.

The x-rays transmitted by the collimators are detected by two Na I (Tl) crystal scintillator detectors which are mounted behind the collimators. The total effective area of the instrument in the direction of a transmission maximum is  $280 \text{ cm}^2$ . Its overall field of view is  $10^\circ$  by  $10^\circ$ , full width at half maximum. The instrument is oriented in azimuth and elevation and is controlled by radio command from the ground. The x-ray counting rate in each detector is telemetered to the ground once per second and recorded.

The instrument was launched from the National Center for Atmospheric Research (NCAR) balloon base at Palestine, Texas. Command and telemetry systems were provided by NCAR. The data gathering portion of the flight lasted for 5 hours, 30 minutes at an atmospheric depth of  $3.74 \text{ cm/cm}^2$ . A source was observed when the telescope was pointed in the direction given by Giacconi et al. <sup>(9)</sup> for Cyg XR-1. The intensity of Cyg XR-1 at the altitude of observation was found to be  $.056 \pm .007 \text{ photons cm}^{-2} \text{ sec}^{-1}$  in the 25 to 100 keV energy range. Because the command equipment malfunctioned during most of the flight, only one good scan, of 8 minutes duration, was made of Cyg XR-1 by the collimators. A Fourier transformation of the data recorded during this scan revealed

a strong periodicity in the x-ray intensity at a frequency consistent with the scan rate, which was determined independently from telemetered engineering data. The probability that random fluctuations were responsible for the periodicity is  $10^{-3}$ ; equivalent to a 3.45 sigma deviation on the normal distribution curve. Possible instrumental effects which could cause an apparent modulation of x-ray intensity were investigated and found to be negligible. The same analysis was applied to data taken during the remaining 5 hours, 24 minutes of the flight when the instrument could be pointed toward and away from the source, but the collimators could not be stabilized. No evidence of significant periodicity was found in these other data. The Fourier coefficients computed from these other data followed the predicted probability law very closely which indicates that the statistical analysis is valid and that the probability quoted above is realistic. The observed periodicity is therefore attributed to a modulation of the Cyg XR-1 intensity by the collimators.

The amplitude of the periodic component indicates that the source diameter is less than 1.4 arc minutes. The result is actually consistent with the hypothesis that Cyg XR-1 is a point source, but the limited observing time and relatively poor statistics introduce too much uncertainty to justify setting a smaller limit than 1.4 arc minute at this time.

Given sufficient observing time, this instrument is capable of measuring diameters of high energy x-ray sources down to 0.1 arc minutes. Flights are planned for both Cyg XR-1 and the Crab Nebula.

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