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FINAL REPORT

THE X-RAY HALO OF CEN X-3

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INTRODUCTION

As a result of the scattering of x-rays by interstellar dust grains, x-ray halos are expected theoretically, and are known observationally to be a feature endemic to Galactic x-ray sources. Candidates for sources affected by dust grain scattering include highly-reddened time-variable compact Galactic x-ray sources whose flux variations and flux distributions are affected by the presence of x-rays which travel indirectly from the source to the observer, and so are delayed in time with respect to direct rays. One important subset of such time-variable sources are the eclipsing compact x-ray binaries. In such sources, the unscattered x-rays are extinguished completely during eclipse, leaving behind only the time-delayed xrays scattered by interstellar grains. Because the characteristic time delay for scattered x-rays is so long, the x-ray halo of an eclipsing binary can persist throughout the eclipse. Observations of such sources are thus free of the uncertainties introduced by the point response function of the telescope due to the otherwise superposed intense point source of unscattered x-rays. By analyzing the time-dependence of the shape of the x-ray halo during the eclipse, it may be possible to determine the distance to the x-ray source as well as to determine the distribution of grains along the line of sight.

Cen X-3 is an eclipsing high mass x-ray binary well suited for such a study. It has an orbital period of 2.087 days, a distance of about 8 kpc and an eclipse duration of approximately 12 hours. These characteristics are expected to provide measurable changes in images of its x-ray halo during eclipse. Fig.1 shows the expected decrease in the halo core during the 12 hour eclipse of Cen X-3. It indicates that one should see the central part of the halo almost completely vanish out to a radius of 10 arc sec in the ROSAT x-ray image. We have observed Cen X-3 at intervals for a period of time beginning near the center of the x-ray eclipse and ending 17.3 hours later. For approximately 6.5 hours in the first part of the observation the source was eclipsed and in the remaining 10.8 hours it was egressing or uneclipsed. The observing times and counting rates for these observations are shown in Fig. 2. The counting rate is near background rates for the first 5 observing periods, a egress begins in the 6th and the source is uneclipsed in the final 12 observing periods. However, it is obvious that there is considerable modulation of the Cen X-3 counting rate after egress from eclipse. This report summarizes the results of reduction and analysis of these data during the 35 hours of effort funded by the present contract.

RESULTS

Much of the present effort was expended learning use of the iraf/pros software used in the reduction and display of the data. Fig. 3 shows the central 1 degree diameter of the x-ray image obtained during the eclipsed portion of the observation and Fig. 4 shows that obtained for the source after egress. In Fig. 4 the central part of the image appears saturated in order to show the counts in the entire 1 degree field selected. Figs. 5 and 6 are these images magnified by 4 to show the central part of the images:now the uneclipsed image appears unsaturated. The data have been binned in 7.5 arc sec pixels. The regions of the image used in analyses described below are contained within the the areas shown in Figs. 5 and 6.

The background subtracted surface brightness of the two images is shown in Fig. 7, Here, the counts have been summed in annuli of constant 37.5 arc sec width and of increasing radii from source center out to 450 arc sec. These summed counts are then divided by the number of pixels in each annulus to obtain the surface brightness. The eclipsed data were multiplied by a factor of 2.6 to account for the difference is observing time. Background was determined in the region from 450 to 750 arc sec in radius, concentric with the Cen X-3 image. Errors from counting statistics are indicated in Fig. 7 and are smaller than the plotting symbols, in most cases. If Cen X-3 is completely eclipsed, the data indicated by the diamonds will be only x-rays scattered by interstellar dust grains. Scattering from the ROSAT mirrors is less than 1 part in 10^4 outside a radius of 100 arc sec at 1 keV. Thus, the two data sets in Fig. 7 should agree beyond 100 arc sec. However, there is disagreement by an average factor of 1.9 for all of these data points. Time delays due to the increased pathlength of scattered rays range from approximately 10^4 to 10^6 sec for angles between 100 and 450 arc sec. Thus, the short term variability exhibited in the uneclipsed observations can not account for the differemces in Fig. 7. The factor of 1.9 discrepancy is not understood, at this time.

The first observation of Fig. 2 occurred about 5.5 hours after the begining of eclipse and the fifth observation took place 11 hours after eclipse. By reference to Fig. 1, we should have observed the void at image center move from 5 arc sec to 10 arc sec and the intensity at 20 arc sec drop by about a factor of 2. The surface brightness, near image center, is shown for these observations in Fig. 8. The expected diminution in the center of the images is not observed. It is likely that this is due to x-rays that are scattered by material local to Cen X-3, perhaps in the accretion disc or in the stellar wind from the companion star. Thus, the source is not completly extinguished in eclipse and a weak central image persists to fill in the center of the distributions in Fig. 8.

Figs. 9 and 10 show images of the two observations plotted in Fig. 8. The number of counts in each 7.5 arc sec pixel is indicated in the image cores along with an x to show where centroid of the uneclipsed image is located. Because of the small number of counts involved, no significant difference is evident.

It is difficult to determine the fraction of x-rays detected in the halo compared to those in the unscattered image.This is because of the uneclipsed source variability indicated in Fig. 2 and because the halo averages such variability over a period of several weeks in a complex way. However, if one sums the counts in the central 450 arc sec of observations 1-5 and 7-18, subtracts background, corrects for the halo counts in images 7-18 and accounts for the difference in observing time one obtains 11.5 % as the halo fraction.

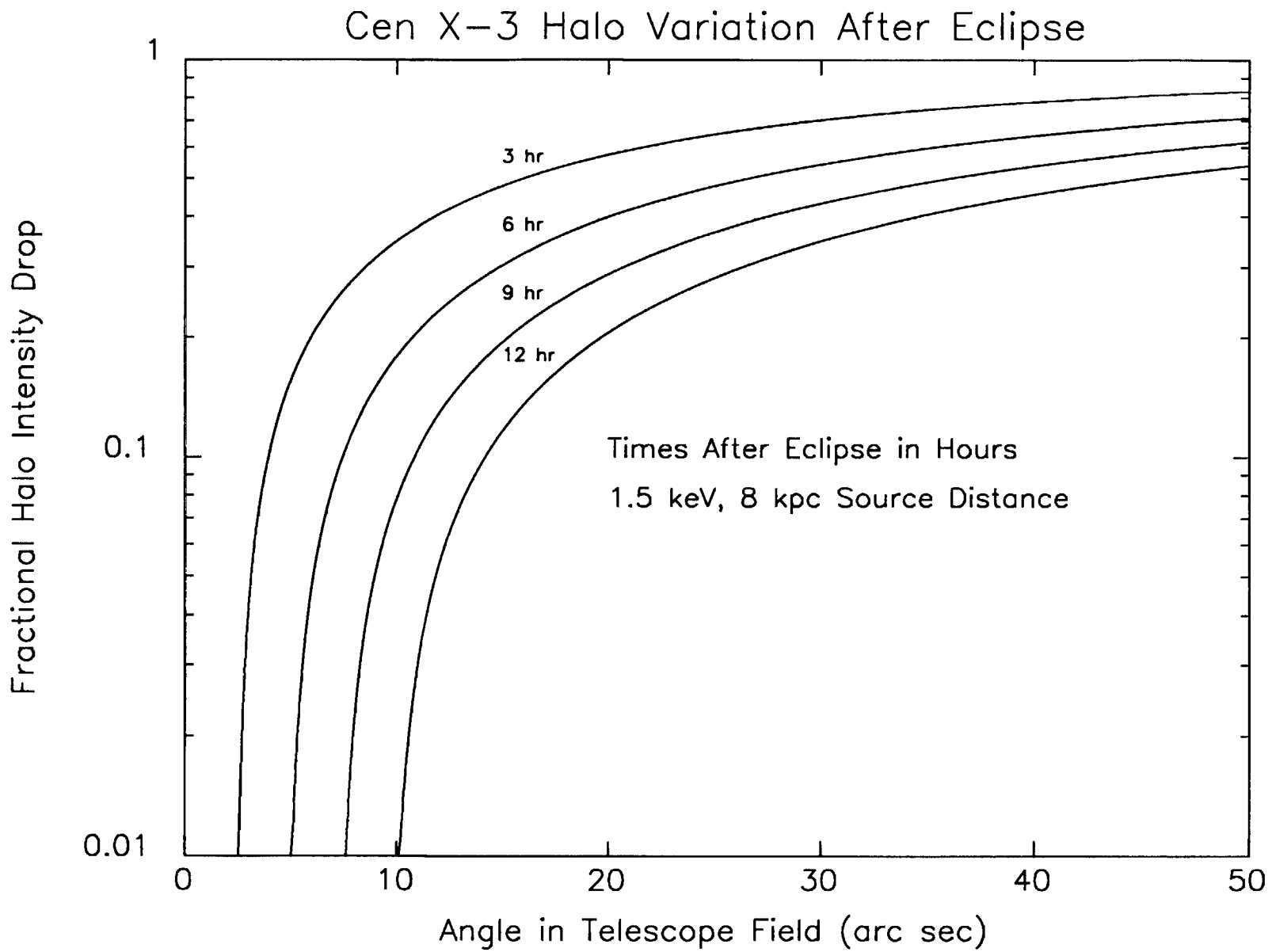

Cen X−3 Halo Variation After Eclipse
Fractional Halo Intensity Drop
1
0.1
0.01
3 hr
6 hr
9 hr
12 hr
Times After Eclipse in Hours
1.5 keV, 8 kpc Source Distance
0
10
20
30
40
50
Angle in Telescope Field (arc sec)

Fig. 1

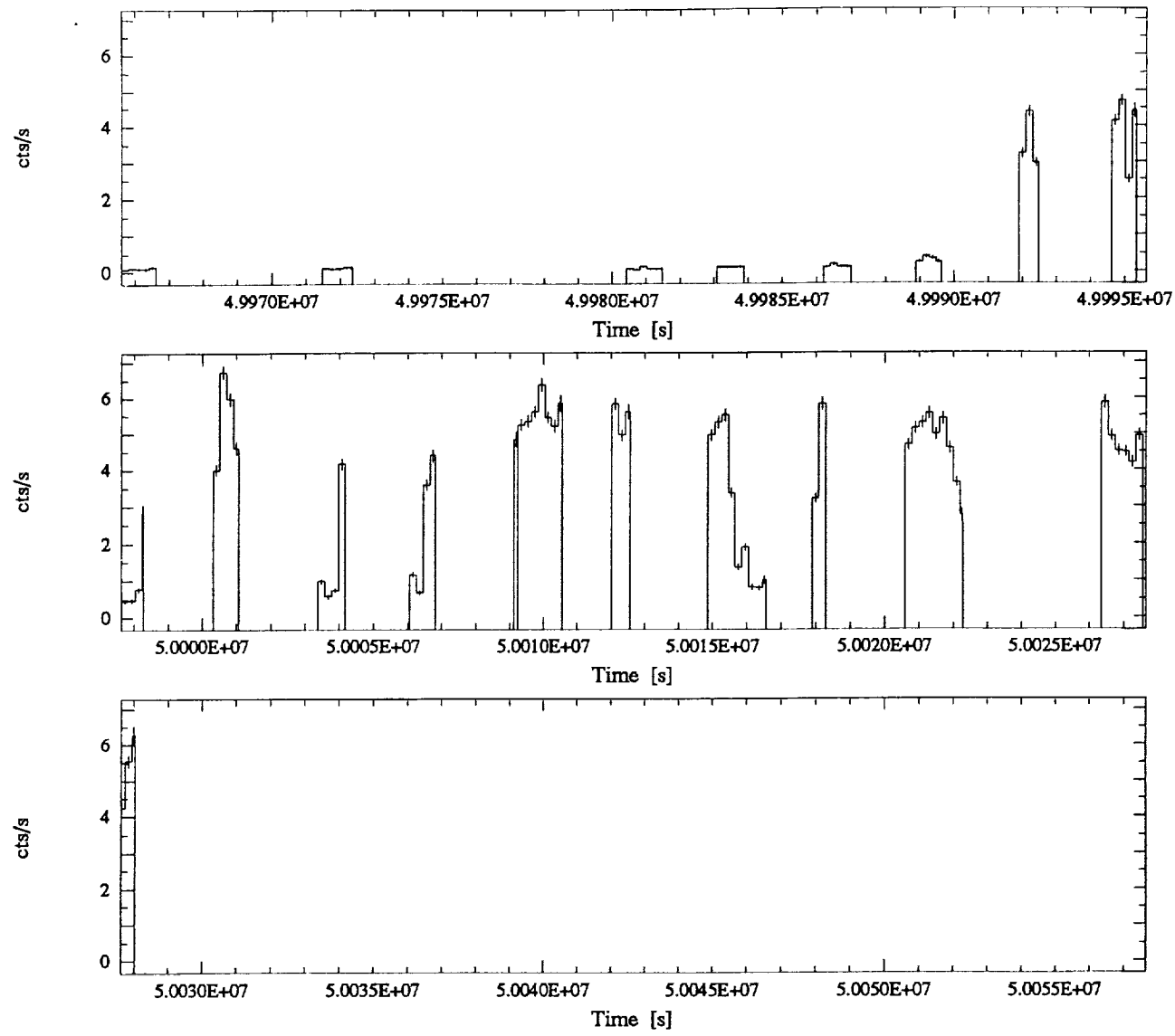


Fig. 2

source Nr. 19(83)

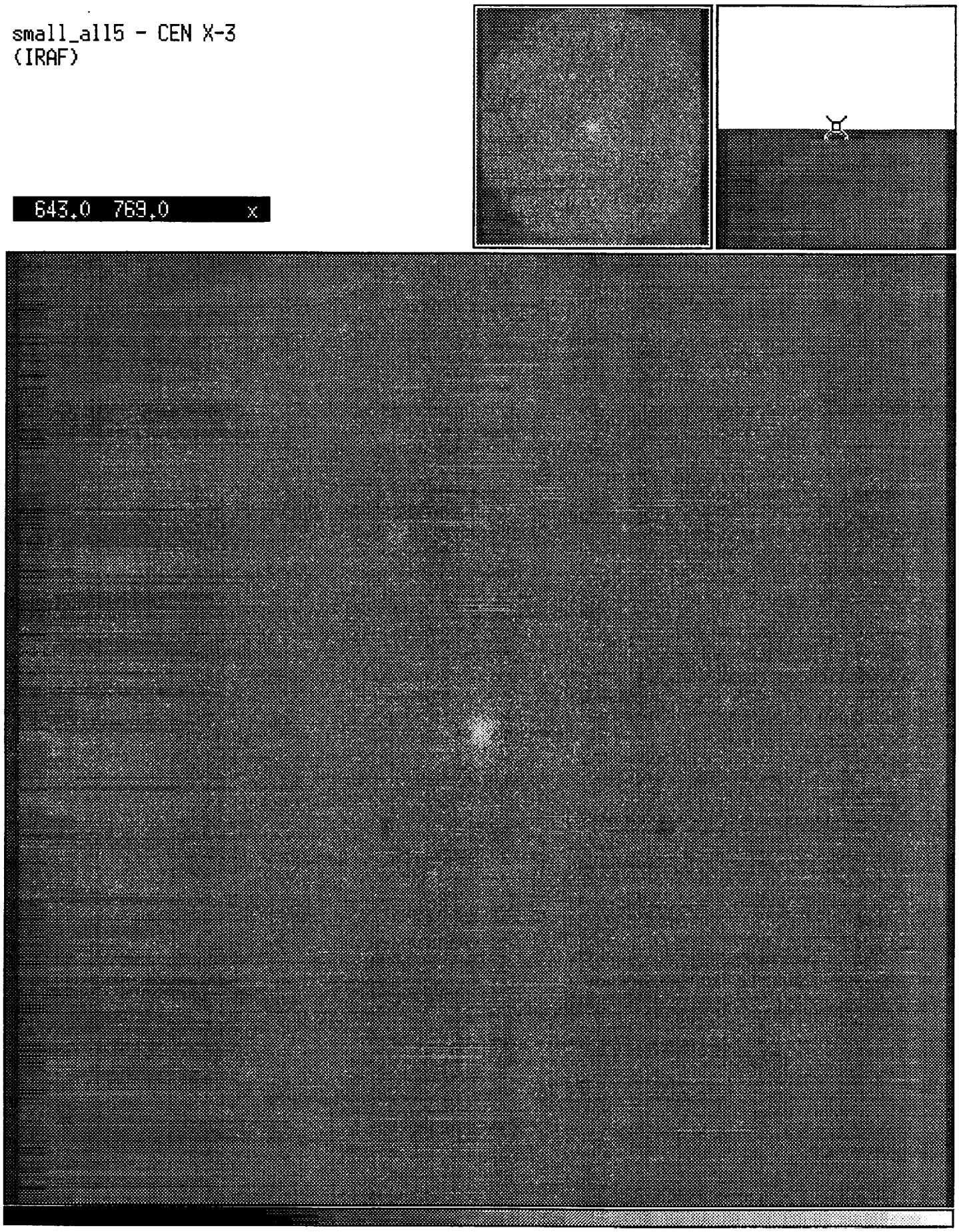


Fig. 3

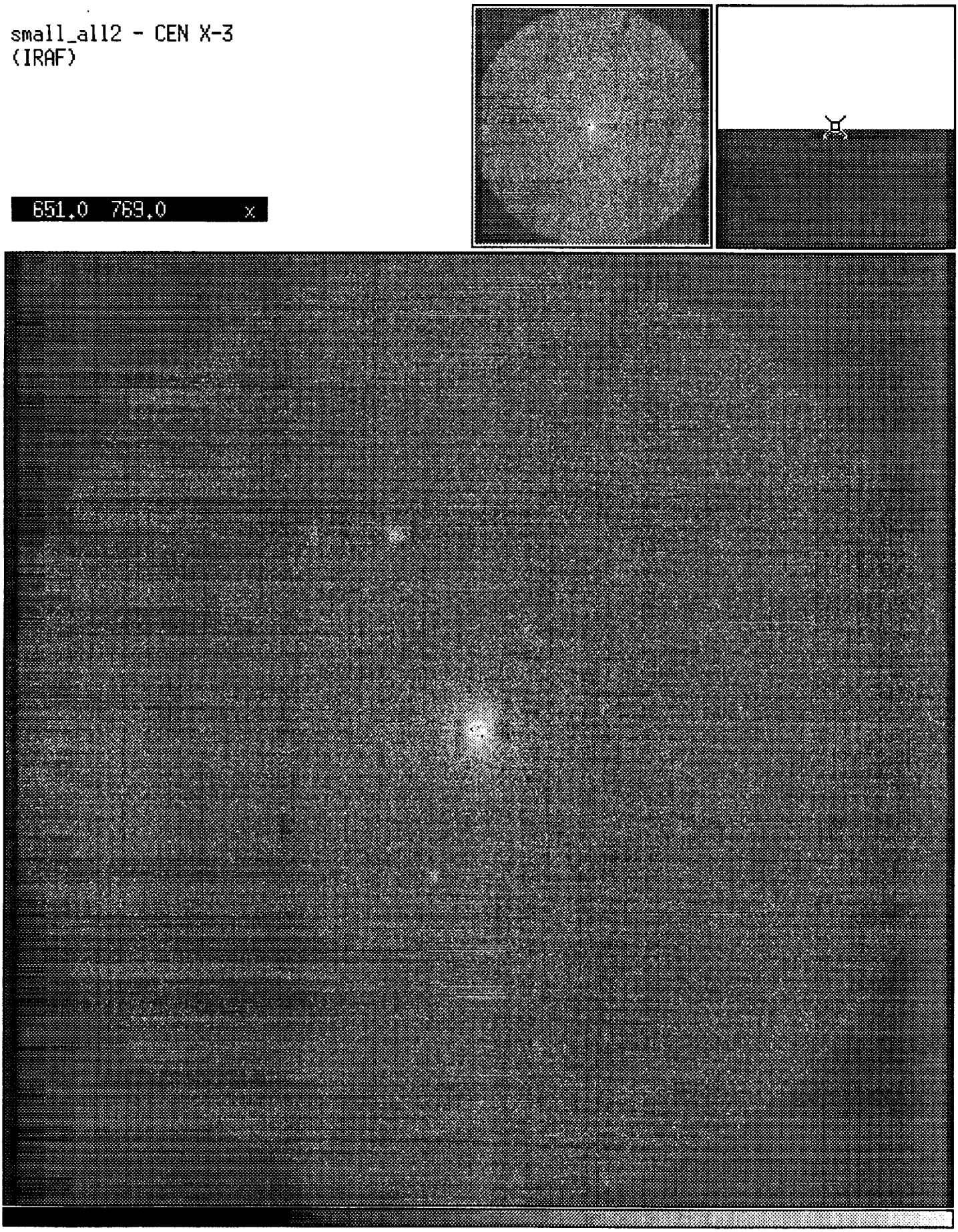
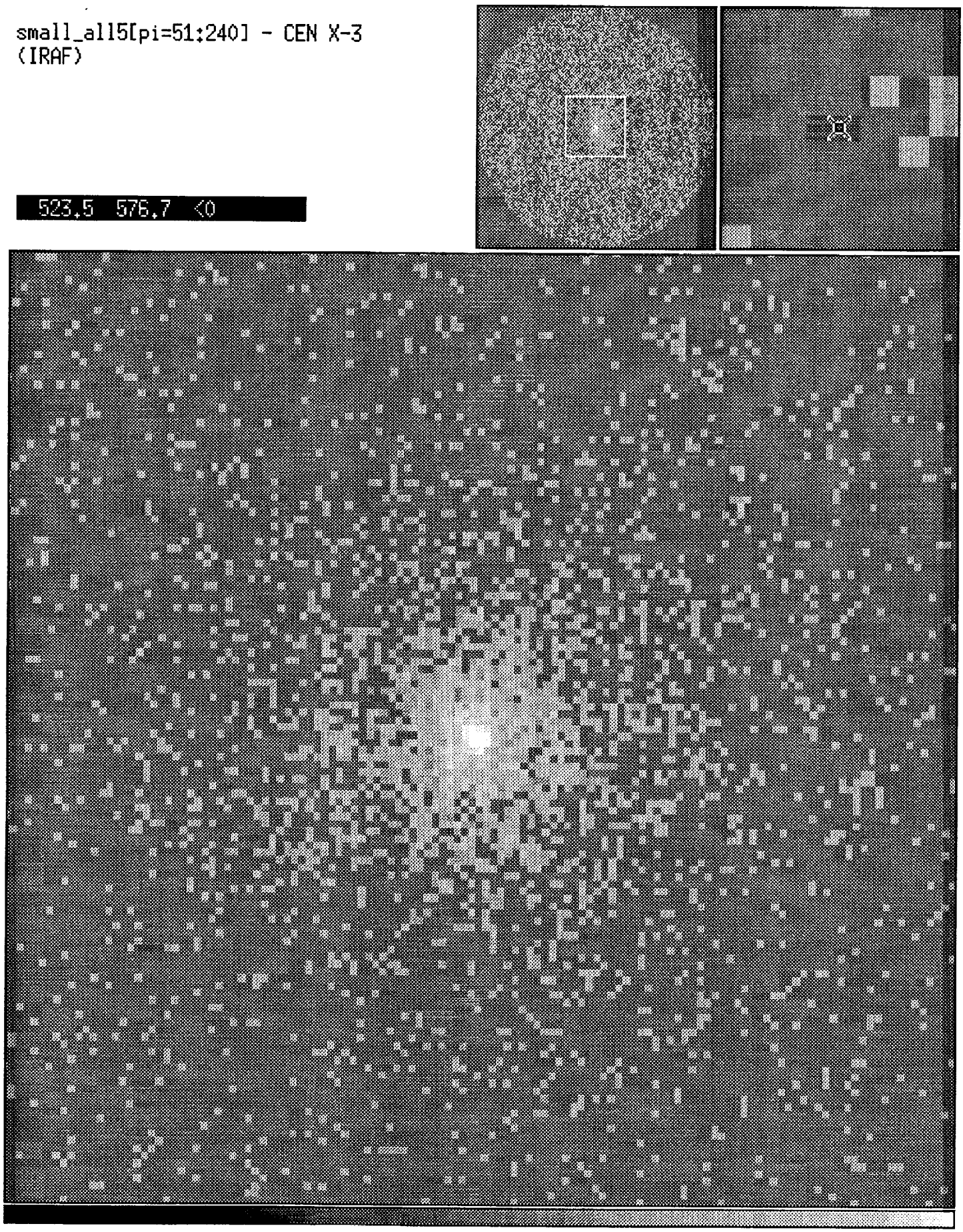

small_all2 - CEN X-3
(IRAF)
851.0 769.0 x
small_all2 - CEN X-3
SAOimage catura@sxt Fri Jul 23 14:19:33 1993

Fig. 4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(IRAF)
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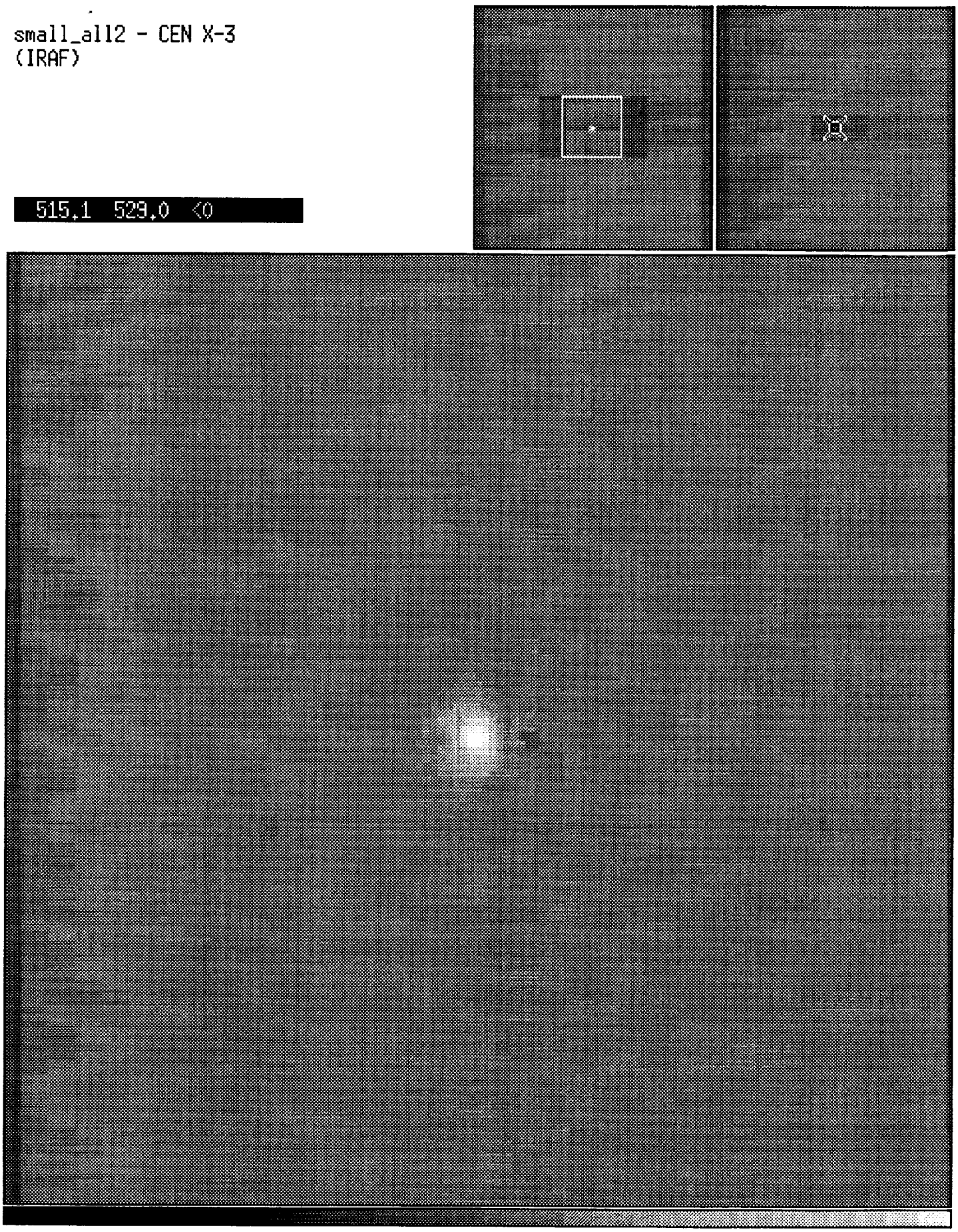
SAOimage caturs@sxt Thu Jul 22 14:10:43 1993

Fig. 5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(IRAF)
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small_all2 - CEN X-3
SAOimage catura@xct Fri Jul 23 14:26:47 1993

Fig. 6

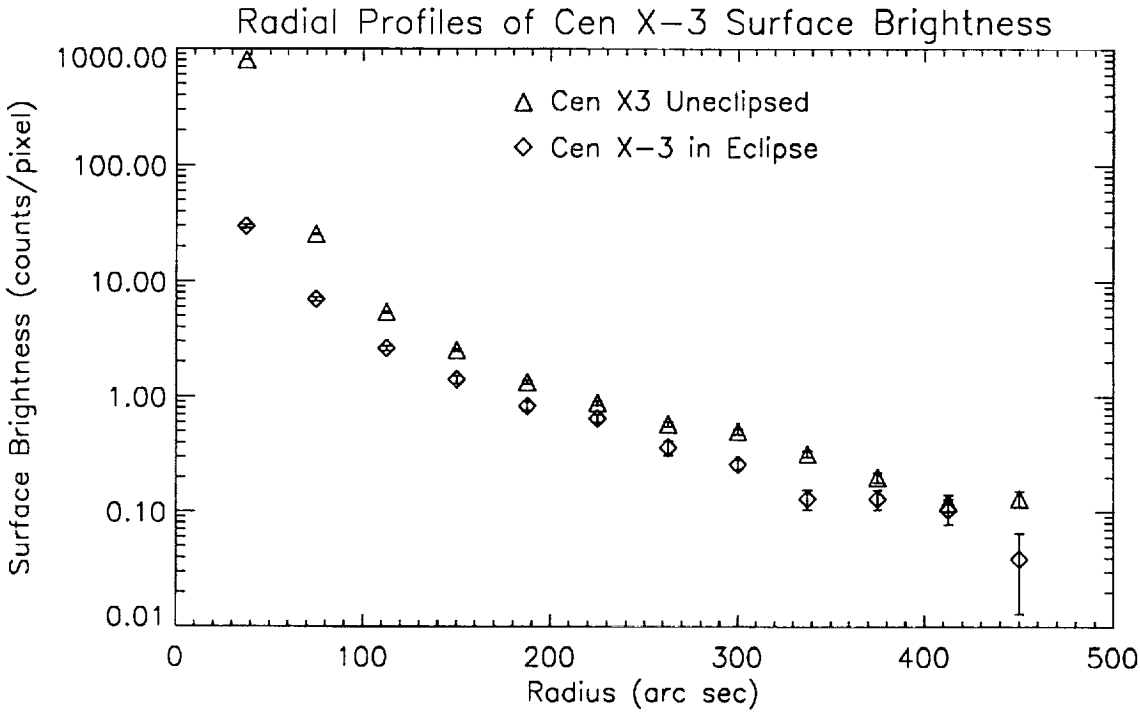
Radial Profiles of Cen X−3 Surface Brightness
Surface Brightness (counts/pixel)
1000.00
100.00
10.00
1.00
0.10
0.01
0
100
200
300
400
500
Radius (arc sec)
Δ Cen X3 Uneclipsed
◇ Cen X−3 in Eclipse

Fig. 7

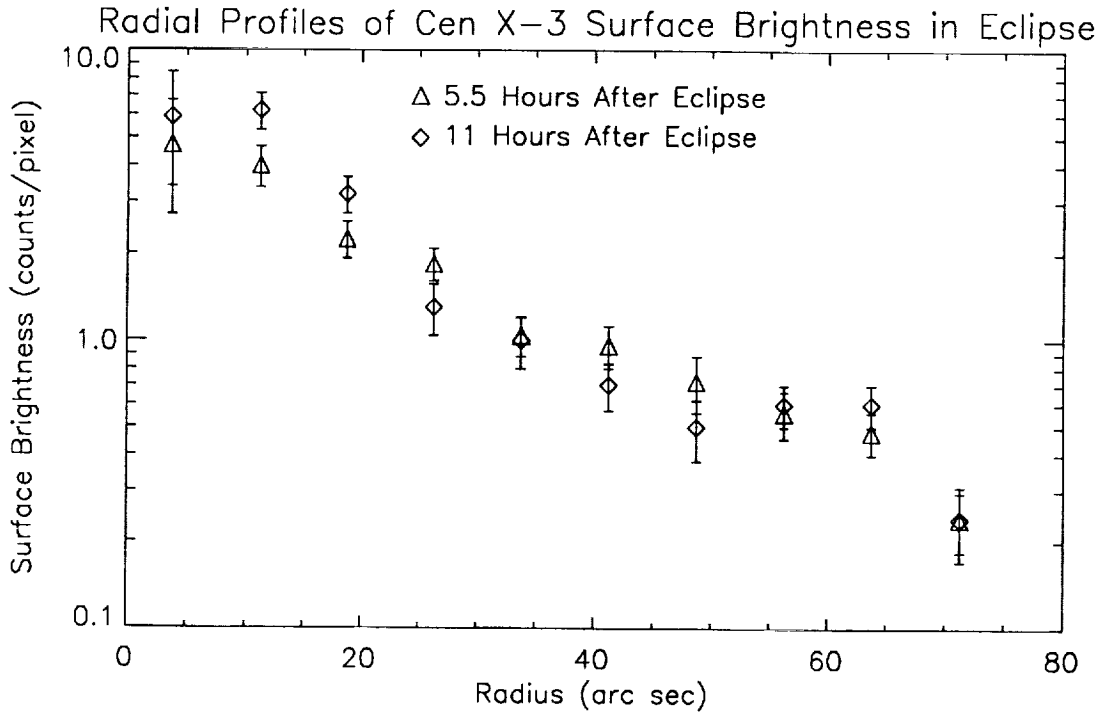
Radial Profiles of Cen X−3 Surface Brightness in Eclipse
Δ 5.5 Hours After Eclipse
◇ 11 Hours After Eclipse
Surface Brightness (counts/pixel)
10.0
1.0
0.1
0
20
40
60
80
Radius (arc sec)

Fig. 8

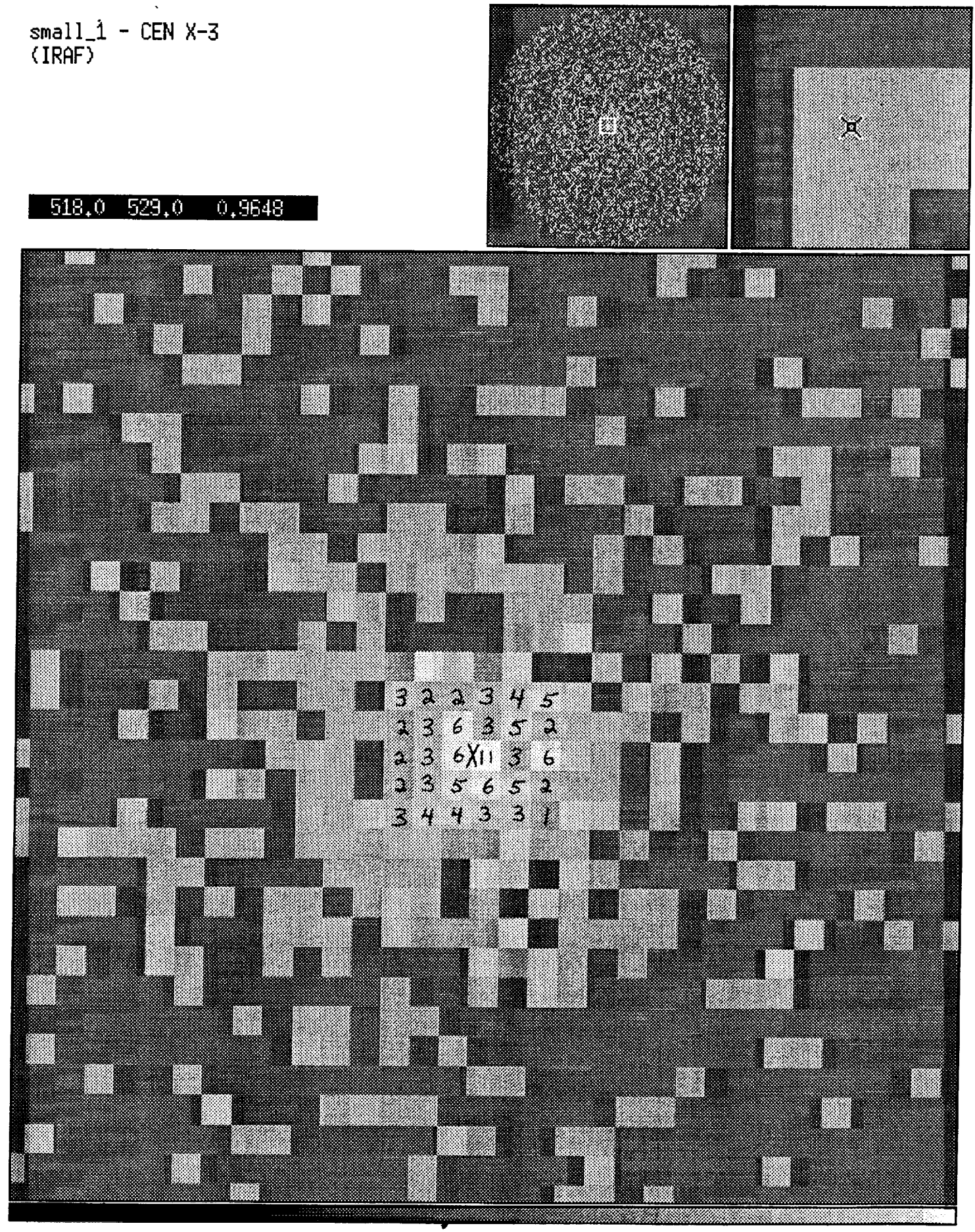

Fig. 9

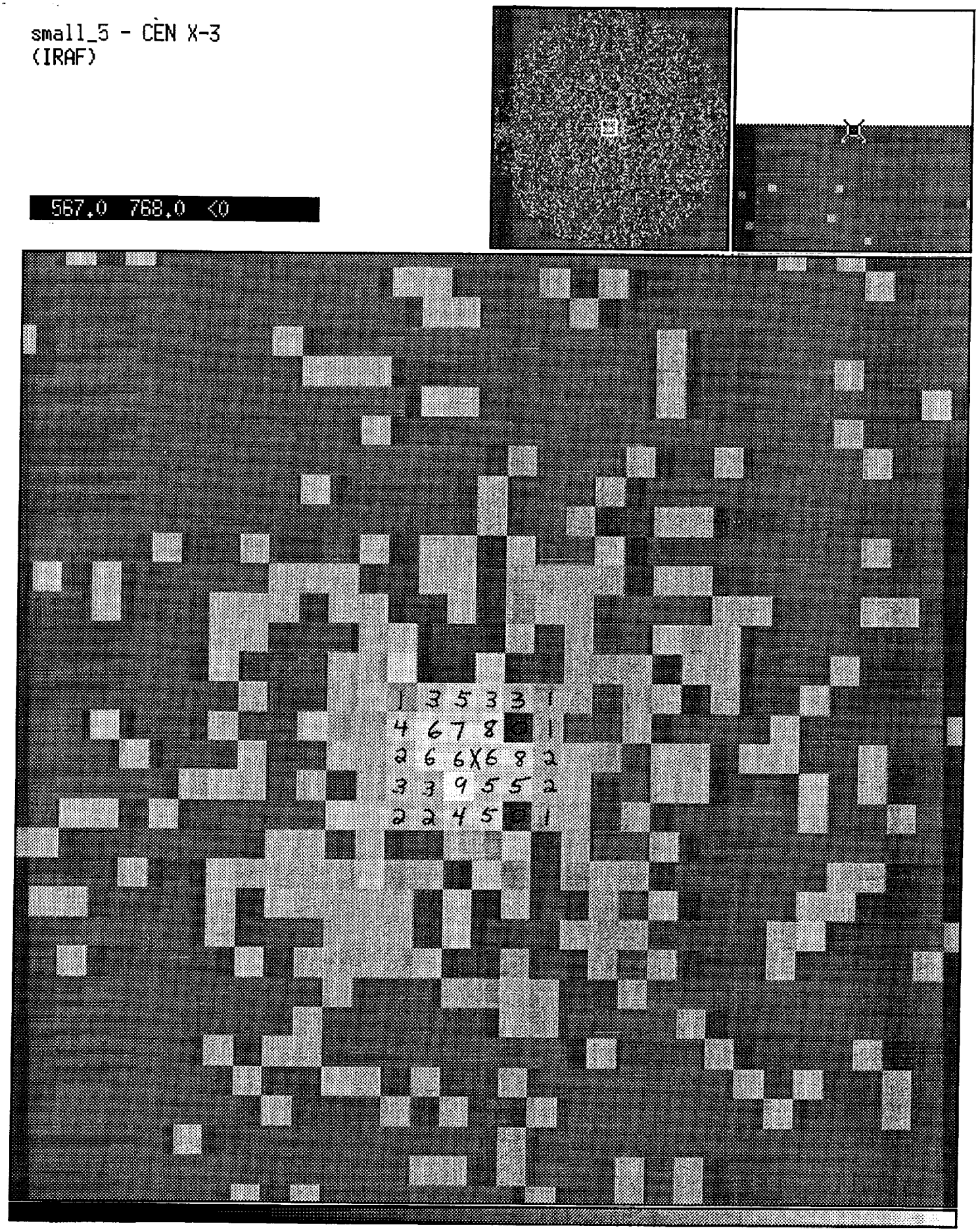
small_5 - CEN X-3
(IRAF)
567.0 768.0 <0
1 3 5 3 3 1
4 6 7 8 6 1
2 6 6X6 8 2
3 3 9 5 5 2
2 2 4 5 6 1
small_5 - CEN X-3
SAOimage catura@sxt Fri Jul 23 13:33:38 1993

Fig. 10

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15. Supplementary Notes

16. Abstract

The objective of this research was to study the halo surrounding the ROSAT image of CEN X-3 formed by scattering of X-Rays by interstellar dust grains. An X-Ray Halo was observed and that comprised 11.5% of the total X-Rays detected in the central unscattered image. Avoid at the center of the halo, that was expected to form during eclipse, was not observed. It is likely the void is filled by X-Rays scattered from cirum-source matter, local to Cen X-3, during eclipse of the X-Ray source.

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