A HIGH ENERGY ASTRONOMY OVERVIEW

Riccardo Giacconi
Harvard/Smithsonian Astrophysical Observatory

INTRODUCTION

The growth of extrasolar X-ray astronomy in the years since the discovery of the first X-ray star has provided one of the most exciting new windows to study high energy phenomena in the universe. As the instrumentation grew in sophistication and sensitivity from the very modest instruments carried aloft by short duration rockets, to dedicated orbiting X-ray observatories — first, of the Uhuru class, and finally of the HEAO-1 size, hundreds of galactic sources and many tens of the nearest extragalactic objects in each class were detected in X-rays (Fig. 1). As the body of observational data grew, it became apparent that X-ray observations revealed to us new phenomena or unsuspected aspects of known objects.

To mention only a few of the many results, the discovery of binary X-ray sources containing a collapsed companion has permitted us to measure, for the first time directly, the mass of neutron stars and to obtain the strongest experimental evidence to date for the existence of black holes. The discovery of the intergalactic medium through the detection of thermal bremsstrahlung emission from intracluster gas clearly demonstrated the unique role of X-ray observations in studying a previously undetected component of the universe containing as much mass as represented by all other known objects.

As exciting and scientifically rewarding as this progress was for many of us it fell far short of achieving the full potential of X-ray astronomy in the study of the more common galactic objects, such as main sequence stars, as well as in the study of objects at cosmological distances.

In order to achieve these aims, a radical improvement in instrumentation was necessary — something comparable to the step taken in visible light astronomy going from Tycho to Galileo.

That grazing incidence X-ray telescopes could in fact provide the means for this radical improvement had been clear to some of us since 1960 when I published with Bruno Rossi an article pointing out the great advantages of using this technique in the study of celestial objects. The fact that, although designs for microscopes had existed since the study by Wolter in 1952 (Fig. 2), no such device had ever been realized, coupled with the fact that no X-ray sources had yet been discovered, may help explain the lack of overwhelming enthusiasm our proposal received at the time. It took approximately 8 years of laboratory developments of telescopes of increasing collecting area and resolution to obtain in 1968 devices suitable for the study of our nearest star: the Sun. Although my first proposal for a large (1.2 m) X-ray telescope to study the stars was made to NASA in 1963, it took the clear demonstration of the capabilities of this technique, shown in Figure 3, to convince NASA to proceed. A study was undertaken under NASA sponsorship for the use of an X-ray telescope in 1968 by groups at Columbia, Goddard Space Flight Center, MIT, and by my own group now at the Harvard/Smithsonian Center for Astrophysics. We formed a consortium in 1970 to successfully propose an integrated X-ray astronomy observatory, centered on the use of an X-ray telescope as part of the HEAO program. Notwithstanding the severe difficulties that draconian fiscal cuts imposed on the program, and the consequent reduction in experimental capabilities, we succeeded in placing in orbit on November 13, 1978 the most advanced X-ray astronomy facility ever flown. The radical improvement in technical approach can be appreciated if one considers that the thousand-fold gain of sensitivity with respect to the very largest arrays of counters ever flown was achieved with a mirror collecting area only one-half as large as that of the Uhuru detectors.

Such qualitative improvements in observational capabilities occur but rarely in science and it is indeed a privilege to be part of this program and to share with you the preliminary findings of the Einstein Observatory.

In a project of this magnitude credits should go to literally hundreds of people in government centers, industry and academic institutions. Although I cannot even begin to do this properly, I would like to emphasize the sense of obligation that all of the scientists most directly involved in the program feel. Although carried out as a principal investigator experiment, the Einstein Observatory has assumed a national significance; we have therefore waived our rights in the matter of observing time and data to permit an ever increasing share of the scientific results to go to investigators in other institutions from all over the world. In the first 5 months of the mission, 150 guest investigator proposals have been approved and are being implemented.

THE EINSTEIN OBSERVATORY

The observatory (Fig. 4) consists of a 0.6 m X-ray telescope, an optical bench, a lazy Susan capable of positioning cameras or spectrometers at the focus, an attitude control system to point us in the sky and a spacecraft to house it, power it and transmit data to the ground receiving stations. The project was carried out under MSFC management; TRW designed and built the spacecraft; AS&E was responsible for many of the observatory common instruments and integration. Perkin-Elmer built the mirror. I will not go into details of the instrumentation which will appear in the June issue of the Astrophysical Journal; I will only recognize some of the great technical feats which we tend now to take for granted:

1) The development of the largest and best X-ray telescope ever built: a 0.6 m, 3.5 arc sec FWHM resolution telescope in which Leon VanSpeybroeck, of CFA, played such a key role (Fig. 5).

2) The development of a high resolution X-ray TV camera at CFA, aided by the University of Leicester (England) group.

3) The development of a large format IPC detector.

4) The development of transmission gratings by the University of Utrecht group.

5) The development of a cryogenically-cooled solid state spectrometer by Goddard Space Flight Center.

6) The development of a high resolution Bragg crystal spectrometer by MIT.

7) The development of a sophisticated software system, including interactive image displays, which allows us to reduce and analyze data in near real time.

Each day the Einstein Observatory is pointed on the average to 10 different fields. In the first 5 months of the mission some 1500 different fields have been examined; about half of them with imaging cameras. In each field there is at least one source (the object pointed at) but more often several. More than 1500 X-ray sources have therefore been studied with the Einstein Observatory, most of them previously unknown.

The sources range in intrinsic luminosity from the weakest X-ray sources ever detected in our own galaxy at 10^{27} erg sec^{-1} in the 0.1 to 3 keV range to the most luminous X-ray objects, the very distant quasars, at 10^{47} erg sec^{-1}. The diversity of physical conditions and objects represented in these two decades of intrinsic luminosity is as great as found in all of astronomy and soon it will be almost impossible to give an overall review of our findings.

In dealing with the subject I have therefore chosen to highlight some representative topics.

STARS AND STAR ASSOCIATIONS

Among the first delightful surprises of the Einstein Observatory returns, the discovery of X-ray emission from 0-B associations is certainly noteworthy. The nature of the observations can be exemplified by the picture of Eta Carinae obtained with the IPC (Fig. 6). Eta Carinae had been known as a weak X-ray source possibly coincident with a supernova remnant, which had been claimed to exist in the region — its relation to the object Eta Carinae itself being unclear. Figure 6 shows no evidence of a SN, but a number of discrete sources in the field accompanied by diffuse emission. One source coincides with the object Eta Carinae, others with a Wolf-Rayet star and O stars. The dark lanes so prominent in visible light can be seen in the X-ray image as well, indicating that the source of the X-ray diffused emission is at the same location as the optical emission, possibly as a result of an ancient SN explosion. When we observe this field with the HRI, we can see greater details of the emission from each source (Fig. 7).

Eta Carinae is a very strange object whose nature is not fully understood. It has been classified as a supernova because it underwent in the 1840's an outburst which made it one of the most luminous objects in the sky. However, the maximum of light lasted for about 20 years and did not at all resemble an SN. Today Eta Carinae is the strongest IR source in the sky. If its radiation is interpreted as coming from a single star, this star would have to be one of the most massive objects in our galaxy. Fred Seward, who has been analyzing this field, finds that the X-ray emission from the O stars in the field is consistent with a point; but that from Eta Carinae is extended. We may be seeing the results of the blast of 1840, as well as the object itself behind the obscuring dust and gas cloud (Fig. 8). The fact that severe upper limits can be placed on the size of the emission region of the O stars puts into question models for X-ray emission in which the emission is due to stellar wind collision with the surrounding medium. Models which invoke a compact object orbiting the O star and accreting from it have been suggested. The small intrinsic luminosity 10^{+30} erg sec^{-1} of these objects, as compared to the classical binaries emission at 10^{38} would be due to the different state of evolution of the primary. As the primary evolves from the main sequence onto the supergiant branch, gas accretion and hence X-ray emission would increase. Although the sample is still small, there is no correlation between X-ray emission and evolutionary state of the O and B stars observed. This then leaves us with the possibility that what we are observing is coronal emission. This is not a trivial finding in that it does not fit well in the current picture on the energy transport mechanisms in the interior of stars. To transport energy from the center of a star to the cooler outer region convection and radiation can be invoked. Noise associated with convection is thought to be responsible for the formation of coronas. Convection occurs efficiently, however, only under particular conditions which depend on the composition and evolutionary state of a star. In a simple picture which has been extremely successful in explaining qualitative characteristics of stars, it was understood that stars earlier than F5 would not sustain convection. This explained the sharp change in rotation velocity around F5. Stars later than F5 have coronas and extended fields which interact with the surrounding medium to slow down rotation while earlier stars would not. Stars earlier than F5 are known to produce radiation driven winds which were thought to be cool. The only possibility for X-ray emission under these conditions would be thermalization of the wind by interaction with the interstellar medium creating a bubble of large dimension. Such simple theories were already having difficulty due to the findings of solar research as well as hints of hot winds in early stars from optical and UV studies.

With Einstein the discrepancies are made much more acute due to the observation not only of F2, F0, A and B stars, but O stars as mentioned above. In fact, one can consider that X-ray observations of coronas from main sequence stars will form the new foundation on which theories will have to be recast. It is an amusing turn of events that with this most powerful of the extrasolar X-ray observatories, we may end up learning much about stars like our own Sun.

An interesting speculation is whether OB associations not only in Eta Carinae, but in Cyg and Orion as well, appearing to contain bright X-ray sources may be connected with events such as shedding of magnetic fields and angular momentum characterizing the birth of stars.

Ultimately, Vaiana and others at CFA are engaged in constructing the X-ray equivalent of an H-R diagram which hopefully will contribute significantly to our understanding of stellar evolutionary processes.

SUPERNOVAS AND PULSARS

If we turn now from stars being born to the results of stellar collapse, a different and interesting aspect of the Einstein Observatory research is found.

First, observe the classical pulsars in Crab and in Vela (Fig. 9). The emission from the Crab pulsar, which is being studied by Tananbaum, can be clearly separated in the image from that of the surrounding nebula. The pulsar emission is observed to pulse at the well-known 33 m sec period. We are in the process of assessing the presence of any non-pulsed component which may be due to black body emission. High energy particles accelerated in the pulsar and streaming in the surrounding magnetic field presumably give rise by synchrotron radiation to the main filament which we see at the NE. This filament coincides with the main filament observed in polarized light. It is puzzling that the region of maximum X-ray emission in the nebula should not be symmetric with respect to the pulsar. A similar picture is found by Harnden for the Vela pulsar with two main differences. No pulsations are observed at the 1 percent level and the source of X-ray emission centered on the pulsar appears extended; we have no ready explanation for this phenomenon.

The usefulness of the imaging capabilities of the Einstein mission is clearly demonstrated by the X-ray picture of other supernova remnants, which are being analyzed by groups led by Pye, Gorenstein and Murray. Figures 10, 11, and 12 show SN 1006, Tycho and Cas A. The steep gradient of the X-ray emission propagation of a shock from the explosion itself. The detailed filamentary structures observed in Cas A correspond to the evaporation of material heated within the shock from fragments of the stellar envelope flung out in the explosion. Spectral measurements with the solid state spectrometer of GSFC detect the presence of Fe, Mg, S, Ca, Argon, etc., with Fe abundance currently estimated to be twice solar.

Although it is widely believed that the enrichment of low Z materials occurs in the interior of the stars, and that SN explosions are the means of injection of the enriched material in the interstellar medium to form new generations of stars, here we appear to be witnessing the actual mechanism by which the material is dispersed. It is quite puzzling that no pulsar is detected near the center of these remnants. Current knowledge of pulsar velocities predicts that the pulsar cannot have moved far from the center of these historical supernovas. Current theories on cooling rates of supernovas also predict that the pulsars should retain temperatures of a million degrees at the present epoch. Black body emission from such an object would be readily observed with Einstein instruments. Their absence could be explained in one of two ways: either pulsars are not always formed as the residue of SN's, or they cool faster than expected. The first explanation further worsens the problem of explaining the large number of pulsars observed, in view of the relatively low frequency of SN explosions. The second requires new cooling mechanisms, such as pion cooling, to play an important role and requires substantial revisions of our theoretical picture of the constitution of a pulsar. The observational program of SN research with Einstein has just begun. Even so, the observations to date include the detection of the remnants of the 14 known supernovas in the large Magellanic Cloud which have been observed to have higher average flux than supernova remnants in our own galaxy by the Columbia group. The study of the characteristic of supernovas phenomena for stars evolved in different conditions of galactic composition and evolution promises to be extremely interesting.

BURSTERS AND GLOBULAR CLUSTERS

The discovery of X-ray bursts by J. Grindlay and H. Gursky has opened one of the exciting new chapters of X-ray astronomy in recent years. Their relation to globular cluster sources and the nature of the underlying system have not yet been fully resolved. On the one hand, the explanation that they are low mass binary systems containing neutron stars explains conveniently many of the observational phenomena; on the other hand, their binary nature has not been directly observed. Models invoking accretion onto massive black holes arising from collapse of cluster cores have difficulty in explaining sources outside of globular clusters and may be difficult to reconcile with some of the optical data on the candidate counterparts. It is hoped that detailed measurement of the position of such sources with respect to the center of the globular cluster gravitational potential well may lead to conclusive evidence in favor of one or the other model. Figure 13 shows how a globular cluster burst source appears to Einstein in four successive 2.5 min exposures of Terzan 2. The identification of the steady source, with the burst source and with the globular cluster which had been suggested by Grindlay, is clearly established. Some eight additional cluster sources have been examined. Most of the X-ray sources appear to cluster within 1 or 2 arc sec of the center (Fig. 14) with one exception, NGC-1851 which is found at 7 arc sec from the center. Although it is too early to fully evaluate systematic and statistical errors and draw strong conclusions on the mass limits for the sources, it is clear that X-ray observations have the potential of probing in detail the mysterious central region of these star clusters.

M-31

Einstein observations have been extended to galactic X-ray sources in M-31. Three IPC exposures are necessary to cover the entire galaxy and 1 HRI exposure of the center has also been obtained. The X-ray source M-31 which at 1 UFU was approximately the limit of detection for previous survey, dissolves into 70 or more discrete sources (Figs. 15 and 16). The optical galactic center appears to be an X-ray source at approximately 10^{37} erg sec^{-1}, and the remainder of the sources are presumably supernova remnants, classical binary X-ray source or globular clusters. (In fact, 4 sources have already been identified with globular clusters and several others with bright optical counterparts which may turn out to be classical binaries containing a supergiant.) Their division in galactic arms and bulge sources is much more clearly revealed than in our own galaxy. Leon VanSpeybroeck has undertaken detailed studies on the relation of X-ray source formations to the evolutionary and dynamical history of different galactic settings.

VIRGO CLUSTER

Weak external galaxies emitting as little as 4×10^{38} erg $\sec^{-1}$ have been detected with Einstein at distances as large as 20 Mpc. This means that a study of galaxy morphology versus creation of strong X-ray emitting sources is quite feasible and can be carried out both by studying individual galaxies in clusters where one can observe many types of objects within a single field, and by studying field galaxies whose emission would be free from obscuring contributory effects due to gas in the cluster. The second approach is that carried out in the deep surveys and the first has been initiated by W. Forman in the detailed study of the Virgo Cluster. Figure 17 shows an X-ray isointensity contour super-imposed on a portion of the Virgo Cluster containing M-86 and M-84. In addition to a diffuse emission from the cluster gas gradually decreasing as we move away from M-87, we see emission arising from around the giant elliptical galaxies M-84 and M-86 as well as from a narrow emission line galaxy (very similar to NGC-2992) and from a tidally disrupted spiral.

It is clear that the emission about M-86 ($\sim 5 \times 10^{41}$ erg $\sec^{-1}$) is extended and we can compute gas density and temperature yielding parameters not too dissimilar from those found in M-87. This phenomenon of clumping of cool gas about massive individual galaxies in a cluster is found in Einstein observations to be a general feature of many clusters and help us significantly in understanding cluster properties.

CLUSTERS OF GALAXIES

Several independent efforts led by Christine Jones, Pat Henry, and Steve Murray, of CFA, are proceeding to study cluster morphology and evolution. Although but a small fraction of the Einstein observing program has been completed and only preliminary analysis of the data has been carried out, certain characteristics seem already to emerge. Clusters seem to show a great diversity of morphological shapes exemplified by the IPC pictures of Cluster A-1367 and A-85. Figure 18 shows the X-ray contours superimposed on the optical data. In addition to the broad X-ray distribution, amounting to approximately 10^{46} erg $\sec^{-1}$ which for an isothermal sphere model extends over about 0.5 Mpc, we see now that the emission is highly clumped. About 2×10^{42} erg s^{-1} are associated with the radio emitting galaxy 3C264. Also, two galaxies, NGC-3842 and NGC-3841, which do not lie near the center of the cluster, have X-ray luminosities of 3.4×10^{41} erg s^{-1} and 5.5×10^{41} erg s^{-1}, comparable to M-86. Other apparent X-ray peaks do not correspond to bright galaxies. If there is a relationship between X-ray enhancements and mass concentration, these bright spots may indicate the presence of previously undetected mass in the cluster. Both Virgo and A-1367 have relatively low velocity dispersion for the galaxies, suggesting that the binding of gas by the potential of individual galaxies is a more important factor than the cluster central potential well.

Figure 19 illustrates the very different picture that we obtain for the cluster A-85. Here the one-dimensional projections show a very strong central peaking as well as an overall smoother X-ray distribution. The isothermal sphere core radius for this cluster is about half that which we obtained for A-1367, the X-ray luminosity is ~ 10^{45} erg s^{-1}, and the temperature is $\gtrsim$ 8 keV (or 100 million deg).

Generalizing our cluster observations, we see that clusters whose emission is broadly spread and clumped around individual galaxies tend to be rich in spiral galaxies, have low velocity dispersions, and X-ray temperature in the few keV range. Clusters which are smooth X-ray sources with well-defined central peaks are spiral poor, have larger velocity dispersions, and have higher X-ray temperatures. These observations can be understood in the framework of cluster evolution models, such as that of Peebles, if we allow clusters in different stages of evolution to be present at a given epoch. Peebles has shown that a cluster begins as a large cloud of galaxies, collapses, and finally reaches equilibrium with an extended halo around a high density core. The broad, highly clumped clusters could be interpreted as clusters in their early evolutionary stages.

Clusters in this early stage would be expected to have a lower density of hot intracluster gas, and therefore, a higher fraction of spirals than in more evolved clusters in which the ram pressure of gas can strip the galaxies of their interstellar matter, transforming them into SO's and perhaps elliptical galaxies.

During the collapse or second phase of cluster evolution, a high density core is formed, thereby enhancing the chances for building a central dominant or cD galaxy at the cluster center, either by dynamical friction leading to galaxy capture, or by tidal stripping of galaxy halos. So far all of the clusters we have observed, which show a strong X-ray peaking, such as A-85, are Bautz-Morgan type I clusters with cD galaxies. The increased X-ray central surface brightness and higher temperature are probably due to the increased gas density at the center, bound by the cluster potential well.

A consequence of these observations is that the previous extended X-ray emission reported by Forman et al. for at least two clusters, A-1367 and A-2666, no longer need be interpreted as evidence for a massive halo outside the isothermal core. Instead, the extent can be understood in terms of broad, highly clumped emission, with negligible total mass.

The observation of distant clusters may also shed light on their evolution, if we assume that the more distant clusters will be observed earlier in their development than the nearby clusters. The dynamic cluster potential models of Perrenod predict a strong evolution in the cluster gravitational potential, with luminosities at a redshift of 1, predicted to be only 1/10 of those at redshifts near 0. Also, the distant clusters provide more tests for the ram pressure gas stripping models or for the evaporative stripping models for converting spirals to SO's or ellipticals after cluster collapse (Peebles' Phase 2). Since Butcher and Oemler have observed many blue, rather than red galaxies in several centrally condensed clusters near $z = 0.4$ in contradiction to this simple picture, one possible way out was to suggest that these clusters do not have the intergalactic medium or gas needed to do the stripping.

Our observation of the redshift 0.46 cluster 3C295, with Einstein IPC, shows that the source has a finite angular extent of 0.6 arc min which corresponds to a core radius of 0.5 Mpc. With this core radius, the measured X-ray luminosity of 1.3×10^{45} erg s^{-1}, and an assumed temperature of 7 keV, we obtain a central ion density of 2×10^{-3} cm^{-3}. Only through X-ray measurements such as these can the hot gas be directly observed and thereby the density determined. This density is sufficiently high that the stripping models predict that contrary to the observed colors, there should be few, if any, spiral galaxies in this cluster. It is possible that the cluster has just recently collapsed and the stripping has not had time to process. Alternatively, Gisler has recently suggested that gas injection from the stars in the galaxies may also be capable of removing momentum from the intergalactic gas, thereby avoiding the stripping process.

With respect to the question of luminosity evolution, we again find a complex situation. This is caused by the large, >100, spread in cluster luminosities as shown in Figure 20. This is a plot of the spectral density received at our detector at an energy corresponding to 2 keV at the cluster, plotted versus redshift. OSO-8 data of Mushotzky et al., and Einstein data are shown. Closed symbols refer to Bautz-Morgan type I and I-II with cD galaxies to which the remainder of the discussion is confined. The smooth curves represent the expected flux versus redshift for an average 7×10^{44} erg s^{-1} B-M type I cluster. Two curves for deceleration parameter 0 and 0.5, but no evolution are indicated as is a curve which evolves according to one of Perrenod's dynamic potential models. The high redshift cD clusters observed so far appear to favor such a model, but clearly more data are required for a definitive test.

QUASARS

We are carrying out a program of observations of known quasars with a wide variety of radio and optical properties, over a significant range of redshifts (>3). Prior to Einstein only quasars at redshift <0.2 had been observed in X-rays. New quasars are also being discovered through optical identification of X-ray sources detected in the deep surveys. Five such quasars have already been identified in Einstein deep surveys with $0.5 < Z < 2.6$.

Figure 21 is a 10,000 sec exposure for the quasar 0537-286 at $z = 3.1$ which emits more than 10^{47} erg s^{-1} in the 0.5 to 4.5 keV band. Other objects detected in the field include a 5.3 magnitude F2 star and a 7 magnitude F5. The other objects are as yet unidentified and correspond to optical candidates fainter than 15 magnitude.

The ease with which we observed QSO 0537-286 and a second quasar, 0420-388, at redshifts of 3.1, indicate that we can expect to detect still more distant quasars. An interesting question is whether in fact still more distant quasars exist. Since the quasars are the first known aggregates to condense from the expanding big bang "gas," the epoch at which they first formed is a most intriguing issue. Have the optical observations to date been limited by instrumental effects as many have suggested, or did the quasars only form at the epoch given by redshift 3.5? Since our X-ray deep surveys are capable of detecting and locating sources much weaker and hence possibly much more distant than we have discussed, we should be capable of detecting these more distant quasars if they exist.

A second important question about the quasars concerns the long-standing question of the nature of the underlying energy mechanism capable of producing luminosities up to 10^{47} ergs s^{-1}. The X-ray observations may be able to provide a unique insight into this question by studying time variability of QSO emission. Figure 22 shows our observations of the quasar OX-169, which is a weak X-ray source, but nonetheless, easily detected by our telescope. The figure shows the data we obtained for six orbits of HRI observations. The observed intensity variation in $\lesssim 100$ min corresponds to a decrease in absolute luminosity from 2.0 to 0.6×10^{44} erg s^{-1}. The probability that the event is due to random fluctuations of a steady source is quite small, although more careful analysis is required to precisely define the size and time scale of these variations.

Observations of time variability, such as we see in OX-169, may be a signature of the ultimate energy source in the nuclei of quasars. For a process involving conversion of a mass into energy, rapid variations in a powerful emitter require a high efficiency, supporting models involving release of gravitational energy through accretion onto a compact object. If one assumes that the X-ray emission is powered by accretion onto a massive black hole and that the Eddington luminosity is not exceeded, the luminosity and time scale for variability can be used to obtain bounds on the mass of the black hole. The short time scales involved in the emission from OX-169 confirm the expectation on theoretical grounds that the X-rays are produced very close to the central source and may therefore provide the means for ultimately understanding the machines powering the quasars and active galaxies in general.

Figure 23 summarizes some of our observations of the quasars. We have plotted the 0.5 to 4.5 keV X-ray luminosity for the individual sources as a function of redshift. The three nearby quasars known prior to the launch of Einstein are shown, as are the Einstein observations now extending to a redshift of 3.1. The luminosities range from 10^{44} erg s^{-1} to 10^{47} erg s^{-1} with no obvious dependence of luminosity on redshift. The absence of low luminosity, high redshift quasars is primarily a measure of the instrument sensitivity limit for a several thousand second observation.

Our observations to date clearly do not satisfy the statistical requirements for a complete sample; for example, they are strongly biased towards radio quasars indicated by filled circles on the slide.

In the meantime, we can use optical luminosity functions for quasars plus a tentative correlation between the optical and X-ray fluxes in order to estimate the possible contribution of the quasars to the X-ray background. We define the quantity α_{ox} which is the slope of a power law connecting the optical data (at 2500Å) with the X-ray data (at 2 keV).

The resulting values of α_{ox} range from 0.95 to 1.71 and show no obvious dependence on redshift or, for example, on radio emission properties. We also note that the range in observed α_{ox} corresponds to a factor of 100 in the ratio of optical to X-ray luminosities. Even though this is a substantial range, we can attempt to use an average value of α_{ox} plus an optical luminosity function to estimate the contribution of the quasars to the X-ray background. Averaging the X-ray luminosities and the optical luminosities, we find an average α_{ox} of 1.5, where the result is dominated by the most luminous quasars.

Neither the optical luminosity function for quasars, nor the rate of evolution are fully determined at present. In our calculations we used recent results of Braccesi et al. (1979) who analyzed all the available data on optically selected quasars. With a Friedmann cosmology and deceleration parameter $q_o = 0$, they found that the number versus magnitude relationship for optically selected quasars implies a strong evolution rate, [with density increasing as $(1 + z)^8$] up to $z = 2.5$, followed by less rapid evolution at higher redshift.

Using this formalism, together with the average α_{ox} of 1.5, we can estimate the contribution of quasars to the X-ray background. The result depends on the limits of the integration and we have assumed that the optical luminosity function is valid over a range which corresponds to limits of 10^{44} to 10^{46} erg s^{-1} for the X-ray luminosity. The calculation leads to an immediate contradiction, since the computed background is 2.5 times the observed "extragalactic" background. Therefore something must be wrong. X-ray luminosity may evolve less rapidly or the Lx/Lop ratio we find is the result of sample selection. It is interesting to note as an aside that the observations can be reconciled with a local theory of QSO only if the local distance scale is assumed to be of 500 Mpc which then is essentially equivalent to a cosmological interpretation of the redshifts.

THE DEEP SURVEYS

I would like to turn to another aspect of Einstein research: the deep surveys. The long-standing question of the diffuse or discrete origin of the X-ray background can be approached directly with Einstein observations by extending the Log N versus Log S curve, or by imaging it at the limit of sensitivity. Given the fact that Einstein deep surveys have achieved already 500 times the sensitivity of any previously reported experiment, we expect for a 3/2 power law extension of the number intensity relation found with Uhuru to be able to observe several million sources in the sky or several tens of sources per square degree. At this source density not only is imaging essential to avoid source confusion, but in fact the IPC is just about confusion limited with 2 arc min resolution and the HRI takes over with 4 arc sec resolving capabilities. We point at selected regions of the sky where we have optical and radio coverage and cover the region with a mosaic of exposures as shown in Figures 24 and 25. Given the fact that we are navigating in unknown lands, we tend to observe everything at least twice with the IPC and use cross-correlations to reassure us about the validity of our automated detection techniques. In Figures 26 and 27 are two examples of superposition of HRI fields in exposures from 10,000 to 50,000 sec in Draco and Eridanus. Several sources can be immediately seen. I have chosen to summarize the results by showing the 4-meter blue plates of the regions obtained by W. Sargent at Kitt Peak and by W. Liller at CTIO with the sources superimposed (Figs. 28 and 29).

HRI positions are marked by the hatched lines while circles define a standard 1 arc min radius error box adopted for IPC position. Several nearby stars can be seen as the optical candidates of the X-ray sources in the pictures. As described above we detect stars of classification F0, F2, G and K_{8-9} in these two fields.

We wish to separate the contribution of nearby stars from extragalactic objects to evaluate the contribution of such discrete objects to the background. This can be done either by direct measurement of the redshifts of the objects, identifying QSO's and compact galaxies, by their optical and radio morphology, or in the case of faint counterparts which may be QSO, BL Lac objects, or white dwarfs, by directly measuring their proper motions over a 25-year span. Some fields appear completely empty, although in one case both a 21.5 magnitude object possibly a cD galaxy and a cluster of galaxies of magnitude 22-23 were observed at the X-ray location with CCD cameras by Westphal and Kristian. Only about one-third of the objects can be stars belonging to known classes of objects. We can then proceed to estimate the contribution of such objects to the background by estimating their number at our limiting sensitivity. We select for this purpose only sources within the central 30 arc min of the field and whose intensity is known better than 5 standard deviations to reduce possible errors due to uncertainty in the intensity of the sources and other effects. The data point on Figure 30 is placed where the number of sources per steradian (of intensity greater than S) is plotted at the survey sensitivity. The Uhuru Log N - Log S curve has been obtained by extrapolating the results in the 2-6 keV range to the 1-3 keV range of this Einstein measurement. The background envelope has been also similarly derived by extrapolating the $E^{-1.4}$ power law valid at energies below 20 keV. The differential contribution of the sources is of order 13 percent. Their integral contributions extrapolated to 1 UFU with a 3/2 power law is 30 percent. Finally, extrapolation to the limit of sensitivity of our current survey or to the limits of known quasars (with X-ray intensity a factor of 4 below the 5 sigma limit) may yield integral contributions of 50 to 60 percent, respectively. Once the point is made that a significant fraction of the background is due to discrete sources, it becomes very interesting to find out both the nature of the objects and the expected turn-over of Log N - Log S. This type of measurement may give us a very useful different approach to the study of QSO evolution.

CONCLUDING REMARKS

It should be clear that the Einstein mission has given X-ray astronomy observational capabilities not too different in their power from those available in the visible or radio range — particularly in the study of objects at cosmological distances. In fact, the Einstein mission has opened for X-ray observation all known classes of stellar and extragalactic objects. X-ray observations have unique capabilities in studying high energy processes, whose fundamental importance in the dynamic and evolution of the universe is becoming increasingly better understood through astronomical observations at all wavelengths.

X-ray astronomy has moved from the consideration of problems intrinsic to the discipline to the study of the great problems of formation and evolution of cosmic objects which are and have been the fundamental questions in astronomy. Yet this observational capability rests entirely on the Einstein mission, which will be over in two short years. I am convinced that just as ST and VLA are essential to modern astronomy, equally essential is the establishment of a permanent orbiting X-ray telescope. I believe this task has the highest priority for all of astronomy in the 1980's.

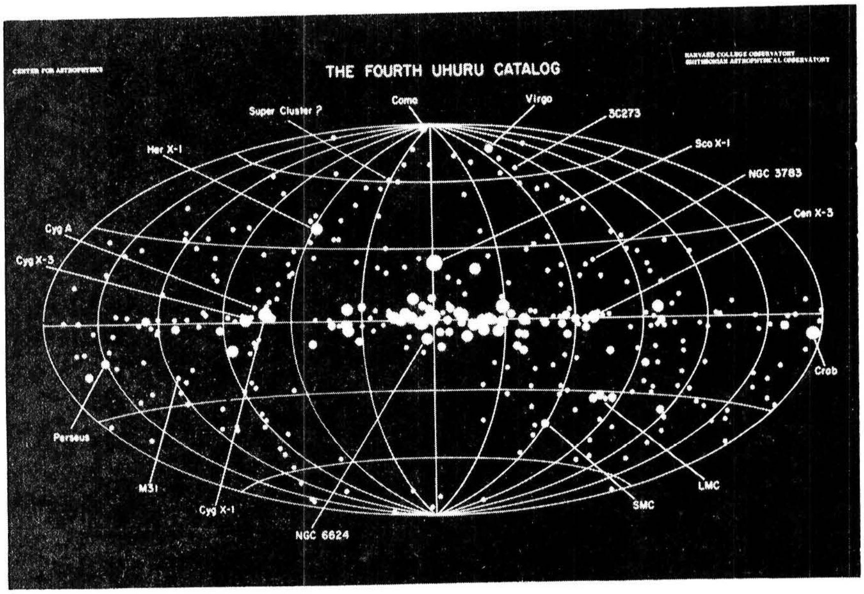

Figure 1

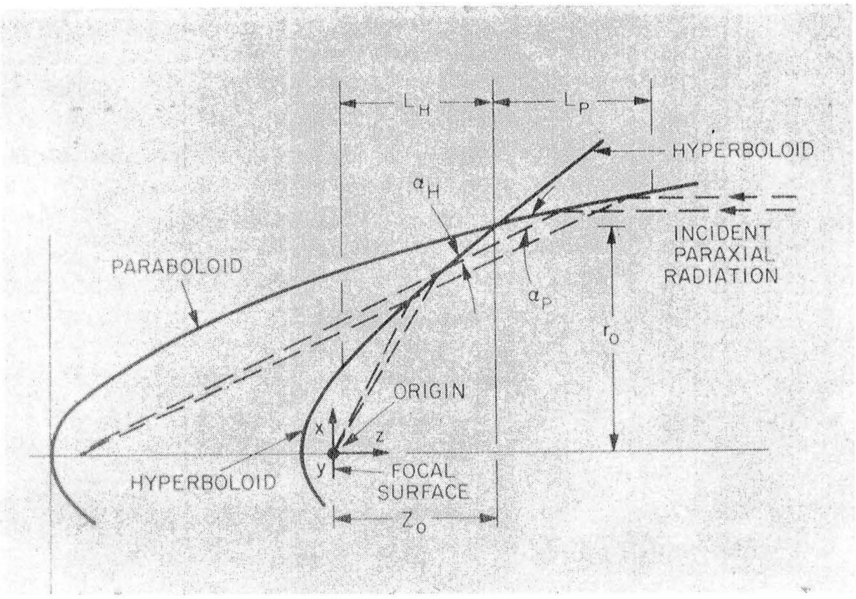

Figure 2

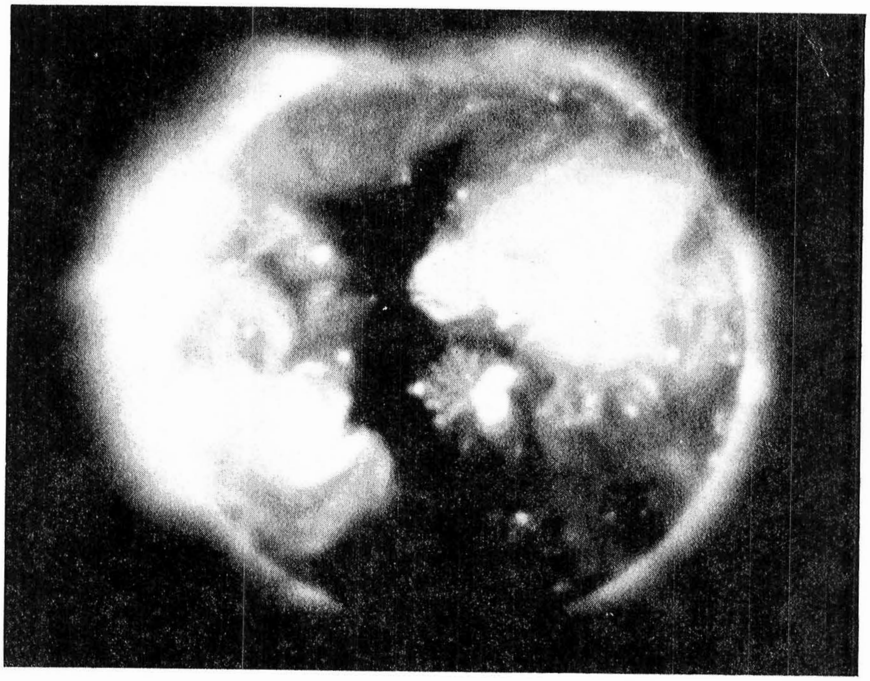

Figure 3

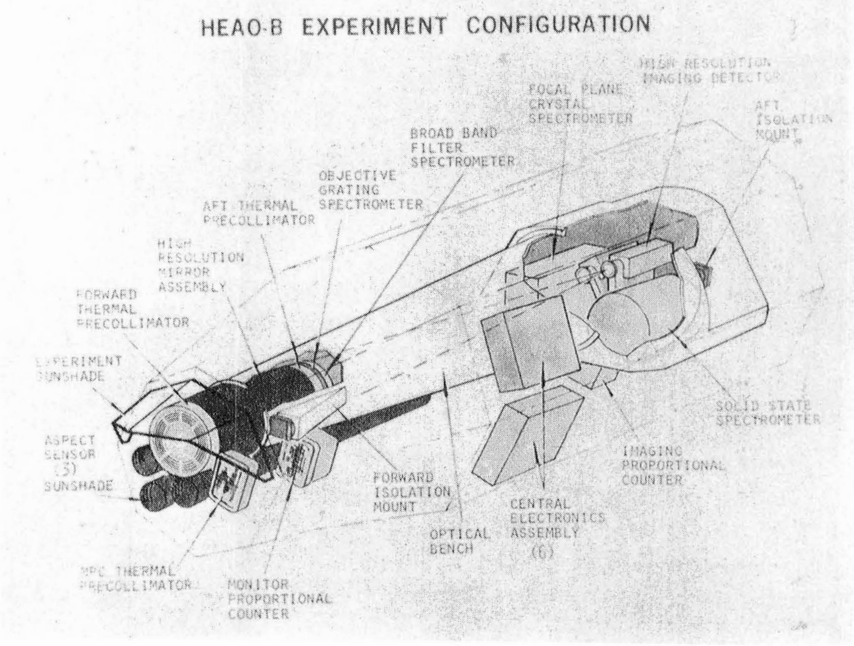

Figure 4

Figure 5

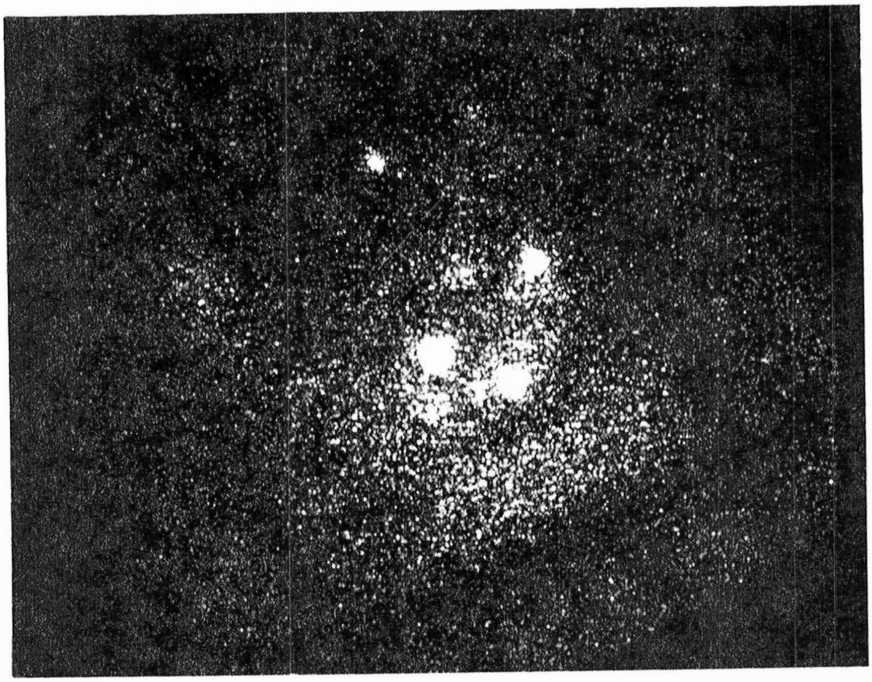

Figure 6

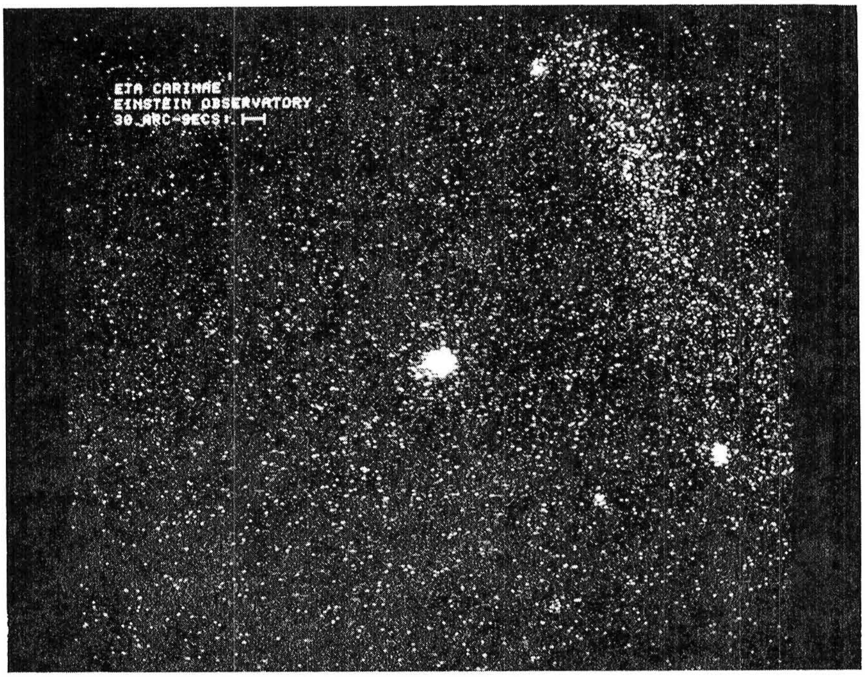

Figure 7

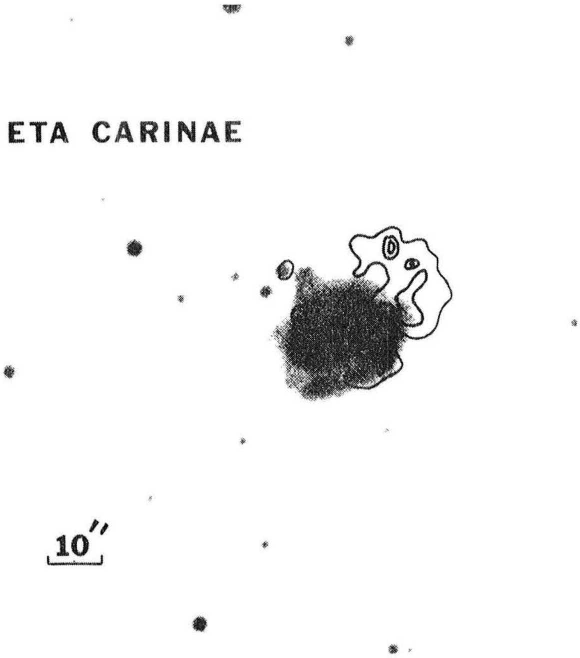

Figure 8

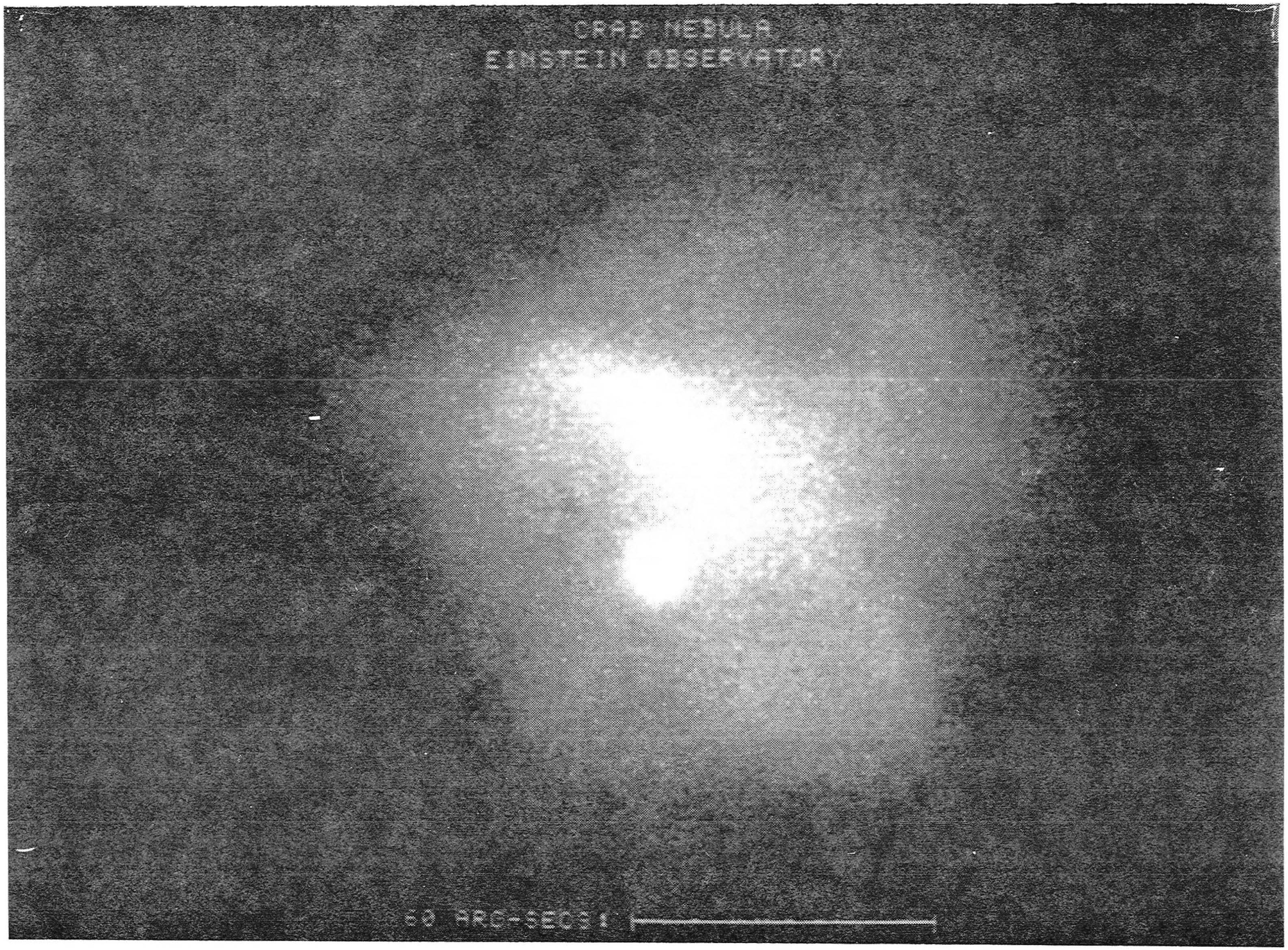

Figure 9

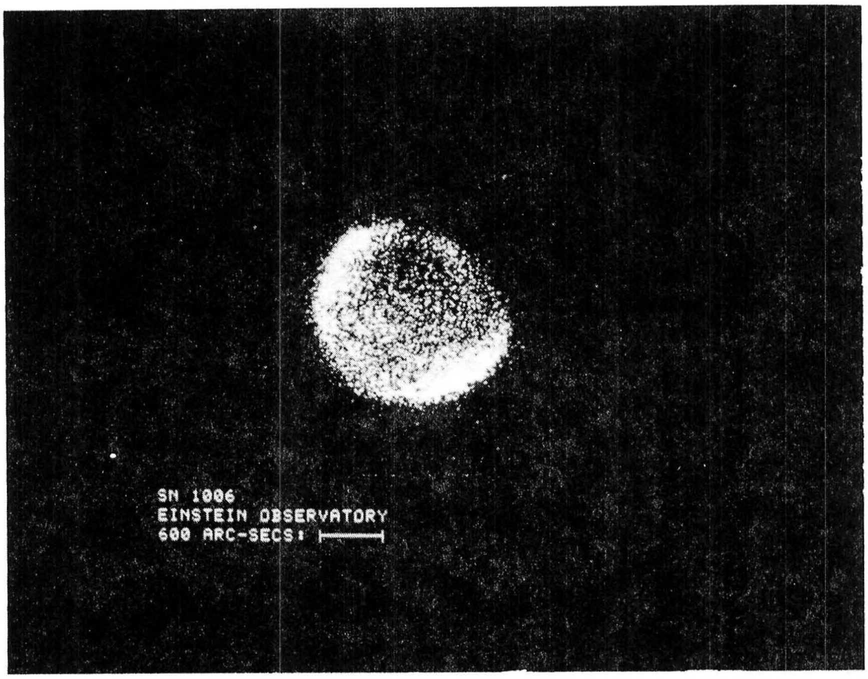

Figure 10

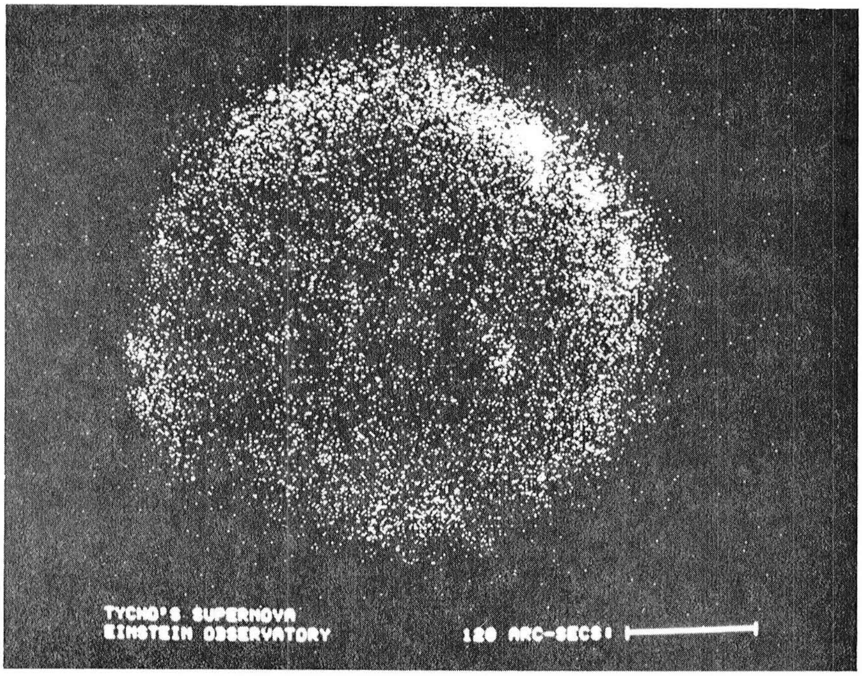

Figure 11

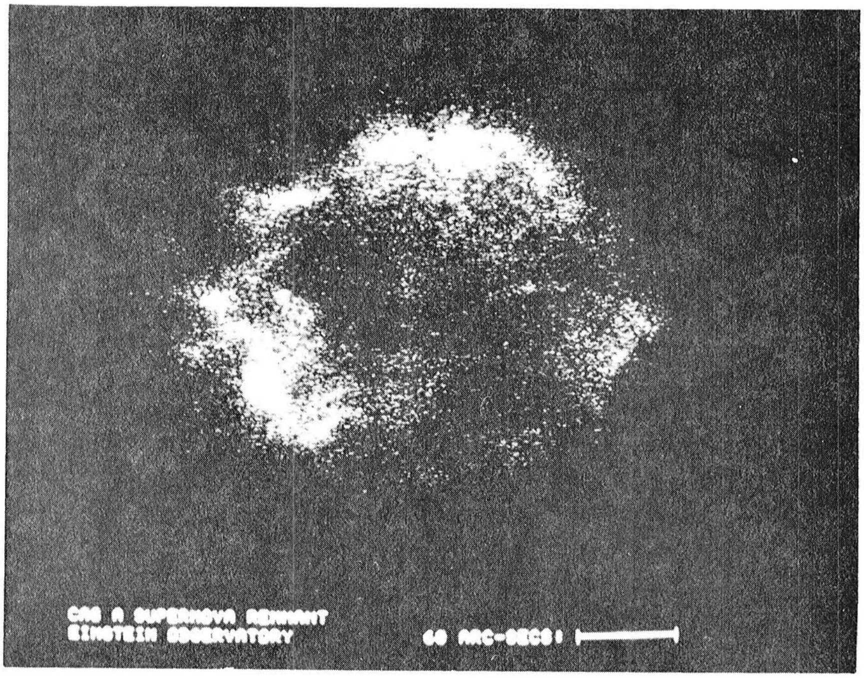

Figure 12

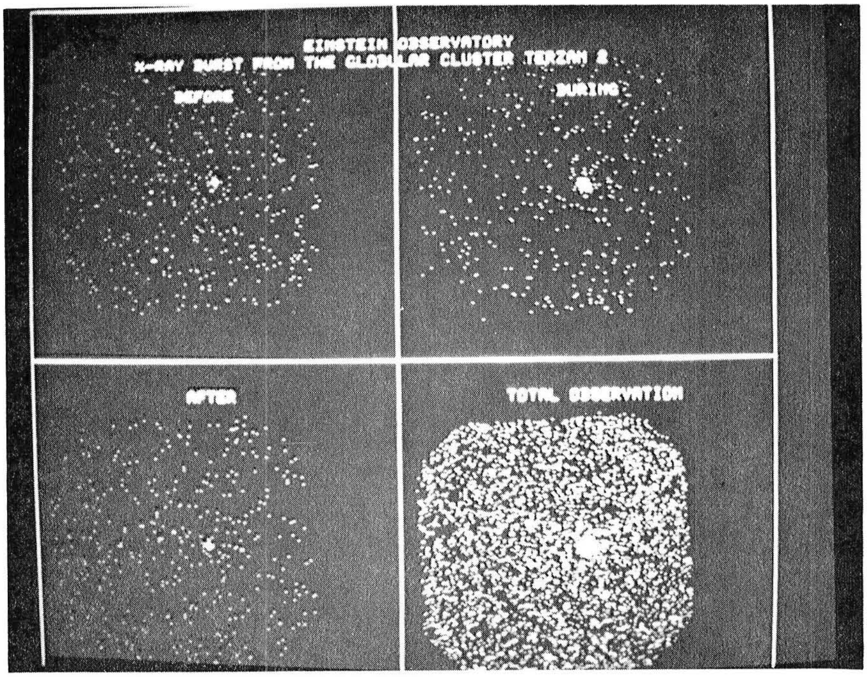

Figure 13

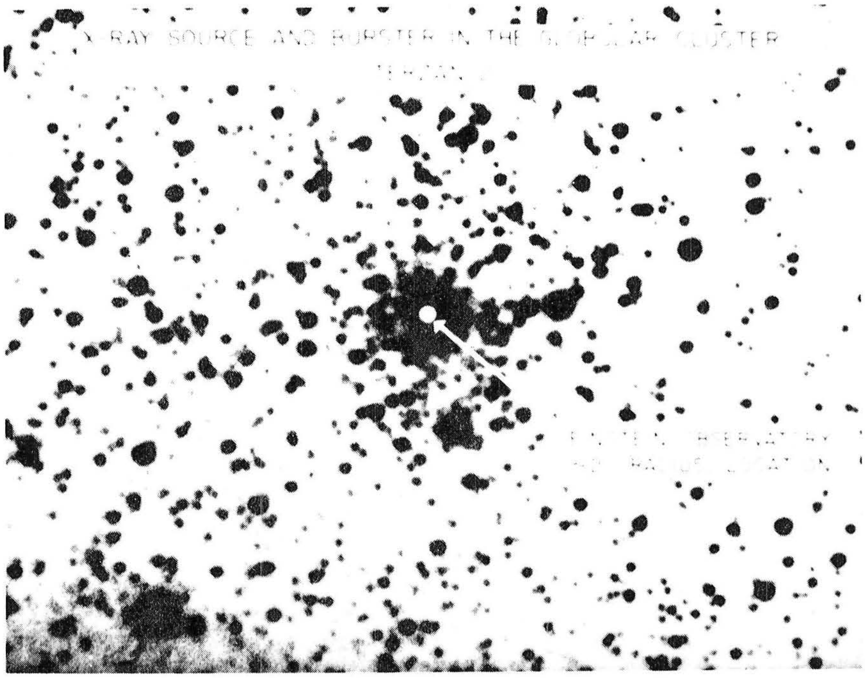

Figure 14

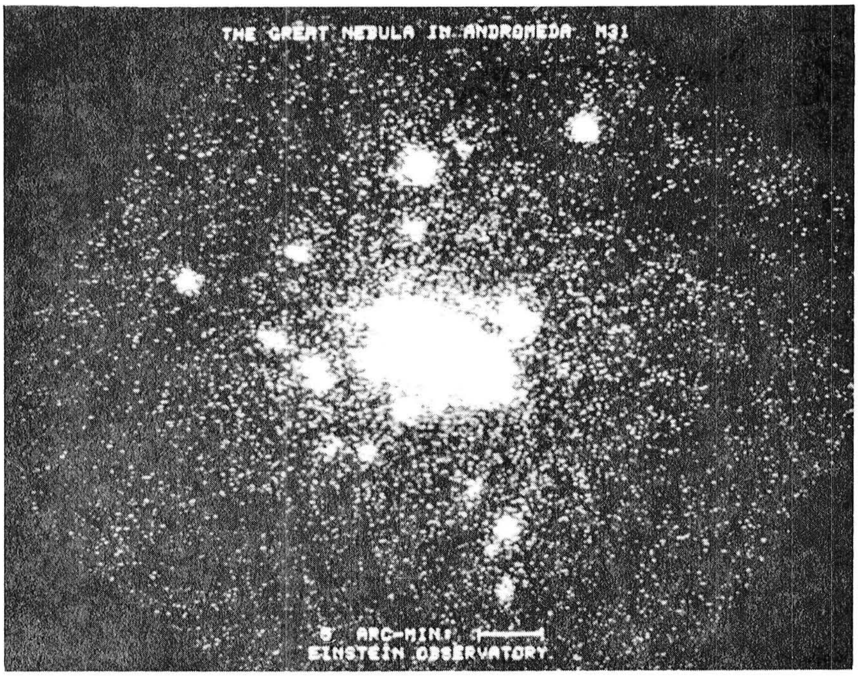

Figure 15

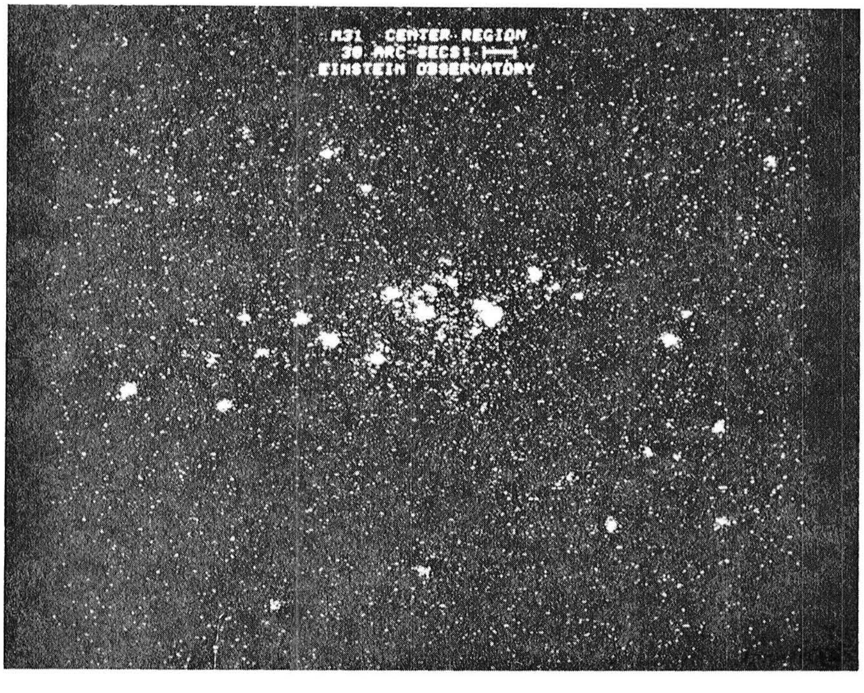

Figure 16

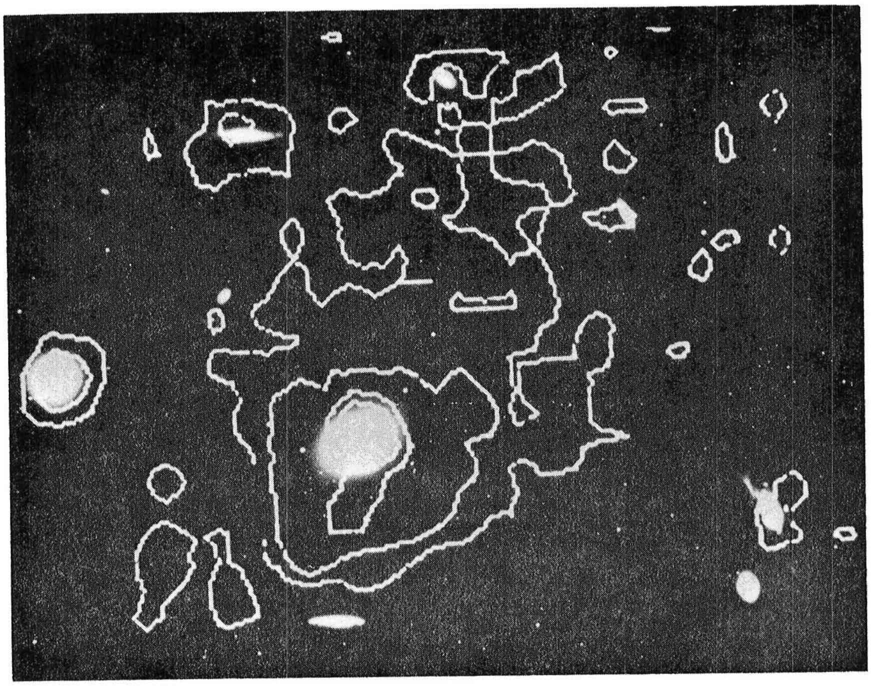

Figure 17

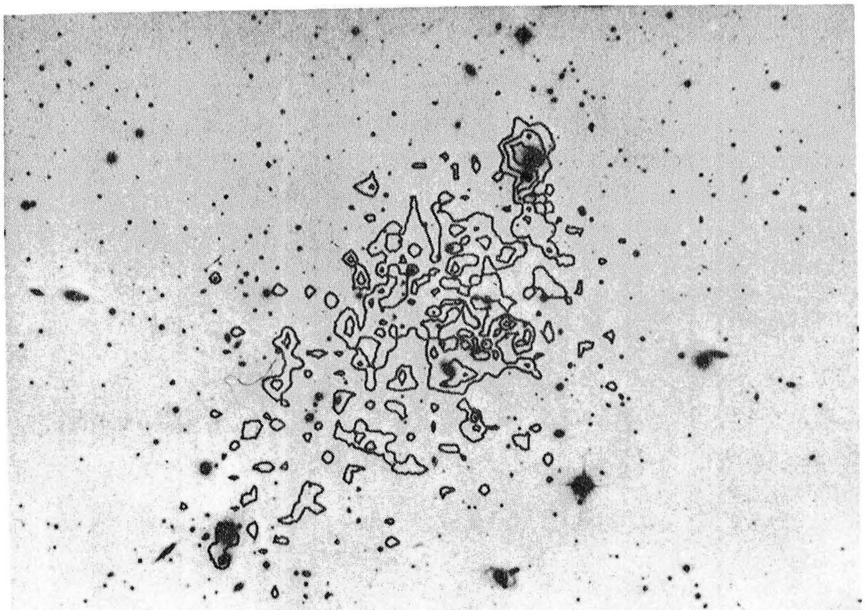

Figure 18

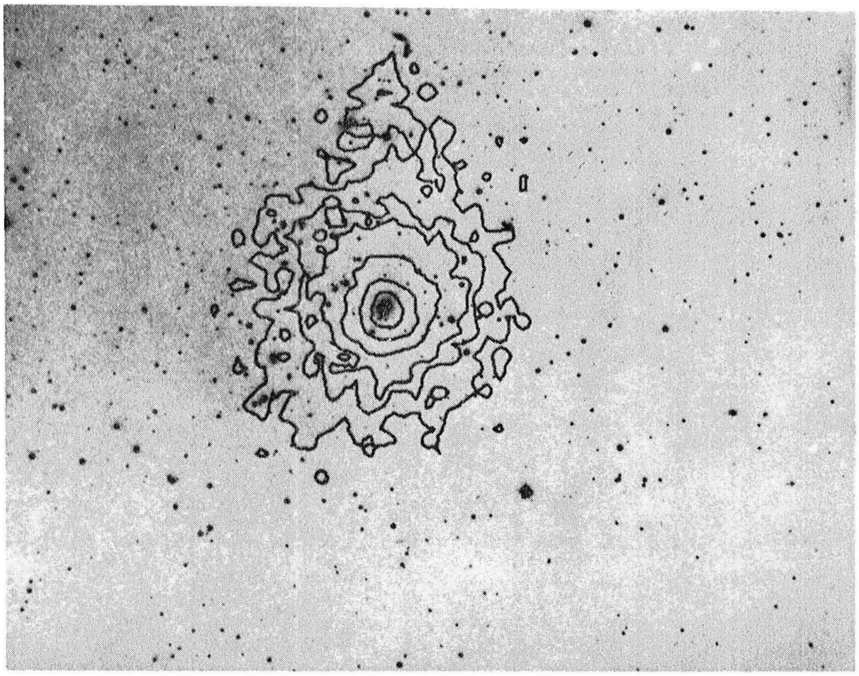

Figure 19

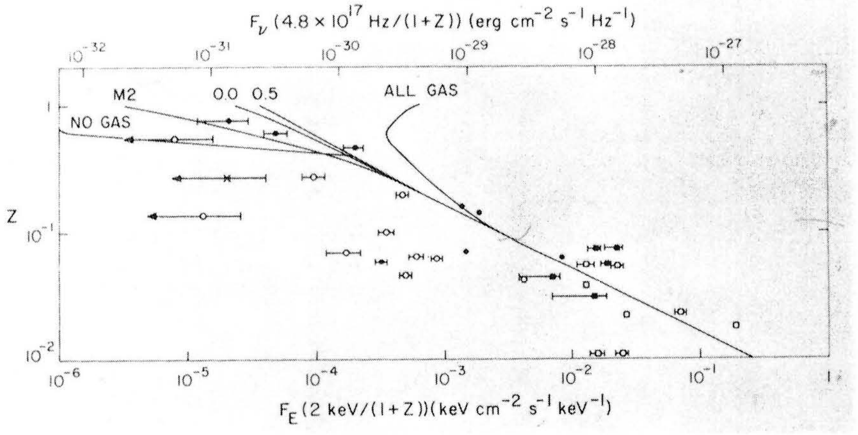

Figure 20

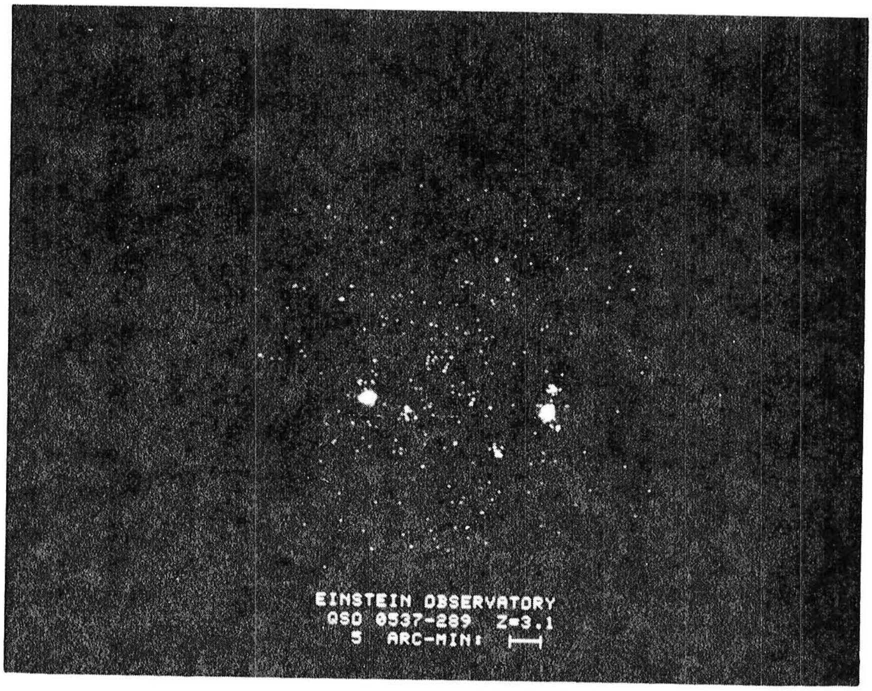

Figure 21

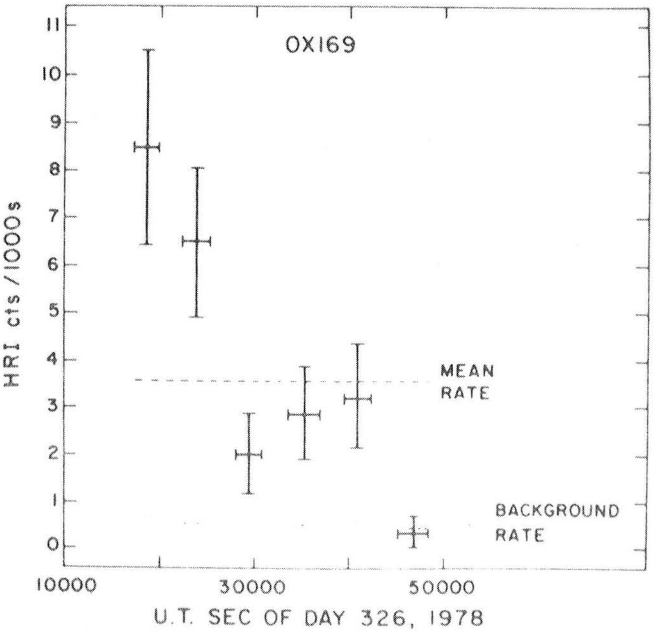

Figure 22

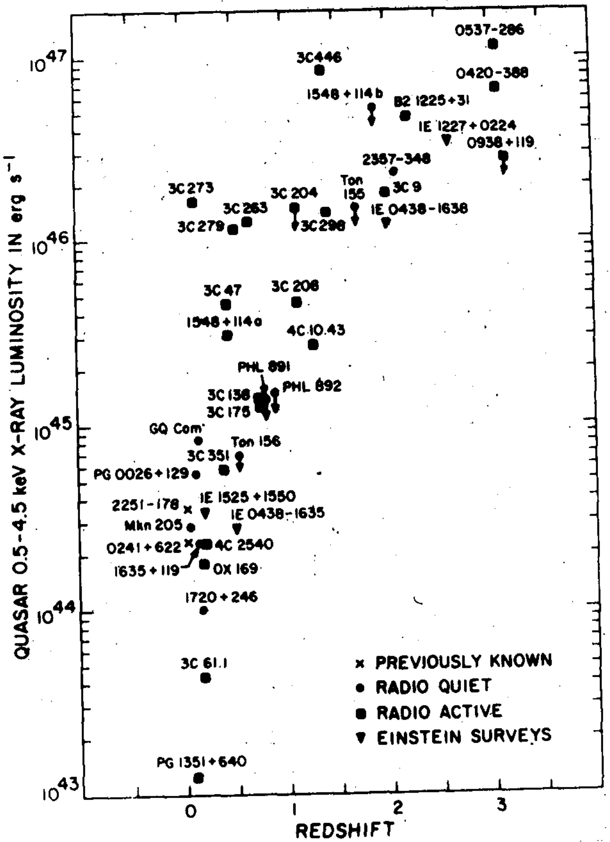

Figure 23

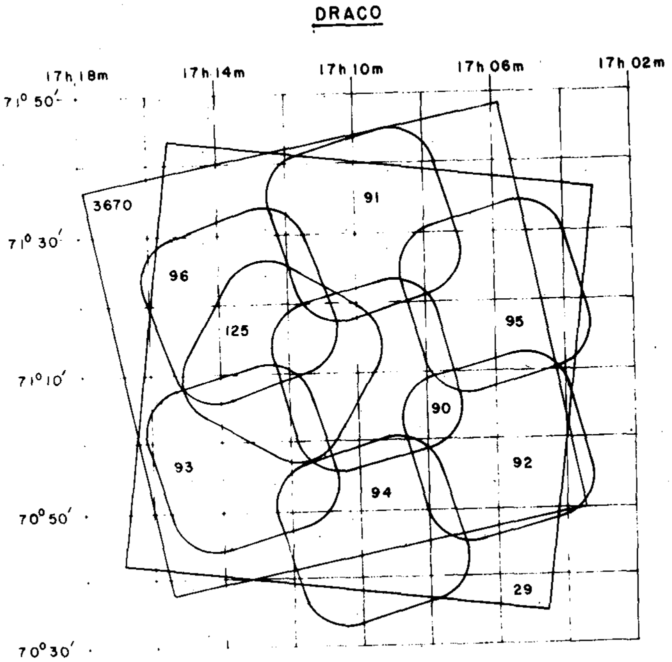

Figure 24

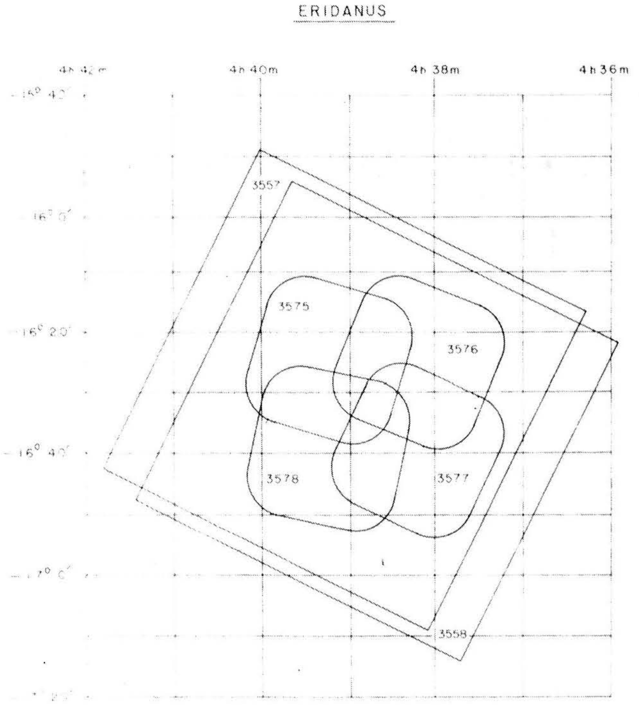

Figure 25

Figure 26

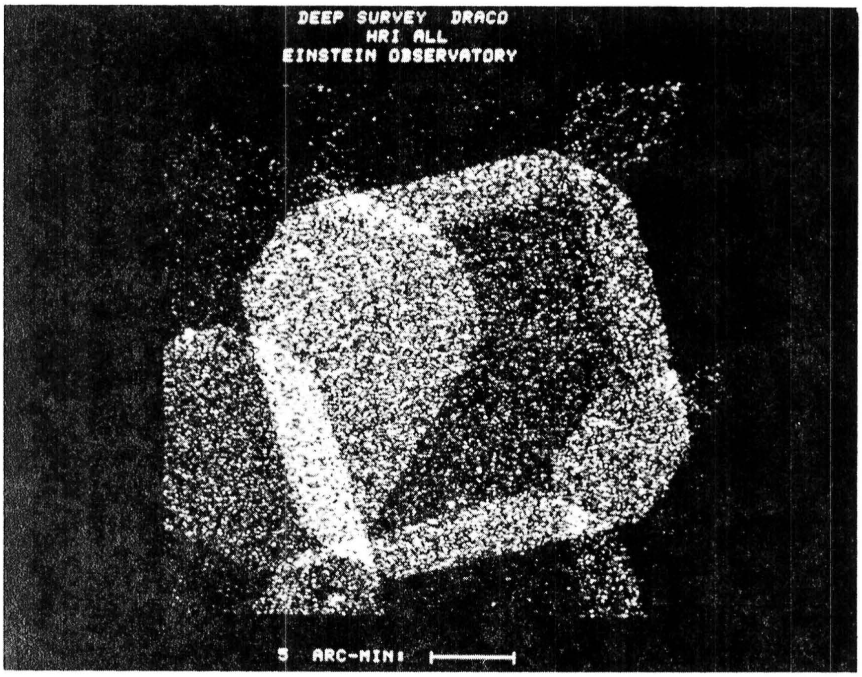

Figure 27

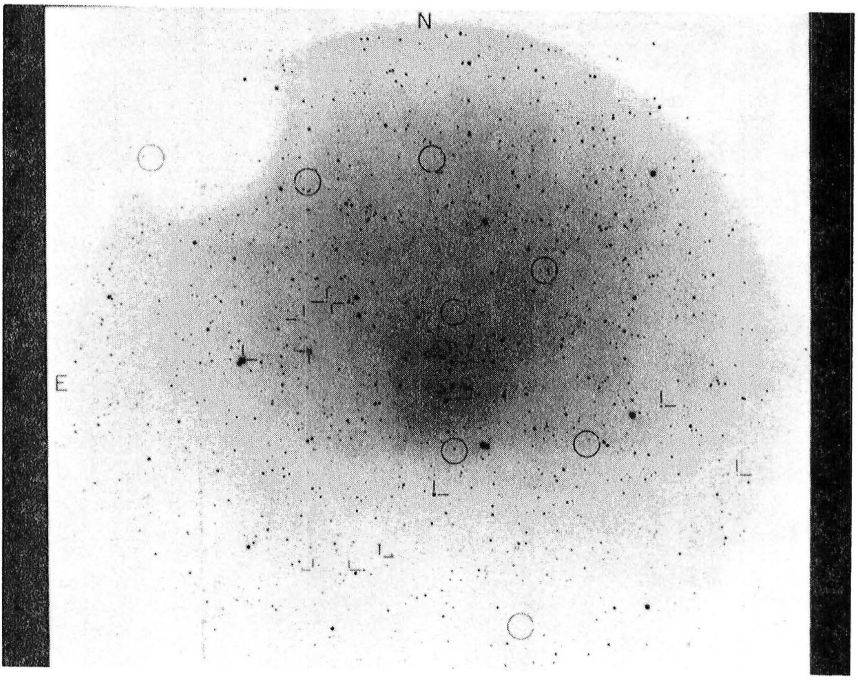

Figure 28

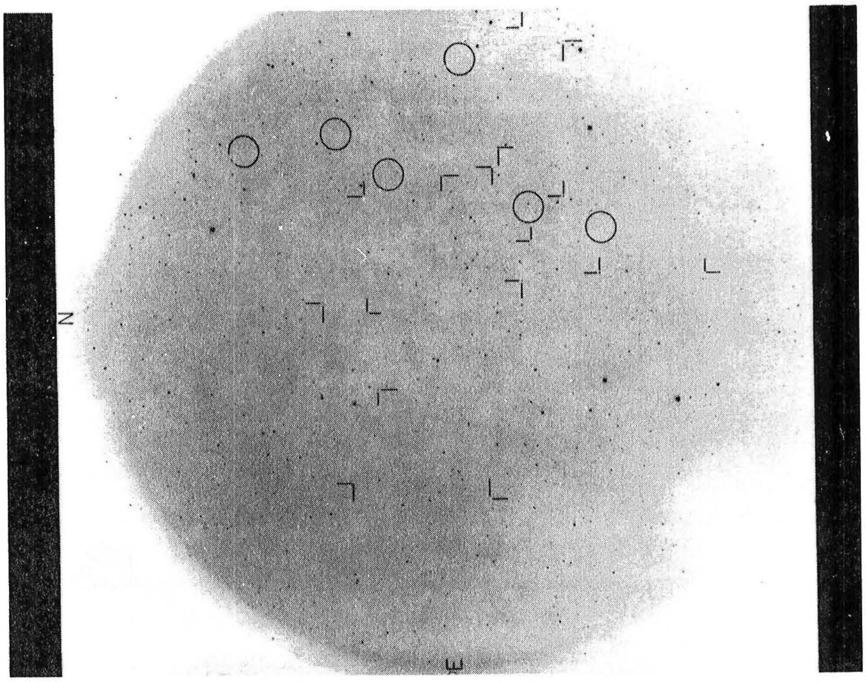

Figure 29

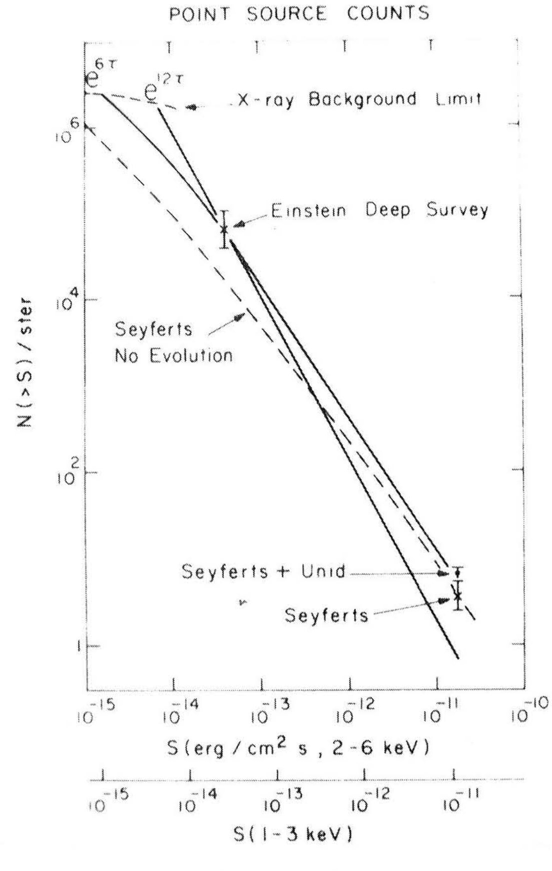

Figure 30