# RECENT X-RAY OBSERVATIONS OF SEYFERTS AND EMISSION-LINE GALAXIES

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It has been just a few years since Type 1 Seyferts were established as a class of X-ray sources with luminosities in the range $10^{42}$ - $10^{45}$ ergs $s^{-1}$ by Elvis et al. (1978) using data from the sky survey instrument on Ariel V, and by Tananbaum et al. (1978) using data from UHURU.

The average error-box sizes for X-ray sources identified with Type 1 Seyferts in the 2A catalog (Cooke et al. 1978) is $\sim$ 0.4 sq. degrees, and $\sim$ 1.0 sq. degrees for those in the 4U catalog (Forman et al. 1978). Improvement in these positions has been made over the past two years by the modulation collimators on board the satellites SAS-3 and HEAO-1. In particular, the HEAO-1 scanning modulation collimator has been used to position a total of 20 X-ray sources, confirming the identification in each case, with the possible exception of Mkn 279 (Dower et al. 1979, Griffiths et al. 1979a). Of the 37 X-ray sources which were discovered prior to the launch of the Einstein Observatory and which have been associated with Type 1 Seyferts, 21 have been positioned to $\sim$ 1 arc minute, representing an improvement by factors of $\sim$ 20 to 100 over the previous 2A and 4U error box sizes. Some examples of the error boxes and identifications confirmed with the HEAO-1 scanning modulation collimator are shown in figs. 1 and 2. In fig. 1 both NGC 7213 (Philips 1979) and MCG - 2 - 58 - 22 (Ward et al. 1978) were discovered to be Seyferts by optical spectroscopy of candidate objects in the error regions of the corresponding X-ray sources. NGC 7213 is a Seyfert nucleus in a galaxy of Type S0 (Philips 1979). In fig. 2, NGC 931 was likewise discovered to be a Seyfert as a result of its X-ray emission (Ward and Wilson 1978).

Timing observations have shown that the X-ray emission from Seyfert galaxies arises in their nuclei. This is confirmed by the high resolution images from the Einstein Observatory in the Center for Astrophysics program of Seyfert observations (fig. 3). The spatial distribution of counts is consistent in all cases with emission from a point source (for the HRI, means a source of extent less than $\sim$ 3 arc secs). The radial distribution of counts around NGC 4151 (fig. 4) fits reasonably with the calculated point response function, as determined from pre-flight



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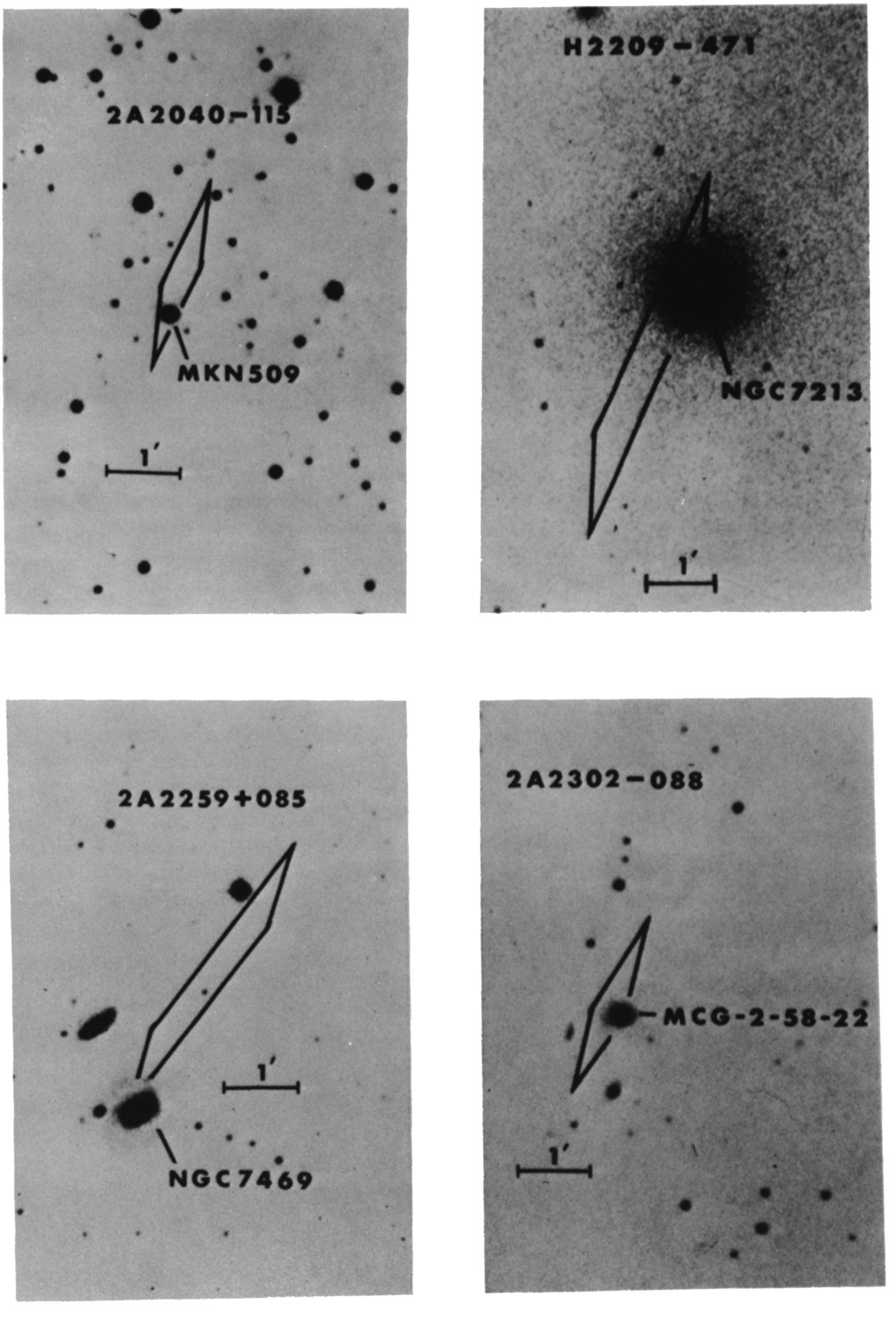


Figure 1. HEAO-1 modulation collimator error boxes for X-ray sources identified with Type 1 Seyferts (from Dower et al. 1979).

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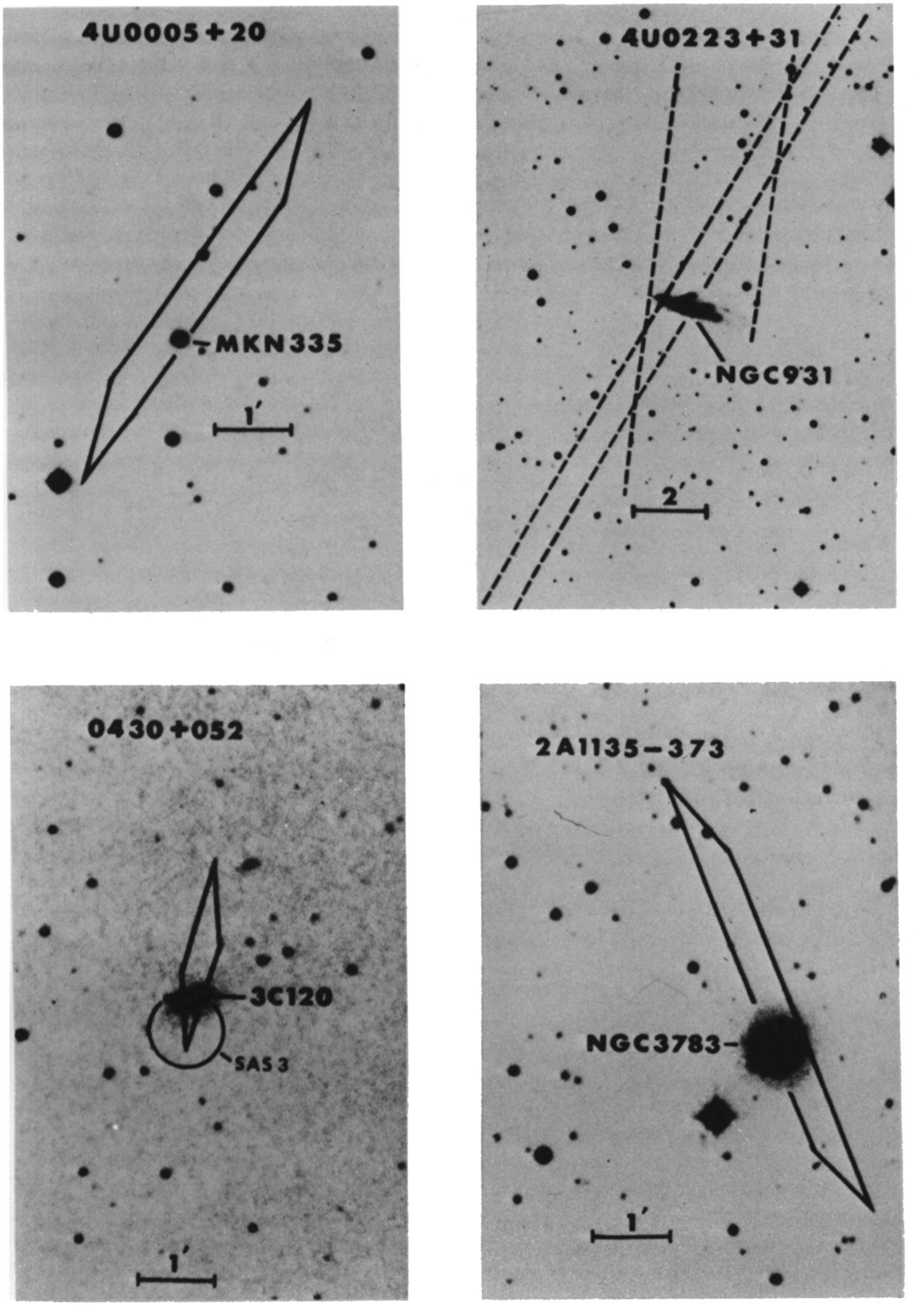


Figure 2. HEAO-1 modulation collimator error boxes for X-ray sources identified with Type 1 Seyferts (from Dower et al. 1979).

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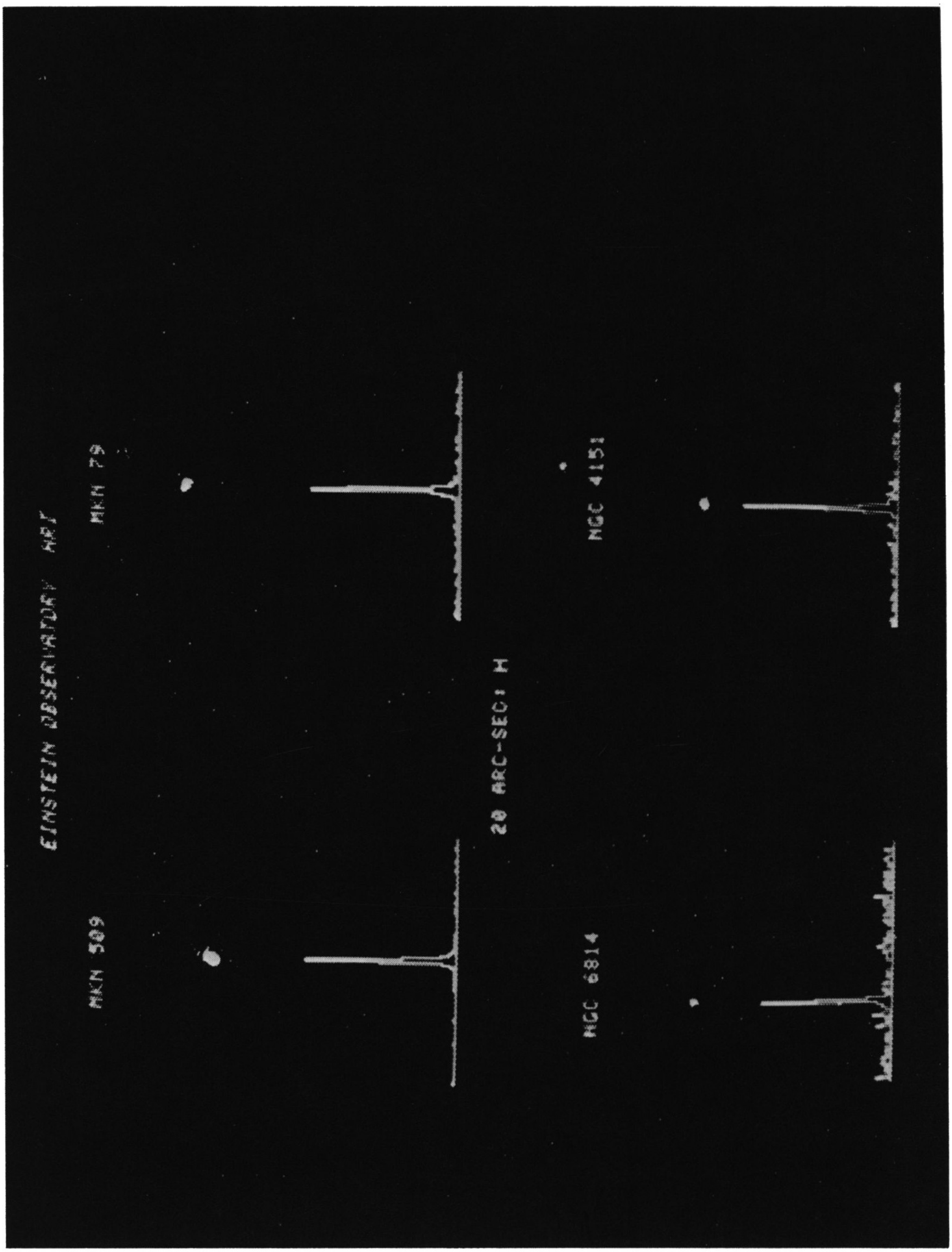


Figure 3. CFA observations of Type 1 Seyferts with the HRI - spatial distribution of counts.

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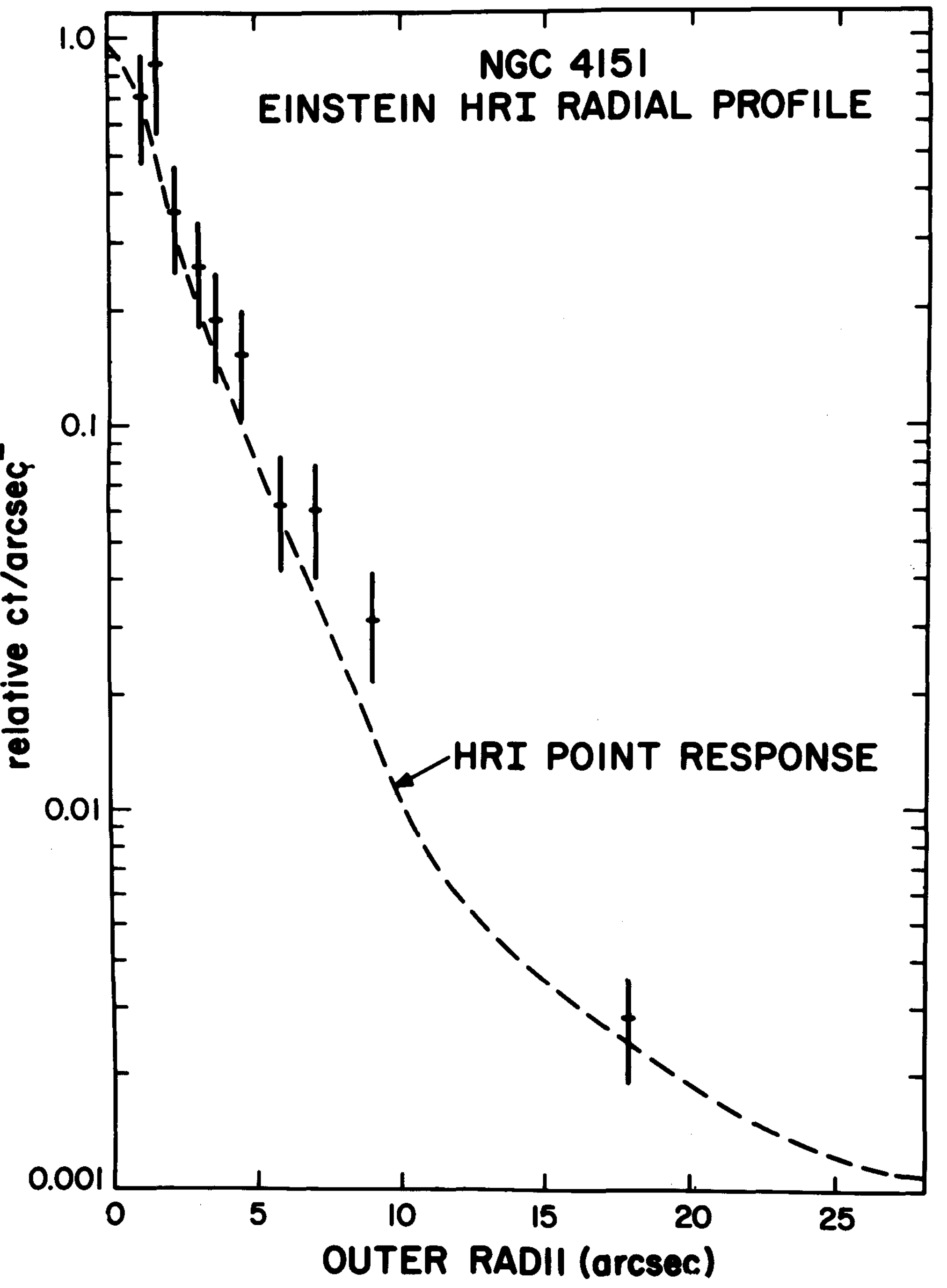


Figure 4. Radial distribution of HRI counts around nucleus of NGC 4151.

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calibrations of the mirror and detector. A more detailed examination of the count rate profile in a search for an extended component is presently underway. At the ∿ 20 Mpc distance of NGC 4151, 2 arc secs = 200 pc, so that the resolution of the instrument is comparable to the angular size of the forbidden-line region (Ulrich 1973). Time variability studies have indicated that at least the bulk of the X-ray emission comes from a region of size between $10^{12}$ and $10^{15}$ cms. To probe the X-ray emitting region, therefore, it is clear that time variability studies are of greatest importance (eg. Lightman et al. 1978) - the Einstein Observatory CFA results on variability in Seyferts and other active nuclei will be presented in the following paper.

The Einstein Observatory X-ray field of NGC 4151 is both interesting and serves as a useful introduction to the emissionline galaxies. Fig. 5a is the proportional counter image showing the nucleus of NGC 4151, the QSO 'r' (Arp 1977), and NGC 4156 (for a description of the corresponding optical field, see Arp 1977). The X-ray luminosities of these three objects are: NGC 4151, $\sim 10^{42}$ ergs $s^{-1}$; QSO 'r' $\sim 10^{46}$ ergs $s^{-1}$ (Z = 1.8, Arp 1979); and NGC 4156, $\sim 10^{42}$ ergs $s^{-1}$ (CZ = 6800 km $s^{-1}$, Sandage 1978). The agreement between the HRI positions (fig. 5b) and those of the optical counterparts are of the order of several arc seconds, within the uncertainties of the measurements.

Emission-line galaxies observed with the Einstein Observatory.

Table 1 summarizes the CFA observations of emission-line galaxies and Type 2 Seyferts made with the Einstein Observatory to date (August, 1979). While the X-ray luminosities of the Type 2 Seyfert NGC 2992 and NGC 4156 are of the order of $10^{42}$ ergs $s^{-1}$, the values of $L_x$ for the other emission-line galaxies are of the order of $10^{40}$ ergs $s^{-1}$. The possibility of distinguishing between Type 2 Seyferts and non-Seyferts based on their value of $L_x$ seems to be stymied by high-excitation narrow-line galaxies of intermediate $L_x$ (eg. NGC 7582 (Ward et al. 1978), NGC 4156 and MCG - 5 - 23 - 16 (Schnopper et al. 1978)).

Individual emission-line galaxies will be discussed in the following sections:

NGC 1672

A bright-nucleus spiral (Sersic and Pastoriza 1965), NGC 1672 was observed recently (July 1979) at the Anglo-Australian Telescope using the Image Photon Counting System (by M.G. Smith, M.J. Ward and R.E.G.) showing low excitation, with narrow H α, H β, [S II] but no [O III] ([O III] 5007: H β $\lesssim$ 0.3), confirming the conclusions of Pastoriza (1967). A preliminary analysis of the proportional counter image of NGC 1672 shows an apparently double structure, with the two components separated by about 2 mins (the separation of the ends of the 'bar'). With the present uncertainty in the absolute positions from the IPC, however, (1 arc min) it is quite likely that one component is identifiable with the nucleus of the galaxy and the other is a background or

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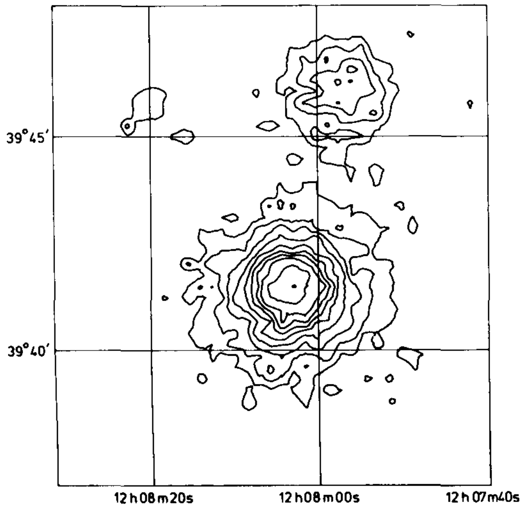
TABLE 1.

C.F.A. OBSERVATIONS OF EMISSION-LINE GALAXIES WITH EINSTEIN OBSERVATORY

| OBJECT | D Mpc | $L_x$ (1-3 KeV) ergs $s^{-1}$ | |
|---|---|---|---|
| N 2992 | 25 | $10^{43}$ | SEYFERT 2 |
| N 4156 | 137 | $10^{42}$ | |
| N 1672 | 15 | $4.10^{40}$ | DOUBLE SOURCE? |
| N 3310 | 15 | $3.10^{40}$ | |
| N 3125 | 22 | $3.10^{40}$ | |
| M 82 | 3 | $10^{40}$ | STRUCTURE (FIG. 6) |



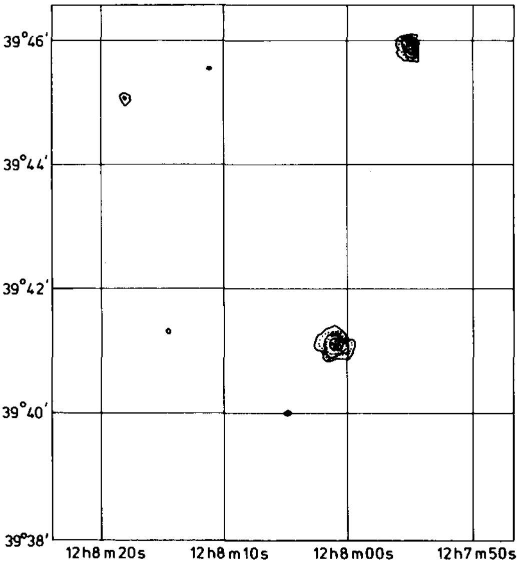




Figure 5a. Einstein Observatory proportional counter image of NGC 4151 field. The nucleus of NGC 4151 is the lower source. QSO 'r' is at upper center, and NGC 4156 is upper left.

Figure 5b. High-resolution image of NGC 4151 field.

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foreground object. This hypothesis is supported by the possibility of radio variability of the nucleus (Tovmassian, 1968).

NGC 3310

NGC 3310 is a small, peculiar, very blue galaxy (an 'extragalactic H II region'), also known as the 'bow and arrow' galaxy (Walker and Chincarini 1967). Its X-ray luminosity, as observed with the IPC, (which does not resolve the galaxy) is $\sim 3.10^{40}$ ergs $s^{-1}$ (1-3 KeV), and the possible sources of this X-ray luminosity are as follows:
(I) The nucleus: there is no intense optical nucleus as in Seyfert galaxies, but a bright, flat-spectrum radion nucleus has been noted (Seaquist and Bignell 1977), two orders of magnitude more luminous than Sag A. It is therefore quite possible that most of the X-ray luminosity arises in the nucleus.
(II) O-Type stars: from observations of the H II regions (Van der Kruit and De Bruyn 1976), it is estimated that $2.10^4$ stars of spectral type 05 are present. From observations of O-stars with the Einstein Observatory in VI Cygni (Harnden et a. 1979) and in $\eta$ Car nebula (Seward et al. 1979) we can estimate a typical X-ray luminosity $L_X \sim 5.10^{33}$ ergs $s^{-1}$ for each O-star. The total X-ray luminosity of Ostars within NGC 3310 is thus likely to fail by two orders of magnitude to account for the observed fluxes.
(III) Diffuse emission from H II regions, as from the $\eta$ Car nebula itself - since, however, the $\eta$ Car nebula has $L_X \sim 10^{35}$ ergs $s^{-1}$, $10^5$ such objects are needed to explain $L_X$ for NGC 3310 (one $\eta$ Car - type nubula for each O-star!) and this is again excessive by about two orders of magnitude.
(IV) X-ray emission from the regions of the non-thermal radio sources (Seaquist and Bignell 1977, and Van der Kruit and De Bruyn 1976) found to be concentrated in the regions where the spiral arms join the ring-like feature around the nucleus. These non-thermal radio sources are $10^3$ - $10^4$ times more luminous than Cas A at 8 GHz, and may result from enhancements in the density of relativistic electrons and magnetic field strength associated with the spiral density wave (Seaquist and Bignell 1977). It seems possible that these regions are also largely responsible for the observed soft X-ray emission (c.f. above discussion on NGC 1672).
(V) Binary X-ray sources - at the level of X-ray emission from the binary SMC X-1 ($\sim 10^{38}$ ergs $s^{-1}$), 100 such sources are required, i.e. $\sim$ 1% of all 'O'-stars present. This does not seem excessive, and such binaries may contribute a substantial fraction, if not all of the X-ray emission present.

A high-resolution observation of NGC 3310 is therefore necessary in order to establish whether the nucleus is the X-ray source or whether the emission is diffuse.

M 82

The problem of deciding on the main X-ray production region in M 82, unresolved by previous observations (Griffiths et al. 1979b), has been

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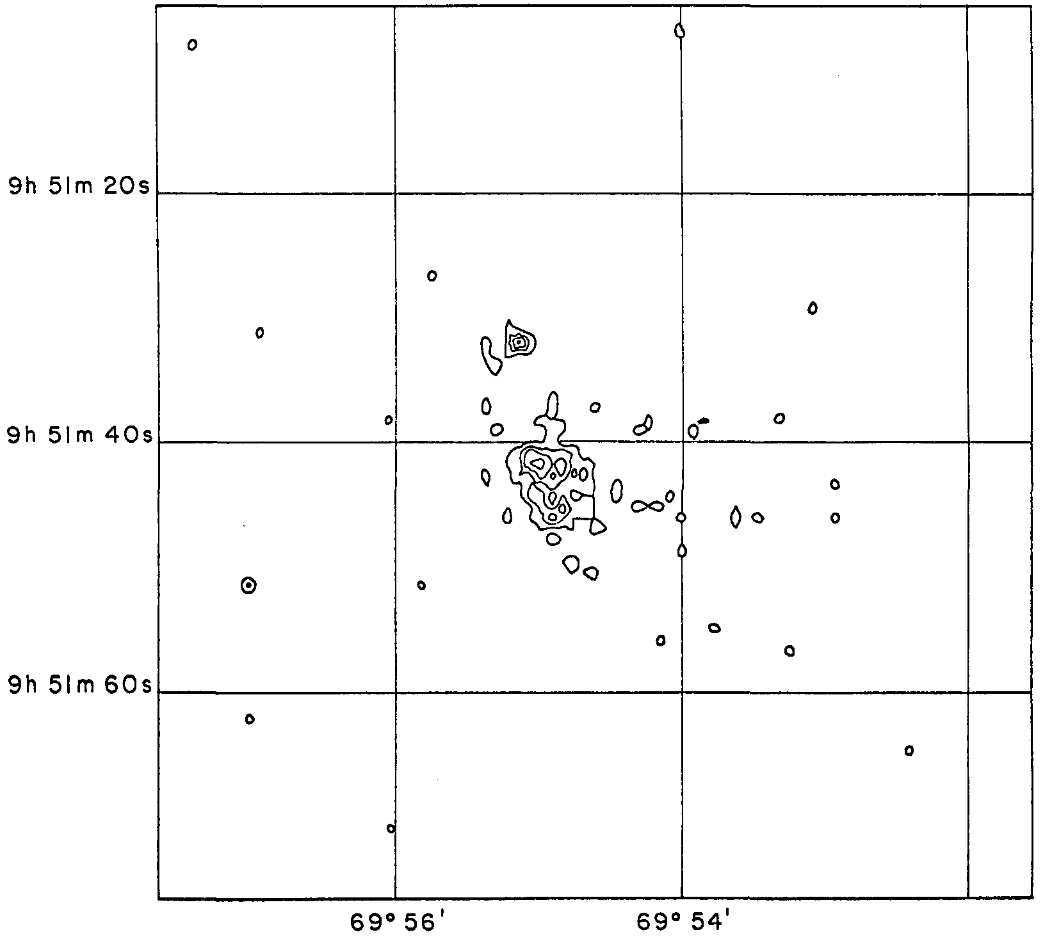


Figure 6. High-resolution image of M 82.

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largely solved by the high resolution imager - the X-ray contour map is shown in fig. 6. A preliminary analysis of the data indicates the presence of two point components, one coincident (within errors of a few arc seconds) with the bright radio nucleus (Hargrave, 1974, Kronberg and Clark, 1978) in fig. 6. and the other near the edge of the optical image, having no obvious optical or radio counterpart. These point sources are each of the order of $\sim 10^{39}$ ergs $s^{-1}$. Hargrave (1974) predicted a nuclear X-ray source of $\sim 10^{40}$ ergs $s^{-1}$ from the inverse-Compton scattering of infra-red photons by the electrons responsible for the radio emission, and this would seem a likely explanation of the observed flux.

The bulk of the X-ray emission from M 82 is, however, diffuse (fig. 6) and extends into the region of the blue globulars (Solinger et at. 1977) as well as outwards into the region of the filaments possibly indicating the presence of hot gas there, or else a synchrotron source. A detailed discussion of the X-ray image of M 82 will be published elsewhere.

In conclusion, the Einstein Observatory data on several unusual emission-line galaxies have indicated X-ray luminosities $L_x > 10^{40}$ ergs $s^{-1}$. In the case of the peculiar galaxy M 82, the emission is observed to come mainly from many discrete sources or a diffuse source extending into the region of the filaments. For the other emission-line galaxies, it is not yet clear whether the X-ray source is principally nuclear or arises from multiple components.

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