X-Ray Surveys with the Einstein Observatory

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Introduction

Two different types of survey with the imaging instruments included in the Einstein Observatory are yielding results of particular interest in extragalactic astronomy and cosmology. The first is known as a "deep field" survey, and we will describe here the results for an observed region in Pavo. The second type is the "medium sensitivity survey" which attempts to identify a complete sample of faint X-ray sources (energy $10^{-11.5}$ to 10^{-13} ergs cm^{-2} s^{-1} in the 0.3–3.5 keV soft X-ray band) detected in the fields of previously known or studied X-ray sources. At present, the "medium sensitivity survey" is still being worked on and results are very preliminary.

The Pavo Field

It was the purpose of the Pavo deep field survey (as well as those in Ursa Minor and Eridanus) described by Giacconi *et al.* (1979, *Ap. J.* **234,** L1) to detect all sources in a restricted field (40 arcminutes square) down to a limiting intensity of 1.3×10^{-14} ergs cm^{-2} s^{-1} in the energy range 1 to 3 keV. In this way one expected to resolve the diffuse X-ray background to this limit and then to identify optically these resolved sources. The Pavo field (21^h 10^m, $-68°$) was chosen because it is at high galactic latitude and contains no unusual optical or radio sources and no previously known X-ray sources. It was first observed with the IPC (Imaging Proportional Counter, whose spatial resolution is ~ 1 arcminute) for 69,000 seconds, and subsequently 4 exposures were made with the HRI (High Resolution Imager whose spatial resolution is ~ 2 arcseconds) with exposure times from 58,000 to 96,000 seconds. The IPC observation revealed 28 X-ray sources of which 22 were detected with the HRI. These 22 sources form the basis of the analysis discussed below.

Deep direct plates of the Pavo field were obtained in colours roughly equivalent to B and V, with the Anglo-Australian Telescope. Magnitudes of all objects, for which J (~ B) was brighter than 23.8, were measured with COSMOS at the Royal Observatory Edinburgh. This process yielded 3,522 point sources (stars and quasars) and 1965 extended sources (galaxies) in the Pavo field. Of the 22 X-ray sources 3 show no optical counterpart in the error boxes, 14 have 1 image, 4 have 2 images and 1 has 3 images.

The number/J magnitude count for galaxies in Pavo is similar to that observed in other parts of the sky. Also the colour-magnitude diagram for stars is similar to other regions, in that one observes 2 populations of stars (or stellar objects); a red population extends redward from B–V ~ 1.6 and fainter than B ~ 20, and a yellow population with approximately constant B–V ~ 0.6 extends over a wide range of magnitude to the plate limit. The effect can be seen in Figure 1. This yellow population of stars is thought to be a halo population extending to 50 kpc from the Galaxy. The equivalent diagram for galaxies is shown in Figure 2.

Spectra of 9 candidate objects in 9 fields have yielded 4 quasars. These spectra of objects as faint as 20.7 were obtained with spectrographs on the AAT and the 3.6-m telescope at La Silla. Because of the low expected surface density of quasars we can say that these 4 identifications are virtually certain. The spectroscopy and direct plate material show that 4 galaxies and 3 stars are included in the candidate list. Because of the much higher surface density of stars and galaxies in this field, the presence of these 7 objects is consistent with chance coincidences with the X-ray error boxes.

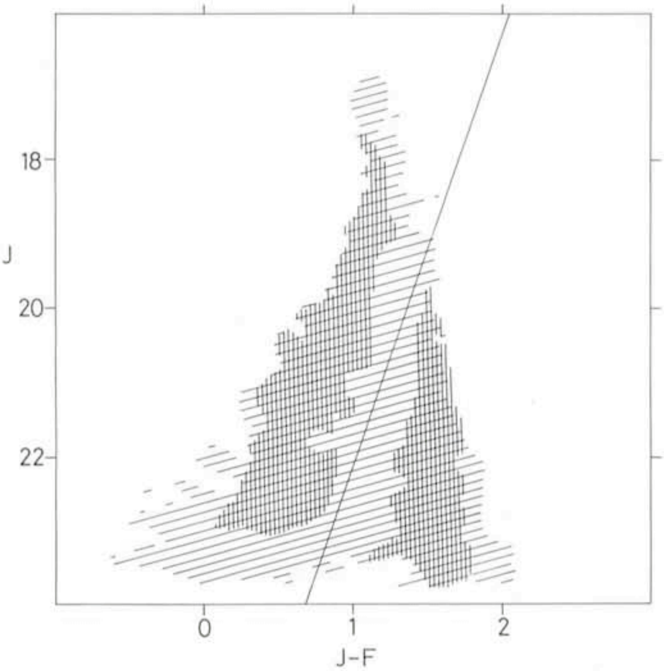

Fig. 1: *Schematic colour-magnitude diagram for point sources in the Pavo field. The shading is intended to convey an idea of the density of points in this graph. J–F is roughly equivalent to B–V.*

We noted above that 3 X-ray sources had no optical counterparts and 4 have certain identifications as quasars. It is therefore the nature of the remaining 15 identifications that is crucial to

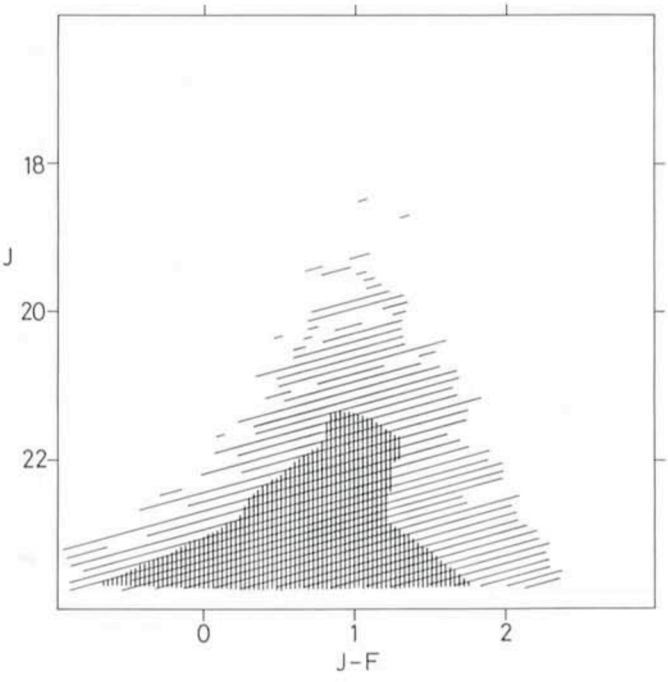

Fig. 2: *Schematic colour-magnitude diagram for extended sources in the Pavo field.*

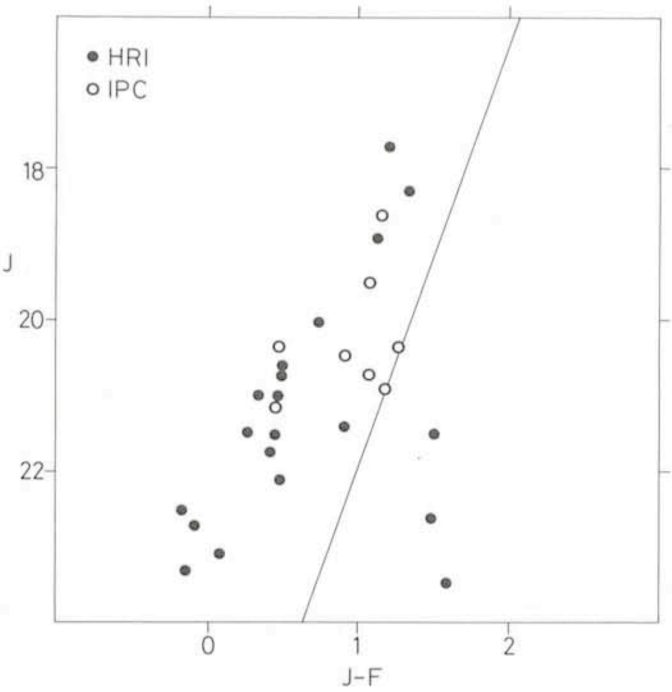

Fig. 3: *Colour-magnitude diagram for selected X-ray point sources in the Pavo field.*

our understanding of the source content. Unfortunately 13 of these X-ray sources have candidates in the error boxes 21 magnitude or fainter, which are at present beyond the reach of currently available spectroscopic equipment in the southern hemisphere. One is therefore forced to resort to statistical arguments to make further progress.

A statistical test comparing the proportion of red and yellow stars in the X-ray candidates and in the field stars shows that a much higher proportion of the X-ray candidates belongs to the yellow population. However, because we have only 17 stellar objects as candidates in the yellow population, we cannot conclude that the number-magnitude relationship is significantly different from that found for the yellow field stars. One sees this effect in Figure 3. Thus far, one has shown only that a reasonably high proportion of these candidates *could* be quasars. The statistics of small numbers does not preclude the possibility that a reasonably high number could be galactic stars. One can argue that number counts for all quasars provide sufficient objects to account for all the X-ray candidates. This is a necessary but not sufficient condition in this statistical approach, since there are also enough yellow field stars to do the same trick! Similarly, an argument based on the ratio of X-ray to optical luminosity of the candidates is only strong enough to be consistent with their being quasars, but does not rule out yellow stars as possible sources. One has noted also that the average colour of the candidates is bluer than the average colour of the yellow field stars. Even if this is a statistically significant result, it is premature to draw strong conclusions from it without knowing what the average colour of faint X-ray *stars* might be. Finally, one should not overlook the fact that Warwick *et al.* (*Monthly Notices of the Royal Astronomical Society* **190,** 243, 1980) have observed a 2.5 to 7.2 per cent anisotropy in the X-ray background which is consistent with galactic stars in an extended halo providing a considerable proportion of the candidates.

Radio observations at 6 cm with the Parkes 64-m telescope detected only one source associated with the X-ray identifications. This was one of the four quasars and it has an inverted spectrum. Thus no unusual radio properties have been observed.

It is now apparent that use of the Pavo deep field survey to settle questions of the X-ray background requires more detailed knowledge of 12 to 14 candidates for which spectra are lacking. Until the Space Telescope is in operation the best possibility for achieving this seems to be multi-colour observations with broad or intermediate band filters capable of distinguishing quasars from stars, and a sensitive linear detector.

The Medium Survey

At this stage the optical observations and analysis of sources detected in the medium survey are continuing, and may eventually lead to stronger conclusions than the deep field surveys have provided. When all the results are combined there should be well over 100 source identifications from both hemispheres to be discussed and evaluated. In the meantime a zoo of interesting identifications is expanding. Members of this zoo include quasars, Seyfert galaxies, clusters of galaxies, BL Lac objects and stars.

Only one BL Lac object has been found in an optical identification programme for a complete sample of *faint* X-ray sources. Since this one object represents 2 per cent of the total content, which is less than the 7 per cent content found for brighter X-ray sources, one can say that BL Lac objects do not evolve similarly to quasars and Seyfert galaxies! These latter objects change their contribution from 41 to 74 per cent over the same range of decrease of X-ray flux. Given this trend it seems probable that BL Lac objects do not contribute significantly to the soft X-ray background. Their evolutionary trend is rather similar to that shown by clusters of galaxies, where only weak cosmological evolution is apparent.

The work described in a qualitative way above results from collaborations with various combinations of the following astronomers: R. E. Griffiths, J. Bechtold, R. Giacconi, S. S. Murray, P. Murdin, M. Smith, H. McGillivray, M. Ward, J. Lub, B. Peterson, A. Wright, M. Batty, D. Jauncey, D. Malin, J. Stocke, J. Liebert, H. Stockman, T. Maccacaro, D. Kunth, H. de Ruiter.

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