maximum is reached at an atmospheric depth of about 100 gm cm^{-2}. It then decreases as the balloon reaches float altitude. The cosmic X-ray background however does not become evident until about 10 gm cm^{-2} has been reached and it then increases with altitude. Figure 1 illustrates the behaviour of the total background counting rate in energy channel 3 (37-47 keV) as a function of atmospheric slant depth which is used instead of vertical depth because of the inclination of the telescope axis at 32° to the zenith. The Pfötzer maximum is evident at $\sim$ 100 gm cm^{-2} as is also the increase due to the cosmic background between $\sim$ 10 gm cm^{-2} and the ultimate floating altitude of the balloon. The actual count rate due to the cosmic component can be obtained if the local background at float altitude is known. This was estimated by using the data points between 10 gm cm^{-2} and 100 gm cm^{-2} (i.e. the pure local background) and extrapolating linearly to float depth. The value obtained was then subtracted from the total background at float depth and the residual counting rate attributed to the cosmic X-ray background. Data obtained when obvious sources were in the field of view has been discarded. Figure 2 shows the spectrum obtained by applying this procedure to each energy channel. Also plotted are results obtained by other workers.[3, 4, 5, 6, 7] The points appear to fit a power-law spectrum of exponent $\lambda \approx -2$.

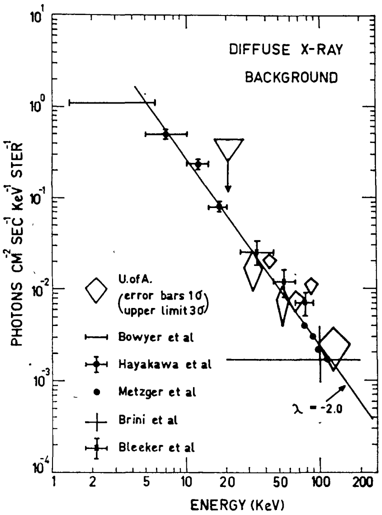

Figure 2.

The possibility of an anisotropy in the diffuse background with respect to the galactic plane has been investigated. At energies of $\approx$ 100 keV no such anisotropy would be expected for a background flux of entirely meta-galactic origin but it certainly would be expected if an appreciable galactic component were present. Maraschi *et al.*[8] have made a theoretical study of diffuse galactic X-ray fluxes likely to result from interactions of the galactic cosmic-ray electron spectrum with matter (producing bremsstrahlung) and also with 3°K photons and starlight photons (producing inverse Compton effect radiation). They predict a greater flux of X-rays from the galactic disk than from the directions of the galactic poles. A degree of anisotropy (α) of between 1 and 10% could be expected, depending on the form of the galactic electron spectrum.

To look at this possibility the background counting rate was divided into two categories according to galactic latitude b^{II}. The counting rate corresponding to telescope axis directions such that $|b^{II}| < 10°$ was compared to the rate for $|b^{II}| > 10°$. The difference between the two counting rates was not statistically significant, however, and we were able only to place an upper limit on the anisotropy. At the 3σ confidence level this upper limit was 30% at photon energies between 27 and 67 keV. This figure represents the first such determination at these energies, although rocket observations at lower energies[9] have set an upper limit of $\approx$ 10%. Improved observations of the degree of anisotropy will be obtained in future flights of the X-ray observatory and should lead to a better understanding of the origin of the diffuse X-ray background and also clarify questions concerning the galactic cosmic-ray electron spectrum.

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Fourier Transform Photography: A New Method for X-Ray Astronomy

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In comparison with all other branches of astronomy, X-ray astronomy suffers from a relative dearth of image forming devices.[1] No X-ray lens is known and image formation by reflection requires glancing incidence optics which have small fields of view and are extremely difficult to fabricate, even for the small apertures (about 2 cm^2) now employed. The only other imaging device which has been successfully employed is the simplest of all, the pinhole camera. Pinhole cameras with resolutions better than 10^{-3} rad are easily constructed, but the apertures are very small—not greater than about 10^{-4} cm^2. The new instrument described here is closely related to the pinhole camera and may be viewed as an attempt to overcome the aperture restrictions of this simple device.

THE MULTIPLE-PINHOLE CAMERA

Consider a pinhole camera having not just one, but a large number of pinholes lying in a plane parallel to the image plane and separated from it by a distance l. Let all pinholes have a diameter d and be randomly distributed to form an 'aperture mask' with a mean transmittance $g < 1$.

The 'image' will consist of the summation of all the images produced by the individual pinholes displaced one from the other in the image plane in the same pattern as the pinholes in the aperture mask. In general, these images overlap. The resolution in each of the identical (except for position) component images is $\sim \theta_0 = d/l$, the same as in a simple pinhole camera, but the flux throughput (considering all images) has been increased by a factor n equal to the number of pinholes. This advantage can be realized only if a way can be found to 'unscramble' the overlapping component images. The information necessary for this operation is contained in the aperture mask.

Recovery of the desired, unscrambled image can be illustrated with the following thought-experiment. Let the external 'scene' to be recorded consist of a distant point source of radiation in an otherwise black sky and suppose that a photographic plate is used to record the multiple-pinhole image. In this case this image is merely the negative of the shadow of the aperture mask cast by the point source. After development of the plate the aperture mask is placed (without rotation with respect to its original position during the exposure) on the multiple image and the number, N, of developed photographic grains visible through the holes are counted. This number is determined for all possible translations (x, y) of the mask in the image plane to form the function $N(x, y)$, essentially the cross-correlation function of the functions, $A(x, y)$, describing the transmittance of the aperture mask and $K(x, y)$ describing the density of developed grains in the photographic plate. Obviously $N(x, y)$ will be greatest (N_{max}) when the mask is positioned so as to coincide exactly with its shadow and will decrease rapidly over a distance $r = \sqrt{(\Delta x^2 + \Delta y^2)} = d/2$ to a much smaller value whose mean $N_{av} \approx g^2 N_{max}$ varies slowly with displacement (because of the finite size of the aperture mask). Thus $N(x, y)$ represents one possible unscrambling of the multiple image. Generalizations to multiple point sources and extended sources may be made.

The methods of accomplishing the cross-correlation described above will not be discussed in this short note although any method selected becomes a vital part of the entire process. The technique which appears to be most suitable is based on the Fourier convolution theorem which states that convolution in the spatial domain corresponds to simple multiplication of spectra in the transform domain. The required Fourier spectra of the multiple image and the aperture mask are generated in a coherent optical system utilizing the Fourier transform relation that exists between the front and back focal planes of a spherical lens when the object is coherently illuminated.[2] The product spectrum is equivalent to a Fourier hologram[3] of the original scene—hence the name Fourier transform photography.

NOISE AND MATCHED FILTERING

The recovery of the desired image through cross-correlation, presented above with no more justification than its workability, is actually one which has useful properties when the recorded image is corrupted, as it inevitably must be, with noise. Such a cross-correlation is one way of realizing the so-called 'matched filter' for the useful signal which, among all linear processes, achieves a maximum peak-signal to rms noise ratio (for the special case in which the noise has a flat Fourier spectrum and the signal-to-noise ratio is small).[4]

The principle sources of noise for celestial photography are the inherent fog of the photographic plate, the additional fog due to any isotropic background radiation and the statistical fluctuations due to the finite number of photons and photographic grains involved. All of these sources of noise lead to essentially flat Fourier spectra in the spatial frequency range of interest and, hence, the matched filter is very appropriate for Fourier transform photography.

In the case of an isolated point source of intensity S photons/cm^2 s in a background of B photons/cm^2 s sterad the signal-to-noise ratio (SNR) defined by the ratio of the signal-peak to rms noise ratio is given by

$$\mathrm{SNR} = (1 - g^2)qATS/\{AF + (qTBA^2/l)\}^{\frac{1}{2}}$$

where A is the clear aperture area, T the exposure time, F the number of intrinsic fog grains per unit area of the photographic plate, and q the photographic quantum efficiency in grains per photon. For many cases of interest $AF \gg qTBA^2/l$ so that the SNR goes simply as the square root of the aperture area. This contrasts with the linear relationship between aperture area and SNR for true focusing devices. Even so, large gains over simple pinhole cameras can be achieved with only modest apertures and without sacrifice of resolution.

APPLICATIONS

When a photographic plate is used for recording, the spectral region for which Fourier transform photography may be useful lies roughly in the range from 100 eV/photon to 10 keV/photon. The minimum energy per photon is determined by the onset of single photon response of the photographic material. This is required since there is no focusing action involved. As a result the probability of multiple photon absorption in a single grain is essentially nil for the case of weak sources. On the other hand, the stopping power of a photographic emulsion becomes very small for photon energies of greater than a few keV.

The limit of angular resolution is determined by the working wavelength λ and the requirement that diffraction effects should be small (as in the case of a simple pinhole camera) and is $\sim \theta_{min} = (\lambda/l)^{\frac{1}{2}}$.

For spectroheliography in the XUV and soft X-ray regions, Fourier transform photography offers a SNR at least two orders of magnitude greater than presently used pinhole cameras (assuming a clear aperture of 1 cm^2 or more) and an angular resolution of 10^{-4} rad (with $l = 30$ cm). Clearly this would be a useful area of application.

The requirements for celestial X-ray astronomy are more difficult to satisfy. Flux levels are much lower than those encountered in solar work. However, a clear aperture of 15 cm^2 and an exposure time of 300 s (about the maximum possible for rocket work) would result in a SNR of about 100 for Sco X-1, the brightest known celestial X-ray source. A field of view of at least 40° with an angular resolution of 10^{-3} rad can be achieved. Hence, broad surveys with sufficient resolution to virtually assure positive optical identification of any source detected are possible.

Since the spectral range for which Fourier transform photography is useful extends to lower energies than are covered by the photon counters now employed in X-ray astronomy, the possibility that sources not detected before may be discovered should not be overlooked.

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