FEATURES IN THE SOFT X-RAY BACKGROUND

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ABSTRACT. The soft X-ray background is explained in terms of emission coming from hot gas. Most of these soft X-ray data were obtained by proportional counters with a poor energy resolution. Instruments having the capability to resolve lines were only flown by two groups: a GSPC by a japanese group and a SSD by a french-american collaboration. They both detected the O VII line emission coming from the soft X-ray background and so proved the thermal nature of the emission. The implications of these results on possible models for the local hot medium will be discussed. The same detectors observed part of the North Polar Spur. They detected emission lines coming from different species (O VII,Fe XVII,Ne IX). Spatial variations of line ratios for this object could be due to non-equilibrium ionization effects.

1.INTRODUCTION

The sky has now been almost entirely scanned in the soft X-ray range by experiments using proportional counters. These detectors have a very poor energy resolution (typically $E/\Delta E \sim 2$ for $E<1$ keV) and the detected X-rays are discriminated by different windows. So their results are given as rates in the following broad bands: Be band (80-110 eV), B band (130-188 eV), C band (160-284 eV) and M bands (M1:440-930 eV; M2:600-1100 eV). In part 2, the broad band results on the soft X-ray background are summarized and we described the spectroscopic observations obtained with detectors having a better energy resolution. These last results are compared to an isothermal model with the additional constraints brought by the broad band rates of the same sky region. The explanation of these spectra as emission coming from an active blast wave is also discussed. In part 3, results obtained with the same kind of detectors are presented for the North Polar Spur. The line intensities of the different species (O VIII,Fe XVII,Ne IX) derived by the two detectors give some indications on the ionization state of the plasma.

2.THE HOT LOCAL BUBBLE

2.1. General characteristics of the soft X-ray background

Maps of the diffuse emission in galactic coordinates for the B and the C bands are shown in McCammon et al(1983). The C map obtained by SAS 3 presents the same general characteristics as the Wisconsin C map (Marshall and Clark, 1984). The most important features of the soft X-ray background are:

1. The B and C maps appear very similar, with the exception of some features appearing in the C map and which are associated to particular objects (North Polar Spur, Eridanus, etc: see below).

2. The flux in the galactic plane is approximately the same at all longitudes in the B and C bands.

3. Again in the B and C bands, the observed flux is generally higher by a factor of two to three at high latitudes. A large scale anticorrelation with the H I column density exists.

4. The ratio of the Be to B band rates is almost constant over 120° of the sky. This strongly suggests a common origin for the two band emissions. Its constancy means that there is no more than about 5.10^{18} H I atoms/cm² between the observer and the bulk of the Be and B band emissions (Bloch et al, 1986). This implies that the soft X-ray emission in these bands must be produced within surely less than ~100 pc.

5. In the M bands (0.5-1.2 keV), the background seems isotropic. In this band, an important contribution of the extragalactic background is expected. One usually assumes that this extragalactic background can be estimated by the extrapolation towards low energies of the following spectrum: $11.E^{-1.4}$ ph/cm².s.keV.sr. with E in keV. This contribution decreases at low galactic latitudes because of the absorption by the interstellar matter. Once this contribution is removed, the remaining M band flux then increases towards the galactic plane, contrary to the emission in the other bands.

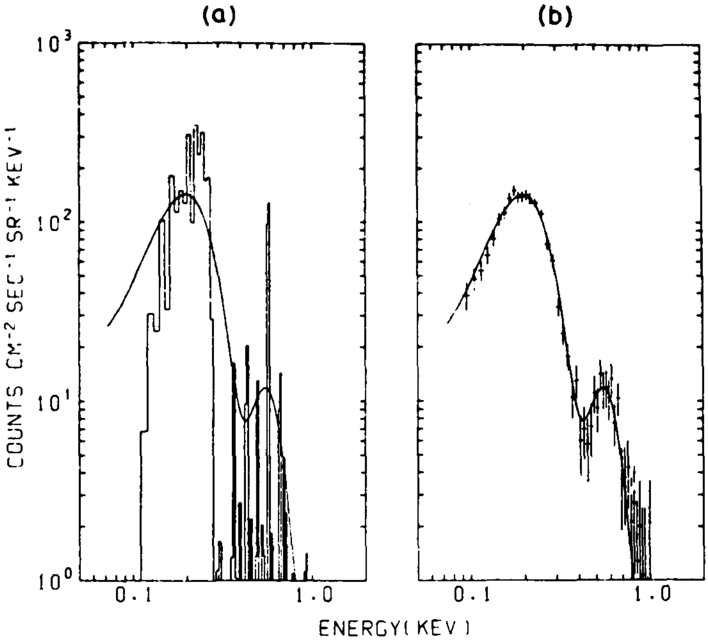


Figure 1: Observation of the Hercules Hole region with a GSPC (Inoue et al, 1979). (a) Thermal spectrum (Kato, 1976) for 1.4 10^6 K integrated in 10 eV bins and convolved with the detector energy response (solid line). (b) The convolved spectrum fitted to the observed one.

2.2. Evidence for line emission

Two experiments were performed by two different groups with detectors having $E/\Delta E \sim 4$ at 600 eV, which is better than usual proportional counters. They measured the soft X-ray background spectrum in particular regions of the sky.

1. A Japanese group observed the Hercules Hole region (20°x20° around $l \sim 80°$ and $b \sim 40°$) with a gas scintillating proportional counter (Inoue et al,1979). This region presents a very low column density in HI ($\sim 1.7\ 10^{20}$ H atoms/cm^2). The observed spectrum is shown in figure 1, the contribution of the extragalactic bakground being subtracted. It revealed a clear peak at about 570 eV which can be identified as the O VII emission line. Emission from continua alone (either power law or thermal bremsstrahlung) can be rejected at better than 99%. The total spectrum is in agreement with a thermal emission at a temperature around $1.4\ 10^6$ K. The model of Kato (1976) was used for the plasma emission.

2. An experiment observed the soft X-ray background with solid state detectors (Rocchia et al,1984). It was made in collaboration between the Smithsonian Astronomical Observatory and the Service d'Astrophysique in Saclay. This experiment scanned the region roughly delimited by $b>10°$, $0<l<180°$ with a ~ 1 ster field of view. In figure 2, we reproduce the spectrum obtained in regions of the sky outside the North Polar Spur, once the contribution of the extragalactic background has been subtracted. The feature around 570 eV is due to the O VII emission line. There is also a strong excess at low energies attributed to a blend of C V (300eV) and C VI (360 eV) emission lines. Their temperature determination was 1.14 +/- 0.08 10^6K (at the 90% confidence level), also with the plasma emission model of Kato (1976).

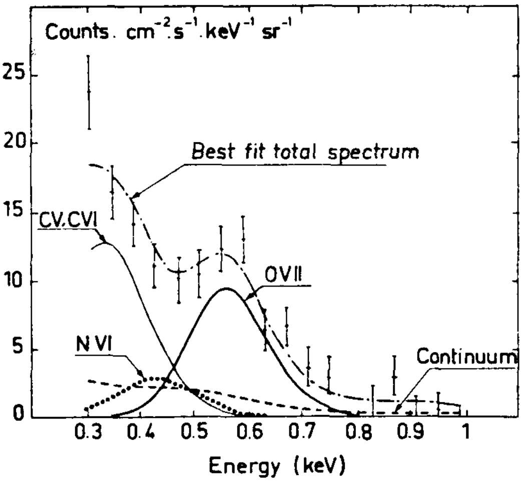


Figure 2: Observation of the soft X-ray backgound with a solid state detector (Rocchia et al,1984). This concerns a region of the sky outside the North Polar Spur. The dot-dashed line is the total spectrum. The contributions of the different ion species are indicated.

2.3. Comparison with an isothermal model

In summary, the band rate observations revealed that the soft X-ray background is (very probably) produced locally (inside 100 pc from the sun) and the spectroscopic results confirmed that the emission is coming from a hot plasma at a temperature around 10^6 K. In this part, we will investigate if the GSPC and the SSD spectra can both be explained by plasma emissions at the same temperature (see Arnaud and Rothenflug, 1989 for a more complete discussion).

One must also have in mind that the broad bands measure in fact emission coming from different lines : at 10^6 K, iron lines (mainly Fe IX and Fe X lines around 72.5 eV) dominate in the Be band, magnesium lines dominate in the B band and silicon lines in the C band. Thus it could be interesting to take broad band rates as additional constraints. Clearly the Be band rate bring information at very low energy not included in the GSPC and SSD data.

1.The SSD spectrum is expected to be more representative of the whole emission than the GSPC spectrum since it was obtained for a large region of the sky. As a first step, we tried to fit an isothermal plasma to this spectrum together with the band rates. For the B,C,M1 and M2 rates, the mean values over the whole sky were adopted as a crude estimate, the contribution of the extragalactic background being subtracted (McCammon et al,1983). For the Be band, a value of 8 cts/s was thought to be appropriate for this part of the sky from the observations of Bloch et al (1986).

The fits of a thermal model was done using the Arnaud and Rothenflug (1985) ionization model coupled with the Mewe et al (1985,1986) emission model. Normal (undepleted) abundances were taken from Meyer (1985). An isothermal model with T= 1.2 10^6 K and $N_H = 4.10^{18}$ H I atoms/cm² gives an acceptable fit to the SSD spectrum and the Be,B,and C band rates (reduced $\chi^2 = 1.8$) but failed to account for the M1 and M2 rates.

2.The GSPC spectrum contains more information than band rates and we included it into our data set to be compared with an isothermal model.The ratio of the GSPC to SSD experiments was then introduced as a free parameter since the SSD data refer to a wider region of the sky. The best fit of a single temperature model is compared to the whole data set on figure 3.

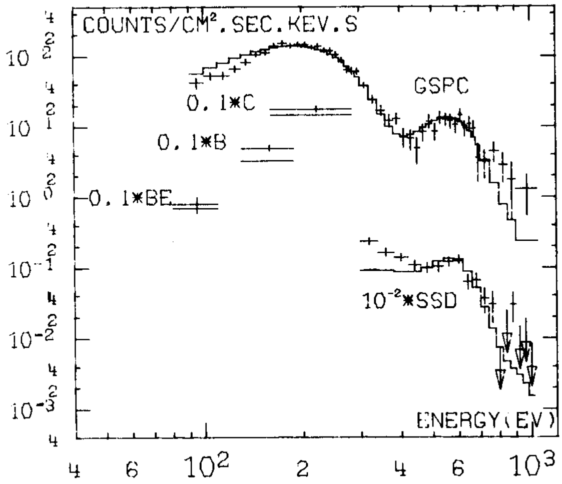


Figure 3: Best fit single temperature model compared to the soft X-ray background spectral observations: GSPC (Inoue et al,1979); SSD (Rocchia et al,1984) Be,B,C: band rates (see text). The M1 and M2 rates are not shown.

The statistical weight of the GSPC data forces the temperature to a value around 1.5 10^6 K. The Be rate forces the N_H value to 5. 10^{18} H atoms/cm². The reduced χ^2 is greater than 3. At such temperature, the predicted carbon line emission is much fainter than the observed SSD flux and so this fit fails to reproduce the carbon line intensity. The higher temperature plasma produces more counts in the M bands: the best fit leads to ~10 counts in the M1 band and ~6 in the M2 band.

Such an enhancement of the carbon line could be due to non-equilibrium ionization effects because of the delay in the ionization of helium-like carbon with respect to other ions (Arnaud et al,1984). This kind of effect is expected if the thermal emission comes from an active shock running into a rarefied interstellar medium.

2.4. Comparison with an active blast wave.

The various possible origins of the local hot bubble were recently reviewed by Cox and Reynolds (1987). Here we will only discuss the case of an active blast wave. Cox and Anderson (1982) devised a model of such a blast wawe developing in a medium with finite pressure. In that model, the parameters are the explosion energy, the external density and temperature. Cox and Anderson provided a simple analytical approximation to the hydrodynamical evolution and structure for this SNR type. They computed the ionization structure at the shock and the emissivities of their remnant in the B,C,M bands. They showed that their model is able to explain the mean B and C rates, but failed to account for the M flux.

Arnaud and Rothenflug (1986) made an attempt to compare the spectra produced by such SNRs with the GSPC and SSD results. They used the analytical expressions given by Cox and Anderson for the SNR evolution. They computed the ionization structure behind the shock and the corresponding spectra, using slightly different atomic physics (see part 2.3).

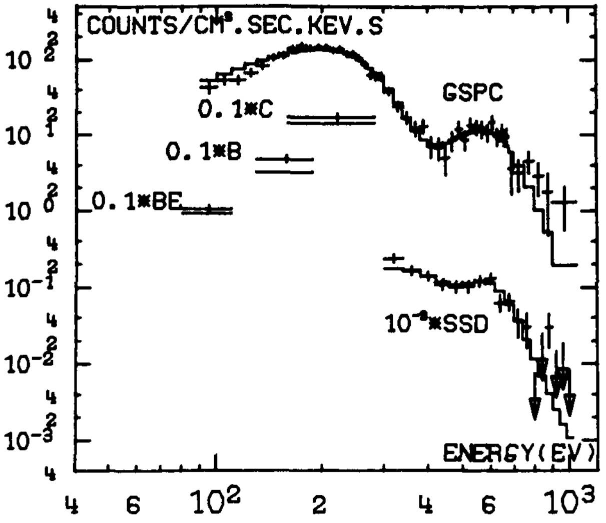


Figure 4: Comparison of spectroscopic and band rate data with the Cox and Anderson model adapted by Arnaud and Rothenflug (1986). Best fit values with depleted abundances:

N_H = 6.10 ^{18} H atoms/cm²;

n_{ext} = 1.25 10^{-2} el./cm³;

R_s = 120 pc;

E_o = 1.3 10^{51} ergs.

They compared them to the GSPC and SSD observed spectra, with the additional constraints brought by the band rates. They showed that SNR models with normal abundances failed to account for the whole data set. An acceptable fit (χ^2=1.7) can be obtained with models allowing depleted abundances. Their best fit is reproduced in figure 4. Possible depletion of the elements in the local hot plasma was also proposed by Bloch et al (1988) to explain the mean energy of the photons observed in the Be band.

In a forthcoming paper, Arnaud and Rothenflug (1989) will extend this discussion to some other possible models of the soft X-ray background. It remains that such SNR models encounter great difficulties to explain why the M flux should increase toward the galactic plane and the B and C fluxes should have an opposite behaviour .

3.THE NORTH POLAR SPUR

Several enhancements show up in the soft X-ray maps. They are explained as emissions from other closeby (d<500 pc) hot cavities, as for instance the Monoceros Loop (Nousek et al,1981). The North Polar Spur (NPS) is the most important of these enhancements.

3.1.The North Polar Spur as SNR.

The NPS forms a part of a 116° diameter circle on the sky called Loop I by radio astronomers: the radius of this shell is estimated to be ~115 pc (Berkuijsen,1973). About 5° outside this radio loop, there is a ridge of neutral hydrogen with an expansion velocity maybe as high as 30 km/s (Heiles et al,1980). Inside the radio emission, the soft X-ray emission is strongly enhanced with a spatial distribution indicating a strong limb brightening (see for instance Davelaar et al,1980 and also the M1 and M2 maps of McCammon et al,1983). The X-ray emission is much harder than outside the spur and its temperature is evaluated around 3.10^6 K or even higher from soft X-ray measurements (Davelaar et al,1980; Iwan,1980).

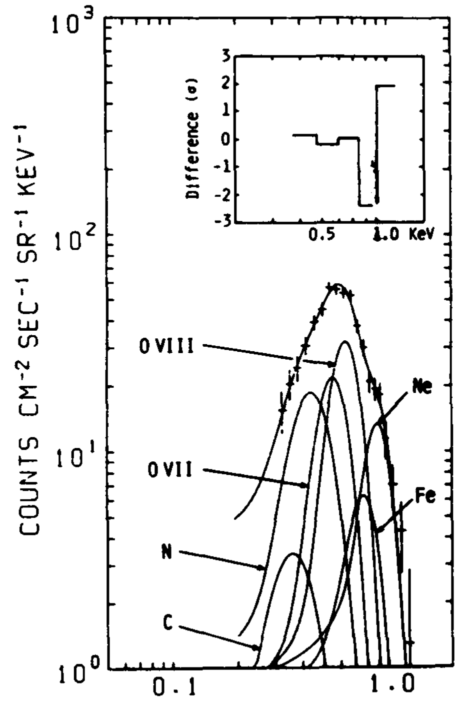
The most probable scenario involves the formation of the HI shell by the stellar winds of an entire association. Its dimension, its density (n_{HI}~ 2 p/cm^3, Heiles et al,1980) and its expansion agree with the characteristics of such HI bubbles as computed by Bruhweiler et al (1980). The stellar winds have created a low density cavity in which the SNR is now developing. The soft X-ray observations implies an external density of $\sim10^{-2}$ p/cm^3 and leads to an explosion energy around 3.10^{51} ergs and an age of ~ 8.10^4 years (Davelaar et al,1980).

3.3.NPS spectral observations.

The soft X-ray enhancements associated with the NPS was partly observed with a GSPC (Inoue et al,1980) and a SSD (Rocchia et al,1984).

a)The GSPC experiment pointed towards the region roughly centered at l~30°, b~25°, with a 10°x10° FWHM field of view (Inoue et al,1980). The highest energy part of this spectrum is shown on figure 5. At temperatures ~3.10^6 K, the most important lines contributing to this energy range are those of oxygen,iron and neon. With the energy resolution of the GSPC, it becomes possible to sort out the contribution of the most intense lines. This was done by Inoue et al (1980) using a deconvolution method. The result is depicted on figure 5 which shows the lines once convolved by the response of the GSPC.

Figure 5: The M band spectrum of the NPS as observed by a GSPC (Inoue et al,1980). Curves indicate the contributions of the six emission-line groups derived by the decomposition and their sum.



b)The SSD experiment had a circular field of view of ~22° FWHM and pointed a region around l~25°, b~25°, 5° away from the region analysed by the GSPC (Rocchia et al,1984). Their spectrum is also characteristic of a relatively high temperature (5.10^6 K). A deconvolution method was applied to these data in order to estimate the intensities of the different lines (Rothenflug et al,1984). The resulting line contributions are sketched on figure 6.

Let us compare the line intensities derived by the two experiments. The Ne IX line intensity will be used as reference. Once corrected for the detector efficiency, we obtain the following intensities:

O VIII	GSPC: 2.9 (+/-0.9)	SSD: 1.3 (+/-0.7)
Fe XVII	GSPC: 0.5 (+/-0.4)	SSD: 2.4 (+/-0.5) (90%confidence)

The O VIII line intensities of the two experiments are marginally compatible. For the Fe XVII line, the two error ranges do not overlap and the intensities measured by the two experiments are quite different.

Let us remark that the GSPC experiment observed a region near the shock (as delimited for instance by soft X-ray maps) and the SSD observed a wider region including it, but also a large NPS part far from the shock. Inoue et al(1980) proposed that the weak Fe XVII line in their data can be explained as a depletion of iron in grains: just behind the shock, grains are present in the gas, but are destroyed far from the shock. Another explanation could be the delay in the ionization of iron with respect to the others elements: a comparison with the computations of Masai(1983) indicates that an ionization parameter of $n_e t \sim 10^{11}$ s/cm^3 could be a crude estimate, where n_e is the electronic density and t the time in seconds. Values given above on the external density and age leads to $\sim 8.10^{10}$ s/cm^3, not very far from that estimate. A modelling of the NPS taking into account these spectroscopic results would be very useful to constrain its age, its shock temperature and the external density.

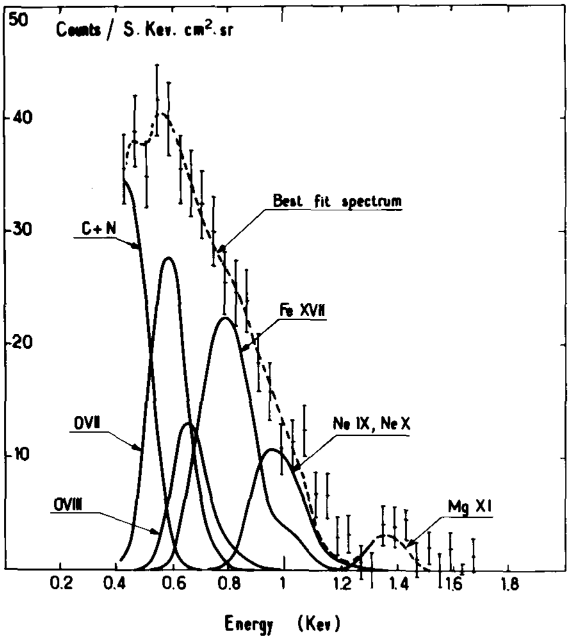


Figure 6: The spectrum of the NPS part observed by the SSD . The contribution of each line blend is drawn together with the total spectrum (Rothenflug et al, 1984).

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DISCUSSION

J. Bloch: The emission mechanism for the M band in the soft X-ray background must be different from the high energy power law and Be,B and C band emissions. This is because the power law does not make up the M band counts and the M band is very isotropic compared to the pole enhanced emission in the Be,B and C bands. How was this other component for the M band taken into account?

P. deKorte: You assume for the fit of spectra, which result in depleted abundances, that the total spectrum is coming from one region. I doubt this very much, especially for part > 0.5 keV.

W.T. Sanders: Your model is able to fit the data from 0.1 to 1. keV in one direction of the sky. The Wisconsin maps show isotropic M band intensity but C variations of a factor of three. How does your model account for this?

Rothenflug: These three questions are related to the emission in the M bands, i.e to the characteristics of the soft X-ray background for energies greater than 0.5 keV. The emission in these M bands contains at least 3 components: the absorbed extragalactic background, a contribution from the local hot medium, and a component with a large scale height (Nousek et al,1982). Our model is able to explain a significative part of the M bands, in a particular direction. The remaining parts are coming from the extragalactic background and from an yet unclear origin. Among the possible candidates, the emission from stars have been proposed.

G. Vaiana: To what extent the detailed conclusions (depleted abundances and non-equilibrium ionization) depend on how well the extragalactic background has been subtracted ? Is the extragalactic background subtracted just the extrapolation of the power law from the high energy part of the spectrum ?

Rothenflug: All these observations assume that the extragalactic background can be estimated by an extrapolation of the part of the spectrum measured above ~2 keV. The same power law is generally used by the different groups (see part 2.1). The contribution of the background is removed taking into account the absorption in the line of sight. For $N_H = 2.10^{20}$ H I atoms/cm^2, McCammon et al (1983) estimated that the contribution of the extragalactic background is ~3% for the B band, ~11% for the C band, ~30% for the M1 band and 39% for the M2 band. Unless the extragalactic background spectrum presents a sharp cutoff below 2 keV, its contribution will not change dramatically wathever its spectrum shape is at low energies.

DISCUSSION-R. Rothenflug

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