SOUNDING-ROCKET EXPERIMENT TO STUDY THE DIFFUSE SOFT X-RAY BACKGROUND USING A Si(Li) DETECTOR

Grant NSG-5304

Final Report

Principal Investigator

Dr. John P. Delvaille

September 1981

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

The NASA Technical Officer for this grant is John G. Guidotti, Code 740, Sounding Rocket Division, Engineering Directorate, Goddard Space Flight Center, Greenbelt, Maryland 20771

SOUNDING-ROCKET EXPERIMENT TO STUDY THE DIFFUSE SOFT X-RAY BACKGROUND USING A Si(Li) DETECTOR

Grant NSG-5304

Final Report

Principal Investigator

Dr. John P. Delvaille

September 1981

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory and the Harvard College Observatory are members of the Center for Astrophysics

The NASA Technical Officer for this grant is John G. Guidotti, Code 740, Sounding Rocket Division, Engineering Directorate, Goddard Space Flight Center, Greenbelt, Maryland 20771

TABLE of CONTENTS

1.0 INTRODUCTION

This sounding rocket program began in September 1978 under the direction of H.W. Schnopper as a study of the soft X-ray background in the energy range 0.4 to 10 keV. It has been a joint effort by scientists at the Smithsonian Astrophysical Observatory and Centre d'Etudes Nucleaires de Saclay. These groups developed a payload which uses a wide-angle, windowless, cooled, Si(Li) semiconductor detector system. With a resolution of less than 150 eV between 0.3 and 2.0 keV, the system is sensitive to an emission equivalent width of about 10 eV.

The Saclay group under the direction of L. Koch and R. Rocchia provided the detector, cryostat, and associated analog electronics. The SAO group provided the power conditioning system and the digital data handling system. The SAO group was also responsible for the interface with the rocket system.

The payload (UH25.047) was launched successfully on 22 March 1980. During this mission we detected carbon and oxygen line emission from the vicinity of the North Galactic Pole and the North Polar Spur. Under the direction of the current Principal Investigator an improved version of the payload (UH27.058) was successfully flown on 4 May 1981. Although the data from this flight have not yet been fully analysed, we seem to see C V, VI emission from the NPS more clearly this time than last.

Based on the results of these experiments we have designed a new and more versatile instrument for which funding may be sought in the future.

2.0 PAYLOADS AND LAUNCHES

2.1 UH25.047

The detection system consists of three independent, 1 cm diameter, lithium drifted silicon (Si(Li)), solid state detectors (SSD), mounted in a liquid nitrogen cooled cryostat. Nearly overlapping fields of view subtend a solid angle of approximately one steradian. Background optical light is removed by a thin, aluminized (13.5 μg cm^{-2}) polystyrene (17 μg cm^{-2}) filter in front of each detector. Electron induced background is suppressed by a magnetic sweeper located above the entrance opening in the cryostat. Ten bit, on board, analog-to-digital conversion in each measurement chain provides a dispersion of approximately 10 eV per channel between 0.3 and 9 keV. In-flight calibration is provided by a 100 μCi Fe55 (5.9 keV) source located on the entrance door. The source is viewed on the up and down legs of a flight but is retracted at altitudes greater than 120 km.

By choosing an appropriate launch date, it is possible to have a region that includes a portion of the NPS within the wide field of view of a spin stabilized Astrobee F rocket. The flight took place from White Sands Missile Range on 22 March 1980 at 0330 AM MST. Approximately 260 s of data were obtained above an altitude of 120 km.

The details of this flight are described in more detail in Appendix A.

2.2 UH27.058

This payload was very much the same as UH25.047 but with the following modifications.

The field of view was decreased to about 0.25 sr and the number of sweeper magnets was doubled. We improved the accessibility of the low energy threshold adjustment. The payload restraints were improved, fortuitously as it turned out. An ACS was incorporated.

Because the vehicle for this flight was to be a Nike-Black Brant, it was necessary to add stiffeners to the skins. Although this last modification resulted in a somewhat medieval appearance, the payload survived the launch admirably.

For this flight, the nominal targets were a region near the NGP, the NPS itself and a short observation looking back into the atmosphere. The launch took place early on 4 May 1981 from WSMR and the primary targets were observed for about 170 seconds each.

Although the cryostat suffered heat damage during re-entry and serious mechanical damage upon impact, the detectors themselves survived intact. The Saclay group has determined that the detectors still function properly.

Apparently, the cause of the cryostat mishap began with a slight nose-down re-entry configuration of the payload. The cryostat shock mounts (which are silicone-filled) were melted by the consequent heating. The cryostat then broke loose at impact, struck the interior payload restraints, and the amplifiers, cryostat and payload shutter were severely damaged. If this payload were to be re-flown, we would recommend (a) hard-mounting the cryostat to the bulkhead and (b) using a GSFC-supplied door in front of the detector system. True, an aft- or side-looking system would preclude these problems but would also entail exceedingly awkward design requirements for the experiment.

3.0 SCIENTIFIC RESULTS

The results of the flight of the UH25.047 payload have been published elsewhere[1-4]. We have included a preprint of the forthcoming definitive paper in Appendix A so we will just briefly summarize the results here.

During the mission we detected carbon and oxygen line emission from the vicinity of the NGP and the NPS. The detection of C V, VI and O VII, VIII emission is direct evidence for the thermal origin of the emission and confirm the presence of a hot component in the interstellar medium. The spectrum is well fitted by a two component, modified Kato model with $T = 1.1 \times 10^6$K and $\langle N_e \rangle^2 R \sim 1.3 \times 10^{-2}$ cm^{-6} pc for the ISM. The NPS temperature is 3.8×10^6K and the emission integral at 100 pc is $\sim 5 \times 10^{57}$ cm^{-3}. These results are preliminary and may be altered somewhat by the following points.

First, we find that the O VIII emission line is modulated with the spin frequency of the rocket. This is consistent with the manner in which the detectors scanned the NPS which is hotter than the ISM. This result could help to reduce the error in the temperature measurement of the ISM.

Second, we find that the fitted temperatures of both the NPS and the ISM are the same when either the Raymond and Smith code or the modified Kato code is used in the computation. This precludes code differences as the cause of the lower ISM temperature we measure when compared with that obtained by other observers using different instruments. The discrepancy may be due to carbon overabundance, a situation which we hope to check with the data from UH27.058.

In regard to this last point our French colleagues presented two talks at the 17th International Cosmic Ray Conference in Paris[5,6]. From the results of the first flight they verify the dimension of the hot bubble in the direction $10° < \ell^{II} < 40°$, $|b^{II}| < 30°$. They also discuss the apparent variation in C and O abundances as determined by different observers of this region.

4.0 FUTURE PROGRAM

The Saclay group has obtained funding from CNES to develop a detector consisting of seven (7) SSD's in a single cryostat*. The SSD's will be nearly adjacent and have a 1 cm diameter each. If such a detector were placed in the focal plane of a Wolter I grazing incidence telescope (an SO56, say), one could accurately determine the temperature of the hot spots in a large supernova remnant.

The Cygnus loop is an obvious candidate for such an observation There are as yet unanswered questions regarding the presence of oxygen lines and the appropriateness of a two-temperature model. In his presentation to CNES, Rocchia further pointed out the following:

- The Cygnus loop is a close and strong object (D $\sim$0.8 kpc).
- The amount of matter along the line of sight is small $\sim 10^{20}$ N_H- cm^{-2} and makes the observation nearly correction free.
- The temperature range is 2 to 5 x 10^6K and is well adapted for the sensitivity range of silicon detectors.
- The Einstein observation was not good because of the uncertain sensitivity of the SSS at low energy.

----

*This number is to be increased to nineteen (19) at a later date.

.. short, this object would be ideal for observation with this soft X-ray imaging spectrometer launched as a rocket payload.

5.0 ACKNOWLEDGEMENTS

On behalf of both the SAO and Saclay groups we thank John Wolff, George Kraft, John Guidotti, and all the staff at GSFC as well as Lloyd Briggs and his staff at WSMR for their marvellous assistance during the integration, launch, and recovery activities.

We also thank the Einstein Experiment Controllers who added cryogen daily to the detector during the period between integration and launch.

6.0 BIELIOGRAPHY

1. Detection of Line Emission From the Hot Interstellar Medium. H.W. Schnopper, J.P. Delvaille, L. Koch, R. Rocchia, and R. Rothenflug, [Abstract] 156th AAS Meeting (Maryland), June 27 (1980).

2. First Detection of Line Emission From the Hot Interstellar Medium with Solid State Detectors. H.W. Schnopper, J.P. Delvaille, R. Rocchia, C. Blondel, C. Cheron, J.C. Christy, R. Ducros, L. Koch, and R. Rothenflug, Adv. Space Res. Vol.1, pp.121-123 (1981).

3. Spectral Observation of the Soft X-ray Background and of the North Polar Spur with Solid State Spectrometers. R. Rocchia, M. Arnaud, C. Blondel, C. Cheron, J.C. Christy, R. Ducros, L. Koch, R. Rothenflug, H.W. Schnopper, and J.P. Delvaille, IAU Symposia, ASSL Books, Jerusalem Symposia, D. Reidel, Publ. (1981).

4. Carbon and Oxygen X-ray Line Emission From the Interstellar Medium. H.W. Schnopper, J.P. Delvaille, R. Rocchia, C. Blondel, C. Cheron, J.C. Christy, R. Ducros, L. Koch, and R. Rothenflug. Ap.J., to be published 1 Feb. (1982).

5. On the Extent of the Hot Interstellar Phase (10 K). M. Arnaud, R. Rocchia, R. Rothenflug, and A. Soutoul, Proc. 17th Int. Cosmic Ray Conf., Paris, XG4.2-4 (1981).

6. Abundances and Temperatures in the Hot Phase of the Interstellar Medium From X-ray Measurements. R. Rothenflug, R. Rocchia, and M. Arnaud, Proc. 17th Int. Cosmic Ray Conf., Paris, XG4.2-5 (1981).

APPENDIX A

CFA/HEA-81-009

CARBON AND OXYGEN X-RAY LINE EMISSION FROM THE INTERSTELLAR MEDIUM

H. W. SCHNOPPER and J. P. DELVAILLE
Harvard/Smithsonian Center for Astrophysics
Cambridge, Massachusetts 02138

R. ROCCHIA, C. BLONDEL, C. CHERON, J. C. CHRISTY, R. DUCROS, L. KOCH, and R. ROTHENFLUG
DPh - EP - SAP, Saclay, France

To be published in Ap.J. 1 Feb. 1982.

ABSTRACT

A rocket borne system consisting of three lithium drifted silicon detectors was used to obtain a soft X-ray spectrum (0.3 - 1.0 keV) from a 1 sr region which includes a portion of the North Polar Spur. Emission lines from Carbon (C V, VI) and Oxygen (O VII, VIII) are clearly present. The spectrum is well fitted by a two component, modified Kato Model (coronal emission in collisional equilibrium) with $T = 1.1 \times 10^6$ K for the local interstellar medium and $T = 3.8 \times 10^6$ K for the NPS.

I. INTRODUCTION

Evidence for the local origin of the soft X-ray background ($E < 1$ keV) comes from analyses of spectra obtained from a broad distribution of pointing directions. These spectra can be fit by models which include no significant correction for low energy attenuation by intervening material. Hayakawa et al. (1978) give upper limits for this material, and Inoue et al. (1979) obtain from their best fit an estimation of 6×10^{19} H atoms cm^{-2}. Low values of absorbing material are also given by Sanders et al. (1977) and Fried et al. (1980). This small amount of absorbing material is consistent with a local origin for the emission. In addition, Apparao et al. (1979) have measured the flux in the direction of the ρ Ophiucus cloud. The lack of absorption in the direction towards the cloud implies that the region of emission does not extend beyond 160 pc. Observations of the ρ OPH dark cloud with the imaging proportional counter (T. Montmerle et al. (1980)) on the Einstein satellite have discovered numerous weak X-ray sources. Column densities along the various lines of sight are $N_H \sim 10^{21} - 10^{22}$ atoms cm^{-2}, one to two orders of magnitude larger than that obtained by Inoue. The low energy attenuation towards these sources argues against a compensation for absorption by the cloud by emission from these sources at $E<1$ keV.

In view of this evidence, the most likely source of the galactic X-ray background appears to be the thermal emission from a hot interstellar plasma of temperatures 10^6 K (Williamson et al. (1974)).

The local, thermal model receives further support from observation of an OVII emission line in the diffuse X-ray spectrum obtained from measurements with a gas scintillation proportional counter by Inoue et al. (1979).

Several complex structures having different spectral characteristics are apparent on maps of brightness distribution. One of them can be associated with the region that contains the North Polar Spur (NPS), a region already known for its enhanced radio emission (see for instance Berkhuijsen et al. 1971)). Soft X-ray emission from the NPS has been studied in some detail following the original report by Bunner et al. (1972). Enhanced emission features have been reported by de Korte et al. (1974), Cruddace et al. (1976), Hayakawa et al. (1977), Burstein et al. (1977), Borken and Iwan (1977), Weaver (1977), and Iwan (1980). These results have all been obtained with thin window proportional counter detectors. Recently, an improved spectrum has been obtained by Inoue et al. (1980) with a gas scintillation proportional counter. The data for the NPS region are representative of a plasma with a higher temperature than that usually reported for the diffuse background.

These results have been interpreted to support a model which describes the NPS as an expanded supernova remnant (SNR) with X-ray emission coming from regions of hot thin plasma produced by the interaction of a shock wave with the interstellar medium. See, for example, the detailed discussions by Cox (1972), McKee and Ostriker (1977), and by Chevalier (1977).

The signature of X-ray emission from a hot thin plasma is the presence of emission line features whose relative strength lead to charge state abundances that are characteristic of the excitation temperature and plasma conditions. The extent to which the lines are resolved will determine the accuracy of the analysis and, therefore, the validity of the interpretation. In this letter we present spectral measurements of the soft X-ray background obtained with cooled Si(Li) solid state detectors. The spectrum is dominated by emission lines arising from C and O ions.

II. EXPERIMENT

By choosing an appropriate launch date, it is possible to have a region that includes a portion of the NPS within the wide field of view of a spin stabilized Astrobee F rocket. The flight took place from White Sands Missile Range on 22 March 1980 at 0330 AM MST. Approximately 260 s of data were obtained above an altitude of 120 km.

The detection system consists of three independent, 1 cm diameter, lithium drifted silicon (Si(Li)), solid state detectors (SSD), mounted in a liquid nitrogen cooled cryostat. Nearly overlapping fields of view subtend a solid angle of approximately one steradian. Background optical light is removed by a thin, aluminized (13.5 μg cm^{-2}) polystyrene (17 μg cm^{-2}) filter in front of each detector. Electron induced background is suppressed by a magnetic sweeper located above the entrance opening in the cryostat. Low level discrimination was set at 300 eV and saturation occurred at 8.8 keV. Ten bit, on board, analog-to-digital conversion in each measurement chain provided a dispersion of approximately 10 eV per channel. In-flight calibration was provided by a 100 μCi Fe55 (5.9 keV) source located on the back of the entrance door. The source was viewed on the up and down legs of the flight but was retracted at altitudes greater than 120 km. No degradation of the signal was observed from which we conclude that no condensation occurred on the detector window during the flight. Signals from a test pulse generator were used to monitor the electronic resolution for periods before and after the observing window. The responses of the three detectors to test signals were 140, 155, and 160 eV (FWHM). Rough pointing information is available from an on board gyroscope system. The energy response of the detectors was calibrated at the synchroton orbit radiation facility at LURE. The calibrations confirm that the sensitivity is a monotonically increasing function from 0.3 to 1.8 keV. No absorption feature is expected nor observed in this range. Preflight and postflight calibrations gave comparable results proving the constancy of the detector sensitivity.

III. RESULTS

In this section we present the preliminary analysis of the spectrum from the 1 sr field of view centered on $\ell^{II} = 65°$, $b^{II} = 55°$ that includes a portion of the NPS (Fig. 1).

To measure the emission of the interstellar medium, the contribution of the isotropic diffuse emission (assumed to be extragalactic) measured above 2 keV has been subtracted using the spectrum $11\ E^{-1.4}\ \exp\ (-\sigma(E)N_H)$ where $\sigma(E)$ is the absorption cross section given by Fireman (1974) and N_H, the column density of intervening material, taken as 6×10^{20} equivalent H atoms cm^{-2}. This column density includes 4×10^{20} H atoms cm^{-2} deduced from 21 cm observations (Daltabuit and Meyer (1972)) and a probable contribution of molecular hydrogen of 2×10^{20} H atoms cm^{-2} deduced from interstellar reddening (Lebrun (1979)). Our conclusions do not depend strongly on the choice of N_H for the intervening material. The residual spectrum plotted in Fig. 2 consists of the summed data from two detectors with similar resolution and noise characteristics. The low energy threshold is adjusted to remove electronic noise, an effect that is almost negligible above 300 eV. Above 1 keV, the spectrum goes rapidly to zero flux.

The superior resolution and detection efficiency of the Si(Li) detector system makes it possible to resolve clearly a feature at about 600 eV. There is also a clear increase in the spectrum around 300 eV. These features can be interpreted as blends of emission lines from ionized species, CV, CVI for 300 eV and OVII, OVIII for 600 eV, respectively. These identifications are a positive signature of the thermal origin for the emission of the interstellar medium in this energy range.

We have tested the significance of several possible models of plasma X-ray emission by comparing them directly with the data. They are:

1. A pure thermal bremsstrahlung.
2. A single temperature component with line emission and solar abundances (Meyer, 1979) with absorption by 6 x 10^{19} H atoms cm^{-2} of intervening material (Inoue et al. (1979)).
3. A two temperature model with line emission and the same solar abundance.

For the calculation of line emission we use a model developed at Saclay which includes atomic data listed by Kato (1976). Our modification of the Kato model includes the following improvements (Rothenflug (1980)):

1. We add the contribution of satellite lines of hydrogenic and helium-like ions. For carbon and oxygen lines, however, this contribution is always less than 15 percent of the intensity of the resonance line for temperatures greater than 10^6 K and the effect of this addition is small.
2. We use the ionization balance of Jacobs et al. (1977 a,b; 1979) instead of those of Jordan (1969) when available, i.e., for Ne, Mg, Si, and Fe. For C and O, this model uses the ionization balance of Jordan (1969) calculated in the low density approximation.

For comparison with the data, the model calculations were convolved with the response of the detector, and a χ^2 test was performed. Values of χ^2 for the three models together with the best fit values of temperature are shown in Table 1. The presence in the field of view of the NPS, which is known to have a harder spectrum than the foreground emission region (Hayakawa et al. 1977), forces our best fit to a two temperature model. The low temperature foreground component is the only source of C emission. For O, however, the low temperature component contributes OVII while the high temperature component, the NPS, contributes primarily to OVIII. The total spectrum is dominated by C and O lines (Fig. 1b). The low temperature component (T = 1.1 x 10^6 K) is associated with the emission of the hot diffuse plasma surrounding the solar system (Tanaka and Bleeker (1977), and references therein). From our observation, we can deduce an emission measure for this plasma $\langle n_e \rangle^2 R \sim 1.3 \times 10^{-2}\ cm^{-6}$ pc. The high temperature component ($T = 3.8 \times 10^6$ K) is associated with the NPS. The emission integral of this component is $\langle n_e \rangle^2 V \sim 5 \times 10^{57} (d/100pc)^2\ cm^{-3}$ assuming an absorption by 4×10^{20} H atoms cm^{-2} of neutral material (Iwan 1980) and the presence of the NPS in the field of view approximately 10 percent of the observation time.

As a check, we have also compared our data to the model of Raymond and Smith (1977). The temperatures of the two components obtained in that way are nearly the same as those deduced from the modified Kato model.

IV. DISCUSSION

As discussed above, the spectrum consists of contributions from a diffuse component that was continuously in the field of view and the NPS which was observed periodically as the rocket revolved about the spin axis. We have performed a crude folding of the data with the average spin period of the payload and find an apparent intensity enhancement in the direction of the NPS. However, we have not yet removed the NPS contribution from the raw data. Therefore, the following discussion must be considered preliminary.

In the range of temperature under consideration, the predominance of lines in the spectrum and the good resolution and sensitivity of the Si(Li) detector for C and O lines make our instrumentation extremely sensitive to a model temperature change. For instance, the C lines which are the dominant component at $T = 1.1 \times 10^6$ K are reduced by a factor more than 5 at $T = 3.8 \times 10^6$ K.

We have to study carefully the consequences of our choice of parameters for the foreground temperature estimation. At $\sim 10^6$ K, a temperature measurement with a solid state detector (SSD) relies essentially on the ratio of C to O lines. This ratio depends not only on the temperature but also on interstellar absorption. Information concerning this additional parameter is not available directly from our data. To take absorption into account, we have to refer to observations made with other detectors. The small amount of absorbing material along the line of sight reported by Sanders et al. (1977) and confirmed by Hayakawa et al. (1978) and Inoue et al. (1979) does not produce any appreciable attenuation in the range of energy in which the SSD is sensitive. The other parameter which may modify our estimation of temperature is the relative abundance of C and O. For a source at $\sim 10^6$ K, proportional counters (PC) with C absorption in their plastic windows are sensitive mainly to O ($E > 0.4$ keV) and Si, S, Fe ($E < 0.3$ keV) whereas SSD are sensitive to C and O ($E > 0.3$ keV). If the relative abundances of all these elements are normal, the temperature T_{PC} and T_{SSD} should be equal within statistical errors. If, for instance, C is overabundant, we should get $T_{SSD} < T_{PC}$. This situation seems to be suggested by our preliminary result: $T = (1.08^{+.18}_{-.37}) \times 10^6$ K (90 percent confidence limits) whereas $T = (1.49 \pm 0.06) \times 10^6$ K (Hayakawa et al. 1978) or $1.4 \pm .1 \times 10^6$ K (Inoue et al. 1979). If this discrepancy were real, it could not be explained by differences between the original Kato model used by Hayakawa et al. and Inoue et al. and our model. A precise measurement of the C/O line ratio is needed and it can be obtained when an SSD spectrum of only the diffuse region is available. Thus, we plan a second flight with a reduced field of view pointing independently at the North Galactic Pole and the NPS.

This program is supported in part by NASA (USA) Grant 5304 and by CNES and CEA (France). We thank J. Gomes and J. Jenkins of SAO and the CERES staff at Saclay for their engineering and technical assistance. We thank O. Testard for the cryogenics and A. Friant for providing the detectors. We also thank the Sounding Rocket Division staff at GSFC and WSMR and the staff at LURE, Orsay, for their assistance and hospitality.

TABLE 1

Model	Temperature	χ^2 for 70 d.o.f.
Bremsstrahlung	2.2×10^6 K	95.
Single temperature component	1.3×10^6 K	112.
Two temperature components	$T_1 = 1.1 \times 10^6$ K $T_2 = 3.8 \times 10^6$ K	66.

FIGURE CAPTIONS

Fig. 1. Overall field of view of the experiment plotted in galactic coordinates. The solid line delimits the region of the sky which is scanned by the detectors during the rotation of the rocket. The dashed line delimits the region which is permanently in the field of each detector. The hatched region is the region of flux enhancement in the soft X-ray bands, associated with the North Polar Spur.

Fig. 2. The experimental points are compared with the convolution of the best fit spectrum and detector response. The line emission contributions of the t temperature components and the total continuum are shown separately. The vertical bars represent 1σ on each experimental point.

Fig. 3. The contributions of the various ion species to the best fit spectrum.

REFERENCES

Apparao, K., Hayakawa, S., and Hearn, D. 1979, Ap. Space Sci., 65, 419.

Berkhuijsen, E.M., Haslam, C.G.T., and Salter, C.J. 1971, Astr.Ap., 14, 252.

Borken, R.J., and Iwan, D. 1977, Ap.J., 218, 511.

Bunner, A.N., Coleman, P.L., Kraushaar, W.L., and McCammon, D. 1972, Ap.J. (Letters), 172, L67.

Burstein, P., Borken, R.J., Kraushaar, W.L., and Sanders, W.T. 1977, Ap.J. 213,405.

Chevalier, R.A. 1977, Ann.Rev.Astr.Ap., 15, 175.

Cox, D.P. 1972, Ap.J., 178, 159.

Cruddace, R.G., Friedman, H., Fritz, G., and Shulman, S. 1976, Ap.J., 207, 888.

Daltabuit, E. and Meyer, S. 1972, Astr.Ap., 20, 415.

deKorte, P.A.J., Bleeker, J.A.M., Deerenberg, A.J.M., Tanaka, Y., and Yamashita, K. 1974, Ap.J. (Letters), 190, L5.

Fireman, E.L. 1974, Ap.J., 187, 57'

Fried, P.M., Nousek, J.A., Sanders, W.T., and Kraushaar, W.L. 1980, Ap.J., 242, 987.

Hayakawa, S., Kato, T., Nagase, F., Yamashita, K., Murakami, T., and Tanaka, Y. 1977, Ap.J. (Letters), 213, L109.

Hayakawa, S., Kato, T., Nagase,F., Yamashita, K., and Tanaka, Y. 1978, Astr. Ap., 62,21.

Inoue, H., Koyama, K., Matsuoka, M., Ohashi, T., Tanaka, Y., and Tsunemi, H. 1979, Ap.J. (Letters), 227, L85.

Inoue, H., Koyama, K., Matsuoka, M., Ohashi, T., Tanaka, Y., and Tsunemi, H. 1980, Ap.J., 238, 886.

Iwan, D., 1980, Ap.J., 239, 316.

Jacobs, V.L., Davis, J., Kepple, P.C., and Blaha, M. 1977 Ap.J., 211, 605.

Jacobs, V.L., Davis, J., Kepple, P.C., and Blaha, M. 1977 Ap.J., 215, 690.

Jacobs, V.L., Davis, J., Rogerson, J.E., and Blaha, M. 1979, Ap.J., 230, 627.

Jordan, C. 1969, M.N.R.A.S., 142, 501.

Kato, T. 1976, Ap.J. Suppl., 30, 397.

Lebrun, F. 1979, Astr. Ap., 79, 153.

McKee, C.F. and Ostriker, J.P. 1977, Ap.J., 218, 148.

Meyer, J.P. 1979. In Les Elements et leurs Isotopes dans l'Universe, 22nd Liege International Astrophysical Symposium (Univ. of Liege Press) pp 153, 465, 477, 489.

Montmerle, T., Koch, L., and Grindlay, J. 1980, Private Communication.

Raymond, J.C. and Smith, B. W. 1977, Ap.J. Suppl., 35, 419 (RS).

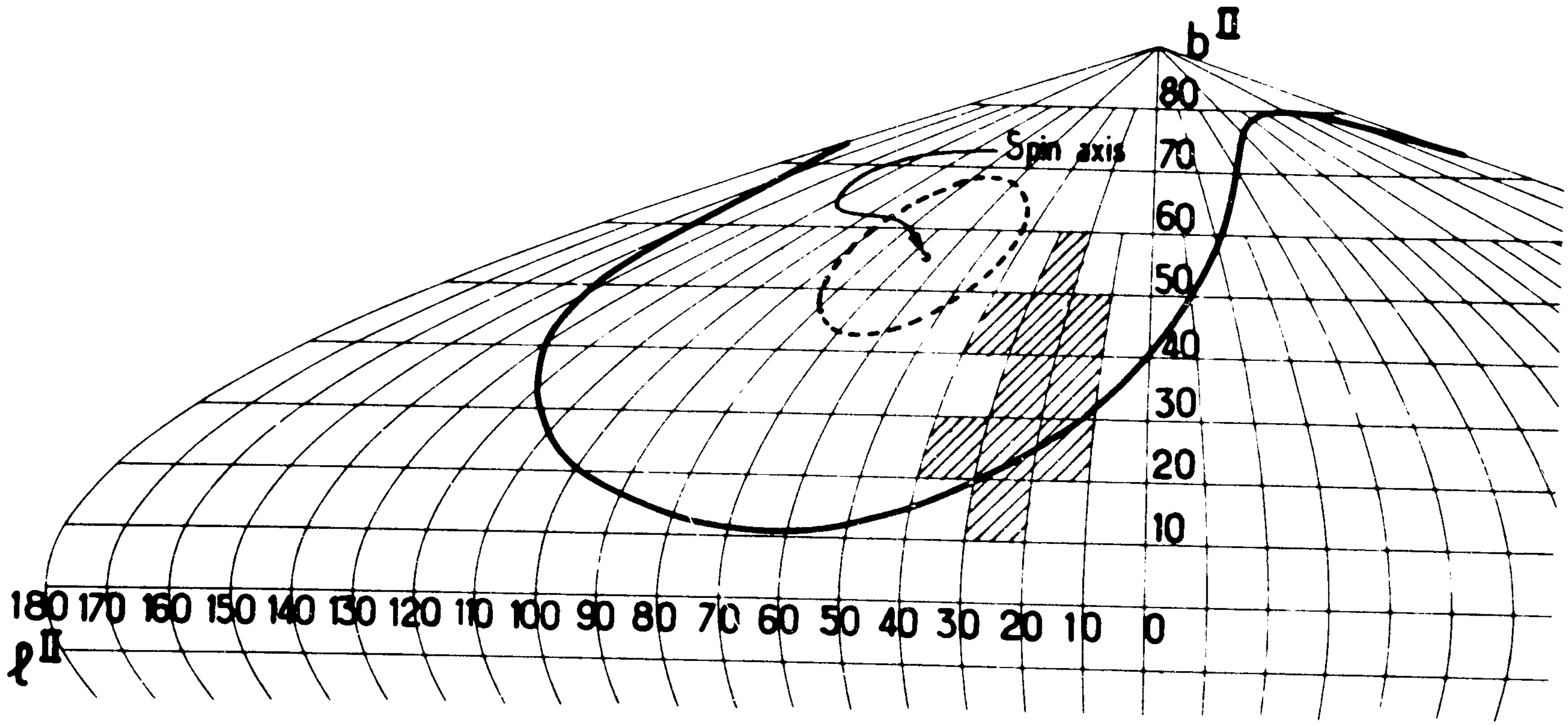
Rothenflug, R. 1980. In preparation.

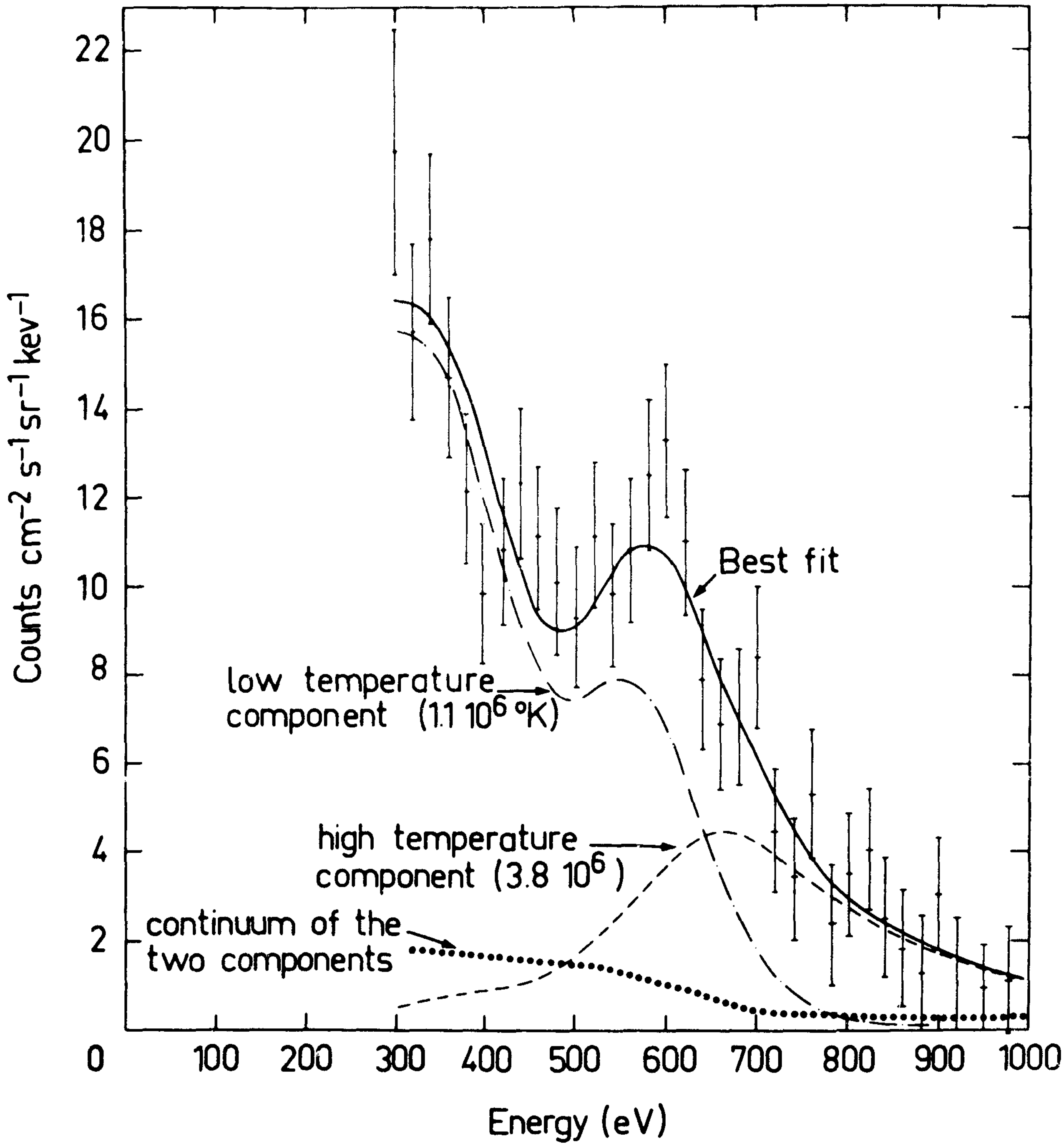
Sanders, W.T., Kraushaar, W.L., Nousek, J.A., and Fried, P.M. 1977, Ap.J. (Letters), 217, L87.

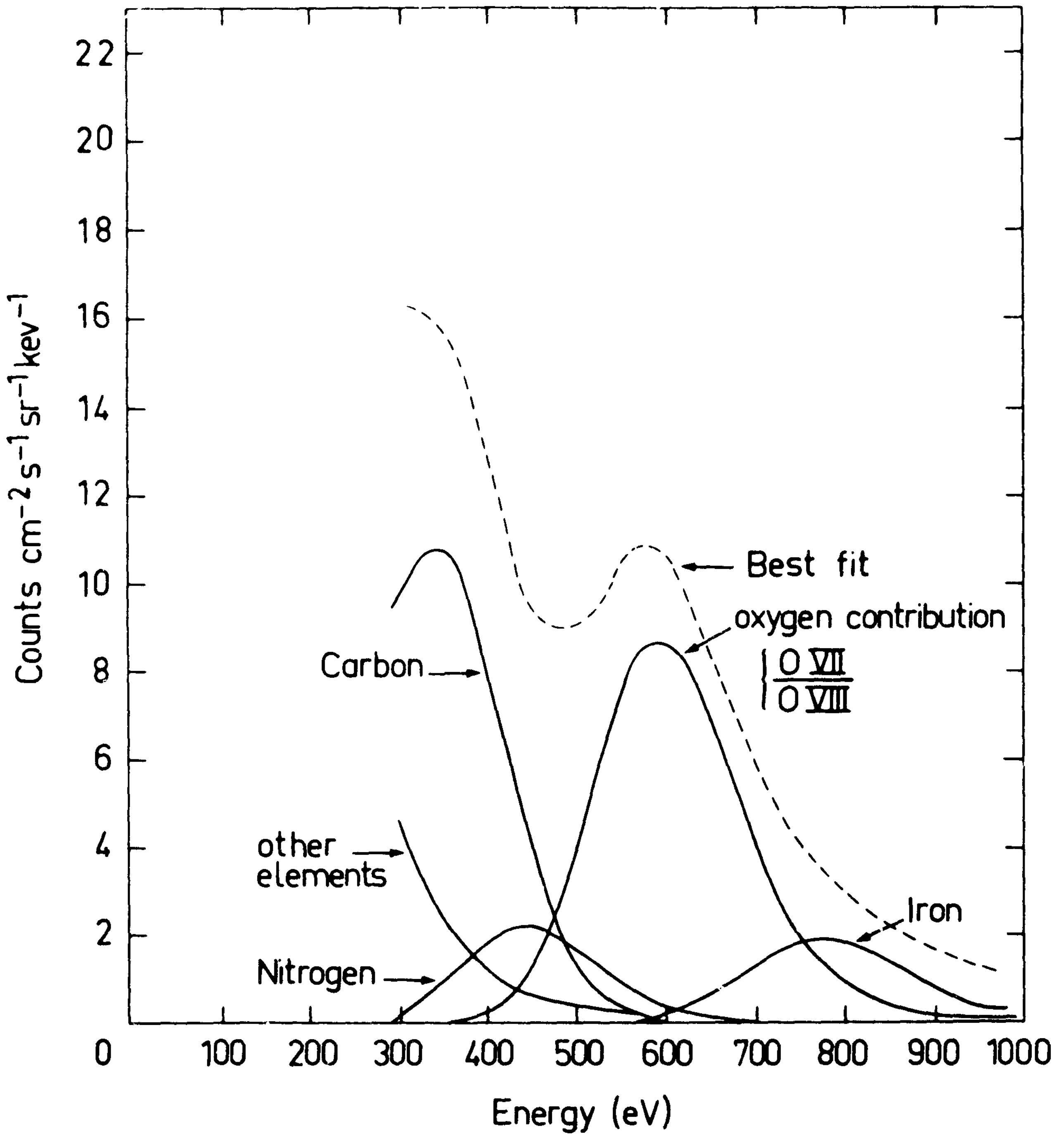
Tanaka, Y. and Bleeker, J.A.M. 1977, Space Sci. Rev., 20, 815.

Weaver, H. 1977, IAU Symposium No. 84, p.295.

Williamson, F.O., Sanders, W.T., Kraushaar, W.L., McCammon, D., Borken, R., and Bunner, A.N. 1974, Ap.J. (Letters), 193, L133.


b^{II}
80
70
60
50
40
30
20
10
Spin axis
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
ℓ^{II}


Counts cm-2 s-1 sr-1 kev-1
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700
800
900
1000
Energy (eV)
Best fit
low temperature component (1.1 10^6 °K)
high temperature component (3.8 10^6)
continuum of the two components


Counts cm^{-2} s^{-1} sr^{-1} kev^{-1}
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700
800
900
1000
Energy (eV)
Best fit
oxygen contribution
O VII
O VIII
Carbon
other elements
Nitrogen
Iron