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To cite this version:
S. Labov, S. Bowyer. SPECTRAL OBSERVATIONS OF THE EXTREME ULTRAVIOLET ASTRONOMICAL BACKGROUND RADIATION. Journal de Physique Colloques, 1988, 49 (C1), pp.C1-63-C1-66. <10.1051/jphyscol:1988111>. <jpa-00227431>

HAL Id: jpa-00227431
https://hal.archives-ouvertes.fr/jpa-00227431
Submitted on 1 Jan 1988
SPECTRAL OBSERVATIONS OF THE EXTREME ULTRAVIOLET ASTRONOMICAL BACKGROUND RADIATION

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RESUME

Les observations faites précédemment sur le fond diffus uv et dans les rayons x à basse énergies impliquent plusieurs composants de gaz chaud (10⁶ à 10⁸ K) dans le médium interstellaire. Si ce gaz est présent en large volume dans le gaz local, des raies d'émissions devraient être produites dans l'extrême ultraviolet (EUV). À ce point, le fond EUV a été détecté par des instruments photométriques mais il n'y a pas d'observations spectroscopiques en dessous de 520Å. Nous avons construit un spectromètre à incidence rasante pour étudier le fond EUV entre 80 et 650Å avec une résolution de 10 à 30Å. Cet instrument a été lancé par une fusée sonde en 1986, et les données démontrent la présence de plusieurs raies d'émissions. Une analyse préliminaire montre que plusieurs raies qui seraient attribuées au gaz interstellaires ont été détectées, en plus des raies interplanétaires de He I 584Å et la raie géocorona He II 304Å. Dans cet article nous discuterons l'analyse de ces raies et les contraintes que l'on peut donc imposer sur les conditions dans le gaz interstellaire local.

ABSTRACT

Observations in the far ultraviolet and soft x-ray bands suggest that the interstellar medium contains several components of high temperature gas (10⁶ to 10⁸ K). If large volumes of local interstellar space are filled with this hot plasma, emission lines will be produced in the extreme ultraviolet (EUV). Diffuse EUV radiation, however, has only been detected with photometric instruments; no spectral measurements exist below 520Å. We have designed a unique grazing incidence spectrometer to study the diffuse emission between 80 and 650Å with 10 to 30Å resolution. This instrument was successfully flown on a sounding rocket in April of 1986 and a preliminary analysis reveals several features. In addition to the expected interplanetary He I 584Å emission and the geocoronal He II 304Å emission, other features appear which may originate in the hot ionized interstellar gas. These features are discussed along with the possible implications to the hot phase of the interstellar medium.

Introduction

Astronomical diffuse radiation in the extreme ultraviolet (EUV: λ=100 to 1000Å) was first detected in the 114 to 150Å wavelength band with a wide field broad band photometer on a sounding rocket. Since then, additional broad band observations have confirmed this detection and have set upper limits for the radiation at longer wavelengths in the EUV band (3, 4, 5, 6). It is generally believed that this background originates from a hot, tenuous gas in the interstellar medium. The origin of this gas, however, is controversial, and a definition of its characteristics is crucial to advancing our understanding of the interstellar medium. In particular, detection of thermal emission lines from this radiation would confirm the existence of this gas and would provide information on its nature.

We have developed and built a spectrometer to measure the diffuse extreme ultraviolet astronomical background. Our spectrometer design features a fast optical system utilizing grazing incidence optics and a large solid angle. Grazing incidence is essential to maintain high efficiency at wavelengths below 400Å, and the large product of solid angle and effective area gives the spectrometer high sensitivity to diffuse emission.

The layout of the spectrometer is shown in Figure 1. Photons enter the instrument through a wire grid collimator which restricts the field of view in one dimension to 40', while allowing 15° of sky to enter the instrument in the orthogonal direction. This wedge of light is then diffracted by an array of flat, blazed, reflection gratings at grazing incidence. Once diffracted, the light is focused in the spectral direction by an array of mirrors through thin film bandpass filters and onto a detector. The measured resolution (λ/Δλ) of the instrument as a function of wavelength is shown in Figure 2. The diffuse EUV spectrometer is actually three separate spectrometers focusing on two different detectors. The medium (230 to 430Å) and long (430 to 650Å) wavelength systems are similar, and focus on the same detector. The short (80 to 230Å) wavelength system uses twice as much area as either the medium or long wavelength spectrometers and has its own detector. The instrument is described in more detail in Labov et al. /7/.
Fig. 1. The optical layout of the medium and long wavelength spectrometers sharing different regions of a common detector. The overall layout of the short wavelength spectrometer is similar with the exception that the left and right arrays of mirrors focus on the same region of the detector.

Observations

The diffuse EUV spectrometer was launched April 22, 1986 from White Sands, New Mexico on a Nike boosted Black Brant sounding rocket. The time of launch was set to optimize viewing in the direction of the Earth's shadow cone thereby minimizing geocoronal emission. The Earth's magnetic field traps ionized helium which strongly scatters the bright solar He II 304Å radiation, and this plasma is shadowed by the earth in the anti-sun direction. A pointing of $l=325^\circ$ and $b=+48'$ was held for 160 seconds, and then shifted 1.5° along the narrow (40') field of view direction and held for another 160 seconds. A comparison of the accumulated spectra during the two pointings indicates that no point source of EUV emission contributed to the observed flux. Toward the end of the mission, the instrument made a scan away from the Earth's shadow cone toward the Earth's horizon to test for geocoronal emission and to characterize any airglow component to the spectrum.

The instrument functioned properly during all phases of the observation, and the pointings have been confirmed by an independent on-board star camera. Post-flight calibration of the instrument indicates that the optical elements of the spectrometer did not shift from their pre-flight alignment.

Preliminary Analysis

The raw data for the three spectrometers are shown in the form of a spectrum in Figure 3. This spectrum includes all the events observed during the time when the instrument was pointed in the anti-solar direction, and the detectors were operating at constant background levels. The short wavelength spectrum (80 to 230Å) includes 329 seconds of data. The medium wavelength spectrum (220 to 440Å) and the long wavelength spectrum (420 to 650Å) only include 234 seconds of data because the detector used with this spectrometer took longer to stabilize to a constant countrate. The background estimation is shown by the dotted curve in Figure 3. This dotted curve is included to indicate the overall shape of the detector induced background spectrum; it is not the detector background observed during the flight. Therefore, the solid line histogram in Figure 3 includes the detector background accumulated during the flight in addition to any EUV emission observed.

In addition to the obvious emission line at 584Å, careful inspection of Figure 3 reveals features at 100, 200, 300 and 635Å. To be considered real, however, an emission line must not be an intrinsic feature of the spectrometer or due to a transient malfunction of the detector and spectrometer system such as a detector "hot-spot" or filter tear. Furthermore, a true emission...
Table 1
Possible emission lines
(preliminary analysis)

<table>
<thead>
<tr>
<th>λ (Å)</th>
<th>Observed counts</th>
<th>Observation time (sec)</th>
<th>Intensity (ph cm⁻²sec⁻¹str⁻¹)</th>
<th>(Rayleighs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>191</td>
<td>369</td>
<td>790</td>
<td>.010</td>
</tr>
<tr>
<td>180</td>
<td>57</td>
<td>369</td>
<td>1,030</td>
<td>.013</td>
</tr>
<tr>
<td>304</td>
<td>72</td>
<td>234</td>
<td>2,080</td>
<td>.026</td>
</tr>
<tr>
<td>584</td>
<td>738</td>
<td>234</td>
<td>70,400</td>
<td>.89</td>
</tr>
<tr>
<td>635</td>
<td>113</td>
<td>234</td>
<td>19,000</td>
<td>.24</td>
</tr>
</tbody>
</table>

The raw spectrum from the flight was fitted with a model composed of the detector background and a number of emission lines. Each line is spread by the instrument resolution at the wavelength of the line and then added to the continuum. For an estimate of how well the model fits the data, the Pearson's \( \chi^2 \) statistic was used as described in Lampton et al. /8/. The model was varied by changing the number of lines used to fit the data beginning with no lines and then increasing the number of lines until no further improvement in the fit was noted. The lines which pass all of the above criteria are listed in Table 1.

Some notes on Table 1 are in order. The 180Å feature is statistically weak, but it is included in Table 1 for completeness. A feature at 610Å passes all the criteria but it is not included in Table 1 because its wavelength and strength suggest it is the second order image of the 304Å emission. Similarly, a feature at 200Å has not been included because it is consistent with being the second order image of the 100Å feature. The observed counts listed in Column 2 are the total number of counts in the line, and do not include the background counts. The intensities listed in Table 1 have been corrected for atmospheric absorption. Finally, the 304Å intensity listed in Table 1 is consistent with the upper limit to 304Å emission in the anti-solar direction (0.02 Rayleighs) reported by Paresce et al. /9/.

Except as noted above, the lines listed in Table 1 pass all the tests to be considered true emission lines. We have concluded that these lines are not the result of ghost images in the spectrometer system, non-uniformities in the detector response, or malfunctions of the filters or detectors. Furthermore, tests indicated that these lines are from a truly diffuse source and that they are not atmospheric in origin. With the exception of the He II 304Å emission, none of these lines appear to emanate from the Earth's geocorona. The 584Å emission is clearly the solar radiation resonantly scattering off the neutral helium flowing through the solar system. This leaves three possible lines, those at 100, 180 and 635Å, which may be produced by the hot interstellar medium.

The lines listed in Table 1 are presented in Figure 4. The non-interstellar lines (304 and 584Å) are indicated by squares, and the other lines are marked with squares. The non-interstellar lines (304 and 584Å) are indicated by squares, and the other lines are marked with squares. The non-interstellar lines (304 and 584Å) are indicated by squares, and the other lines are marked with squares. The non-interstellar lines (304 and 584Å) are indicated by squares, and the other lines are marked with squares.

**Fig. 4.** The detected emission lines are indicated: the squares are non-interstellar lines and the circled points are the lines which could be interstellar in origin. The bold lines indicate the upper limits to line radiation inferred from this observation, and the dashed lines indicated the upper limits (and detection at \( \lambda=114 \) to 180Å) derived from previous observations.
circles. The regions of the spectrum with no features has been converted to upper limits, corrected for atmospheric absorption and then plotted with a heavy solid line in Figure 4. Also shown in Figure 4 (dashed curves) is the strength necessary for a single line to produce the broad band detections and upper limits from the Apollo-Soyuz EUV telescope observations /2,3/, and the upper limits to line radiation found with the Voyager instrument /4/. Note that shortward of 500Å, the upper limits from this observation are the only existing spectral measurements of the diffuse EUV background.

Discussion and Conclusions

As can be seen in Figure 4, the short wavelength lines (100 and 180Å) are consistent with the previous observations. The 635Å line is however, above the upper limits set by the Voyager instrument. Above the 635Å intensity is terrestrial in origin and would therefore not be observed by Voyager during its interplanetary cruise. However, examination of the line intensities as a function of atmospheric path length, and angle from the Earth’s shadow suggest that this line is not due to atmospheric or geocoronal emission. If the emission is interstellar in origin, it would be subject to strong absorption by neutral interstellar hydrogen and the brightness of the line would be extremely sensitive to the geometry of the emitting and absorbing regions. It is therefore possible that this is an interstellar emission line which happens to be weaker in the direction observed by Voyager.

The features detected at 100, 180 and 635Å may indeed be produced by hot gas in the local interstellar medium. In particular, the feature at 635Å could be the O VI resonance emission line at 630Å. This feature, along with the upper limits derived for the parts of the spectrum with no features, could only be produced by gas near 10^{15}K. The feature at 100Å could be produced by several different highly ionized species such as Si V, Ne VII, Ne VIII or Fe XVIII, and the 180Å feature could be produced by O VI or Fe VIII to Fe XI/10,11/. Further analysis will explore the confidence of these results and implications to models of the hot interstellar medium.

The results presented here are fairly direct evidence that the diffuse EUV background is line emission produced by hot interstellar gas. This experiment has produced the first spectrum of the diffuse background between 80 and 500Å, and has provided enticing hints to the information available from the EUV background.

Acknowledgements

The spectrometer design was initiated by Chris Martin. We thank Anne Miller for continuing assistance in fabrication assembly and testing, and Aileen Corelli for editorial assistance. This work was supported by NASA grant NGR 05-003-450 and NGT 05-003-805.

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