EURD DATA PROCESSING ⋆

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Abstract. EURD (Espectrógrafo Ultravioleta extremo para la Radiación Difusa) is one of the scientific instruments on board MINISAT 01. EURD is a spectrograph with very high sensitivity and spectral resolution (∼ 5 Å), designed to obtain extreme ultraviolet (∼ 350 − 1100 Å) spectra of diffuse radiation. We outline the processing of EURD data, and how we obtain information from these data on the scientific goals of the mission: hot interstellar medium, neutrino decay line, nightglow emission, and early-type stars.

1. Introduction

The EURD spectrograph (Espectrógrafo Ultravioleta extremo para la Radiación Difusa, i.e., Extreme Ultraviolet Spectrograph for Diffuse Radiation) is an instrument composed of two spectrographs specially designed to detect diffuse line emission on the 350–1100 Å band (see Morales *et al.*, 1998).

The detection of spectral lines at this scarcely-studied spectral band would help to answer several important open questions, in very different astrophysical topics. The main scientific goals of EURD are:

– To obtain a conclusive evidence about the presence of hot gas ($10^5 - 10^6$ K) around the Sun, and to find the physical parameters of this gas, specially its temperature (Bowyer *et al.*, 1968; Breitschwerdt and Schmutzler, 1994). This would have implications on the study of galactic structure and dynamics.

– To detect the spectral signature of the decay of massive neutrinos (Sciama, 1990a,b). This would have implications on the determination of the lifetime of the Universe.

– To determine the FUV flux of early-type stars, and compare with current models of stellar atmospheres (Brune *et al.*, 1979; Holberg *et al.*, 1982; Buss *et al.*, 1995). This would have implications on the ionization conditions in galaxies.

⋆ Based on the development and utilization of the Espectrógrafo Ultravioleta extremo para la Radiación Difusa, a collaboration of the Spanish Instituto Nacional de Técnica Aeroespacial and the Center for EUV Astrophysics, University of California, Berkeley

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Astrophysics and Space Science is the original source of this article. Please cite this article as: *Astrophysics and Space Science* **276:** 233–238, 2001.

– To study the physical processes in the upper atmosphere, in particular those involving thermospheric oxygen, and their relation with magnetospheric and solar events. Only an OII line at 834 Å has been detected in the night spectrum (Chakrabarti *et al.*, 1984)

The unprecedently high spectral resolution (5 Å) and sensitivity (200 photon s^{-1} cm^{-2} sr^{-2}) of EURD make this project specially well-suited to successfully pursue these scientific goals, and to obtain novel and relevant results. For a review of the EURD results on these important topics, see the talks by Edelstein, Bowyer, Morales, and López-Moreno at this meeting.

The study with EURD of each of these topics requires different data processing strategies. Careful reduction of EURD data is a very time-consuming task given the large amount of data produced by our instrument (about 10 Mbytes per day).

2. Data Properties

Photons detected by EURD are codified into data packets. For each photon, these packets carry information on time of detection, wavelength and spatial position (along the spectrograph slit). The *Centro de Operaciones Científicas* (Science Operation Center) provides the EURD science team with these EURD data, along with attitude data containing the satellite coordinates and EURD pointing on the sky, as a function of time.

For calibration purposes, EURD is equipped with a filter wheel. The incident radiation passes through the filter exposed at each moment (open, MgF, closed). The 'open' position allows all the incident radiation to enter the spectrograph. This position corresponds to the raw, uncalibrated data (see Figure 1). The 'MgF' and 'closed' positions give us a measure of the internal background, that should be subtracted from the data.

3. Particular Data Reduction

3.1. Interstellar medium and neutrino decay studies

These studies involve the detection of extremely weak lines. Therefore, very long integration times are required to achieve enough sensitivity for their detection. We regularly update files containing the accumulation of photons gathered during the whole mission. From these files, we can obtain a spectrum per spectrograph, with the highest possible signal-to-noise ratio to date (Figure 2).

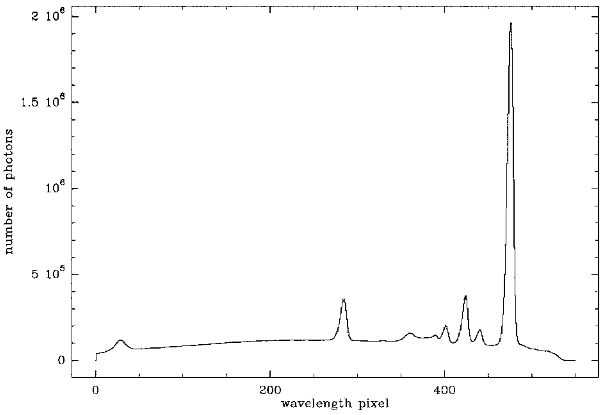

Figure 1. Raw, uncalibrated spectrum, obtained by summing the spectrograph image along the spatial dimension.

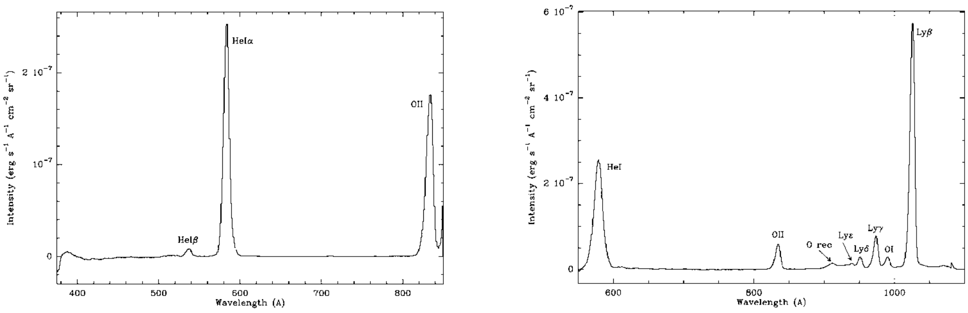

Figure 2. Calibrated spectra obtained by accumulated data from the whole mission (up to 1999 January 31), for both spectrographs. This amounts to $\sim$ 805 h of total observing time through the 'open' position of the filter wheel. Data from days with lunar contamination have been excluded. Data with obvious stellar emission have also been excluded for wavelengths longer than 912 Å. The identification of the most conspicuous spectral signatures is marked in the figures (they all are atmospheric features). Note the high S/N of the spectra.

3.2. Upper Atmosphere Nightglow

EURD observes in the anti-sun direction, and during the night-time part of the orbit. This means that our instrument is collecting data of the physical processes occurring in the atmosphere above MINISAT orbit ($\sim$ 600 km) during the night. The accumulated spectra for all the mission have allowed us to detect several atmospheric lines for the first time (López-Moreno *et al.*, 1998).

We can also study the dependence of line intensities with several variables. For instance, we can study line variation as a function of zenith angle.

MINISAT and COC provide us with data on satellite position and EURD pointing as a function of time. These vectors allow us to separate the incoming photons on the basis of zenith angle. To illustrate this, Figure 3 shows the spectra for the most extreme cases: $Z = 90°$, and $Z = 0°$.

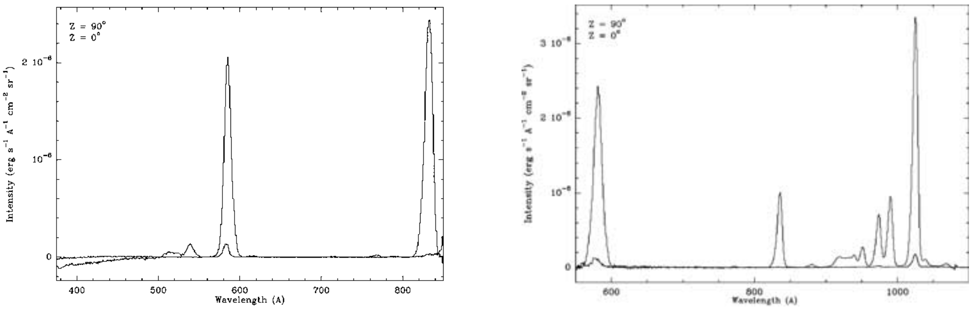

Figure 3. Calibrated spectra obtained for zenith angles $Z = 90°$ (the more intense lines) and for $Z = 0°$ (the weaker lines), with both spectrographs. Note the strong variation of lines with zenith angle.

Even for a particular zenith angle, there could be other variables that could influence atmospheric line emission. Ongoing work is focusing in studying time variations of flux along the mission, and correlate them with magnetospheric or solar activity phenomena.

3.3. Spectra of early-type stars

Only the most massive stars (spectral types O and B) emit enough radiation in the extreme ultraviolet to be detected by EURD. We have found stellar emission at wavelengths longer than 912 Å for those stars. Since EURD always points in the anti-sun direction, we get radiation from stars which lie within a few degrees from the ecliptic plane. EURD has been designed to receive diffuse radiation, not point sources. Therefore, processing of stellar data poses some additional difficulties.

When a star gets into the EURD field of view ($\sim$ 8° long on the Y axis of MINISAT, and $\sim$ 26° on the X axis), we get an image that contains the stellar emission in the long-wavelength spectrograph (Figure 4). While the spectrographic process retains the spatial information about the Y coordinate of the star, spatial information about the X coordinate is completely lost (in return, we get wavelength information). This means that two stars that fall into the EURD field of view with the same Y coordinate, but with different X coordinates, would appear in the spectrograph image at exactly the same location. This is a problem for a possible identification of stars, specially when more than one appear simultaneously in the image, and has to be carefully studied.

For the next step in identification of stars, we use the *Bright Star Catalog*. From the satellite data that give us EURD pointing and the orientation of the field of view (every ten seconds), and the catalog positions of stars, we calculate which stars should be within the EURD field of view at each moment. We then compare the expected position of the catalog stars during the whole day along the short (spatial) dimension with the distribution of the stellar light in our data, along that

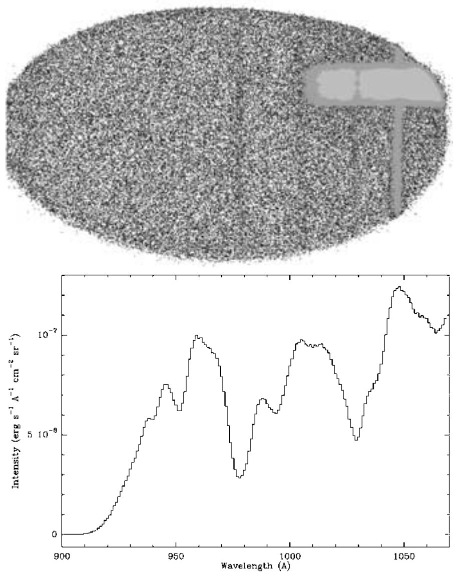

Figure 4. Top: Long-wavelength spectrograph image for 99 April 19. Note the strong emission of α Vir. Bottom: Calibrated spectrum of α Vir.

dimension. A correlation between the theoretical position and the observed flux, gives us the identification for the star.

We can produce an image of the spectrograph every few seconds, to precisely locate the star in the detector. The subtraction of instrumental background and atmospheric emission is performed, using the area of the spectrograph image contiguous to where the star shows up.

Data on α Vir (the brightest one detected) can also be used to check the reliability of the pointing provided to us by MINISAT via COC. Since we can locate the star every second, we can compare its observed position on the detector with the predicted one from MINISAT pointing information and the catalog position of the star. This gives us an estimate of possible systematic or random errors of MINISAT pointing data.

We found the estimates of random errors to be fairly stable in time, with a standard deviation of $\sigma = 0\overset{\circ}{.}25$, and a maximum deviation of $0\overset{\circ}{.}75$. Systematic errors vary with time, but in all cases we have studied, they are below $0\overset{\circ}{.}68$. Therefore, the errors we have found are much lower than the nominal pointing accuracy required for MINISAT ($2\sigma = 5°$).

Acknowledgements

The development of EURD has been partially supported by INTA grant IGE 490056. C.M. and J.T. acknowledge support from DGCYT grant PB94-0007. JFG is supported in part by DGICYT grant PB95-0066 and by Junta de Andalucía (Spain).

The UCB authors wish to thank Yumi Odama for help in the data processing. Partial support for the develpment of the EURD instrument was provided by NASA grant NGR 05-003-450. When NASA funds were withdrawn by Ed Weiler, the instrument was completed with funds provided by S. Bowyer. The UCB analysis and interpretation work is carried out through the volunteer efforts of the authors.

References

Breitschwerdt, D. and Schmutzler, T.: 1994, *Nature* **371**, 774.

Brune, W.H., Mount, G.H. and Feldman, P.D.: 1979, *Astrophys. J.* **227**, 884.

Buss, R.H., Kruk, J.W. and Ferguson, H.C.: 1995, *Astrophys. J.* **454**, 55.

Chakrabarti, S., Kimble, R. and Bowyer, S.; 1984, *J. Geophys. Res.* **89**, 5660.

Holberg, J.B., Forrester, W.T., Shemansky, D.E. and Barry, D.C.: 1982, *Astrophys. J.* **257**, 656.

López-Moreno, J.J., Morales, C., Gómez, J.F., Trapero, J., Bowyer, S., Edelstein, J., Lampton, M. and Korpela, E.J.: 1998, *Geophys. Res. Lett.* **25**, 2937.

Morales, C., Trapero, J., Gómez, J.F., Bowyer, S., Edelstein, J. and Lampton, M.: 1998, in: D. Breitschwerdt, M.J. Freyberg and J. Trümper (eds.), *The Local Bubble and Beyond, Lecture Notes in Physics* **506**, Springer, Berlin, 41.

Sciama, D.W.; 1990a, *Phys. Rev. Lett.* **65**, 2839.

Sciama, D.W.: 1990b, *Astrophys. J.* **364**, 549.