EURD DATA PROVIDE STRONG EVIDENCE AGAINST THE SCIAMA MODEL OF RADIATIVE DECAY OF MASSIVE NEUTRINOS*

STUART BOWYER, ERIC J. KORPELA, JERRY EDELSTEIN and MICHAEL LAMPTON
Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450

CARMEN MORALES, JUAN PÉREZ-MERCADER, JOSÉ F. GÓMEZ and JOAQUÍN TRAPERO**
Laboratorio Astrofísica Espacial y Física Fundamental, INTA, Apdo. Correos 50727, E-28080 Madrid, Spain

Abstract. Data obtained with a high resolution, high sensitivity spectrometer flown on the Spanish MINISAT 01 satellite were used to test the Sciama model of radiatively decaying massive neutrinos. The observed emission is far less intense than that expected in the Sciama model.

1. Introduction

Relic neutrinos, if massive, could contribute significantly to the density of the universe, and if appropriately concentrated, could explain puzzling characteristics of luminous matter in galaxies. Melott (1984) suggested that if these particles were radiatively decaying, they could be responsible for the sharp hydrogen ionization edges seen in many galaxies and that this decay would not violate existing observational data if the decay energy was somewhat greater than 13 eV and the lifetime for decay was about 10^{24} s. In a subsequent paper, Melott *et al.* (1988) showed this idea was consistent with observations of star formation, galaxy formation and morphology, and other phenomena. Subsequently, Sciama and collaborators in an extensive set of papers (Sciama, 1990, 1993, 1995, 1997a, 1997b, 1998; Sciama *et al.*, 1993) showed that if the decay lifetime was an order of magnitude less than that suggested by Melott, his theory could explain a large number of otherwise puzzling astronomical phenomena, including the ionization state of the intergalactic medium and the anomalous ionization of the interstellar medium (ISM) in our own Milky Way Galaxy. Although massive neutrinos cannot be contemplated within the framework of the standard model of particle physics, they can be accommodated in the supersymmetric extensions of the standard model, especially if R-parity is broken (cf. Gato *et al.*, 1985; Bowyer *et al.*, 1995). Recent observational and

* Based on the development and utilization of the Espectrógrafo Ultravioleta de Radiación Difusa, a collaboration of the Spanish Instituto Nacional de Tecnica Aeroespacial and the Center for EUV Astrophysics, University of California, Berkeley

** Present address: Universidad SEK, Cardenal Zúñiga s/n, Segovia, Spain

Astrophysics and Space Science is the original source of this article. Please cite this article as: *Astrophysics and Space Science* **276:** 155–161, 2001.

experimental results suggest they do, in fact, have mass (Fukuda *et al.*, 1998a,b; Athanassopoulos *et al.*, 1998a,b).

A number of searches have been made for evidence of radiatively decaying massive neutrinos in clusters of galaxies. Davidsen *et al.* (1991) severely constrained the parameter space available for these particles through observations of the cluster of galaxies Abell 665, and Fabian *et al.* (1991) obtained similar results from a study of the cluster of galaxies surrounding the quasar 3C263. However, Sciama *et al.* (1993) and Bowyer *et al.* (1995) have shown that these observations do not rule out the Sciama scenario.

An all-pervading neutrino flux in the Galaxy at a wavelength near the ionization limit of hydrogen would be difficult to observe because of absorption by the ISM. An additional observational complexity is emission from an upper atmosphere oxygen recombination feature at 911 Å (Chakrabarti *et al.*, 1983).

In this paper we report results of spectral observations made in the region $\leq$ 912 Å where the radiation in the Sciama scenario would be present, and compare the data obtained with the flux expected.

2. Observations

The Espectrógrafo Ultravioleta extremo para la Radiación Difusa, (EURD) is capable of providing measurements of the diffuse UV background which are more than 100 times more sensitive than existing measurements in this band-pass, with a spectral resolution of about 6 Å. The instrument is described in detail by Bowyer *et al.* (1997). This instrument was flown on the MINISAT 01 spacecraft and has been providing high quality data for over two years.

We examined EURD data in the 890 to 915 Å bandpass obtained from 18 June 1997 to 29 June 1998 in an attempt to detect the emission which would be present if the Sciama scenario was operative. Data from the spectrometer were typically collected over the entire night-time portion of the orbit. Higher count rates are always experienced at spacecraft sunrise and sunset due to geocoronal effects, but deep night intensities are typically constant and low. For the search for radiation from the Sciama scenario, we sorted the data to exclude all sunrise and sunset data and all other data associated with high backgrounds.

The EURD spectrograph employs a number of vetoes to reduce unwanted background and to permit evaluation of those background events which cannot be otherwise eliminated.

The detector is surrounded by an anti-coincidence shield and all counts triggering this shield (about 20 percent) are rejected. Remaining internal background components include charged particles that are missed by the anti-coincidence system, Compton scattered γ-rays, and radioactivity within the detector and in the spacecraft. An additional background is produced by photons scattered by the grating onto the detector. This scattered emission is mostly a continuum arising

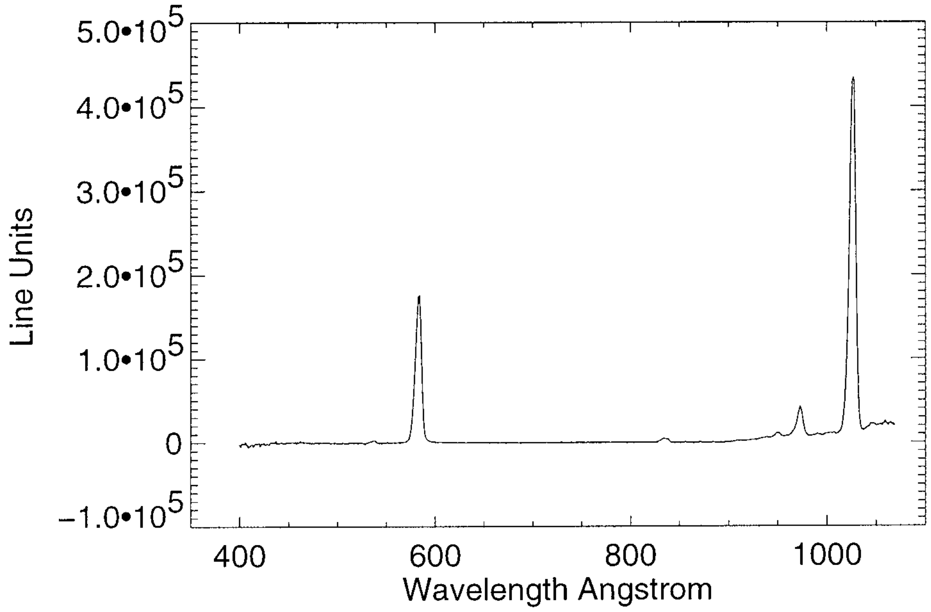

Figure 1. Background subtracted EURD long wavelength spectrum consisting of about 3×10^5 seconds of shutter open time.

from the wings of the zero and first order of the hydrogen Lyman-alpha line whose peaks were designed to fall beyond the ends of the detector.

The entrance aperture of the instrument has a filter wheel with three positions: Open, Closed, and a MgF_2 filter. The Open position provides spectral data plus backgrounds. The Closed position gives an estimate of the internal background, and the MgF_2 filter position gives an estimate of the scattered radiation. Observations were carried out sequentially with each of these apertures; the complete cycle time was 90 s.

We corrected the deep night spectral data for backgrounds using the MgF_2 and Closed apertures. In Figure 1 we show the data from the long wavelength band using 3×10^5 seconds of 'Open' data with appropriate background subtraction. The high quality of these data is obvious.

To investigate the Sciama model we summed the background corrected data in the 890 to 915 Å band as a function of time. We included data to 915 Å to assure all counts shortward of 912 Å were included in the sample given the spectral resolution of the instrument. In some neutrino decay scenarios, two lines will be produced whose relative intensities are uncertain. However, the sum of both of these lines is the key parameter to be measured, and in the Sciama scenario these lines will be separated by 0.2 eV, or 13 Å at 900 Å. Hence the flux from both these lines will be included in the data reported here. Data were summed over 10 day

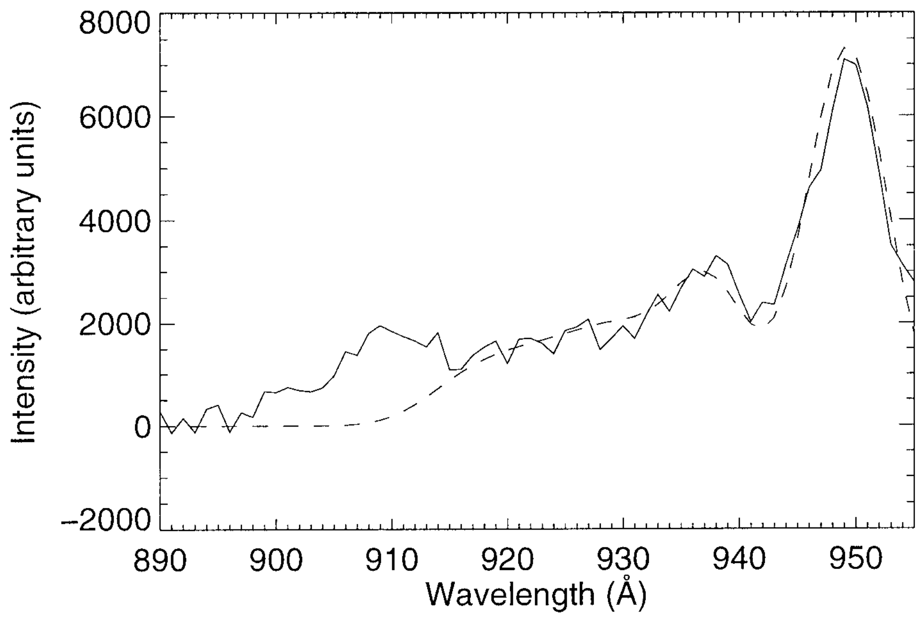

Figure 2. The observed spectrum of the region around 911 Å where radiation in the Sciama scenario is expected. The solid line shows a straight line interpolation of the spectrum from about 60 hours of shutter open observations during a period when emission from the oxygen recombination feature was more pronounced. The dashed line shows the expected hydrogen Lyman series lines with an electron temperature of 0.4 eV folded with the instrument resolution and fit to the average intensity of the Lyman series lines during this period.

intervals, providing typically about 3500 counts in the region of interest, to obtain good counting statistics.

Unfortunately in regards to our search for the Sciama line, oxygen recombination radiation was substantial at the altitude of the MINISAT satellite even in the anti-Sun view direction. A spectrum of the radiation detected around 912 Å is shown in Figure 2. This spectrum shows a profile that is consistent with the line shape obtained by Feldman *et al.* (1992) given the resolution of this instrument. Just longward of 912 Å the spectrum is dominated by the Lyman series lines of geocoronal hydrogen (López-Moreno *et al.*, 1998). Both the oxygen recombination feature and the Lyman series of hydrogen vary in time; the data shown in Figure 2 are from a period when the oxygen recombination radiation was more pronounced.

We determined the EURD counts-to-flux conversion factor in the region around 800 Å using an in-flight calibration strategy based on simultaneous EUV observations of the Moon with EUVE and EURD (Flynn *et al.*, 1998), and, longward of 912 Å, to fits to stellar spectra (Morales *et al.*, 2000). It is estimated that this calibration is good to ±20% in the band around 912 Å because of the quality of the fit to stellar spectra. This in-flight calibration yields a conversion of 6.5×10^4 ph cm^{-2} str^{-1} per count at 912 Å. The resulting fluxes are shown in Figure 3. These

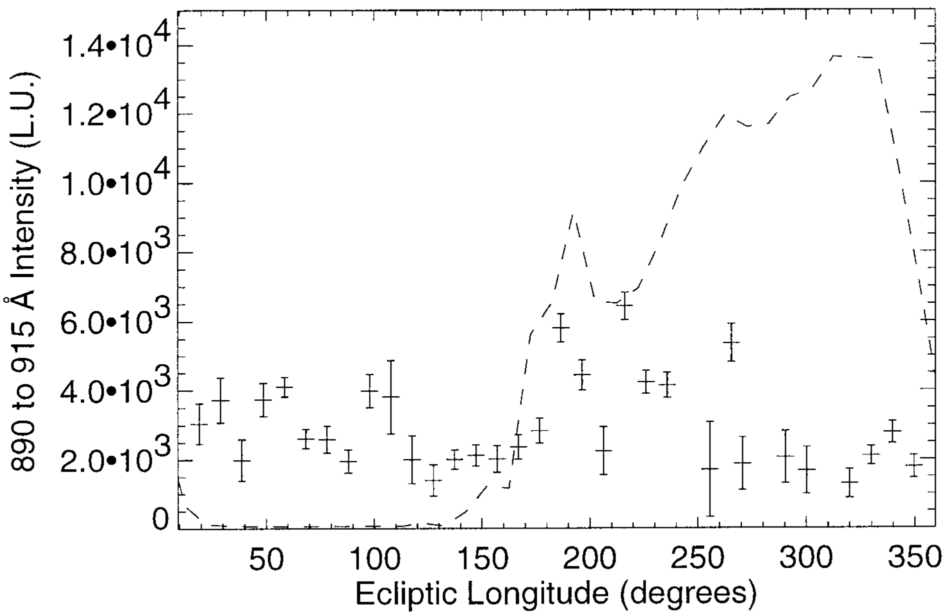

Figure 3. The expected signature from the radiative decay of massive neutrinos as predicted by the Sciama scenario is shown as a dashed line. This signature depends upon ecliptic longitude because of absorption by the LIC and the size of the open region beyond. The integrated intensity of the observed emission from 890 to 915 Å is also shown. Each data point is a sum of 10 days of deep night data.

fluxes are the total fluxes obtained in this bandpass, uncorrected for any Lyman series emission as seen in Figure 2.

The expected emission in the Sciama scenario can best be considered in two parts. The first is produced in the Local Interstellar Cloud (LIC) which surrounds the Sun; this emission is intermixed with absorption. The second component is emission from beyond the LIC which is absorbed by this cloud.

Formally, the emission is given by the relation:

$$I(l) = B + \frac{R_{\rm prod}}{4\pi n_o \sigma}\left(1 - \exp\left[-n_o \sigma d_{\rm cl}(l)\right]\right) + \frac{R_{\rm prod}\left[d_e(l) - d_{\rm cl}(l)\right]}{4\pi} \exp\left[-n_o \sigma d_{\rm cl}(l)\right] \quad (1)$$

where we have included a background, B (which could be due to anything, but is mostly due to oxygen recombination radiation); $R_{\rm prod}$ is the photon production rate; n_o is the density of the LIC; σ is the effective ISM cross section for absorption (Rumph *et al.*, 1994); $d_{\rm cl}$ is the distance to the cloud edge; and d_e is the distance to the edge of the neutral free region. The symbol l indicates variation with ecliptic longitude. The most recent (small) revision of the theory (Sciama, 1998) requires a photon production rate of $2 \pm 1 \times 10^{-16}$ s^{-1} cm^{-3}.

We have used the model of Redfield and Linsky (1999) for data on the LIC. This is a three dimensional model which is based on ISM absorption features in the spectra of nearby stars obtained with HST, EUVE, and ground based telescopes. Minimum hydrogen columns in the plane of the ecliptic in this model are $\sim 2.5 \times 10^{16}$ cm^{-2}, maximum columns are $\sim 2.5 \times 10^{18}$ cm^{-2}.

In the region beyond the LIC, Welsh *et al.* (1998) used high resolution optical spectroscopy to determine the amount of ISM sodium in the line of sight to stars within 300 pc of the Sun. They found that the ISM is essentially free of neutral gas out to more than 70 pc in most directions. Sfeir *et al.* (1999) have obtained an extensive set of sodium absorption data and have modeled the extent of this ionized region, or Local Bubble. We have used the $N(H) = 1 \times 10^{19}$ cm^{-2} contour of their model, where the ionized region of the Local Bubble abruptly ends, as the limit to the region from which the Sciama line could be detected. This contour is typically at 100 pc in the plane of the ecliptic. We have incorporated these results in Equation 1, and we show the expected emission in the plane of the ecliptic for the Sciama scenario in Figure 3.

3. Discussion and Conclusions

The geocoronal oxygen background is obvious in the data shown in Figure 3, but in those view directions in which the absorption by the LIC is small because of the Sun's location within the cloud, the flux from radiatively decaying neutrinos should be far more intense than the oxygen emission. It is obvious by inspection that the emission predicted by the Sciama theory is not present.

We have fit our data shown in Figure 3 to a model described by Equation 1 in which we treat the background B and the photon production rate $R_{\rm prod}$ as parameters. Our best fit value for B is 2200 ph s^{-1} cm^{-1} str^{-1}. Our best fit for $R_{\rm prod}$ is consistent with zero and has a 95% confidence upper limit of 0.6×10^{-16} s^{-1} cm^{-3}, which is one third of the production rate required by the theory.

The EURD data appear to be completely incompatible with the Sciama model of radiatively decaying massive neutrinos.

A complete analysis of this result is provided in Bowyer *et al.* (1999).

Acknowledgements

We wish to acknowledge many useful discussions with Dennis Sciama. We thank Jeff Linsky and Seth Redfield for access to their model before publication, and Seth Redfield for help in utilizing this model. We thank Daphne Sfeir for access to her model before publication and her help in utilizing this model. The authors wish to thank J. Cobb for devising and implementing complex data processing programs which convert the spacecraft data to forms amenable to scientific analysis. Partial support for the development of the EURD instrument was provided by NASA grant NGR 05-003-450 and INTA grant IGE 490056.

When the NASA funds were withdrawn from the instrument development at Berkeley by Ed Weiler, the instrument was completed with funds provided by S. Bowyer. The UCB analysis and interpretation is carried out through the volunteer efforts of S. Bowyer, J. Cobb, J. Edelstein, E. Korpela and M. Lampton. The work by C. Morales and J. Trapero is supported in part by DGCYT grant PB94-0007.

J.F. Gómez is supported in part by DGYCIT grant PB95-0066 and Junta de Andalucía (Spain). J. Pérez-Mercader is supported by funds provided by the Spanish ministries of Education and Defense.

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