Searching *EUVE* Data for Transient/Flaring Extreme Ultraviolet Sources

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The *Extreme Ultraviolet Explorer* (*EUVE*), because of its sky survey strategy, performed two observations of each point along a 180° by 1° strip of the ecliptic during the initial survey phase of the mission. One observation used the deep survey telescope, and another, 90 days earlier or later, used the all sky scanner telescopes, two of which have a nearly identical passband to that of the ecliptic deep survey. Since the completion of the initial sky survey, *EUVE* has been used to carry out deep, pointed observations of selected targets. Many areas of the sky have therefore been observed two or more times, allowing us to compare count rates for some objects over a long temporal baseline. Objects with significantly varying count rates for widely separated times are of particular astrophysical interest.

With this technique, we have discovered one such object, which appears in the First *EUVE* Source Catalog as EUVE J2056-171. We present upper and lower limits on how frequently other highly-variable objects will be detected by *EUVE* in future observations.

1. *EUVE* Survey Strategy

The *EUVE* mission began with a six-month survey period, consisting of an all-sky survey in four EUV bandpasses (100 Å, 200 Å, 400 Å, and 600 Å) and a simultaneous deep survey in the 100 Å and 200 Å bandpasses, covering a 1° by 180° strip along the ecliptic. The deep survey telescope was pointed in the anti-sun direction for the duration of the survey phase, while the all-sky scanning telescopes, pointing 90° away from the deep survey axis, swept out great circles along lines of ecliptic longitude at a rate of about one revolution per orbital night. After six months, a narrow 180° strip along the ecliptic had been observed by the deep survey telescope, with average integration times on the order of 10000 s, and the all-sky survey telescopes had observed about 90% of the sky, with total integration times ranging from about 500 s along the ecliptic plane to 20000 s near the ecliptic poles (Bowyer et al. 1994; Bowyer et al. 1996).

Since the initial survey, *EUVE* has been used to conduct many deep, pointed observations of selected targets using the deep survey/spectrometer telescope. The all-sky survey telescopes are also used to perform concurrent observations at 90° angles from the spectrometer pointing via the *EUVE* Right Angle Program (RAP; McDonald et al. 1994).

Since the entire sky was covered in the initial *EUVE* survey, any detection in deep survey, guest observer (GO), or RAP data can be compared to the all-sky survey maps. Our approach is to compare each pointed observation with the all-sky survey data for the same field, looking for discrepancies between count rates of any sources detected in that region during any phase of the mission. Since the effective exposure times of pointed observations are typically several orders of magnitude longer than the all-sky survey exposure for most parts of the sky, the pointed data will generally give a tight upper limit on any quiescent emission from the possible source.

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2. Detection Criteria for EUV Transients

Our goal is to determine whether or not there is a population of objects which are normally faint in the 100 Å EUV band, but are subject to occasional significant outbursts which could be detected by *EUVE*, and whether any of our catalogued detections which lack known optical counterparts could be due to these EUV transients.

We invoke four criteria for candidate EUV transient detections. First, the object must be detected at the 5 σ confidence level in one or more observation. Second, the object must brighten or dim by a factor of 5 or more between observations. Third, the 3 σ confidence limits on the count rate for each observation must not overlap, after correcting for the different effective areas of the all-sky and deep survey telescopes. Fourth, the object has no well-known optical or X-ray counterpart.

3. Data Selection

We chose to study a group of detections that met the detection criteria for the Second *EUVE* Source Catalog, but were not yet optically identified. Some of these objects were observed only during the all-sky survey; since no RAP, GO, or deep survey data were available for comparison purposes, they were excluded from this study. The remaining 22 objects with multiple observations were reprocessed to recover the unbinned photon data, which includes enough timing information to produce light curves. The reprocessed data was analyzed to obtain detection significance, maximum likelihood count rate, and 3 σ confidence intervals for the count rates.

One of these objects, EUVE J2056-171, underwent a large flare during a deep survey observation. This source was not detected in the all-sky survey, and was the only object from our sample to meet all the criteria for a significant transient.

4. Flaring and Quiescent Observations of EUVE J2056-171

A light curve for the deep survey observation of EUVE J2056-171 was generated by splitting the approximately 2.5 days worth of view time into individual orbits, each consisting of approximately 2000 s of uninterrupted view time. These data are shown in Figure 1. The light curve shows a significant flare with a peak count rate of about 0.55 counts s^{-1}. It is not clear from this data whether the object was ever in a truly quiescent state during the deep survey observation; most of the data preceding and following the main flare are consistent with a count rate of approximately 0.1 counts s^{-1}.

Three months later, the neighborhood of EUVE J2056-171 was observed by the scanning telescopes during the all-sky survey. The total exposure time was about 500 s, spread out over about five days. The object was not detected during this set of observations ($\chi^2 = 2.1$, compared to our nominal detection threshold of 25); the 3 σ confidence interval for the count rate includes (after correcting for the different effective areas of the two telescopes) the 0.1 counts s^{-1} "quiescent" rate derived from the deep survey data, and is also consistent with zero counts s^{-1}.

EUVE J2056-171 has been identified with a *HST* Guide Star Catalog object GSC_06349_00200 by Mathioudakis et al. (1995). Follow up optical and ultraviolet spectroscopy of this object suggests a dwarf star with spectral type between dK7e and dM0e, at a distance of 50 ± 12 pc.

The flare on EUVE J2056-17.1 has several similarities to the AU Mic flare reported by Cully et al. (1994), where it was suggested that the AU Mic flare was associated with a large coronal mass ejection. Very energetic flare events from low mass stars

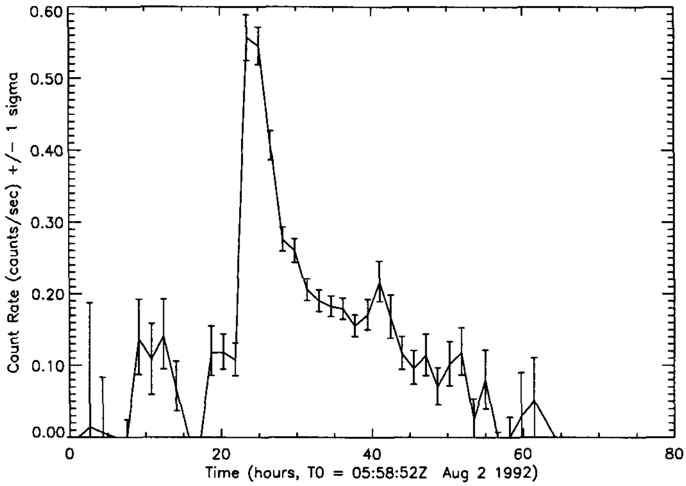

FIGURE 1. Light curve of EUVE J2056-171

may constitute the most efficient way by which angular momentum is lost by the star's atmosphere, leading to rotational spin down and consequently affecting the dynamo generated atmospheric heating process.

5. Statistical Limits on Frequency of EUV Transients

From the single confirmed transient observed during the deep survey phase of the mission, we can calculate upper and lower limits on the frequency of detection of similar events. It is assumed that the events are uniformly distributed over the sky, and that the number of events in a given time interval can be modeled as a Poisson random variable.

We treat the entire deep survey data set as a single "bin" in which one event was observed. The maximum likelihood estimate of the Poisson parameter λ is exactly one event per bin, as observed. To obtain the upper and lower limits of a 90% confidence interval around this value, we use a procedure similar to that used in for *EUVE* source detection and count rate estimation:

Let N be the number of observed events in our single bin, and $\lambda_{\rm exp}$ be the number of expected events. We vary $\lambda_{\rm exp}$ until the statistic

$$C = 2(\lambda_{\rm exp} - N \log \lambda_{\rm exp}) \tag{5.1}$$

is minimized. In our case, $\lambda_{\rm min} = N = 1$, and $C_{\rm min} = 2.0$. The quantity $(C - C_{\rm min})$ for other values of λ follows a χ^2 distribution about $\lambda_{\rm min}$ with 1 degree of freedom. A 90% confidence interval for λ corresponds to a $\Delta\, C$ of 2.71, giving a range from approximately 0.11 to 3.6 events per "bin."

It is of interest to determine the size of the search space identified here as a "bin." The field of view of the deep survey 100 Å filter is about 2 square degrees and the observation period spanned 6 months, therefore one "bin" roughly corresponds to 1 year-degree^2 of sky coverage. In principle, the expected number of flare detections would be proportional to the observation time and field of view (all else remaining equal); in practice, however, the actual number of detections is also extremely sensitive to the survey strategy, making extrapolation from the deep survey result difficult.

For example, the all-sky survey instrument has a field of view about 12 times larger than that of the deep survey 100 Å filter. However, if EUVE J2056-171 had undergone an identical flare during the all-sky survey observation, only about 15 photons would have been received during the 24 hrs of maximum brightness. The flare would not have been detected, even if we somehow knew when and where to look for it. The detection efficiency for equivalent flares is therefore almost zero when the all-sky survey data is used in isolation, negating any benefit from the larger field of view.

If the survey telescopes had been pointed at EUVE J2056-171 for the same 24 hours, the flare very likely would have been detected. This suggests that the RAP and GO pointed data are likely to contain detectable transient events, although background, effective area, and point spread function differences may degrade the detection efficiency from that expected by extrapolating from the deep survey flare detection rate.

6. Conclusions

The design of the *EUVE* survey mission allows us to compare views of the same object at different times to detect variability. The most significant transient event detected so far appears to be a stellar flare. We estimate (based on limited statistics) that the frequency of events of this magnitude is approximately one per year per square degree. In the existing database of EUV objects, there are a number of flare stars, so there is a significant population of candidate objects that are observable at EUV wavelengths. We expect that continuing guest observer pointings and Right Angle Program pointings will reveal further objects undergoing outburst.

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