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ARE THE RECENTLY OBSERVED SOFT γ-RAY BURSTS FROM STELLAR SUPERFLARES?

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Recently, Klebesadel, Strong and Olsen[1] reported the exciting discovery of γ-ray bursts having a typical duration of the order of seconds and typical photon energies of the order of hundreds of keV. This observation has now been confirmed by Cline, Desai, Klebesadel and Strong using the detector aboard the satellite IMP-6 (Cline, private communication).

Predictions of γ-ray bursts from supernovae have been made by Colgate[2], but there are several difficulties in interpreting the observed bursts as originating in supernovae. In particular, the observed bursts have typical durations of the order of seconds with multiple bursts being common. They also appear to have soft exponential spectra with photon energies in the range of 150 to 250 keV. They have been observed to occur frequently with no apparent correlation with observed supernova events.

In contrast to the observed events, Colgate[2] has predicted that γ-ray bursts from supernovae would have durations of the order of 10^{-5}s and hard power law energy spectra with a characteristic energy of about 2 GeV. It thus appears to us possible that the observed bursts do not originate in supernovae and that alternate possibilities for the origin of these bursts should be explored. We suggest here the alternate possibility that these outbursts are simply giant versions of the X-ray bursts typically seen in solar flares.

The observed γ-ray bursts bear a strong resemblence in many respects to the solar X-ray bursts observed recently with a 2 s time resolution[3,4]. Figure 1 shows a representative non-thermal solar X-ray burst. This burst is dominated by two impulsive spikes, each about 10s in duration. If a burst such as this were emitted by a star other that the sun, than only the narrowest parts of the burst might be detected above the background noise. Such bursts would appear to be shorter than solar bursts as is the case with the recently observed non-solar bursts. Thus there may be little intrinsic difference between the time-scales of solar and the suggested stellar bursts at the source. In both cases, the time scale is much longer than that predicted for supernovae.

The spectral characteristics of the non-solar bursts have been measured by Cline, et.al (Cline, private communication). These spectral data from IMP-6 are found to be well described by an exponential spectrum of the form $I \propto e^{-E/E_o}$ with E_o being between 150 and 250 keV for a typical initial burst. Subsequent bursts in multiple-burst events appear to be softer with $E_o \sim 100$ keV. The spike component of solar X-ray bursts could also fit an exponential energy spectrum with $E_o \sim 100$ keV[3]. The multiple spike characteristics seen in the non-solar bursts are commonly seen in solar X-ray bursts.as well.

We therefore consider it generally plausible that these bursts are caused by the bremsstrahlung of electrons accelerated to high energies in a stellar flare event. Assuming the acceleration to depend only on the strength of the effective field seen by the electrons, and not on electron energy, the final energy of the electron will be determined by the time the electron spends in the field. If we assume this acceleration time to be randomly determined,the average time being T, the probability P of an electron being accelerated for time t is given by the Poisson distribution

$$dP/dt = T^{-1}e^{-t/T}. \qquad (1)$$

The spectrum of accelerated electrons would then be of the form

$$I(E)dE \propto (dE/E_o)e^{-E/E_o} \tag{2}$$

where the mean acceleration rate is given by the constant E_o/T and E_o is the average electron energy. The resulting photon spectrum should then also approximate an exponential form. The above considerations are fairly general and it appears that they may be applicable to both solar and non-solar bursts.

We conclude that the time-scale, mean photon energy, and energy spectrum shape (therefore possibly the acceleration mechanism) for both the solar and non-solar bursts are strikingly similar. There is so much similarity, that it is a bit surprising considering that there is such a wide variation of surface conditions among the various stars in the galaxy. There does however appear to be one important difference. The non-solar bursts that have been observed, which presumably must be both the closest and strongest of the non-solar bursts, have a much greater intrinsic intensity than their solar counterparts. The strongest solar flares could have a total energy of $\sim 10^{32}$ erg.[5] The bursts seen by Klebesadel, et al.[1], involve an energy flux of $\sim 10^{-5}$-10^{-4} erg/cm^2. Denoting this flux by ϵ, the energy at the source is given by

$$\mathcal{E} \simeq 2\pi R^2 \epsilon \tag{3}$$

assuming the source-flare radiates into 2π Sr. Assuming $\epsilon \simeq 3 \times 10^{-5}$ erg/cm^2, a source at a distance R = 10pc would have a typical total X-ray energy $\mathcal{E} \simeq 2 \times 10^{35}$ erg. A stellar burst of the type hypothesized here would then involve the acceleration of $\sim 10^6$ to 10^7 times more electrons than a strong solar flare. We may speculate that such an event might involve a star with a magnetic field strength $\sim 10^3$ times larger than the sun. Such fields may not be uncommon, particularly in stars earlier than F0, although the observational establishment of these fields is difficult and often impossible[6]. In addition, common white dwarf stars may have surface fields up to 3×10^7 G[7] so that they may be likely sources for these bursts. It seems reasonable to assume that such stars likely to produce the observed bursts should be near enough so that no concentration toward the galactic plane should be expected.

The stellar flare hypothesis immediately lends itself to various observational tests. Possible observational consequences are (1) repititions of the bursts at the same position, (2) simultaneous radio bursts at the same position, (3) γ-ray lines at 0.51 MeV (positron annihilation), 2.23 MeV ($n+p \rightarrow d+\gamma$), 4.4 MeV (C^{12*}) and 6.1 MeV (O^{16*}) as have been seen in strong solar flares.[8] These lines may be present because the flare may accelerate protons as well as electrons so that various nuclear reactions may occur in the flare.

If the stellar flare hypothesis is verified, it may imply a significant source of low-energy cosmic-rays in the solar neighborhood, depending on the frequency and intensity of the flares.

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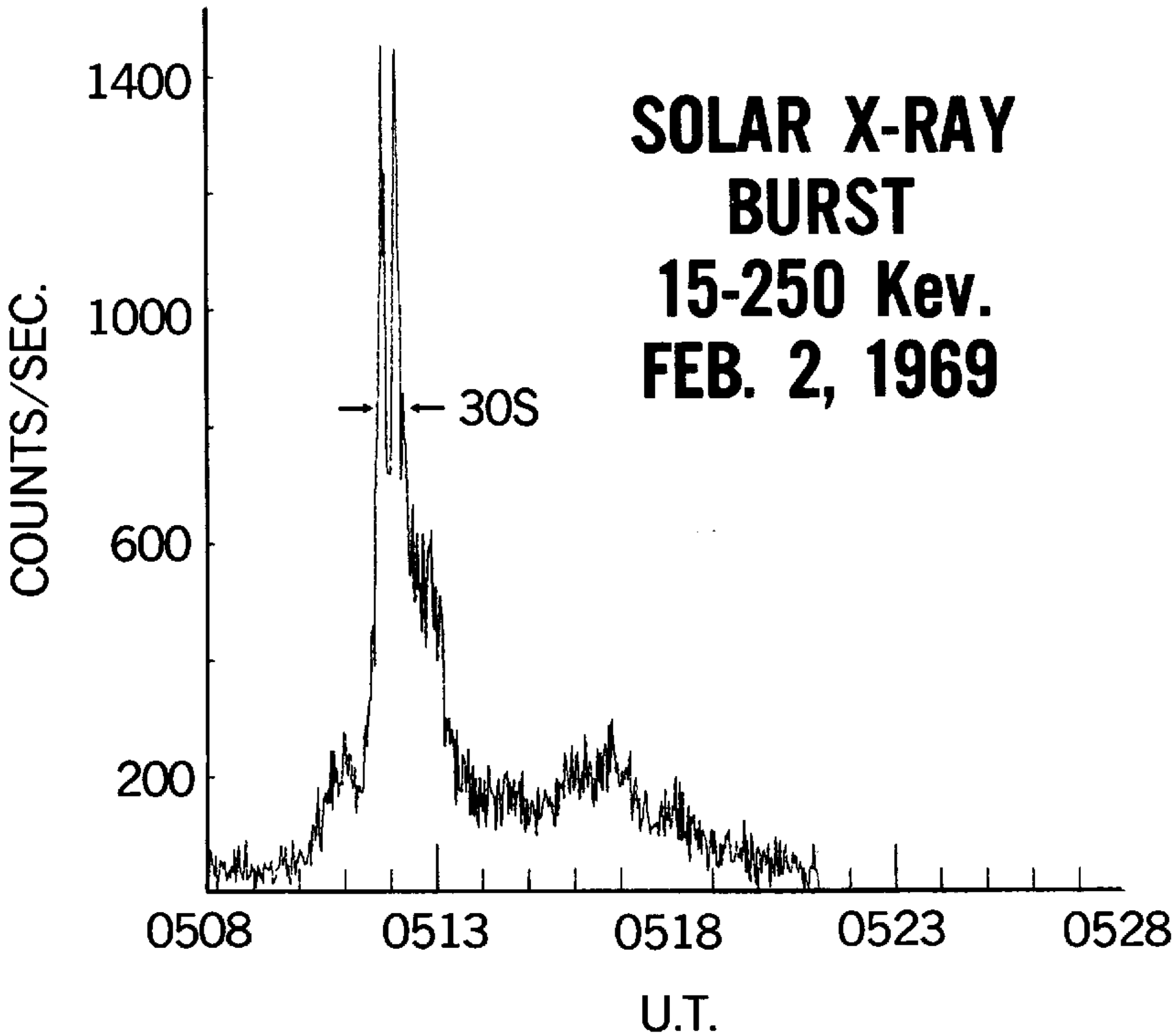
Figure 1. A solar X-ray burst observed on OSO-5 with a time structure similar to that observed for the non-solar bursts.



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