ON THE NATURE OF TWO GAMMA BURSTS WITH SPECTRAL EVOLUTIONS OBSERVED BY THE KONUS EXPERIMENT

by

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ON THE NATURE OF TWO GAMMA BURSTS WITH SPECTRAL EVOLUTIONS OBSERVED BY THE KONUS EXPERIMENT

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Abstract

Several unique features of the evolving spectra of the April 2, 1979B, and November 11, 1979 gamma-ray bursts observed by the Konus experiment can be used to determine a number of critical parameters of the sources, within the context of the thermal synchrotron model, including their luminosity distance. These results shed much light on the origin of these events and possibly gamma bursts in general.

I. INTRODUCTION

Recently, Mazets *et al.* (1981) published a comprehensive catalogue of gamma-ray burst spectra for more than a hundred events observed by the Konus experiment. Among the many events in which detailed spectral evolution were recorded, the events of April 2, 1979B, and November 11, 1979, exhibit unique spectral characteristics. (1) In both events the spectra taken over the first four seconds exhibit low-energy cutoff, while the spectra taken over the third four-second interval exhibit no cutoff. (2) The late-time spectra show emission features at low energies. (3) The spectra have emission features above the continuum at ~ 400 keV resembling the redshifted 511 keV pair annihilation line. In this letter we point out that these unique properties, when combined with the thermal synchrotron (TS) interpretation of the high-energy continuum (Liang 1982, Liang *et al.* 1982), allow us to determine uniquely a number of critical parameters associated with the source, including the temperature, magnetic field strength, electron (pair) column density, intrinsic flux and luminosity distance, etc. These results have important implications for the universal nature of most of the gamma-ray bursts.

The idea that gamma-burst spectra may be due to thermal synchrotron (TS) emission of mildly relativistic electrons has been proposed by several authors (Ramaty *et al.* 1981, Lamb 1982, Katz 1982, Liang 1982). That most of the burst spectra can indeed be fitted by TS models has been substantiated only recently after a comprehensive analysis of the entire catalogue of Mazets *et al.* [1981] (Liang *et al.* 1982). The TS fits to the continuum spectra of the above two events are given in Figures 1 and 2 together with the corresponding values of $\nu_* \equiv \nu_L T^2 \langle \sin\theta \rangle$, where the Lamor frequency $\nu_L \equiv e\hbar B/mc$ is in keV, $T \equiv kT_e/mc^2$ and $\theta \equiv$ (unknown) angle between $\vec{B}$ and line of sight. The low-energy turnovers for spectra 1 in both events (Figures 1 and 2) have slopes close to that of Rayleigh-Jeans and are most naturally interpreted as synchrotron self-absorption. Apparently, the low harmonic emissions at this early time are buried in the blackbody tail. The later time spectra (number 3 in both events), on the other hand, exhibit no self-absorption but instead show peaks and valleys reminiscent of harmonic emissions. In the April 2 event both first and second harmonics are evident, while in the November 11 event the second (and maybe third) harmonics are marginal (dotted curves). If we accept the first peaks as the first harmonic, then the values of B and T (for time bin 3) can be determined. If we further assume that the ambient B-field did not change significantly during the burst, a questionable but plausible assumption, then these values of B can be combined with the parameters of spectra 1 to determine T, $n_e h$ (electron column density), L_{syn}/A (synchrotron flux), etc. Independently, upper limits to the luminosity distance can be estimated from the specific flux of the Rayleigh-Jeans part of the spectra.

It is also tempting to interpret the emission feature at ~ 400 keV as due to redshifted 511 keV radiation, leading to a surface redshift of z ~ .278. Using this redshift, the above analysis can be repeated. Finally, the intensity of the redshifted annihilation feature, coupled with the above distance estimates, gives values for the pair density, etc., at the source.

An unexpected piece of information provided by the spectral evolutions is that the effective emission surface area must have _increased_ (by a factor > 3) during the ~ 12 seconds of observation, since the later spectra have _lower_ temperature, yet show no self-absorption and even have _higher_ detected fluxes than the early spectra at ~ 30 keV. The quantitative results from the above analyses are listed in the next section.

II. RESULTS

The empirical data needed for our analyses are listed in Table I. Relevant formulae for computing the various quantities can be found in Petrosian (1981), Lamb (1982) and Liang (1982; the numerical factor in Eqs. (11), (14), etc. of that article should be lowered by a factor of ~ 2.7). The results for both events are tabulated in Table II, where we list both the derived values corresponding to z = 0 and z = .278. The excellent agreement between the observed and theoretical estimates of the first to second harmonic fluxes substantiates the synchrotron model. (While their absolute amplitudes are probably uncertain due to deconvolution ambiguities (Fenimore et al. 1982), their ratio is less sensitive to such ambiguities.) From Table II we see that unless the emission surface areas are much less than a km^2, both of these sources are extragalactic. This shows that the March 5, 1979, event is not unique and the Magellanic clouds and nearby galaxies may well be significant contributors to the gamma-burst events. We emphasize, however, that these events are not representative of all gamma bursts. The overwhelming majority of the spectra in the Konus catalogue do not show self-absorption down to ~ 20 keV (Liang et al. 1982) and hence are much closer than these two events. This is consistent with findings from log N-log S analyses (e.g., Mazets et al. 1981), which show that the majority of the sources are likely galactic. It would be interesting to try to convolve the theoretical synchrotron luminosities with the log N-log S distributions. Note that the intrinsic synchrotron fluxes at the sources are definitely super-

Eddington, and the emitting particles must be confined by magnetic forces. Note also the uniform thinness of the emission column density $n_e h \sim 10^{21} - 10^{22}$ (see also Liang et al. 1982). In future papers we will try to exploit this peculiarity to develop viable burst models.

As many authors have emphasized, the TS spectral fit, we admit, is not unique and the details of the low-energy part of the spectra may be uncertain. However, what is amazing is that when these data are naively interpreted with the TS model, different independent parameters, including the harmonic flux ratios, all come together and fit into a self-consistent, coherent picture. We believe that such remarkable coincidence should not be dismissed offhand.

Table I.

Empirical Parameters

Superscripts 1 or 3 denote time bins. All frequencies are in keV.

ν_c is defined in text.

ν_a is apparent absorption frequency.

ν_L^o is apparent peak of first harmonic emission.

$\nu_{e^\pm}$ is apparent peak of (redshifted) 511 keV line.

f_1/f_2 is ratio of apparent first to second harmonic peak fluxes.

F is total observed energy flux of the entire spectrum in erg/cm^2·s.

Event	4/2/79B	11/11/79
ν_c^1	50	5.9
ν_c^3	13	2.5
ν_a^1	60	50
ν_a^3	<30	<25
ν_L^{o3}	32	28
$\nu_{e^\pm}^1$	400	400
f_1^3/f_2^3	1.23	2.75
F^1	~1.2×10^{-5}	~7×10^{-7}

Table II.

Derived Parameters

All frequencies are in keV. Superscripts 1 or 3 denote time bins. All frequencies refer to intrinsic values at the source.

Definition of symbols:

z = assumed redshift

ν_L = intrinsic Lamor frequency

B = intrinsic field strength in 10^{12} G

T = kT_e/mc^2

$n_e h$ = electron (pair) column of density emission region in cm^{-2}

L_{syn}/A = intrinsic synchrotron flux in $erg/km^2 \cdot s$

d_{syn} = luminosity distance estimated from the synchrotron continuum flux, in kpc

d_{BB} = luminosity distance estimated from the self-absorbed Rayleigh-Jeans specific flux, in kpc

A = effective emission surface area in km^2

$F_{\pm}$ = intrinsic annihilation photon flux in $photons/cm^2 \cdot s$

n_+ = positron density in annihilation region in cm^{-3}

h = thickness of continuum gamma emission layer in cm

$h_{\pm}$ = thickness of annihilation layer in cm

f_1^T/f_2^T = theoretical estimates of the first to second harmonic flux ratio based on the temperature determined

$\sigma_{\gamma\gamma}$ = pair annihilation cross-section at rest

Event	4/2/79B		11/11/79	
z	0	0.278	0	0.278
ν_c^1	50	64	5.9	7.5
ν_c^3	13	17	2.5	3.2
ν_a^1	60	77	50	64
ν_a^3	<30	<38	<25	<32
ν_L	73	93	47	60
T^1	.83	.83	.35	.35
T^3	.43	.43	.23	.23
B	6.3	8.0	4.1	5.2
$(n_e h)^1$	1.4×10^{22}	1.8×10^{22}	1.2×10^{21}	1.47×10^{21}
$(n_e h)^3$	$<8.2\times10^{20}$	$<1.0\times10^{21}$	$<1.6\times10^{20}$	$<2.0\times10^{20}$
$(L_{syn}/A)^1$	2.6×10^{42}	5.4×10^{42}	4.4×10^{40}	9.2×10^{40}
$(d_{syn}/A^{1/2})^1$	60	53	32	28
$(d_{BB}/A^{1/2})^1$	<81	<71	<38	<33
A^3/A^1	>3.6	>3.6	>3.0	>3.0
$F_\pm^1$	10^{37}	1.4×10^{37}	6.8×10^{35}	9.6×10^{35}
$n_\pm^1$ (if $n_+\sigma_{\gamma\gamma}h_\pm \simeq 1$)	3.3×10^{26}	4.7×10^{26}	2.3×10^{26}	3.2×10^{26}
$h_\pm^1$ (if $n_+\sigma_{\gamma\gamma}h_\pm \simeq 1$)	0.015	0.011	0.022	0.016
h^1 (if $n_+ \simeq n_-$)	2.1×10^{-5}	1.9×10^{-5}	2.6×10^{-6}	2.3×10^{-6}
$(f_1^T/f_2^T)^3$	1.16	1.16	2.2	2.2

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FIGURE CAPTIONS

Figure 1 Gamma spectra of the April 2, 1979B event fitted with the thermal synchrotron model. ν_c of the theory curves are in keV. Dashed curve denotes Rayleigh-Jeans limit, and dotted curves denote possible low harmonic emission features. Arrows indicate location of emission feature at ~ 400 keV. Note that the feature was broader at time 1 than at time 3.

Figure 2 Same as Figure 1 for the November 11, 1979, event. Here the spectra are considerably softer.

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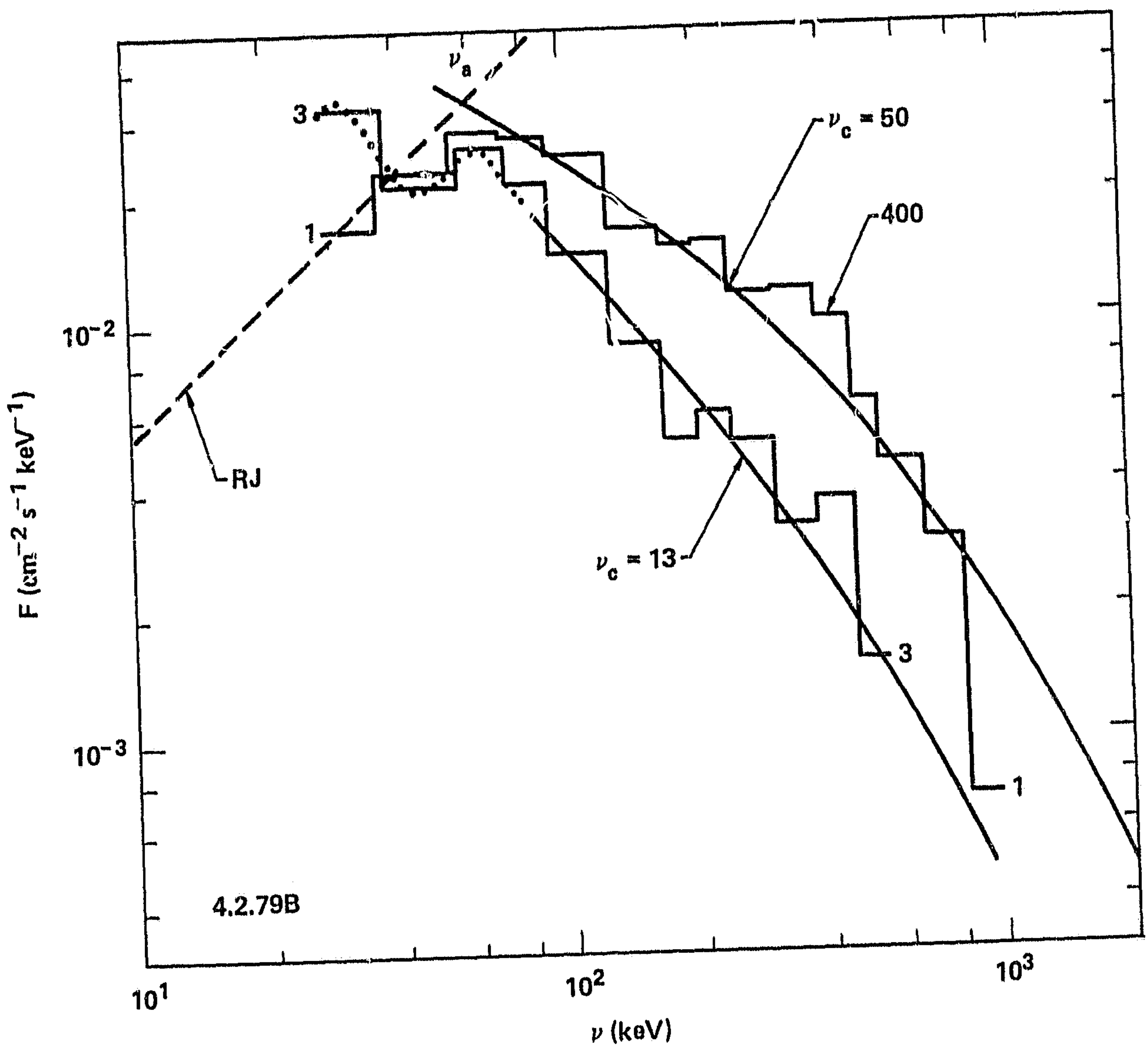

Figure 1

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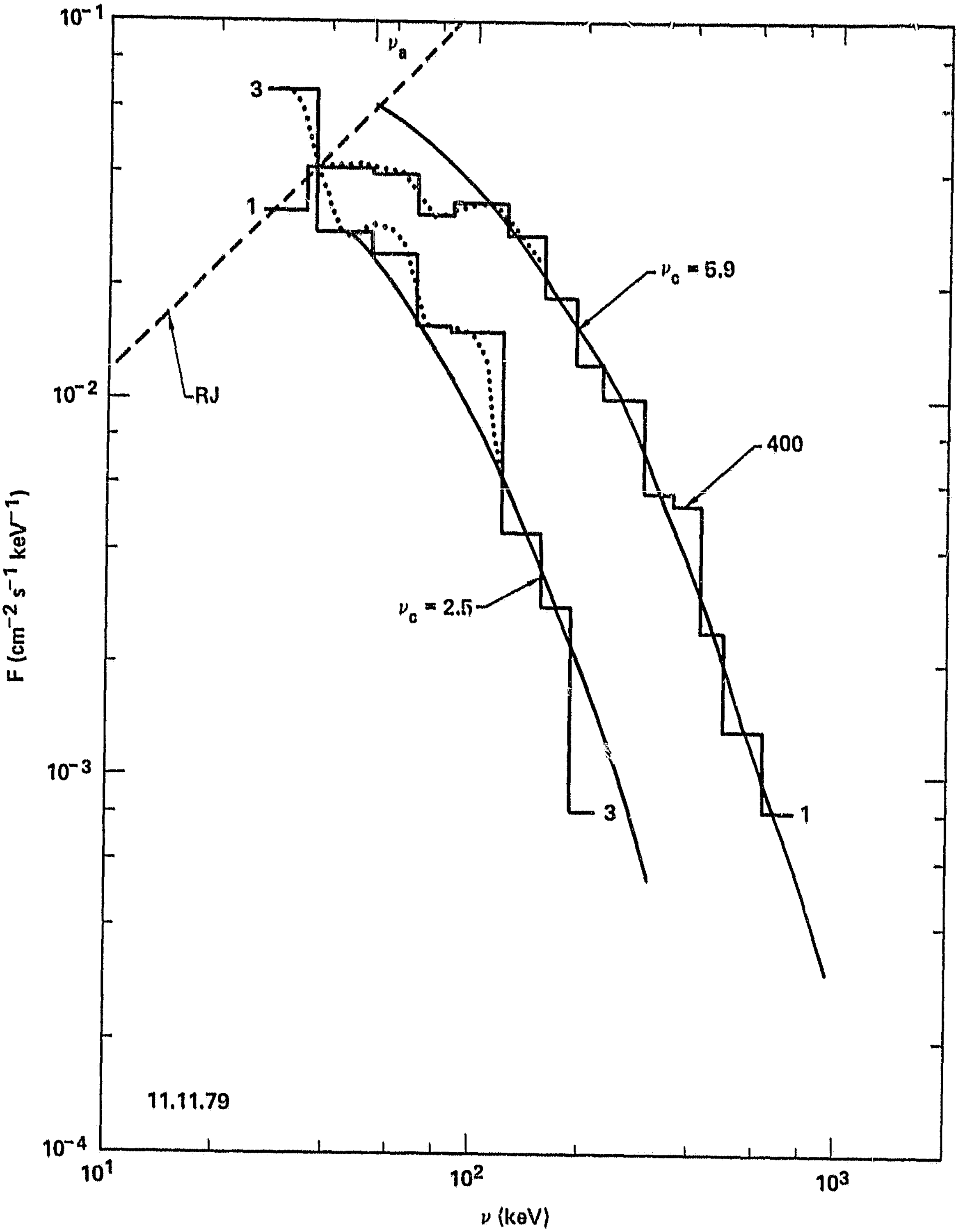

Figure 2