ON THE EMISSION REGION OF GAMMA RAY BURSTS

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1. Introduction. Within the last few years the rapid accumulation of gamma ray burst spectral data, especially those of KONUS and SMM, has made the confrontation between theories of the gamma ray emission mechanisms and observations much more urgent and challenging . At present the most viable model seems to be some combination of inverse Comptonization and synchrotron emission (see Ref. 1 for review). In this paper we will try to limit the acceptable parameter space of the emission region by taking into account the maximum set of observational constraints. We then apply these to two specific scenarios: surface emission versus magnetospheric emission and consider some observable predictions based on these scenarios.

2. Observational Constraints On N_e and B. Let us consider the most model-independent constraints that can be drawn from the raw data. Taken together they strongly constrain the electron (pair) density N_e and magnetic field B of the source:

1. The SMM data show no evidence of cutoff or decrement above the gamma-B pair production threshold. For gamma rays of $h\nu$ = 50 Mev, this requires the field strength orthogonal to the line of sight to be less than 4.10^{11}G.
2. Both the existence of narrow line features (with FWHM << kT) and lack of Wien hump at ~3kT require that the Compton scattering depth by hot electrons < 1. This means $N_e.H < 3.10^{24} cm^{-2}$ where H is the thickness of the hot emission column along the line of sight.
3. If the narrow absorption dips in the x-rays are indeed cyclotron absorption lines this suggest an absorption cold electron column depth of $N_c.H \sim 10^{21-22} cm^{-2}$ independent of the origin of the hot continnum.
4. If the low energy turnover is indeed due to synchrotron self-absorption then the hot electron column density $N_e.H < 10^{21} cm^{-2} f(B_{12}, T/mc^2)$ where $B_{12}=B/10^{12}$G and f is of order unity when $B_{12} \sim 1$ and $T \sim mc^2$.
5. For the spectra with simultaneous self absorption turnover and annihilation lines, the observed line intensity plus the Compton thin requirement constrains the pair density $N_+ > 10^{24-26}$/cc.
6. If the burst energy comes from release of stressed magnetic fields B_s in the magnetosphere, the current j needed would be $4\pi j/c \sim B_s/L$ where j~Nec and L is the

size of the stressed field. Hence the minimum column density is NL $>10^{20} cm^{-2} B_{s12}$. Note that this is still consistent with the above constraints.
7. If the stressed field energy is the only source of the gamma burst, we have the constraint: $B_s^2 . L_s^3 / 8\pi > E$ (total gamma output). Hence $B_{s12}^2 . L_6^3 > 0.1(E/10^{40} erg)$.
8. The energy flux in magnetic waves must exceed the gamma flux: $B^2 . c/4\pi > F$,
i.e. $B > 1.5.10^{10} G.(F/10^{30} ergcm^{-2})^{.5}$
9. The optical flashes must originate from regions with plasma frequency $w_e/2\pi < hv_{optical} \sim 10^{16} Hz$. This requires an electron density $N_{eopt} \sim < 10^{22}/cc$.
10. Magnetic confinement of the plasma requires that:

$$B^2/8\pi > N\,kT \quad \text{or } N < 4.10^{28} cm^{-3} B_{12} T/mc^2;$$

and $$B^2/8\pi > F\tau/c \quad \text{or } N.H.F/10^{30} < 10^{27} cm^{-2}\ B_{12}.$$

3. <u>Emission Scenarios</u>. We now consider two specific scenarios:

A. Surface Emission

If the continuum emission, together with the lines etc indeed originate from the surface of a strongly magnetized neutron star, then the above constraints, taken together, would be most consistent with the burst being powered by a large flux of magnetic waves which heats a thin surface layer for the gamma production while confining it at the same time. This is the well known "hot thin sheet synchrotron model" originally proposed by Ramaty et al[2] for the March 5th event. Here we will address not the overall merit of that model but the more restricted question of how a large flux of low frequency Alfven-like waves impinging onto a neutron star surface, independent of its origin, can be absorbed and convert its energy into suprathermal particles with energies ranging up to many Mevs, which then radiate the observed gammas via synchro-Compton processes.

While there must be large uncertainties, we believe the qualitative picture must resemble something like Fig. 1. As the waves penetrate into higher and higher densities, the wave amplitude B must increase as the Alfven speed decreases. The nonlinear interaction between incident and reflected waves then favor the parametric conversion of the low frequency hydromagnetic waves into high frequency kinetic modes, which ultimately decay into whistlers and Langmuir waves. Whistlers can only exist when $(w_{ec}.w_{ic})^{.5} < w_e < w_{ec}$, where ec denotes electron cyclotron and ic ion cyclotron. Hence we crudely identify the $w_e = (w_{ec}.w_{ic})^{.5}$ boundary as the beginning of the absorption layer. In a strong B field the Langmuir wave can only propagate along the field lines. So its resonance with Maxwellian tail particles can only produce suprathermals with momenta along field lines. Transverse momenta (or large pitch angles= high Landau levels) must be gained by the resonant scattering of the longitudinal suprathermals with the transverse electric fields of the whistlers satisfying the condition $w = k.\ v_{//}$. Note that despite its high $p_{//}$ they cannot leak out much beyond the absorption layer because of scattering by the downward wave flux. In some sense this forms a collisionless shock with the momentum flux of the wave balancing the pressure of the suprathermals and the radiation pressure of the emitted gammas. One of the unavoidable consequence of this picture is the existence of copious amounts of Langmuir waves, leading to the enhanced emission of w_e and possibly $2w_e$ coherent plasma radiations, which would range from the XUV down to optical frequencies. The brightness temperature of such radiation could be much higher than that of the suprathermals. It is a potential candidate for the optical flashes.

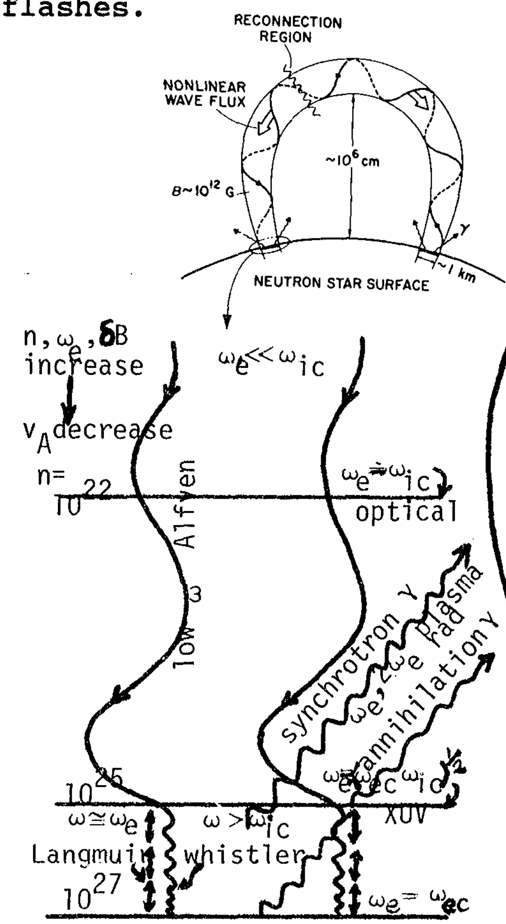

Fig. 1 Absorption of Alfven waves at neutron star surface

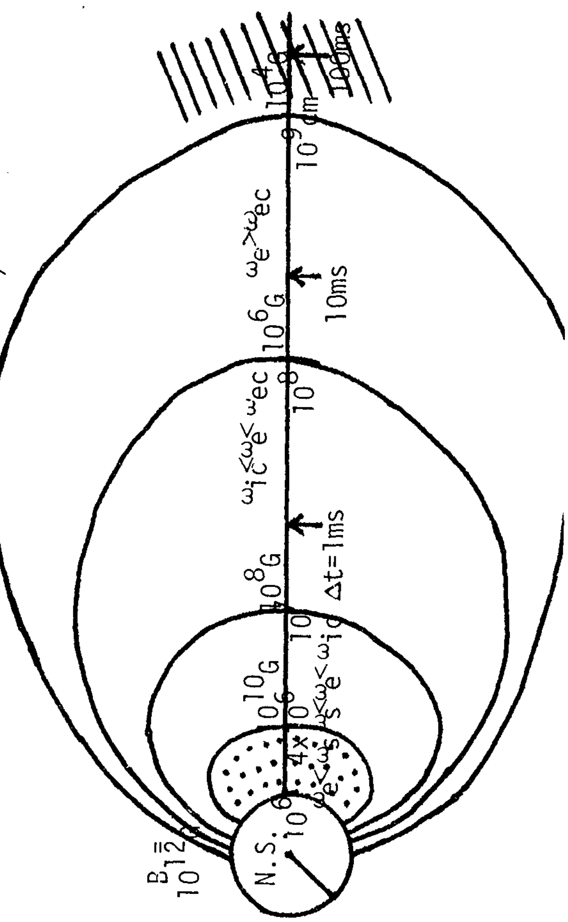

Fig 2 Emission region in magnetosphere

B. Magnetospheric Emission:

If we assume that (1) the magnetospheric field is roughly dipole so $B=10^{12}G(r/10^{6}cm)^{-3}$; (2) the emission region has dimension $\Delta r \sim r$ for $r >> 10^{6}cm$; (3) only constraint on the density comes from Compton thinness: $\langle N\rangle\Delta r \sim \langle N\rangle r < 10^{25}cm^{-2}$ so that $\langle N\rangle < 10^{25}/cc/r$, then we have the picture illustrated in Fig. 2. The dotted region is such that even collisionless processes cannot keep the electrons hot against synchrotron losses, whereas the hatched region is such that even Coulomb collisions provide adequate heating. This suggest that if the gamma rays originate from the magnetosphere, the source must be quite far away from the stellar surface, where the field is below $\sim 10^{10}G$. Interestingly this is consistent with the requirement of no pair production attenuation by the magnetic field on hard gammas. However, in this case the line features must be produced separately from the hot continuum.

4. Conclusion. Based on all the data taken together, it seems most plausible that different part of the gamma burst spectrum are produced at different places:
1. The hard power law beyond a few Mev must be produced in the far-field magnetosphere by Compton or small pitch angle synchrotron by relativistic electrons.
2. The annihilation lines (and cyclotron lines if real) are produced very close to or at the surface.
3. The exponentially shaped sub-Mev continuum must be produced within a compact region ($<\sim 10^{7}cm$) near the star because of the very fast rise time (<~ms) seen in many spike structures.

Since the SMM spectral evolution data strongly suggest that the hardest part of the spectrum rises first, this suggest that the initial source of the gamma burst is probably situated in the far field and then propagate along field lines down to the polar regions at the surface as the spectrum softens. However, since the magnetic field energy density decreases as r^{-6}, the energy available in the far field region would be miniscule to power a burst. This poses a fundamental dilemma that must be faced by any global model of gamma ray burst origin.

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References

1. S. Woosley, ed. High Energy Transients in Astrophysics, AIP Conf. Proc. No. 101 (AIP, N.Y. 1984).
2. R. Ramaty et al, Ap. and Sp. Sc. 75, 193 (1981).