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UHE leptons and neutrons feeding precessing γ jet in GRBs - SGRs: A SGR 1806-20 link to EeV CR?(*)

D. Fargion(1)(2) and M. Grossi(1)

(1) *Dipartimento di Fisica, Università "La Sapienza" - Rome, Italy*
(2) *INFN, Sezione di Roma 1, Rome - Italy*

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Summary. — Soft Gamma Repeaters are widely believed to occur as isotropic Magnetar explosion. We suggest on the contrary that they may be described by thin collimated spinning and precessing gamma jets, flashing and blazing along the line of sight. The jet (for SGRs) may be powered by an accretion disk in binary system and it produces huge outflows and blazing features oscillating mode as observed in the light curve of the Giant Flare from SGR 1806-20. The precessing and spinning nature of the blazing gamma jets reflects, at smaller intensity, the same behaviour observed in short GRBs jetted Supernova, as well as re-brightening and bumps in their afterglows. The SGR γ beam may be powered by Inverse Compton Scattering (ICS) or by synchrotron radiation of electron pairs, respectively, at GeVs or PeVs energies. In the latter case, tens of PeV leptons (muons later decaying into PeV electrons) might be originated while EeV nucleons jets (protons-neutrons) are in photopion equilibrium with infrared photons surrounding the source. The neutron jet might survive and remain collimated. It may be already detected as an EeV cosmic ray anisotropy in the AGASA map pointing toward observable known SGRs: SGR 1900 +14 and SGR 1806-20. If the SGR-EeV connection is correct, a parasite trace of PeVs neutrinos as well PeV-TeVs gamma rays might be found in present or future data records, among the other CR array detectors, and inside the Amanda, Baikal volumes and Milagro muon bundle tracks.

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1. – Precessing jets in GRBs and SGRs: the blazing engine

The huge GRBs luminosity may be due to high collimated and aligned blazing jet powered by a Supernova output; this explains the rare SN-GRB connection (while on the line of sight) and the apparent GRB 990123 extraordinary power (billions of Supernova luminosity). This also explain the rarer, because nearer, GRB-SN event as the April 1998 one, whose jet was off axis (increasing its probability detection), but whose GRB

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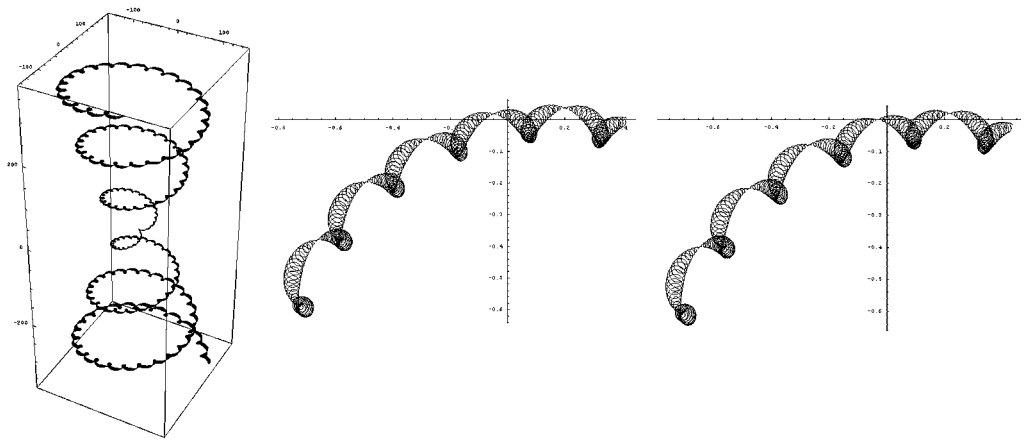

Fig. 1. – A possible 3D structure view of the precessing jet obtained with non linear precessing, while spinning γ jet; at its centre the "explosive" SN-like event for a GRB or a steady binary system system for a SGRs where an accretion disc around a compact object powers a collimated precessing jet. The Lorentz factor is $\gamma_e = 10^9$, corresponding to a $\sim$ PeV electron pair energy; two different 2D trajectory of the precessing jet and of the way it blazes the observer along the line of sight at the center, by a fine tuned beaming to the observer, while on the right the off-axis flashes of the same jet.

luminosity was extremely low. This beaming selection in wider cosmic volumes explains the puzzling evidence (the Amati-Ghisellina law) of harder and powerful GRBs at higher and higher distances. This "law" is for isotropic Fireball explosion, contrary to the opposite cosmic trend required by the Hubble-Friedmann law: the further the distances, the larger the redshifts and the softer the expected GRB event. To make GRB-SN in energy equipartition the jet must be very collimated $\frac{\Omega}{\Delta\Omega} \simeq 10^8$–$10^9$ (Fargion, Salis 1995; Fargion 1999; Fargion, Grossi 2005); because of the statistics between GRB-SN rates, its jet decaying activity ($\dot{L} \simeq (\frac{t}{t_o})^{-\alpha}$, $\alpha \simeq 1$) must hold for long timescales, $t_o \simeq 10^4$ s.

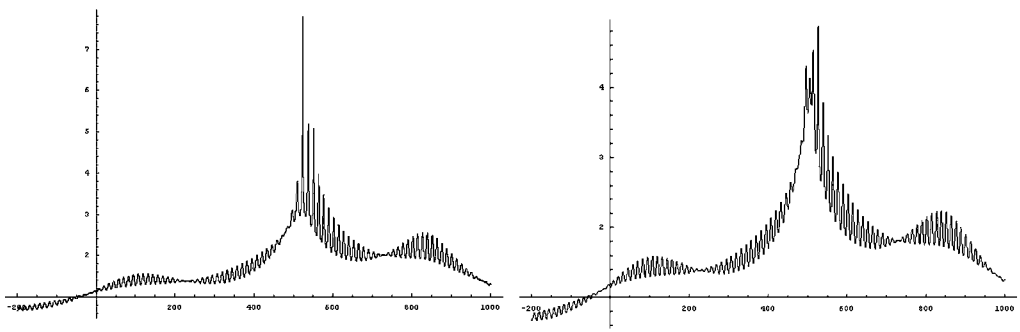

Fig. 2. – A close up of the two corresponding light curve profile. (Left panel: the multiple oscillatory signals may mimic the oscillatory bumps in SGR γ and the huge amplification of giant flare, while the multi-precessing tracks of the jet may lead to re-brightening and multi-bumps in the light profile of the GRB X afterglows. Right panel: note that the off-axis beaming induce a different SGR profile and a much limited amplification.)

TABLE I. – *The parameters adopted for the jet model represented in fig.* 1.

$\gamma = 10^9$	$\theta_a = 0.2$	$\omega_a = 1.6 \cdot 10^{-8}$ rad/s
$\theta_b = 1$	θ_{psr}=1.5 $\cdot 10^7/\gamma$	θ_N=5 $\cdot 10^7/\gamma$
ω_b=4.9 $\cdot 10^{-4}$ rad/s	ω_{psr}=0.83 rad/s	ω_N=1.38 $\cdot 10^{-2}$ rad/s
$\phi_b = 2\pi - 0.44$	ϕ_{psr}=$\pi + \pi/4$	ϕ_N=3.5 $\pi/2 + \pi/3$
$\phi_s \sim \phi_{psr}$	θ_s=1.5 $\cdot 10^6/\gamma$	$\omega_s = 25$ rad/s

Similar issues arise from the surprising giant flare from the soft gamma repeater SGR 1806-20 that occurred on 2004 December 27: if it has been radiated isotropically (as assumed by the the magnetar model), most of (if not all) the magnetic energy stored in the neutron star NS should have been consumed at once. On the contrary we think that a thin collimated precessing jet $\dot{E}_{SGR-jet} \simeq 10^{36}$–$10^{38}\,\mathrm{erg\,s^{-1}}$, blazing on-axis, may be the source of such apparently (the inverse of the solid beam angle $\frac{\Omega}{\Delta\Omega} \simeq 10^8$–$10^9$) huge bursts $\dot{E}_{SGR-Flare} \simeq 10^{38} \cdot \frac{\Omega}{\Delta\Omega} \simeq 10^{47}\,\mathrm{erg\,s^{-1}}$ with a moderate (X-Pulsar, SS433) jet output power. In our model, the temporal evolution of the angle between the jet direction and the rotational axis of the NS can be expressed as $\theta_1(t) = \sqrt{\theta_x^2 + \theta_y^2}$, where $\theta_x(t) = \sin(\omega_b t + \phi_b) + \theta_{psr} \cdot \sin(\omega_{psr} t + \phi_{psr}) \cdot Abs(\sin(\omega_N t + \phi_N)) + \theta_s \cdot \sin(\omega_s t + \phi_s) + \theta_N \cdot \sin(\omega_N t + \phi_N) + \theta_x(0)$ and $\theta_y(t) = \theta_a \cdot \sin\omega_0 t + \cos(\omega_b t + \phi_b) + \theta_{psr} \cdot \cos(\omega_{psr} t + \phi_{psr}) \cdot Abs(\sin(\omega_N t + \phi_N)) + \theta_s \cdot \cos(\omega_s t + \phi_s) + \theta_N \cdot \cos(\omega_N t + \phi_N)) + \theta_y(0)$. Where γ is the Lorentz factor of the relativistic particles of the jet. See table I above and figs. 1 and 2. See also earlier papers (Fargion 1999 and Fargion 2003).

The simplest way to produce the γ emission would be by ICS of GeVs electron pairs onto thermal infra-red photons. However also electromagnetic showering of PeV electron pairs by synchrotron emission in galactic fields, ($e^{\pm}$ from muon decay) may be the progenitor of the γ blazing jet. The same muons showering may occur in GRB. In particular, muon bundles have the advantage to avoid the opacity and escape the dense GRB-SN-isotropic radiation field (Fargion, Grossi 2005). However most of these IC PeVs showering in GRB-SN scenario degrades the electrons to tens GeVs energy leading to γ jet by ICS. Here we propose also that the emission of SGRs is due to a primary hadronic jet producing ultra relativistic $e^{\pm}$ (1–10 PeV) from hundreds PeV pions, $\pi \to \mu \to e$, or EeV neutron decay in flight: primary protons can be accelerated by the large magnetic field of the NS up to EeV energy. The protons could emit directly soft gamma rays via synchrotron radiation with the galactic magnetic field ($E_\gamma^p \simeq 10(E_p/\mathrm{EeV})^2(B/2.5 \cdot 10^{-6}\,\mathrm{G})$ keV), but the efficiency is poor because of the too long timescale of proton synchrotron interactions. Photopion production must occur to produce the observed neutron excess, a process that also gives birth to neutral and charged pions. The energy of the thermal photons necessary to produce pions is $\epsilon_\gamma = 0.2\,\mathrm{GeV}^2/E_p = 0.2\,\mathrm{eV}$ for $E_p = 10^{18}\,\mathrm{eV}$. Photopion production with ambient galactic IR photons ($p+\gamma_{IR} \to \Delta^+ \to n+\pi^+$) is favoured compared to proton-proton collisions ($p + p \to n + p + N\pi$)(Medina-Tanco and Watson, 2001). Charged pions (born with roughly a tenth of the original energy of the proton) decay into muons and then into electrons with $E_e \leq 10^{16}\,\mathrm{eV}$ (note the photon opacity and the possible SGR-EeV correlation map in fig. 3, or details in Fargion, Grossi 2005).

By interacting with the local galactic magnetic field such electrons lose energy via synchrotron radiation, $E_\gamma^{sync} \simeq 4.2 \times 10^6 \left(\frac{E_e}{5 \cdot 10^{15}\,\mathrm{eV}}\right)^2 \left(\frac{B}{2.5 \cdot 10^{-6}\,\mathrm{G}}\right)$ eV, with a characteristic timescale $t^{sync} \simeq 1.3 \times 10^{10} \left(\frac{E_e}{5 \cdot 10^{15}\,\mathrm{eV}}\right)^{-1} \left(\frac{B}{2.5 \cdot 10^{-6}\,\mathrm{G}}\right)^{-2}$ s. This mechanism would produce a few hundreds keV radiation as it is observed in the intense γ-ray flare from

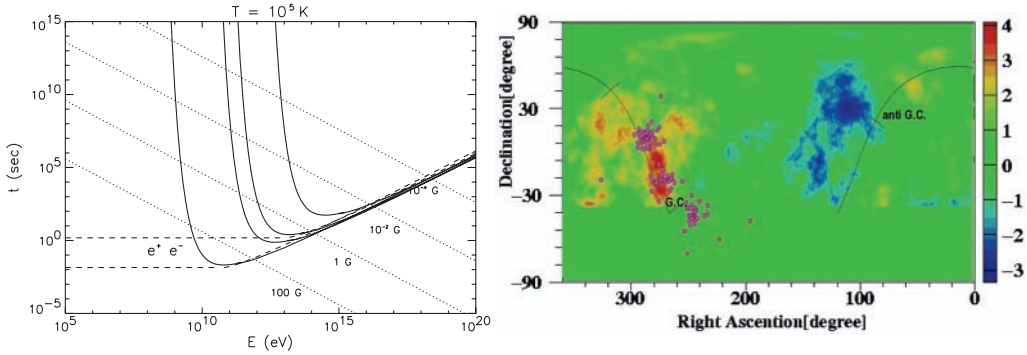

Fig. 3. – Left panel: the Supernova opacity (interaction length) for PeV electrons at different times; PeVs muons jets may overcome it and decay later in γ showering electrons (see for details Fargion, Grossi 2005). Right panel: the correlation between the BATSE data, the AGASA discovery of an anisotropy in the arrival direction of EeV CRs near the galactic center and the position of the galactic SGRs. The three clusters of the data from BATSE in the left-hand side of the map correspond from top to bottom SGR 1900+14, SGR 1806-20, SGR 1627-41, recorded during 1997-2000. AGASA was unable to record SGR 1627-41 because below its horizons.

SGR 1806-20. The Larmor radius is about two orders of magnitude smaller than the synchrotron interaction length and this may imply that the aperture of the jet is spread by the magnetic field, $\frac{R_L}{c} \simeq 4.1 \times 10^8 \left(\frac{E_e}{5{\cdot}10^{15}\,\mathrm{eV}}\right)\left(\frac{B}{2.5{\cdot}10^{-6}\,\mathrm{G}}\right)^{-1}$ s. In particular a thin ($\Delta\Omega \simeq 10^{-9}$–$10^{-10}$ sr) precessing jet from a pulsar may naturally explain the negligible variation of the spin frequency $\nu = 1/P$ after the giant flare ($\Delta\nu < 10^{-5}$ Hz). Indeed it seems quite unlucky that a huge ($E_{Flare} \simeq 5 \cdot 10^{46}$ erg) explosive event (as the needed mini-fireball by a magnetar model (Duncan *et al.* 1992)) is not leaving trace in the rotational energy of the SGR 1806-20, $E_{rot} = \frac{1}{2} I_{NS}\omega^2 \simeq 3.6{\cdot}10^{44} \frac{P}{7.5s}^{-2} \left(\frac{I_{NS}}{10^{45}\,\mathrm{g\,cm^2}}\right)$ erg. The consequent fraction of energy lost after the flare must be severely bounded: $\frac{\Delta(E_{Rot})}{E_{Flare}} \leq 10^{-6}$. We foresee that if the role of nucleons as primaries of the soft gamma emission of SGR 1806-20 is correct, the giant flare might also be source of a prompt (and possibly repeating) γ-induced shower (made by γ photons from the decay of PeV neutral pions) that may have been detected by Milagro in correspondence with the 2004 December 27 flare. We also expect that a rich component of the EeV neutrons (or protons from their decay) might appear in the AUGER or HIRES detectors, in rough coincidence with this event. Because of the delayed arrival time of protons, one should expect also a long and persistent UHECR afterglow. Finally a signal of secondary muons at PeV energies, induced by high-energy neutrinos from the SGR, might occur in Amanda. To conclude, we imagine that if the precessing jet model gives a correct interpretation of the properties of SGRs, SGR 1806-20 will still be active in the next months and this year.

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