Rebrightening in GRBs by Precessing Jet

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Abstract. A clear gamma polarization in the $\gamma$ signals from GRB021206 probes the presence of a very thin collimated jet (opening angle $\Delta \theta \lesssim 0.6^\circ$; $\Delta \Omega \lesssim 2.5 \cdot 10^{-5}$) in Gamma Ray Burst, GRBs. The last and well proved GRB030329/SN2003dh time and space coincidence confirms definitively the earliest GRB980425/SN1998bw connection among GRB and Supernova. The apparent extreme GRBs luminosity is just the extreme beamed blazing gamma Jet observed in axis during a Supernova birth. The maximal isotropic SN power, $\dot{E}_{SN} \approx 10^{45}$ erg s$^{-1}$, because of its probable energy equi-partition, should be collimated even into an even thinner jet $\Delta \Omega \lesssim 10^{-8}$, in order to explain at once the apparent observed maximal GRBs output, $\dot{E}_{GRB} \approx \dot{E}_{SN} \frac{\Omega}{\Delta \Omega} \approx 10^{53}$ erg s$^{-1}$. Consequently one-shoot thin Jet GRBs needs many more $N_{GRBs} \approx \frac{\Omega}{\Delta \Omega} \cdot N_{Fireball}$ event rate than any spread isotropic Fireballs. Such a rate exceed even the known Supernova one. To overcome the puzzle a persistent precessing decaying jet (life-time $\tau_{Jet} \geq 10^3 \tau_{GRB}$) is compelling. The late relic GRBs sources may be found in compact SNRs core, as NS or BH jets; at much later epoch, their lower power $\gamma$ jets may be within detectability only from nearby galactic distances, as Soft Gamma Repeaters (SGRs) or anomalous X-ray Pulsars, AXPs. This common Jet nature explain some connection between GRBs and SGRs spectra. The geometrical multi-precessing beaming and their reappearance to the observer may explain the puzzling presence of X-Ray precursors in GRBs as well as in SGRs. A mysterious re-brightening afterglows observed in early and late GRB 030329 optical transient, like in the 27 August 1998 and 18 April 2001 SGR 1900 $+14$ events, might be understood as the damped oscillatory imprint left by such a multi-precessing $\gamma$-X-Optical and Radio Jet.

1. INTRODUCTION:

Gamma Ray Burst mystery lays in its huge energy fluence, sharp variability, extreme cosmic distances and very different morphology. A huge isotropic explosion disagree with the shortest millisecond time scales and non-thermal spectra. The huge GRBs powers as GRB990123 made the final collapse of the Fireball model. New families of Fire-Ball Jet (and their different label names like Hyper-Nova, Supra-Nova, Collapsar ) models alleviated the energy budget, by a mild Jet beaming. However in this compromise attitude the puzzle of the GRB980425/SN1998bw (which require a very thin Jet observed off-axis (Far-
Fargion & Salis 1995), (Fargion 1999), has been cured by most skeptical authors by a tenacious cover-up (neglecting or refuting The GRB-SN existence) or claiming the co-existence of a new zoo of GRBs (Bloom 2000), (Kulkarni). These new compromised fountain-like Fireball model has been collimated in a Jet within a $10^\circ$ angle beam, as a soft link between past Fireball and emerging Jet. However the apparent required GRB power output is still huge ($10^{50}$ erg s$^{-1}$), nearly $10^5$ more intense than other known maximal explosion power (the Super-Nova one). More and more evidences in last years and more recently have shown that Super-Nova might harbor a collimated Jet Gamma Ray Burst (GRB980425/SN1998bw, GRB030329/SN2003dh). To combine the Super-Nova Luminosity and the apparent huge GRBs power one need a very much thinner beam jet, as small as a solid angle $\Delta \Omega/\Omega \simeq 10^{-7}$ or $10^{-8}$ respect to $\Omega \simeq 4\pi$ (corresponding to a Jet angle $0.065^\circ - 0.02^\circ$ ). There is a statistical need (Fargion 1999) to increase the GRB rate inversely to the beam Jet solid angle. The needed SN rate (to explain GRBs) may even exceed the observed one (at least SN type Ib and Ic) event in our observable Universe ($N_{NS} \leq 30s^{-1}$). Indeed assuming that only a fraction of the SN (with optimistic attitude 0.1 of all known SN) experience an asymmetric Jet-SN explosion, than the corresponding observed rate $N_{GRBs} \simeq 10^{-5}s^{-1}$ and $N_{SN} \simeq 3s^{-1}$ imply $\frac{N_{GRBs}}{N_{SN}} \simeq 10^2 s^{-1} \leftarrow 10^3 s^{-1}$ a result nearly $2 - 3$ order of magnitude larger than the observed SN rate. In this frame one must assume a GRB Jet with a continuous active, decaying life-time much larger than GRBs duration itself at least by a corresponding scale $\tau_{Jet} \simeq 10^3 \tau_{GRBs}$. Indeed we considered GRBs (as well as Soft Gamma Repeaters SGR) as very thin blazing ($\leq 0.1^\circ$) precessing Gamma Jets spinning and precessing (Fargion & Salis 1995, 1996, Fargion 1999); in this scenario GRBs are born within a Super-Nova power collimated inside a very thin beam able to blaze us by an apparent GRB intensities.

The inner angle geometrical dynamics while spinning and precessing induce the wide $\gamma$ burst variability able to fit the very different observed GRBs ones. The averaged $\gamma$ jet deflection from the axis of sight defines a main early power law decay; an inner damped oscillatory substructure may be observed, as the amazing damping oscillatory afterglows in GRB030329. The very thin and collimated and long life decaying jet (opening angle $\theta \leq 0.05^\circ$, whose decay power law-time of a few hours occurs with an exponent $\alpha \simeq -1$), while spinning and precessing at different scale times, it may trace and may better explain the wobbling of the $\gamma$ GRBs and the long train of damped oscillations of the X tail afterglows within hours, the optical transient during days and weeks later. The GRBs re-brightening are no longer a mystery as in a one-shoot model. These wobbling signatures may be also be found in rarest and most powerful and studied SGRs events. The spread and wide conical shape of these precessing twin jets may be recognized in a few relic SNRs as in the twin SN 1987A wide external rings, the Vela arcs and the spectacular Egg Nebula dynamical shape.

1.1. The geometrical multi-precessing Gamma Jet by I.C. in GRB

We imagine the GRB and SGR nature as the early and the late stages of jets fueled first by SN event and later by an asymmetric accretion disk or a companion (WD, NS) star.
Figure 1. A possible inner structure 3D of a multi precessing Jet; its cone structures and its stability at late stage it maybe reflected in the quasi-periodic repetitions of the Soft Gamma Repeaters while beaming to us along the cone edges toward the observer. Its early blast at maximal SN out-put may simulate a brief blazing GRBs event, while a fast decay (hours scale) may hide its detectability below the threshold, avoiding in general any common GRB repeater.

Figure 2. The observed structure 3D of a multi precessing Jet in SS433; its structures maybe reflected in the quasi-periodic repetitions of the Soft Gamma Repeaters while beaming to us along the cone edges toward the observer.
Figure 3. Left: Multi bump afterglow behaviour of the intense precessing Jet above whose blazing shows the characteristic oscillatory damped decay as the recent GRB 030329 and the intense SGR on 27 August 1998. The luminosity starting time is assumed near zero (at SN birth time). In present simulation the assumed Lorentz factor is $\gamma_c = 2 \cdot 10^3$. Right: Semi Log. Multi bump Flux Intensity behaviour in linear time scales, normalized to visual magnitude for the previous precessing Jet simulating the characteristic oscillatory damped decay as the recent GRB 030329 and the intense SGR on 27 August 1998; time scale are arbitrary; in the GRB 030329 the unity corresponds to nearly day scale while in SGR event the unity in much smaller tens seconds scale

The binary angular velocity $\omega_b$ bends the angle as

$$\theta_1(t) = \sqrt{\theta_{1m}^2 + (\omega_b t)^2}$$

or more generally a multi-precessing angle

$$\theta_1(t) = \sqrt{\theta_{1m}^2 + \theta_b^2 + \theta_{psr}^2 + \theta_N^2}$$

$$\theta_x(t) = \theta_b \sin(\omega_b t + \varphi_b) + \theta_{psr} \sin(\omega_{psr} t + \varphi_{psr}) + \theta_N \sin(\omega_N t + \varphi_N)$$

$$\theta_y(t) = \theta_{1m} + \theta_b \cos(\omega_b t + \varphi_b) + \theta_{psr} \cos(\omega_{psr} t + \varphi_{psr}) + \theta_N \cos(\omega_N t + \varphi_N)$$

where $\theta_{1m}$ is the minimal impact angle parameter of the jet toward the observer, $\theta_b, \theta_{psr}, \theta_N$ are, in the order, the maximal opening precessing angles due to the binary, spinning pulsar, nutation mode of the multi-precessing jet axis. The arbitrary phase $\varphi_b, \varphi_{psr}, \varphi_N$, for the binary, spinning pulsar and nutation, are able to fit the complicated GRBs flux evolution in most GRB event scenario. Naturally it is very possible to enlarge the parameter to a fourth precession angular component whose presence may better fit the wide spread of scale variability; here we shall constrains to a three parameter precession beam.

For a 3D pattern and its projection along the vertical axis in an orthogonal 2D plane see following descriptive pictures. The different angular velocities are combined in the multi-precession wobbling. Each bending component is keeping memory either of the pulsar jet spin angular velocity ($\omega_{psr}$) and its opening angle $\theta_{psr}$, its mutation speed ($\omega_N$) and mutation angle $\theta_N$ (due to possible inertial momentum anisotropies or beam-accretion disk torques); a slower precession by the binary $\omega_b$ companion (and its corresponding open angle $\theta_b$) will modulate the overall jet precession. On average, from eq.(3) the $\gamma$ flux and the $X$, optical afterglow are decaying on time as $t^{-\alpha}$, where $\alpha \simeq 1 - 2$; however the more complicated spinning and precessing jet blazing is responsible for inner small scales wide morphology of GRBs and SGRs as well as their partial internal periodicity. The consequent $\gamma$ time evolution and spectra derived in this ideal models may be compared successfully with observed GRB data evolution.
The $\gamma$ Jet is born mainly by Inverse Compton Scattering by GeVs electron pairs onto thermal photons (Fargion 1995-96-98-99) in nearly vacuum space. Therefore these electron pairs are boosted in the Jet at Lorentz factor $\gamma_e \geq 2 \cdot 10^3$. Their consequent Inverse Compton Scattering will induce a parallel $\gamma$ Jet whose beam angle is $\Delta \theta \leq \frac{1}{\gamma} \simeq 5 \cdot 10^{-3} \text{rad} \simeq 0.0285^\circ$ and a wider, less collimated X, Optical cone. These beaming angles agree with the ones assumed to explain the required beamed GRBs-SN powers. Indeed, the electron pair Jet may generate a secondary beamed synchrotron radiation component at radio energies, in analogy to the behaviour of BL Lac blazars whose hardest TeV $\gamma$ component is made by Inverse Compton Scattering while its correlated X band emission is due to the synchrotron component. Anyway the inner jet is dominated by harder photons while the external cone contains softer X, optical and radio waves. A jet angle related by a relativistic kinematics would imply $\theta \sim \frac{1}{\gamma_e}$, where $\gamma_e$ is found to reach $\gamma_e \simeq 10^3 \div 10^4$ (Fargion 1999). At first approximation the gamma constrains is given by Inverse Compton relation: $< \epsilon_\gamma > \simeq \gamma_e^2 kT$ for $kT \simeq 10^{-3} - 10^{-1} \text{eV}$ and $E_e \sim \text{GeV}$s leading to characteristic X-$\gamma$ GRB spectra. The origin of GeVs electron pairs are very probably decayed secondary related to primary inner muon pairs jets, able to cross dense stellar target (Fargion 2003).

2. Conclusions: Neutrino-Muon Jets Progenitors for Gamma-X-Burst

The same GeVs electron pair Jet may generate a secondary beamed synchrotron radiation component at radio energies, in analogy to the behaviour of BL Lac blazars whose hardest TeV $\gamma$ component is made by Inverse Compton Scattering while its correlated radio bumps is due to the synchrotron component. Anyway the inner jet is dominated by harder photons while the external cone contains
softer X, optical and radio waves. The very peculiar oscillating GRB970508 optical variability did show both a re-brightening and remarkable multi-bump variability in radio wave-length. For this reason and we believe that this fluctuations were indeed to be related to the jet precession and not to any interstellar scintillation. There is not any direct correlation between the $\gamma$ Jet made up by I.C. scattering and the Radio Jet because the latter is dominated by the external magnetic field energy density: there maybe a different beaming opening and a consequent different time modulation respect to the inner $\gamma$ Jet. However the present wide energy power emission between SN2002ap and GRB030329 radio light curves makes probable a beaming angle comparable: $\leq 10^{-3} - 10^{-4}$ radiant.

These GRBs Jets are originated by NSs or BH in binary system or disk powered by infall matter; their relics (or they progenitors) are nearly steady X-ray Pulsars whose fast blazing is source of SGRs. This external $\gamma$ Jet has a chain of progenitor identities: it is very probably originated by a very collimated inner primary muon Jet pairs at TeVs-Pevs energies. These muons could cross with negligible absorption the dense target lights along the SN explosions, nearly transparent to photon-photon opacities. The high energy relativistic muons (tens TeVs-PeVs energies) decay in flight in electron pairs where the baryon density is still negligible; these muons are source, by decay in flight to Tevs-GeV electron pair showering whose final Inverse Compton Scattering with nearby thermal photon is the final primary of the observed hard $X-\gamma$ Jet. The cost of this long chain of reactions is a poor energy conversion, but the benefit is the possibility to explain the $\gamma$ escape from a very dense explosive and polluted (by matter and radiation) narrow volume. Its inner Jet ruled by relativistic Inverse Compton Scattering, has the hardest and rarest beamed GeVs-MeVs photons (as the rare and long 5000 s life EGRET GRB940217 one) but its external Jet cones are dressed by softer and softer photons. The complex variability of GRBs and SGRs are simulated successfully by the equations above (Fargion & Salis 1995,1996,1998, Fargion 1999); the consequent geometrical beamed Jet blazing may lead also to the observed widest morphology $X-\gamma$ signatures and rapid re-brightening as X-ray precursors. The mystery therefore is not longer in an apparent huge GRB luminosity, but in an extreme beam jet collimation and precession.

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