GRBs-SN and SGR-X-Pulsar as blazing Jets

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Abstract Old and recent puzzles of GRBs and SGRs find a solution with a model based on the fast blazing of very collimated thin gamma Jets. Damped oscillating afterglows in GRB 030329 find a natural explanation assuming a very thin Jet - $\frac{\Delta\Omega}{\Omega} \leq 10^{-8}$ - whose persistent activity and different angle of view maybe combined at once with the Supernovæ power and the apparent huge GRBs output: $\dot{E}_{\mathrm{GRBs}} \simeq \dot{E}_{\mathrm{SN}} \frac{\Omega}{\Delta\Omega}$. This leads to a better understanding of the remarkable GRB-Supernovæ connection discovered in the GRB 980425/SN 1998bw and in the most recent GRB 030329/SN 2003dh events. The same thin beaming offer an understanding of the apparent SGR-Pulsar power connection: $\dot{E}_{\mathrm{SGRs}} \simeq \dot{E}_{\mathrm{Xpuls}} \frac{\Omega}{\Delta\Omega}$. A thin collimated precessing Gamma Jet model for both GRBs and SGRs, at their different scaled luminosity ($10^{38} - 10^{44}$ erg s^{-1}), explains the existence of few identical energy spectra and time evolution of these sources leading to a unified model. Their similarity with the huge precessing Jets in AGN, QSRs and Radio-Galaxies inspires this smaller scale SGR-GRB model. The spinning-precessing Jet explains the rare ($\approx 6\%$) mysterious X-Ray precursors in GRBs and SGRs events. Any large Gamma Jet off-axis beaming to the observer might lead to the X-Flash events without any GRB signals, as the most recent XRF 030723. Its possible re-brightening would confirm the evidence of the variable pointing of the jet in or off line towards the observer. Indeed a multi-precessing Jet at peak activity in all bands may explain the puzzling X or optical re-brightening bumps found in the GRB 021004, GRB 030329 and the SGR 1900 + 14 on 27 August 1998 and once again on the 18 April 2001. Rarest micro-quasars neutron star in our galaxy as SS433, and Herbig Haro objects and Cir-X-1 describe these thin precessing Jet imprints in the spectacular shapes of their relic nebulae.

1 INTRODUCTION: FIRE-BALL MODELS IMPLOSION

The clear evidence of gamma polarization in the γ signals from GRB 021206 (Coburn & Boggs) proves in the eyes of most skeptical Fireball theorists the presence of a thin collimated jet (opening angle $\Delta\theta \leq 0.6°$; $\frac{\Delta\Omega}{\Omega} \leq 2.5 \times 10^{-5}$) in Gamma Ray Bursts (GRBs). The time and space coincidence of GRB 030329 with SN 2003dh definitely confirms the association of GRB and Supernovae discovered in the GRB 980425/SN 1998bw event. Therefore the extreme GRBs luminosity is just the consequence of a collimated gamma Jet observed on axis during a Supernova

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event. Nevertheless the maximal isotropic SN power, $\dot{E}_{\text{SN}} \simeq 10^{45}\,\text{erg s}^{-1}$, should be collimated even into a thinner jet $\frac{\Delta\Omega}{\Omega} \leq 10^{-8}$, in order to explain at the same time the apparent observed maximal GRBs output, $\dot{E}_{\text{GRB}} \simeq 10^{53}\,\text{erg s}^{-1}$. Consequently one-shot thin Jet GRBs needs many more events - $\dot{N}_{\text{GRBs}} \simeq \frac{\Omega}{\Delta\Omega} \geq 10^{8}$ - than any spread isotropic Fireballs, a rate that even exceeds the one of the observed Supernovae. To overcome this puzzle a precessing jet with a life-time $\tau_{\text{Jet}} \geq 10^{3}\,\tau_{\text{GRB}}$ is compelling. Relic GRBs sources may be found in compact SNRs core, as NS or BH jets; at later epochs, their "weakened" γ jets may be detectable only within galactic distances, as Soft Gamma Repeaters (SGRs) or anomalous X-ray Pulsars, AXPs. This common nature may explain some connections between GRBs and SGRs, given that rare spectra of SGRs show similar properties to GRBs. Also X-Ray precursors detected in both GRBs and SGRs suggest the need for a precessing Jet model. A surprising multi 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 the damped oscillatory imprint of such a multi-precessing γ-X-Optical and Radio Jet.

2 THE NEW GRBS PUZZLES

The Gamma Ray Burst mystery lays in its huge energy fluence, sharp variability, extreme cosmic distances and very different morphology. A huge isotropic explosion (the so called Fireball) was the ruling wisdom all along last decade. However the observed millisecond time scales called for small compact objects, so confined to become opaque to their own intense luminosity (over the Eddington limit) because of the abundant pair production, and so small in size and masses (few solar masses) to be unable to produce the large isotropic energies needed. Moreover, the spectra, had to be nearly thermal in a Fireball, contrary to the data evidence. The Fireball became an hybrid and complex model, where power law after power law, it tried to fit each GRBs spectra and time evolution. The huge GRBs power as in GRB 990123, made the final collapse of the model. New families of Fireball models including Jets collimated within a $10°$ beam have been introduced (as Hyper-Nova, Supra-Nova, Collapsar), which allow to lower, because of the beaming, the energy budget requested. However the apparent required GRB power is still huge $(10^{50}\,\text{erg s}^{-1})$, nearly 10^{5} more intense than other known maximal explosion events (such as the Supernova one). Further evidence in the last few years have shown that Supernova might harbour a collimated Jet Gamma Ray Burst (GRB 980425/SN 1998bw ,GRB 030329/SN 2003dh). To combine the Super-Nova Luminosity and the apparent huge GRBs power one needs a very much thinner beam, as small as $\Delta\Omega/\Omega \simeq 10^{-7}$ or 10^{-8} respect to $\Omega \simeq 4\pi$, (corresponding to a Jet angle $0.065°$–$0.02°$). 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 for SN type Ib and Ic ($\dot{N}_{\text{NS}} \leq 30\,\text{s}^{-1}$). Assuming that only a fraction of the SN (at most 0.1) experiences an asymmetric Jet-SN explosion, the corresponding observed rates $\dot{N}_{\text{GRBs}} \simeq 10^{-5}\,\text{s}^{-1}$ and $\dot{N}_{\text{SN}} \simeq 3\,\text{s}^{-1}$ imply $\frac{\dot{N}_{\text{GRBs}}}{\frac{\Delta\Omega}{\Omega}} \simeq 10^{2}\,\text{s}^{-1} \longleftrightarrow 10^{3}\,\text{s}^{-1}$, which is nearly $2 - 3$ orders of magnitude larger than what is observed for SN events. In this scenario one must assume a GRB Jet with a decaying life-time (to guarantee the energy conservation) much larger than the observed duration of GRBs, at least $\tau_{\text{Jet}} \simeq 10^{3}\tau_{\text{GRBs}}$.

We considered GRBs (as well as Soft Gamma Repeaters SGR) as originated by very thin ($\leq 0.1°$) spinning and precessing Jets (Fargion 1994; Fargion & Salis 1995a, 1995b; Fargion et al. 1996a; Fargion 1999; Fargion 2001; Frontera & Hjort 2001). In this scenario GRBs are born within a Super-Nova, collimated in a very thin beam which make them glow with an apparent GRB intensity. The inner geometrical dynamics of the spinning and precessing jet, may explain the wide γ burst variability observed in different events.
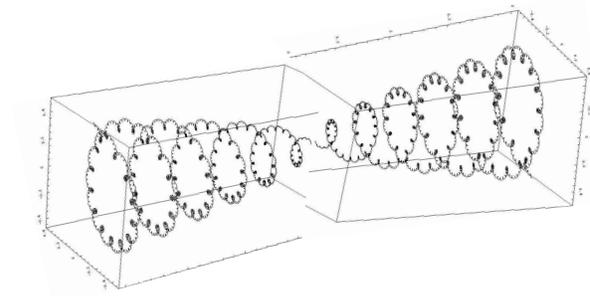
Fig. 1 A possible inner 3D structure of a multi precessing Jet. The conical structures and the stability at late stages may be reflected in the quasi-periodic repetitions of the Soft Gamma Repeaters whose emission is beamed toward the observer. Its early blast at maximal SN output may simulate a brief blazing GRBs event, while a fast decay (in a few hours time-scale) may hide its detection below the threshold, avoiding in general any GRB repeater.

The averaged γ jet deflection from the line of sight defines a power law decay; an inner damped oscillatory substructure may be observed, as the peculiar damped oscillating afterglows in GRB 030329. The thin, collimated ($\theta \leq 0.05°$) and long-lived jet (decaying in a few hours as a power law with index $\alpha \simeq -1$) spinning and precessing at different time-scale, may better explain the wobbling of the GRBs and the long sequence of damped oscillations of the X afterglows within hours, and of the optical transient within days and weeks. The GRBs re-brightening are no longer a mystery in a one-shot model. These wobbling signatures may be also be found in the rarest and most powerful 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.

3 THE GEOMETRICAL MULTI-PRECESSING GAMMA JET IN GRB

We imagine the GRB and SGR nature as the early and the late stages of jets fueled by a SN event first and then by an asymmetric accretion disk or by a companion star (white dwarf, WD, or neutron star, NS). The ideal spinning Jet points in a fixed direction; however the presence of a companion star influences the stability of the jet. Indeed a binary system angular velocity, ω_b, affects the beam direction whose bending angular evolution may be described in a simple case as follows: $\theta_1(t) = \sqrt{\theta_{1m}^2 + (\omega_b t)^2}$. More generally a multi-precessing angle $\theta_1(t)$ (Fargion et al. 1996a, 1996b) may be described by: $\theta_1(t) = \sqrt{\theta_x^2 + \theta_y^2}$

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

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

where $1/\gamma$ is the characteristic jet opening angle, and γ is the Lorentz factor of the θ_{1m} is the minimal angular distance (impact parameter angle) of the jet pointing toward the observer, θ_b, θ_{psr}, and θ_N (all proportional to $1/\gamma$) are respectively the maximal precessing angles due to the binary system, the spinning pulsar, and the nutation mode of the multi-precessing axis of the jet. The arbitrary phases φ_b, φ_{psr}, φ_N for the binary, spinning pulsar and nutation, are able to fit the complicated GRBs flux evolution in most GRB event scenario. It is possible
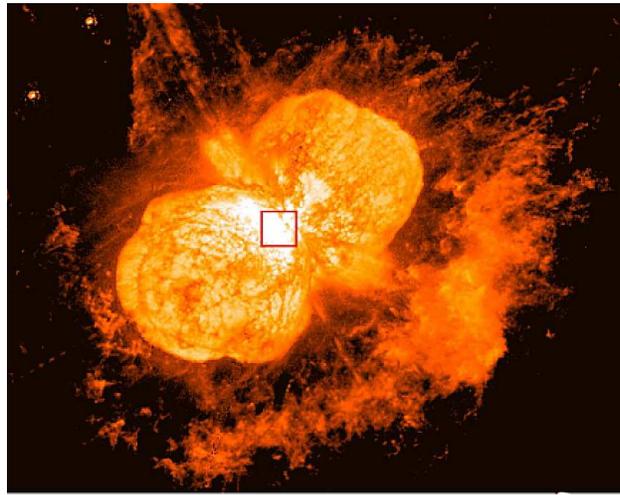
Hubble Space Telescope   Eta Carina

Fig. 2 Eta Carina Conical Hour Glass Shape. Such a mysterious twin lobes may be originated by an inner thin precessing Jet hidden in the center of the nebula. The blow up of the nebula could be due to the pressure of a multi precessing jet leading to a twin Homunculus or a Hour-Glass Nebula. The presence of the thin jet escaping from the center has been observed at certain angles of view (finger-like structures) (Redman, Meaburn, Holloway 2002); the bending of the jet is due to an accretion disk or to a compact binary companion.
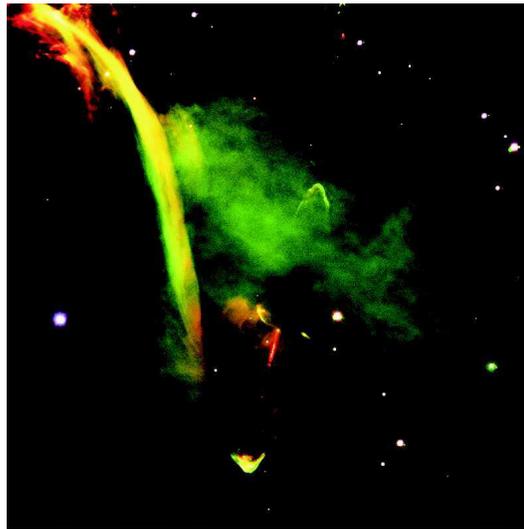
Protostar HH-34 in Orion   (VLT KUEYEN + FORS2)

ESO PR Photo 40b/99 (17 November 1999)   © European Southern Observatory

Fig. 3 The whip-like jet of HH34 micro-quasar. The long tail visible both in the front and behind the star describes a thin moving jet. An internal spinning sub-structure may be hidden inside the width of the tail.
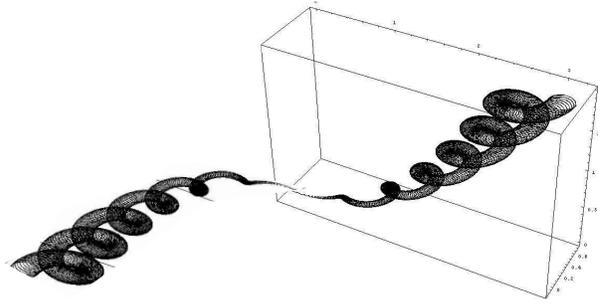
Fig. 4 A twin spinning and precessing jet whose appearance along the line of sight, at maximal supernova output, produces the sudden GRBs. At later stages, the less powerful jet would rather appear as a SGRs, visible only within nearby, galactic-like distances
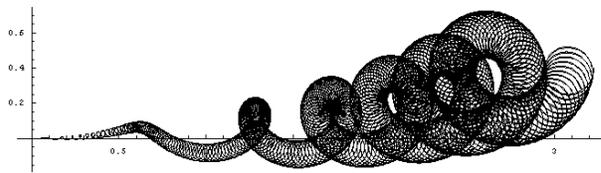
Fig. 5 The twin spinning and precessing jet configuration projected onto a 2dimensional screen.

to increase the number of the parameters with a fourth precession angular component whose presence may better fit the wide range of variability observed. Here we shall stick to a three parameter precessing beam.

Figure 4 displays a 3D pattern of the jet and Fig. 5 its projection along the vertical axis in a 2D plane. The combination of the different angular velocities determine the multi-precession of the jet. Each component includes the pulsar jet spin angular velocity (ω_{psr}) and its angle θ_{psr}, the nutation speed (ω_N) and nutation angle θ_N (due to possible inertial momentum anisotropies or beam-accretion disk torques). A slower component due to the companion of the binary system, ω_{b}, (and the corresponding angle θ_{b}) will modulate the total jet precession. On average, from Eq. (3) the γ flux and the X, optical afterglow are decaying as a power-law with time, $t^{-\alpha}$, where $\alpha \simeq 1-2$. The spinning and precessing jet is responsible for the wide range of GRBs and SGRs properties and of their partial internal periodicity. The γ time evolution and spectra derived in this ideal model may be compared successfully with observed GRB data (see Figs. 7 and 8).

4 HARD γ-X JET BY INVERSE COMPTON SCATTERING BY ELECTRON PAIRS

The γ Jet is originated mainly by Inverse Compton Scattering of GeVs electron pairs onto thermal photons (Fargion 1994; Fargion & Salis 1995a, 1995c, 1998; Fargion 1999) in nearly vacuum conditions. Therefore these electron pair are boosted at Lorentz factor $\gamma_e \geq 2 \times 10^3$.
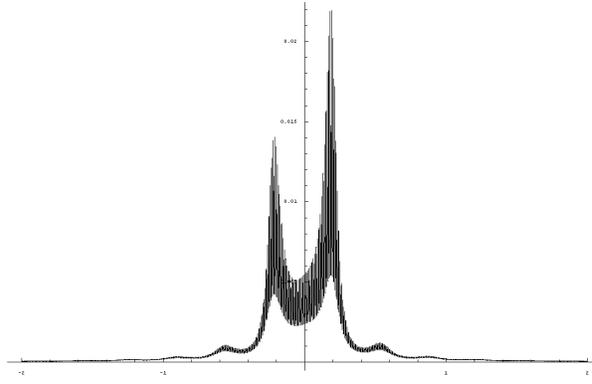
Fig. 6 Multi-bump afterglow behaviour of the precessing Jet shown above, with the characteristic damped oscillatory decay as found in the GRB 030329 and the SGR of the 27 August 1998. The luminosity starting time is assumed near zero (at SN birth time). In the present simulation the assumed Lorentz factor is $\gamma_e = 2 \times 10^3$
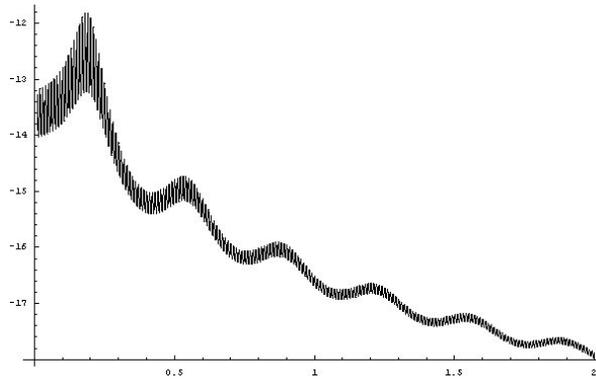
Fig. 7 Multi bump Flux Intensity in linear scale, normalized to the visual magnitude for the same precessing Jet displayed in Figs. 3 and 4. The profile shows the characteristic oscillatory damped decay as that observed in GRB 030329 and in the 27 August 1998 SGR. The time scale is arbitrary: in the GRB 030329 the unit corresponds to about a daily scale, while in SGR events the unit is in minutes.

Their consequent Inverse Compton Scattering will induce a γ Jet whose beaming angle is $\Delta\theta \leq \frac{1}{\gamma} \simeq 5 \times 10^{-4}$ rad $\simeq 0.0285°$ and a wider, less collimated X, optical cone. These angles are compatible with the beaming required to explain the transition from the SN to the GRB power. In addition the electron pair Jet may generate a secondary synchrotron radiation component at radio energies, in analogy with BL Lac blazars where the hardest TeV γ component is made by Inverse Compton Scattering and the correlated X band emission is due to the synchrotron emission. The inner jet is dominated by the harder photons while the external cone contains softer X, optical and radio waves. The jet aperture, according to the theory of relativity, would imply $\theta \sim \frac{1}{\gamma_e}$, where $\gamma_e \simeq 10^3 \div 10^4$ (Fargion 1999; Fargion et al. 1996b). In a first approximation
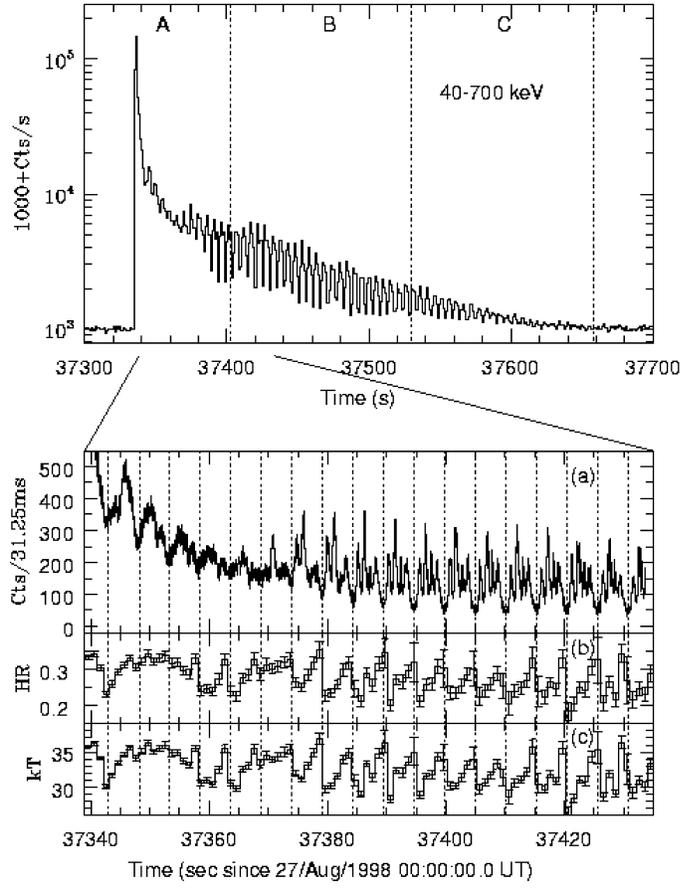
Fig. 8 The observed gamma profile of the intense SGR on 27 August 1998. The burst decay seems to follow the damped oscillatory behaviour shown above.

the constraint on the gamma energy range is given by the Inverse Compton relation: $\langle \epsilon_\gamma \rangle \simeq \gamma_e^2 \, kT$ for $kT \simeq 10^{-3} - 10^{-1}$ eV and $E_e \sim$ GeV leading to characteristic X-γ GRB spectra. GeV electron pair are likely to be related to primary muon pair jets, able to cross dense stellar target (Fargion & Salis 1998). The consequent adimensional photon number rate, as a function of the angle θ_1 becomes (Fargion 1999)

$$\frac{\left(\frac{dN_1}{dt_1 \, d\theta_1}\right)_{\theta_1(t)}}{\left(\frac{dN_1}{dt_1 \, d\theta_1}\right)_{\theta_1=0}} \simeq \frac{1 + \gamma^4 \, \theta_1^4(t)}{[1 + \gamma^2 \, \theta_1^2(t)]^4} \, \theta_1 \approx \frac{1}{(\theta_1)^3} \quad . \tag{2}$$

The total fluence at the minimal impact angle θ_{1m} responsible for the average luminosity is

$$\frac{dN_1}{dt_1}(\theta_{1m}) \simeq \int_{\theta_{1m}}^{\infty} \frac{1 + \gamma^4 \, \theta_1^4}{[1 + \gamma^2 \, \theta_1^2]^4} \, \theta_1 \, d\theta_1 \simeq \frac{1}{(\theta_{1m})^2} \quad .$$

These spectra fit GRBs observed ones (Fargion & Salis 1995a, 1995c; Fargion et al. 1996b; Fargion 1999). Assuming a beam jet intensity I_1 comparable with maximal SN luminosity,
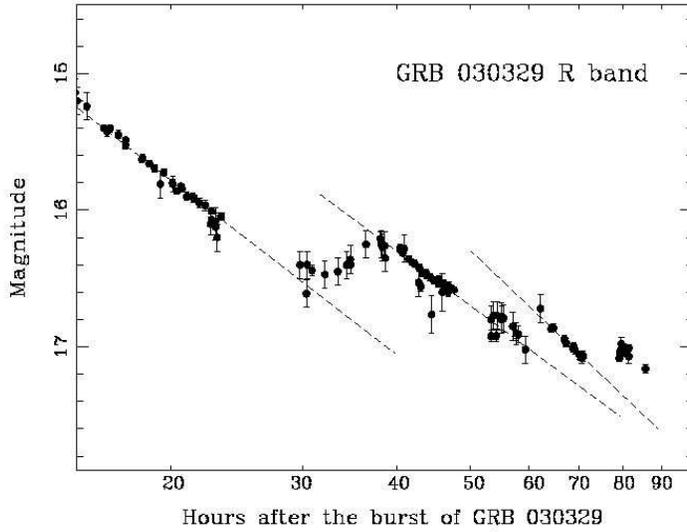
Fig. 9 The multi bump behaviour or "re-brightening" observed in GRB 030329. Its puzzling imprint maybe described by a precessing γ, X and optical jet.

$I_1 \simeq 10^{45}$ erg s^{-1}, and replacing this value in the above adimensional equation we find a maximal apparent GRB power for beaming angles $10^{-3} \div 3 \times 10^{-5}$, $P \simeq 4\pi I_1 \theta^{-2} \simeq 10^{52} \div 10^{55}$ erg s^{-1}, just within the observed values. We also assumed that the jet intensity decays in time as the following power law

$$I_{\text{jet}} = I_1 \left(\frac{t}{t_0} \right)^{-\alpha} \simeq 10^{45} \left(\frac{t}{3 \cdot 10^4 s} \right)^{-1} \text{ erg s}^{-1}$$

assuming that at a time scale of 1000 years it may reach the observed intensity of known galactic micro-jets such as SS433: $I_{\text{jet}} \simeq 10^{39}$erg s^{-1}. This offers a natural link between the GRB and the SGR output powers. We used the model to evaluate if the April precessing jet might hit us once again. It should be noted that a steady angular velocity would imply an intensity variability ($I \sim \theta^{-2} \sim t^{-2}$) corresponding to some of the earliest afterglow decay law. These predictions have been proposed a long time ago, (Fargion 1999). Similar descriptions with more parameters and within a sharp time evolution of the jet have been also proposed by other authors (Blackman, Yi, & Field, 1996; Portegies Zwart et al. 1999).

5 PRECESSING RADIO JET BY SYNCHROTRON RADIATION

As we have mentioned in the last section, the same GeV Jet of electron pair may generate a secondary beamed synchrotron radiation component at radio energies, in analogy to the behaviour of BL Lac blazars.

However the inner jet is dominated by harder photons while the external cone contains softer X, optical and radio waves. Their wide precessing angle is the source of the radio bumps emitted on a time scale of days, clearly observed in the GRB 980425, GRB 030329 light curves.

The peculiar and oscillating optical variability of GRB 970508 did show a re-brightening nearly two months later, and it did also show a remarkable multi-bump variability in radio wavelength. For this reason we are more inclined to believe that this fluctuations were indeed related to the Jet precession and not to any interstellar scintillation. There is not any direct correlation between the γ Jet made up by Inverse Compton 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 γ Jet. However the present wide energy power emission between SN 2002ap and GRB 030329 radio light curves makes probable a comparable beaming angle: $\leq 10^{-3} - 10^{-4}$ radiant. The appearance of re-brightening is not unique of GRBs and SGRs. It should also occur in the X-Ray-Flare (XRF) event that have been recently associated to GRBs. Indeed the recent XRF 030723 (Butler et. al 2004) exhibit an X-Ray re-brightening; also the Optical Afterglow of GRB 021211 (Della Valle et al. 2003) did show such a surprising increase in luminosity at very late times in the GRB afterglow.

6 X-RAY PRECURSOR BY PRECESSING JET

The thinner the jet, the larger the sample of events, the source volume (large redshift) and the harder is the γ Jet observed. This explain why, despite the Hubble cosmic expansion and the time dilution, the most variable and the most powerful observed GRBs with the hardest spectra are not the nearest ones but the most distant. Isotropic explosions can not explain such a scenario. Indeed the extreme γ energy budget, requiring a comparable ν emission, exceeds in isotropic models few or many solar masses, even assuming an (ideal) entire mass-energy conversion. To probe how the Jet model may fit the GRB features, let us consider the most distant ($z = 4.5$) GRB observed so far - GRB 000131 - and its X-ray precursor. This burst while being red-shifted and slowed down by a factor 5.5, shows a short time scale and a very fine structure in disagreement with any fireball model, but well compatible with a thin, fast spinning precessing γ jet. Moreover let us notice the presence of a weak X-ray precursor pulse lasting 7 s, 62 s before the main γ burst trigger GRB 000131 (Fargion 2001). Its arrival direction within 12 degree from the GRB event is consistent only with the main pulse (the probability for this coincidence to occur by chance is below $3.6 \cdot 10^{-3}$). Given the time clustering proximity (one minute over a day GRB rate average), the probability to occur by chance is below one thousandth. The overall probability to observe this precursor by chance is below 3.4 over a million making inseparable its association with the main GRB 000131 event. This weak burst signal corresponds to a power of more than a million Supernovae and have left no trace or Optical/X transient just a minute before the more energetic gamma event (peak power > *billion* Supernova). No isotropic GRB explosive progenitor could survive such a disruptive precursor nor any multi-exploding jet. Only a persistent, pre-existing precessing Gamma Jet pointing twice near the observer direction could naturally explain such a luminosity evolution. These X-ray precursor are not unique but are found in $3\% - 6\%$ of all GRBs. Similar X precursors occurred in SGRs event as the $1900 + 14$ on 29 August 1998.

7 CONCLUSIONS: NEUTRINO-MUON JETS PROGENITORS

We believe that GRBs and SGRs are persistent blazing flashes from lighthouse-like, thin γ Jets spinning in multi-precessing modes (binary, precession, nutation). These GRBs Jets are originated by NSs and/or BH in binary systems, or accretion disks fuelled by infalling matter. Their relics (or they progenitors) are nearly steady X-ray Pulsars whose fast blazing may be the source of SGRs. The Jets are not single explosive events in GRB, but they are powered at maximal output during the long period of a SN explosion. The power of the beamed Jet
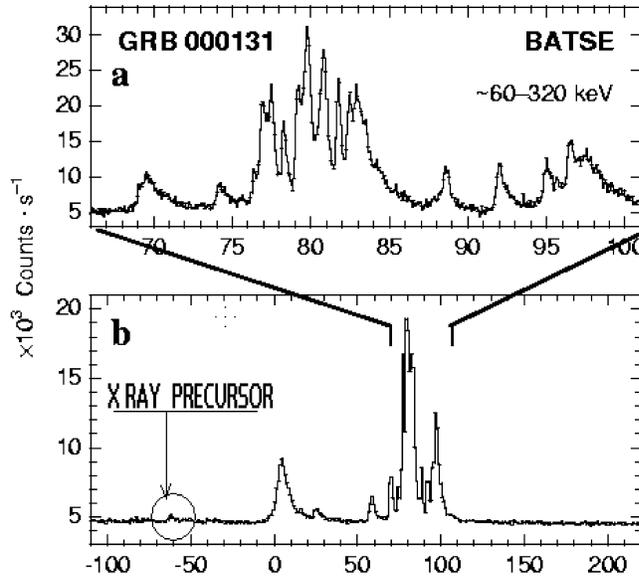
Fig. 10 X precursors in GRB 000131, the most distant γ burst observed so far ($z = 4.5$).

is comparable to that of a SN at the peak luminosity. The external γ Jet is originated by a series of processes linked one to the other. First the jet may be originated in the SN and/or BH birth, and it is probably due to a very collimated primary muon pair Jet at TeVs-Pevs energies. These muons might propagate with negligible absorption through the dense photon background produced by the SN explosion, and they are nearly transparent to photon-photon opacities. We speculate that such muon pair progenitors might be secondaries of a ultra-high energy neutrino Jet, originated in the interior of a new born NS or BH, because neutrinos are able to escape from the dense matter envelopes obscuring the Super-Nova volume (Gupta 2003; Fargion 2002). The high energy relativistic muons (at tens of TeV-PeV) decay in flight in electron pair where the baryon density is still negligible. The Inverse Compton Scattering of such electronic pair with nearby thermal photon is the final step to produce the observed hard X- γ Jet. The cost of this long chain of reactions is a poor energy conversion, but it has the advantage of being able to explain the γ escape from a very dense environment "polluted" by matter and radiation. The relativistic morphology of the Jet and its multi-precession geometry is the source of the complex X-γ spectra signature of GRBs and SGRs. The inner Jet produces by relativistic Inverse Compton Scattering the hardest and rarest beamed GeVs-MeVs photons (as the rare and long 5000 s life EGRET GRB 940217 one). The external edges of the Jet create softer and softer photons.

The complex variability of GRBs and SGRs is discussed and compared. We find that the properties of both events are successfully described by a multi-precessing Jet whose angular evolution is described by the Eq. (1) (see Fargion & Salis 1995a, 1995b; Fargion 1999). Such a beamed Jet may also explain the wide range of X-γ signatures. Therefore the puzzle of GRBs is no longer in their apparent huge luminosity, but in the mechanism able to originate such an extreme jet collimation and its precession.

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