# SSC EMISSION AS A SOURCE OF THE GAMMA RAY AFTERGLOW OBSERVED IN GRB 980923

N. Fraija, M. M. González and W. H. Lee, Instituto de Astronomía, UNAM

GRB 980923 was one of the brightest bursts observed by BATSE. Previous studies have detected two distinct components in addition to the main prompt episode, which is well described by a Band function. The first of these is a tail with a duration of 400s, while the second is a high-energy component lasting 2s. After summarizing the observations, we have modeled this event and conclude that the tail can be understood as the early afterglow from forward shock synchrotron emission, while the high-energy component is described by the SSC emission from the reverse shock. The main assumption is that of a thick-shell case from highly magnetized ejecta. The calculated fluxes, break energies, starting times and spectral index are all consistent with the observed values.

## INTRODUCTION

The most successful theory to explain GRBs and their afterglows is the fireball model (Mészáros, 2006). This model predicts an expanding ultrarelativistic shell that moves into the external medium. The encounter of this shell with another (internal shocks), or the surrounding interstellar media (external shocks) could give rise to radiation emission through the synchrotron and SSC processes. Additionally, when the expanding relativistic shell encounters the external medium, two shocks are generated: an outgoing shock (the forward shock) that propagates into ISM, accelerating electrons, and a reverse shock that propagates into the ejecta heating up the material in the shell and accelerates electrons when crossing the shell. Now, although the contribution of the synchrotron emission of reverse shock in the X-ray band could be small, electrons in the reverse shock region can upscatter the synchrotron photons (SSC process) to higher energies. Here we study synchrotron self-inverse Compton radiation from the reverse shock considering a thick shell to explain the short-duration hard MeV-component of the GRB 980923.

## GRB980923

GRB 980923 was observed by BATSE on 1998 September 23 at 20:10:52 UT for 32.02 s. It was localized to $23.4^0$ with respect to the pointing-axis direction of CGRO. In accordance to Gonzalez (2011), the prompt emission consists of three spectral components (Sacahui, 2010). The first component is the typical prompt emission. The second one is a smooth tail lasting 400s which can be described by a Smooth Broken Power Law as reported by Giblin (1999). The last component is a hard MeV-component described by a Power Law with spectral index of $\Upsilon = -1.44 \pm 0.07$, extending up to ≈ 200 MeV. The smooth tail is well studied by Giblin (1999), who finds that the evolution of the synchrotron cooling break in the slow-cooling regime starting at t0=32 seconds, with a characteristic value for the power index of p= 2.4± 0.11. However, Gonzalez (2011) points out that the tail could begin before or at 14s from the burst trigger. Thus the transition from fast to slow cooling of the tail occurred in a short period of time between 14s and 32s.

## DYNAMICS OF THE FORWARD AND REVERSE SHOCK

In general t0=0 is defined by the trigger time of the burst. The assumption that the tail starts at 14s implies that at this time the GRB ejecta collides with the ISM generating a forward and a reverse shock.

For the forward shock, we assume that electrons are accelerated in the shock to a power law distribution. Computing the typical and cooling frequencies of the synchrotron emission (Sari, 1998), we obtain

$$\begin{aligned}
\nu_{\rm m,f} &\sim 6.5\times10^{14}\left(\frac{1+z}{2}\right)^{1/2}\epsilon^2_{e,f,-2}\,\epsilon^{1/2}_{B,f,-4}\,E_{52}^{1/2}\,t_1^{-3/2}\ \ {\rm Hz}\\
\nu_{\rm c,f} &\sim 4.2\times10^{19}\left(\frac{1+z}{2}\right)^{-1/2}(1+x_f)^{-2}\,\epsilon^{-3/2}_{B,f,-4}\,n^{-1}_{f,0}\,E_{52}^{-1/2}\,t_1^{-1/2}\ \ {\rm Hz}\\
F_{\rm max,f} &\sim 6.9\times10^{2}\left(\frac{1+z}{2}\right)\epsilon^{1/2}_{B,f,-4}\,n^{1/2}_{f,0}\,D_{28}^{-2}\,E_{52}\ \mu{\rm Jy}\\
t_{\rm tr,f} &\sim 1.55\times10^{-4}\left(\frac{1+z}{2}\right)\epsilon^{2}_{B,f,-4}\,\epsilon^{2}_{B,f,-2}\,n_{f,0}\,E_{52}\,{\rm s}
\end{aligned}$$

Therefore, taking as starting time of the tail t0=14s, we obtain that the transition time from fast to slow cooling is $10^{-4}$s and that the energy domain of the smooth tail is around hundred of keVs with a cooling frecuency of 133.7 keV in agreement with the results of Giblin (1999).

For the reverse shock, we consider the thick shell case where the spectral characteristics of the forward and reverse shock synchrotron emission are related (Zhang, 2003) by

$$\begin{aligned}
\nu_{\rm m,r} &\sim \mathcal{R}_e^2\,\mathcal{R}_B^{-1/2}\,\mathcal{R}_M^{-2}\,\nu_{m,f}\\
\nu_{\rm c,r} &\sim \mathcal{R}_B^{3/2}\,\mathcal{R}_x^{-2}\,\nu_{c,f}\\
F_{\rm max,r} &\sim \mathcal{R}_B^{-1/2}\,\mathcal{R}_M\,F_{max,f}
\end{aligned}$$

where $\mathcal{R}_B = \epsilon_{B,f}/\epsilon_{B,r}$ , $\mathcal{R}_e = \epsilon_{e,r}/\epsilon_{e,f}$ , $\mathcal{R}_x = (1+x_f)/(1+x_r+x_r^2)$ and $\mathcal{R}_M = \Gamma_c^2/\gamma$

And

$$\nu_m^{\rm (IC)} \sim \gamma_m^2, \nu_{m,r}\,; \qquad \nu_c^{(IC)} \sim \gamma_c^2\,\nu_{c,r}\,; \qquad F_{max}^{(IC)} \sim k\tau\,F_{\rm max,r};$$

where $k = 4(p-1)/(p-2)$ and $\tau = \frac{\sigma_T N_e}{4\pi R_d} = \frac{c}{3}\left(\frac{1+z}{2}\right)^{-1}\sigma_T\,n\,\Gamma_c^4\,\gamma^{-1}$

Finally the SSC energies and flux are given by,

$$\begin{aligned}
\nu_{\rm m}^{(IC)} &\sim 5.6\times10^{22}\left(\frac{1+z}{2}\right)^{-7/4}\left(\frac{\epsilon_{e,r}}{0.9}\right)\left(\frac{\epsilon_{B,r}}{0.009}\right)^{1/2}\gamma^4_{r,3}\,n^{3/4}_{r,1}\,E_{52}^{-1/4}\left(\frac{T}{2s}\right)^{3/4}\ {\rm Hz}\\
\nu_{\rm c}^{(IC)} &\sim 5.35\times10^{16}\left(\frac{1+z}{2}\right)^{3/2}\left(\frac{1+x+x^2}{6}\right)^{-4}\left(\frac{\epsilon_{B,r}}{0.009}\right)^{-7/2}n^{-3}_{r,1}\,E_{52}^{-1/2}\,\gamma^{-6}_{r,3}\left(\frac{T}{2s}\right)^{-5/2}\ {\rm Hz}\\
F_{\rm max}^{(IC)} &\sim 1.29\times10^{-4}\left(\frac{1+z}{2}\right)^{9/4}\left(\frac{\epsilon_{B,r}}{0.009}\right)^{1/2}n^{3/4}_{r,1}\,D_{28}^{-2}\,E_{52}^{-5/4}\,\gamma^{-2}_{r,3}\left(\frac{T}{2s}\right)^{-5/4}\ {\rm Jy} \qquad (14)
\end{aligned}$$

Thus for the hard MeV-component, described as SSC in the reverse shock, we obtain that the break energies are $E^{IC}_c$≈0.2 keV, $E^{IC}_m$≈229.8 MeV with a $\nu F_{\nu\,\max}$=44737 keV/cm$^2$/s, in agreement with the results given by Gonzalez (2011). The expected spectral index is -1.5 in agreement with the observed value of $\Upsilon = -1.44 \pm 0.07$. The required magnetic fields are related by $B_f = 2.6\ 10^{-3}\ B_r$ implying a highly magnetized ejecta.

## CONCLUSIONS

We have showed that the smooth tail of GRB980923 can be explained as synchrotron emission from an external forward shock, while the hard MeV-component is explained as SSC emission from an external reverse shock into a magnetized ejecta. The SSC spectrum corresponds to the fast-cooling regime. The obtained spectral indexes, fluxes and break energies, are in agreement with the observations.

## REFERENCES

1. Giblin, T.W., et al. 1999. ApJ, 524, L47
2. González M. et al. 2011, ApJ, submitted
3. Sari et al 1998, ApJ 497, L17
4. Zhang B. et al. 2003, ApJ 595, 950
5. Mészáros, P. 2006 Report of progress in physics 69, 2259
6. Sacahui J.A. et al. 2011, RevMexAA SC, submitted