What about Black Hole Spin Down in Gamma-Ray Bursts?

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ABSTRACT According to Blandford & Znajek (1977), the spin energy of a rotating black hole can be extracted electromagnetically, should the hole be endowed with a magnetic field supported by electric currents in a surrounding disk. As a result of this mechanism, the black hole spins down. We argue that this can be the case for the central engines of Gamma-Ray Bursts (GRBs) and we show that the duration of the burst depends on the magnetic flux accumulated on the event horizon of the black hole. We derive an analytic formula for this spin down procedure. We find that the theoretical curve fits very well the X-ray light curves of several GRBs.

Subject headings. Black hole physics; gamma-ray bursts; magnetic fields;

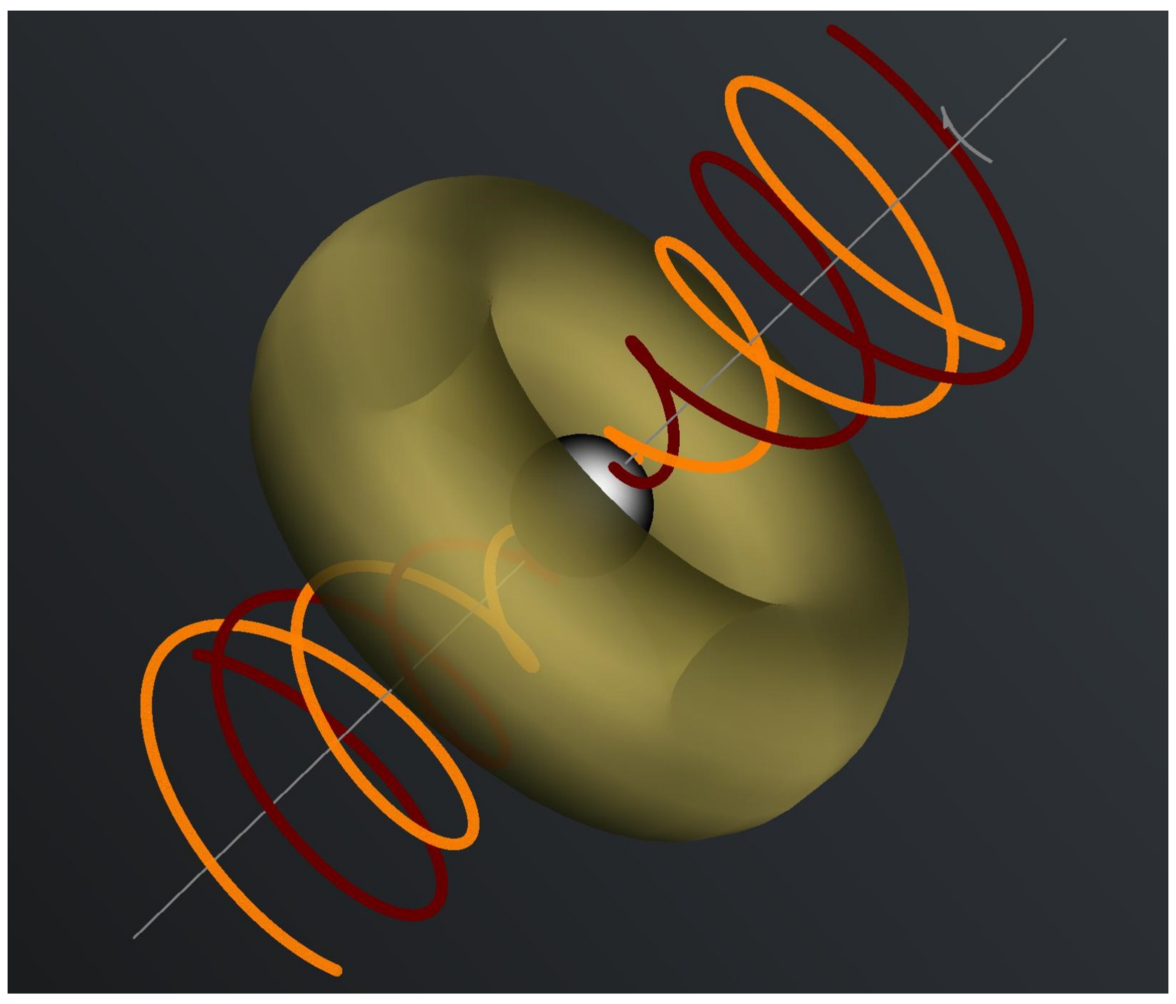

Figure 1. The structure of the magnetosphere close to the event horizon of a maximally rotating black hole (spin parameter close to unity). Magnetic field lines (depicted in dark red and orange) based on the solutions of (Nathanail & Contopoulos 2014). A massive torus of material (transparent) holds the magnetic flux to the event horizon

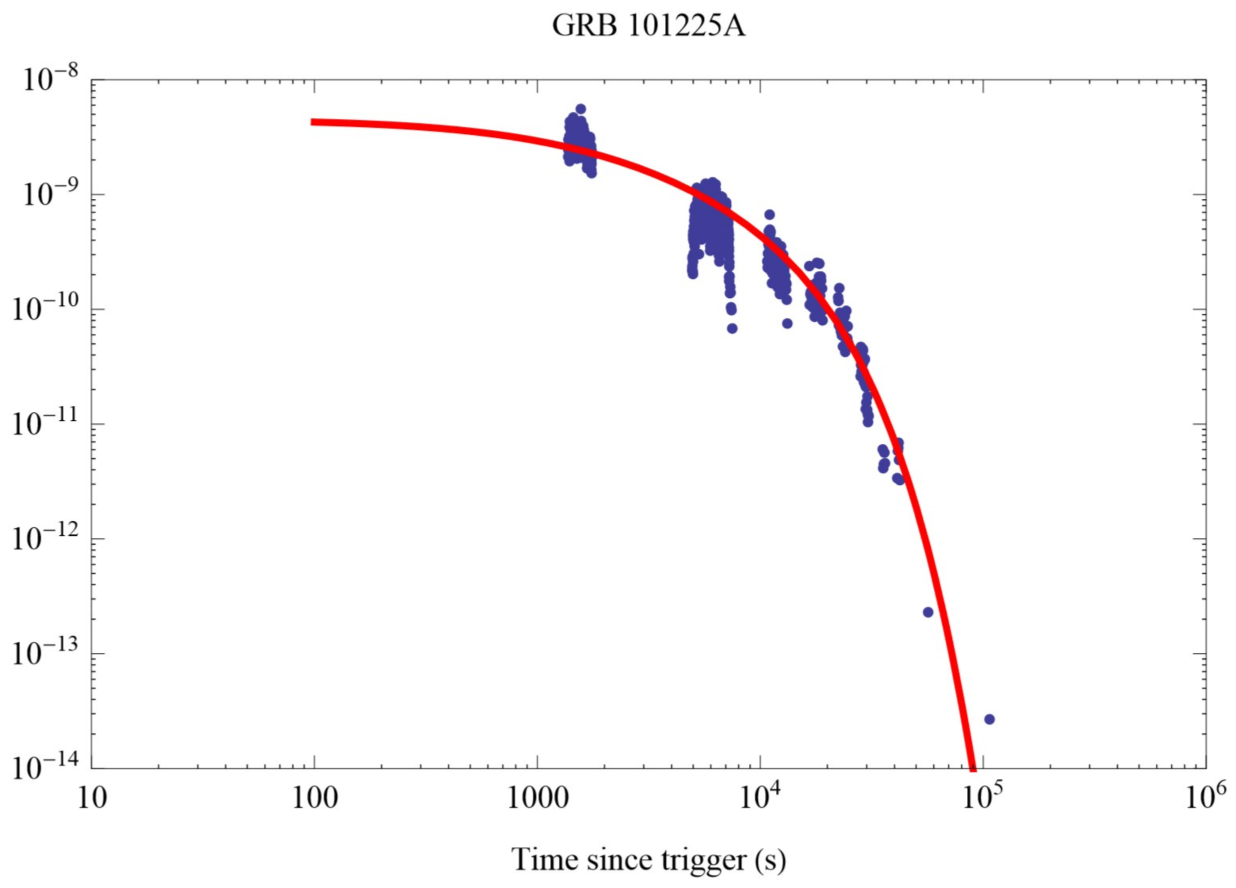

Figure 2. Ultra Long GRB 101225A, the red curve is the theoretical black hole spin down. Log-log plot, energy flux at 0.3 – 10 keV.

Let us consider a supermassive progenitor star whose core collapses and forms a maximally rotating black hole. Highly conducting matter from the interior of the star will drive the advection of magnetic flux during the collapse. A certain amount of magnetic flux Ψm is then going to cross the horizon. A thick disk (torus), formed around the black hole due to the rotational collapse, will act as a strong barrier that will hold the magnetic flux initially advected. As long as this is the case, the black hole will lose rotational/reducible energy at a rate (Blandford & Znajek 1977)

$$\dot{E} \approx -\frac{1}{6\pi^2 c}\Psi_m^2\Omega^2 \ ,$$

The available rotational/reducible black hole energy is aGM2Ω/c where a ≡ J/M is the black hole spin parameter (Christodoulou & Ruffini 1971), and G is the gravitational constant. The black hole will therefore spin down as

$$\dot{E} = \frac{\mathcal{G}M^2}{c}\frac{\mathrm{d}(a\Omega/M)}{\mathrm{d}t}$$

Equating the above we can find the energy loss rate due to the electromagnetic spin down, if we approximate it we get (Contopoulos et al. 2014)

$$\dot{E} \approx \dot{E}_o \frac{e^{-t/\tau}}{2-e^{-t/\tau}} \approx \dot{E}_o e^{-t/\tau}.$$

where

$$t_{BZ} \equiv \frac{24c^5}{\mathcal{G}^2B^2M} = 2.6\left(\frac{B}{5\times 10^{16}\ \mathrm{G}}\right)^{-2}\left(\frac{M}{10M_\odot}\right)^{-1}\ \mathrm{sec}$$

is a very important physical parameter that indicates the timescale of black hole spin down.

We searched the new population of Ultra Long GRBs and looked for signs of black hole spin down (Nathanail & Contopoulos 2015). Two of them can be seen in figures 1,2,3. We are currently searching for signs of black hole spin down in the Long GRB population (Nathanail et al. In preparation).

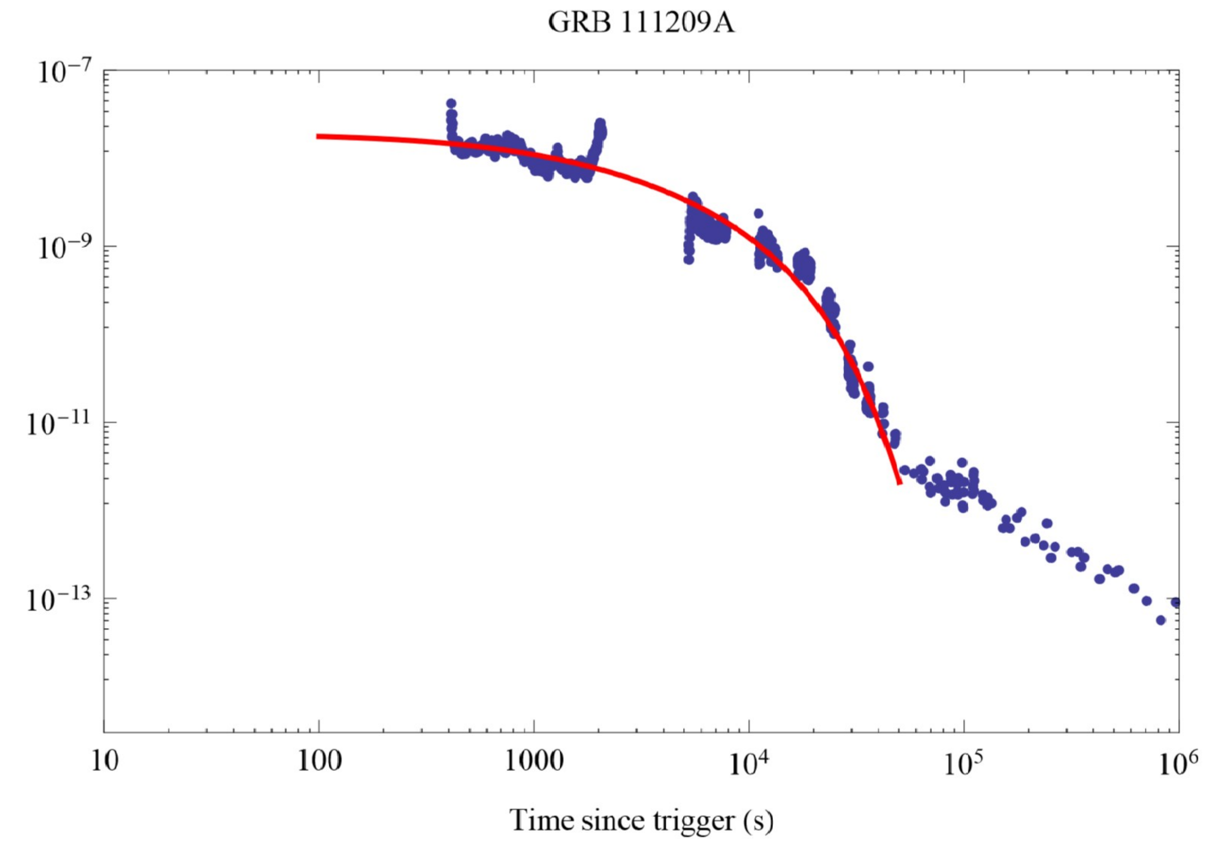

Figure 3. Ultra Long GRB 111209A, the red curve is the theoretical black hole spin down. Log-log plot, energy flux at 0.3 – 10 keV.

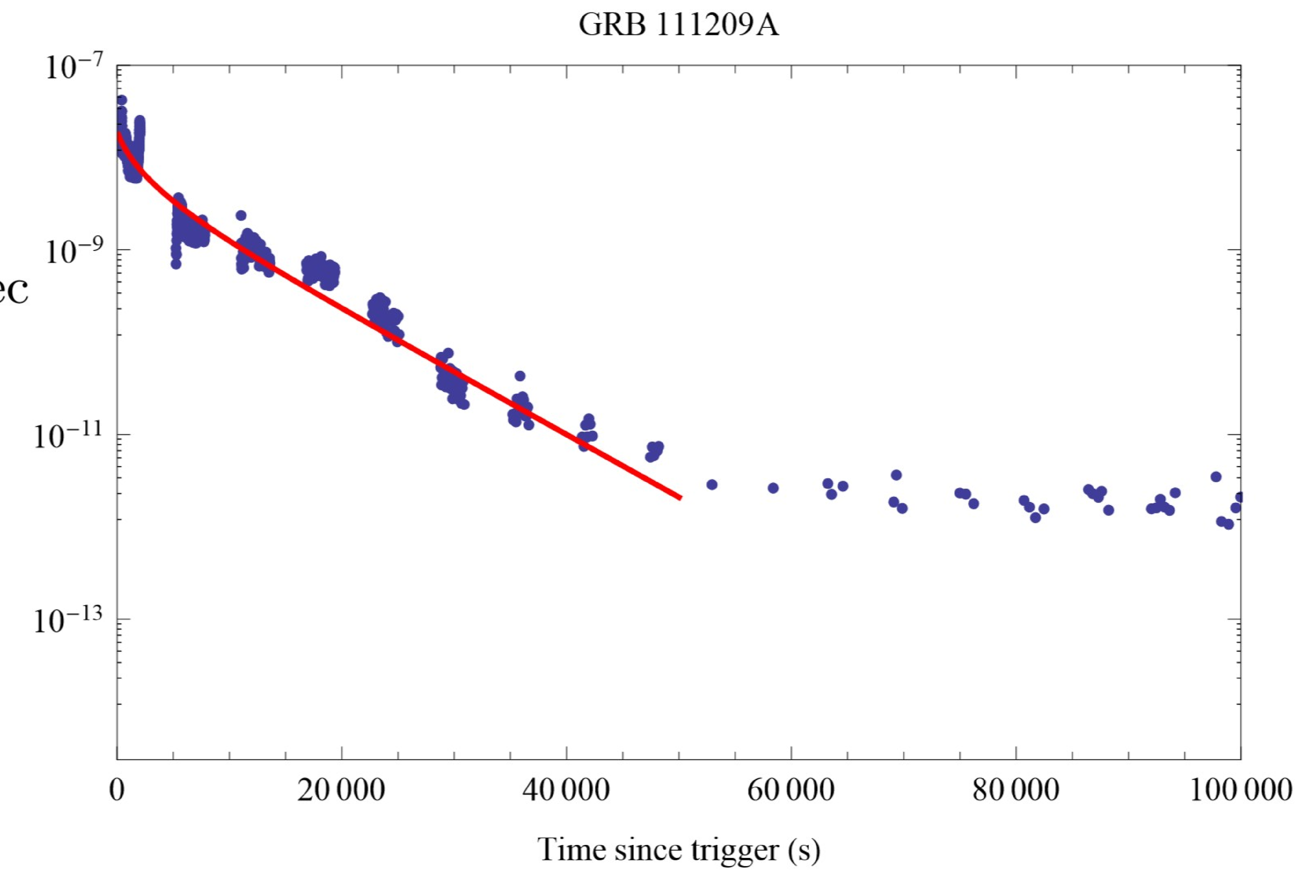

Figure 4. Ultra Long GRB 111209A, the red curve is the theoretical black hole spin down. Log-linear plot, energy flux at 0.3 – 10 keV.

References

1. Blandford R. D. , Znajek R., 1977, MNRAS 179, 433
2. Christodoulou D., Ruffini R., 1971, PhRvD 4, 3552
3. Contopoulos I., Nathanail A., Pugliese D., 2014 ApJ 780, 5
4. Nathanail A., Contopoulos I., 2014, ApJ 788, 186
5. Nathanail A., Contopoulos I., 2015 arxiv: 1504.03906

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