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Observational evidence for black hole spin down in Swift/BAT data of long GRBs

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Abstract. We report on a preliminary matched filtering analysis of light curves of 44 long GRBs randomly selected from the Swift/BAT catalogue. An optimal match is found between a normalized light curve to a template for black hole spin-down against matter at the Inner Most Stable Circular Orbit (ISCO), that includes gravitational wave emissions. Our results confirm earlier findings on the basis of 600 long GRBs light curves of the BATSE/CGRO catalogue.

Keywords : gamma-ray bursts – prompt – lightcurves

1. Introduction

Across an exceptional range in energy, the Transient Universe reveals supernovae, cosmological GRBs, Ultra-High Energy Cosmic Rays (UHECRs) from nearby extragalactic sources with energies up to and above 10^{19} eV (Abraham et al. 2007), and, possibly, an extragalactic < 5 ms radio-burst (Lorimer et al. 2007).

Novel radiation processes may be at work in their mysterious inner engines that, broadly speaking, are either powered by accretion or the spin energy of a compact object. In case of core-collapse supernovae and GRBs, the compact object is believed to be a (proto-)neutron star (PNS) or black hole. It is believed that relatively heavy stars are more likely to produce black holes and, under favorable circumstances such as membership of a binary, their collapse should produce rapidly rotating black holes (Woosley 1993; Paczyński 1998). A number of long GRBs are known to be associated

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with core-collapse supernovae with the possible exception of those with no optical supernova signature, for example the Swift event GRB 060614. Such events might, instead, be produced by mergers that involve rapidly spinning black holes (van Putten 2008).

Of particular interest is the potential of gravitational-wave emission from core-collapse supernovae and long GRBs in view of the upcoming advanced generation of gravitational-wave detectors LIGO, Virgo, the LCGT and ET. Here, a prior extracted from electromagnetic observations on the possibility of a PNS or black hole is useful, given the anticipated distinct signatures in gravitational-waves. Some hyper-energetic events, for instance, cannot be accounted for by the limited spin energy of a PNS (van Putten, Della Valle & Levinson 2011). No such limitation is found for rotating black holes.

Here, we focus on extracting information on the evolution of the inner engine of long gamma-ray bursts (GRBs) by application of matched filtering to light curves from the Swift/BAT catalogue. Our analysis follows the earlier analysis of a sample of 600 randomly selected light curves of long GRBs from the BATSE/CGRO catalogue (van Putten & Gupta 2009), to extract a normalized light curve for comparison with a model template representing black hole spin-down against surrounding high density matter.

In Section 2, we describe our model for long GRBs from rapidly rotating Kerr black holes. In Section 3, we present our matched filtering result for two model templates differentiated for the presence of gravitational radiation. We summarize our findings in Section 4.

2. Long duration GRBs from Kerr black holes

A rotating black hole surrounded by high density matter is a natural outcome of core-collapse of relatively massive stars and mergers of binary neutron stars or a neutron star and a companion black hole. Rotating black holes are *scale-free* and *universal*, i.e., with no particular memory to their formation except to the mass and angular momentum of the progenitor in accord with the no-hair theorem. In contrast, a PNS has a limited mass range of 1.5-2 $M_{\odot}$ with a corresponding limit on its rotational energy. Thus, black holes are universal in ways that PNS are not.

We commonly anticipate that matter is magnetized, whose lowest order component of axisymmetric magnetic flux will form a torus magnetosphere. When the black hole spins rapidly, the inner torus magnetosphere may mediate energy and angular momentum transfer outwards, sweeping up the inner face of the torus into a state of forced turbulence (van Putten 1999) to excite the formation of non-axisymmetric multipole mass-moments by thermal and magnetic pressures (van Putten 2002; Bromberg, Levinson & van Putten 2006). If so, the torus will be luminous in gravitational radiation for the lifetime of rapid spin of the black hole with a contemporaneous output in high-energy emissions produced in the dissipation of an ultra-relativistic baryon-poor jet emanating along the spin-axis (van Putten 2001; van Putten & Levinson 2003).

In this model, therefore, the *GRB light curve is determined by the rate of spin-down of the black hole against surrounding matter.* As a result, the GRB light curve carries an imprint of the state of matter, i.e., its location relative to the inner most stable circular orbit (ISCO) and any dependency thereof on its radiation in lower-energy emission channels, notably, gravitational-waves, MeV-neutrinos and magnetic winds. For this reason, it is of interest to pursue a detailed analysis of the light curves of long GRBs in the time-domain, here by way of matched filtering of a preliminary sample of light curves from the Swift catalogue.

3. Matched filtering on the Swift catalogue

Long GRBs represent the complete life-cycle of a relativistic inner engine (e.g. Piran & Sari 1998). Their diversity includes a most variable event GRB 990510 and least variable events such as GRB 970508 and GRB 980425. In general, variability and luminosity of GRBs are correlated (Reichert et al. 2001). By causality, their short time-scale variability reflects intermittent behavior of a long lived inner engine (Piran & Sari 1998).

We searched for the presence of a viscous time-scale representing black hole spin-down in the 600 randomly selected long GRBs light-curves in the BATSE catalogue using matched filtering to extract a normalized light curve for comparison with a model template (van Putten & Gupta 2009). Fig. 1 of van Putten & Gupta (2009) shows a comparison of the template with the normalized light curves of two notable low-variable, low-luminosity events (Reichert et al. 2001). Because these single Fast Rise Exponential Decay (FRED)-like events are rare, we developed a normalized light curve (nLC) representing an average of individually normalized light curves in duration and count rates following matched filtering to a template. The match of the nLC to the template can be used to infer a relative likelihood for the underlying model to be meaningful. In this process, all intermediate time scale variabilities in the ensemble of light curves are filtered out.

Fig. 1 shows the results of our analysis applied to 44 randomly selected Swift/BAT light curves of long GRBs on the basis of two models A and B, representing black hole spin-down against surrounding matter at the Inner Most Stable Circular Orbit (ISCO) (model A) and matter further out, where the angular velocity is one-half that of the black hole (model B). Here, model A includes gravitational radiation, whereas model B is dominated by an energy output in MeV-neutrinos. The results show that the discrepancy, measured in standard deviation of the residual between the nLC and its generating model template, is about one-half for model A compared to model B. The results are completely consistent with our results from van Putten & Gupta (2009).

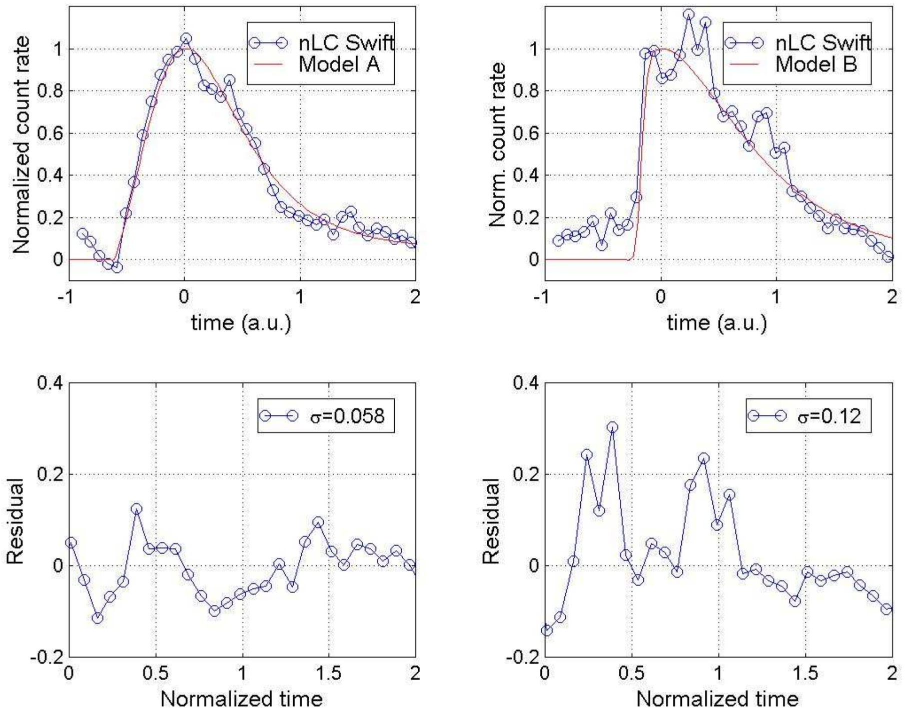

Figure 1. Matched filtering analysis of 44 light curves of long GRBs detected by Swift, following an earlier analysis of light curves of long GRBs from the BATSE catalogue in van Putten & Gupta (2009). The fitting of the normalized light curve (nLC) to model template A is about twice as good as that of the nLC to model B, consistent with the results obtained for the BATSE catalogue.

4. Conclusion

We report on a preliminary matched filtering analysis of light curves of long GRBs from the Swift/BAT catalogue. Our findings on a preferred match for black hole spin-down against matter at the ISCO is in good agreement with our earlier results by the same analysis of light curves of long GRBs from the BATSE catalogue.

Our light curve analysis shows that the inner engines of long GRBs are scale-free and universal, two properties that are characteristic for rotating black holes but not PNS.

Acknowledgments

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