A SIGNIFICANT PROBLEM WITH USING THE AMATI RELATION FOR COSMOLOGICAL PURPOSES

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ABSTRACT

We consider the distribution of many samples of gamma-ray bursts when plotted in a diagram with their bolometric fluence (S_{bolo}) versus the observed photon energy of peak spectral flux ($E_{peak,obs}$). In this diagram, all bursts that obey the Amati relation (a luminosity relation where the total burst energy has a power-law relation to $E_{peak,obs}$) must lie above some limiting line, although observational scatter is expected to be substantial. We confirm that early bursts with spectroscopic redshifts are consistent with this Amati limit. But we find that the bursts from *BATSE*, *Swift*, *Suzaku*, and Konus are all greatly in violation of the Amati limit, and this is true whether or not the bursts have measured spectroscopic redshifts. That is, the Amati relation has definitely failed. In the S_{bolo}–$E_{peak,obs}$ diagram, we find that every satellite has a greatly different distribution. This requires that selection effects are dominating these distributions, which we quantitatively identify. For detector selections, the trigger threshold and the threshold for the burst to obtain a measured $E_{peak,obs}$ combine to make a diagonal cutoff with the position of this cutoff varying greatly detector to detector. For selection effects due to the intrinsic properties of the burst population, the distribution of $E_{peak,obs}$ makes bursts with low and high values rare, while the fluence distribution makes bright bursts relatively uncommon. For a detector with a high threshold, the combination of these selection effects serves to allow only bursts within a region along the Amati limit line to be measured, and these bursts will then appear to follow an Amati relation. Therefore, the Amati relation is an artifact of selection effects within the burst population and the detector. As such, the Amati relation should not be used for cosmological tasks. This failure of the Amati relation is in no way prejudicial against the other luminosity relations.

BACKGROUND INFORMATION

A now famous test for GRB luminosity relations is the so-called "Nakar and Piran" test (i.e. Nakar and Piran, 2005). In this work, Nakar and Piran developed a test specifically for the Amati relation, the beauty of the test being that the redshift of bursts were not needed. This test has since been generalized in several independent investigations (e.g. Band & Preece 2005; Schaefer & Collazzi 2007; Goldstein et al. 2010). The essence of the test involves combining the Amati relation with the inverse square law for to eliminate $E_{\gamma,iso}$ as demonstrated below.

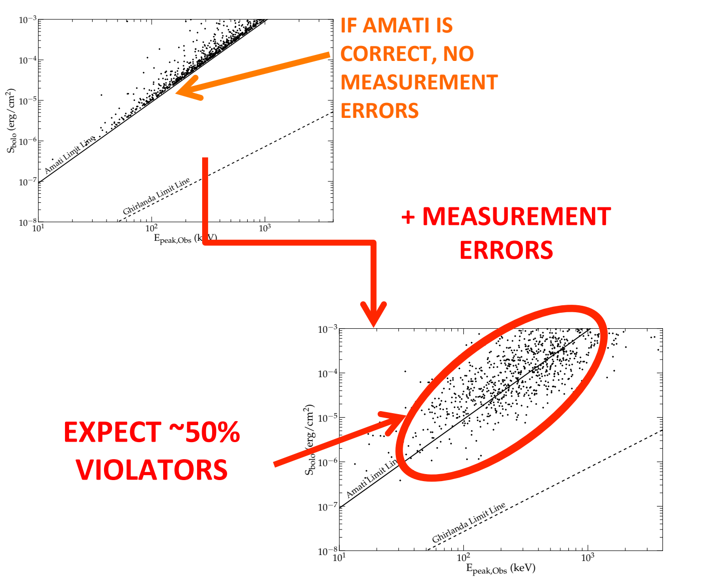
$$E_{\gamma,iso} = A\left[E_p\left(1+z\right)\right]^{\eta} \quad + \quad E_{\gamma,iso} = \frac{4\pi d_L^2 S_{bolo}}{1+z} \quad = \quad \frac{E_{peak}^{\eta}}{S_{bolo}} = \frac{4\pi d_L^2}{(1+z)^{\eta+1}A}$$

Here, A is a constant, $E_{\gamma,iso}$ is the isotropic gamma-ray energy, d_L is the luminosity distance as derived with the concordance cosmology, S_{bolo} is the bolometric fluence, and *z* is the redshift of the burst. As the distance rises, d_L^2 gets larger and $(1+z)^{-(\eta+1)}$ gets smaller which gives a maximum value for the right side. This creates a peak in the function at ***z* ~ 3.6**. This creates a maximum value for which we can test the Amati relation even for bursts without redshifts. This test has been subsequently used to show a maximum for the Ghirlanda relation (e.g. Band & Preece 2005), and shown to not have maximum for the other luminosity relations (e.g. Schaefer & Collazzi 2007), however, recent results suggest that the Ep – L luminosity relation may have a turnover for even a slightly different index (Goldstein et al. 2012).

There has been wide disagreement in the literature over how many bursts fail this test. These numbers have ranged from an ***expected*** number of violators (~44%, e.g. Nakar and Piran 2005; Schaefer & Collazzi 2007) to >80% (e.g. Band & Preece 2005; Goldstein et al. 2010). With the differences in the violator fraction and the interpretation, we have a core dilemma for the Amati relation, and the understanding of these differences is the core of this project.

In this project, we first start by presenting and explaining the Nakar and Piran test, which following Band & Preece (2005) we extend by considering bursts in a plot of their S_{bolo} versus $E_{peak,obs}$. In addition, we explain why a certain amount of violators are expected, and what the observed distributions of bursts tell us to expect. We follow this by showing gathered data from various detectors and providing a comprehensive examination of how each detector's data performs under the Nakar and Piran test. Following this, we provide an explanation for why the vast majority of the data sets have too many violators of the Amati limit, and therefore the Amati relation is not good as a luminosity relation. Finally, we examine several sources of systematic offsets that are actually the cause of the Amati relation in the first place, which only further condemns the Amati relation's usefulness.

HOW MANY VIOLATORS TO EXPECT



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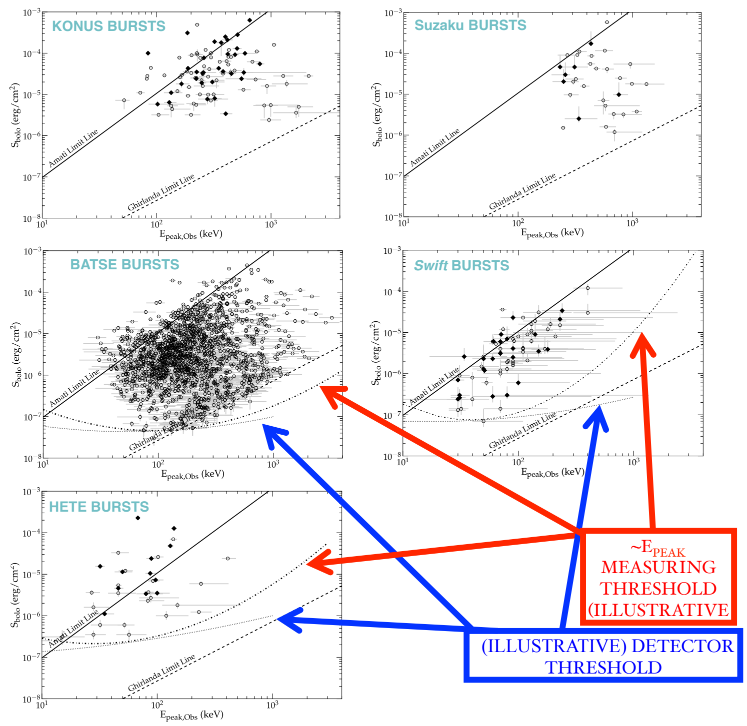
THE S_{bolo} – E_{peak} DIAGRAM

Below is a visualization of the Nakar and Piran test via the S_{bolo} – E_{peak} diagram (e.g. Goldstein et al. 2010). In this, the solid line represents the Amati limit for the test, and the dashed line represents the Ghirlanda limit for the test. The reason for plotting the bursts this way is to visualize how we are observing gamma-ray bursts detector by detector. This is to discover any kinds of systematic effects that exist. Finally, it is important to realize that any points plotted ABOVE the limit lines agree with the relation (see above), and therefore *not a violator of the test*. Filled circles are bursts that have associated spectroscopic redshifts.



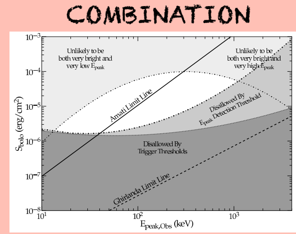
THE AMATI RELATION IS THE RESULT OF A COMBINATION OF SELECTION EFFECTS

The S_{bolo}–$E_{peak,obs}$ diagram has two limit lines, where bursts cannot be below that line if the Amati or Ghirlanda relation holds. Actually, with the fairly large total uncertainties, substantially larger than the simple measurement errors quoted in the literature, we can expect nearly half of the bursts to be scattered below the Amati limit line. So a simple test of the Amati relation is whether the *average* burst falls below the Amati limit. (This is similar to the original test proposed by Nakar & Piran, except that agreement with the Amati relation corresponds to about 40% violators.) We apply this test to many burst samples. The samples of early bursts with spectroscopic redshifts (as originally used to calibrate the Amati relation) pass this test, as does the sample of HETE bursts (even though the scatter about the Amati relation is unusably large). All other satellites have a large fraction of violators far below the Amati limit line. This is true whether we look at bursts with or without measured spectroscopic redshifts. This constitutes a proof that the Amati relation could possibly apply, at best, to ***only a small and unrecognizable*** fraction of GRBs. Indeed, the wide variations in distribution from detector to detector constitute a proof that selection effects must dominate the Amati relation.

We find that four selection effects restrict the distribution on all sides. The best-known detector selection effect is the trigger threshold, which produces a roughly horizontal and fuzzy cutoff. A more subtle and more restrictive selection effect is that for an $E_{peak,obs}$ value to be reported, the burst must be brighter than some threshold, with this threshold rising fast with increasing $E_{peak,obs}$. These two detector selection effects will cut out bursts that are some combination of faint and hard, with these effects changing greatly from detector to detector. The third and fourth selection effects operate to restrict the burst population as it appears in the sky. The third selection effect is that bursts have a log-normal distribution of $E_{peak,obs}$ with the mean value shifting to lower values for faint bursts. This effect will also reduce the number of detectable bursts that are faint and hard. The fourth selection effect is that bright bursts are much rarer than faint bursts, as quantified by the usual power-law log[N (> P)] − log[P] curve. The combination of the third and fourth effects means that the bright and soft bursts are doubly rare, so that the upper left side of the S_{bolo} – $E_{peak,obs}$ diagram will be empty.

For a detector with a range of spectral sensitivity and a low detection threshold, the distribution in the S_{bolo} – $E_{peak,obs}$ diagram will extend relatively low, with a large fraction of violators below the Amati limit (like for BATSE). For a detector with a low energy range of sensitivity and a low detection threshold, the cutoff will be a diagonal line just below the Amati limit. When combined with the paucity of bright-soft bursts in the GRB population (i.e., those above the Amati limit line), we have a combined selection effect that picks out bursts near the Amati limit. Such a burst sample would then appear to follow the Amati relation. Thus, the very strong selection effects for the early bursts with spectroscopic redshifts will create the Amati relation without any need for a physical connection between the $E_{peak,obs}$ and S_{bolo}. That is, the Amati relation is not real, but its appearance in some data sets is simply a result of various selection effects by the detectors and within the GRB population. Recently, Kocevski (2011) used a simulated burst population and also found the Amati relation to be heavily dependent on selection effects. In this way, we have two results that nicely complement each other in showing that the Amati relation is the result of selection effects.

ILLUSTRATION OF THE EFFECTS IN COMBINATION



With the correct conditions, bursts which agree with the Amati relation are all that are visible!

THE 3-σ ARGUMENT

The issue has been raised in recent tests (e.g. Ghirlanda 2011) that what we are seeing in these failures is just the scatter about a relation which is ever changing with new bursts every day. The primary argument is that the Nakar and Piran test limit should also account for the 3-sigma scatter of the data around the limit. As a result, the Amati limit would be considerably higher. There are a variety of problems with this argument. The first of which being that there is already an allowance made for the Amati relation to have up to 40% violators and not be considered as failing for the data set. Therefore, the scatters are already being accounted for, and it is overkill to use such a generous limit to perform the test. If the test is done in this manner, no longer can allowances be made for any violators (or, more precisely, there needs to be less than 0.3% violators). Even by the groups own tests, there are violators on the order of a few percent, depending on the test. This is an unacceptable violator rate considering they are violating a limit from the three-sigma deviation from the model. Finally, another question that arises is that the bursts we see all seem to be biased in one direction. If we were seeing the result of measurement scatter about the Amati relation, we should expect to see an equal fraction of bursts well above the limit line. Instead, we see that for almost all data sets, the bursts are systematically in one direction from the limit. Therefore, this argument does not reflect what we are seeing in the observations.