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**Review of Ph.D. thesis by Roberta Del Vecchio:
"New study of afterglow light curves in gamma ray bursts"**

Ph.D. thesis of Roberta Del Vecchio contains 7 chapters, bibliography, and 3 additional sections with supplementary information. All material, in English, is enclosed in 407 pages of very nicely formatted book.

The thesis is dedicated to study of light curves of gamma ray bursts. In particular, main focus is placed on analysis of late time phase of gamma ray burst afterglows showing in many cases a plateau followed by a rapid decline in X-rays. The main goal of the thesis is to establish the relation (or lack thereof) between the level of X-ray emission at the plateau phase and steepness of the declining part of light curve and to find relation based on light curve parameters that would allow to estimate gamma ray burst luminosity. Both issues are approached in phenomenological manner and both relations are constructed from the analysis of rich observational data delivered by SWIFT mission. The first relation is intended to help to understand the physics of late time emission of gamma ray bursts, while the second relation is to utilize gamma ray bursts as standard candles that would allow distance measurements to large redshifts (up to $z \approx 9$). Both issues are important part of modern astrophysics and any progress may potentially benefit many areas of research from high energy physics to classical astronomy.

At first, I will discuss the overall content and quality of thesis chapters, giving my main criticism and praise. Then I will follow with specific and detailed comments on the shortcomings of some arguments and weak points of this thesis.

First chapter, called "Introduction" (22 pages), contains a regular style introduction to the thesis topic, in which Ph.D. candidate gives overall description of gamma ray bursts and historical outline of progress. This chapter is rather well organized and it includes majority of the basic and necessary information about observations of gamma ray bursts. It is a bit too shallow to give comprehensive introduction to various known relations and extensive phenomenology of gamma ray bursts. However, this is covered in Chapter 3 and 4.

Second chapter, called "GRB models" (22 pages), continues with the introduction. In this chapter, various GRB models are presented from different perspectives. As

the first chapter covers basic observational properties of gamma ray bursts, this one covers theoretical aspects of this research field. Both, first and second chapter, contain also some information on supernovae and gravitational-wave sources. I do not think this is necessary in this thesis. This additional information is presented in somewhat chaotic and confusing manner and does not add value to the overall line of the thesis.

Third chapter, called "The GRB correlations among prompt parameters" (49 pages), contains a published review article and presents the current state of gamma ray burst phenomenology in context of various correlations observed for prompt emission of gamma ray bursts. This review is based on a collection of 267 research papers. In this part Ph.D. candidate demonstrates knowledge of the research field and technical skills in paper preparation. The Ph.D. candidate is the second author of this review, and she has collected relevant literature for this review along with some work on figure preparation and text. Although these are important skills for any Ph.D. candidate, they do not indicate the scientific strengths and weaknesses of the candidate. This chapter may be treated as an extended introduction to Ph.D. research project that is contained in chapters 5 and 6. In this context, the introduction is already becoming rather lengthy (running to total of 93 pages at this point). Sections 3.3.10, 3.3.11, 3.3.12 in this chapter contain results of a study in which Ph.D. candidate was not a contributing author. Yet, 11 pages from this study are included in the Ph.D. thesis. This inclusion is based on claims that the candidate was involved in some discussions leading to publication of this study. This is unacceptable. Ph.D. candidate is to present her own original research, or otherwise synthesize introduction or supporting information from other papers or studies and not simply to attach them to her thesis.

Fourth chapter, called "Correlations among afterglow and prompt-afterglow parameters" (55 pages), contains another published review article. Ph.D. candidate was a second author and was responsible for paper selection to be included in this review, along with some help on figure, table and text preparation. This is another extension to the introduction, as it does not include any original research by Ph.D. candidate. At this point the length of the total combined introduction (148 pages) becomes unreasonable. This also seems counter-productive shadowing the main results of the thesis that by comparison take only 19 pages (chapters 5 and 6). Ph.D. candidate should at the minimum learn how to synthesize data from the above two reviews and be able to present a good (and self-restricted and self-written) introduction to her own research.

Fifth chapter, called "Selection Effects in Gamma Ray Burst Correlations: Consequences on the Ratio between Gamma Ray Burst and Star Formation Rates" (6 pages), contains results from the published research paper, in which Ph.D. candidate was a second author. This is the first chapter in which Ph.D. candidate contributed science; namely estimate of selection biases affecting luminosity and time measurements in SWIFT observations of gamma ray bursts. The description is not exhaustive and leaves some details unclear (see detailed points). This is somewhat surprising as the candidate dedicated about 150 pages on prior introduction, and here there are only 6 pages dedicated to the science performed by the candidate. What is really missing in this section is a part where significance of the results is discussed. Since

the selection effects are found not to differ significantly from earlier studies what does it mean? Have these results give/do not give any support to some physical (which?) models of GRBs? In summary, in this chapter the candidate shown a technical skills in fitting the data and identifying trends, but it is not clear whether the candidate understands a broader context of the conducted research.

Sixth chapter, called "Study of the decaying part of the X-ray afterglow" (13 pages), contains results from the published research paper, in which Ph.D. candidate was a first author. This chapter contains the major scientific result of this thesis and it is clear that this research was performed by Ph.D. candidate herself. The chapter is neatly constructed, transparent and gives very clear results. The intended aim is two-fold: through an estimate of a correlation between gamma ray burst plateau X-ray luminosity and slope of the subsequent light curve decline to (1) probe the properties of medium surrounding burst and thus to constrain the progenitor model and to (2) provide means to use gamma ray bursts as standard candles. There are several technical difficulties with the presentations (see detailed points), but overall message is clear. The only point that I find troubling is the fundamental issue whether gamma ray bursts can be used as standard candles at all? This is due to the fact that large luminosity variations (over many orders of magnitude) may, and most likely do, originate from various explosion engine properties, different viewing angles and various types of surrounding medium. As it happens, this study seem to point to such an end. However, the candidate presents the results in rather opposite (optimistic) manner leading toward the conclusion that more work is needed to deliver the working relation that will make gamma ray bursts into standard candles. Whatever the answer is, more work of this type (incremental progress) is clearly needed to resolve this debate.

Seventh chapter, called "Summary and final remarks" (2 pages), contains general summary of the thesis. Detailed outline of the future progress of this line of work could have been included in this chapter.

Detailed and technical comments on the thesis:

1. **Abstract:** L_{LT} not clear what it is.
2. **Intro:** first statement that GRBs release the same energy (isotropic energy given: $10^{48} - 10^{55}$ erg) as Sun in its lifetime (10^{50} erg) may not be correct as GRBs are not isotropic.
3. **Intro:** language is not precise in places, for example:

"Nevertheless, this discovery has already produced several scenarios to describe how a BHBH merger can become a GRB: Li et al. (2016) proposed that in a dense medium (see also Loeb 2016) GRBs are created by a BH via accretion of a mass = $105M_{\text{sun}}$, or, as described by Perna et al. (2016), an SN explosion of a two-high mass, low metallicity stars and the matter emitted can produce an accretion disk and following an SGRB."

matter is not emitted but ejected.

4. **Intro:** The discussion of GW150914 in context of gamma-ray emission shows only one side of the equation: possible connection of this merger to gamma ray bursts. However, it was shown (and it is now accepted in the community) that this two events (LIGO merger and Fermi detection) were not connected: Greiner et al. 2016, ApJ 827, L38
5. **Sec.1.1.1:** Fig.1.1.1 (adopted from literature) is set to demonstrate GRB light curve components, but these components are not identified nor described. Fig.1.1.2 (adopted from literature) has no units on vertical axis. And the units are not given in caption nor in text.
6. **Sec.1.1.2:** "Around one day after the burst, the brightness of the optical afterglow phase is about 19 – 20 mag." This has no meaning as GRBs are observed in very broad redshift (distance) range: $z = 0.1 - 9$, so apparent magnitude must change... or is it supposed to be an absolute magnitude?
7. **Sec.1.1.4:** T_{90} is not defined for readers.
8. **Sec.2.4.1:** "In the collapsar model three constraints are present for a star to produce a GRB: (1) the mass of the star needs to be large (at least 30 solar masses on the main sequence) to produce a BH, (2) to generate a torus able to emit jet, the rotation of the star has to be high, (3) low metallicity of the star is requested to remove its hydrogen layer, so the surface can be reached from the jets."
 Actually mass of a star may be as low as 15-20 Msun to produce a BH according to the latest models.
 Low metallicity is not needed as majority of massive stars (> 50%) reside in binary systems and close interactions with companion may very easily remove H-rich envelope.
9. **Sec.2.4.2:** Description of progenitor models is rather chaotic and lacking depth. Supranova model is first claimed to produce a very luminous SN remnant: "A supranova is a very luminous SN remnant ($\sim 10 \times$ SN luminosity) obtained from the collapse of a massive star (few Msun)."
 while later it is claimed that SGRB produced by supranova is not associated with SN: "Even if this model appears similar to the collapsar model, they differ for the following reason: in the collapsar model an SN bump is present as a characteristic feature of the afterglow light curve, while in the supranova model it is absent."

Another example comes in a second paragraph describing NS-helium systems: this entire paragraph is incomprehensive. Final sentences of this paragraph really sum this up: "They also investigated the merging NShelium star system and concluded that to have the highest formation rate of merging binary systems the helium core in the NShelium star system is relevant. In fact, the presence of a NS merging with its helium companion star leads to a formation rate of merging binary systems one order of magnitude smaller. Nevertheless, the

formation rate of the NShelium star merging system is sufficient to allow the formation of an SGRB."

10. **Sec.3.1:** Number of small errors and inconsistencies. For example:

"GWs were not observed until 2016 Abbott et al. (2016b), because they are not..." GWs were detected on Sep 14, 2015. this is a major discovery awarded a Noble prize.

"GRBs are good candidates for standard candles because they would allow for an extension of the Hubble Diagram (HD) an order of magnitude further than SNe Ia. In fact, GRBs are detected until redshift $z = 9.4$ (Cucchiara et al., 2011), while SNe Ia until $z = 2.26$..."

This is factor of 4.2 increase, and not an order of magnitude. And something is not a "good candidate" just by the virtue of happening at large redshifts.

"the isotropic energy of GRBs extends over 8 orders of magnitude (Lin et al., 2015), but these phenomena can trace the cosmic SFR (Totani, 1997; Porciani and Madau, 2001; Bromm and Loeb, 2006; Kistler et al., 2009; de Souza et al., 2011) and report on the intergalactic medium physics..."

followed by:

"Therefore, GRB correlations are potential extremely powerful tools to explain the physics of GRBs, define a good distance indicator, and examine the universe at high redshift (Salvaterra, 2015)."

I do not see how objects that show 8 orders of magnitude difference in (isotropic) luminosity, and with unknown correction factors to get intrinsic (beamed) luminosity can "define a good distance indicator". This is an empty statement not backed up by any arguments in the text.

11. **Fig.3.3.12:** Labels on vertical scale are unreadable. It applies to some other figures as well (e.g., Fig.4.2.10 or Fig.5.2.2).

12. **Sec.5.2:** "It is shown that the SFR obtained by Li (2008) (see Fig.5.2.1) describes the sample better than the models by Robertson and Ellis (2012) and Kistler et al. (2013),..."

Where is it shown? Definitely not in Figure 5.2.1. What is the SFR obtained by Li 2008? Why is it not shown and compared to observational data on star formation (e.g., Madau-type plot)? Same figure is claimed (caption) to show GRB rate density (in what units?), while the label on vertical axis says "N" with no unit (which usually indicates number of events per bin).

13. **Fig.5.2.2:** Unreadable: labels too small. Line colors are not defined, blue points changing from panel to panel not defined.
14. **Sec.6.3:** The selection of light curves (only well-behaved ones), as well as parts of light curves (clean power-laws) for fitting and estimate of $\alpha_{X,a}$ seems to be

rather subjective and made "by eye". How one could improve on this part of analysis? Can any science be derived from rejected GRB light curves?

15. **Sec.6.4:** "It should be noted that the large scatter of the GRB luminosity distribution cannot be due only to the fitting method used for its derivation. Significant contribution to this scatter must result from the very nature of the GRB sources, possibly modified by the explosion geometry."

And Fig.6.4.1. shows about 8 orders of magnitude luminosity scatter at the same power-law slope index. Why does the candidate think that GRBs can be made into standard candles? Is not the opposite more likely?

16. **Sec.6.4:** 3 subpopulations of GRBs differentiated by luminosity are presented in Fig.6.4.2 (cumulative plot). However, there is no fit ($L_{X,a}$ as a function of $\alpha_{X,a}$) given for these subpopulations so one can not readily judge how shallow (or weak) are correlations between luminosity and the slope for these subpopulations. The fit is given only for overall sample in text and shown as red line in Fig.6.4.1: where it is clearly visible how weak is the dependence of luminosity on the slope.
17. **Sec.6.5.1:** This section gives a hint of what could be learned from measuring luminosity-slope correlation. These remarks lend basic support for this study. However, the conclusions presented in this section leave reader unconvinced that anything was learned. Why clear interpretation/connection is missing? In other words, it is not clearly stated what type of medium surrounding GRB (and thus what type of progenitor) is favored by the estimated here dependence (0.3 – 0.4) of luminosity-slope relation.
18. **Sec.6.5.2:** The major aim of this section is to present a way to use the calculated luminosity-slope correlation to estimate distance to GRBs. This is calibrated at slope $\alpha = 1.4$. Inspection of Fig.6.4.7 shows that luminosity scatter of GRBs at this slope is about 3 orders of magnitude; this would introduce large error on distance estimate. How big are largest distance errors expected from the proposed here toy model? What could be done to improve on this model?

In conclusion, despite a number of small errors and inconsistencies, the submitted Ph.D. thesis by Roberta Del Vecchio contains scientifically sound and original results, and therefore it fulfills all official and customary requirements of Ph.D. dissertations. I recommend this thesis for a public defense.

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