Gamma Ray Burst the most Explosive Phenomena in the Universe

Dr. Maria Giovanna Dainotti

NAOJ, DIVISION OF SCIENCE, Tokyo
Sokendai University, Japan,
SPACE SCIENCE INSTITUTE (Colorado, USA)

Fulbright Visiting Scholar Lectures Puerto Rico, 29th January 2022

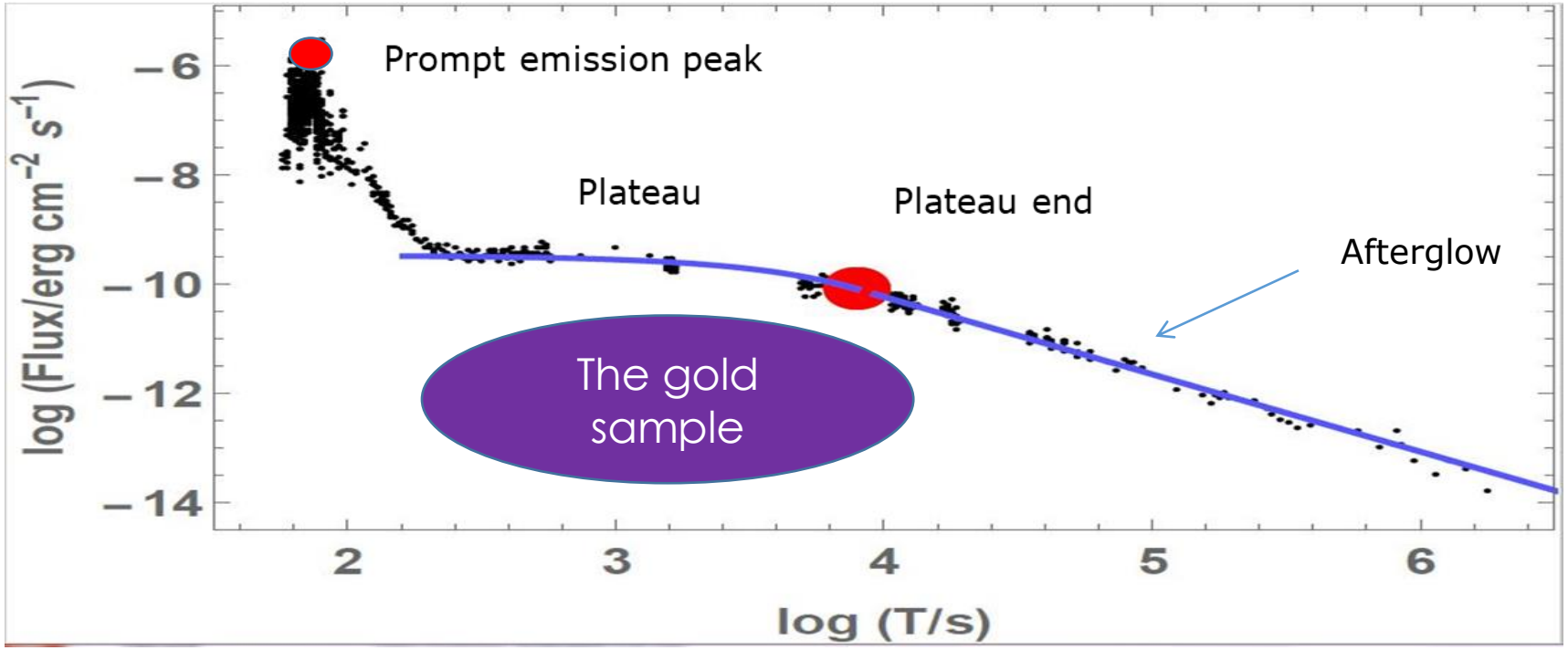
What are GRBs?

Gamma-Ray Bursts: Explosion of massive stars or merging of two neutron stars

Extragalatic objects: furthest GRBs observed z ~ 9.4 – 13.14 billions of light-years.

GRB phenomenology and their history

- **Flashes of high energy photons in the sky (typical duration is few seconds). Discovered by the Vela Satellites in 1967 by chance.**
- **Extremely energetic and short: the greatest amount of energy released in a short time (not considering the Big Bang).**
- **X-rays and optical and radio radiation observed after days/months (afterglows), distinct from the main γ-ray events (the prompt emission).**
- **Observed spectrum non thermal.**
- **GRBs are important for their energy emission mechanisms.**



Important features of a well-sampled GRB light curve observed by Burst Alert Telescope+ X-Ray Telescope +Swift (2004-ongoing). The blue line is the phenomenological Willingale model.

Why are GRBs potential cosmological tools?

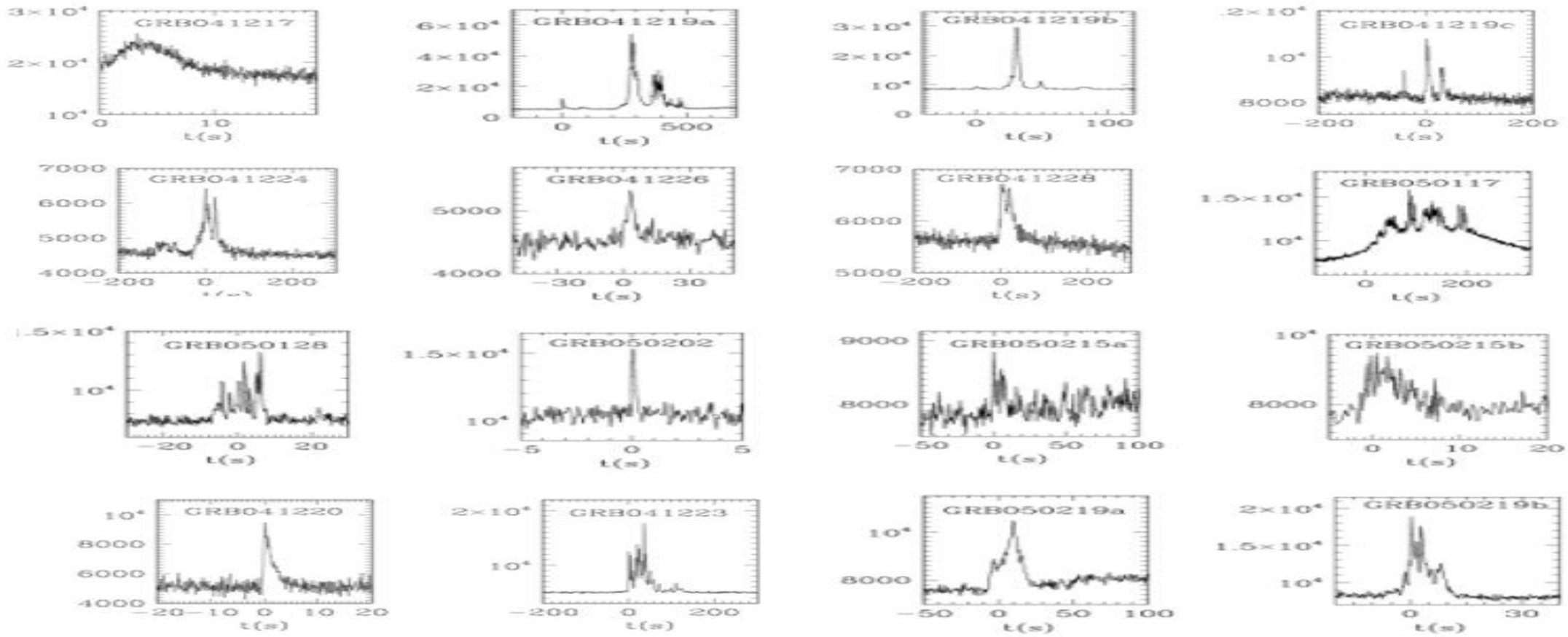
Because They…

- Can be probes of the early evolution of the Universe.
- Are observed beyond the epoch of reionization.
- Allow us to investigate Pop III stars.
- Allow us to track the star formation.
- Are much more distant than SN Ia (z=2.26) and quasars (z=7.54).

But They…

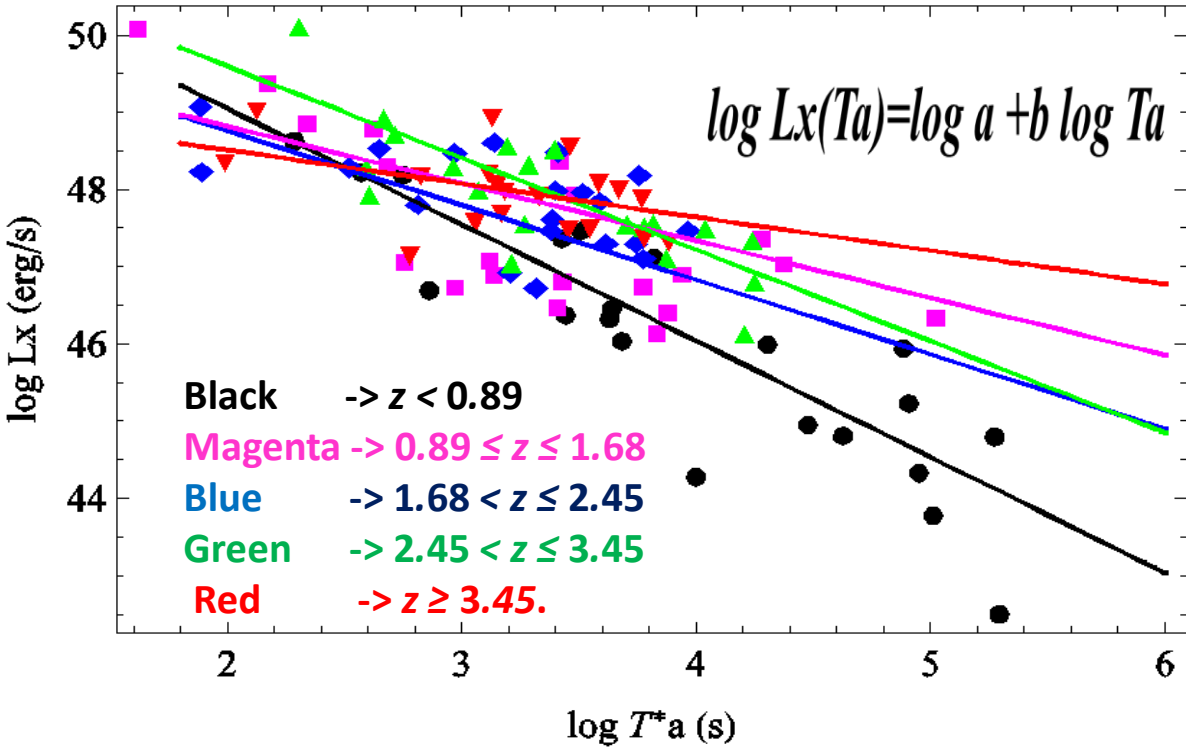
- Don't seem to be standard candles with their isotropic prompt luminosities spanning over 8 order of magnitudes.

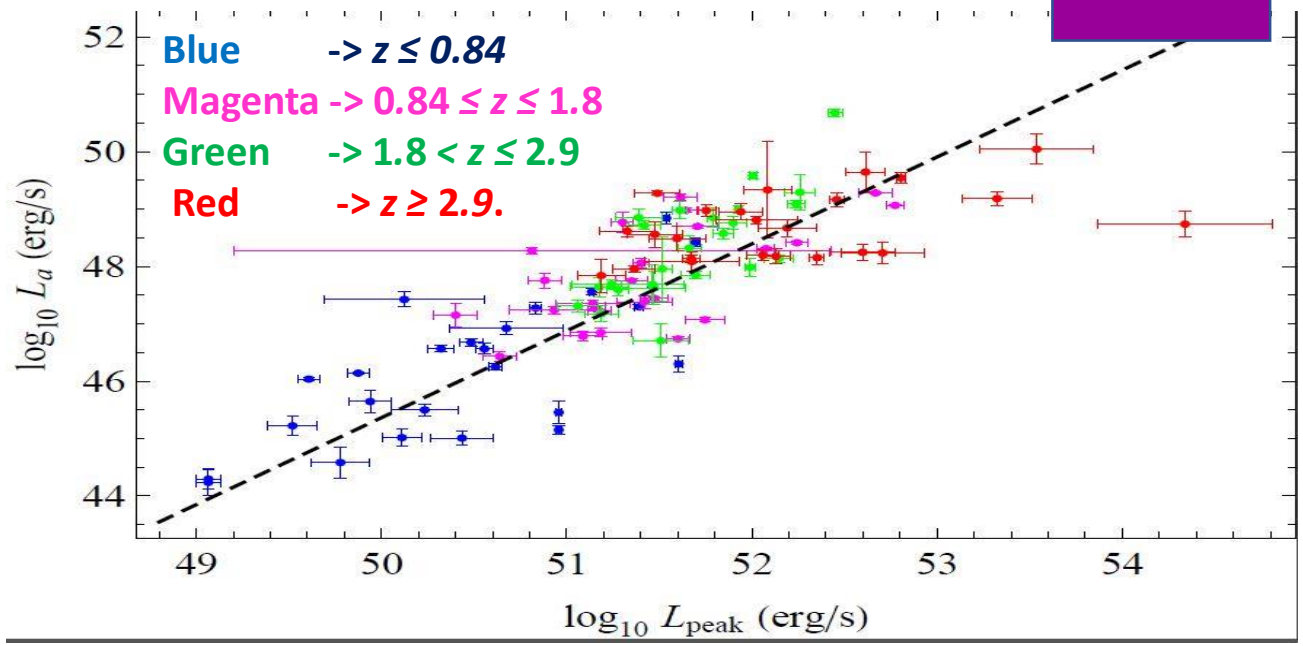
For 20 years, we've been struggling: how to use GRBs as standard candles?
Challenge: Light curves vary widely - "if you've seen one GRB, you've seen one GRB" -



Swift lightcurves taken from the Swift repository

Possible reliable candidates are the $L_X - T^*_a$ and Lpeak-La correlations





Log Lx(Ta)= log A +B log Lpeak

b=-1.0 -> Energy reservoir of the plateau is constant

La-Ta correlation first discovered by **Dainotti, et al. (2008), MNRAS, 391, L 79D**, later updated by **Dainotti et al. (2010), ApJL, 722, L 215; Dainotti et al. (2011a), ApJ, 730, 135; Dainotti et al. (2015a), ApJ, 800, 1, 31. The La-Lpeak first discovered by Dainotti et al., MNRAS, 2011b, 418, 2202.**

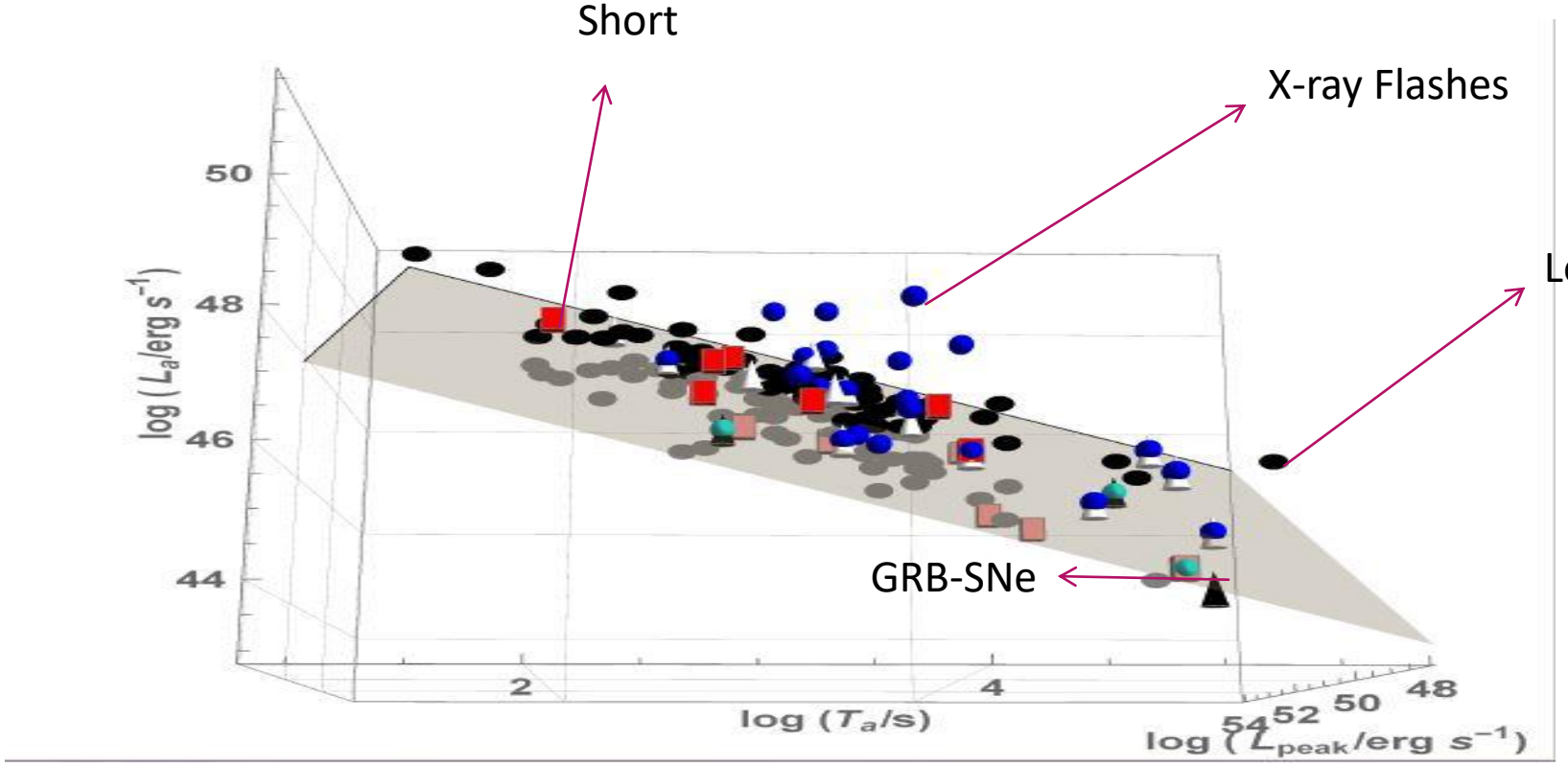
To account for selection biases **Dainotti et al. 2013, ApJ, 774, 157 and Dainotti et al. 2015b, MNRAS, 451, 4** showed that both **these correlations are intrinsic to GRB physics and not to selection biases.**

AN EXTENSION OF THE LX-TA AND LX-LPEAK CORRELATIONS GIVEN THEIR INTRINSIC NATURE

Press release by NASA:
https://swift.gsfc.nasa.gov/news/2016/grbs_std_candles.html
Mention in Scientific American, Stanford highlight of 2016, INAF Blogs, UNAM gaceta, and many online newspapers took the news.

Dainotti, Postnikov, Hernandez, Ostrowski 2016, ApJL, 825L, 20

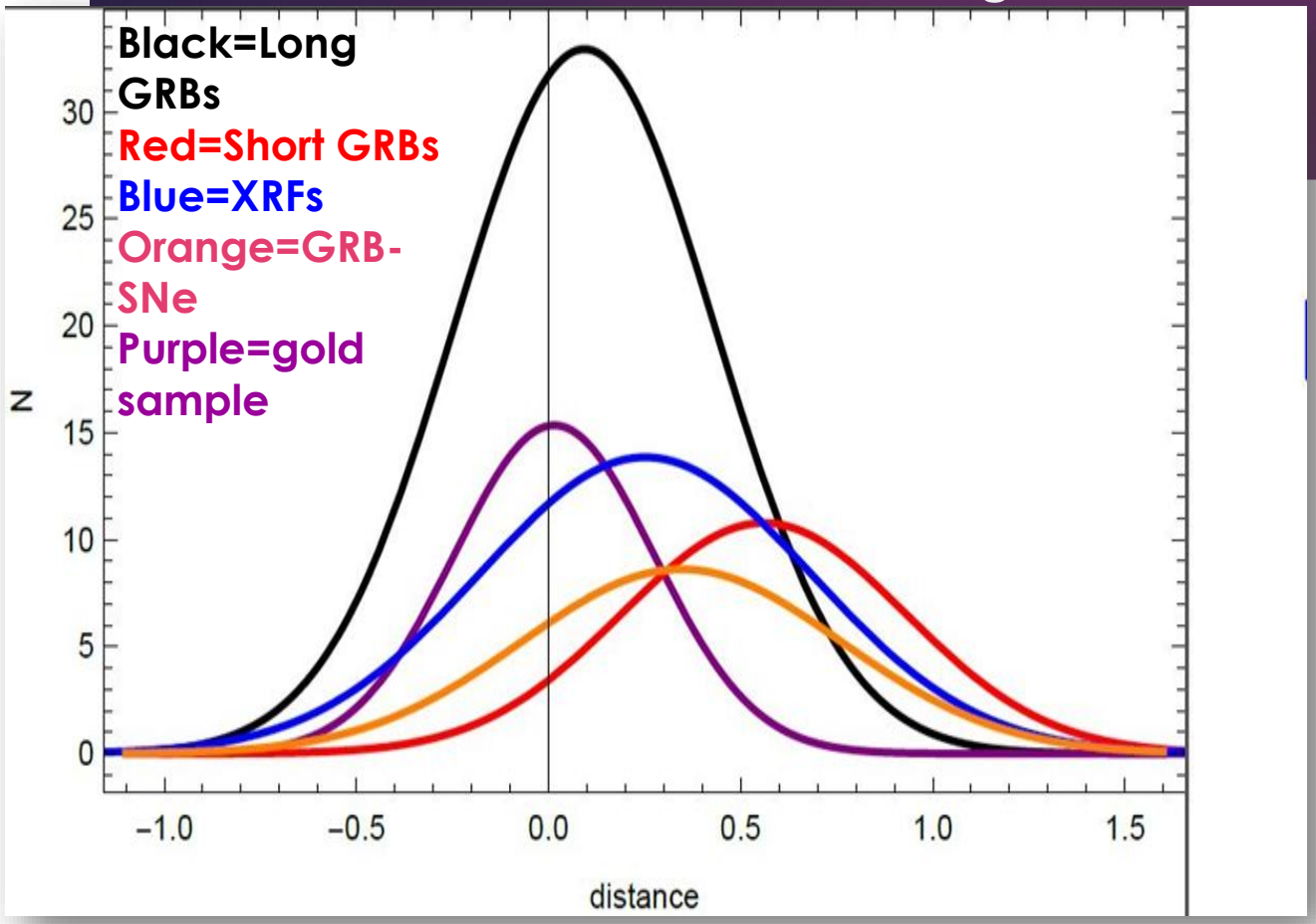
- the 3D Lpeak-Lx-Ta correlation **is intrinsic** and it has a reduced scatter, σint of 24 %.



Distance from the planes

Total sample of 184 GRBs

Dainotti, Hernandez, Postnikov, Nagataki, Obrien, Willingale, Striegel, 2017, ApJ, 848, 88



the gold sample fundamental plane is a reference (placed in 0). The gold sample has the smallest scatter.

Press releases by INAF, Nature-Index, a research highlight at Stanford, and Le Scienze (Scientific American in Italian): tinyurl.com/22fjy2ak, tinyurl.com/3dy26pkv

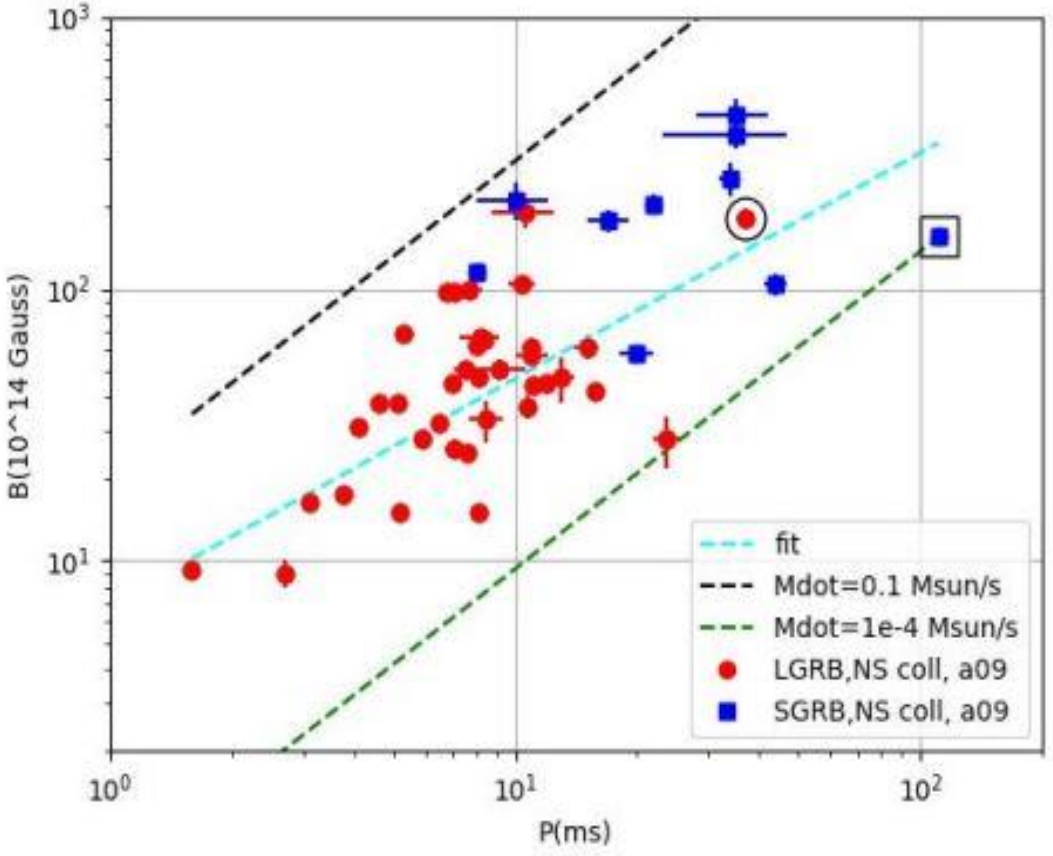
Marie Curie Fellow of the week
5-12 May 2018

Facebook Marie Curie: tinyurl.com/ehvyjaj3

Interviewed by the Italian National daily news on Women day

What is the interpretation of the plateau luminosity correlation?

Two different classes within the magnetar scenario



Stratta, Dainotti, Dall'Osso, Hernandez, de Cesare 2018, ApJ, 869, 155

- The spin-down luminosity of the magnetar is entirely beamed within θjet.
- The long GRB 070208 (circle) and the peculiar GRB 060614A (square).
- Previous literature: Dall'Osso et al. 2011, Bernardini et al. 2012, 2013, 2015, **Rowlinson et al. 2014 including Dainotti, Rea et al. 2015 (ncluding Dainotti)**, Beniamini et al. 2017, Beniamini & Mochkovitch 2017. See Liang et al. 2018 for comparison with isotropic emission.
- Within the external shock model (Srinivasagaravan, **Dainotti et al. 2020**, Warren et al. 2017).

The fundamental plane relation for new classes: Ambushing the standard candle in its own nest

Dainotti, Lenart, Sarracino, Nagataki, Capozziello & Fraija 2020, ApJ, 904, issue 2, 97, 13

- **The platinum sample:** a subset of the gold sample obtained after removing gold GRBs with at least one of the following features:
  - Tx is inside a large gap of the data, and thus has a large uncertainty.
  - A small plateau duration <500 s with gaps after it. This could mean that the plateau phase is longer than the one observed.
  - Flares and bumps at the start and during the plateau phase.
  - It reduces the scatter of 31%, $\sigma_{int}=0.22$.

Press release distributed by the AAS, issued by Jagiellonian, Space Science Institute, and by INAF (Italian National Astrophysics Institute) and interview by INAF.

The fundamental plane relation for new classes (Ambushing the standard candle in its own nest)

Dainotti et al. 2020, ApJ, 904, issue 2, 97, 13

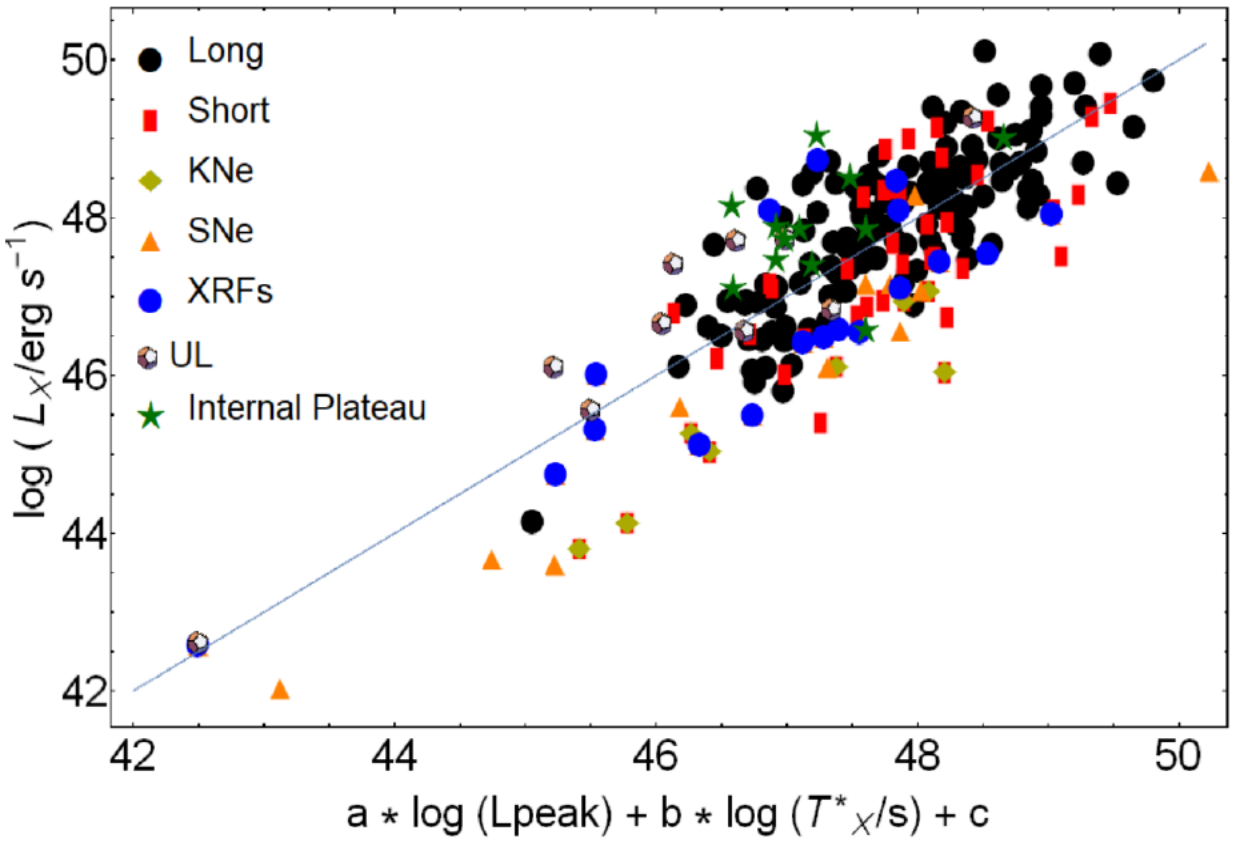


Figure 1. The 2D projection of the $L_X - T_X^* - L_{peak}$ relation for the 222 GRBs of our sample, with a plane fitted including LGRBs (black circles), SGRBs (red rectangles), KN-SGRBs (dark yellow rhombuses), SN-LGRBs (orange triangles), XRFs (blue circles), ULGRBs (dodecahedrons), and GRBs with internal plateaus (green stars).

* KNe are transient objects which are derived by the mergers of two neutron stars.
* Several KN have been associated with short GRBs.
Here we consider all cases presented in Rossi et al. 2020

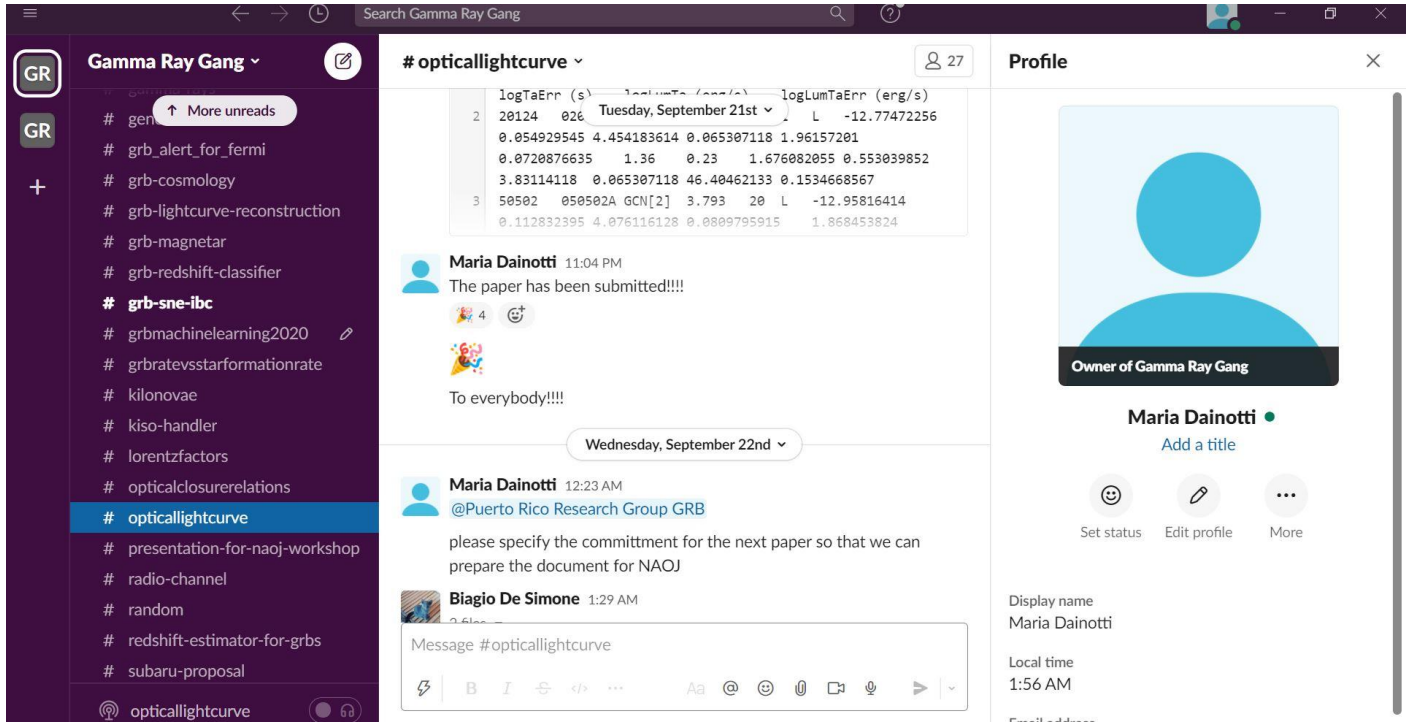
* The temporal power-law (PL) decay index of the plateau, α_i: a very steep decay, $\alpha_i \geq 3$ for Li et al. (2018) and $\alpha_i \geq 4$ for Lyons et al. (2010), indicates the possible internal origin of the plateau (Willingale et al. 2007) related to the magnetar.

The adventure of correlations continues in optical

How we tackle the research project?

- A knowledge of derivatives and Mathematics I are good knowledge to start with. Basics of astronomy are also welcome to understand more the project.
- Assign easy tasks in the beginning
- Complicate the tasks so that the students can have a steep learning degree
- Meet regularly with the students at least once a week for 2 hours or 2 hours and a half. Ideally twice per week for shorter time.
- Open a slack channel in which students are connected with the mentor and senior and other students.
- Define the rules of being part of a group.
- Open sharing of the resources

The means of the internships: the SLACK channel

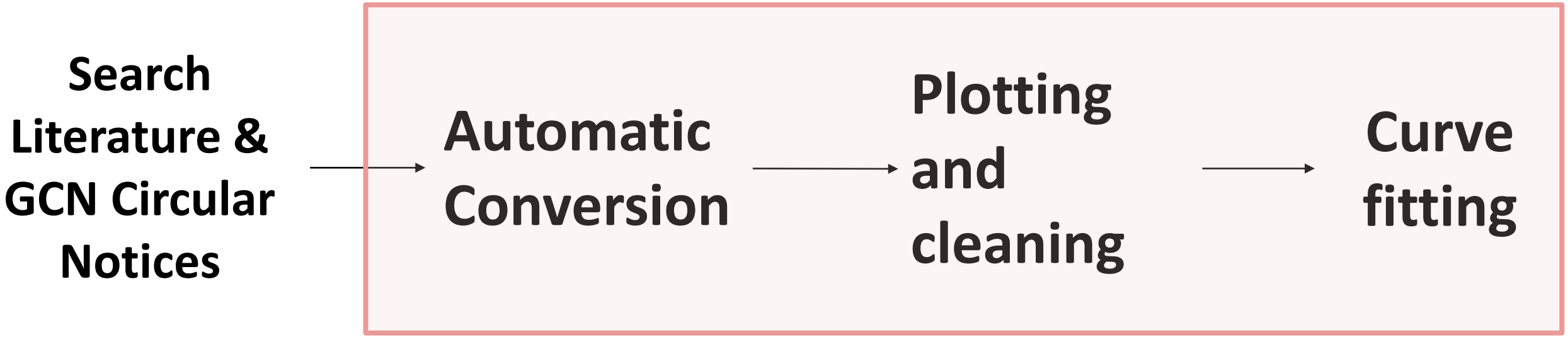


Creation of a github repository

- This is shared by all the students and me
- Sharing piece of code with Mathematica

The search continues...

- Problem: extracting & wrangling all of these data points is **HARD**
- An open-source Python package for better data-gathering and wrangling for otherwise difficult to gather data:



NASA GCN Circulars Archive

- Notices for astronomical events

GCN Circulars Archive (in serial number order)

This page changes after each Circular submission, so hit the <reload> button NOW.

The processing of Circulars to this page was stopped (from ~01:30 to ~18:00 UT 01 Dec 2020).
The Circulars page has been fixed as of ~18:00 UT 01 Dec 2020.
(The Circulars WERE ALWAYS BEING DISTRIBUTED -- it is only this archive web page (and sub-pag

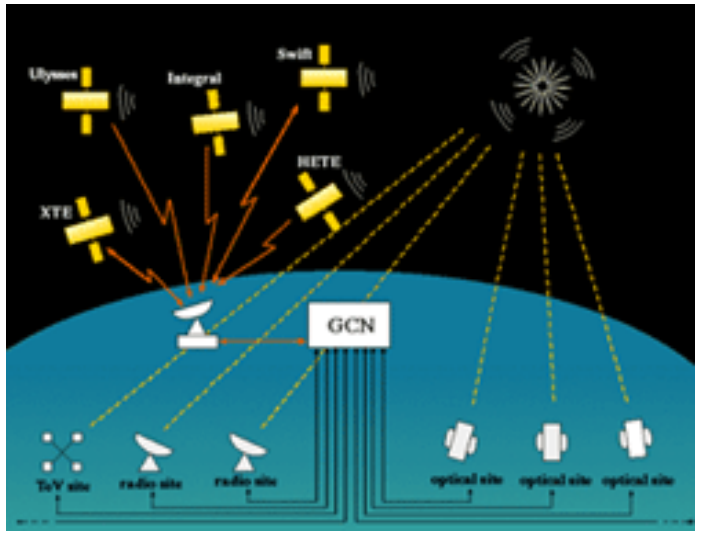
1. The Latest Circulars
2. Older Circulars
3. Tarfile of all Circulars
4. Circulars grouped by each Event
5. All Circulars on the GRB source type
6. All Circulars on the GW source type
7. All Circulars on the SGR source type
8. All Circulars on the misc source type (ie not in any of the above 3 pages).

This is the archive of all the GCN Observation Report Circulars (listed in reverse serial number order, nev

To learn more about the GCN Circulars and how to subscribe; and to unsubscribe here.

1) The Latest Circulars (listed in reverse serial number order -- newest first)

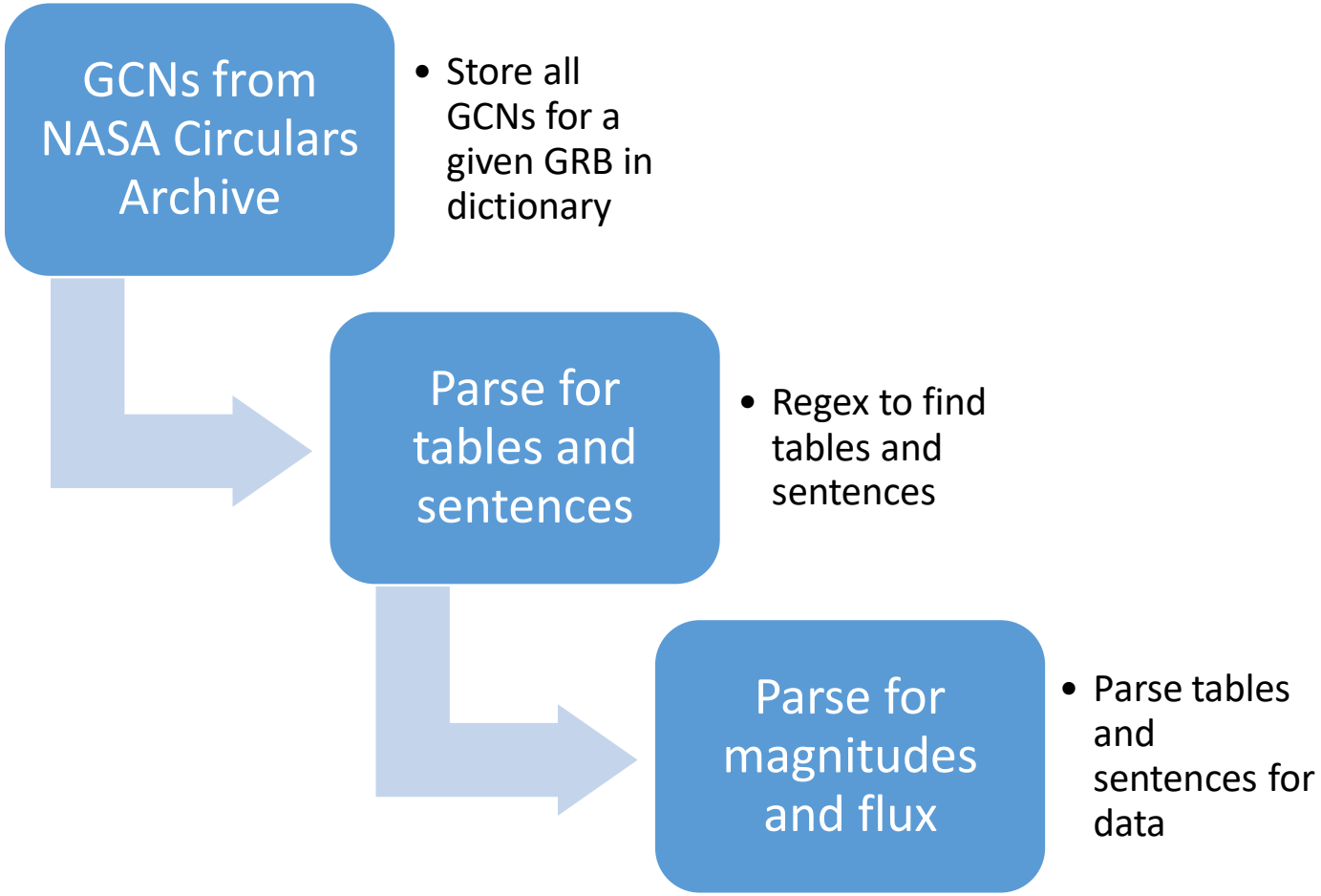
- 30538 GRB 210702A: MeerKAT radio detection
- 30537 GRB 210726A: Swift-XRT refined Analysis
- 30536 GRB 210726A: Swift-BAT refined analysis




```
TITLE:   GCN CIRCULAR
NUMBER:  28743
SUBJECT: GRB 201020B: Swift/UVOT Detection
DATE:    20/10/22 12:34:19 GMT
FROM:    Alice Breeveld at MSSL-UCL  <a.breeveld@ucl.ac.uk>

A. A. Breeveld (UCL-MSSL) and A. Y. Lien (GSFC/UMBC) report on behalf of the Swift/UVOT team:

The Swift/UVOT began settled observations of the field of GRB 201020B 72102 s after the Fermi
GMB/LAT trigger (Fermi GBM team, GCN Circ. 28702; Malacaria and Meegan, GCN Circ. 28710; Arimoto et
al., GCN Circ. 28716).
A source consistent with the Master position (Lipunov et al., GCN Circ. 28718), also detected by Xu
et al., (GCN Circ. 28719), Ridnaia et al. (GCN Circ. 28723), Belkin et al. (GCN Circ. 28723) and
Sbarufatti et al. (GCN Circ. 28740), is detected in the initial UVOT exposures. We note there is a
faint USNO-B1.0 source (1670-0037526, Bmag ~21.7) 5.2" away from this position.

Preliminary detections using the UVOT photometric system (Breeveld et al. 2011, AIP Conf. Proc.
1358, 373) for the early exposures are:

Filter         T_start(s)    T_stop(s)      Exp(s)          Mag

white            73636         73973          332         19.54 ± 0.09
v                73979         74316          331         19.30 ± 0.28
u                72102         72821          708         19.12 ± 0.11
u                73293         73631          332         19.41 ± 0.19

The magnitudes in the table are not corrected for the Galactic extinction due to the reddening of
E(B-V) = 0.15 in the direction of the burst (Schlegel et al. 1998).
```

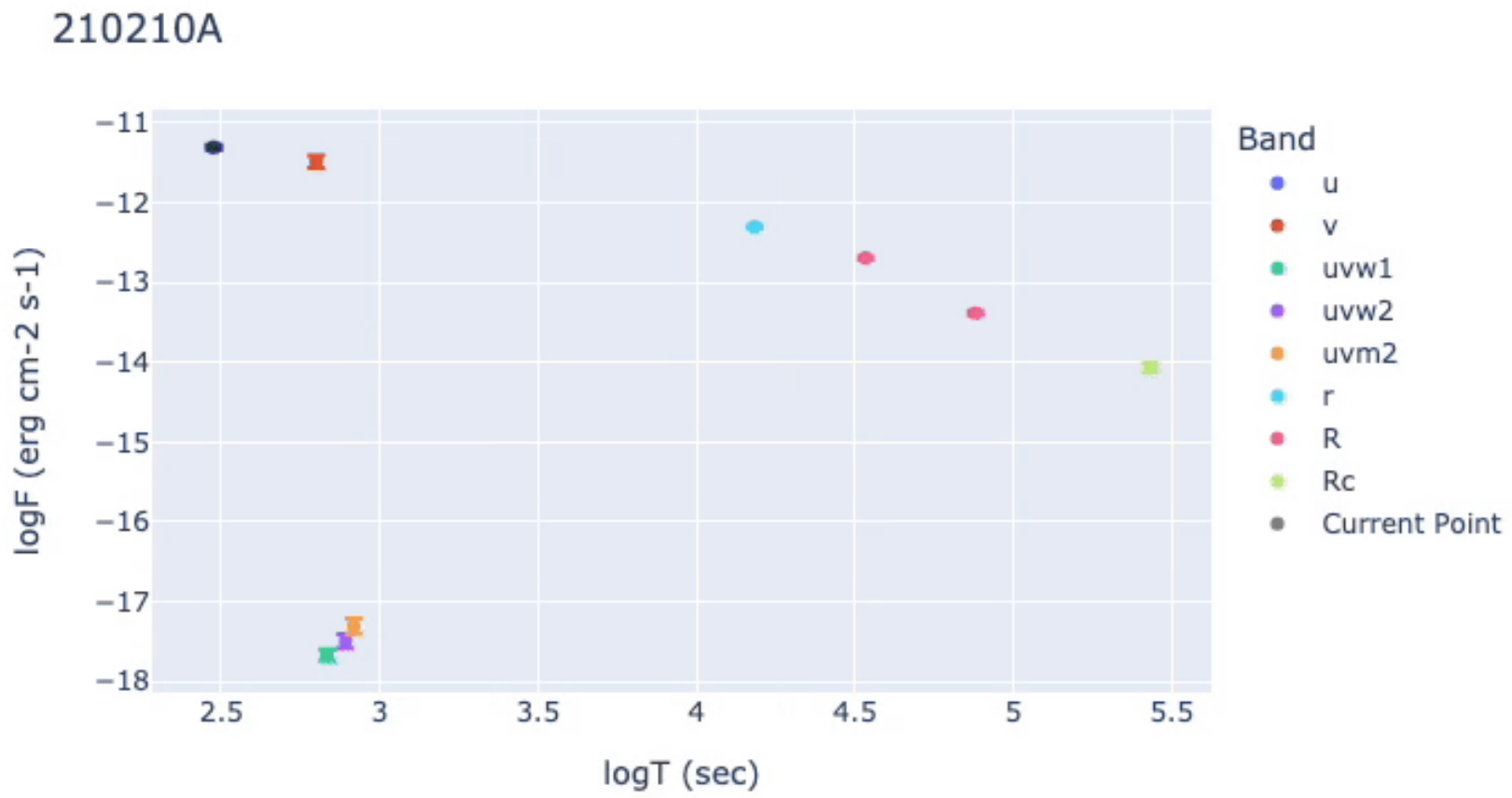
Pipeline Structure

- Work in progress to create a package for public use!



Plotting and Cleaning

- User-friendly interface to quickly go through individual light curves, accepting or rejecting points to fit.



Fitting

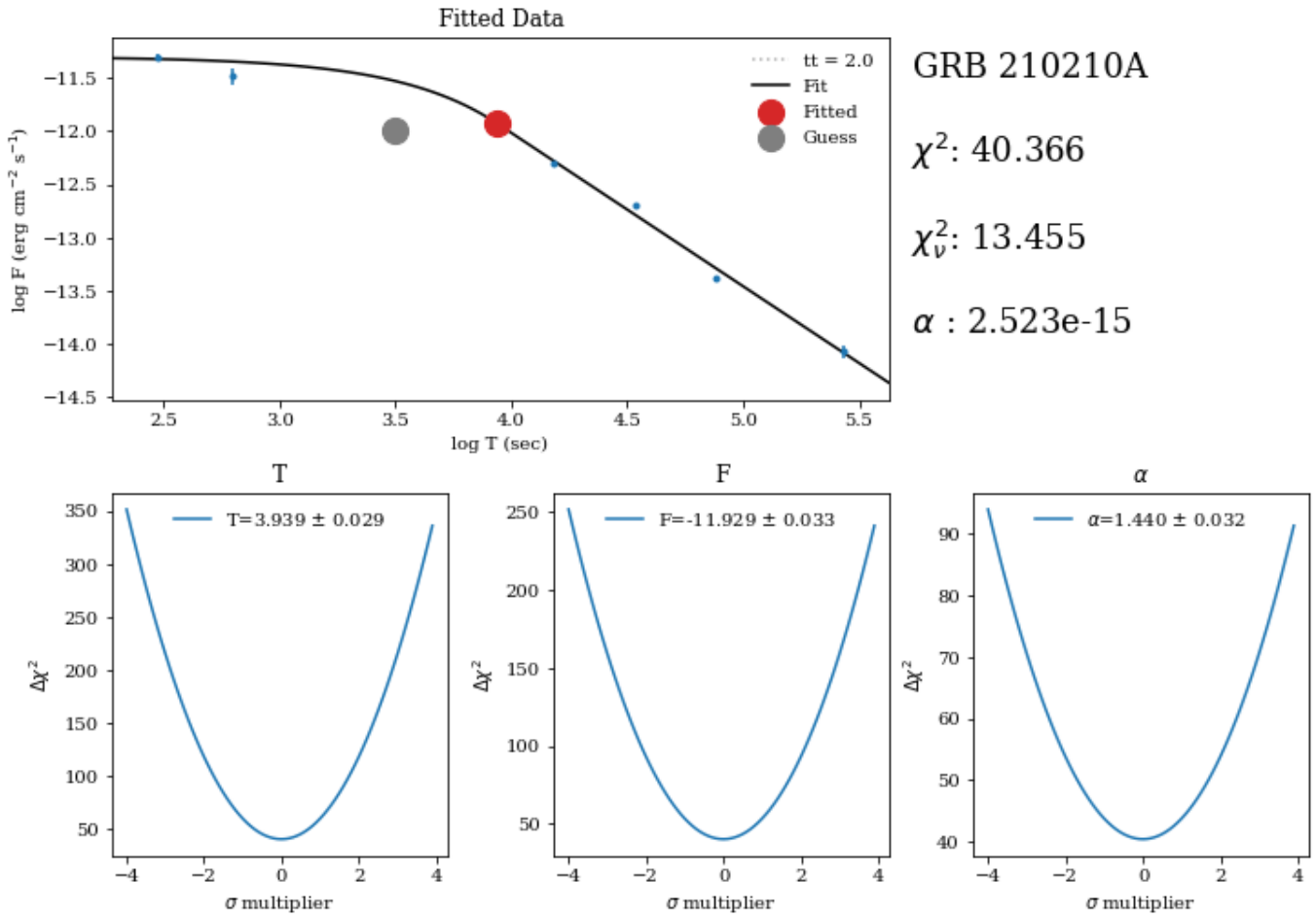
- User can quickly provide initial guess and the fit will be immediately returned.

User Inputs Guess:

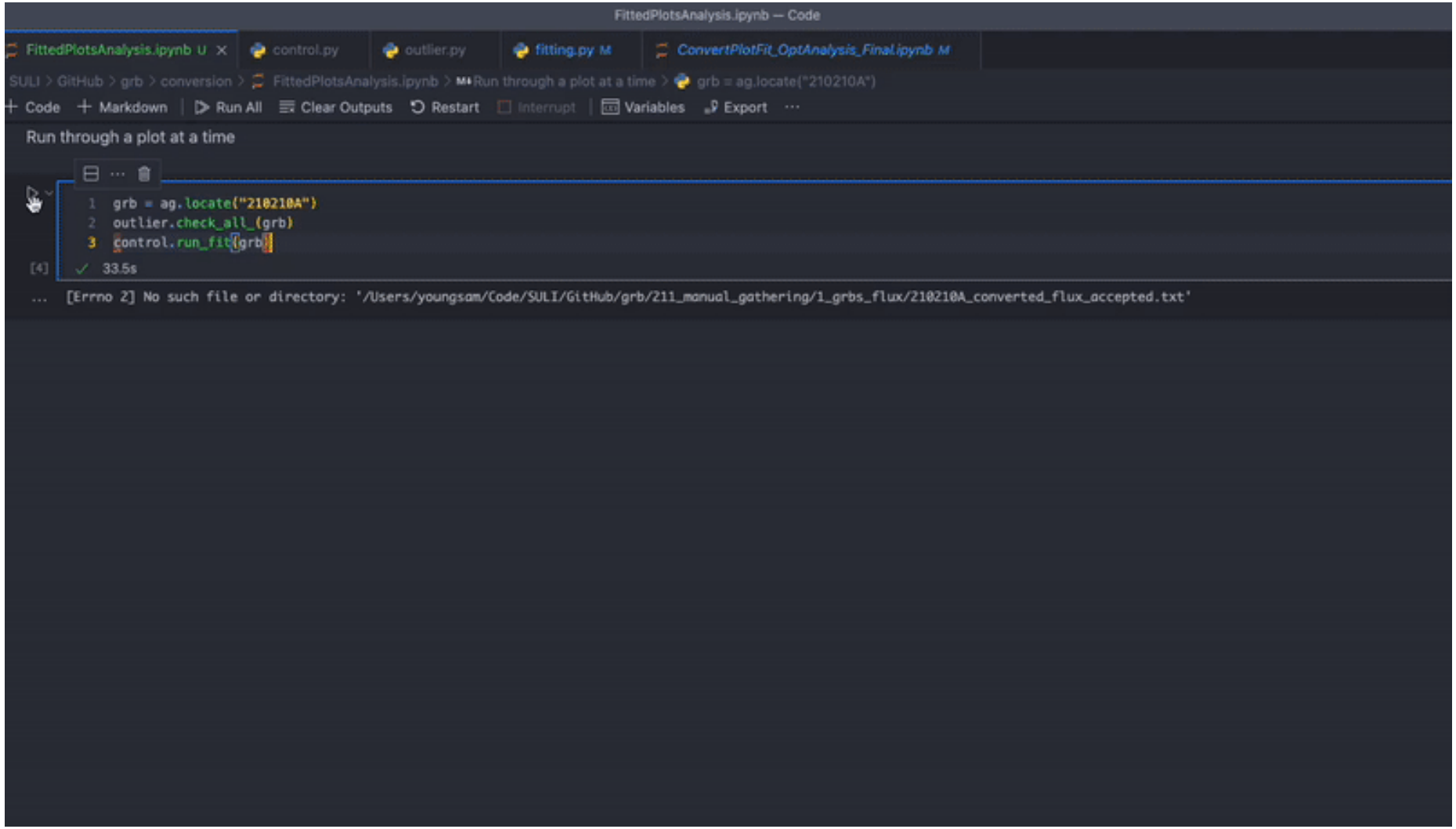
- Plateau start (tt)
- Time, Flux at end of Plateau (T, F)
- Temporal power-law decay index (α)
- Initial rise timescale (t)

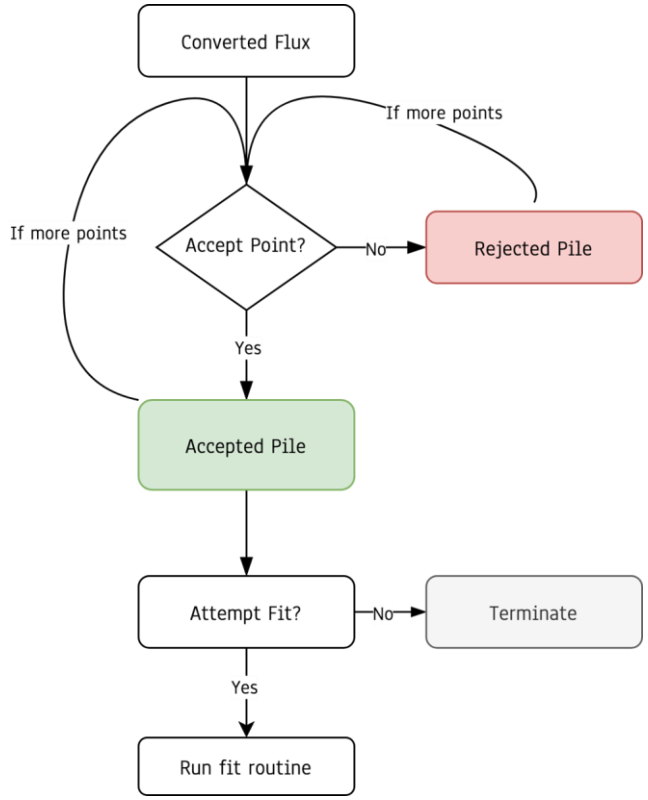
$$f(t) = \begin{cases} F_c \exp\left(\alpha_c - \frac{t\alpha_c}{T_c}\right) \exp\left(-\frac{t_c}{t}\right) & \text{for } t < T_c \\ F_c \left(\frac{t}{T_c}\right)^{-\alpha_c} \exp\left(-\frac{t_c}{t}\right) & \text{for } t \geqslant T_c \end{cases},$$

Willingale et al. (2007)



The end-user's process

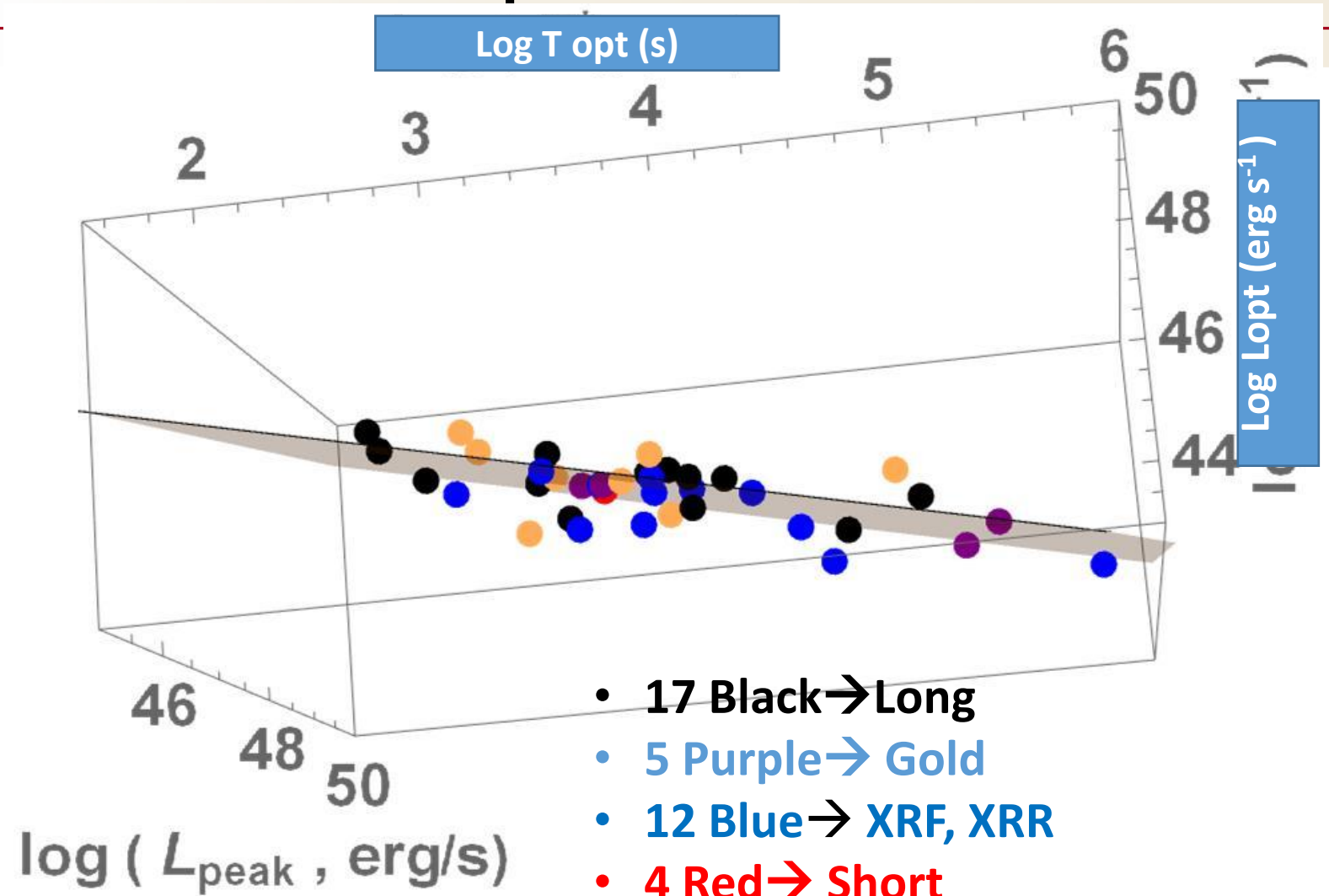




What we did with the students in one year!

- 2000+ points gathered and plotted through our pipeline
- 44 good, fitted LC's in additional to previous 131 → **175**
  - Overall **70% increase** in sample size from Dainotti et al. (2020)
  - On-the-fly conversion from fitted flux to ***luminosity***
  - Automatic gold and platinum sample selection
  - Automatic paper-grade figures created
    - 2D correlation
    - Comparisons between Optical and X-ray
  - Packaging for release to the scientific community
  - Updated computations of 2D correlation in optical
  - Novel computation of 3D correlation in optical

The 3D optical correlation exists for 47 GRBs



For comparisons see **Dainotti et al. 2016, 2017b, 2020a**

- **17 Black→Long**
- **5 Purple→ Gold**
- **12 Blue→ XRF, XRR**
- **4 Red→ Short**
- **1 Red → Short-KN**
- **8 Orange→ GRB-SNe Ib/c**

students from Leaf from Puerto Rico

Sam Young from University of Pennsylvania

What are the facilities we use?

Satellites: The Swift and Fermi Observatories for detecting the Gamma-ray signal.
The X-ray Telescope to identify precisely the location
The optical UVOT Telescope to further refine the position

Ground Based Telescopes:
The Subaru (8.2 meter class Telescope, operated by NAOJ)
The KISO (recently started the test observations)
DDOTI (operated at UNAM in Mexico) and
All other telescopes which provide observational data

Advantages of being part of this internship

- 1) Being a part of an international team of scientists and students
- 2) Meet with young students of your age in other countries (Italy, Poland, mainland US, Puerto Rico, India, Japan)
- 3) Knowing new cultures and learning how to work in group
- 4) helping each other in an environment with positive vibe which allow you to learn with a fast paste
- 5) PUBLISH IN AN INTERNATIONAL PEER REVIEWED JOURNAL

THIS IS THE PAPER WE SUBMITTED TO APJ

The autocome so far of the paper…

- Reviewer's Comments:
  This paper reports a continued effort by the first author and colleagues to explore 2D or 2D correlations invoking a GRB afterglow temporal break at the end of a shallow decay phase (also termed as "plateau"). Previous work focused on X-ray plateaus. Dainotti et al. (2021a), which was published in ApJL, started to investigate similar relations in the optical band. This paper reports the expansion of this analysis to a larger sample of 181 cases in 502 optical lightcurves. The methodology of this analysis is similar to the one used in previous papers. The results, especially the correlations, remain more or less the same, with the coefficients updated with a larger sample of data...
- **The paper is worth publishing.**
-

So the adventure continues with this paper…

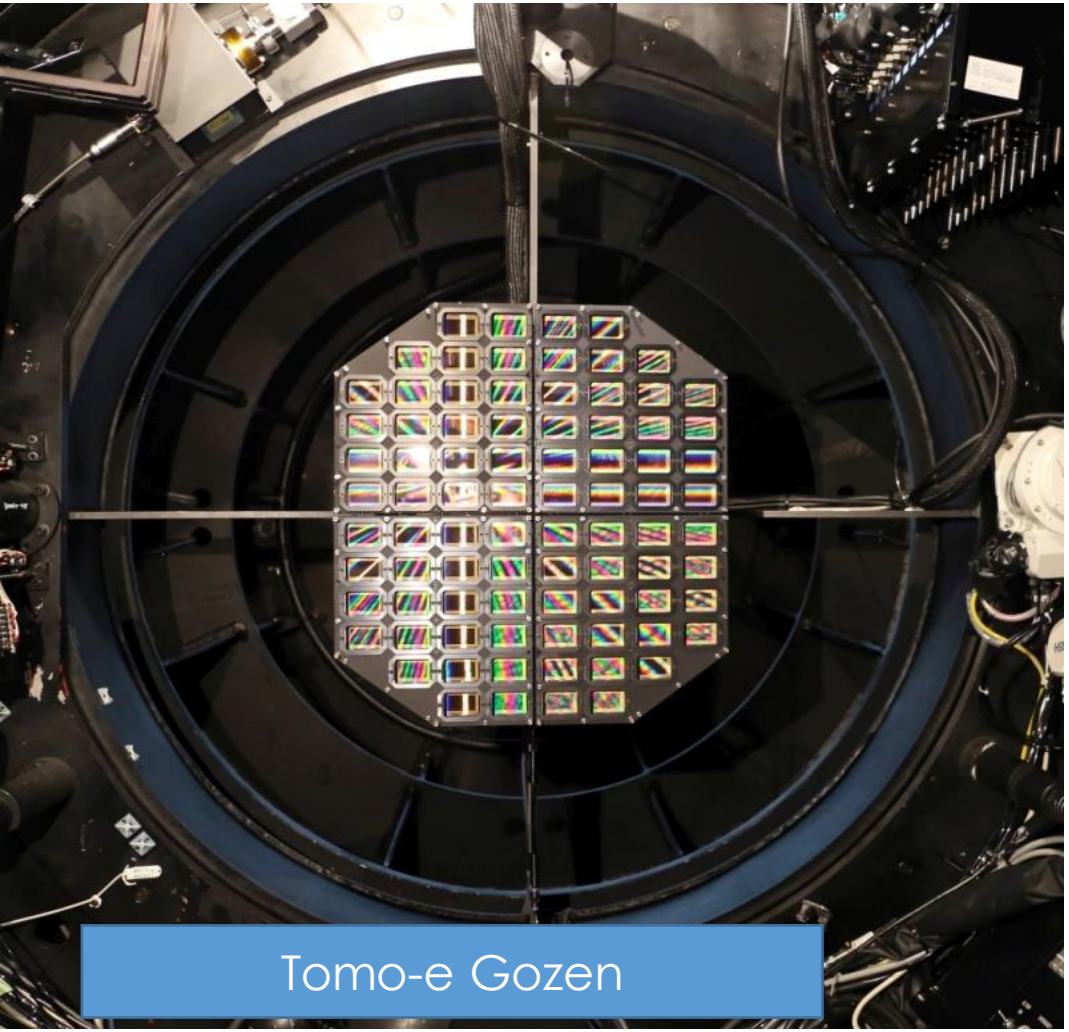
- We are all excited to see the paper published after some additional work..

The adventure continues with other projects

Tomo-e Gozen from KISO with DDOTI

SLAC

Deca-Degree Optical Transients Imager



Tomo-e Gozen

DDOTI is separated by 108 degrees in longitude from KISO. The different location and the similar goals allow this alliance to be successful.

THANK YOU VERY MUCH FOR YOUR ATTENTION AND YOU ARE INVITED TO JOIN US !!!

Contact me

Email:maria.dainotti@nao.ac.jp