USING MACHINE LEARNING TO ESTIMATE FERMI GRB REDSHIFTS

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OUTLINE

- Brief Introduction.
- Estimation redshift of GRBs:
  - GRB data selection - Fermi & Konus-winds.
  - Preliminary Results.
- Summary.

Brief introduction

Probing Gamma-ray Bursts as Possible Cosmological Standard Candles using Machine Learning

- High-quality of GRBs data from different satellite instruments are now available (e.g., *Fermi*, *Konus-Wind*, *INTEGRAL*, *SWIFT*, and other) followed by ground-based optical telescope and gamma-ray telescopes such as *H.E.S.S* and *MAGIC*.

Motivation

Supernova Type Ia:

- Observed only up to z = 2.
- Have been used as standard candles.
- Can be determine the relatively predictable intrinsic brightness based on their light curve shape.

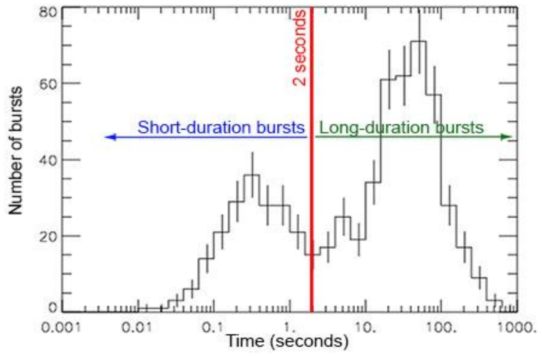
Use GRBs as standard candles
Just like SNe Ia

- High redshift: z = 9.2
- Energy dominated in range of KeV-MeV.
- Gamma rays from GRBs do not suffer dust extinction when they propagate to us, unlike optical emission from the SNe Ia.

Brief introduction

Duration of GRBs - **:** The duration of GRBs is less than a second to a maximum of a few minutes.

$\boldsymbol{T_{90}}$: the time to detect 90% of GRBs fluence.



Credit: NASA/L. Rozzella

Use GRBs as standard candles just like SNe Ia – Phenomenological relations

Is relation between two or more parameters found from spectral modelling.

Amati correlation (2002) for example: $\frac{E_{iso}}{10^{52}\, erg} = \mathbf{10}^{k} \left(\frac{E_{i}, peak}{E_{o}\, keV}\right)^{m}$

LGRBs

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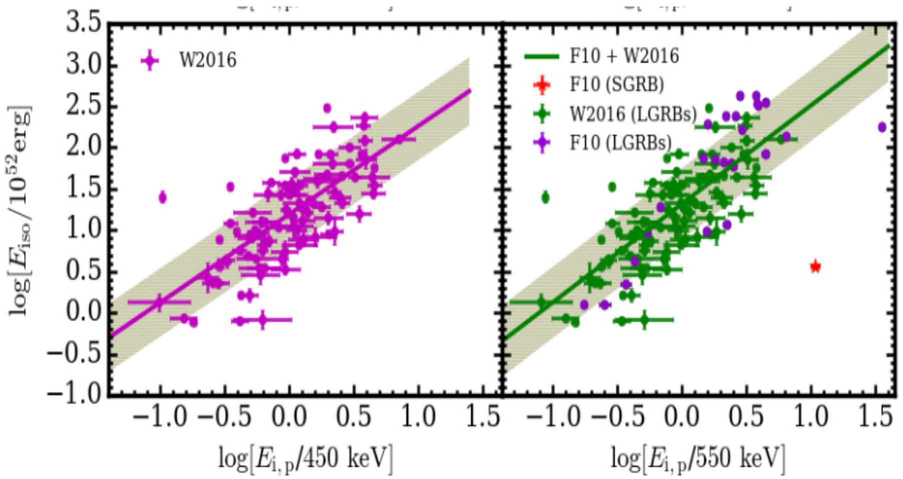
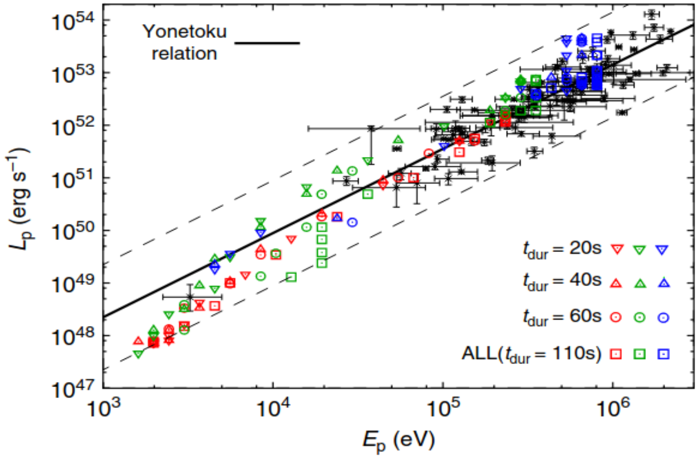
Yonetoku correlation (2004) : $\frac{L_{iso}}{10^{52}} = \mathbf{10}^{k} \left(\frac{E_{i,peak}}{E_{o}\, keV}\right)^{m}$

LGRBs & SGRBs



Dirirsa,F.F, Razzaque,S. , and Piron, F., et al. 2018, 2019

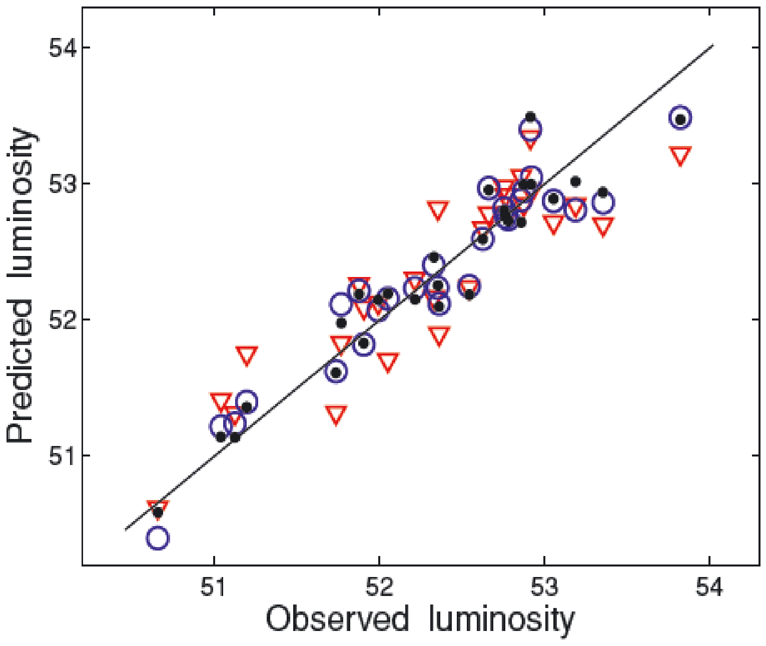


Ito, Hirotaka, et al . 2019

Brief introduction

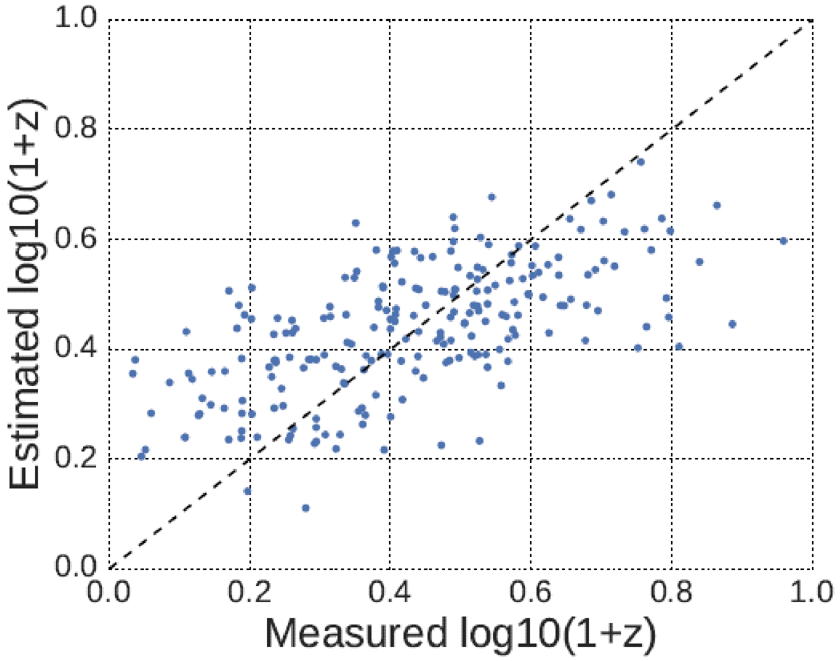
GRBs and Machine Learning : New method to find set of observables that best fit the cosmological indicator.

- Calibrate GRBs as cosmological indicators using different correlations.



Koen,C., et al.,2009

- To get a **pseudo redshifts*** of GRBs.



Racz, Istvan., et al., 2017

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* Atteia, J.L et al,. 2003.

Brief introduction

- Spectral analysis: Joint fit for Fermi-LAT and GBM data : from 2018 – up to date.
  Start with Rmfit – 3ML.
  https://threeml.readthedocs.io/en/stable/

- Extract spectral lag : Using cross-correlation (crosscrr) tool from heaSoft 6.19 –
  https://heasarc.gsfc.nasa.gov/xanadu /xronos /xronos.html

- Estimation GRBs redshift :
  - Fermi-GBM data: gmb-tools.
  - Konus-wind data.
  - Regression algorithms in neural networks.

I need help.

Estimation redshift of GRBs - Data selection

- The datasets : from the Fermi GRB Monitor (**Fermi-GBM) Catalog and Konus-winds*:**
- Energy band used in Fermi-GBM (10 - 1000 keV) and Konus-wind (80 - 1200 keV).
    - From 2008 to 2018 (Fermi-GBM) – 2005 – 2018 (KW) with known redshift.
    - Spectral fitting parameters from two models:

    - **Band**: with indices α, β, and spectral peak energy E_p in keV.

$$N_{Band}(E) = A_{Band} \begin{cases} \left(\frac{E}{100\ keV}\right)^{\alpha} exp\left[-\frac{E(2+\alpha)}{E_p}\right] & if\ E \le E_b \\ \left(\frac{E}{100\ keV}\right)^{\beta} exp(\beta-\alpha)\left[-\frac{E_p}{100\ keV}\frac{\alpha-\beta}{2+\alpha}\right]^{\alpha-\beta} & if\ E > E_b, \end{cases}$$

Band D et al ,. 1993

- **Comptonized**: the photon index γ, and the peak energy E_p.

Steiner J. F. et al., 2009

$$N_{Comp} = A_{Comp}\left(\frac{E}{100\ keV}\right)^{\gamma} \exp\left[-(2+\gamma)\frac{E}{E_p}\right]$$

* https://heasarc.gsfc.nasa.gov - A. Tsvetkova, et, al,. 2021.

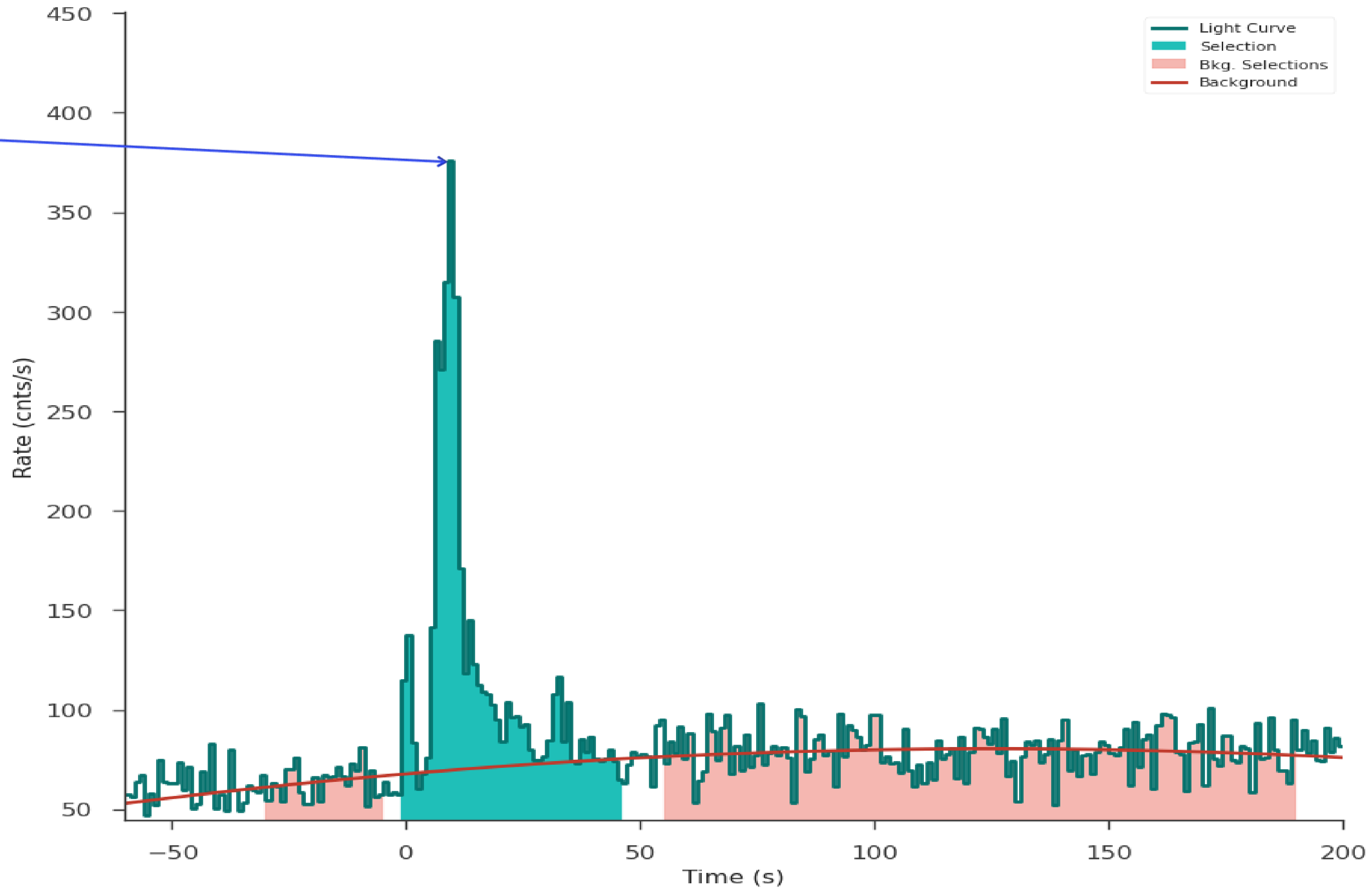
Estimation redshift of GRBs – Data selection

$$E_{iso} = \frac{4\pi d_L^2}{1+z} S_{bolo} \quad , \quad L_{iso} = 4\pi d_L^2 P_{bolo}$$

Bolometric :

- Fluence/T_{90} - S_{bolo}
- Peak Flux - P_{bolo}

Light curve*
GRB130427A
Fermi - LLE

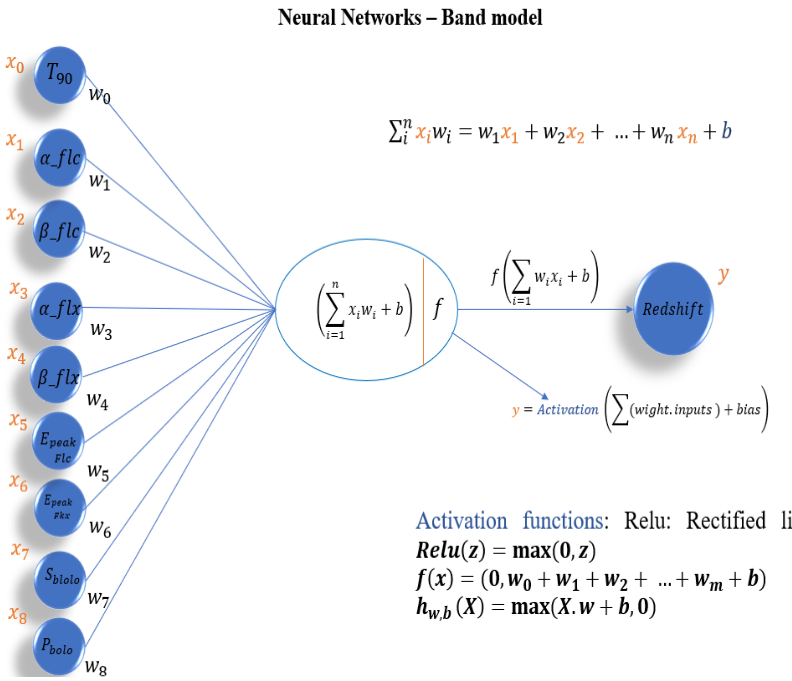


* Light curve produced by 3ML.

Estimation redshift of GRBs

- **Regression - Deep Neural Networks (DNNs)**

Spectral Parameters		
Bolometric	Peak Flux	Fluence/T_{90}
Band	$\alpha, \beta, E_p, P_{bolo}$	$\alpha, \beta, E_p, S_{bolo}$
Comptonized	$\alpha_{index}, E_p, P_{bolo}$	$\alpha_{index}, E_p, S_{bolo}$



Activation functions: Relu: Rectified linear units.

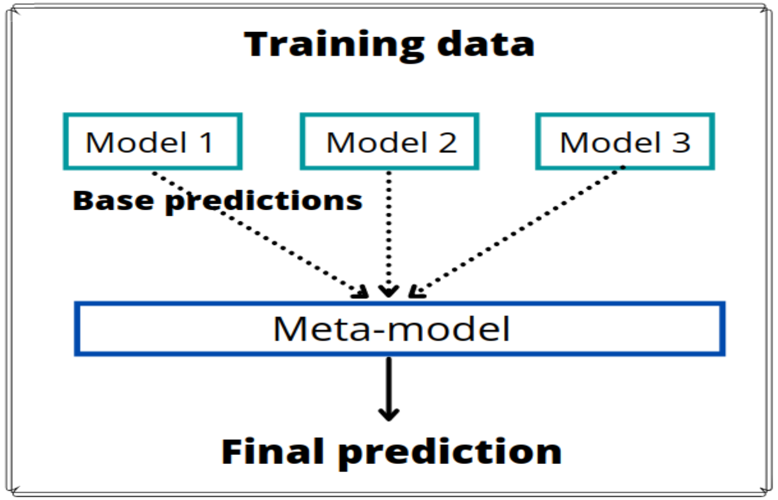
$\boldsymbol{Relu}(z) = \max(0, z)$

$f(x) = (0, w_0 + w_1 + w_2 + ... + w_m + b)$

$h_{w,b}(X) = \max(X.w + b, 0)$

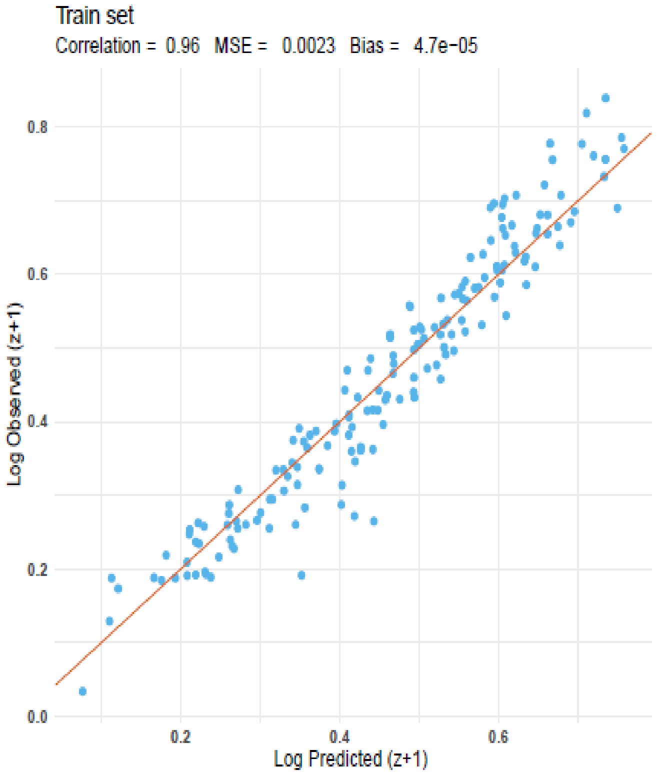
Ensemble Stacking

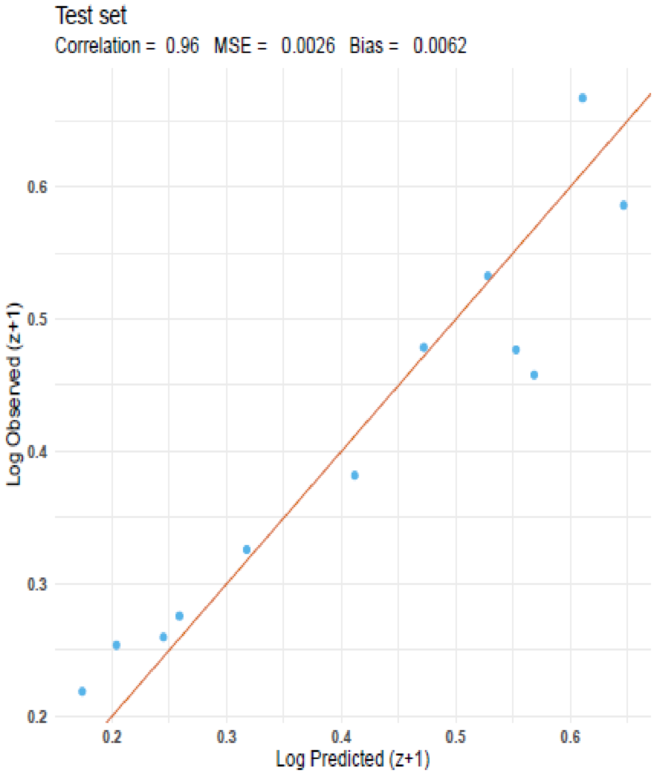
Wang, L., et al. 2020



Estimation redshift of GRBs – Pervious work

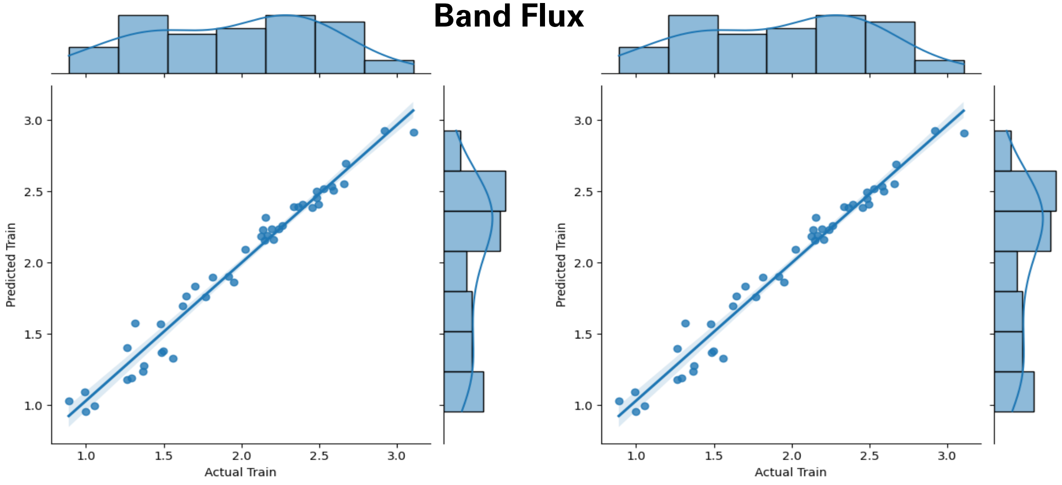
Several previous works used supervised machine learning algorithms, e.g., SuperLearner, to estimate possible non-linear relations between the redshift and GRB properties (T_{90}, photon index, hydrogen column density, fluence, peak flux, etc.).
This was done using existing data from 171 *Swift* GRBs collected from January 2005 until January 2019 with a known redshift obtained a correlation coefficient of 0.96 and a mean squared error of 0.003 between actual and predicted redshifts (*Maria Dainotti et al,. 2019*).



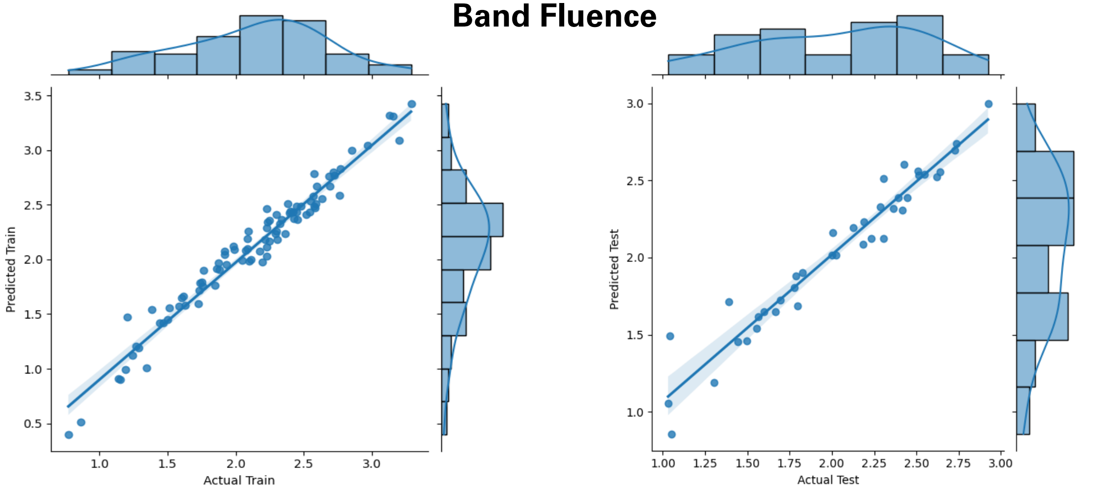


Estimation redshift of GRBs - Preliminary Results

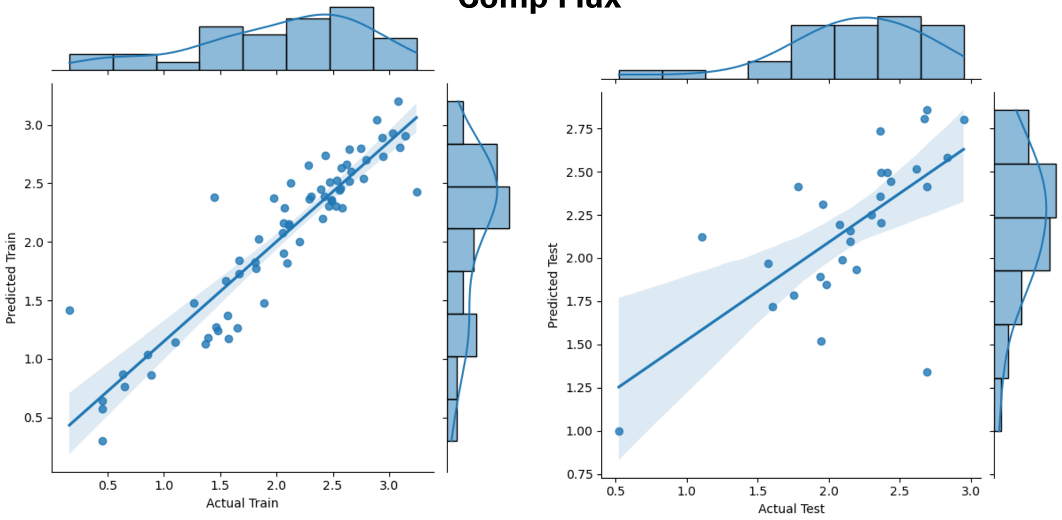
Band Flux



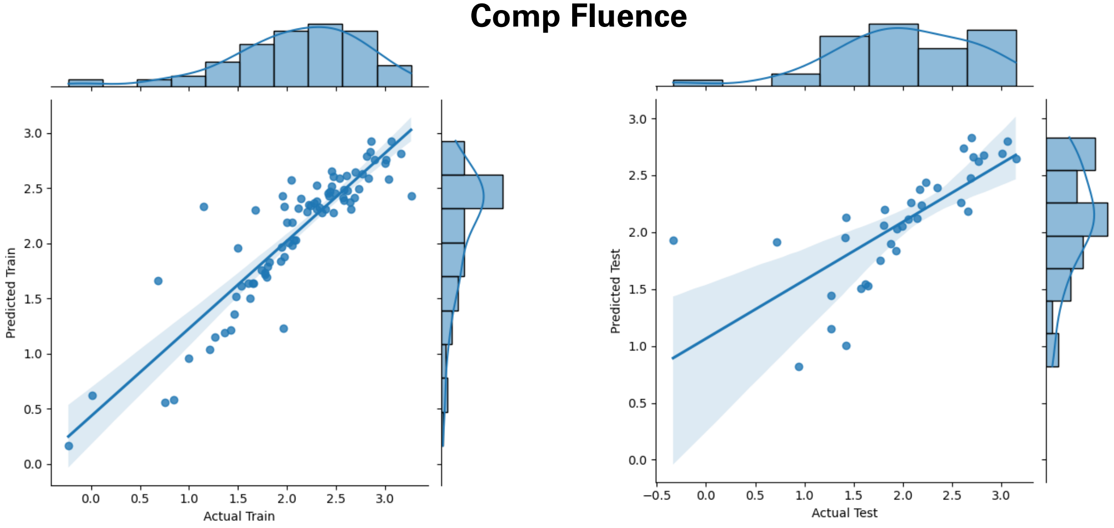
Band Fluence



Comp Flux



Comp Fluence



SUMMARY

Obtaining pseudo redshift is useful to standardize GRBs as cosmological probes, we use a different tools or techniques in machine learning (Regression-DNN) as different supervised tools used in the previous works. The best fit is obtained using the training and test set alone with band models depend on the R^2 and MAE.

THANK YOU

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