–Title of my thesis–

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Indian Institute of Technology Hyderabad

Department of Artificial Intelligence

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Declaration

I declare that this written submission represents my ideas in my own words, and where ideas or words of others have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited, or from whom proper permission has not been taken when needed.

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Approval Sheet

This Thesis entitled –Title of my thesis– by Shreeprasad Bhat is approved for the degree of Master of Technology from IIT Hyderabad

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Abstract

This is not a document on how to use latex. It rather explains how to use iiththesis.cls file to write your thesis for PhD/M.Tech/MSc. This file is generated using the class iiththesis.cls. This document draws a broad picture of the structure and formatting of your thesis.

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Chapter 1

Model-independently calibrating the luminosity correlations of GRBs using deep learning

1.1 Introduction

The accelerating expansion of the universe is first found from the fact that the luminosity of type Ia supernovae (SNe Ia) is dimmer than expected [1]. This led to the discovery of Dark energy [2]. One of the few ways to measure properties of dark energy is to extend the Hubble Diagram(HD) to high redshift. The only way to extend HD to higher redshift is to Gamma Ray Burts (GRB). GRB have been found to be reasonably good standard candles in the usual sense that light curve and/or spectral properties are correlated to the luminosity, exactly as for Cepheids and supernovae, then simple measurements can be used to infer their luminosities and hence distances. The default expectation is the simplest model for the Dark Energy, where it does not change in time. This can be parametrized with the equation of state of the Dark Energy. The concordance case has w = -1 at all times, and this is the expectation of Einstein's cosmological constant, or if the Dark Energy arises from vacuum energy. Given the strong results from supernovae for redshifts of less than 1, the frontier has now been pushed to asking the question of whether the value of w changes with time (and redshift).

The best way to measure properties of the Dark Energy seems to be to measure the expansion history of our Universe and place significant constraints on models of the Universe. Hubble diagram can be used to measure it. The Hubble diagram (HD) is a plot of distance versus redshift, with the slope giving the expansion history of our Universe. been proposed to determine the distances and redshifts of two thousand supernovae per year out to redshift 1.7 with exquisite accuracy. The default expectation is the simplest model for the Dark Energy, where it does not change in time. This can be parameterized with the equation of state of the Dark Energy. The best way to measure whether dark energy changed with respect to redshift, is to measure it over wide range of redshifts, but supernovaes cannot be deteceted above 1.7 even with modern satelites. But GRBs offer means extend HD over redshift > 6. The reason is that GRBs are visible across much larger distances than supernovae.

GRBs are now known to have several light curve and spectral properties from which the luminosity of the burst can be calculated (once calibrated), and these make GRBs into 'standard candles'.

1.2 Literature Survey

The first work on luminosity correlation of GRBs was done by [3]. [4] shows that not all luminosity correlations are applicable across all redshifts. [5] prooves otherwise. [6] shows that is not true. [7] have model independetently verified this using deep learning.

1.3 Observational Data

1.3.1 GRB

The GRB dataset we use is from Wang et al. In Table 1, we list the variables of 116 GRBs that we use in fitting luminosity correlations

1.3.2 Pantheon

Pantheon compilation (Scolnic et al. 2018) is the combined sample of SNe Ia discovered from different surveys to form the largest sample consisting of total of 1048 SNe Ia raning from $0.01 < z < 2.3$.

1.3.3 Union

The updated supernova Union2.1 compilation of 580 SNe is available at http://supernova.lbl.gov/Union

1.4 Model Architecture

1.4.1 Gaussian Processes

to be written...

1.4.2 Reccurent Neural Networks

to be written...

1.5 Reconstruction of distance modulus

Training the neural network for with early stopping. loss plots

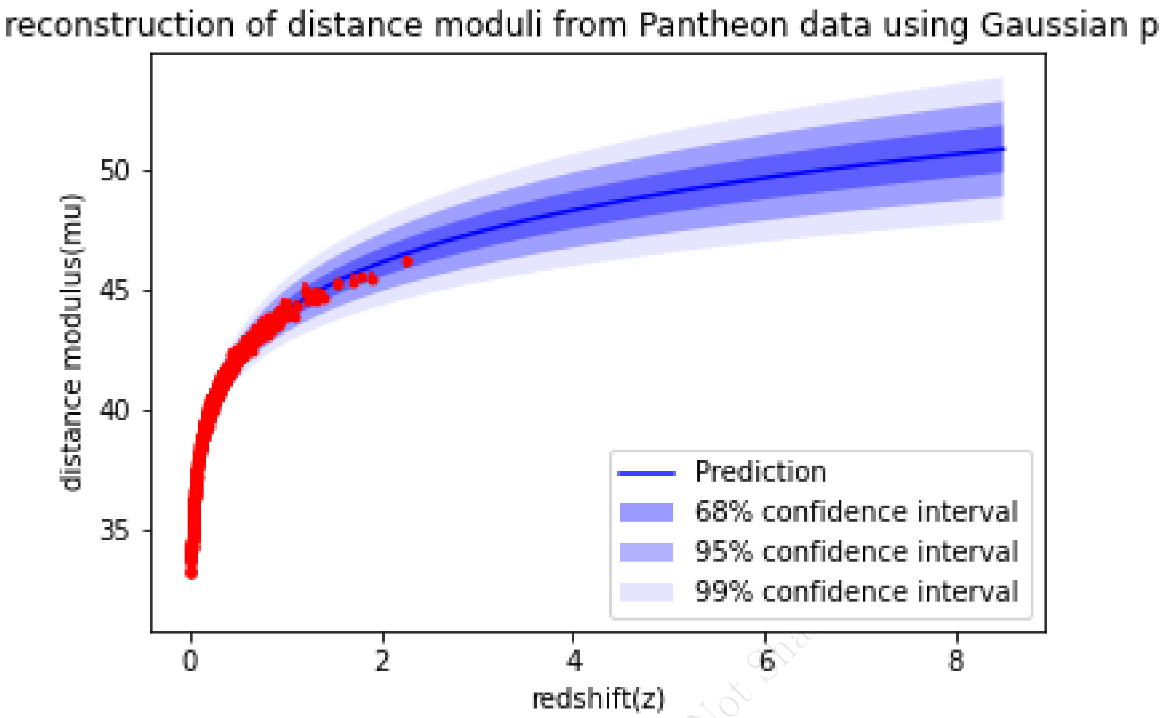

Figure 1.1: Reconstruction from Gaussian Processes

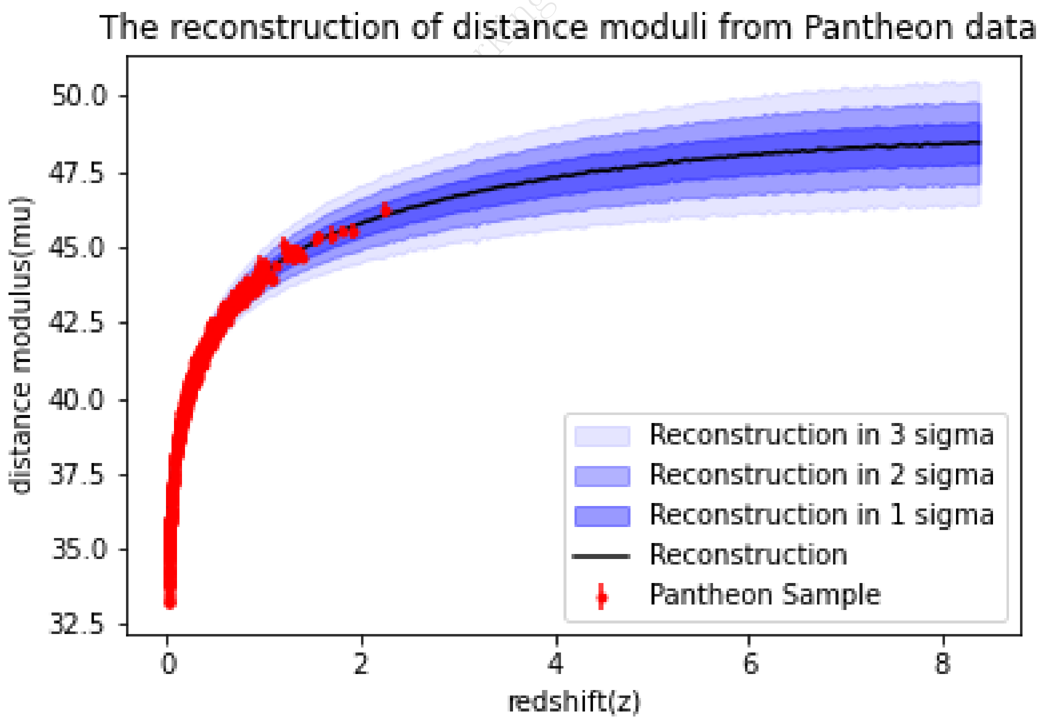

Figure 1.2: Reconstruction from LSTM+BNN with uncertainty

1.6 Testing redshift dependence of luminosity correlations

The luminosity relations are connections between measurable parameters of the light curves and/or spectra with the GRB luminosity. Specifically, I will be using the power law relationships between explained below. This section will discuss the calibration of all six relations. The calibration will essentially be a fit on a log-log plot of the luminosity indicator versus the luminosity. For this calibration process, the burst's luminosity distance must be known to convert Pbolo to L (or Sbolo to Egamma) and this is known only for bursts with measured redshifts. However, an important point is that the conversion from the observed redshift to a luminosity distance is done by machine learning model. The observed luminosity indicators will have different values from those that would be observed in the rest frame of the GRB. That is, the light curves and spectra seen by Earth-orbiting satellites suffer time-dilation and redshift. The physical connection between the indicators and the luminosity is in the GRB rest frame, so we must take our observed indicators and correct them to the rest frame of the GRB. For the two times (Tlag and TRT), the observed quantities must be divided by 1+z to correct for time dilation. The observed V value varies as the inverse of the time stretching, so our measured value must be multiplied by 1 + z to correct to the GRB rest frame. The observed Epeak value must be multiplied by 1 + z to correct for the redshift of the spectrum. The number of peaks in the light curve is defined in such a way as to have no z dependance. The dilation and redshift effects on thetajet and Egamma,iso have already been corrected in equations 1 and 2. A possibly substantial problem for the Tlag, V , and TRT relations is that we are in practice limited to the available energy bands (c.f. Table 5) whereas these correspond to different energy bands in the GRB reference frame. Ideally, we would want to measure these indicators in observed energy bands that correspond to some consistent band in the GRB frame

1. Lag versus Luminosity 2. Variability versus Luminosity 3. Epeak versus Luminosity 4. Epeak versus Egamma 5. TRT versus Luminosity 6. Epeak versus Eiso

$$\log \frac{L}{\mathrm{erg\,s^{-1}}} = a_1 + b_1 \log \frac{\tau_{\mathrm{lag},i}}{0.1s}, \tag{1.1}$$

$$\log \frac{L}{\mathrm{erg\ s^{-1}}} = a_2 + b_2 \log \frac{V_i}{0.02}, \tag{1.2}$$

$$\log \frac{L}{\mathrm{erg\ s^{-1}}} = a_3 + b_3 \log \frac{E_{p,i}}{300\mathrm{keV}} \log \frac{E_\gamma}{\mathrm{erg}} = a_4 + b_4 \log \frac{E_{p,i}}{300\mathrm{keV}}, \tag{1.3}$$

$$\log \frac{L}{\mathrm{erg\ s}} = a_5 + b_5 \log \frac{\tau_{\mathrm{RT},i}}{0.1\ \mathrm{s}}, \tag{1.4}$$

$$\log \frac{E_{\mathrm{iso}}}{\mathrm{erg}} = a_6 + b_6 \log \frac{E_{p,i}}{300\mathrm{keV}} \tag{1.5}$$

Assuming that GRBs radiate isotropically, the isotropic equivalent luminosity can be derived from the bolometric peak flux P_{bolo} by (Schaefer 2007)

$$L = 4\pi d_L^2 P_{\mathrm{bolo}}\ ,$$

where d_L is the luminosity distance of GRB, which can be obtained from the reconstructed distance moduli of Pantheon presented in section B with the relation

$$\mu = 5\log\frac{d_L}{\mathrm{Mpc}} + 25.$$

Hence, the uncertainty of L propagates from the uncertainties of P_{bolo} and d_L. The isotropic equivalent energy E_{iso} can be obtained from the bolometric fluence S_{bolo} by

$$E_{\text{iso}} = 4\pi d_L^2 S_{\text{bolo}} (1+z)^{-1},$$

the uncertainty of E_{iso} propagates from the uncertainties of S_{bolo} and d_L. If on the other hand, GRBs radiate in two symmetric beams, then we can define the collimation-corrected energy E_γ as

$$E_\gamma \equiv E_{\text{iso}}\, F_{\text{beam}}\ ,$$

where $F_{\text{beam}} \equiv 1-\cos\theta_{\text{jet}}$ is the beaming factor, θ_{jet} is the jet opening angle. The uncertainty of E_γ propagates from the uncertainties of $E_{\text{iso and}}$ F_{beam} .

1.7 Calibrating distance modulus from $E_{peak} - E_{gamma}$ relation

1.8 Constraints on the dark energy

1.9 Redoing analysis with Union Data

1.10 Conclusion

References

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Chapter 2

Dark Energy Model

Chapter 3

Figures

3.1 Referencing figures

The figure where ever possible must be centered. Each figure must have a caption centered to the figure. Every single figure in the document must be referred in the text. For example IITH logo is displayed in Fig. 3.1.

Figure 3.1: This is IITH logo

Use “Fig". to refer to a figure if the reference to it appears not at the beginning of a sentence. If the sentence starts with reference to figure use “Figure". For instance refer to the following text. Figure 3.1 is a compressed logo of IITH.

3.2 File formats

You can use jpeg, png, pdf, or eps file format for the figures. However, depending on the file type you will have to use either *pdflatex* or *latex*. Please refer to Chp. 5 for further details.

$$\eta = 1 - \left(\frac{v_2}{v_1}\right)^{\gamma-1} = 1 - \left(\frac{p_1}{p_2}\right)^{(\gamma-1)/\gamma} \tag{3.1}$$

$$\eta = 1 - \left(\frac{v_2}{v_1}\right)^{\gamma-1} = 1 - \left(\frac{p_1}{p_2}\right)^{(\gamma-1)/\gamma} + \tag{3.2}$$

$$\frac{x}{y} + \frac{z}{x} + \frac{z}{y} \tag{3.3}$$

Chapter 4

Tables

4.1 Referencing tables

The tables where ever possible must be centered. The table caption must appear at the top of the table and must be centered to the table. Every table in the document must be referred in the text. Please use capitalized “T" whenever a reference to table is made. i.e Table 4.1 rather than table 4.1.

Table 4.1: This is an example table.

Parameter	Value
Density	1
Specific heat	1

Chapter 5

Compiling the *.tex* file

5.1 Options

If you are using jpeg or pdf format for the figures please use*pdflatex* to compile the tex file. If you are using eps format you can use *latex* command to compile the tex file. The *latex* command will create *dvi* output which may be converted to *pdf* by using *dvipdf* on any linux distribution.

5.2 Compilation sequence

You have to execute the following sequence to commands to get the proper output file.

```
latex thesis.tex
bibtex thesis
latex thesis.tex
latex thesis.tex
```

Notice that you have to tex the document twice after running bibtex.