Structured Grammatical Evolution for Modeling the Multi-band Light Curves of Supernova

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1. Introduction

There is an interest in describing the supernova phenomenon that increases its luminosity until it reaches a peak and then decreases before it disappears. The Supernova Parametric Model (SPM) attempts to describe the typical behavior of SN light curve; however, SPM requires the adjustment of multiple variables and the prediction is complex, due to the limited availability of data and difficulties in terms of tracking. This is why symbolic regression through evolutionary algorithms emerges as an interesting technique to obtain simpler and more specific models for different types of supernovae and the bands of light that compose them.

1.1 SPM

The Supernova Parametric Model (SPM) attempts to describe the typical behavior of SN light curve [1].

$$f_{sne}(t;\theta) = f_{early}(t)\cdot(1-g(t)) + f_{late}(t)\cdot g(t)$$

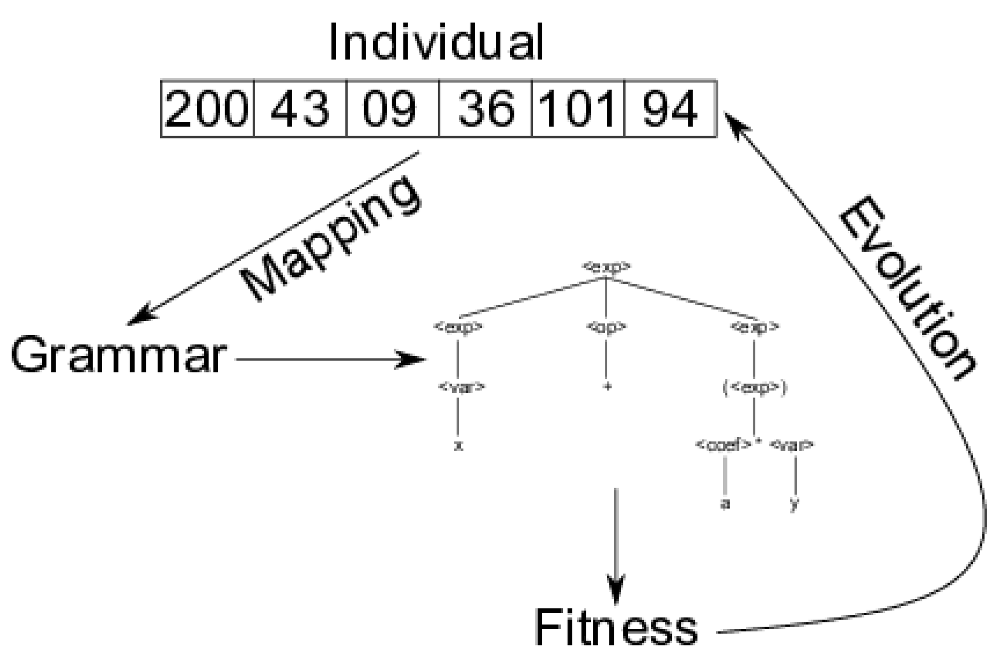
$$g(t) = \sigma(s\cdot(t-(\gamma+t_0)))$$

$$f_{early}(t) = \frac{A\cdot(1-\beta'\frac{(t-t_0)}{\gamma})}{1+exp(\frac{-(t-t_0)}{\tau_{rise}})}$$

$$f_{late}(t) = \frac{A\cdot(1-\beta')\cdot exp(\frac{-(t-(\gamma+t_0))}{\tau_{fall}})}{1+exp(\frac{-(t-t_0)}{\tau_{rise}})}$$

1.2 SGE

Grammatical evolution is an evolutionary algorithm that can evolve complete programs in an arbitrary language.



Grammatical Evolution Scheme.

In Structured Grammatical Evolution (SGE) each gene is linked to a specific non-terminal and is composed by a list of integers.

2. Method

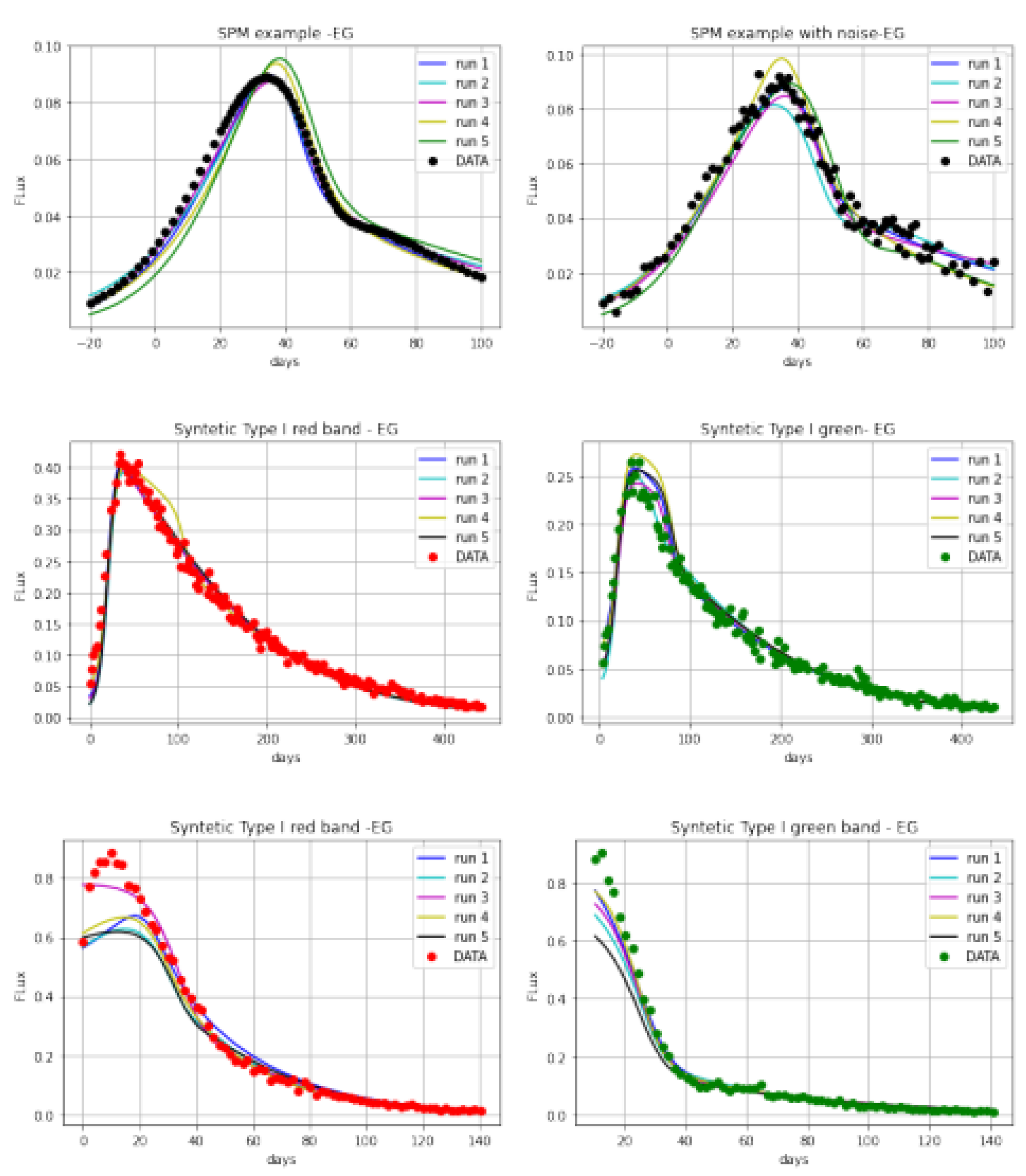
Two aproaches to solve the SR problem:

1. **Explicit grammar (EG)**: The start symbol is setted as the SPM structure, and a population is evolved to optimize the SPM parameters.
2. **Simplified grammar (SG)**: The start symbol is the sum between a number and an expression, where the expresion is a non-terminal set, that includes basic operations $[+,-,*,/]$ and complex operations $[exp, sigmoid]$, also we defined a free-constant and a variable t.

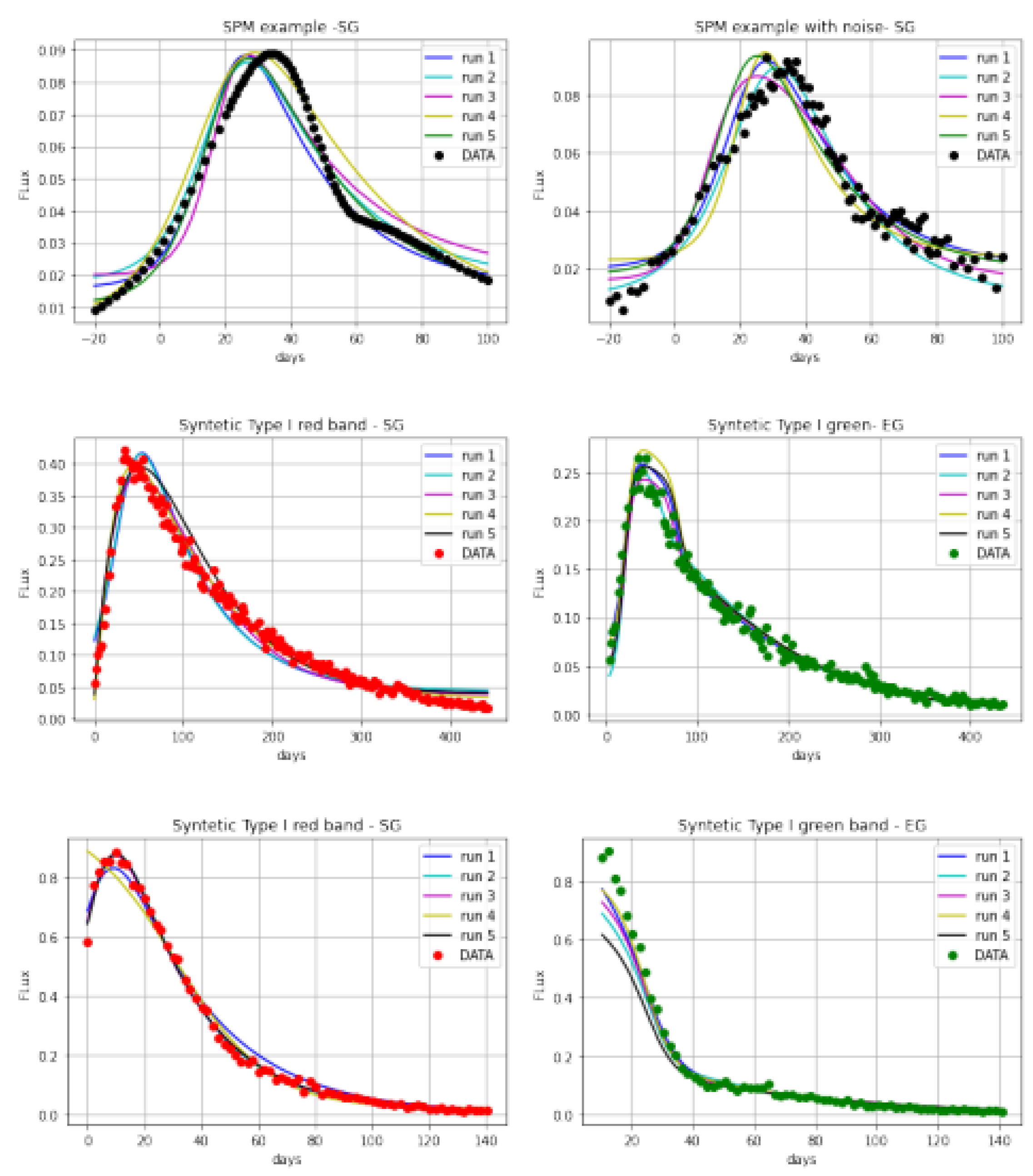
We used six datasets. The firt one was generated from SPM using the following parameters: $A = 0.18$, $t_0 = 33.941$, $\gamma = 18.975$, $\beta = 0.666$, $\tau_{rise} = 13.416$ and $\tau_{fall} = 40.076$, those values were taken from [2]. The second dataset was the same as first one but adding Gaussian noise. Additionally, we used four synthetic datasets. The synthetic data represent examples of green and red energy bands of two supernova type I. For the Generation of Synthetic Observations we based in [3]

3. Results

Even though the RMSE achieved with EG was less than SG in the four first used datasets there were no statistically significant differences in RSME archived with both grammars.



Functions obtained with explicit grammar



Functions obtained with simplified grammar

We noticed that the majority of functions obtained with SG have the following structure: a number that represents the first observation plus a fraction, where the denominator is similar to the SPM, and the numerator has a sigmoid.

4. Conclusions

SGE was used to generate a model that describes the Supernova, using two different grammars: One that uses the Parametric Model of Supernovae and that allows the adjustment of the parameters and another simpler one composed of sigmoid and exponential operations that generates different models for different cases maintaining a structure that allows the detection of increase, peak and decrease of the flux caused by the phenomenon. For multi-band supernovae SGE using the parametric model achieves good results that are close to the data, while for specific red and green bands the performance is not of quality. On the other hand, SGE with a simpler grammar achieves good performance in both cases, thus allowing to have a model generator that fits different SN types and different bands. The generation of simpler expressions than the parametric model allows a more practical and faster analysis of this phenomenon, as well as allowing to observe and theorize about differences in the models for each type of Supernova. The simplicity of the expressions allows to reduce the time needed for them to be evaluated, which could be useful for massive data processing of different phenomena of this nature.

References

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