IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10157-6

Neural network classification of gamma-ray bursts(*)

A. Balastegui(1), P. Ruiz-Lapuente(1)(2) and R. Canal(1)(3)

(1) *Departament d'Astronomia i Meteorologia, Universitat de Barcelona Martí i Franqués 1, Barcelona 08028, Spain*
(2) *Max-Planck-Institut für Astrophysik - Karl-Schwarzschild-Strasse 1 85740 Garching bei München, Germany*
(3) *Institut d'Estudis Espacials de Catalunya, Nexus Building 2-4 Gran Capità, Barcelona 08034, Spain*

(ricevuto il 23 Maggio 2005; pubblicato online il 20 Ottobre 2005)

Summary. — From a cluster analysis it appeared that a three-class classification of GRBs could be preferable to just the classic separation of short/hard and long/soft GRBs (Balastegui A., Ruiz-Lapuente P. and Canal R. *MNRAS* **328** (2001) 283). A new classification of GRBs obtained via a neural network is presented, with a short/hard class, an intermediate-duration/soft class, and a long/soft class, the latter being a brighter and more inhomogenous class than the intermediate duration one. A possible physical meaning of this new classification is also outlined.

PACS 98.70.Rz – γ-ray sources; γ-ray bursts.
PACS 02.50.Sk – Multivariate Analysis.
PACS 07.05.Mh – Neural networks, fuzzy logic, artificial intelligence in physics.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The existence of two different classes of gamma-ray bursts (GRBs) has been known since 1993 [1]. The bimodal distribution of the duration logarithms defined the separation between long ($T_{90} > 2$ s) and short ($T_{90} < 2$ s) GRBs. It was also known that short GRBs have harder spectra than long GRBs. That is the classical separation between short/hard and long/soft GRBs. In 1998 Horváth [2] made the first step towards a three-class classification of GRBs by fitting the duration distribution with three Gaussians. However, these firsts classifications were unable to assign individual bursts to definite classes: they only defined limiting durations, while short and long GRBs durations are overlapped.

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

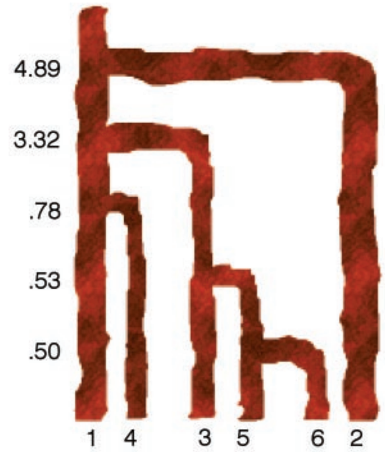

Fig. 1. – Dendrogram of the 11-dimensional analysis. The numbers at the bottom of the diagram are identifiers of the groups, and those at the left are the criterion values. A large increase in the criterion value is used to decide the number of classes. In this case the largest increase in the criterion value, occurs when merging cluster 3 and 1, thus suggesting a three-class classification.

2. – Cluster analysis

Duration is not the only relevant characteristic of GRBs, and the BATSE catalogue supplies up to nine physical quantities intrinsic to the burst: four fluences (corresponding to the four energy channels: Ch#1 25–50 keV; Ch#2 50–100 keV; Ch#3 100–300 keV; Ch#4 $>$ 300 keV), three peak fluxes (corresponding to the three time-scales of integration: 64, 256 and 1024 ms) and two durations (T_{50} and T_{90}). In addition, here we use the hardness ratio H_{32} and $V/V_{\max}$. A cluster analysis is applied to the logarithms of these 11 quantities. We use the Ward's method [3], that is an agglomerative hierarchical clustering method which starts from n points separated in the 11-dimensional space. These points will be grouped, on the basis of their dissimilarity, until one ends up with only one cluster. The method looks for clusters with minimum variance among objects belonging to that group, and with maximum variance between clusters. The algorithm

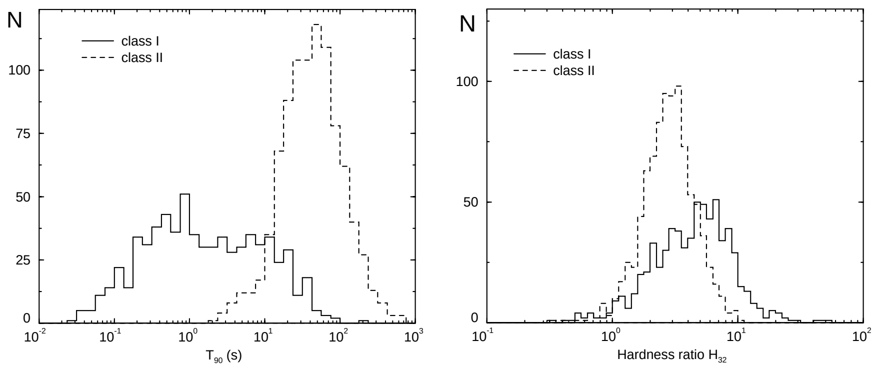

Fig. 2. – Duration (left) and hardness (right) distributions of the two-class classification from a neural network.

TABLE I. – *Characteristics of the neural network classification.* T_{90} *is in units of s,* P_{1024} *in* γ *cm*$^{-2}$ *s*$^{-1}$*, and* $F_{\rm total}$ *in units of* 10^{-6} *erg cm*$^{-2}$*.* $\langle H_{32}\rangle$ *is the hardness, the ratio of fluences of channels* 3 *and* 2*. Error intervals are* $\pm 1\sigma$*.*

Class	**2–I**	**2–II**	**3–I**	**3–II**	**3–III**
N	685	914	531	341	727
$\langle \mathbf{T}_{90}\rangle$	6.24±0.50	63.5±2.3	3.05±0.34	25.0±1.4	71.8±2.8
$\langle \mathbf{H}_{32}\rangle$	5.50±0.18	3.12±0.05	6.20±0.22	3.05±0.10	3.15±0.05
$\langle \mathbf{V}/\mathbf{V}_{\rm max}\rangle$	0.288±0.015	0.159±0.008	0.287±0.017	0.307±0.019	0.123±0.008
$\langle \mathbf{P}_{1024}\rangle$	0.94±0.04	3.82±0.22	0.81±0.04	1.25±0.08	4.51±0.28
$\langle \mathbf{F}_{\rm total}\rangle$	1.44±0.09	25.1±2.0	1.13±0.07	2.82±0.16	30.8±2.5
$\langle \cos\theta\rangle$	+0.002±0.024	−0.024±0.021	−0.003±0.027	−0.012±0.033	−0.022±0.023
$\langle \sin^2 b - 1/3\rangle$	−0.005±0.012	+0.001±0.010	−0.014±0.014	+0.009±0.016	+0.003±0.012

uses a weighted Euclidean distance between the last two joined groups, as the criterion value used to decide the number of classes. Figure 1 shows the dendrogram with the last six levels of clustering. We see that the most important increase of the criterion value occurs when joining group 3 with group 2, telling us that we have merged two groups with rather different characteristics. There is also a rise, but not so important, in the criterion value when merging cluster 2 with cluster 1. This analysis favours the three-class classification over the classical two-class classification.

3. – Neural networks

One step beyond cluster analysis is the neural network classification which can handle non-linear relationships. Neural networks are artificial intelligence algorithms that can be used for an automatic and objective classification. We have used the *Self-Organizing Map* algorithm [4], a non-supervised algorithm, since we do not want to start from any known classification. Like in the cluster analysis, the entrance parameters will be the logarithms of the same 11 variables. We have to specify to the program the dimension of the output space, and based on the results of the cluster analysis we will run the network two times asking for a two and a three-dimensional output space, grouping thus two or three classes of GRBs.

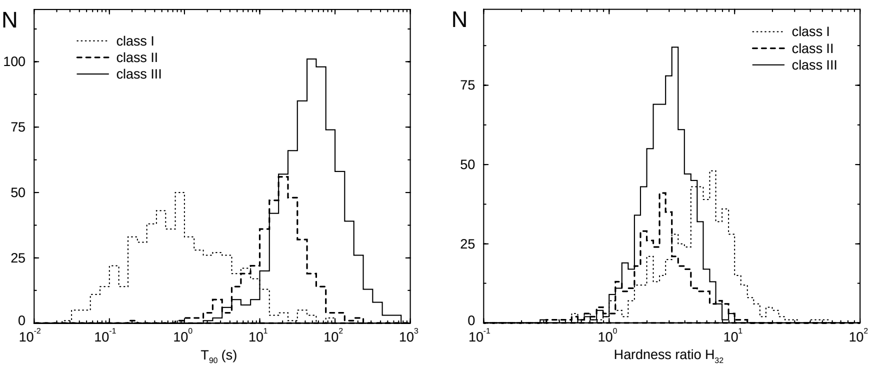

Fig. 3. – Duration (left) and hardness (right) distributions of the three-class classification from a neural network.

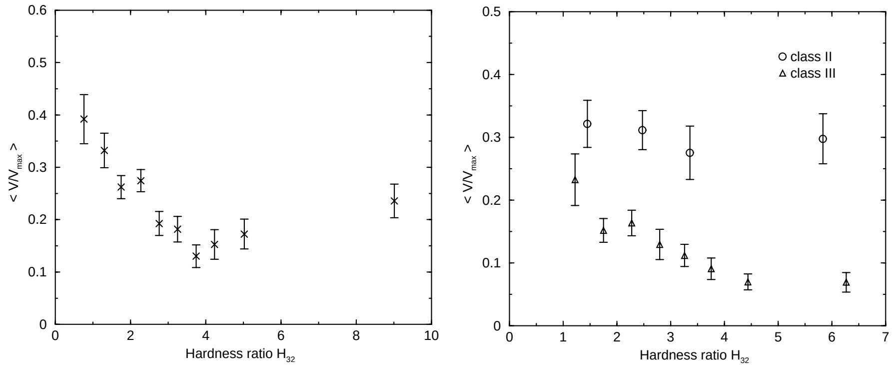

Fig. 4. – $\langle V/V_{\rm max}\rangle$ *vs.* H_{32} for GRBs with $T_{90}> 2$ s (left) and for classes 3-II and 3-III (right). Error bars represent $\pm 1\sigma$ interval.

4. – New classification

Table I summarizes the characteristics of the two-class and three-class classifications of the neural network. As can be seen the two-class classification recovers the classical short/hard and long/soft GRBs, but now we are able to classify individual bursts in the overlapping region (see fig. 2). It is surprising that classical short GRBs have durations up to 100 s. In the three-class classification, the new class 3-II is composed by the longer and softer bursts from class 2-I, and by the shorter bursts from class 2-II. This new class of intermediate duration has the same hardness as the long duration class. In contrast they have different fluences, peak fluxes and rather different values of $\langle \mathrm{V/V_{max}}\rangle$. All classes derived from the neural network are compatible with isotropy, as seen from the values of the dipole ($\langle\cos\theta\rangle$), and quadrupole ($\langle\sin^2 b - 1/3\rangle$) moments.

5. – Hardness evolution

$\langle V/V_{\rm max}\rangle$ gives a measure of the maximum redshift of a sample of GRBs [5], the lower its value the deepest the population being, so class 3-III GRBs are the farthest ones. Figure 4 (left) shows that classical long-duration GRBs are harder the farther away they are produced. With a Spearman rank test, the significance level for this correlation is $4{\cdot}10^{-13}$ for class III, thus implying a strong correlation between $\langle V/V_{\rm max}\rangle$ and H_{32}, while the significance level for class II is 0.51, meaning that the null hypothesis of no correlation cannot be rejected for this class. GRBs produced from collapsars are expected to take place at very long distances and may possess such evolution with distance, that making them good candidates to produce class 3-III GRBs. On the other hand, compact-object mergings are expected to happen at shorter distances and lack such evolution, that making them good candidates to produce classes 3-I and 3-II GRBs.

REFERENCES

[1] Kouveliotou C. *et al.*, *ApJ*, **413** (1993) L101.
[2] Horváth I., *ApJ*, **508** (1998) 757.
[3] Murtagh F. and Heck A., *Multivariate Data Analysis*, in *Astrophysics and Space Science Library* (Dordrecht Reidel) 1987.
[4] Kohonen T., *IEEC Proc.*, **78** (1990) 1464.
[5] Mao S. and Paczyński B., *ApJ*, **388** (1992) L45.