GHostS – Gamma-Ray Burst Host Studies

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GHostS is the largest public data-base on gamma-ray burst (GRB) host galaxies and is accessible at the URL *http://www.grbhosts.org.* Started in 2005, it currently contains photometric and spectroscopic information on 39 GRB hosts, almost 2/5 of the total number of GRBs with measured redshift. It will continue to grow, together with the unstoppable data flow from the observatories all over the world, every time a new event is discovered. Among other features, GHostS uses the Virtual Observatory resources.

The Gamma-Ray Burst phenomenon

Gamma-ray bursts (GRBs) are the most energetic events in the Universe, and also among the fastest. They are associated with the death of massive stars (core collapse supernovae) or the merging of compact objects, such as neutron stars and black holes. During the explosive phase, they emit most of their energy as a collimated flux of gamma-ray photons from neutrino-antineutrino annihilations, and as gravitational waves. The gamma emission lasts from a few milliseconds to a few minutes.

The first GRB was discovered in 1967, by the US military satellite Vela, but it took six years, until 1973, for the first paper to appear in a scientific journal. The first redshift was measured in 1997, when GRBs were finally confirmed to be cosmological sources. Today there are 108 GRBs with measured redshift, the highest being GRB 050904, at $z = 6.3$. The typical energy emitted by a GRB, in a couple of minutes, is 10^{51} ergs, equivalent to the energy emitted by the sun in 10 billion years.

Today GRBs are primarily discovered by the satellite *Swift* (*http://swift.gsfc.nasa.gov*), the dedicated NASA mission which in two years of operation helped to double the number of measured redshifts. With the growing data collected from space and ground telescopes, and the advent of Swift, our group decided to create a database, available to scientists, which collects observational results on the galaxies hosting GRB events. We called it GHostS, or GRB Host Studies. Our focus is to explore and unveil the nature of galaxies in which GRBs occur. Our goal is to answer fundamental questions, such as: are these galaxies different from the general galaxy population; are they special in any way; can we use them to understand galaxy formation under extreme conditions?

Today the GHostS database includes results for 39 GRB host galaxies. This is a large number, considering that only 108 GRBs have known redshift (see Figure 1).

The GRB host galaxy population

There is no doubt that studies of GRB host galaxies are entering into a realm of galaxy formation that was hardly known before. The reason is that GRB hosts are generally faint and detected at high redshifts. Similar galaxies are very hard to find using conventional techniques, because they would require very long integration times, even for the largest and most efficient telescopes.

GRB events offer a shortcut to the quest for faint and distant galaxies. They are detected as short and energetic events. The localisation (and for a fraction of them the redshift) is measured from the bright X-ray and optical afterglow. We know that long-duration GRBs occur in regions of star formation, therefore, they are associated with galaxies. Dedicated programmes can observationally complete the investigation.

In our GHostS search, we want to explore many of the most interesting galaxy parameters, such as metallicity, star-formation rate, stellar mass, age of the stellar population and dust extinction. Each of these parameters are very difficult to derive. One difficulty is the faintness of the typical GRB host. Moreover, the data obtained by the community are often not homogeneous. To complicate the picture, the tools often used to derive the physical quantities are affected by systematic uncertainties which are sometimes greater than the relations being derived.

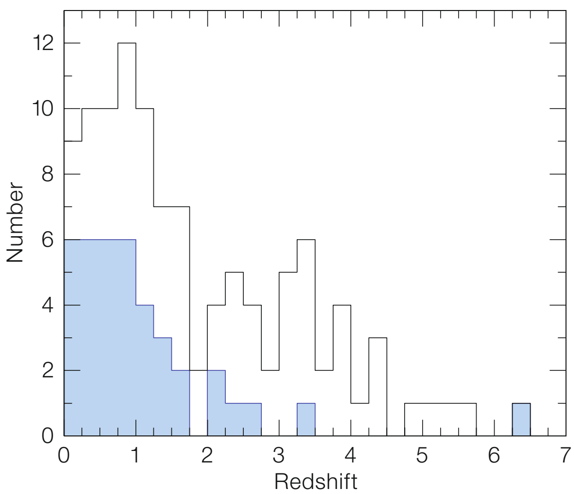


Figure 1: Redshift distribution of all GRBs (empty histogram) and the subsample of GRBs included in the GHostS database (blue histogram).

The typical GRB host is a star-forming, low-mass and low-metallicity galaxy, detected at redshift below $z = 2$. The mean stellar mass we derived in our sample is similar to the stellar mass of the Large Magellanic Cloud (Figure 2). Observational limitations prevent us from fully exploring the same parameters in GRBs at larger redshift, but in exceptional cases. The detection of the cold interstellar medium in high-redshift hosts indicates that there the population is different, with larger stellar masses, higher star-formation rates and higher metallicities (Berger et al. 2005, Fynbo et al. 2006, Savaglio 2006). It is still unclear if this means a different population, or different observational biases. Such issues will be faced and fully exploited by the future generation of telescopes and instruments.

In general, we know that GRB hosts are very peculiar galaxies. We still do not know whether this is because our traditional observational technique cannot reach the extreme limits attained by GRB detections, or because GRB hosts are intrinsically different. The main limitation is the small number of galaxies discovered so far. This number is still below 100, while the number of galaxies in today's surveys exceed 10^5.

The GHostS database

GHostS includes GRB hosts for which photometric and spectroscopic information is available from the literature (Figure 3). In total 39 galaxies, out of a total of 108 GRBs whose redshift is known, have been gathered from 81 different papers and sources.

One of the spectra in the GHostS database is shown in Figure 4. The galaxy hosting GRB 990712 at redshift $z = 0.433$ was observed at the Very Large Telescope (Küpcü Yoldaş, Greiner, Perna, 2006). It has very strong emission lines, originating in regions of the galaxy where star formation is very active. We derived a stellar mass of the galaxy of a few times $10^9\ M_\odot$, similar to the stellar mass of the Large Magellanic Cloud, but it forms stars at a rate that is ten times higher, about $6\ M_\odot\ yr^{-1}$. This gives a specific star formation (the SFR per unit stellar mass) of 100 times that in the Milky Way. Similar

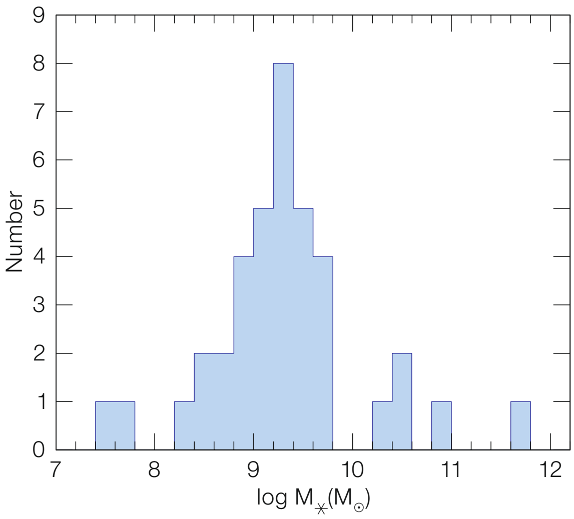


Figure 2: Histogram of the stellar mass of GRB host galaxies in the redshift interval $0 < z < 6.3$, from the GHostS sample. The mean stellar mass is of the order of the stellar mass of the Large Magellanic Cloud. This is ten times smaller than the stellar-mass limit reached by the deepest high-redshift galaxy surveys, performed by todays' largest telescopes.

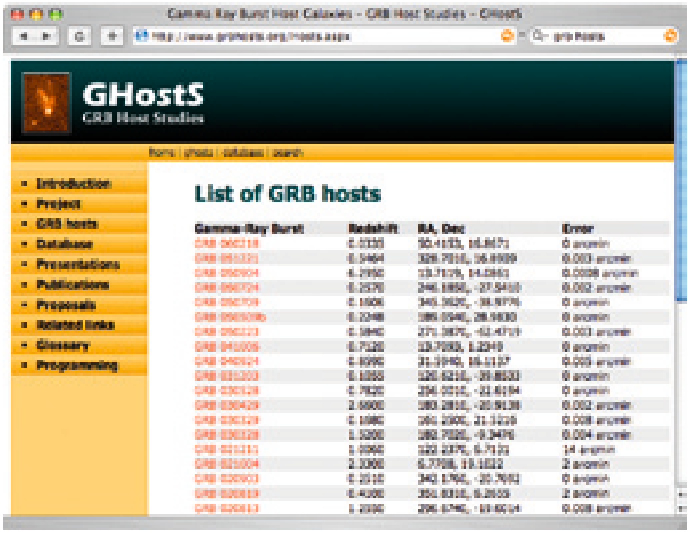


Figure 3: Example of the GHostS database web pages. Each GRB entry includes basic information on the event, together with access to relevant papers available in the literature. It reports multi-band photometry, fluxes of emission lines and images of the field.

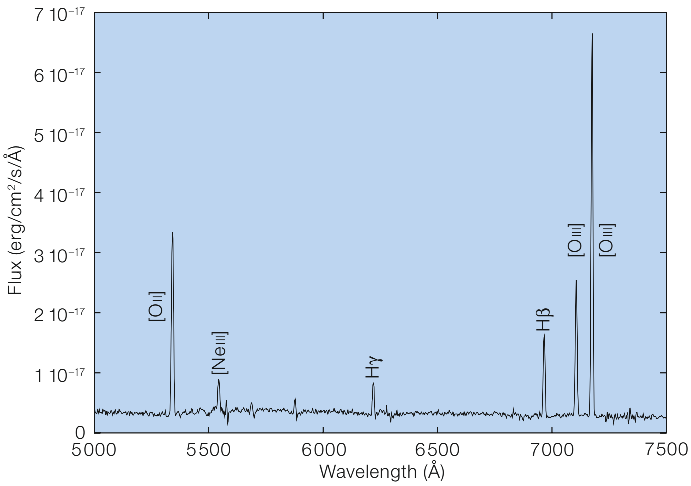


Figure 4: Very Large Telescope spectrum of the galaxy hosting GRB 990712 at redshift $z = 0.433$ (Küpcü Yoldaş et al. 2006).

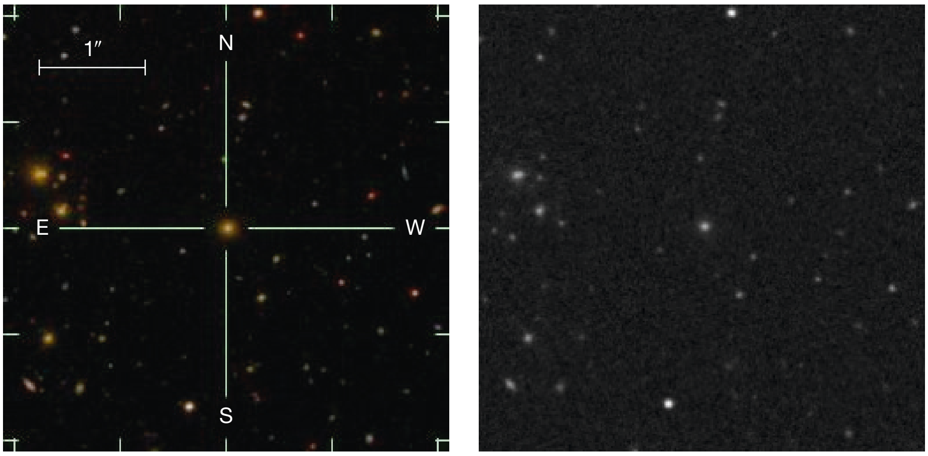


Figure 5: One example of the tools offered by GHostS. The images show the field of GRB 050509b, at redshift $z = 0.2248$ (Gehrels et al. 2005), obtained from the Sloan Digital Sky Survey (left) and Digitalized Sky Survey (right) archives, through the Virtual Observatory.

galaxies hosting GRBs are detected up to a distance when the Universe was less than 1 Gyr old. They are very hard to find using normal tools of investigation. Most surveys, probing the high-redshift Universe today, can reach, in terms of stellar mass, galaxies similar to or larger than the Milky Way.

It is generally not easy to collect results published by the GRB community, because the number of papers available for each event can be large. One extreme case was GRB 060218, which occurred in February 2006, at redshift $z = 0.0335$, associated with a supernova, detected three days after the alert (Masetti et al. 2006). In about a year and a half, more than 20 articles dedicated to this event have been published (or are in the process of being published) in refereed journals, four of which appeared in *Nature*.

This proliferation of material is one of the main motivations for the existence of GHostS. Observational results are searched, collected, homogenised and made easily accessible for the whole community. The database is constantly growing in terms of total number of objects, and in terms of tools offered. We plan to eventually include all host galaxies discovered in the past and in the future for the years of operation of Swift, and it will likely contain a final sample of a few hundred galaxies.

The Virtual Observatory

The Virtual Observatory (VO) is one of the features offered in our database. The VO is one of the newest and most promising tools introduced in the astronomy world, allowing scientists to easily access data from multiple astronomical observatories, both ground- and space-based facilities, through one portal (see for instance *http://www.us-vo.org/*). Its components have been added to the GHostS web portal (Figure 5). Using information about the GRBs and their hosts stored inside our SQL database, one can automatically enhance the view of the catalogued hosts by using various VO resources. The details pages currently show images of the relevant pieces of the sky as seen by the Sloan Digital Sky Survey (SDSS) and the legacy Digitized Sky Survey (POSS, SERC). Other types of automated searches are also in the works, e.g., for finding spectra at the given position. These VO additions, the efficient database, and the presentation of the scientific data, make the website not only an invaluable research tool for GRB host studies, but also very enjoyable to navigate. GHostS will feature in the future advanced search capabilities for the community, fine-tuned for astronomical data and will eventually dynamically search VO resources for relevant observations, such as images and spectra.

The future

The future of GRB science fully depends on the life of GRB hunting machines, i.e. gamma-ray detectors. Today it almost exclusively relies on the existence of Swift, which has been funded for an additional four years.

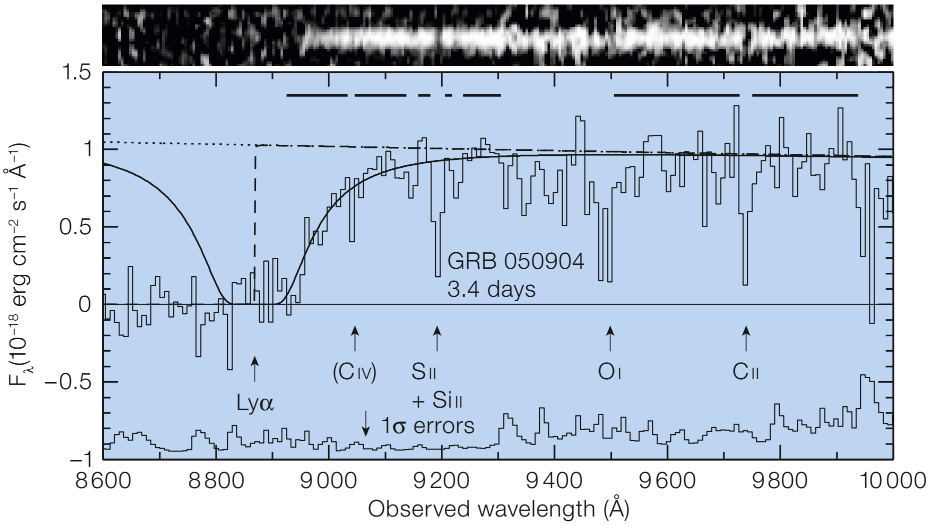
Among the many unexplored territories, we mention the discovery of the very high redshift GRBs, at $z > 6$. We know that there are collapsed objects at those times. We do not know under which physical conditions these objects formed: are they stars, galaxies or massive black holes? At $z > 6$, QSO searching has failed in providing a satisfactory picture, and galaxies are incredibly hard to find. GRBs on the other hand have shown some very promising results. In the first two years of operations, Swift has discovered 8 GRBs at redshift larger than 4, and 4 at redshift larger than 5. This is 7 % and 3.5 % of the total GRB population with measured redshift, and probably the numbers would be larger if we were able to observe all GRB afterglows early on. In fact, 2/3, of the Swift GRBs have no measured redshift. The fractions of $z > 4$ and $z > 5$ known QSOs are 0.8 %. and 0.03 % of the total, with only 17 QSOs known with redshift larger than 5.

Particularly impressive was GRB 050904, the record holder at $z = 6.3$ (Kawai et al. 2005). This GRB was observed with the Japanese telescope Subaru more than three days after the Swift alert, when it had already faded 11 magnitudes from its initial brightness. Fortunately at high redshifts the brightness of a fading object is helped by time dilation, the effect described in Einstein's theory of General Relativity. If this GRB had occurred in the local Universe, it would have faded at a rate more than seven times faster. The spectrum of this spectacular event is shown in Figure 6 (from Totani et al. 2006). The host galaxy is barely detected by the Hubble Space Telescope and Spitzer Space Telescope (Berger et al. 2006). We estimate a stellar mass which is half that of the Large Magellanic Cloud, and a rate of star formation ten times higher. Although this event happened less than 900 million years after the Big Bang, the absorption lines detected in its spectrum indicate a surprisingly high pollution of heavy elements in the interstellar medium in the host galaxy, of the order of 1/10 that of the solar vicinity (Totani et al. 2006;

Savaglio 2006). This is hardly explained by most theories of chemical enrichment in the primordial Universe. Galaxies like these are very likely faint and dormant today, because they would have consumed their gas reservoir for star formation in less than one Gyr, i.e. by redshift $z = 3$.

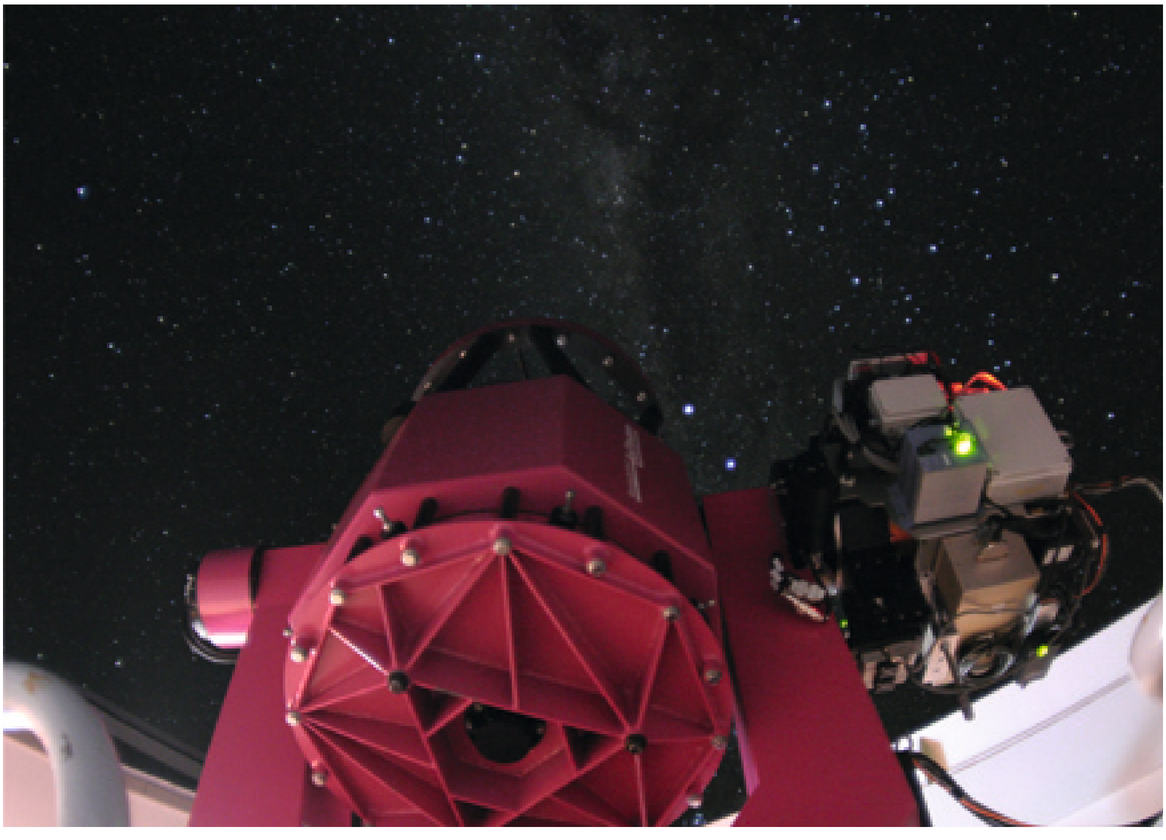
If GRB 050904 were observed two hours after the Swift alert, its spectrum would have been much more spectacular, with a signal-to-noise ratio ten times better than that of the Subaru spectrum. Nothing like this has ever been achieved in the remote Universe with normal galaxies or QSOs. It is only a matter of time that, sooner or later, Swift will trigger similar events at higher redshift. Then telescopes from the ground will be ready to catch the fading sources and deliver a unique data set to the scientific community, for new exciting discoveries. We will be there to continue our service to the community with GHostS, in the attempt to fully characterise those galaxies parenting one of the most extraordinary objects in the Universe.

Figure 6: Subaru spectrum of the most distant GRB ever discovered, GRB 050904 at $z = 6.3$ (Totani et al. 2006). It was observed more than three days after the alert given by the gamma-ray burst finder Swift, when it had already faded 11 magnitudes from its initial brightness.



References

Berger E. et al. 2005, ApJ 642, 979
Berger E. et al. 2006, ArXiv Astrophysics e-prints, arXiv: astro-ph/0603689
Fynbo J. P. U. et al. 2006, A&A 451, L47
Gehrels N. et al. 2005, Nature 437, 851
Kawai N. et al. 2005, GRB Coordinates Network 3937, 1
Küpcü Yoldaş A., Greiner J. and Perna R. 2006, A&A 457, 115
Masetti N. et al. 2006, GRB Coordinates Network 4803, 1
Savaglio S. 2006, New Journal of Physics 8, 195
Totani T. et al. 2006, PASJ 58, 485



The Rapid-Eye Mount (REM) 0.6-m telescope at the ESO La Silla Observatory, which is dedicated to the follow-up of gamma-ray bursts, is shown in operation. ESO PR 26/07 provides details of the telescope and some science results.