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GAUDI: a preparatory archive for the COROT mission [4]

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ABSTRACT

The GAUDI[1] database (Ground-based Asteroseismology Uniform Database Interface) is a preparatory archive for the COROT[2] (COnvection, ROtation and planetary Transits) mission developed at LAEFF[3] (Laboratory for Space Astrophysics and Theoretical Physics). Its intention is to make the ground-based observations obtained in

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[1]http://sdc.laeff.esa.es/gaudi/

[2]http://www.astrsp-mrs.fr/projets/corot/

[3]http://www.laeff.esa.es

preparation of the asteroseismology programme available in a simple and efficient way. It contains spectroscopic and photometric data together with inferred physical parameters for more than 1 500 objects gathered since January 1998 in 6 years of observational campaigns. In this paper, the main functionalities and characteristics of the system are described.

Subject headings: Astronomical databases: Catalogues; Stars: fundamental parameters

1. Introduction

The COROT satellite (Baglin et al. 2002) will be launched in 2006 and is intended to perform high-precision (micromagnitude) photometric monitoring of stellar targets to achieve two main objectives:

- Asteroseismology of about a hundred dwarf stars to give direct information on the structure and dynamics of their interiors; among those, a few bright stars (F,G dwarfs, β Cep, and δ Sct; V $\leq$ 6.5) will be monitored for up to 5 months, and up to 10 fainter (V $\leq$ 9.5) stars per field will be observed simultaneously, so as to cover the HR diagram as completely as possible.
- The detection of planets down to Earth-sized telluric planets, using the method of transits.

In addition to this, the mission will provide accurate, continuous, photometric monitoring of thousands of fainter stars (11.5 $\leq$ V $\leq$ 16). Such space-based photometry will have a signal–to–noise ratio several orders of magnitude better than can be obtained using ground-based facilities and will provide a mass of highly original data on a wide diversity of stars.

The intrinsic nature of the seismology programme of the COROT mission (very long observations of a small number of bright stars) makes the target selection a critical issue. In order to take full advantage of the COROT data and to strongly constrain stellar evolution models, the seismic information needs to be complemented with precise and reliable knowledge of the fundamental stellar physical parameters (i.e. effective temperatures, luminosities, surface gravities, rotational velocities and chemical abundances). Also, it is necessary to identify potential doubled-lined spectroscopic binaries (SB2), due to the difficulty of disentangling the individual oscillation information from the composite spectra. Finally, peculiarities such as photometric or spectroscopic variability, magnetic

[4]Based on observations collected at La Silla (ESO proposals 67.D-0169, 69.D-0166 and 70.D-0110), Telescopio Nazionale Galileo (proposal 6-20-068), Observatoire de Haute-Provence, South African Astronomical Observatory, Tautenburg Observatory and Sierra Nevada Observatory.

activity, spectral line asymmetries, etc... also need to be identified. For an optimal definition of the final target list it is, therefore, essential to gather as much a priori information as possible on the physical parameters and characteristics of the stars. However, it was soon realized that the available information for many of the potential targets was insufficient for a reliable selection. For this reason an ambitious ground-based observing programme, to obtain Strömgren photometry and high resolution spectroscopy in order to accurately and reliably determine the physical parameters for more than 1 500 objects, was launched within the framework of the COROT mission.

To cope with this vast and heterogeneous (different instrumentation, reduction procedures, analysis techniques, people,...) dataset in a convenient way it was necessary to develop a user-friendly access system. This was considered as a fundamental objective by all the scientific groups involved in the COROT project and, in March 2001, LAEFF was nominated as responsible for the development and long-term maintenance of GAUDI.

2. The data

The requirement for long and continuous observations on the same field imposes the necessity for a polar orbit for the satellite, with the line of sight almost perpendicular to the orbital plane to avoid eclipses from the Earth. As the line of sight has to be in opposition with the Sun, every six months the satellite will be rotated by 180°. In April 2001, the COROT scientific council made the final decision for the orbital plane of the satellite defining an accessibility zone centered at α=6h50m and 18h50m and δ=0°, and about 10° in radius. This zone was named scenario 4 to distinguish it from other observing windows previously considered. In a first stage the catalogue contained all stars at a distance less than 10 degrees from the centre of the accessibility zone with a visual apparent magnitude brighter than V=8. Whenever possible, giants were excluded on the basis of their Hipparcos parallaxes. It was then noticed that limiting the input catalogue to objects brighter than V=8 was sometimes insufficient to take full advantage of the instruments capabilities (to monitor up to 10 targets simultaneously in the seismology field) as there were not enough faint candidates around the bright main targets. To overcome this situation an extension of the spectroscopic and photometric campaigns was recently initiated to cope with the stars with $8 \leq V \leq 9.5$ in the fields of the COROT main targets. All the new observational data as well as the physical parameters obtained in the characterization study will be included in the GAUDI archive in the coming months leading to an increase of about 50% in the present content of the database.

2.1. Echelle Spectroscopy

Most of the spectroscopic observations were conducted on telescopes of the 2m and 4m class, equipped with high resolution echelle spectrographs ($R = 40\,000 - 50\,000$) from three different sites (OHP with the ELODIE instrument on the 1.93m telescope, La Silla with FEROS on the 1.52m

and 2.2m telescopes and La Palma with the SARG spectrograph on the 3.5m TNG). Typical signal-to–noise ratios range from 100 to 150 at 5500 Å. The wavelength interval covered was 3 900–6 800 Å, 3 800–9 100 Å and 4 600–6 800 Å for ELODIE, FEROS and SARG respectively.

In addition to these three main sites, a few more spectra were secured at La Silla with the 1.2m Swiss telescope equipped with the CORALIE spectrograph, at SAAO (South Africa) with the 1.9m Radcliffe telescope equipped with the GIRAFFE echelle spectrograph, and at Tautenburg (Germany) with the 2m telescope and Coudé spectrograph.

For the reduction of spectroscopic data acquired with the ELODIE, FEROS and CORALIE spectrographs, the first steps (order localization, background estimate and subtraction and wavelength calibration) were performed using available on-line reduction pipelines. Special attention was paid to the blaze and flat-field correction. Instead of the standard correction implemented in the available pipelines, we used the following procedure: (1) one or several spectra of O-type stars were acquired during the observations. (2) The extracted orders of these reference spectra were used to define the blaze function by fitting low-order cubic splines to sets of data points across each order, carefully avoiding regions containing the few spectral lines in these spectra. The extracted spectra of our programme stars were corrected separately for pixel-to-pixel response using Tungsten flat-field spectra and from the blaze response as described above. Such procedures led to significant improvements on the goodness of the results, also in those cases with well settled reduction pipelines (for instance, see Rainer (2003) for FEROS).

Special care was taken with the flat-field correction of SARG data given the different sensitivity of the spectral output depending on the position angle of the image derotator. Furthermore, periodic and spurious signals due to CCD electronics and affecting some of the spectra, prevented a standard cleaning procedure via FF techniques, requiring instead an optimized fitering and data extraction (see Tsymbal et al. (2003) for full details on the reduction procedure).

The data from Tautenburg were reduced using the IRAF package with a standard spectroscopic reduction pipeline whereas for the SAAO GIRAFFE data, we used the Esprit reduction package as described in Donati et al. (1997). GIRAFFE is a copy of the MUSICOS spectrograph, fully described in Baudrand & Bohm (1992).

In addition to the reduced echelle spectra, the mean photospheric line profiles of the stars were computed following the LSD (Least Square Deconvolution) method described in Donati et al. (1997). In this method, a line pattern function is constructed, containing all the lines supposedly present in the spectrum as Dirac functions, with heights set to the central line depths as calculated by the SYNTHE programme (Kurucz 1979). The observed spectrum is then deconvolved with this line pattern function, yielding a "mean" photospheric line profile. This method has proved to be a powerful tool to calculate accurate rotational velocities as well as to detect multiple systems, line asymmetries and spectroscopic anomalies.

All reduced spectra and mean profile files were recorded as standard FITS binary tables, with a normalized header including all necessary information on the object, on the instrument, on the

exposure, and on the reduction. For FEROS and ELODIE spectra the binary table contains five columns with information on wavelength, flux (both un-normalized and normalized), signal–to–noise ratio and echelle order. The SARG spectra also contains the same five columns but with null values in the un-normalized flux and the echelle order columns.

2.2. Strömgren photometry

Observations on the $ubvy\beta$ system were obtained over two-week runs for each summer and winter observing periods during the years from 2000 to 2004. The fully-automated six-channel ($uvby\beta$) spectro-photometer on the 0.9-m telescope at the Sierra Nevada Observatory (OSN) was used for these observations. In the paper by P.J. Amado (in preparation) details of the observing, reduction and transformation procedures are given in full. The telescope, the photometer, the autocentring process and the data acquisition are all taken care of by TELESTROM, a software package developed at the Instituto de Astrofísica de Andalucía.

Observations of programme stars were taken interleaved with those of standard stars. Between three and six standards were observed once every one or one and a half hours during the night to follow and determine the extinction. Sky background observations were made according to the Moon's phase and its position in the sky. On nights with no or very low sky background flux, one sky observation was taken with the extinction stars. This number was increased for nights with higher sky flux, with up to two sky measurements per star, one before and one after the measurement of the star.

Transformation to the standard system followed Gronbech et al. (1976) with the standard system defined by stars selected from the catalogues of Olsen (1993; 1994a; 1994b).

2.3. Data policy

Data in the GAUDI archive become public to the world community after one year of proprietary time starting in January 2003 for data delivered before this date and at the time of ingestion into GAUDI if this happened after January 2003. This means that the first release of public data took place in January 2004. At the time of writing, 851 spectra of 433 objects out of a total of 2 369 spectra as well as Strömgren photometry for 1 407 objects are publicly available.

Public data are free with no restrictions. Any user connected to the internet is able to query the archive. Private data are available only for people involved in the preparation of the COROT mission. They must be registered and identify themselves when logging into the system using a user-name and password provided by the GAUDI staff. Information on the release dates of the private datasets can be obtained from the welcome page of the GAUDI system. Research work benefitting from the use of both public and private GAUDI data should include the following acknowledgment

in publications: "Based on GAUDI, the data archive and access system of the ground-based asteroseismology programme of the COROT mission. The GAUDI system is maintained at LAEFF which is part of the Space Science Division of INTA".

3. The GAUDI system. Functionalities

Data archiving typically comprises the data ingestion, data storage, data management and data retrieval through an interface. Once the data were reduced they were shipped to LAEFF for their ingestion in the GAUDI archive. The reduced spectroscopic data were adapted to the spectral data model defined for GAUDI. To ensure integrity, metadata were extracted from the FITS headers of the spectroscopic data and ingested in the GAUDI database in an automated way. The data themselves reside on a mass storage system (magnetic disks) in FITS format. Data safekeeping is guaranteed with a well-defined backup policy. Moreover, a number of quality control tests have been defined to ensure the reliability of the data and metadata provided by the archive.

The friendliness of the user interface is extremely important for the archive to be effectively used. With this aim, GAUDI is HTML-based to allow straight forward access (no need to implement special software on the user's side) through the Web.

3.1. Archive search

The query to the access catalogue is made by means of a fill-in form. In addition to the "classical" query keywords (object name or list of names and coordinates), GAUDI allows project-related interrogation of the system (observing scenario, instrument, programme) as well as the possibility to explore the spectroscopy (signal–to–noise ratio), photometry (dereddened color indexes) and stellar physical parameter space (spectral type, effective temperature, surface gravity, absolute magnitudes, metallicity) (Fig. 1). Searches are case independent and wildcards are permitted. The system also incorporates a built-in name resolver allowing queries by any of the names provided by the SIMBAD database.

The three output fields (spectroscopy, photometry and physical parameters) can be presented in different formats (HTML, ASCII, tab-separated or comma-separated values) and ordered by different criteria (coordinates, object, spectral type, programme and scenario). As stated in Section 2.3, only the spectroscopic and photometric data (and not the physical parameters) are presently accessible from the public interface.

3.2. Result from search

The information available in GAUDI is divided into three categories: spectroscopy, photometry and physical parameters.

3.2.1. Spectroscopic field

For each observation, the spectroscopy field provides information on the object name, the coordinates, the visual magnitude and spectral type, programme, scenario, observing date and time, exposure time and the instrument used for the observation. In addition to this, the following utilities are provided if the HTML output format is selected (Fig. 2).

- Link to SIMBAD: by clicking the object name, the information contained in the SIMBAD database is displayed.
- Spectral retrieval: Spectra may be retrieved individually or in groups. For multiple retrieval it is possible to include/exclude individual spectra. Multiple spectra retrieval generates a file in either zip or tar format that can be compressed for network efficiency. Single spectra are retrieved uncompressed.
- FITS Header Display: Links are provided to display the FITS primary and binary table headers of each requested echelle spectrum or mean photospheric line profile file.
- Data previews: A browse plot of the echelle spectrum as well as the associated mean photospheric line profile is generated by clicking on the corresponding link. A panel summarizing the observation is displayed next to the plot, and the full FITS header can be listed from there. Zoom plots of 30 Å or 30 kms^{-1} (depending on whether an echelle or a mean photospheric line profile file is displayed), may be generated by entering the desired central wavelength or radial velocity displacement. A new viewport is created allowing an overview of the entire set of data and a simultaneous view of the selected region. This viewport is automatically refreshed for subsequent zooms. A copy of a browse or zoom plot can be saved as a GIF file (Fig. 3).

3.2.2. Photometric field

For each observation, the photometric field provides information on the coordinates, visual magnitude, the (B-V) color, programme, scenario, observing date and time, the airmass, the Strömgren indices m_1, c_1, β, (b-y) and the dereddened values $(b-y)_0$, m_0, c_0, dm_0, dc_0 and their corresponding errors. Dereddened indices have been obtained using the TEMPLOGG package (Rogers 1995).

3.2.3. Physical parameters

For a given object, the physical parameter field gives information on coordinates, visual magnitude, the (B-V) color, programme, scenario, spectral type, luminosity class, proper motion, radial velocity, projected rotational velocity, absolute magnitude, effective temperature, surface gravity and metallicity. The physical parameters have been obtained using different methods. GAUDI provides information on the "best" value as well as an error estimate, the method used and eventual comments associated to the measurement. The best value was defined using a hierarchical scheme agreed within the COROT project. Information on the adopted hierarchy can be obtained by clicking on the corresponding column label.

3.3. On-line documentation and HelpDesk

For the system to be properly used, it must include well-structured, and have easy-to-find, documentation both on the COROT project and the GAUDI system. In order to efficiently answer the user's needs, the following multi-layer approach (from the most general to the most specific questions) has been adopted:

- On-line access to project documentation: a detailed description of the project, the archive and the access system is given on-line from the GAUDI welcome page. Links to the COROT project and LAEFF web pages are also available.
- On-line help: help on a specific keyword of the system query form can be obtained by simply clicking on it.
- Helpdesk: for those questions not channeled through the previous levels and to provide a continuous support to the archive users.

4. GAUDI in the framework of the Virtual Observatory

Although astronomical archives constitute a basic tool for modern Astrophysics as revealed by their intensive usage, the efficiency in information retrieval is seriously limited by the lack of interoperability among them. The Virtual Observatory[5] (VO) is an international project aimed at solving the problems that this lack of interoperability creates for multiwavelength astronomy. Accordingly, one of the VO main objectives is the creation of a federation of astronomical Data Centres that, with the implementation of new technologies and standards, provides an easy and efficient access to the astronomical data. GAUDI is part of the Spanish Virtual Observatory[6] and,

[5]http://www.ivoa.net

[6]http://svo.laeff.esa.es

as such, has been designed following the standards and requirements defined in the framework of the Virtual Observatory. This will permit a transparent access to the archives and databases that will form the EURO-VO Data Centre Alliance (DCA), a collaborative and operational network of European data centres which, by the uptake of new VO technologies and standards, will publish data, metadata and services in a VO-compliant way.

One of the VO requirements that GAUDI already incorporates is the SSA (Simple Spectral Access) protocol, a standard defined for retrieving spectroscopic data from a repository of astronomical data. Through this method, a client searches for available data that match certain client-specified criteria using a HTTP GET request. The response is a table (in VOTable[7] format, an XML format defined for the exchange of tabular data in the context of the Virtual Observatory) describing the available data including metadata and access references (implemented as URLs) for retrieving them.

5. Conclusions

The characterization of the COROT fields requires a lot of resources. A well-designed, properly-implemented data archive and access system like GAUDI is demonstratively a major contribution towards the full exploitation of these expensive-to-obtain observational data. Homogeneity and uniformity have been two basic requirements for GAUDI. This makes it possible to conduct global archive searches in order to confirm/discard characteristics associated to a given group of objects. A good example of this is the discovery of 17 new Be stars (Neiner et al. 2004) based on GAUDI data. Moreover, the advent of the Virtual Observatory, an initiative to allow global electronic access to available astronomical data, both space– and ground–based, will boost the use of astronomical archives. GAUDI, designed to fulfill the VO requirements, will access a massive amount of different datasets (images, spectra, catalogues) covering the sky at all wavelengths which will allow very efficient real multiwavelength research.

The contents of GAUDI will increase in the near future by the ingestion of new photometric and spectroscopic data as well as some photometric monitoring data described in Poretti et al. (2003).

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[7]http://cdsweb.u-strasbg.fr/doc/VOTable

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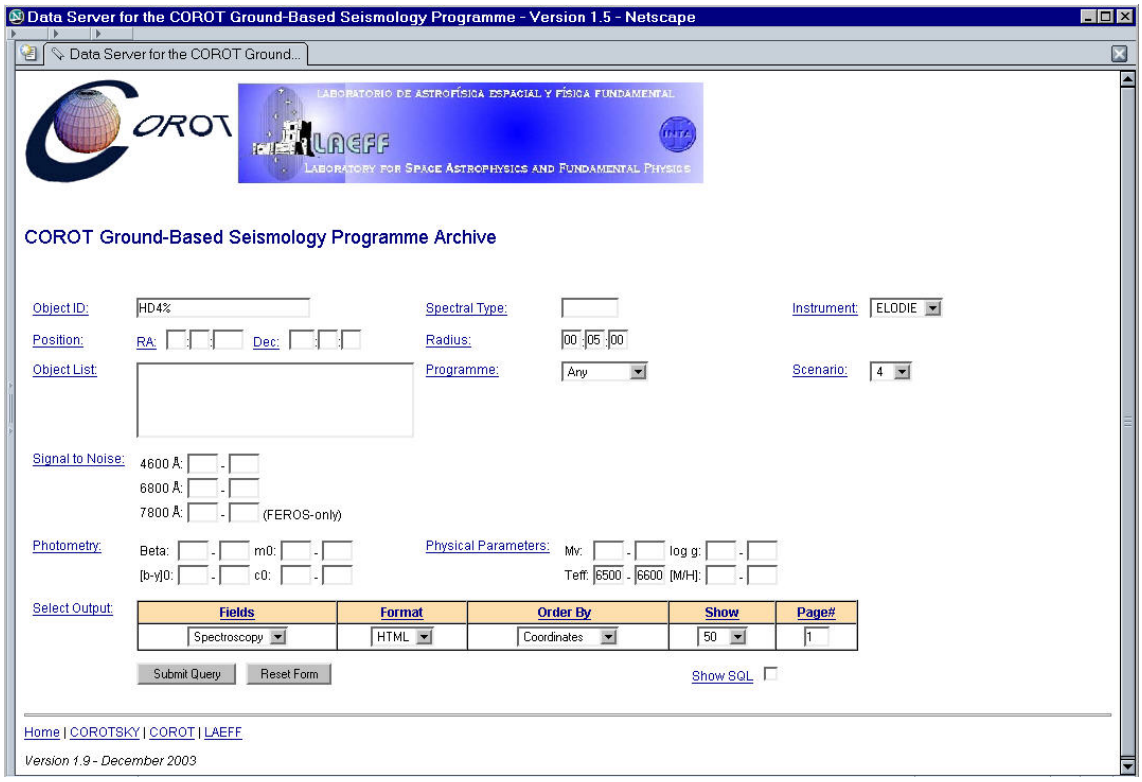

Fig. 1.— GAUDI search capabilities (See Sect. 3.1 for details).

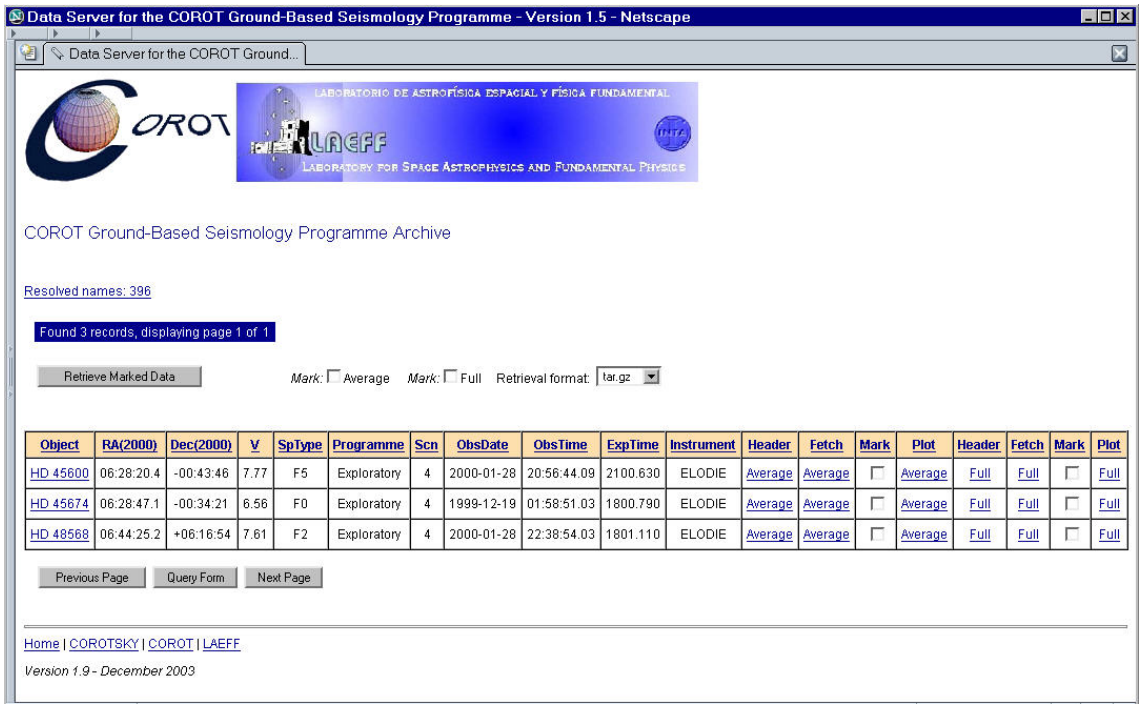

Fig. 2.— Result of the search displayed in Fig. 1. For this example, the spectroscopic output field in HTML format was chosen.

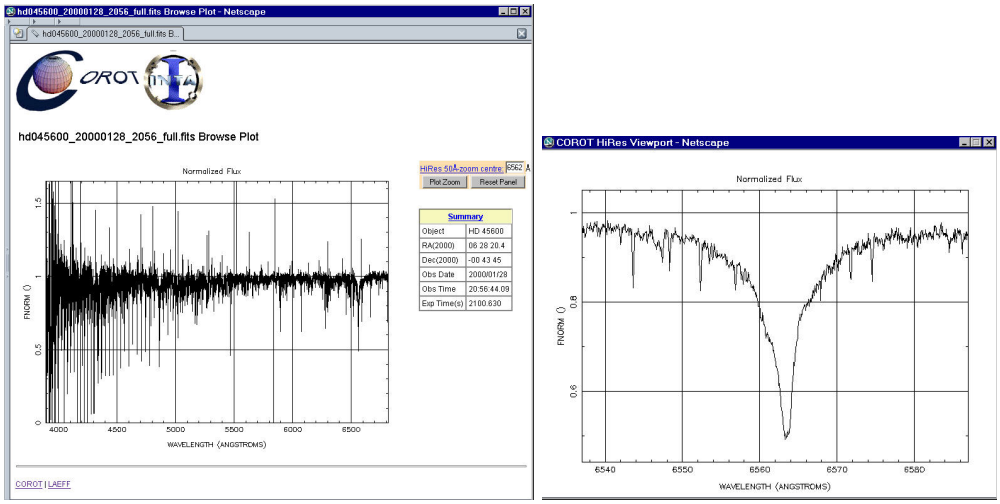

Fig. 3.— GAUDI data previewing capabilities. A high resolution spectrum is shown on the left. The shaded box allows a detailed view of part of the data (here the Hα region) which is shown on the right.