GUAIX: The UCM Group of Extragalactic Astrophysics and Astronomical Instrumentation

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Abstract We present a short summary of the activities developed by GUAIX, the UCM Group of Extragalactic Astrophysics and Astronomical Instrumentation. At present we are focused in the development of data reduction pipelines for several future instruments for the Spanish 10 m GTC (Gran Telescopio Canarias). The careful treatment of the random error propagation throughout the data reduction is one of the main improvements of those pipelines. The first hardware development leaded by the GUAIX group will be FISIR, a fully-criogenic (optimized for the K band) tunable filter in the near-Infrared, to be installed within CIRCE, a near-IR camera for GTC.

1 Introduction

The front-ends of astronomical research areas are typically linked to new instrumental and telescope improvements, like the building of 10m-class (and probably larger in a near future) telescopes, and instruments with increasingly larger data gathering capabilities (CCD mosaics, multislits and IFUs for spectroscopy). These technological improvements have led to a situation in which is quite common that astronomers are faced with a huge amount of data that they have to handle in order to extract the useful information.

Within the Departamento de Astrofísica of the Universidad Complutense de Madrid (UCM) we have developed expertise in the design and execution of large survey-type scientific projects using the newest technology in 10 m class telescopes (e.g., GOYA, `http://www.astro.ufl.edu/GOYA/home.html`; OTELO Cepa et al. 2008; `http://www.iac.es/project/otelo/`), and in the development of state-of-the-art software tools for data reduction and analysis. With

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the aim of taking advantage of the expertise acquired in both fronts, we have formed a new group of extragalactic astrophysics and astronomical instrumentation, GUAIX (see web page at `http://guaix.fis.ucm.es`), which aims at exploiting the synergy of such combination. GUAIX formed at the beginning 2008 from the merger of three previous UCM research teams: (1) the Star-forming Galaxies Group and (2) the Elliptical Galaxies Group. GUAIX is part of a larger collaborative effort ASTRID (`http://www.astrid-cm.org/`), which is providing the framework to facilitate the collaboration between different universities, institutions and industry within the Madrid region involved in the development of ground-based and satellite astronomical instrumentation. ASTRID coordinates the activities of ten R+D groups and fourteen companies.

GUAIX is also part of the GTC Consolider-Ingenio 2010 project (P.I. J.M Rodriguez-Espinosa, `http://www.iac.es/consolider-ingenio-gtc/`). Nowadays a total of five faculties, five postdoctoral researchers and ten Ph.D. students belong to GUAIX.

Main lines of GUAIX development are astrophysical research and the development of astronomical instrumentation. More information about the lines of research can be found in other contributions of the GUAIX members to this conference. In the field of Astronomical Instrumentation, at present GUAIX is involved in developing the data reduction pipelines for two instruments for the Spanish 10 m telescope GTC (Gran Telescopio Canarias, see the web page `http://www.gtc.iac.es`), namely EMIR and FRIDA (see short descriptions below). One of the main goals in the development of those pipelines is to provide the astronomers with reduced data ready to be employed in their scientific analysis. This, which is the normal situation with data from space observatories, is not so common in ground-based observations, where astronomers are used to self-reduce their own data once back at their home institutions. In order to convince the reluctant astronomers about the reliability of the reduced products provided by the pipelines, it is critical to include a proper handling of errors (and their propagation) in the data treatment, which apart from facilitating the necessary quality control, provides the critical information to constrain the reliability of the scientific measurements. An immediate benefit of the use of instrument-tuned pipelines is that the reduced data can be incorporated into databases with the guarantee that they have been homogeneously derived.

2 Pipelines for GTC instruments

As previously mentioned, GUAIX is directly involved in the development of the data reduction pipelines for two instruments of GTC. In this section we briefly describe the main characteristics of those instruments.

2.1 EMIR

EMIR (`http://www.ucm.es/info/emir`) is a wide-field, near-infrared, multi-object spectrograph proposed for the Nasmyth focus of GTC. It will allow observers to obtain up to ∼fifty intermediate resolution spectra simultaneously in one of the nIR bands Z, J, H, K. A configurable slit unit will be used for target acquisition. EMIR is designed to address the science goals of the proposing team (GOYA project) and of the Spanish community at large. EMIR will provide (at the end of 2010) a robust second-generation instrument for GTC while providing an observing mode unique among 8–10 m class telescopes.

EMIR is being built by a consortium of Spanish and French institutions, led by the Instituto de Astrofísica de Canarias. The PI is Dr. Francisco Garzón.

2.2 FRIDA

FRIDA (`http://www.astroscu.unam.mx/ia_cu/proyectos/frida`) is an infrared camera and integral-field spectrograph for the adaptive optics focus of the Gran Telescopio Canarias.

FRIDA will use a 2048×2048 HAWAII 2 detector with sensitivity from ~ 0.9 to 2.5 microns. For integral field spectroscopy, it will use an image slicer similar to the one used in FISICA at the 4m KPNO. FRIDA will provide spectral resolutions of roughly 1000, 4000, and, uniquely for a diffraction-limited integral-field spectrograph, 30000.

FRIDA is being constructed by the Instituto de Astronomía of the Universidad Nacional Autónoma de México (UNAM), the Instituto de Astrofísica de Canarias, the Department of Astronomy of the University of Florida, the Departamento de Astrofísica of the Universidad Complutense de Madrid, and the Laboratoire Astrophysique de Toulouse. The PI is Dr. José Alberto López.

3 Error handling in the data reduction

In a classic view, a typical data reduction pipeline can be considered as a collection of filters, each of which transforming input images into new output images, after performing some kind of arithmetic manipulation. Under this view, three different approaches can in principle be employed to determine random errors in completely reduced images (for a more thorough discussion see Cardiel et al. 2002, 2003):

1. **Comparison of independent repeated measurements.** This is the simplest and most straightforward way to estimate errors, since, in practice, errors are not computed nor handled during the reduction procedure, but through the comparison of the end products of the data processing. The only requirement is the avail-

ability of a sufficiently large number of independent measurements. Although as such can be considered even the flux collected by independent pixels in a given image (e.g. when determining the sky flux error in direct imaging), in most cases this method requires the comparison of different images. Considering that for many purposes this an extremely expensive method in terms of observing time, its applicability on a general situation seems rather unlikely.

2. **First principles and brute force: error bootstrapping.** Making use of the knowledge concerning how photo-electrons are generated (expected statistical distribution of photon arrival into each pixel, detector gain and read-out noise), it is possible to generate an error image associated to each raw-data frame. By means of error bootstrapping via Monte Carlo simulations, numerous fake data frames can be generated and be completely reduced as if they were real observations. The comparison of the measurements performed over the whole set of reduced simulated observations provides then a good estimation of the final errors. However, and although this method overcome the problem of wasting observing time, it can also be terribly expensive, but now in terms of computing time.
3. **First principles and "elegance": parallel reduction of data and errors.** Instead of wasting either observing or computing time, it is also possible to feed the data reduction pipeline with both, the original raw-data frame and its associated error frame (computed from first principles), and proceed only once throughout the whole reduction process. In this case every single arithmetic manipulation performed over the data image must be translated, using the law of propagation of errors, into parallel manipulations of the error image. Unfortunately, typical astronomical data reduction packages (e.g. Iraf, Midas, etc.) do not consider random error propagation as a "by default" operation and, thus, some kind of additional programming or scripting work is unavoidable.

4 Error correlation and aliasing: good reasons for a modified data reduction scheme

The problem with the third method described previously is the handling of error correlation. Due to the unavoidable fact that the information collected by detectors is physically sampled in pixels, this approach collides with a major problem: errors start to be correlated as soon as one introduces image manipulations involving non-integer pixel rebinning or shifts of data. A naive use of the analysis tools would neglect the effect of covariance terms, leading to dangerously underestimated final random errors. Actually, this is likely the most common situation since, initially, the classic reduction operates as a black box, unless specially modified for the contrary. In this sense, preventing the correlation to appear is the best way to avoid it. This can be achieved with a modified data reduction scheme, in which the pipeline produces semi-reduced data and image characterizations that must be handled by a clever analysis tool (Cardiel et al. 2002, 2003). This clever tool has to perform its tasks taking into account that some reductions steps have not been carried out (only properly characterized). For instance, if one considers the study of a 2D spectroscopic image, the analysis tool should use the information concerning geometric distortions, wavelength calibration scale, etc., to obtain, for example, an equivalent width through the measurement in the partially reduced (uncorrected for geometric distortions, wavelength calibration, etc.) image.

It is important to highlight that, apart from introducing error correlation, and additional side effect of image rectification is the introduction of aliasing, which constitutes a very important source of systematic uncertainty. Although the use of clever interpolation strategies during the rectification process can help to alleviate this problem, a general solution is not easy to devise. This is another important reason to try avoiding image rectification in data reduction pipelines.

5 FISIR

FISIR is a new instrumental development leaded by the GUAIX group to produce the first fully-criogenic tunable filter in the near infrared. FISIR will be optimized for the K band (2.0-2.4μm), but it will also work in the H and the J bands. The expected field of view will be close to 1×1 arcmin, with a spectral resolution $R \sim 700$. FISIR principal investigator is Prof. Gallego.

FISIR is being designed to be mounted inside the CIRCE instrument (near-infrared camera for GTC, see `http://www.astro.ufl.edu/circe/`). When ready, it will be the first tunable filter to work in the K band and the first available for a 10m class telescope in the Northern Hemisphere.

FISIR is now in the phase of feasibility study, focusing meanly to obtain a mechanical interface with CIRCE as easy as possible to avoid having FISIR limited to campaign-style observations. The device could be ready as soon as the end of 2010. FISIR development cost could be as low as $0.3 million and will come from the Spanish Ministry of Science and Innovation, the GTC Consolider-Ingenio project and the Universidad Complutense de Madrid.

Main scientific goal for FISIR will be deep surveys of distant galaxies (for example Lα emitters at $z \sim 9$ or Hα emitters at $z \sim 2$) and narrow-band imaging in the n-IR. This development will be a pathfinder for the future generation of astronomical instruments to be installed in the 42 m European Extremely Large Telescope (E-ELT).

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