GLORIA is funded by the European Union 7th Framework Programme (FP7/2007-2013) under grant agreement n° 283783

GLObal Robotic telescopes Intelligent Array for e-Science

Report for standard methodology for offline experimentation and the choice of the off-line experiments

CODE: DEL-024

VERSION: 01

DATE: October 23rd, 2012

Authors:	Francisco M. SÁNCHEZ (UPM) Aleksander Filip ZARNECKI (UNIWARSAW) Lech MANKIEWICZ (UNIWARSAW) Alberto CASTRO-TIRADO (CSIC) Miquel SERRA (IAC) Carlos PÉREZ DEL PULGAR (UMA) Robert SIMPSON (UOXF) Chris LINTOTT (UOXF)
Collaborators:	
Revised by:	Fernando IBÁÑEZ (UPM)
Approved by:	Alberto CASTRO-TIRADO (CSIC) Francisco M. SÁNCHEZ (UPM)

Distribution List:

Name	Affiliation	Date
Alberto CASTRO-TIRADO	CSIC	October 23rd, 2012
Lech MANKIEWICZ	UNIWARSAW	October 23rd, 2012
Aleksander Filip ZARNECKI	UNIWARSAW	October 23rd, 2012
Miquel SERRA	IAC	October 23rd, 2012
Carlos PÉREZ DEL PULGAR	UMA	October 23rd, 2012
Francisco M. SÁNCHEZ	UPM	October 23rd, 2012
Fernando IBÁÑEZ	UPM	October 23rd, 2012
Robert SIMPSON	UOXF	October 23rd, 2012
Chris LINTOTT	UOXF	October 23rd, 2012

Change Control

Issue	Date	Section	Page	Change Description
01	23/10/2012	All	All	Creation

Reference Documents

Nº	Document Name	Code	Version
R.1	D7.5-SRS_for_the_demonstrator	DEL-011	01

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1. Introduction

This document explain the SRS (software requirements specifications) for the **off-line experiments**. As the rest of the software made in GLORIA project, the work is split in definitions, programing, deployment & testing and support to the community. Therefore the experiments software will be done in the following WP:

- **WP3 -> definitions work**. Even though UMA and UPM are the coordinator and deputy respectively of this WP, all partners of GLORIA participate in this WP though. This document D3.11 is the report of this work.
- **WP8 -> programming work**. Performed mainly by UOXF & UWAR.
- **WP6 -> deployment & testing**. Performed mainly by UWAR & UOXF.
- **WP4 -> Support to the communit**y. Performed mainly by CSIC & FZU-CAS

During the lifetime of GLORIA project SRS could change and therefore new versions of software will be developed and deployed. Furthermore, as it was stated in R.1), since we are developing an authoring tool for allowing anybody to develop **off-line** experiments, new **off-line** experiments can be added in the future to GLORIA network.

Even though it was stated in the original proposal that there will be two off-line demonstrators, after the discussion among partners it is was decide not to restrict ourselves and be open to additional off-line experiments, as the ones described below. These off-line experiments are described in the following section. The assumption is that the image analysis framework which are being developed for GLORIA, will be sufficiently flexible to cover all (or at least most) concepts proposed and the choice of the actual demonstrator experiments which will be released to users can be made later.

2. Taxonomy of off-line experiments

There are several different categories of offline experiment, which involve different activities on the part of the user and the database, which can be considered either **at educational** or **at research level**, depending on the expected outcome. It can be also useful to think in terms of such a taxonomy of experiments when imagining what is possible with a system such as GLORIA. The following taxonomies are not mutually exclusive:

1. **Multi-wavelength studies -** With a variety of instruments available, users will be able to find data on an object from across different filters. For example one can imaging locating images of the Sun from the same time period, but across a selection of filters, including white light, colour bands, H-alpha and even some UV or IR filters.
2. **Multi-epoch or time-domain studies -** Similar to 1, users may be able to utilise the network to access observations of an object or region from across a wide range of times. By searching data across even relatively short time frames, astronomers can detect transient or moving objects. Using baselines of months and years there may be variable objects - such a stars - accessible by the GLORIA network. Multi-epoch studies can use data from similar telescopes in different parts of the world.
3. **Classification experiments -** One simple way that network users can use GLORIA to further research is by adding information and metadata to existing observations. Users would be able to, for example, find images of galaxies in the data and add metadata describing their morphology, in the style of Galaxy Zoo (http://galaxyzoo.org). Such an experiment is likely best performed as a community-wide experiment, but it is possible for individuals to undertake it as a regular offline experiment.
4. **Discovery experiments -** As well as providing metadata, as in 3, users may also be able to discover and note new features in existing data. For example, in images of the Sun it may be possible for users to mark

and record the locations of Sunspots to allow these to be searched as data objects in addition to the images themselves. Such discovery tasks also include spotting new, unknown phenomena and features in data taken by the users themselves, or in data.

5. **Meta experiments -** In addition to doing all of the above it should also be possible for users to mark and report on experiments themselves. By accessing the collection of community and offline experiments, any member of the network could also rate, comment-on or even improve existing experiments in a coordinated fashion.

3. Educational off-line Experiments

3.1. The first generation off-line educational experiment: Planet orbit reconstruction with BOOTES-1 and -2 all-sky images

The BOOTES-1 and -2 stations as part of GLORIA; contains an existing astronomical archive including all-sky images taken by the CASANDRA devices at the BOOTES stations since 2001. With a time resolution of 60s, each image reveals thousands of stars as well as the images of the brightest Solar System planets. See Fig.1 and http://www.youtube.com/watch?v=yq5Plw4pDGo for a sample of the path of Mars across the sky in 2012 as seen by the CASANDRA instruments at the BOOTES stations.

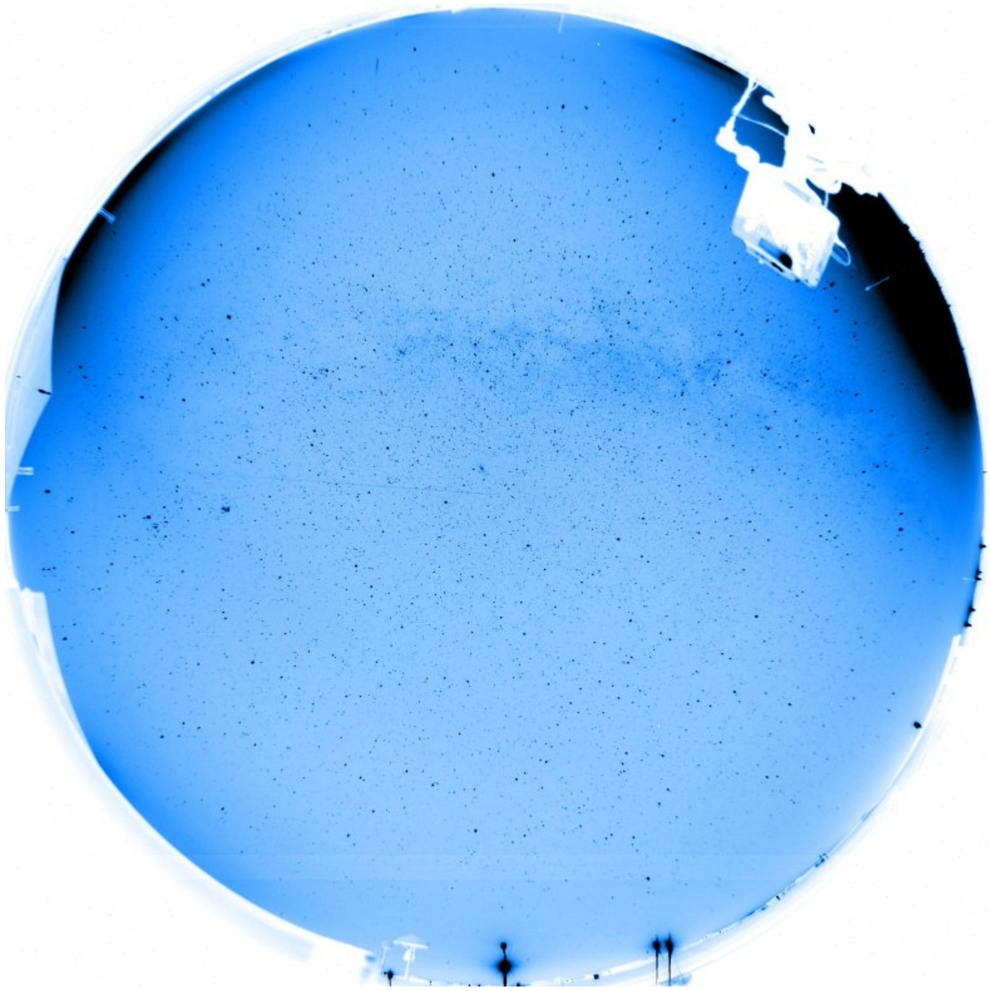

Figure 1: A typical CASANDRA image at the BOOTES-1 station in Spain, showing the entire celestial sphere on a 42s shot, with stars fainter than the ones seeing a first sight being recorded.

Planets were known from the ancient times as wandering objects thus their Greek name is *planetoi* which simply means “wanderers”. This term included both the Sun, Moon and all five planets visible without additional optics. Ancient Greek astronomer Plato thought that the world was made with geometric simplicity and elegance, thus he felt save that all know “wanderers” need to have the simplest constant and circular motion.

This notion was contrary to observations. Despite the fact that all stars are encircling the North Star, it was clear that even the Sun changes its position through seasons. Some of the “wanderers” (i.e. Mars, Jupiter and Saturn) were caught to be not only wandering straight, but also doing kind of bizarre loops every year or so. This problem was partially solved by Plato’s student Eudoxus who assumed the Sun to be attached to the transparent sphere inside the fixed stars’ sphere. Exploring this effect in real, all-sky data is an excellent education tool.

Hipparchus introduced concept of the epicycle, to account for the motion of the Moon and the retrograde motion of Mars, for example. It’s a small round motion of the planet which goes around big round motion. You could go with several epicycles to be infinitely correct. Moreover it explained variation in the speed of the Moon, Sun, planets, and the retrograde motion of the planets. It also explained why the apparent brightness of planets can change over time. This model was developed (involving up to 80 nested cycles!), described and calculated by Ptolemy’s and written in his immense book, the “Almagest”.

One of the concepts of Ptolemy’s model was an *equant*, point around which planet (or the center of epicycle) moves with uniform speed. This reference point solved one of the problems in the planets motion and was disliked by Copernicus. His reluctance to idea of equant was his major motivation construct his heliocentric system. Although Copernicus used lots of epicycles he made Earth spinning, and revolving around the Sun. His idea has completely changed our state of mind and was one of the main driving forces for Galileo’s quest for finding the truth state of the Universe.

To be able to take people on this journey, using real image of the sky is a great way to learn not only about astronomy but the history of astronomy also. We intend to implement an all-sky viewer that allows a website users to mark and track the positions of the ‘wandering’ planets.

Alongside this, educational material will guide them through thousands of years of astronomical understanding and bring them up to the modern era.

3.2. The second generation off-line educational experiments.

We have also designed six second generation experiments, which could be eventually implemented in the near future. These are:

a) Variable objects in the sky

There are many objects in the sky which show periodic or irregular variations of brightness. We identify variable objects by comparing images (and resulting brightness measurements) taken at different times. Timescales of variability range from single hours to many years. Having a larger set of measurements we reconstruct the so called light curves, which are an ordered series of brightness measurements spanning a given period of time. The light curve of the object allows us to determine (in most cases) what is the reason of (physical process behind) its variability. The aim of this educational level experiment is to visualize different types of variability based on the known variable sources with proper information about the variability mechanism. More advanced, research level experiment of this kind, is described in 4.1.

The experimental procedure in this case should be like that (subsequent steps GLORIA user has to take):

1. Login to GLORIA network
2. Selection of experiment type (out of the experiment list)
3. Target selection.
   - User selects object from the predefined list of "GLORIA interesting object". One can also search for object of interest in the catalogue of known variables (either stars in our Galaxy or extragalactic objects).
4. Light curve reconstruction
   - This step is done by the data analysis server associated with given off-line experiment. Data specified by user are being analyzed and the light curve of the object is reconstructed.
5. Light curve visualization.
   - Light curve is displayed in the dedicated web interface. In case of periodic sources the phased light curve, i.e. brightness as a function of variability phase is also displayed.
6. Object classification
   - User, by comparing the considered light curve with examples of different variability types (should be displayed side-by-side) will decide how the target should be classified.
   - User classification is verified. If wrong, possible hints can be given. If correct, additional information about the object and its variability are presented.

b) Search for Optical Transients and previously unknown variables.

User can request automatic comparison of images of the given sky part, taken at different times. The unique feature offered by GLORIA is that images from different telescopes can be compared. The analysis algoriithm will create a list of objects observed at each image and match objects between different images. Objects identified as variable (with the set of criteria, which can be adjusted by user) will be flagged and their light curves displayed. If the object is known to be variable, the corresponding information will also be displayed.

By looking at the reconstructed light curves (and even colour changes) the user will be able to verify the variability and classify objects into categories. Possible categories include: periodic variable (with possible further division), single outburst (brightening), sigle occultation (brightness decrease).

c) Search for occultations of stars by the Solar System objects.

This experiment can use the results from previous one (search for optical transients). In case of the single brightness decrease user can verify if it could be due to occultation of star by asteroid. Based on the telescope location around the Earth and exposure time, the system will search for possible match in the asteroid ephemerides and calculate the expected effect on the star brightness. The user will have to verify if the hypothesis is consistent with the data or not.

Alternative procedure is to select an asteroid calculate the predicted occultations of stars. Then the corresponding images can be searched for in the image archives (past occultations) or a new observation can be scheduled (future occultations). However, asteroid ephemerides are not known with sufficient precision to be sure the observation will be successful and hence, simultaneous observations by several GLORIA instruments will be the rule. Therefore, looking at old images, especially from telescopes with large field of view, seem to be a better approach.

d) "Find your star" experiment.

The user will be able to search for star, which was over (in zenith) given point on Earth at given time. These can be ones birith or wedding coordinates. System will calculate the actual position on the sky and search for an object in the catalogue. Information about the closest object found (with possible other restrictions specified by user) can be displayed together with the corresponding sky image (if already taken or can be scheduled). In most cases an image of this part of sky should be available in the GLORIA archive, at least from the large field-of-view monitoring. In not, user should be able to schedule the observation of the object (on-line experiment). Object description and image should be sent to the user in a nice graphical form, allowing for high quality printing. We just want to add, following the International Astronomical Union guidelines, that like true love and many other of the best things in human life, the beauty of the night sky is not for sale, but is free for all to enjoy. True, the 'gift' of a star may open someone's eyes to the beauty of the night sky. This is indeed a worthy goal, but it does not justify deceiving people into believing that real star names can be bought like any other commodity.

e) Selection of the "Gloria image of the week".

Each user running on-line experiment should be encouraged to select, after his observations are finished, to select the best image and put it on a public display with short description, so other users can comment and vote. The image which gets most votes is selected "GLORIA image of the week" and will be posted on the main GLORIA web page. Collection of best images from subsequent weeks will also be accessible, but voting is only limited to new images. "Image of the week" voting is independent from commenting and voting on the scientific value of the observation/experiment performed.

f) Experimenting solar activity

In addition to the on-line experiment on solar activity, it is also possible to conduct a solar off-line experiment using archival images as well, available in the GLORIA archive too. The goals will be to check for solar differential rotation (making use of the 22 days period) and to discover in the archival data the existence of solar flares recorded through the H-alpha filter.

4. Research off-line Experiments.

4.1. The first generation off-line research experiment: Light curve reconstruction and classification of variable objects

Lightcurves are an ordered series of brightness measurements spanning a given period of time. There are many objects in the sky which show periodic or irregular variations of brightness. The light curve of the object allows us to determine (in most cases) what is the reason of (physical process behind) its variability. GLORIA will allow to combine observations of the object from different telescopes (including possible dedicated observations from GLORIA, if requested, but also using images from other astronomical archives).

The experimental procedure in this case should be like that (subsequent steps GLORIA user has to take):

1. Login to GLORIA network
2. Selection of experiment type (out of the experiment list)
3. Target selection.
    - User can specify object to be studied by name or by coordinates on the sky. Coordinates can be given with some tolerance (error), otherwise a range of coordinates could be specified.
    - Based on the available sky catalogue and/or GLORIA object database, system should show the list of objects fulfilling user query. Objects known to be variable should be clearly marked.
    - User selects object of interest from the list.
    - User should also be able to select object from the GLORIA interesting object list (objects suggested to be observed and/or classified by user). or to search for object of interest in the catalogue of known variables (either stars in our Galaxy or extragalactic objects).
    - User has to select which data will be considered in the analysis. External astronomical archives

can be searched in addition to the GLORIA observation data base.
- Before user is asked to accept the target and the data sets, system should give the estimated number of observations.

4. Light curve reconstruction
   - This step is done by the dedicated LUIZA framework implemented on the data analysis server associated with given experiment. Data specified by user are being analyzed and the ligth curve of the object is reconstructed.
5. Light curve analysis (done interactivly by user using web interface)
   - User should be able to select observations for final analysis, based on telescope ID, observation time, observation conditions, photometry algorithm used, etc.
   - Light curve is displayed for selected measurements
   - User should then be able to display phased light curve, i.e. brightness as a function of variability phase (in case of periodic sources). To do so, user has to give the expected variability period.
   - If the exact period is unknown, user can specify the expected range and the application should calculate the best period value with the assumed method.
   - User can also request period determination in a subsample of data (selected eg. by observation time).
6. Object classification
   - After the period is determined, the parameters of the Fourier transform can be calculated from the phased light curve.
   - Based on the Fourier coefficient ratios and phase differences, likelihood for the object to fall into different variability types can be calculated.
   - System should present example light curves for 2-3 most probably choices (or user's choices).
   - User, by comparing the considered light curve with examples of different variability types (should be displayed side-by-side) will decide how the target should be classified.
   - Classification should be stored in the experiment database, together with the shape parameters and period.

This experiment can be easily extended to the comunity-wide experiment. Other users can verify classification by using same reconstructed light curve. Objects for which there was no unique classification (i.e. there was no clear majority in selected variability type) can be selected for more detailed analysis or for dedicated observations.

As the experiment is based on the LUIZA framework, designed within GLORIA for efficient analysis of astronomical data, users will be able to profit from its flexibility. Image analysis resulting in the object light curve can be adjusted by user to fit his needs best. This can include changing of analysis parameters, choosing alternative photometry algorithms (from those implemented as the so called LUIZA processors) or applying additional correction. Most experienced users will also be able to implement their own analysis algorithms (thanks again to modular structure and flexibility of LUIZA).

The demonstrator for this experiment will be based on the preselected data from the Pi of the Sky telescope in Chile (T9). Thanks to the wide field of view of the telescope same image sample will allow for variability analysis of bright variable objects of different kind. Predefined objects, which can be selected by user include: V1388 Ori - eclipsing binary of Algol type (detached) with period of about 2.2 days and W Gem - classical cepheid (delta Cep type) with period of about 7.9 days.

The web interface for this demonstrator experiment will provide a simple way to fit a gaussian curve to any dips seen in the transit data, in order to derive simple statistical properties for the lightcurve data. Initially the web interface will require users to load an existing file of lightcuvre data, or one of several examples.

4.2. The second generation off-line research experiments.

We have also designed three second generation experiments, which could be eventually implemented in the near future. These are:

a) Search for variable stars evolution with time

This experiment is a possible extension of the variable object classification experiment described in 4.1. In most cases for galactic targets, star variability is very stable. However, about 1 star out of about 1000 variable stars show significant changes in variability period and/or shape for time scales of the order of years. Such objects are extremely interesting, as significant changes of variability indicate that the star is evolving very fast and rapid changes are possible (eg. due to star merging in the binary system). Such objects should be monitored closely.

Searching for variability changes over time can be performed using similar scheme as used for object classification (described above). The simplest method for spotting variability change is overlying phased light curves reconstructed from different data taking periods. User can then decide if the data indicate any changes or not. The interface should allow for doing a sequence of comparisions for a list of objects. When user decides that the object is suspected to change its variability, a more detailed analysis can be done, including the possibility of fitting the description of the variability change. At the final step user has to decide if the analysis including variability evolution does describe the data significantly better than the standard approach. If so (and if same opinion is shared by more users) the object should be selected for more detailed analysis and constant monitoring.

b) Supernovae monitoring

Supernovae are stellar explosions which are extremely luminous and cause a burst of radiation that often briefly outshines an entire galaxy, before fading from view over several weeks or months. During this short interval a supernova can radiate as much energy as the Sun is expected to emit over its entire life span. The explosion expels much or all of a star's material at a velocity of up to 30,000 km/s (10% of the speed of light), driving a shock wave into the surrounding interstellar medium. This shock wave sweeps up an expanding shell of gas and dust called a supernova remnant. Although no supernova has been optically observed in the Milky Way since 1604, supernovae remnants indicate that on average the event occurs about once every 50 years in the Milky Way. They play a significant role in enriching the interstellar medium with higher mass elements. Furthermore, the expanding shock waves from supernova explosions can trigger the formation of new stars. Supernovae in nearby galaxies (like NGC 6496) are important to discover and monitor its evolution in order to better understand the end of the stellar lives products, leading to the formation of new neutron stars and black holes in the Universe. The GLORIA archive should contain data of past supernova (which surely were obtained as soon as the given supernova discovery was announced) taken with the available telescopes, probably in different filters. The user should download the data and register the maximum in the lightcurve (happening normally about 15 days post-explosion) and the subsequent decay in all available images, also deriving the color evolution as function of time.

c) 24-hr continuous monitoring of variable targets

The potential of a network of telescopes like GLORIA is the continuous monitoring of suitable relevant targets in the celestial sphere. The GLORIA archive should contain images for relevant targets (for instance a black hole binary in outburst) which should have monitored continuously (weather permitting) for several days and from a number of stations (minimum three, like BOOTES-3 in New Zealand, WATCHER in South Africa and the 0.5m telescope in Chile). The user should access these dataset and compare the images to determine the overall light curve during at least 24 hr (or several days if possible) to study the evolution, a possible periodicity (which could be indicative of a rotation period), etc.

5. References

A.F.Zarnecki et al., Analysis framework for GLORIA, Talk given at XXXth IEEE-SPIE Joint Symposium on Photonics, Web Engineering, Electronics for Astronomy and High Energy Physics Experiments (Wilga, Poland, 31.05.2012). Invited paper published in Proc. of SPIE Vol. 8454 845408-6 (2012).

GLORIA Partners

UPM
Universidad Politécnica de Madrid
SPAIN

AUAV
Astronomical Institute, Academy of Sciences of the Czech Republic
CZECH REPUBLIC

CSIC
Consejo Superior de Investigaciones Científicas
SPAIN

INAT & CVUT
Czech Technical University in Prague
CZECH REPUBLIC

IP-ASCR
Institute of Physics of the Academy of Sciences of the Czech Republic
CZECH REPUBLIC

IAC
Instituto de Astrofísica de Canarias
SPAIN

INAF
Istituto Nazionale di Astrofisica
ITALY

SAO
Special Astrophysical Observatory of Russian Academy of Sciences
RUSSIA

UCDNUID
University College Dublin
IRELAND

UC
University of Chile
CHILE

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University of Oxford
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POLAND