Observation Preparation Software for LINC-NIRVANA

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ABSTRACT

LINC-NIRVANA is a Fizeau Interferometer using the two 8.4 m mirrors of LBT in the combined focus. The images can be obtained in K, H and J Band over a 10" × 10" Field of View by means of Multi-Conjugated Adaptive Optics (MCAO) and a Fringe and Flexure Tracker System (FFTS). In interferometry, the planning of observations is much more tightly connected to the reduction of data than in traditional astronomy. Such observations need to be carefully prepared, taking into account the constraints imposed by scientific objectives as well as features of the instrument. The Observation Preparation Software (OPS), currently under development at MPIA, is a tool to support an astronomer (observer) in the complex process of preparing the observations for LINC-NIRVANA. The main goal of this tool is to provide the observer with an idea what he or she can do and what to expect under given conditions.

Keywords: Observing Tools, Proposal Preparation, LINC-NIRVANA, MCAO

1. INTRODUCTION

LINC-NRVANA (The **L**BT **IN**terferometric **C**amera and **N**ear– **IR**/**V**isible **A**daptive **IN**terferometer for **A**stronomy)[1] is a near-infrared imaging interferometer for the **L**arge **B**inocular **T**elescope (LBT). It will combine the two 8.4 m primary mirrors of the LBT in so-called "Fizeau" mode. The beams collected by the two telescope units are corrected by two adaptive optics systems, then co-phased in real time and combined inside a cryogenic camera, interfering in the focal plane. LINC-NIRVANA will operate at wavelengths between 0.6 and 2.4 microns, using state-of-the-art detector arrays. It is expected to have unprecedented imaging performance in the near-infrared, both in terms of angular resolution and limiting magnitude, thanks to the interferometric mode and to the large collecting area of the two mirrors. The LINC-NIRVANA instrument will deliver the sensitivity of a 12 m telescope and the spatial resolution of a 23 m telescope, over a field 10"×10".

Astronomical observation with interferometers is more complex then conventional imaging or spectroscopy. It not only needs advanced data reduction algorithms to extract the information from the data, but also needs well-prepared observations, taking into account the constraints imposed by scientific objectives as well as features of the instrument. Since observing with LINC-NIRVANA depends on the earth's rotation to present different object position angles there is considerably less freedom in the preparation and scheduling process. We may need first a particular position angle on a particular source, then move to another position angle on another source for a while, then return. Our aim is to create a coherent software that guides a scientific project through all stages of the LINC-NIRVANA proposal and observation program preparation. It should support the observer in advance to get an idea what kind of observation he has to do and what quality of data he can expect under given conditions. The focus of this work is to develop a concept for the LINC-NIRVANA observation preparation software.

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2. THE PROCESS OF PROPOSAL PREPARATION. RELATED WORKS.

When talking about observing proposal process for modern telescopes, one normally distinguishes between two steps, called *phase-* 1 and 2 accordingly. In the phase-1 it is assumed that an astronomer has a science project in mind and has to describe an observation program with its objectives and scientific goals, defending the science. In the phase-2, the successful proposal must be provided with the well-defined, precise and complete executable observing information. At this stage the astronomer needs to realize many aspects of the instrument's operation and characteristics; how much time is required for his/her project in order to reach the scientific objective, etc.

The idea behind the construction of an observation preparation tool is to provide all information to the astronomer, so that at the end of the proposal preparation process the observatory would receive a self-consisted, feasible and schedulable observing program.

The diversity of the software in this field owes largely to the various observatories and their instruments. We did a study of existing software with an aim to reuse it if applicable to our problems. The following comparison attempts only to be representative rather than exhaustive:

- The ESO Phase-2 Proposal Preparation Tool P2PP[2] is used to define observations at all the ESO telescopes and instruments. P2PP is an application, integrating a set of user interfaces that are needed to prepare, so-called, Observation Blocks (OBs)* with which instruments at ESO telescopes are operated, and to provide the observatory with ancillary execution information.
- The Gemini Observatory has a proposal preparation tool which incorporates the tasks for phase- 1 and -2 that guides the user through the process and leads them to completion. The next generation proposal preparation software, called Observing Tool (OT), uses classes from Jsky library[3] and catalog widgets for the telescope Position Editor. The tool provides a graphical view of the observation and has interactive capabilities to modify elements of it.
- The Astronomer's Proposal Tool (APT)[4] is a software that can be used to submit phase - 1, 2 proposals for the Hubble Space Telescope (HST). APT† is an integrated toolset consisting of editors for filling out proposal information, an Orbit Planner for determining feasibility in Phase 2, diagnostic and reporting tools, and an integrated Visual Target Tuner (VTT) for viewing exposure specifications overlaid on images, performing object checks, and querying the HST Archive .
- The Spitzer Planning Observations Tool (SPOT) for the Spitzer Space Telescope is a client-server multi-platform package used by Spitzer observers to plan observations and submit proposals. Together with other software package (Leopard), it has comparable functionalities with the tools described above.

One thing that became clear during our study was that an important aspect of the observation preparation tools is their visualization and ability to enable the astronomer to understand the instrument. Besides, in the process of the observation preparation the various steps should be governed by rules which must be carefully defined for a given instrument.

3. LN OPS GENERAL DESCRIPTION

3.1. The Development Process

The LN OPS is planed as a tool to assist scientist to create a valid observation program, focusing on the features when observing with LINC-NIRVANA. We favor to the reuse-oriented development which relies on the following process stages:

- requirements definition;
- analysis of existing tools and components;

*A more detailed definition of the OB for LN will be done in 3.4.1

†The APT is further development of the Scientist's Expert Assistant (SEA)[5]

- requirements modification;
- system design with reuse;
- development and integration

3.2. The Functions

In summary the main functions of the LN observation preparation software are:

- to built an observation program with various elements of the observation program[‡];
- to allow automatic derivation of certain elements in the observation program;
- to allow automatic propagation of the certain items among elements of the observation program;

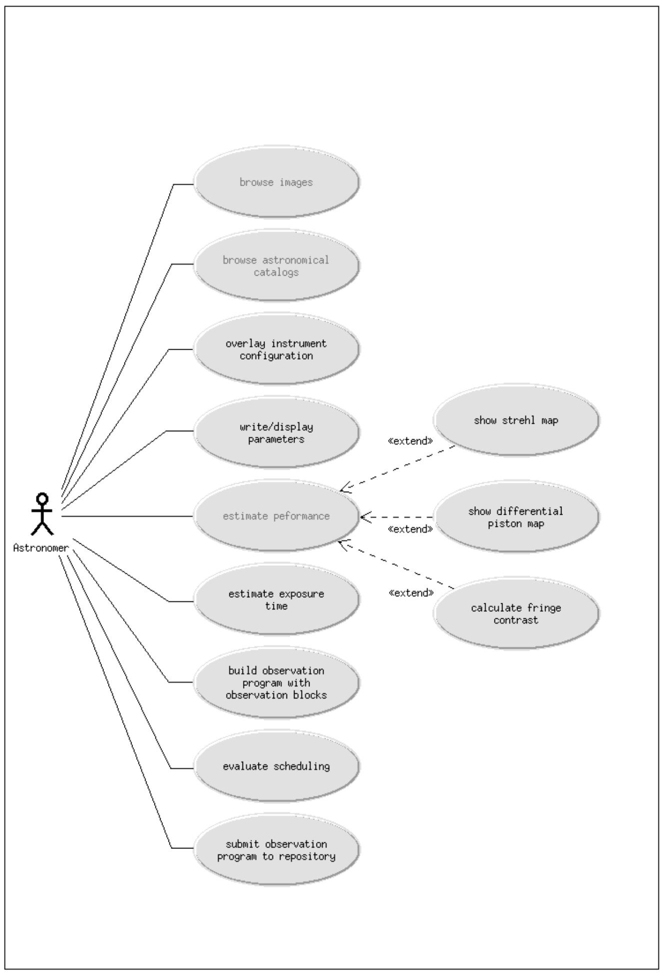

Figure 1. Use case diagram for the LN Observation Preparation Software.[6] The general functionalities of the system are derived from this use case.

- to allow interactive work with astronomical catalogs (remote or local);

[‡]Observation program is a full set of observations the observer sets up to achive his scientific goal (details see in 3.4.1).

- to allow the performance estimation and the investigation of the parameter space for justification of the scientific objectivities;
- to enforce feasibility and consistency checks of the observation program as well as verification of certain elements of the observation program;
- to allow submission of observation program to an observation program repository for authorized users;
- to allow the observatory staff to retrieve and modify some of components of the observation program;
- to allow on-line (at the telescope) and off-line (away from the telescope) work.

We've used the concept of use cases for discovering and recording functional requirements. In the Figure 1 the use case diagram for the LN OPS is given, from which the general aspects of the system listed above were derived.

3.3. Operating enviroment

The operating system is the Java language based on the Java Virtual Machine, which has a great deal of power and flexibility. The desicion was based on the requirements that OPS should work as a standalone platform-independent application.

3.4. Dataflow of the OPS

Figure 2 depicts a simple context diagram of the OPS with relationship to the external systems and actors:

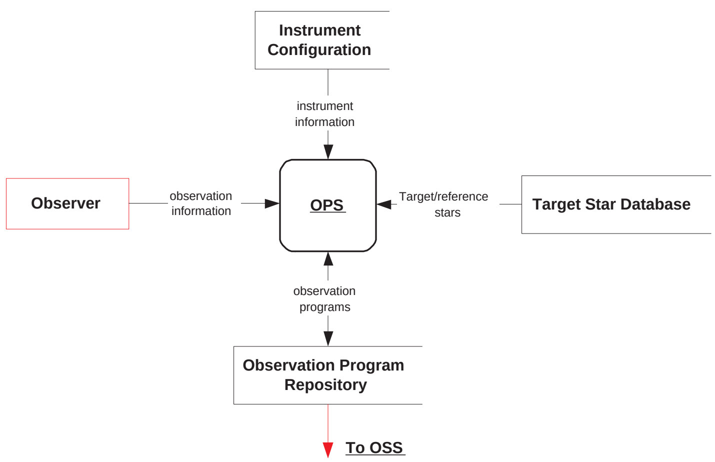

Figure 2. The context diagram which shows a data flows between the LN OPS and external entities. The arrows represent the information recieved or generated by the OPS. The closed and opened boxes represents an actor(observer) and data stores respectively.

- **Observer.** This is an astronomer who would like to create a proposal and has to provide his/her observation program with the observation information. The LN OPS is planed in mined with both novice and expert observers.
- **Target Star Databases.** The system takes advantage of access to external data bases (remote or local) in order to present the observers with helpful information about their targets, reference stars, or other such information.
- **Instrument configuration.** The base configuration of the LN instrument must be provided to complete an observation program. This information together with the observation one will be fed into the hierachical-structured observation program (details see below).

- **Observation Program Repository**. The efficiency of LN will depend strongly on the availability of various observation programs with different constraints. It may be not possible to receive all images for one program in one night: the observations can spread over several nights or run due to the fact of availability of parallactic angles, atmospheric conditions or instrument problems. Therefore, it is reasonable to have a repository of available observation programs (located at the telescope) to keep track of the completion of the programs. The OPR feeds the OSS (Observation Support Software) with available programs for the following scheduling and execution.[7] The specific feature of the LN scheduler will be to scan the OPR and to re-optimize the schedule during the observation, reacting to current circumstances (reactive scheduler[8]).

3.4.1. The hierachical structure of the LN observation program

In order to get a set of accurate and unambiguous LN observation programs we consider a hierarchical structure of the observation program (shown on Fig. 3) with the following main entities (important for the LN data flow):

- **Observation Program.** An Observation Program (OP) is defined as a full set of observations the observer sets up to achive his/her scientific goal. It contains all the information associated with one proposal. Thus, each OP consists of:
  - multiple target list;
  - scientific objectives;
  - multiple instrument setups;
  - multiple exposures;
  - multiple MCAO and FFT observation constrains, includuding multiple set of reference stars;
  - multiple calibrations.
- **Observation Target Unit.** We introduce an Observation Target Unit (OTU) that contains all of the information associated with one target, i.e. for each tagret there is a separate OTU. An OTU is a self contained entity and possess a target, predifine observing constraints, scientific objective, multiple instrument configurations with multiple calibrations and exposure times (see Fig. 3). Astronomers specify their programs in terms of OTU, definining a target with the number of paralactical angles. Exposures taken at different angles are needed to obtain a better uv-covarage; an aperture synthesis image reconstruction procedure can provide reconstructed high-resolution images from LBT raw data with a spatial-resolution which reaches that of a 22.8 m single-dish telescope (see e.g.[9])). Using OTU, ”single” observations which present different position angles for a given object, are grouped together to allow sharing the parameters among the elements of the OTU.
- **Observation Block.** Following P2PP software concept, the initial model for the LN OPS is also based on an Observation Block which is central to the VLT Data Flow System. An OB is the smallest schedulable entity that contains all the information necessary to obtain a ”single” observation. The changes to one of the parameters of the OB in a given OTU affect in general all OBs of the OTU, i.e. it will automatically propagate the changes to the other OBs associated with the same OTU by synchronization method. On the other hand any parameter within the OB can be marked explicitly as non-shared (if is necessary) in order to avoid the propagation of the changes to all others OBs of the OTU.

The hierarchical structure of an OP (OB$\subset$OTU$\subset$OP) is somewhat redundant because the complete information of the observation is presenented on the level of OBs. However, such hierarchical representation allows not only to facilitate the astronomer to generate a number of OBs and to get more synthesized picture of the data but also to perform a monitoring of the OP for the incomplete, missing or illegal information.

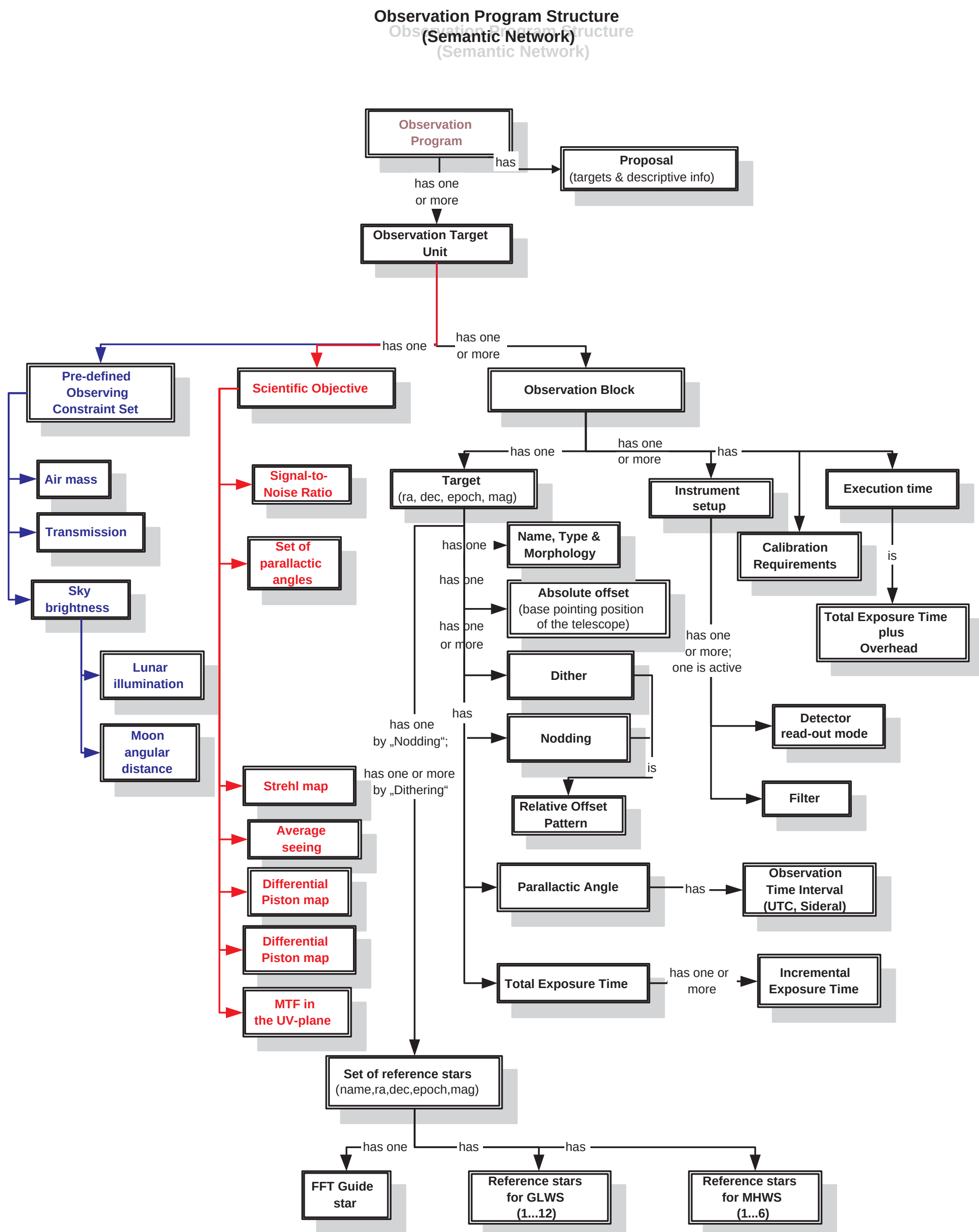

Figure 3. Breakdown of the Observation Program. It demonstrates in terms of semantic network a hierarchical structure introduced for the LN OP. There are three types of OP elements that together define an Observation Target Unit: predifine observing constraints (conditions), a scientific objective and observation block(s) (smallest schedulable entities, see text).

4. LANDSCAPE OF LN OPS COMPONENTS

The main characteristic of reuse-oriented process is that it requires a large base of reusable software components We are prototyping our software reusing the components from two software observation preparation tools, mentioned in introduction: APT[§] and OT[¶]. Usually, there is not an exact match and the components which may be used provide only some of the functionality required. The underlying software for both tools is an object-oriented Java-based system which allows us to easily expand their features. Below we describe main components of the LN OPS. It is evident, however, that the components have to evolve and the number of components has to grow with the developement of the system.

- **Observation Program Editor.** As a main GUI the Observation Program Editor will be implemented that contains a navigator area on the left side which shows the components in hierachical structure and editors for each observation component on the right side. This seems to be a natural design since the OP has a hierachical structure.
- **Target Star Selector.** The Target Star Selector is a catalog navigator that is going to be used to perform search and extraction of the objects (targets and reference stars) from available remote (or local) catalogs.
- **Elevation Plot.** The Elevation Plot provides a panel for displaying a plot of the elevation, airmass and parallactic angles for a given target. We've extended it with the features to define interactively a number of OBs and the suitable time slot for each of them. It also can provide the "perfect" point-spread function (PSF) and the modulation transfere function (MTF) of the ideal LBT interferometer. On Figure 4 a screenshot of the Elevation Plot with the perfect PSF is shown.

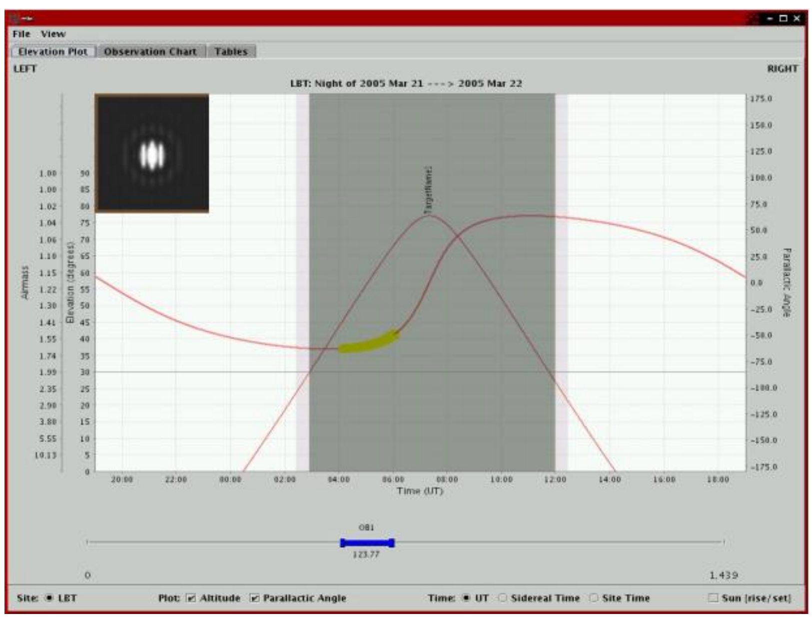

Figure 4. The extended Elevation Plot component for the LN OPS. The user can specify interactively the number of parallactical angles along with the appropriate time slots. It helps then to determine an optimal timeline for scheduling. The "perfect" PSF (see image at the left corner of the plot panel) may be also provided to verify a possible smearing in the case of fast changing of the defined parallactical angle.

[§]Granted to MPIA due to Software Usage Agreement between NASA and MPIA.
[¶]Granted to MPIA from Gemini Observatory.

- **Visual Target Tuner.** The Visual Target Tuner for the LN OPS provides a graphical view of the observation and allows interactively modify elements of it. Together with the Target Star Selector it enables an image of the field of the target to be overlayed with the field-of-views of the MCAO and available reference stars (see Fig. 6).
- **Instrument Setup Editor.** The Instrument Setup Editor will define the static configuration of the LN instrument for a given OB.
- **Offset Pattern Editor.** The Offset Pattern Editor will be used to construct a nod-, dither- mosaic pattern of the telescope motion.
- **Performance Estimator.** The Perfomance Estimator is one of the important component of the OPS that should provide observer with an idea what he/she can expect under the given conditions. In the next subsection, we will consider the concept for the development of the LN perfomance estimator in detail.

4.1. The Performance Estimator for the LN OPS

The task of the performance estimation for the LN in the framework of the OPS is complicated by the fact that it should assess the performance in 2-3 minutes (maximum). The precise numerical simulations are not appropriate because they demand a lot of time (hours). Thus, the aim of this tool is to give to the LN user an initial evaluation of the achievable performance in terms of fringe contrast (FC) which depends on the strehl-ration (SR) and whenever possible of the PSF. The achievable FC value is dominated by the behaviour of the MCAO and the FFT systems which are determined by the selected guide stars and the final SR, the MCAO can provide with the current atmospheric conditions. The LN MCAO system consists of two sensors for each telescope arm: one for the gorund layer (GWS), the other for layers between 6 and 15 km (MHWS). The AO system works in the visible wavelength using the multiple field of view approach with a 2' – 6' diameter field of view for the GWS and the central 2' for the MHWS. The FFT uses the infrared wavelength in the rectangular of 1' by 1.5'.

Since the selection of the guide stars have a very strong impact on the performance of the observation, the LN OPS should propose an observer the best available guide star constellation. Some rules (see e.g. Table 1) can be derived from the main instrument characteristics such as the geometry and orientation of the field-of-views for the MCAO and FFT as well as the orientation and travel range of the star enlargers as explained in Fig. 5.

Integrated magnitude for the asterism	Min. separation between the stars		Min. number of reference stars	Max. number of reference stars	
	MHWS	GWS	MHWS & GWS	MHWS	GWS
$R < 19$	20 arcsec	30 arcsec	3	8	12

Table 1. In this table are listed the main constrains used for the selection of the Natural Guide Stars: an integrated magnitude of the reference stars, their maximal and minimal numbers as well as a minimal and maximal separation between them.

The performance knowledge is based upon existing results of AO facilities such as NAOS and on the simulations[10–12] which have already been performed for LINC-NIRVANA.

In the multiple field of view (MFoV) Layer Oriented[13] approach all the reference stars in each WS FOV are simultaneously sensed and the contribute to the signal of each star is weighted by its brightness (intensity). The different weight introduces a sort of anisoplanatism to the correction that is more and more important increasing the brightness difference between the reference stars. In particular we saw that in most astronomical cases a magnitude range of about 3 is acceptable. To solve the performance estimation in a fast way we identify the main parameters that draw the correction (or in other term the SR map over the field of view and in a fixed seeing condition):

- The overall brightness of reference stars;

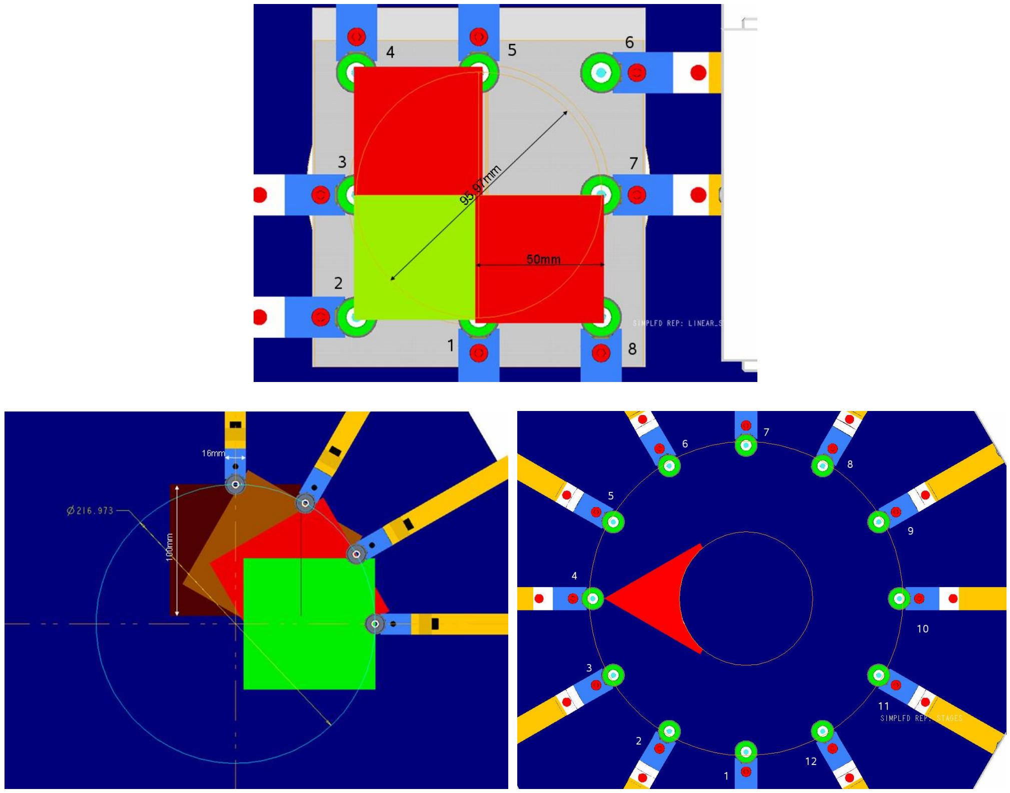

Figure 5. Star enlargers (SE) arrangement around the field-of-view and constraints for reference star selections are presented. On **the top plot** the SE of the MHWS is shown, the three SE are fully superimposed in a quandrant, therefore it has to be taken care of collisions; on **the bottom left plot** the travel range of the GWS SEs is shown for individual SE; each set of three GWS SE can only reach a certain area (e.g. for the SEs {3-4-5} – the triangle area on **the right bottom plot**).

- The magnitude range between reference stars;
- The intensity barycentre.

These three parameters do not solve completely the problem but give a reasonable guess to what will be the SR distribution. Actually to solve definitely the performance estimation the distribution of the stars all over the MCAO field of view is needed instead of the barycentre. Taking into account the full distribution of the guide stars makes a fast computation impossible. Finally we draw a strategy to use the three parameters above coupled to numerical simulations in order to define a hyper-grid of possible results to be used. Analyzing the impact of the parameters we have selected, we can underline different level of the approximation to the results: the overall brightness of the reference stars defines the signal to noise ratio of the measurements and it sets what will be the average correction (average SR over the technical field of view); the magnitude range is the first approximation used to evaluate the uniformity level; finally the barycentre should define the position of the peak of SR map. Of course we have to take into account possible cross-talks between the two loops. For example if the stars of the GWS are very bright and the barycentre light falls outside the central 2 arcmin FoV and the MHWS reference stars are very faint (integrated magnitude 16) then the MCAO system will apply a large correction with the secondary mirror but very un-uniform peaked outside the MHWS FoV; moreover the MHWS will be to much affected by noise to succeed compensating the anisoplanatism introduced by the ground loop on the central 2 arcmin (both on FFTS and scientific FoV). Taking into account these different issues the way we want to proceed is to create a database of numerical simulations with fixed atmospheric condition, science wavelength computed for the zenith case. This database will be a 6 parameters space in which we let vary the

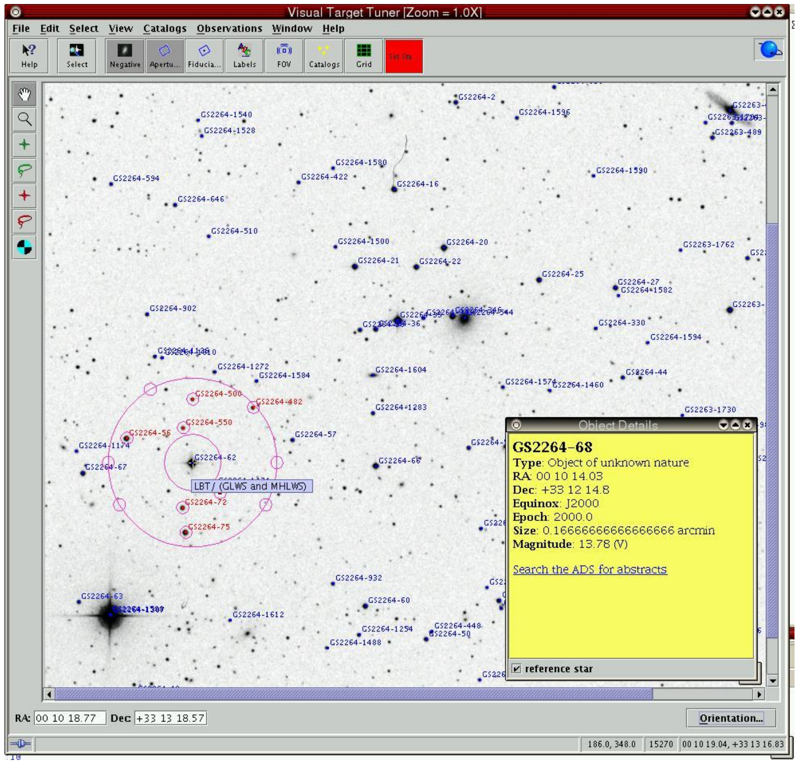

Figure 6. A screenshot of the Visual Target Tuner component for the LN OPS. The fields-of-view for the MHWS and GWFS are shown thereby six guide stars are covered by star enlarges of the GWFS. The user can select the guide stars automatically or manually. By mouse click on the object a detailed information about each star in the field may be presented in the Object Details window.

parameters we have identified above both for the GWS and the MHWS. Once the LN user will define the target to be observed the OPS will retrieve the possible reference stars configuration for AO and will compare it with the existing database finding out the simulation that fits mostly the characteristics of the reference star field. To retrieve the performance estimation the simulated data will be corrected for the Zenithal angle, the scientific wavelength and the atmospheric seeing.

5. CONCLUSION AND OUTLOOK

Observing an astronomical object with the LINC-NIRVANA interferometer requires a careful preparation process. We have explored state of the art of the software tools for the observation preparation: the fundamentals of preparing a proposal are common to most observatories; in the last years considerable efforts have been done to (re-)write observation preparation tools, taking advantages of the new technologies such as multi-platform Java language and widespread use of the Internet. The LN OPS is planed as a tool to assist scientist to create a valid observation program, focusing on the features when observing with LINC-NIRVANA. We follow the concept of the observation preparation software developed in the APT and OT where all phases of the proposal process are combined in a uniform tool. Indeed, many of the software components such as for example the "extended elevation plot", the "target/reference star selector" and the "performance estimator" can be useful in the exploratory phase and in phases- 1,2. We are developing the prototype of the LN OPS based on the APT and OT tools, reusing and expanding some of their components which are universal in the preparation process for any telescope. In the framework of the OPS the performance estimator should be developed in order to give an astronomer the idea about the expected perfomance of the LN instrument. A first step into this direction is an endeavour to extract the knowledge information from the existing results of MCAO simulations

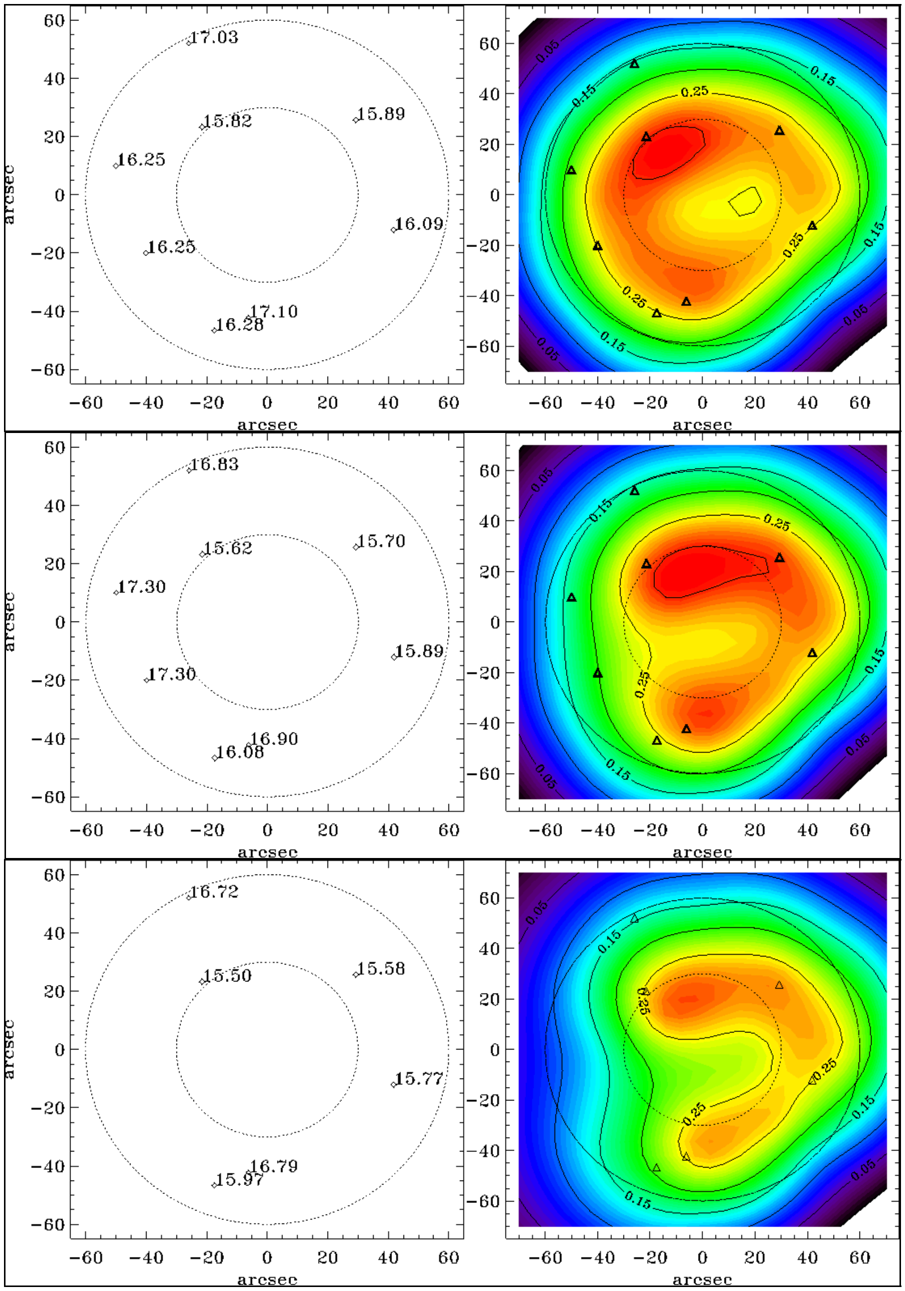

Figure 7. The simulated strehl-ratio map for the three different cases of constellation for the LN MHWS. The three simulated SR map represent different configuration taking constant the overall integrated magnitude and adding in the bottom left side two stars. We would like to stress that how the SR uniformity is driven by the reference stars geometry.

for LINC-NIRVANA. This approach seems to be promising, but it needs comparison with real simulations of science targets.

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