Instrument-specific features within the observation preparation software for LINC-NIRVANA

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ABSTRACT

The LINC-NIRVANA (LN) Observation Preparation Software (LOPS) supports an observer during the complex process of preparing the observations for LINC-NIRVANA (LN). LN is a German-Italian beam combiner for the Large Binocular Telescope. The instrument exploits its full capability by means of Multi-Conjugated Adaptive Optics and an IR Fringe and Flexure Tracker. These sub-systems of the LN instrument and the fixed geometry of the telescope put specific constraints on the observation and scheduling process. LOPS is committed to a generic approach which allows to easily include new features on the so called procedure-plug-in level (low level). Considering specific aspects of the LN instrument the implementation on the generic procedure level is not adequate enough, because an user/observer needs to deal with a lot of instrument-specific parameters when preparing an observation program (OP). For this reason, LOPS provides a high-level application plug-in system which allows to maintain the features of an OP also as separate application in order to benefit from the more advanced GUI. In this paper we present the Guide Star Buffer concept as an exemplary feature-specific application in the framework of LOPS. It is dedicated to search, select and organize guide stars in the corresponding groups needed for LN observations.

Keywords: LINC-NIRVANA, observation preparation software, guide star selection

1. INTRODUCTION

1.1. Specific features of the LN instrument

LINC-NIRVANA is a Fizeau interferometer for the Large Binocular Telescope (LBT). The LBT has two primary mirrors with a diameter of 8.4m each and a center-to-center distance of 14.4m on one common alt-az mounting. LINC-NIRVANA[1] will combine the light from the two primary mirrors coherently in Fizeau mode. In this interferometry type, the light comes together in the focal plane on the detector. The single telescopes thus act like holes in a mask covering a much larger telescope. For such a configuration, true imaging over a wide field-of-view is possible, with an angular resolution corresponding to the maximum edge-to-edge distance in the telescope configuration, i.e. 22.8m.

To achieve such a high angular resolution, LINC-NIRVANA will make use of a sophisticated Multi-Conjugated Adaptive Optics (MCAO) system. It corrects the deformations of the wavefront introduced by the atmosphere. The two beams that will be combined in the camera are corrected by an MCAO system, aiming to cancel the turbulence in a scientific field of view (FoV) of 2 arcminutes. The MCAO wavefront sensors will be two for each arm, with the task to sense the atmosphere at two different altitudes (the ground one and a second variable one between a few kilometers and a maximum of 15 kilometers). The scheme of the MCAO for one of the 8.4m mirrors is shown in Figure 1. The first wavefront sensor, namely the Ground- layer Wavefront Sensor (GWS), will drive the secondary adaptive mirror of LBT. The second wavefront sensor, namely the Mid-High-layer Wavefront Sensor (MHWS) will drive a deformable mirror which will also have the possibility to be conjugated to the same altitude of the correspondent wavefront sensor. The entire system is duplicated for the two telescopes. It is based on the Multiple Field of View (MFoV) layer-oriented technique, having thus different FoVs to select the suitable references for the two wavefront sensors. The GWS usess the light of an annular FoV from 2 to 6 arcminutes, while the MHWS uses the central 2 arcminutes part of the FoV. In order to be able to integrate on the science detector for longer than fractions of a second without loosing fringe contrast and the respective

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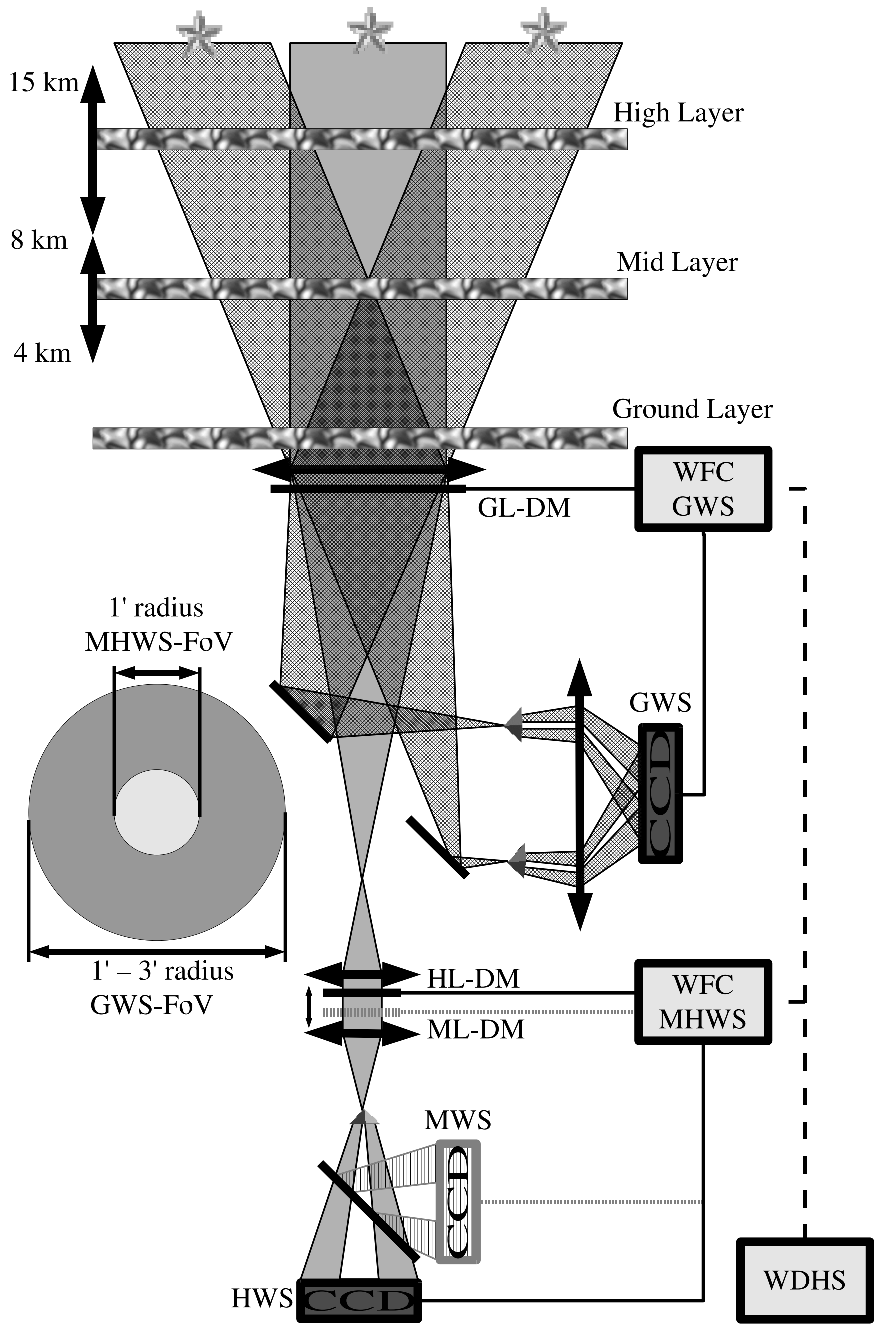

Figure 1. *Scheme of the the LN MCAO for single 8.4m dish. The outer annulus from* $1'$ *to* $3'$ *radius is used by the Ground-Layer Wavefront Sensor (GWS). Up to 12 Natural Guide Stars (NGS) can be optical co-added. The central field of* $1'$ *radius is used with up to 8 NGS by the Mid-High-layer Wavefront Sensor (MHWS), which splits the light to the Mid-Wavefront Sensor (MWS) CCD and the High-Wavefront Sensor (HWS) CCD. Both Sensors have their own Wavefront Computer (WFC) running the control loops independently. A Wavefront Data Handling System (WDHS) optimizes the control loops and off-loads modes from one to the other in order to avoid saturation. The High-layer and Mid -layer Deformable Mirrors (HL-DM, ML-DM) can be adjusted together to their conjugated altitude, HL-DM between 8 km and 15 km, ML-DM between 4 km and 8 km, respectively. In the first step only HWS and GWS are implemented. Therefore the MWS and its DM is only shaded in this picture.*

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gain in spatial resolution LN contains an elaborated system, the so-called Fringe-and-Flexure-Tracker (FFT) system. It measures and corrects the optical path differences introduced by the atmosphere and vibrations of the telescope (see Figure 2a.). The FFT uses the infrared wavelength in the FoV of 1 by 1.5 arcminutes (see Figure 2b.).

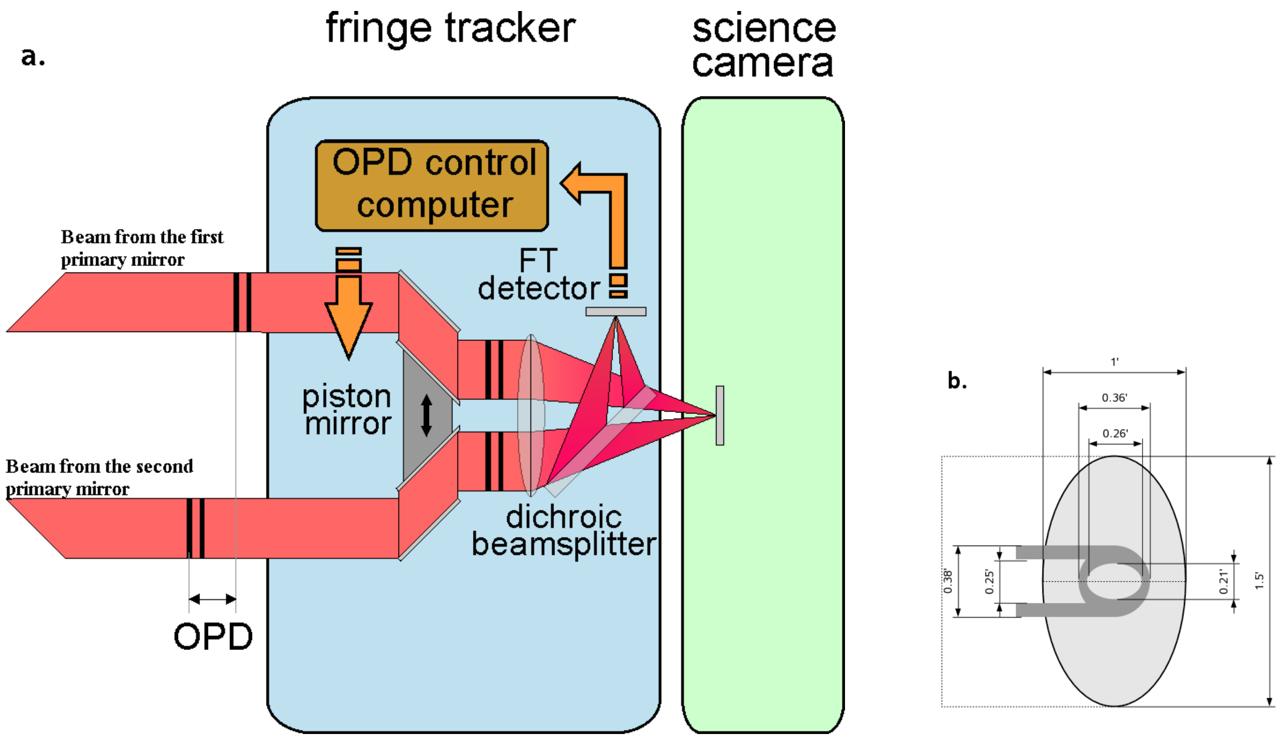

Figure 2. a. *Schematic view of a ground-based optical interferometer featuring a fringe tracker. Perturbed wave segments passing through the interferometer are corrected for each channel individually. The remaining perturbation is differential piston, or optical path-length difference (OPD), between the channels. In the fringe tracking servo loop, differential piston is measured by analyzing the fringe pattern of a reference target in the combined focal plane. A correction signal is determined and a compensating OPD is introduced by moving the piston mirror. Just like in the AO loop, the fringe tracking detector is located behind the piston mirror in the optical path. Thus, the sensor measures the residual differential piston after the correction applied in previous cycles.* **b.** *Field-of-view and vignetted areas in the FFT system.*

1.2. Observation with LINC-NIRVANA

Astronomical observation with interferometers is more complex then conventional imaging or spectroscopy. The ideal Point-Spread-Function (PSF) of LINC-NIRVANA is a combination of the PSF of a individual telescope, dissected by fringes, which are caused by the interferometeric combination of the light from the two telescopes. To reconstruct the full angular resolution in all directions, images taken at different time (parallactic angles) have to be combined.

Thus, 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/or scheduling process of the observation program. One might need, for example, first a particular position angle on a particular source, then move to another position angle on another source for a while, then return and etc.

LINC-NIRVANA offers an exceptional and so far unprecedented combination of wide field of view, high angular resolution (9 milliarcseconds at 1.25m) and large collecting area (110 m). The achivable performance is dominated by the behaviour of the MCAO and the FFT systems which are determined by the selected guide stars and the final Strehl-ration provided by the MCAO under the current atmospheric conditions.

Therefore, the selection of the guide stars has a very strong impact on the performance of the observation. This demands a specific consideration in the process of preparing the observation programs.

In this paper, we first outline the conceptual design of LOPS including its complex data model in section 2.1. Section 2.3 describes the key components of our software. Subsequenly, we introduce in section 2.4 our concept of the instrument-specific Guide Star Buffer that allows to search, select and organize guide stars needed for observations with LINC-NIRVANA. Finally, a short summary is given in section 3.

2. LOPS SYSTEM

The LN Observation Preparation Software (LOPS) is a software tool that supports astronomers in constructing a full observing project for the LINC-NIRVANA instrument. The process of the preparation of such observing projects is strongly imposed by the scientific goals and the complexity of the LINC-NIRVANA instrument set-up. LOPS allows the observer to prepare and assemble high-level science observation programs using a graphical representation of the components.

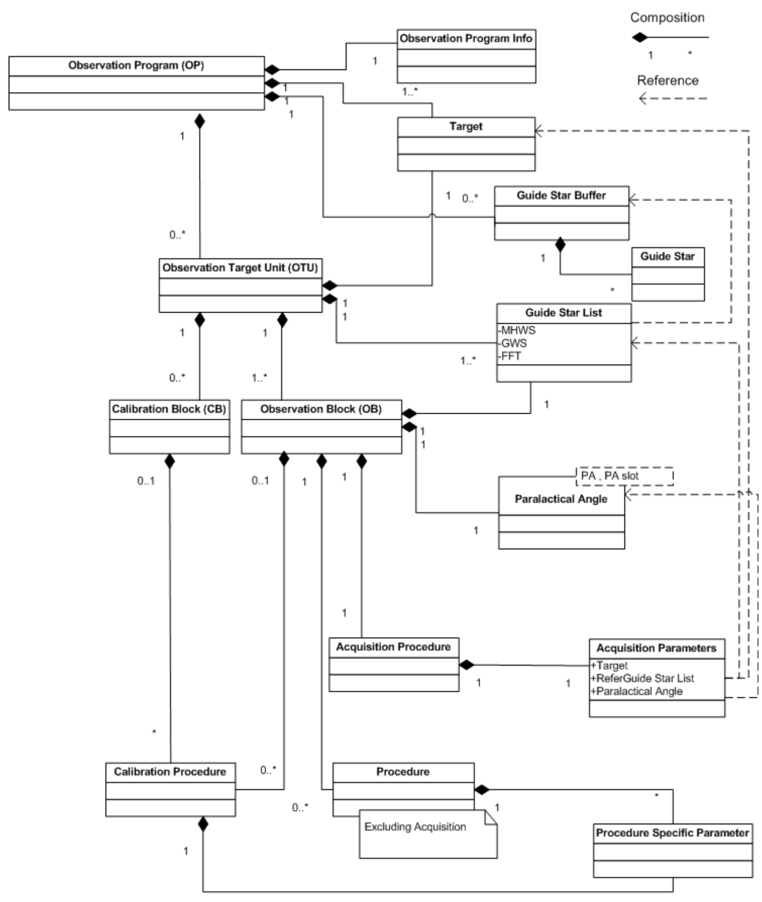

Figure 3. *Basic class diagram including the main elements of the LOPS data model.*

2.1. Data model

- **Observation Target Unit** (OTU) contains all the information associated with one Target and includes a set of single observations (observation blocks). This means that for each target there is a separate OTU.

Each OTU is a self-contained entity and possesses a target, predefined observing constraints, scientific objective, multiple instrument configurations including multiple calibrations and exposure times. Astronomers specify OTUs, defining a target with the number of paralactical angles at which it is observed. Within an OTU certain parameters are shared among its elements.

- **Observation Block** (OB) is the smallest schedulable entity that contains all information necessary to obtain a single observation. Each OB is composed of a number of instrument-mode-specific procedures which are grouped in a procedure sequence table. Each procedure contains a number of parameters which are defined by the user
- **Procedures** are pre-defined scripts that describe the smallest (atomic) activities at top level that includes a set of parameters.
- **Parameters** are elements of a procedure and can be either fixed parameters (from the script) or need to be specified by user.

Figure 3 depicts a simple class diagram of the main LOPS model elements. The hierachical structure of an observation program (Parameter $\subset$ Procedure $\subset$ OB $\subset$ OTU $\subset$ OP) allows to share data between its components in an optimal way.

2.2. Modules

The LOPS GUI is build on top of a flexible plug-in system* that provides a common way to add specific tools/modules. The different modules available to the user are the main user interface components within LOPS. Each module is inter-connected to other related modules and the module framework of LOPS ensures a persistent data handling between the modules.[3]

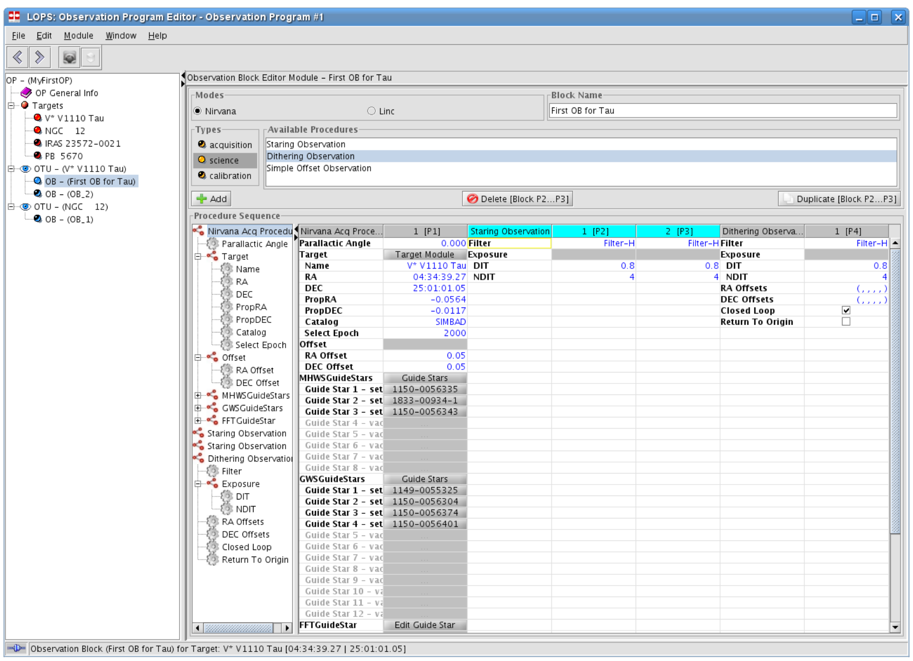

Figure 4. *The 'observation block editor' module in the framework of the LOPS 'observation program editor'.*

*Basic components of the LOPS plug-in system are re-used from APT[2]

2.3. Observation program and block editors

- **OPE:** The main GUI of the LOPS is the Observation Program Editor (OPE) which 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 (see Figure 4). The OPE represents a single OP and contains all components which allow astronomers to interact with the current observation program.
- **OBE:** The Observation Block Editor (OBE) module is a fundamental component of the LOPS to create a single observation block, i.e. an observing sequence of pre-defined procedures (scripts) similar to templates in P2PP.[4] The user can select specific procedures according to its type (acquisition, science, or calibration). The corresponding procedures are listed on the right side of the OBE GUI (see right side on the Figure 4). The editing and specification of the sequence is done in the procedure table while the procedure tree is meant to give an overview and to help to navigate within the sequence of procedures. A procedure can be selected and then added to the OBEs procedure sequence table. The OBE displays the parameters of each added procedure in the form of a two-column table entry, where the 1st column includes the parameter names (labels) and the 2nd column allows to set-up and modify the parameter values.

2.4. Guide star buffer

The first procedure that must be a part of any science OB is an acqusition procedure. The LINC-NIRVANA acquisition procedure contains the informations related to the target and includes instrument set-up. It demands a definition of many parameter groups. In order to facilitate the astronomer's work LOPS provides a mechanism that allows a connection to other modules for certain parameter types such as target and guide stars. In particular, this is very useful in the case of guide stars which can be selected as a group from on-line catalogs.

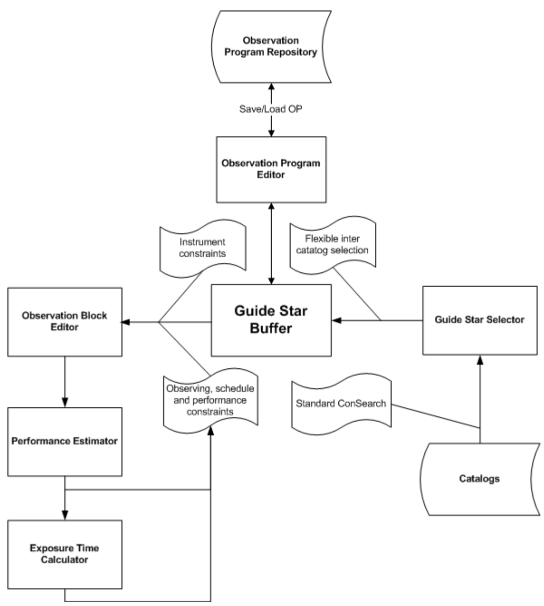

Figure 5. *Guide star buffer scheme.*

For this purpose, we introduced the Guide Star Buffer(GSB) that enables detailed specification of the LINC-NIRVANA MCAO and FFT guide star parameters. It provides connections to the external multi-magnitude catalogs and allows the selection of available guide star constellations according to the main instrument characteristics such as the geometry and orientation of the FoVs for the MCAO and FFT system.

To create/add a pre-selected guide star list, the GSB module uses the Guide Star Selector (GSS) to retrieve stars from on-line catalogs (see Figure 5). The GSB allows an observer to select natural guide stars (from the pre-selected guide star list) based on the following main instrument constraints:

- The MCAO system using the MFoV approach (in the visible wavelength):
  - 2' to 6' diameter FoV for the GWS
  - central 2' for the MHWS
- FFT using the infrared wavelength in the FoV of 1' by 1.5'; vignetted area
- maximal number of guide stars as defined for the LN instrument by the number of the so-called "star enlargers":
  - 12 guide stars for the GWS
  - 8 guide stars for the MHWS
  - 1 FFT star
- minimal number of guide stars:
  - 3 guide stars for GWS and MHWS together (derived from the performace simulation)
  - 1 FFT star
- the integrated magnitude of the guide stars being ≤ 19 (derived from the performance simulation)
- magnitude range of guide stars: In the MFoV layer-oriented approach all the guide stars in each wavefront sensor FoV are sensed simultaneously. The contribution to the signal of each star is weighted by its brightness. The different weight introduces a sort of anisoplanitism to the correction that is more and more important inreasing the brightness variance between the guide stars. In particular we found out[5,6] that in most astronomical cases a maximal magnitude range of about 3 is acceptable.

The GSB module will later-on communicate with the Performance Estimator as well as with the Exposure Time Calculator (ETC) module. Thus, the best asterism based on the estimates of Strehl-ratio and fringe contrast can be proposed. In this context the ETC module allows the calculation of the exposure time for a given S/N-ratio or vice versa, based on magnitude, Strehl-ratio and filter. Screenshots of the GSB and related modules are presented in the Figures 6, 7, and 8 accordingly.

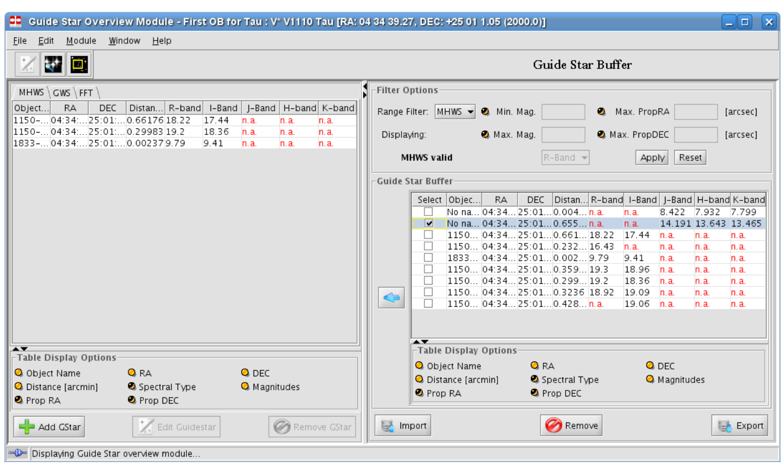

Figure 6. *Screenshot of the Guide Star Buffer module.*

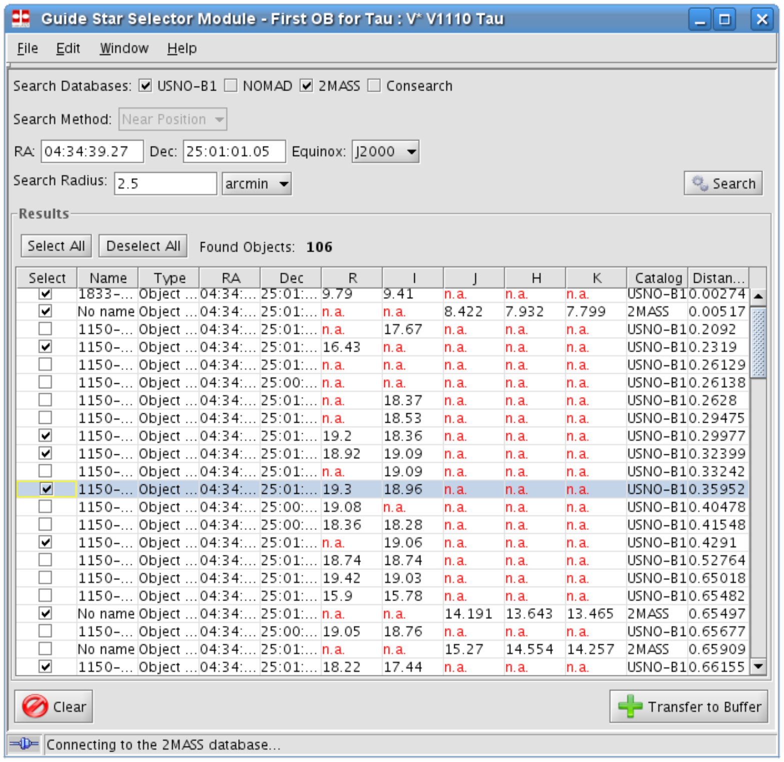

Figure 7. *Screenshot of the Guide Star Selector module.*

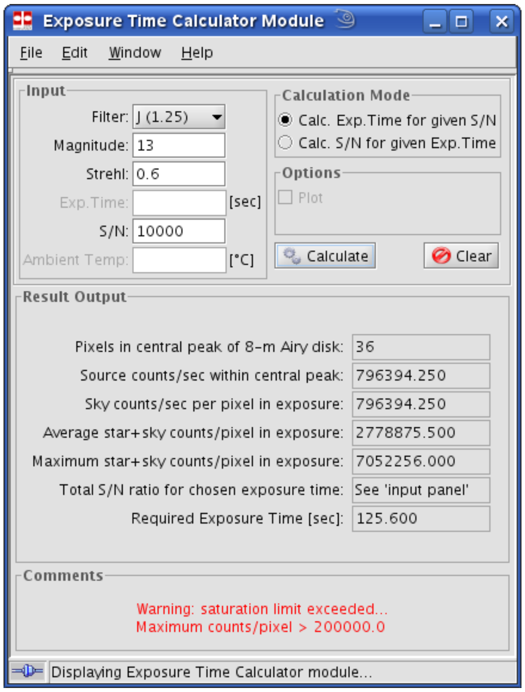

Figure 8. *A simple version of the implemented ETC module.*

3. CONCLUSION

LOPS provides a high-level application plug-in system which allows to maintain the features of an OP also as separate applications in order to benefit from a more advanced GUI. The impemented Guide Star Buffer instrument-specific module enables detailed specification of the LINC-NIRVANA MCAO and FFT guide star parameters. It is especially useful for astronomers, who need an efficient way to test many instrument set-ups and share observing information among a number of observation targets, each having its own observing preferences and constraints.

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