The Fly-Eye Telescope, Development and First Factory Tests Results

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ABSTRACT

The development and deployment of ESA's Fly-Eye NEO Survey Telescope, based on the innovative technology developed by OHB-Italia [1], is in progress. The NEO Survey Telescope Deployment (NEOSTED) project has the goal to develop, accept and deploy on site the first Fly-Eye prototype. OHB Italia is the prime contractor and the technical coordinator of a multinational Consortium composed by Emil Lundgren (NO), Actemium-Cegelec (DE), Ixion/TTI (ES), Anafocus-E2V (ES), Hitec (LU), Toptec (CZ), Creotech (PL), Enviroscopy (RO), Prooptica (RO). The main components have been procured and accepted, comprising the Equatorial Mount with all telescope optical and opto-mechanical Subsystems.

The first project phase foresees the implementation of eight optical channels covering 22 sq. deg. i.e. half of the overall 44 sq. deg. Field of View (FoV). All optical components and opto-mechanical equipment necessary to implement the half FoV have been accepted and integrated in the telescope. The telescope has then been tested with two EGSE (Electronic Ground Support Equipment) CCD Cameras that demonstrated the telescope performance within the seeing limitations of the factory integration site.

The design, development and acceptance of the required eight CCD cameras, necessary to populate the half FoV focal planes with astronomic grade 4k x 4k imaging sensors, is currently under implementation, with the factory acceptance of the half FoV telescope expected for spring 2019. In parallel, the procurement of the remaining eight optical channels, necessary to complete the telescope to the full FoV, has been launched, with the introduction of a dedicated alignment procedure, based on Newton's ring technique, allowing the integration of the additional components on the already functioning half FoV telescope.

We present the telescope architecture and validation program, as well as the overall program status and the activities performed in coordination with ASI and ESA, to integrate and validate equatorial mount and opto-mechanical subsystem at the final installation site, Monte Mufara (Palermo, Italy).

1 INTRODUCTION

The Near Earth Object Survey Telescope (NEOSTEL) is an innovative project of the NEO segment of the ESA's SSA programme and will in particular focus on the survey and tracking of Near Earth Objects (NEOs). It will represent the core optical sensor of the NEO-SSA ground based optical observation network.

NEOSTEL, based on the Fly-Eye concept, will allow a wide survey strategy, which consists in scanning two thirds of the visible sky three times per night to detect NEO objects characterized by apparent magnitudes down to 21.5. NEOSTEL shall also allow the detection of fast approaching NEO objects, moving at apparent speeds up to 1.5 arcsec/min. NEOSTEL shall also be able to perform all required follow-up activities, necessary for catalogue maintenance and upgrading, impact monitoring, alert and mitigation, etc.

2 WIDE SURVEY STRATEGY

The application of the Fly-Eye Telescope demonstrated to be particularly effective in NEO-SSA field, for the implementation of the 'Wide Survey Strategy'.

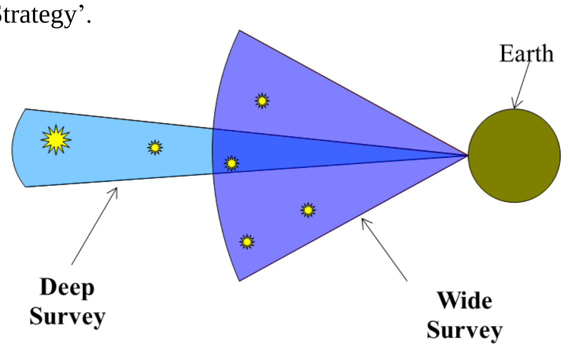

Figure 1. Wide Survey Observation Strategy Concept

This observation strategy allows to observe 2/3 of the whole visible sky three times per night from one station

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down to mag. 21.5. This observation concept is orthogonal to the so-called 'Deep Survey' strategy.

Having at least 4 or 5 stations spread in latitude (in both hemispheres) and longitude, allows to cover all the visible sky from ground except near the Sun, the Moon and the galactic plane.

Due to the low meteorological correlation, this survey system is capable to observe many nights a year.

As the illumination source is the Sun, the operating wavelength band of NEOSTEL is limited to the visible (VIS) spectral range, in particular to 450-770 nm. NEOSTEL observations shall be accompanied by infrared and spectroscopic observations, performed with additional telescopes at different observational sites.

The aim of targeting objects at above mentioned Magnitude while scanning two thirds of the visible sky three times per night, requires a one meter class aperture telescope together with a very large FoV and exposure times in the order of some tens of seconds (typically 40s) [2].

The above reported requirements are embodied in the Fly-Eye architecture resulting in a fast optics, limited by astronomical seeing.

3 NEOSTEL ARCHITECTURE

The telescope consists of the following components:

- A spherical primary mirror;
- A centre piece;
- A secondary structure hosting the secondary fly-eye core optics;
- An equatorial mount with declination fork and right ascension housing.

NEOSTEL is in practice a configuration of sixteen distinct and equivalent telescopes.

Each of these telescopes collects the image of 1/16 distinct portion of the overall FoV with its single optical channel.

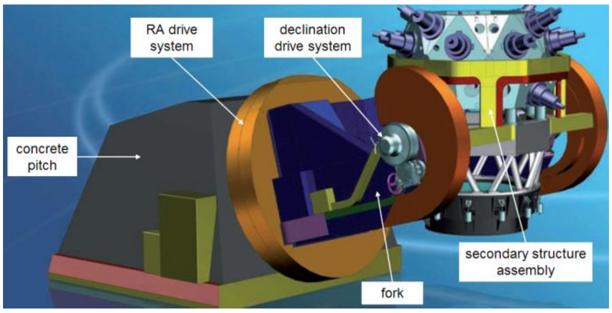


Figure 2. NEOSTEL Architecture

The primary mirror is expressly selected with a spherical surface shape, in order to allow the equivalence of all 16 identical optical channels.

In this view the architecture of the Fly-Eye Telescope is modular, therefore the FoV can be populated progressively, by adding subgroups of optical Channels that define a sub-portion of the overall FoV, without the need to disassemble the already functioning 'Eyes'.

The modularity of the NEOSTEL architecture is a key element for its industrialization and series production.

3.1 Mechanical Structure

To avoid the application of sixteen independent de-rotators, one for each single optical channel, the NEOSTEL is provided with an Equatorial Mount, which characteristics are summarised in the following table

declination stroke	± 75° (from Zenith)
right ascension stroke	± 210°
position accuracy	± 5"
right ascension assembly	Ø ≈ 2 m, $L \approx 0.5$ m
required dome-size	≈ 13÷15 m

Table 1. NEOSTEL Structural characteristics

From the opto-mechanical point of view, the requirements necessary for wide survey observation impose a stiff structure allowing fast repositioning with angular speeds up to 7 deg/s.

Every vibration after telescope repositioning and subsequent image acquisition has to be avoided to prevent degrading the optical quality delivered by the optics.

3.2 Optical Structure

The NEOSTEL secondary optics architecture is composed by

- A Central Beam Shaper (CBS);
- Sixteen identical Secondary Optical Tubes (SOT);
- An opto-mechanical system allowing the integration and alignment of the secondary optics elements and the overall Telescope structure.

The CBS represents the optical catadioptric core of NEOSTEL and is constituted of:

- A Beam Splitter (BS) composed of a prismatic faceted mirror with 16 facets
- Sixteen aspheric dioptres

The optical tubes are necessary to correct the wave front generated by the primary mirror at the beam shaper exit, up to the required optical resolution, in order to produce the sub-images of the total observed FoV in the individual Focal Planes (FPs), where suitable CCD image-recording elements are placed

effective focal length	2000 mm
entrance aperture diameter	1180 mm
central obstruction diameter	600 mm
overall optical throughput	80 %
limiting magnitude at 40 s exposure time	21.5 VMag at 1.5 "/min
total FoV	6.7° x 6.7°
FoV of each optical channel	≥ 1.67° x 1.67°
encircled energy	> 80 % in < 1’’ radius

Table 2. NEOSTEL Optical Characteristics

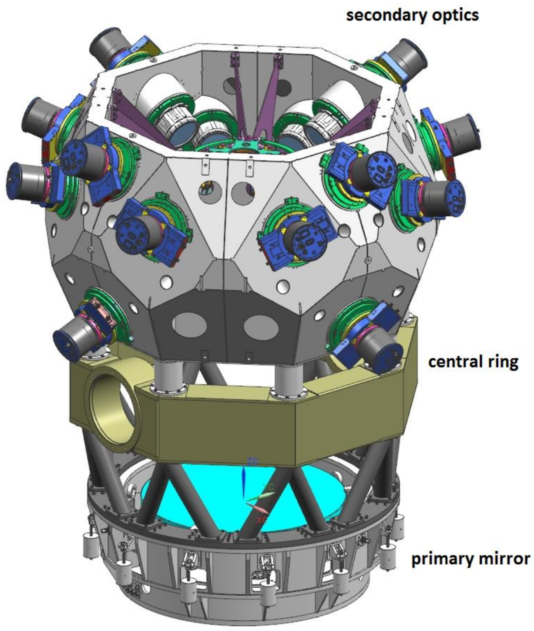


Figure 3. NEOSTEL Opto-mechanical Assembly

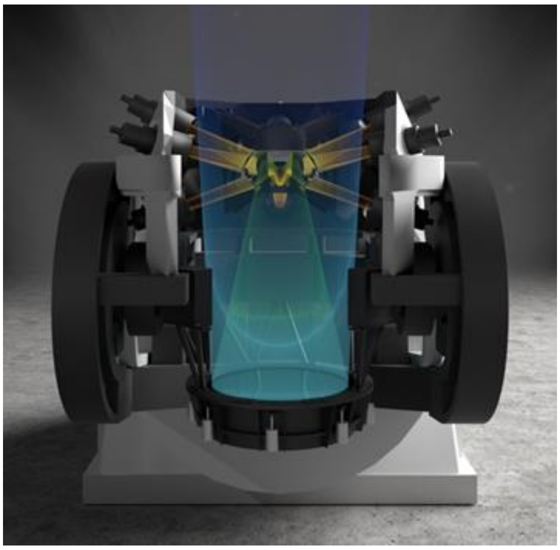


Figure 4. Fly-Eye Optical Architecture Concept

The primary mirror is constituted by Zerodur and is supported by an off-loading system, properly designed to reduce the surface deformation, induced by gravity, to less than 40nm peak to valley (conventional 632.8nm He-Ne laser).

Figure 5. NEOSTEL Primary Mirror within Off-load System during Integration and Test

The primary mirror was finally polished by means of ion beam figuring and tested at the INAF laboratories of Osservatorio Astronomico di Brera in Merate (Italy).

3.3 NEOSTEL CCD Camera and Sensor

The NEOSTEL CCD camera is a state-of-the-art astronomical camera that provides low noise I/F capabilities as well as remote control via an EPICS protocol over Ethernet and a vibration-free mechanical shutter. In the following table the characteristics of the CCD camera are reported.

The NEOSTEL CCD camera is under development within the ESA ASTROCAD program.

resolution	4096 pixels x 4096 pixels
pixel size	15 µm x 15 µm
image area	61.44 mm x 61.44 mm
pixel scale	1.5’’
nominal exposure time	40 s
shutter exposure band	10 – 300 s
wavelength band	450 – 770 nm
readout time	< 2.5 s
readout noise (at 2 MHz)	10 e- (RMS)
Quantum Efficiency (peak)	> 95 %
Quantum Efficiency (mean)	> 75 %
file format	FITS
ambient temperature range	-20°C to +30°C

Table 3. NEOSTEL CCD Camera characteristics

The CCD sensor is an astronomic grade CCD array sensor and is operated at -50°C by means of a suitable cooling based on a Peltier Thermoelectric Cooler (TEC). To allow the maintenance of the operational temperature level, avoid frost on the CCD Sensor surface and limit heat exchange, the CCD Sensor is located in a vacuum chamber, sealed and kept in vacuum without active pumping. To achieve this challenging technical aspect, very low outgassing materials have been selected for the vacuum chamber implementation. To preserve suitable vacuum levels for sufficiently long maintenance periods (six to twelve months), a particular care has been dedicated to sealing and seal interfaces, with the introduction of advanced technologies, inherited from material processing and high energy particles fields.

To extract the dissipated heat, the hot side of the TEC cooler is in contact with a heat exchanger connected to a chilled fluid circuit.. A detailed thermomechanical study has been conducted in order to properly design the CCD camera components (geometry, materials, etc.) to allow the optimal functioning of the TEC Peltier module.

4 STATUS OF DEVELOPMENT AND DEPLOYMENT OF NEOSTEL FIRST PROTOTYPE

The development and deployment of the NEOSTEL first prototype has been articulated in two phases, leading to a progressive implementation of the full instrument capability, namely:

a) A first phase, leading to the implementation of an already operable instrument, provided with half FoV optics (eight optical channels corresponding to an overall 22 sq. deg. FoV);
b) A second phase, leading to the completion of the full FoV (second octuplet of optical channels, completing the full 44 sq. deg. FoV).

4.1 NEOSTEL first phase achievement

The half FoV Telescope Opto-mechanical System (Telescope Body) has been procured, integrated and tested in Factory, at the OHB premises, in Turate (Italy).

Figure 6. NEOSTEL mounted on a mechanical ground support, allowing two axes rotations, during night sky observation campaign at OHB Turate's premises.

The Factory tests have been performed by means of a Mechanical Ground Support, equipped with motorised wheels, allowing to perform Sky Observations at the factory location.

The Instrument Equatorial Mount has been developed, deployed and accepted in parallel to the half FoV Optics, during the first phase of development, at the manufacturer's factory in Villafranca (Italy).

Figure 7. NEOSTEL Equatorial Mount at manufacturer's premises during acceptance tests

The first testing has been performed with two EGSE CCD Cameras, allowing to demonstrate performances compatible with the astronomic seeing available at the factory site (3.5-4.0 arc sec. average).

In particular, due to the lack of sidereal tracking capability of the laboratory mount, short exposure times have been selected (0.5s) to minimise star trails during exposure.

A dedicated seeing measurement apparatus has been installed at the factory observation site, to compare the obtained results with the recorded astronomical seeing.

The collected data have been processed preliminarily with standard astronomic tools, in terms of astrometric reduction and object identification, in order to assess both the quality of the optical performances and the limiting magnitude and thus to exptrapolate to the expected performances of the telescope when operated in actual astronomic site conditions.

An image example obtained during night sky observation and processed for source extraction is provided in the following figure.

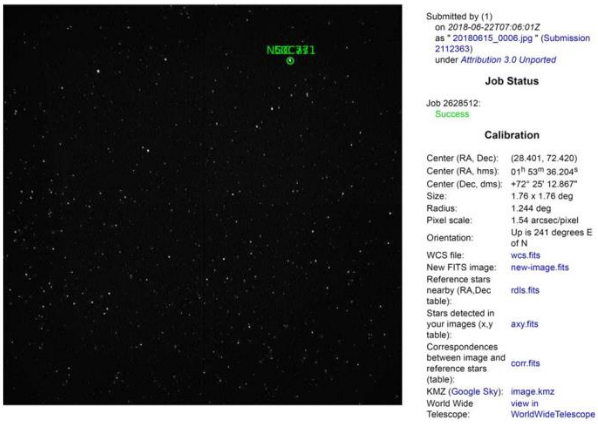


Figure 8. Example of a calibrated and astrometrically reduced image, as obtained by a 0.5s exposure at the factory observation site. It was possible to identify c.a. 2300 catalogued sources per optical channel.

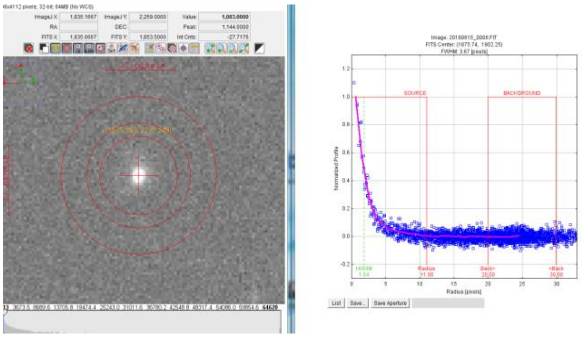


Figure 9. A star with FWHM 3.67" near the field center, comparable with the astronomic seeing of the observing facility

4.2 NEOSTEL full FoV completion

The full FoV completion phase has started with the procurement of long lead item components (raw glass materials) and the manufacturing of the second set of eight Secondary Optics Tubes (SOTs), allowing populating the second half of the Telescope FoV, to reach a total 44 sq. deg. of sky coverage for every single exposure.

As already mentioned, the incremental approach was possible due to the modularity intrinsic in the Fly-Eye optical architecture.

Each SOT is composed of twelve spherical lenses – different glassy materials are used to correct chromatic aberrations – some of which exceed the 190mm in diameter. The SOT corrects the aberrations introduced by the spherical mirror and the aspheric field lens of the CBS to generate a properly corrected image in the focal plane of the pertinent channel, where the CCD sensor is positioned. Moreover a band pass filter with almost flat response >95% transmittance in the 450nm-770nm spectral segment is inserted at the SOT entrance to prevent fringing in the NIR region (the CCD is back illuminated) and main sky scattering components in the Blue-Near UV region of the solar spectrum.

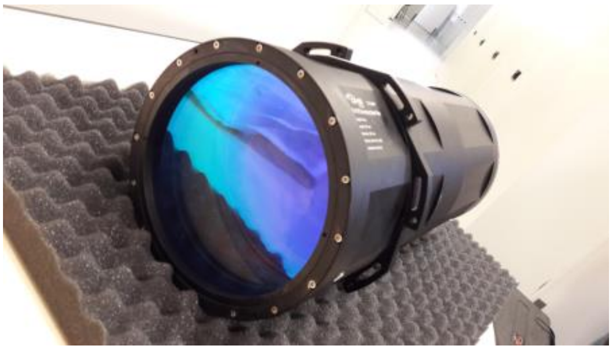
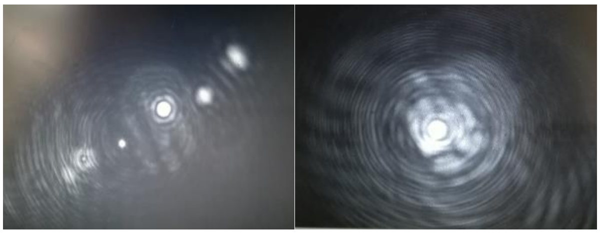


Figure 10. Secondary Optical Tube as seen from the pass band filter side.

To avoid disassembling part of the Telescope during the SOTs integration and optical alignment phases, a dedicated approach based on Newton's rings technique [3] has been set up. This way, during the insertion and preliminary alignment of a new optical channel, the already aligned ones and the overall opto-mechanical structure are maintained in the optimised positions.



a) b)

Figure 11. Newton's ring families generated by the optical channel components a) before and b) after alignment.

4.3 NEOSTEL first prototype deployment

The location for the deployment of the first NEOSTEL prototype has been studied and identified, in coordination with the Italian Space Agency (ASI), at the Monte Mufara on the Madonie Chain in Sicily.

The study has evidenced the high level requirements for the hosting infrastructure.

The key issues identified for the dome are:

- Protection of the telescope against bad atmospheric conditions
- Elimination of temperature gradients that can cause distortion in the acquired image
- Protection of the observation instruments
- Structure freedom of movement, work and testing space

A dedicated seeing monitoring system, provided with a meteorological station for environmental data collection, has been installed at the future observatory site to collect statistics of the expected observation conditions.

Figure 12. Rendering of the Observatory Site, selected for deployment at the Monte Mufara location (Sicily, Italy).

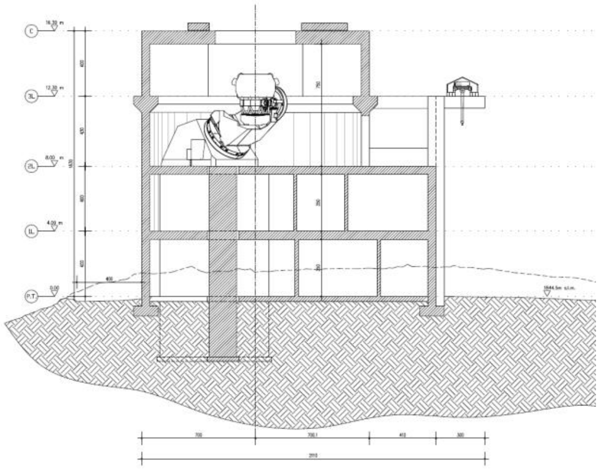


Figure 13. Draft NEOSTED Telescope Site Infrastructure Concept for Monte Mufara

5 CONCLUSIONS

The procurement of the first NEOSTEL prototype, based on the Fly-Eye technology, is in advanced state of achievement for the half FoV configuration.

Initial on-sky test campaigns were performed at the factory site by using a laboratory mount and two EGSE CCD Cameras as provisional image detectors. The obtained results are in line with expectations, i.e. are compatible with the sky observational conditions of the factory location (astronomic seeing, lack of sidereal tracking, sky background, etc.).

The completion of the full FoV has started, in parallel with the identification and deployment of the Observatory Site that will be implemented at Monte Mufara in Sicily.

6 REFERENCES

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