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INNOVATIVE TECHNOLOGIES FOR AN OFF-AXIS TELESCOPE OPTIMIZED FOR ANTARCTICA

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Abstract. It has long been demonstrated that the properties of the atmosphere above the Antarctic Plateau are unique on Earth, especially at Dome C. Already by the end of 2010, the European ARENA network roadmap summarized the exceptional atmospheric conditions that make the site uniquely favorable for infrared astronomy. To capitalize the remarquable Antarctica sites properties, we propose to develop an off-axis telescope, the only concept able to offer the highest possible dynamic range for photometry, the most reduced self thermal emissivity, a high angular resolution and a wide-field. An innovative technology has been proposed to produce the off-axis parabolic mirror and a proposal was submitted to the Horizon-2020 program on this subject (FET).

Keywords: infrared astronomy, instrumentation, Antarctica, optics

1 Introduction

As demonstrated by numerous campaigns since ten years (Aristidi et al. 2009 and references therein, Gredel 2010, and Aristidi et al. 2012), the Concordia scientific station on the Antarctic Plateau gather all the required advantages to become a major site for astronomical observations in the coming years, at all wavelengths but particularly in the infrared. The French-Italian station Concordia, at Dôme C, is successfully operating all year round since 2005. To benefit from the Antarctic performances, several countries have scientific stations, with astronomical observatories, currently operating or under development on other sites of the Antarctic Plateau.
At Concordia, an extremely cold and dry place, the sky transparency, particularly in the infrared, is considerably increased and the thermal infrared sky background radiation is lower by a factor of 10 to 20 in the 2-3 m window, compared to other sites like Mauna Kea or Paranal.
In the medium terms, the future large ground-based and space projects such as E-ELT, ALMA, JWST, EUCLID, GAIA will require new large scale surveys (such as LSST in the Northern hemisphere) to accompany their missions and key-programs to single out and follow-up new sources. We proposed to the ANR a New Generation Infrared Sky Survey (NGISS) from Antarctica, based on an off-axis telescope that could derive the greatest benefit from the polar atmospheric conditions (Vauglin et al. 2013). The only place on Earth where large and deep infrared surveys beyond 2.3μm can be carried out is the Antarctic Plateau. ANGISS is positioned to be able to perform unique and high impact science. It would supersede 2MASS survey by a factor ~ 1000 in sensitivity and ~ 3 in angular resolution and extend the spectral coverage beyond 2.3μm.
Not selected by the ANR, we keep going on with a R&D project of creating an aspheric mirror, based on a novel technology, submitted to FET-H2020.

2 Sciences drivers

The science cases have been extensively debated among the ARENA european network members to identify the highest priorities (see Epchtein et al. 2010 and references therein). The sciences programs proposed for ANGISS

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are uniquely possible with the exceptional polar atmospheric conditions of Dôme C using an off-axis telescope. This optical concept allows to minimize light scattering, to reduce self thermal emissivity, to have far superior contrast and to have a filled aperture - that means no azimuthal PSF structure and non missing wavefront errors. Coupled to a specific ground-layer adaptive optics (GLAO) technique matching the very thin turbulent layer of Dôme C (Carbillet et al. 2010), it will lead to a very performant high dynamic range telescope.
Thus, the combination of wavelength range, sensitivity, angular resolution, stability of the sky makes ANGISS unrivaled for studying:
(i) extra-solar planets and low mass K and M–type stars (detection and characterization of exoplanets with the transit and micro-lensing techniques)
(ii) the stellar populations in the Magellanic Clouds and other nearby galaxies to understand star forming processes
(iii) the distant universe: with the H_2 line, which is a tracer of star formation and peaks in the K band for galaxies at $z = 2$ to 3; the Type Ia supernovae light curves in the near infrared, much less affected by dust extinction and reddening in dusty galaxies, to improve constraints on the cosmological parameters.

The expected characteristics of the global system telescope, specific GLAO and infrared camera are given in table 1.

Primary mirror sizes	$\sim 2.5m$ (4m possible)
Configuration	Off-axis 3-mirror combination
Field of View	≥ 1 degree
Sky coverage (mini)	5000 deg^2
Focal plane configuration	16 buttable HgCdTe Hawaii RG4
Spectral range	2-5 μm
Pixel scale	≤ 0.15 arcsec
Final PSF FWHM	0.3 arcsec
Field of view of the camera	40 arcmin $\times$ 40 arcmin
Filter set (3 minimal)	K_d, L_s, L' (+ possibly K_s, M', Grism, narrow bands)
Read out time	5 sec
Integration time per frame (typical)	100 s
Diameter of 80% encircled energy spot	≤ 0.2 arcsec
expected sensitivities (point source)	$K_d \sim 25.3$ / $L_s \sim 20.8$

Table 1. Main characteristics and performances of ANGISS camera on an off-axis telescope equipped with GLAO system

3 Technological developments

A better telescope concept, based on an off-axis optical design that allows excellent dynamic range for photometry, high angular resolution together with a wide field imaging is proposed. Thus, it capitalizes the exceptional atmospheric and environmental Antarctic conditions for astronomical observations over the optical and thermal infrared wavelengths.
One of the main goals of ANGISS project was to to design and build a ~ 50 cm prototype off-axis telescope to validate the concept and to design a GLAO device compliant with the specific atmospheric turbulence properties of the site, concentrated in a very thin layer (≤ 30 m).
To be upmost efficient from this unique environment, the instrument and focal instrumentation must be fully optimized. The three-mirror decentered, not tilted (Moretto et al. 2012 and Moretto et al. 2012b) provides an inherently low scattered light design, minimizing the emissivity of the telescope and is optimized for a wide 1x1 deg field of view. The optical performance across the field is shown in Figure 1. Note that the blur in this system is only weakly dependent on the off-axis angle and the telescope will be entirely seeing limited.

ANGISS has not been funded by ANR. We persevere because the observing conditions are really unique on Earth and also because France and Europe are at the forefront of polar research, having a vast experience in overwintering and operations in polar environnement.

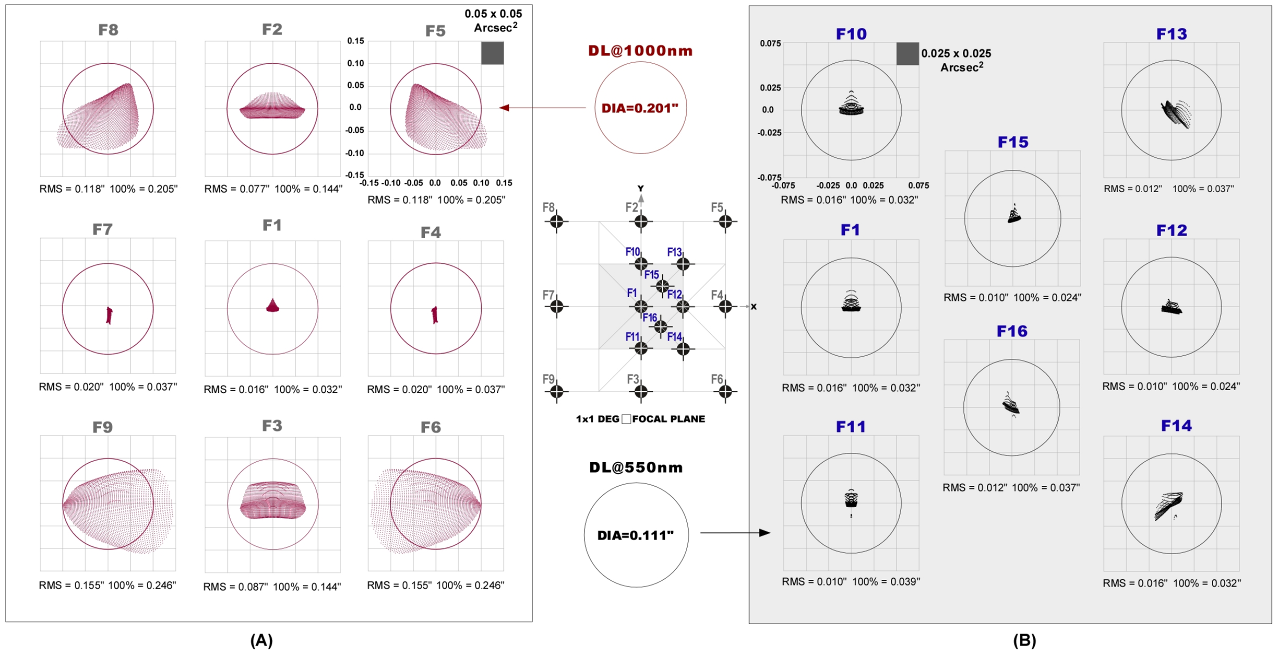

Fig. 1. Geometric optical performance over a flat Field Of View. Left: (A) The PSF computed on the edge and center of a 1×1 deg^2 FOV. Right: (B) The PSF computed across a 0.5 × 0.5 deg^2 FOV. The diffraction limit diameter is 0.111 arcsec at λ = 550 nm and 0.201 arcsec at λ = 1000 nm. Note in (A) : comparing spots F8&F5, F7&F4 and F9&F6 confirm the optical bi-lateral symmetry of the **decentered** system.

We proposed a project to the european Horizon 2020 Work Programme *Future and Emerging Technologies (FET)* called **Live-Mirror** (PI: G. Moretto). Innovative Optics Ltd. has developed a breakthrough *Live Mirror* technology yielding high quality smooth parabolic mirrors with less than 1/10th the scattered light of ordinary polished mirrors. The purpose of the Live-mirror project is to develop a cutting-edge technology aiming at creating large, extremely light-weight, diffraction-limited “live” mirror and optical system. The main goals of our project are to model, optimize and create large light-weight and accurate aspheric optical surfaces generated by a “deterministic non-contact slumping” technique, with extremely smooth optical surface which is never abrasively polished. The large-scale mirror shape is obtained with a controlled active 3D-printed force actuators and sensors.
The purpose of the project is to build and test a 1m diffraction-limited prototype to demonstrate these technologies after which it will be possible to build large precise off-axis parabolic mirrors at much lower cost.

4 Conclusions

Even if the current period is not favorable to future prospects of new telescopes and instruments in Antarctica, we are convinced that a performing camera mounted, with specific GLAO, on a the best possible telescope placed there will lead to major advances in the identified science cases. A medium aperture telescope on the Antarctic Plateau have the potential to undertake tasks previously thought to be possible only in space, for example the imaging and spectroscopy of Earth-like extra-solar planets.
The international efforts to develop astronomy from Antarctica became a Scientific Research Program of Scientific Committee on Antarctic Research (SCAR) in 2010, named Astronomy & Astrophysics from Antarctica (AAA). Broadly stated, its objectives are to coordinate astronomical activities in Antarctica in a way that ensures the best possible outcomes from international investment in Antarctic astronomy, and to maximize the opportunities for productive interaction with other disciplines.
The SCAR AAA third workshop was held on August 2015 in Hawaii during IAU General Assembly bringing together the key players in Antarctic astronomy to further develop SCAR AAA Plan and Tasks for Today (http://subarutelescope.org/Projects/scar_aaa/talks/session8/tasksfortoday.pdf). The efforts made by the French astronomers at Dome C were presented at this meeting.

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