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Preliminary design of the Kunlun Dark Universe Survey Telescope (KDUST)

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Abstract. From theoretical analysis and site testing work for 4 years on Dome A, Antarctica, we can reasonably predict that it is a very good astronomical site, as good as or even better than Dome C and suitable for observations ranging from optical to infrared & sub-mm wavelengths. After the Chinese Small Telescope ARray (CSTAR), which was composed of four small fixed telescopes with diameter of 145 mm and the three Antarctic Survey Telescopes (AST3) with 500 mm entrance diameter, the Kunlun Dark Universe Survey Telescope (KDUST) with diameter of 2.5 m is proposed. KDUST will adopt an innovative optical system which can deliver very good image quality over a 2 square degree flat field of view. Some other features are: a fixed focus suitable for different instruments, active optics for miscollimation correction, a lens-prisms that can be used as an atmospheric dispersion corrector or as a very low-dispersion spectrometer when moved in / out of the main optical path without changing the performance of the system, and a compact structure to make easier transportation to Dome A. KDUST will be mounted on a tower with height 15 m in order to make a full use of the superb free atmospheric seeing.

Keywords. Dome A, astronomical sites, telescopes, KDUST, seeing

1. Introduction

Four years of site led by the Chinese Center for Antarctic Astronomy (CCAA) shows that the highest Antarctic inland plateau Dome A (latitude 80°22′02″S, longitude 77°21′11″E, elevation 4,093 m) can be reasonably predicted as an excellent site for ground-based astronomical observation, which would be as good as Dome C where the mean seeing is about 0.27″ above 30 m from the ground (Lawrence *et al.* 2004) or even better (Yang *et al.* 2010; Bonner *et al.* 2010). China has been actively promoting Antarctic astronomy since 2005. The first-generation Chinese Antarctic optical telescope is known as Chinese Small Telescope Array (CSTAR; Liu & Yuan 2009) composed of four identical telescopes with diameter 145 mm and four different filters (G, R, I and open band). CSTAR was deployed on Antarctic Dome A in January 2008 and mainly used for variable sources detection and site testing. The Antarctic Survey Telescopes AST3 are the second-generation Chinese telescopes on Dome A. AST3 is composed of three large field of view optical telescopes matched with G, R or I filters (Yuan & Su 2012), with entrance pupil diameter 500 mm, primary mirror diameter 680 mm, and field of view $2.92^\circ \times 2.92^\circ$ corresponding to a 10K × 10K CCD. The main scientific goals include a survey of Ia supernovae to study the dark energy of the universe, micro-lensing to search for exoplanets and to find new variable sources. The first AST3 telescope for I band was installed on Dome A in January 2012. The other two AST3 telescopes will be installed there in 2014. Then will come the third-generation Chinese Antarctic telescopes, including a 2.5 m optical/infrared telescope and a 5 m sub-mm telescope. The 2.5 m Kunlun Dark Universe Survey Telescope, abbreviated to KDUST, will make a full use of the superb free atmospheric seeing and deliver high resolution image over a large field of view. The sensitivity of KDUST in the optical band and NIR will be better than 8 m telescopes on temperate sites, and even comparable with a $\sim$ 30 m telescope on a temperate site in the K–band. The main science goals of KDUST are: weak lensing to study dark matter, Type Ia supernovae and the dark energy of the universe, the Galaxy and exoplanets.

2. Preliminary design of KDUST

Technical challenges. Dome A has excellent astronomical observing conditions such as continuous observing time for around 4 month per year, low turbulence boundary layers and very good free atmospheric seeing, very low sky background in the thermal IR etc. But the very low temperature (ranges from -30° to -83°C) and low air pressure, high relative humidity, harsh transportation conditions and very limited working time on site per year bring many challenges in both logistics and infrastructure (Burton *et al.* 2010) for developing a 2.5 m high resolution telescope for Dome A. Some technical challenges are listed here, for example, study on large FOV and compact optical system with high resolution image quality which can be matched with the excellent seeing conditions on Dome A; fast f-ratio mirror manufacturing technology; deicing and removing snow from a large optical surface without degrading mirror seeing; precise tracking, pointing & focusing under very low temperatures; thermal and humidity control technology (Saunders *et al.* 2008); assembly & alignment of a large telescope on site in a limited time; anti-vibration transportation for precise devices; remote control and long-time unattended operation; huge data acquisition, storage and pipeline; clean and automatic energy supply of about 20 kW for KDUST in the polar environment.

Main characteristics of KDUST. After study and comparison of several types of optical system which can all deliver very good images over large fields of view, such as the R–C system with correctors (SDSS etc.), Paul-Baker systems (LSST etc.), TMA systems (SNAP etc.) and a LAMOST-type system, we have chosen to use the Chinese 2.16 m type coudé system. The optical layout and image spot diagram are shown in Fig. 1. This system differs from the traditional coudé system, with an aspheric tertiary mirror which can achieve high resolution image quality over a large field of view, fixed focus and flat focal plane. The main characteristics of KDUST are:
Diameter: 2.5 m
Field of view :$\sim 1.5^\circ$
F-ratio: ~ 9.5
Plate scale: $\sim 0.1''/10\mu$m
Working wavelength range: 400–2200 nm
Image quality: 80% in less than $0.3''$
Supporting tower: 15 m
Low-dispersion spectrum ($\sim 10''$ length)

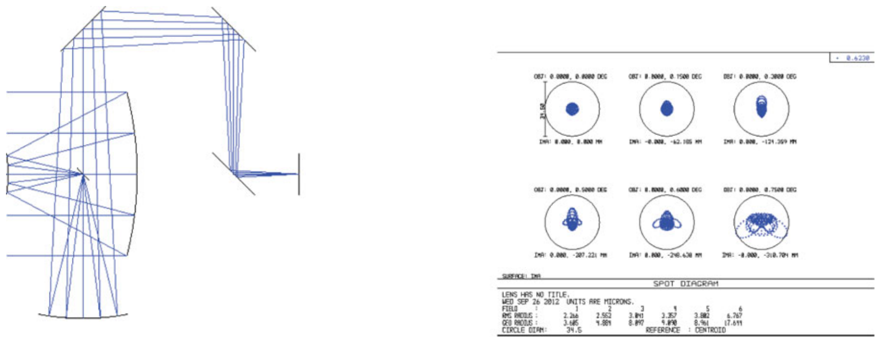

Figure 1. Optical layout (left) and spot diagram (right) for KDUST (the circle shows 0.3″).

The 2.5 m primary mirror has a fast f-ratio of about 1.05, thus it is quite challenging to produce this mirror. We are considering using a temperature optimized lightweighted Zerodur blank and stress lap to polish this mirror. Active optics will be necessary to correct the mis-collimation error since the tolerance for both secondary and tertiary mirror is tight. A pair of lens-prisms can be designed near the exit pupil, which is near the edge of the primary to compensate for atmospheric dispersion. This lens-prism can be moved in and out of the main optical path without changing the performance of the system. It can also be used in a contrary way at sites like Dome A or space where the sky brightness is very low, thus it can produce a very low dispersion spectrum of about 10 arcseconds length in lieu of multicolour photometry for celestial objects over the whole FOV. The flat mirror near the exit pupil can be used as a tip-tilt mirror to remove most of the turbulence above the telescope and tower wind shake. The model of the telescope with its compact structure and 15 m high tower and open dome are shown in Fig. 2.

Figure 2. Model of KDUST with compact structure, open dome and 15 m tower.

The structure of the KDUST Project. Five workpackages are planned for the KDUST project, including site & facility, telescope unit, instruments, data & operations and project management. A flow diagram outlining this structure is shown in Fig. 3. Each of the workpackages involves several work groups. For example, the telescope unit includes

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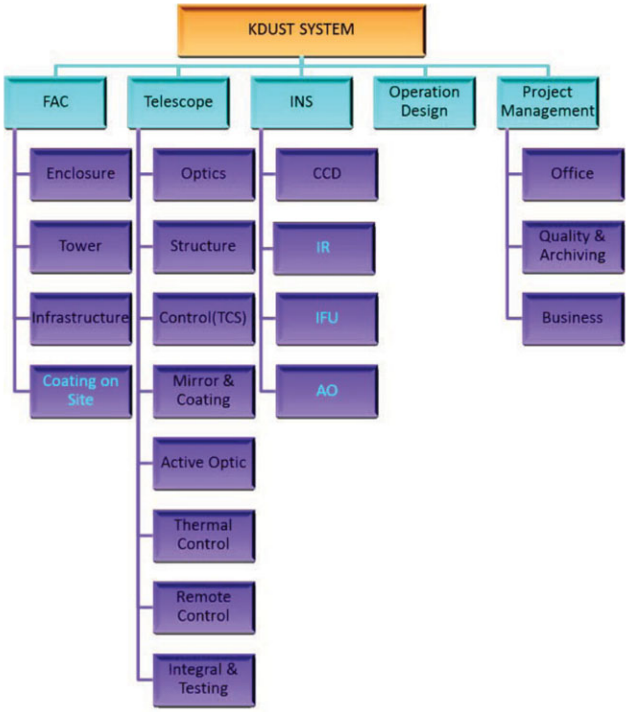

Figure 3. A structure diagram for the KDUST project.

optics, structure, telescope control system, mirror & coating, thermal control, remote control, integration and testing, undertaken by eight groups. The instrument workpackage includes the first generation instruments for a large array of imaging CCDs, and consideration of second generation instruments such as IR detectors, IFUs etc.

At this stage the KDUST project is at the phase of submitting proposals for the Twelfth Five-Year National Science Project. Related key technologies are also being studied and tested at the same time.

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