Performance of the second Antarctic Survey Telescope at Dome A

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ABSTRACT

Due to its extremely cold, dry, tenuous, and stable atmosphere, the Antarctica plateau is widely considered to be an excellent astronomical site. The long periods of uninterrupted darkness at polar sites such as Dome A provide a possibility of continuous observation for more than 3 months, which is quite suitable for time-domain astronomy. The second Antarctic Survey Telescope (AST3-2), the largest optical telescope in Antarctica so far, is a 0.5m entrance diameter large field of view optical imaging telescope which was deployed to Dome A, Antarctic in January 2015. It was used to study variable objects, such as supernova explosions and the afterglow of gamma-ray bursts, and to search for extrasolar planets. For the remoteness of the Antarctic plateau, it is designed to observe autonomously and operate remotely via satellite communication. With only 20 days attending maintenance annually, it has experienced 3 winters. It has observed for 3months in 2015 and 4 months in 2016. In the third year of 2017, the observing time of AST3-2 has covered all the polar night from March to September, the data reached to nearly 30TB with more than 200,000 exposures for searching supernovas and exoplanets. AST3-2 was also the only one telescope in the Antarctic plate that joined the optical observations of LIGO GW170817.

Keywords: Antarctic Telescope, Dome A, AST3, performance, remote operation

1. INTRODUCTION

in Jan. 2005, Chinese scientific expedition team first reached Dome A(80°25'03"S, 77°05'32"E), which is widely considered as a candidate of the best astronomical site on earth for observing wavelengths ranging from visible to infrared and submillimetre[1]. After that, Chinese astronomers in alliance with American and Australian has being dedicated to the research on Antarctic wide-field and high-resolution optical photometric telescopes.

In Jan. 2008, the first generation telescopes, named Chinese Small Telescope Array (CSTAR), four diameter telescopes for variable stars detection, measurement of atmosphere extinction, sky background and cloud coverage, had continuously observed 20 deg^2 area around the southern celestial pole for several winters[2].

Thereafter the trio Antarctic Survey Telescopes (AST3) project, inherited the characteristics of multi band and wide field, consists of three catadioptric telescopes with 680mm primary mirror and 500mm entrance pupil diameter, was proposed and constructed. Each telescope of AST3 has a modified Schmidt system (Fig.1), about half shorter tube comparing with normal one[3], with 4.14 deg^2 field of view and 2.2-meter total optical length. Due to high latitude towards polar, the equatorial mount is adopted for its just tilting less than 10 degrees and quite similarity with altazimuth mount. So that it can benefit the merits of both equatorial mount, including constant tracking speed, non-rotation image in the focal plane, and having no zenith blind spot, and altazimuth mount, including stability and easier-balancing. Gear transmission with dual-motor anti-backlash servo system[4] is used in all three telescopes. In comparison with direct drive system, it needs less energy and power. Dual motors can be an excellent redundancy in the whole control system. Low thermal expansion materials, both of the optics and the structure, such as Zerodur and fused silica for most of the optical components, INVAR36 for the main structure, was selected to reduce the drift of focus position. The transparent aspheric plate, one part of the optical system, also serving as the sealing window, is coated with a thin layer of Indium Tin Oxide(ITO) film, a kind of transparent conductor. When electric current flows through the ITO film, the heat vaporizes the ice and frost on the mirror, which was also experienced by CSTAR.

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Ground-based and Airborne Telescopes VII, edited by Heather K. Marshall,
Jason Spyromilio, Proc. of SPIE Vol. 10700, 107005P · © 2018 SPIE
CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2311291

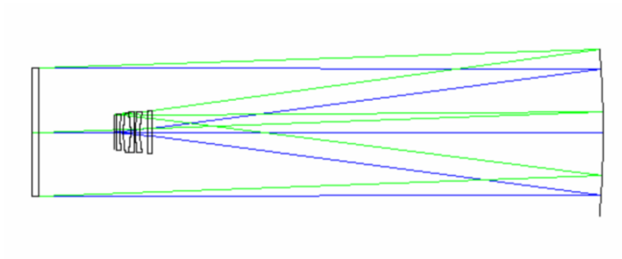

Fig.1 Layout of AST3

The first one of the series, named AST3-1, was deployed to Dome A in January 2012 and decommissioned in 2017. Commissioning was carried out between March and May 2012, including a repeatedly survey nearly 500 fields covering 2,000 deg^2. It is achieved that a survey depth of 19.3mag in 60s exposures with 5mmag precision in the light curves of bright stars.

AST3-2, the second one of the project, was installed in early 2015. Based on the experience of CSTAR and AST3-1, some improvement and update, mainly in control system, were made on AST3-2, including:

- high resolution encoder instead of resolver as axis position feedback,
- more powerful motion controller with DSP as a key processor in multi-axis high precision control,
- more efficient set of transmission chain,
- diversified sensors to measure temperature, current and voltage and more webcams to get in-situ photos,
- updated defrosting methods,
- easier onsite assembly,
- better safety system,
- better material (Titanium alloy tube with INVAR rod)to get a better dimensional stability,
- better anti-vibration design for safe transportation

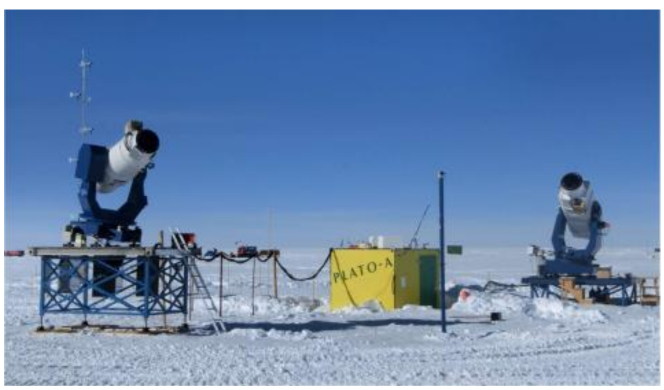

Fig2. AST3-1(right) and AST3-2(left) on Dome A

In the first operation year of 2015, we truly encountered some difficulties. The first problem that happened was the power module of ITO film failed. Then one of the four servo-motor drivers kept showing alert information and breaking every few moments, which was proved to be electromagnetic interference by the next year attending team. That led to the cease of operation on May 2015. After annual maintenance, in the next year of 2016 it turned out to be a much better operation winter until the mount were stuck in both axes after a heavy storm in late June. Ice and snow in the gear transmission boxes, which was not sealed so scrupulously, was estimated and verified later to be the main cause. So some snow-proof reinforcement measures were done during the expedition traverse. At last in the third year of 2017, AST3-2 survived the entire observing season, getting nearly 30TB data with more than 200,000 frames.

2. TELESCOPE

2.1 Logistics and annual service

Dome A located in the central East Antarctic ice sheet (EAIS), is the highest summit of the Antarctic ice sheet with 4093m altitude. According to the Kunlun Automated Weather Station installed in the year of 2011, The average temperatures at 2m and 14.5m altitude are -54℃ and -46℃. A strong temperature inversion existed at all heights for more than 70% of the time, which indicates an extremely stable atmosphere[5]. The second generation Kunlun Automated Weather Station (KLAWS-2G) for monitoring astronomical site at Dome A was installed in 2015 and has operated for more than 3 years. The lowest temperature it has measured reach to below -80 Celsius degrees. The average wind speed is 1.5m/s and average air pressure is 586hPa.

Kunlun station (80°25’2.42”S, 77°6’59.21”E), the southernmost of Chinese research stations in Antarctica, about 7.3 kilometers southwest of Dome A, was established officially in January 2009. So far the infrastructures at Kunlun Station can accommodate 30 people over summer, but it is still hardly possible for people to live through winter due to the extremely coldness and remote in winter.

Logistics and shipping, provided by Chinese Arctic and Antarctic Administration, is essential for Antarctic projects. Every year it takes much time and a long distance for explorers to get to Dome A. Typically, Chinese Antarctic Research Expedition (CHINARE) team, taking Chinese Antarctic support vessel named XueLong, departs at the beginning of November each year. After a month of voyage, they arrive at Zhongshan station, a year-round station and also a base for inland expedition. The actual vessel unloading locations is about several hundred meters away from the coast, so helicopter is used to shuttle cargoes from the vessel to the base. The capacity of the helicopter will be the bottleneck of the whole transportation. In the middle of December, after some preparation, the subsequent haulage is towed by snow vehicles across over1200 km to the Kunlun station. One or two days before Gregorian New Year, typically, they arrive at the destination and start about 20 days stressful work, usually including servicing PLATO, maintaining telescope and weather station, retrieving scientific data, etc. With temperature dropping fast, they starts the journey to get back. So it takes nearly three months, not counting the time for return, to acquire 20 days working time.

Another challenge is that astronomy has to be balanced with other Antarctic sciences. For instance, in the year of 2014 and 2018, the traverse to Kunlun station was forced to give way to the new research station. So it was very harsh for astronomical facilities to survive two successive winters without service and maintenance. Under these circumstances, various transportation methods are quite necessary. In January of 2017, China’s polar flight plane Snow Eagle 601 has landed on Kunlun Station, the first time for a fixed-wing aircraft in human’s history. The aircraft may offer another alternative for transportation of supply for the research station in the future.

2.2 Deicing system

As mentioned earlier, a sealing window is mounted on the front side of the tube. Frost and snow on the window will inevitably diminish mirror transmittance and decrease limit magnitude. In order to better understand the substances on the window mirror, we have deployed several webcams which snap and save pictures periodically or by remote instructions. The substances on the mirror are mainly three types of the transformation: frost, ice and snow, as is shown in Figure 3.

It’s quite common on Dome A that the temperature fluctuates more than 15 Celsius degree within just a few hours. And the relative humidity ranges from 40% to 80%. When the temperature rise up rapidly, while the window mirror is still quite cold, warmer air will be cooled down and water vapor precipitated on the mirror, in the form of frost.

Besides frost, snow and ice is also very easy to adhere to the window mirror. Dome A has commonly clear skies and constant light winds. The average wind speed is 1.5m/s at 4 m elevation. Snowfall is also rare, precipitation in the form of fine ice crystals, no more than a few centimeters a year. But occasionally, when high wind occurs, over 10m/s, it may lead to a blizzard in which a combination of high winds and blowing snow. So everything outside, especially the window mirror, will be coated with snow.

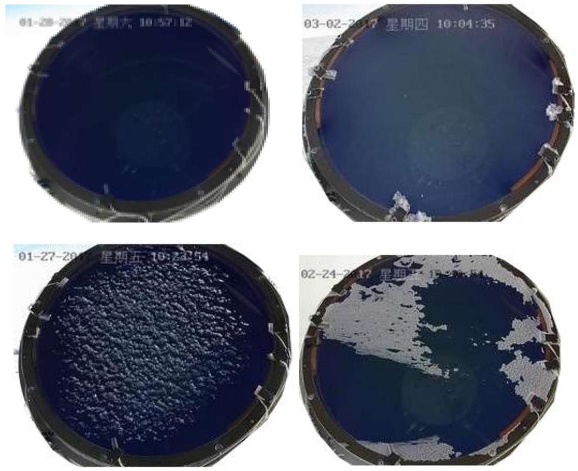

Fig.3 clear mirror, frost on mirror, snow on mirror

Night begins to show up in the middle of March every year, then polar night comes in the middle of May and ends up until August, after that in late September is the beginning of uninterrupted daylight. So in the long night time, especially in deep winter, frost and snow cannot be sublimated with the sunrise but accumulating and thickening repeatedly. While sometimes it falls off the mirror because of gravity, or the wind blows it off. Frost should be removed in the early stage of its formation, otherwise its growth rate will increase rapidly.

As it is mentioned in previous section, ITO film with adjustable power was coated on the window to make the surface a bit warmer than the ambience, preventing the surface from icing or frosting. Blowers (Fig.4) were also mounted alongside with the telescope to help remove snow and frost from the window. These are the most effective defrost methods so far.

Fig.4 Defrost equipments

2.3 Tracking

The entire optical elements, telescope mount and electronics on it, such as gears, motors, encoders and CCD, are exposed to the harsh environment. Only encoder readers and CCD controller, which cannot survive the extreme cold temperature, have heating and thermal insulation. The storm that mentioned before is also a challenge to the movement components. Once snow crams the gap between two relative movement components, axis will be stuck and cannot move. That did happen in the first two operation years. After excluding the effect of snow, by reinforced snow-proof measures, the control system shows a very good robustness.

Telescope control software (TCS) samples from the motion controller every 100 millisecond to check the telescope status including axes positions, error and warning signals, as well as following error, which was the error between the actual position and desired position. Fig. 5(the left one) shows following error of a period about 10 minutes, as well as RMSs in 30 seconds fluctuating around 0.2 arcsecond. That indicates most of the energy will be concentrated in 0.2 arcsecond, which is illustrated by the histogram of following error shown as Fig.5(the right one).

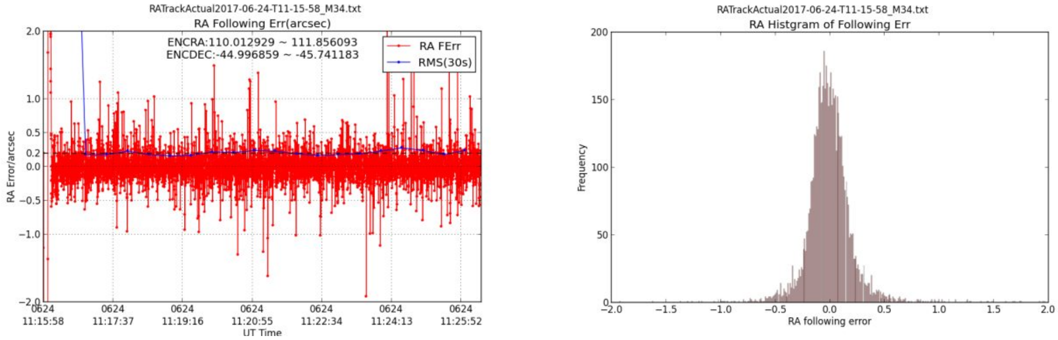

Fig. 5 following error and histogram

In dual-motor anti-backlash servo system, used in AST3-2, two identical servomotors cooperate to drive the motion of the axis. The differences of output torque and direction between the motors much diminish the affection of transmission gap. The specific strategy is accomplished by the motion controller. The output torque can be reflected by the motor drivers output current. Fig. 6 shows the current of both polar axis and decline axis motor drivers in over three months during the observation season. The current are quite stable even under strong wind(8m/s). It seems that the system has a very good robustness in a large range of temperature variations (-30~ -80℃). In entire winter, the control parameter is seldom changed and tracking performance keeps high accuracy.

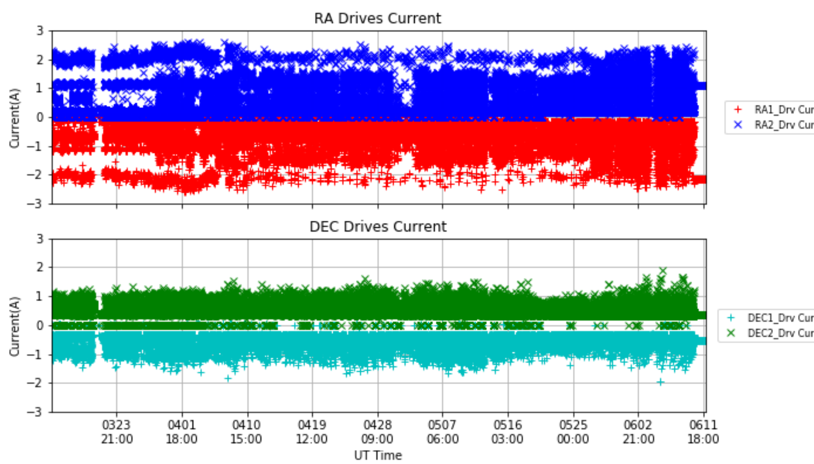

Fig.6 drivers current in 3 months

3. SCIENTIFIC DATA

AST3-2 is equipped with SDSS i filter and the STA1600FT CCD camera, designed and manufactured by Semiconductor Technology Associates, Inc., with 10560 x 10560 pixels of 9 μm, corresponding to 1 arcsec on the focal plane of AST3. Without a shutter, the camera was operated in frame-transfer mode using half of the FOV. The designed image quality of AST3 is 80% energy encircled in 1 arcsecond with distortion in the whole field less than 1 pixel.

Time domain astronomy is quite suitable to be carried out by AST3. The main sciences for AST3 are variable stars, very early discovery of supernova and exoplanets searching. In the observing three years, more than 500 fields, 4.3deg2 each, was surveyed repeatedly with real-time processing to find supernovas. The survey depth is 19.0mag in 60s exposures with 2mmag precision. We also observed exoplanets with over 200 candidates are picked up for further high-precision Radial-Velocity follow-up observation. The scientific data in three years totally are near 35TB with .

In 2017, AST3-2 was the only one telescope located in Antarctic that joined in the multi-messenger observations of GW170817[6][7]. The data show a rapidly fading transient at around 1 day after the GW trigger, with the i-band magnitude declining from 17.23±0.13 magnitude to 17.72±0.09 magnitude in ~1.8 hour. The brightness and time evolution of the optical transient associated with GW 170817 are broadly consistent with the predictions of models involving merging binary neutron stars. The merging process inferred from the data ejected about ~10-2 solar mass of radioactive material at a speed of up to 30% the speed of light.

4. CONCLUSION

After great efforts, AST3-2 can finally realize all winter observation in 2017. The tracking system has so good robustness that it keeps high precision operation for three years, especially after the gear boxes' reinforced sealing to proof snow. A variety of defrosting methods can effectively prevent and remove frost on the window mirror. The scientific data in three years is close to 35TB. The whole AST3 project will be a good test bench for the development of future larger aperture optical/infrared Antarctic telescopes[8].

5. ACKNOWLEDGEMENT

We would like to thank the Chinese Arctic and Antarctic Administration and the Polar Research Institute of China (PRIC) for organizing the Antarctic Research Expeditions. We express our thanks to all the expedition members for providing invaluable assistance for us to install and maintain the telescopes. Also we would like to give our thanks to Australia cooperators for their great works on PLATO and helpful discussions on telescope development. The authors are also grateful for the support by the National Basic Research Program of China , the Important Direction Project of Chinese Academy of Sciences (CAS) Knowledge Innovation Project, Tsinghua University and Nanjing University for their financial support.

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