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Operation of AST3 Telescope and Site Testing at Dome A, Antarctica

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ABSTRACT

We have successfully operated the AST3 telescope remotely as well as robotically for time-domain sky survey in 2015 and 2016. We have set up a real-time system to support the operation of the unattended telescope, monitoring the status of all instruments as well as the weather conditions. The weather tower also provides valuable information of the site at the highest plateau in Antarctica, demonstrating the extremely stable atmosphere above the ground and implying excellent seeing at Dome A.

Keywords: Telescope operation, remote control, AST3, site testing, Antarctica

1. INTRODUCTION

Dome A, Antarctica is located at 80.37°S, 77.53°E and at an altitude of 4093 meters above sea level. Due to its atmospheric and geological conditions, Dome A has been considered a promising site for superb astronomical observations. Recent site testing experiments have been proving this. SNODAR[1] shows that the median thickness of the atmospheric boundary layer is only 13.9m, indicating that excellent free atmosphere seeing can be achieved easily above this layer. Pre-HEAT,[2] Nigel,[3] and FTS[4] have demonstrated that the perceptible water vapor at Dome A is even lower than Atacama, the best temporal astronomical site for sub-millimeter observations. In the optical regime, the sky background, airglow and aurora have also been studied with various instruments including Gattini,[5,6] Nigel,[7] HRCAM,[8] and the Chinese Small Telescope ARray (CSTAR).[9]

CSTAR has 4 optical telescopes with an entrance pupil of 14.5 cm[10] and a field of view of 20 square degrees. It was deployed to Dome A by the 27th Chinese Antarctic Research Expedition (CHINARE) in 2007 when astronomers first joined the expedition. Chinese Kunlun Station was established in 2009 at Dome A. Built on the experience and technologies of CSTAR, the three Antarctica Survey Telescopes (AST3) has a modified Schmidt design[11] with an entrance pupil of 50 cm and a field of view of 4.3 square degrees. The first and second AST3 telescopes have been installed at Dome A in 2012 and 2014, respectively. We have also set up a 15m tall Kunlun Automatic Weather Station (KLAWS) to assist the operation of AST3 as well as site testing. The power and Iridium communication for AST3, KLAWS as well as other instruments are provided by PLATO-A, an automated observatory platform.[12] The operation of AST3 has been completely remotely via Iridium satellite or robotically. In general, we are only able to service the instruments once every year if CHINARE plans the mission to Dome A.

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2. CONTROL, OPERATION AND DATA SYSTEM (CODS)

We have developed for AST3 a control, operation and data system (CODS)[13] to take care of all the needs of running the remote telescopes for supernova (SN) cosmology and exo-planet search, as well as other time-domain astronomical research. Over the past several years, the CODS has been optimized and upgraded a lot to accommodate the changes of the project and unforeseen problems, while the basic structure of CODS does not change. The CODS consists of three sub-systems: main control system (MAIN), data storage system (ARRAY), and pipeline system (PIPE), as well as the supporting software suites. Each of the three subsystems has two identical components for redundancy and can also be used as backup.

As shown in Figure 1, our remote computer at National Astronomical Observatories, CAS (NAOC) in Beijing connects to MAIN through SSH tunnel via Iridium satellites, so we are able to operate remotely on MAIN. All the local computer systems reside in the instrument module of PLATO-A at Dome A. The temperature inside the instrument module can be controlled at a level that is optimized for all the electronics, which is usually above $0°C$. MAIN is the brain of the entire system. We equip it with two 1TB SSD disks for fast data exchange. The PCIe data acquisition card of the CCD camera is also installed on MAIN and connects with the CCD controller via fibre optics. We managed to use two MAIN computers to communicate with one CCD camera by splitting the signal via a 1-to-2 fibre optics at the computer end. This has been tested to work very well and therefore enhance the reliability of the unattended, robotic operation.

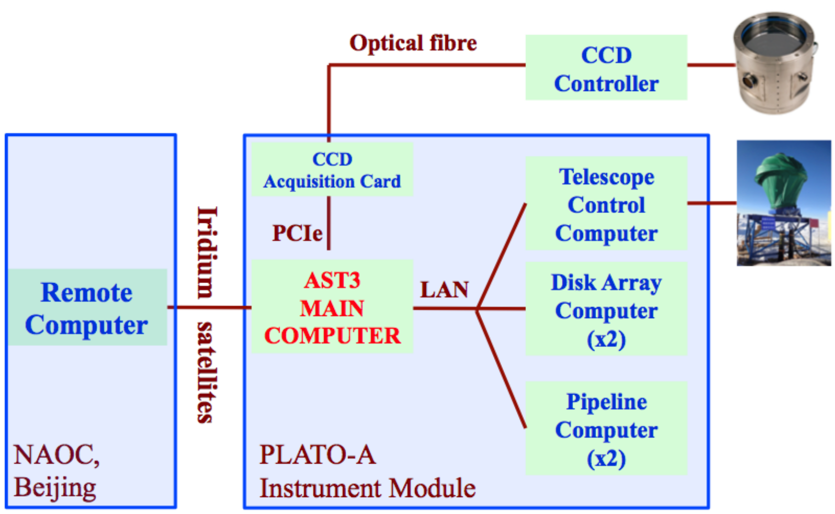

Figure 1. Schematic diagram of the AST3 operation system.

In general, MAIN decides what to observe based on the scientific needs, and points the telescope by communicating with the telescope control computer (TCC) which directly controls the hardware of the telescope. When the telescope is ready, MAIN tells the CCD camera to take images, and send the images to ARRAY for permanent storage, and to PIPE for real-time data reduction and analysis. The photometry results and transient candidates are sent back to MAIN which in turn sends them back to Beijing through Iridium satellites for further analyses.

ARRAY has been designed to have an expandable disk array controlled by a computer. The disk array consists of 8 boxes of five 2.5in disks of which the size has evolved from 500MB to 1TB, but currently 2TB disks are a little too thick to fit into the box. To achieve this, we use PCIe-to-SATA card to expand the SATA ports, each of which is connected with a SATA multiplier that can support 5 disks. ARRAY is customized to have very low power with thermal control. Each disk of ARRAY can be turned on/off independently so that we only need to keep one disk on for active data storage. Once a disk is full, ARRAY turns it off for data safety and switches to next disk automatically. In case of an unexpected temperature drop inside the instrument module, ARRAY can turn on its heater at $-5°C$ and off at $5°C$ to ensure proper working temperature for the disks. The on/off heating temperature can also be configured.

Recent technology development has seen 8TB 3.5in single disks, such as the HGTS Ultrastar He8. We can easily replace our disk boxes with these disks. The drawbacks include more power consumption, and losing more data if a disk fails, but there are also obvious advantages that the commercial disks are stable, and can simplify the ARRAY structure. Individual Ultrastar H8 disks have been successfully used inside PLATO-A with minimal thermal protection by simply wrapping them with plastic bubble sheets (private communication).

PIPE is responsible for our real-time data reduction. Since we have a huge amount of survey data, it is not possible to transfer even a single image (>100MB) back for analysis via the 128kbps Iridium OpenPort system. We have therefore developed a complicated pipeline to reduce data on-site.[13] Images received from MAIN will be processed by the pipeline automatically and the results will be sent back to MAIN as well as being stored on PIPE's local disks.

3. AST3 OPERATION AND SOFTWARE SUPPORTS

Besides the CODS hardwares, AST3 operation is also supported by our survey control software *ast3suite*, which has lots of daemon servers to communicate with individual devices/instruments, basic commands as clients to call daemons, and scripts to integrate the commands for more complicated tasks.

AST3 sky survey has been designed to be fully automatic. Although we are able to connect to MAIN from NAOC in Beijing and control all the instruments with basic commands remotely, it is not recommended because of the slow, sometimes unstable satellite communication, and it is unnecessary if all instruments work properly. For automatic survey, we provide three operation modes: SN Mode, Exo-planet Mode, and Special Mode. These are realized with our survey program *ast3skysurvey* running on MAIN. It is a script-based program managing and monitoring the entire system, calling different tasks, and communicating with various network ports, to fulfill the automatic survey requirements. In addition, we also provide script operation with more flexibilities, as well as pure manual operation.

3.1 Automatic Operation

3.1.1 SN Mode

The SN Mode is for the supernova survey to repeatedly (every 1-2 days) observe large sky areas (divided into individual fields according to the camera's field-of-view) provided by the scientific group. A key component in this mode is the observing scheduler which MAIN calls and receives the coordinates of the field to observe. To decide the best field when MAIN asks, the scheduler must weight on several factors, including telescope current position, minimal telescope movement to save time, elevations of the Sun and Moon, mechanical position limits of the telescope, zenith angle etc. MAIN then points the telescope, take CCD images, and send images to ARRAY and PIPE.

Our pipeline has both aperture photometry and image difference photometry for which the templates are accumulated and built for each field during early observing season. For supernova survey, the image difference photometry is mainly used to select point sources that become brighter, exclude false alarms of CCD defects, ghost images, edge effects, saturation stars etc, and finally obtain candidates of transients. These candidates are further classified as variable stars or "unknown" transients based on their positions in the astronomical catalogs. Only the unknown transients are transferred back for visual inspection on a webpage automatically generated with stamp images of the source in the template image, observed image, and difference image as well as other information (Figure 2). Those transients near a galaxy are given a higher priority because they are more likely to be supernovae.

We have a server/client system to transfer (small) files, including the above transient stamp images, from Dome A back to NAOC. The server is located on MAIN at Dome A, managing 9 sub-directories with 9 priorities. Any file sent to these directories will be transferred to the client at NAOC according to their priorities. The transients are found by PIPE, sent to different sub-directories, and then received by the client. The webpage is updated with new available transients every 20 minutes which can be customized.

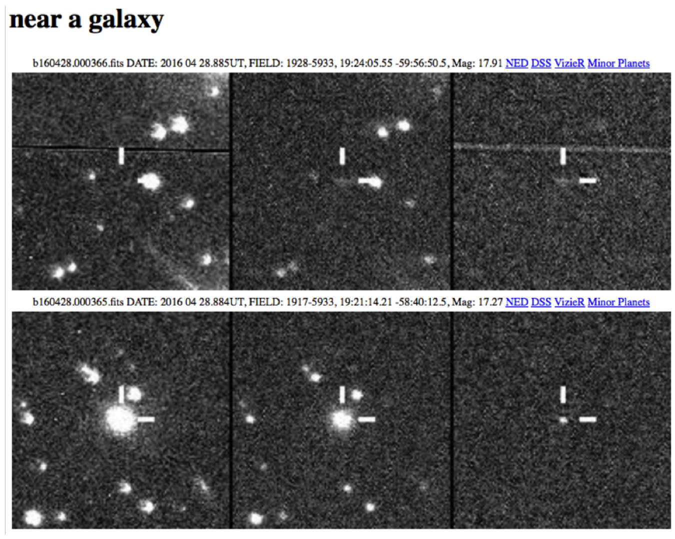

Figure 2. Two examples of the transient candidates on the website. The stamp images are, from left to right, template image, observed image, and difference image showing the detected transient. Listed on top of each candidate are image file name, observing date and time, field name, RA, Dec, magnitude of the transient, as well as links to other astronomical databases for easy comparison and visual check.

3.1.2 Exo-planet Mode

The Exo-planet mode is very similar to the SN mode except that it looks at bright stars in a much smaller area (e.g., 12 fields) repeatedly and continuously during the polar night. The exposure time is shorter and the data rate is higher, therefore the SN pipeline is not suitable for this and all data are stored in the disk array based on the original plan.

A customized pipeline based on script operation (Sec. 3.2) is being developed for the Exo-planet survey to derive light curves of bright stars before the data are available for more careful analysis.

3.1.3 Special Mode

The special mode is designed for cases when one wants to interrupt the automatic survey for a special target and then resume the automatic survey. This could happen when a newly discovered Gamma-ray burst (GRB) or SN triggers AST3 for a follow-up observation, or some targets need to be observed at a specific time. This is done by manually or automatically uploading a special target list which *ast3skysurvey* can immediately detect and execute the observations in the list, and then go back to where the normal survey is interrupted. This greatly saves observing time that otherwise could be lost for slow human operation.

3.2 Script Operation

When automatic survey is not desired, the script operation can be used. It is simple, flexible and powerful. Anyone can write a script to call basic commands to control the telescope, CCD camera, data analyses etc., but it needs to be very careful not to violate certain rules/limits of various hardware because simple scripts do not have the complicated error handler functions that *ast3skysurvey* has.

We have developed a rich class of scripts for general use, such as checking the status of instruments, analyzing data to monitor the image quality etc. Most of these scripts can be used even when the automatic operation is in use, but some scripts that also operate hardware (e.g., telescope, CCD) should not be used during the automatic operation.

3.3 Manual Operation

Manual operation is not recommended. Most basic commands can be called as command-line commands, but it is very slow on the remote computer at NAOC which connects to MAIN via Iridium. Only during troubleshooting do we use this mode. Whenever possible, we upload scripts to MAIN and run them there for even simple tasks.

3.4 Real-time Status

CODS is able to run the telescopes fully automatically, from observation scheduling to obtaining photometry results. However, we cannot run the survey blindly. Real-time monitoring is essential for quality control and safety of instruments. It also give people a sense of how the system is working.

The real-time monitoring system has a web-based interface for easy and open access, displaying a picture of the site and the telescope taken with a webcam every hour (http://aag.bao.ac.cn/klaws/). During the operation season, CODS runs many daemon programs and scripts in the background to collect information from different sources which is transferred back via Iridium satellites, organized into a database, and then shown on our website in real-time. All data sampling rates can be customized remotely. We are able to show key status of the telescope, including various temperatures, voltages and currents, pointing and tracking, and focusing etc. We are also able to monitor the CCD camera temperatures and image quality in real-time. CODS also collects information on its MAIN, ARRAY, and PIPE as well.

There is also an alarming system. When *ast3skysurvey* detects any malfunction or pre-defined conditions, it sends messages back to NAOC which triggers the alarming system immediately to send SMS of the detected problem to different people in charge.

In addition, we have set up a weather tower to provide weather information for AST3 operation as well as site testing (Sec. 4). The weather plots are updated whenever the page is reloaded.

4. KUNLUN AUTOMATIC WEATHER STATION AND SITE TESTING

The second generation Kunlun Automatic Weather Station (KLAWS-2G) has a 15-m weather tower with sensors at various heights for site testing as well as assisting the operation. It was built based on the experience of and lessons learned from the first such tower.[14] There are 10 temperature sensors (-1m, 0m, 1m, 2m, 4m, 6m, 8m, 10m, 12m and 14m), 7 wind speed and direction measurements (2m, 4m, 6m, 8m, 10m, 12m, and 14m),

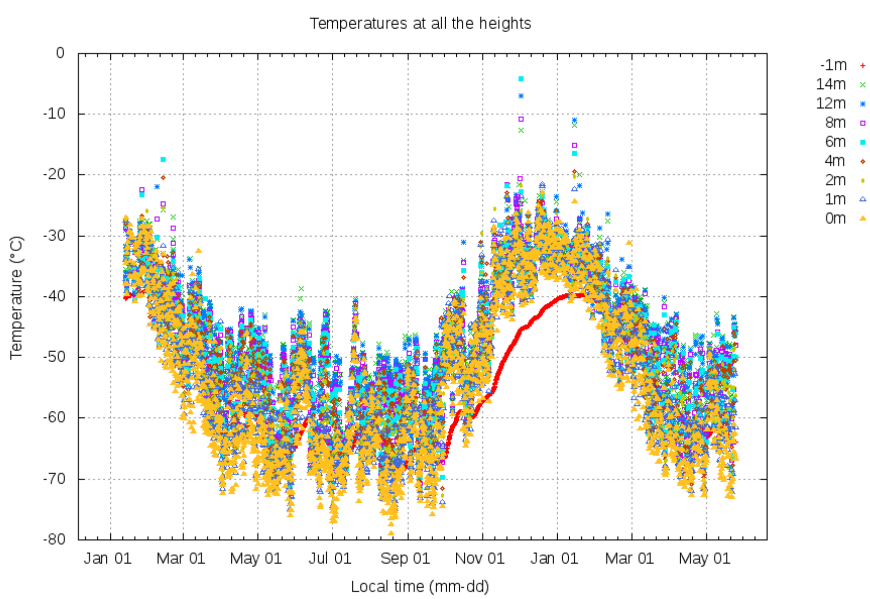

Figure 3. KLAWS-2G temperatures at different heights from Jan 2015 to June 2016.

one pressure measurement (2m), and one relative humidity measurement (2m). Temperature is measured with Young 4-wire RTD (Model 41342). Wind speed and direction are measured with propeller anemometers (Young Wind Monitor-AQ model 05305V). Air pressure is measured with barometric pressure sensor (Young Model 61302V). Relative humidity is measured with a relative-humidity/temperature probe (Young Model 41382VC). The customized electronic box of KLAWS-2G sits at the foot of the mast with an active thermal control system to keep it at working temperature. The KLAWS-2G is connected to PLATO-A for power and real-time data transfer via Iridium satellites. According to the manuals from Young company, the uncertainty on all temperature measurements is 0.32 Degrees Celsius, but it should be more accurate,[14] the wind speed error is 0.2m/s, the wind direction error is 0.5 degree (plus installation offset), and the pressure error is 15hPa. The air pressure sensor has not been properly working likely because of low temperature, and we need to improve this during next traverse.

KLAWS-2G records very strong temperature inversion, especially in local winter (Figure 4), confirming what we have found in 2011.[14] The temperature inversion not only indicates a very stable atmosphere, it also implies thin atmospheric boundary layer above which excellent free atmosphere seeing can be easily obtained.[14] Based on all the data we have, we believe that the temperature inversion exists at Dome A very often in winter when astronomical observations can take place. This indicates Dome A being a very promising site for astronomical observations. Further data analysis will quantitatively evaluate the quality of the site as an astronomical observatory for large telescopes. KLAWS-2G has been working well and we will continue the long-term monitoring for the site-testing purpose.

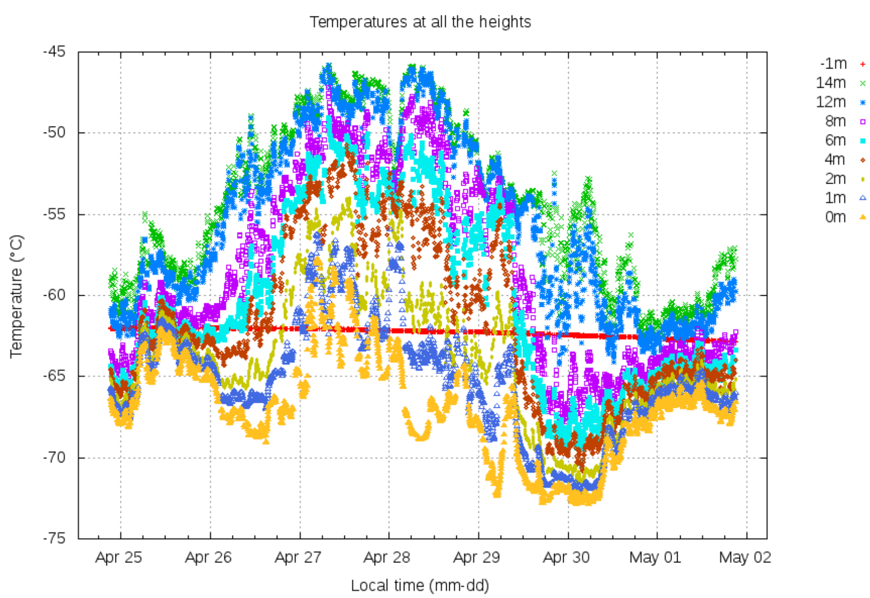

Figure 4. An example of temperature inversion in 2016 winter. It lasted more than a week.

5. FUTURE WORK

Both hardware and software of the AST3 CODS system have been working as designed at Dome A, Antarctica. Since AST3 sky survey will eventually has three telescopes running altogether, *ast3skysurvey* has the function to coordinate the observations of the three telescopes and CCD cameras, but we have not had a chance to test this with real instruments.

During the operation, we did sometimes stop the survey manually to protect the instruments from bad weather, such as high wind speed. We plan to integrate the weather information from KLAWS-2G into *ast3skysurvey* to make the survey even more intelligent and robust. This will need some more work to understand the weather pattern so as to define good criteria.

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