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Gattini: a multisite campaign for the measurement of sky brightness in Antarctica

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ABSTRACT

We present the Gattini project: a multisite campaign to measure the optical sky properties above the two high altitude Antarctic astronomical sites of Dome C and Dome A. The Gattini-DomeC project, part of the IRAIT site testing campaign and ongoing since January 2006, consists of two cameras for the measurement of optical sky brightness, large area cloud cover and auroral detection above the DomeC site, home of the French-Italian Concordia station. The cameras are transit in nature and are virtually identical except for the nature of the lenses. The cameras have operated successfully throughout the past two Antarctic winter seasons and here we present the first results obtained from the returned 2006 dataset. The Gattini-DomeA project will place a similar site testing facility at the highest point on the Antarctic plateau, Dome A, with observations commencing in 2008. The project forms a small part of a much larger venture coordinated by the Polar Research Institute of China as part of the International Polar Year whereby an automated site testing facility called PLATO will be traversed into the DomeA site. The status of this exciting and ambitious project with regards to the Gattini-DomeA cameras will be presented.

Keywords: Antarctica, optical sky brightness, site testing cameras, Gattini

1. GATTINI-DOMEC

We present a brief summary of the Gattini cameras in this section given a full description of the Gattini-DomeC project is found elsewhere [1]. Shown in Figure 1 and Figure 2 are summaries of the two transit cameras starting with the wide field All-sky version that contains a fish-eye lens to obtain roughly 100^{o} of sky coverage per image. The Gattini-SBC camera is identical except for a longer focal length lens that enables deeper exposures over a narrower field, centered on the South Pole.

1.1 Location

For 2006 the cameras were located on the roof of a scientific laboratory near the 30m tower, roughly 1km from the Concordia station in the dark sector. Before the 2007 season the cameras were moved to the roof of the Concordia station where they reside currently. We have no evidence to show there is a location dependent effect on the sky brightness magnitudes using cameras of this nature.

1.2 The 2006 dataset

The cameras have been operational since their installation in January 2006. Each camera takes an image every 5 minutes when the sun is below the horizon that spans the period roughly March to September. The images are saved to local hard disk drives as only a small amount can be transferred off-site via the Iridium satellite network that is largely for status checks. At the end of the season the full dataset is copied at the site and then hand-delivered to the mainland by the winter-over astronomer.

1.3 Data volume

The 2006 dataset is more than 600 Gigabyte in size and has the following statistics:

- 85740 images (total)
- 42431 SBC images
- 43309 all-sky images
- Total size $>$600GB

1.4 SBC missing filter

After analysis of the returned 2006 dataset and after subsequent discussion with the 2007 winter-over astronomer at the time, it was found that the sloan g' filter was missing from the front of the lens of the SBC camera. The lens had been removed and not replaced during the previous season. The filter was replaced immediately but only in time for the 2007 winter season. For this reason the results presented here are based on non-photometrically calibrated data, and we await the reduction of the 2007 data for calibrated photometry.

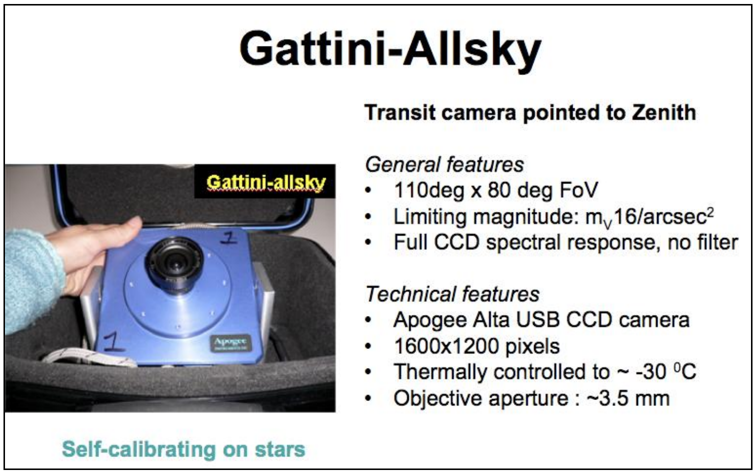

Figure 1: The specifications for the Gattini Dome C allsky camera.

Figure 2: The specifications for the Gattini Dome C allsky camera.

1.5 SBC window icing

A further complication to this first season was the internal window icing experienced by the SBC camera, note not the All-sky camera that has a different window, during the cold winter months. This problem was solved mid-way through the 2007 season by installing a small fan close to the inside of the flat glass window. Unfortunately it meant that much of the SBC data for the 2006 season was too contaminated with icing issues to be useful, a real annoyance as the camera itself performed extremely well, and we rely almost universally on the performance of the All-sky camera for the results presented here.

1.6 Data reduction

We present a summary of the data reduction procedure employed for reduction of data from both cameras. The data reduction was performed at the University of New South Wales.

The data reduction, performed using IRAF and a range of bash scripts, can be briefly summarized a follows (1) flat fields were composed for each camera using the variation of stellar magnitude across the field versus catalogue values; (2) A rudimentary coordinate system is added to each image such that they are correctly orientated as shown in Figure 3; (3) stars across the correctly flat-fielded images were identified using *AptAstrom*; and (4) using *AptPhot* aperture photometry is performed on the stars identified in the previous step.

For step (3) above stars stars were correctly identified to within 0.13 pixel (1.5 arcsec) rms for the SBC and 0.7 pixel (180 arcsec) rms for the All-sky.

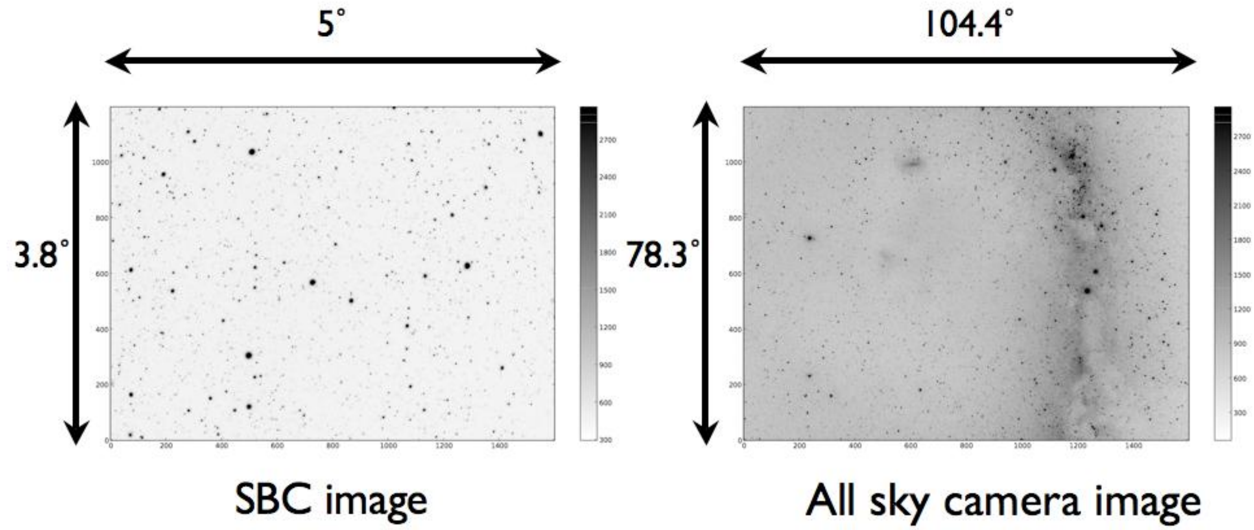

Figure 3: Correctly orientated and flat-flat fielded images from the SBC camera (left); and the wide field All-sky (right)

Roughly 7-30s of processing time is required per image that translates to weeks of CPU time to reduce the entire dataset. In total 22 million star measurements were made (~4500 individual stars) to produce a final database a little over 1GB in size.

1.7 Results

We present optical sky brightness results for the 2006 All-sky dataset based on roughly 6.5 months of continuous sky monitoring. The magnitude values presented are uncalibrated as the All-sky camera contains no astronomical filter. In addition it employs a (necessary) highly curved dome as the window that is unfortunately a perfect scatterer of stray light into the camera. As discussed in several places the SBC camera incorporates a sloan g' filter and is designed to produce accurate optical sky brightness statistics, but this can only commence with the arrival of the 2007 dataset.

Though many factors affect the visual sky brightness [2] by far the two largest are the sun and moon. We separate the two affects in the following discussion.

1.8 The Sun during a Dome C winter

Figure 4 presents the calculated sky brightness values as a function of solar zenith angle. The data points are color coded using the right-hand scale for moon elevation, the lowest corresponding to an elevation angle of -13^{o}. The traditional definition of Astronomical twilight at -18^{o} is marked with a solid line; the true limit of Astronomical twilight at the Dome C high altitude site is more representative at -13^{o}.

The origin of the scatter in the magnitude values at a solar elevation angle of less than approximately 11^{o}, around 1 magnitude rms, is not clear at this stage and requires further analysis of the data from both this camera and the SBC. It does not equate to the error in fitting stellar magnitudes across the field that is around 0.1 magnitude, after assuming an offset corresponding to the unfiltered All-sky passband compared to the V band catalogue values. It is possibly a problem with the low photon count per pixel (the All-sky camera was not designed to measure sky brightness to this level) or a stray light issue due to the highly curved dome window and no camera baffling.

We think it unlikely to be a feature of the site and almost certainly an instrument introduced effect. Analysis of the 2007 dataset we hope will answer this.

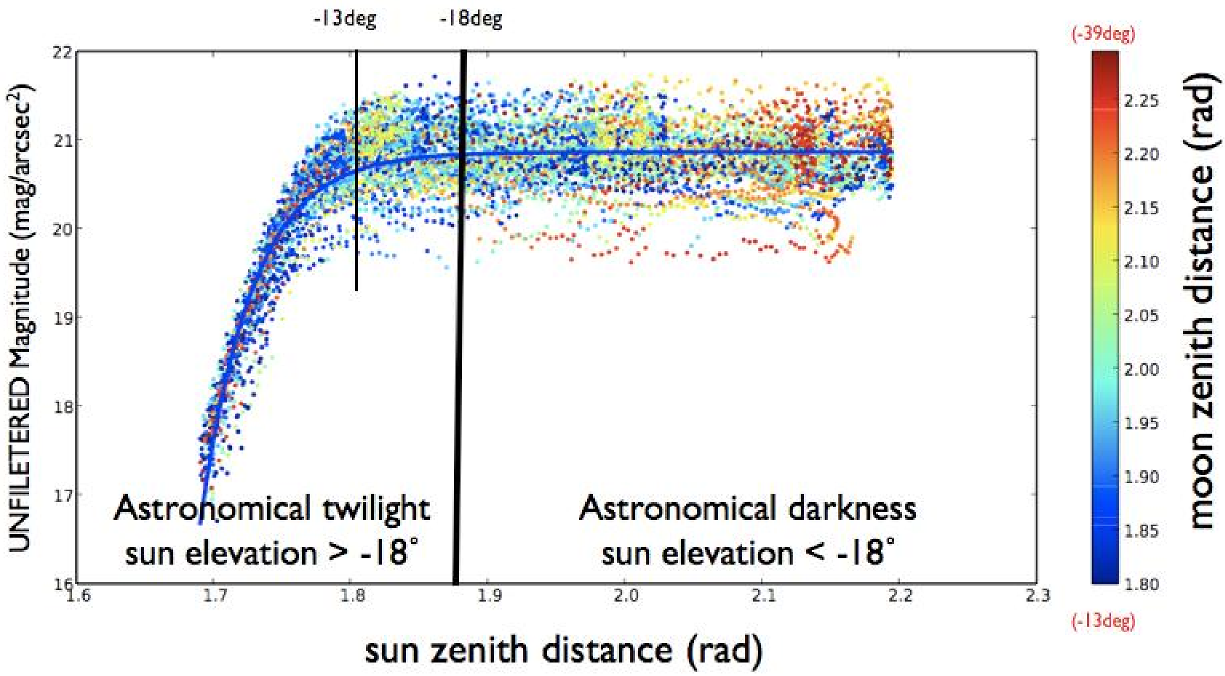

Figure 4: Optical sky brightness of the winter-time sky above the Dome C site as a function of solar zenith distance. The traditional astronomical twilight condition of -18^o is shown as a solid line and a more representative value of -13^o is shown for the Dome C site. The camera is unfiltered therefore the sky brightness values are not photometrically calibrated.

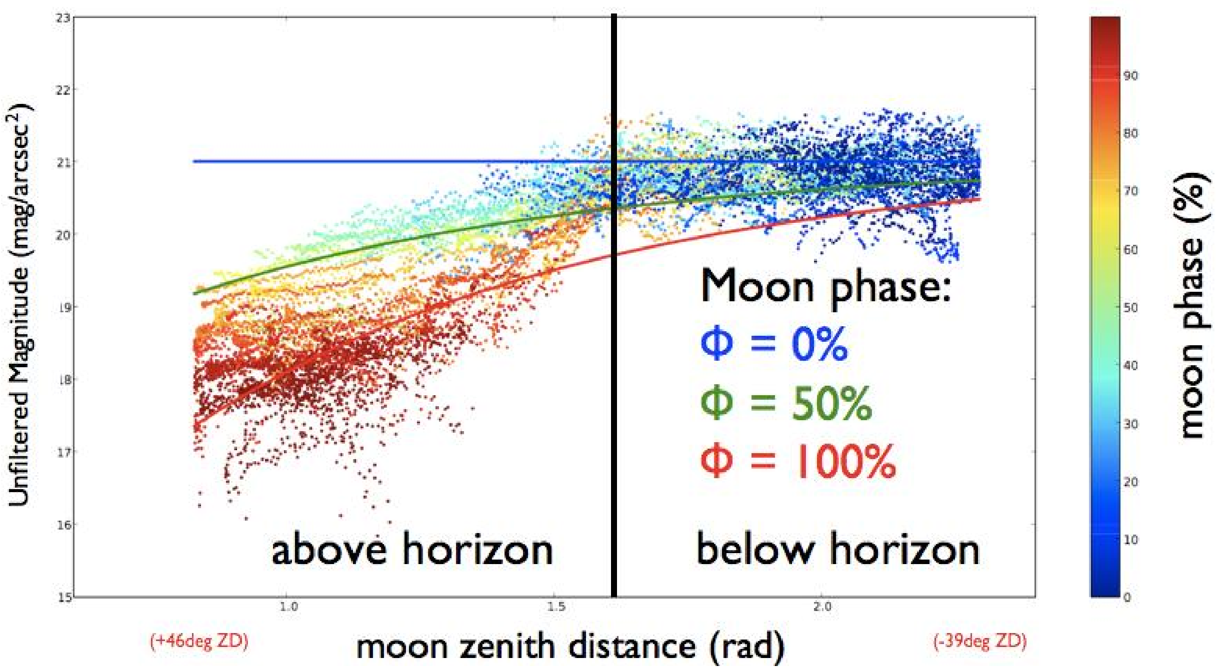

Figure 5: The effect of the moon on optical sky brightness at the Dome C site as a function of lunar zenith distance and phase. There is no contribution from the sun in this data. The solid black vertical line represents a zenith distance of 90^o.

1.9 The effect of the moon during a Dome C winter

Shown in Figure 5 are data for sky brightness versus lunar elevation and phase at epochs when the sun is below the astronomical twilight condition. It can be seen that the moon starts to increase the sky brightness measurements of the All-sky camera only when close to the horizon, marked with a solid black line in the Figure. There is roughly 3-4 orders of magnitude difference between the brightness values with the moon below the horizon and a dark sky compared to the moon at full phase and maximum altitude.

The large scattering in the data, especially for data corresponding to the lunar elevations above the horizon are in part is due to the scattering from the window of the moon into the unbaffled fish-eye lens. A baffle was added to the All-sky camera in 2007 to reduce the amount of scattering of moonlight and subsequent contamination, in particular for low lunar elevation angles, and again we await for the arrival of the 2007 season data to confirm the performance.

1.10 Cloud cover

Cloud cover statistics were derived from analysis of the All-sky camera dataset. It is not always possible to visually resolve the clouds and two methods were employed to automatically calculate the percentage of photometric conditions available from the 40,000 or so stack of images. The images were first analyzed for number of stars per image. An image was classed as photometric if all stars could be identified. The second method employed is to calculate the extinction across the image. If it is low, the image was classed as a low extinction image, again a sign for little cloud cover.

The results for the entire 2006 winter-time dataset are as follows:

- Photometric images: 83%
- Low extinction images: 85%
- Photometric, low extinction images: 79%

These numbers provide a lower bound on the number of cloud free images for the period April 1 to Oct 12, 2006 based on a dataset of over 40,000 images. These values are reasonably consistent with the results presented in [3] where a comprehensive duty cycle analysis based on the visual estimates of cloud cover that were taken during the same season from an asteroseismology perspective where bright targets are of interest.

The next stage of analysis for the Gattini data is to combine the 2006 and 2007 All-sky datasets and produce a 2-season duty cycle analysis for a range of target faintness.

1.11 Auroral detection

Neither of the Gattini cameras were designed to detect directly auroral events and cannot produce accurate statistics with certainty that any increase in sky brightness is due to aurora. To do this with sufficient sensitivity one can either design a camera adopting a large fish eye lens (eg. [4]) with a collimated space for narrow band filters, or use a spectrograph (eg. [5]). However, if sufficiently bright aurora occur within the field of view of the Gattini-allsky camera it is possible to identify using structure detection. Only one such event was detected during the 2006 season.

1.12 The future

The team is extremely excited that the 2007 dataset will be reduced shortly that contains the ice-free SBC data taken with the sloan g' filter in place. The cameras have been powered again for the third successive year of operation.

1.13 GATTINI-DomeC Acknowledgements

The Gattini-DomeC team is indebted to the following institutions for financial and logistical aid: Istituto Nazionale di Astrofisica (INAF) for funding the Gattini cameras; the Australian Antarctic Division; Institut Polaire Francais Paul Emile Victor (IPEV) and Programma Nazionale di Ricerche in Antartide (PNRA) for logistical support to the Dome C site and for their continuing support of the project; and lastly the United States Antarctic Program for continuing support of the Iridium communications.

2. GATTINI-DOMEA

Gattini-DomeA is an experiment to quantify the optical sky brightness properties of the DomeA night sky. It is based on the successful Gattini-DomeC project with several additional instrumental features aimed at maximizing the scientific return. Gattini-DomeA are two cameras based on a 2k by 2k interline CCD camera from Apogee Instruments. The cameras are identical except for the optical lens and the filter set. This is discussed further in the section below. The cameras and computer were assembled in a very short time period, roughly 12 weeks, in order to participate in a unique site testing opportunity.

2.1 Instrument goals

The goals for this experiment are to (1) measure the optical sky brightness contribution of the night sky above Dome A in three Sloan filter bands (g', r' and i'); (2) obtain accurate cloud cover statistics for the winter season; (3) obtain statistics on auroral events detected in Astronomical filter bands, of particular importance for this Antarctic site and; (4) obtain frequent measurements of the airglow due to hydroxyl line emission over as wide a field as possible. The combined results will give an accurate value for the total amount of astronomical dark time available at the site for a single winter season at optical wavelengths.

2.2 Instrument description

Two cameras fulfill the instrument goals as well as providing some redundancy and cross-checking capability. Both cameras are based on the Apogee 2k by 2k interline CCD camera used in the Gattini-DomeC campaign and are transit in nature. The narrow field camera, called the Sky Brightness Camera (SBC) and shown in Figure 6, adopts a 300mm focal length Nikon lens (Nikon Telephoto AF-S Nikkor 300mm f/4D ED-IF) with 75mm aperture to produce an image 2.8^o x 2.8^o that is roughly centered on the South Pole at an elevation of $\sim 81^o$ at the Dome A site. The filter wheel contains the Sloan g', r' and i' photometric filters in addition to an opaque mask for dark current testing if required given that the system contains no mechanical shutter. The exposure times are nominally 20 seconds, equivalent to the time taken for a star to cross a single pixel, however this value is remotely configurable. The pixel sampling of the Gattini-SBC at Dome A, just over 5 arcsec/pixel, results in the least stellar contamination per pixel, not a site testing consideration but for precision photometry in the case of scientifically important variable stars within the field.

The Gattini-allsky camera shown in Figure 7, is optimized for cloud cover measurements, however, given the large field of view, 90^o x 90^o, it is used to detect auroral contributions that occur in astronomical filter bands and for the frequent measurement of hydroxyl line emission, commonly termed airglow. The CDD camera and filter wheel are identical to the SBC, with the lens replaced by a Nikon wide field lens (10.5mm f/2.8G ED AF DX Nikkor) of focal length just over 10mm resulting in a pixel sampling of 145.4 arsec/pixel. The filter wheel contains three Bessell filters (B, V and R) and one longpass red filter (RG665) for hydroxyl line emission redward of ~665nm.

The cameras are housed in separate heated enclosures that allow use of economical off-the-shelf components such as the Apogee cameras and filter wheel and keep the entire budget for the cameras and control computer below 45k$US. Acrylic domes permit optical transmission without ice accumulation and internal fans provide air circulation.

The camera enclosures are directly mounted to the roof of the PLATO laboratory at an elevation of proximately 80^o. Internal temperatures are monitored constantly.

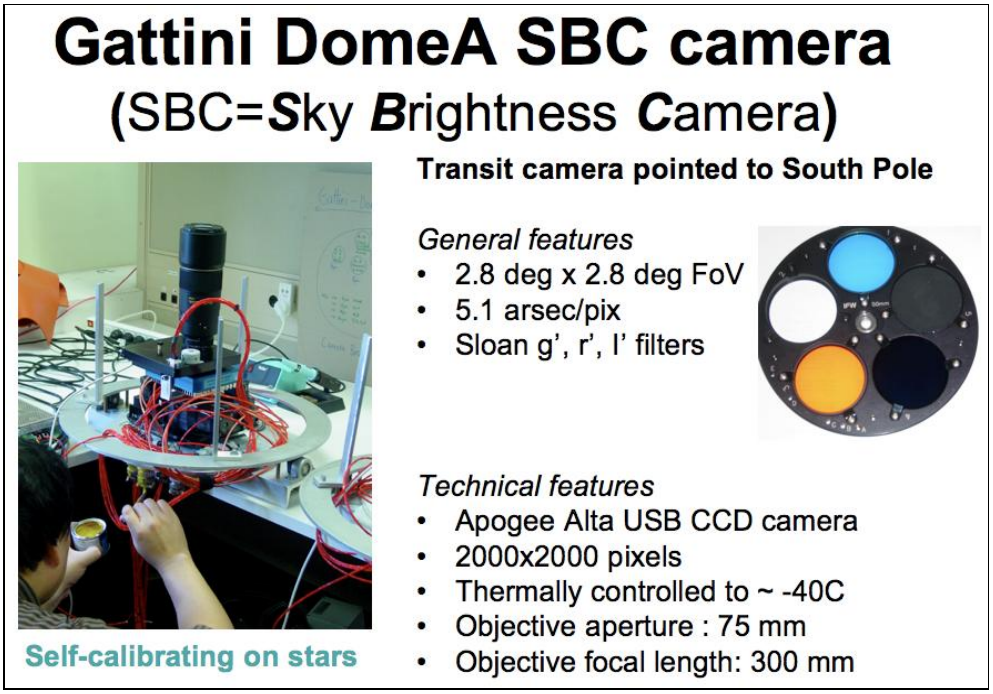

Figure 6: The Gattini-DomeA Sky Brightness camera is a multicolor transit camera centered on the South Pole with a field of view of just under 3^o. (Left) The internals of the camera are shown prior to assembly.

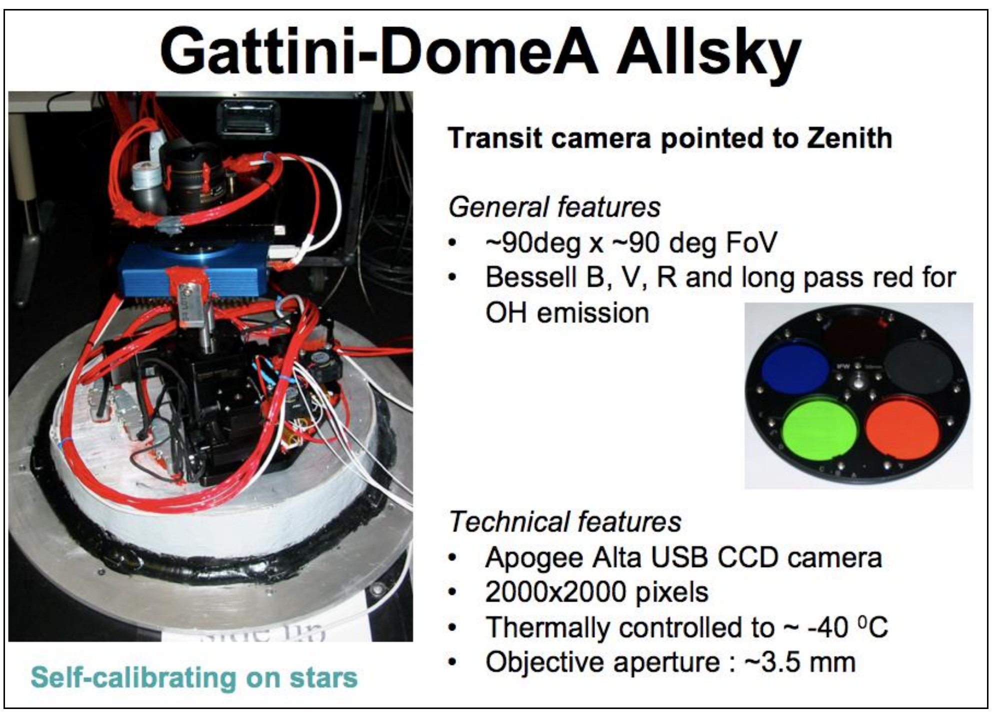

Figure 7: The Gattini-DomeA All Sky camera incorporates a wide-angle lens to produce images large enough for the determination of cloud cover statistics and airglow detection. (Right) The filter wheel houses four filters comprising Bessell B, V, R and a long pass red filter, the latter for airglow detection.

The Gattini cameras and DASLE experiment are jointly controlled by a Linux-based computer system. The control of all instrumentation is accomplished through a custom software suite. This software controls all aspects of how the instruments gather data, switch between operational modes, and correct for errors in the operations of the subsystems. Data archiving is accomplished daily, and uses a bank of four 500GB hard drives.

The custom software suite is a fully autonomous system. The software suite contains the following functions relevant to the camera control: (1) control of observations using both Apogee CCD cameras, including proper dark correction; (2) operation of filter wheels in conjunction with CCD observations; (3) temperature control of camera enclosures, using measurements, heaters and fans; (4) full status checks of all subsystems, corrections as necessary; (5) comprehensive logging of all system functions; (6) hard drive management, including adjustments for heard drive errors or failure; (7) data archiving and quality checks and; (8) error correction for instrument and subsystem errors.

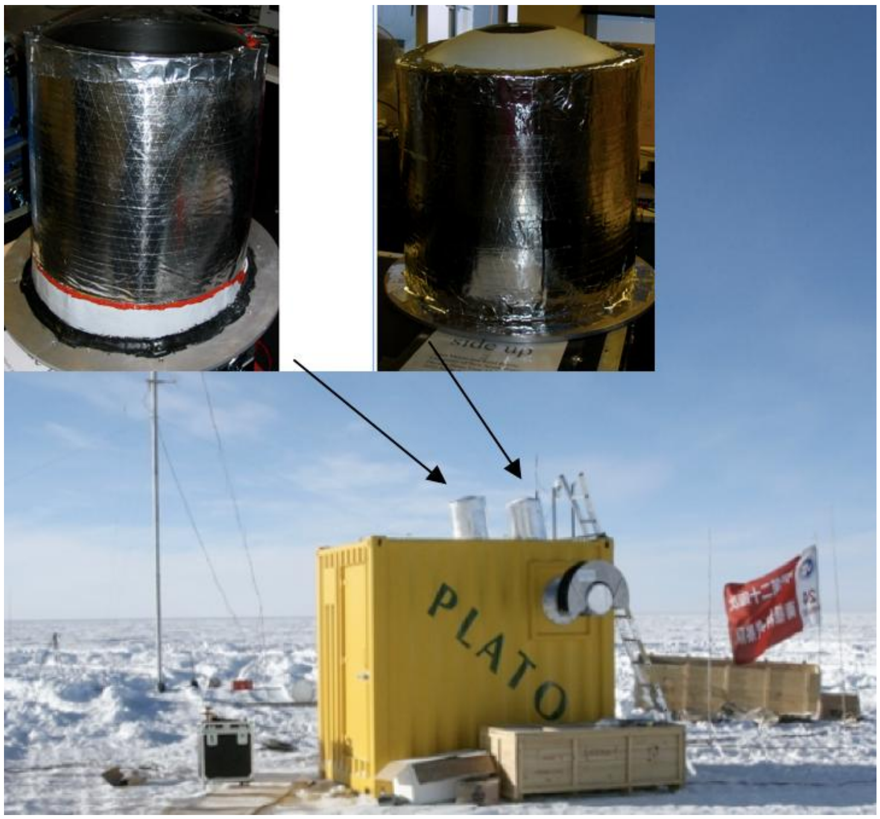

Figure 8: (Inset Top Left) The Gattini-DomeA allsky camera and enclosure prior to shipment. (Insert Top Right) The Gattini-DomeA SBC camera and enclosure. (Bottom) The location of the cameras on the roof of the PLATO module at the remote Dome A location.

2.3 Status

The Gattini cameras were activated in late March 2008 after testing of the PLATO supervisor software and associated hardware was completed. The control computer booted successfully. It was realized within a week of the cameras taking images that the internal enclosure heaters had failed since their successful test in January 2008 (either a loose connection or the cable had been disconnected by mistake on departure). As such the off-the-shelf cameras could only be power cycled at very low temperatures. We continue in this non-optimal mode, though both cameras have already begun to show signs of communications failure with the control computer as of mid-April 2008. The USB hard disk drives were operational for a month only before becoming corrupted, and we are reasonably certain this was a software conflict issue with the camera USB drivers, only occurring after several weeks of operation.

2.4 Summary and extension for 2008

With the realization that the site testing datasets would not be obtained for 2007 the National Science Foundation granted an extension such that a replacement Gattini-allsky camera and control computer could be transported to Dome A during the 2008/2009 summer season. The Gattini-allsky replica and control computer, with suitable upgrades such as the use of firewire hard disk drives, will be installed by the traverse team. The current cameras will be retruned to Caltech and will be re-deployed after repair. The Gattini-allsky is a unique facility at Dome A and this will be true even for next season given that the existing optical telescopes at the site, CSTAR, are narrow field devices.

2.5 GATTINI-DomeA Acknowledgements

The Gattini-DomeA team would like to thank the following for financial and logistical support: Apogee Instruments, the National Science Foundation, the Polar Research Institute of China and the United States Antarctic Program.

The GATTINI-DomeC team

The Gattini-DomeC team consists of the following members: Anna Moore, Eric Aristidi, Michael Ashley, Runa Briguglio, Maurizio Busso, Maurizio Candidi, Giuseppe Cutispoto, Elisa Distefano, Jon Everett, Suzanne Kenyon, Jon Lawrence, Brice Le Roux, Daniel Luong-Van, Andre Phillips, Roberto Ragazzoni, Lucia Sabbatini, Piero Salinari, John Storey, Melinda Taylor, Gino Tosti and Tony Travouillon.

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