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ALL SKY CAMERA OBSERVATIONS OF CLOUD AND LIGHT POLLUTION AT THIRTY METER TELESCOPE CANDIDATE SITES

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RESUMEN

Cámaras fotográficas de cobertura hemisférica fueron instaladas en los sitios candidatos del Telescopio de Treinta Metros (TMT) para obtener imágenes que permitieron estimar las estadísticas de cobertura de nubes, y evaluar el nivel de contaminación lumínica. Dos métodos fueron empleados para estudiar la cobertura de nubes; el primero un método manual basado en la inspección de películas en las bandas azul y rojo, y el segundo un método automático basado en la análisis fotométrico de las imágenes. Desarrollamos un procedimiento para el estudio de la contaminación lumínica que demostró que esta contaminación, en los sitios candidatos, no es relevante para la selección de sitio de TMT.

ABSTRACT

All Sky Cameras were deployed at all Thirty Meter Telescope (TMT) candidate sites to gather images for assessing the cloud statistics and light pollution. We developed two methods to assess clouds, a manual method based on inspection of blue and red movies, and an automated method based on photometric analysis of the images. We developed a light pollution analysis procedure and find that light pollution at the candidate sites is currently unimportant for TMT site selection.

Key Words: atmospheric effects — instrumentation: miscellaneous — light pollution — methods: observational — site testing

1. INTRODUCTION

Five TMT candidate sites were investigated, Cerros Tolar, Armazones and Tolonchar in Northern Chile, San Pedro Mártir in Baja California, Mexico and 13N Mauna Kea, Hawaii (Schöck et al. 2009). The site testing systems included all weather All Sky CAmeras (ASCA) (Walker et al. 2006; Riddle et al. 2008). Night sky images were taken with b, r, y and z bands every 4 minutes over 180° (0.19° per pixel).

We summarize the manual method of cloud assessment and confirmation of the technique using line-of-sight Multi Aperture Scintillation Sensor (MASS) measurements (Els et al. 2008). We mention the photometric method developed to measure sky transparency and that limitations of the technique precluded its use for generating cloud statistics.

A procedure was developed to extract light pollution information from the ASCA data set, to determine if light pollution would be a factor in the final selection of the TMT site.

2. MANUAL CLOUD ASSESSMENT METHOD

Movies for each hour were made with all quasi-simultaneous blue and red images. Each image is overlaid by a target, see Figure 2. Assessors categorised each movie as one of the following, producing a time series of cloud categorization from which statistics were compiled, see Table 1:

clear - no cloud inside the target area in either blue or red wavebands, ignore cloud outside target area
outer - cloud definitely seen in both wavebands in outer target annulus but not in the inner circle
inner - cloud definitely seen in both wavebands in the inner circle
cloudy - more than 50% of opaque clouds within the target area, integrated over time and area
moon up - if any of the frames (even a single frame) are short exposure moon up frames
questionable - if unable to make a confident assessment but there is no fundamental problem with the data, e.g. camera covered in snow
no data - such as a zero length movie

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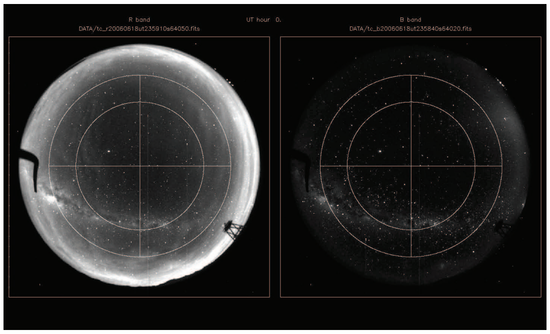

Fig. 1. Example of an ASCA movie frame. The inner circle (zenith distance 0° to 44.7°) and outer annulus (44.7° to 65°, the operational limit for TMT) are of equal area when projected on to the sky.

TABLE 1

THE CLOUD STATISTICS DERIVED FROM THE ASCA MOVIES[a]

	Clear[b]	Outer	Inner	cloudy
Tolar	77.4%	6.3%	14.5%	1.8%
Armazones	82.5%	4.3%	9.3%	3.9%
Tolonchar	72.4%	5.4%	10.4%	11.8%
SPM	72.6%	5.3%	11.5%	10.6%
MK 13N	70.9%	6.5%	9.8%	12.8%

[a]These numbers are not equal to the long term cloud statistics due to the short time span of measurements.

[b]The clear category does not necessarily correspond to what would be classed as photometric.

Identification of sky glow or thin clouds and the decision to assign the cloudy category requires subjective judgements by the assessor. Differences in camera sensitivity may make the detection of thin clouds somewhat site dependent. However, by comparing assessments of the same movies by different assessors and against line-of-sight measurements (see § 3), the categorization scheme was improved until it was robust and resulted in assessment uncertainties that were acceptable for site comparison. Repeatability of 1% between assessors was found for all sites except Tolonchar, where the repeatability was 4%. The categorization scheme allows for a confident comparison between sites. We are confident that any clouds that would impact laser AO operations are within the detection limits of our method.

Instrument down times (normally due to equipment failures) are usually uncorrelated with clouds, but there are exceptions. Weather related shutdowns or analysis preferentially happen during seasons with above-average cloud cover, missed nights might contain more clouds than average conditions, biasing toward increasing clear fraction. Movies have to be excluded when the moon is up. The fraction of movies missed is larger in the summer (shorter nights) than in the winter, this biases toward decreasing clear fraction at all sites. We believe that the combined effect of the competing biases is small and within the inherent uncertainty of the analysis.

TABLE 2

STATISTICAL COMPARISON OF THE SUMMED ASCA CLEAR AND OUTER CATEGORIES VERSUS MASS LOSSAM <0.06 FOR SIMULTANEOUS DATA[a]

	ASCA	MASS <0.06	Difference	Site elevation
Tolar	84.8%	84.4%	0.4%	2290 m
SPM	80.1%	81.6%	−1.5%	2830 m
Armazones	88.0%	85.1%	2.9%	3064 m
MK 13N	86.7%	81.2%	5.5%	4050 m
Tolonchar	80.7%	74.5%	6.2%	4475 m

[a]Note: The MASS only operates during clear conditions so the clear fractions reported here are over-estimates.

3. CROSS CHECK OF MANUAL CLOUD ASSESSMENT METHOD AGAINST THE LOSSAM METHOD

The MASS (Els et al. 2008) measures the flux coming from a bright star with photo multipliers at 1 kHz, variations of the flux are detected with high accuracy. The LOSSAM (Line of Sight Sky Absorption Monitor) (Sarazin 2000) is based on the observation that the RMS flux fluctuations of a bright star, averaged over several minutes and divided by the mean flux correlate well with the atmospheric extinction coefficient. The LOSSAM value can be calculated whenever MASS data are available. The RMS fluctuations are averaged over 10 minutes. If the telescope changes star during this time the 10 minute set is excluded from further analysis. All valid 10 minute sets corresponding to a one hour ASCA movie category are averaged to give a mean LOSSAM value for that hour. We compared a range of LOSSAM values with simultaneous ASCA categories, a value of 0.06 gives the closest match, i.e. clear $< 0.06 <$ cloudy. Table 2 shows the statistical match for all five candidate sites. The statistical values are the fraction of clear categories for all of the ASCA or all of the MASS measurements that are simultaneous.

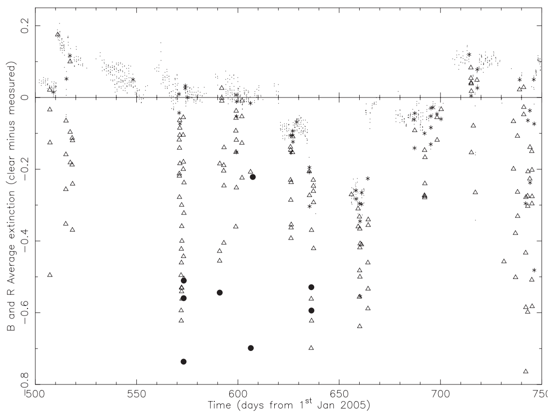

Fig. 2. Plot to show the systematic effects on the mean hourly blue and red extinction for the inner target area. Each point represents the mean extinction for all stellar detections in all blue and red images in a particular hour. The corresponding manual cloud category is indicated by the point shape, dots indicate the 'clear' manual category, stars indicate 'outer', triangles are 'inner', filled circles are the 'cloudy' category.

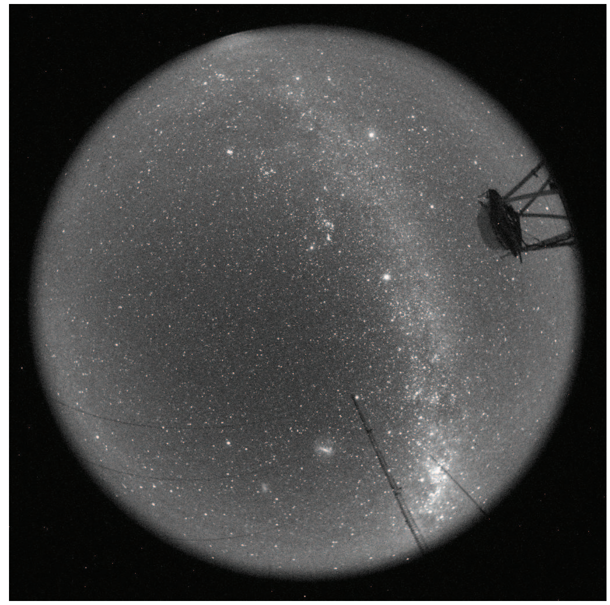

Fig. 3. A single ASCA image from Cerro Armazones taken on the night of December 8, 2007, north is to the top, and east to the right.

4. PHOTOMETRIC EXTINCTION SOFTWARE

A system to measure the flux of stars in the ASCA images was developed (based on the Pan-STARRS system; Magnier 2006). The measured output magnitudes, positions, catalogue magnitudes, etc., for each star in each frame are stored in a database. The photometry system fails when insufficient stars are detected in an image, so the system only operates in relatively clear conditions. Using the database, an automated method was developed for determining the extinction at the position on the sky of each stellar detection in every $b$and r ASCA image. We compared the average extinction values over the target areas in Figure 2 with the manual method, see Figure 2.

Each photometric measurement has a typical signal to noise ratio of about 10, systematic noise sources (predominantly due to spatial sensitivity variations between pixels) dominate the noise. There are up to a few thousand detections in a clear sky image. Due to the large number of stars typically detected the statistical uncertainty on the averaged extinction value for a particular image is small.

Problems such as the accumulation of dust on the camera cover and periodic cleaning introduced trends into the averaged extinction values, limiting the subsequent cloud categorizations to an unacceptable level. Figure 2 demonstrates these systematic effects in the measured mean hourly extinctions for b and r images. Groups of 'clear' points (dots) indicate the clear sky extinction, and variations in the 'clear' extinction level clearly span the range in which some movies are classed as having clouds in the manual cloud analysis method. The short term correlation between the manual cloud analysis and automatic extinction measurements is good, but the large amplitude longer term systematic variations complicate any categorization based on the extinction levels.

5. ANALYZING ASCA IMAGES FOR LIGHT POLLUTION

Figure 3 is a raw b filter image from Cerro Armazones taken on a clear, new Moon night, at a time deep in astronomical twilight when any city lights should still be prevalent (i.e. early enough for people to still be out). North is to the top, east to the right. The image is dominated by stars and the Milky Way. To illustrate the difficulty of determining light pollution from a single image, the city of Antofagasta is at about 345° and the light pollution is not very noticeable on the horizon in this image. A single image does not enhance the light pollution compared to the star and galaxy light, and faint sources of light pollution (unlike Antofagasta, a city of 300,000 people) may not appear in a single image at all.

A method to enhance the light pollution effects in the image while removing contamination from astronomical sources was developed. Clear nights at

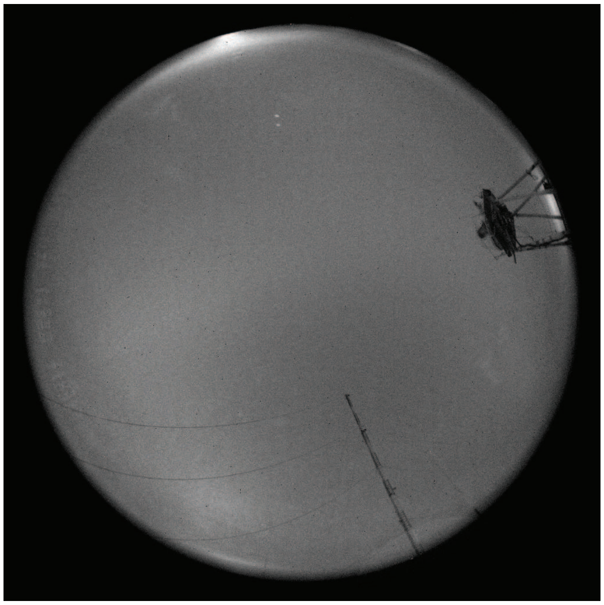

Fig. 4. Light pollution at Cerro Armazones. The light from the El Peñon Mine is seen behind the telescope.

new Moon were selected for the light pollution data set. This selection gives the most usable images of any single night for the analysis. A 10th percentile median image was created of the ASCA observations during the night, this was found to be the best compromise between dark sky and avoiding low signal pixel issues. The light pollution scattering on the horizon is well defined and clearly evident. Figure 4 is one of these images; it is for the same site and night as Figure 3. In Figure 4, there is no evidence of single stars. This enhancement makes it a much simpler process to find light sources on the horizon.

Figure 4 is an example of a clean light pollution analysis image. However it is necessary to examine as many nights as possible from each of the sites as changes occur due to distant low clouds and changes in light sources.

6. CONCLUSIONS

The manual cloud analysis method is reported to be highly repeatable amongst different assessors and shown to correlate well with MASS LOSSAM measurements. The automated extinction method that was developed is shown to correlate with the manual cloud analysis method, but systematic effects on the derived extinction values cause uncertainties that are larger than the accuracy required to compare sites. The cloud statistics derived using the manual assessment method of the ASCA observations for each site are listed in Table 1.

A method was developed to measure light pollution, using a 10% median image to separate light pollution from astronomical effects in the ASCA images. An analysis of the light pollution images demonstrates that all candidate sites are dark sites with some level of light pollution. However, light pollution at the sites is below the zenith angle limit of 65° for TMT.

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The San Pedro Mártir ASCA system is owned and operated by the LSST project and data is made available to TMT as part of a data sharing agreement.

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