All-Sky Mid-Infrared Imagery to Characterize Sky Conditions and Improve STELLAs Observational Performance

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ABSTRACT

The All Sky Infrared Visible Analyzer (ASIVA) is an instrument principally designed to characterize sky conditions for purposes of improving ground-based astronomical observational performance. The ASIVA's primary functionality is to provide radiometrically calibrated imagery across the entire sky over the mid-infrared (IR) spectrum (8-13 μm). Calibration procedures have been developed for purposes of quantifying the photometric quality of the sky. These data products are used to provide the STELLA scheduler with real-time measured conditions of the sky/clouds, including thin cirrus to better optimize observing strategy. We describe how this can be used in the definition of the observing programs to make best use of the telescope time. Additional research is underway to correlate infrared spectral radiance with visible-spectrum extinction.

Keywords: Astronomical Instrumentation, Data Analysis and Techniques

1. INTRODUCTION

The mid-infrared (mid-IR) atmospheric window from 8-13 microns (μm) has long been known to hold great promise in characterizing sky conditions for the purposes of improving astronomical observational performance.[1] A thermal IR imager has the distinct advantage of directly detecting emission from clouds, rather than relying on scattered light or obscured starlight, and does not suffer from the presence of the Moon (nor the Sun), thus providing consistent and reliable information under a wide variety of conditions. The primary functionality of the All Sky Infrared Visible Analyzer (ASIVA) instrument[2,3] is to provide radiometrically-calibrated imagery across the entire sky in the mid-IR. Fig. 1 shows the clear-sky downwelling radiance as simulated using MODTRAN4[4] for a standard mid-latitude summer atmosphere pointed at the zenith for 1 mm and 5 mm of precipitable water vapor (PWV), typical of conditions found at astronomical observatories. Absorption and therefore thermal emission is dominated by water vapor at wavelengths less than 8 μm, by carbon dioxide at wavelengths greater than 13 μm, and by ozone near 9.5 μm. Water vapor absorption lines are present throughout this spectral interval but are least prevalent in the 10.2-12.2 μm region. For this reason, a custom 10.2-12.2 μm filter for optimizing clear-sky/cloud contrast was fabricated for the ASIVA instrument. The spectral response of this filter (which includes the combined effects of filter/lens transmission and detector sensitivity) is also shown in Fig. 1. This paper will discuss how this filter is used to determine sky quality. Data presented here were collected with the STELLA-ASIVA, which is operated by the Leibniz-Institute for Astrophysics Potsdam (AIP). Possibilities to use the ASIVA to more effectively schedule observations are discussed.

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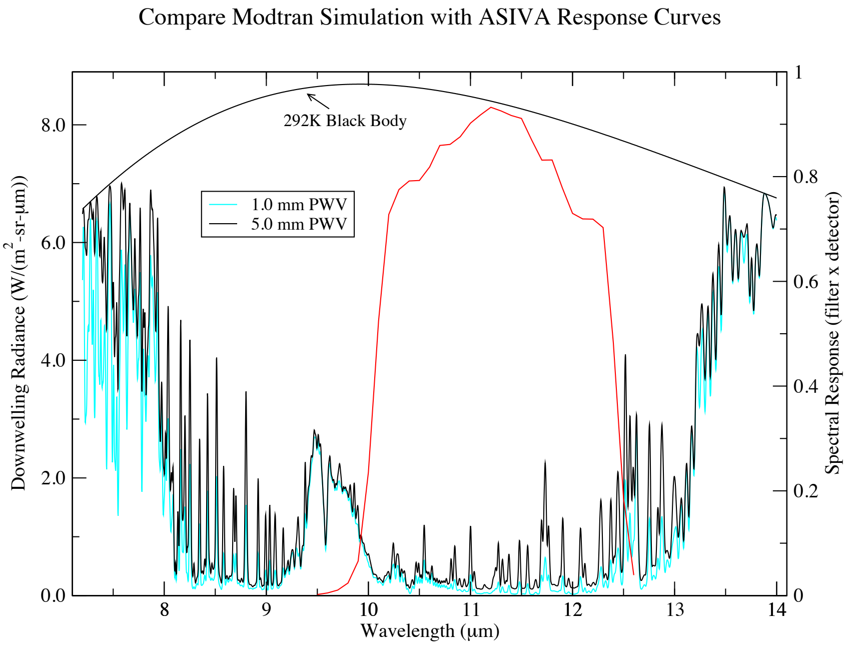

Figure 1. Simulated clear sky radiance in the mid-infrared for 1mm and 5mm PWV. Also shown is the response function of the custom 10.2-12.2 μm filter used to determine sky quality.

Figure 2. The ASIVA at its location near the STELLA building at the Teide observatory on Tenerife. The observatory hosts two telescopes, one equipped with a high resolution spectrograph (left), the other with a wide-field imaging instrument.

2. THE STELLA OBSERVATORY

STELLA (short for STELLar Activity) is a fully autonomous observatory located at Teide observatory on Tenerife, Spain. The observatory is located at longitude 16°30′35”W and at latitude 28°18′00”N at an altitude of 2390m above sea level, the layout of the observatory building and the relative location of the ASIVA instrument is shown in Fig. 2. STELLA consists of two independent, 1.2m telescopes, each of them serving a single instrument to avoid the necessity of instrument change. Both telescope are modern az-alt telescopes with a slewing speed of 10°/sec. The observatory building was finished in spring 2002, well before the telescopes have been delivered. It features two roll-off roof-halves, which can be closed at any orientation of the telescopes, which ensures a reliable protection of the instruments during bad weather periods. The observatory is operated completely automatically, there is no personal on site, and no operator is remotely controlling the telescopes. A scheduler decides which target is best suited for observations at any given time, and these observations are then carried out.

The Stella-I telescope, which is an f/8 Cassegrain system with two Nasmyth foci, is optimized for wide field-imaging with an field-of-view of 24 arc minutes, but was originally feeding the STELLA Echelle Spectrograph (SES), which achieved first light on this telescope in 2005. An adapter was constructed for the fixed Nasmyth port, which contained the fiber input to the spectrograph, a focus pyramid and a gray beam-splitter to divert 4% of the light to a small, uncooled KAF-0402 detector which was used for acquisition and guiding.[5]

SES features in brief:

- 4kx4k E2V CCD with 15μm pixel and support four-amplifiers readout (4kx4k E2V CCD with 13.5μm pixel until 2012)
- Full optical wavelength coverage from 390nm to 860nm
- Spectral resolution of 55 000

The STELLA-II telescope has a very simple optical system with a spherical mirror and a prime-focus corrector leading to corrected field of 1 arc minute at f/8.4. It has a single focal station at the primary focus, where light is picked up with a fiber, which, in turn, is connected to the SES. It was put into operation in 2010, feeding the SES since then. This made room for the wide-field imaging photometer WiFSIP (Wide Field Stella Imaging Photometer) at STELLA-I.

WiFSIP features in brief:

- 4kx4k ITL chip with 15μm pixel and support four-amplifiers readout
- The useable field-of-view is 22 arc-minutes squared.
- Johnson UBV(RI)$_C$, Sloan u'g'r'i'z' filters, and a full Strømgren set uvby including H_β wide and narrow.
- H_α photometry with a wide (FWHM=18nm) and a narrow filter (FWHM=3nm).

During 2012, WiFSIP will receive a new CCD detector system to increase the photometric accuracy, which is currently limited by the bad cosmetics of the current CCD detector. Furthermore, SES will receive a new fiber feed to increase efficiency and spectral resolution. This will mark the final

3. DATA PRODUCTS

The ASIVA at the STELLA observatory is currently configured to acquire a set of observations every 5 minutes. Each set consists of a series of images (usually 8) contained in one data cube for each filter. Several data products are presently generated from the raw sky and blackbody reference images to determine the presence of clouds and the photometric sky quality. Most notably these include a calibrated spectral radiance image, a temporal standard deviation image (generated by taking the standard deviation of the eight individual images stored in the data cube), and a spatial standard deviation image (generated by taking the difference of the first and last image in the data cube and then replacing each pixel value with the standard deviation of pixel values within a

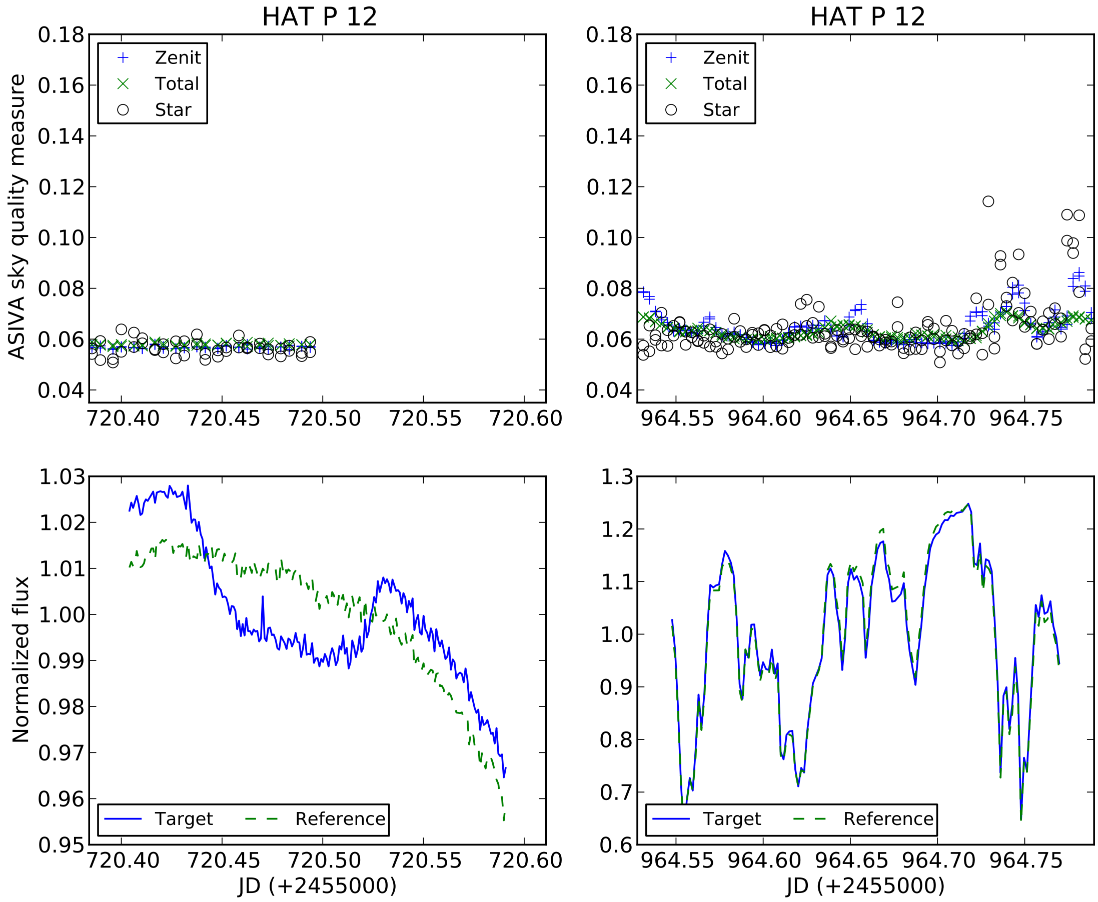

Figure 3. Sky quality during HAT P 12 transit observations. Top panel: The sky quality measure from the ASIVA at the zenith, around the star's position and averaged over the whole sky. Bottom panel: Normalized flux of the target star (solid line) and the normalized sum of the reference stars' flux. During the second transit observation, the variability of the signal is dominated by sky transparency effects, while during the first transit observation the light dip is clearly visible in the raw data.

box centered on that pixel). These three images are then combined to produce a single metric for the photometric sky quality on a scale from zero to one for every pixel in the array. Additional research is being done to refine this metric. In particular analysis procedures have been developed to subtract the clear-sky radiance from the spectral radiance images improving the metrics robustness with regards to varying PWV and airmass. The sky quality map is also smoothed which essentially extends the boundaries of cloud structures. In practice, this will help avoid the selection of photometric skies that are too close to those that are not. The sky quality map can then be used by the observatory scheduler to make appropriate telescopic observation decisions.

4. SKY QUALITY DURING TRANSIT OBSERVATIONS

Besides the core science program of the Wide-Field imager (WIFSIP) instrument, which is a stellar cluster survey, a number of supplementary programs are executed. One such program consists of the observation of planetary transits to supplement contemporary observations using more specialized instruments. In the last half year, two such planetary transits were observed successfully while the ASIVA was collecting data. One transit was observed during near perfect observing conditions, unfortunately the ASIVA data has a gap right in the

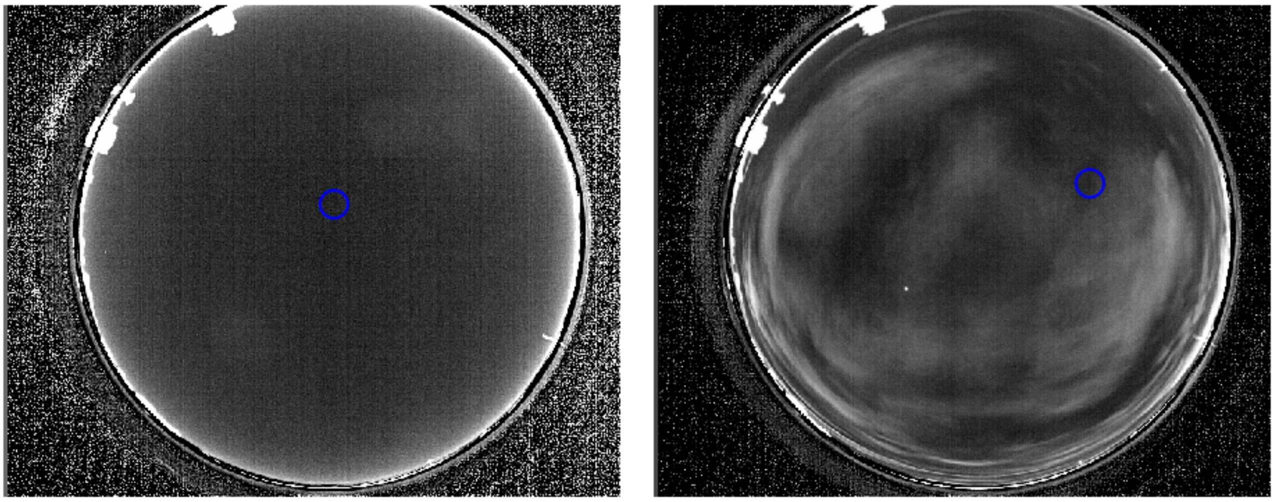

Figure 4. ASIVA infrared radiance images (in the 10.2–12.2 μm filter) of the sky at the beginning of the two transits shown above. The blue circles mark the approximate location of the target on the sky at that time, while the skyline of the solar telescopes towards the North-West and the full moon in the second image are readily visible. Note that the two faint spots in the clear sky image at the left are due to changes in lens transmission and dictates that the instrument requires recalibration.

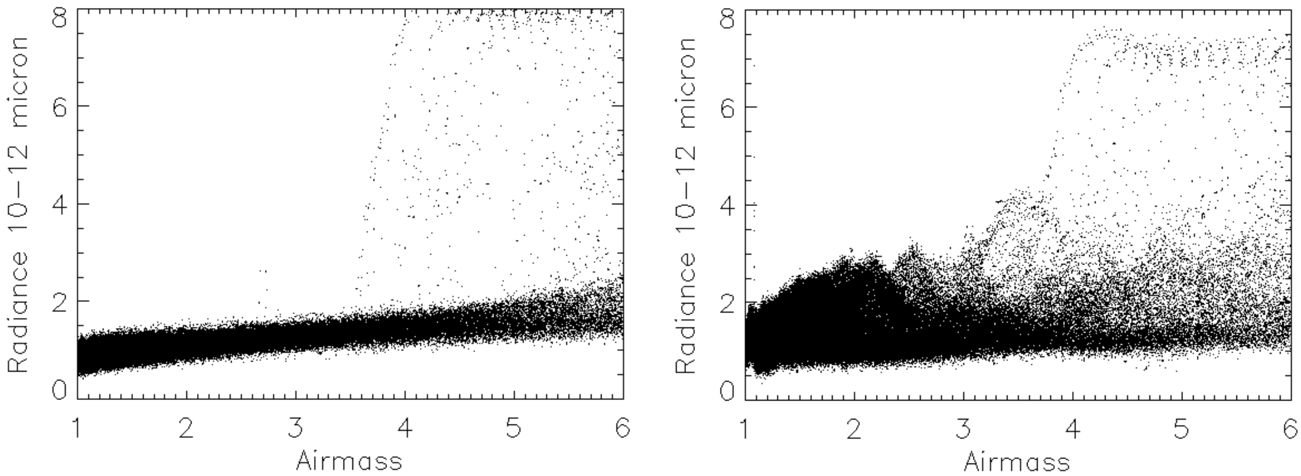

Figure 5. Radiance vs. airmass for the two images in Fig. 4. The high amount of scatter in the clear sky image (left side) is one more sign of the need for recalibration.

middle of this data set. The other transit was observed during slightly overcast skies. Both transit were observed in one photometric bandpass only, the first in June 2011 using the Sloan r' filter , the second in February 2012 using the Johnson V filter. The photometric flux of the target stars, along with the sum of the flux from the reference stars, are shown in the bottom panel of Fig. 3. In the top panel of Fig. 3, the contemporaneous sky quality measures from the ASIVA instrument. For comparison, infrared radiance images at the beginning of the respective observing blocks are shown in Fig. 4. The approximate position of the target is marked with a blue circle, the thin clouds during the second observing block are clearly visible.

This example illustrates that clear skies produce a sky quality measure of less than 0.06 with very little scatter in time. But the total sky quality index is not much worse for mixed conditions. One hint to the bad photometric conditions in during the second night is the large deviation between the total and Zenith sky quality measures, and the large temporal scatter. Thus, in order to derive reliable information about whether the sky is photometric or not requires the analysis of more than one ASIVA image. Implementation of the clear-sky subtraction discussed above will greatly improve the sensitivity of the sky quality metric reducing the need for

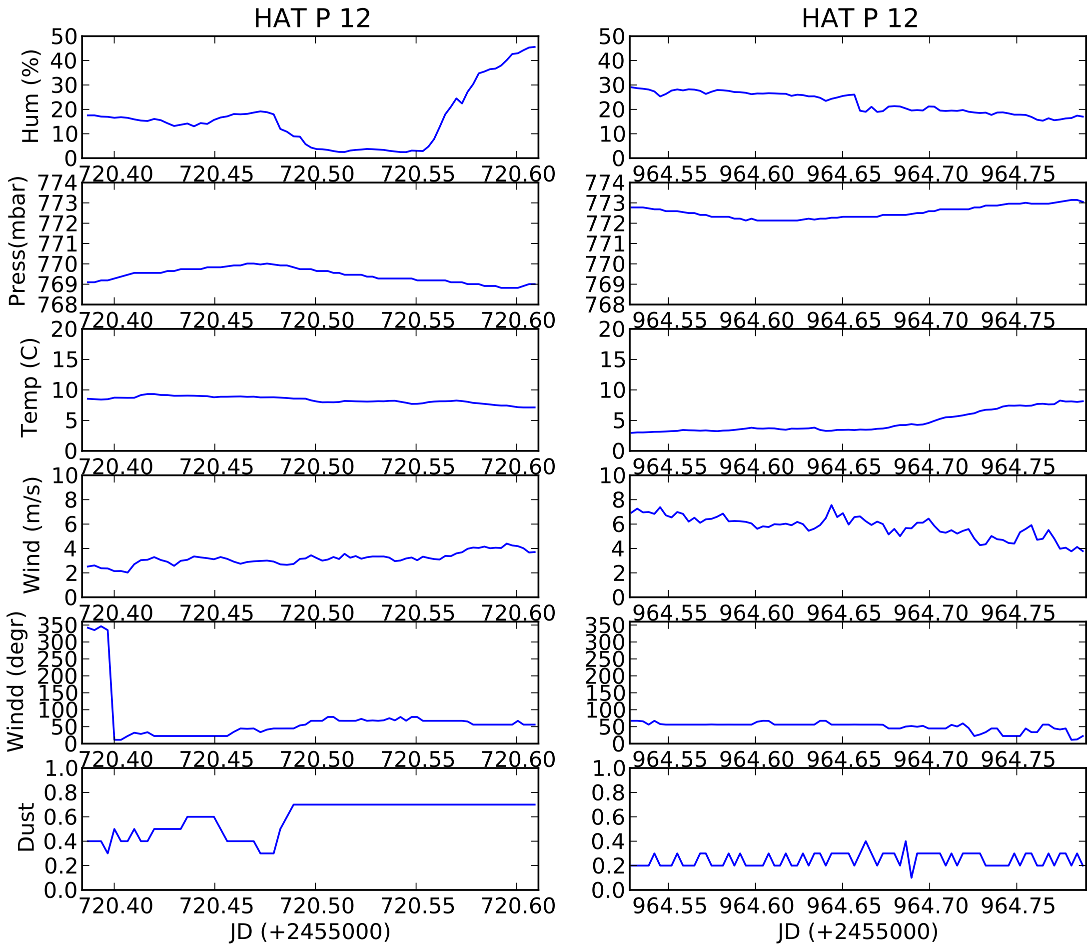

Figure 6. Weather sensor reading during the two transit observations. From these readings it is not obvious that the first time span has far superior weather conditions. To the contrary, the rising humidity and the fairly low atmospheric pressure would characterize it as a below average night, while the second night looks near perfect, especially for a winter night.

multiple ASIVA images.

Since the ASIVA restarted observations in 2011 after a serious hardware failure earlier that year, problems with the control computer were keeping us from doing a long overdue recalibration of the unit. We finally replaced the computer in question, and the recalibration of the archival images is in progress, but too late to make it into this report. In Fig. 5 the sub-optimal calibration can easily be seen in the amount of scatter in the lower envelope of the left (clear sky) plot of airmass vs. radiance.

5. DISCUSSION

Currently, the ASIVA is only used to determine if the sky quality is worth opening the dome of the observatory. As illustrated in Fig. 6, the regular weather sensors are necessary to determine if it is safe to open the roof, but can not reliably detect sky conditions. Even on good astronomical sites like the Canary Islands, overcast skies are possible without suspicious weather sensor readings. This is a good extension to normal environmental sensors, which keeps us from exposing the instruments without any chance of useful observations. But even more useful, the information available can determine if the sky is photometric of not. This is nice to know when analyzing the data, but for a automatic observatory it can help scheduling observations with a high demand on the sky quality like planet transit observations more efficiently, but also for spectroscopic observations in need of stable conditions. The most trivial step is to add a scheduling parameter that requires a minimum sky quality measure at the target position at the time the target is about to be observed. In case that requirement is not met, the merit of the target is reduced to zero. A simple extension of this merit function would be to add Zenith and total sky quality as possible parameters instead of the target position.

A more advanced merit function could include a time span for which the sky quality measure has to be below a certain value. This would be especially useful for targets that have to be observed for a long timespan like planetary transits, since these need stable conditions during all of the observing window. Care has to be taken, that this improvement of the scheduling algorithm does not discriminate against long term observations after bad weather clears up. An even more sophisticated approach would be to include a forecast feature, namely track the evolution of the cloud cover and focus the observations at spots in the sky that are less likely to be overcast for the time needed to fulfill the observing request.

The all-sky camera could also play an important role in the overall scheduling process of the two STELLA telescopes, especially for the imaging instrument WiFSIP. The infrared images deliver information on sky transparency even during daytime, thus we envision utilizing these for nightly predictions on photometric sky quality, in turn raising and lowering priorities of programs that need photometric conditions. If clouds are detected, areas of the sky can be masked in the course of the selection process. If possible, (slow) motions of the clouds may also be detected and enter the selection process as an additional constraint. A difference image in the to IR wavelength will be calibrated against our ground-layer dust sensor, hopefully allowing a better characterization on Calima. The optical camera may be used during night not also for all-sky photometry, but also for wavelength-dependent transparency measurements.

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