



Extraordinary Solutions

ASIVA

All Sky Infrared Visible Analyzer

This ASIVA capabilities report has been prepared by:

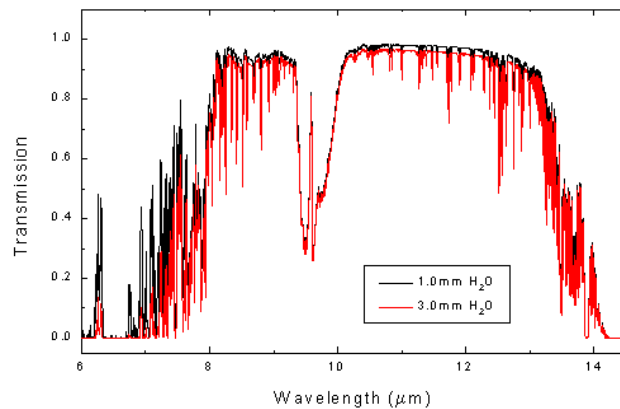
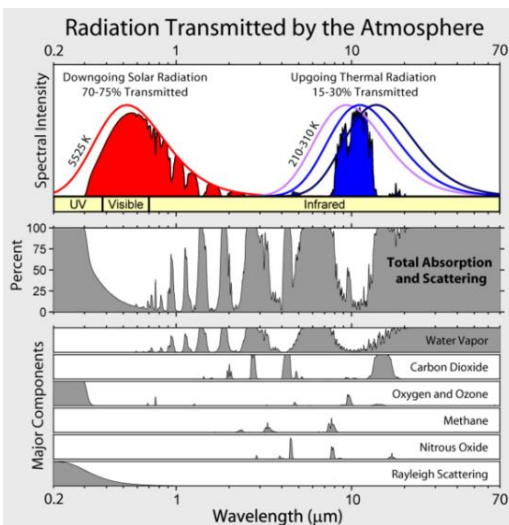
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President Solmirus Corporation

Introduction:

The Solmirus All Sky Infrared Visible Analyzer (ASIVA) is a multi-purpose visible and infrared sky imaging and analysis instrument designed to operate autonomously or as a component in an instrument cluster. Its utility ranges from astronomy to meteorological applications. Potential data products include the following:

- Cloud/No Cloud Reporting
- Cloud Cover Determination
- Photometric Quality Assessment
- Sky Opacity/Transmission Determination
- Visible/IR Correlation and Integration
- Water Vapor and Ozone determination
- Sky/Cloud Temperature (brightness and color) Measurements
- All-Sky (180 degree field-of-view) Radiometric Maps and Analysis

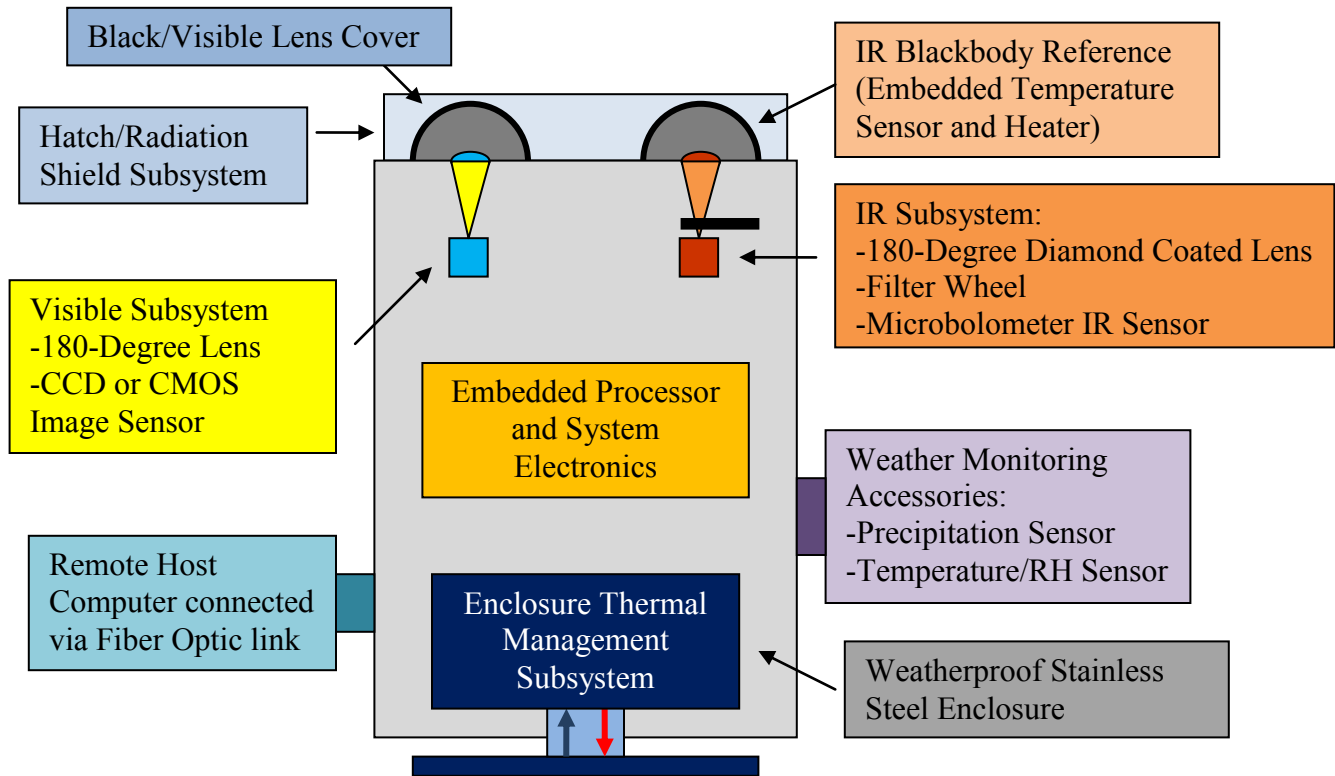
The ASIVA's primary function is to provide radiometrically-calibrated imagery in the mid-infrared (IR) atmospheric window which stretches from 8-13 microns. The following figures show clear sky atmospheric transmission in this spectral interval.



Absorption is dominated by water vapor at wavelengths less than 8 microns, by carbon dioxide at wavelengths greater than 13 microns, and by ozone near 9.5 microns. Water vapor absorption lines are seen strewn throughout this spectral interval but are least prevalent in the 10.2-12.2 micron region. For this reason, Solmirus now offers a custom 10.2-12.2 micron filter for optimizing cloud/clear-sky contrast. This filter is highly recommended in detecting clouds in humid environments as well as differentiating thin clouds from variable water vapor conditions. In general, clouds are essentially gray bodies and are easily detected against the background of the highly transmitting infrared sky.

ASIVA System Architecture Description:

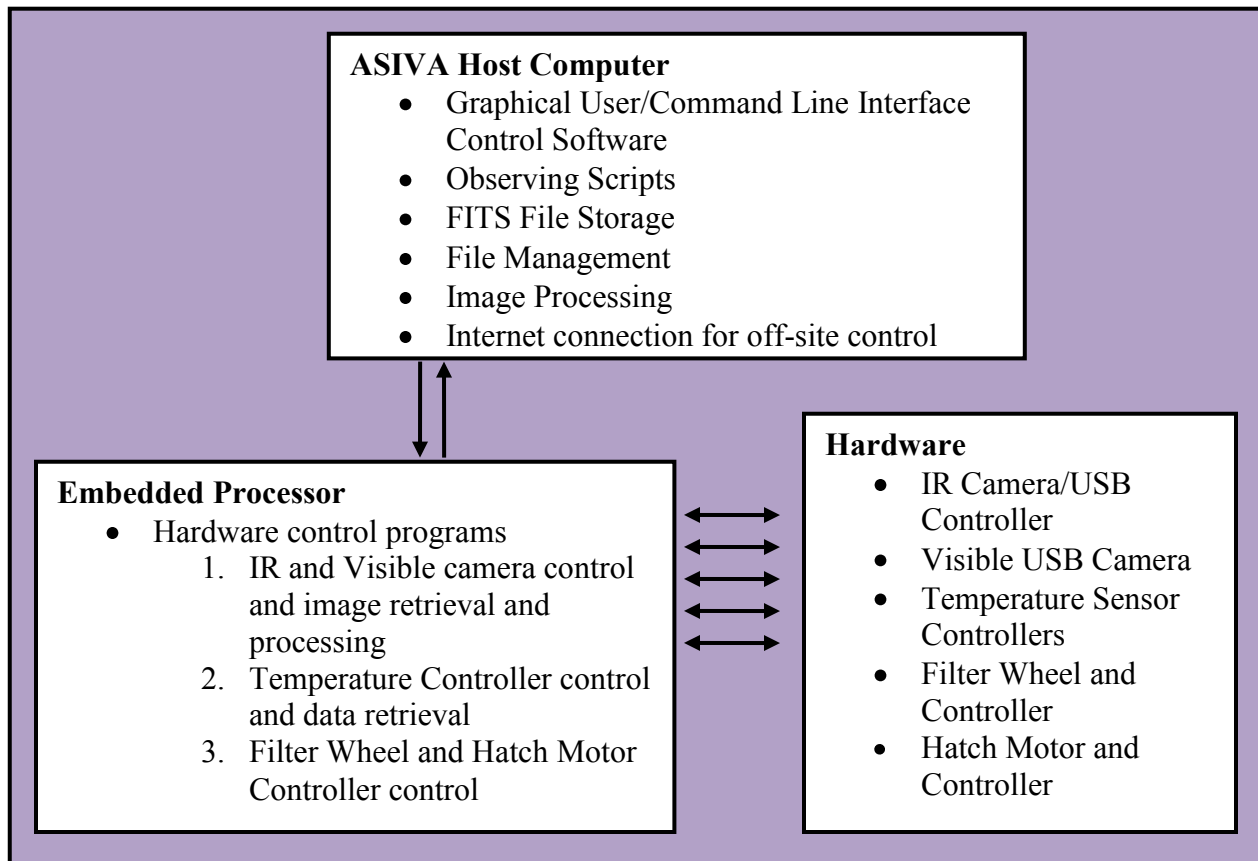
A block diagram of the ASIVA instrument and its primary functionality is shown below:



At the heart of the ASIVA instrument lays the infrared and visible imaging subsystems. The infrared subsystem includes a 640×512 uncooled microbolometer array sensitive to 8-14 micron radiation, a 180-degree (all sky) custom designed diamond coated lens, and a six-position filter wheel for use with 1-inch filters. Custom infrared filters can be cost prohibitive. We find that a good selection of affordable 1-inch filters can be found from optics manufacturer JDSU (www.jdsu.com) in their sample filter catalog. As mentioned above, Solmirus offers a custom 10.2-12.2 micron bandpass filter for optimum cloud/clear-sky contrast. The visible subsystem consists of a 1-megapixel monochrome CCD or CMOS detector coupled with a 180-degree off-the-shelf lens. An optional six-position filter wheel for use with 1-inch filters is also available for the visible subsystem as well as color CCD or CMOS detectors.

The brain of the ASIVA instrument is the embedded processor that communicates with and controls the imaging subsystems and other subsystems such as the hatch-motor, filter-wheel, temperature-meters, and weather-monitoring subsystems. Data (both raw and processed) is passed over a fiber optic link to the host computer where it can be archived and displayed. Operational control of the ASIVA instrument, additional image processing, and off-site control through the Internet is done via the host computer. Operational control software with either graphical user or command line interface has been developed and is customizable to the

customer's needs. This operation and control architecture is illustrated in the following block diagram:



One of the unique innovations of the ASIVA instrument is its Hatch/Radiation Shield Subsystem which provides the following features:

- The blackbody reference and visible lens cover remain in the same protected orientation (pointed downward) as the hatch mechanism is opened and closed.
- The hatch provides a weatherproof seal when it is in the closed position.
- The hatch drive motor, position encoder, and magnetic limit switches are housed within the enclosure for superior protection and durability.
- Temperature sensors and a heating element are embedded in the IR blackbody reference for accurate in situ temperature/flux calibration.
- A radiation shield surrounds the IR blackbody reference allowing it to better track the ambient temperature.

The ASIVA is also outfitted with an autonomous enclosure thermal management system designed to provide a reasonable operating temperature within the enclosure environment over a broad range of exterior temperatures.

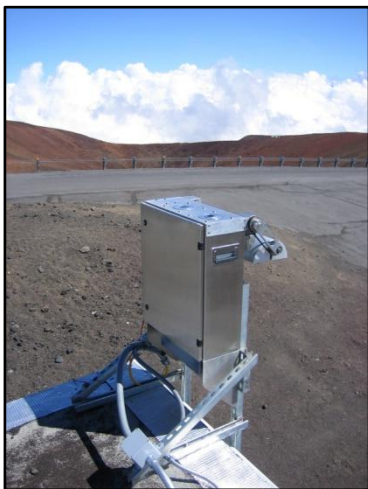
Solmirus is currently in the final manufacturing phases of three ASIVA production instruments. These instruments will be delivered to the Institute for Astronomy to be operated on Mauna Kea,

Hawaii, to the Instituto de Astrofisica de Canarias to be operated on the island of Tenerife, Spain, and to the National Optical Astronomy Observatory to be operated on Cerro Pachón, Chili. All three instruments will be used to support astronomical research and are slated for a late 2009 or early 2010 delivery timeframe. Exterior pictures of one of the production instruments are shown below:



The Demonstration ASIVA (D-ASIVA):

In the summer of 2007, Solmirus built a demonstrational prototype (D-ASIVA) that has now been extensively field tested on Mauna Kea, Hawaii, the ARM Climate Research Facility's Southern Great Plains site in Oklahoma, and atop the Colorado College physics building in Colorado Springs, Colorado. The D-ASIVA was built as a test-bed to refine hardware, software, and data retrieval and analysis procedures. Lessons learned from the D-ASIVA have been incorporated in all production ASIVA instruments. The D-ASIVA utilizes a smaller format (324x256 pixels) IR camera but has essentially the same sensitivity as the 640x512 array used in the production instruments. Pictures of the D-ASIVA instrument are shown below.



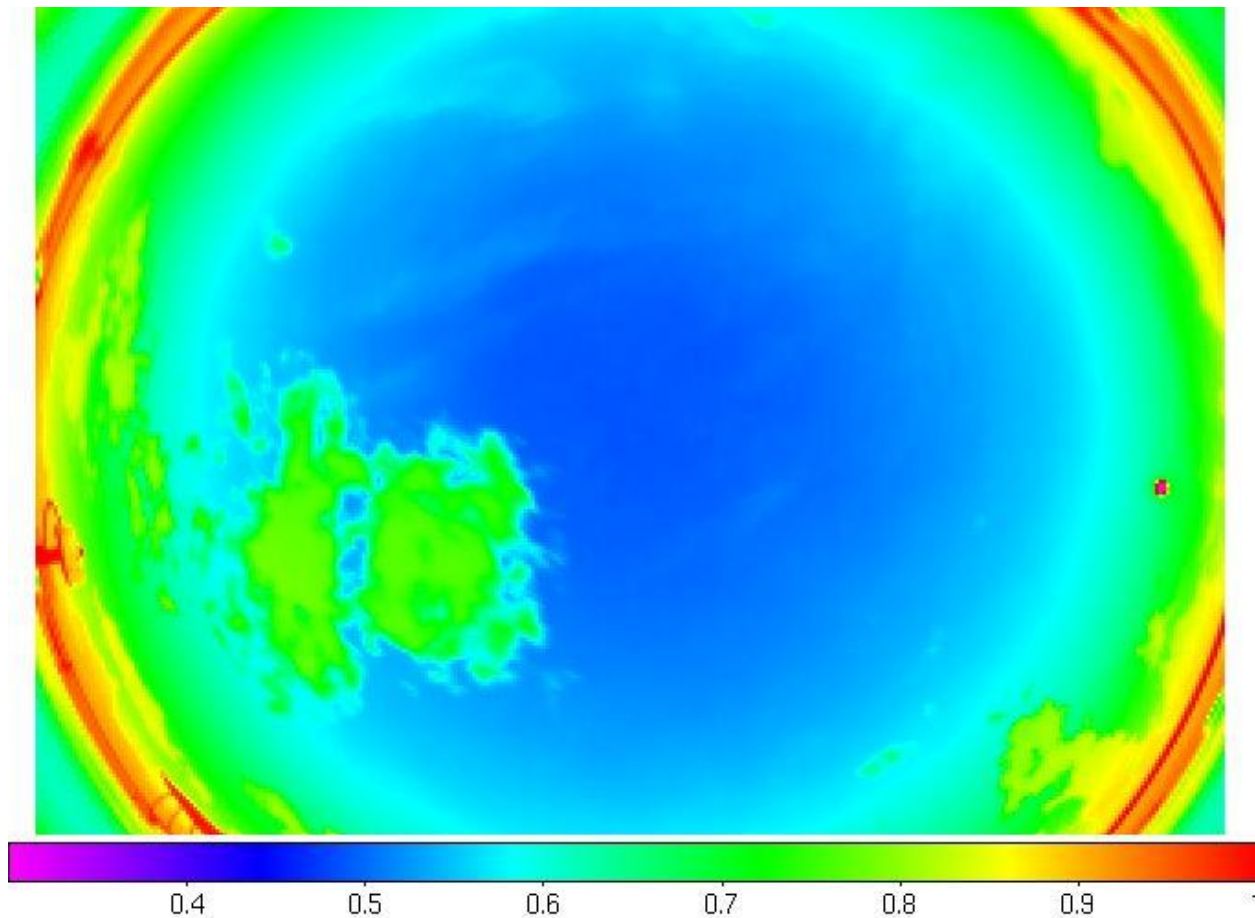
D-ASIVA on Mauna Kea, HI



D-ASIVA in Colorado Springs, CO

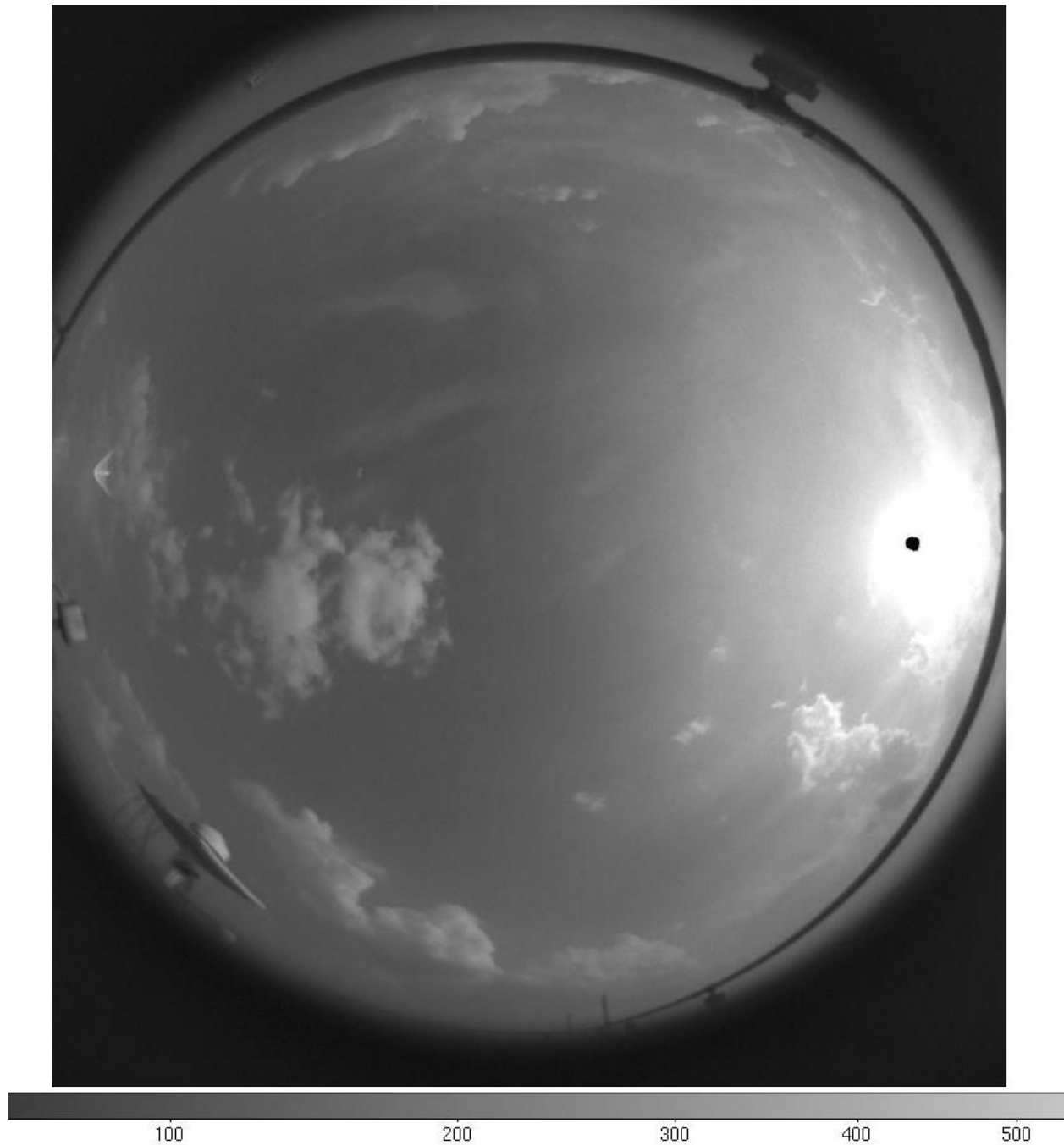
ASIVA Performance and Data Products:

The ASIVA showcases a microbolometer infrared sensor that demonstrated an order of magnitude improvement in signal-to-noise performance over previous generations of the ASIVA instrument which utilized a BST (Barium-Strontium-Titanate) based infrared detector. The microbolometer provides data that allows for absolute calibration, something that has proven to be extremely difficult for the BST detector. The microbolometer provides much better sensitivity to thin clouds as well as the means for accurate determination of both brightness and color temperature of the sky and clouds. The following image represents a sample of a radiometrically-calibrated IR image taken with the D-ASIVA instrument in the summer of 2009 at the ARM Climate Research Facility's Southern Great Plains site in Oklahoma.



This image represents an 8 second exposure in the 10.2-12.2 micron band also utilizing Solmirus' custom 180-degree (all sky) diamond coated lens. The field-of-view is somewhat truncated as compared to the production ASIVA instruments due to the smaller format array used in the D-ASIVA instrument. The water vapor column based on available ARM data was 3.3 centimeters for the time of this observation. The data is presented as a normalized flux ratio given by $F_{\lambda_{sky}}/BB_{\lambda}$ where BB_{λ} is the blackbody radiance calculated for the ambient temperature. This flux ratio is an approximation to the sky's emissivity.

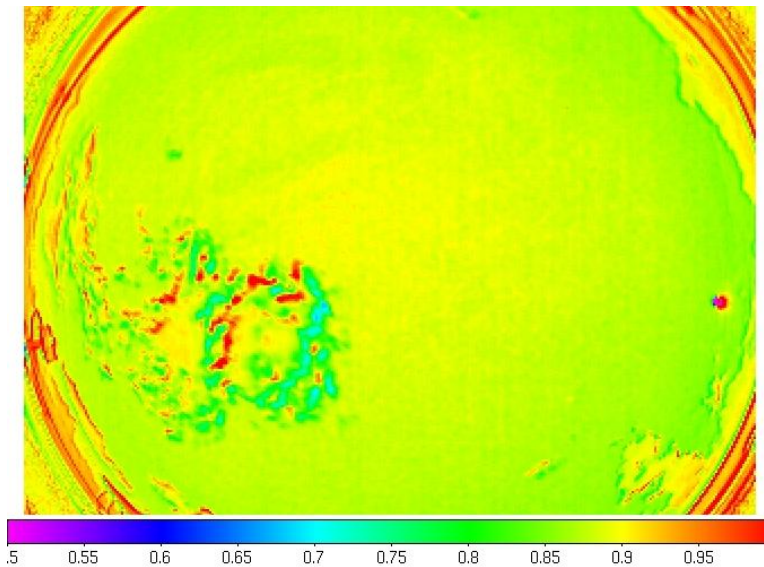
The corresponding R-band visible image taken by the D-ASIVA's color CMOS imager is shown below:



The CMOS detector works very well in daytime conditions despite not using a sun occulter. Also note that the thin cirrus clouds seen in the visible image are easily detected in the IR image illustrating the sensitivity of the IR sensor through humid skies. For reference, a corresponding image from the ARM facility's Total Sky Imager (TSI) is shown below. This instrument is used to determine daytime cloud fraction for the ARM site.



A corresponding IR image in the 8.25-9.25 micron was also taken. The flux ratio of this image to the 10.2-12.2 micron image produces the following result.

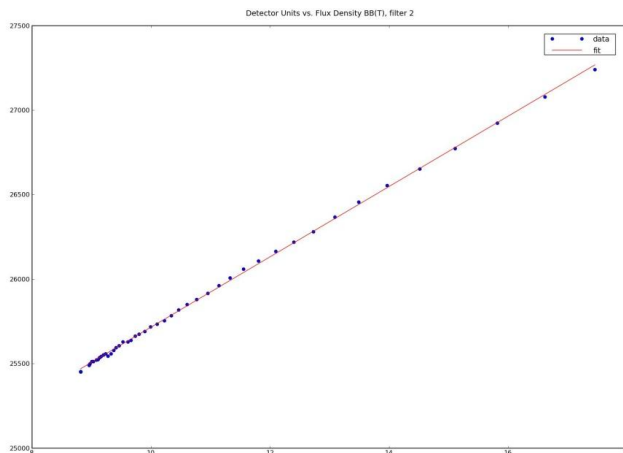


This image can be used to provide a color temperature of the sky. For the filters used, the following table gives the temperature scale associated with the above image.

$T_{Color}(K)$	200	210	220	230	240	250	260	270	280	290	300
$\frac{BB_{\lambda_1}(T_{Color})}{BB_{\lambda_2}(T_{Color})}$.53	.58	.63	.68	.73	.78	.82	.87	.91	.96	1.00

This method can ultimately be used to determine cloud temperatures once water vapor contributions are subtracted from the radiometrically calibrated images. Some anomalies associated with cloud motion can be seen in the above image. This can be mitigated by using shorter exposure time and reducing the time between filter changes.

Results from the calibration procedure performed with the D-ASIVA are shown below:



In this procedure, the blackbody reference was heated to ~ 70 degrees Celsius and then allowed to passively cool to ambient temperature. As one can see the detector response is quite linear over a broad temperature range. This data is used to determine the gain coefficients for each pixel which are then used to produce radiometrically calibrated images.

A variety of IR data products are available for the ASIVA instrument. Our current data retrieval scheme goes as follows: Sky images are stored as 3-dimensional FITS images 640x512 pixels (324x256 for the D-ASIVA system) by 16 images deep. Each image in the 3-D FITS image represents ~ 0.5 seconds exposure acquired by co-adding sixteen (16) $1/30^{\text{th}}$ second frames. The 3-D FITS image can therefore be co-added to provide a single ~ 8 second exposure. An advantage to this data acquisition scheme is that it allows for the computation of the standard deviation of each pixel across time and in some cases can be an excellent discriminator of cloud structure.

The D-ASIVA achieves a Noise Equivalent Power (NEP) of $0.016 \text{ W/m}^2/\text{sr}$ for a single 0.5 second image. NEP is determined by differencing consecutive images and calculating its RMS fluctuations. Similar results are obtained by calculating the RMS fluctuations for each pixel using the 16 individual values stored for that pixel in the 3-D image file. The NEP specification equates to a Noise Equivalent Temperature Difference (NETD, computed at 300 K) of 20 mK which compares very nicely with the camera manufacturer's quoted NETD specification for a single $1/30^{\text{th}}$ second frame of 85 mK. At $T = 273 \text{ K}$, one can also translate the NEP specification to a noise equivalent optical depth of 0.0005. This means that one should be able to detect optical depth (and therefore sky emissivity/transmission) variations at the 0.5% level with a signal-to-noise (S/N) ratio of 10 in a 0.5 second exposure. A factor of four improvement in S/N ratio is obtained by co-adding the 16 images stored in the 3-D FITS file. A reduction in S/N ratio of ~ 5 when utilizing narrower (~ 1 -micron) bandpass filters.

This document represents the status of the ASIVA instrument as of November 23, 2009. Please contact Solmirus (www.solmirus.com) for further details.