A Search for Astrophysical Transients with a Small-Aperture Telescope

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Abstract

AggieCam is a wide-field, small aperture instrument that was used to survey young (<50 Myr) and nearby (<150 pc) stellar associations for transiting exoplanets and eclipsing binaries. The data analysis is based on a difference-imaging pipeline in an attempt to increase the detection capabilities. Difference imaging matches the quality of two frames of the same star field and subtracts them, leaving only the change in flux due to *bona-fide* astrophysical events in the output image. This method is also highly sensitive to the detection of other astronomical events which were not part of the main scientific goals of the survey (stellar flares, asteroids or supernovae). These types of events, called transients, appear as correlated residuals on the differenced frames and can be easily detected against the background. An analysis of over 200 hours of AggieCam data resulted in the detection of 49 possible transients and 8 possible Near Earth Objects (NEOs). We also report preliminary results from follow-up observations obtained at McDonald Observatory.

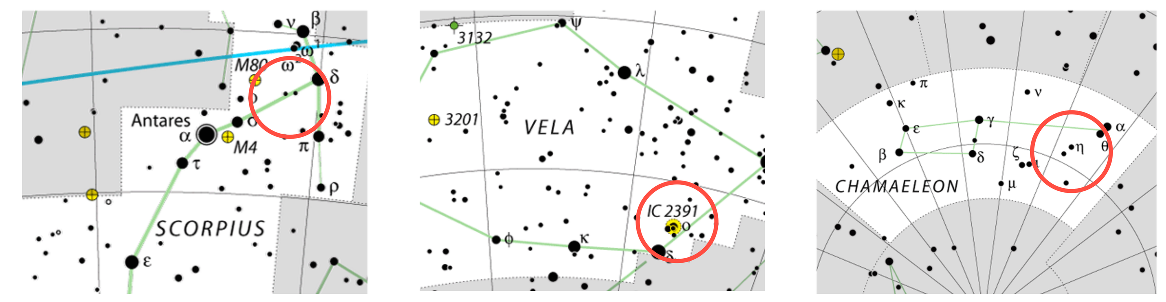
Introduction

Texas A&M University partnered with the Institute for Theoretical and Experimental Astrophysics and the University of Cordoba (Argentina) to install a wide-field imager at Bosque Alegre Astrophysical Station from September 2013 to October 2014. The instrument, nicknamed “AggieCam”, consists of an Apogee Alta F16M camera, with a 4096×4096 pixel Kodak KAF-16083 CCD that is thermoelectrically cooled to $\Delta T = -45°C$ relative to ambient. Testing of the CCD shows a dark current of 0.2 e/pix/s at temperatures of -25°C. The optics include a Mamiya photographic 300mm lens with a Hoya UV and IR cut filter to restrict the wavelength range from 400 to 700 nm. Total transmission of the system is near 45%. The pixel scale for the detector is 6.2 arcsec/pix, leading to a total field of view of nearly 50 square degrees.

The primary scientific goal of AggieCam was to survey young (<50 Myr) and nearby (<150 pc) stellar associations for “Hot Jupiters” and pre-main sequence binary stars (*see Figure 4*). The survey monitored three stellar associations (Upper Scorpius, IC 2391 in Vela, and η Chamaeleontis) for 200+ hours. After debiasing, flat fielding and sky subtraction the images were astrometrically aligned and run through a difference imaging pipeline to match the image quality between frames (Oelkers+ 2015). Using difference imaging any star with constant flux will subtract to zero while a variable source will leave a correlated residual on the differenced image.

Difference image analysis is susceptible to the detection of any changes in flux between two images, such as those originating from variable stars or transient events. Transients are astrophysical phenomena marked by an increase in flux, which can originate from known objects or seemingly empty areas of the sky. Examples of these types of objects include supernovae and stellar flares. Near-Earth objects (NEOs) can also cause these changes in flux if they happen to cross the field of view (FoV).

Young Stellar Associations



The location of each surveyed field in the constellations Scorpius (left), Vela (middle) and Chamaeleon (right). The approximate location of each field is circled in red. The images are courtesy of the International Astronomical Union in collaboration with Sky and Telescope magazine.

Method and Results

The technique described previously simplifies the search for transients because all non-variable sources will subtract to zero in the differenced image. Since we were only interested in transients, we masked the positions of known objects and added the absolute values of all differenced images from a given night to increase the signal-to-noise ratio of the resulting detection frame. These were visually inspected for positive correlated residuals, and the positions and date of detection of all possible transients were recorded for further study.

Each detection frame was broken into 20×20 pixel stamps around each transient candidate and the flux from the brightest pixel in each stamp was measured relative to the sky background. Two or more consecutive detections with significance exceeding 25σ prompted a visual inspection of the stamps in question. The rough shape (circular or elliptical) and possible motion of the transient candidate was recorded.

We used a master frame, produced by co-adding many individual images, to determine the approximate celestial coordinates of each transient candidate. These were confirmed using the NASA/IPAC Infrared Science Archive. Next, we used the SIMBAD Astronomical Database to search for known objects in the vicinity of each transient. We also used the IAU Minor Planet Center website to investigate moving transients.

We measured the flux of each object using the APER task in the IDL DAOPHOT library (Stetson 1987). The flux was corrected for exposure time, zero pointed and combined with the flux from the master frame to convert to a magnitude scale. The results were plotted against the Julian date of the observation (*see Figures 1, 2, and 3*).

Using the described methods we found 30 transient events in Upper Scorpius, 10 transient events in Vela and 9 transient events in η Chamaeleontis. Of the 49 possible transients, 8 appeared to be stationary and 41 appeared to be in motion. 8 of the 41 moving objects can be associated with known NEOs. On average, we detected 1 transient per 4 hours of observation in these fields.

Follow Up Photometric Observations

The AggieCam survey detected 200+ possible pre-main sequence binary stars in all 3 surveyed fields. Higher precision photometric follow-up spanning a variety of colors is necessary to further constrain the orbital parameters of each system and confirm the light curve modulation is due to binary eclipses. One such known young star, U014334 (RA=16:16:59.8, Dec=-21:54:27), was observed using the 0.8m telescope at McDonald Observatory on July 23rd, 2015. Images were obtained through Johnson/Cousins B, V, R and I filters with exposure times ranging from 90 to 180s.

Based on the orbital ephemeris calculated from AggieCam data, the system was expected to be moving out of primary eclipse during our observations. Figure 4 shows the preexisting AggieCam light curve, the best-fit binary star model (Southworth+ 2013) and preliminary measurements based on the new McDonald data. For visualization purposes, the latter have been roughly transformed to the photometric system of AggieCam using ~30 nearby stars.

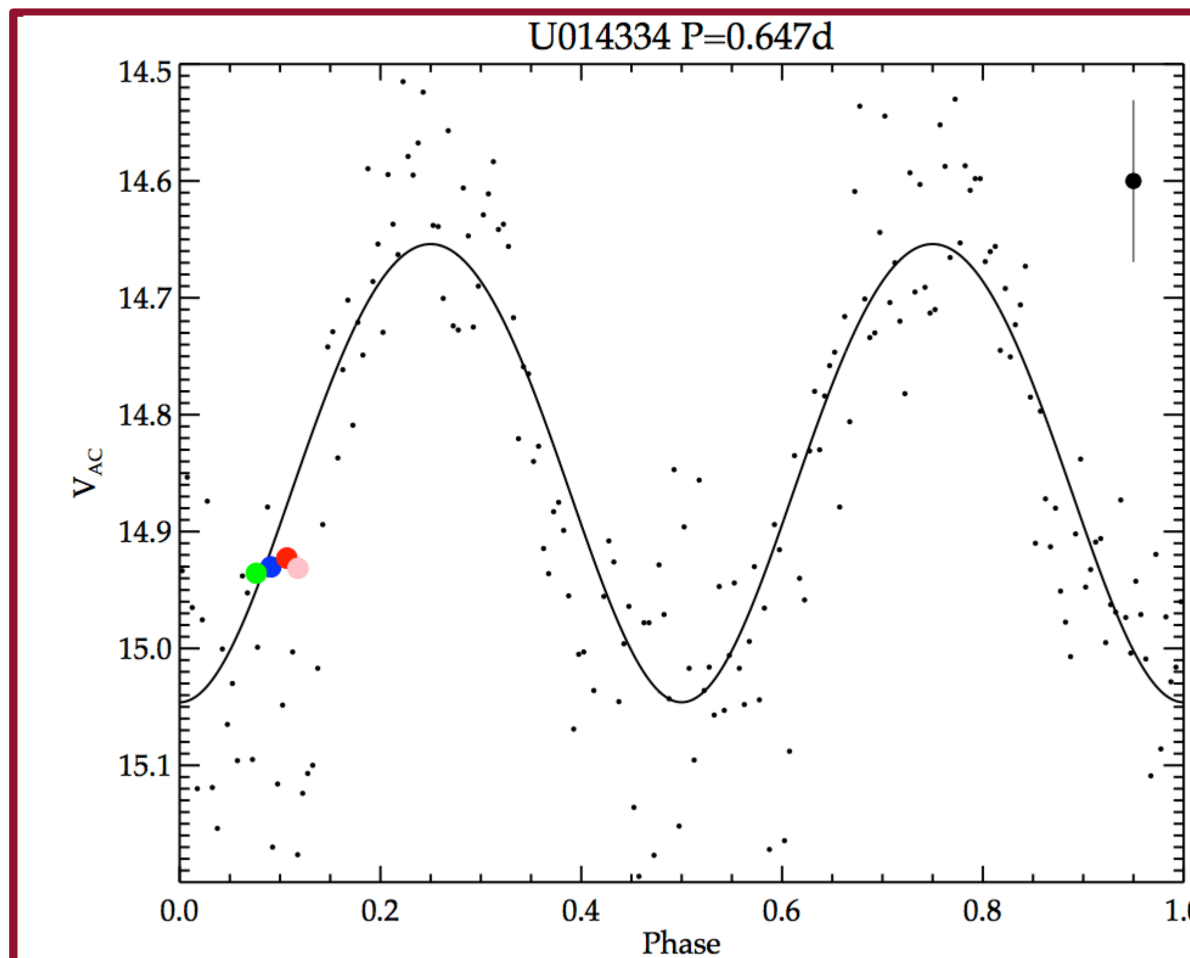


Figure 4: The AggieCam survey light curve of the pre-main sequence binary candidate U014334 phased on a period of 0.647d and binned into 200 data points. The star was observed from McDonald Observatory on July 23, 2015. The black dots are binned AggieCam data. The black line shows the best fit binary model. The colored points are the measured median B (blue), V (green), R (red) and I (pink) magnitudes. The size of the data points are equivalent to the photometric error for each point. The error for the AggieCam data is shown at the top right.

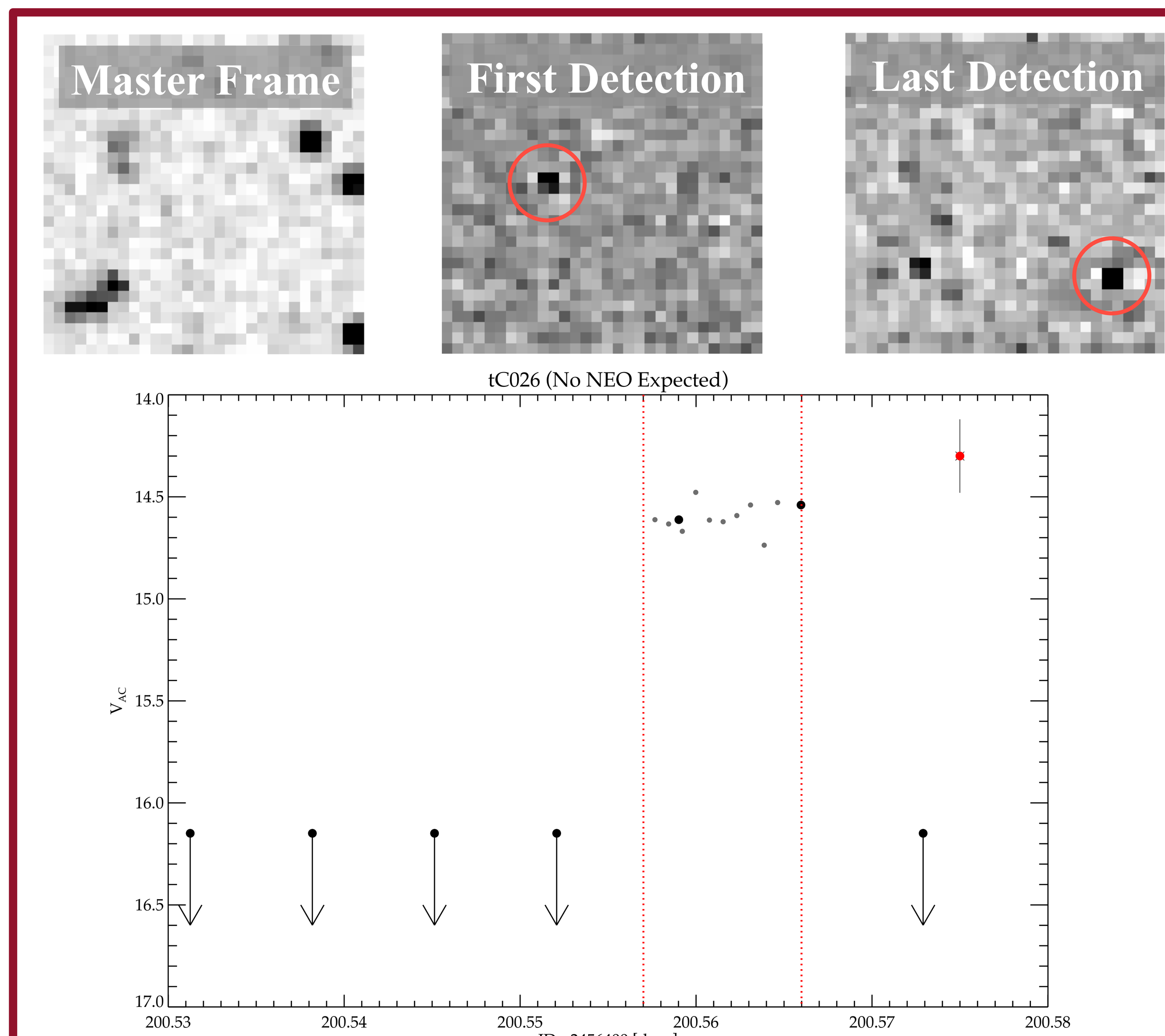


***Figure 1**:* tC026 in η Chamaeleontis (RA=09:06:08.9, Dec=-77:45:23) appeared to be in motion but no known NEOs were expected in the FoV at the time. *Top Left:* master frame. *Top Middle:* initial detection. *Top Right:* last detection. *Bottom:* light curve of the transient. A typical error bar is shown spanning the red symbol. Upper limits are plotted using downward-pointing arrows.

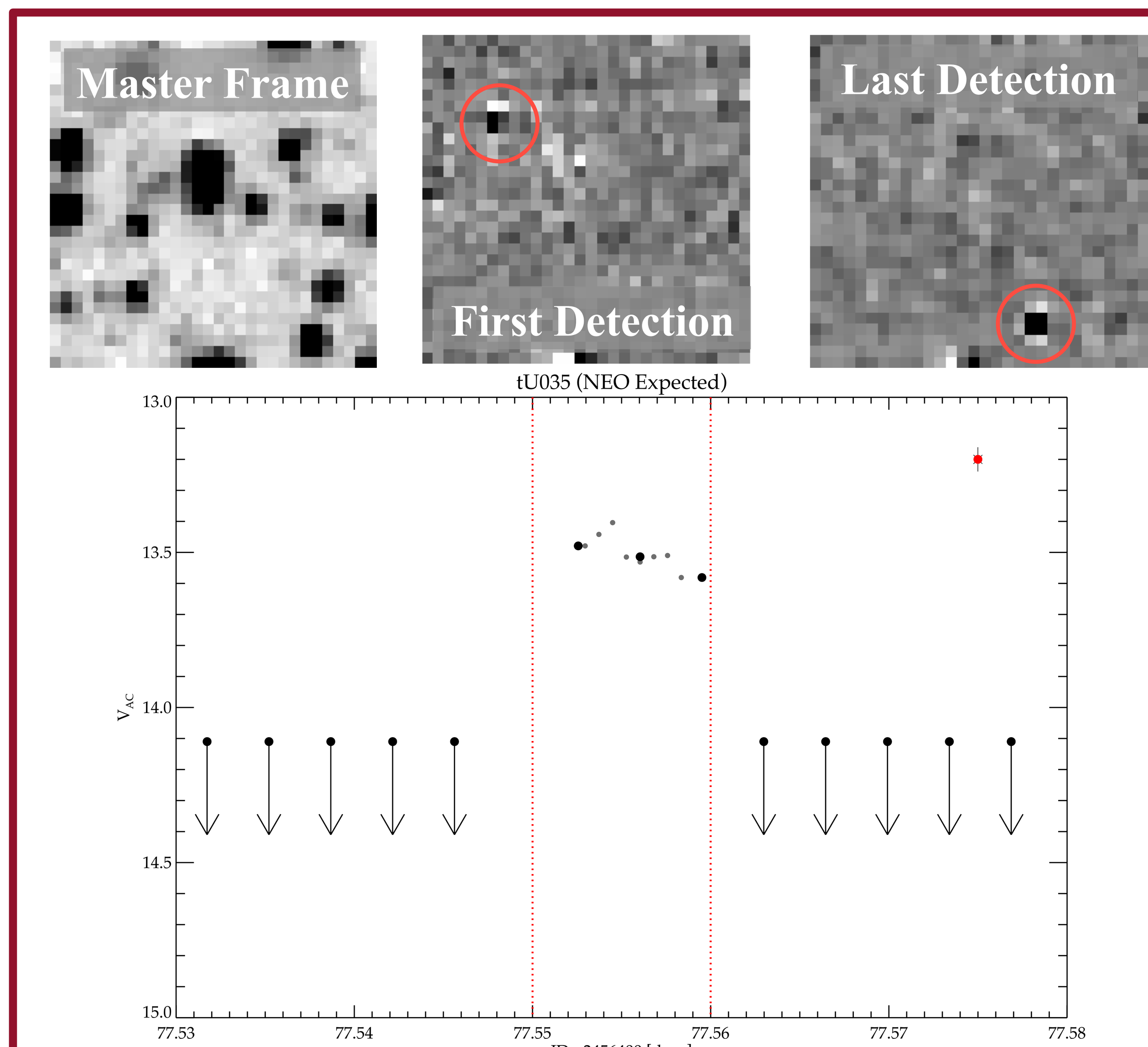


Figure 2: tU035 in Upper Scorpius (RA=15:59:18.0, Dec=-24:57:54) appeared to be in motion and a previously-known NEO (2001 UJ205) was expected in the FoV. Panels are identical to those in Figure 1.

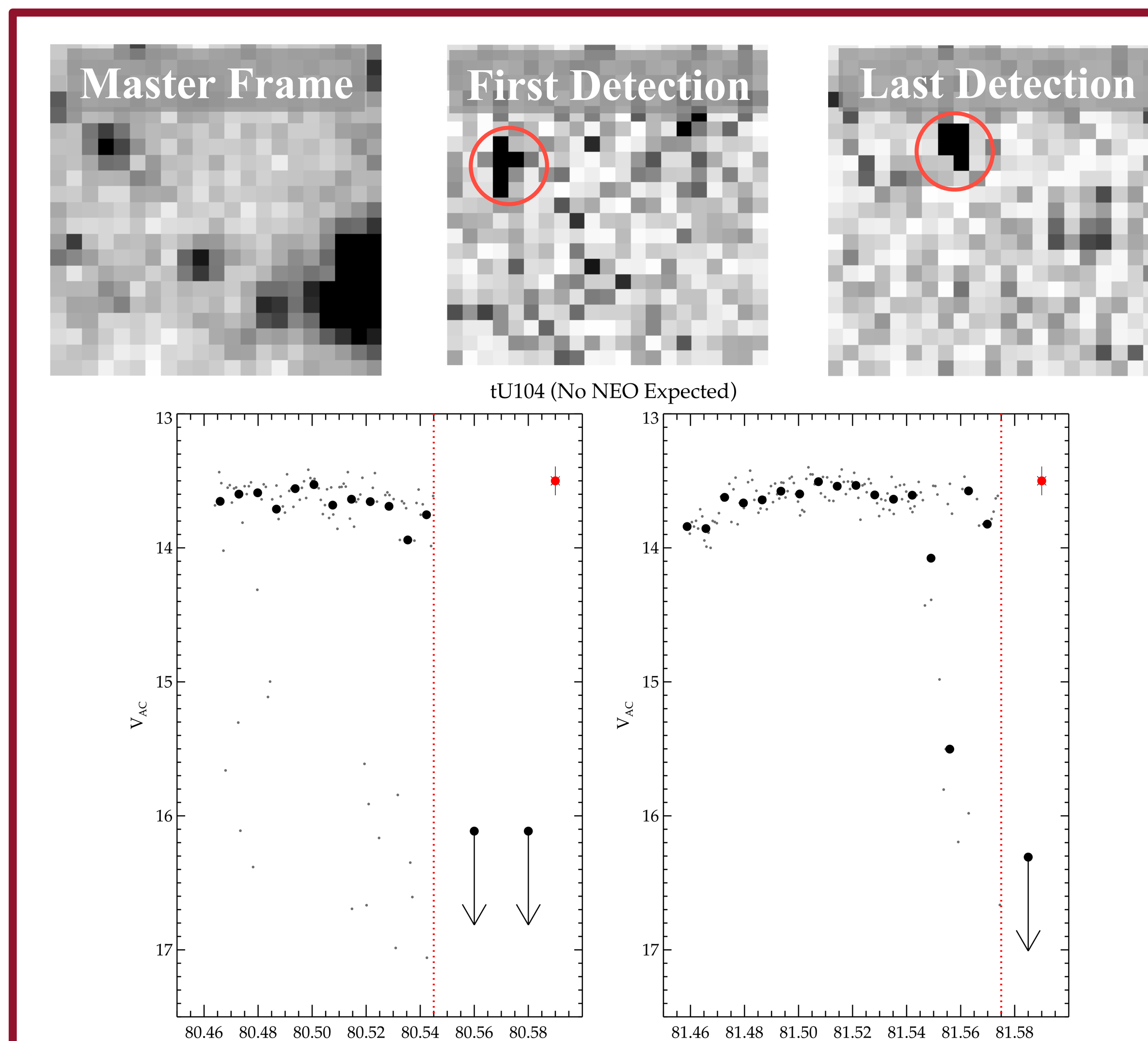


Figure 3: Object tU104 in Upper Scorpius (RA=15:56:27.8, Dec=-26:21:53) appeared to be in motion and was detected on two nights. No known NEOs were expected in the FoV. Panels are identical to those in Figure 1.

References: Oelkers, R. J. et. al, 2015, AJ, 149, 50O ◆ Southworth, J. et al. 2013, A&A, 557A, 119S ◆ Stetson, P. 1987, PASP, 99, 191S

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