AAVSO

Number 2
June 2022

AAVSO Meeting Abstracts

Abstracts of presentations made at meetings of
The American Association of Variable Star Observers

The American Association of Variable Star Observers
185 Alewife Brook Parkway, Suite 410, Cambridge, MA 02138, USA

The Journal of the American Association of Variable Star Observers

The Board of the American Association of Variable Star Observers 2021–2022

ISSN 2768-5225 (print)
ISSN 2768-5233 (online)

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Publication Information

AAVSO Meeting Abstracts is usually published twice a year, June and December, and contains Abstracts of presentations (oral and poster) made at AAVSO meetings. The AAVSO usually holds two meetings per year, but if it holds fewer or more meetings in a year, the number of *AAVSO Meeting Abstracts* published in a year will vary accordingly.

The submission window for inclusion in *AAVSO Meeting Abstracts* is the same as the window for submission of Abstracts for an AAVSO meeting; it will therefore vary from issue to issue. Those interested in giving a presentation at an AAVSO meeting should monitor the Meetings page of the AAVSO website (https://www.aavso.org/aavso-meetings) for relevant announcements regarding instructions and deadlines.

An author may not specify in which issue an Abstract is to be published; Abstracts will be published in the issue appropriate to the meeting at which the presentation was given, except under extraordinary circumstances.

AAVSO, 185 Alewife Brook Parkway, Suite 410, Cambridge, MA 02138, USA

Telephone: 617-354-0484
email: aavso@aavso.org
website: https://www.aavso.org

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Abstracts of Presentations Made at the 110th Annual Meeting of the AAVSO, Held in Somerville, Massachusetts, November 5–7, 2021

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Abstracts of Presentations Made at the 110th Annual Meeting of the AAVSO, Held in Somerville, Massachusetts, November 5–7, 2021

Gainers Under the Veil: High Mass Transfer and Thick Disks in the Semi-detached Binary System AU Mon

Antonio Armeni
Via Golino 27, Follonica 58022, Italy; anto.armeni10@gmail.com

AU Mon (HD 50846) is an eclipsing, double-lined spectroscopic binary caught in a stage of rapid mass transfer. It has many features in common with β Lyr, the prototype of such systems, such as a permanent thick accretion disk around an intermediate mass main sequence star, but is less extreme and more tractable. The orbital inclination of about 80° opens a direct line of sight toward the gainer and permits a study of its interaction with the accretion environment. Besides eclipses and other optical photometric modulation on the orbital period, 11.11 days, the AU Mon system shows photometric variability of around 0.25 mag on a timescale of about 37.5 times the orbital period (so is included among the Double Periodic Variables, DPV).

This work presents a multiwavelength spectroscopic study using the available archival data of the system: IUE low and high resoluton (1200–3200 Å) spectra in the UV range and optical spectra (from about 3700 to 9000 Å) from FEROS, HARPS, and SOPHIE.

New parameters have been obtained for the temperature and gravity of the gainer. There is evidence for nonaxisymmetric structures in the accretion disk, possibly connected with the impacting stream, and indications of mass loss from the system. The long term variability appears to be due to changes in the accretion disk structure and circumsystem environment rather than a simple magnetic cycle.

These results highlight the complex interplay between physical mechanisms that regulate the evolution of interacting binary stars.

Investigating the Science Capability of the Unistellar eVscope

Richard Berry
2230 SE Laura Lane, Dallas, OR 97338; rberry@wvi.com

The Unistellar eVscope is a popular addition to the observational astronomer's toolbox, with thousands of new-to-astronomy users. I undertook this work to determine the science capabilities of this novel instrument.

The eVscope is marketed as a recreational instrument, but technically it is a 114-mm f/4 reflector with a 1.3-megapixel CMOS sensor. The instrument is commanded via Wi-Fi link to a smartphone. The system features a computer-controlled alt-azimuth mounting. It can locate fields autonomously using on-board plate solving and then track and stack multiple short exposures to make deep-sky images, reaching 16th magnitude in 60 seconds of integration.

Using the eVscope, I observed the variable star XX Cygni for three hours and thirty minutes, capturing one complete cycle of variation. I uploaded the data stored in the eVscope to Unistellar and received 3,300 FITS format images in return. Using AIP4Win software, I performed differential photometry on these images, producing a well-defined light curve. I determined the time of maximum light by fitting a sixth-order polynomial to data points near the peak. I also performed astrometry on test images of Barnard's Star.

I find that the eVscope is as capable of producing science results equaling other telescopes of similar aperture. However, because the eVscope is extremely easy to use, the instrument has the potential to make photometry and astrometry available to a wider base of amateur astronomers, students, and schools.

Taking a Supergiant's Temperature

Tom Calderwood
1184 NW Mt. Washington Drive, Bend, OR 97703; tjc@cantordust.net

The Great Dimming of Betelgeuse is typically ascribed either to dust obscuring our view of the star, or to a drop in temperature causing the star to emit less light to begin with. A year after the event, professional astronomers are still wrestling with these options and even proposing combinations of the two.

The temperature of a late K or early M star is usually inferred from titanium oxide absorption features. This can be done via spectroscopy or narrow-band photometry, the latter method being within the reach of amateurs. These techniques will be explained, and the assorted and sometimes contradictory results for Betelgeuse will be reviewed.

The AAVSO Photoelectric Photometry Section is starting to experiment with the narrow-band method and it is hoped that we may contribute to the understanding of Red Supergiant physics–a topic of active research interest.

Detection and Study of the Multiplanetary System WASP-148

Loïc Capitaine
Chloé Gac
Anica Lekic
10, rue Bizet, Drancy 93700, France; anica.lekic@ipsa.fr

As part of our studies, we carried out a project focusing on the spectral study of stars and the links existing with exoplanets. In order to learn more about our Universe, observers nowadays are interested in planets outside our solar system. In this context, French astronomers discovered in 2020 an extrasolar system with two interacting planets revolving around the star WASP-148. In April of the following year, the French Astronomy Association (AFA) called the non-professional observers to take

part in scientific research; creating a participative campaign of observation, the association invites astronomy enthusiasts to help ongoing research on exoplanets.

The aim of this campaign was not only to validate the parameters such as the eccentricity, the inclination, and the planet's mass but also to determine the existence or not of a timing variation which could demontrate the presence of other planets around WASP-148; multiplanetary systems like this one are particulary interesting for the studies of their dynamics.

To detect a transit, it is necessary to measure the luminous intensity of the studied star: if a planet passes in front, its apparent brightness decreases slightly. Dynamics can also be studied in systems composed of more than one planet when transit-timing variations (TTVs) are detected. TTVs are particularly difficult to observe from the ground as transit timing depends on short-duration events easily perturbated by any kind of noise. We participated in this scientific work by analyzing the images obtained by members of the AAVSO in different observatories in the United States. After having used several software to correct the luminosity and determine the position of the wanted object (AstroImageJ, Siril, etc.), we then moved on to a photometric study using reference stars to calibrate the measurements. Thanks to our results, we were able to obtain significant light curves validating the transit of WASP-148b, one of the two planets orbiting around WASP-148. Our work has finally been shared with the AFA to feed their database.

These observations constitute the first detection from the ground of variations in timing for a resonant planetary system. The different observations of the system have prooven that the two planets WASP-148b and WASP-148c periodically find themselves in the same configuration after having performed a different number of orbits: the first one rotates four times faster than the second one, implying that the system approaches 4:1 resonance. In the coming months and years, the WASP-148 multiplanetary system will be the subject of numerous theoretical studies and additional observations, which will allow us to refine the measurements of its properties and to better understand its structure and evolution.

Sub-Classification of Type Ia Supernovae in the SDSS Supernova Survey

David Corliss
11580 Parkview, Plymouth, MI 48170; davidjcorliss@gmail.com

Ia supernovae play an important role in research due to their frequent use as standard candles. This makes it important to understand variations in the physical processes that can affect the observations used on light curves.

In this study, 81 supernova light curves in the SDSS-II survey data are divided into observationally distinct subsets of light curves using similarity analysis, a machine learning classification algorithm. As this method uses unsupervised learning to classify time series by their pattern over time, it is ideal for identifying previously unobserved subsets in the data. The analysis finds two subsets, one presenting a reversal of the decline in brightness in the near-infrared z filter about 30 days after the maximum, resulting in a secondary peak followed by another decline, and also greater brightness in the ultraviolet u filter. The other group of light curves does not show these features.

The observed differences between the two light curve subsets in the light curves are presumed to be driven by different physical processes. One subset shows increases in two of the filters, possibly indicated a difference in their physical properties relevant to their use as standard candles.

Removing Atmospheric Effects: An Alternative Approach

Matthew Craig
1104 7th Avenue South, Moorhead, MN 56563; mcraig@mnstate.edu

The availability of dozens of stars with high quality photometry from surveys like APASS in a wide-field CCD image makes it possible to remove atmospheric effects on an image-by-image basis by performing a fit of instrumental magnitudes to catalog magnitudes. We compare this approach with three other ways of removing atmospheric effects: using magnitude differences between the target and a set of comparison stars, calculating the relative flux of the target star to the flux of a set of comparison stars, and calculating extinction coefficients and transforms to a standard magnitude system. The approach proposed here performs well enough to recover exoplanet transits in bright stars. It also has the advantage of being easily reversible, in the sense that instrumental magnitudes can be recovered from the atmosphere-adjusted magnitudes. Finally, it is potentially useful for compensating for the increased atmospheric reddening that occurs with increasing frequency due to smoke in the summers in the continental United States.

Comparison Stars and Photometry for TrES-3b

Eli Gendreau-Distler
eli.gendreaudistler@gmail.com

Comparison stars, or comp stars, are used to perform differential photometry on the light of a transiting exoplanet's host star. Selecting appropriate comp stars is essential to producing accurate measurements of an exoplanet's transit. Ideally, most unsaturated comp stars near the host star would produce similar photometry for the same set of images. As part of NASA's Exoplanet Watch, 150 time-series images from a single transit of TrES-3b taken by the 0.4-m Las Cumbres Observatory (LCO) Global Telescope Network were reduced with version 1.6.0 of the Exoplanet Transit Interpretation Code (EXOTIC), a project of NASA JPL Exoplanet Watch. TrES-3b is a Hot Jupiter exoplanet with a short period of 31 hours (Bonomo et al. 2017). The same images were reduced nine times using different comparison stars identified by the AAVSO Variable Star Plotter (VSP). Each comp star produced a visually clean light curve, yet the resulting mid-transit times from the fitted light curves varied by nearly 20 minutes, a time span far too large to provide a meaningful indication of the mid-transit time accuracy.

To resolve this disparity, the images were subsequently reduced using alternative photometric techniques produced with Our Solar Siblings (OSS) Pipeline Photometry, such as source extractor. Source extractor photometry yielded mid-transit time values ranging approximately eleven minutes for the nine comp stars. After removing reductions with comp stars that were close to another star, the mid-transit times spanned just seven minutes. The dimmest of the comp stars, which was also the closest to the target, was removed to reduce the span to just four minutes. Crowded or dim comps are expected to have compromised photometry, even with otherwise high quality images, so the additional photometric scatter might have compromised the fit. Color disparity between each comp star and the target eliminated four additional comps. Perhaps the observed mid transit time variation with comp stars of different color occurred because of the changing differential brightness as a function of airmass during the course of the observation. Inconsistencies of results between EXOTIC and source extractor photometry eliminated two more, allowing the selection of a single comp star and reporting of a corresponding mid-transit time measurement for these images. Not surprisingly, the differential photometry of this comp star had the lowest standard deviation compared to the other eight comp stars. It is suspected that an ensemble comp would produce a similar mid-transit time to the selected comp star because the scatter of mid-transit times was not consistently skewed in either direction.

In conclusion, the wide range of mid-transit times calculated from the same data with different comp stars highlights both the importance and the difficulty of selecting comp stars. Although choice of comp star is not expected to make a noticeable difference in the mid-transit time provided all comp stars are stable, it made a considerable difference in the computed mid-transit time (up to 20 minutes in this study) across different photometric techniques. Consistency in the mid-transit times produced using a single comp star with multiple photometric techniques provides evidence that the comp star is a reliable baseline. By examining the color difference from the target and proximity to other stars (including the target) in addition to the consistency of mid-transit times across photometric techniques, the most reliable comp star can be identified.

Transatlantic Collaboration of Citizen Astronomers in Follow-up Exoplanet Detection: A Joint Observation of TOI 2031.01

Bruno Guillet
78 Rue des Potiers, Caen 14000, France; guilletbruno@yahoo.fr

Justus J. Randolph
Athens, GA; justusrandolph@gmail.com

Thomas M. Esposito
SETI Institute, Carl Sagan Center, Mountain View, CA 94043; Unistellar Corp., San Francisco, CA 94110; Astronomy Department, University of California Berkeley, Berkeley, CA 94720; espos13@gmail.com

Global networks of professional and citizen astronomers will play a significant role in meeting the growing need for follow-up observations of transiting exoplanets. Here, we demonstrate the feasibility of citizen astronomers coordinating efforts to detect exoplanet transits with an example of a joint, two-telescope, transatlantic observation of TESS planet candidate TOI 2031.01. This type of coordination mitigates constraints set by visibility from a single site, thus making more transits observable from the ground.

Two citizen astronomers—one located in France and one located in the United States—connected through the Unistellar Network. They used the Swarthmore Transit Database to identify a target and plan the observation. Specifically, each citizen astronomer observed complementary parts of a transit by the hot Jupiter TOI 2031.01 on November 18, 2020, using identical 4.5-inch Unistellar eVscopes. Data were reduced using the SETI Institute's custom Python pipeline and the individual data sets were combined to create a complete light curve. The citizen astronomers also independently reduced the data using EXOTIC. Transit parameters including mid-transit time and depth were estimated via modeling by astronomers at SETI and Unistellar, with the light curves later submitted to the AAVSO Exoplanet Database (https://app.aavso.org/exosite/).

The data showed a positive, high signal-to-noise ratio detection of TOI 2031.01. The time of mid-transit was consistent with a prediction based on the TESS ephemeris, being just 6.1 ± 3.4 minutes later than predicted (1-σ uncertainty). In summary, we have provided evidence of the feasibility of citizen astronomers' ability to successfully select, coordinate, and observe exoplanet transits across continents.

Characterizing δ Scuti and γ Doradus Variable Stars in the Kepler "Superstamp" Field of Open Cluster NGC 6819

Joyce Ann Guzik
Los Alamos National Laboratory, Los Alamos, NM E-mail: joy@lanl.gov

Andrzej Baran
ARDASTELLA Research Group, Pedagogical University of Cracow, Poland; Embry-Riddle Aeronautical University, Department of Physical Science, Daytona Beach, FL

Sachu Sanjayan
ARDASTELLA Research Group, Pedagogical University of Cracow, Poland; Centrum Astronomiczne im. Mikołaja Kopernika, Warsaw, Poland

Peter Nemeth
Astronomical Institute of the Czech Academy of Sciences, Czech Republic; astroserver.org, Malomsok, Hungary

NGC 6819 is an open star cluster in the constellation Cygnus discovered by Caroline Herschel in 1784. NGC 6819 is about 2.4 billion years old (half the age of the Sun) and is about 8000 light years away. This cluster was in the NASA Kepler spacecraft continuous field-of-view from 2009 to 2013. The central part of the cluster was observed during these four years in 30-minute cadence photometry, providing a unique long time-series high precision data set for asteroseismology. Studying clusters is advantageous for asteroseismology, because the cluster members presumably formed together and have a common age and element abundances, providing additional modeling constraints.

Since the cluster is younger than the Sun, the stars at the cluster main-sequence turnoff are somewhat more massive than the Sun, near the expected mass range for γ Doradus-type pulsating variables, which pulsate with gravity mode periods of about one day. This cluster also contains "blue straggler" stars, i.e., stars on the main sequence above the cluster turnoff that should have already left the main sequence to become red giants. Blue stragglers are believed to have formed either via stellar mergers or mass transfer from a companion sometime in the star's past. The NGC 6819 blue stragglers have the right temperatures to show δ Scuti-type pulsations, i.e., acoustic-mode pulsations with periods of around two hours. If pulsations are found, stellar modeling and asteroseismic analysis may help to better understand the origins of these blue stragglers.

We present light curves and pulsation frequency analyses for δ Scuti and γ Doradus star candidates for five confirmed cluster members. Four of these stars are blue stragglers and one is near the cluster turnoff. We searched for variations in each superstamp pixel and designed custom masks for each target. We used simple aperture photometry (SAP) for the light curves, and prepared final light curves using our custom scripts and PyKE software. The membership probabilities were derived using astrometry data from Gaia Early Data Release 3. Two of these five stars show a rich spectrum of δ Scuti pulsation modes, with 236 and 84 significant frequencies identified, respectively, while two stars show mainly low-frequency modes characteristic of either γ Doradus pulsations or global Rossby modes. The fifth star has an unusual spectrum including several harmonics of two main frequencies, which may be best explained by either a four-star system with two eclipsing binaries, or an eclipsing binary with light contamination from an unidentified binary in the field. We also briefly summarize pulsation properties for seven additional stars in the superstamp field that are non-members.

What's Happening with V838 Mon

Arne Henden
106 Hawkins Pond Road, Center Harbor, NH 03226; ahenden@gmail.com

V838 Mon (Nova Mon 2002) went into outburst in January of 2002. It rose to a peak brightness of around V = 6, and faded through the spring and summer, reaching a minimum magnitude of 16 by the end of the year. Since then, it has been slowly rising in brightness, and now is around V = 13. The nova was extremely peculiar, being one of the reddest on record, with several theories as to its origin (the most likely is a binary merger of two stars). This paper will highlight the original outburst, give some recent information regarding distance, and discuss theories as to why this star is still brightening, two decades after the outburst.

RSGs are Just Plain Cool: An Observing Program and Online Tool

Lauren Herrington
P.O. Box 434, 30 N. Main Street, Ketchum, OK 74349; lauren@tiedyeastronomer.com

Characterized by high masses, cool temperatures, and enormous diameters, red supergiants (RSGs) represent a brief yet important extreme of stellar evolution. RSGs are variable stars, and show spectroscopic changes as well as photometric ones, but their periods are long and their behavior irregular, making it difficult for researchers to acquire spectroscopic observations which cover a long enough time span to study this variability in detail. Fortunately, this is an area in which anyone with a spectrograph can help.

To assist with the construction of an observing program, I used Python to combine several sources from the literature and create an interactive online catalog of RSGs. The primary function of this catalog is as a target selection tool for spectroscopic observations, but it includes many other features which will be of interest to anyone who enjoys learning about RSGs.

My hope is that the use of this new online tool will inspire fresh interest in RSGs, and result in an increase in observations, both spectroscopic and photometric. Through collaboration with our fellow observers, we have the potential to grow within the AAVSO Spectroscopy Database, AVSpec (https://app.aavso.org/avspec/search), a library of RSG spectra which is dense in coverage and extensive in time, offering researchers an opportunity to unlock the secrets of RSGs through detailed spectroscopic analysis, and producing a historical record which will become of enormous scientific interest as these bright stars continue to evolve and explode as supernovae.

Characterizing Four Subsets of Kepler O'Connell Effect Binaries

Matthew Knote
325 E. University Boulevard, Apt. 75, Melbourne, FL 32901; mattknote@yahoo.com

We have used the Kepler Eclipsing Binary Catalog to better understand the enigmatic O'Connell effect—the presence of unequally bright maxima in eclipsing binary light curves—by selecting a sample of 258 KEBC systems showing the phenomenon (https://www.aavso.org/oconnell-effect-target-list). In the process of analyzing these systems, we have identified four classes of systems that stand out from others in our sample, either because of the unusual features their light curves display or the character of their component stars. The first class of 59 systems displays strong temporal variation in their light curves. The second class of ~24 systems features eclipse minima that are asymmetric. The third class includes ~9 systems showing a concave-up region between the eclipse minima, giving the light curve the appearance of an eclipsing binary signal superimposed on a sinusoid. The final class consists of the sole white dwarf in our sample.

Our goal is to determine how these four classes' characteristics differ from the rest of our sample. To that end, we will run statistical tests between systems belonging to each class with the rest of our sample. These tests include the K–S test to determine if the two samples are drawn from the same population, and Spearman's ρ coefficient to determine correlations between the characteristics. Ultimately, the analysis of these tests' results provides insight into the similarities and differences of these classes compared to our sample. This insight gives a clearer picture of what physical processes occur in these systems and additional observational signatures that may be related to the O'Connell effect.

Orbital Mechanics Design to Maximize Satellite Service Time for Earth-Based Regions of Interest

Krithi Koodli
kkoodli936@gmail.com

In addition to satellite-based Internet services such as Starlink and OneWeb, the advent of cubesat and rideshare programs has made it easier for student-led groups and citizen science efforts to launch satellites for astronomical and Earth-based imaging. Many of these satellites carry instruments for Earth observation, such as sea level mapping, recording the rate of deforestation, and polar ice cap melting. Through orbital mechanics with vector analysis and computing, my project develops a method of maximizing the observation time, i.e., the time that a satellite spends over a user-specified region on the Earth's surface. Although the primary focus of this project is Earth observation satellites, a similar approach and some similar instrumentation could be used on cubesats for astronomical imaging. This will become especially important when the Hubble Space Telescope is eventually decommissioned, since cubesats' positions above the atmosphere makes them ideal for measuring photometry in the ultraviolet region of the spectrum. Moreover, as cubesats can be launched through rideshares with commercial space missions, their cost puts them within reach of college projects.

I developed 3-D vectors for the position of a target region on Earth's surface, as well as for the position of the satellite, based on the satellite's semi-major axis, eccentricity, longitude of ascending node, inclination, and argument of perigee. I also developed geometric models to represent the shape of the target region. I then performed trigonometric vector computation in Python to determine a specific angle, ω, between these two vectors that would result in the satellite's being within viewing distance of the target. Given ω, I determined the fraction of the orbit that was spent in viewing distance, and by accounting for precession and the Earth's rotation, the total observation time over the course of a satellite's lifetime. Through iteration over all possible orbital elements, I computed a unique orbit that maximizes the observation time for any given target on the surface of the Earth. I confirmed that as expected, my algorithm yielded geostationary and polar orbits for targets on the equator and the North Pole, respectively.

There are three main conclusions that can be drawn from my project. First, for Low Earth orbits, an inclination that is similar to the target's latitude is necessary to ever be within viewing distance of the target. Although this is true for higher orbits as well, those orbits have a wider range of inclinations that allow viewing of the target. Second, the initial longitude of the ascending node as well as the argument of perigee have little effect on the observation time, as precession and the Earth's rotation will eventually move the satellite and target out of synchronization. Third, an eccentric orbit with a low perigee and high apogee yields the highest observation time when paired with the above factors, as this allows the satellite to move slower and thus spend more time viewing the target region. Understanding the constraints and instrumentation of earthward-looking satellites could have applications in many astronomical studies, including those that take advantage of cubesats' positions above the atmosphere to look skyward.

To Everything, Turn, Turn, Turn—Or Not: Misclassified ASAS-SN Rotators

Kristine Larsen
286 Francis Street, New Britain, CT 06053; larsen@ccsu.edu

The ASAS-SN (All-Sky Automated Survey for Supernovae) project used machine learning techniques to identify, characterize, and classify over 400,000 variable stars. However, as noted by John Percy and collaborators, the associated automated light curve analysis algorithm has difficulty discerning the complex periodicities and subtypes of pulsating red giants.

Rotating variables are also known for their complex behaviors, including varying amplitudes and mean magnitudes and periodicities that are not precisely defined (due to changing numbers and sizes of spots). It is therefore likely that the ASAS-SN algorithm will likewise encounter difficulties in classifying and analyzing periods for rotating stars. This study utilized VStar software to analyze the ASAS-SN light curves and phase plots of 96 stars classified as general rotator (ROT) by ASAS-SN. These stars were selected due to their having Argelander letter/V-number names in VSX, suggesting that their behavior is more likely to be well-known with reasonable confidence than stars that are known only by their ASAS or ASAS-SN names.

While slightly more than half of the stars were already classified as rotating stars in VSX, all had defined sub-classes (e.g. RS, BY, TTS, etc.) in VSX that were not discernable by the ASAS-SN algorithm. Roughly one third of the entire sample was found to have erroneous ASAS-SN periods (largely multiples of the VSX period). A quarter of the sample was found to be Cepheids or RR Lyrae stars, an interesting finding, as a critique of the original ASAS catalog algorithm was the number of rotating stars it mis-classified as Cepheids. Apparently the converse is also true.

The ASAS-SN public light curve interface currently includes a warning about potential blending of star data in crowded fields and limitations of the "saturation correction procedure" for data points brighter than 10th-11th magnitude. However, a close study of the non-rotating stars in this sample classified as rotators by the ASAS-SN automated system suggests other properties of light curves that confound the algorithm, information that could be of use when considering datasets of less-well studied ASAS-SN-discovered variables in VSX.

Near-Infrared Spectroscopy of (3122) Florence and (357439) 2004 BL86 During Near-Earth Encounters

Skylar Larsen
2453 Avenida Canora, Alpine, CA 91901; skylarlarsen@gmail.com

Near-Earth asteroids (NEAs) are widely thought to be the source of water and organics delivered to early Earth. Additionally, some NEAs, including Florence and 2004 BL86, are considered potentially hazardous objects (PHOs), and they could make threateningly close approaches to Earth.

The NEAs (3122) Florence, an S-type trinary asteroid, and (357439) 2004 BL86, a V-type binary asteroid, flew by Earth in 2017 and 2015, respectively. We conducted near-infrared (NIR) spectroscopic observations of these two NEAs as they flew by Earth to investigate their surface compositions; in other research, variable star astronomers use similar spectroscopic techniques of different wavelengths to study multiple features of variable stars, including but not limited to radii, surface temperature, and apparent brightness. Our hypothesis is that Florence and 2004 BL86 are featureless in the 3-μm band and do not possess features indicating water or organics; as S-type and V-type asteroids they are seemingly not carbonaceous/primitive objects.

We used the Infrared Telescope Facility (IRTF) located at Mauna Kea, Hawaii, to measure long wavelength cross-dispersed (LXD) spectra of both Florence and 2004 BL86 with SpeX mode. The measured spectra wavelength ranged from 1.67 to 4.2 μm, which includes the 3-μm feature attributed to water/hydroxyl. The data were processed and reduced using Spextool, an IDL based spectral reduction program provided by the IRTF. To model and correct the data's thermal emission component (beyond 2.5 μm) and isolate the desired reflected component, we used the Near-Earth Asteroid Thermal Model (NEATM). The band depth at approximately 2.90 μm was calculated and used as a proxy to whether or not water was present.

Preliminary results suggest that Florence potentially exhibits a 3-μm band feature indicating the presence of water/hydroxyl, while 2004 BL86 lacks this feature.

In this investigation, we will explore the possible causes of the 3-μm band feature detected on Florence. There are multiple possible and/or theorized explanations for the detection of water/hydroxyl on small solar system objects, including the presence of endogenic hydrated minerals on their surfaces, and exogenic sources such as solar wind implantation or carbonaceous impactors. The presence of water/hydroxyl on Florence is unexpected and relevant; trace amounts of water may be found on objects never considered to host this volatile compound. This analysis has relevance to the effect of solar wind interactions on celestial bodies.

Historical Evidence for the Failure of Occam's Razor in Understanding New Types of Astronomical Sources

Tom Maccarone
Texas Tech University, Department of Physics and Astronomy, Box 41051, Texas Tech University, Lubbock, TX 79409-1051; thomas.maccarone@ttu.edu

I aim to determine what lessons can be learned from historical classification of various classes of transient and variable objects that may help us in classifying and understanding new classes of transient and variable objects. As new windows on the variable and transient Universe have opened up, and continue to open up, with the advent of wide field variability surveys in the optical and radio bands as well as gravitational waves, new classes of astronomical transients have already been found in great numbers, and this trend can be expected to continue. Often when the first member of a new class is explained, astronomers will invoke Occam's Razor and argue that all other members of the class must have the same mechanism. I have looked at some historical examples of new classes of transients, with the main emphasis on discussion of novae and gamma-ray bursts. In both these cases, and several others, multiple mechanisms explain the class as originally defined, and the classes have been broken into multiple subclasses. I will discuss also some cases where a single mechanism has explained a new phenomenon. I then consider the circumstances under which a new class of transients is likely versus unlikely to be broken into many subcategories. As a corollary, I will consider the situation by which many theoretical models to explain transients have been largely correct, but applied to the wrong class of observational data. I will also highlight some of the ways in which AAVSO observers can contribute to helping identify subclasses of transients in the era of large professional variability surveys.

Spectroscopic Analysis of Four Dynamo-driven Chromospherically Active RS Canum Venaticorum Binary Stars

Enza Magaudda

The RS Canum Venaticorum stars are close binary systems with tidal synchronization of spin and orbital motion. They display the indicators of strong magnetic dynamos, including starspots, coronal X-ray, emission, and flaring.

I carried out and I present an analysis based on high cadence and high spectral resolution spectroscopy of four canonical RS Canum Venaticorum binary systems (AR Lac, Z Her, V711 Tau, and UX Ari), to show the effect of including the stellar activity on the spectral formation and the derived property of the systems.

From the computed radial velocity (RV) profiles for all targets I found the stellar masses for both components and possible chromospheric structures visible in the line profiles. To analyze the activity of each stellar component I separated the two contributions and computed a grid of synthetic NLTE spectra with the PHOENIX model atmosphere code, using a scaled solar chromosphere attached to a photospheric model, and compared these synthetic data to new high-resolution phase resolved visible-range (3700-9000 Å) data obtained in 2017 from July to mid-November with the HEROS spectrograph. I concluded that while AR Lac and Z Her show weaker activity with a relative emission strength in Ca II, H-K, UX Ari and V711 Tau are very active, and they show a shift between the chromospheric and photospheric velocity curves. The Ca II line profiles revealed a possible extended structure, which moves with a different velocity amplitude than the center of mass and is likely a prominence at high latitude.

Finally, I derived new systemic parameters and also confirmed that Z Her is the only system showing an inverted mass ratio. Assuming no mass and angular momentum loss from the system, the mass transfer event for Z Her probably occurred at the beginning of the subgiant branch.

A Glimpse into the Life and Works of Radha Gobinda Chandra, the Village Astronomer from the Indian Sub-continent

Dipankar Maitra
351 Willow Street, Mansfield, MA 02048;
maitra_dipankar@wheatoncollege.edu

Born in a small village called Bagchar in undivided India (currently in Bangladesh), Radha Gobinda Chandra (1878–1975) became one the major contributors of variable star observations to organizations like the AAVSO and the British Astronomical Association. If he lacked higher education (having never gone to college), he more than made up for it through dedication and meticulousness. Between 1919 and 1955 he contributed an astonishing 51,850 visual observations to AAVSO. These observations were primarily made using either a 3-inch refractor that Chandra bought with all his savings, or a 6.25-inch refractor loaned to him by AAVSO.

While most of Chandra's own papers and correspondence were lost when he had to relocate after the partition of British India into India and East and West Pakistan, most of the letters and original data submission forms sent by him to AAVSO have been well preserved in the AAVSO archives. Over the past few months I have been digitizing these documents, especially his correspondence and observing report summaries. These correspondences, especially with the early Recorders/Directors of AAVSO Leon Campbell and Margaret Mayall, reveal interesting insights about his work, his scientific temperament, and other events that shaped his life.

I will present a summary of these historical documents, and share what we have learned about Chandra and his remarkable journey through the stars spanning more than three decades.

How is T Coronae Borealis Getting Ready for Its Next Nova Eruption?

Koji Mukai
8132 Quill Point Drive, Bowie, MD 20770-4370; Koji.Mukai@umbc.edu

N. Paul M. Kuin
Mullard Space Science Lab (UCL), Flat 2, Dudley House, High Street, Cranleigh, Surrey GU6 8AE; npkuin@gmail.com

Gerardo J. M. Luna
IAFE/Conicet, Casilla de Correo 67-Suc. 28, Buenos Aires 1425, Argentina; gjmluna@iafe.uba.ar

Jennifer L. Sokoloski
Columbia Astrophysics Lab, 526 West 113th Street, Apt. 43, New York, NY 10025; jeno@astro.columbia.edu

The 2021 eruption of the recurrent nova, RS Ophiuchi, has provided a lot of excitement for AAVSO observers and professional astronomers alike. T Coronae Borealis is a similar system—both T CrB and RS Oph are symbiotic stars and confirmed recurrent novae—and can reach magnitude 2.0 at the peak of its eruption. Given that the previous eruptions were seen in 1866 and 1946, a naive extrapolation would suggest its next eruption will be in or around 2026. Many observers are preparing for this anticipated spectacle—but we shouldn't just observe it during eruption. We can learn a lot by also studying T CrB as it approaches its next eruption.

Nova eruptions are powered by nuclear fusion of accreted material on the white dwarf surface. A key question in recurrent nova research is how much matter is accreted to fuel these eruptions. The accretion rate can be estimated using UV and X-ray observations. Optical data indicate that T CrB began to brighten starting in 2014, in a manner strikingly similar to the historical brightening observed during 1938–1945, just before the 1946 eruption. By combining insights gained from the optical monitoring and occasional UV and X-ray observations, we (Luna *et al.* 2020, *ApJLett*, **902**, L14) have suggested that T CrB accumulates much of the fuel for nova eruptions during these high states, lasting for about a decade each. We plan to continue our high energy observations using Swift, XMM-Newton, and HST as often as the time allocation committees let us. In the meantime, we are counting on the AAVSO observers to provide densely sampled optical light curves so that we can track the accretion rate until T CrB erupts again as a spectacular nova.

Search for the Binary Period in the Recent Nova V1369 Cen

Gordon Myers
5 Inverness Way, Hillsborough, CA 94010; GordonMyers@hotmail.com

Frederick M. Walter
Stony Brook University, Department of Physics and Astronomy, Stony Brook, NY 11794-3800; frederick.walter@stonybrook.edu

To make sense of the sheer variety of nova types, we need to understand the underlying binary system (orbital period, inclination, masses, magnetic field, etc.) in a wide range of novae. Here we report on a search for the orbital period of a recent nova, V1369 Cen (N Cen 2013). V1369 Cen, one of the brightest novae of the current millennium, was a slow, dust-forming nova that is currently in the nebular phase. In this phase, the envelope is optically-thin, and the underlying binary system is, in principle, observable.

We analyzed TESS data (JD 2458596–2458623; 5.4 years after maximum), and obtained seventeen nights of time-series ground observations over 15 months (JD 2458878–2459331; 6.1–7.4 years after maximum), using a Planewave 17-inch CDK telescope located at Siding Spring, Australia. Over this interval the V magnitude of the nova faded from about 13.4 to 13.7. The TESS data, spanning 27 nearly contiguous days, show a clear 0.15654-day sinusoidal modulation. The ground-based data suggest a somewhat longer 0.16477-day modulation, but with significant aliasing. The amplitude of the modulation was ~ 0.01 mag, with the significance fading with time.

We will discuss possible reasons for the discrepant periods, from true changes in the period to limitations in a poorly-sampled data set. We will suggest observing techniques that may mitigate against the uncertainties that plague this kind of observation.

Finally, these data have implications for the progenitor binary system. Observations of bright post-novae, while challenging, can contribute significantly to our understanding of the nova phenomenon.

Daylight Photometry of Betelgeuse at Conjunction with the Sun

Otmer Nickel
Zum Schollberg 11, Mainz D55129, Germany; otmar.nickel@web.de

Betelgeuse is a variable star of great astrophysical interest with many observations in the AAVSO International Database. There is an annual gap of 3 to 4 months, where Betelgeuse is close to the sun and is not observable at night. This gap could be filled with daylight observations, because the star is bright enough to be imaged with small telescopes at daytime.

Daylight photometry of Betelgeuse was taken with an amateur telescope equipped with an interline-transfer CCD camera and photometric V and neutral density filters. The method used is a variation on ensemble photometry (using other bright daytime stars), and involves large stacks of short exposures. This method provided V magnitudes of Betelgeuse with calculated errors of 0.020±0.008 mag from February to April 2021. The results compared favorably with contemporaneous nighttime photometry. From May to July 2021, at the closest distances to the sun, the photometry of Betelgeuse could be continued with mean errors of 0.040 ± 0.013 mag.

CCD photometry in daylight with amateur equipment is possible with an acceptable accuracy. Observers with suitable equipment are encouraged to contribute such observations of Betelgeuse to fill the light curve gaps in the future.

Unanswered or Intriguing Questions about Low-Mass Pulsating Yellow Supergiant Stars

John R. Percy
Sara Haroon
Department of Astronomy and Astrophysics, University of Toronto, Toronto, ON M5S 3H4, Canada; john.percy@utoronto.ca

Low-mass pulsating yellow supergiants include W Virginis stars (Population II Cepheids), RV Tauri (RV) stars, which are characterized by alternating deep and shallow minima, and SRd stars, which are semiregular. These stars appear to be in interesting stages of evolution, either executing "blue loops" from the asymptotic-giant branch (AGB) in the Hertzsprung-Russell diagram, or making the final transition from AGB star to white dwarf. We have recently carried out a study of the variability of 14 of these stars in detail, and 27 in less detail, using AAVSO visual data, and the Fourier and wavelet routines in the AAVSO time-series package VStar*. The results simply emphasized how much we still do not know about these stars. Here, we list some still unanswered or intriguing questions about their behavior. As usual, more observations and more analyses are needed.

- Why are SRd stars semiregular rather than regular like W Virginis stars?
- RV stars can be modelled as having two pulsation periods in a ratio of exactly 0.5, but why do there seem to be few if any SRd stars with two pulsation periods in some other ratio? Or have we not yet found them?
- There are RV stars with "long secondary periods" (classified as RVb) but why do there seem to be few if any SRd stars with long secondary periods? Or have we not yet found them?
- Why do the pulsation amplitudes of RV and SRd stars vary non-periodically by up to a factor of ten, on time scales of 20 to 30 pulsation periods?
- These stars are in relatively fast stages of evolution. Can evolutionary period changes be detected? What is the potential for using wavelet analysis (within VStar), rather than the usual (O–C) analysis to try to do this?
- The period changes in these stars seem to be dominated by random cycle-to-cycle fluctuations, as in pulsating red giants. What causes these fluctuations?

We thank the AAVSO (www.aavso.org) for making available the International Database of observations, and the VStar time-series analysis. We also thank the University of Toronto Work-Study Program for support.

*Link to the project: Percy and Haroon (2021) https://tspace.library.utoronto.ca/handle/1807/106550

Neutrinos: The Other Light from Stars

Barry Pointon
7438 Broadway, Burnaby, BC V5A 1S4, Canada; barry_pointon@bcit.ca

Neutrinos are everywhere. They are produced by nuclear processes, from fission in reactor cores to decays in humble bananas. Observing neutrinos emitted by astrophysical objects, such the sun and supernovae, has opened a new window on the universe, unobscured by atmospheres and interstellar dust. Neutrino observatories are enormous, with exotic locations such as beneath a mountain in Japan or under the ice at the South Pole. In this talk, I will present an brief overview of neutrino astrophysics. I will also describe an opportunity for astronomers everywhere to become involved in a global network of neutrino observatories (SNEWS) in the coordinated effort to prepare for the next great astronomical event—a galactic supernova.

Project PANOPTES: A Citizen Science Project to Discover Transiting Exoplanets

Preethi Krishnamoorthy
Subaru Telescope, NAOJ, Hilo, HI; preethi524@gmail.com

Wilfred Tyler Gee
Macquarie University, New South Wales; wilfred.gee@students.mq.edu.au

Josh Walawender
W. M. Keck Observatory, Waimea, HI; joshwalawender@me.com

Joshua Liberman
Colgate University, Hamilton, NY

Jeff Bary
Colgate University, Hamilton, NY

Olivier Guyon
University of Arizona, Tucson; Subaru Telescope, NAOJ, Hilo, HI

PANOPTES team

PANOPTES (Panoptic Astronomical Networked Observatories for a Public Transiting Exoplanets Survey) is a citizen science project that helps to build and maintain a collaborative, worldwide network of robotic telescopes. The PANOPTES units are fully automated and work in a survey mode on the night sky to detect nearby transiting exoplanets. The units are designed to be low-cost, easy to build with a clear set of instructions, and constructed with readily available off-the-shelf hardware. PANOPTES is a multifaceted project that requires and trains the builders in a wide range of skillsets, such as building hardware, software to control the unit, data analysis, and follow up science study. Hence, the project benefits from having diverse community participation. PANOPTES units, so far, have been built by school students, graduate students, astronomy enthusiasts, and citizen scientists from different countries. There are currently 24 units in various stages of deployment across the world, with at least two more units under construction. The light curves from different PANOPTES units will be combined to improve sensitivity and to build a more continuous light curve. The project's success relies directly on the number of units across the world.

PANOPTES units use commercial Canon DSLR cameras with a medium telephoto lens to carry out wide-field imaging, with a field of view of $10° \times 15°$. This allows PANOPTES to image a large area of the sky at a reduced precision to produce a catalog of candidate transiting exoplanets that would have the potential for follow-up studies with large telescopes for exoplanet characterization. However, DSLRs are not designed for traditional photometry and hence their Bayer arrays do not directly correspond to the standard astronomical filter bands. The real challenge is the complex interaction between the Bayer color array and the star images, yielding large errors with conventional photometry approaches. We have resolved this issue with a custom algorithm, now yielding percent-level photometric precision on individual frames. We are currently working on creating a standard magnitude system for PANOPTES photometry that will allow us to combine the light curves from different units.

While the focus of Project PANOPTES is to find transiting exoplanets, the units can play a significant role in observing transient events, variable stars, comets, or be used for wide-field astrophotography. Some of our immediate goals are to standardise the PANOPTES photometry, combine the light curves from different units, and upload our observations of variable stars and exoplanets to the AAVSO International Database (https://www.aavso.org/aavso-international-database-aid) and the AAVSO Exoplanet Database (https://app.aavso.org/exosite/), respectively. In this talk, we will give you an overview of the project, its scientific goals, hardware and software components, data acquisition and reduction, science products, community reach, challenges, and plans.

Measurements of Transiting Objects and Variable Star periods in the Age of Large Surveys

Brett Schulz

Maxibillion Thompson
519 Voyageur Road, Ely, MN 55731; maxibillionthompsonmusic@gmail.com

Matt Craig
1104 7th Avenue South, Moorhead, MN 56563; mcraig@mnstate.edu

We report on the measurement of a potential low-amplitude variable star in the field of the transiting exoplanet KELT-16b, on the importance of including survey data when measuring the period of variable stars, and on the timing of a transit of the object KELT-1b using the Paul P. Feder Observatory at Minnesota State University Moorhead. We report on our observations of a potential transiting system in the field of KELT-16b, Gaia DR2 1864883699097368448, which was found to exhibit transit-like behavior in a recent paper (Brossard and Kaitchuck 2021) and

which does not appear in surveys, such as ZTF, sensitive enough to detect its small change in magnitude. We serendipitously had observed the field in 2018 and re-observed it in 2021. We discuss the importance of including available survey data along with one's own data when measuring and reporting a period update of a variable star, using examples from the field of KELT-16b. The transiting object KELT-1b was discovered in 2012, and the period was first revised in 2015, and most recently in 2017. We observed the difference between the calculated and observed time of transit for the 2017 period. We also briefly summarize our analysis techniques.

Differential Dark Residuals (DDR)—A New Characterization of CMOS Camera Performance

Gary Walker
114 Cove Road, West Dennis, MA 02670; bailyhill14@gmail.com

With the demise of CCD chips, CMOS cameras have made considerable inroads into astro imaging and photometry. Along with this new technology has come a plethora of new options and techniques. Setting the gain, the offset, and using stack on the FLI and StackPro are among them. The author has developed a new test for evaluating these options called Differential Dark Residuals (DDR), which appears to be more important than read noise and dark current in the performance of CMOS cameras. Test results of many popular models are presented along with some surprises relative to cost. The author concludes that Differential Dark Residuals is a significant indicator of camera and photometry performance, and hopes that DDR stimulates designers and manufacturers to develop better equipment, resulting in better photometry for the community.

ODYSSEUS: A Coordinated Campaign to Study Accretion onto Pre-main Sequence Stars

Frederick M. Walter
Stony Brook University, Department of Physics and Astronomy, Stony Brook, NY 11794-3800; frederick.walter@stonybrook.edu

In anticipation of the eventual loss of the ultraviolet spectroscopic capabilities of the Hubble Space Telescope (HST), the Space Telescope Science Institute is undertaking a two-year program called ULLYSES (Ultraviolet Legacy Library of Young Stars as Essential Standards). Many of the targets have been scheduled simultaneously with TESS observations. Part of the ULLYSES program is focused on low mass pre-main sequence stars (the T Tauri stars). ODYSSEUS (Outflows and Disks around Young Stars: Synergies for the Exploration of ULLYSES Spectra) is a program designed to obtain supporting observations needed to properly interpret the HST UV spectra of the T Tauri stars. An important part of this program is photometry supplied by AAVSO observers, and through the AAVSOnet robotic telescopes.

Four T Tauri stars are being monitored extensively with HST; there are single HST observations of another 60 targets to sample a wide range of stellar masses and accretion rates. Because T Tauri stars are highly variable, contemporaneous optical photometry is crucial to knowing the state of the system at the time of the HST observations (is it brightening or fading? is it in a deep absorption dip, or flaring?). Calibrated photometric colors are useful for interpreting the variations in the single-band TESS light curves.

I shall describe the goals of this program, and provide some early results, with emphasis on the optical photometry from AAVSO observers.

Statistical Study of Binaries of Solar-type Stars from the SDSS-III MARVELS Survey

Gary Xu
Science Talent Training Center; Troy High School, Fullerton, CA; garyxu88@gmail.com

Matthew Zhang
Science Talent Training Center; University of Minnesota

Jian Ge
Science Talent Training Center; Shanghai Astronomical Observatory, Chinese Academy of Sciences

Kevin Willis
Science Talent Training Center; University of Florida

Binary systems, which we will commonly refer to in this paper as binaries, are invaluable to the study of stars as a whole and all aspects of the universe due to multiple reasons, including that: 1) it is well known that binaries comprise a large portion of all star systems in the universe; 2) binaries have the unique capability to directly determine masses of stars, thus indirectly determining other stellar properties such as stellar radius; and 3) statistical analysis of binaries yields possible constraints on stellar formation. Though many reports on binaries have been conducted previously, new research is warranted because previously, it has been impossible to select large, homogeneous, and unbiased samples of binaries. Thus, inconsistent results among binaries research represents a hole in our complete understanding of stellar evolution and formation. We address this issue by offering a comprehensive study and statistical analysis of over 300 single-lined spectroscopic binaries, by far the largest homogenous and unbiased sample ever.

This study was performed on over 300 spectroscopic binaries (SBs) identified and selected from the homogeneous sample of 3,300 stars surveyed and monitored by The Multi-object APO Radial Velocity Exoplanet Large-area Survey (MARVELS), which is part of the SDSS-III program. Analysis of solved radial velocity orbits for over 300 spectroscopic binaries using doppler spectroscopy, advanced programs, and MCMC fitting, has concluded: 1) period and eccentricity correlation reveals near-circular orbits at low periods ($P < 11$ days) due to tidal circularization at shorter periods; 2) period distribution displays a significant drop-off at $P = 85$ d and two peaks indicating two possible methods of binary formation; 3) eccentricity distribution exhibits the same, double peak pattern at $e = 0.2$ and $e = 0.5$; 4) mass distribution shows no excess of "twins" as theorized previously, but a peak at $q = 0.25$; and 5) the frequency rate for single-star system is 50%.

These results on companions to solar-like stars reveal both confirmations of previous discoveries and new discoveries. Further studies on these elusive binaries may provide valuable insights and theories to stellar formation as a whole.

Supporting Students and Researchers in a Virtual Exoplanet Research Workshop

Paige Yeung
Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA; pcy@mit.edu

Research contributions of ordinary citizens can significantly help the progress of science. In NASA's Exoplanet Watch, for example, citizens observe transits of exoplanets using small telescopes and analyze them afterward, saving time for more powerful telescopes to observe less accessible phenomena. Participating in research also helps budding scientists and other non-experts develop their abilities in scientific inquiry within professional-amateur communities. However, though these accessible research experiences can help both researchers and non-scientists alike, most classrooms do not incorporate this model of learning.

We designed a virtual exoplanet research workshop modeled off the astronomy research seminar course taught at a variety of high schools and colleges, where students conduct a research project over the course of a semester and publish in a journal. With a collection of transit images that would be time-consuming to process on an individual machine, we reasoned that other students would be able to help us process transit images at a larger scale while developing their own skills in astronomy research. The workshop makes use of the Exoplanet Transit Interpretation Code (EXOTIC) program for data reduction. Materials are shared using Google Drive, and participants contribute data analysis using Google Colaboratory notebooks.

So far, over 200 students have contributed observations of the exoplanet Qatar-1 b to Exoplanet Watch through the workshop. Two teams have submitted their papers to the *Journal of the American Association of Variable Star Observers*, and more teams have papers currently in progress. We are continuing to publish online resources for learning about exoplanet research and relevant tools and techniques, providing an entry point into practical astronomy research for students worldwide.

Exoplanet Watch: You Can Help NASA Observe Other Worlds!

Rob Zellem
Jet Propulsion Laboratory, California Institute of Technology, M/S 169-237, 4800 Oak Grove Drive, Pasadena, CA 91109; rzellem@jpl.nasa.gov

NASA's Universe of Learning's Exoplanet Watch (https://exoplanets.nasa.gov/exoplanet-watch/about-exoplanet-watch/overview/) is a citizen science project, currently geared toward amateur astronomers and astronomy students at colleges and universities, to observe transiting exoplanets—planets outside our solar system—with small telescopes. A transiting exoplanet is a planet outside of our solar system that periodically passes in front of its host star, causing the star to appear to slightly dim (typically by ~1%). Observing exoplanet transits is important, as they provide direct measurement of a planet's radius and composition. Ground-based observations, particularly with small telescopes (<1 meter), constrain the exoplanet's orbital period (how quickly a planet orbits around its host star) which in turn provides better mass measurements. Exoplanet Watch will help increase the efficiency of exoplanet studies by large telescopes to characterize exoplanet atmospheres by reducing uncertainty about the predicted timing of transit events.

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