ASTRO BEAT

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Figure 1: (Left) The eVscope, a 4.5” Newtonian-like reflector digital telescope designed and built by Unistellar. (Top) An improvised star party in Austin, TX during the 2019 South by Southwest festival.

Democratizing Observational Astronomy

By Franck Marchis (SETI Institute and Unistellar)

Observational Astronomy vs. the Reality

People love astronomy, and media is fully aware of this interest. Every day, newspapers report on new discoveries in the field, more than in most other fields of research even though those discoveries rarely have a direct impact on the daily lives of people. This interest is also reflected in the number of telescopes purchased, which is estimated to be at least 4 million per year. Most of those are entry-level devices with modest apertures (<10 cm) and equipped with a visual eyepiece used to observe moons and the planets. But even high-end telescopes, with large apertures and electronic cameras, are difficult to use and

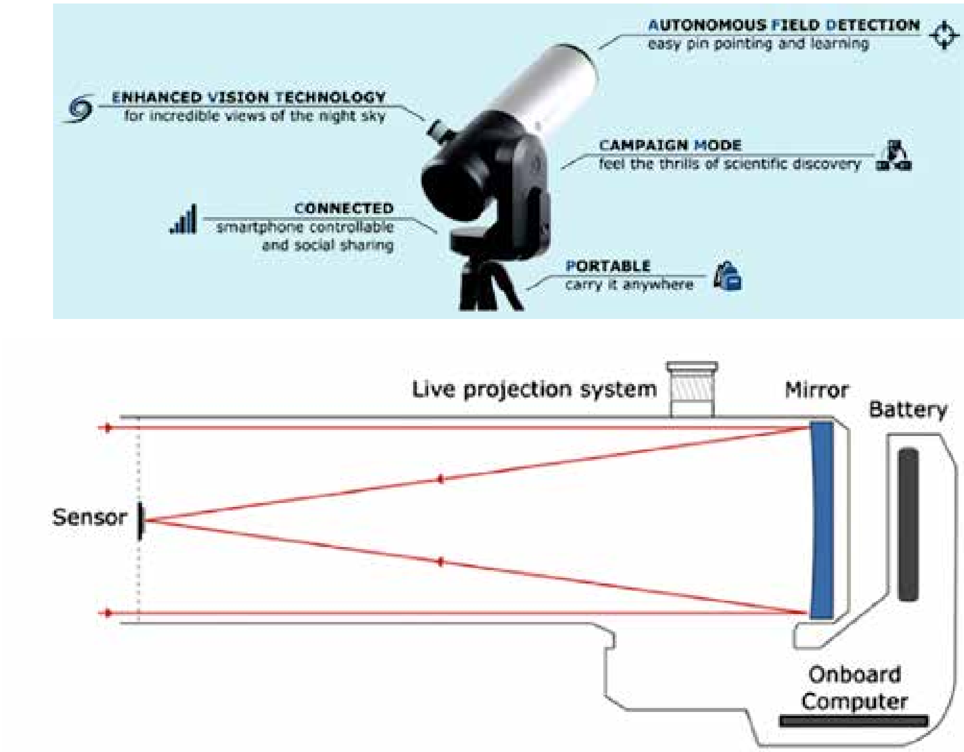

Figure. 2. [top] Five unique features of the eVscope. [bottom] Design of the eVscope.

can’t provide a visual experience as beautiful as the images the public sees in the media, which means that people are missing the truly awe-inspiring colors and details of many deep-space objects. Most ordinary telescopes are also difficult to use, and require users to be skilled at proper setup and alignment. Most people live in cities or suburbs where the night sky is hidden by ambient light, which severely limits the number of targets visible with a classical telescope to 10-11th magnitude with a 4.5” (11.4 cm) telescope. Finally, because of their complexity and the aridity of the experience they provide, the use of those telescopes remains a lonely activity, with few opportunities -if any- to engage with friends and family members. Consequently, most buyers quickly grow disappointed at what they see through their telescopes and wind up moving them into the basement, where they gather dust.

The eVscope and its Potential

I’d like to share with you a new innovation that can address these issues and help democratize observational astronomy. Unistellar proposes to reinvent popular astronomy with its Enhanced Vision Telescope (eVscope), a compact mass-market digital device. The company’s primary goal is to make observational astronomy far more fun, exciting, and easy to do than it is today, while fostering a strong, growing interest in astronomical research and citizen science. I officially joined the company in 2017, bringing my expertise in astronomy and instrumentation and a partnership with the SETI Institute, a scientific institution located in the Bay Area, CA.

The eVscope is equipped with a sensor located at the prime focus of the telescope (Figs. 1-2). The sensor is a CMOS* low-light bayer* matrix detector (*see Glossary at the end). Because of its low noise, it permits the recording of multiple frames during a given period of time without altering the image quality. An onboard computer stacks and processes those frames as they are taken, to produce an improved image that is projected in real time through the eyepiece. The projection system consists of an OLED* display of extremely high contrast plus an optical setup designed to mimic observations of the dark sky, providing the same experience and comfort as a classical eyepiece.

The eVscope keeps amazing us with its sensitivity, allowing us to image fainter and fainter objects in the sky. From even San Francisco, we can detect stars up

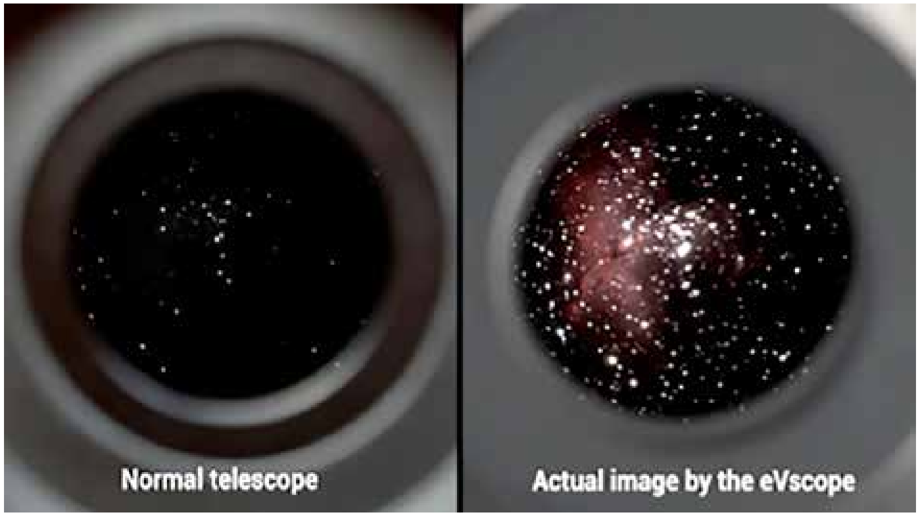

Figure 3. Observation of the Eagle Nebula with a classical telescope and with the eVscope.

to magnitude 15.1 (so 200,000 times fainter than stars typically visible from cities) using this algorithm with a few minutes of exposure time. This means that eVscope users can observe more than 5,000 asteroids, and more than 10,000 deep-sky objects every night from their backyard, benefiting from almost the same real-time experience as direct observations, combined with almost the same visual intensity as astrophotography images.

The eVscope is equipped with **Autonomous Field Detection (AFD),** an algorithm that uses an internal database of coordinates of several million stars to accurately pinpoint the telescope onto a target. The database includes coordinates and data for numerous celestial objects including the large planets, Messier Objects, and around ~2000 NGC* targets, as well as ~5,000 small Solar System bodies (described further in a recent paper: Marchis et al. 2020). The number of targets available in our database will increase regularly, and it's always possible to point the telescope directly using celestial coordinates.

Enhanced Vision is a proprietary algorithm that stacks and displays in real time the images received from this sensor and executes signal processing to produce extremely sharp, detailed images of even faint astronomical objects -- even from cities. The resulting image is projected in real time into the telescope's eyepiece. This technology mimics the light-gathering capability of significantly larger reflector telescopes used for years by professional astronomers. Fig. 3 compares observations of the Eagle Nebula (M16) with both a classical telescope and an eVscope after a few tens of seconds of Enhanced Vision. The gain in signal is dramatic, and the structures and the colors of the nebula are obvious in the eyepiece.

After a successful Kickstarter campaign at the end of 2017, we have designed a commercial version of the eVscope which is now being manufactured. We have shipped almost 1,000 units to our backers, and we are delighted to see pictures posted on the web taken by them. We are about to create the largest network of citizen astronomers.

Become a Citizen Astronomer

There is much to be gained from continuous observations of the night sky using telescopes spread around the globe, and by coordinating observations and sending alerts to users in order to study faint objects like comets or supernovae. Several groups of amateur and professional astronomers, including the International Occultation Timing Association (IOTA), American Association of

Variable Star Observers (AAVSO) and others, have understood for decades the value of those astronomy networks and collaborative efforts including citizen scientists.

In partnership with the SETI Institute, my team is working on developing the scientific contribution of the Unistellar network for professional astronomy research. We are building several collaborative projects with schools, museums, and community colleges, as well as non-profit organizations dedicated to astronomy like the ASP, to enhance the impact of the eVscope in astronomy and expand its potential.

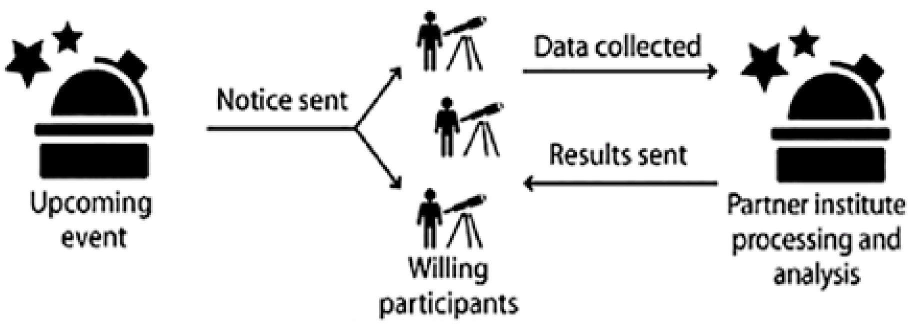

Figure 4. Campaign mode is a partnership between professional and amateur astronomers to study transient events.

We envision that any owner of an eVscope will be able to receive notifications on their smartphone of transient events visible in the sky, such as comets, supernovae, asteroid flybys, occultations, and more. Professional astronomers will request observations through the eVscope network as a campaign.

- If this campaign's transient event is predicted a few days/weeks ahead of time (e.g. an occultation) and eVscope owners are able to accept the request coming from the SETI Institute, they will get instructions on the way to conduct the observations (location, time, sky quality), and regular updates from the astronomers leading the campaign.
- If the event happens while observing (e.g. a small asteroid flyby), the telescope will interrupt the observations and automatically point to the correct field-of-view to record data.

The data will be sent to the SETI/Unistellar server, where it will be processed and analyzed by astronomers, and then return to the observer a report. This will allow communities of amateur and professional astronomers to work together to monitor and characterize transient events, combining the few observations taken with 8-10m class telescopes with the large number of observations collected with the eVscope network.

First Scientific Results

Today, we are running a pilot program based on this vision that is relevant to NASA, the NSF (National Science Foundation), and other scientific institutions around the world, and already have collected significant scientific results.

In **Planetary Defense,** our software can detect the passage of potentially hazardous objects (PHOs) reported in professional databases (MPC*, ESA*, JPL-NEOS *), and warn our users very quickly so they can collect data. This could be used to:

- Confirm the detection of PHOs (averages about 1 event per week).
- Derive the orbits of near-earth asteroids and the potential impact zone of PHOs.

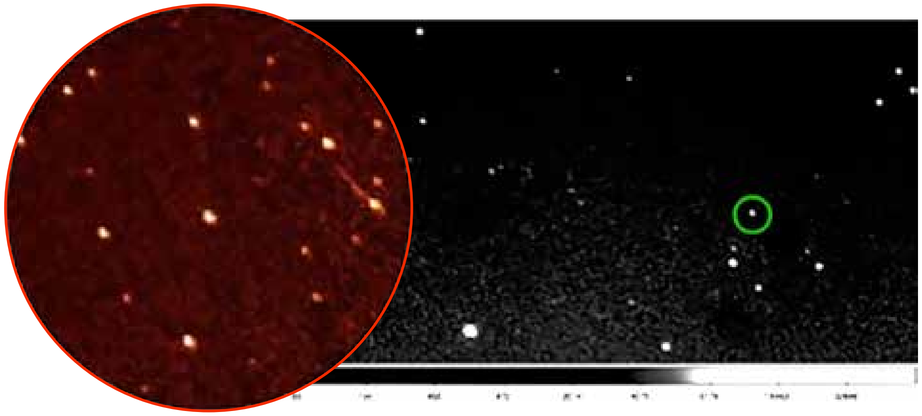

Figure 5. [Left] Stacked observations of 1999 KW4 (straight line at 3 o'clock on the image) observed over eight minutes on June 5, 2018 from San Francisco, CA. [Right] Observation of Echeclus on Dec 9, 2017 shortly after an outburst event had been announced. The AFD algorithm identified the Centaur asteroid.

Asteroid Occultations have been getting a lot of attention recently since the Gaia mission allows astronomers to precisely derive the location of the path of an occultation.

Our calculation shows that 40 asteroid occultations involving bright stars (visual magnitude < 11.2) are observable each day on Earth, but most of them are missed. Our network of eVscopes observing asteroids (Fig. 6) could be a helpful contribution to:

- Derive the shape, size, and multiplicity by occultation (in collaboration with IOTA and Euraster *).
- Support future NASA missions toward asteroids. Our team has for instance detected the first and only occultation by the asteroid Orus from the country of Oman in September 2019 (Marchis et al. 2019).

Exoplanets— What about becoming an exoplanet hunter? That's possible with our eVscope and quite useful. A network of small telescopes can crucially aid transiting exoplanet missions (e.g., to-be-launched JWST* and ARIEL*, and future conceptual missions like LUVOIR* or HABEX*) by providing up-to-date and accurate transit trajectory data of planets discovered with surveys like TESS*, and the future PLATO*. We have demonstrated the potential of a unique eVscope to detect transit of a Jupiter-size exoplanet in orbit around a sun-like star (Fig. 7). A robust program with our network will be able to help with:

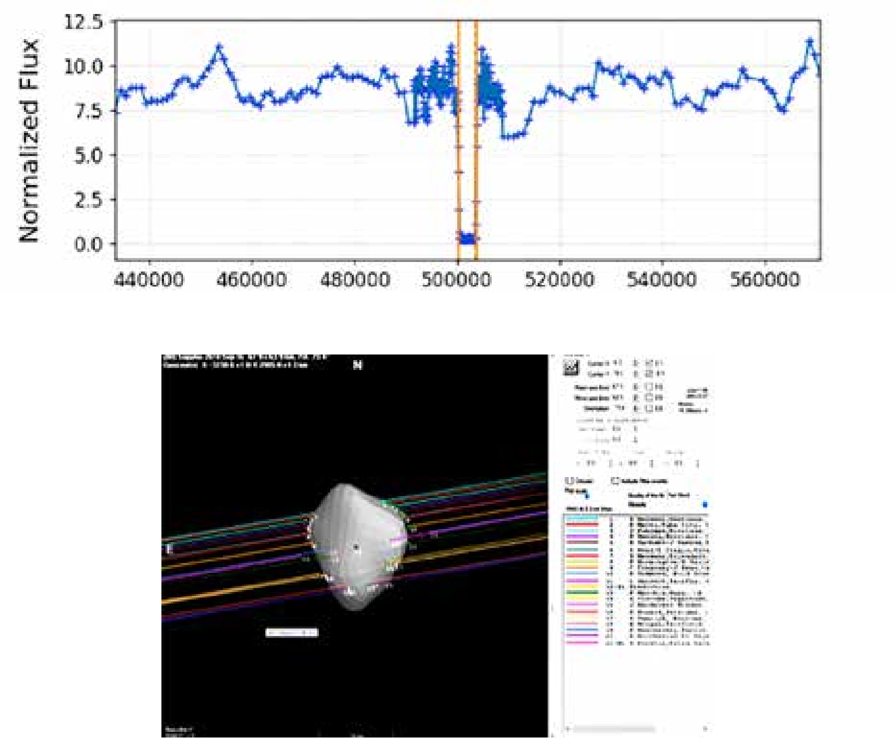

Figure 6: Occultation of (80) Sappho observed with the eVscope from San Francisco, CA and comparison between one of the shape models of the asteroid derived from lightcurve observations, like pictured at the top. From this type of observation, we can refine the shape, detect moons in orbit around the asteroid, and derive its volume and density.

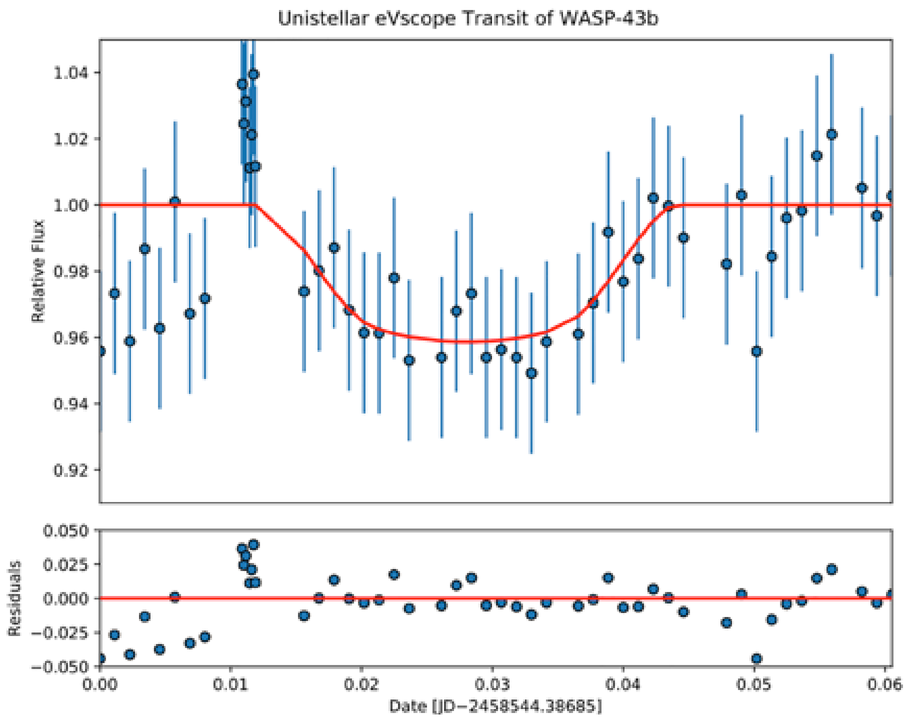

Figure 7: Transit observed with the eVscope prototypes in August 2018 (HD 209458b)). Despite the suburban observing conditions for the WASP-43b data and the faintness of the star (V=12.4), the transit of the exoplanet was detected. (source: Zellem et . 2020)

- Follow-ups of TESS (and later PLATO) discoveries
- Characterization of the orbits, TTV*, rings, and moons

The next step for us is to develop and support citizen science activity at Unistellar. To this purpose we need to design the tools in the app and the eVscope software which will allow citizen astronomers to contribute easily to scientific campaigns. We are currently running several pilot programs for occultations and exoplanet transits which are described in our blog on the Cosmic Diary (http://cosmicdiary.org/).

Figure 8: Recent picture of the comet C/2019 Y4 (ATLAS) observed from San Francisco with the eVscope. This comet is expected to be visible to the naked eye by the end of May, but eVscope users can already observe it from their backyard even in the middle of large cities.

And of course there is more science that can be done with this powerful network of identical telescopes. Additional science investigations related to transient events can be conducted with our eVscope network.

They have not yet been fully tested but will be implemented in the future. Observations could include:

- Cometary activity and main-belt comets. (See Fig. 8 for a very recent example.).
- Artificial satellites and Space Situational Awareness*.
- Localization of gravitational wave events or afterglow of Gamma-ray bursts.

As a researcher of the SETI Institute, I should also mention an exciting, but very hypothetical science case. With so many eVscopes ready to observe the sky 24/7, we could one day detect in those data the signal of a laser pulse from an extra-terrestrial civilization. This discovery would be extraordinary and tell us that indeed 'we are not alone.' It seems surreal that today from your backyard, one could achieve such a discovery. We indeed live in a wonderful time for science and technology.

*Glossary

ARIEL: Atmospheric Remote-sensing Infrared Exoplanet Large-survey (https://sci.esa.int/web/ariel).

Bayer pattern: A Bayer-filter sensor uses a color filter array that passes red, green, and blue to selected pixel sensors. Consequently, each pixel becomes sensitive to one color. Numerical algorithms are used to generate a color image from those colored pixels.

CMOS: A CMOS detector is one of the types of digital image sensors. Cameras in small consumer products like webcams, cars, and doorbells use CMOS sensors, which are cheaper and more reliable.

ESA: European Space Agency (https://www.esa.int/).

Euraster: A website for Asteroidal Occultation Observers in Europe (www.euraster.net).

HabEx: Habitable Exoplanet Observatory (https://www.jpl.nasa.gov/habex/).

JPL-CNEOS: Jet Propulsion Laboratory - Center for Near-Earth Object Studies (https://cneos.jpl.nasa.gov/).

JWST: James Webb Space Telescope (https://www.jwst.nasa.gov/).

LUVOIR: Large UV/Optical/IR Surveyor (https://asd.gsfc.nasa.gov/luvoir/).

MPC: Minor Planet Center (https://www.minorplanetcenter.net/iau/mpc.html).

NGC: The New General Catalogue (NGC) of Nebulae and Clusters of Stars is a catalogue of deep-sky objects originally compiled by John Louis Emil Dreyer in 1888.

OLED: Organic Light-Emitting Diode is a digital technology used to display images on devices such as television screens, smartphones, and game consoles. OLED enables a greater contrast ratio than LCDs and provides a deeper black level.

PLATO: PLAnetary Transits and Oscillations of stars (https://sci.esa.int/web/plato).

Space Situational Awareness: Refers to keeping track of objects in orbit and predicting where they will be at any given time (https://www.spacefoundation.org/space_brief/space-situational-awareness/).

TESS: Transiting Exoplanet Survey Satellite (https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite).

TTV: Transit-timing variation (TTV) is a method for detecting exoplanets by observing variations in the timing of a transit.

References

Marchis et al. 2020 https://www.sciencedirect.com/science/article/pii/S0094576519312950

Marchis et al. 2019 https://ui.adsabs.harvard.edu/abs/2019EPSC...13..898M/abstract

Zellem et al. 2020 https://arxiv.org/abs/2003.09046

Videos

Demonstration of the eVscope from Lowell Observatory, Tokyo, Marseille, and San Francisco https://www.youtube.com/channel/UCwMBOkLSgp_DO0aYfEg9KVg

The eVscope: A user-friendly telescope https://www.youtube.com/watch?v=DoV9ux5_I7M&t=1s

About the Author

Dr. Franck Marchis is a Senior Scientist at the SETI Institute and Co-founder & Chief Scientific Officer at Unistellar. Marchis earned his PhD in Astrophysics at the Université Paul Sabatier, France, in 2000. He is a planetary astronomer with 22 years of experience in academic, international, and non-profit scientific institutions and has conducted multiple research projects in a wide range of areas. He is best known for his discovery and characterization of multiple asteroids, his study of volcanism on Io (a moon of Jupiter), and imaging of exoplanets – planets around other stars. In April 2007, the asteroid numbered 1989SO8 was named "(6639) Marchis" in honor of his work in the field of multiple asteroids.

Work at the SETI Institute is anchored by three centers: the Carl Sagan Center for the Study of Life in the Universe (research), the Center for Education, and the Center for Outreach. A key research contractor to NASA and the National Science Foundation (NSF), SETI collaborates with industry partners throughout Silicon Valley and beyond.

Figure 9. (Left) The author and his eVscope at the star party organized at the USS Hornet Museum in July 2019 for the celebration of the 50th anniversary of the Apollo XI moon walking. (Right) The author.

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