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Unistellar eVscopes: Smart, Portable, And Easy-To-Use Telescopes For Exploration, Interactive Learning, and Citizen Astronomy

Franck Marchis[a,b,*], Arnaud Malvache[a], Laurent Marfisi[a], Antonin Borot[a], Emmanuel Arbouch[a]

[a] *Unistellar, 19 Rue Vacon 13001 Marseille, France,* franck.marchis@unistellaroptics.com
[b] *SETI Institute, Carl Sagan Center, 189 Bernardo Avenue, suite 200, Mountain View, CA, USA*
[c] *Observatoire de Paris, LESIA, Meudon, France*
* Corresponding Author

Abstract

Unistellar has created the Enhanced Vision Telescope (eVscope), a compact telescope that amplifies light so users can see hundreds of nebulae and galaxies directly through its electronics eyepiece. It can also pinpoint and identify objects in the sky, making amateur astronomy fun and more accessible to the public. Thanks to its sensitivity and accuracy, the eVscope is a powerful tool able to generate data that can be used by scientists to search for transient events like supernovae, near-Earth asteroids, and comets. This constellation of small, & smart telescopes could also enhance and supplement data generated by the small number of large telescopes operating today. Unistellar initiated a partnership with the SETI Institute to identify and implement scientific applications for a network of eVscopes. We summarize in this article the technology behind the eVscope and its real-time data processing (Enhanced Vision, Automatic Field Detection), then show several applications accessible to future users, including asteroid occultations, the detection of the atmosphere of Pluto and observations of near-Earth asteroids. The Unistellar network has the potential to make citizen astronomy a popular reality by offering all users (new or experienced) a tool to explore the night sky with a powerful and reliable instrument while they contribute to scientific investigations.

1. Introduction

The general public has a broad interest in astronomy, the natural science that studies celestial objects (planets, moons, nebulae, galaxies) and the cosmos. The media is fully aware of this interest and reports regularly 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 at least 4 millions per year [1]. Most of those are entry-level devices with modest apertures (<10 cm) 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 can't provide images as beautiful as the ones the public sees in the media, which means that people are missing the truly awe-inspiring colours and details of many deep-space objects. Most telescopes are also difficult to use, and require users to be skilled at proper 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, observing with 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. Figure 1 summarizes the expectations of an amateur astronomer versus the reality of his experience using a classical telescope.

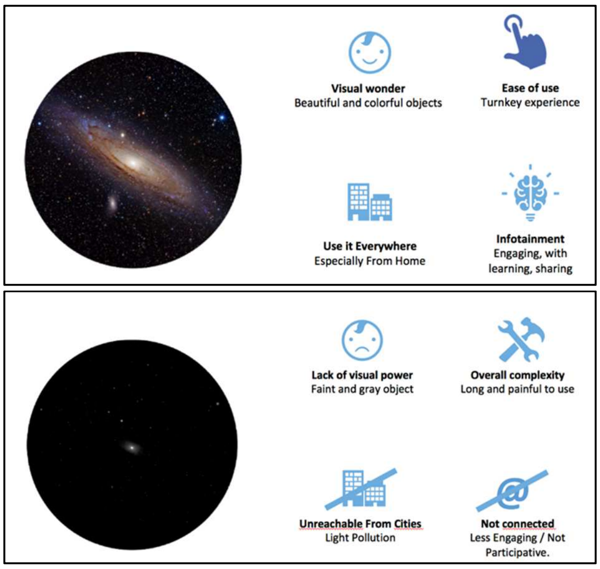

Fig. 1. Citizen Astronomer Expectations (top) and the reality (bottom) with a classical telescope (credit: Unistellar)

Unistellar proposes to reinvent popular astronomy through the development of the Enhanced Vision Telescope (eVscope), a compact mass-market device.

Our 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.

In this paper we present the technology behind the eVscope in Section 2, then discuss the opportunities it creates for citizen science, and finally show in Section 3 a few scientific results related to observations of asteroids and occultation by asteroids.

2. eVscope Technology

Unistellar's new eVscope is a 4.5" (11.4 cm) Newtonian-like (focal = 450 mm, magnification of 50) telescope designed specifically to work in urban and countryside environments. This compact (9 kg) connected device is equipped with a sensor, an on-board computer, and a projecting system. The eVscope is smart, autonomous, and able to deliver a colour image of a celestial object in just a few seconds. We have designed the eVscope to have 5 features not yet offered by classical telescopes, as summarized in Figure 2. [2]

Fig. 2. Five unique features of the eVscope (credit: Unistellar)

2.1 Sensor and Enhanced Vision

The eVscope is equipped with a sensor located at the prime focus of the telescope (see Fig 3). The sensor is a CMOS low-light detector IMX224 (1/3-type, 1.27 megapixels, 12-bit, up to 60 fps) produced by Sony and characterized by a gain amplifier of up to 72 dB and a low-read noise of less than 1 e- which allows us to record multiple frames with an exposure time between 1 ms and 4s. An on-board computer stacks and processes those frames (dark and background removal, shift-adding and stacking) to produce an improved image which is projected in real time through the electronics eyepiece. Each individual frame is stored in the telescope and can be accessed in 12-bit TIFF format by the user for at posteriori data processing and analysis. 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.

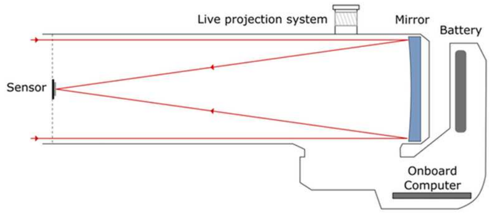

Fig. 3: Design of the eVscope (credit: Unistellar Kickstarter)

Enhanced Vision is a proprietary algorithm that accumulates light received from this sensor, producing extremely sharp, detailed images of even faint astronomical objects. The resulting image is projected in real time into the telescope's eyepiece. Enhanced Vision technology mimics the light-gathering capability of significantly larger reflector telescopes, thus delivering accurate views of night-sky objects previously inaccessible to amateur astronomers. Figure 4 shows an observation of the Eagle Nebula (M16) with a classical telescope and with an eVscope. The gain in sensitivity is obvious and in a few seconds the structures and the colours of the nebula are seen in the eyepiece. We have used the eVscope to demonstrate that we can observe Pluto (Vmag=14.5) from urban downtowns (see Figure 5) in a few tens of seconds of total exposure.

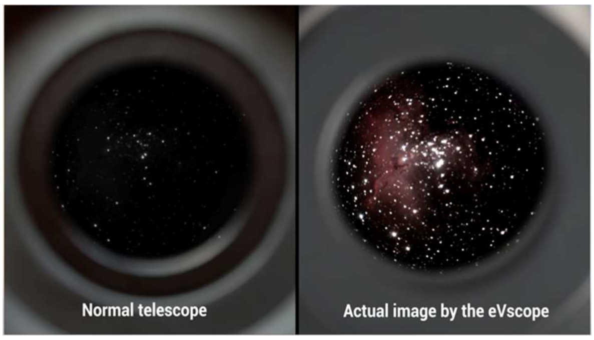

Fig. 4: Observation of the Eagle Nebula with a classical telescope and with the eVscope (credit: Unistellar)

2.2 Autonomous Field Detection

We developed an Autonomous Field Detection (AFD) algorithm that uses an internal map of coordinates of tens of millions of stars to accurately identify any object in the telescope's field of view. This allows our eVscope to overcome two problems that frustrate most amateur astronomers: It can automatically point at objects in the night sky, making it easy for users to find the targets they want to observe. Second, it provides information about that target that can be overlaid during observations, making astronomy informative as well.

The AFD database will include coordinates and data for several celestial objects, including:

- The main planets and the moon
- 110 Messier Objects
- at least 7840 NGC targets
- Several thousand small solar-system bodies including main-belt asteroids, Jupiter Trojans, and dwarf planets (V<15.5)

Figure 5 displays the identification of Pluto, whose coordinates are based on our on-board ephemeris generator and which is identified using the AFD.

Fig. 5: Identification of Pluto with the AFD detected from San Francisco, USA.

2. Citizen Science

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 [3]. In July 2017, the SETI Institute and Unistellar announced a partnership to develop scientific applications of the eVscope network [4]. The SETI Institute is convinced that the eVscope can play a major role in research on planetary defense, the search for supernovae, and the study of many transient astronomical events. The SETI Institute has robust outreach and education programs and is committed to use the eVscope to make astronomy a far more interactive and popular science.

2.1 Campaign Mode

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 can request observations through the eVscope network. If the owner of an eVscope accepts the request, the telescope will automatically point to the correct field of view and collect data as the citizen astronomer observes the event in the eyepiece. This data will be collected in the SETI/Unistellar server, where it will be processed and analysed by astronomers. 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.

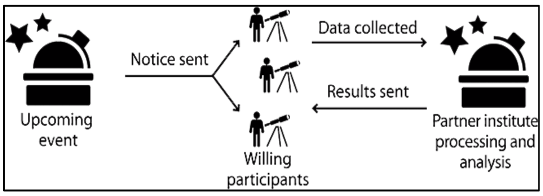

Fig. 6: Campaign mode is a partnership between professional and amateur astronomers to study transient events (credit: Unistellar)

2.2 Event Detection

Data collected by an eVscope user can be stored in our Unistellar database. These data will include observations collected by the network of telescopes as well as metadata necessary to properly process and calibrate observations. The SETI Institute and Unistellar are developing a pipeline to process frames collected by users, including bad pixel removal, flat-field correction, and astrometric calibration.

Event-detection algorithms will be executed on this large dataset of observations to detect, validate, and characterize transient events such as supernovae, asteroids, comets, and more. The large dataset created by a 24/7 network of eVscopes will provide alerts similar to survey telescopes used by professional astronomers (Catalina, Pan-Starrs, and the future LSST). The magnitude of these events is limited only by the stability of the eVscope's sensitivity and the robustness of the algorithms we've developed to combine observations from multiple eVscopes.

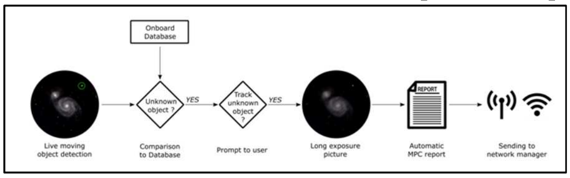

Fig. 7: An event detection consists in running *a posteriori* data analysis on archived data collected by

the eVscope network to deliver alerts on transient events.

3. First Scientific Results

In 2017, Unistellar built and tested two eVscope prototypes that were designed to achieve three goals: publicly demonstrate the power of Enhanced Vision and AFD during star parties; test and validate our on-board algorithms; and serve as tools to test the eVscope's potential for scientific investigations. Here we detail a few scientific observations recorded with the eVscope.

3.1 Observations of Small Solar System Bodies

We implemented an ephemeris generator, embedded in the eVscope and used by the AFD to pinpoint and identify small solar-system bodies. In June 2018, we conducted several tests to image asteroids during Asteroid Day. In one night we observed several main-belt and near-Earth asteroids (NEAs), confirming the eVscope's ability to contribute to planetary defense [3]. We selected one main-belt asteroid ((187) Lamberta) and two NEAs ((1627) Ivar and (66391) 1999 KW4) that were visible shortly after dark. The conditions were far from perfect since we were in San Francisco, a densely populated city whose famous fog had begun rolling in. All targets were, however, detected and imaged. With a magnitude of 14.2 in the visible band, 1999 KW4 was the most challenging. We detected the 1.3km-diameter asteroid that was at only 0.12 AU from us (50 times the distance Earth-Moon).

Fig.8: Stacked observations of 1999 KW4 (straight line at 3 o'clock on the image) observed over 8 minutes on June 5, 2018 from San Francisco

A global network of eVscopes will allow us to coordinate observations of similar NEAs by relying on several hundred volunteer eVscopes. Scientists can use this data to refine the orbit and shape of NEAs while eVscope owners use their devices to watch these objects in the sky. Simulations and test observations will be conducted as soon the network is implemented. We will focus on collecting data for 3-5 events per month involving 30-50m asteroids.

3.2 Occultation by Main-Belt Asteroids

Astronomers are very interested in the shape and the size of asteroids because this helps them understand how they formed. Unfortunately, most main-belt objects are too small to be imaged directly using a telescope, even an 8m-class one in an ideal location like Chile or Hawaii. But astronomers have discovered a trick that helps them measure the size of asteroids—one that relies on the fact that asteroids move with respect to stars and sometimes-even occult a star. Because the orbits of several asteroids are well known, it is possible to predict where and when such occultations can be seen—that is, where a shadow equal in size to the asteroid will move across the Earth

On January 27 2018, scientists from the International Occultation Timing Association (IOTA) [5] predicted that asteroid (175) Andromache would occult TYC 1399-01064-1, a V=11.3 star. Centrality (i.e., the path of the shadow) was predicted to be a few-km-width line that started in south Japan, crossed into China, Kazakhstan, and Romania, and ended in Spain [6]. Of special interest to Unistellar was the fact that the asteroid would occult the star not too far from Marseille, our headquarters city.

We developed a fast-frame recording capability for the eVscope with an individual exposure time of 100 ms (which gives us 10 images per second). At 18:37 UT, our team noticed the disappearance of the star for about eight seconds, very close to the time and duration predicted on the IOTA web site. By combining our observations with others taken in France and Italy, the EURASTER team [7] was able to derive an estimated shape for the asteroid.

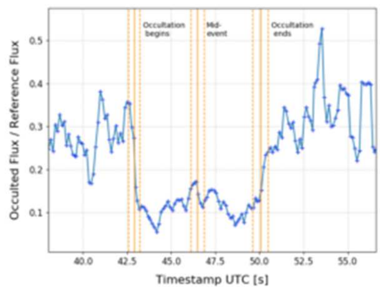

Fig.9: Lightcurve showing the occultation event by (175) Andromache. The beginning and end timings of the event were estimated on this lightcurve.

More recently, we attempted another occultation of a second main-belt asteroid, (80) Sappho, which was occulted a 7.2-mag star on September 16 2018. The occultation was predicted to be visible in a narrow band 70 km north of San Francisco. The US-based Unistellar team successfully recorded it using slightly improved software, which allowed us to observe the event at 50 milli-seconds (ms) and get a timing accuracy better than 12 ms. The lightcurve shown in Figure 10 has a better sampling and a sharp drop in magnitude. Multiple stations observed the event and the data are being analysed to derive the shape model and size of (80) Sappho [8].

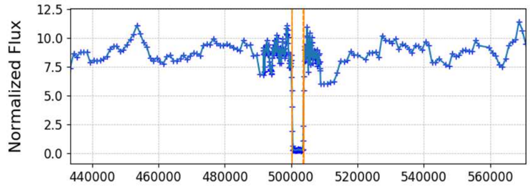

Fig. 10: Lightcurve of the occultation event by (80) Sappho. The error on the timing of the beginning and end of the event is less than 12 milli-seconds.

3.3 Occultation by Pluto

The Lucky Star collaboration [9] announced the existence of a very favorable upcoming occultation involving the dwarf planet Pluto and faint 13-mag star on August 15 2018. Because Pluto is drifting away from the Milky Way, these kinds of events were becoming more rare, especially with such a bright star (Gaia magnitude G~13). And, as an extra kicker, the last occultation, observed in 2016, suggested that Pluto's atmosphere might have started its shrinking. Moreover, complex climate models suggest that the nitrogen in the atmosphere is coming from a large reservoir of icy nitrogen named Sputnik Planitia, a very bright area of Pluto, which is now cooling down because of the planet's orientation with respect to the sun [10]. In short, by combining high-resolution images from the New Horizons spacecraft with past studies of Pluto's atmosphere, meteorological astronomers think that they are beginning to understand the climate of an exotic icy world located 7.5 billion kilometers from us.

Together with a team of the SETI Institute, the Observatoire de Paris, and Oceanside Photo and Telescope (OPT), the Unistellar team travelled to Southern California to observe this rare event. The observation was successful and a quick analysis of the eVscope's data in comparison with data collected simultaneously with an EMCCD Raptor Photonics Merlin on a C14 telescope (Fig 10) (processed by J. Marques Oliveira from the Obs. de Paris) which confirmed that we had indeed captured the occultation event which lasted 118 s. The profile is slightly different since our IMX224 is sensitive to the visible and part of the NIR.

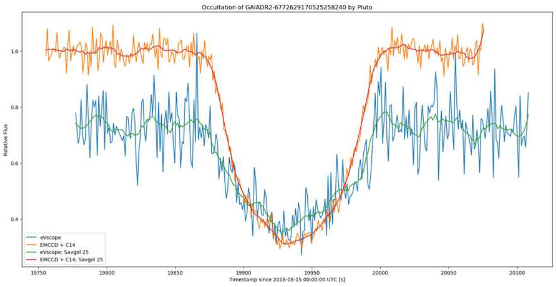

Fig.10: eVscope lightcurve showing the occultation event by Pluto and the detection of its atmosphere in blue (green after applying a Savgol filter). For comparison we added the profile of the same event taken simultaneously with a C14 & an EMCCD camera (in orange & blue with a Savgol filtering).

This preliminary lightcurve shows the presence of the atmosphere because of the gradual disappearance and reappearance of the star and confirms that the timing of the occultation was within the 5-s accuracy. The team of astronomers working together that night will combine all of their lightcurves to draw conclusions about the current state of Pluto's atmosphere. But the night was a success to validate the use of the eVscope to observe occultation events involving large bodies with an atmosphere, like Pluto and other Dwarf Planets in the future.

This was a useful rehearsal for Unistellar in that it not only confirmed the capabilities of the telescope but also embedded our efforts within the context of existing large community of Pro-Am collaborations.

4. Conclusions

Unistellar's goal is to democratize astronomy with the eVscope, a smart, compact, and easy-to-use telescope, making observational astronomy fun, educational, and interactive. Through its partnership with the SETI Institute, the project has taken on another dimension: encouraging and allowing users to participate in scientific observations and to collect research data. Unistellar's network could become the largest array of connected telescopes in the world, able to observe the dark sky 24/7 and provide information on what's happening around Earth and beyond in our galaxy.

After a fundraising campaign that generated about 2,000 telescope pre-orders, the project is on track for a delivery of its first eVscope in Q3 2019. In the meantime, Unistellar will conduct additional tests and implement new ideas designed to expand the scientific and educational impacts of the eVscope.

Acknowledgements

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