Citizen Science and Scientific Results from the World's Largest Network of Backyard Astronomers

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THE UNISTELLAR NETWORK

Astronomy is on the brink of radical change thanks to the arrival of digital telescopes such as the Unistellar eVscopes that were launched at the end of 2019, provide unparalleled access to the dark sky, and extend the joy of scientific discovery to a broader part of the population.

In previous years we discussed the development of the Unistellar network for outreach, education, and citizen science [1,2]. This is an update focused on our activities in 2020-2021.

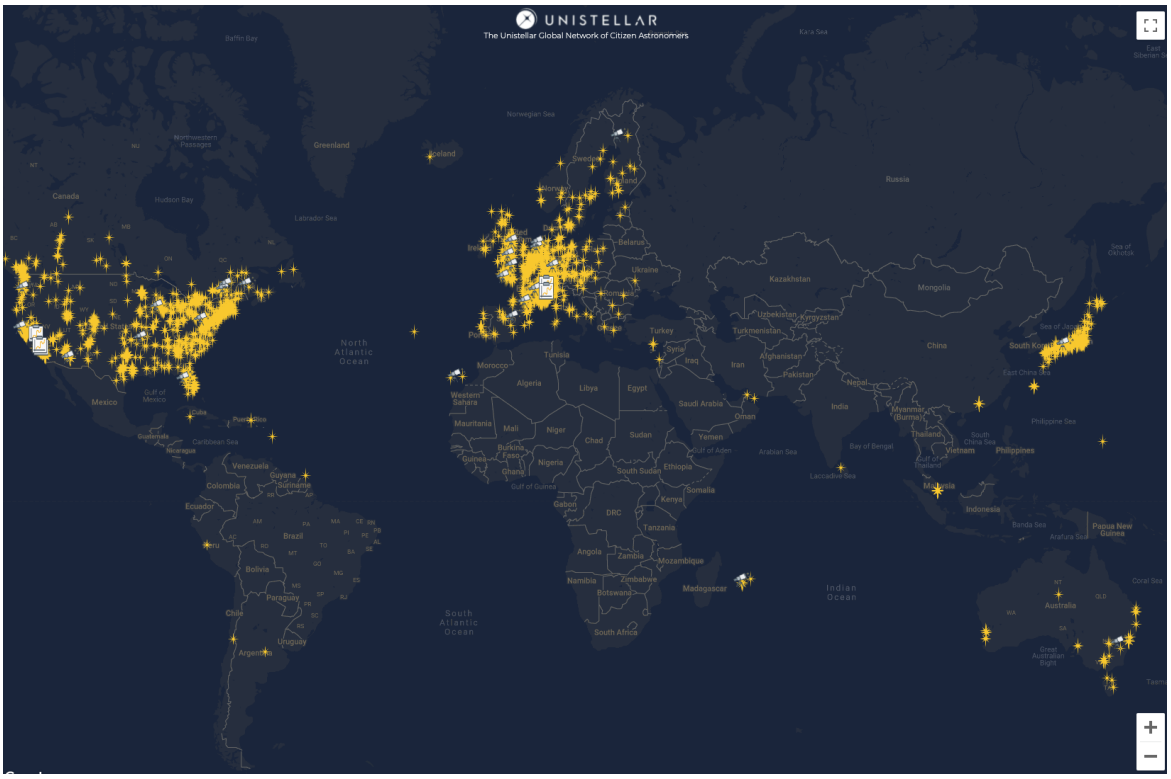


Figure 1. *Map of eVscope Citizen Astronomers as of February 2021*

The Unistellar's eVscope network is now made up of ~5,000 digital telescopes mostly in Europe, North America and Japan, but we expanded our network in Australia/New-Zealand, South America, India, Hong-Kong, Singapore and very recently in the Middle-East. An updated map is shown in Figure 1.

Users of eQuinox and eVscope are fully part of our network. We host numerous citizen science opportunities each month, conducted in collaboration with SETI Institute and Unistellar's quickly growing, global community. They also get to exchange in dialogue with these professional astronomers.

Our users become citizen astronomers and re-discover and apply the scientific method by doing astronomy and learning about space exploration.

OUTREACH PROGRAMS IN 2021

The year 2020 was complicated by the beginning of the COVID-19 pandemic which rattled our communication and outreach plans. Most Star Parties, social events and conferences have been cancelled across the world, and people started living in lockdown with in some cases a strict restrictions of motion (e.g. less than 10 km around their home without specific permit) for several months. This happens unfortunately at the time a large number of backers from our Kickstarter were receiving their eVscope.

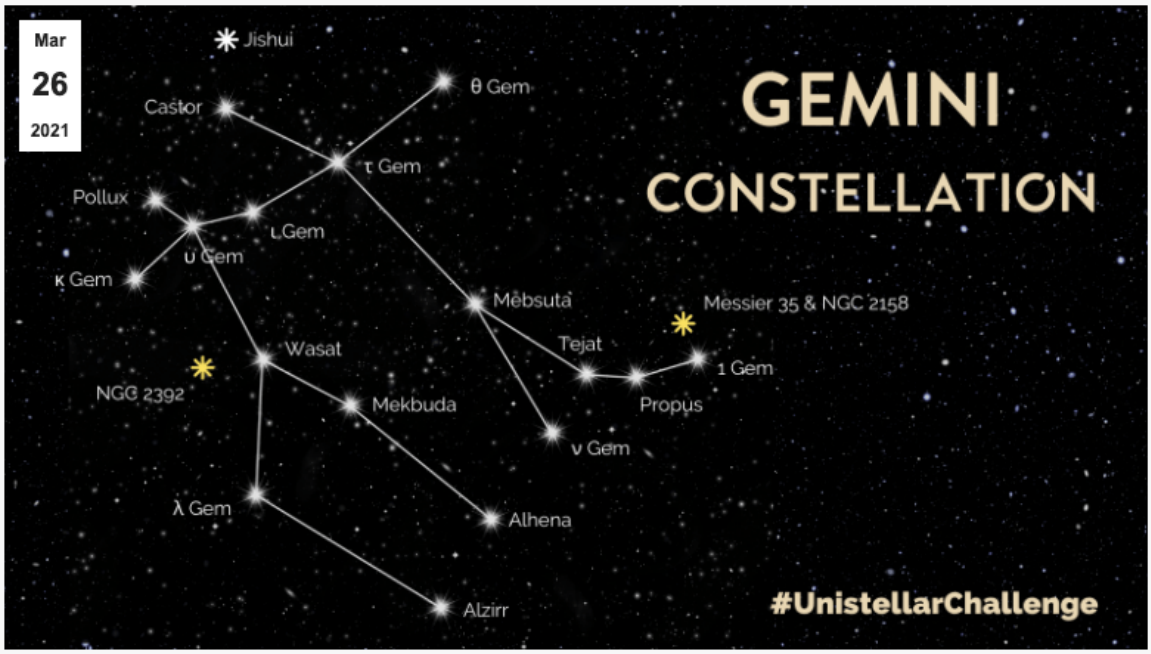
We quickly pivoted our outreach activity to adapt to this new situation focusing on remote star parties, increasing contents on our social media and web site, with the goal of motivating our network to join the Unistellar community and use their eVscope at their best even from their balcony or backyard for the most fortunate. As the pandemic got tamed with the availability of vaccines across the world and a better understanding of the sickness, the restrictions across the world relaxed but we continued our outreach program since we faced several drawbacks over the year (e.g. a third contamination peak in December in California).

Astronomical Women and their Deep-Sky Discoveries

Observations • By Val •March 19, 2021 •

In honor of Women's History Month, we're highlighting women who made amazing deep-sky discoveries! Unistellar Citizen Astronomers are invited to participate in this week's quest to observe deep-sky objects discovered by notable women in astronomy, so get out your eVscope and follow along! Caroline Herschel Caroline Herschel had many firsts not only...

Details ▸



Gemini Constellation

Observations • By Val •March 26, 2021 •

Unistellar Citizen Astronomers are invited to participate in this week's quest to observe celestial objects in the Gemini constellation! Quick facts about the Gemini constellation: In Latin, Gemini literally means "twins." In Greek and Roman mythology, Zeus placed the twin brothers Castor and Pollux in the

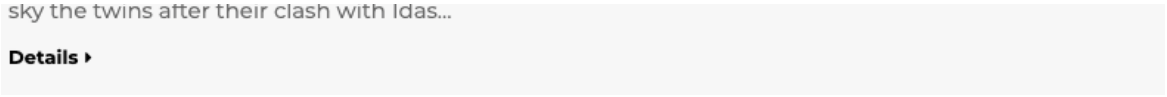


Figure 2: *examples of weekly challenges proposed in 2021*

A few examples of our outreach activities in the year 2021 are listed here:

- A **weekly challenge** so our network observed interesting deep sky objects visible at the time. We consider the moon phase to propose targets which are best to observe at the time. We also link the targets to specific events (e.g. Startrek day, Valentine's day, a specific constellation tour, Women's discoveries,…). See a few examples in Fig. 3.

- The **blog section** in our web site became very active with ~120 post since January 2021 on a broad number of topics from the weekly challenges, to stream events, conferences on line and scientific campaigns and results.

- We **participated to SxSW** (Fig. 4) which was fully remote to feature citizen astronomy with Marc Kuchner, Astrophysicist and NASA's Citizen Science Officer, Rachel Knight, an active citizen astronomer from the Unistellar network, Connie Walker, scientist at NSF's NOIRLab and director of Globe at Night, Franck Marchis, Unistellar's Chief Scientific Officer and Senior Astronomer at the SETI Institute.

- **Small in-person campaigns** to gather before an observations of an occultation (e.g. the asteroid Varsavia occulting a star above the Bay Area in California) which dinner, scientific discussion, training for those citizen astronomers.

- **Scientific challenges** (e.g. detect a brown dwarf, occultations of Apophis, image a black hole …) announced on our blog, social media, mailing list,…

- Announcement for **general astronomy events**, often unrelated to Unistellar telescope capabilities, like the Lunar eclipse on May 26, Discovery of a new comet C/2021 O1 Nishimura, …

- **Youtube videos** on discovery made by our citizen astronomers (Patroclus occultation on May 9 2021), unexpected used of the eVscope (launch of SpaceX at Vanderberg recorded by an eVscope) and more…

- **Partnership with established astronomical events** (Asteroid Day in June, #OnTheMoonAgain in July, Space Week in October), with live interviews, art competition, and e-books (see Fig 5).

- **Star parties** in the middle east (e.g. in Dubai for IAC events and the Expo2020) linked to the distribution of our telescopes in the UAE.

Figure 3: *The announcement of our SxSW panel discussion (fully remote) including professional and citizen astronomers*

FORMAL EDUCATION

Thanks to a **financial grant** from the Gordon and Betty Moore Foundation, the SETI Institute and Unistellar are providing eVscope telescopes, training workshops for students and educators and network collaboration opportunities to 25 community colleges throughout the United States, as well as to Chabot Space & Science Center's Galaxy Explorer program for high school students.

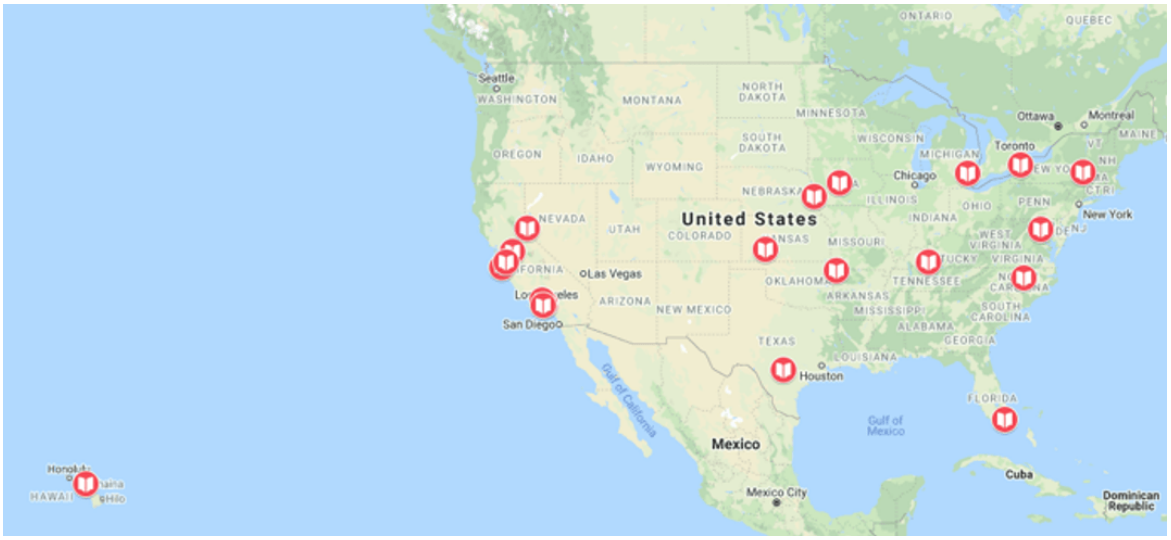


***Figure 4**. Location of the Community colleges recipients of an eVscope and part of the NCCN program.*

The SETI Institute is well-poised to implement eVscopes in community college settings, including workshops, training, curriculum and program evaluation. The colleges were chosen by virtue of being pilot participants in a significant NASA-funded initiative run by the SETI Institute, the NASA Community College Network, bringing cutting-edge NASA space science to community college teachers and

students. While the two programs are separate, having a group of participating community college instructors in place for eVscope distribution and testing will provide national coverage and a way to examine the impact of this new technology across a diversity of student demographics.

In addition to providing telescopes and training to community colleges, this program will also distribute several eVscopes to the Galaxy Explorer youth development program at Chabot Space & Science Center in Oakland, CA. With a 20-year legacy of providing learning and leadership opportunities for local high school students, the Galaxy Explorer program offers hands-on community service work, jobs skills development, increased STEM knowledge and enhanced public speaking. Continuing Chabot's "Learning Everywhere" initiative, students will integrate eVscope observations into their community engagement activities. The eVscopes will fuel accessible STEAM experiences for younger children, peers and families at Oakland's schools, libraries, fairs, and community centers.

At the time of writing, most community colleges and the Galaxy Explorer program have received their eVscope and received a training on how to use it. The goal of the program is to include those education centers and others in our network. To this purpose we will:

• Develop **education programs** with the Unistellar Network with a focus on scientific investigations of their choice (see Section III)

• **Interact regularly with teachers and students** to present the eVscope, help them conduct observations adapted to the schedule and curriculum of their classroom;

• **Collaborate closely with educators** and advise them on properly calibrating their data for the scientific investigations;

• **Process and analyze data** collected with the eVscope using the Unistellar science pipeline;

• **Promote and present at conferences** and present the scientific results;

We want those students and their educators to be fully involved in the scientific method, meaning that they will be able to create their own scientific programs, conduct the observations, process and analyze their data and finally publish their findings in conferences as well in scientific papers (in JAAVSO, MPB and other journals).

SCIENTIFIC RESULTS: IN NUMBERS

Since the delivery of the first eVscope in 2019, our group has seen a growing interest in scientific studies from the global community of citizen astronomers. Every month, using our website, we select 20-40 exoplanet transits observable with our network, one or two asteroids that will fly by Earth, and 50-60 occultations by asteroids observable from someplace on the globe. Those are the main scientific study being conducted with the Unistellar Network so far.We also alert our citizen astronomers in case of the appearance of a nova, supernova and a bright comet. In the future, we will also integrate those scientific studies in our pipeline.

The citizen science program of Unistellar has been quite successful in 2021, with more than 1000 events observed and submitted to several data repositories in October. On March 5 2021, we officially initiated a scientific program to observe TESS Object of Interest, so candidate planets observed by the NASA mission. To date, we have collected 383 observations of **exoplanets by transit**, including 107 detections, by 94 different citizen astronomers (see an example in Fig. 5 and ref [3]). For the **Planetary Defense** program, we have observed 10 Near-Earth asteroids in 2021, in 150 observing run (typically a continuous 30 min observation of an asteroid) and submitted more than 800 astrometric positions to the Minor Planet Center. Shape modeling of several of those targets based on our lightcurve data is in progress. For the **occultation program**, the network has observed 280 occultation events since May 2021, including 45 positive ones.

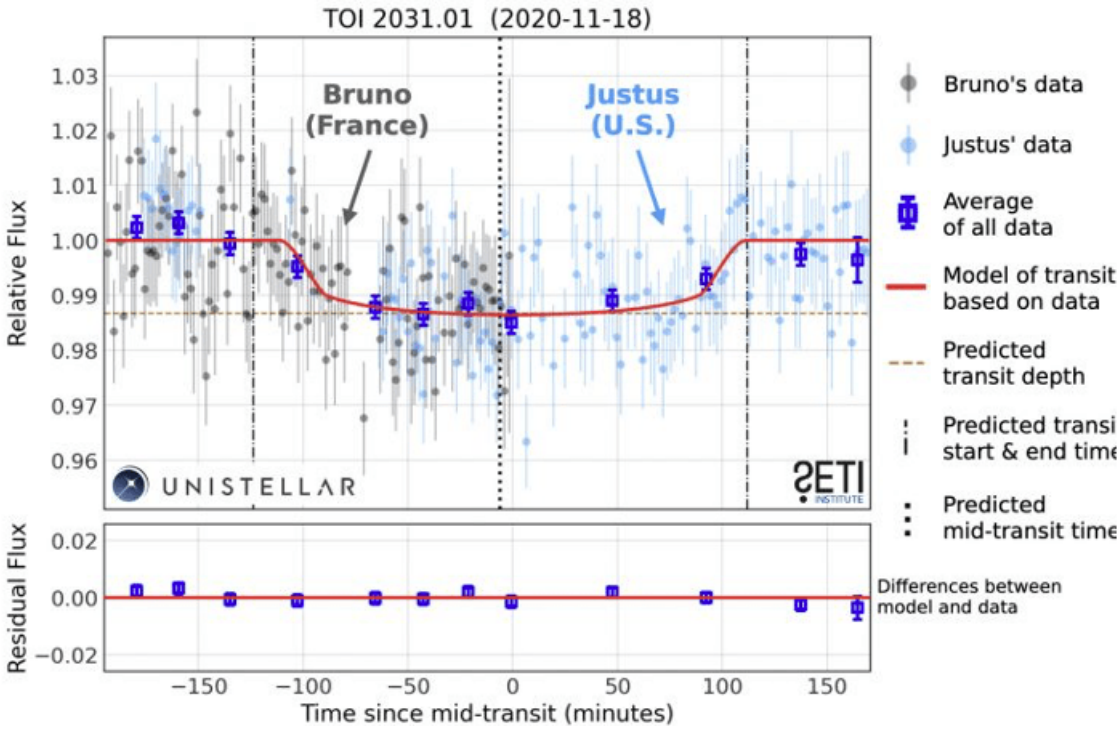


Figure 5: *Transit light curves like this one are used to visualize an exoplanet transit from collected data.* *In mid-November of 2020, Guillet, in France, took the first shift, watching TOI 2031.01 until around 3:45 a.m. his time. He then passed the torch to Randolph, who finished the observation from the U.S.* *This light curve shows the transit of TOI 2031.01 as it passed in front of its star, which caused the flux (brightness) of its host star to dim and then return to normal. Timing the transit tells us that the planet orbits close to its star (circling once every 5.7 days) and, as a result, is very hot (over 1000 °C). The depth of the dip tells us about the planet's size; about 1/10th the diameter of its star, or a little larger than Jupiter.*

OCCULTATION HIGHLIGHT: NEA APOPHIS

Occultation by Apophis on March 2021: The Story

On February 1, Josselin Desmars, from Observatoire de Paris, found out when the potentially hazardous asteroid (99942) Apophis would occult bright stars during its upcoming close approach to Earth. He identified two interesting events, one on February 22 and the other on March 7. During both events, the asteroid's path crossed the United States at almost the same location, a thin line that stretched from Montana to Louisiana.

The PHA asteroid (99942) Apophis is an interesting target. There are about one million asteroids in the solar system, 20,000 of which are near-Earth objects. Apophis, which was discovered in 2004 by Roy Tucker, David Tholen and Fabrizio Bernardi is an Aten asteroid that's about 370 m wide and comes close to Earth every decade or so. It is usually considered as one of the most potentially hazardous near-Earth asteroids of the next decades.

Recent observations taken with the ESA space telescope Gaia surprised astronomer David Tholen: it showed that the object's orbit is accelerated because it interacts with the Sun. This means that the asteroid's orbit is not very well known —not what we want to hear for something that has a 1-in-150,000 chance of crashing into Earth in 2068.

We quickly concluded that a detection of Apophis during those stellar occultations would give us a very accurate fix on its location (i.e., accurate to 0.2 km) and refine the orbit significantly. So on February 10, we opened a can of worms and announced this occultation on our Unistellar web site in the hope that it would motivate our citizen scientists to observe the object.

Unfortunately, the weather gods were not with us on February 22. The entire observing area was cloudy or rainy. One Unistellar citizen astronomer, Karen Flair, attempted to observe Apophis in Park City, UT, but without success because of the clouds.

Figure 6: *Meeting just before the Apophis Occultation somewhere in Colorado*

On March 6 with we organized a “private citizen science even” in Colorado, the best place to observe this event. We took into account the odds of having clear weather, a significant number of citizen astronomers nearby to help out, and accessibility during the current pandemic. On March 2, we sent to fifty potential citizen astronomers a note explaining them the importance of this event, the difficulty of the observation, and how their contribution could help “save the world” or at least help humanity to sleep better by nailing down the orbit of the “God of Chaos” asteroid. A dozen citizen astronomers replied expressing interest in participating.

In the meantime, the NASA-JPL team attempted to observe Apophis using the Goldstone radar antenna, and after combining data generated during multiple nights of observing managed to obtain an echo that allowed us to refine the orbit of Apophis. Josselin Desmars refined the path based on this new information, which shifted asteroid’s trajectory by 1 km to the south with an uncertainty of 1.5 km on the surface of Earth.

At 9:30 p.m., seven of us met at Colorado Mountain Skydive, a small airport located south of Greeley. The sky was clear just above us even though clouds loomed all around.

All stations were in place and ready, including distant ones like Bob MacArthur and his son (A36, 17 km from us), John and Ellie Visser (A47, 40 km from us), Charlie and Christina Bicknell (A35, 50 km from us), and Ryan and Sharon Tirashi (A36, 80 km from us). At 11 pm MST we almost simultaneously recorded observations of the event (Figure 7).

Shortly, we found out that three of astronomers from IOTA in Oakdale, LA did indeed detect the event! These were located nearby the lines A28, A29, A30, and so only 700 m from our stations. In their observation, David Dunham and Richard Nugent saw the star disappear for of 0.1s, roughly half the time it takes you to blink your eye.

The event seems to have lasted longer (some predicted only 0.035 ms) than what was expected. It’s possible that the asteroid’s shape and the pole solution we used to make this timing prediction was in fact inaccurate—or maybe, Apophis is bigger than expected. Second, we have now an extremely accurate position for this asteroid, which will allow us to refine its orbit. NASA-JPL has already calculated a new orbit and will use this data to predict the track for a future occultations, maximizing the chance of success

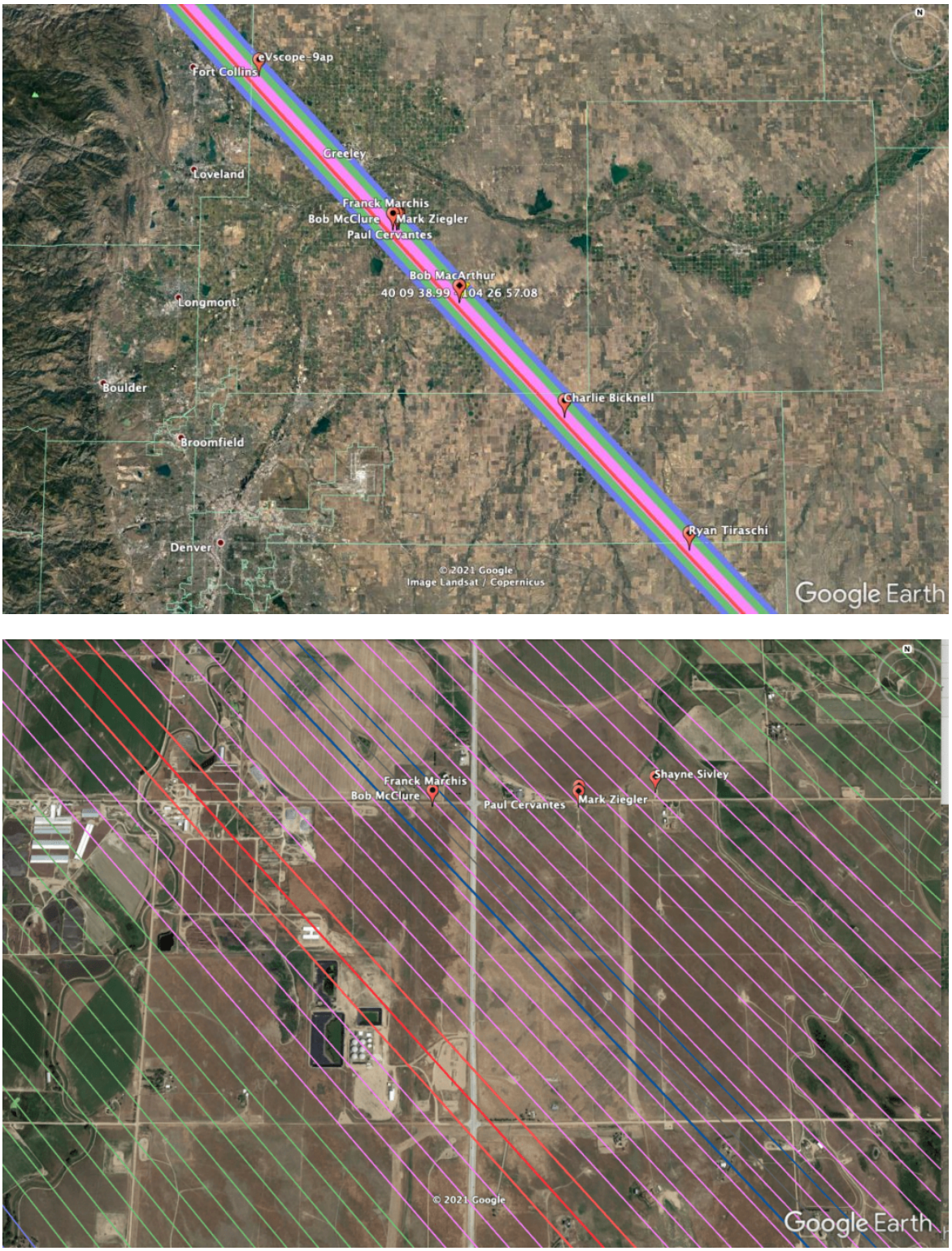


Figure 7: *Occultation path from JPL (the pink lines correspond to numbered from A1 to A70 chords labelled by M. Buie from SWRI), and the tag showd the locations of Unistellar citizen astronomers. The red line indicates the location of the shadow determined from positive occultation in Louisiana. The Unistellar astronomers were only 700 m away.*

FUTURE WORK AND CONCLUSION

Using the Unistellar network composed of 5,000 eVscopes around the world, we have developed a robust outreach, education and citizen science programs. Our network is not only a tool to explore the night sky but also a way for people, eVscope users or not, to learn about the wonder of the Universe thanks to our modern outreach program.

The education program with Community Colleges in the US is promising since it will allow us to test the integration of the eVscope into existing curriculum with instructors who already have an interest in space since they applied to the competitive NCCN program. We envision this network to grow in the future, so will probably seek funding to deliver more eVscopes to community colleges with the goal of creating a network in observational astronomy for under-represented communities.

Thanks to our citizen science program, citizen astronomers can make significant discoveries while learning about the targets that they observe. It is remarkable that this technology allows them to detect exoplanets, and participate to planetary defense program or the study of asteroids from their home. Even with a mediocre sky, most citizen astronomers live in city or suburbs, they can participate to those scientific programs.

The main-stream media loved the story of Tim Russ (aka Tuvok), a Startrek actor who dedicated part of his time to help NASA by observing Patroclus, one of the targets of the Lucy mission, suggesting that outreach and citizen science are powerful program to promote space exploration. We believe that our project provides new content for a press which is looking for meaningful, and fun, activity to captivate their audience.

Figure 8: *Snapshots of citizen astronomers who are part of the Unistellar network.*

Our programs will improve over the next years. One of the main obstacles in citizen science is that most citizen astronomers don't have the background, knowledge, or skills to identify targets of interest visible from their location—or, more importantly, know how to observe them. We will accelerate the transformation of people from eVscope users to skilled, committed citizen scientists by simplifying the way scientific observations can be collected through the Unistellar App, adding more content to the App to better inform users of the importance of scientific investigations, and

developing a robust backend pipeline to reduce the lag between the acquisition of an observation and the publication of a result. This App will become the backbone of a “New Astronomy” that involves every citizen astronomer (Fig. 8) willing to participate in the global enterprise that is science. By creating a new tool based on this App, we can harness the energy and creativity of citizen astronomers of all ages and keep them motivated in observing the night sky, making significant discoveries, and creating positive outcomes for future generations.

ABSTRACT

Thanks to the Unistellar network, citizen scientists and ordinary people all over the world can now enjoy the wonders of the night sky while also making important scientific discoveries. More than 5,000 people who own an eVscope—a digital, smart, and portable telescope—are doing precisely that thanks to a collaboration between Unistellar and scientists at the SETI Institute.

The eVscope has already achieved many significant breakthroughs, including the detection by 79 observers of 85 transits by Jupiter-sized exoplanets, 281 asteroid occultations (including forty-five positive ones), and three shape and spin solutions for near-Earth asteroids. The network has also lent important support to NASA's TESS mission by making transatlantic observations of an exoplanet transit, and to NASA's Lucy mission by profiling Trojan asteroids this spacecraft will soon visit. These data are collected by observers in Europe, North America, Japan, Australia, and New Zealand, and the Unistellar network will soon expand to the rest of Asia and to South America, ensuring that each of these accomplishments is the product of coordinated efforts by hundreds or even thousands of observers across the globe.

Our team is also working with NASA to develop several education programs involving the Girl Scouts of America, and community colleges around the US designed to connect teachers, professors, amateur astronomy clubs, and informal education partners. Our goal is to give every observer of the night sky the chance to experience the thrill of space exploration while we also educate young people to ensure that they are ready to carry humanity to and across the next frontier.

(https://agu.confex.com/data/abstract/agu/fm21/4/6/Paper_977664_abstract_915821_0.png)

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