

TESS Planet Candidate Follow-up by Citizen Scientists in the Global Unistellar eVscope Network

Thomas M. Esposito^{1,2,3}, Arin Avsar^{2,3}, Dan Peluso^{1,2,4}, Franck Marchis^{2,1}, Peter Santana⁵, Val Klavans², Ludovic Nachury²
 1. SETI Institute, Carl Sagan Center, Mountain View, CA, USA; 2. Unistellar, Marseille, France; 3. UC Berkeley, Berkeley, CA, USA;
 4. University of Southern Queensland, Toowoomba, Australia; 5. University of Puerto Rico, Mayagüez, PR, USA



Contact:

Tom Esposito, tesposito@seti.org
 Exoplanets Assistant Researcher, SETI Institute
 Space Science Principal, Unistellar

To learn more:
<http://www.unistellar.com>



Citizen Science

SETI astronomers collaborate with telescope company Unistellar to run observational campaigns with its network of citizen astronomers for Exoplanet Transits, asteroid occultations & light curves, planetary defense, comets, supernovae, & novae.



A Networked Telescope

Enhanced Vision technology
Beautiful images
Light pollution compensation

Automatic Field Detection
Educative and Interactive

4.5 in. reflector
37'x28' FOV
1.7 "/pixel
CMOS sensor

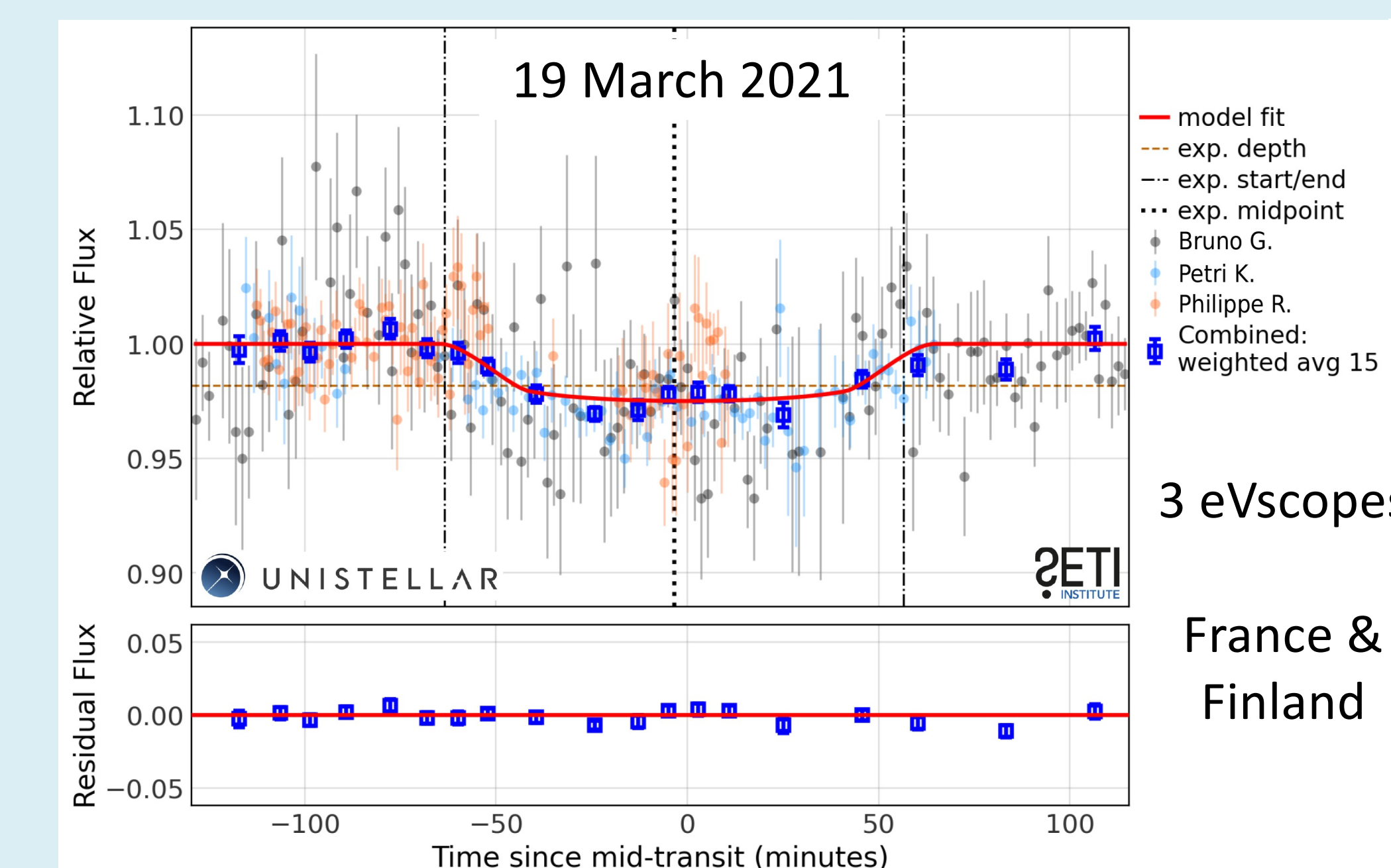
Portable and autonomous
Fits in an urban backpack

Connected
Science campaigns
Wi-Fi data uploads

The eVscope

Example Campaign: TOI 1811.01 Timing

We monitored one TOI's transit timing over multiple months. Poor weather at some sites meant the highest SNR detections were achieved by combining data from multiple eVscopes.



Target

$V = 12.0$
 $\sim K3$ star
 $d = 128$ pc

$R_{\text{planet}} = 11.9 R_{\oplus} (\pm 0.8)$
 Period = 3.7 d
 Transit depth = 1.80%

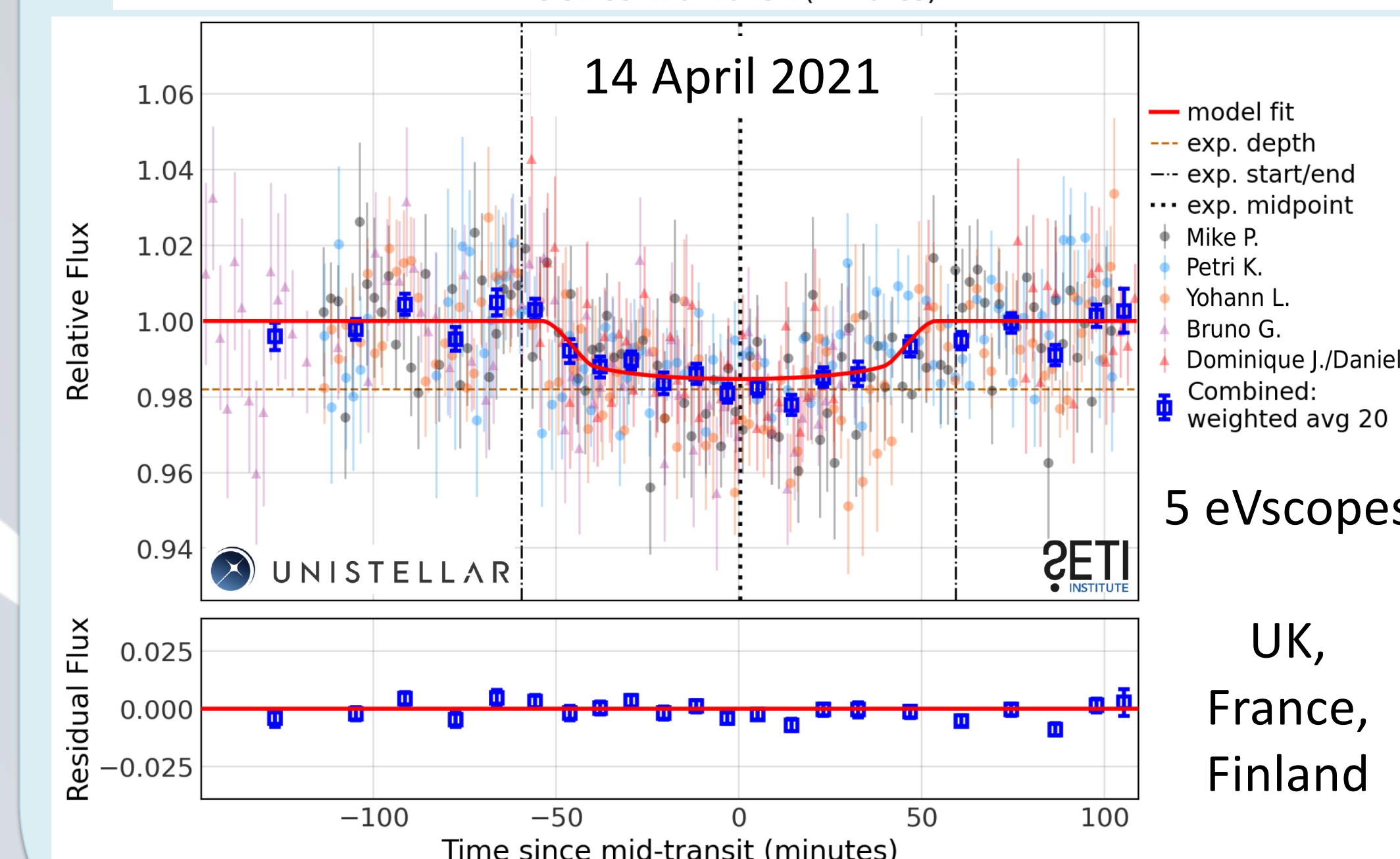
ExoFOP-TESS: <https://exofop.ipac.caltech.edu/teess/>

Conclusions

Measured mid-transit times compared to TESS-based predictions:
 March: $+3.45 \pm 1.82$ min
 April: -0.36 ± 1.91 min

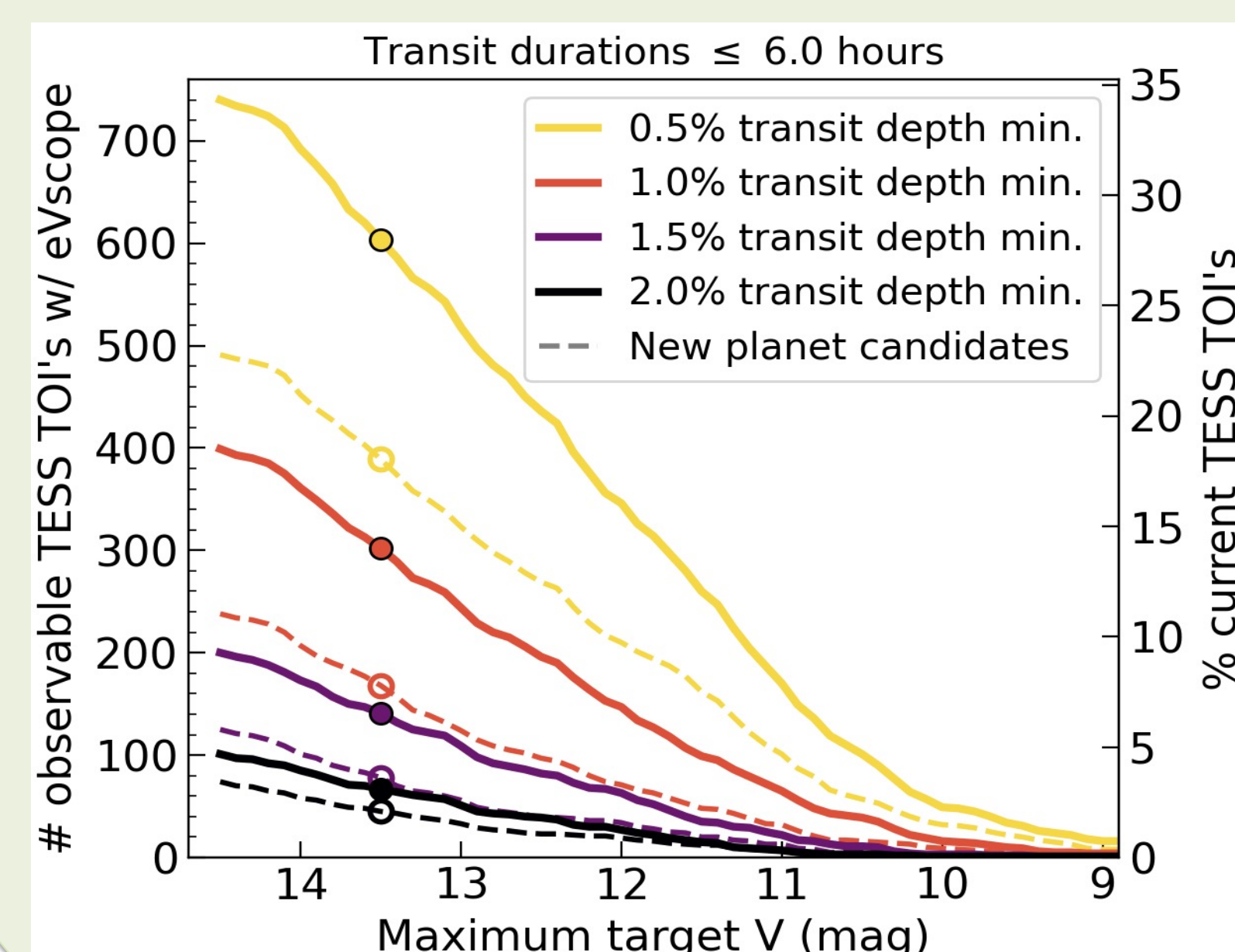
IMPACT: We can reliably measure transit timing to within 6 minutes at 99.7% confidence for hot Jupiters; sufficient for ephemeris maintenance and also TTV detections, perhaps even down to super-Earth perturbors.

See <https://unistellaroptycs.com/citizen-science/exoplanets/results/> for even better performance on the brighter host star of HD 189733b.



TESS Follow-up Photometry Goals

1. Measure **mid-transit times** for new planet candidate TESS Objects of Interest (TOI's) to refine ephemerides for JWST/Ariel/LUVOIR follow-up.
2. Help confirm planet candidates by **ruling out false positives** (e.g., nearby eclipsing binary stars).
3. Contribute **data to public archives** such as the [AAVSO Exoplanet Database](#) (obs code "UNIS").
4. Measure **transit timing variations** (TTV's) in collaboration with TFOP & [NASA Exoplanet Watch](#).
5. Detect **long duration and long period transits** requiring broad geographic & continuous sky coverage for TESS single and duo transits.



Nearly 200 TOI planet candidates are already detectable by single eVscopes, within limits of $\sim 1\%$ depth with host $V \leq 13.5$.

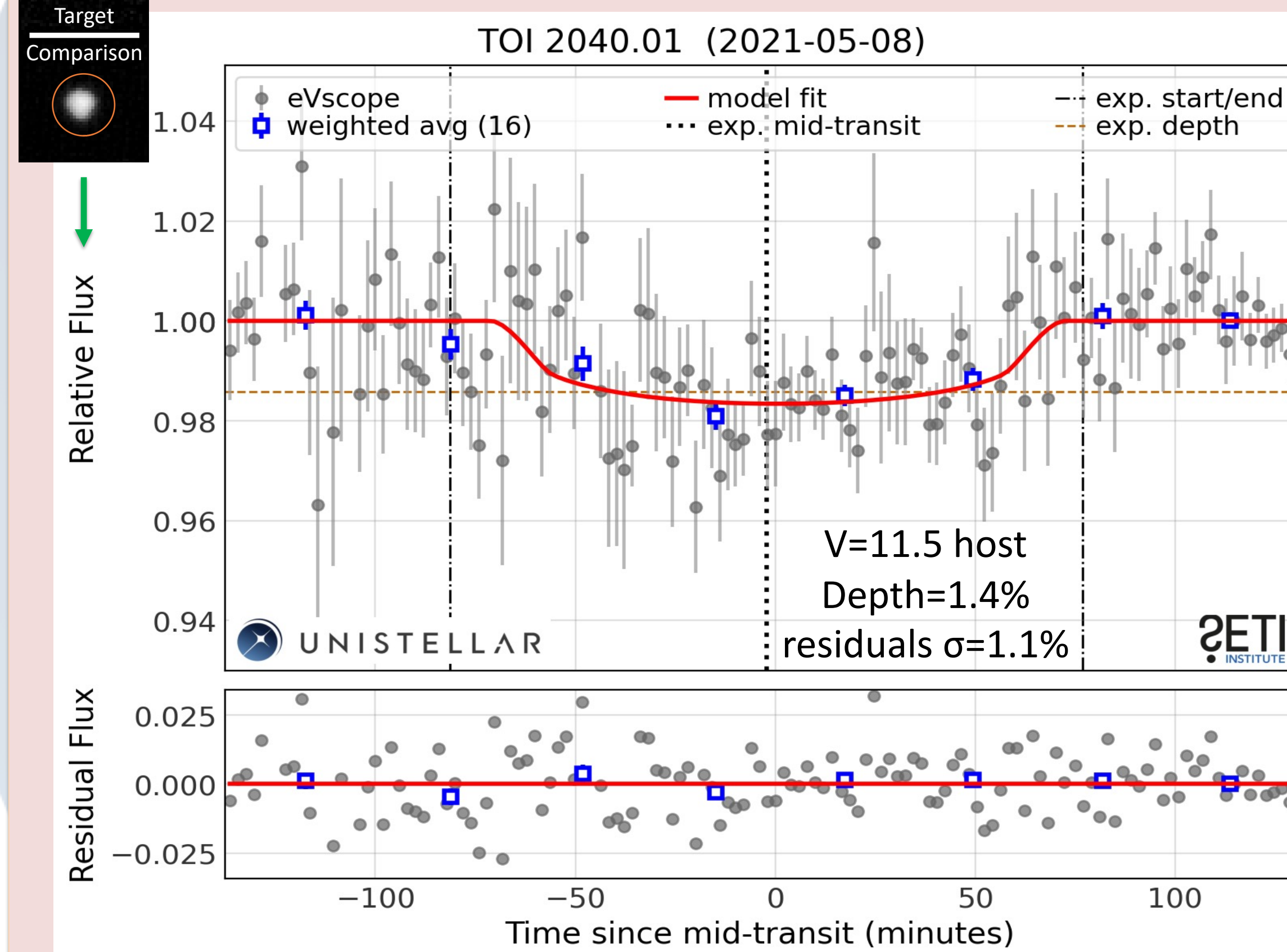
Transit Results from the Network

April 2020 – June 2021

Transits observed (total): **268**
 Transits detected: **76 total (45 TOI's)**
 Unique TOI's detected: **16**
 Database submissions (total): **13**
 Unique observers: **78**

The Process

1. SETI/Unistellar astronomers **select scientifically valuable targets and alert observers** via email/Slack/website/social media.
2. Citizen astronomers **image the target field and upload data** to Unistellar cloud storage via wi-fi.
3. SETI/Unistellar astronomers perform image calibration & **differential photometry with pipeline customized for eVscope data**. Multiple models are fit: [pycheops](#) least-squares & [EXOTIC](#) nested sampler (Zellem+ 2020).
4. **Light curves (e.g., at left) and measurements are sent back to the observer and submitted to public databases** when suitable (AAVSO, TFOP). Highest value results are published in journals.



A typical eVscope light curve, showing a detection of candidate hot Jupiter TOI 2040.01 around a $\sim K2$ star observed by citizen astronomer Justus R. from Athens, GA, USA (Bortle 5/6). The best-fit model from a nested sampler is compared to the gray circles only (2 min of integration per point). Vertical & horizontal lines mark predicted values.

Future Campaigns

- Measure mid-transit times at the $\sigma \leq 5$ min level for ~ 40 TOI planet candidates per year over the next 3 years to support future characterization missions.

- Highlight 25–45 transit events per month on the Unistellar website, mostly TOI's.
- Confirm a long-period (>300 d) "cold Jupiter" analog.
- Search for exomoon, circumplanetary ring, and "dipper" transit signals.

Outreach & Education

With the foundations of our scientific campaigns laid, we are now working to expand their reach and impact over the next year by:

1. **Expanding participation** in schools, community colleges, universities, and engineering schools in the U.S. & Europe, and informal education centers like the Girl Scouts of America. Our goal is to reach an audience beyond those with the motivation and means to buy their own telescopes.
2. Making the **telescopes easier to use for scientific events**.
3. Providing code, curriculum, and educational materials for **citizen astronomers, teachers, & students to process their own data and arrive at their own results**. Inquiry-based projects will engage learners more closely with valuable concepts and skills of the scientific process, aligning with leading research-based science education reform (e.g., Next Generation Science Standards and Modeling Instruction).