Our Collaborative Exploration for New Planets with Small Telescopes

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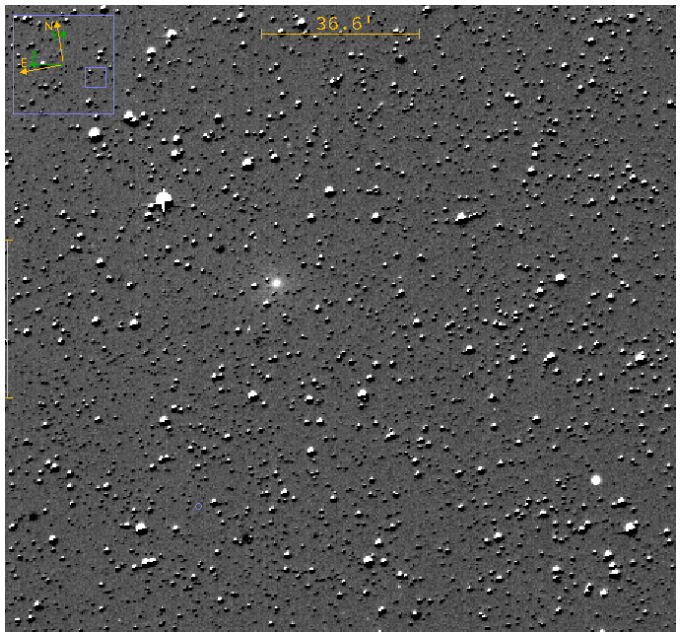
Abstract

While it may seem that stars are steadily unwavering in their brightness, some of them subtly fluctuate from rotation, pulsations, eclipsing stellar companions, and the occasional transiting planet. In collaboration with KELT (Kilodegree Extremely Little Telescope) and NASA's TESS (Transiting Exoplanet Survey Satellite),the University of Louisville uses small telescopes in Kentucky, Arizona, and Australia to confirm discoveries and characterize properties of these extrasolar planets and their host stars. Focused on precision measurements of stellar brightness and velocity, we have found among others one of the hottest known planets that leaves a comet-like tail as it orbits its star; a multi-planet system where gravitational interaction keeps the orbits in step; and enormous flares on our nearest neighboring star that may endanger any chance for life on the planet in its habitable zone.

Highlights

- The variable sky
- Transiting planets
- Kilodegree Extremely Little Telescope
- Transiting Exoplanet Explorer Satellite
- Our resources
- KELT-9b – A very hot planet
- TESS TOI-125 – Near-resonance sub-Neptunes
- Proxima Centauri – Too many flares

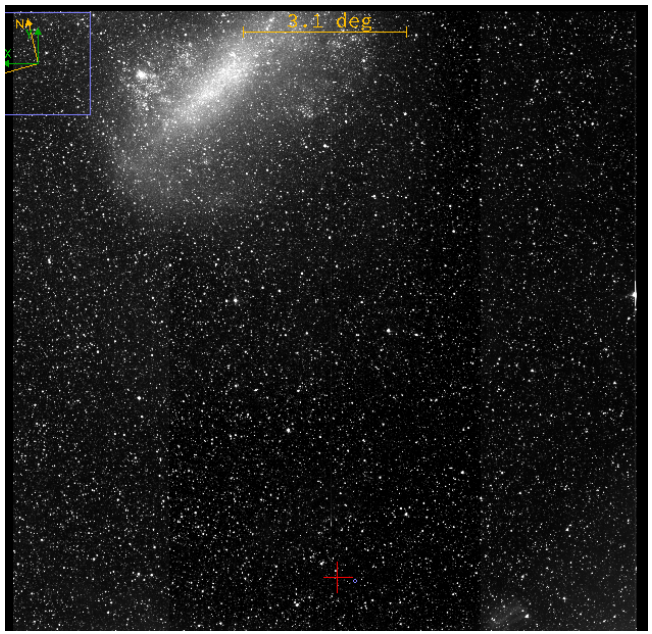
The variable sky



A close view of changes in TESS sector 5 camera 1. (click)

A comet enters from the lower left and moves across the field. The images are 30 minutes apart. Notice the variable stars and also an asteroid. Small changes over more than a few pixels are due to variations in scattered light from the Earth and the Moon.

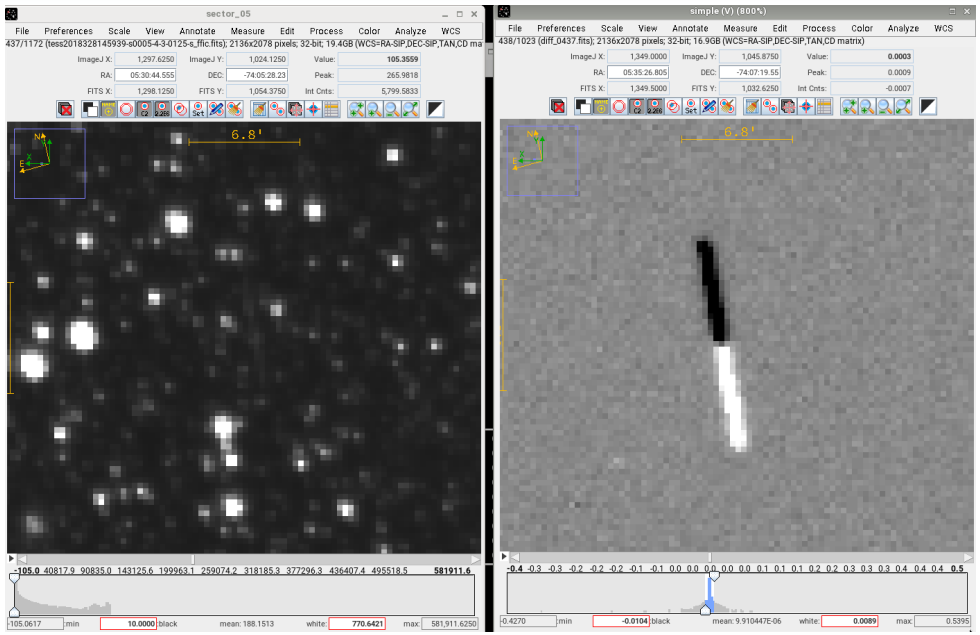
The variable sky



A full frame of TESS sector 5 camera 4.

The Large Magellanic Cloud is in the overlapped region of most sectors while TESS is observing the southern ecliptic hemisphere.

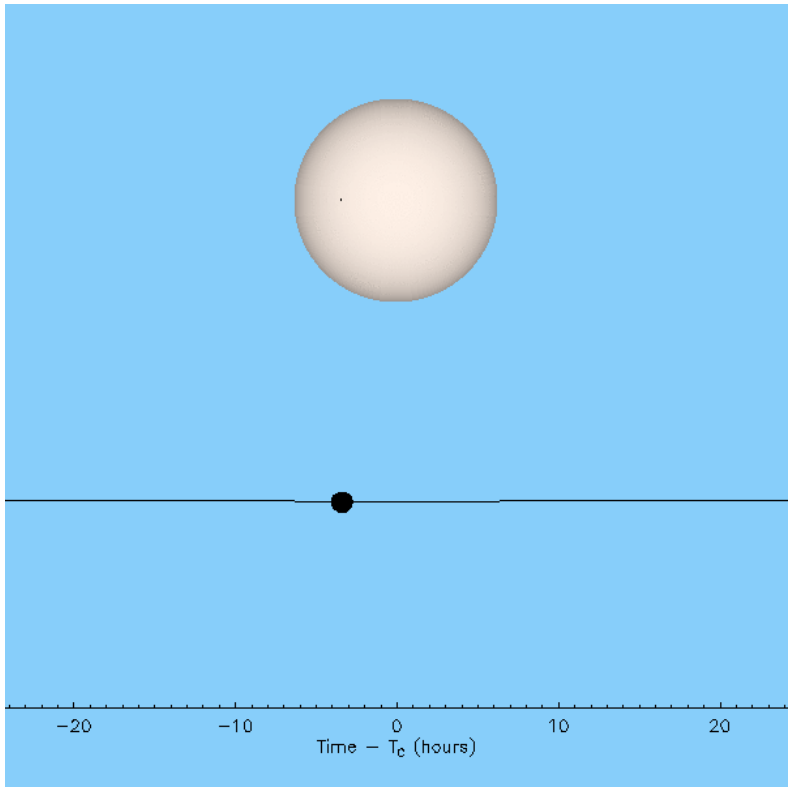
The variable sky



Variable components are highlighted by processing to show changes from frame to frame. (click)

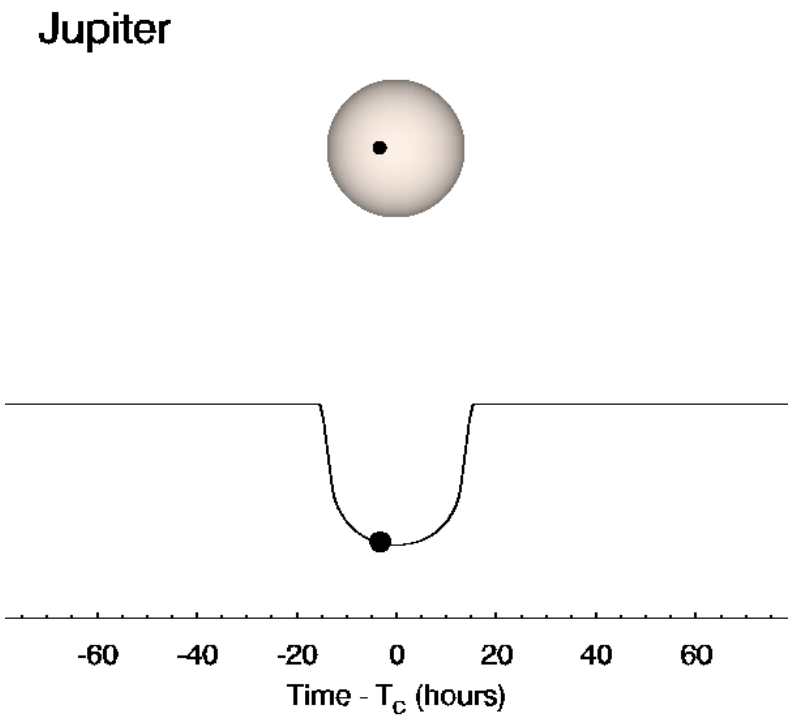
A near-Earth asteroid (possibly (4953) 1990 MU) crosses the full frame in two days and moves significantly during a 30 minute exposure.

Transiting planets



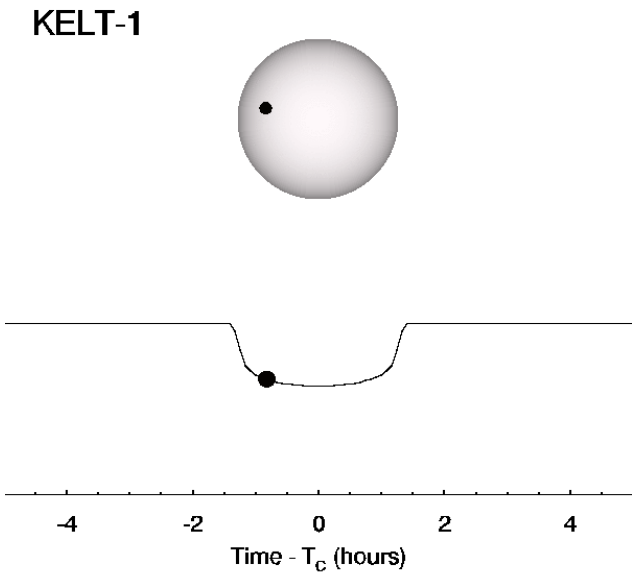
Transiting Earth as it would appear from another star. (click)

Transiting planets



Transiting Jupiter as it would appear from another star. (click)

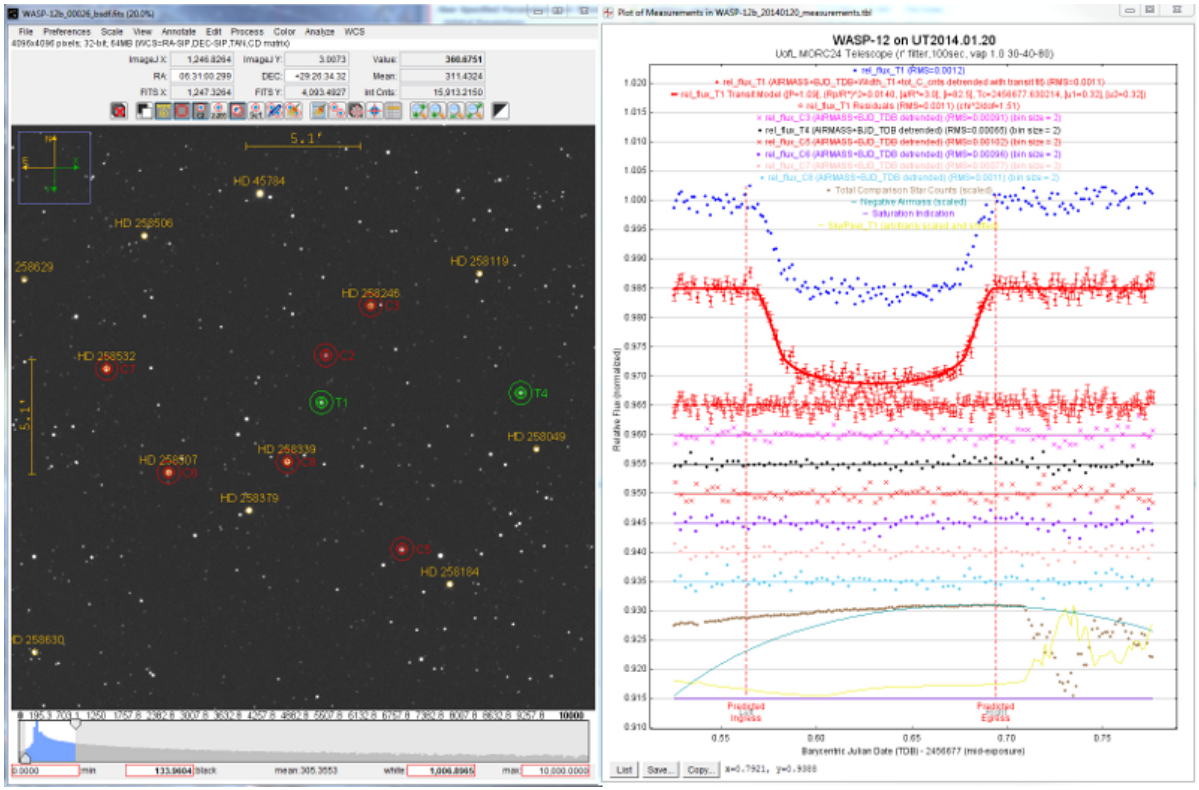
Transiting planets



Transiting brown dwarf KELT-1b. (click)

The host F-type star is somewhat hotter than the Sun. In our sky it appears at magnitude 10.7 (about 100× fainter than the faintest naked-eye star). KELT-1b is 27× Jupiter's mass.

Transiting planets



AstroImageJ is our open source software that is widely used by professional and amateur astronomers to make precision measurements of transit and variable star light curves.

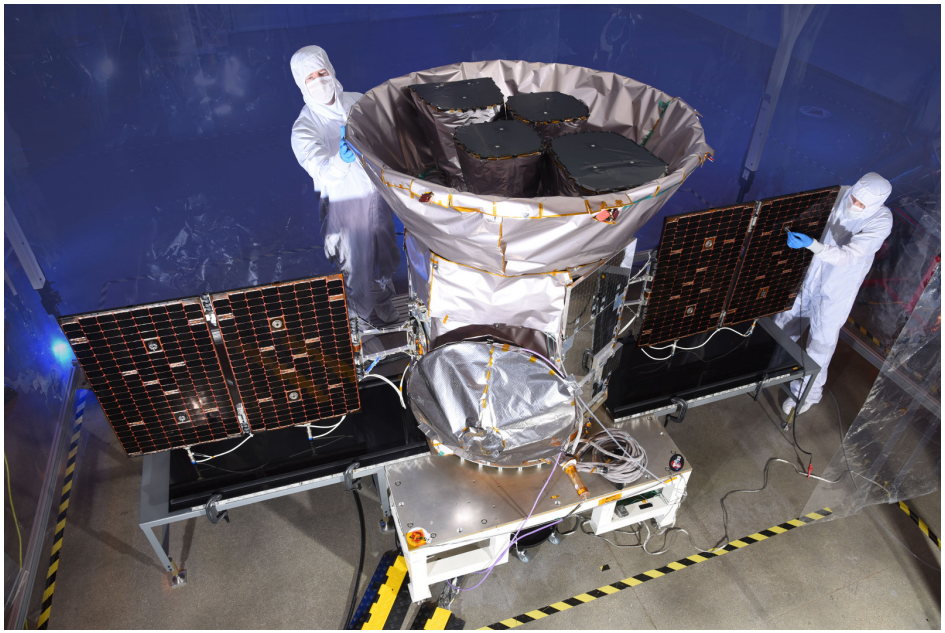
KELT

Lens	Mamiya f/1.9 with 42 mm aperture
Camera	Apogee AP16E 4096×4096 $9\,\mu\mathrm{m}$ pixels
Field of View	$26^\circ \times 26^\circ$ and $23''$ per pixel
Mounting	Softwave Bisque Paramount ME
Locations	Sonoita, Arizona, and Sutherland, South Africa
Science Operation	Since 2005

KELT

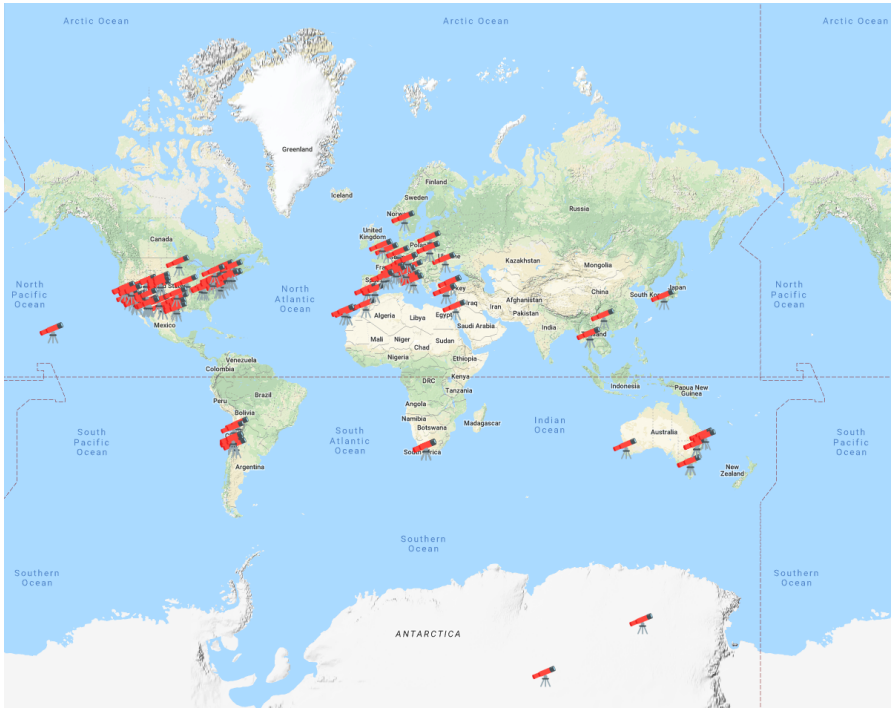
The KELT Follow-Up Network (KFUN).

TESS



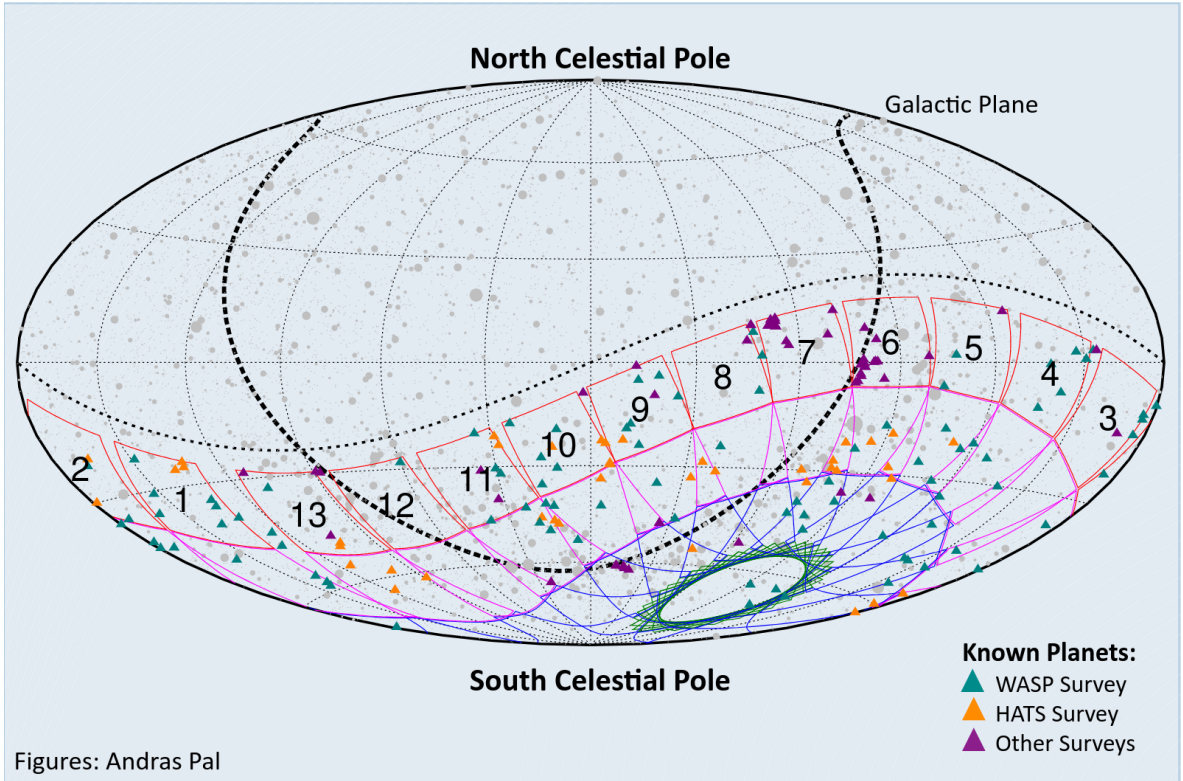
NASA's Transiting Exoplanet Survey Satellite was launched in April 2018. Its four cameras stare at a sector of the sky from the ecliptic pole to the ecliptic equator for a month at a time. New planets, and other time dependent events it discovers are studied by ground-based telescopes and future space-based missions.
U of L is a member of TESS follow-up programs.

TESS



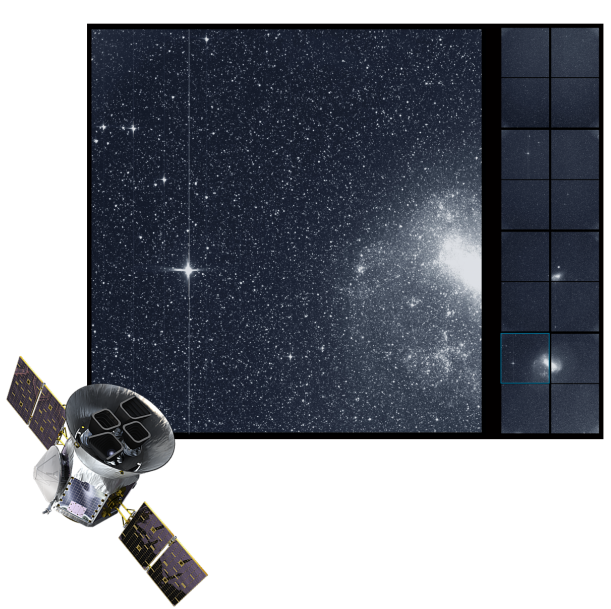
Precision photometry follow-up is a coordinated effort of TESS SG-1 TFOP with telescopes and collaborators worldwide. Data from TFOP are proprietary for 1 year and shared in joint publications.

TESS



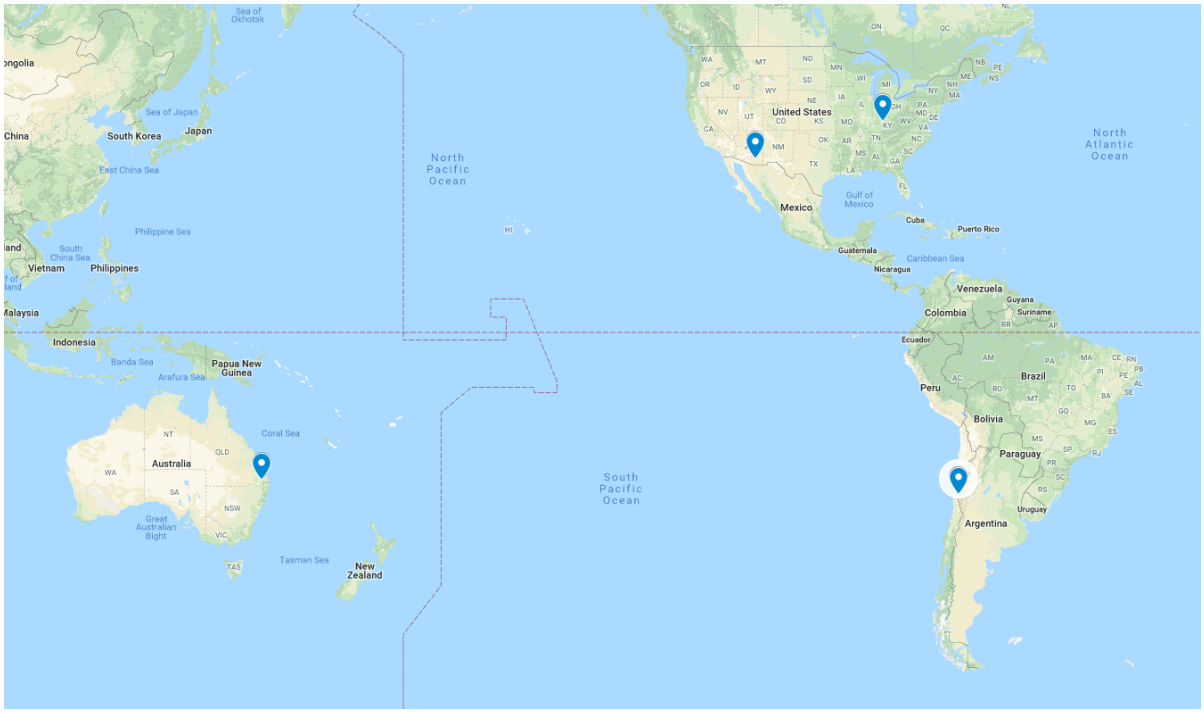
TESS is currently observing the southern ecliptic sky and is working on sector 8. Raw and processed data for sectors 1-5 have been released to the public.

TESS



- Orbit resonant with the Moon for stable operation to 2038
- Excellent camera performance (16 4-megapixel CCD's)
- On-board data compression enables full frame images
- Sector 8 in progress
- Discovery of more than exoplanets likely

Our resources



- Remotely operated telescopes in Kentucky, Arizona, and Queensland
- Minerva Australis – Precision stellar spectroscopy
- Large Synoptic Survey Telescope (LSST) – Data in 2022

Remotely operated and robotic instruments

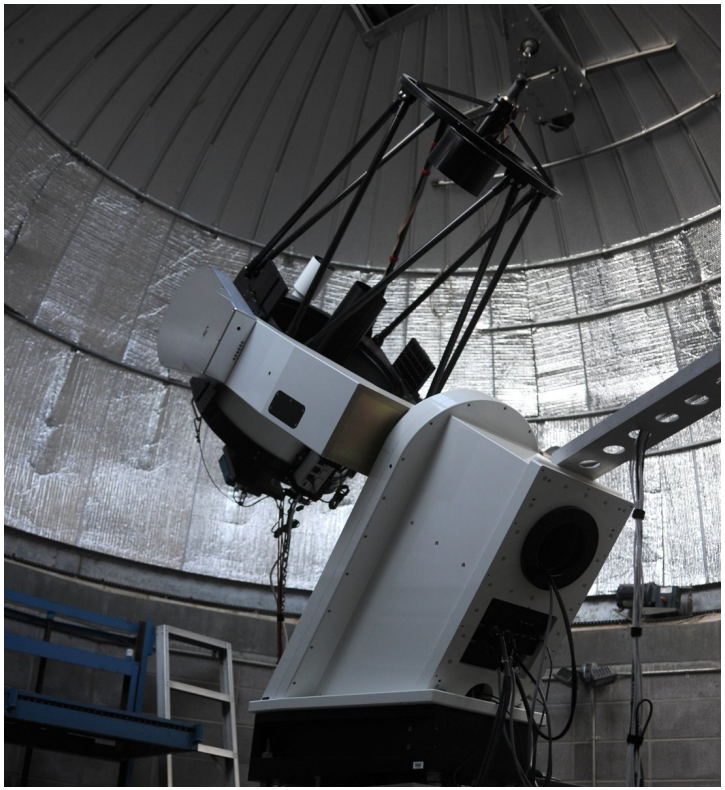
Astronomy is an "observational" science. Our knowledge derives from detecting light and thoughtfully analyzing it with physics.

Moore Observatory

Walter Lee Moore
1898 - 1989

Dr. Moore demonstrates the movements of the planets by means of a small planetarium, the property of William Marshall Bullitt. The planetarium shows the sun, Mercury, Venus, the earth and Mars, and the movement of the moon about the earth.

Moore Observatory



Moore Observatory has three research telescopes that are remotely operable. This 0.6-meter Ritchie-Chriétien and a similar one on Mt. Lemmon in Arizona produce some of the best ground-based exoplanet transit photometry in the world.

Moore Observatory

Our 0.5 meter corrected Dall-Kirkham telescopes are tools for exoplanet transit studies and student observing. This one at Moore has a twin at Mt. Kent in Australia.

Moore Observatory

Dr. Daniel Azari has donated his 0.5 meter telescope that will be used instrument development, student training, and rapid-response time-sensitive observations.

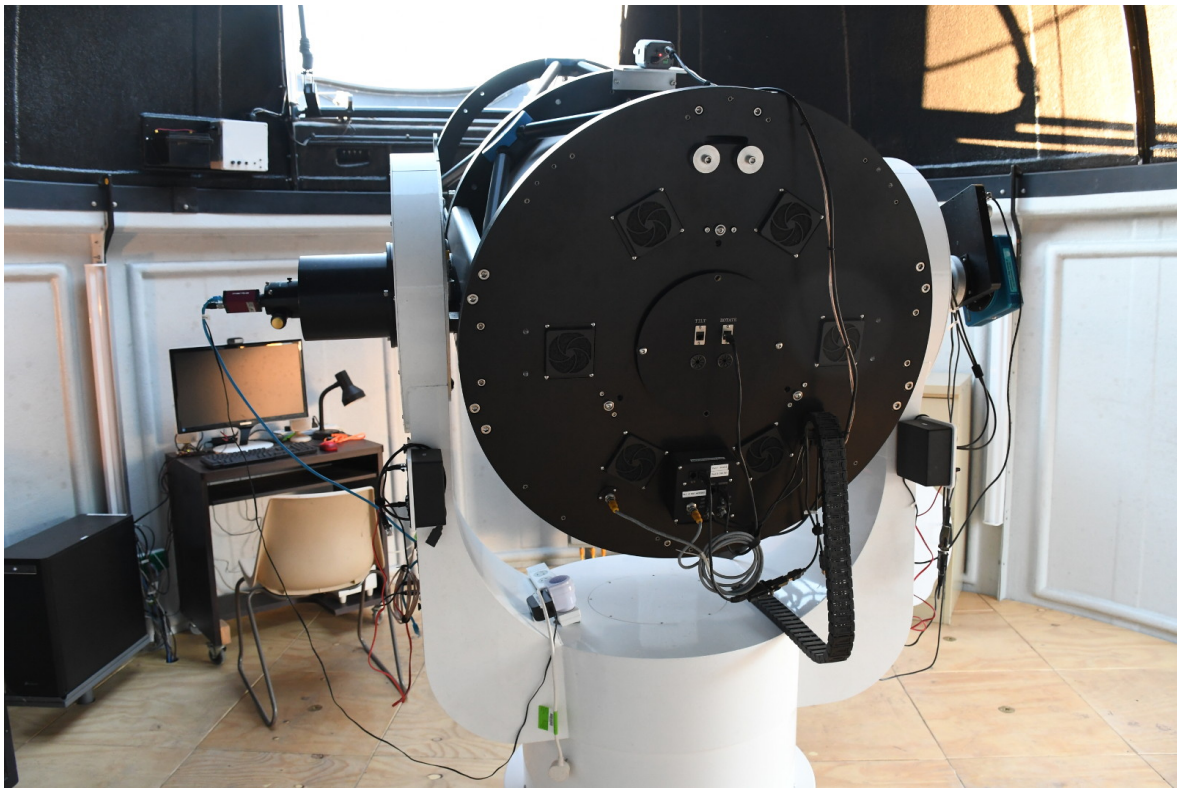
Mt. Lemmon

A gift from Mark Manner of Nashville, Tennesse, provided the 0.6 meter Manner telescope on Mt. Lemmon at Steward Observatory in Arizona.

Australian skies

The University of Louisville collaborates with the University of Southern Queensland in Australia in a Shared Skies Partnership for research and education. Our team at USQ includes Brad Carter, Rhodes Hart, Stephen Marsden, and Rob Wittenmyer.

Mt. Kent Observatory

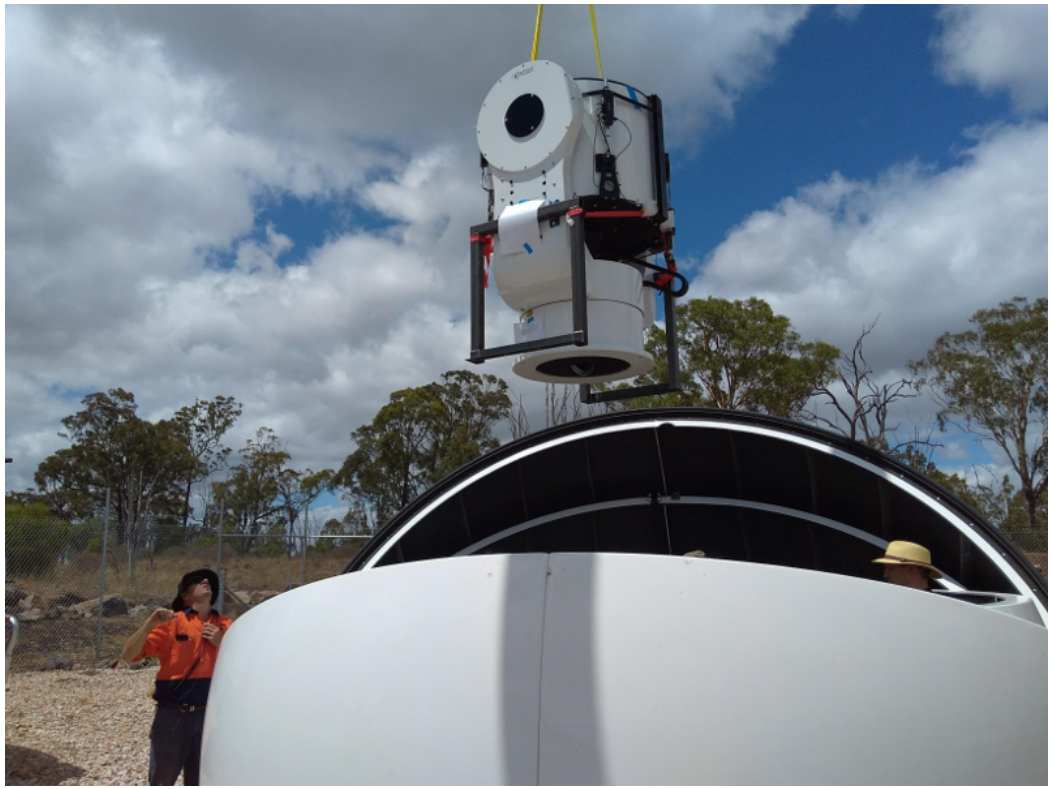


At Mt. Kent Observatory in Queensland this 0.7 meter telescope, a companion 0.5 meter telescope, and an echelle spectrograph are used to study objects identified by NASA's TESS satellite.

Minerva Australis

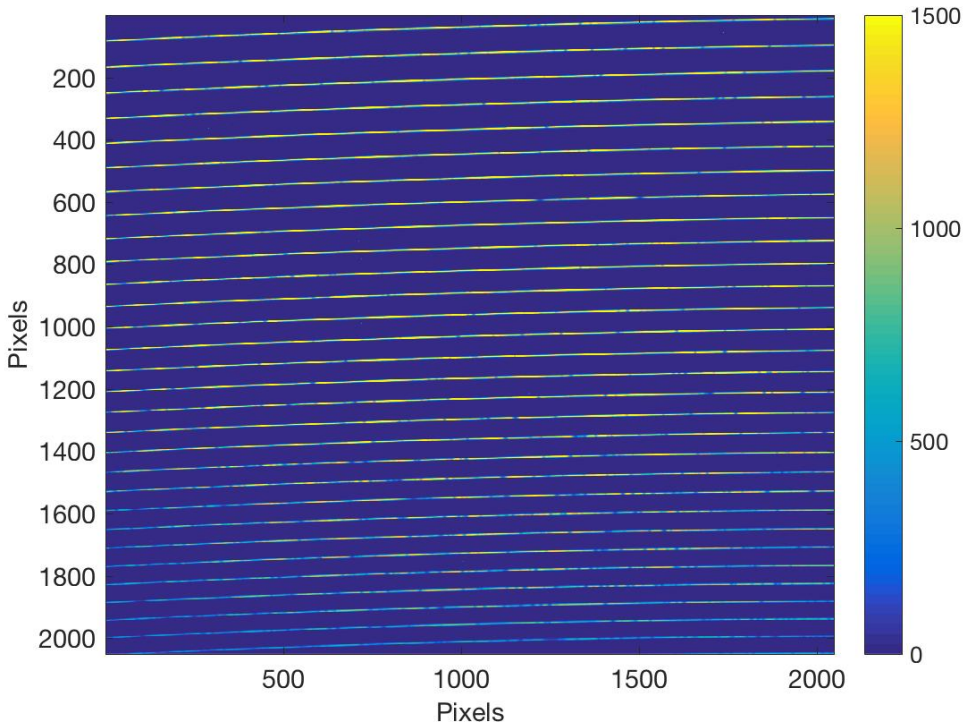
The University of Louisville is a partner in Minerva Australis, a precision stellar spectroscopy facility. Other institutions include the Universities of Southern Queensland and New South Wales, the University of California Riverside, George Mason, and MIT.

Minerva Australis



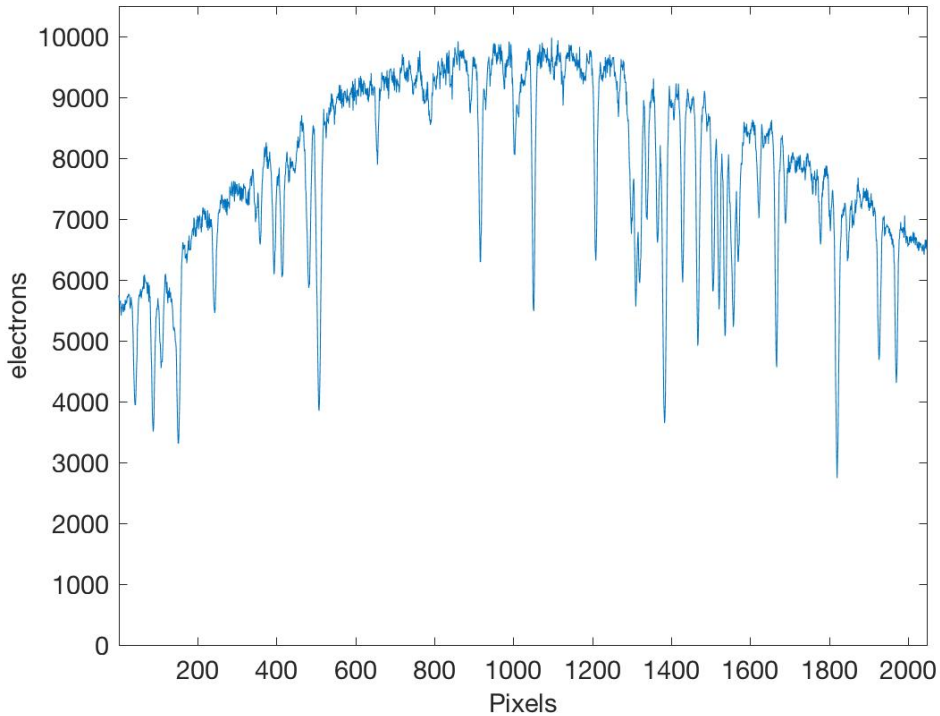
The second and third telescopes were installed in February 2019. There will be 5 CDK700 telescopes feeding the spectrograph. The equivalent aperture of the array is a 1.6 meter telescope. (click)

Minerva Australis



Minerva's spectrograph is fed by optical fibers combining light from several telescopes. An echelle grating produces spectra like this. Each horizontal band is a piece of the stellar spectrum that placed end to end span from the blue to the red.

Minerva Australis

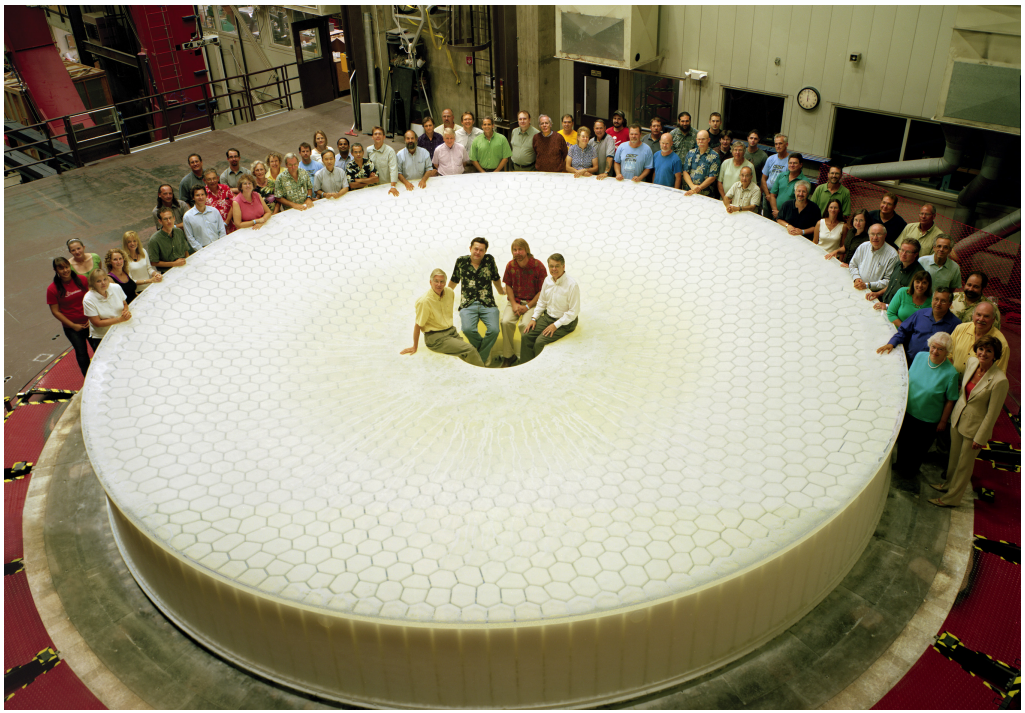


A slice of the spectrum measures the flux from the star calibrated by a stable reference spectrum of molecular iodine with a precision measured in radial velocity of 1 meter per second.

LSST

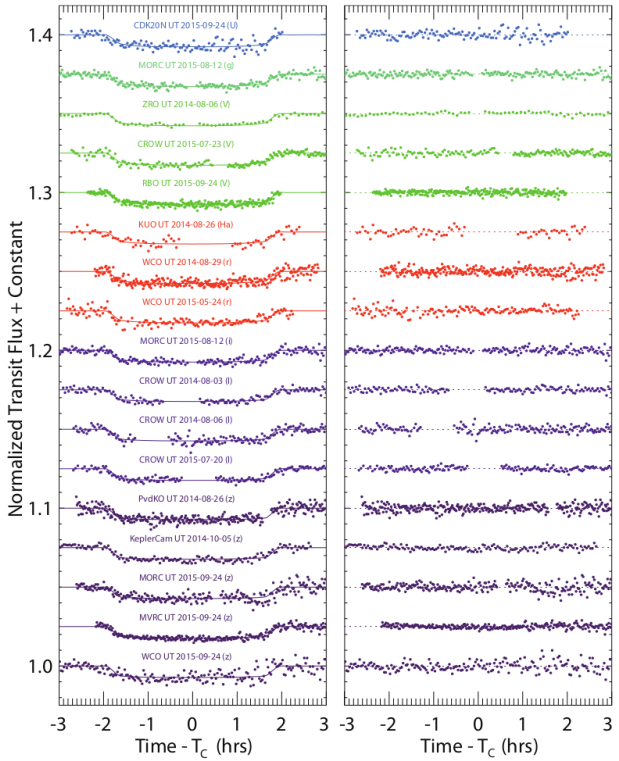
The Large Synoptic Survey Telescope's 6.5 meter mirror will see starlight for the first time in 2020. It will bring an era of large data to astronomy by surveying the visible sky weekly for transient events. U of L and UK are members of the organization building the telescope and planning its observing and outreach programs.

LSST



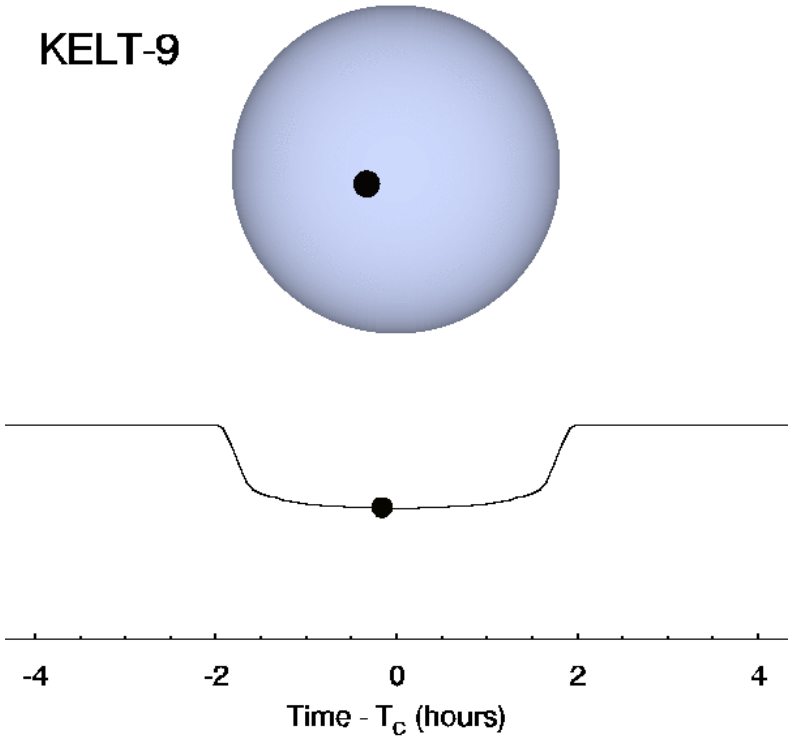
The LSST primary mirror is the largest component of its optical system that is designed to image a unprecedented field 3.5 degrees in diameter in one exposure. The construction is funded by private foundations, the National Science Foundation, and the Department of Energy.

KELT-9b



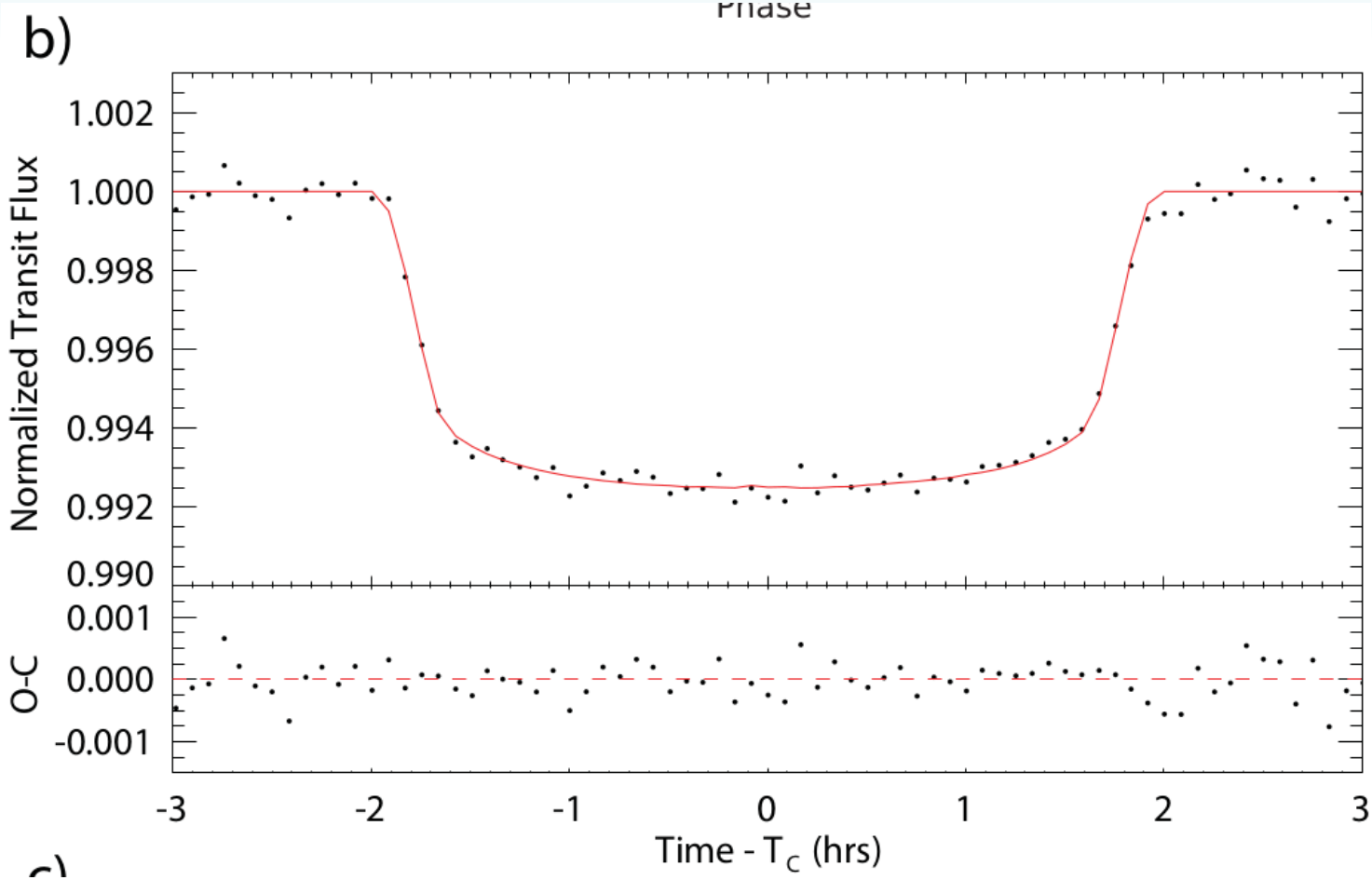
When a planet passes between us and its host star it blocks out a tiny part of the star's light, producing a unique periodic signature we can measure. Here data on a bright (7.5 magnitude) hot (7430 K) nearby (206 parsecs) star HD 195689 were used to confirm its companion KELT-9b (Nature 2017).

KELT-9b



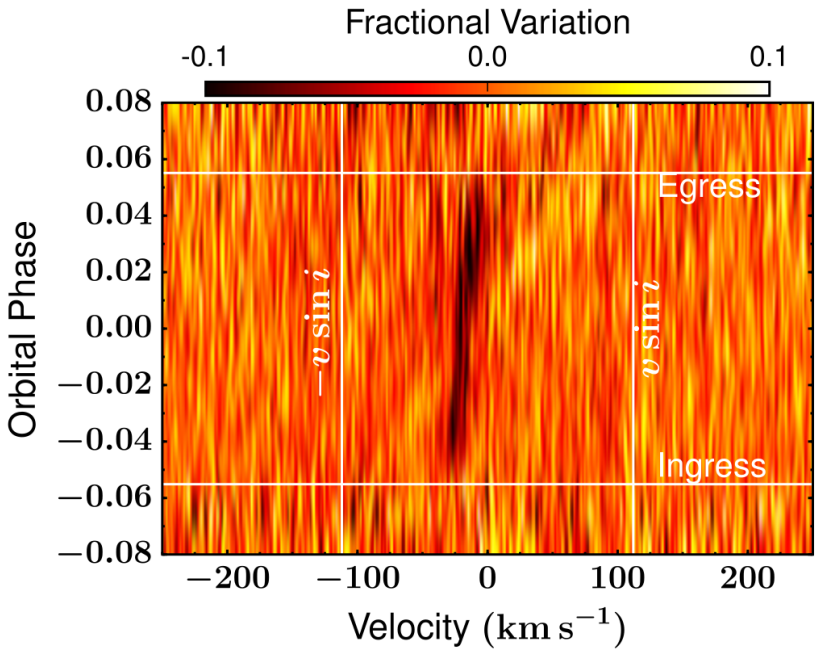
Model of the KELT-9 transit. (click)

KELT-9b



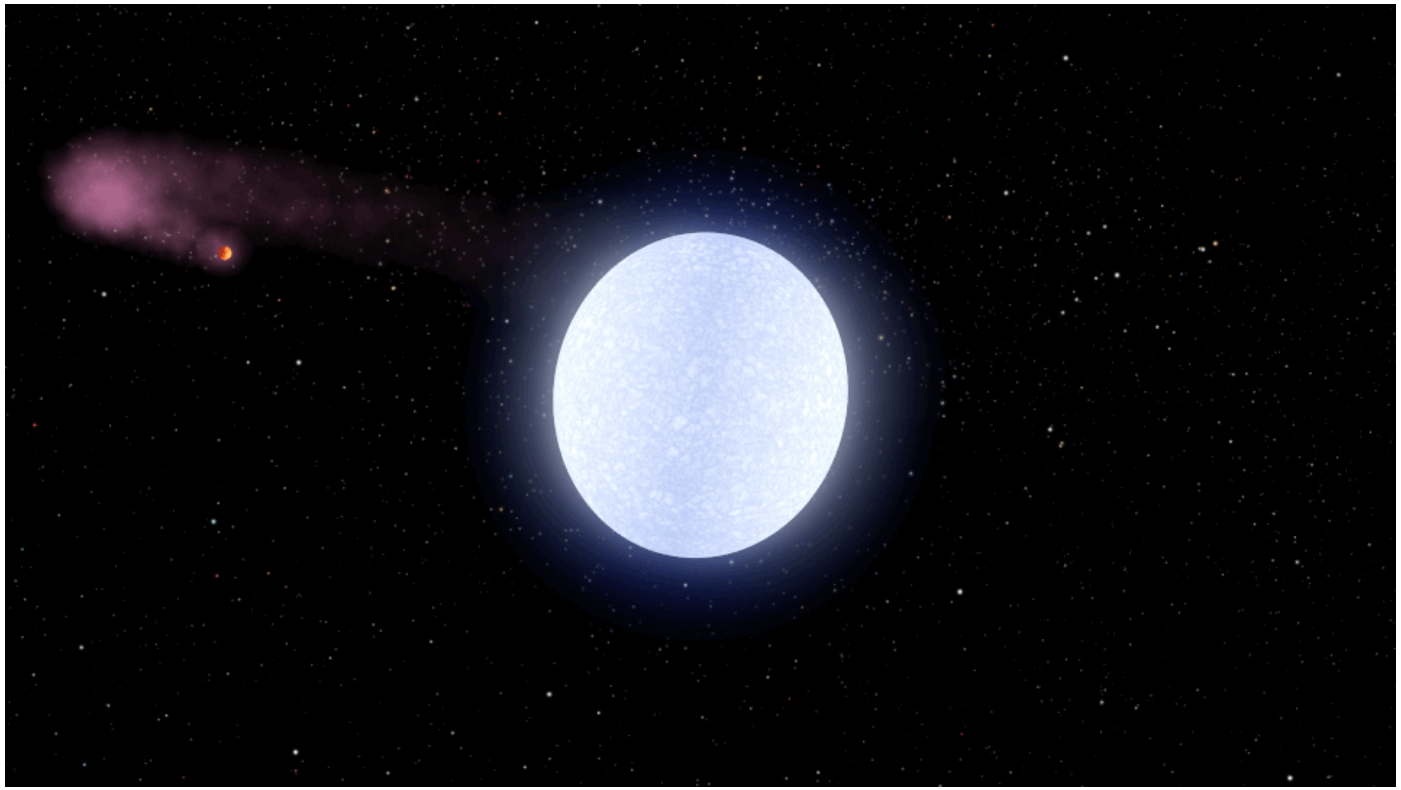
Higher precision is obtained by combining many measurements of KELT-9b, and by fitting those to physics-based models of the star, the planet, and its orbit (Nature 2017).

KELT-9b



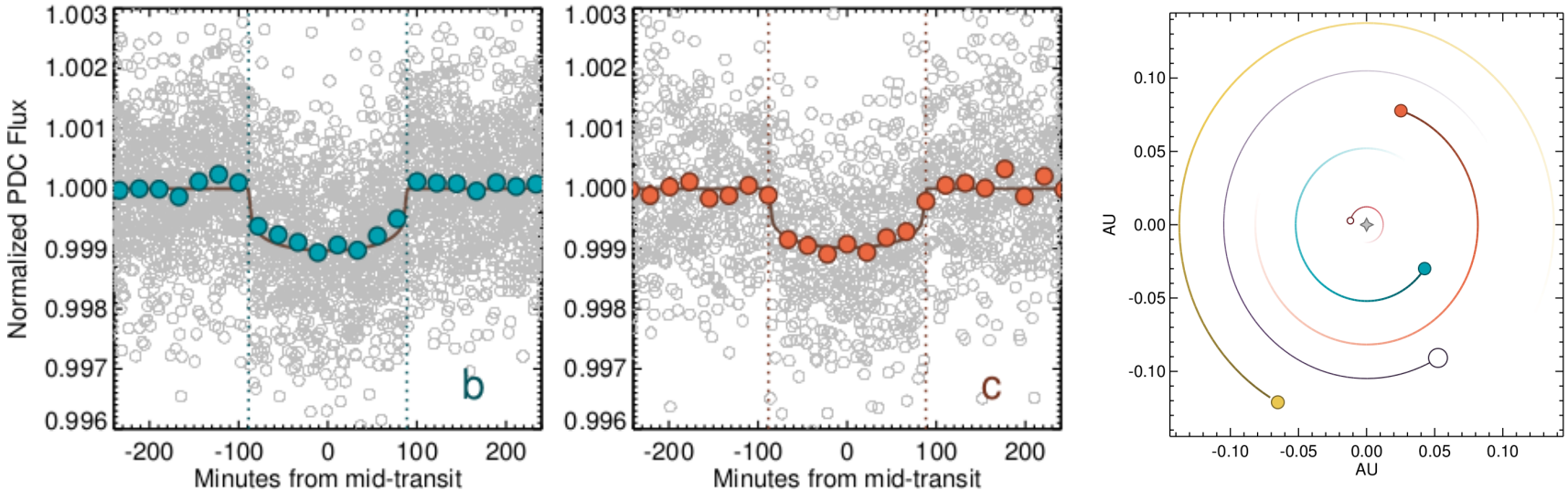
Precision spectroscopy gives the radial velocity of the star as it is pulled by the planet, and it also reveals the shadow of the planet in the spectrum where it removes frequencies corresponding to the rotational velocity of that part of the star it is blocking. The technique is called *Doppler tomography* (Scott Gaudi, et al., Nature 2017).

KELT-9b



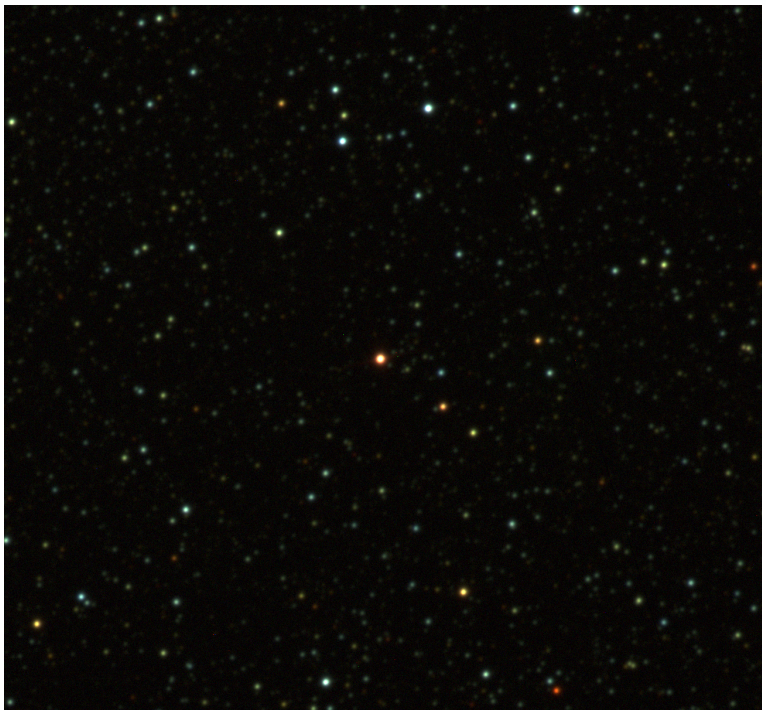
Visualization of the KELT-9 system. (click)

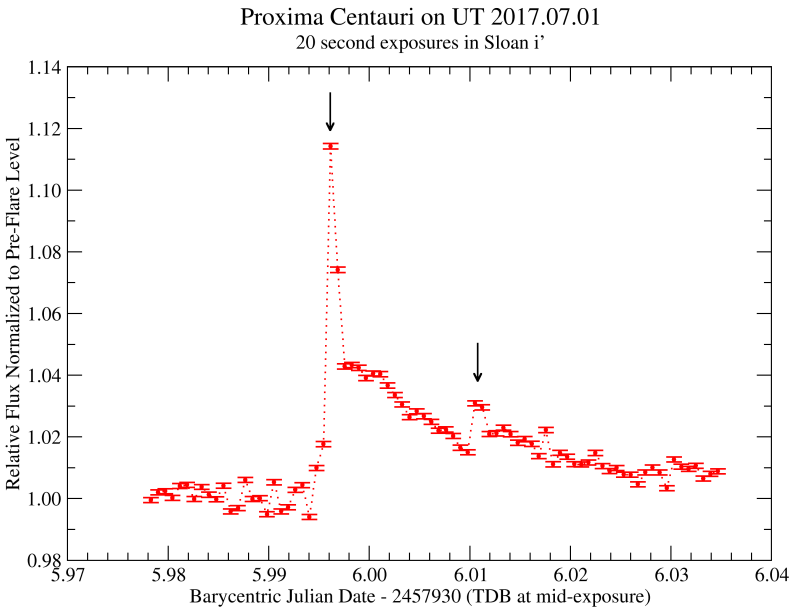
TESS TOI-125



TESS full-frame images reveal a planet candidate and follow-up spectroscopy (Sam Quinn, et al.) found evidence of 5 planets with periods from 0.5 to 20 days smaller than Neptune orbiting a cool K0 star. The system is unique, with two of the massive planets just inside a 2:1 resonance. Planets of this type are possible progenitors of Earth-like planets if they lose mass by photo-evaporation.

Proxima Centauri





The nearest star only 4.2 light years away, Proxima Centauri is a cool M-dwarf companion to hot bright α Centauri out of view. A planet of roughly Earth mass orbits in its habitable zone every 11 days. Proxima has frequent low energy flares, but this one is a "super" flare capable of disrupting any nearby life.

Thanks!

- KELT: keltsurvey.org
- TESS at NASA: www.nasa.gov/content/about-tess
- TESS at MIT: tess.mit.edu
- University of Louisville Astronomy: www.astro.louisville.edu
- *Email:* john.kielkopf@louisville.edu