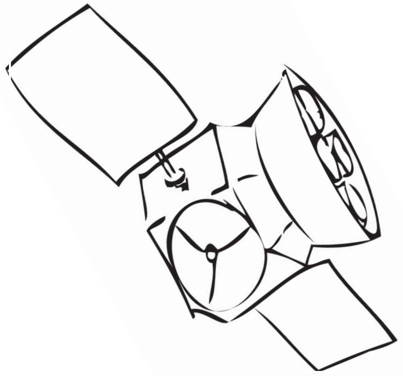
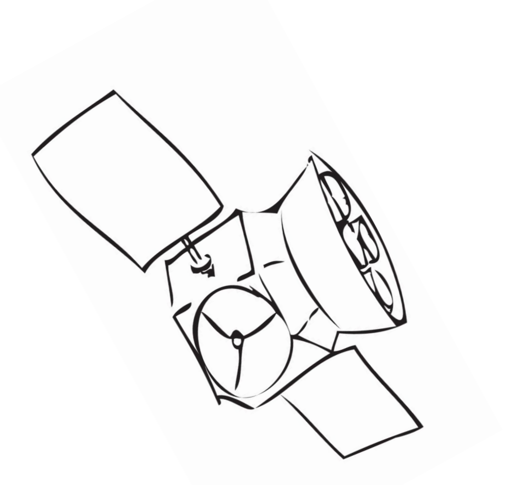
Exoplanets and The Transiting Exoplanet Survey Satellite (TESS)



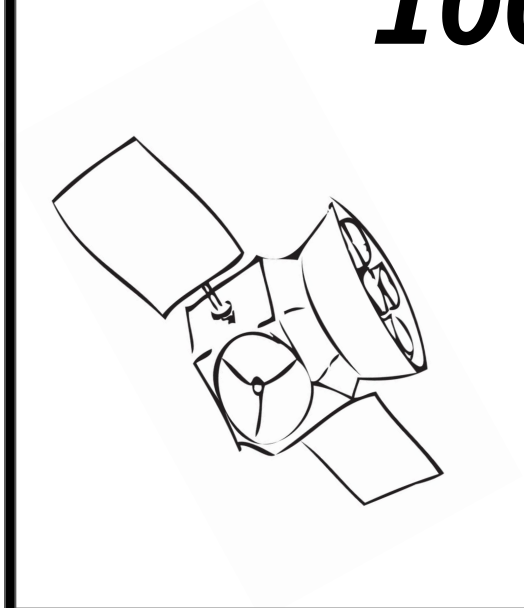
Ryan J. Oelkers

Monday, June 25, 2018
QuarkNET 2018

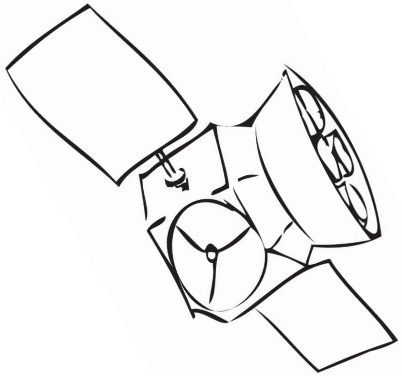
It is estimated that nearly all stars in the Milky Way Galaxy have 1-1.5 planets orbiting them.



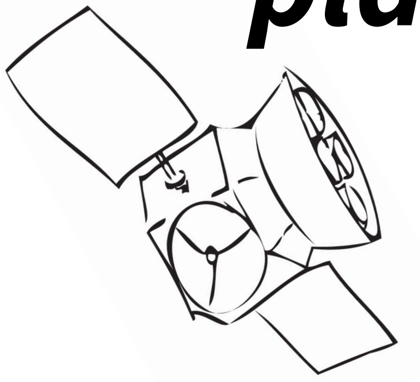
Each galaxy has approximately 100-400 billion stars.



The Universe may have 100 billion galaxies



This means there could be more than 60,000,000,000,000,000,000,000 planets in the Universe!

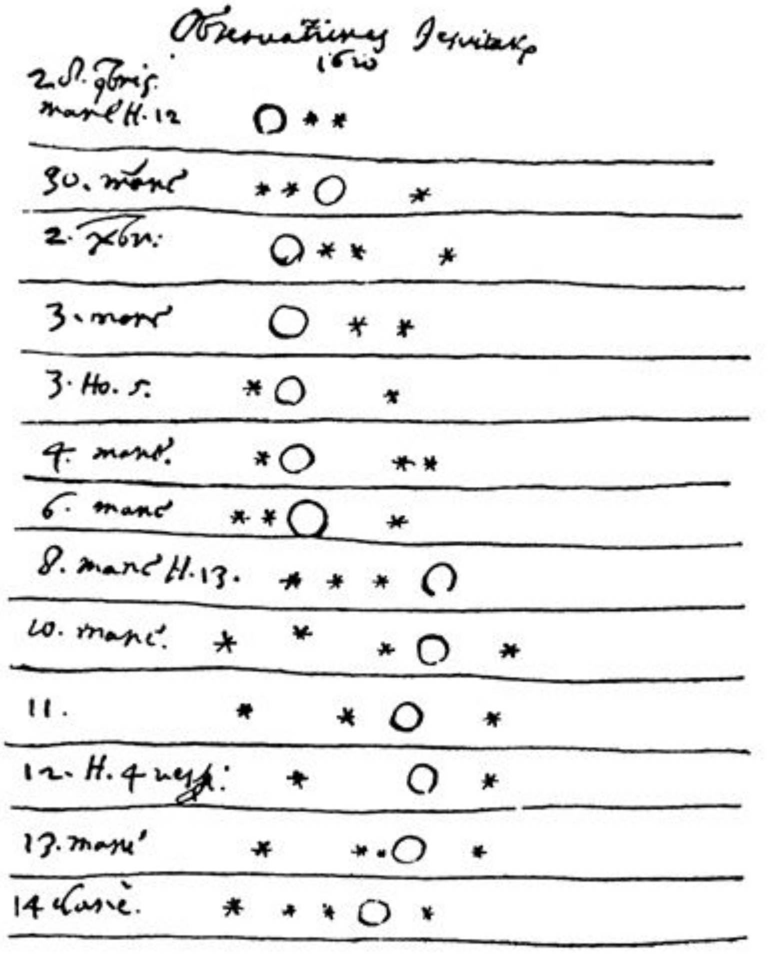


The History of Time Domain Astronomy

Taking measurements of stars with time (time-series), form the basis for most of our understanding of stellar and planetary astrophysics.

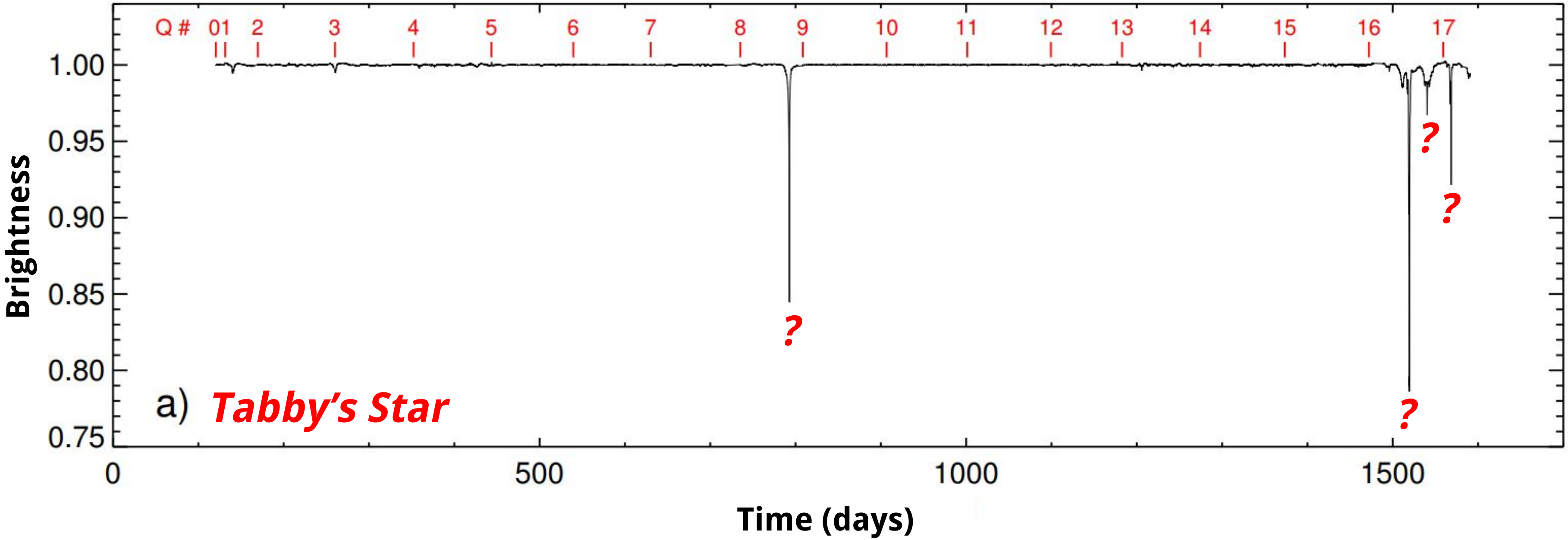
Many of the time-series studies of the past decade have been pioneered with small-moderate aperture telescopes.

These surveys not only dominated the observations of thousands of stars on a nightly basis, but they also provided an insight into reducing their large data sets on reasonable timescales.



Drawings of Jupiter’s moons from Galileo in 1610

The History of Time Domain Astronomy



Boyajian, T. et al., 2016 MNRAS, 457, 39

What is a planet?

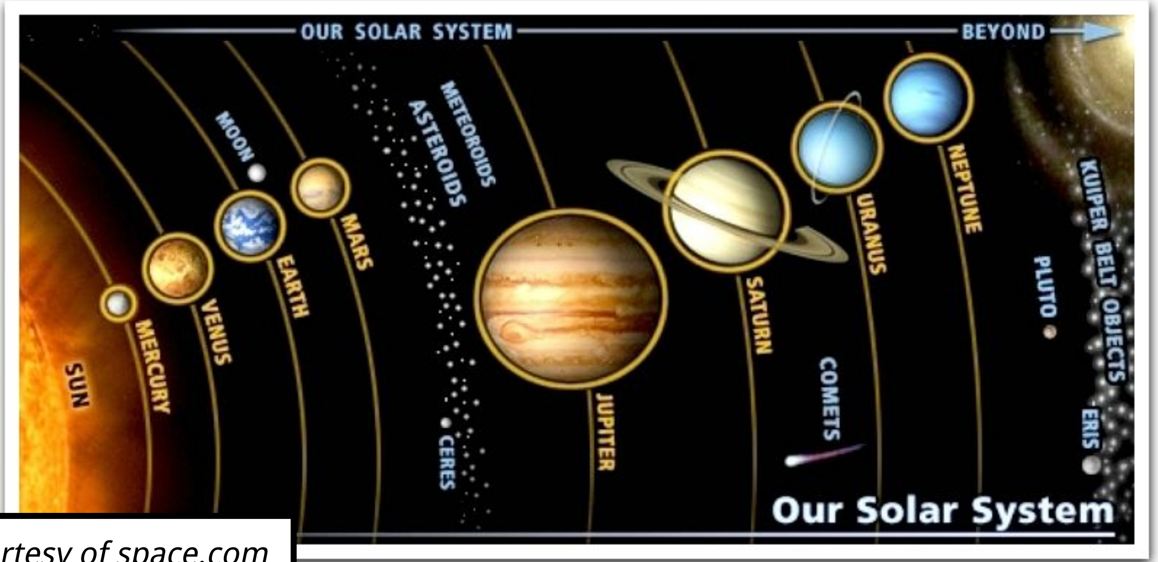


Image courtesy of space.com

A planet must meet these three requirements:

(A) The object must orbit the Sun or its host Star.
(B) The object must be round.
(C) The object must have cleared its orbit. This means it cannot orbit anything other than the Sun or its host star.

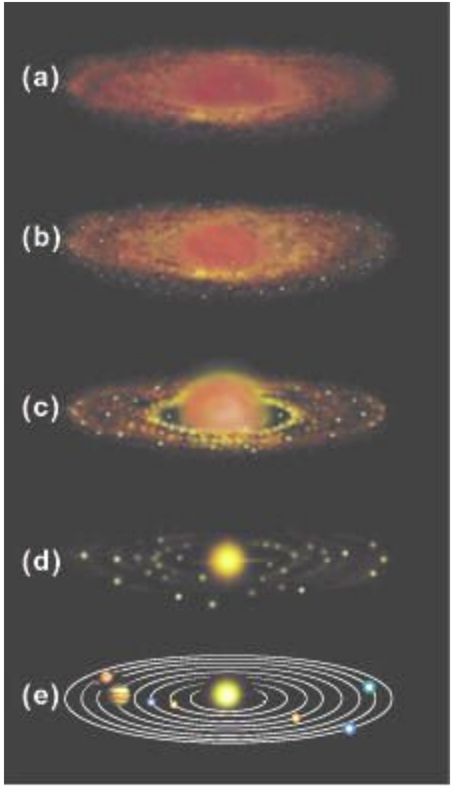
What is a planet?

Image courtesy of NASA.gov

Formation of Exoplanets

The most popular theory of planet and star formation involves:

(A) The collapse of a large spinning cloud of gas and dust.
(B) The collapsing cloud becomes a disk.
(C) The proto-star forms and heats the disk.
(D) The colliding objects become planetesimals which continue to collide.
(E) Large planetesimals, clear their orbits and create planets.

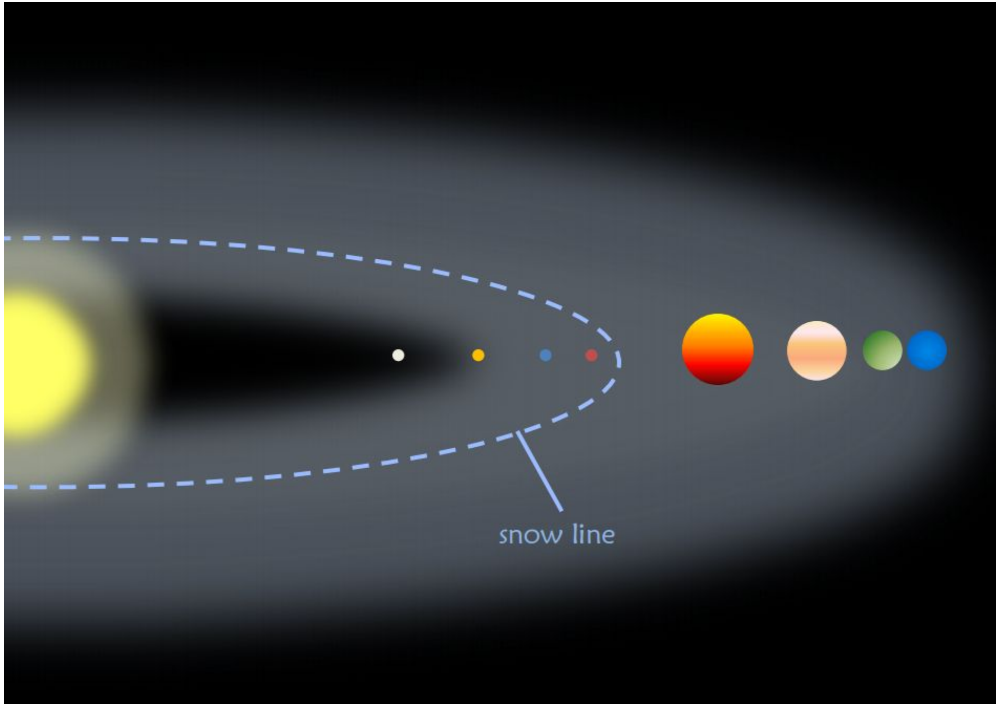


How did our Solar System Form?

Condensation theory explains our solar system very well.

Our solar system is very hierarchical -- and supports the snow line theory.

The snow line is an imaginary line in space where icy particles can form on the planetesimals causing them to grow large and retain large atmospheres.

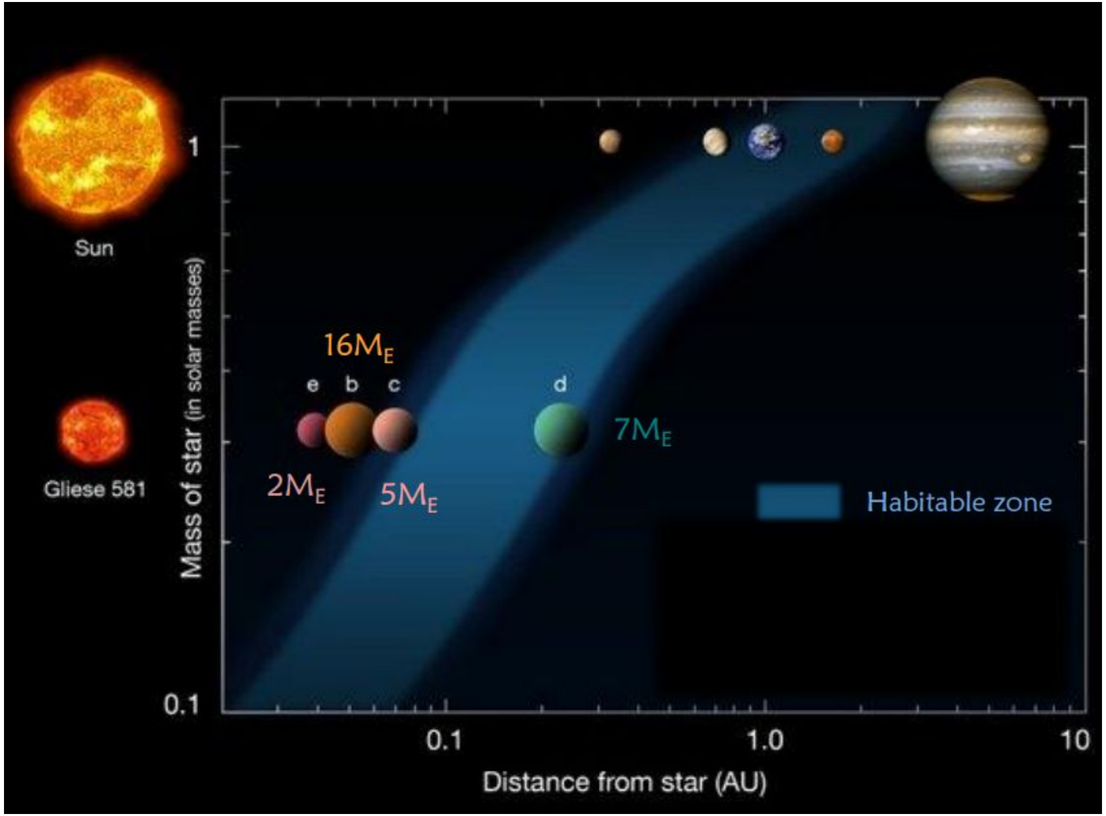


The Habitable Zone

The "Habitable Zone" (HZ) is the area in a solar system where liquid water could exist on the surface of a planet.

The HZ definition is mainly dependent on the power output of the star, and does not consider atmospheric effects.

Venus, Earth, and Mars are in the Sun's habitable zone.



The History of Exoplanets

The first identified exoplanets did not match our expectations from the solar system.

PSR B1257+12 is a pulsar which was shown to have two terrestrial sized objects orbiting it. A pulsar is a rapidly rotating neutron star which is a remnant of a supernova.

51 Pegasi is a sun-like star with a Jupiter sized object on a 4.2 day orbit. Mercury has an 88 d orbit around the Sun.

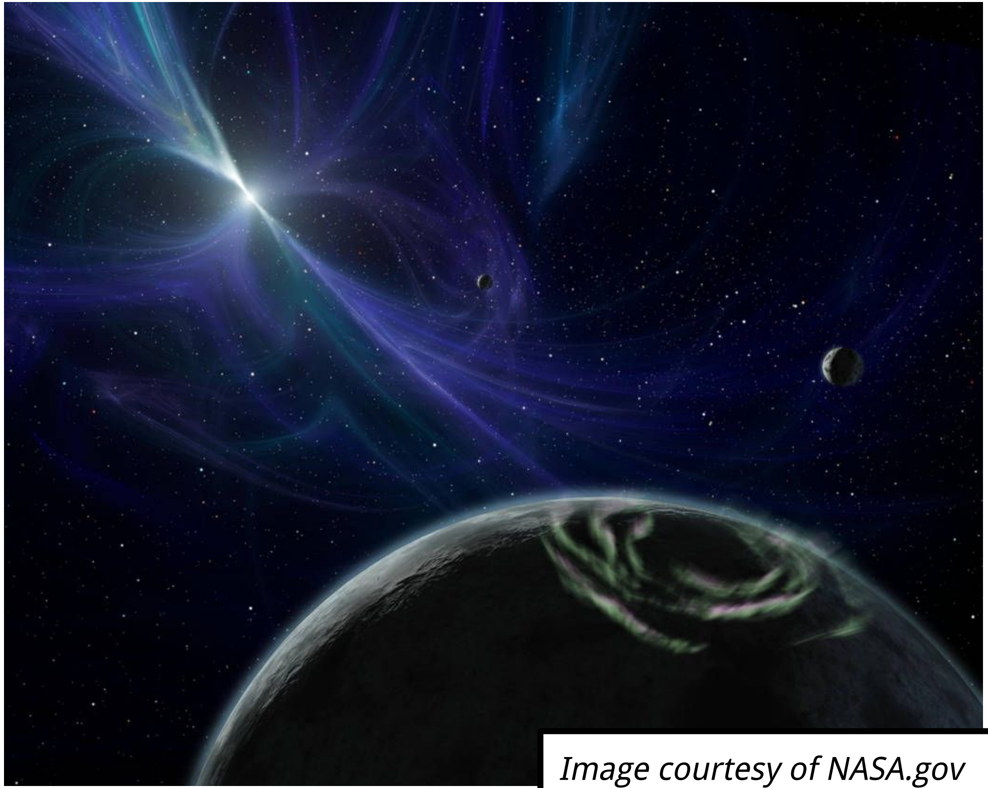
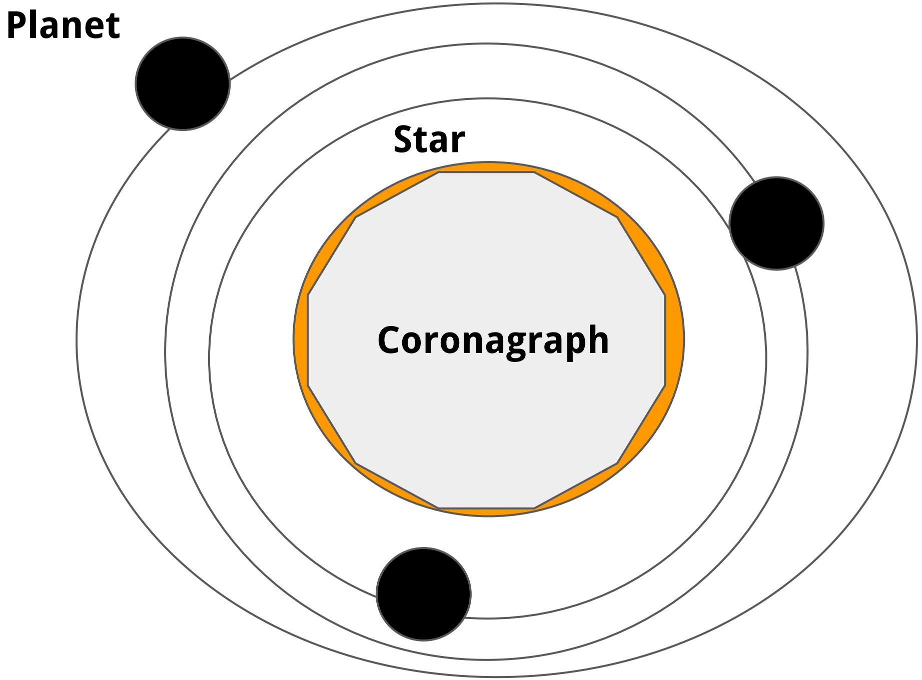


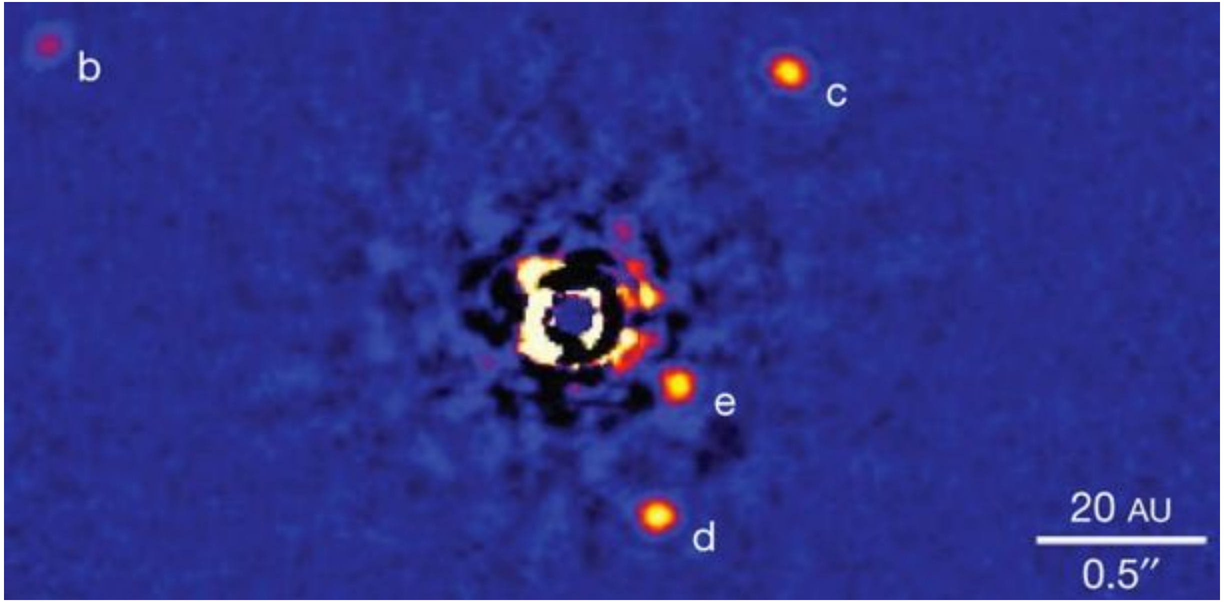
Image courtesy of NASA.gov

The Direct Imaging Method

If the planet's are large enough, and distant enough from a bright, nearby star, they may be able to be directly imaged if a coronagraph is placed over the star.



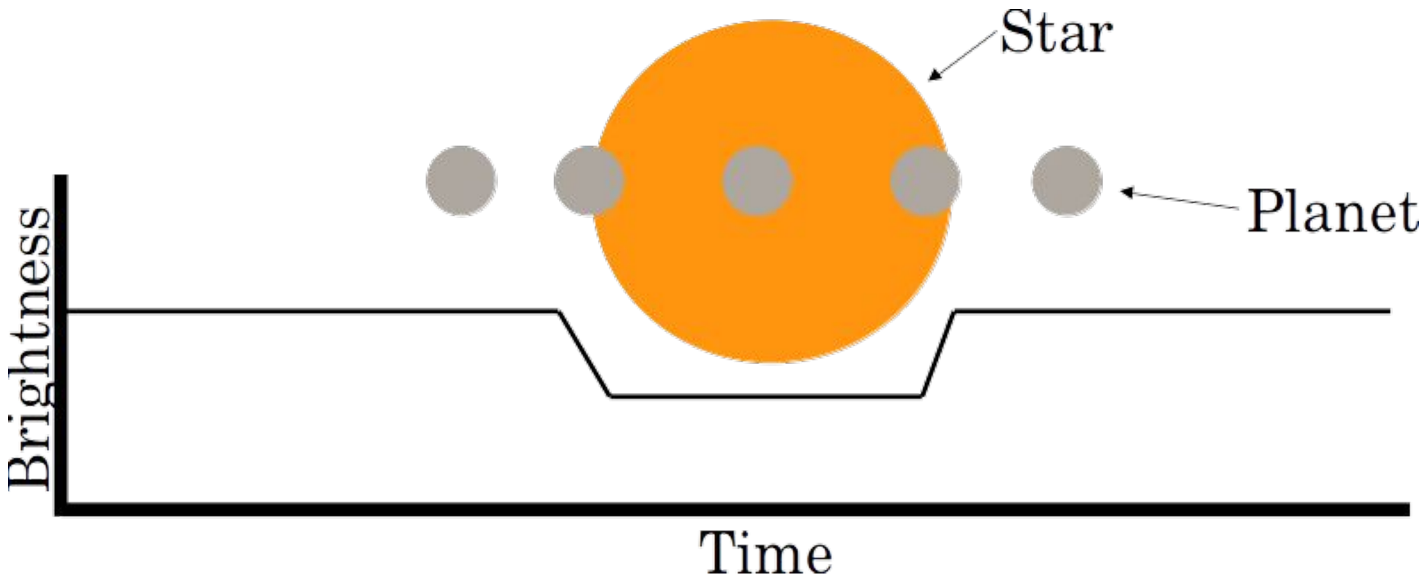
The Direct Imaging Method



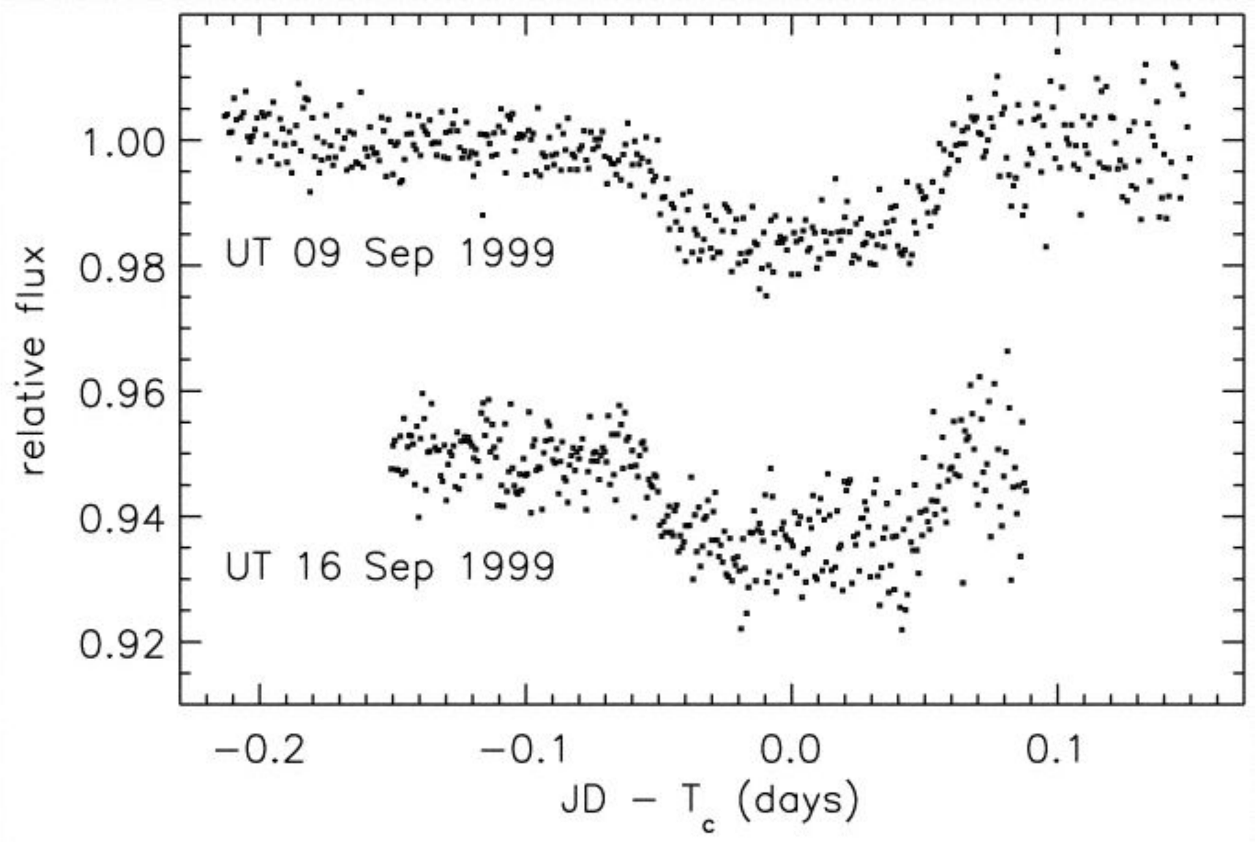
HR8799 Marois et. al 2010

The Transit Method

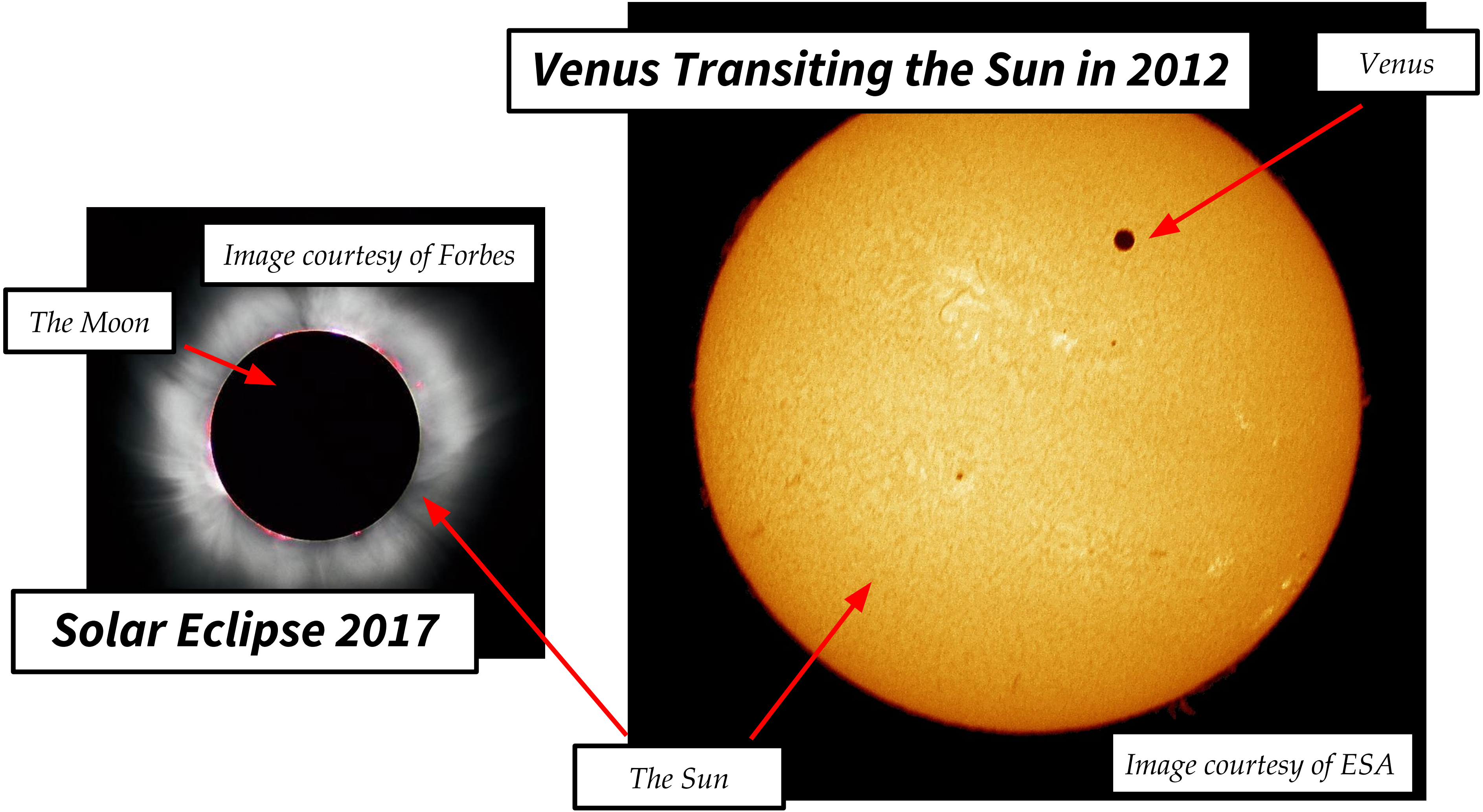
As a planet moves between its host star and the observer, the planet blocks a portion of the host star's light, and creates a noticeable drop in brightness from the host star.



The Transit Method

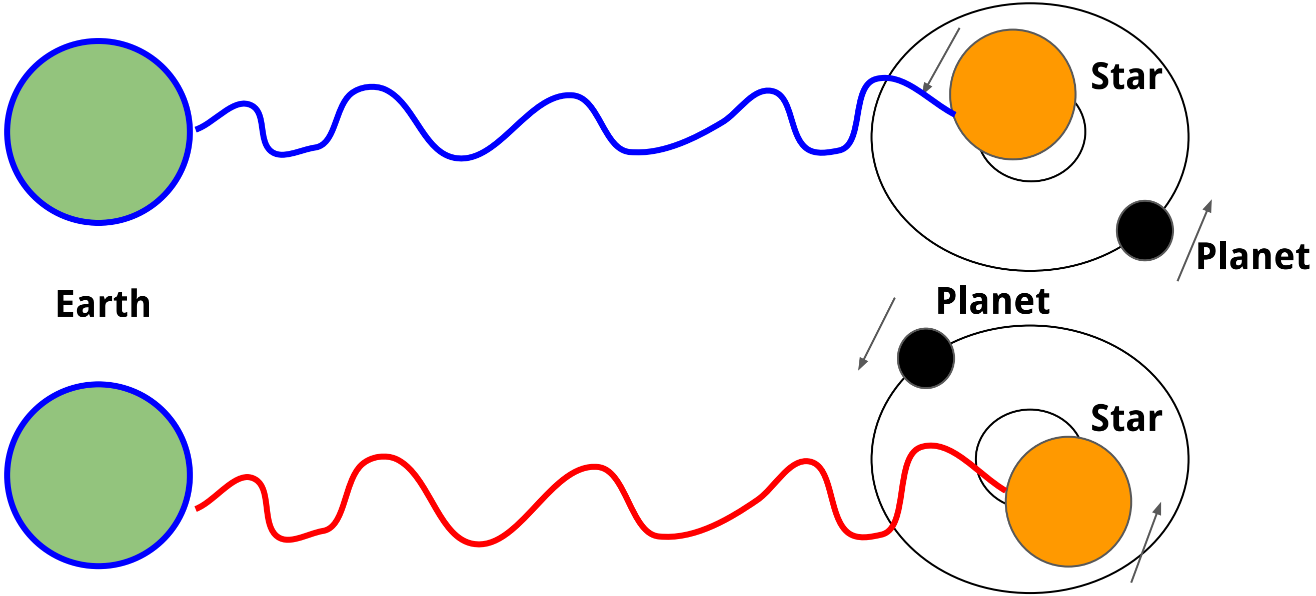


HD 209458 Charbonneu et al. 1999

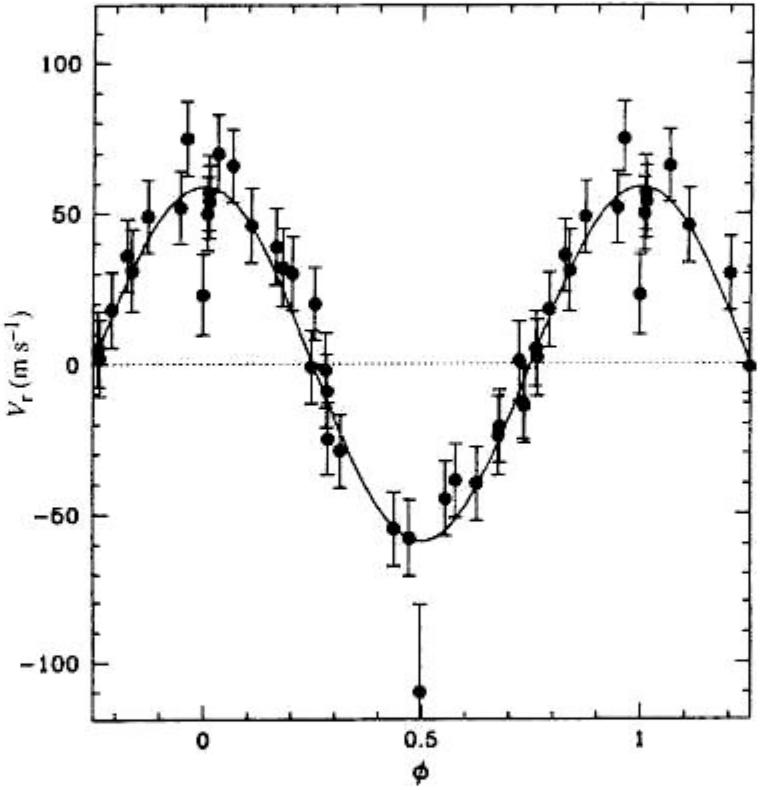

Venus Transiting the Sun in 2012
Venus
Image courtesy of Forbes
The Moon
Solar Eclipse 2017
The Sun
Image courtesy of ESA

The Radial Velocity Method

As a planet orbits around its host star, its gravity tugs the star towards the planet. This effect is noticeable in the spectrum of the star. It appears blue as the star moves towards the observer, and redder as the star moves away from the observer.



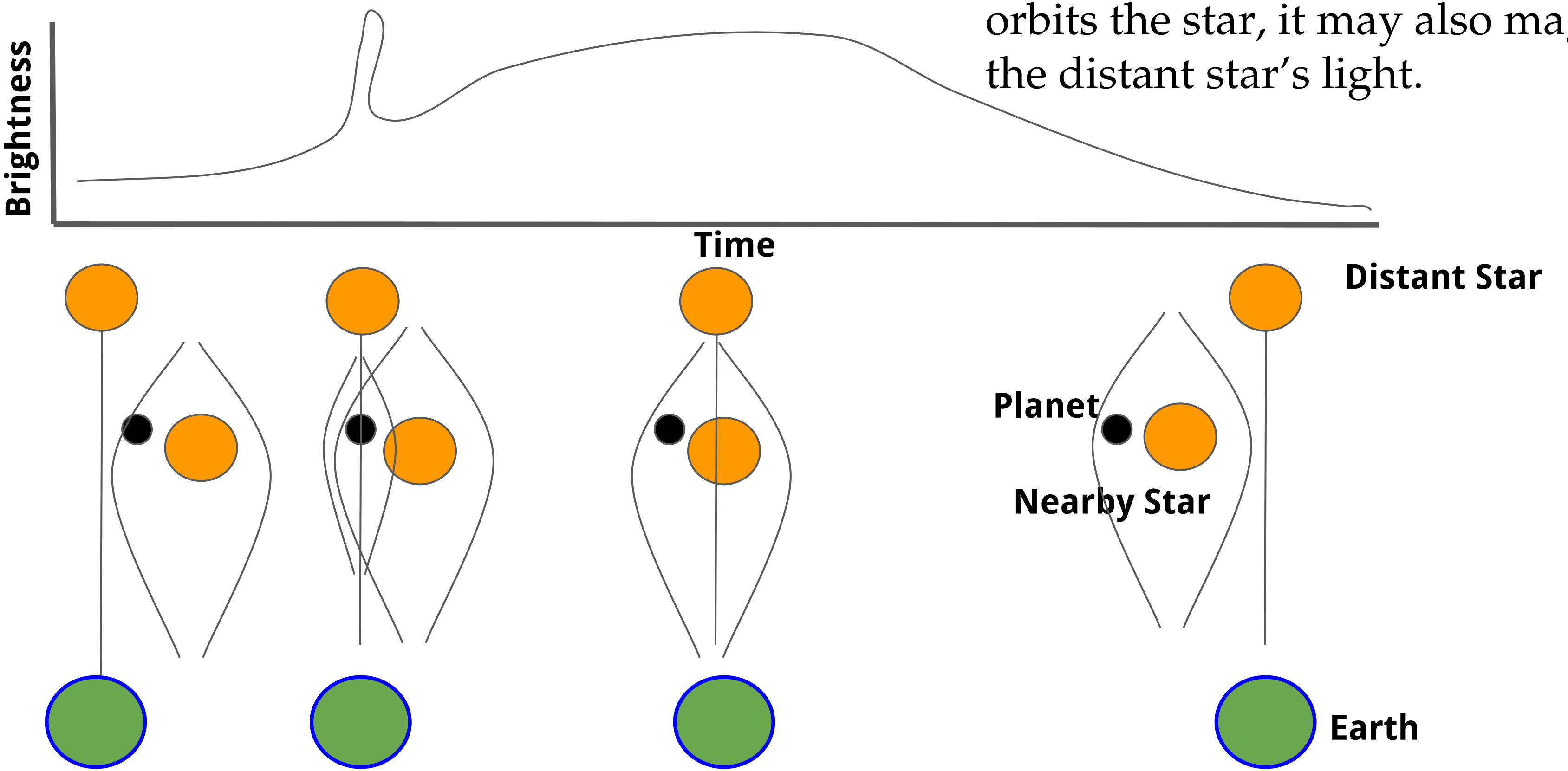
The Radial Velocity Method



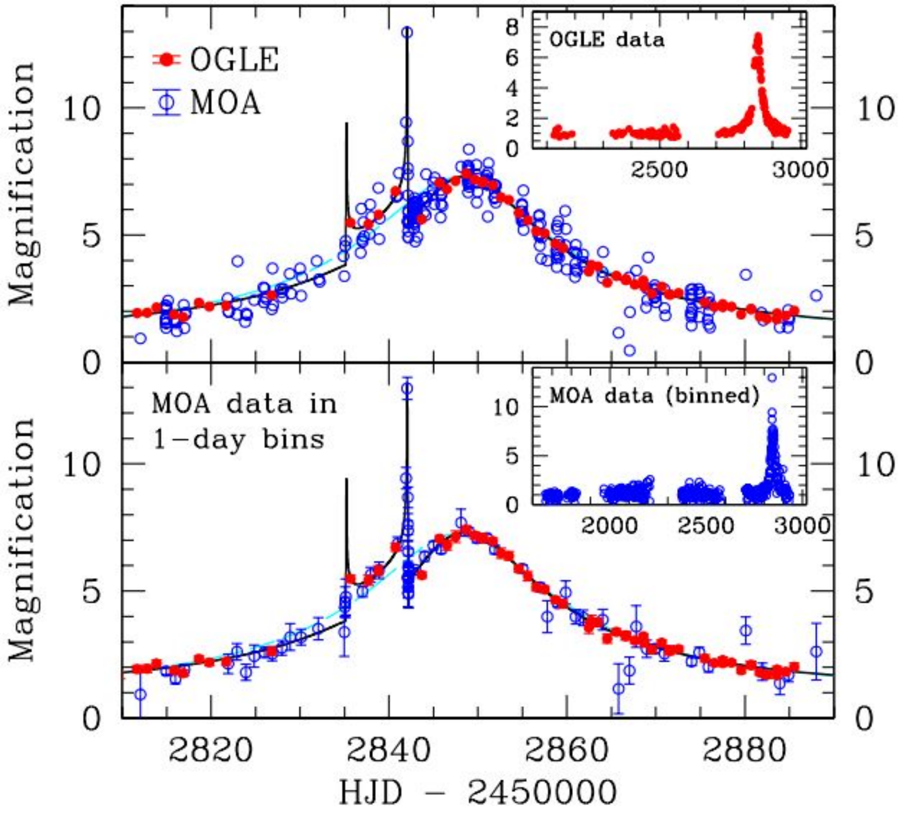
51 Pegasi Mayor and Queloz 1995

The Microlensing Method

A "nearby" star may move between Earth and a distant star, magnifying the distant star's light. If a planet orbits the star, it may also magnify the distant star's light.

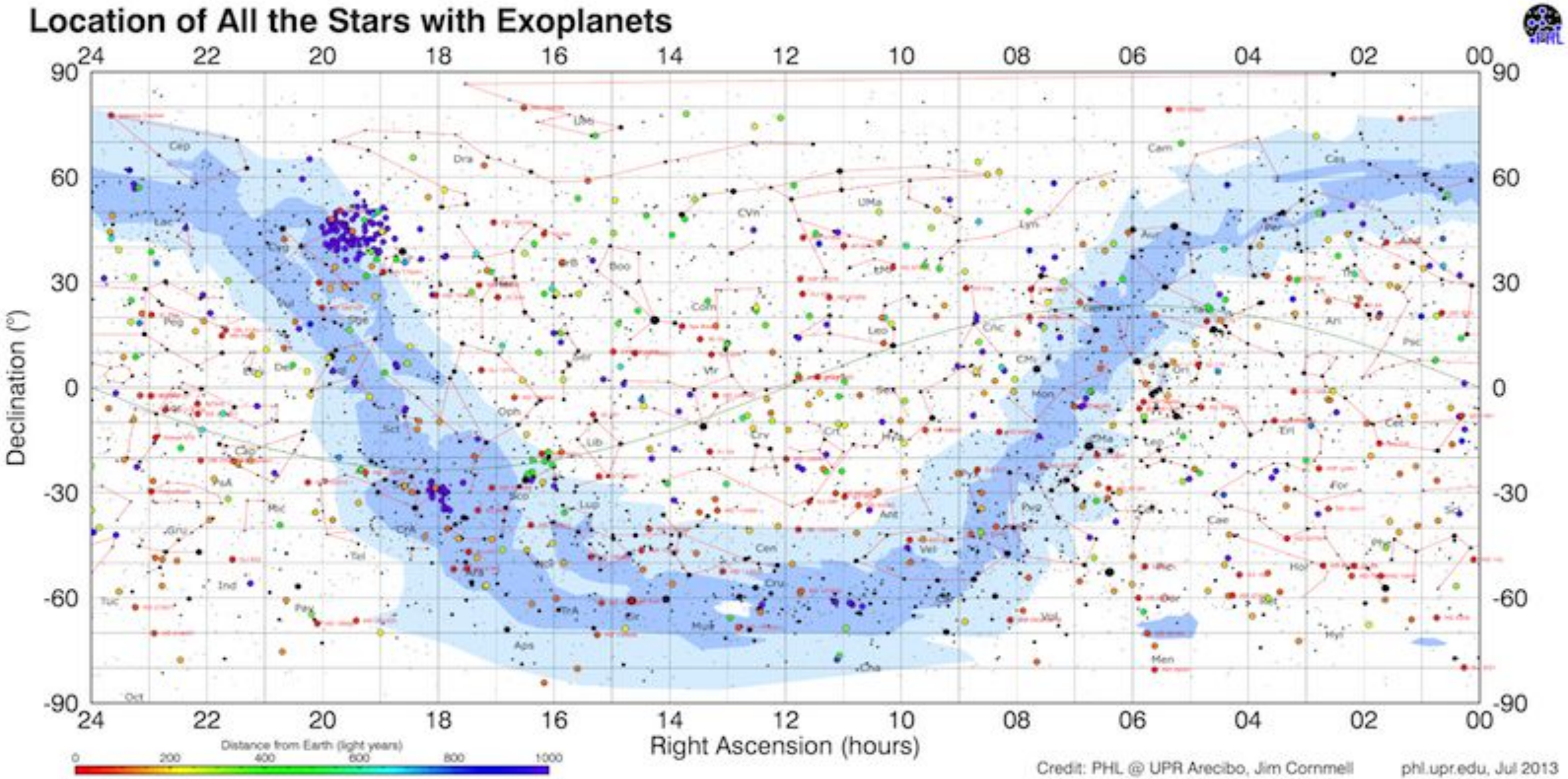


The Microlensing Method



OGLE 2003–BLG–235, MOA 2003–BLG–53 Bond et al. 2004

Exoplanet Discoveries



The Transit Method

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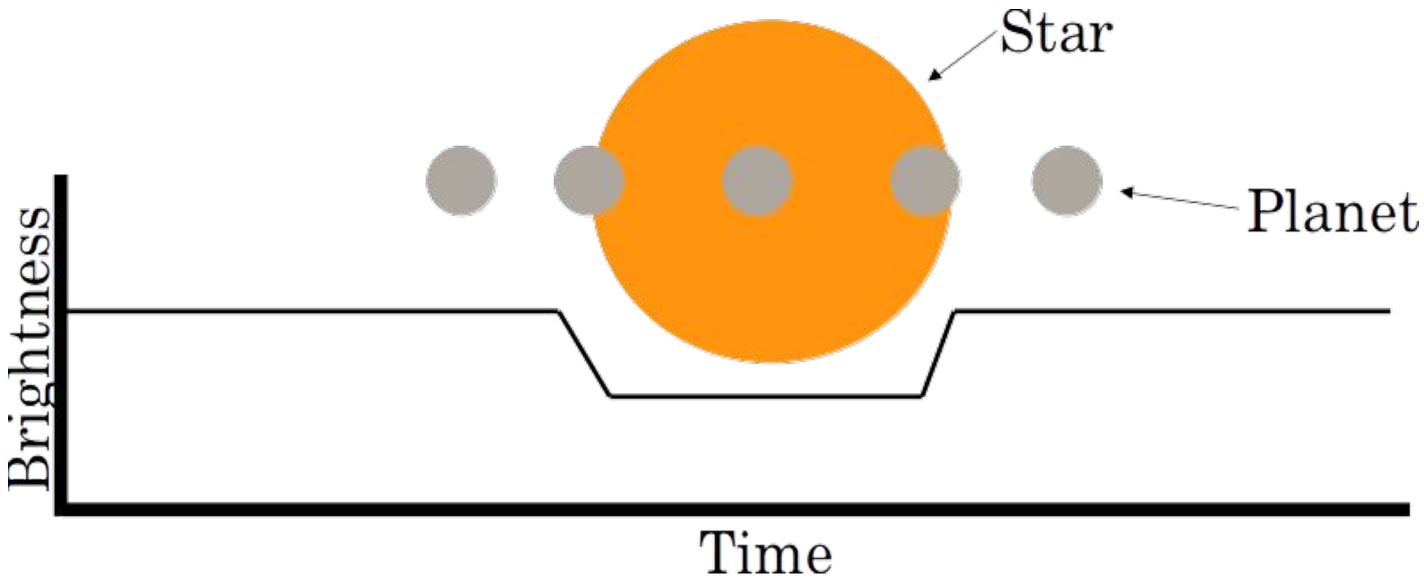


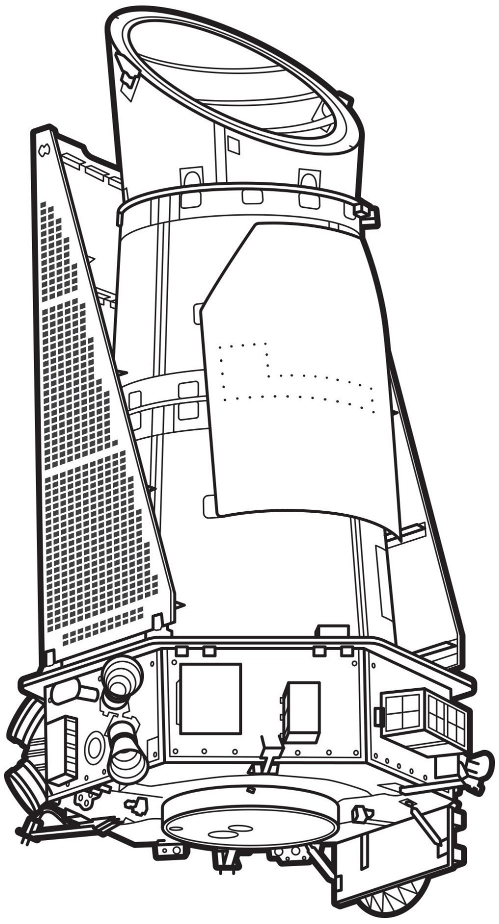
The Kepler Space Satellite

1. Launched in 2009, Kepler provided nearly continuous observations for ~150,000 stars.

2. Two of the four reaction wheels failed in 2013 forcing the first mission to end.
   a. 2331 confirmed planets with 5500+ candidates

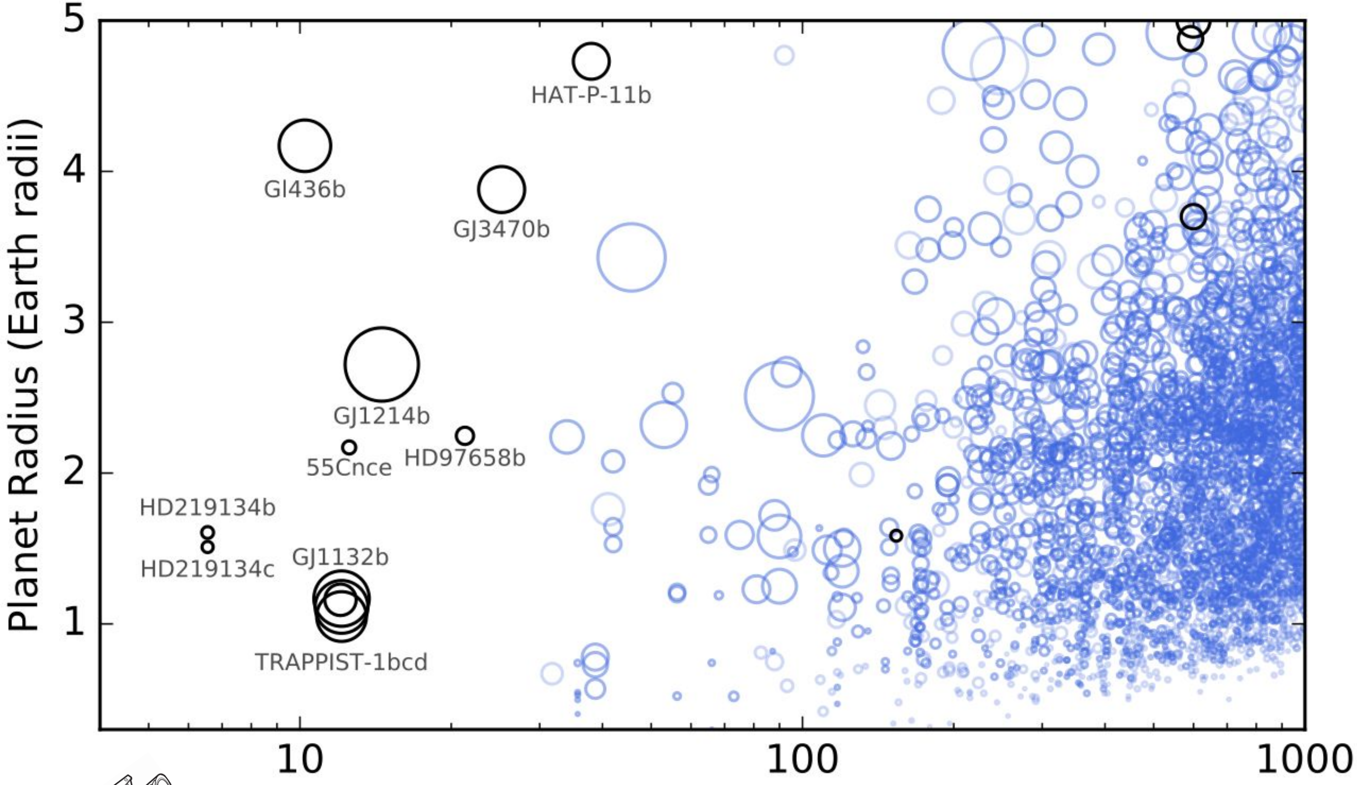
3. The second mission, K2, observes varying ecliptic fields.
   a. 173 confirmed planets with 400+ candidates.

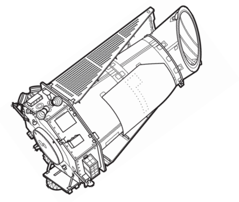
4. There are numerous variable star and asteroseismic discoveries as well!



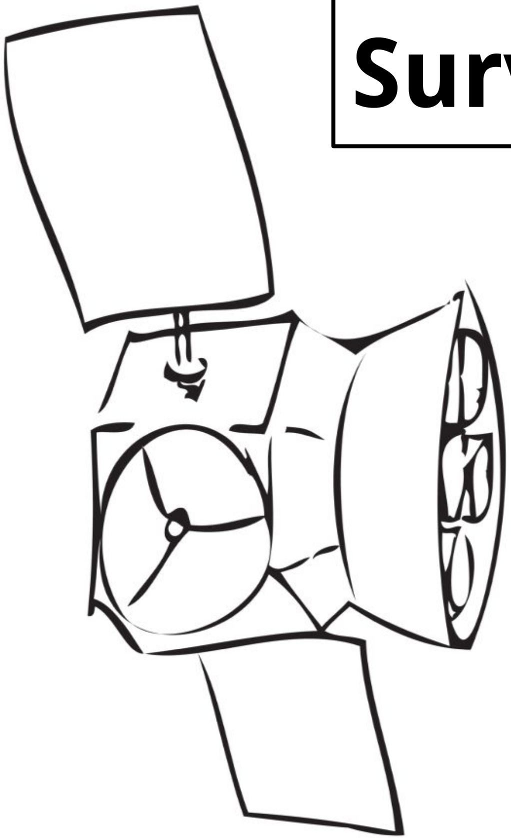
Kepler sketch courtesy of Wired.com - Chris Philpot

The Kepler Detections





The Transiting Exoplanet Survey Satellite (*TESS*)

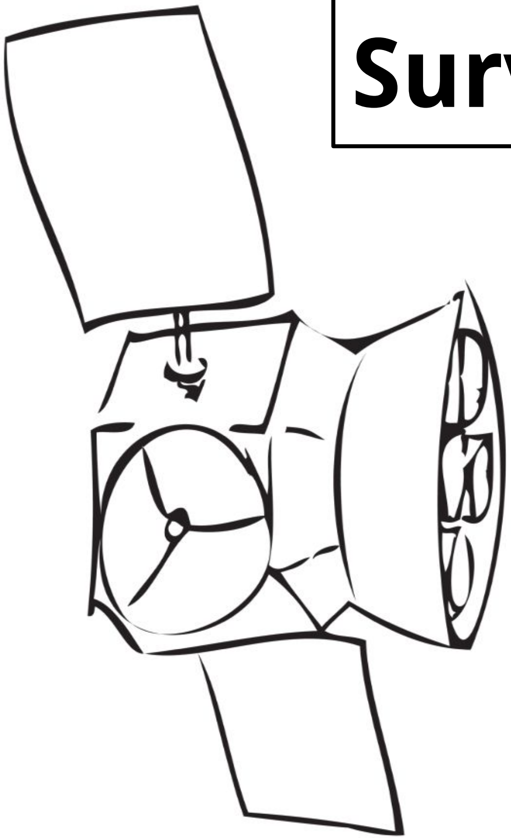


TESS is an all-sky, wide-field survey of solar-type and cooler stars for Earth and Neptune-sized planets.

- → The survey expects to find ~2000 candidates (300 Earth-sized objects) using the transit method.

There are 4 cameras, each with 4 CCDs, for a combined field-of-view of 24° x 96° per pointing.

- → 100 mm effective pupil
- → 16.7 megapixel cameras
- → 600-1000 nm bandpass



The Transiting Exoplanet Survey Satellite (*TESS*)

200,000-400,000 stars will be observed every 2 minutes, and nearly 420 million stars will be observed every 30 minutes.

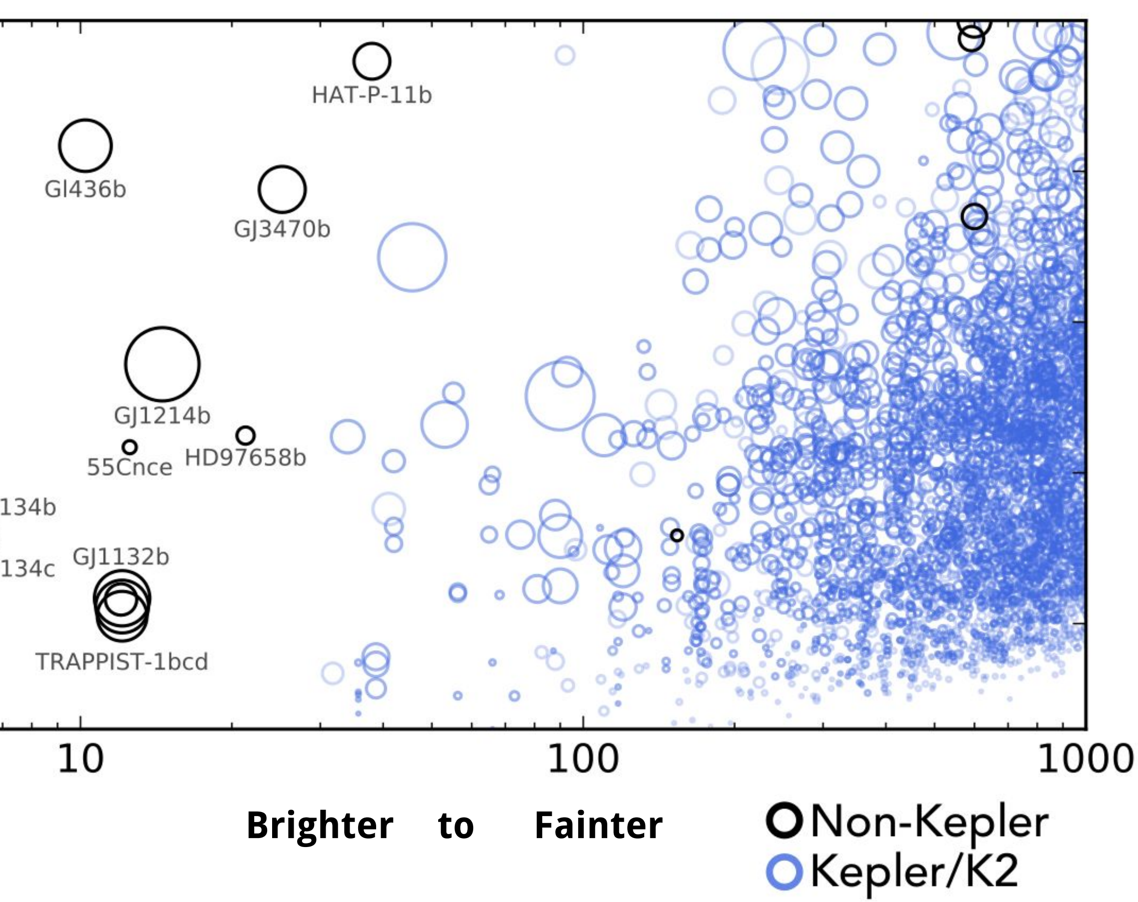
→ The stars observed every 30 mins will not have light curves provided by the mission, instead NASA will provide full-frame-images.

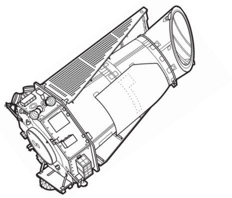
There is no proprietary period on the data, and most data products will be available 4 months after downlink.

The Transiting Exoplanet Survey Satellite

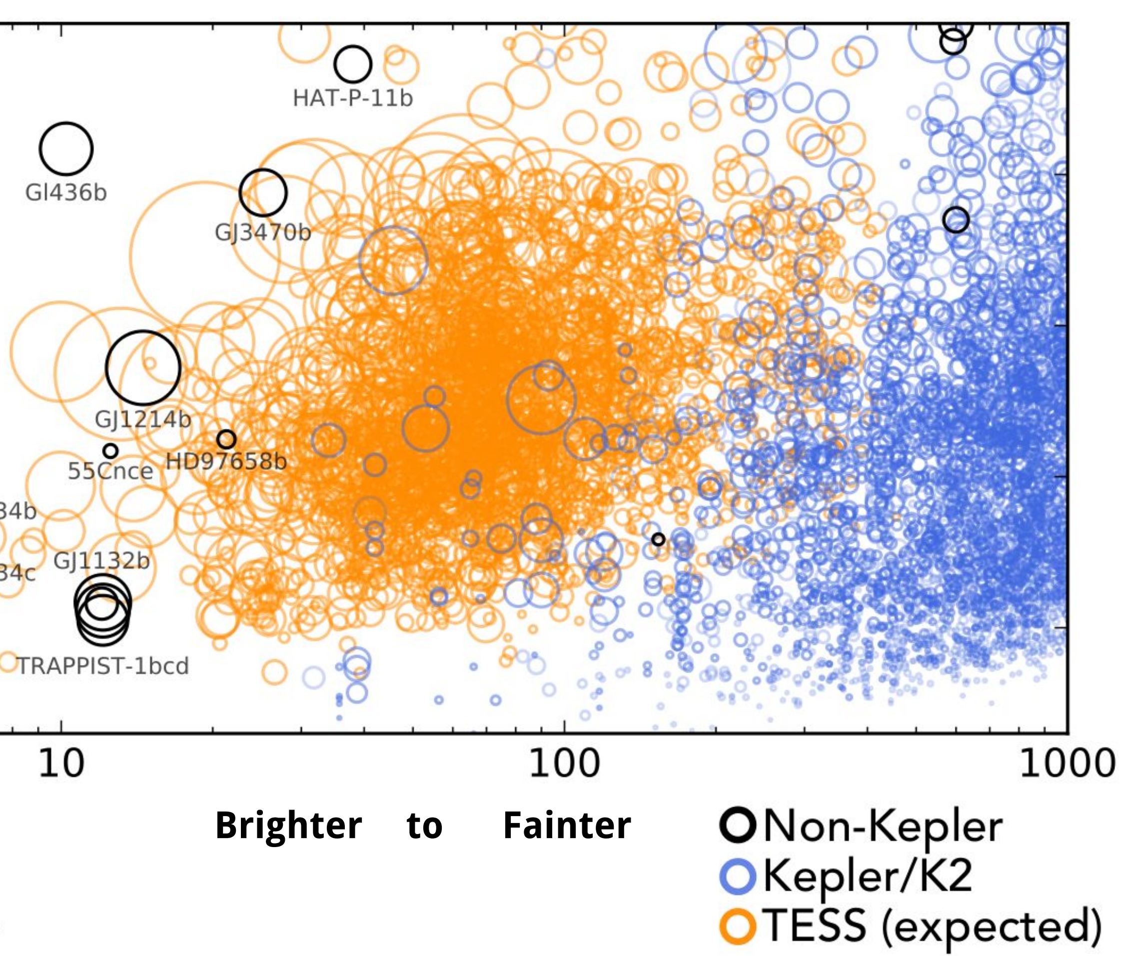
Image courtesy of Nature

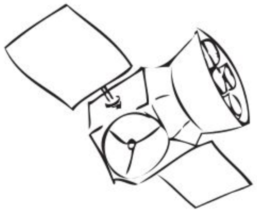
The Kepler Detections





TESS Detections





Successful Launch of TESS in April

Image courtesy of R. Oelkers

Successful Launch of TESS in April

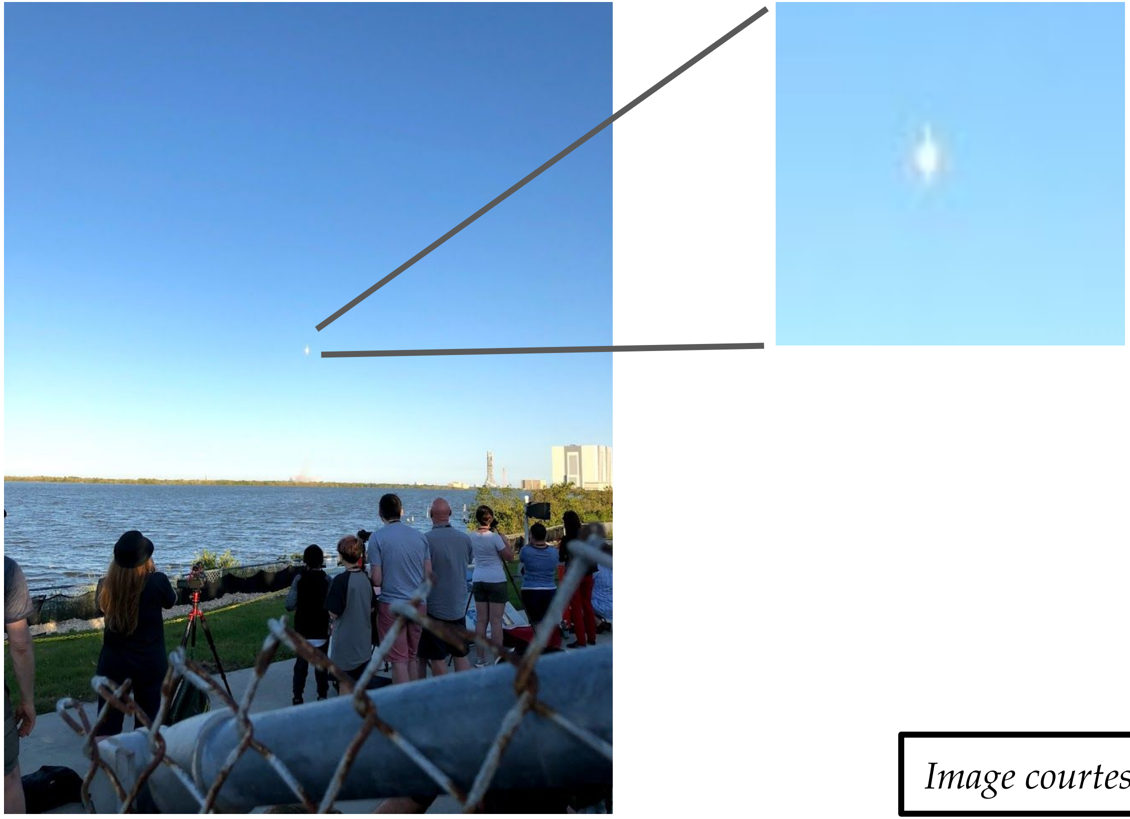
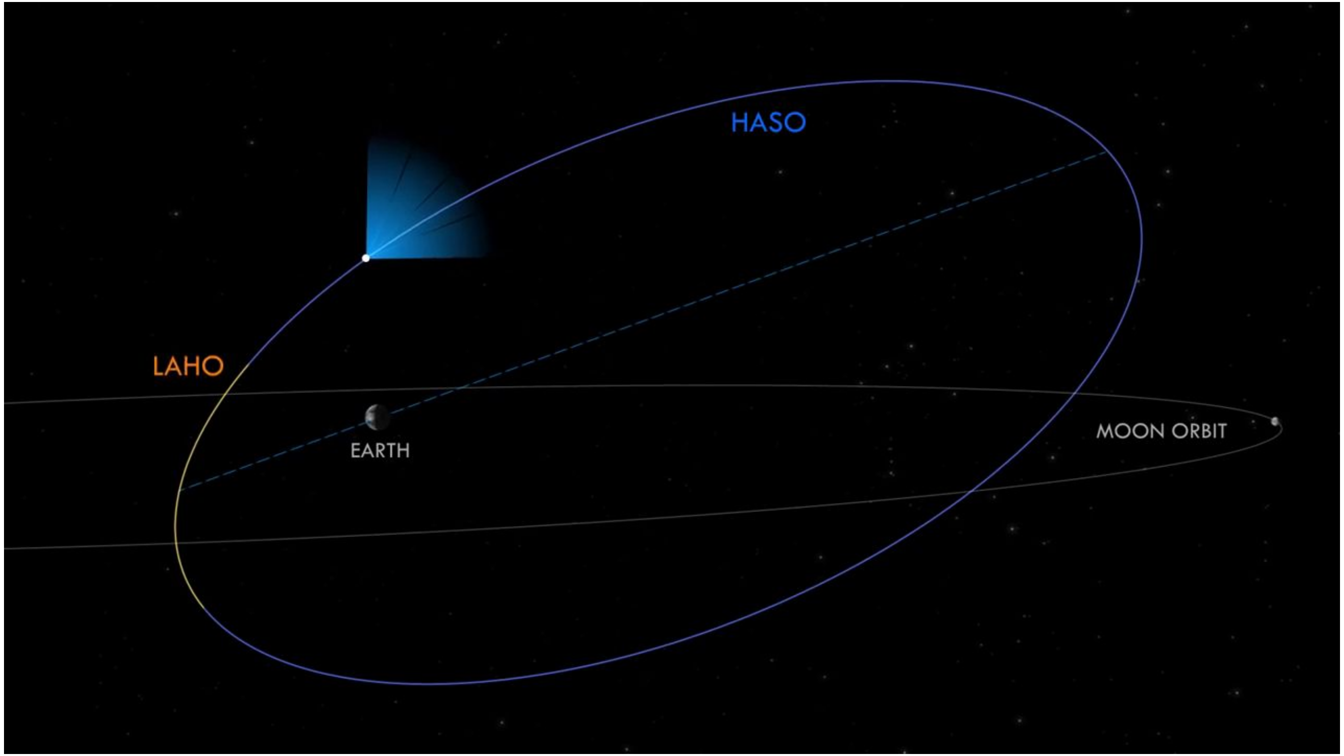


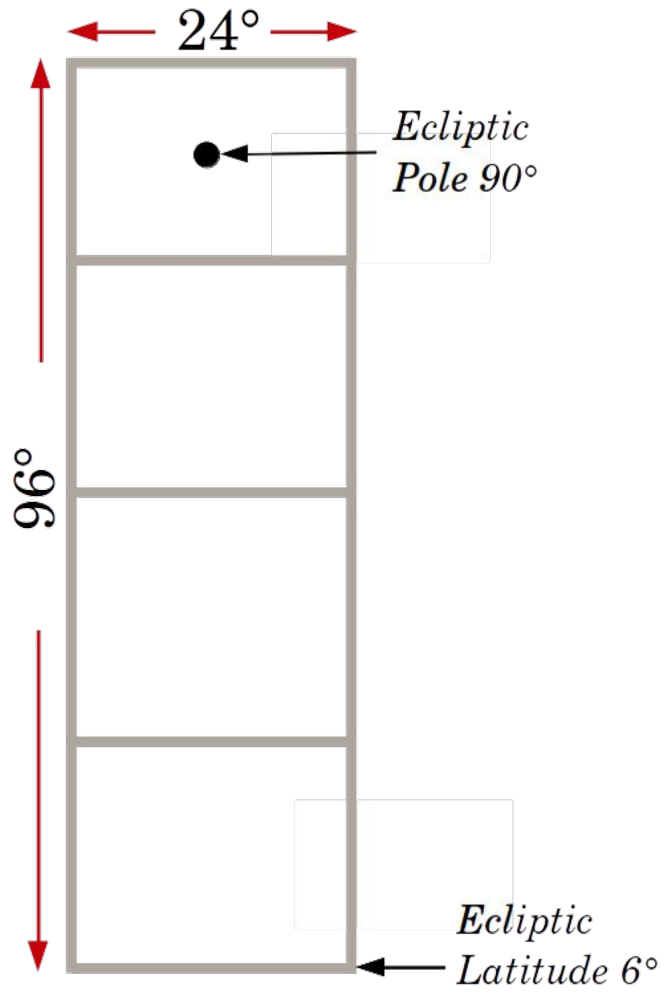
Image courtesy of R. Oelkers

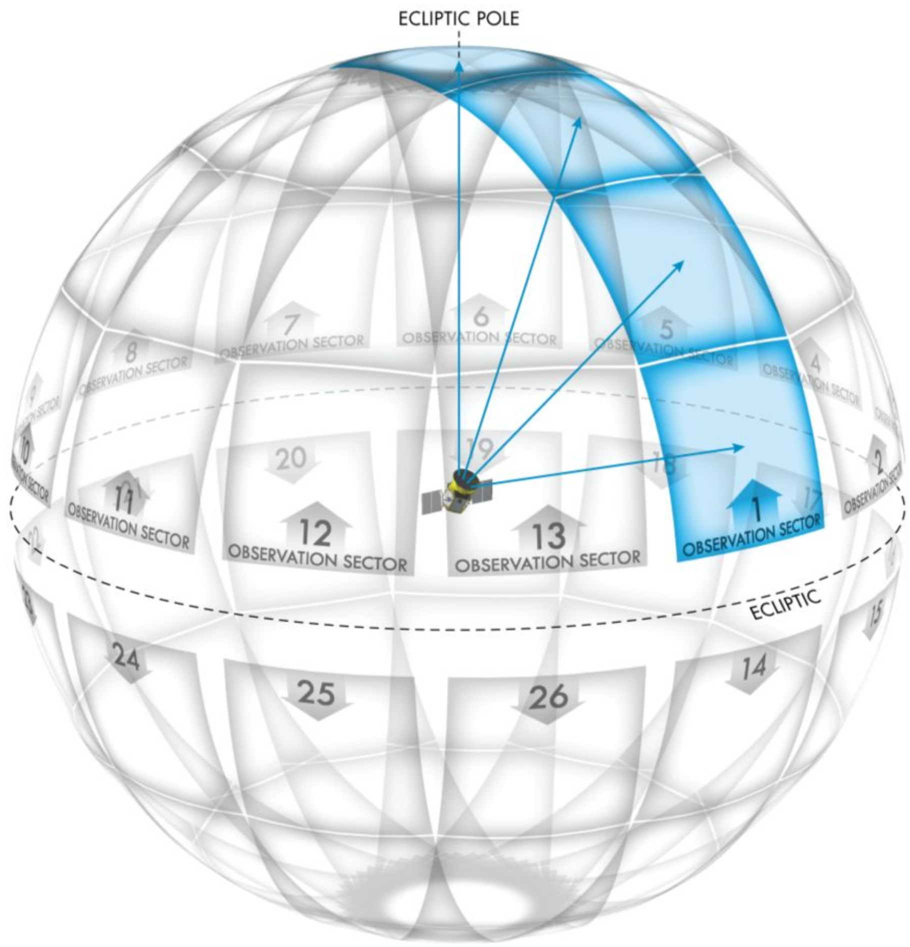
Successful Launch of TESS in April

Image courtesy of Space Flight Insider

TESS Orbit

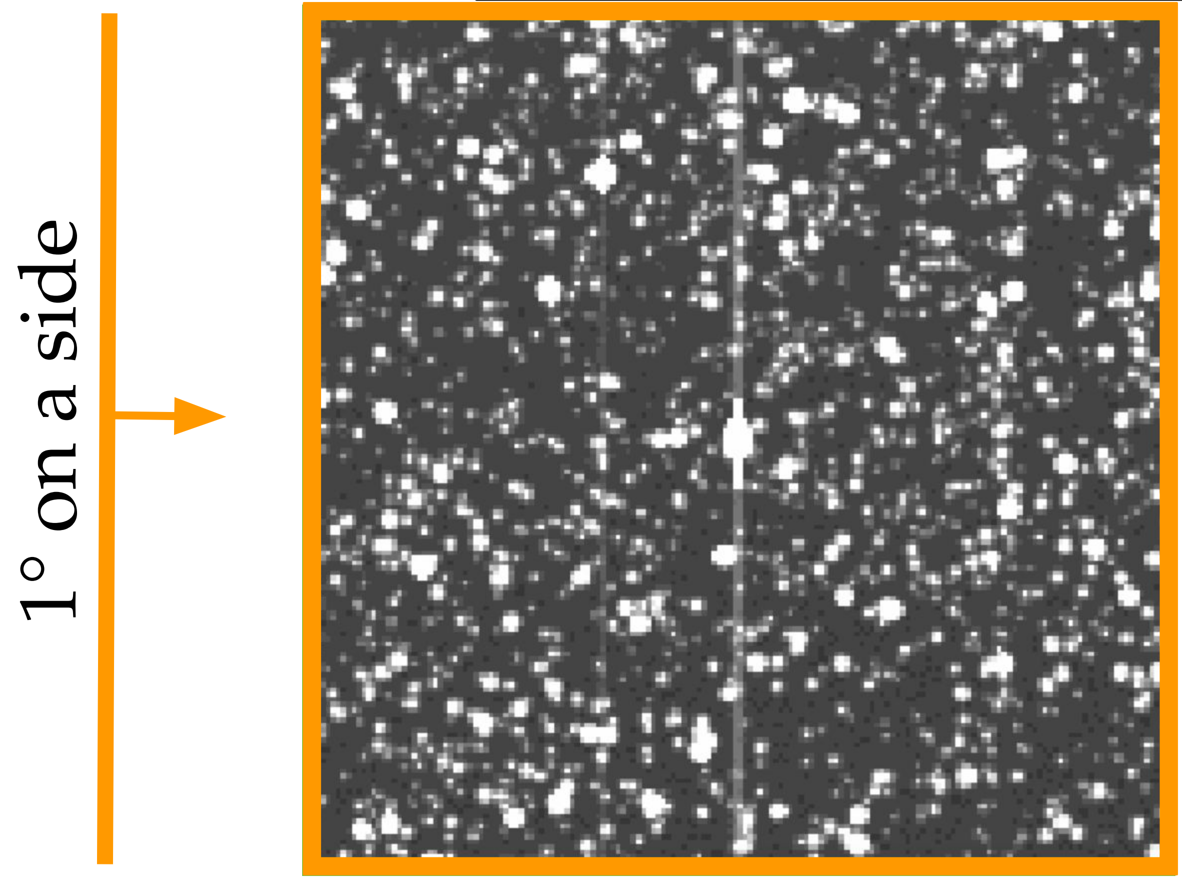






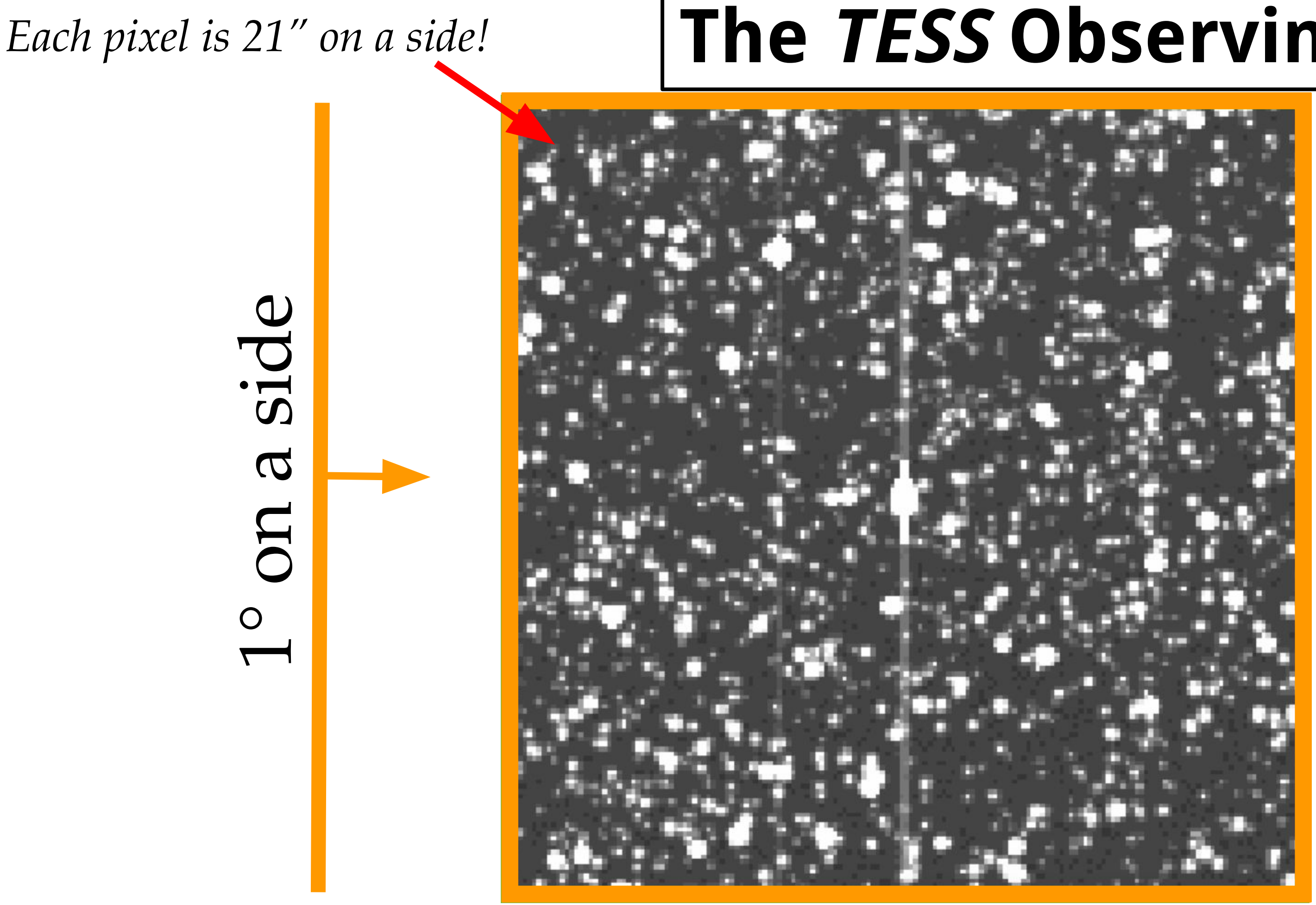
Ricker et al. 2014, Sullivan et al. 2015

The *TESS* Observing Strategy



Images and slide sequence courtesy of Zach Berta-Thompson

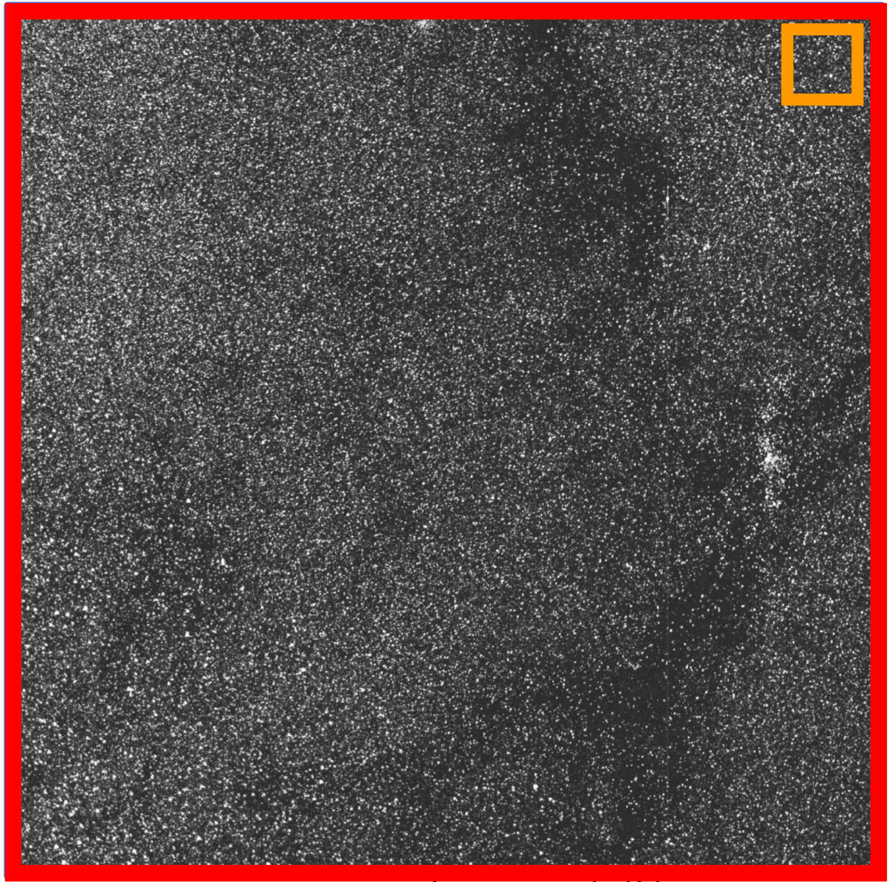
The *TESS* Observing Strategy



Images and slide sequence courtesy of Zach Berta-Thompson

The *TESS* Observing Strategy

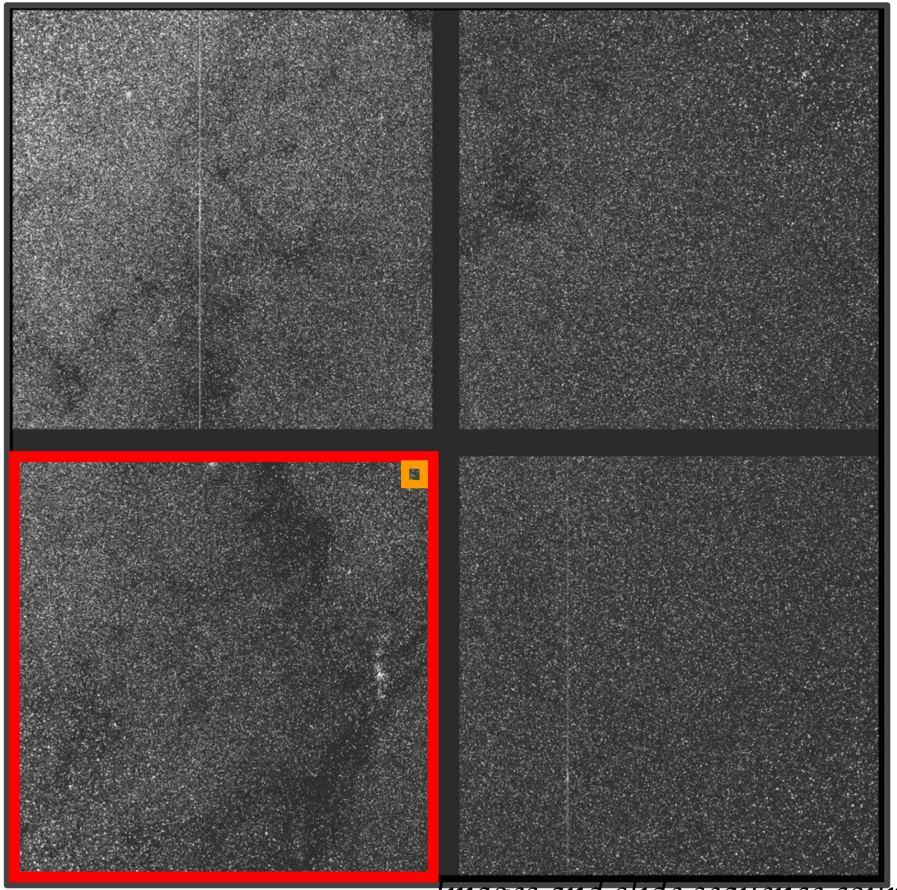
12° on a side -- one CCD



Images and slide sequence courtesy of Zach Berta-Thompson

The *TESS* Observing Strategy

24° on a side -- one camera



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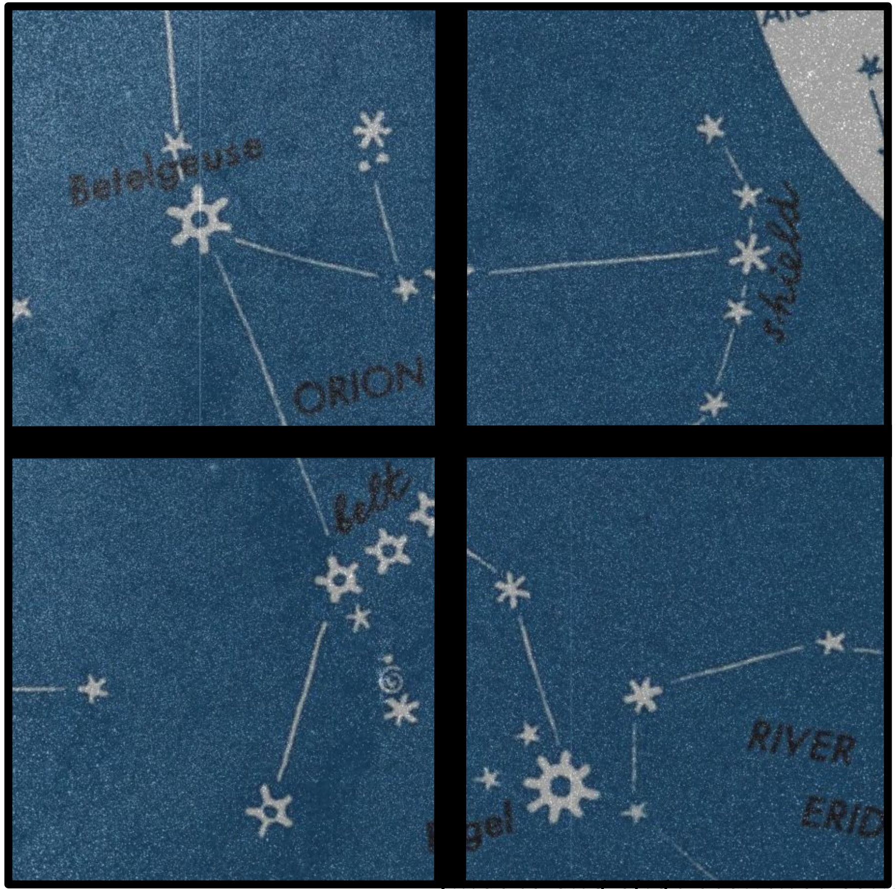

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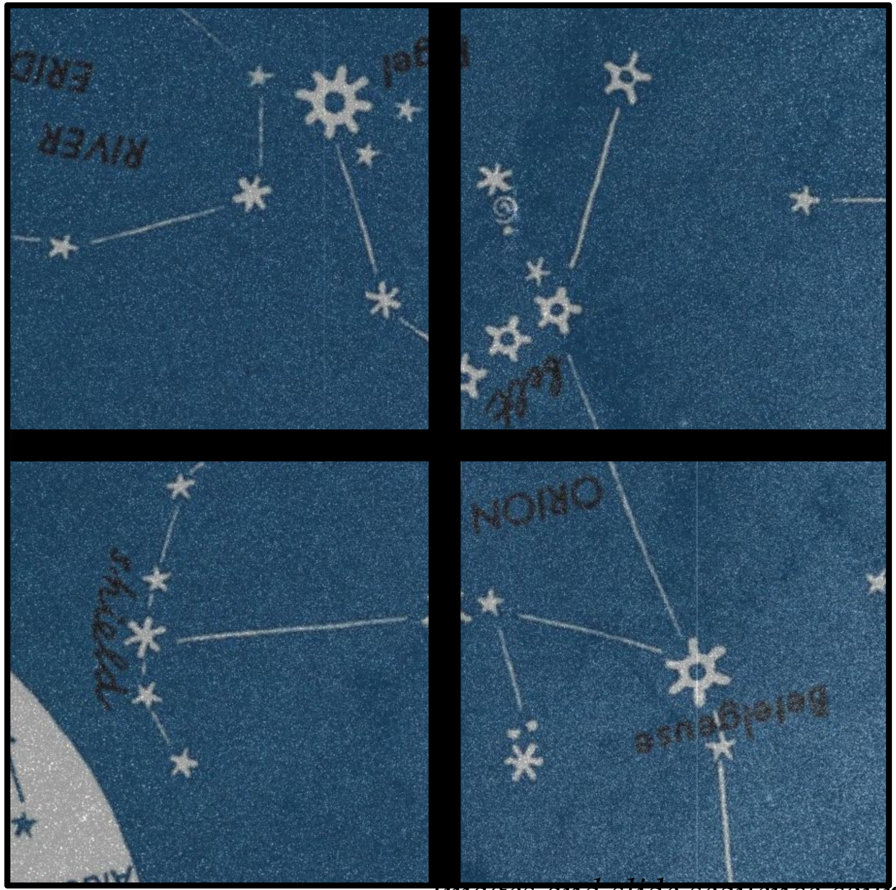


Images and slide sequence courtesy of Zach Berta-Thompson

"First-light" Image from TESS

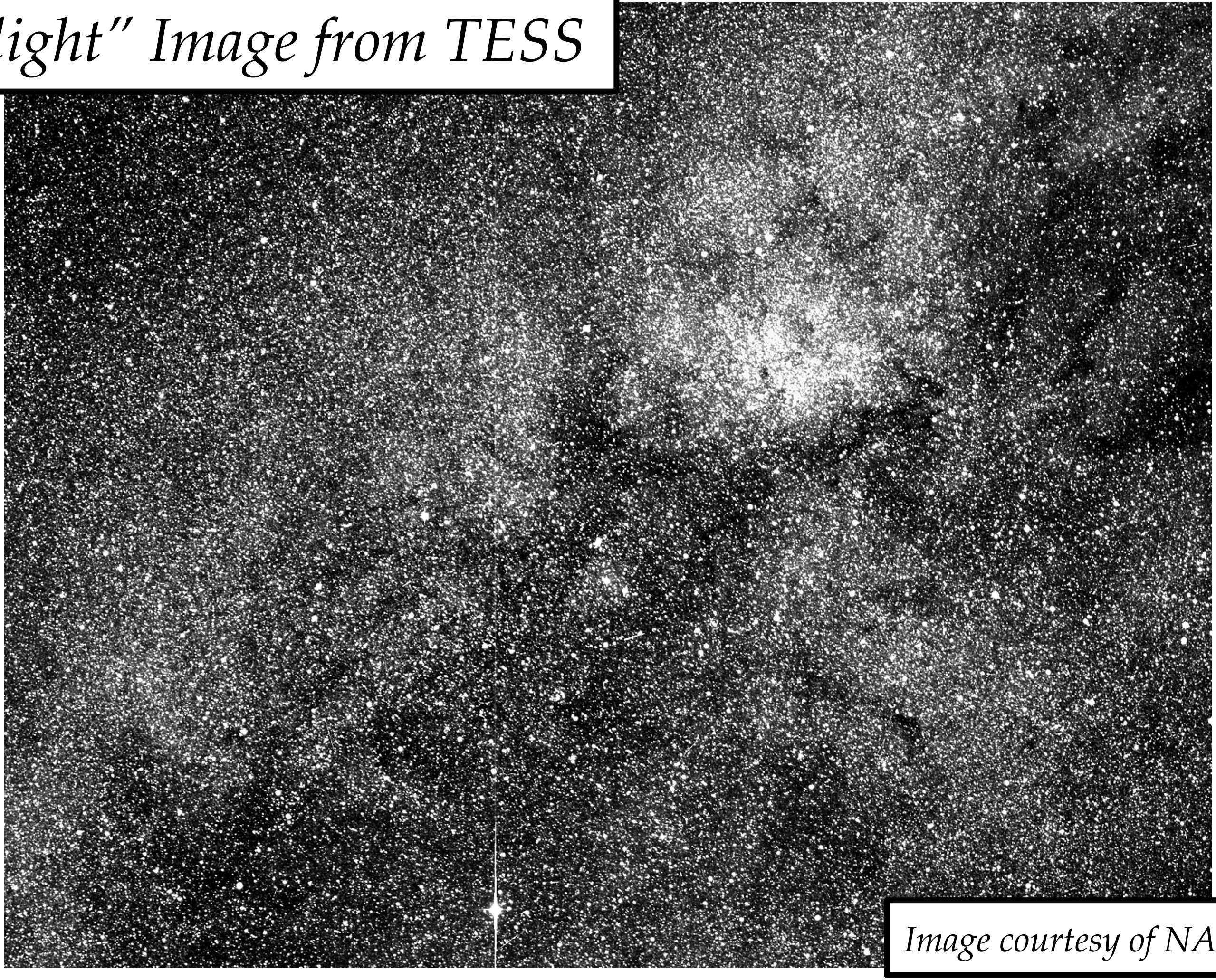


Image courtesy of NASA

“First-light” Image from TESS

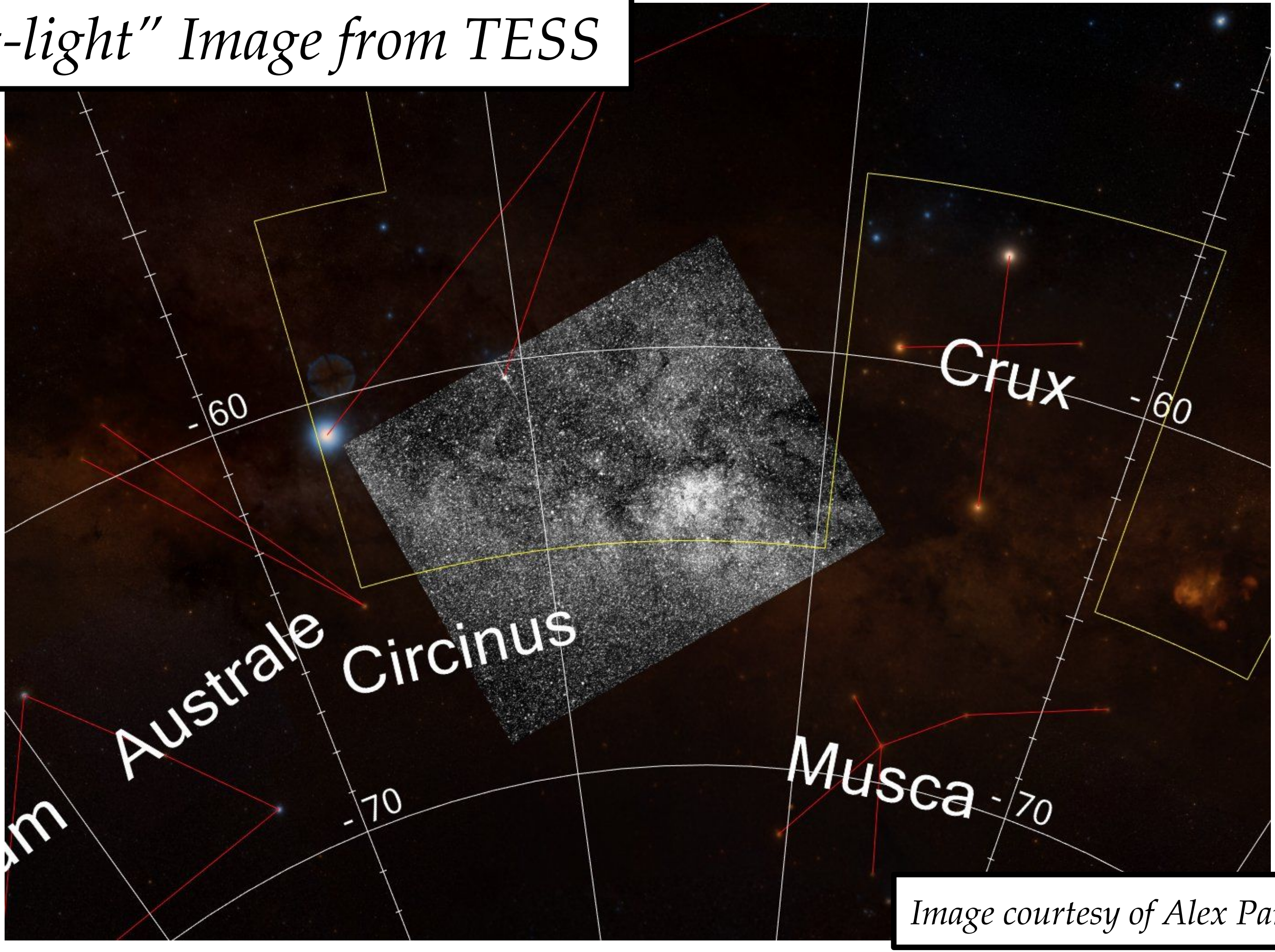


Image courtesy of Alex Parker

What is the *TESS* Input Catalog (TIC)?

- The *TESS* Input Catalog (TIC) is an attempt to create a uniform catalog of stellar parameters for every optically persistent, luminous (~V<16) object to aid in 2-min target selection.
- The TIC has more than 400 million objects currently, and will expand to more than 1.5 billion before 2019.
- The TIC will be used by both the scientific team, and *hopefully* the public.

Where can I access the TIC?

- Specific data subsets can also be created in .csv format upon request, and the current Candidate Target List (CTL) can be access through *Filtergraph* at the URL https://filtergraph.com/tess_ctl.
- Filtergraph is a powerful tool for teaching and learning!

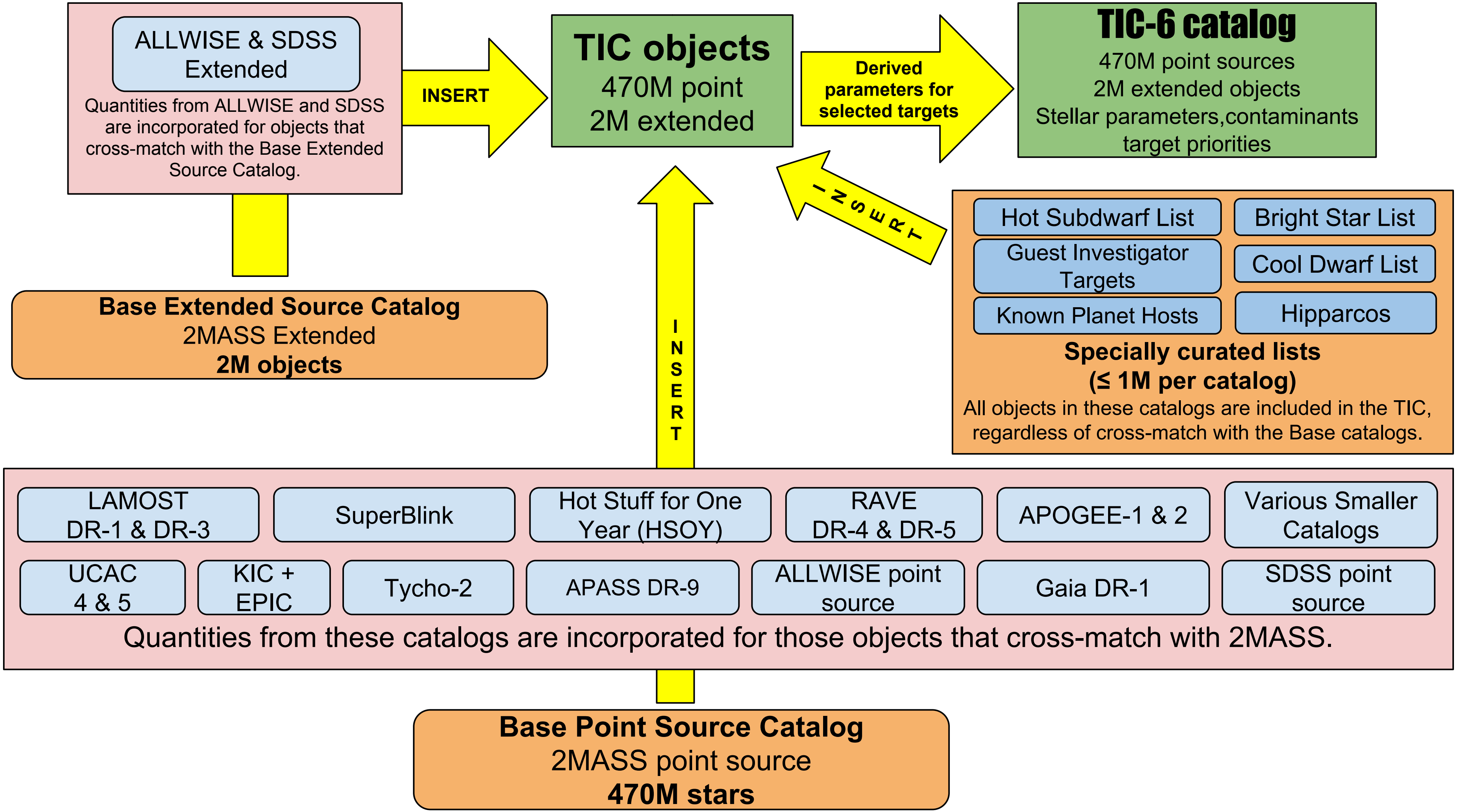
Catalogs:
2MASS (Skrutskie+ 2016), Gaia (Gaia-Collaboration+2016), SDSS (Alam+ 2015), KIC+EPIC (Brown+2015), RAVE DR4 & DR5 (Kordopatis+ 2013), APOGEE I & II (Majewski+ 2015), LAMOST DR1 & 3 (Luo+ 2015), Tycho-2 (Høg+ 2000), ALLWISE (Cutri+ 2013), APASS DR9 (Henden+ 2009), Hipparcos (ESA 1997), Gaia-TGAS (van Leeuwen+ 2016), Superblink (Lepine), UCAC 4 & 5 (Zacharias+ 2013), SPOCS (Brewer+ 2016), MEARTH (Irwin+ 2014), Gaia-ESO (Stonkute+ 2016), Galah (Martell+ 2016), Geneva-Copenhagen (Holmberg+ 2008), PASTEL (Soubiran+ 2016), Cool Dwarf list (Muirhead+ 2017), Hot-Stuff for One Year (Altmann+2017), HERMES-TESS (Sharma+2017)

Proper Motion Preferences:
(1) TGAS-Gaia, (2) Superblink, (3) Tycho2, (4) Hipparcos,
(5) UCAC4 ($\mu > 1800$ mas), (6) UCAC5 (200 mas $< \mu <$ 1800 mas), (7) HSOY ($\mu < 200$ mas)

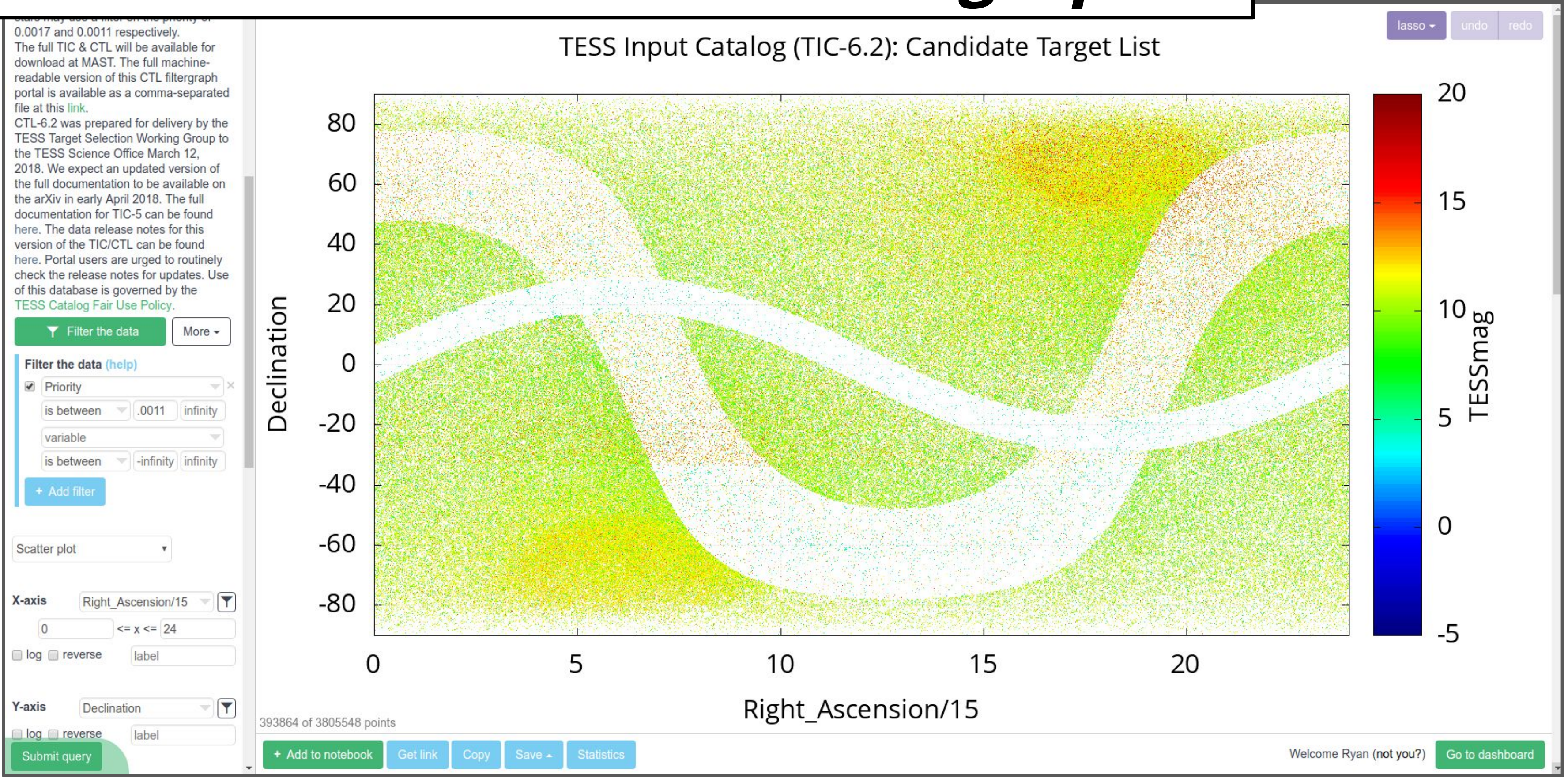
Parallax Preferences:
(1) TGAS-Gaia, (2) Hipparcos

Spectroscopic Preferences:
(1) SPOCS, (2) PASTEL, (3) Gaia-ESO, (4) GALAH, (5) HERMES/TESS DR-1, (6) APOGEE II (DR-14), (7) APOGEE I (DR-12), (8) LAMOST DR-3, (9) LAMOST DR-1, (10) RAVE DR-5, (11) RAVE DR-4

Observed Magnitudes:
APASS, 2MASS, ALLWISE, HIPPARCOS, TYCHO, SDSS


ALLWISE & SDSS Extended
Quantities from ALLWISE and SDSS are incorporated for objects that cross-match with the Base Extended Source Catalog.
INSERT
TIC objects
470M point
2M extended
Derived parameters for selected targets
TIC-6 catalog
470M point sources
2M extended objects
Stellar parameters,contaminants
target priorities
INSERT
Hot Subdwarf List
Bright Star List
Guest Investigator Targets
Cool Dwarf List
Known Planet Hosts
Hipparcos
Specially curated lists
(≤ 1M per catalog)
All objects in these catalogs are included in the TIC, regardless of cross-match with the Base catalogs.
Base Extended Source Catalog
2MASS Extended
2M objects
INSERT
LAMOST DR-1 & DR-3
SuperBlink
Hot Stuff for One Year (HSOY)
RAVE DR-4 & DR-5
APOGEE-1 & 2
Various Smaller Catalogs
UCAC 4 & 5
KIC + EPIC
Tycho-2
APASS DR-9
ALLWISE point source
Gaia DR-1
SDSS point source
Quantities from these catalogs are incorporated for those objects that cross-match with 2MASS.
Base Point Source Catalog
2MASS point source
470M stars

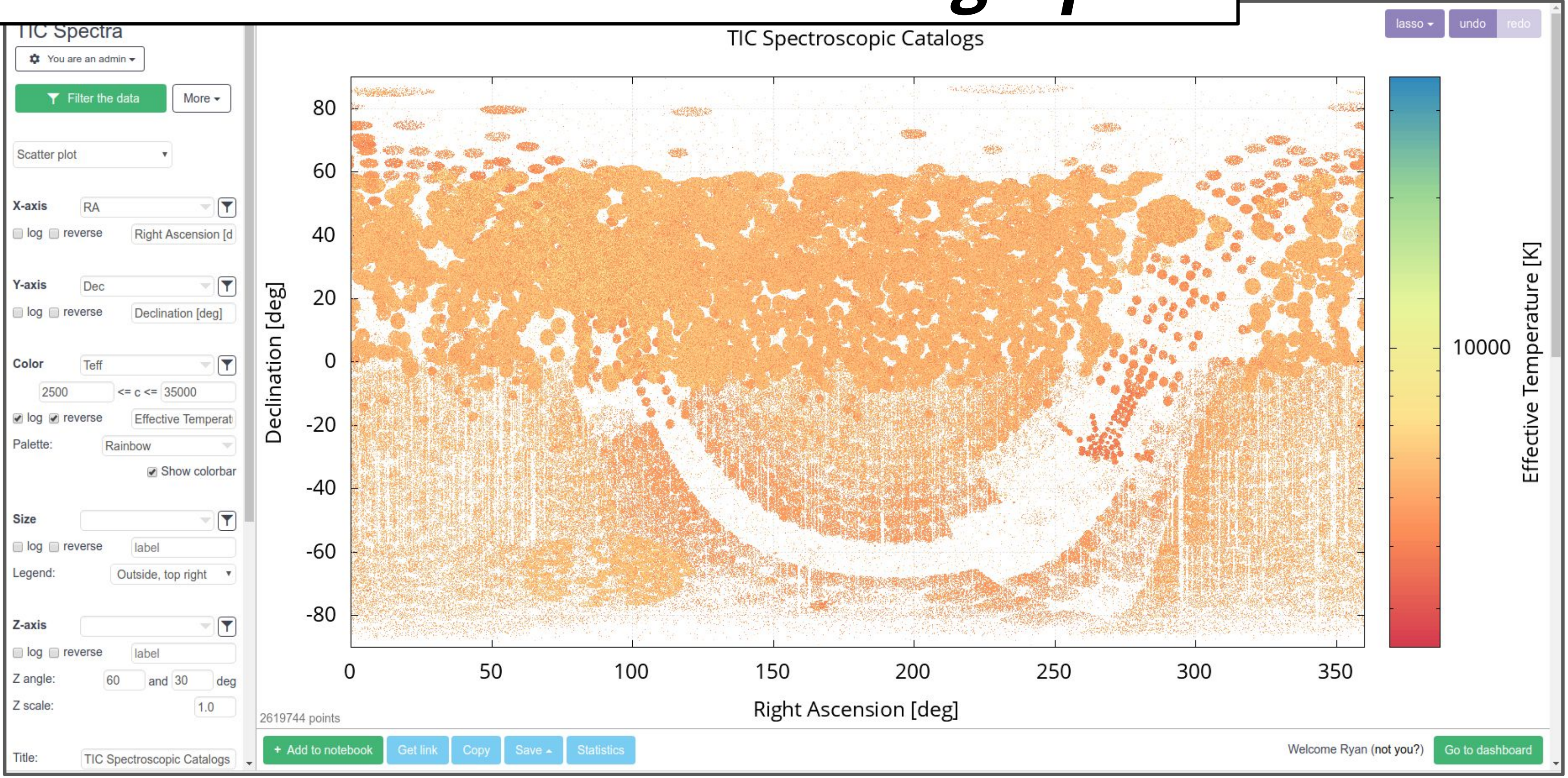
Data Visualization with *Filtergraph*



Burger, D., et al., 2013, ASPC, 475, 399

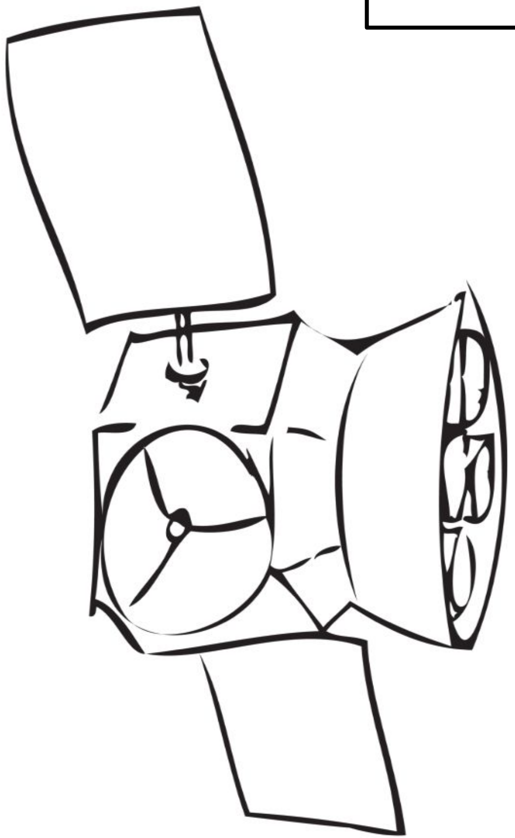
https://filtergraph.com/tess_ctl

Data Visualization with *Filtergraph*



https://filtergraph.com/ticspectra

Summary



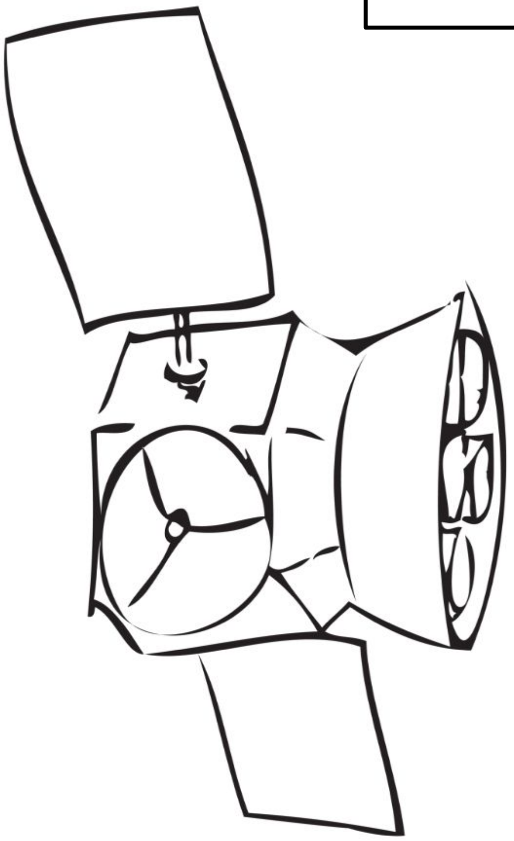
The astronomical community has made many advancements in exoplanet discovery in the past two decades.

TESS is an all-sky, wide-field survey of solar-type and cooler stars for Earth and Neptune-sized planets.

The survey expects to find ~2000 candidates (300 Earth-sized objects) using the transit method.

Filtergraph is a powerful tool to for data visualization of large data sets.

Questions?



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https://sites.google.com/site/rjoelkersresearch/