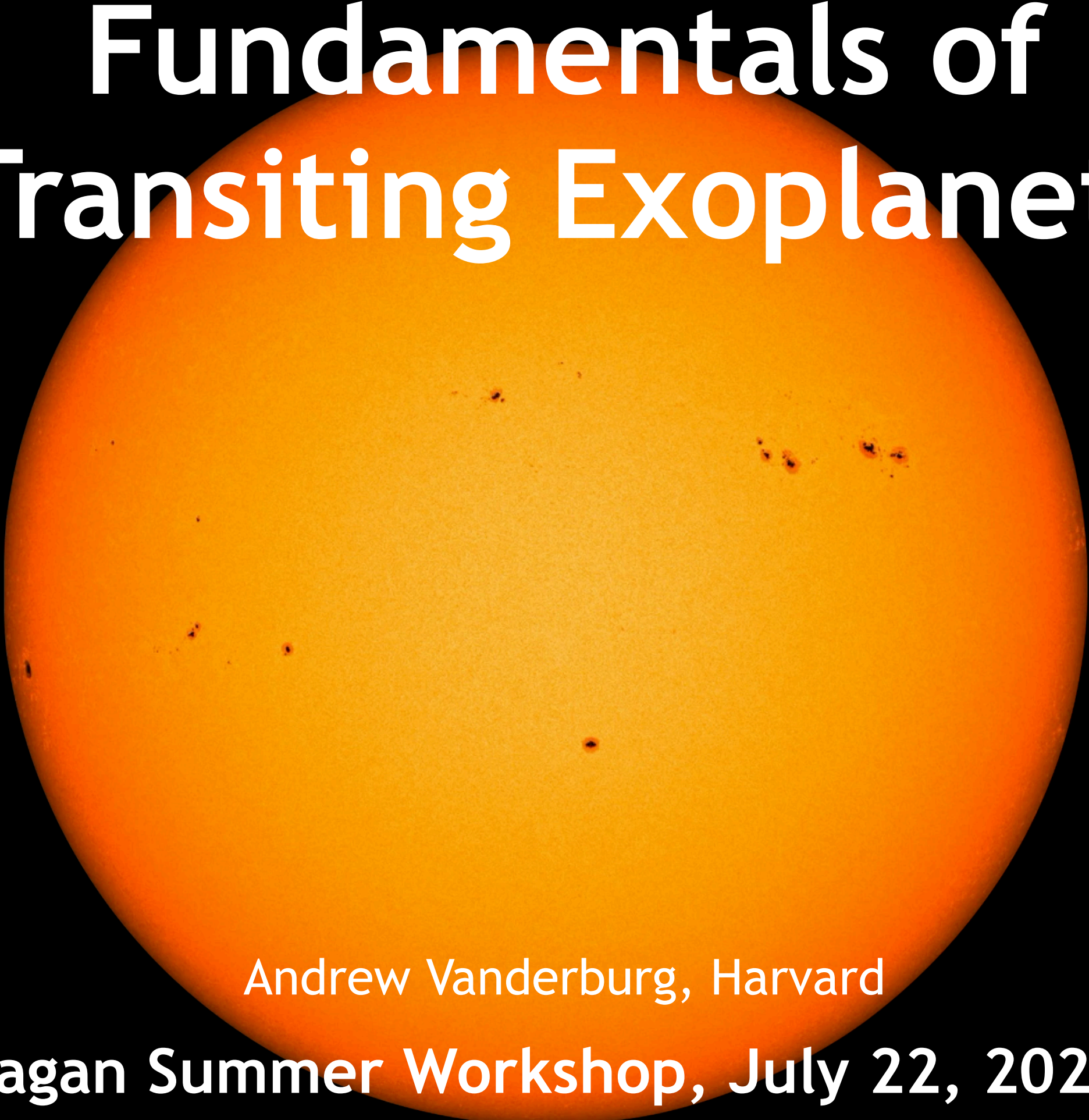


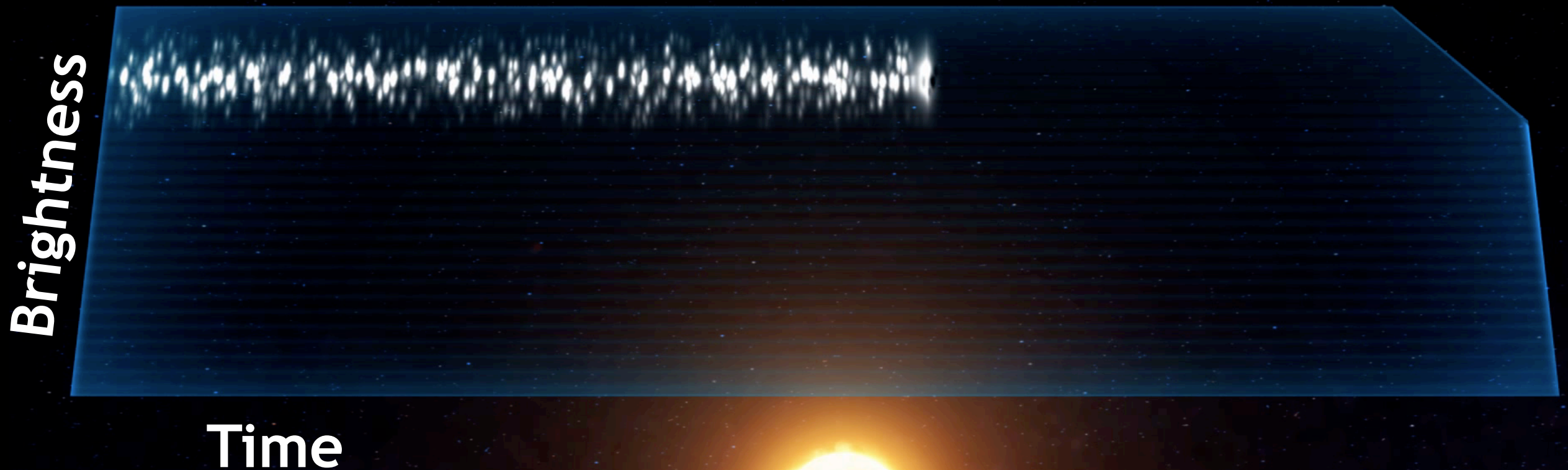
Fundamentals of Transiting Exoplanets



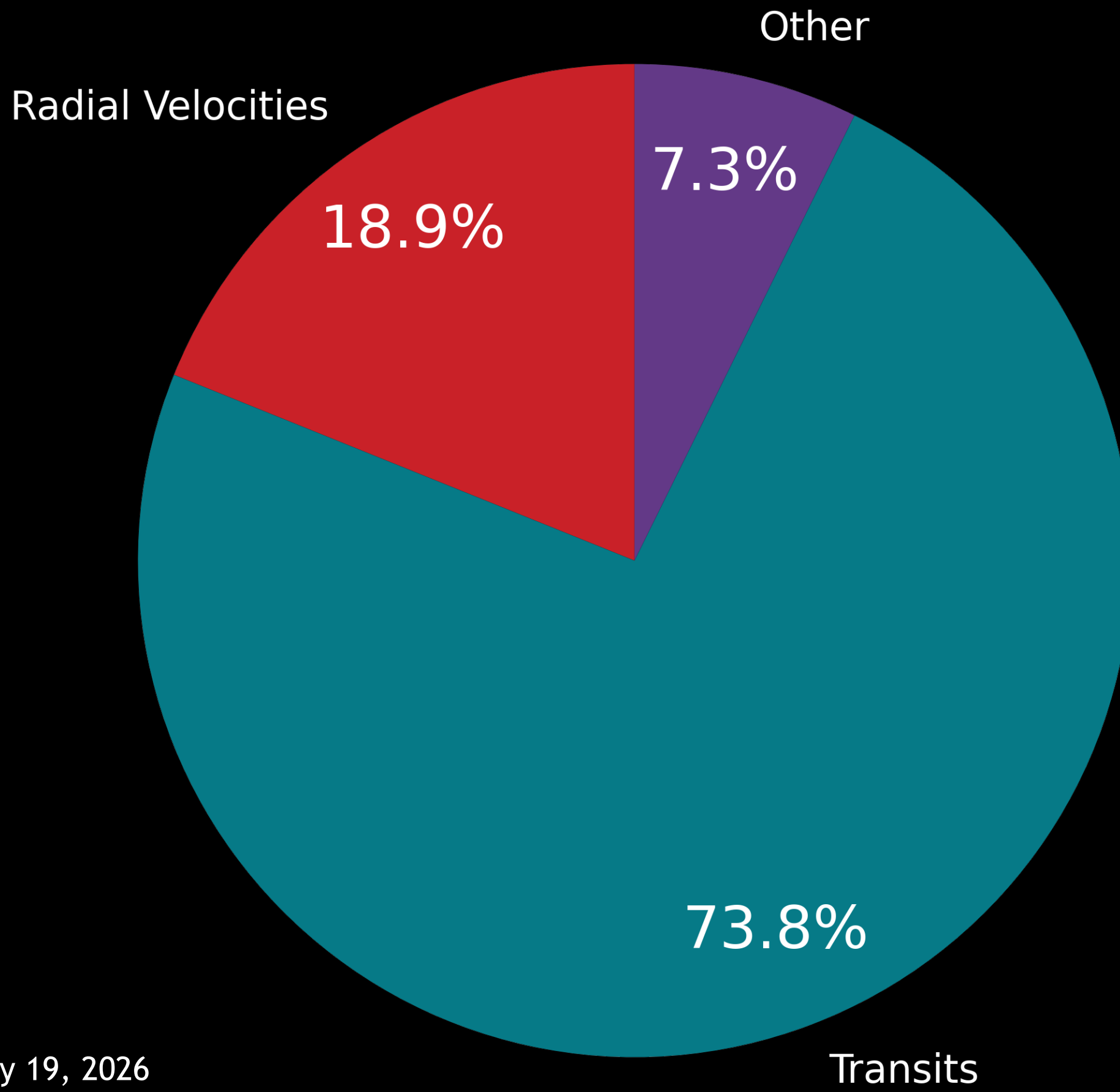
Andrew Vanderburg, Harvard

Sagan Summer Workshop, July 22, 2026

Planets with orbits aligned with our line of sight **transit** their stars and cause the star's brightness to dim.



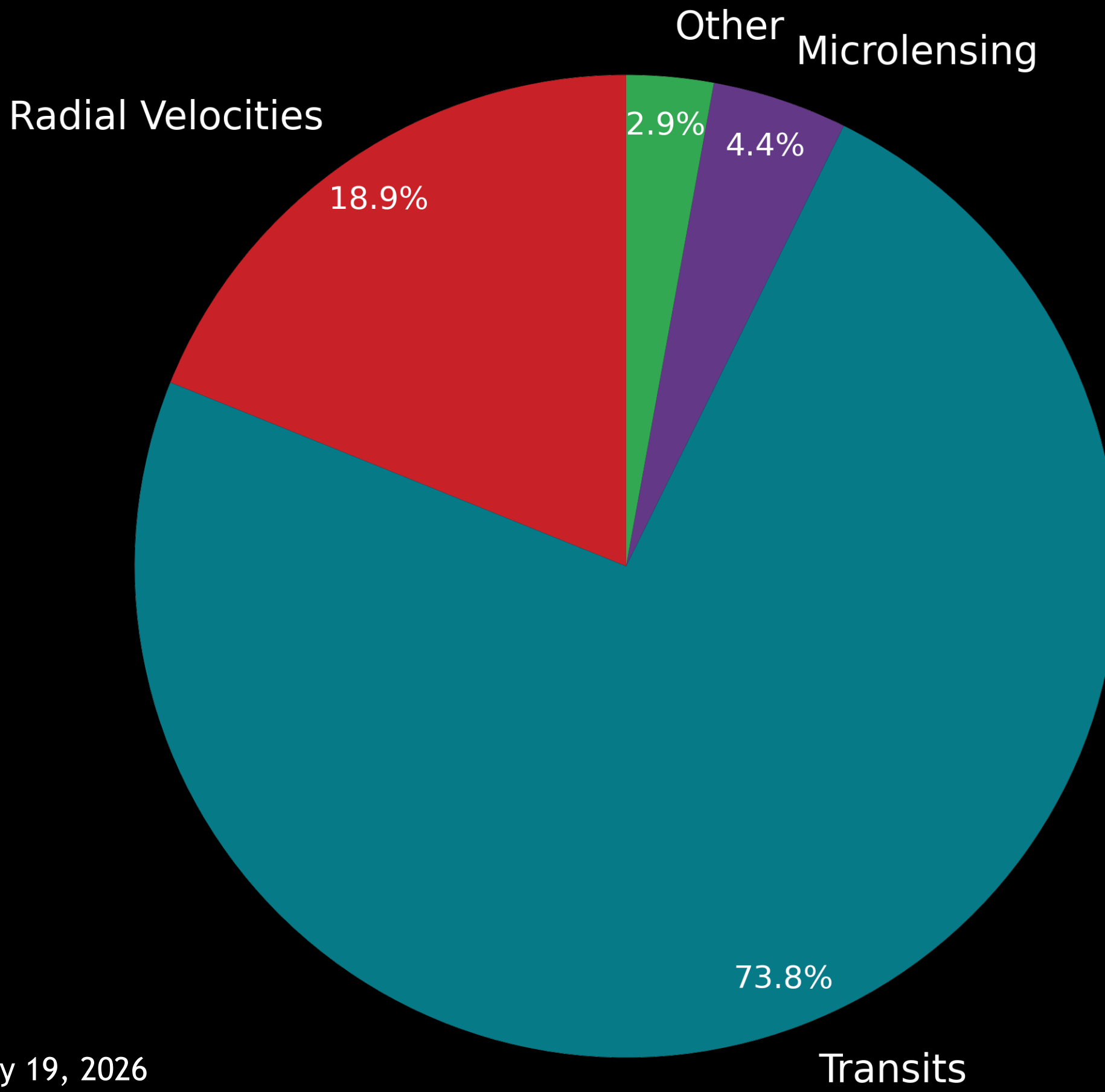
Transits dominate the exoplanet census



As of July 19, 2026

Transits

Transits dominate the exoplanet census



As of July 19, 2026

Transits

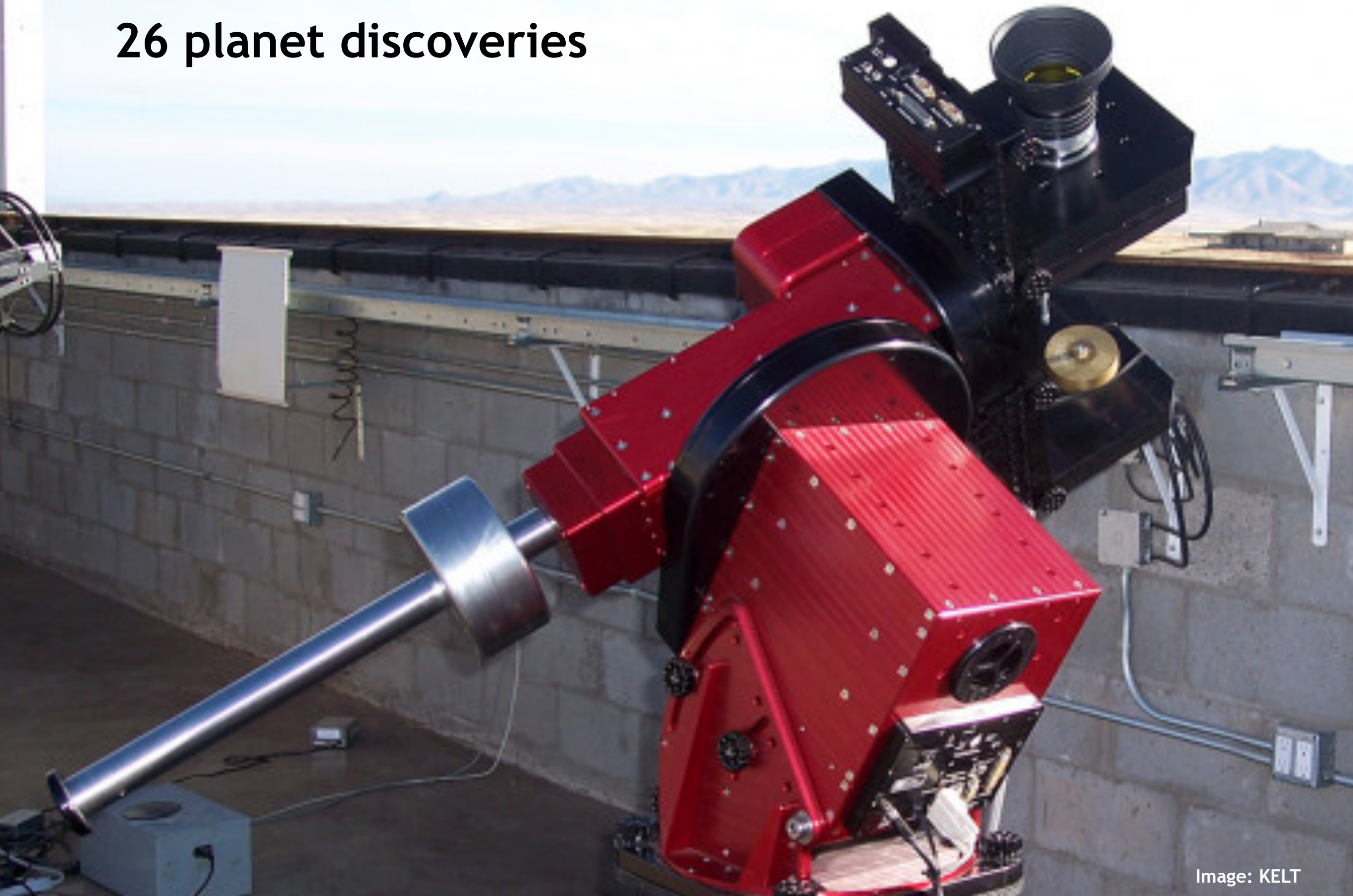
Why?

1. Transit observations are simple.



the Kilodegree Extremely Little Telescope (KELT)

26 planet discoveries





Mamiya 645

MAMIYA-SEKOR C

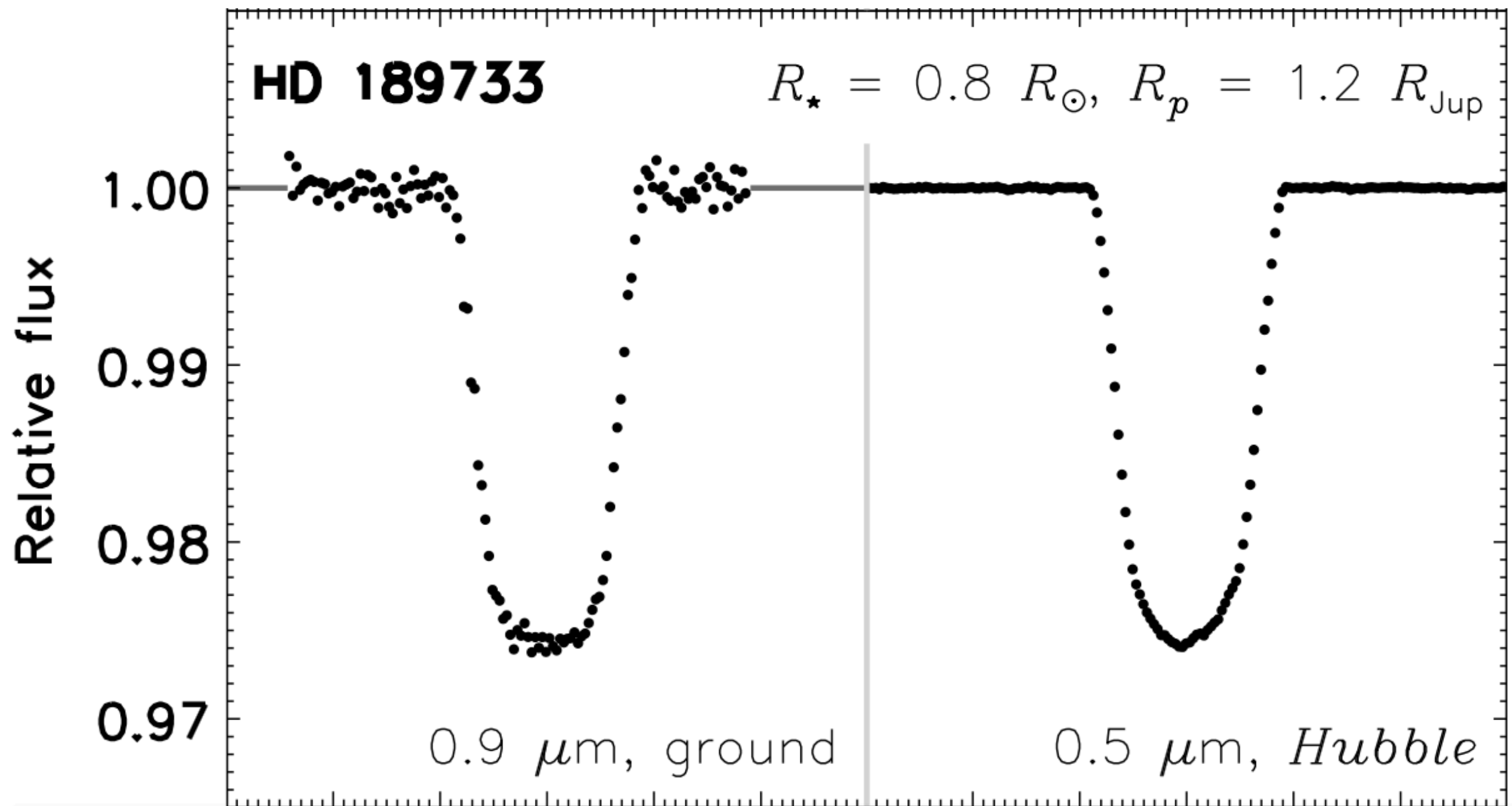
80mm

1:1.9 N

LENS

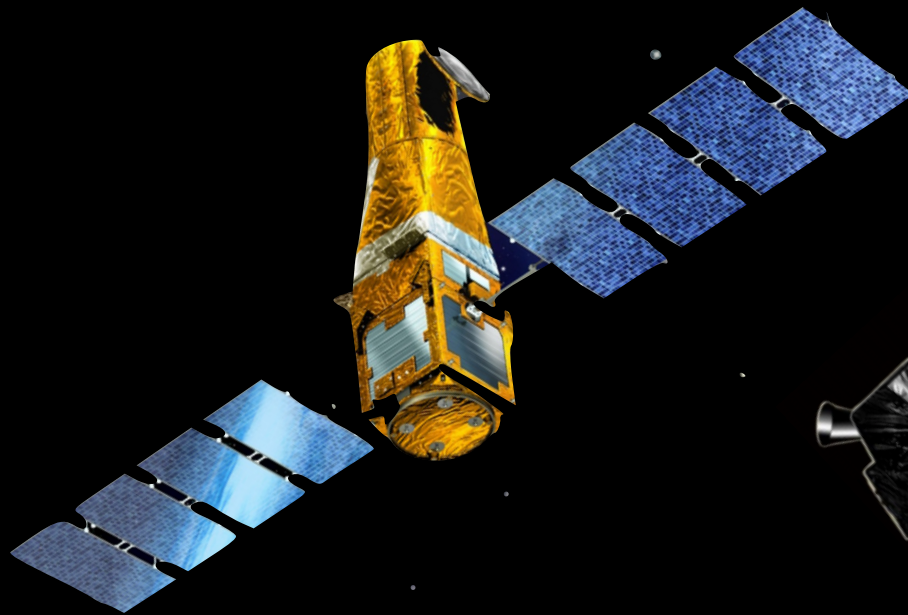
**2. Investments in space missions
with extreme sensitivity.**

Ground-based versus Space-based photometry

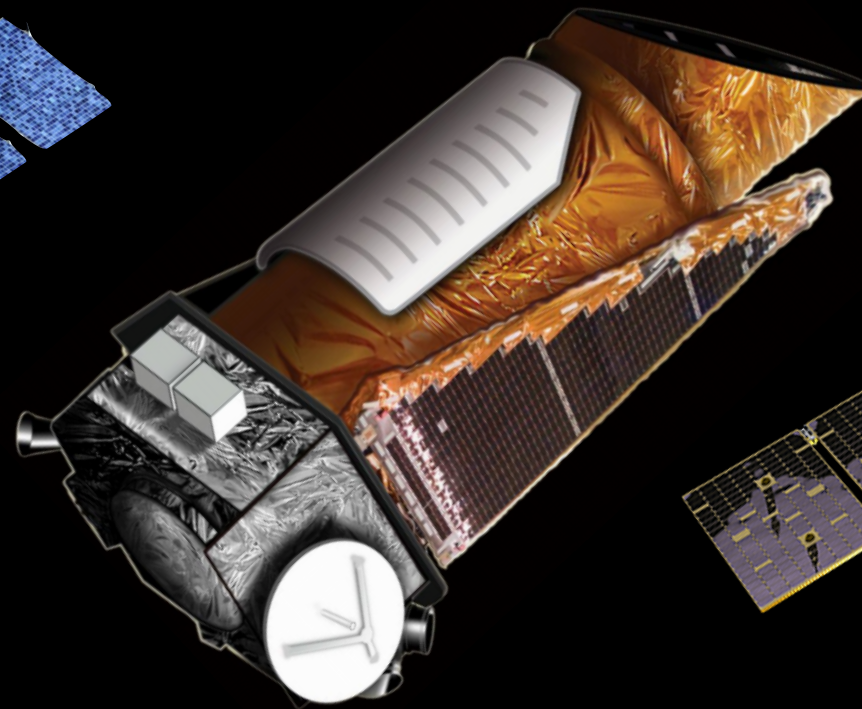




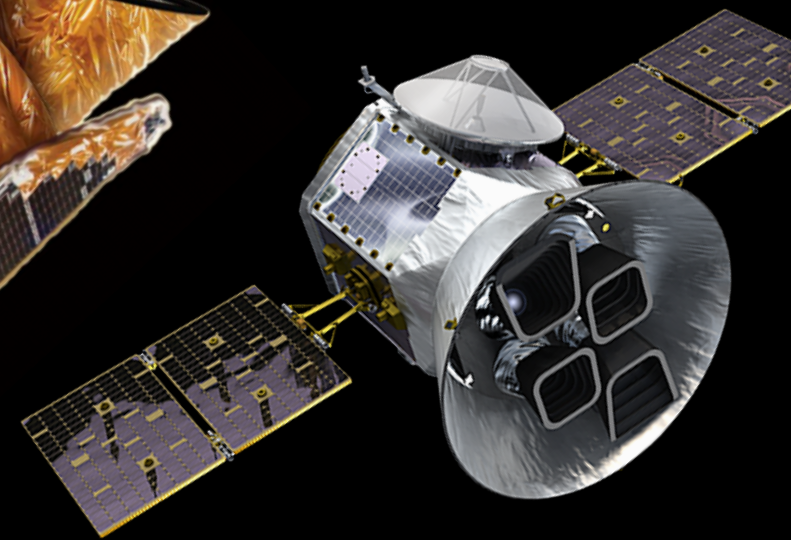
MOST



CoRoT

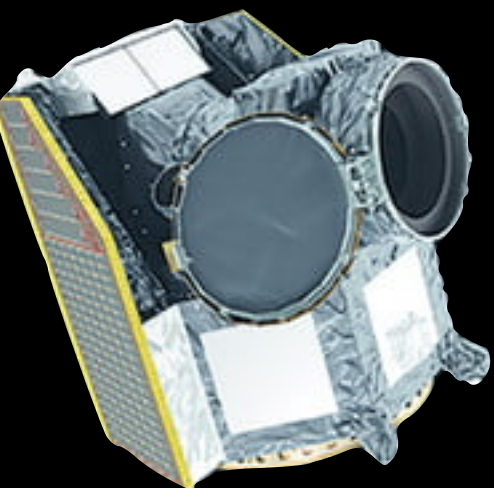


Kepler



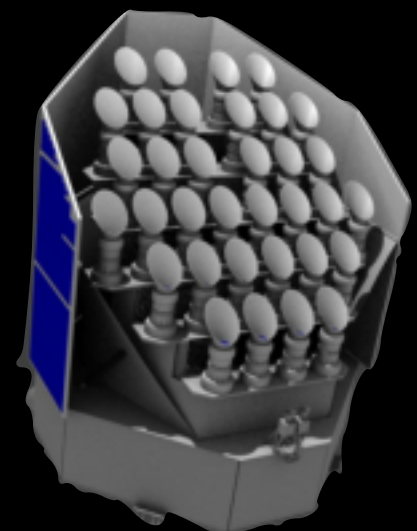
TESS

CHEOPS



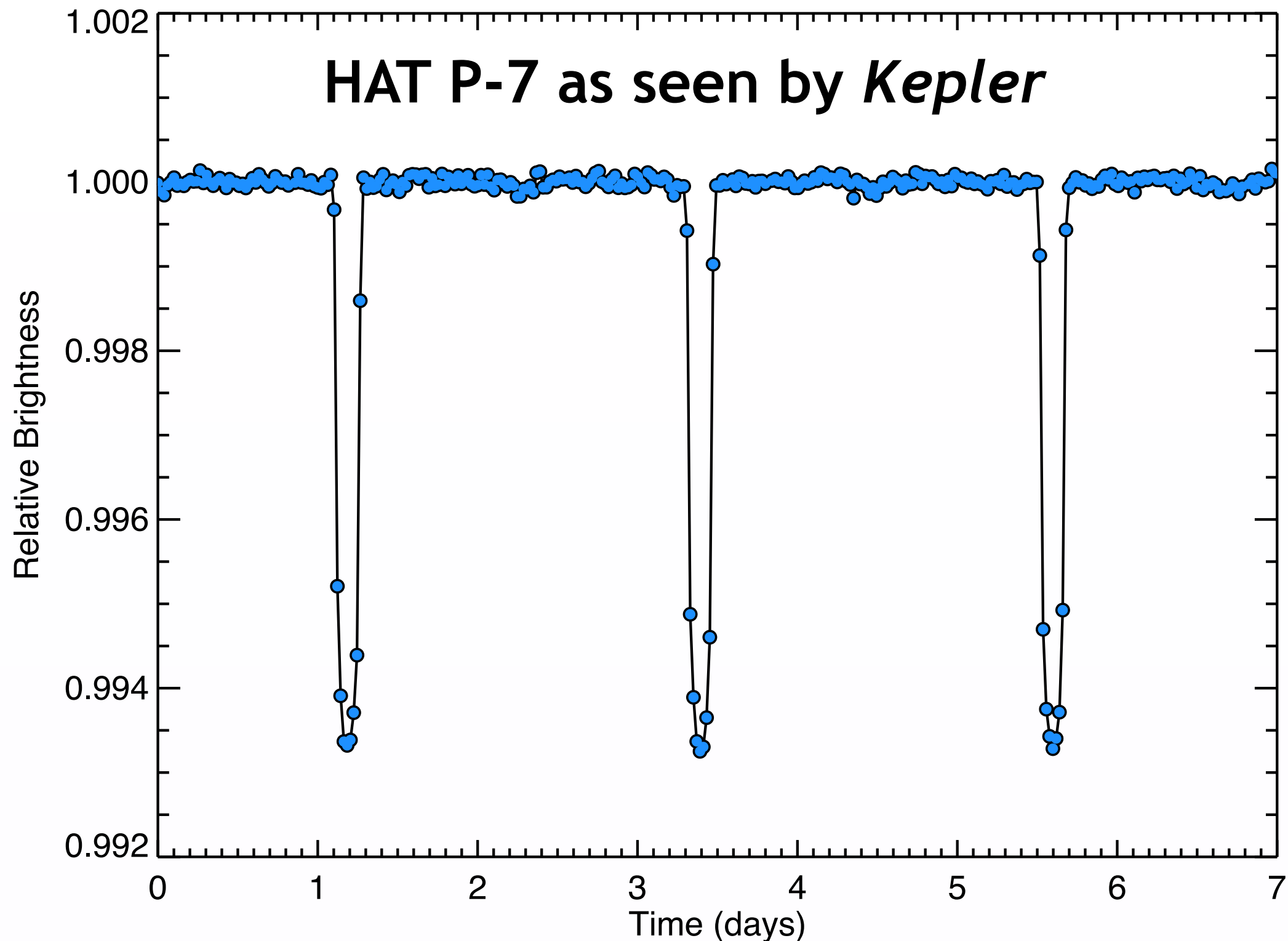
Roman (2026)

PLATO (2027)

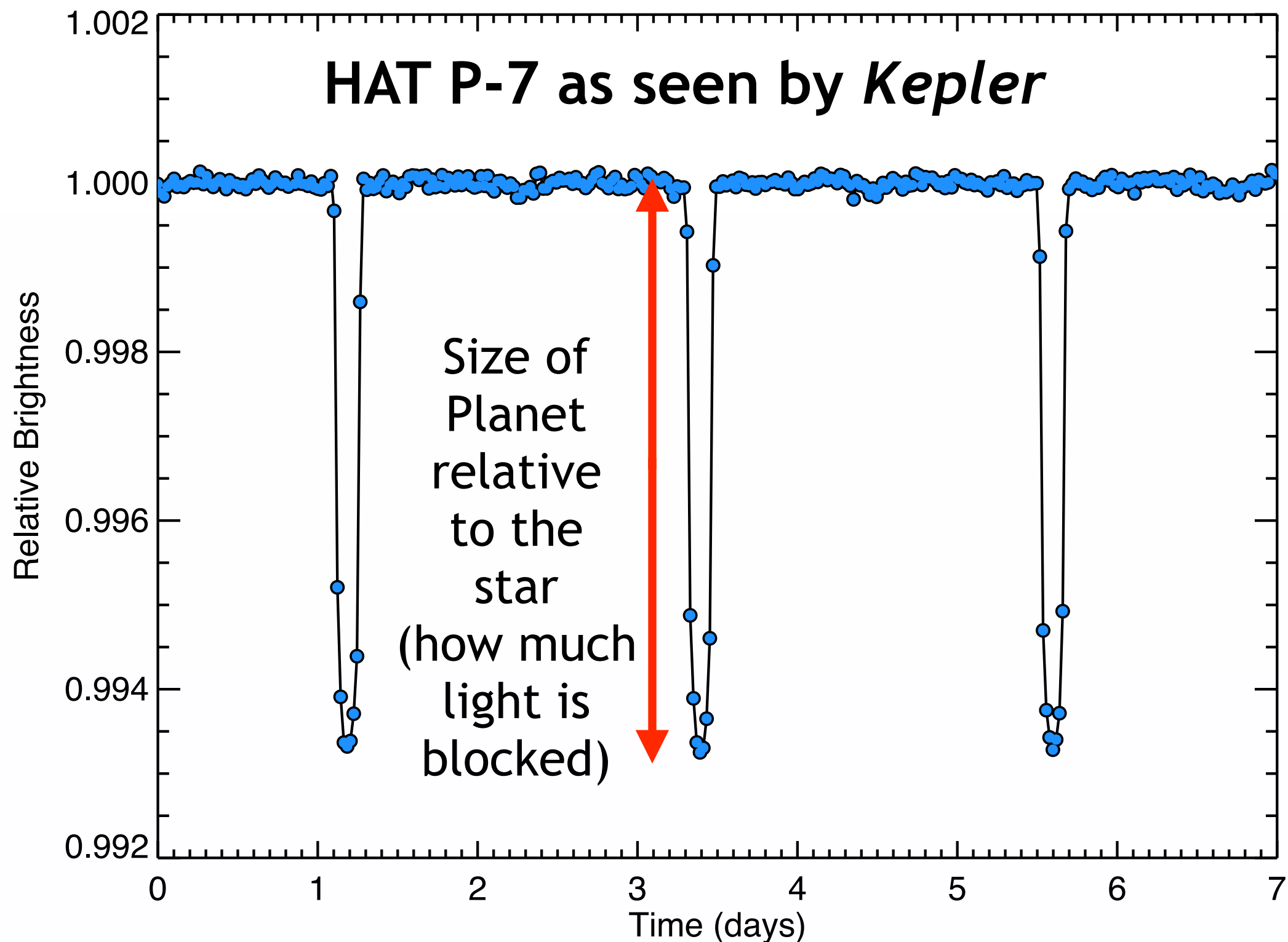


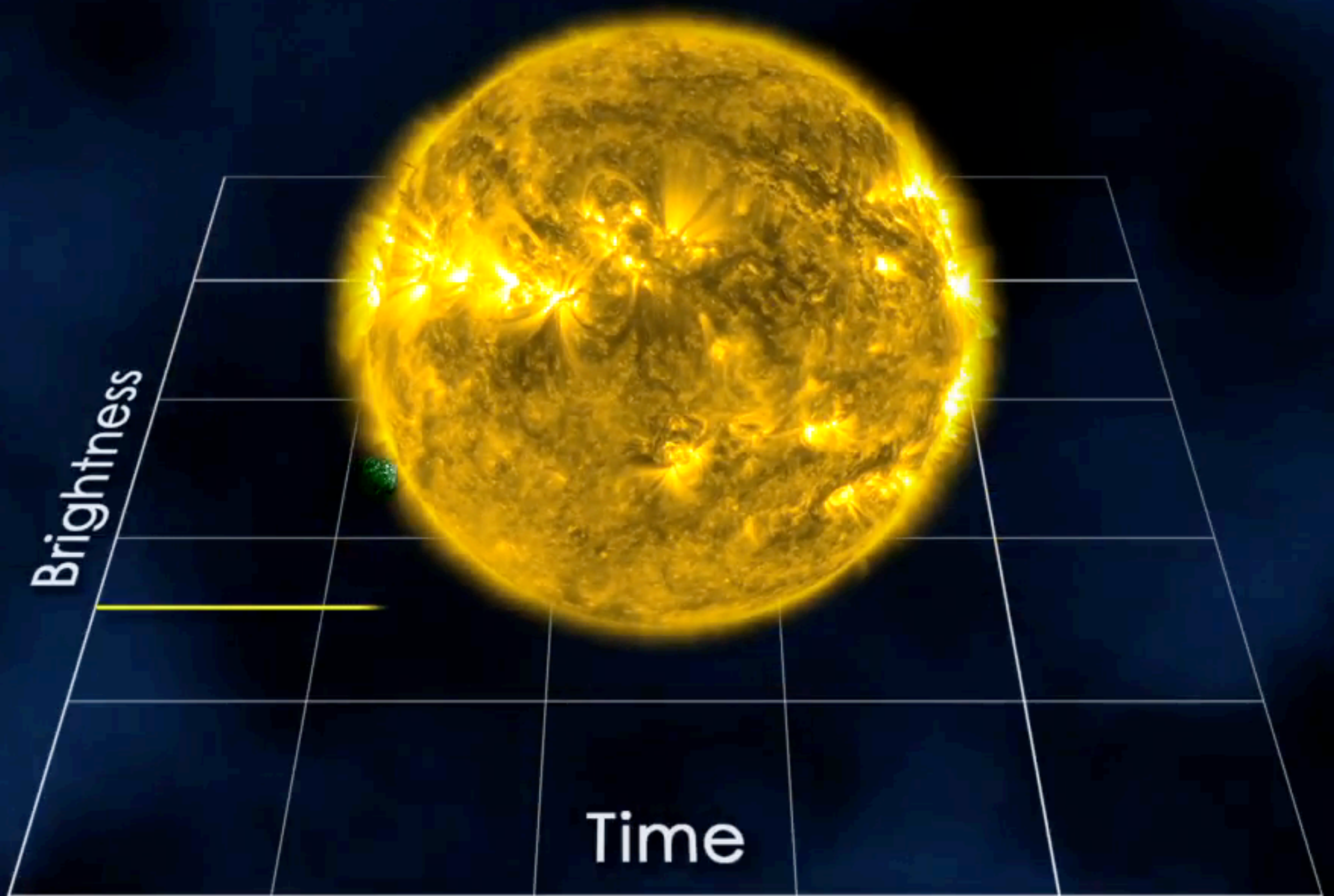
3. Transiting planets are especially valuable

What can we learn from transit light curves?

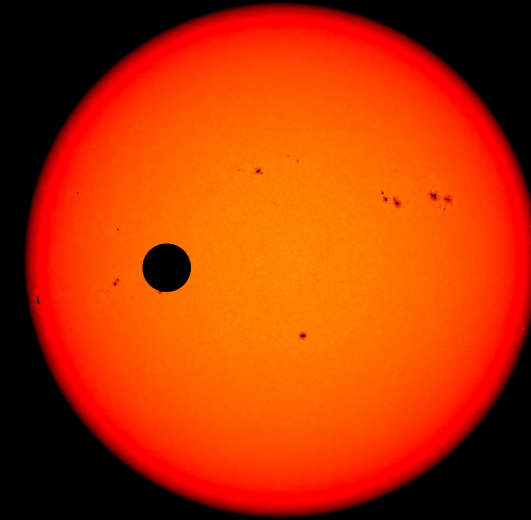
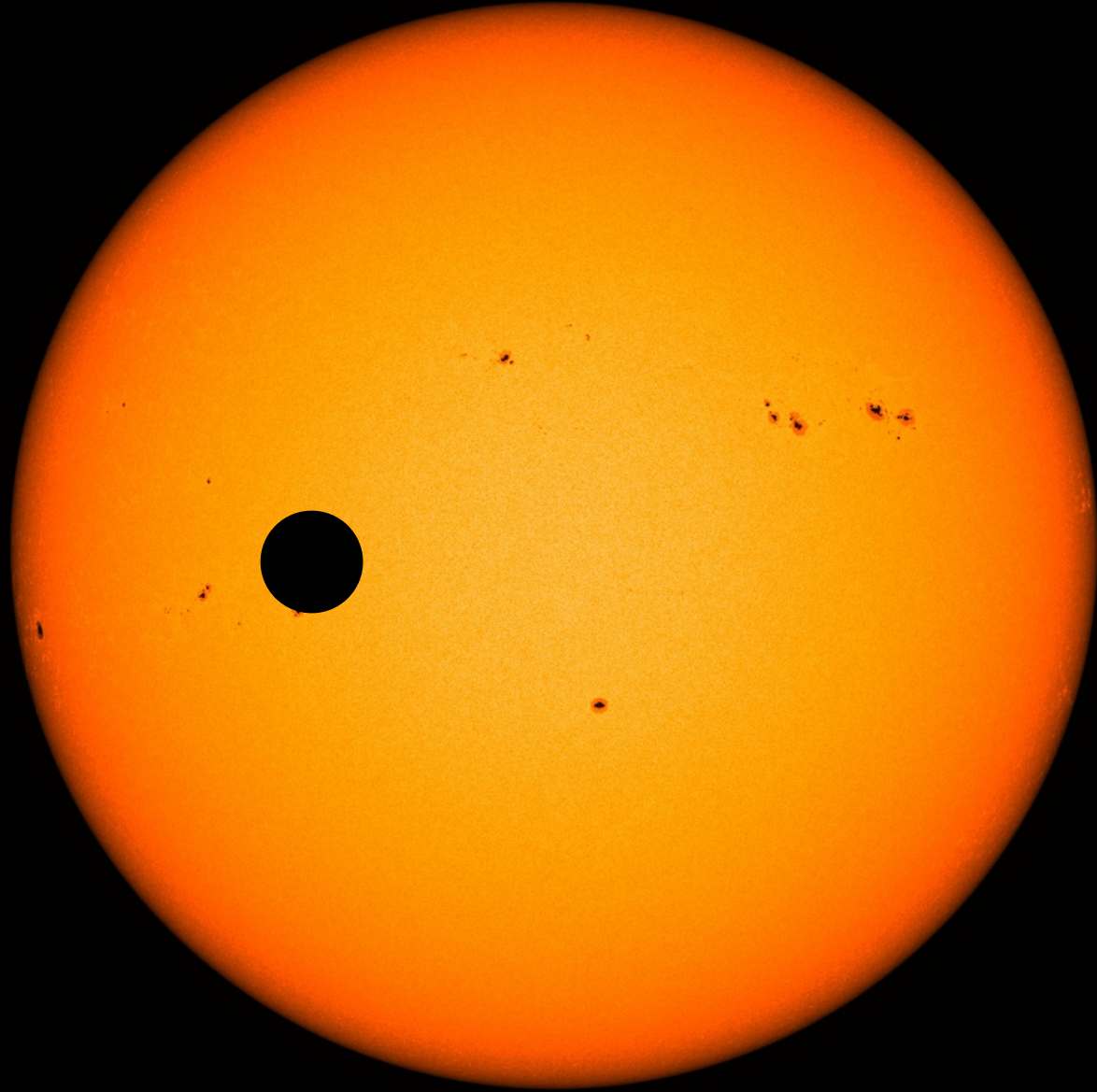


Transit Measurables: Depth

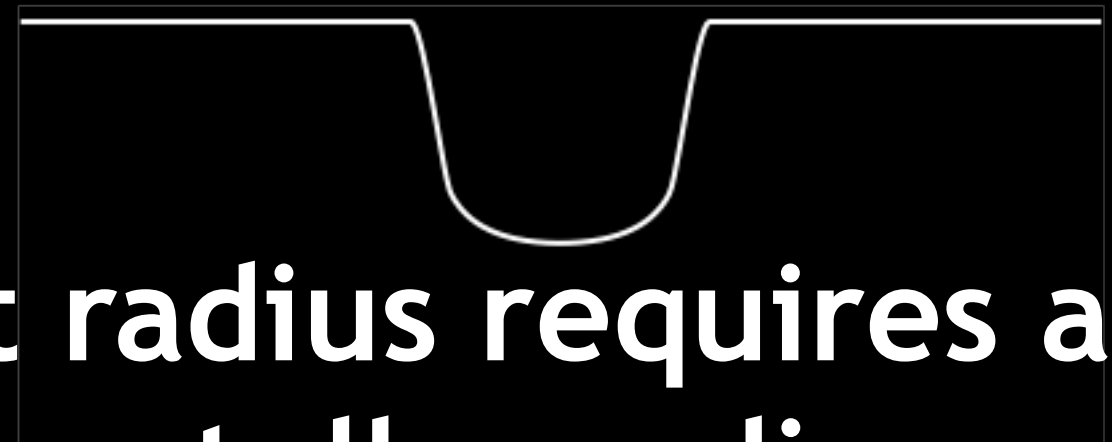
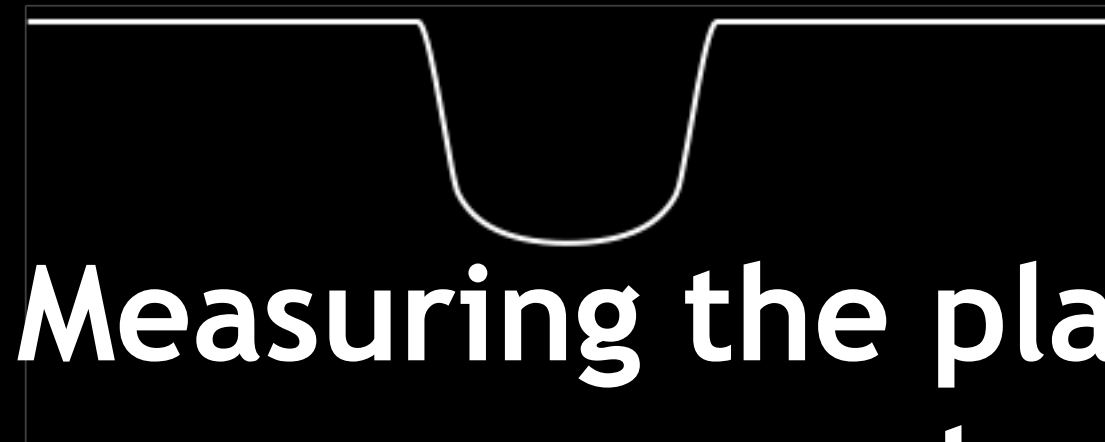




Transit depth gives the relative size between the star and planet

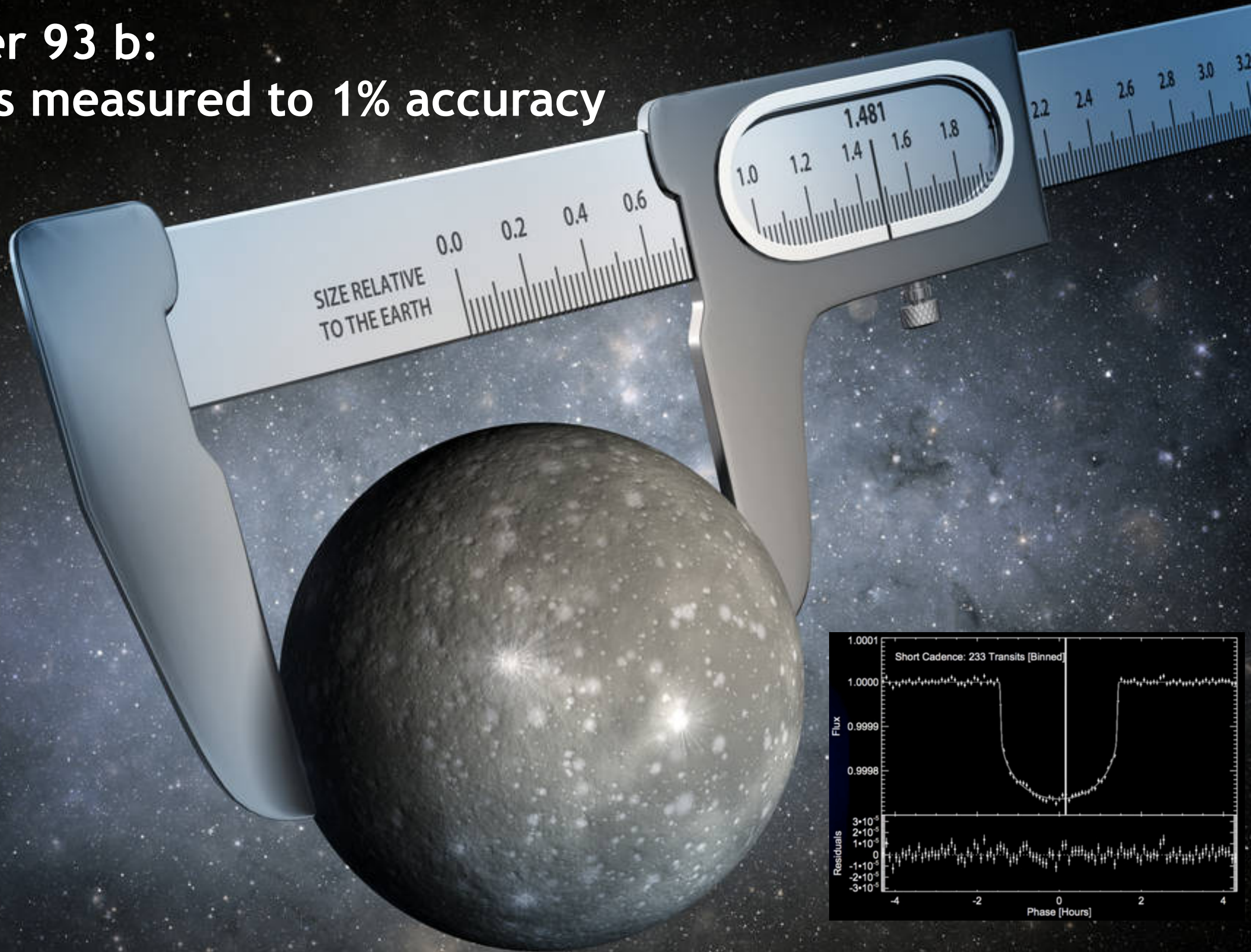


SDO/HMI Quick-Look Continuum: 20150514_003000



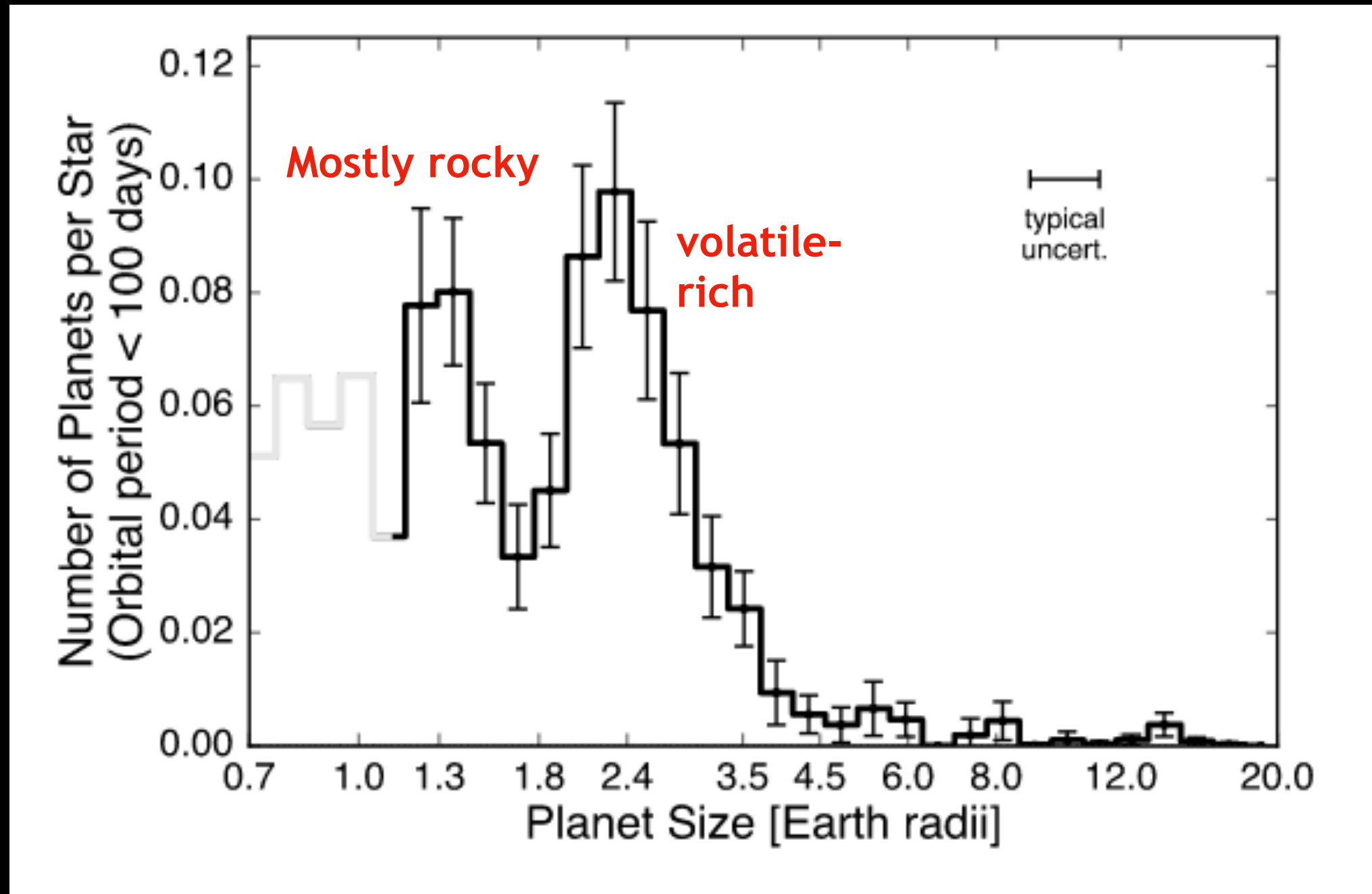
Measuring the planet radius requires a measurement of the stellar radius.

Kepler 93 b: radius measured to 1% accuracy

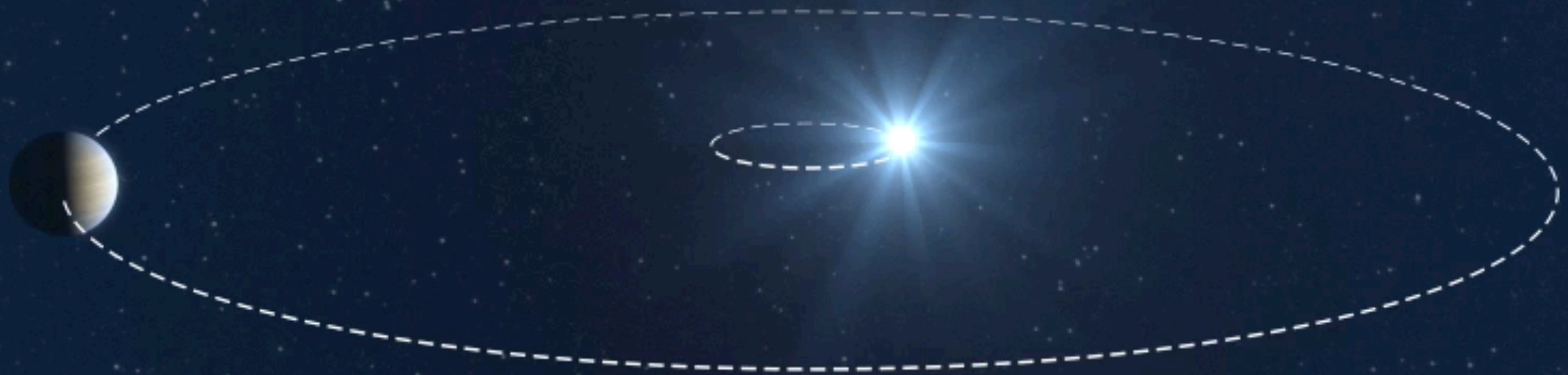


Ballard et al. 2015

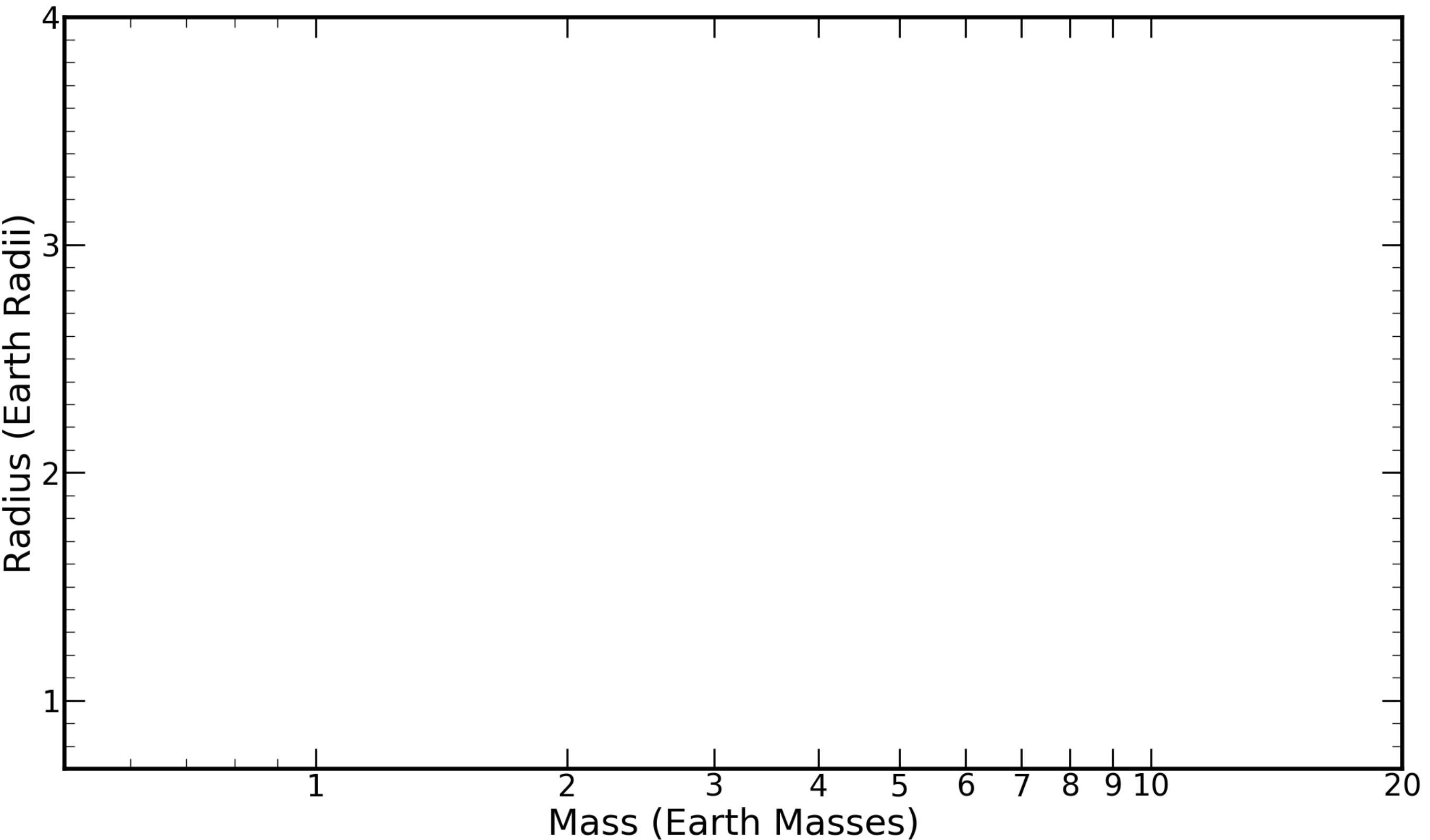
A large sample reveals a dichotomy between mostly rocky planets and those with volatiles.



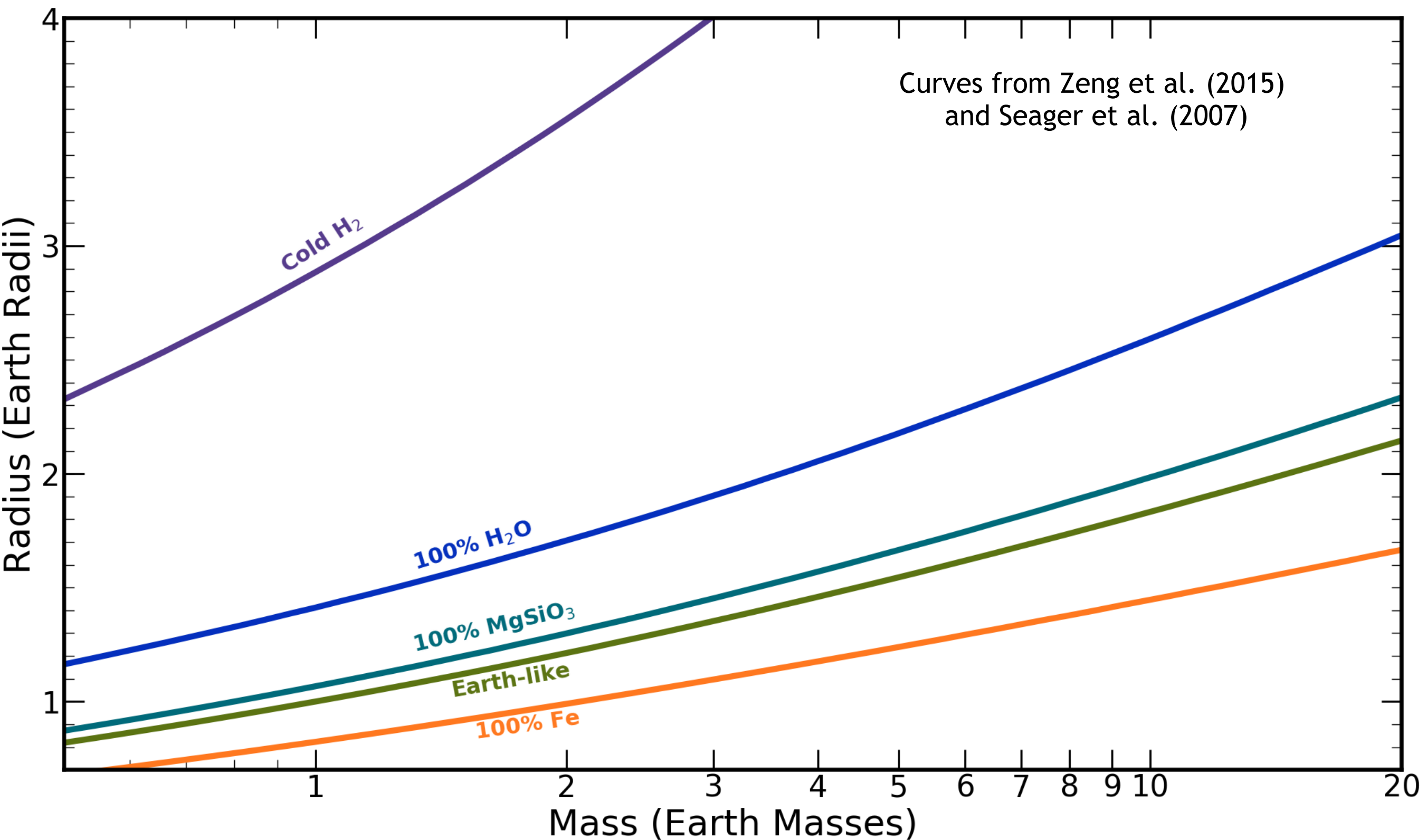
Combining transits with radial velocity observations



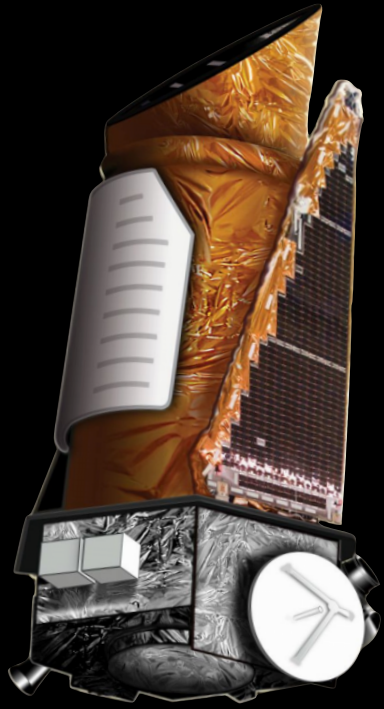
Exoplanet Mass/Radius Diagram



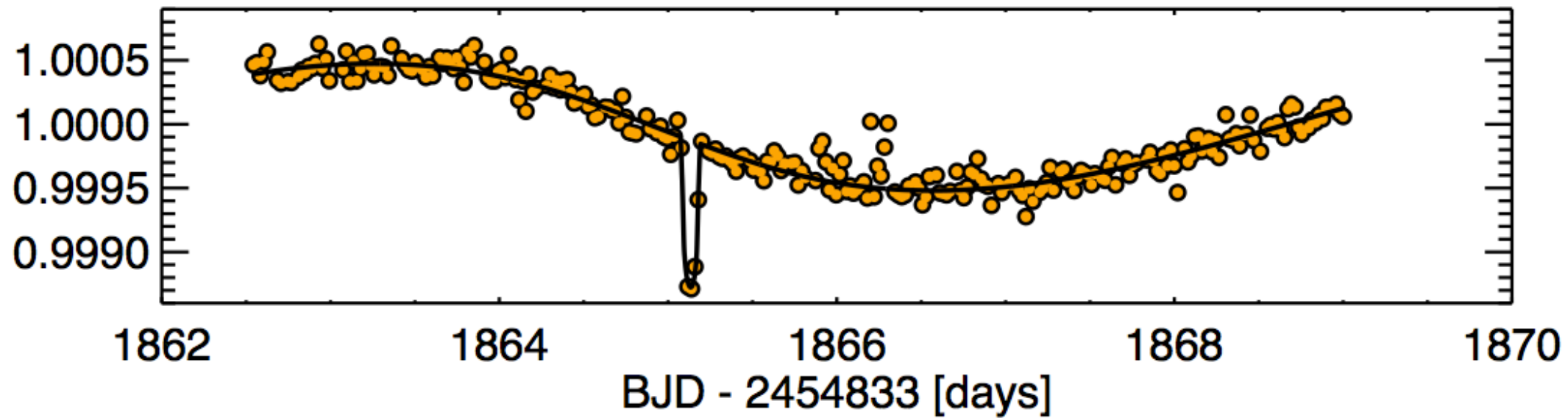
Exoplanet Mass/Radius Diagram



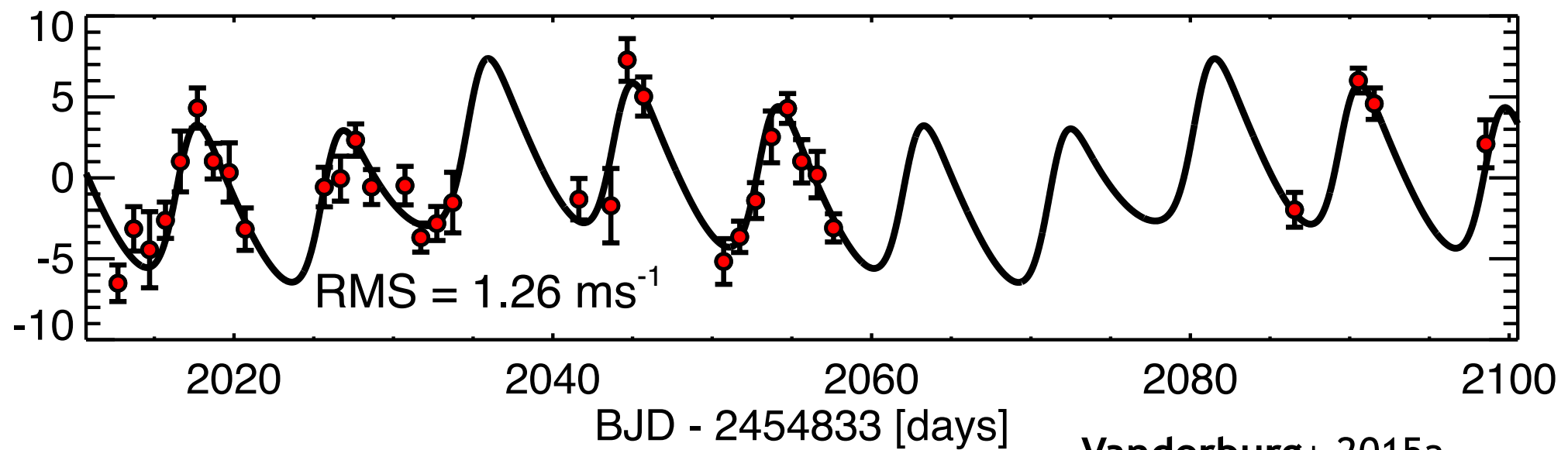
Observations of HIP 116454



Relative Brightness

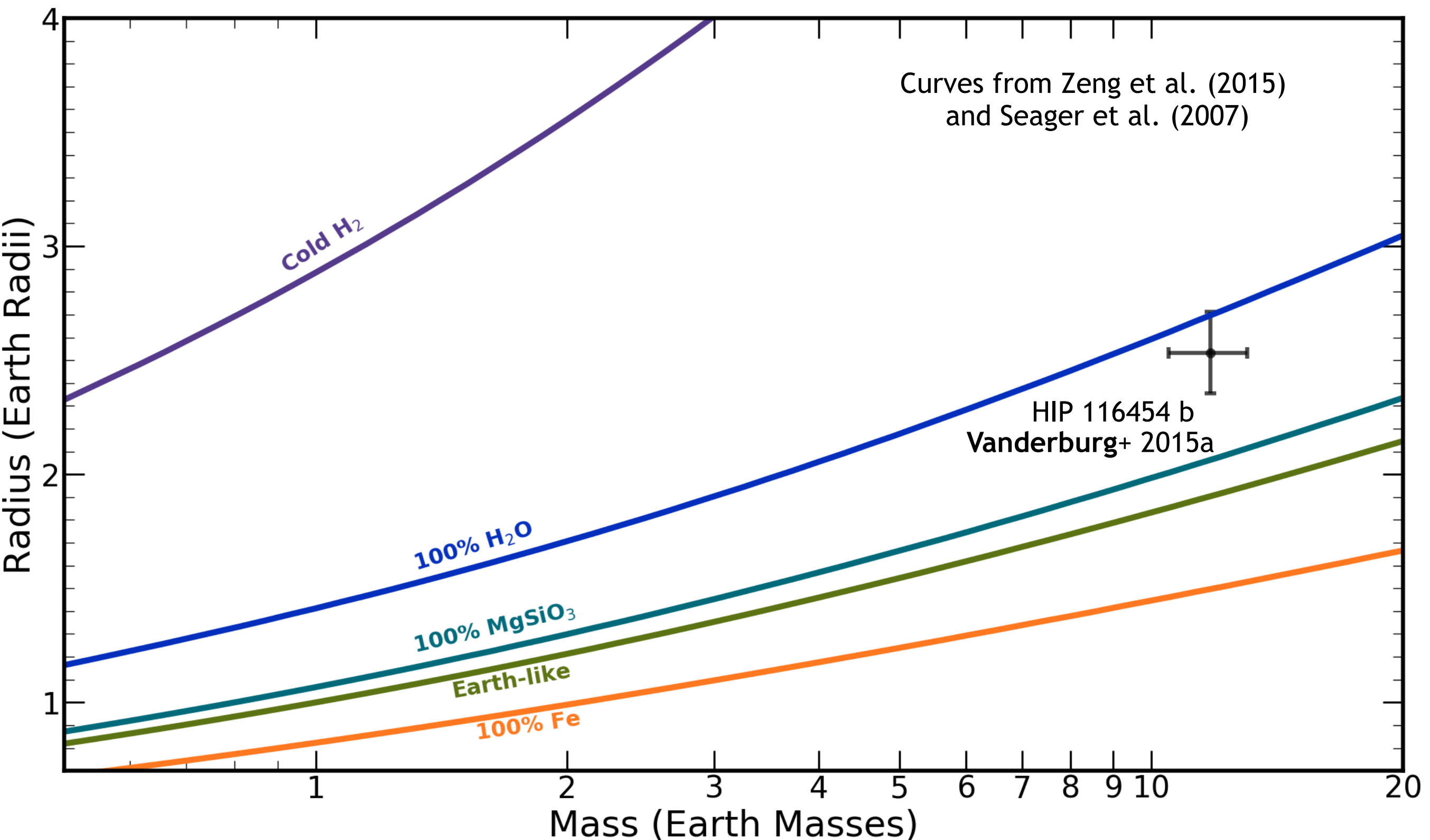


Radial Velocity [ms^{-1}]

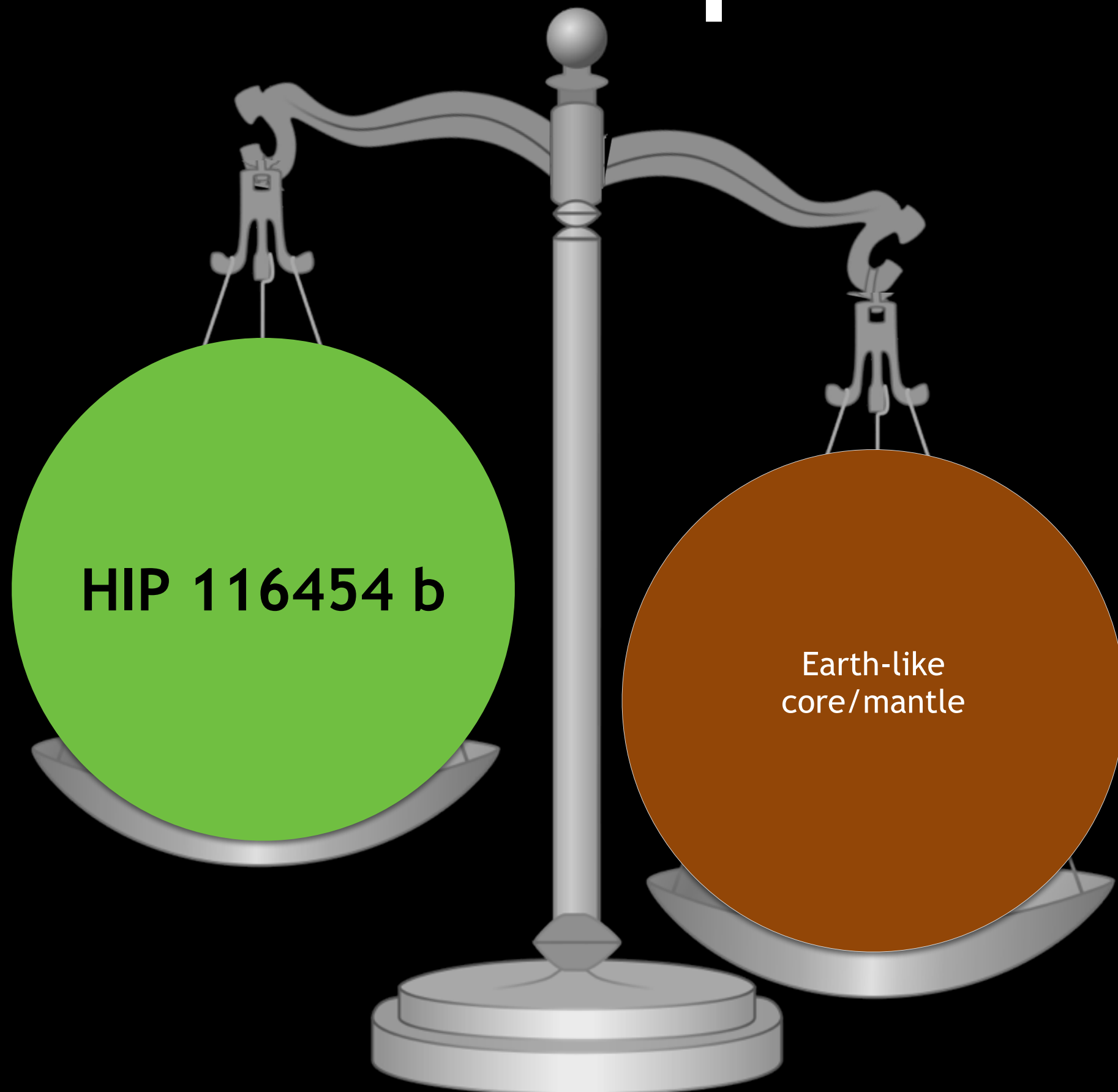


Vanderburg+ 2015a

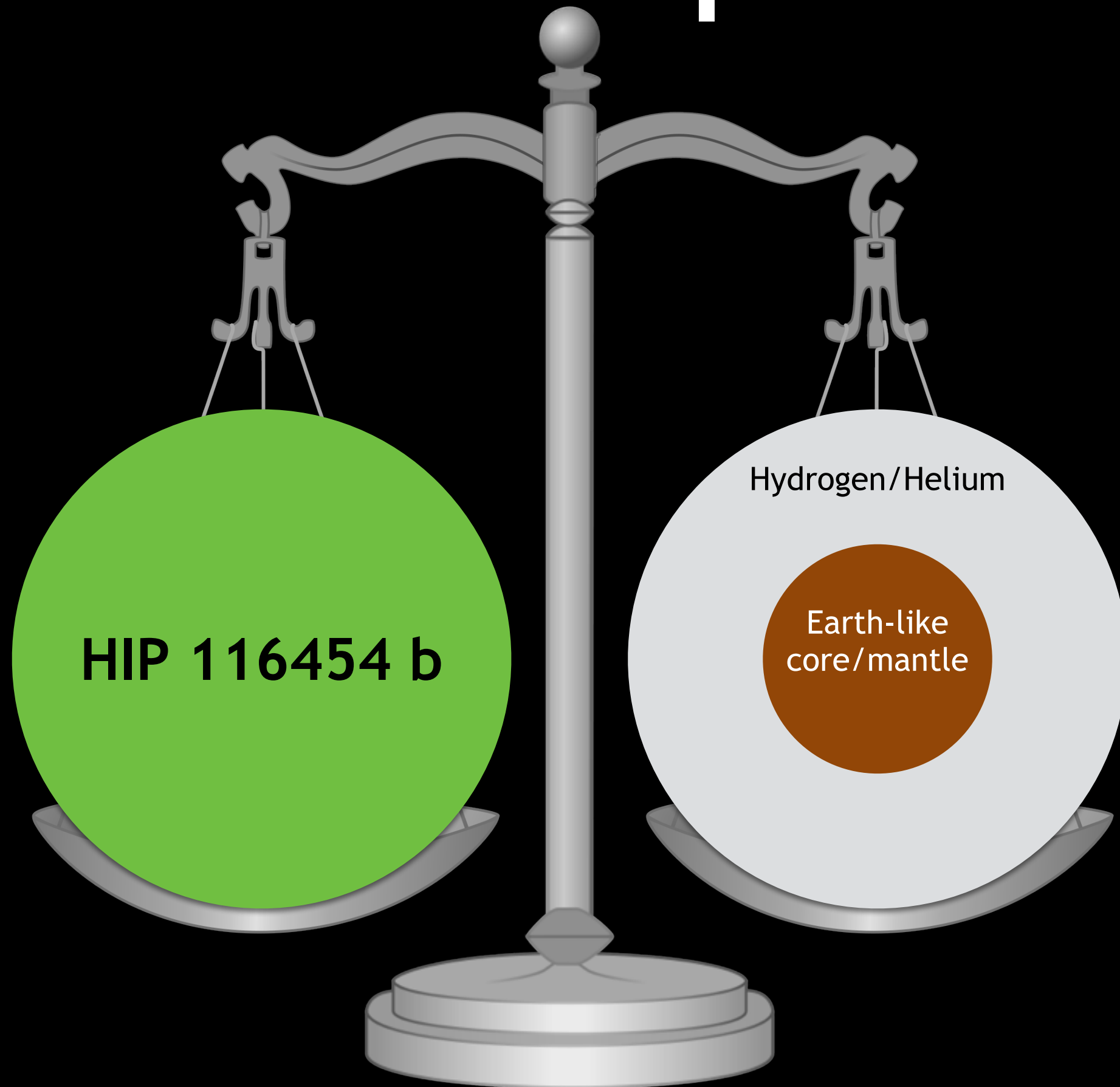
Exoplanet Mass/Radius Diagram



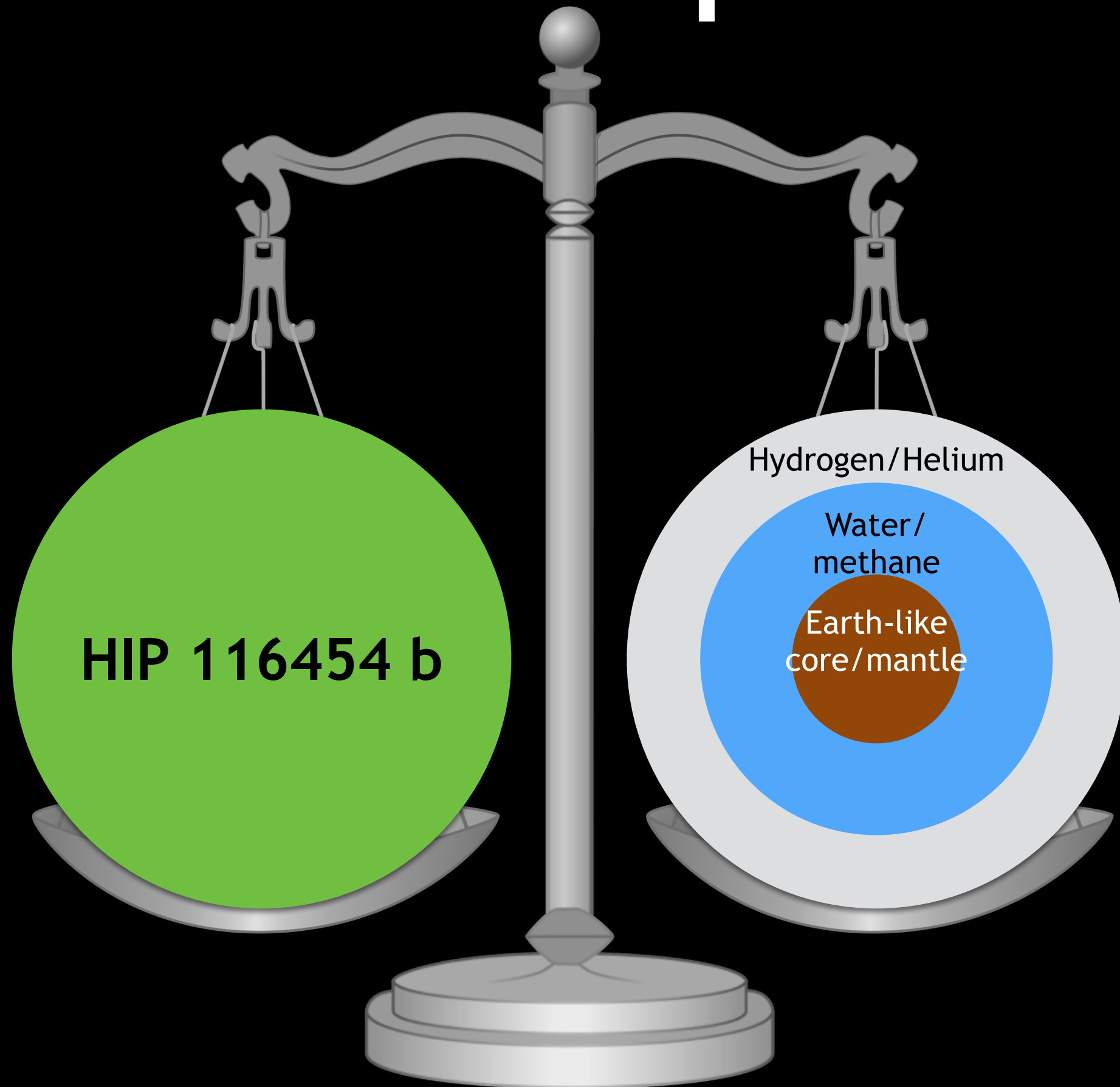
Possible Compositions

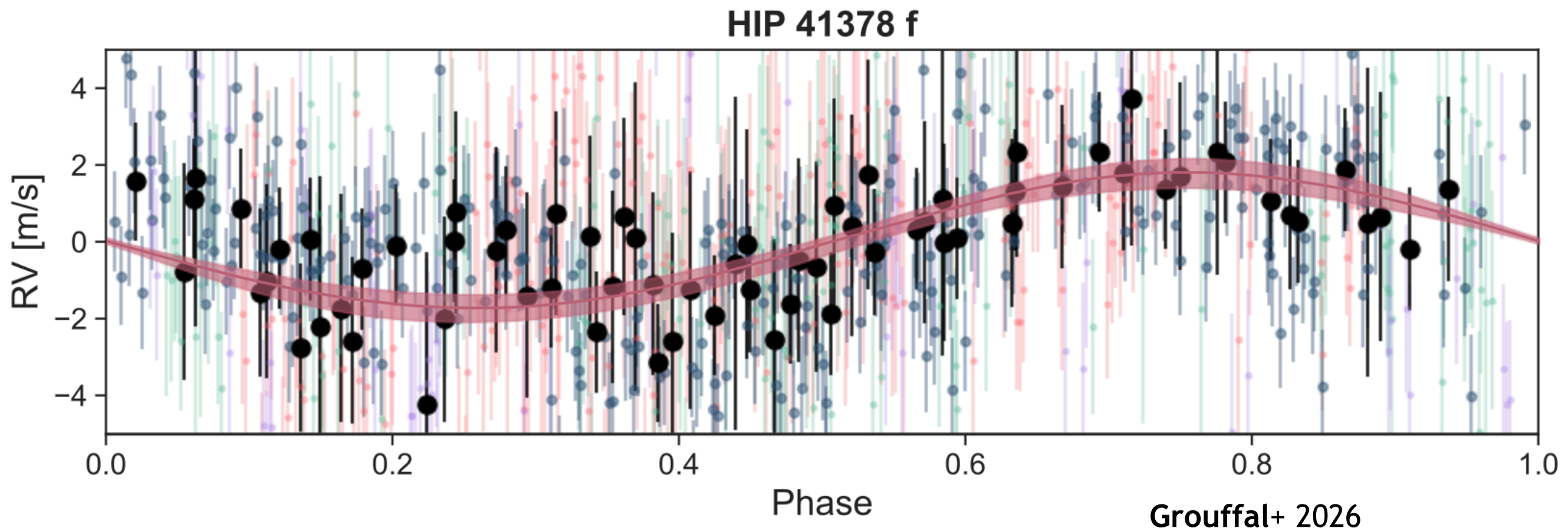
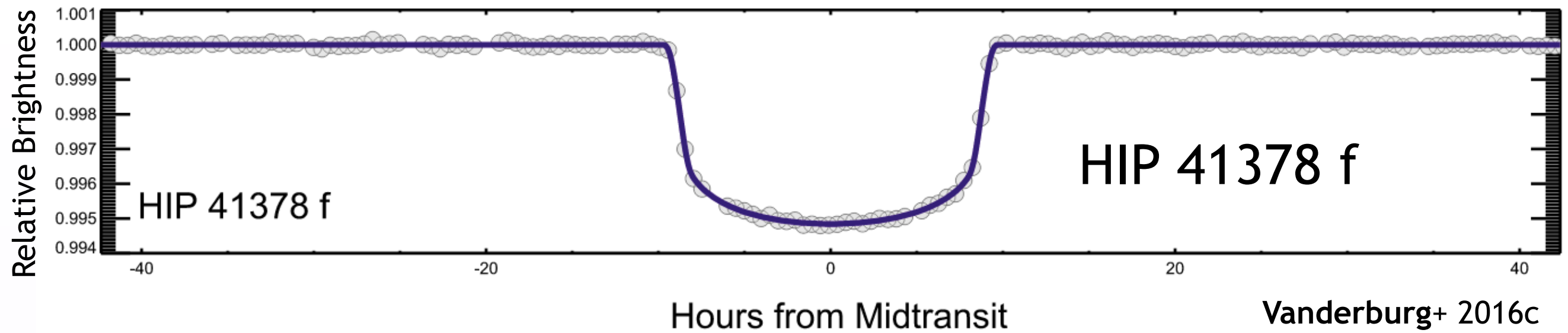


Possible Compositions



Possible Compositions





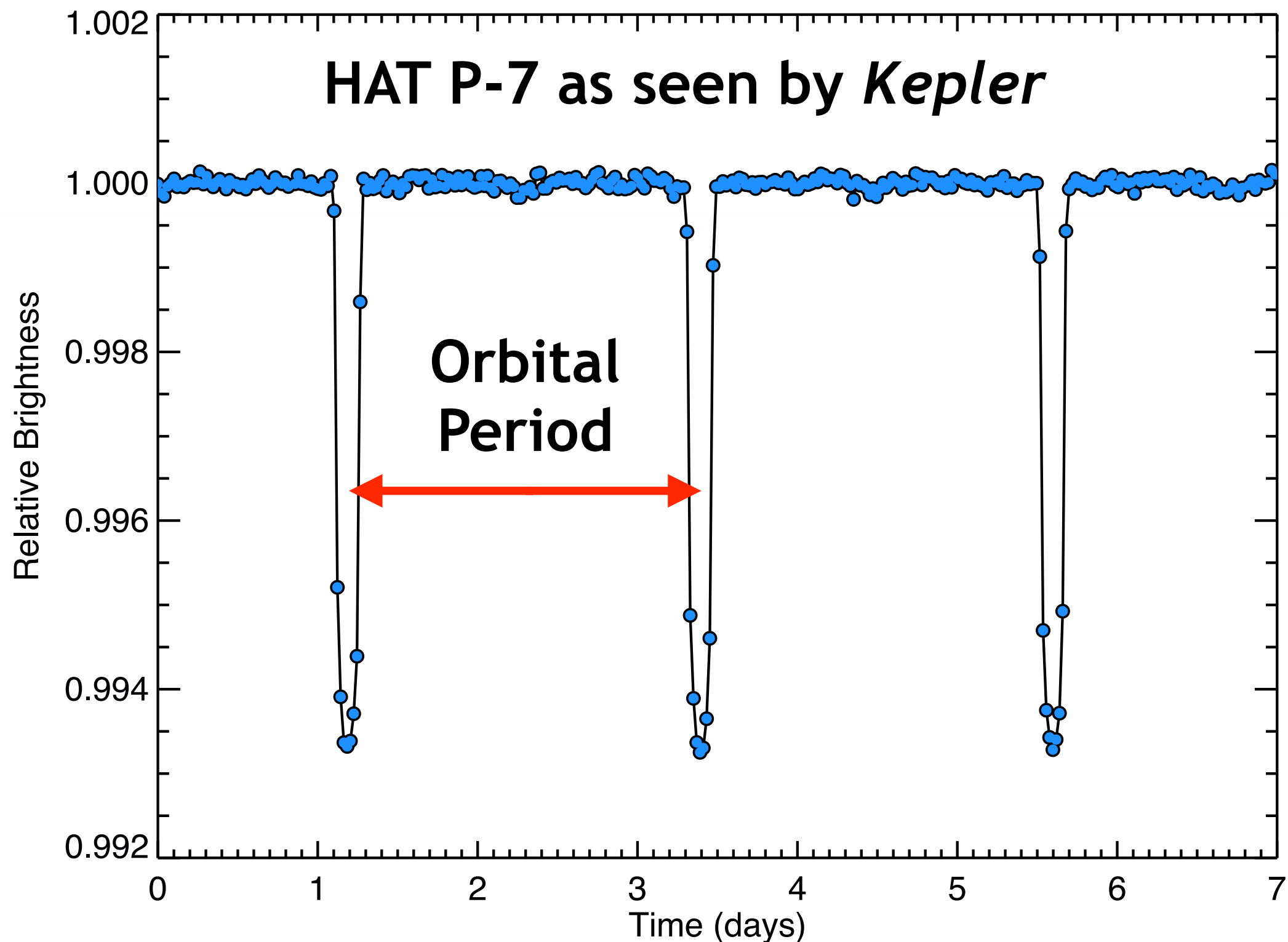
Radius = $9.5 R_{\oplus}$
Mass = $25 M_{\oplus}$

Density =
 0.16 g/cm^3



Lower density than marshmallows

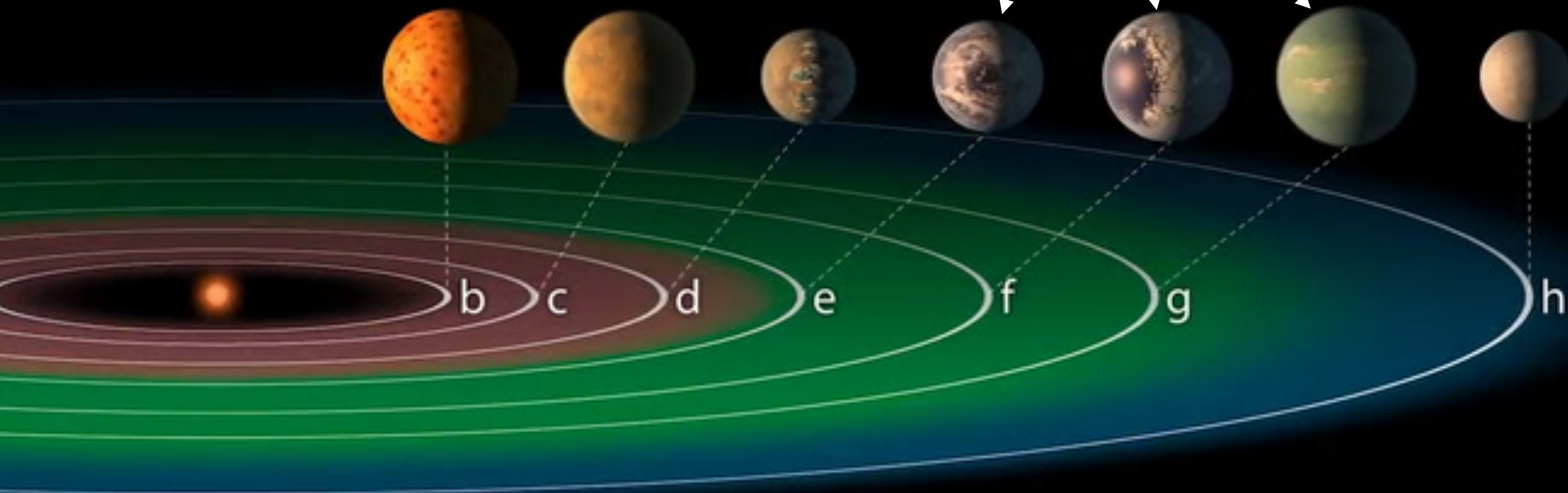
Transit Measurables: Period



TRAPPIST-1 System

Habitable zone

Illustrations

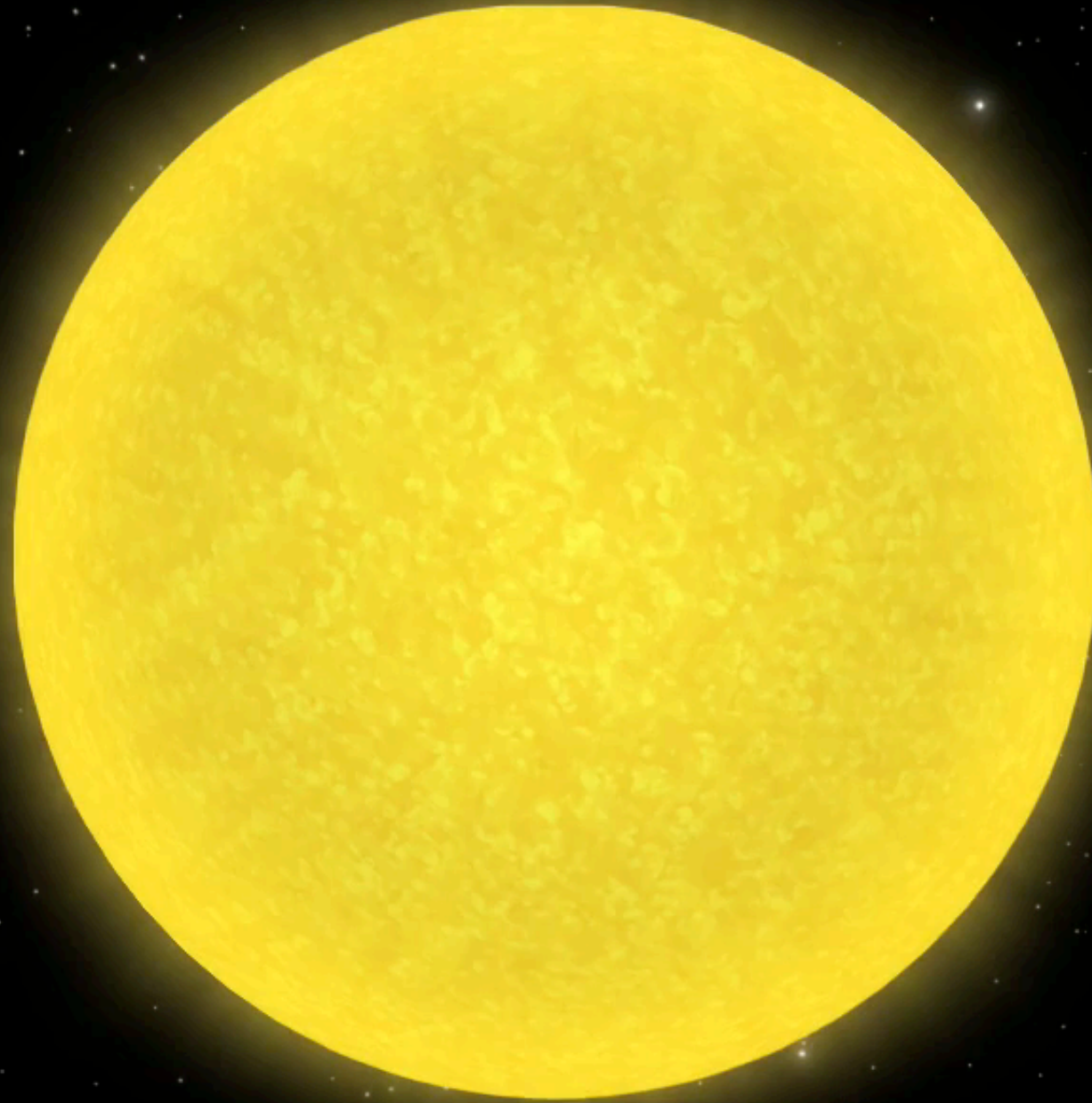
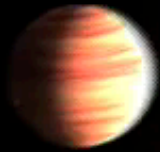


Relative scale
of Earth

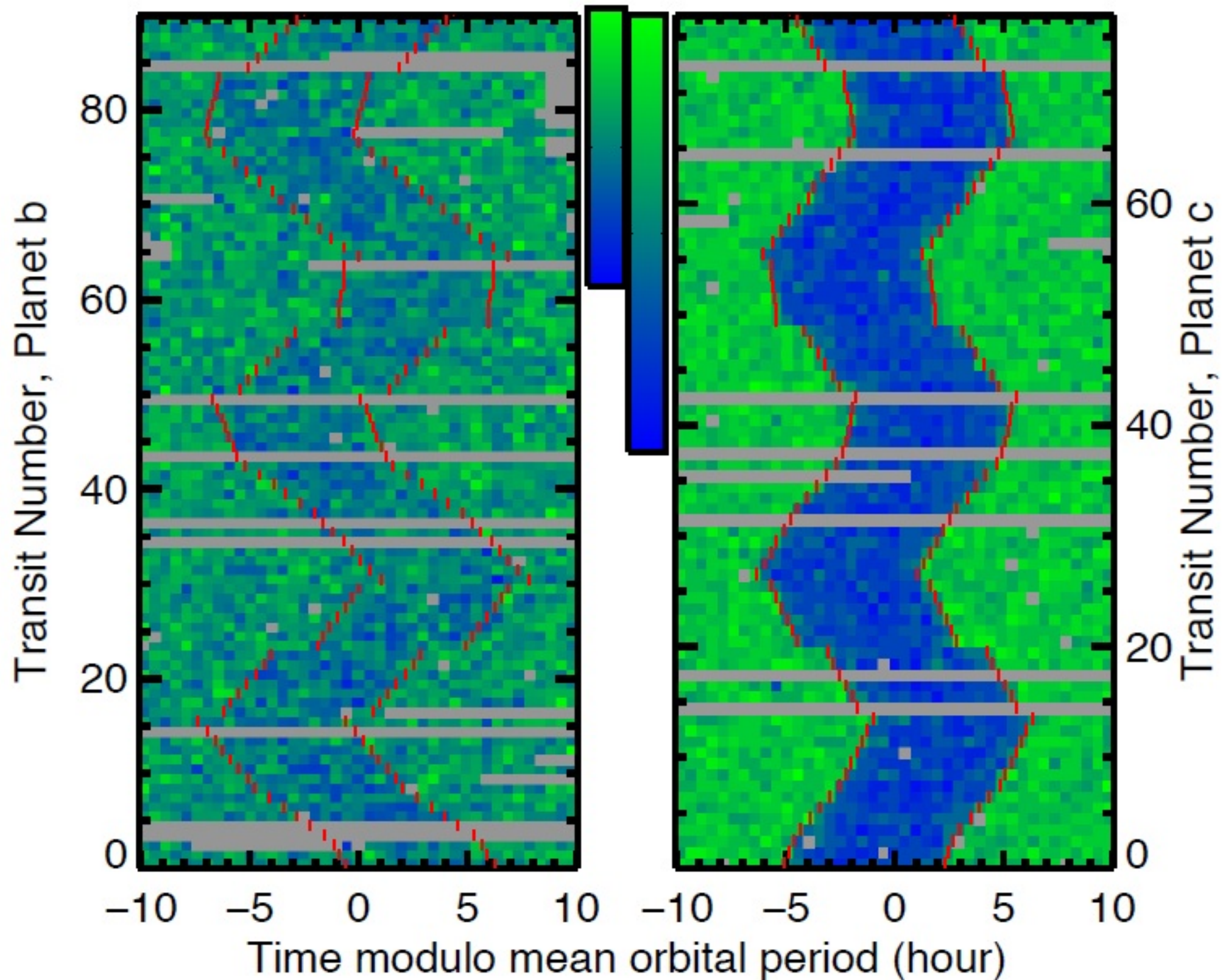


Star and orbits shown in scale
Planets enlarged approximately 7,600x

Transit Timing Variations

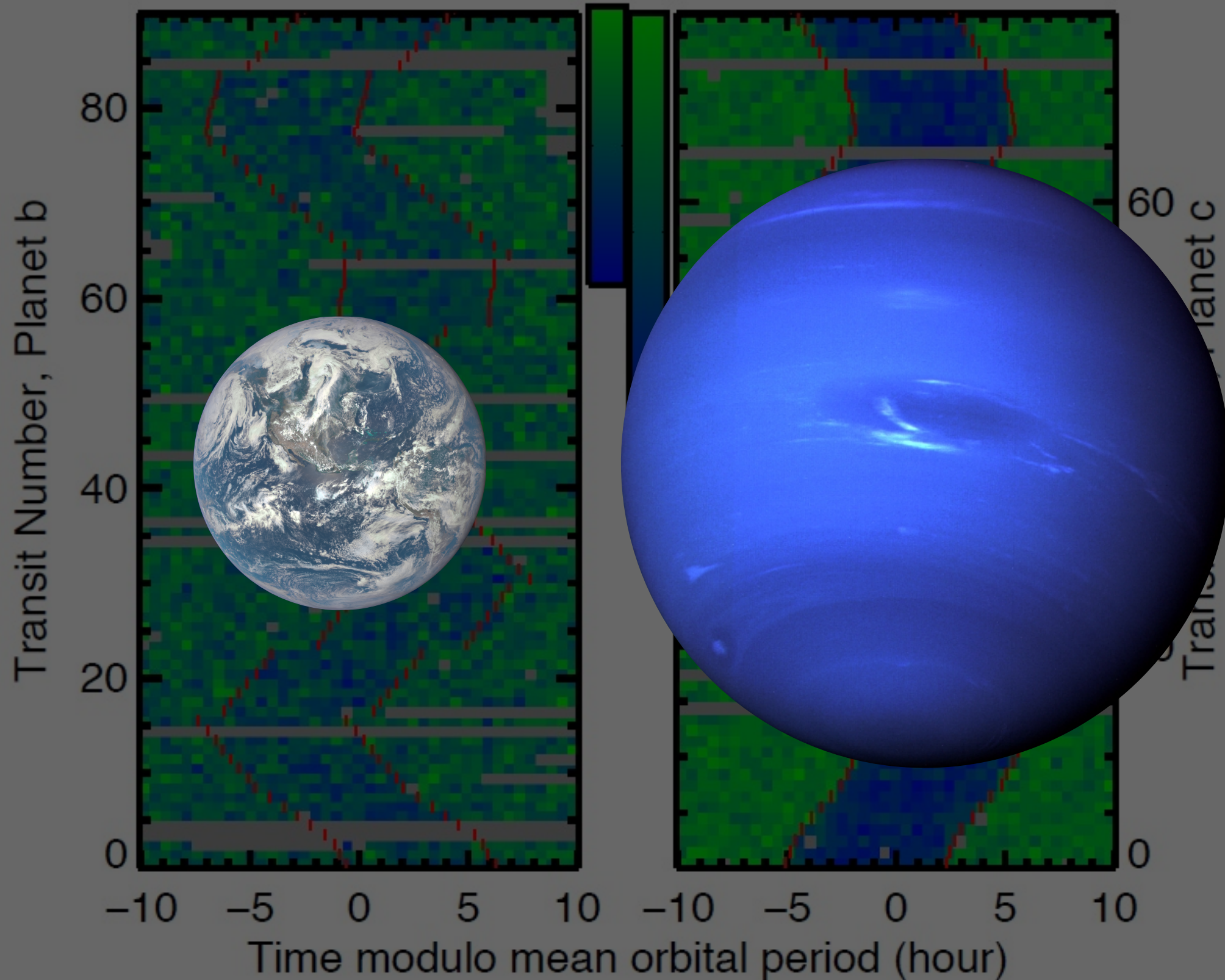


Transit Timing Variations



Carter et al. 2012

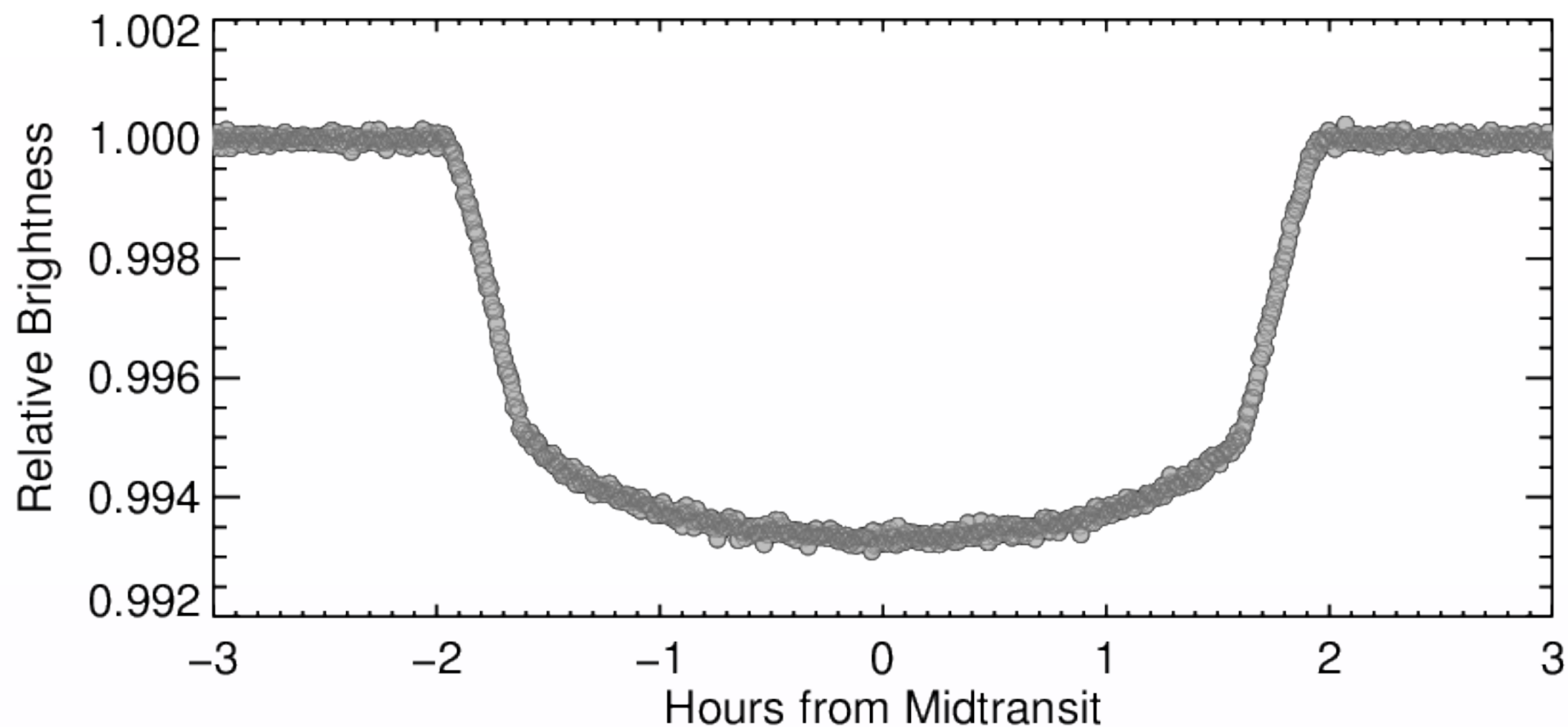
Transit Timing Variations



Carter et al. 2012

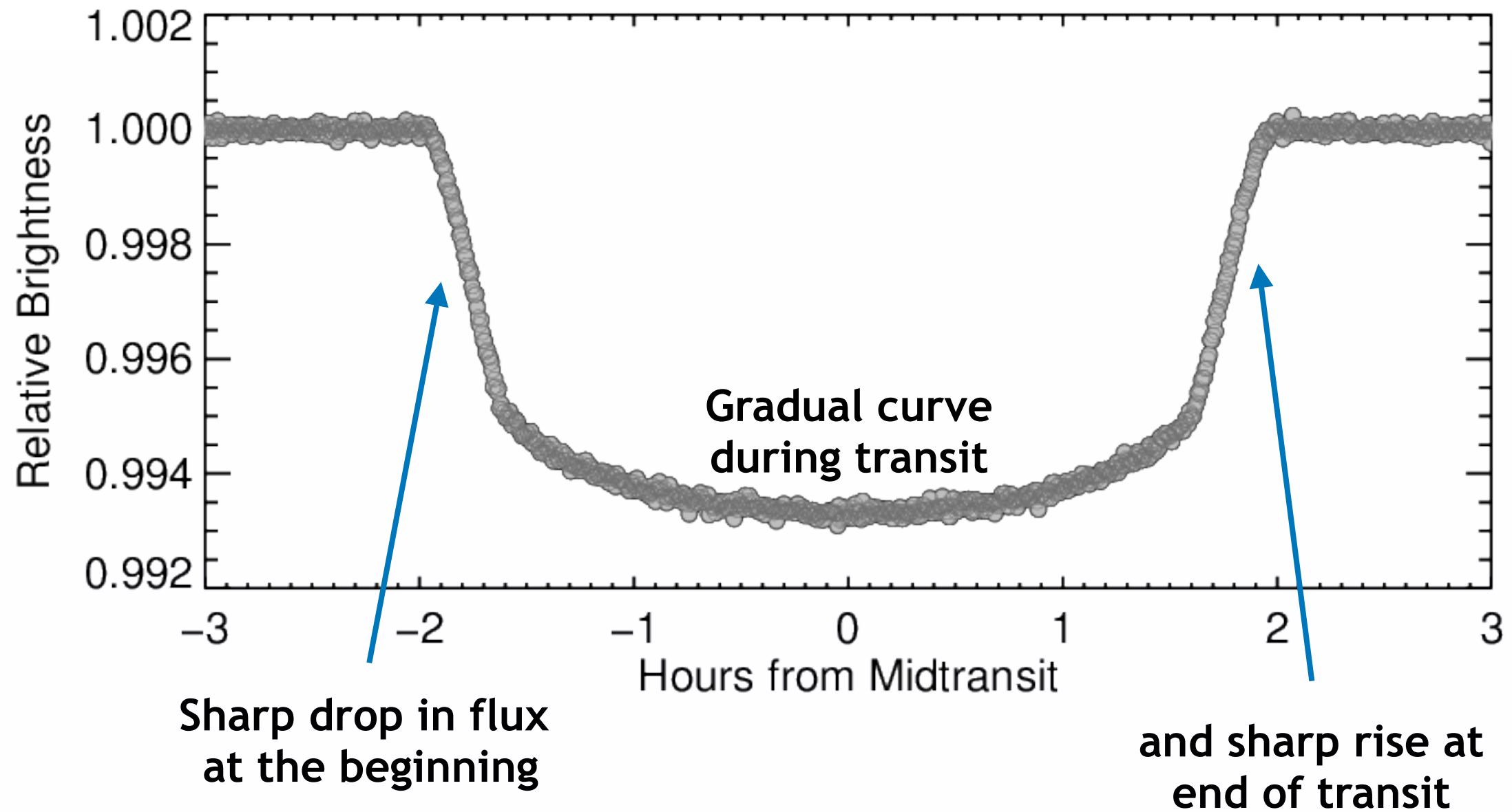
Transit Measurables: Duration

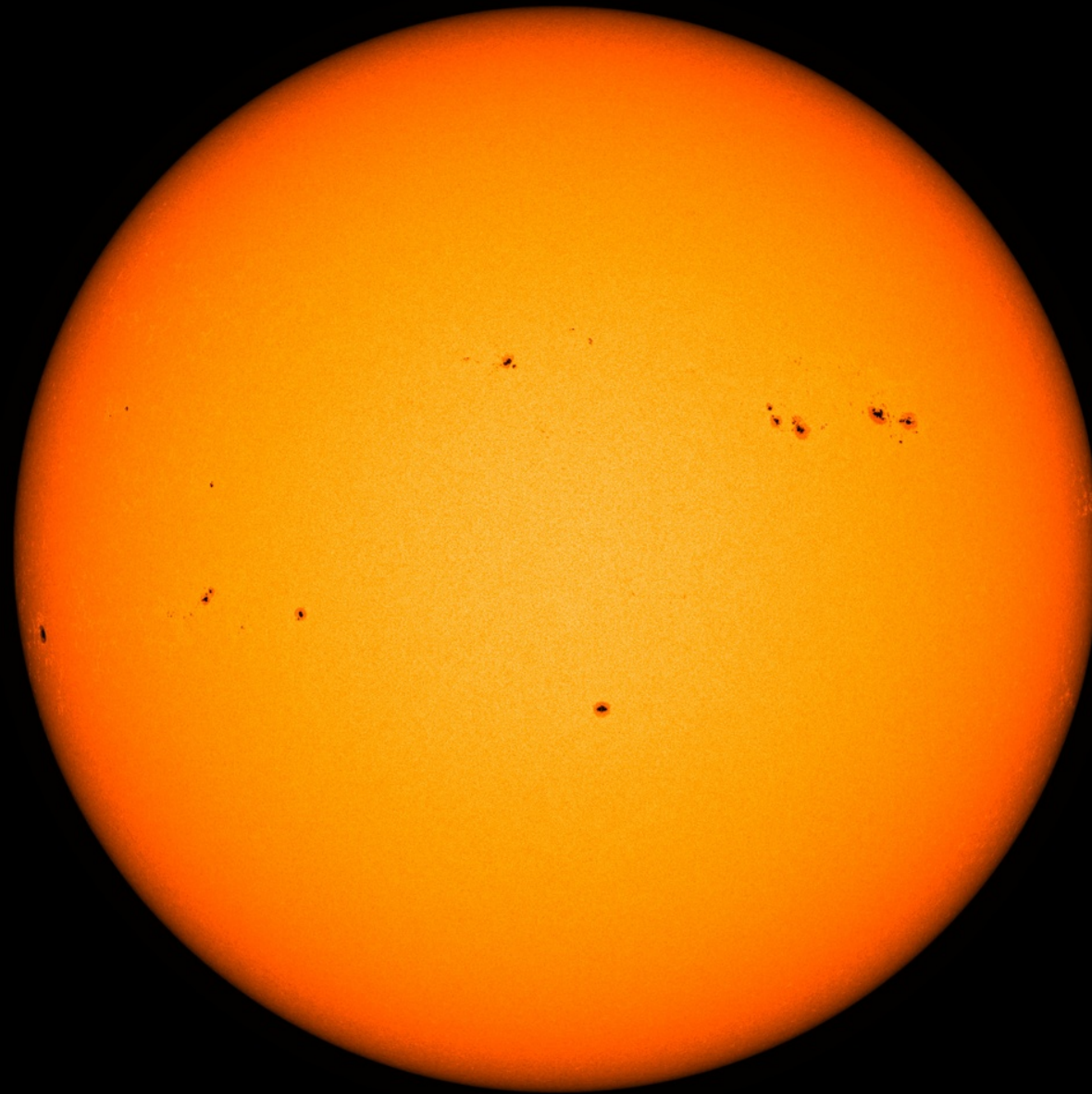
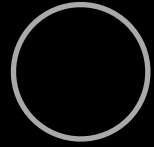
HAT P-7 as seen by *Kepler*



Transit Measurables: Duration

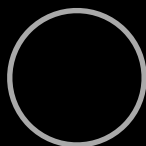
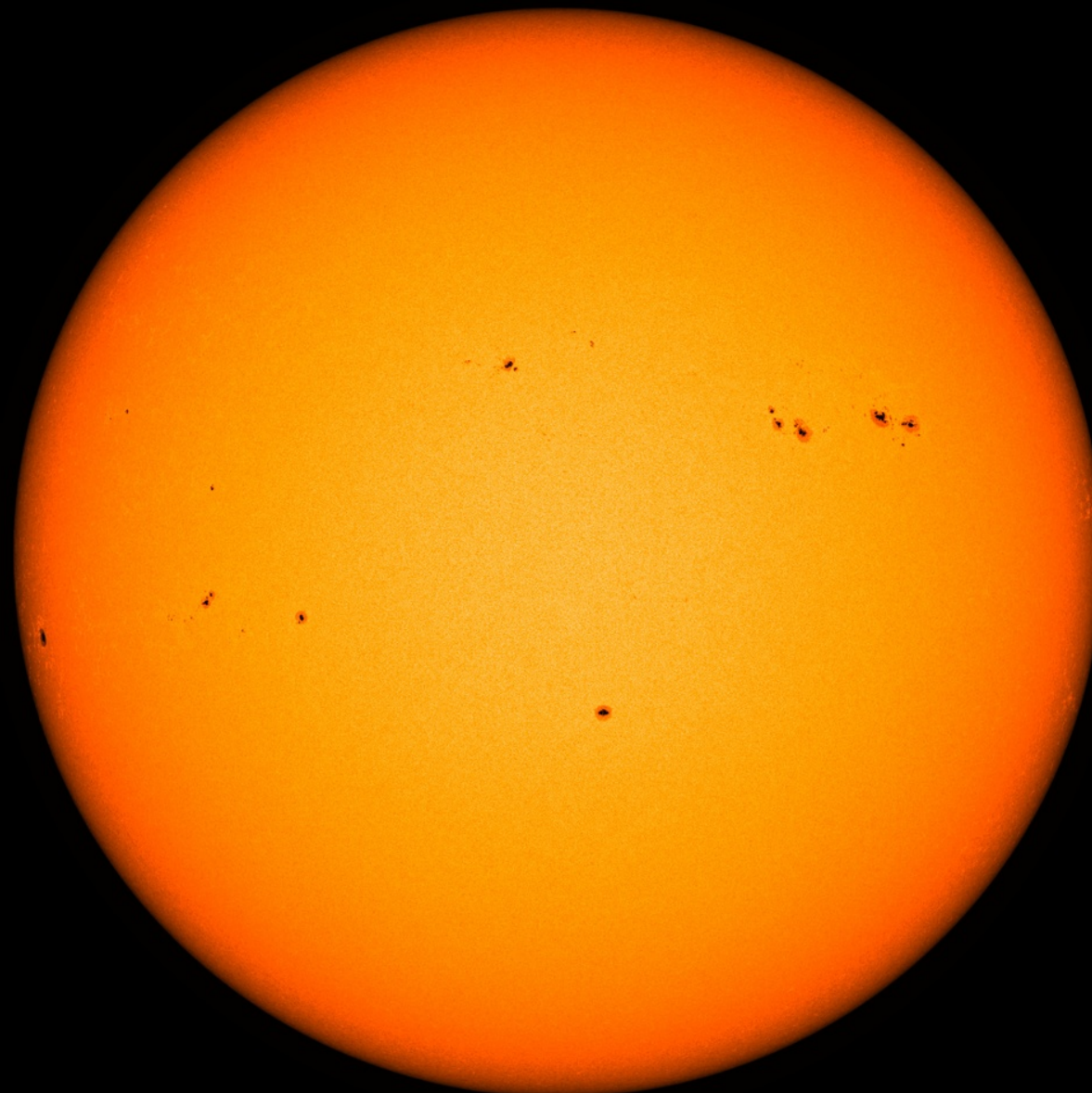
HAT P-7 as seen by *Kepler*





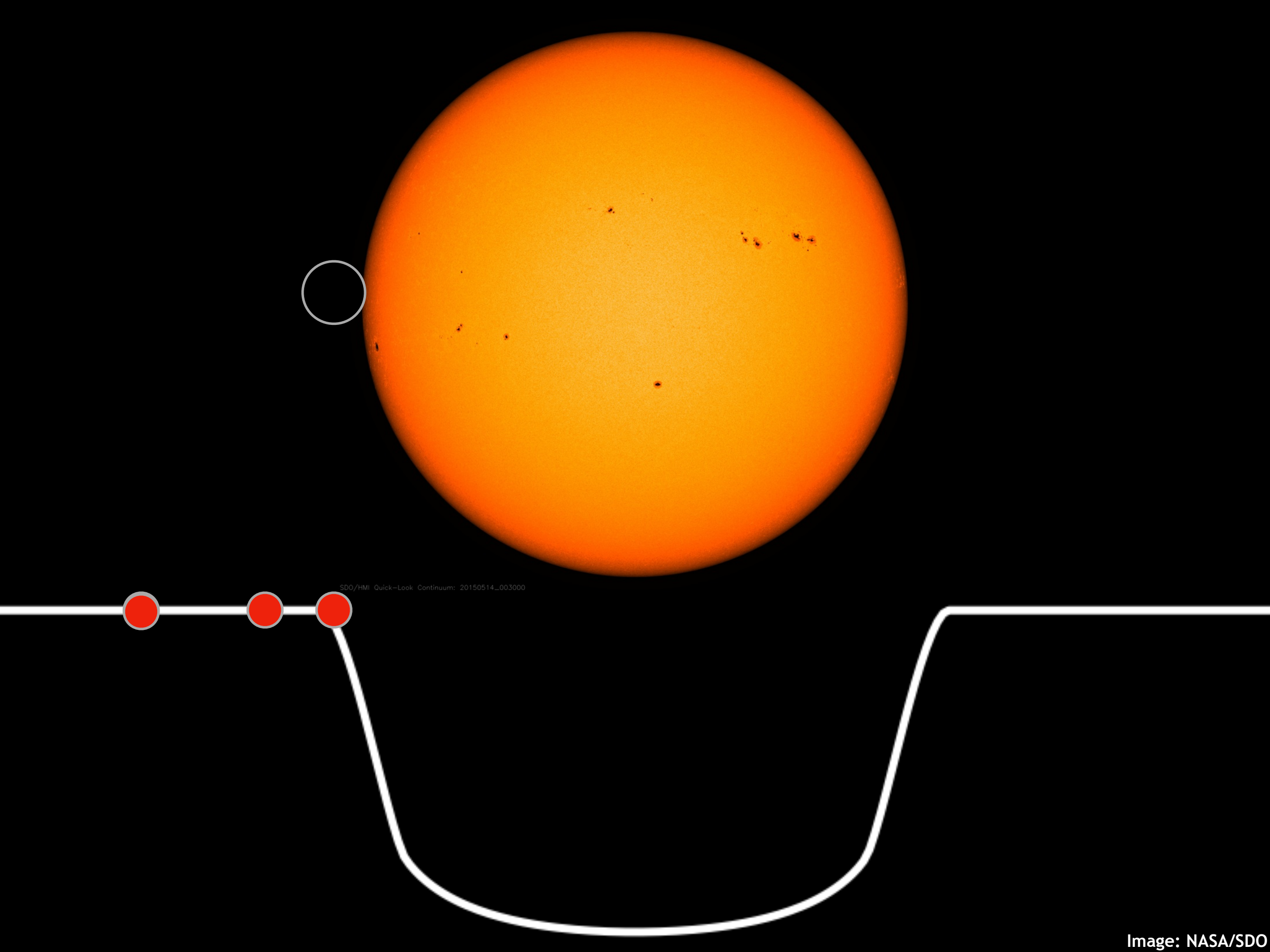
SDO/HMI Quick-Look Continuum: 20150514_003000



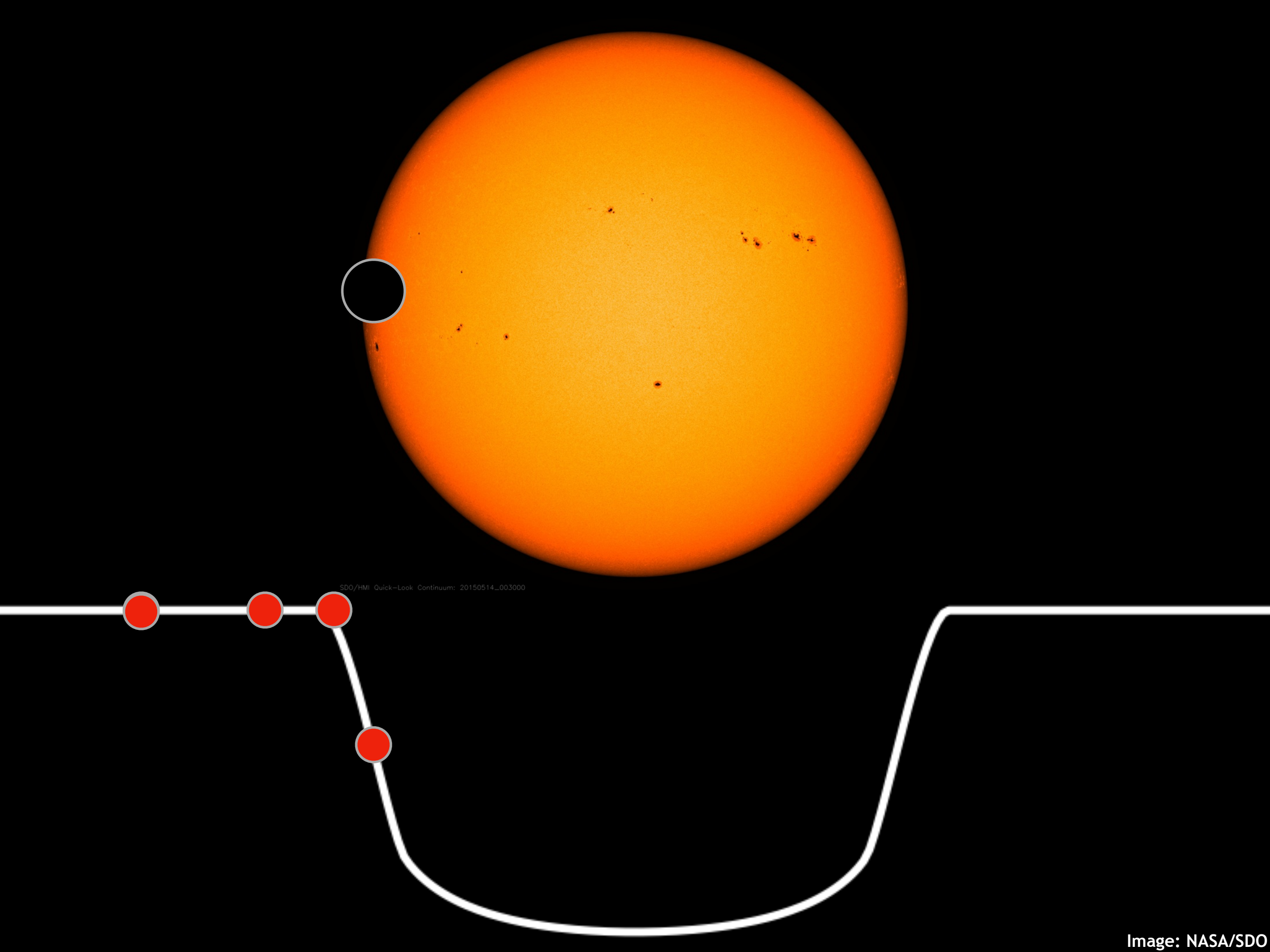


SDO/HMI Quick-Look Continuum: 20150514_003000

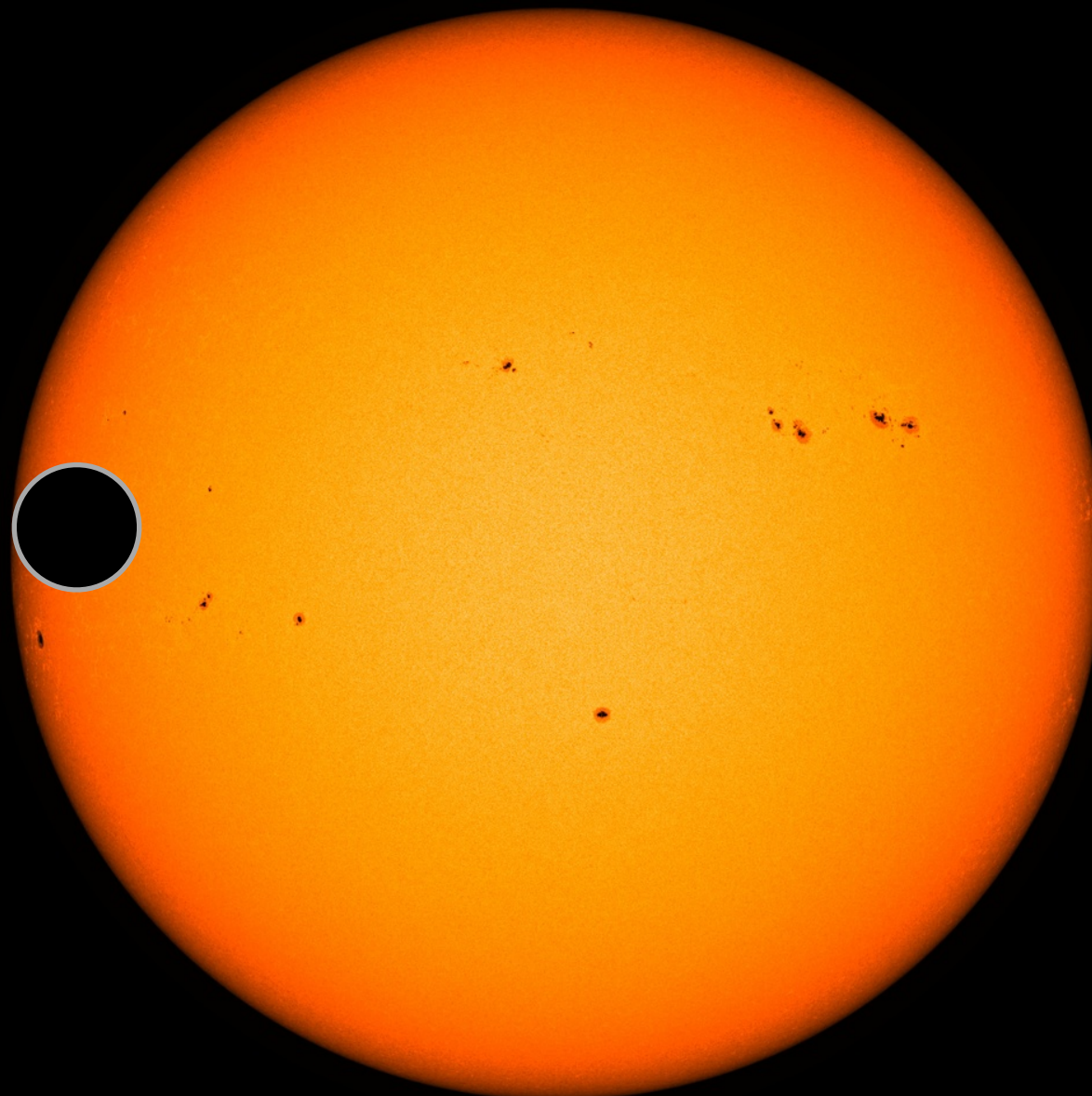




SDO/HMI Quick-Look Continuum: 20150514_003000

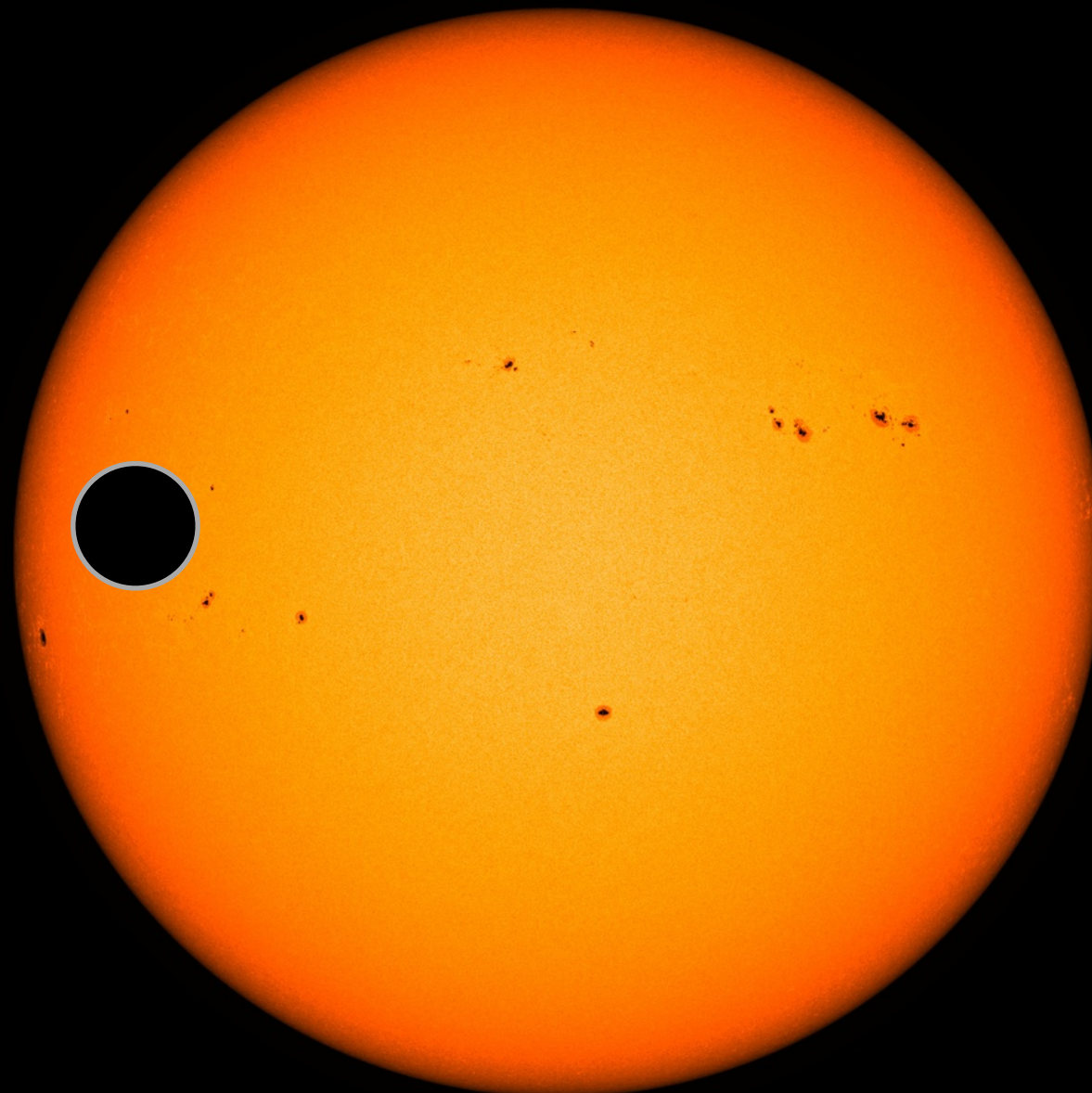


SDO/HMI Quick-Look Continuum: 20150514_003000

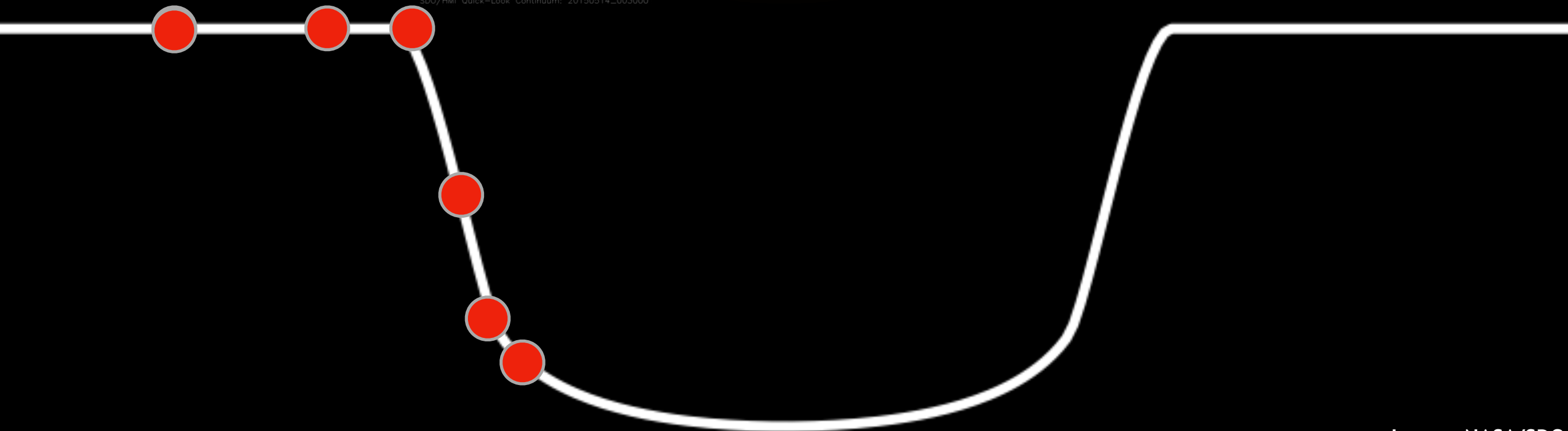


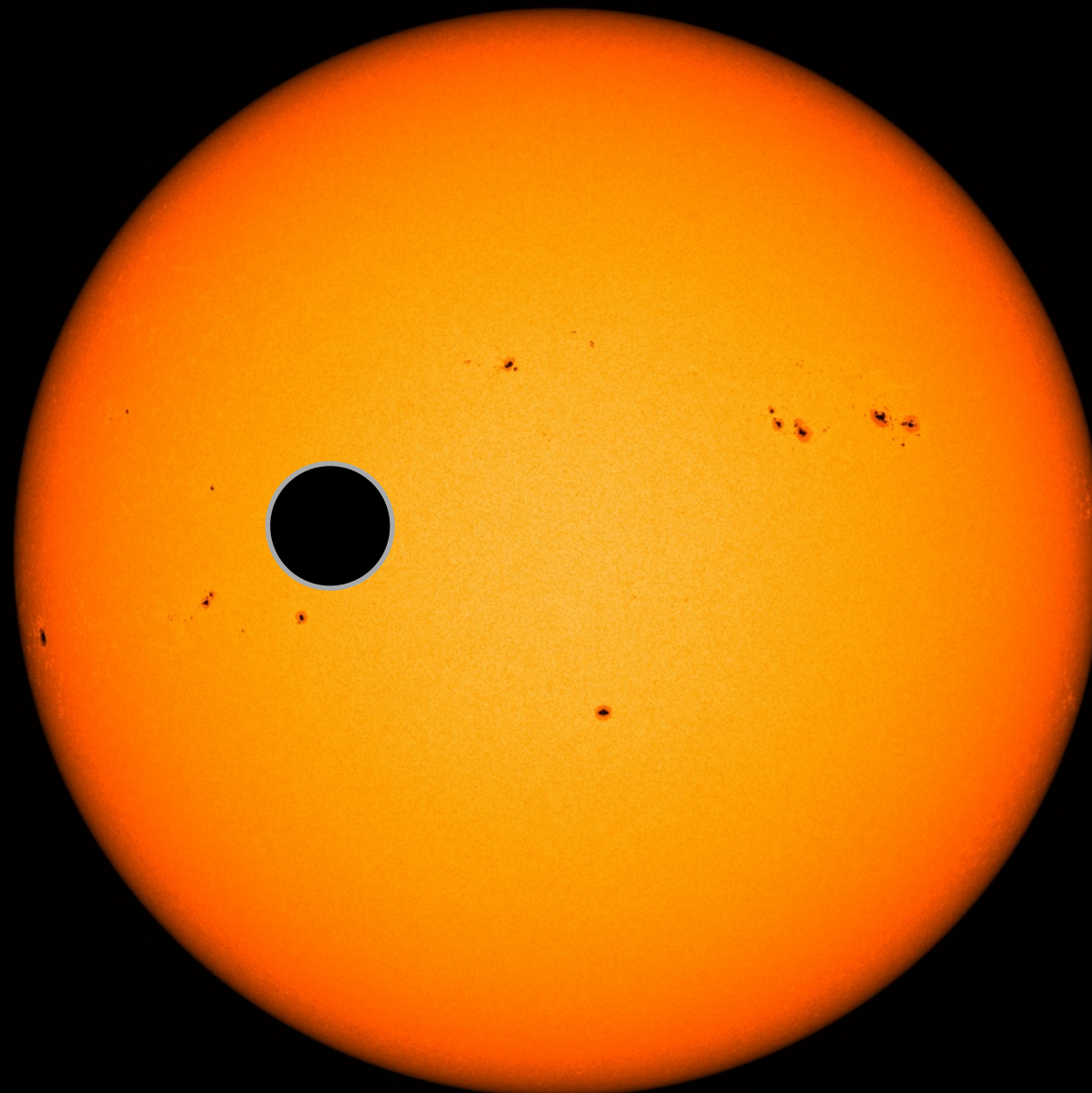
SDO/HMI Quick-Look Continuum: 20150514_003000



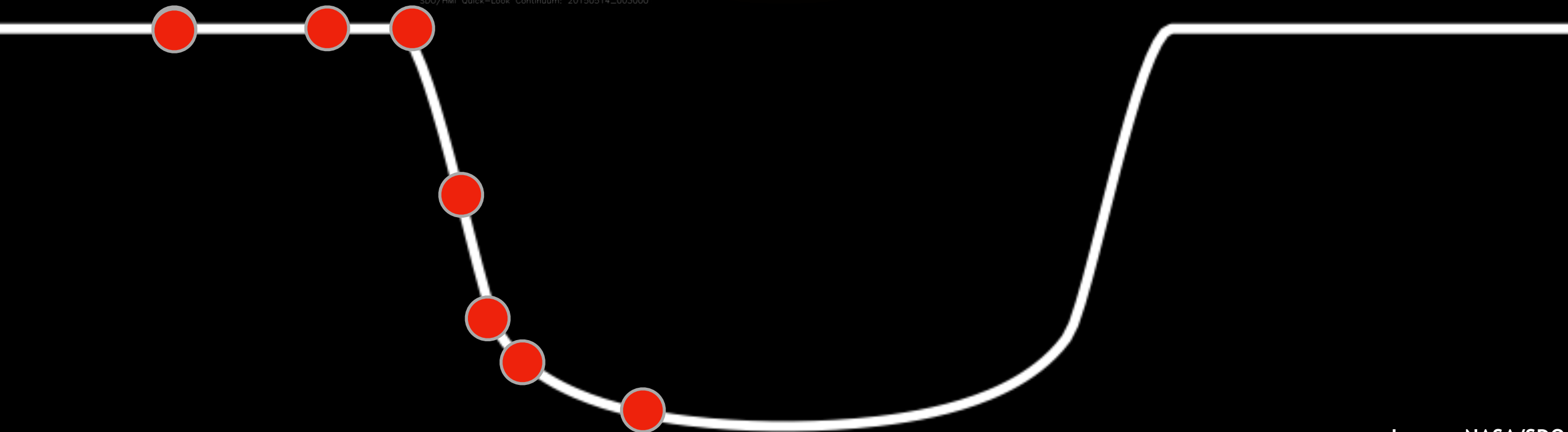


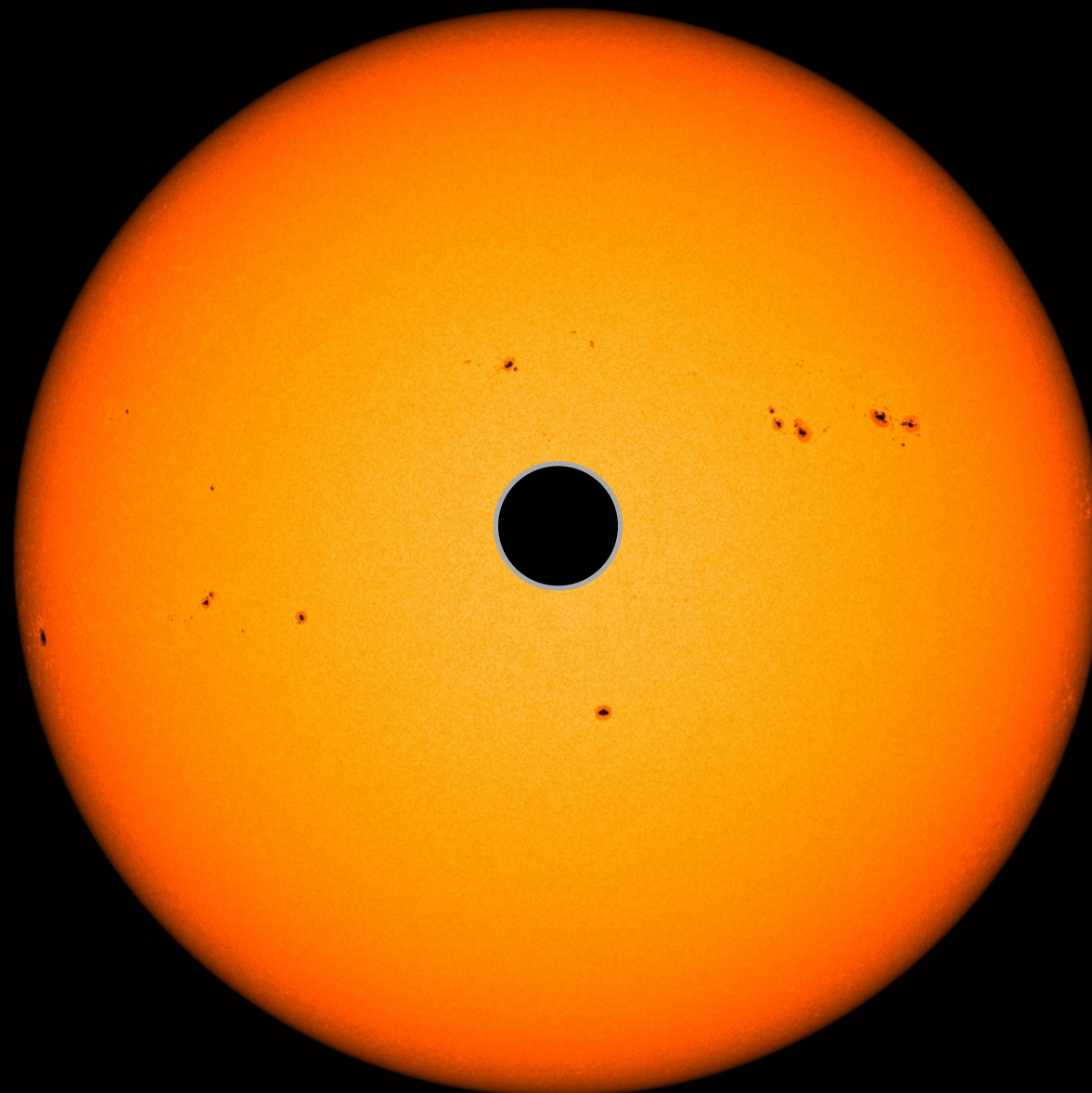
SDO/HMI Quick-Look Continuum: 20150514_003000





SDO/HMI Quick-Look Continuum: 20150514_003000





SDO/HMI Quick-Look Continuum: 20150514_003000

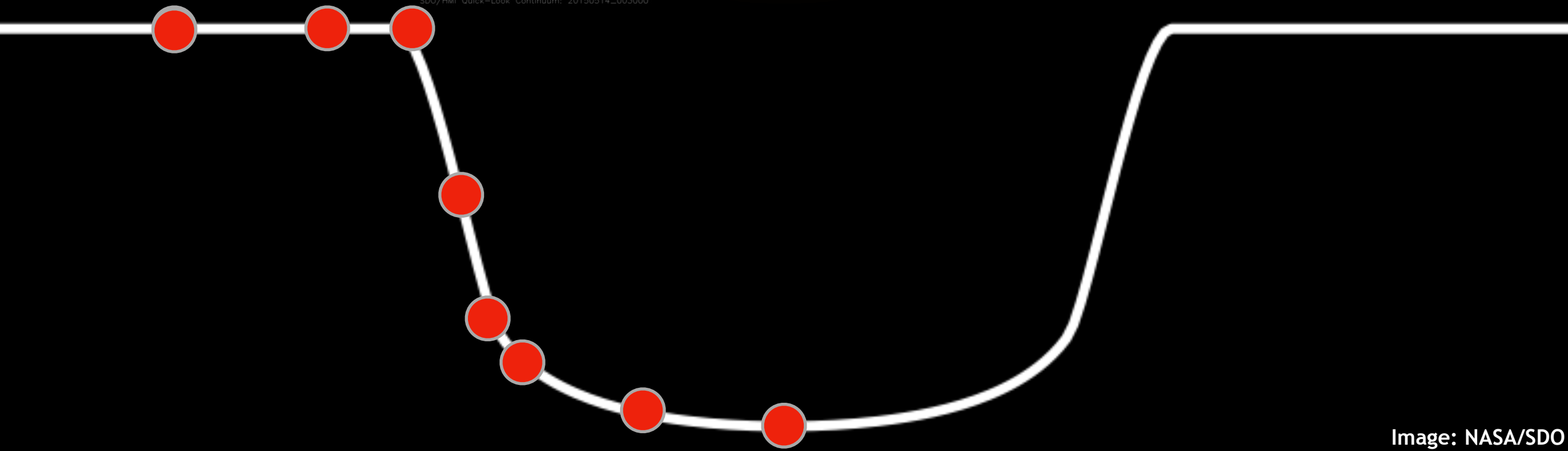
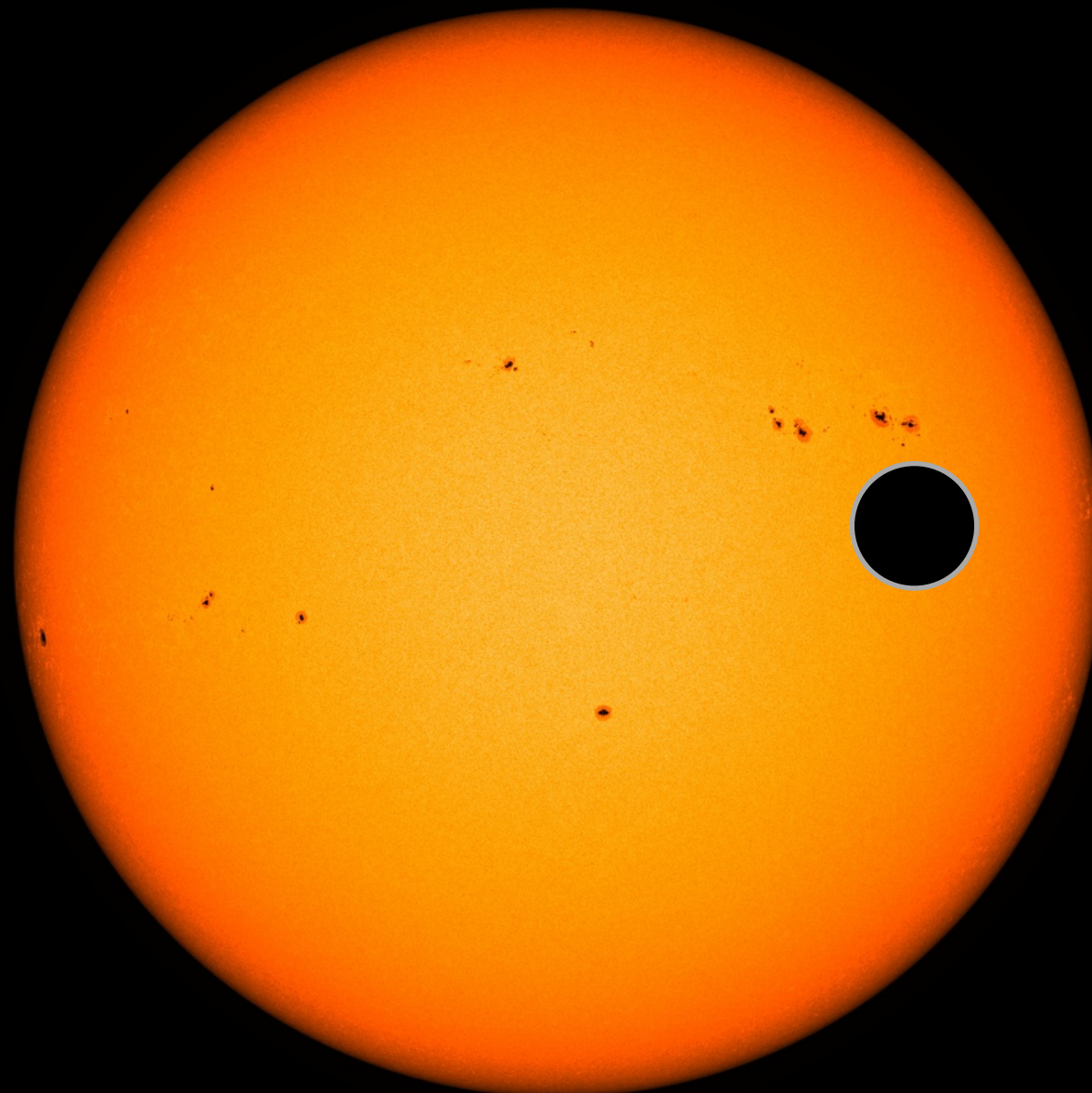
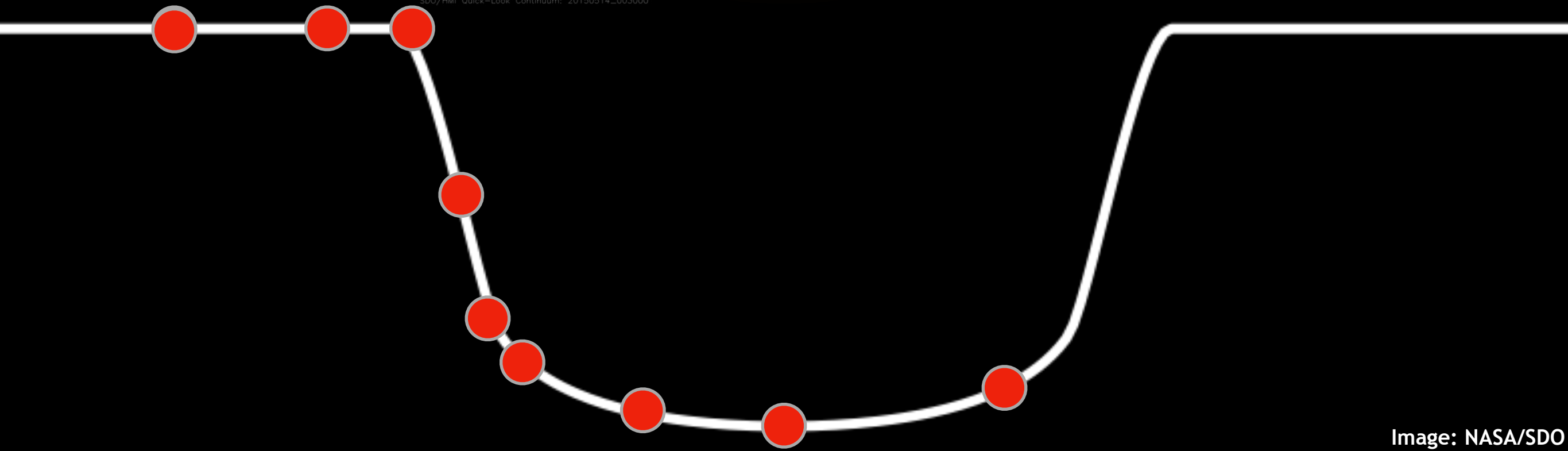
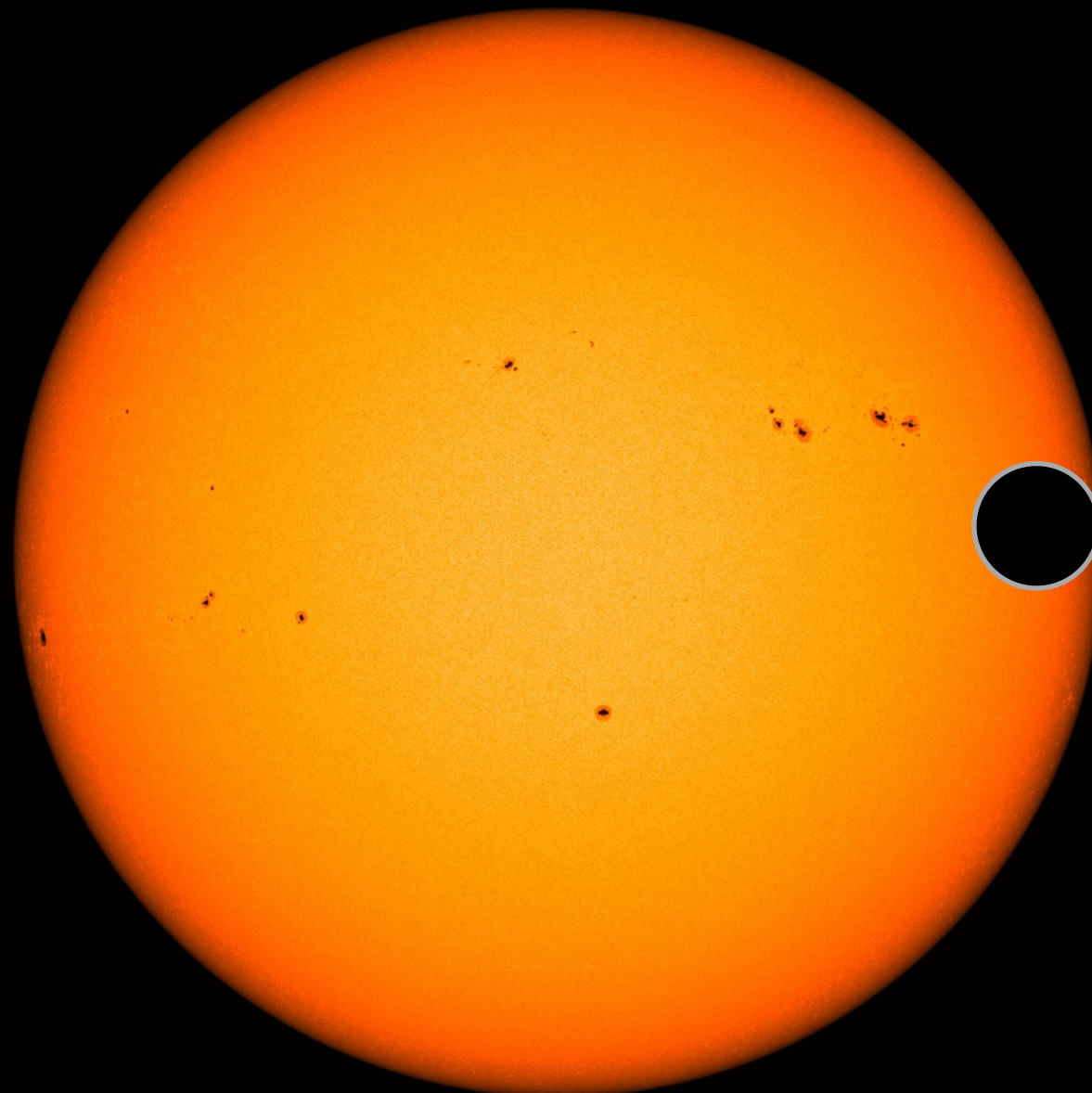


Image: NASA/SDO



SDO/HMI Quick-Look Continuum: 20150514_003000





SDO/HMI Quick-Look Continuum: 20150514_003000

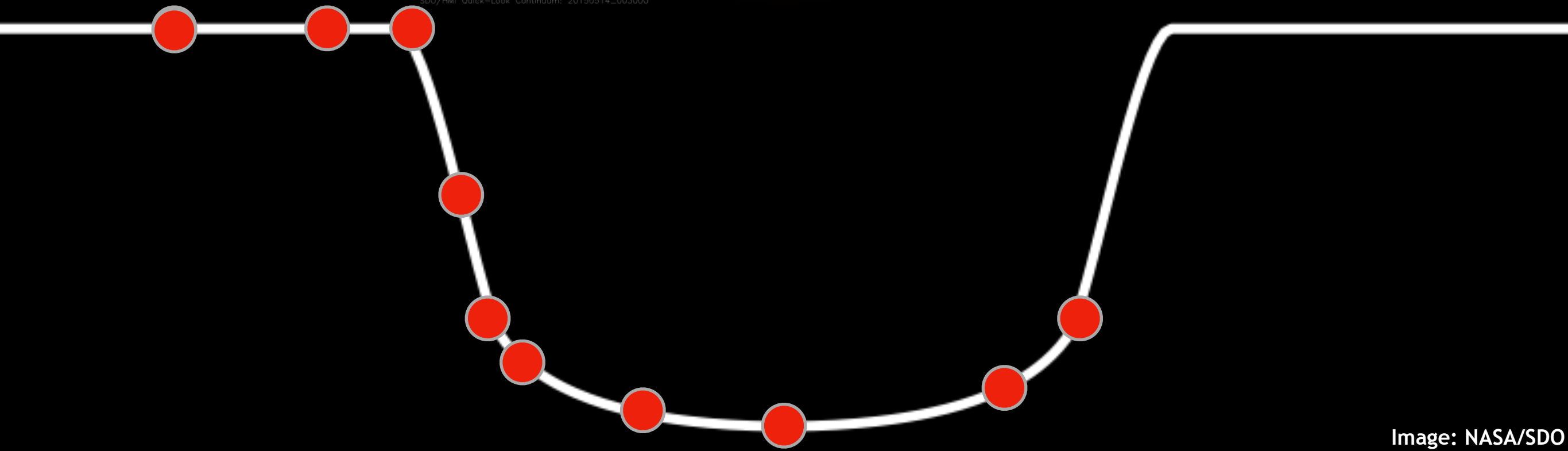
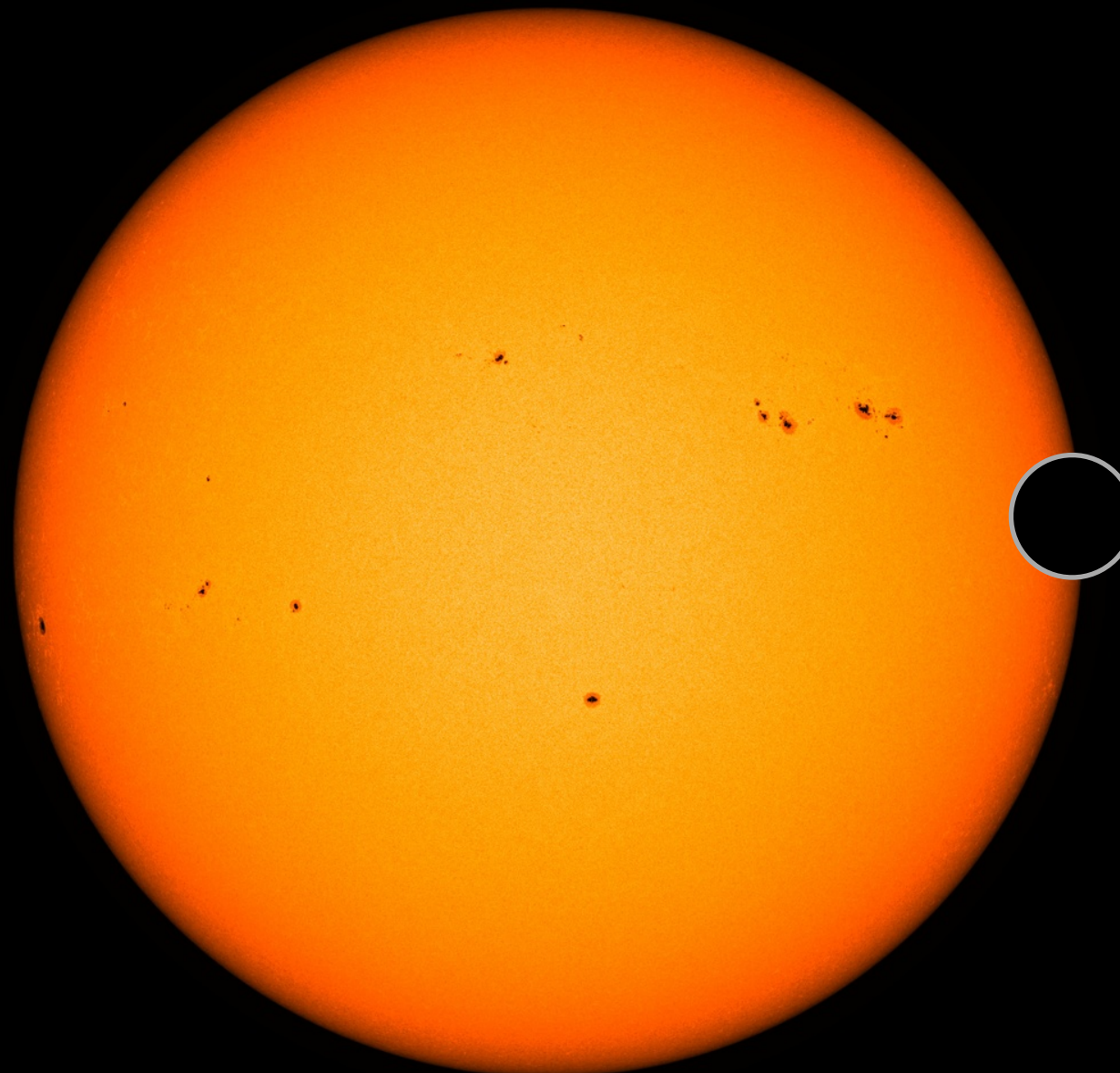
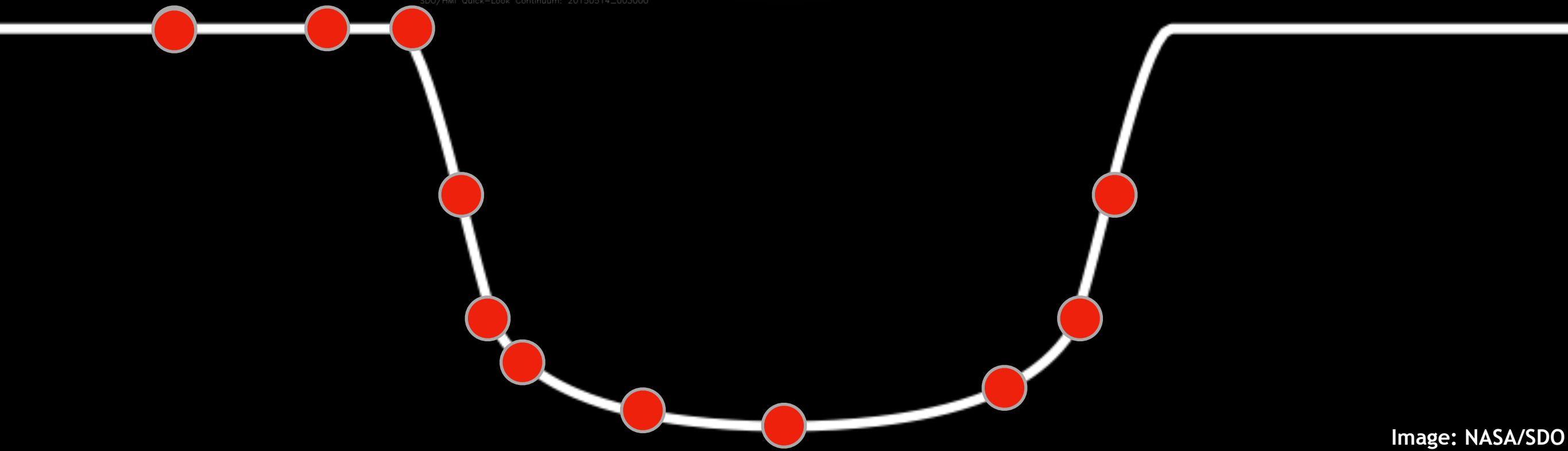


Image: NASA/SDO

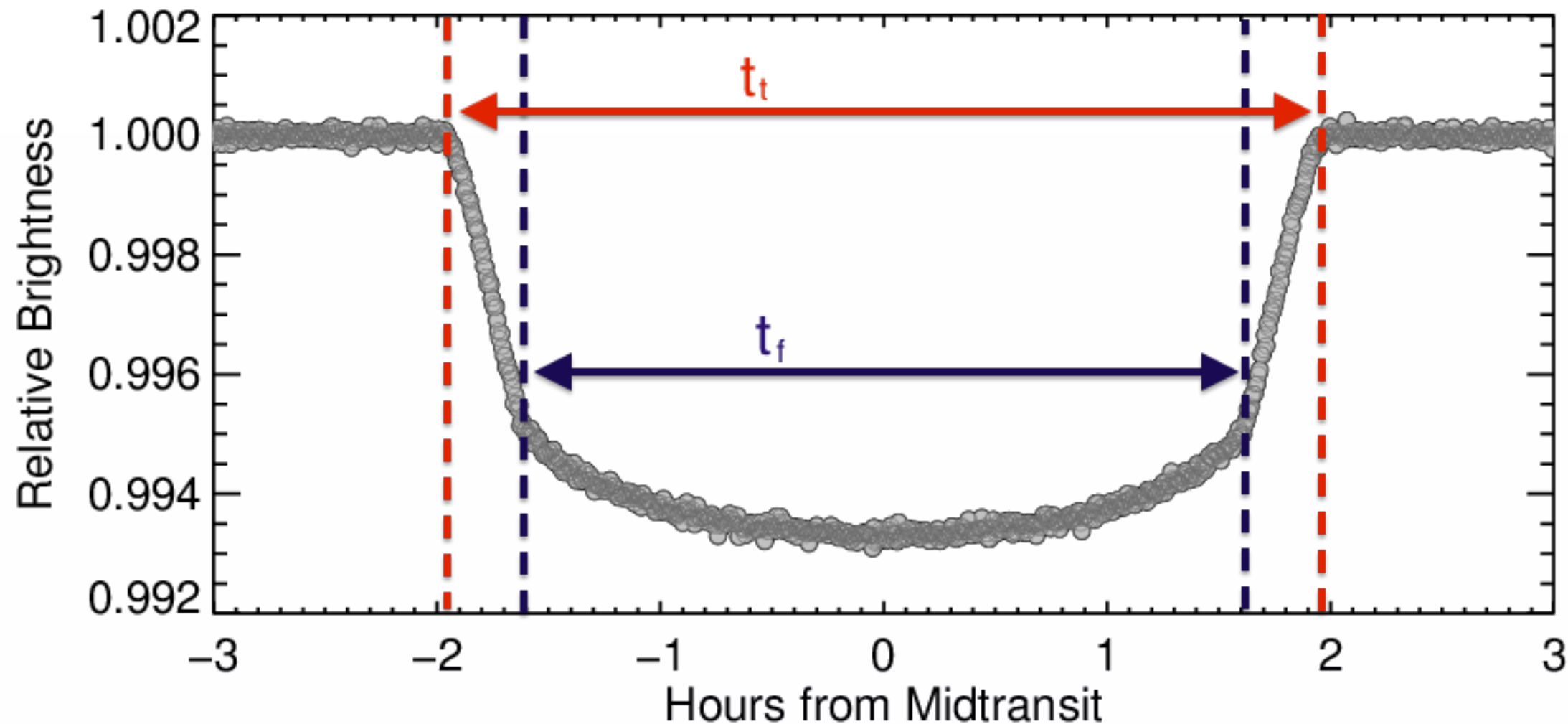


SDO/HMI Quick-Look Continuum: 20150514_003000

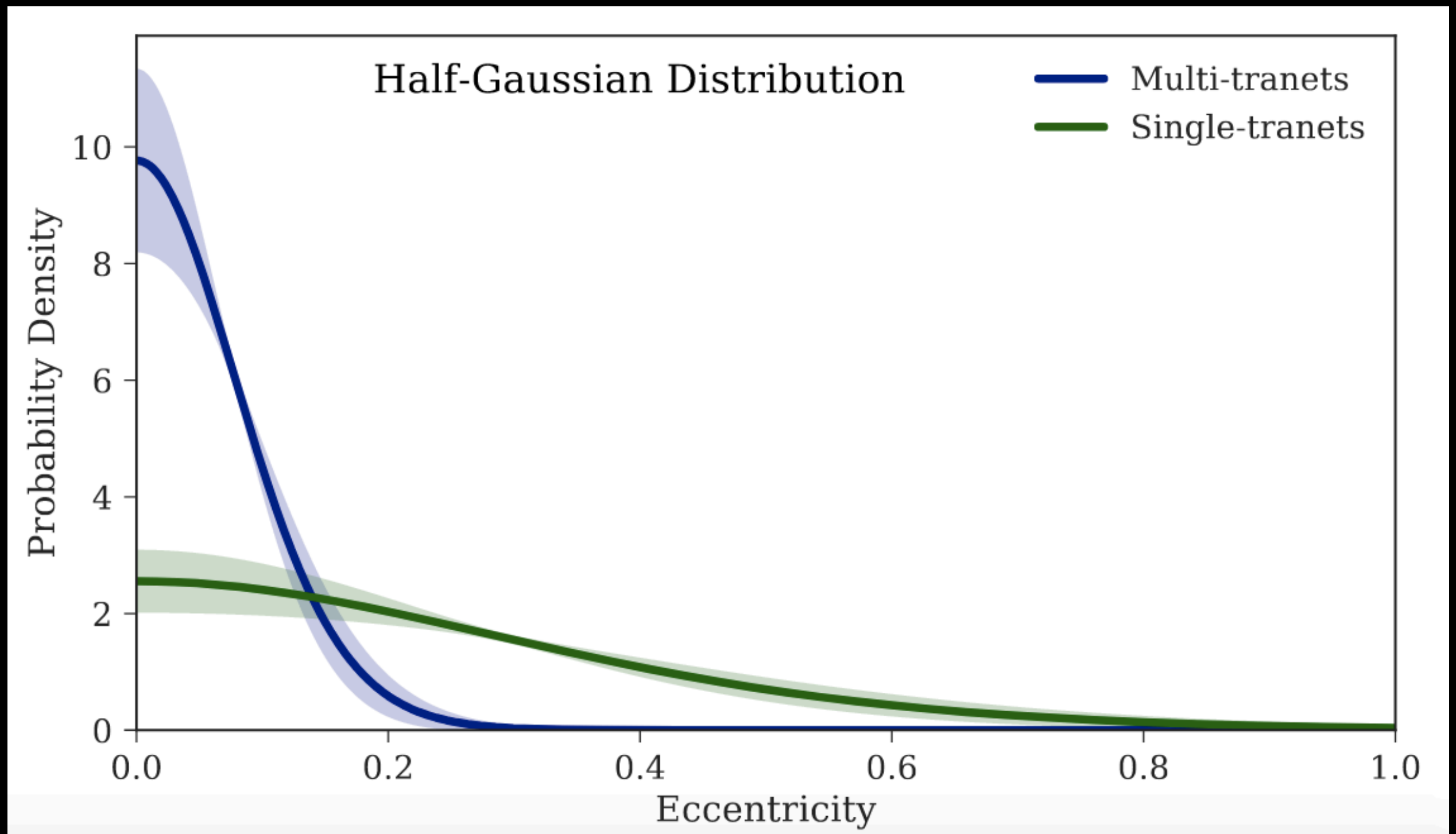


The transit and ingress/egress duration yields the normalized orbital speed during transit

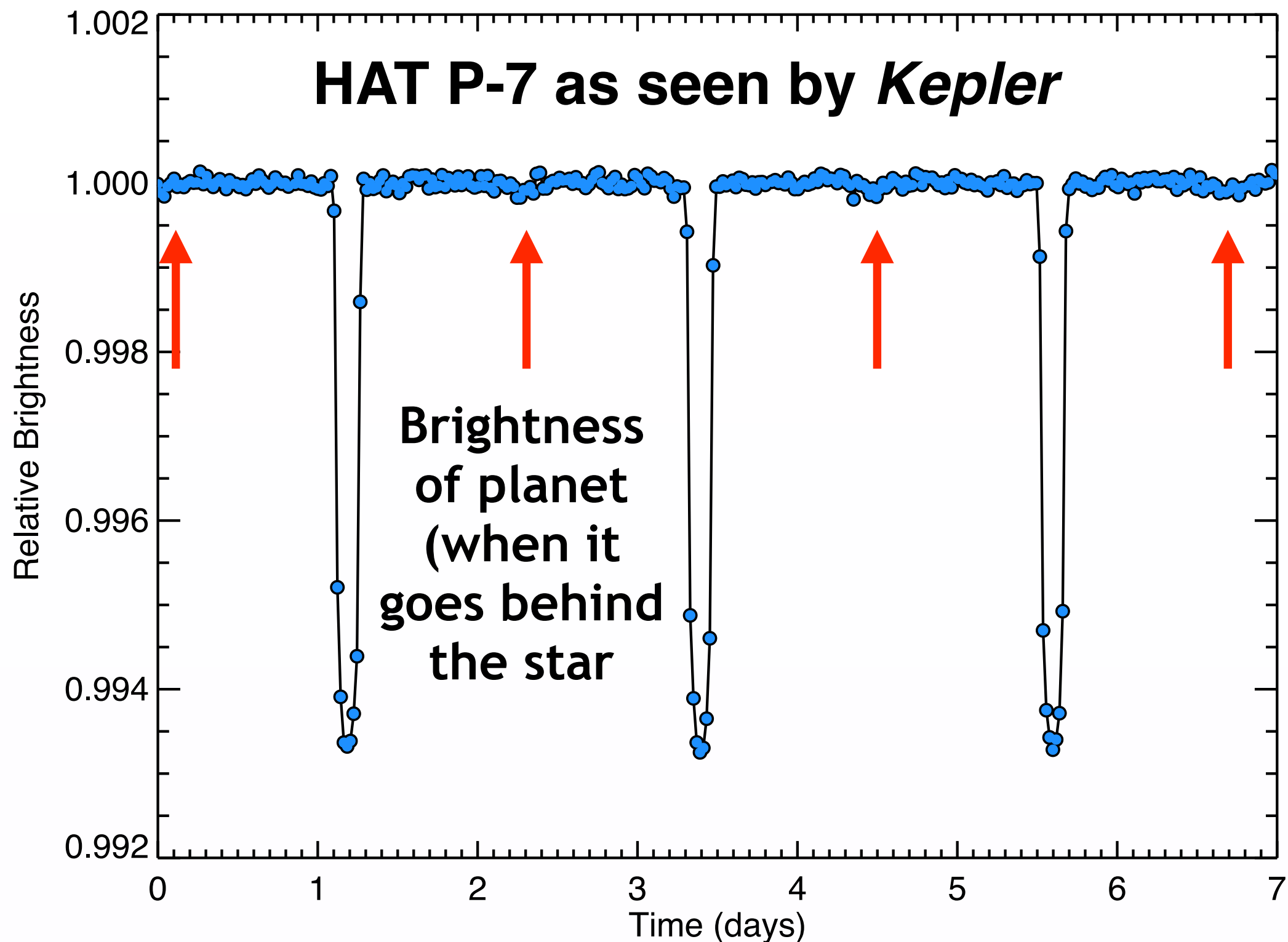
HAT P-7 as seen by *Kepler*



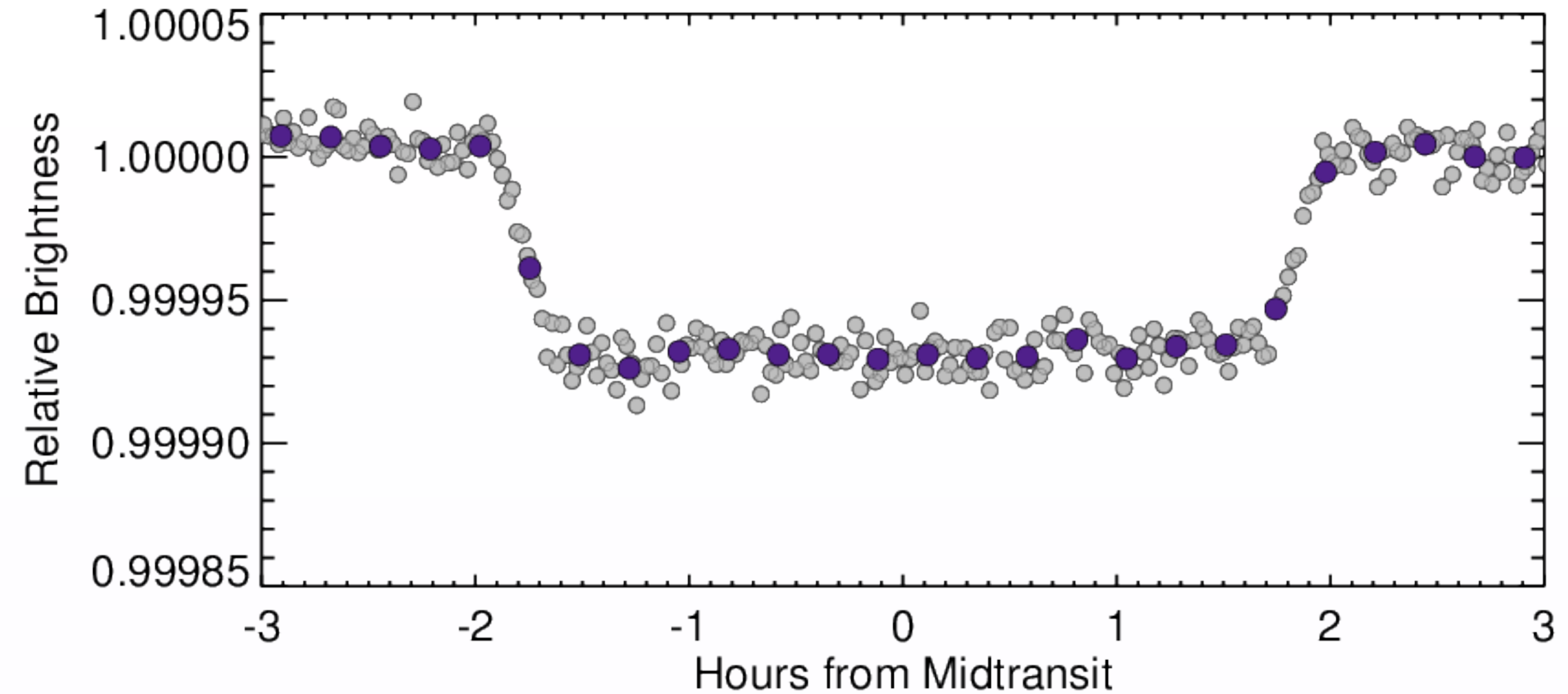
The distribution of orbital speeds can constrain eccentricity.



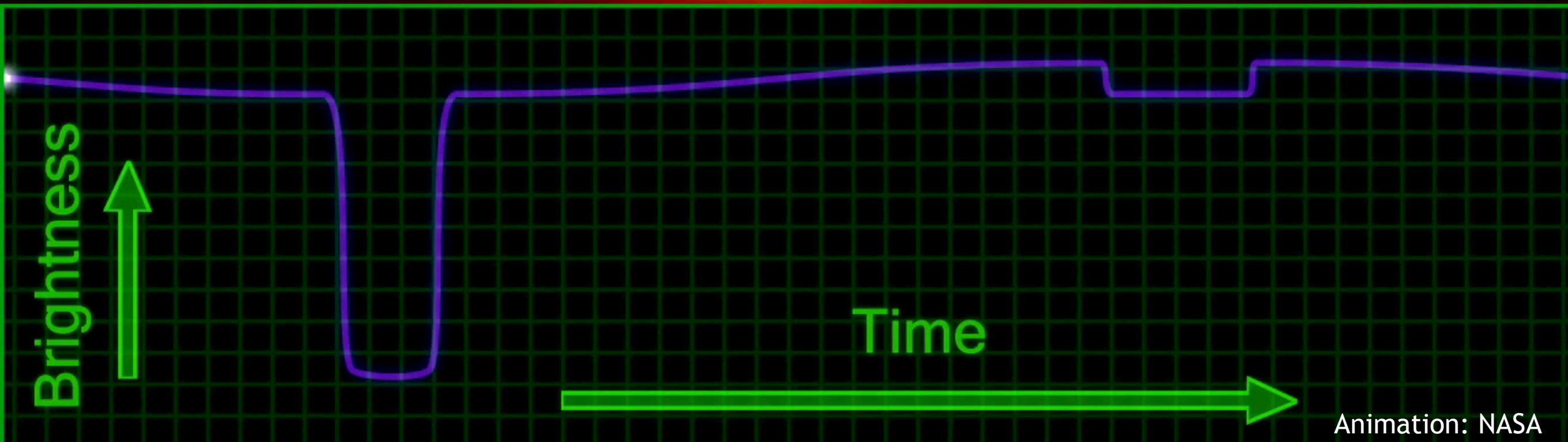
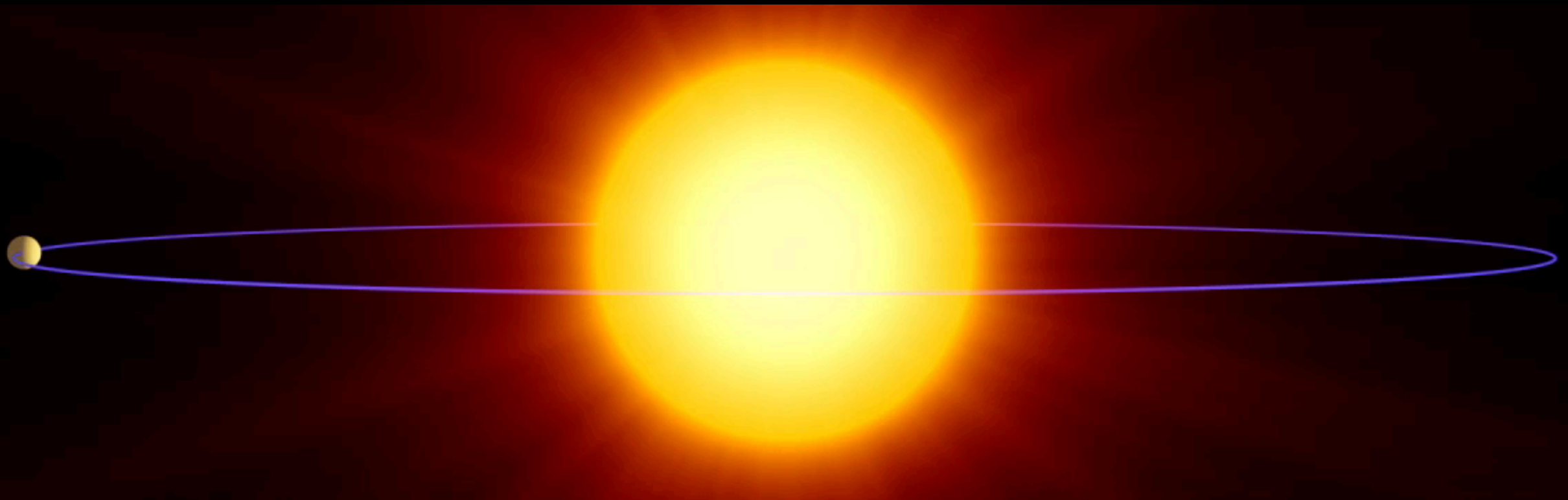
Transit Measurables: Eclipse



Transit Measurables: Eclipse

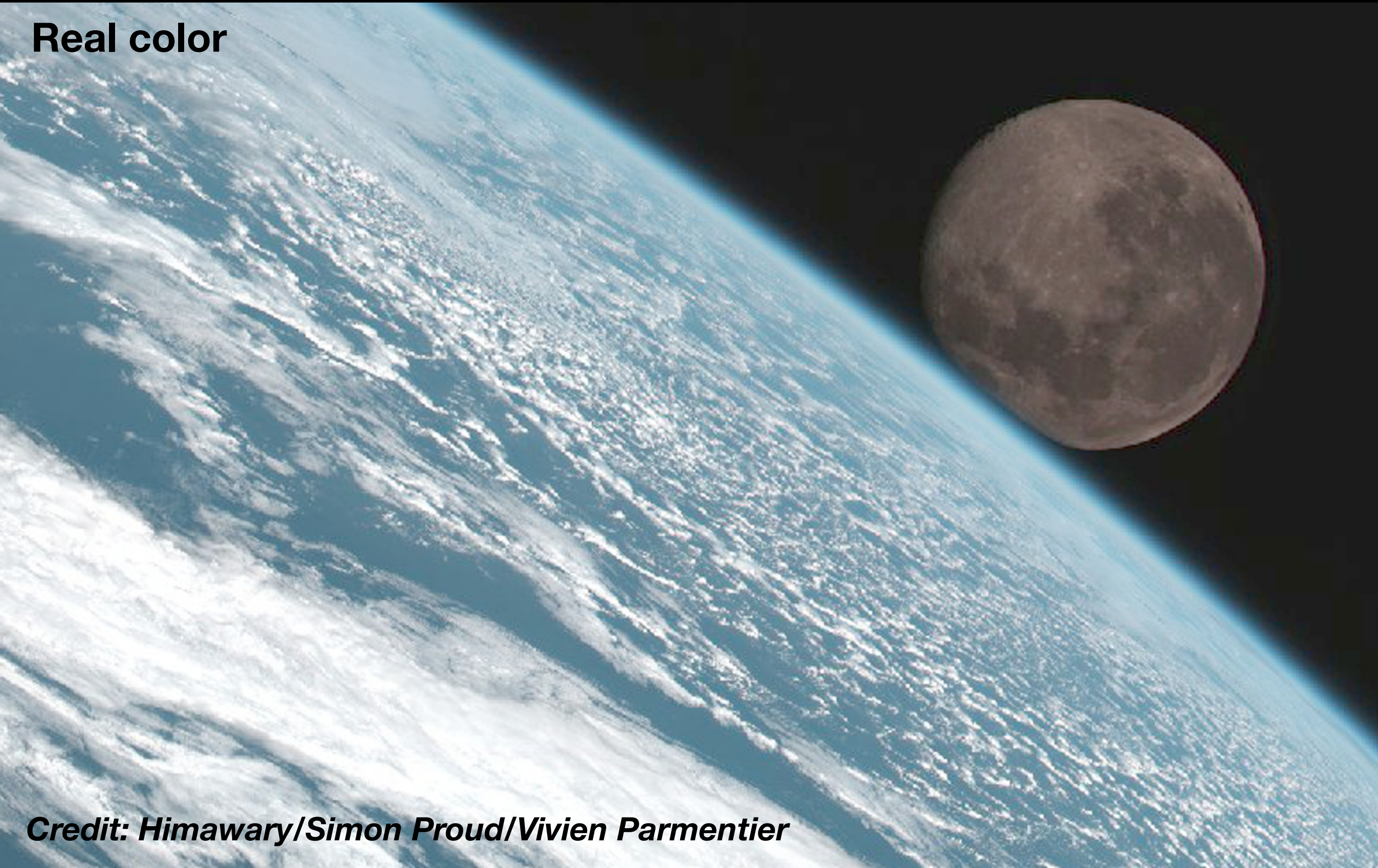


Transits give two ways to study atmospheres: transmission and eclipse



Transmission Spectroscopy: Planets can appear different sizes at different wavelengths due to molecules in the atmosphere.

Real color



Credit: Himawary/Simon Proud/Vivien Parmentier

Transmission Spectroscopy: Planets can appear different sizes at different wavelengths due to molecules in the atmosphere.

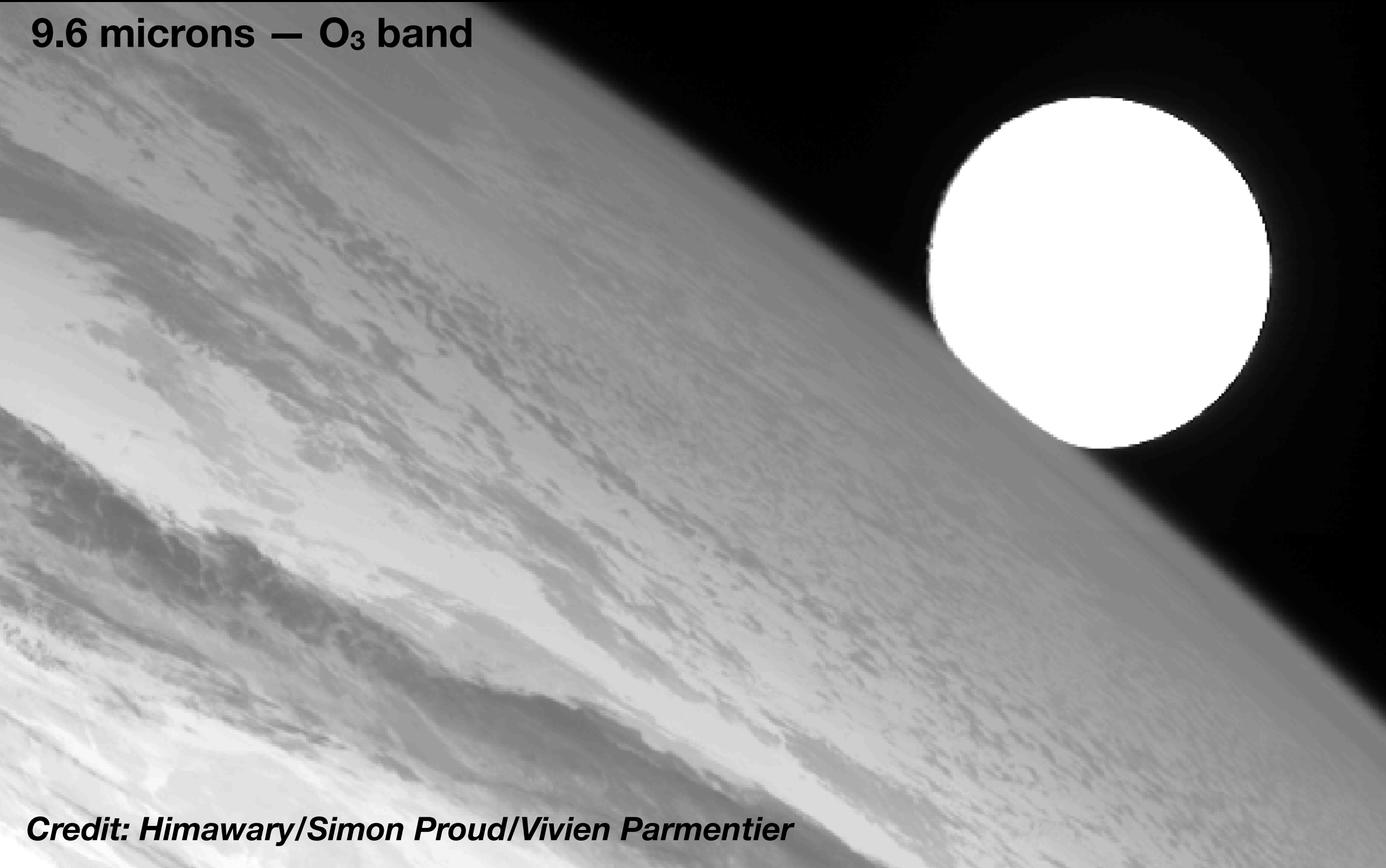
8.6 microns



Credit: Himawary/Simon Proud/Vivien Parmentier

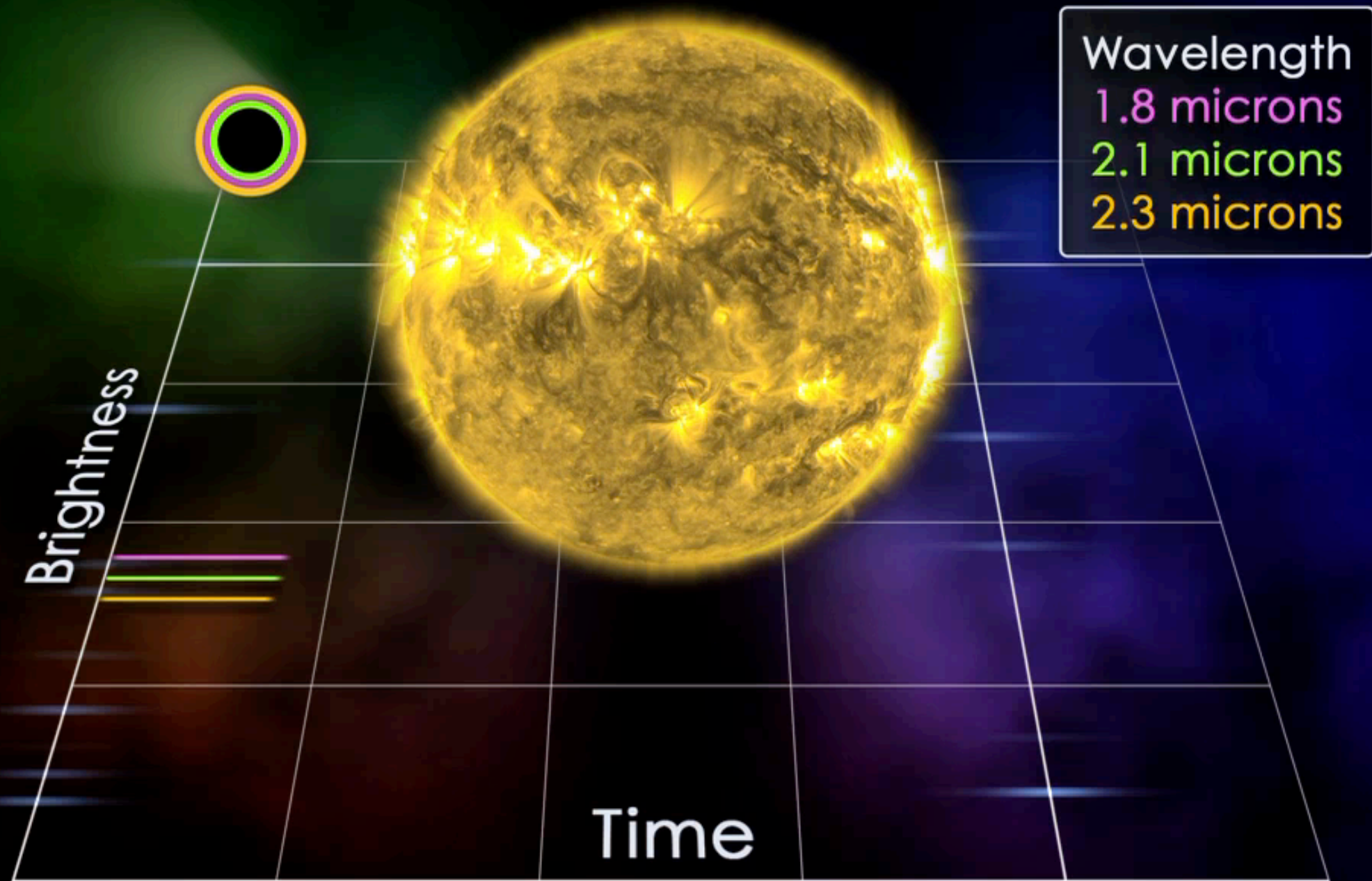
Transmission Spectroscopy: Planets can appear different sizes at different wavelengths due to molecules in the atmosphere.

9.6 microns — O₃ band

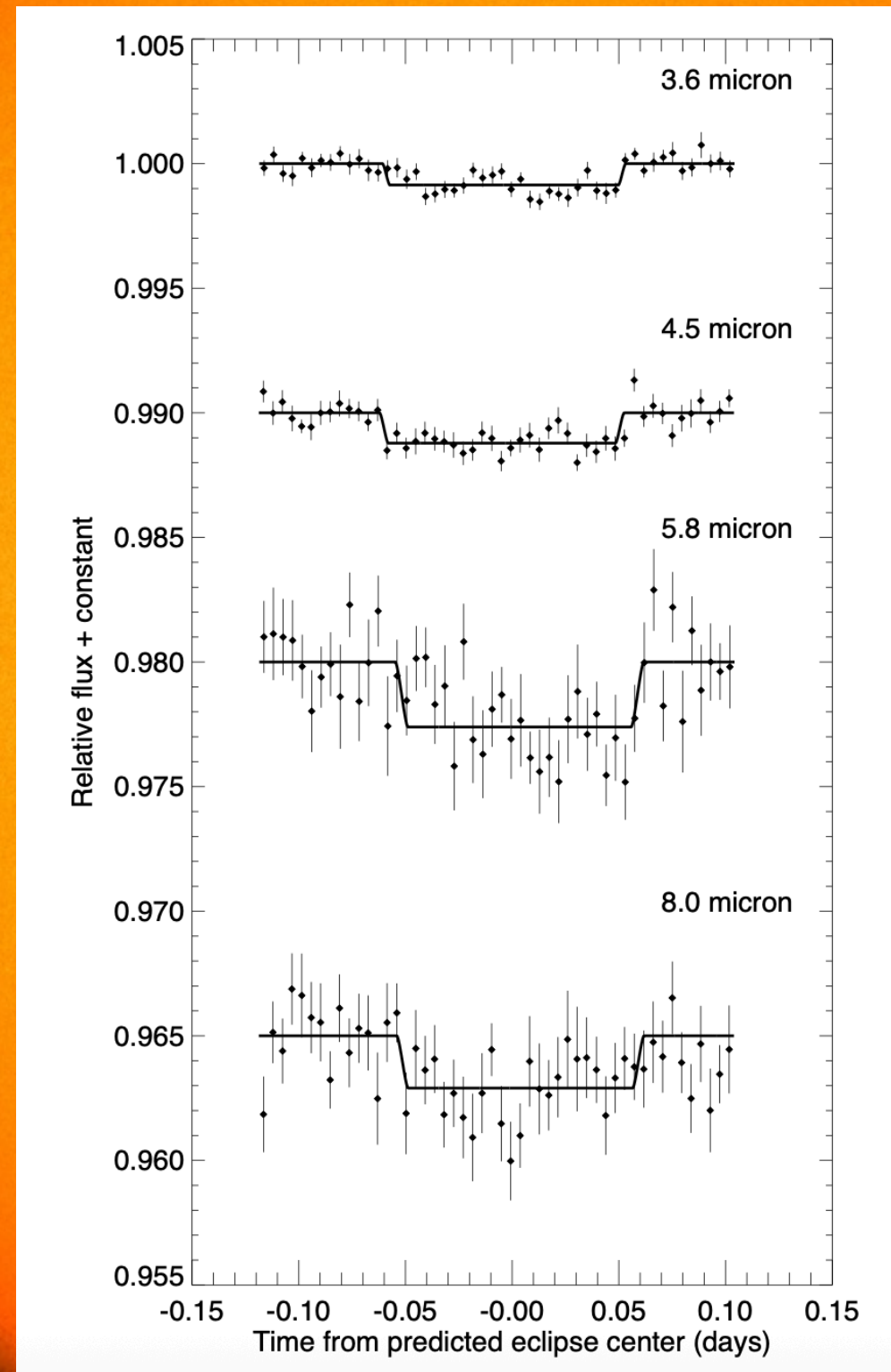


Credit: Himawary/Simon Proud/Vivien Parmentier

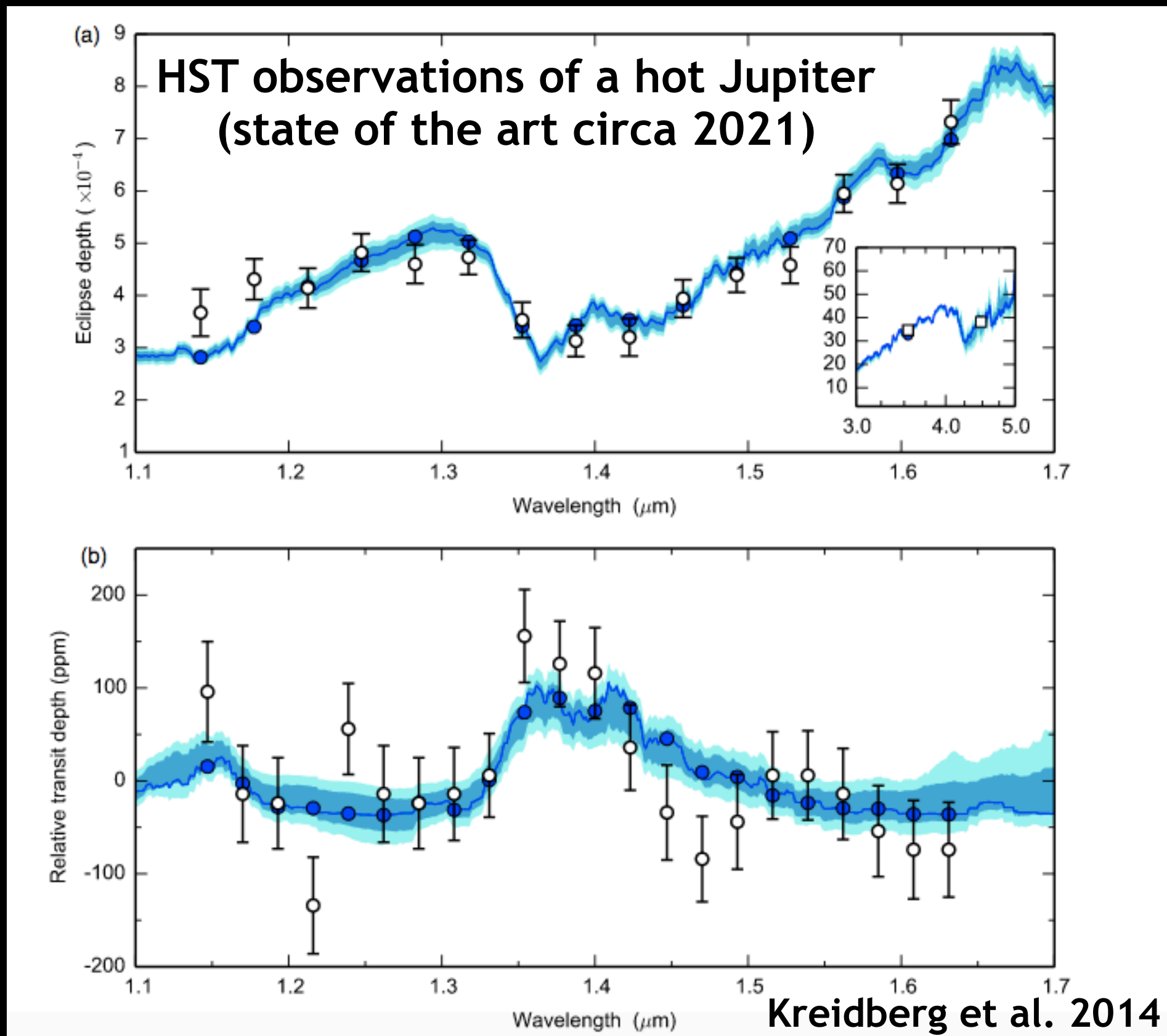
Transmission spectroscopy



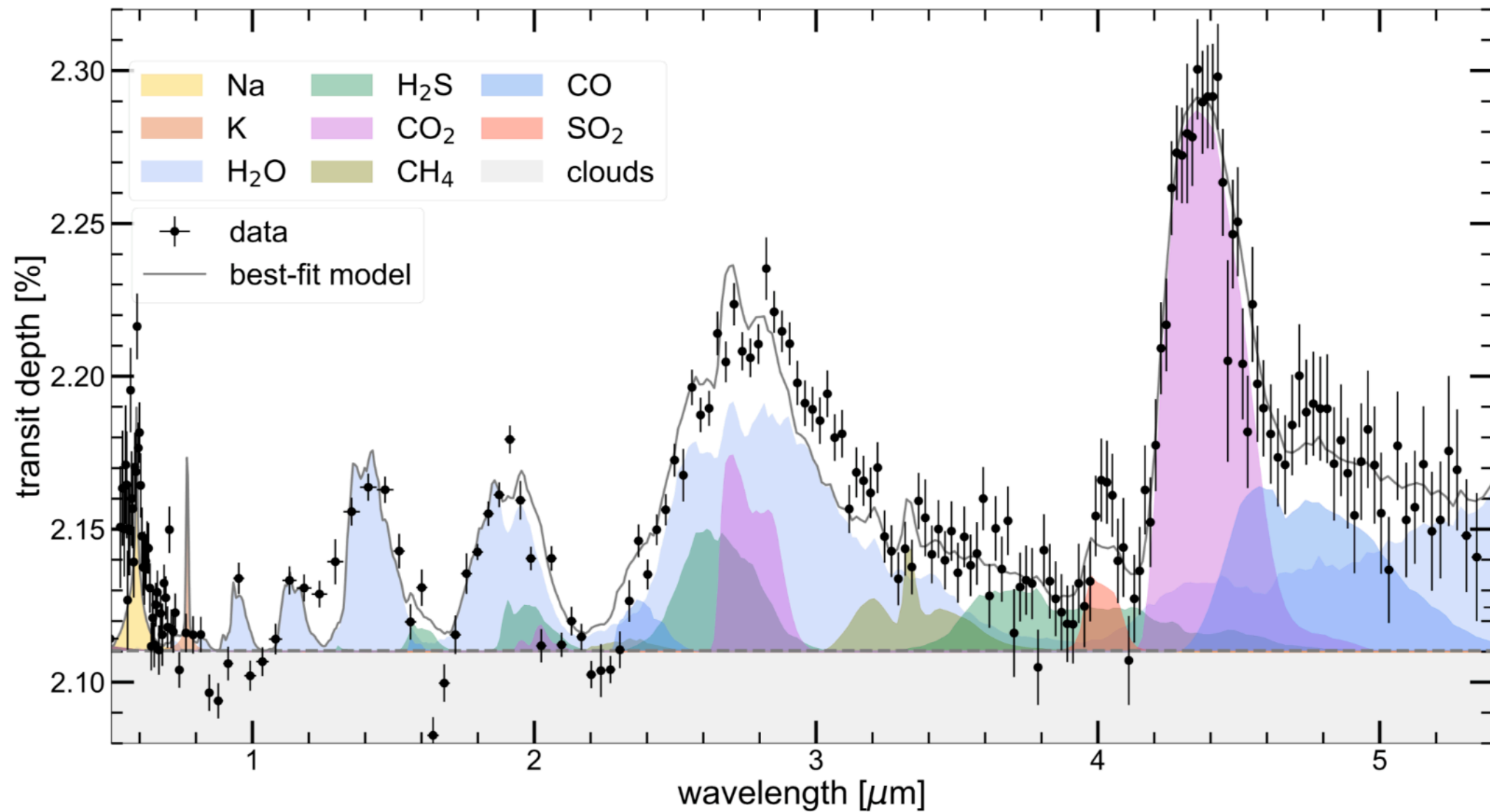
Eclipse spectroscopy: Measure amount of missing planet light at different wavelengths



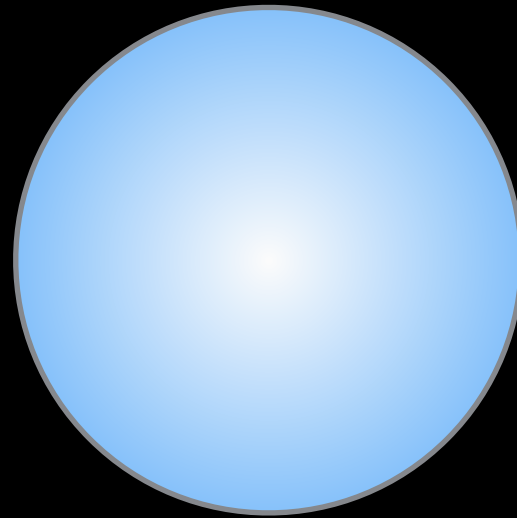
JWST has been revolutionary



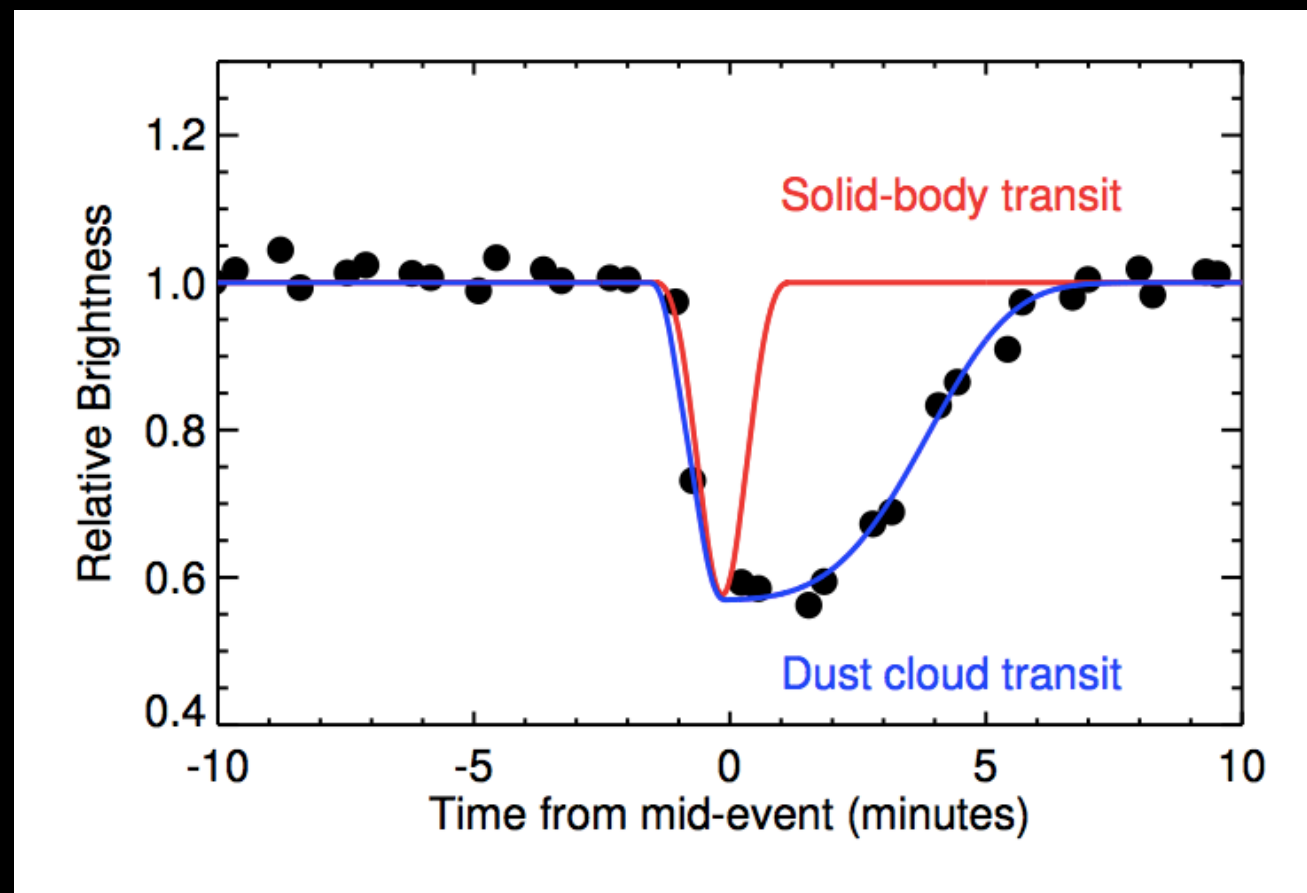
JWST has been revolutionary



Transits don't have to be of planets orbiting stars. Asymmetry can reveal other scenarios



White dwarf WD 1145+017 with transiting rocky debris

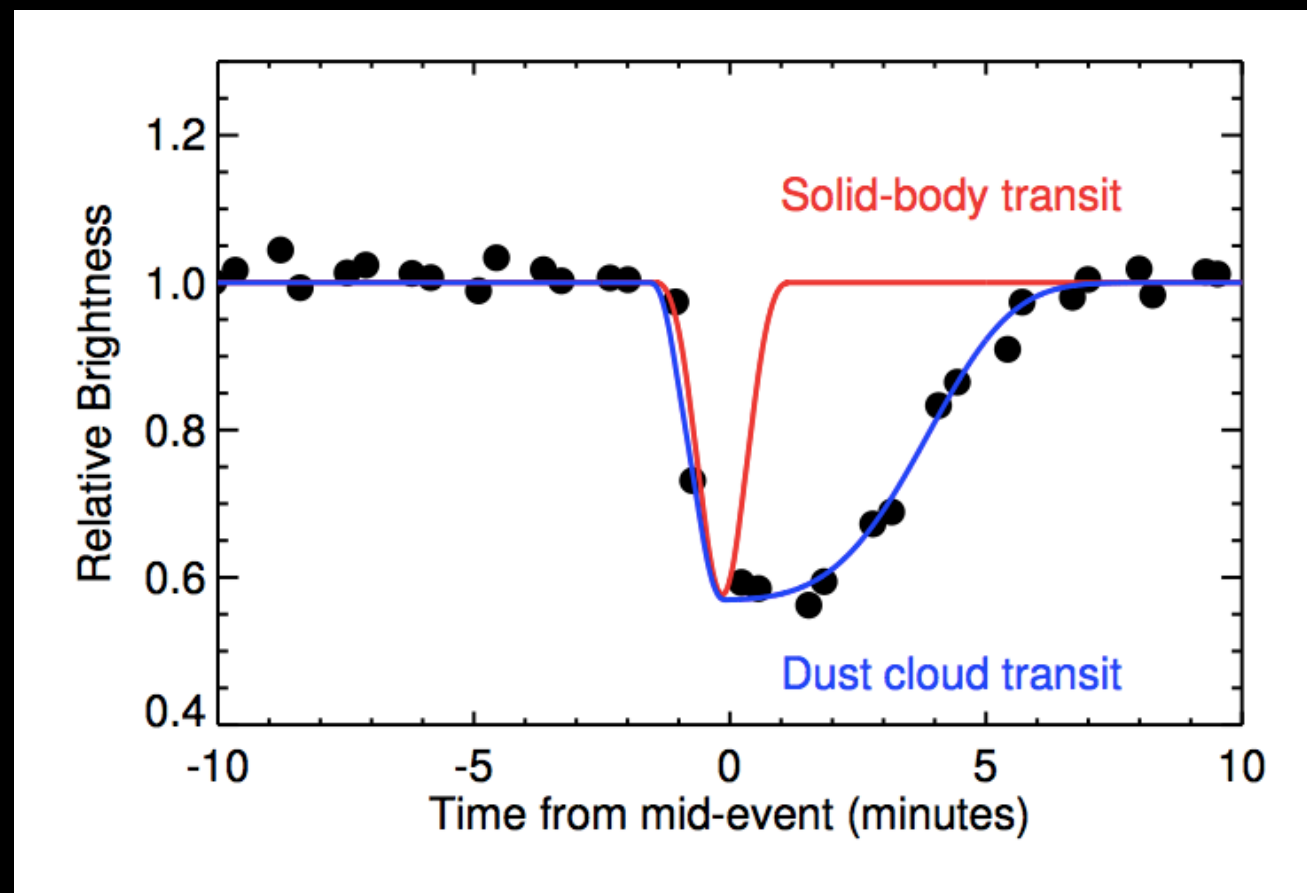


Vanderburg+2015b

Transits don't have to be of planets orbiting stars. Asymmetry can reveal other scenarios

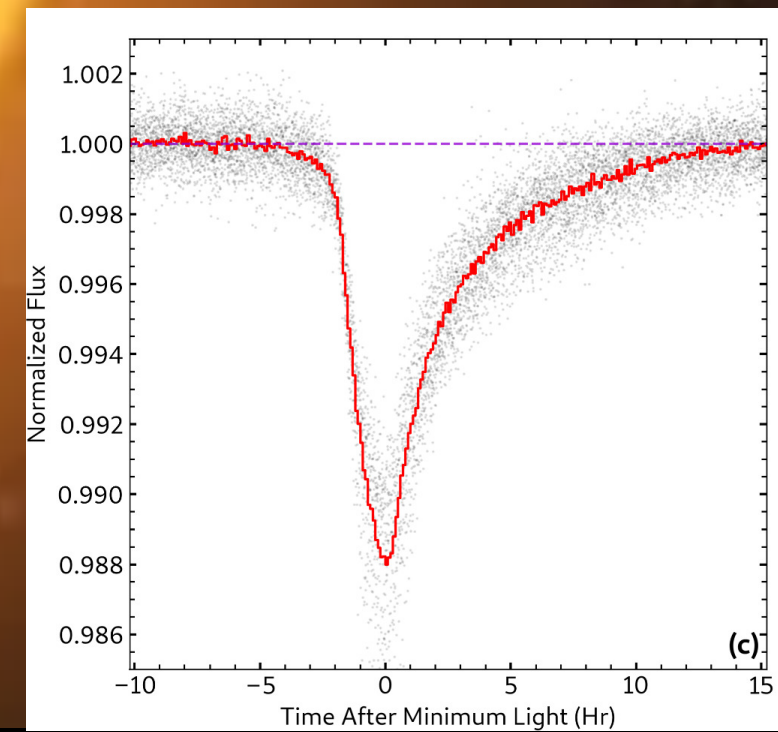


White dwarf WD 1145+017 with transiting rocky debris



Vanderburg+2015b

Evaporating sub-Mercuries producing dust clouds

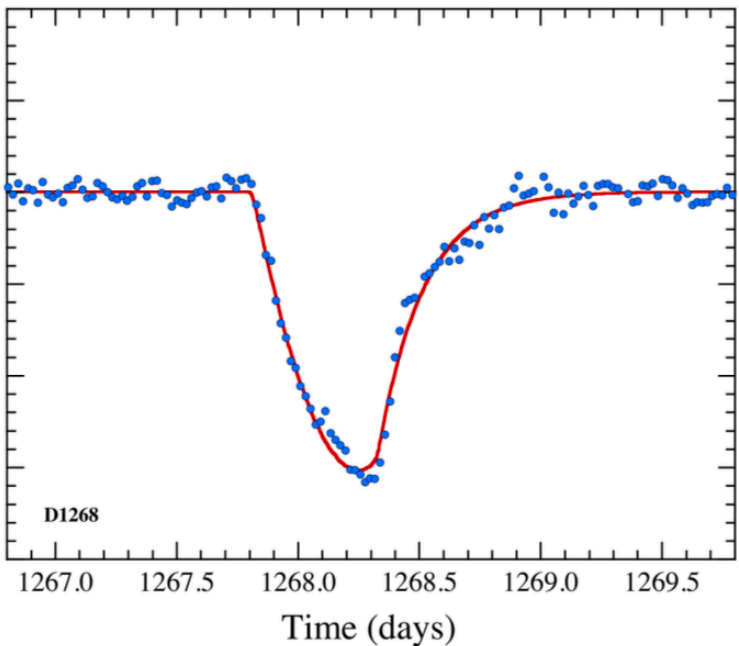
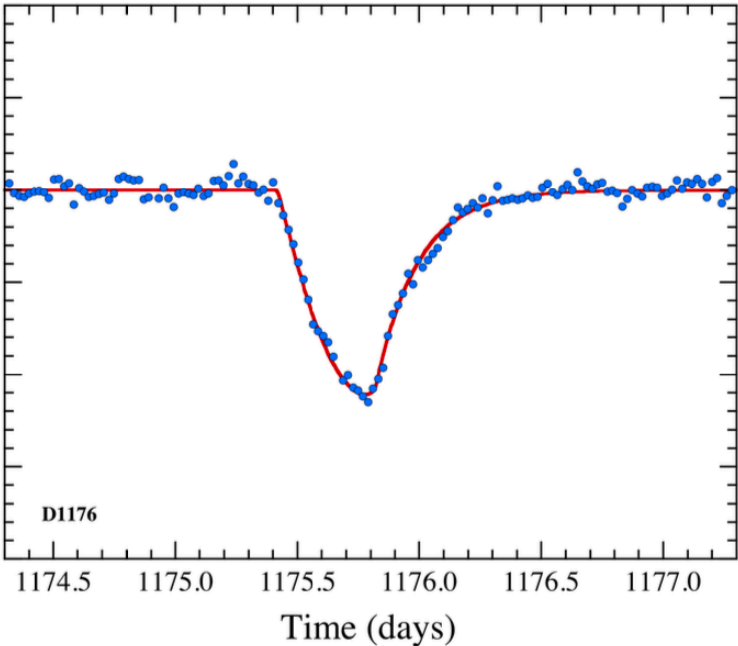
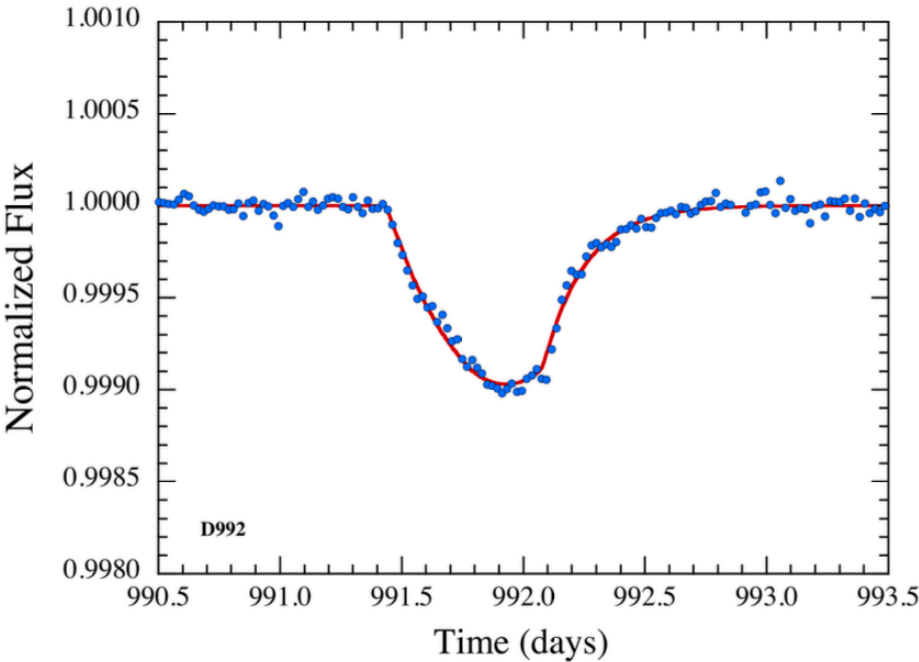


Hon+ (including Vanderburg) 2025

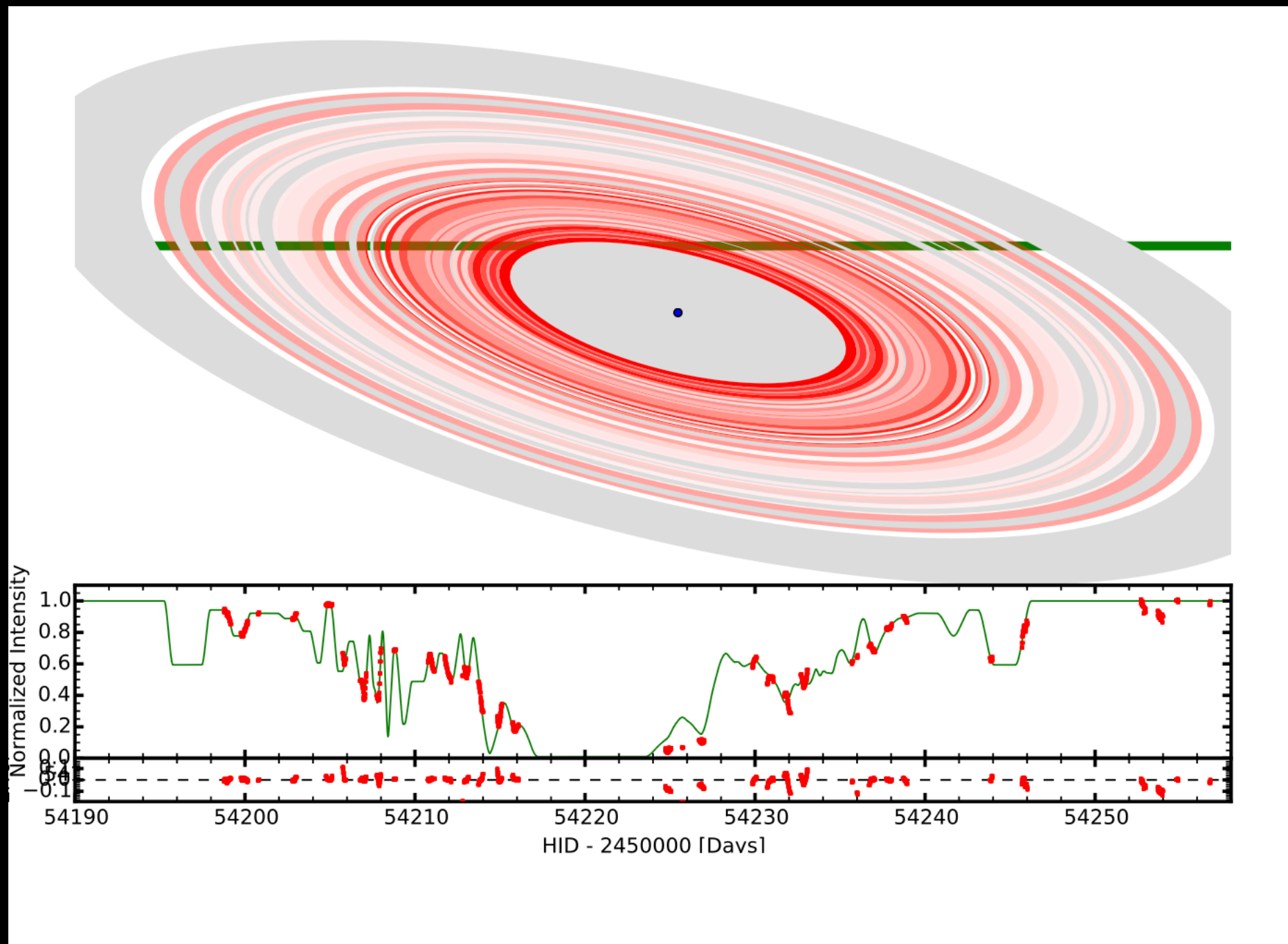


Rappaport, Vanderburg+2018

Image: Danielle Futselaar



Rings/circumplanetary disks can create very complex transit signals

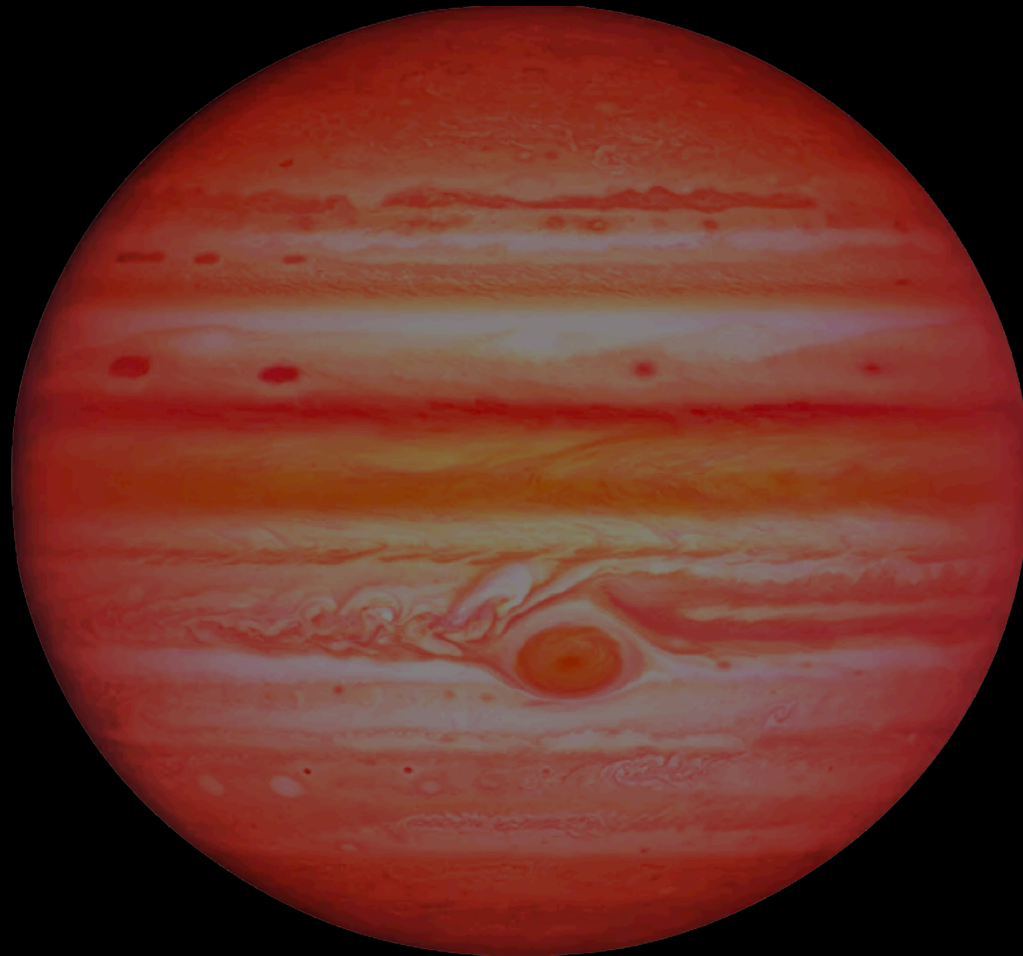


Light curve of 1SWASP J140747.93-394542.6

We can also detect transits of moons across planets

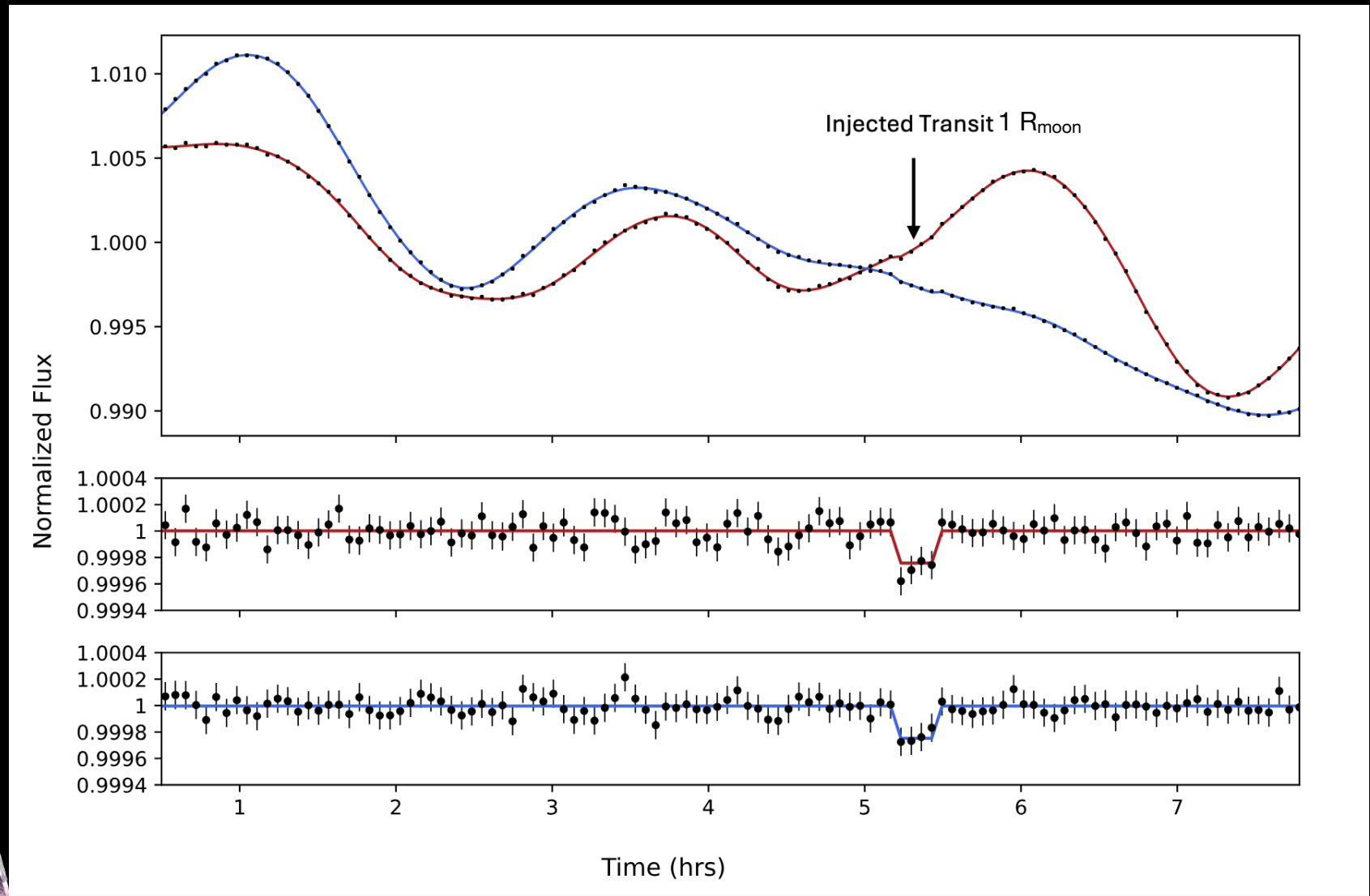
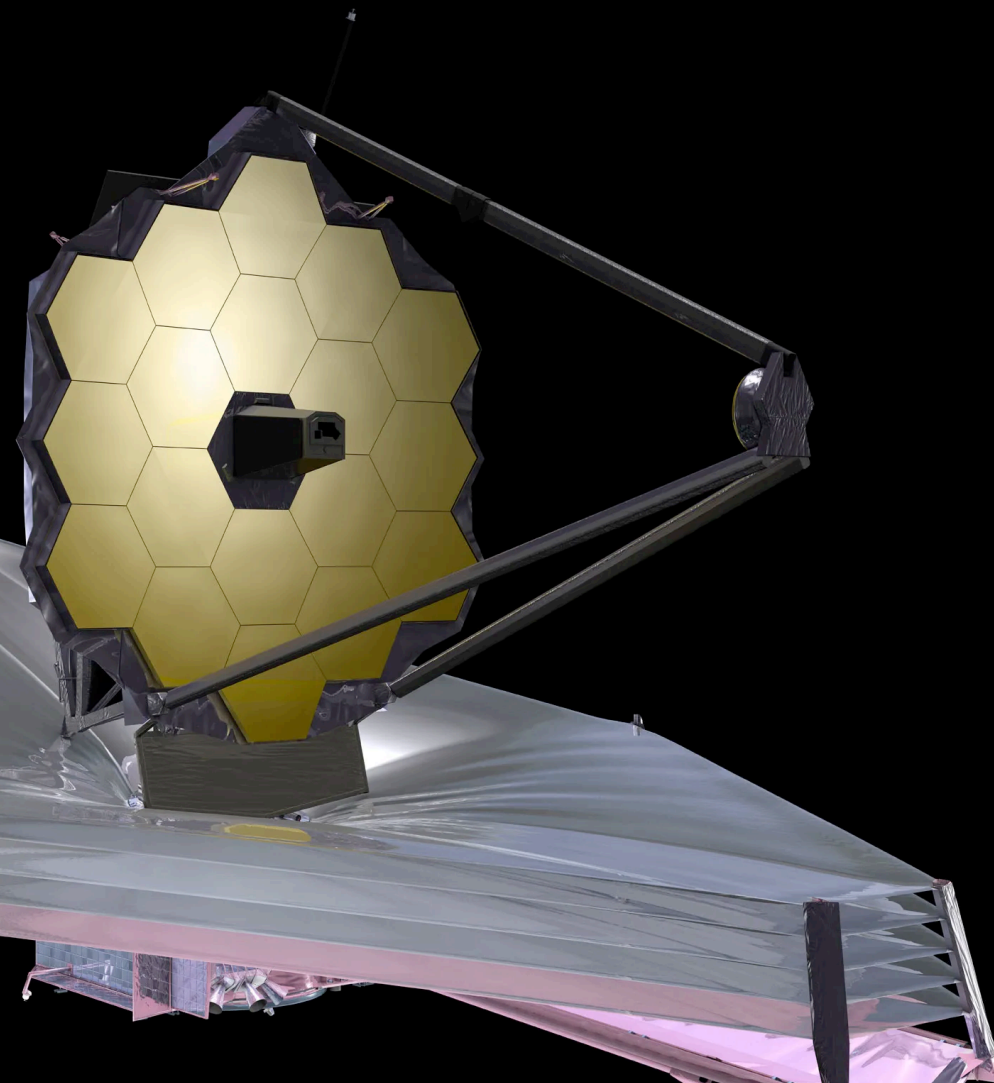


Can we look for exomoons transiting their planets?



Observe widely-separated or free-floating planets
in thermal radiation at long wavelengths

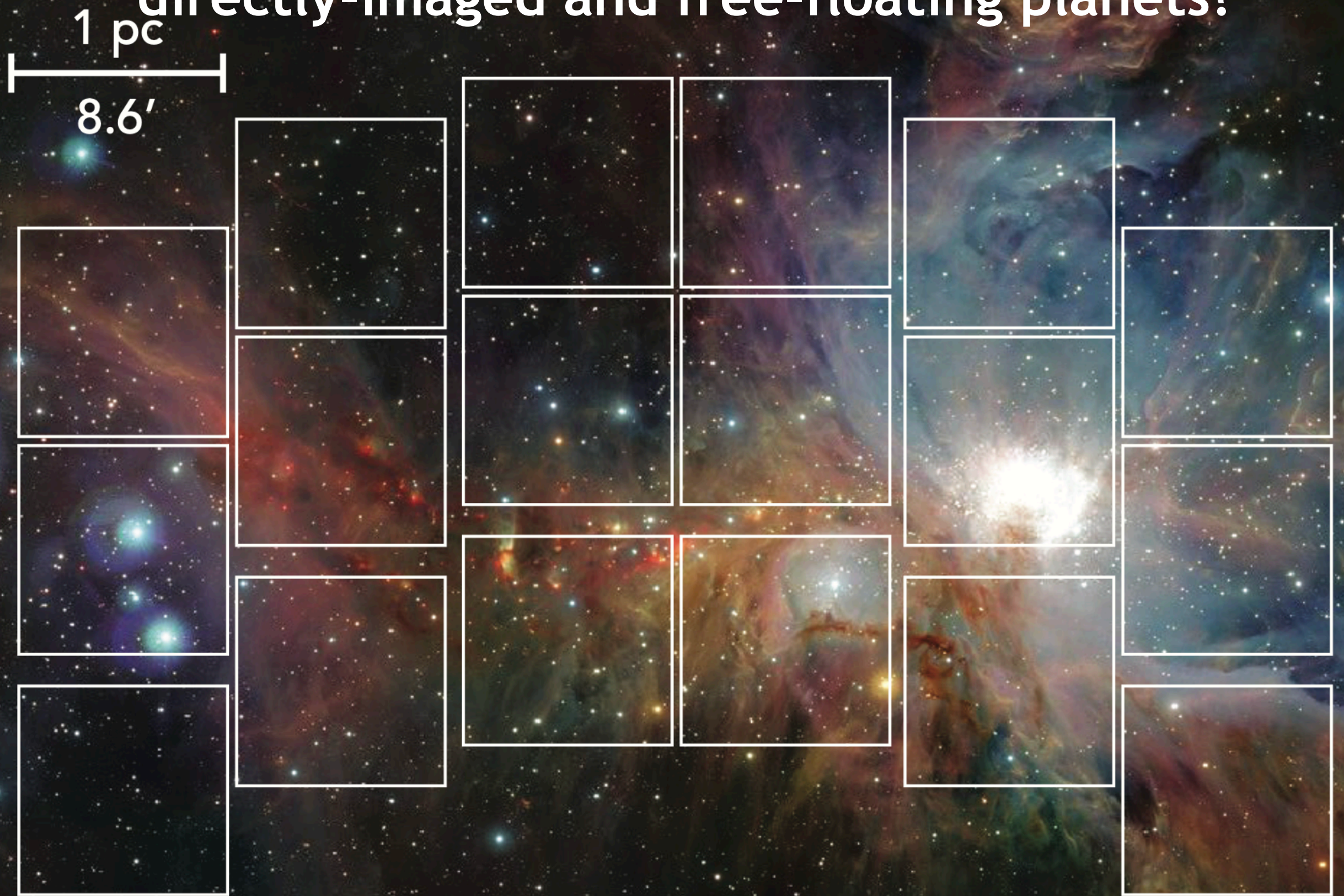
JWST is sensitive to Solar System moon analogs



Householder+ (including Vanderburg) 2025

But existing data is sparse. Can we do this in a systematic way?

What if we pointed Roman at Orion and observed
directly-imaged and free-floating planets?



The TEMPO Survey

Transiting Exosatellites, Moons, and Planets in Orion



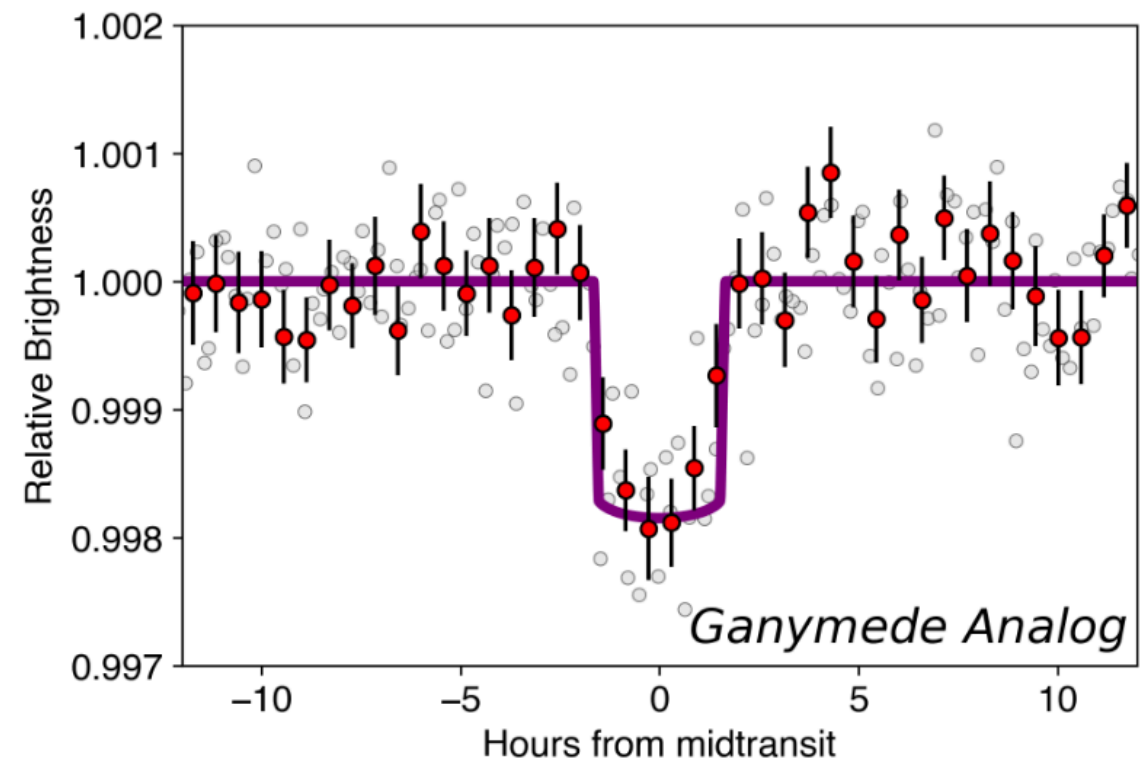
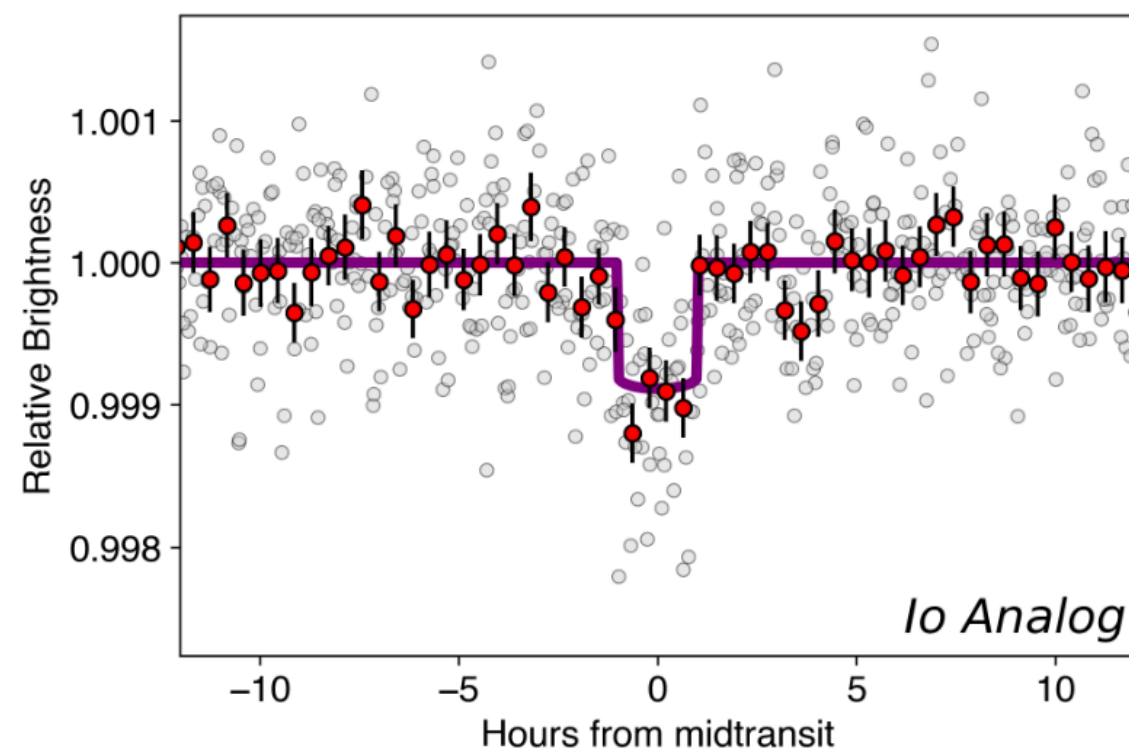
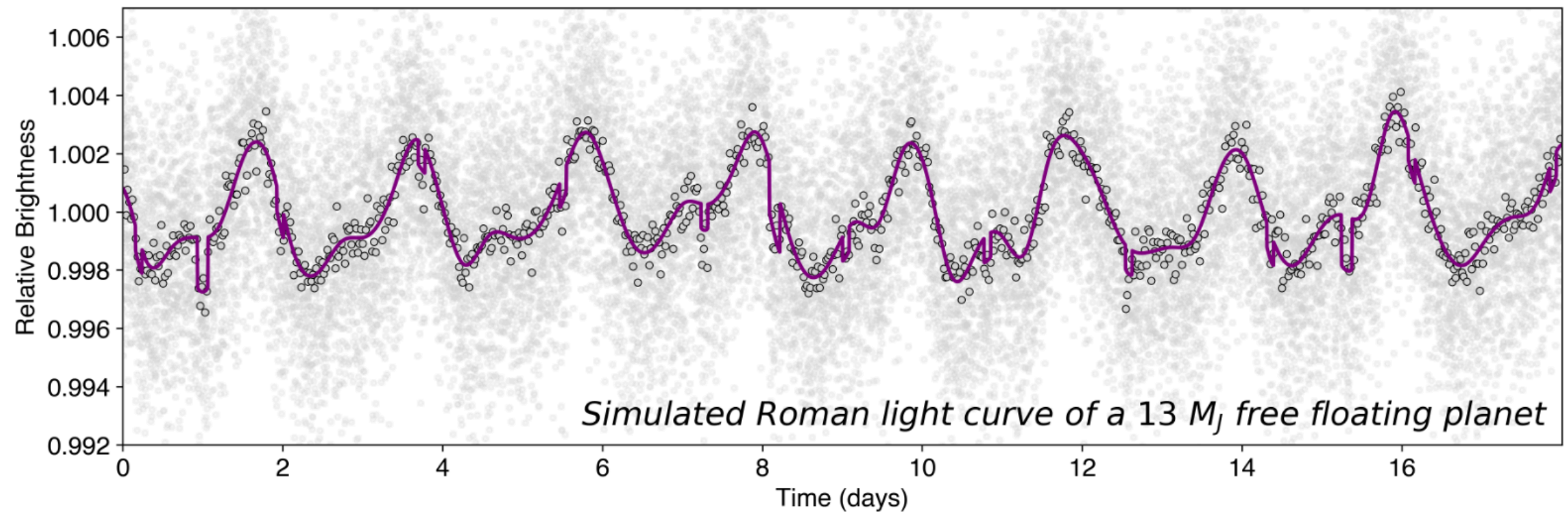
Mary Anne Limbach
Former Texas A&M grad student
Research Scientist at U Michigan

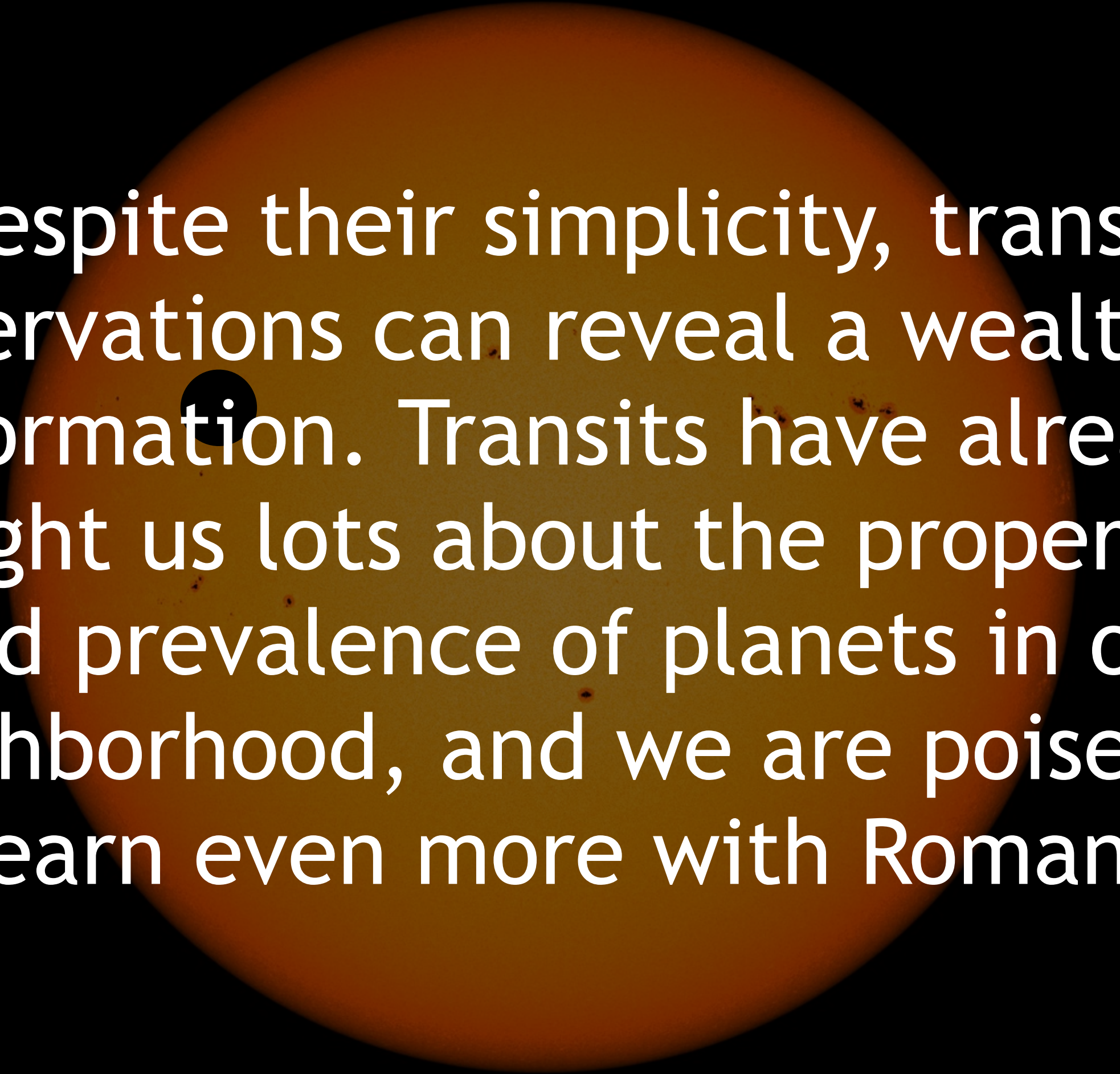


Melinda Soares-Furtado
Faculty at U. Wisconsin

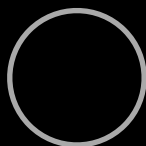
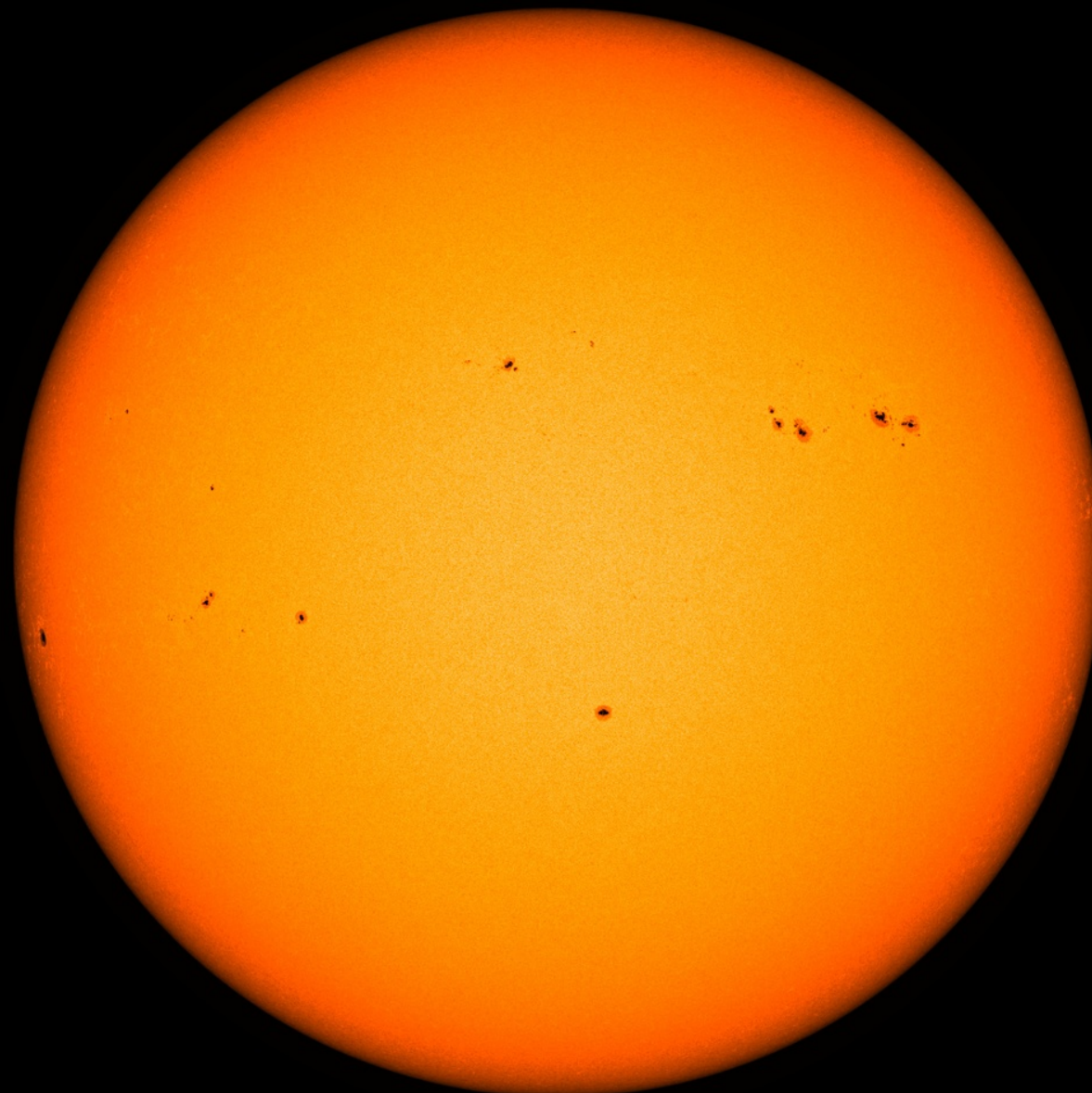
Image: NASA

Roman could find Galilean moon analogs — if we choose to look.



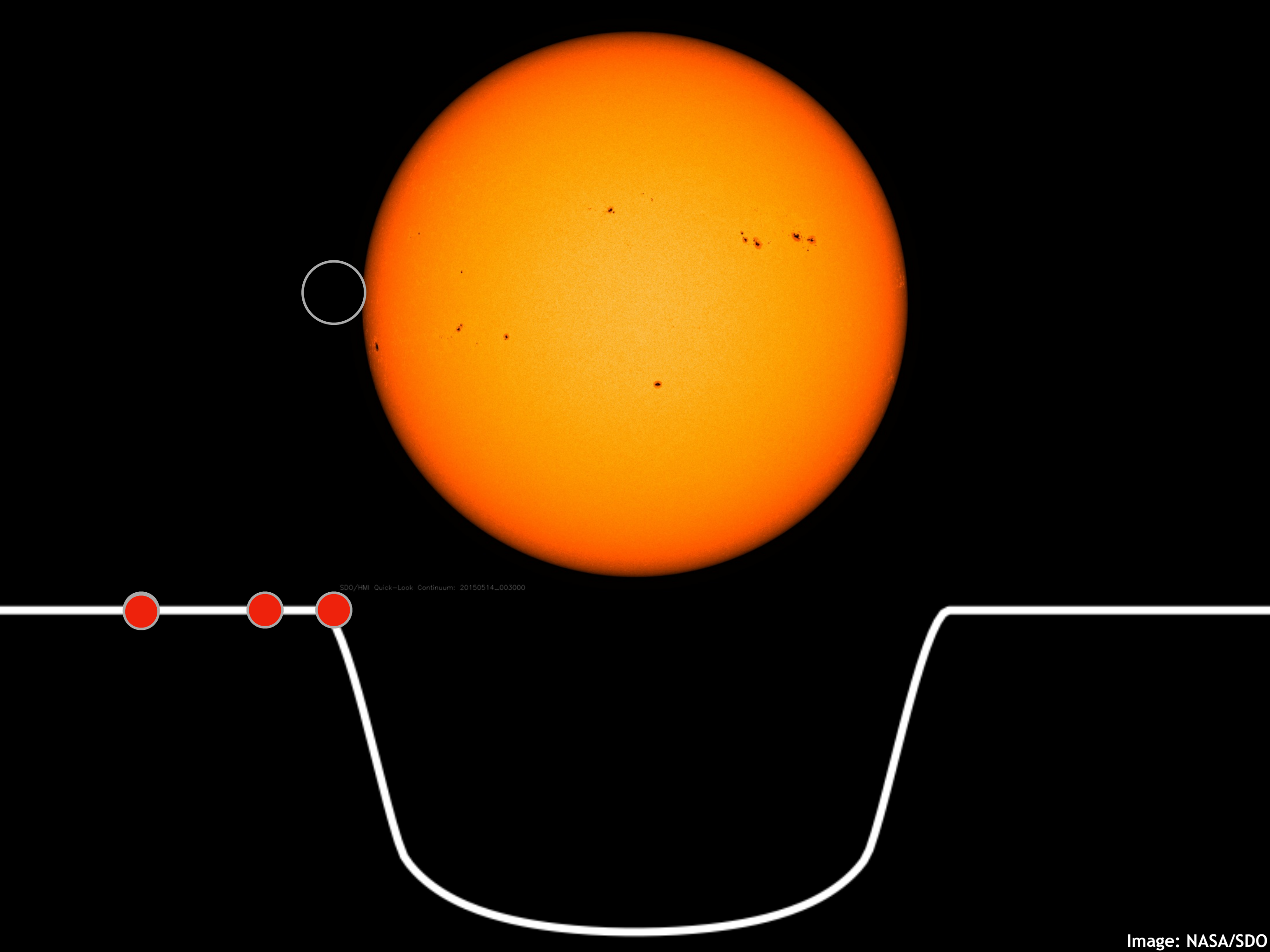


Despite their simplicity, transit observations can reveal a wealth of information. Transits have already taught us lots about the properties and prevalence of planets in our neighborhood, and we are poised to learn even more with Roman.

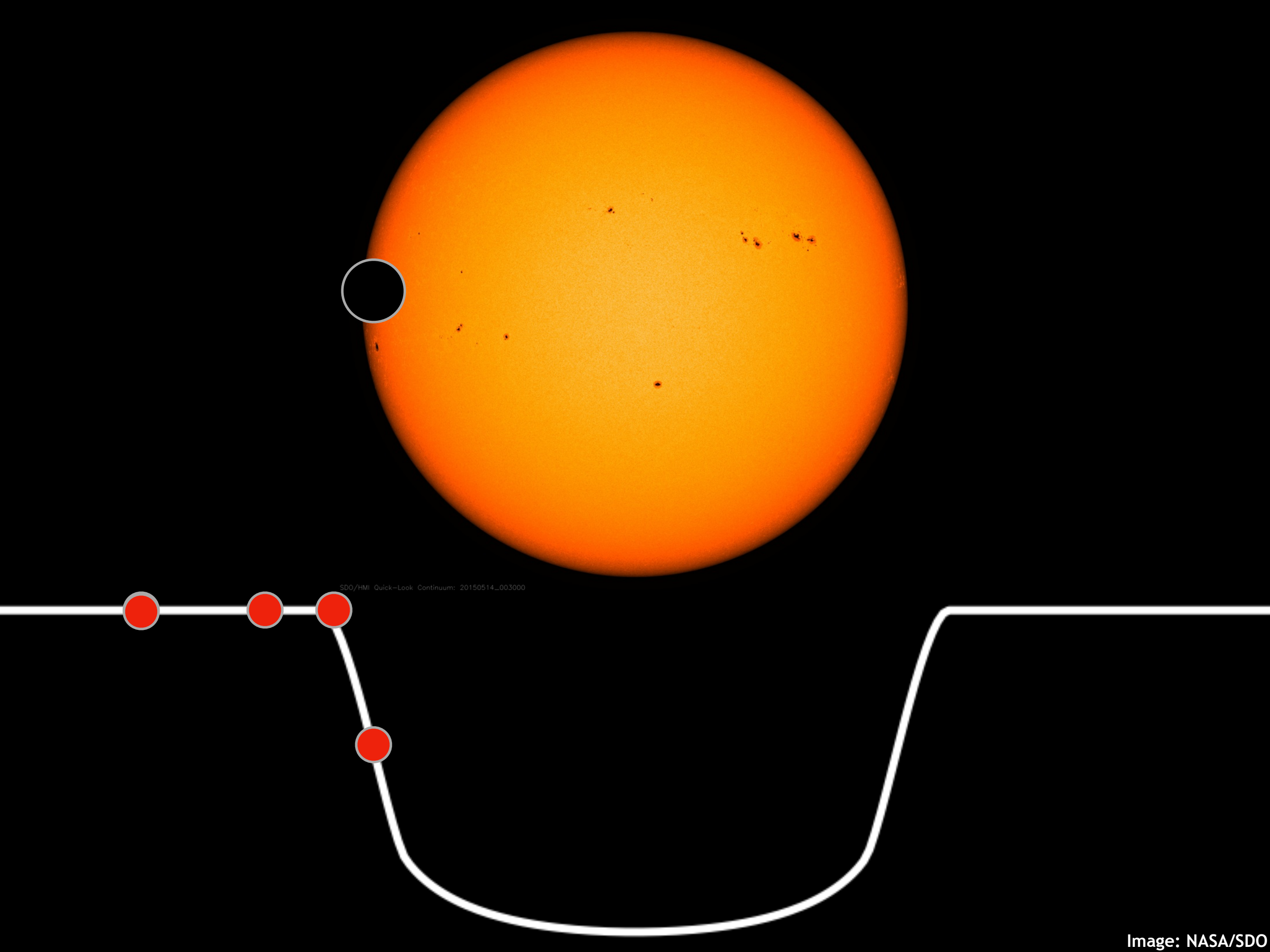


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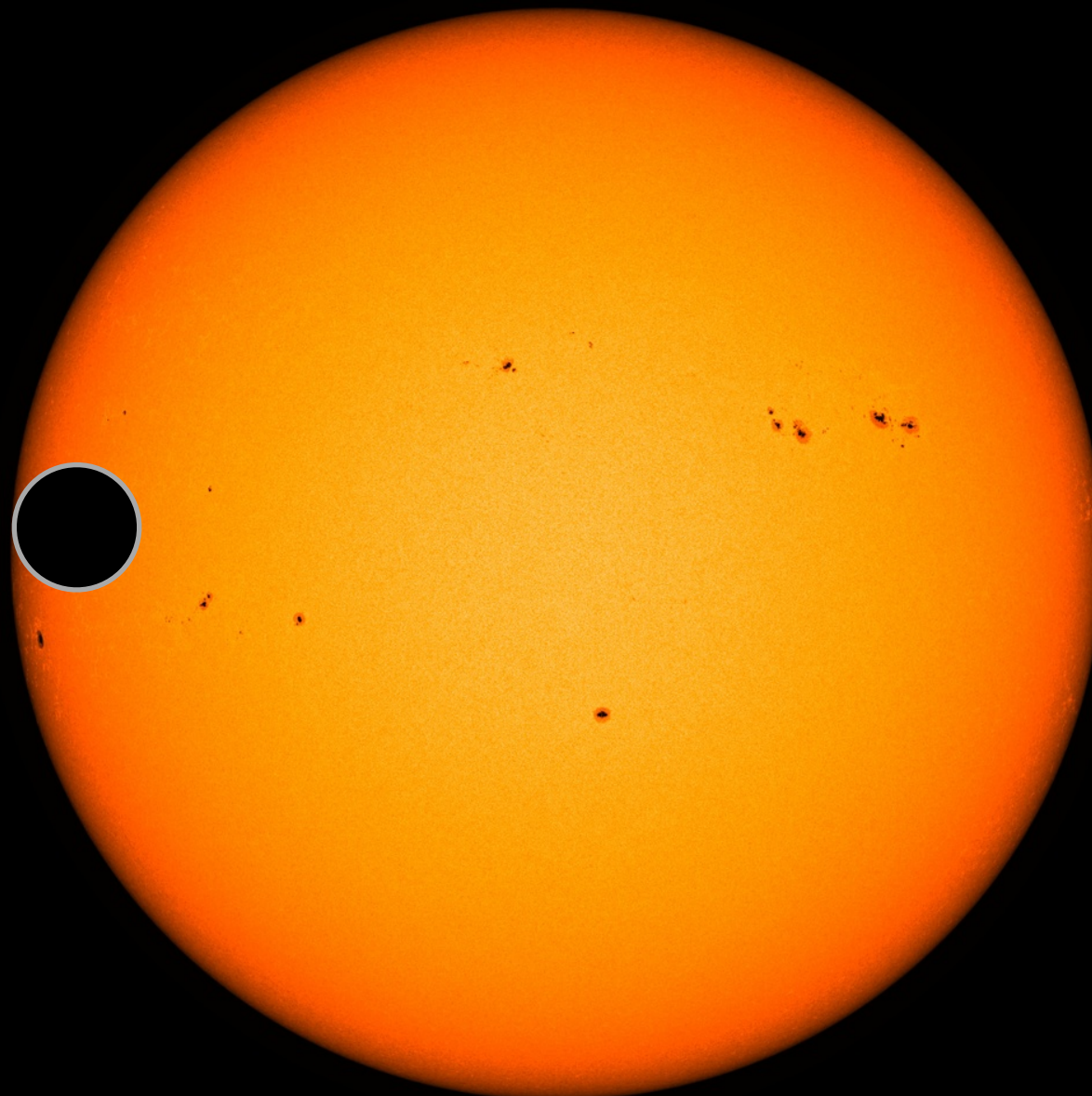




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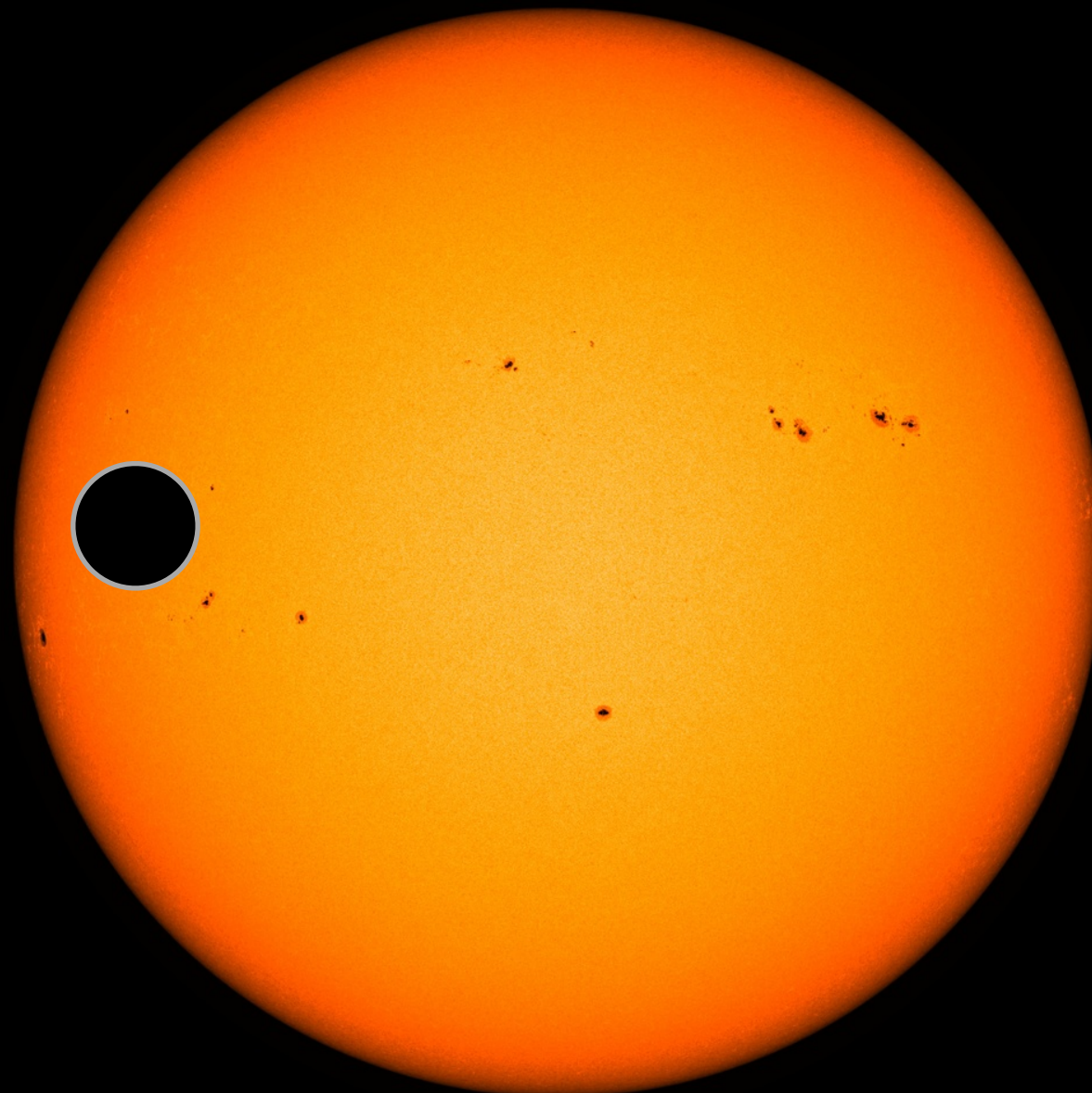


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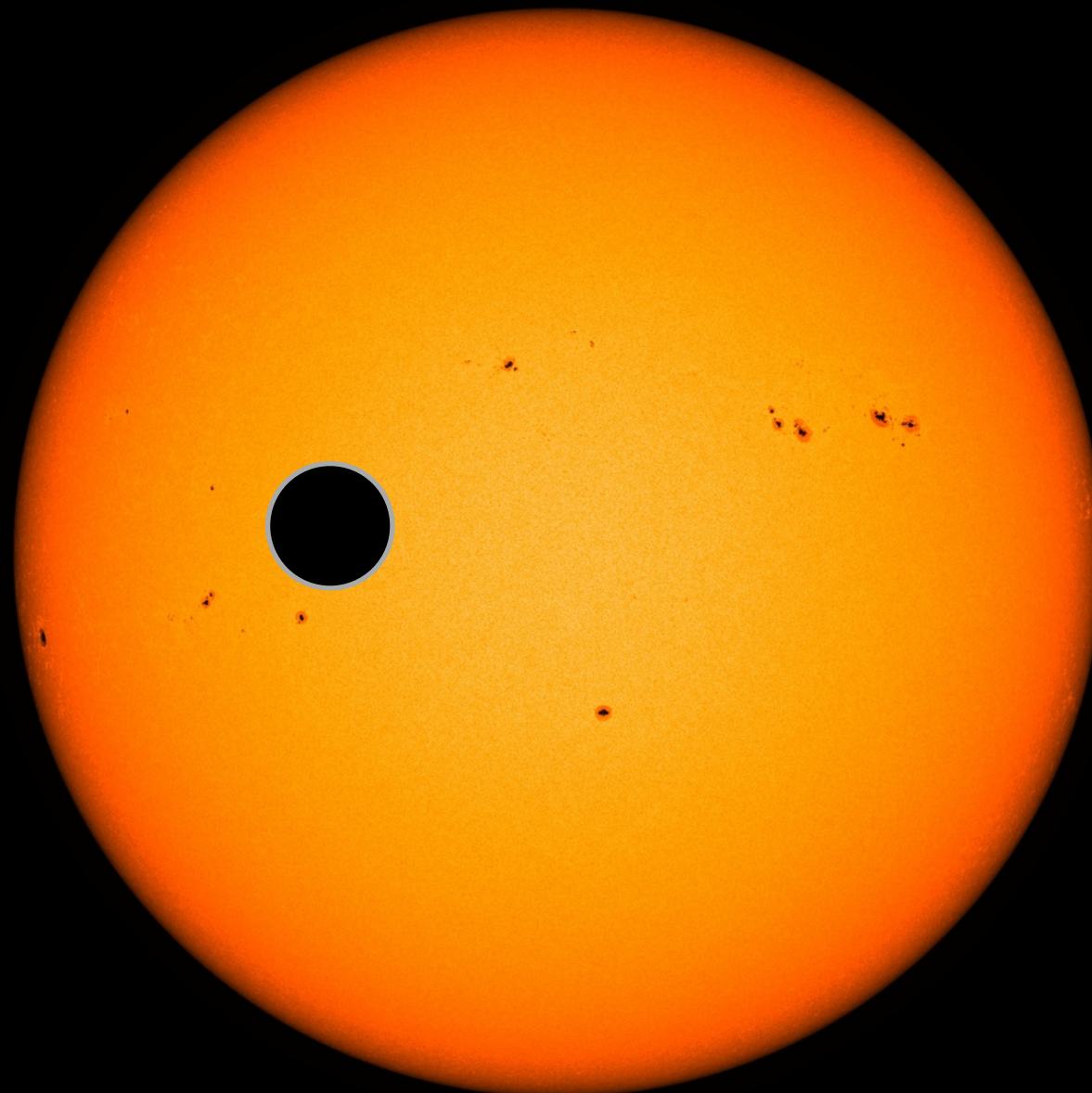
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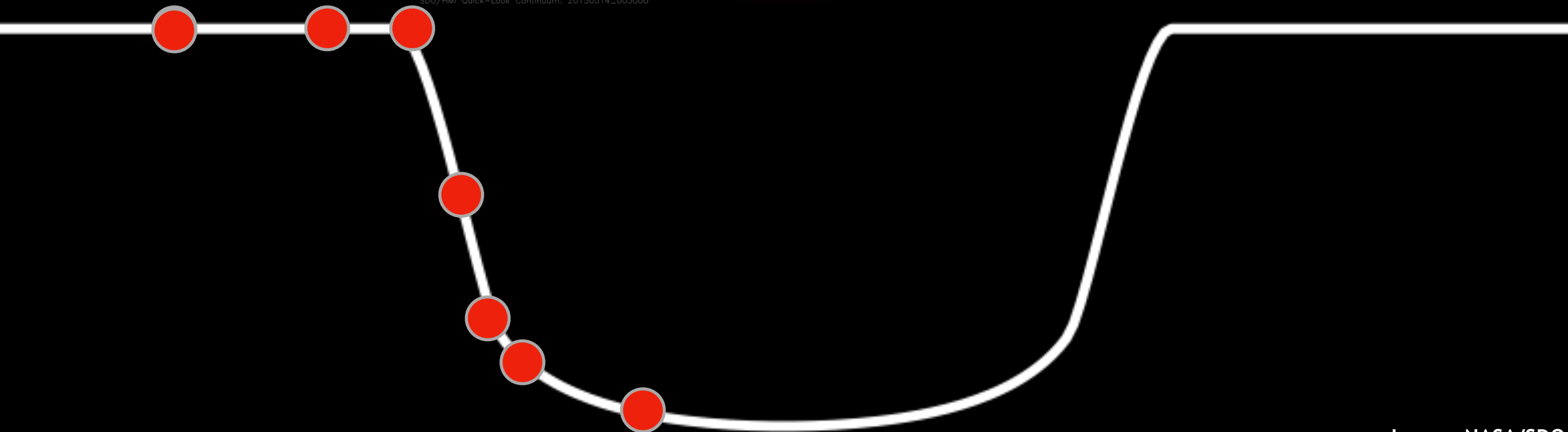
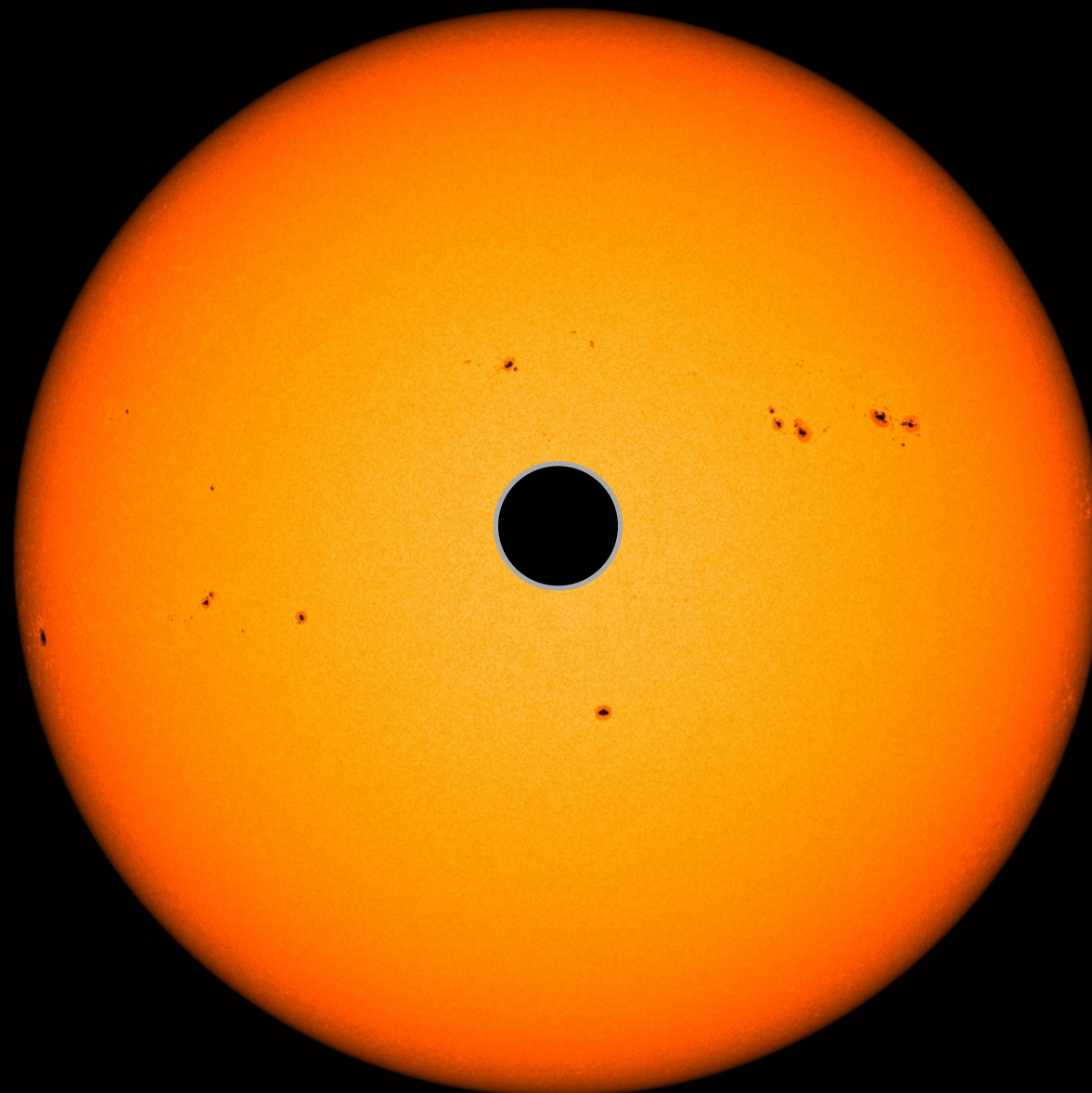
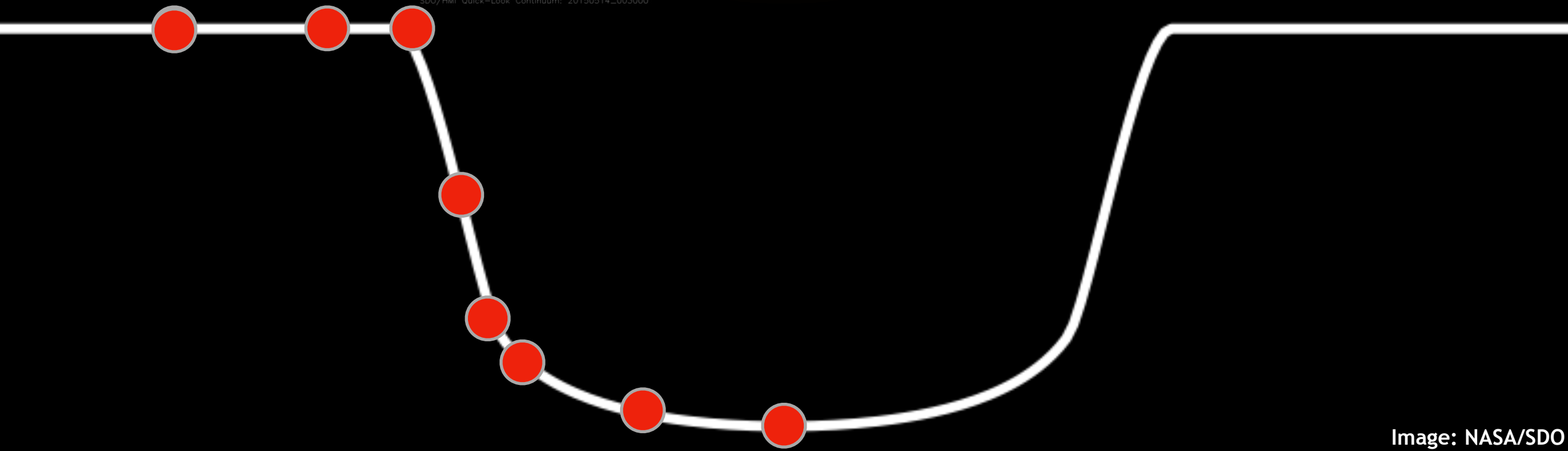
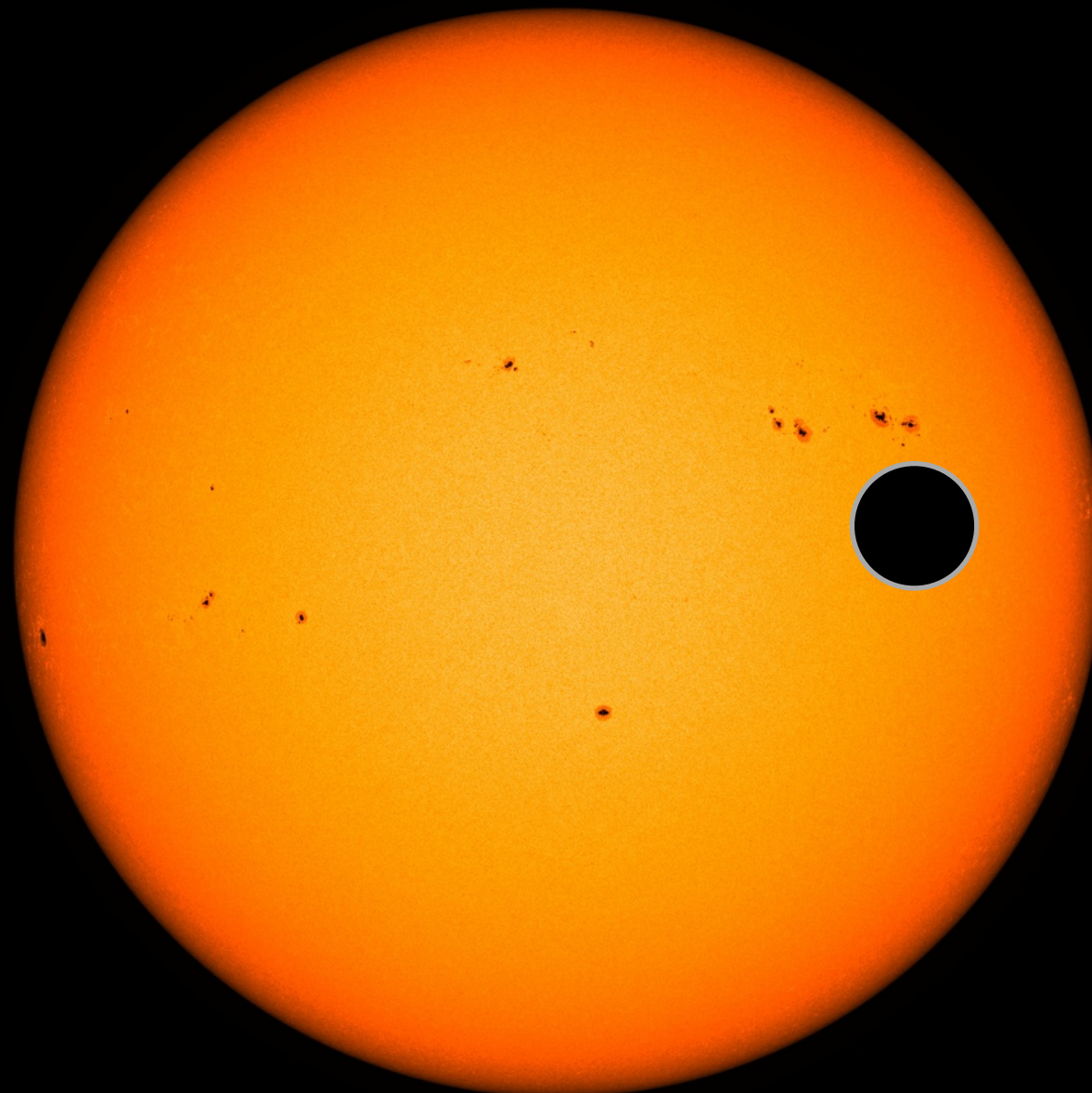


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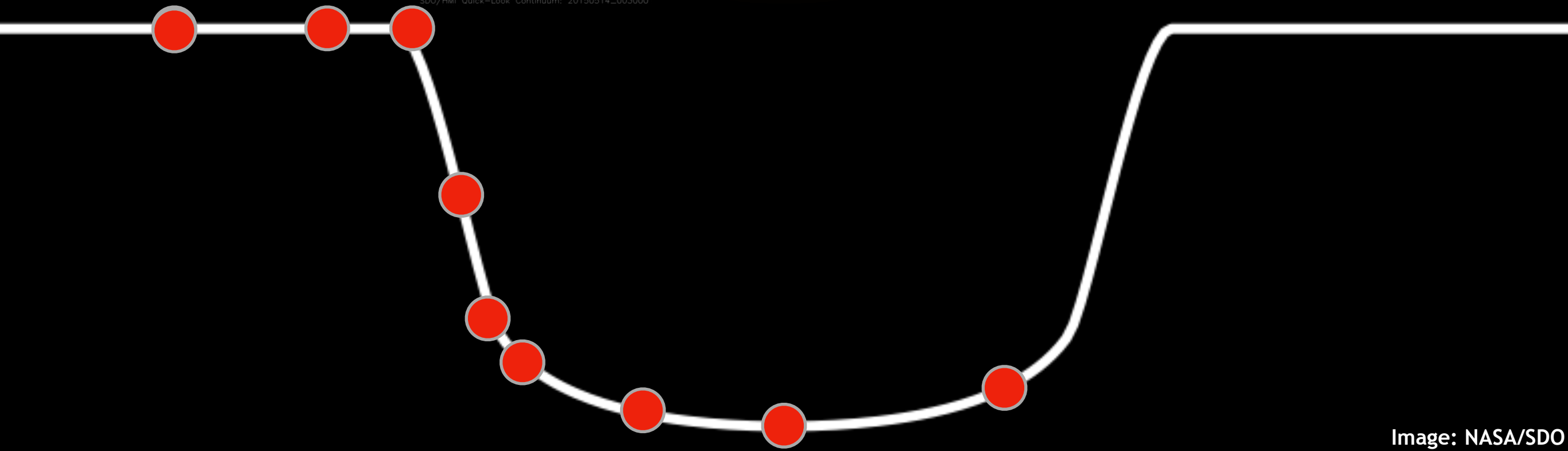


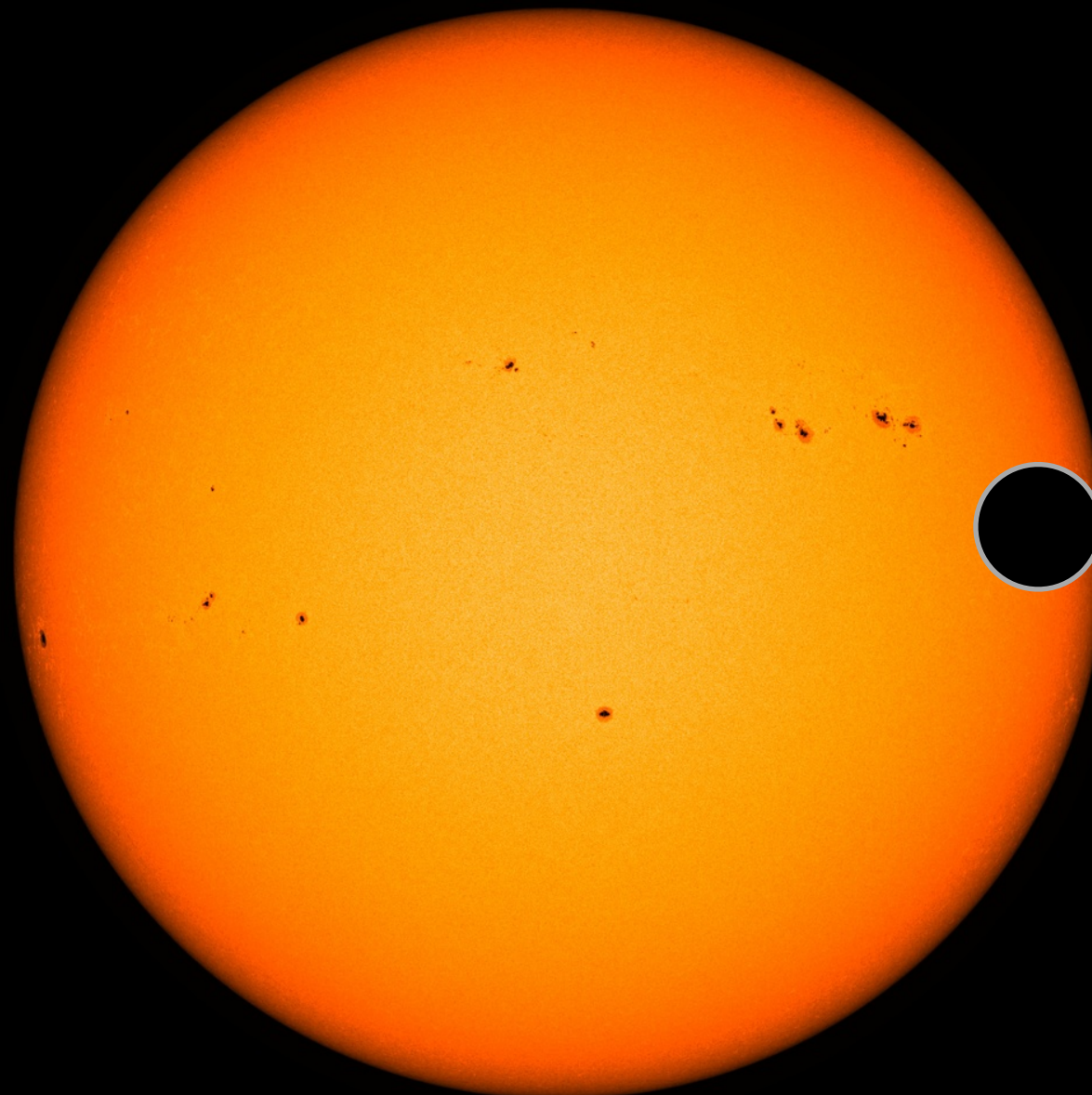
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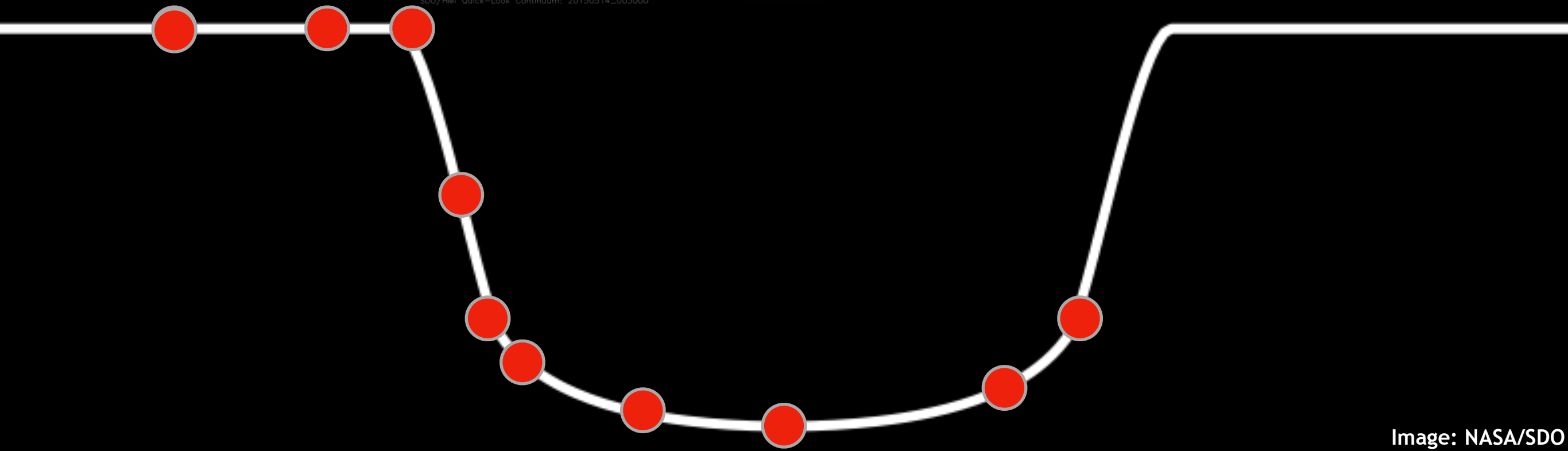
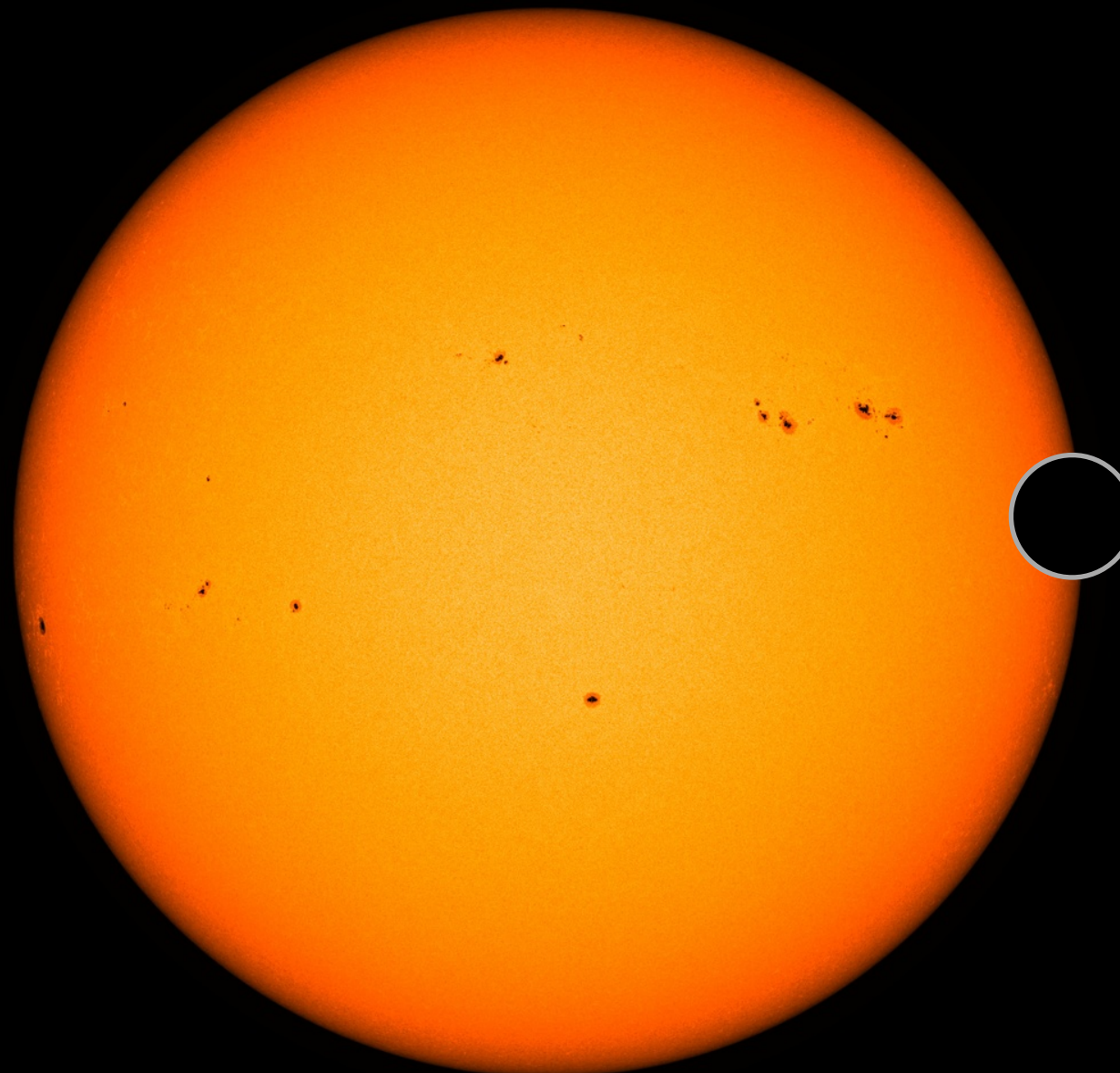
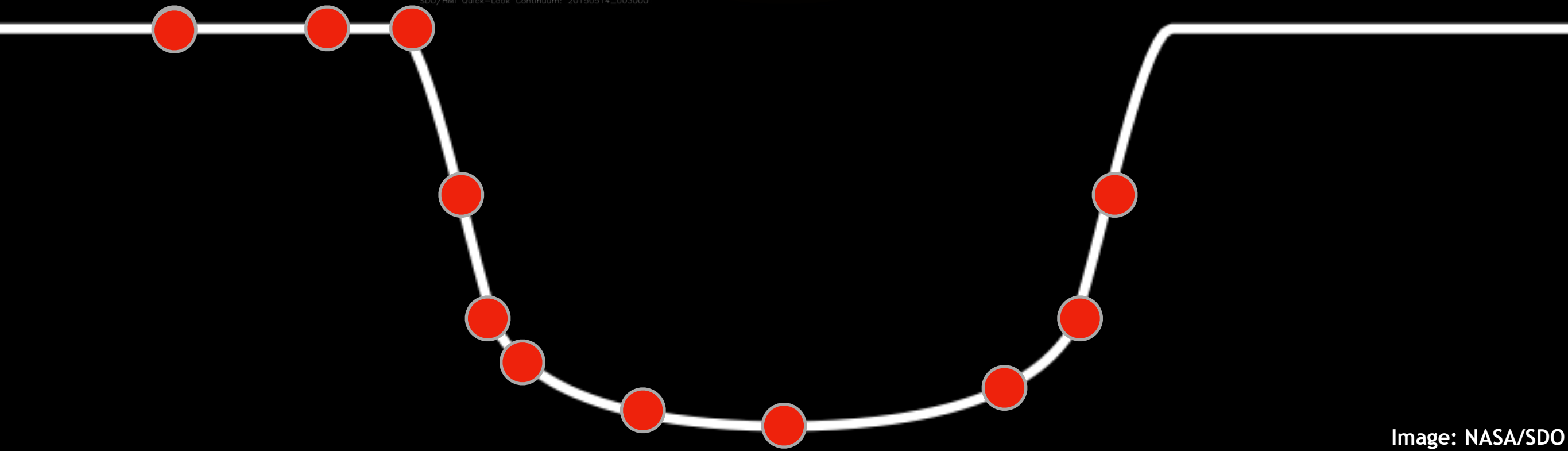
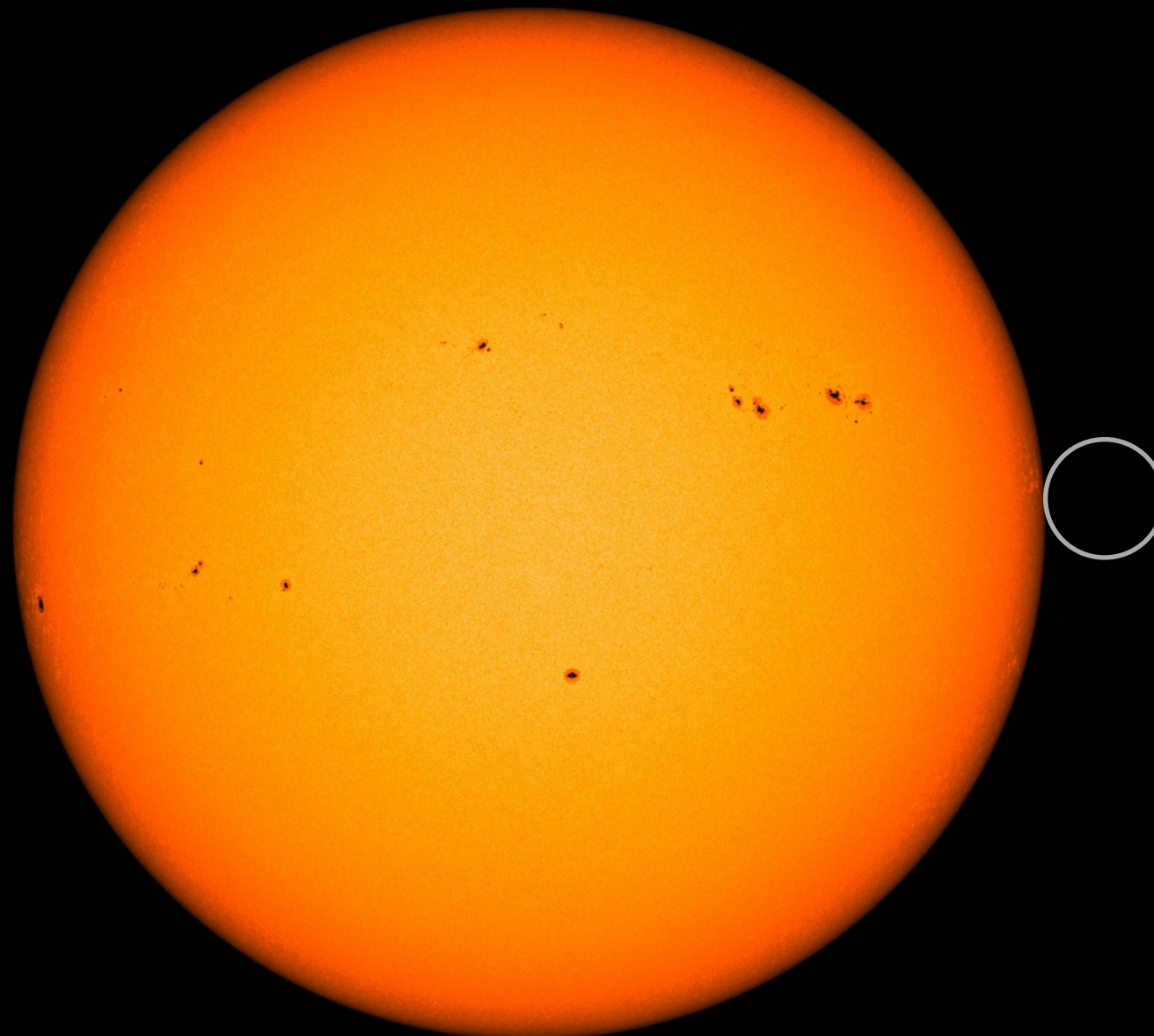


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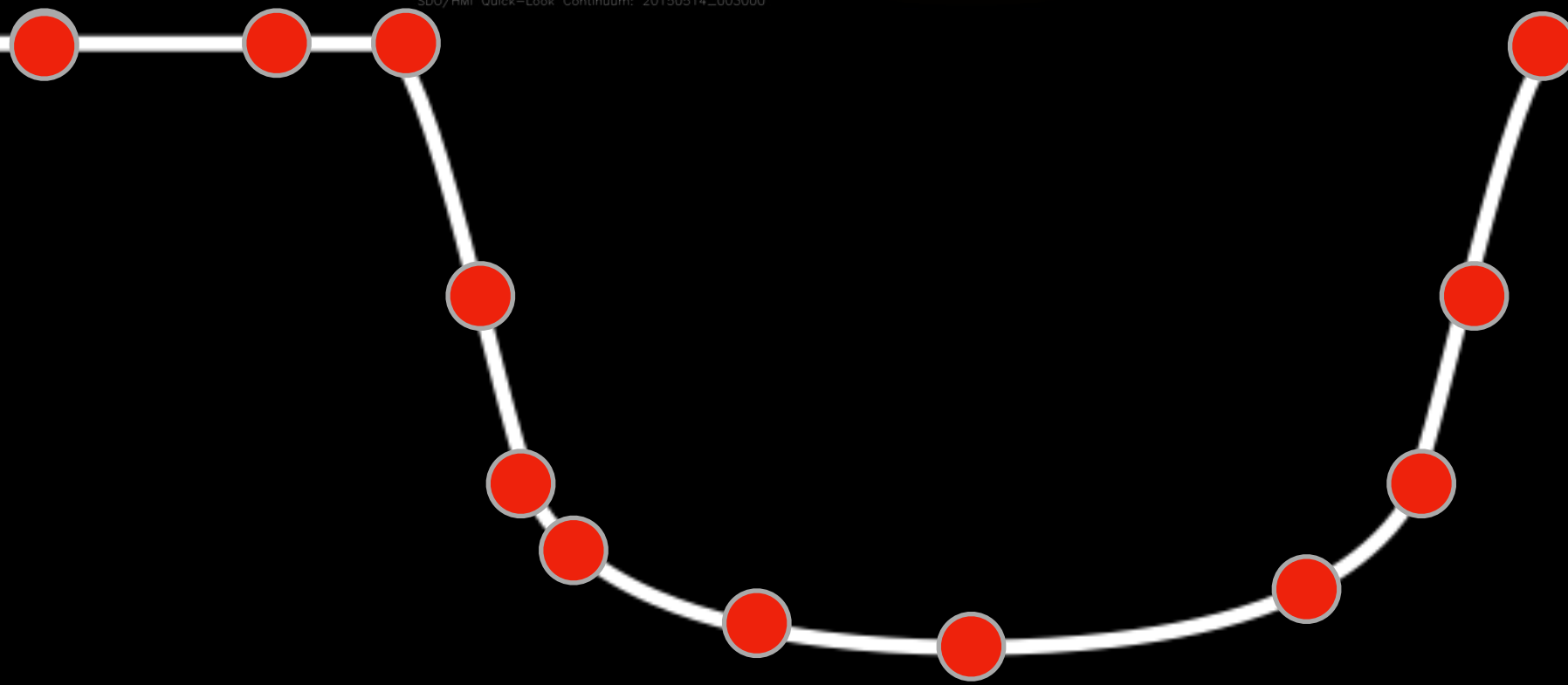


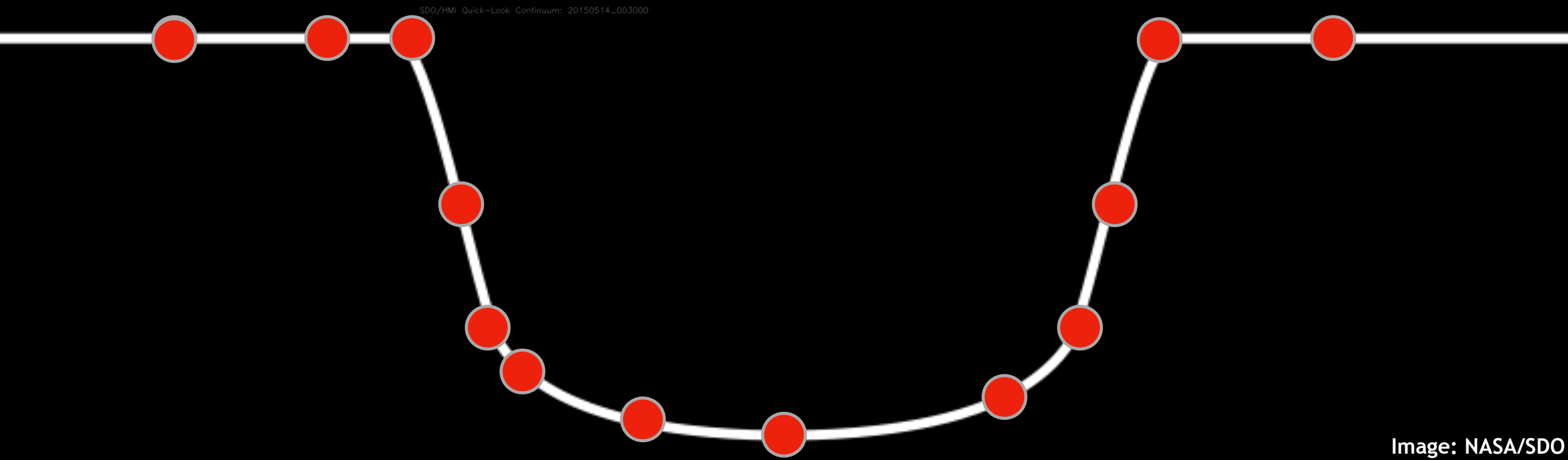
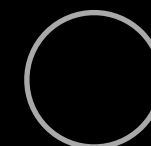
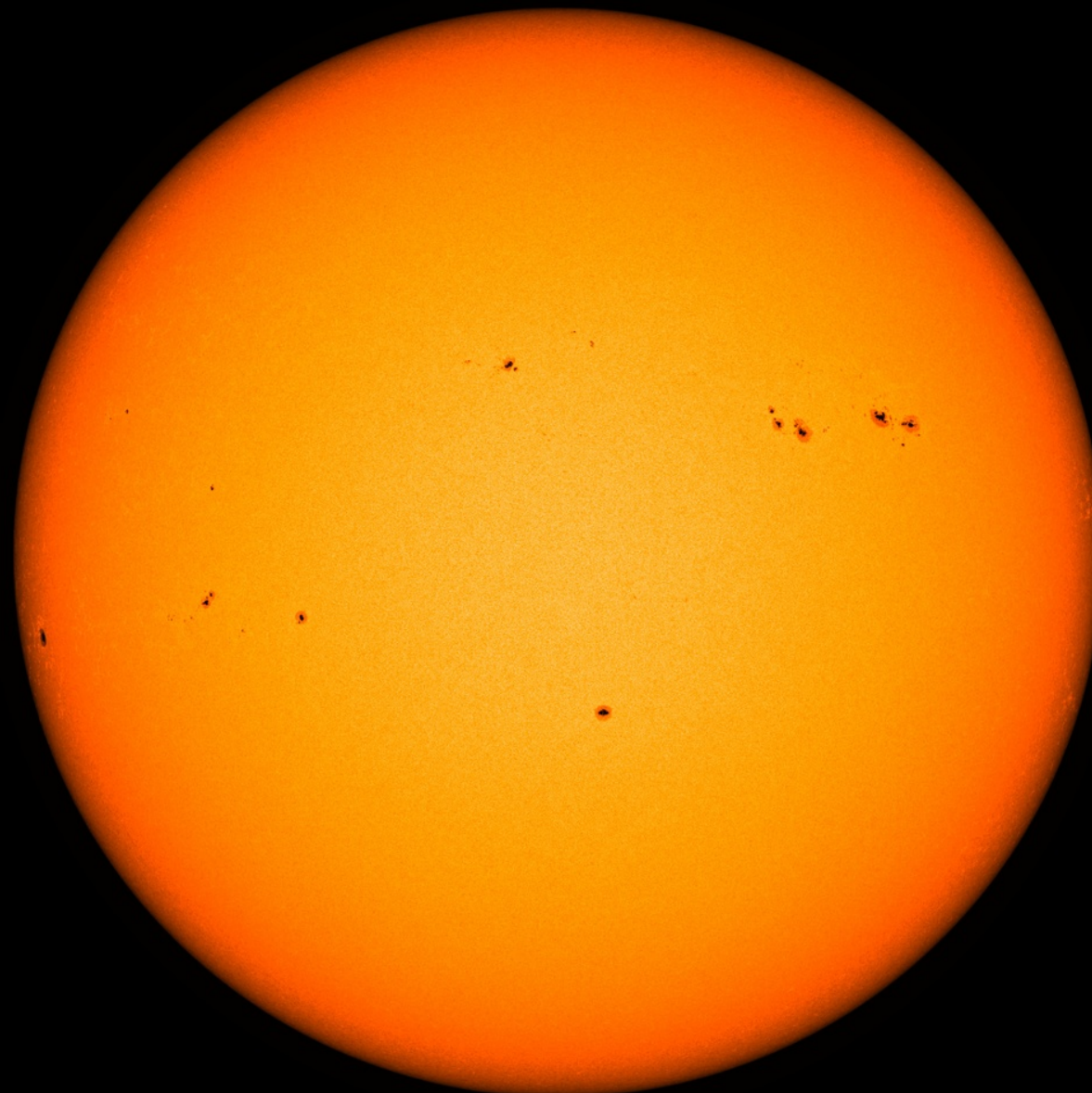
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Image: NASA/SDO