Exoplanets:
Probing alien ... worlds

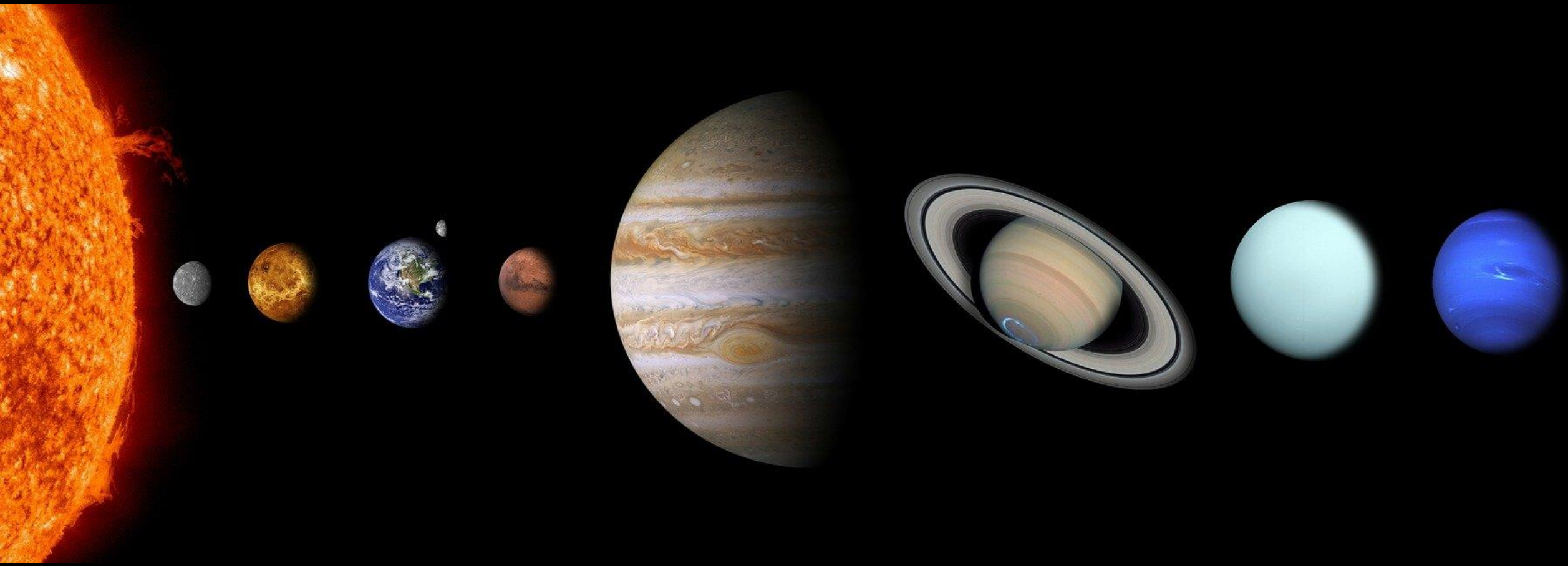
Jake Clark

PhD Candidate & Science Communicator
University of Southern Queensland

@spacejayk

JOSH
CALCINO

What is a planet?



Body in orbit around the Sun

has sufficient mass to assume hydrostatic equilibrium

has "cleared the neighborhood" around its orbit

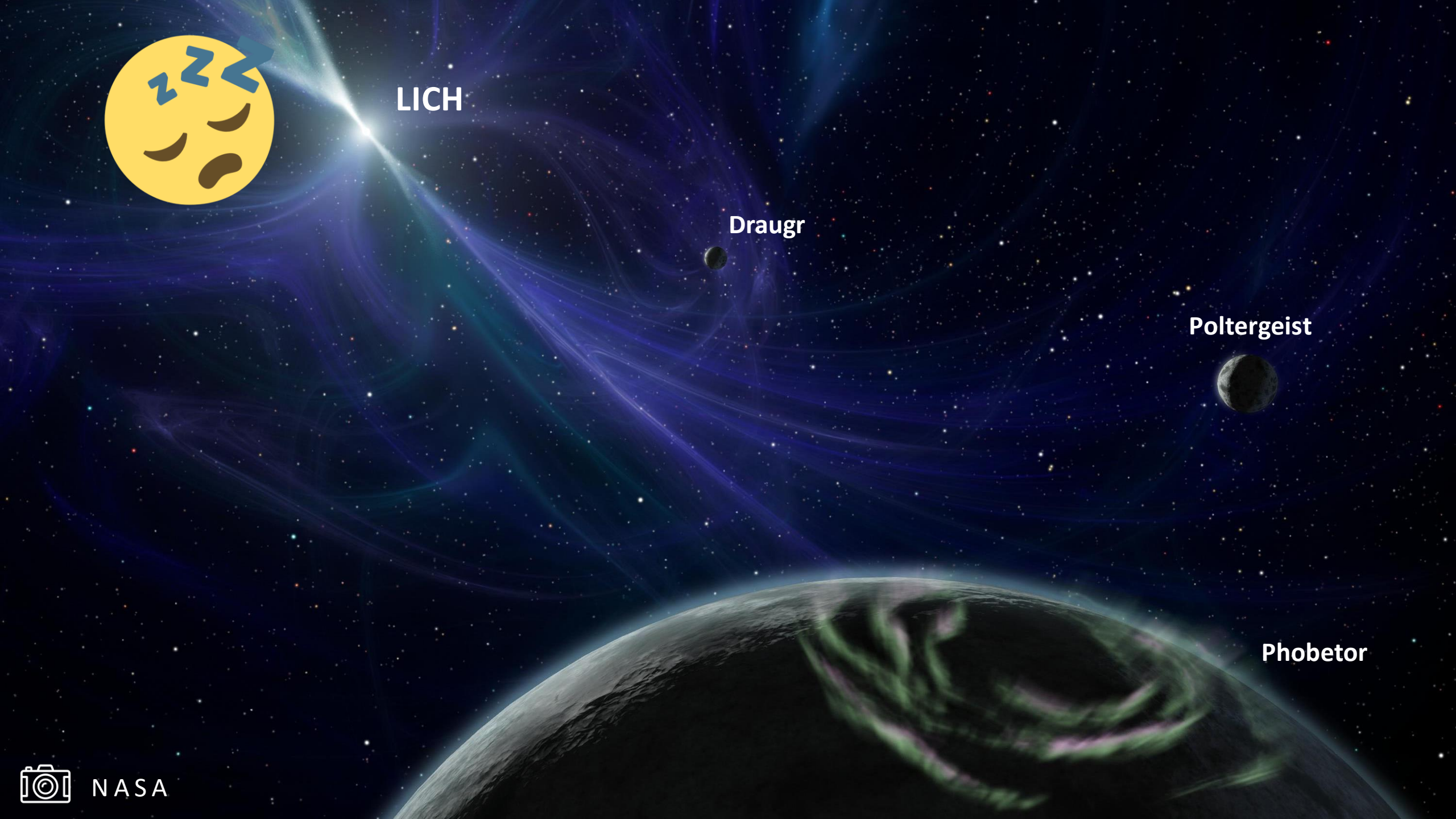
So what's an exoplanet…

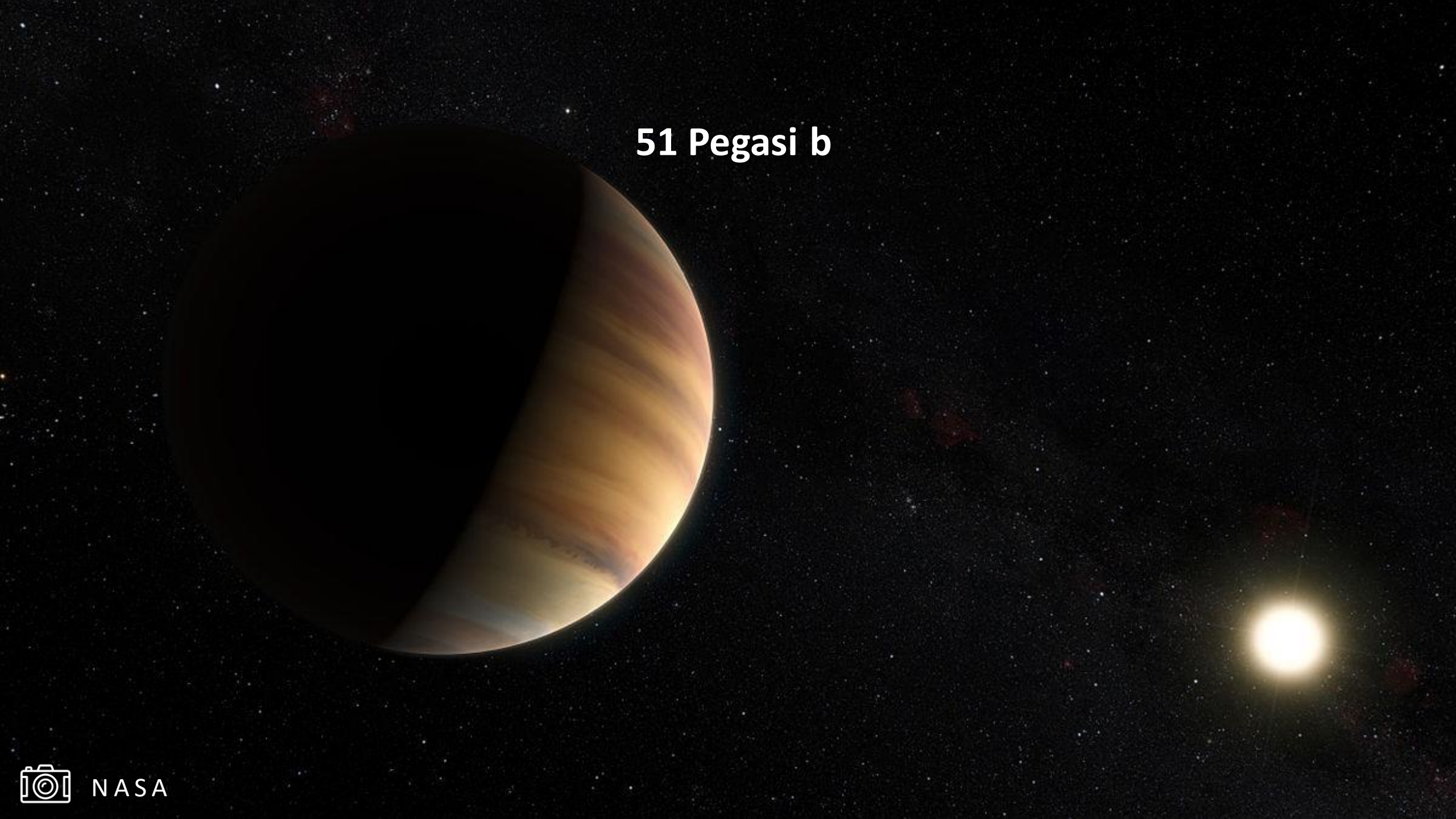
CURRENTLY NO ACCEPTED DEFINITION

BALLPARK:

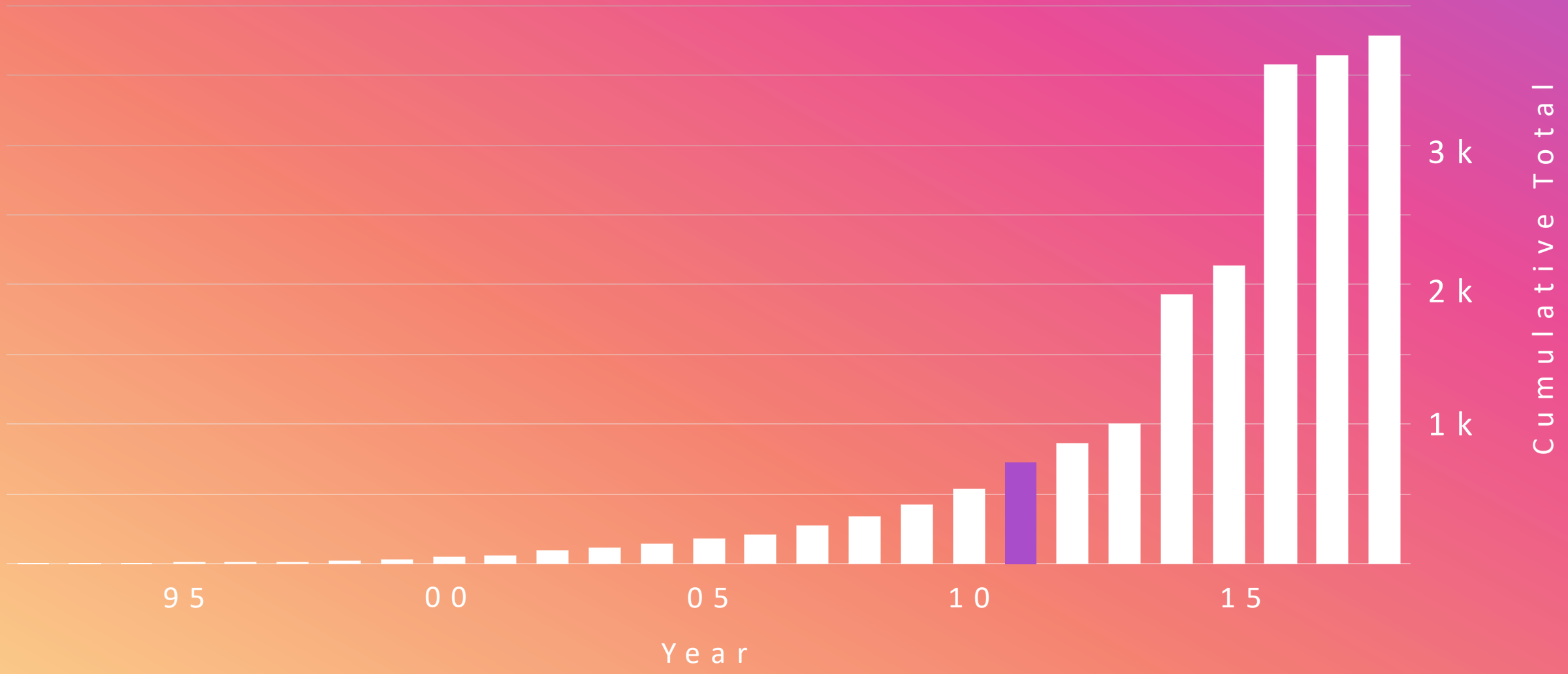
Any 'planet-like' object below 13 Jupiter masses (M_J) outside of our solar system


Bodacious year of
1992

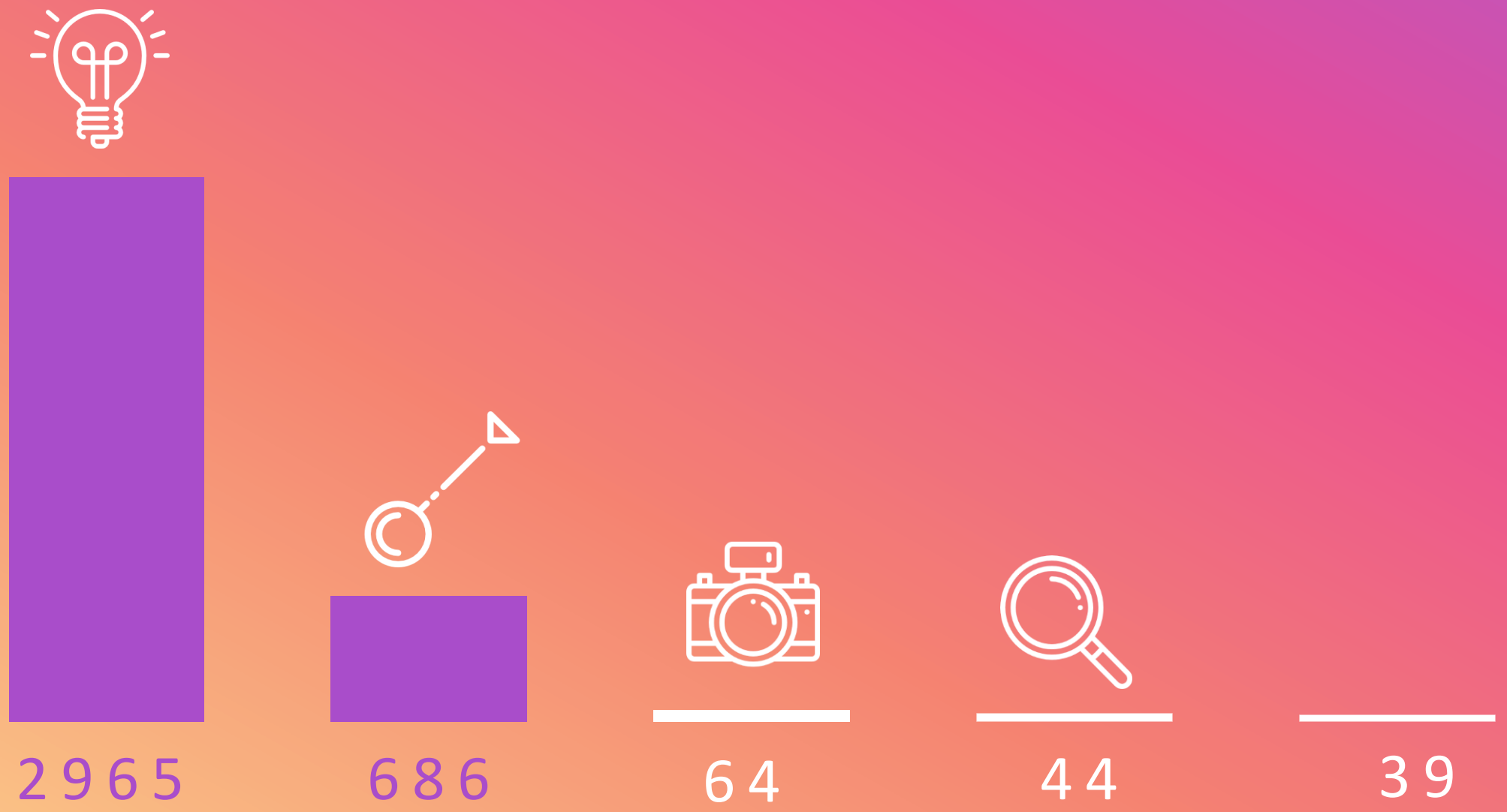

LICH
Draugr
Poltergeist
Phobetor
NASA

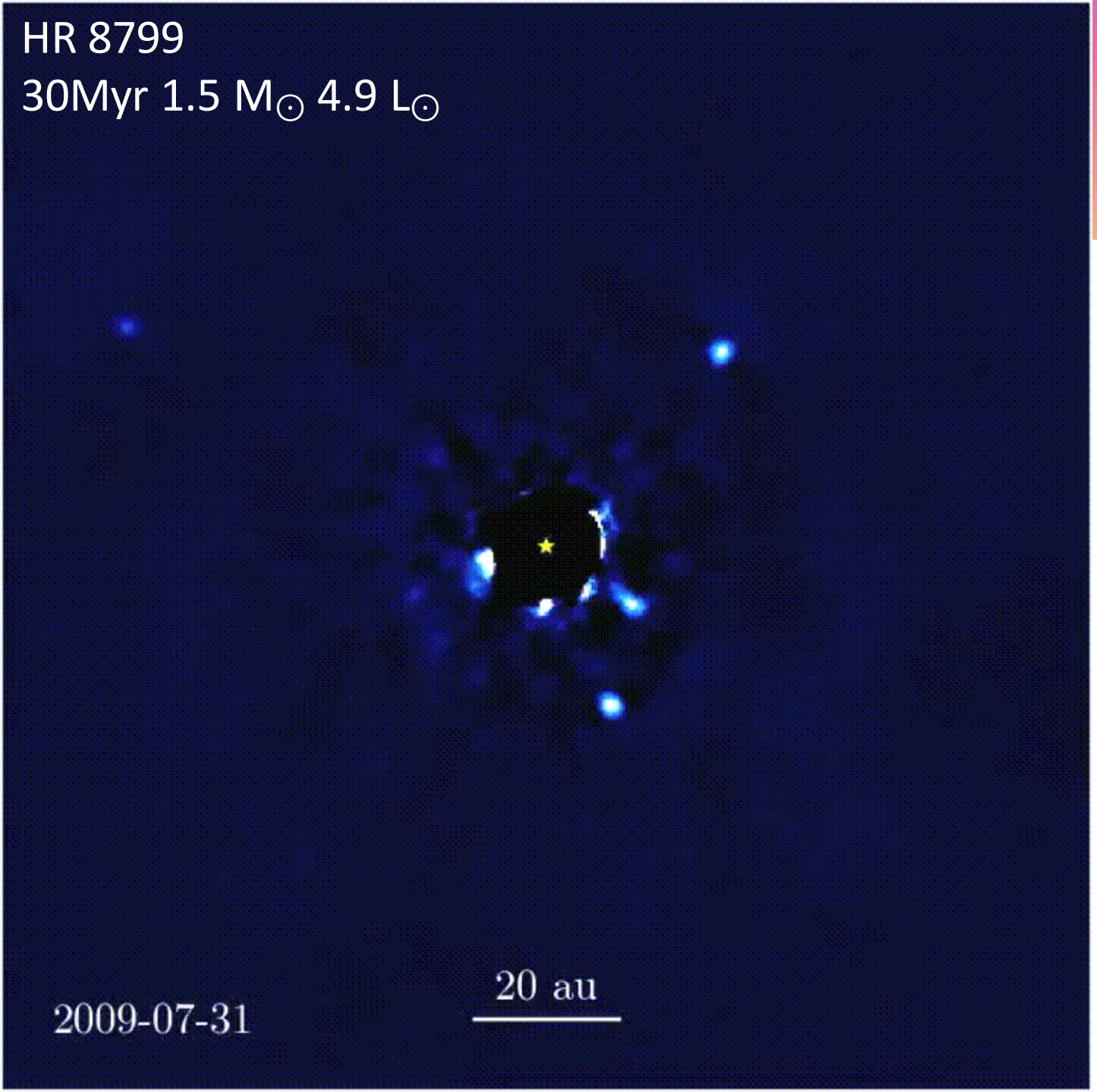

51 Pegasi b
NASA

GOLDEN ERA OF EXOPLANETS



POPULAR WAYS TO DETECT AN EXOPLANET





DIRECT IMAGING

Block out starlight using coronagraph

(1 in 10,000,000,000)

Only proven method of direct detection

Biased towards young, hot worlds

JASON WANG, et al

MICROLENSING

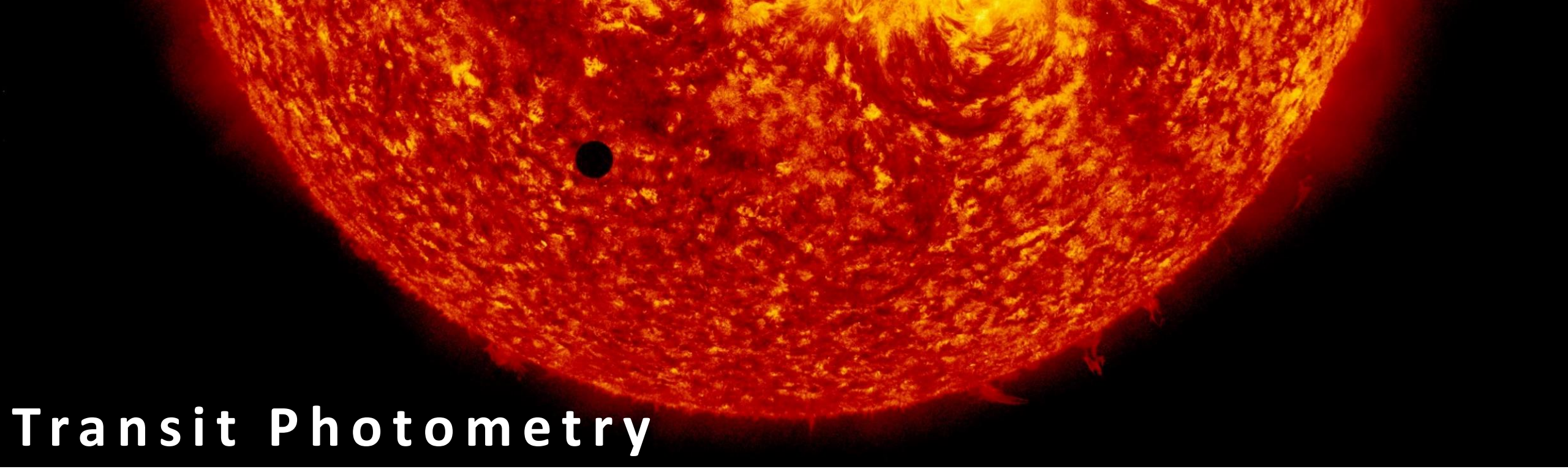
Background star ‘magnifies’ light from exoplanet

Discovers exoplanets 10,000’s of light years away

Extremely difficult / impossible to follow-up

NASA


LIGHT
TIME



Transit Photometry

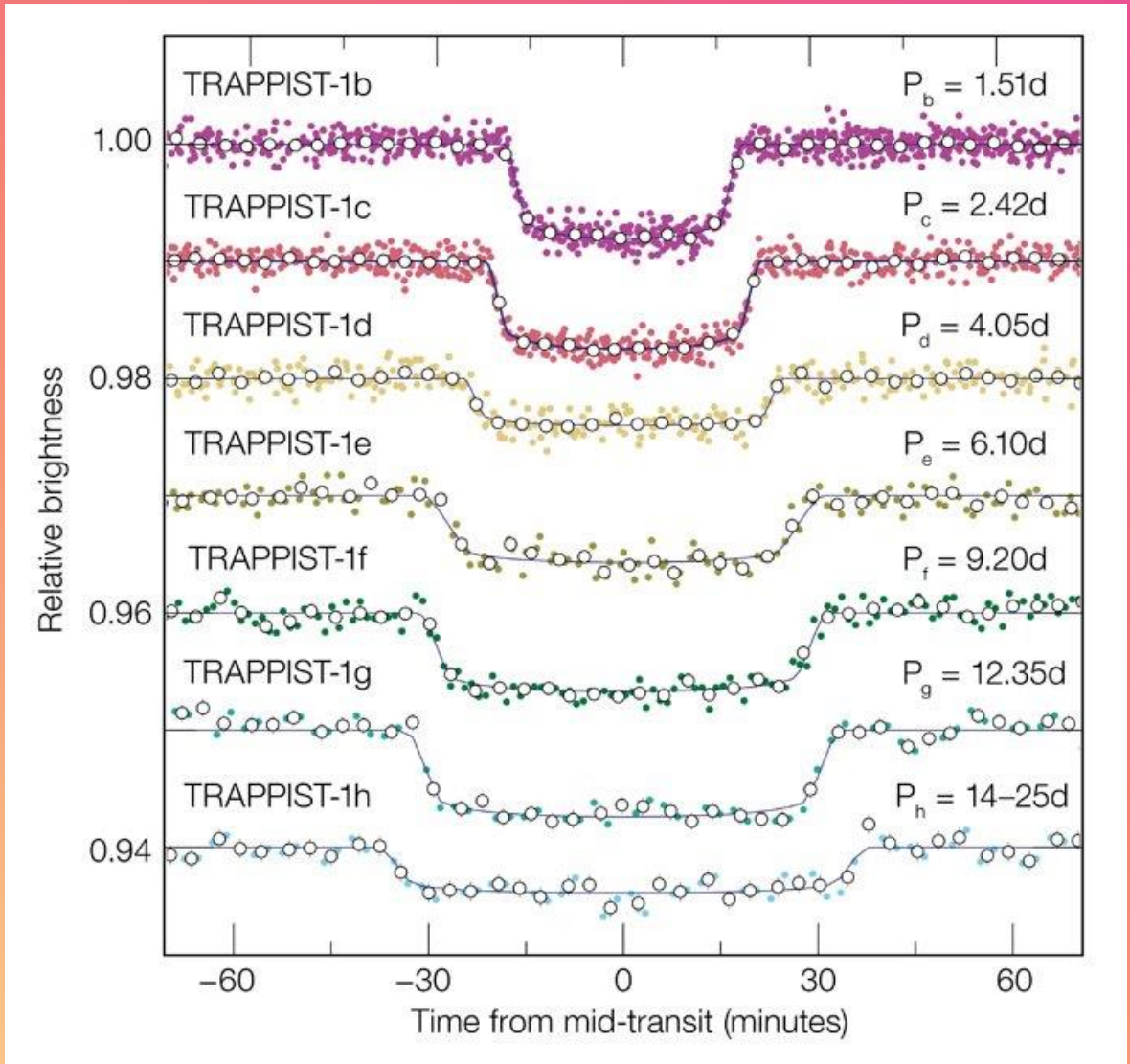
3 transits are needed to confirm detection

Exoplanet's radius R_p can be discovered through change in Stellar flux, F

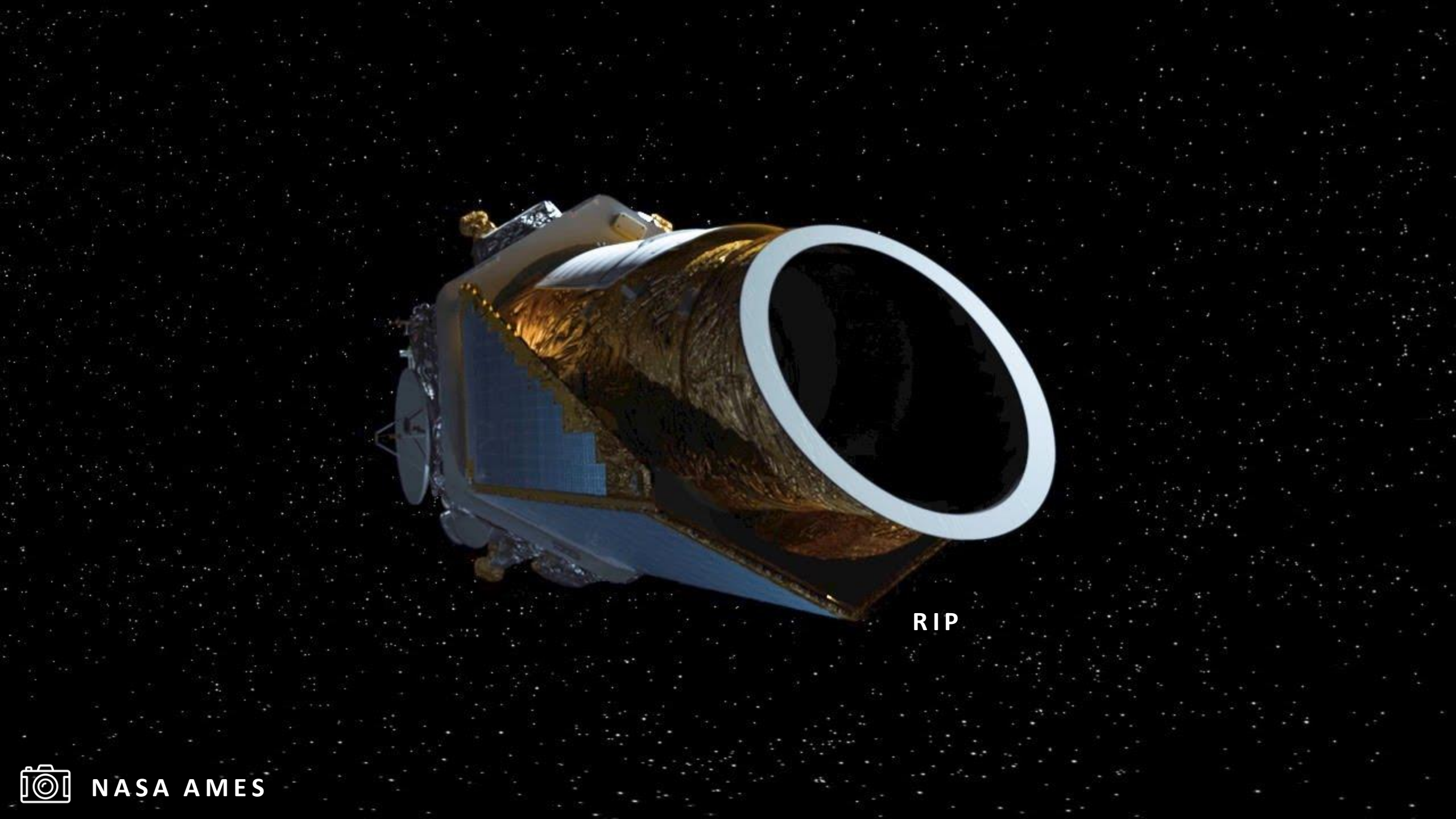
$$R_p = R_\star \sqrt{\frac{\Delta F}{F}}$$

NASA

TRAPPIST-1



ESO/
M. Gillon et al


RIP
NASA AMES

2

WHEELY BAD REACTOR WHEELS

9.5YRS

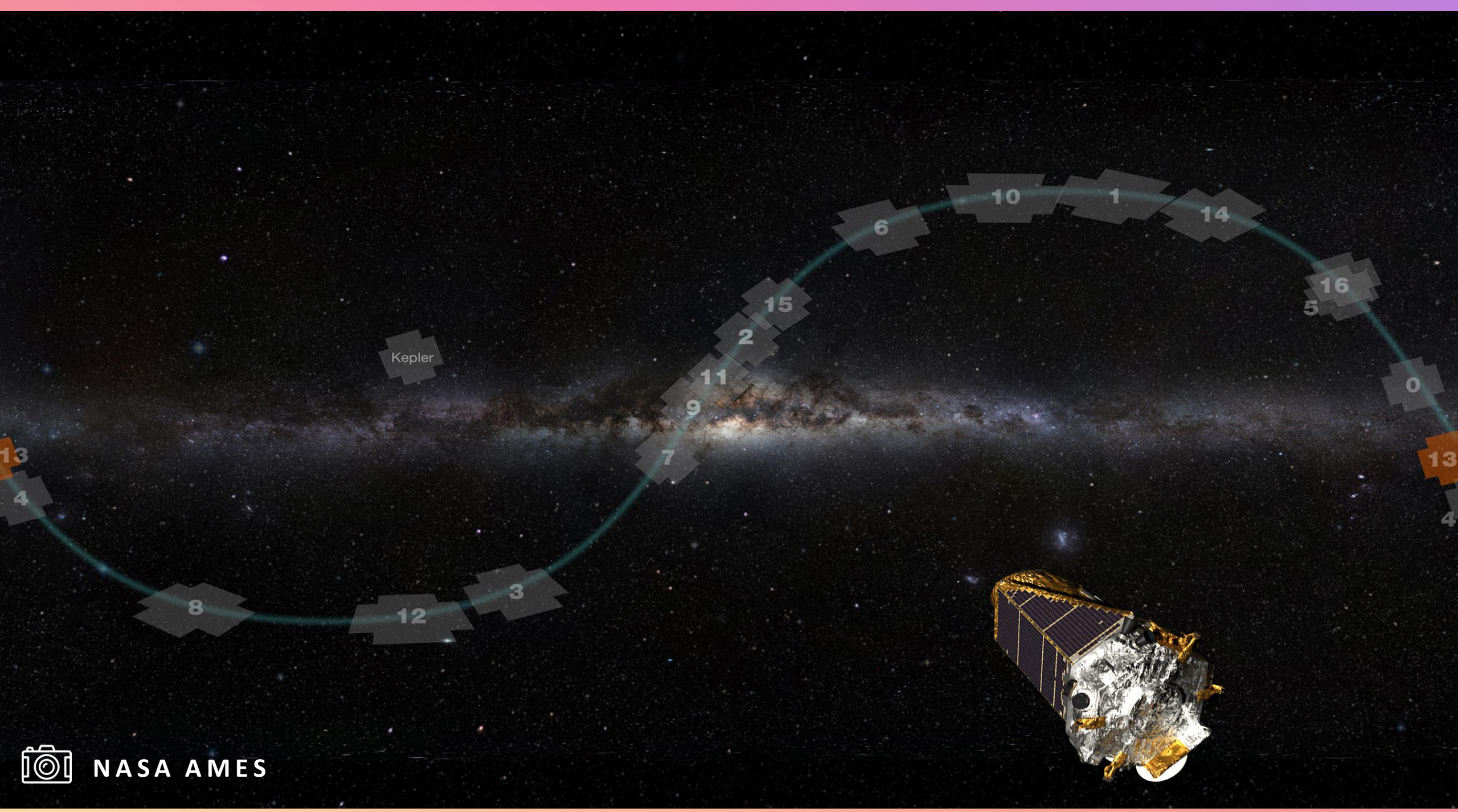
INTO A 3.5 YEAR LONG MISSION

70%

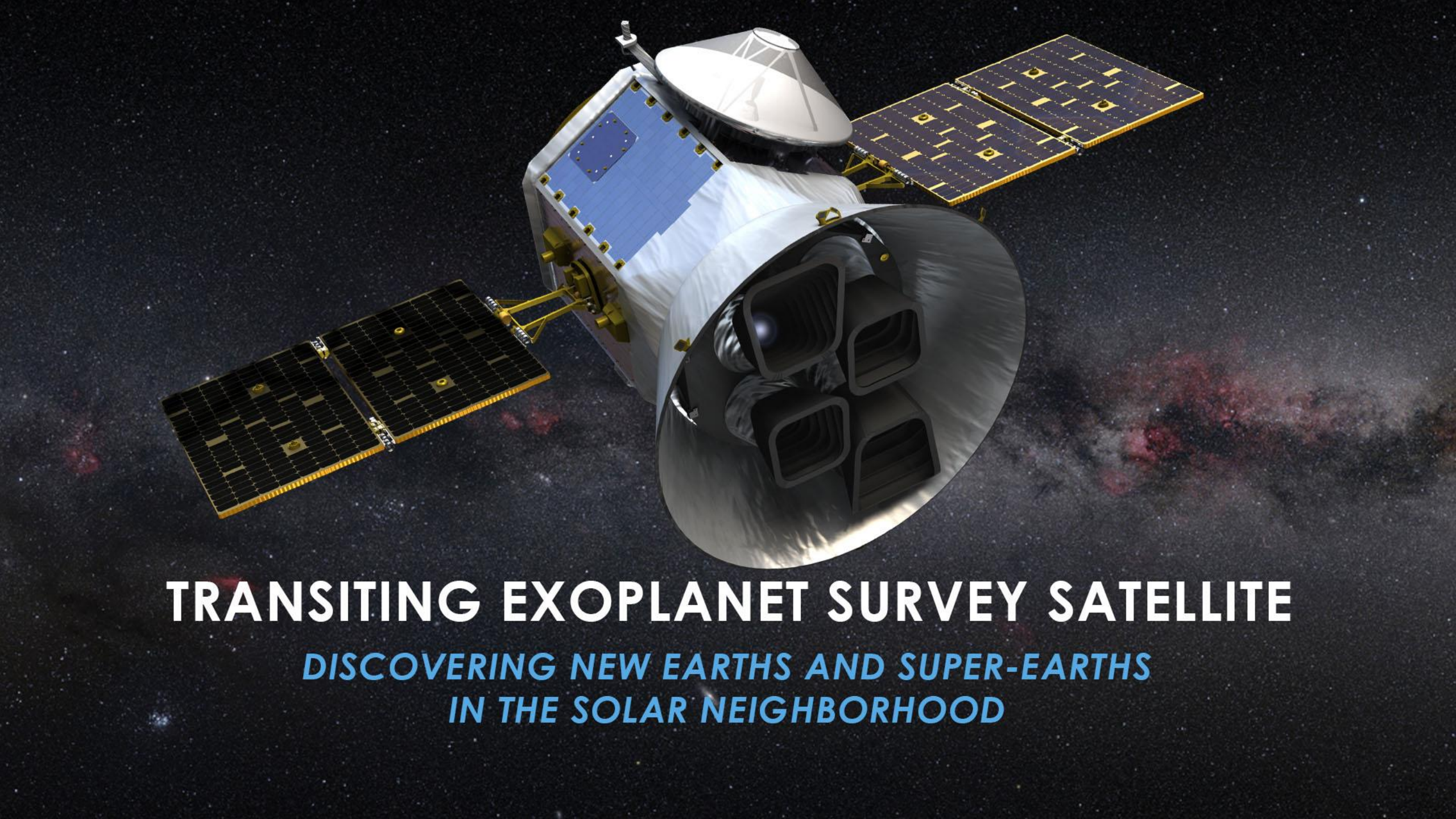
OF ALL PLANETS DISCOVERED

5%

OF THE NIGHT SKY MONITORED FOR EXOPLANETS



NASA AMES


TRANSITING EXOPLANET SURVEY SATELLITE
DISCOVERING NEW EARTHS AND SUPER-EARTHS
IN THE SOLAR NEIGHBORHOOD

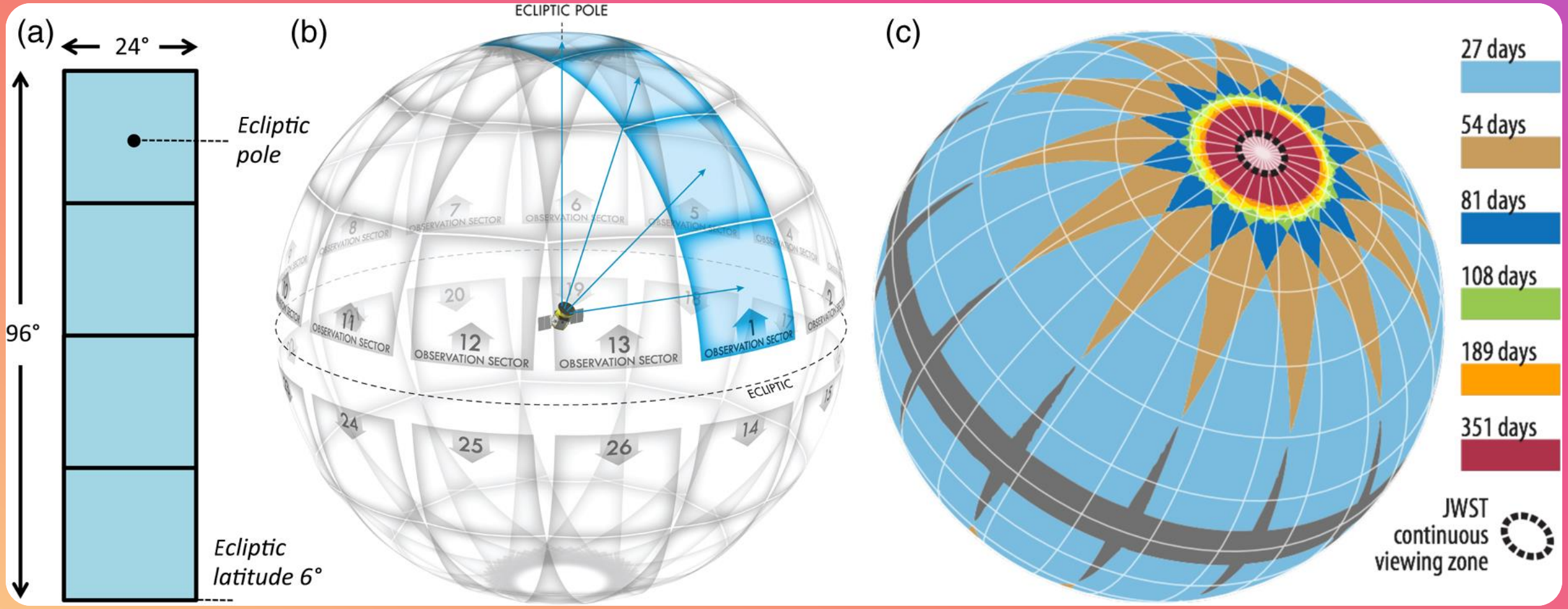
THE TESS MISSION

TWO YEAR MISSION

‘ALL-SKY’ SURVEY

PRE-SELECTED 200k – 400k HIGH PRIORITY STARS

SURVEYING ~85% OF NIGHT SKY



G. RICKER ET. AL, 2016

TESS' PRIMARY OBJECTIVES

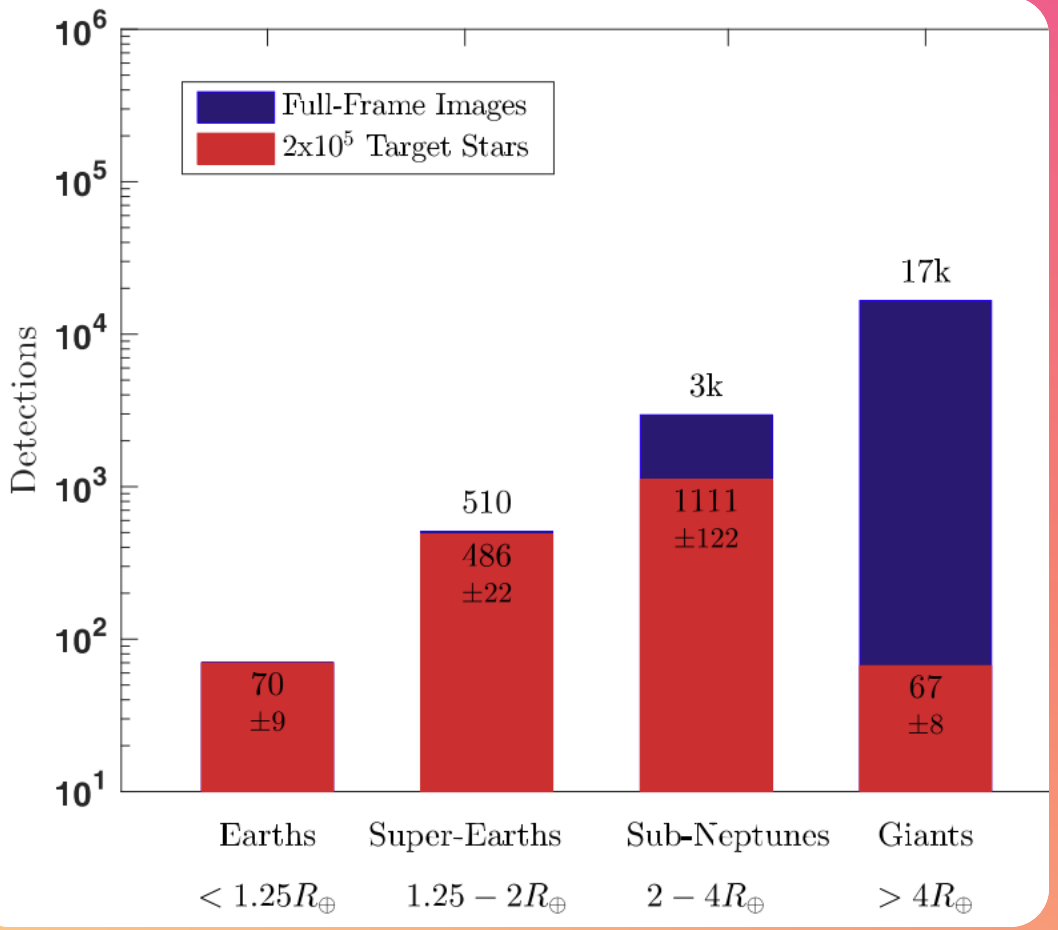
DISCOVER PLANETS ORBITING NEARBY STARS

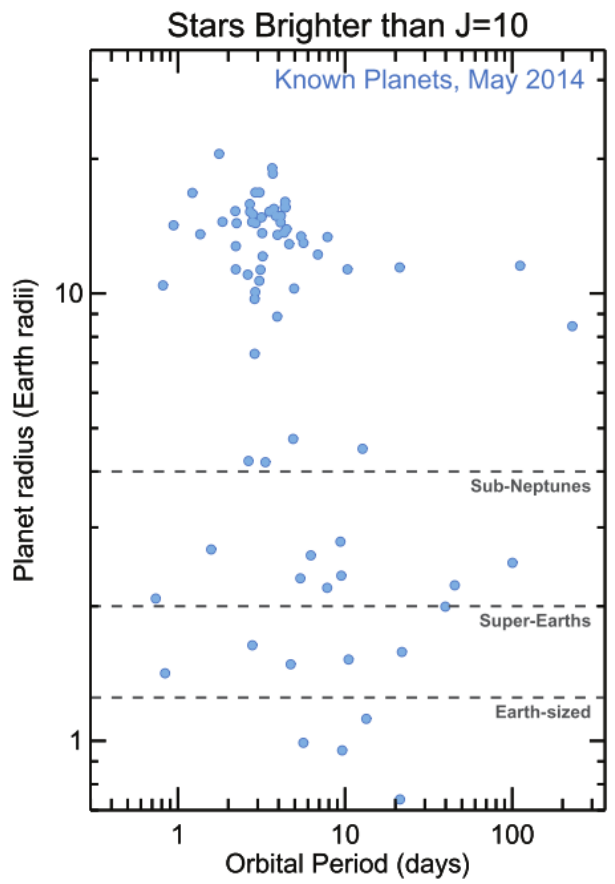
(P < 10, R < 2.5$R_{\oplus}$)

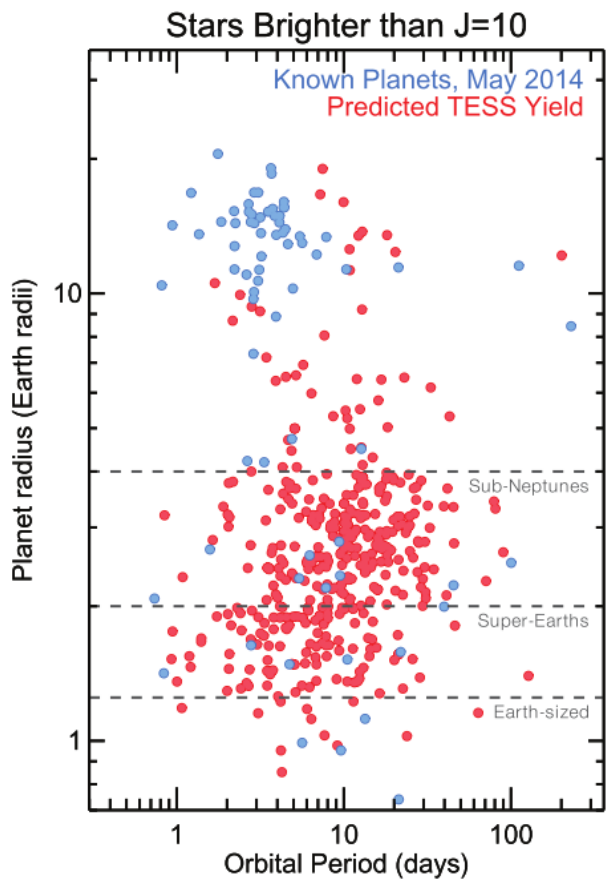
SEARCH FOR PLANETS WITH LONG ORBITS NEAR THE ECLIPTIC POLES

DETERMINE THE MASSES FOR AT LEAST 50 PLANETS SMALLER THAN 4 EARTH RADII

EXPECTED EXOPLANETARY YIELD FROM TESS

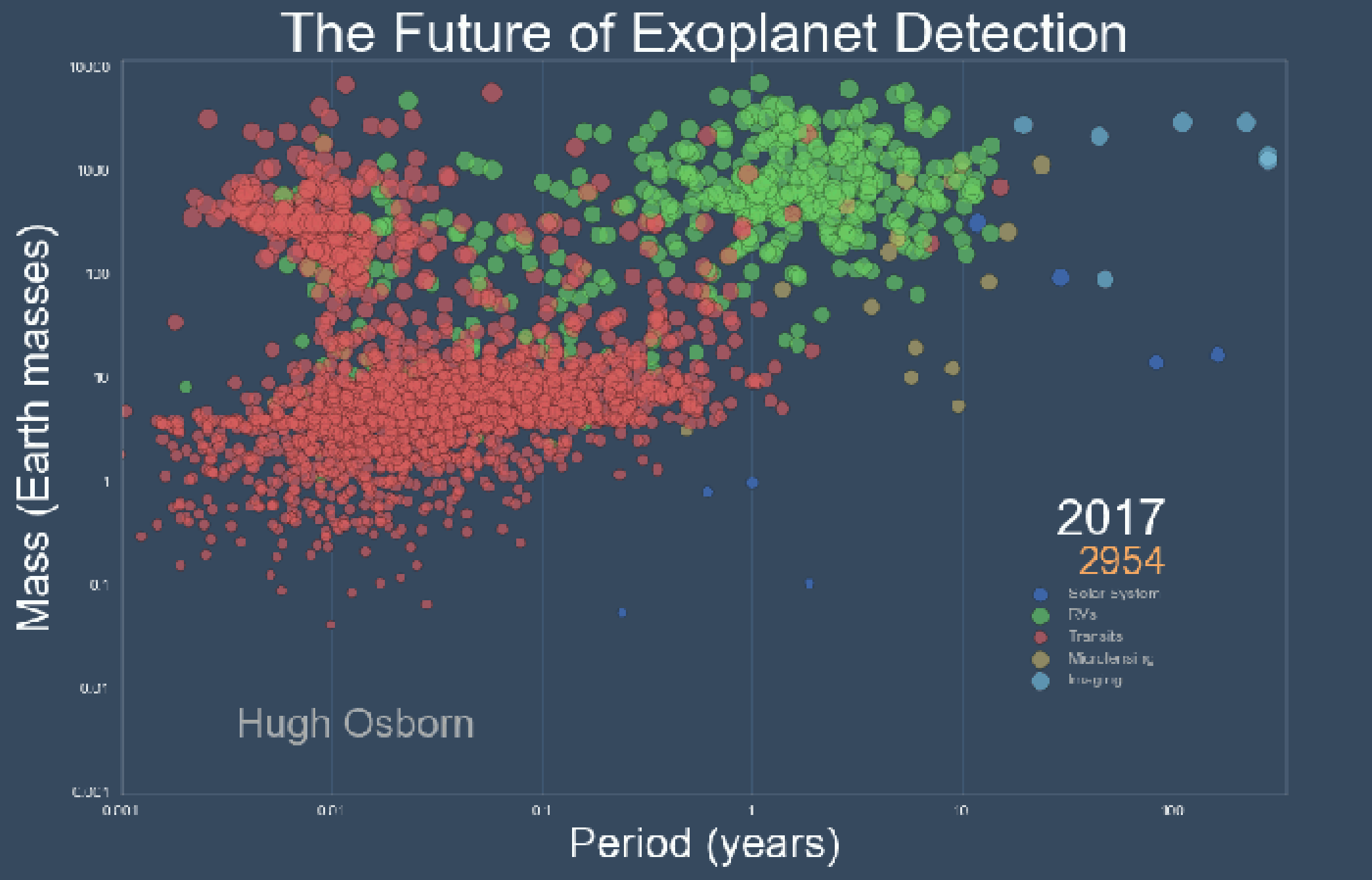






P SULLIVAN ET.AL, 2015

G. RICKER ET. AL, 2016


The Future of Exoplanet Detection
Mass (Earth masses)
Period (years)
2017
2954
Hugh Osborn

TOO MANY PLANETS
NOT ENOUGH TELESCOPES

UNIVERSITY OF SOUTHERN QUEENSLAND

UNIVERSITY OF LOUISVILLE

TEXAS
The University of Texas at Austin

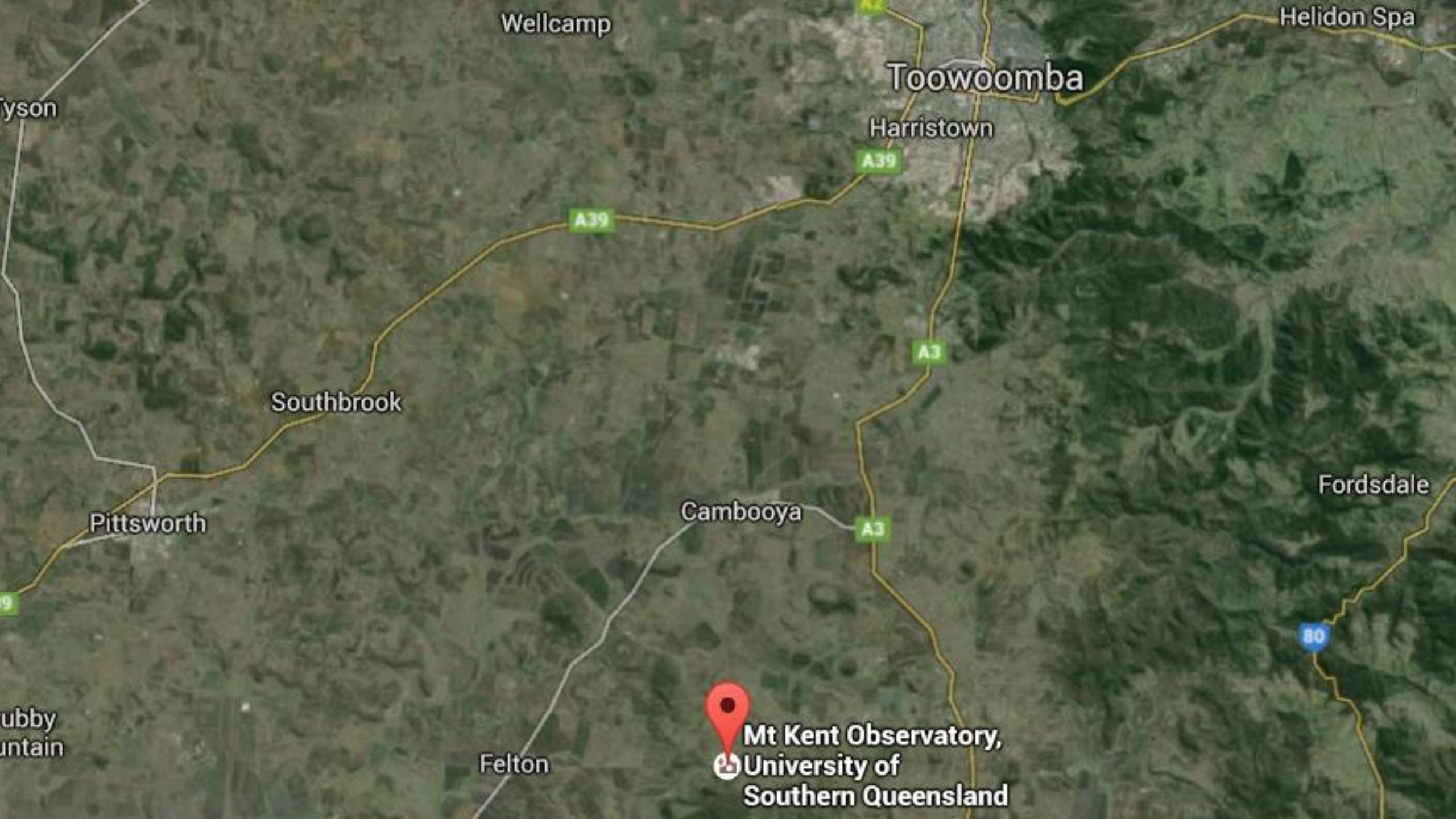
NANJING UNIVERSITY 1902

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

GEORGE MASON UNIVERSITY

MIT


Wellcamp
Helidon Spa
Toowoomba
yson
Harristown
A39
A39
A3
Southbrook
Fordsdale
Pittsworth
Cambooya
A3
80
ubby
untain
Felton
Mt Kent Observatory,
University of
Southern Queensland


PlaneWave
INSTRUMENTS

MINERVA AUSTRALIS

ONLY DEDICATED OBSERVATORY IN THE ENTIRE SOUTHERN HEMISPHERE

5 SEPARATE TELESCOPES (0.7m)

4 DEDICATED TO **DOPPLER SPECTROSCOPY**

THE DOPPLER PROCESS

1

OBSERVE STAR WITH ‘CANDIDATE’

2

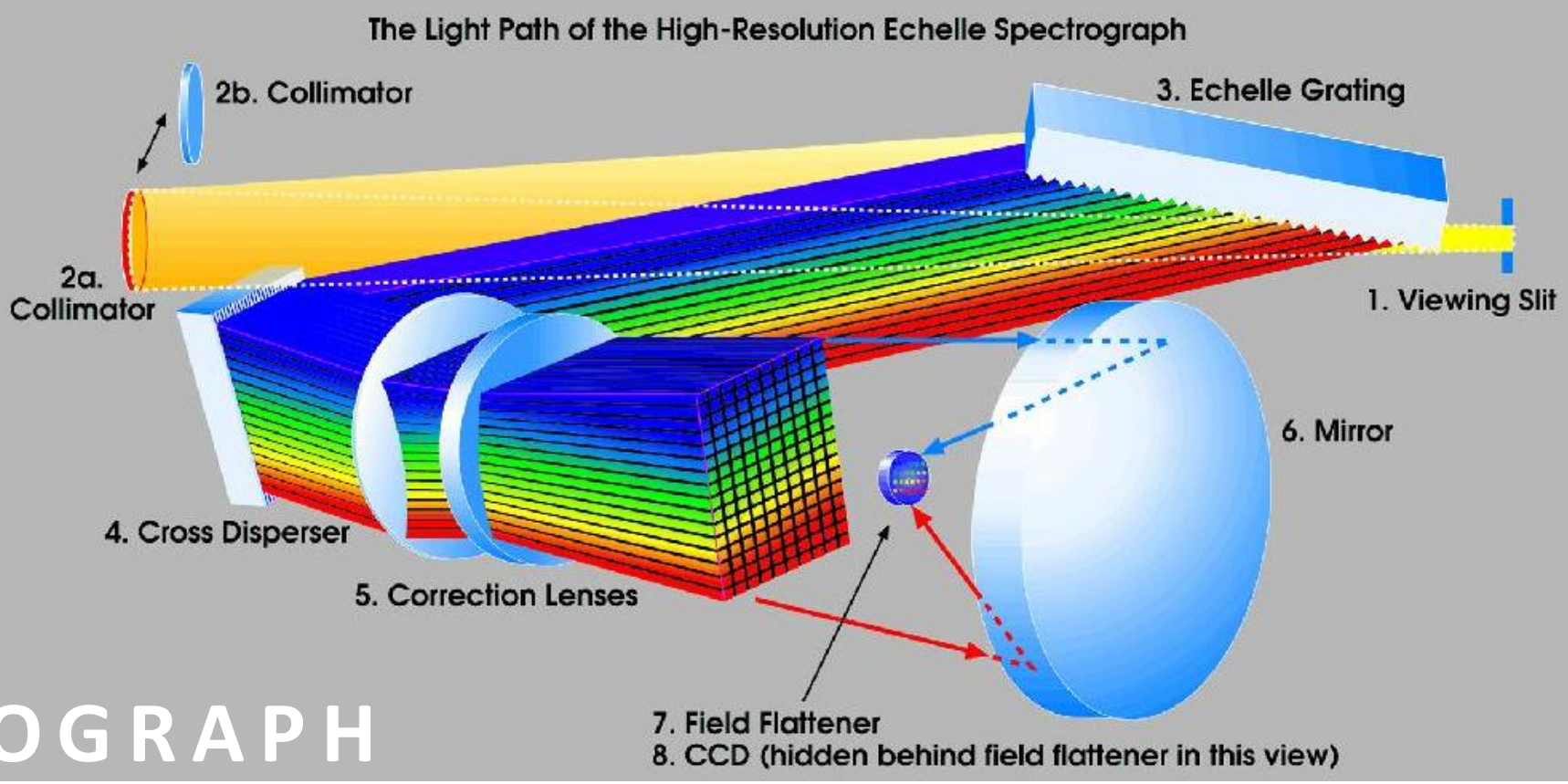
SPLIT LIGHT UP TO LOOK FOR ‘WOBBLE’

3

STATISTICALLY ANALYSE SIGNAL

4

HOORAY, YOU’VE FOUND A PLANET!



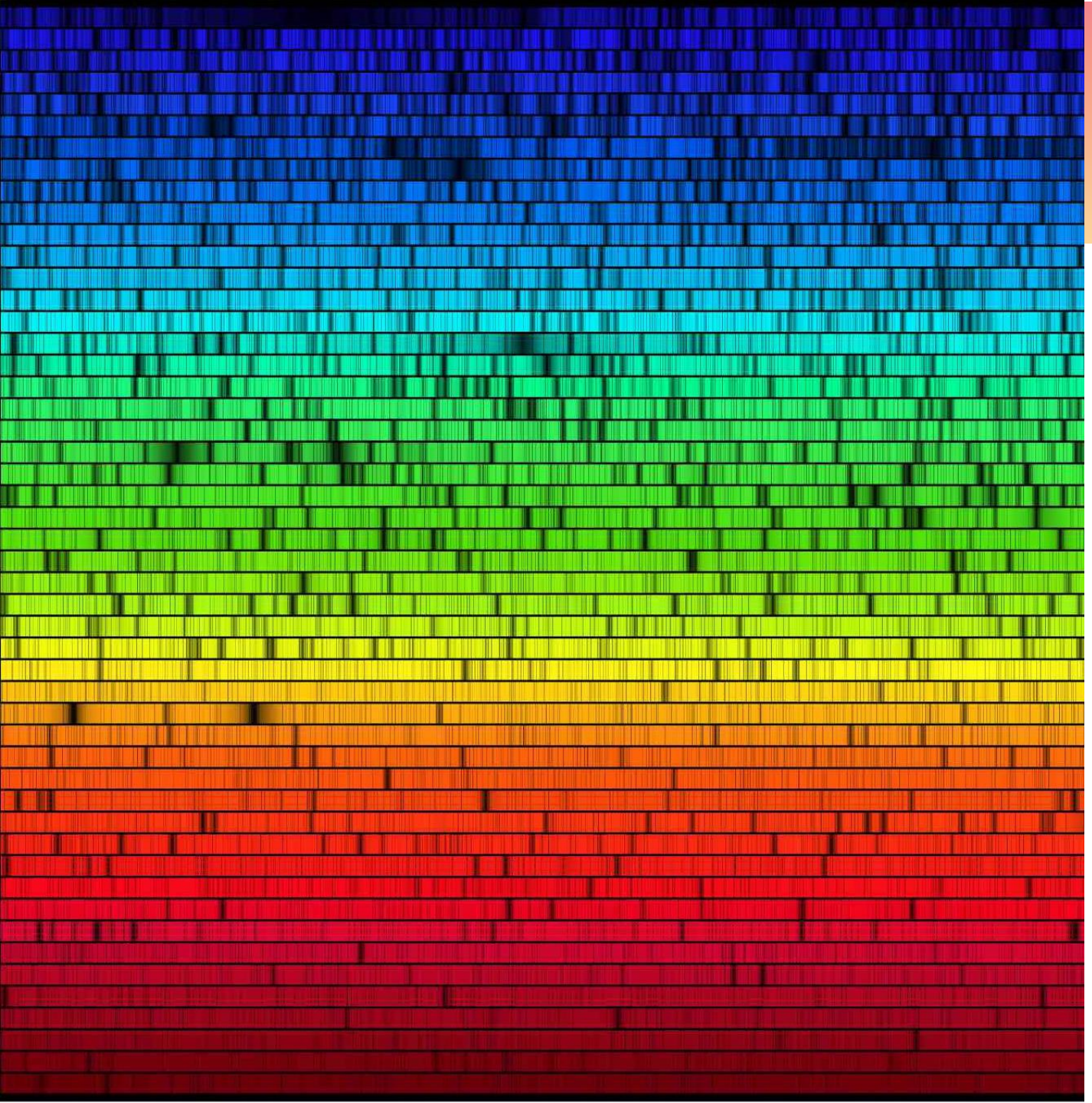
SPECTROGRAPH

Designed to detect 'Super-Earths' within HZ of nearby bright stars

Resolving power of ~ 80,000 with a range from 500 - 630 nm

$$R \approx = \frac{\Delta\lambda}{\lambda}$$

HIRES

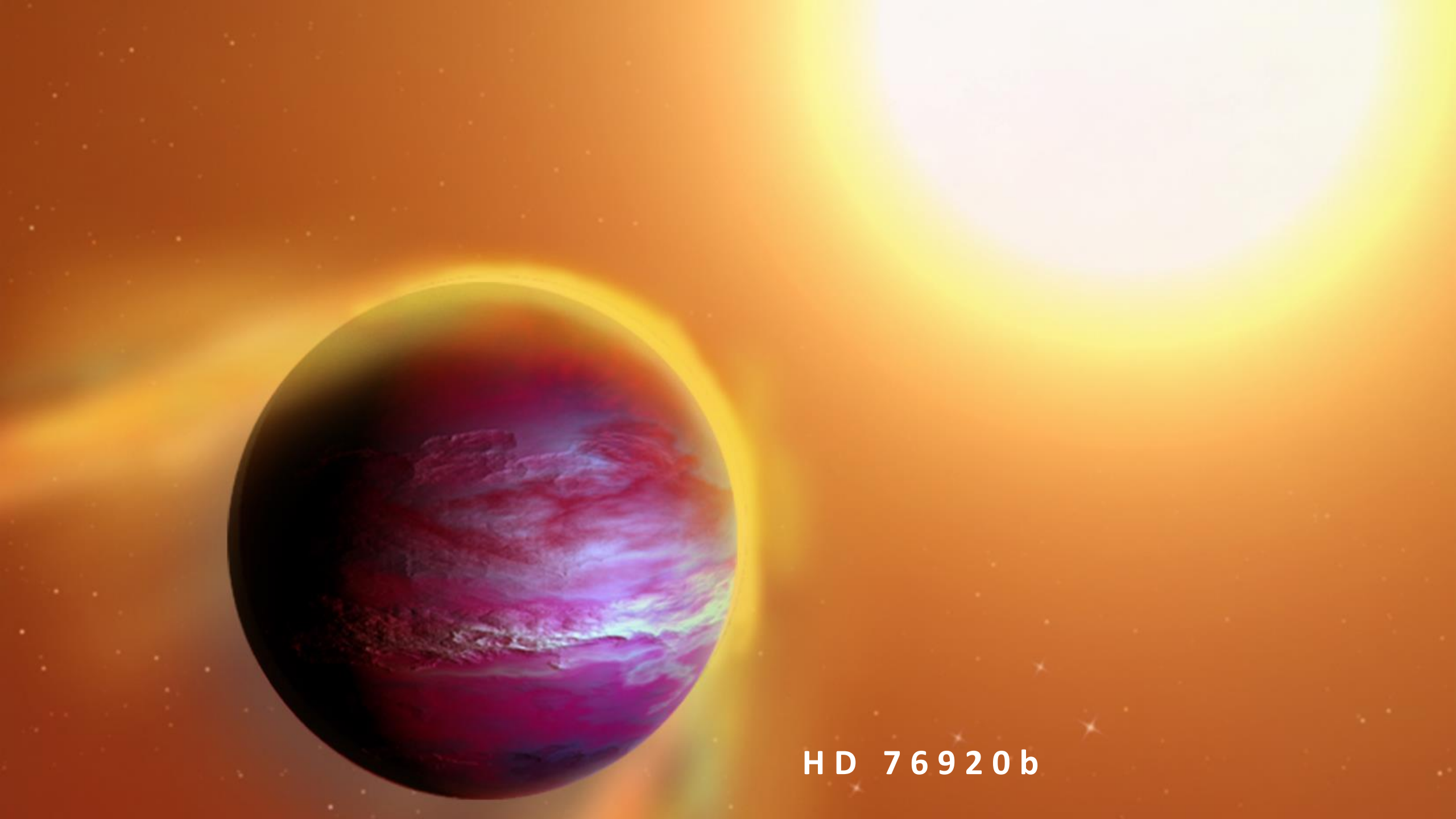


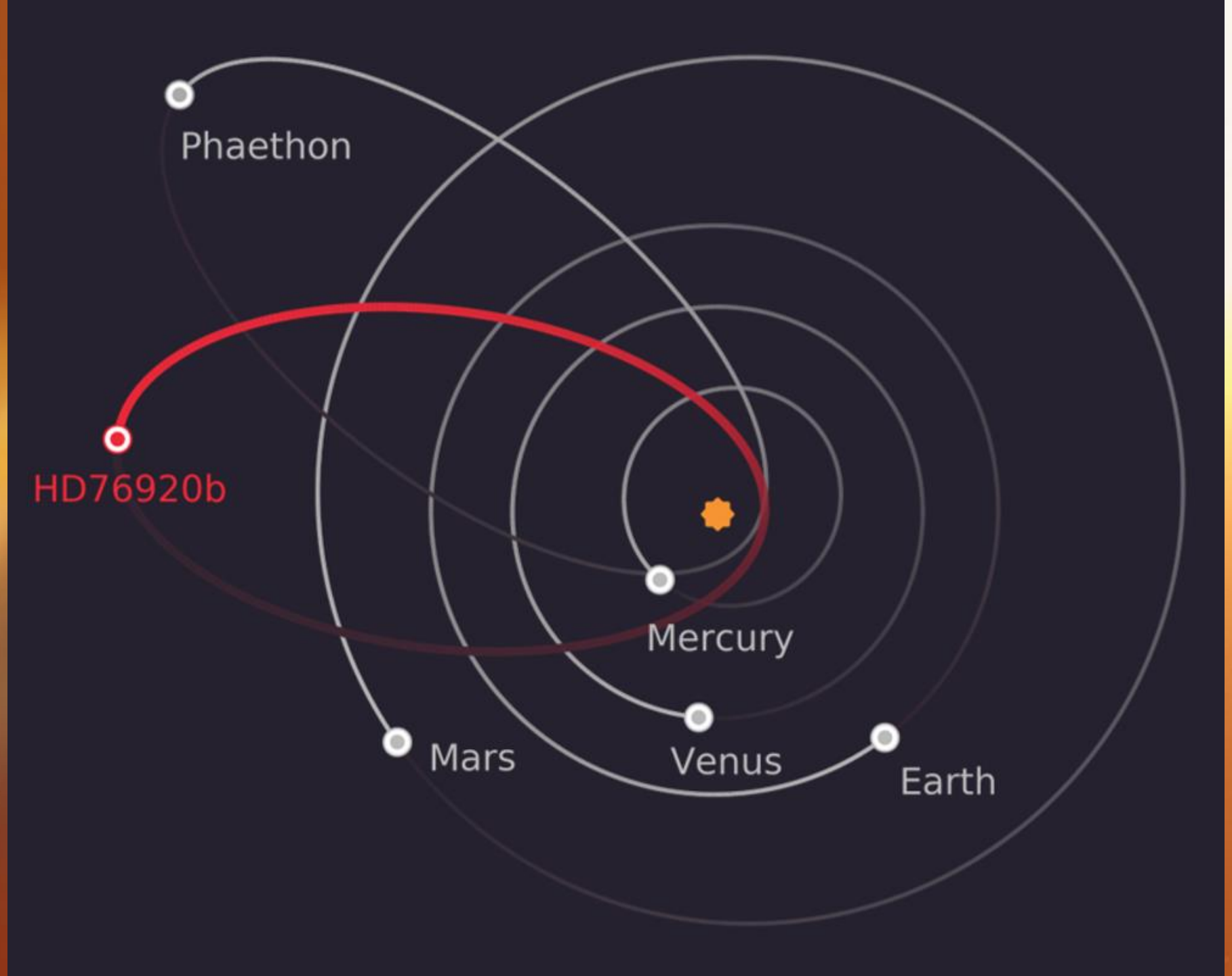
DOPPLER PROCESS

Observed wavelength changes from rest wavelength

Using the Doppler equation, relate wavelength to velocity

$$v = \frac{c\Delta\lambda}{\lambda}$$


HD 76920b


Phaethon
HD76920b
Mercury
Mars
Venus
Earth

DOPPLER PROCESS

From Kepler's laws radial velocity v,

$$v = K\,[cos(\omega + \nu) + ecos\omega]$$

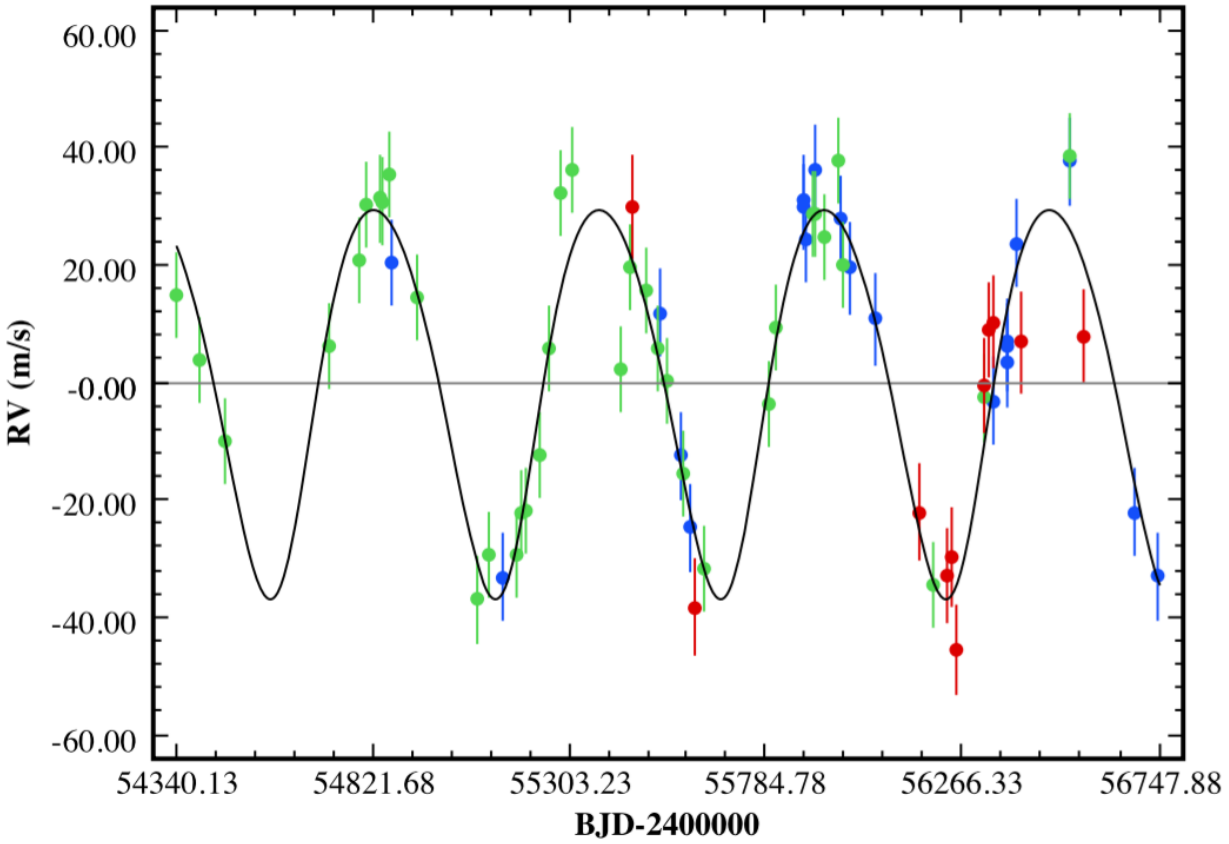
Semi-Amplitude K is related to the planet mass M_p by:

$$K = \left(\frac{2\pi G}{P}\right)^{-\frac{1}{3}} \frac{M_p sini}{(M_\star + M_p)^{\frac{2}{3}}} \frac{1}{\sqrt{1-e^2}}$$

$$\frac{M_p sini}{M_\oplus} = \frac{\sqrt{1-e^2}}{0.0895 * K}\left(\frac{M_\star}{M_\odot}\right)^{\frac{2}{3}}\left(\frac{P}{yr}\right)^{\frac{1}{3}}$$

HD 33844b

P = 551 days , e = 0.15, w = 211, K = 33.5 m/s, msini = 1.96 MJ



WITTENMYER et al

THE DOPPLER PROCESS

1

OBSERVE STAR WITH ‘CANDIDATE’

2

SPLIT LIGHT UP TO LOOK FOR ‘WOBBLE’

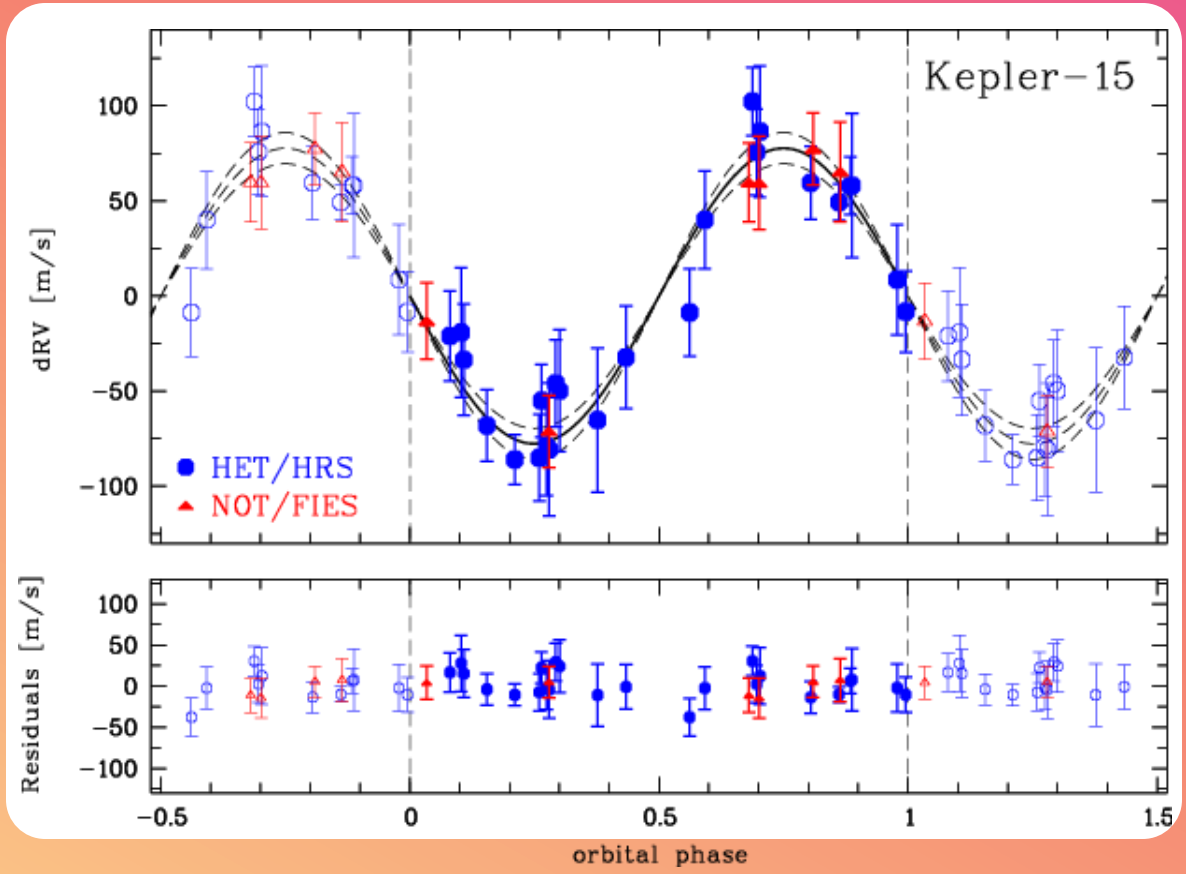
3

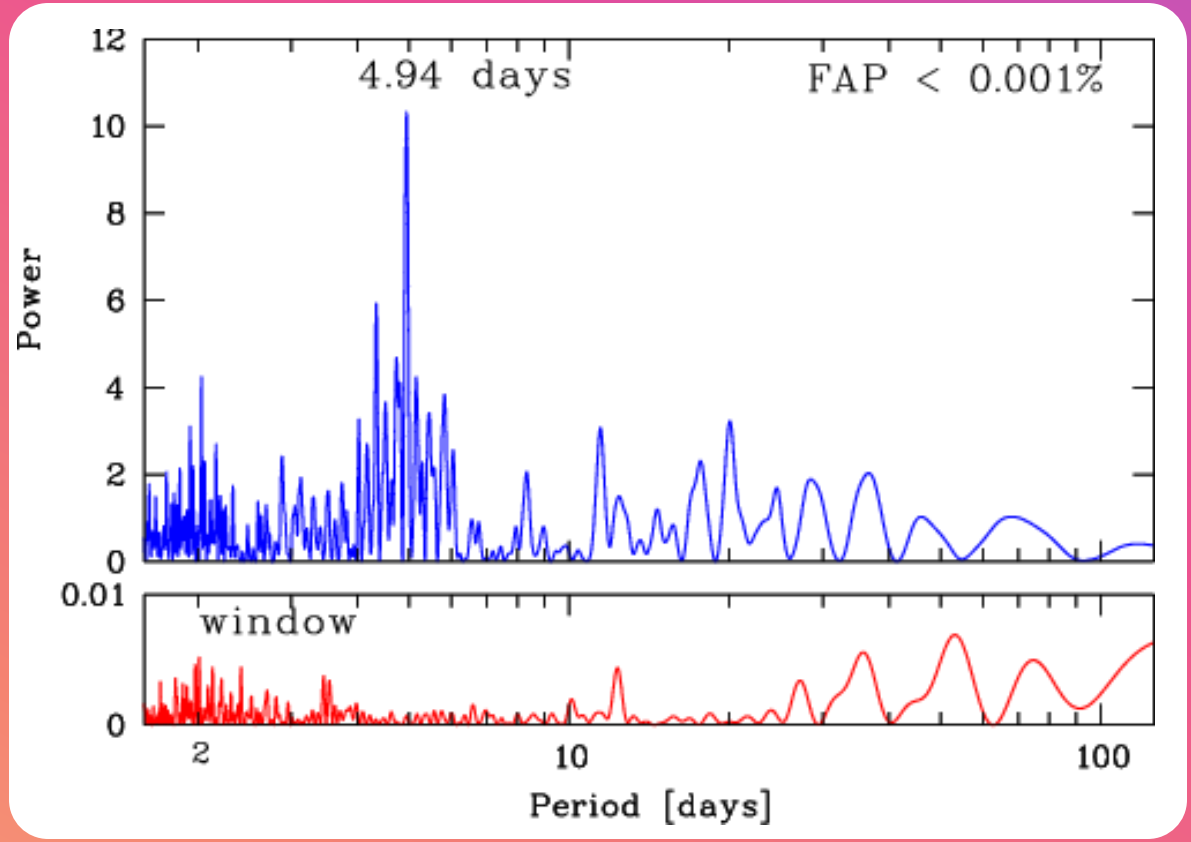
STATISTICALLY ANALYSE SIGNAL

4

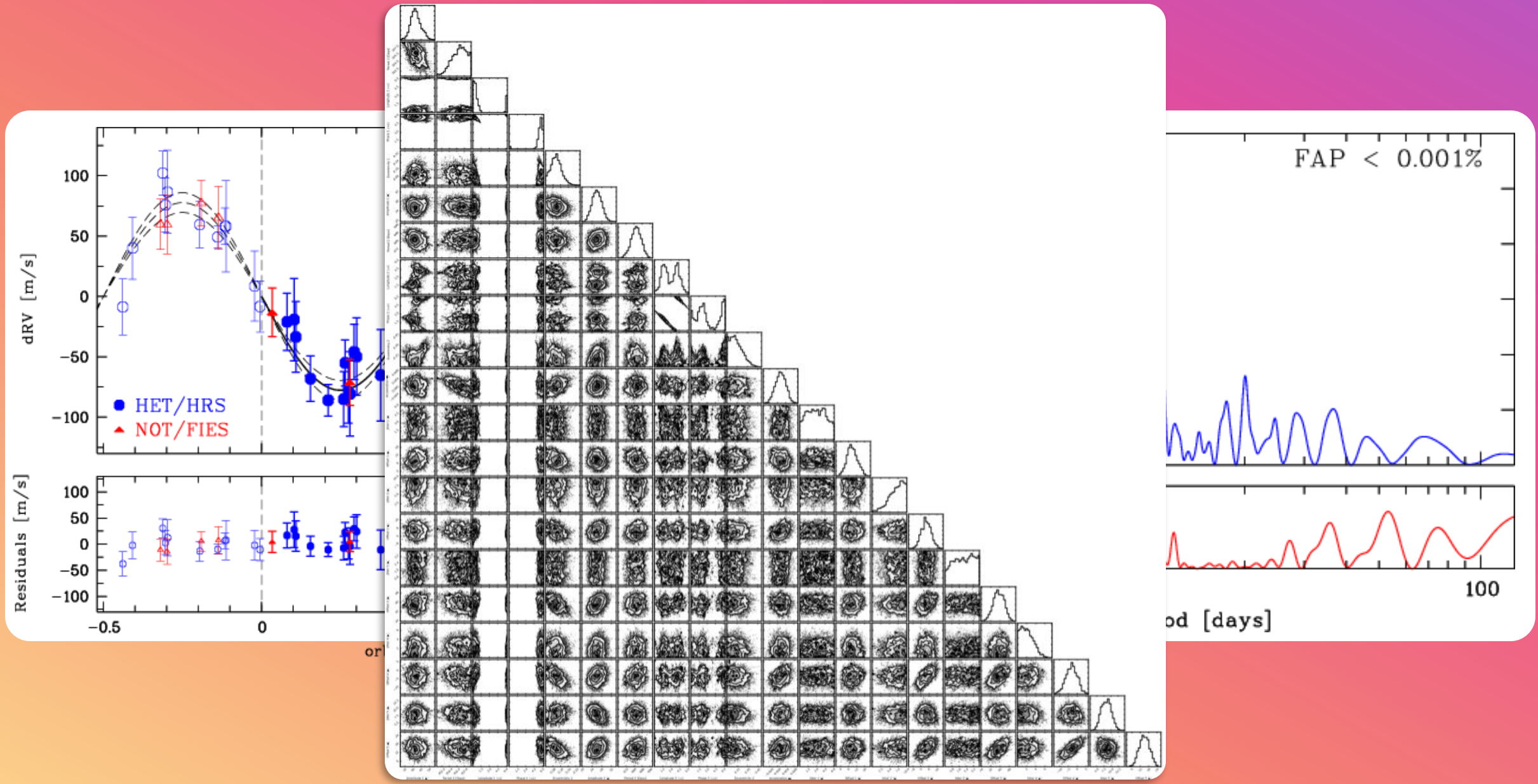
HOORAY, YOU’VE FOUND A PLANET!

PLANET DETECTION RECIPE FROM RV

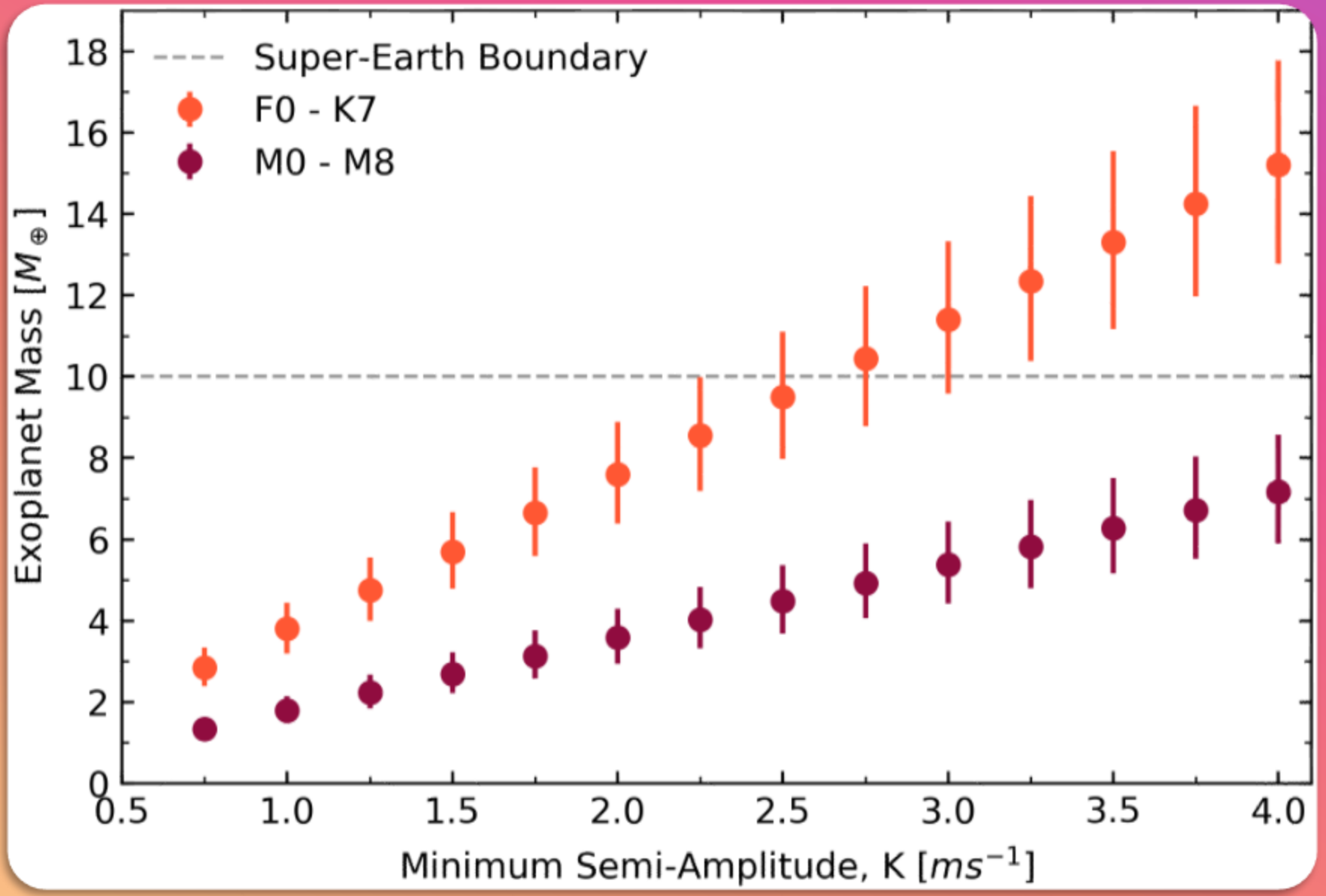


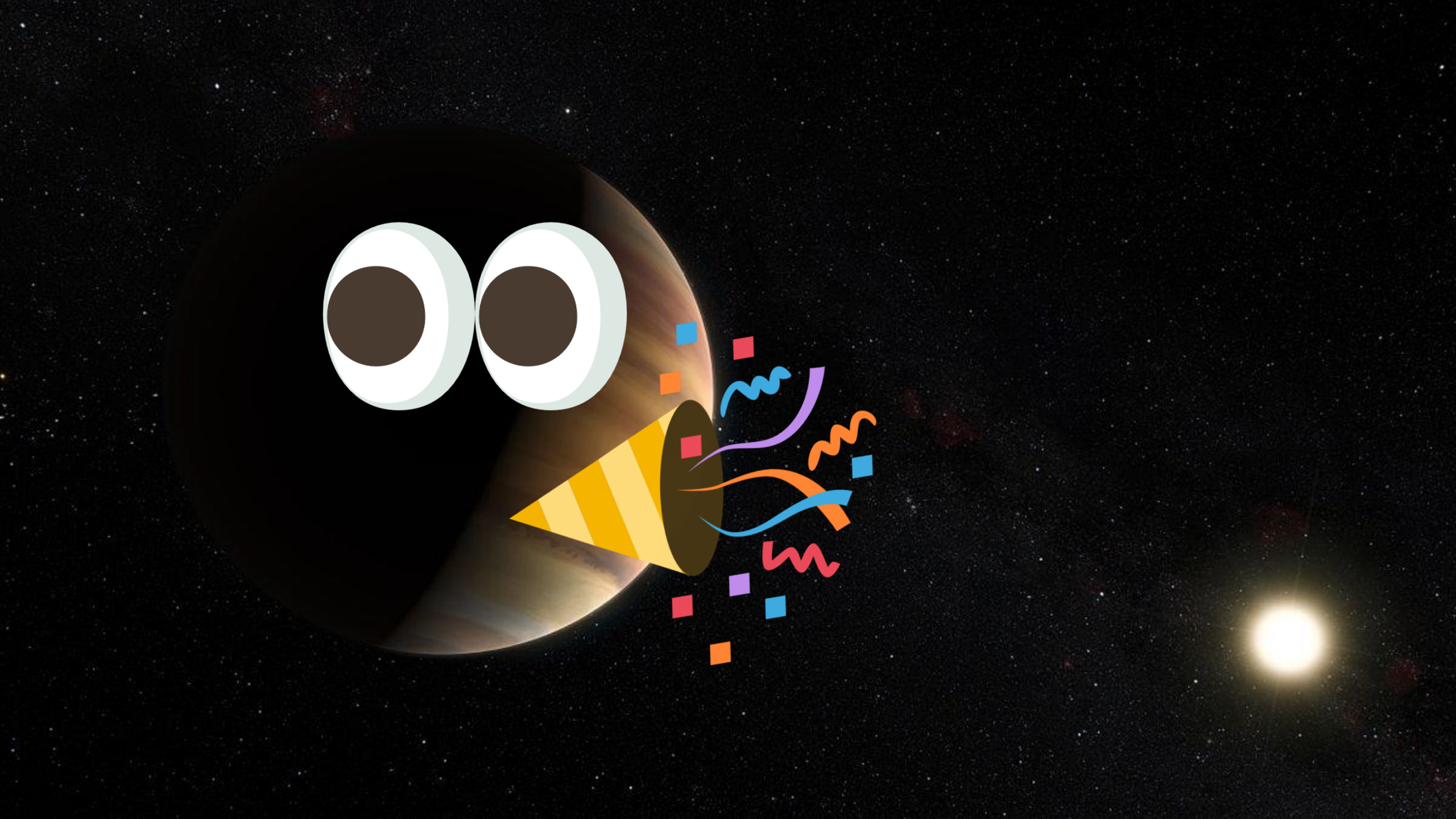


PLANET DETECTION RECIPE FROM RV

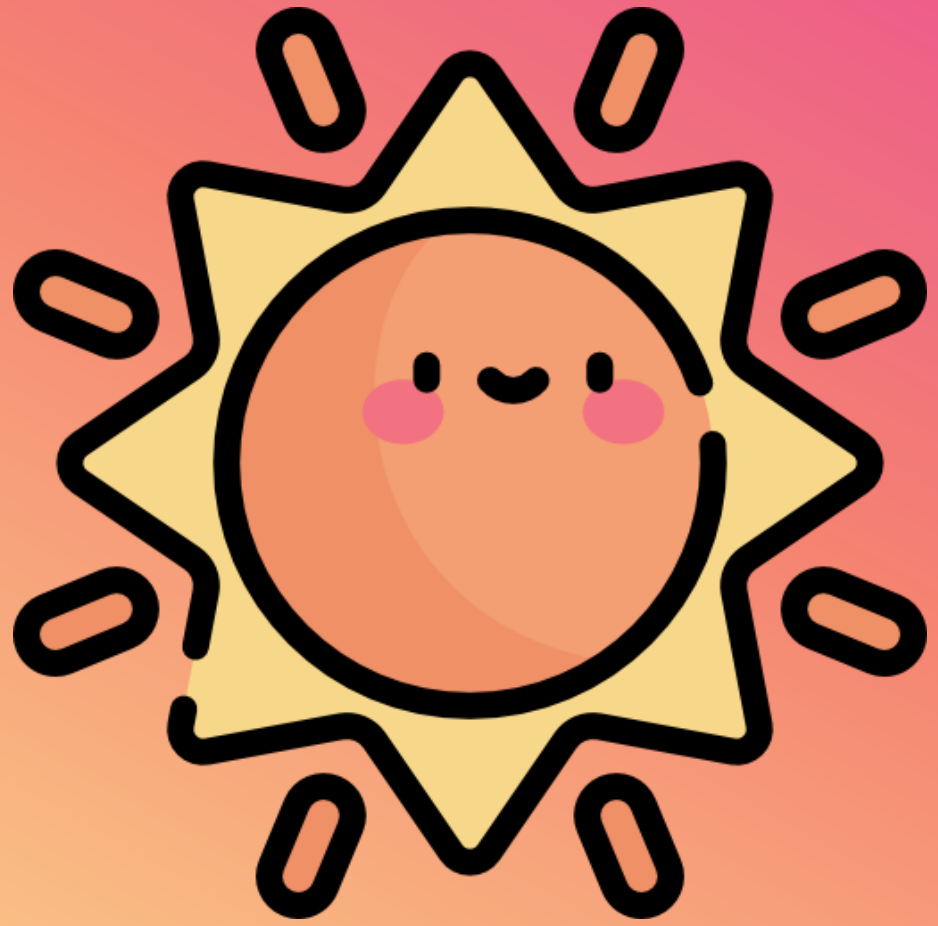


MINERVA-AUSTRALIS





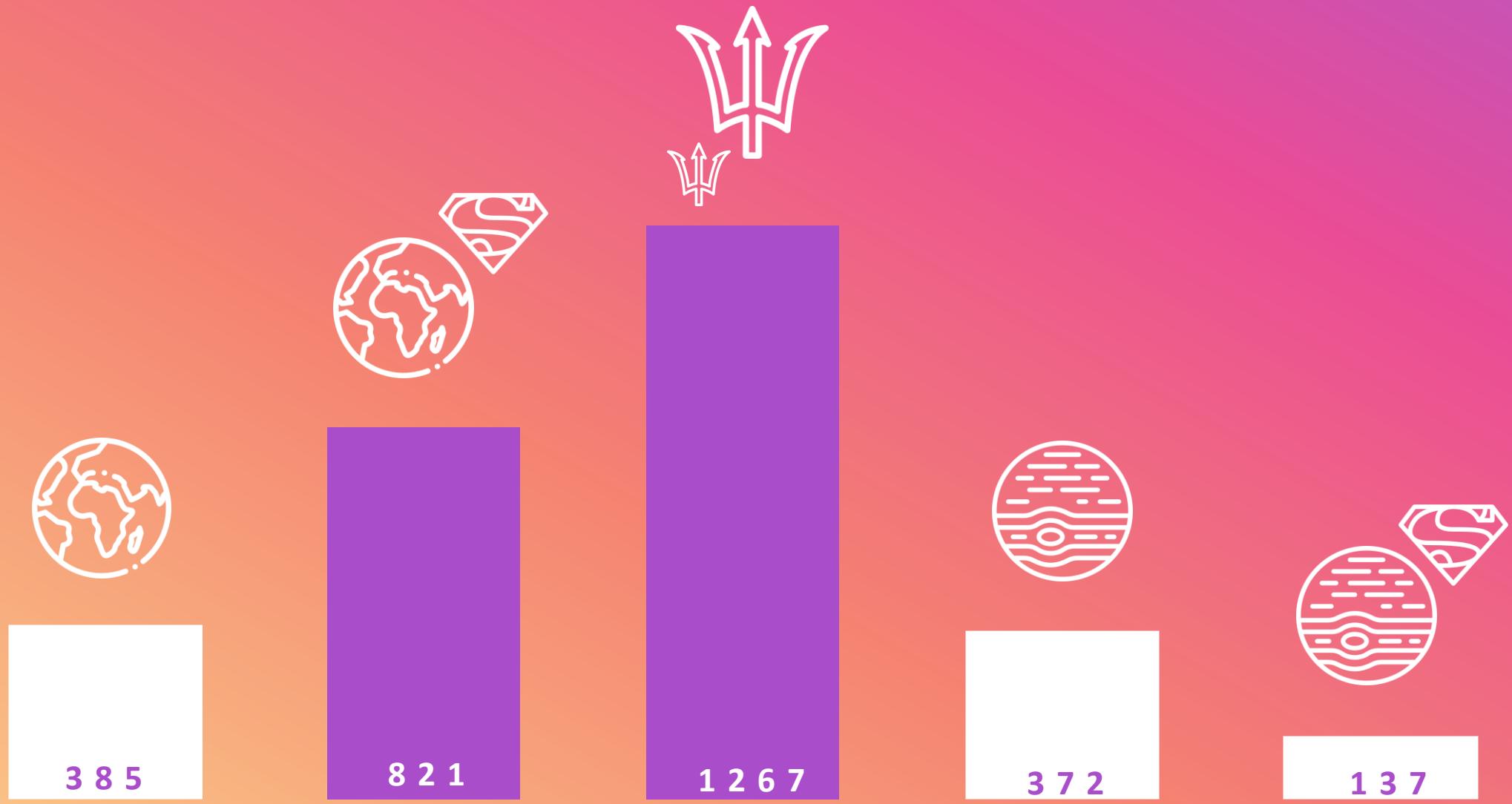
IS IT A PLANET THOUGH?



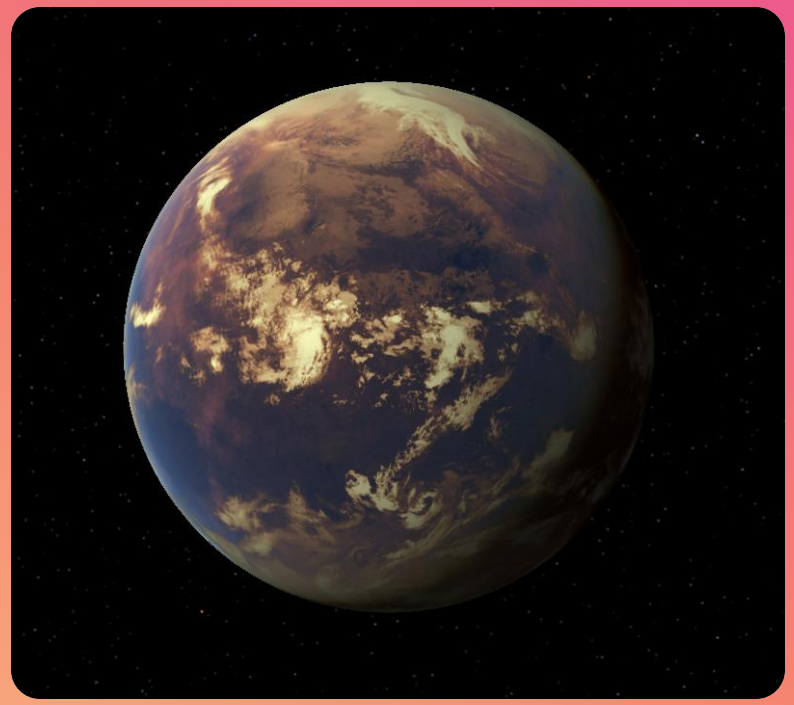
- Stellar Rotation
- Spots, Faculae and Plage Regions
- Asteroseismology
- Still unknown how to fully and reliably model all activity-induced RV variations

FROM DETECTION TO CATEGORISATION…

CURRENT EXOPLANET STATS

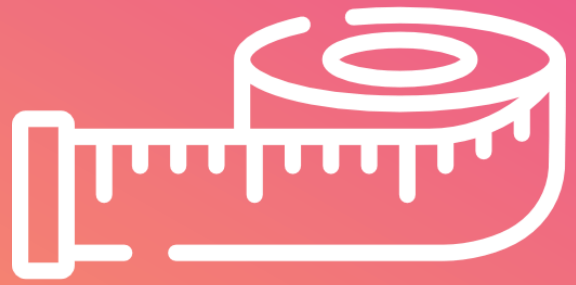


WHAT'S A 'SUPER-EARTH' or 'SUB-NEPTUNE'



- Mass: 1.25 – 10 Earth masses
- Radius: 1 – 1.6 Earth radii
- 'Terrestrial'
- Vague general term

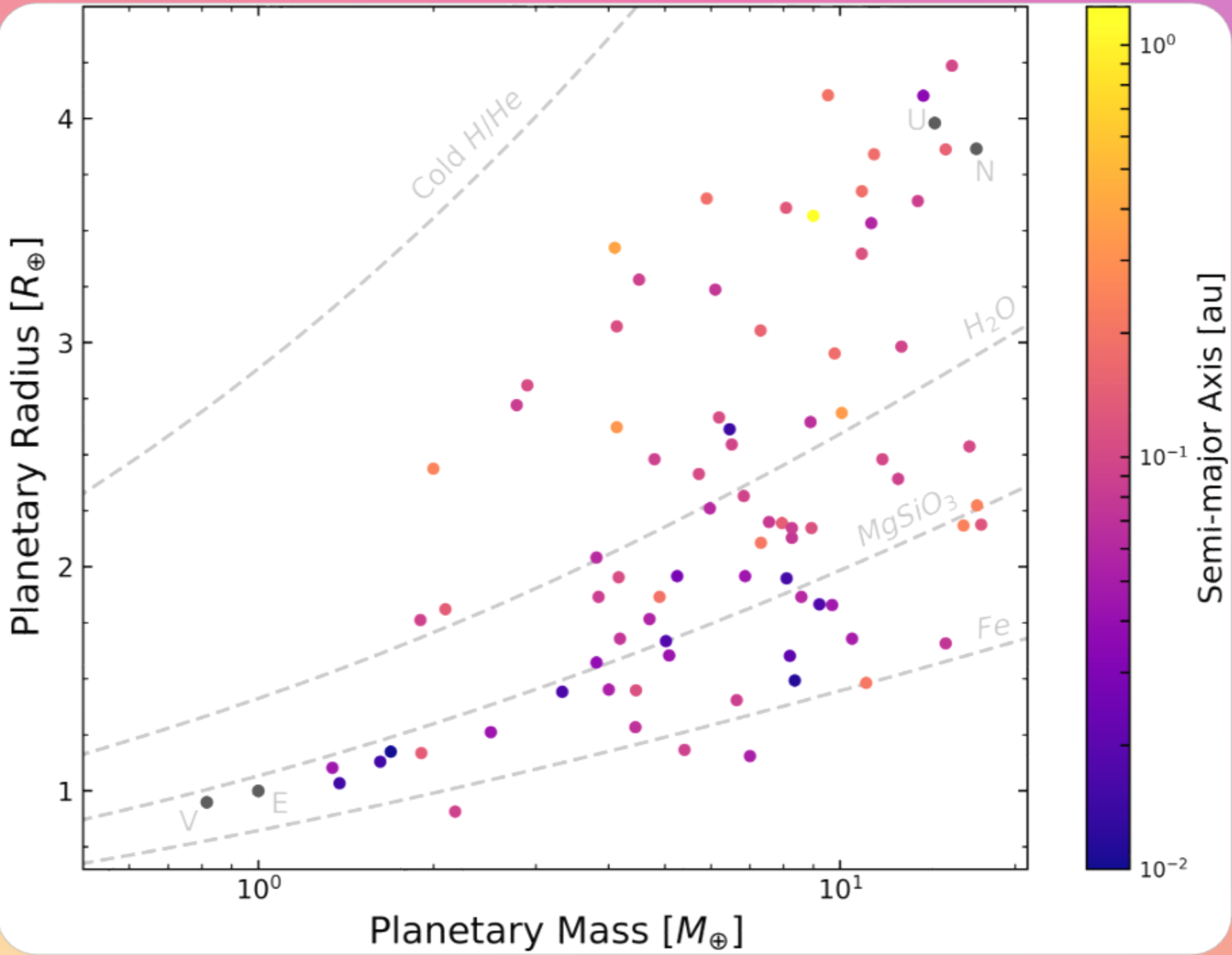
- Class of 'Super-Earth'
- Radius range 1.6 – 4 Earth radii
- 'Ice World'
- Lack of compositional data



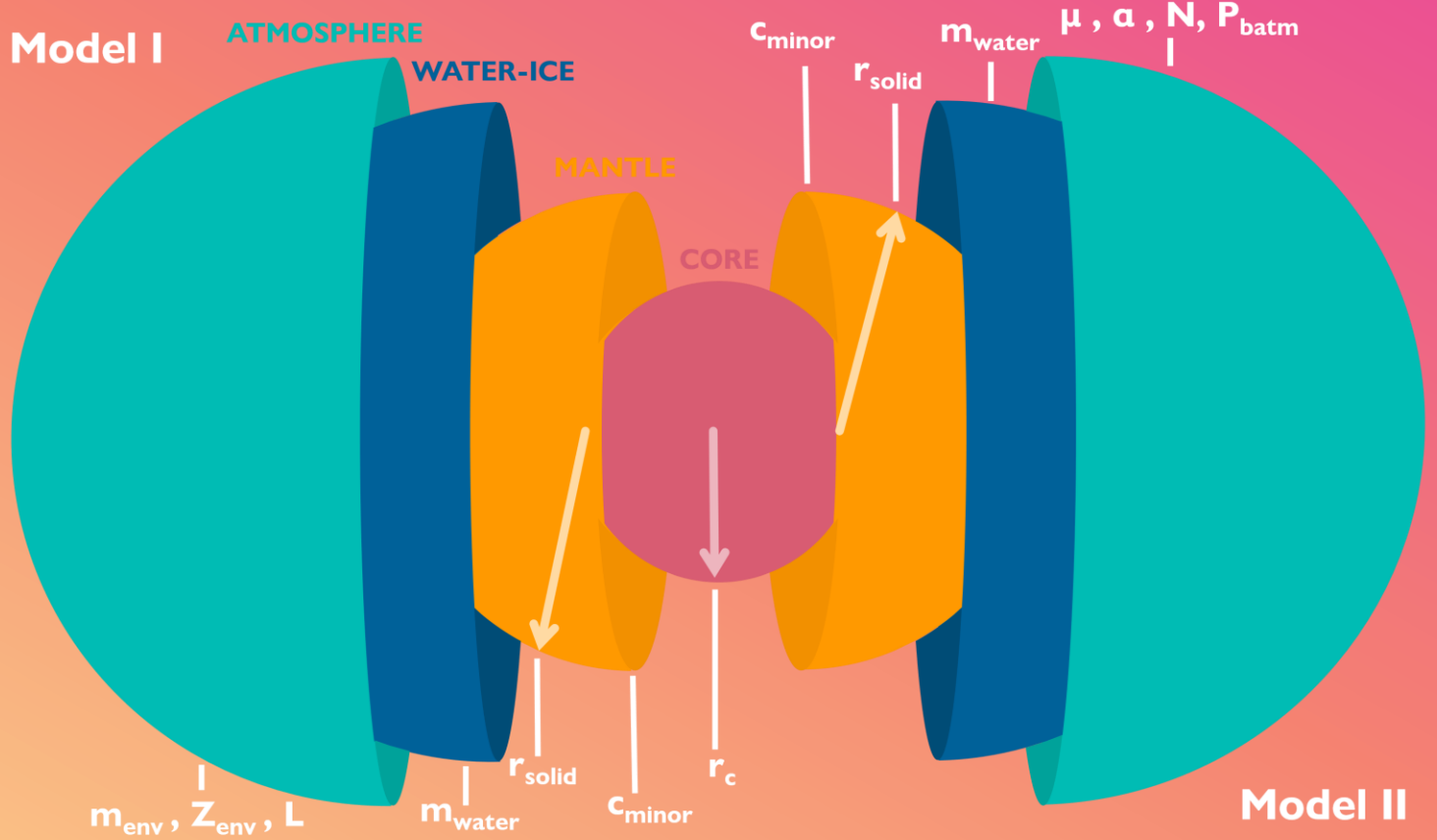
TRANSIT = SIZE

DOPPLER = MASS

THESE MEASUREMENETS ALONE CAN TELL US A LOT ABOUT A PLANET…


Planetary Radius [$R_\oplus$]
Planetary Mass [$M_\oplus$]
Semi-major Axis [au]
Cold H/He
H_2O
$MgSiO_3$
Fe
U
N
V
E
1
2
3
4
10^0
10^1
10^0
10^{-1}
10^{-2}

DORN'S BAYESIAN MODEL



PRIORS

Planetary mass and radius

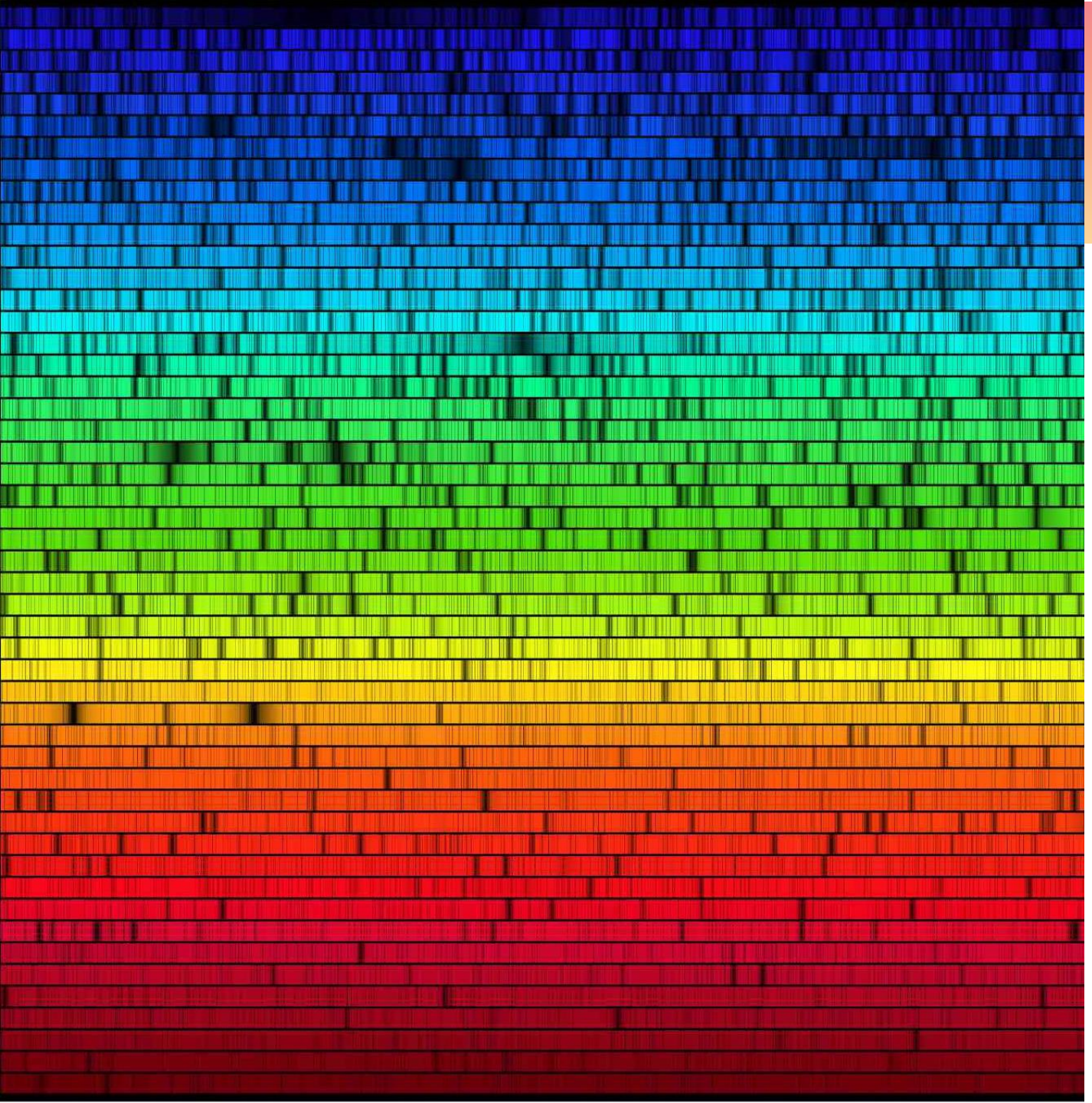
Stellar abundances of iron, silicon and magnesium

Stellar radius and effective temperature

Semi-major axis

Minor composition of mantle

+ assumptions



STELLAR ABUNDANCES

Each atom has a unique barcode known as absorption lines

Strength of lines is proportional to elemental abundance

Can start to create a stellar ingredient list

Stars with high [Fe/H] are known to host larger planets

STELLAR-PLANET CONNECTION

Elemental abundance ratio of Mg/Si and Fe/Si are similar for both star and planet

Fe/Si controls core to mantle ratio

Mg/Si controls what silicates will dominate in mantle

RICARDO RAMIREZ

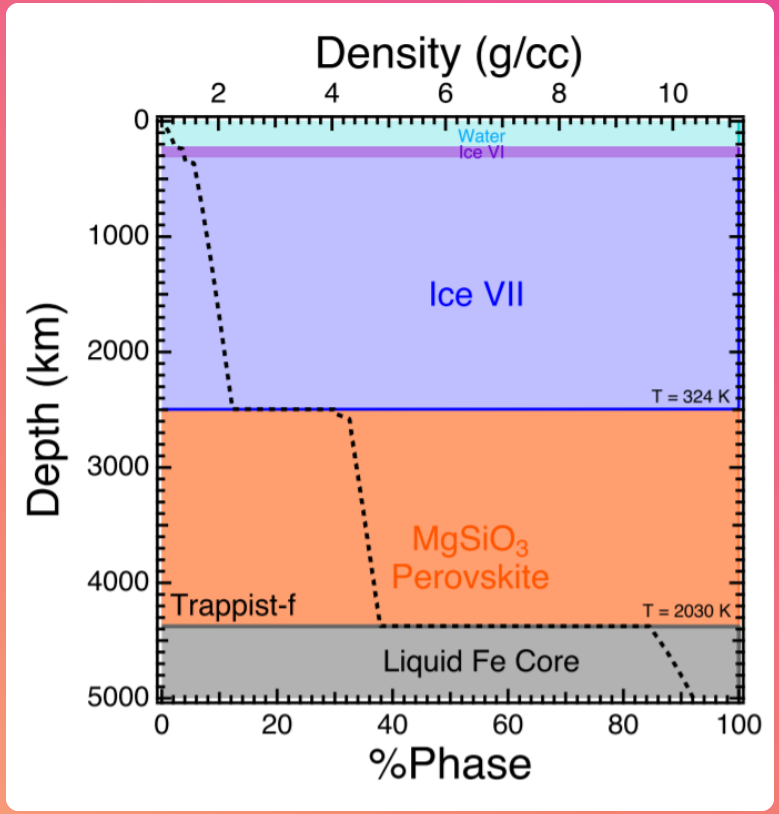
High resolution spectrograph survey determining the abundances for 300,000+ southern stars

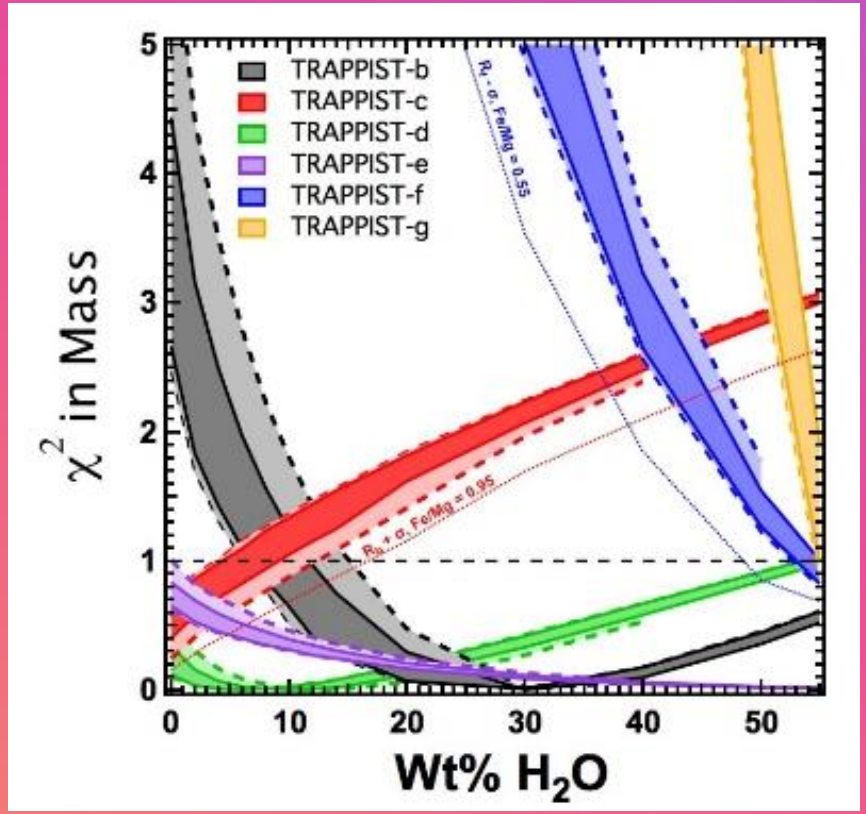
Overlap with TESS high priority stars

Exoplanetary community to utilise data in categorising newly found worlds

GALACTIC ARCHAEOLOGY SURVEY

SHUTTERSTOCK
ANDREA IZZOTTI





UNTERBORN 18

NOW LEARNING ABOUT THE PLANETARY MAKEUP AND HABITABILITY LIKE NEVER BEFORE

Exoplanets:
Probing alien ... worlds

Jake Clark

PhD Candidate & Science Communicator
University of Southern Queensland

@spacejayk

jake.clark@usq.edu.au