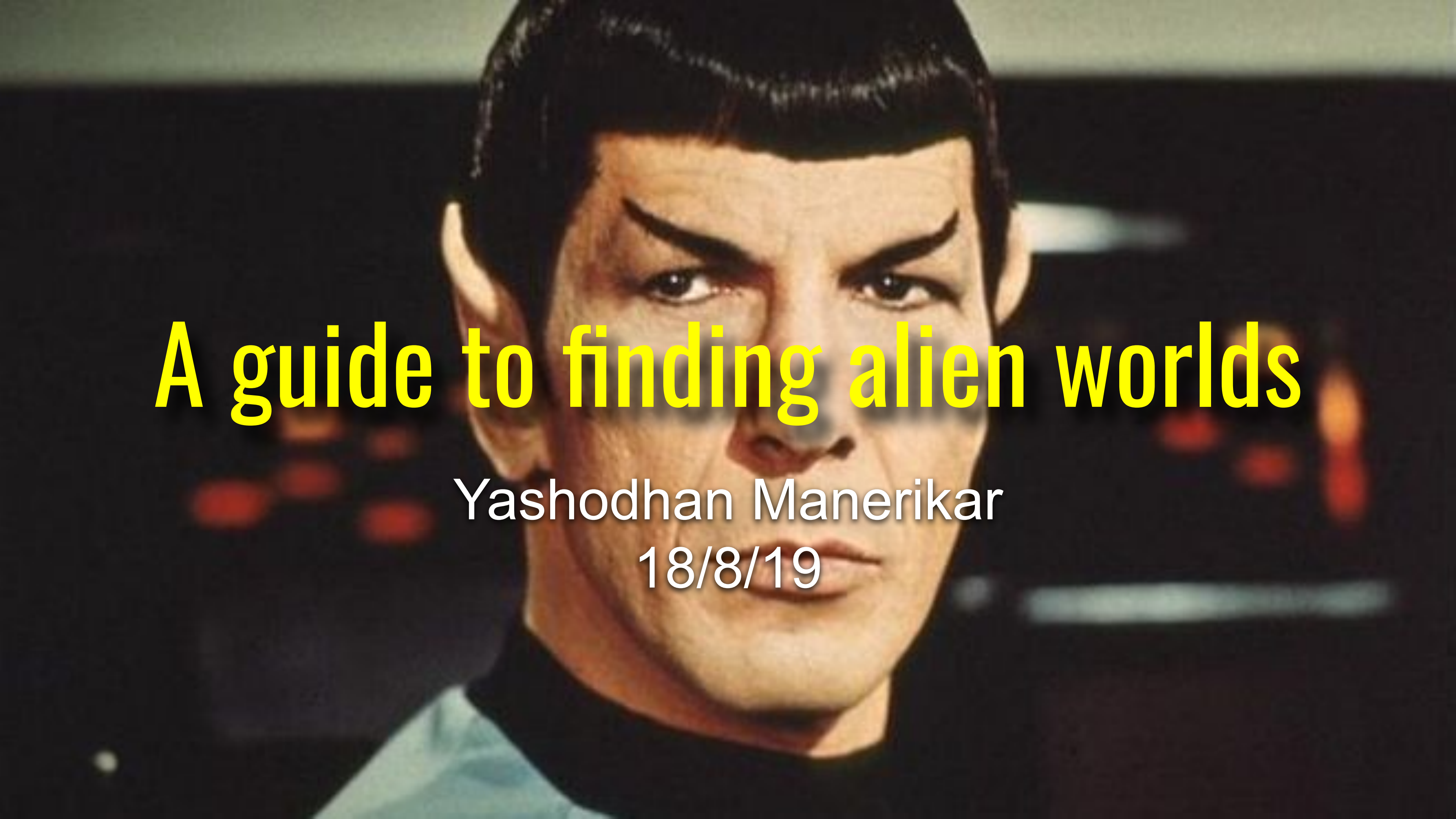
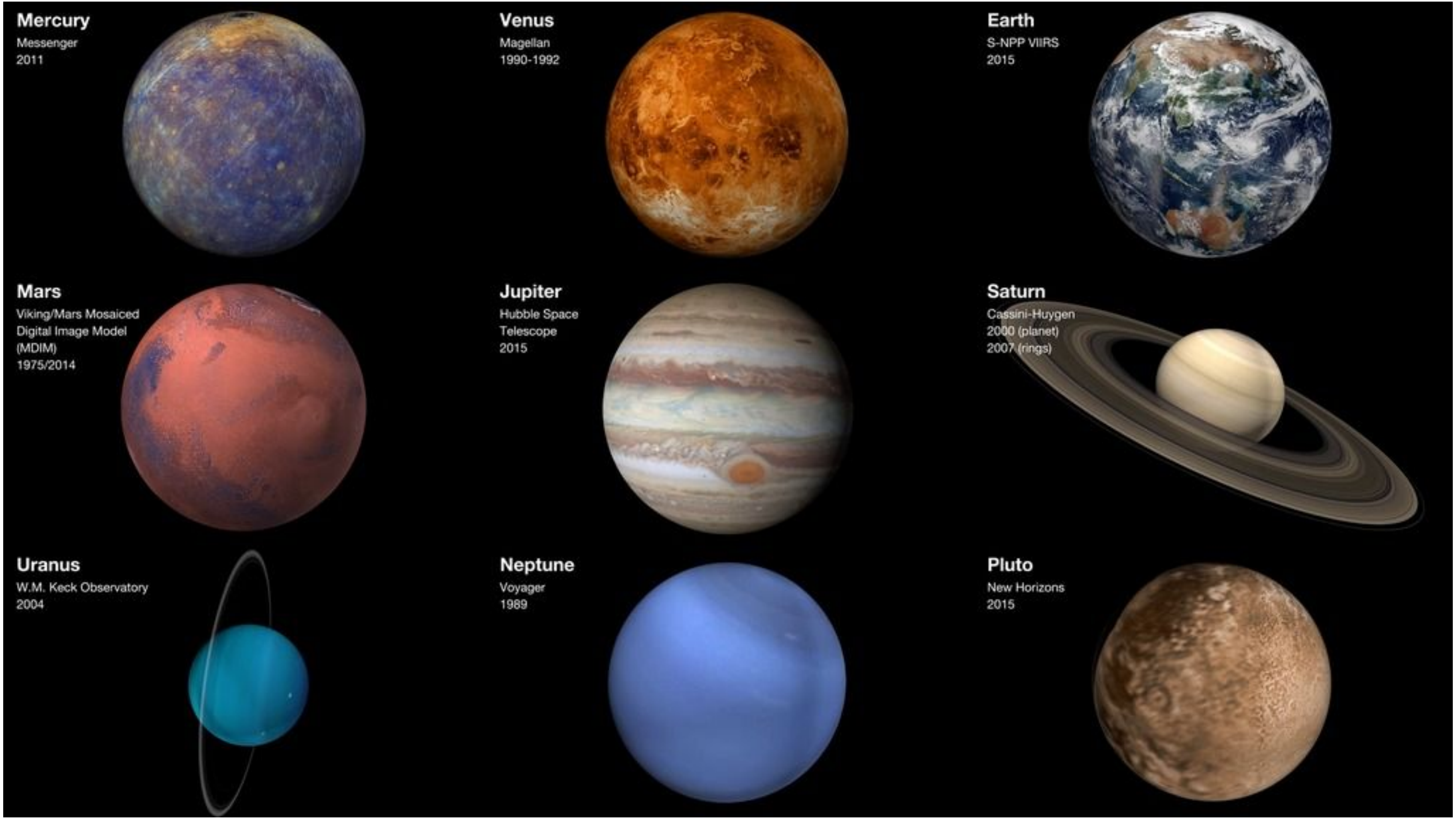


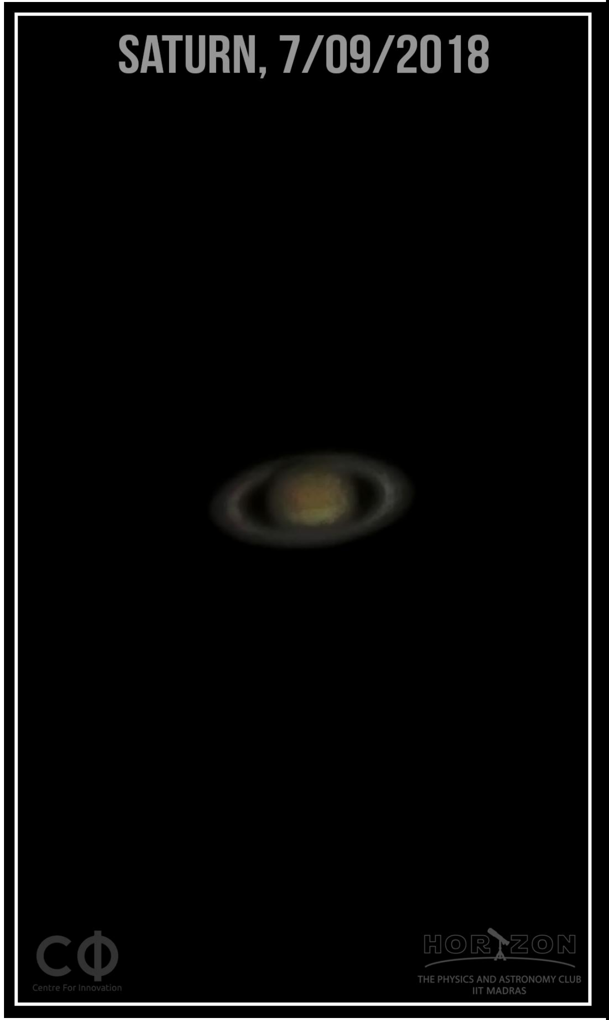
A guide to finding alien worlds

Yashodhan Manerikar

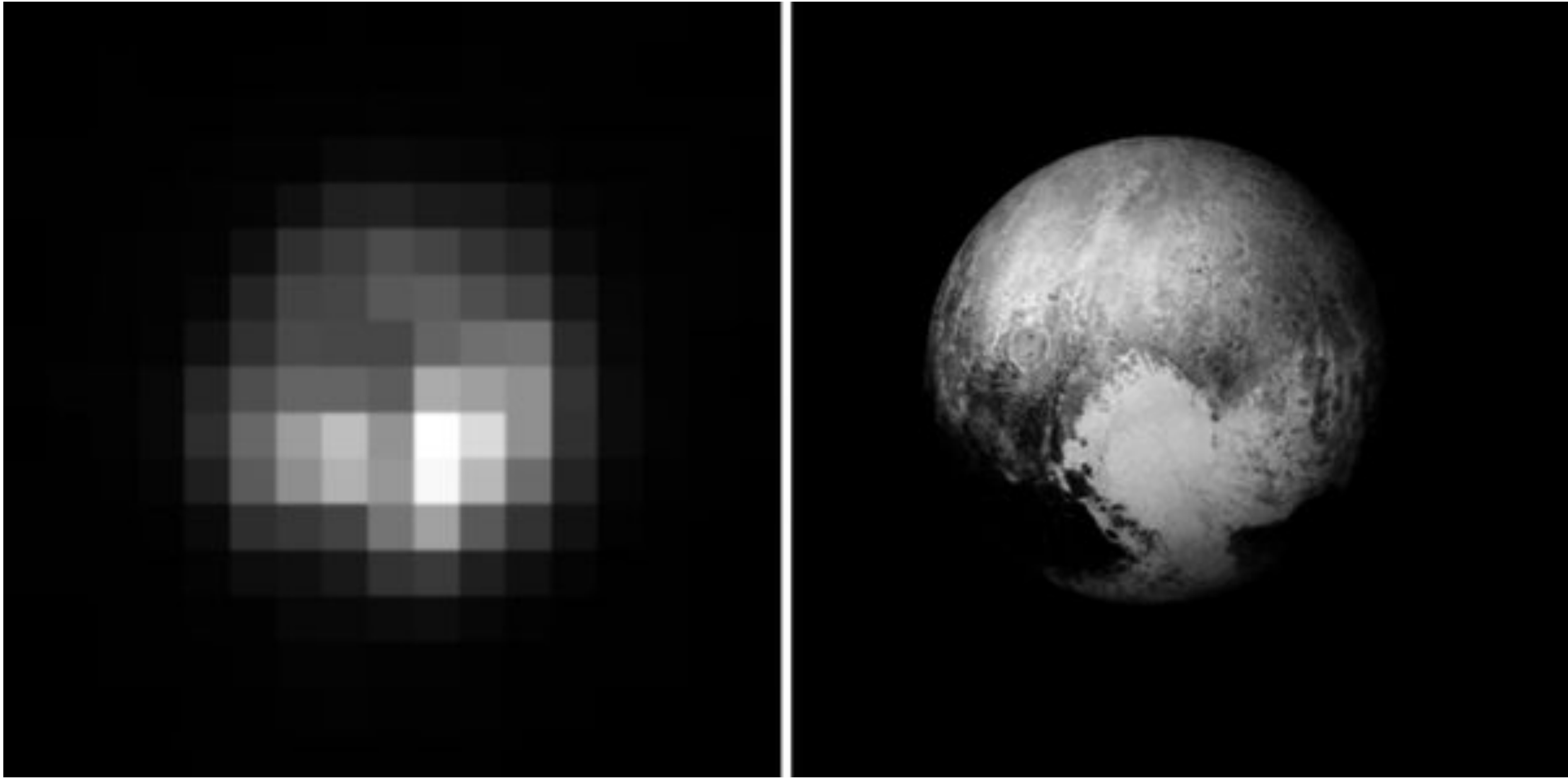
18/8/19

How many of you have seen a planet?


Mercury
Messenger
2011
Venus
Magellan
1990-1992
Earth
S-NPP VIIRS
2015
Mars
Viking/Mars Mosaiced
Digital Image Model
(MDIM)
1975/2014
Jupiter
Hubble Space
Telescope
2015
Saturn
Cassini-Huygen
2000 (planet)
2007 (rings)
Uranus
W.M. Keck Observatory
2004
Neptune
Voyager
1989
Pluto
New Horizons
2015


SATURN, 7/09/2018
Centre For Innovation
HORIZON
THE PHYSICS AND ASTRONOMY CLUB
IIT MADRAS


MARS, 7/09/2018
Centre For Innovation



What is a planet?
Are there more planets?

IAU definition of *planet*

From Wikipedia, the free encyclopedia

This article is about the formal definition established in 2006. For prior usage, see Definition of p

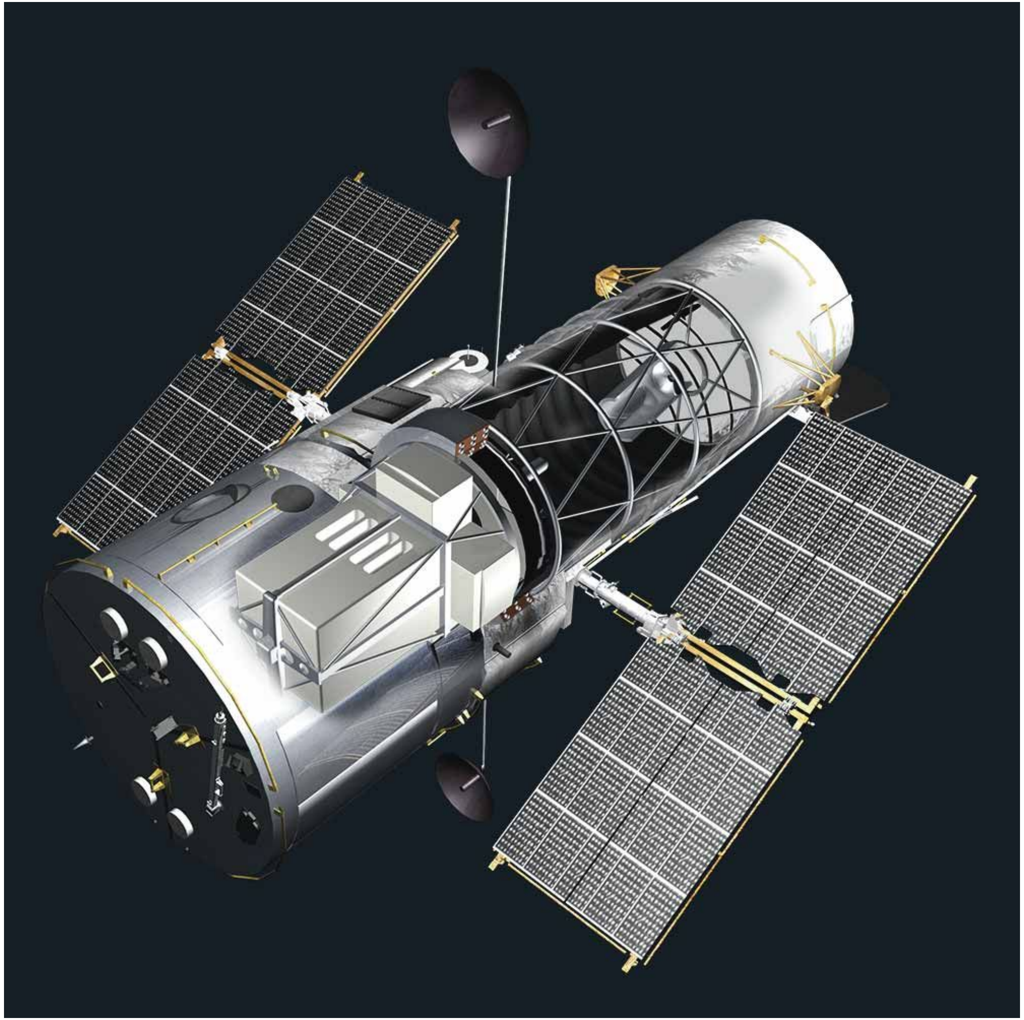
The International Astronomical Union (IAU) defined in August 2006 that, in the Solar System, a planet is a celestial body which:

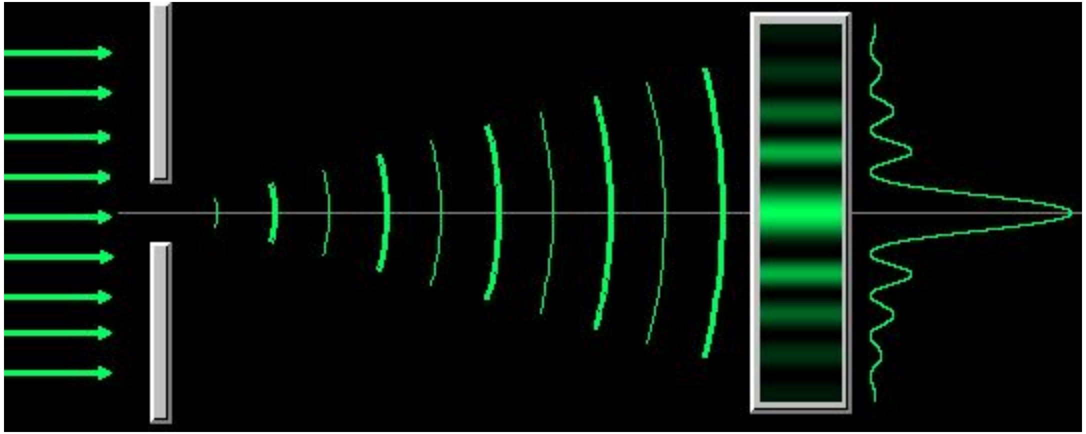
1. is in orbit around the Sun,
2. has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and
3. has "cleared the neighborhood" around its orbit.

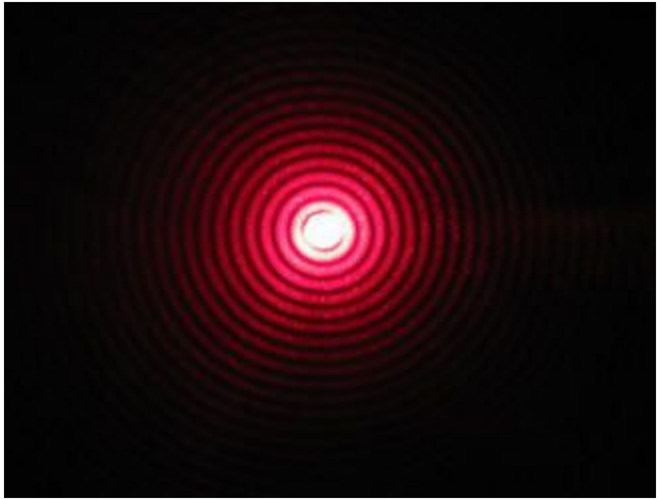
How many of you have seen a star?

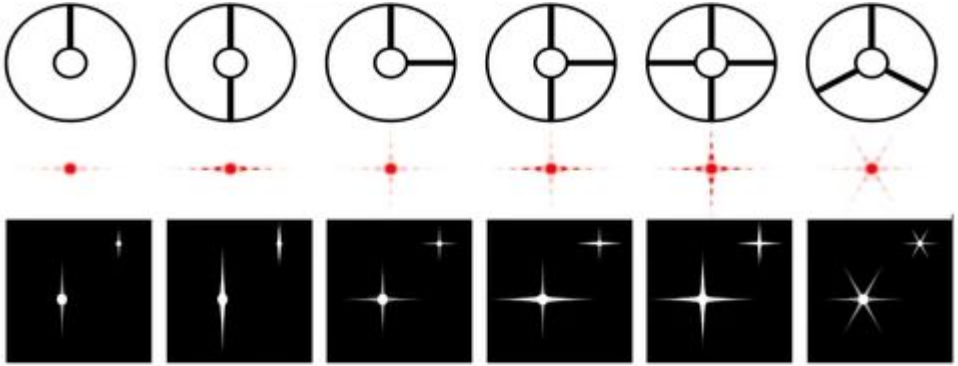

by Yuuji Kitahara

If that is not the radius, then what is the circle?









In case you were starting to get bored.

By now we have established that it’s not possible to detect an exoplanet directly.
Unless we get TMT.


IMT
+
DISCOVERY
IMT
+
MAUNA
KEA
=

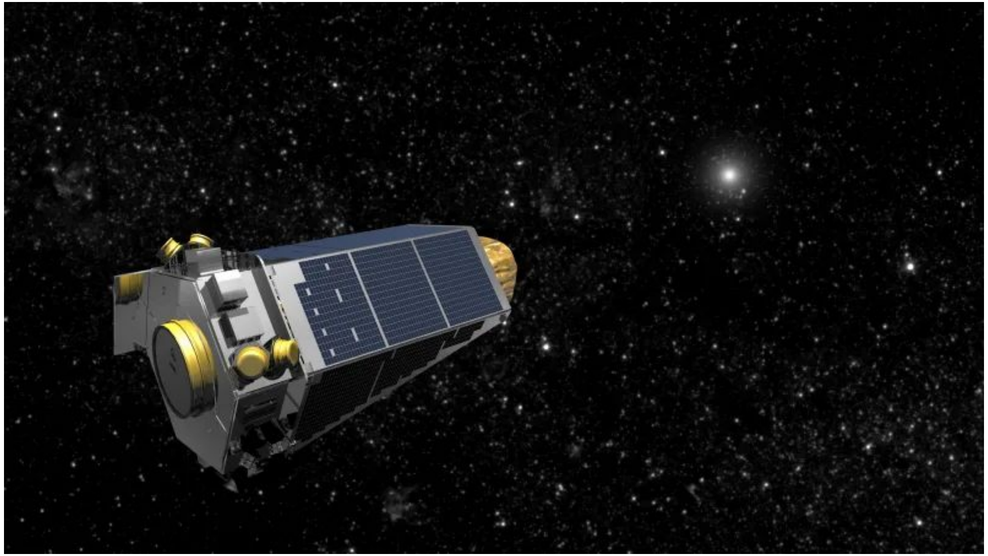
Okay, so what CAN we see?

Stars!

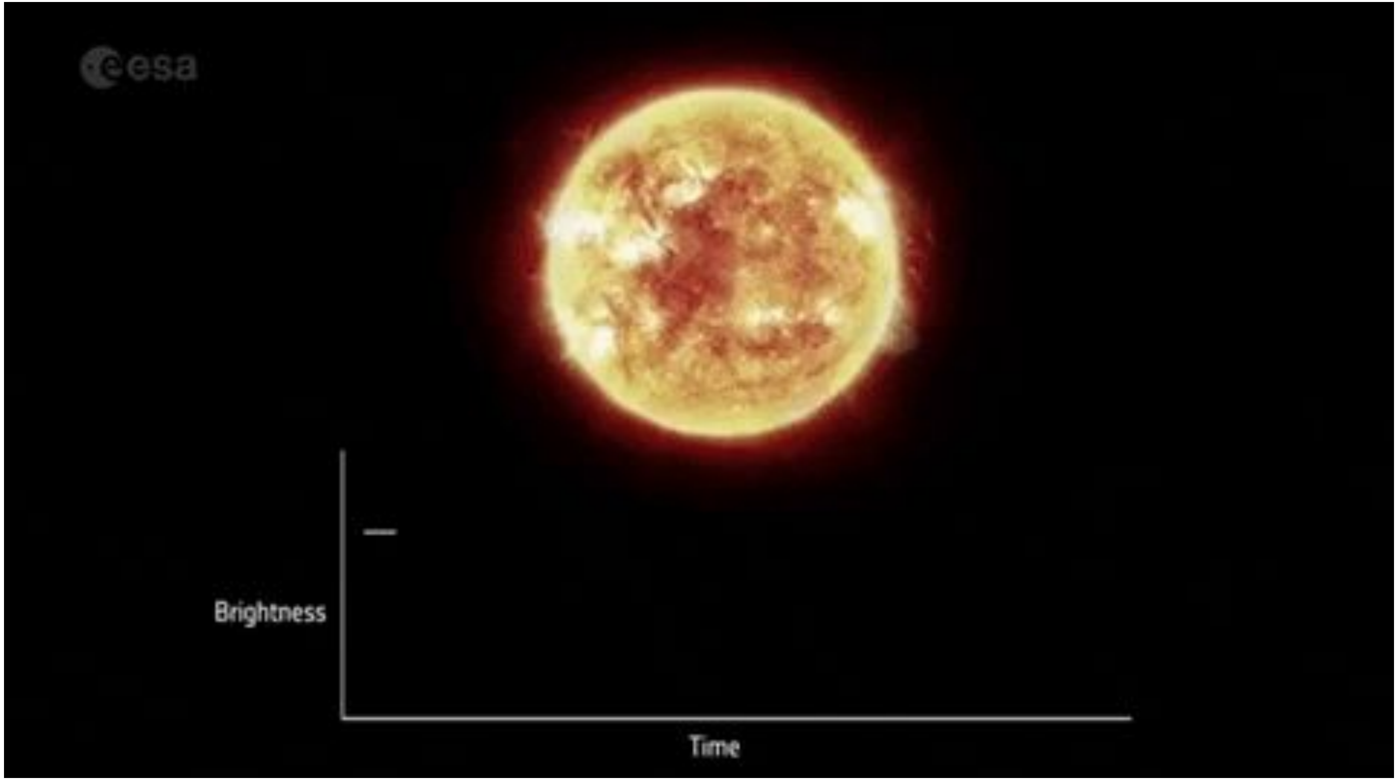
We now have to find a way to extract the information about an exoplanet by observing a star.

Method 1: Photometry

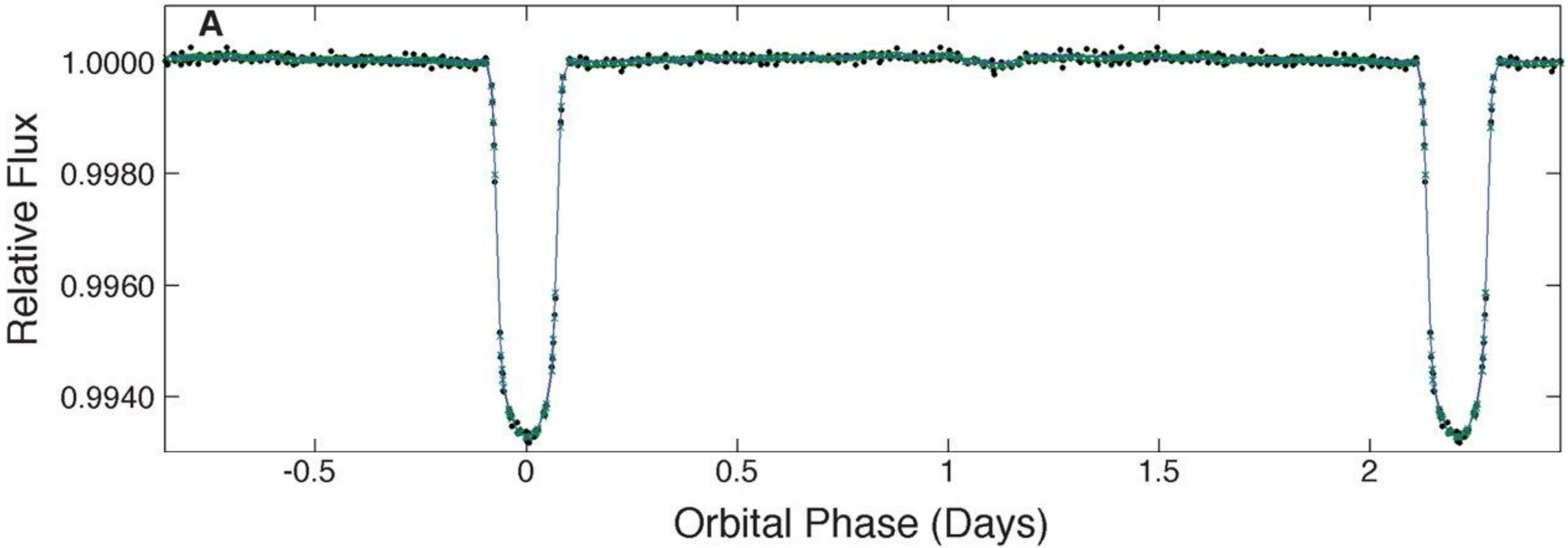
In this method we will use nothing but the brightness of the star over time to find an exoplanet.



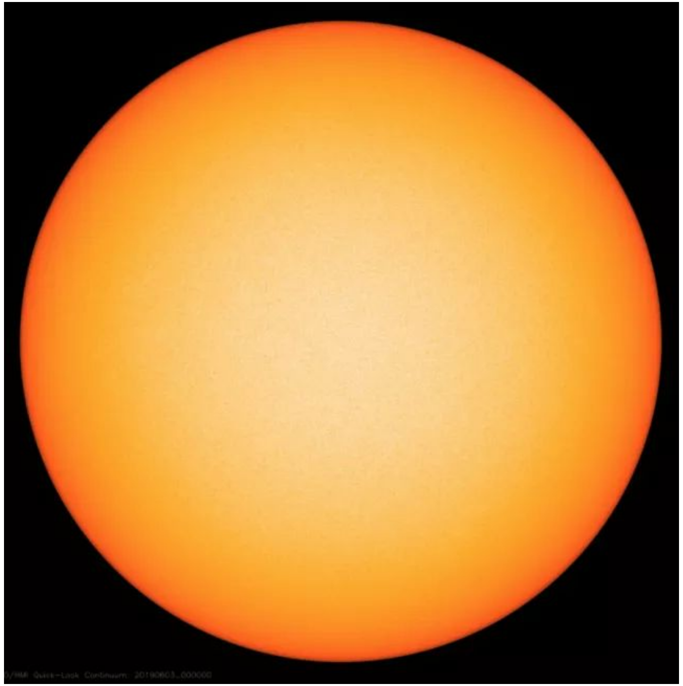
Theory:



Data:


A
1.0000
0.9980
0.9960
0.9940
Relative Flux
-0.5
0
0.5
1
1.5
2
Orbital Phase (Days)

Limb darkening:



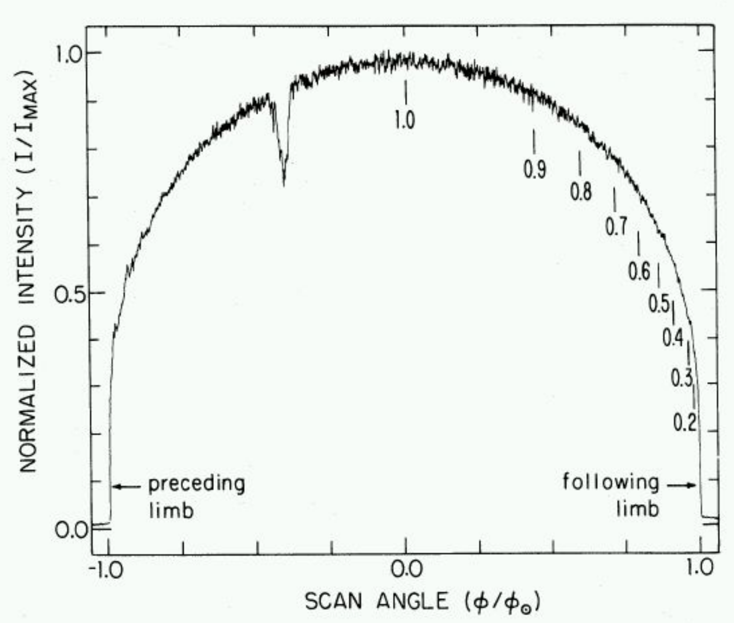
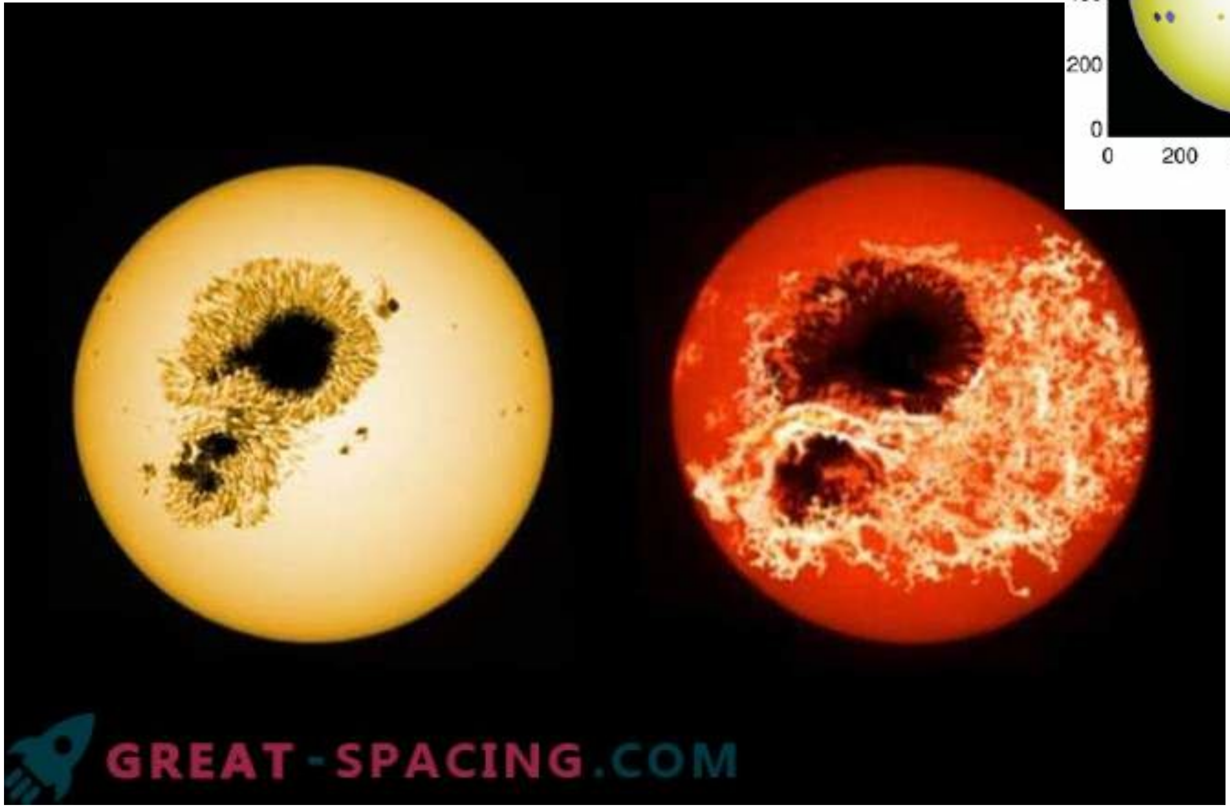
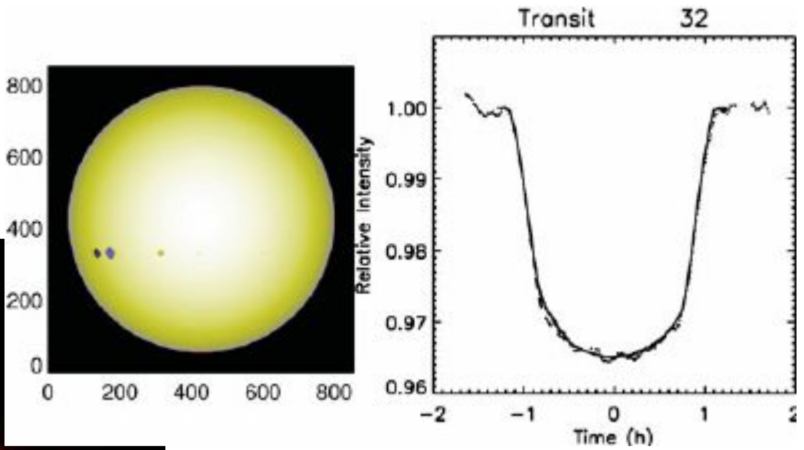


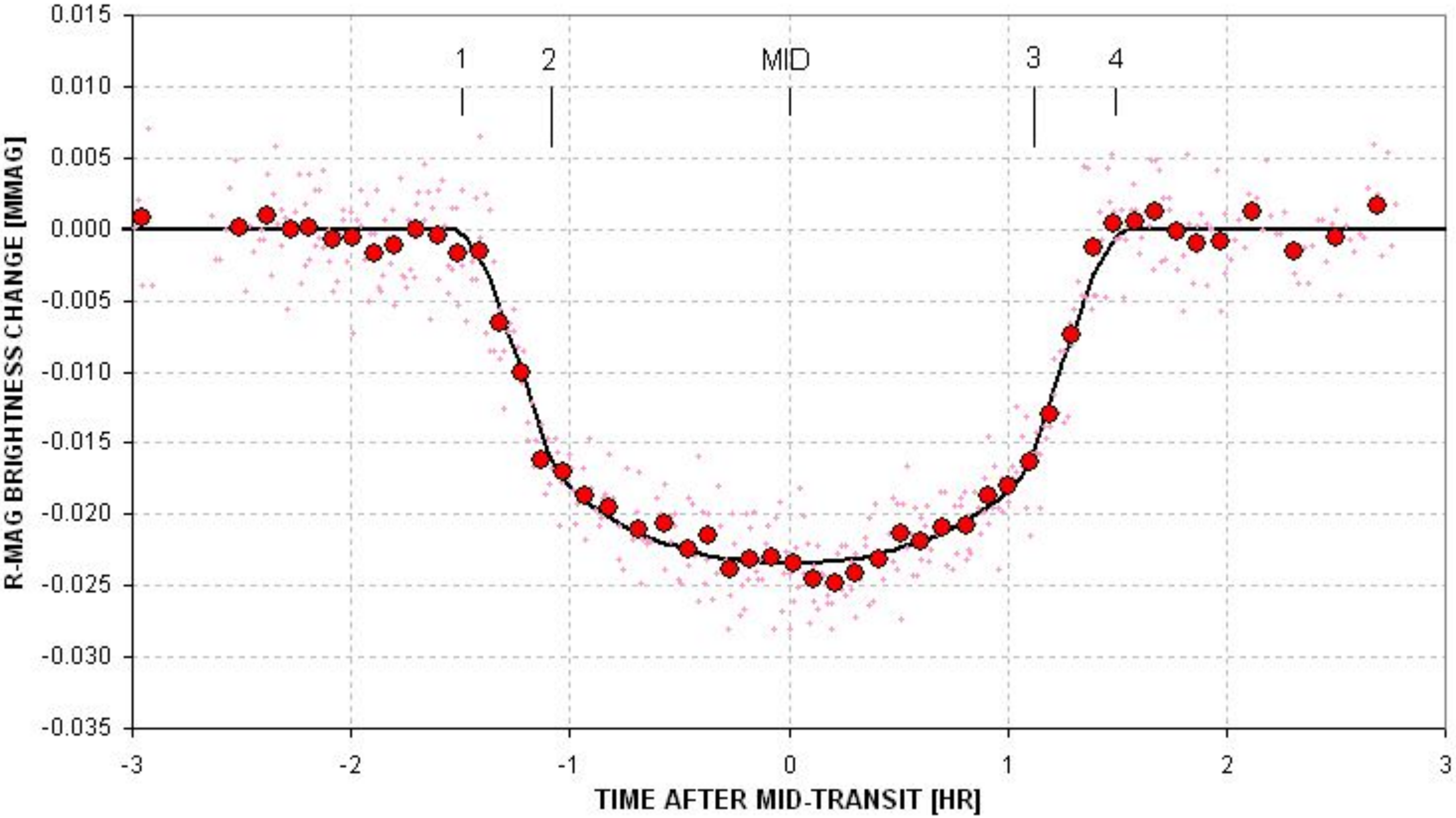
FIG. 1.—A typical drift scan plotted against scan angle $\phi/\phi_{\odot}$. The intensities plotted here have been corrected for zero point and normalized. Representative values of $\mu = \cos\theta$ are marked along the following half of the scan.

STARS SPOTS


GREAT-SPACING.COM


Transit 32
800
600
400
200
0
0 200 400 600 800
Relative Intensity
1.00
0.99
0.98
0.97
0.96
−2 −1 0 1 2
Time (h)

Parameters you can estimate from a dip:



Parameters such as orbital inclination, radius of the exoplanet, radius of the orbit, eccentricity can be found out using the dips and the period of the dips.

Now let’s try to find out the radius of the exoplanet from the data on the previous slide.

Table Of Contents

This Page

Tutorial

In this tutorial, we'll go through `batman`'s functionality in more detail than in the Quickstart. First let's initialize a model with nonlinear limb darkening:

Initializing the model

```
import batman
import numpy as np
import matplotlib as plt

params = batman.TransitParams()       #object to store transit parameters
params.t0 = 0.                        #time of inferior conjunction
params.per = 1.                       #orbital period
params.rp = 0.1                       #planet radius (in units of stellar radii)
params.a = 15.                        #semi-major axis (in units of stellar radii)
params.inc = 87.                      #orbital inclination (in degrees)
params.ecc = 0.                       #eccentricity
params.w = 90.                        #longitude of periastron (in degrees)
params.limb_dark = "nonlinear"        #limb darkening model
params.u = [0.5, 0.1, 0.1, -0.1]      #limb darkening coefficients [u1, u2, u3, u4]

t = np.linspace(-0.025, 0.025, 1000)  #times at which to calculate light curve
m = batman.TransitModel(params, t)    #initializes model
```

The initialization step calculates the separation of centers between the star and the planet, as well as the integration step size (for "square-root", "logarithmic", "exponential", "nonlinear", "power2", and "custom" limb darkening).

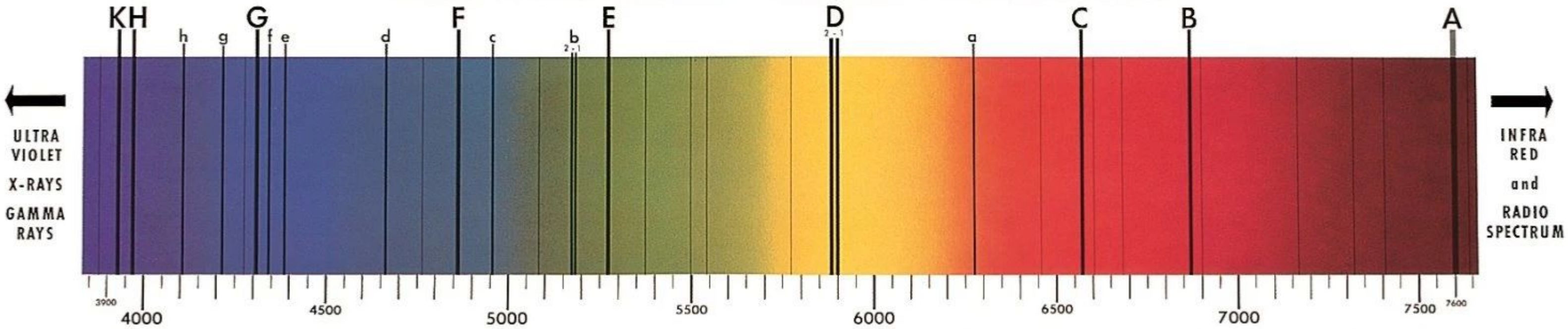
Method 2: Radial Velocity analysis.

What else can we observe from a star?

Anything special that can give us a whole lot of information about a star?

SOLAR SPECTRUM

VISIBLE PORTION SHOWING PROMINENT FRAUNHOFER LINES



FRAUNHOFER LINES

In 1802, the English Scientist, William Wollaston, noticed black lines crossing the visible Solar Spectrum. Later, Fraunhofer, the inventor of the diffraction grating, assigned letters to these lines. These lines have, since, been used as reference points for measuring the indexes of refraction glasses, spectroscopic calibration etc.

Kirkhoff, in 1859, proved that they are absorption lines of elements in the atmosphere of the Sun or Earth, and that they have the same wave length or frequency as the emission lines of the incandescent or electrically excited vapors of these elements.

Under high resolution, several of the lines, for example the "G" lines, are seen to be multiple lines and are due to more than one element. For example, the "G" line, Fe and Ca 4308.

The Fraunhofer lines above, on the chart, are exaggerated in width, for visibility. The wave length scale is in Angstrom units (1×10^{-8} cm).

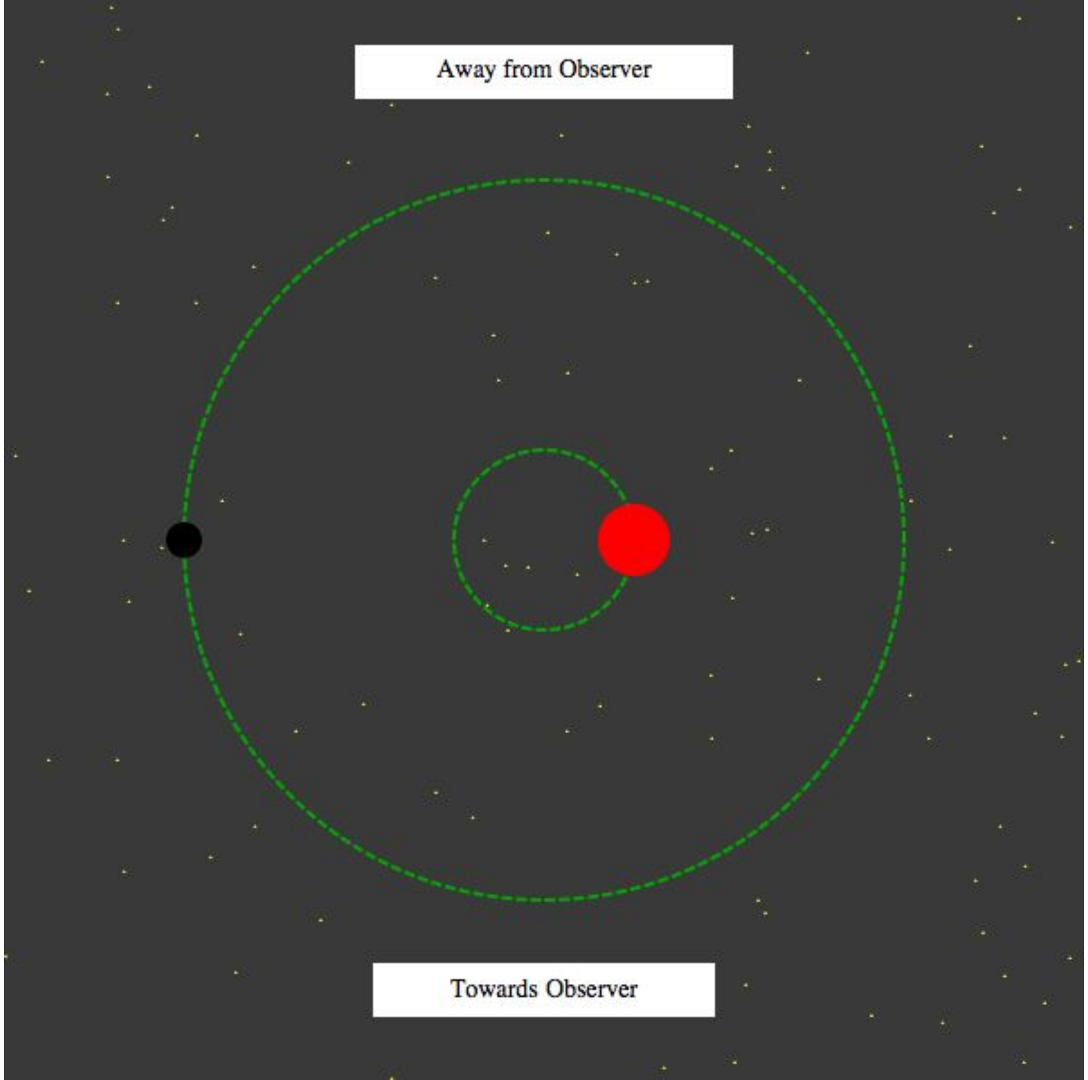
There are approximately 15,000 Fraunhofer lines in the entire Solar Spectrum, including the Infra-Red and the Ultra-Violet.

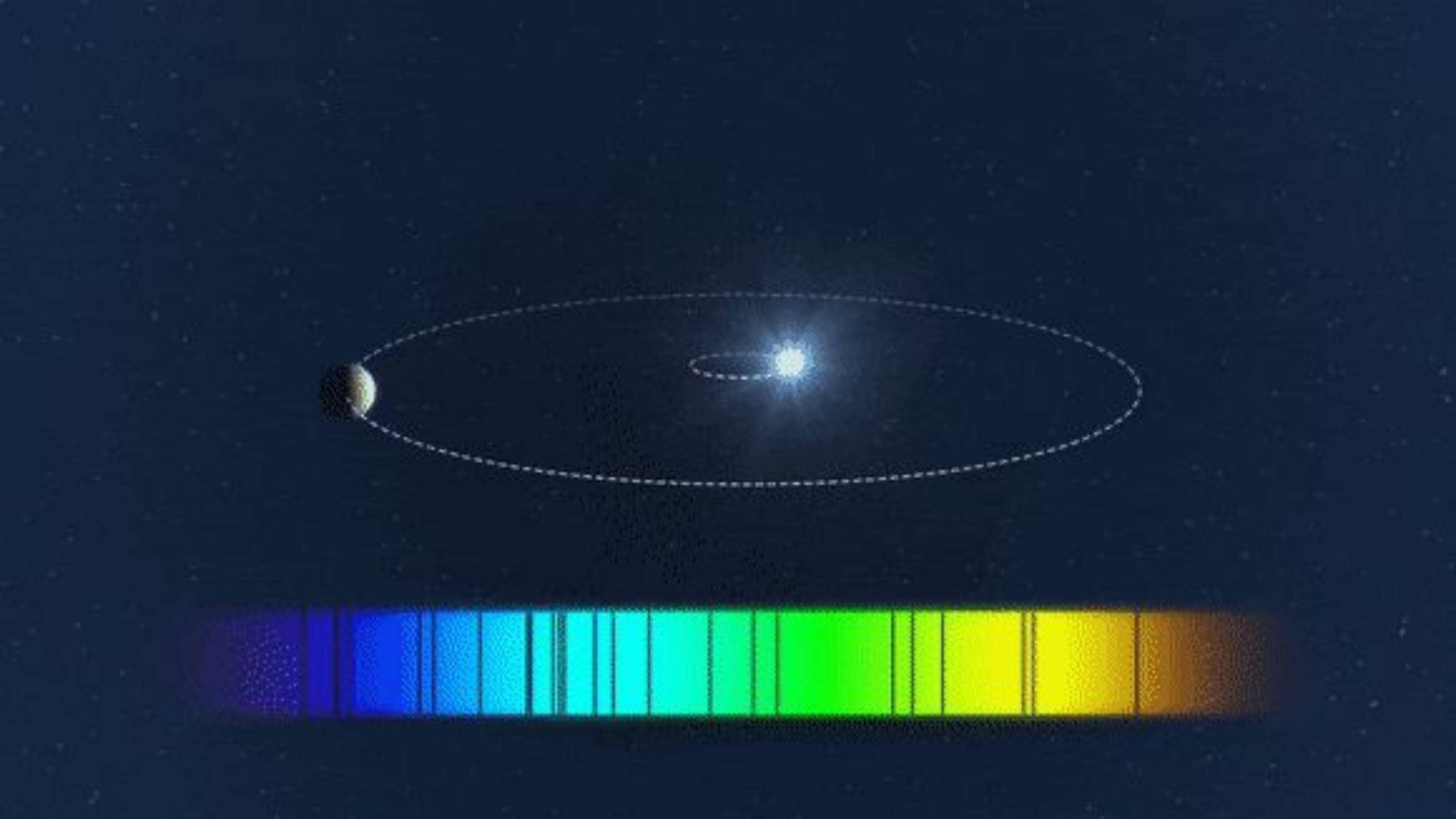
PROMINENT FRAUNHOFER LINES (APPROXIMATE TO NEAREST ANGSTROM UNIT)

LINES	DUE TO	WAVE LENGTHS
A – (band)	O_2	7594 to 7621
B – (band)	O_2	6867 – 6884
C	H	6563
a – (band)	O_2	6276 – 6287
D – 1, 2	Na	5896 & 5890
E	Fe	5270
b – 1, 2	Mg	5184 & 5173
c	Fe	4958

LINES	DUE TO	WAVE LENGTHS
F	H	4861
d	Fe	4668
e	Fe	4384
f	H	4340
G	Fe & Ca	4308
g	Ca	4227
h	H	4102
H	Ca	3968
K	Ca	3934

Does the Earth go around the Sun?

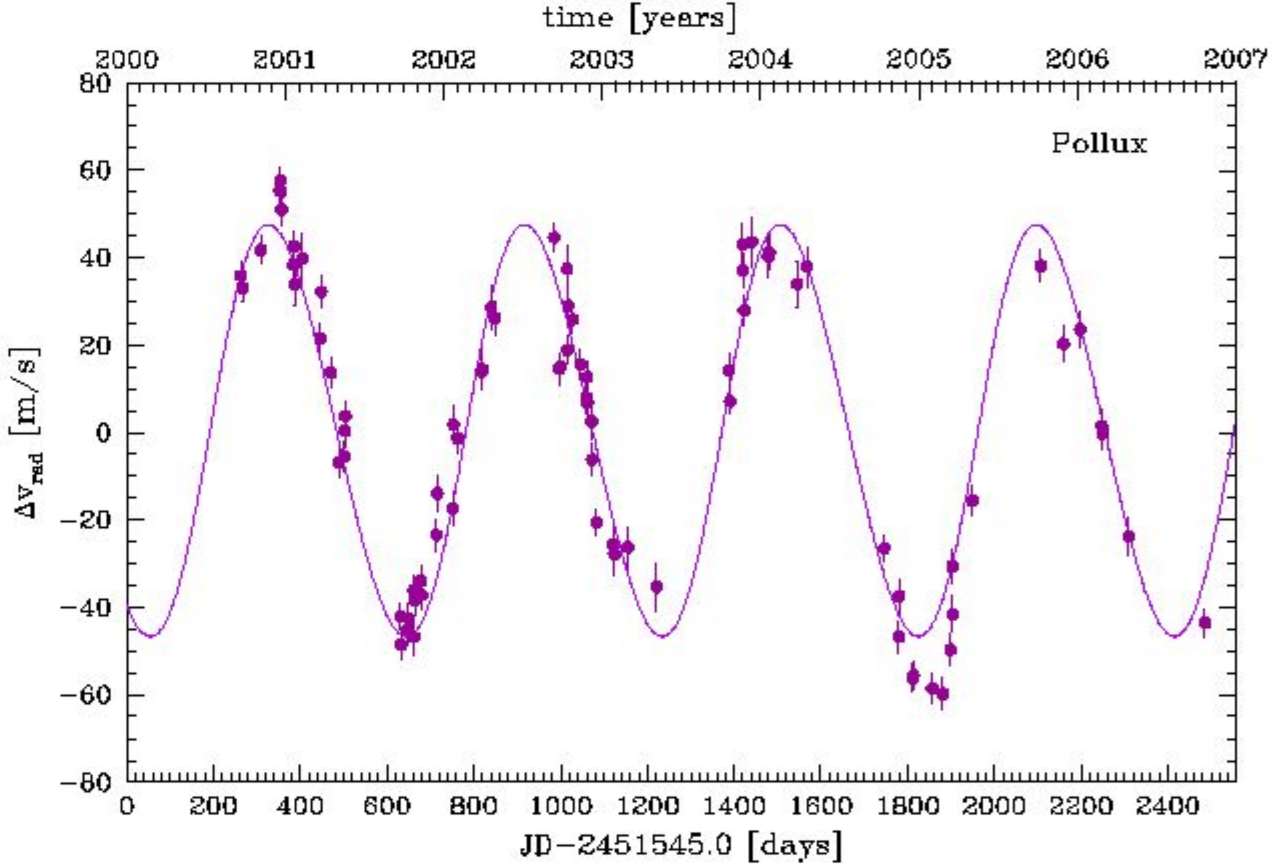

Away from Observer
Towards Observer





omie

DATA

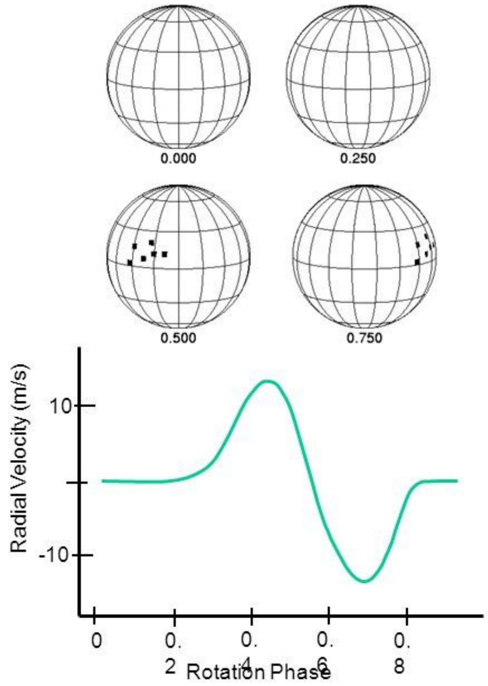


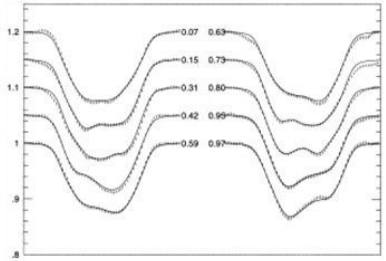
time [years]
2000
2001
2002
2003
2004
2005
2006
2007
Pollux
Δv_{rad} [m/s]
80
60
40
20
0
−20
−40
−60
−80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
JD−2451545.0 [days]

From this data you can estimate the following parameters:
Minimum mass
Orbital period and radius

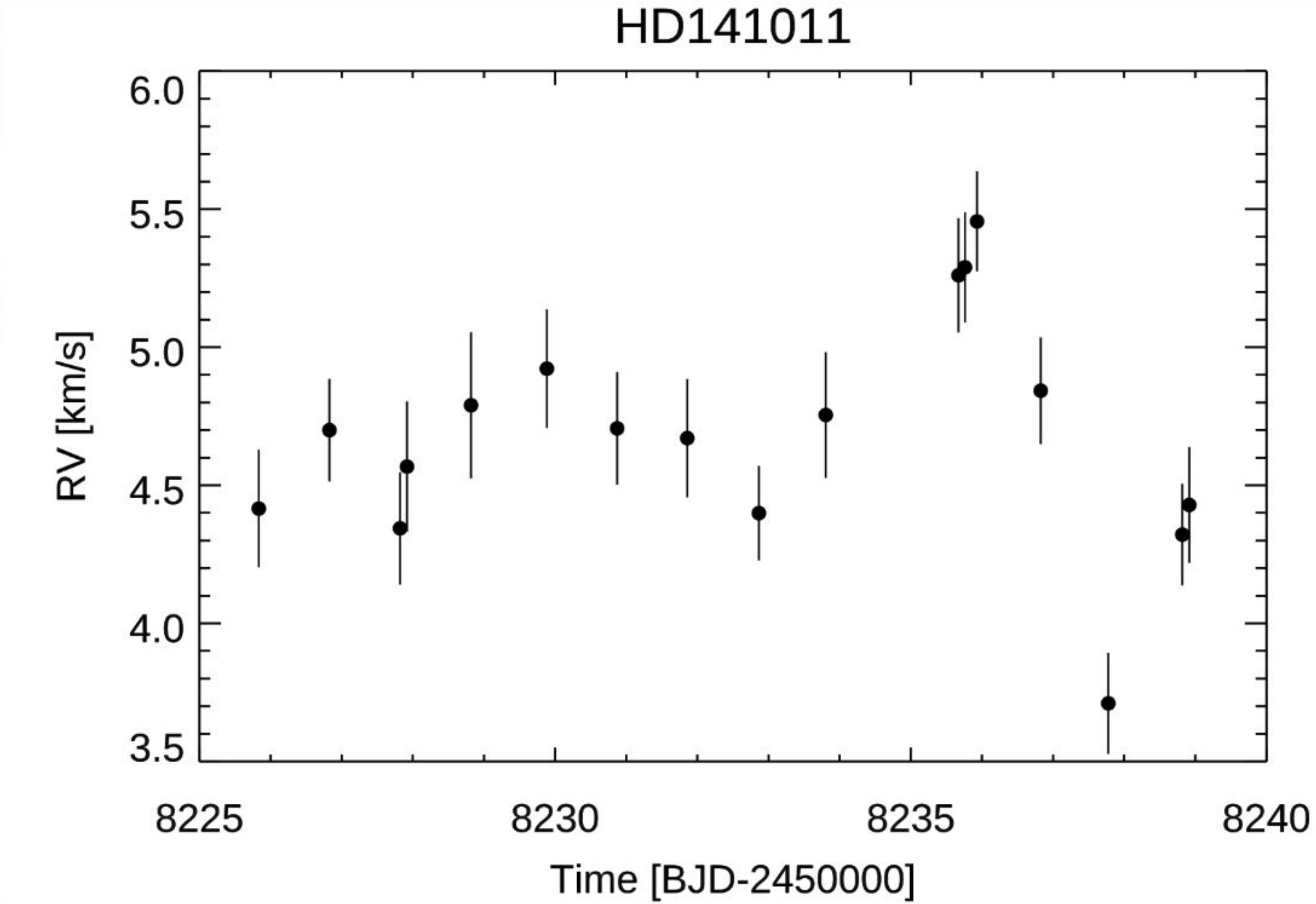
STAR SPOTS AGAIN

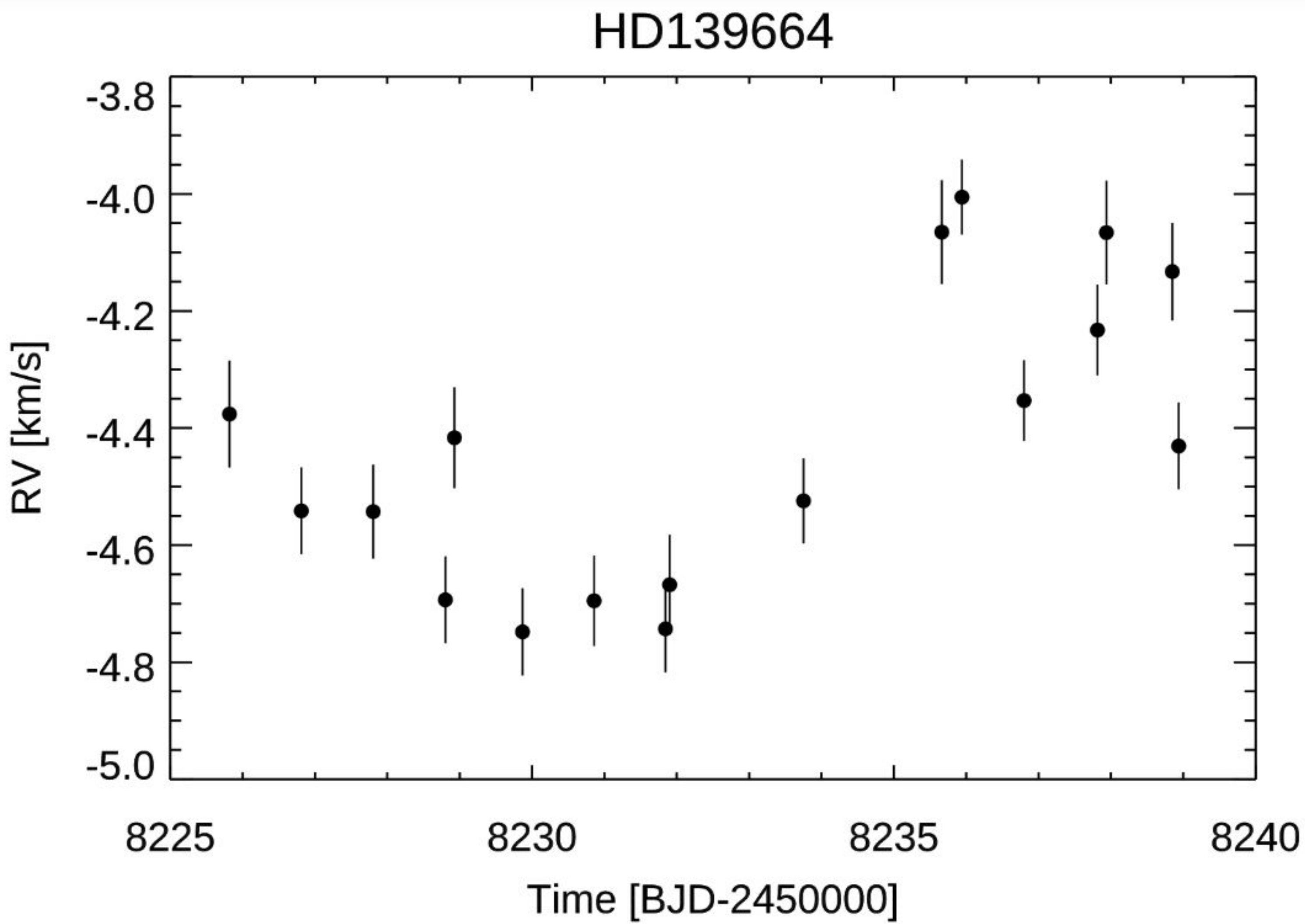
Starspots can produce Radial Velocity Variations

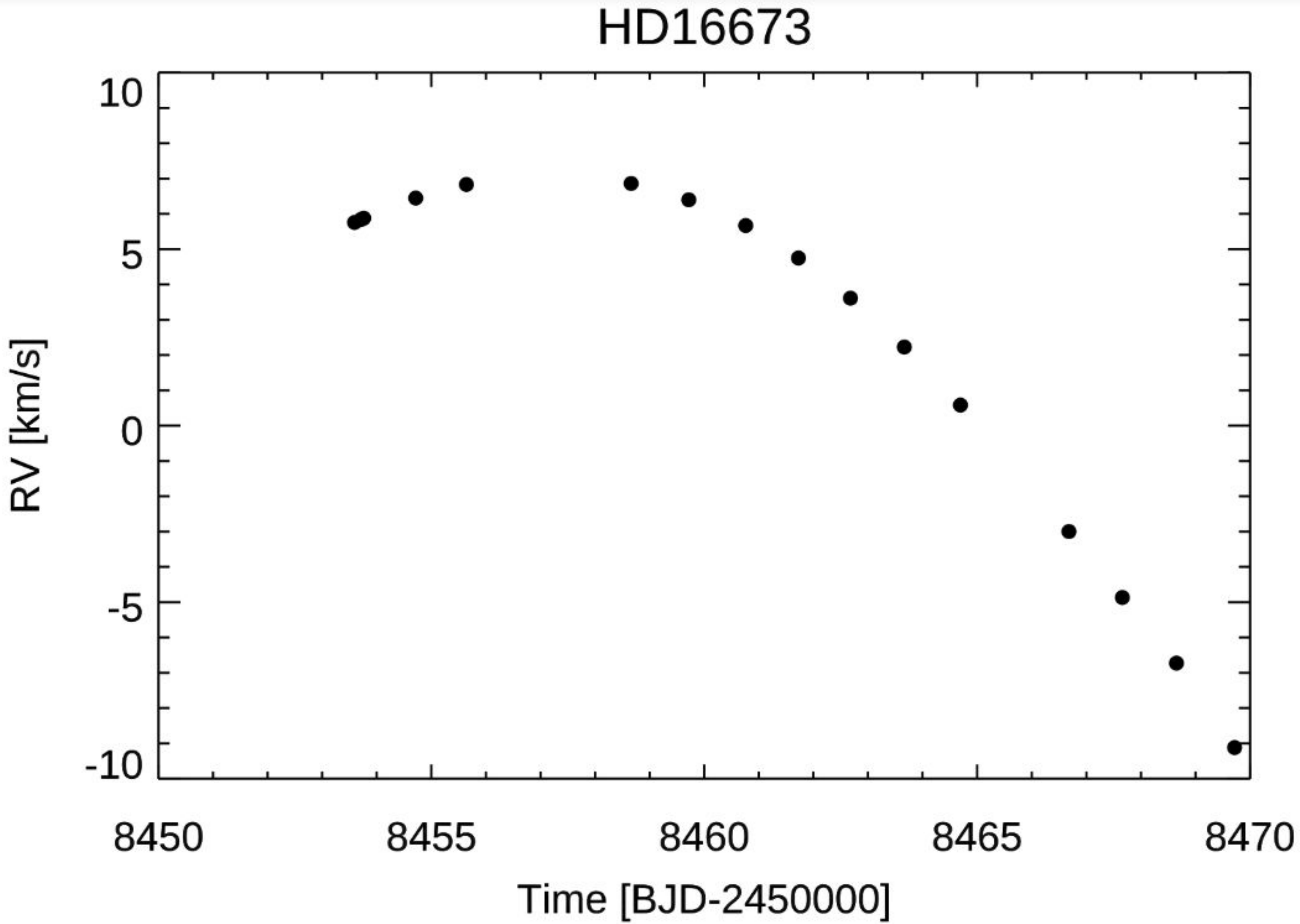




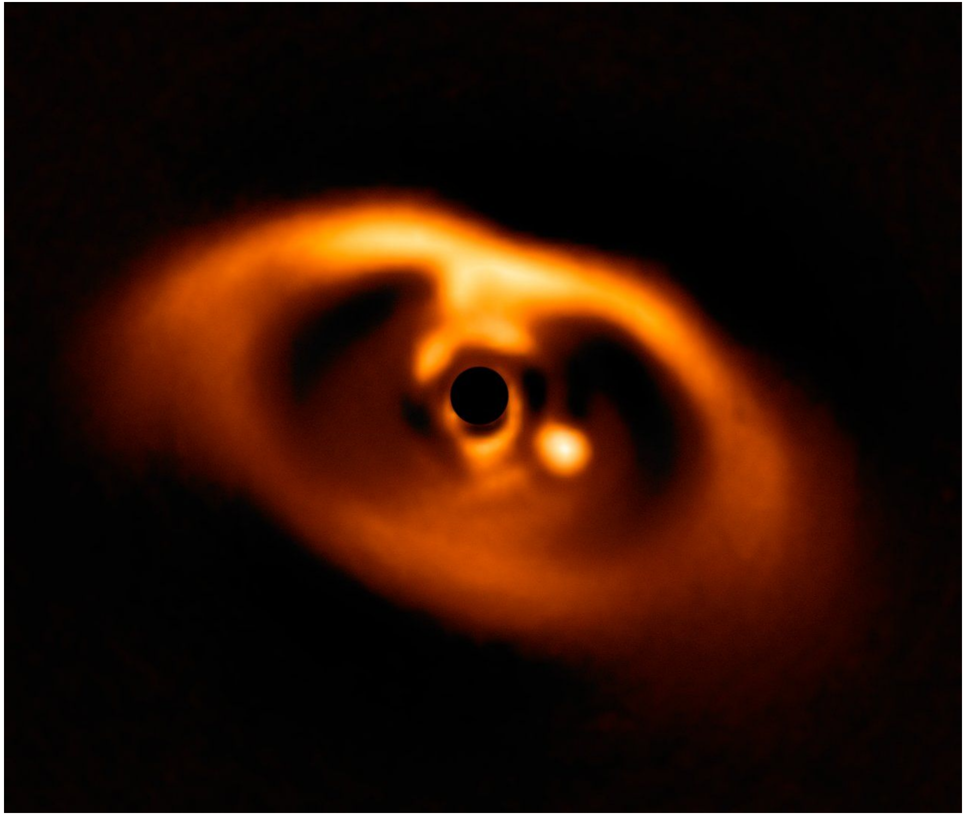
Spectral Line distortions in an active star that is rotating rapidly


HD141011
6.0
5.5
5.0
4.5
4.0
3.5
RV [km/s]
8225
8230
8235
8240
Time [BJD-2450000]

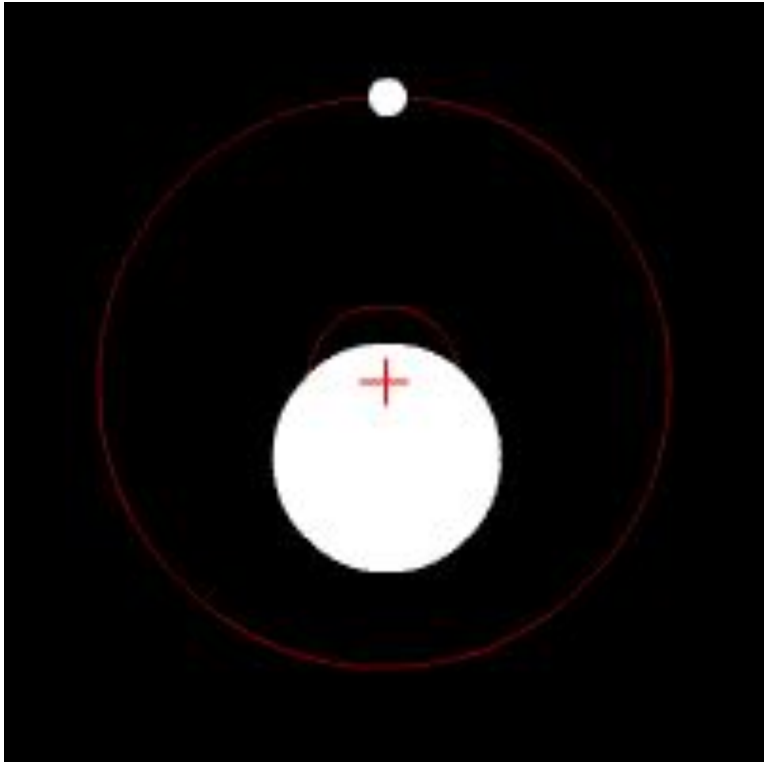

HD139664
RV [km/s]
-3.8
-4.0
-4.2
-4.4
-4.6
-4.8
-5.0
8225
8230
8235
8240
Time [BJD-2450000]


HD16673
RV [km/s]
10
5
0
-5
-10
8450
8455
8460
8465
8470
Time [BJD-2450000]

Method 3: Direct imaging



Method 4: Astrometry



Other funky techniques:

Relativistic beaming

Polarimetry

Gravitational microlensing


Thank you for coming.
Live long and prosper.