Finding Other Earths

Jason H. Steffen

Asset Earth
Waubonsee Community College
October 1, 2009

True Earth Analog

Necessities:

1) Main Sequence Star
2) Within the Stellar Habitable Zone
3) Roughly Earth Mass and Size

True Earth Analog

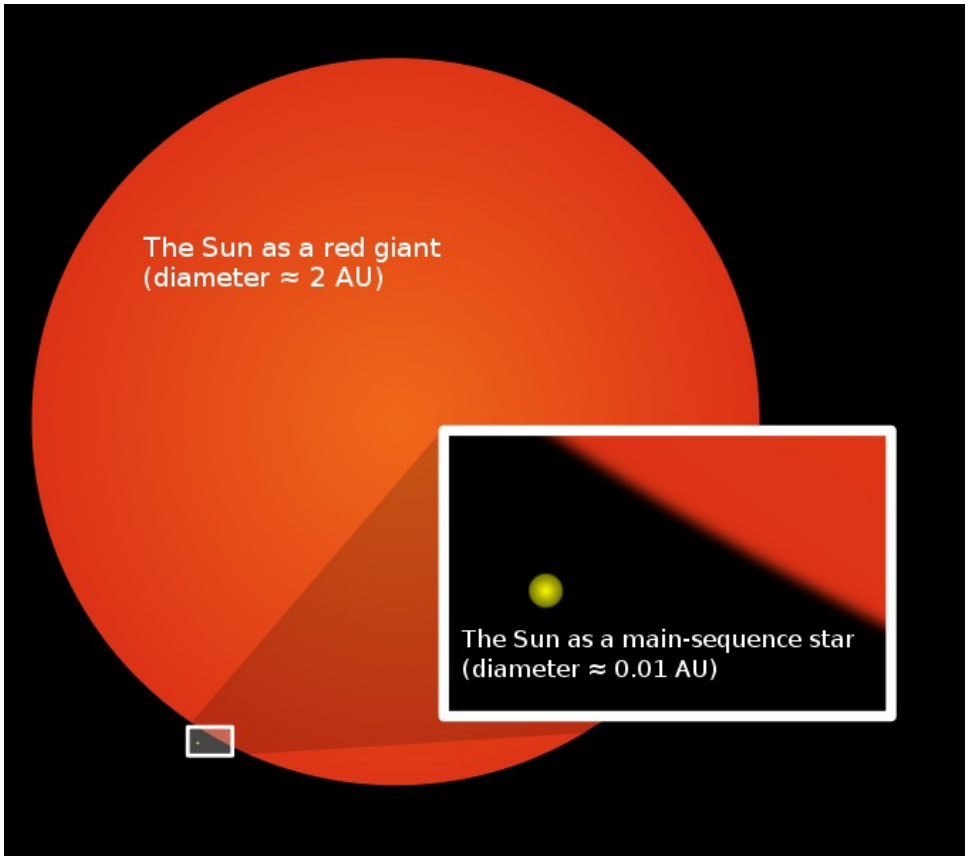
Necessities:

1) Main Sequence Star
2) Within the Stellar Habitable Zone
3) Roughly Earth Mass and Size

Niceties:

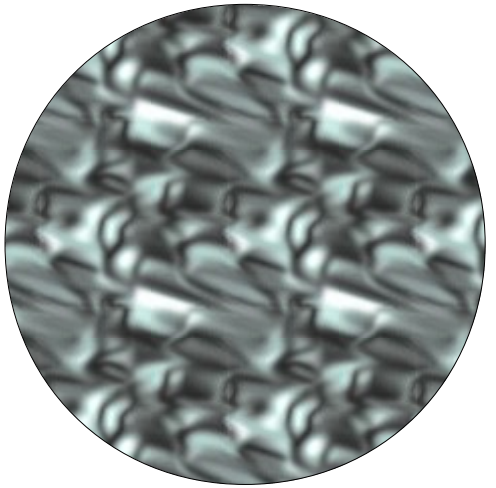
1) Nearly Circular Orbit
2) Jupiter-like Planet
3) Large Moon
4) Plate Tectonics
5) Galactic Habitable Zone
6) Single Star

Non-main Sequence Stars



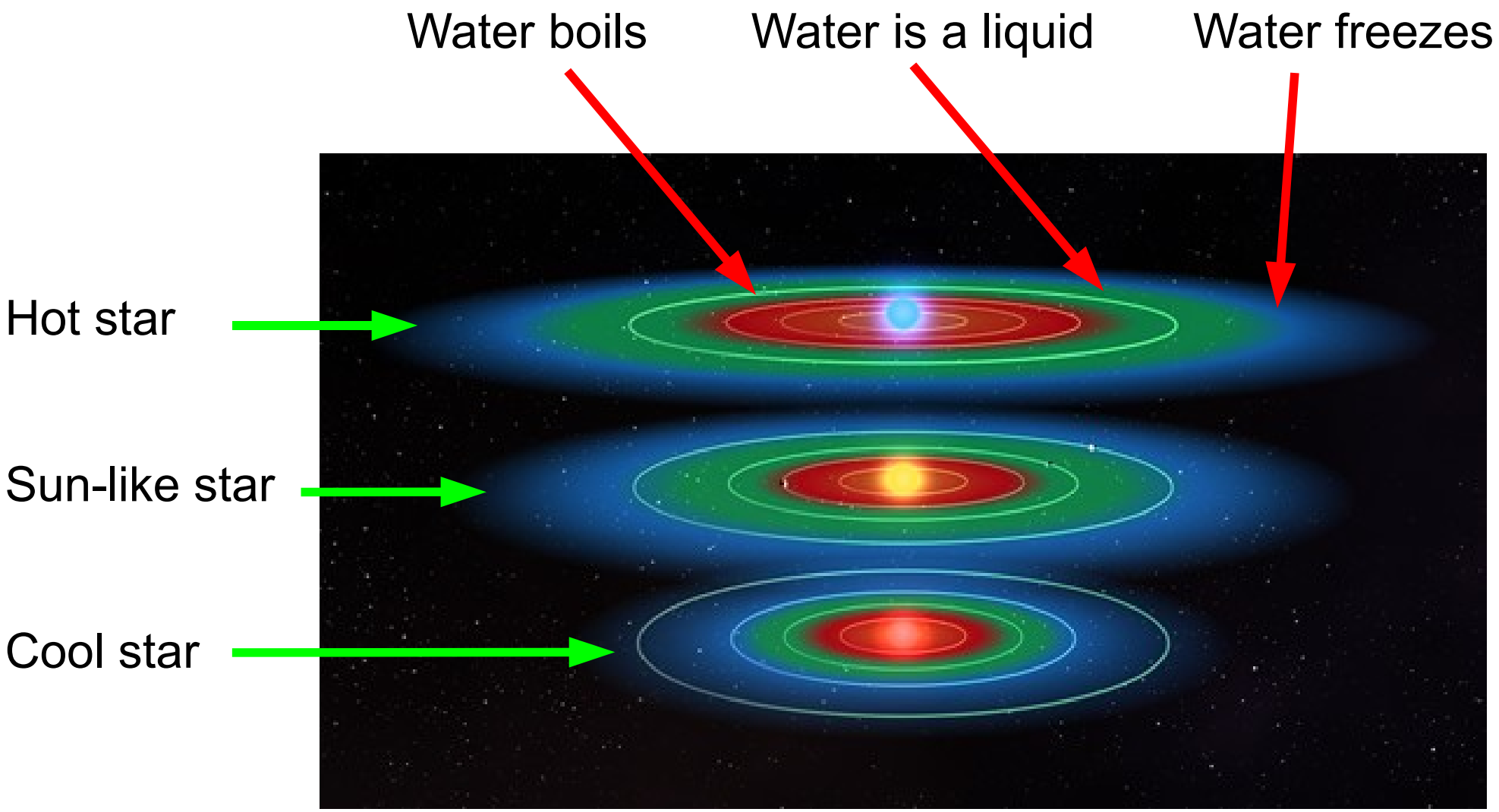
Giant Stars

White Dwarf Stars

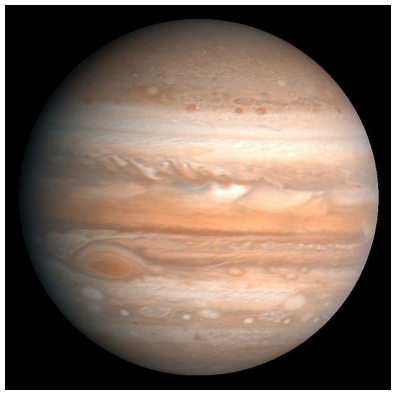


Neutron Stars

Stellar Habitable Zone

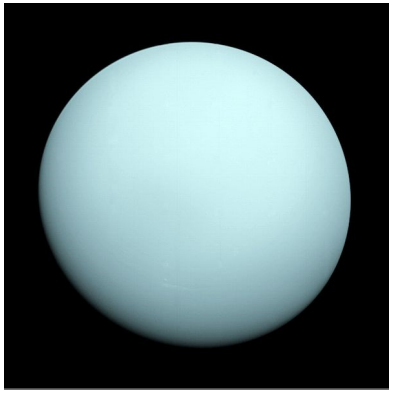


Earth Mass and Earth Size Planets



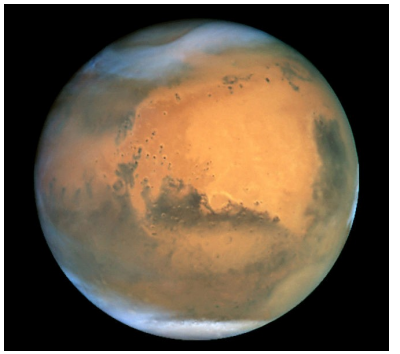
320x Earth mass
11x Earth diameter

15x Earth mass
4x Earth diameter



0.82x Earth mass
0.95x Earth diameter

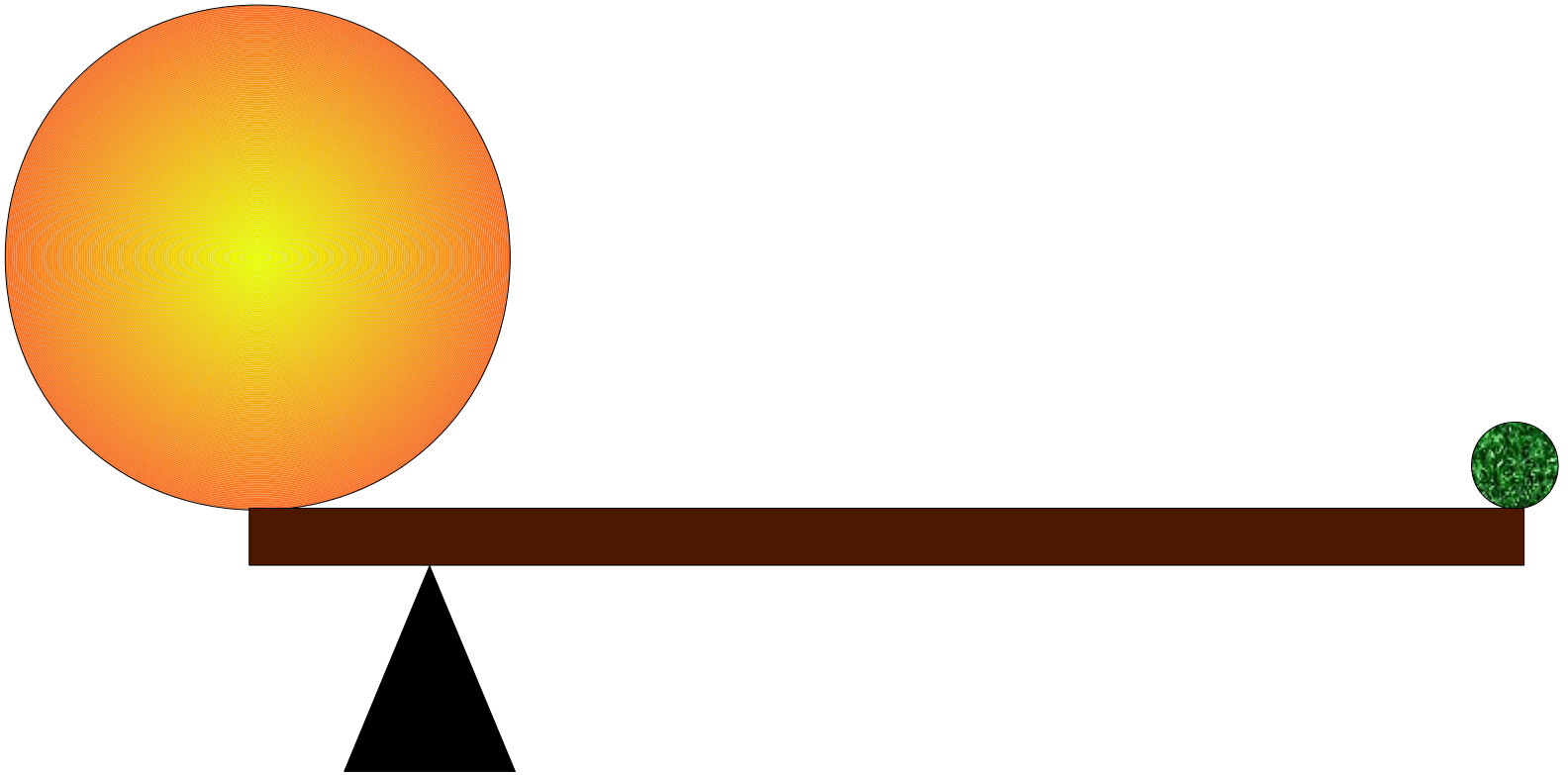
0.11x Earth mass
0.53x Earth diameter



0.012x Earth mass
0.27x Earth diameter

Note: Moons orbiting gas giants in the habitable zone are fair game.

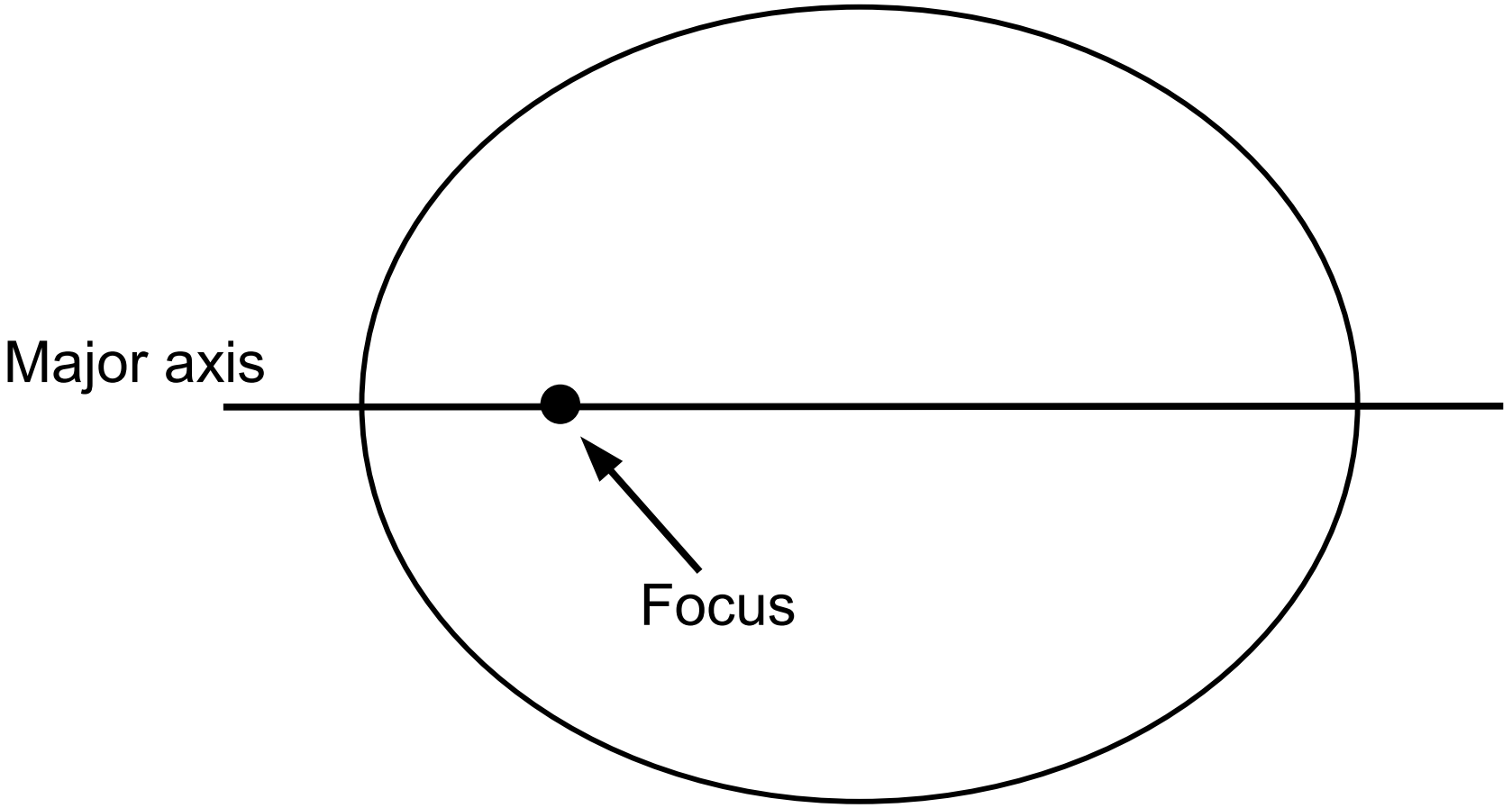
Planetary Orbits



Stars and planets both orbit about their mutual center of mass.

Planetary Orbits

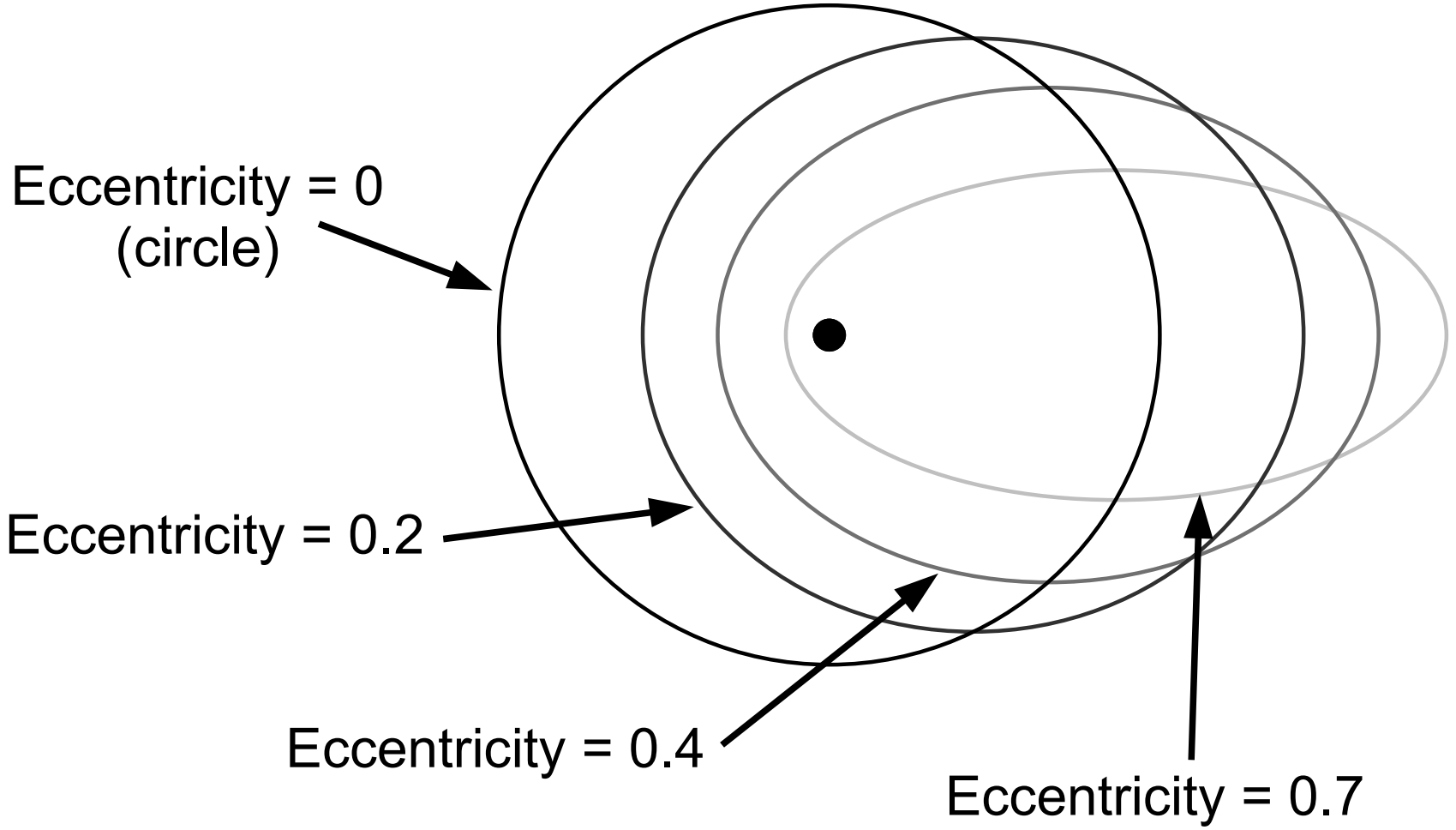
Orbits are elliptical with the center of mass at one focus.



The average distance from the planet to the focus is equal to half of the major axis (semimajor axis).

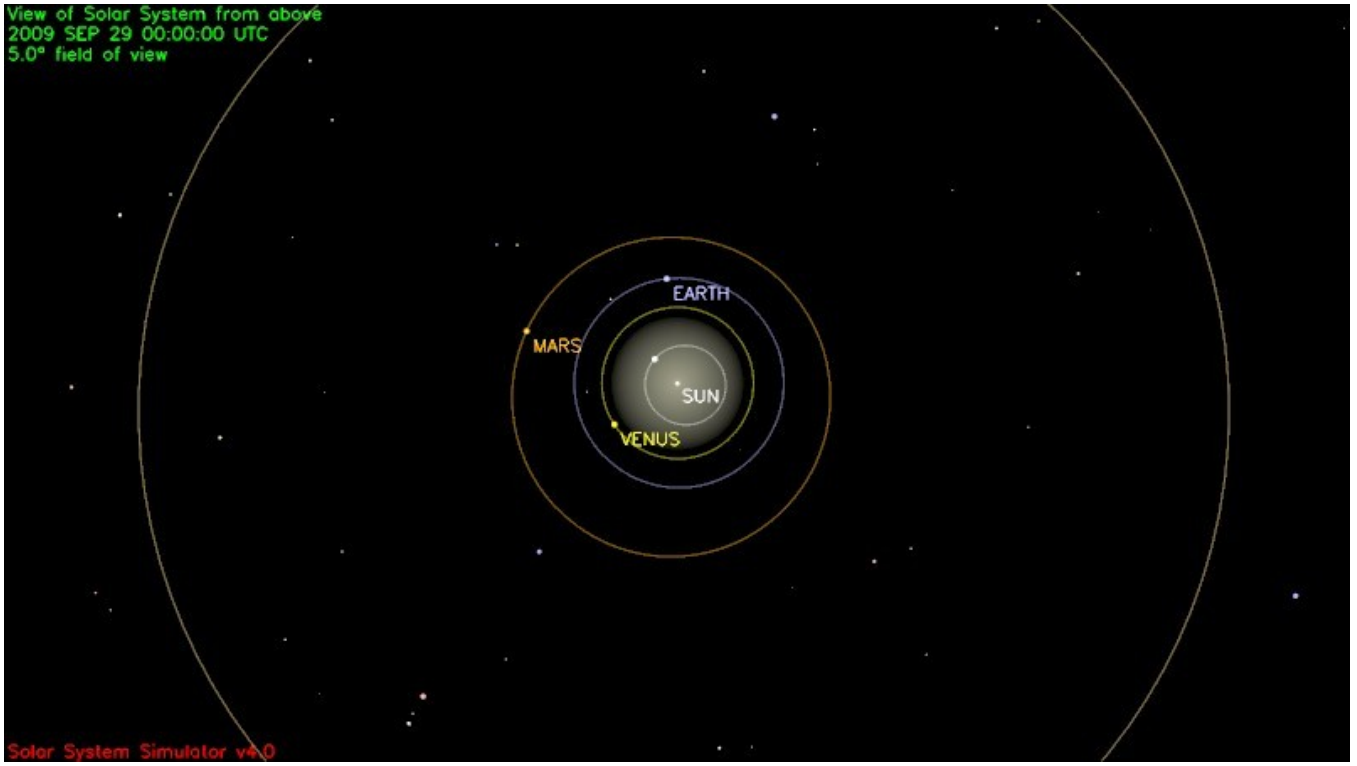
Planetary Orbits

The eccentricity of an orbit gives the flattening of the ellipse.



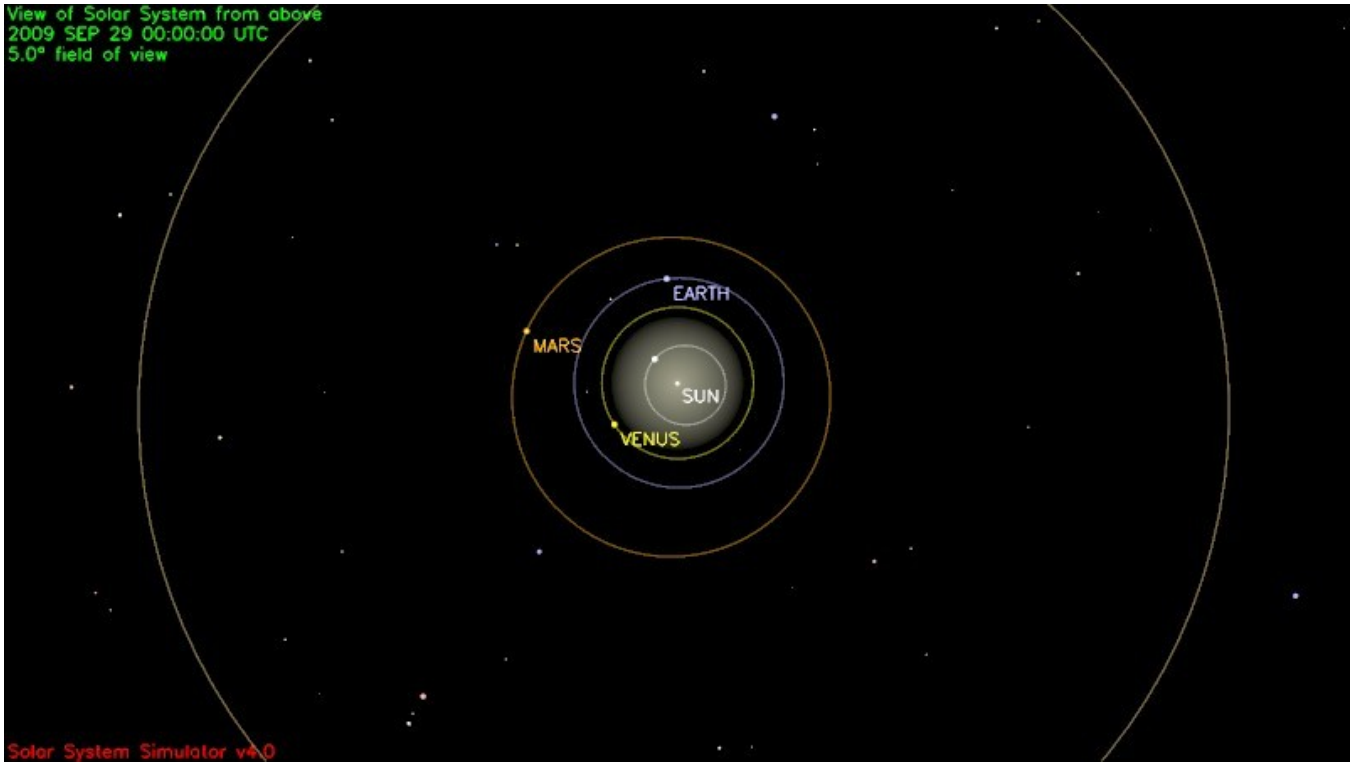
Planetary Orbits

PLANET	*a*	*e*
Mercury	0.39	0.206
Venus	0.72	0.007
Earth	1.00	0.017
Mars	1.52	0.093
Jupiter	5.20	0.048
Saturn	9.54	0.054
Uranus	19.2	0.047
Neptune	30.1	0.009



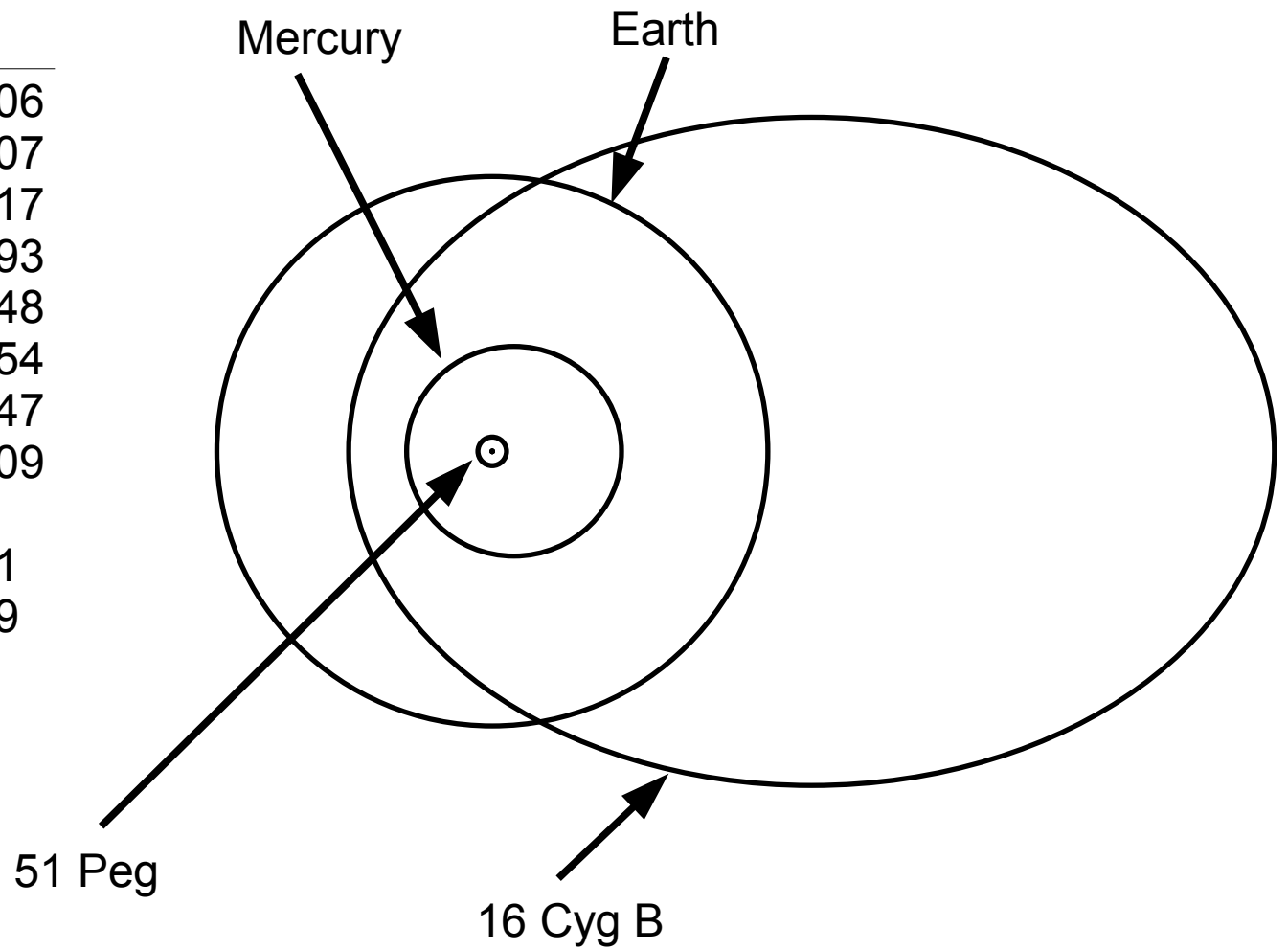
Planetary Orbits

PLANET	*a*	*e*
Mercury	0.39	0.206
Venus	0.72	0.007
Earth	1.00	0.017
Mars	1.52	0.093
Jupiter	5.20	0.048
Saturn	9.54	0.054
Uranus	19.2	0.047
Neptune	30.1	0.009
51 Peg	0.052	0.01
16 Cyg B	1.68	0.69



Planetary Orbits

PLANET	*a*	*e*
Mercury	0.39	0.206
Venus	0.72	0.007
Earth	1.00	0.017
Mars	1.52	0.093
Jupiter	5.20	0.048
Saturn	9.54	0.054
Uranus	19.2	0.047
Neptune	30.1	0.009
51 Peg	0.052	0.01
16 Cyg B	1.68	0.69



Planet Detection Techniques

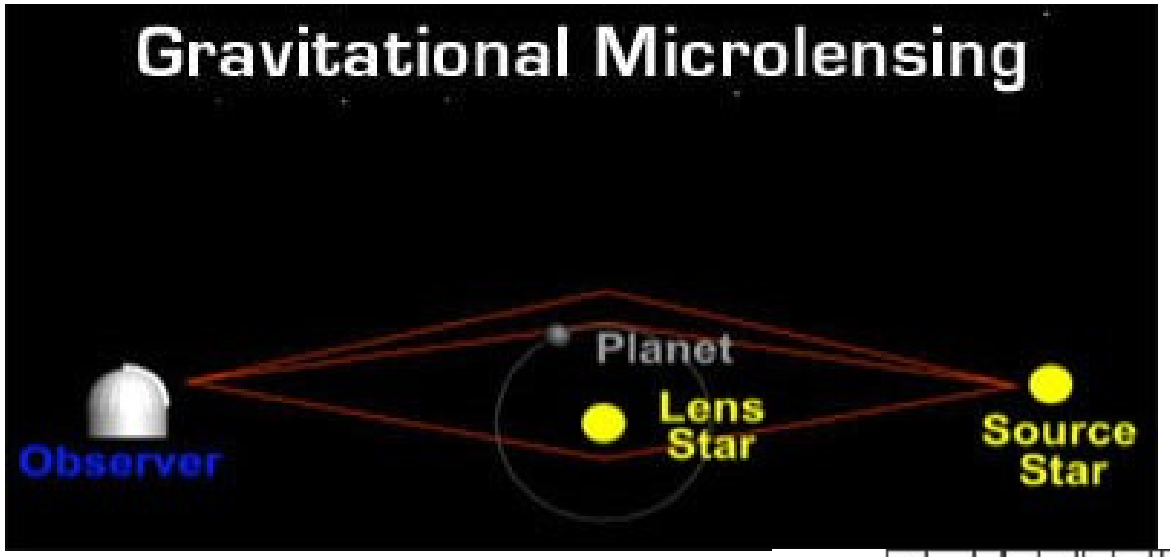
1) Pulse Timing
2) Gravitational lensing
3) Astrometry
4) Direct Imaging
5) Radial Velocity (Doppler)
6) Transits

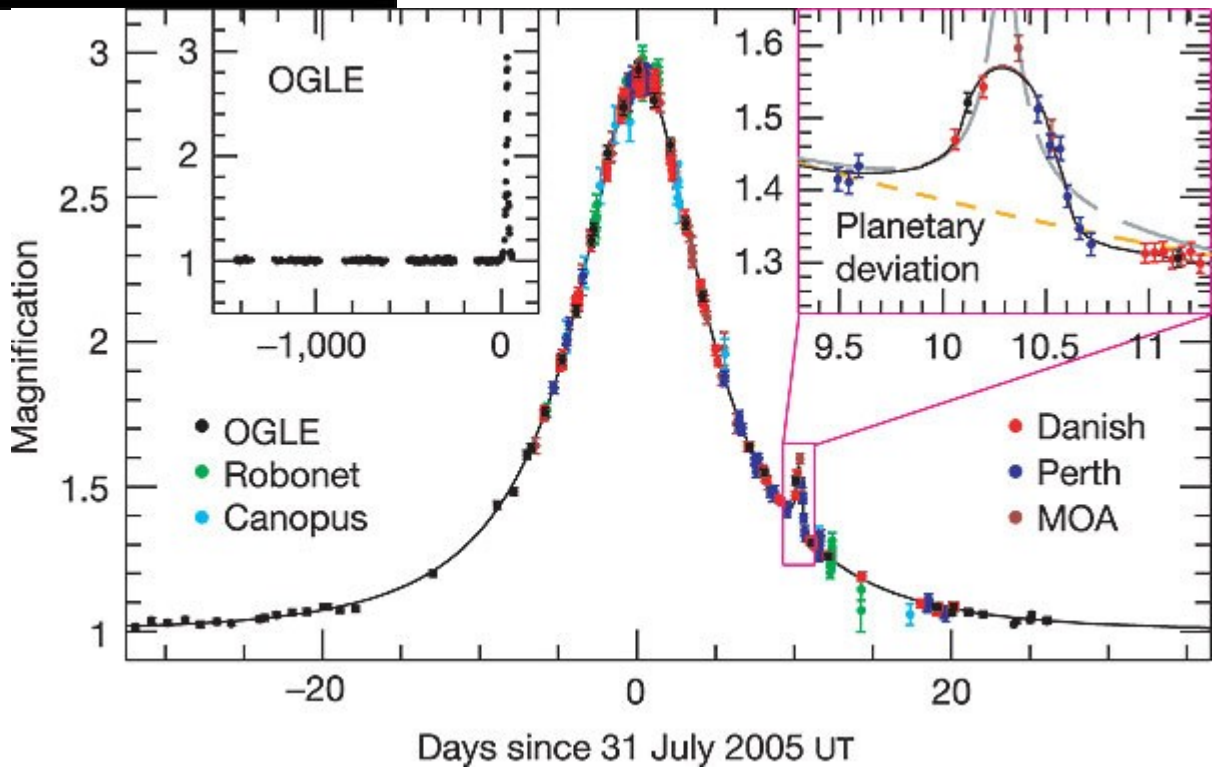
Pulse Timing Technique

Pulse Timing Technique

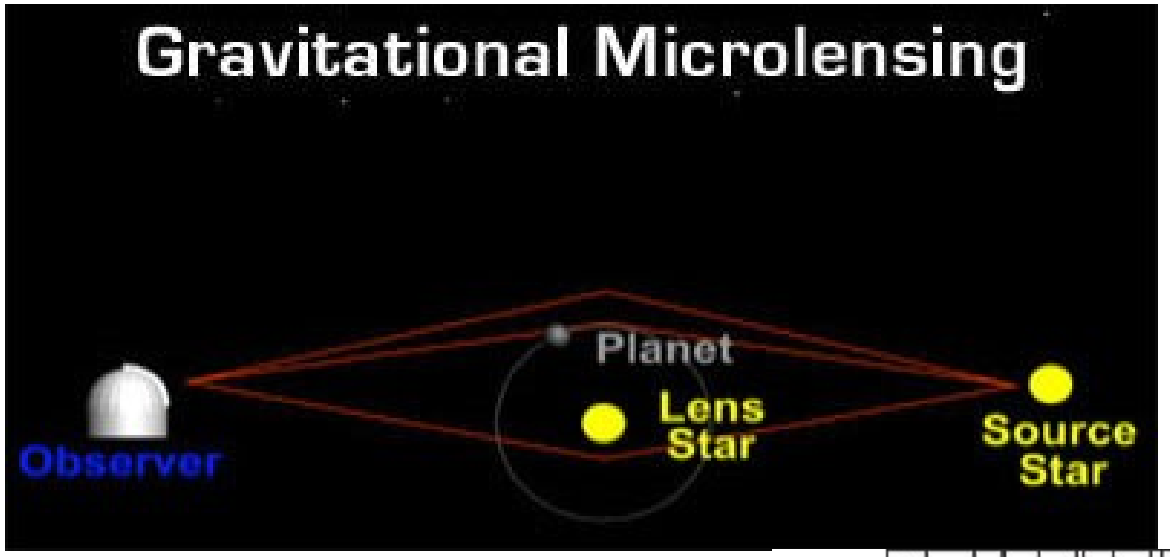
These aren't the planets you're looking for.

Gravitational Lensing Technique



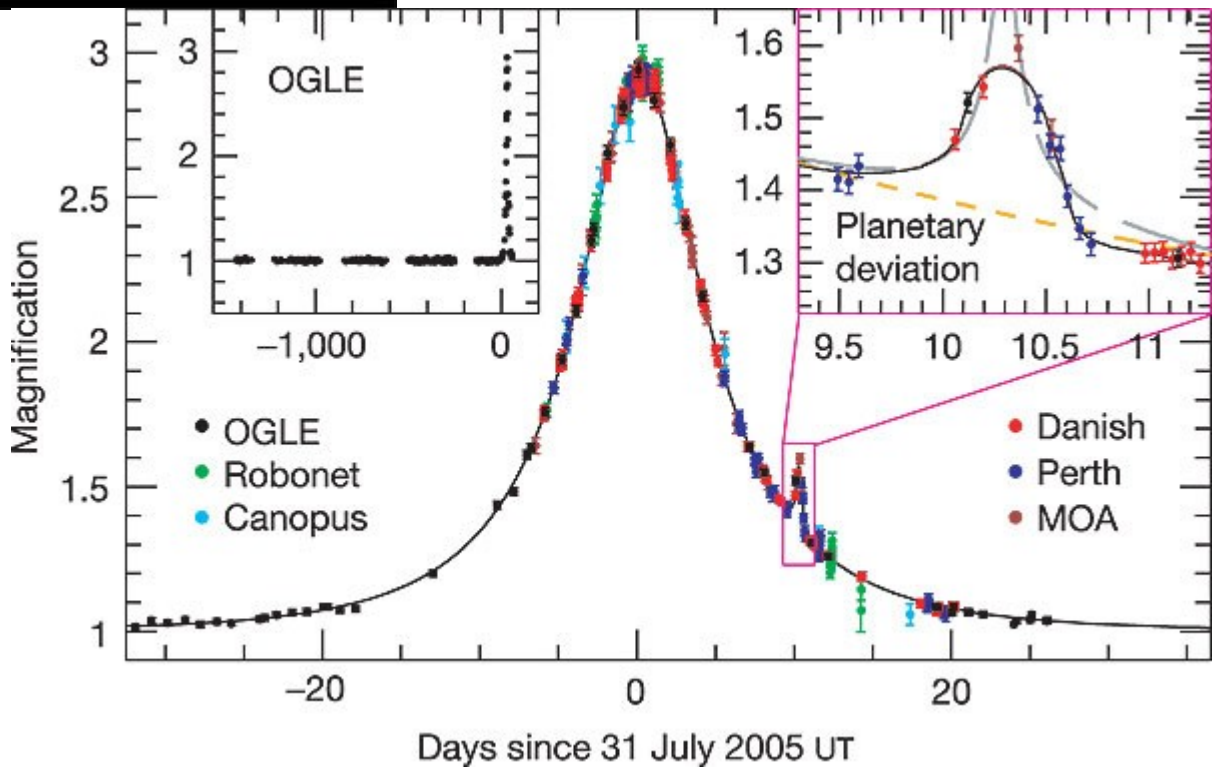


Gravitational Lensing Technique

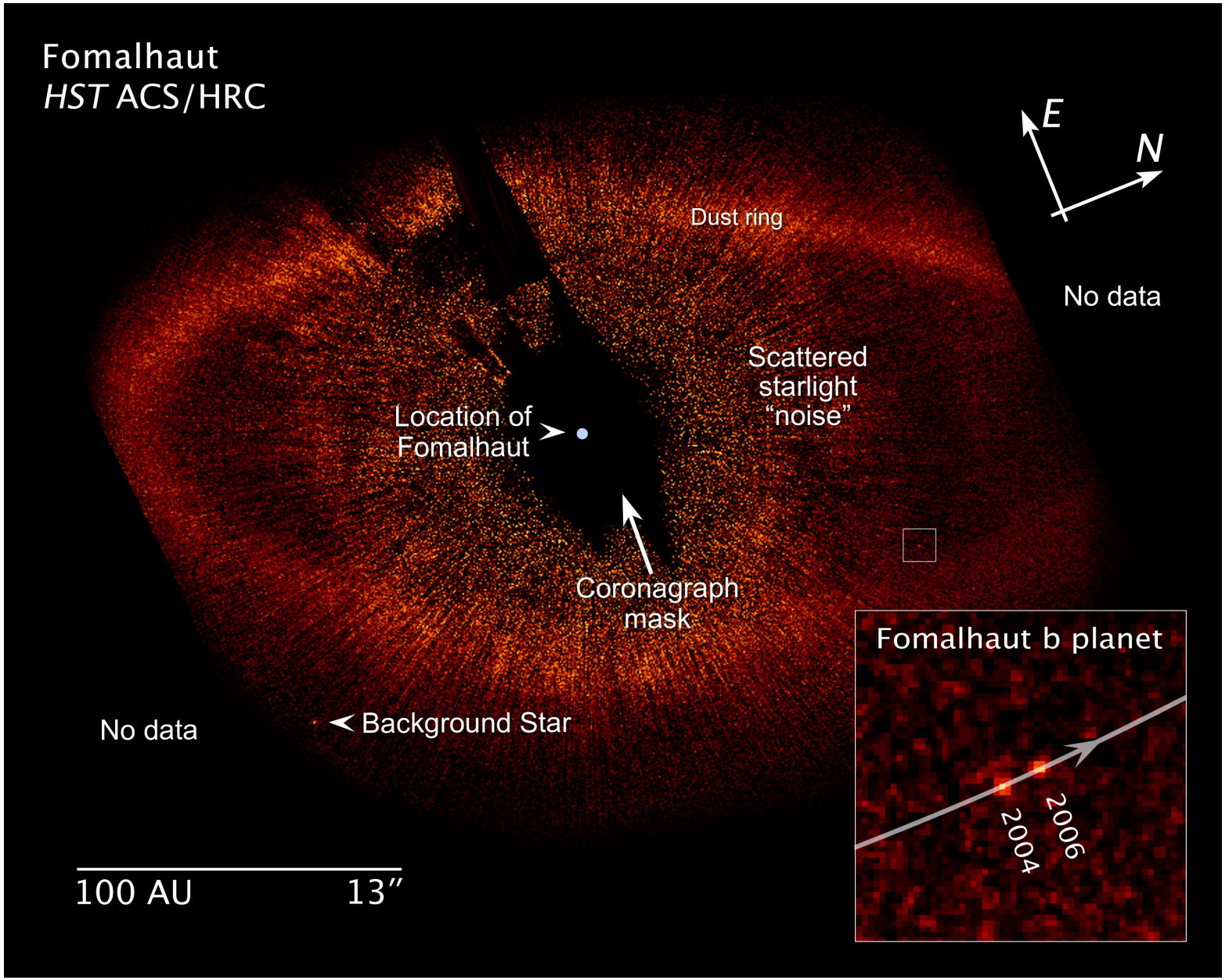


Currently, the only way to get a galaxy-wide census of planets.

These are planets that you can't see orbiting stars that you can't see.

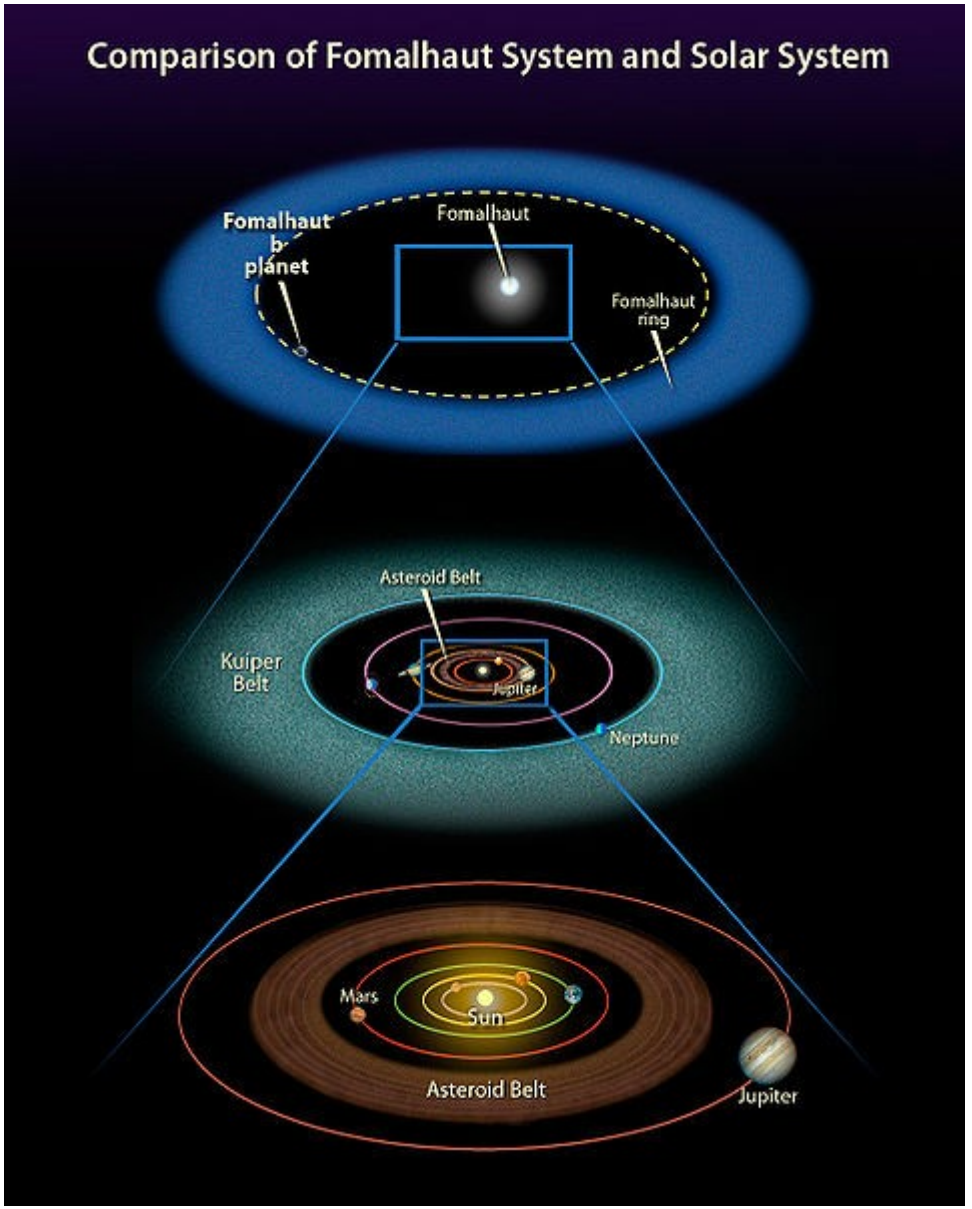


Direct Imaging Technique



Direct Imaging Technique

Fomalhaut b
- Mass: ~1 Jupiter
- Period: ~1000 years
- Orbit Dist: ~10B miles
- Ecc: ~0.1

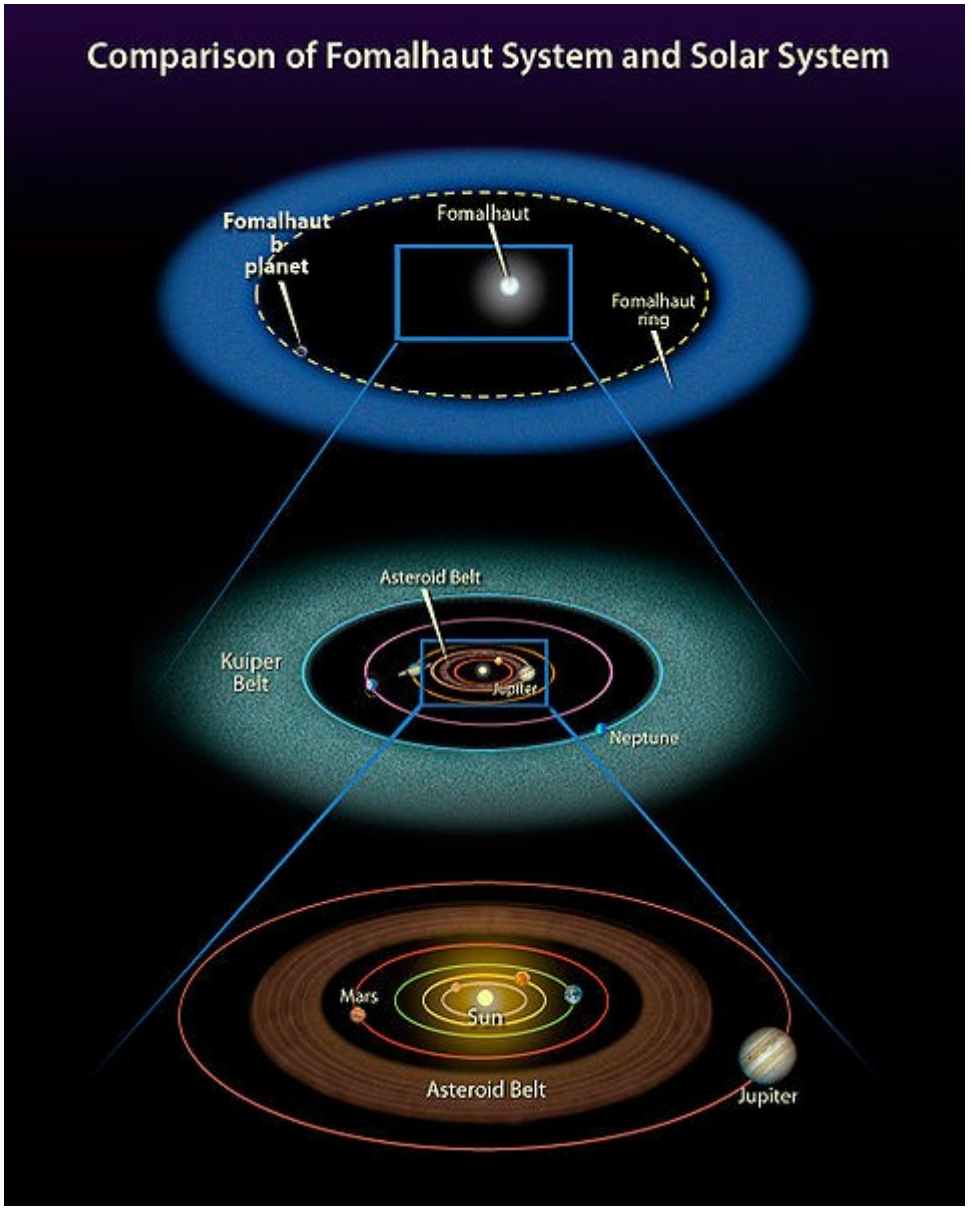


Direct Imaging Technique

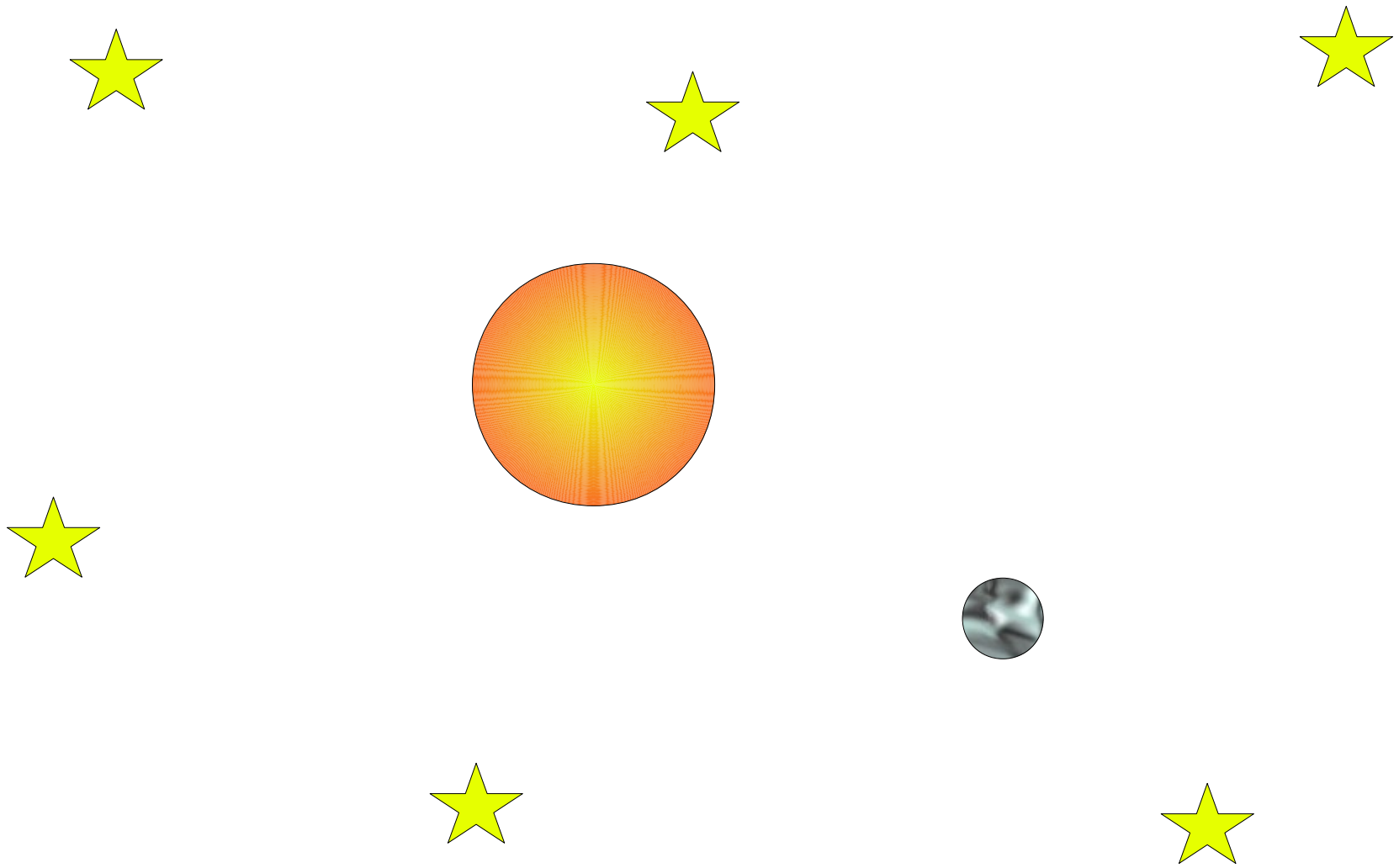
Fomalhaut b
- Mass: ~1 Jupiter
- Period: ~1000 years
- Orbit Dist: ~10B miles
- Ecc: ~0.1

Contrast Ratio:
- State of the art = 1e-5
- 1 part per 100,000

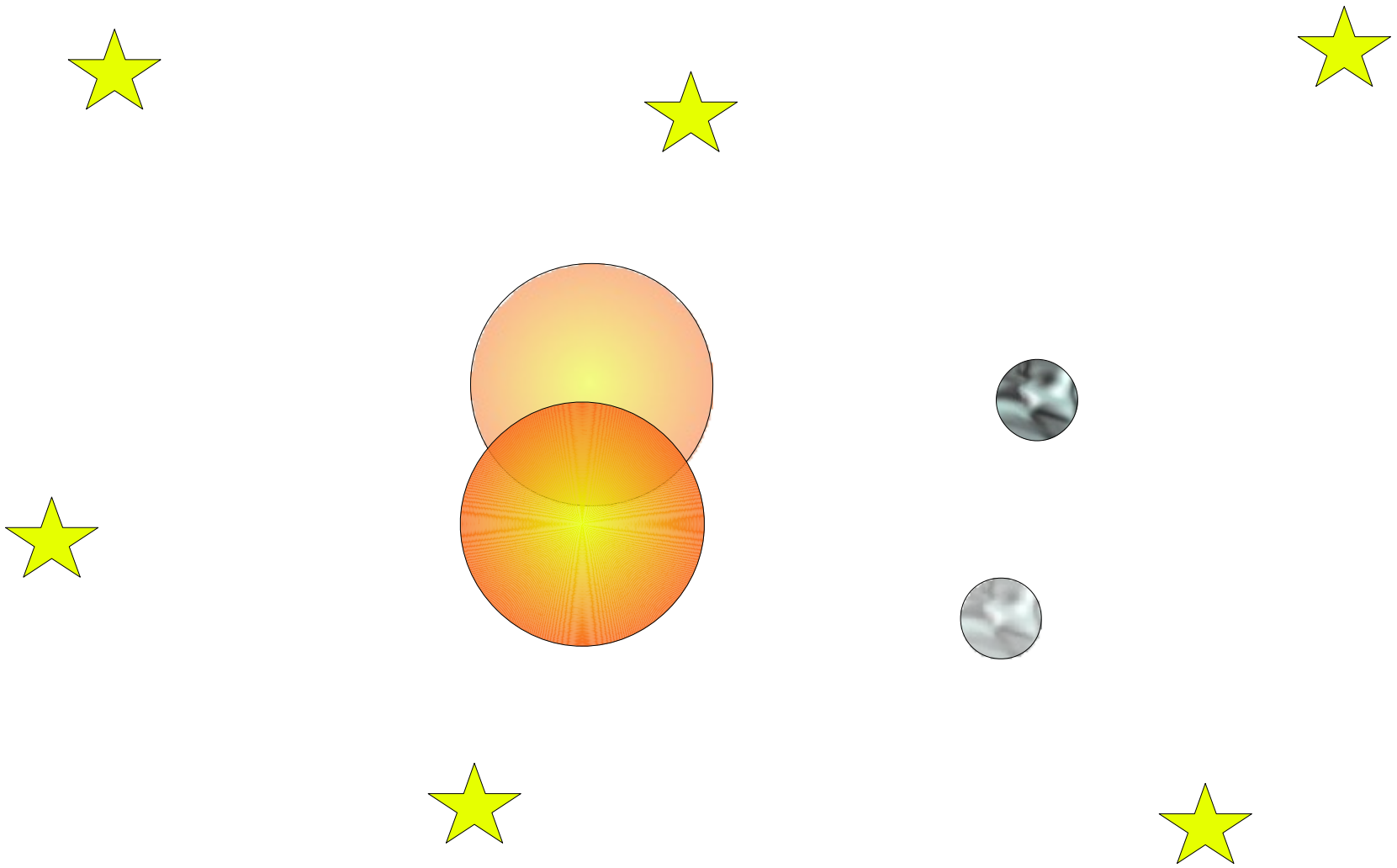
- To see Earth = 1e-11
- 1 part per 100,000,000,000



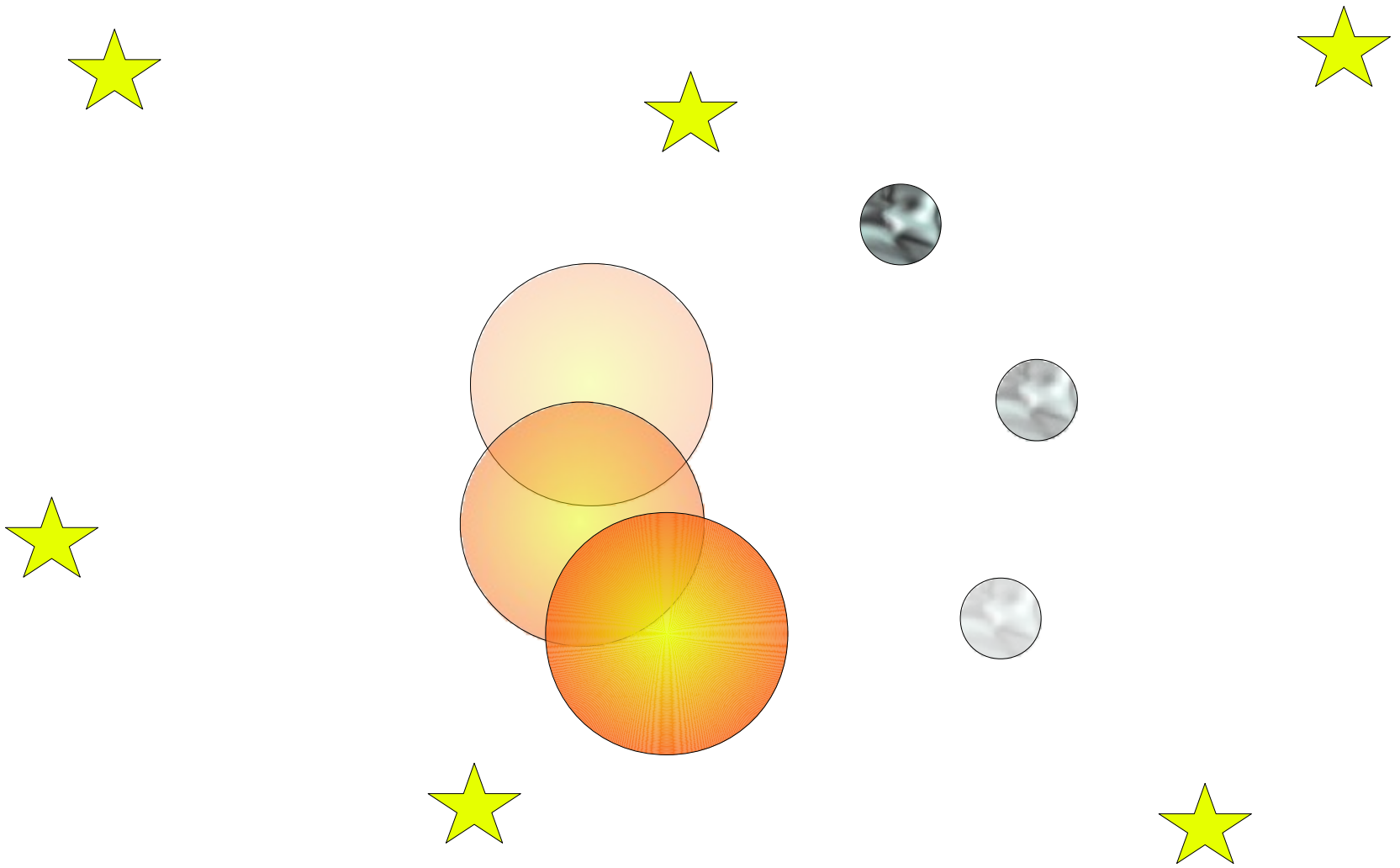
Astrometric Technique



Astrometric Technique



Astrometric Technique



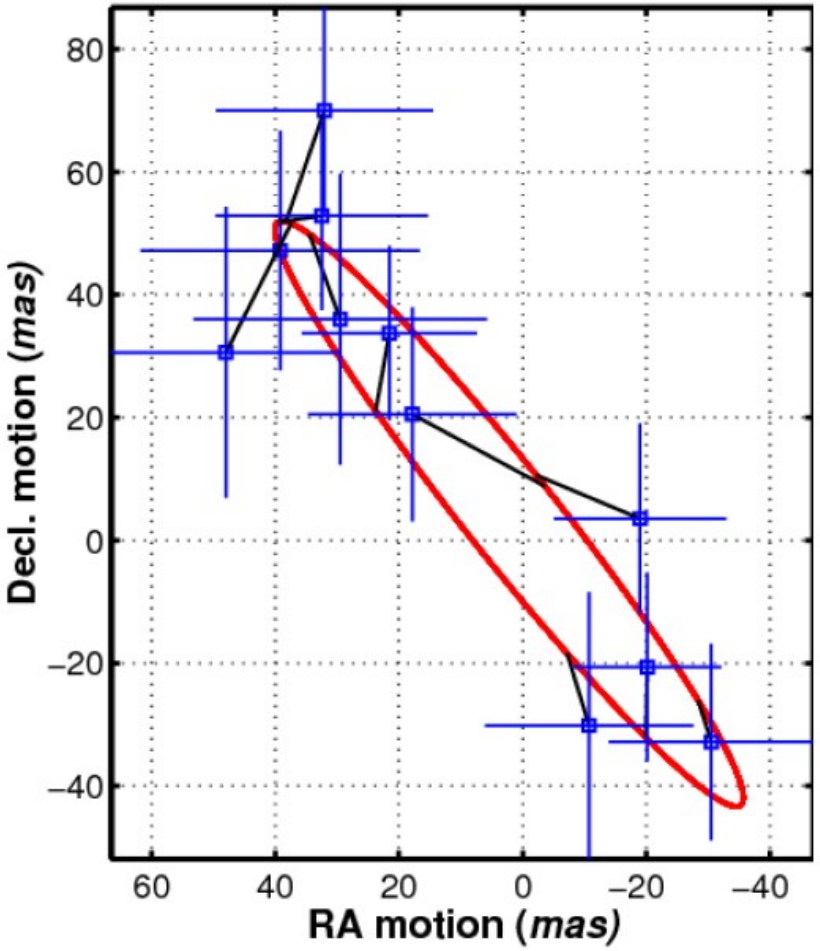
Astrometric Technique

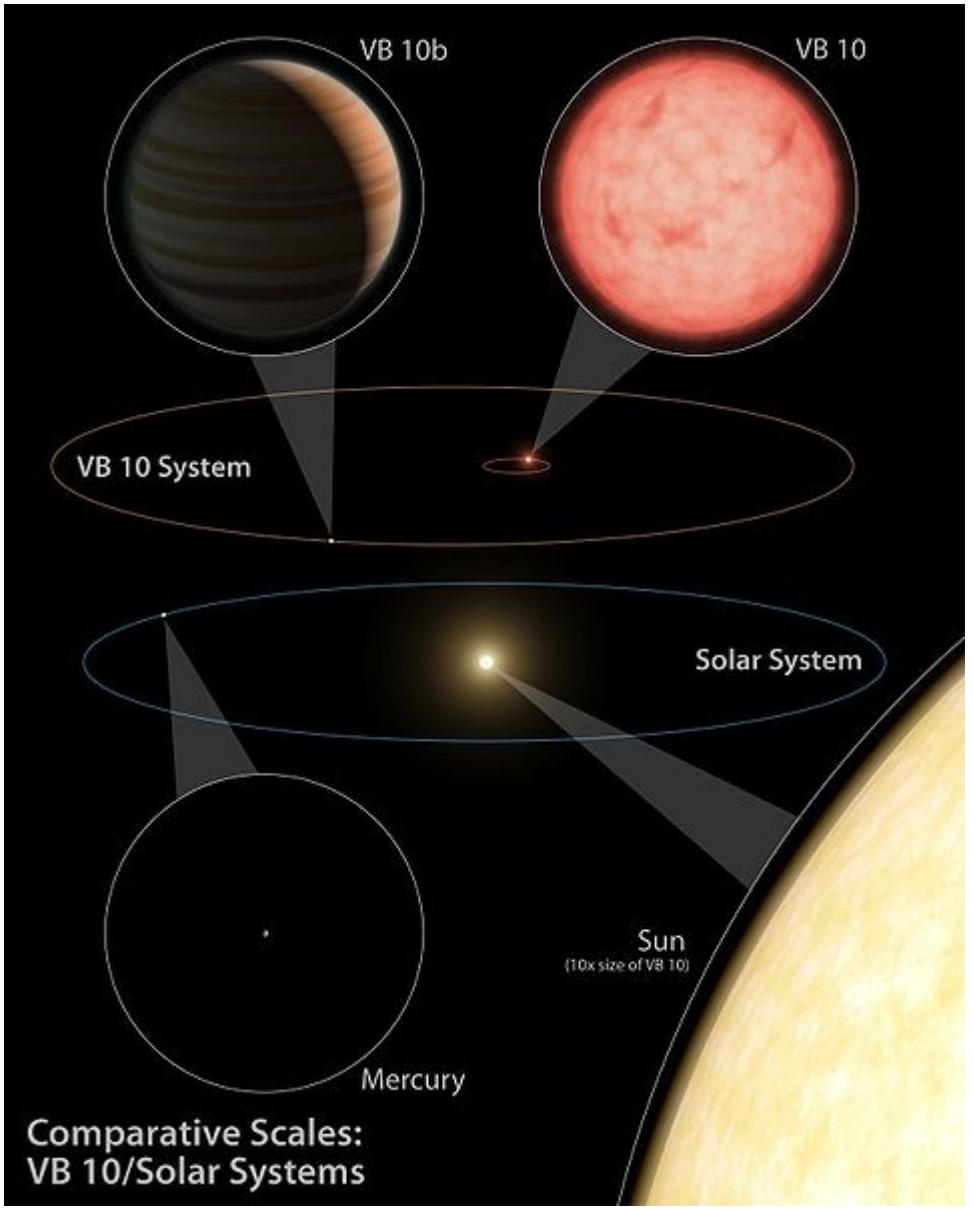
VB 10b

Mass: ~5 Jupiters

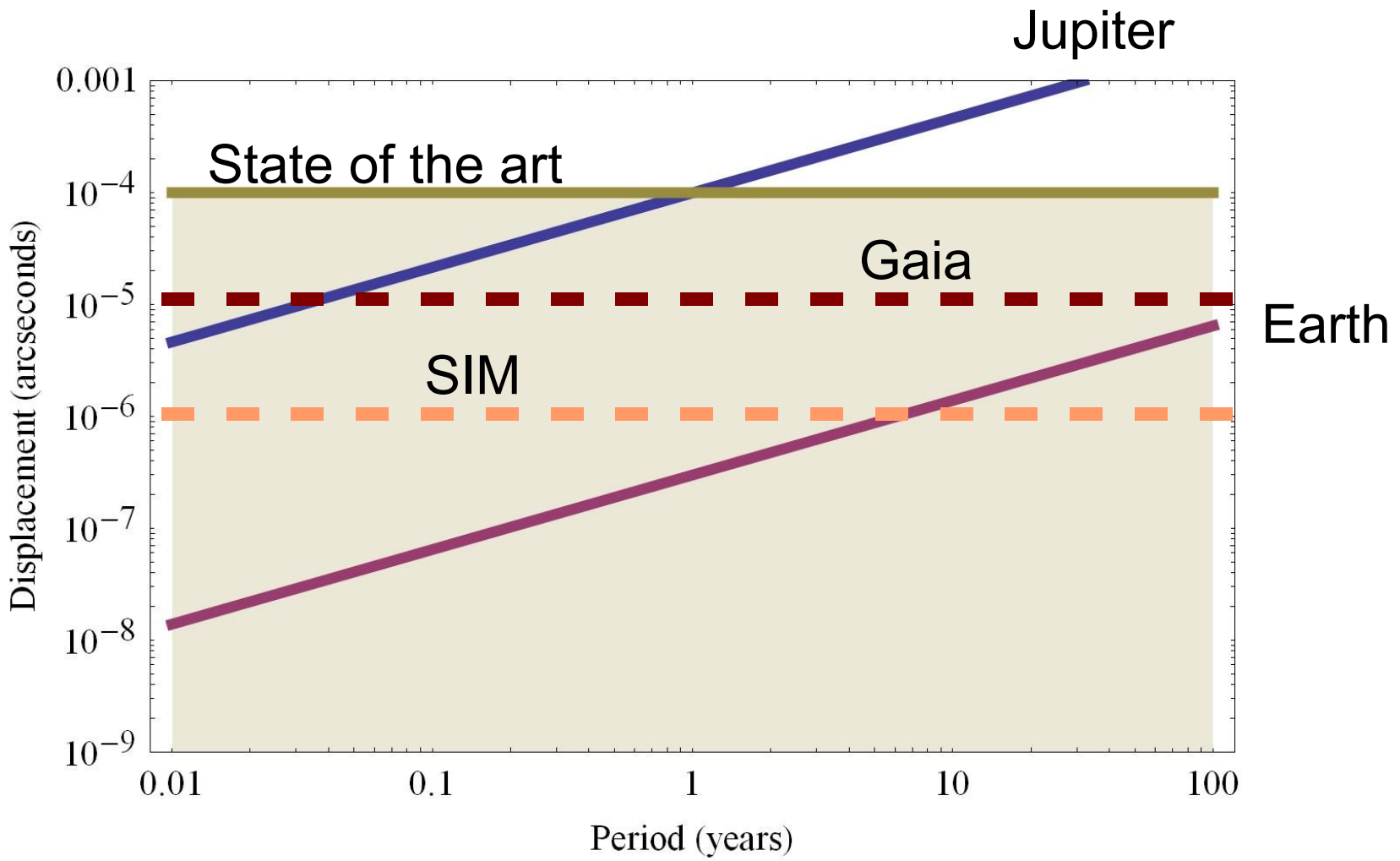
Period: 271 Days

Orbit Dist: ~0.36 AU

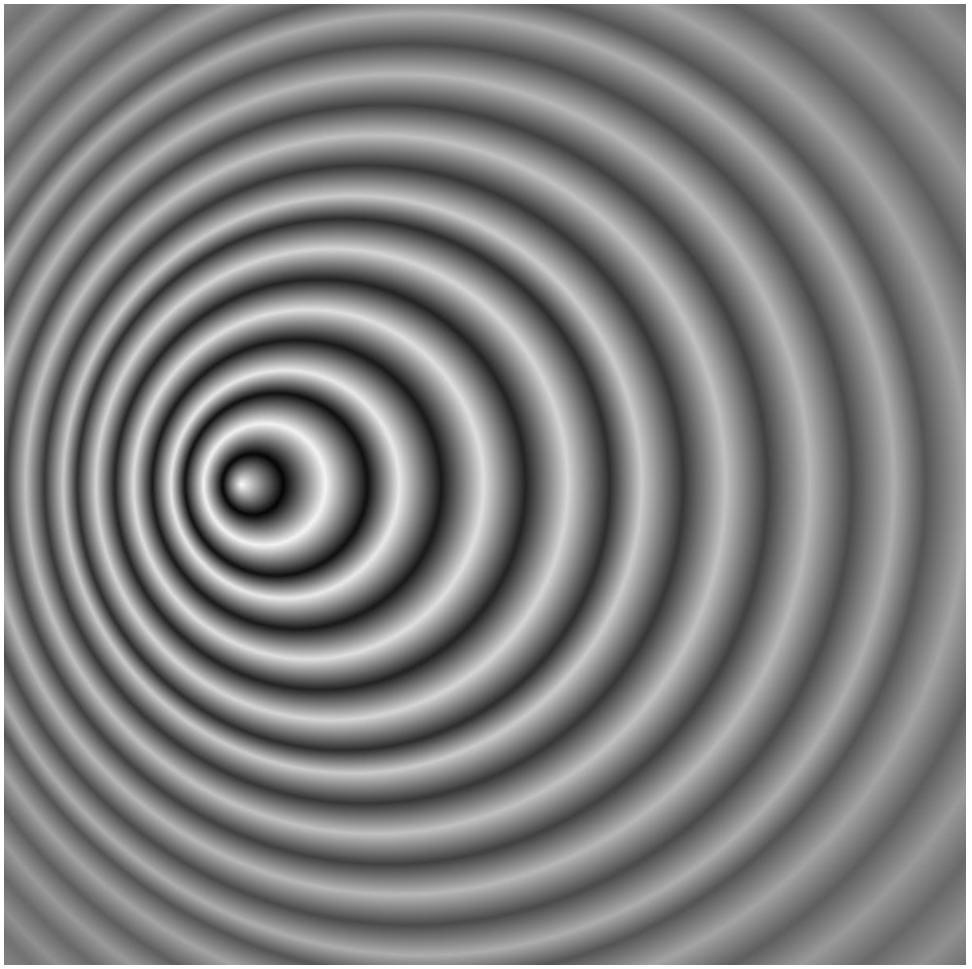




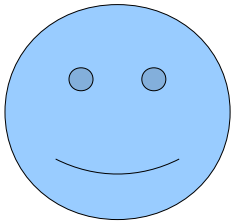
Astrometric Technique



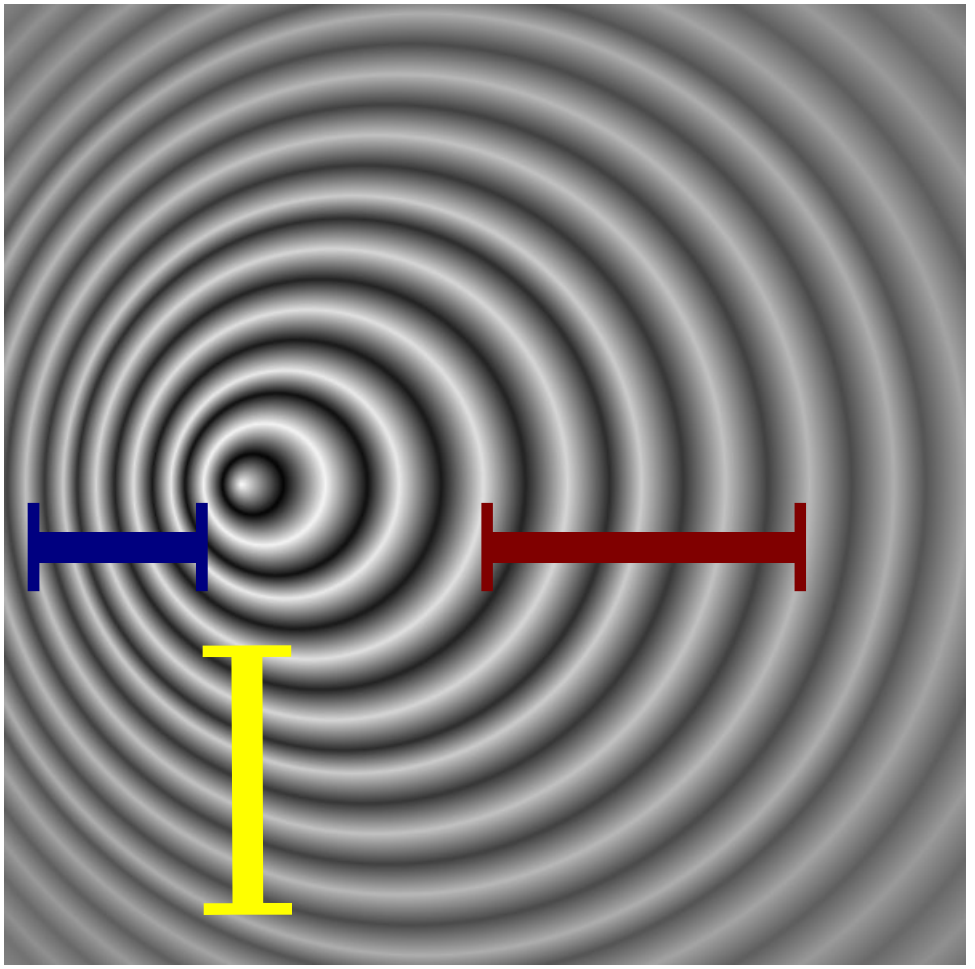
Radial Velocity Technique

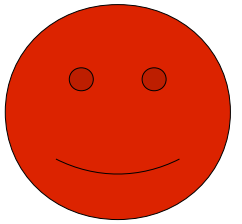


Radial Velocity Technique

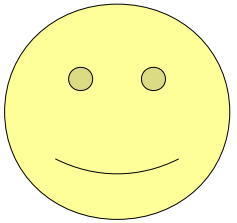


Wavelength is compressed: “blueshift”





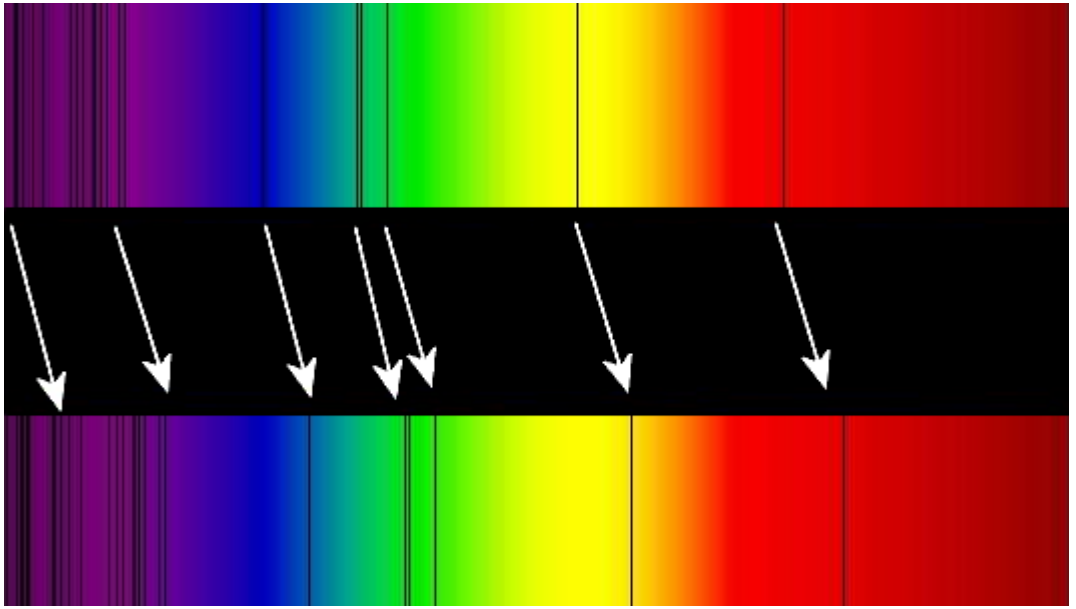
Wavelength is expanded: “redshift”



Wavelength is unchanged

The Radial Velocity Technique

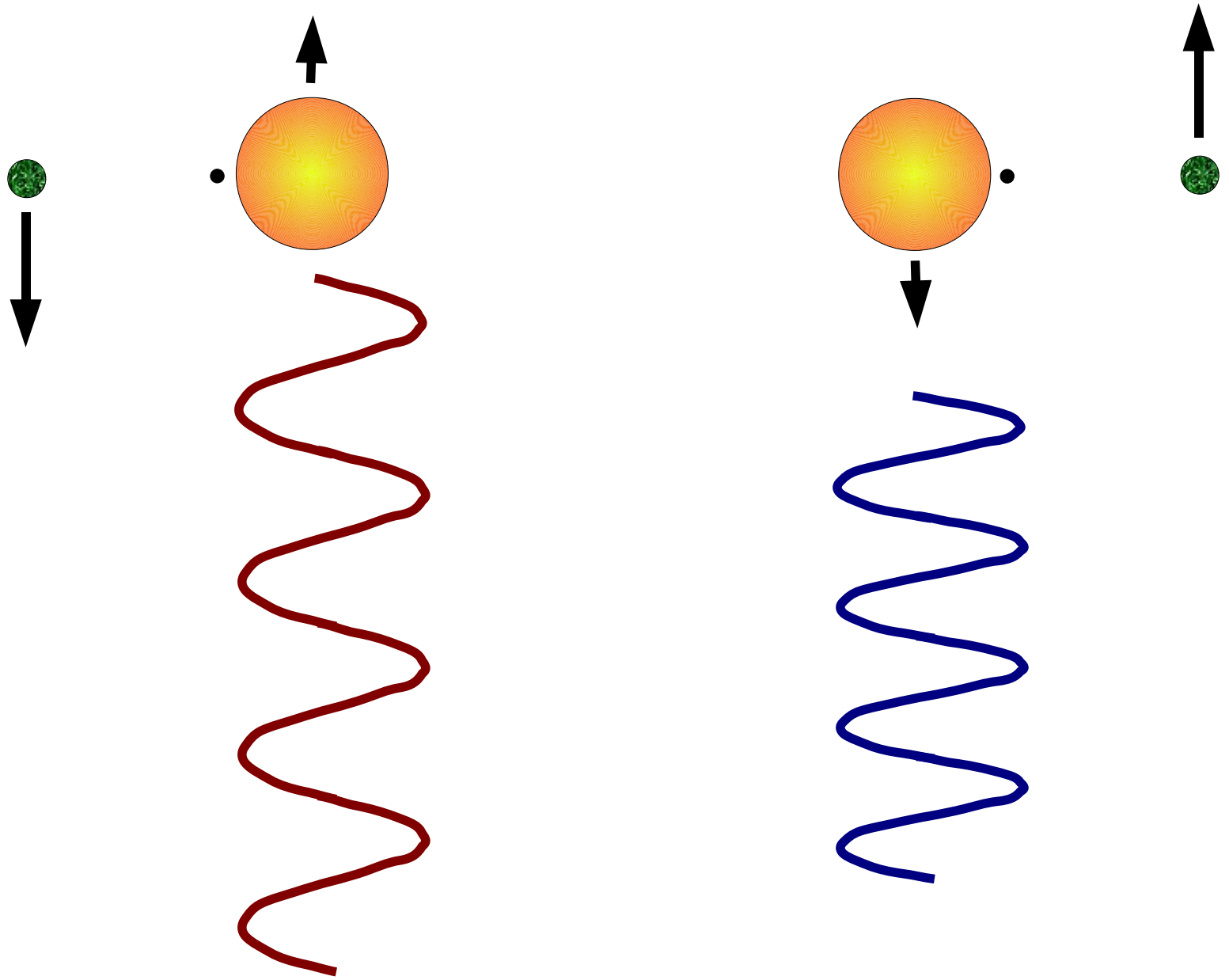
Spectrum measured in a laboratory



Spectrum of a star

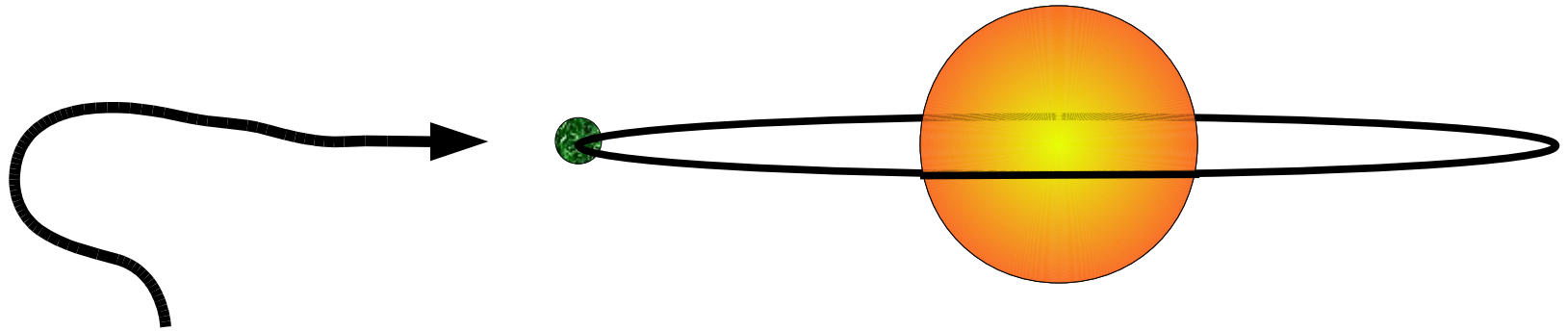
This spectrum has been redshifted.
The star is moving away from the observer

Radial Velocity Technique

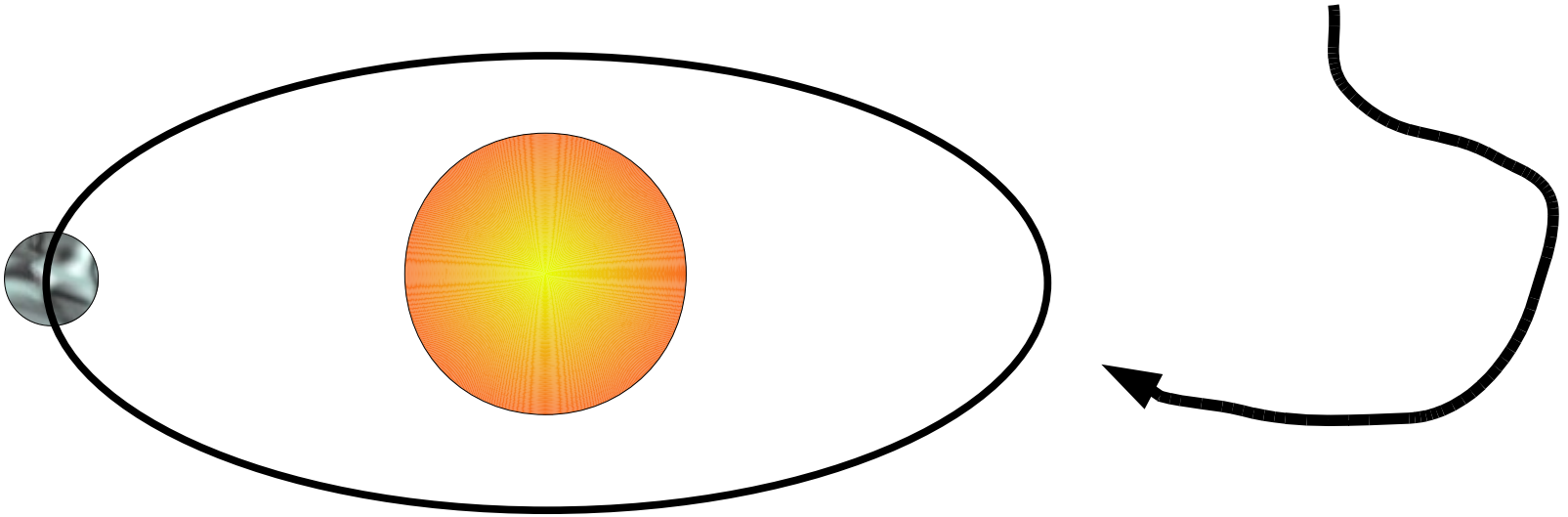


Radial Velocity Technique

You can only measure radial velocities along the line of sight.



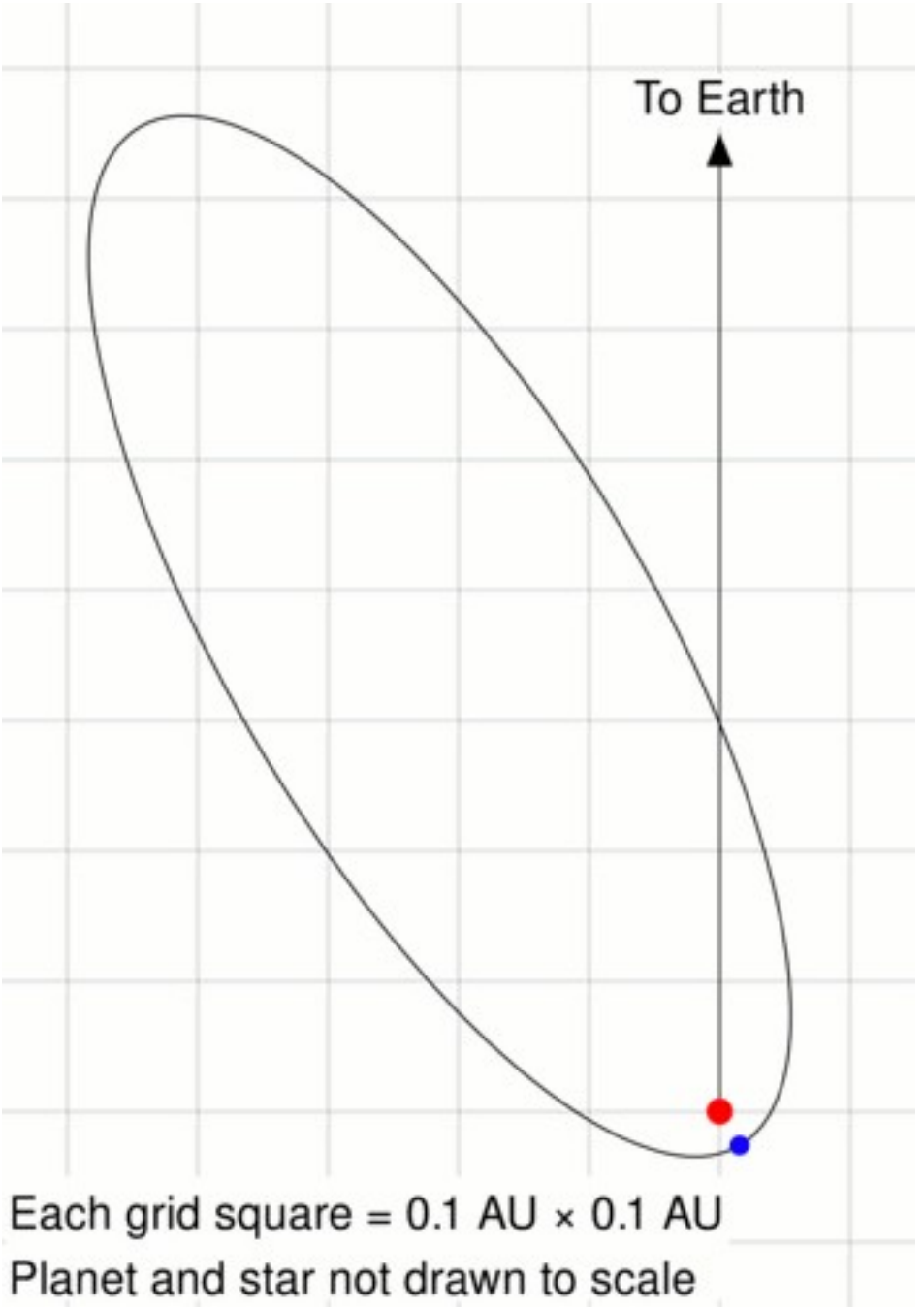
This system looks identical to this system.



Radial Velocity Technique

HD 80606
Period: 111 days
Eccentricity: 0.934

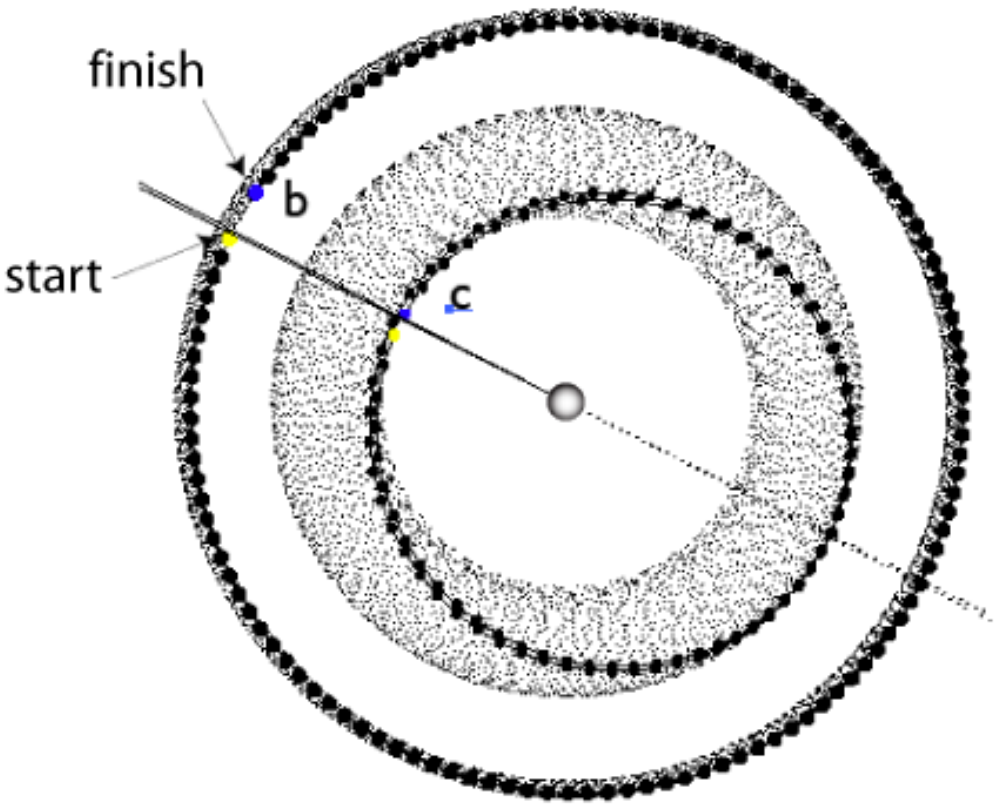
Recently found to transit



Radial Velocity Technique

GJ 876

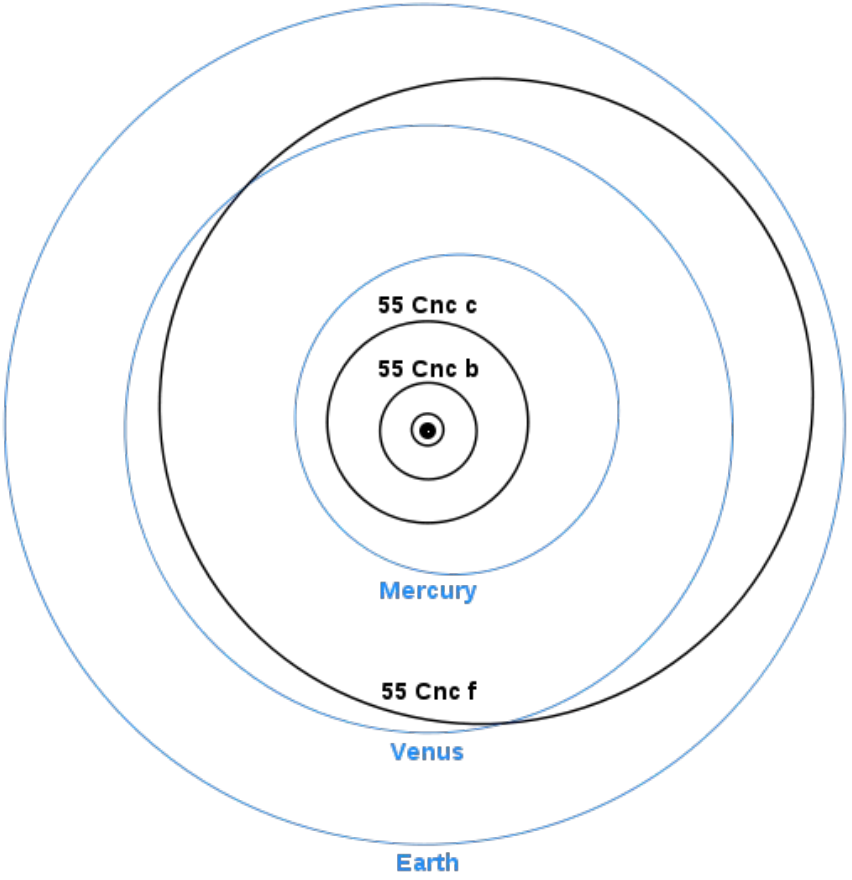
Two planets with very
Strong mutual interactions

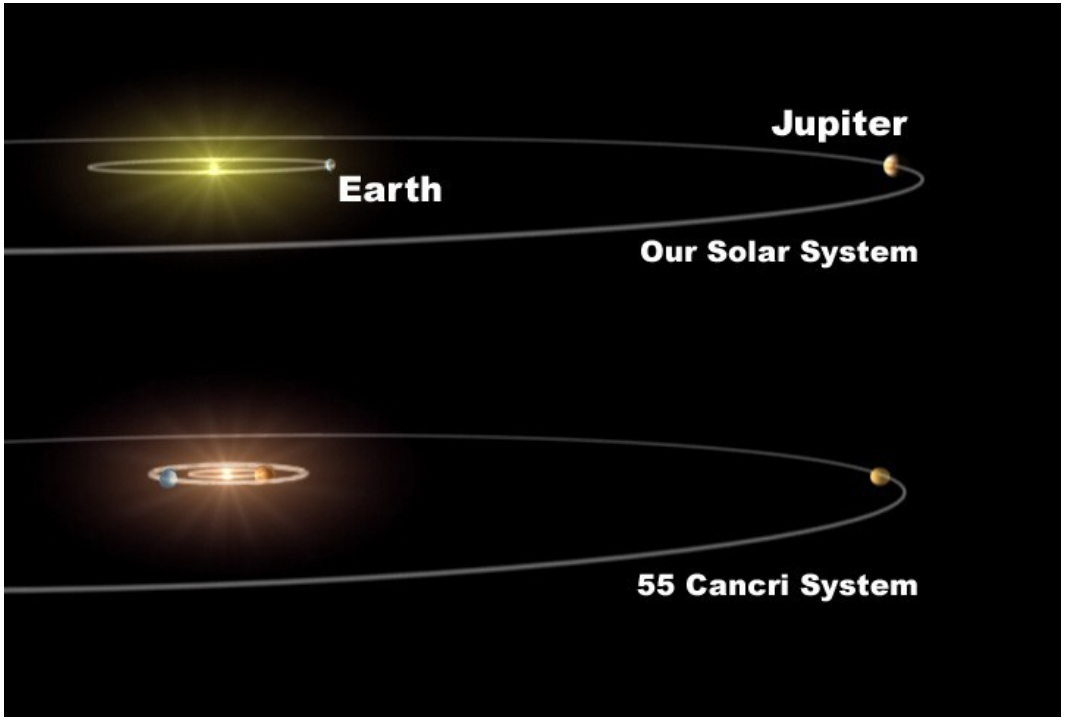


Radial Velocity Technique

55 Cnc

5 planets with orbits between 3 days and 14 years and masses between 10 Earths and 3 Jupiters.

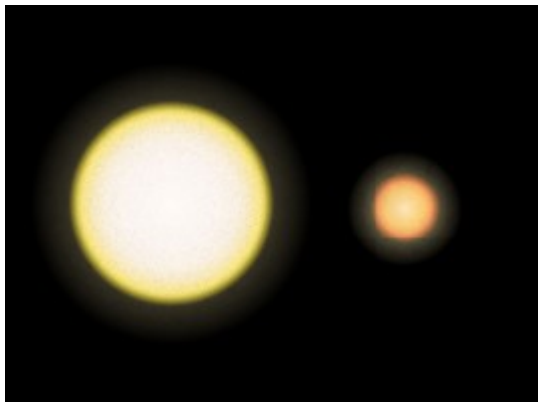


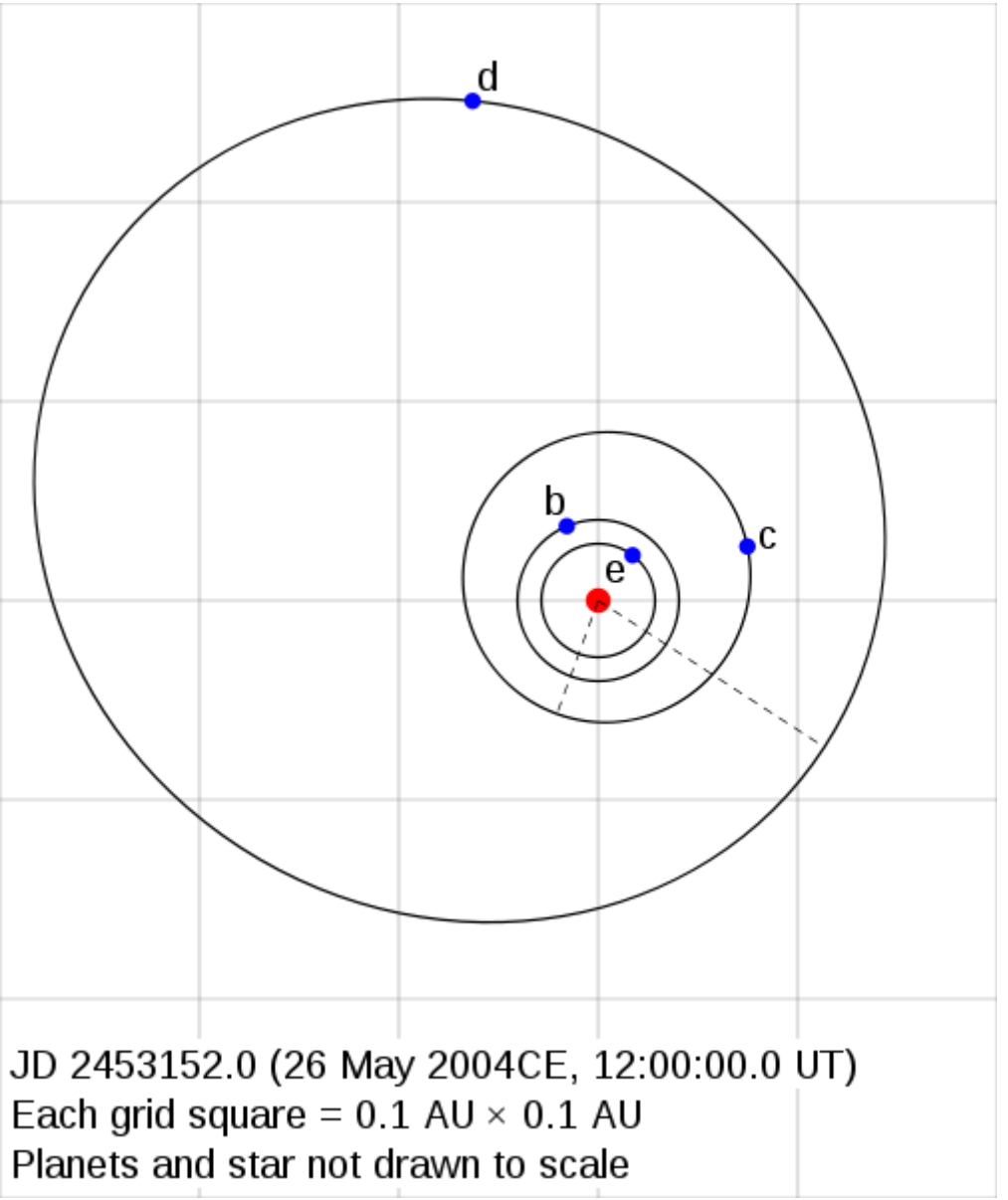


Radial Velocity Technique

GJ 581

Two planets near the habitable zone

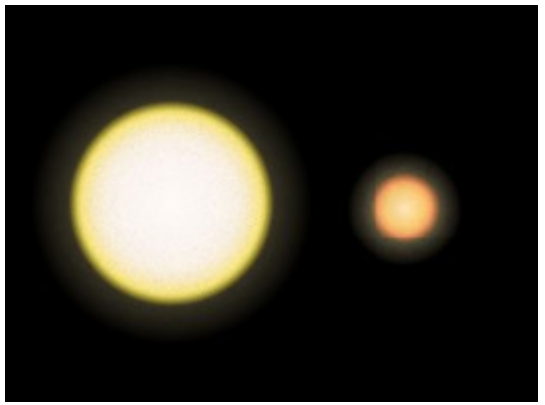


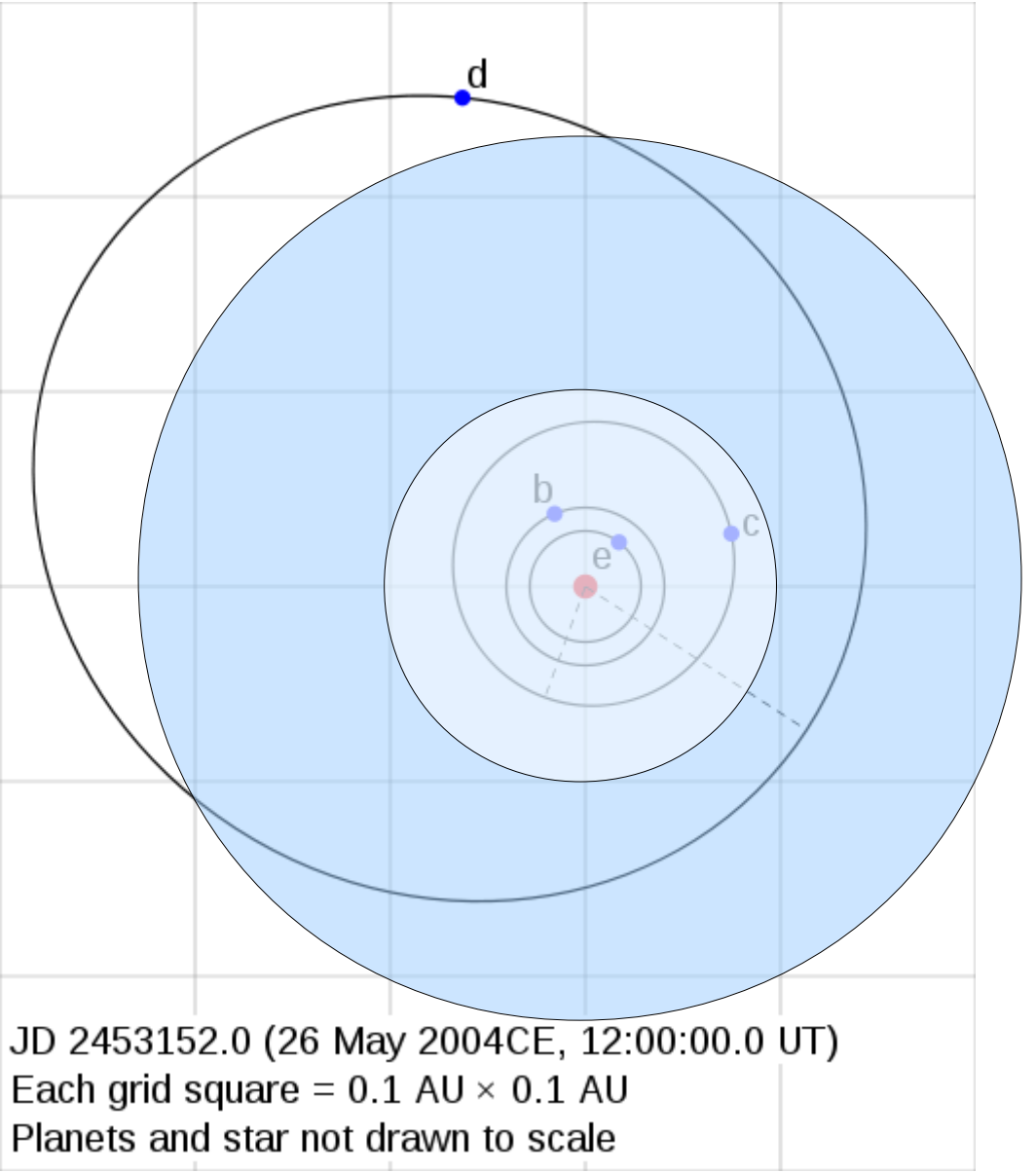


Radial Velocity Technique

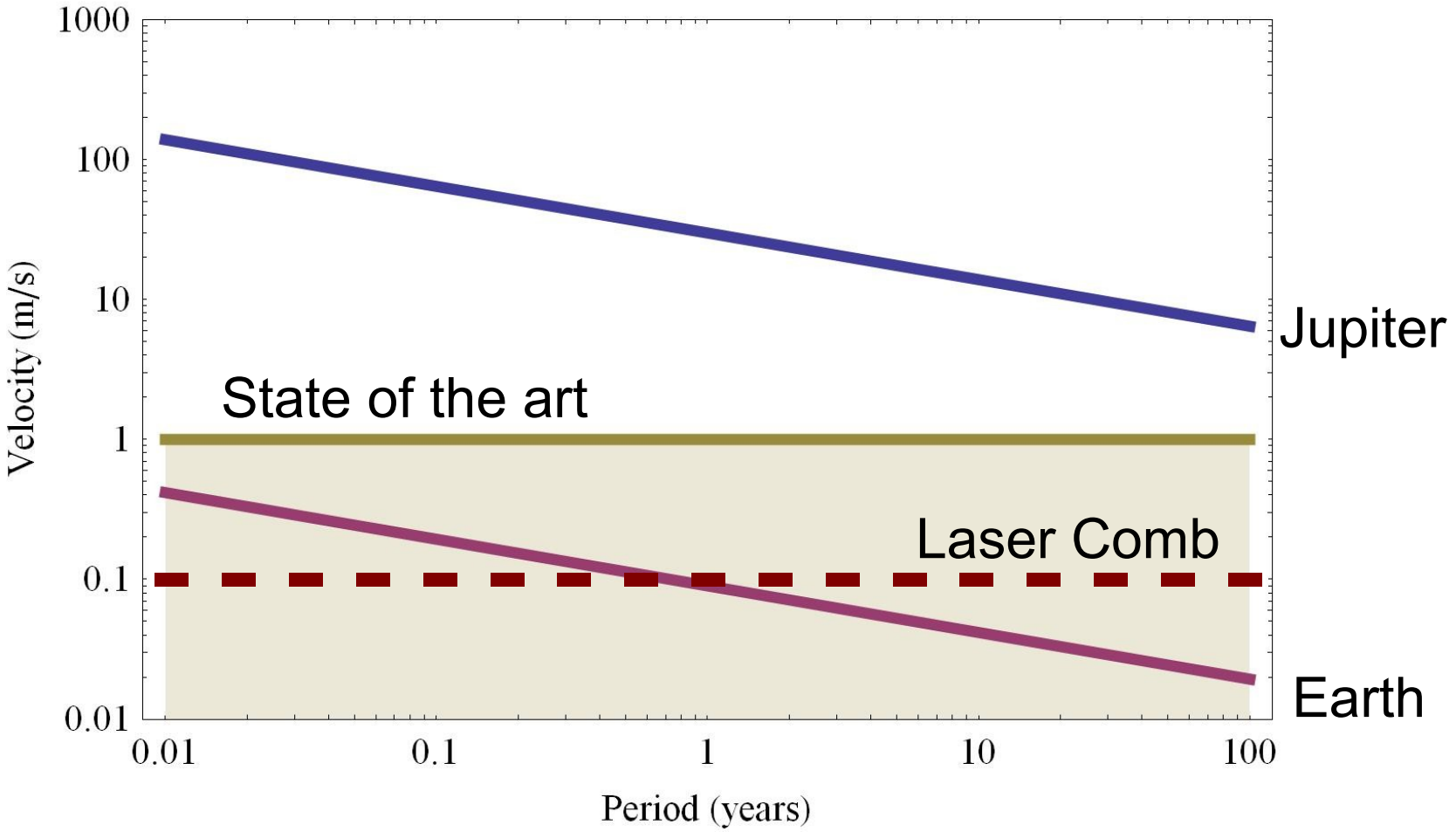
GJ 581

Two planets near the habitable zone





Radial Velocity Technique

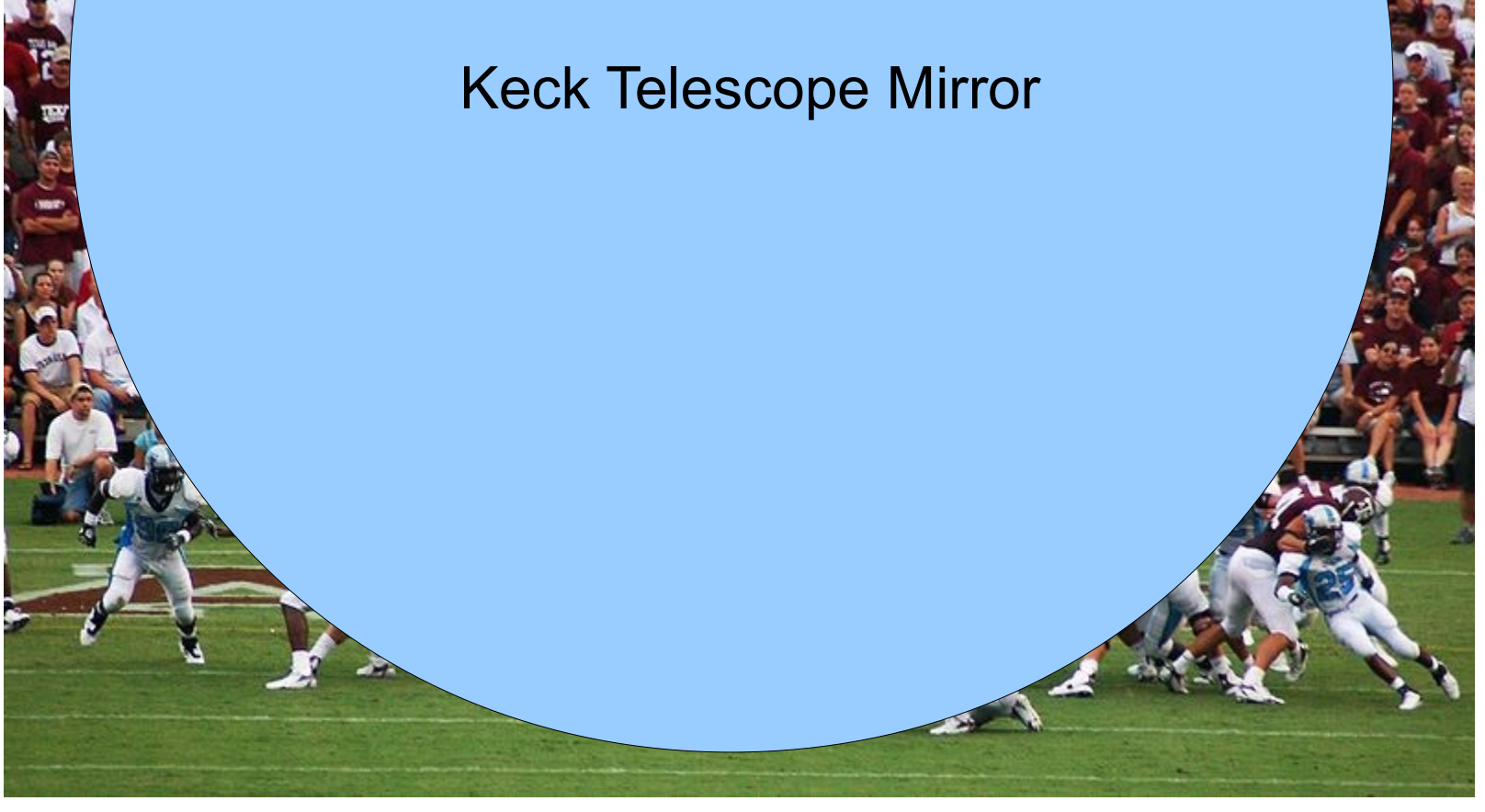


Planet Transit Technique

Transit of Venus (courtesy of David Cortner)

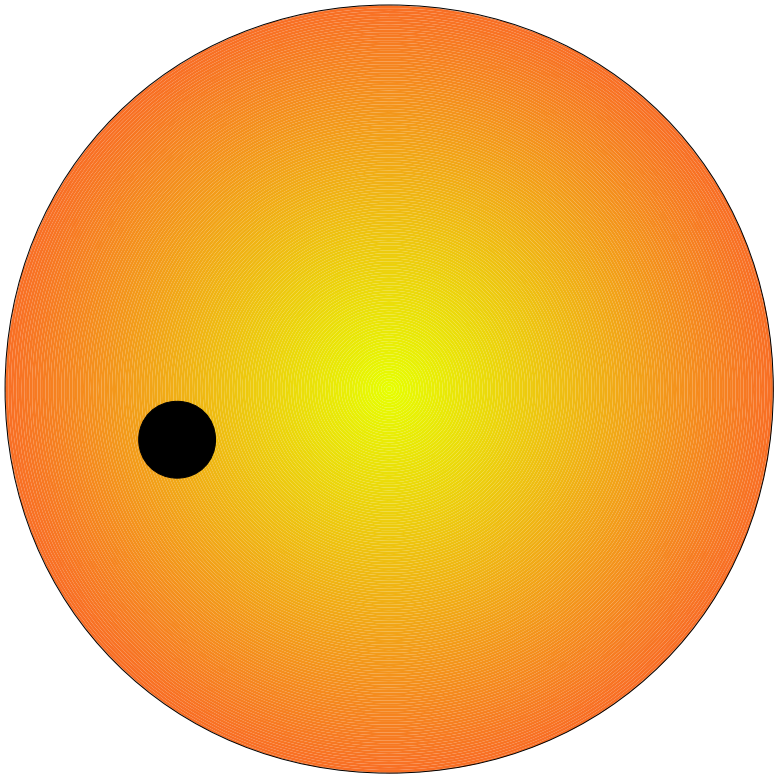
Radial Velocity Measurements

Radial Velocity Measurements

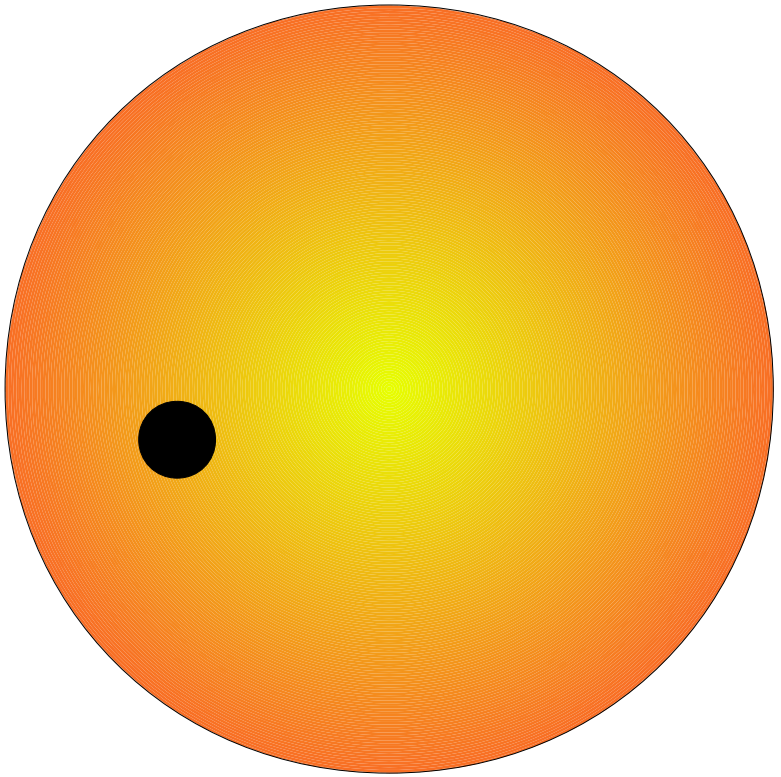


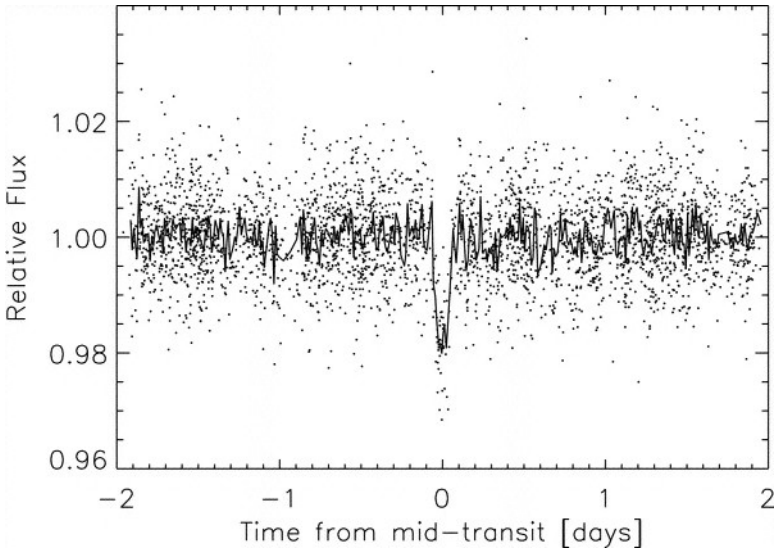
Keck Telescope Mirror

Planet Transit Technique



Planet Transit Technique

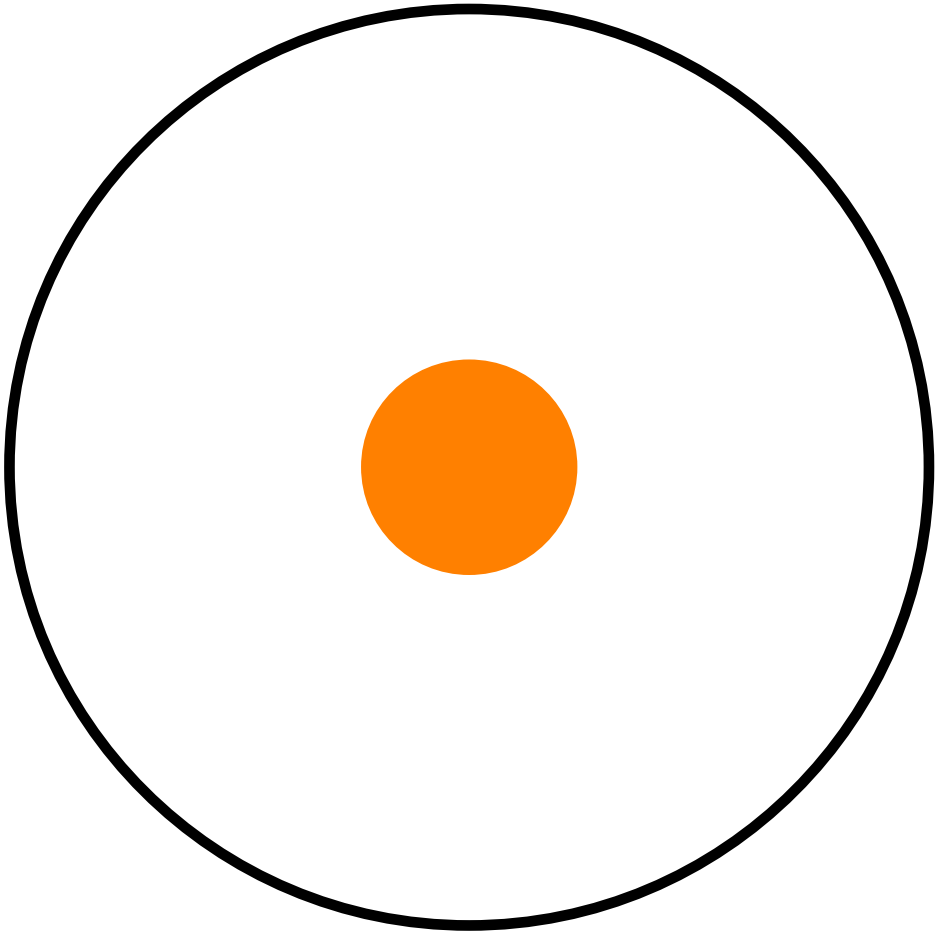




Planet Transit Technique

CoRoT-7b
- Period: 0.85 days
- Mass: ~5 Earths

CoRoT-7c
- Period: 4.5 days
- Mass: 8.4 Earths

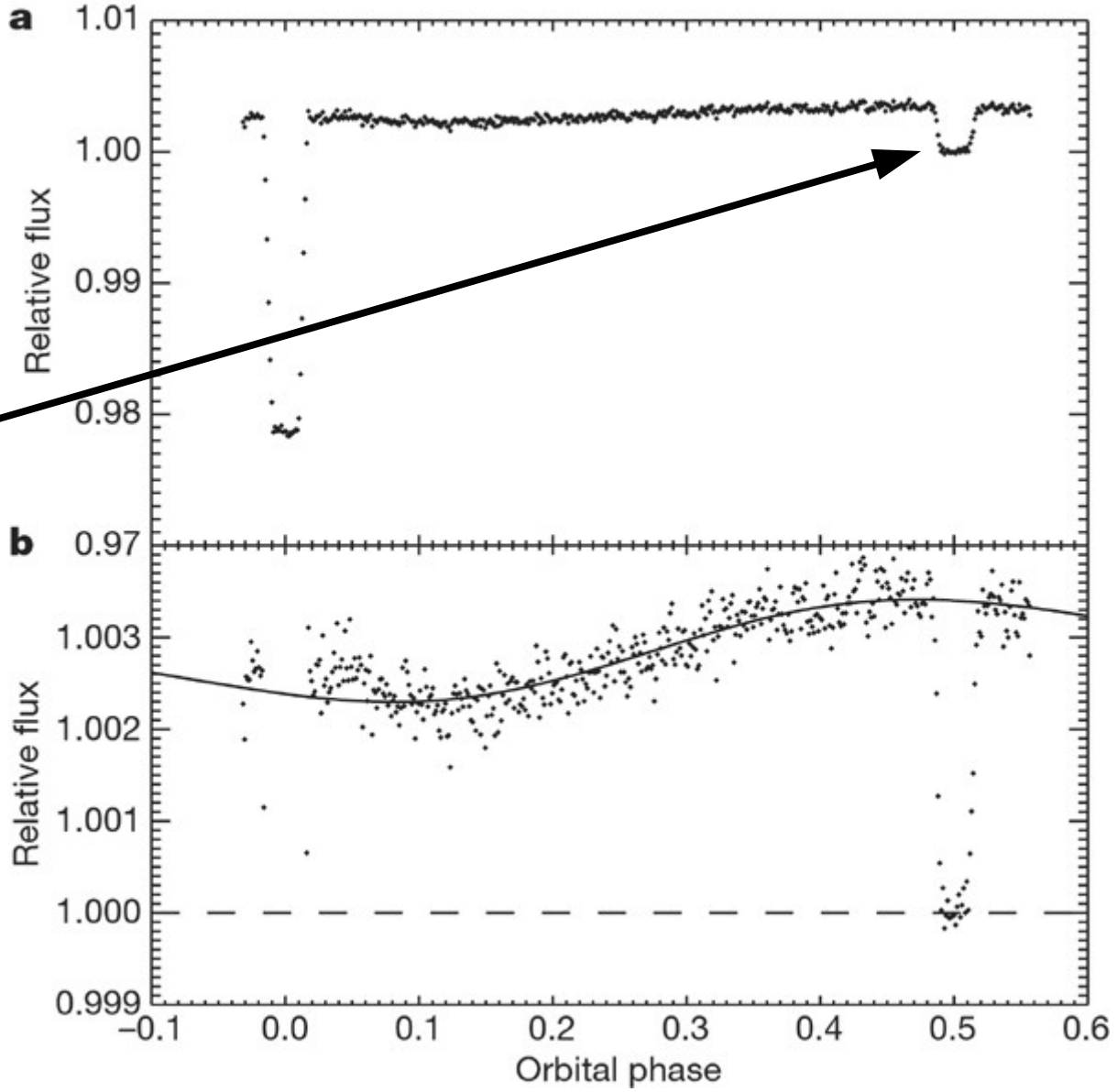


Planet Transit Technique

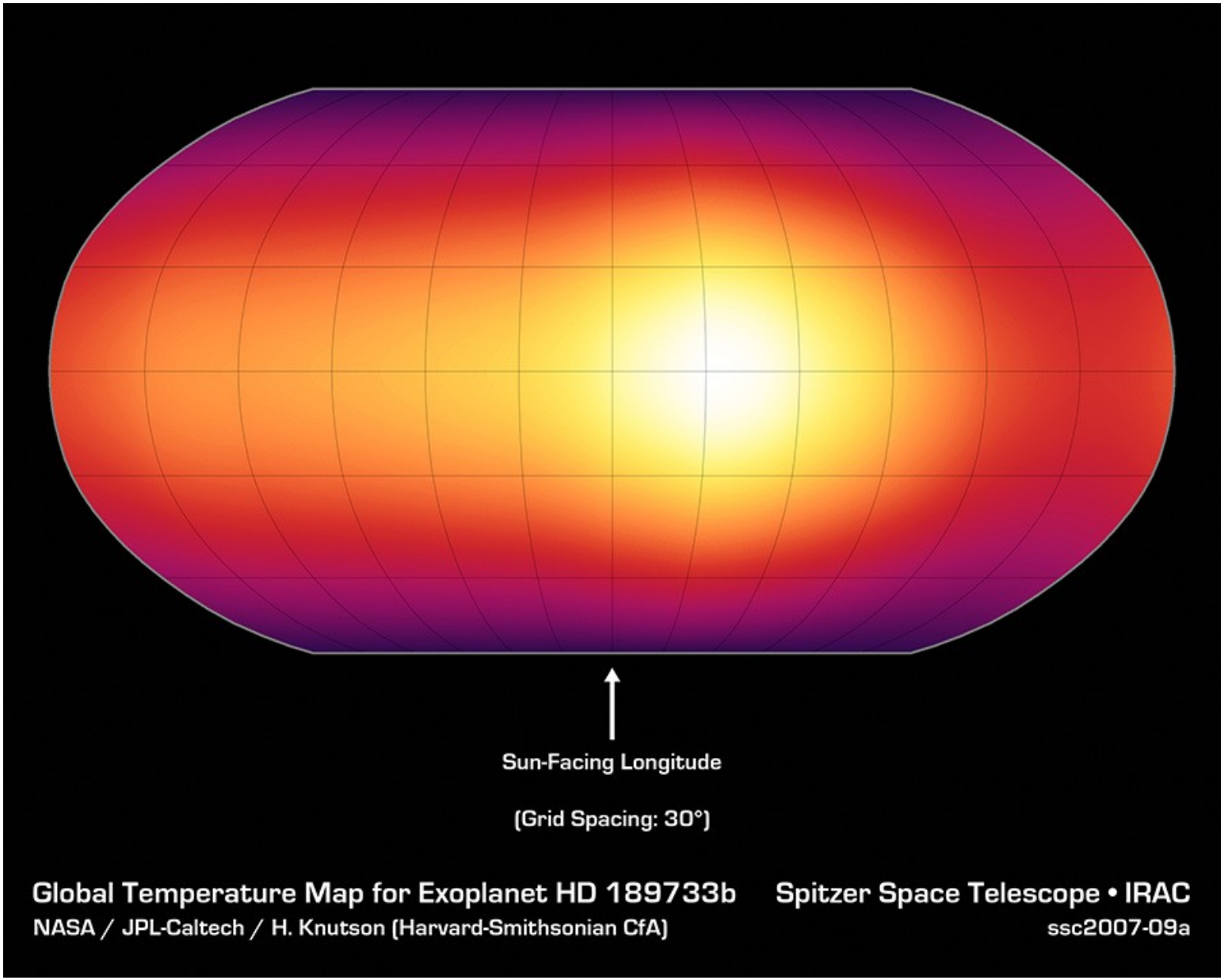
HD 189733b
Period: 2.2 days
Mass: 1.1 Jupiters

Secondary eclipse

Phase variations

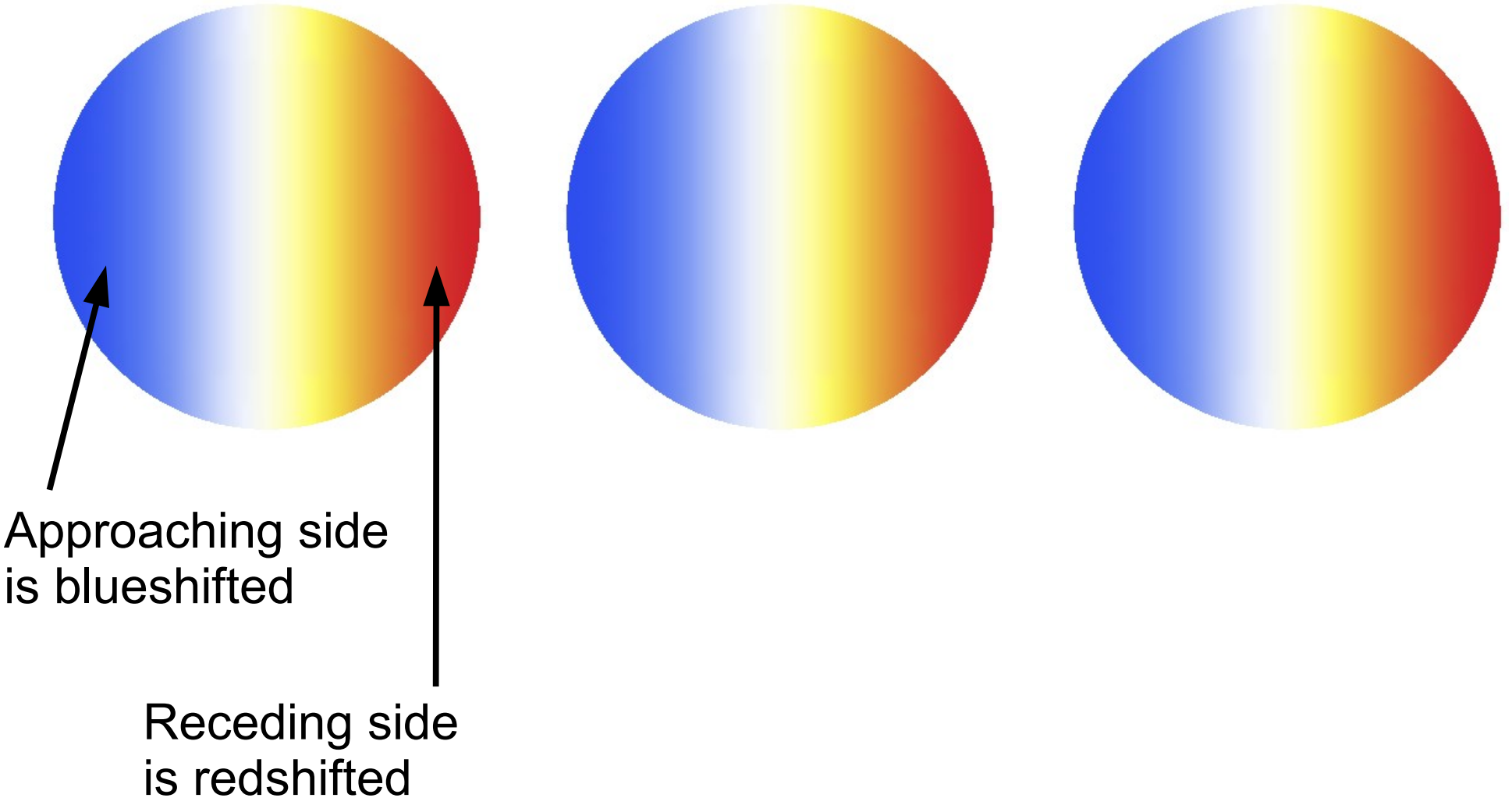


Planet Transit Technique



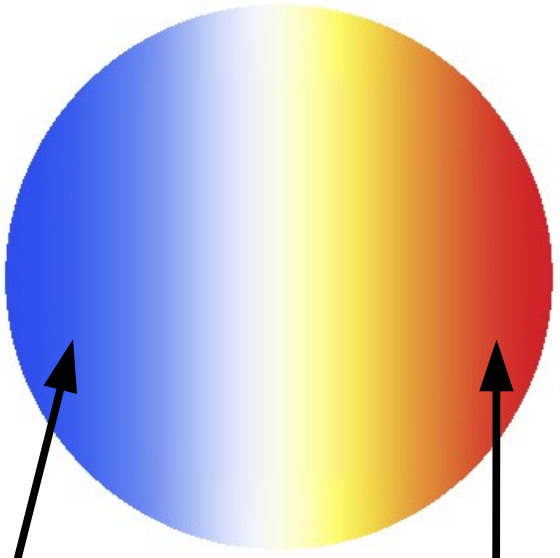
Planet Transit Technique

The Rossiter-McLaughlin effect for rotating stars



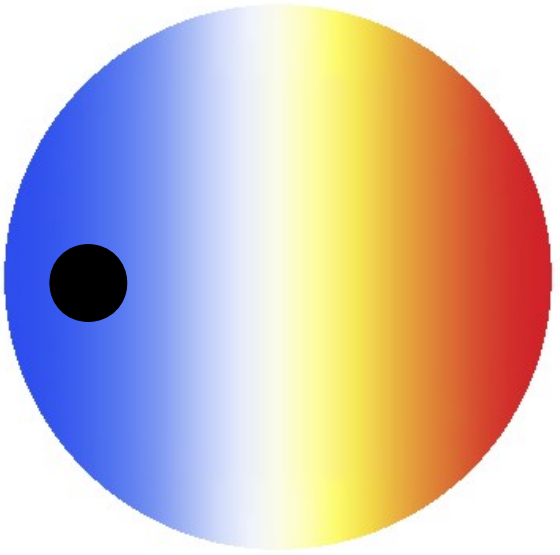
Planet Transit Technique

The Rossiter-McLaughlin effect for rotating stars

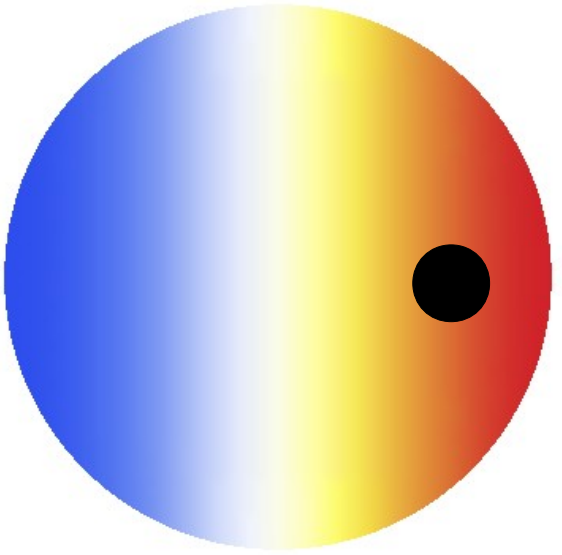


Approaching side
is blueshifted

Receding side
is redshifted



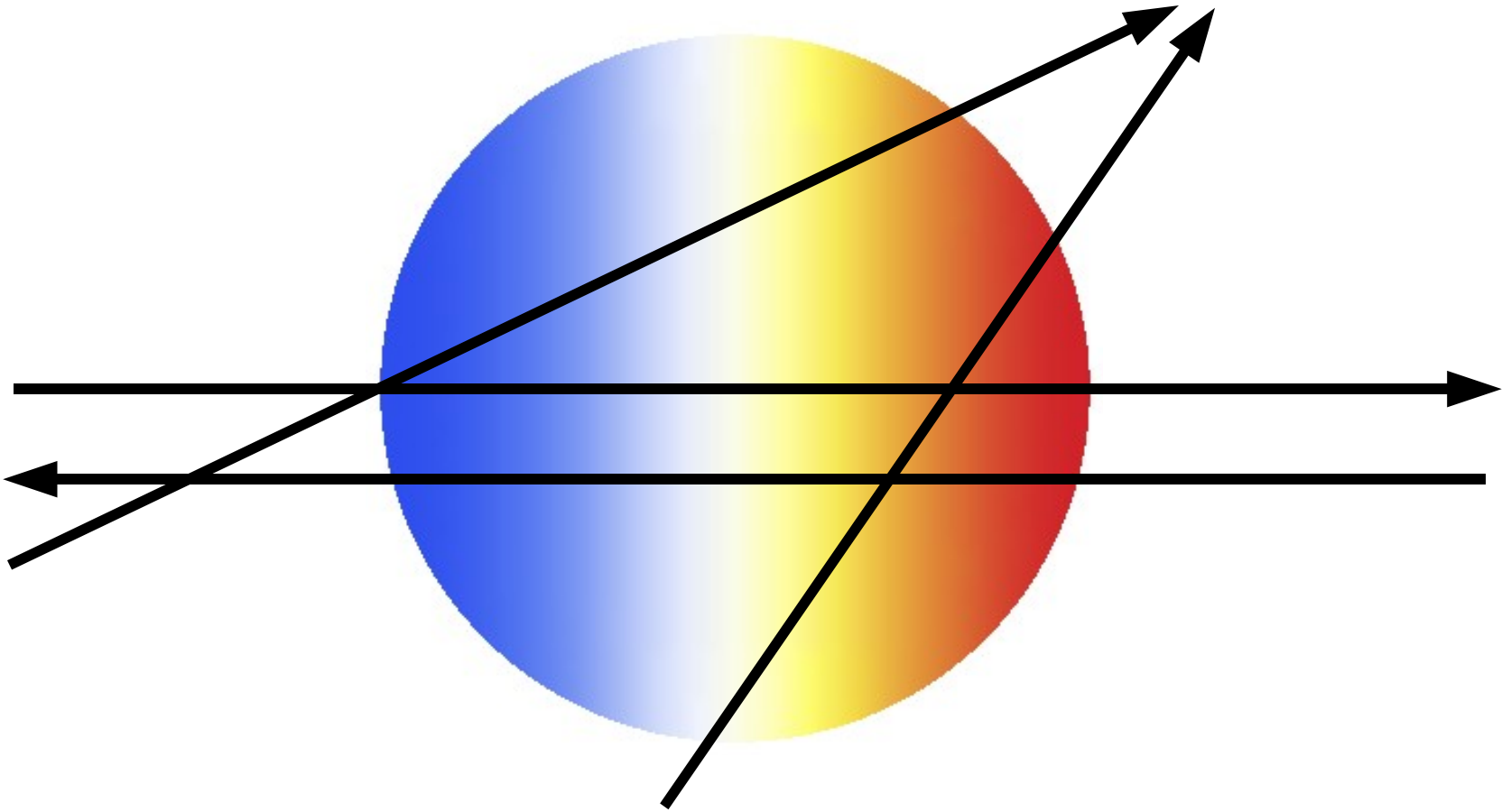
A planet on this side
causes an apparent
redshift.



A planet on this side
causes an apparent
blueshift.

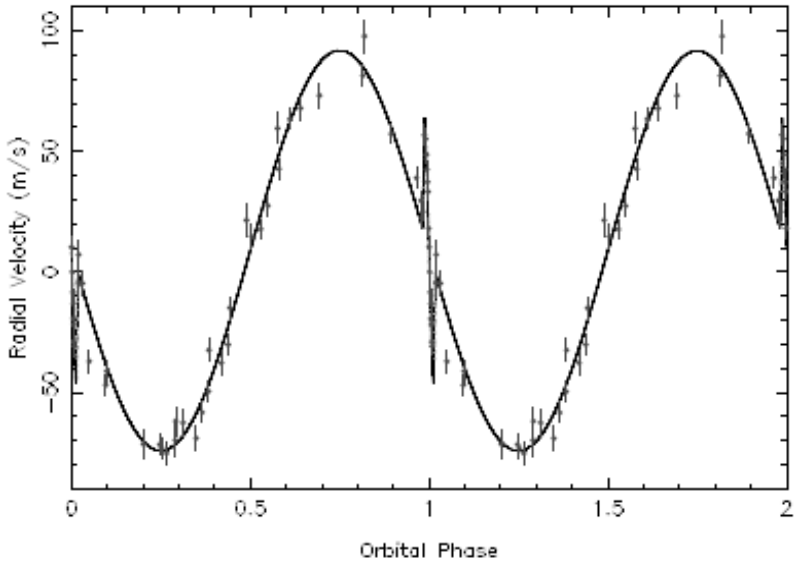
Planet Transit Technique

The Rossiter-McLaughlin effect for rotating stars

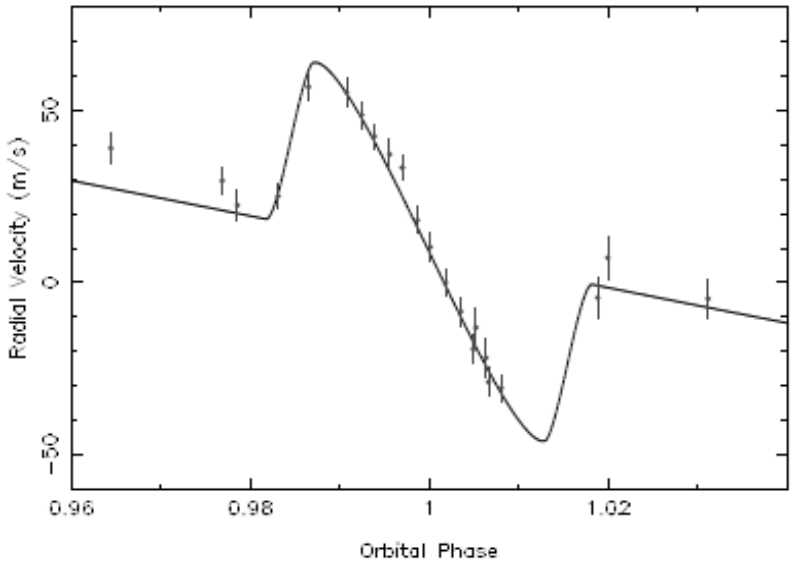


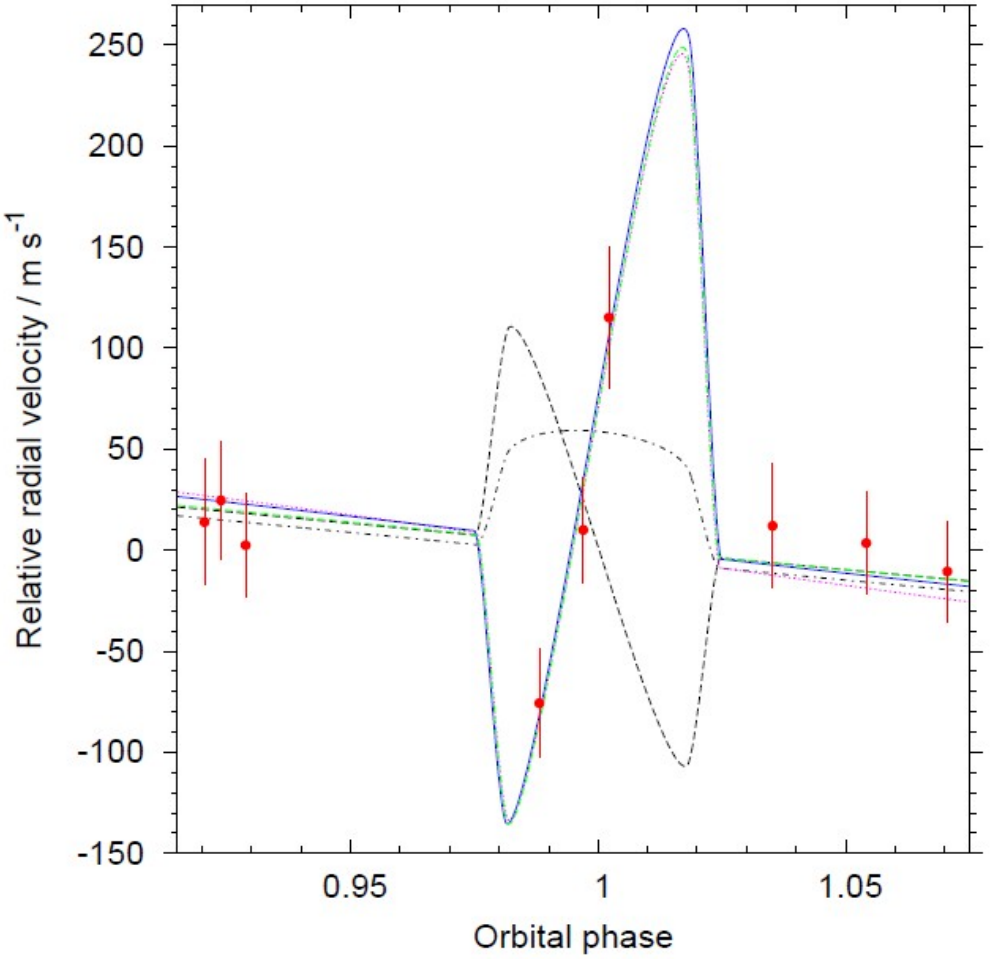
Transits along different trajectories give different signatures.

Planet Transit Technique



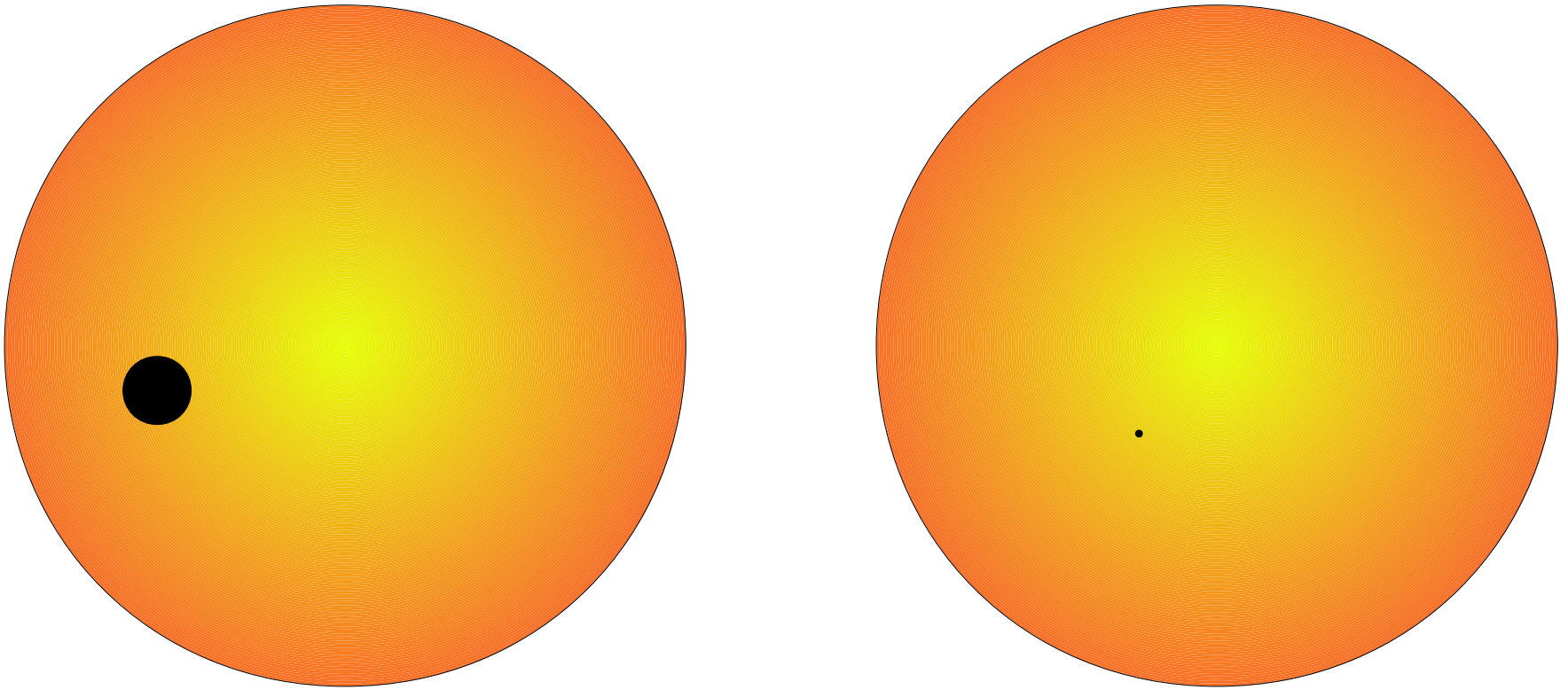
RM effect for HD 209458



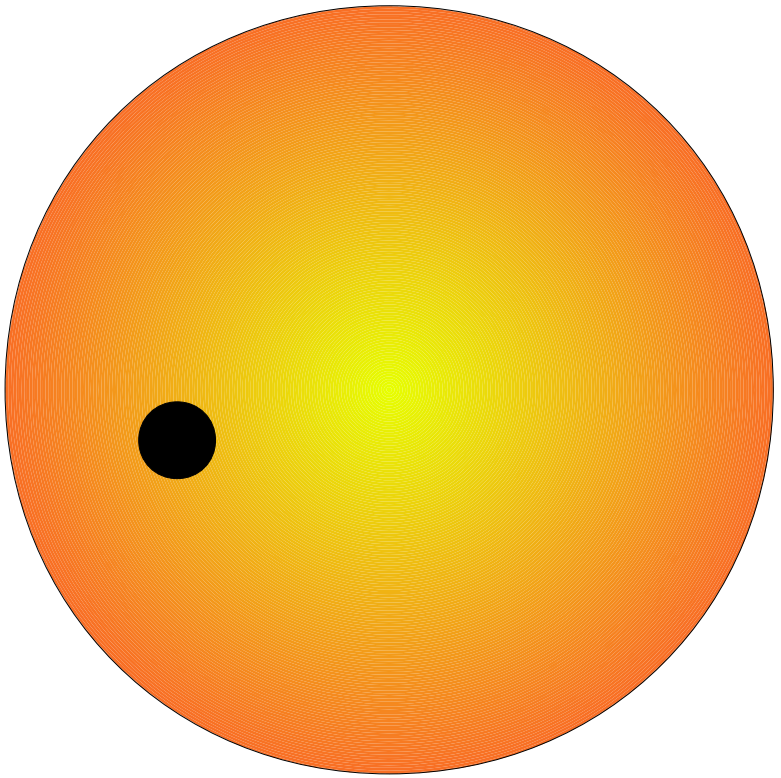


RM effect for WASP 17

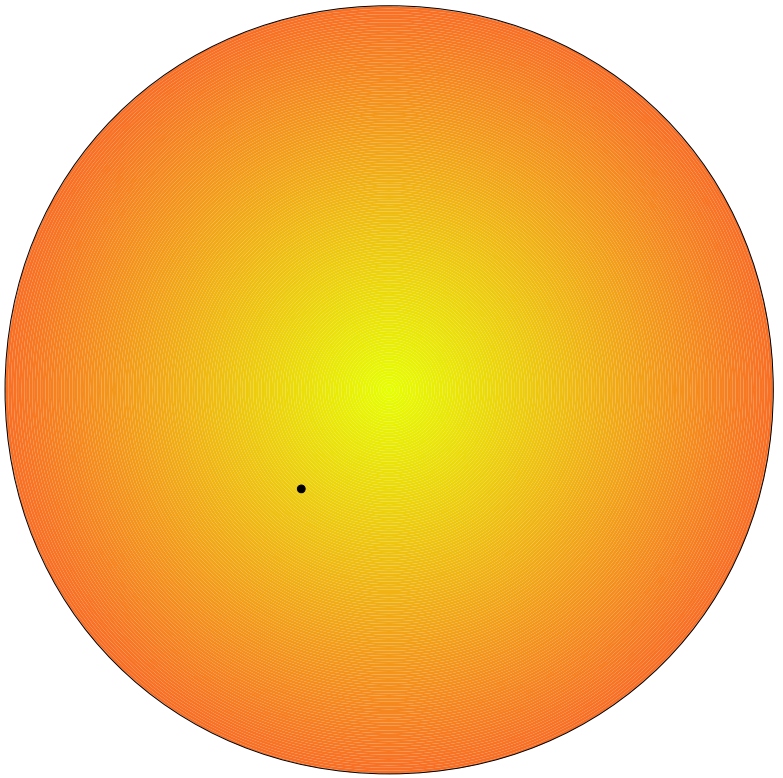
Planet Transit Technique



Planet Transit Technique



Jupiter: need 1 part per 1000.



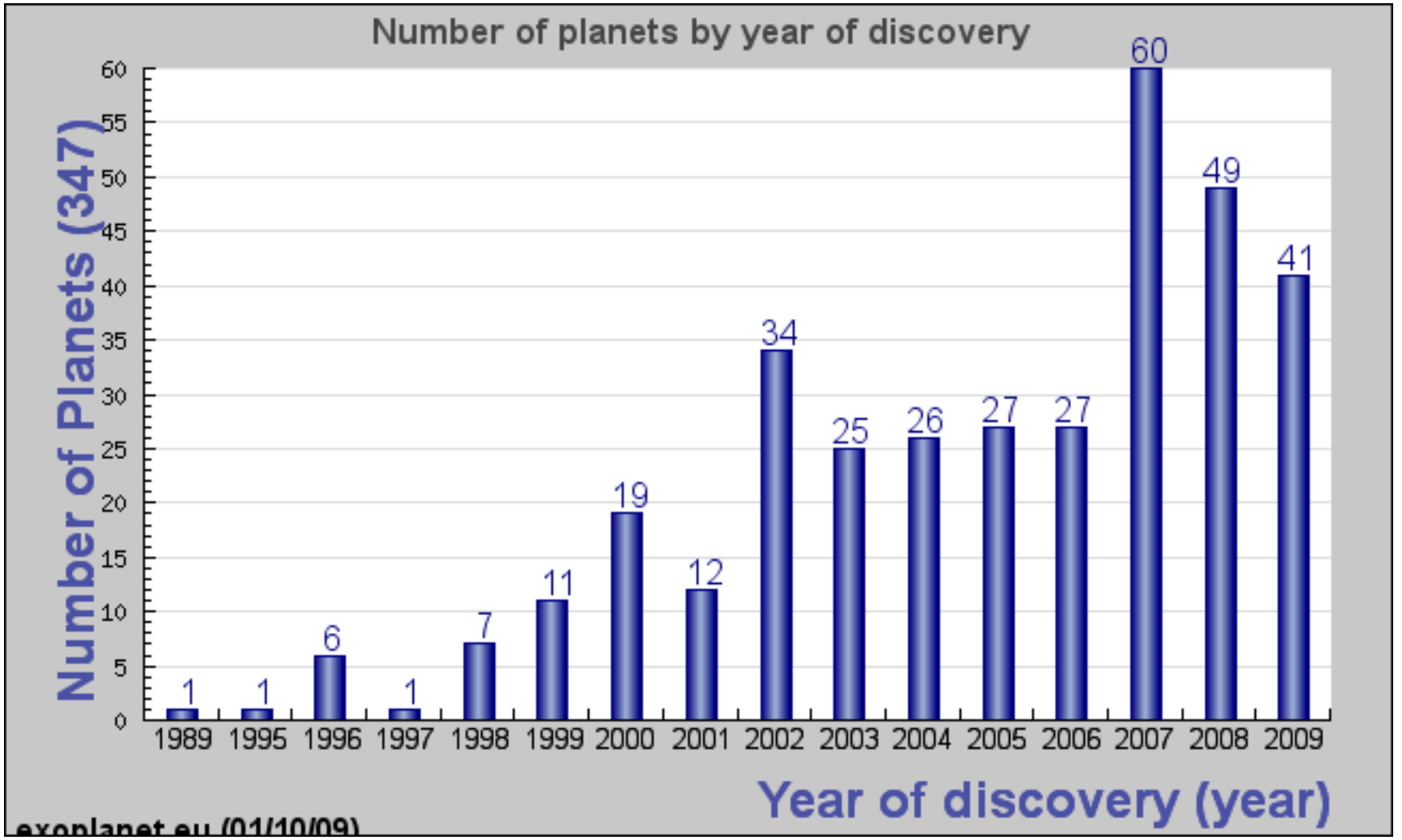
Earth: need 1 part per 100,000.

More on this in a moment.

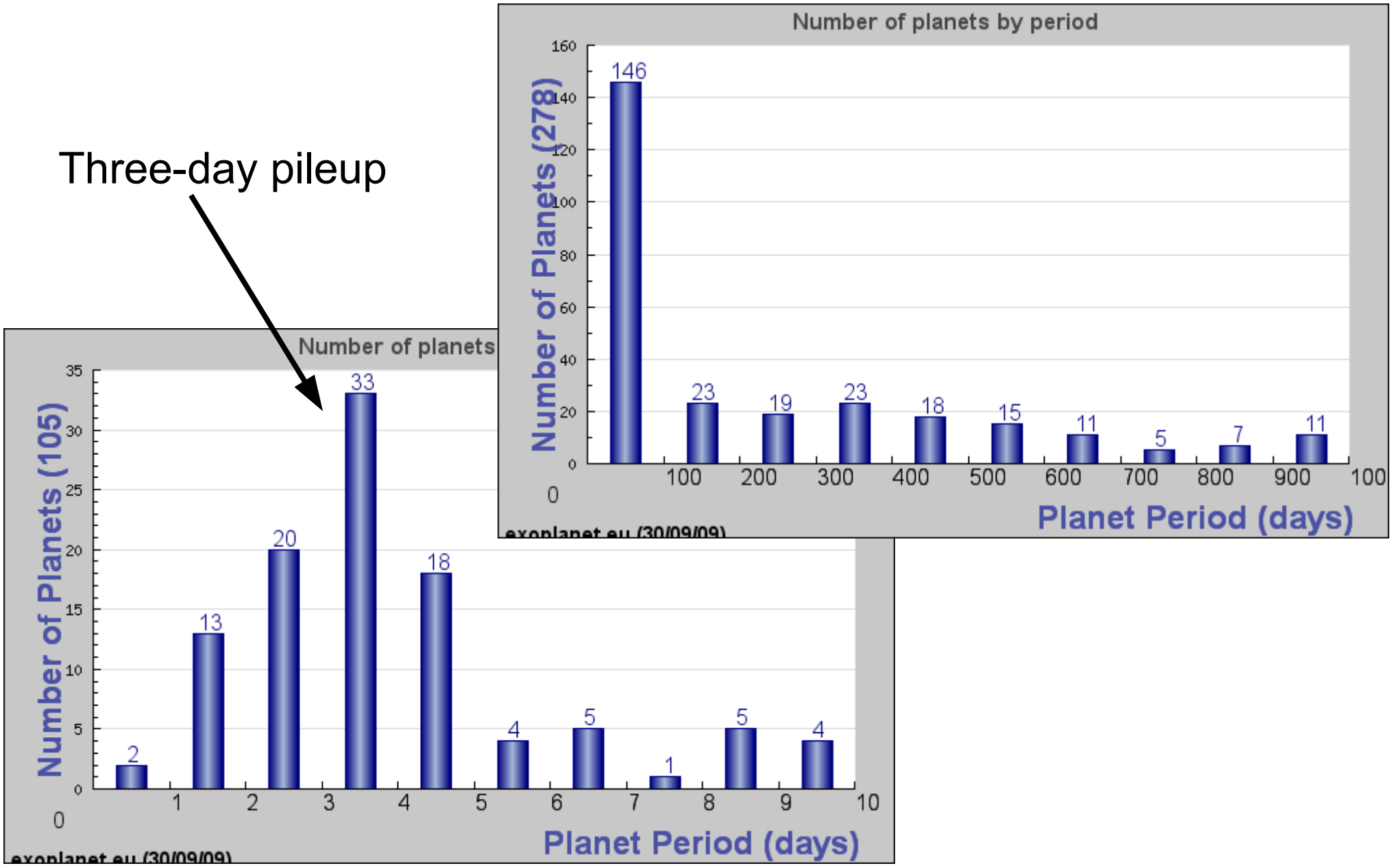
Census of the Planets

- 374 Total Planets
- 347 from Radial Velocity alone (includes transiting planets)
- 62 known transiting planets
- 39 multiple planet systems
- At least one planet detected from each of the six methods

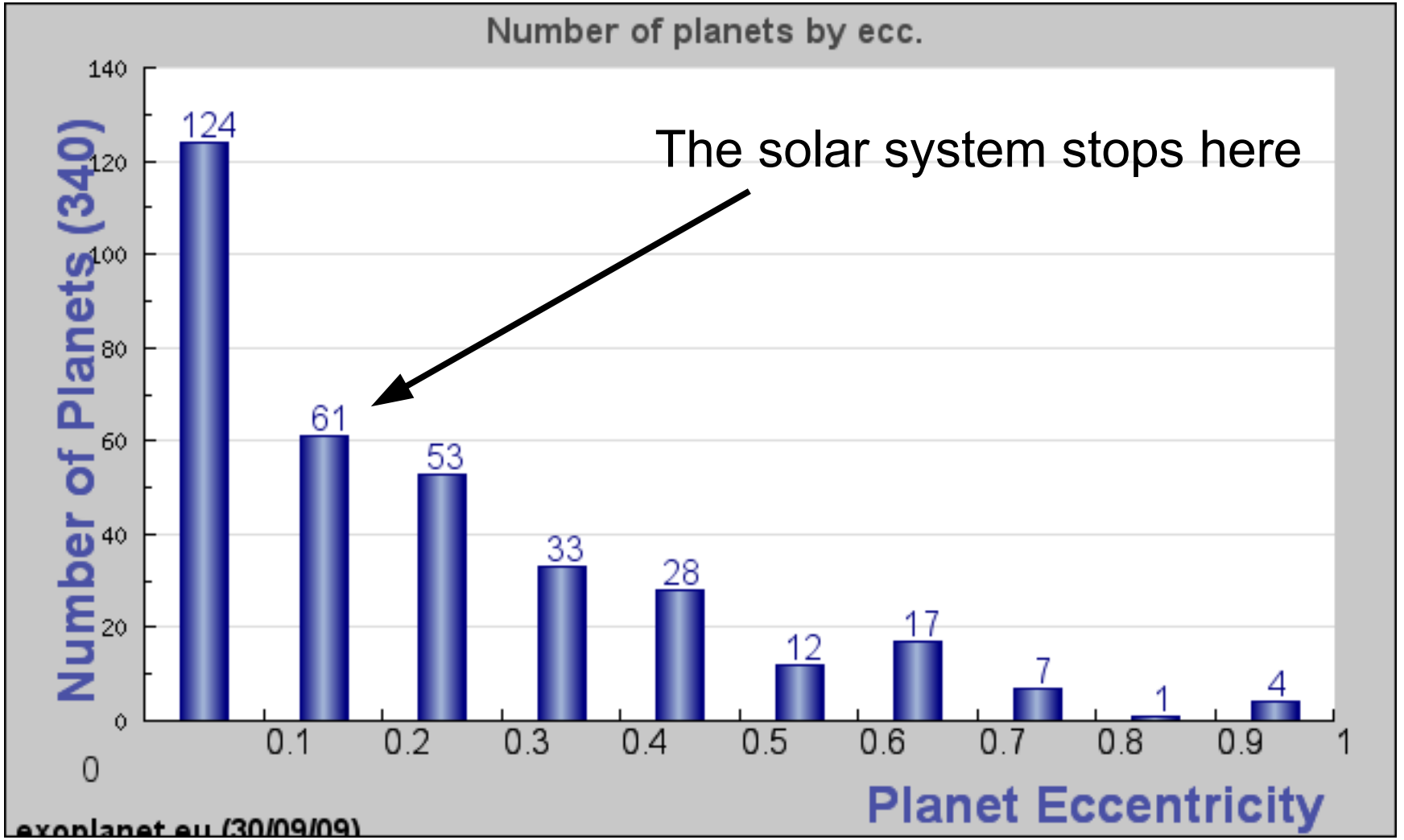
Census of the Planets



Census of the Planets

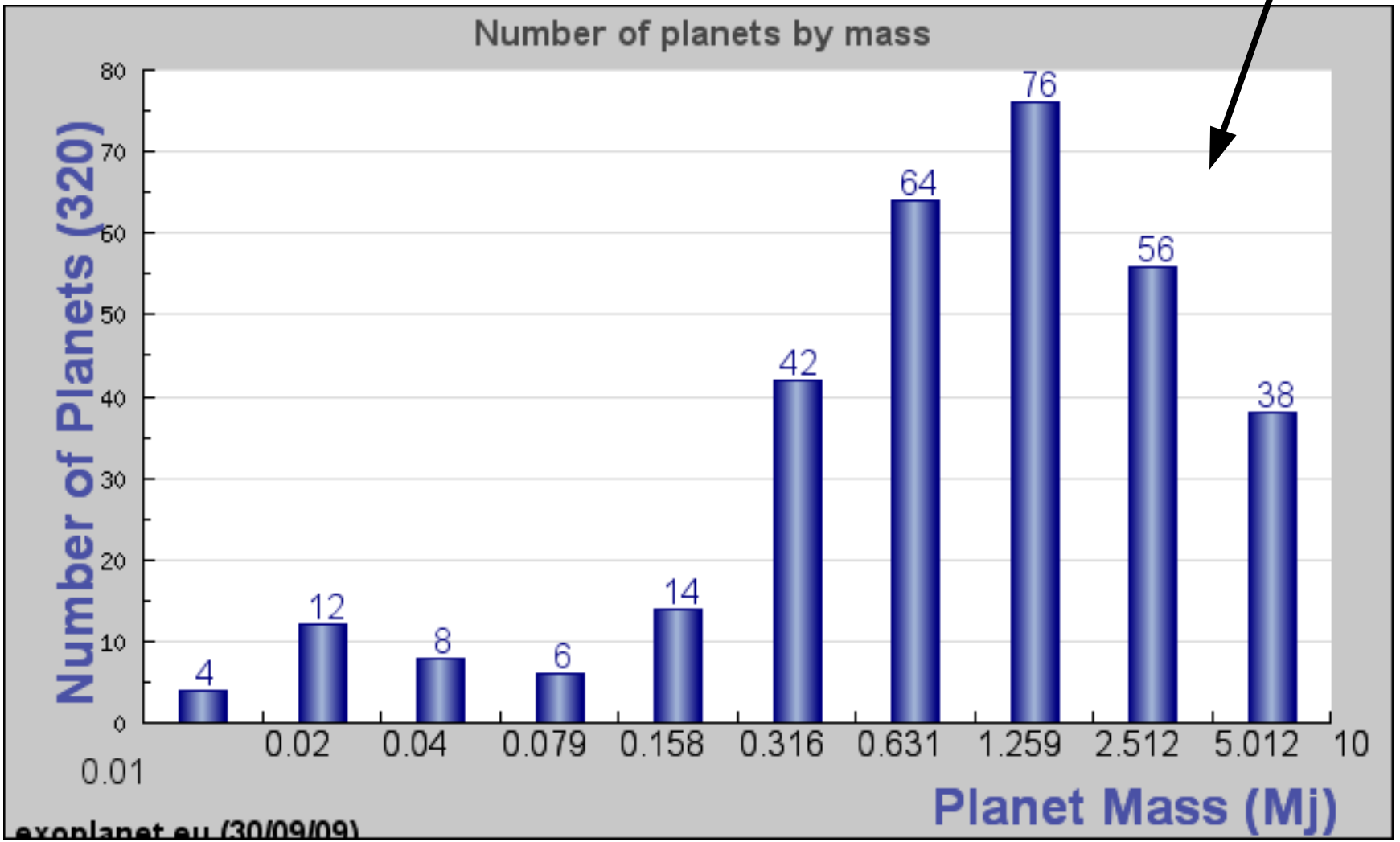


Census of the Planets

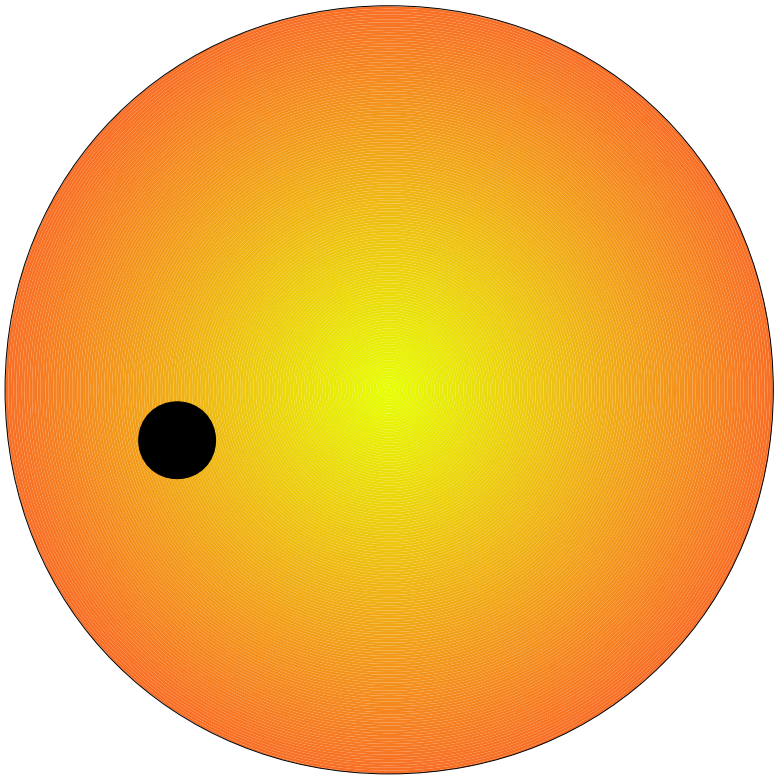


Census of the Planets

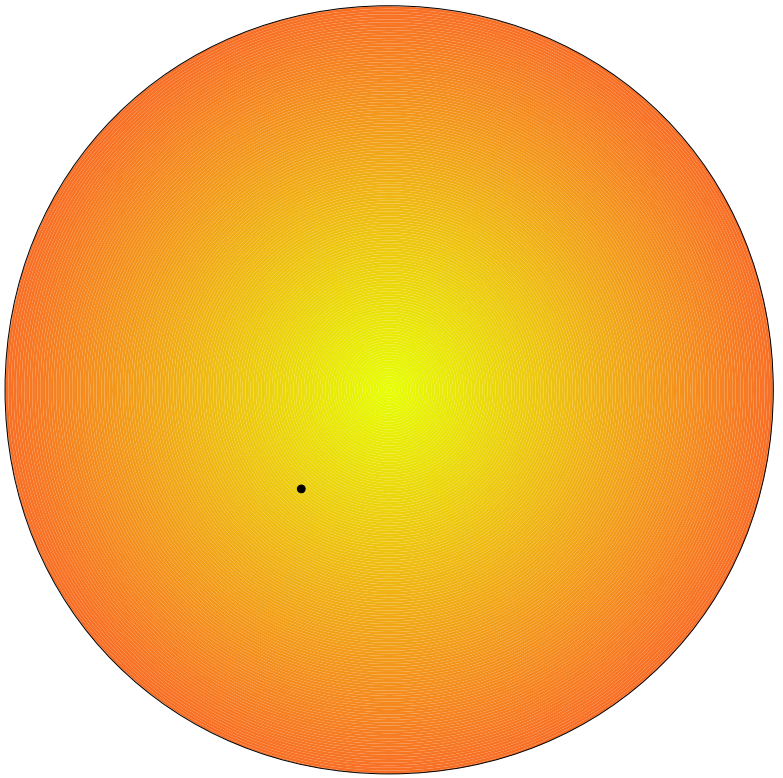
The brown dwarf desert



Finding Other Earths

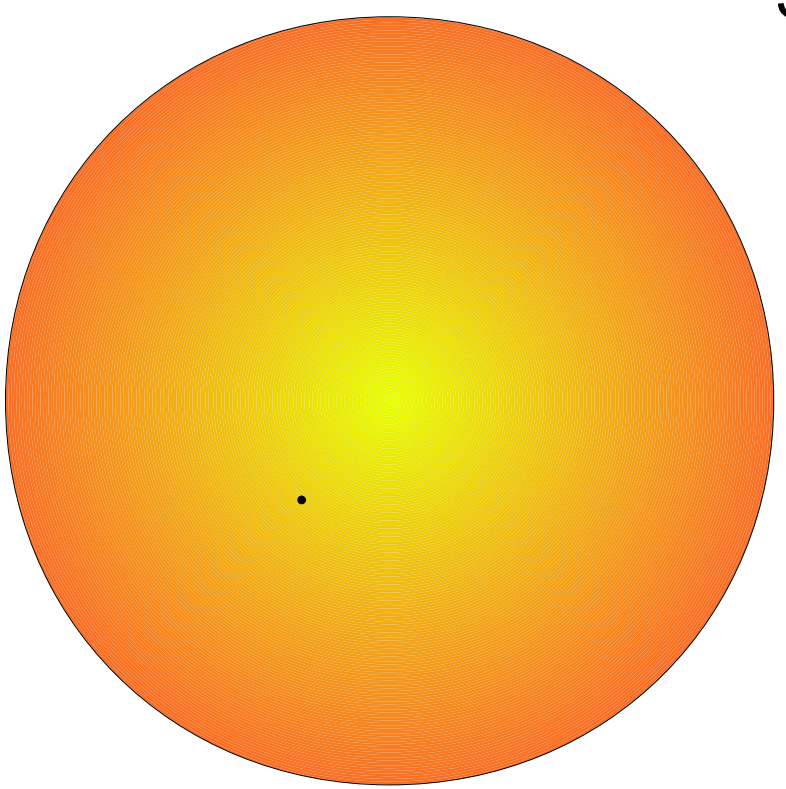


Jupiter: need 1 part per 1000.



Earth: need 1 part per 100,000.

Finding Other Earths

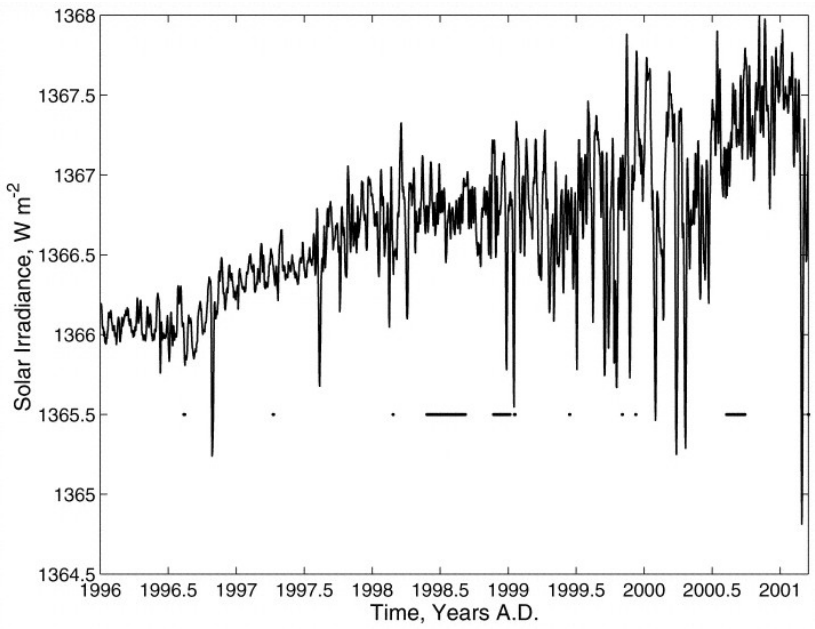


Sunspots

Solar variability

Neptune

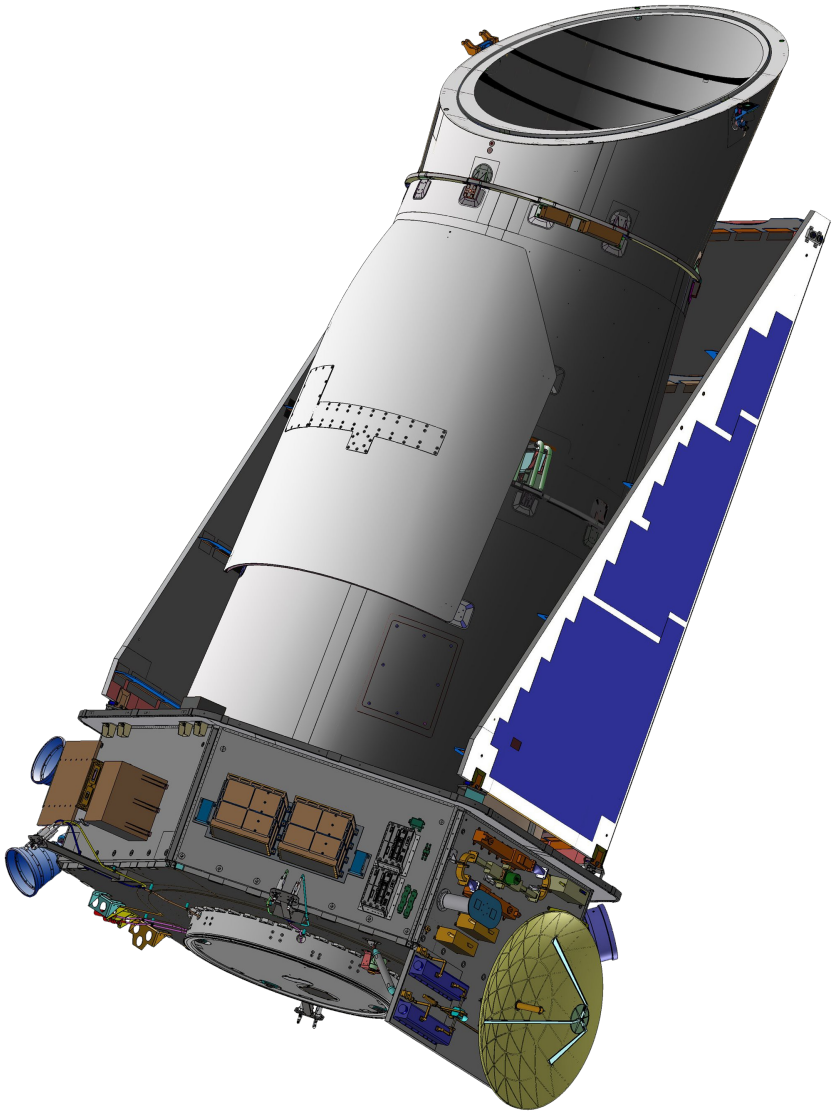
Earth

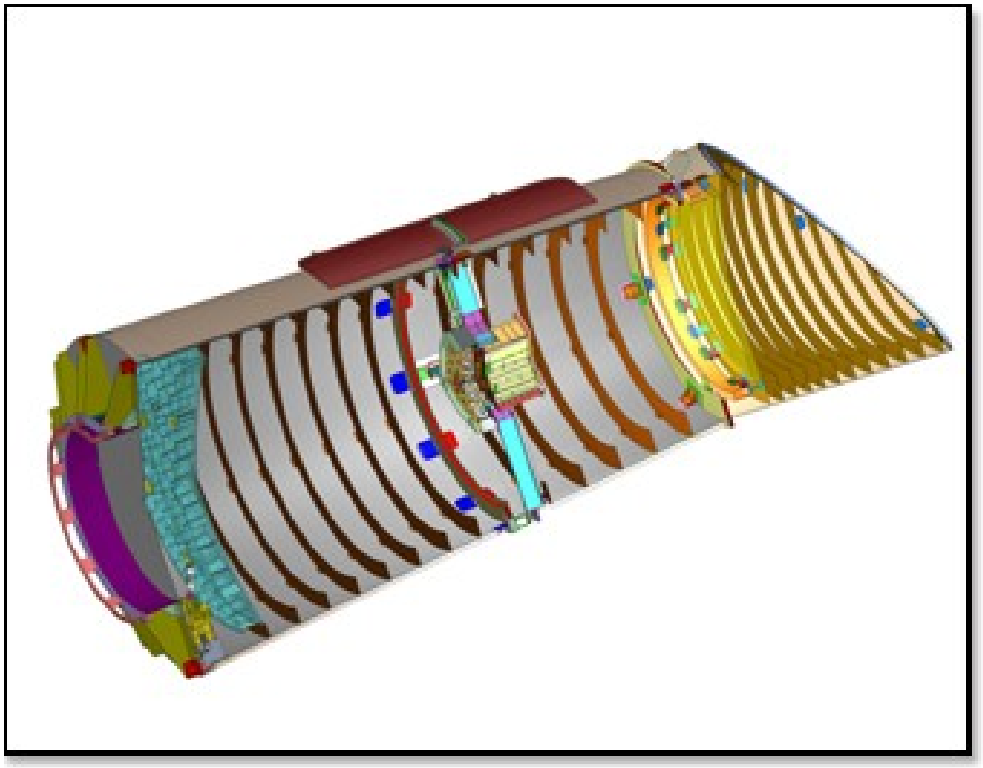


Finding Other Earths

Kepler

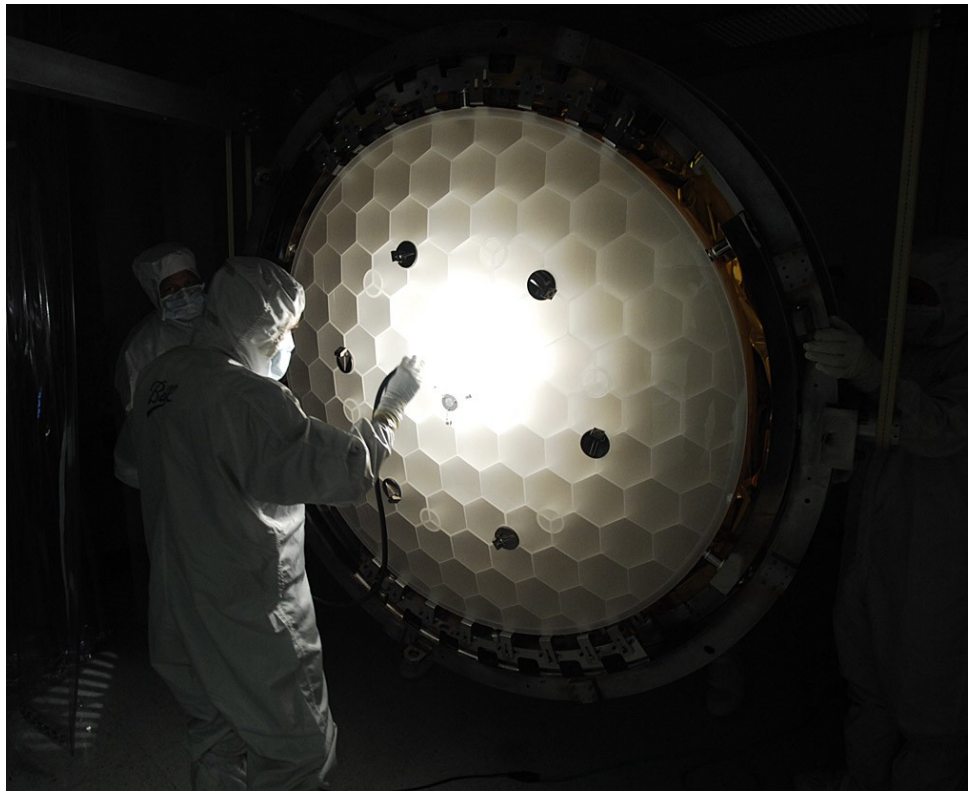
Finding Other Earths

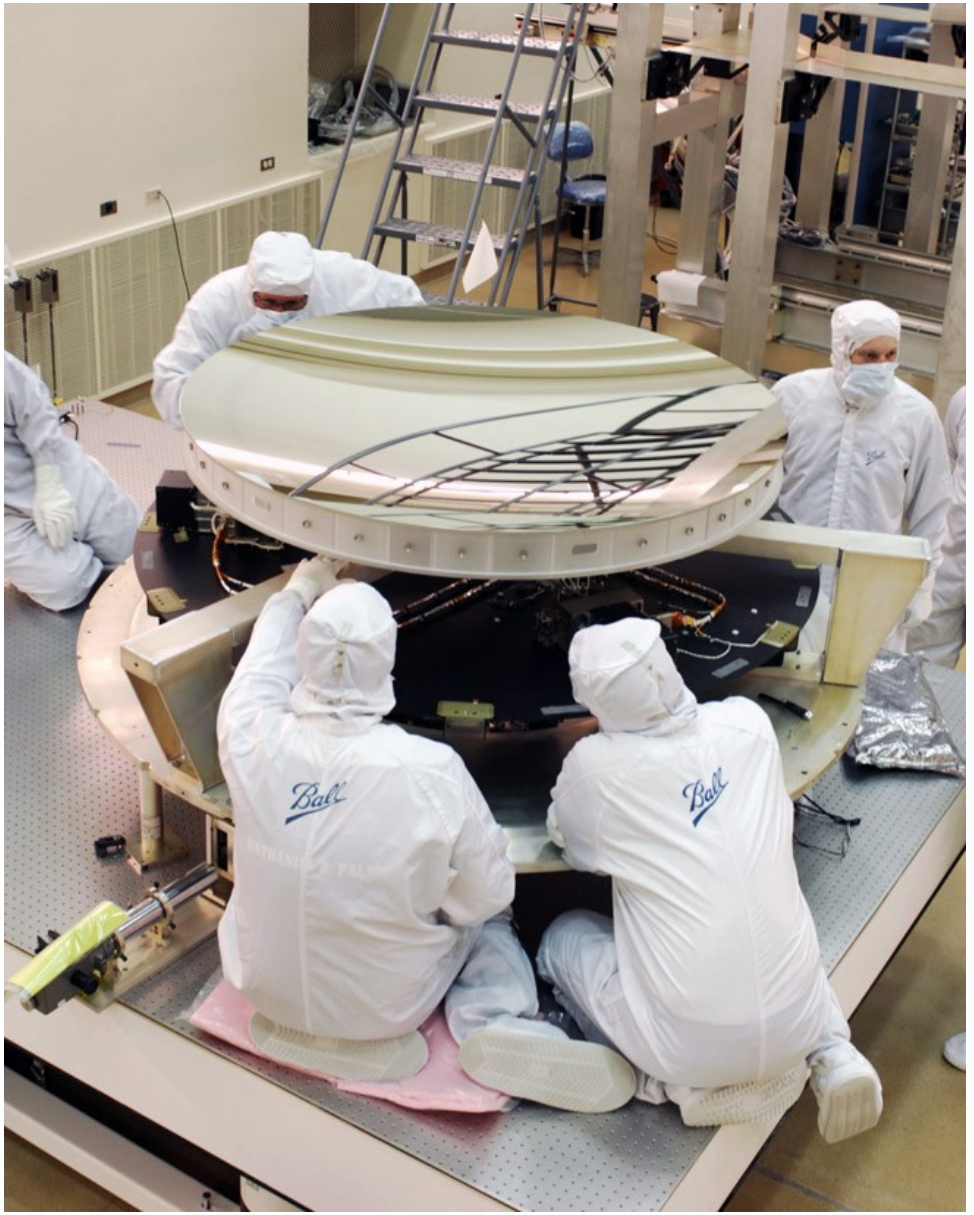




Finding Other Earths

Kepler mirror: 0.95m





Finding Other Earths

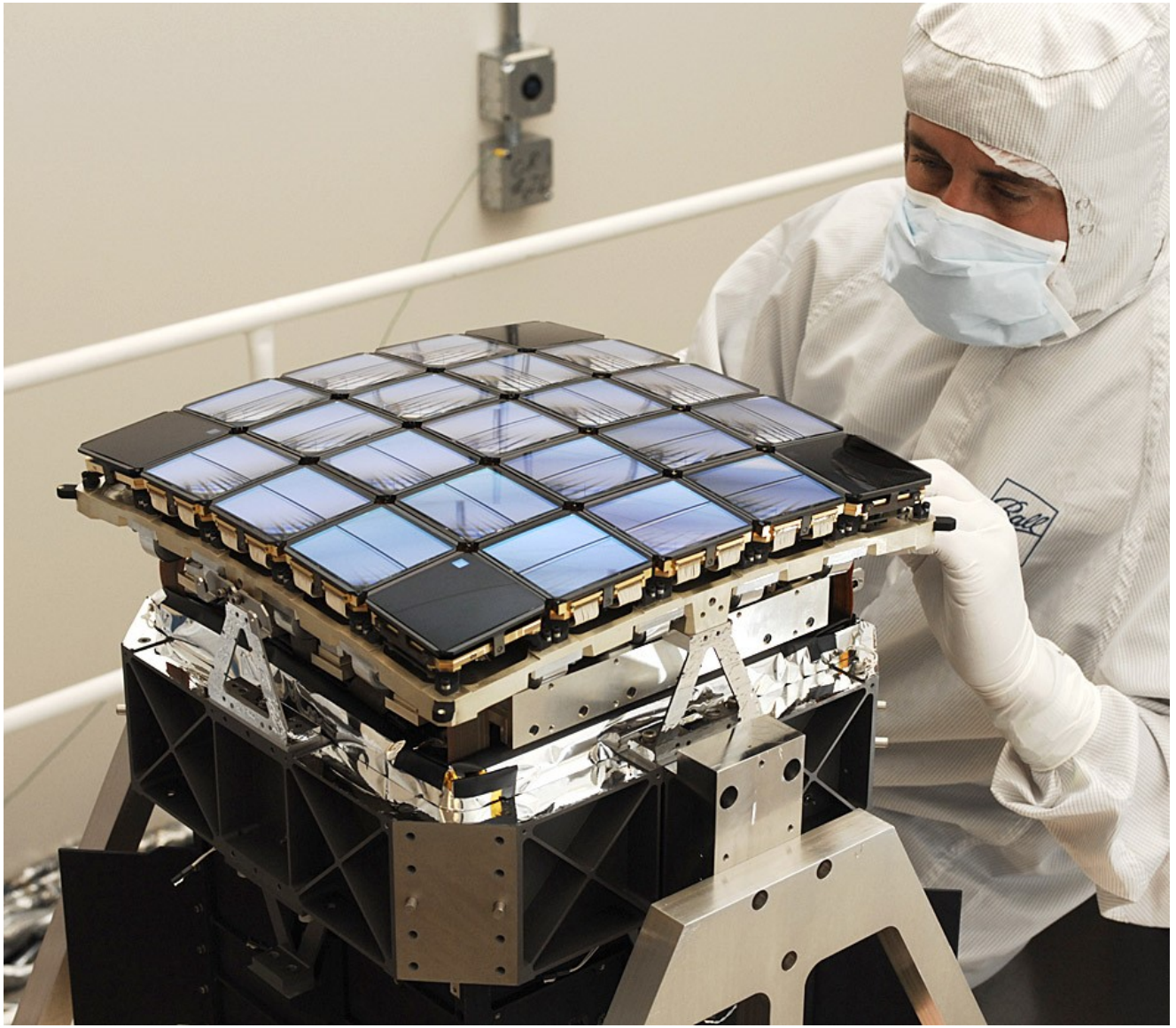
42 CCD chips

95 million pixels

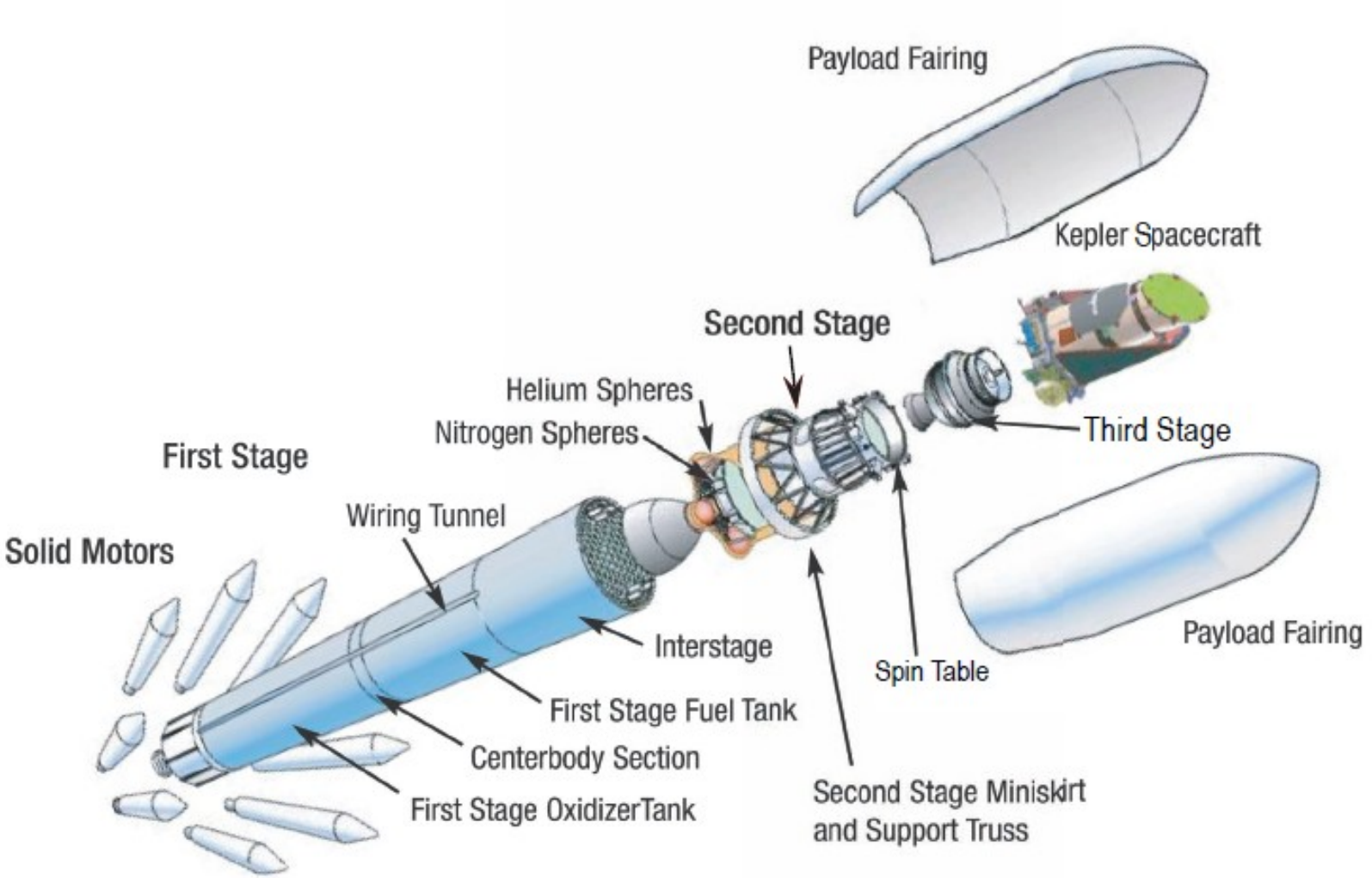
Continuously monitor ~150,000 target stars

Images are de-focused

Only target pixels are sent back to Earth



Finding Other Earths

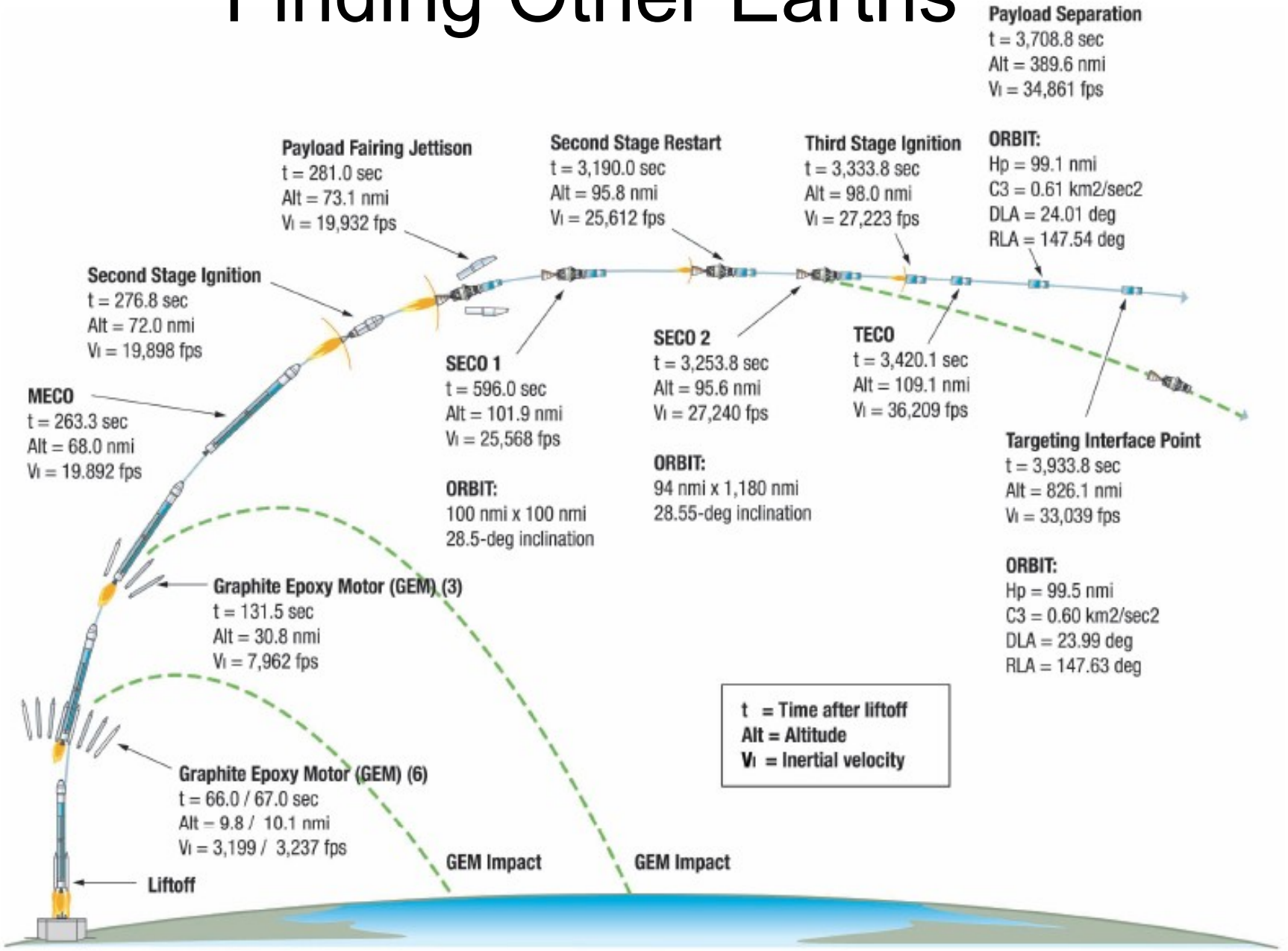


Delta Launch Vehicle with Kepler Spacecraft

Finding Other Earths

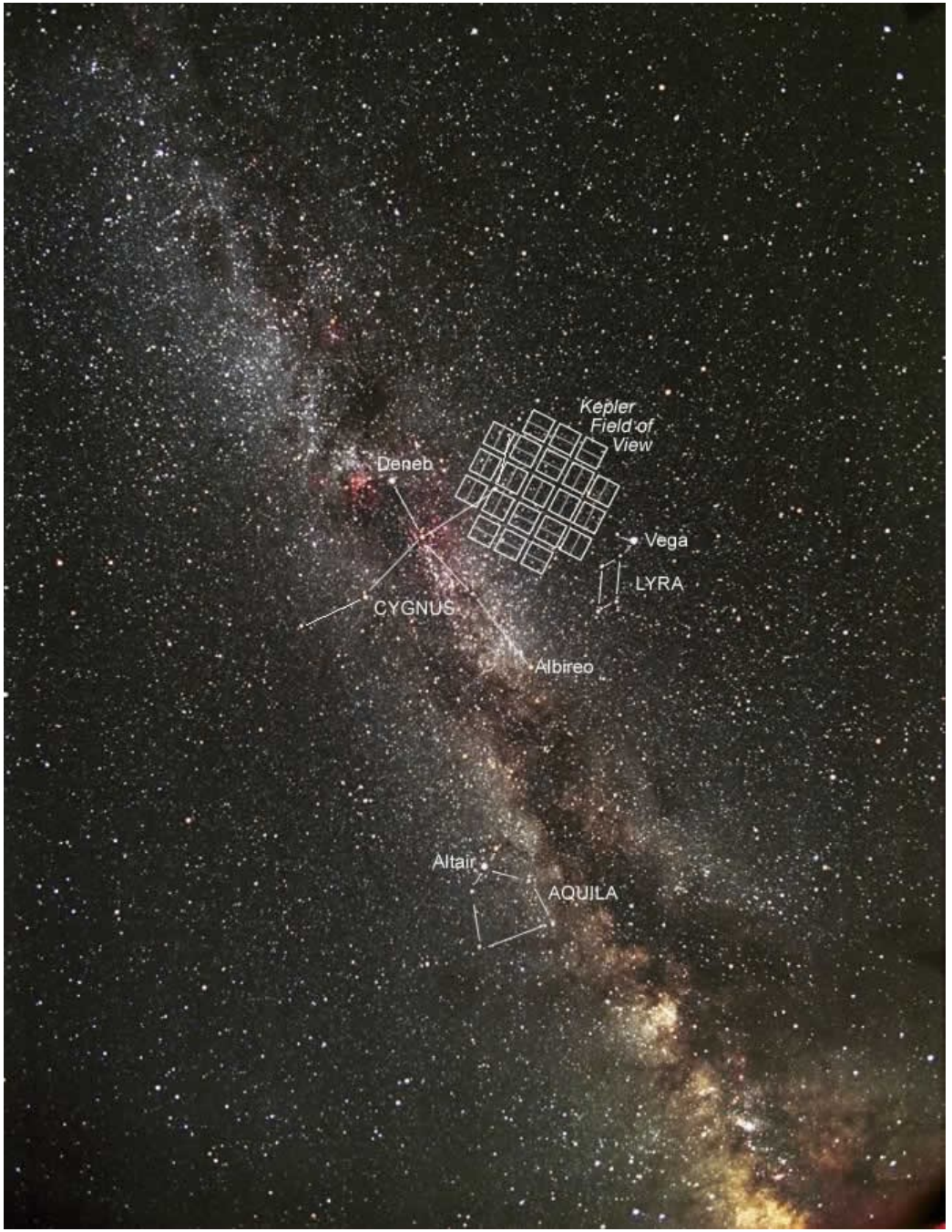
March 6, 2009

Finding Other Earths

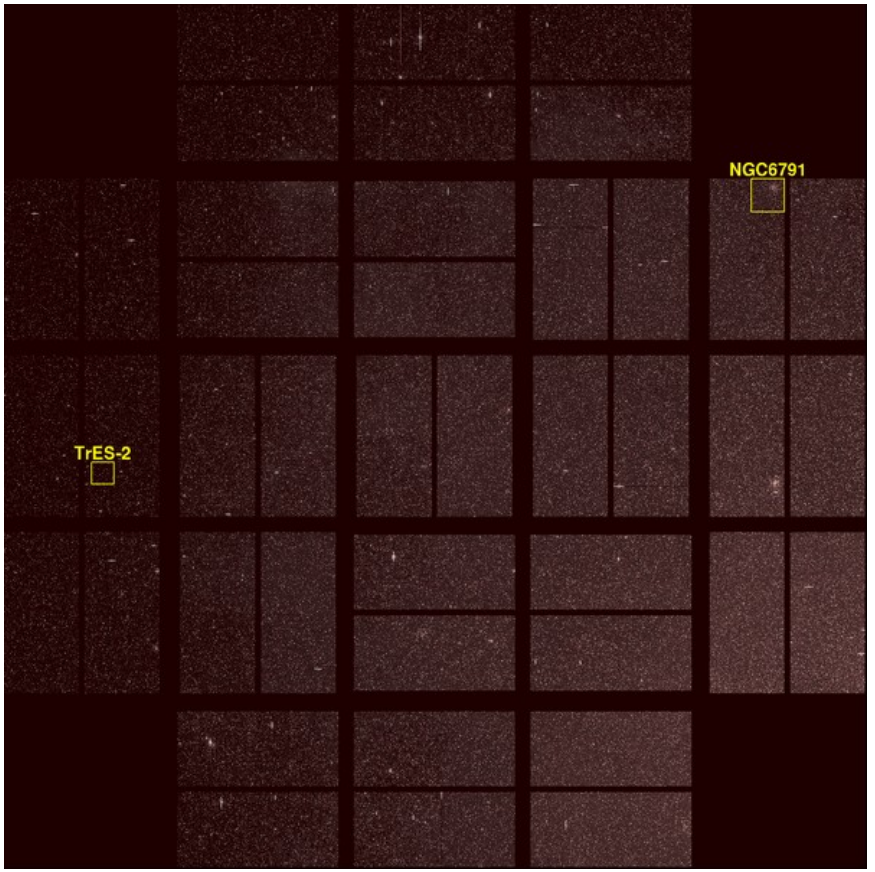


Kepler Launch Profile

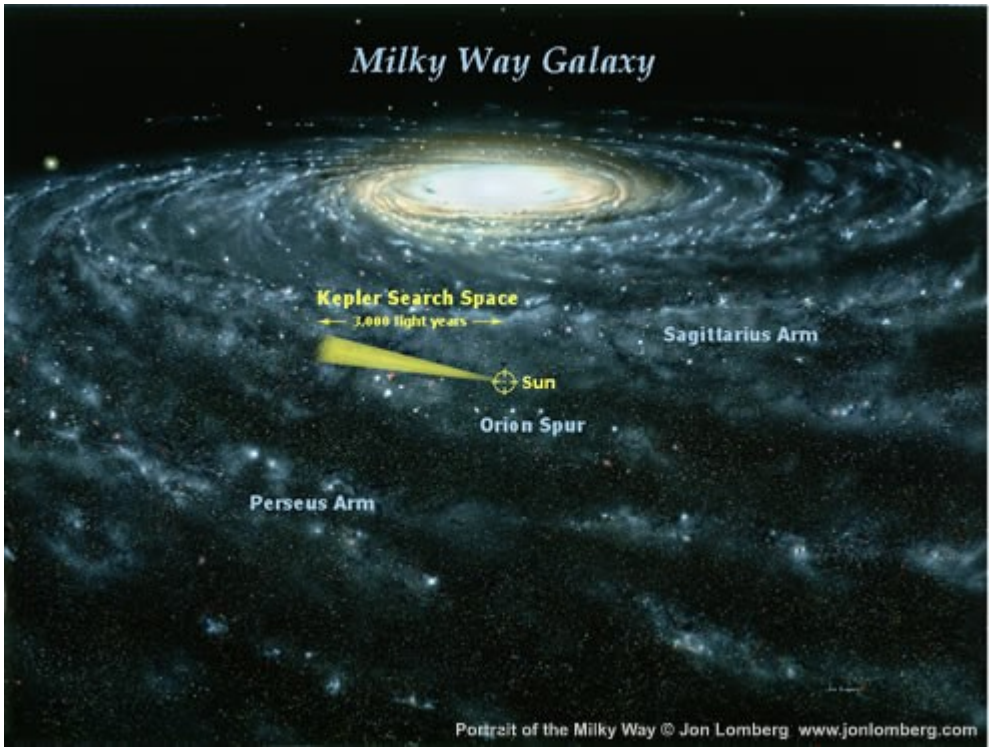
Finding Other Earths

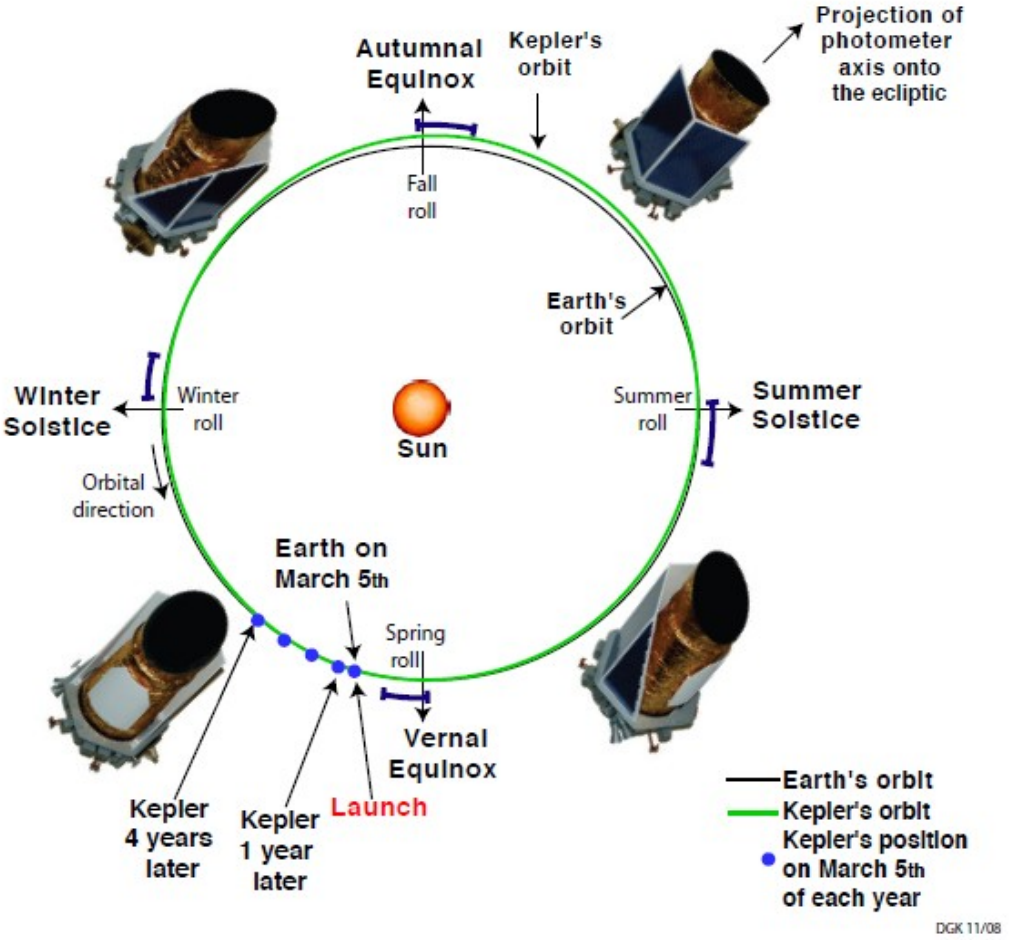


First light image



Finding Other Earths

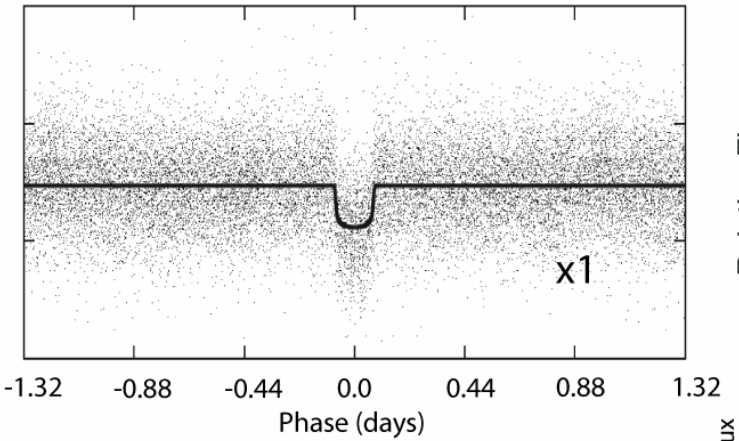




View from the ecliptic North Pole

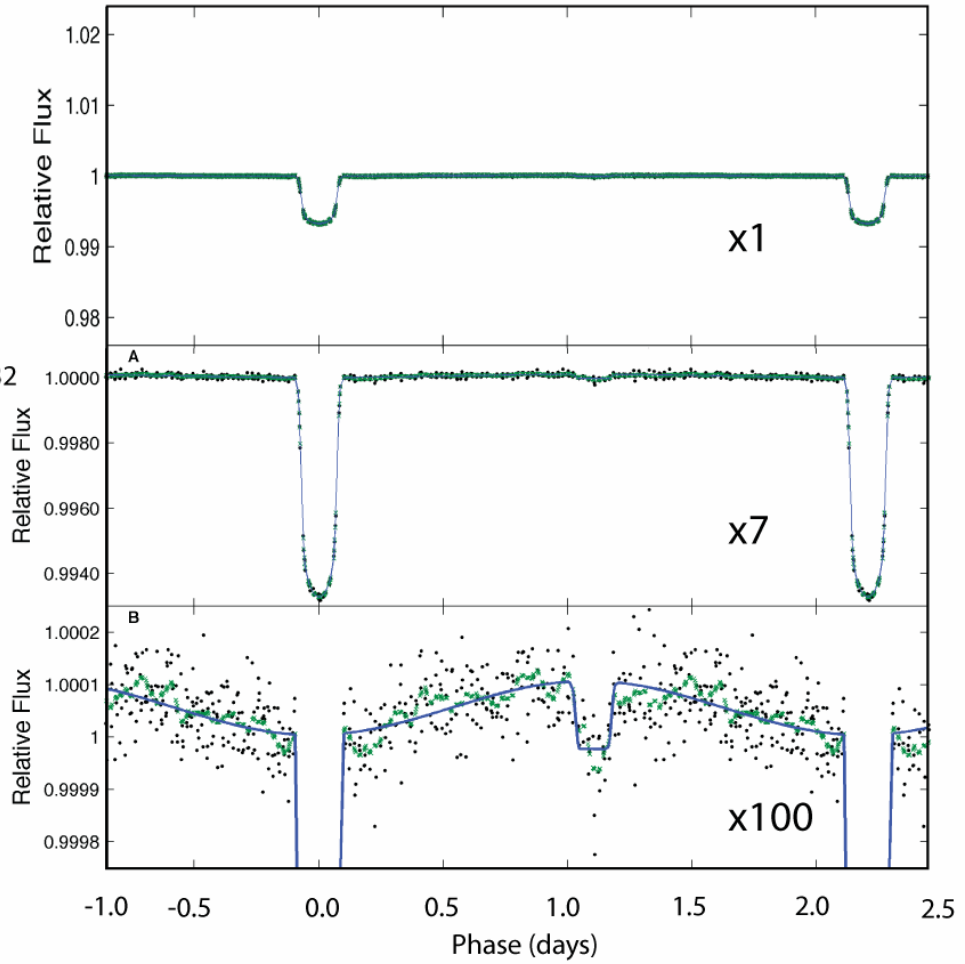
Finding Other Earths

First Kepler science results



16,620 HATNet data points (57.7 days of data)

HAT-P-7b data from the ground
A. Pal et al., 2008



Kepler is working as planned.

Kepler Commissioning data (10 days)
W. Borucki et al., 2009

Finding Other Earths

- Kepler is slated to run for 3.5 years with a possible extension to 7 years.
- Kepler is the first instrument capable of detecting a true Earth analog.
- Kepler has met expectations for its performance, expect results soon.