The Search for Earth-like Planets

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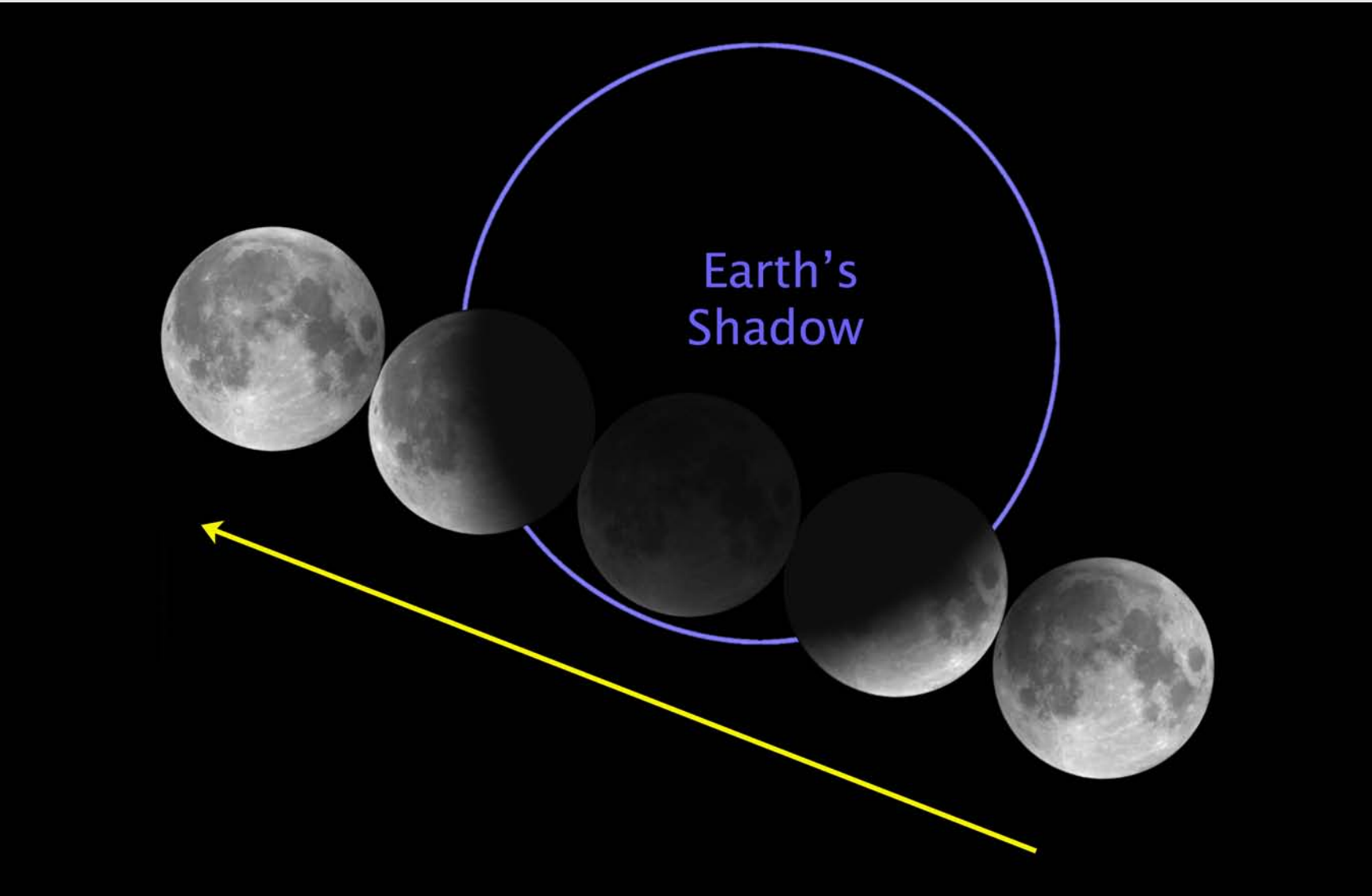
2010 March 29

Princeton Club of Vero Beach

http://www.princeton.edu/∼rvdb

Some History—The Earth is a Sphere



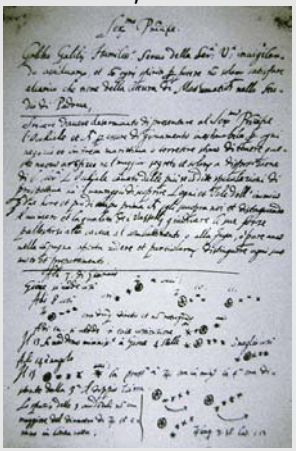
1609: Telescope is Invented (Hans Lippershey)

1610: Galileo Looks at Jupiter

Galileo Galilei

"I should disclose and publish to the world the occasion of discovering and observing four Planets, never seen from the beginning of the world up to our own times, their positions, and the observations... about their movements and their changes of magnitude; and I summon all astronomers to apply themselves to examine and determine their periodic times...."

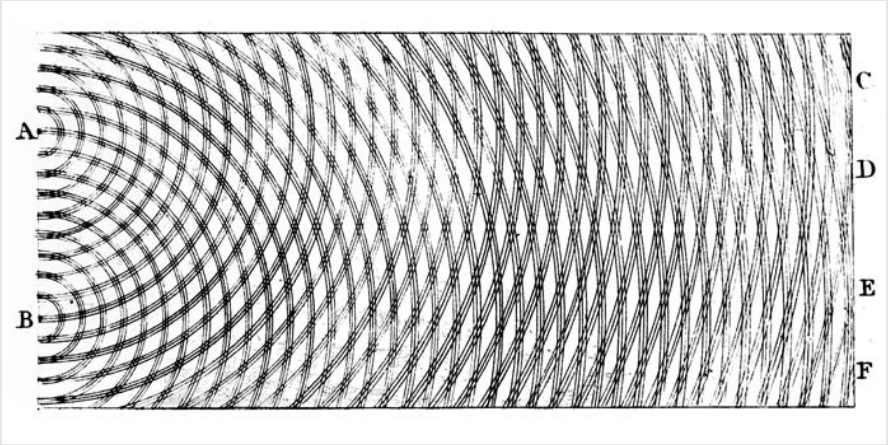
March, 1610



(Convicted of heresy, 1633.
House arrest until his death.
Sentence rescinded October, 1992)

Christiaan Huygens (1678): Light is a Wave

Young's two-slit diffraction experiment:

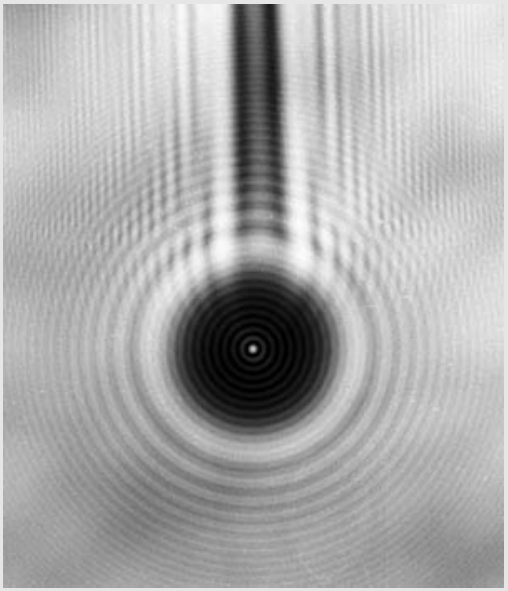


Siméon Poisson/Francois Arago (1818)

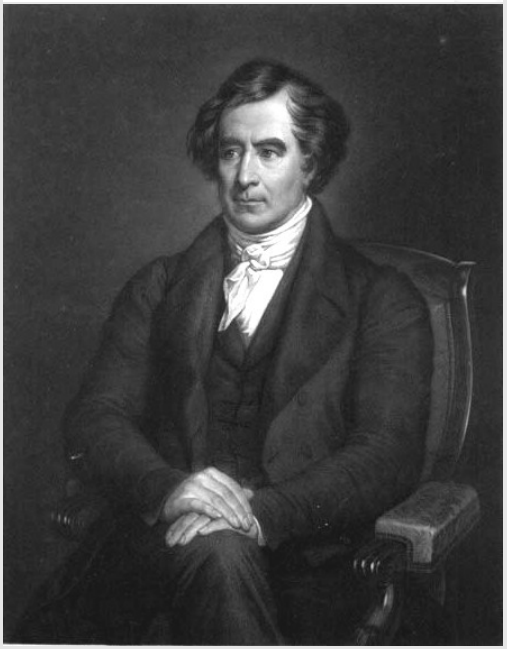
Poisson didn't believe the wave theory of light.
He pointed out that light falling on a circular object would have a bright spot at the center of its shadow.

Arago did the experiment.

Poisson was wrong.



Poisson's spot



James Clerk Maxwell (1862): Light is an Electro-Magnetic Wave

And God Said

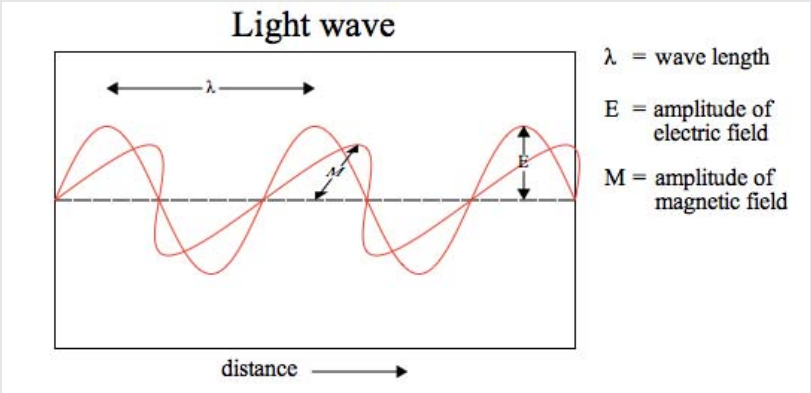
$$\nabla \cdot \vec{D} = \rho_{\text{free}}$$

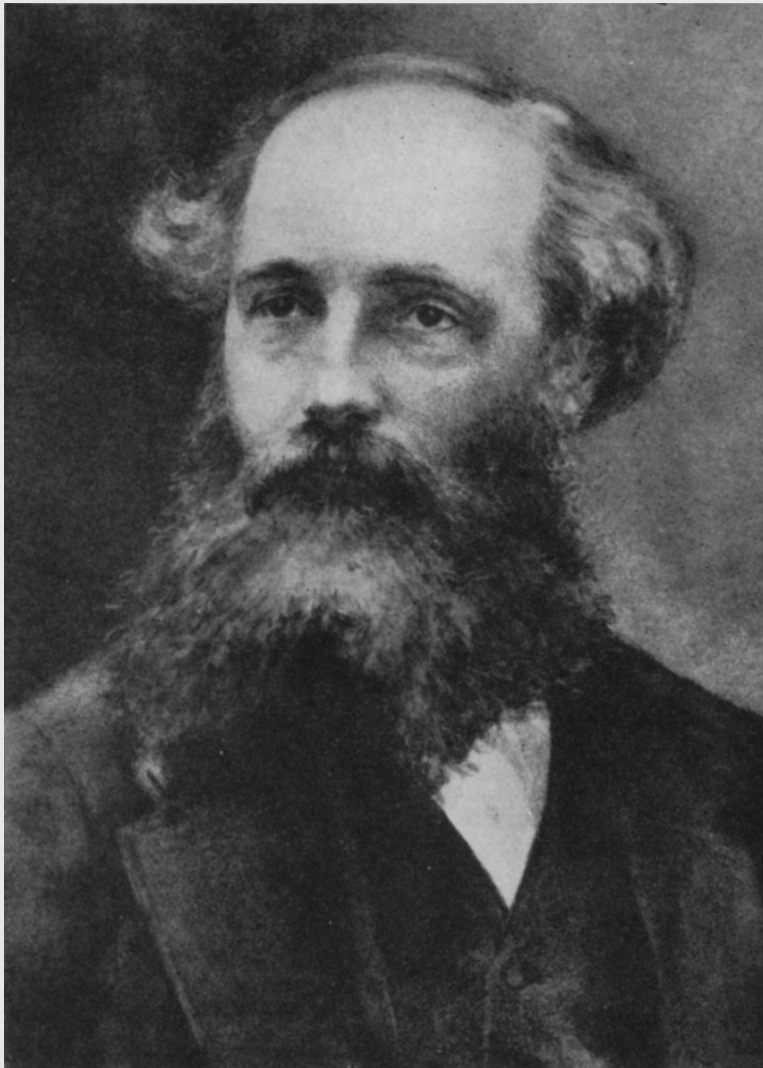
$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{H} = \vec{J}_{\text{free}} + \frac{\partial \vec{D}}{\partial t}$$

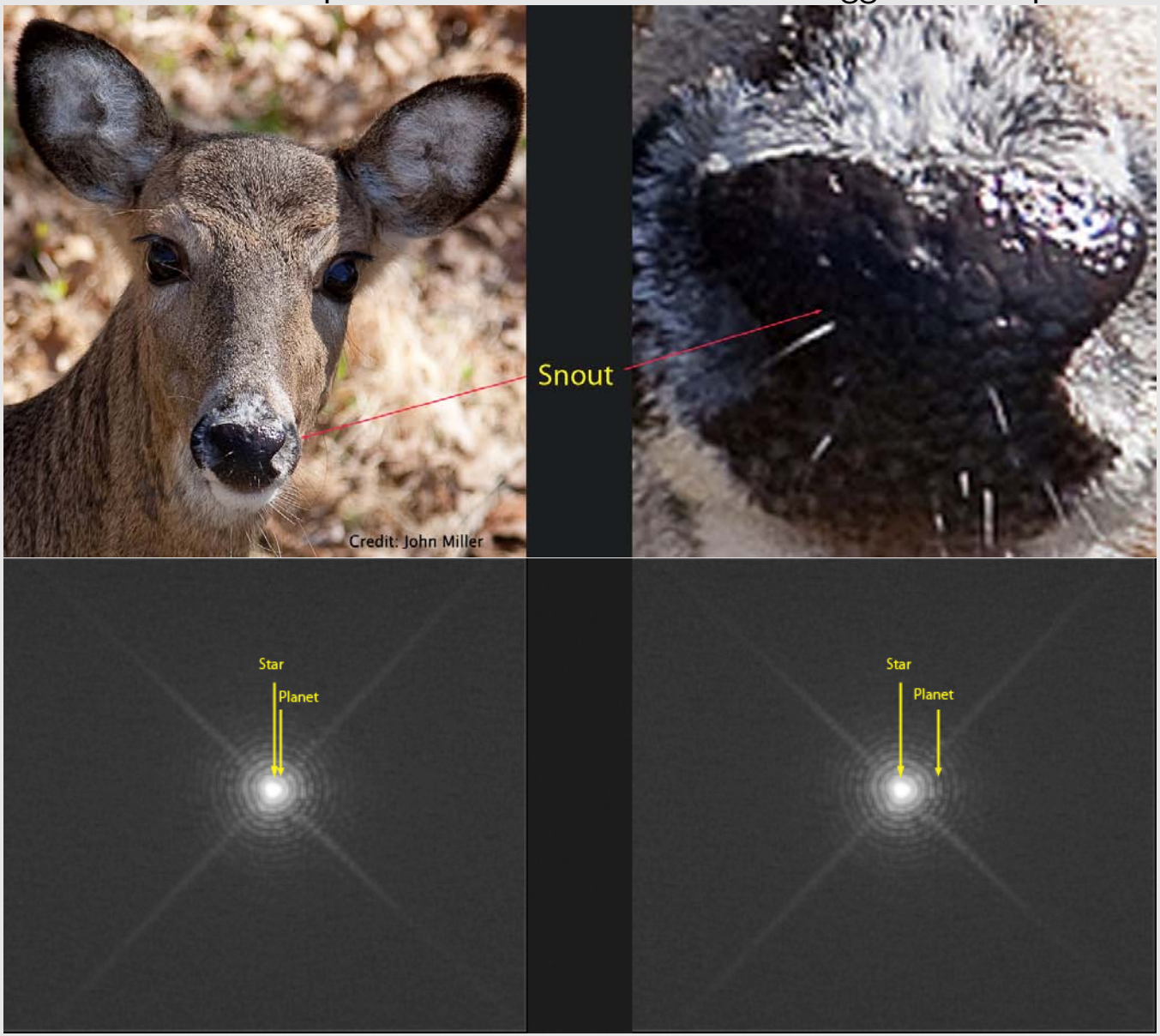
and *then* there was light.





Telescope

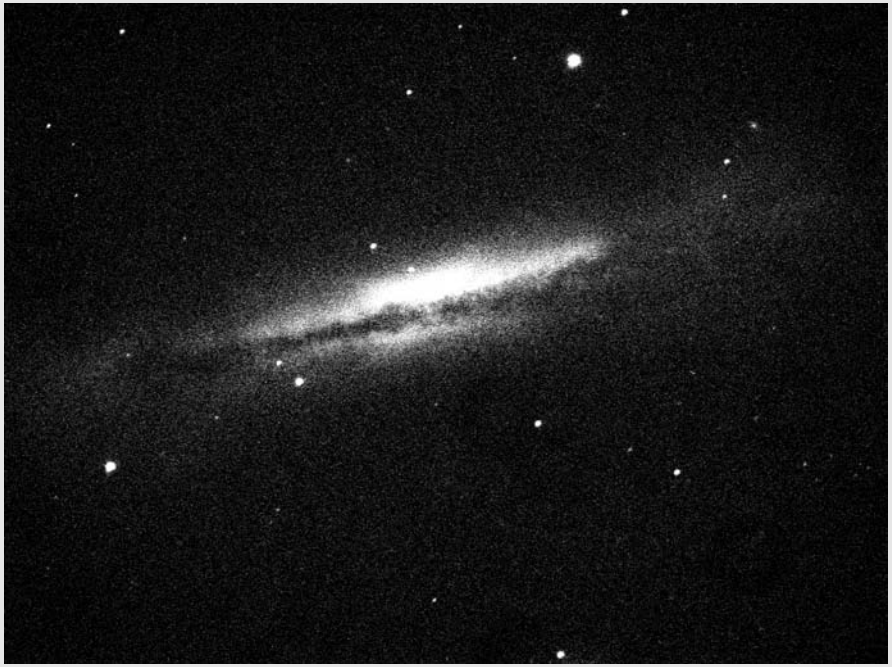
$6\times$ Bigger Telescope

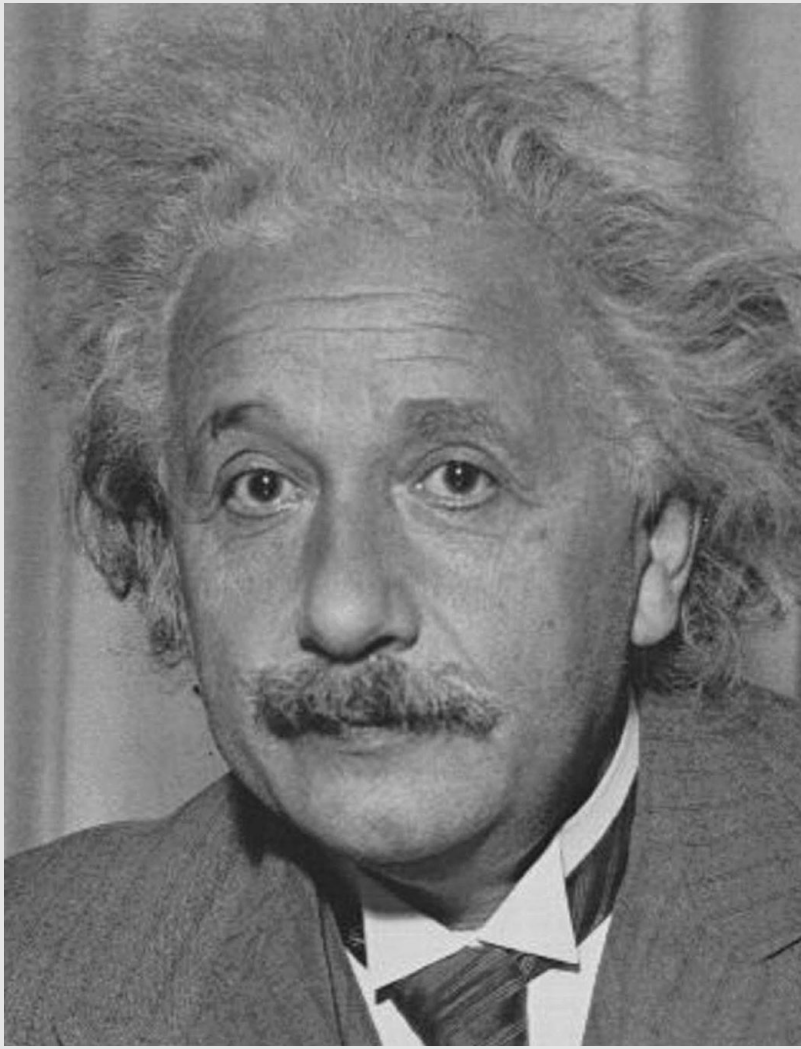


Albert Einstein (1905): Light is a Particle

Explained the photoelectric effect,
which led to the new field of *quantum mechanics*.
Einstein himself never accepted it.

Modern CCD cameras count *photons*.





21st Century Question: Are We Alone?

Indirect Detection Methods

More than 400 planets found so far

(since 1995)

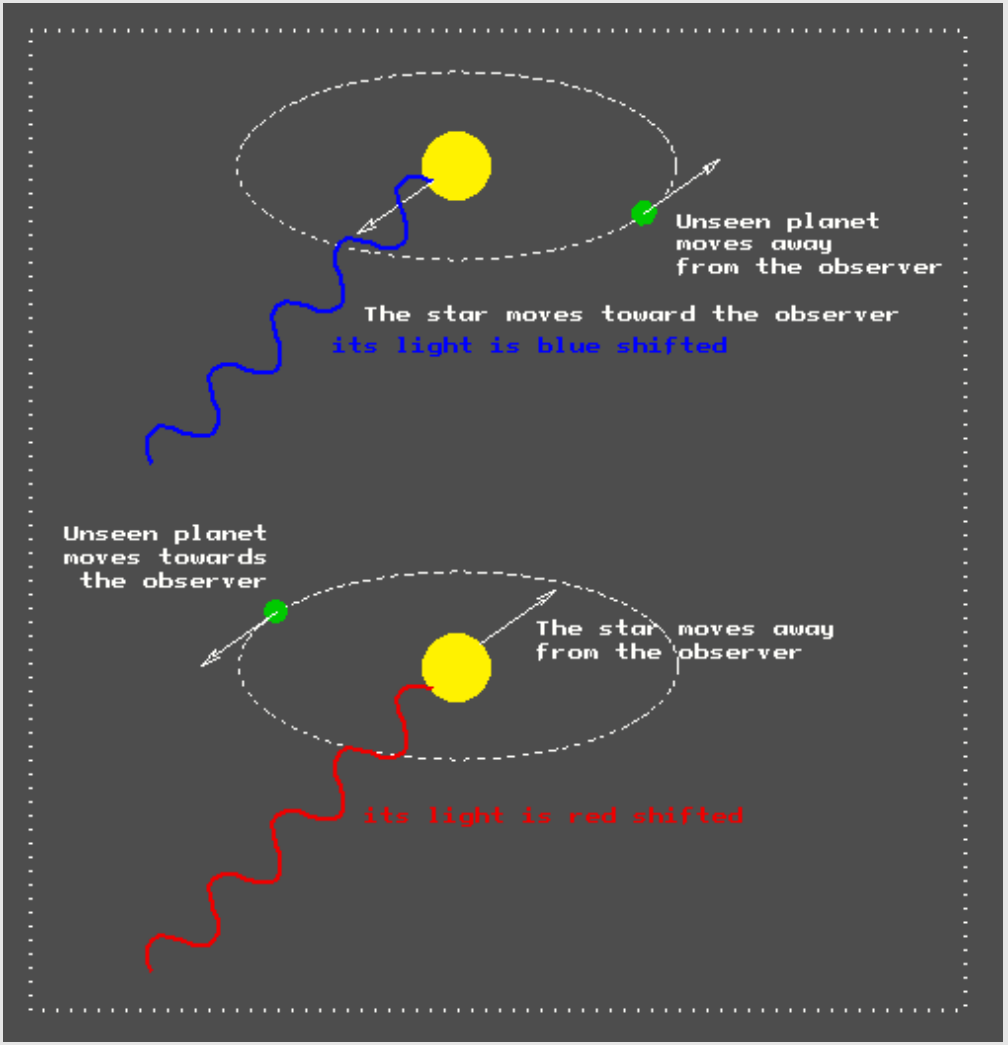
Wobble Methods

Radial Velocity.

For edge-on systems.
Measure periodic doppler shift.

Astrometry.

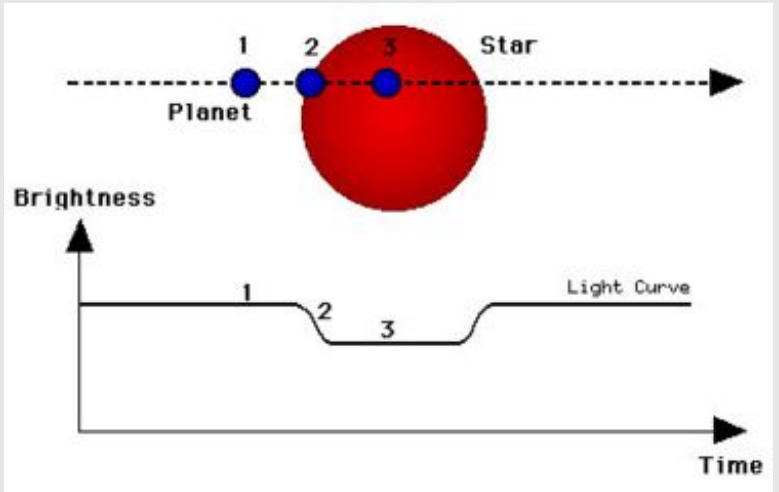
Best for face-on systems.
Measure circular wobble against background stars.



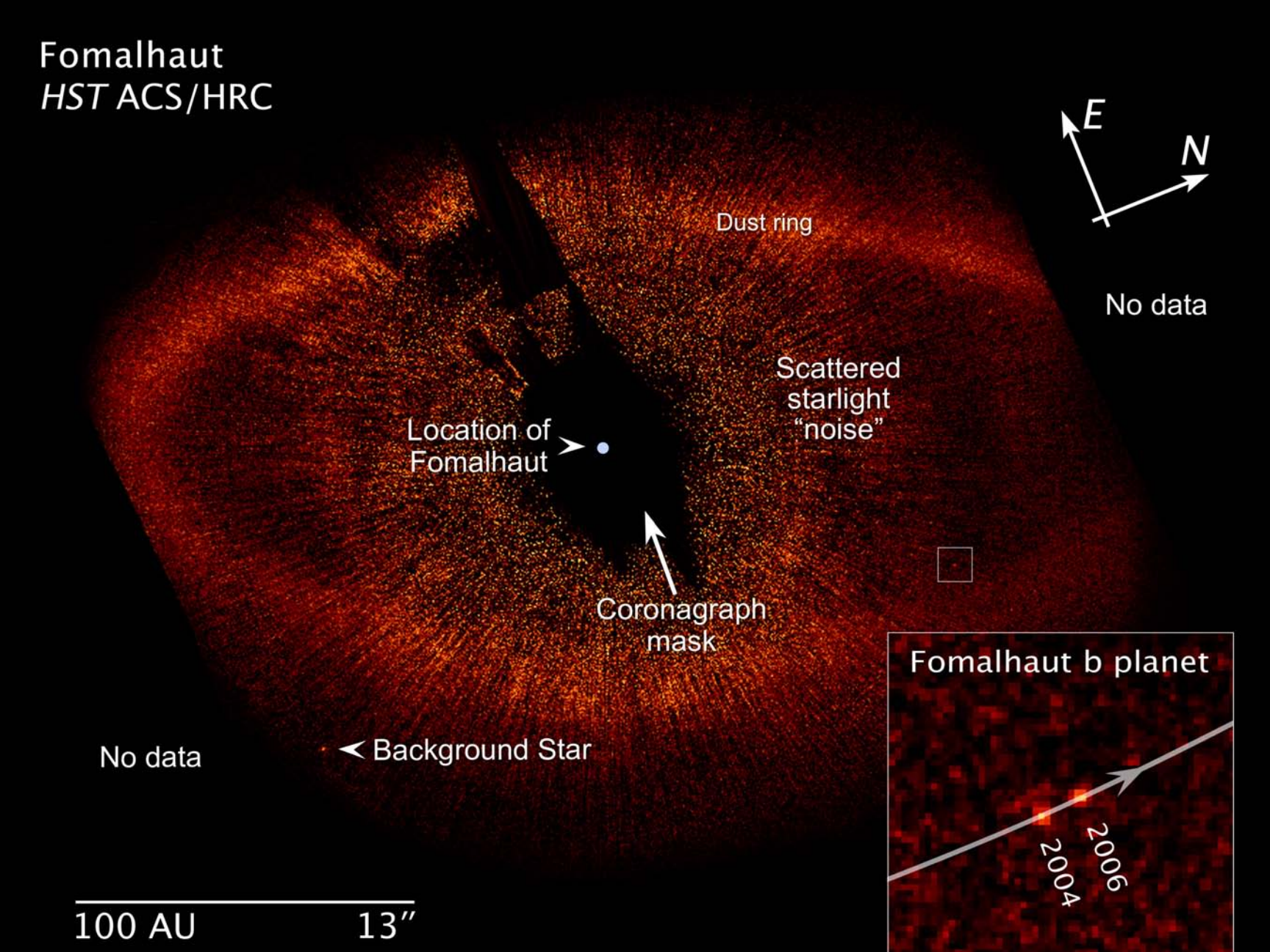
Transit Method

- HD209458b confirmed both via RV and transit.
- Period: 3.5 days
- Separation: 0.045 AU (0.001 arcsecs)
- Intensity Dip: $\sim 1.7\%$
- Radius: $1.3R_{\mathrm{J}}$
- (Venus Dip $= 0.01\%$, Jupiter Dip: 1%)

Venus Transit (R.J. Vanderbei)



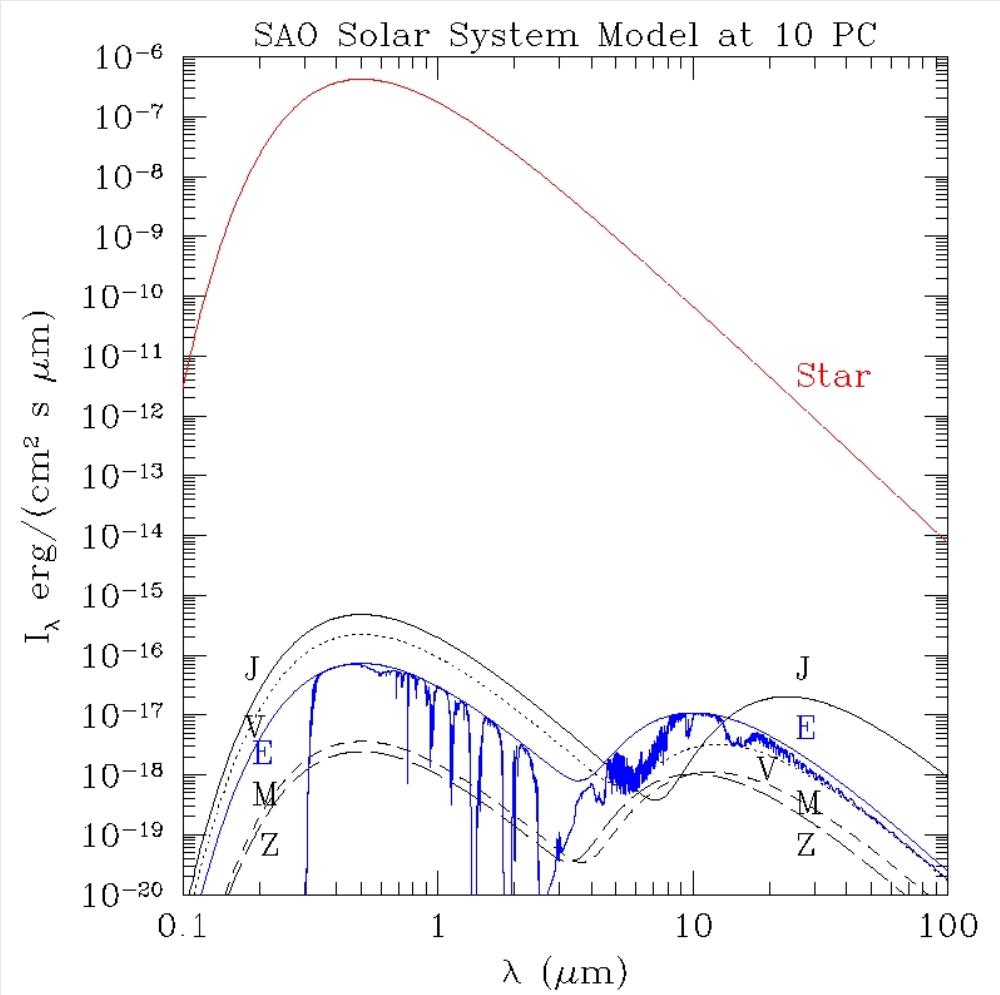
Direct Detection


Fomalhaut
HST ACS/HRC
E
N
Dust ring
No data
Scattered
starlight
"noise"
Location of
Fomalhaut
Coronagraph
mask
Fomalhaut b planet
2006
2004
No data
Background Star
100 AU
13″

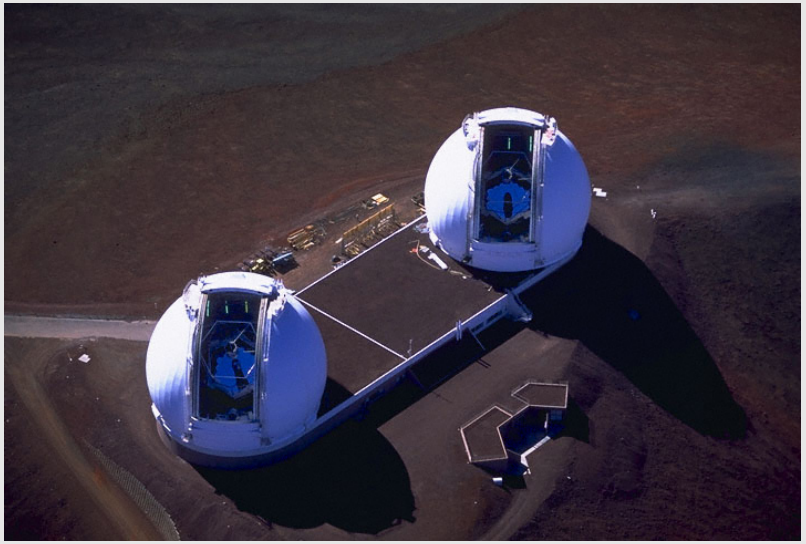
Why It's Hard

Premise: If there is intelligent life "out there", it probably is similar to life as we know it on Earth.

- *Bright Star/Faint Planet:* In visible light, our Sun is ten billion times brighter than Earth.
- *Close to Each Other:* A planet at 1 AU from a star at 33 light-years can appear at most 0.1 arcseconds in separation. (The full moon is 1800 arcseconds in diameter.)
- *Far from Us:* There are less than 100 Sun-like stars within 10 parsecs.



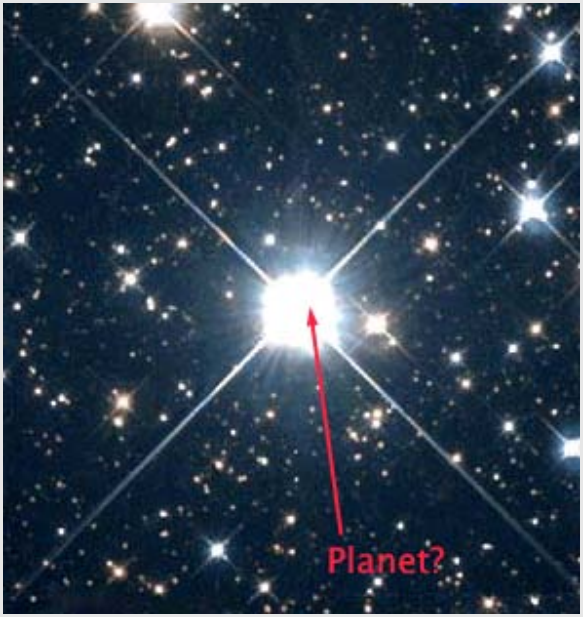
Can Ground-Based Telescopes Do It?



- Atmospheric distortion limits *resolution* to about 1 arcsec.
  Note: Resolution refers to equally bright objects.
  If one is much brighter than the other, then it is more difficult.
- Large aperture with adaptive optics.
- Interferometry.

No they can't!

Can Hubble Do It?

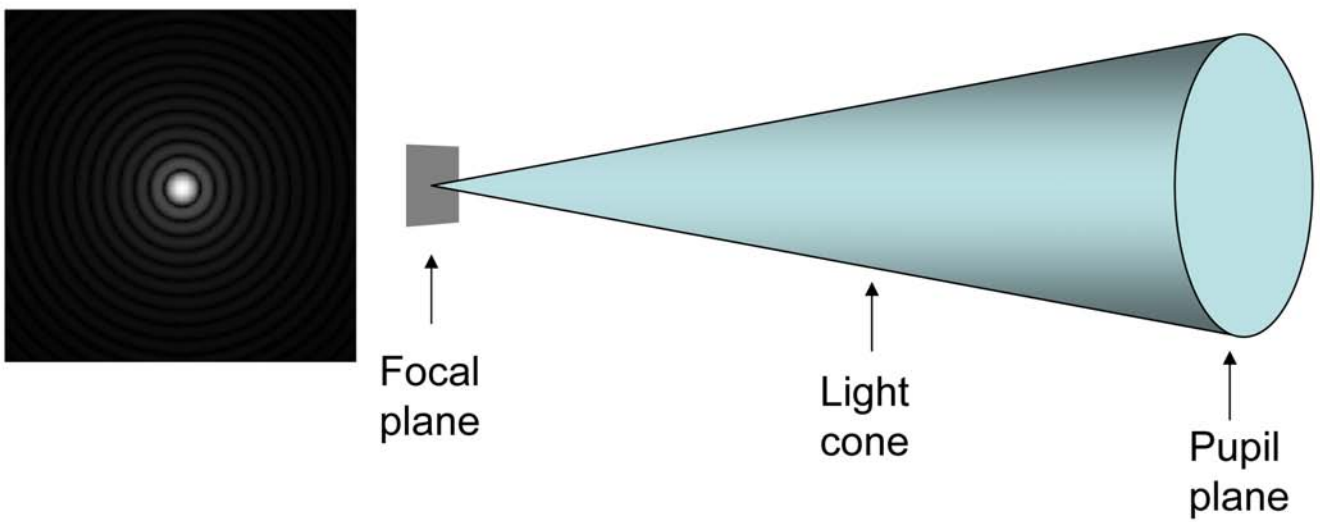


No it can't!

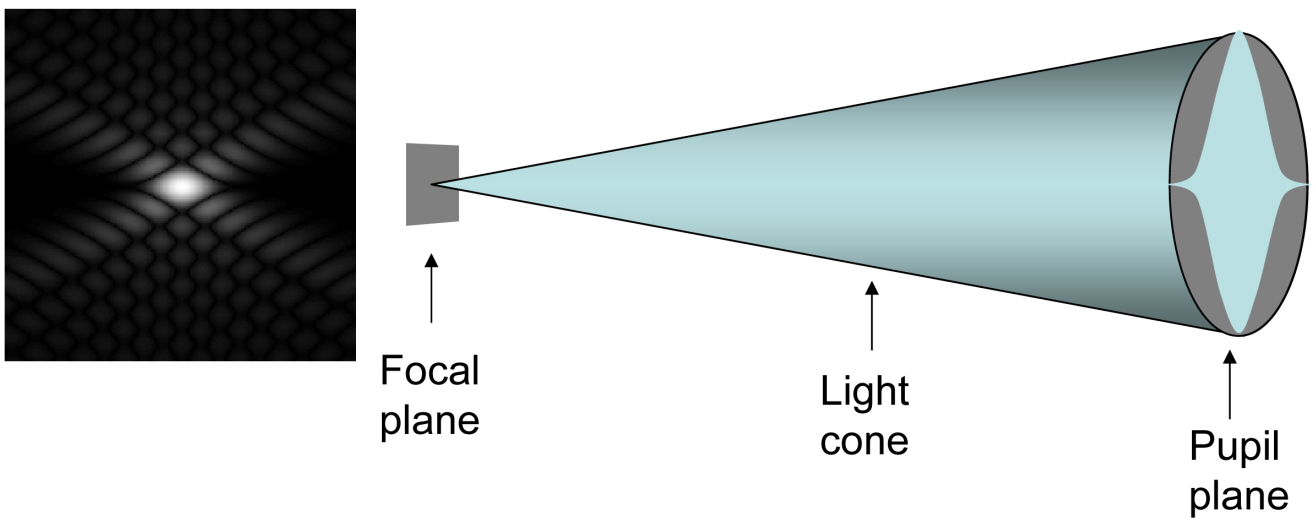
The problem is diffraction

Would have to be $1000\times$ bigger

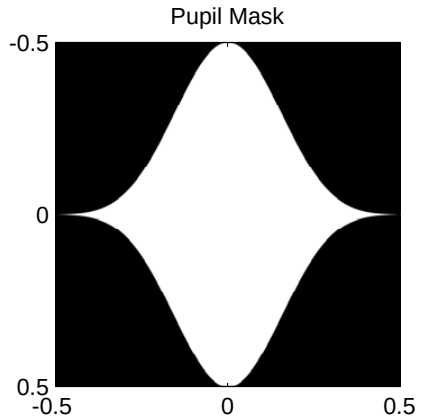
Diffraction Control via Shaped Pupils

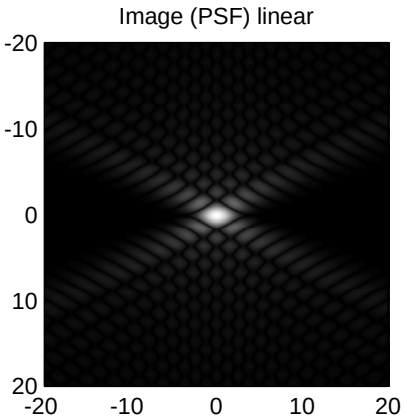


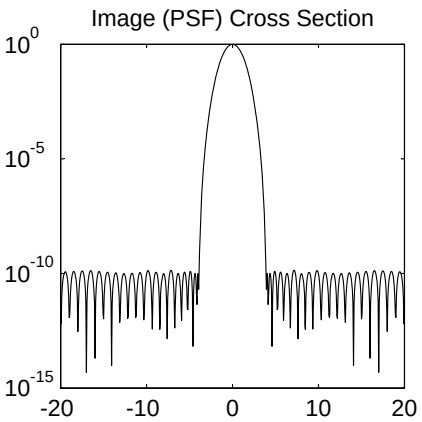
Diffraction Control via Shaped Pupils

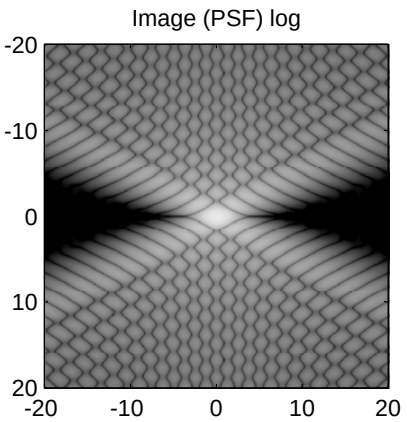


The Spergel-Kasdin-Vanderbei Pupil

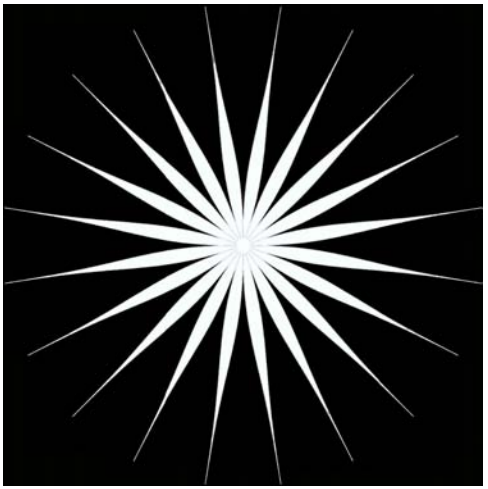




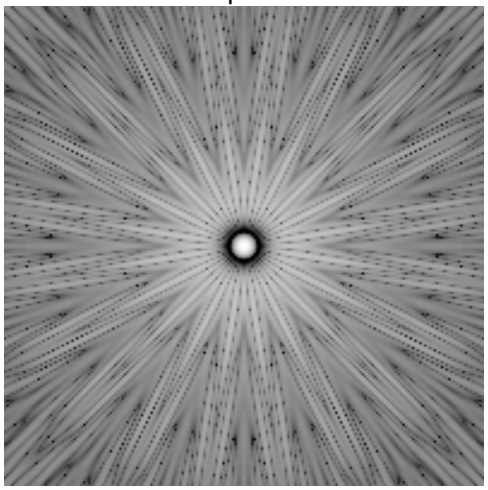




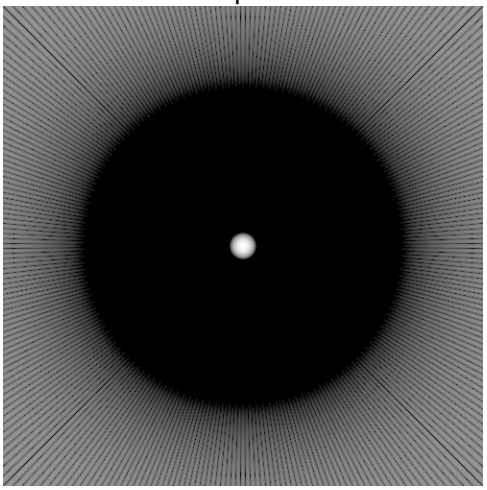
Shaped Pupil Coronagraph (TPF-C)



20 petals



150 petals



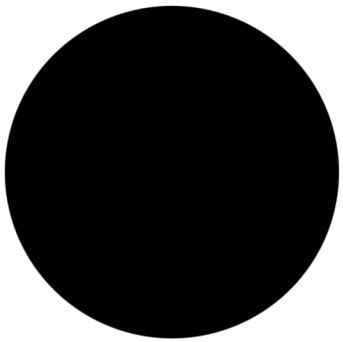
Maybe We Can!

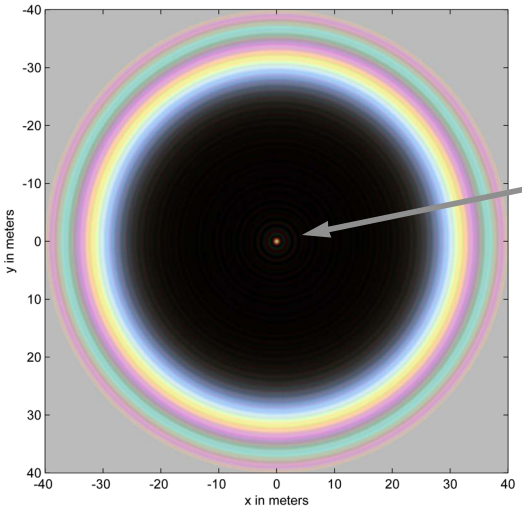
Space-based Occulter (TPF-O)

Telescope Aperture: 4m, Occulter Diameter: 50m, Occulter Distance: $72,000$km

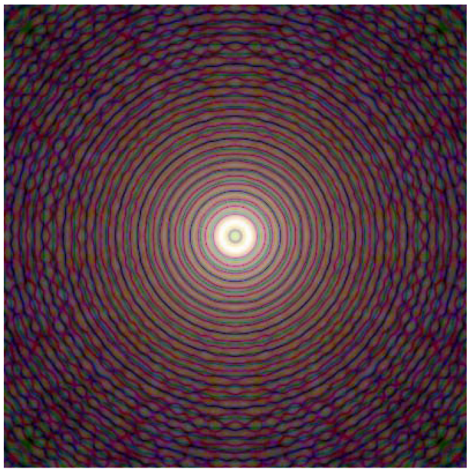
Plain External Occulter (Doesn't Work!)

Circular Occulter

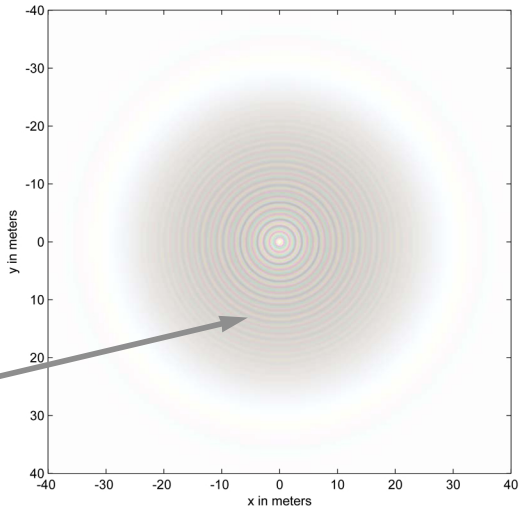




Poisson's Spot!



Simulated star/planet image



Shadow isn't dark enough

Shaped Occulter