The Search for Earth-like Planets

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http://www.princeton.edu/~rvdb
Some History—The Earth is a Sphere
1609: Telescope is Invented (Hans Lippershey)
1610: Galileo Looks at Jupiter

Callisto
Europa
Io
Ganymede
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 Sentence rescinded October, 1992)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.
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.
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: \(1.3R_J\)
- \((\text{Venus Dip } = 0.01\%, \text{ Jupiter Dip: } 1\%)\)

Venus Transit (R.J. Vanderbei)
Direct Detection
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 arc-seconds 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
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The Spergel-Kasdin-Vanderbei Pupil

Pupil Mask

Image (PSF) linear

Image (PSF) log

Image (PSF) Cross Section
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: 72,000km
Plain External Occulter (Doesn’t Work!)

Circular Occulter

Shadow isn’t dark enough

Poisson’s Spot!

Simulated star/planet image
Shaped Occulter