The Search for Other Earths

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STScI
August 17, 2009
“There are infinite worlds both like and unlike this world of ours...We must believe that in all worlds there are living creatures and planets and other things we see in this world.”

Epicurium

c. 300 B.C
Galileo, 1609
"There are countless suns and countless earths all rotating around their suns in exactly the same way as the seven planets of our system . . . The countless worlds in the universe are no worse and no less inhabited than our Earth”

Giordano Bruno
in De L'inifinito Universo E Mondi
# Exoplanet Discovery Timeline

<table>
<thead>
<tr>
<th><strong>Past</strong></th>
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<tbody>
<tr>
<td>1992</td>
<td>Pulsar planets</td>
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<tr>
<td>1994</td>
<td>Protoplanetary disks resolved in visible light</td>
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<td>1995</td>
<td>Radial velocity extrasolar planet discovery</td>
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<td>1999</td>
<td>Extrasolar planet transits observed</td>
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<td>2001</td>
<td>Extrasolar planet atmospheres measured</td>
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<td>2003</td>
<td>New planets discovered with transit method</td>
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<tr>
<td>2004</td>
<td>Planet discovered with microlensing method</td>
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<td>2006</td>
<td>Transit planet day side temperature measured</td>
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<table>
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<th><strong>Present</strong></th>
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<tbody>
<tr>
<td></td>
<td>Transiting hot Jupiter atmospheres measured in detail</td>
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<td></td>
<td>First transiting super-Earths</td>
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<td></td>
<td>Direct imaging of young hot Jupiters</td>
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<table>
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<tr>
<th><strong>Future</strong></th>
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<tbody>
<tr>
<td>2011</td>
<td>Statistical frequency of earthlike planets determined (Kepler)</td>
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<tr>
<td>2011</td>
<td>Planets found around Alpha Centauri?</td>
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<tr>
<td>2013</td>
<td>JWST: transits and eclipses of planet around nearby red dwarfs</td>
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<tr>
<td>2015</td>
<td>Search for nearby Earths and super Earths</td>
</tr>
<tr>
<td>2030</td>
<td>Definitive sampling of biospheres on exoplanet survey</td>
</tr>
<tr>
<td>2040?</td>
<td>Direct imaging of all sizes of exoplanets</td>
</tr>
<tr>
<td>2101?</td>
<td>First interstellar AI mission to directly sample exobiology</td>
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</tbody>
</table>
\[ N = R f_{\text{neff}} L \]
**Drake Equation**

\[ N = R \times f_s \times f_p \times n_e \times f_l \times f_i \times f_c \times L \]

- **R**: average rate of star formation
- **f_s**: fraction of good stars that have planetary systems
- **n_e**: number of planets around these stars within an “ecoshell”
- **f_l**: fraction of those planets where life develops
- **f_i**: fraction of living species that develop intelligence
- **f_c**: fraction of intelligent species with communications technology
- **L**: lifetime of the “communicative phase”
THE OBSERVABLE DRAKE EQUATION

$$ETL = N_p \times F_{TP} \times FP_w \times FP_L$$

ETL = Planets with extraterrestrial life in the Galaxy
Np = Number of exoplanets
Fpt = Fraction of terrestrial planets
FPw = Fraction of terrestrial planets with liquid water
FPl = Fraction of terrestrial planets with carbon-based life
Protoplanetary Disks
Orion Nebula

HST • WFPC2

PRC95-45b • ST ScI OPO • November 20, 1995
M. J. McCaughrean (MPIA), C. R. O’Dell (Rice University), NASA
Planet Detection

Doppler Shift due to Stellar Wobble
Detectability of the Solar System

Precision: 3 m/s

Simulated Doppler Velocity of the Sun

Velocity (m/s)

Years

0  10  20  30  40  50  60  70

-30 -20 -10  0   10   20   30
Hubble detects a transiting planet

Astronomers use Hubble to measure the differences in luminosity, or brightness, between the unobstructed central star and the star partially obstructed as its orbiting companion passes between its face and the observer (Hubble). The companion orbits the star over 3 to 4 days.

“Dip” in luminosity → Period of orbit (3–4 days)
Sagittarius Window Eclipsing Extrasolar Planet Search
HST detects additional sodium absorption due to light passing through planetary atmosphere as planet transits across star.

- Sun-like star
- Gas-giant planet orbits its sun in 3.5 Earth days (orbit not to scale)
- Light absorbed by planet itself
- Additional light absorbed by planetary atmosphere
- Duration of transit
- Brightness of star

Wavelength (nm)

Normal absorption spike depth from star

Additional absorption due to planetary atmosphere
Hubble detects carbon dioxide in extrasolar planetary atmosphere

Star HD 189733

Planet HD 189733b

Planet HD 189733b passes behind its star

Hubble takes spectrum of star and fully illuminated planet. By subtracting the star's spectrum from the combined spectrum, the spectrum of the planet is obtained.
A disc positioned between a space telescope and the target solar system blocks out light from the star, leaving any Earth-like planet visible.
An inventory of stars within 32 light-years' distance from Earth
An optical/near-infrared space telescope with a filled aperture of at least 8-meters will probably be required to definitively answer the question “Are we alone?”
5th grade on the planet "Zorba" in the Orion Arm of the Milky Way Galaxy......

EARTH
A typical barren wasteland in space...

Temperature never rises above 140 degrees F.

There is no life on the Earth, because there is not enough methane gas in its atmosphere to support life. As we learned in class today, life needs methane gas, carbon monoxide, and an adequate temperature of 350° F in order to survive........

On second thought, I take that back about wanting to be an astronaut...

Good idea.

A living nightmare...!

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Inside Gliese 436b

- Small Rocky Core
- Water Compressed Into Solid Form
- Thin Outer Envelope of Hydrogen and Helium Gas
Life in the Universe

- All Life
- Chemical Energy
- Carbon-based
- Liquid water
• A thermodynamic disequilibrium
• An environment capable of maintaining links between carbon, hydrogen, and other atoms
• A liquid environment
• A molecular system that can support Darwinian evolution.
Total number of stars >100 billion

Total number of planets ~ several trillion ?

Total number of moons ~ 10s of trillions ?

Earthlike Planets? .01% = 1 billion??