Prospecting for Habitable Worlds

Jon M. Jenkins
NASA Ames Research Center

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All the Known Planets In 1994
A Search for Earth-size Planets

NASA's 1995 ExNPS Report

Transit Photometry not Recommended!
The *Kepler* Mission

What fraction of sun-like stars in our galaxy host potentially habitable Earth-size planets?
Exoplanet Discoveries Over Time*

Radii estimated for non-transiting exoplanets
Discovery data dithered slightly

*According to https://exoplanetarchive.ipac.caltech.edu as of 8/29/17
Enabling Kepler

- Back illuminated CCDs (20 ppm photometric precision)
- Sophisticated algorithms
- Computational infrastructure
A Search for Earth-size Planets

How Hard is it to Find Good Planets?

Jupiter (~1%)

Earth (~0.01%)

\[ \text{Rp} = 9.7 \text{Re} \quad \text{P} = 331.6 \text{d} \]

\[ \text{Rp} = 0.87 \text{Re} \quad \text{P} = 19.58 \text{d} \]
Launched March 7 2009
A Search for Earth-size Planets

Launched March 7, 2009

First Light Image
Inset – Stellar oscillation Detections before Kepler.

Main: Kepler’s 4 years of study show the stars amplitudes (ppm) as color coded points. Extended study provides –

- Stellar ages and radii
- Internal differential rotation
- Convection zone depths
- Rotation axis orientation
- Heliophysics-like results

...for 15000+ stars
Kepler-452b
A Search for Earth-size Planets
Kepler's Small Habitable Zone Planets
As of May 10, 2016

This graph illustrates various planets in the habitable zone of their stars, comparing their energy received with their surface temperatures. Different colors and symbols indicate newly validated versus previously verified planets.
Correcting Systematic Errors

Original Flux

Systematic Error-Corrected Flux
The Search Problem

A Search for Earth-size Planets
Solar Variability

A Search for Earth-size Planets
Sophisticated Signal Processing Algorithms

An overcomplete, shift-invariant dyadic wavelet decomposition
The Search Problem
The Search Problem
Keeping Up with the Data
64 hosts, 712 CPUs,
3.7 TB of RAM,
148 TB of raw disk storage
Hardware Architecture: NAS Pleiades Supercomputer

7.25 Pflop/s peak cluster
246,048 cores
938 TB of memory
15 PB of storage
Kepler taught us that planets are ubiquitous:

What Next?
The View from Proxima b
NASA’s TESS Mission

Slated for launch by mid 2018
Transiting planets provide opportunities to determine the bulk planetary density and to characterize their atmospheres.

Exoplanet Missions

- TESS
- JWST
- Kepler
- Spitzer
- Hubble
- Ground-based Observatories

+ ESA's CHEOPS (2018)

+ ESA's PLATO Mission (2026)