New Worlds: NASA’s Search for Exoplanets

Dr. Nikole Lewis (STScI)
Dr. Stephen Rinehart (NASA GSFC)
Mary Dussault (Harvard-Smithsonian CfA)
Dr. Kevin Stevenson (STScI)
Additional Resources

http://nasawavelength.org/list/1607

- Transiting Exoplanet Survey Satellite (TESS)
- DIY Planet Search
- DIY Planet Search YouTube tutorial
- Eyes on Exoplanets
- Universe Discovery Guide (April)
- Website: Exoplanet Exploration
- Kids News: 20 Years of Exoplanets
- Podcasts: Discovery of Exoplanet Using X-rays
Exoplanet Detection Methods

Nikole K. Lewis
STScI
Radial Velocity Method

• The most successful method of detecting exoplanets until 2010

• Measures shifts in the stellar spectrum to determine the presence of a planetary companion

• Can be used to determine the approximate mass of the planet as well as the semi-major axis, period, and eccentricity of the orbit
Radial Velocity Method
Microlensing Method

- Like a lens, the gravity of a planet or star focuses light from background stars
- Requires a large number of background stars
- Can detect earth-like planets (and free floating planets!)
Microlensing Method

~51 planets detected

Mass Ratio and Angular Separation is Measured
Direct Imaging Method

- Planetary systems can be imaged directly if the stellar light that would normally drown the planetary signal is removed in some way

- Methods first developed to observe solar corona, hence coronagraphy
Direct Imaging Method

Sophisticated optical designs, use of adaptive optics, and optimization of post-processing methods have increased the achievable contrast ratios from the ground.

HR 8799 System
Marois et al. (2008)
Transit Method

- Detects planetary companions by measuring a drop in stellar brightness as the planet occults a portion of the stellar disk
- Currently only way to directly measure the radius of the planet
- Requires alignment of the planet star system along the line of sight to earth
- Method used by ground-based surveys, CoRoT, and Kepler

Transit Depth = \( \left( \frac{R_p}{R_\star} \right)^2 \)

Ingress/Egress constrains inclination
RV follow-up gives Mass
Transit Method

![Graph showing the discovery of exoplanets with Jupiter, Neptune, and Earth as reference points. The graph plots planetary radius against year of discovery.]
Transit Method: Kepler

2009-2013
Transit Method

Primary Eclipse
- Measure size of planet
- See star's radiation transmitted through the planet atmosphere

Secondary Eclipse
- See planet thermal radiation disappear and reappear

Learn about atmospheric circulation from thermal phase curves

Figure by S. Seager
Exploring the Diversity of Worlds

S. Rinehart, NASA Goddard
The Missions of Exoplanet Discovery

Exoplanet Missions

WFIRST

Hubble

Spitzer

Kepler

JWST

TESS

Ground-based Observatories

AFTA

New Worlds Telescope

2001 Decadal Survey

2010 Decadal Survey

Astronomy and Astrophysics in the New Millennium

New Worlds, New Horizons in Astronomy and Astrophysics
Kepler vs. TESS

• Kepler: The Statistics of Exoplanets - \textbf{Find} \eta_{\text{Earth}}
• TESS: Open the Door for \textbf{Characterizing} Exoplanets
Video

https://youtu.be/FlJyuDQOeoo
Anticipated TESS Discoveries

- Detectable planets around **200,000 pre-selected stars**
- Detectable planets around **20,000,000 stars in full images**
TESS Discoveries: The Numbers

Over 500 Small Planets!

Sullivan, et al. 2015

Full-Frame Images

2x10^5 Target Stars

Detecteds

10^5

10^4

10^3

10^2

10^1

Earth's < 1.25R

Super-Earths 1.25 - 2R

Sub-Neptunes 2 - 4R

Giants > 4R

70 ± 9

1.4k

486 ± 22

1111 ± 122

67 ± 8

3.0k

Sullivan, et al. 2015
One Parameter is Not Enough

- Hydrogen
- Water
- Rock (MgSiO₃)
- Iron

**Our Solar System**
- Super-Earths
- A few other exoplanets

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Seager et al. 2007

- Jupiter
- Earth
- Venus

- Our Solar System
- Super-Earths
- A few other exoplanets

- $R/R_{\text{earth}}$
- $M/M_{\text{earth}}$
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Need Bright Stars

Planet Radius (R_E)
Ideal Targets for Future Observation
After JWST: WFIRST
The BIG Goal
Future Large Missions...

Future large telescope for exoplanets

Solar System from 10 parsec with coronagraph and 12-m telescope

ATLAST HDST LUVOIR HabEx
Do-It-Yourself Planet Search

Detect an exoplanet transit with your own telescope data!

Mary Dussault
Harvard-Smithsonian Center for Astrophysics

Museum Alliance Briefing:
New Worlds: NASA’s Search for Exoplanets
HOSTING A GROUP WORKSHOP

HOW TO DETECT A PLANET
Welcome to the MicroObservatory Robotic Telescope Network operated by the Harvard-Smithsonian Center for Astrophysics.

Explore the Universe with telescopes you control over the internet!

Follow Us

MicroObservatory Access Portals

- Observing with NASA
  - MicroObservatory for everyone!

- Laboratory for the Study of Exoplanets
  - Explore exoplanets!
  - For teachers and students

- Observatory
  - Full access legacy portal
  - Login required

- DIY Planet Search
  - Beta Version
Welcome Planet Searchers.

Join the Community of DIY Planet Searchers

You are about to take part in one of the most exciting frontiers of science—the search for other worlds and other earths. Using a telescope that you control online, you’ll take your own images of distant solar systems, interpret and share the data you gather, and become part of a community of planet searchers!

Check Out Public Participation Map and Data
DIY Planet Search

Join the search for other planets

Begin your search using the DIY tools to collect and analyze your own images. You can work alone or with a group to investigate a few data points or an entire transit event. Gather and save data and information about your planets in My Planet Search.

Compare, combine, and communicate your findings with others in the DIY Planet Search community on the Community page. Here, you can also follow the development of scientists in their search for habitable planets.

Weekly Schedule of Targets

- **Tuesday November 29, 2016**
  - No viewable targets today

- **Wednesday November 30, 2016**
  - Qatar-1

- **Thursday November 1, 2016**
  - WASP-50

- **Friday December 02, 2016**
  - No viewable targets today

What’s New!!

**Telescope**

- Requesting Images
  - In addition to requesting upcoming images, now the telescope tool also allows you to collect images that the telescope already collected the past month.

**Brightness Tool**

- All Improved
  - We improved our brightness tool to allow you to better measure and find your target stars.
**Do-It-Yourself Tools**

**Choose Target**

*Instructions*

Begin your search by choosing the target for Today’s date. Or pick a date in the future when you know that a particular target will be available. You can learn more about the targets by clicking on their name. Or you may go directly to the Telescope page by clicking the “Observe” button.

**November 2016**

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Control the Telescope

Use the MicroObservatory telescopes to take images of target stars.

Instructions

1. Select the star system you would like to observe.
2. Select the hour and minute from the available (highlighted) time slots.
3. Select setting for the telescope

The telescope will automatically point toward the selected object at the requested time, and take an image. To retrieve the images tomorrow, visit the Images Collected link.

What's Going On

Exoplanets are too far away to see directly. As a planet orbits its star, it blocks some of the star's light. You can detect this periodic dimming using the telescope to take a series of images of the star over the course of the night.

Telescope Tutorial
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Telescope Tutorial

1 Select Planet

Current Target: Qatar-1

Choose an appropriate exposure time and filter. 
Note: for the current targets listed, please choose a 60 second exposure time and a clear filter.

2 Choose Time

Selected Time:
Qatar-1: All available hours

Exposure: 60 seconds

Filter: Clear

3 Select Settings

Image was requested.
Qatar-1 (114 Images Requested)

Take Image
My Planet Search

Host a Group
Host a Group creates a one-time joint planet search for a specific target star and date. You and your invited group will be able to work together to analyze images and create a single light curve for a predicted exoplanet transit.

Create a Group

Which star would you like to observe?
Name of Group
MaryD@Qatar-1@2016-11-13

Who would you like to invite?
Invite your Friends
Aladdin
fsienkie
erikaw
Aladdin1
Additional DIY members
Please add emails separated by a comma.

Add Friends
Add Additional Members

Group Members
PlanetHunter1 remove
PlanetHunter2 remove
PlanetHunter3 remove
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# Images Collected (2016 Collected)

## Pending

## Current (Last 5 Days)

## Past

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Detect a Planet

Chart the brightness of your star system over time

Instructions

Using the images you have taken with the telescope, see if you can detect a planet orbiting its star. The video tutorial will get you going. For each image you’ll need to:

1. Calibrate the image
2. Measure the target star
3. Measure two comparison stars
4. Measure two dark areas of the sky

What’s going on:
The observed brightness of your star changes as a planet orbits in front of it. Use this tool for each image to measure and calculate the brightness of your star at a given time of the night. Calculating the brightness of your star for several images throughout the night will allow you to observe the dimming of the star’s light as the planet passes in front of it.

Brightness Tutorial.
Star Finding Tutorial.
Interpret & Share Your Results

Instructions

Now it’s time to analyze and interpret your results.

1. Select a star that you have measured. The graph for all of the data you analyzed for this star will appear on the graph.
2. Look for a tell-tale dip in the graph. Do you think you’ve detected a planet?
3. Can you tell from the graph when the planet crossed in front of the star? To see when this transit was predicted to occur, click on See Predicted Transit
4. Need more data? Click on View Reference Graph to see additional points. How do your points compare to these?

Interpret your results:

The size and shape of your graph can tell you a lot about the planet and its star.

How deep is the dip in your graph? A larger planet will block out a larger percentage of the star’s light making the dip in the graph bigger. Do you think you have a large or small planet?

What is the shape of your graph? Do you see a “V” shape or a “U” shape? Planets can cross the center face of a star producing a “U” shaped dip. Or, the orbit of the planet might be tilted, and only part of the planet passes in front of the star. This “grazing transit” will block out less light for a shorter time and produce a “V” shaped graph.

What does your graph look like?

Please comment.
Interpret your results:

The size and shape of your graph can tell you a lot about the planet and its star.

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What does your graph look like?

This was the night of the full Super Moon, so the data is really noisy. But it is in the same ballpark as other observers data.
These findings are a contribution by the Public

1. Pick a Participant or Target
   - erinspace.
   - erin.space.
   - alfrodas.
   - smith.shannon217.
   - carlos alfredo cortez
   - alvarez.
   - shaheeniazli.
   - jatkins.

2. Narrow By Participant

Results and Findings

Qatar-1 on 2014/6/6

A V shape can be seen from -1 hour to 1 hour from center of predicted transit. But most dots lie between 2.20 to 2.40, which is higher than seen range.

There is a dip in the center of predicted transit period.

Although the spots seem unstable, but we can still notice a dip in the middle.

Looks like a V.
These are the star systems that you can explore using the MicroObservatory telescope. Click on the name or image to learn more.
The Calendar page will show you when each of these is available. Check back here often as we are adding new stars all the time.

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Qatar-1 b is a gas giant exoplanet that orbits a G-type star. It is at least 1.29 x Jupiter, takes 1.42 days to complete one orbit of its star, and is 0.02332 AU from its star. Its discovery was announced in October 2011.

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Images (215 Collected)
Data (39 Points)
Qatar-1 b is a gas giant exoplanet that orbits a G-type star. It is at least 1.29 x Jupiter, takes 1.42 days to complete one orbit of its star, and is 0.02332 AU from its star. Its discovery was announced in October 2011.
Next Steps for DIY Planet Search:
Enable DIY User Community to upload their light curve data to the NASA Exoplanet Archive

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This product is based upon work supported by NASA under award number NNX16AC65A. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration.