Observing Exoplanets and looking for Life around other Stars

Contact:
ALL known Planets until 1989
Exoplanets identified – we are now starting to identify Earth-size planets.
First discoveries: Oddballs

PSR 1257+12: 3 planets around a pulsar

How could planets survive a supernova? Planets may have formed from debris after the supernova explosion.

51 Peg b: The first confirmed “Hot Jupiter”

A Jupiter-size planet at only 5.3% of the Sun-Earth distance from its host star, orbiting in 4.2 days.
What makes planets habitable?

Size matters: not too big, not too small

Moon: too small
No atmosphere

Earth

Jupiter: too big
Mostly gas
What makes planets habitable?

The planet must be in the **habitable zone** of its star: not be too close or too far.

**Venus:** too close, too hot

- Venera 13 lander, survived 127 mn at 457 C, 89 atm

**Mars:** too far, too cold

Image credit: NASA/JPL-Caltech/MSSS
Approximately 10% of stars have a habitable planet

200 billion stars in our galaxy

→ approximately 20 billion habitable planets

Imagine 200 explorers, each spending 20s on each habitable planet, 24hr a day, 7 days a week.

It would take >60yr to explore all habitable planets in our galaxy alone.

x 100,000,000,000 galaxies in the observable universe
>~10% of stars have potentially habitable planet
First potentially habitable planets now identified

Potentially Habitable Exoplanets

Ranked by the Earth Similarity Index (ESI)

Artistic representations. Earth, Mars, Jupiter, and Neptune for scale. ESI value is between brackets. Planet candidates indicated with asterisks.
How do astronomers identify exoplanets?

HIGH PRECISION OPTICAL MEASUREMENTS OF STARLIGHT (indirect techniques)

Earth around Sun at ~30 light year

→ Star position moves by 0.3 micro arcsecond (thickness of a human hair at 20,000 miles)

→ Star velocity is modulated by 10cm / sec (changes light frequency by 1 part in 3,000,000,000)

If Earth-like planet passes in front of Sun-like star, star dims by 70 parts per million (12x12 pixel going dark on a HD TV screen 70 miles away)
Exoplanet transit
If the planet passes in front of its star, we see the star dimming slightly

Transit of Venus, June 2012
Kepler (NASA)
Directly imaging planet is necessary to find life

We need to take spectra of habitable planets

Spectra of Earth (taken by looking at Earthshine) shows evidence for life and plants
Beta Pictoris

8 Jupiter mass planet

Orbits young massive star in ~20yr

Beta Pictoris

Hubble Space Telescope - ACS/HRC

Location of Star

Primary Disk

Secondary Disk

Occulting Mask

10 billion miles

100 AU

ESO VLT image

(Lagrange et al.)

NASA, ESA, and D. Golimowski (Johns Hopkins University)
HR8799 imaged with Large Binocular Telescope

Four planets, orbital periods on the order of 100yr
Each planet 5 to 7 Jupiter Mass

$L'$ band

Defrere et al.

LBTAO/PISCES H-band

Skemer et al..
Taking images of habitable exoplanets: Why is it hard?
Saturn

Earth
Coronagraphy … Using optics tricks to remove starlight (without removing planet light)

We need a better coronagraph… and a larger eye (telescope)
Water waves diffract around obstacles, edges, and so does light.

Waves diffracted by coastline and islands.

Ideal image of a distant star by a telescope. Diffraction rings around the image core.
Vacuum testbeds at NASA JPL
PIAA testbed at NASA JPL: lab results

An Earth-like planet could be seen!

Monochromatic light (800nm, vacuum)

Location of the star (mostly blocked)

6 $\lambda/D_{\text{sky}}$

7.5% wide band (770 – 830 nm, in air)

3 runs, contrast values averaged from 2 to 4 $\lambda/D$ between $5.10^{-10}$ to $9.10^{-10}$

(figure shows $7.3.10^{-10}$ result)

5.10$^{-8}$ contrast from 2 to 4 $\lambda/D$

2.10$^{-8}$ contrast from 3 to 4 $\lambda/D$

Contrast performance limited by wavefront instability (test in air)
Space telescopes

WFIRST-AFTA telescope, 2.4m diameter

ATLAS 8m telescope project
The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system
Exciting future opportunities

Next generation of large telescopes on the ground will be able to image habitable planets around nearby low mass red stars. 3 projects, ~30m diameter.

Space telescopes with coronagraphs will be able to image and study Earth-like planets around sun-like stars.
Proxima Centauri
Discovering transiting exoplanets requires monitoring large parts of the sky for long periods of time.

The most efficient way to do this is to use inexpensive digital cameras.

PANOPTES is a citizen science project aimed at discovering a large number of exoplanets.

Cameras: Canon EOS SL1 (x2), Lenses: Rokinon 85mm F1.4 (x2)
Mount: iOptron IEQ30
Weather and cloud sensor
12V computer. All system runs on 12V battery charged by 120V AC (resilient to short power failures)
Python-based software
PANOPTES prototypes (2010-2014)

Project started in 2010 with deployment of prototype #1 at the Mauna Loa observatory (Hawaii, USA).

2013: prototype #3 deployed at Mauna Loa observatory

Quasi-continuous robotic operation of prototypes since early 2011
Precision flux measurement

Color DSLR cameras have “colored” pixels → we can’t simply add pixel values to measure star brightness

We use comparisons between ~100,000 star images available in each field to calibrate flux
Orion field (image processed by Jon Talbot)
Comet Lovejoy (image processed by Jon Talbot)
Example image (Cygnus field):
>100,000 stars in a single image

Transit Field #1 (in Cygnus), camera 2 (Sept 11, 2012 UT)
More info, how to join PANOPTES

Project website: www.projectpanoptes.org
Software: https://github.com/panoptes
Joining request: info@projectpanoptes.org