TPF-

Sally Heap & Don Lindler

Extrasolar Planet Research and Observatories

"Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature."

Albertus Magnus (1193–1280)

"We may object that we have been thinking of the stars as mere bodies . . . but should rather conceive them as enjoying life and action. On this view the facts cease to appear surprising."

Aristotle (384–322 BC)
On the Heavens, Book II, Part 12

Extrasolar Planets

Our solar system is composed of nine planets, including Earth, that circle a central star, the Sun. Astronomers and philosophers have speculated for millennia about whether other stars harbor worlds like Earth and whether these worlds are inhabited. However, it is only in the last decade that telescopes have become powerful enough to detect whether planets of any type circle other stars. In 1995, astronomers discovered the first solar system besides our own. Since then, astronomers have found over 100 planets orbiting other stars—and the number continues to climb with new discoveries.

All of the extrasolar planets discovered to date are either very large planets or planets that circle very close to their parent stars. Some extrasolar planets are many times larger than the largest planet in our solar system, Jupiter, and orbit even closer to their parent star than the closest planet to our Sun, Mercury. Because of the obscuring effects of the Earth's atmosphere, the detection and characterization of small planets with normal orbits like Earth is extremely challenging using ground-based telescopes.

NASA's Astronomical Search for Origins program will use a variety of techniques this decade to greatly expand the number and variety of known extrasolar planets. New space telescopes like the Spitzer and James Webb Space Telescopes, the Kepler mission, and the Space Interferometry mission, will search newly formed planets circling young stars, take planetary surveys of thousands of faraway stars, and detect planets only a few times larger than Earth around very nearby stars.

The results from these telescopes will be used in the design of an advanced space telescope, the Terrestrial Planet Finder, to be launched during the next decade. The Terrestrial Planet Finder will be capable of finding Earth-like planets and detecting the chemicals in their atmospheres. Just as plants and animals have changed Earth's atmosphere over time, the detection of specific chemicals on other worlds would indicate that life has evolved on them, as well.

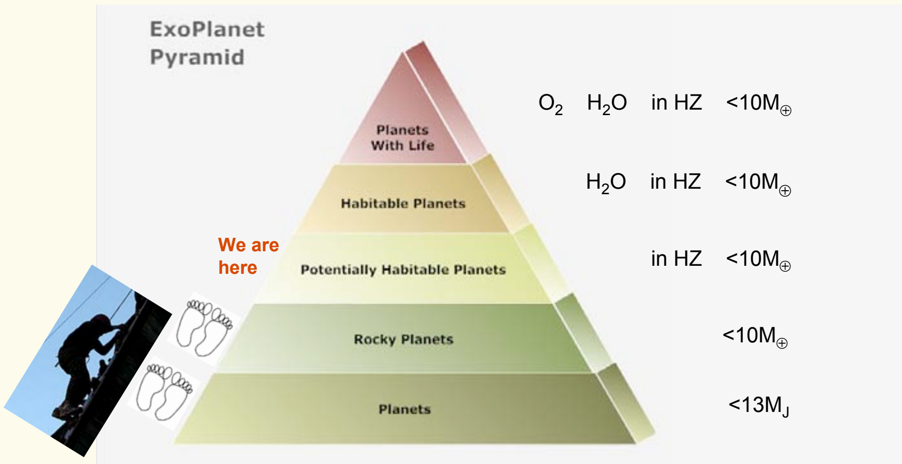
If the Terrestrial Planet Finder discovers extrasolar planets with evidence of life, NASA would pursue additional space telescopes after 2020 that can confirm the existence of life on these worlds and image their features. Life Finder or Planet Imager telescopes would likely be very large and complex spacecraft located far from Earth. A human presence in deep space could be necessary to help erect and upgrade such future telescopes.

The Vision for Space Exploration

THE VISION FOR SPACE EXPLORATION (January 2004)

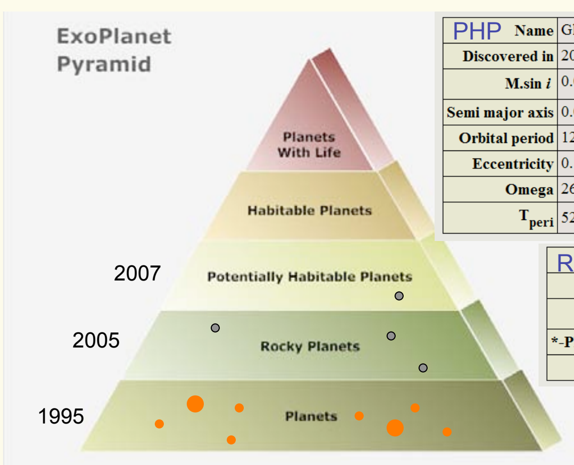
TPF will be capable of finding Earth-like planets and detecting the chemicals in their atmospheres …
If TPF discovers planets with evidence for life, NASA would pursue [Life Finder] to confirm the existence of life on these worlds

Eyes on the Prize



Each step makes incremental but revolutionary progress

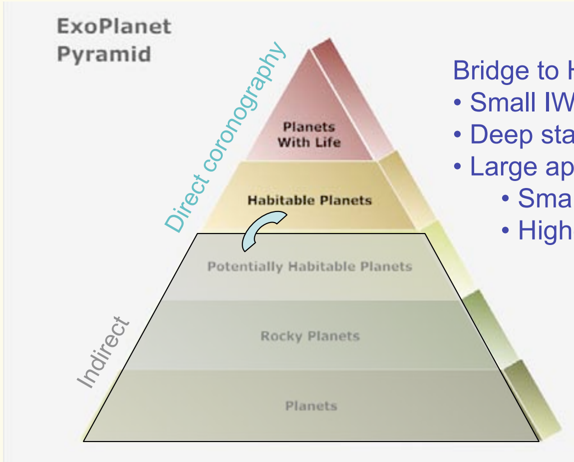
The Pace of ExoPlanet Research Quickens



PHP Name	Gl 581 c	
Discovered in	2007	
M.sin *i*	0.0158 M_J	ref.
Semi major axis	0.073 *AU*	ref.
Orbital period	12.932 (± 0.007) *days*	ref.
Eccentricity	0.16 (± 0.07)	ref.
Omega	267 (± 24) *deg.*	ref.
T_{peri}	52993.38 (± 0.96) *JD 2.400.000*	ref.

Rocky Name	OGLE-05-390L b	
Discovered in	2005	
M.sin *i*	0.017 M_J	ref.
*-Planet Dist. (proj.)	2.1 *AU*	ref.
Orbital period	3500 *days*	ref.

Finding Habitable Planets Requires Spectral Observations of Planet Light



Bridge to Habitable Planets
- Small IWA at H_2O line
- Deep starlight suppression
- Large aperture
  - Smaller exo-zodi bkg
  - Higher sensitivity

H_2O 0.94μ gives best chance of detecting water

S/N level in the continuum (per resolution element at R=70) required for a 5-sigma line detection

Species	λ (μm)	Width (μm)	*n* (samples)	Abundance	Depth	S/N	*t* (days)
H_2O	0.94	0.06	9	10ppm	0.025	108	169
				100ppm	0.124	22	7.0
				1000ppm	0.401	6	0.5
				10000ppm	0.795	3	0.1
H_2O	.82	0.02	3	10ppm	0.003	1570	---
				100ppm	0.025	188	460
				1000ppm	0.118	38	18.8
				10000ppm	0.379	11	1.6
H_2O	0.72	0.02	4	10ppm	0.003	1360	---
				100ppm	0.024	170	353
				1000ppm	0.130	30	11.0
				10000ppm	0.441	8	0.8
O2	0.76	0.01	2	1%	0.150	38	17.7
				10%	0.338	16	3.5
				21%	0.474	11	1.6
				50%	0.565	9	1.1

Source: DesMarais et al. 2001

S/N Matters …

Model Spectrum of (Dry) Earth-Like Planet

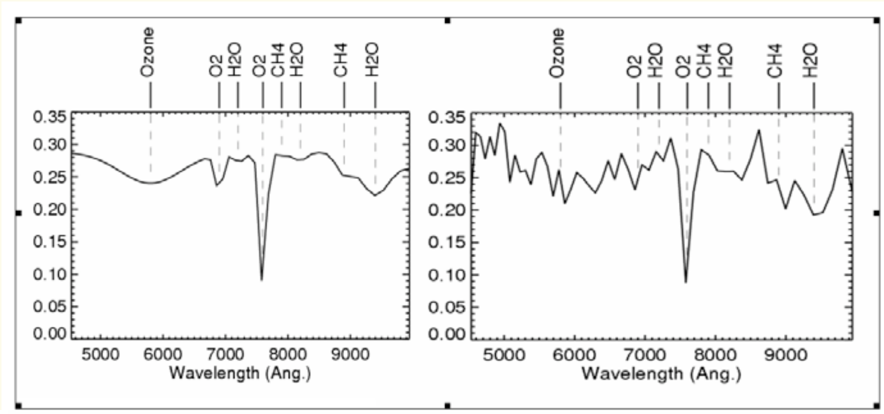


Figure 1: Input and predicted S/N=10 spectrum of an Earth-twin. The input spectrum (R=70) is based on DesMarais et al.'s curves of growth and an assumed atmospheric composition: H_20= 100 ppm, O_2 = 21%, O_3=2 ppm, CH_4=100 ppm, CO_2=10 ppm.

S/N=22 needed for 5-σ detection

Comparison of Approaches Using a 4-m Telescope

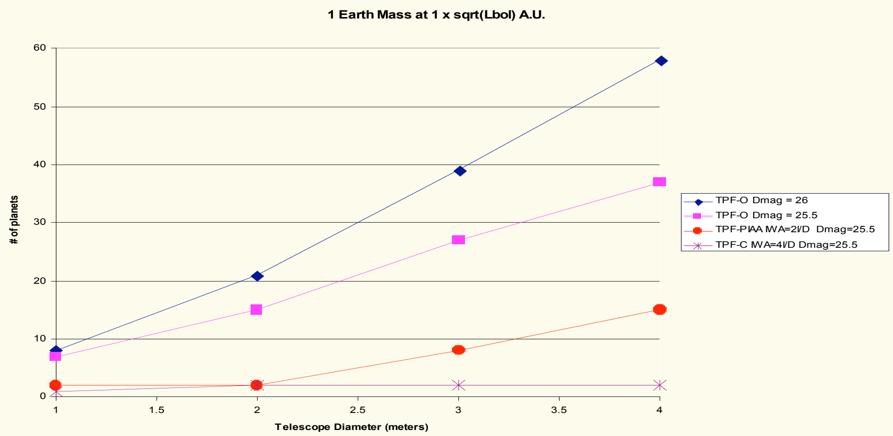
Optical Throughput and Angular Resolution

TPF Concept	Reflectance ×	Lyot Stop ×	Cor. Mask =	Throughput	Res. (mas)
Int. Coron.					
TPF-Lyot	0.83(.98^9)	0.8	0.6	0.40	34
TPF-PIAA	0.67 (0.9*.98^15)	1.0	1.0	0.74	31
Ext. Occulter					
TPF-O	0.85 (.98^8)	1.0	1.0	0.85	31

Inner Working Angle (mas)

Starlight Suppression System	Detection (λ_{long}=0.60 μm)	V-I Color (λ_{long}=0.90 μm)	Spectroscopy (λ_{long}=1.00 μm)
Internal coronagraph			
IWA=2 λ/D	62	93	103
IWA=4 λ/D	124	186	206
External Occulter			
Sep=72,000 km	<72	72	<72

3-σ Detection of H_2O (1000 ppm) at 0.94 μ in 10 Days or Less



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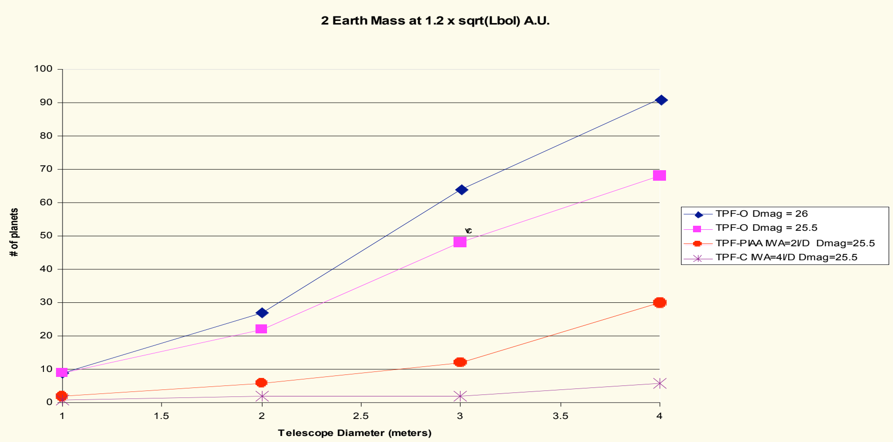
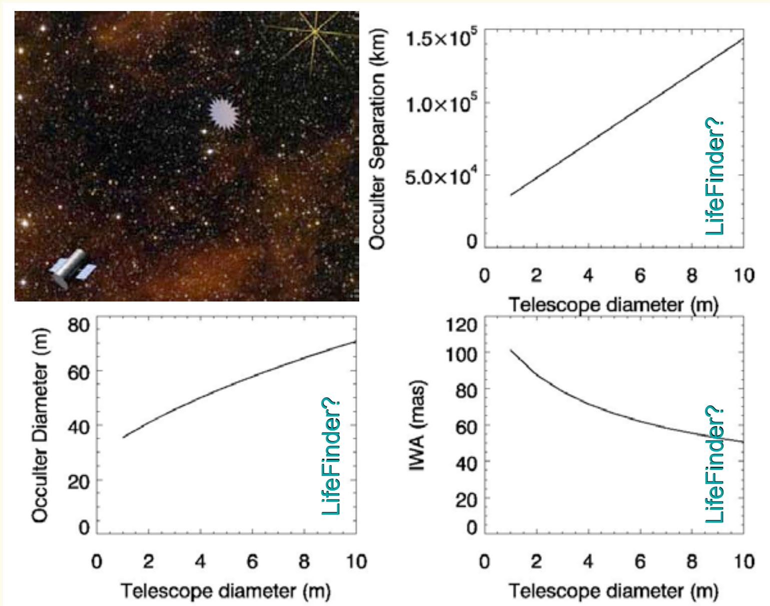


TPF-O is scaleable: From ExoP-mini to LifeFinder



"Aia ke ola i ka wai"
(Life is found where there is water)

This motto is displayed in front of an elementary school on the island of Oahu, near the beach shown.

VHZs = Very Habitable Zones

Steve Kilston

Since we're in the land of the Giants …