**SPIE**

**Austin, TX, June 2018**

# The Instruments and Technologies that will Discover Life in the Galaxy

## Panel Discussion

- Dr. David Bennett
- Dr. Misato Fukagawa
- Dr. Scott Gaudi
- Dr. N. Jeremy Kasdin
- Dr. Michael Shao

Moderator: Dr. Nick Siegler
Program Chief Technologist
NASA Exoplanet Exploration Program
Jet Propulsion Laboratory, California Institute of Technology

"All the News That's Fit to Print"

The New York Times

LATE CITY EDITION

Weather: Rain, warm today; clear tonight. Sunny, pleasant tomorrow. Temp. range: today 80-66; Sunday 71-66. Temp.-Hum. Index yesterday 69. Complete U.S. report on P. 50.

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X

10 CENTS



# EVIDENCE FOR LIFE DISCOVERED ON DISTANT PLANET

## Atmosphere consistent with life on Earth

### Clear signs of biosignatures

EAGLE (the lunar module): Houston, Tranquility Base here. The Eagle has landed.

HOUSTON: Roger, Tranquility, we copy you on the ground. You've got a bunch of guys about to turn blue. We're breathing again. Thanks a lot.

TRANQUILITY BASE: Thank you.

HOUSTON: You're looking good here.

TRANQUILITY BASE: A very smooth touchdown.

HOUSTON: Eagle, you are stay for T1. [The first step in the lunar operation.] Over.

TRANQUILITY BASE: Roger. Stay for T1.

HOUSTON: Roger and we see you venting the ox.

TRANQUILITY BASE: Roger.

COLUMBIA (the command and service module): How do you read me?

HOUSTON: Columbia, he has landed Tranquility Base. Eagle is at Tranquility. I read you five by. Over.

COLUMBIA: Yes, I heard the whole thing.

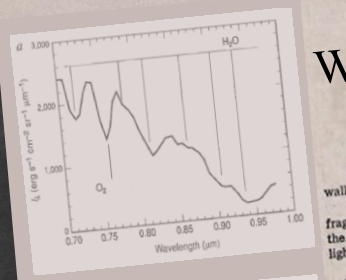
HOUSTON: Well, it's a good show.

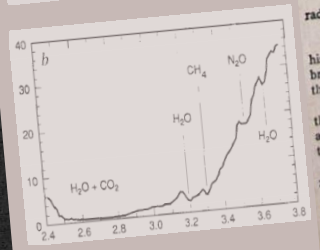
COLUMBIA: Fantastic.

TRANQUILITY BASE: I'll second that.

APOLLO CONTROL: The next major stay-no stay will be for the T2 event. That is at 21 minutes 26 sec-

...the landing craft after taking the first step on the surface of the moon




### We are not alone!

By JOHN NOBLE WILFORD

Special to The New York Times

HOUSTON, Monday, July 21—Men have landed and walked on the moon.

Two Americans, astronauts of Apollo 11, steered their fragile four-legged lunar module safely and smoothly to the historic landing yesterday at 4:17:40 P.M., Eastern daylight time.

Neil A. Armstrong, the 38-year-old civilian commander, radioed to earth and the mission control room here:

"Houston, Tranquility Base here. The Eagle has landed."

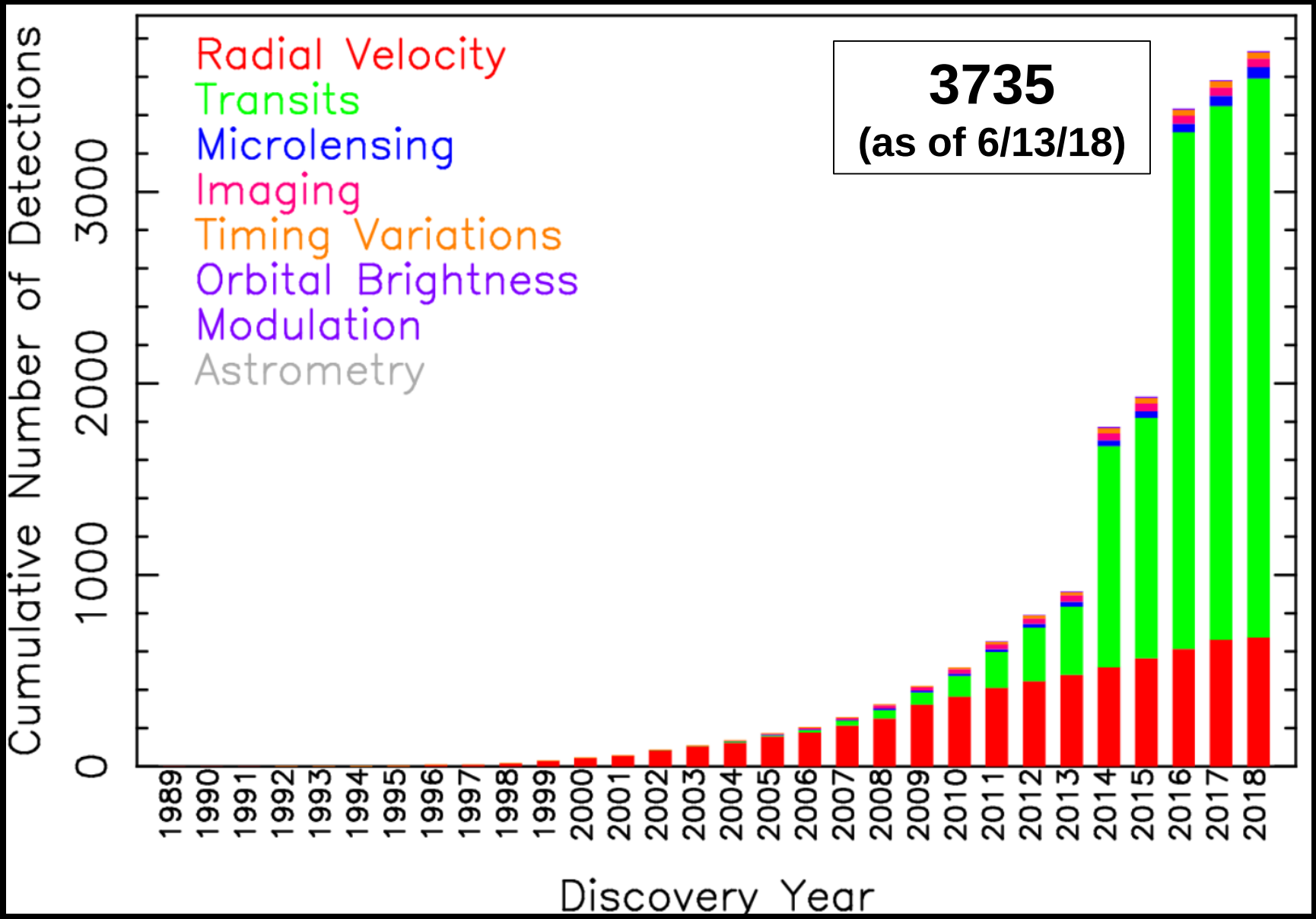
The first men to reach the moon—Mr. Armstrong and his co-pilot, Col. Edwin E. Aldrin Jr. of the Air Force—brought their ship to rest on a level, rock-strewn plain near the southwestern shore of the arid Sea of Tranquility.

About six and a half hours later, Mr. Armstrong opened the landing craft's hatch, stepped slowly down the ladder and declared as he planted the first human footprint on the lunar crust:

"That's one small step for man, one giant leap for mankind."

His first step on the moon came at 10:56:20 P.M., as a television camera outside the craft transmitted his every move to an awed and excited audience of hundreds of millions of people on earth.

**Tentative Steps Test Soil**




exoplanetarchive.ipac.caltech.edu

# *We now know that in our Galaxy…*

Planets are common (> 1 per star).

Planets with sizes 0.5-2 times Earth are the most common.

Earth-size planets in the Habitable Zone are common.

**…and more coming**

# Transit Exoplanet Survey Satellite (TESS)

Launched April 18, 2018

Credit: NASA

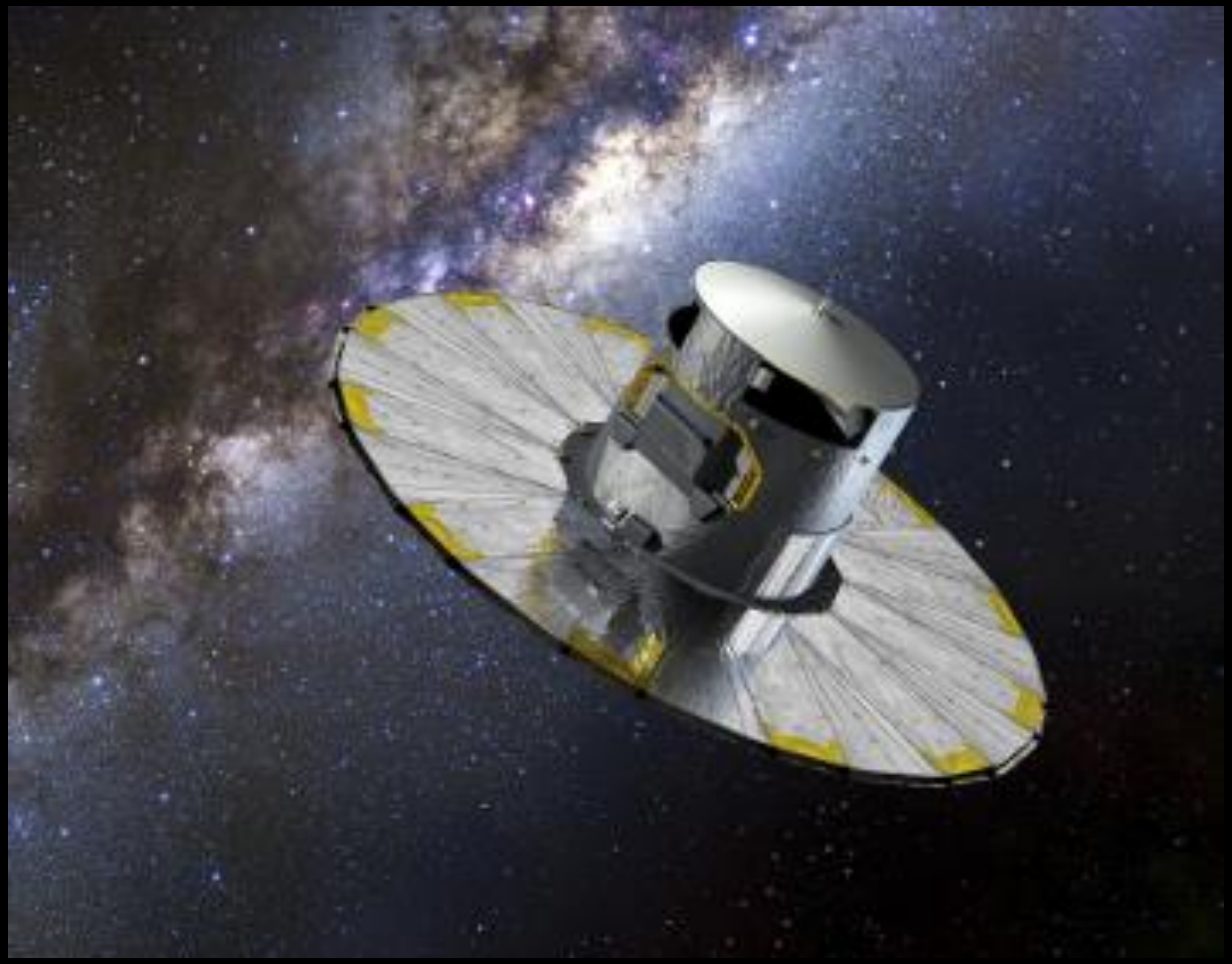
# James Webb Space Telescope

Planned launch approximately May 2020


Credit: Northrop Grumman

# Gaia

Astrometric Discovery of Exoplanets



Credit: ESA

Launched December 2013

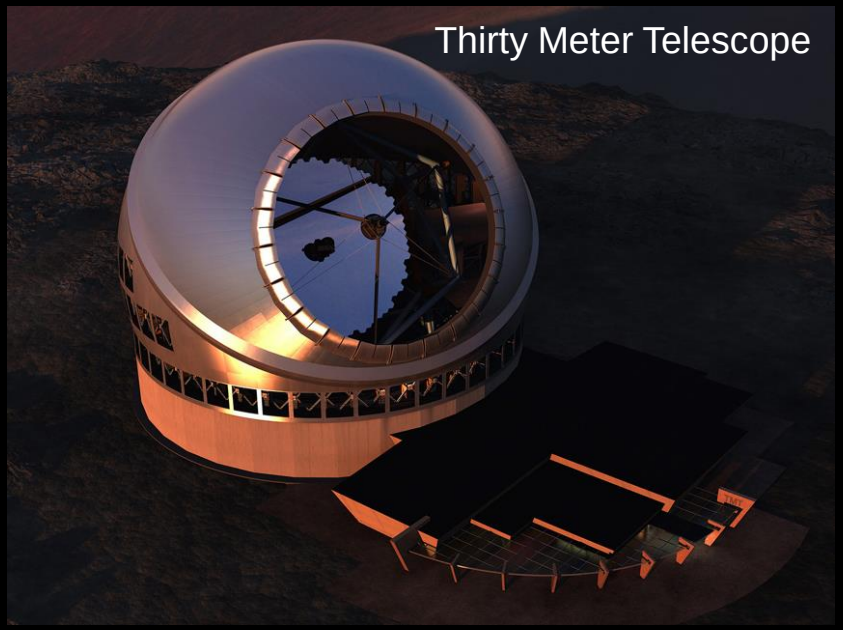
# Wide Field InfraRed Survey Telescope (WFIRST)

Launch date approximately mid-2020s

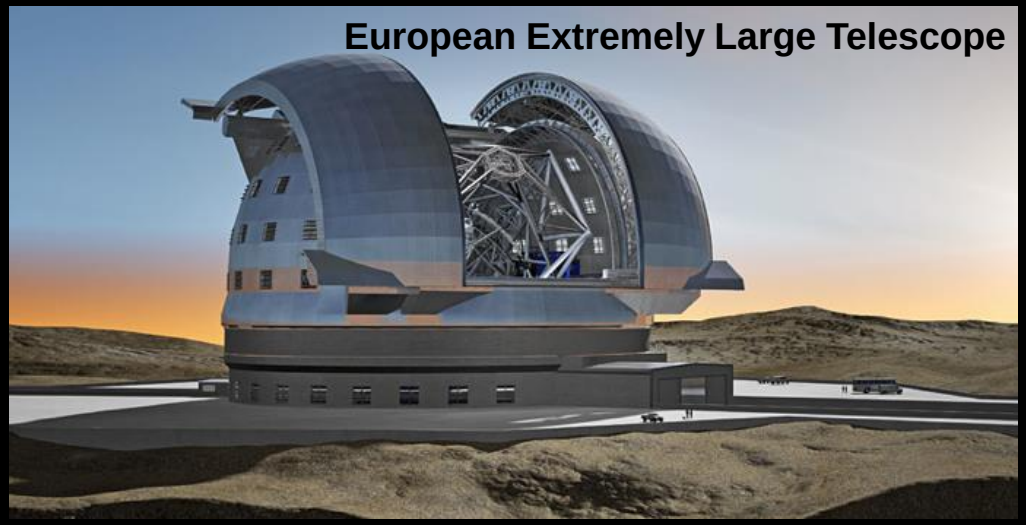
Photo: NASA

# New Ground-Based Extremely Large Telescopes

24 – 40 meters in diameter, approximately 2020s







## TECHNOLOGY

- Angular Resolution: Interferometry
- Angular Resolution and Collecting Area: Large Space Telescopes
- Contrast Stability: Ultrastable Structures
- Detection Sensitivity: Advanced Detectors
- Starlight Suppression: Starshades
- Starlight Suppression: Coronagraphs

## MISSIONS


Hubble


Spitzer


Kepler


TESS

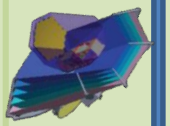

JWST


WFIRST


Starshade Rendezvous


LUVOIR


HabEx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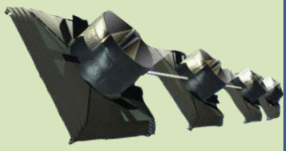
Exo-Earth Interferometer

Possible Pending Decadal Survey

## TODAY | 2020s | 2025s | 2030s | 2035 and beyond

## SCIENCE

- Exoplanetary Atmospheres
- Hot Jupiters
- Exoplanet Abundance
- Nearest Transiting Planets
- Atmospheric Chemistry
- Direct Imaging
- Exozodiacal Dust
- Exoplanet Diversity
- Habitable Exo-Earth Discovery
- M-Dwarf Rocky Planet Biosignatures
- Cool Gas Giants
- Exo-Earth Biosignatures
- Habitable Exo-Earth Abundance
- Life Verification

Version 2018_03_07, NASA ExEP

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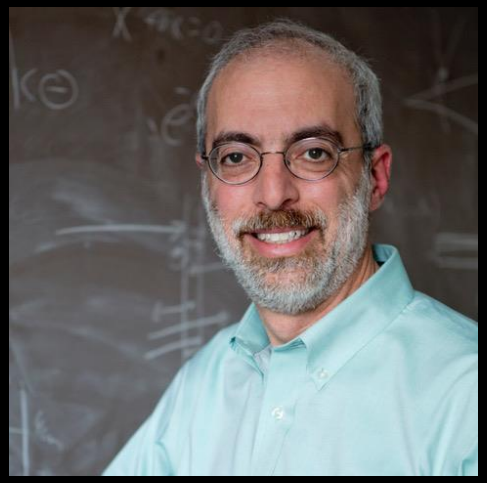


**Dr. N. Jeremy Kasdin**
Princeton University

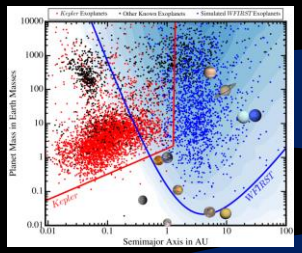
**Dr. Michael Shao**
NASA JPL

1. *What type of evidence is needed to infer life on an exoplanet?*

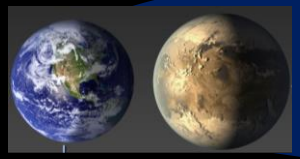
2. *What observational methods will be important in obtaining the evidence for life?*

3. *What is the technology readiness of each of these methods? What's still needed? and How hard will that be?*

1. ***What type of evidence is needed to infer life on an exoplanet (i.e. to persuade you to agree with this headline)?***




Complete census of planetary systems



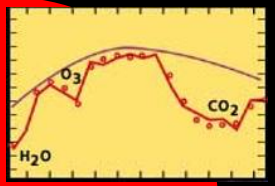
Near-complete understanding of systems with habitable-zone planets around nearby stars

- ✓ Orbital stability?
- ✓ Exo-zodi?
- ✓ Internal structure?
- ✓ Spin, magnetic field?
- ✓ Time-varying features (weather)?
- ✓ Host star activity?

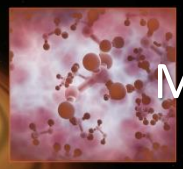
Good sample for deep spectroscopy

What are the signatures of life?

Origin of life



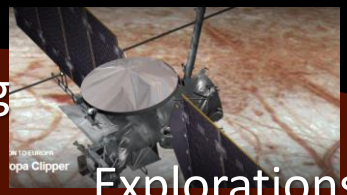

Discovery of evidence of life



Modeling

Organic molecules in disks, snowline

Laboratory experiments

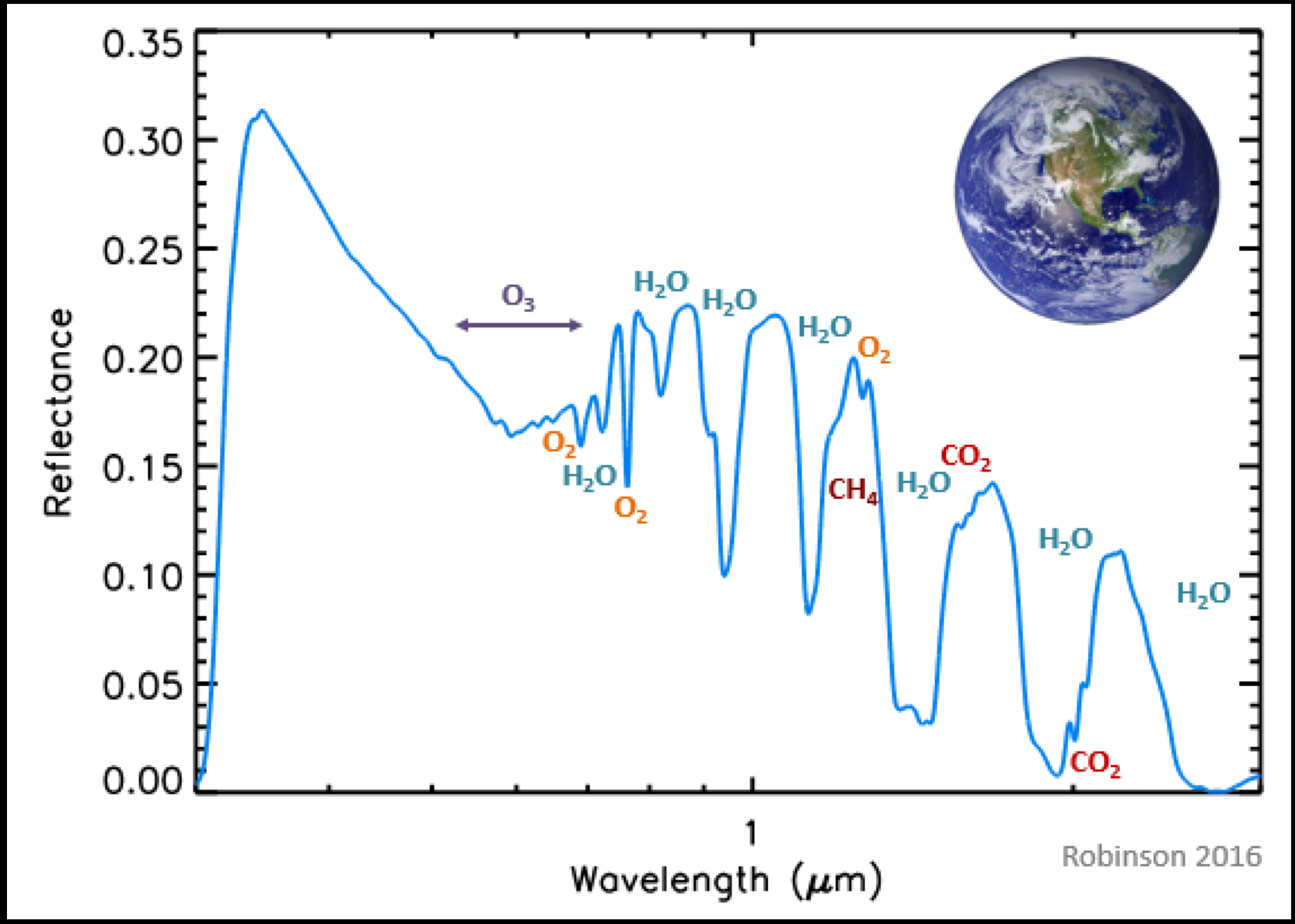


Explorations of Solar-system planets/moons

SETI

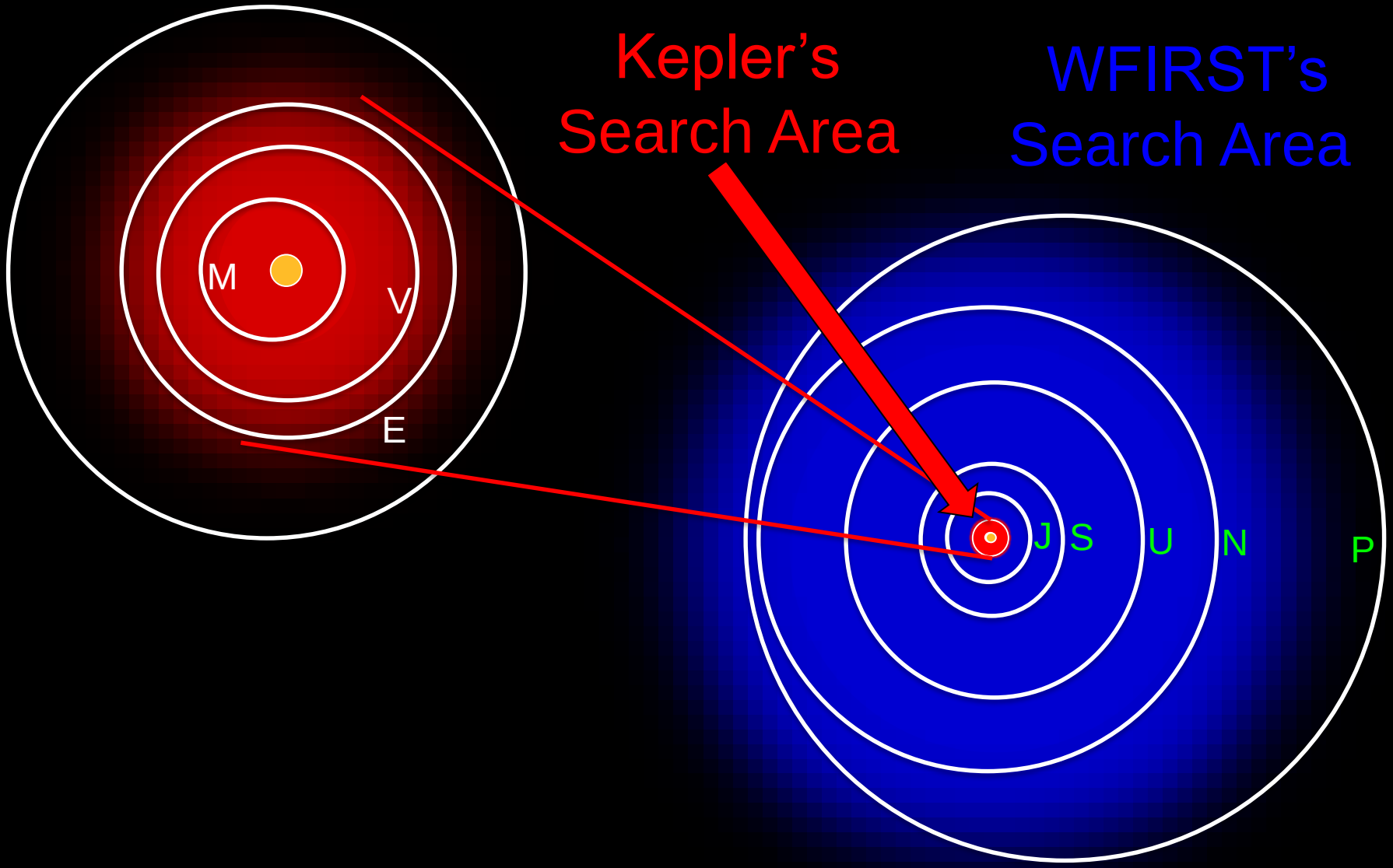
# Potential Biosignature Gases

Spectral Lines

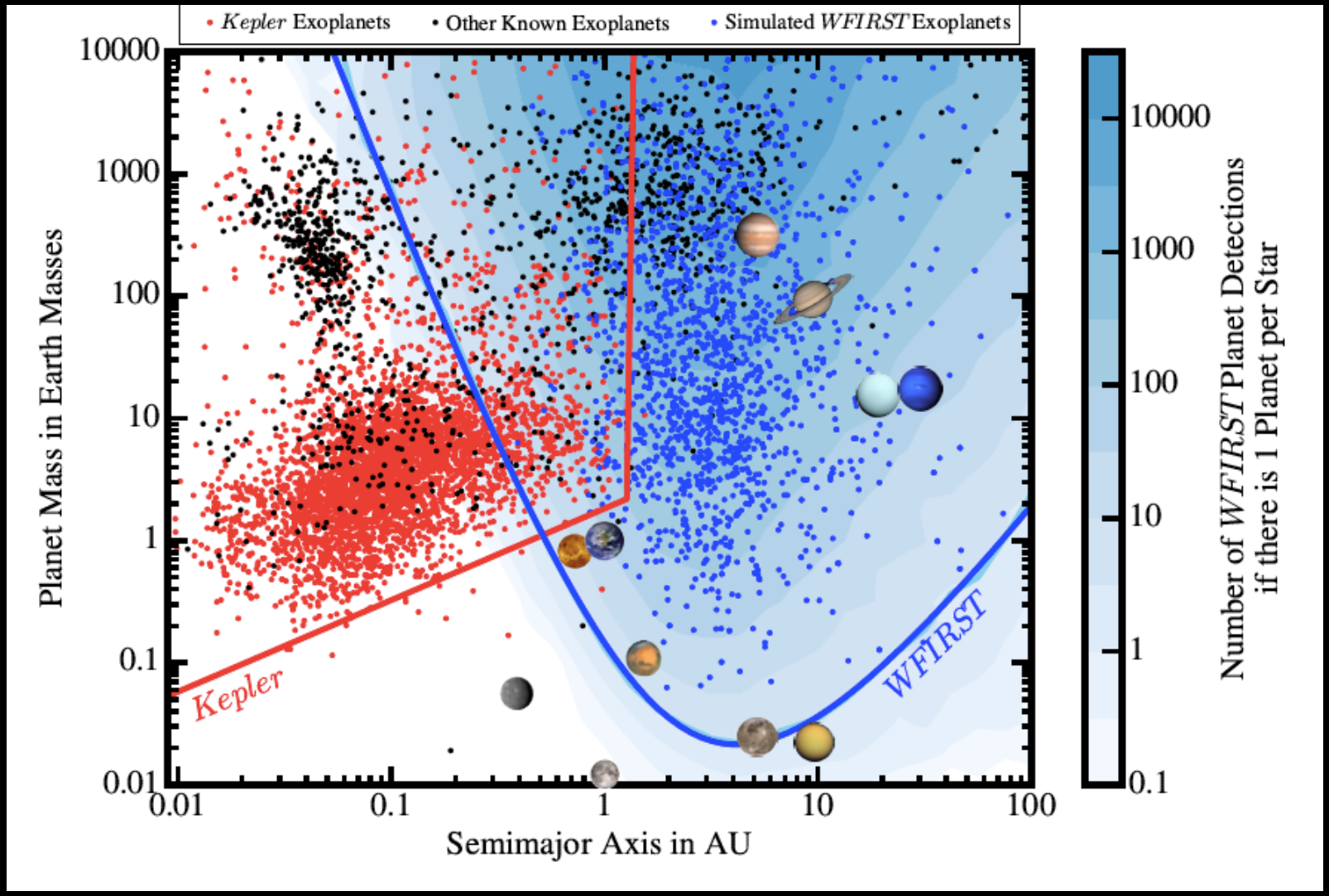


2. ***What observational methods will be important in obtaining the evidence for life?***

# WFIRST Gravitational Microlensing Completes the Exoplanet Census Started by Kepler

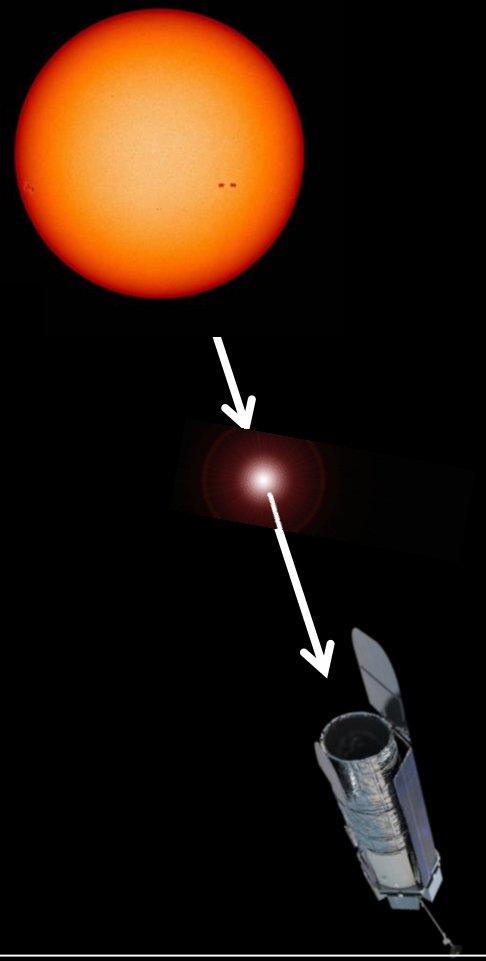


# WFIRST Gravitational Microlensing Completes the Exoplanet Census Started by Kepler

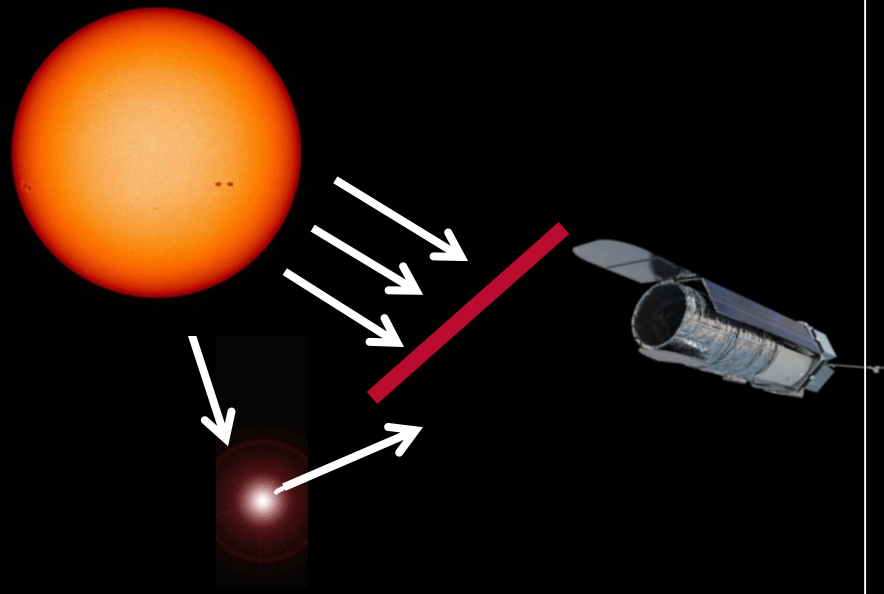


# Acquiring Spectroscopy of Exoplanets

## Transmission

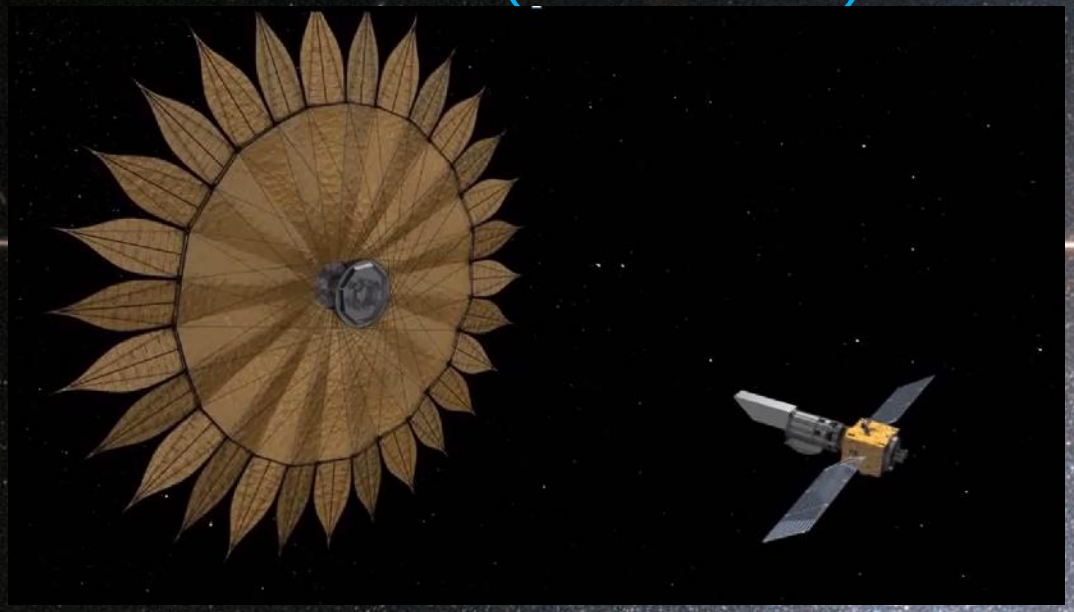


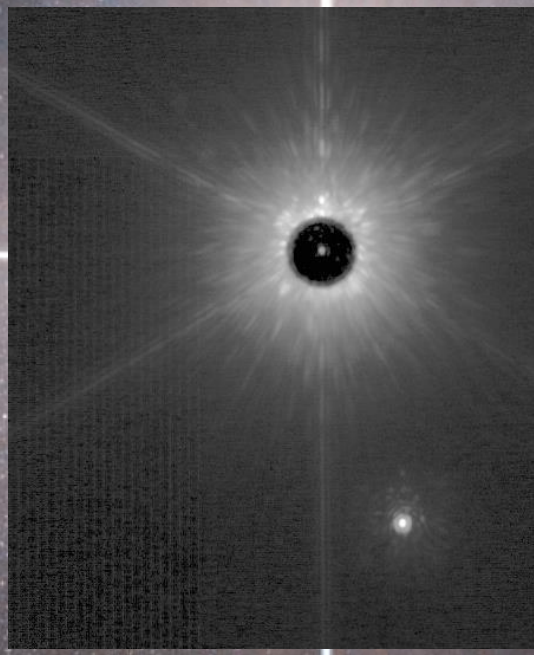
## Reflection



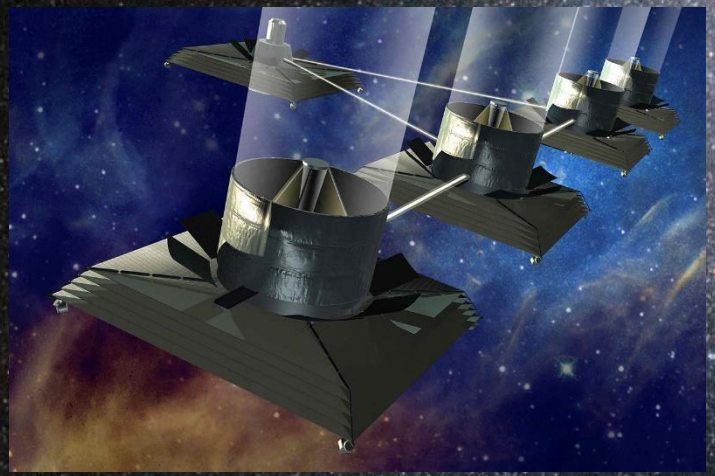
# Starlight Suppression Technologies

## External Occulters (Starshades)

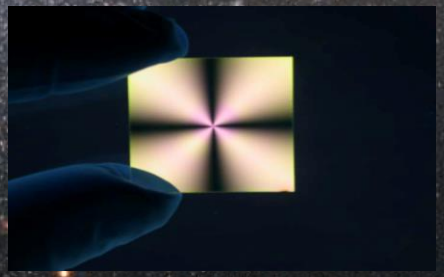




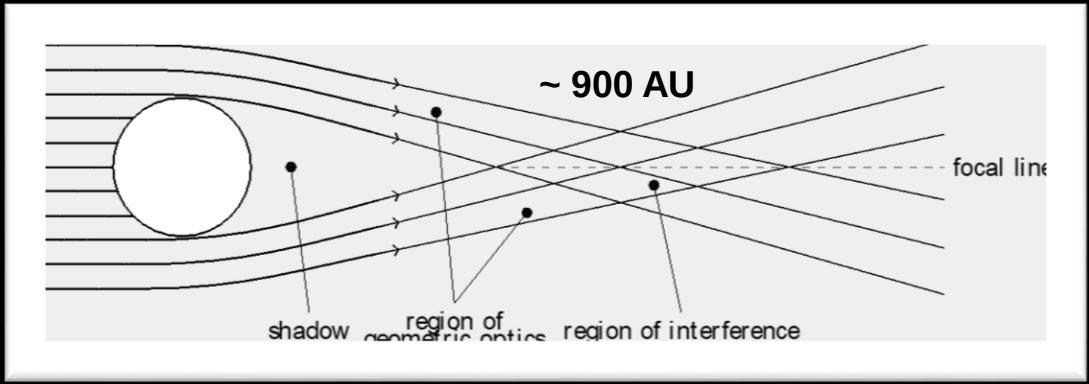
## Nulling Interferometry

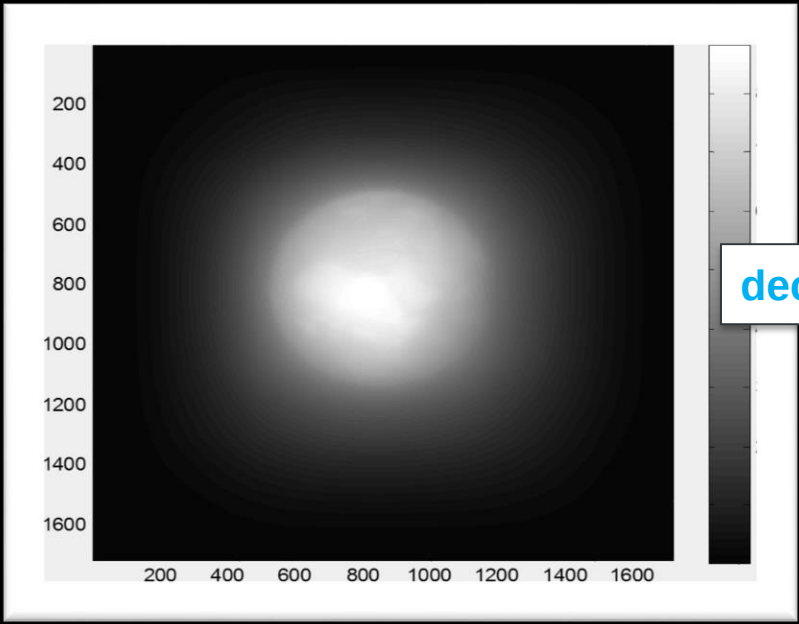


## Internal Occulters (Coronagraphs)

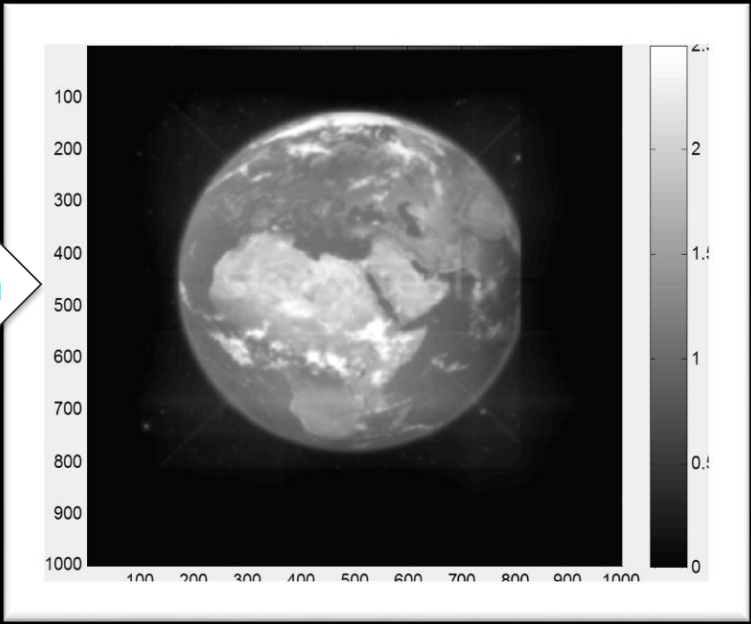


# Using the Sun as a Gravitational Lens




deconvolution




**Highly abberated image**

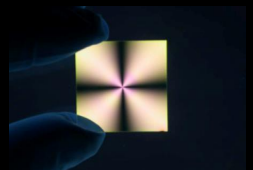
**Multi-pixel deconvolved image**

Credit: S. Turyshev and M. Shao

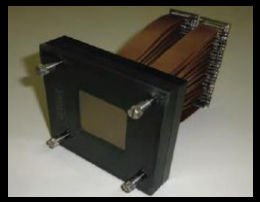
3. *What is the technology readiness of each of these methods? What's still needed to be matured? and How hard will that be?*

# V-NIR Coronagraph/Telescope Technology Gaps

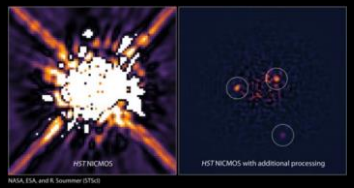
## Contrast



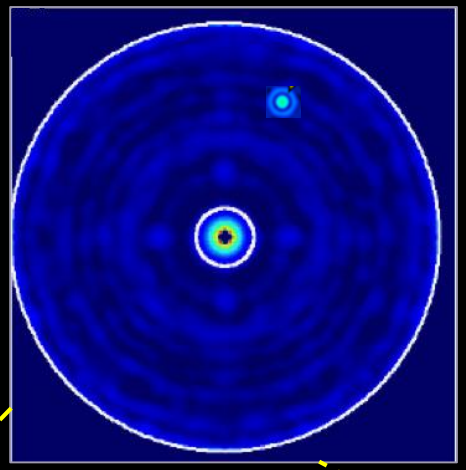
CG-2: Coronagraph Architecture



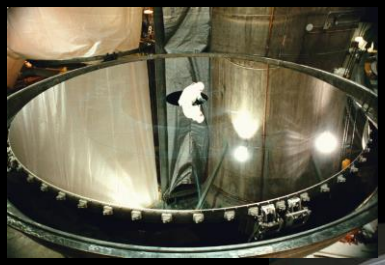
CG-3: Deformable Mirrors




CG-4: Data Post-Processing



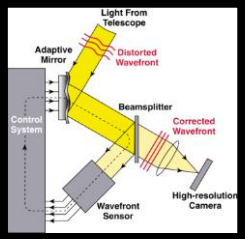
## Angular Resolution



CG-1: Large Monolith Mirrors

CG-1: Segmented Mirrors

## Contrast Stability

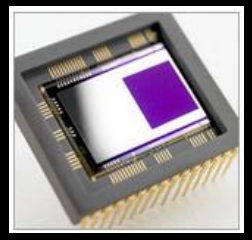


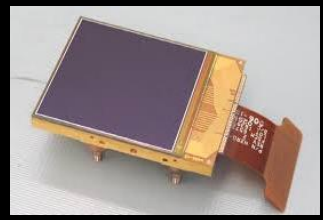

CG-5: Wavefront Sensing and Control

CG-6: Mirror Segment Phasing

CG-7: Telescope Vibration Sensing and Control or Reduction

## Detection Sensitivity



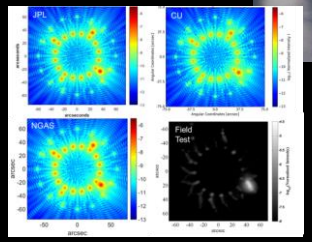


Ultra-low Noise Visible (CG-8) and Infrared (CG-9) Detectors

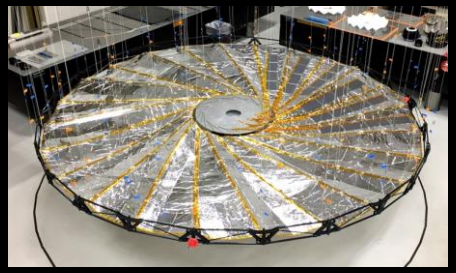
# Starshade Technology Gaps

## Starlight Suppression

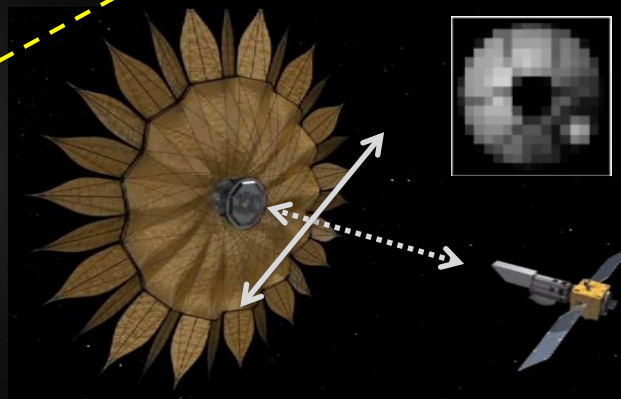
S-1: Controlling Scattered Sunlight




S-2: Starlight Suppression and Model Validation

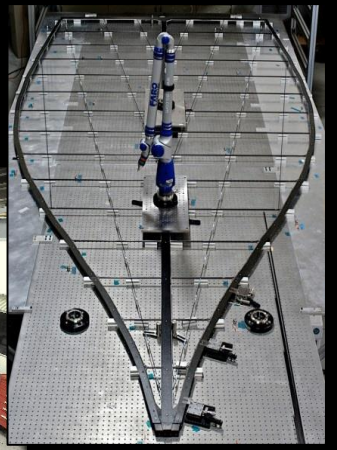


## Formation Sensing



S-3: Lateral Formation Sensing

## Deployment Accuracy and Shape Stability



S-4: Petal Shape And Stability

S-5: Petal Positioning Accuracy and Opaque Structure