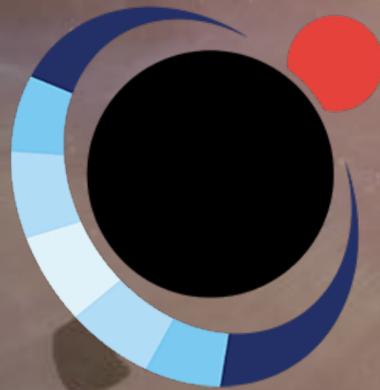


THE ROMAN CORONAGRAPH

IMAGING GIANT EXOPLANETS IN REFLECTED LIGHT



Roman School
Europe

March 9
2026

Julien Girard

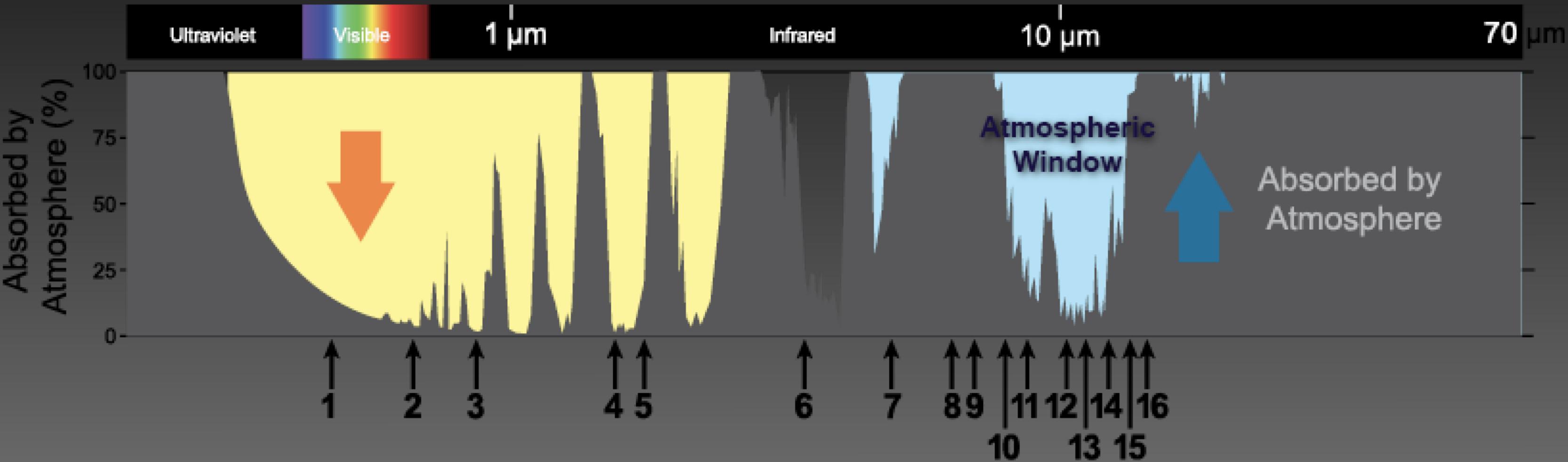
Space Telescope Science Institute (SOC)
Community Participation Program (CPP)

WAVELENGTHS

Atmosphere: obvious advantage to space

SPACE

$$\lambda/D \longrightarrow$$



Instrument size, cost, multiplexing & servicing:
advantage to the ground

GROUND

EXOPLANET MISSIONS & FACILITIES

National Aeronautics and Space Administration

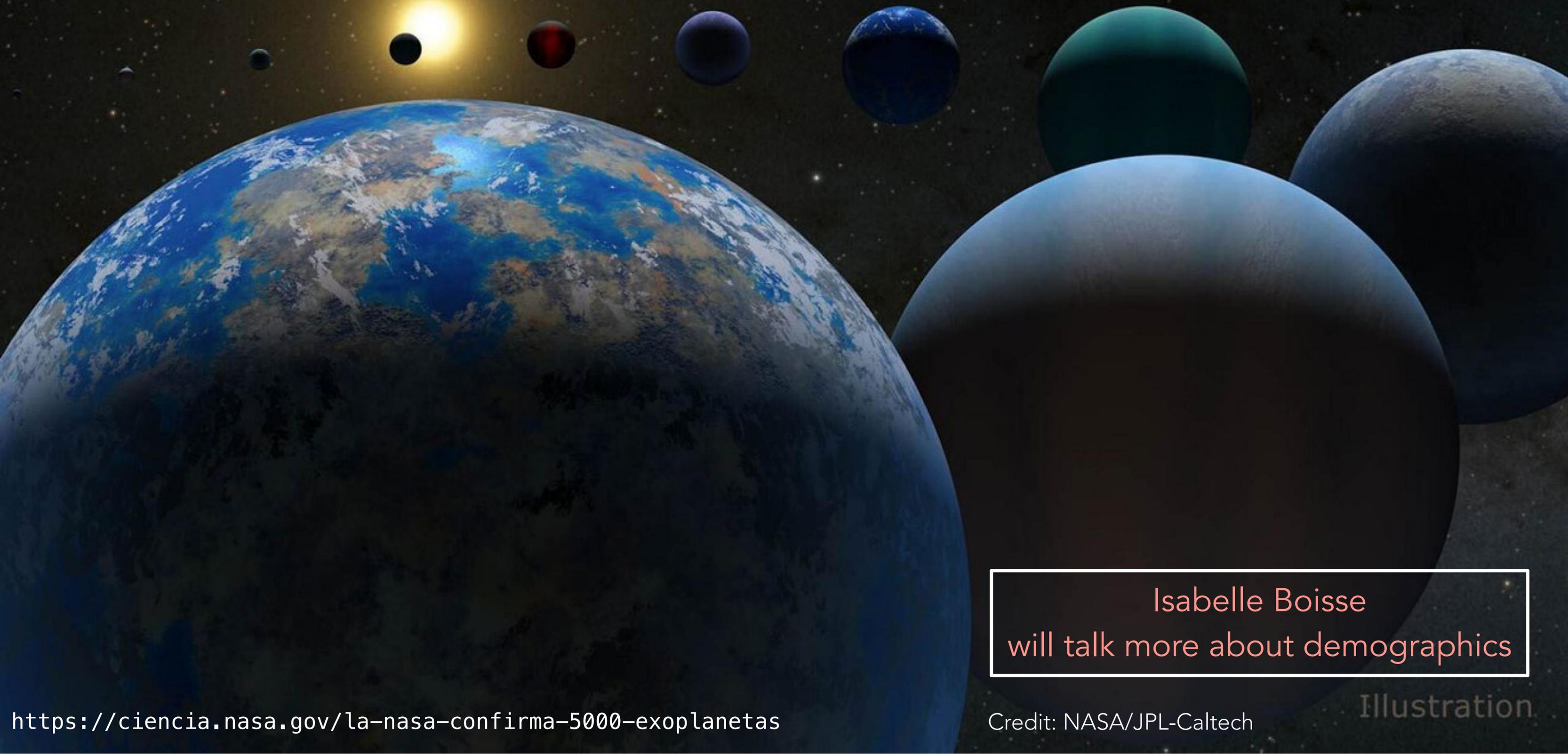


Exoplanet Missions

- ¹ NASA/ESA Partnership
- ² NASA/ESA/CSA Partnership
- ³ CNES/ESA
- ⁴ ESA/Swiss Space Office
- ⁵ NSF Partnership (NN-EXPLORE)



OVER 6,100 EXOPLANETS!



Isabelle Boisse
will talk more about demographics



5,000 Exoplanets: Listen to the Sounds of Discovery (NASA Data Sonification)

Radial Velocity 913

Transit 3846

Imaging 58

Microlensing 129

Year: 2022

Exoplanets: 5005



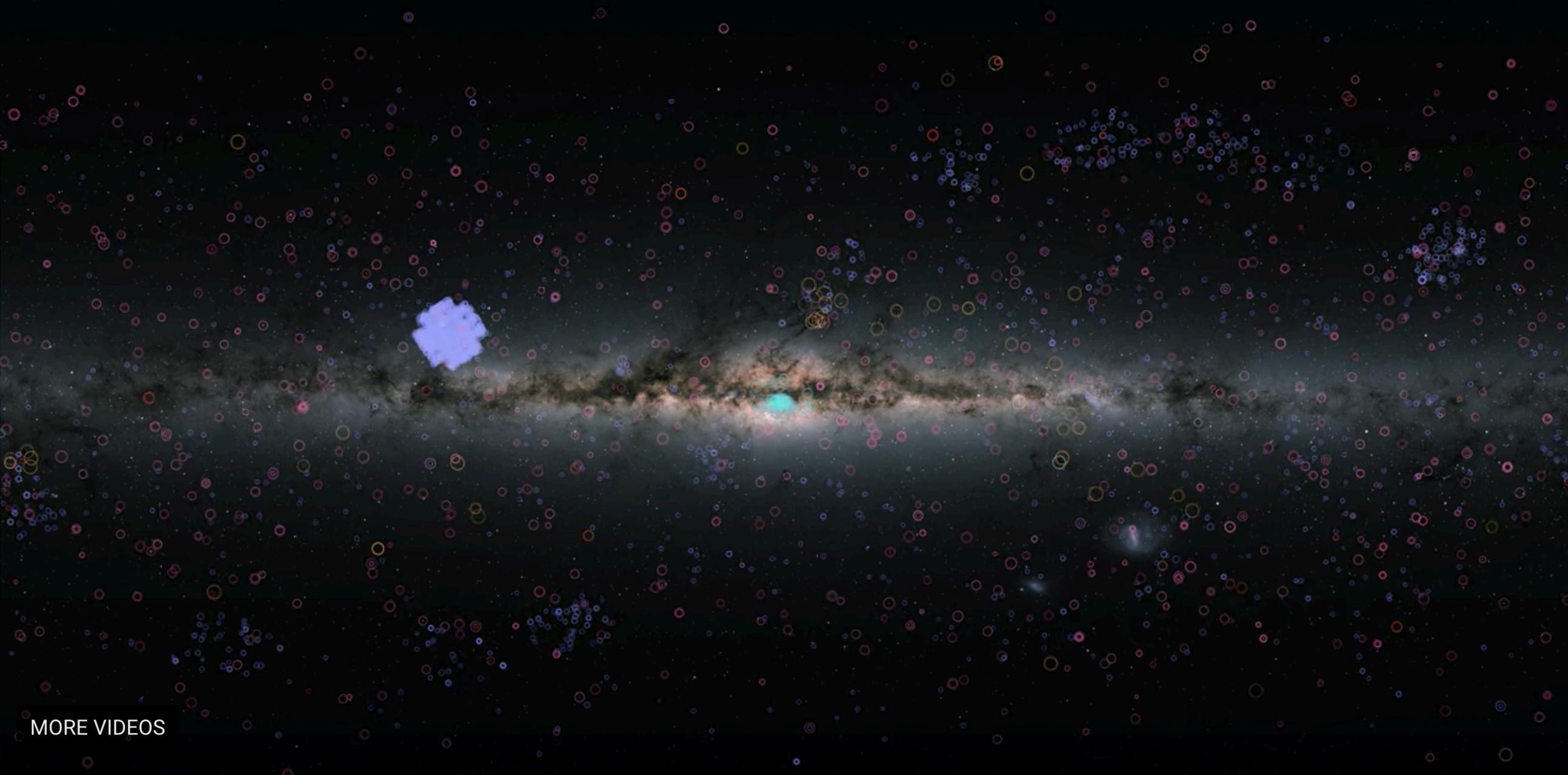
4 Watch later

Share

9 Orbital Brightness Modulation

1 Astrometry

1 Disk Kinematics



MORE VIDEOS



1:07 / 1:17



YouTube



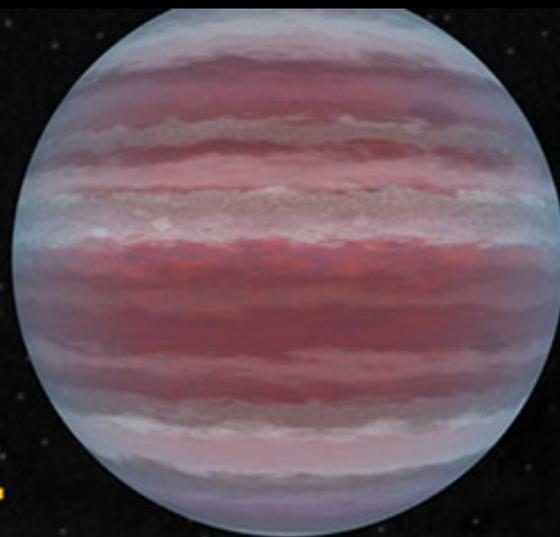
EVERYWHERE

Credit: NASA/JPL-Caltech

SO FAR

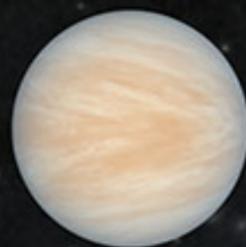
30%
GAS GIANT

The size of Saturn or Jupiter (the largest planet in our solar system), or many times bigger. They can be hotter than some stars!



31%
SUPER-EARTH

Planets in this size range between Earth and Neptune don't exist in our solar system. Super-Earths, a reference to larger size, might be rocky worlds like Earth, while mini-Neptunes are likely shrouded in puffy atmospheres.



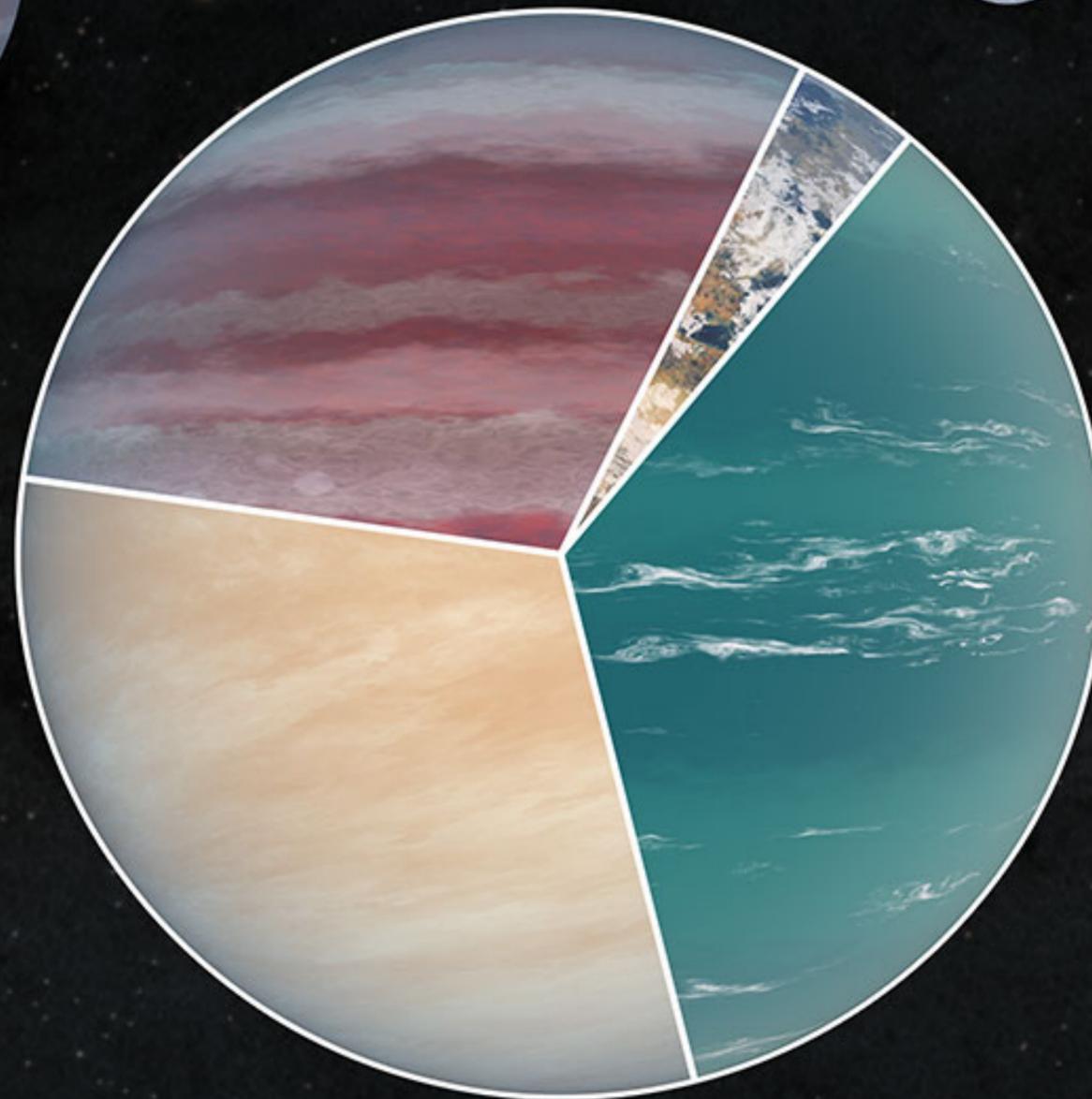
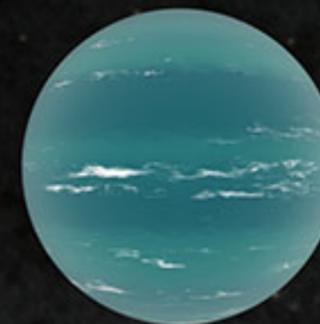
4%
TERRESTRIAL

Small, rocky planets. Around the size of our home planet, or a little smaller.



35%
NEPTUNE-LIKE

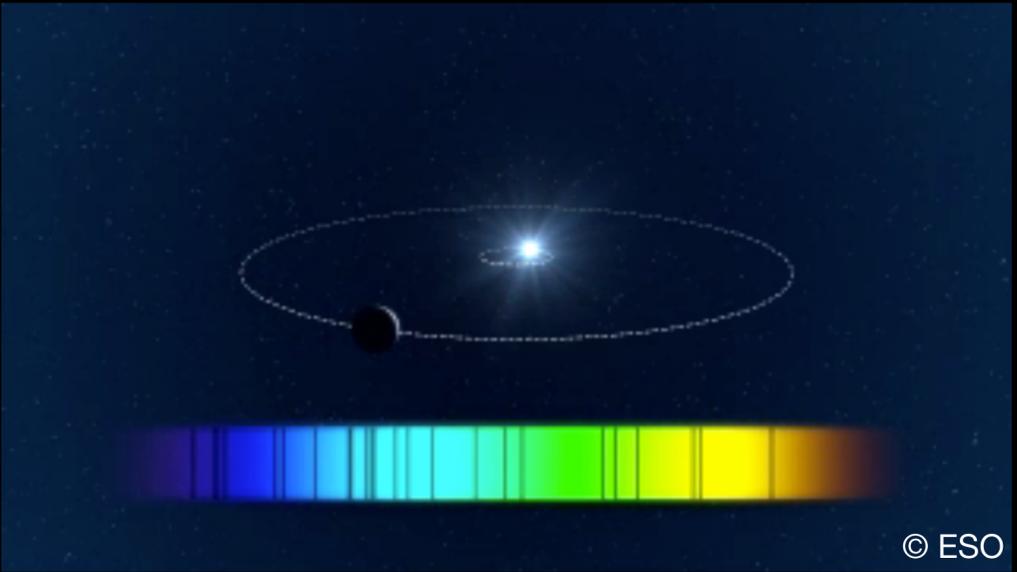
Similar in size to Neptune and Uranus. They can be ice giants, or much warmer. "Warm" Neptunes are more rare.



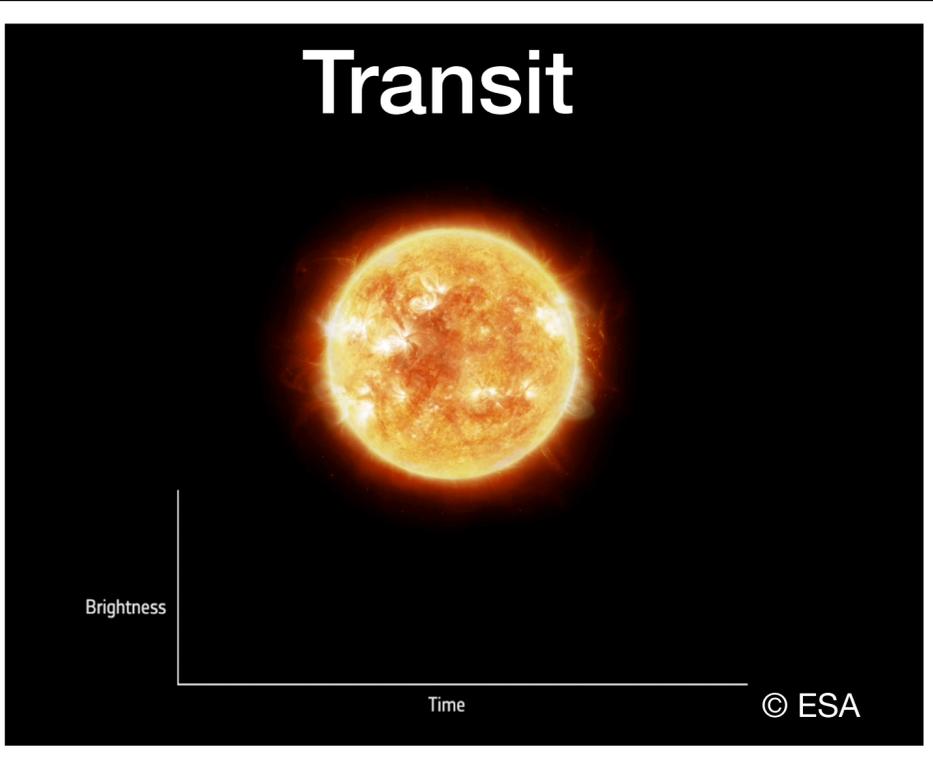
~~61~~
5000+
PLANETS FOUND

EXOPLANET DETECTION METHODS

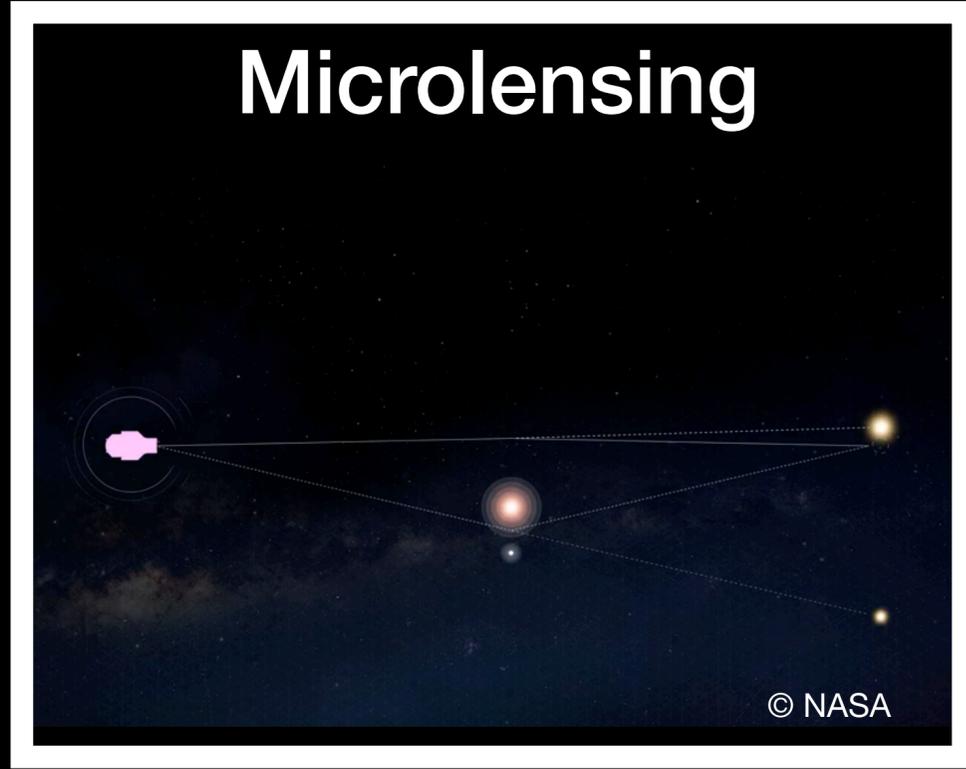
Radial Velocity



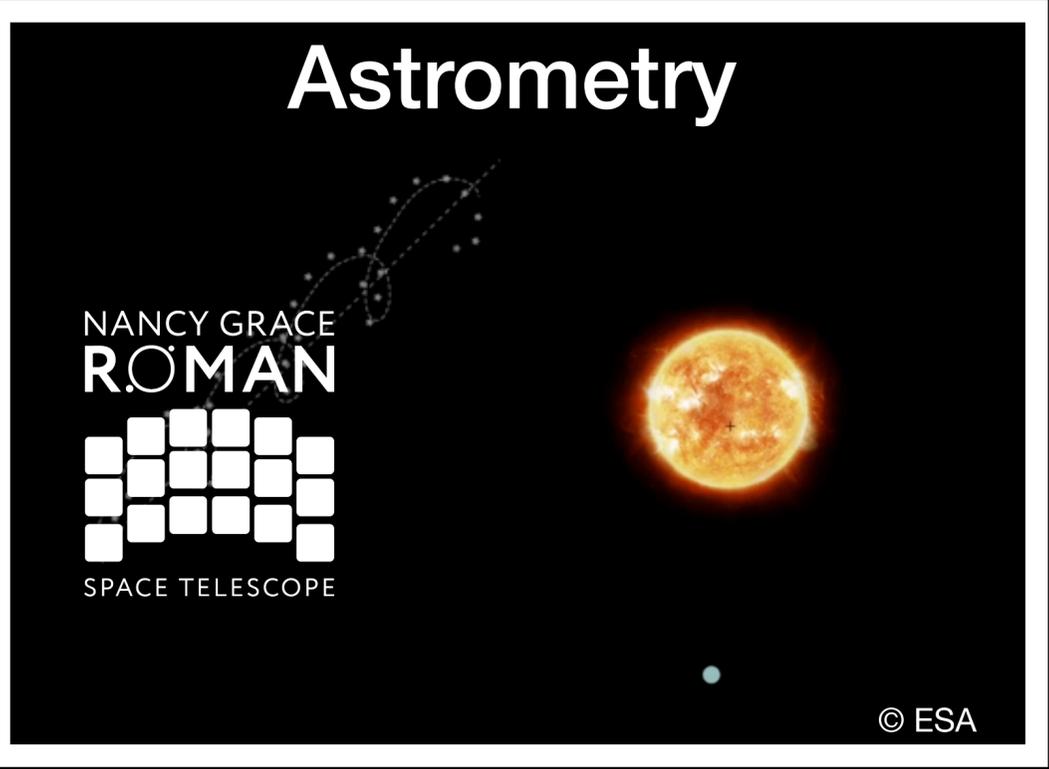
Transit



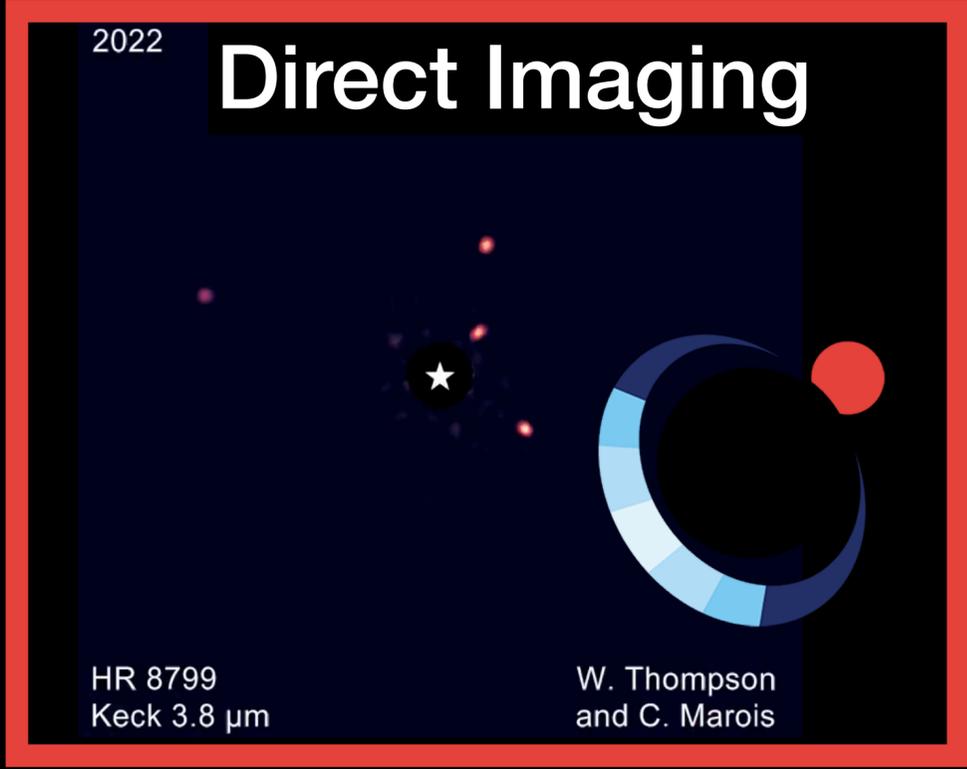
Microlensing



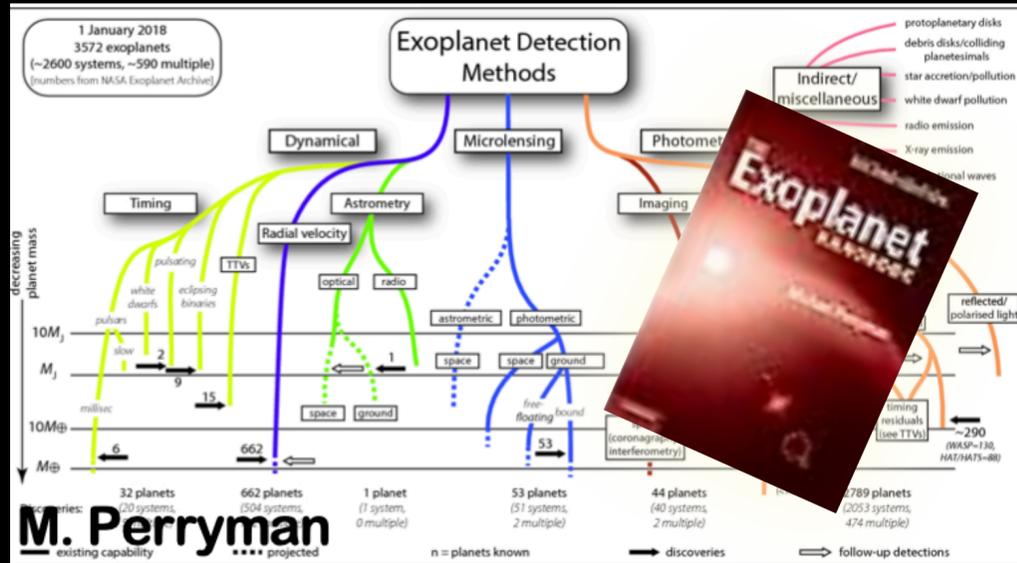
Astrometry



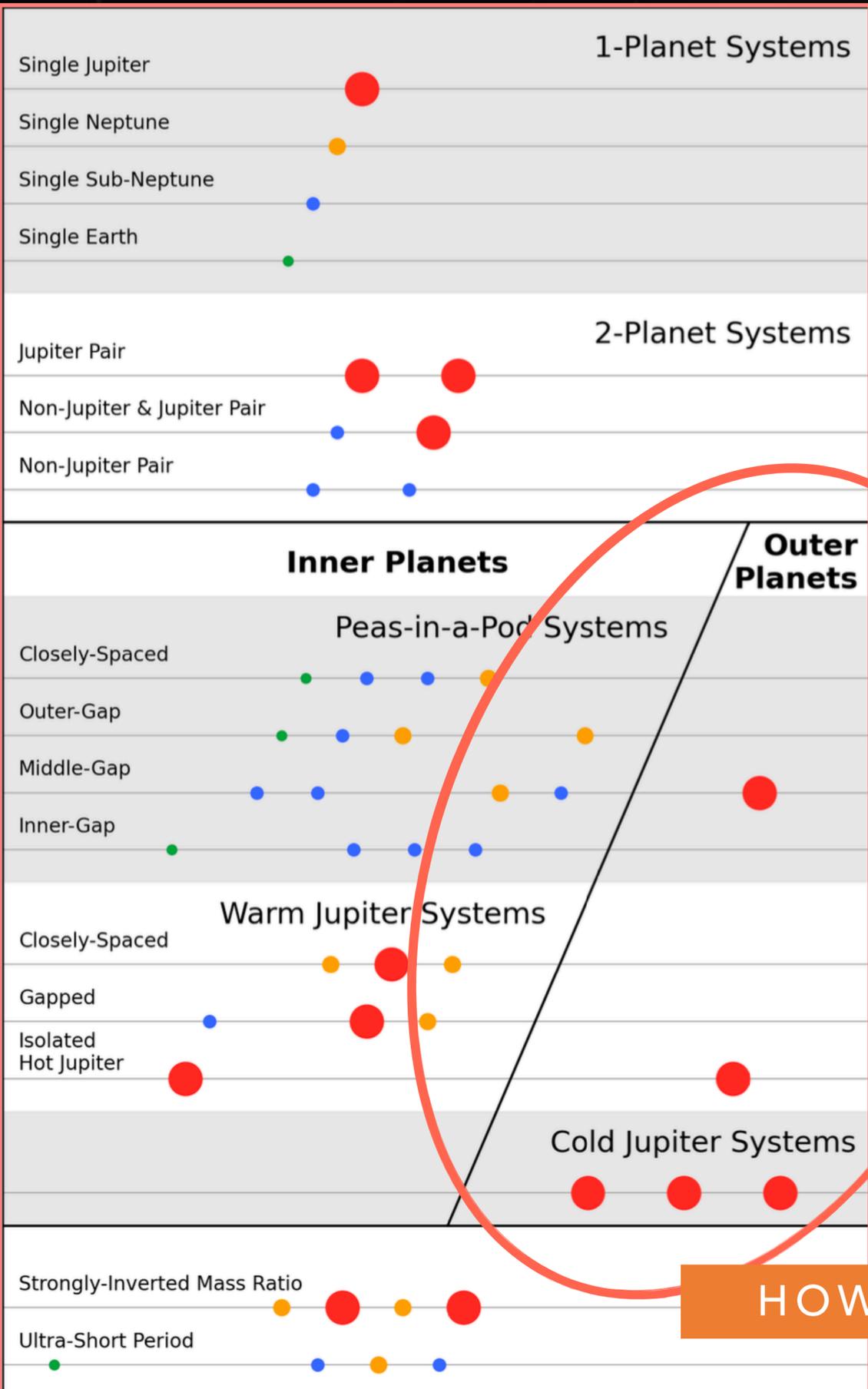
Direct Imaging



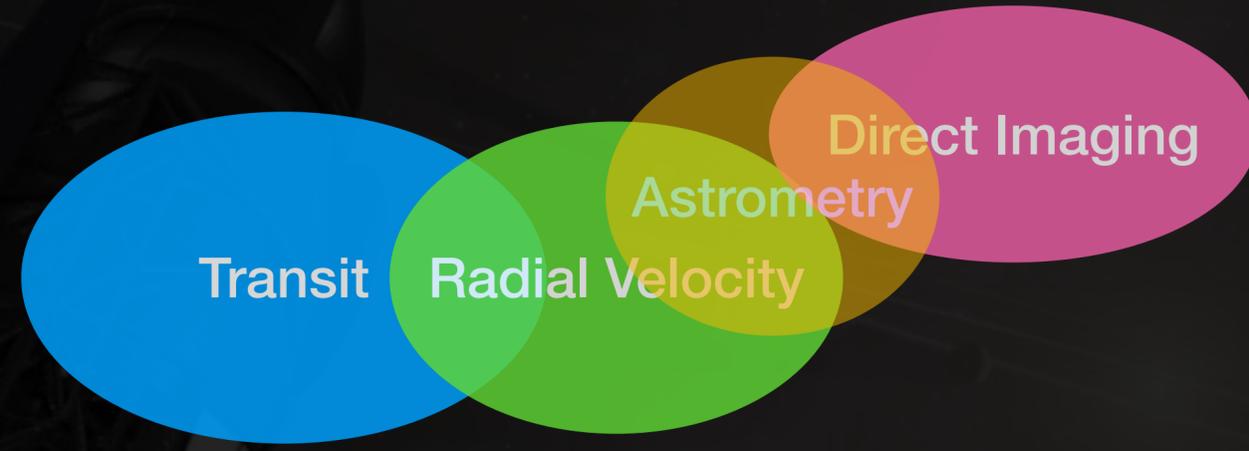
Other Methods



EXOPLANETS WE CAN/CAN'T IMAGE



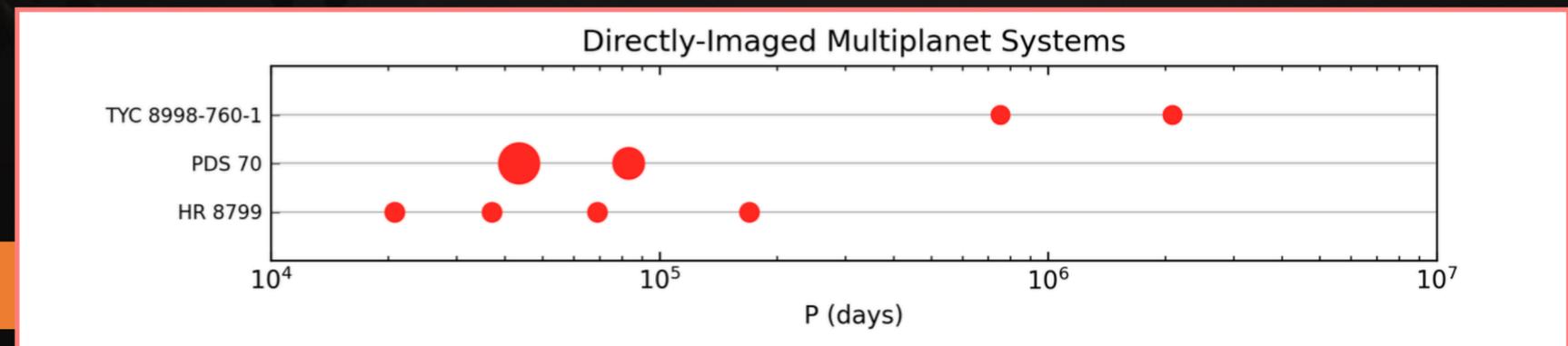
Mass



Period

μ lensing is essentially for demographics (too far / no possible follow-ups)

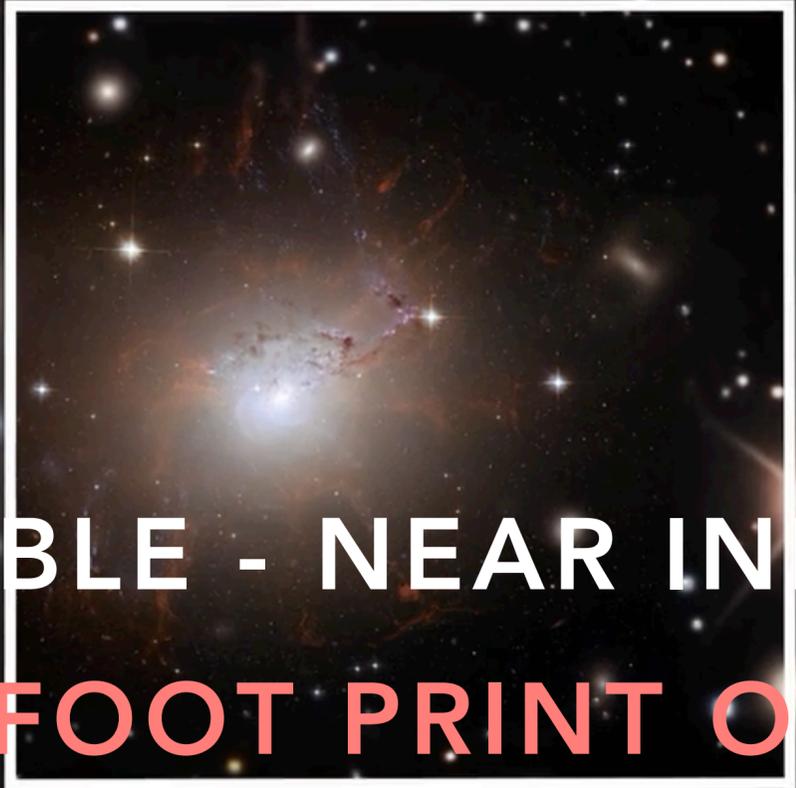
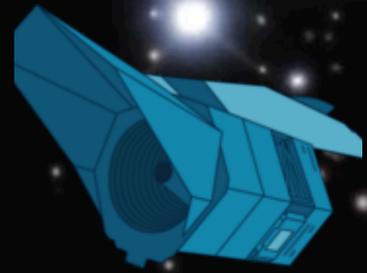
HOWE+ 2025



Nancy Grace Roman was NASA's first Chief Astronomer

appointed 1959



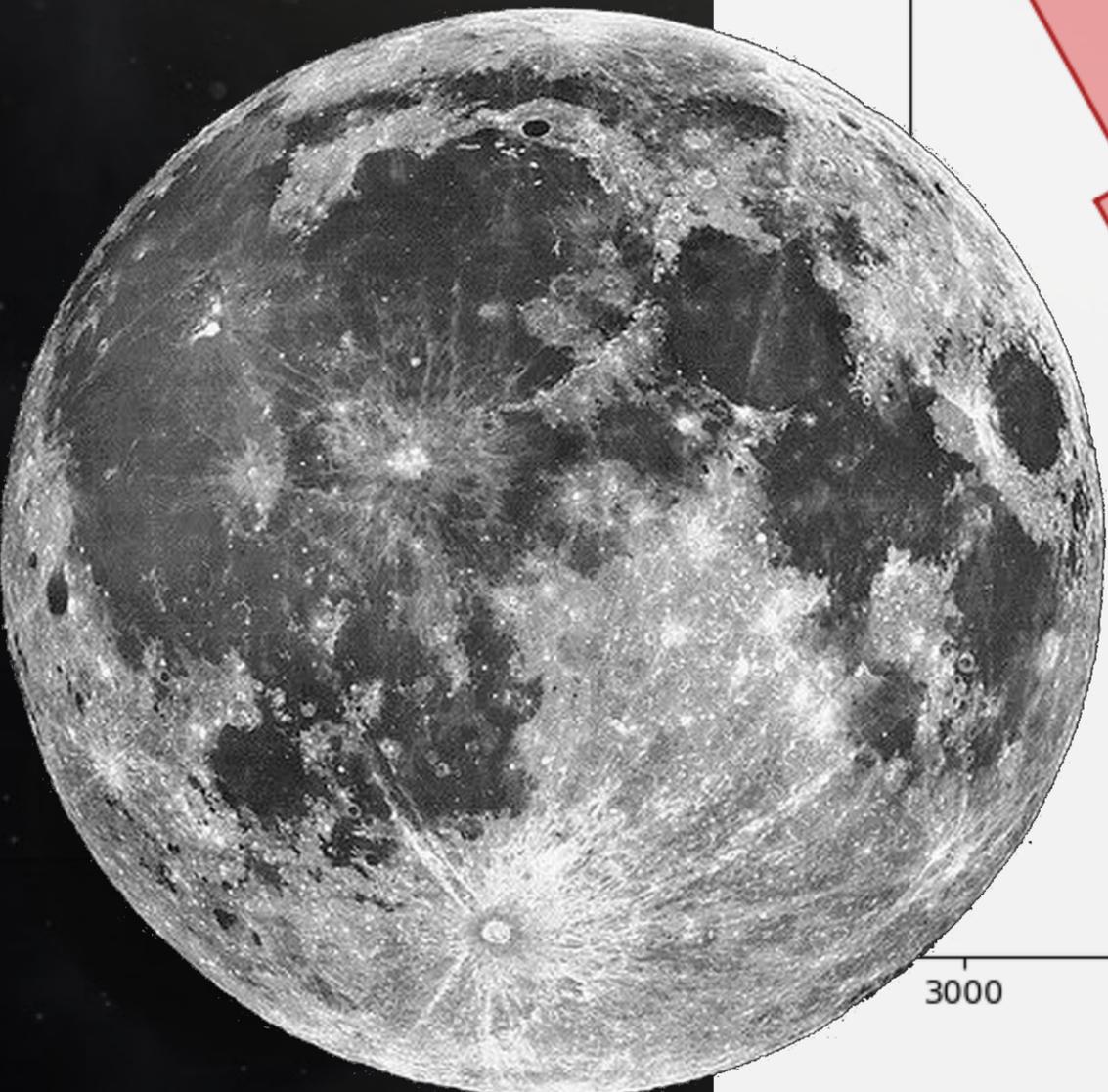
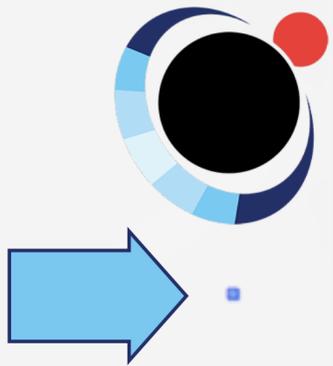
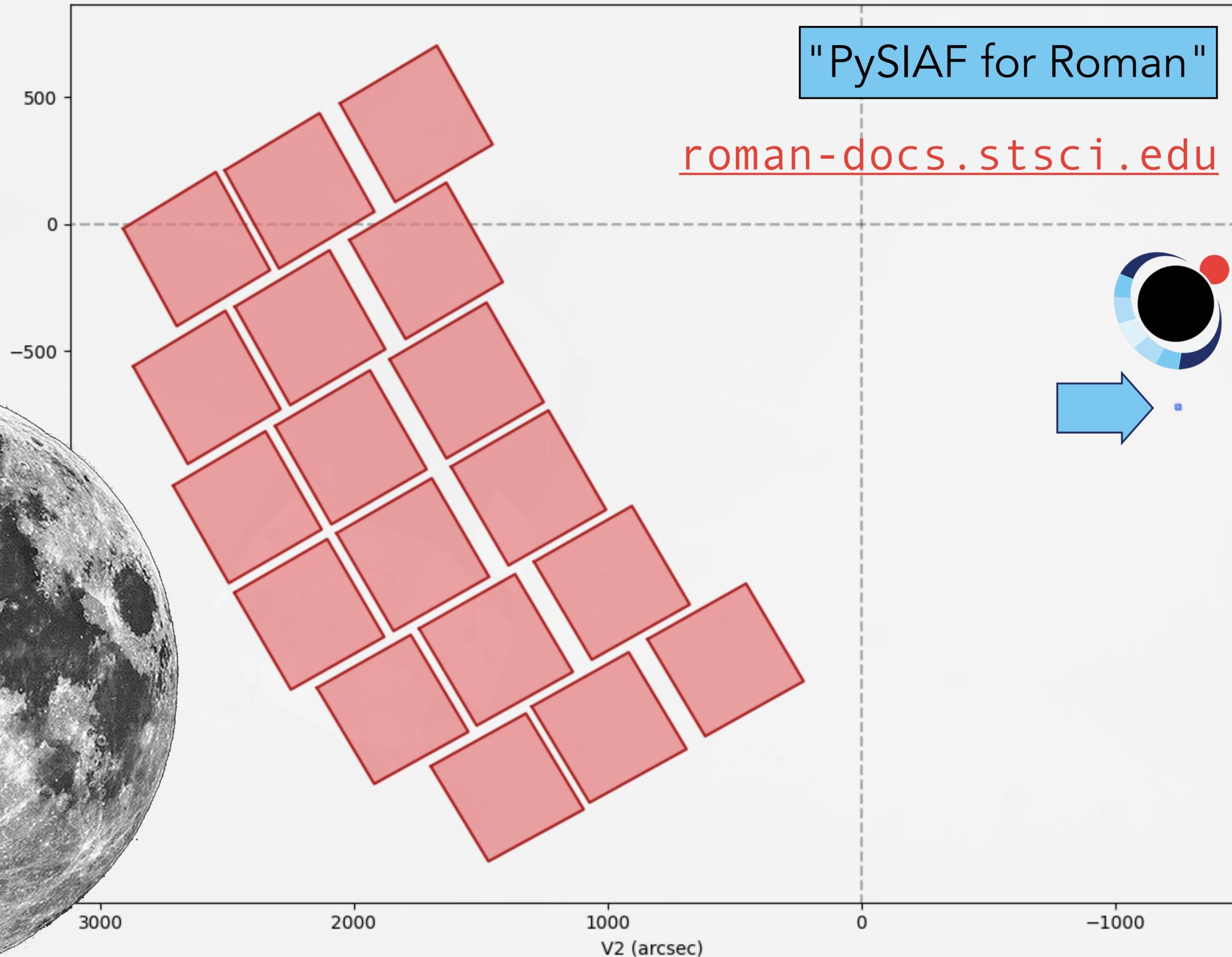


VISIBLE - NEAR INFRARED
100X FOOT PRINT OF HUBBLE

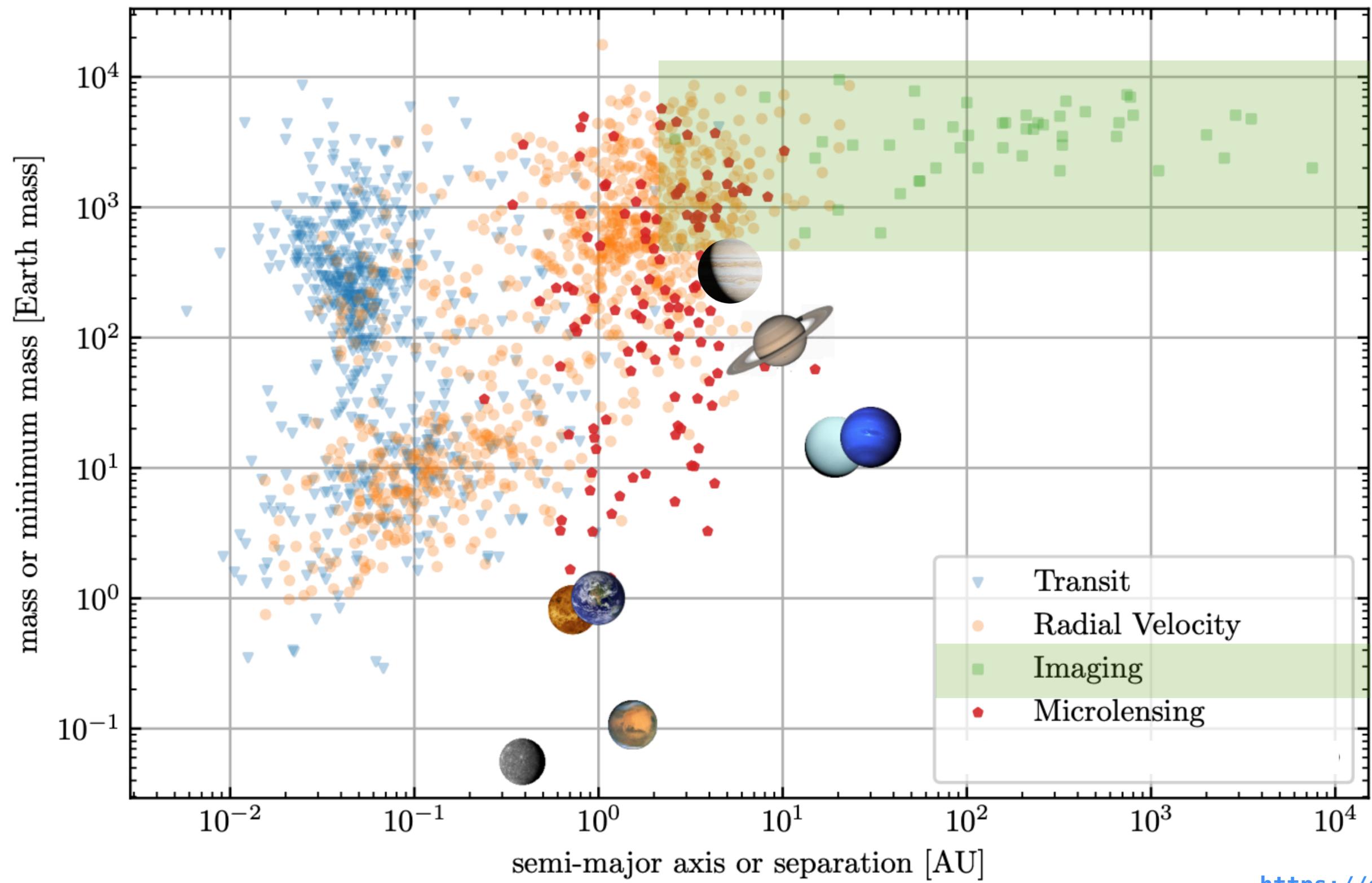
ROMAN'S
WIDE FIELD INSTRUMENT

"PySIAF for Roman"

roman-docs.stsci.edu



DETECT SOLAR SYSTEM ANALOGS



Young, gaseous
giant planets
Detected at 1-5 μ m

IWA ← Distance →

Age ↓

Diameter or baseline

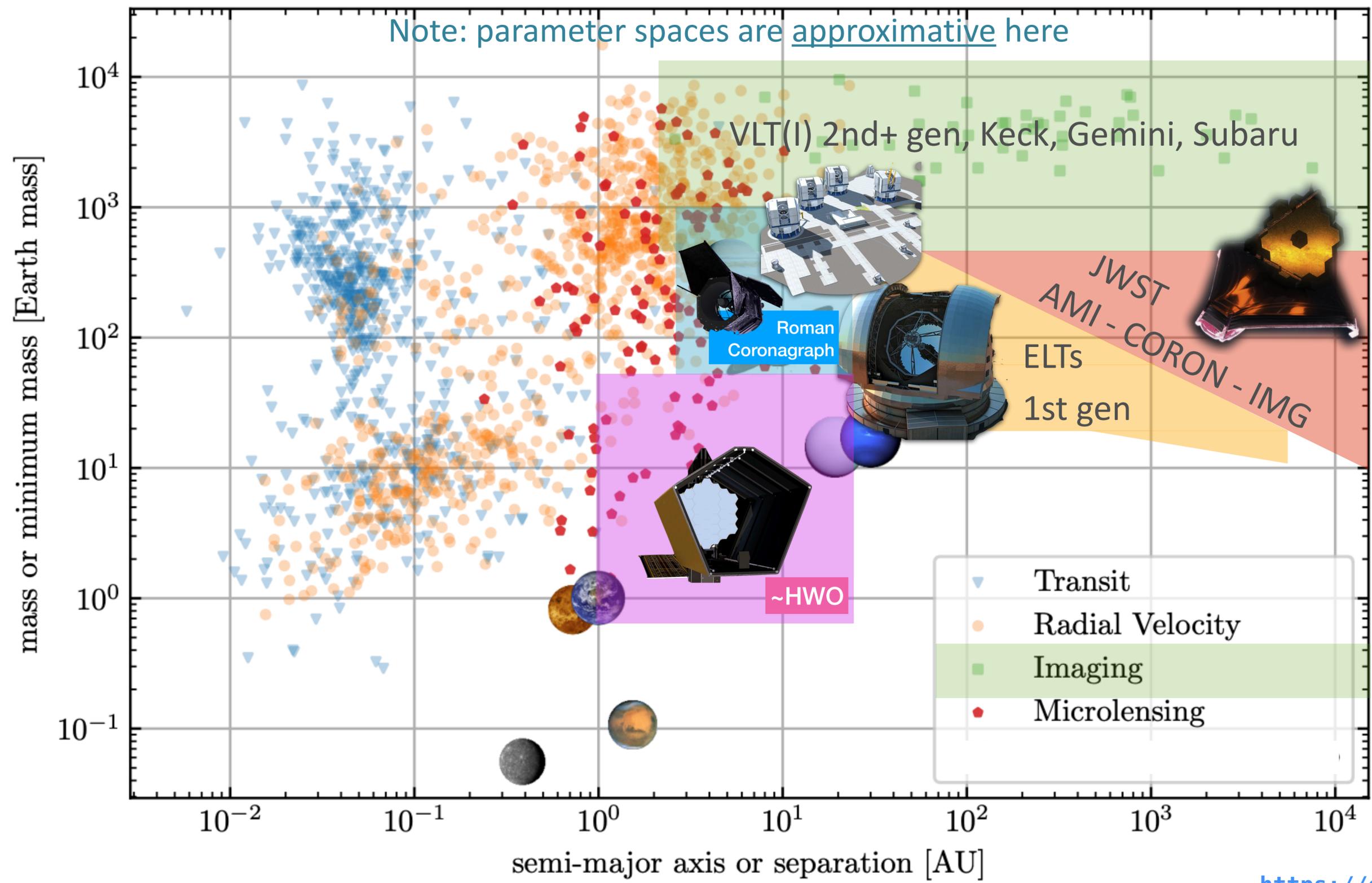
Inner-planets
Reflected light planets (VIS)

CONTRAST

Coronagraph/WF control
Post-processing
Stability (Space)
Sensitivity (Space)

Lower mass planets
Cold start/GI planets
More mature systems

DETECT SOLAR SYSTEM ANALOGS



Young, gaseous giant planets
 Detected at 1-5 μ m

IWA ← Distance →

Age ↓

Diameter or baseline

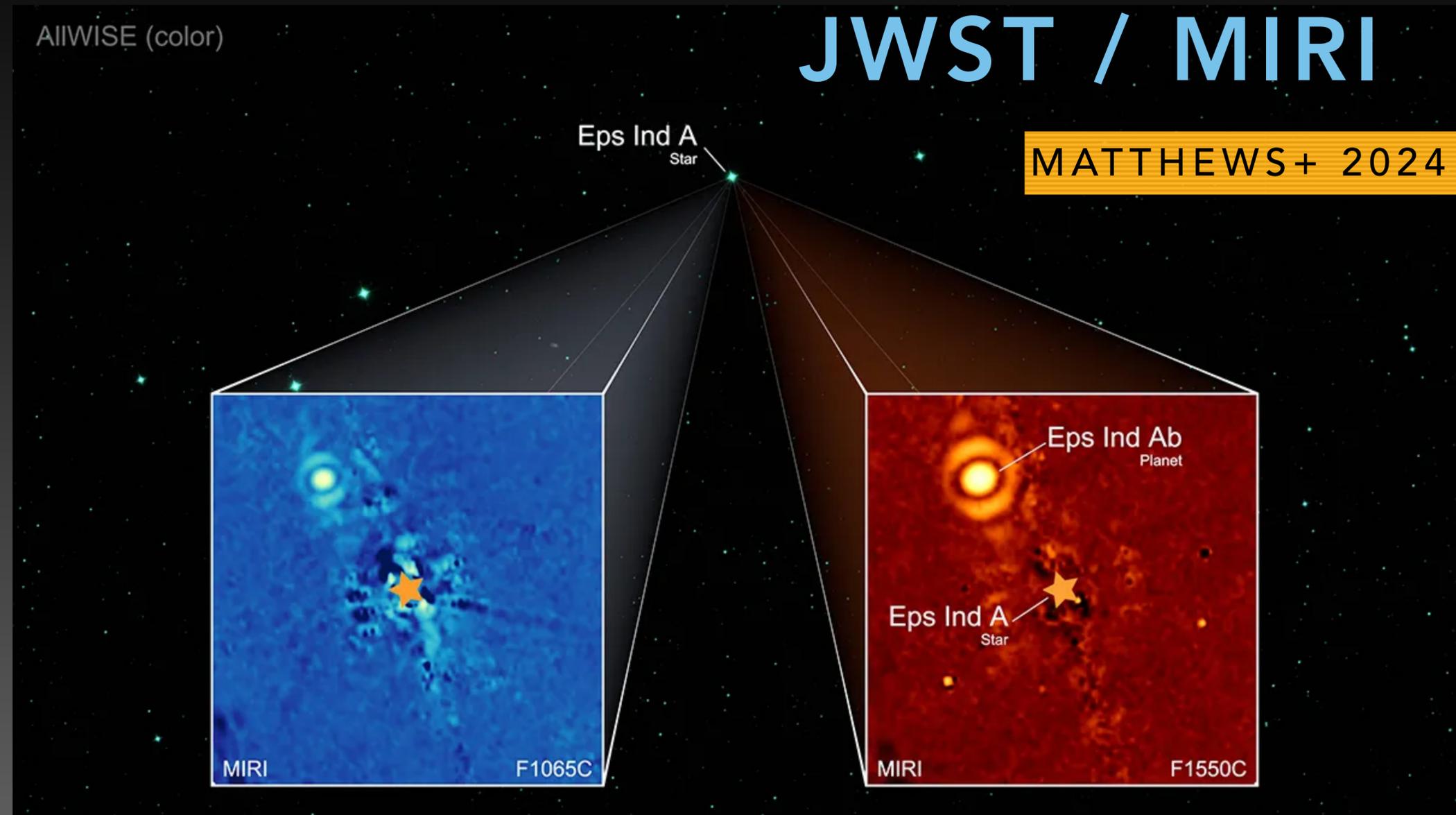
Inner-planets
 Reflected light planets (VIS)

CONTRAST

Coronagraph/WF control
 Post-processing
 Stability (Space)
 Sensitivity (Space)

Lower mass planets
 Cold start/GI planets
 More mature systems

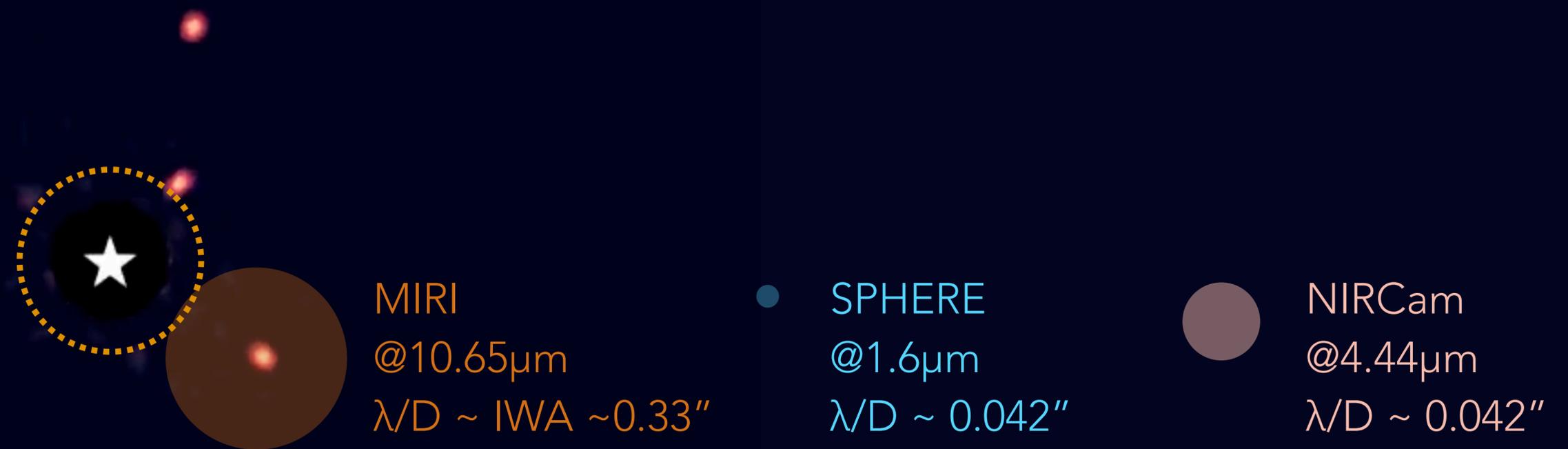
AGE



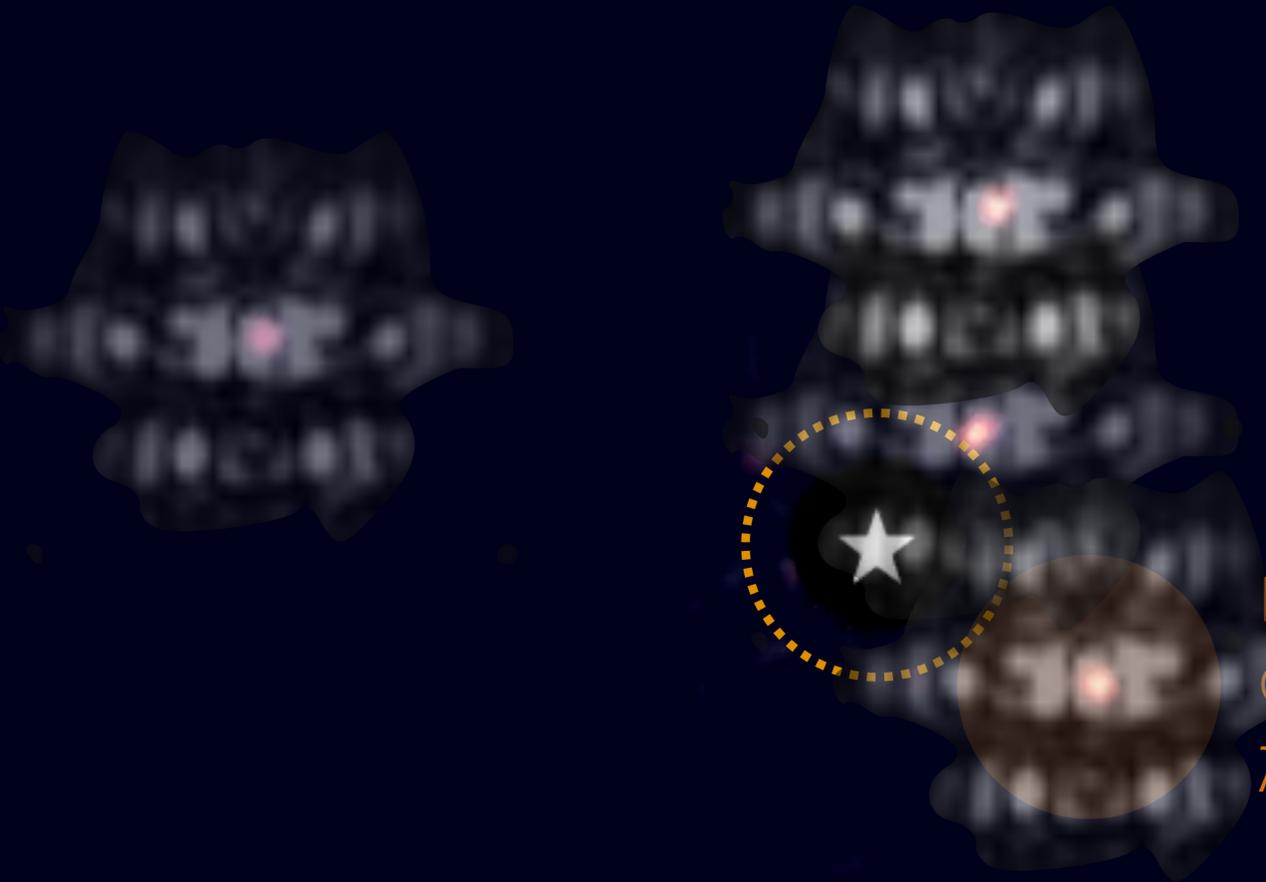
JWST: access to more mature, colder long-period giant planets

New planets in direct imaging, exciting upcoming results and surveys!

ANGULAR RESOLUTION JWST'S λ/D PROBLEM



ANGULAR RESOLUTION JWST'S λ/D PROBLEM



MIRI
 @10.65 μ m
 $\lambda/D \sim$ IWA $\sim 0.33''$

● SPHERE
 @1.6 μ m
 $\lambda/D \sim 0.042''$

● NIRCam
 @4.44 μ m
 $\lambda/D \sim 0.042''$

Deconvolution is 

BUT ALSO A TREMENDOUS SENSITIVITY & STABILITY !!!!

DEMOGRAPHICS: COMPLETE OR TARGETED?

Large (ground) xAO NIR surveys like SPHERE/SHINE or GPI/GPIES

Samples selected with age/distance/moving groups, etc.

Statistically meaningful & extremely useful

Data uniformity (modes/depth)

Time consuming/inefficient (hundreds of nights, orbits)

Hundreds of stars to detect a **dozen new giant planets**

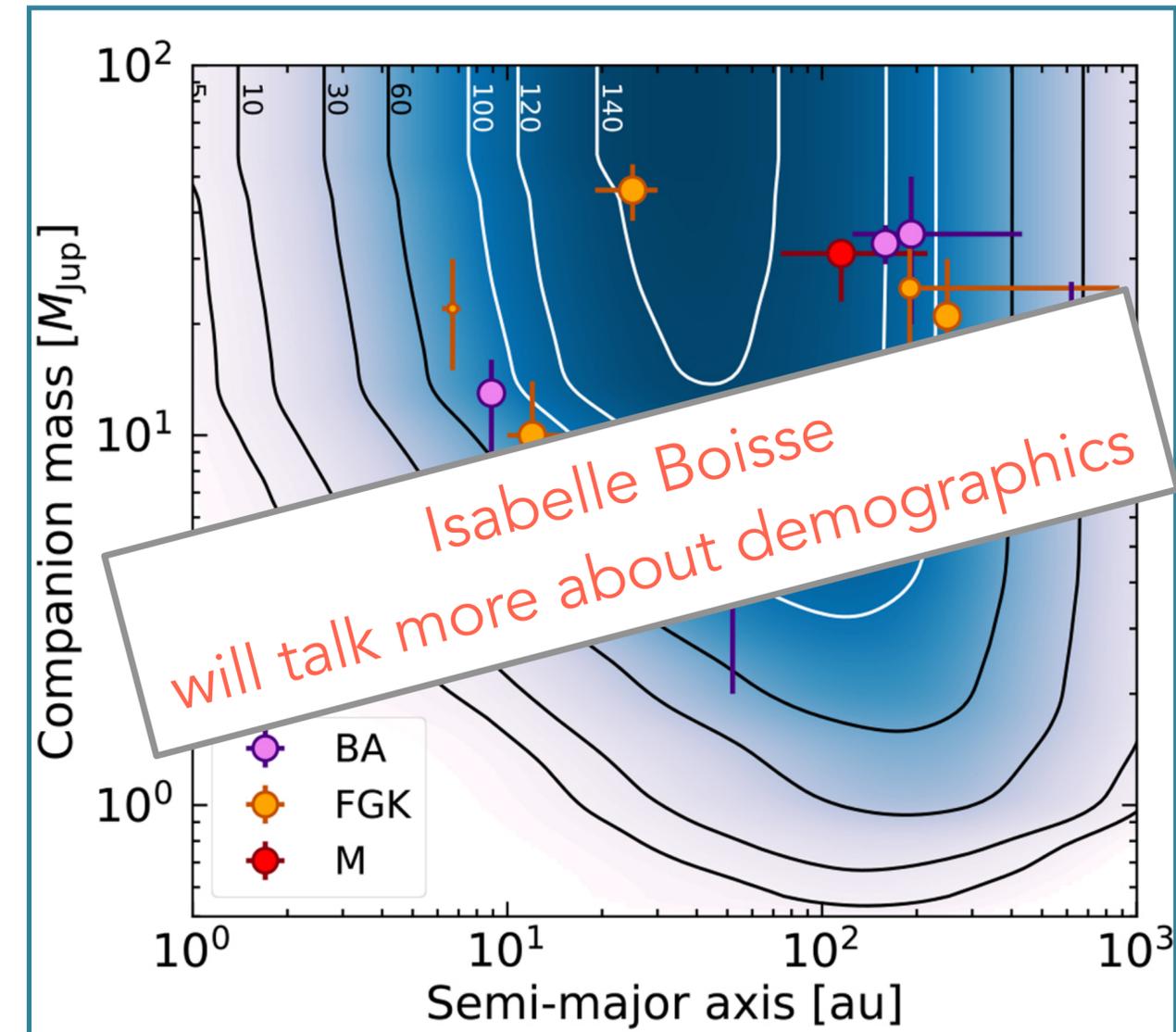
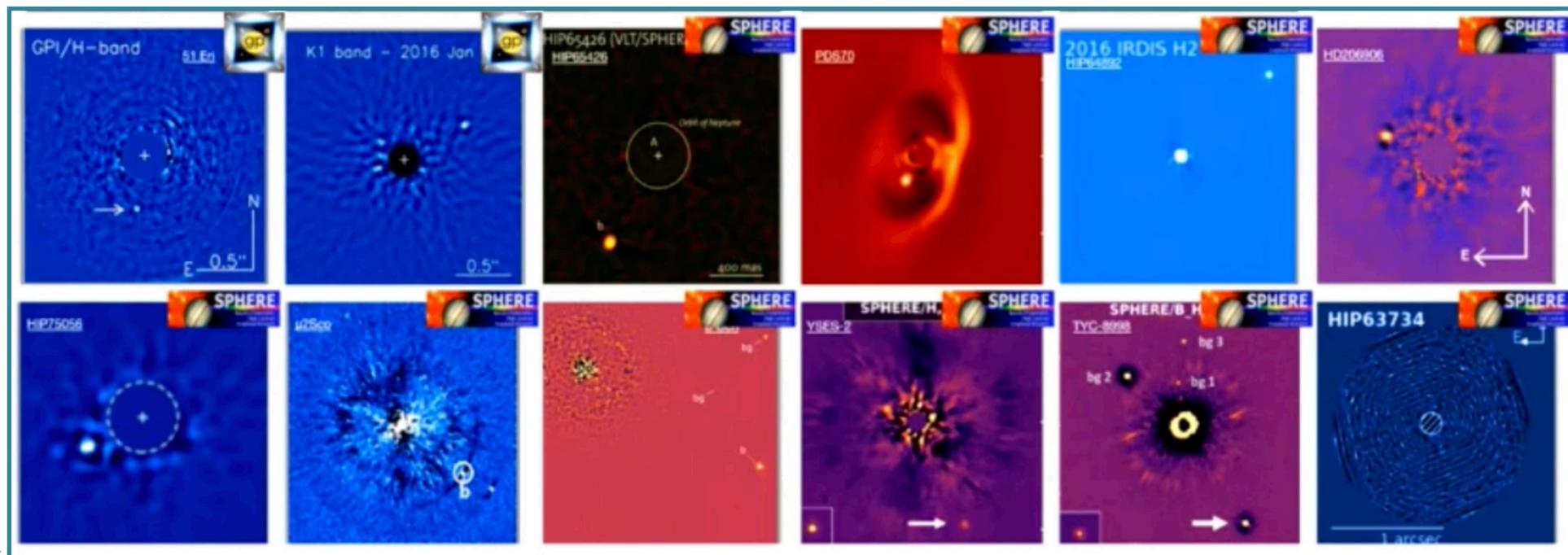
Relatively shallow: planets may have been missed



Gael Chauvin

NIELSEN ET AL. 2019

VIGAN ET AL. 2021



Isabelle Boisse
will talk more about demographics

- BA
- FGK
- M

TARGETED SEARCHES

Roman CGI is all about targeted searches

Dynamical masses!

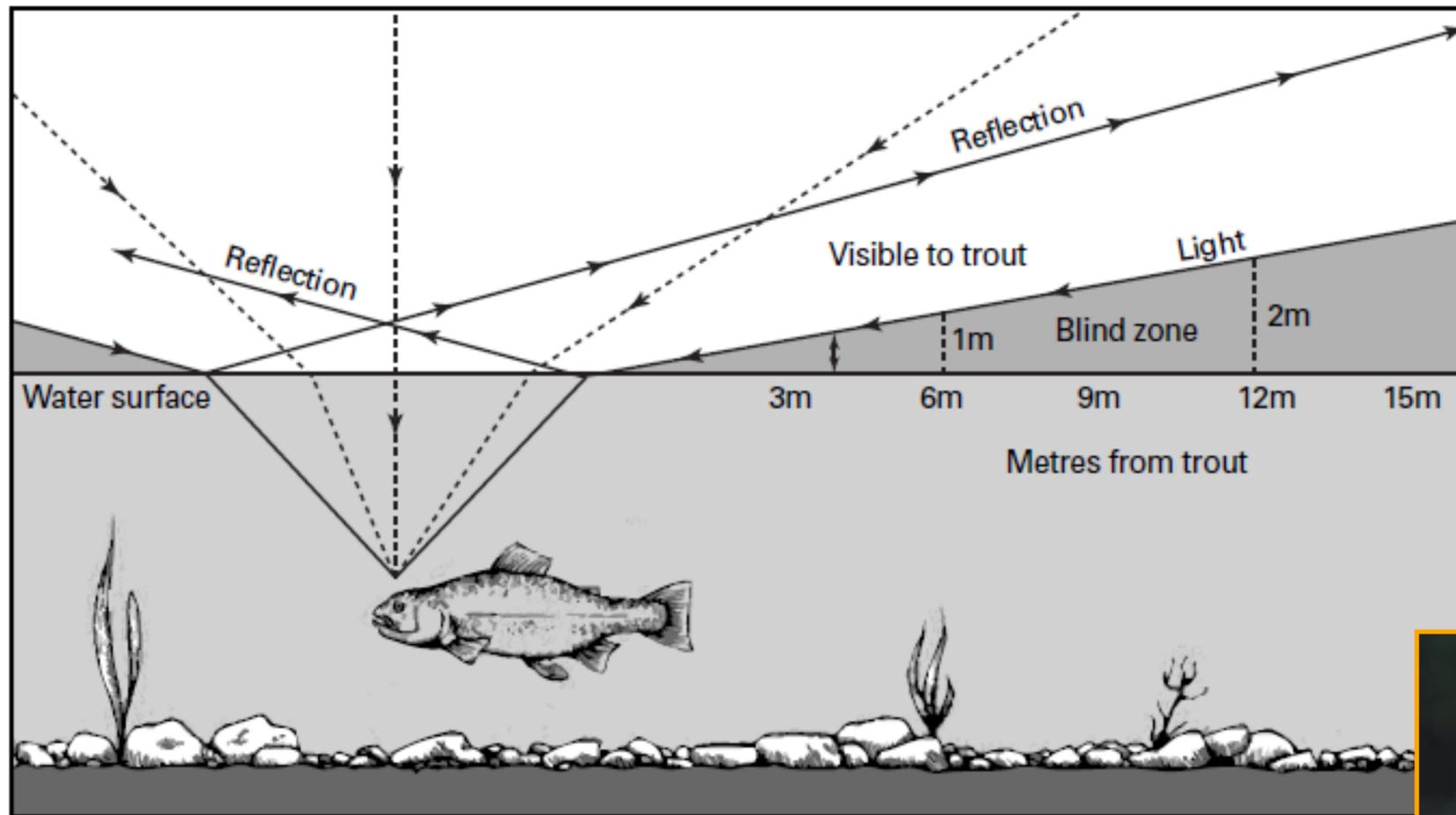
BRANDT+ 2019,2021

FRANSON+ 2022

RICKMAN+ 2022

Ok, it's "fishing"
but **informed fishing**

E.g. fly fishing



Targets are **informed by**

RV trends, astrometric accelerations, etc.

BOWLER+ 2016

New detections

LAGRANGE+, NOWAK+ 2021 β Pic c!!

RANSON+, DE ROSA+, MESA+ 2023 AF Lep b

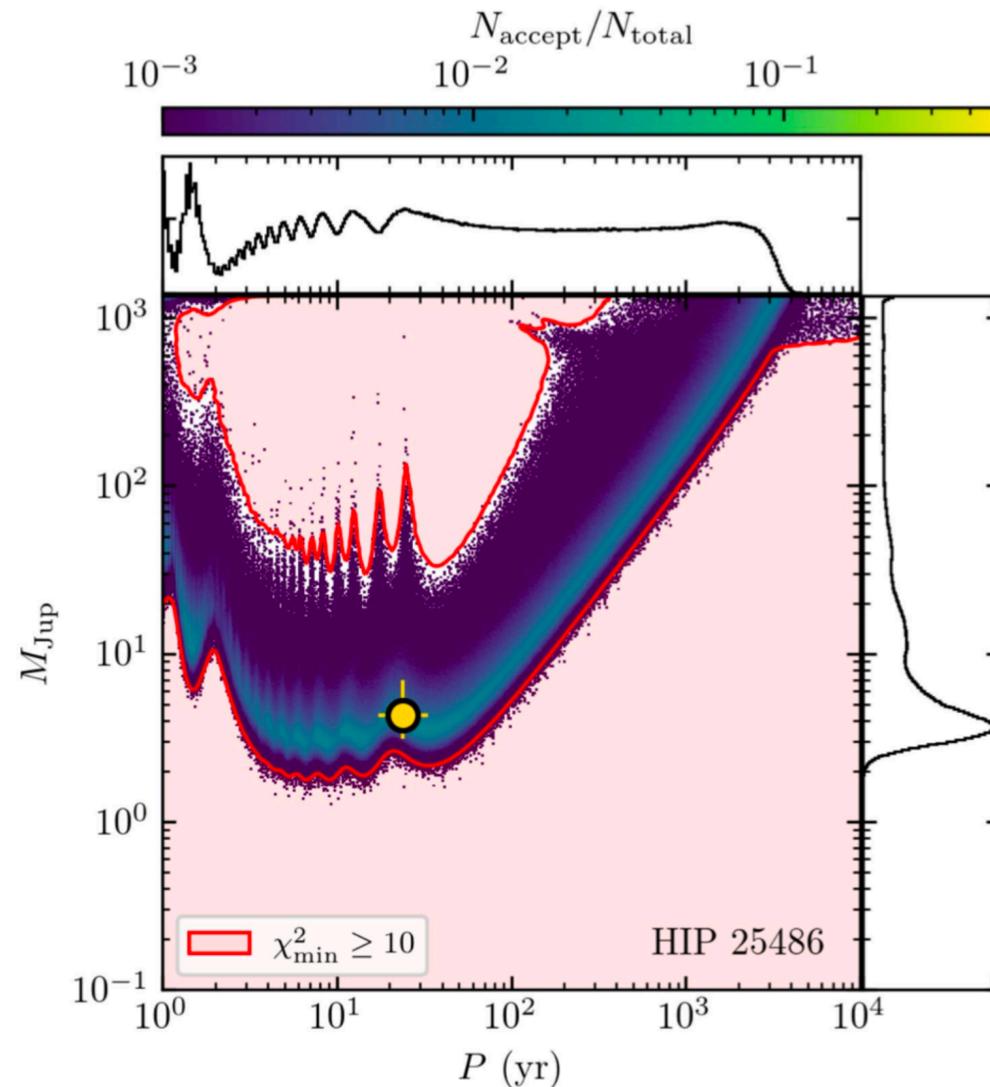
CURRIE+. 2023 HIP 99770 b



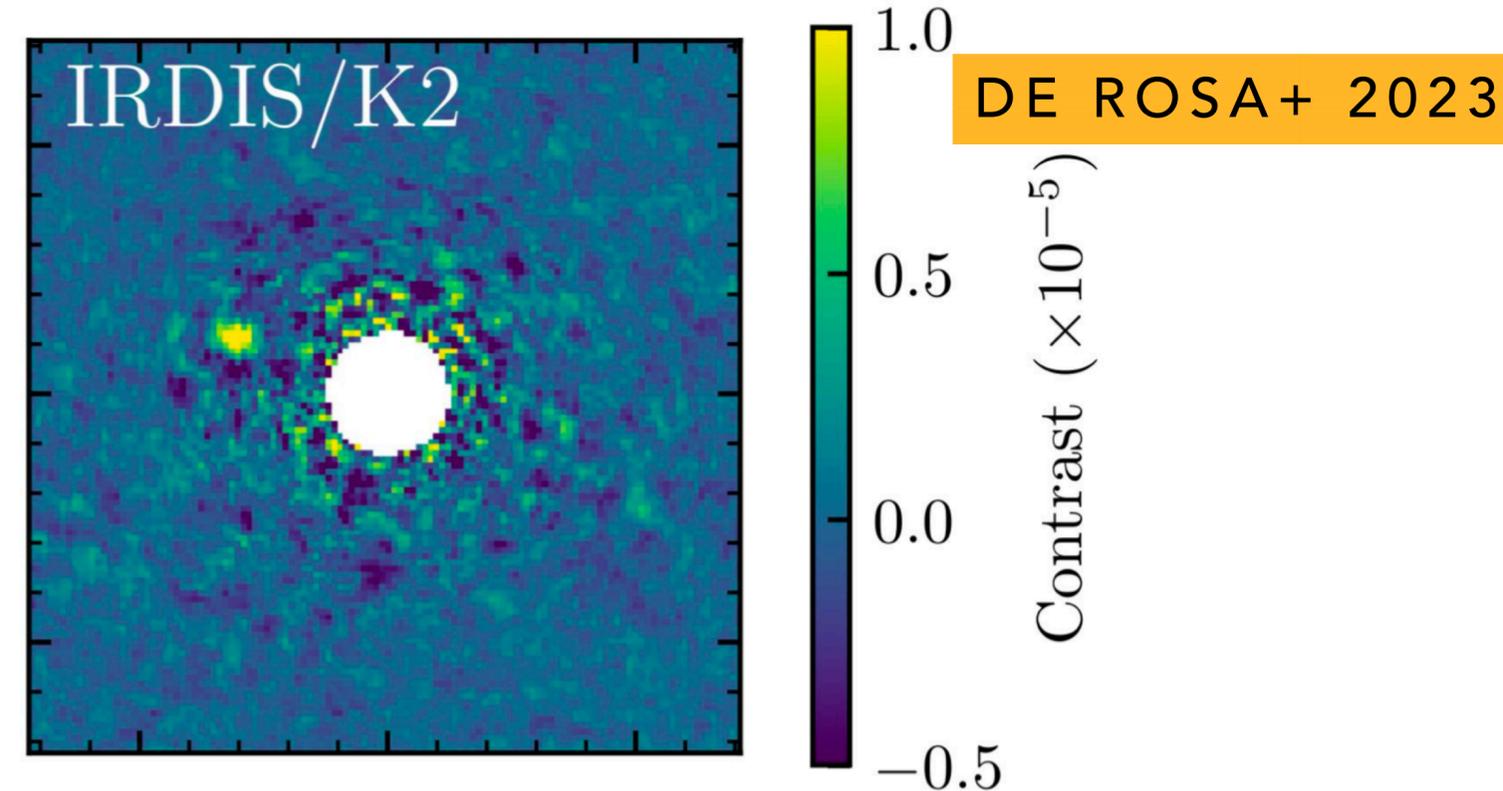
DIRECT IMAGING / GAIA HIPPARCOS SYNERGY

“Informed targets”, the way to optimize telescope time
Especially important for the Roman Coronagraph CPP

HIPPARCOS - GAIA Proper motion anomaly



VLT/SPHERE targeted search



Check out D. Savransky's Mission Data Base
to see prediction for Roman CGI

plandb.sioslab.com

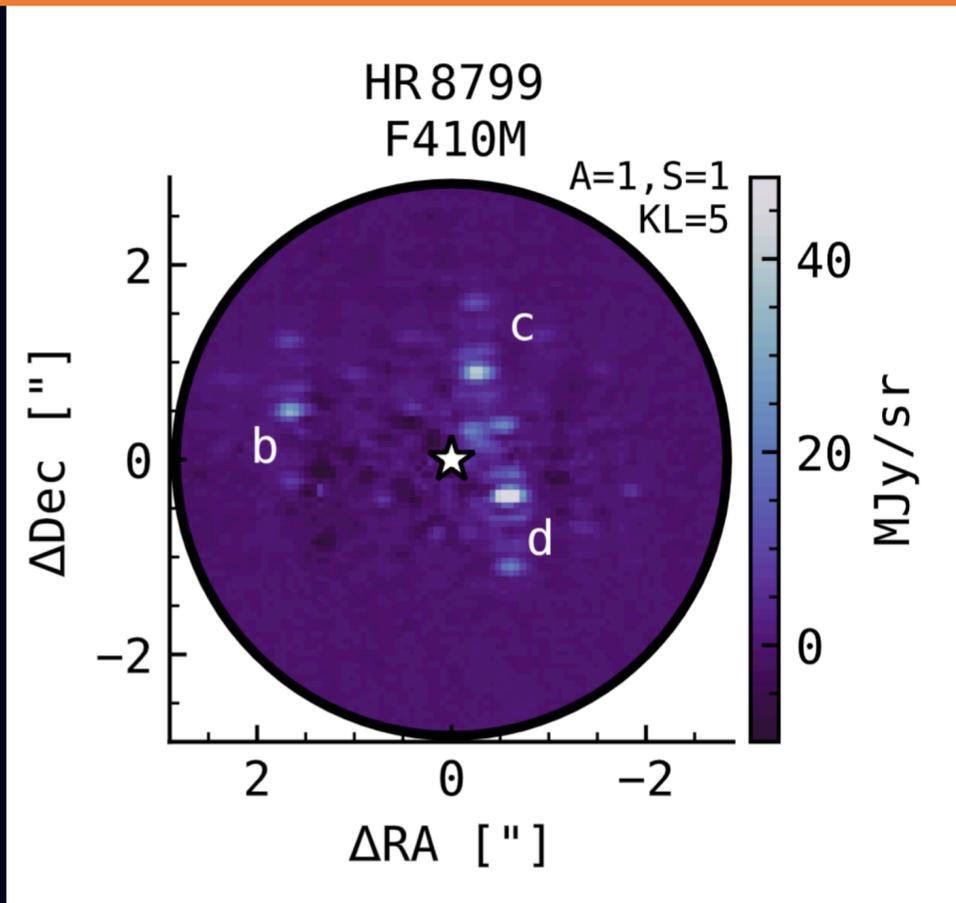
FRANSON+ 2023

Keck/NIRC2 Lp

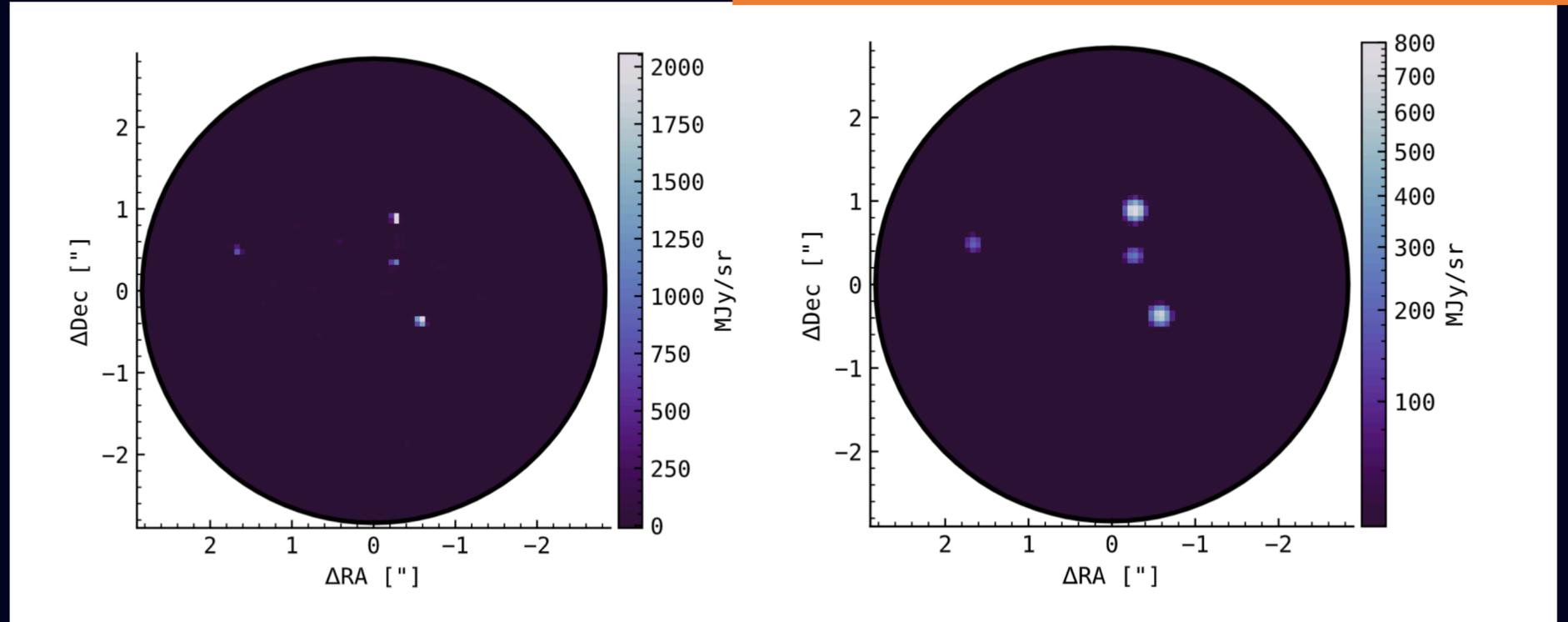
MESA+ 2023

Also SPHERE

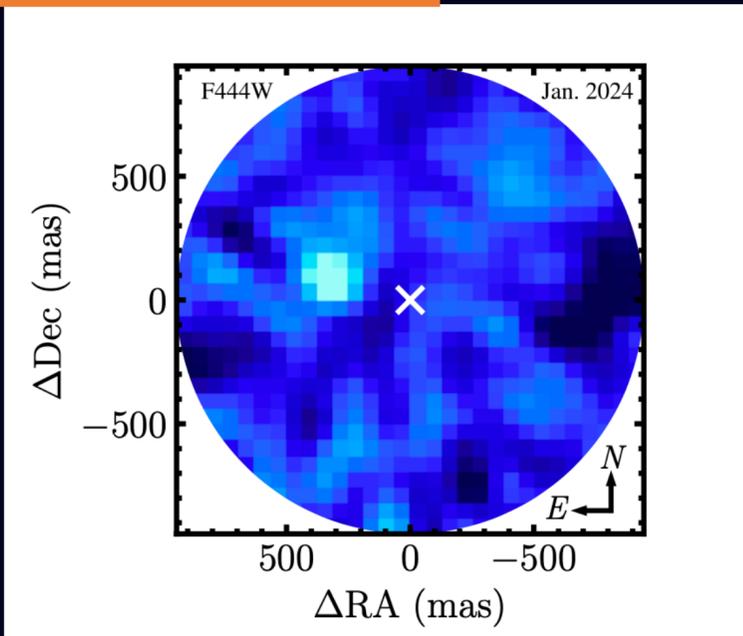
+JWST/NIRCam



JWST'S λ/D PROBLEM



Kellen Lawson's deconvolution with a spatially varying PSF (NIRCam's Coronagraph) is 🙌



~ 2λ/D

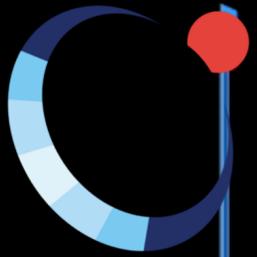
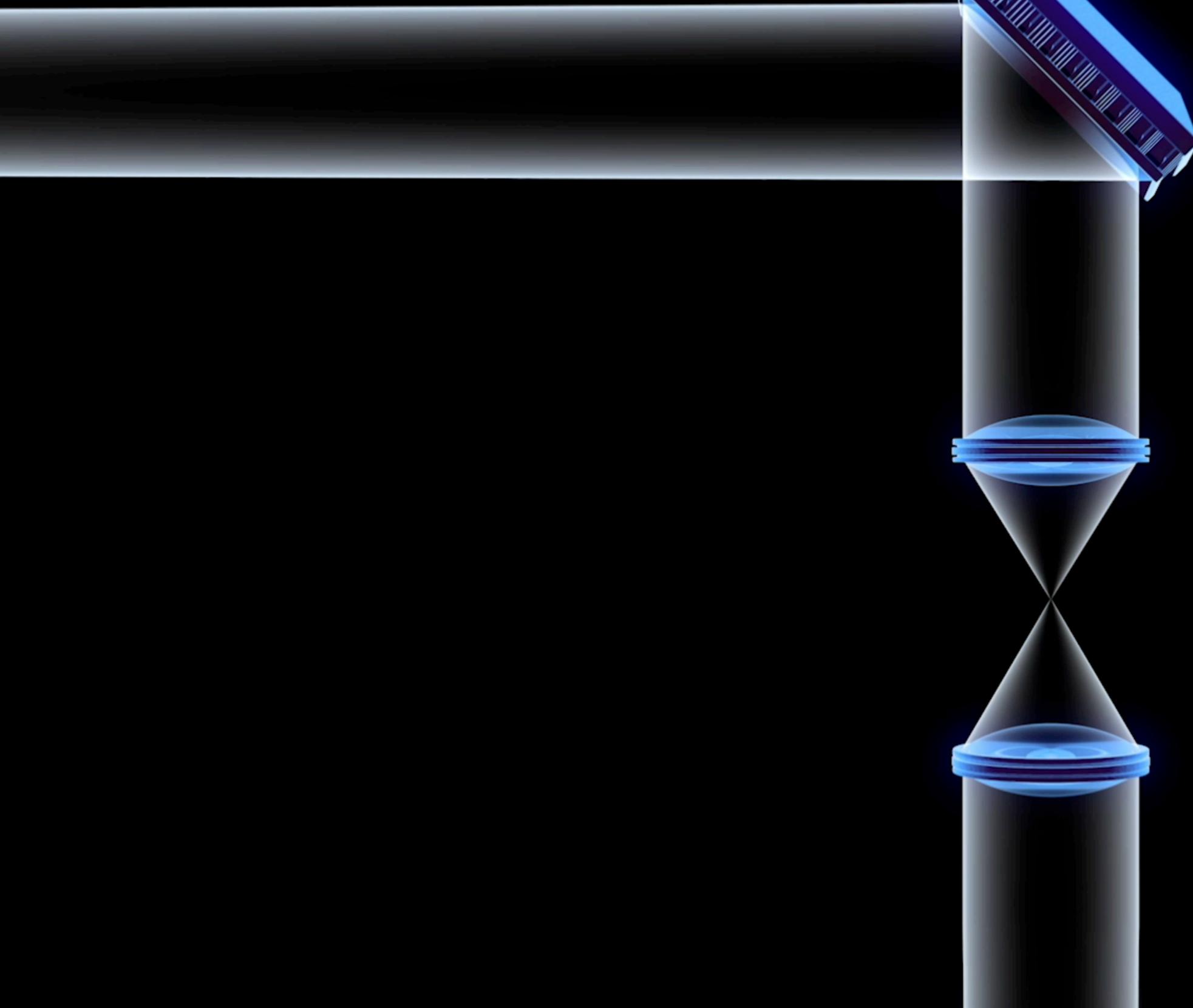
Deconvolution is 🔑

BUT ALSO A TREMENDOUS SENSITIVITY & STABILITY !!!!

CORONAGRAPH?

Axel will talk more about that

THE ROMAN CORONAGRAPH

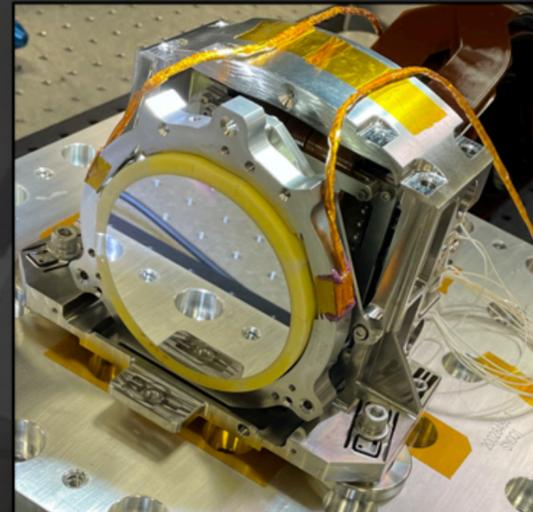


Axel will talk more about that

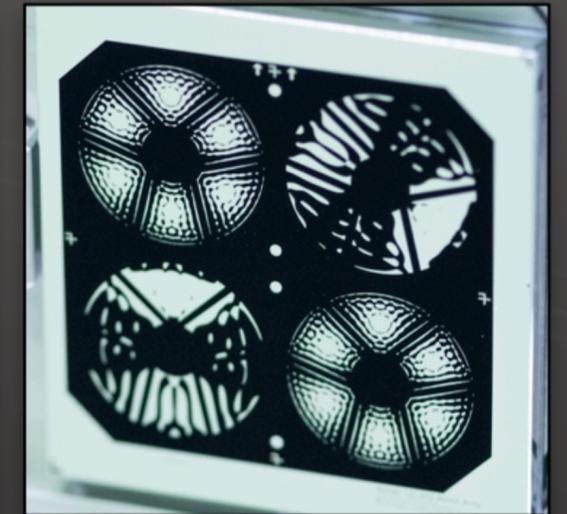
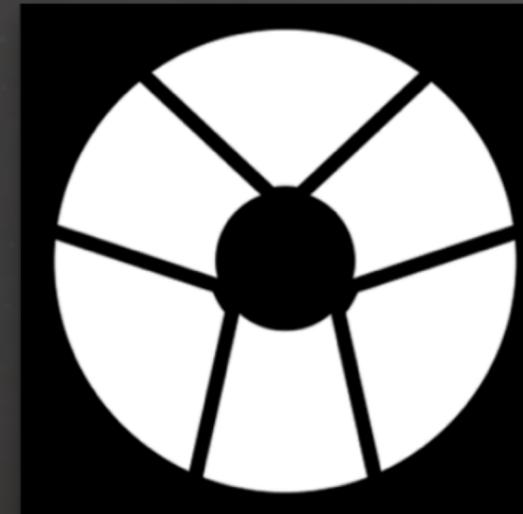
KEY TECHNOLOGIES

TEST
AND
ON-ORBIT
VALIDATION

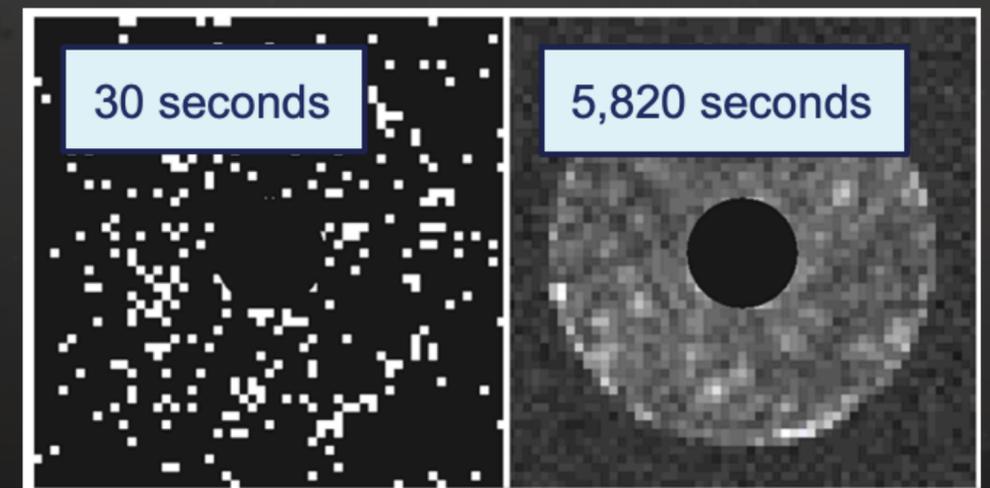
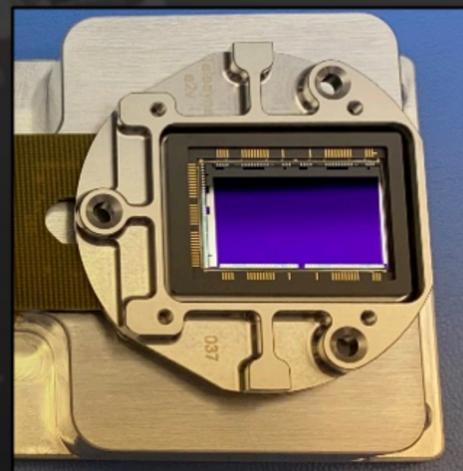
Large-format
Deformable Mirrors



High-performance Coronagraphs
and Pupil Masks

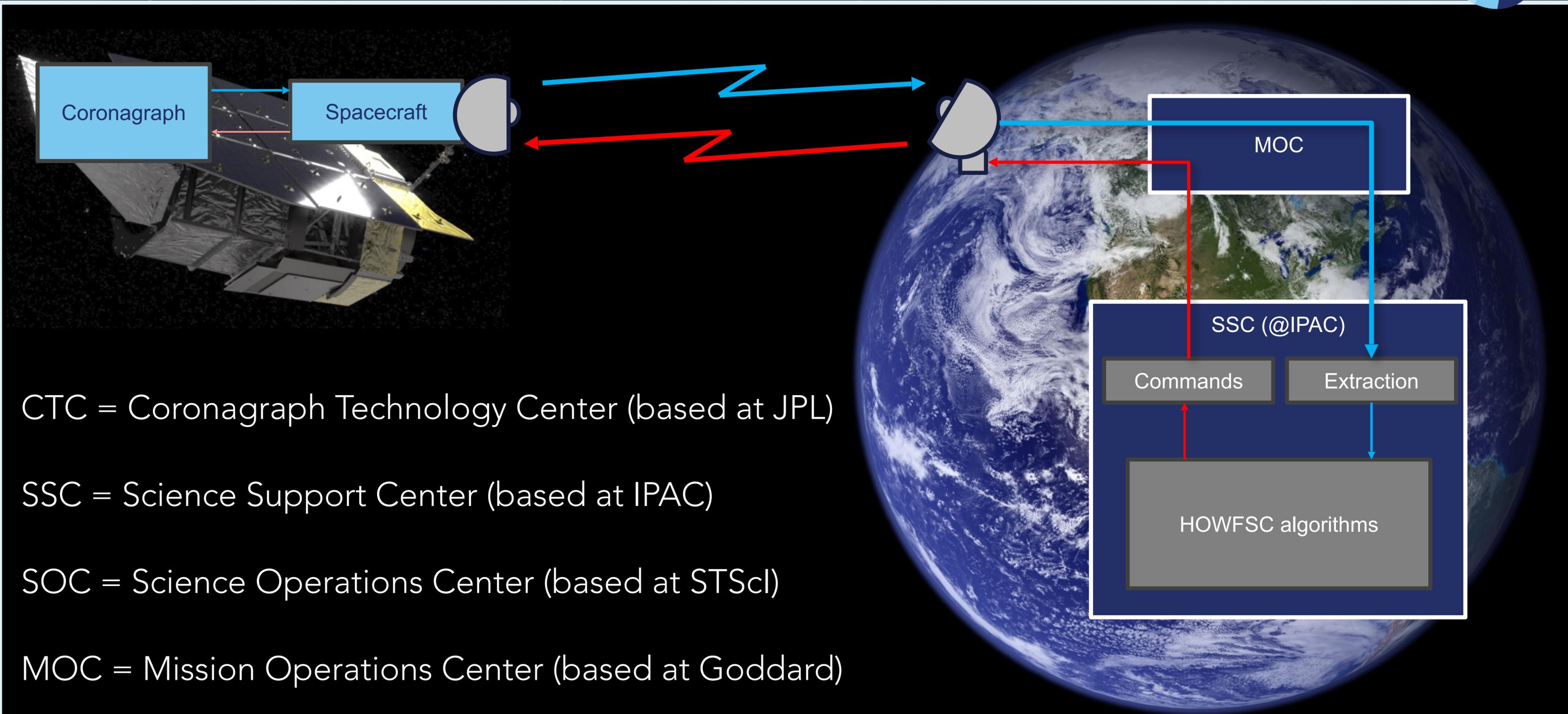


Ultra-low-noise Camera

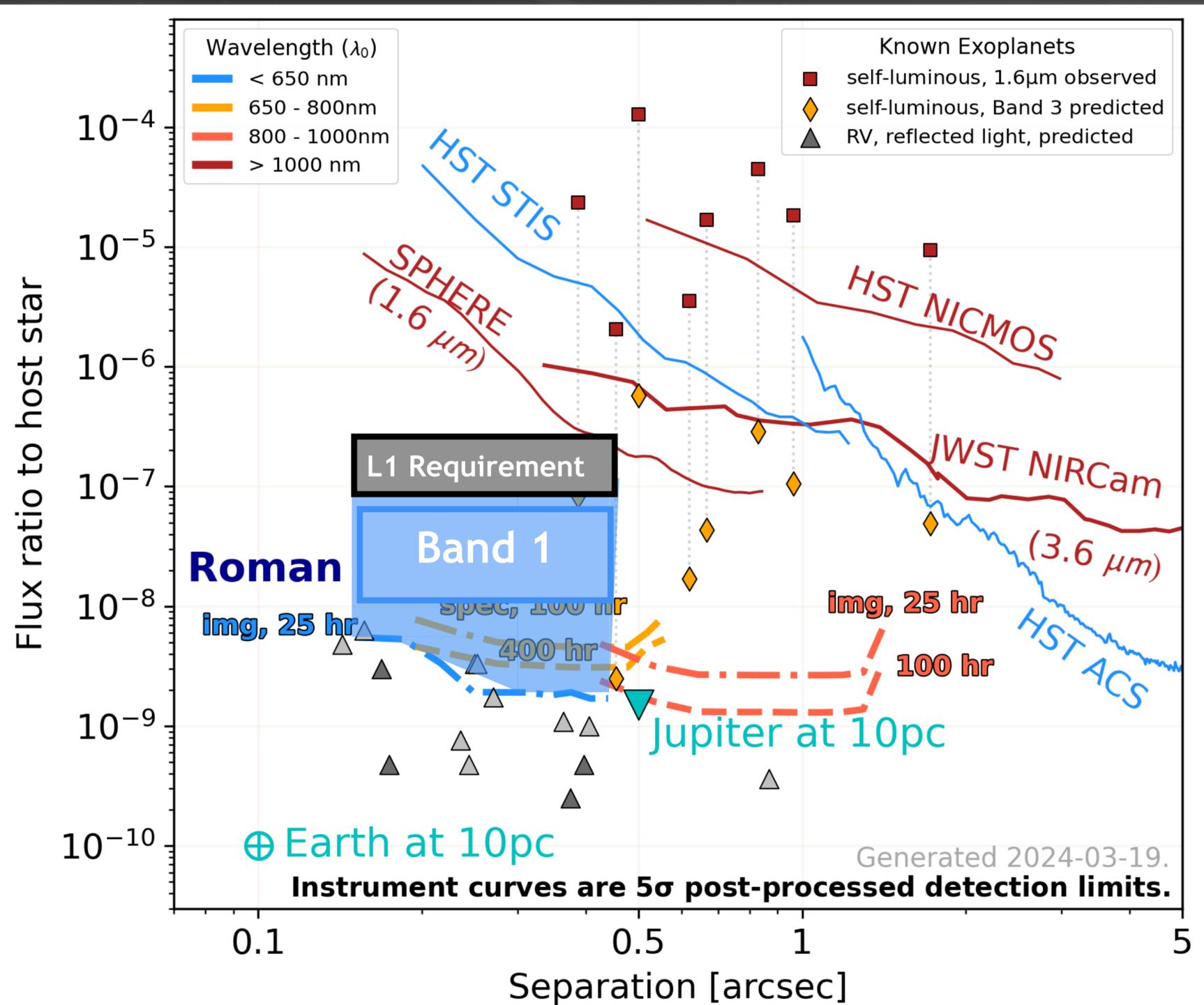


WAVEFRONT CONTROL
IN SPACE!

"GROUND IN THE LOOP" (GITL)



NEW CONTRAST REGIME



For $V \sim 5$ stars

The expected contrast is

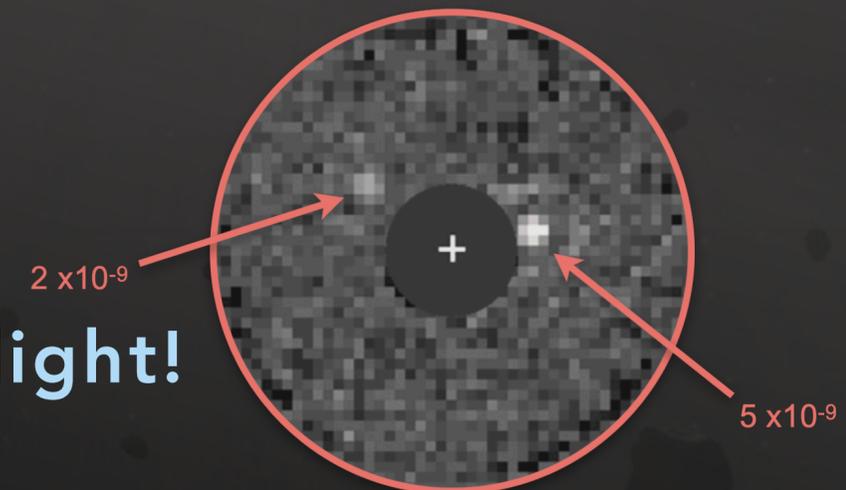
$< 10^{-7}$ (L1 requirement)

$\sim 10^{-8} - 10^{-9}$ (predicted/goal)

100 to 1,000 times better than current facilities.

Goal: image mature "Jupiters"

@ 10-50pc
in reflected light!



NEW SCIENCE

A futuristic space telescope is shown in space, oriented vertically. The telescope has a long, dark cylindrical body with a complex internal structure visible. At the bottom, there are several white rectangular panels and a circular dish. The background is a dark space filled with stars, a ringed planet (like Saturn) in the upper left, and a large planet in the lower left. A bright light source is visible on the right, creating a lens flare effect.

OUR BEST SHOT
AT

BEFORE 2030

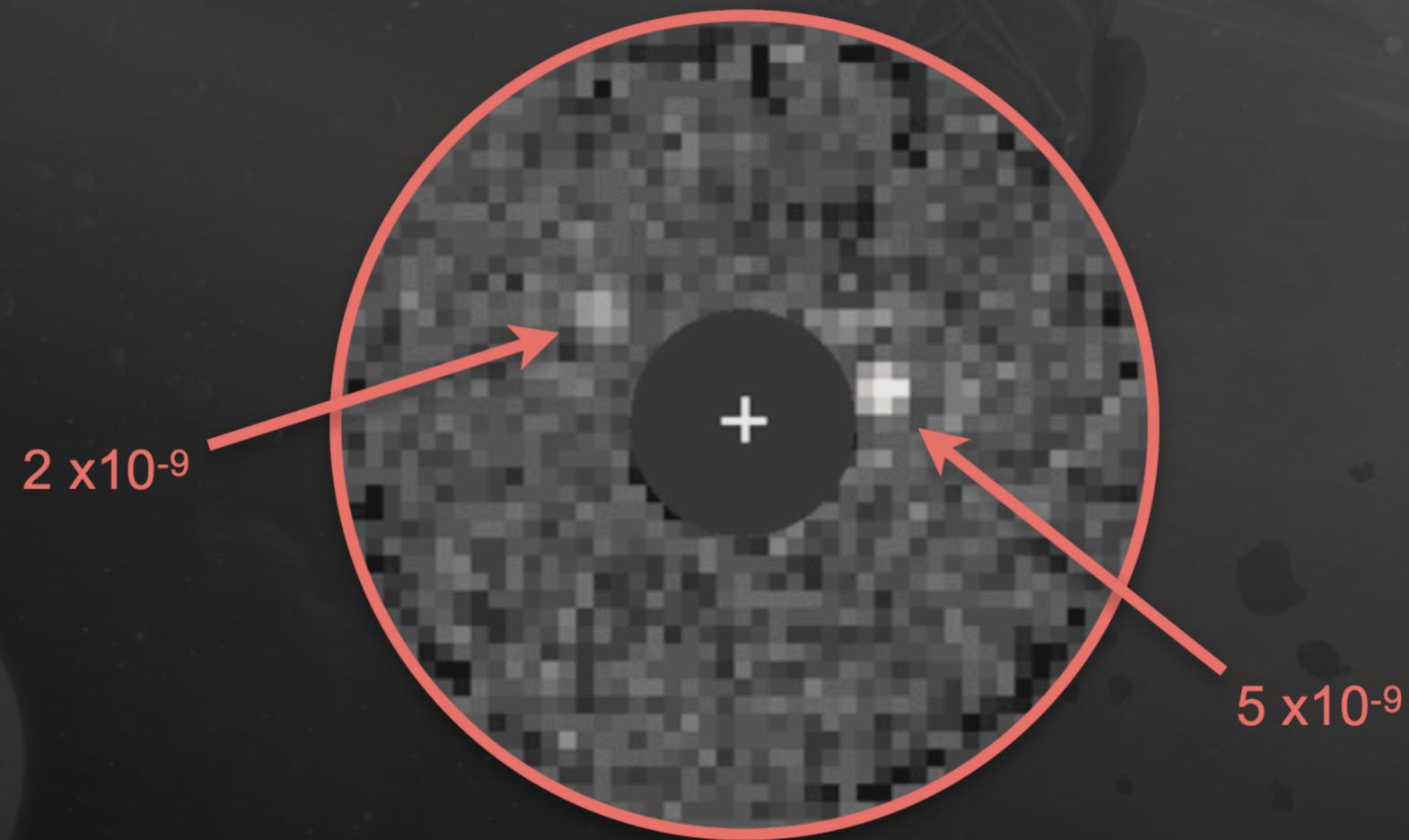
IMAGING GIANT EXOPLANETS
IN REFLECTED LIGHT

CORONAGRAPH EXPECTED CONTRAST

$> 10^8$

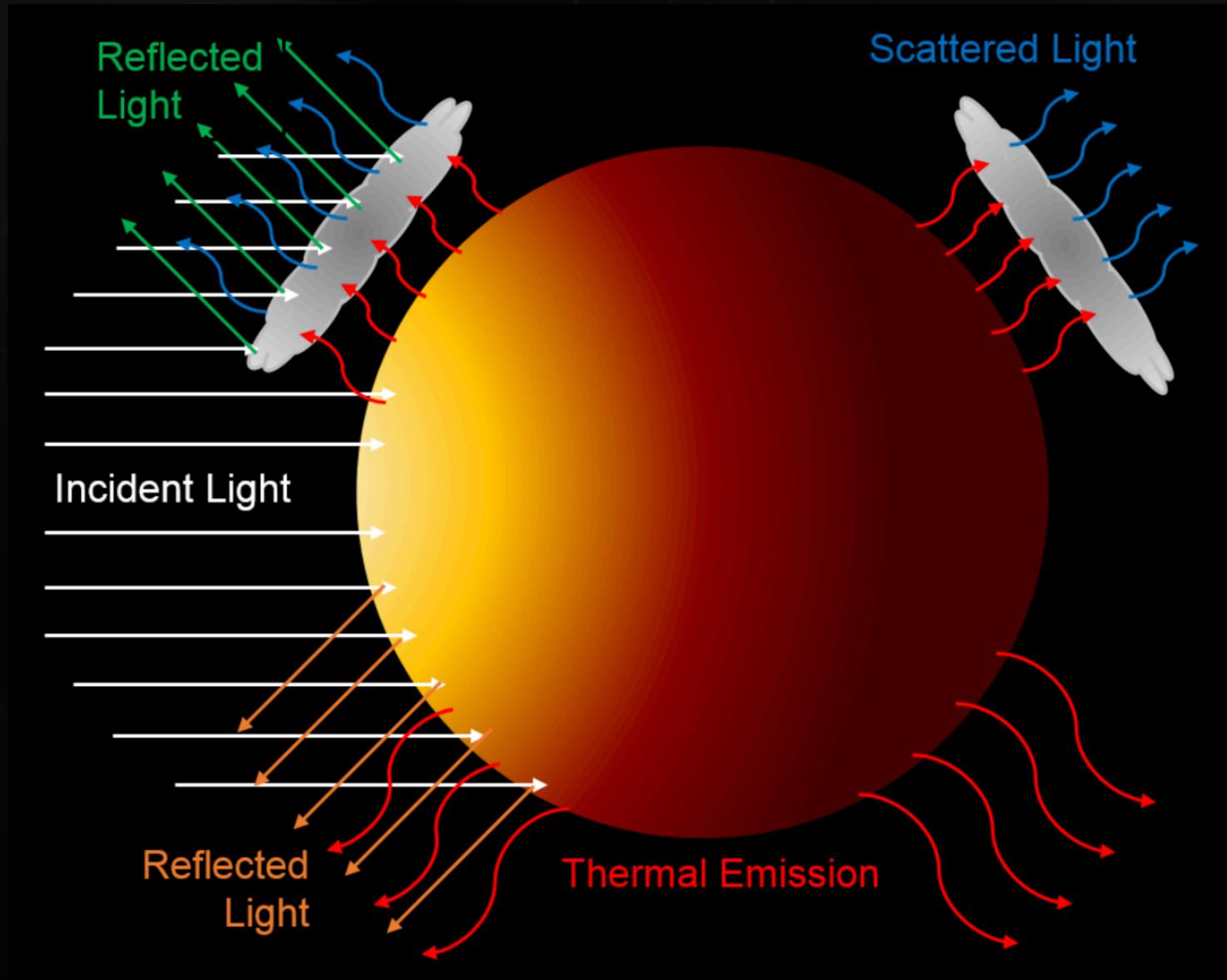


Imaging Exoplanets in Visible Reflected Light



OS11 Simulation (Krist et al. 2023)

PLANETS IN REFLECTED LIGHT



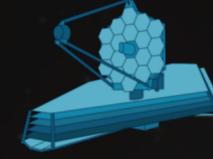
LIKE JUPITER
IN THE NIGHT SKY



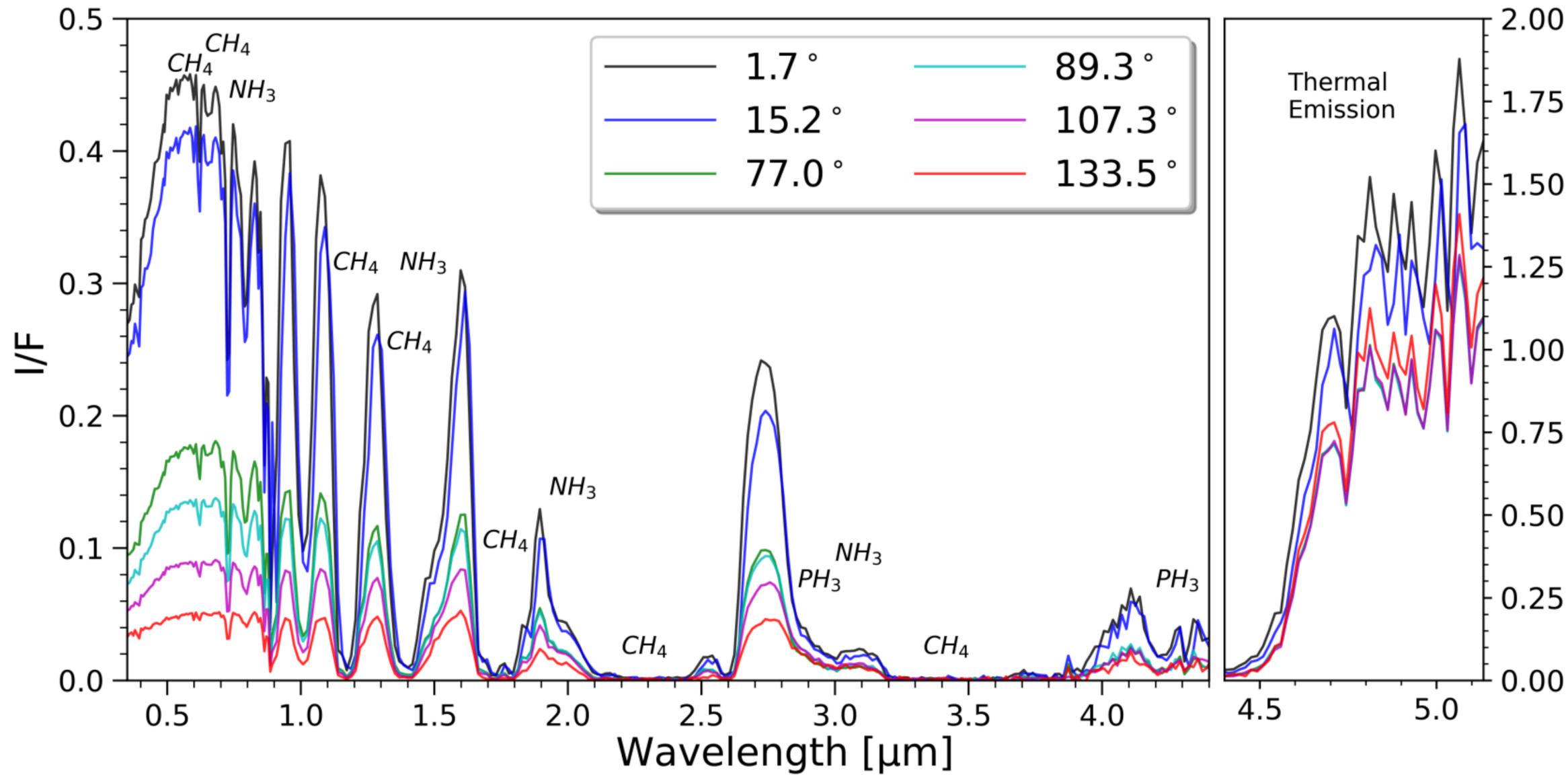
JUPITER'S SPECTRUM



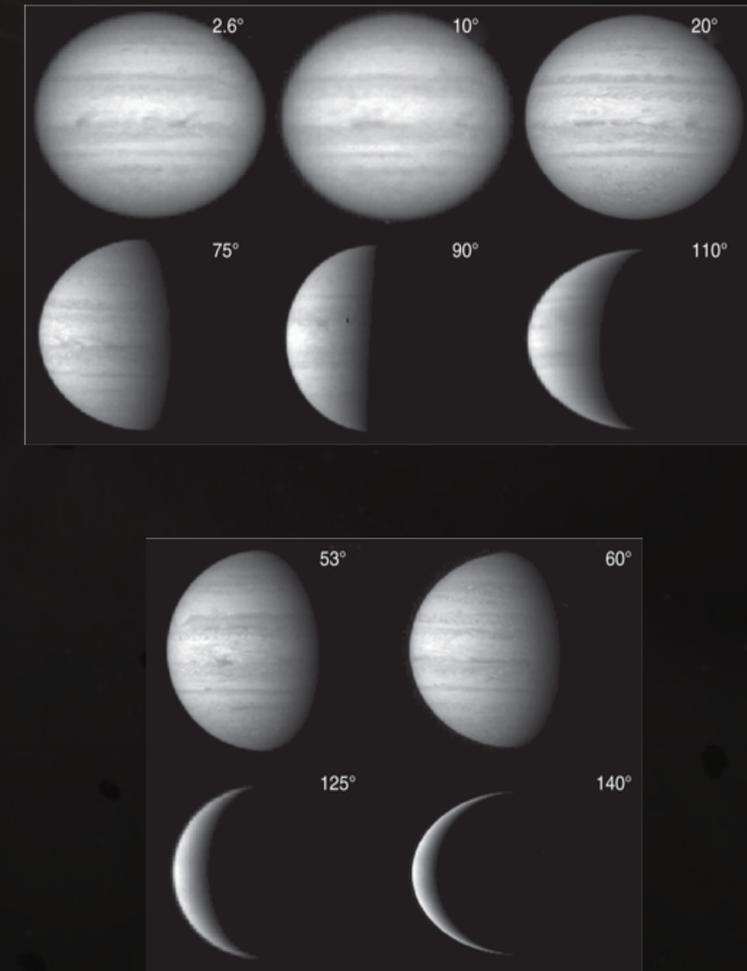
REFLECTED LIGHT



THERMAL LIGHT



PHASES



REFLECTED LIGHT PLANETS



The star (47 UMa)
has been subtracted out.

3 fictitious planets orbit
in the system and their
flux is attenuated by the
HLC coronagraph
throughput and the
effect of the phase in
reflected light

NOISELESS SIMULATION

Noiseless simulation made
for the Roman Exoplanet Imaging Data Challenge
(2019, Neil Zimmerman, OS 6)

$\Delta T = 0.01 \text{ yr}$

ROMAN CORONAGRAPH REQUIREMENT



Narrow Field Imaging

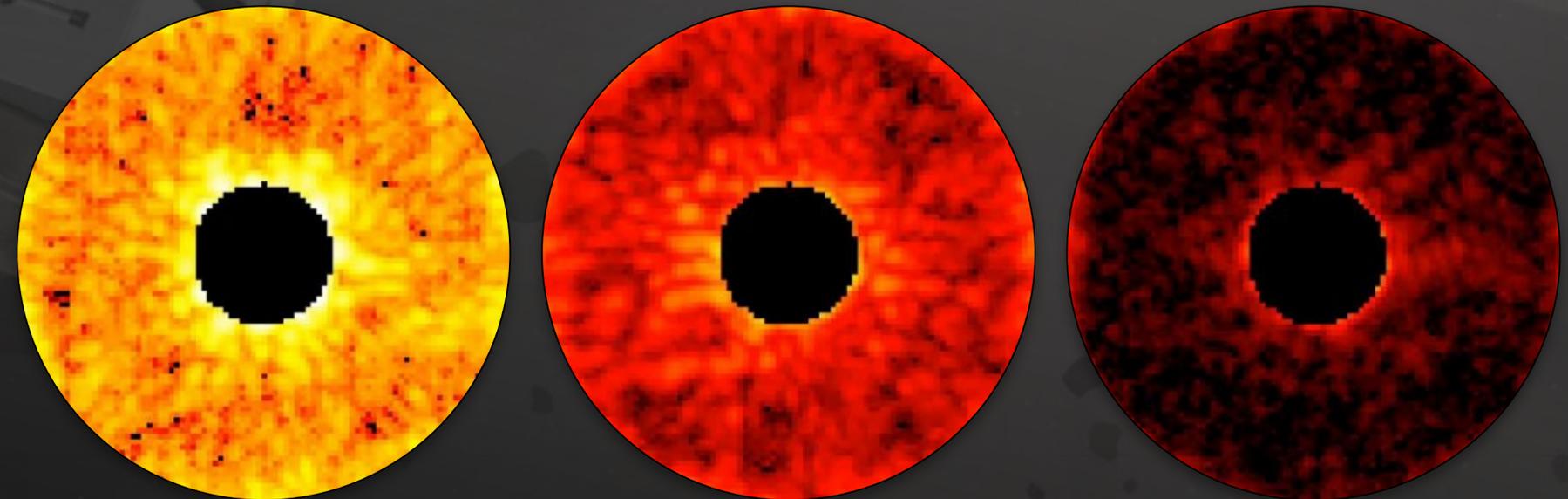
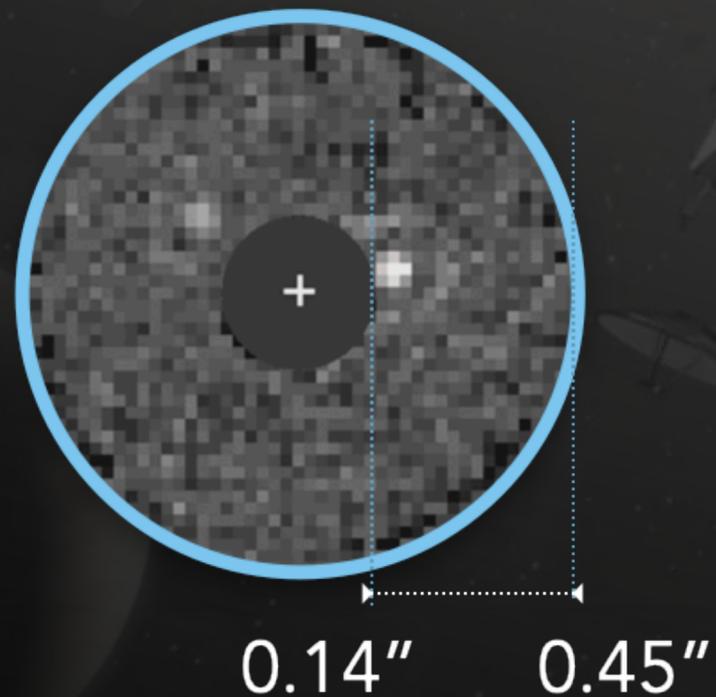
(required)

Image a point source
 10^7 times fainter than central star
from 6 to 9 λ/D ($\sim 0.3''$ to $0.45''$)

Dark Hole "Digging": Laboratory Demonstration

Credit: NASA/JPL-Caltech

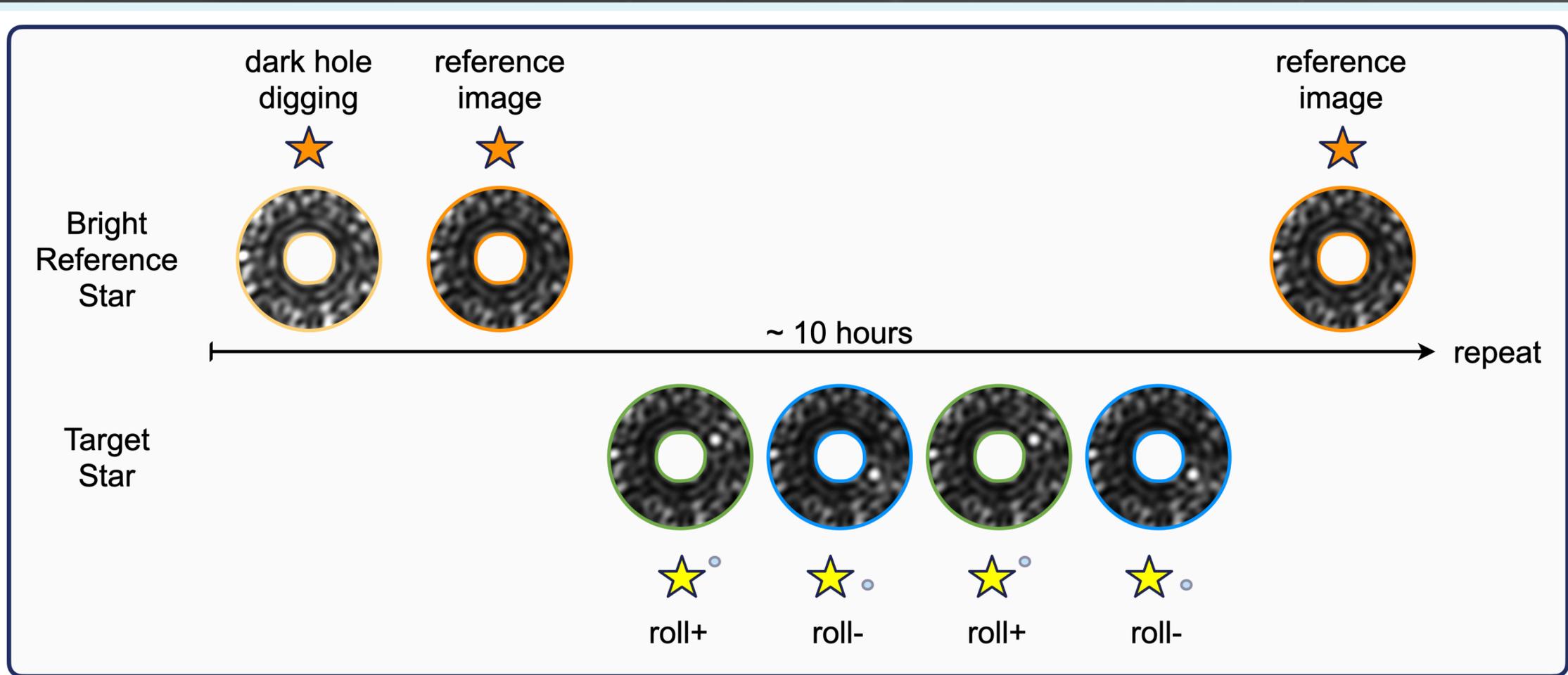
575 nm
Band 1



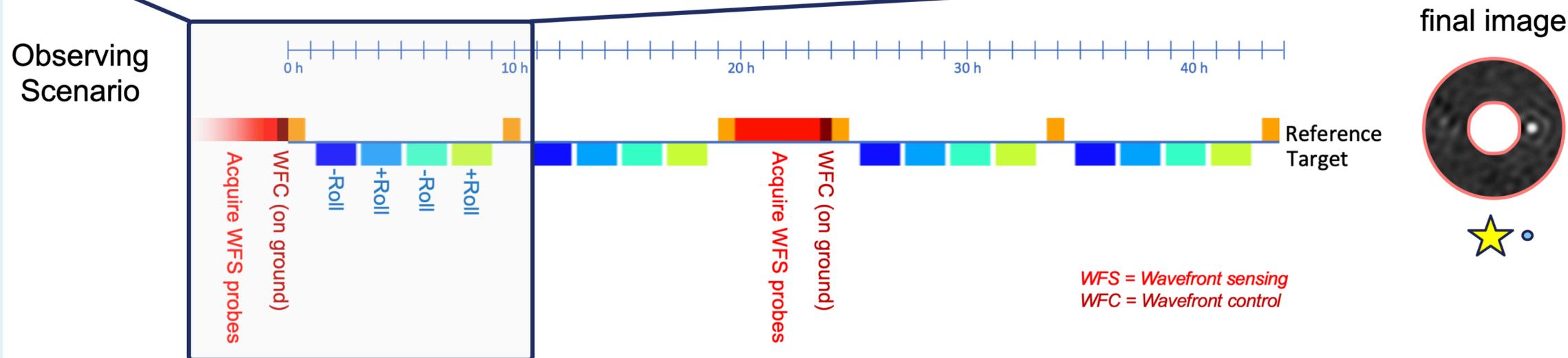
Wavefront Control iterations



TYPICAL OBSERVING SCENARIO



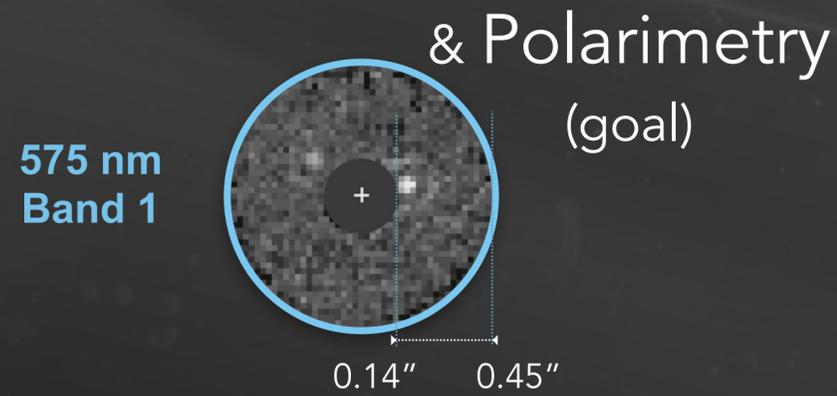
Reflected light planets observations will take several tens of hours



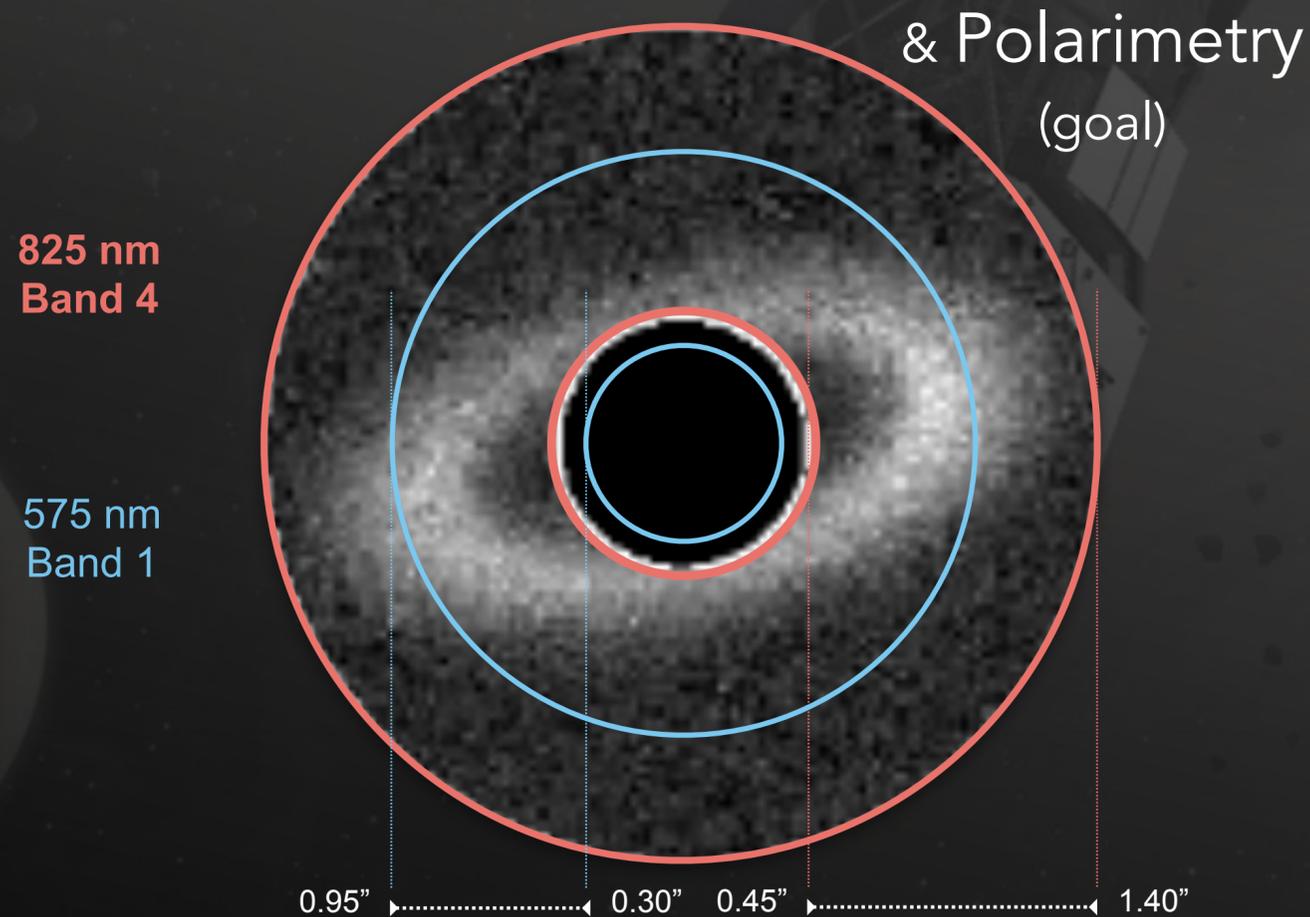


OBSERVING MODES

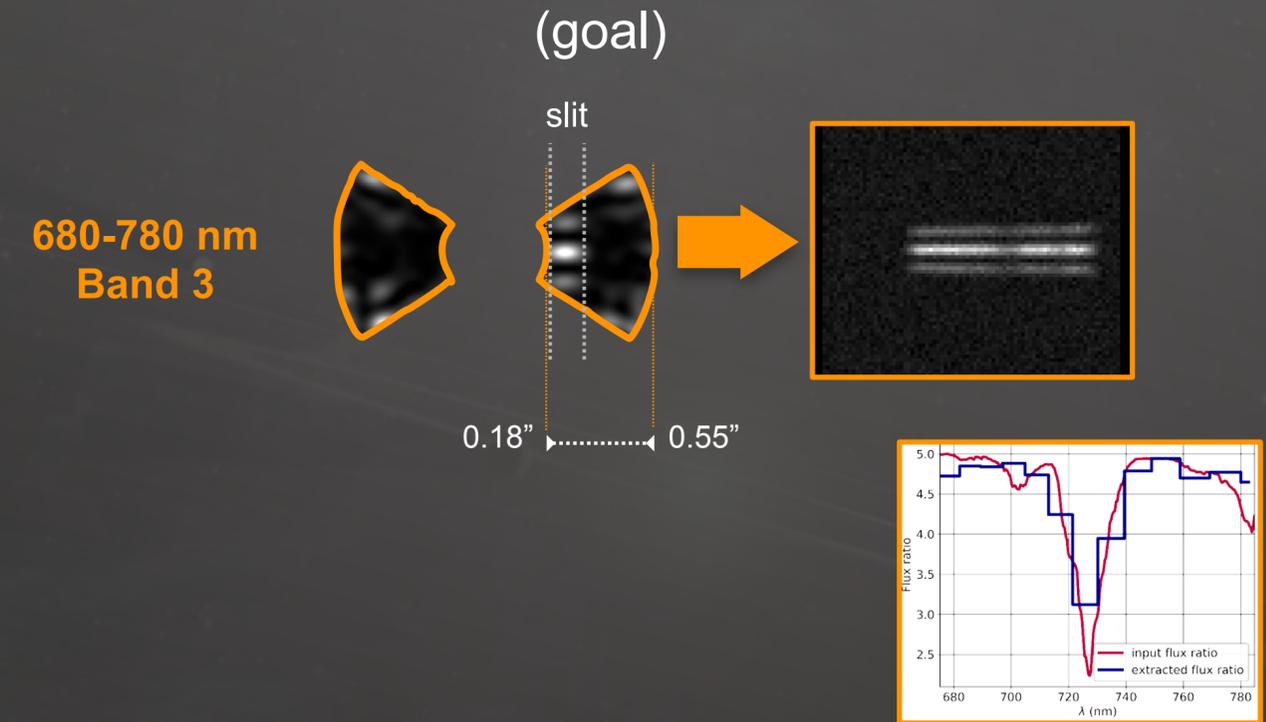
Narrow Field Imaging - HLC
(required)



Wide Field Imaging - SPC
(goal)



Grism Spectroscopy - SPC
(goal)



Methane absorption

Goal modes
are best effort basis

A NECESSARY STEP TOWARDS

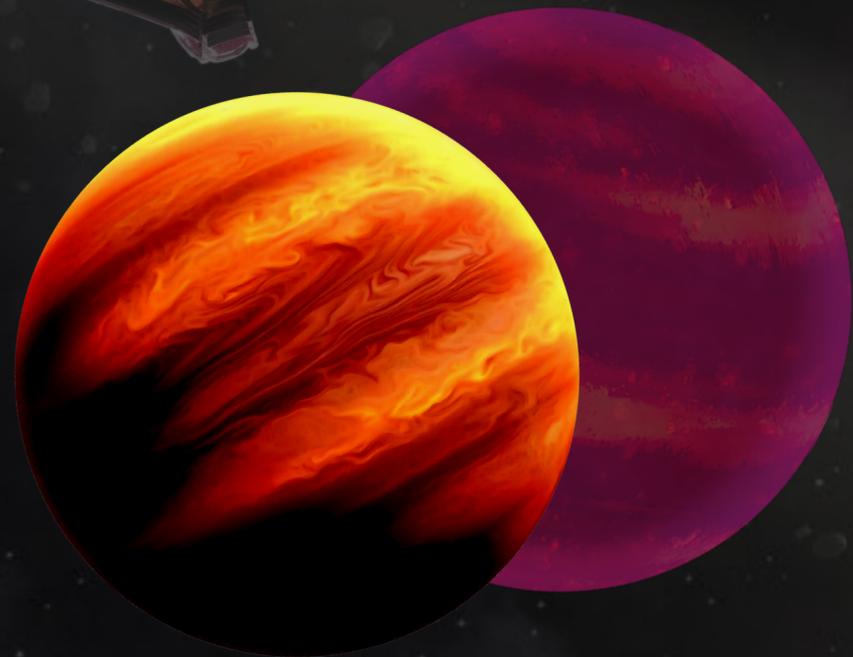




Habitable Worlds OBSERVATORY

DIRECT IMAGING "ROADMAP"

Today



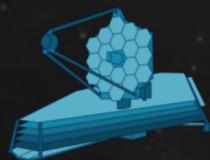
Young giants

emitted light

Ground & Space

NIR / IR + H α

JWST: > 5 μ m



< 2030



Jupiter analogs

reflected light

Space

Optical

Roman Coronagraph

+ Exo
Saturns?
Neptunes?



> 2040



Earth-like

reflected light

Space

Optical

HabWorlds

+ emitted
thermal
light?

IR

LIFE

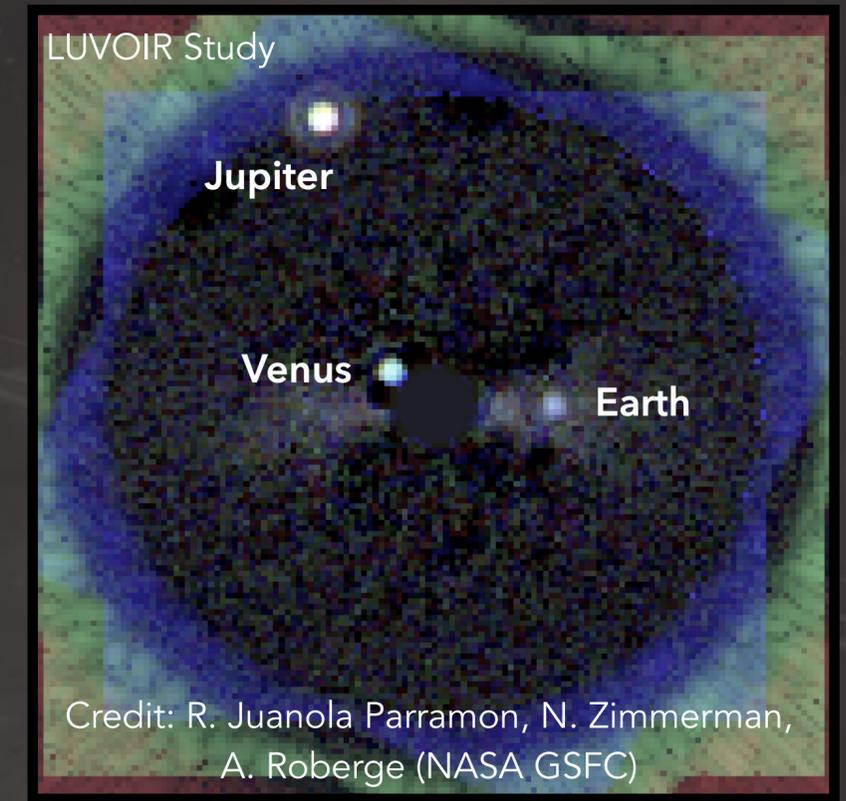
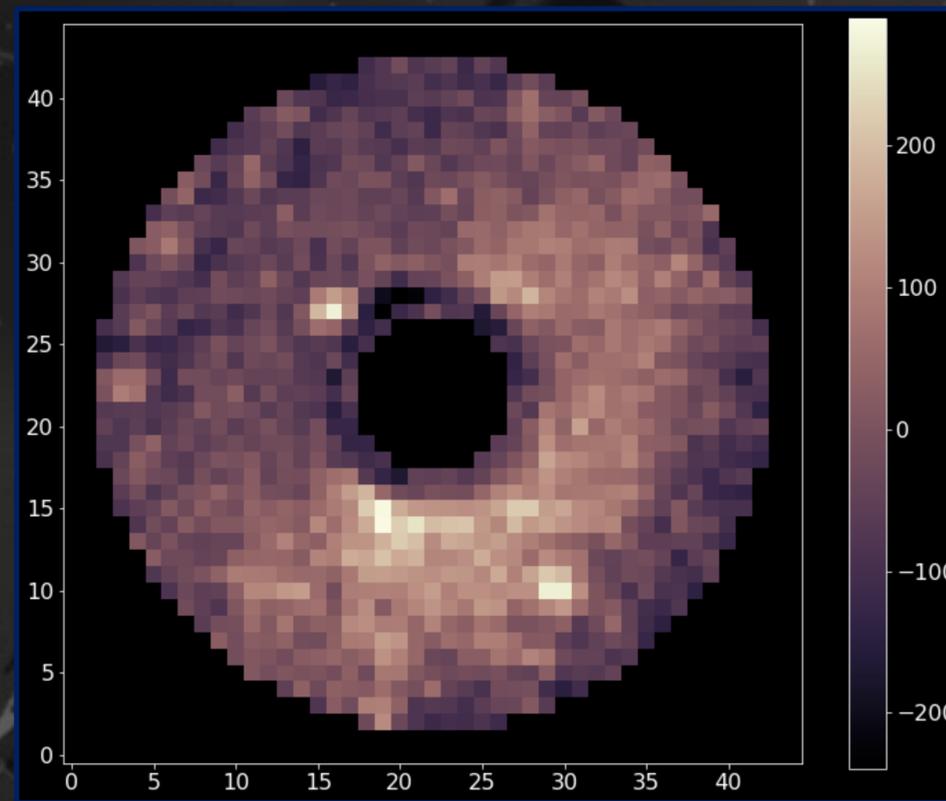
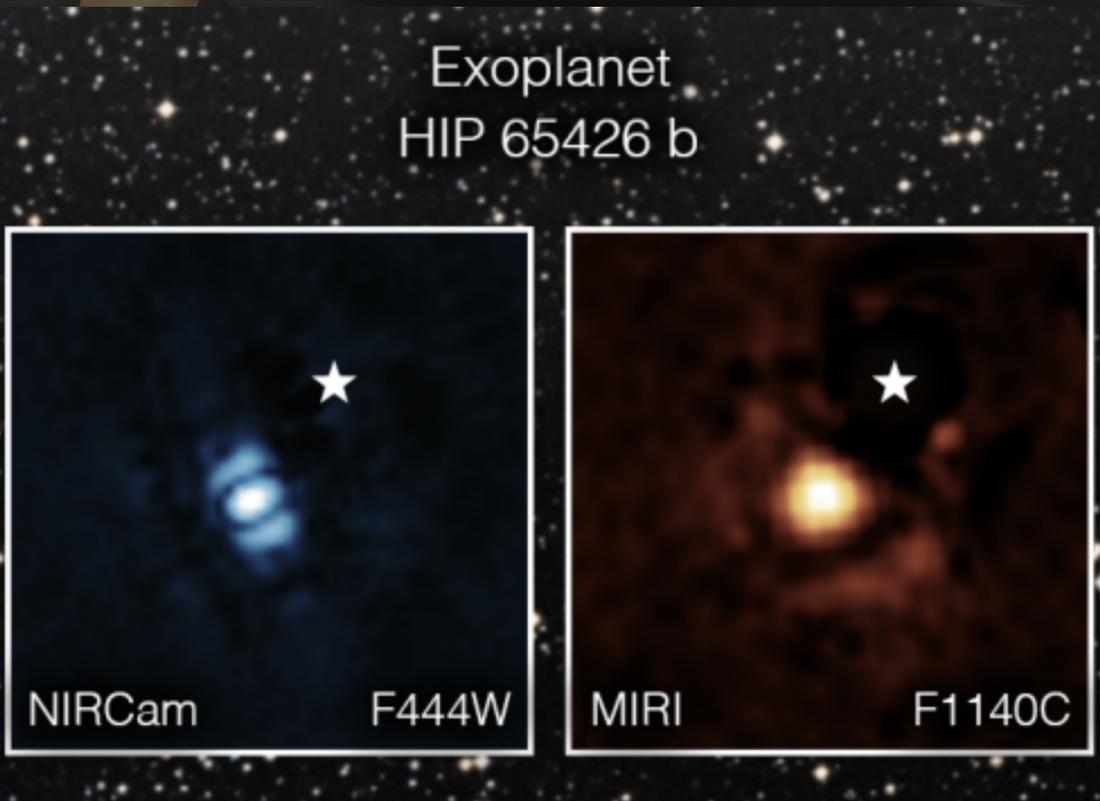


DIRECT IMAGING "ROADMAP"

Today

< 2030

> 2040



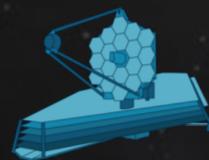
Young giants

emitted light

Ground & Space

NIR / IR + H α

JWST: > 5 μ m



Jupiter analogs

reflected light

Space

Optical

Roman Coronagraph

+ Exo
Saturns?
Neptunes?



Earth-like

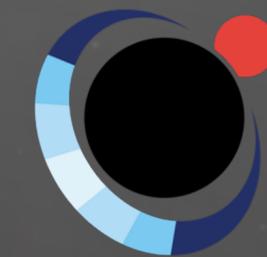
reflected light

Space

Optical

HabWorlds

COMMUNITY PARTICIPATION PROGRAM



Community Participation Program (CPP) \Rightarrow maximize scientific & technical return

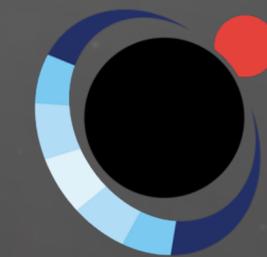
Project teams (JPL, IPAC, GSFC), 15 US PIs, ~100 Project Team members, members international partners (JAXA, CNES, ESA, MPIA)

CPP

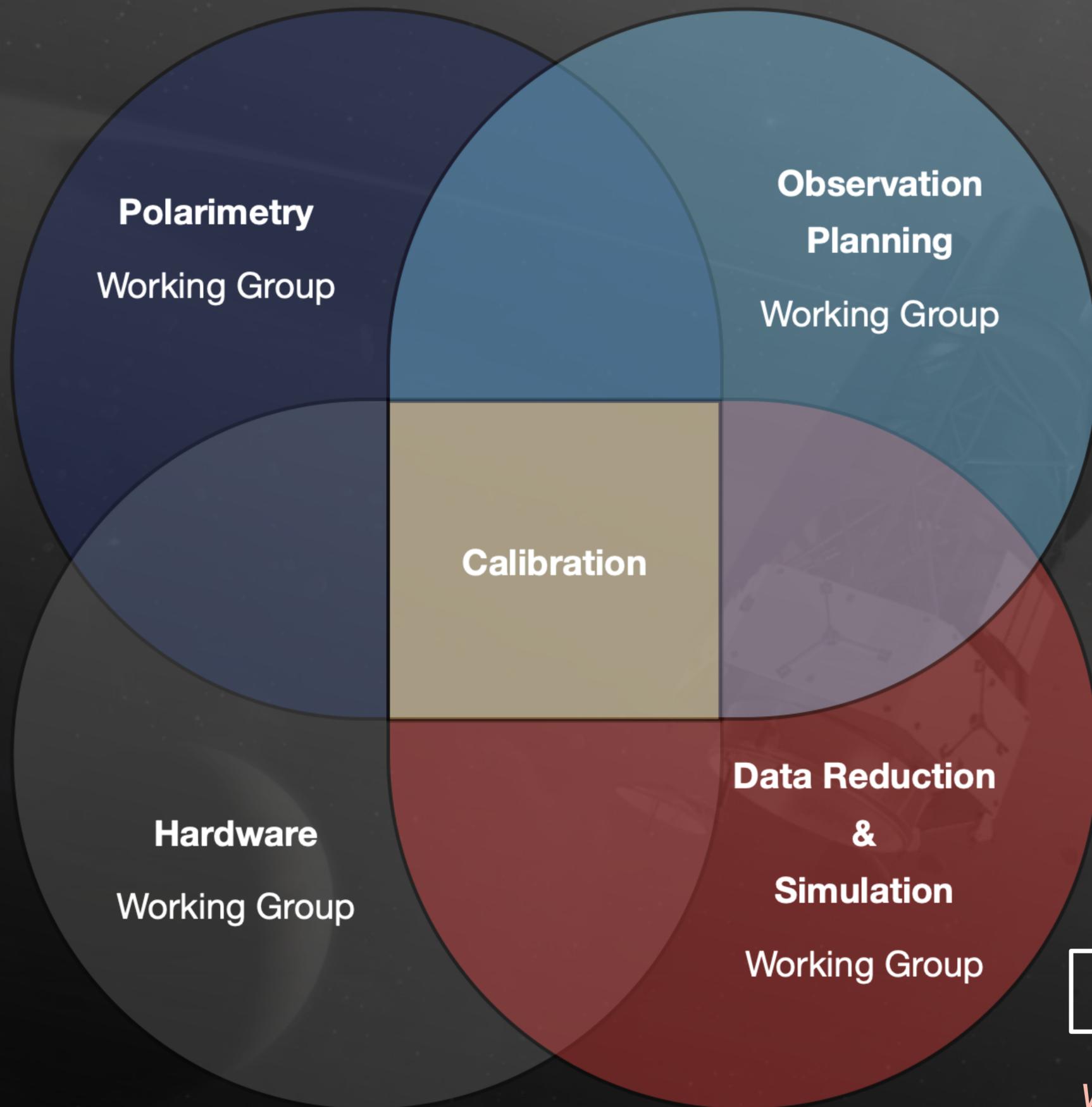


roman.ipac.caltech.edu

www.romancoronagraph.space



CPP



WORKING GROUPS

Schuyler Wolff will talk more about that

www.romancoronagraph.space

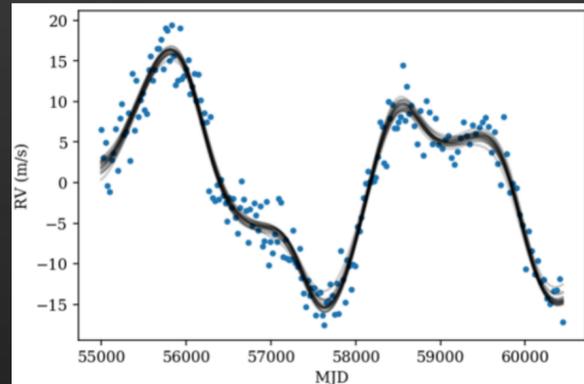
PREPARING FOR ON-SKY OBSERVATIONS



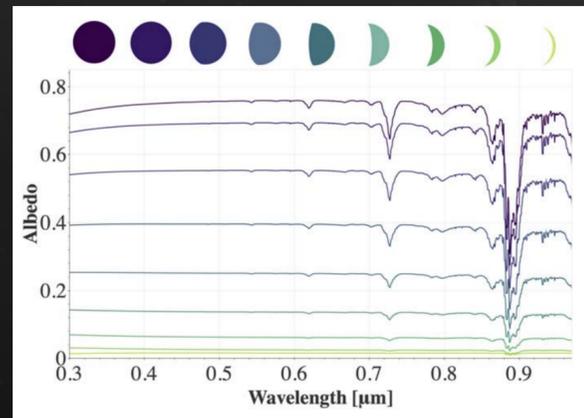
CPP

Launch window this fall 2026, operations early 2027!

Formal commitment is May 2027 but we are ahead of schedule!



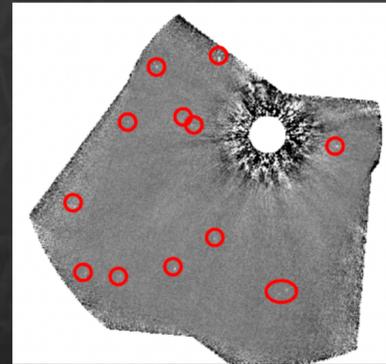
Identifying optimal science targets
across the sky



Plan and simulate observing sequences
develop necessary tools

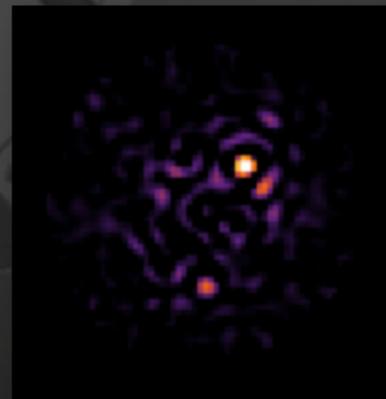


Plan the ~2,200 hour observing program
During 18 months



Target vetting & precursor observations

Vet for binaries & background objects and measure stellar radii

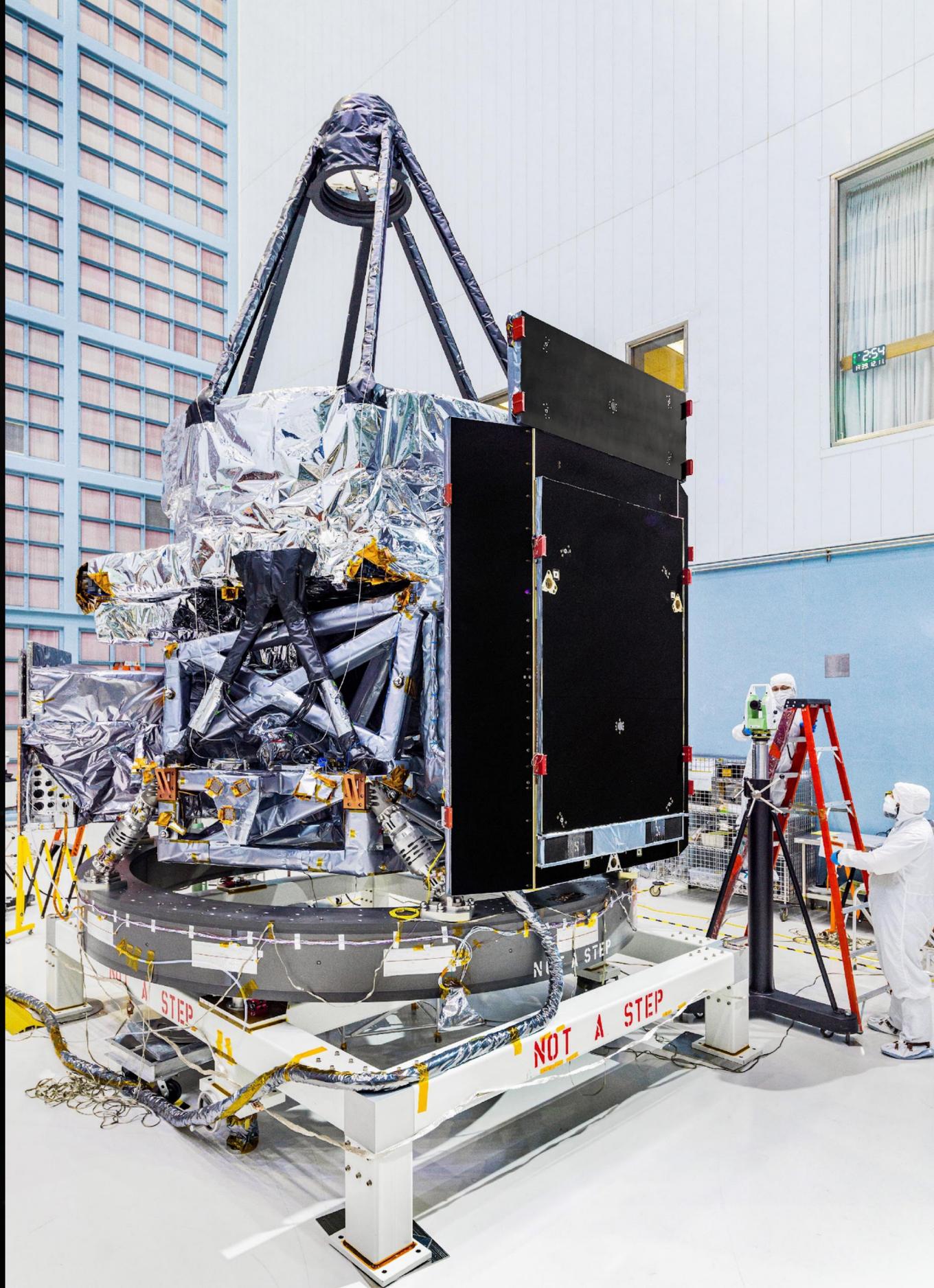


Develop the Data Reduction Pipeline

Analysis and calibrations

Schuyler Wolff will talk more about that

www.romancoronagraph.space



ROMAN CORONAGRAPH STATUS



Has matured multiple key technologies
to lay foundation for HWO

Was delivered to GSFC in May
and integrated in December (2024)

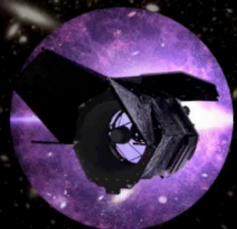
Testing demonstrated performance
at least 4x beyond requirement

+ dark hole in one additional "best effort" mode

Outlook improving for some use
of one or more "best effort" modes on sky

On track for science operations in **2027**

MORE PHOTOS



NASA's Nancy Grace Roman Space Telescope

PRO

NASA's Nancy Grace Roman Space Tel...

26 Followers • 7 Following



211 Photos

Joined 2022

About

Photostream

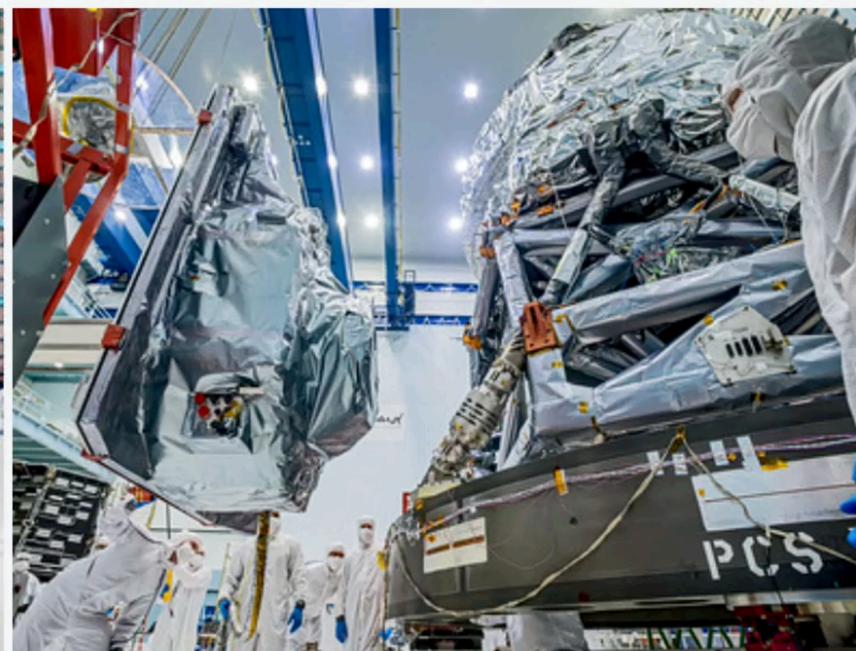
Albums

Faves

Galleries

Groups

Date uploaded ▾



> 1,600 people have helped create the Roman Coronagraph!!!



MORE INFORMATION



Coronagraph Primer

roman.ipac.caltech.edu

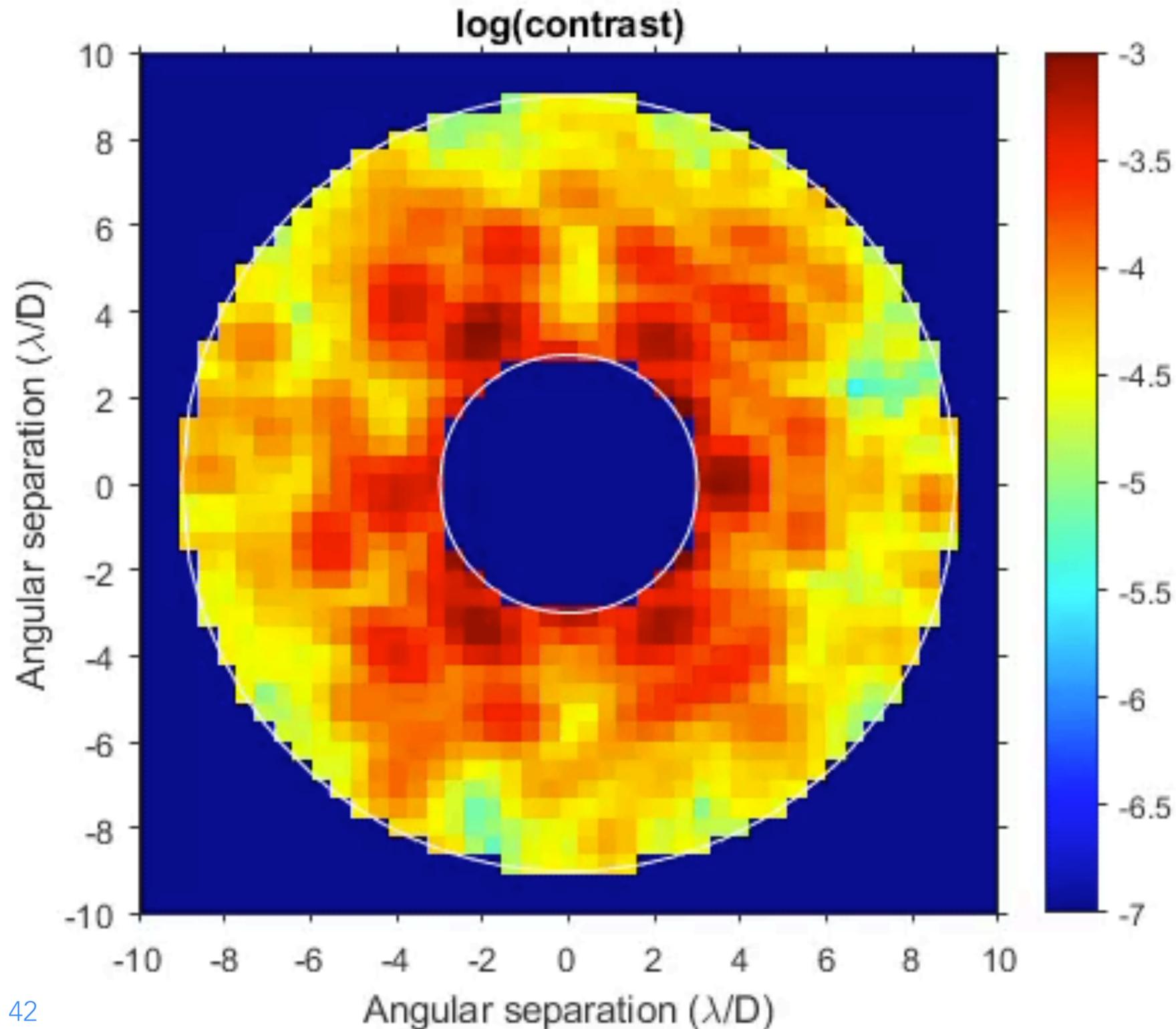
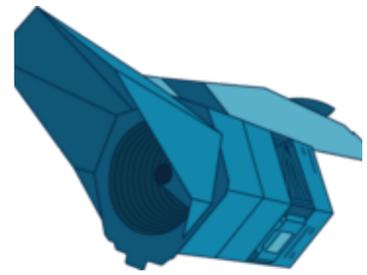
www.romancoronagraph.space

EXTRA SLIDES





LAB/TVAC DARK HOLE DIGGING



Real (TVAC) Band1 data
acquired at JPL in March 2024

Preliminary raw contrast
(pending better calibration)
 $\sim 10^{-8}$ at 6 to 9 λ/D

It's working beyond TTR5

Calibrations can improve

A FEW YEARS AGO

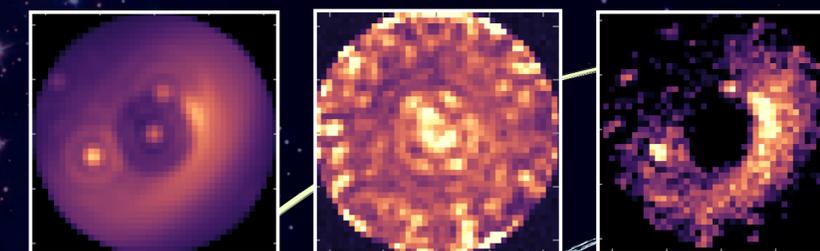
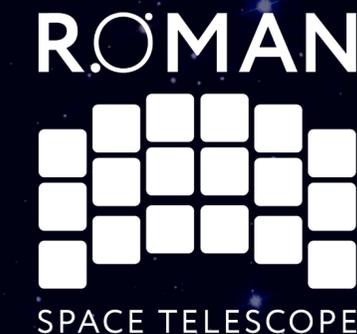


~ 2018-2021

EXOPLANET IMAGING

COMMUNITY

DATA CHALLENGE

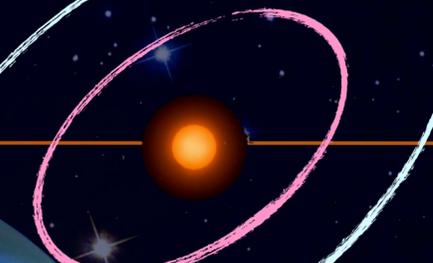
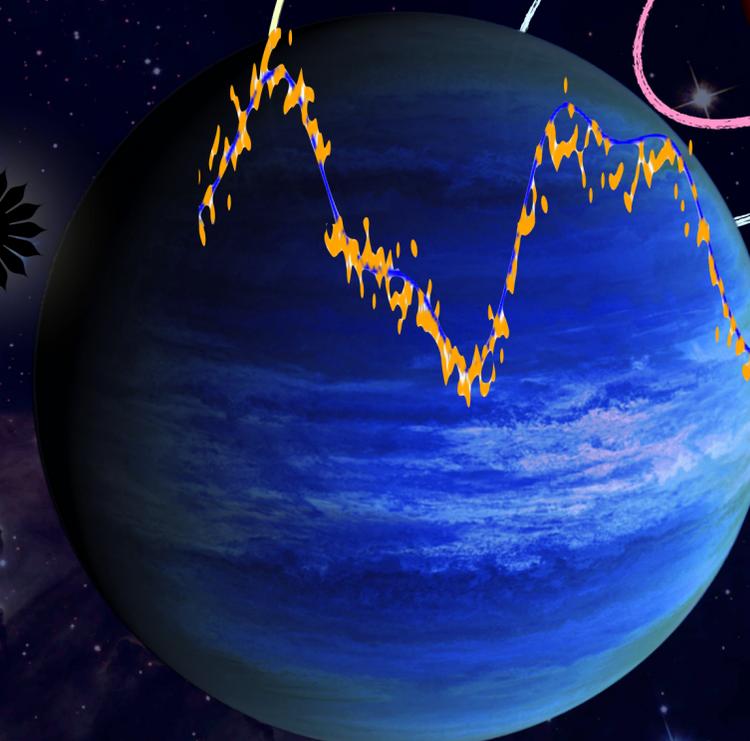
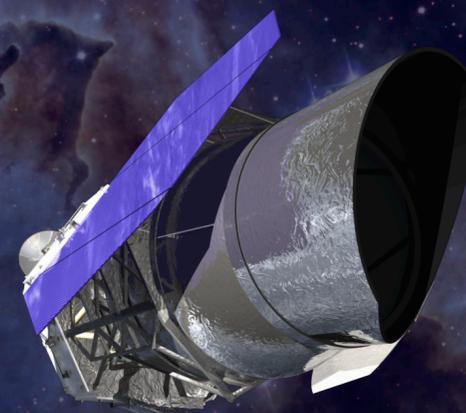


www.exoplanetdatachallenge.com

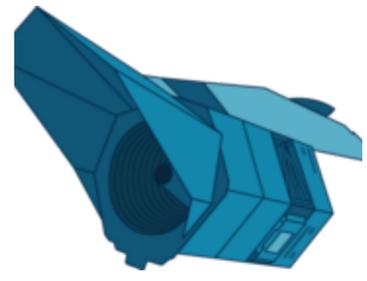
Julien Girard & Turnbull SIT

 @djulik

STScI Liaison for the Coronagraph Instrument



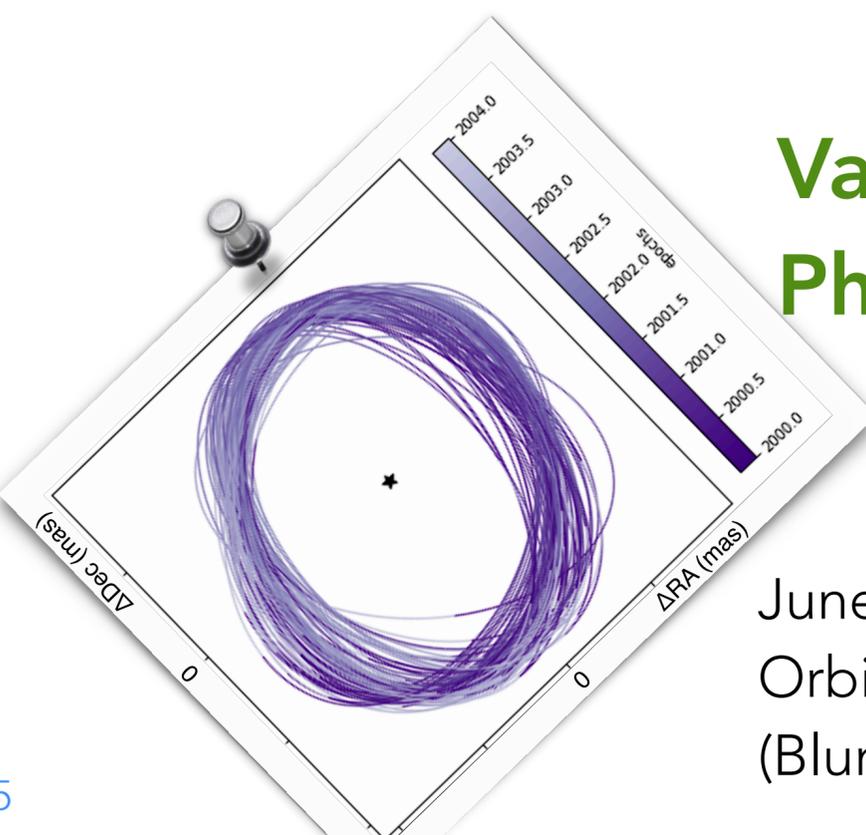
ROMAN EXOPLANET IMAGING DATA CHALLENGE



- **6 imaging epochs** of the same target throughout mission: 47 UMa
- 3 planet with matching and realistic **radial velocity data**
- Extract sources, compute relative photometry & astrometry, disentangle from background sources, exozodiacal light
- Compute orbital solution using all the information available

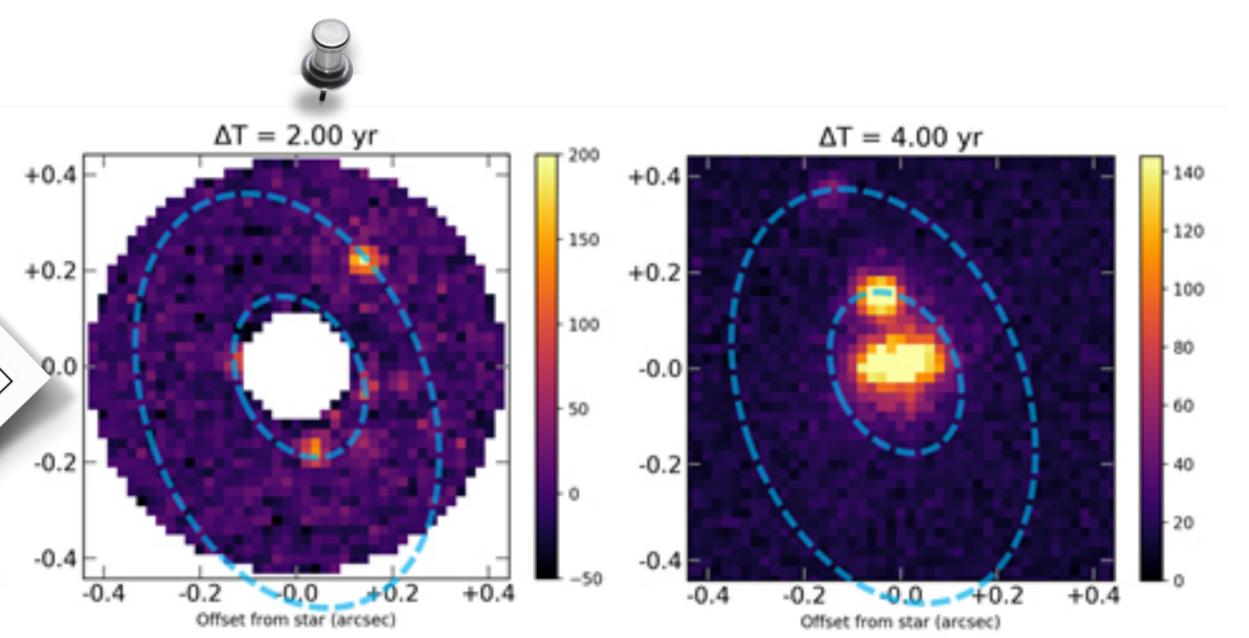
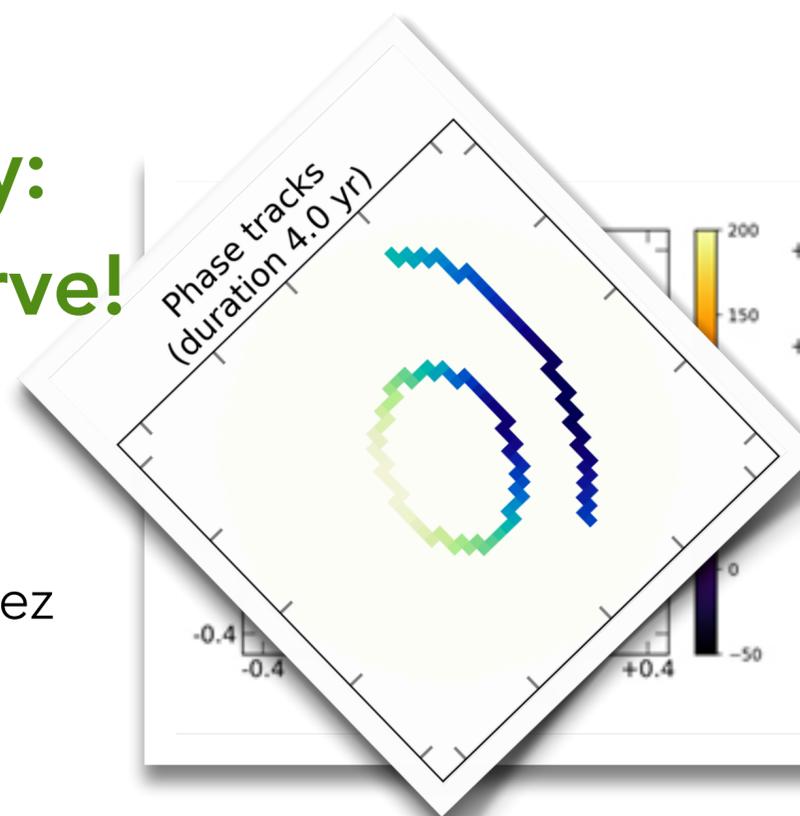


www.exoplanetdatachallenge.com

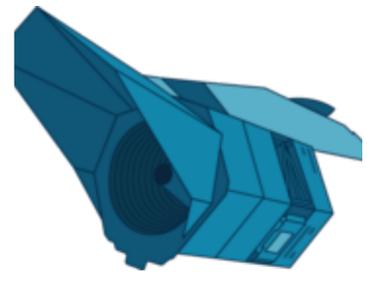


Variability:
Phase curve!

Junellie Gonzalez
Orbitize/OFTI
(Blunt 2017)



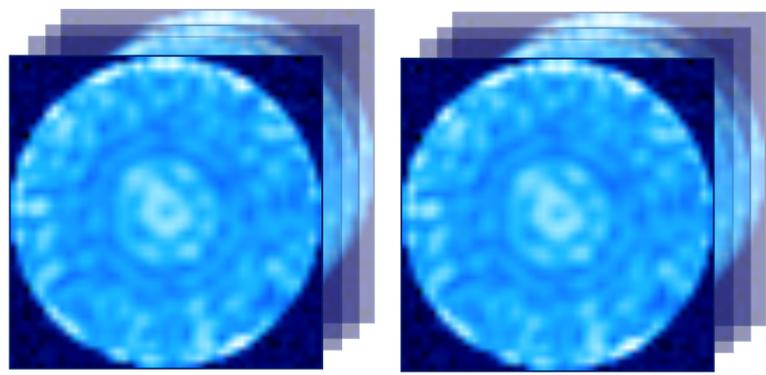
THE ROMAN EXOPLANET IMAGING DC: 4 STEPS



DATA

6 imaging epochs throughout the mission

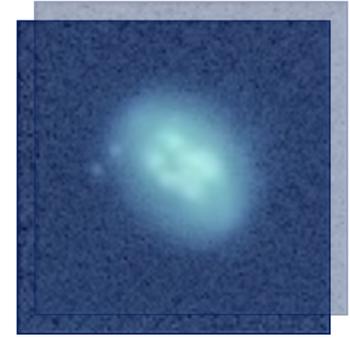
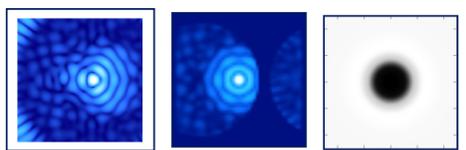
Realistic simulations: OS6 Speckle field time series, detector model, background contamination sources, exozodiacal light



Hybrid Lyot Coronagraph

4 epochs, 2 rolls

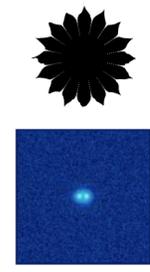
+ Calibrations



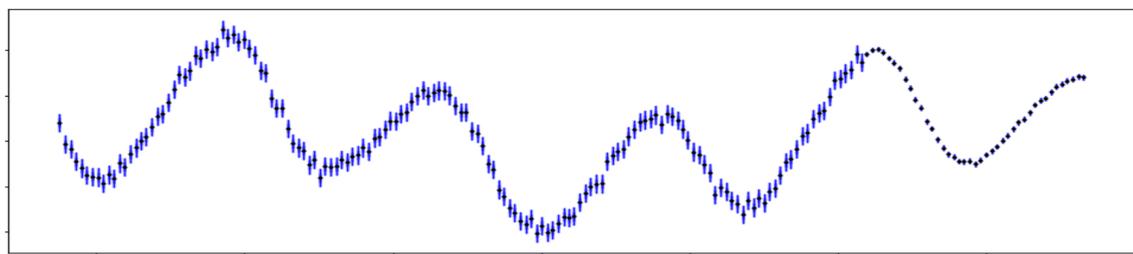
Star Shade

2 epochs

+ Calibrations

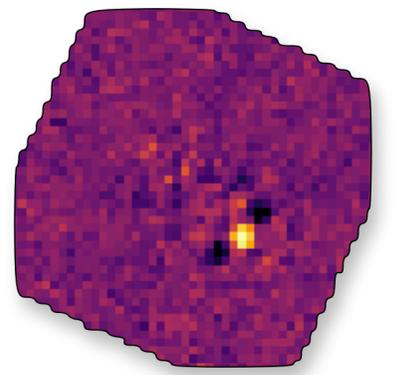


& 15 years of precursor RV data

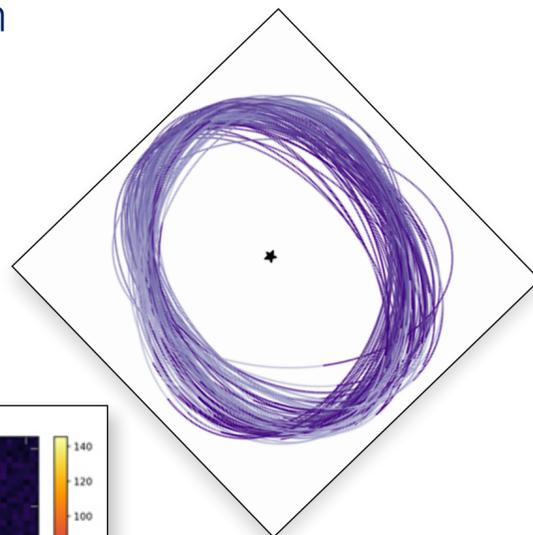


CHALLENGE

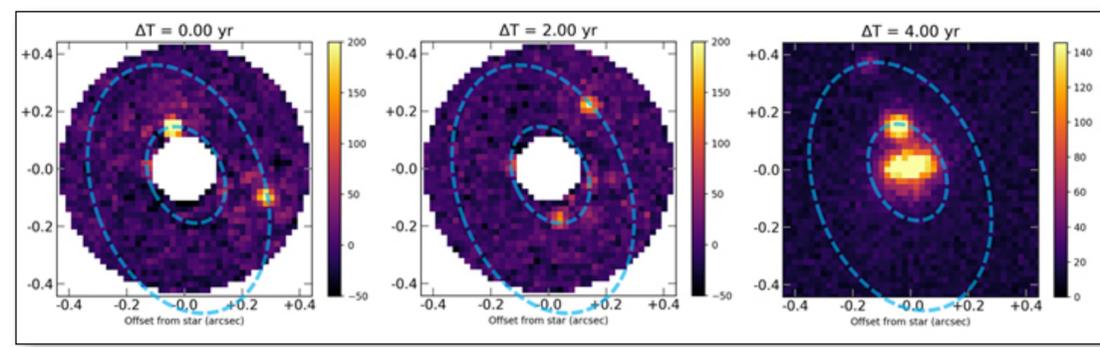
1. **Extract & identify point sources** in 4 HLC epochs, disentangle from background sources, provide **census and rough astrometry**



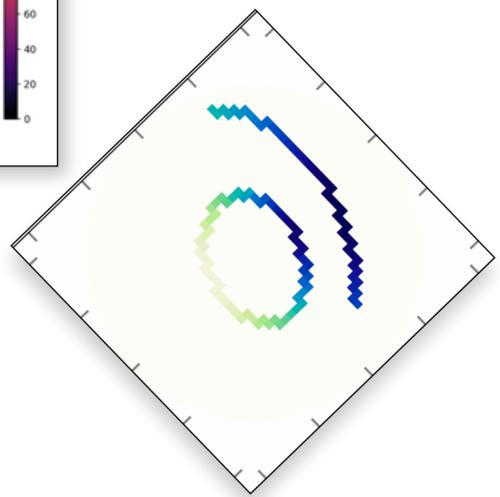
2. **Compute orbital parameters & masses** with those 4 epochs, use **priors from RV data**



3. **Refine orbital parameters & masses** using additional 2 SS epochs, all the information available

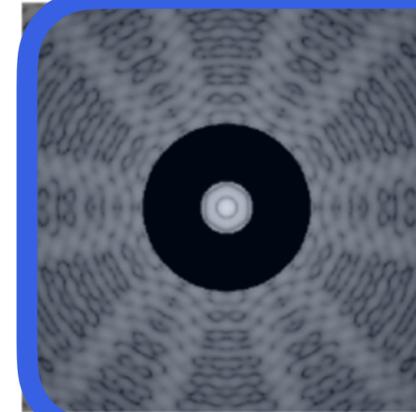
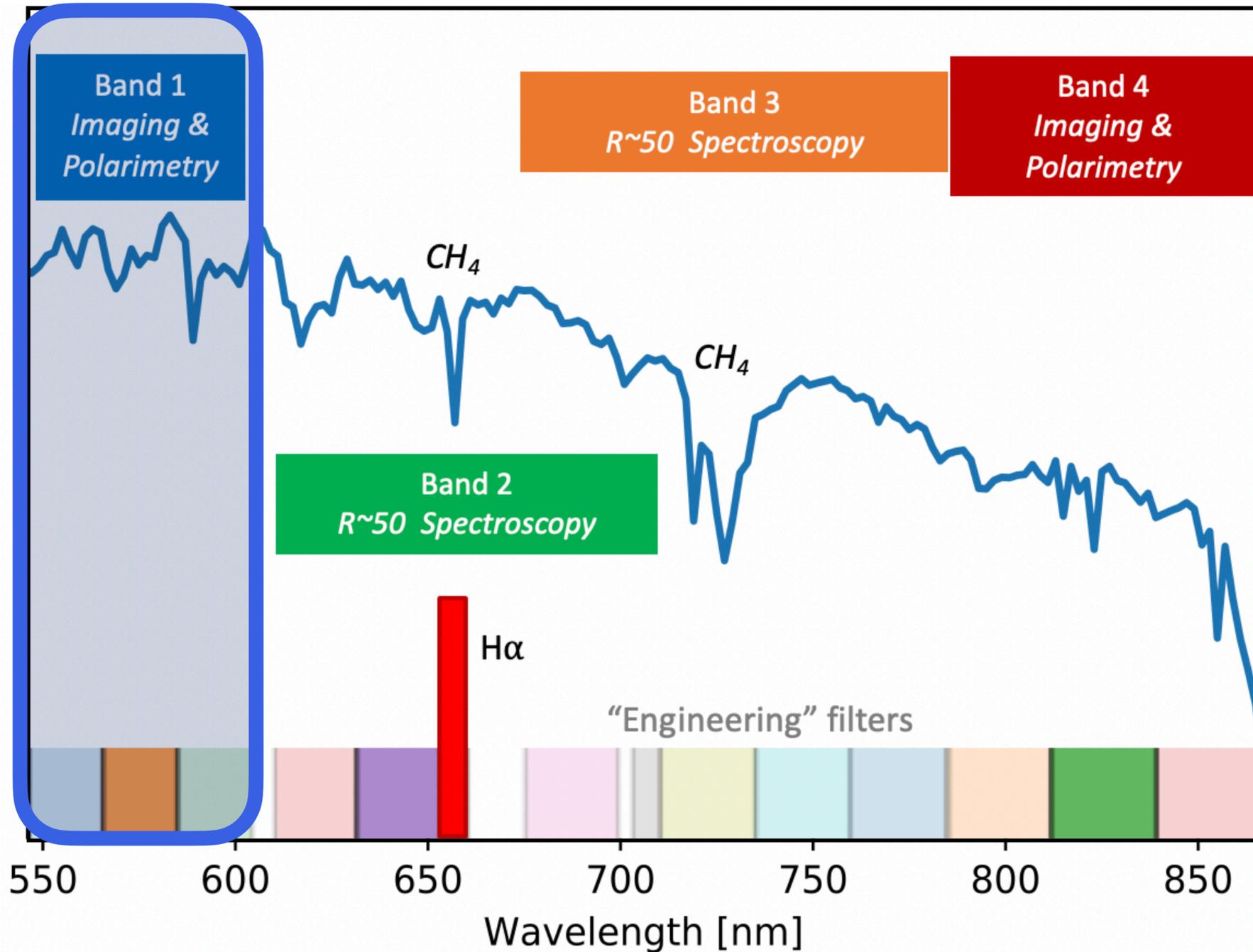
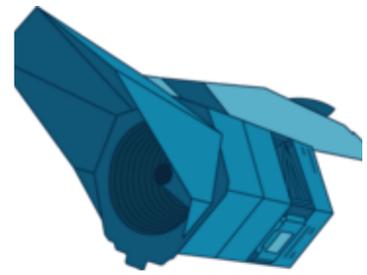


4. For a given planet, measure the **phase curve** assuming it is Lambertian, provide **radius & albedo** given mass-radius relationship



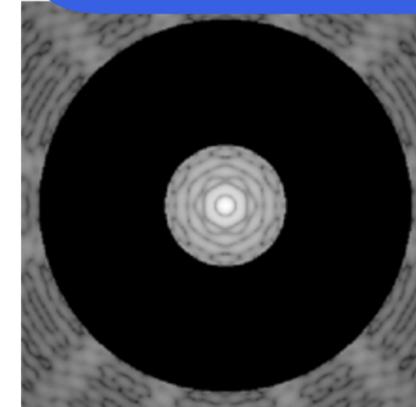


ROMAN CORONAGRAPH DC MODES



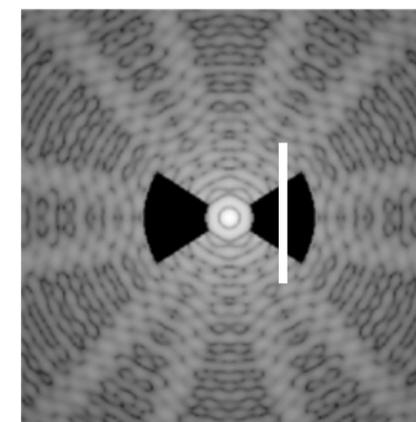
Narrow field of view mode

Full 360 deg
Inner working angle (IWA): $3 \lambda/D$ (0.15")
Outer working angle (OWA): $9 \lambda/D$ (0.45")
Band 1: 575 nm, 10.1% bandwidth



Wide field of view mode

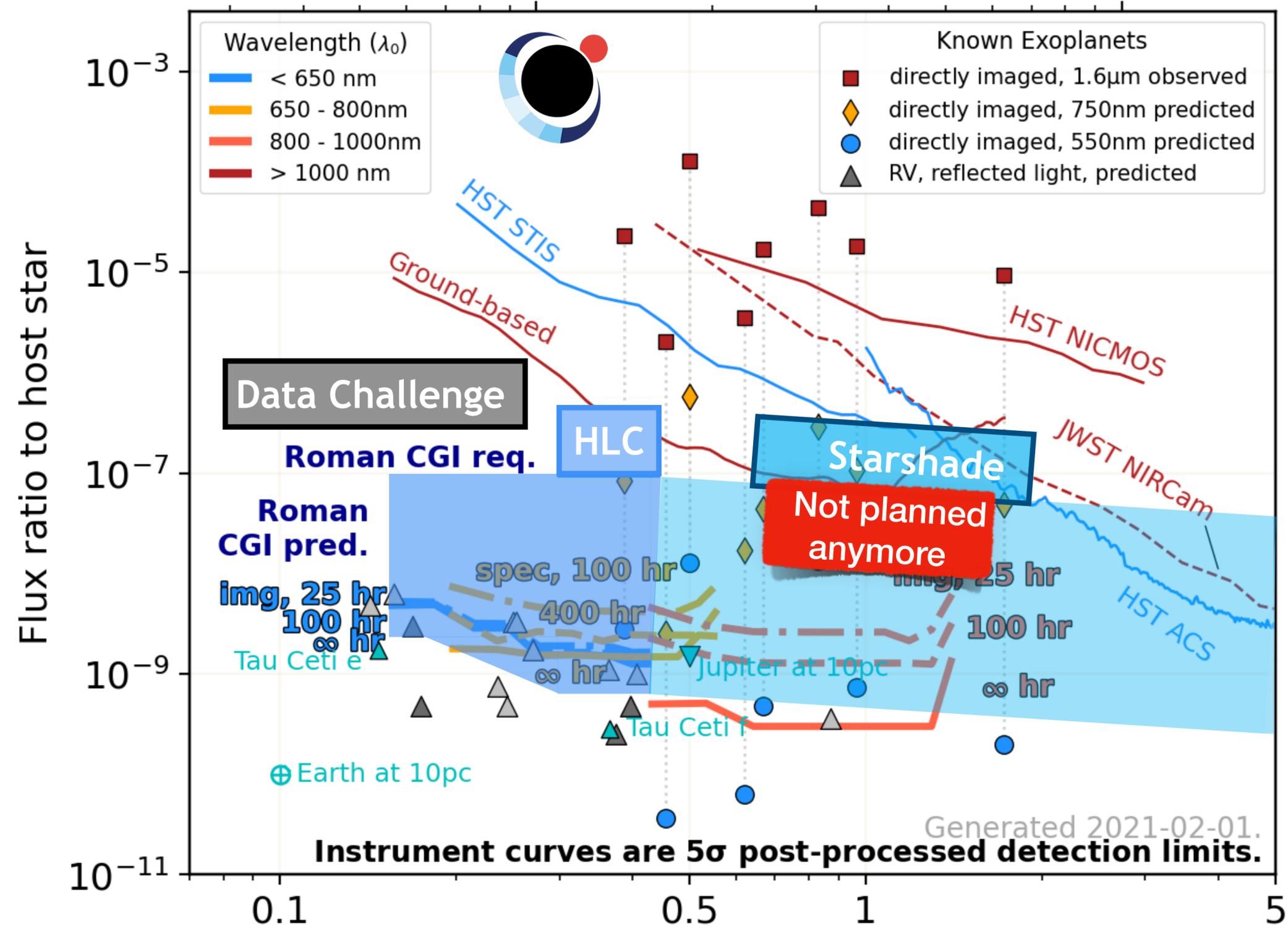
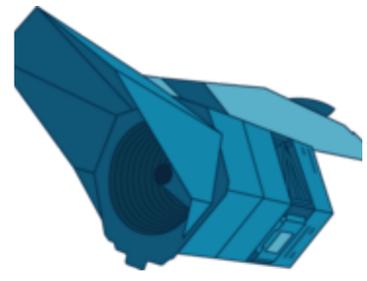
Full 360 deg
IWA: $6.5 \lambda/D$ (0.43")
OWA: $20 \lambda/D$ (1.45")
Band 4: 825 nm, 9.9% bandwidth



Spectroscopy mode

Prism+ slit
Band 3: 730 nm, 16.7% bandwidth

ROMAN EXOPLANET IMAGING DATA CHALLENGE



For $5 < V < 6$ stars

The expected contrast is
< 10^{-7} (required)
 $\sim 10^{-9}$ (predicted)

100 to 1,000 times better than current facilities. Optimistically, image "Jupiters" to "Neptunes" @ 10-50pc in reflected light!