KU ExoLab

Exploring Exoplanets

Yoni Brande

jbrande@ku.edu

@YoniAstro

Fernbank Science Center

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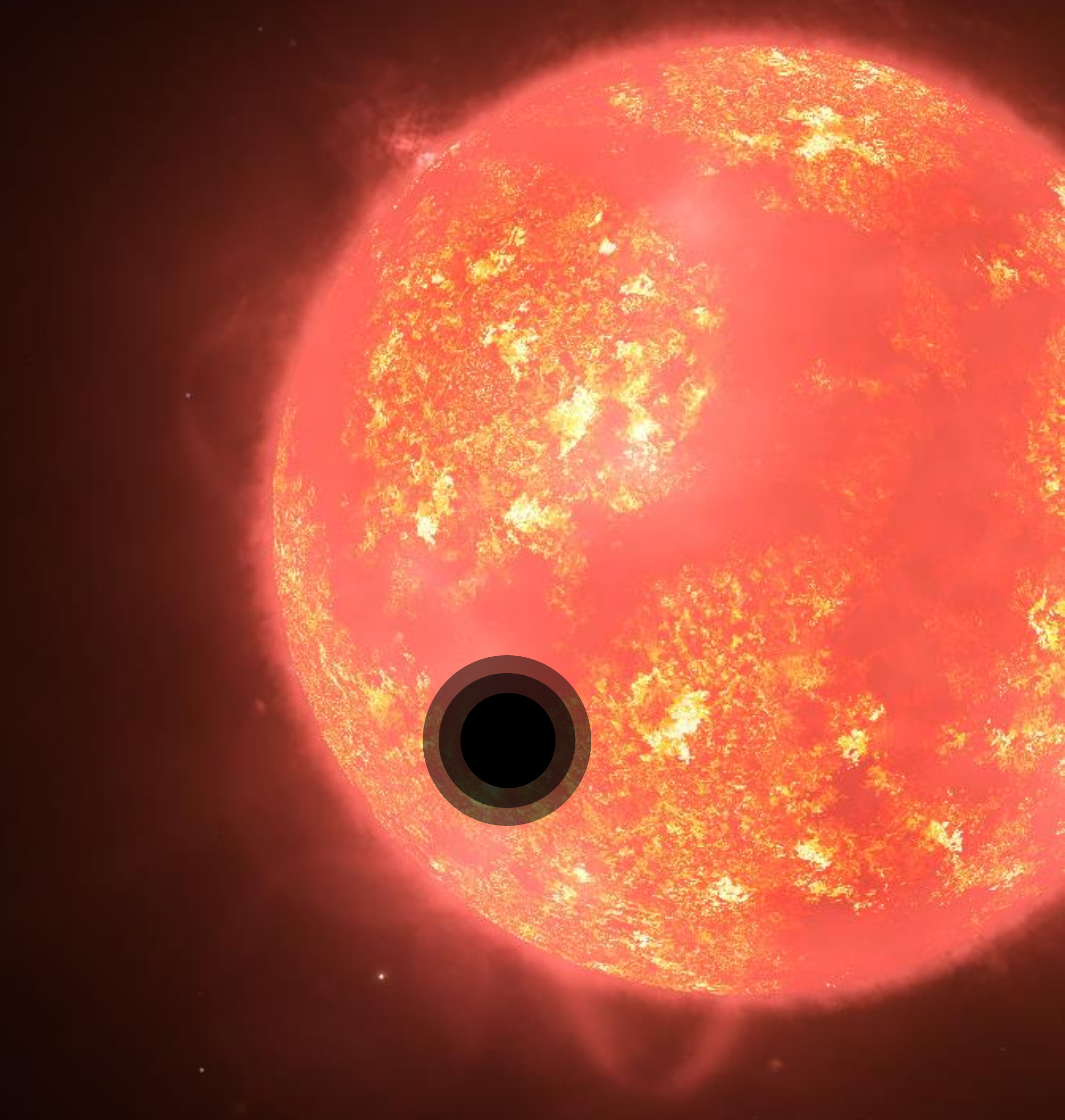
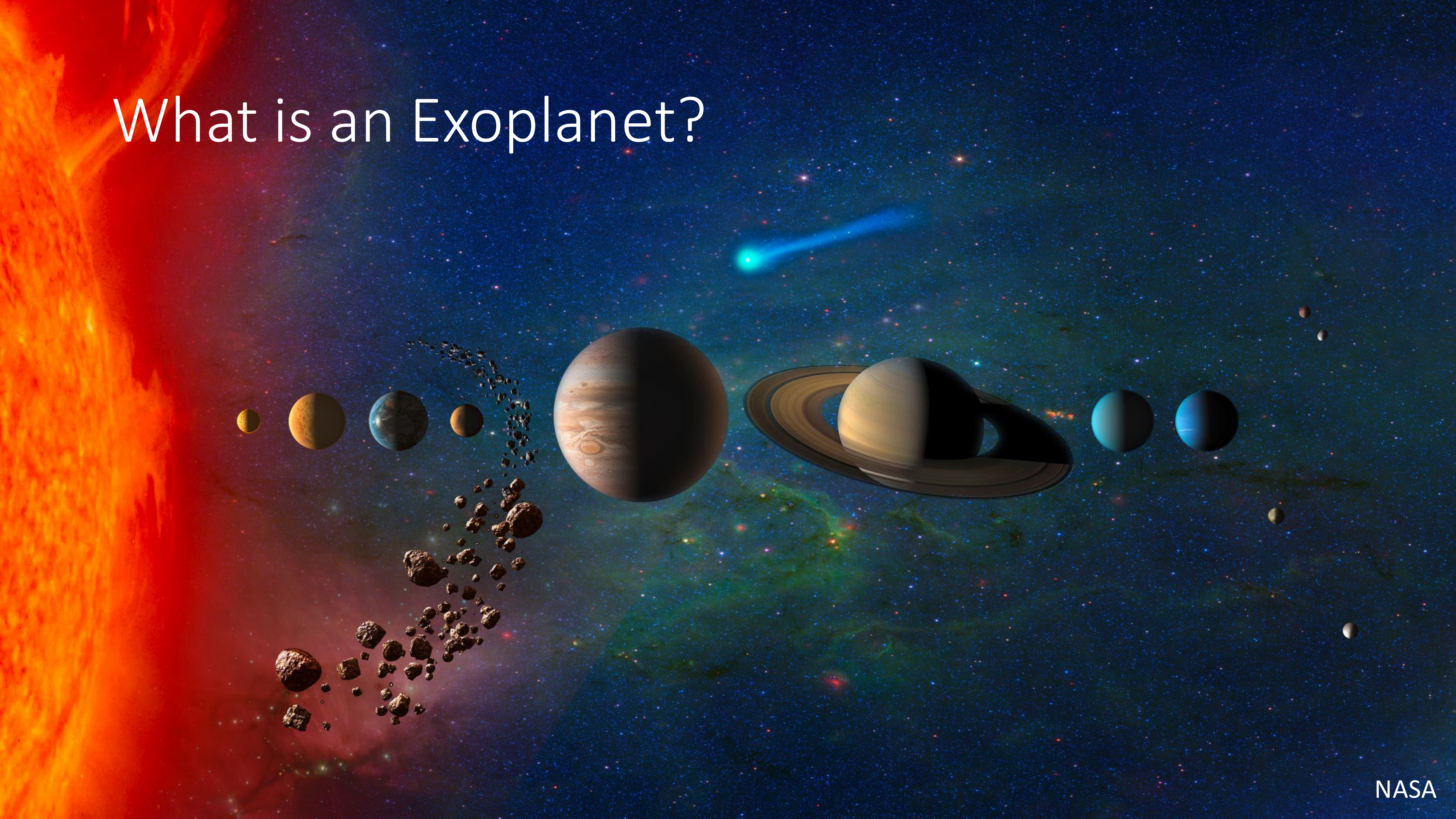
KU Department of Physics and Astronomy

College of Liberal Arts & Sciences



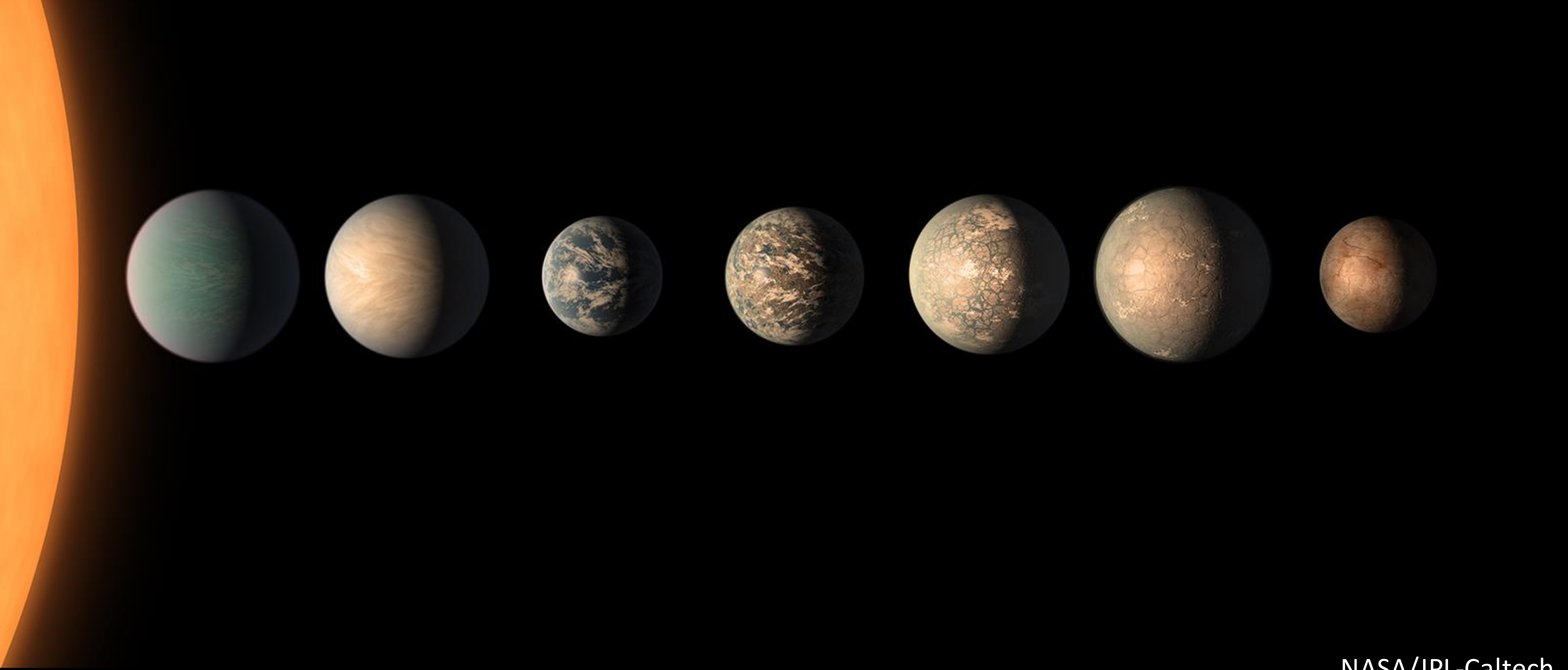
Elite Dangerous, Frontier Developments

What is an Exoplanet?



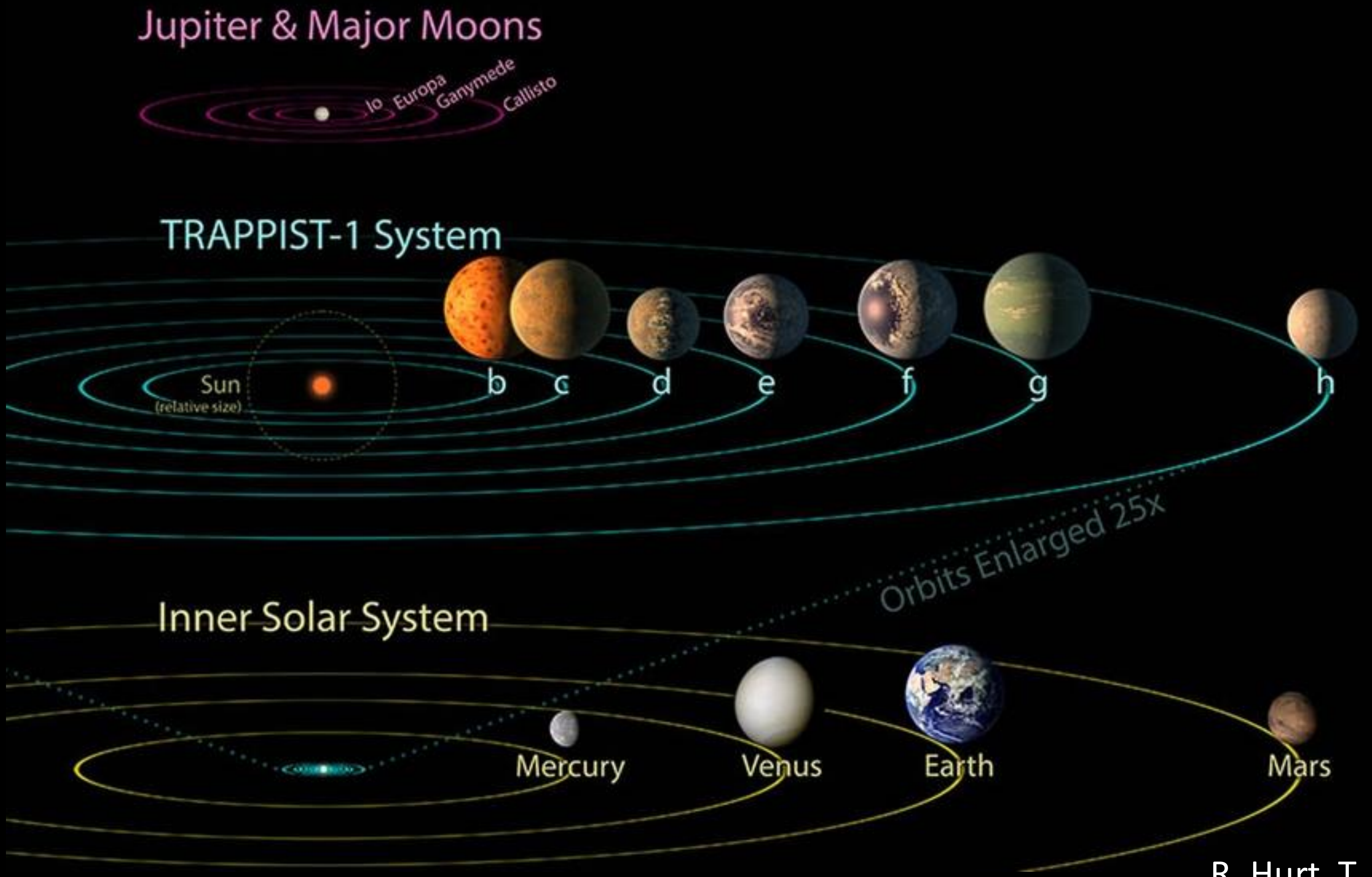
NASA

What is an Exoplanet?



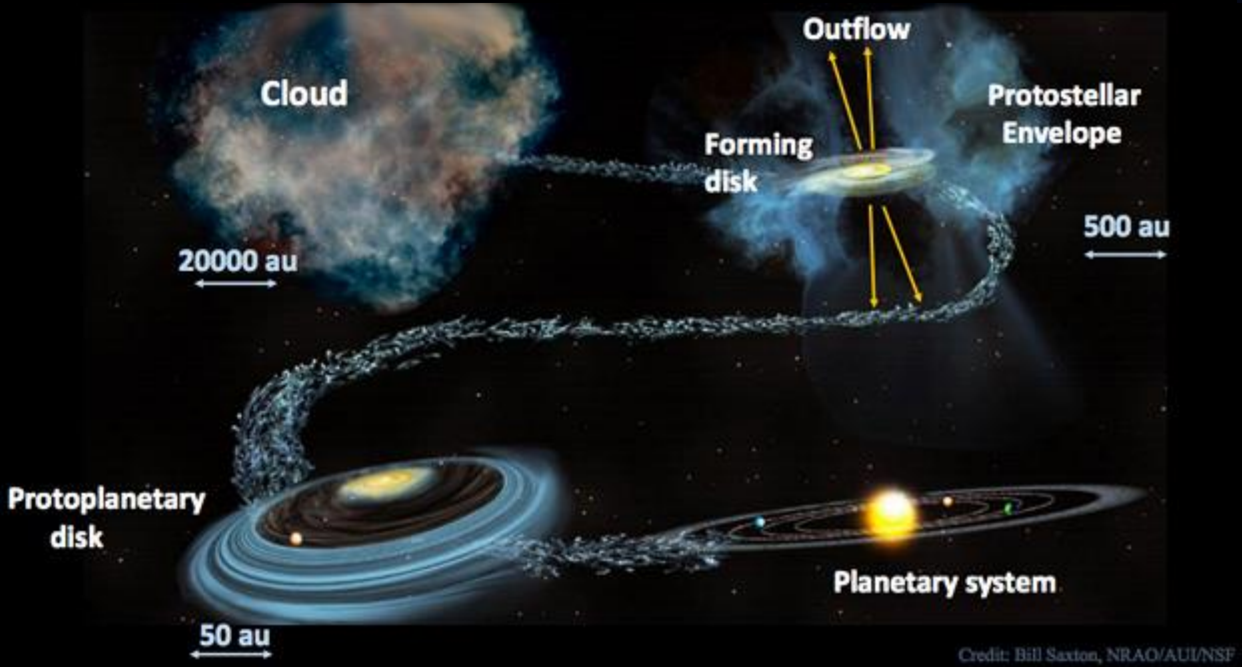
NASA/JPL-Caltech

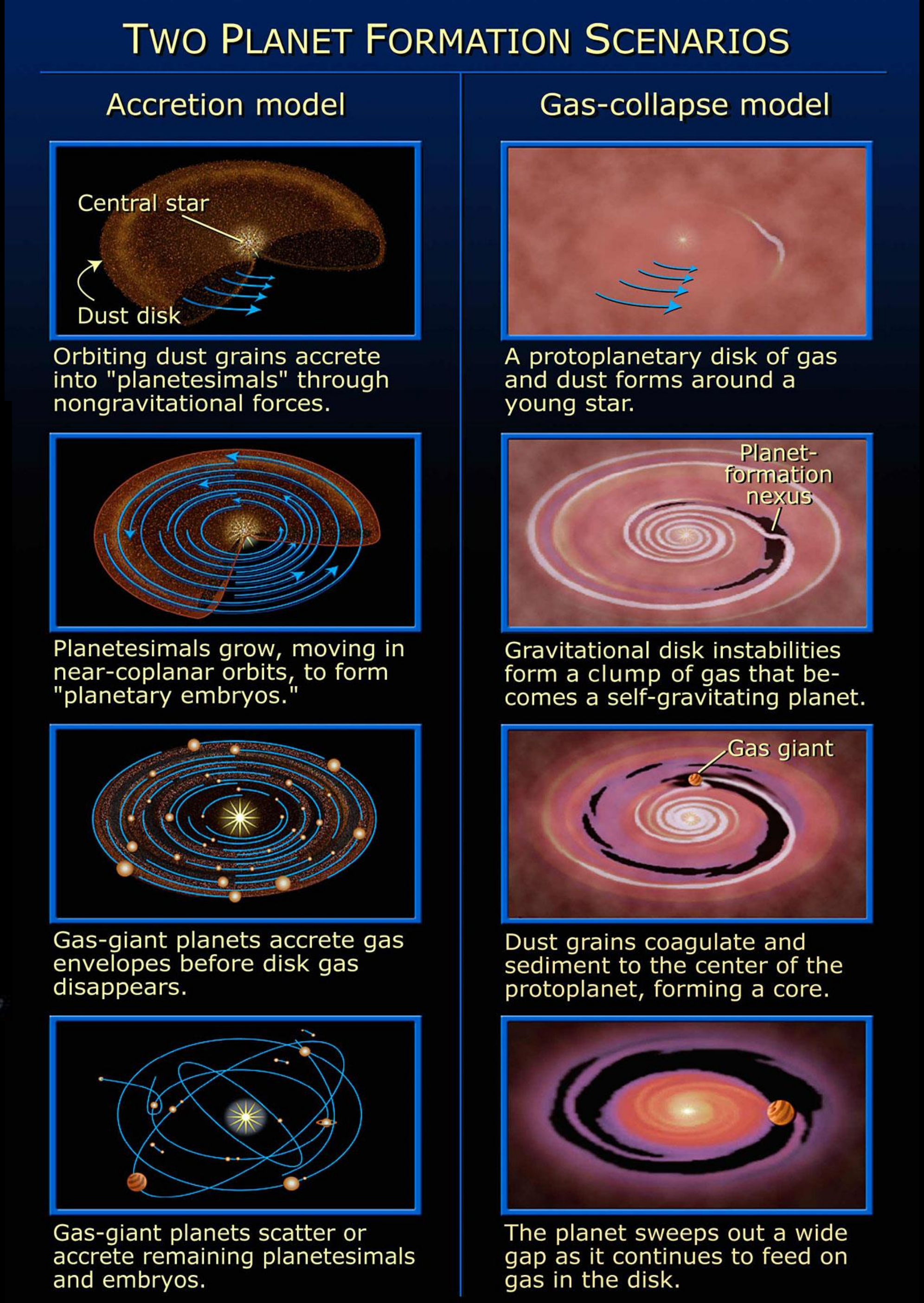
What is an Exoplanet?



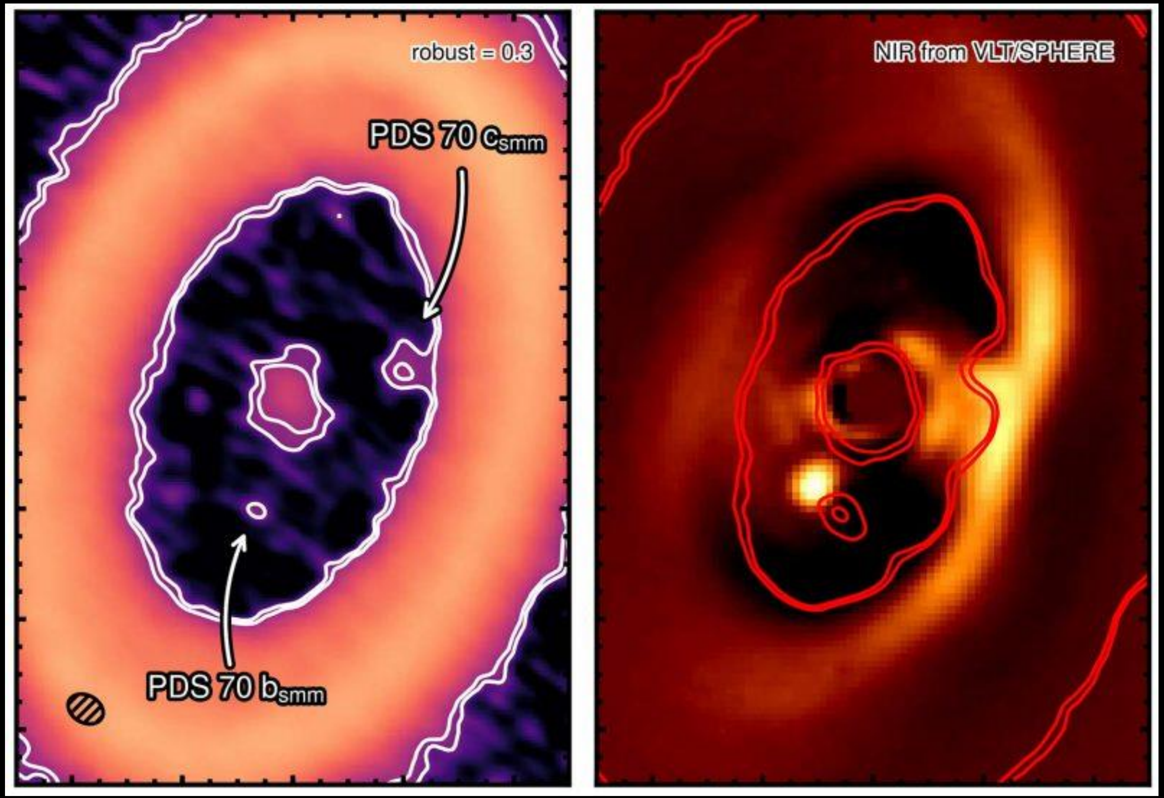
R. Hurt, T. Pyle/NASA JPL-Caltech

Planet Formation



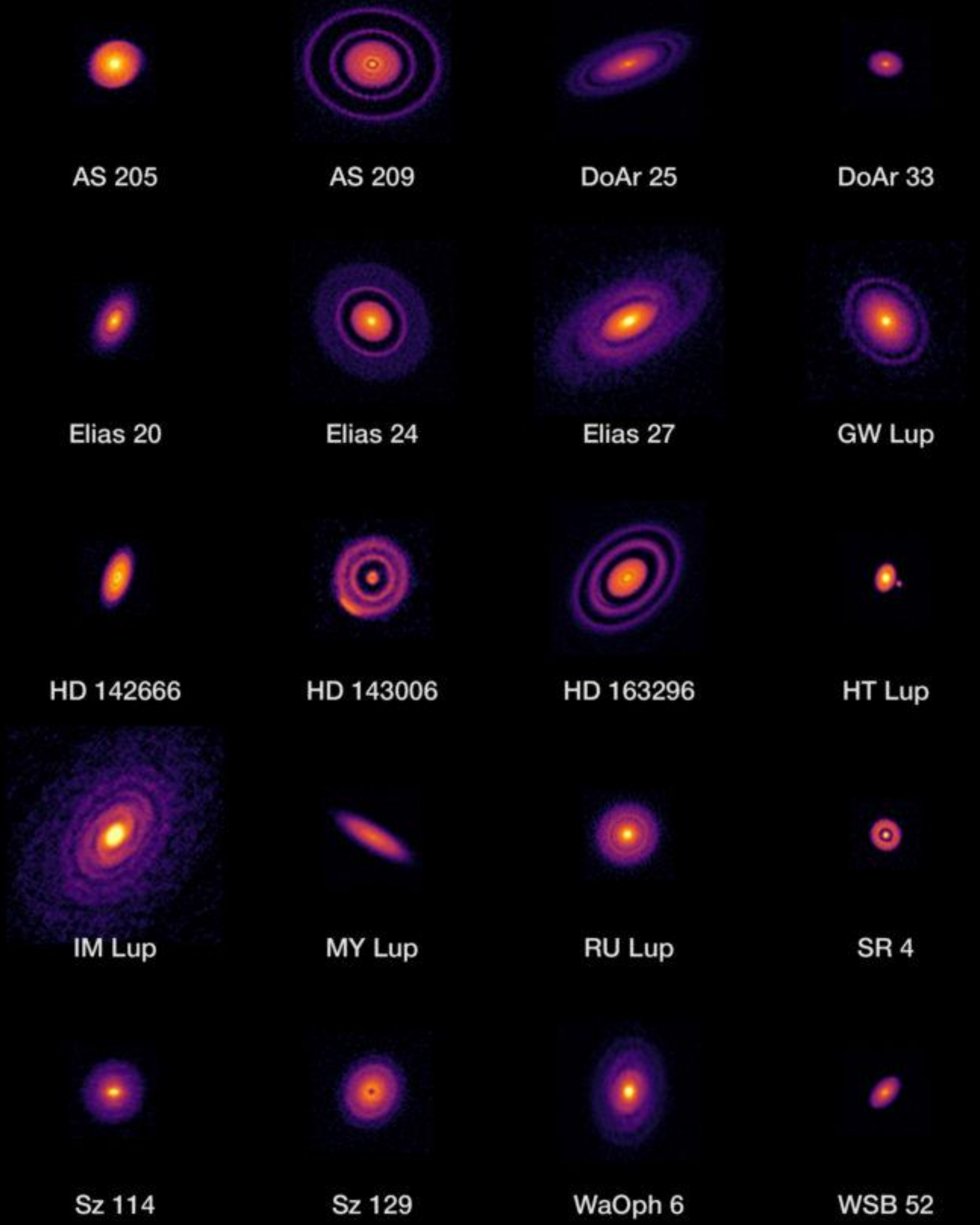


NASA/ESA and A. Feild (STScI)



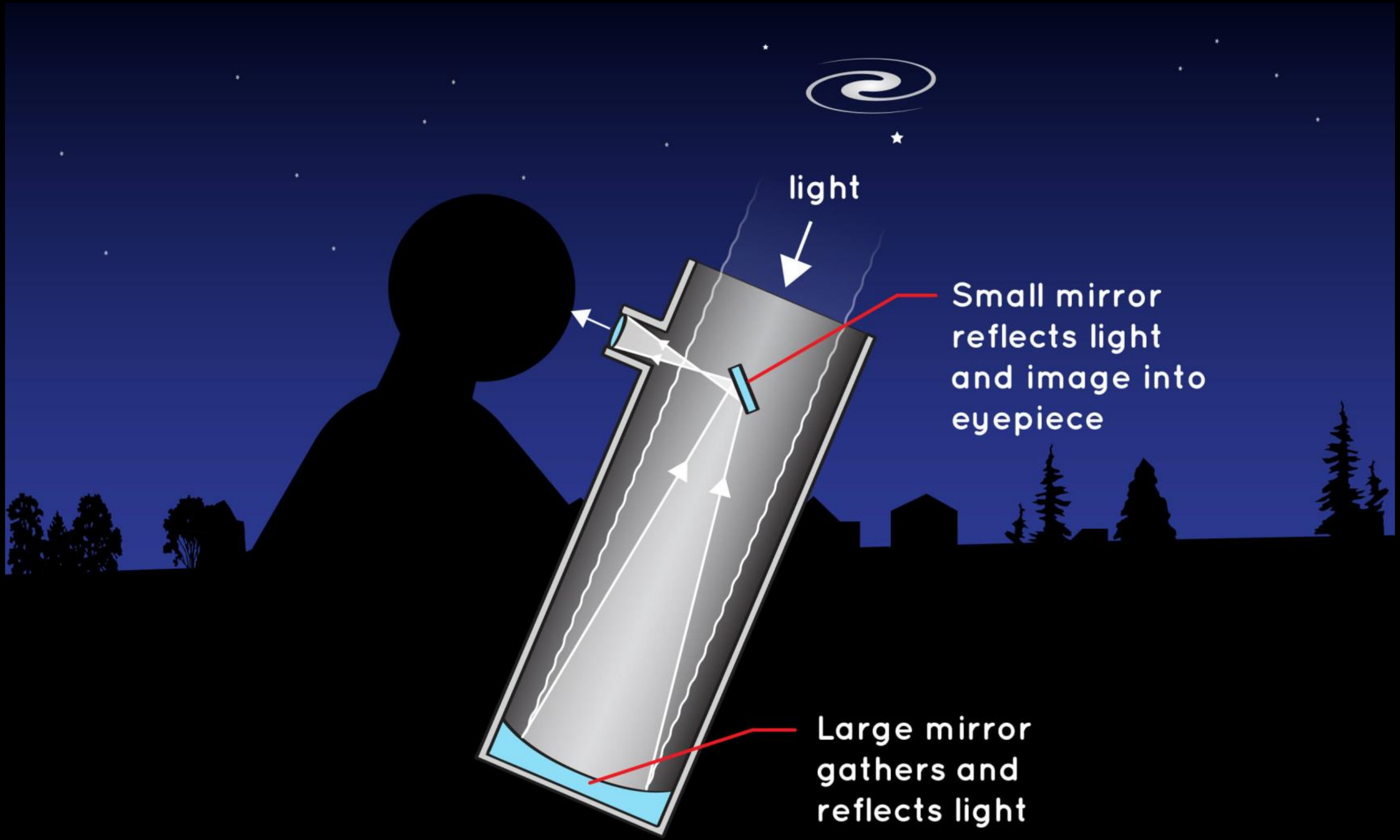
A. Isella/ALMA (ESO/NAOJ/NRAO)/Rice University.

ALMA (ESO/NAOJ/NRAO), S. Andrews et al.; N. Lira



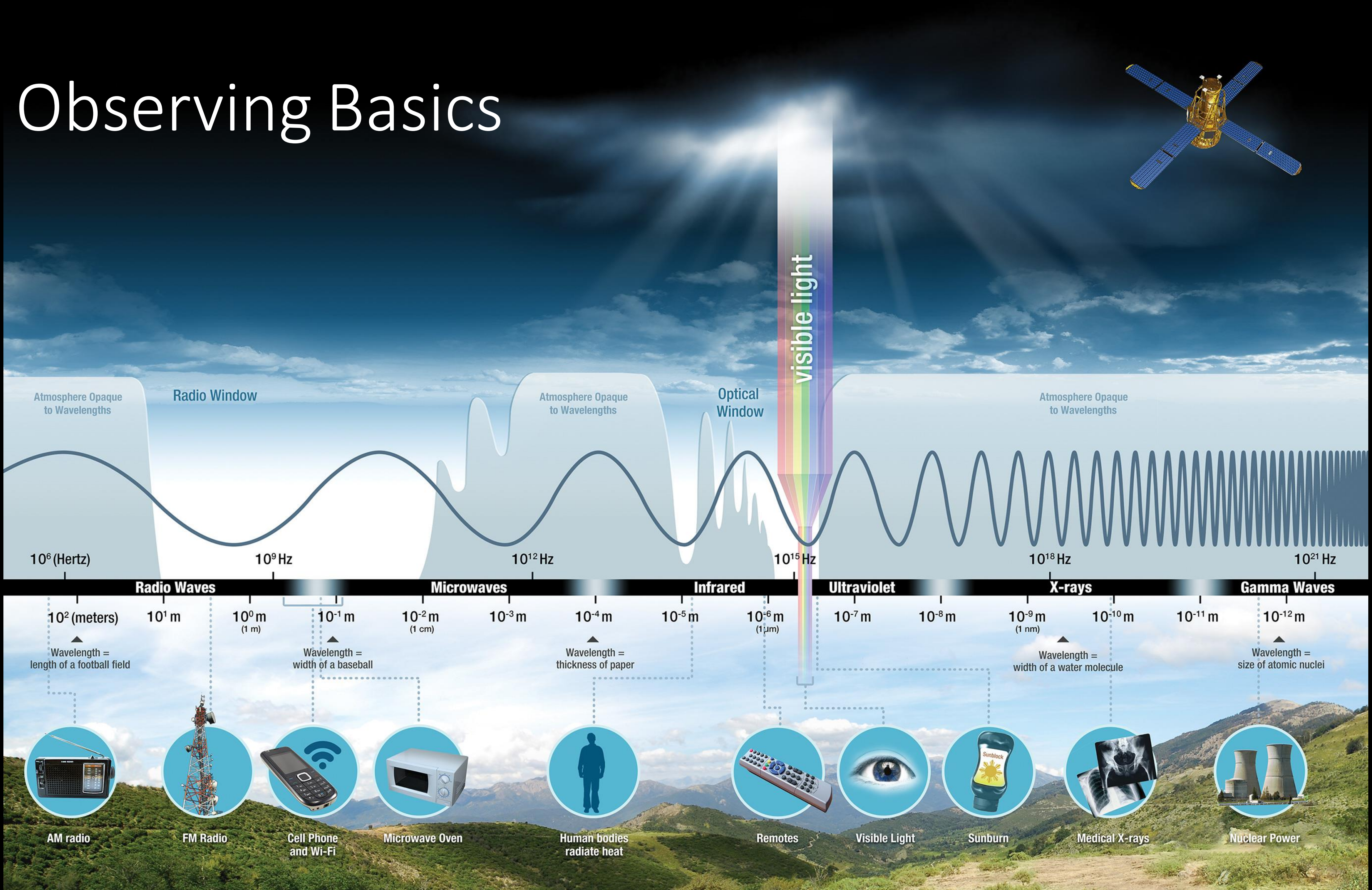
Theory to Observations

Observing Basics



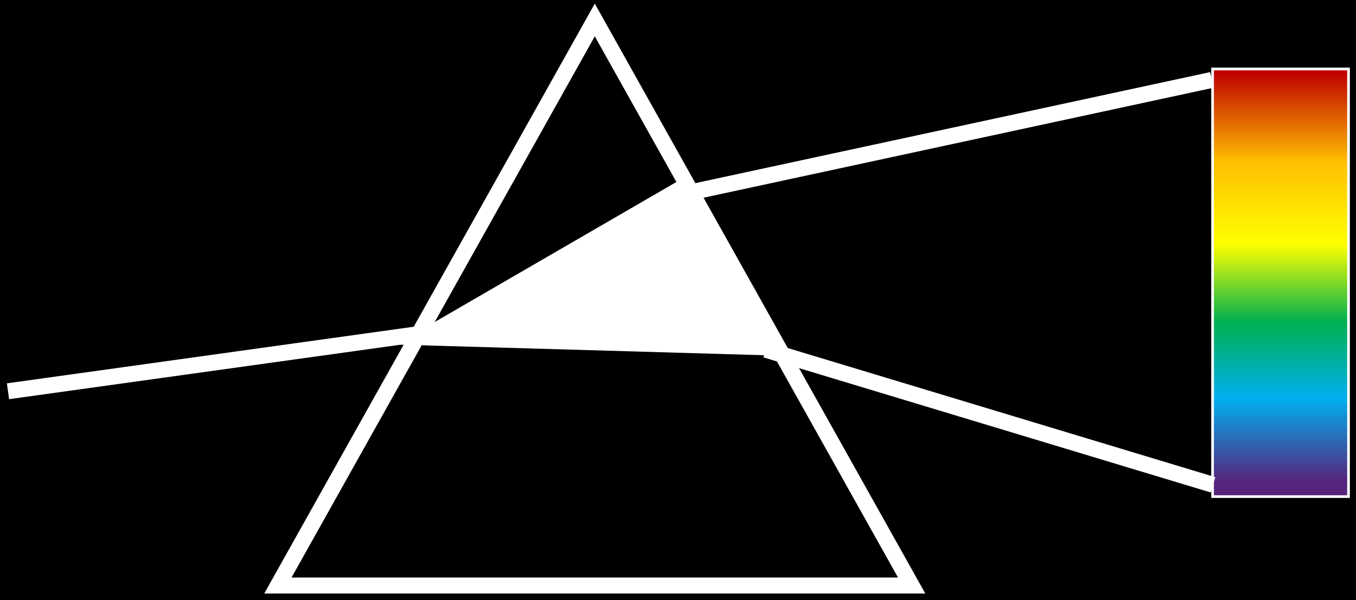
NASA/JPL-Caltech

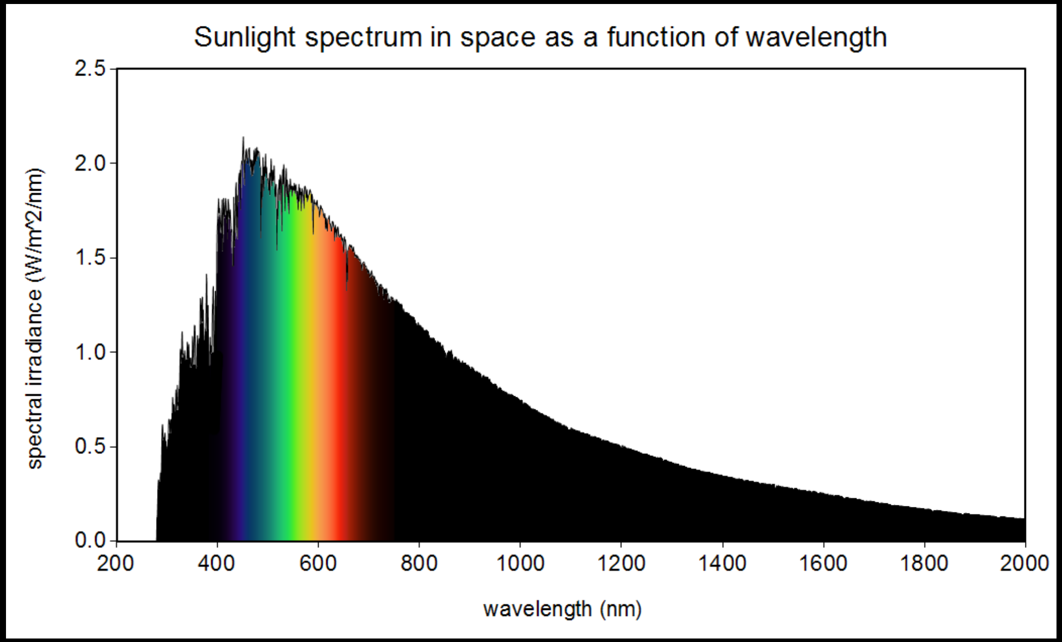
Observing Basics



NASA

Observing Basics

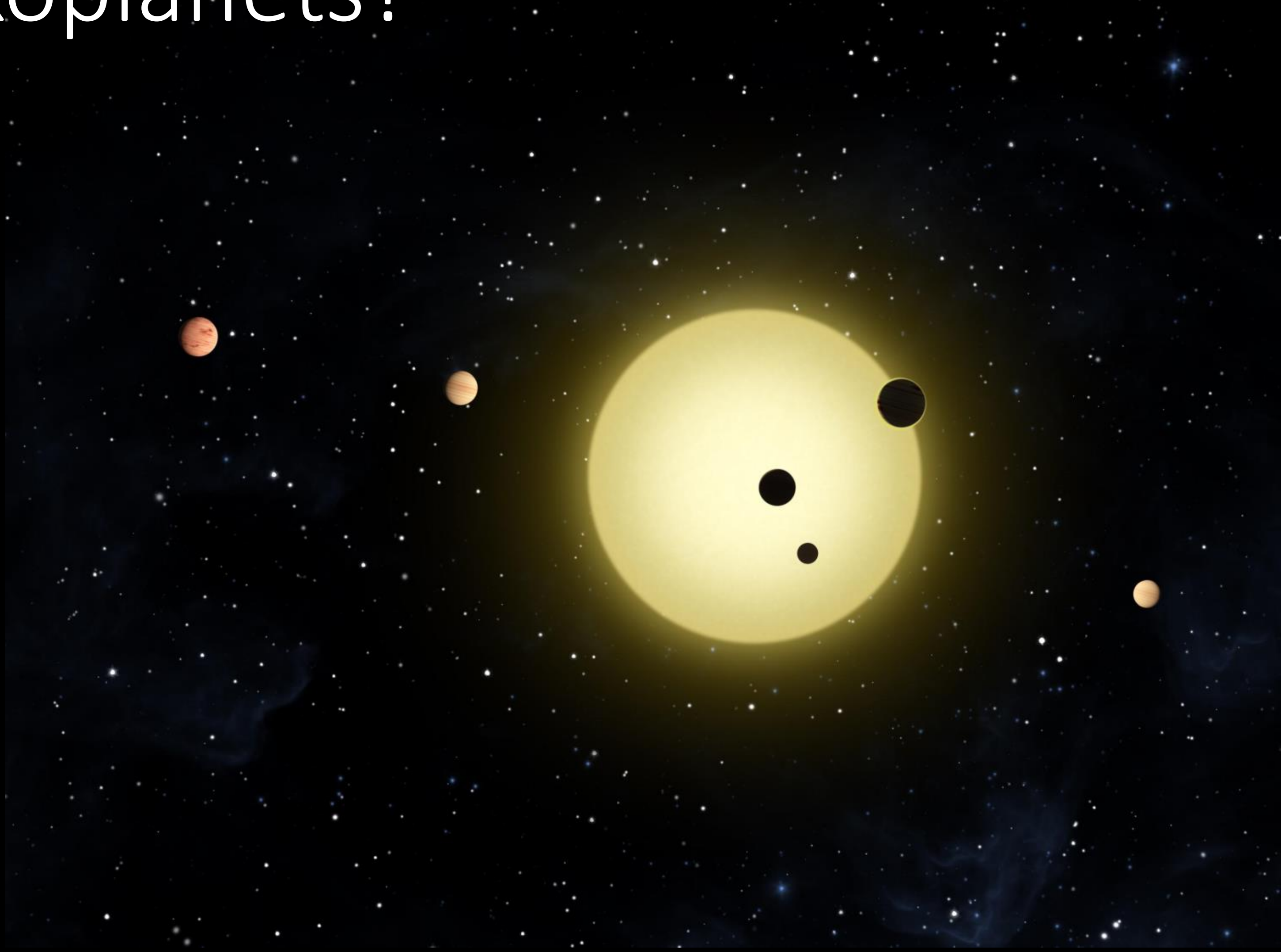




C. Baird, WTAMU

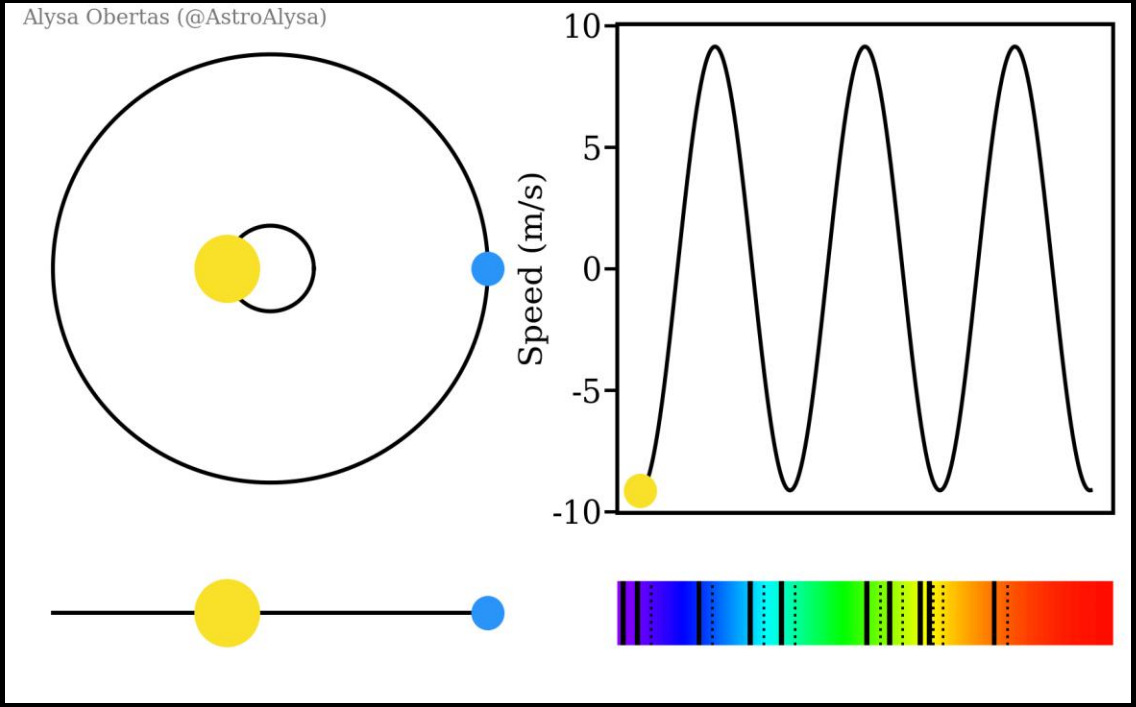
How Do We Find Exoplanets?

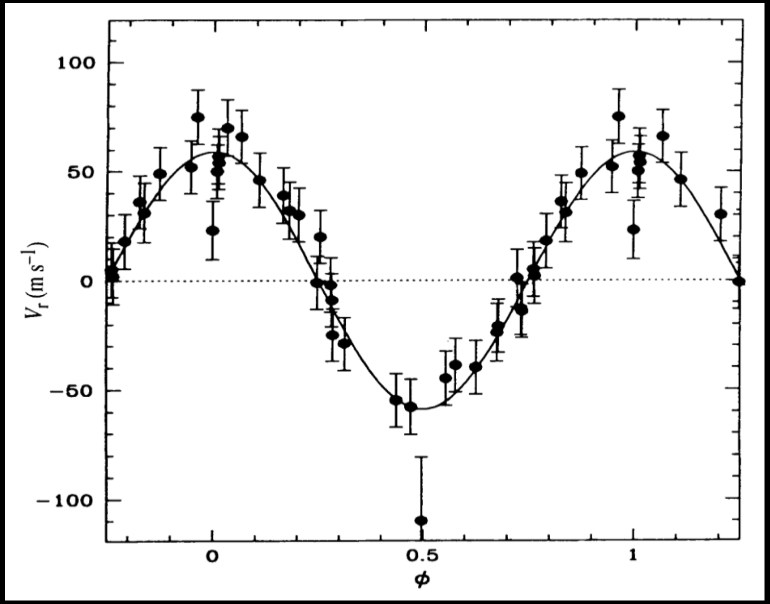
- Radial Velocity
- Transits
- Imaging
- Microlensing
- Astrometry
- Others (Timing/Eclipse Variations, Brightness Modulation)



Radial Velocity

- Indirect detection, measure the spectrum of a star, look for Doppler shifting
- Amplitude of signal gives mass of planet
- First really successful method
- Sensitive to massive planets, but many surveys have long baselines



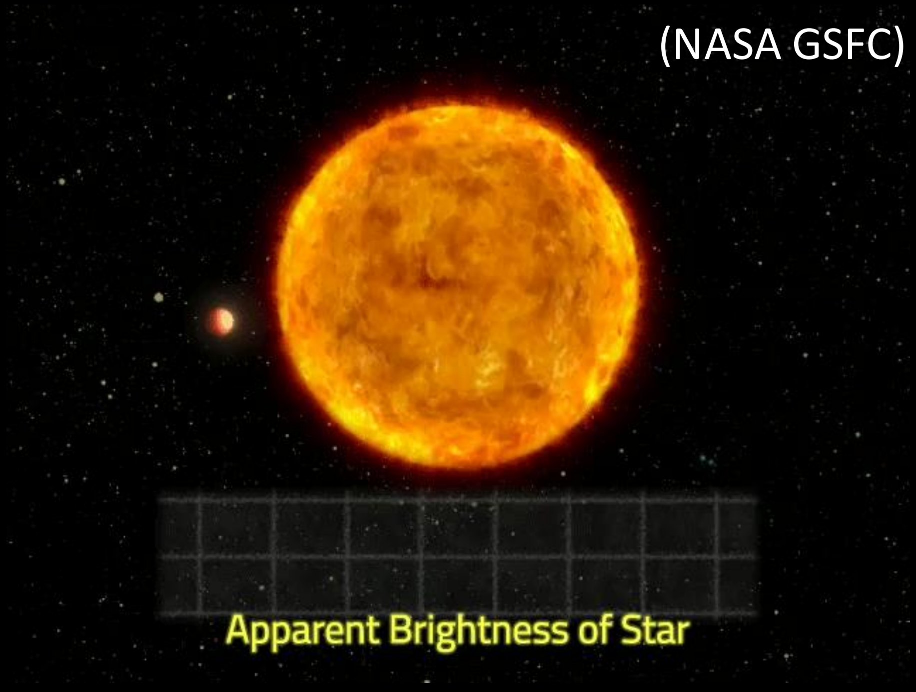


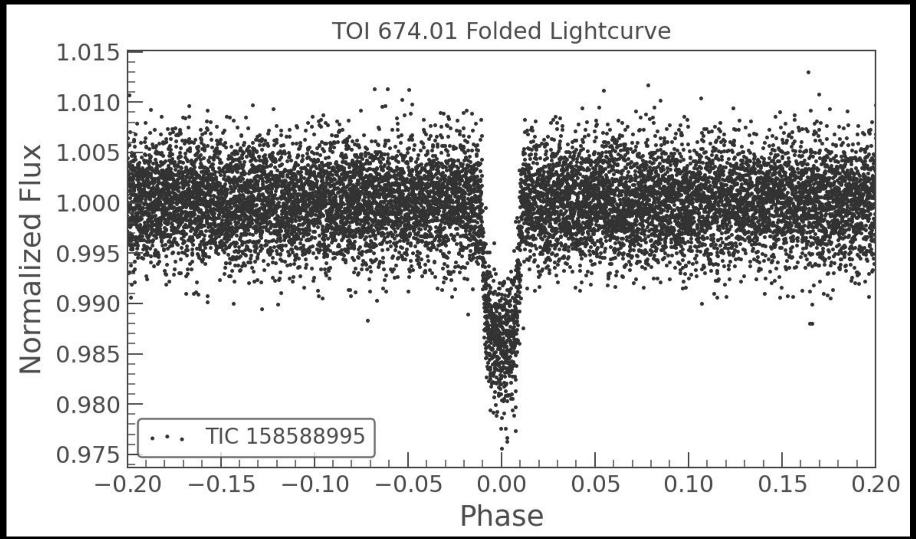
2019 Nobel Prize in Physics!

Mayor and Queloz (1995)

Transits

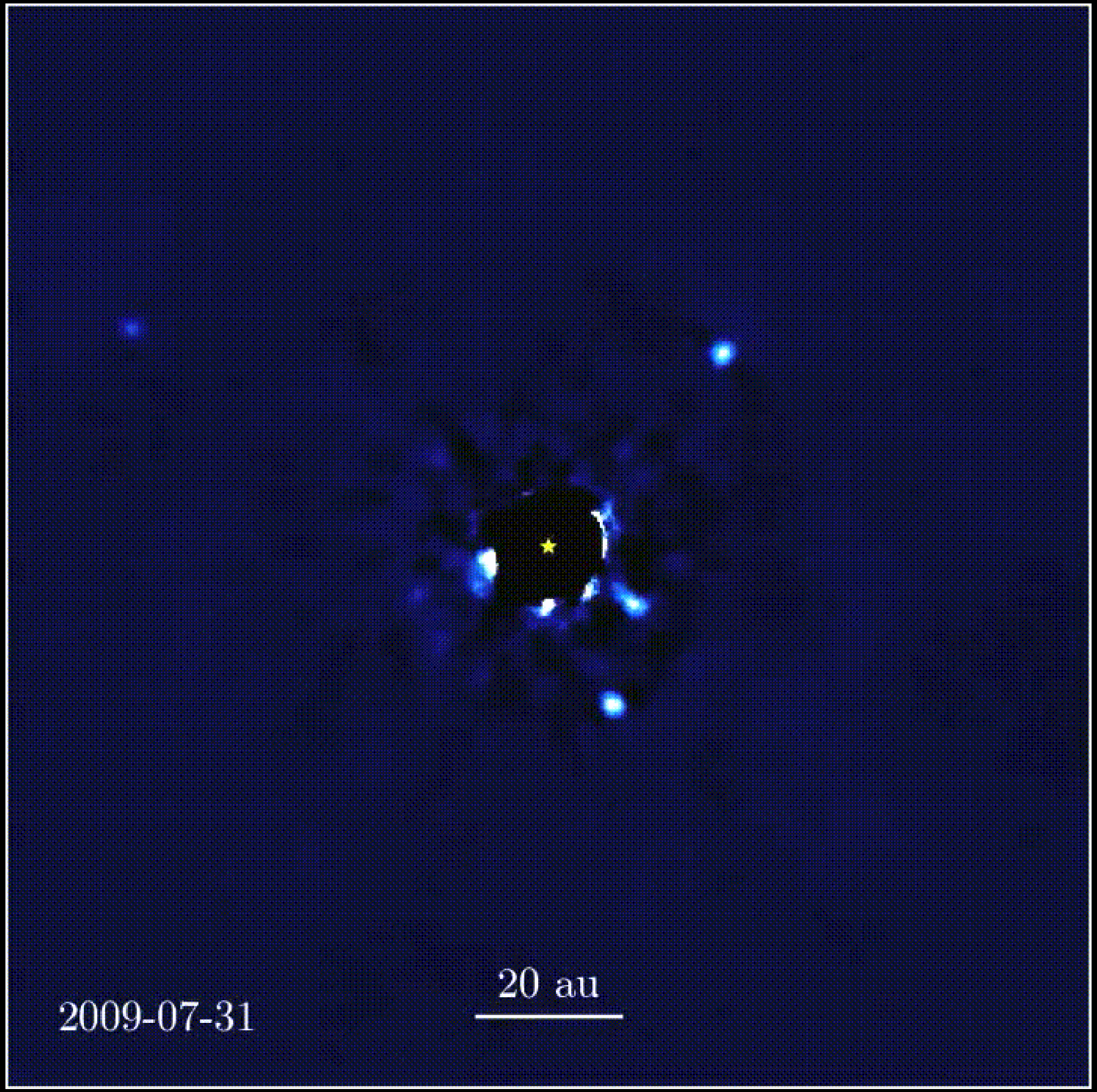
- Indirect detection, measure the brightness of a host star and look for variations
- Short, periodic signals can indicate exoplanets
- Need to rule out false positives
- Often combined with other methods
- Precision photometry can find very small planets
- Requires very specific orbital orientations





Imaging

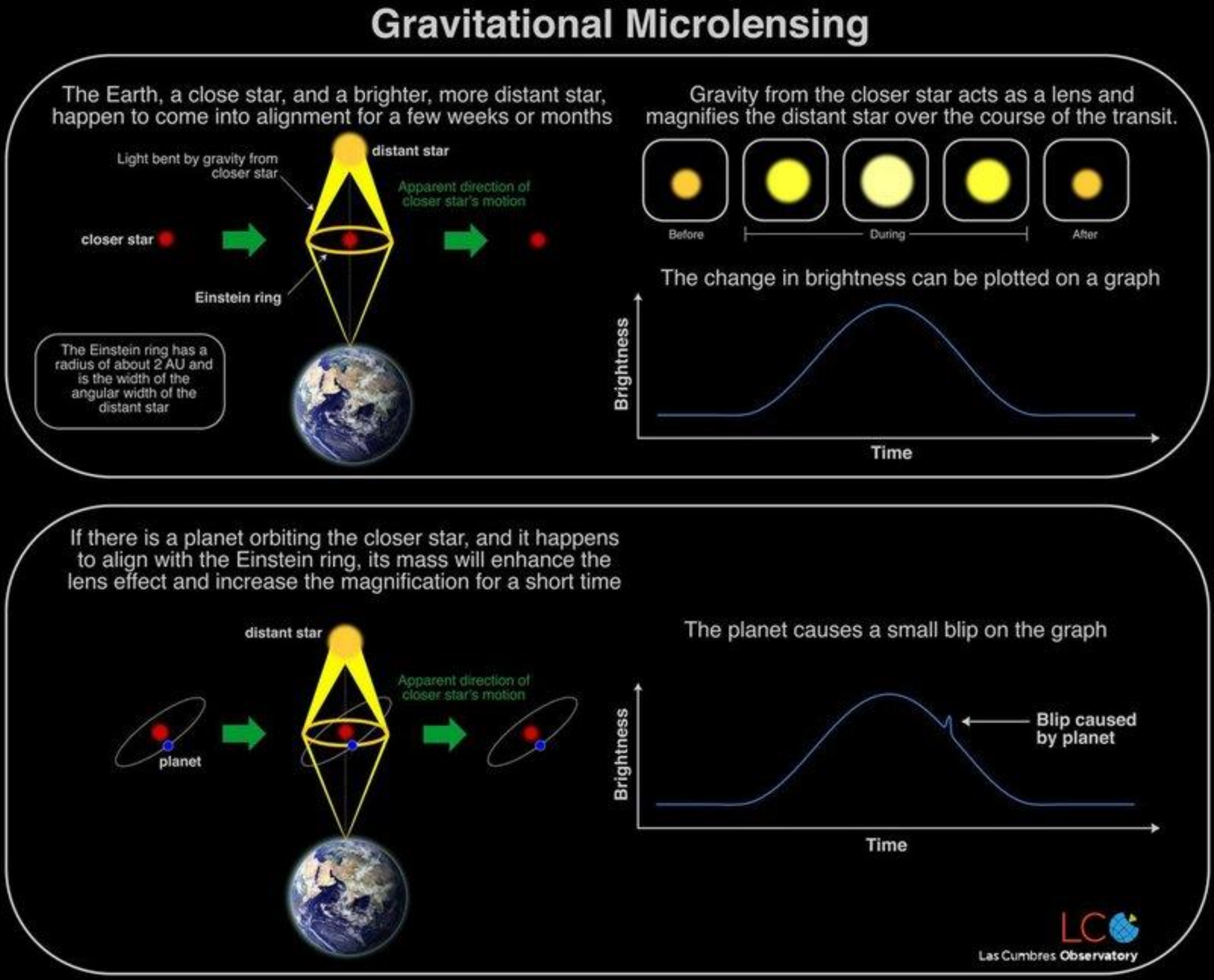
- Direct observations!
- Take a picture of space and collect light coming from a planet
- Often need to suppress the bright host star
- Large ground-based coronagraphs main drivers of direct imaging
- Space telescopes have some capability, JWST will do this!



J. Wang, Caltech

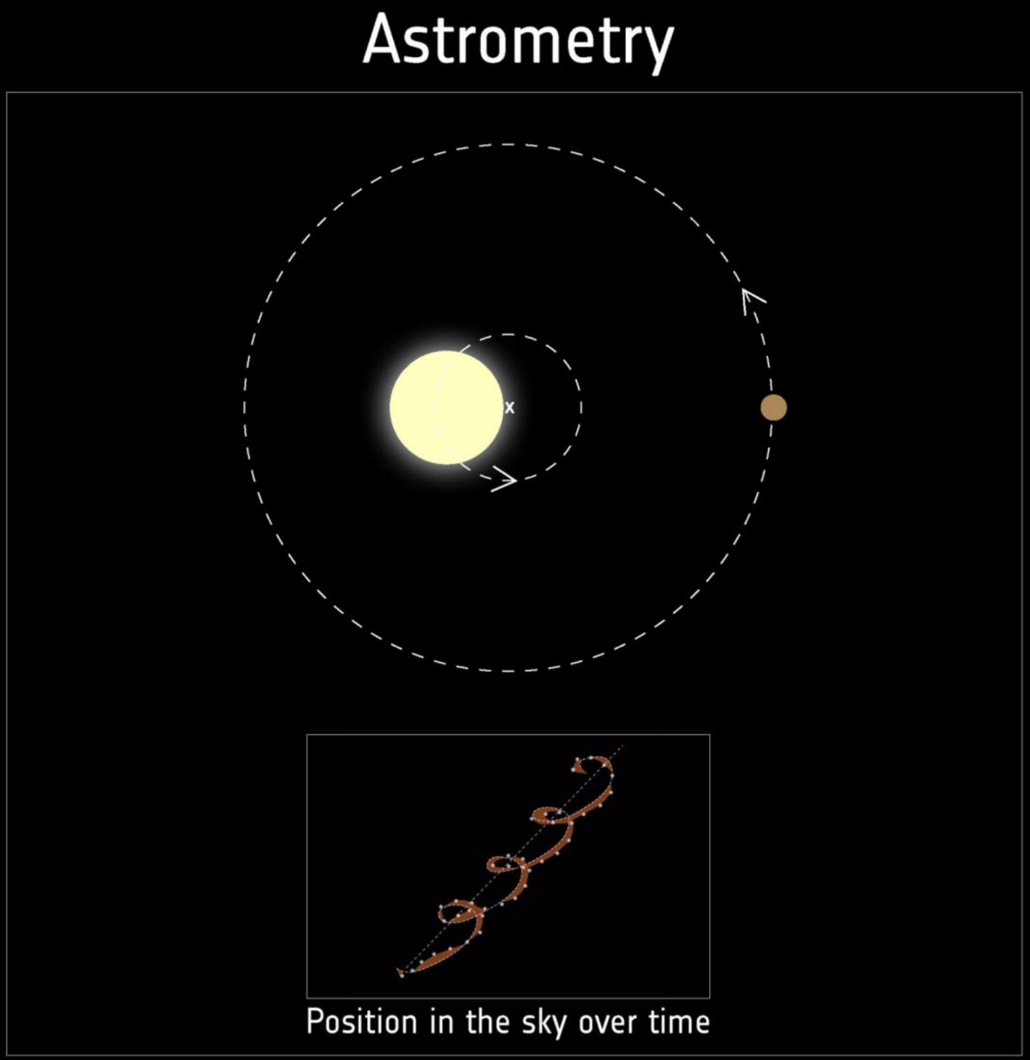
Microlensing

- Transient method
- Can’t revisit planets
- Can get some size information on planet
- Good for large, shallow surveys
- Future Roman Space Telescope



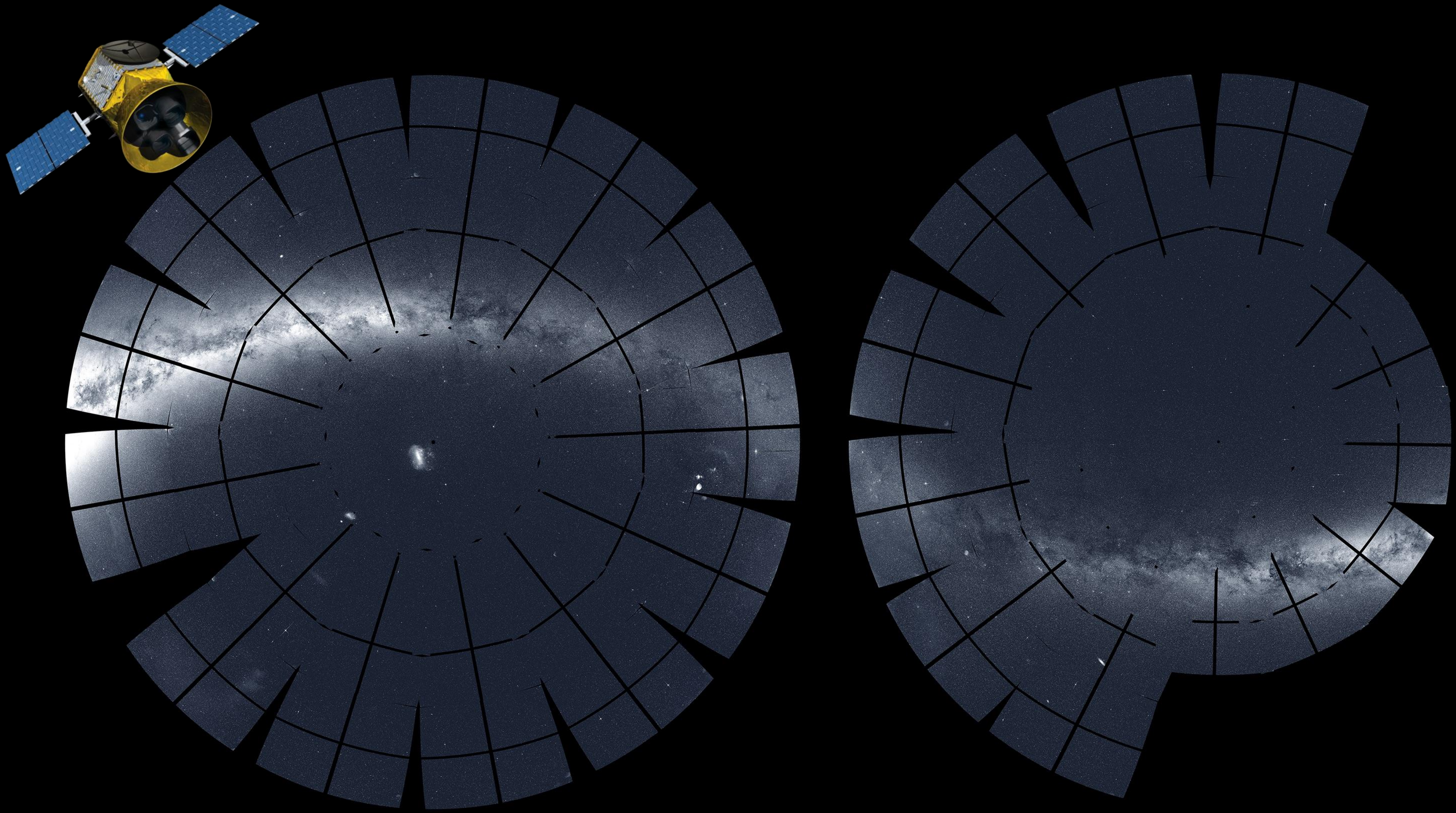
Astrometry

- “Oldest” discovery method
- Optical counterpart to RVs
- Indirect method, but gives similar parameters (orbits, masses) to other detections
- GAIA mission will discover thousands of astrometry planets in the next few years



ESA

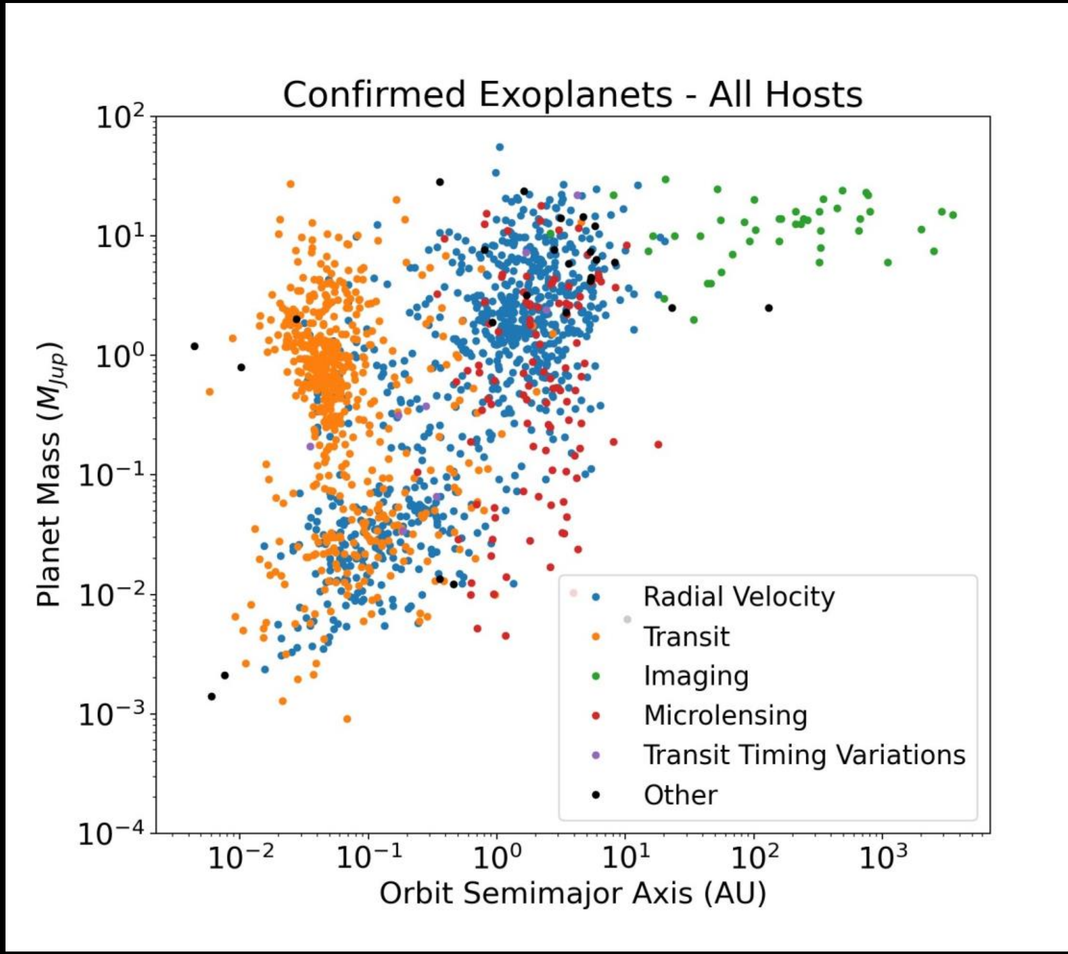
Discovery Process

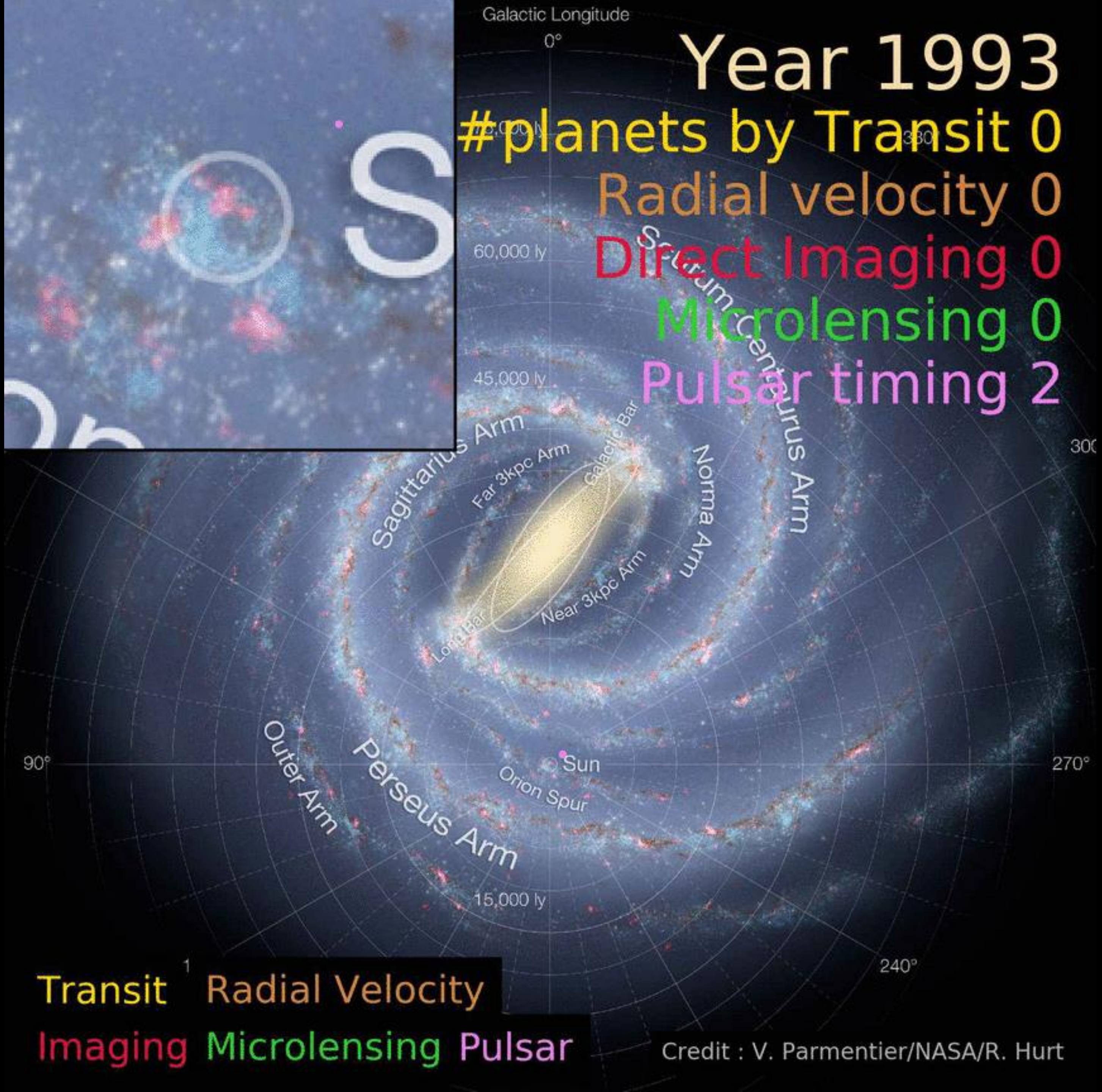


NASA/MIT/TESS and Ethan Kruse (USRA)

Current Status

- Where does this leave us now?
- We know of >4300 exoplanets
- What do we do with all this data?



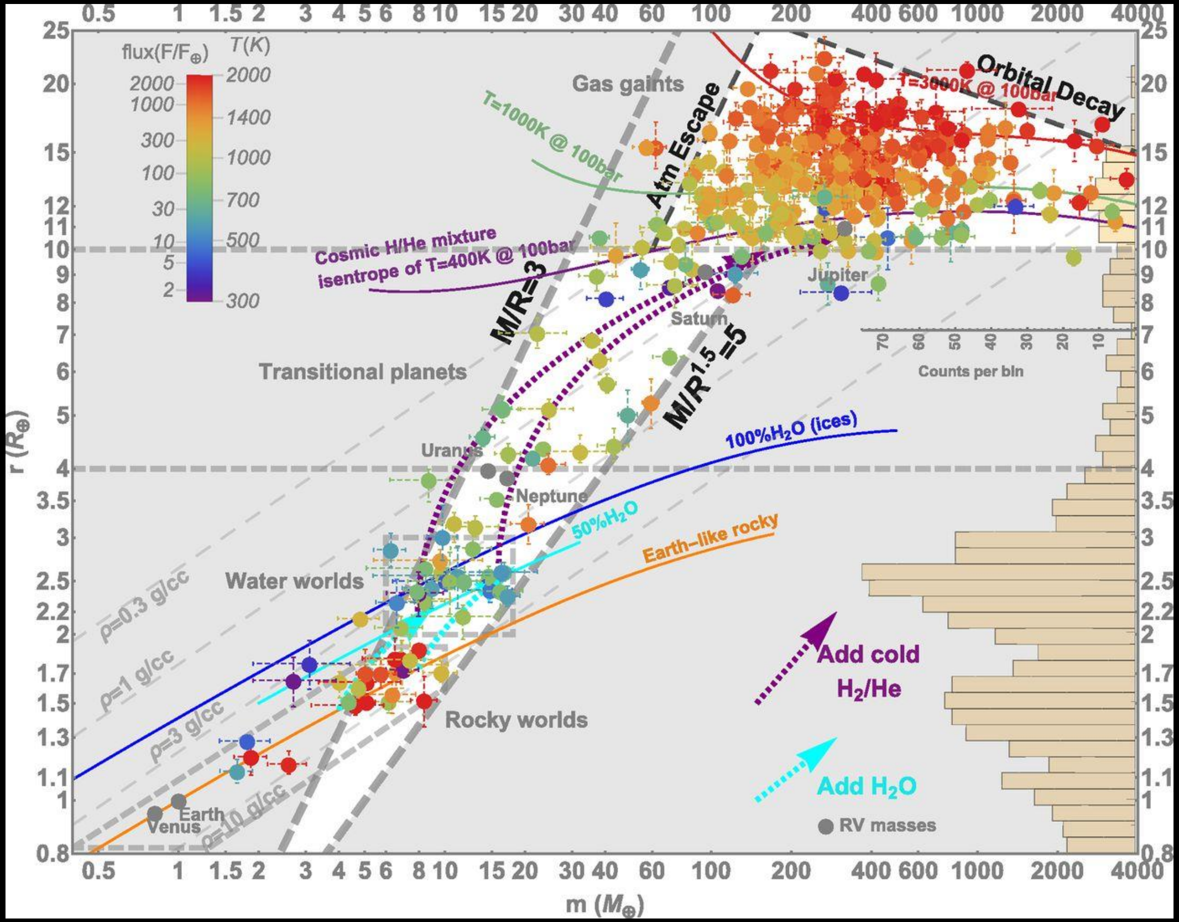


Year 1993
#planets by Transit 0
Radial velocity 0
Direct Imaging 0
Microlensing 0
Pulsar timing 2
Galactic Longitude
0°
60,000 ly
45,000 ly
15,000 ly
90°
270°
240°
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
Sun
Orion Spur
Transit Radial Velocity
Imaging Microlensing Pulsar
Credit : V. Parmentier/NASA/R. Hurt

Planet Characterization

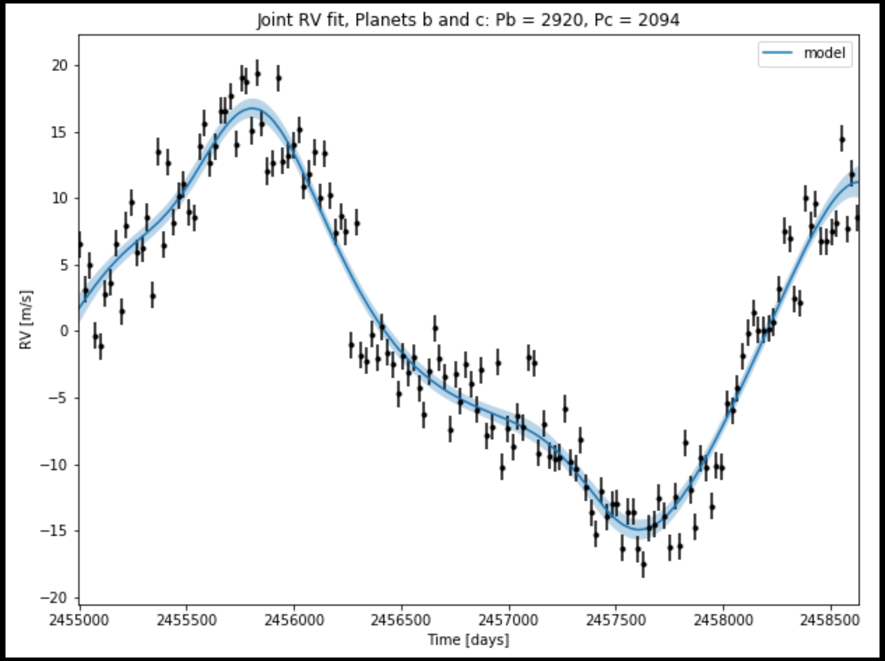
Planet Characterization

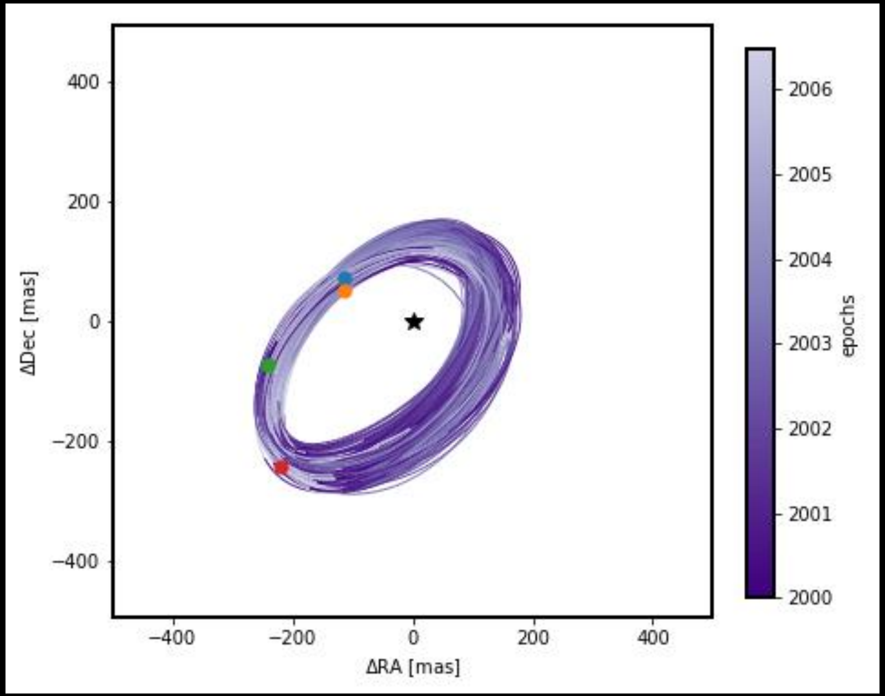
- We can combine methods like Transits/RVs to understand more about a planet
- Radius + Mass -> density -> bulk composition
- Useful for interpreting other observations



Planet Characterization

- Combining RV/Direct Imaging can do things that transits + RVs can’t
- Orbital architecture shows true mass of planet
- Luminosity/spectroscopy of planet can help distinguish formation mechanisms

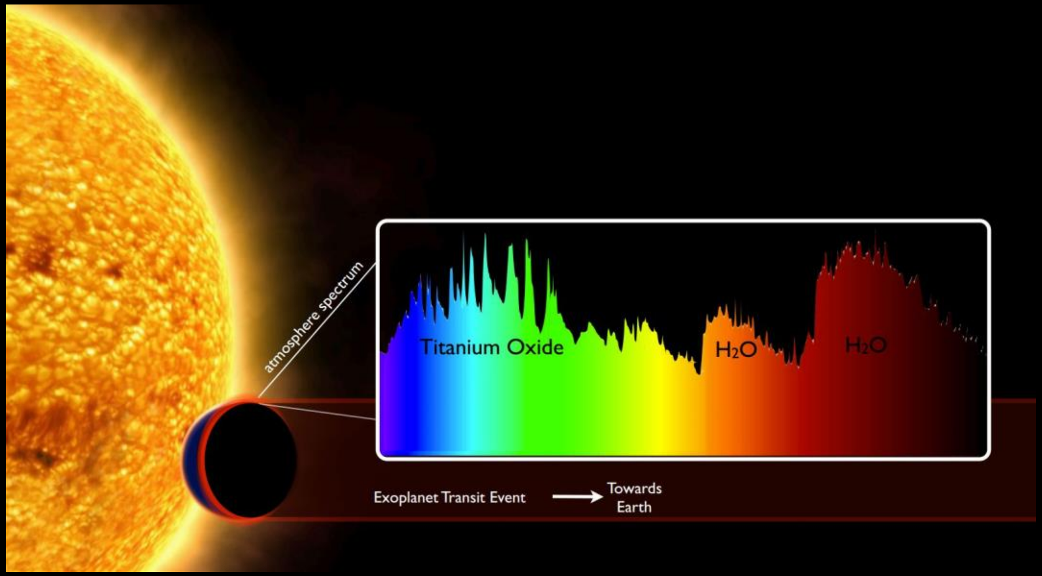


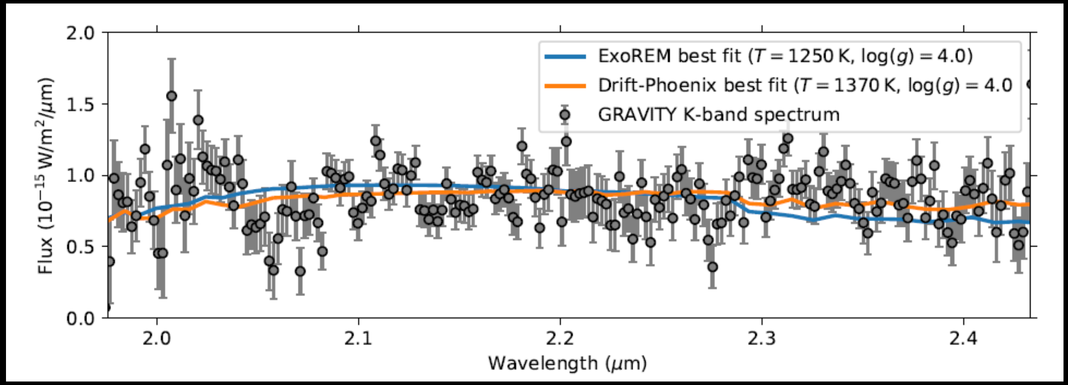


Planet Characterization

- Transit spectroscopy shows absorbing species in atmosphere
- Often hard to interpret without good stellar spectra, planet atmosphere models
- Spectroscopy also possible from direct imaging, but needs specific targets

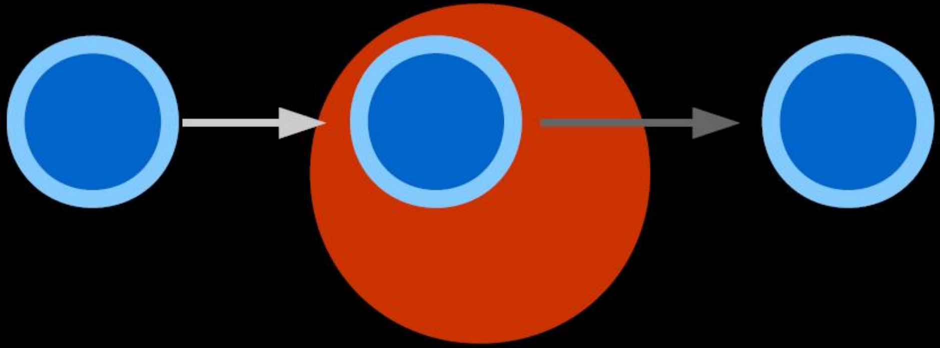
(ESA, Plato Mission)

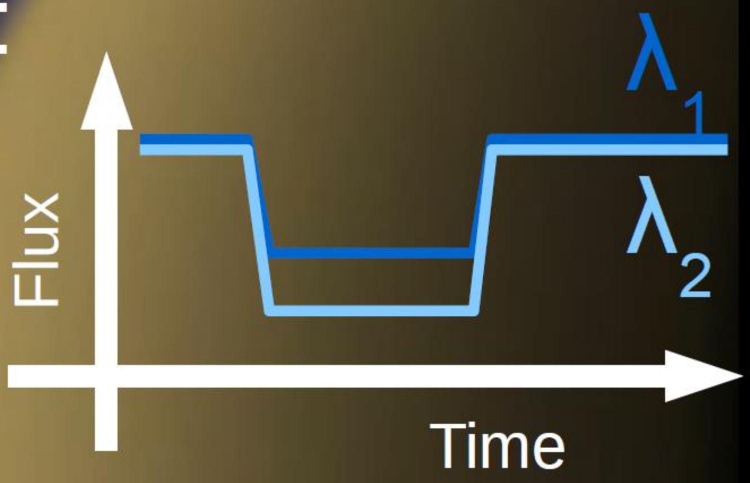


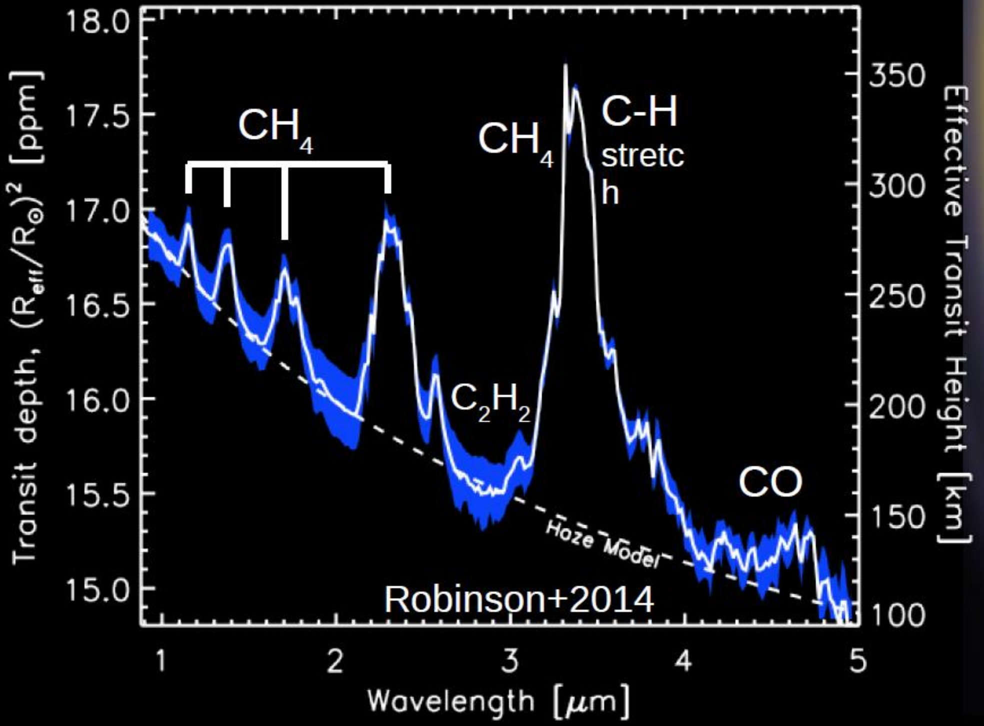


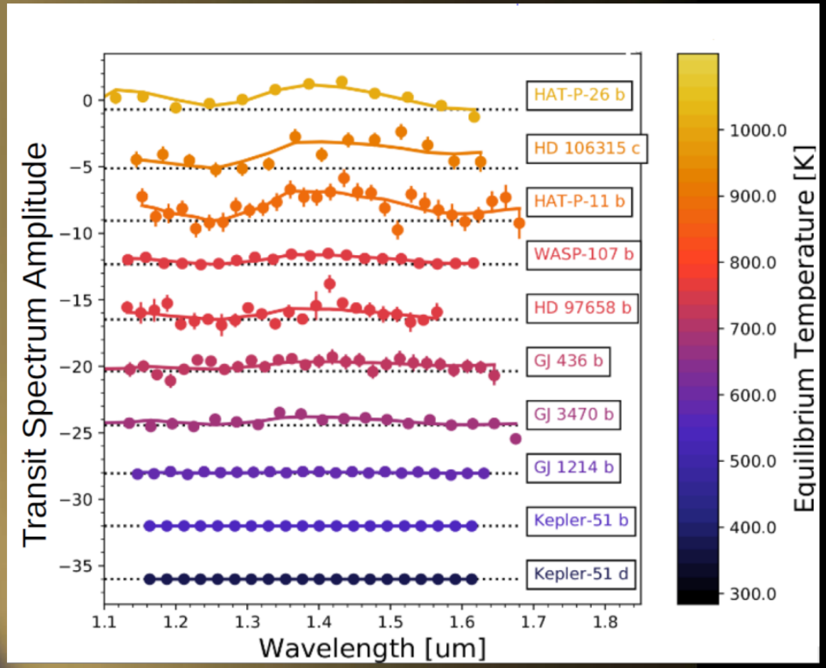
Nowak et al. 2020

Transit spectroscopy probes exo-atmospheric makeup:



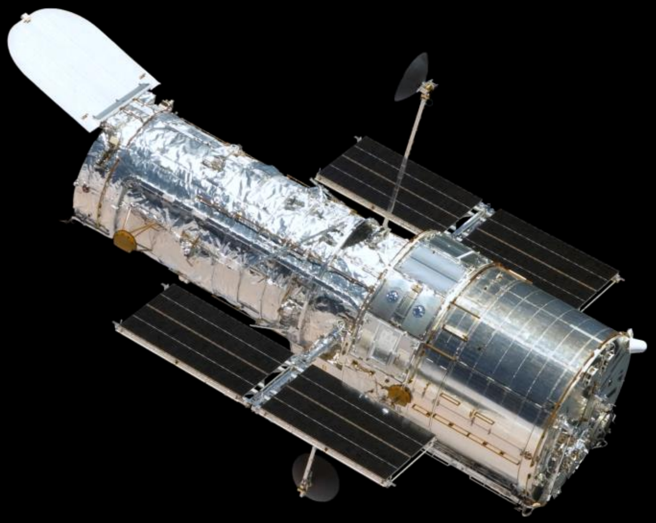


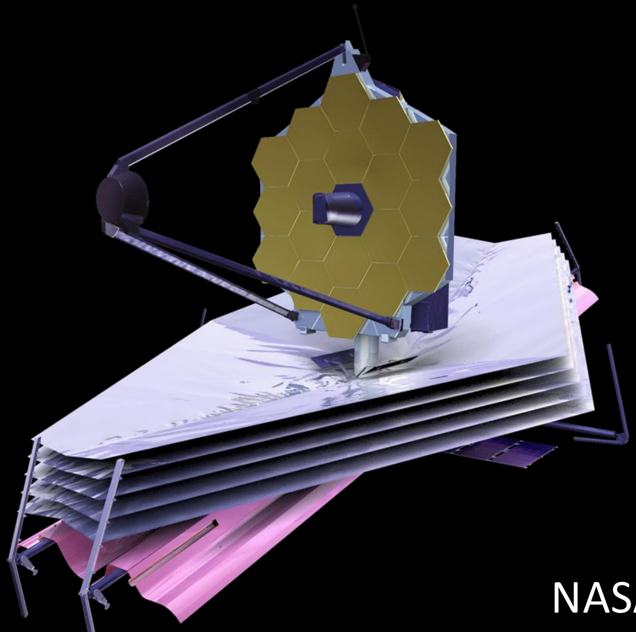




Observatories and Instruments!

Keck Observatory

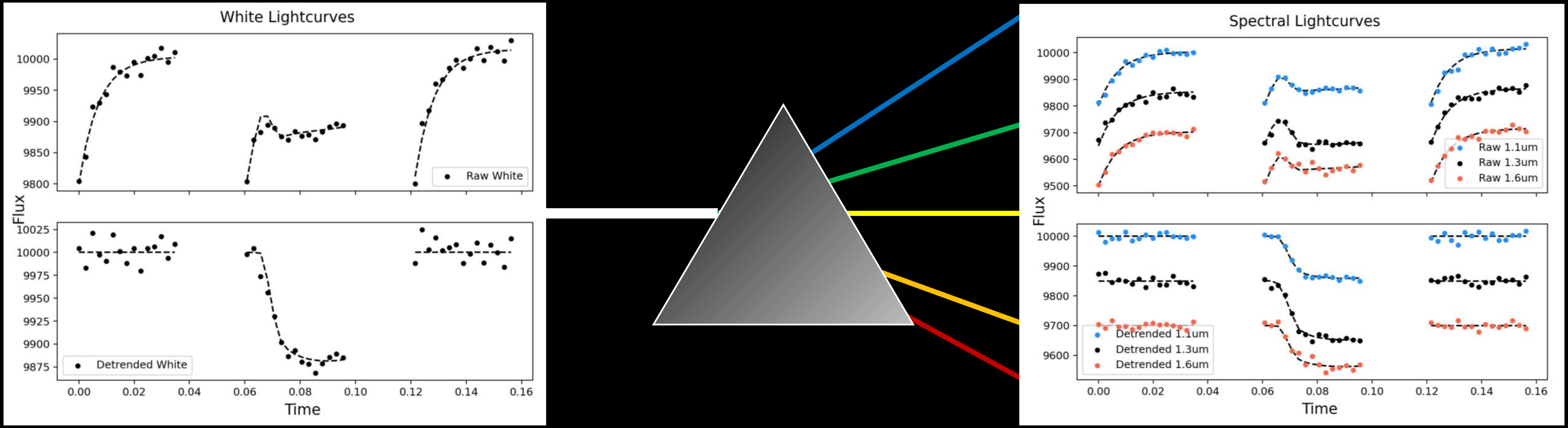




NASA

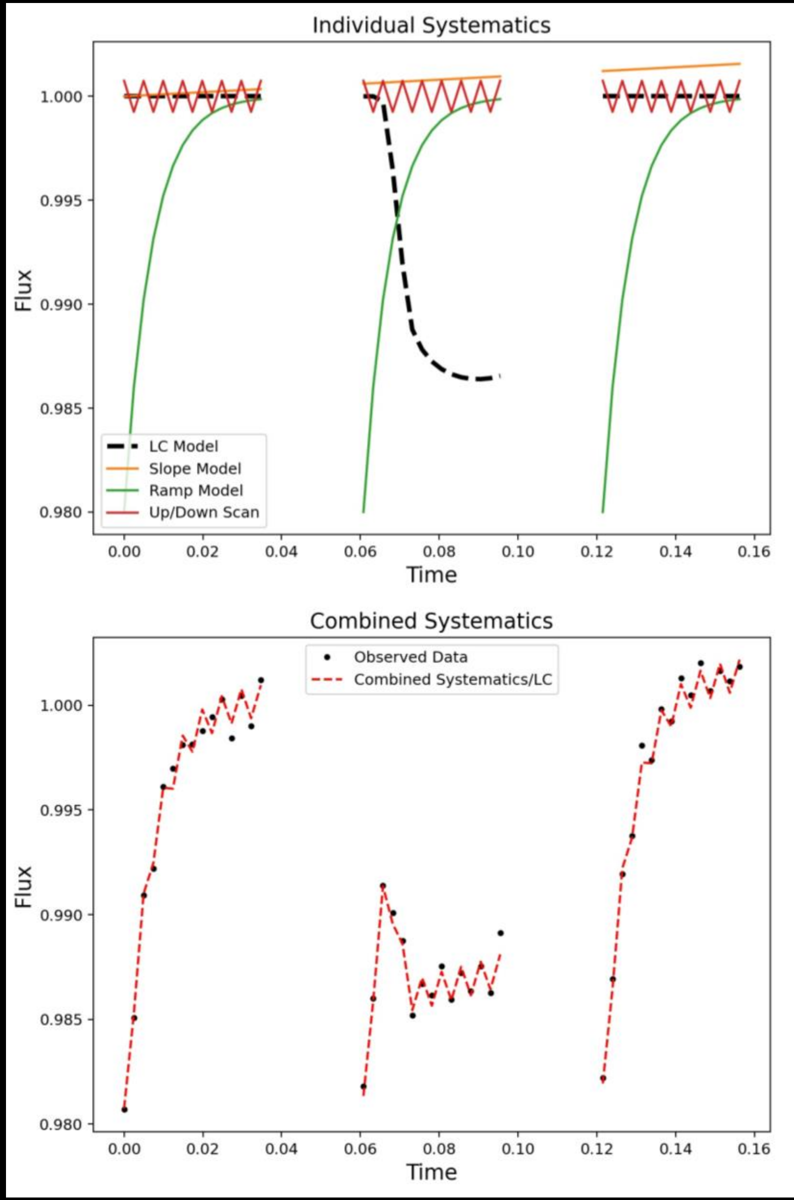
What We’re Doing

What am I doing, anyway?



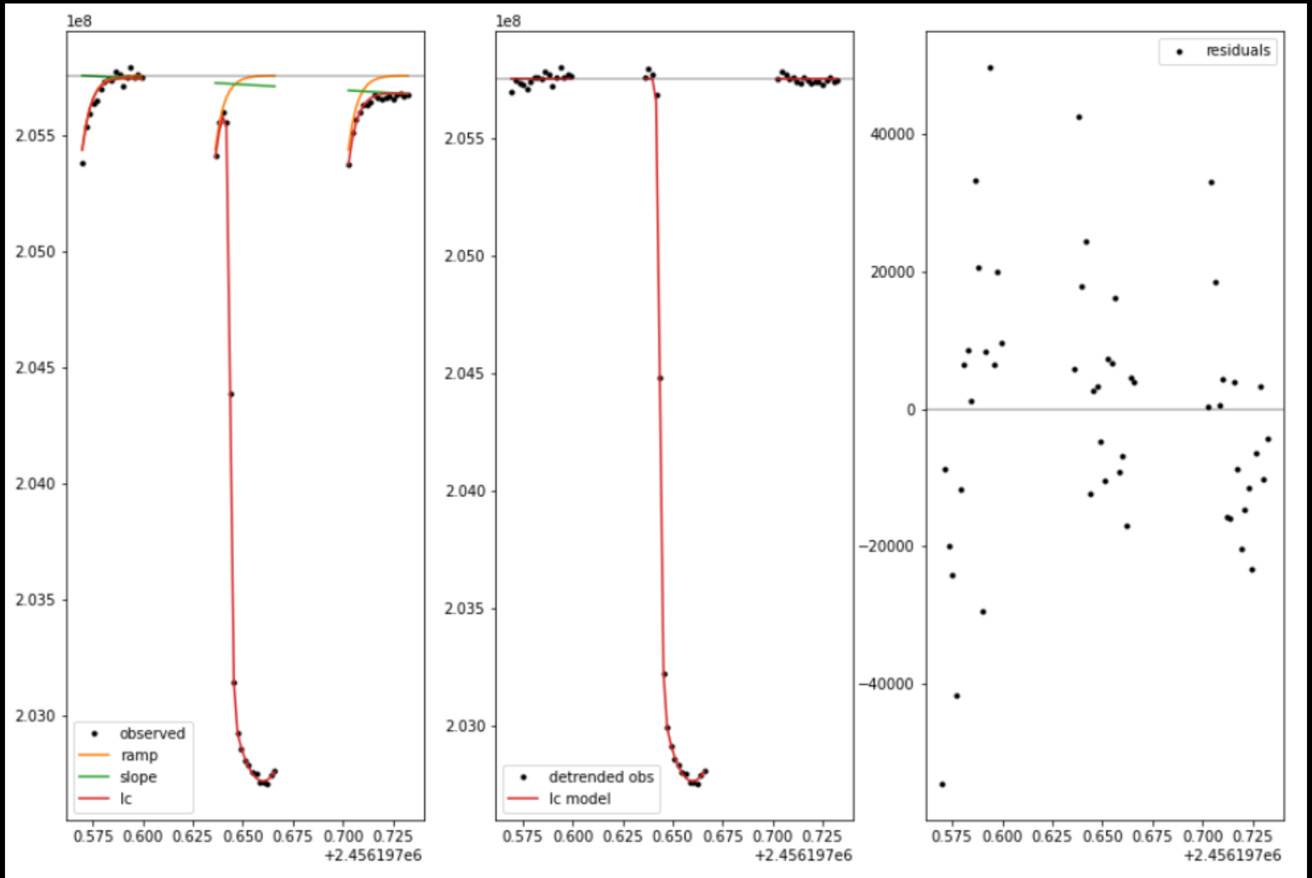
What am I doing, anyway?

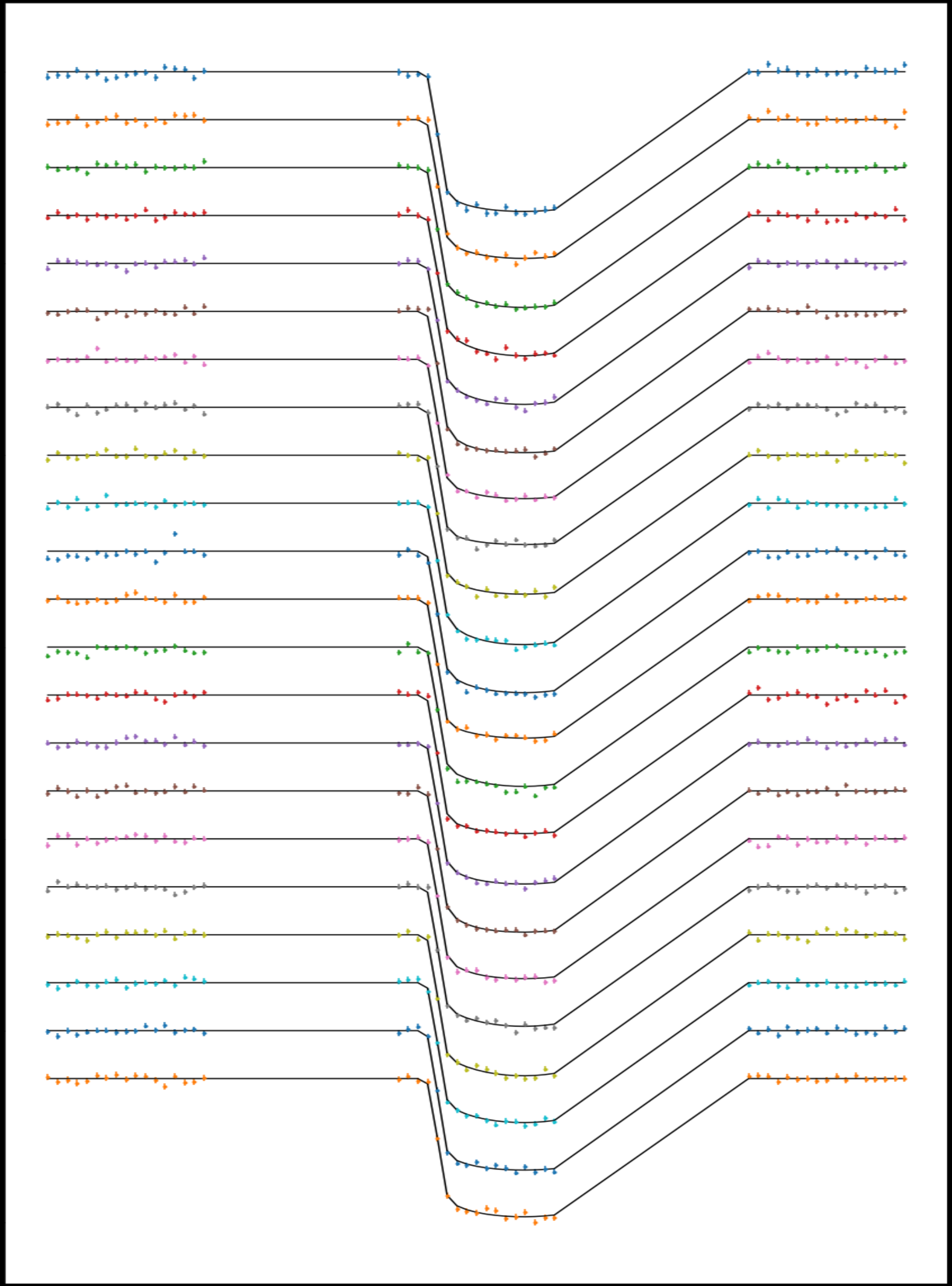
- Lightcurve modeling
  - "true" transit model
  - "true" systematics model
  - Fit components from Kreidberg+ 2014, need to fit for every spectral band
- MCMC sampling over (possibly very) large hierarchical models -> want speedy sampling
- exoplanet – improved sampling performance with Hamiltonian Monte-Carlo, "new" to astrophysics



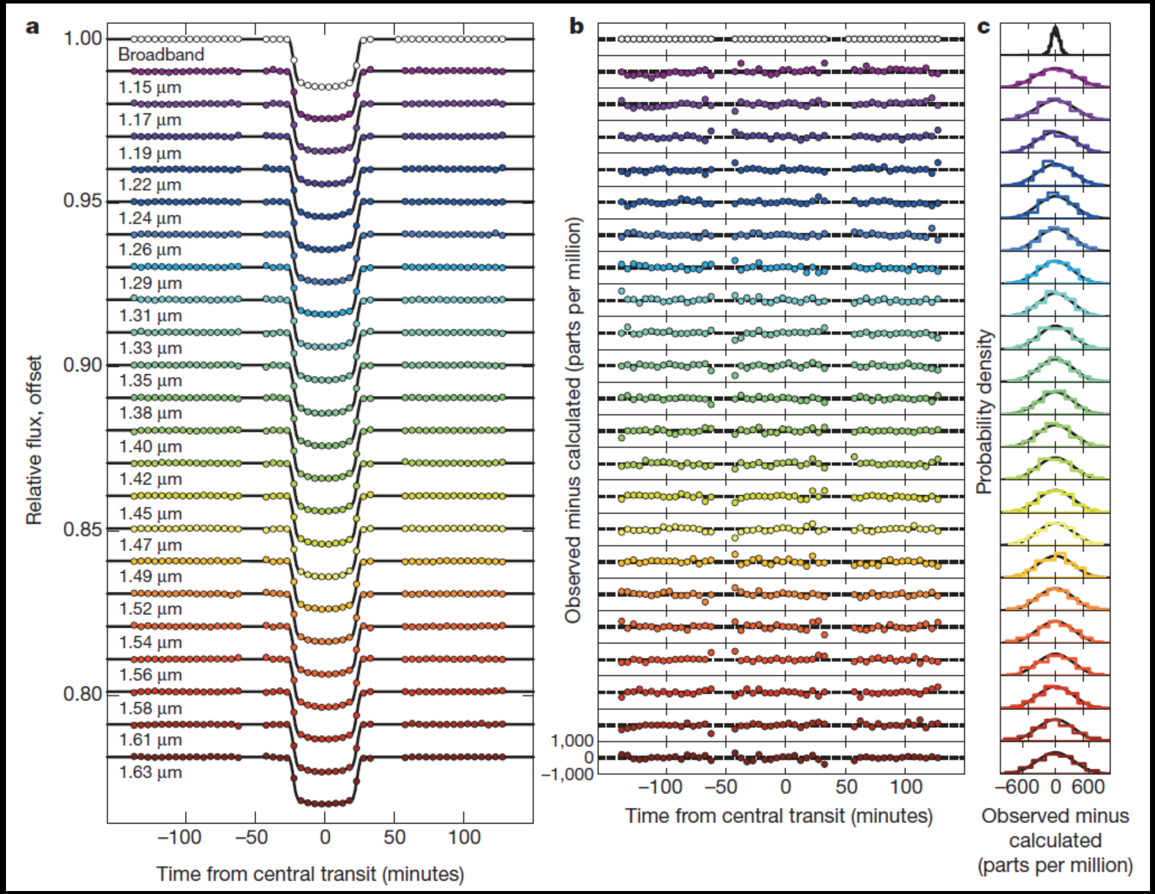
exoplanet (Foreman-Mackey+ 2019)
docs.exoplanet.codes

Real Data! GJ 1214 b

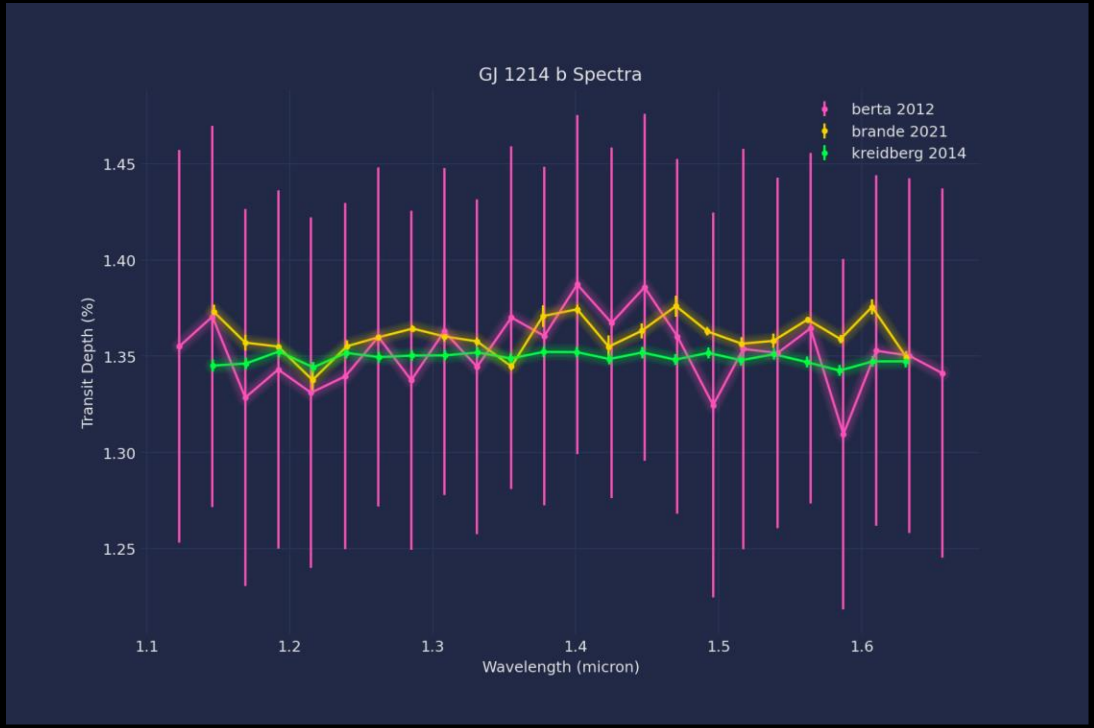




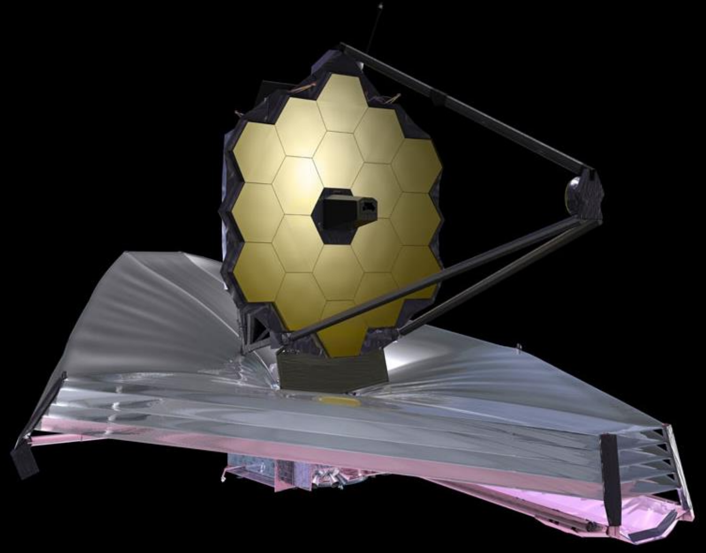
GJ 1214 b – Flat Spectra, Thick Clouds



Kreidberg+ 2014



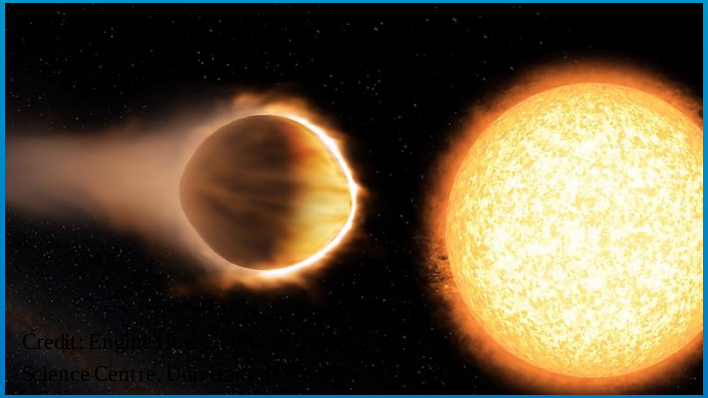
Next steps

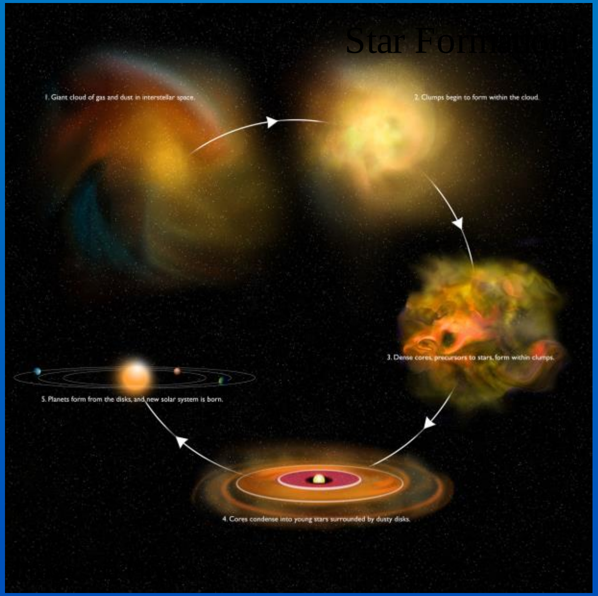


(NASA)

- Continue validating code
- Work on spectral lightcurve extraction
- HST IR spectra of other new exoplanets
- NASA IRTF infrared spectra next month!
- JWST? Who knows!
- Helium escape, atmospheric erosion? -> tracing EUV flux from host star
- General interest – H2O in temperate planet atmospheres -> "habitable" zone
- Find good spectral retrieval codes to interpret results

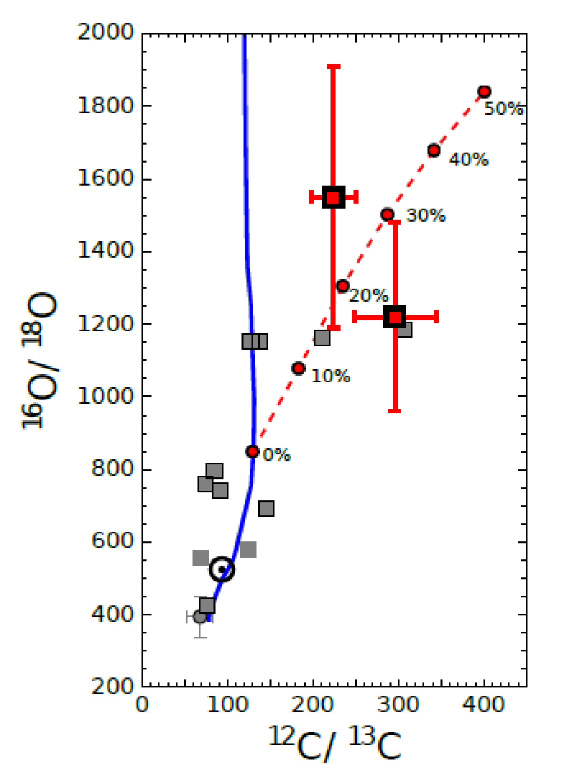
CO Isotopic Abundances in Solar Twin Stars





David Coria || KU ExoLab

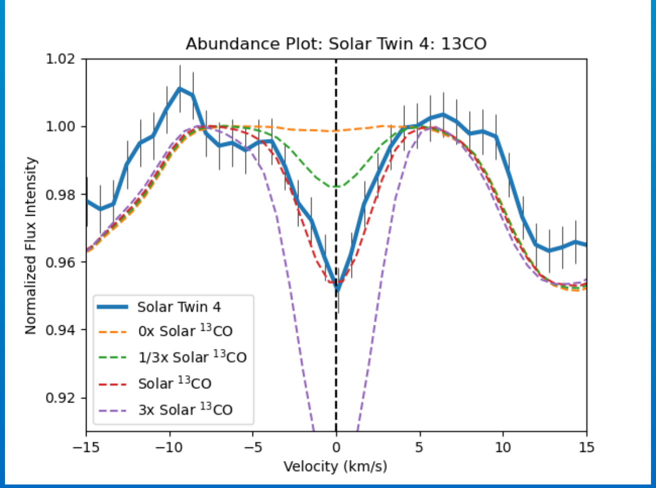
Isotopic Abundances + Galactic Chemical Evolution

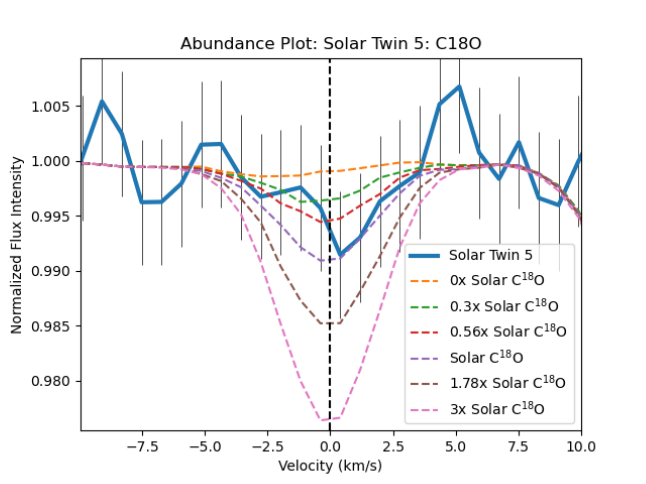


M-Dwarfs (Crossfield+ 2019):
Young Stellar Objects:
Kobayashi (2011) GCE Model:
Proposed GCE Correction:

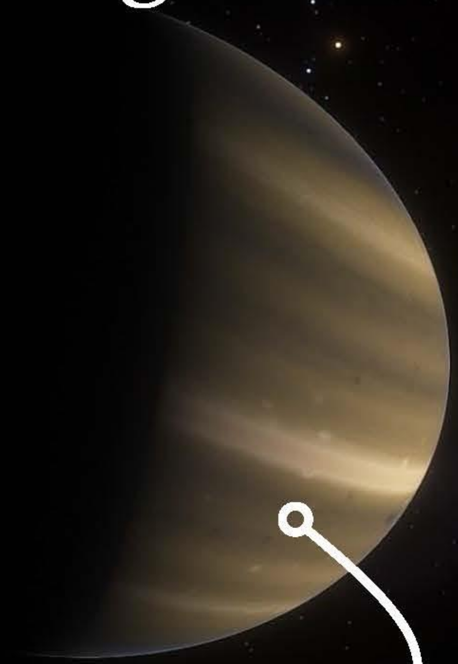
Coria+ in prep.

Calculating Isotopic Abundances

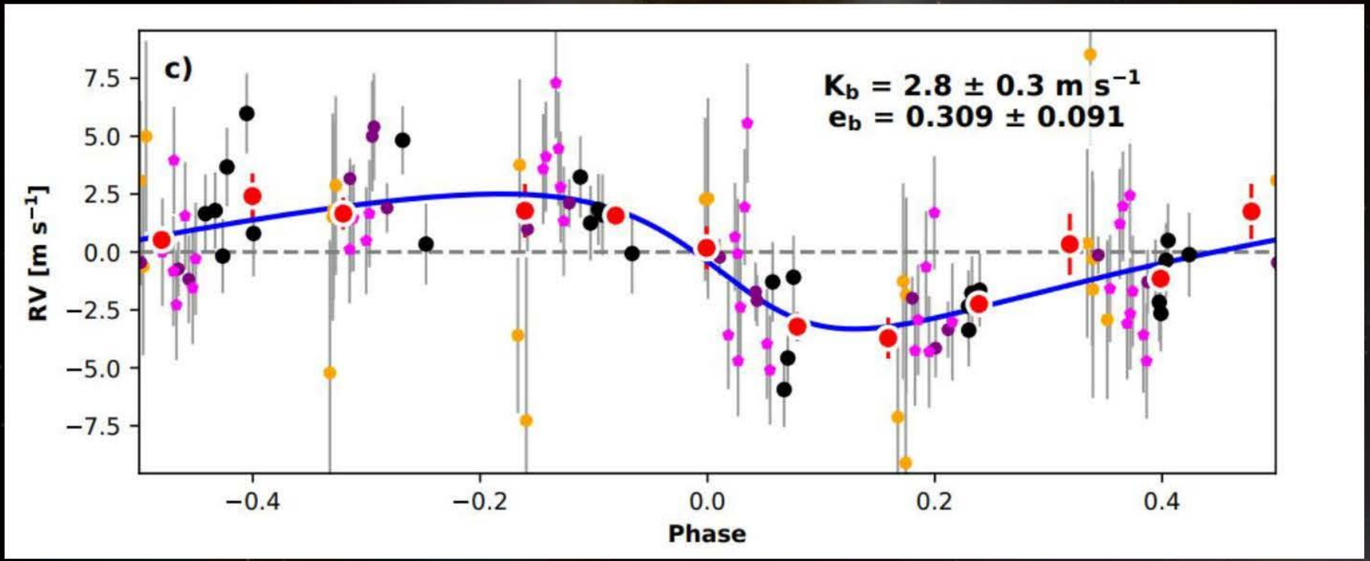




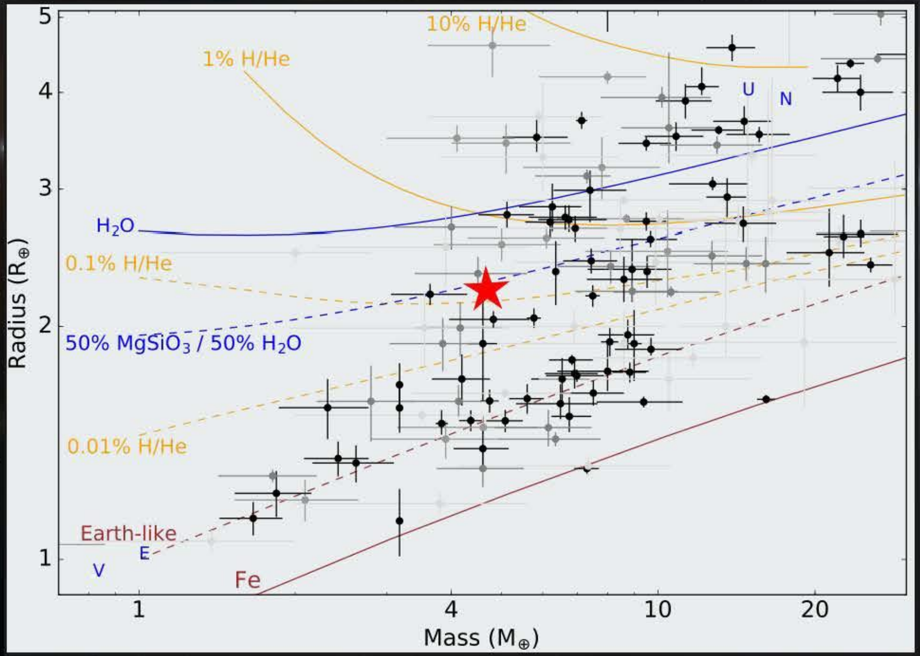
Weighing a Planet....



Measuring the mass of Wolf 503b reveals a planet over 6 times the mass of Earth making it a sub-Neptune that may be 50% water!

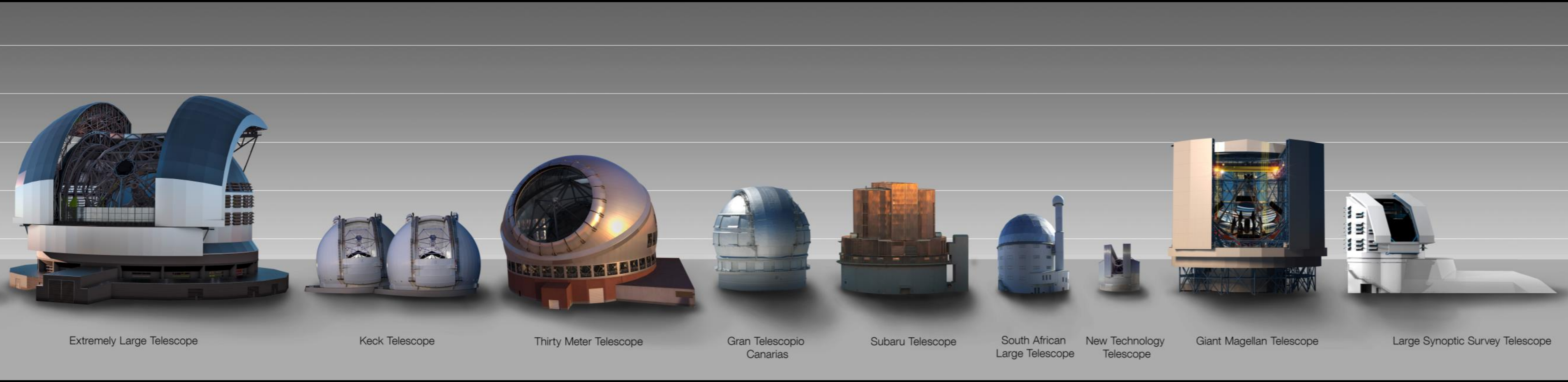


Polanski et al. (Submitted)

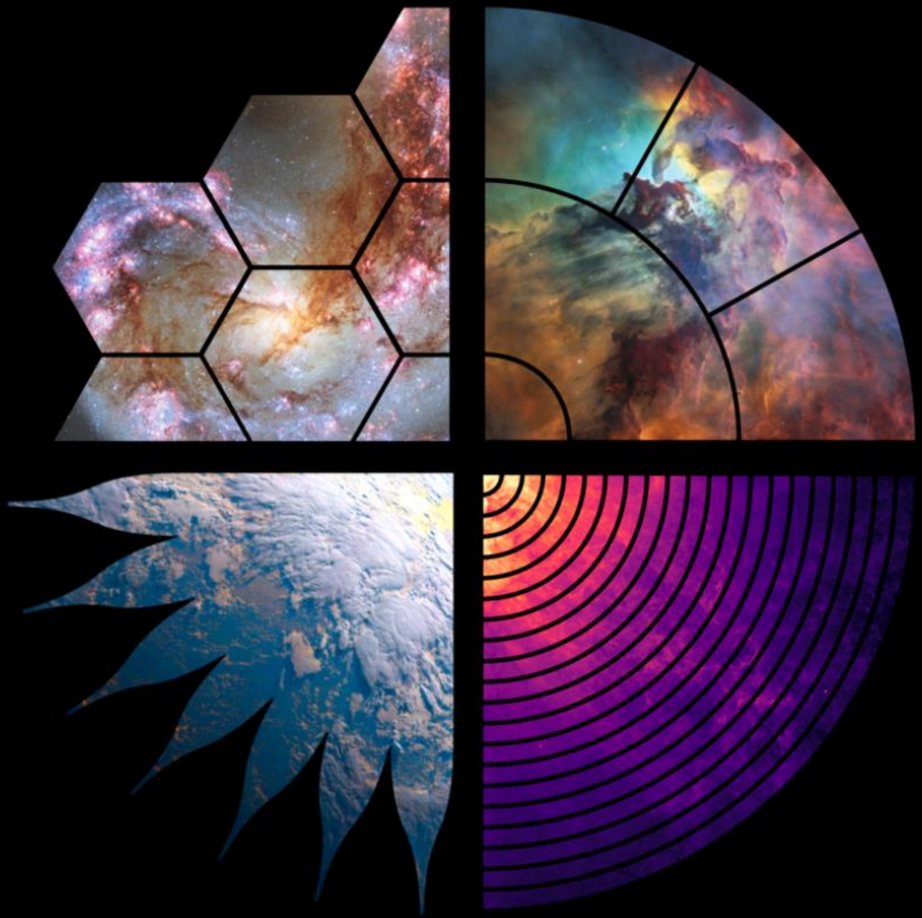


Future Efforts

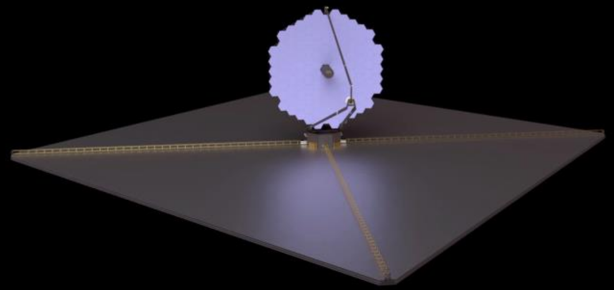
Ground-Based (mid-late 2020s, early 2030s)

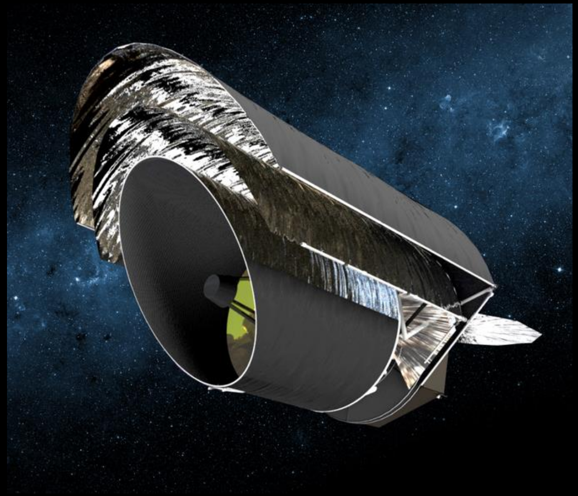


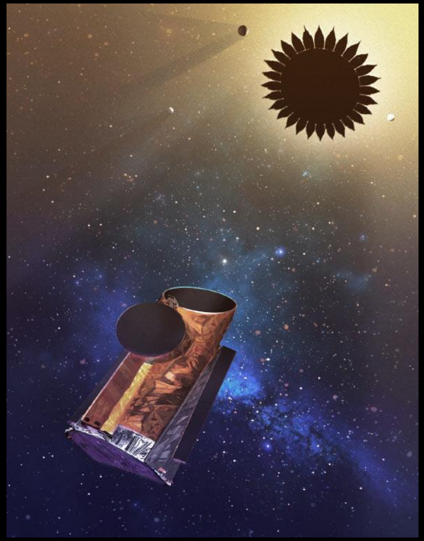
Space-Based (mid-late 2030s)

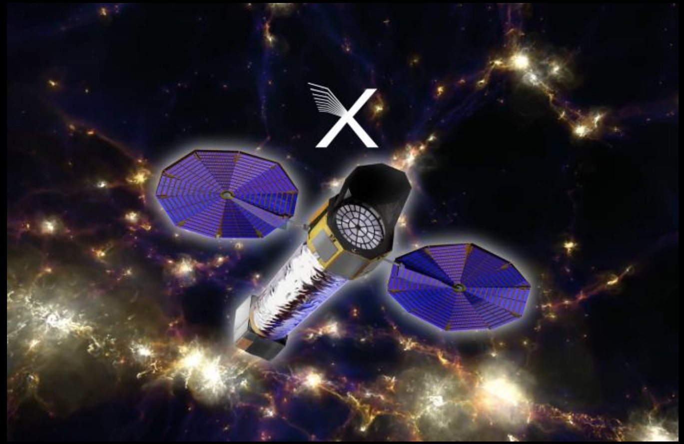


R E M A I N I N L I G H T









Questions!