



# Enduring Quests Daring Visions

NASA Astrophysics in the Next Three Decades

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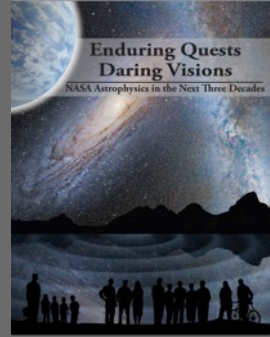
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# Roadmap charter

- ⦿ Roadmap **is ...** a compelling, science-based 30+ year vision, with notional missions
  - Starts from the Astro2010 Decadal
  - Considers cross-cutting opportunities & larger context of ground-based and international astrophysics
  - Considers technology needed to achieve science goals
- ⦿ Roadmap **is not ...**
  - A mini-decadal survey with recommendations & priorities
  - An implementation plan
- ⦿ Ignores budgetary concerns



# Centered around three enduring science questions




















**How does the universe work?**

**How did we get here?**

**Are we alone?**

# Divided into three eras

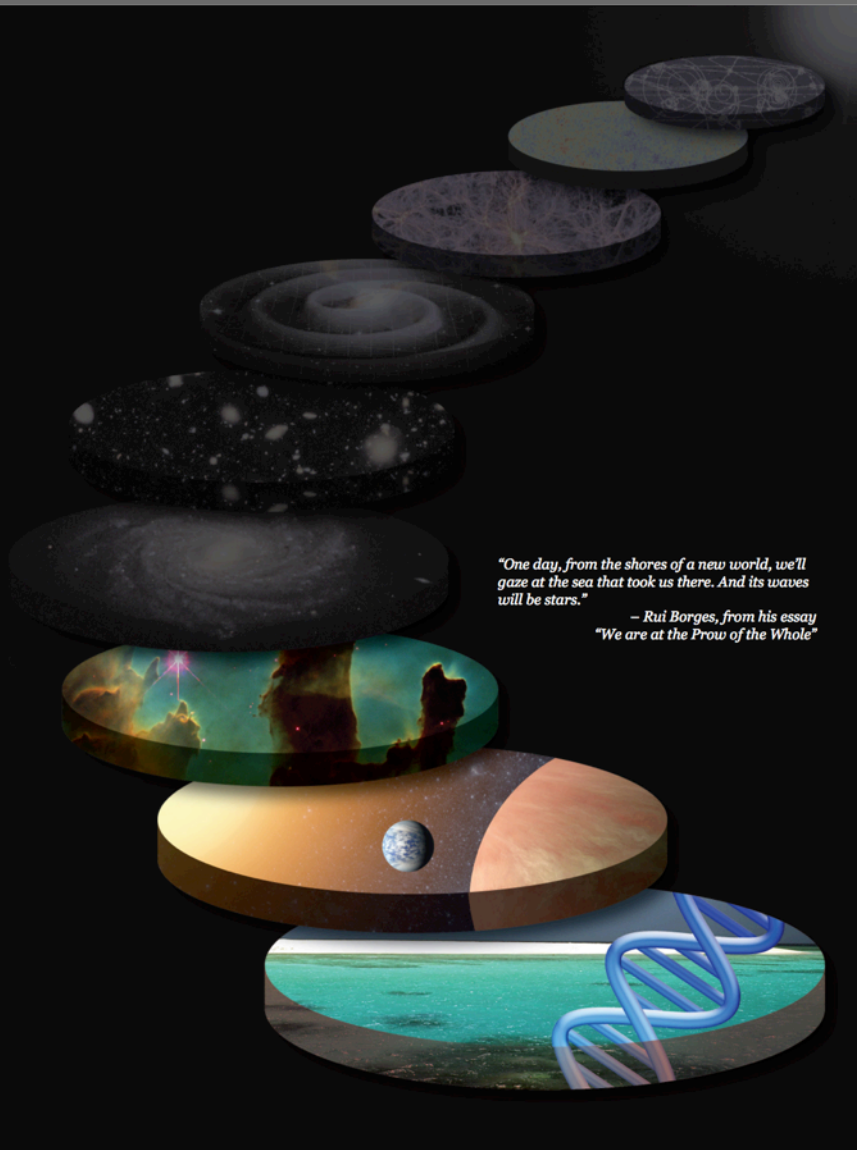
	Near-Term	Formative	Visionary
Gravitational Waves		 Gravitational Wave Surveyor	 Gravitational Wave Mapper
Cosmic rays	 JEM-EUSO		
Radio			 Cosmic Dawn Mapper
Microwaves		 CMB Polarization Surveyor	
Infrared	 JWST	 Far IR Surveyor	
Optical	 WFIRST-AFTA	 LUVOIR Surveyor	 ExoEarth Mapper
Ultraviolet	 Euclid		
X-rays	 TESS		
Gamma rays	 Gaia		
	 NICER	 Astro-H	
		 Xray Surveyor	 Black Hole Mapper

**Near-Term Era  
now to 2020**

**Formative Era  
2020 – 2030**

**Visionary Era  
2030+**

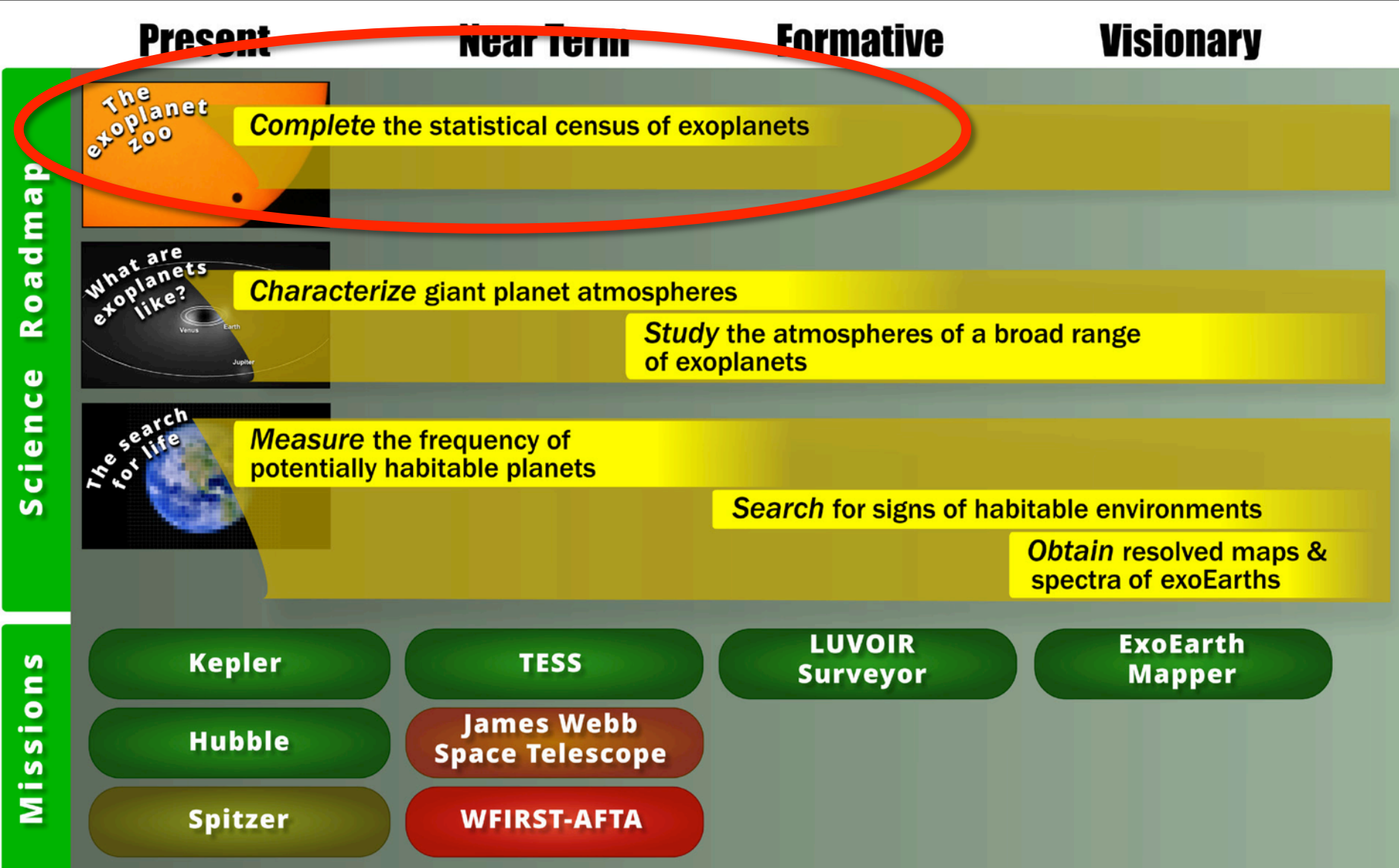
# Are we alone?



## Three exoplanets quests

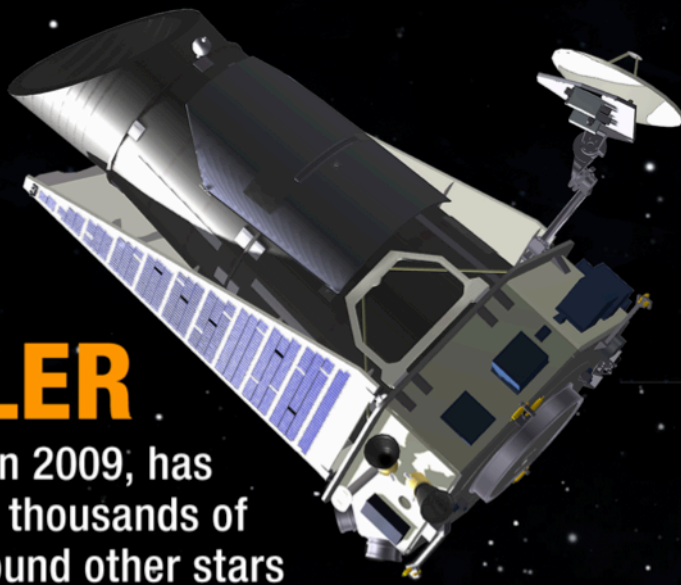
1. The exoplanet zoo
2. What are exoplanets like?
3. The search for life

# Quest 1 – The exoplanet zoo



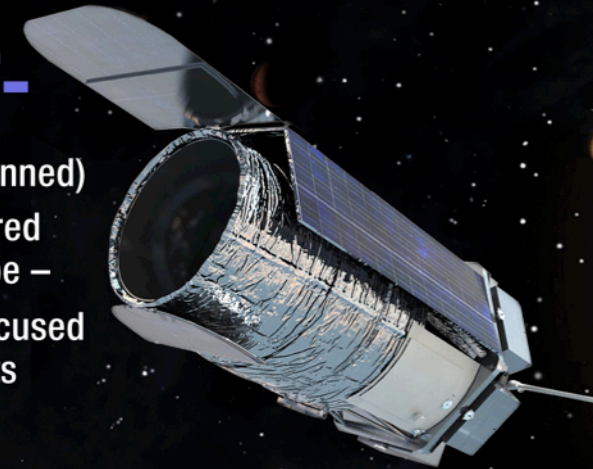
# KEPLER

Launched in 2009, has discovered thousands of planets around other stars

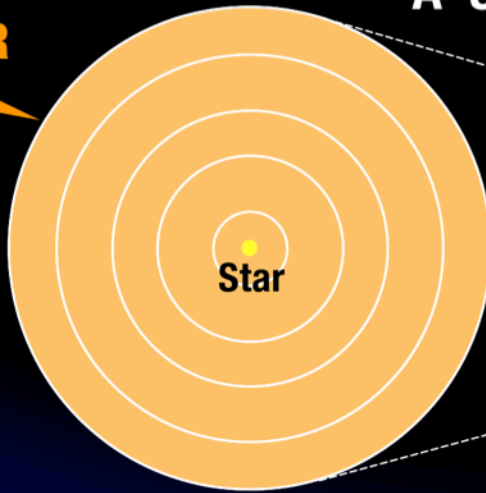


# WFIRST-AFTA (Planned)

Wide Field Infrared Survey Telescope –  
Astrophysics Focused Telescope Assets



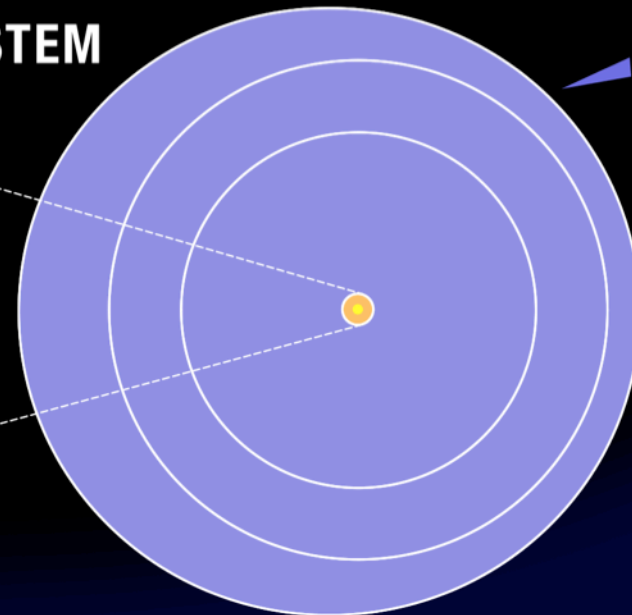
**KEPLER**  
looks  
here



Inner orbits

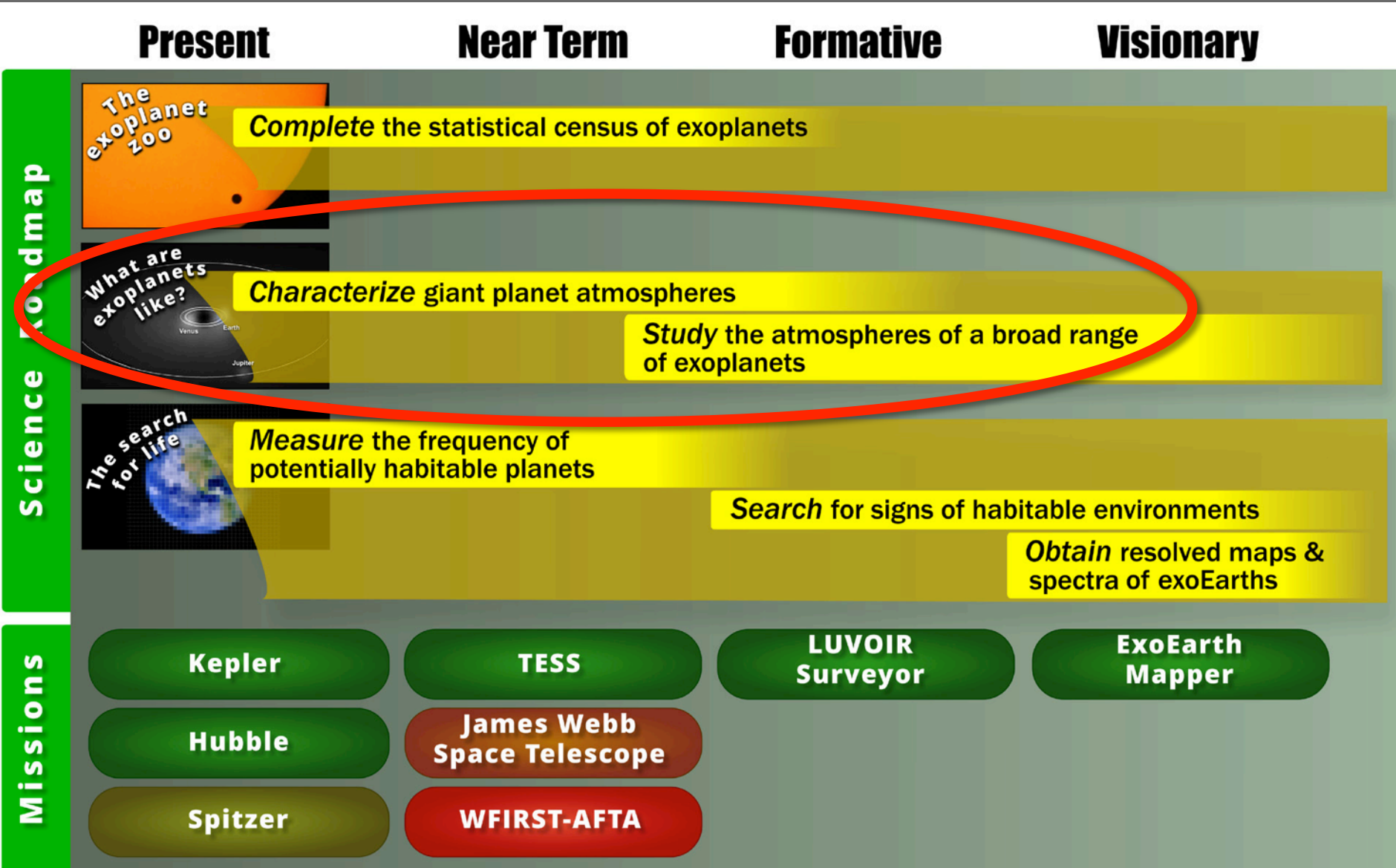
## A SOLAR SYSTEM

**WFIRST**  
will look  
here



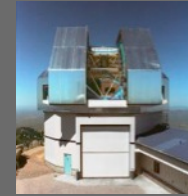
Outer orbits

# Quest 2 – What are exoplanets like?

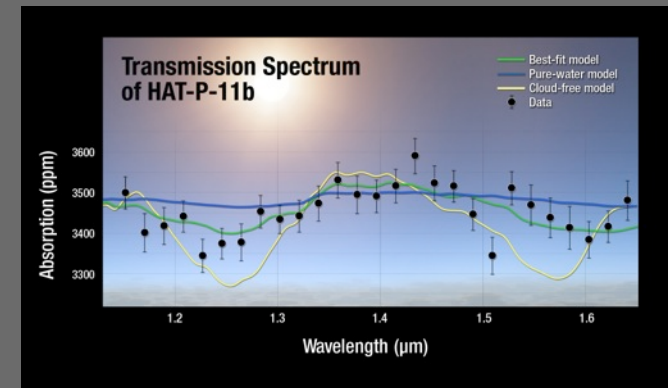
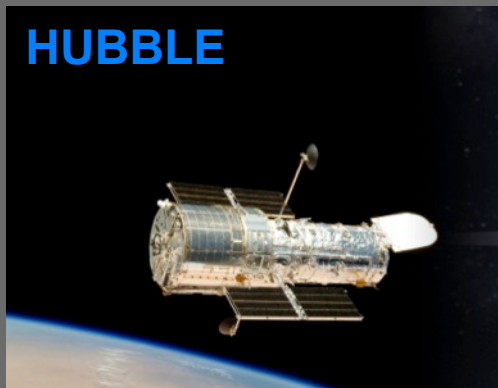


# Spectroscopy

Support from  
ground-based RV

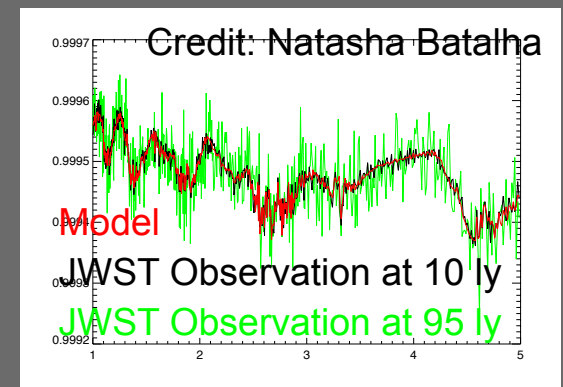
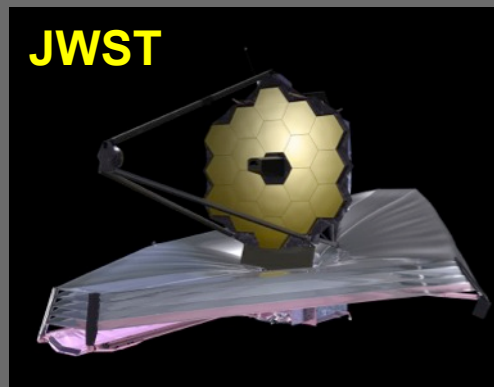


**Now:** Hot Jupiters



Credit: NASA / ESA / STScI

**Near Future:** Hot to warm Neptunes & super-Earths



# Quest 3 – The search for life

**Present**

**Near Term**

**Formative**

**Visionary**

Science Roadmap

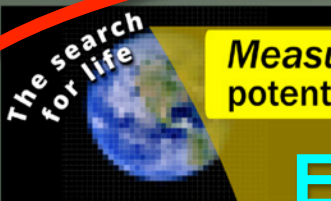


Complete the statistical census of exoplanets



Characterize giant planet atmospheres

Study the atmospheres of a broad range of exoplanets



Measure the frequency of potentially habitable planets

**$\text{Eta}_{\text{Earth}} \sim 10\%$**   
(e.g. Petigura et al. 2013)

Search for signs of habitable environments

Obtain resolved maps & spectra of exoEarths

Missions

Kepler

TESS

LUVOR  
Surveyor

ExoEarth  
Mapper

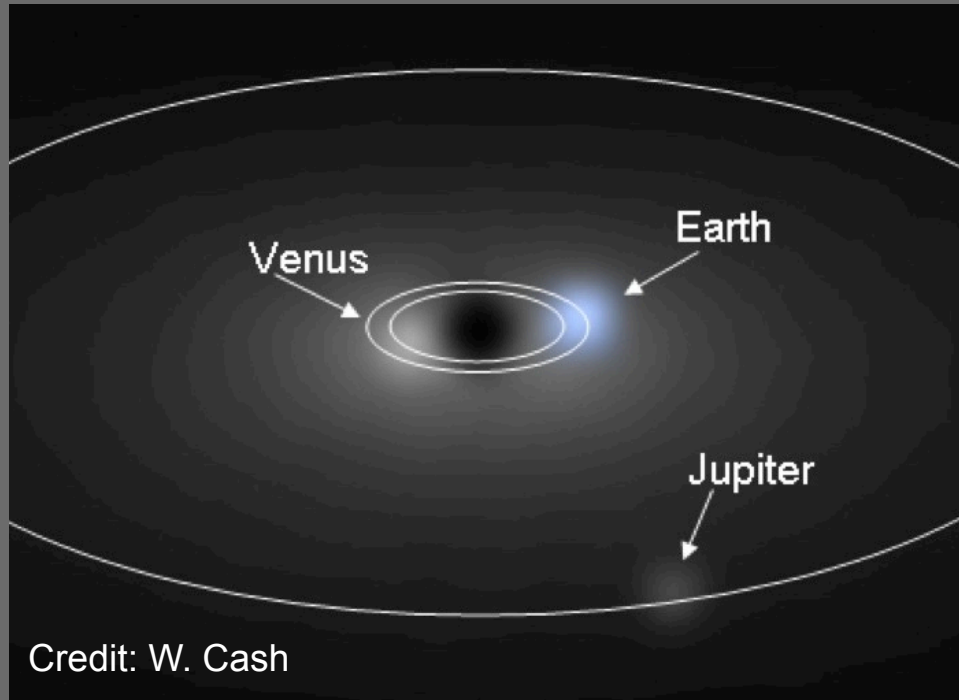
Hubble

James Webb  
Space Telescope

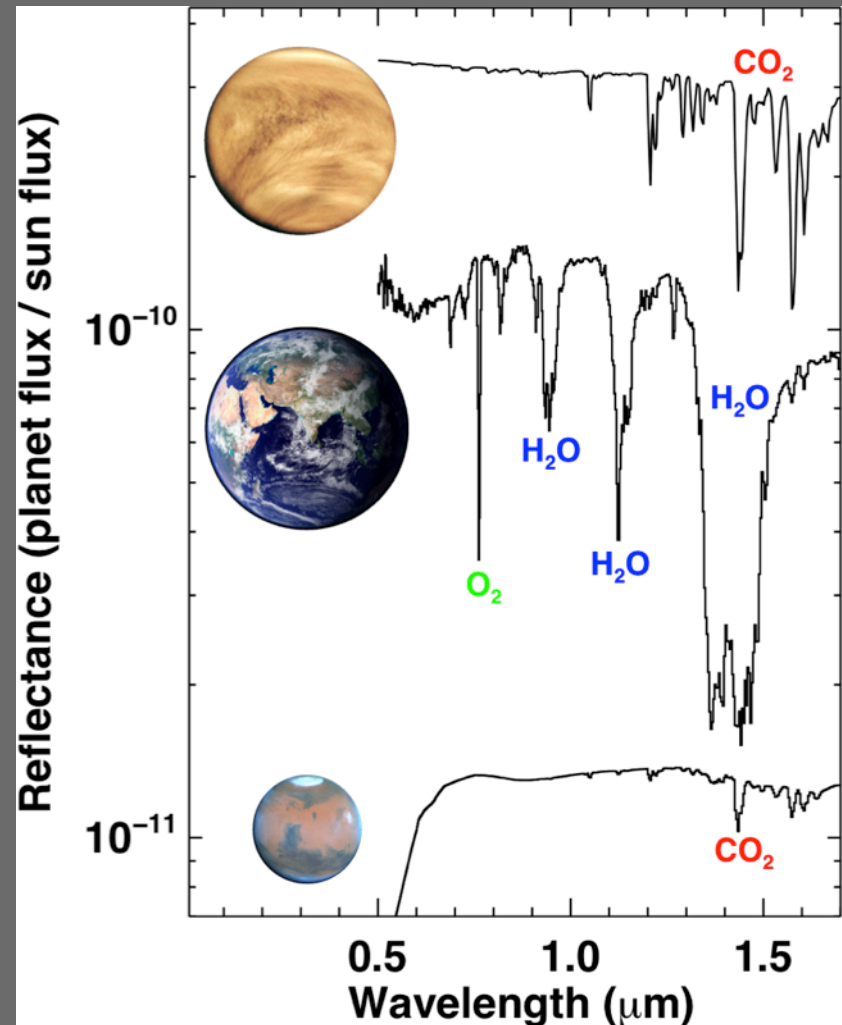
Spitzer

WFIRST-AFTA

# Formative era: Pale blue dots



**Direct UV / optical / NIR  
spectroscopy  
of terrestrial planets**

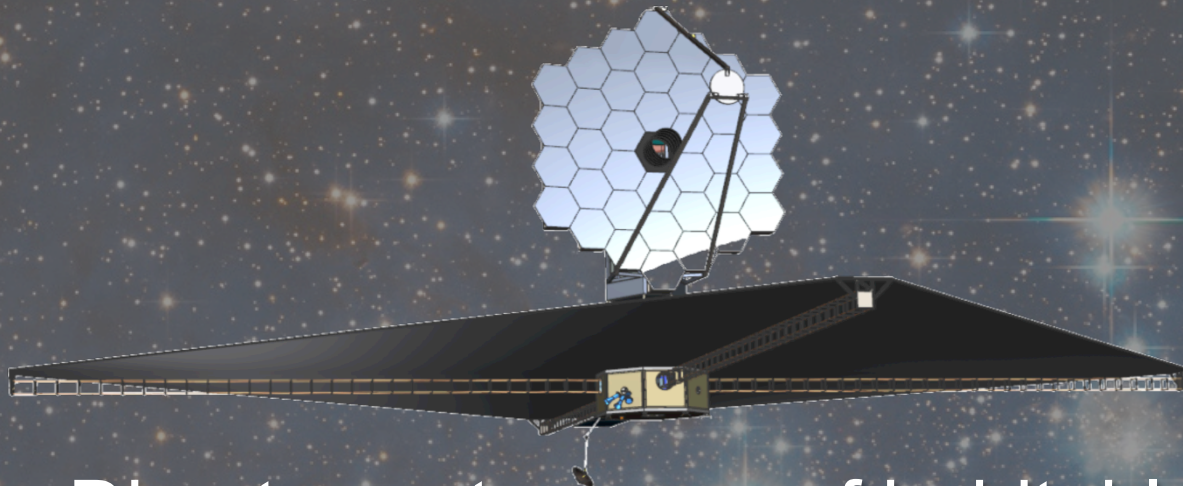


Credit: VPL / A. Roberge

# Why direct UVOIR observations?

- ◉ Unlikely to obtain many spectra of Earth-like planets around Sun-like stars with transits
  - Few planets transit due to geometry
  - Small atmospheric cross-section relative to star
  - Sensitivity to cloud layers
- ◉ UVOIR offers access to valuable diagnostic gases :  $\text{H}_2\text{O}$ ,  $\text{O}_2$ ,  $\text{O}_3$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ , ...
  - Technology for mid-IR direct observations viewed as immature (ref. previous ExoPAG discussions)

# Large UV / Optical / IR Surveyor



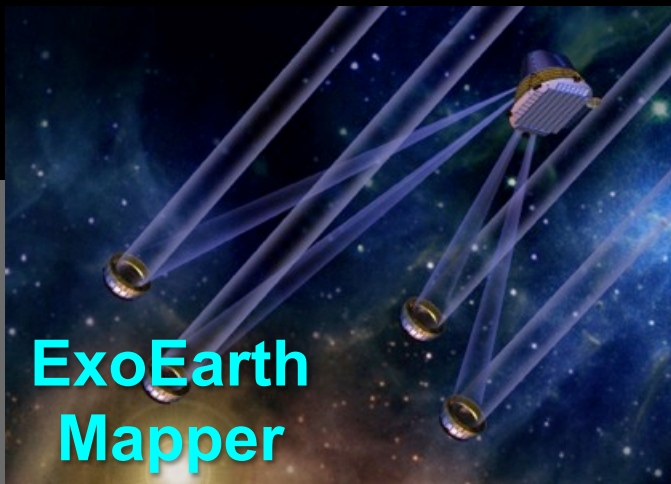
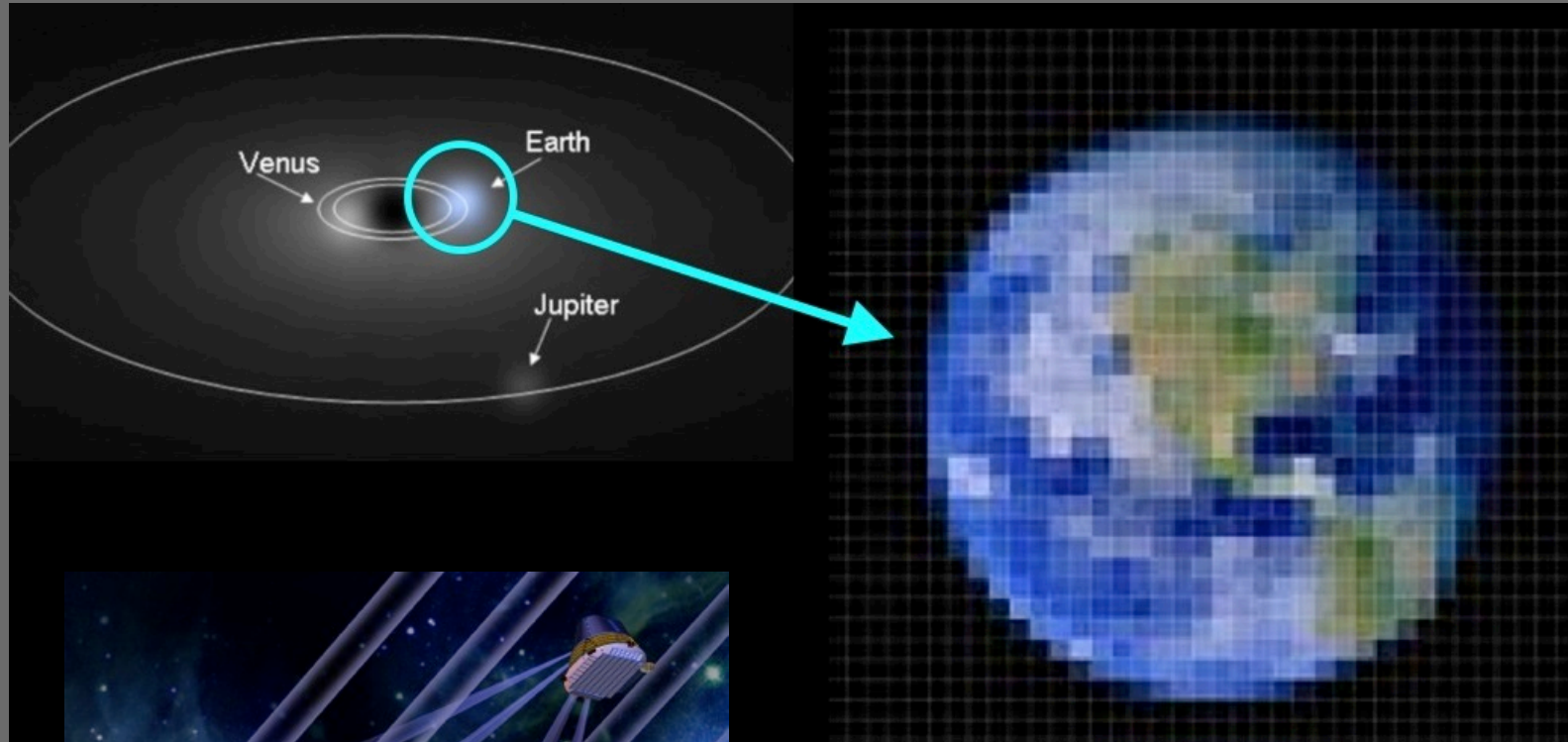
**Support from  
ground-based RV**



- Direct spectroscopy of habitable zone terrestrial planets around Sun-like stars
- Direct & transit spectroscopy of planets with wide range of sizes and temperatures
- Broad range of general astrophysics



# Visionary era: Mapping exoEarths



**Progression from unresolved  
to resolved observations  
(oceans, continents,  
weather, seasons, vegetation)**

# Technology

## ◉ LUVOIR Surveyor

- Larger apertures (8+ meters desired)  
*“The telescope should therefore be as large as technologically realistic within the Formative Era.”*
- Starlight suppression (coronagraphs and/or starshades)
- Low (or zero) noise detectors

## ◉ ExoEarth Mapper

- Space-based interferometry
- Few hundred km baselines,  $\sim 500 \text{ m}^2$  collecting area

