Multiple Techniques Required For Full Characterization of Inhabited Worlds

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On the subject of stars … We shall never be able by any means to study their chemical composition. ---
August Comte, 1835

Beichman et al Protostars & Planets V.

Comparative Planetology and the Search for Life Beyond the Solar System

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What Makes a Planet Habitable?

Environment

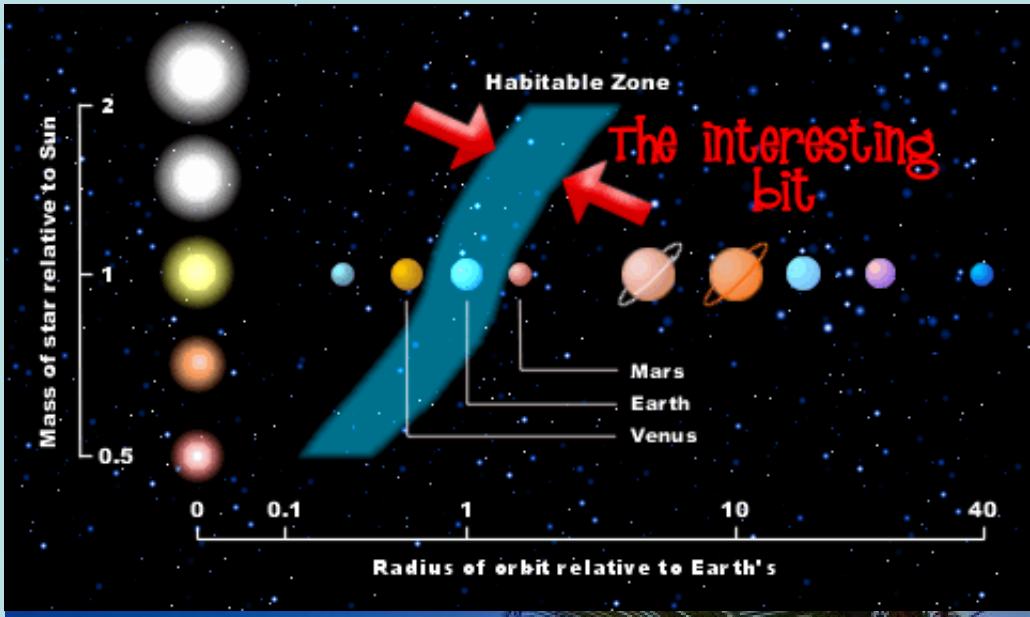
- Distance from Star
- Low eccentricity orbit for stable temperatures
- Long term orbital stability
- Low bombardment rate
- Low UV/X-ray Flux

Planet size & mass

- No runaway accretion but able to retain atmosphere
- Plate tectonics for active carbon cycle
- Molten core for magnetic field for solar wind protection

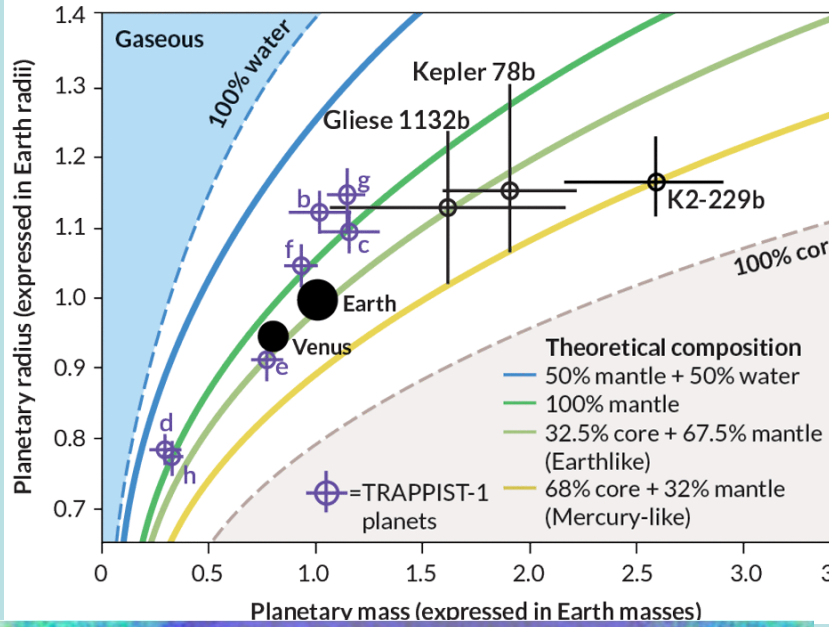
Composition

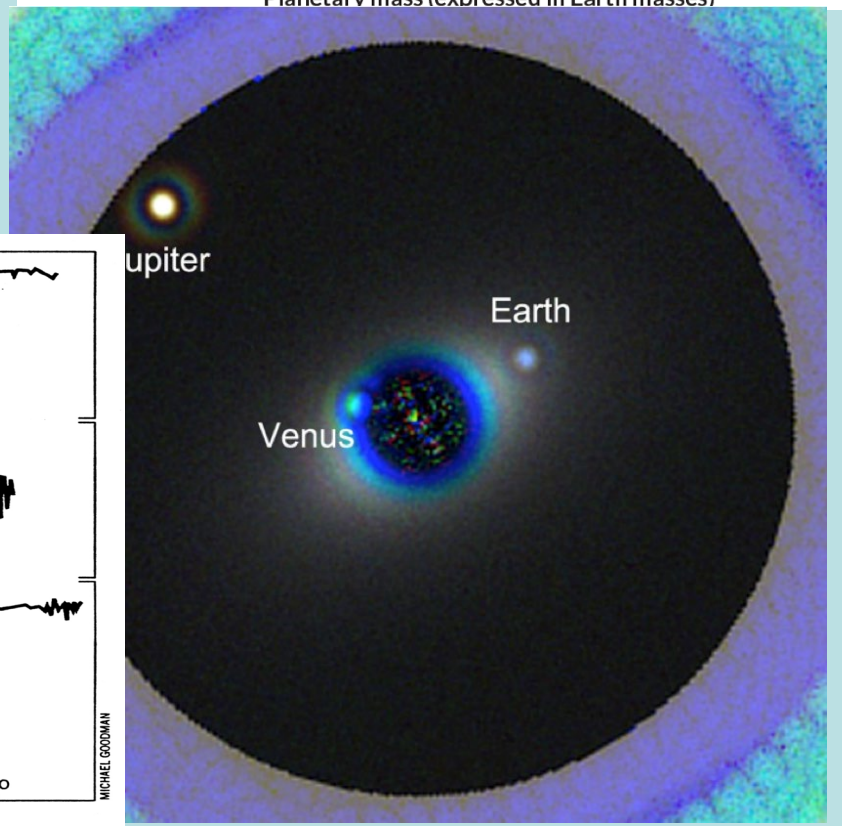
- Surface Temperature
- Supply of water and volatiles
- Solid surface for life



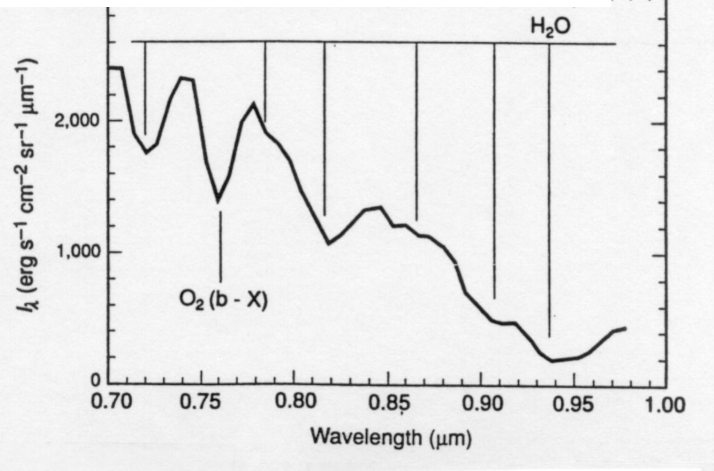
Available Techniques

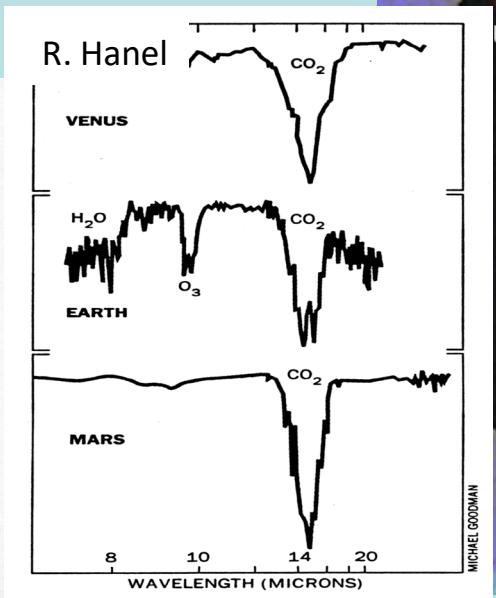
- Dynamical measurements
  - Mass
  - Full orbital information incl eccentricity
  - inner/outer planets and coplanarity
- Direct imaging
  - Orbital position
  - Composition from low resln spectroscopy
  - Brightness as f(wavelength and time)
  - Exozodi brightness





Sagan et al. (1993), Toby Owen (1980)



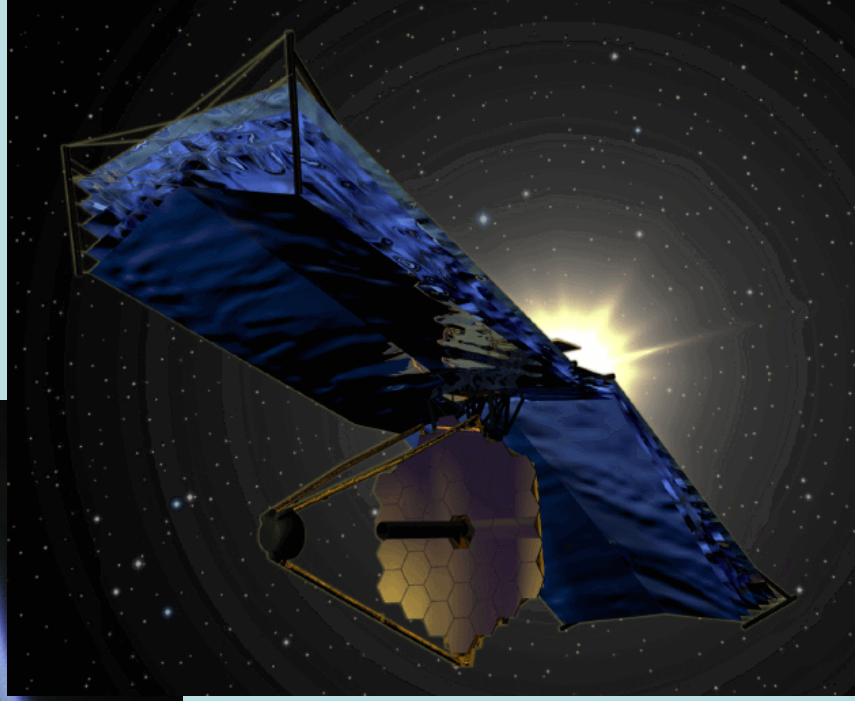


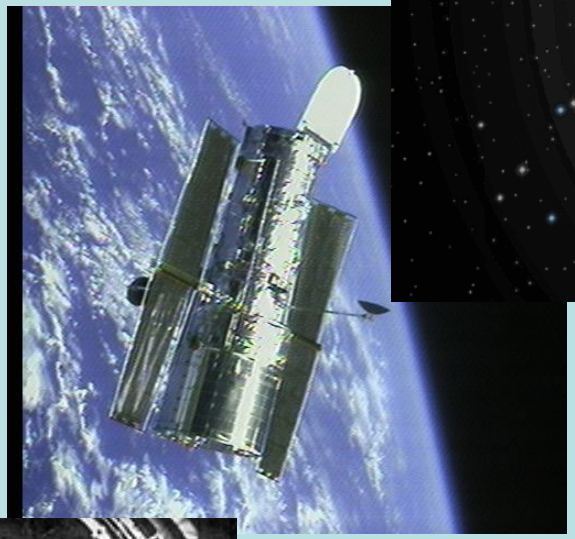
Measurement Synergies

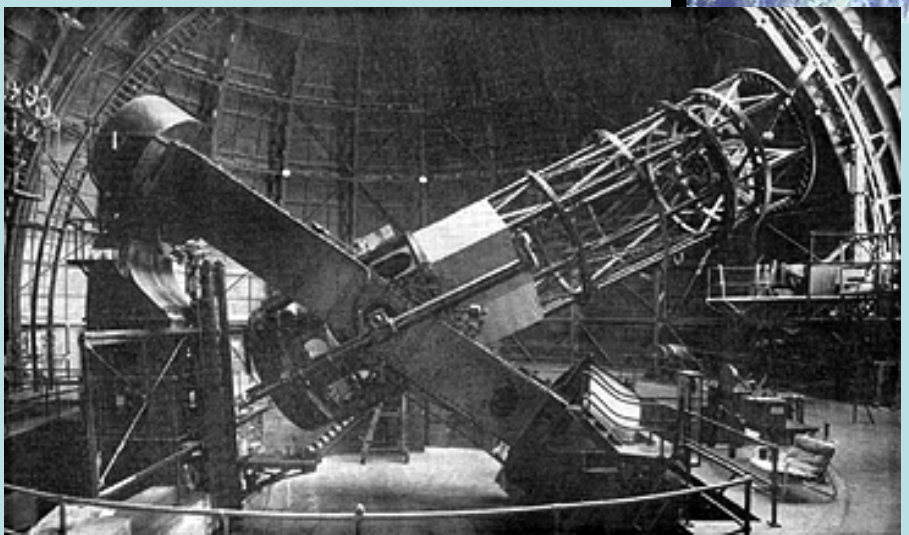
Parameter	RV	Astrometry	UV	Visible	Near-IR	Mid-IR
Stable Orbit & Temp	Measure	Measure	Estimate	Estimate	Estimate	Estimate
Other Planets	Measure	Measure		Estimate	Estimate	Estimate
Planet Mass	Measure	Measure				
Planet Temp.				Estimate	Estimate	Measure
Planet Radius				Joint	Joint	Measure
Planet Albedo			Joint	Joint	Joint	Joint
Surface Grav.	Joint	Joint		Joint	Joint	Joint
Bulk Comp.	Joint	Joint		Joint	Joint	Joint
Atmos Comp.			Measure	Measure	Measure	Measure
Surface Comp.			Measure	Measure		
Clouds & Hazes			Measure	Measure		
H2O Presence					Measure	Measure
Biomarkers			Meas (O3)	Meas (O2)	Measure	Meas (O3)
ExoZodi (bombardment)				Measure		Measure

Search For Life Will Require Many Techniques And Many Decades

- Like cosmology, the search for planets and life will motivate broad research areas and utilize many telescopes for **decades** to come







- Field of planet & characterization will be broad and rich, with results on many time scales
- Exciting, mid-term efforts to detect and characterize gas giants, water worlds, Super-Earths and even Earths