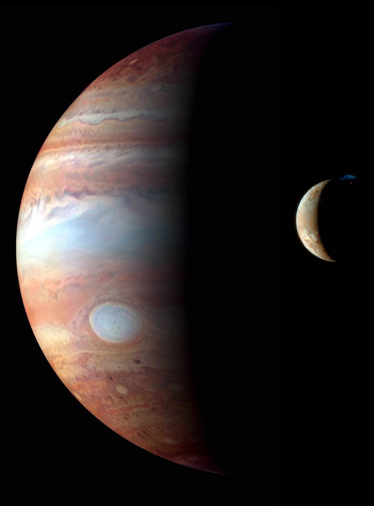

Image: NASA

Exomoon Sensitivity
of the Keck Planet Imager and Characterizer (KPIC)

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Why is it important to look for moons?

The detection of satellites around exoplanets, or exomoons, remains a largely unexplored territory

- Search for exomoons to constrain their occurrence rates and bulk properties
  - Insights into the **formation of exoplanets and circumplanetary disks**
  - Provide **new places to search for habitability**

How to Detect Moons

Only a few exomoon candidates have been proposed to date

- Transit method (*1, 2*) – 2 candidates
- Direct imaging (*3*) – 1 candidate

Combining high resolution spectroscopy with high contrast imaging can be used to **measure the radial velocities of planets directly to search for exomoons**

- **The next generation of high-resolution spectrographs** may provide the precision necessary to **perform searches for solar system-like exomoons** around directly imaged planets (mass ratios of $q \sim 10^{-4}$)
  - HISPEC planned for the W. M. Keck Observatory (Keck)
  - MODHIS planned for the Thirty Meter Telescope (TMT)

Exomoon Formation Theory

- Exomoon formation paths:
  - In the **circumplanetary disk (CPD)** around an exoplanet
  - **Disk instabilities**, such as brown-dwarf binaries (*3*)
  - Capture (*4*)
  - Collisions with protoplanets (*5*)

Circumplanetary Disk

- CPD total dust mass relative to planet $\sim 10^{-4}$ *(6, 7)*
- Larger planets could form even larger moons (*6*):

$$m_{moon} \propto M_{planet}^{3/2}$$

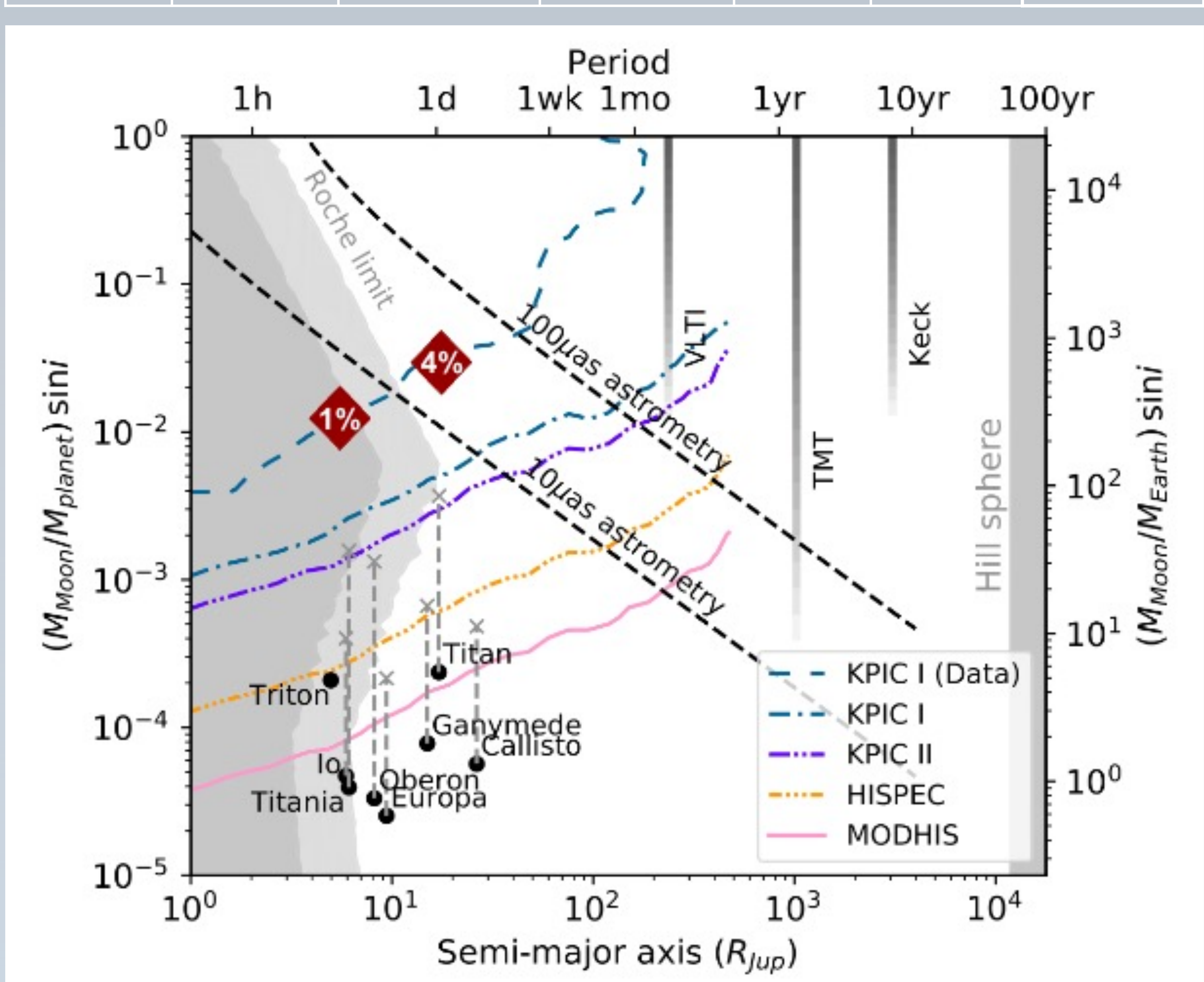
Disk Instabilities

- Mass ratios ~1
- Thought to form in bound systems as often as ~45% when orbiting a host star (8)

Sensitivity of KPIC and Future Instruments

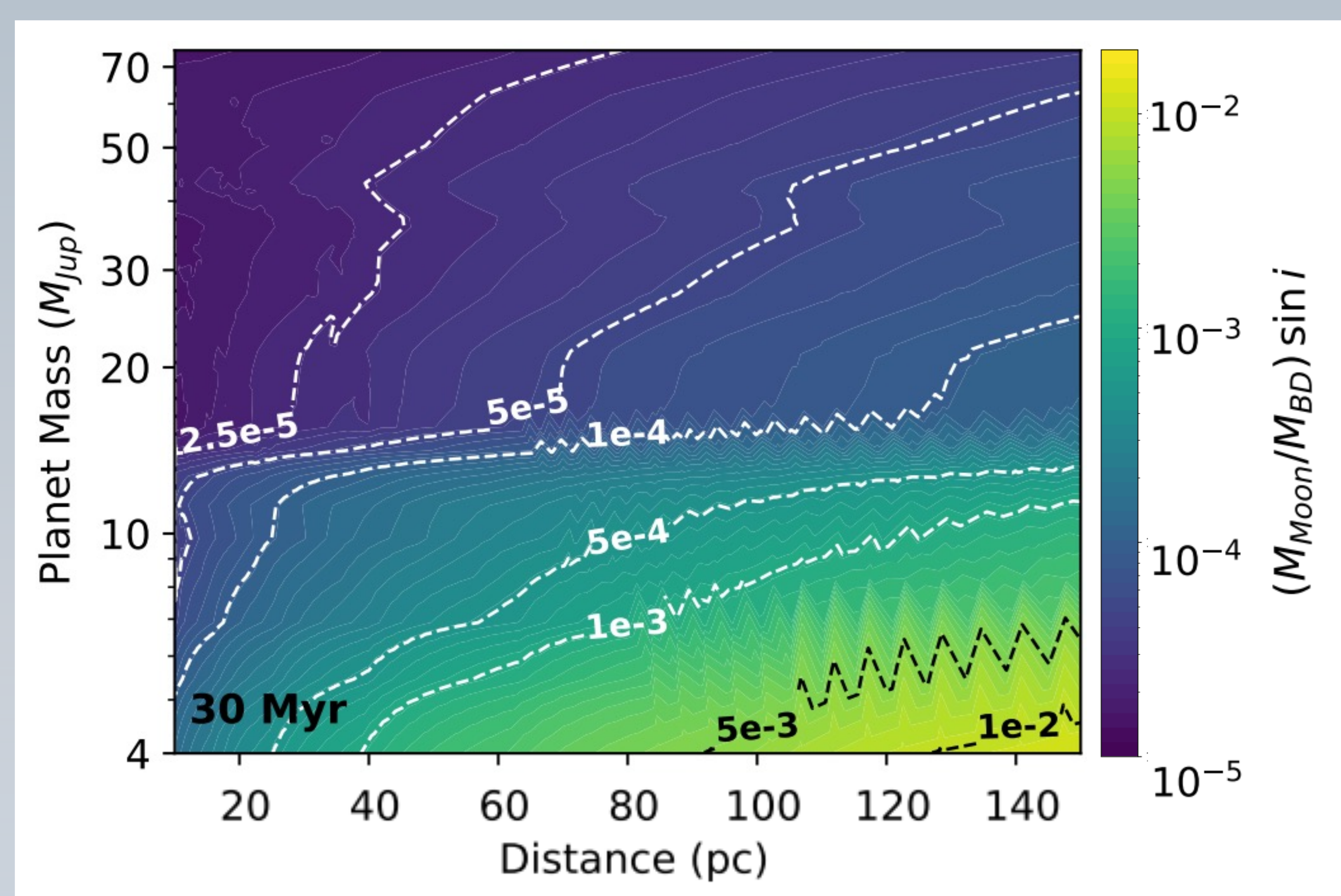
Properties of Brown Dwarf HR 7672B (9, 10, 11)

Mass	Separation	Spectral Type	Temperature	Spin	Apparent Magnitude (K)	Distance
$68.7^{+2.4}_{-3.1}\ M_{Jup}$ (8)	790 mas (9)	L4.5±1.5 (9)	1510-1850 K (9)	40 km/s (10)	13.04 (8)	17.77±0.11 pc (8)



Prospects for exomoon detection around the brown dwarf companion HR 7672 B

- The sensitivity of KPIC for ~1.5 nights of data is shown in blue. The hypothetical sensitivity for 6 nights of data, determined using PSISIM (*13*), of HISPEC and MODHIS in are shown in orange and pink respectively. Example mass ratios and separations are shown for example moons in our solar system. The black dot indicates the true mass ratio and separation from the moon's host planet, while the dotted line with the X marker indicates the mass ratio scaled to the mass of HR 7672B ($m_{moon} \propto M_{planet}^{3/2}$ (*6*))



Predicted radial velocity sensitivity for MODHIS created using PSISIM (13)

- Radial velocity sensitivity for different masses and distances of planets orbiting an example host star with the same properties at HR 8799 for 6 nights of observations over 25 days

Takeaways:

- **Left: KPIC sensitive to 1-4% mass ratios at Galilean satellite-like separations (instability moons)**
- **Right: Future instruments on TMT could be orders of magnitude more sensitive than current (CPD moons)**

Current & Future Work

- **KPIC upgrades and data reduction pipeline (DRP)**
  - KPIC upgrades
    - Laser frequency comb, which will provide substantial gains in RV precision (calibration accuracy expected <10 m/s)
  - KPIC DRP
    - Build a dedicated radial velocity DRP
- **Exomoon Survey**
  - Snapshot survey for binary planets (high mass ratio)
  - Deep observations of best candidate planets/brown dwarfs

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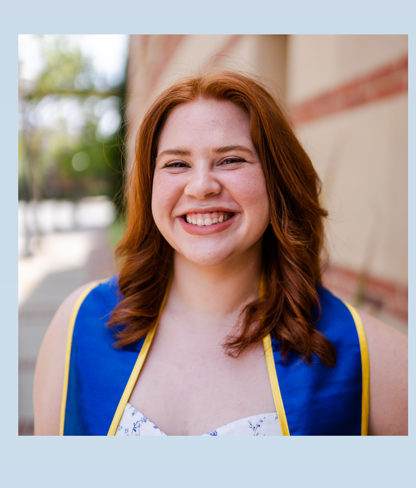
Contact



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