How do Ultra-Massive Planets Form?

Gaining New Insight by Measuring the Orbital Tilt of a Rare Transiting Brown Dwarf

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Image Credit: NASA/JPL-Caltech/SwRI/MSSS/Gerald Eichstädt/Sean Doran

Planets more massive than Jupiter exist

but they are **rare** and **poorly understood**

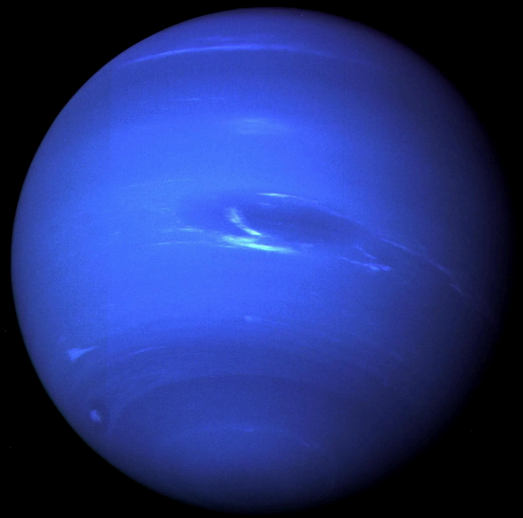
Ultra-massive planets and brown dwarfs

?

Earth

0.3% Jupiter mass

Image Credit: NASA Earth Observatory



Neptune

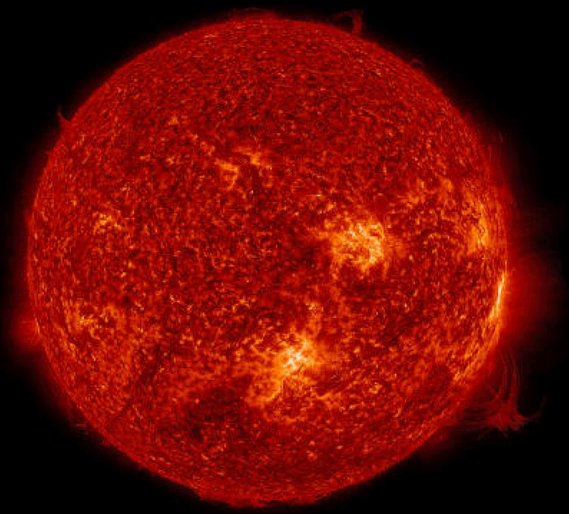
5% Jupiter mass

Image Credit: NASA/JPL

Jupiter

1x Jupiter mass

Image Credit: NASA/ESA/A. Simon



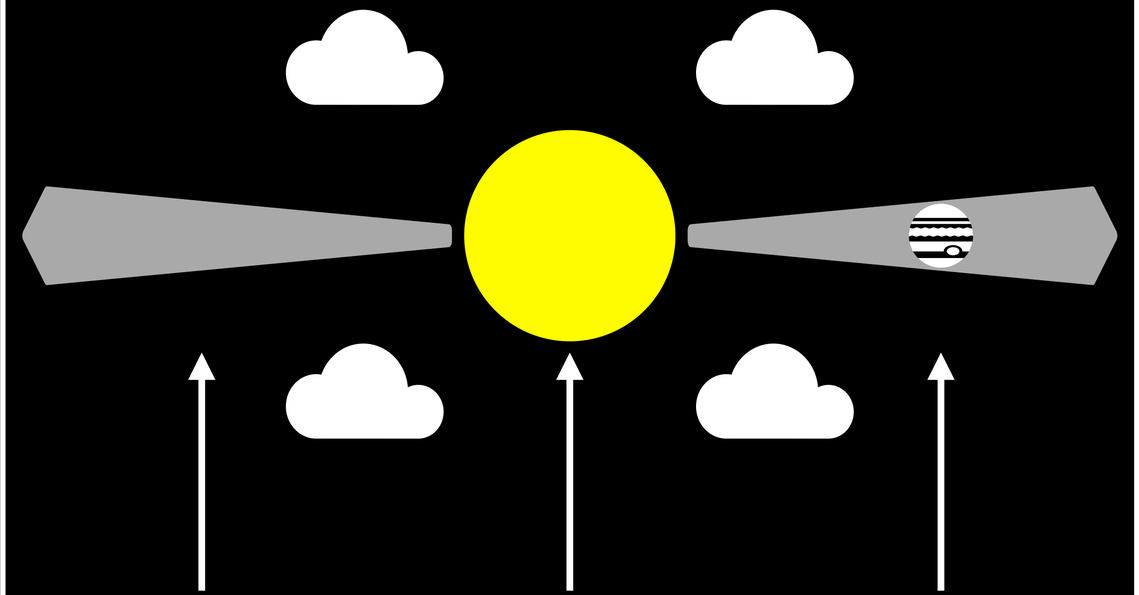
M dwarf star

80x Jupiter mass

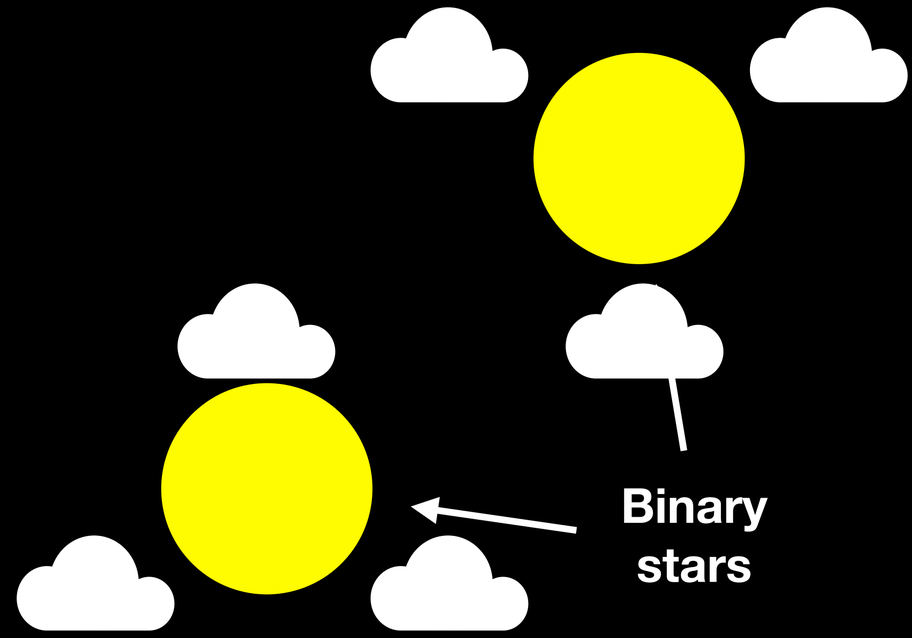
Image Credit: NASA/SDO/AIA/EVE/HMI

Do these massive objects form like **planets** or like **binary stars**?

Planet formation



Binary star formation



Theory predicts that they can form via **both pathways**, but where is the evidence?

Brown dwarfs are known to form like stars sometimes, but direct **observational evidence that they also form like planets is lacking**.

We present new, key evidence that brown dwarfs sometimes form like planets, near the midplanes of these dusty disks.

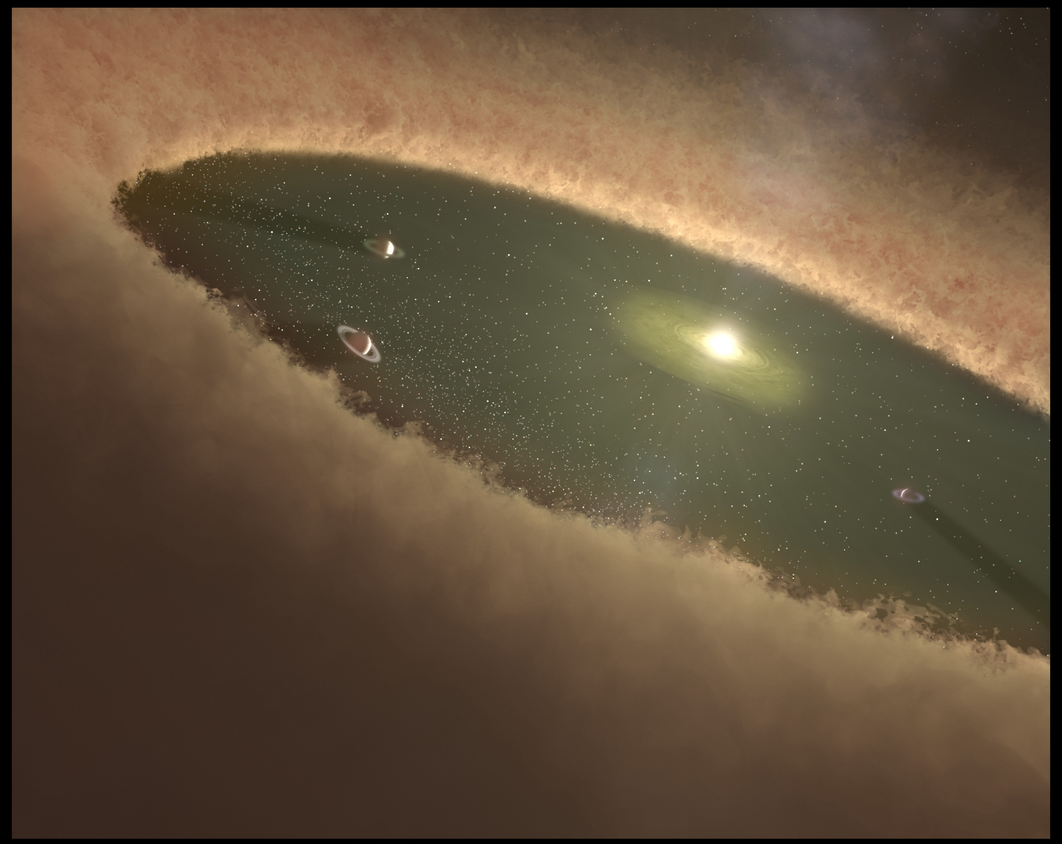
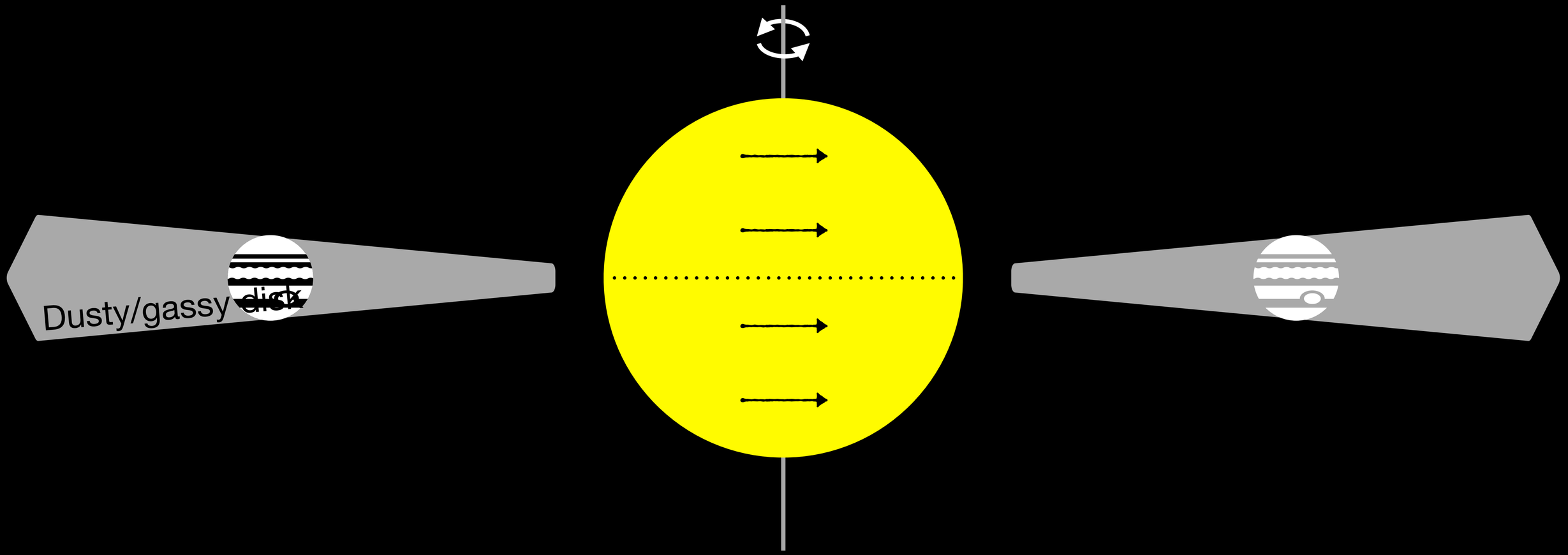


Image Credit: NASA/JPL-Caltech/T. Pyle (SSC)

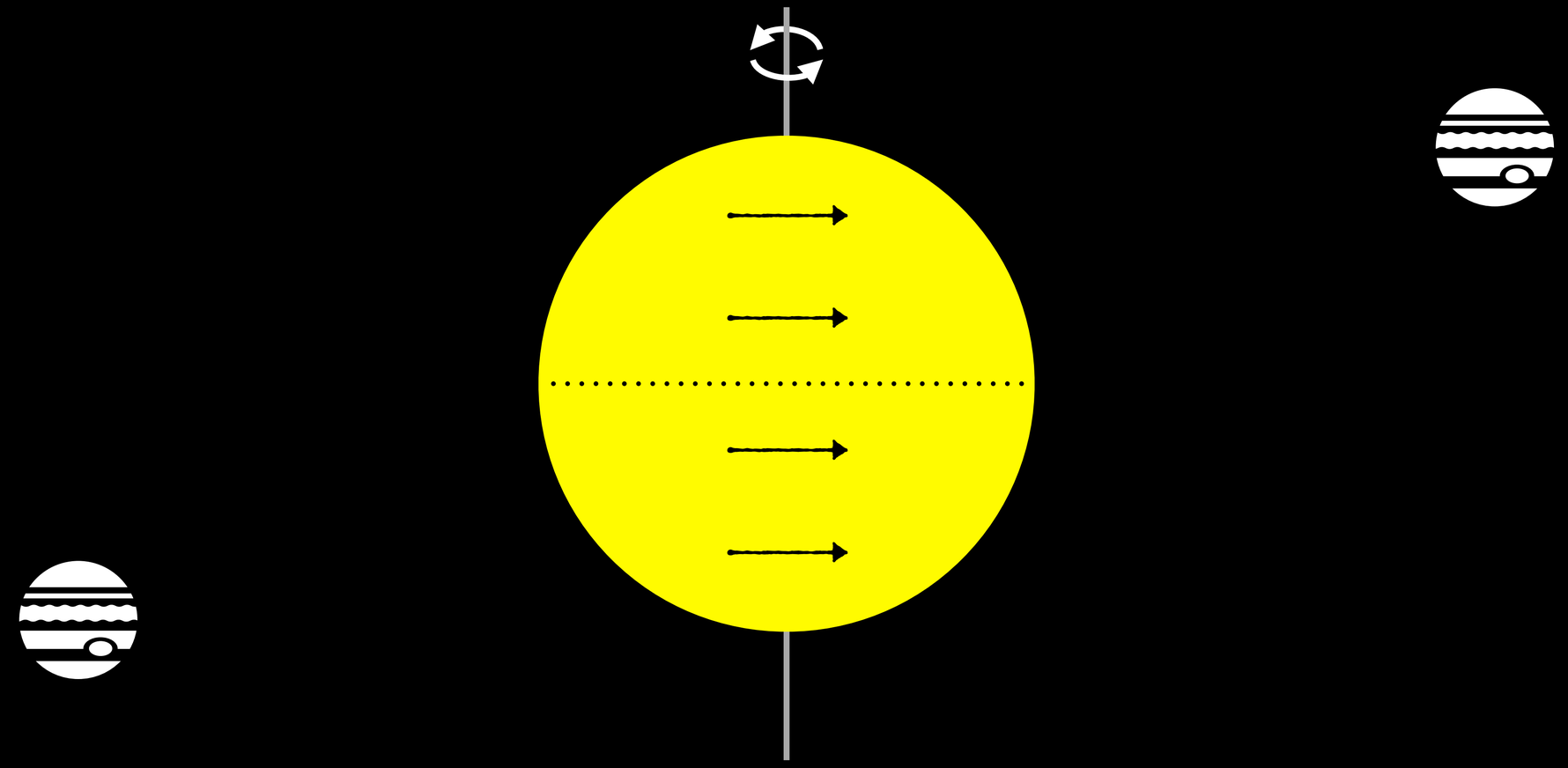
The **orbital tilt** of the object encodes its **formation history**

Orbits **aligned** with stellar equator likely **originated in the disk**



The **orbital tilt** of the object encodes its **formation history**

Orbits **misaligned** with stellar equator likely **originated outside the disk**



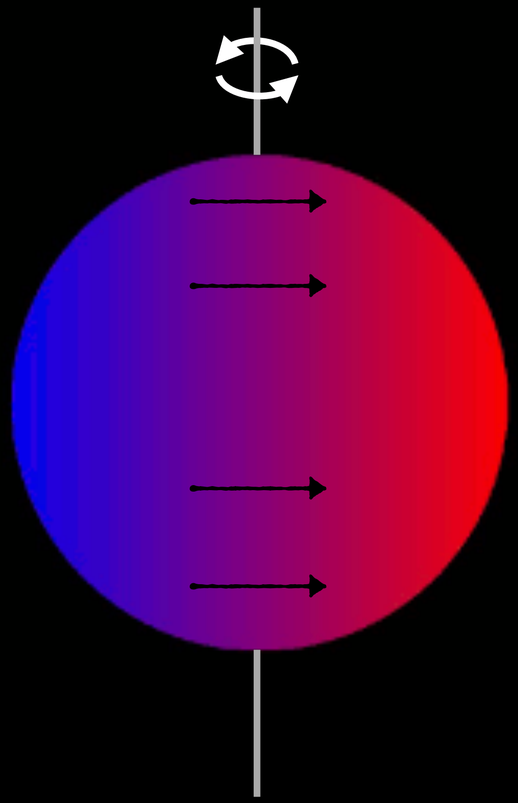
GPX-1b: a brown dwarf with a small orbital tilt

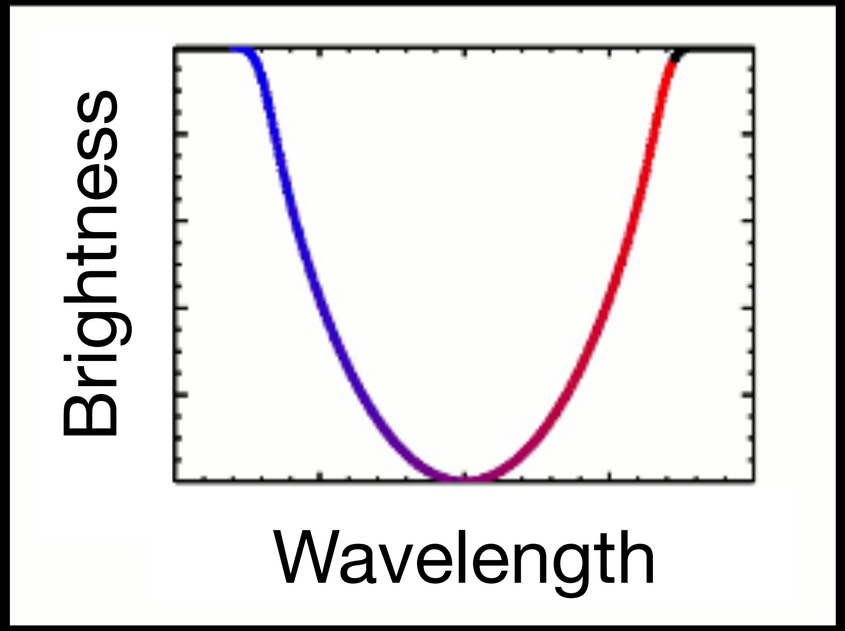
Image Credit: ESA/ATG Medialab/Forbes

- A **transiting** brown dwarf **20x more massive than Jupiter** orbiting close to its central star.
- Discovered by the Galactic Plane eXoplanet survey and the NASA TESS mission in 2021 (Benni et al., published in MNRAS).
- **We measured an orbital tilt that is well-aligned to the stellar equator** (Giacalone et al., in prep), suggesting that it may have **formed in the disk like a planet**.

We measured the orbital tilt of GPX-1b using the new **Keck Planet Finder** spectrograph

This ultra-stable, high-resolution spectrograph at the W.M. Keck Observatory **can detect subtle warping of the stellar spectrum** caused by the object's transit. **This warping reveals the orbital tilt.**





Animation Credit: Marshall Johnson

Recap + the future of ultra-massive planets

- It is unknown if ultra-massive planets and brown dwarfs form like **planets (in disks surrounding their young stars)** or like **stars (outside of these disks)**.
- To gain new insight, **we measured the orbital tilt of the brown dwarf GPX-1b**. Our results suggest that it **likely formed in the disk** like a planet.
- We **plan to observe similar systems** to build a sample with which to perform **robust statistical analyses**.
- These objects are **rare** and are mostly **found around faint stars**. We need a modern spectrograph on a large telescope to accomplish this. **KPF on the Keck 10-meter telescope is one of the best tools available.**

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