**DIRECT DETECTION OF CO IN THE PLANET AROUND CI TAU: PLANET FORMATION CONSTRAINTS FROM A YOUNG HOT JUPITER.** Laura Flagg¹, Christopher Johns-Krull², Larissa Nofi³, Joe Llama³, Lisa Prato³, Kendall Sullivan⁴, Daniel T. Jaffe⁴, and G. N. Mace⁴. ¹Department of Physics and Astronomy, Rice University, 6100 Main St. MS-108, Houston, TX 77005, USA, Institute for Astronomy, University of Hawai`i at Mānoa, 2680 Woodlawn Drive, Honolulu, HI 96822, USA, ²Lowell Observatory, 1400 W Mars Hill Road, Flagstaff, AZ 86001, USA, ³McDonald Observatory and the Department of Astronomy, The University of Texas at Austin, Austin, TX 78712, USA.

**Introduction:** The first hot Jupiter was discovered in 1995. After nearly a quarter century, the origin of these close in massive planets remains a mystery [1]. More generally, the primary mechanisms by which giant planets form – core accretion or gravitational instability – is not firmly established [2]. Different formation models for giant planets differ substantially in the physical parameters expected at young ages [3]. Observing very young, newly formed planets, such as a candidate ~11 M Jupiter in a 9 day orbit around the ~2 Myr old T Tauri star CI Tau [4], is perhaps the best way to test the various models.

**Methods:** We analyzed a total of 40 K band spectra of CI Tau obtained with the IGRINS spectrometer at the 2.7 m Harlan J. Smith telescope of McDonald Observatory and the 4.3 m DCT of Lowell Observatory. We focused on 4 orders of the echelle format which contain numerous CO lines between 2.3 and 2.4 microns. After removing telluric and stellar lines, we used the orbit of the star to shift the lines expected from the planet to the systemic velocity and then co-added spectra from different epochs. We cross correlated this co-added spectrum with a template of the expected planetary spectrum.

**Results:** Figure 1 shows the cross correlation significance with a peak (5.7σ) at the expected location of CI Tau b based on the discovery paper [4]. This indicates a direct detection of CO in the planet’s atmosphere, confirming the existence of the planet and allowing us to directly study its properties. Based on the planet’s measured velocity amplitude, we calculate a mass of 11.6 M Jupiter for CI Tau b.

**We also estimated the contrast ratio between the star and the planet. Combined with the K-band magnitude of CI Tau and the Gaia distance to the star, we estimate the absolute K-band magnitude of CI Tau b at 8.17. CI Tau b is the youngest confirmed exoplanet as well as the first exoplanet around a T Tauri star with a directly determined, model-independent, dynamical mass.**

**Conclusions:** Figure 2 shows the absolute K band magnitude vs age for a sample of young planet candidates including CI Tau b, as well as hot & cold start planet models [3]. Only Beta Pic b and CI Tau b have independent measurements of their mass and brightness and these strongly favor hot start models. Follow up work to detect H2O and CH4 will be done to constrain the planet’s composition and link this to the nature of gas giant planet formation.

![Figure 1: The cross-correlation function significance plotted as a function of planet velocity amplitude and systemic velocity.](image1.png)

![Figure 2: A sample of known young planets giving their K band absolute magnitude vs age. Also shown are hot (red) & cold (blue) start models [3].](image2.png)