

Is the HL Tau Disk Gravitationally Stable?



Alice S. Booth (Leiden Observatory) and John Ilee (University of Leeds)

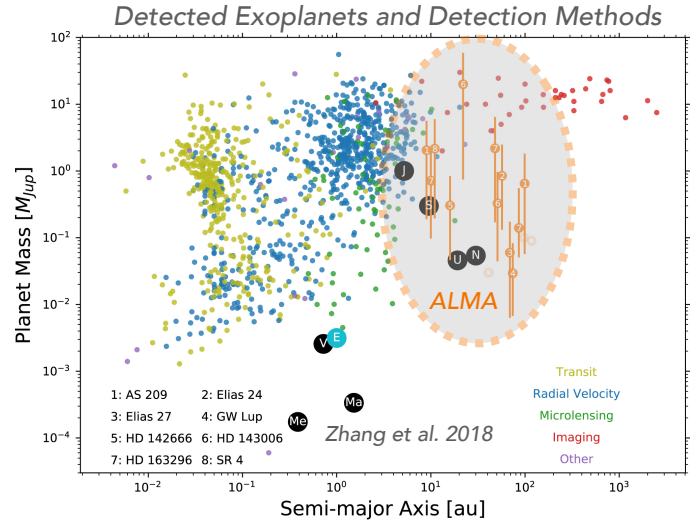
Email: aboorth@strw.leidenuniv.nl

Twitter: [@alice_centauri](https://twitter.com/alice_centauri)



★ How and when do giant planets form?

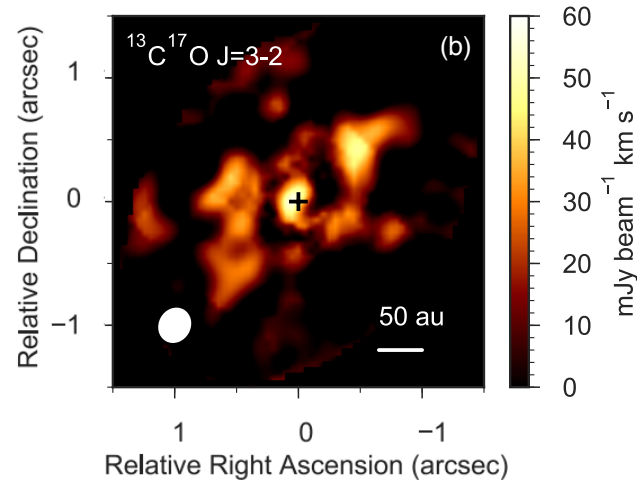
- ▶ ALMA observations of disks now point towards the early ($< 1\text{Myr}$) formation of giant planets (Tychoniec et al. 2020, Andrews et. al, 2020, Pinte et al. 2018)
- ▶ The population of planets detectable with ALMA are on wide orbits and may pose a challenge for core accretion planet formation models
- ▶ Gravitational instability in the outer disk is an alternative route to planet formation - **if the disk is massive enough** (Boss 1997)



★ Measuring the HL Tau disk mass

- ▶ In gas rich disks like HL Tau the more abundant CO isotopologues, including C^{18}O , will be optically thick in the inner disk - **masses will be underestimated!** (As shown for HD 163296 - see Booth et al. 2019b)
- ▶ We use the rarest CO isotopologue $^{13}\text{C}^{17}\text{O}$ to constrain the disk mass to $0.20 \pm 0.06 M_{\odot}$
- ▶ This is consistent with a dust mass of $1-3 \times 10^{-3} M_{\odot}$ and 10x higher than the previous C^{18}O measurement (Carrasco-González+ 2016, Wu+2019)

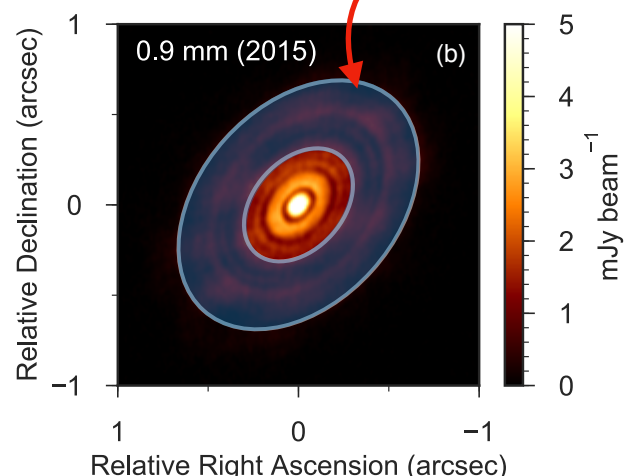
Integrated intensity map of $^{13}\text{C}^{17}\text{O}$ used to constrain total disk gas mass



★ Is the HL Tau disk gravitationally unstable?

- ▶ A $0.2M_{\odot}$ disk is gravitationally unstable from ~ 50 to ~ 120 au with the Toomre $Q < 1.7$ (assuming a stellar mass of $1.8 M_{\odot}$, Pinte et al. 2016)
- ▶ The region of instability crosses a proposed planet carved gap at 77 au (Dippiero+2015, Carrasco Gonzales+2019)
- ▶ **Where are the spirals?** With a stable inner disk a planet can survive inward migration and this migration can erase the GI induced spirals (Rowther and Meru 2020, Rowther et al. 2020)

HL Tau continuum image with region where $Q < 1.7$ in blue



See [Booth and Ilee 2019](#) full details on this project