Exploring Hidden Planet Formation: The JWST/NIRCam Coronagraphic Observations of the HD 163296 System

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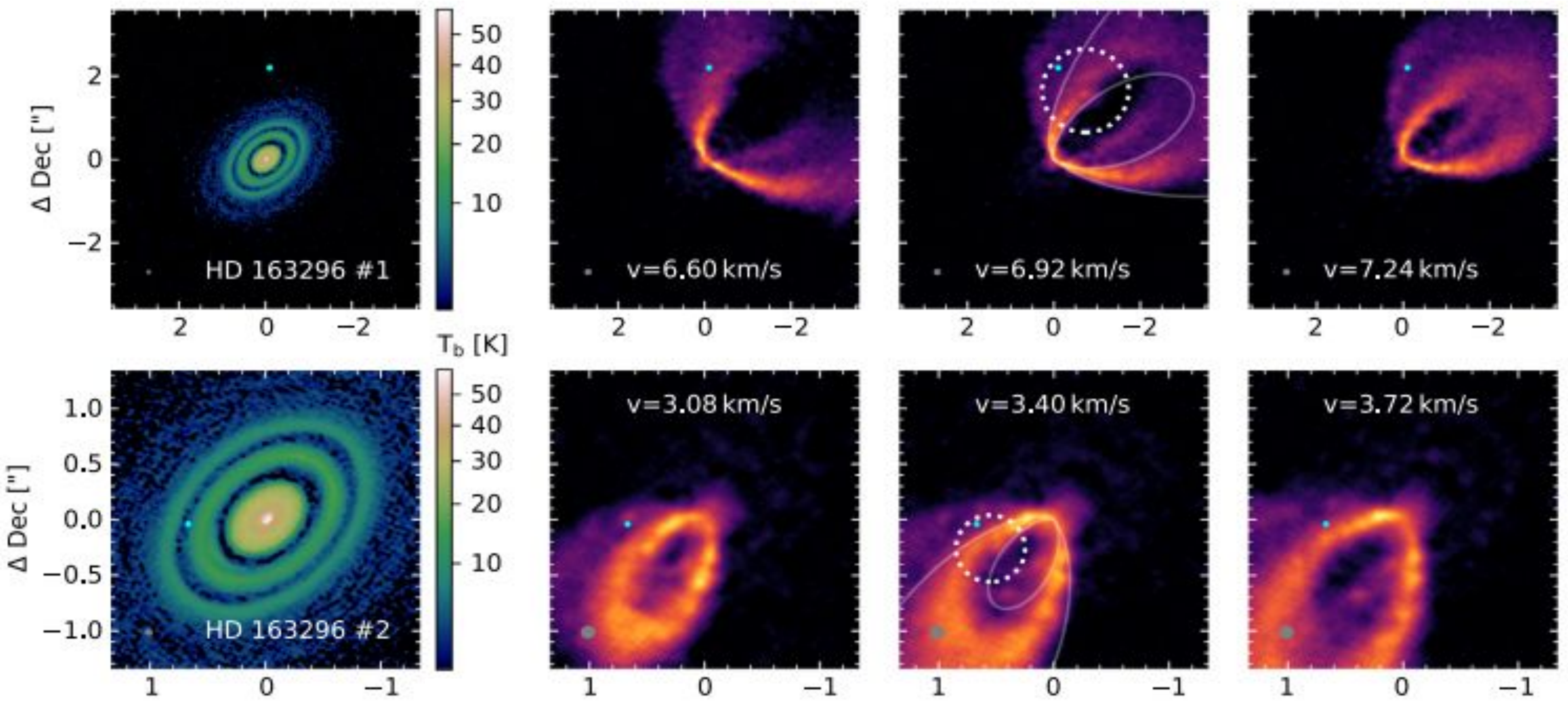
Introduction

Direct imaging of exoplanets embedded in protoplanetary disks yields crucial insights into planet formation, evolution mechanisms, and planet-disk interactions. In general numerous high-angular resolution observations with ALMA or adaptive optics instruments showed diverse disk features which could be related to planet formation, but most follow-up direct imaging observations to test the hypothesis fell short in detecting planet candidates embedded in disks. To address this challenge, we undertook JWST/NIRCam deep coronagraphic observations in Cycle 1.

Target - HD 163296

A ~2Myr Herbig Ae/Be star with the protoplanetary disk having multiple ring/gap features and velocity kinks (Pinte et al. 2020; right figure). However, no convincing planet candidates were reported by ground-based telescopes

- Keck/NIRC2: Guidi et al. (2018); Wallack et al. (2024)
- VLT/SPHERE: Mesa et al. (2019), MUSE: Xie et al. (2020)
- Subaru/SCExAO: Rich et al. (2019); Hasegawa et al. (2024)



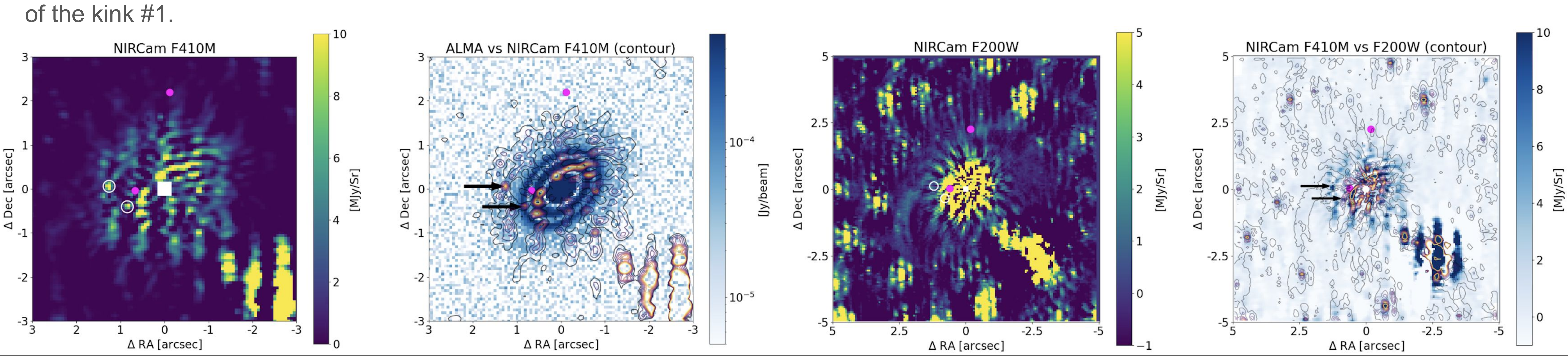
JWST/NIRCam observations

- Filter/Mask configurations
  F200W/MASK210R (+ F410M/MASK210R by-product)
  F410M/MASK430R (+ F200W/MASK430R by-product)
- Data Reduction: Angular Differential Imaging using spaceKLIP (Kammerer et al. 2022; Carter et al. 2023) with a 10-degree roll angle change.

Post-processed images

The NIRCam data did not confirm the predicted protoplanets at the velocity kinks (indicated by magenta dots), but we found interesting features:

- Multi-ring and other extended features in the F410M image (left two figures)
- Two point-like red sources with 1e-5~1e-6 contrast (with SNR~3-3.5; indicated by white circles or black arrows in the images below) at F410M within 2″, which are consistent with ~2-4 Mjup objects. Other bright point-like features in the F410M are likely speckles as they are variable at different KL modes.
- An outermost faint disk seen in F200W (~3.7" semi-major axis), which is a clearer detection than the HST coronagraphic imaging (Grady et al. 2000), coincident with the velocity kink #1 (the second right figure). The presence of the ring indicates some optically-thick feature at the location of the kink #1.



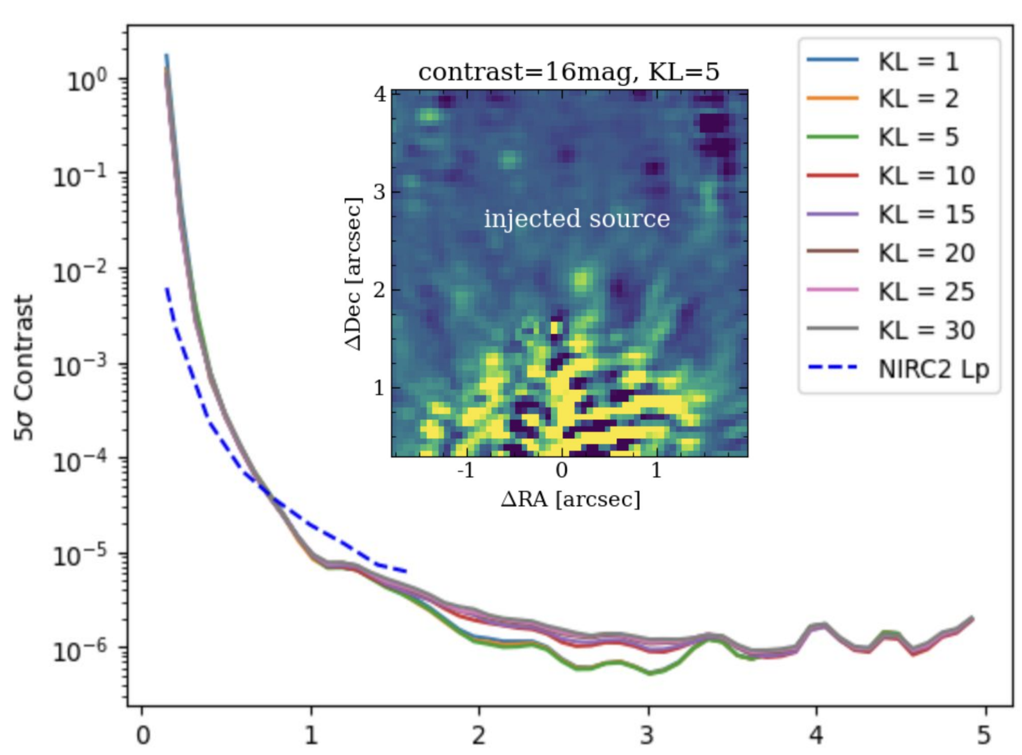
Discussions

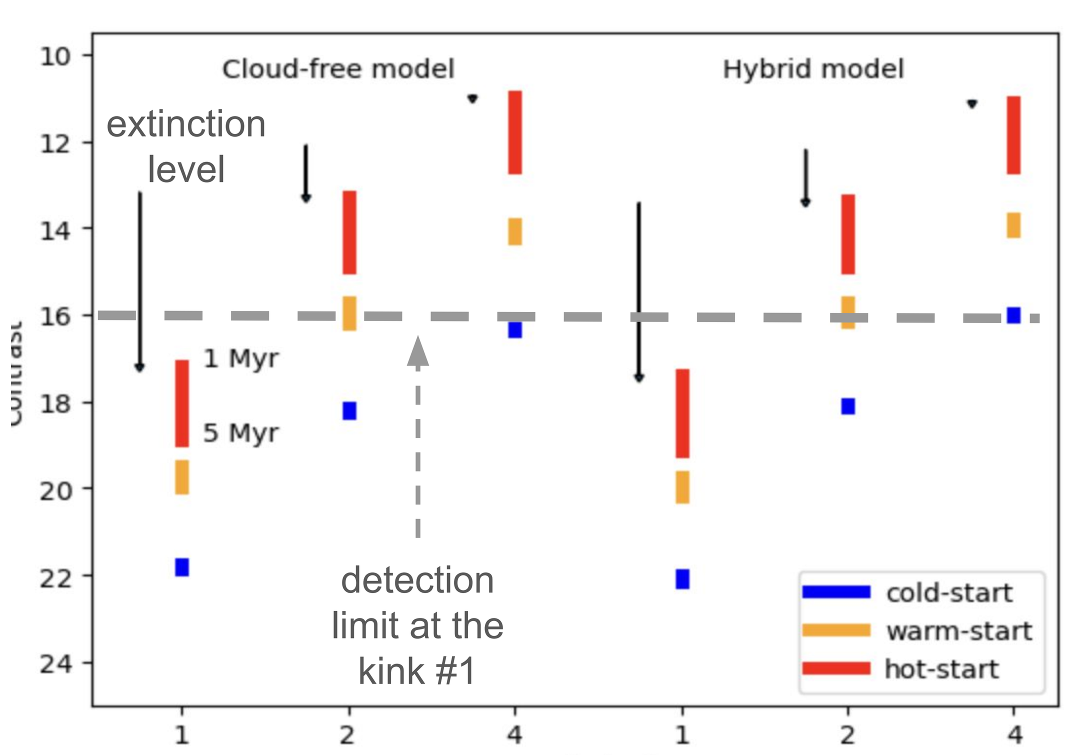
・Point-like Sources

- The outer source in F410M is collocated with the outermost area of the ALMA dust continuum (Isella et al. 2018), but does not have a counterpart in the F200W image (the second right image above). It has a very red color (F200W - F410M > 3 mag, from the F200W detection limit), which is redder than HD 163296 (F200W - F410M = 1.77 mag) and is not consistent with any spectral types without reddening.
- The inner source in F410M overlaps with the outer edge of the ALMA dust gap (D141) and the inner edge of the ring (B159), and is interestingly close to (but clearly offset from) the velocity kink #2. This is also collocated with an extended feature in the F200W image, which may suggest that this feature is part of the disk. There could be a connection with the velocity kink with this extended feature (the second right image above).

・Detection Limit

The left figure shows the radial profile of the 5σ contrast limits at F410M, overlaid with Keck/NIRC2 L'-band contrast limit (Wallack et al. 2024). In the right figure, we particularly focused on constraining the mass of the potential embedded planet at the velocity kink #1 (16-mag; see the inserted panel in the left figure). We converted this contrast limit into the mass limit (the right figure), assuming potential extinction effect by surrounding disk (black arrows; Sanchis et al. 2020), and compared it with the hot-/warm-/cold-start evolutionary models (colored bars; Spiegel & Burrows 2012). Comparison with the contrast limits with the extinction and the evolutionary models concludes that the F410M data could constrain a warm-start 2 Mjup embedded object.





References: Carter et al. 2023, ApJ, 951L, 20; Grady et al. 2000, ApJ, 544, 895; Guidi et al. 2018, MNRAS, 479, 1505; Hasegawa et al. 2024, AJ, 167, 105; Isella et al. 2018, ApJ, 869L, 49; Kammerer et al. 2022, SPIE, 12180, 3N; Mesa et al. 2019, MNRAS, 488, 37; Pinte et al. 2020ApJ, 890L, 9; Sanchis et al. 2020, MNRAS, 492, 3440; Spiegel & Burrows 2012ApJ, 745, 174; Xie et al. 2020, A&A, 644A, 149; Wallack et al. 2024 in press, AAS journals