Doppler Flips in Protoplanetary & Debris Disks: A Possible Indicator of Hidden Planets

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Deviations From Keplerian Velocity

Kepler's Laws of orbital motion predict that the velocity of an orbiting body is proportional to its semi-major axis. Recent work[1,2] has shown that deviations from Keplerian rotation in the analysis of protoplanetary disk gas emission can point to the presence of exoplanets that are otherwise difficult to detect. The purpose of this study was to apply these methods to debris disk data.

Velocity kinks (also known as velocity wiggles):

- Visible in data channel maps (the slices of the emission data at a given velocity)
- A planet will distort the iso-velocity curve in a distinctive manner across multiple velocity channels

Doppler Flips:

- Observable in the residuals of intensity-weighted velocity (also known as moment 1 map) model fitting
- A planet will cause strong arc-like residuals with an abrupt sign change

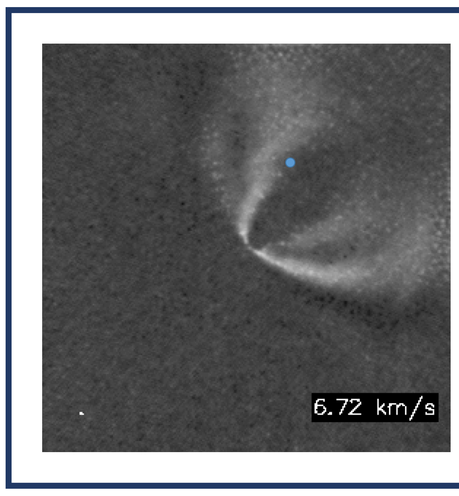

Figure 1: The HD163296 iso-velocity channel map of CO emission at 6.72km/s. A velocity kink is visible in the upper-right, where a blue circle marks the possible position of a planet.

Protoplanetary Disk: ^{12}CO *(J=2-1)* Emission from HD163296

- Pinte et al. (2018) reported a velocity kink in the disk of HD163296
- We used data from the DSHARP survey (Isella, 2018) modeled with eddy code (Teague, 2019) to verify that we could recover the signal
- Data was from the Atacama Large Millimeter/ submillimeter Array (ALMA) at angular resolution 0.04" (linear resolution ~5 au)

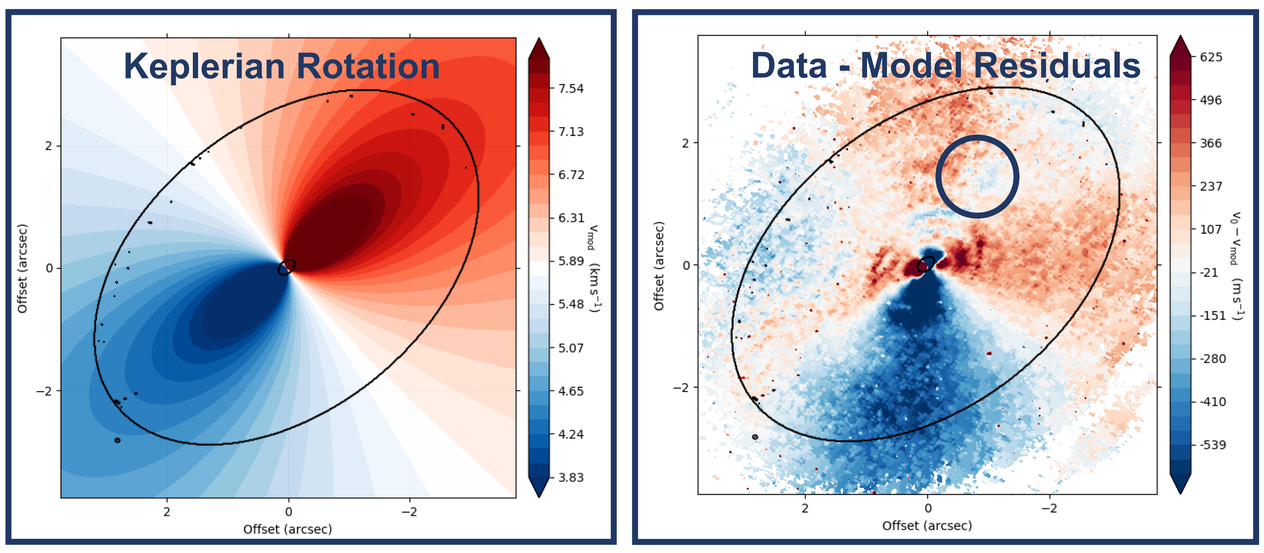

Figure 2: (Left) The model fitted to the intensity weighted velocity (moment 1) map of HD163296 CO data. (Right) The $V_0 - V_{mod}$ (residual plot) for the model pictured left, showing a Doppler Flip at about (-0.5", 1.5"). The Doppler Flip is visible as the arc-like residuals with an abrupt sign change.

References

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4. Isella, A. and 13 colleagues 2018. The Disk Substructures at High Angular Resolution Project (DSHARP).IX. A High-definition Study of the HD 163296 Planet-forming Disk. The Astrophysical Journal 869
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Debris Disk: CI *($^3P_1$-$^3P_0$)* & ^{12}CO *(J=3-2)* Emission from 49 Ceti

- Channel maps showed no evidence of velocity kinks
- Residuals of best fit model for CI did not show any Doppler Flips

CI Emission:

- Data from ALMA (Higuchi, 2019) at angular resolution 0.25" (linear resolution ~14 au)

CO Emission:

- Data from ALMA at angular resolution 0.13" (linear resolution ~8 au)

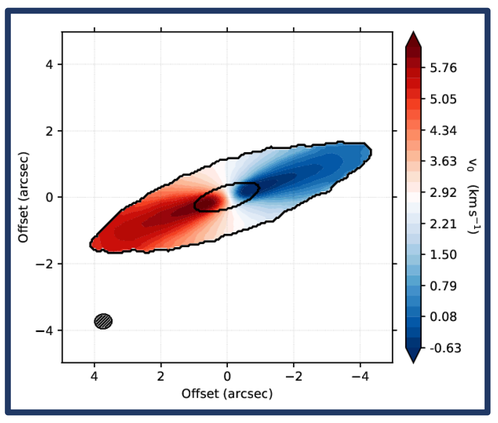
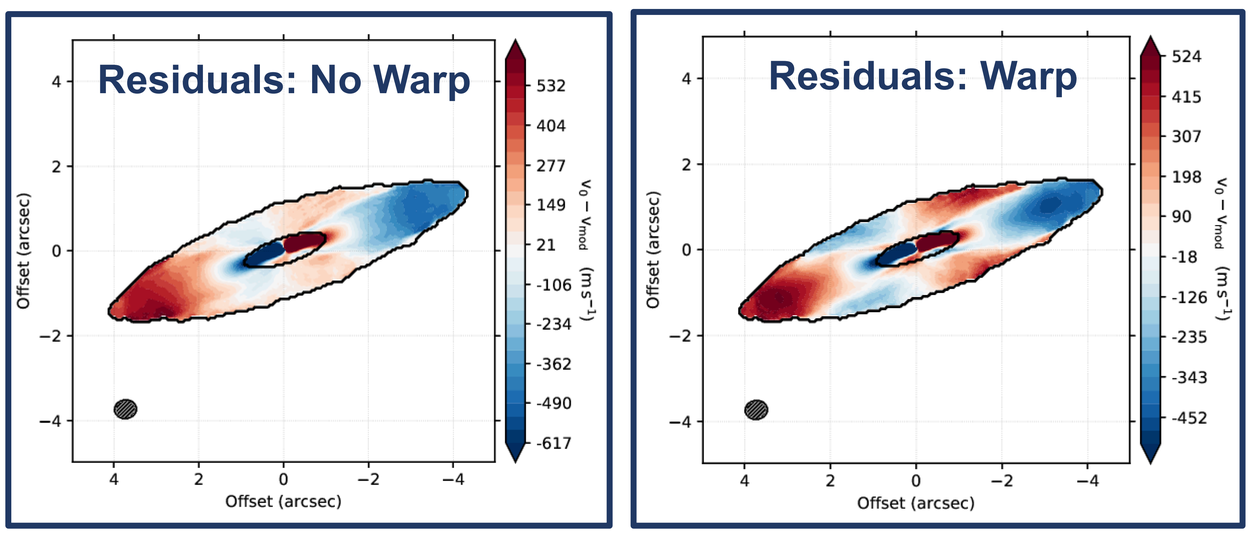


Figure 3: (Above) The intensity-weighted velocity (moment 1) map of 49 Ceti CI emission. (Below) The intensity-weighted velocity map of 49 Ceti CO emission.

Warp or No Warp?

- We used Akaike & Bayes Information Criterion statistical tests to determine if the additional parameters for a warp in the CI & CO emission are justified for a better fit
- AIC = 0.039 & BIC = 13.7 (CI) and AIC = 0.049 & BIC = 14.2 (CO) indicate model with the warp parameters is a moderately better fit

Figure 4: (Left) The $V_0 - V_{mod}$ (residual plot) for the 49 Ceti CI emission best fit model without warp parameters. (Right) The $V_0 - V_{mod}$ for the 49 Ceti CI emission best fit model with warp parameters. Statistical analysis indicates the difference in residuals shows moderate evidence of a warp.



Summary & Future Prospects

HD163296:

Our analysis verified the presence of velocity kinks/wiggles and a Doppler Flip in the protoplanetary disk of HD163296, confirming the results of previous studies.

49 Ceti:

Our analysis did not show any velocity kinks/wiggles, however disk models do indicate moderate evidence of a warp. Our analysis of the CI emission rules out planets orbiting 49 Ceti with semimajor axes between 60 and 260 au and provides proof of concept for similar studies of a wider variety of debris disks in the future.

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