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DETECTING HIDDEN PLANETS IN THE PROCESS OF FORMATION:

Adam Moses (Vassar '21), Hannah Stickler (Wellesley '22), and Prof. Colette Salyk; Department of Physics and Astronomy

INTRODUCTION

PROTOPLANETARY DISKS

Stars are formed through the gravitational collapse of molecular clouds. Gas and dust are prevented from collapse by centrifugal motion and form a plane of material out of which planets grow. The disk is opaque at short wavelengths, however, and therefore obscures the process of planet formation.

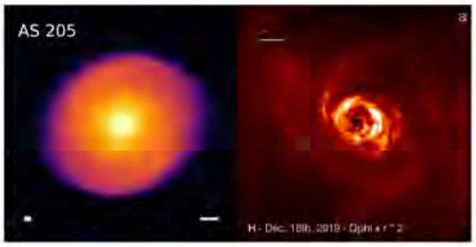

Figure 1: mm-wave image of AS 205 N (left) (Andrews et al. 2018) and polarized light image of AB Aurigae (right) (Boccaletti et al. 2020)

CARBON MONOXIDE EMISSION AND VARIABILITY

Carbon Monoxide (CO) is a diatomic molecule that exhibits both rotational and vibrational energy. These energy states are quantized, meaning that they can only exist in fixed energy levels and not in between. When a CO molecule makes a jump in rotational energy state, there is likewise a change in vibrational energy. Emission occurs when there is a transition to a lower energy state, upon which a photon with the same energy associated with the transition is released. A protoplanetary disk has many CO molecules experiencing different jumps in rotational and vibrational energy; spectroscopy of these disks will reveal a multitude of emission lines corresponding to these transitions. The details associated with each transition are catalogued in the HITRAN database from which we've collected our data for theoretical rovibrational emission lines.

The line shape profiles of these emission lines reflect physical properties of the CO within protoplanetary disks. Studying how the line profiles change over time gives us a means to probe how the disk's properties, too, are changing. Changes in width can be associated with gas moving inwards or outwards within the disk. Changes in line flux can be due to increased area of emission, temperature, and the number of emitting molecules. Asymmetries in line shape profiles can also be an indication of an embedded planet (Brittain et al. 2014; Regály et al. 2010, 2014).

AS 205

ABOUT THE SOURCE

AS 205 is a binary T Tauri system consisting of the stars AS 205 N and AS 205 S with stellar masses M_1=1$M_\odot$ and M_2=0.6$M_\odot$ (Salyk et al. 2014). AS 205N is a good target for this study due to high line/continuum ratios at IR wavelengths (Salyk et al. 2008).

DATA

Spectra reviewed herein were collected in the M band, which measures around 5 µm, with NIRSPEC, a high resolution spectrograph on Keck II situated at Mauna Kea.

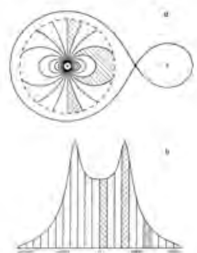

Figure 3: This figure from Horne et al. 1986 shows how emission line profiles are contributed to by gas from different parts of the disk

Many emission lines were omitted due to small Doppler shifts on the chosen observation leading to poor characterization of emission lines after application of a telluric absorption cutoff of 60%. However, of those emission lines we did look at, there is a pretty clear visual decrease in peak line flux, with roughly constant wing velocities. The decrease in peak flux may correspond to a decrease in emission from particles at lower orbital velocities, closer to the host star. We performed a calculation for the decrease in emitting area required for this variability assuming a constant temperature (although that need not be true). The average decrease in line flux of v=1-0 emission lines between 2011 June 20 and 2013 June 24 indicates a decrease in emitting area of ~15.2%.

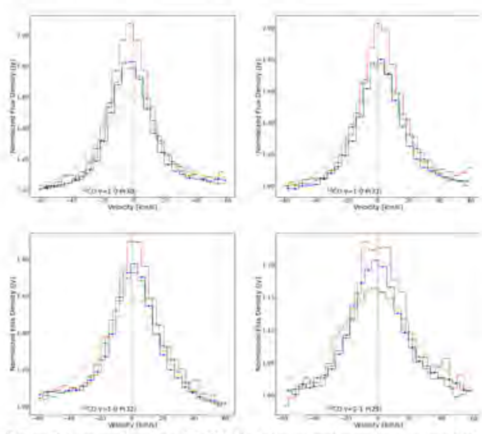

Figure 2: Line profiles from AS 205 N of chosen emission lines on each of the observation dates. Vertical dashed lines are the theoretical wavelengths for CO emission, collected from the HITRAN database.

AB AURIGAE

AB Aurigae is a Herbig Ae/Be star belonging to the Taurus-Auriga system (Oppenheimer et al. 2008). AB Aurigae has been widely observed and shows evidence of a plethora of structure including a surrounding gas envelope, asymmetry of the inner disk, and a spiral disk structure from 120 to several hundred AU (Fukagawa et al. 2004; Millan-Gabet et al. 2006). This study focuses on the inner several AU of the compact disk.

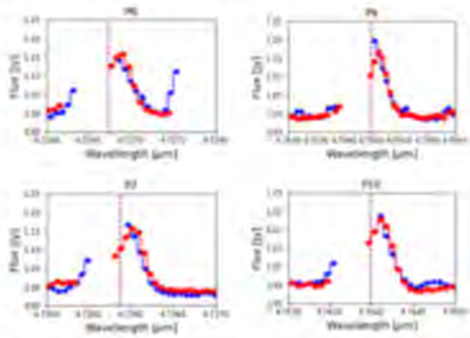

Figure 4: Line profiles from AB Aurigae of chosen emission lines on each of the observation dates. Vertical dashed lines are the theoretical wavelengths for CO emission, collected from the HITRAN database.

AB Aurigae has low line/continuum ratios, providing very limited information on the nature and structure of the disk. There is no evidence found of variable patterns in these data.

CONCLUSIONS

CO rovibrational spectroscopy is a powerful tool to study parts of protoplanetary disks otherwise unseen. We find clear signs of variability in the spectra from AS 205 N, although making any connections to unseen embedded planets would require further exploration. The dynamics in AS 205 N are changing in such a way that reduced emission is occurring from CO at low radial velocities (which may correspond with higher orbital distances). This could potentially be attributed to a lower surface area of emitting particles, a decreasing temperature, or decreasing numbers of emitting molecules. We find no significant variability in the spectra from AB Aurigae.

ACKNOWLEDGEMENTS + REFERENCES

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Andrews, S. M., Huang, J., Pérez, L. M., et al. 2018, ApJ, 869, L41
Brittain, S. D., Carr, J. S., Najita, J. R., et al. 2014, ApJ, 791, 136
Boccaletti, A., Di Folco, E., Pantin, E., et al. 2020, A&A, 637, L5
Fukagawa, M., et al. 2004, ApJ, 605, L53
Horne, K. & Marsh, T. R. 1986, MNRAS, 218, 761
Millan-Gabet, R., et al. 2004, ApJ, 645, L77
Oppenheimer, B., Brenner, D., Sivaramakrishnan, A., Soummer, R., et al. 2008, ApJ, 679, 1574
Regály, Z., Sándor, Z., Dullemond, C. P., et al. 2010, A&A, 523, A69
Regály, Z., Király, S., & Kiss, L. L. 2014, ApJ, 785, L31
Salyk, C., Pontoppidan, K. M., Blake, G. A., et al. 2008, ApJ, 676, L49
Salyk, C., Pontoppidan, K., Corder, S., et al. 2014, ApJ, 792, 68