First Detection of HC_5N Within A Protoplanetary Disk

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Molecular Inventory of Class II Disks

In the past 10 years of ALMA operations, our inventory of molecules in protoplanetary disks has nearly doubled due to ALMA's high sensitivity, spatial, and spectral resolution. Yet fundamental limitations of the column densities of larger species in disks suggest that we may be approaching the current limits of the instrument[1]. Here we present the first detection HC_5N in a disk, representing the largest molecule detected to date in a Class II disk. Its detection suggests that with the significantly upgraded bandwidth of the ALMA wideband sensitivity upgrade, we may still have room for further molecular discoveries in disks.

Table 6

List of Molecules, Including Rare Isotopic Species, Detected in Protoplanetary Disks, with References to Representative Detections

2 Atoms		3 Atoms		4 Atoms		5 Atoms		6 Atoms	
Species	Ref.	Species	Ref.	Species	Ref.	Species	Ref.	Species	Ref.
CN	1, 2	H_2O	3, 4, 5	NH_3	6	HC_3N	7	CH_3OH	8
$C^{15}N$	9	HCO^+	1, 2	H_2CO	2	HCOOH	10	CH_3CN	11
CH^+	12	DCO^+	13	H_2CS	14, 15	c-C_3H_2	16		
OH	17, 5	$H^{13}CO^+$	18, 13	C_2H_2	19	CH_4	20		
CO	21	HCN	1, 2						
^{13}CO	22	DCN	23						
$C^{18}O$	24	$H^{13}CN$	25						
$C^{17}O$	26, 27	$H^{15}CN$	25						
$^{13}C^{18}O$	39								
$^{13}C^{17}O$	40								
H_2	28	HNC	2						
HD	29	DNC	14						
CS	30, 31, 32	H_2S	33						
$C^{34}S$	14, 15	N_2H^+	34, 35						
^{13}CS	14, 15	N_2D^+	36						
SO	37	C_2H	2						
		C_2D	14						
		CO_2	38						

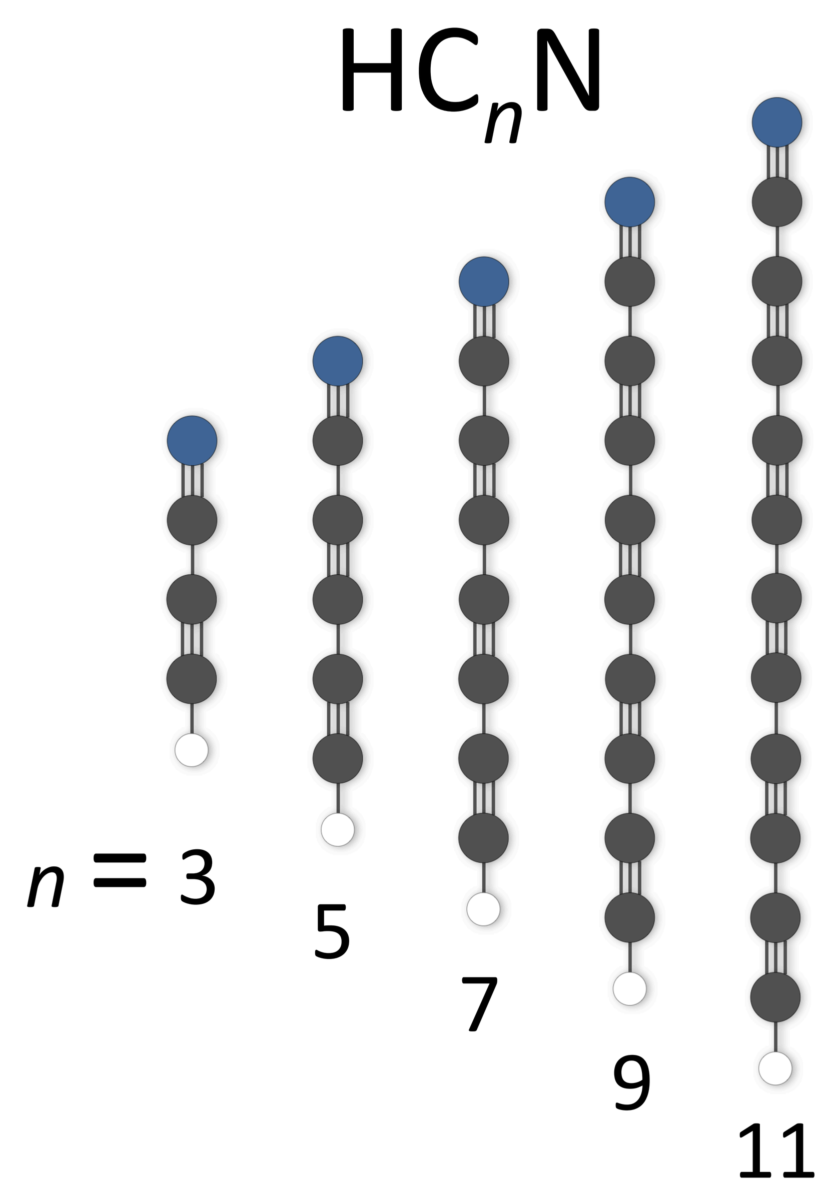
References. The earliest reported detection of a species in the literature is provided on a best-effort basis. Tentative and disputed detections are not included (see text). (1) Kastner et al. 1997; (2) Dutrey et al. 1997; (3) Carr et al. 2004; (4) Hogerheijde et al. 2011; (5) Salyk et al. 2008; (6) Salinas et al. 2016; (7) Chapillon et al. 2012; (8) Walsh et al. 2016; (9) Hily-Blant et al. 2017; (10) Favre et al. 2018; (11) Öberg et al. 2015; (12) Thi et al. 2011; (13) van Dishoeck et al. 2003; (14) Loomis et al. 2020; (15) Le Gal et al. 2019; (16) Qi et al. 2013; (17) Mandell et al. 2008; (18) van Zadelhoff et al. 2001; (19) Lahuis et al. 2006; (20) Gibb & Horne 2013; (21) Beckwith et al. 1986; (22) Sargent & Beckwith 1987; (23) Qi et al. 2008; (24) Dutrey et al. 1994; (25) Guzmán et al. 2015; (26) Smith et al. 2009; (27) Guilloteau et al. 2013; (28) Thi et al. 1999; (29) Bergin et al. 2013; (30) Ohashi et al. 1991; (31) Blake et al. 1992; (32) Guilloteau et al. 2012; (33) Phuong et al. 2018; (34) Qi et al. 2003; (35) Dutrey et al. 2007; (36) Huang & Öberg 2015; (37) Fuente et al. 2010; (38) Carr & Najita 2008; (39) Zhang et al. 2017; (40) Booth et al. 2019.

McGuire et al. 2021[1]

Cyanopolyynes

Cyanopolyynes are long carbon-chain COMs of the form HC_nN. Due to their linear nature, cyanopolyynes have only J rotational transitions, and high dipole moments due to the terminal N. Combined with a low fundamental frequency (scaling with mass), this leads to a regularly spaced spectrum with the opportunity to fit multiple emission lines into one ALMA spectral window. In particular, they have many strong emission lines in current Bands 1 and 3 (and soon in Band 2).

Cyanopolyynes have been abundantly observed in other mediums such as cold dark clouds all the way up to $HC_{11}N$[2], where they serve as important probes of astrophysical properties due to their multiple easily observed transitions. However, due to inherently lower column densities, detection and detailed characterization of these species within disks has proven more difficult.[3]

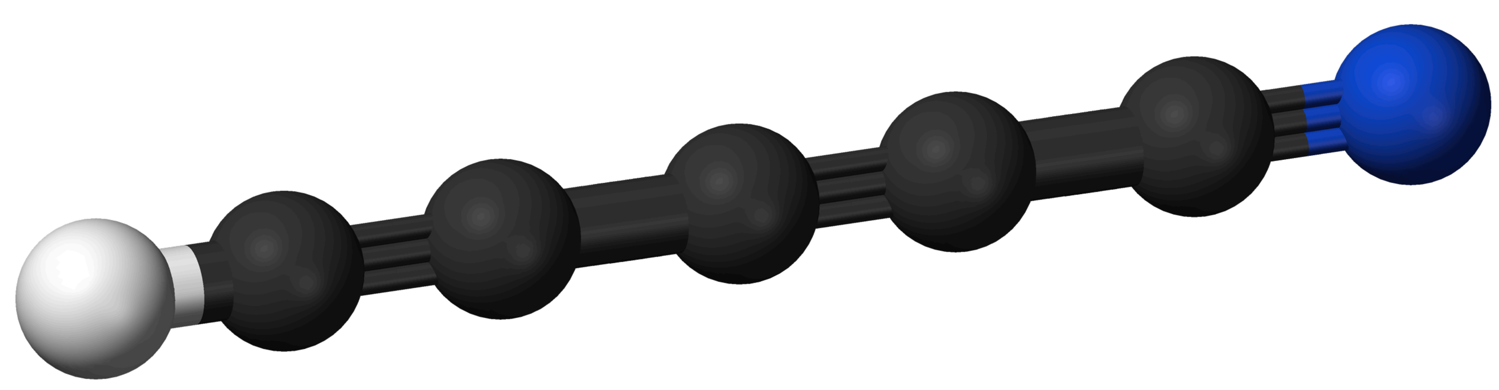


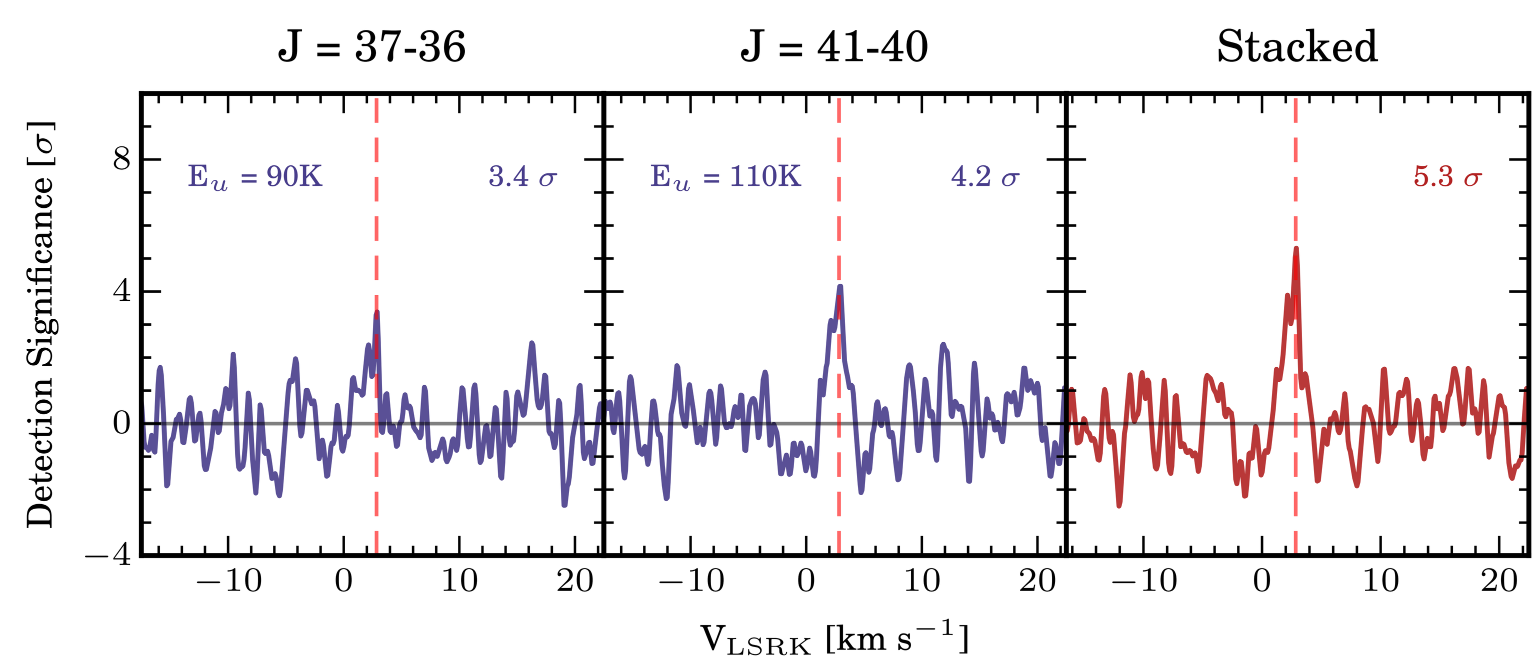
Detection of HC_5N in TW Hya

Within observations targeting HC_3N toward the nearest protoplanetary disk, TY Hya, we serendipitously detected two transitions, J=41-40 and J=37-36 of HC_5N. These transitions were detected by using a matched filtering analysis[4] and stacking the lines[5] rather than in the image plane directly. The three panels show the robustness of the detections, with detection significance of 3.4 σ and 4.2σ for the individual lines, and 5.3σ stacked.

This detection pushes the boundary of what ALMA can currently achieve in terms of detecting large molecules in disks, representing the most complex species yet detected in a Class II disk.

Weakness of the individual lines precludes a rotation diagram analysis for extracting a column density and temperature, but future observations closer to the rotational emission peak in ALMA Band 1 could potentially allow for this sort of analysis.

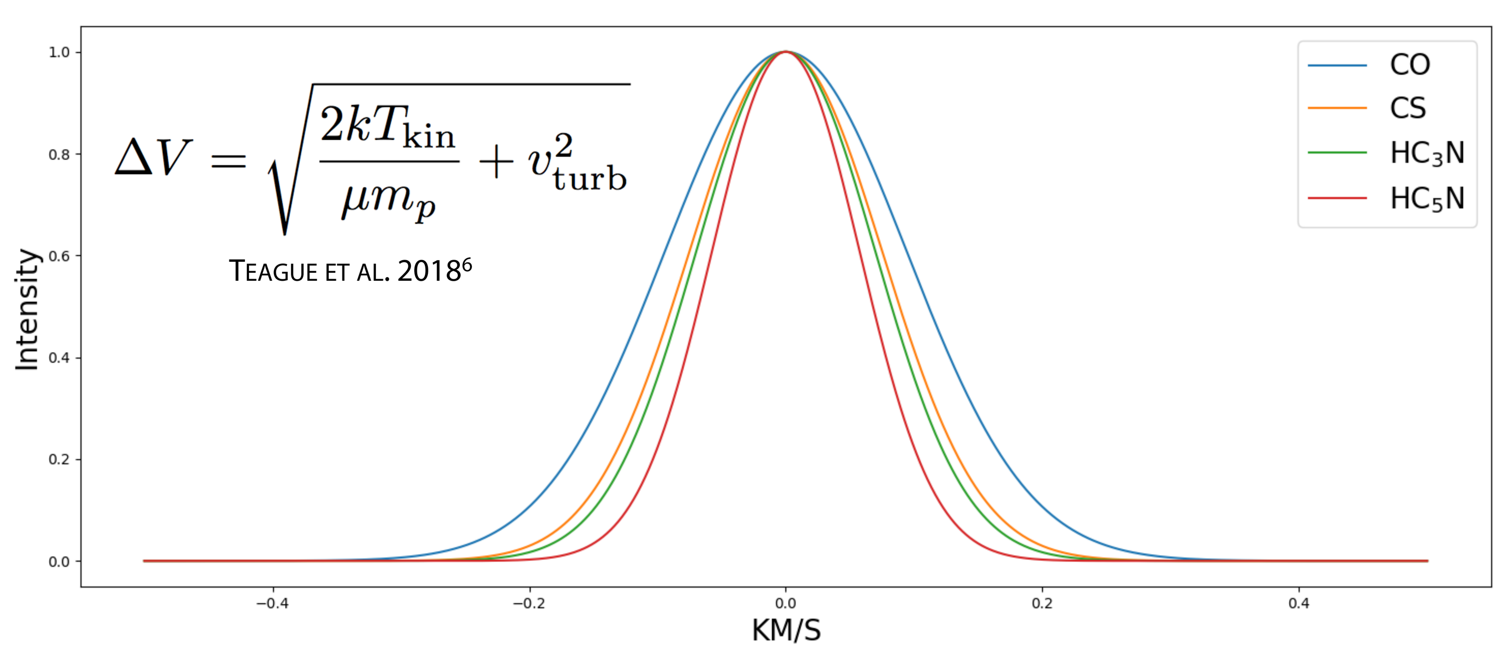




HC_5N Future Utility

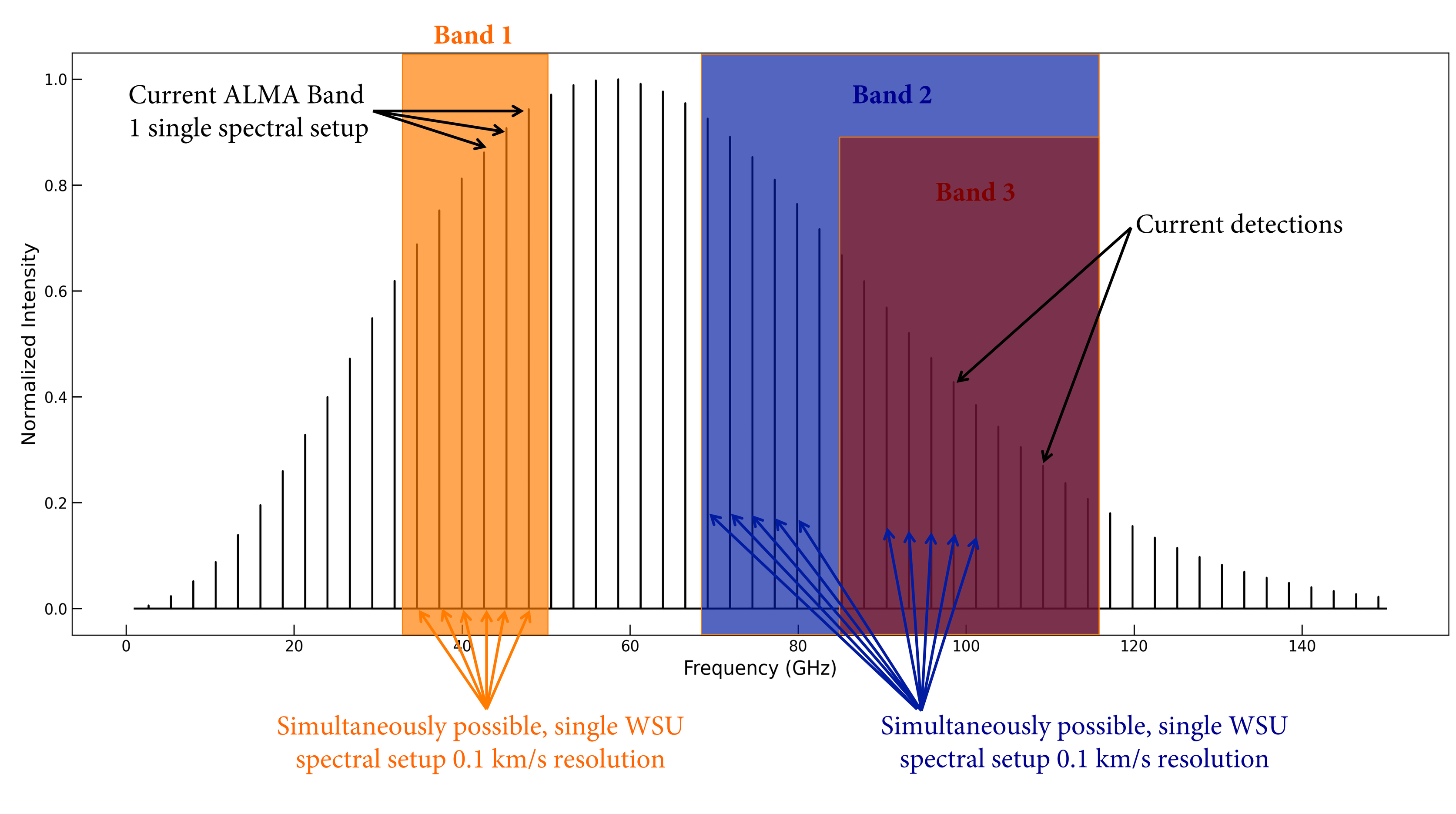
Observations of transitions from more massive species allows for a reduced impact of Doppler broadening effects on rotational spectral lines. By subtracting this thermal broadening, one can potentially infer the properties of non-thermal effects, such as the turbulence within the disk[6]. Detection of higher intensity transitions of HC_5N and other large molecules may prove to be useful probes of these effects by reducing the thermal linewidth contribution and therefore lowering uncertainty on the turbulence. These potential observations will be much easier in the near future with the ALMA 2030 WSU and later the construction of the ngVLA.

Linewidth at 30K



Looking Forward with WSU and ngVLA

Here, we detected high-J transitions of HC_5N in ALMA Band 3. With the addition of Band 1, Band 2, and the WSU upgrade, ALMA will be able to detect many more (and brighter) lines of HC_5N within a single spectral setup, and at a <u>much</u> higher spectral resolution. These wider bandwidths are readily combined with the matched filtering technique used in our detection, and this may lead to similar serendipitous detections of even larger species. The same will hold true later on for the ngVLA.



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ALMA is a partnership of ESO (representing its member states), NSF (USA) and NINS (Japan), together with NRC (Canada) and NSC and ASIAA (Taiwan), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, AUI/NRAO and NAOJ.

References

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