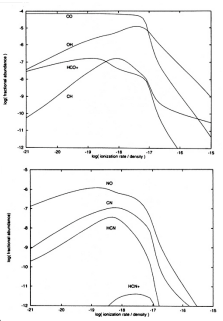
Molecular Line Surveys of Nearby T Tauri Stars: Late-time Chemistry of Protoplanetary Disks

Joel H. Kastner & Kristina Punzi (*RIT Lab for Multiwavelength Astrophysics*); David Rodriguez (*U. de Chile*); G. Germano Sacco (*INAF, Arcetri Obs., Italy*); Pierre Hily-Blant & Thierry Forveille (*IPAG-Grenoble, France*); B. Zuckerman (*UCLA*)

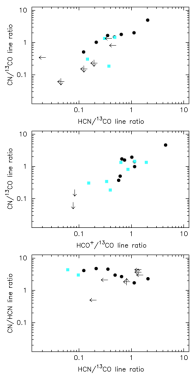
ABSTRACT

We have conducted mm-wave molecular line surveys of the evolved, irradiated circumstellar disks orbiting the nearby, roughly solar-mass, pre-main sequence (T Tauri) stars TW Hya, V4046 Sgr, T Cha, and LkCa 15. All four are transition disk systems with relatively advanced ages (5-12 Myr), yet display spectral signatures of ongoing stellar accretion. Our radio spectral line surveys were performed with the APEX 12 meter and IRAM 30 meter telescopes. In the cases of the TW Hya, V4046 Sgr, and LkCa 15 disks -- all of which are known to retain significant residual gaseous components, as evidenced by previous radio and infrared detections of molecular and atomic emission lines -- we performed unbiased broad-band observations intended to yield a complete census of bright mm-wave emission lines. Initial results from these survey data include first-time detections of the molecules CCH (in TW Hya and V4046 Sgr) and CS (in all three disks), as well as complete coverage of hyperfine transitions of CN and CCH. In the case of T Cha, we have obtained the first direct detection of its rotating, gaseous disk, in the form of double-peaked emission lines of CO and lines of HCN, CN, and HCO+. Our line survey results thereby provide new constraints on models describing late-stage disk protoplanetary gas dissipation and chemical evolution, and point out future directions for ALMA imaging of these and other, similarly resolvable T Tauri star disks.

1. WHAT PROCESSES GOVERN THE MOLECULAR CHEMISTRY OF EVOLVED, PROTOPLANETARY DISKS?



Radio-wave molecule emission lines are key tracers of the compositions and physical conditions in protoplanetary disks. To date, however, investigations of the molecular content of protoplanetary disks orbiting pre-main sequence stars have been limited to *targeted* observations of relatively few species. **We are performing *unbiased* mm-wave spectral line surveys of a small sample of chemically rich nearby disks to establish their full complement of molecular lines and thereby constrain the effects of disk irradiation by UV and X-rays from the central star.**



Figures: *Left*, predicted molecular abundances within an irradiated cloud as functions of X-ray ionization rate (from Lepp & Dalgarno 1996). *Right*, T Tauri star disk molecular line ratios indicative of the potential impact of pre-MS star irradiation (from Salter et al. 2011).

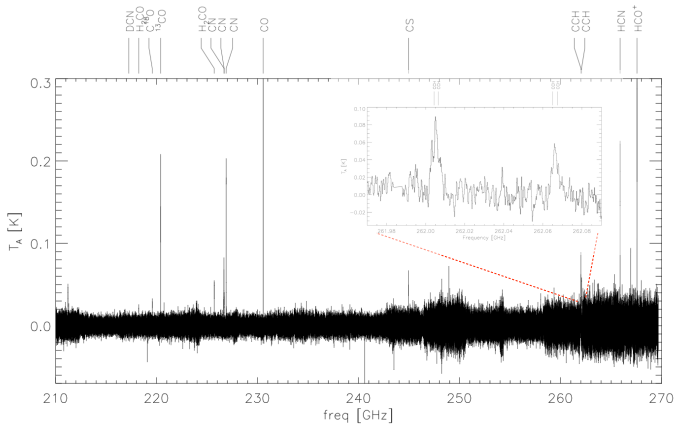
2. PROTOPLANETARY DISK EMISSION LINE SURVEYS: TARGETS

Name	Group	D (pc)	Age (Myr)	Sp Type	dM/dt ($\times 10^{-9}$ $M_\odot$/yr)	Survey	Ref.
LkCa 15**	Tau/Aur	140	2-5	K5	3	IRAM 30m: Unbiased 210-270 GHz	Punzi et al. (2013, AAS)
V4046 Sgr	β Pic	73	12	(K5+K5) + (M1+M1?)	0.6	APEX 12m: Unbiased 265-356 GHz	Kastner et al. (2013, AAS)
TW Hya	TWA	54	8	K6 + M8	1-10	APEX 12m: Unbiased 265-356 GHz	Kastner et al. (2013, AAS)
T Cha**	ε Cha	103	6-7	K0 + M3	3	APEX 12m: CO, HCN, CN, HCO^+	Sacco et al. (2013, A&A, submitted)
MP Mus	ε Cha	(86-)103	6(-17)	K1	0.4	APEX 12m: CO, HCN, CN, HCO^+	Prop. under review

Sources: Torres et al. (2008, in *Handbook of Star Forming Regions*); Curran et al. (2011); Kastner et al. (2011, 2012); Isella et al. (2012)

**Candidate protoplanet detected; see Kraus & Ireland (2012; LkCa 15) and Huelamo et al. (2012; T Cha)

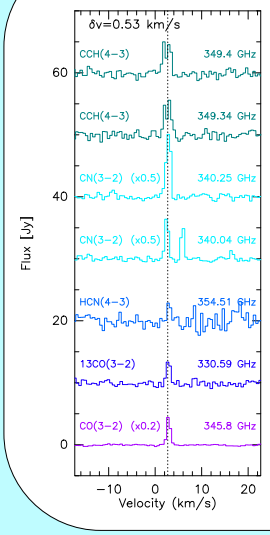
3. **LkCa 15**: IRAM 30 m TELESCOPE 1.3 mm EMISSION-LINE SURVEY



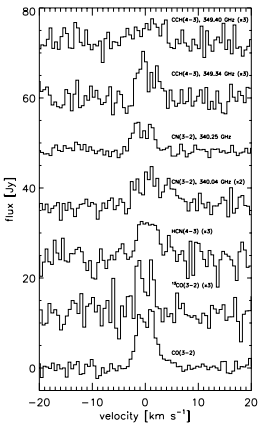
The 210-270 GHz spectrum of LkCa 15, obtained with the IRAM 30 m telescope. Some previously detected and/or easily identified molecular spectral lines are indicated. The inset shows a blowup of the 262 GHz spectral region, highlighting emission lines of CCH.

This IRAM spectral survey has yielded first-time detections of $C^{18}O$, CS, and many transitions of previously detected molecules such as H_2CO and CCH. We are now in the process of identifying the weaker lines in this spectrum and in the 0.8 mm APEX spectra of TW Hya & V4046 Sgr (see next panel).

4. **V4046 Sgr and TW Hya**: APEX 12 m TELESCOPE 800 MICRON EMISSION-LINE SURVEYS

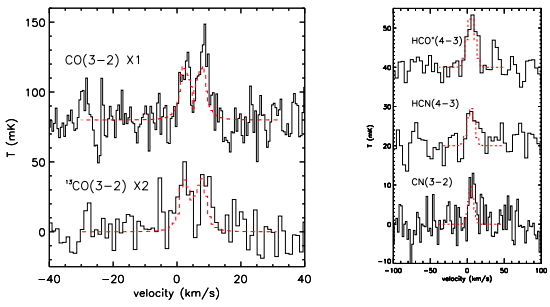


Preliminary results from Atacama Pathfinder Experiment (APEX) 12 m telescope molecular line surveys of TW Hya and V4046 Sgr (left and right panels, respectively; from Kastner et al. 2013, in prep.). Here, we show the brightest lines detected in the 280-355 GHz frequency range (with spectral baselines offset for clarity). Note the different line profiles for the two systems, due to their different disk viewing geometries (7° for TW Hya vs. 37° for V4046 Sgr).



These APEX spectral surveys have yielded first-time detections of the molecules CCH and CS in both disks and the first measurements of submm-wave transitions of several species previously detected in V4046 Sgr.

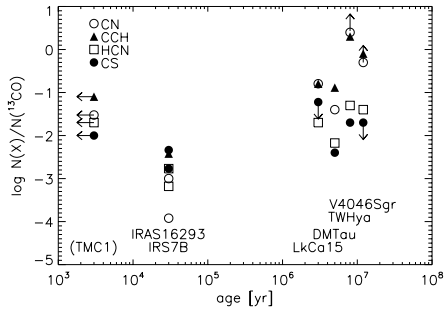
5. **T Cha**: NEWLY DISCOVERED EXAMPLE OF COLD GAS IN A PROTOPLANETARY DISK NEAR EARTH



Left, **^{12}CO(3–2) and ^{13}CO(3–2) line profiles of T Cha** as measured with APEX (solid histograms) overlaid with best-fit Keplerian disk model profile (red dashed line). Right: **detections of HCO^+, HCN, and CN**, with Gaussian fits (used to verify line velocities consistent with CO lines) overlaid. From Sacco et al (2013, A&A, submitted).

Analysis of the CO emission line data indicates that the disk around T Cha has a mass similar to, but is more compact than, the other nearby transition disks (e.g. V4046 Sgr, TW Hya, MP Mus) in which cold molecular gas has been previously detected.

6. ENHANCED CN & CCH ABUNDANCES AT LATE TIMES IN DISK EVOLUTION?



Plot of fractional molecular abundances of CN, CCH, HCN & CS vs. system age for a cloud core (TMC 1), two Class 0 protostars (IRAS 16293-2422 & R CrA IRS 7B), and four T Tauri disks for which all four species have been measured thus far. (Molecular line data from this work and Henning et al. 2010, Dutrey et al. 1997, Thi et al. 2004, Watanabe et al. 2011, Schoier et al. 2002, and Ohishi et al. 1992.)

This plot suggests that the fractional CN and CCH abundances in disks orbiting 3-12 Myr-old T Tauri stars are strongly enhanced over those characteristic of very young, low-mass protostars. It furthermore appears that the two oldest disks, TW Hya and V4046 Sgr, display very large fractional CN and CCH abundances relative to the somewhat younger DM Tau and LkCa 15 as well as to TMC 1, which is presumably representative of the natal cloud cores of T Tauri stars.

Send comments and queries to Joel Kastner (jhk@cis.rit.edu)

This research is supported by grants to RIT from the National Science Foundation (award AST–1108950) and the NASA Astrophysics Data Analysis Program (award NNX09AC96G).