

Extragalactic Molecular Line Primer (ALMA Band 3 & 6)

David S. Meier

Molecule ¹	ν (GHz)/transition ²	Description	Density ³	I_{pk} ⁴	Example References ⁵
c-C ₃ H ₂	85.3389 (2 ₁₂ – 1 ₀₁)	<i>Form:</i> C ⁺ + C _n H _m Abundant where C ⁺ and hydrocarbons are abundant (PDRs, low A_V gas)	high	$\frac{1}{50}$	Gal: Madden et al. 1989, AJ, 97, 1403 SD: Wang et al. 2004, A&A, 422, 883 INT: ...
SiO	86.8470 (2-1) 217.1050 (5-4) 260.5180 (6-5)	<i>Form:</i> Grain core liberation of Si traces strong shocks	high	$\frac{1}{50}$	Gal: Martin-Pintado et al. 1992 A&A, 254, 315 SD: Sage & Ziurys 1995, ApJ, 447, 625 INT: Garcia-Burillo et al. 2000 A&A, 355, 499
C ₂ H	87.28-[87.3169]-87.33 (1-0; $\frac{3}{2}$ - $\frac{1}{2}$) [87.4020]-87.45 (1-0; $\frac{1}{2}$ - $\frac{1}{2}$) 261.98-[262.0043]-262.01 (3-2; $\frac{7}{5}$ - $\frac{5}{2}$) 262.01-[262.0650]-262.08 (3-2; $\frac{5}{2}$ - $\frac{3}{2}$) [262.2086]-262.26 (3-2; $\frac{5}{2}$ - $\frac{5}{2}$)	<i>Form:</i> See c-C ₃ H ₂ Traces PDRs, low A_V gas	intermediate	$\frac{1}{25}$	Gal: Wootten et al. 1980, ApJ, 239, 844 SD: Henkel et al. 1988, A&A, 201, L23 INT: Meier & Turner 2005 ApJ, 618, 259
HNCO	87.9252 (4 ₀₄ – 3 ₀₃) 109.9058 (5 ₀₅ – 4 ₀₄) 219.7983 (10 ₀₁₀ – 9 ₀₉) 241.7740 (11 ₀₁₁ – 10 ₀₁₀) 263.7486 (12 ₀₁₂ – 11 ₀₁₁)	<i>Form:</i> grain mantle evaporation (unsaturated?) traces moderate shocks/hot cores	high	$\frac{1}{25}$	Gal: Zinchenko et al. 2000, A&A, 361, 1079 SD: Nguyen-Q-Rieu et al. 1991, A&A, 241, L33 INT: Meier & Turner 2005 ApJ, 618, 259
HCN	88.6316 (1-0) 265.8864 (3-2)	<i>Form:</i> CH ₂ + N -or- HCNH ⁺ + e ⁻ dense gas tracer ; possibly IR pumped or PDR enhanced	high	$\frac{1}{10}$	Gal: Schilke et al. 1992, A&A, 256, 595 SD: Gao & Solomon 2004, ApJ, 606, 271 INT: Imanishi et al. 2007, AJ, 134, 2366
HCO ⁺	89.1885 (1-0) 267.5576 (3-2)	<i>Form:</i> H ₃ ⁺ + CO (intermediate) density tracer ; high abundances in low gas A _v	inter./high	$\frac{1}{15}$	Gal: Turner 1995, ApJ, 449, 635 SD: Gracia-Carpio et al. 2006, ApJ, 640, L135 INT: Imanishi et al. 2007, AJ, 134, 2366
HNC	90.6636 (1-0) 271.9811 (3-2)	<i>Form:</i> See HCN dense gas tracer ; possibly IR pumped	high	$\frac{1}{15}$	Gal: Schilke et al. 1992, A&A, 256, 595 SD: Aalto et al. 2002, A&A, 381, 783 INT: Meier & Turner 2005 ApJ, 618, 259
HC ₃ N	90.9790 (10-9) 100.0764 (11-10) 109.1736 (12-11) 218.3247 (24-23) 227.4189 (25-24) 236.5128 (26-25) 245.6063 (27-26) 254.6995 (28-27) 263.7920 (29-28) 272.8848 (30-29)	<i>Form:</i> C ₂ H ₂ + CN traces dense gas excitation	very high	$\frac{1}{30}$	Gal: Morris et al. 1976, 205, 82 SD: Lindberg et al. 2011 INT: Meier et al. 2011, AJ, 142, 32

Extragalactic Molecular Line Primer (ALMA) — Cont.

Molecule ¹	ν (GHz)/transition ²	Description	Density ³	I_{pk} ⁴	Example References ⁵
CH ₃ CN	91.96-[91.9871]-91.99 ($5_k - 4_k$) 110.33-[110.3835]-110.39 ($6_k - 5_k$) 220.23-[220.7472]-220.75 ($12_k - 11_k$) 238.48-[239.1379]-239.14 ($13_k - 12_k$) 256.69-[257.5274]-257.53 ($14_k - 14_k$)	<i>Form:</i> grain mantles ?? probe of dense gas / hot core kinetic temperature	very high	$\frac{1}{50}$	Gal: Remijan et al. 2004, ApJ, 617, 384 SD: Mauersberger et al. 1991, A&A, 247, 307 INT: ...
N ₂ H ⁺	93.1734-[93.1738]-93.1740 (1-0)	<i>Form:</i> H ₃ ⁺ + N ₂ traces dense, quiescent gas Sensitive to N ₂ ; possible 'chemical clock'	very high	$\frac{1}{30}$	Gal: Womack et al. 1992 ApJ, 387, 417 SD: Sage & Ziurys 1995, ApJ, 447, 625 INT: Meier & Turner 2005 ApJ, 618, 259
CH ₃ OH	95.91-[96.7414]-97.58 (2_k-1_k) 241.7-[241.7914]-241.9 (5_k-4_k)	grain mantle evaporation (saturated) traces moderate shocks/hot cores	intermediate	$\frac{1}{25}$	Gal: Bachiller et al. A&A, 295, L51 SD: Hüttemeister et al. 1997, A&A, 326, 59 INT: Meier & Turner 2005 ApJ, 618, 259
C ³⁴ S	96.4130 (2-1) 241.0160 (5-4)	<i>Form:</i> See CS Optically thin version of CS traces CS column density	high	$\frac{1}{50}$	Gal: Chin et al. 1996, A&A, 305, 960 SD: Martín et al. 2005, ApJ, 620, 210 INT: Meier & Turner 2005 ApJ, 618, 259
CS	97.9810 (2-1) 244.9356 (5-4)	<i>Form:</i> C + SO -or- C ⁺ /S ⁺ + SO/CH dense gas tracer possible PDR contribution	high	$\frac{1}{15}$	Gal: Myers et al. 1991, ApJ, 376, 561 SD: Baan et al. 2008, A&A, 477, 747 INT: Peng et al. 1996, ApJ, 470, 821
C ¹⁸ O	109.7822 (1-0) 219.5604 (2-1)	<i>Form:</i> Many paths Optically thin version of CO traces molecular column density	intermediate	$\frac{1}{25}$	Gal: Myers et al. 1983, ApJ, 264, 517 SD: Aalto et al. 1995, A&A, 300, 369 INT: Meier et al. 2001, ApJ, 551, 687
¹³ CO	110.2014 (1-0) 220.3987 (2-1)	<i>Form:</i> See C ¹⁸ O Optically thinner version of CO traces molecular column density	low	$\frac{1}{8}$	Gal: Myers et al. 1983, ApJ, 264, 517 SD: Aalto et al. 1995, A&A, 300, 369 INT: Turner & Hurt 1992, ApJ, 384, 72
CN	113.12-[113.1913] ($1-0; \frac{1}{2}-\frac{1}{2}$) 113.49-[113.4910]-113.52 ($1-0; \frac{3}{2}-\frac{1}{2}$) 226.29-[226.3599] ($2-1; \frac{3}{2}-\frac{3}{2}$) 226.62-[226.6596]-226.68 ($2-1; \frac{3}{2}-\frac{1}{2}$) 226.87-[226.8748]-226.91 ($2-1; \frac{5}{2}-\frac{3}{2}$)	<i>Form:</i> CH + N high density PDR tracer possible XDR tracer	high	$\frac{1}{10}$	Gal: Savage et al. 2002, ApJ, 578, 211 SD: Aalto et al. 2002, A&A, 381, 783 INT: ...
H ₂ CO	218.222 ($3_{03} - 2_{02}$)	<i>Form:</i> grain mantle evaporation ?? density and temperature probe sensitive to ice mantle conditions	high	$\frac{1}{40}$	Gal: Mangum & Wootten 1993, ApJS, 89, 123 SD: Hüttemeister et al. 1997, A&A, 326, 59 INT: ...

TABLE COMMENTS: (1) Bright chemical species in ALMA Bands 3 & 6. (2) For transitions displaying a range of ν , the bracketed value is that of the brightest hyperfine component (except CH₃CN where it is the $k = 0$ component). Frequencies are NRAO recommended values from Splatalogue. (3) An indication of the density regime traced by the molecule. Low $\sim 10^3$ cm⁻³, intermediate $\sim 10^4$ cm⁻³, high $\sim 10^5$ cm⁻³ and very high $\sim 10^6$ cm⁻³, but the exact critical density depends on transition and radiative transfer. (4) The typical brightness relative to ¹²CO(1-0) in a star forming galaxy. (5) Sample references for observational studies of the molecule (GAL = Galactic; SD = extragalactic single-dish; INT = extragalactic interferometric.)

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