Extragalactic Molecular Line Primer (VLA Bands L, S, C, X, K, Q) David S. Meier				
Molecule[1]	ν(GHz)/transition[2]	Description	Density[3]	Example References[4]
OH	1.612-[1.6674]-1.721 $^2\Pi_{3/2}$ $J = 3/2$ 6.016-[6.0351]-6.049 $^2\Pi_{3/2}$ $J = 5/2$ 13.435-[13.4414]-13.442 $^2\Pi_{3/2}$ $J = 7/2$ 23.805-[23.8266]-23.839 $^2\Pi_{3/2}$ $J = 9/2$	*Form:* O + H_3^+ -or- $O^+ \overset{2-3\times H_2}{\rightarrow} H_2O^+/H_3O^+$ followed by dissociative recombination **traces AGN disks/high IR rad. fields** *often a maser transition*	inter.	Gal:te Lintel Hekkert et al. A&AS, 90, 327 SD: Henkel et al. 1987, A&A, 185, 14 INT: Turner 1985, ApJ, 299, 312
CH	3.263-[3.3355]-3.349 $^2\Pi_{1/2}$ $J = 1/2$	*Form:* $C^+ \overset{H_2}{\rightarrow} CH_2^+ \overset{e^-}{\rightarrow} CH$ **traces PDRs, XDRs and low A_v gas** *potentially a weak maser*	inter.	Gal: Magnani et al. 2005, AJ, 130, 2725 SD: Whiteoak et al. 1980, MNRAS, 190, 17 INT: ...
H_2CO	4.8297 ($1_{10} - 1_{11}$) 14.4885 ($2_{11} - 2_{12}$) 28.9748 ($3_{12} - 3_{13}$) 48.2845 ($4_{13} - 4_{14}$)	Form: grain mantle evaporation ?? **density and temperature probe** sensitive to ice mantle conditions *potentially masing*	high	Gal: Downes et al. 1980, 40, 379 SD: Baan et al. 1986, ApJ, 305, 830 INT: ...
c-C_3H_2	18.3431 ($1_{01} - 1_{01}$) 21.5874 ($2_{20} - 2_{11}$) 46.7556 ($2_{11} - 2_{02}$)	*Form:* $C^+ + C_nH_m$ Abundant where C^+ and hydrocarbons are abundant **(PDRs, low A_V gas)**	high	Gal: Madden et al. 1989, AJ, 97, 1403 SD: Wang et al. 2004, A&A, 422, 883 INT: ...
SiO	43.4238 (1-0; v=0)	*Form:* Grain core liberation of Si **traces strong shocks**	high	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
HNCO	21.9816 ($1_{01} - 0_{00}$) 43.9630 ($2_{02} - 1_{01}$)	*Form:* grain mantle evaporation **traces moderate shocks/hot cores**	high	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
HC_3N	9.097-[9.0983]-9.100 (1-0) 18.194-[18.1963]-18.199 (2-1) 27.292-[27.2944]-27.297 (3-2) 36.390-[36.3924]-36.395 (4-3) 45.488-[45.4903]-45.493 (5-4)	*Form:* C_2H_2 + CN **traces dense gas excitation**	high	Gal: Morris et al. 1976, 205, 82 SD: Lindberg et al. 2011 INT: Meier et al. 2011, AJ, 142, 32
CH_3CN	18.396-[18.3980]-18.400 ($1_k - 0_k$) 36.793-[36.7956]-36.798 ($2_k - 1_k$)	*Form:* grain mantles (?) **probe of dense gas / hot core** **kinetic temperature**	very high	Gal: Remijan et al. 2004, ApJ, 617, 384 SD: Mauersberger et al. 1991, A&A, 247, 307 INT: ...
CS	48.9910 (1-0)	*Form:* C + SO -or- C^+/S^+ + SO/CH **dense gas tracer** possible PDR contribution	high	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

Extragalactic Molecular Line Primer (VLA) — Cont. David S. Meier				
Molecule[1]	ν(GHz)/transition[2]	Description	Density[3]	Example References[4]
SO	13.0438 ($N_J = 2_1 - 1_1$) 30.0016 ($0_1 - 1_0$)	*Form:* S + OH **traces chemical age** **CS/SO → the O/C elemental ratio**	high	Gal: Rydbeck et al. 1980, ApJ, 235, L171 SD: Petuchowski & Bennett, 1992, 391, 137 INT: ...
CH_3OH	6.6685 (5_{15}-6_{06}) 12.1786 (2_{02}-3_{-13}) 36.1693 (4_{-14}-3_{03}) 44.0695 (7_{07}-6_{16}) [48.3725]-48.377 (1_{01}-0_{00})	grain mantle evaporation **traces moderate shocks/hot cores** 6, 12GHz: Class II (rad) maser — Star form. 36, 44GHz: Class I (coll) maser — Shocks 48 GHz: thermal — shocks/hot cores	inter.	Gal: Walsh et al. 1997, MNRAS, 291, 261 SD: Impellizzeri et al. 2008, A&A, 484, L43 INT: ...
NH_3	23.692-[23.6945]-23.696 ($1_1 - 1_1$) 23.720-[23.7226]-23.725 ($2_2 - 2_2$) 23.867-[23.8701]-23.873 ($3_3 - 3_3$) 24.137-[24.1394]-24.142 ($4_4 - 4_4$) 24.530-[24.5330]-24.536 ($5_5 - 5_5$) 25.053-[25.0560]-25.059 ($6_6 - 6_6$) 25.712-[25.7152]-25.718 ($7_7 - 7_7$) 26.516-[26.5190]-26.522 ($8_8 - 8_8$) 27.4779 ($9_9 - 9_9$)	*Form:* $N^+ \overset{4\times H_2}{\rightarrow} NH_4^+ \overset{e^-}{\rightarrow} NH_3$ -or- grain mantle evaporation **traces gas kinetic temperature**	inter.	Gal: Ho & Townes 1983, ARA&A, 21, 239 SD: Mauersberger et al. 2003, A&A, 403, 561 INT: Ho et al. 1990, ApJ, 355, L19
H_2O	22.2351 ($6_{16} - 5_{23}$)	*Form:* grain mantle evaporation -or- $O \overset{H_2}{\rightarrow} OH \overset{H_2}{\rightarrow} H_2O$ (shocks) **traces Shocks — kinematics/dynamics** *maser transition*	high	Gal: Genzel & Downes 1977, A&AS, 30, 145 SD: Lo 2005, ARA&A, 43, 625 INT: Greenhill et al. 1995, ApJ, 440, 619

TABLE COMMENTS: (1) Bright chemical species in VLA Bands: L – Q. (2) For transitions displaying a range of ν, the bracketed value is that of the brightest hyperfine component (except CH_3CN 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 exact critical densities depend on transition and radiative transfer. (4) Sample references for observational studies of the molecule (GAL = Galactic; SD= extragalactic single-dish; INT = extragalactic interferometric.)

Atomic Hydrogen:													
HI	$1.42041 - {}^2\Sigma_{1/2}$	H	$1.39937 - 167\alpha$	H	$2.04928 - 147\alpha$	H	$3.17286 - 127\alpha$	H	$5.29373 - 107\alpha$	H	$9.81686 - 87\alpha$	H	$21.38479 - 67\alpha$
H	$1.01377 - 186\alpha$	H	$1.42473 - 166\alpha$	H	$2.09154 - 146\alpha$	H	$3.24871 - 126\alpha$	H	$5.44426 - 106\alpha$	H	$10.16130 - 86\alpha$	H	$22.36417 - 66\alpha$
H	$1.03025 - 185\alpha$	H	$1.45072 - 165\alpha$	H	$2.13496 - 145\alpha$	H	$3.32699 - 125\alpha$	H	$5.60055 - 105\alpha$	H	$10.52204 - 85\alpha$	H	$23.40428 - 65\alpha$
H	$1.04709 - 184\alpha$	H	$1.47734 - 164\alpha$	H	$2.17959 - 144\alpha$	H	$3.40780 - 124\alpha$	H	$5.76288 - 104\alpha$	H	$10.90006 - 84\alpha$	H	$24.50990 - 64\alpha$
H	$1.06431 - 183\alpha$	H	$1.50461 - 163\alpha$	H	$2.22548 - 143\alpha$	H	$3.49126 - 123\alpha$	H	$5.93154 - 103\alpha$	H	$11.29641 - 83\alpha$	H	$25.68628 - 63\alpha$
H	$1.08190 - 182\alpha$	H	$1.53256 - 162\alpha$	H	$2.27266 - 142\alpha$	H	$3.57746 - 122\alpha$	H	$6.10685 - 102\alpha$	H	$11.71220 - 82\alpha$	H	$26.93916 - 62\alpha$
H	$1.09988 - 181\alpha$	H	$1.56120 - 161\alpha$	H	$2.32119 - 141\alpha$	H	$3.66652 - 121\alpha$	H	$6.28914 - 101\alpha$	H	$12.14866 - 81\alpha$	H	$28.27487 - 61\alpha$
H	$1.11826 - 180\alpha$	H	$1.59057 - 160\alpha$	H	$2.37110 - 140\alpha$	H	$3.75857 - 120\alpha$	H	$6.47876 - 100\alpha$	H	$12.60708 - 80\alpha$	H	$29.70036 - 60\alpha$
H	$1.13706 - 179\alpha$	H	$1.62067 - 159\alpha$	H	$2.42246 - 139\alpha$	H	$3.85372 - 119\alpha$	H	$6.67607 - 99\alpha$	H	$13.08885 - 79\alpha$	H	$31.22331 - 59\alpha$
H	$1.15627 - 178\alpha$	H	$1.65154 - 158\alpha$	H	$2.47532 - 138\alpha$	H	$3.95211 - 118\alpha$	H	$6.88149 - 98\alpha$	H	$13.59549 - 78\alpha$	H	$32.85220 - 58\alpha$
H	$1.17593 - 177\alpha$	H	$1.68320 - 157\alpha$	H	$2.52972 - 137\alpha$	H	$4.05388 - 117\alpha$	H	$7.09541 - 97\alpha$	H	$14.12861 - 77\alpha$	H	$34.59638 - 57\alpha$
H	$1.19603 - 176\alpha$	H	$1.71567 - 156\alpha$	H	$2.58572 - 136\alpha$	H	$4.15917 - 116\alpha$	H	$7.31829 - 96\alpha$	H	$14.68999 - 76\alpha$	H	$36.46626 - 56\alpha$
H	$1.21659 - 175\alpha$	H	$1.74899 - 155\alpha$	H	$2.64340 - 135\alpha$	H	$4.26814 - 115\alpha$	H	$7.55061 - 95\alpha$	H	$15.28149 - 75\alpha$	H	$38.47336 - 55\alpha$
H	$1.23763 - 174\alpha$	H	$1.78317 - 154\alpha$	H	$2.70280 - 134\alpha$	H	$4.38095 - 114\alpha$	H	$7.79287 - 94\alpha$	H	$15.90519 - 74\alpha$	H	$40.63050 - 54\alpha$
H	$1.25915 - 173\alpha$	H	$1.81825 - 153\alpha$	H	$2.76399 - 133\alpha$	H	$4.49778 - 113\alpha$	H	$8.04560 - 93\alpha$	H	$16.56329 - 73\alpha$	H	$42.95197 - 53\alpha$
H	$1.28117 - 172\alpha$	H	$1.85425 - 152\alpha$	H	$2.82705 - 132\alpha$	H	$4.61879 - 112\alpha$	H	$8.30938 - 92\alpha$	H	$17.25821 - 72\alpha$	H	$45.45372 - 52\alpha$
H	$1.30372 - 171\alpha$	H	$1.89121 - 151\alpha$	H	$2.89204 - 131\alpha$	H	$4.74418 - 111\alpha$	H	$8.58482 - 91\alpha$	H	$17.99256 - 71\alpha$	H	$48.15360 - 51\alpha$
H	$1.32679 - 170\alpha$	H	$1.92916 - 150\alpha$	H	$2.95903 - 130\alpha$	H	$4.87416 - 110\alpha$	H	$8.87257 - 90\alpha$	H	$18.76916 - 70\alpha$		
H	$1.35041 - 169\alpha$	H	$1.96813 - 149\alpha$	H	$3.02811 - 129\alpha$	H	$5.00892 - 109\alpha$	H	$9.17332 - 89\alpha$	H	$19.59111 - 69\alpha$		
H	$1.37460 - 168\alpha$	H	$2.00816 - 148\alpha$	H	$3.09936 - 128\alpha$	H	$5.14870 - 108\alpha$	H	$9.48782 - 88\alpha$	H	$20.46177 - 68\alpha$		

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