

Cover Page



Universiteit Leiden



The following handle holds various files of this Leiden University dissertation:

<http://hdl.handle.net/1887/74478>

Author: Bacalla, X.

Title: Electronic spectroscopy of molecules of astrophysical interest

Issue Date: 2019-07-02

Bibliography

- Adams, W. S. “Some results with the Coudé spectrograph of the Mount Wilson Observatory.” *Astrophys. J.* **93** (1941) 11.
- Albertsson, T., Indriolo, N., Kreckel, H., et al. “First time-dependent study of H₂ and H₃⁺ ortho-para chemistry in the diffuse interstellar medium: Observations meet theoretical predictions.” *Astrophys. J.* **787** (2014) 44.
- Allamandola, L. J., Tielens, A. G. G. M., & Barker, J. R. “Polycyclic aromatic hydrocarbons and the unidentified infrared emission bands — Auto exhaust along the Milky Way.” *Astrophys. J.* **290** (1985) L25.
- Allen, M. & Robinson, G. W. “The molecular composition of dense interstellar clouds.” *Astrophys. J.* **212** (1977) 396.
- Araki, M., Cias, P., Denisov, A., et al. “Electronic spectroscopy of the nonlinear carbon chains C₄H₄⁺ and C₈H₄⁺.” *Can. J. Chem.* **82** (2004) 848–853.
- Bacalla, X., Zhao, D., Salumbides, E. J., et al. “The B²Π–X²Π electronic origin band of ¹³C₆H.” *J. Mol. Spectrosc.* **308–309** (2015) 41–44.
- Bacalla, X. L. “The B²Π–X²Π electronic origin transition of the ¹³C₆H isotopologue.” Master’s thesis, University of San Carlos (2014).
- Barlow, M. J., Swinyard, B. M., Owen, P. J., et al. “Detection of a noble gas molecular ion, ³⁶ArH⁺, in the Crab Nebula.” *Science* **342** (2013) 1343–1345.
- Beals, C. S. & Blanchet, G. H. “A line at $\lambda\lambda 4430.5$ of possibly interstellar origin.” *Publ. Astron. Soc. Pac.* **49** (1937) 224.
- Belloche, A., Garrod, R. T., Muller, H. S. P., et al. “Detection of a branched alkyl molecule in the interstellar medium: iso-propyl cyanide.” *Science* **345** (2014) 1584–1587.
- Berden, G. & Engeln, R. (eds.). *Cavity Ring-Down Spectroscopy*. John Wiley and Sons Ltd (2009). ISBN 1405176881.
- Berden, G., Peeters, R., & Meijer, G. “Cavity ring-down spectroscopy: Experimental schemes and applications.” *Int. Rev. Phys. Chem.* **19** (2000) 565–607.
- Berné, O., Mulas, G., & Joblin, C. “Interstellar C₆₀⁺.” *Astron. Astrophys.* **550** (2013) L4.
- Berné, O., Cox, N. L. J., Mulas, G., et al. “Detection of buckminsterfullerene emission

- in the diffuse interstellar medium.” *Astron. Astrophys.* **605** (2017) L1.
- Bhatt, N. H. & Cami, J. “A sensitive spectral survey of interstellar features in the near-UV [3050–3700 Å].” *Astrophys. J. Suppl. S.* **216** (2015) 22.
- Birza, P., Khoroshev, D., Chirokolava, A., et al. “Lifetime broadening in the gas phase $B^2\Pi - X^2\Pi$ electronic spectrum of C_8H .” *Chem. Phys. lett.* **382** (2003) 245–248.
- Bohlin, R. C., Savage, B. D., & Drake, J. F. “A survey of interstellar H I from L-alpha absorption measurements. II.” *Astrophys. J.* **224** (1978) 132–142.
- Bonaca, A. & Bilalbegović, G. “Optical spectrum of proflavine and its ions.” *Chem. Phys. Lett.* **493** (2010) 33–36.
- Bregman, J. D., Dinerstein, H. L., Goebel, J. H., et al. “Observations of NGC 7027 from 5.2 to 7.5 microns — The detection of Ni II and additional dust features.” *Astrophys. J.* **274** (1983) 666.
- Brown, S. T., Rienstra-Kiracofe, J. C., & Schaefer III, H. F. “A systematic application of density functional theory to some carbon-containing molecules and their anions.” *J. Phys. Chem. A* **103** (1999) 4065–4077.
- Cami, J. & Cox, N. L. J. (eds.). *The Diffuse Interstellar Bands, IAU Symposium*, volume 297. Cambridge Univ. Press, Cambridge (2014).
- Cami, J., Sonnentrucker, P., Ehrenfreund, P., et al. “Diffuse interstellar bands in single clouds: New families and constraints on the carriers.” *Astron. Astrophys.* **326** (1997) 822–830.
- Cami, J., Bernard-Salas, J., Peeters, E., et al. “Detection of C_{60} and C_{70} in a young planetary nebula.” *Science* **329** (2010) 1180.
- Cami, J., Cox, N. L. J., Farhang, A., et al. “The ESO Diffuse Interstellar Band Large Exploration Survey (EDIBLES).” *The Messenger* **171** (2018) 31–36.
- Campbell, E. K., Holz, M., Gerlich, D., et al. “Laboratory confirmation of C_{60}^+ as the carrier of two diffuse interstellar bands.” *Nature* **523** (2015) 322–323.
- Campbell, E. K., Holz, M., Maier, J. P., et al. “Gas phase absorption spectroscopy of C_{60}^+ and C_{70}^+ in a cryogenic ion trap: Comparison with astronomical measurements.” *Astrophys. J.* **822** (2016a) 17.
- Campbell, E. K., Holz, M., & Maier, J. P. “ C_{60}^+ in diffuse clouds: Laboratory and astronomical comparison.” *Astrophys. J. Lett.* **826** (2016b) L4.
- Cao, Z. & Peyerimhoff, S. D. “Electronic spectra of linear isoelectronic species HC_6H^+ , C_6H , HC_5N^+ .” *Phys. Chem. Chem. Phys.* **3** (2001) 1403–1406.
- Cardelli, J. A., Clayton, G. C., & Mathis, J. S. “The relationship between infrared, optical, and ultraviolet extinction.” *Astrophys. J.* **345** (1989) 245.
- Carruthers, G. R. “Rocket observation of interstellar molecular hydrogen.” *Astrophys. J.* **161** (1970) L81.
- Cernicharo, J. & Guélin, M. “Metals in IRC+10216 — Detection of NaCl, AlCl, and KCl, and tentative detection of AlF.” *Astron. Astrophys.* **183** (1987) L10–L12.
- Cernicharo, J., Guélin, M., Menten, K. M., et al. “ C_6H : Astronomical study of its fine and hyperfine structure.” *Astron. Astrophys.* **181** (1987) L1–L4.
- Cernicharo, J., Goicoechea, J. R., & Caux, E. “Far-infrared detection of C_3 in Sagit-

- tarius B2 and IRC+10216.” *Astrophys. J.* **534** (2000) L199–L202.
- Cernicharo, J., Guélin, M., Agúndez, M., et al. “Detection of C₅N[−] and vibrationally excited C₆H in IRC+10216.” *Astrophys. J.* **688** (2008) L83–L86.
- Chambaud, G., Levy, B., Millie, P., et al. “Charge exchange and fine-structure excitation in O-H⁺ collisions.” *J. Phys. Pt. B Atom. M. P.* **13** (1980) 4205–4216.
- Chang, C.-H., Agarwal, J., Allen, W. D., et al. “Sub-doppler infrared spectroscopy and formation dynamics of triacetylene in a slit supersonic expansion.” *J. Chem. Phys.* **144** (2016) 074301.
- Cheung, A. C., Rank, D. M., Townes, C. H., et al. “Detection of water in interstellar regions by its microwave radiation.” *Nature* **221** (1969) 626–628.
- Cohen, M., Anderson, C. M., Cowley, A., et al. “The peculiar object HD 44179 (‘The Red Rectangle’).” *Astrophys. J.* **196** (1975) 179.
- Cordiner, M. A. & Sarre, P. J. “The CH₂CN[−] molecule: carrier of the λ8037 diffuse interstellar band?” *Astron. Astrophys.* **472** (2007) 537–545.
- Cordiner, M. A., Cox, N. L. J., Trundle, C., et al. “Detection of diffuse interstellar bands in M31.” *Astron. Astrophys.* **480** (2008) L13–L16.
- Cordiner, M. A., Cox, N. L. J., Lallement, R., et al. “Searching for interstellar C₆₀⁺ using a new method for high signal-to-noise HST/STIS spectroscopy.” *Astrophys. J.* **843** (2017) L2.
- Cordiner, M. A., Linnartz, H., Cox, N. L. J., et al. “Confirming interstellar C₆₀⁺ using the Hubble Space Telescope.” *Astrophys. J. Lett.* **875** (2019) L28.
- Cox, N. L. J., Ehrenfreund, P., Foing, B. H., et al. “Linear and circular spectropolarimetry of diffuse interstellar bands.” *Astron. Astrophys.* **531** (2011) A25.
- Cox, N. L. J., Cami, J., Kaper, L., et al. “VLT/X-Shooter survey of near-infrared diffuse interstellar bands.” *Astron. Astrophys.* **569** (2014) A117.
- Cox, N. L. J., Cami, J., Farhang, A., et al. “The ESO Diffuse Interstellar Bands Large Exploration Survey (EDIBLES).” *Astron. Astrophys.* **606** (2017) A76.
- Crawford, M. K., Tielens, A. G. G. M., & Allamandola, L. J. “Ionized polycyclic aromatic hydrocarbons and the diffuse interstellar bands.” *Astrophys. J.* **293** (1985) L45.
- Crawford, T. M. “Error sources in the ‘ring down’ optical cavity decay time mirror reflectometer.” In: Stotlar, S. C. (ed.), *Southwest Conference on Optics ‘85, SPIE*, volume 0540 (1985) .
- Dalgarno, A. “Interstellar chemistry special feature: The galactic cosmic ray ionization rate.” *P. Natl. Acad. Sci. USA* **103** (2006) 12269–12273.
- Danks, A. C. & Lambert, D. L. “Line profiles of the diffuse interstellar lines at 5780 Å, 5797 Å.” *Mon. Not. R. Astron. Soc.* **174** (1976) 571–586.
- Davis, L., Jr. & Greenstein, J. L. “The polarization of starlight by aligned dust grains.” *Astrophys. J.* **114** (1951) 206.
- de Almeida, A. A. “Possible OH⁺ submillimeter emission in Orion-KL.” *Rev. Mex. Astron. Astrofis.* **21** (1990) 499–503.
- de Almeida, A. A. & Singh, P. D. “The OH⁺ molecule in interstellar clouds: Absolute

- oscillator strengths and equivalent widths for OH⁺ ($A^3\Pi_i - X^3\Sigma^-$) bands." *Astron. Astrophys.* **95** (1981) 383.
- Dekker, H., D'Odorico, S., Kaufer, A., et al. "Design, construction, and performance of UVES, the echelle spectrograph for the UT2 Kueyen Telescope at the ESO Paranal Observatory." In: Iye, M. & Moorwood, A. F. (eds.), *Optical and IR Telescope Instrumentation and Detectors, SPIE*, volume 4008 (2000) 534–545.
- Denisov, A. "Electronic spectroscopy of unsaturated hydrocarbons and sulfur-terminated carbon chains by cavity ringdown." Ph.D. thesis, Universität Basel (2006).
- Dickens, J. E., Irvine, W. M., Ohishi, M., et al. "Detection of interstellar ethylene oxide (c-C₂H₄O)." *Astrophys. J.* **489** (1997) 753–757.
- Diplas, A. & Savage, B. D. "An IUE survey of interstellar H I Ly α absorption. I: Column densities." *Astrophys. J. Suppl. S.* **93** (1994) 211–228.
- Douglas, A. E. "Origin of diffuse interstellar lines." *Nature* **269** (1977) 130–132.
- Douglas, A. E. & Herzberg, G. "Band spectrum and structure of the CH⁺ molecule: Identification of three interstellar lines." *Can. J. Res.* **20a** (1942) 71–82.
- Doyle, T., Shen, L., Rittby, C., et al. "A C≡C stretching vibration of the C₆H (hexatriynyl) radical in Ar at 10 K." *J. Chem. Phys.* **95** (1991) 6224–6228.
- Ehrenfreund, P., Cami, J., Jiménez-Vicente, J., et al. "Detection of diffuse interstellar bands in the magellanic clouds." *Astrophys. J.* **576** (2002) L117–L120.
- Elyajouri, M., Lallement, R., Cox, N. L. J., et al. "The EDIBLES survey. III. C₂-DIBs and their profiles." *Astron. Astrophys.* **616** (2018) A143.
- Federman, S. R., Weber, J., & Lambert, D. L. "Cosmic ray-induced chemistry toward Perseus OB2." *Astrophys. J.* **463** (1996) 181.
- Ferrière, K. M. "The interstellar environment of our galaxy." *Rev. Mod. Phys.* **73** (2001) 1031–1066.
- Fiedler, S. E. "Incoherent broad-band cavity-enhanced absorption spectroscopy." Ph.D. thesis, Technical University of Berlin (2005).
- Fiedler, S. E., Hese, A., & Ruth, A. A. "Incoherent broad-band cavity-enhanced absorption spectroscopy." *Chem. Phys. Lett.* **371** (2003) 284–294.
- Foing, B. H. & Ehrenfreund, P. "Detection of two interstellar absorption bands coincident with spectral features of C₆₀⁺." *Nature* **369** (1994) 296–298.
- Foing, B. H. & Ehrenfreund, P. "New evidences for interstellar C₆₀⁺." *Astron. Astrophys.* **317** (1997) L59–L62.
- Forney, D., Fulara, J., Freivogel, P., et al. "Electronic absorption spectra of linear carbon chains in neon matrices. I. C₆⁻, C₆, and C₆H." *J. Chem. Phys.* **103** (1995) 48–53.
- Freivogel, P., Fulara, J., Jakobi, M., et al. "Electronic absorption spectra of linear carbon chains in neon matrices. II. C_{2n}⁻, C_{2n}, and C_{2n}H." *J. Chem. Phys.* **103** (1995) 54–59.
- Friedman, S. D., York, D. G., McCall, B. J., et al. "Studies of diffuse interstellar bands V. Pairwise correlations of eight strong dibs and neutral hydrogen, molecular

- hydrogen, and color excess.” *Astrophys. J.* **727** (2010) 33.
- Fulara, J., Jakobi, M., & Maier, J. P. “Electronic and infrared spectra of C_{60}^+ and C_{60}^- in neon and argon matrices.” *Chem. Phys. Lett.* **211** (1993a) 227–234.
- Fulara, J., Lessen, D., Freivogel, P., et al. “Laboratory evidence for highly unsaturated hydrocarbons as carriers of some of the diffuse interstellar bands.” *Nature* **366** (1993b) 439–441.
- Furton, D. G. & Witt, A. N. “Extended red emission from dust in planetary nebulae.” *Astrophys. J.* **386** (1992) 587.
- Galazutdinov, G. & Krełowski, J. “Looking for the weak members of the C_{60}^+ family in the interstellar medium.” *Acta Astronomica* **67** (2017) 159–169.
- Galazutdinov, G., Lee, B.-C., Song, I.-O., et al. “A search for interstellar naphthalene and anthracene cations.” *Mon. Not. R. Astron. Soc.* (2011) 1259–1264.
- Galazutdinov, G. A., LoCurto, G., & Krełowski, J. “High-resolution profiles of diffuse interstellar bands.” *Astrophys. J.* **682** (2008) 1076–1086.
- Galazutdinov, G. A., Shimansky, V. V., Bondar, A., et al. “ C_{60}^+ — looking for the bucky-ball in interstellar space.” *Mon. Not. R. Astron. Soc.* **465** (2017) 3956–3964.
- Geballe, T. R. “The diffuse interstellar bands — A brief review.” *J. Phys. Conf. Ser.* **728** (2016) 062005.
- Geballe, T. R., Najarro, F., Figer, D. F., et al. “Infrared diffuse interstellar bands in the galactic centre region.” *Nature* **479** (2011) 200–202.
- Gerin, M., Luca, M. D., Black, J., et al. “Interstellar OH $^+$, H $_2$ O $^+$ and H $_3$ O $^+$ along the sight-line to G10.6–0.4.” *Astron. Astrophys.* **518** (2010) L110.
- Glassgold, A. E. & Langer, W. D. “Model calculations for diffuse molecular clouds.” *Astrophys. J.* **193** (1974) 73–91.
- González-Alfonso, E., Fischer, J., Bruderer, S., et al. “Excited OH $^+$, H $_2$ O $^+$, and H $_3$ O $^+$ in NGC 4418 and Arp 220.” *Astron. Astrophys.* **550** (2013) A25.
- Gottlieb, C. A., McCarthy, M. C., & Thaddeus, P. “Vibrationally excited C $_6$ H.” *Astrophys. J. Suppl. S.* **189** (2010) 261–269.
- Gredel, R., Black, J. H., & Yan, M. “Interstellar C $_2$ and CN toward the Cyg OB2 association.” *Astron. Astrophys.* **375** (2001) 553–565.
- Greenberg, J. M. & Stoeckly, R. “Shape of the diffuse interstellar bands.” *Nature Physical Science* **230** (1971) 15–16.
- Guélin, M., Cernicharo, J., Gomez-Gonzalez, J., et al. “Detection of a heavy radical in IRC+10216: The hexatriynyl radical C $_6$ H?” *Astron. Astrophys.* **175** (1987) L5–L8.
- Haddad, M. “Cavity ring-down laser spectroscopy of carbon-chain molecules.” Ph.D. thesis, Vrije Universiteit Amsterdam (2014).
- Haddad, M., Zhao, D., Linnartz, H., et al. “The $^2\Pi - \tilde{X}^2\Pi$ electronic spectra of the long carbon-chain $^{(13)}\text{C}_{2n}$ H/D molecules for ($n = 4 - 6$).” *Mol. Phys.* **113** (2015) 2063–2072.
- Hall, J. S. “Observations of the polarized light from stars.” *Science* **109** (1949) 166–167.
- Hartmann, J. “Investigations on the spectrum and orbit of δ Orionis.” *Astrophys. J.*

- 19** (1904) 268.
- Heger, M. L. “The spectra of certain class B stars in the regions 5630Å–6680Å and 3280Å–3380Å.” *Lick Observatory Bulletin* **10** (1922) 146–147.
- Herbig, G. H. “The diffuse interstellar bands. I. A possible identification of λ 4430.” *Astrophys. J.* **137** (1963) 200.
- Herbig, G. H. “The diffuse interstellar bands. IV — The region 4400–6850 Å.” *Astrophys. J.* **196** (1975) 129.
- Herbig, G. H. “The diffuse interstellar bands.” *Annu. Rev. Astron. Astr.* **33** (1995) 19–73.
- Herbst, E. & Klemperer, W. “The formation and depletion of molecules in dense interstellar clouds.” *Astrophys. J.* **185** (1973) 505.
- Herbst, E. & van Dishoeck, E. F. “Complex organic interstellar molecules.” *Annu. Rev. Astron. Astr.* **47** (2009) 427–480.
- Herriott, D. R. & Schulte, H. J. “Folded optical delay lines.” *Appl. Opt.* **4** (1965) 883.
- Herzberg, G. *Molecular Spectra and Molecular Structure I. Spectra of Diatomic Molecules*. D. Van Nostrand, New York (1950).
- Herzberg, G. *Molecular Spectra and Molecular Structure III. Electronic Spectra and Electronic Structure of Polyatomic Molecules*. D. Van Nostrand, New York (1966).
- Herzberg, G. “Remarks on the diffuse interstellar lines.” In: van Woerden, H. (ed.), *Radio Astronomy and the Galactic System, IAU Symposium*, volume 31 (1967) 91.
- Hiltner, W. A. “On the presence of polarization in the continuous radiation of stars. II.” *Astrophys. J.* **109** (1949) 471.
- Hobbs, L. M., York, D. G., Thorburn, J. A., et al. “Studies of the diffuse interstellar bands. III. HD 183143.” *Astrophys. J.* **705** (2009) 32–45.
- Hodges, J. N. & Bernath, P. F. “Fourier transform spectroscopy of the $A^3\Pi - X^3\Sigma^-$ transition of OH⁺.” *Astrophys. J.* **840** (2017) 81.
- Hodges, J. N., Bittner, D. M., & Bernath, P. F. “Improved ultraviolet and infrared oscillator strengths for OH⁺.” *Astrophys. J.* **855** (2018) 21.
- Hollenbach, D., Kaufman, M. J., Neufeld, D., et al. “The chemistry of interstellar OH⁺, H₂O⁺, and H₃O⁺: Inferring the cosmic-ray ionization rates from observations of molecular ions.” *Astrophys. J.* **754** (2012) 105.
- Holmlid, L. “Rydberg matter as the diffuse interstellar band (DIB) carrier in interstellar space: the model and accurate calculations of band centres.” *Phys. Chem. Chem. Phys.* **6** (2004) 2048.
- Hoshina, K., Kohguchi, H., Ohshima, Y., et al. “Laser-induced fluorescence spectroscopy of the C₄H and C₄D radicals in a supersonic jet.” *J. Chem. Phys.* **108** (1998) 3465–3478.
- Hougen, J. T. “Rotational energy levels of a linear triatomic molecule in a $^2\Pi$ electronic state.” *J. Chem. Phys.* **36** (1962) 519–534.
- Iglesias-Groth, S., Manchado, A., García-Hernández, D. A., et al. “Evidence for the naphthalene cation in a region of the interstellar medium with anomalous microwave emission.” *Astrophys. J.* **685** (2008) L55–L58.

- Iglesias-Groth, S., Manchado, A., Rebolo, R., et al. “A search for interstellar anthracene towards the perseus anomalous microwave emission region.” *Mon. Not. R. Astron. Soc.* **407** (2010) 2157–2165.
- Indriolo, N. & McCall, B. J. “Investigating the cosmic-ray ionization rate in the galactic diffuse interstellar medium through observations of H_3^+ .” *Astrophys. J.* **745** (2012) 91.
- Indriolo, N. & McCall, B. J. “Cosmic-ray astrochemistry.” *Chem. Soc. Rev.* **42** (2013) 7763.
- Indriolo, N., Geballe, T. R., Oka, T., et al. “ H_3^+ in diffuse interstellar clouds: A tracer for the cosmic-ray ionization rate.” *Astrophys. J.* **671** (2007) 1736–1747.
- Indriolo, N., Neufeld, D. A., Gerin, M., et al. “Chemical analysis of a diffuse cloud along a line of sight toward W51: Molecular fraction and cosmic-ray ionization rate.” *Astrophys. J.* **758** (2012) 83.
- Indriolo, N., Neufeld, D. A., Gerin, M., et al. “Herschel survey of galactic OH^+ , H_2O^+ , and H_3O^+ : Probing the molecular hydrogen fraction and cosmic-ray ionization rate.” *Astrophys. J.* **800** (2015) 40.
- Indriolo, N., Bergin, E. A., Falgarone, E., et al. “Constraints on the cosmic-ray ionization rate in the $z \sim 2.3$ lensed galaxies SMM J2135-0102 and SDP 17b from observations of OH^+ and H_2O^+ .” *Astrophys. J.* **865** (2018) 127.
- Ityaksov, D. “Cavity ring-down optical extinction measurements of atmospheric molecules.” Ph.D. thesis, Vrije Universiteit Amsterdam (2009).
- Jenkins, E. B. “A unified representation of gas-phase element depletions in the interstellar medium.” *Astrophys. J.* **700** (2009) 1299–1348.
- Jenkins, E. B., Drake, J. F., Morton, D. C., et al. “Spectrophotometric results from the copernicus satellite. V. Abundances of molecules in interstellar clouds.” *Astrophys. J. Lett.* **181** (1973) L122.
- Jenniskens, P. & Désert, F.-X. “A survey of diffuse interstellar bands (3800–8680 Å).” *Astron. Astrophys. Suppl. Ser.* **106** (1994) 39–78.
- Jochnowitz, E. B. & Maier, J. P. “Electronic spectroscopy of carbon chains.” *Annu. Rev. Phys. Chem.* **59** (2008) 519–544.
- Jog, C. J. “Starbursts triggered by cloud compression in interacting galaxies.” In: Barnes, J. E. & Sanders, D. B. (eds.), *Galaxy Interactions at Low and High Redshift, IAU Symposium*, volume 186 (1999) 235.
- Junkkarinen, V. T., Cohen, R. D., Beaver, E. A., et al. “Dust and diffuse interstellar bands in the $z_a = 0.524$ absorption system toward AO 0235+164.” *Astrophys. J.* **614** (2004) 658–670.
- Kaur, D., de Souza, A. M., Wanna, J., et al. “Multipass cell for molecular beam absorption spectroscopy.” *Appl. Opt.* **29** (1990) 119.
- Kawaguchi, K., Kasai, Y., Ishikawa, S.-I., et al. “A spectral-line survey observation of IRC+10216 between 28 and 50 GHz.” *Publ. Astron. Soc. Jpn.* **47** (1995) 853–876.
- Knöckel, H., Bodermann, B., & Tiemann, E. “High precision description of the rovibronic structure of the I_2 B-X spectrum.” *Eur. Phys. J. D* **28** (2004) 199–209.

- Kogut, A., Banday, A. J., Bennett, C. L., et al. "Microwave emission at high galactic latitudes in the four-year DMR sky maps." *Astrophys. J.* **464** (1996) L5–L9.
- Kotterer, M. & Maier, J. P. "Electronic spectrum of C₆H: $^2\Pi$ –X $^2\Pi$ in the gas-phase detected by cavity ringdown." *Chem. Phys. Lett.* **266** (1997) 342–346.
- Kovalenko, A., Dung Tran, T., Rednyk, S., et al. "OH⁺ formation in the low-temperature O^{+(4S)} + H₂ reaction." *Astrophys. J.* **856** (2018) 100.
- Kramida, A., Ralchenko, Y., Reader, J., et al. NIST Atomic Spectra Database (ver. 5.1) [Online], Available:<http://physics.nist.gov/asd>, National Institute of Standards and Technology, Gaithersburg, MD (2013).
- Krätschmer, W. "Carbon molecules as possible carrier of the diffuse interstellar bands." *Astrophys. Space Sci.* **128** (1986) 93–99.
- Krełowski, J. & Walker, G. A. H. "Three families of diffuse interstellar bands?" *Astrophys. J.* **312** (1987) 860.
- Krełowski, J., Beletsky, Y., & Galazutdinov, G. A. "Hydroxyl cation in translucent interstellar clouds." *Astrophys. J. Lett.* **719** (2010a) L20–L22.
- Krełowski, J., Beletsky, Y., Galazutdinov, G. A., et al. "Evidence for diacetylene cation as the carrier of a diffuse interstellar band." *Astrophys. J.* **714** (2010b) L64–L67.
- Krełowski, J., Galazutdinov, G., & Kołos, R. "Can H₂CCC be the carrier of broad diffuse bands?" *Astrophys. J.* **735** (2011) 124.
- Kroto, H. W. "The stability of the fullerenes C_n, with n = 24, 28, 32, 36, 50, 60 and 70." *Nature* **329** (1987) 529–531.
- Kroto, H. W. & Jura, M. "Circumstellar and interstellar fullerenes and their analogues." *Astron. Astrophys.* **263** (1992) 275–280.
- Kuhn, M., Renzler, M., Postler, J., et al. "Atomically resolved phase transition of fullerene cations solvated in helium droplets." *Nat. Commun.* **7** (2016).
- Kulesa, C. A. "Molecular hydrogen and its ions in dark interstellar clouds and star forming regions." Ph.D. thesis, The University of Arizona (2002).
- Kurucz, R. L. & Bell, B. *Atomic line list*. Smithsonian Astrophysical Observatory, Cambridge, MA (1995).
- Lallement, R., Cox, N. L. J., Cami, J., et al. "The EDIBLES survey II. The detectability of C₆₀⁺ bands." *Astron. Astrophys.* **614** (2018) A28.
- Le Petit, F., Roueff, E., & Herbst, E. "H₃⁺ and other species in the diffuse cloud towards ζ Persei: A new detailed model." *Astron. Astrophys.* **417** (2004) 993–1002.
- Leger, A. & d'Hendecourt, L. "Are polycyclic aromatic hydrocarbons the carriers of the diffuse interstellar bands in the visible?" *Astron. Astrophys.* **146** (1985) 81–85.
- Leger, A., D'Hendecourt, L., Verstraete, L., et al. "Remarkable candidates for the carrier of the diffuse interstellar bands - C₆₀⁺ and other polyhedral carbon ions." *Astron. Astrophys.* **203** (1988) 145–148.
- Leitch, E. M., Readhead, A. C. S., Pearson, T. J., et al. "An anomalous component of galactic emission." *Astrophys. J.* **486** (1997) L23–L26.

- Lepp, S., Dalgarno, A., van Dishoeck, E. F., et al. “Large molecules in diffuse interstellar clouds.” *Astrophys. J.* **329** (1988) 418.
- Lew, H. “Electronic spectrum of H_2O^+ .” *Can. J. Phys.* **54** (1976) 2028–2049.
- Linnartz, H., Motylewski, T., Vaizert, O., et al. “Electronic ground and excited state spectroscopy of C_6H and C_6D .” *J. Mol. Spectrosc.* **197** (1999) 1–11.
- Linnartz, H., Bossa, J.-B., Bouwman, J., et al. “Solid state pathways towards molecular complexity in space.” In: Cernicharo, J. & Bachiller, R. (eds.), *The Molecular Universe, IAU Symposium*, volume 280. Cambridge University Press (CUP) (2011) 390–404.
- Linnartz, H., Ioppolo, S., & Fedoseev, G. “Atom addition reactions in interstellar ice analogues.” *Int. Rev. Phys. Chem.* **34** (2015) 205–237.
- Liszt, H., Sonnentrucker, P., Cordiner, M., et al. “The abundance of C_3H_2 and other small hydrocarbons in the diffuse interstellar medium.” *Astrophys. J.* **753** (2012) L28.
- Liu, R., Zhou, X., & Pulay, P. “*Ab initio* study of the geometry, stretching, vibrations, and assignment of the observed frequencies of the ground state C_6H (hexatriynyl) radical.” *J. Chem. Phys.* **97** (1992) 1602–1605.
- Lloyd, G. M. & Ewart, P. “High resolution spectroscopy and spectral simulation of C_2 using degenerate four-wave mixing.” *J. Chem. Phys.* **110** (1999) 385–392.
- Loomis, F. W. & Brandt, W. H. “The band spectrum of OH^+ .” *Phys. Rev.* **49** (1936) 55–67.
- Maier, J. P., Walker, G. A. H., Bohlender, D. A., et al. “Identification of H_2CCC as a diffuse interstellar band carrier.” *Astrophys. J.* **726** (2011a) 41.
- Maier, J. P., Chakrabarty, S., Mazzotti, F. J., et al. “Assignment of 5069 Å diffuse interstellar band to HC_4H^+ : Disagreement with laboratory absorption band.” *Astrophys. J. Lett.* **729** (2011b) L20.
- Martin, F., Bacis, R., Churassy, S., et al. “Laser-induced-fluorescence fourier transform spectrometry of the XO_g^+ state of I_2 : Extensive analysis of the $\text{BO}_u^+ \rightarrow \text{XO}_g^+$ fluorescence spectrum of $^{127}\text{I}_2$.” *J. Mol. Spectrosc.* **116** (1986) 71–100.
- Martin, P. G., Illing, R., & Angel, J. R. P. “Discovery of interstellar circular polarization in the direction of the Crab nebula.” *Mon. Not. R. Astron. Soc.* **159** (1972) 191–201.
- McCall, B., Thorburn, J., Hobbs, L., et al. “Rejection of the C_7 -diffuse interstellar band hypothesis.” *Astrophys. J. Lett.* **559** (2001) L49.
- McCall, B. J. & Griffin, R. E. “On the discovery of the diffuse interstellar bands.” *P. Roy. Soc. A-Math. Phy.* **469** (2013) 2012.0604.
- McCall, B. J., Huneycutt, A. J., Saykally, R. J., et al. “An enhanced cosmic-ray flux towards ζ Persei inferred from a laboratory study of the H_3^+-e^- recombination rate.” *Nature* **422** (2003) 500–502.
- McCarthy, M., Gottlieb, C., Gupta, H., et al. “Laboratory and astronomical identification of the negative molecular ion C_6H^- .” *Astrophys. J. Lett.* **652** (2006) L141.
- McCarthy, M. C. & Thaddeus, P. “Rotational spectrum and carbon-13 hyperfine struc-

- ture of the C₃H, C₅H, C₆H, and C₇H radicals.” *J. Chem. Phys.* **122** (2005) 174308.
- McGuire, B. A. “2018 Census of interstellar, circumstellar, extragalactic, protoplanetary disk, and exoplanetary molecules.” *Astrophys. J. Suppl. Ser.* **239** (2018) 17.
- McGuire, B. A., Carroll, P. B., Loomis, R. A., et al. “Discovery of the interstellar chiral molecule propylene oxide (CH₃CHCH₂O).” *Science* **352** (2016) 1449–1452.
- McKellar, A. “Evidence for the molecular origin of some hitherto unidentified interstellar lines.” *Publ. Astron. Soc. Pac.* **52** (1940) 187.
- McKellar, A. “Some topics in molecular astronomy.” *J. R. Astron. Soc. Can.* **54** (1960) 97.
- McManus, J. B., Kebabian, P. L., & Zahniser, M. S. “Astigmatic mirror multipass absorption cells for long-path-length spectroscopy.” *Appl. Opt.* **34** (1995) 3336.
- Menten, K. M. & Wyrowski, F. “Molecules detected in interstellar space.” In: Yamada, K. M. T. & Winnewisser, G. (eds.), *Interstellar Molecules, Springer Tracts in Modern Physics*, volume 241 (2011) 27–42.
- Merer, A. J., Malm, D. N., Martin, R. W., et al. “The ultraviolet emission spectra of OH⁺ and OD⁺. Rotational structure and perturbations in the A³Π_i – X³Σ[−] transition.” *Can. J. Phys.* **53** (1975) 251.
- Merrill, P. W. “Unidentified interstellar lines.” *Publ. Astron. Soc. Pac.* **46** (1934) 206.
- Merrill, P. W. & Wilson, O. C. “Unidentified interstellar lines in the yellow and red.” *Astrophys. J.* **87** (1938) 9.
- Motylewski, T. & Linnartz, H. “Cavity ring down spectroscopy on radicals in a supersonic slit nozzle discharge.” *Rev. Sci. Instrum.* **70** (1999) 1305–1312.
- Motylewski, T., Linnartz, H., Vaizert, O., et al. “Gas-phase electronic spectra of carbon-chain radicals compared with diffuse interstellar band observations.” *Astrophys. J.* **531** (2000) 312.
- Moutou, C., Krełowski, J., D’Hendecourt, L., et al. “On correlations between diffuse interstellar bands.” *Astron. Astrophys.* **351** (1999) 680–688.
- Muller, S., Müller, H. S. P., Black, J. H., et al. “OH⁺ and H₂O⁺ absorption toward PKS 1830–211.” *Astron. Astrophys.* **595** (2016) A128.
- Nagarajan, R. & Maier, J. P. “Electronic spectra of carbon chains and derivatives.” *Int. Rev. Phys. Chem.* **29** (2010) 521–554.
- Neufeld, D. A. & Wolfire, M. G. “The cosmic-ray ionization rate in the galactic disk, as determined from observations of molecular ions.” *Astrophys. J.* **845** (2017) 163.
- Neufeld, D. A., Goicoechea, J. R., Sonnentrucker, P., et al. “Herschel/HIFI observations of interstellar OH⁺ and H₂O⁺ towards W49N: A probe of diffuse clouds with a small molecular fraction.” *Astron. Astrophys.* **521** (2010) L10.
- Öberg, K. I. “Photochemistry and astrochemistry: Photochemical pathways to interstellar complex organic molecules.” *Chem. Rev.* **116** (2016) 9631–9663.
- O’Keefe, A. & Deacon, D. A. “Cavity ring-down optical spectrometer for absorption measurements using pulsed laser sources.” *Rev. Sci. Instrum.* **59** (1988) 2544–2551.
- Ossenkopf, V., Müller, H. S. P., Lis, D. C., et al. “Detection of interstellar oxidaniumyl: Abundant H₂O⁺ towards the star-forming regions DR21, Sgr B2, and NGC6334.”

- Astron. Astrophys.* **518** (2010) L111.
- Pauzat, F. & Ellinger, Y. “The lowest two electronic states of the hexatriynil radiacal: C_6H .” *Astron. Astrophys.* **216** (1989) 305–309.
- Pearson, J. C., Gottlieb, C. A., Woodward, D. R., et al. “Laboratory detection of the C_6H radical.” *Astron. Astrophys.* **189** (1988) L13–L15.
- Pfluger, D., Motylewski, T., Linnartz, H., et al. “Rotationally resolved $A^2\Pi_u - X^2\Pi_g$ electronic spectrum of tetraacetylene cation.” *Chem. Phys. Lett.* **329** (2000) 29–35.
- Phan, V. H. M., Morlino, G., & Gabici, S. “What causes the ionization rates observed in diffuse molecular clouds? The role of cosmic ray protons and electrons.” *Mon. Not. R. Astron. Soc.* **480** (2018) 5167–5174.
- Porras, A. J., Federman, S. R., Welty, D. E., et al. “ OH^+ in diffuse molecular clouds.” *Astrophys. J. Lett.* **781** (2014) L8.
- Puget, J. L., Leger, A., & Boulanger, F. “Contribution of large polycyclic aromatic molecules to the infrared emission of the interstellar medium.” *Astron. Astrophys.* **142** (1985) L19–L22.
- Puspitarini, L., Lallement, R., Babusiaux, C., et al. “The Gaia-ESO survey: Extracting diffuse interstellar bands from cool star spectra.” *Astron. Astrophys.* **573** (2015) A35.
- Rachford, B. L., Snow, T. P., Tumlinson, J., et al. “A far ultraviolet spectroscopic explorer survey of interstellar molecular hydrogen in translucent clouds.” *Astrophys. J.* **577** (2002) 221–244.
- Rachford, B. L., Snow, T. P., Destree, J. D., et al. “Molecular hydrogen in the far ultraviolet spectroscopic explorer translucent lines of sight: The full sample.” *Astron. and Astrophys. Suppl. Ser.* **180** (2009) 125–137.
- Raghunandan, R., Mazzotti, F. J., & Maier, J. P. “Electronic spectra of C_6H^+ and $C_6H_3^+$ in the gas phase.” *J. Am. Soc. Mass Spectr.* **21** (2010) 694–697.
- Rice, C. A. & Maier, J. P. “Electronic spectroscopy of carbon chains and rings of astrophysical interest.” *J. Phys. Chem. A* **117** (2013) 5559–5566.
- Riechers, D. A., Bradford, C. M., Clements, D. L., et al. “A dust-obscured massive maximum-starburst galaxy at a redshift of 6.34.” *Nature* **496** (2013) 329–333.
- Rimmer, P. B., Herbst, E., Morata, O., et al. “Observing a column-dependent ζ in dense interstellar sources: the case of the Horsehead nebula.” *Astron. Astrophys.* **537** (2011) A7.
- Rodebush, W. H. & Wahl, M. H. “The reactions of the hydroxyl radical in the electrodeless discharge in water vapor.” *J. Chem. Phys.* **1** (1933) 696–702.
- Romanini, D., Ventriillard, I., Méjean, G., et al. “Introduction to cavity enhanced absorption spectroscopy.” In: Gagliardi, G. & Loock, H. (eds.), *Cavity-Enhanced Spectroscopy and Sensing, Springer Series in Optical Sciences*, volume 179. Springer-Verlag, Berlin Heidelberg. ISBN 9783642400025 (2014).
- Russell, R. W., Soifer, B. T., & Willner, S. P. “The 4 to 8 micron spectrum of NGC 7027.” *Astrophys. J.* **217** (1977) L149.
- Saha, M. N. “Molecules in interstellar space?” *Nature* **139** (1937) 840–840.

- Salama, F., Galazutdinov, G., Krełowski, J., et al. “Polycyclic aromatic hydrocarbons and the diffuse interstellar bands: A survey.” *Astrophys. J.* **526** (1999) 265.
- Salama, F., Galazutdinov, G. A., Krełowski, J., et al. “Polycyclic aromatic hydrocarbons and the diffuse interstellar bands: A survey.” *Astrophys. J.* **728** (2011) 154.
- Sarre, P., Miles, J., Kerr, T., et al. “Resolution of intrinsic fine structure in spectra of narrow diffuse interstellar bands.” *Mon. Not. R. Astron. Soc.* **277** (1995) L41–L43.
- Sarre, P. J. “Diffuse bands in emission.” *Nature* **351** (1991) 356–356.
- Sarre, P. J. “The diffuse interstellar bands: A major problem in astronomical spectroscopy.” *J. Mol. Spectrosc.* **238** (2006) 1–10.
- Searles, J. M., Destree, J. D., Snow, T. P., et al. “Searching for naphthalene cation absorption in the interstellar medium.” *Astrophys. J.* **732** (2011) 50.
- Sellgren, K., Werner, M. W., Ingalls, J. G., et al. “C₆₀ in reflection nebulae.” *Astrophys. J.* **722** (2010) L54–L57.
- Sheffer, Y., Rogers, M., Federman, S. R., et al. “Ultraviolet survey of CO and H₂ in diffuse molecular clouds: The reflection of two photochemistry regimes in abundance relationships.” *Astrophys. J.* **687** (2008) 1075–1106.
- Shnitko, I., Fulara, J., Batalov, A., et al. “³Σ⁻ – ³Σ⁻ electronic transition of linear C₆H⁺ and C₈H⁺ in neon matrixes.” *J. Phys. Chem. A* **110** (2006) 2885–2889.
- Smith, I. W. “Laboratory astrochemistry: Gas-phase processes.” *Annu. Rev. Astron. Astr.* **49** (2011) 29–66.
- Snow, T. P. “Diffuse interstellar bands: Past and present.” In: *The Diffuse Interstellar Bands, IAU Symposium*, volume 297 (2014) 3–12.
- Snow, T. P. & McCall, B. J. “Diffuse atomic and molecular clouds.” *Annu. Rev. Astron. Astr.* **44** (2006) 367–414.
- Snow, T. P., Zukowski, D., & Massey, P. “The intrinsic profile of the 4428 Å diffuse interstellar band.” *Astrophys. J.* **578** (2002) 877–884.
- Snow, T. P., Jr. & Cohen, J. G. “Diffuse interstellar band formation in dense clouds.” *Astrophys. J.* **194** (1974) 313.
- Sobolewski, A. L. & Adamowicz, L. “*Ab initio* characterization of electronically excited states in highly unsaturated hydrocarbons.” *J. Chem. Phys.* **102** (1995) 394–399.
- Solomon, P. M. & Wickramasinghe, N. C. “Molecular and solid hydrogen in dense interstellar clouds.” *Astrophys. J.* **158** (1969) 449.
- Sonnentrucker, P., York, B., Hobbs, L. M., et al. “A modern census of the broadest diffuse interstellar bands.” *Astrophys. J. Suppl. Ser.* **237** (2018) 40.
- Sorokin, P., Glownia, J., & Ubachs, W. “Current status of the H₂ diffuse interstellar bands theory.” *Farad. Discuss.* **109** (1998) 137–163.
- Sorokin, P. P. & Glownia, J. H. “Nonlinear spectroscopy in astronomy: assignement of diffuse interstellar absorption bands to L(α) -induced, two-photon absorption by H₂ molecules.” *Chem. Phys. Lett.* **234** (1995) 1–6.
- Spieler, S., Kuhn, M., Postler, J., et al. “C₆₀⁺ and the diffuse interstellar bands: An

- independent laboratory check.” *Astrophys. J.* **846** (2017) 168.
- Spitzer, L. *Physical processes in the interstellar medium.* New York Wiley-Interscience (1978).
- Stancil, P. C., Schultz, D. R., Kimura, M., et al. “Charge transfer in collisions of O⁺ with H and H⁺ with O.” *Astron. Astrophys. Suppl. Ser.* **140** (1999) 225–234.
- Stecher, T. P. “Interstellar extinction in the ultraviolet.” *Astrophys. J.* **142** (1965) 1683.
- Suzuki, H., Ohishi, M., Kaifu, N., et al. “Detection of the interstellar C₆H radical.” *Publ. Astron. Soc. Jpn.* **38** (1986) 911–917.
- Swings, P. “A note on molecular absorption in interstellar space.” *Mon. Not. R. Astron. Soc.* **97** (1937) 212.
- Swings, P. & Rosenfeld, L. “Considerations regarding interstellar molecules.” *Astrophys. J.* **86** (1937) 483–486.
- Taylor, T. R., Xu, C., & Neumark, D. M. “Photoelectron spectra of the C_{2n}H⁻ ($n = 1 - 4$) and C_{2n}D⁻ ($n = 1 - 3$) anions.” *J. Chem. Phys.* **108** (1998) 10018–10026.
- Thoma, M. L., Kaschow, R., & Hindelang, F. J. “A multiple-reflection cell suited for absorption measurements in shock tubes.” *Shock Waves* **4** (1994) 51–53.
- Thorburn, J. A., Hobbs, L. M., McCall, B. J., et al. “Some diffuse interstellar bands related to interstellar C₂ molecules.” *Astrophys. J.* **584** (2003) 339–356.
- Tielens, A. G. G. M. & Hagen, W. “Model calculations of the molecular composition of interstellar grain mantles.” *Astron. Astrophys.* **114** (1982) 245–260.
- Tran, T. D., Rednyk, S., Kovalenko, A., et al. “Formation of H₂O⁺ and H₃O⁺ cations in reactions of OH⁺ and H₂O⁺ with H₂: Experimental studies of the reaction rate coefficients from $T = 15$ to 300 K.” *Astrophys. J.* **854** (2018) 25.
- Trumpler, R. J. “Preliminary results on the distances, dimensions and space distribution of open star clusters.” *Lick Observatory Bulletins* **14** (1930) 154–188.
- Tulej, M., Kirkwood, D., Pachkov, M., et al. “Gas-phase electronic transitions of carbon chain anions coinciding with diffuse interstellar bands.” *Astrophys. J. Lett.* **506** (1998) L69.
- Ubachs, W., Hinnen, P. C., & Reinholt, E. “Observation of inter-Rydberg transitions in H₂ coinciding with diffuse interstellar bands.” *Astrophys. J.* **476** (1997) L93–L96.
- Valencic, L. A., Clayton, G. C., & Gordon, K. D. “Ultraviolet extinction properties in the Milky Way.” *Astrophys. J.* **616** (2004) 912–924.
- van der Tak, F. F. S. & van Dishoeck, E. F. “Limits on the cosmic-ray ionization rate toward massive young stars.” *Astron. Astrophys.* **358** (2000) L79–L82.
- van der Werf, P. P., Isaak, K. G., Meijerink, R., et al. “Black hole accretion and star formation as drivers of gas excitation and chemistry in Markarian 231.” *Astron. Astrophys.* **518** (2010) L42.
- van der Zwart, G. P. & Allamandola, L. J. “Polycyclic aromatic hydrocarbons and the diffuse interstellar bands.” *Astron. Astrophys.* **146** (1985) 76–80.
- van Dishoeck, E. F. & Black, J. H. “Comprehensive models of diffuse interstellar clouds — Physical conditions and molecular abundances.” *Astrophys. J. Suppl. S.*

- 62** (1986) 109–145.
- van Dishoeck, E. F., Herbst, E., & Neufeld, D. A. “Interstellar water chemistry: From laboratory to observations.” *Chem. Rev.* **113** (2013) 9043–9085.
- van Winckel, H., Cohen, M., & Gull, T. R. “The ERE of the ‘Red Rectangle’ revisited.” *Astron. Astrophys.* **390** (2002) 147–154.
- Vázquez-Semadeni, E. “Are there phases in the ISM?” *EAS Publications Series* **56** (2012) 39–49.
- Verbraak, H., Verdes, D., & Linnartz, H. “A systematic study of ion and cluster ion formation in continuous supersonic planar plasma.” *Int. J. Mass Spectrom.* **267** (2007) 248–255.
- Vos, D. A. I., Cox, N. L. J., Kaper, L., et al. “Diffuse interstellar bands in upper Scorpions: probing variations in the DIB spectrum due to changing environmental conditions.” *Astron. Astrophys.* **533** (2011) A129.
- Walker, G. A. H. “Photoelectric measures of the 4430 Å diffuse interstellar band.” *Mon. Not. R. Astron. Soc.* **125** (1962) 141–167.
- Walker, G. A. H., Bohlander, D. A., Maier, J. P., et al. “Identification of more interstellar C₆₀⁺ bands.” *Astrophys. J.* **812** (2015) L8.
- Walker, G. A. H., Campbell, E. K., Maier, J. P., et al. “Gas-phase absorptions of C₆₀⁺: A new comparison with astronomical measurements.” *Astrophys. J.* **831** (2016) 130.
- Walker, G. A. H., Campbell, E. K., Maier, J. P., et al. “The 9577 and 9632 Å diffuse interstellar bands: C₆₀⁺ as carrier.” *Astrophys. J.* **843** (2017) 56.
- Walsh, A., Zhao, D., Ubachs, W., et al. “Optomechanical shutter modulated broadband cavity-enhanced absorption spectroscopy of molecular transients of astrophysical interest.” *J. Phys. Chem. A* **117** (2013) 9363–9369.
- Watson, J. K. G. “Assignment of the λ1369.13 diffuse interstellar absorption band and three other far-ultraviolet interstellar absorption lines to the CH molecule.” *Astrophys. J.* **555** (2001) 472–476.
- Wegner, W. “The total-to-selective extinction ratio determined from near IR photometry of OB stars.” *Astron. Nachr.* **324** (2003) 219–237.
- Wehres, N., Romanzin, C., Linnartz, H., et al. “C₂ emission features in the Red Rectangle.” *Astron. Astrophys.* **518** (2010) A36.
- Weinreb, S., Barrett, A. H., Meeks, M. L., et al. “Radio observations of OH in the interstellar medium.” *Nature* **200** (1963) 829–831.
- Welty, D. E. & Hobbs, L. M. “A high-resolution survey of interstellar K I absorption.” *Astron. Astrophys. Suppl. Ser.* **133** (2001) 345–393.
- Western, C. “PGOPHER (version 8.0), a Program for Simulating Rotational Structure.” (2014).
- Wheeler, M. D., Newman, S. M., Orr-Ewing, A. J., et al. “Cavity ring-down spectroscopy.” *J. Chem. Soc., Faraday Trans.* **94** (1998) 337–351.
- White, J. U. “Long optical paths of large aperture.” *J. Opt. Soc. Am.* **32** (1942) 285.
- Wolfire, M. G., McKee, C. F., Hollenbach, D., et al. “Neutral atomic phases of the

- interstellar medium in the galaxy.” *Astrophys. J.* **587** (2003) 278–311.
- Wooden, D. H., Charnley, S. B., & Ehrenfreund, P. “Composition and evolution of interstellar clouds.” In: Kronk, G. W. (ed.), *Comets II*. University of Arizona Press, Tucson (2004) 33–66.
- Wyrowski, F., Menten, K. M., Güsten, R., et al. “First interstellar detection of OH⁺.” *Astron. Astrophys.* **518** (2010) A26.
- Yuan, H. B. & Liu, X. W. “Detections of diffuse interstellar bands in the SDSS low-resolution spectra.” *Mon. Not. R. Astron. Soc.* **425** (2012) 1763–1771.
- Zagury, F. “Analysis of the Schmidt, Cohen & Margon (1980) features in the Red Rectangle nebula.” *The Open Astronomy Journal* **2** (2009) 26–38.
- Zhao, D., Haddad, M. A., Linnartz, H., et al. “C₆H and C₆D: Electronic spectra and Renner-Teller analysis.” *J. Chem. Phys.* **135** (2011a) 044307.
- Zhao, D., Haddad, M. A., Linnartz, H., et al. “Structure determination of the nonlinear hydrocarbon chains C₉H₃ and C₁₁H₃ by deuterium labeling.” *J. Chem. Phys.* **135** (2011b) 074201.
- Zhao, D., Wehres, N., Linnartz, H., et al. “Electronic spectra and molecular geometry of the non-linear carbon chain C₉H₃.” *Chem. Phys. Lett.* **501** (2011c) 232–237.
- Zhao, D., Linnartz, H., & Ubachs, W. “The electronic spectrum of the C_s-C₁₁H₃ radical.” *J. Chem. Phys.* **136** (2012) 054307.
- Zhao, D., Galazutdinov, G. A., Linnartz, H., et al. “Detection of OH⁺ in translucent interstellar clouds: New electronic transitions and probing the primary cosmic ray ionization rate.” *Astrophys. J. Lett.* **805** (2015) L12.
- Zhou, Z., Sfeir, M. Y., Zhang, L., et al. “Graphite, tubular PAHs, and the diffuse interstellar bands.” *Astrophys. J.* **638** (2006) L105–L108.

