Interplay between collisions and radiative effects in the analyses of diffuse interstellar bands

Takeshi Oka

Department of Astronomy and Astrophysics, and Department of Chemistry
The Enrico Fermi Institute, University of Chicago

In laboratory experiments, collisions dominate thermalization and the molecular rotational distribution is Boltzmannian. In contrast, in interstellar space where the number density is lower by more than 10 orders of magnitude, the rates of collisional and radiative processes are often comparable and non-Boltzmannian distribution resulting from their competition is more the rule than the exception. For such a case, a set of equations of detailed balancing has to be solved taking into account the collisional and radiative processes simultaneously.

Out of over two hundred stars observed, we have discovered that the star Herschel 36, is unique in giving diffuse interstellar bands (DIBs) whose spectral shape is very different from those toward other stars.[1] The observed anomalous Extended Tail toward Red (ETR) has been interpreted as due to radiative pumping by the near-by infrared star Herschel 36 SE. Reduction of rotational constant upon electronic excitation was invoked to explain the anomaly.[2] This introduced a new category in speculating the carrier of DIBs — polar molecules sensitive to radiative effects and non-polar molecules insensitive. Carriers of three DIBs λλ 5780.5, 5797.1, and 6613.6 were shown to be polar molecules and their size was estimated to be less than 8 heavy atoms.

Using this result, the λ 5797.1 DIB which shows a clear and sharp central absorption feature has been analyzed based on three premises: (1) Its carrier molecule is polar, (2) the central feature is Q-branch of a parallel band of a prolate top molecule, and (3) the radiative temperature of the environment is $T_r = 2.73$ K. A comparison with observed spectrum indicated that the carrier contains 5-7 heavy atoms.[3]

To further strengthen this hypothesis, we have looked for vibronic satellites of the λ 5797.1 DIB. Since its anomaly toward Her 36 was ascribed to bond elongation upon electronic excitation, vibronic satellites involving stretch vibrations are expected. Among the 73 DIBs observed toward HD 183143 to the blue of 5797.1 Å, two DIBs, λ 5545.1 and λ 5494.2 stand out as high correlated with λ 5797.1 DIB. Their correlation coefficients 0.941 and 0.943, respectively, are not sufficiently high to establish the vibronic relation by themselves but can be explained as due to uncertainties caused by their weakness and their stellar blends. They are above the λ 5797.1 DIB by 784.0 cm^{-1} and 951.2 cm^{-1}, respectively, approximately expected for stretching vibrations.

[1] J. Dahlstrom, D,G. York, D.E. Welty, T. Oka, L. M. Hobbs, et al. ApJ 773, 41 (2013)
[2] T. Oka, D.E. Welty, S. Johnson, D.G. York, J. Dahlstrom, L.M. Hobbs, ApJ 773, 42 (2013)
[3] J. Huang, T. Oka, Mol. Phys. J. P. Maier Special Issue (2015), in press.