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# The telescope and the spectroscope

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**Abstract.** A brief outline of the role of laboratory spectroscopy in the understanding of and interpretation of the spectra of astrophysical sources has been given, citing a few illustrative examples. With increasing volume of spectral data of celestial sources fillip has to be given to laboratory studies of spectra of astrophysical interest. This will be helpful not only in the interpretation of the data but also in determining the composition and structure of the sources studied by the astrophysicist.

## 1. Introduction

Spectral studies in respect of celestial bodies and interstellar space together with laboratory observations and the development of necessary theory, contribute immensely to our proper understanding of interactions between energy and matter on this planet, stars, galaxies and the space lying in between. The telescope and the spectroscope, words standing for their generic names, used together as well as the latter alone having frequent and planned stints with laboratory sources, are the valuable tools used for obtaining a wider and deeper view of the Universe.

If one looks at the history of the developments in the field of spectral studies of heavenly bodies and interstellar space one comes across two main channels. The spectra obtained, in a way or so, have already been observed and studied in the laboratory, making it easy to identify the celestial source (emitter or absorber). In the second case one has to obtain the already observed spectrum of the astronomical source in the laboratory. This is not always easy because one has to be dependent on a number of fortuitous guesses and trials. Very often laboratory attempts are hampered by experimental limitations because even if the guess is correct the laboratory conditions are likely to be quite different from those existing in the remote sources lying billions of light years away or more and additionally or alternatively the transitions responsible for the spectra may be the forbidden ones. In such cases laboratory experiments require great ingenuity.

## 2. Examples

There are many cases when a number of terrestrial investigations have revealed unexpected things about the conditions prevailing in the celestial space and the objects existing therein. Before they were observed in the laboratory, the identification of nebular lines on the basis of term values obtained from the observations of allowed transitions in OII, OIII and NII, though an old story is very instructive. This shows how careful experimental and theoretical studies together made earlier can help in untangling knotty problems arising later.

(*a*) *Cosmic Masers*: Although the optical spectra of $H_2O$ and OH were well known and thoroughly studied for a long time, their radio frequency spectra naturally came to be studied comparatively much later. Obviously a knowledge of the rotational energies of these molecules and their structure should be helpful in the location and understanding of their microwave spectra. On the basis of this data (Dennison, 1940) the 1.35 cm band of $H_2O$ was observed in absorption by Becker and Autler (1946). It was more than two decades after the discovery of this weak absorption in the laboratory that this spectrum was observed in emission in interstellar medium. Depending on the region or the source Doppler shifts corresponding to velocities $+15\ \mathrm{kmsec}^{-1}$ to $-20\ \mathrm{kmsec}^{-1}$ have been detected. One surprising thing is that contrary to expectation, the intensity of the spectrum is very high, more than 500 times that of full solar luminosity, whereas of the two levels involved in the transition (fig. 1) $6_{-5} - 5_{-1}$ (or $6_{16} - 5_{23}$), the level $6_{-5}$ decays more rapidly than $5_{-1}$. This along with the sharpness of the line points to maser action. Transfer of requisite energy by quasi resonance collisions between $H_2$ and $H_2O$ molecules has been proposed by Varshalovich et al. (1983).

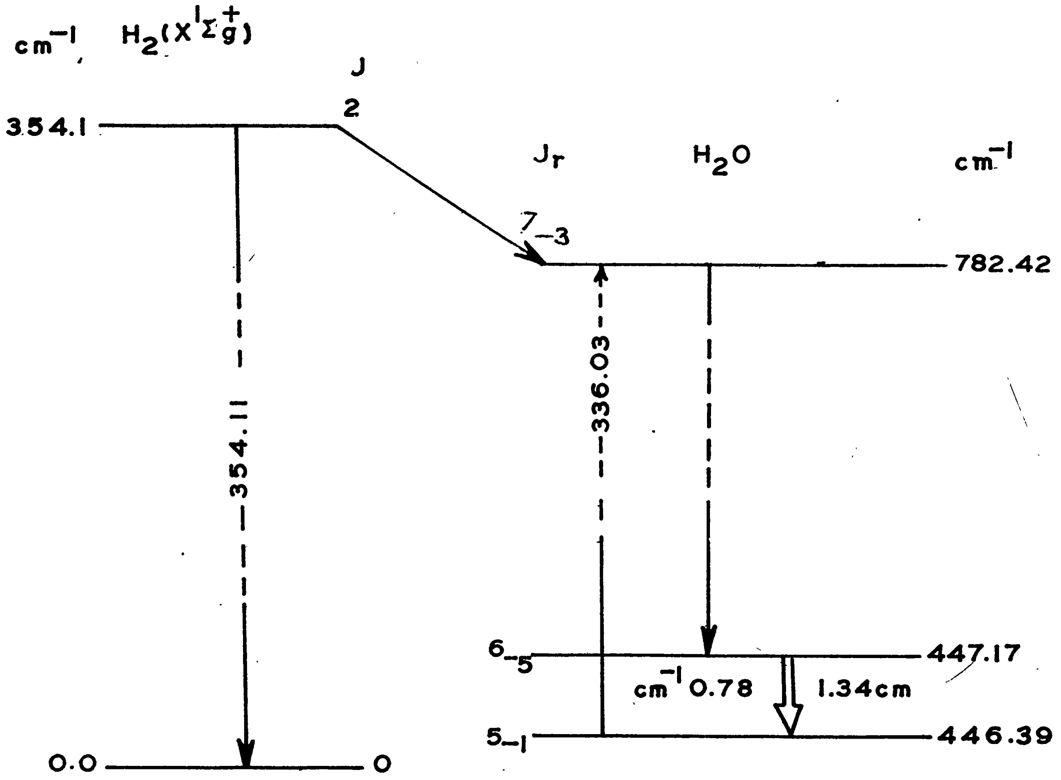

Figure I

**Figure 1.** Quasi-resonance collision showing pumping mechanism leading to maser radiation at 1.34 cm wavelength. The separation between the $5_{-1}$ and $6_{-5}$ levels has been exaggerated. The energy levels of $H_2O$ are based on data given by Dennison.

Dousmanis et al. (1955) obtained the radiofrequency spectrum of OH radical and reported four lines in the 18 cm region but it was a decade later in 1965 that the same spectrum was observed in emission in the Great Orion Nebula and afterwards, along with other lines, in the spectra of interstellar medium, specially regions associated with protostar formation.

(*b*) *Cometary spectra* : So far we have discussed the cases associated with the spectra of celestial sources whose laboratory counterpart had already been investigated in some form at least in the laboratory. Let us recall that difficulty arises when there is no such background available. There is a very interesting example concerning the 4050 Å group of bands in the cometary spectra. Whereas a large number of lines and bands had been identified as being due to $C_2$, CH, CN, NH, OH, $CH^+$. $CO^+$ and $N_2^+$, the features at 4050 Å could not be identified for want of laboratory studies. Though Swings (1942) thought that these might be due to $NH^+$, Herzberg, in view of the spectral features, data and Mulliken's prediction that an electronic transition in $CH_2$ should lie in the region 4000 - 4500Å assigned the bands tentatively to this molecule. Subsequently he obtained these bands in an interrupted discharge through flowing $CH_4$ vapour. However, Monfils and Rosen (1949) and later, using highter resolution, Douglas and Herberg repeated the experiment replacing $CH_4$ by $CD_4$, but in both cases the spectra so obtained did not show the expected isotope shift, confirming thereby that the group of bands at 4050 Å, was not due to $CH_2$. Douglas (1954) then using a mixture of $C^{12}H_4$ and $C^{13}$ $H_4$ in equal parts observed that the 4050 Å band was replaced by six bands indicating a triatomic radical or molecule as emitter. Detailed analysis has established it as linear $C_3$ molecule, thus identifying after more than seven decades, the elusive culprit(?) who had left his first signatures on the scene in 1882.

## 3. Epilogue

The cursory observations made above are only an indication that for determining the composition, structure, temperature, motions, nature of the ambient atmosphere and many other parameters of heavenly sources, not only their spectra but their identification are essential. Unfortunately a large number of important and crucial observations remain incompletely understood for want of corroborative evidence by way of identification of the emitter/absorber and its properties. These days spectroscopy is no longer a fashionable discipline. The luminaries present in the workshop here will do well to forge a stronger bond between the duo : the astrophysicist and the laboratory spectroscopist.

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