

## THE SPECTROSCOPY OF COMETS: INTRODUCTORY REMARKS

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Thirty years ago, the trend in cometary spectroscopy still was on wavelengths and identifications. Now, the emphasis has turned to production rates, because they open the door to more fundamental clues about the origin and the history of the solar system, through the understanding of comet chemistry.

In order to establish production rates quantitatively, much progress is yet to be made, in particular: (a) we must study the lifetimes of all hypothetical parents, against all processes of decay, namely photodissociations, photoionizations and ion-molecule reactions. (b) We must also study the velocity of all molecular fragments resulting from all the decay processes, through the balance sheet of the energy distribution before and after each decay process.

These studies must be pursued both theoretically and in the laboratory. However, we should not neglect the analysis of the brightness profiles of the cometary heads, radially sunwards and tailwards, in the monochromatic light of each radical or each ion. The two-dimensional tracing of the monochromatic isophotes would be even much better, but experience shows that it is much more difficult to achieve with the same spatial and spectral resolving power than the brightness profiles in two opposite directions along the slit of a spectrograph. At least for the neutral species (and excepting those that reach  $10^6 - 10^7$  km like hydrogen seen in Lyman- $\alpha$ ), the amount of information collected from a single brightness profile is only marginally lower than that from two-dimensional isophotes, because the quasi symmetry of the coma extends to much more than  $10^5$  km.

The brightness profiles set the scale length of decay of the (unknown or dubious) parent molecules, as well as that of the observed radical or atom, allowing for the checking of the theoretical lifetimes and/or velocities.

They are also important for fine structure studies. For neutral radicals and atoms, we have never observed really fine structure in space distribution; it is likely that there is none to be seen. What we see is only a smooth deviation from computed models, apparently coming from changes in the steady-state of the production rates.

Standing in contrast, the spatial fine structure in the brightness profiles of ions shows considerably wavy patterns. With Mike Combi, I have pioneered the study of these ionic profiles, that are telltales of the interaction of the cometary plasma with the solar wind (Delsemme and Combi 1976, 1979; Combi and Delsemme 1980). Fast image intensifiers, allowing to take cometary spectrograms in less than one or two minutes, have also allowed us to show that plasma ripples and troughs move fast tailwards, in characteristic times of ten to twenty minutes; we have followed their displacements, allowing the measure of a ripple velocity of 17 km/s in the plasma of Comet Bennett (Delsemme and Combi 1979).

With the photographic plate, the absolute calibration remains difficult; but better detectors are emerging, and with linear detectors of the CCD type, subtracting the sky or even the cometary continuum will become possible as if by black magic.

What we now want for cometary spectra is better spatial resolution, better spectral resolution, and better temporal resolution.

For comets at an average distance from the earth, most brightness profiles have a spatial resolution between  $10^4$  and  $10^3$  km. Only for exceptional comet Burnham, that came down to 0.20 AU from the earth, has a space resolution better than  $10^3$  km been achieved (Malaise 1966).

We also need a higher spectral resolution in cometary spectrograms, because theory is ahead of observations. For instance, resolving the vibronic structure of CN has been easy; for this reason, the anomalous and irregular distribution of light in the different vibronic terms has resulted in the qualitative suggestion (Swings 1941) of the irregular "pumping" of the electronically excited state, by the action of Doppler-shifted Fraunhofer bands of the sun. This so-called "Swings effect" was quantitatively demonstrated to be correct by his co-workers (Hunaerts 1950, 1953; Arpigny 1965; Malaise 1966) extending it to other molecular bands, including the OH bands discovered in 1941.

The differential Swings effect (often called the Greenstein effect) which changes the vibronic distribution tailwards and sunwards, by the slight change of the radial velocity of the molecules because of their expansion from the cometary nucleus, was found by Greenstein (1958).

It has been quantitatively verified by Malaise (1970) who used it to establish the expansion velocity of the molecules in the coma, because the sharp Fraunhofer lines of the sun make the pumping more sensitive to the Doppler shift than what can be achieved by measuring the Doppler shift itself.

However, we are limited in this direction by the spectral resolution of the spectra as well as by the accurate knowledge of the solar spectrum, averaged over the solar disk at the time of the observations.

Now, when a good space resolution of the spectrum is achieved, the Swings effect is smoothed out in the vicinity of the nucleus by collisional de-excitation. This pressure effect, that extends throughout the collisional zone ( $10^4$  km), was discovered by Malaise (1970).

Finally, we have not yet observed in cometary radicals the anomalous vibronic distribution coming from a recent photodissociation of a parent molecule, predicted by Donn and Cody (1978) from physical chemistry data.

The problem of the isotopic ratio of carbon is another excellent example where a larger spectral resolution is needed. The Swan bands of  $C_2$ , in particular in the (stronger) (1-0) system, show the band heads of  $C^{12}C^{12}$  at 4737Å,  $C^{12}C^{13}$  at 4744Å, and  $C^{13}C^{13}$  at 4752Å. Qualitatively  $C^{12}C^{13}$  is two orders of magnitude fainter than  $C^{12}C^{12}$  and the  $\Delta v = 1$  sequence extends to the violet only. Therefore, it is only a matter of exposure time to bring  $C^{12}C^{13}$  out of the background noise; apparently a separation of 7Å does not seem to require a very large dispersion. Unfortunately, there is usually a blend with the cometary  $NH_2$  band and for this reason, even a spectral resolution of 0.16Å has yielded unreliable results with large error bars for the isotope ratio (Danks et al. 1974). An effort to go to spectral resolution better than 0.10Å is clearly needed. This is the only isotope ratio that has ever been measured in comets. The significance of the deuterium ratio to hydrogen would be great, but its cosmic abundance ( $2 \times 10^{-5}$  that of H) makes it difficult to detect in a molecular band or an atomic line.

Beyond classical spectroscopy in the visual, two new ranges of cometary observations have opened up in the last decade. These are radio astronomy and vacuum ultraviolet spectroscopy.

In radio astronomy, the rotational lines of OH have not only beautifully confirmed the variable pumping effect predicted by Swings, verified on OH by Hunaerts (1950, 1953) but also have brought new refinements and new quantitative data. The new identifications are well known and will be discussed here by other speakers.

In the vacuum ultraviolet, comprehensive vacuum UV cometary spectra are now known for comet West (1976 VI) from rocket observations and for comets Seargent (1978m) and Bradfield (19791) from the IUE; at the time of this talk, comet Encke was being observed with the IUE, adding a fourth comet to this collection.

Difficulties in establishing production rates are still serious (since the excitation of each observed line must be discussed and all possible mechanisms understood), but the atomic resonance lines of H, C, O, S observed in the VUV (plus N, probably too weak and too close to Lyman- $\alpha$  to

have been detected so far) give hope for an elemental quantitative analysis of the volatile fraction, because molecular dissociations happen in lifetimes that are short compared to the lifetimes of the neutral atoms (against ionization).

Finally, I want to stress the importance of the dependence on distance of the different production rates, since they are telltales of the vaporization temperature of the nucleus.

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