

Resolution of the [O I] + NH₂ blend in comet P/Halley[★]

C. Arpigny¹, P. Magain², J. Manfroid^{1,★★}, F. Dossin¹, A. C. Danks^{3,***}, and D. L. Lambert⁴

¹ Institut d'Astrophysique, Université de Liège, B-4200 Ougrée-Liège, Belgium

² European Southern Observatory, Casilla 19001, Santiago 19, Chile

³ Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48224, USA

⁴ McDonald Observatory and Department of Astronomy, University of Texas, Austin, TX 78712, USA

Received February 20, accepted May 11, 1987

Summary. Spectra of comet P/Halley have been taken at very high resolution (0.015 nm) with a view to evaluating the contamination of the forbidden oxygen doublet at 630 nm by NH₂ features at low resolution. Comparison is made with a few other bright comets.

Appreciable variations are found not only in the NH₂/[O I] ratio but also in the relative intensities of the various NH₂ emissions themselves. We comment upon the accuracy obtained on the oxygen abundance derived from the [O I] lines. Mapping of these emissions over the coma is required in order to correctly remove any important NH₂ contribution at low resolution. This should in addition provide information bearing upon the origin of the oxygen atoms in the ¹D level.

Key words: forbidden oxygen lines – coma – abundance

1. Introduction

The determination of the abundance and of the origin of the oxygen atoms present in the gas produced by comets represents one of the important items in our endeavour to unravel the problem of the chemical composition of the cometary nuclei. Now, the forbidden lines of oxygen at 630.0 and 636.4 nm, which contrary to the other cometary emissions cannot be excited by fluorescence on account of their very low transition probabilities, are emitted by atoms directly produced in their upper ¹D level and decaying radiatively at a well-known rate. As a result, the measurement of their intensity in principle provides a straightforward means for evaluating the abundance or production rate of those oxygen atoms, as well as of their parents provided the relevant O(¹D) yield is known. That the latter oxygen-bearing molecules are important cometary constituents is indicated by the strength of the red doublet observed in many spectra and this was already pointed out by Biermann and Trefftz (1964). The situation is not so simple, however, because aside from the superposition of

the telluric [O I] emission which can be taken care of readily, the oxygen emission is also rather severely blended with cometary NH₂ features to a degree that should be estimated in each case. Excellent detailed discussions of this problem have been given by Festou and Feldman (1981), Spinrad (1982), and by Fink and Johnson (1984).

Halley's comet has offered the opportunity to use a very high resolution to separate all the components of the [O I] + NH₂ blend and we report briefly here on our observations of this spectral region. We wanted, in particular, to assess the validity of the assumption made by Spinrad and others that the NH₂ contribution to the intensity of the 630.0 feature observed at low resolution is equal to the intensity of another, purely NH₂ feature at 633.4. Comparison has also been made with spectra of four other comets observed at fairly high resolution.

2. Observations

Our own observations of comet P/Halley were carried out at the European Southern Observatory (ESO) with the Coudé Echelle Spectrometer equipped with a Reticon and fed by the 1.4 m Coudé Auxiliary Telescope on 6, 27, and 28 April 1986. The heliocentric distances of the comet were 1.26, 1.58 and 1.60 a. u., respectively. The resolving power was about 50 000 (resolution ~0.015 nm) and the slit height was 20", corresponding to approximately 6500 km and 10 000 km projected on the comet on the first date and on the other two dates, respectively. In most cases the comet's image was centred on the slit. At this very high resolution the Doppler shift is more than enough to separate the cometary and telluric [O I] emissions and the problem of sky contamination is eliminated ipso facto. An example of such a spectrum appears in Fig. 1. On the other hand, the usual reduction procedure was followed and the spectrum of Mars and of the star HR 6165 were used for photometric calibration.

In order to compare P/Halley with other bright comets we were fortunate to have a series of high quality spectra obtained by various astronomers at the Lick Observatory using the 120-inch and 24-inch auxiliary aperture together with image intensifiers, and kindly made available to some of us by Dr. G. Herbig. These spectra of comets Kohoutek (1973 XII), Bradfield (1974 III), Kobayashi-Berger-Milon (1975 IX), and West (1976 VI), have resolutions of about 0.08 to about 0.2 nm; they were microphotometered using a slit covering 5000 to 9000 km centred on the comet.

Send offprint requests to: C. Arpigny

[★] Based on observations made at the European Southern Observatory (Chile) and at the Lick Observatory (USA)

^{★★} Senior research associate, Belgian National Fund for Scientific Research

^{***} Present address: Dept. of Physics, Florida International University, Miami, FL 33199, USA

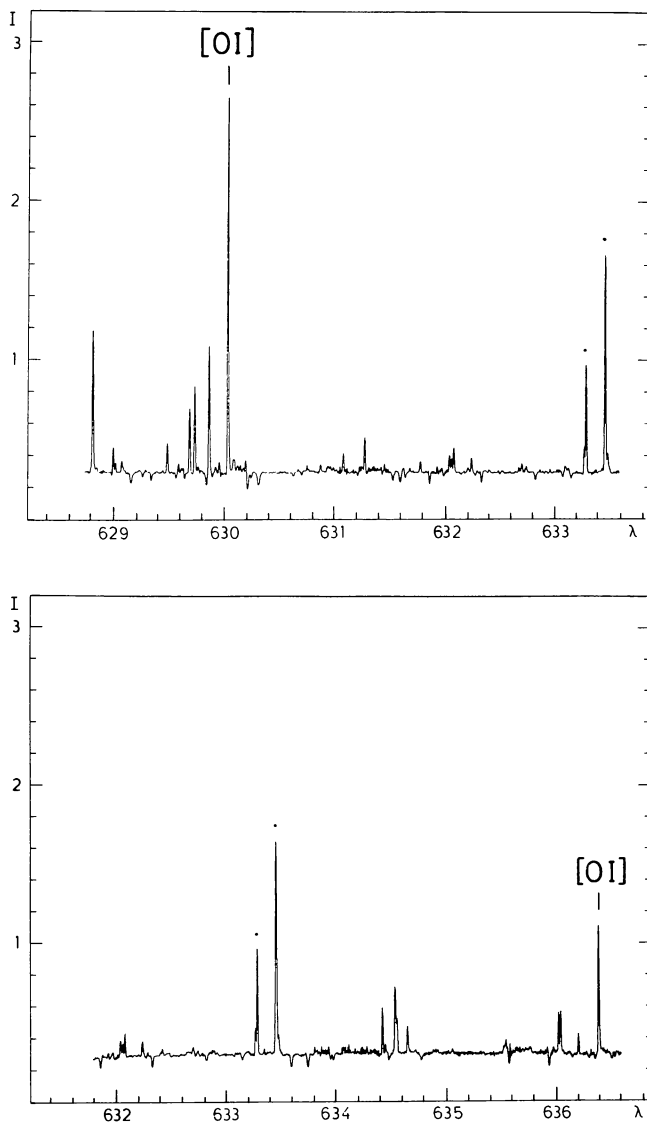


Fig. 1. High-resolution (0.015 nm) spectrum of the central region of comet P/Halley showing the two components of the [O I] red doublet and the neighbouring emissions due to the (0, 8, 0) – (0, 0, 0) band of NH₂. The intensity is plotted on an arbitrary scale. The two NH₂ lines marked by dots merge at low resolution into a single feature designated by c in the text and used as a reference in previous work

3. Results

The complete separation of the various NH₂ lines (which all belong to the 8–0 band) and of the forbidden oxygen lines in comet P/Halley allows the measurement of the relative intensities of the individual components of the blend they would form at lower resolution and hence the evaluation of their contributions to these blends. Let us refer to the middle panel in Fig. 2, which defines various groupings of the lines; the letters will also designate the sum of intensities of the lines in each group, except for *a* which represents the intensity of the [O I] 630.023 line by itself.

In order to estimate the effect of the blending we consider two types of resolutions, say (1) 0.4–0.6 nm and (2) 1.0–1.5 nm:

– in Case (1), we would observe the two blends (*a* + *b*) and *c* separately from the other features,

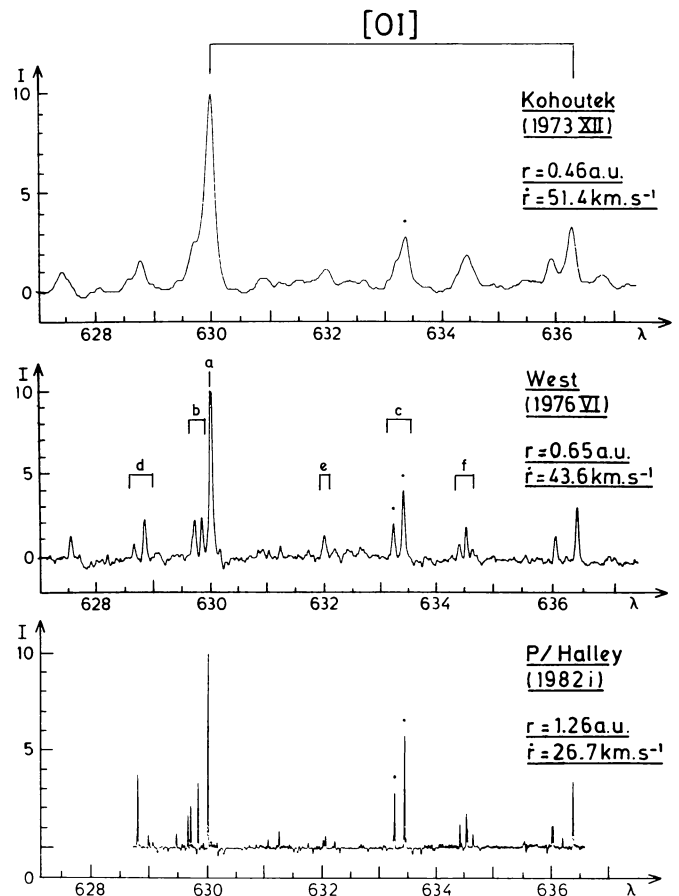


Fig. 2. The region of the [O I] red doublet at progressively higher resolution (0.2, 0.08, and 0.015 nm, respectively)

– in Case (2), *d* would be included in the first blend, *e* and *f* in the second; let us further call $B = b + d$ and $C = e + c + f$ in this case.

Thus the “feature” at 633.4 (dots on the spectra shown here), used as a reference in the “decontamination” procedure mentioned above, actually represents either *c* or C in our examples.

We have accordingly calculated the *b/c* and B/C ratios and found values of 0.5 – 0.65 and 0.85 respectively from the spectra of Halley’s comet.

As for the other comets, Figs. 2–4 show some definite variations of the various NH₂ emissions either among different comets or in a given comet at different distances from the Sun. In the 0.2 nm resolution spectra the *b* contribution to the (*a* + *b*) blend has been extracted approximately by very simple curve fitting using gaussians. The above ratios then range from 0.4 to 1.3 and from 0.6 to 1.0, respectively. Thus, appreciable departures from the assumed value of 1.0 exist. A detailed analysis would be required to examine whether the fluorescence excitation of the NH₂ emissions could explain these variations.

It is very difficult to carry out a detailed evaluation of the uncertainties of intensity measurements derived from photographic spectra, particularly from spectra obtained with image tubes: many factors would have to be taken into account, most of them unknown. Fortunately, however, a significant indicator of the overall precision achieved in the reduction process is provided by the [O I] 636.4/630.0 intensity ratio, since this should be equal

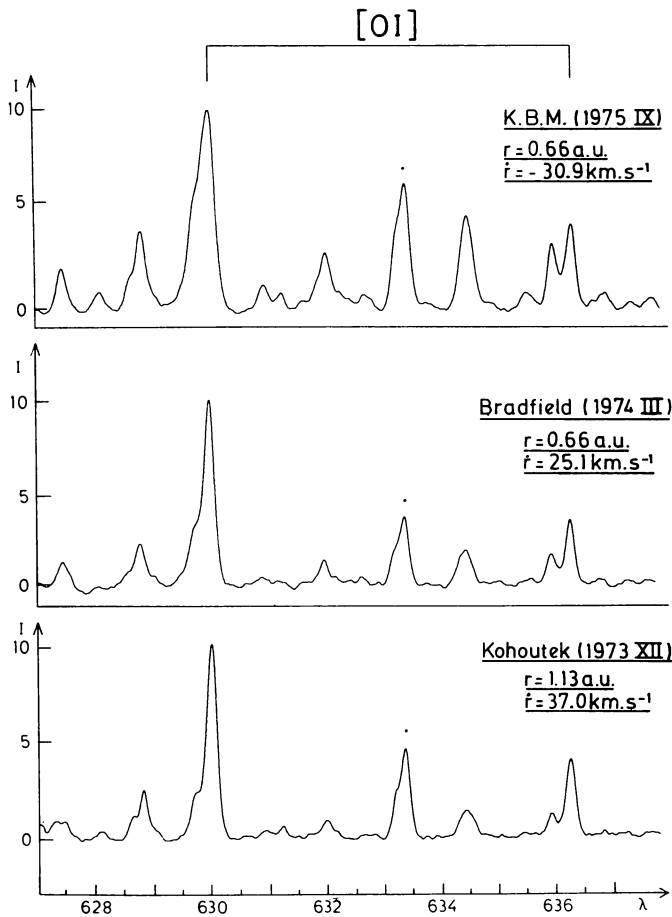


Fig. 3. Comparison of the region of the [OI] red doublet in three comets (resolution 0.2 nm)

to the ratio of the corresponding transition probabilities. This quantity is known both from experimental measurements, 0.32 ± 0.03 (Kernahan and Pang, 1975), and from theoretical calculations, 0.325, with an estimated error not exceeding 10% (Garstang, 1956; Mendoza, 1983). The value obtained from our high-resolution spectrum of comet P/Halley comes out very close to these estimates: 0.34, with an uncertainty placed at a few percent. On the other hand, as can already be seen from Figs. 2–4, this oxygen line ratio remains rather constant, as it should, from one cometary spectrum to the next. This relative constancy and the agreement with the above numbers of the average value derived from measurements on the eight photographic spectra, 0.33 ± 0.04 (r. m. s. deviation), seem quite satisfactory. This rather good accuracy no doubt results from the conjunction of several favourable circumstances (*relative* intensities of lines separated by a small wavelength interval, low and uniform plate background, unsaturated exposures, low geometrical distortion).

However, the important question is to know how these results affect the estimate of the production rate of the O(¹D) atoms. To investigate this we evaluate a/a^* , where a^* represents the value of the [OI] 630.0 intensity (or flux) which would be derived under the assumption that $b = c$ or $B = C$, i.e. $a^* = (a + b) - c$ or $(a + B) - C$

Comet West (1976 VI)

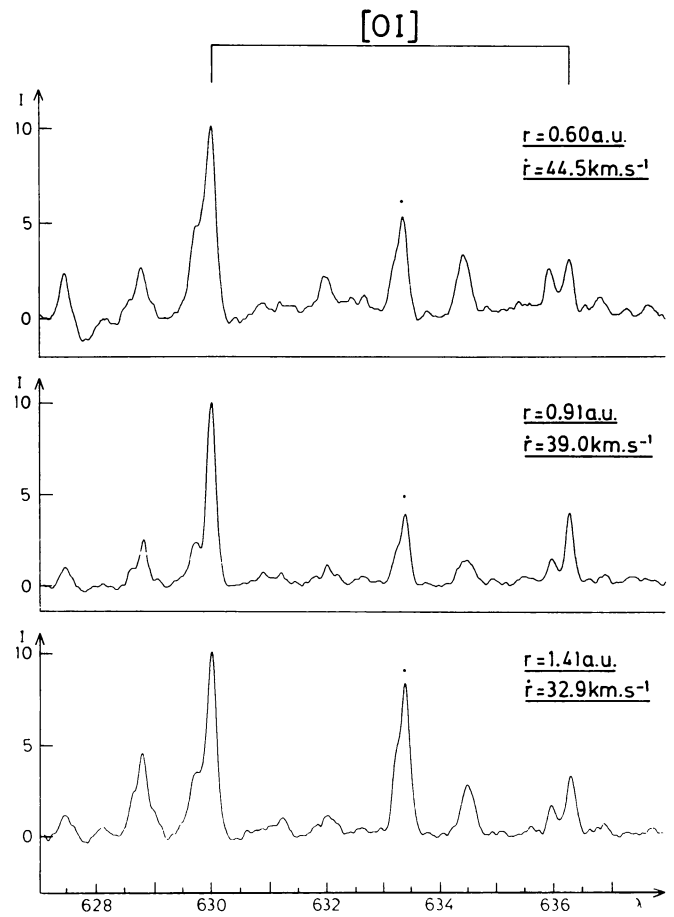


Fig. 4. Evolution with heliocentric distance of the region of the [OI] red doublet in comet West (resolution 0.2 nm)

Table 1. The a/a^* ratio

Comet	Case (1)	Case (2)
P/Halley	1.7	1.3
Other comets	0.9–2.3	1.0–2.2

a is the true intensity of the 630.0 component of the red doublet, a^* the value derived for this intensity from low-resolution spectra by simply subtracting the intensity of the 633.4 feature from that of the blend observed at 630.0

in Case (1) or (2), respectively. This ratio turns out to vary as well, as shown in Table 1.

We have examined the incidence of the errors of measurements, estimated as explained above, on the a/a^* ratio and found that the uncertainty on the latter ratio is less than 10% for the spectra of comet P/Halley, while it lies between 15 and 30% for the photographic spectra of the other comets. Thus, we see, for

instance, that observations at low resolution of the comets in our sample would, in some cases, have led to underestimate the [O I] flux or luminosity and the corresponding production rate Q by a factor of the order of 2, had the above hypothesis been adopted, even if this hypothesis sometimes happens to be appropriate.

4. Conclusion

In view of the importance of the determination of $Q(O^1D)$ for identifying the origin of the excited oxygen atoms, it appears desirable, when the NH_2 emission is appreciable, to ascertain its contribution to the blends observed at low resolution by means of an appropriate method. This can be achieved by taking advantage of the different spatial distributions of the NH_2 and [O I] emissions. Such a procedure has already been applied on a few comets (Delsemme and Combi, 1983; Fink and Johnson, 1984). Furthermore, mapping the [O I] radiation over the coma provides additional data related to the production mechanism(s) of the corresponding atoms and to the nature of their parents. Although there are indications that the photodissociation of H_2O plays a major rôle, it would be interesting to study the possible existence

of other sources such as the photodissociation of CO_2 or the dissociative recombination of ions like H_2O^+ or CO_2^+ .

Acknowledgements. We are very grateful to G. Herbig for lending us a number of excellent cometary spectrogrammes secured at the Lick Observatory. We also thank D. Baade for taking a spectrum of P/Halley on his own run and H. Lindgren for help in some of our observations at the ESO Coudé Auxiliary Telescope.

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