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Forbidden oxygen lines in the spectrum of 153P/2002 C1 (Ikeya-Zhang)

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Abstract. High resolution spectroscopy observation of comet 153P/2002 C1 Ikeya-Zhang was performed on April 20, 2002 with the echelle spectrograph SARG on the 3.5 m Telescopio Nazionale Galileo in La Palma. The atomic O emission lines at 5577, 6360 and 6363 Å are clearly visible in the spectrum. In order to verify the hypothesis that water is the main parent species of these emissions, we determined the intensity ratio of the green line to the sum of the red lines. The measured value for this ratio, 0.12 ±0.01, led us to conclude that during the observation water was the parent species of atomic O lines.

Key words. comets: individual: 153P/2002 C1 Ikeya-Zhang – comets: general

1. Introduction

Since the early seventies it is well known (Blamont & Festou 1974; Keller 1973a,b) that water ice is the main constituent of cometary nuclei, and as a consequence gaseous H_2O and its dissociation products (OH, O and H) are the dominant species in the coma at heliocentric distances closer to the Sun than 3-4 AU. Unfortunately, water molecule is difficult to detect, while it is much easier to detect its main dissociation products: for example, OH has been extensively studied and used to retrieve the properties of the parent.

As far as regards atomic oxygen, three important emission lines can be observed in the visible part of spectra with enough high spectral resolution: the green line at 5577.339 Å (^1S - ^1D) and the forbidden red oxygen doublet at 6300.304 and 6363.776 Å (^1D - ^3P). These lines cannot be produced by solar resonance fluorescence excitation of the ground-state oxygen atom, but represent a "prompt emission" (Festou & Feldman 1981), which means that they can be produced directly in the excited ^1D and ^1S states by photodissociation of a parent molecule.

Not all the reactions that can produce these forbidden lines involve water molecule: they can also involve CO and CO_2. The question of the origin of O lines is interesting for two reasons. The first one is that, because the lifetime of the ^1D state at 1 AU from the Sun is much shorter than the corresponding lifetime of water molecule, the red emission lines are a good tracer of water molecule

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distribution in the cometary coma. The second and more important reason is that, if water is the main producer of these lines, then from the O column density the H_2O production rate can be deduced.
One or more of these lines were detected many times (Fink & Johnson 1984; Magee-Sauer et al. 1990; Schultz et al. 1993; Morrison et al. 1997; Cochran & Cochran 2001; Zhang, Zhao, & Hu 2001; Morgenthaler et al. 2001), but their unambiguous detection, especially the line at 5577 Å, is very difficult. High spectral resolution is necessary to discriminate the three lines from the usually strong telluric O emission lines; moreover, the red line at 6300 Å is very close to the Q branch of a NH_2 band, and the green line at 5577 Å is in the middle of a crowded C_2 band ((1,2) P-branch).
Discovered in the 2002 by a Japanese and a Chinese amateur astronomers (Hasegawa & Nakano 2002), the comet Ikeya-Zhang was observed with the echelle spectrometer at the NASA Infrared Telescope Facility on Mauna Kea, Hawaii, between March 21 and April 13, 2002 (0.51 and 0.78 AU post-perihelion). From several H_2O hot-band lines near 2.9 μm a water production rate curve was deduced by Dello Russo et al. (2004): $Q_{H_2O} = (9.2 \pm 1.1) \times 10^{28}[R_h(-3.21 \pm 0.26)]$ molecules s^{-1}. The mixing ratio of CO was $(4.7 \pm 0.8) \times 10^{-2}$ at 0.78 AU post-perihelion (Di Santi et al. 2002). Comet Ikeya-Zhang showed a moderately high gas-to-dust ratio from 2.7 AU to the perihelion according to Schleicher & Birch (2002) observations.

2. Observation and reduction

We observed the comet on April 20, 2002 with the cross dispersed echelle spectrograph SARG on the 3.5 m Telescopio Nazionale Galileo in La Palma (Canary Islands, Spain) (Capria et al. 2002). During the observation the comet had a heliocentric distance of 0.89 AU and a geocentric distance of 0.43 AU (Tab. 1).
We used a slit with 0.80 × 5.3 arcsec and the yellow grism covering a spectral range of 4620-7920 Å on the mosaic of two CCDs, providing a resolving power R=57000. The data along the slit length, corresponding to 1627 km on the comet, were summed, obtaining a one-dimensional spectrum.

Table 1. Observing parameters

UT Date	20 Apr 2002
R_h (AU)	0.89
$\dot{R}_h$ (kms^{-1})	29.06
$\triangle(AU)$	0.43
$\dot{\triangle}$ (kms^{-1})	-8.3
Exposure time (s)	2400

The data were reduced using the IRAF ECHELLE package. 55 orders were obtained in the range 4620-7920 Å. Due to the good quality of data thousands of lines are visible: we are presently listing and identifying all these lines by comparison with existing catalogs (Cochran & Cochran 2002; Brown et al. 1996; Zhang, Zhao, & Hu 2001). The cometary atomic oxygen green line and the red doublet are clearly visible in the orders 24 of the blue part and 2 and 3 of the red part, respectively (see Figs. 1, 2 and 3).

Looking at the plot of Fig. 1, the telluric line, while laying very close to the cometary line, is clearly distinguishable. The surrounding C_2 lines are much weaker than the O lines; altough some contamination could be present, it is not substantial. The cases of the red doublet lines are similar (Figs. 2 and 3): the telluric lines are still closer and blended with the cometary lines, but their contribution can still be well separated.

3. The ratio of the atomic oxygen lines

The ratio of the two red lines can give us a first idea of the quality of our data. The intensity of an emission line can be written as:

$$I = 10^{-6}\tau_p^{-1}\alpha\beta N$$

where τ is the dissociative lifetime of the parent, α is the yield of photodissociation, β is the branching ratio and N is the column density (Cochran & Cochran 2001). In the case of the

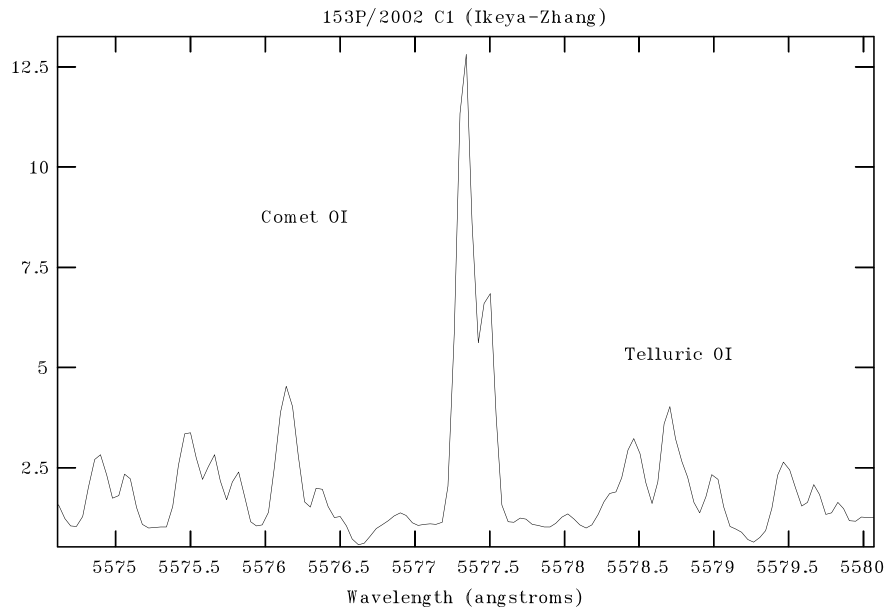

Fig. 1. Oxygen atomic line at 5577 Å (green line); vertical axis is in arbitrary units. The telluric line is visible.

red doublet, the ratio of the two line strengths should be the same as the ratio of the branching ratios, because they are both transitions from the $(2p^4)^1D$ state to the $(2p^4)^3P$ ground state. In our case, the value of the ratio is 2.9±0.01, in good agreement with the value of 3.027 given by Storey & Zeippen (2000).
The intensity ratio of the green to the sum of the two red lines is much more interesting because it allows to verify the assumption that the parent molecule is mainly water. In the case of green to red intensity ratio, if we assume that there is only one parent the column densities are almost the same and the effective excitation ratio for dissociation of a parent molecule is proportional to:

$$\frac{I_{5577}}{I_{6300} + I_{6364}} = \tau^{-1}\alpha\beta$$

For this ratio we obtain a value of 0.12 ± 0.01. This value can be compared with the values listed in the Tab. 2, taken from Festou & Feldman (1981): the obtained value seems to be consistent with the production of O atoms predominantly from the H_2O dissociation.

Table 2. Theoretical value of the ratio $O(^1S)/O(^1D)$ (Festou & Feldman 1981)

PARENT	RATIO $O(^1S)/O(^1D)$
H_2O	~ 0.1
CO_2	~ 1
CO	~ 1

4. Discussion and conclusion

When the observation of comet Ikeya-Zhang was performed the projection of the slit, centered at the comet nucleus, corresponded to a length of 1627 km. For the comet Ikeya-Zhang this means that we are looking into the inner coma region. The major source of production of meta-stable O-species in the inner coma is the dissociation of H_2O, while the major loss

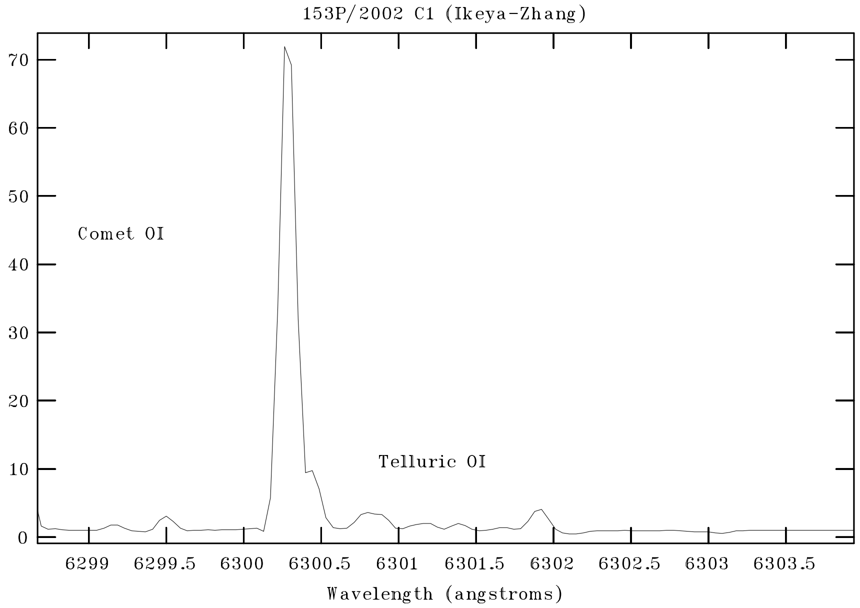

Fig. 2. Oxygen atomic line at 6363 Å (red doublet);vertical axis is in arbitrary units. The telluric line is visible.

Table 3. Oxygen lines ratio in the literature

Comet	$O(^1S)/O(^1D)$	r_h (AU)	$\triangle_h$ (AU)	Reference
C/Iras-Araki-Alcock	0.022-0.034	1.02	...	Cochran (1984)
C/1996 B2 Hyakutake	0.12-0.15	1.083 - 1.002	0.120-0.119	Morrison et al. (1997)
C/1995 O1 Hale-Bopp	0.22-0.18	0.920 - 0.991	1.322-1.627	Zhang, Zhao, & Hu (2001)
C/1999 S4 LINEAR	0.06 ± 0.01	0.97 - 0.79	1.21-0.45	Cochran & Cochran (2001)
153P/Ikeya-Zhang	0.125 ± 0.01	0.85	0.43	This work

processes are quenching (collision reactions with H_2O) and radiative de-excitation.

Our observation is not the first measurement of the intensity ratio between the green and the red doublet lines of atomic oxygen in the comets. Tab. 3 presents this ratio for other comets, along with the heliocentric and geocentric distance of the comet and the corresponding bibliographic reference.
Looking at the Tab. 3, it can be seen that all the measurements obtained until now point to the water as the only, or at least the dominant, parent of O atomic lines. However, it should be noted that the set of measured ratios is not representative, because all the ratios refer to comets at a heliocentric distance close to 1 AU, where it is well known that water ice sublimation is the main driver of the activity and the sublimated water constitutes the major part of the cometary gas. It would be very interesting to measure the ratio of green to red atomic O lines at a point along the cometary orbit where the sublimated water (and its products) is not the major constituent of the

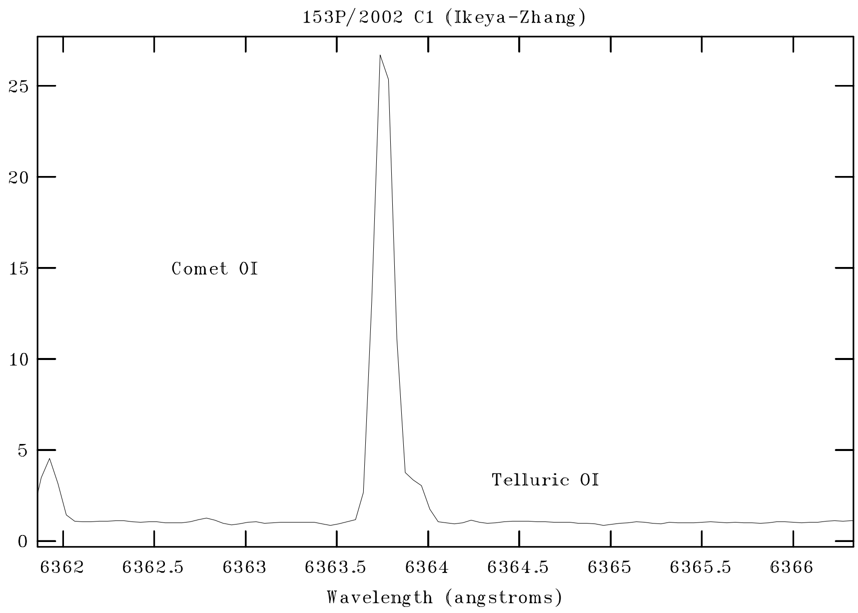

Fig. 3. Oxygen atomic line at 6363 Å (red doublet);vertical axis is in arbitrary units. The telluric line is visible.

gaseous coma. We believe that at such times this ratio-value can be different from those shown in the Tab. 3. It is interesting to note from Tab. 3 that the highest ratio ($\simeq 0.2$) was obtained for the comet Hale-Bopp. A possible reason could be that the CO abundance in this comet was very high (Bockelée-Morvan & et al. 2004). As can be noted from Tab. 2, the ratio of green to red lines will tend towards unity with increasing abundance of CO and CO_2 relative to water.

To conclude, the observed intensity ratio of the green to red lines of atomic oxygen lead us to say that H_2O is the main parent species of the O lines on comet Ikeya-Zhang. However, in our opinion this conclusion holds only at heliocentric distances of ~ 1 AU from the Sun.

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