Rev. Mexicana Astron. Astrof., 6, 335-337 (1981)

ON THE CN(0,0) SPECTRUM OF COMET KOHOUTEK 1973 XII

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RESUMEN

Se presentan resultados del análisis de la banda CN(0,0) en el cometa Kohoutek 1973 XII, donde se resuelven las ecuaciones de equilibrio estadístico incluyendo colisiones. Se han obtenido los siguientes resultados: *a)* La temperatura rotacional de este cometa a una distancia al Sol de $r = 0.83$ UA es $T_{rot} = 445 \pm 30°$K. *b)* Las colisiones contribuyen mayoritariamente al poblar el nivel vibracional inferior. *c)* La constante R_1 en este y otros cometas es muy cercana a 1.0×10^{-4}.

ABSTRACT

An analysis of the CN(0,0) band of comet Kohoutek 1973 XII, solving the equations of statistical equilibrium including collisions, has given the following results: *a)* The rotational temperature of this comet at a solar distance of $r = 0.83$ AU is $T_{rot} = 445 \pm 30°$K. *b)* Collisions are important in populating the lower vibrational level. *c)* The constant R_1 in this and other comets is close to 1.0×10^{-4}.

Key words: COMETS – SOLAR SYSTEM -GENERAL

I. INTRODUCTION

There have been some observations of the (0,0) ibrational band of the CN molecule in comets, reported ı the literature. This is one of the few band systems /here the rotational structure can be observed clearly at igh resolution. For example, the rotational lines of the ·2 molecule are too close to each other to be seen even t 5 A mm^{-1}. So, there is some interest in understand- ıg the CN(0,0) band in comets, since it can provide ome physical information about its structure.

Before 1957, the available spectra of this band were ot able to resolve the rotational structure. Nevertheless, wings (1941) noticed that the form of the spectrum /as highly dependent on the available solar energy at the ne wavelength, and thus on the radial velocity of the omet with respect to the sun. Since then, this mechaism is known as Swings's effect.

Greenstein (1958) took the first high resolution pectra in which the rotational structure was fully esolved. He used the high resolution spectrograph of the 00-inch telescope of the Hale Observatory. Conseuently, a large amount of new information was ıbtained. However, Greenstein carried out only a qualitaive analysis of the spectrum.

Hunaerts (1959) was the first to attempt a theoretical xplanation of the rotational line intensities, assuming hat collisions populate the lower vibrational level ·verwhelmingly. The upper vibrational level, however, /as populated according to the available solar energy at he line wavelength. Thus Hunaerts took into account Swings's effect. He was able to obtain a reasonable fit to the observed spectrum obtained by Greenstein. The flourescence mechanism was thus fully confirmed.

This treatment of the resonant flourescence was questioned by Arpigny (1964), which implies that the equations of statistical equilibrium must be solved with the solar residual intensities taken into account, in order to obtain the populations of the upper and lower levels. From these populations line intensities can be predicted. Note that no collisions were included in this procedure. The intensities of the rotational lines of the (0,0) band of CN in comet Mrkos were compared with theory, and again a fair fit was reached. The radial velocity of the comet was obtained from the orbital data.

Note that the procedures of Hunaerts and Arpigny, represent two extreme cases. On the one hand, Hunaerts populates the lower vibrational level only with collisions, and so he is assuming that there was local thermodynamic equilibrium, (LTE). On the other hand, Arpigny considered that collisions were not important in view of the presumably low densities in the cometary coma. Thus there was non-LTE and the full set of statistical equilibrium equations had to be solved. None of these authors considered the possibility of having an intermediate case.

Malaise (1970) suspected that collisions were important in populating the lower vibrational level of this molecule. Thus he took them into account when calculating the intensities of the rotational lines. He used only low resolution observations in which the R-branch was not fully resolved. Although the effect of collisions was well demonstrated, his low resolution spectra made his results quite uncertain. An additional uncertainty was introduced by the lack of a high resolution spectrum of the integrated light of the sun. Notice that the comet sees the full solar disk, but that most solar atlases give the solar spectrum at the center of the disk or at selected values toward the edge. Thus a center-of-the-disk spectrum does not provide the true solar intensity.

Ferrín (1977) corrected this last problem by using residual intensities obtained from the *High Resolution Spectral Atlas of the Solar Irradiance from 380 to 700 nanometers*, by Beckers *et al.* (1976), which contains the integrated solar intensity at intervals of 0.005 A. Ferrín also attempted an intermediate solution between those of Hunaerts and Arpigny, by allowing a least squares solution between two extreme conditions: that of a purely collisionally excited lower level, and that of a purely flourescent lower level. If X_k gives the population of the k-th rotational level then

$$X_k = \alpha\ X_k^b(T) + (1 - \alpha)\ X_k^f\ , \qquad (1)$$

X_k^b and X_k^f are the Boltzmann and flourescent populations of the k-th rotational level of the lower vibrational level. Thus α gives the proportion of both. Ferrín also allowed variations of the following parameters: rotational temperature, T_{rot}, velocity of the comet relative to the sun, v_{spec}, and α. The solution was found from a least square fit on the four parameters. This method was applied to the high resolution observations of comet Mrkos made by Greenstein (1958). Ferrín found that the sum of the squares of the residuals could be reduced by a factor of ten if collisions were included. He thus concluded that the situation was an intermediate one between that of Hunaerts and that of Arpigny, since his value for α was $\alpha = 0.43 \pm 0.03$. Thus collisions are important in cometary atmospheres.

In this work we will follow essentially the solution by Ferrín (1977). We will apply this method to observations of comet Kohoutek 1973 XII, carried out by Ishii and Tamura (1980). These authors obtained two solutions to their spectra: the Hunaerts's solution and the Arpigny's solution, and concluded that both explain equally well the spectrum. Our re-analysis of their observations show that collisions are indeed important in this comet, and that a rotational temperature can be inferred from their observations. Precise values for α, R_1, v_{spec} and T_{rot} have been obtained.

II. RESULTS

The results of our analysis are presented in Table 1 where we show that the sum of the residuals are considerably reduced by including collisions. In Figur 1, a comparison of the observed and theoretical spec trum is carried out when collisions are included an when they are neglected. The improvement is clearl significant. Collisions account for 78% of the populatio of the lower level.

TABLE 1

SUMMARY OF CALCULATED AND OBSERVED VALUES

R_r (r = 0.83 AU) = (6.7 ± 0.12) × 10^{-5}
R_1 (r = 1.0 AU) = (9.7 ± 1.7) × 10^{-5}
T_{rot} (°K) = 445 ± 30
α = 0.78 ± 0.09
v_{comet} (spectroscopic) = (45.7 ± 0.3) km s^{-1}
v_{comet} (cel mech) = 41.6 km s^{-1}
Σ_R (residuals with collisions)^2 = 8.8
Σ_R (residuals without collisions)^2 = 35.2

Arpigny's value (1964) for the parameter R has bee transformed to r = 1 AU multiplying by a factor r^2 (r = heliocentric distance). The value found is close t 1.0×10^{-4}.

There is a significant discrepancy between the spe troscopic and the orbital velocity of the comet obtaine from celestial mechanics. This discrepancy may t

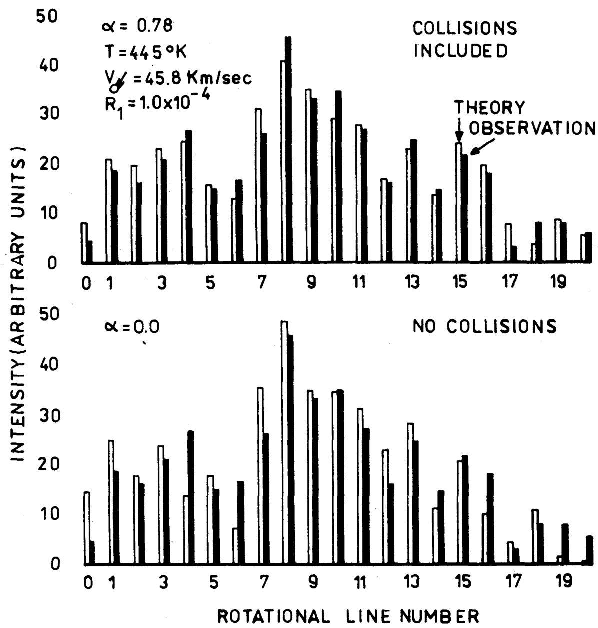

Fig. 1. A comparison between observations and theory. It show how including collisions in the model improves the fit to th observed spectrum. The improvement is especially important fc low and high rotational line numbers.

explained in the following way. When the cometary gases evaporate from the nucleus, they do so toward the Sun. However, they soon have to turn around due to the solar radiation pressure. They then move toward the tail, where Hyder *et al.* (1974) have observed velocities of propagation of 250 km s^{-1}. The discrepancy we found amounts to 4.1 km s^{-1} away from the Sun. Thus if the spectrograph slit was slightly behind the nucleus of the comet, the measured motion would be away from the Sun and larger than the motion of the comet. Had the spectrograph slit been set slightly in front of the nucleus (that is, toward the Sun), the spectroscopic velocity would have been smaller than the orbital velocity. The small error of the spectroscopic velocity, due to the use of the high resolution atlas of Beckers *et al.* (1976), gives an indication of how precise our method is.

Finally, Figure 2 shows a comparison of our rotational temperature with the dust temperature derived by Ney (1974). The agreement is fairly good. We do not expect dust and molecules to exhibit the same temperature, but they should not be very different either. This seems to be the case.

In conclusion, we may say that physical information about a comet can be derived from high resolution observations of the CN(0,0) band. Thus they should be carried out whenever possible. Also, the importance of collisions has been demonstrated. They certainly have to be included in theoretical calculations.

We acknowledge the Consejo de Desarrollo Científico y Humanístico of the Universidad de Los Andes, for their continuing support for our research projects. One of us, O.E., thanks the Consejo Nacional de Investigaciones Científicas y Tecnológicas for their support for his thesis research.

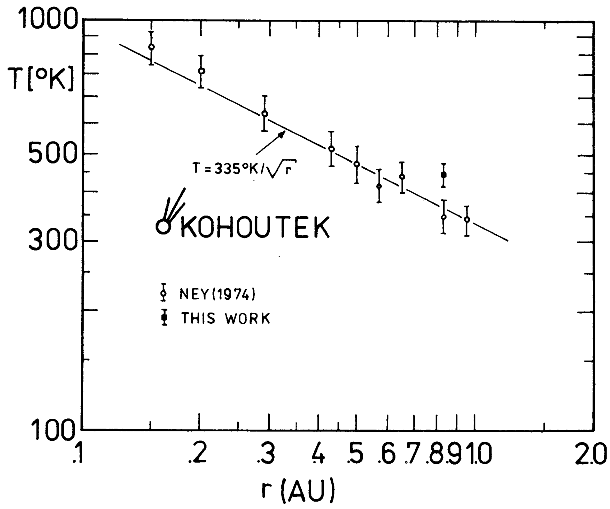

Fig. 2. A comparison between the derived rotational temperature, and temperatures measured by Ney (1974) in the infrared.

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DISCUSSION

Mendoza, C.: Ustedes usan una ecuación lineal que relaciona las colisiones con la flourescencia. ¿Es esto válido?

Ferrín: No. Es una aproximación que realizamos para ver si las colisiones eran importantes. Las colisiones deben ser incluidas en las ecuaciones de equilibrio estadístico. Pero esto es considerablemente complicado, y lo estamos haciendo ahora.

Pérez-de-Tejada: La temperatura de la atmósfera cometaria también está influenciada por el viento solar. ¿Cómo afecta esto el valor que ustedes terminaron?

Ferrín: Lo que se mide en el espectro es la temperatura rotacional de la molécula del CN. Aunque el viento solar podría influenciar la rotación de las moléculas de la atmósfera cometaria, hasta ahora nadie lo ha calculado. Mi impresión es que no la afecta, o que la afecta poco. Hay procesos más importantes.

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