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HIGH-RESOLUTION OBSERVATIONS OF THE SPATIAL AND VELOCITY DISTRIBUTION OF COMETARY HYDROGEN

Michael E. Brown and Hyron Spinrad
Dept. of Astronomy, University of California, Berkeley, CA

ABSTRACT

We have obtained high velocity and spatial resolution long-slit Hα spectra of comets Austin ($1989c_1$) and Levy (1990c). Spectra of both comets clearly show the existence of a low velocity thermalized component of hydrogen gas. The amount of slow hydrogen is estimated for comet Austin. The Levy spectrum shows an unusual high-velocity spatially-confined blob of hydrogen emission of unknown origin.

INTRODUCTION

Hα 6562Å emission has been observed in comets since Kohoutek (Huppler *et al.* 1975, Magee-Sauer 1988). Although the excitation mechanism is weak – Hα emission is produced by fluorescence following solar Lyβ excitation of cometary hydrogen – Hα is observable because hydrogen is the most abundantly produced and longest-lived species in cometary comae.

Hydrogen is produced primarily by photodissociation of water through the following reactions (Crovisier 1989):

$$H_2O + h\nu \rightarrow H + OH. \tag{1}$$

$$OH + h\nu \rightarrow H + O. \tag{2}$$

In reaction (1) the typical hydrogen ejection velocity is about 18 km/sec, while in reaction (2) the typical velocity is about 8 km/sec. Models of the hydrogen coma have also suggested the existence of a slow (~ 2 km/sec) thermalized component caused by hydrogen-water collision in the dense inner coma (Combi and Smyth 1987).

High resolution spectroscopy of Hα should be able to disentangle the different velocity components of the hydrogen coma. Previous spectroscopy, using Fabry-Perot methods (Huppler *et al.* 1975, Magee-Sauer 1988) has not had sufficient resolution to separate the components. We present here the first spectra with sufficient resolution to clearly observe the difference between the slow thermal component and the faster ejection products.

OBSERVATIONS

We observed Hα in comets Austin ($1989c_1$) and Levy (1990c) using the Lick Observatory Hamilton Echelle Spectrometer (Vogt 1988). An order sorting filter centered at 6562Å with a 15Å FWHM was placed in the light path to isolate the order containing Hα, and the decker, which normally confines the spatial extent of the spectrum to about 3 arc seconds (about seven CCD pixels), was removed to allow use of the full one arc minute spatial height of the slit (about 200 pixels). The resulting long-slit spectrum covers 15Å at about ~.05Å resolution and has a projected spatially range of about 20000 km for comet Austin.

The raw spectrum is flat-fielded in the usual way, and the slit function and filter function are removed using a lunar spectrum. The spectrum now contain emissions from the sky, cometary dust (a reflected solar spectrum), coma gas, and geocoronal Hα. The sky emission is removed by examining the dust continuum far from the nucleus: a lunar spectrum plus a constant sky is fit to the dust and sky spectrum. The proportion of lunar to constant is chosen such that the depths of the Fraunhofer lines agree. The constant

Table 1: Observational Parameters

comet	date (UT)	Δ (AU)	r (AU)	$\dot{\Delta}$ (km/sec)	$\dot{r}$ (km/sec)
Austin ($1989c_1$)	15 May 1990	0.32	0.96	-24	34
Levy (1990c)	12 Sept 1990	0.69	1.19	42	-17

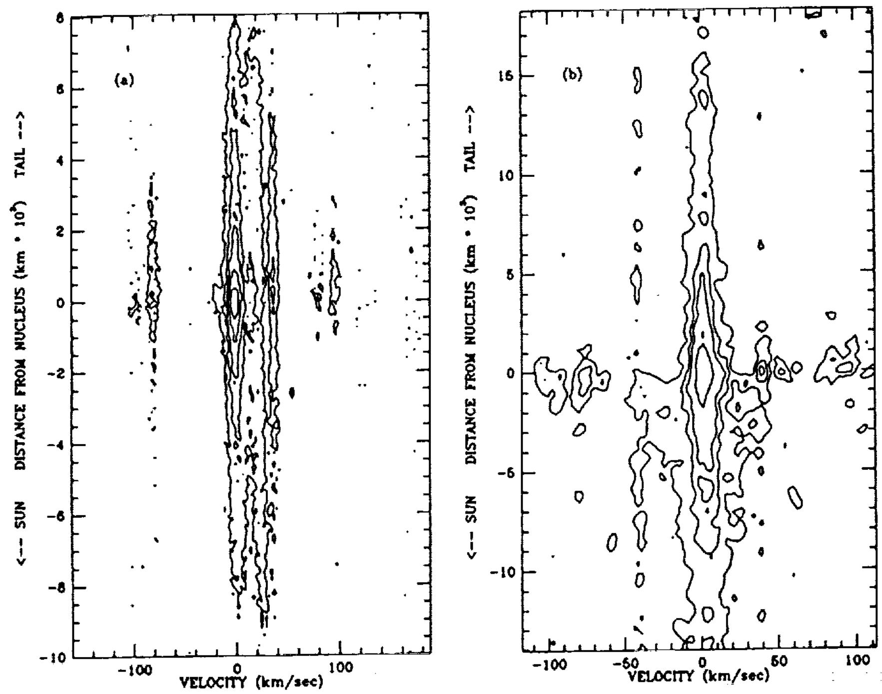

Figure 1: Long slit Hα spectra. Distance is projected distance from nucleus; velocity is cometocentric velocity. (a) Austin: note that the line at +23 km/sec is geocoronal Hα emission. Other lines are unidentified. (b) Levy: geocoronal Hα is at -42 km/sec.

sky is then subtracted from the whole frame. The OH and geocoronal Hα emission are easily separated from cometary emission as they are spatially constant along the slit. The earth-comet velocity separates geocoronal and cometary Hα.

To analyze the Hα emission, the reflected dust continuum must also be removed. This removal is accomplished by taking spatial profiles of the dust where it is uncontaminated by gas emission and then subtracting a lunar spectrum scaled by the dust spatial profile from the cometary spectrum. The resulting spectrum now contains only cometary gas emission (and sky and geocoronal line emission). Table 1 gives observational parameters of the Austin and Levy observations. Figure 1 shows the reduced two-dimensional spectra in contour form.

ANALYSIS OF THE OBSERVATIONS

Austin ($1989c_1$)

To analyze the velocity distribution of the high quality Austin data, we developed a simple radially symmetric collisionless Monte Carlo model based on the method of Combi and Delsemme (1980). The model tracks the photodissociation of H_2O into H and OH and of OH into O and H. A long-slit spectrum of the model is constructed based on the real observational parameters.

Figure 2 (a) compares the velocity profile of the inner 1200 km of the Austin data (solid line) with the simulated data (dashed line). Clearly the Austin velocity distribution contains a surplus of low-velocity hydrogen not accounted for by the model. This is the first direct observation of slow thermalized hydrogen in a cometary coma.

Slow hydrogen can be artificially injected into the model. As an estimate for the amount of slow hydrogen expected we calculate the percentage of water dissociated within the collision radius,

$$r_c = \frac{Q_{H_2O}\sigma}{4\pi v}. \tag{3}$$

With a water production rate of $Q_{H_2O} = 10^{29}$ sec^{-1}, a collision cross section of $\sigma = 5 \times 10^{-15}$ cm^2 and a water outflow velocity of $v = 1$ km/sec, the collision radius is about 4000 km. For an exponential decay lifetime of τ, the fraction f of water dissociated within r_c is

$$f = 1 - \exp(-r_c/v\tau). \tag{4}$$

With $\tau = 8 \times 10^4$sec, the fraction of water dissociated within the collision radius is about 5%.

Figure 2 (b) compares the Austin data with a model spectrum including 5% hydrogen at a velocity of 2 km/sec. This model begins to better reproduce the observed hydrogen velocity distribution, but still does not contain enough slow hydrogen. The best fit to the velocity distribution is a model with 20% of the hydrogen in the thermalized component, shown in Figure 2(c). The observed and modelled spatial distributions are shown in Figure 2 (d) - (f). The model spatial distributions have slow hydrogen components of zero, 5%, and 20%, respectively. Notice the different models are nearly indistinguishable; in all cases the modelled spectrum is more peaked than the true spectrum. We are currently attempting more sophisticated modelling to understand this behavior.

Levy (1990c)

Although the data for Levy are noisier, one feature stands out in figure 1 (b): a blob of fast gas is clearly visible from 0 to 5000 km sunward of the nucleus at velocities of 20 km/sec to 50 km/sec. This blob is puzzling because of both its high velocity and its spatial confinement. No known water dissociation ejects a large amount of hydrogen at such high velocities, yet the integrated intensity of emission within the blob is a significant fraction of the total Hα emission. The hydrogen could have been ejected from a heavier-than-water parent, but its spatial distribution would still be difficult to understand: If the blob is travelling at a moderate, say 45° angle to the line-of-sight, it would take only six minutes to reach a projected distance of 5000 km. But the exposure time for this spectrum was 45 minutes, so the blob would have to have been fortuitously ejected in the six minutes just prior to the end of the exposure. If instead the blob were travelling directly towards the earth it could have been ejected anytime prior to the observation, but the range of angles that would force the blob to stay so sharply confined to the sunward side of the nucleus is so small as to make this scenario seem unreasonable also. We intend to continue monitoring Hα in future comets in order to determine the frequency of such blobs and to understand the physical mechanism behind their formation.

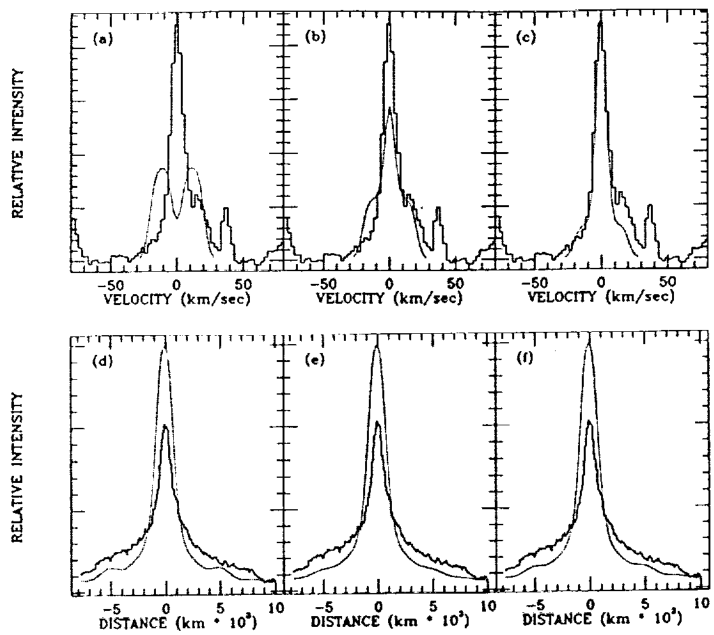

Figure 2: (a) Austin hydrogen velocity distribution (solid line) and model with no slow hydrogen (dotted line). Line at +23 km/sec is geocoronal Hα emission. Other lines are unidentified. (b) Model with 5% slow hydrogen. (c) Model with 20% slow hydrogen. (d) Austin projected hydrogen spatial distribution (solid line) and model with no slow hydrogen (dotted line). (e) Model with 5% slow hydrogen. (f) Model with 20% slow hydrogen

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