Chapter 9

Final detections of CN, C_2 and C_3

Emission bands of the CN, C_3, C_2 and NH_2 radicals have been followed in this observing campaign. While all emission bands already appeared in the first observations at 4.6 AU pre-perihelion [Rauer *et al.*, 1997], emissions of NH_2 could be followed up to 4.7 AU post-perihelion, C_2 up to 5.0 AU, and C_3 and CN even up to 7.0 AU and 9.8 AU, respectively, see also Rauer *et al.* [2002]. The detected emissions of the daughter products are significant indicators for the activity of their parent ices.

The heliocentric distance at which a species is detected for the first or the last time can give important clues on the properties of the parent species associated with the observed radicals. Assuming a simple non-differentiated nucleus, the activity starts when the sublimation temperature is reached and stops when the temperature drops below this value.

Assuming a more complex internal structure of the nucleus, a sublimation model is needed. For these models the range of activity for the different species are valuable input parameters.

Only few emissions of gaseous species have been observed at large distances, beyond 5 AU. In comet Schwassmann-Wachmann 1, CO, CO^+ and CN have been detected (e.g.: Cochran *et al.* [1991], Senay and Jewitt [1994]). In addition, a detection of CN emission in Chiron at 11.3 AU has been reported during an activity outburst [Bus *et al.*, 1991]. In comet Hale-Bopp, CN was first detected at r_h = 6.8 AU pre-perihelion [Fitzsimmons *et al.*, 1996].

The most distant detection of CN during the longterm monitoring program was obtained on November 13, 1999 using the VLT(UT1)/FORS1. The heliocentric distance of the comet at this time was 9.8 AU. Displayed in the left part of Figure 9.1 is the average of 6 spectra of the CN (0,0) emission band. This is equivalent to a total exposure time of 6100 s. The spectrum is flux calibrated and the underlying continuum caused by solar light scattered on dust particles has been subtracted. The horizontal direction covers a radial distance of $5 \cdot 10^5$ km around the nucleus. The vertical direction covers a wavelength range of 3600 – 4200 Å. The spectrum has been binned by a factor of 10 in spatial direction and a factor of 2 in wavelengths direction to increase the signal-to-noise ratio. The right shows the same spectrum as to the left, but binned further (factors 4 and 2 in spatial and wavelengths direction, respectively). The CN (0,0) emission band is clearly visible.

Figure 9.2 is the spectrum at 80000 km projected nucleocentric distance sunward, taken from the left spectrum in figure 9.1. The spectrum has been averaged by a factor 5 in wavelengths.

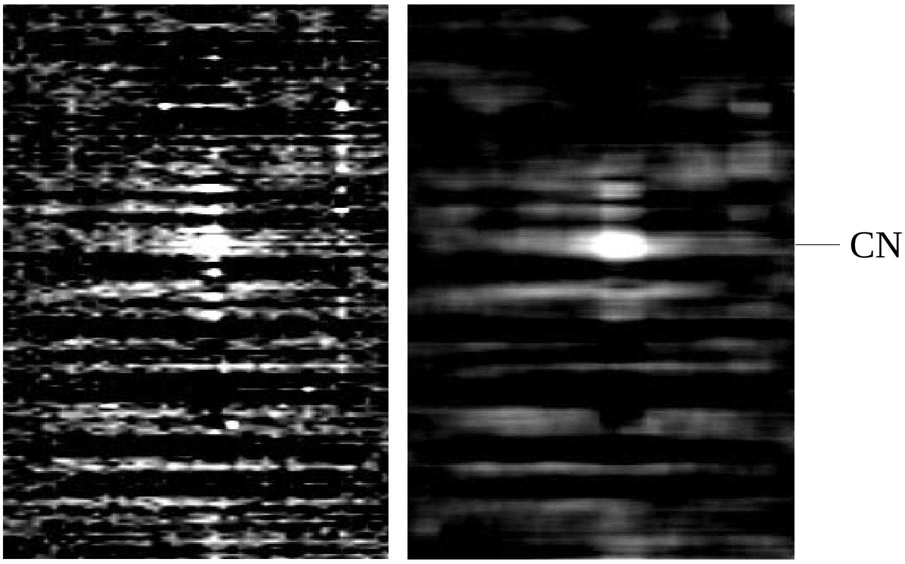

Figure 9.1: **left:** Detection of the CN (0,0) emission band obtained at r_h = 9.8 AU on November 13, 1999, using the VLT(UT1)/FORS1. The spectrum has been averaged by a factor of 10 in spatial direction and a factor of 2 in wavelengths direction. **right:** Same spectrum as to the left, but binned further (factors 4 and 2 in spatial and wavelengths direction, respectively) [Rauer *et al.*, 2002].

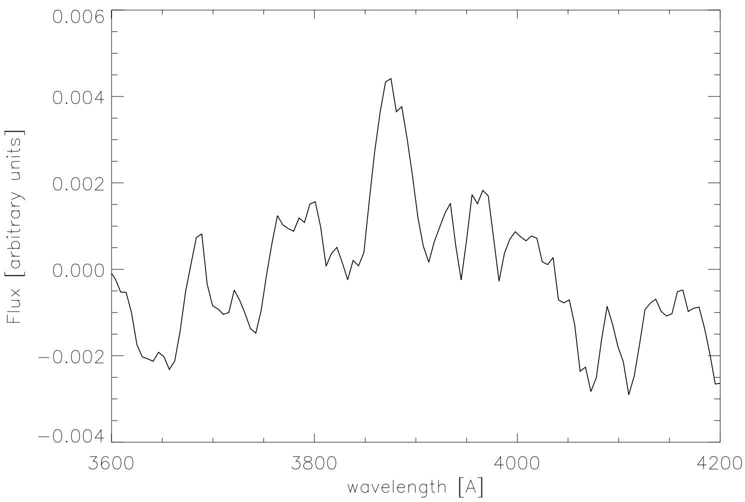

Figure 9.2: Spectrum at 80000 km projected nucleocentric distance sunward averaged over 31000km, the CN (0,0) emission band appears at 3880 Å [Rauer *et al.*, 2002].

The CN emission band appears at 3880 Å.
The last detection of the C_3 radical was obtained on November 25, 1998. Comet Hale-Bopp

had at this time a heliocentric distance of $r_h = 7.0$ AU. The right panel in figure 9.3 shows the average of two spectra obtained on November, 25, 1998 ($r_h = 7.0$ AU, 2400 s total exposure time).The spectrum is flux calibrated and the underlying continuum caused by solar light scattered on dust particles has been subtracted. The horizontal direction covers approx. $6 \cdot 10^5$ km radial distance around the nucleus. The vertical dispersion direction covers 3800 – 4300 Å. For comparison the left panel of figure 9.3 shows a spectrum obtained on January 21, 1998 ($r_h = 4.1$ AU, 1200 s exposure time). The spectrum is again fully reduced. Both spectra were binned by a factor 10 in spatial direction. The position of the CN, CO^+ and C_3 emission bands are indicated.

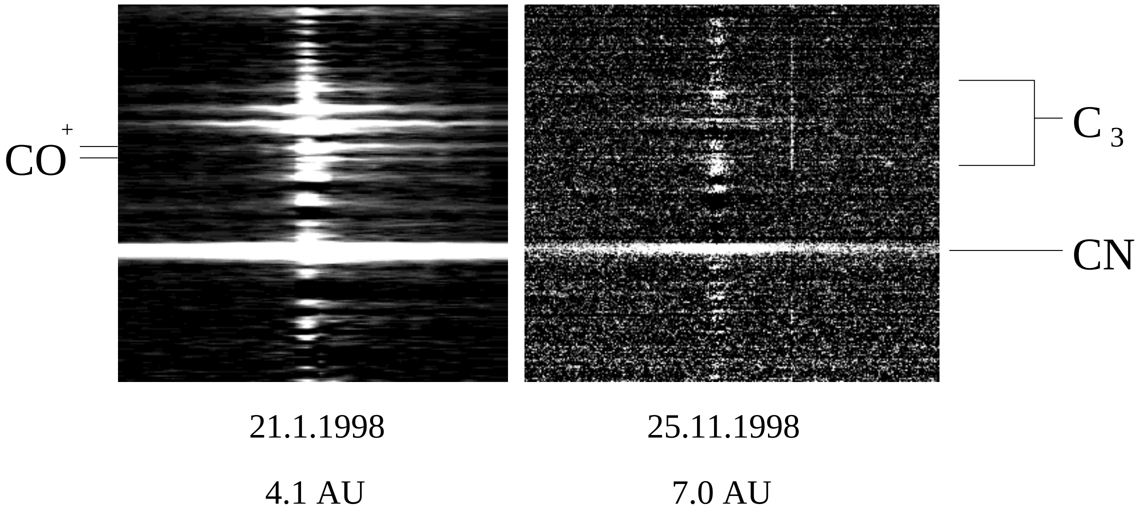

Figure 9.3: The left panel shows a spectrum obtained on January 21, 1998 ($r_h = 4.1$ AU, 1200 s exposure time) for comparison. The right side displays an average of two spectra obtained on November, 25, 1998 ($r_h = 7.0$ AU, 2400 s total exposure time). The position of the CN, CO^+ and C_3 emission bands are indicated [Rauer *et al.*, 2002].

Figure 9.4 displays cuts through spectra obtained at different heliocentric distances, taken at about $7 \cdot 10^4$ km sunward. The spectrum at 4.1 AU has been reduced by a factor of 5 in intensity and is shown only for comparison. The spectra at 7.0 AU and 7.4 AU are offset in intensity for display. The C_3 emission bands are visible at 4.1 AU and 7.0 AU, but not anymore at 7.4 AU.

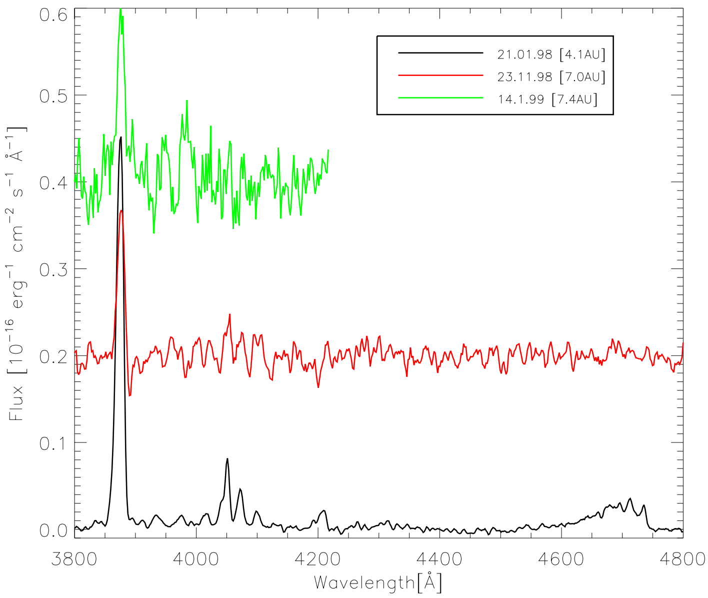

Figure 9.4: Cuts through spectra obtained at different heliocentric distances, taken at about $7 \cdot 10^4$ km projected distance sunward. The spectrum at 4.1 AU has been reduced by a factor of 5 in intensity. The spectra at 7.0 AU and 7.4 AU are offset in intensity for display [Rauer *et al.*, 2002].