

LONG SLIT SPECTROSCOPY OF NH₂ IN COMETS HALLEY, WILSON AND NISHIKAWA-TAKAMIZAWA-TAGO

p. 4

Terrence W. Rettig and Stephen C. Tegler (University of Notre Dame), Susan Wyckoff and Rodney Heyd (Arizona State University), Raylee Stathakis (Anglo-Australian Observatory) and D. A. Ramsay (Herzberg Institute of Astrophysics, NRCC)

ABSTRACT

Long-slit spectra of comets Halley, Wilson and Nishikawa-Takamizawa-Tago were obtained with the 3.9 meter Anglo-Australian Telescope. Spectra of comets Halley and Wilson were obtained with the IPCS at a spectral resolution of 0.5 Å and a spatial resolution of 10³ km. Spectra of comets Wilson and Nishikawa-Takamizawa-Tago were obtained with a CCD at a spectral resolution of 1.5 Å and a spatial resolution of approximately 3x10³ km. Surface brightness profiles for NH₂ were extracted from the long-slit spectra of each comet. The observed surface brightness profiles extend along the slit to approximately 6x10⁴ km from the nucleus in both sunward and tailward directions. By comparing surface distribution calculated from an appropriate coma model with observed surface brightness distributions, the photodissociation timescale of the parent molecule of NH₂ can be inferred. The observed NH₂ surface brightness profiles in all three comets compares well with a surface brightness profile calculated using the vectorial model, an NH₃ photodissociation timescale of 7x10³ seconds, and an NH₂ photodissociation timescale of 34,000 seconds.

1. INTRODUCTION

Comets that pass sufficiently close (≤ 5 AU) to the sun develop a transient atmosphere due to sublimation of nucleus ices. These ices probably condensed from solar nebular gases 4.5 billion years ago at the earliest solar system epochs, and have remained relatively unprocessed. Therefore, analysis of the molecular composition of comet comae can reveal important information on the physical state and chemical abundances in the early solar nebula. Neutral molecules observed in the visible spectra of comets (C₂, C₃, CH, CN, NH₂, [OI]) are photodissociation fragments of parent molecules which sublimated from the nucleus. The identities of the parent molecules are largely unknown.

A technique used to determine the identities of parent molecules is to analyze the spatial distributions of the radicals using a suitable model. The parent molecule photodissociation timescales can be inferred from a comparison between calculated and observed surface brightness distributions. The parent photodissociation timescale identifies, hopefully uniquely, the parent molecule. Long slit spectroscopy has been used to determine the spatial distributions of individual molecules in comet coma (Cochran and Barker 1986, Wyckoff *et al.* 1988). In the past, low to moderate spectral resolution (~5-10 Å) long slit spectra have been used to trace the spatial distribution of a given molecular species in comet comae. Moderate resolution spectra, however, may not provide unique tracers of individual molecules because of confusion with other molecular emission lines and background dust continuum. The ideal technique to map the spatial distribution of a given molecular species in a comet coma is high resolution imaging spectroscopy using a long slit (>3 arcmin). Here we report observations of NH₂ spatial distributions in three comets at approximately the same heliocentric distance ($r \approx 1.3$ AU). The unambiguous NH₂ spatial profile has been analyzed to determine information about the source of NH₂.

2. OBSERVATIONS

Long-slit spectral observations of comets Halley, Wilson and Nishikawa-Takamizawa-Tago were obtained with the 3.9 meter Anglo-Australian Telescope. Observations of P/Halley were obtained on 1986 April 14 and observations of C/Wilson and C/Nishikawa-Takamizawa-Tago were

obtained on 1987 May 10. Spectra of comets Halley and Wilson were obtained with the Image Photon Counting System (IPCS) over the 3800 to 6800Å wavelength interval at a spectral resolution of 0.5 Å. In addition, long slit spectra of comets Wilson and Nishikawa-Takamizawa-Tago (NTT) were obtained with the CCD spectrograph over the 3800 to 6800Å spectral interval at a resolution of 1.5 Å. The size of the CCD images and IPCS images were 576x386 pixels and 2020x220 pixels. The IPCS and CCD sampling rates were 0.05Å/pixel and 0.7Å/pixel. The slit was centered on the peak brightness of each comet and oriented along the extended solar radius vector and had dimensions 3.6 arc min by 1 arc sec. The IPCS and CCD had spatial samplings of 1 arcsec/pixel and 0.56 arcsec/pixel respectively. The measured surface brightness profiles extend to approximately 6×10^4 km from the nucleus in both sunward and tailward directions. The three comets were observed at nearly the same heliocentric distance (1.240, 1.296 and 1.38AU for comets Wilson, NTT and Halley), the geocentric distances were 0.710, 0.771 and 0.430AU respectively.

Data reduction was performed with the Image Reduction and Analysis Facility (IRAF) at Arizona State University and Figaro at the Anglo-Australian Observatory. The CCD images were wavelength calibrated using standard Cu-Ar arc lamps and flux calibrated using a standard A1 IV star (BS 4819) and mean extinction coefficients. The IPCS images were wavelength calibrated using standard He-Ne-Ar arcs.

An extraction parallel to the dispersion axis resulted in a spectrum of the NH₂ (9-0) band for comet Wilson (Figure 1). This spectrum includes the underlying dust continuum. The three molecular lines used in this analysis are the 1₀₁-1₁₁, 0₀₀-1₁₀ and 1₀₁-2₁₁ lines.

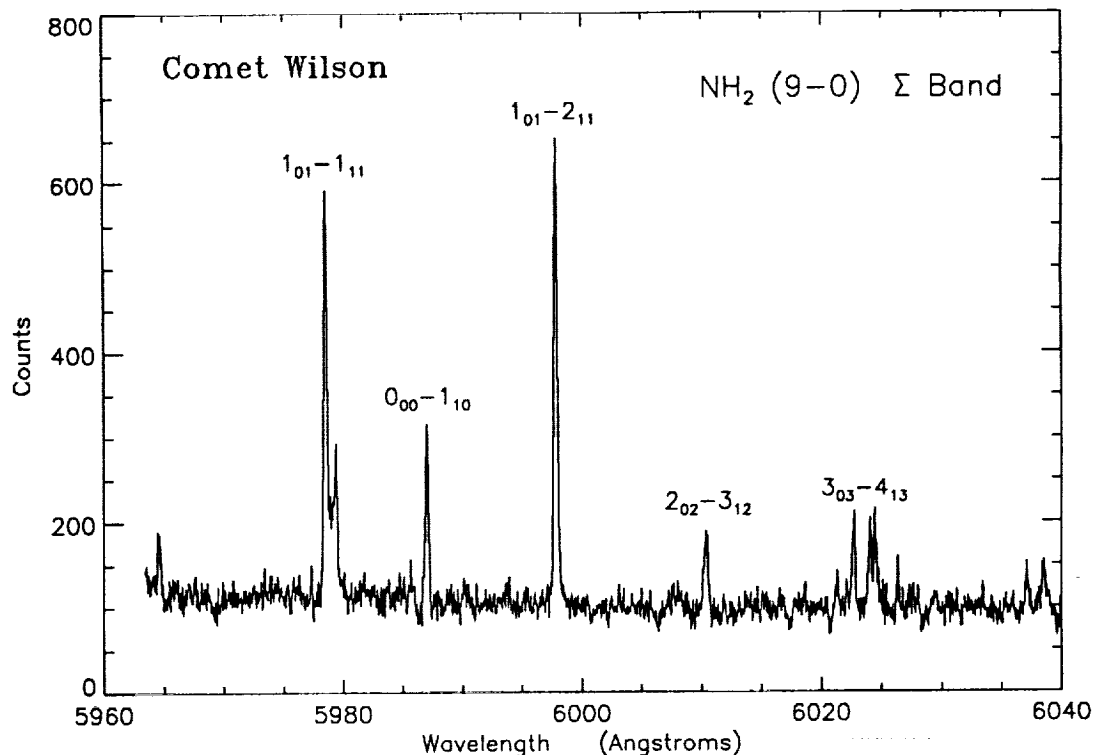


Figure 1. Spectra of the NH₂(9-0) band for comet Wilson.

Extractions perpendicular to the dispersion axis resulted in surface brightness profiles for NH₂. A surface brightness profile for each molecular line in Figure 1 was obtained as follows. First an

extraction centered on a molecular line was obtained. This extraction included not only the surface brightness of the molecular line, but also the surface brightness of the underlying continuum. The continuum contamination was removed by obtaining another extraction offset to a nearby continuum bandpass. The continuum surface brightness profile was subtracted from the molecular line plus continuum profile resulting in an isolated molecular line surface brightness distribution.

An examination of the $1_{01}-1_{11}$, $0_{00}-1_{10}$ and $1_{01}-2_{11}$ rotation lines of the NH_2 (9-0) band showed that each line had the same surface brightness distributions within the observational uncertainties, hence, the individual profiles for the NH_2 lines were averaged for each comet. Figure 2 shows the average NH_2 (9-0) surface brightness profile for each comet. Also, the individual profiles showed no obvious systematic sunward - tailward asymmetry. The error bars in Figure 2 result from photon counting statistics. The NH_2 surface brightness profiles for the comets appear the same within the uncertainties.

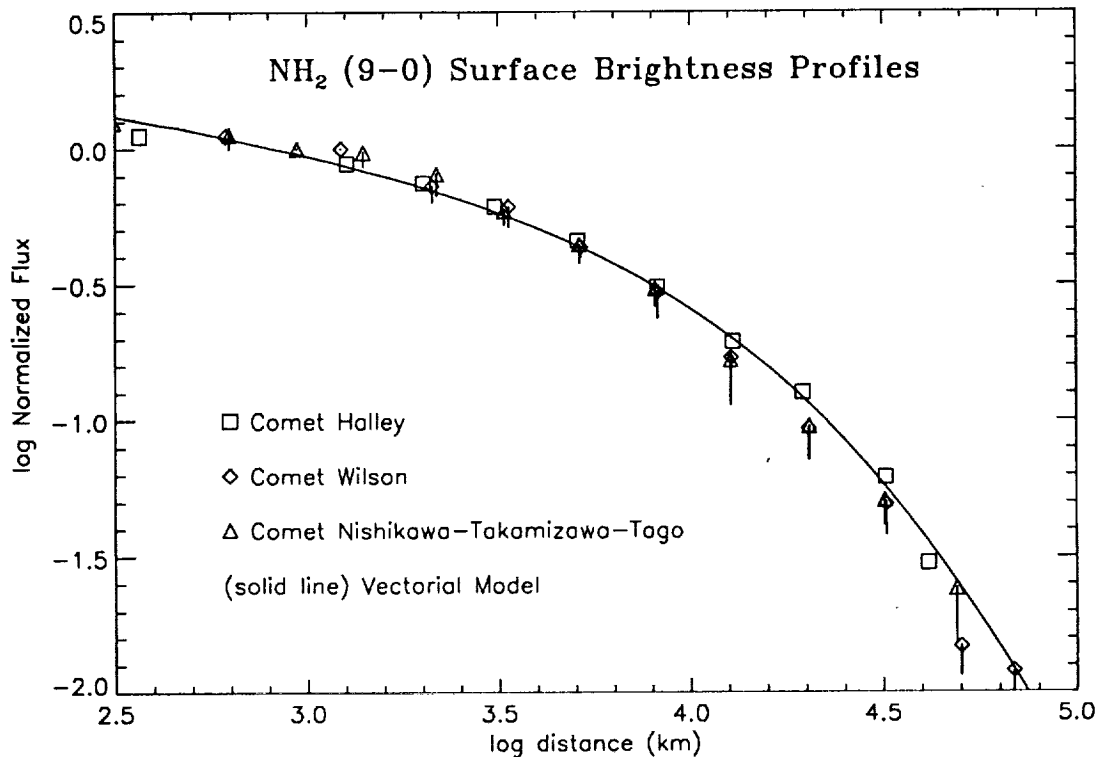


Figure 2. Surface brightness profiles for the $\text{NH}_2(9-0)$ band for three comets.

3. DISCUSSION

It is important to identify the parent molecules of photodissociation fragments in the comae of comets because molecular abundances in comets provide significant constraints on the extent of chemical and physical processing in the early solar system. Using the observed surface brightness profiles of photodissociation fragments and a coma model, we can in principle determine the lifetimes of parent molecules and hence constrain the identity of parent molecules.

A surface brightness profile was calculated for NH_2 using the vectorial model (Festou 1981a,b). The calculation assumed NH_2 is created and destroyed by the reactions



and



The photodissociation timescales for the reactions in equations (1) and (2) were calculated from photodissociation cross-sections and satellite observed solar fluxes (Engel and Wyckoff 1991). In particular, NH_3 and NH_2 photodissociation time scales of 7700 and 34,000 seconds (1AU) were used in the calculation (Engel and Wyckoff 1991). A parent outflow velocity of 1km/sec was assumed in the calculation (Eberhardt *et al.* 1986, Lammerszahl *et al.* 1986, Larson *et al.* 1986, Scholerb *et al.* 1986) and the velocity imparted to daughter molecules resulting from the excess energy of photodissociation was assumed to be 1km/sec (Tegler *et al.* 1992).

In Figure 2, the calculated NH_2 surface brightness profile is shown (solid line). From Figure 2 the calculated and observed surface brightness profiles agree to within 10% out to a projected distance of $\log r = 4.8$ ($6 \times 10^4 \text{ km}$). The agreement between observed and calculated profiles is consistent with NH_3 being the parent molecule. Similar conclusions, that NH_3 is a parent molecule of NH_2 , have been noted by Tegler *et al.* (1992) and Fink and DiSanti (1991).

4. CONCLUSION

Our results indicate a relatively short photodissociation timescale for the parent molecule of NH_2 , in basic agreement with other determinations (Wyckoff *et al.* 1988, Fink and DiSanti 1991, Tegler *et al.* 1992). As can be seen from the model-observation comparison in Figure 2, the two-step decay process in equations (1) and (2) provide a good description of the NH_2 surface brightness profile. The agreement shown here, however, does not preclude other sources for NH_2 such as HCN polymers.

This research was supported by the Jesse Jones Foundation at the University of Notre Dame and the National Science Foundation.

5. REFERENCES

- Cochran, A.L., and Barker, E.S. (1986) Spectrophotometric Observations of Comet Halley, In Twentieth ESLAB Symposium on the Exploration of Halley's Comet Vol.1, (ESA SP-230), p. 439.
- Engel, L., and Wyckoff, S., 1991, Ap. J., in preparation.
- Festou, M.C. (1981a) The Density Distribution of Neutral Compounds in Cometary Atmospheres, Astr. Ap., **95**, 69.
- Festou, M.C. (1981b) The Density Distribution of Neutral Compounds in Cometary Atmospheres II, Astr. Ap., **96**, 52.
- Fink, U., and DiSanti, MA. (1991) P/Halley: Spatial Distributions and Scale Lengths for C_2 , CN, NH_2 and H_2O , Ap. J., in press.
- Lammerszahl, P. *et al.* (1987) Expansion Velocity and Temperatures of Gas and Ions Measured in the Coma of Comet Halley, Exploration of Halley's Comet, 169-173.
- Larson, H.P., Davis, D.S., Mumma, M.J., and Weaver, H.A. (1986) Kinematic Properties of the Neutral Gas Outflow from Comet P/Halley, Exploration of Halley's Comet, 391-397.
- Scholerb, P., Claussen, M. and Tacconi-Garman, L. (1986) OH Radio Observations of Comet P/Halley, Exploration of Halley's Comet, 469-474.
- Tegler, S. C. *et al.* (1992) NH_3 and NH_2 in the Coma of Comet Brorson-Metcalf Ap.J. **384** (in press)
- Wyckoff, S., Tegler, S., Wehinger, P., Spinrad, H., and Belton, M.J.S. (1988) Abundances in Comet Halley at the Time of the Spacecraft Encounters. Ap. J., **325**, 927.