Spectroscopic studies of the molecular parentage of radical species in cometary comae

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Abstract

We have observed several comets using an integral-field unit spectrograph (the George and Cynthia Mitchell Spectrograph) on the 2.7m Harlan J. Smith telescope at McDonald Observatory. Full-coma spectroscopic images were obtained for various radical species (C_2,C_3, CH, CN, NH_2). By constructing azimuthal average profiles from the full-coma spectroscopic images we can test Haser model parameters with our observations. The Haser model was used to determine production rates and possible parent lifetimes that would be consistent with the model. By iterating through a large range of possible parent lifetimes, we can see what range of values in which the Haser model is consistent with observations. Also, this type of analysis gives us perspective on how sensitive the model's fit quality is to changes in parent lifetimes. Here, we present the work completed to date, and we compare our results to other comet taxonomic surveys.

Observations

The data were obtained using an integral-field unit (IFU) spectrograph to conduct full-coma spectroscopic imaging. This instrument, the George and Cynthia Mitchell Spectrograph (née VIRUS-P)(Hill et al. 2008), is a high-efficiency, low- to moderate-resolution fiber-optic spectrograph designed for use on the 2.7 m Harlan J. Smith Telescope. As shown in Figure 1, the 1.7 arcmin x 1.7 arcmin array contains 246-247 optical fibers, each with a diameter of 4.1 arcsec. The observations were obtained with a grating covering the passband from 3600-5800Å with a resolving power of 850.

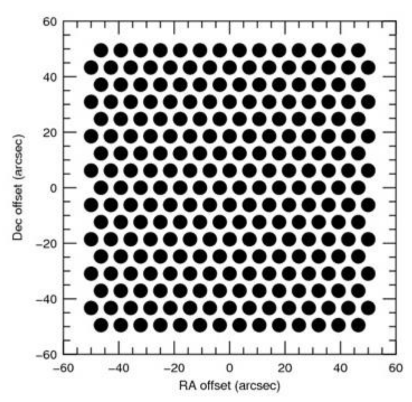


Fig. 1: The spatial distribution of fibers for the IFU spectrometer consisting of 246 fibers.

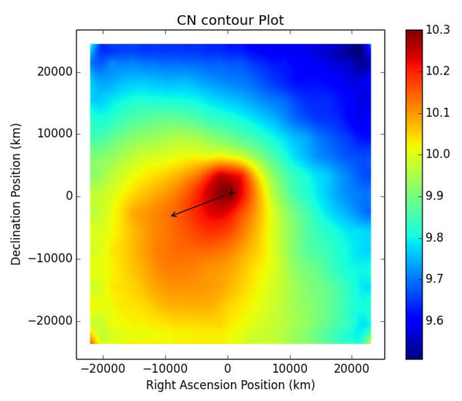


Fig. 2: Contour plot of the IFU data using 2D linear interpolation.

Observation Parameters:

Comet	Observation Date	R_H (AU)	Δ (AU)
10P/Tempel 2	2010 Jul 15	1.43	0.72
10P/ Tempel 2	2010 Sept 13	1.60	0.67

Azimuthal Average Profile

The azimuthal average profile is a set of points where each point is averaged with respect to position angle. The pixel corresponding to the lowest value of ρ is designated as the optocenter. Surrounding pixels are then chosen to form concentric rings about the optocenter, and the corresponding column densities for these surrounding pixels are averaged. Because of the hexagonal symmetry of the fiber optic array, each ring can correspond to 6 or 12 data points, where ρ is constant for all points within the set for a given ring.

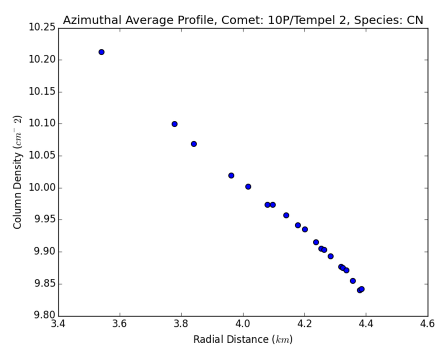


Fig. 3: Azimuthal average profile in $\log_{10}$ units.

Haser Model Analysis

Fixed Parameters:

- Outflow velocity of the radical species is in the radial direction. The same outflow velocity is used for both daughter and parent species. The outflow velocity normalized to 1AU used is $v(1\mathrm{AU}) = 0.85$ km s^{-1}.
- The heliocentric distances of the comet are given in the observations section.
- The scale length is scaled by a power law using the heliocentric distance ($R_H{}^n$). For this work, $n = 2.0$ was chosen for all species, except for C_2 where $n = 2.5$ was chosen (Cochran 2012).
- Daughter Lifetimes (normalized to 1AU) used are: (Cochran 2012, Delsemme 1982)

Species	Lifetime (s)
C_2	1.2e5
C_3	1.5e5
CH	4.8e3
CN	3.0e5
NH_2	6.2e4

Free Parameters:

Production Rate:

The production rate (Q_d) is the number of daughter molecules produced in the coma per second. For a given production rate and parent and daughter scale length, we compute the R^2 fit value between the radial profile produced by the Haser model and the Azimuthal Average Profile. By constructing an array of production rates and running the Haser model for each one, we can find the global maximum of the R^2 vs Q_d curve. This allows us to determine the production rate for a given set of parent and daughter scale lengths.

Parent Lifetime:

The purpose of this work is to determine the possible parent lifetime (L_p). We construct an array of L_p values, then run the Haser model for each value. For each L_p, we run through an array of Q_d values. Our result is an R^2 vs L_p curve which has a global maximum. The global maximum gives us the best fit L_p.

Best Fit Parent Lifetimes:

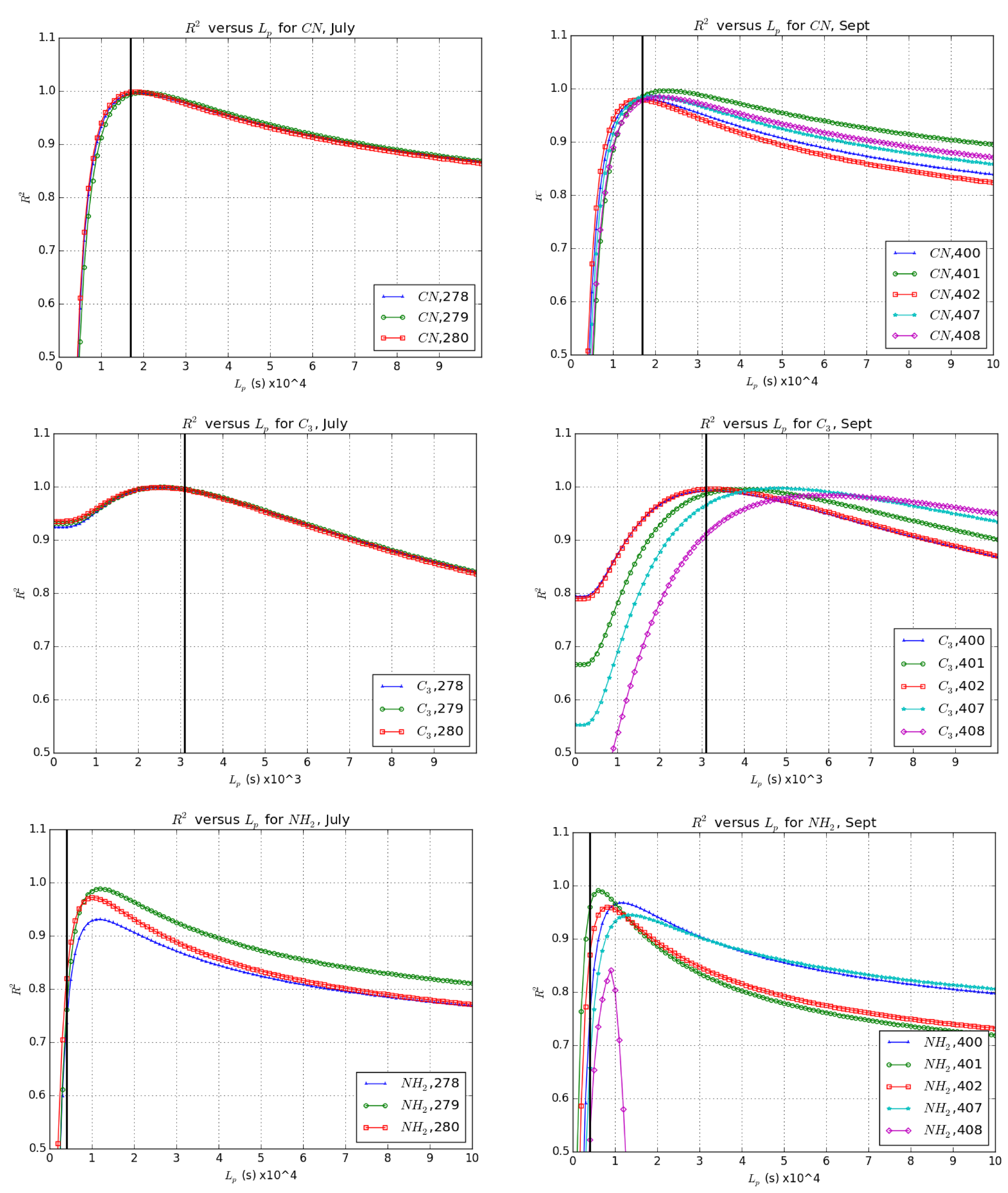
Observation	L_p (s)	σ (s)
CN Sept	1.9E+04	2.7E+03
CN July	1.9E+04	1.0E+03
CN Avg	1.9E+04	2.1E+03
C_3 Sept	4.4E+03	1.4E+03
C_3 July	2.5E+03	1.0E+02
C_3 Avg	3.7E+03	1.4E+03
NH_2 Sept	9.8E+03	3.2E+03
NH_2 July	1.1E+04	1.2E+03
NH_2 Avg	1.0E+04	2.6E+03

Results

R^2 vs Lifetime Curves:

In Figure 2, curves of R^2 vs L_p are given. All of the datasets from the same observation date and species are graphed in the same window for comparison purposes. The vertical line represents the lifetime for the particular species cited in Cochran 2012. The syntax (400,401,…,ect) label the observations. To see R^2 values on these R^2 vs L_p curves for cited L_p values see Table 1.

R^2 vs L_p:



Comparisons To Other Works

We compare our best fit parent lifetimes to previous works. We compare our results to other works be determining how many standard deviations away their results are from ours ($\Delta\sigma$). In Table 1, we catalog cited results from other works, and calculate $\Delta\sigma$ for the July 15, September 13, and overall.

Table of Parent Lifetime Comparisons:

			Standard Deviations ($\Delta\sigma$)				
Daughter Species	Parent Species	Parent Lifetime	July	Sept	all	R^2	Source
CN	None	2.0E+04	1.0	0.2	0.4	0.96	Cochran 1986
	None	3.5E+04	16.0	5.8	7.4	0.99	Festou et al. 1998
	None	2.4E+04	4.5	1.5	2.0	0.99	Feldman 2004
	None	1.3E+04	6.0	2.4	2.9	0.97	Randall et al. 1993
	HCN	9.1E+04	71.9	26.5	33.8	0.87	Jackson 1976
	HCN	7.7E+04	57.9	21.3	27.2	0.89	Huebner and Carpenter 1979
	HCN	7.7E+04	57.9	21.3	27.2	0.89	Huebner 1985
	HCN	7.7E+04	57.9	21.3	27.2	0.89	Huebner et al. 1992
	HCN	6.7E+04	47.7	17.5	22.4	0.90	Bockelee-Morvan and Crovisier 1985
	HCN	2.2E+06	2.20e3	8.15e2	1.04e3		Fray et al. 2005
	HC_3N	1.3E+04	6.0	2.4	3.0	0.97	Jackson 1976
	HC_3N	3.6E+04	16.7	6.0	7.8	0.96	Huebner and Carpenter 1979
	HC_3N	3.6E+04	16.7	6.0	7.8	0.96	Huebner 1985
	HC_3N	2.6E+04	6.6	2.3	3.0	0.98	Huebner et al. 1992
	HC_3N	2.9E+04	10.4	3.7	4.8	0.97	Krasnopolsky 1991
	HC_3N	1.5E+04	3.8	1.6	1.9	0.98	Crovisier 1994
	CH_3CN	1.5E+05	1.30e2	48.1	61.3		Bockelee-Morvan and Crovisier 1985
	C_2N_2	1.1E+04	8.0	3.1	3.9	0.94	Jackson 1976
	C_2N_2	3.2E+04	13.3	4.8	6.1	0.97	Bockelee-Morvan and Crovisier 1985
C_3	None	3.6E+03	11.4	0.5	0.0	0.98	Cochran 1986
	None	3.0E+03	4.9	1.0	0.5	0.98	Randall et al. 1992
	None	2.8E+03	2.9	1.1	0.6	0.98	Randall et al. 1993
	C_3H_2	7.7E+03	51.8	2.3	2.8	0.91	Helbert 2003
NH_2	None	4.8E+03	5.6	1.6	2.1	0.84	Cochran et al. 1992
	None	4.0E+03	6.4	1.8	2.4	0.76	Krasnopolsky and Tkachuk 1991 / Fink et al. 1991
	NH_3	2.1E+04	8.2	3.5	4.0	0.83	Jackson 1976
	NH_3	5.6E+03	5.0	1.3	1.8	0.89	Huebner and Carpenter 1979
	NH_3	5.6E+03	5.0	1.3	1.8	0.89	Huebner 1985
	NH_3	5.6E+03	5.0	1.3	1.8	0.89	Huebner et al. 1992
	NH_3	6.7E+03	4.0	1.0	1.4	0.92	Allen 1987
	NH_3	5.6E+03	5.0	1.3	1.8	0.89	Hatchell et al. 2005

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