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"Spectroscopy of Comet P/Encke in 1980-81"

Report No. 1

FINAL REPORT under JPL Contract BP-724869

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TECHNICAL CONTENT STATEMENT

"This report contains information prepared by The University of California under JPL sub-contract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Insitute of Technology, or the National Aeronautics and Space Administration."

ABSTRACT

Digital spectroscopic scans of P/Comets Encke, Stephan-Oterma, and Gunn were obtained with a sky-subtraction scanner system at Lick Observatory in 1980-81.

Quantitative fluxes for the cometary emission bands of CN, C_3, C_2, NH_2, and the 'D [OI] red auroral line are presented for P/Encke. The Stephan-Oterma data is not yet all reduced. P/Gunn at r ~ 4 A.U. showed only a faint (V ~ 18) continuum without gaseous emission.

The most straight-forward and model-independent line flux to interpret is the λλ6300, 6364 forbidden oxygen doublet. After an NH_2 blending correction, the oxygen production rate may be directly measured from the Lick small-aperture fluxes, as very little of the ^1D emission overfilled the nuclear-centered apertures.

The oxygen production rates increased rapidly with decreasing heliocentric distance for both P/Encke and P/Stephan-Oterma. A rough power-law exponent in r with $n \cong -2.5$ describes the change in oxygen production for P/Encke.

Compared to the water production rates inferred from IUE satellite spectra showing the λ3080 OH band, our oxygen production rates are <u>consistently</u> lower by a factor of 11. This implies a common origin for the two species; H_2O is the likely sole [OI] ^1D parent.

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INTRODUCTION

This contract was initiated to support research costs for telescopic observing of faint comets (particularly P/Encke) with the digital image-tubes [Wampler scanner] at the Lick Observatory. This equipment, described by Robinson and Wampler (1972) produces linearized, sky-subtracted fluxes of faint objects over the optical spectrum to which the S-25 front-end photocathode has sensitivity.

The prime objective of this work was to detect Comet Encke far from the sun, and to follow the onset and progress of its gaseous emission activity as a function of heliocentric distance. The pre-perihelion apparition in the autumn of 1980 was a favorable time to begin this research, and the following Cometary Observing Log lists the dates of the relevant scanner observations and derived V magnitudes. An illustration (Figure 1) of the spectrum of P/Encke is also attached; at the epoch of the data shown ($r = 0.83$ A.U.) P/Encke was relatively bright and showed strong gaseous emission bands superposed upon a weak solar reflected-light continuum.

Later reductions of the scanner spectra provided many line and band fluxes; the data rate for moderately bright comets is very large, so that the complete interpretation of all the quantitative cometary spectroscopy has lagged well behind the observations. Only a few conclusions are now firm, and these will be briefly discussed in this report.

COMETARY OBSERVING LOG - LICK SCANNER SPECTRA

(a) P/Encke

Telescope	Date (V.T.)	Regions Scanned	V	Notes
1-m	Oct. 16, 1980	YR	-	8" ap. r = 1.14 A.U.
1-m	Nov. 3, 1980	YR	-	8" ap. r = 0.85 A.U.
3-m	Aug. 21, 1980	Bl, YR	19.1	$\bar{r}$ = 1.90 A.U.
3-m	Aug. 22, 1980	Bl		4" ap.
3-m	Sept. 6, 1980	Bl, YR	18.4	$\bar{r}$ = 1.69 A.U.
3-m	Sept. 7, 1980	Bl, YR		4" ap.
3-m	Oct. 10, 1980	Bl, YR	-	Miller observer at low dispers. r = 1.23 A.U.
	Nov. 4, 1980	Bl, YR, IR		
3-m	Nov. 5, 1980	YR	15.1	$\bar{r}$ = 0.83 A.U.
	Nov. 6, 1980	UV		4" ap.

(b) P/Stephan-Oterma

Telescope	Date (V.T.)	Regions Scanned	V	Notes
1-m	Oct. 16, 1980	Bl, YR	-	8" ap. r = 1.70 A.U.
1-m	Nov. 3, 1980	YR	-	8" ap. r = 1.62 A.U.
3-m	Aug. 21, 1980	Bl	16.2	4" ap.
3-m	Aug. 22, 1980	Bl, YR, IR		r = 2.054 A.U.
3-m	Sept. 6, 1980	YR	-	4" ap. r = 1.93 A.U.
3-m	Nov. 6, 1980	UV	-	4" ap. r = 1.62 A.U.
3-m	Dec. 8, 1980	YR	13.0	4" ap. & 8" ap. r = 1.57 A.U.
3-m	Feb. 1, 1981	Bl, YR	-	4" ap. r = 1.70 A.U.
3-m	Mar. 6, 1981	Bl, YR	-	4" ap. r = 2.17 A.U.

(c) P/Gunn

Telescope	Date (V.T.)	Regions Scanned	V	Notes
3-m	Feb. 1, 1981	Bl, YR	> 18	4" ap. r = 4.04 A.U.
3-m	Apr. 4, 1981	Bl, YR	~ 18	4" ap. r = 3.89 A.U.

TECHNICAL DISCUSSION AND COMET ENCKE FLUXES

The measurements presented in the attached flux-table were derived by integration over the cometary emission bands and linearly subtracting out the surrounding continuum. Some effort was made in defining the continuum positions to be free of (weaker) cometary emission features. The tabulated fluxes are thought to be photometrically precise to about 10-20%. However, they have not yet been corrected for the variations in the underlying solar continuum, which especially modulates the CN(0,0) band flux in comets with considerable dust-continuum (like P/Stephan-Oterma).

As P/Encke approached the sun, its gaseous emission features rapidly increased in strength. The fluxes of the [OI] ^1D lines increased with about the -2.5 power of the comet's solar distance. The molecular bands increased at about the same pace, but their interpretation is more model-dependent than that of the ^1D oxygen lines, so are not discussed here. The Lick scanner data was obtained with entrance apertures much smaller than the cometary CN and C_2 scale-lengths.

P/Stephan-Oterma showed moderately strong bands, even at $r = 2.05$ A.U., above a strong reflected solar dust-continuum. The data for this comet are still partly in the reduction stage, but we can already see that this comet had a spectroscopic activity level that increased very rapidly (as did its visual light) with decreasing heliocentric distance ($n \approx -6$).

P/Gunn was distant and faint ($V \sim 18$) when the scans were obtained. It did not show any CN, C_2, or [OI] emission on the observation dates in early 1981, and this was perhaps to be expected, as $\overline{r} = 3.96$. Still, the Lick program has continued to attempt quantitative spectroscopy of (faint) comets at $r > 3$ A.U., with the hope of detecting species more volatile than water.

COMETARY FLUX INTEGRATIONS FOR P/ENCKE

Date (1980)	Telescope	m_ν(blue cont.) m_ν[red cont.]	Line and Band Fluxes (cgs) CN	 C_3	 C_2*	 NH_2	 [OI]
August 21.5	120"	(19.75) [18.98]	5.5 (-15)	2.1 (-15)	1.0 (-15)	3.3 (-16)	7.8 (-16)
Sept. 6	120"	(18.78)	1.4 (-14)	6.3 (-15)	1.9 (-15)		
Sept. 6.5	120"	(19.08) [18.08]	1.5 (-14)	7.7 (-15)	3.6 (-15)	1.1 (-17)	1.9 (-15)
Oct. 16.5	40"	(17.90)	3.2 (-13)	1.4 (-13)	1.4 (-13)		
Oct. 16.5	40"	[16.69]				2.8 (-14)	2.3 (-14)
Nov. 4.5	120"	(16.32)	1.8 (-12)	7.8 (-13)	8.9 (-13)		
Nov. 4.5	120"	[16.53]				4.3 (-14)	8.2 (-14)
Nov. 6.5	120"	(15.76)	6.0 (-12)	2.6 (-12)	2.7 (-12)		
Nov. 5 (Ave. 5)	120"	(16.35) [16.33]	2.0 (-12)	1.0 (-12)	7.5 (-13)	5.9 (-14)	1.1 (-13)

*C_2: λλ4600-4740 Å in the C_2 (1,0) band.

CONCLUSIONS AND RECOMMENDATIONS

The oxygen ^1D fluxes were corrected for NH_2 line contamination with the help of an adjacent pure NH_2 blend; then the cometary oxygen production rates were determined [this is simple, as the ^1D state decays quickly to the ground level of the oxygen atom with an emission of the λ6300 line in 196^s (Kernahan and Pang 1975; Wiese et al. 1969)]. The ^1D lines are very concentrated to cometary nuclei; there seems to be little "spill-over" outside our small entrance diaphrams in most cases.

The P/Encke oxygen production rates ranged from 2.4×10^{26} atoms s^{-1} at $r = 1.89$ A.U. (Aug. 21.5, 1980) to about 1.7×10^{27} atoms s^{-1} at $r = 0.83$ (Nov. 4, 1980).

I have compared the forbidden oxygen production rates of P/Encke and several other recently observed P/comets, with the appropriate-time water production rates determined by Weaver et al. (1981). These come from the IUE satellite observations of the λ3080 OH band.

Impressively, the ratio of water/oxygen production averages a consistent 11 ± 4 for all the P/comets; it is also about 11 for the two P/Encke observation dates (at $r = 0.8$ and 1.0 A.U.). The constancy of this water/oxygen ratio and its relative proximity to the theoretical predicted H_2O-dissociation branching value of about 7 implies a common oxygen origin in the water molecule as a likely single parent for these relatively "worn" comets. No extra source of oxygen, like CO or CO_2 is needed for this cometary sample. A similar test on a bright new comet is an obviously desired future comparison, and it is hoped that more coordinated ground-based and satellite spectrophotometry will be possible then.

NEW TECHNOLOGY

This work was carried out using equipment and techniques developed at the University of California (Berkeley and Santa Cruz campuses) under other grants, particularly those from the NSF (galactic Astronomy). No new technology is attributable to the funds provided by this contract.

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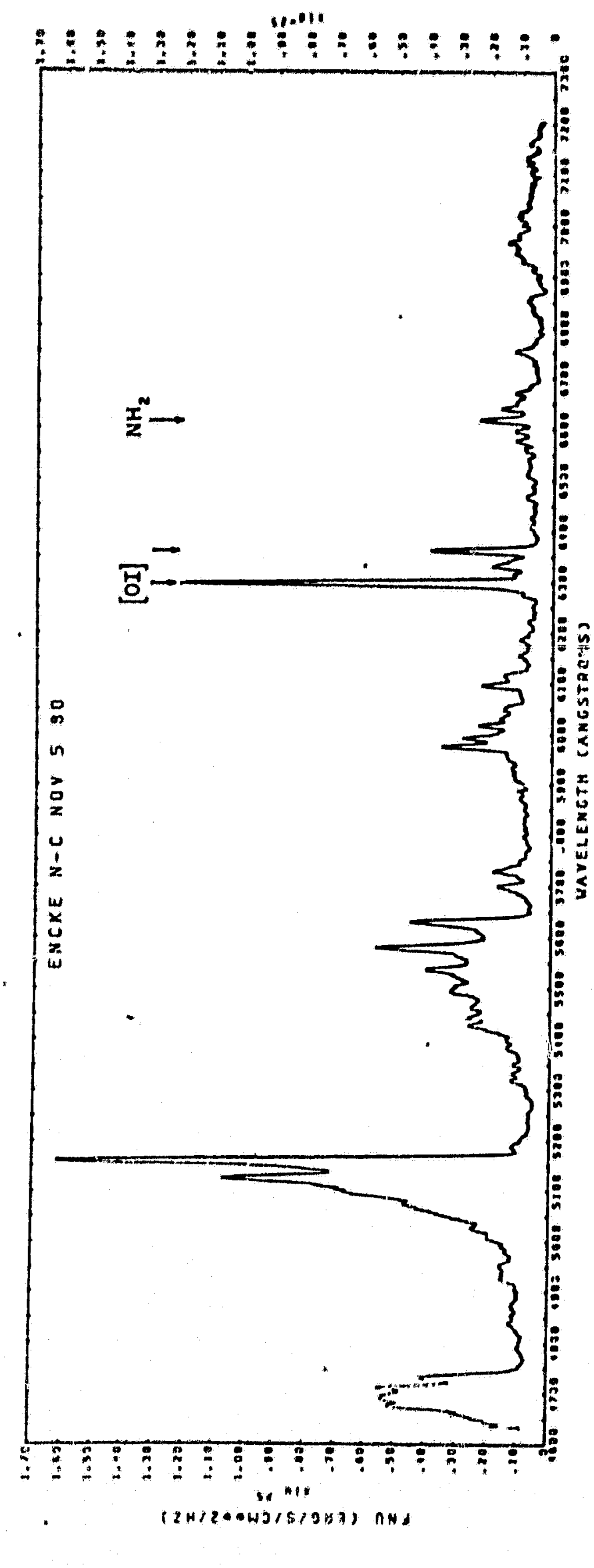
FIGURE CAPTION

Fig. 1. A sample green-red Lick IDS spectrum of P/Encke in early November 1980. The strong bands of C_2, the weaker NH_2 bands, and the strong ^1D around oxygen lines at λλ6300, 6364 are evident. The ordinate is flux per unit frequency (cgs).



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