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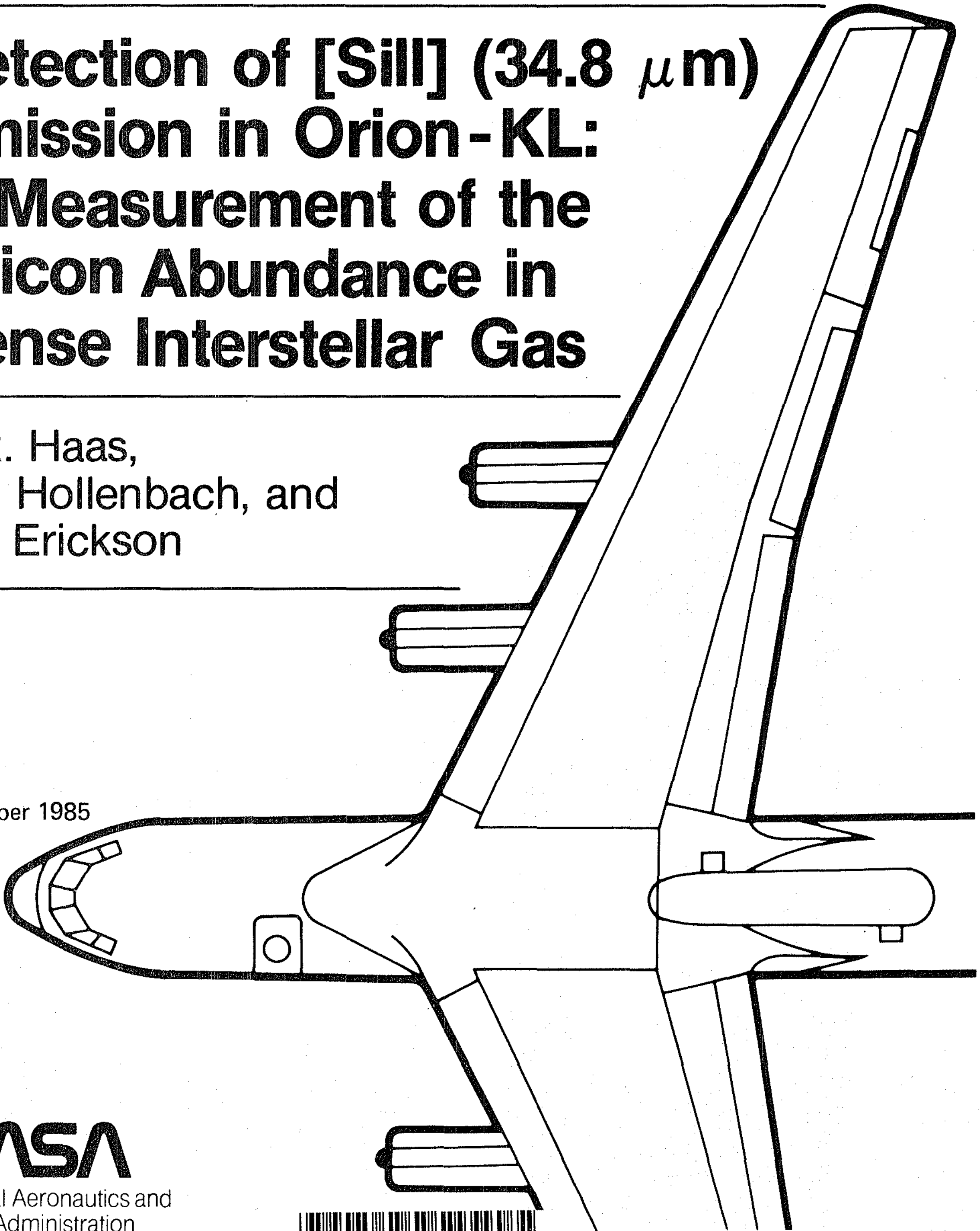

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Detection of [SiII] (34.8 μm) Emission in Orion-KL: A Measurement of the Silicon Abundance in Dense Interstellar Gas

M. R. Haas, Mycol, Inc., Sunnyvale, California
D. J. Hollenbach,
E. F. Erickson, Ames Research Center, Moffett Field, California

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Ames Research Center
Moffett Field, California 94035

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ABSTRACT

We report the first detection of the ground state fine structure transition of Si^+ at a rest wavelength determined to be $34.815 \pm 0.004 \mu m$. These observations were obtained with the facility spectrometer on NASA's Kuiper Airborne Observatory. A 6' NW-SE strip scan across the Orion-KL region shows [SiII] emission from both the extended photodissociation region surrounding Θ^1Ori C and from the shocked gas NW of BN-KL. The inferred gas-phase silicon elemental abundance relative to hydrogen in the dense ($\sim 10^5$ cm^{-3}) primarily neutral photodissociation region is approximately 2.6×10^{-6}, a factor of 0.075 times the solar value and 3.4 times greater than the abundance in the moderate density ($\lesssim 10^3$ cm^{-3}) cloud toward ζ Oph. The silicon abundance in the shocked gas is approximately solar, indicating that any pre-existing grains have been destroyed in the shock wave or that the preshock gas carries a near solar abundance of gas phase silicon. The shock-excited [SiII](34.8μm) emission may arise from shocked wind material in the outflow around IRc2, with wind velocities $\gtrsim 100$ km/s.

I. INTRODUCTION

The gas-phase elemental silicon abundance in different phases of the interstellar medium is important for understanding interstellar chemistry and the formation and destruction of interstellar dust. Ultraviolet observations of gas-phase silicon depletions in diffuse clouds coupled with infrared observations of solid-state silicate absorption features suggest that a large fraction ($\gtrsim 90\%$) of the silicon may reside in refractory silicate material in the interstellar medium (cf. Savage and Mathis 1979). However, theoretical models of the destruction of interstellar silicate grains by supernova-driven shock waves indicate that interstellar silicate grains may be destroyed faster than they can be reinjected by red giant winds and/or supernovae ejecta (Draine and Salpeter 1979; Dwek and Scalo 1980; Seab and Shull 1985). Consequently, in the absence of any other grain formation process, silicon would be expected to suffer little depletion in the diffuse interstellar medium. The apparent discrepancy between the observed depletion and the theoretical expectations could be resolved if, for example, silicon accreted onto grains in the denser phases of the interstellar medium (preferably in the form of silicates to produce the 9.7 μm feature) or if the previous theoretical models of shock destruction of silicate grains seriously overestimate the efficiency of the process. These possibilities can be constrained by estimates of the silicon depletion in the dense neutral gas which produces strong [SiII](34.8μm) emission.

Silicon lies below carbon in the periodic table and has a similar electronic structure. The [SiII](34.8μm) line is a $^2P_{3/2} \rightarrow {}^2P_{1/2}$ ground state magnetic dipole transition analogous to the [CII](157.7μm) transition first detected by Russell et al. (1980). These two lines, as well as the [OI](63μm) line, are the dominant coolants in $T \lesssim 5000$ K atomic interstellar gas which includes FUV-ionized ($h\nu < 13.6$ eV) metals (e.g., carbon and silicon) in the singly ionized state (cf Dalgarno and McCray 1972). In such a gas, with relative electron abundances $\lesssim 10^{-3}$, atomic hydrogen collisions dominate the excitation of these lines. Various line parameters are given in Table 1; the range in excitation energy and critical density illustrate that these lines probe the density, temperature, and elemental abundance of the gas. High temperatures ($T \gtrsim$ 100 K) and densities ($\gtrsim 10^4$ cm^{-3}) are prerequisites for [OI] and [SiII] to dominate the cooling. Such high pressures are found, for example, in the

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photodissociation regions (PDRs) bordering HII regions (Tielens and Hollenbach 1985a,b) and behind high velocity ($v_s \gtrsim 50$ km/s) shock waves which heat, compress, dissociate, and ionize the preshock gas (cf McKee, Chernoff, and Hollenbach 1984).

Previous observations of Orion-KL have demonstrated the presence of a PDR producing [OI](63, 145μm), [CII](157.7μm), [CI](370, 610μm), and low-J transitions of CO (references in Tielens and Hollenbach 1985b). Just north of BN-KL is a region of shocked gas which was first detected by its 2μm H_2 emission (Gautier et al. 1976) and has now been seen in a variety of other species including high-J rotational transitions of CO (Goldsmith et al. 1981; Storey et al. 1981, Watson 1982), rotational transitions of OH (Storey, Watson, and Townes 1981; Viscuso et al. 1985), and the ground state fine structure transition of [OI](63μm) (Werner et al. 1984). Here we report the first detection of the [SiII](34.8μm) line in a series of observations spanning Orion-KL and interpret the emission as arising in both the PDR and in the shocked gas.

II. THE OBSERVATIONS

The observations were carried out with the 91 cm telescope of the Kuiper Airborne Observatory on February 14, 1985 using the facility cooled grating spectrometer (CGS) described by Erickson et al. (1984, 1985). The beam had a FWHM of 46.5" with an effective area corresponding to a 48.3" diameter disc. The chopper throw was ~4' in azimuth (approximately E-W). The resolution was 114 km/s. The total bandpass of the six Ge:Ga photoconductor detectors was ~ 3.3 resolution elements, sufficient to include both the line and the adjacent continuum using a single grating position. Sequences of four 10 s integrations were taken with the source placed alternately in right and left beam. The [SiII](34.8μm) line was observed at 8 spatial positions in the Orion region which lie in a NW-SE line through KL and the Trapezium. In Fig. 1 we show these positions superimposed on the 5 GHz radio continuum map of Martin and Gull (1976), which shows the physical extent of the ionized gas. Absolute positions were determined to ±5" by offsetting from Θ^1Ori C or Θ^2Ori A. The infrared boresight established on the ground was verified in flight to ±5", assuming that the 63.07μm continuum peaks at KL (R.A.(1950)=$5^h32^m46.7^s$, δ(1950)=$-5°24'27"$) (Werner 1982).

The absolute flux calibration and the relative detector response were determined from observations of KL in the continuum adjacent to the line. The calibrations done at the beginning and end of the observing leg agreed to ±4%. This spectral region has no telluric absorption features >2% and the instrument response function is flat to 10%. Hence the final reduced spectra are simply the signals obtained at the map positions divided by the signals obtained on the KL continuum and multiplied by the flux from KL as measured by Erickson et al. (1981) in a similar sized beam (50"). The effects of diffraction in the telescope were estimated to be $\lesssim$3% and were ignored. The overall uncertainty in the absolute calibration is probably less than ±25%.

The spectra obtained at the ionization bar (P3), the Trapezium (P5), and NW of KL (P6) are shown in Fig. 2. Since this was the first observation of the [SiII](34.8μm) line, we used two grating positions to confirm it at the first spatial position observed (P3). The solid curves in Fig. 2 are fits to the data using a flat continuum and the width, intensity, and wavelength of a superimposed gaussian line profile. The wavelength of the [SiII] transition is given as

$34.804\mu m$ by Morton and Smith (1973) and as $34.814\mu m$ by Moorwood et al. (1978). We determine a rest wavelength of $34.815 \pm 0.004\mu m$. The line widths are consistent with the nominal instrumental resolution except at P3 (ionization bar), where the FWHM is 88±3 km/s, less than the expected value of 114 km/s. Because the source is imaged on the individual field mirrors in the CGS (Erickson et al. 1985), a possible explanation is that the bulk of the [SiII] line intensity at P3 originates in an area significantly smaller than the beam. The apparent continuum at P6 has a definite slope not seen elsewhere. This spectrum was fitted using the slope of the continuum as a fifth free parameter. The FWHM and the wavelength of the fitted line profile are consistent with those found at the other positions. The line intensities are plotted versus position in Fig. 3.

III. INTERPRETATION AND DISCUSSION

Here we present some simple calculations which constrain the physical conditions in the [SiII]($34.8\mu m$) emitting region and then compare the observed intensities with the results of more detailed calculations to estimate the Si^+ abundance.

A. The Photodissociation Region (PDR)

Observational evidence and theoretical considerations indicate that, with the exception of the localized (~1') emission north of BN-KL, all of the extended [SiII]($34.8\mu m$) emission arises from the PDR in Orion, and not from the molecular cloud as a whole or from shocked gas. Observationally, the [SiII] emission spatially correlates with the extended [OI](63, $145\mu m$) and [CII]($158\mu m$) emission (Ellis and Werner 1985), which have already been successfully modelled as arising in the PDR (Tielens and Hollenbach 1985b). Theoretically, one would not expect Si^+

to exist in the dark molecular interior of OMC-1, which is shielded from the photons which ionize Si. Alternatively, the silicon is predominantly in higher ionization states in the HII region surrounding Θ^1C Ori (Rubin, private communication). In PDRs, however, nearly all of the gas phase silicon is expected to be in the form of Si^+.

Face-on PDRs such as Orion are expected to have insufficient column densities to produce optically thick [SiII] transitions. If all the PDR gas-phase silicon lies in the ground state of Si^+, the maximum line-center optical depth of [SiII] is $\tau_{max} \approx N_{22}\delta/\Delta v$, where Δv is the line-of-sight velocity dispersion in units of km/s, δ is the gas phase silicon abundance relative to its solar abundance $x_\odot$ (Table 1), and N_{22} is the hydrogen column density in units of 10^{22} cm^{-2} (Hollenbach and McKee 1979). The grain attenuation of ultraviolet photons limits the extent of the warm gas in PDRs to $A_V \lesssim 3$ or $N_{22} \lesssim 0.6$, δ is probably $\lesssim 0.1$ (the value in diffuse gas), and velocity dispersions in PDRs are typically $\Delta v \sim$ 1-5 (Tielens and Hollenbach 1985a,b), so that $\tau_{max} \lesssim 0.06$.

Fig. 4 plots the intensity I of the [SiII](34.8μm) transition as a function of the column density $N(Si^+)$ for various values of the hydrogen density n_0 and temperature T, assuming $\Delta v = 2$. The linear dependence of I on $N(Si^+)$ for values $\lesssim 3\times10^{17}$ cm^{-2} marks the optically thin regime. Using Fig. 4 and assuming $N_{22} \lesssim 1$, the observed value of $I = 6.1\times10^{-3}$ erg cm^{-2} s^{-1} sr^{-1} at the Trapezium immediately shows that $n_0 \gtrsim 10^4$ cm^{-3}, $T \gtrsim 100$K, and $\delta \gtrsim 0.03$.

Tielens and Hollenbach (1985b) have constructed a detailed model of the PDR behind the Trapezium, tailored to fit the observed far-infrared continuum and the [OI](63μm, 145μm), [CII](158μm), and [CI](609μm) integrated line intensities. Assuming $\delta = 0.022$ (the depletion determined from UV absorption measurements of the heavily depleted cloud toward ζ Oph; Morton 1974), they predicted an intensity of 1.8×10^{-3} ergs cm^{-2} s^{-1} sr^{-1} for the [SiII](34.8μm) line towards the Trapezium. This value is a factor of 3.4 smaller than we observe. The intensity of the [SiII] line scales with δ in their model, so our observation implies δ = 0.075 or a silicon abundance of 2.6×10^{-6}. These models are characterized by densities $n_0\sim10^5$ cm^{-3}, temperatures T~500K, and column densities of warm hydrogen N_{22} = 0.5 consistent with Fig. 4.

The [SiII] intensity is sensitive to the collisional rates which are uncertain by ±50% (cf Launay and Roueff 1977b with Dalgarno and McCray 1972). The Orion models of Tielens and Hollenbach (1985b) produce adequate fits (factor of 2) to the observations with peak PDR temperatures ranging from 250 K to 1000 K and $n_0\sim1-3\times10^5$ cm^{-3}. Including the absolute calibration uncertainty, we estimate that the silicon abundance is determined to within a factor of 2-3 and conclude that silicon is certainly no more depleted and probably somewhat less depleted in the denser ($n_0\sim10^5$ cm^{-3}) Orion than in the less dense ($n_0\lesssim10^3$ cm^{-3}) ζ Oph. This is the first determination of silicon depletion in the outer layers of a dense molecular cloud. The trend toward increasing silicon depletion with increasing cloud density seen in diffuse clouds by UV absorption measurements (Snow and Joseph 1985) does not seem to extend into this dense PDR.

B. The Shocked Region

The emission peak north of BN could be produced by density or temperature fluctuations in the PDR gas. However, the spatial coincidence of this [SiII] peak with the peaks in the shock emission from H_2, CO, [OI], and OH is strong evidence that the enhanced [SiII] emission arises from shocked gas. The coincidence with the [OI] shocked gas (Werner et al. 1984) is especially convincing, since the [OI] emission demonstrates the presence of a significant component of shocked atomic gas of similar excitation. Comparing the intensity at position P6 with that at the other map positions in Fig. 3, we estimate that the shock-produced emission is $\sim 4\text{-}7\times10^{-3}$ ergs cm^{-2} s^{-1} sr^{-1}.

Hollenbach (1982) and Chernoff et al. (1982) model the shocked gas in BN-KL as consisting of two components: a shocked outflow or wind with shock velocities $v_s \sim 100$ km/s sufficient to dissociate and ionize the preshock gas and create a "J" shock, and a molecular "magnetic" or "C" shock caused by previously shocked supersonic gas sweeping up ambient molecular gas (see Draine 1980 or McKee et al. 1984). Hollenbach (1985) shows how the [OI](63μm) luminosity from the wind shock might be used to measure the mass loss rate from the protostar, and Werner et al. (1984) model the [OI] shock emission in BN-KL as a wind shock, obtaining $\dot{M}$ $\sim 3\times10^{-3}$ $M_\odot$/yr. They argue that the [OI] emission is too intense to be explained by the molecular shock, which has been invoked by Draine and Roberge (1982) and Chernoff, Hollenbach, and McKee (1982) to model the H_2, CO, and OH emission. However, the C shock model of Draine and Roberge comes within a factor of a few of matching the observed [OI] intensity if a large fraction of the oxygen is assumed to be in the atomic form in the preshock molecular gas. Thus, the analysis of the [OI](63μm) emission does not conclusively establish the existence of a wind J shock.

The observation of shocked [SiII] provides additional evidence that the [OI] and [SiII] emission arises from a wind J shock and not the molecular C shock. In the C shock, the hydrogen is mostly molecular and any pre-existing Si^+ is quickly converted to SiH^+ and $SiH_2{}^+$ by reactions of "hot" Si^+ and SiH^+ ions with H_2. On the other hand, the $v_s \sim 100$ km/s J shock provides a natural explanation for the

[SiII] emission. This shock dissociates and ionizes any pre-existing molecular gas phase silicon (cf Shull and McKee 1979). In addition, the shock sputters solid phase silicon from grains into the gas (cf Draine and Salpeter 1979, Seab and Shull 1983). The silicon is ionized to Si^{++} and Si^{+++} in the hot ($T \sim 10^5$ K) post shock gas, but as the gas cools to $T \lesssim 10^4$ K downstream from the shock front, the Si^{+++} and Si^{++} recombine to Si^+. The recombination of Si^+ is offset by the photoionization caused by the FUV photons from the hot postshock gas. The hydrogen column density of warm ($T \gtrsim 100$ K) FUV-ionized gas can be as high as 10^{21} cm^{-2} if the preshock density is $n_{ps} \gtrsim 10^5$ cm^{-3} (see Hollenbach 1980). Thus, if nearly solar abundances of Si^+ are assumed and $n_{ps} > 10^5$ cm^{-3}, a column $N(Si^+) \approx 3\times10^{16}$ cm^{-2} can be obtained in the J shock model, consistent with the observational results (cf Fig. 4).

These qualitative conclusions are demonstrated in a more quantitative fashion by the detailed results of numerical J shock calculations (McKee, Chernoff, and Hollenbach 1984). These results include the destruction of preshock silicate grains and predict [SiII](34.8μm) intensities of 2.4×10^{-4} ergs cm^{-2} s^{-1} sr^{-1} for $n_{ps} = 10^4$ cm^{-3} and $v_s = 100$ km/s, and 7.6×10^{-3} ergs cm^{-2} s^{-1} sr^{-1} for $n_{ps} = 10^6$ cm^{-3} and $v_s = 100$ km/s. Chernoff et al. (1982) estimated $n_{ps} \sim 10^5$ cm^{-3} in the wind shock around IRc2; therefore the wind shock model naturally provides an explanation for the silicon emission from the shocked gas. The observed intensity of shocked [SiII](34.8μm) is sufficiently high to suggest that either preshock silicate grains have been destroyed in the wind shock or that the preshock wind carries a near solar abundance of gas phase silicon.

In conclusion, the [SiII](34.8μm) line is a valuable diagnostic of the physical conditions in shocked atomic gas and the grain destruction processes which may occur therein. It is also an important new probe of the gas phase silicon depletion in dense ($\sim 10^5$ cm^{-3}) interstellar clouds which cannot be observed with conventional UV techniques.

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References*

Allen, C. W. 1973, Astrophysical Quantities (London: Athlone).

Chernoff, D. F., Hollenbach, D. J., and McKee, C. M. 1982, Ap. J., 259, L97.

Dalgarno, A., and McCray, R. A. 1972, Ann. Rev. Astr. Ap., 10, 375.

Draine, B. T. 1980, Ap. J., 241, 1021.

Draine, B. T., and Salpeter, E. E. 1979, Ap. J., 231, 438.

Draine, B. T., and Roberge, W. G. 1982, Ap. J., 259, L91.

Dwek, E., and Scalo, J. M. 1980, Ap. J., 239, 193.

Ellis, H. B., and Werner, M. W. 1985, in preparation.

Erickson, E. F., Knacke, R. F., Tokunaga, A. T., and Haas, M. R. 1981, Ap. J., 245, 148.

Erickson, E. F., Houck, J. R., Harwit, M. O., Rank, D. M., Haas, M. R., Hollenbach, D. J., Simpson, J. A., Augason, G. C., and McKibbin, D. D. 1984, Airborne Astronomy Symposium, NASA Conference Publication 2353 (Ed. Thronson, H. A., and Erickson, E. F.), p. 313.

Erickson, E. F., Matthews, S., Augason, G. C., Houck, J. R., Rank, D. M., and Haas, M. R. 1985, Proceedings of the Society of Photo-Optical Instrumentation Engineers, 509, 129.

Gautier, T. N., Fink, U., Treffers, R. R., and Larson, H. P. 1976, Ap. J., 207, L129.

Goldsmith, P. F., Erickson, N. R., Fetterman, H. R., Clifton, B. J., Peck, D. D., Tannenwald, P. E., Koepf, G. A., Buhl, D., and McAvoy, N. 1981, Ap. J., 243, L79.

Hollenbach, D. J., and McKee, C. F. 1979, Ap. J. Suppl., 41, 555.

Hollenbach, D. J. 1980, in Interstellar Molecules, Ed. B. H. Andrews (Dordrecht: Reidel), 445.

Hollenbach, D. J. 1982, Annals of N. Y. Acad. Sci., 395, 242.

Hollenbach, D. J. 1985, Icarus, 61, 36.

Launay, J.-M., and Roueff, E. 1977a, Astron. Astrophys., 56, 289.

Launay, J.-M., and Roueff, E. 1977b, J. Phys. B., 10, 879.

Martin, A. H. M., and Gull, S. F. 1976, M. N. R. A. S., 175, 235.

*Format differs from standard NASA publication. If you have questions about a particular reference, please question the author(s) or the NASA contact point listed on the standard bibliography page.

McKee, C. F., Chernoff, D. F., and Hollenbach, D. J. 1984, Galactic and Extragalactic Infrared Spectroscopy, (Proceedings of the XVIth ESLAB Symposium, held in Toledo, Spain, December 6-8, 1982), Reidel Publishing Company (Ed. Kessler, M. F., and Phillips, J. P.), p. 103.

Moorwood, A. F. M., Baluteau, J.-P., Anderegg, M., Coron, N., and Baraud, Y. 1978, Ap. J., 224, 101.

Morton, D. C. 1974, Ap. J., 143, L35.

Morton, D. C., and Smith, W. H. 1973, Ap. J. Supp., 26, 333.

Russell, R. W., Melnick, G., Gull, G. E., and Harwit, M. O. 1980, Ap. J., 250, L35.

Savage, B. D., and Mathis, J. S. 1979, Ann. Rev. Astron. Astrophys., 17, 73.

Seab, C. G., and Shull, J. M. 1983, Ap. J., 275, 652.

Seab, C. G., and Shull, J. M. 1985, Proceedings of the NASA Workshop on the Inter-relationships Among Circumstellar, Interstellar, and Interplanetary Dust Grains, NASA CP, in press.

Shull, J. M., and McKee, C. F. 1979, Ap. J., 227, 131.

Snow, T. P., and Joseph, C. L. 1985, Ap. J., 288, 277.

Storey, J. W. V., Watson, D. M., Townes, C. H., Haller, E. E., and Hansen, W. L. 1981, Ap. J., 247, L136.

Storey, J. W. V., Watson, D. M., and Townes, C. H. 1981, Ap. J., 244, L27.

Tielens, A. G. G. M., and Hollenbach, D. J. 1985a, Ap. J., 291, 722.

Tielens, A. G. G. M., and Hollenbach, D. J. 1985b, Ap. J., 291, 747.

Viscuso, P. J., Stacey, G. J., Harwit, M., Haas, M. R., Erickson, E. F., and Duffy, P. B. 1985, Ap. J., in press.

Watson, D. M. 1982, Ph. D. Thesis, University of California, Berkeley.

Werner, M. W. 1982, Symposium on the Orion Nebula to Honor Henry Draper, Annals of the New York Academy of Sciences, (Ed. Glassgold, A. E., Huggins, P. J., and Schucking, E. L.), Vol. 395, 79.

Werner, M. W., Crawford, M. K., Genzel, R., and Hollenbach, D. J. 1984, Ap. J., 282, L81.

Table 1.

Strong Cooling Lines in Warm Atomic Gas

Species	λ (μm)	$h\nu/k$ (°K)	I.P.[a] (eV)	$x_{\odot}$[b]	$N_H(\tau=1)$[c] (cm^{-2})	n_{cr}[d] (cm^{-3})
CII	158	92	11.3	3.7(-4)	1.2(21)	2.8(3)
OI	63	228	13.6	6.7(-4)	1.0(21)	4.7(5)
SiII	35	413	8.2	3.5(-5)	4.6(23)	3.4(5)

[a]Ionization potential of the neutral species. [b]Solar abundances relative to hydrogen (Allen 1973). [c]Column density of hydrogen required for optical depth unity at line center, assuming a line-of-sight velocity dispersion of Δv = 1 km/s and a solar abundance of the species in its ground state. [d]Critical atomic hydrogen density; collisional rates for CII from Launay and Roueff (1977b), for OII from Launay and Roueff (1977a), and for SiII from Dalgarno and McCray (1972).

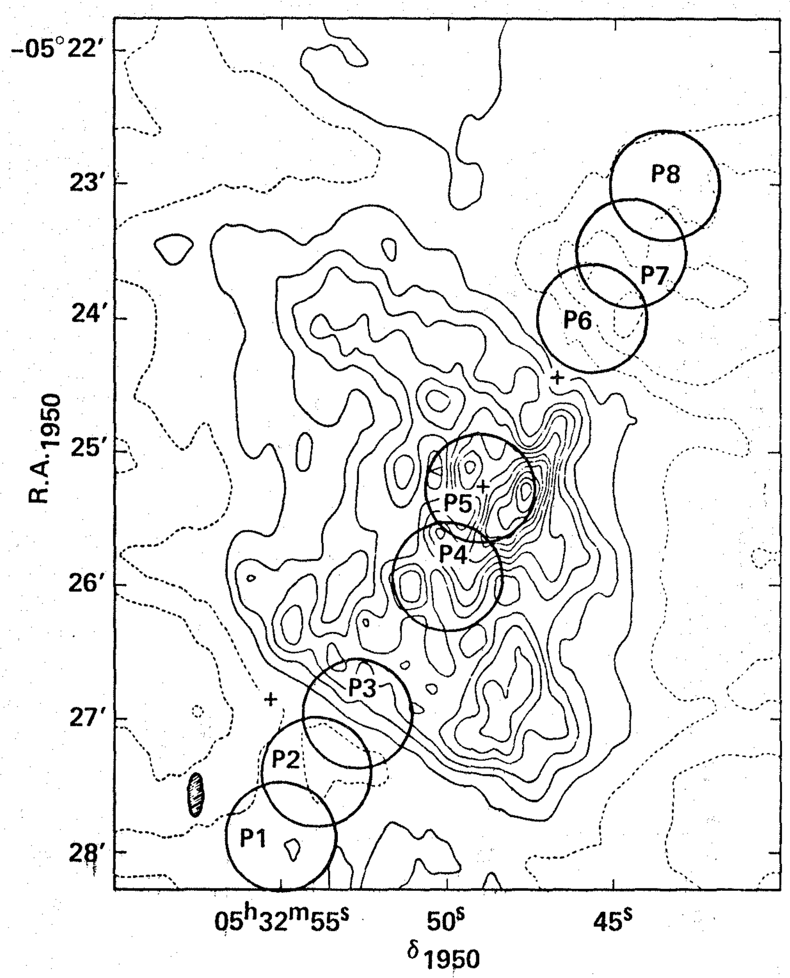
Figure Captions

Figure 1. The beam locations at which [SiII](34.8μm) was observed. Starting in the lower right, the three crosses mark the positions of Θ^2Ori A, Θ^1Ori C, and the far-infrared continuum peak of the Kleinmann-Low nebula.

Figure 2. The [SiII](34.8μm) line and neighboring continuum (a) at the ionization bar (P3), (b) at Θ^1Ori C (P5), and (c) NW of the Kleinmann-Low nebula (P6).

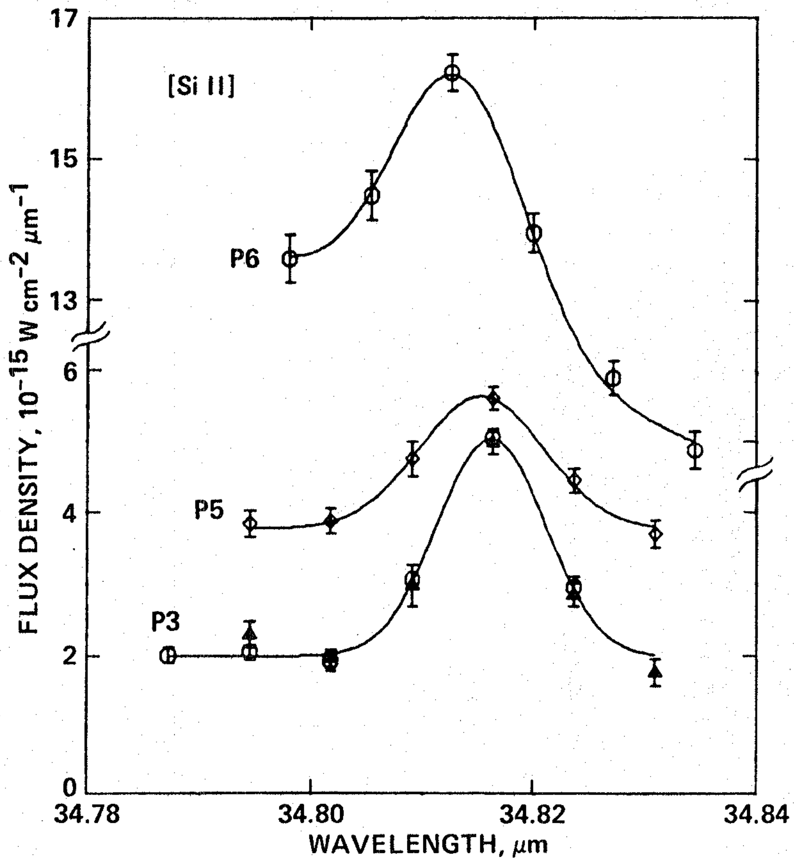
Figure 3. The [SiII](34.8μm) line intensity as a function of position across Orion-KL. The error bars are one standard deviation of the mean; they represent formal statistical errors only.

Figure 4. A theoretical prediction of the [SiII](34.8μm) line intensity versus the column density of Si^+ for different combinations of density and temperature (n_o, T). $n_o = \infty$ corresponds to $n_o >> n_{cr} = 3.4 \times 10^5$ cm^{-3}; $T = \infty$ corresponds to $T >> 413$ K.



-05°22′
23′
24′
25′
26′
27′
28′
R.A.$_{1950}$
05^{h}32^{m}55^s
50^s
45^s
δ_{1950}
P1
P2
P3
P4
P5
P6
P7
P8

Fig. 1



[Si II]
P6
P5
P3
FLUX DENSITY, 10^{-15} W cm^{-2} μm^{-1}
WAVELENGTH, μm
0
2
4
6
13
15
17
34.78
34.80
34.82
34.84

Fig. 2

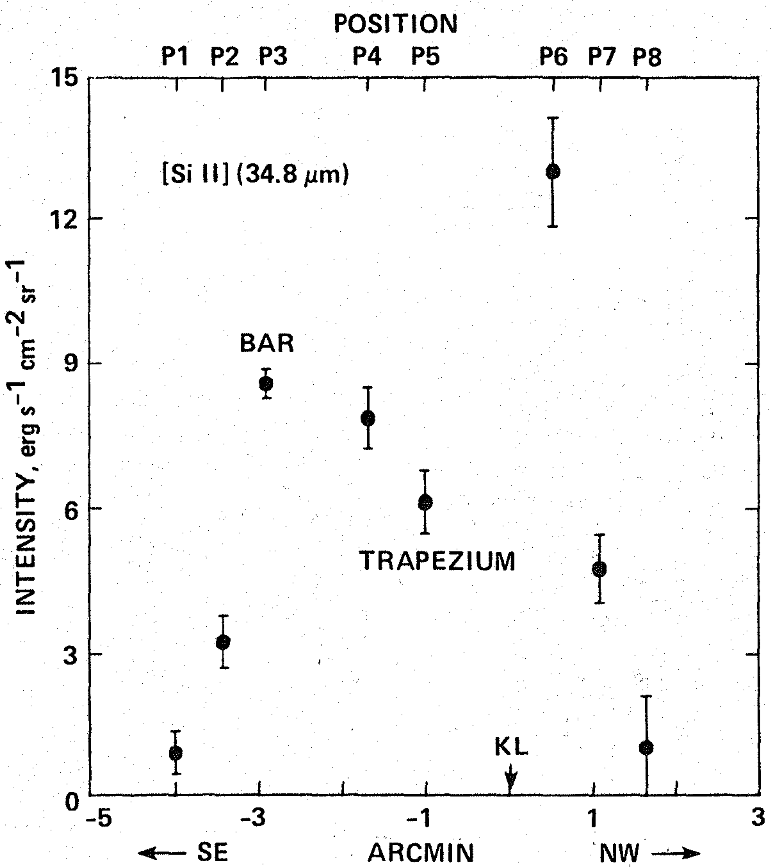
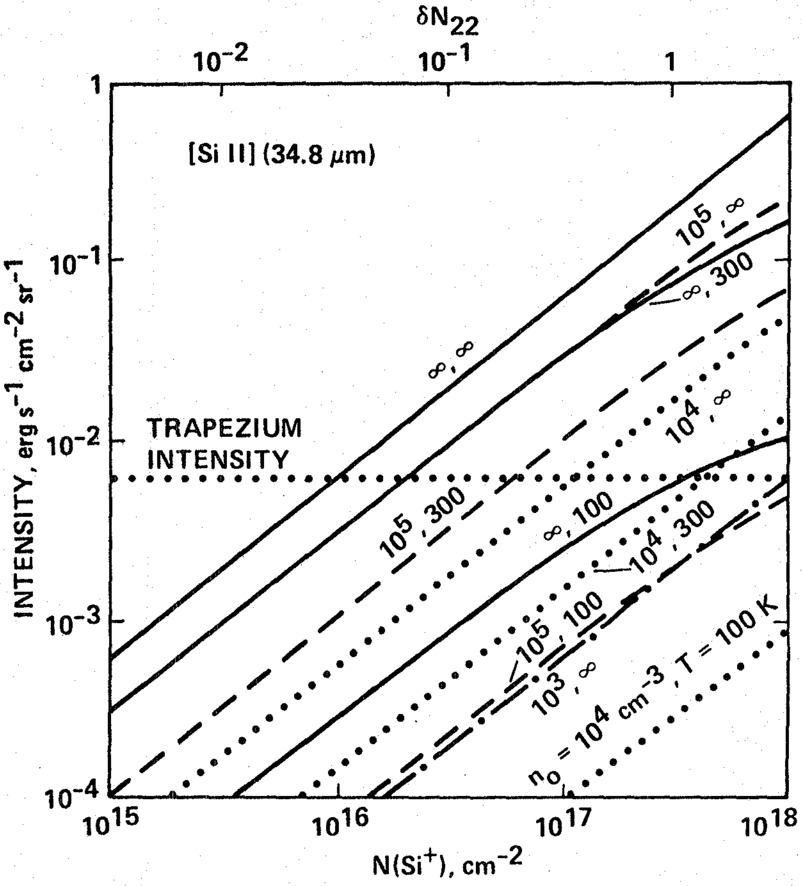

POSITION
P1 P2 P3 P4 P5 P6 P7 P8
[Si II] (34.8 μm)
BAR
TRAPEZIUM
KL
INTENSITY, erg s⁻¹ cm⁻² sr⁻¹
15
12
9
6
3
0
-5
-3
-1
1
3
← SE
ARCMIN
NW →

Fig. 3



δN22
10-2
10-1
1
[Si II] (34.8 μm)
INTENSITY, erg s-1 cm-2 sr-1
TRAPEZIUM
INTENSITY
∞, ∞
10^5, ∞
∞, 300
10^4, ∞
10^5, 300
∞, 100
10^4, 300
10^5, 100
10^3, ∞
n_o = 10^4 cm-3, T = 100 K
1
10-1
10-2
10-3
10-4
10^15
10^16
10^17
10^18
N(Si+), cm-2

Fig. 4

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7. Author(s)
M. R. Haas*, D. J. Hollenbach† and E. F. Erickson†

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9. Performing Organization Name and Address
*Mycol, Inc., 1067 Mango Ave., Sunnyvale, CA 94087
†Ames Research Center, Moffett Field, CA 94035

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16. Abstract

We report the first detection of the ground state fine structure transition of Si^+ at a rest wavelength determined to be 34.815 ±0.004 μm. These observations were obtained with the facility spectrometer on NASA's Kuiper Airborne Observatory. A 6' NW-SE strip scan across the Orion-KL region shows [SiII] emission from both the extended photodissociation region surrounding θ^1Ori C and from the shocked gas NW of BN-KL. The inferred gas-phase silicon elemental abundance relative to hydrogen in the dense ($\sim 10^5$ cm^{-3}) primarily neutral photodissociation region is approximately 2.6×10^{-6}, a factor of 0.075 times the solar value and 3.4 times greater than the abundance in the moderate density ($\lesssim 10^3$ cm^{-3}) cloud toward ζ Oph. The silicon abundance in the shocked gas is approximately solar, indicating that any pre-existing grains have been destroyed in the shock wave or that the preshock gas carries a near solar abundance of gas phase silicon. The shock-excited [SiII] (34.8 μm) emission may arise from shocked wind material in the outflow around IRc2, with wind velocities $\gtrsim 100$ km/s.

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