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THE INTERSTELLAR MEDIUM ON THE GAMMA CASSIOPEIAE LINE OF SIGHT

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ABSTRACT

The interstellar medium on the γ Cas line of sight is studied through the observations of O I, H_2, H I, D I, and Ar I absorption features with the *Copernicus* satellite. By using the velocity structure of the line of sight previously determined through atomic nitrogen, we demonstrate that these neutrals are located in the same physical regions and that the O I and Ar I abundances could be solar, on the average, relative to N I in all components. We also reevaluated the D/H ratio: $(1.3 \pm 0.25) \times 10^{-5}$. The 1066.660 Å Ar I line profile is contaminated by an unidentified line, already detected in the spectrum of ζ Pup. Furthermore, we report a peculiar behavior of the Ar I abundance in the different components, possibly associated with high-velocity interstellar gas present on that line of sight.

We conclude that the γ Cas line of sight could intercept a dense cloud which has been engulfed and disrupted by a shock.

Subject headings: interstellar: abundances — interstellar: matter — stars: individual — ultraviolet: spectra

I. INTRODUCTION

The knowledge of interstellar abundances provides important constraints for models of interstellar clouds, of grain formation, and of chemical evolution of galaxies. But the presence of multiple components on a given line of sight may raise interpretational difficulties. We have recently pointed out a new method to more accurately determine the velocity structure of a complex line of sight through the analysis of the nitrogen absorption features in the UV spectrum of hot stars. An illustration of this method is given in the case of γ Cas by Ferlet *et al.* (1980). Thus it is now possible to deduce more reliable estimates of component-by-component column densities. Therefore, detailed studies of abundance variability can be performed.

In this paper, we use the structure of the γ Cas line of sight previously determined through the analysis of atomic nitrogen absorption features to study some other absorption lines observed with the *Copernicus* satellite such as O I, H I, D I, Ar I, and H_2, since, if interstellar clouds contain N I, they ought to contain these other elements (York 1975).

Section II describes the data processing method, including the linkage between the different velocity scales, since the available lines were not recorded during the same observing program. In § III, we first link the UV observations with the ground-based ones using H_2 lines. Then, using the H I data, we derive the physical parameters of the components detected in nitrogen. In § IV, we apply these results to the D I and Ar I profiles. The physical conditions on the γ Cas line of sight are discussed in § V. Finally, we summarize our conclusions in § VI.

II. DATA PROCESSING METHOD

The general principles and techniques used to analyze the data are described by Vidal-Madjar *et al.* (1977), Laurent, Vidal-Madjar, and York (1979), and Ferlet *et al.* (1980). This last paper includes the nitrogen results for the γ Cas line of sight.

If we assume that all the studied species are in the same physical regions of the interstellar medium, two of the three parameters defining the nitrogen absorption features are closely related to those of the other species: the radial velocity V, and the velocity spread parameter b. Therefore, the nitrogen results provide us the number of components (four in the case of the γ Cas line of sight—see Ferlet *et al.* 1980) and, for each component, three input data: the velocities, the extreme values of b, and the column density ratios of N I for the components. We detail these three points below.

a) *Relative Column Densities*

As a first approximation, we use the relative column density of N I in the components as a guide to the column density of Ar I, D I and O I in each component. Solar abundances (Ross and Aller 1976) are assumed. This assumption gives a reasonable starting set of parameters. However, to get final fits, column densities of each component will be free to vary.

[1] Guest Investigator with the Princeton University telescope on the *Copernicus* satellite, which is sponsored and operated by NASA.

b) The Extreme Values of b

The b-value (b_X) of the species X is related to the nitrogen b-value ($b_{N\,I}$) by the relation:

$$b_{N\,I} \leq b_X \leq (14/A_X)^{1/2} b_{N\,I} \tag{1}$$

(or the inverse signs if the atomic mass of the species X (A_X) is greater than 14). For purely turbulent line broadening $b_X = b_{N\,I}$, and for purely thermal broadening $b_X = (14/A_X)^{1/2} b_{N\,I}$.

c) Relative Velocities

Relative velocities are known to ± 1 km s^{-1} as already mentioned in Ferlet *et al.* (1980) for the lines recorded during the same observing program as nitrogen (set 2 in Table 1). In the case of H I, D I, two O I lines, and one H_2 line recorded during previous observations by Vidal-Madjar *et al.* (1977) (set 1 in Table 1), only the velocity separation between each component is known. The problem is then to link the wavelength scales of the two observing programs. Since the different available H_2 lines do not correspond to the same rotational level, and may thus not show identical properties in a given component, the only way to fulfil our purpose is to use the O I lines, the theoretical f-values of which are given by Zeippen, Seaton, and Morton (1977).

First, we try to fit the very saturated set 2 O I line at 1302.169 Å. Notice that, from equation (1), $b_{O\,I} \sim b_{N\,I}$. Thus the column densities of O I are the only unknown parameters. The quality of the fit (Fig. 1) demonstrates that a solar N I/O I ratio for the entire line of sight can be used.

Then, using the b-values and the column densities just found we try to fit two weaker, but still saturated, O I lines: the 971.738 Å line (near Lγ) and the 950.885 Å line (near Lδ). This process gives the velocity shift between the two sets of data: 6 km s^{-1} for the Lδ one and $+11$ km s^{-1} for the Lγ one. Therefore, the velocity scales are now linked. Using f-values for these O I features given by Zeippen, Seaton, and Morton (1977), we again find that a solar N I/O I ratio fits the data.

The total O I column density toward γ Cas is: N(O I) $= (0.8 \pm 0.3) \times 10^{17}$ atoms cm^{-2}. The rather large error bar is due to the absence of unsaturated O I line in our sets of observations, as already mentioned.

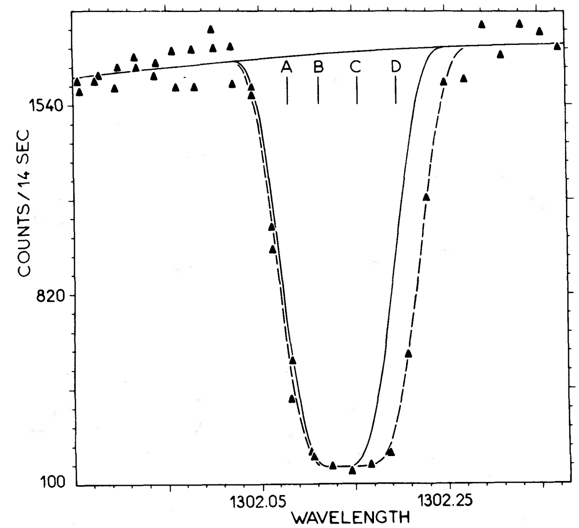

FIG. 1.—Best final fit for the interstellar atomic oxygen line near 1302 Å, assuming four clouds (named A, B, C and D, and derived from the previous nitrogen analysis) on the γ Cas line of sight. Lines are the theoretical absorption profiles convoluted with the apparatus function, along with the evaluated stellar continua. A solar N I/O I ratio for the entire line of sight seems to be an acceptable description in spite of the strong saturation effects. The narrower absorption feature corresponds to the same fit without components A and D. This demonstrates the sensitivity of the 1302 Å line to the two weakest components which column densities are in fact known in oxygen with a quite high accuracy ($\sim \pm 20\%$). The zero level for the scan is assumed to be the average of the three lowest points.

TABLE 1

INTERSTELLAR LINES ANALYZED ON THE γ CASSIOPEIAE LINE OF SIGHT

Observing Program	Lines	λ_{lab}(Å)	f
First, set 1	D I	937.548	7.80 (−3)[a]
	H I	937.803	7.80 (−3)
	D I	949.485	1.39 (−2)
	H I	949.743	1.39 (−2)
	O I	950.885	1.57 (−3)
	O I	971.738	1.48 (−2)
	(II, 0)R(0)H_2	971.984	1.76 (−2)
	D I	972.272	2.90 (−2)
	H I	972.537	2.90 (−2)
	D I	1025.443	7.91 (−2)
	H I	1025.722	7.91 (−2)
Second, set 2[b]	Ar I	1048.218	2.30 (−1)
	Ar I	1066.660	5.94 (−2)
	(2,0)R(3)H_2	1081.710	6.577 (−3)
	O I	1302.169	4.85 (−2)

[a] Notation to be read: 7.80×10^{-3}.

[b] Plus nitrogen and H_2 lines presented in Ferlet *et al.* 1980.

III. DETERMINATION OF THE PHYSICAL PARAMETERS OF THE DIFFERENT COMPONENTS

The radial velocities for the γ Cas line of sight are now known relative to the nitrogen observing program for the Lδ and Lγ lines, and thus can be fixed. But we still cannot link them to the ground-based absolute velocity scale related to that of interstellar lines observed with ground-based telescopes. We shall use H_2 lines for that purpose.

a) Molecular Hydrogen Analysis

The hydrogen molecule plays a central role in a variety of processes that influence the chemical and physical state of the interstellar medium (see, e.g., Spitzer 1978). However, the detailed study of H_2 is well beyond the scope of this paper. We shall just use here the available H_2 lines to confirm our tentative identification of the main N I component with the main Na I component since, from Spitzer and Morton (1976), Na I is assumed to be located in the same physical region as H_2 in $J = 0$ rotational level.

For that purpose, using the nitrogen model of the line of sight, we search for a possible velocity shift of the main H_2 component in the 971.98 Å H_2 ($J = 0$) line from observation 2 (Table 1) versus the main N I component. We find that the H_2 velocity has to be shifted by less than 3 km s^{-1}. Therefore, as N I components B and C are separated by more than 9 km s^{-1}, we confirm here independently the identification of the main N I component (B) with the one observed in Na I and thus the main one observed in Ti II.

Moreover, we obtain an evaluation of the column densities for the $J = 0$ rotational level: $N[H_2(0)] \sim 3.2 \times 10^{14}$ molecules cm^{-2}. This result is well below the upper limit given by Savage *et al.* (1977), $N[H_2(0)] < 1.3 \times 10^{17}$ molecules cm^{-2}, but close to their lower limit, $N[H_2(0)] > 2.6 \times 10^{14}$ molecules cm^{-2}.

Finally, since one H_2 ($J = 3$) line was recorded during the nitrogen observing program (Ferlet *et al.* 1980), we also analyze this line. We find that the main component of the $J = 3$ level H_2 line presents no velocity shift with respect to the main component of the $J = 0$ line and that the $J = 3$ column density is about 1.6×10^{14} molecules cm^{-2}. This last result shows that the column density of H_2 in the $J = 3$ level is equivalent to the column density of $J = 0$. Therefore our results confirm that the total H_2 column density is low and negligible when compared to the atomic hydrogen column density.

b) H I *Analysis*

Vidal-Madjar *et al.* (1977) noted that for an H I column density of the order of 10^{20} atoms cm^{-2} (which is the case for the γ Cas line of sight), the Lδ equivalent width is quite sensitive to b, but not to N(H I). Since the atomic mass of hydrogen is smaller than that of nitrogen, it should be possible to evaluate rather accurate b-values for each component through the fit of the H I Lδ absorption feature.

We thus first try to determine the component b-values by fitting the H I Lδ line under two assumptions (see eq. [1]): thermal broadening or turbulent broadening for the four components (named A, B, C, and D; see Ferlet *et al.* 1980). We also start with the same component column density ratio as in N I. Using thermal broadening, we obtain a profile which is too broad while the other assumption provides a profile that is too narrow. Therefore, to proceed in our analysis, we fix the main cloud (component B) b-value and look for possible solutions, letting the b-values of the weaker components vary. This procedure is followed for a variety of b-values in the main component.

The best fit is obtained for a main cloud b-value corresponding to a 10,000 K temperature (a purely thermal broadening corresponds to a 12,000 K temperature) and purely turbulent b-values for the three weaker components (A, C, and D). We find also that it is impossible for the b-value of the main component to be less than the value corresponding to 9000 K by introducing a large thermal contribution in the other components. We thus conclude that the main component B is mainly thermal while the others are mainly turbulent.

Knowing now the b-values of each component, the next step is to evaluate their column densities. A good fit is found for the Lγ line by keeping relative ratios for the component densities similar to the nitrogen ones. We therefore confirm the b-values and estimate the total H I column density which is about 1.25×10^{20} atoms cm^{-2}. If we allow the column densities of the three weak components to vary, we find that the relative ratio of these components cannot vary by more than a factor 5 (although component C is less precisely evaluated).

Finally, we check the final H I solution in the two other available Lyman lines, not linked with our nitrogen observations. We deduce velocity shifts of +5 km s^{-1} for Lβ and −3 km s^{-1} for Lϵ, consistent with the fact that each line was scanned at different temperatures of the spectrometer. Note that the velocity shifts we obtain between the four H I Lyman lines are in good agreement with those found by Vidal-Madjar *et al.* (1977) based on a one cloud solution (in effect, in the case of H I, our solution is close to a one-cloud solution since our main cloud is mainly thermal and represents $\sim 97\%$ of the total column density). The Lϵ profile analysis, which allows a good check on the b-values since this less saturated line is mainly sensitive to this parameter, confirms that the main component temperature cannot be less than 9000 K, while the Lβ analysis implies a total column density near 1.15×10^{20} atoms cm^{-2}.

In summary, we have demonstrated the thermal origin of the broadening for the main component detected in the line of sight toward γ Cassiopeiae, with a slight contamination by turbulence. By combining the N I, H I, and Na I b-values (Hobbs 1976), we estimate a temperature $T = (10{,}000 \pm 1000)$ K and a turbulent velocity $V_t = (1.7 \pm 0.6)$ km s^{-1} for this main cloud.

The three weaker components show that broadening by turbulence dominates. We find $b_A \approx 1.2$ km s^{-1}; $b_C \approx 4.9$ km s^{-1}, and $b_D \approx 3.4$ km s^{-1} s^{-1}.

For the component C, the thermal contribution to the b-value may be larger than for the two other clouds, but a purely thermal broadening for this component is excluded. The N I/H I abundance ratio in the main cloud is almost solar. This abundance ratio in the three other weaker components differs by less than a factor of 5 from the solar value.

IV. D I AND Ar I ANALYSIS

All the parameters for components of Ar I and D I are known except the column densities. Therefore, in the forthcoming analysis, the velocities and the b-values of each component will be fixed parameters. Note, however, that for component C, the physical meaning of the b-value is still uncertain because this weak component is blended with two other components (nevertheless, this uncertainty has no effect for the following analysis).

a) D I *Absorption Line Analysis*

Only three D I lines are available, the Lβ one being blended with the very saturated H I line.

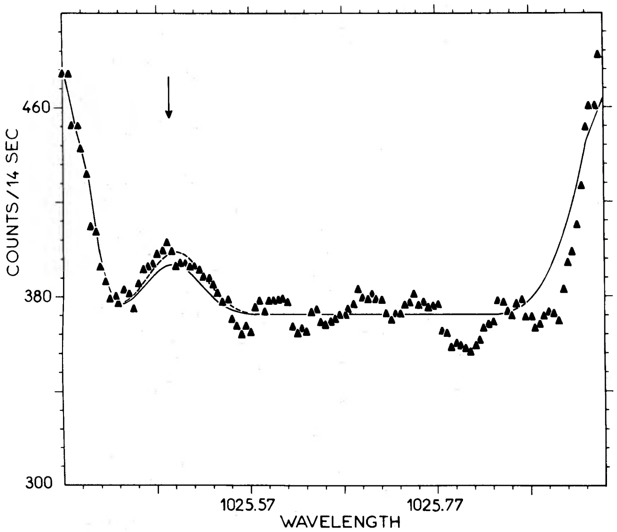

FIG. 2.—Bottom of the Lβ H I and D I lines fitted with the four cloud solution (the velocities and the b-values have been determined in § IIb). The arrow indicates that the H I and D I profiles are actually separated. The two theoretical curves correspond to the minimum and the maximum total H I column density acceptable for the γ Cas line of sight: N(H I) = (1.1 ± 0.11) × 10^{20} atoms cm^{-2}. The zero level is taken to be the horizontal line at the bottom of the profile.

From the less saturated line (Lϵ), we estimate the total deuterium column density. By using this starting value in Lδ and Lγ, and assuming the same column density ratio between each component as in nitrogen and hydrogen, we find a compatible solution for these two D I lines: N(D I) = (1.40 ± 0.15) × 10^{15} atoms cm^{-2}.

To obtain the D/H ratio, since we have a D I solution, we may use the Lβ H I and D I lines to derive a more accurate value of the total N(H I). We have plotted in Figure 2 the bottom of the H I and D I Lβ absorption profile. The arrow on this figure shows some data points at the bottom of the line which indicate that the D I and H I absorption features are actually separated. The velocities being fixed by the deuterium blue wing, the H I Lβ absorption shape depends only on the column densities. The two theoretical curves in Figure 2 correspond to the minimum and maximum acceptable values of total N(H I). Thus, N(H I) = (1.1 ± 0.10) × 10^{20} atoms cm^{-2} compatible in all the Lyman lines (the poor fit of the red side of the Lβ line in Fig. 2 is due to the presence of an absorption H_2 line which laboratory wavelength is 1025.932 Å [Morton and Dinerstein 1976]). This final value of N(H I) is lower than that given by Bohlin, Savage, and Drake (1978), who found N(H I) = (1.45 ± 0.28) × 10^{20} based on Lα. The discrepancy may be an indication of extra absorption features that could be present in the Lα wings and related to unobserved high velocity gas present on that line of sight (Cowie *et al.* 1979). A future detailed analysis of the Lα wings may confirm this hypothesis.

The ratio N(D I)/N(H I) is (1.3 ± 0.25) × 10^{-5}. This average value of D/H for the line of sight concerns in fact essentially the main component.

b) Ar I *Absorption Line Analysis*

We can also use the nitrogen structure of the γ Cas line of sight in the case of the two Ar I lines at 1048.218 and 1066.660 Å. The oscillator strengths are taken from Morton (1975) (see Table 1). The lines were scanned during the same observing program as nitrogen; the relative radial velocity of each cloud is thus known to ±1 km s^{-1}. According to the H I study, the b-values are also known for each cloud. If we keep the same density ratios in Ar I as in the other species for each component, no solution is found in either line whatever the total column density is (see Fig. 3a). Therefore, we search for the best fits, allowing the densities of each component to vary. We find a solution for each line, but we are in the untenable situation in which the two solutions are incompatible.

To discriminate between these two solutions, we try the parameters found for the weakest line (1066.660 Å) in the 1048 Å one which is slightly saturated. We obtain too large an absorption profile for this last line, demonstrating that the 1066 Å line solution is probably blended and that the 1048 Å line solution is the only one acceptable. The corresponding fit is shown on Figure 3b, where the Ar I column densities are:

$$N_A(\text{Ar I}) \lesssim 5.6 \times 10^{11} \text{ atoms cm}^{-2} ,$$
$$N_B(\text{Ar I}) \sim 4 \times 10^{14} \text{ atoms cm}^{-2} ,$$
$$N_C(\text{Ar I}) \sim 1.5 \times 10^{13} \text{ atoms cm}^{-2} ,$$
$$N_D(\text{Ar I}) \lesssim 5.8 \times 10^{11} \text{ atoms cm}^{-2} .$$

We obtain a total column density of:

$$N(\text{Ar I}) \sim 4.2 \times 10^{14} \text{ atoms cm}^{-2} .$$

Although our total Ar I column density is derived from only one line, we can estimate the mean depletion factor,

$$D = \log \left[\frac{N(\text{Ar I})}{N(\text{H I})}\right]_{\gamma\,\text{Cas}} - \left[\frac{N(\text{Ar I})}{N(\text{H I})}\right]_{\odot} ,$$

of argon on the γ Cas line of sight: $D \approx +0.53$. That means a rather surprising overabundance of argon, about a factor 4 relative to the Sun, in disagreement with the basic knowledge of interstellar abundances. However, the argon solar abundance that we use here from Ross and Aller (1976) is still quite controversial. For instance, with the value used by Morton (1978), the D factor decreases down to ~ -0.09, indicating then a slight depletion. The unreliability of the argon solar abundance outlines therefore a major problem for interpretations.

Nevertheless, argon is the only element that we have studied which presents a special behavior. Whatever the solar abundance value is, the fit of the 1048 Å line allows us to conclude that both extreme clouds (A and D) have lower values of the ratio N(Ar I)/N(N I) than the central components. Assuming N I is solar, argon is deficient in components A and D by factors of 8(> 4.5) and 6(> 3.5),

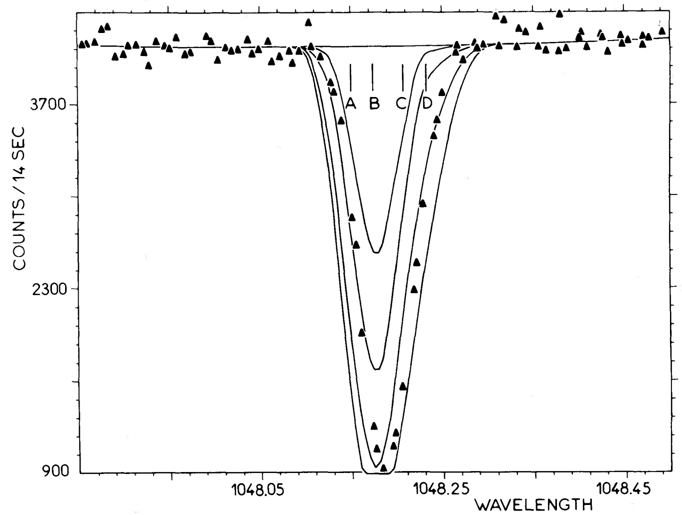

FIG. 3*a*

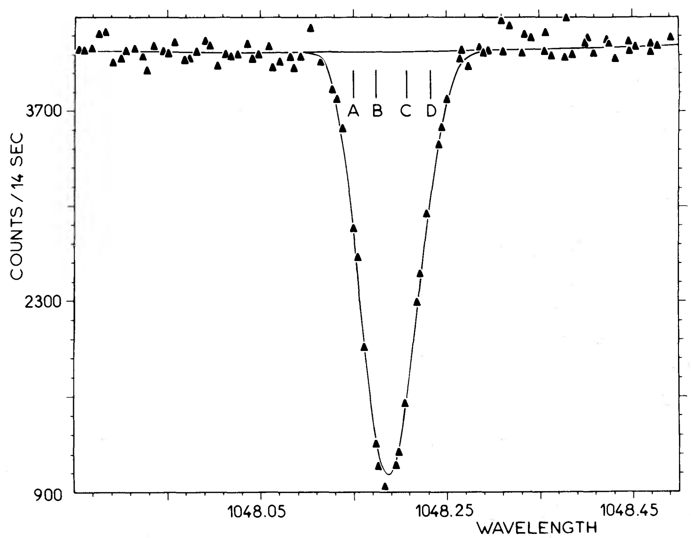

FIG. 3*b*

FIG. 3.—(*a*) This figure present a set of calculations in which we try to fit the 1048 Å line with a four cloud model presenting the same column density ratio between the different clouds as the one found in the N I solution. The only changing parameter here is the total Ar I column density on the line of sight. Obviously, it is absolutely impossible to fit simultaneously the wings and the core of the line. As mentioned in the text, the only way to fit the line is to change the Ar I/N I ratio in the different clouds. The zero level is 900 counts per 14 s, determined from nearby saturated lines. (*b*) The best fit of the slightly saturated 1048 Å line with the nitrogen structure of the line of sight and the *b*-solutions found in the H I study. The column densities of the two extreme clouds A and D have strongly decreased with respect to the ones of clouds B and C. The total N(Ar I) is $\sim 4.2 \times 10^{14}$ atoms cm^{-2}.

respectively. This apparent deficiency is certainly significant.

To go further in our analysis, we shall try now to understand the apparent incompatibility between the 1048 Å line and the 1066 Å one. In effect, one can see on Figure 4*a* that the 1066 Å line, as expected, is not well-fitted by the 1048 Å line parameters. The large discrepancy is obviously due to too much absorption at the bottom of the line and may be also on the far blue wing. A first explanation could be that the *f*-values ratio $f(1066)/f(1048)$ is incorrect. Since these two lines are not part of a doublet, the observational *f*-values cannot be theoretically checked to the required accuracy. However, the measured Ar I *f*-values are reliable to $\pm 10\%$ (Meyer 1978). Thus this simple explanation apparently fails, since furthermore the discrepancy in Figure 4*a* is asymmetrical.

Another hypothesis could be the existence of some contamination by another species. Morton (1978) has observed, in the interstellar spectrum of ζ Puppis, 52 lines which have no reasonable indentifications among the

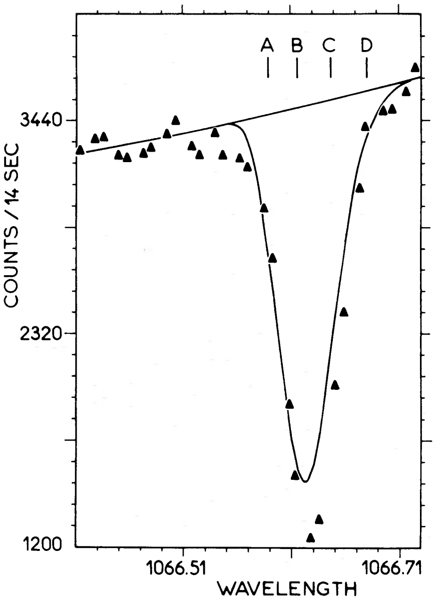

FIG. 4*a*

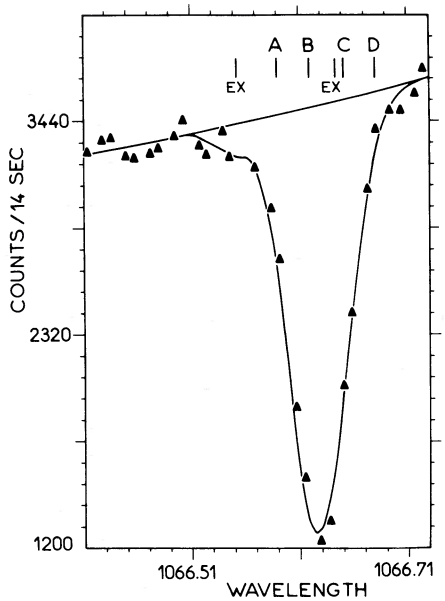

FIG. 4*b*

FIG. 4.—(*a*) The solution shown in Fig. 3*b* for the 1048 Å line is used for the weaker 1066 Å line profile. The poor fit of the bottom of the line and its far blue wing actually suggest a blend of Ar I with an unidentified line. The zero level is 900 counts per 14 s, similar to that of the nearby 1048 Å line of Ar I. (*b*) The final fit of the 1066 Å line is obtained by introducing two "extra" components (EX) at LSR velocities around -10.7 km s^{-1} and -34.7 km s^{-1} with respect to the 1066.660 Å line. This velocity separation is very close to the one of clouds A and D. This unidentified line which has already been observed in the spectrum of ζ Pup (Morton 1978), seems to be related to high velocity interstellar clouds.

published wavelengths of resonance lines. One of them is listed at the observed wavelength of 1066.540 Å, which could imply, according to Morton's reduction method, a laboratory wavelength equal to (1066.500 $\pm$ 0.04) Å.

If we assume such a contamination of the 1066 Å Ar I line, it is necessary to introduce two "extra" components at local standard of rest (LSR) radial velocities around -10.7 and -34.7 km s^{-1}, with respect to 1066.660 Å Ar I line. The final fit of this line, with six components, is shown on Figure 4*b*. The large change in quality of fit between Figures 4*a* and 4*b* is quite obvious. Note, however, that only the component at -10.7 km s^{-1} is clearly identified as an extra component, the other one being quite weak and undetectable on the 1066 Å Ar I line that was scanned at the beginning of our observing program.

This last remark shows that although the blended line hypothesis looks to be quite satisfactory, it seems that in our case a third one should also be considered. In effect, as just mentioned, the 1066 Å Ar I line was scanned two times at the beginning and at the end of our observing program, of the order of 15 hours apart. Because these two scans look quite different as far as the stellar continuum as well as the absorption feature shape are concerned, it seems that stellar flux variability as already observed in the case of γ Cas by Marlborough, Snow, and Slettebak (1978) and by Hammerschlag-Hensberge *et al.* (1979), could be the cause of part of the observed perturbation. If we assume that kind of perturbation, we may even say that the stellar variability has to take place during a scan time, i.e., on a period of time of the order of 1 minute or less.

The conclusion of the 1066 Å line study is that this line seems certainly to suffer a blend with another line and probably some changes due to stellar flux variations, and thus should be ignored or used with extreme care in all interstellar abundance Ar I ultraviolet studies. In the present paper, for the evaluation of the Ar I column densities, we have ignored this line and used only the Ar I information linked to the 1048 Å line which also was scanned at the beginning and the end of our observing program and presented no significant change. The existence of at least another extra absorption feature in the 1066 Å line will nevertheless be used in the forthcoming section in order to deduce some physical characteristics of the interstellar medium (ISM) along the line of sight.

V. THE γ CAS LINE OF SIGHT

To link our extra component found at -10.7 km s^{-1} with one of the four interstellar clouds observed on the γ Cas line of sight, we may use the laboratory wavelength evaluation made by Morton (1978) which is $\lambda_{\rm lab} = 1066.500 \pm 0.04$ Å. Under these conditions the corresponding cloud velocity should be at $+34.3$ km s^{-1}, extremely far from any of our four components observed in N I (between -24.6 and $+1.3$ km s^{-1}). This means either that this unknown component is related to an undetected cloud which contains very little N I, O I, or H I, which is extremely unlikely, or that the laboratory wavelength evaluation made by Morton (1978) is wrong just because he assumed the unidentified line to be generated inside the main component of the ζ Pup line of sight which may be not true.

The ζ Pup line of sight has been previously analyzed through the Lyman H I and D I absorption lines by Vidal-Madjar *et al.* (1977). They report the presence of a high velocity H I cloud with a heliocentric velocity between -54 and -36 km s^{-1}. On the other hand, this line of sight is included in the survey of high velocity interstellar ions by Cohn and York (1977). A blue absorption feature around -24 km s^{-1} heliocentric velocity is obviously observed by these authors in N II, C II, C III, and Si III profiles. Furthermore, an absorption feature at -3 km s^{-1} heliocentric velocity is observed by Hobbs, as reported by Morton (1978), in the Na I profile, and at -2 km s^{-1} by Spitzer and Morton (1976) in the H_2 profile. Consequently, in the case of ζ Pup line of sight, the unknown species responsible for the unidentified line could be related to several other velocity components.

If we assume then that the unknown component is related to the ionized component at a velocity of -24 km s^{-1}, we may say that the laboratory wavelength of this species is $\lambda_{\rm lab} = 1066.625$ Å. With this value we can reevaluate the LSR radial velocity of our extra component which is then equal to -0.8 km s^{-1} and could be reasonably identified then with our D component ($V_{\rm D} = +1.3$ km s^{-1}); note that under this condition the other much weaker extra component, if real, could also be identified with our component A.

Our working hypothesis thus will be the most probable one: we identify component D and A with high velocity gas on the γ Cas line of sight. For component A, we note that N(Ti II)/N(N I) is much greater than in component B, consistent with identification of component A with high velocity gas. The four components may be physically unrelated. However, Cowie and York (1978) suggested that high velocity components in general may arise from pressure fluctuations at surfaces of low velocity clouds.

The observation of two absorbing regions (clouds A and D) with low velocities and hydrogen column densities of the order of 10^{18} atoms cm^{-2} may be explained by an H I cloud which has been engulfed in a shock. From a theoretical discussion of the mechanism involved when a shock front passes over a cloud, it results that such a cloud is likely to be disrupted completely by the resultant field of flow becoming turbulent because of various instabilities (Spitzer 1978). Numerical computations of an H I cloud subject to a passing external shock (Woodward 1976) confirms clearly the highly irregular compressed regions produced after the shock first reaches the cloud, assumed initially to be a uniform sphere.

We have now to understand why the Ar I/N I ratio is so different in clouds A and D with respect to clouds B and C (§ IV*b*). It is extremely difficult to argue upon different ionization levels of the two species to explain the observations, since, as shown by Summers (1974) through collisional ionization equilibrium calculations, the behavior of the two species is almost identical. Nevertheless, observations of Ar II and N III should give a definitive answer to this problem.

Another explanation could be that the nucleosynthetic history of Ar is very different from N and thus may explain local differences which were in effect observed already in the Cas A supernova remnant (Peimbert and van den Bergh 1971; Chevalier and Kirshner 1979). In fact, argon is produced in similar conditions to sulfur, calcium, and silicon. Calcium and silicon are often depleted and highly variable; so any study of the N(Ca)/N(Ar) or N(Si)/N(Ar) ratios may be ambiguous; but sulfur is normally undepleted. Hence, a study of the N(S)/N(Ar) ratio would be useful in testing for variations in interstellar abundances due to local effects of nucleosynthesis.

Finally, the last possible explanation is that the strong depletion of Ar I in components A and D is related to their physical characteristics, i.e., to their possible association with high velocity gas. Variations in abundances with velocity have been noted for refractory elements (Fe, Si) (Cowie 1978), but one generally finds depletions decreasing as velocity increases, as if gas normally depleted in grains were liberated in high velocity clouds. Clearly a detailed study of Fe and Si with velocity would be useful for this line of sight.

It is possible that argon is locked into some types of grains. We note that in meteorites, noble gases could be isolated into small inclusions (Lewis, Srinivasan, and Anders, 1975; Jessberger and Dominik 1979) indicating that a separate type of grains may exist. One should note also that the solar wind is retained differentially inside the lunar dust grains. Perhaps, in association with special physical conditions involving high velocities, a mechanism can be found to reduce the ratio N(Ar I)/N(N I) in some clouds.

In conclusion, the marked underabundance of Ar I in components A and D may be related to their probable characteristic of being high velocity gas. A more complete study of Ar I in the high velocity gas will probably give a precise answer.

VI. CONCLUSION

We demonstrate in this paper that it is possible to give a rather accurate description of a given line of sight through the analysis of UV absorption lines due to interstellar neutral species. Using the velocity structure (four components) and the cloud parameters previously determined through the atomic nitrogen features (Ferlet *et al.* 1980), we fit the H_2, O I, H I, D I, and Ar I profiles obtained from the *Copernicus* satellite on the γ Cas line of sight. A detailed summary is given in Table 2. In this direction, atomic nitrogen, oxygen, and argon could have on average solar abundances relative to H I; the D I/H I ratio is $1.3 \times 10^{-5} \pm 20\%$; and the molecular hydrogen represents a negligible contribution to the total hydrogen column density. The physical regions in which all the studied species are located can be separated in two sets of physical conditions: (*a*) one main warm cloud ($\sim$ 10,000 K); (*b*) three secondary clouds with velocity broadening due primarily to turbulence (A, C, and D). Among these, A and D, are similar in having anomalous ratios N(Ar I)/N(N I) and in showing an unidentified line which, in the

TABLE 2

COLUMN DENSITIES

	Component A	Component B	Component C	Component D	Total
V_{LSR} (km s^{-1})	-24.6	-17.1	-7.8	1.3	...
Nitrogen:					
b(km s^{-1})	$1.2(+0.8, -0.7)$	3.8 ± 0.2	$4.9(+1.0, -1.9)$	>3.4	...
N(N I)	$(1\text{–}5) \times 10^{14}$	$(9 \pm 1) \times 10^{15}$	$(1.5 \pm 0.6) \times 10^{14}$	$5(+1.5, -1.0) \times 10^{13}$	$\sim 9.3 \times 10^{15}$
Oxygen:					
N(O I)	$(0.9\text{–}4) \times 10^{14}$	$\sim 8 \times 10^{16}$	$\sim 1.3 \times 10^{14}$	$\sim 4.5 \times 10^{14}$	$8(\pm 3) \times 10^{16}$
Molecular hydrogen:					
$N(J = 0)$	$\sim 8 \times 10^{12}$	$\sim 3 \times 10^{14}$	$\sim 5 \times 10^{12}$	$\sim 3 \times 10^{12}$	$\sim 3.2 \times 10^{14}$
$N(J = 3)$	$\sim 5 \times 10^{12}$	$\sim 1.5 \times 10^{14}$	$\sim 3 \times 10^{12}$	$\sim 1 \times 10^{12}$	$\sim 1.6 \times 10^{14}$
Hydrogen:					
b(km s^{-1})	~ 1.2	12.8 ± 1	~ 4.9	~ 3.4	...
N(H I)	$\sim 3 \times 10^{18}$	1.05×10^{20}	$\sim 2 \times 10^{18}$	$\sim 6 \times 10^{17}$	$1.1(\pm 0.1) \times 10^{20}$
Deuterium:					
N(D I)	$\sim 4 \times 10^{13}$	1.3×10^{15}	$\sim 2.5 \times 10^{13}$	$\sim 8 \times 10^{12}$	$1.4(\pm 0.15) \times 10^{15}$
Argon:					
N(Ar I)	$\lesssim 5.6 \times 10^{11}$	$\sim 4 \times 10^{14}$	$\sim 1.5 \times 10^{13}$	$\lesssim 5.8 \times 10^{11}$	$\sim 4.2 \times 10^{14}$

case of ζ Pup, can be attributed to some unidentified species in high velocity gas.

Finally, the confirmation of the identification of our main component B with the main component observed from the ground in Na I and Ti II and of the very different observed ratio N(Na I)/N(N I) (Ferlet *et al.* 1980) between components B and C seems to indicate that the volume density of the low column density cloud C is in fact rather high. A separation of clouds by the simple ratio N(Na I)/N(N I) may lead to an interesting categorization of interstellar clouds not possible previously. We intend to pursue this matter in hopes of isolating physical differences, as a function of velocity, for interstellar clouds.

While we feel that column densities as a function of velocity are well understood in this line of sight, that there must be a large thermal component in the line of sight, and that the value D/H is unambiguously determined in spite of the complexity of the line of sight, we reiterate our caution (Ferlet *et al.* 1980) that the Ca II profile is peculiar with respect to our four-component model and that the detailed velocity structure along this line of sight is not understood. Observations with a resolving power near 10^5 for UV lines will apparently be necessary for further progress in understanding this line of sight in detail.

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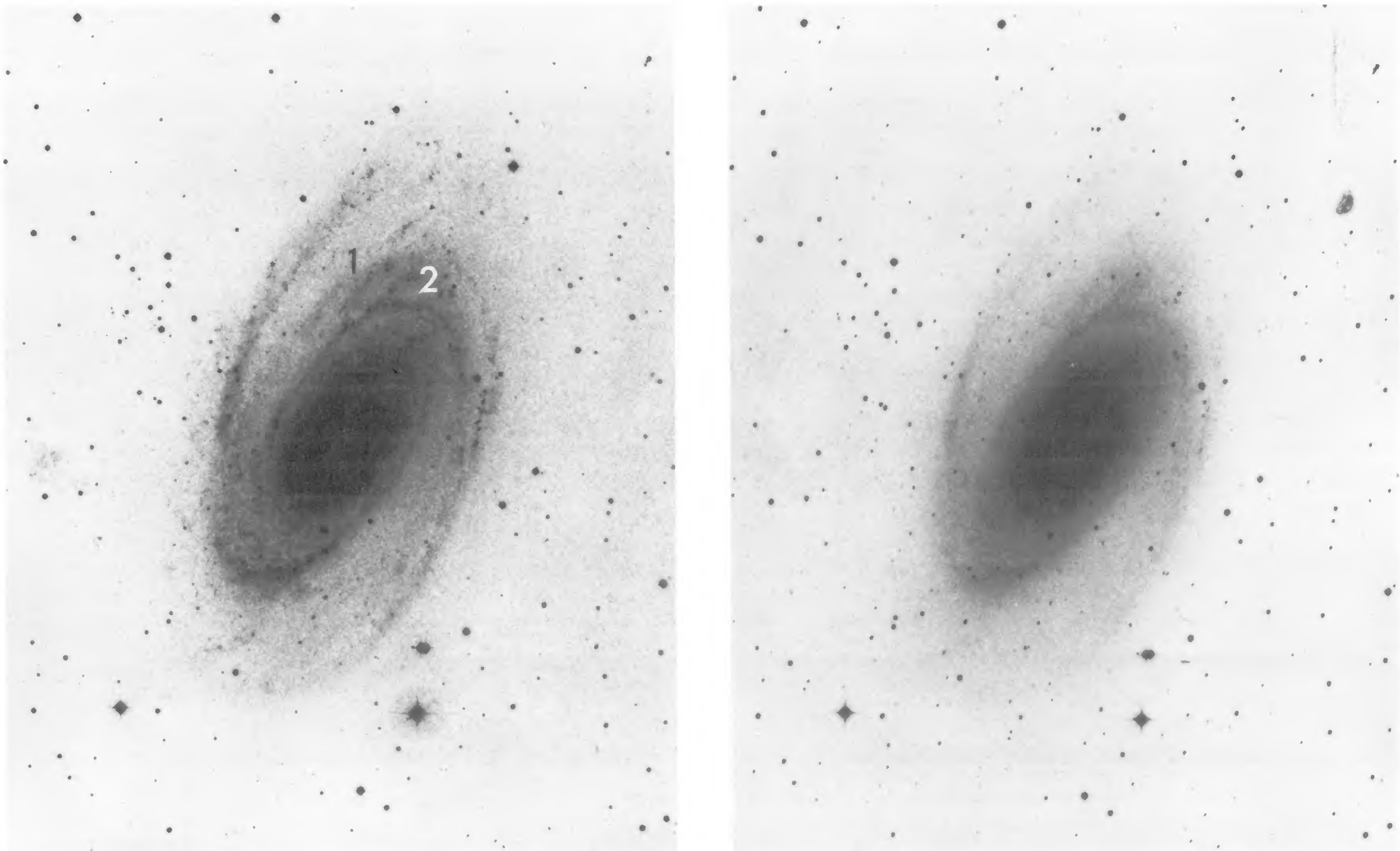

FIG. 2.—Photographs of NGC 3031 taken on the Palomar 1.2 m Schmidt telescope. (*a*) *B* plate (103a-O + GG385, 12^{m}), with spurs numbered. (*b*) *I* plate (hypersensitized IV-N + Wr 88A, 120^{m}); slight trailing was caused by slippage in the autoguider.

ELMEGREEN (*see* page 528)