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THE GASEOUS COMPONENT OF THE DISK AROUND BETA PICTORIS[1]

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ABSTRACT

Optical spectra of α Lyr, α PsA, and β Pic have been obtained at a velocity resolution of 3 km s^{-1}. No circumstellar absorption lines of Ca II or Na I are detected toward α Lyr or α PsA at sensitive limits. In the favorable case of β Pic, where the circumstellar disk imaged by Smith and Terrile is seen nearly edge-on, a strong, narrow, circumstellar Ca II K absorption line previously reported by Slettebak and weaker, still narrower circumstellar Na I D lines are detected. Negative results of high sensitivity also are obtained for the Ca I λ4226 and CH^+ λ4232 lines, along with upper limits on the Zn II $\lambda\lambda$2026, 2062 doublet from archival *IUE* spectra. Under assumptions which agree with other well-established observations of the gaseous abundances of calcium and zinc, the total gaseous column density of hydrogen along a radius of the circumstellar disk is $1 \times 10^{18} \lesssim N(\mathrm{H}) \lesssim 4 \times 10^{20}\ \mathrm{cm}^{-2}$. Within the boundaries of the dust disk detected by Smith and Terrile, the total gaseous mass then is $(M_g/M_\oplus) \lesssim 2$, or less than 1% of the mass of our own planetary system. A simplified model of the density distribution in the gaseous disk yields a characteristic total density $n_{\mathrm{H}} \approx 10^5\ \mathrm{cm}^{-3}$, which exceeds that of all interplanetary gas at Earth's position by a factor of $\sim 10^4$.

Subject heading: stars: circumstellar shells

I. INTRODUCTION

An excess of infrared radiation at wavelengths of 25, 60, and 100 μm from the A stars α Lyr (= Vega), α PsA (= Fomalhaut), and β Pic was discovered in observations from the *IRAS* satellite (Aumann *et al*. 1984; Aumann 1984). The spectrum of this excess from Vega was subsequently extended to 193 μm in the airborne observations of Harper, Loewenstein, and Davidson (1984). Although their respective interpretations differ importantly in detail, both groups attribute the observed IR excess from Vega to thermal reradiation of starlight absorbed by dust particles at $T \approx 85$ K which are seen to about 85 AU from the star and which have the striking property that they are at least several orders of magnitude larger than normal interstellar grains. Optical imaging observations at 0.89 μm by Smith and Terrile (1984) provide important additional information about the dust surrounding β Pic. These authors recorded scattered starlight which delineates a highly flattened, nearly edge-on disk of dust extending at least 400 AU from the star. No well-defined upper limit on the total mass contained in the circumstellar dust could be derived directly from these IR and optical observations.

The presence of a gaseous circumstellar disk about β Pic had been previously established from optical and UV spectra which led to the recognition of β Pic as an unusual member of the presently small class of A–F shell stars (Abt and Moyd 1973; Slettebak 1982; Slettebak and Carpenter 1983). We have obtained new optical spectra at much higher resolution which are intended to allow the detection and some analysis of any sufficiently extensive, gaseous circumstellar shells around the three A stars reported by the *IRAS* investigators to have strong IR excesses. Our principal results are that a confirmation and extension of Slettebak's discovery are obtained for the disk around β Pic, which is favorably oriented for absorption studies, and that no gaseous shells are detected around α Lyr or α PsA, which are probably seen more nearly pole-on.

II. OBSERVATIONS

High-dispersion echelle spectra were obtained at the Ca II K line and the Na I D lines for all three stars and in a region including both Ca I λ4226 and CH^+ λ4232 for β Pic. Two sets of observations were acquired (Table 1). The first were obtained with the 1.4 m Coudé Auxiliary Telescope (CAT) of the European Southern Observatory (ESO) at La Silla on 1984 October 19 and 20, using the Coudé Echelle Spectrometer (CES) equipped with a cooled Reticon array of 1872 photodiodes (Ferlet and Dennefeld 1984). The instrumental resolution (FWHM) was $\Delta v = 3$ km s^{-1}. Further observations were carried out at the 2.7 m reflector of McDonald Observatory on 1984 November 10, 12, and 13, using the coudé spectrograph

[1]Partly based on observations collected at the European Southern Observatory, La Silla, Chile.

TABLE 1

EQUIVALENT WIDTHS AND COLUMN DENSITIES FOR NARROW COMPONENTS[a]

Star	W_λ(K) (mÅ)	N(Ca II) (10^{10} cm^{-2})	$W_\lambda(D_2)$ (mÅ)	N(Na I) (10^{10} cm^{-2})	W_λ(4226) (mÅ)	N(Ca I) (10^{10} cm^{-2})	W_λ(4232) (mÅ)	N(CH$^+$) (10^{12} cm^{-2})
α Lyr	< 4.0	< 4.4	< 5.2	< 2.5	...	...	...	...
α PsA	< 4.4	< 4.8	< 5.9	< 2.9	...	...	...	...
β Pic	97 ± 10	190 ± 50	9.5 ± 1[b]	4.9 ± 0.5	< 5.7	< 2.2	< 5.7	< 2.6

[a] The D line data for β Pic are based on ESO spectra; the Ca I and CH$^+$ data and the data for α Lyr, on McDonald spectra; the remaining data, on spectra from both observing runs.

[b] For the corresponding D_1 line, $W_\lambda = 5 \pm 1$ mÅ.

with the echelle grating and the Digicon detector. The instrumental resolution (FWHM) selected for α Lyr and α PsA again was 3 km s^{-1}. Because its minimum zenith distance is 81° at McDonald, all observations of β Pic were made there with a wider (1''2) slit, which yielded a corresponding resolution of 5.3 km s^{-1}.

Some of the spectra obtained are shown in Figures 1 and 2. In the McDonald data of Figure 1 the only correction which has been applied is that of division by a quartz-iodine lamp spectrum, to remove the high-frequency portion of the instrumental response function. Similar flat-fielding of the ESO spectrum in Figure 2 has been carried out. Neither the many well-known telluric absorption features near the D lines nor the various stellar lines exemplified by those evident in Figures 1 and 2 are of interest here. The spectra of Vega and Fomalhaut in fact show no additional detectable features, which might have arisen in circumstellar gas. Accurately centered on the respective stellar lines of β Pic, however, are the very strong, narrow K line discovered by Slettebak (1975) and weaker, still narrower D lines observed here for the first time.

The observed equivalent widths and the derived gaseous column densities $N = \int n(l)\,dl$ of the several atoms and ions along the light paths through the respective circumstellar shells are given in Table 1. The assumption of a purely absorbing gas was used in deriving the column densities from the line profiles (Spitzer 1978); the oscillator strengths of Morton and Smith (1973) were adopted for the atomic lines, along with the value $f = 0.014$ (Brooks and Smith 1975) for the CH$^+$ line. The optically thin relation $W_\lambda = (\pi e^2/m_e c^2) N f \lambda^2$ has been used in all cases except that of the partially resolved, optically thick K line of β Pic, for which N(Ca II) was calculated instead by the method of line profile fitting. The upper limits given in Table 1 are based on the assumption that, for weak lines, the widths (FWHM) of the intrinsic profiles are 6.2 km s^{-1} for β Pic, as is discussed below, and 10 km s^{-1} for α Lyr and α PsA, somewhat arbitrarily.

Important information about the absorbing gas also is provided by the relative widths of the circumstellar Na I and Ca II lines detected toward β Pic. The directly observed full widths at half-depth are 4.2 ± 0.3 and 7.4 ± 0.4 km s^{-1} for the D lines and the K line, respectively. After approximate corrections are made during the process of line profile fitting, for both the instrumental resolution of 3 km s^{-1} and, in the case of the K line, for optical depth effects, the derived intrinsic widths (FWHM) of the Gaussian optical depth functions $\tau(\lambda)$ or $\tau(v)$ are $\Delta v_0 = 2.9 \pm 0.2$ and 6.2 ± 0.8 km s^{-1}, respectively. The values of the corresponding velocity dispersion parameter $b \equiv (4 \ln 2)^{-1/2} \Delta v_0$ are $b = 1.8 \pm 0.2$ and 3.7 ± 0.5 km s^{-1}, respectively (Spitzer 1978). Since thermal broadening of the D lines must exceed that of the K lines at a given temperature, the narrower D lines indicate that most of the Na I and Ca II absorption must arise in respectively different regions of the gaseous disk and that nonthermal broadening of the lines by mass motions probably is important.

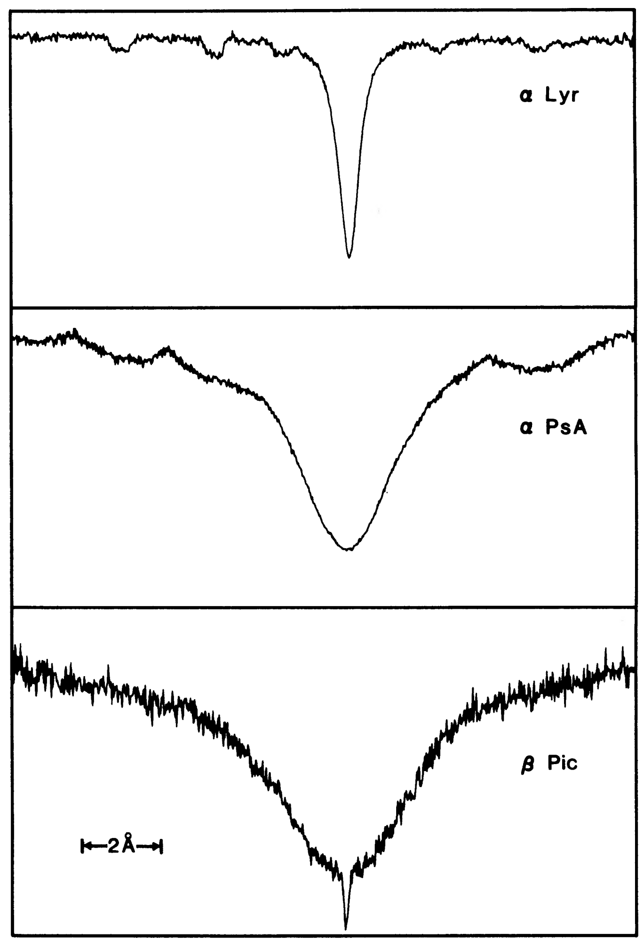

FIG. 1.—The spectra of α Lyr, α PsA, and β Pic over an interval of about 16 Å in the region of the Ca II K line. The bottom border of each panel is the zero point for the relative intensity, and wavelength increases to the right.

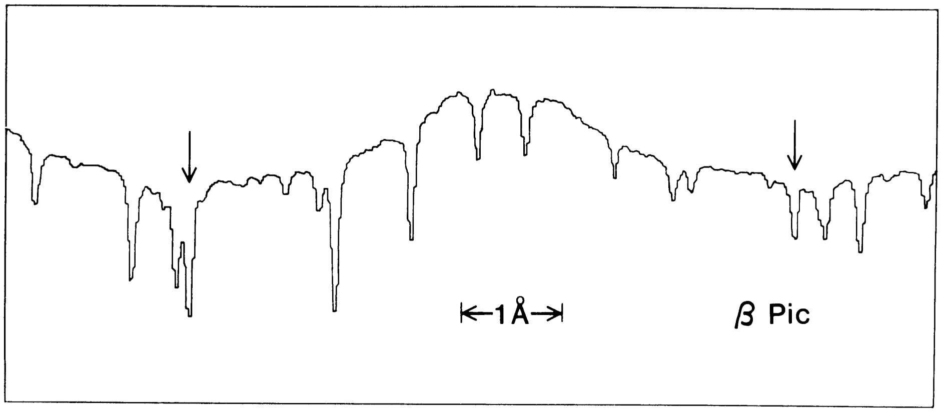

FIG. 2.—The spectrum of β Pic over an interval of about 9 Å in the region of the Na I D lines. The bottom border of the panel gives a relative intensity of approximately 75% of the continuum reached near the center of the displayed spectrum, and wavelength increases to the right. The broad stellar D lines and many well-known telluric absorption lines can be seen, along with the circumstellar components indicated by arrows. The circumstellar D_2 line is heavily blended with one of the water vapor lines.

An interstellar, rather than circumstellar, origin for the narrow absorption lines of Ca II and Na I seen in the spectrum of β Pic can be excluded on several grounds: (1) For a star at ~ 16 pc, the K line is much stronger than the interstellar K line seen toward any other comparably nearby star (Munch and Unsold 1962). (2) A ratio $N(\text{Ca II})/N(\text{Na I}) \gg 1$ is found only in interstellar lines arising in high-velocity gas, in contrast to the case for β Pic (Hobbs 1983). (3) Narrow absorption lines arising from excited, metastable, lower levels of Fe II, from which no interstellar absorption has been detected, have been extensively observed in the spectrum of β Pic (Slettebak and Carpenter 1983).

III. PROPERTIES OF THE GASEOUS DISK AROUND BETA PICTORIS

a) *Total Column Density*

A simple, reliable lower limit on the total column density $N(\text{H})$ of hydrogen in all gaseous forms along essentially a full radius of the disk around β Pic can be estimated as follows. It is necessarily true that $N(\text{Ca}) \gtrsim N(\text{Ca II})$. In the β Pic disk, we further assume that $A(\text{Ca}) \leq A_\odot(\text{Ca})$, where the fractional abundance by number is $A(x) \equiv n(x)/n(\text{H})$; although calcium is frequently present in cosmic gases at less than its solar abundance, it is unlikely to be overabundant (e.g., Albert 1983). Therefore,

$$N(\text{H}) = N(\text{Ca})/A(\text{Ca}) \geq N(\text{Ca II})/A_\odot(\text{Ca}) \approx 1 \times 10^{18}\ \text{cm}^{-2}, \tag{1}$$

where $A_\odot = 2.2 \times 10^{-6}$ (Ross and Aller 1976). The $\lambda 4226$ and K lines in Table 1 show directly that $N(\text{Ca I}) \ll N(\text{Ca II})$. The discussion in § IV suggests that $N(\text{Ca III}) < N(\text{Ca II})$ as well, in which case $N(\text{Ca}) \approx N(\text{Ca II})$, so that the equality in equation (1) probably in fact applies if calcium is undepleted from the gas around β Pic.

An upper limit on $N(\text{H})$ can be similarly obtained from UV observations of the Zn II resonance doublet at $\lambda\lambda 2026, 2062$. Archival high-dispersion *IUE* spectra of β Pic (LWR 9835) and δ Cas (LWR 9831), an A5 III comparison star without shell lines, therefore have been measured. The spectra were very kindly supplied by Dr. Arne Slettebak. The spectrum of β Pic shows no detectable circumstellar Zn II lines, at the available instrumental resolution $\Delta v \approx 30$ km s^{-1}, and approximate upper limits are $W_\lambda(2026) \leq 65$ mÅ and $W_\lambda(2062) \leq 75$ mÅ. In the optically thin limit, the oscillator strength $f = 0.41$ (Morton and Smith 1973) of the stronger $\lambda 2026$ line then yields $N(\text{Zn II}) \leq 4.4 \times 10^{12}$ cm^{-2}. With the same velocity dispersion parameter $b = 3.7$ km s^{-1} as that noted above for Ca II, it can be shown straightforwardly that optical depth corrections cannot raise this upper limit above $N(\text{Zn II}) \leq 1.1 \times 10^{13}$ cm^{-2}, the value therefore adopted here. York and Jura (1982) have shown that zinc is usually depleted from the interstellar gas by no more than a factor of 2 and may be generally undepleted below its solar value $A_\odot(\text{Zn}) = 2.8 \times 10^{-8}$ (Ross and Aller 1976). We also expect $N(\text{Zn I}) \ll N(\text{Zn II})$ and $N(\text{Zn III}) \ll N(\text{Zn II})$ in both the interstellar gas and the disk around β Pic (§ IV). In the disk, we therefore assume that $A(\text{Zn}) \approx A_\odot(\text{Zn})$ and that $N(\text{Zn II}) \approx N(\text{Zn})$, which require that

$$N(\text{H}) = N(\text{Zn})/A(\text{Zn}) \approx N(\text{Zn II})/A_\odot(\text{Zn}) \lesssim 4 \times 10^{20}\ \text{cm}^{-2}. \tag{2}$$

Because the properties of the circumstellar matter around β Pic may be quite different from those of normal interstellar matter, we have avoided invoking any of the latter here, except for the present assumption that $A(\text{Zn}) \approx A_\odot(\text{Zn})$.

b) *Kinetic Temperature*

An upper limit upon the thermal broadening of the Na I D lines, and hence on the kinetic temperature T of the gas, follows from the derived intrinsic line width (FWHM) Δv_0 and the well-known relation for a Gaussian velocity distribution, $\Delta v_0 \geq [(8 \ln 2)(kT/m)]^{1/2}$. With the value $\Delta v_0 = 2.9$ km s^{-1} from § II we obtain $T \leq 4{,}200$ K. The discussion in

§ IV suggests that the actual temperature of the gas is lower than this rigorous upper limit.

c) Total Mass of Gas

In order to obtain an estimate of the total gaseous mass in the circumstellar disk of β Pic, we consider a uniform cylindrical disk of density $\langle n_{\rm H} \rangle$, radius l, and total height $0.2l$. The gaseous mass M_g in the disk is approximately

$$M_g = 0.2\pi m_p \langle n_{\rm H} \rangle l^3 = 0.2\pi m_p N({\rm H}) l^2,$$

where m_p is the mass of the hydrogen atom. The estimate is independent of $\langle n_{\rm H} \rangle$ but depends on the assumed geometrical factor 0.2 and, especially, on the unknown value of l^2. Uncertain but plausible limits on the characteristic size of the gaseous disk are

$$0.1 \leq l \leq 400 \text{ AU}, \tag{3}$$

where the lower limit is the position of the circumstellar gas for typical A stars with shells (Slettebak 1979), and the upper limit is the size of the dust disk imaged by Smith and Terrile. The limits obtained from equations (1), (2), and (3) are

$$2 \times 10^{18} \lesssim M_g \lesssim 1.5 \times 10^{28} \text{ g}, \tag{4}$$

or $4 \times 10^{-10} \lesssim (M_g/M_\oplus) \lesssim 2$, or $(M_g/M_*) \lesssim 4 \times 10^{-6}$, where the mass of β Pic is $(M_*/M_\odot) \approx 2$.

It therefore seems very unlikely that the present total mass of the generally distributed gaseous component of the disk within the boundaries imaged by Smith and Terrile exceeds 1% of the mass of our own planetary system. The data available here cannot exclude the possibility that the total gaseous mass is still smaller by many orders of magnitude. If a more massive planetary system is to exist around β Pic, either it has formed already, or it is in the process of coalescing from the relatively large dust particles detected from *IRAS*, if their total mass eventually is demonstrated to be appropriately large.

IV. DISCUSSION

The properties of the gaseous disk around β Pic deduced so far have been derived quite directly from the observations and have been largely free of uncertain, detailed assumptions about the nature and distribution of the gas. In this section, we adopt the more speculative procedure of constructing a very simplified model of the disk in order to explore its properties further.

a) Ionization Balance

From the measured energy distribution of β Pic (Jamar *et al.* 1976), the known distance to β Pic (Hoffleit 1982), and the energy density and spectrum of the interstellar radiation field given, for example, by Witt and Johnson (1973), it is clear that, at $\lambda \gtrsim 1700$ Å, the radiant energy density from β Pic, which decreases outward according to the inverse-square law, exceeds that of the interstellar field out to a distance $d' \approx 0.1$ pc $\approx 2 \times 10^4$ AU from β Pic, i.e., throughout the entire circumstellar disk. For example, at $d' = 100$ AU, the ratio of the two energy densities at $\lambda \gtrsim 1700$ Å is at least 4×10^4. The opposite conclusion will be true at some wavelength sufficiently shorter than 1700 Å, which depends strongly on the unknown spectrum of β Pic at $\lambda \lesssim 1500$ Å, where the flux of A5 V stars diminishes sharply. As judged from the fluxes F_λ measured for various stars in the range A0–A7 by Jamar *et al.* (1976) and Code *et al.* (1976), it seems plausible to assume that, in the disk, the stellar flux from β Pic is negligible at $\lambda \lesssim 1200$ Å or $h\nu \gtrsim 10.2$ eV, i.e., shortward of Lyα.

The abundant elements H, He, N, and O, which have ionization potentials IP ≥ 13.6 eV, should therefore remain predominantly neutral in the gas around β Pic, just as in typical cool, neutral interstellar clouds (Spitzer 1978). In contrast, the heavier elements with IP $\lesssim 8$ eV, and perhaps even IP $\lesssim 10$ eV, should be very strongly photoionized into the form of first ions by the intense flux from β Pic. In addition, C will be singly ionized and will provide most of the free electrons found in the disk. Virtually all molecules, except possibly H_2 and CO, probably will be of low abundance, owing to their low energies of dissociation. The small ratio N(Ca I)/N(Ca II) $\lesssim 0.01$ and the absence of CH^+ which are reported in Table 1 provide some observational evidence which confirms these expectations. In short, the circumstellar gas probably is cool and predominantly neutral, with $T < 10^3$ K and $n_e/n({\rm H}) \lesssim 10^{-4}$, but with even smaller fractions of (observable) neutral metals and diatomic molecules than in typical cold interstellar clouds.

b) A Simplified Density Model

To ascertain the general order of magnitude of the gaseous density in the circumstellar disk of β Pic, a simplified radial density law of the form

$$n_{\rm H}(r) = n_{\rm H}(r_2)(r_2/r)^n, \qquad r_1 \leq r \leq r_2 \tag{5}$$

can now be assumed. From the preceding discussion, we assume that the dominant forms of calcium and sodium throughout the disk are Ca II and Na II, respectively. The results derived below prove to be consistent with that assumption. In that case, we have $n_{\rm Ca\,II}(r) = n_{\rm Ca\,II}(r_2)(r_2/r)^n = A({\rm Ca})n_{\rm H}(r_2)(r_2/r)^n$ and $n_{\rm Na\,I}(r) = n_{\rm Na\,I}(r_2)(r_2/r)^{2(n-1)} = [\alpha A({\rm Na})A_e n_{\rm H}^2(r_2)/\Gamma(r_2)](r_2/r)^{2(n-1)}$, where A(Ca), A(Na), and A_e are the total fractional abundances of calcium, sodium, and electrons, respectively, in the gas, and Γ and α are the usual Na I photoionization and Na II radiative recombination coefficients, respectively (e.g., Hobbs 1974; Spitzer 1978). We have used $\Gamma \propto r^{-2}$ and have crudely assumed that $\alpha(T)$ is constant in the disk. The correct expression for $n_{\rm Zn\,II}(r)$ is exactly analogous to that for $n_{\rm Ca\,II}(r)$.

For illustrative purposes we will adopt $n = 1$ here (Vidal-Madjar *et al.* 1985), so that $n_{\rm H} \propto r^{-1}$, $n_{\rm Zn\,II} \propto r^{-1}$, $n_{\rm Ca\,II} \propto r^{-1}$, and $n_{\rm Na\,I} \propto$ const. The observable column densities $N = \int_{r_1}^{r_2} n(r)\,dr$ then are

$$N({\rm Zn\,II}) = A({\rm Zn})\,n_{\rm H}(r_2)\,r_2 \ln(r_2/r_1), \tag{6a}$$

$$N({\rm Ca\,II}) = A({\rm Ca})\,n_{\rm H}(r_2)\,r_2 \ln(r_2/r_1), \tag{6b}$$

$$N({\rm Na\,I}) = A({\rm Na})\,A_e\left(\frac{\alpha}{\Gamma}\right)_{r_2} n_{\rm H}^2(r_2)(r_2 - r_1), \tag{6c}$$

results which are generally insensitive to the exact estimate of r_1. The principal unknowns to be determined from equations (6) are $n_H(r_2)$, A(Ca), and perhaps r_1. If we adopt $A(\mathrm{Na}) = A_\odot(\mathrm{Na}) = 2 \times 10^{-6}$, $A_e \approx 10^{-4}$, $(\Gamma/\alpha)_{r_2} \approx 10^4$ cm^{-3}, and, preliminarily from equation (3), $r_1 = 0.1$ AU and $r_2 = 400$ AU, then equation (6c) gives

$$n_H(r_2) \approx 2 \times 10^4 \text{ cm}^{-3} \qquad (7)$$

and consequently $n_e(r_2) = A_e n_H(r_2) = 2$ cm^{-3}. In effect, the magnitude of the total density in the disk governs, and can be deduced from, the observed column density of any "undepleted, recombination" species such as Na I. The derived value of $n_H(r_2)$ depends only on the square root of a combination of the numerical values assumed above and, to that extent, is unlikely to contain large errors. A characteristic gas density in the disk on this model therefore is $n_H \approx 10^5$ cm^{-3}, at $r \approx 80$ AU. This density exceeds that of all interplanetary gas at Earth's position, which consists principally of the hot, ionized solar wind, by a factor of about 10^4. This comparison emphasizes the much larger amounts of generally distributed gas found in the much younger disk around β Pic, a result qualitatively suggested at once by the universal nondetection of corresponding "circumsolar" absorption lines of Ca II and Na I.

The choices $r_1 \approx 14$ AU and $A(\mathrm{Ca}) \approx 5 \times 10^{-9}$, which leave equation (7) essentially unchanged, are perhaps the simplest ones which now are allowed by the assumption $A(\mathrm{Zn}) = A_\odot(\mathrm{Zn}) = 2.8 \times 10^{-8}$ and by the "observed" values of N(Zn II), N(Ca II), and, less importantly, from an equation corresponding to equation (6c), N(Ca I). We note in passing that the result $A(\mathrm{Ca})/A_\odot(\mathrm{Ca}) \approx 2 \times 10^{-3}$ is comparable to that in typical interstellar gas (e.g., Hobbs 1974). Finally, the resulting total gaseous mass in this model, $M_g = 0.4\pi m_p n_H(r_2) r_2^3 = 9 \times 10^{27}$ g, is consistent with equation (4). In brief, among many possible choices, this particular illustrative model apparently can be made to accommodate, in a natural way, the limited observations currently available.

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REFERENCES

Abt, H. A., and Moyd, K. I. 1973, *Ap. J.*, **182**, 809.
Albert, C. E. 1983, *Ap. J.*, **272**, 509.
Aumann, H. H. 1984, *Bull. AAS*, **16**, 483.
Aumann, H. H., *et al.* 1984, *Ap. J. (Letters)*, **278**, L23.
Brooks, N. H., and Smith, W. H. 1975, *Ap. J.*, **196**, 307.
Code, A. D., Davis, J., Bless, R. C., and Hanbury Brown, R. 1976, *Ap. J.*, **203**, 417.
Ferlet, R., and Dennefeld, M. 1984, *Astr. Ap.*, **138**, 303.
Harper, D. A., Loewenstein, R. F., and Davidson, J. A. 1984, *Ap. J.*, **285**, 808.
Hobbs, L. M. 1974, *Ap. J.*, **191**, 381.
______. 1983, *Ap. J.*, **265**, 817.
Hoffleit, D. 1982, *The Bright Star Catalogue* (4th ed.; New Haven: Yale University Observatory).
Jamar, C., Macau-Hercot, D., Monfils, A., Thompson, G. I., Houziaux, L., and Wilson, R. 1976, *Ultraviolet Bright-Star Spectrophotometric Catalogue* (*ESA SR-27*).
Morton, D. C., and Smith, W. H. 1973, *Ap. J. Suppl.*, **26**, 333.
Munch, G., and Unsold, A. 1962, *Ap. J.*, **135**, 711.
Ross, J. E., and Aller, L. H. 1976, *Science*, **191**, 1223.
Slettebak, A. 1975, *Ap. J.*, **197**, 137.
______. 1979, *Space Sci. Rev.*, **23**, 541.
______. 1982, *Ap. J. Suppl.*, **50**, 55.
Slettebak, A., and Carpenter, K. G. 1983, *Ap. J. Suppl.*, **53**, 869.
Smith, B. A., and Terrile, R. J. 1984, *Science*, **226**, 1421.
Spitzer, L. 1978, *Physical Processes in the Interstellar Medium* (New York: Wiley-Interscience).
Vidal-Madjar, A., Hobbs, L. M., Ferlet, R., Gry, C., and Albert, C. E. 1985, in preparation.
Witt, A. N., and Johnson, M. W. 1973, *Ap. J.*, **181**, 363.
York, D. G., and Jura, M. 1982, *Ap. J.*, **254**, 88.

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