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HIGH DISPERSION *IUE* OBSERVATIONS OF THE PLANETARY NEBULA NGC 3918

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RESUMEN

Se han medido los flujos absolutos de las líneas de NGC 3918 en una exposición de alta dispersión y longitud de onda corta (λλ1200-2000 A). Entre las líneas medidas hay varios multipletes que dependen de la densidad, también están los dobletes de resonancia de C IV y N V.

La densidad electrónica promedio derivada es de 5×10^3 cm^{-3}; esta densidad es compatible con determinaciones previas.

Se mide un valor anómalo de 1.2 ± 0.1 para el cociente de intensidades del doblete λλ1239/1243 de N V. Se discuten los posibles mecanismos de absorción que afectan este cociente.

ABSTRACT

We have measured absolute fluxes of the lines present in a high dispersion short wavelength exposure of NGC 3918. Amongst the measured lines we have several density dependent multiplets and the C IV and N V resonance doublets.

The mean electron density derived is of 5×10^3 cm^{-3}, in agreement with previous determinations. We find an anomalous value of 1.2 ± 0.1 for the ratio of λλ1239/1243 of N V. We discuss its implications.

Key words: **INTERSTELLAR-MATTER – NEBULAE-PLANETARY – ULTRAVIOLET-SPECTRA**

I. INTRODUCTION

We have observed this object as part of an observing program of planetary nebulae that has been carried out since 1973 to determine physical parameters and abundances of high surface brightness nebulae. In this program a first analysis of NGC 3918 was made from optical observations by Torres-Peimbert and Peimbert (1977; TPP). More recently, Torres-Peimbert, Peña, and Daltabuit (1981; Paper I) obtained low dispersion *IUE* data; the analysis of these data, compared to ionization structure models, permitted them to derive a general picture of ionization structure and abundances for this object. The models derived in Paper I depend on the density of the object, thus we have tried to secure a high dispersion exposure, to obtain a better determination of it.

II. OBSERVATIONS AND DATA ANALYSIS

We present here, high dispersion data obtained from SWP 3215, a large aperture, 120 minute exposure. We measured the flux in all the lines present in the spectrum. The measured intensity of each line, is listed in Table 1 in *IUE* flux numbers from the ripple corrected file provided by NASA. We also list the flux in erg cm^{-2} s^{-1}, obtained by applying the calibration to *IUE* high dispersion spectra by Cassatella, Ponz, and Selvelli (1981).

The internal errors are ⩽ 4% for the bright lines and of 10% for those lines marked with a colon; the line marked with double colon is more uncertain. In our exposure, λλ1548, 1551 of C IV, λ1640 of He II and λλ1907, 1909 of C III] were saturated.

The derived flux values, for the lines not saturated, are smaller by a factor of 1.6 ± 0.1 than those reported for this object in low dispersion (Paper I). The low dispersion results were reported previous to the correction of the bad ITF; upon later examination of the low dispersion spectra, with the new ITF correction we can see that only the faint lines in the λλ1240-1900 region were affected. That is, the intensities of the unsaturated lines reported here are the correct ones.

From our measurements, we obtain a ratio of O III] λλ1661/1666 of 2.46, which coincides with the expected value of 2.45 derived from the ratio of transition probabilities. Such measurement gives us confidence in our data.

We have derived densities from the intensity ratios of the $^3P - {}^1S_0$ transitions of C III] (λλ1907/1909), Si III] (λλ1883/1892) and N IV] (λλ1483/1486), and from the

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[1] *IUE* guest observer

TABLE 1

OBSERVED LINE INTENSITIES

λ (A)	Ion	*IUE* Counts (10^3)	Flux (10^{-12} erg cm^{-2} s^{-1})
1238.7	N V	2.1:	1.6:
1242.7	N V	1.8:	1.4:
1399.7	O IV]	2.4:	1.2:
1401.0	O IV]	4.92	2.54
1404.6	O IV]	3.8:	2.0:
1407.3	O IV]	0.9::	0.5::
1483.1	N IV]	7.67	4.43
1486.3	N IV]	5.07	2.92
1548.1	C IV	>80.4	>48.9
1550.7	C IV	>59.7	>36.3
1601.3	Ne IV]	2.1:	1.1:
1640.2	He II	>145.0	>52.3
1660.6	O III]	4.64	1.99
1665.9	O III]	11.4	4.92
1749.4	N III]	8.12	2.56
1752.0	N III]	3.9:	1.2:
1882.5	Si III]	3.9:	1.0:
1891.8	Si III]	3.0:	0.7:
1906.5	C III]	>186.0	>43.7
1908.6	C III]	>174.	>40.9

$^4P - {}^2P^0$ transitions of O IV (λ1401 multiplet) and N III (λ1750 multiplet). We present the observations in Figure 1. For these ions, we have calculated the density dependence of the relative intensities of the lines, under the assumption of statistical equilibrium. For the calculations we have used the atomic data from the compilation of Mendoza (1982).

In Table 2 we present the densities obtained from the measured ratios, where we have assumed the electronic temperature to be 10^4 °K as representative of the whole nebula, since the above density diagnostics are not sensitive to temperature. The uncertainties in the densities are internal and correspond to the uncertainties in the measurements. The mean value for the density is of log N_e=3.7 from the collisionally excited lines. We do not find systematic effects with degree of ionization. Such density is in agreement with the values calculated from optical data by Torres-Peimbert and Peimbert (1977); they obtained log N_e = 3.7 from [O II] λλ3737/3729 and log N_e (rms) = 4.0.

III. THE RESONANCE LINES

Several anomalies of the C IV resonance doublet in nebulae have been reported. On the one hand, they appear systematically fainter than the intensities predicted from model structures, e.g., in NGC 7662, C IV λλ1548 + 1551 is 2.8 times fainter than predicted as reported by Harrington *et al.* 1982; and Pequignot, Aldrovandi and Stasinska (1978) reported a factor of ∼ 2 for NGC 7027; such deficiencies have been attributed to dust absorption within the nebulae. On the other hand, the λλ1548/1551 intensity ratio has been reported, in some cases, to be different from the expected value of 2.0, and even the doublet profiles have been found to be of different shape (e.g., Feibelman 1982; Nussbaumer 1982).

In the case of NGC 3918, intensity deficiencies of a factor of ∼ 3 for C IV λλ1548 + 1551, and of a factor of ∼ 6 for N V λλ1239 + 1243, relative to the values predicted by ionization structure computations, were reported in Paper I.

In our observations, the core of the C IV lines are over-exposed and we can derive the intensity ratio only from the external pixels of the image; we find it to be 1.9 ± 0.2 in accordance to expectations. However, we measured the N V λλ1239/1243 ratio to be 1.2 ± 0.1; these lines are faint and could have large errors, but we do not find anomalous ratios in similarly faint lines (like those listed in Table 2). We present these lines in Figure 2.

The low intensities of the C IV and N V resonance lines, as well as the anomalous ratios of the N V λλ1239/1243 doublet could be attributed to: (a) dust absorption within the nebula, which becomes more effective for resonance lines due to multiple scatterings; (b) absorption of the intervening hot interstellar gas; or (c) absorption in an extended tenuous envelope. We analyze these possibilities.

a) *Effects of Internal Dust*

Moseley (1980) and Cohen and Barlow (1980) have observed planetary nebulae from 8μ to 100μ and find that almost all their objects show infrared excess. In particular, the infrared emission of NGC 3918 peaks at 35μ, which can be interpreted as the emission of optically thin dust at 100 °K. This moderate amount of gas is heated mainly by the absorption of resonance photons.

TABLE 2

DENSITY DEPENDENT INTENSITY RATIOS

Ion	Wavelength	Observed Ratio	log N_e
O IV]	1405/1401	0.77 ± .05	3.7 ∓ .1
	1407/1401	0.30 ± .10 [a]	3.5 ∓ 0.3
N IV]	1483/1486	1.5 ± 0.1	⩽4.0
Si III]	1883/1892	1.3 ± 0.1	$4.0\,{}^{-0.5}_{+0.4}$
N III]	1752/1749	0.5 ± 0.1 [b]	⩾4.0
C III]	1907/1909	1.3 ± 0.1 [b]	3.7 ∓ 0.3
Mean value			3.7

a. We have taken the mean of λ1407 and λ1399.

b. Ratio measured from the border of the image.

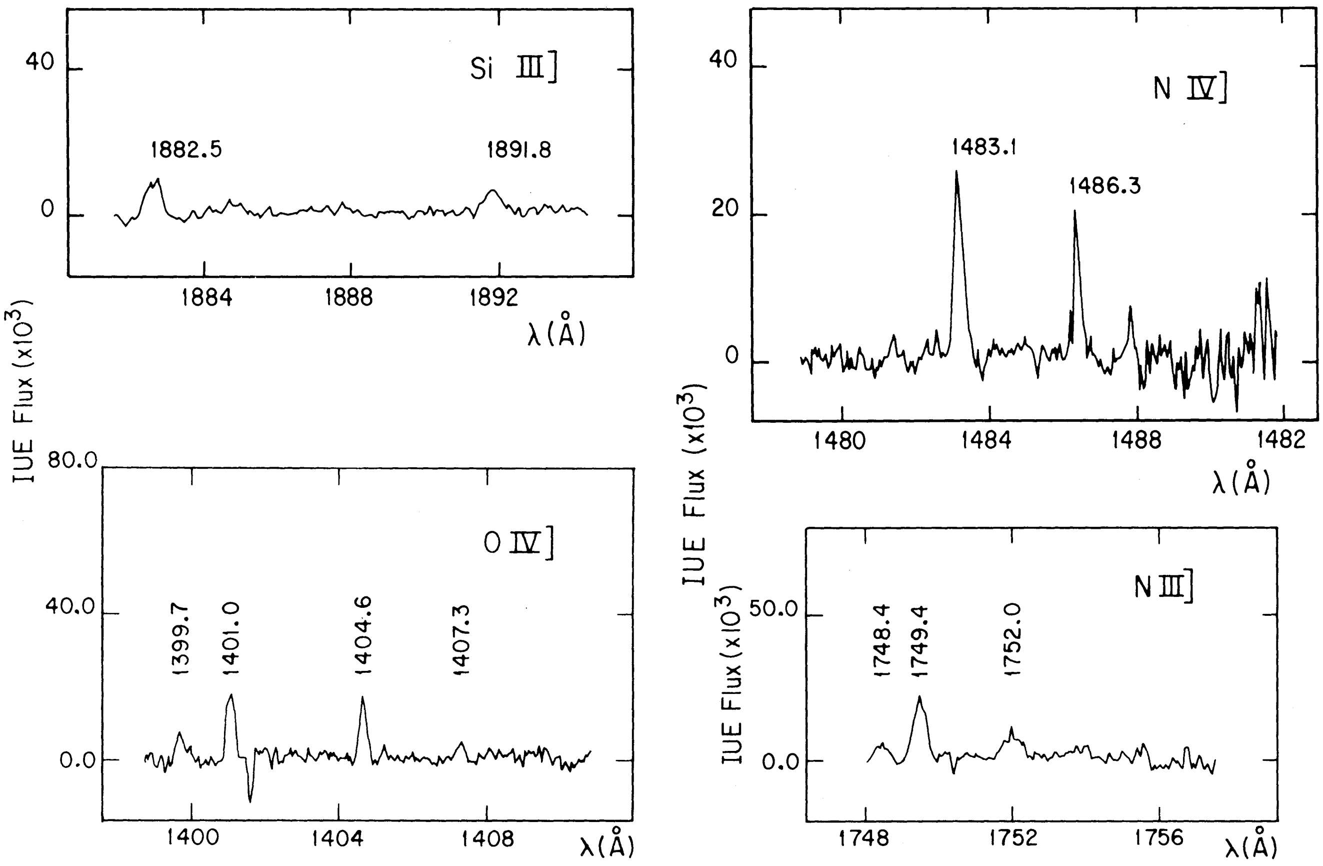

Fig. 1. Density dependent multiplets in NGC 3918.

The energy loss by dust absorption of resonance line photons, undergoing a large number of scatterings in an optically thick medium, has been studied for a plane parallel medium by Hummer and Kunasz (1980). They computed, for a slab of optical thickness τ_g, the fraction of the emitted energy that escapes from this medium, f_e, and found that it depends only on a parameter $\alpha = \rho\ \tau_d$, where ρ is the ratio of the distance travelled by photons (with no dust present) to the half length of the slab, and τ_d is the optical half thickness of the dust.

Their results show that the total distance travelled by the scattered photons is not very sensitive to optical thickness (see Figures 1 and 2 of Hummer and Kunasz). In our case, this means that, although the absorption coefficients for the doublet line are different by a factor of 2, that is $\kappa(\lambda 1239) = 2\ \kappa(\lambda 1243)$, the mean distance travelled by the photons in each line is essentially the same, $\rho(\lambda 1239) \simeq \rho(\lambda 1243)$ and the fraction of escaping energy in both lines is the same, $f_e(\lambda 1239) \simeq f_e(\lambda 1243)$; consequently the escaping intensity ratio is not altered from the emitted ratio.

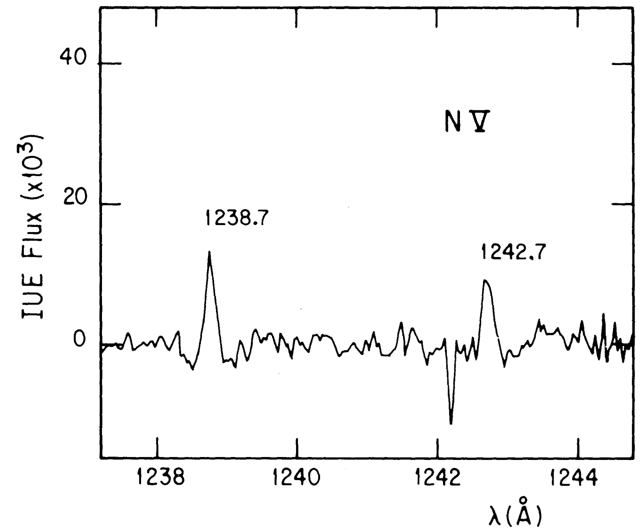

Fig. 2. N V resonance doublet. The measured intensity ratio for λλ1239/1243 is 1.2 ± 0.1. The ratio of emissivities should be 2.

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We have attempted to derive the required optical thickness of the dust from our observations of each N V line independently. To do it, we have adopted the following restrictions:

a) A value for the line damping parameter of $a = 4.7 \times 10^{-4}$.

b) Values for the line optical thickness of τ_g (λ1239) $= 6.7 \times 10^3$, τ_g (λ1243) $= 3.4 \times 10^3$, as derived from the model computations of Paper I.

c) An observed intensity ratio of 1.2 and a reduction of the total line intensity of 1/6.

The last restriction leads to the fractions of escaped energy f_e (λ1239) $= 0.14$ and f_e(λ1243) $= 0.23$. From these input data and using Table 3 and Figure 2 of Hummer and Kunasz, we derive α(λ1239) $= 4$, α(λ1243) $= 2.4$, and ρ(λ1239) $= 15$, ρ(λ1243) $= 13$, and finally we obtain the dust optical thickness τ_d(λ1239) $= 0.27$, τ_d(λ 1243) $= 0.18$. We do not expect dust to have such a steep wavelength dependence, and thus we find no solution compatible with both lines of the same doublet.

That is, internal dust can be very effective in reducing the overall intensity of resonance lines, but it does not change significantly the relative ratio of N V or C IV resonance doublets.

b) *Effects of Absorption by the Generalized Interstellar Medium*

We will now examine the possibility that absorption by hot interstellar gas might be reducing the resonance line intensities, as well as altering the doublet intensity ratio.

Cowie, Taylor, and York (1981), in a survey of 46 distant stars, find a generally distributed hot ionized medium of density n(C IV) $= 2 \times 10^{-9} - 4 \times 10^{-9}$ cm^{-3} along the plane of the galaxy, and a higher value of $\sim 9 \times 10^{-9} - 18 \times 10^{-9}$ cm^{-3}, in the direction of HD 101131 ($\ell = 294^\circ\!.8$, $b = -1^\circ\!.6$), which is close to the direction of NGC 3918 ($\ell = 294^\circ\!.7$, $b = +4^\circ\!.7$). In general they do not detect absorption lines of N V λ1239 ($W_\lambda < 50$ mÅ), which sets a limit to the N V density of the generalized interstellar medium of n(N V) $< 5 \times 10^{-9}$ cm^{-3}. In some particular objects they find a large value of the N V column density; for these cases there seems to be no correlation with C IV.

TABLE 3

RESONANCE LINE INTENSITY RATIOS

Ion	Wavelength	Observed Ratio	Expected Value
C IV	1548/1551	1.9 ± 0.2 [a]	2.0
N V	1239/1243	1.2 ± 0.1	2.0

a. Ratio measured from the border of the image.

If we assume that the anomalous line intensity ratio of λλ1239/1243 is produced by absorption by N V ions in such generalized hot interstellar medium, we require the optical depth in the lines to be τ(λ1239) ~ 1 and τ(λ1243) ~ 0.5. For a medium of temperature T_e the column density is

$$N(\text{N V}) = 2 \times 10^{13}\ \tau(\lambda 1239)\ (T_e/10^5)^{1/2}\ \text{cm}^{-2}\,.$$

According to Spitzer and Jenkins (1975), the temperature of this medium is expected to be between 2×10^5 and 3×10^6 °K so adopting $T_e = 2 \times 10^5$ °K, we would require a column density N(N V) $= 3 \times 10^{13}$ cm^{-2}.

The distance to NGC 3918 has been derived by TPP, who obtained 1.3 kpc and by Cohen and Barlow (1980), who gave 0.8 kpc. These distances, for a uniform distributed gas, yield a spatial density of n(N V) $= 8 \times 10^{-9} - 13 \times 10^{-9}$ cm^{-3}. This value although higher is still compatible with the upper limit found by Cowie *et al.* (1981).

In a similar manner, we can derive a value for the C IV column density. From the atomic data of N V and C IV resonant doublets, we have

$$\frac{N(\text{C IV})}{N(\text{N V})} = 0.7\ \frac{\tau(\lambda 1548)}{\tau(\lambda 1239)}\ ;$$

that is, the ratio of column densitites is directly proportional to the ratio of optical depths in the lines. As mentioned earlier, our measurements of the C IV doublet are very uncertain since the lines were saturated, but if we adopt I(λ1548)/I(λ1551) $= 1.9$, as measured from the external pixels, the required value for τ (λ1548) is $\lesssim 0.1$ so, we find that our N V and C IV observations can be explained with a medium of

$$\frac{N(\text{C IV})}{N(\text{N V})} = 0.07.$$

This ratio is substantially lower than the value of N(C IV)/N(N V) $= 2$ predicted from time dependent ionization calculations of hot bubbles in the interstellar medium of normal cosmic composition by Castor, Mc Cray, and Weaver (1975).

The required value for τ(λ1548) is also incompatible with the optical depth in the C IV lines in the direction of HD 101131, which can be calculated from the results of Cowie *et al.* (1981). The measured C IV density in the generalized interstellar medium, yields for NGC 3918 a value for τ (λ1548) from 0.3 to 1, depending on the adopted distance; this value is higher than the upper limit of τ(λ1548) < 0.1 required to explain the normal doublet intensity ratio.

The only possibility to explain the different behavior of C IV and N V doublets is to assume that the interstellar medium in the direction of NGC 3918 is extremely N/C rich.

c) *Characteristics of a Possible Very Extended Envelope (VEE)*

It is generally thought that asymptotic red giant stars evolve into planetary nebulae. According to Renzini (1981), (see also Kwok, Purton, and FitzGerald 1978) there are two stages of mass loss: the wind phase and the superwind phase; the wind phase lasts about 10^6 years with a mass loss rate $\lesssim 10^{-6}$ $M_\odot$ yr^{-1}, while the superwind phase lasts about 10^3 years with a mass loss rate of 10^{-3} $M_\odot$ yr^{-1}

Giant low density haloes around PN have been observed at optical wavelengths (e.g., Millikan 1974) and they might have been produced during the later stages of the wind phase. It is possible that at even larger densities material ejected at the beginning of the wind phase and at even lower densities is presented forming a VEE. If such is the case in NGC 3918, our observations require that

$$\frac{N(N\ V)}{N(C\ IV)} = 14.$$

We can expect a nitrogen overabundance of a factor of $\sim$ 4 with respect to solar neighborhood values from the envelope of an asymptotic giant branch star (e.g., Peimbert and Torres-Peimbert 1971), also there might be some carbon enrichment although some carbon might be tied up in dust grains and not show up as gas. In addition to the N over-abundance we also need a somewhat higher degree of ionization than that provided by the models of Hummer and Mihalas (1970), this could be the case if there is some X-ray contribution to the ionization of the VEE from the central star of NGC 3918.

Since $\ell \sim 1$ pc and the column values are $N(N\ V) \sim 10^{13}$ cm^{-2} for the VEE then it follows that the required density is $N_e \sim 0.01$ cm^{-3}.

If this type of VEE is present we should expect similar situations to prevail around other PN. To check this suggestion, N V and C IV columns should be determined in the direction of stars located close in the sky to nearby PN, but farther away than them.

IV. SUMMARY

The mean density derived from our observations of NGC 3918, log $N_e = 3.7$, is in agreement with previous determinations. We found no evidence of systematic variations with ionization degree.

The N V λλ1239/1243 intensity ratio is equal to 1.2 ± 0.1, while the C IV λλ1548/1551 intensity ratio is 1.9 ± 0.2. More observations of this object should be performed to confirm these measurements.

We have tried to explain the low value of the resonant doublet ratio by analyzing several absorbing media. We find that:

a) Internal dust that absorbs trapped radiation can explain a decrease of the intensity of both lines, but it cannot explain a N V line ratio significantly different from 2.

b) The generally distributed hot gas in the interstellar medium can explain the N V ratio, but for normal conditions, we would expect the C IV doublet to be also affected.

c) We postulate a nitrogen enriched very tenuous gas in a very extended envelope surrounding the main planetary shell, as a possible mechanism for the anomalous ratio. This outer envelope, if indeed exists, should also become apparent in other planetaries.

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REFERENCES

Cassatella, A., Ponz, D., and Selvelli, P.L. 1981, *NASA IUE Newsletter No. 8*, 1.
Castor, J., McCray, R., and Weaver, R. 1975, *Ap. J.*, **200**, L107.
Cohen, M. and Barlow, M.J. 1980, *Ap. J.*, **238**, 585.
Cowie, L.L., Taylor, W., and York, D.G. 1981, *Ap. J.*, **248**, 528.
Feibelman, W.A. 1982, in *IAU Symposium No. 103, Planetary Nebulae*, ed. D.R. Flower (Dordrecht: D. Reidel in press.
Flower, D.R. and Nussbaumer, H. 1975, *Astr. and Ap.*, **45**, 145.
Harrington, J.P., Seaton, M.J., Adams, S., and Lutz, J.H. 1982, *M.N.R.A.S.*, **199**, 517.
Hummer, D.G. and Kunasz, P.B. 1980, *Ap. J.*, **236**, 609.
Hummer, D.G. and Mihalas, D. 1970, *JILA Report* No. 101.
Kwok, S., Purton, C.R., and FitzGerald, P.M. 1978, *Ap. J. Letters*, **219**, L125.
Mendoza, C. 1982, in *IAU Symposium No. 103, PLanetary Nebulae*, ed. D.R. Flower (Dordrecht: D. Reidel), in press.
Millikan, A.G. 1974, *A.J.*, **79**, 1259.
Moseley, H. 1980, *Ap. J.*, **238**, 892.
Nussbaumer, H. 1982, private communication.
Peimbert, M. and Torres-Peimbert, S. 1971, *Ap. J.*, **168**, 413.
Pequignot, D., Aldrovandi, S.M.V., and Stasinska, G. 1978, *Astr. and Ap.*, **63**, 313.
Renzini, A. 1981, in *Physical Processes in Red Giants*, eds. I. Iben Jr. and A. Renzini, (Dordrecht: D. Reidel), p. 431.
Spitzer, L. Jr. and Jenkins, E.B. 1975, *Ann. Rev. Astr. and Ap.*, **13**, 133.
Torres-Peimbert, S. and Peimbert, M. 1977, *Rev. Mexicana Astron. Astrof.*, **2**, 181 (TPP).
Torres-Peimbert, S., Peña, M., and Daltabuit, E. 1981, in *The Universe at Ultraviolet Wavelengths*, ed. R.D. Chapman, NASA CP-2171 (Paper I).

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