Astronomy Express, 1:3 *Received 1984 September 25*

NOVAE AND GALACTIC CHEMICAL EVOLUTION

Manuel Peimbert and Antonio Sarmiento
Instituto de Astronomía, Universidad Nacional Autónoma de México

Keywords: Stars-Novae Galaxies-Evolution Interstellar-Abundances

ABSTRACT
It is estimated that the ejected shell masses of novae are about one order of magnitude smaller than previously thought. The implications of this result for galactic chemical evolution are analyzed. It is found that novae may be important sources for the interstellar enrichment of ^{15}N but not of ^{14}N .

1. INTRODUCTION

Several authors have suggested that novae might be important sources of ^{7}Li, ^{13}C , ^{15}N, and ^{17}O enrichment of the interstellar medium (e.g. Truran 1982; Vigroux and Arnould 1979). Moreover Williams (1982) has suggested that novae might even be the main source of ^{14}N in the ISM of our galaxy and other galaxies. Alternatively Aller *et al.* (1981) argue that the planetary nebulae, PN, of the Small Magellanic Cloud contribute nearly enough N to enrich the ISM, but that massive stars may also be involved. The N produced by novae would be of primary origin while most of that produced by PN would be of secondary origin (Peimbert 1984). The difference has profound implications for models of galactic chemical evolution since according to Serrano and Peimbert (1983) most of the N in the ISM has to be of secondary origin in order to explain the galactic and extragalactic N/O versus O/H diagram. Primary elements are those that are directly synthesized from H and He, and secondary elements are those synthesized from heavier elements that were already present in the star when it was formed. It is the purpose of this note to reevaluate the relative importance of novae and PN for the enrichment of N in the interstellar medium of the galaxy.

2. MASSES EJECTED BY NOVAE

Since the pioneering work of Pottasch (1959) determinations of the mass ejected by novae outbursts cluster around 10^{-4} $M_\odot$ (e.g. Pottasch 1959, Williams 1982). Most mass determinations are based on the intensity of recombination lines (mainly Balmer lines) at times when they are optically thin and therefore depend on the density square, that is they are root mean square masses given by

$$M(\text{rms}) = \mu_e\, m_H \int N_e(\text{rms})\, dV, \quad (2.1)$$

where m_H is the mass of the hydrogen atom and μ_e is the number of atomic units of mass per free electron. μ_e is typically between 1.4 and 3 and is given by

$$\mu_e = \frac{N(H) + 4N(He) + 12N(C) + 14N(N) + \ldots}{N(H) + aN(He) + bN(C) + cN(N) + \ldots}, \quad (2.2)$$

where a,b,c, denote the number of free electrons provided by each atom. There are two other types of masses that can be derived: i) M(Local) which is based on the N_e(Local) density derived from two lines of the same ion that originate in different energy levels like λλ1663 and 5007 of OIII, and ii) M(ε) where it is assumed that only a fraction, ε, of the observed volume is filled with N_e(Local) and that the rest is empty. It can be shown that in the case of spatial density fluctuations (e.g. Peimbert 1966)

$$M(\varepsilon) = \varepsilon^{1/2} M(\text{rms}) = \varepsilon\, M(\text{Local}); \quad (2.3)$$

equations 2.1 and 2.3 apply to spheres as well as to shells and in the second case ε is the filling factor within the shell.

Snijders *et al.* (1984) have computed the gaseous mass of the shell of Nova Aquilae 1982 and have obtained an $M(\varepsilon) = 5\times10^{-6}$ $M_\odot$ and a filling factor $\varepsilon = 1.7\times10^{-5}$. This very low filling factor implies that most of the high density material responsible for the emission is in clumps, filaments or thin sheets and that the material in between is at much lower densities and presumably at higher temperatures. By considering the mass in the form of dust grains a total ejected mass of $\sim1\times10^{-5}$ $M_\odot$ is obtained (Snijders *et al.* 1984).

We have determined M(Local), M(rms) and M(ε) for Nova Cygni 1978 from the observations by Stickland *et al.* (1981) at D = 88 days. By assuming a homogeneous sphere expanding at v = 760 km s^{-1} a radius of 6×10^{14} cm is obtained, which together with N_e(Local) = 8×10^{7} cm^{-3} and the ionic composition given by Stickland *et al.* yields M(Local) = 9×10^{-5} $M_\odot$. It is possible to determine N_e(rms) from the recombination line fluxes of C II λ1335, C III λ2297 and N IV λ1718, corrected for reddening according to the normal extinction law by Seaton (1979), and equations of the type

$$N_e(\text{rms}) = \left\{ I(1335)\, \frac{N(H)}{N(C)}\, \frac{4\pi d^2}{V(C^{+2})\,\alpha(C^{+2})}\, \frac{\beta}{h\nu(1335)} \right\}^{1/2}, \quad (2.4)$$

where d is the distance to the object, β is the number of electrons per hydrogen atom in the region where the line is formed, α is the effective recombination coefficient for λ1335 and $V(C^{+2})$ is the volume where the line originates and for a homogeneous sphere is equal to V $N(C^{+2})/N(C)$ where V is the total volume. With the input data to eq.2.4 by Stickland *et al.* we obtain $N_e = 2.5\times10^{7}$ cm^{-3} which together with M(Local) and eqs. 2.1-2.3 yield M(rms) = $3\times10^{-5} M_\odot$, ε = 0.1, and M(ε) = 9×10^{-6} $M_\odot$. By adopting a higher velocity of expansion we would have obtained a larger volume for the nebular shell; it can be shown that: M(Local) $\propto$ V, M(rms) $\propto V^{1/2}$ and that M(ε) is independent of V. For this object the amount of mass in the form of dust grains is negligible (Gehrz *et al.* 1980) and since we obtain practically the same M(rms) at 88 days and at 304 days the amount of material expected in neutral form is also negligible.

Without a good knowledge of the density structure or the filling factor it is not possible to derive an accurate value for the shell mass of a given object. The often quoted value of 1×10^{-4} $M_\odot$ for the ejected shell masses is an rms value and consequently an upper limit to the real value. For Nova Aquilae 1982 and Nova Cygni 1978, where the filling factor was taken into account, the shell masses are $\sim10^{-5}$ $M_\odot$. Therefore we conclude that much more work is needed in this area but that 1×10^{-5} $M_\odot$ is a more representative value for the mass of the ejected shells than 1×10^{-4} $M_\odot$.

3. NITROGEN ENRICHMENT

We will assume that the N enrichment in the ISM is only due to PN and novae (for a discussion of other objects that also enrich the ISM with N see Serrano and Peimbert 1983), and that the mass of their progenitors is similar so that to a first approximation time delays, producing a differential enrichment, can be neglected.

3.1 Planetary Nebulae

Under the assumption that of the N due to PN in the ISM 20% comes from Type I and 80% from Type II objects, it is found that the chemical composition of PN ejecta is given by log N/H = −3.4 and that the total mass, M_{total}, and the H mass, M_H, are related by: $M_{total} = 1.5\ M_H$ (Peimbert 1981).

By adopting the Cudworth (1974) distance scale Alloin *et al.* (1976) found that the total number of PN in our galaxy is of 10,000, and estimate that they are visible during $\sim$30,000 years which implies that the PN rate of formation, $\dot{n}_{PN}$, is equal to $\sim$ 1/3 per year.

From the computations by Renzini and Voli (1981) and the initial mass function by Serrano (1978), Serrano and Peimbert (1981) estimate that the average ejected mass per object by PN progenitors is of $\sim$0.33 $M_\odot$. These estimates imply that PN inject $\sim$0.11 $M_\odot$ per year to the ISM. To estimate the N enrichment it is necessary to multiply the mass loss rate by the fraction of the ejected mass in the form of N. The results are presented in Table I. The $\dot{M}_N$ results for PN should be reliable within a factor of two.

3.2 Novae

The N/H ratio varies considerably from object to object, we will adopt log N/H = −1.7 as an average value (Williams 1982). The ratio of the total mass to the hydrogen mass of the ejecta also varies considerably from object to object, we will adopt $M_{total} = 3\ M_H$ (e.g. Snijders *et al.* 1984). From the previous considerations it is found that log M_N/M_{total} = −1.03.

To determine the novae production rate in our galaxy we can assume that our galaxy and M31 have the same ratio of PN to novae. Ford (1978) has estimated that the nova rate, $\dot{n}_N$, in M31 is of 38±5 per year; Jacoby (1980) has estimated that the number of PN in M31 is of 20,000 which together with the estimate by Alloin *et al.* (1976) yield $\dot{n}_N$=19 y^{-1}

TABLE I

ABUNDANCES AND MASS LOSS RATES FOR PN AND NOVAE IN THE GALAXY

Parameter	PN	Novae
log N/H	-3.4[a]	-1.7[b]
η	10,000[c]	...
$\dot{\eta}$(year^{-1})	1/3[c]	25[d,e]
$M_{ejected}(M_\odot)$	0.33[f]	1×10^{-5}[e]
$\dot{M}(M_\odot$ year$^{-1}) = \dot{\eta}$ M	0.11	2.5×10^{-4}
$\dot{M}_N = \dot{M}\ M_N/M_{total}$	4.1×10^{-4}	2.33×10^{-5}

[a]Peimbert 1981; [b]Williams 1982; [c]Alloin *et al.* 1976; [d]Ford 1978, Jacoby 1980, Truran 1982; [e]This paper; [f]Serrano and Peimbert 1981, Renzini and Voli 1981.

for our galaxy. If the number of PN in our galaxy is larger than estimated by Alloin *et al.* the value just derived becomes a lower limit. Other estimates of $\dot{\eta}$ are in the 20 to 30 range (e.g. Truran 1982), in what follows we will adopt a value of 25 y^{-1}.

To obtain the total N ejected by novae into the ISM we just need to consider the ejected mass per outburst, Mej, which according to §II is $\sim 1\times10^{-5}$ $M_\odot$. The results are presented in Table I. The main uncertainty in the $\dot{M}_N$ value probably is due to the ejected mass per outburst.

4. ^{15}N AND ^{13}C

We will compare the production of ^{15}N, ^{13}C and ^{17}O in nova outburst models with the observed ISM values. Since Mej is not well known, in this section we will use it as a free parameter.

Under the assumptions that PN and novae are the producers of ^{14}N in the ISM and that all the ^{15}N in the ISM is produced by novae the ^{14}N/^{15}N ratio may be expressed as

$$({}^{14}N_N + {}^{14}N_{PN})/{}^{15}N_N = \gamma, \qquad (4.1)$$

where the subscript N stands for novae. In what follows we will adopt a value of $\gamma = 300$ for the ISM (e.g. Wannier 1980). From Table I we note that the ratio of the N produced by novae to that produced by PN would be equal to unity if Mej were 1.77×10^{-4} $M_\odot$, therefore

$$ {}^{14}N_{PN}/({}^{14}N_N + {}^{15}N_N) = (1.77\times10^{-4} M_\odot/Mej) = \delta. \qquad (4.2)$$

Eqs. (4.1) and (4.2) yield

$$ {}^{14}N_N/{}^{15}N_N = (\gamma-\delta)/(\delta+1), \qquad (4.3)$$

which is plotted in Fig. 1 as a function of Mej.

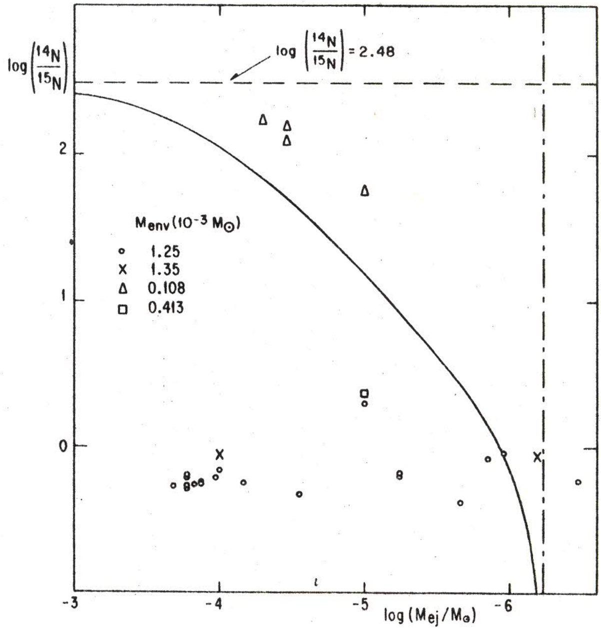

Fig. 1. $^{14}N/^{15}N$ in novae shells *versus* the ejected mass per outburst, Mej. The solid line gives the ratio needed to explain the abundances of the ISM under the assumptions that $^{14}N/^{15}N$ = 300 in the ISM and that novae have produced all the ^{15}N in the ISM. The horizontal line corresponds to the observed ISM value and the vertical line corresponds to the minimum Mej required to explain the ^{15}N in the ISM. Also in this figure we present the predicted $^{14}N/^{15}N$ values by nova outburst models (Starrfield *et al.* 1972, 1974, 1978) where we have indicated the mass of the stellar envelope.

Also in Fig. 1 we present the predictions made from nova outburst models by Starrfield *et al.* (1972,1974,1978). From Fig. 1 it can be seen that under the present assumptions most models can be disregarded since they predict an ^{15}N production far in excess to that given by eq. (4.3).

Under a similar relation to that given by eq. (4.3) for the $^{12}C_N/^{13}C_N$ ratio with $\gamma(C)$= 90 and $^{12}C/^{14}N$= 5 it can be shown that even if the models with a stellar envelope mass of 1.08×10^{-4} $M_\odot$, and Mej = 3.5×10^{-5} and $5\times10^{-5}M_\odot$, predict a reasonable ^{15}N abundance they would overproduce ^{13}C by about an order of magnitude with respect to the observed ISM value.

The only models that do not overproduce by a large factor ^{15}N or ^{13}C are those with Mej $\leq 10^{-5}$ $M_{\odot}$.

5. CONCLUSIONS

Most determinations of the mass ejected by novae are root mean square masses which in the presence of spatial density fluctuations overestimate the real value by $\varepsilon^{-\frac{1}{2}}$ where ε is the filling factor. For Nova Aquilae 1982 and Nova Cygni 1978, where the presence of spatial density fluctuations was taken into account, it was obtained that Mej $\sim 1\times10^{-5}$ $M_{\odot}$, a value an order of magnitude smaller than the typical values previously adopted.

By adopting an Mej = 1×10^{-5} $M_{\odot}$ and under plausible assumptions about physical parameters for PN and novae (see Table I) it is found that PN inject 17 times more N to the ISM than novae. Therefore the N produced by novae, which is of primary nature, does not play a role in explaining the N/O *vs.* O/H diagram.

The theoretical models with Mej $>10^{-5}$ $M_{\odot}$ either overproduce ^{15}N by two orders of magnitude or ^{13}C by one order of magnitude relative to the observed values in the ISM. The only models that are not in contradiction with observed ISM abundances are those with Mej $\leq 10^{-5}$ $M_{\odot}$. From these considerations it follows that novae might be an important source of ^{15}N, ^{13}C and ^{17}O enrichment of the ISM but not of ^{14}N.

It is a pleasure to acknowledge several fruitful discussions with M.J. Seaton and S. Torres-Peimbert.

REFERENCES

Aller, L.H., Keyes, C.D., Ross, J.E., and O'Mara, B.J. 1981, M.N.R.A.S., 194, 613.
Alloin, D., Cruz-González, C., and Peimbert, M. 1976, Ap. J., 205, 74.
Cudworth, K.M. 1974, A.J., 79, 1384.
Ford, H.C. 1978, Ap. J., 219, 595.
Gehrz, R.D., Hackwell, J.A., Grasdalen, G.L., Ney, E.P., Neugebauer, G., and Sellgren, K. 1980, Ap. J., 237, 855.
Jacoby, G.H. 1980, Ap. J. Suppl., 42, 1.
Peimbert, M. 1966, Ap. J., 145, 75.
Peimbert, M. 1981, in Physical Processes in Red Giants, eds. I. Iben Jr., and A. Renzini (Dordrecht: Reidel), p. 409.
Peimbert, M. 1984, Rev. Mexicana Astron. Astrof., in press.
Pottasch, S. 1959, Ann. Astrophys., 22, 394.
Renzini, A., and Voli, M. 1981, Astr. Ap., 94, 175.
Seaton, M.J. 1979, M.N.R.A.S., 187, 73p.
Serrano, A. 1978, Ph. D. Thesis, University of Sussex, England.
Serrano, A., and Peimbert, M. 1981, Rev. Mexicana Astron. Astrof., 5, 109.
Serrano, A., and Peimbert, M. 1983, Rev. Mexicana Astron. Astrof., 8, 117.
Snijders, M.A.J., Batt, T.J., Seaton, M.J., Blades, J.C., and Morton, D.C. 1984, preprint.
Starrfield, S., Truran, J.W., Sparks, W.M., and Kutter, G.S. 1972, Ap. J., 176, 169.
Starrfield, S., Sparks, W.M., and Truran, J.W. 1974, Ap. J. Suppl., 28, 247.

Starrfield, S., Truran, J.W., and Sparks, W.M. 1978, Ap. J., 226, 186.
Stickland, D.J., Penn, C.J., Seaton, M.J., Snijders, M.A.J., and Storey, P.J. 1981, M.N.R.A.S., 197, 107.
Truran, J.W. 1982, in Essays in Nuclear Astrophysics, eds. C.A. Barnes, D.D. Clayton, and D.N. Schramm (Cambridge: Cambridge University Press), p. 467.
Vigroux, L., and Arnould, M. 1979, in Les Elements et leurs Isotopes dans L'Universe, eds. A. Boury, N. Grevesse, and L. Remy-Battiau (Liege: Université de Liege), p. 47.
Wannier, P.G. 1980, Ann. Rev. Astr. Ap., 18, 399.
Williams, R.E. 1982, Ap. J., 261, L77.