SUPERNOVAE BLAST WAVES IN PROTO-DWARF GALAXIES

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Abstract: Gas mass loss in proto-dwarf galaxies can be efficiently driven out by blast waves created by the first generation of supernovae. There is, however, a threshold set by the total gravitational potential beyond which gas mass loss does not occur. This limit is in agreement with the one predicted by some Cold Dark Matter senarios.

I. Introduction: Supernovae explosions could explain the chemical and dynamical evolution of dwarf galaxies (Vader 1986, Wyse and Silk 1985; hereafter WS); and could provide an important clue to several outstanding cosmological questions such as the the origin of Lyman absorber clouds (Shields *et al.* 1987), a mechanism for bias galaxy formation and, therefore, a mechanism to differenciate between dwarf and normal galaxies (Dekel and Silk 1986). The mass loss process is expected to be strongly constrained by the overall gravitational potential of the galaxy; WS have shown that the condition for gas removal for a galaxy after one free-fall time and in terms of the one dimensional velocity dispersion σ_{1D}, is given by:

$$\sigma_{1D} \leq 0.58\left(n_{0\chi}^{3}\right)^{1/22} E^{4/11} G^{3/22} m_p^{1/22} M_{sn}^{-3/11} \qquad (1).$$

where $n = n_{tot}/\chi = n_0/1\mathrm{cm}^{-3}$ is the gas density; E is the supernova energy; M_{sn} is the mass in forming stars required to create one supernova; G is the gravitational constant and m_p the proton mass. For $\chi = 10$, $E = 10^{51}$ erg and $M_{sn} = 100 M_{\odot}$, $\sigma_{1D} \sim 57 n_0^{1/22}$ km s^{-1}, or in terms of the three dimensional velocity dispersion, $\sigma_{3D} \lesssim 104 n_0^{1/22}$ km s^{-1}, or a total mass of $\sim 10^9$ $M_{\odot}$. In these calculations we are interested in how the gas mass loss process depends on the total system mass, the amount of gas and the initial gas metallicity.

The effect of the first generation of stars, as a main mechanism to drive the gas mass loss in the presence of non- luminous matter (NLM), has been recently addressed by Dekel and Silk (1986), and it is in this context that we have calculated models of blast waves created by early supernovae in proto-dwarf galactic systems (see Noriega-Crespo and Bodenheimer 1987).

II. Models with NLM: Dwarf galaxies could be embedded in massive non-luminous halos (Aaronson 1986, Kormendy 1987). The luminous and non-luminous gravitational potentials were modeled by King distribution (King 1966). The gas dynamics in these potentials was followed by means of a one dimensional hydrodynamical code. The ratio between the luminous mass and NLM was chosen to be approximately 1/9 or 1/30; the ratio of their respective core radii was chosen to be $\sim 1/12$. The supernovae rate is assumed to be dominated by Type II supernovae. The number of massive stars($M > 20 M_{\odot}$) was initially determined from a Salpeter initial mass function, but essentially it was considered a free parameter. Since the King models

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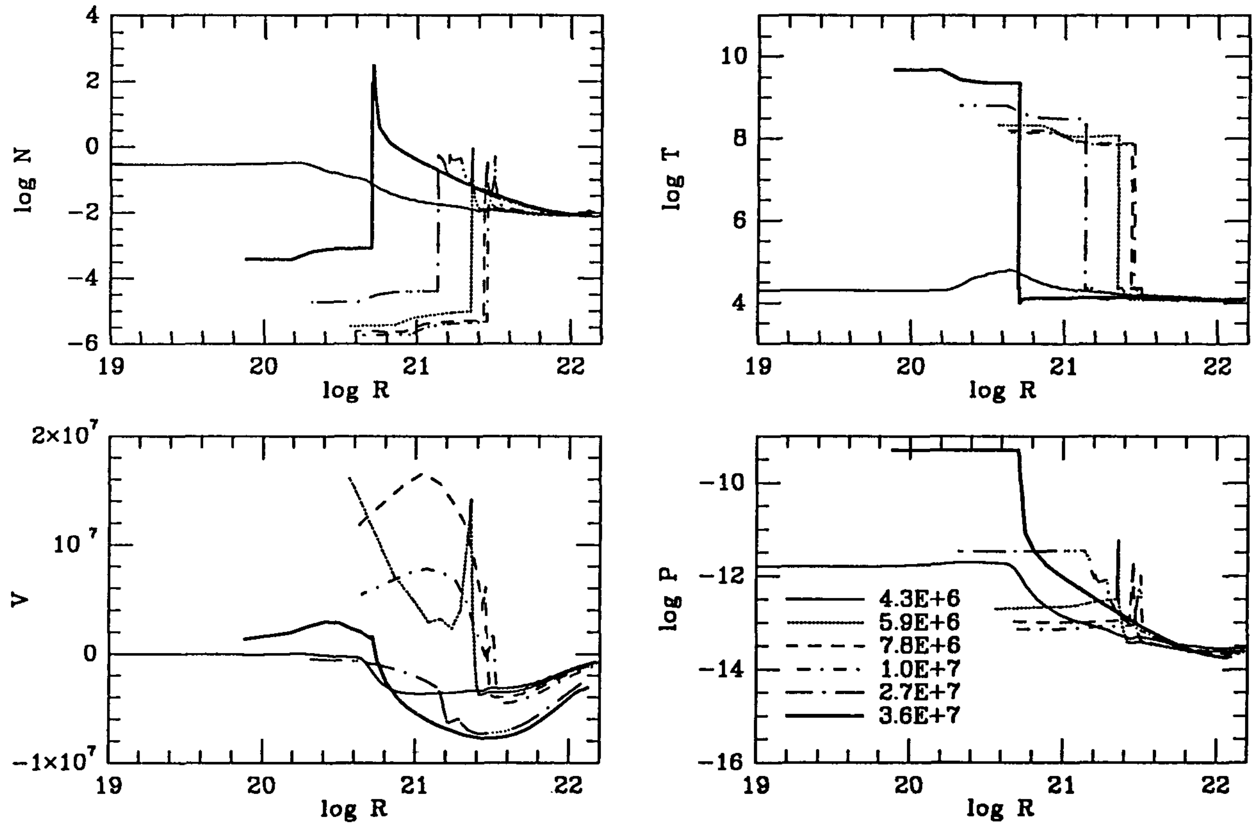

Fig. 1 The evolution of Case 3. Density in cm^{-3}, temperature in K, velocity in cm s^{-1} and pressure in dyne cm^{-2} are plotted as function of radius (in cm) at different times (in yrs). The initial time corresponds to the structure left by the HII region, at $\sim 4.3 \times 10^6$ yrs (thin solid line). The gas driven by the supernovae explosions moves outwards up to $\sim 2.7 \times 10^7$ yrs. After this time the evolution is dominated by the infalling gas; at $\sim 3.6 \times 10^7$ yrs, most of the gas is collapsing at large velocities (thick solid line).

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are characterized by a tidal radius, gas that flows beyond this radius has been removed from the model. The fraction of gas has been assumed to be comparable to the total mass in stars (see Table 1). All the cases have an ionizing flux of 2×10^{53} photons s^{-1}, an initial gas temperature of 3×10^3 K, a 5 kpc tidal radius, and a stellar component of 10^8 $M_\odot$.

Computed models are shown on Table 1. The models are in a "non-equilibrium" state, in the sense that the residual gas is initially assumed to be infalling although star formation has already begun. The photoinization of the gas was carried on for a time t_{sn} and then turned off. At this moment the supernovae energy was introduced.

Table 1. Supernovae in Proto-dwarf Galaxies with NLM

(1) Case	(2) ρ_0 g cm^{-3}	(3) Z $Z_\odot$	(4) M_{nlm} $M_\odot$	(5) M_{gas} $M_\odot$	(6) E_{sn} erg	(7) E_b erg	(8) t_{sn} yrs	(9) Mass Loss
1	1.3×10^{-26}	10^{-2}	9.0×10^8	$1. \times 10^8$	$2. \times 10^{55}$	7.9×10^{53}	4.9×10^6	yes
2	1.3×10^{-26}	1	9.0×10^8	$1. \times 10^8$	$2. \times 10^{55}$	8.0×10^{53}	4.8×10^6	no
3	1.3×10^{-26}	10^{-2}	3.0×10^9	$1. \times 10^8$	$2. \times 10^{55}$	2.5×10^{54}	4.3×10^6	no
4	4.2×10^{-27}	10^{-2}	3.0×10^9	3.2×10^7	$2. \times 10^{55}$	7.8×10^{53}	4.2×10^6	no
5	4.2×10^{-27}	1	3.0×10^9	3.2×10^7	$2. \times 10^{55}$	8.0×10^{53}	3.4×10^6	no

Column (1) gives the number of the case, (2) the central gas density in c.g.s units, (3) the gas metallicity, with Z = 1 for a solar abundance, (4) the total non-luminous mass of the model in solar masses, (5) the mass of gas in solar masses, (6) the supernovae energy in ergs,(7) the binding energy of the gas in the gravitational potential of the model in ergs,(8) the time in years, at which the supernovae energy was inserted in the model.

There is just one case from Table 1, Case 1, in which mass loss occurred because of a single blast wave. The escape velocity or, equivalently, the one dimensional velocity dispersion at the stellar core radius (1 kpc) for this case was ~ 60 km s^{-1}. The binding energy of the gas (E_b) was ~ 26 times smaller than the supernovae energy (E_{sn}). The mass gas loss process begins at $\sim 10^7$ yrs after the initial blast, and continues fairly rapidly. At $\sim 3.2 \times 10^7$ yrs, approximately 70% of the gas has been removed, and at $\sim 7. \times 10^7$ yrs $\sim$ 98% of the primeval gas has left the system. Case 1 behaves as expression (1) predicts. The importance of the initial gas metallicity is illustrated in Case 2, where for identical parameters as in Case 1 except for higher Z, gas mass loss did not occur in $\sim 10^8$ yrs because of increased energy loss by cooling.

Models more massive than Case 1 were calculated (Table 1), with total masses of $\sim 3.0 \times 10^9$ $M_\odot$, or an escape velocity of ~ 100 km s^{-1}. There was no gas mass loss in any of the cases during $\sim 4. \times 10^7$ yrs. In all cases the gas has stalled, turned around and collapsed. It could be argued, however, that the gas could bounce back from this collapse; this seems unlikely since at the last time calculated, the gravitational binding energy of the gas was several times larger

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than the kinetic and thermal energies; and energy losses by radiative cooling have become more important. The evolution of Case 3 is shown in Fig. 1. The supernovae energy was equivalent to 2×10^4 supernovae explosions (10^{51} erg per supernova). Since most of the mass of gas is accreted with velocities of ~ 30 km s^{-1}, just the innermost regions ($r \leq 1$ kpc) have expanded during the supernovae evolution. The maximum radius reached by the blast wave was less than 1 kpc.

III. Discussion: The idealized models that have been calculated are in agreement with expression (1) as long as the initial gas metallicity is low (Case 1). High metallicity increases the effect of radiative cooling and reduces the supernovae effect (Case 2 and 5). In models with total masses higher than 3.0×10^9 $M_{\odot}$, or escape velocity ~ 100 km s^{-1} for our King models, there was no gas mass loss. The models have concentrated in the first burst of star formation, and have assumed implicitly that star formation has been effective enough to transform at least 50 % of the gas into stars. For cases below the threshold where gas mass loss occurred,this seemed quite reasonable. For cases above the threshold, however, even though $\sim 90\%$ of the gas has been transformed into stars, and all the SN available from the IMF were used, there was no mass loss.

References.

Aaronson, M., 1986, in *Stellar Populations*, ed by C.A. Norman, A. Renzini, and M. Tosi. Cambridge University Press.

Dekel, A., and Silk, J., 1986, Ap. J., **303**, 39.

King, I., 1966, Astron. J. **71**, 64.

Kormendy, J., 1987, in *Nearly Normal Galaxies: From the Planck to the Present*, ed. S.M. Faber. New York: Spring-Verlag, in press.

Noriega-Crespo, A., and Bodenheimer, P., 1987, in preparation.

Shields, G., Silk, J., Wyse, R. F.G., 1987, preprint.

Vader, J.P., 1986, Ap.J., **305**, 669.

Wyse, R.F.G., and Silk, J., 1985, Ap. J. Lett., **296**, L1. (WS).

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