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Preliminary report

THE FUTURE OF GALAXIES AND THE FATE OF INTELLIGENT LIFE

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SUMMARY: We investigate the influence of recent advances in research on the gaseous content of the universe on our knowledge of star formation histories of spiral galaxies. The discovery of low-redshift population of absorbers and first steps made in understanding of the transition between high-redshift intergalactic and low-redshift galactic population of QSO absorption systems significantly reshape our picture of the gaseous content of the universe. It turns out that large quantities of gas which has not been astrated or astrated only weakly are bound to galaxies at later epochs, and present a potential reservoir of gas not only for solution of the gas consumption puzzle in spiral disks, but also a fuel for future star formation. This baryonic transition, although still hard to establish quantitatively, is a result of the simple physical processes. The resulting increase in the star formation timescales of spiral galaxies has some interesting consequences for the long-term future development of life and intelligent observers in the galactic context. Admittedly highly speculative, this qualitative picture may hopefully provide a motivation for detailed numerical modelling of the physical processes involved.

1. INTRODUCTION

> *Before the sun and the light, and the moon, and the stars are darkened and the clouds return after the rain.*
>
> **Ecclesiastes**, 12:2

Star formation histories of spiral galaxies are dominated by the interplay between incorporation of baryons into collapsed objects (stars, stellar remnants and smaller objects, like planets or dust grains) and return of baryons into diffuse state. The latter process can be two–fold: (i) mass return from stars to the interstellar medium (ISM) through stellar winds, planetary nebulae, novae and supernovae, which happens at the local level; and (ii) net global infall of baryons from outside of the disk (if any). The latter is far more controversial, since although the infall in the disk is visible through 21cm, optical recombination emission or absorption against high latitude stars, the compensating outflow is mainly hidden, being presumably very hot, X-ray emitting gas expelled from the disk by Galactic supernovae. It is easy to show (Sec. 3 below) that process (i) is insufficient to support continuous star formation for a time period similar to the Hubble time. Therefore, in investigation how long can the present *stelliferous epoch* (Adams and Laughlin 1997) in the history of the universe last, we have to take into account both of these processes. The availability of fresh gas for fueling the star formation must also be considered as a limiting factor for the length of this epoch.

The basic idea of the present paper is very simple: if the tendency of increase of the two-point correlation function (hereafter TPCF) with cosmic time continues, more and more intergalactic Lyα clouds will be accreted in galactic haloes. This process can not continue indefinitely, since the Hubble expansion will stop it at some time in the future. If we judge by rough analogy with the growth of primordial perturbations, this process of gravitationally inducing correlation will be slow and incomplete. Still, a large amount of baryons will be incorporated in galaxies in the gaseous state with very low metal abundances, which will eventually serve as a fuel for continuous star formation. This hypothesis necessarily includes a transitional stage in which the baryons are located in the extended gaseous haloes of normal galaxies, cooling and infallling toward the disk to be supported by its angular momentum. The exciting possibility is that these baryons are observed as the low-redshift higher column density Lyα and metal absorption line systems.

This process of baryonic accretion (and subsequent infall) certainly has important consequence for both the past and the future history of galaxies. Past influences could be read from the clues offered by chemical abundance patterns (Rana 1991). Future influences are interesting field of speculation, and may be of wider interest when we take into account that the future itself is defined by the advent of intelligent observers, namely ourselves. This is the purpose of the emerging branch of cosmology, *physical eschatology* which discusses final fate of the astrophysical objects and the fate of intelligent observers in the universe of far future. Since galaxies are the basic building blocks of the universe, it is natural to start any such discussion by galactic considerations.

The future of our Galaxy (and, by analogy, that of generic $L \sim L_*$ spiral galaxies) has been recently considered in a number of works motivated by the anthropic principle (see Barrow and Tipler 1986 for an encyclopedic discussion; relevant literature up to 1991 is gathered in Balashov 1991). Tipler (1986) has discussed cosmological limits on computation, beginning his analysis with the estimate of what could be called "Galactic lifetime", i.e. the timescale on which the stellar energy of Galactic stars presents a viable supply of energy for computational purposes of intelligent life. This is directly dependent on length of the star formation history of a typical L_* galaxy. Similar discussion in somewhat greater detail was recently given by Adams and Laughlin (1997). One unsatisfactory feature of these estimates for period of time remaining before "the sun and stars are darkened" is that they essentially use the closed box assumption, the same one which was shown to be false by the famous G-dwarf problem (Rana 1991, and references therein). Thus, in a sense, they present us with a *lower limit* on this quantity, which we shall call τ_R. In this paper, we would like to explore the maximal value of τ_R, as well as what influence various factors can play to modify these estimates.

The plan of exposition in this paper is as follows. We shall first discuss the fate of baryons seen as Lyα absorption line systems and indications for their transition from one physical population to another, before we attack the problem from the other, galactic side in the Sec. 3. Next necessary chains in our line of reasoning include the observed and theoretical concept of the baryonic infall in the disk from the halo (Section 5) considered on the example of the Milky Way, and a necessary speculative discussion of the rate of incorporation (Section 6) of Lyα cloud baryons into the disk, and its subsequent reinvigoration. Finally, last two sections are devoted to the discussion of consequences of prolonged star formation timescale on the galactic evolution and organization of intelligent life, anthropic considerations and prospects for obtaining detailed numerical models of the evolution of baryons in the universe.

2. TWO Lyα CLOUD POPULATIONS AND GALAXIES

The idea of two populations of the Lyα clouds in its modern form was recently discussed by Boksenberg (1995), Fernández-Soto et al. 1996 and Ćirković and Lanzetta (1999).[1] In short, the totality of existing observational data seems to be best explained with two distinct Lyα absorbing population: (i) tenuous, diffuse, intergalactic clouds showing no significant clustering, and (ii) a strongly clustered population (at small velocity scales) with higher median column density associated with normal galaxies. Population (i) seems to be predominant at early epochs, and original discussion of Sargent et al. (1980) mainly applies to this type of clouds; the same is true for models of Lyα forest as inhomogeneous IGM (e.g. Bi and Davidsen 1997). The clustered population (ii) dominates at low and, possibly, intermediate redshifts (Lanzetta et al. 1995; Chen et al. 1998). Obviously, there has to be a transition between the two populations, although, as we shall see, there is no reason to believe that baryon in the low-redshift halo population stays there forever as well.

The major tool for investigation of properties of these two populations is the TPCF. It was discussed in Fernández-Soto et al. (1996) in connection with the C IV absorption as indicator of the Lyα forest clustering. Songaila and Cowie (1996) also discuss clustering of the Lyα forest as inferred from the C IV measurements. The reason for this are manyfold difficulties inherent in the direct measurement of the small-scale TPCF amplitudes for the Lyα clouds themselves. Still, this task has been performed by Cristiani et al. (1997), and we review here one of their results of relevance for physical eschatology (see also Crotts 1989; Ćirković and Lanzetta 1999).

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[1] But see also Tytler (1987) for an interesting discussion of the population problem.

Before we present the argument for baryonic transition from a diffuse to a clustered form, we briefly review properties of low-redshift, clustered Lyα absorbing haloes. The spatial column density distribution of neutral hydrogen around galaxies in absorption-selected sample of Chen et al. (1998) can be written as

$$\log\left(\frac{N_{\rm HI}}{10^{20}\ {\rm cm}^{-2}}\right) = -\alpha \log\left(\frac{\rho}{10\ {\rm kpc}}\right) + \\ + \beta \log\left(\frac{L_B}{L_{B_*}}\right) + \gamma, \tag{1}$$

where α, β and γ are constants, which are equal to (with 1σ uncertainties) $\alpha = 5.33 \pm 0.50$, $\beta = 2.19 \pm 0.55$, and $\gamma = 1.09 \pm 0.90$. Such haloes extend to the distances of

$$R_{\rm max} = R_* \left(\frac{L_B}{L_{B_*}}\right)^{\zeta}, \tag{2}$$

where L_{B_*} is the fiducial B-band luminosity of Schechter (1976) L_* galaxy, and fiducial gaseous radius R_* and index ζ are constants to be determined from observations. Lanzetta et al. (1998) give the best-fit estimates as $R_* = 190 \pm 34\ h^{-1}$ kpc, and $\zeta = 0.40 \pm 0.09$. Small value for ζ is in accordance with the similar results for the luminosity scaling of metal-absorbing haloes obtained by Bechtold and Ellingson (1992) and Steidel, Dickinson and Persson (1994); see also a nice discussion in Steidel (1993). This is another argument in favor of the idea that both metal-line and Lyα forest absorbers predominantly belong to the same *galactic* parent population (at least at low redshift). The information contained in Eqs. (1) and (2) presents a powerful tool for investigation of the cosmic gaseous budget.

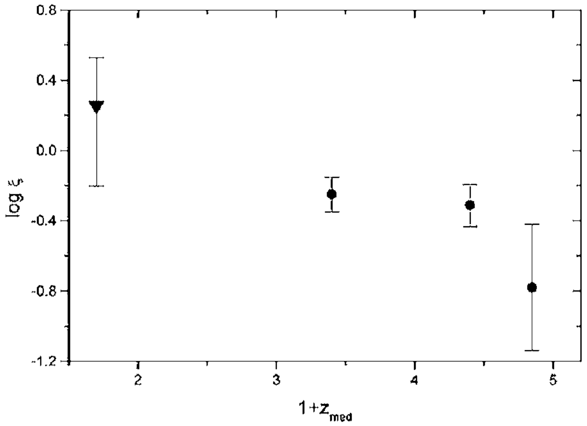

Fig. 1. *The redshift dependence of the TPCF amplitude in the first two ($v \leq 200$ km s^{-1}) velocity bins in the data of Cristiani et al. (1997) and Ulmer (1996).*

In Fig. 1, we show the redshift dependence of the average TPCF amplitude in the first two ($v \leq 200$ km s^{-1}) velocity bins of Cristiani et al. (1997). With $z_{\rm med}$ we denote the median redshift in each of the three redshift bins of Cristiani et al. (1997), which are represented by solid circles. A triangular point represents the result of Ulmer (1996) low-z analysis. It is not exactly comparable to the other points, since it represents clustering at velocity scales $250 \leq v \leq 500$ km s^{-1}, but we include it since it can be understood as the *lower limit* for the true clustering at $v < 250$ km s^{-1}. The trend of decreasing TPCF amplitudes with increasing redshift in Cristiani et al. (1997) sample is not noticed at $v > 200$ km s^{-1}, which can be accounted for, since only very weak clustering is expected above some maximum velocity dispersion $\sigma_{\rm max}$, which value is set by the physics of extended gaseous haloes.

This is certainly to be expected from the association with galaxies, since we confidently know that correlation of galaxies was smaller in the past. Since large galaxy surveys of our time have become available, such investigations were performed several times (Infante and Pritchet 1992; Bernstein et al. 1994) with clear result: amplitude of the small-scale clustering increased by a factor of ~ 2 from the $z = 0.3$ epoch to the present epoch ($z < 0.1$). It should be emphasized that the obstacles in precise quantification of this effect are enormous, and are discussed in detail in Bernstein et al. (1994). Also, but less significantly, the theoretical work on N-body simulations (e.g. Yoshii, Peterson and Takahara 1993) came to the same conclusion about the general trend of the galaxy TPCF evolution. Thus, increased clustering of the Lyα absorbers may be better understood in framework of the same physical processes which govern the evolution of clustering of normal galaxies. In this manner, as the cosmic time passes, more and more diffuse baryons become associated with galaxies. Observational discussion of these halo baryons in the local universe is given by Dahlem (1997). We shall return to the rate of this incorporation of baryons, but let us before try to answer the question of their fate after they are incorporated in a galaxy.

In the adiabatic halo models of Mo (1994) and Mo and Miralda-Escudé (1996), the hot ($T \sim 10^6$ K) phase remaining from the galaxy formation phase is experiencing slow transition to the cold ($T \sim 10^4$ K) clouds which sink in the galaxy gravitational potential until they eventually coalesce with the disk, and subsequently are supported by the angular momentum. Originally, this models considers only effects of mergers, and the resulting reheating of the halo gas. The natural extension of this model includes the mass accretion both in galactic mergers, and accretion of the IGM clouds (and, on really long timescales, the accretion of the ambiental IGM itself).

3. GAS CONSUMPTION PROBLEM

It is clear that accretion of baryons by galaxies should leave traces in the galactic structure and star formation history as well. We may identify these traces by investigation of Galactic chemical evolution, or by looking for the signs of evolutionary changes in galactic properties. The timescale of such changes should give us some hold on the characteristic timescales of star formation histories.

To the best of present knowledge (Mezger 1988; Young 1988), the star formation rate (hereafter SFR) in the Milky Way today is

$$\psi_0 \sim 5.1 \; M_\odot \; \mathrm{yr}^{-1}. \tag{3}$$

On the other hand, the return fraction of gas to the galactic ISM through mass-loss and supernovae, integrated over the classical Miller-Scalo (Miller and Scalo 1979) IMF is $r = 0.42$. This value gives the lockup rate (i.e. the rate at which ISM transformed into stars is permanently locked up in low mass and dead stars) as

$$\frac{dM_{\mathrm{star}}}{dt} = (1 - r)\psi(t) \sim 3.0 \; M_\odot \; \mathrm{yr}^{-1}. \tag{4}$$

As the Galaxy is $\sim 10^{10}$ years old, it should have used up $\sim 3 \times 10^{10}$ $M_\odot$ of interstellar gas during its history. Today's gaseous content of the galactic *disk* is estimated to several times 10^9 $M_\odot$. It is obvious that the present gas supply is going to be exhausted on the timescale short compared to the lifetime of the galaxy, as first pointed out by Tinsley and Danly (1980) and Larson et al. (1980). This is the (in)famous gas consumption problem in spiral disks. The average time scale for consuming all of the disk gas supply in the sample of Larson et al. (1980) is about 4 Gyr, in contradiction with the absence of significant evolution in the SFR on this scale (see also Tinsley 1980). For newer treatment which somewhat decreases the discrepancy, see Kennicutt, Tamblyn and Congdon (1995). If we wish to avoid resorting to an anthropic explanation (Barrow and Tipler 1986), it is necessary to invoke the existence of a reservoir for replenishing the disk gas supply. Larson et al. (1980) first postulated such fresh gas infall and estimated the relevant infall rates.

As far as the exponent of the power-law IMF is concerned, there is still no evidence of its variation (see a review by Richer and Fahlman 1998). It seems that some sort of infall would present desired solution, continuously providing fuel for ongoing star formation. An intriguing suggestion was made by Pfenniger et al. (1994), that steady SFR in a large, isolated spiral could be obtained in a natural way by the gradual extension of the physical size of the star forming disk. Extension of the optical disk into the regions with fresh gas would account for the exhaustion in the inner regions; since, at the same time, outer regions are thought traditionally to be dominated by dark matter, governing the dynamical properties of a galaxy, this would also explain flatness of the rotation curves obtained within the optical radius. In any case, this is a further suggestion along the line of thought that a significant fraction of the dark matter associated with galaxies is not only baryonic, but also gaseous in nature and subject to known physical processes, like the star formation.

The scenario exposed above gives *natural* source of infalling gas, and further numerical work may show whether the quantification of this proposition is realistic enough. It is consequent to assume that the gaseous halo is such a gas reservoir, rather than diffuse IGM or satellite systems (which tend to be gas-poor in general).

4. STAR FORMATION TIMESCALES

Characteristic timescale for the total gas exhaustion is in the first approximation given by (Adams and Laughlin 1997)

$$\tau = \frac{M_{\mathrm{gas}}}{\psi_0}. \tag{5}$$

As we have seen above, this timescale is short in comparison to the Hubble time. Thus, in a billion years from now—only a small fraction of the present age of the Galaxy—star formation will cease in the Milky Way. In fact, it will cease somewhat earlier, due mainly to the existence of star formation threshold at finite disk surface density (Kennicutt et al. 1995 and references therein). This universal bound which we shall not discuss in detail here applies to gaseous disks no matter how many additional processes we add to make our picture more realistic.

When we take recycling of gas into account we can write, as a conservative estimate,

$$\tau_R = \frac{M_{\mathrm{gas}}}{\dot{M}_{\mathrm{star}}} = \frac{M_{\mathrm{gas}}}{(1 - r)\langle \psi(t) \rangle}. \tag{6}$$

The increase thus obtained is a factor of 2–3 (somewhat more conservative than that proposed by Adams and Laughlin 1997). A further step is to assume that the SFR is proportional to the gas mass:

$$\psi(t) = p M_{\mathrm{gas}}(t), \tag{7}$$

where is the constant of proportionality in units of yr^{-1} (we may assume that other time dependencies, like the global metallicity, etc. are incorporated in value of p). There is some observational evidence that this assumption is correct (Gavazzi and Scodeggio 1996). For this case, the timescale becomes

$$\tau_R = \frac{1}{p(1 - r)} \ln \frac{M_0}{M_f}, \tag{8}$$

where M_0 is the initial quantity of gas in the galaxy, and M_f is the final mass of the gas when the star formation ceases. The question of the final mass is intimately connected with the problem of star formation thresholds, and will not be considered here. We only mention that, following the example of Adams and Laughlin (1997), we can obtain absolute upper limit to this timescale by extreme requirement $M_f \sim 1 \; M_\odot$.

If we now postulate gaseous infall characterized, over the period of time t_i by the infall rate $I(t)$ (in units of $M_\odot$ yr^{-1}), simple reasoning gives us the gaseous mass of the galaxy at any time t before the infall ceases ($t \leq t_i$) as

$$M_{\rm gas}(t) = e^{-p(1-r)t} \left[M_0 + \int\limits_0^t I(t) e^{a(1-r)t} dt \right] . \quad (9)$$

It is impossible to give a specific prediction for $I(t)$ without a comprehensive model of galactic gaseous haloes which has not been yet devised, so we shall have to discuss only a simplest case. For a constant infall rate $I(t) \equiv I$ ($t \leq t_i$), and $I(t) \equiv 0$ ($t > t_i$), the resulting timescale is given as

$$\tau_R = t_i + \frac{1}{p(1-r)} \ln \left[\frac{M_0 e^{-p(1-r)t_i} + \frac{I}{p(1-r)}}{M_f} \right] . \quad (10)$$

This is valid under the assumption that the infall rate is larger than the lock-up rate, $I > (1-r)\psi(t)$, which is probable (as we shall see in the next section). The scale t_i is determined by the halo gas depletion. If we denote gaseous halo mass with $M^g_{\rm halo}$, the simplest estimate for this parameter is

$$t_i = \frac{M^g_{\rm halo}}{I} = 10^{10} \left(\frac{M^g_{\rm halo}}{10^{11}\, M_\odot} \right) I_{10}^{-1} \text{ yr}, \quad (11)$$

where $I_{10} \equiv I/(10\ M_\odot$ yr). Of course, the quantity $M^g_{\rm halo}$ should be understood not as the quantity of gas *currently* present in the halo, but rather as the amount of gas *ever* to be in the halo. As we shall see below, this quantity can be limited from above by assuming the maximal incorporation of IGM clouds into galaxies in the far future. In more realistic calculations, which will be done in continuation of the present work, more realistic assumption of the monotonously decreasing infall rate will be considered, since the cooling process becomes very inefficient at low densities, and evacuation of the hot phase necessary leaves densities $\sim 10^{-4}$ cm^{-3}.

5. OBSERVED BARYONIC INFALL

Observational indications for the present-day baryonic infall are strong. The infall rate $\dot{M}$, when integrated over all infall velocities, and generalized from the existing observations, is quite large (de Boer and Savage 1984; Savage 1995):

$$\dot{M} \sim 46 f_i \left(\frac{R_d}{10 \text{ kpc}} \right)^2 M_\odot \text{ yr}^{-1}, \quad (12)$$

where f_i is the fraction of the galactic disk over which the inflow occurs, and R_d is the radius of the galactic disk. Since R_d is between 10 and 30 kpc (and probably closer to the latter value), the net infall rate is $\sim 2 \times 10^2 f_i$. It is certainly much larger than lock-up rate, except if the f_i is very small, on the order of $\sim 10^{-2}$. In that case, we run into "anthropic" troubles, since if the fraction of disk covered by inflow is so small, its very observation is highly improbable. It is, therefore, highly probable that inflow is partially compensated by large-scale outflow from the disk, as envisaged in various galactic fountain models (Shapiro and Field 1976; Corbelli and Salpeter 1988; Benjamin and Danly 1997). Unfortunately, observational evidence for such a large outflow is currently lacking. As far as such situation persists, inflow of the magnitude similar to one in Eq. (12) will cause an increase in the integrated disk mass of

$$\dot{\Omega} = 5.2 \times 10^{-3} f \left(\frac{\langle R_d \rangle}{10 \text{ kpc}} \right)^2 h \text{ Gyr}^{-1}, \quad (13)$$

where $\langle R_d \rangle$ is the average value of R_d taken over the Schechter luminosity function. Parameters of the Schechter function used for mass integration are chosen to be (Willmer 1997) $\varphi_* = 2.5 \times 10^{-2} h^3$ Mpc^{-3}, and $\gamma = 1.27$. Just for comparison, the total cosmological density in *visible* baryons is only (Persic and Salucci 1992):

$$\Omega_{\rm vis} \approx 2.2 \times 10^{-3} + 6.1 \times 10^{-4} h^{-1.3}. \quad (14)$$

From Eq. (13), we see that the numerical value of *uncompensated* inflow is between values of $\dot{\Omega}_{\rm max} = 3.7 \times 10^{-2}$ Gyr^{-1} ($\langle R_d \rangle = 30$ kpc, $f = 1$, $h = 0.8$) and $\dot{\Omega}_{\rm min} = 1.25 \times 10^{-4}$ Gyr^{-1} ($\langle R_d \rangle = 10$ kpc, $f = 0.1$, $h = 0.5$). It should be added that baryonic infall can help solve many different problems in astrophysics, particularly those with the baryonic dark matter (Carr 1994), faint galaxy counts (Phillipps 1993) or the galactic chemical evolution (Rana 1991), where the infamous G-dwarf problem invariably plagues all evolutionary models without infall. Infall models have been discussed since the early works of Sciama (1972) and Cox and Smith (1976). They are related, although should not be identified, with the models of protogalactic baryonic infall (e.g. Blumenthal et al. 1986).

6. RATE OF INCORPORATION

If we take a conservative viewpoint and insist that the presence of galactic absorption in even a fraction of the high-redshift Lyα absorption lines is unfounded, then the change in physical properties (notably mass) indicated by the changes (seemingly small) in the column density distribution function when we go from higher to lower redshifts. On the other hand, if we relax our assumptions and allow for early-formed gaseous haloes to represent a non-negligible fraction of the high-z Lyα absorbing population then the fascinating constancy of the parameters of the column density distribution (e.g. Kim et al. 1997) testifies on the (yet unknown) halo physics which determines sizes and densities of clouds.

In any case, we envisage the slow transition expressible in terms of the cosmological density fraction of a component i ($\Omega_i \equiv \rho_i/\rho_{\rm crit} = 8\pi G\rho_i/(3H_0^2)$) as

$$a\,\Omega_{{\rm Ly}\alpha} \rightarrow \Omega_{gg}, \qquad (15)$$

followed by

$$b\,\Omega_{gg} \rightarrow \Omega_{\rm stars}. \qquad (16)$$

Here, Ω_{gg} is the cosmological density fraction contained in the galactic gas, and $\Omega_{\rm stars}$ is the density in stars; a and b are fractions of the total mass undergoing transitions, $0 \leq a, b \leq 1$ and they are presumably functions of redshift and maybe some subtler parameters (like the morphological galactic type). The parameter a can, in principle, be determined from the temporal changes in clustering of Lyα clouds; i.e. the improved graph similar to the one in Fig. 1 should show not only the rate of baryonic incorporation, but also the asymptotic value of the fraction of absorbing clouds which will *ever* be clustered on the intragalactic velocity scales. Further research will be needed in this direction, since a fraction of gas may be bound to mini-haloes which is possible to account for (Chiba and Nath 1997). Such mini-halo gas may or may not ever be available for star formation; this is dependent on the same question of star formation threshols as is the parameter M_f in the discussion above.

The parameter b deals only with intragalactic physics and should be much easier to model. On very long timescales, except for the same threshold effects, b should approach unity, but the exact manner of its time-dependence requires better knowledge of the baryonic infall and its long-term effects on the galactic dynamics.

However, it is possible to limit the amount of gas which could, *under the ideal circumstances and irrespectively of any models* be used for star formation. The cosmological density in Lyα forest has been estimated by Weinberg et al. (1997) as

$$\Omega_{{\rm Ly}\alpha} = 0.02\,h^{-\frac{3}{2}}. \qquad (17)$$

Corresponding gaseous mass per L_* galaxy is $M \sim 1.8 \times 10^{11}\,h^{-\frac{5}{2}}\,M_\odot$. This represents the absolute upper limit to the baryon density which could be subsequently incorporated in galaxies. Although it is only an upper limit, it is interesting to calculate for how long can the star formation timescale be extended by this maximal infall. By using the approximate relations of the Sec. 4, we obtain

$$t_i = 1.8 \times 10^{10}\,h^{-\frac{5}{2}} I_{10}^{-1}\ {\rm yr}. \qquad (18)$$

For $h = 0.5$, the resulting timescale is close to

$$\tau_R = 10^9\,(102\,I_{10}^{-1} + 83.7 + 3.45\ln I_{10})\ {\rm yr}. \qquad (19)$$

This is valid under the assumption (discussed above) of $p(1-r) = (3.45 \times 10^9\ {\rm yr})^{-1}$ and $M_f = 1\ M_\odot$. We see that τ_R is smaller than about $(2-3) \times 10^{11}$ yrs. If we use the maximal value of the range for τ in Eq. (5) in the Kennicutt et al. (1995) sample, this timescale is increased by a factor of ~ 5, thus obtaining the value of $\tau_R \sim 10^{12}$ yrs. This is in accordance with the results of Tipler (1986) and Adams and Laughlin (1997), essentially confirming the conclusions that the average duration of the stelliferous era is about 1000 Gyr, we living at the very beginning of it.

7. DISCUSSION: FATE OF INTELLIGENT BEINGS

The gas consumption problem is, therefore, another instance in which we may regard present state of the universe as somewhat "special". In order to avoid special initial conditions and fine-tuning of the parameters, we may choose to regard the present rate of star formation and consumption of interstellar matter in the Milky Way as natural consequence of large-scale processes to which our presence as observers is incidental (à la Dirac), or to view it as a necessary requisite of the growth of complexity which is to include intelligent observers (à la Dicke). The latter view has the advantage of not explicitly requiring any new physical mechanisms, and moreover, we can give predictions on the course of star formation history of our Galaxy. The attempt to make these predictions as specific as possible, and their comparison with the models of chemodynamical evolution starting at the "first principles" is going to be subject of the subsequent work.

It should be emphasized that in all discussions of physical eschatology, it is significant to consider the fate of intelligent life, since all other lifeforms will almost certainly be extinct on shorter timescales by local processes (e.g. their sun's leaving the main sequence). Only intelligent beings could purposely manipulate the galactic resources as long as there is available energy. The epoch in which star formation in a typical galaxy like the Milky Way ceases is discussed by Tipler (1986; see also Barrow and Tipler 1986) and Adams and Laughlin (1997), as the first step in the "ladder of calamities" through which the global entropy increase is manifested, and which will present more and more difficult obstacles to survival and evolution of life and/or intelligent observers in galactic context.

It should be emphasized that from the very context of this discussion it is obvious that we do not consider Tipler's Final Anthropic Principle (FAP) seriously founded, while admitting the usefulness of the weaker versions of the anthropic principle. On the other hand, one is still able to search for the refutation of the FAP by finding a compelling physical reason for cessation of all intelligent life. Parenthetically, it seems that one such reason can be found in recently reported strong observational arguments in favor of a large ($\Omega_\Lambda \sim 0.7$) cosmological constant (Perlmutter et al. 1998; Reiss et al. 1998); if they are confirmed by new data, this would be the first proof that the universe will *necessarily* become uninhabitable at some finite point in the future. This constraint, however, lies extremely far in the future, and it is still interesting to search for constraints occuring at smaller timescales, on non-cosmological scales, like the one of a typical galaxy. As we have seen, the classical time-scales for degradation of a prototype galaxy could be substantially prolonged in comparison with the naive expectation (following from the gas cunsumption problem) $\tau \sim 1$ Gyr. In this sense, it becomes *less plausible* to attack the FAP on these timescales.

8. PROSPECTS

Apart from putting tighter constraints on the parameters of IGM accretion by galactic haloes and halo gas accretion by galactic disks, we shall, in the course of future work, investigate the consequences of this extension of star formation timescale for intelligent beings and their evolution in the Galaxy. One of the effects not taken into account here is the presence of star formation thresholds (Kennicutt et al. 1995), through which the stelliferous timescale is shortened. Another is the accretion of the disk gas by stars, the effect which is usually considered negligible in astrophysical discussions, but we can not be certain that this remains so over the vast timescales discussed in physical eschatology.

On the other hand, the major problem remains the determination of the incorporation rate of intergalactic baryons. In a project currently in preparation, we shall use a large sample of recent low-z data (Jannuzi et al. 1998) to measure the TPCF amplitudes at low redshift. This should give us a better hold on the rate of transition from intergalactic to galactic regime, and hence the relevant timescales. In a related work, we shall try to estimate the rate of cooling and infall of the gas from the halo within a specific, weakly non-adiabatic quasi-hydrostatic model of the galactic gaseous haloes.

In any case, it seems that we could approach the problem of future star forming histories (which our descendants will have, hopefully, to face in the far future) with somewhat greater optimism than it was the case until recently.

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БУДУЋНОСТ ГАЛАКСИЈА И СУДБИНА РАЗУМНОГ ЖИВОТА

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Претходно саопштење

Разматра се утицај недавних открића везаних за гасни садржај космоса на нашу слику историјата формирања звезда у спиралним галаксијама. Откриће апсорпционих система на малом црвеном помаку и први кораци учињени у правцу разумевања транзиције између интергалактичке популације апсорпционих система на високом црвеном помаку и локалне галактичке популације, значајно мењају наш поглед на количину и расподелу бариона у универзуму. Испоставља се да су велике количине гаса које никада нису биле астриране, или астриране само у врло малом степену, у познијим епохама везане за галаксије и представљају потенцијалне резервоаре гаса не само за решавање проблема потрошње гаса у спиралним галаксијама, већ и као горива за будуће формирање звезда. Овај барионски прелаз, мада још увек недоступан квантитативном разматрању, представља резултат сразмерно једноставних физичких процеса. Резултујуће продужење временске скале за формирање звезда има неке интересантне последице за будући развитак интелигентних бића у галактичком контексту. Иако веома спекулативна, ова слика може мотивисати детаљно нумеричко моделирање релевантних физичких процеса.