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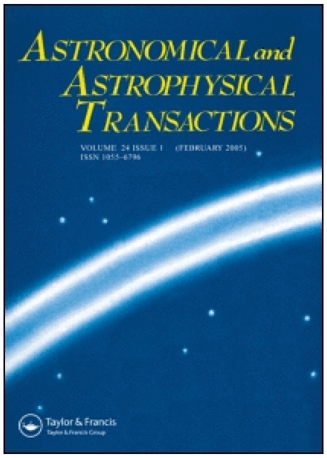

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METAL ENRICHMENT OF THE INTERGALACTIC MEDIUM

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METAL ENRICHMENT OF THE INTERGALACTIC MEDIUM

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Recent observations show the presence of metals in low-density Lyα forest absorbers at high redshift ($z \sim 3$). It remains still far from being clearly understood what mechanisms spread metals over Mpc scales from the parent galaxies, whether metals are homogeneously distributed in the intergalactic medium (IGM), how metallicity of the IGM does evolve. These questions are brifely addressed in this review.

Keywords: Cosmology: theory; Intergalactic medium; Quasars; Absorption lines

1 INTRODUCTION

During the last decade it became clear owing to cosmological hydrodynamic simulations that the Lyα forest is a result of the growth of large scale structure in the universe in the presence of UV field [1–4]. In this scenario the baryons in the universe form a network structure where most of gas and galaxies are accumulated in narrow and dense walls of the web, while the most of volume is filled with gas of lower density (close or below the mean cosmic baryon density). These under-dense regions are known as voids and represent the truly intergalactic medium, which is seen in the Lyα forest lines of the low column density end, $\log N(HI) < 14.5\,\mathrm{cm}^{-2}$.

First detections of metals in high-redshift ($z \sim 3$) Lyα forest systems with metallicity $[\mathrm{C/H}] \simeq -2.5 \pm 1$ were related basically to the intermediate range of column densities, $\log N(HI) \geq 14.5$ (cm^{-2}) [5, 6]. In 1998 two independent groups observed Lyα forest with lower column densities [$\log N(HI) < 14.5$], and using different observational techniques have reached controversary conclusions: Cowie and Songaila [7] with pixel-to-pixel optical depth observations reported on metal detection with $[\mathrm{C/H}] = -2.5$ at $z \simeq 3$ for $\log N(HI) = 13.5$; Lu *et al.* [8] with a stacking observations were only able to reach an upper limit $[\mathrm{C/H}] < -3.5$ for $\log N(HI) < 14$. In [9] the two techniques were critically analyzed and both found to suffer limitations. It was concluded, however, that the stacking is stronger subjected to smearing out due to a random redshift offset between the Lyα and CIV lines, and thus the amount of metals is underestimated. Instead, they found the pixel-to-pixel optical depth procedure to be more robust against the redshift offset, and the abundances obtained with using this technique more confident. Applying pixel-to-pixel

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measurements for the currently most sensitive Keck/HIRES spectra of QSO APM 08279+5255 ($z = 3.87$) [9] and Q1422+231 ($z = 3.625$) [10] the abundance of carbon in low-density ($\log N(HI) < 14.5$) Lyα forest was found as [C/H] $= -2.6$. Observations in OVI lines allow detection of absorptions from HI optical depths of one order of magnitude lower than CIV absorptions do, and thus can probe less dense Lyα gas. The first detection of OVI absorptions at $z = 2$–3 from underdense regions ($\rho/\langle\rho\rangle \leq 1$, which represent thus the true IGM) was reported in [11]. Very recently Songaila [12] has examined the presence of metals at highest redshift, and concluded that the column density distribution of CIV remains invariant up to redshift $z = 5.5$ where Lyα forest becomes thick, and the metallicity at this redshift exceeds $[Z] \simeq -3.5$. The invariancy of the CIV density distribution may indicate that analogously to lower z the metallicity of low density regions lies in same range. The presence of metals at high redshift gives direct evidences of stellar activity at early epochs in the universe corresponding to redshifts as high as at least $z > 5.5$. The question of a primary importance here is, however, how the metals were spread over Mpc scales in the IGM very far from the galaxies where they have been synthesized. The seriousness of this question becomes obvious if we formally divide the characteristic size of typical void of several Mpc over the Hubble time $t_H(z)$: at $z = 3$ this is $\sim 500\,\mathrm{km\,s^{-1}}$.

2 POP III OBJECTS AND SUPERNOVAE DRIVEN GALACTIC OUTFLOWS

Two episodes of metal enrichment of the Lyα forest absorbers are being discussed: early pre-enrichment by a widespread initial star formation, normally attributed to Pop III objects [13–16], and local enrichment at later stages either by star formation within the clouds themselves or by contamination from nearby galaxies [17]. The estimated amount of metals produced by the Pop III objects (presumably the first galaxies of small masses) is sufficient to pollute the IGM to an average metallicity from $\sim 10^{-4} Z_\odot$ [13–15] to $\sim 0.003\,Z_\odot$ [16]. The expected spatial distribution of metals is apparently very putchy, and strongly depends on the mixing processes. The amount of metals in a hot cavity produced by the exploded SNe in Pop III objects can reach 0.2–0.4 $Z_\odot$ [16] or even $\sim Z_\odot$ [18]. If however, the metals are mixed with the swept up shell, the resultant metallicity decreases by two orders of magnitudes to the level shown above. In general, the gas metallicity is $Z = M_Z/V_Z$, where M_Z is the total mass of metals ejected in the volume $V_Z = 4\pi R_e^3/3$, R_e is determined from the condition that the blowing out flow is confined by the IGM pressure

$$R_e = \sqrt{\frac{\dot{M}_e v_e}{4\pi P_{\mathrm{igm}}}}, \tag{1}$$

$\dot{M}_e$ is the mass ejection rate, v_e, the velocity of the outflow. Assuming $\dot{M}_e$ to be a fraction $\xi \sim 0.1$ of the star formation rate $\dot{M}_* \propto M_h$ [19], and $M_Z = \dot{M}_e \tau$ with τ being the period of star formation activity, and substituting for v_e the escape velocity for a dark matter halo of mass M_h and radius r_h: $v_e = \sqrt{GM_h/r_h}$, one arrives at the metallicity inversely proportional to galactic mass $Z \propto \tau(f M_h)^{-1}$ where $f = f(M_h)$ is the fraction of mechanical energy of the galaxy which can blow out, $f \simeq 1$ for galaxies of small masses $\Omega_b M_h < 10^9(1+z)^{-3/2} M_\odot$, and decreases for larger masses [18]. It is readily seen that even if the metals are mixed inside the blown out spheres, their spatial distribution in the IGM is highly non-homogeneous varying from one parent galaxy to the other. Thus, even in those cases when the volume filling factor of the blown out spheres is $q \sim 1$ and they are partially overlapped (see, *e.g.* [16]), an efficient mixing mechanism must be present in the early universe in order that the metals were distributed homogeneously. Note, however

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that metal enriched gas loses its energy radiatively very easily, forming due to thermal instability dense condensations, and thus preventing efficient mixing on smaller scales [20].

For low mass galaxies a few SNe explosions taking place in an OB-association of a moderate mass can be enough to drive a blowout. The situation changes in large galaxies, where due to increasing sizes and potential well ejection of shock processed gas becomes more difficult, so that most of metals remains confined to the galaxy. The fraction of mechanical energy f of the galaxy which can drive a blowout is [18]

$$f = \frac{\ln(N_M/N_c)}{\ln(N_M/N_m)}, \tag{2}$$

where N_M (N_m) is the maximum (minimum) possible number of SNe in OB-associations, $N_c = t_{\rm ob} L_c/\varepsilon_0$ is the critical number of SNe corresponding to the critical mechanical luminosity required for a blowout to occur (see [18])

$$L_c \sim 10^{14} c_h^2 \Omega_b \left(\frac{M_h}{M_\odot}\right)(1+z)^{3/2}\,{\rm erg\,s^{-1}}, \tag{3}$$

c_h is the sound speed in gaseous galactic halo, $t_{\rm ob} \sim 30$ Myr, the life time for the lowest SNe progenitor mass, $\varepsilon_0 = 10^{51}$ erg. Thus, f vanishes logarithmically when N_c is approaching N_M. Assuming that N_M does not depend on galactic mass, one can obtain the critical galactic mass above which blowout events are inhibited. For $N_M = 10^3$ and $c_h \sim 100\,{\rm km\,s^{-1}}$ the critical mass is $\Omega_b M_h \sim 10^{11}(1+z)^{-3/2} M_\odot$, meaning that more massive galaxies do not contribute to the enrichment of the IGM and the main pollutors are the low mass galaxies.

The volume filling factor of the regions containing the blown out material remains always much less than one, $q \sim 10^{-4}$ [18], only if most of the galaxies experienced a starburst regime the corresponding filling factor may reach $q \gtrsim 0.2$ [16]. Thus, if metals in the IGM are distributed relatively homogeneously, one has to assume that efficient mixing mechanisms were acting in the early universe. In this connection, it is interesting to note that observations of the local Lyα forest place limits on metal spread within 150–200 kpc from the galaxy [21].

3 TURBULENT MIXING

It was suggested in [17] that metals are transported predominantly by violent gas flows following galactic mergings. This idea was further developed in [18] where peculiar motions of galaxies and subgalactic halos were shown to power efficiently turbulent flows of the ejected gas. The diffusion coefficient needed for an efficient mixing can be estimated by requiring that in proper Hubble time $t_H(z)$ turbulence spreads metals over the characteristic distance between galaxies $\sim 150h^{-1}(1+z)^{-1}$ kpc [16], where $h = H_0/100\,{\rm km\,s^{-1}\,Mpc^{-1}}$: $\kappa \sim 6 \times 10^{29} h^{-1}(1+z)^{-1/2}\,{\rm cm^2\,s^{-1}}$. In [18] the turbulent diffusion coefficient was estimated approximately as $\kappa_t \sim \Omega_b^{-1} c_s^2 t_J$, where c_s is the sound speed in the IGM, $t_J = (N_h \lambda_J^2 \sigma)^{-1}$, the characteristic time interval between subsequent encounters of the halos onto a Jeans sphere in the IGM, λ_J is the corresponding Jeans length, N_h, the number of dark halos in unit volume, σ is their velocity dispersion. For the IGM temperature $T \simeq 2 \times 10^4$ K and a comoving number density of dark halos of $70h^3\,{\rm Mpc^{-3}}$ (corresponding approximately to $M_h \sim 10^8 h^{-1} M_\odot$) [16], one can estimate $\kappa_t \sim 4 \times 10^{29} h^{-1} m^{-1}\,{\rm cm^2\,s^{-1}}$, m is Mach number of halos in the IGM. As a consequence, the turbulent zones are shown to get partially over-laped at $z \sim 1$, and reach the porosity $q \simeq 1$ at $z \sim 0$ [18]. However, metals still remain

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distributed rather inhomogeneously, only at $z \sim 0$ the scatter is $0.03\,Z_\odot$ around the mean value $0.1\,Z_\odot$, while at $z \sim 3$ it is more than two orders of magnitude. Thus, even under such a strong diffusivity the enriched regions keep the identity of the parent galaxy produced pollution.

4 RADIATION PRESSURE

Dust particles ejected from galaxies by radiation pressure can be one of the possible sources of metals in the IGM. This possibility was first discussed in [22] with a negative conclusion. Detailed study initiated in [23] showed instead that the galactic radiation field is sufficient enough to expell dust particles in a relatively short time $\sim 10^8$ yr at high distances from the plane, practically into the intergalactic space. In [24] dynamics of radiatively ejected dust were considered with incorporation the effects of grain destruction. The characteristic column density $N(H)$ needed for destruction of a grain with radius a is $N_d(H) \simeq 4\rho a/Y_s m_T$, where $\rho = 3\,\mathrm{g\,cm^{-3}}$ is the grain density, Y_s is the angle-averaged sputtering yield, m_T, the target mass. For a fast moving grain, $v_g > 100\,\mathrm{km\,s^{-1}}$, $Y_s \sim 0.1$ in collisions with helium, and $Y_s \sim 0.01$ in collisions with hydrogen [25, 26]. Substituting here $m_T \sim 20 m_H$ one obtains $N_d(H) \sim 3 \times 10^{20}(a/0.1\,\mu\mathrm{m})\,\mathrm{cm^{-2}}$, which determines a lower limit for the grain sizes to be survived: the vertical galactic column density should be smaller than the critical value, $N(H) < N_d(H)$. The critical column density $N_d(H)$ for $a = 0.1\,\mu$m is practically coincident with the maximal vertical column densites of hydrogen and electrons in the Milky Way. Fast particles of smaller sizes can survive only if they start at $z \geq 500$ pc above the plane. One should stress, however, that at lower distances from the plane, $z < 200$, dust particles move much slower, $v_g \ll 100\,\mathrm{km\,s^{-1}}$ [27], so that Y_s drops sharply by several orders of magnitude.

For a destroying grain the extinction and radiation pressure decrease as a, resulting in decrease of the velocity of the ejected particle: for graphite and silicate particles of the initial radius $a = 0.1\,\mu$m, starting at $z = 1$ kpc above the galactic plane, their asymptotic velocities at time $\sim$100 Myr drop from $\sim$1600 to $800\,\mathrm{km\,s^{-1}}$, and from $\sim$700 to $\sim 350\,\mathrm{km\,s^{-1}}$, respectively, when dust destruction is taken into consideration [24]. However, after $t \sim 1$ Gyr the corresponding distances can reach $\sim$1 Mpc for graphites, and $\sim$0.7 Mpc for silicates. Thus, at redshift $z \sim 3$ radiatively driven $0.1\,\mu$m dust particles can, in principle, transport metals from galaxies into the IGM over Mpc scales. Smaller particles, though, are strongly confined to galactic disks mainly by collisional drag, so that both graphite and silicate grains with the initial radius $a = 0.01\,\mu$m can reach in 1 Gyr only $\sim$20–30 kpc from the disks [24]. The resulting steady distribution of the density of dust particles is highly nonuniform, with $\rho_d \sim 10^{-30}\,\mathrm{g\,cm^{-3}}$ at $r \sim 30$–60 kpc, and $\rho_d \sim 10^{-32}$ $r \sim 120$ kpc, which is steeper than r^{-2}.

Therefore, only large particles can be efficient in spread of metals in the IGM. For a galaxy with radiation flux G in Habing units ($1.6 \times 10^{-3}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$), and gravitational acceleration g (in $10^{-9}\,\mathrm{cm\,s^{-2}}$), only grains with $a < 0.2\;G g^{-1}\,\mu$m can be radiatively ejected. Assuming $g \propto M/R^2$ and $G \propto M$, one can find for galaxies satisfying a Tully-Fisher relation with $R \propto M^{1/3}$ that only grains of radius $a < 0.1(M/M_{\mathrm{MW}})^{2/3}\,\mu$m can be ejected, M_{MW} is the mass of the Milky Way galaxy. As soon as the sizes of dust particles are restricted from below in order that they were survived when being ejected, one can conclude that only massive galaxies are efficient in pollution of the IGM with metals. Note however, that if at smaller distances from the plane dust particles are transported by slow hydrodynamic motions, such that the sputtering yield remains $Y_s \ll 0.01$, and only at higher distances, $z \gtrsim 500$ pc, they are accelerated by radiation pressure to high velocities, $v_g > 100\,\mathrm{km\,s^{-1}}$, the lower limit can be as small as $a < 10\,$Å. At such conditions a still considerable mass fraction of

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dust (for a standard size distribution) can be expelled into the IGM. Quite recently this mechanism was explored in framework of large scale cosmological simulations [28]. It is worth noting, that spatial distribution of dust (and as a consequence, metals in gas phase) is demonstrated in these simulations to be highly inhomogeneous: at $z = 3$ low density regions [with $N(HI) < 10^{15}\,\mathrm{cm}^{-2}$] show metallicities in the range $Z = 10^{-5}$–0.1 (absolute values). It is quite similar to the predictions of [18] based on a model of turbulent mixing.

Regular magnetic field in the insterstellar medium can change the picture crucially. Dust grains in diffuse intercloud gas exposed to the ionizing radiation field are positively charged up to $\sim 200\,e$ [29]. The corresponding gyro-radius of a grain is $r_g = m_g c v_g / Z_g e B \sim 3 \times 10^{15}\,\mathrm{cm}$ for $a = 0.1\,\mu\mathrm{m}$, $v_g = 10^6\,\mathrm{cm\,s}^{-1}$ (typical velocity dispersion in the intercloud gas), and $B = 1\,\mu\mathrm{G}$. It was suggested in [30] that due to fluctuations of charging processes dust grains spend considerable time intervals in a neutral state. However, characteristic charging times for a grain with $a \sim 0.1\,\mu\mathrm{m}$ are very short: $\sim 10^2$–10^3 s, for charging due to photoemission of electrons and recombination of electrons on the grain, so that the equilibrium between the two processes provides the grain charge of the order of $200\,e$. At these conditions, the probability of a fluctuation which can neutralize such a high grain charge is negligible. It is obvious that even in dwarf galaxies where magnetic field seems to be weaker, the gyro-radius remains much smaller than characteristic galactic scales. Note however, that recent polarimetric observations show that dwarf galaxies can posses a sufficiently strong magnetic field: $\sim 8\,\mu\mathrm{G}$ in NGC 4449 [31]. This means that dust particles are strongly confined to magnetic field, and thus can be ejected out of galactic disks only in those regions where magnetic field has a predominantly vertical component. In spiral galaxies (and in those dwarfs with sufficiently strong magnetic field) such a vertical magnetic field can form due to the Parker instability, which in turn can be initiated easily by SNe explosions with the total explosion energy much less than required for a blowout [32, 33]. At latest stages (typically 100 Myr) growing magnetic loops seem to connect to the infinity, and thus provide corridors for photoejection of dust. Under certain conditions the Parker instability can be initiated by radiation pressure acting on dust particles, as mentioned in [30] and recently investigated numerically in [34].

The effects of magnetic field are also important in those cases when dust particles are confined in clouds or clumps, for which the charge to mass ratio is zero, and correspondingly $r_g = \infty$. In this case the proper magnetic field of clouds is connected to the galactic magnetic field, so that magnetic tension $(\mathbf{B} \cdot \nabla)\mathbf{B}/4\pi \gtrsim 3 \times 10^{-33} B_{\mu\mathrm{G}}^2$ [for $|\nabla| \sim (100\,\mathrm{pc})^{-1}$] is always larger than momentum transfered from radiation field $\sim 3 \times 10^{-36} G n$, where G is in Habing units, and the abundance of dust is taken 10^{-12}.

5 CONCLUSIONS

Detection of metals in low column density Lyα forest absorbers seem to imply that efficient ejection and transport mechanisms are at work at high redshift. The nature of these mechanisms is not yet clearly understood. Nevertheless, recent studies have largely enlightened the problem, and can be summarized as:

1. At early stages metals ejected into the IGM are confined relatively close to the pollutant galaxies by the IGM pressure. The volume filling factor can be large only when the star formation efficiency is high, corresponding to a starburst mode. However, even in this case spatial distribution of metals is highly inhomogeneous – inversly proportional to the mass of a pollutant galaxy.

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2. In order to make the distribution more smooth and widespread, efficient mixing mechanisms must have been acting. Of these mechanisms turbulent mixing by tidal interactions of galaxies may be quite a powerful, resulting in a large volume filling factor of metal enriched IGM. In this case the spread in metallicities is smaller, but still can be as large as two orders of magnitude at $z \sim 3$, and about $\pm 0.03\ Z_\odot$ at $z = 0$. In both these cases though, an enhanced radiative cooling of the metal enriched gas initiates growth of dense condensations through thermal instability, which prevents smooth redistribution of metals, thus exacerbating the mixing problem.
3. Similar distribution is expected also if the IGM is enriched through radiatively driven ejection of dust from galaxies. However, not all is clear here. In particular, such questions as: what fraction of dust particles can be expelled into the IGM from deep regions of the galactic disks, with $N(H) > N_d(H)$ where they are mainly produced; how galactic magnetic field affects this process; how the ejection efficiency varies with redshift – are still to be answered.

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References

[1] Petitjean, P., Mücket, J. P. and Kates, R. E. (1995). *Astron. & Astrophys.*, **295**, L9.
[2] Hernquist, L., Katz, N., Weinberg, D. H. and Miralda-Escudé, J. (1996). *Astrophys. J.*, **457**, L51.
[3] Zhang, Y., Meiksin, A., Anninos, P. and Norman, M. L. (1998). *Astrophys. J.*, **495**, 63.
[4] Rauch, M. (1998). *Ann. Rev. Astron. & Astrophys.*, **36**, 267.
[5] Cowie, L. L., Songaila, A., Kim, T. and Hu, E. M. (1995). *Astron. J.*, **109**, 1522.
[6] Tytler, D., Fan, X. M., Burles, S., Cottrell, L., Davis, C., Kirkman, D. and Zuo, L. (1995). QSOs absorption lines. In: Meylan, G. (Ed.), *Proc. ESO Workshop.* Springer, Heidelberg.
[7] Cowie, L. L. and Songaila, A. (1998). *Nature*, **394**, 44.
[8] Lu, L., Sargent, W. L. W., Barlow, T. A. and Rauch, M. (1998). preprint, astro-ph/9802189.
[9] Ellison, S. L., Lewis, G. F., Pettini, M., Sargent, L. W. L., Chaffee, F. M. and Irwin, M. J. (1999). *Astrophys. J.*, **520**, 456.
[10] Ellison, S. L., Songaila, A., Schaye, J. and Pettini, M. (2000). Cosmic evolution and galaxy formation: Structure, interactions and feedback. In: Franco, J., Terlevich, E., López-Cruz, O. and Artexaga, I. (Eds.), *ASP Conf. Series.* **Q1**
[11] Schaye, J., Rauch, M., Sargent, W. L. W. and Kim, T.-S. (2000). *Astrophys. J.*, **541**, L1.
[12] Songaila, A. (2001). *Astrophys. J.*, **561**, L153.
[13] Gnedin, N. Y. and Ostriker, J. P. (1997). *Astrophys. J.*, **486**, 581.
[14] Miralda-Escudè, J. and Rees, M. J. (1997). *Astrophys. J.*, **478**, L57.
[15] Nath, B. and Trentham, N. (1997). *Month. Not. Roy. Astron. Soc.*, **291**, 505.
[16] Madau, P., Ferrara, A. and Rees, M. J. (2001). *Astrophys. J.*, **555**, 92.
[17] Gnedin, N. Y. (1998). *Month. Not. Roy. Astron. Soc.*, **294**, 407.
[18] Ferrara, A., Pettini, M. and Shchekinov, Yu. A. (2000). *Month. Not. Roy. Astron. Soc.*, **319**, 539.
[19] Ferrara, A. and Tolstoy, E. (2000). *Month. Not. Roy. Astron. Soc.*, **313**, 291.
[20] Dedikov, S. and Shchekinov, Yu. A. (2002). *Astr. Rept.* (submitted).
[21] Penton, S. V., Stocke, J. T. and Shull, J. M. (2002). *Astrophys. J.*, **565**, 720.
[22] Pecker, J. C. (1972). *Astron. and Astrophys.*, **18**, 253.
[23] Ferrara, A., Ferrini, F., Franco, J. and Barsella, B. (1991). *Astrophys. J.*, **381**, 137.
[24] Shustov, B. M. and Vibe, D. Z. (1995). *Astron. Rept.*, **39**, 578.
[25] Draine, B. T. and Salpeter, E. E. (1979). *Astrophys. J.*, **231**, 77.
[26] Draine, B. T. (1995). *Astrophys. Space Sci.*, **233**, 111.
[27] Dettmar, R.-J., Schröer, A. and Shchekinov, Yu. A. (1999). *Proc. 26th ICRC*, 298 p.
[28] Aguirre, A., Hernquist, L., Katz, N., Gardner, J. and Weinberg, D. (2001). *Astrophys. J.*, **556**, L11.
[29] Ferrara, A. and Dettmar, R.-J. (1994). *Astrophys. J.*, **427**, 155.
[30] Ferrara, A. (1998). The local bubble and beyond. In: Breitschwerdt, D., Freyberg, M. J. and Trümper, J. (Eds.), *Lecture Notes in Physics*, Vol. 506, 371 p.
[31] Chyzy, K. T., Beck, R., Kohle, S., Klein, U. and Urbanik, M. (2000). *Astron. Astrophys.*, **355**, 128; **356**, 757.
[32] Kamaya, H., Mineshige, S., Shibata, K. and Matsumoto, R. (1996). *Astrophys. J.*, **458**, L25.
[33] Steinecker, A. and Shchekinov, Yu. A. (2001). *Month. Not. Roy. Astron. Soc.*, **325**, 208.
[34] Kopp, A. and Shchekinov, Yu. A. (2002) (in preparation).