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GREAT ATTRACTOR AS A TEST OF COSMOLOGICAL MODELS

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SISSA Ref. 186/92/A (Oct 92)

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ABSTRACT

Modelling of the Great Attractor as a large scale peak of the adiabatic Gaussian perturbations is perfomed in the framework of two-component (dark matter and baryons) Universe. The conditions of realization of such peaks and their observational displays in different cosmological models are investigated.

Subject headings: great attractor: gaussian peaks: contraflows: X-ray emision: CMB anisotropy

1. Introduction

The discovery of the considerably large scale disturbations of the Hubble expansion in the neighbourhood of Local Group of galaxies became the most important result in the observational cosmology of last years. More then 15 years ago Rubin et al. (1976) discovered a large peculiar velocity of the Local group ($\approx 450 km/s$) for the sample of 96 spirals at distances up to $\approx 50h^{-1}Mpc$ (H=100 h km/s/Mpc is the Hubble constant). Collins, Joseph & Robertson (1986) found that the peculiar velocity in this region has a still more value ($\approx 970 km/s$).

From analysis of the sample of 400 elipticals in the region $\approx 40h^{-1}Mpc$ Dressler et al. (1987) and Lynden-Bell et al. (1988) revealed the internal structure of the flow: the large scale motion has a character of roughly convergent infall toward the centre, the Great Attractor (GA). Faber & Burstein (1989) included in the analysis other samples containing spirals and confirmed the convergent character of the large scale flow, as well as made more accurate determination of the flow parameters: the distance of the Local Group from the GA centre $r_{LG} = 42h^{-1}Mpc$ and the peculiar velocity $U_{LG} = 535 km/s$. The new data of Burstein, Faber & Dressler (1990), Dressler & Faber (1990a,b) and Mathewson (1990) indicated the existence of galaxies with negative peculiar velocities beyond the GA centre.

Such a big scale flow of galaxies is a serious problem for the theory of origin of the large-scale structure of the Universe. In most general view prompted by theory and observations today, the structure forms due to gravitational growth of initially small random Gaussian density fluctuations. The peculiar velocities in the GA region are long correlated and considerably larger than the r.m.s. one's predicted in theory. Additional difficulties of GA interpretation arise when explaning the roughly spherical convergent flow with an increasing velocity toward the centre (Bertschinger & Juszkiewicz 1988). Here the GA phenomenon may be interpreted only as a large scale

density peak in the field of random Gaussian perturbations. This conclusion is backed by the results of the reconstruction of the three-dimensional distribution of density, peculiar velocity and gravitational potential in the GA region (Bertschinger et al. 1990) and is in accordance with interpretation of the large-scale streaming velocities as a result of the common gravitational action of the known clusters (Rowan-Robinson et al. 1990), the latter means the existence of the sub-structure of the GA-precursor peak in a smaller scale. (There are other interpretations of the coherent bulk velocities which are also possible).

Our purpose is to investigate the possibility to find in different cosmologies the coherent peculiar velocities $\sim 500km/s$ on typical scale $\sim 40h^{-1}Mpc$ modelled by a positive density perturbation peak of random Gaussian field, to evaluate characteristic parameters of such peaks and find their observational evidences including generation of the relic background anisotropy. We must emphasize that we do not take into consideration particular properties of the local GA since our purpose - constraining cosmological models - is in fact a purely statistical matter where detailed knowledge of one object can be a minor help. (From the real GA phenomenon we take just the idea that the major part of the Local Group velocity against the microwave relic background can be provided by a positive density peak of large scale. We also do not discuss here observational data or other possibilities, e.g., that the coherent velocity is a game of the positive and negative peaks, or that the half of it may be due to another positive peak such as Shapley concentration , etc.). A more relevent observational grounds of our statistical GA-modelling come rather from the cluster map found by Tully et al. (1992) and demonstrating a very clumped actual distribution of clusters where the local GA looks like a typical moderate cluster peak.

For realization of such program we performed the numerical calculations of non-linear evolution of the adiabatic growing mode perturbation peak in a flat ($\Omega_{tot} = 1$) two-component Universe dominated by weakly interacting non-relativistic particles.

The other component is the hydrogen-helium primordial plasma with a small relative density $\Omega_b \ll 1$. The evolution of baryon matter was taken in hydrodynamical ap-

$$\int_0^{x_0} \xi(r) r^2 \, dr = 0.27 x_0^3 / b_g^2 \tag{2}$$

with $x_0 = 10h^{-1}Mpc$ and statistical biasing parameter b_g calculated by Hnatyk, Lukash & Novosyadlyj (1991c). Here $\xi(r)$ is the correlation function of density fluctuation for the galactic Gaussian filter $R_f = 0.35h^{-1}Mpc$,

$$\xi(r; R_f) = \frac{1}{2\pi^2} \int_0^{\infty} P(k) \frac{sinkr}{kr} e^{-k^2 R_f^2} k^2 dk \tag{3}$$

(P(k) is the power spectrum of density perturbations versus comoving spatial frequency). These spectra are shown at Fig. 3. We must note here that nornalization by the r.m.s. mass fluctuation $\Delta M/M(8h^{-1}Mpc) = 1$ gives rise the spectrum amplitudes for not more than 1.5 times.

Table 1. The parameters of cosmological models.

	HDM(1) 1	HDM(3) 2	CDM 3	HC(0.3) 4	HC(0.5) 5	CDM+X 6	CDM+Z 7
Ω_b	0.1	0.1	0.1	0.0	0.0	0.1	0.1
Ω_{CDM}	-	-	0.9	0.7	0.5	0.9	0.9
Ω_{HDM}	0.9	0.9	-	0.3	0.5	-	-
b_g	0.64	0.51	1.62	1.4	1.4	1.69	1.76
$\sigma_{0g}^{*)}$	2.00	2.00	2.89	2.1	1.4	2.58	2.34

*)the r.m.s. density fluctuation on galactic scale, $\sigma_{0g} = \sigma_0(0.35h^{-1}Mpc)$

For the initial shape of density peaks we choose the mean profiles according to the statistical theory of random Gaussian fields (Doroshkevich 1970, Bardeen et al.

1986). The peaks of high amplitude, $\nu = \delta_0/\sigma_0 \gg 1$, tend to be spherically symmetric with the mean profile

$$\delta(r; R_f) = \nu \cdot \xi(r; R_f)/\sigma_0(R_f), \tag{4}$$

where both, $\sigma_0(R_f) = \xi(0; R_f)^{1/2}$ and the correlation function $\xi(r; R_f)$, depend on the spectrum and peak scale (the latter being proportional to the Gaussian filter R_f). Normalisation for the resulting GA peculiar velocity at redshift z=0, $U(r = 42h^{-1}Mpc) = 535km/s$, leaves us with the one-parameter family (4) of initial conditions (say, R_f). Note,that all the actual peaks simulated for the models in Table 1 proved to be rather high, $\nu > 3$ (except those for HDM(3)), what justifies the applicability of eq. (4) in our case within the region $r \leq 4\sigma_0$ where scatter around the mean profile remains small and which certainly includes the normalization scale r_{LG} employed here.

3. Evolution of GA-scale peaks

Results of simulation. For calculation of the fluctuation evolution we have elaborated the numerical code analogous to that proposed by Shapiro & Struck-Marcell (1985) for the joint dynamical study of baryons and collisionless particles, but we included also the derivation of the kinetics of elementary processes (Novosjadlyj & Hnatyk 1991).

The results of the calculations are presented in Table 2. It is shown that such peaks may be found in all cosmological models, however the probability of their realization is essentially various for different models. The parameters of the upper and lower mean profile peaks are listed in Table 2. Here $\delta_0 = \delta(0; R_f)$ is the linear amplitude approximated to z=0, the GA central region stops expanding (decouples from the Fridmannian background) at z_s and first collapses (with contraflows in the collisionless component) at z_c, N is the total number of GAs within the contemporary horizon with the mean separation d between them.

Table 2. The parameters of the Gaussian density perturbation peaks resulting in GA phenomenon ($U(r_{LG} = 42h^{-1}Mpc) = 535km/s$), found in different cosmological models (see Table 1). The left and right columns for each model correspond to the Faber & Burstein (1989) fitting (made on the non-linear stages) and to the minimal ν-value, respectively.

	HDM(1)		HDM(3)		CDM	
R_f, Mpc	24.0	30.0	20.0	30.0	22.0	30.0
$R_{\delta/2}$,Mpc	39.6	49.0	41.6	53.4	40.0	52.6
ν	5.8	4.8	2.1	1.7	10.5	8.6
δ_0	2.20	1.32	1.98	1.02	1.90	1.03
z_s	1.07	0.24	0.86	-0.04	0.79	-0.03
z_c	0.30	-0.22	0.17	-0.40	0.12	-0.39
N	6	580	$2 \cdot 10^6$	$2 \cdot 10^6$	10^{-15}	$2 \cdot 10^{-8}$
N_{sp}	0	12	$4 \cdot 10^4$	$4 \cdot 10^4$	0	0
d, Mpc	10^4	$2.3 \cdot 10^3$	150	170	$2 \cdot 10^9$	$7 \cdot 10^6$

	HC(0.3)		HC(0.5)		CDM+X		CDM+Z	
R_f, Mpc	18.0	26.0	18.0	26.0	14.0	24.0	13.0	20.0
$R_{\delta/2}$,Mpc	39.7	50.5	41.6	51.4	33.6	45.6	31.2	38.0
ν	6.7	5.4	5.95	4.83	5.8	4.2	5.5	4.1
δ_0	2.11	1.14	2.04	1.13	1.88	0.83	1.87	0.98
z_s	0.98	0.07	0.92	0.06	0.77	-0.22	0.76	-0.08
z_c	0.24	-0.33	0.20	-0.33	0.11	-0.51	0.10	-0.42
N	$5 \cdot 10^{-2}$	38	4	474	13	$7 \cdot 10^3$	100	10^4
N_{sp}	0	1	0	10	0	150	2	270
d, Mpc	$5.4 \cdot 10^4$	$5.7 \cdot 10^3$	$1.2 \cdot 10^4$	$2.5 \cdot 10^3$	$8.2 \cdot 10^3$	10^3	$4.2 \cdot 10^3$	830

As we can see, the GA phenomena are practically improbable in CDM but typical in HDM(3). In HDM(1) and biased HC, CDM+X and CDM+Z spectra GA phenom-

ena are still rare (mind the biasing parameter of the models in Table 1: GAs would become standard objects with $\nu \sim 2 \div 3$ in the unbiased extrapower and hybrid models). The mean profile peaks which model the upper (Faber-Burstein) limitting profile must have higher amplitude and smaller size R_f accordingly. Such peaks in some models (with initial linear amplitudes $\delta \geq 1.67/(z+1)$) develop to a strong non-linearity near GA centre: contraflows in the dark matter, shock wave in the baryonic component and X-ray gas appearing as a consequence. Say, in case of the GA-precursor peak with $\delta_0 = 0.2$ (CDM+Z spectrum, h=0.5) the contraflows and shock wave are generated at z=0.3. By the moment z=0 the shock wave passes the distance $\sim 5Mpc$ and heats the gas up to the high temperature $\sim 10^8 K$ with X-ray luminosity $L_X \sim 10^{44} erg/s$. (A small part $< 10\%$ of the gas in central GA region cools down to the temperature $\sim 10^4 K$). However, there could be reasons for a lesser violent hydrodynamic activity occuring near GA center for more realistic cases - non-spherical collaps, fragmentation of the infalling gas to smaller size clouds, etc.

As a result of the contraflows, the large peculiar velocities of galaxies in the central GA region ($U_{pec} \geq 1000 km/s$) are expected. Practically all GAs formed in the upper case (see Table 2) are the X-ray GAs and might be observed as very rich X-ray clusters. The CDM predicts the absence of such attractors at the stage of violent relaxation of the central regions, from a few to few dozens of such objects may form in case of hybrid, CDM+X and CDM+Z spectra, but in the HDM(3) their number is $\sim 2 \cdot 10^6$ with the mean separation $\sim 200Mpc$ between them.

Discussion. Our results on the realization probabilities of density perturbation peaks which cause the GA phenomenon (coherent peculiar velocities $\sim 500 km/s$ on typical scale $\sim 40h^{-1}Mpc$) in CDM and CDM+X cosmologies are close to those of Bertschinger & Juszkiewicz (1988) obtained by the Monte Karlo method. However, the values of the ν parameter obtained by Bertschinger et al. (1990) for CDM are actually less ($\sim 2b_g$). Since it is crucial for the CDM status, we would like to explain

our point in a more detail.

For simplicity, let us use the linear perturbation theory. Then the minimal amplitude of density perturbation which is necessary for generating the Local Group peculiar velocity, is reached when the perturbation is homogeneous within the region $0 \leq r \leq r_{LG}$. From the Euler equation we have in this case $\delta_{min} = \left(\frac{\Delta M}{M}\right)_{LG} = 3\frac{U_{LG}}{Hr_{LG}} \simeq 0.38$. In our normalization for the CDM spectrum, $\sigma(R_{TH} = r_{LG}) = 0.12/b_g$ (see also Bardeen et al. 1986). Thus we obtaine

$$\nu_{min} = \delta_{min}(r_{LG})/\sigma_0(r_{LG}) \cong 3.2 \cdot b_g.$$

ν is minimal here. Inded, decreasing the peak size (while leaving it in the form of the top-hat sphere with radius $R \leq r_{LG}$) needs the increase of its amplitude $\propto R^{-3}$ to keep the necessary $\Delta M/M$. As $\sigma_0 \propto R^{-(3+n)/2}$, we have $\nu \propto R^{(n-3)/2}$ which grows to smaller R for the scale invariant power spectra with $\mid n \mid < 3$. No, if R increases beyond r_{LG}, $\nu(r) \propto R^{(n+3)/2}$ which also grows with R.

In a more realistic case of inhomogeneous density perturbation, say, for $\delta(r; R_f) = \nu \cdot \xi(r; R_f)/\sigma_0(R_f)$, the condition on the mass excess is as follows:

$$\frac{\Delta M}{M}(r_{LG}) \equiv 3\nu \frac{\int_0^{r_{LG}} \xi(r; R_f) r^2 dr}{r_{LG}^3 \sigma_0(R_f)} = 3\frac{U_{LG}}{Hr_{LG}}.$$

Substituting here the correlation function from eq.(3) yields the folloving peak height versus to scale:

$$\nu = 2\pi^2 \frac{U_{LG}}{Hr_{LG}} r_{LG}^3 \sigma_0(R_f) / \int_0^\infty P(k) \cdot e^{-k^2 R_f^2} (sinkr_{LG} - kr_{LG} \cdot coskr_{LG}) \frac{dk}{k}.$$

The results of calculations for CDM, HDM(3) and CDM+Z are shown on Fig.4. As we see, in the case of the inhomogeneous density perturbation the minimal peak height is $\nu_{min} \approx 5.2b_g$, $3.3b_g$ and $2.2b_g$ for the models respectively (the nonlinearity does not change essentially these numbers). The antibiasing $b_g \cong 0.51$ taken for HDM(3) makes this model more suitable for GA like phenomena.

Let us now reverse the problem. In fact, in the GA case we deal with some distribution of mass which is actually within our lower and upper limits (see Fig.1). To evaluate ν-parameter we can test this distribution for different top-hat filters:

$$\nu(R_{TH}) = 3\frac{\int_0^{R_{TH}} \delta(r) r^2 dr}{R_{TH}^3 \cdot \sigma_0(R_{TH})}.$$

The results of calculations for the models mentioned, are given at Fig.5 for the limitting profiles. As we see, a fair ν-estimate should be done for the filters which are close to the core-radius of the real GA-mass distribution. Say, in case of CDM we have $\nu \sim (3.5 \div 4.5) b_g$ for $R_{TH} \sim 20 \div 25 h^{-1} Mpc$ (some discrepancy with ν_{min} at Fig.4 is due to various filter shapes). Taking $\nu \sim 2b_g$ for $R_{TH} = 14 h^{-1} Mpc$ would underestimate the real effect in the context of the CDM ability.

4. GAs and cosmic microwave background anisotropy

The distribution of gravitational potential in the Supergalactic plane would cause the fluctuation of temperature of the cosmic relic background which might be detectable for an observer at nearly horizon distance (Bertschinger, Gorski & Dekel 1990). However, the initial linear GA profiles calculated in this paper for the fluctuation of gravitational potential $\phi(r)$, density $\delta(r)$ and velocity U(r) enables to take into account all the essential effects (Sachs-Wolfe, adiabatic and Doppler) according to the formula:

$$\frac{\Delta T}{T}(\theta) = \frac{\phi(r)}{3c^2} + 0.4\left(\frac{1}{3}\frac{\delta(r)}{z_{dec}+1} + \frac{U_r(r)}{c\sqrt{z_{dec}+1}}\right) \tag{5}$$

(here we neglected the recombination width which is few times as less than the GA size). We assume that a GA just statistically determined above, crosses the last-scattering surface at $r = r(\theta) = \sqrt{l^2 + (2c\theta/H)^2}$ (l is the distansce from the GA centre to the last-scattering surface, it is positive when the peak centre is closer to

us; θ is the angular distance on the celestial sphere and U_r is radial component of the peculiar velocity measured by observer). Coefficient 0.4 takes into account smaller baryon fluctuation amplitude in comparison to the total perturbation at GA-scale ($k \simeq 0.03h/Mpc$, Holtzman 1989), $z_{dec} = 10^3$.

Our calculations for h=0.5 show that even the lower amplitude GA peak with $\delta_0 = 1.08/(z+1)$ and $56 \geq l \geq -28Mpc$ causes fluctuation (the hot spot) of $\Delta T/T \geq 6.6 \cdot 10^{-5} \approx 3\sigma_T$ in the angular scale $\approx 30'$ which is quite amenable for registration by existing technique (see Fig.6). Here σ_T is the present upper limit of the temperature anisotropy on this scale, $\Delta T/T \leq 3.5 \cdot 10^{-5}$ at 90% c. l. (Berlin et al.1984, Vittorio et al. 1991). The problem in the detection is a small number of such spots expected on the celestial sphere.

Indeed, it is necessary to have $\sim 0.6c/(H\Delta l) \sim 50$ GA precursors inside the horizon in order to have at least one spot on the sky. The expected number of detectable spots N_{sp}, like the total GA number N, varies for different models (see Table 2). Say, in case of the optimal CDM+Z spectrum (which predicts the r.m.s. temperature fluctuations $\sim \sigma_T$) there will be ~ 270 hot spots in the whole sky with $\Delta T/T \geq 3\sigma_T$, or one spot in the area $13^o \times 13^o$. The same number of cold spots originated from the negative peaks of density fluctuations, is expected. The largest number of such spots is generated in HDM(3) model which however contradicts the σ_T upper limit. We must also note, that the spot's number is very sensitive to the uncertainities in parameters of the density peaks and should be considered as an estimate.

5. Conclusion

We have shown that in the framework of gravitational instability theory the GA precursors are density peaks with the linear amplitude $\delta_0 = (1 \div 2)/(z+1)$ and half-width $R_{\delta/2} = (20 \div 25)/(z+1)h^{-1}Mpc$. Such peaks are rare events in most

cosmological models based on initially random Gaussian fluctuations and bias distribution of visible matter. Moreover, GAs are extremely improbable in standard CDM. In the biased hybrids there may be not more than $\sim$ 500 GAs within the horizon, whereas for CDM+X and CDM+Z this number renders up to $\sim 10^4$.

The central regions of some GA objects today evolve in a violent non-linear stage with high peculiar velocities of galaxies and shocked X-ray gas. There can be $\sim$ 100 of such X-ray GAs in CDM+Z, while in hybrids they are just few.

The GA precursors at the last-scattering surface generate excessible $\Delta T/T$ spots in scale $\sim 30'$. However, there cannot be many of such spots found on the celectial sphere. The most optimistic CDM+Z spectrum predicts $\sim$ 500 of the hot and cold spots in the whole sky, or one hot spot in the area $13^o \times 13^o$. It is the discovery (finding) of such spot features in the relic $\Delta T/T$ map that could be an important test for Gaussian perturbation theories of the large scale structure formation.

Acknowledgements. VNL and BN are grateful to Dennis W. Sciama for the hospitality and possibility to work one month in SISSA where the stimulating academic atmosphere allowed to finish this work. BN would also like to thank ICTP for the support.

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Figure captions

Fig.1 The density (top) and peculiar velocity (bottom) profiles modelling the Great Attractor at linear (l) and non-linear (nl) stages (for z=0). The lower (1) and upper (2) limitting profiles, as well as the Faber & Burstein (1989) approximation (circles) and Bertschinger et al. (1990) data (squares) and its error bars are presented.

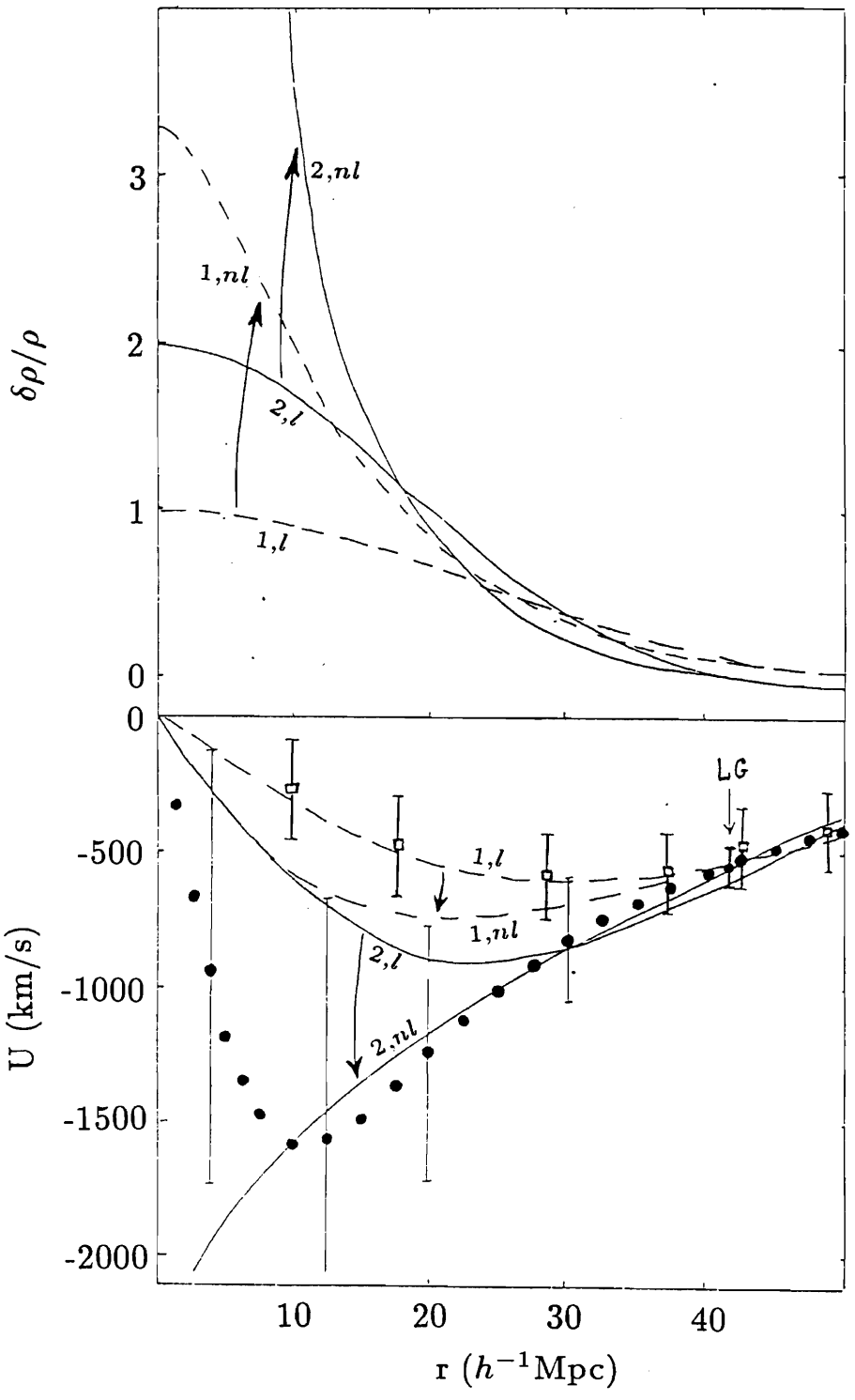
Fig.2 The density (top) and peculiar velocity (bottom) GA profiles (1,nl and 2,nl; see Fig.1) and the result of theirs smoothing by Gaussian filter $R_f = 12h^{-1}$Mpc (shown by arrows).

Fig.3 The power spectra of primordial density perturbations for the models in Table 1.

Fig.4 The ν parameter of high peaks of Gaussian density perturbations (smoothed by Gaussian filter R_f) modelling GA for different primordial perturbation spectra: CDM (a), HDM(3) (b) and CDM+Z (c). Solid lines - linear theory; dashed lines - non-linear simulation.

Fig.5. The function $\nu(R_{TH}) = \frac{\Delta M/M(R_{TH})}{\sigma_0(R_{TH})}$ versus to top-hat radius R_{TH} for the lower (1,l) and upper (2,l) cases of GA precursors at Fig.1. $\sigma_0(R_{TH})$ was derived for the CDM (a), HDM(3) (b) and CDM+Z (c) models.

Fig.6. The hot spot $\Delta T/T$ profiles generated by GA precursors (1,l) (see Fig.1) at the last-scattering surface. The modulus distance between the GA centre and last-scattering surface $\mid l \mid = 0$ (1), 28 (2), 56 (3) and 84 (4) Mpc; (a): $l \geq 0$ (the peak centre is closer to us); (b): $l \leq 0$.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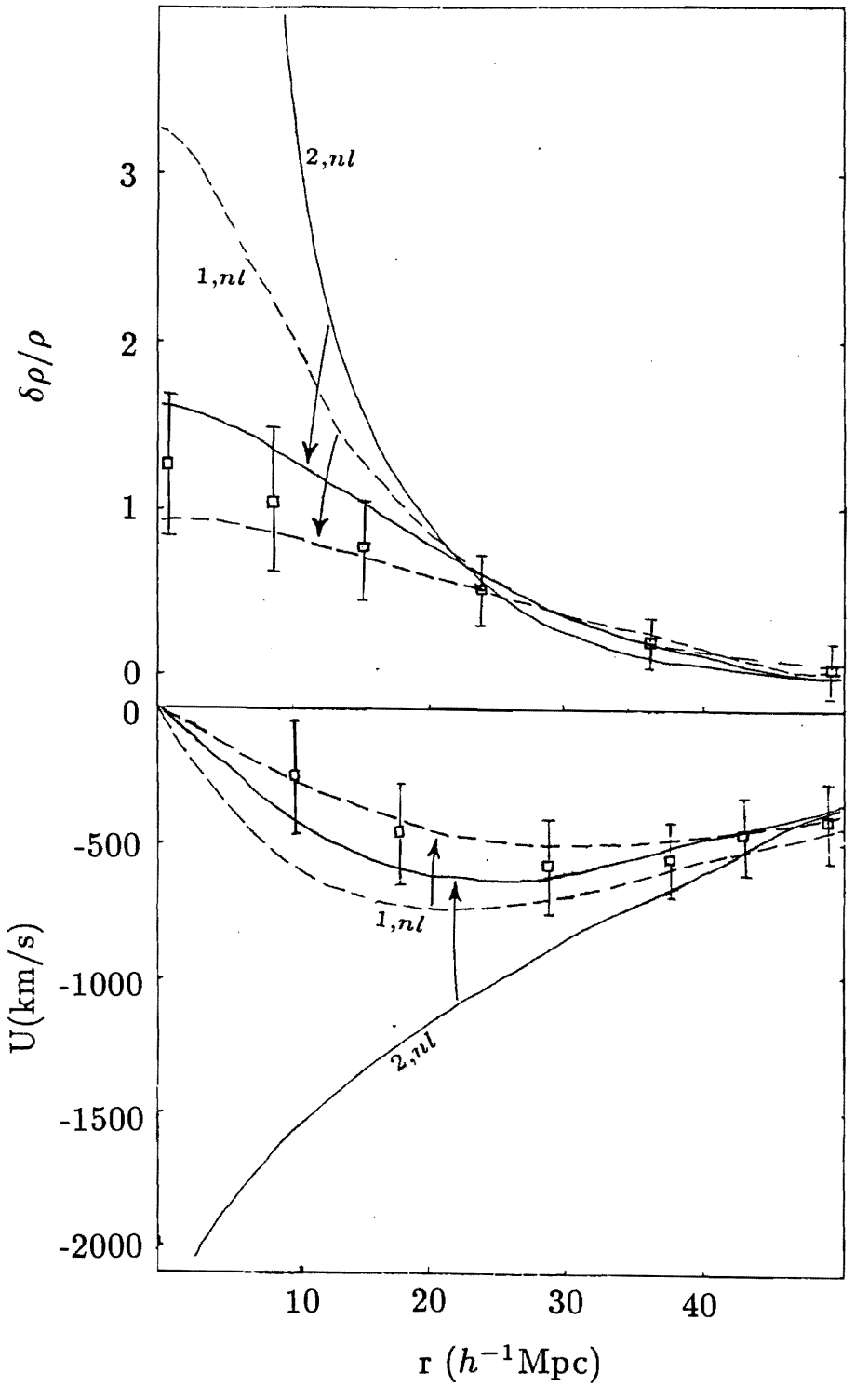
1
0
2,nl
1,nl
2,l
1,l
0
-500
-1000
-1500
-2000
U (km/s)
LG
1,l
1,nl
2,l
2,nl
10
20
30
40
r (h^{-1}Mpc)

Fig. 1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1,nl
δρ/ρ
3
2
1
0
0
-500
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U(km/s)
1,nl
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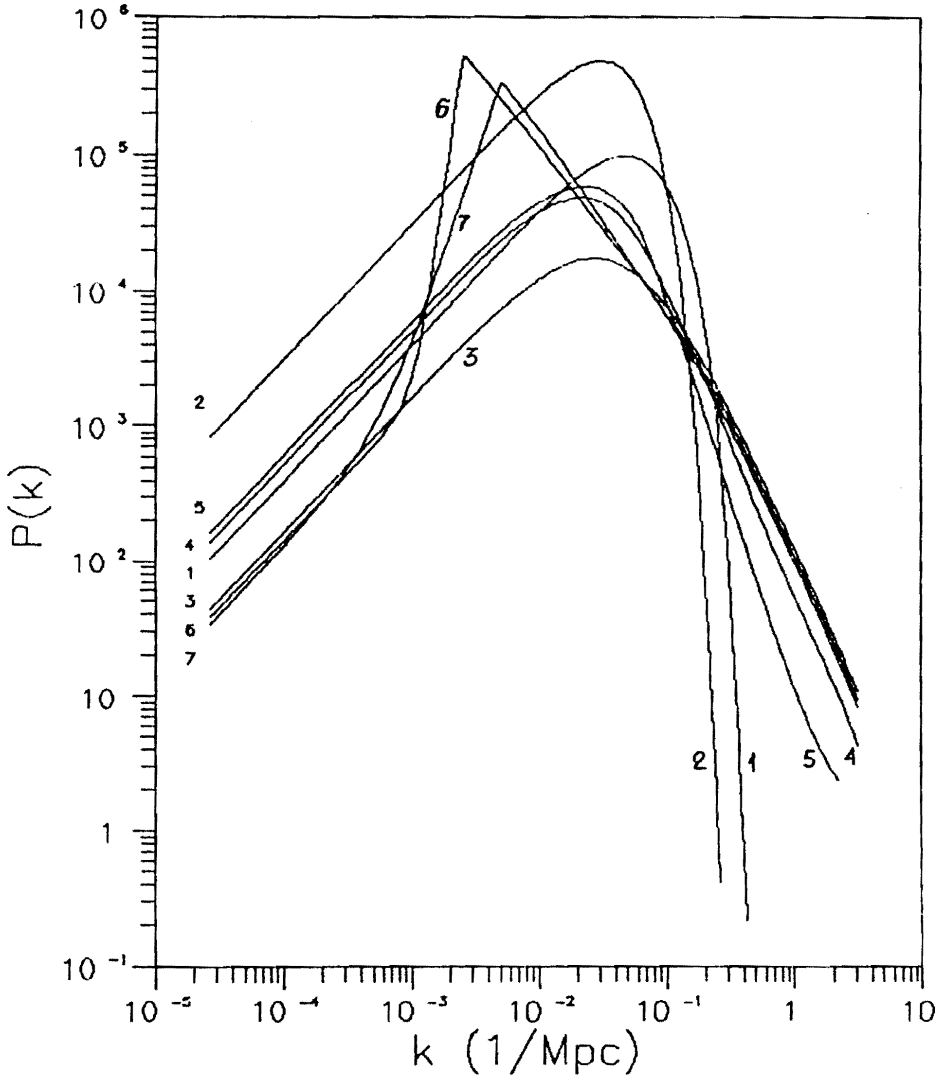
10
20
30
40
r (h^{-1}Mpc)

Fig. 2


P(k)
k (1/Mpc)
10 6
10 5
10 4
10 3
10 2
10
1
10 -1
10 -5
10 -4
10 -3
10 -2
10 -1
1
10
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4
1
3
6
7
6
7
3
2
1
5
4

Fig. 3

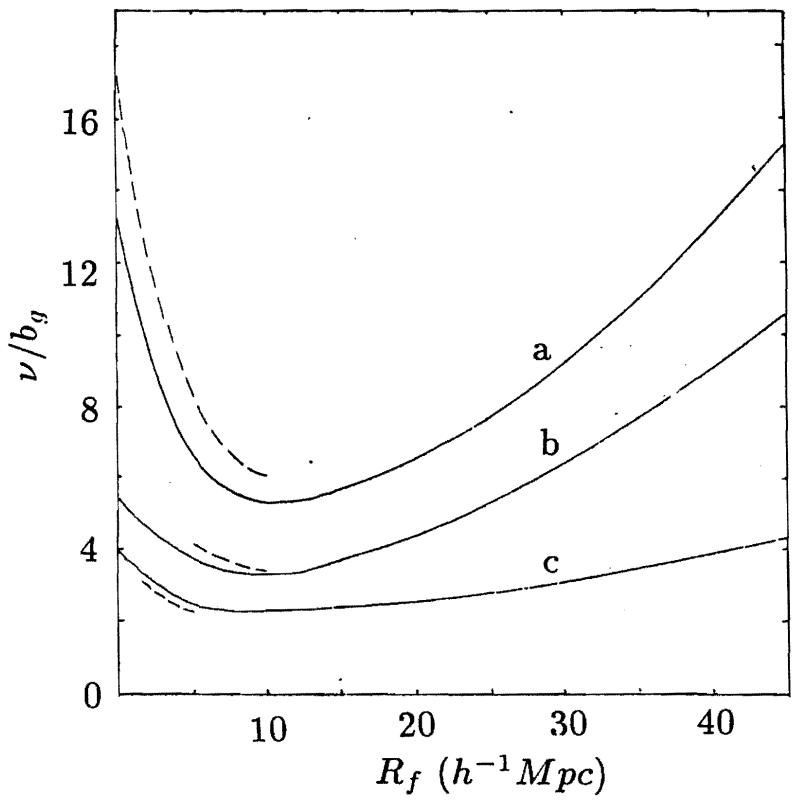


Fig. 4

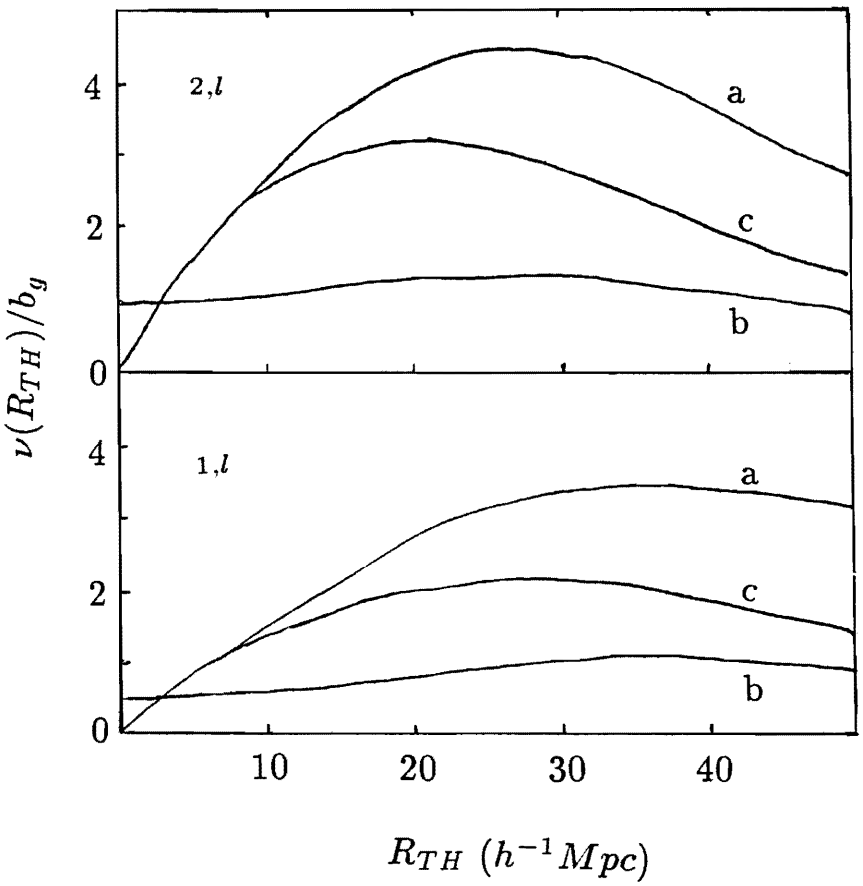
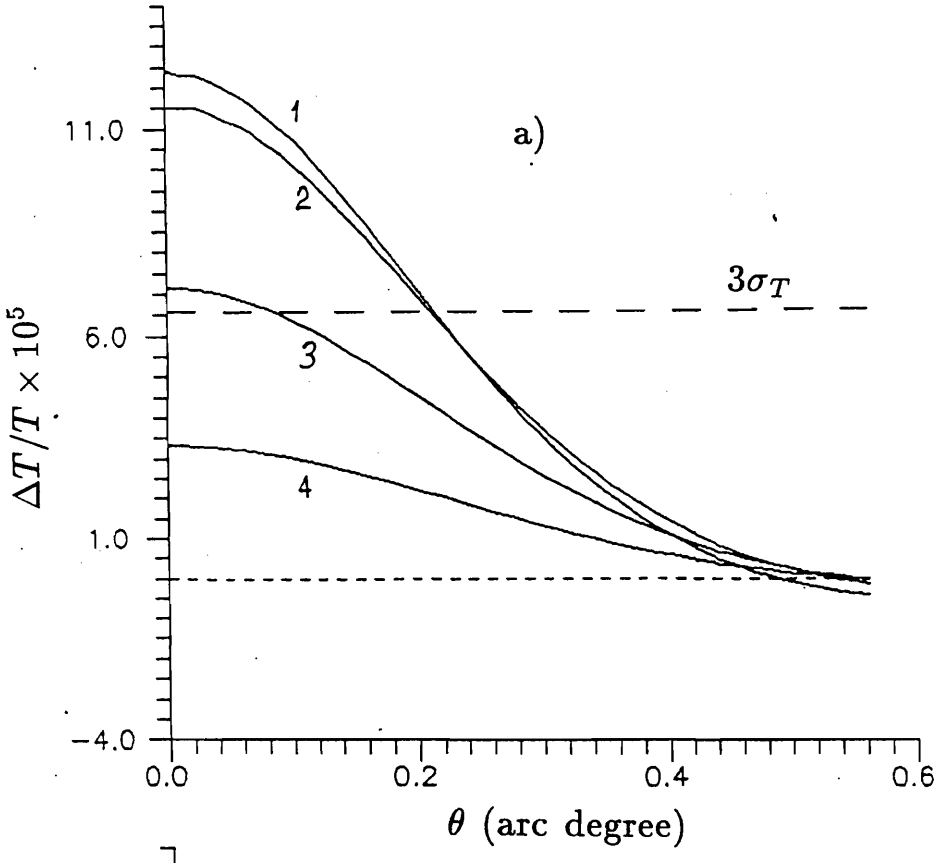


Fig.5


a)
11.0
6.0
1.0
−4.0
$\Delta T/T \times 10^5$
$3\sigma_T$
1
2
3
4
0.0
0.2
0.4
0.6
θ (arc degree)

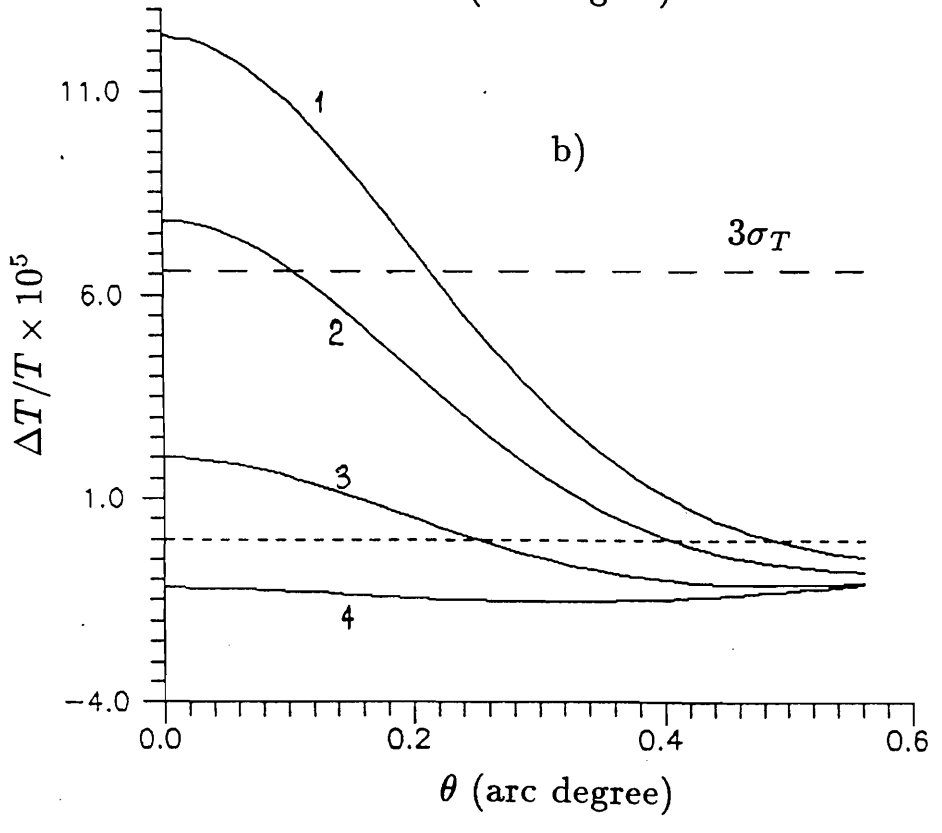

b)
11.0
6.0
1.0
−4.0
$\Delta T/T \times 10^5$
$3\sigma_T$
1
2
3
4
0.0
0.2
0.4
0.6
θ (arc degree)

Fig. 6