MINIVOIDS IN THE LOCAL VOLUME

ti@hotbox.ru, avt@gtn.ru
Anton V. Tikhonov / Saint-Petersburg State University
ikar@sao.ru
Igor D. Karachentsev / Special Astrophysical Observatory, Russian Academy of Sciences, N. Arkhyz, KChR, Russia

ABSTRACT.

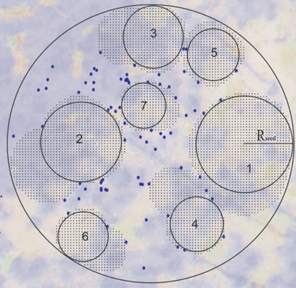
We consider a sphere of 7.5 Mpc radius, which contains 355 galaxies with accurately measured distances, to detect the nearest empty volumes. Using a simple void detection algorithm, we found six large (mini)voids in Aquila, Eridanus, Leo, Vela, Cepheus and Octans, each of more than 30 Mpc^3. Besides them, 24 middle-size "bubbles" of more than 5 Mpc^3 volume are detected, as well as 52 small "pores". The six largest minivoids occupy 58% of the considered volume. Addition of the bubbles and pores to them increases the total empty volume up to 75% and 81%, respectively. The detected local voids look like oblong potatoes with typical axial ratios b/a = 0.75 and c/a = 0.62 (in the triaxial ellipsoid approximation). A correlation $\mathcal{T}$-function of the Local Volume galaxies follow a power low with a fractal dimension D = 1.5. We found that galaxies surrounding the local minivoids do not differ significantly from other nearby galaxies on their luminosity, but have appreciably higher hydrogen mass- to-luminosity ratio and also higher star formation rate. We recognize an effect of local expansion of typical minivoid to be $\Delta H/H_0 = (25 \pm 15)\%$.

1. INTRODUCTION.

With the discovery of the first cosmic voids in the constellation Bootis (Kirshner et al., 1981) and in other sky regions (Joveer et al., 1978, Gregory and Tompson, 1978, de Lapparent et al., 1986), a new branch of extragalactic astronomy - "voidology" was formed. The concept of voids as basic elements of large-scale structure of the Universe proved to be required in modern cosmological models (Ghigna et al., 1994, Peebles 2001, Patiri et al., 2005). It is evident that the most reliable characteristics of voids can be obtained by investigating the nearest ones. In his Catalog and Atlas of Nearby Galaxies, Tully (1988) noted the presence in the Local Supercluster (LSC) of the so-called Local void which begins directly from the boundaries of the Local Group and extends in the direction of North Pole of the LSC by ~20 Mpc. The Local void looks practically free from galaxies. Studying the distribution of nearby galaxies in a volume of radius 10 Mpc, Karachentsev (1994) noted the presence in it of small voids of different sizes completely free from galaxies. At the present time, the sample of galaxies with distances less than 10 Mpc numbers about 450 galaxies. For half of them the distances have been measured to an accuracy as high as 8-10% (Karachentsev et al., 2004). The study of properties of voids in the most nearby sample, restricted by the distance, has an obvious advantage since we see here dwarf systems down to their minimum size/luminosity. The absence of the effect of ``God's fingers" in the Local Volume because of the virial motions of galaxies simplifies the analysis of the shape and orientation of nearby voids. Below we undertake the first attempt to map voids in the Local Volume on the basis of quantitative reception of their finding.

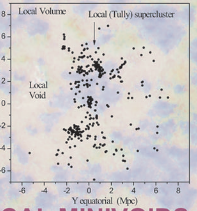
2.VOID DETECTION ALGORITHM

- 3D grid (to refer the nodes of this grid to this or that void).
- Empty seed sphere of largest possible radius is identified.
- Expansion of this first seed sphere by spheres with radius $R_{sph} > 0.9\ R_{seed}$ and with centers inside already fixed part of a void.
- Next seed sphere is determined and expanded.
- Process continues until R_{seed} > threshold.
- Voids are thick enough throughout their volumes
- Voids are divided into lying completely inside boundaries and voids touching when constracted the sample boundaries.



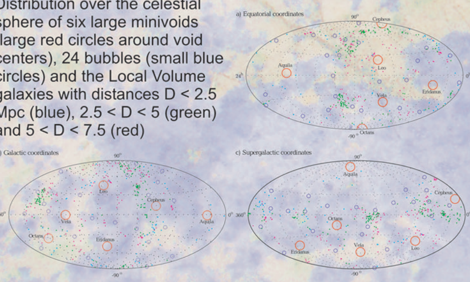
2D-case of point-like distribution. Seed circles and voids growing from them are shown. The numerals indicate the order of identification of voids.

Resolution of the grid Step = 0.1 Mpc. Volumes of voids were estimated as $Step^3 N$, where N is the number of nodes inside the void. Since with growing distance from the observer an abundance of galaxies of low luminosities drops, and the number of galaxies with measured distances also decreases, we limited the search of voids with a sphere of radius 7.5 Mpc around us. This volume of 1766 Mpc^3 contains 355 galaxies about 90% of which distance estimates measured irrespective of their radial velocities. Thus, the average volume for one galaxy is V_1 = 5.0 Mpc^3. Voids with volumes > 30 Mpc^3 have sufficiently high statistical significance with respect to Poisson.



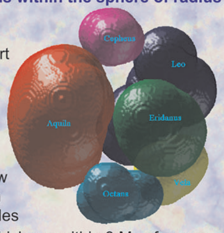
6 mini-voids, 24 bubbles and galaxies of Local Volume over the sky

Distribution over the celestial sphere of six large minivoids (large red circles around void centers), 24 bubbles (small blue circles) and the Local Volume galaxies with distances D < 2.5 Mpc (blue), 2.5 < D < 5 (green) and 5 < D < 7.5 (red)



Distribution of six large minivoids within the sphere of radius 7.5 Mpc.

¼ of Local Volume is occupied by Void №1 in Aquila. It is the front part of the Local (Tully) void.



To check an idea of the presence/absence in the empty volumes of dwarf galaxies of extremely low luminosity or intergalactic hydrogen clouds of low (M(HI) < $10^5\ M_{sun}$) masses, one can use data on six most nearby bubbles & pores (Table 2), the centers of which are within 3 Mpc from us. **Distribution of two nearest bubbles** (No 20 and 18) **and four pores** (No 72, 38, 71, 26) **with distances to their centers less than 3 Mpc.** Perspective is XZ plane in equatorial coordinates. The circle indicates the Milky Way. location.

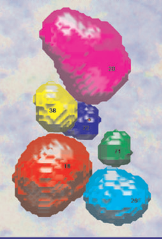


Table 2: Six the nearest bubbles/pores

Id	RA h	DEC deg	D_c Mpc	Volume Mpc^3	Neighboring galaxies
72	7.53	-6.7	0.83	1.5	Phoenix, Fornax, LeoII, LMC
38	12.60	18.8	1.23	2.1	SexA, LeoI, LeoA, KK230
71	23.81	-48.8	1.32	1.1	WLM, Tucana, E294-010
20	8.34	85.0	2.19	11.1	M31, U8508, N1569, Ua86, M82, KKH37
18	10.96	-54.8	2.24	11.1	N3109, E321-014, I3104, Circinus
26	0.54	-70.7	2.77	4.6	I3104, I5152

3. CENSUS OF THE LOCAL MINIVOIDS AND BUBBLES

Table1

Id	RA h	DEC deg	D_c Mpc	R_{seed} Mpc	Volume Mpc^3	Constellation
1	19.02	2.9	3.80	3.33	443.6	Aquila
2	3.63	-12.6	4.40	2.94	159.8	Eridanus
3	9.52	22.8	3.92	2.38	219.5	Leo
4	8.51	-40.0	5.46	2.06	61.2	Vela
5	0.23	75.3	5.56	1.92	59.1	Cepheus
6	0.82	-86.0	5.39	1.86	85.2	Octans

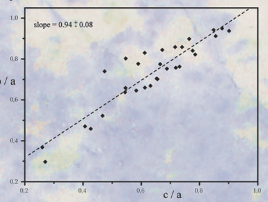
RA, DEC, D_c – equatorial coordinates of void center

Our void-finder has detected:

- 6 *minivoids* with volumes > 30 Mpc^3 (Table1)
- 24 *bubbles* with volumes > V_1
- 52 smaller *pores*

4.SHAPE AND ORIENTATION OF THE MINIVOIDS AND BUBBLES.

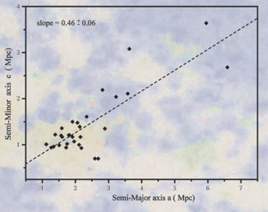
We approximate the surface of each empty volume identified by our algorithm by a equivalent triaxial ellipsoid that has the same moments of inertia as a body enclosed by the void.



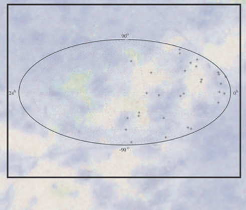
Compressions of voids along minor **c** and middle **b** axes of equivalent ellipsoids.

Correlation characteristic of the **prolate** but not oblate configurations.

Voids looks like oblong "potatoes" among which there are no too long of too flat shapes.



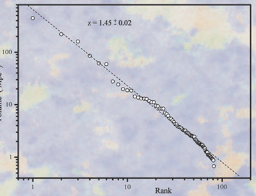
Axes of equivalent ellipsoids of voids. Minor and major axes are also correlated. The mean ellipticity remains almost independent of the size of a void.

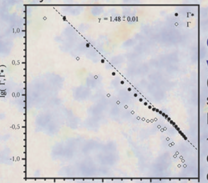


Directions of major axes of equivalent ellipsoids of 30 minivoids and bubbles over the right half of the celestial hemisphere.

5. RANKED VOLUME STATISTICS

Being arranged by the size of their volume, local voids follow the Zipf power law (for fractal structure) Volume(rank) = $B(rank)^z$ (Gaite & Manrubia, 2002). Formally calculated fractal dimension D_z=3/z ~ 2.1. One can not correctly measure D_z of 3D fractal set unless 2<D<3 because surface of void of nondegenerate form has topological dimension d=2 (Gaite, 2006). Application of our void-finder to different fractal sets showed this clearly.



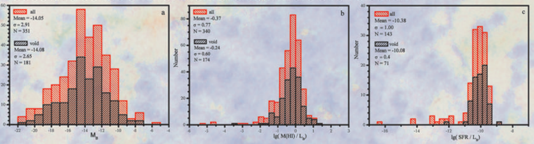


Correlation $\mathcal{T}$-function of 355 galaxies within sphere of radius 7.5Mpc. (Coleman, Pietronero, 1992). Density in spheres and sphere shells is calculated. Fractal dimension $D_{\mathcal{T}} = 3 - \gamma = 1.5$. Bump at ~3.5 Mpc may be associated with the characteristic distance between the centers of groups in Local Volume

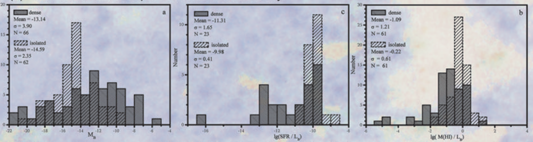
6. GALAXIES AROUND MINIVOIDS AND BUBBLES.

In different scenarios of formation of voids it is assumed (Peebles, 2001, Hoffman et al., 1992) that galaxies in voids may be different in their global parameters (luminosity, gas supply, star formation rate) from the population of dense regions, in particular, voids should be filled with galaxies of low luminosity. To check this assumption, we have considered in the Local Volume all galaxies which are located in layers 0.1 Mpc thick around empty volumes. It should be emphasized that the assumption that the regions of low density are populated predominantly by objects of low luminosity is not confirmed by observations. The differences between galaxies around voids and in the general field are of opposite character. Luminosity Function of dense regions is wider because of "tidal" dwarfs and luminous mergers.

As it follows from diagrams, the expected differences of galaxies around the voids in the form of enhanced HI abundance and higher star formation rate do have actually take place. In order to check the systematic differences of global properties of galaxies in dependence on their environment, we have applied a distinct approach. We have selected galaxies within a radius of 0.8 Mpc around of which no neighbors are present and compared them with the galaxies that have more than 5 neighbors within 0.3 Mpc. The differences noted above for galaxies in loose and dense environment are seen here even clearer.



(a) - B-band absolute magnitude distribution of the Local Volume galaxies and galaxies around local voids;
(b) - ratio of hydrogen mass to blue luminosity in solar units;
(c) - star formation rate per unit of blue luminosity.



(a) - B-band absolute magnitude distribution of isolated galaxies and galaxies in dense environment of the Local Volume;
(b) - ratio of hydrogen mass to blue luminosity in solar units;
(c) - star formation rate per unit of blue luminosity.

7. EXPANSION OF LOCAL VOIDS.

The galaxies surrounding nearby voids give us a unique opportunity to check whether the expansion of empty volumes does occur. In this case the galaxies located at the front boundary of a void will have radial velocities on average lower than in the homogeneous Hubble flow. On the farther side of a void the galaxies, correspondingly, have excess of radial velocities. We have selected on the near and back sides of the largest mini-voids 27 galaxies with accurately measured distances and velocities, and derived for them the mean difference of radial velocities $< \Delta V > = (28 \pm 19)$ km s^{-1}. Here from the radial velocity of each galaxy the regular Hubble component V = H_0 D was subtracted with H_0 = 72 km $s^{-1}Mpc^{-1}$. Thus, on the scale of effective radius of typical local minivoid ~1.5 Mpc an effect of local expansion with an amplitude $\Delta H/H_0 = (25 \pm 15)\%$ is observed. The ignificance of the expected effect could be increased by means of measuring distances to other galaxies behind the nearby minivoids, which is quite possible now with the facilities of the Hubble Space Telescope.

8. CONCLUSION.

When identifying voids in the Local Volume, we were based on the assumption that minivoids, bubbles and pores are completely free from galaxies. This assumption, important in theoretical models (Peebles, 2001), can be tested in subsequent observations. The "blind" survey of the whole southern sky made in the HI line of neutral hydrogen at the 64-m Parks radio telescope led to detection of new dwarf galaxies, in particular, in the Zone of Avoidance of the Milky Way (Kilborn et al., 2002, Staveley-Smith et al., 1998). A similar survey of the northern sky is conducted in Jodral Bank (Boyce et al., 2001). A much more sensitive blind survey in the HI line is now conducting at the 300-m radio telescope in Arecibo (Giovanelli et al., 2005). The minivoids Aquila, Leo, Eridanus as well as six other bubbles of smaller size fall partially within the zone of the Arecibo survey, DEC. = [0, + 38]. We expect that the results of this survey will have a chance to confirm or reject the idea of complete absence of galaxies in nearby voids. The detection of new nearby galaxies and measurement of their distances from the luminosity of red giant branch stars will allow a more detailed study of the shape and kinematics of the nearest voids. As was noted above, the Local void in Aquila, detected by Tully, extends far beyond the limits of the Local Volume. By the present time, the number of nearby galaxies with radial velocities < 3000 km s^{-1} has reached about seven thousand. This new observational material presents a possibility of detecting and investigating voids by two orders of magnitude exceeding the volume considered here.