Practical cosmology with the Local Volume galaxies

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Abstract: After recent systematic optical, IR, and HI surveys, the total number of known galaxies within 10 Mpc increased to 575. About half this Local Volume (LV) sample is now imaged with HST, yielding the galaxy distances with accuracy about 8%. For the majority of the LV galaxies we currently have H-alpha fluxes that allow us to reconstruct the star formation history of our neighborhood.

The local Hubble flow around the LV groups is found to be very cold, with rms deviations of ~25 km/s that is a signature of the universe vacuum-dominated on small scales. The cold infall pattern around nearby groups provides us with a new method to determine the total mass of the groups independent from virial mass estimates.

The data obtained on the LV galaxies imply important cosmological parameters, in particular, the mean baryonic density, the HI mass density, as well as the star formation rate density.

1. Introduction

«The most central problem in observational cosmology concerns distances to galaxies. Our knowledge of the formation and subsequent development of the Universe depends on the outcome of various tests of cosmological models, each of which depends in some way on knowledge of distances». This sentence was premised by Allan Sandage (1988) to his «Atlas of Galaxies Useful for Measuring the Cosmological Distance Scale» contemplated as the first collection of targets for the Hubble Space Telescope (HST).

At that time, just 20 years ago, there were known about 180 nearby galaxies with expected distances less than 10 Mpc from us. Only a dozen of them had accurate (~10%) distances measured via Cepheids. At present in the same Local Volume (= LV), we know 575 galaxies, and about 250 of them have accurate distances determined mainly from the luminosity of the tip of red giant branch (TRGB).

2. Recent observations of the LV galaxies

During the last decade, a lot of comprehensive programs to study the LV sample were undertaken by different observational teams.

a) The entire-sky search for new nearby dwarf galaxy candidates was realized by Karachentseva & Karachentsev (1998) and their co-workers. This so-called KK-survey of POSS-II and ESO/SERC plates yielded about 400 new small dwarf galaxies of low surface brightness.

b) All the galaxies from KK-lists were observed by Huchtmeier et al. (1997, 2000) in the HI line with different (Effelsberg, Nancey, ATCA) radio telescopes. About 100 new dwarf galaxies were added to the LV list.

c) Recent «blind» wide-sky surveys: HIPASS (Staveley-Smith et al. 1998, Koribalski et al. 2004), ALFALFA (Giovanelli et al. 2005) lead to discovering many new gas-rich dwarf galaxies, especially situated in the Zone of Avoidance.

d) A lot of the LV galaxies were imaged with CCD in optical (B,V,R,I) bands by Makarova (1999), Jerjen et al. (2000), Sharina et al. (2008) and others. About 150 LV members were resolved into stars in the first time.

e) High angular resolution observations of the LV galaxies were performed abroad the Hubble Space Telescope, and accurate TRGB distances were measured for ~250 galaxies. The results were summarized in the Catalog of Neighboring Galaxies (Karachentsev et al. 2004, = CNG).

f) More than 300 LV galaxies were imaged in the H-alpha line by James et al. (2004), Hunter & Elmegreen (2004), Gil de Paz et al. (2003), Karachentsev & Kaisin (2007), and Kaisin & Karachentsev (2008). As a result, the global star formation rate (SFR) was measured for these objects in the first time.

g) About 350 galaxies from the CNG sample have been viewed in UV with GALEX (Thilker, 2008) giving a representative data on SFR in the Local Volume.

h) Several projects were dedicated to study detailed HI kinematics of the LV galaxies with the largest radio telescopes (VLA, ATCA, GMRT): LVHIS (Koribalski, 2008), THINGS (Walter, 2008), FIGGS (Begum et al. 2006, 2008). In spite of present incompleteness, these projects give us accurate HI maps, HI rotation curves and the baryon mass fraction for 150 LV galaxies.

3. The local over/under densities

The sky distribution of the LV galaxies looks extremely inhomogeneous owing to the presence of galaxy groups (Karachentsev, 2005) and voids (Tikhonov & Karachentsev, 2006). Distribution of the nearest galaxies inside and around the Local Group (LG) is presented in Fig.1 in Supergalactic coordinates. Galaxies of different linear diameters are shown by different size balls. The circle indicates the radius of zero-velocity surface ($R_0 = 0.9$ Mpc) separating the LG against the cosmic Hubble expansion.

Fig.1. The Local Group and its surroundings.

The Local Volume galaxies within a radius of 10 Mpc are highly clustered too. Apart from the Local Group, there are 20 prominent groups that contain 3/4 of the galaxies in the LV. Most of the remainder lie within the filamentary structure that occupies the Supergalactic equatorial plane.

One of the basic properties of the LV is its porosity. At our doorstep there is the Local Void of >400 Mpc^3 in Aquila (Tully 1987) and the Local Minivoid of 160 Mpc^3 in Eridanus. Apart from them, there are four other minivoids, each of more than 50 Mpc^3 (Tikhonov & Karachentsev, 2006). Their total volume occupies about 70% of the total LV space. Within them, there is not a single known galaxy brighter than M_v = -11 mag. The existence of voids even in the distribution of extreme dwarfs is unexpected and may provide strong cosmological constraints (Peebles, 2002).

4. The local Hubble flow

While having accurate velocities and distances for ~250 LV galaxies, one can study distribution of peculiar velocities within the Volume. A peculiar velocity map for the LV galaxies in the LG reference frame shows the local Hubble flow to be generally calm with peculiar velocity variations within ± 30 km/s. There is only a small area of negative peculiar velocities about - 250 km/s in direction towards the Leo constellation. According to Tully et al. (2008) this phenomena (the Local Velocity Anomaly) is caused by motion of the Local Sheet as a whole from the large Local Void towards the neighboring Leo cloud. Fig.2 presents the distribution of nearby galaxies in Supergalactic coordinates. The vector extending from our location indicates the Local Group motion (320 km/s) with respect to galaxies within 3000 km/s as the vector sum of two components: 260 km/s away from the Local Void and 180 km/s toward the Virgo cluster. It should be stressed here that the local peculiar velocity field on a scale of 10 Mpc can not be described simply as the so-called «Virgo-centric infall» used often by different authors to «improve» (?!) distances to nearby galaxies via their radial velocities.
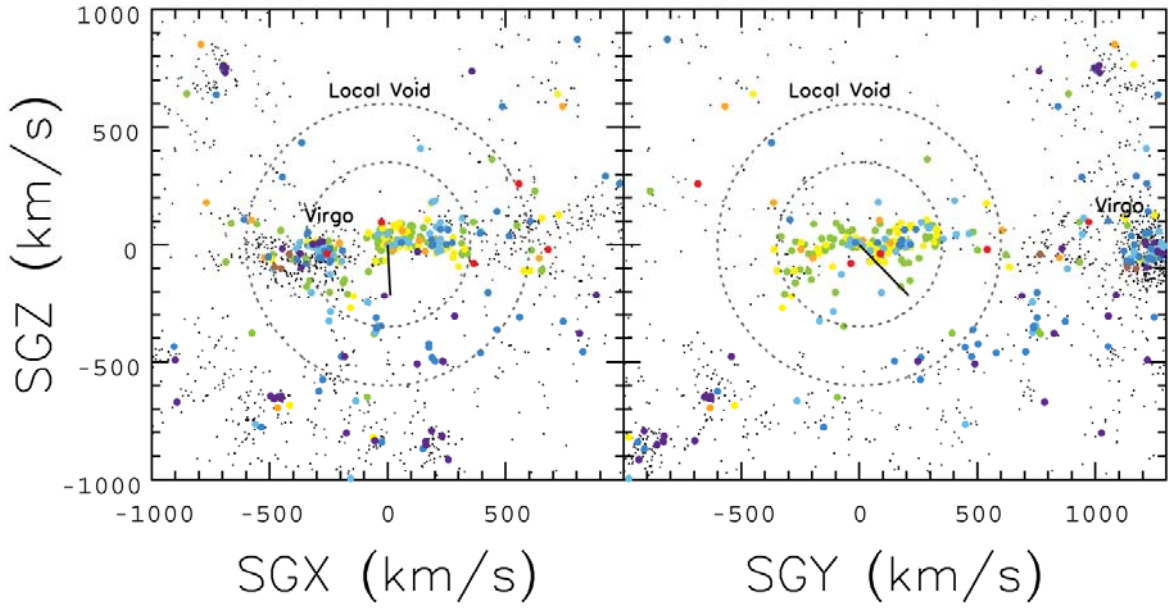

Fig. 2. The local Sheet and its neighborhood.

5. Basic properties of the nearest groups

Over the last few years, searches for new nearby dwarf galaxies and accurate distance measurements to them lead to a significant increasing the population of known neighboring groups. Table 1 presents basic parameters of 7 nearest groups situated within 5 Mpc from us: distance to the group centroid, number of the group members with known radial velocities, 1D velocity dispersion, projected radius, crossing time, virial mass, total blue luminosity and virial mass-to-luminosity ratio.

Table 1. Basic parameters of the nearest galaxy groups.

Parameter	M.Way	M31	M81	CenA	M83	IC342	Maffei
D, Mpc	0.01	0.78	3.63	3.66	4.56	3.28	3.01
N_v	18	18	24	29	13	8	8
σ_v, km/s	76	77	91	136	61	54	59
R_p, Mpc	.16	.25	.21	.29	.16	.32	.10
T_{cross}, Gyr	2.1	3.3	2.3	2.2	2.7	5.9	1.8
M_{vir}, $10^{10} M_\odot$	95	84	157	725	86	76	100
L_B, $10^{10} M_\odot$	3.3	6.8	6.1	6.0	2.5	3.2	2.7
M/L, solar	29	12	26	121	34	24	37

Remarkably, centroids of the groups have a radial velocity dispersion around the local Hubble flow to be only 25 km/s.

Precise measurements of distances and radial velocities for galaxies surrounding a group permits us to determine the radius of zero-velocity surface, R_0, which separates the group from the global cosmic expansion, and total mass of the group defined by Lynden-Bell (1981) as

$$M_t = (\pi^2 / 8G) \cdot R_0^3 \cdot T_0^{-2} \tag{1}$$

Fig.3 exhibits the local Hubble flow in the immediate surroundings of the Local Group. Distances and velocities are given with respect to the LG centroid. Similar «cold» velocity patterns are seen also around other nearest groups, yielding R_0 values within 0.7 - 1.4 Mpc.
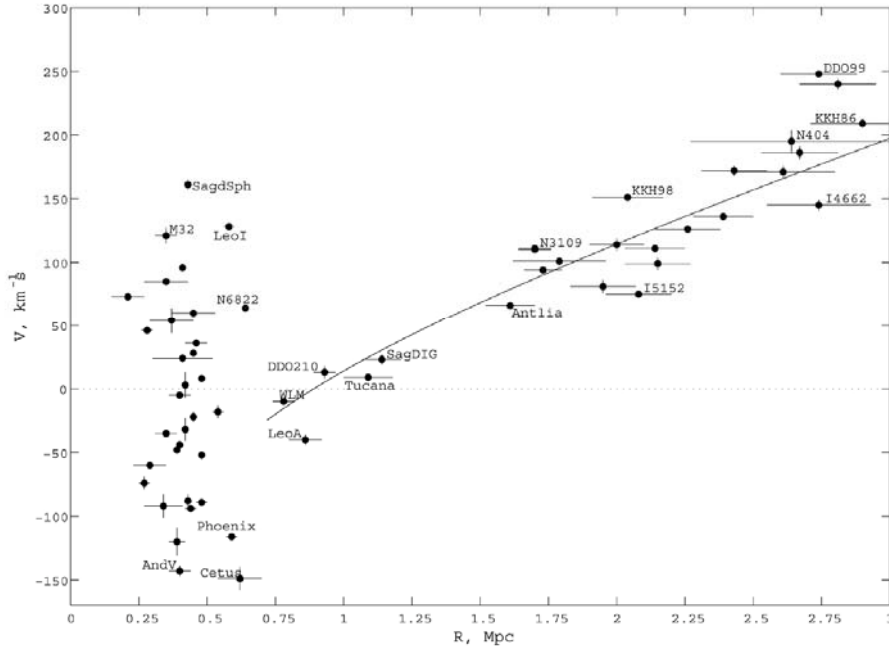

Fig. 3. The local Hubble flow.

It should be emphasized that the number density of dwarf galaxies in the LV is much higher than in any other distant volumes. Therefore, systematic investigating the LV has great advantage in studying the dark matter distribution on scales of 0.3 – 3 Mpc. In this respect we note that the sum of virial mass for 7 nearest groups (around the Milky Way, M31, M81, CenA, M83, IC342, and Maffei) consists of $1.3 \cdot 10^{13}$ $M_\odot$. But the sum of their total masses estimated via R_0 from external galaxy motions is $0.86 \cdot 10^{13}$ $M_\odot$ for the classical case $\Lambda = 0$, and $1.25 \cdot 10^{13}$ $M_\odot$ for the case $\Omega_\lambda = 0.73$. Because the mean radius R_0 for the groups exceeds 5 times their mean virial radius, the observed agreement of independent internal and external mass estimates is actually not trivial, looking as the absence of large amounts of dark matter between R_{vir} and R_0.

6. Some cosmological parameters

In spite of the presence of local voids, the average density of luminosity within the radius of 8 Mpc around us exceeds 1.5 - 2.0 times the global luminosity density (Karachentsev et al. 2004). Almost the same excess is also seen in the local HI mass density (Zwaan et al. 2003). About 2/3 of the LV galaxies belong to the known virialized groups like the LG. Because the average virial mass-to-luminosity ratio for them is 43 $M_\odot/L_\odot$, the mean local mass density within 8 Mpc turns out to be 0.10 in units of the global critical density. This quantity is 2 - 3 times lower than the global density of matter, $\Omega_m = 0.27$. To remove the discrepancy between the global and local quantities of Ω_m, we assume that the essential amount of dark matter (~70%) exists outside the virial volume of the groups.

7. Global star formation rate in the LV galaxies

Systematic H_α imaging made for the LV galaxies allows us to measure star formation rate (SFR) for them in extremely wide range of magnitudes. As distinct from other samples, the LV sample offers an unique possibility to study the SFR for galaxies of different types and in different environment without significant selection biases.

Left and right panels of Fig.4 present the SFR of nearby galaxies versus their blue absolute magnitude and hydrogen mass, respectively. The dashed lines correspond to a constant SFR per unit luminosity or unit hydrogen mass. As can be seen from the left diagram, most of the galaxies brighter -13 mag follow a linear regression with the constant specific SFR. However, SFRs and hydrogen masses demonstrate a steeper relationship: $\log[SFR] \sim \{3/2\}\log(M_{HI})$, shown on the right panel by the steeper line.
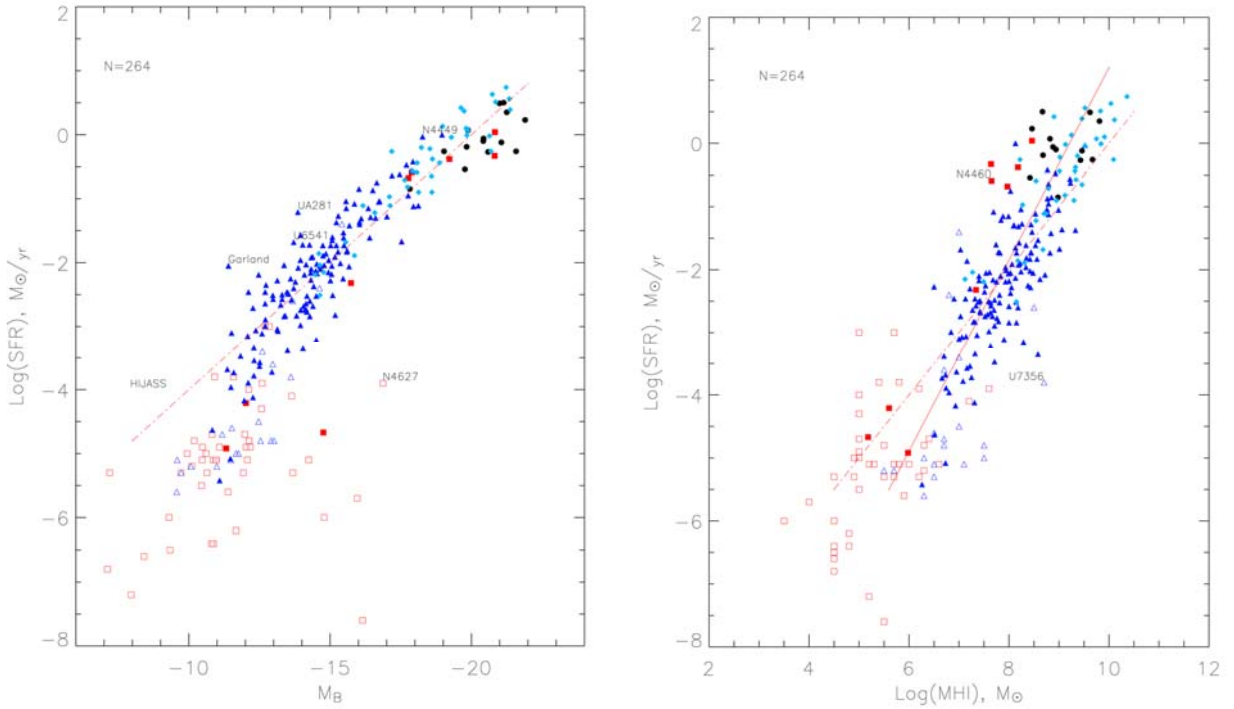

Fig. 4. SFR for the LV galaxies versus their total blue luminosity (a) and total hydrogen mass (b).

This feature seems to be in harmony with the following considerations noted by Tutukov (2006). According to Schmidt law for local SF sites, their rate of transformation of gas into stars is proportional to the square of gas density:

$$d(n_g)/dt \sim (n_g)^2 \tag{2}$$

As was shown by Roberts (1969), hydrogen masses of disk-like galaxies follow the empirical relation

$$M_g \sim R^2 \tag{3}$$

meaning that HI surface brightness of giant and dwarf disks is almost the same. Taking it into account, we find that

$$SFR \sim R^3 \cdot d(n_g)/dt \sim R^3 \cdot n_g^2 \sim M_g^{3/2} \tag{4}$$

i.e. obtain the known Schmidt-Kennicutt law (Kennicutt, 1998), but for the galaxies themselves, not for individual HII regions only. Therefore, evolutionary history of disks of galaxies looks to be driven mainly by internal SF processes.

It is generally accepted that the enhanced star formation in galaxies is triggered by their interaction. But we did not find clear evidence for such suggestion. Curiously, the strongest disturbed tidal dwarf «Garland» near NGC 3077 and very isolated blue galaxy UGCA 281 have almost the same extremely high specific SFR (see left panel in Fig.4).

5

After corrections for internal and external (Galactic) extinction, we derived the mean local star formation rate density to be 0.025 $M_\odot$/year/Mpc^3, in reasonable agreement with the global estimates obtained based on UV and IR data.

8. Some relations between global parameters of the LV galaxies

Besides the global Hubble law, galaxies follow another (internal) «Hubble-2» law, the linear relation between their rotation velocity and standard radius:

$$V = hR \tag{5}$$

where $h = 137H_0$, or $1/h = 100$ Myr. This leads to the known empirical relations between total mass M_t, luminosity L, total angular momentum J, and surface brightness SB of a galaxy:

$$M_t \sim L \sim RV^2 \sim R^3 \tag{6}$$

meaning that the average spatial densities of giant, normal, and dwarf galaxies are almost the same;

$$L \sim V^3 \tag{7}$$

corresponding in logarithmic scale to the famous Tully-Fisher relation;

$$J \sim MVR \sim M^{5/3} \tag{8}$$

that is known as Muradyan law, valid for much wider range of celestial bodies from asteroids to galaxy superclusters (Carrasco et al. 1982);

$$SB \sim L/R^2 \sim R \tag{9}$$

i.e. Binggeli-Grebel relation, valid also for E and dSph galaxies, that orders to search for extremely dwarf galaxies among the objects of the lowest surface brightness. These empirical scaling relations probably mean that stellar population of dwarf and giant galaxies are locked in dark matter haloes of a standard profile. Taking into account eq.(3), we find also two other scaling relations:

$$M_g / M_t \sim R^2 / R^3 \sim M_t^{-1/3} \ , \tag{10}$$

meaning that dwarf galaxies are relatively more gas-rich systems, being capable of longer star formation activity than giant ones;

$$M_g \sim RV \sim j \tag{11}$$

This Zasov relation between total hydrogen mass and specific angular momentum of galaxies means that galaxy disks are situated in the state of equilibrium just above the threshold of gravitational instability driving their star formation processes (Zasov, 1974).

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