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# ON THE GENERAL MORPHOLOGY AND DYNAMICS OF NEAR-BY NORMAL SPIRALS

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**Abstract**

Properties of three types of integral mass distribution in normal spiral galaxies pointed out by (Burstein & Rubin 1985) are discussed from a point of view of a compactness (or, equally, of its denseness), from the standpoint of physical similarity, and circumstances of formation and evolution of disk galaxies (Efremov, Chernin 1994).

## 1 Introduction

A study of rotation curves in a several tens of galaxies of different Hubble types ( Burstein et al. 1982, Burstein & Rubin 1985) pointed out that there are three main types of integral mass distribution (without a sharply rising density (a cusp) in theirs centres) which do not correlate with morphological type of a galaxy. It means that the spatial mass distribution in the galaxy may not depend on global properties of the galaxy: a luminosity, a mass of a disk and a total mass. Burstein & Rubin (1985) concluded that the integral mass distribution (IMD) in spiral galaxies is determined in numbers of influences by initial environment of protogalaxies(PG). [1]

The mass distribution of spirals firstly depends on their rotation defined by initial evolution, i.e. on angular momentum and contraction and evolutionary features of PG. The angular momentum of the galaxy strongly depends on the interaction of the protogalactic gas cloud with its similar and supersonic matter motions in the earlier Universe (Chernin 1993).

The newly accepted quantity of the compactness (different from common one through the surface-brightness distribution [2]) is an implied feedback of

[1] For short we omit a discussion of further Rubin's results which are certainly mutually complementary.

[2] See this Conference S. Ninkovic and Z. Cvetkovic, Dynamics of Galaxies (the preliminary list of abstracts) p.37, http://www.astro.spbu.ru/dogtale/abstracts.pdf

the dependence of the type of the IMD on the angular momentum and star formation history and directly reflects dependence of the type of the IMD on a packing the galaxy with substance.

We will try to clear the problem using methods of analysis of scales and physical similarity (Dibay & Kaplan 1976, Kurt 1975). We intend to examine the problem of the IMD as the problem of general physical similarity of galaxies. Stellar systems are notable for rather intricate physical similarity, which broadens known mechanical similarity when potential energy is a homogeneous function of co-ordinates (Landau, Lifshitz 1973).

## 2 Hubble's type and blue luminosities of the normal spirals

In Table 1 (from (Maksumov, Sakhibov 1987)) data received by Rubin and her collaborators (Rubin 1983) are shown.

T a b l e 1 **Main dynamic parameters of galaxies and Hubble and van den Bergh classifications**

| $M_B$<br>cl.<br>$HT$ | $-18^m \div -19^m$<br>III-IV,III<br>$R = 3 \div 7 (kps)$ | $-20^m \div -21^m$<br>II-III,II<br>$7 \div 20$ | $-22^m \div -23^m$<br>I-II,I<br>$20 \div 50$ | $\mathsf{M}_t / L_B$ |
|---|---|---|---|---|
| $Sa$ | $\mathsf{M}_t = 2.5 \div 8$<br>$V_{max} = 140 \div 200 (km/s)$ | $8 \div 35$<br>$200 \div 300$ | $35 \div 110$<br>$300 \div 430$ | $6.1 \pm 0.7$ |
| $Sb$ | $\mathsf{M}_t = 1 \div 4$<br>$V_{max} = 100 \div 150$ | $4 \div 30$<br>$150 \div 230$ | $30 \div 125$<br>$230 \div 320$ | $4.4 \pm 0.4$ |
| $Sc$ | $\mathsf{M}_t = 0.7 \div 2.5$<br>$V_{max} = 85 \div 120$ | $2.5 \div 15$<br>$120 \div 180$ | $15 \div 60$<br>$180 \div 250$ | $2.6 \pm 0.2$ |

$$[\mathsf{M}_t] = 10^{10}\ M_\odot.$$

$L_B, M_B$ - blue luminosity and appropriate absolute magnitude, cl. - luminosity class on van den Bergh, $HT$ - Hubble type, $R$, $V_{max}$ - accordingly, radius and maximum value of rotation velocity of galaxies, $\mathsf{M}_t$ - integral (luminous and non-luminous, dynamical) mass [3].

As it is shown by Rubin (ibid.), luminosities $L_B$ and the masses $\mathsf{M}_t$ on the average change equally for galaxies of all types with growth of their dimensions under the law $R^{1.6}$. Therefore $\mathsf{M}_t \;/\; L_B \;\approx\; const$ for given Hubble type. The density in a galaxy should decrease lower than $\propto\; R^{-1.4}$. $V_{max} \propto\; R^{0.3}$.

## 3 Hubble's type and integral masses of normal spirals

Below we study Hubble classification depending on total mass, as well as we discuss a situation with distribution of this integral mass.

Table 2 represents data given by Rubin and her collaborators (Rubin et al. 1985), having added those by physically important relative quantities (last column). $M_H$ - absolute magnitude in infrared, $\mathsf{M}_t$ - integral mass in the sense of table 1, $\mathsf{M}_d$ - mass of disk components, $HT$ - Hubble type, $L_H$ - luminosity in infrared, $L_B$ - blue luminosity, $R$, $V_{max}$ - accordingly, radius and value of maximum rotation velocity of galaxies.

T a b l e 2 **Variety of mass distributions of normal spirals**

| $M_H$ — $HT$ | $-20^m \div -21^m$ $\mathsf{M}_t = 10^{10}$ | $-22^m \div -23^m$ $\mathsf{M}_t = 10^{11}$ | $-24^m \div -25^m$ $\mathsf{M}_t = 10^{12}$ | $\mathsf{M}_t/\mathsf{M}_d$ — $L_H/L_B$ |
|---|---|---|---|---|
| $Sa$ | $R = 3$ $V_{max} = 130$ | 9 190 | 40 280 | 4 – 3 |
| $Sb$ | $R = 5$ $V_{max} = 100$ | 14 160 | 50 250 | 3 – 2 |
| $Sc$ | $R = 7$ $V_{max} = 100$ | 18 150 | 70 216 | 2 – 1 |

$[R]$ - kps, $[V_{max}]$ - km/s, $[\mathsf{M}_t] - M_\odot$

[3] Within $R_{25}$, i.e. the distance where the surface brightness has fallen to 25 $B$ mag arcsec $^{-2}$. The discussed masses $\mathsf{M}_t$ do not include hidden mass outside $R_{25}$ (Burstein et al. 1982; Rubin et al. 1985).

# 4 Physical interpretation

From Table 2 it is clear, that angular momentum of galaxies $P$, concentrated in their disk component and determined by formula

$$P \ = \ \mathsf{M}_d \cdot R \cdot V \ = \ \frac{G{\mathsf{M}_t}^2}{V} \cdot \frac{\mathsf{M}_d}{\mathsf{M}_t}, \tag{1}$$

grows to late types. This fact was realized yet by (Brosche 1971) It is visible, that a galaxy of given mass can have different Hubble type depending on angular momentum, different sizes and, hence, various distribution of mass. So else masses, sizes of galaxies of a given Hubble type are diverse. Thus, the masses of galaxies are distributed by a various way even within one Hubble type.

Multiplying the left and right side of (1) by angular velocity of a disk $\Omega$ we shall define the doubled ratio of energy of rotation to total gravitational energy in a galaxy.

$$P \cdot \Omega = \frac{G\mathsf{M}_t \cdot \mathsf{M}_d}{R}, \quad or, \quad (P \cdot \Omega) \ / \ (\frac{G{\mathsf{M}_t}^2}{R}) = \frac{\mathsf{M}_d}{\mathsf{M}_t} \tag{2}$$

(2) is the record of virial theorem for a galactic disk in bulky halo.

The value of relative disk mass $\mathsf{M}_d$ / $\mathsf{M}_t$ according to (2) is equal for double Ostriker-Peebles parameter of global stability $t$ (Ostriker, Peebles 1973). According to the table 2 $t$ appears equal 0.125 for $Sa$ - galaxies, 0.15 - for $Sb$ - and 0.25 - for $Sc$ - galaxies. Mass-ratio ($\mathsf{M}_t$ / $\mathsf{M}_d$) are found by the authors in (Maksumov, Sakhibov 1987). Disk components of galaxies with developed spiral structure of $Sb-$, $Sc$-types are undergone to global instability, as $t > t_{cr} \approx 0.14$.

But the stability or instability of galaxies as dynamic system is determined and by distribution of mass in it. And so the conclusion about lack of correlation of integral mass distribution and Hubble type cannot be absolute because of dynamic nature of a spiral structure as a density wave (Lin, Shu 1964). Simply, it means that the type of IMD forms before emergence of spiral structure, as it was often emphasized above, while density wave effect on the type of IMD is weak.

In fact, let's consider due to (Rubin 1983) [4] measure of compactness of galaxies as quantity, determined as specific (per unit mass) energy of contraction $G\mathsf{M}_t/R$. From centrifugal and gravitational forces balance at

[4]See explanations to Table1

radius $R$ this is equal and to quantity square of rotation velocity of a stellar disk of galaxies $V^2$, i.e. $V^2 = G\mathsf{M}_t/R$,

$$\mathsf{M}_t = \frac{V^2 \cdot R}{G}, \quad \frac{\mathsf{M}_t}{\mathsf{M}_m} = \frac{V^2}{V_m^2} \cdot \frac{R}{R_m}, \quad V_m^2 = \frac{G\mathsf{M}_m}{R_m}, \tag{3}$$

where $\mathsf{M}_m$, $R_m$ and $V_m$ - scaling quantities, describing distribution of mass in galaxies. They are determined below and somewhat analogous to those of (Burstein, Rubin 1985).

As it is clear from Table 2, the compactness falls to late types at increasing relative disk mass and fixed integral mass (infrared luminosity). And within of each type ( at fixed relative disk mass) it grows with growth of the sizes and integral masses (infrared luminosities) of galaxies. If galaxies were similar to an isothermal sphere, their measure of compactness would not vary, as at $\delta \propto R^{-2}$ $\mathsf{M}_t \propto \delta R^3 \propto R$ and $G\mathsf{M}_t/R$ does not depend on $R$ (Marochnik,Suchkov 1984; Burstein, Rubin 1985). Mass of disk component, for all this, would be small, the disk would be thin. The compactness, hence, points to a degree of contraction of galaxies both to a plane of symmetry, and mass concentration to a centre in the presence of massive coronas, as well as anticorrelates with value of relative disk mass and angular momentum of galaxies on table 2 columns (see the formula (1)) [5]

According to Table 2, there is also interrelation between compactness of a galaxies and intensity of star formation. Therefore the intensity of star formation can also influence integral mass distribution in galaxies. The ratio blue luminosity to infrared one reflects intensity of star formation in spiral galaxies. Let's consider mentioned luminosities ratio depending on a morphological type and dynamic parameters of galaxies ( Rubin et al. 1985 ). The observable mass-luminosity relation consistently monotonously decreases lengthways of Hubble sequence: $\mathsf{M}_t \ / \ L_B = 6, 4, 2$ for galaxies of $Sa-$, $Sb-$, $Sc-$ types accordingly. At the same time the integral mass to infrared luminosity $L_H$ ratio does not depend on a morphological type: $\mathsf{M}_t \ / \ L_H = 2$ ( Rubin et al. 1985). From this obviously, that the infrared luminosity to blue one ratio is function of the Hubble type $L_H \ / \ L_B = 3, 2, 1$, for galaxies of $Sa-$, $Sb-$, $Sc-$ types accordingly (see Table 2). We shall note, that the theoretical calculations of star formation in disk galaxies (Larson and Tinsley 1978) give the luminous mass - blue luminosity relation as

[5] Many results point at the existence of a constant density core in the center of the dark matter halos (like to a pseudo-isothermal sphere) rather than a cuspy core (like to a N(avarro)F(renk)W(hite) profile), whatever the type of the galaxy from Sab to Im.). See this Conference P.Amram Dark matter distribution in nearby galaxies www.astro.spbu.ru/dogtale/abstracts.pdf p.25; and S. Blais-Ouellette et al. 2001

function of Hubble type $\mathsf{M}_{lum} \ / \ L_B \ = \ 3, 2, 1$ for galaxies of $Sa-$, $Sb-$, $Sc-$ type. That is the role of star formation grows to late types of galaxies and by that acts in the sense of decrease of their compactness.

In general, on the [ $log\mathsf{M}/\mathsf{M}_m, logR/R_m$ - plot the type I of IMD is the least curved; the type III of that is the most curved. Type II is intermediate between I and III for $logR/R_m \ < \ 0$ and similar to type III for $logR/R_m \ > \ 0$ (Burstein, Rubin 1985). According to the formula (3), hence, slower (the little by little) is reached $V_m(R/R_m)$ and weakest is the bulge system, the less is curved mass distribution of galaxies on the diagram $log\mathsf{M}/\mathsf{M}_m$ , $logR/R_m$. The majority of $Sc-$ type galaxies have I type of mass distribution. And all three the type of IMD can be found between galaxies of each morphological types $Sa$, $Sb$, $Sc$. And as at fixed relative disk mass or fixed morphological type the more massive (bulky) galaxies are more compact, it is possible to speak about connection between the type of IMD and compactness for a given Hubble type of galaxies. The mass-luminosity relation is constant for a Hubble type, but compactness is not.

The existence of only several base types of IMD revealed by Rubin and collaborators shows that galaxies form classes of similar objects accordingly to the type of IMD. The latter turns out even more universal characteristic than Hubble type. As it could be seen from Table 2 neither disk to total mass ratio nor mass-luminosity relation by itself cannot 'make out' the type of IMD. The latter forms during initial (cosmogonical) or active (in the sense of galaxies and star formation) stages of evolution of future $Sa-$, $Sb-$, $Sc-$ normal spirals. Type of IMD can be considered as the general physical similarity phenomenon.

Similarity is expressed by similarity criteria which are dimensionless complexes of physical quantities determining some phenomenon, the type of IMD in our case. (See APPENDIX.)

Dimensionless combination $\Pi_V$

$$\frac{G\mathsf{M}_t}{R} \cdot V^{-2} \ = \ \Pi_V$$

attributed to an arbitrary galaxy can be taken for the similarity criterion in a case of its numerical constancy because in such case it is invariant relative to the uniform scale transformation of mass, length and time (Dibay, Kaplan 1976, ch.7, §1). Its sense is more broad than force balance in the formula (3).

Numerical values of $\Pi_V$ for $\mathsf{M}_t$, $R$, $V$ given in Table 2 in $cgs-$ system units for defining parameters has the value near unity what it must be according to (3).

Numerical values of $\Pi_V$ vary, though in the narrow interval $(0.6 \div 1.4)$. It is equal to unity on the average, statistically. This takes place not without reason and can be treated as similarity on a different scale for individual galaxies. It will be recalled that Rubin and her collaborators scaled each individual mass distribution by its mass scale length, $R_m$, to give the minimum scatter from each other within the type of IMD (Burstein et al. 1982, Burstein, Rubin 1985).

Supposing $\Pi_V = (G\mathsf{M}_t) \ / \ (V^2 \ \cdot R) \approx 1, V = \Omega \cdot R, \ \mathsf{M}_t \sim \delta \cdot R^3$, we find $\delta \sim \Omega^2 \ / \ G$. Relation for mean density of a galaxy appears to be similar to period-density relation for pulsating stars. Similarity of mechanical motions in the gravity field consisting in small deviations from equilibrium for stars pulsations and swing of pendulum was pointed out by ( Dibay, Kaplan 1976, ch.1, §4). In general, situation for disk rotation in a galaxy gravity field in spirals obeies the general law of gravitating system: their temporal characteristics (including a rotational period) are related to mean system density ( Dibay, Kaplan 1976, ch.2, §1). Recall, that mean system density is the system compactness measure also.

The steeper and higher raises the rotational curve, the galaxy is more compact, its mean density is higher, and the type of IMD number is larger. The smallest numerical value of $\Omega$ corresponds to least compact galaxies, to the I type of IMD and low luminosity. Larger values of $\Omega$ correspond to II and III type of IMD, to higher luminosity.

So, by means of the criterion $\Pi_V$ explanation can be given to the fact that all three types of IMD are proper for $Sa-$ $Sb-$galaxies (Burstein, Rubin 1985). This takes place because they have 3 type of rotational curves which differ by height and steepness, and so galaxies may have different compactness (mean densities). But for $Sc-$galaxies which rotational curves do not have such differences is proper I type of IMD only(!).

So all spirals must satisfy this similarity criterion. As it was often pointed out above, the structure of spirals indeed in the first instance depends on their rotation, and also on their compactness. But types of IMD are determined also by cosmic scale turbulence, by earlier star formation, gas radiation and their influence on galaxy rotation and compactness during gravitational contraction of protogalaxies and disk components formation.

$\Pi_L = L\mathsf{M}_t^{-1}RV^{-3}$ can be interpreted in a several way including such as luminous to kinetic energy ratio in active evolutionary phases of the galaxy (or any its subsystem - buldge, halo, disk, or galaxy typical parts within $R_m$) at time-scales proper to Efremov - Chernin's scenario (Efremov & Chernin 1994).

$\Pi_L$ is quantity $\sim\ 1$, if $L/\mathsf{M} \sim 1, R \sim 10^{21}, V \sim 10^7$ (in $cgs-$ system units), which coincide with scaling of (Burstein, Rubin 1985) and (Efremov & Chernin 1994).

$\Pi_L$ is quantity $\sim\ 1$. Let's transform the relation of quantities which it contains in the physically more clear form, namely $R^2 \cdot \Omega^3 \sim L/\mathsf{M}_t$, or $V_p^3 \sim R \cdot (L/\mathsf{M}_t)$, or $V_p \sim (R \cdot (L/\mathsf{M}_t))^{1/3}$. Attributed to a protogalaxy in the primery turbulent state, this is Kolmogorov-Obukhov law from theory of isotropic turbulence with $(L/\mathsf{M}_t)$ as dissipative factor, and $V_p$ and $R$ as characteristic velocity and scale of turbulent motion (Baum et all 1958, Landau, Lifshitz 1986). Primary 'eddies' evolve owing to decay in a galaxy with disk system carriing off the angular momentum of a galaxy. Large-scale turbulence and dynamical criticality and chaos cause also gently (than isothermic or cuspy) slope of the galaxy density profile [6].

Generally speaking, due to $\Pi$-theorem one can write the similarity criterion of the form of arbitrary function from found dimensionless complexies, which are taking into account greate numbers of determining parameters, namely $\mathcal{F}(\Pi_V, \Pi_P, \Pi_L) = 0$.

# 5 Conclusions

Availability (existence) of physical similarity of normal spiral galaxies, their conformity with certain similarity criteria and accordance with Chernin & Efremov's cosmogonic scenario have been shown as resulting from observations under the guidance of V. Rubin.

So one can conclude. Though the masses and luminosities of normal spirals differ in 100 times, and the sizes do in 10, relative characteristics ( relative disk mass, compactness, luminosities-ratio ) and $V_{max}$ are distinguished only in 3 times, and $\Pi_V, \Pi_P, \Pi_L\ \sim\ 1$. The relative characteristics follow typical mass distributions in them, marking their variety. Compactness and mass distribution are determined by the same factors - rotation achieved, balance between rotational and gravitational energy in a protogalaxy, as well as by star formation. From this follows and their interrelation. The main cause of the type of IMD variety lies in the manner of physical similarity of galaxies conditioned by determining physical factors - gravitation, rotation, radiation processes and star formation and fixed in dimensionless complexes $\Pi_V, \Pi_P, \Pi_L$ and an arbitrary function $\mathcal{F}$ form.

So, one can give affirmative answer the question raised by authors of (Burstein et al. 1982) "Or is the morphological type the ultimate result of a

[6] On the possible bar-driven dark halo evolution see M. D. Weinberg and N. Katz 2002

variety of influences, including environmental ones?", consider it as rhetorical one in the light of our discussion.

# 6 APPENDIX: A dimension matrix and dimensionless complexes

To find first dimensionless complex compose a dimension matrix taking centimetre ($cm$) - gram ($g$) - second ($s$) system as fundamental (primary) one and four parameters $\mathsf{M}_d,\ R,\ (G\mathsf{M}_t),\ V$ ( Dibay, Kaplan 1976):

$$\begin{array}{ccccc} & \mathsf{M}_d & R & G\mathsf{M}_t & V \\ g & 1 & 0 & 0 & 0 \\ cm & 0 & 1 & 3 & 1 \\ s & 0 & 0 & -2 & -1 \end{array} \tag{4}$$

Search for the dimensionless complex:

$$\Pi \ = \ \mathsf{M}_d^{k_1} R^{k_2} (G\mathsf{M}_t)^{k_3} V^{k_4}$$

Using the dimension matrix we derive the following system for $k_i$ exponents:

$$\begin{array}{c} k_1 + 0 \cdot k_2 + 0 \cdot k_3 + 0 \cdot k_4 = 0,\ (i.e.\ k_1 = 0) \\ 0 \cdot k_1 + 1 \cdot k_2 + 3 \cdot k_3 + 1 \cdot k_4 = 0 \\ 0 \cdot k_1 + 0 \cdot k_2 - 2 \cdot k_3 - 1 \cdot k_4 = 0 \end{array} \tag{5}$$

Suppose $k_3 = 1$, then $k_4 = -2$, and $k_2 = -1$. So, the dimensionless complex, denote it $\Pi_V$, take the form:

$$\frac{G\mathsf{M}_t}{R} \cdot V^{-2} \ = \ \Pi_V.$$

If one adds to (4) once more determining parameter the angular momentum $P$ with dimension $[P] = g \cdot cm^2 \cdot s^{-1}$, and replaces $V$ by $\Omega$, and searches for the dimensionless combination, one will derive

$$\Pi_P \ = \ (P \cdot \Omega)(G\mathsf{M}_t \cdot \mathsf{M}_d/R)^{-1}$$

identical to (2).

Take four parameters: $\mathsf{M}_t,\ R,\ L,\ V$. Their dimensionless combination obtained as it was shown above will be

$$\Pi_L = L\mathsf{M}_t^{-1} R V^{-3}\,.$$

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