ON THE NATURE OF LOW-LUMINOUS SPIRAL GALAXIES

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Nizhnij Arkhyz, 2019

Dwarf spiral galaxies are rarely occurring type of low-mass discy galaxies possessing the extended and at least partly ordered (by visual inspection) stellar arms or filaments. Unlike Irr-galaxies, they usually reveal a well defined bright central region (bulge?).

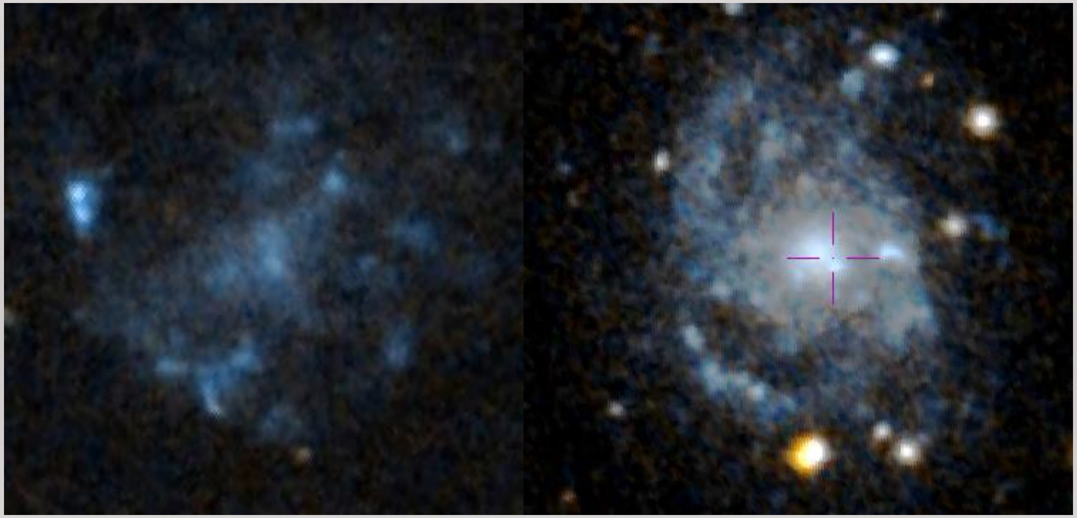
Edmunds, Roy 1993: a spiral structure is absent in galaxies with $M_b > -17$

- UGC catalog: : there only about a dozen of dSs among the 12000 galaxies. RC3 catalog: no galaxies at all marked as dS. But there is observational selection effect: this type of galaxies has low luminosities and angular sizes.

Exclusions are rare,

but they exist!

dIrr dS



Qs.

Why do dwarf discy galaxies usually avoid a spiral structure?

Low velocity of rotation?

A high ratio of C_z/Vrot?

Low disc self-gravity?

Hidalgo-G'ames results

The only paper where the sample of dS galaxies was analyzed by their properties is Hidalgo-G´amez 2014 (+several works about gas properties in these galaxies):

about 100 dS galaxies were extracted from the sample of Sm-galaxies in UGC catalog as non-interacting galaxies with M_B>-18 and diameter D_{25}<10 kpc (to exclude LSB-galaxies), which demonstrate a spiral structure.

It was concluded, that:

- dS galaxies are among the brightest and biggest ones in the sample of galaxies;
- Most likely, dS galaxies have higher SFE;
- They do not belong to rich clusters;
- There is a deficiency of barred galaxies among dSs with respect to non-dwarf spirals of the comparison sample;
- Mass of HI in dS galaxies is lower in the mean than in the non-dwarf spiral galaxies of the comparison sample, most of which possess a higher luminosity;
- Spectral features of dS galaxies do not differ from those of Irr -galaxies.

Our sample of dS galaxies

Dwarf spiral galaxies were extracted from the list of non-interacting galaxies from the HyperLeda database.

- Type: Sa-Sm-Irr
- Visible brightness: $B<15^m$
- Luminosity: $M_B>-18$ ($H_0=75$ km/s/Mpc)
- Diameter: $D_{25}<10$ kpc
- Disc inclination: $30^0<i<75^0$

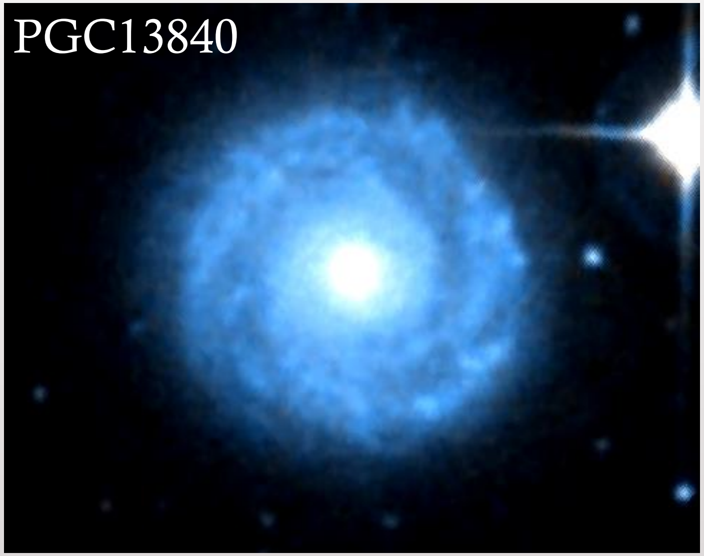
Type	Amount in sample
Sa	3
Sb	1
Sc	22
Sd	12
Sm (spiral)	8
Sm (non-spiral)	34
Irr	73

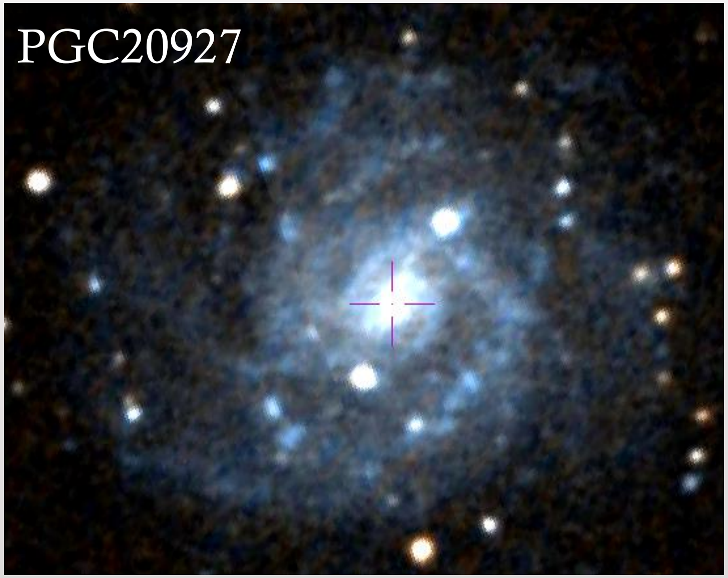
dS galaxies have clear signs of spiral arms (or ring-like structures in some cases), easily seen in the available images (SDSS, DSS, Legacy Survey). The remaining non-dS galaxies of general sample make up a control sample.

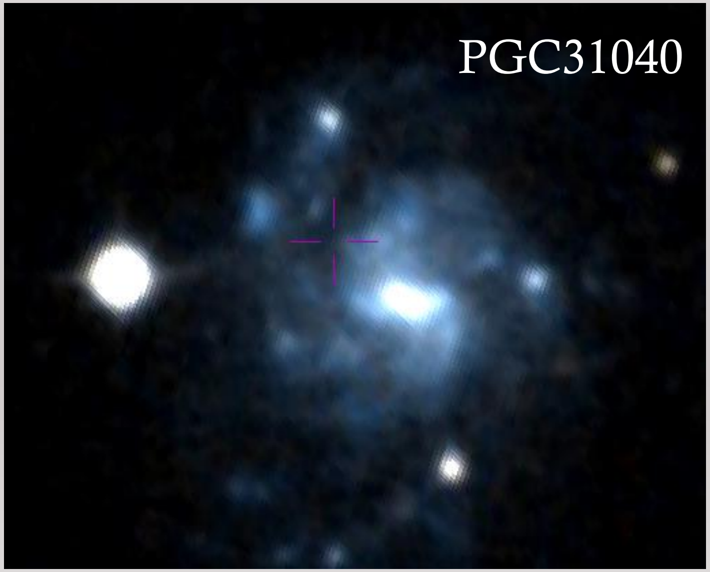
Our sample of dwarfs galaxies consists of 153 members: 46 objects were classified as dS, 34 as Sm and 73 as Irr-galaxies.

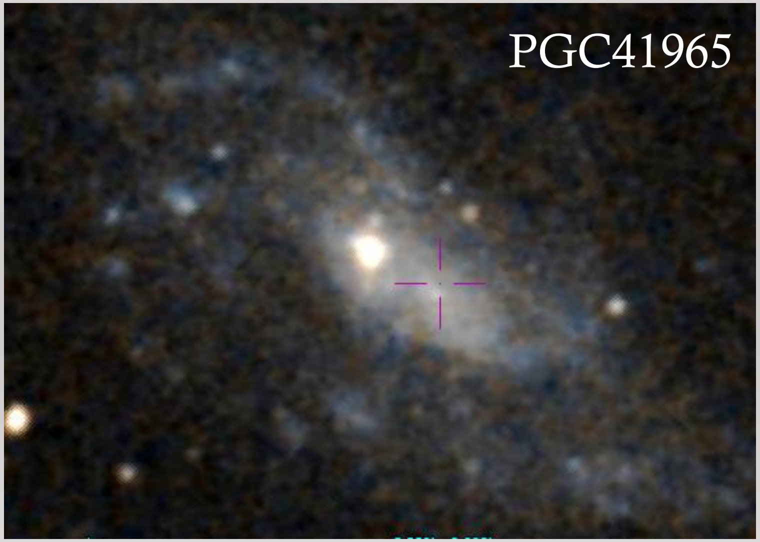
Spiral structure in some dS-galaxies may be attributed to GD-type, some - to flocculent one, although there is no a strict borderline between them.

The examples of flocculent dS

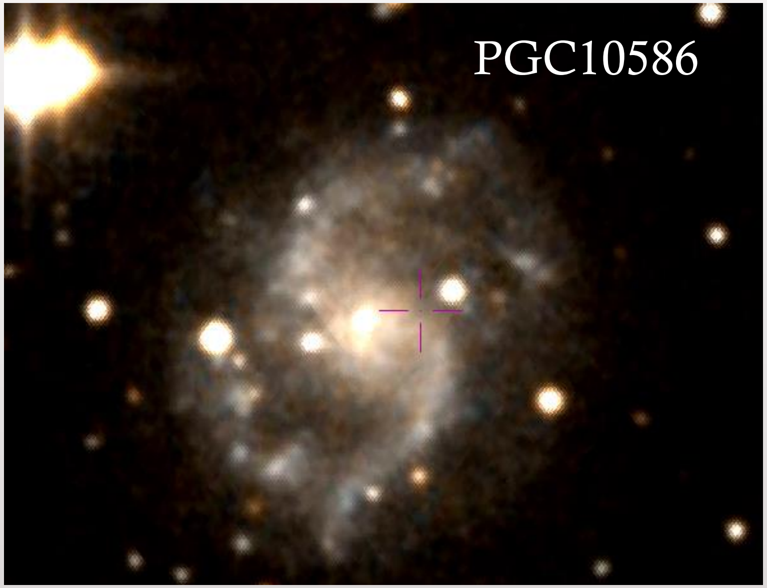


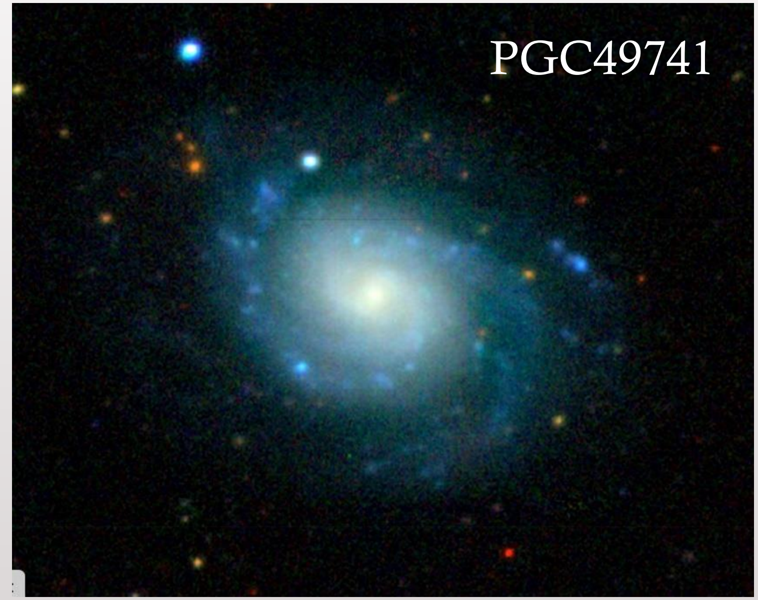


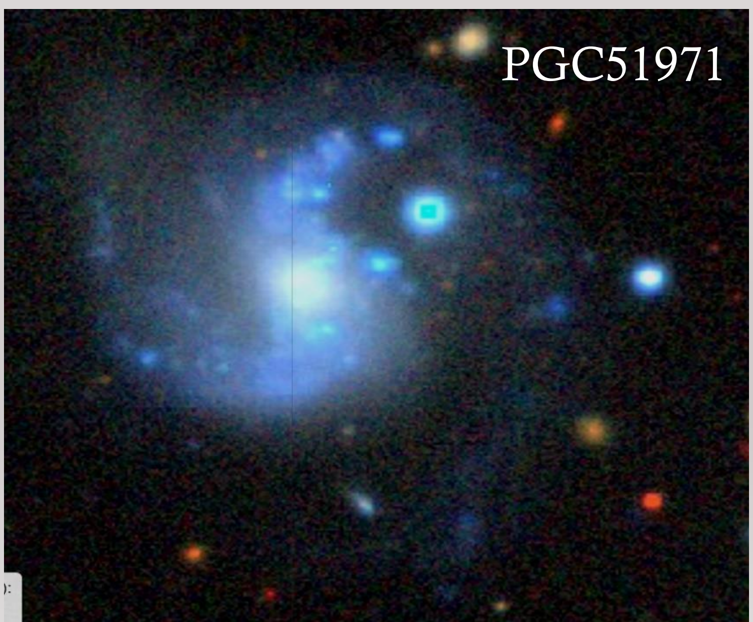


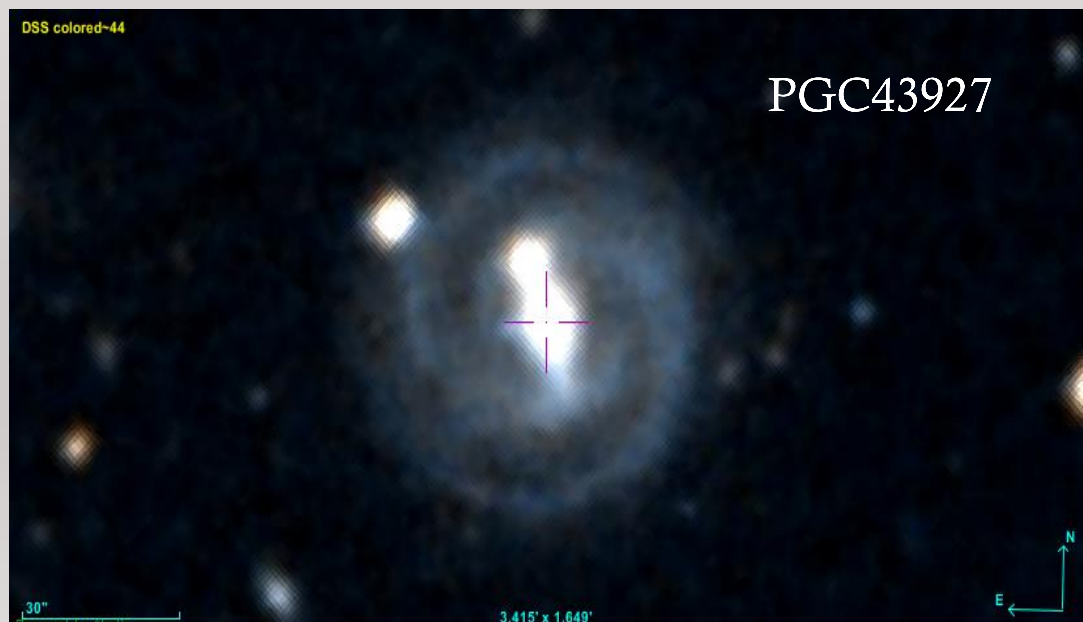


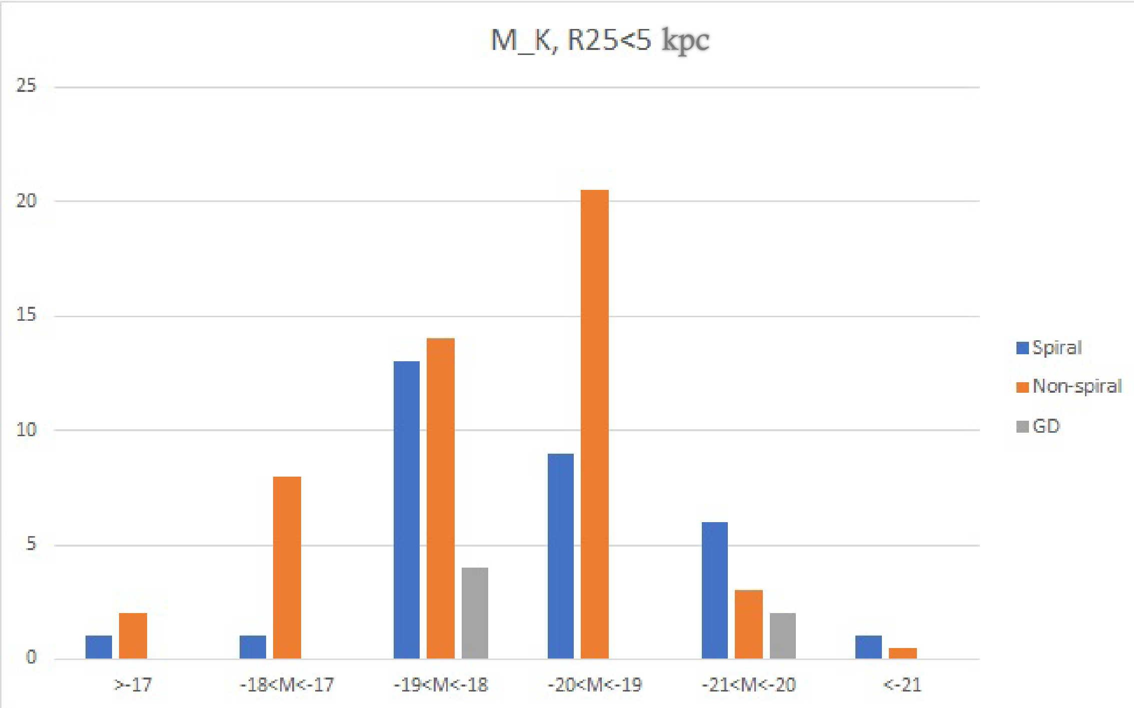
The examples of GD-type dS





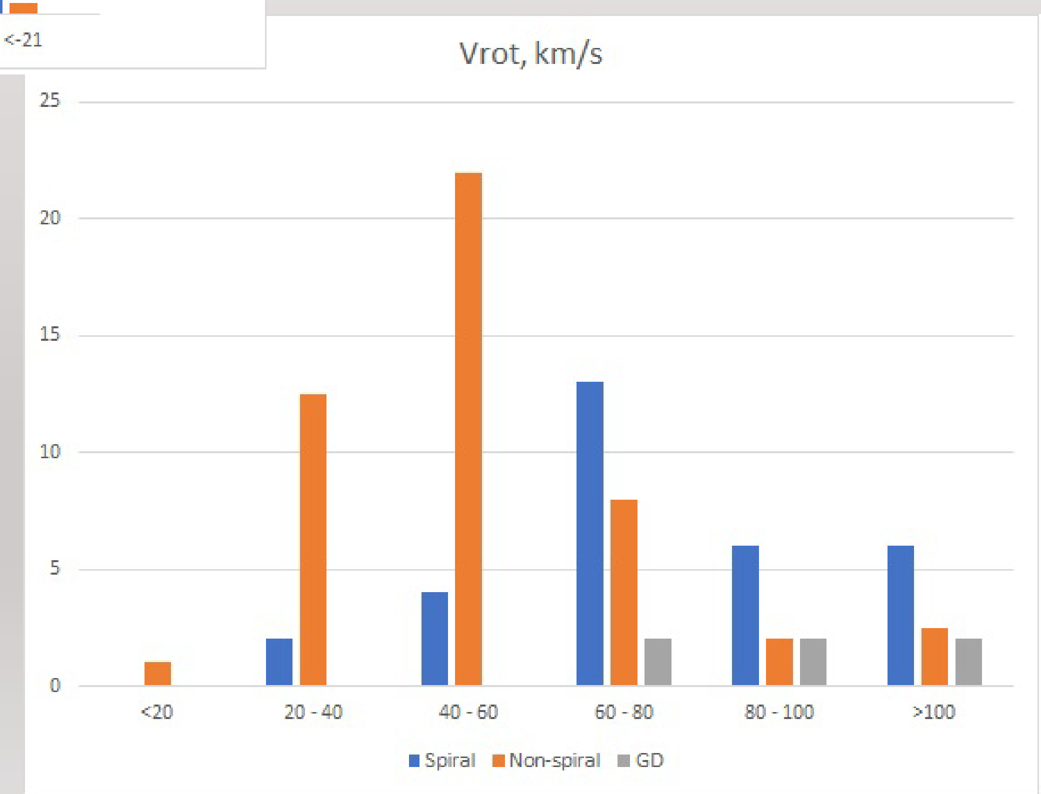




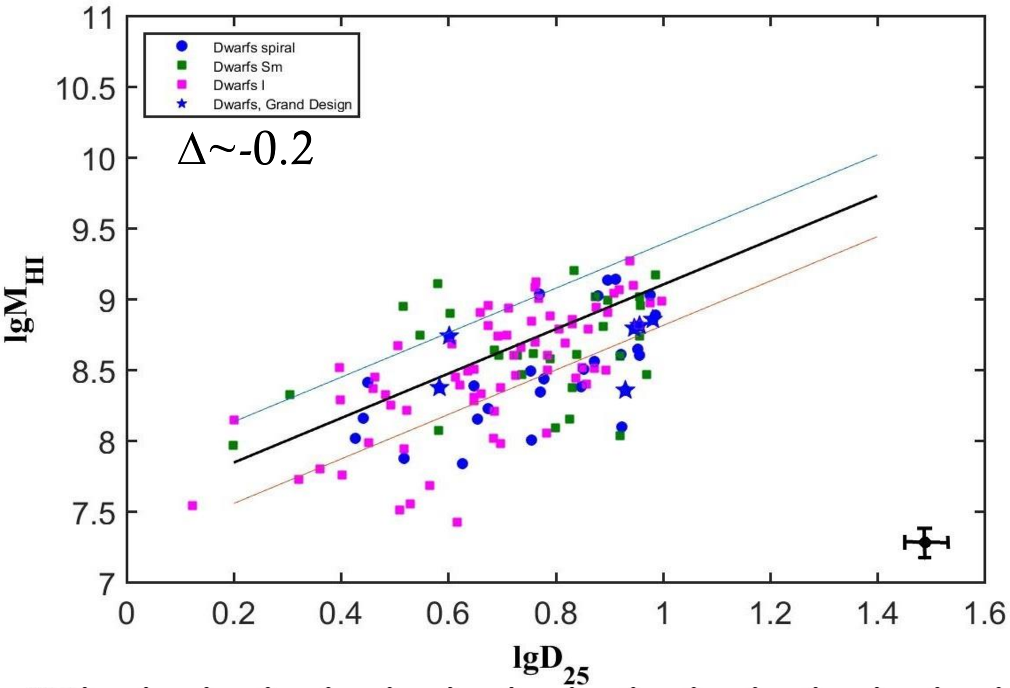


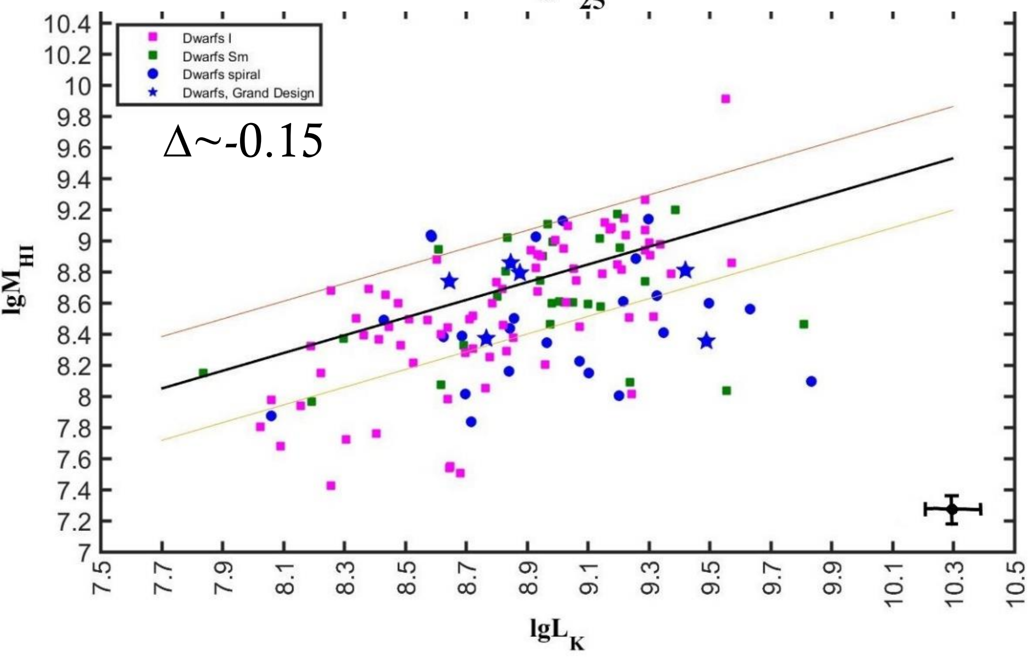
GD dwarfs belong to the most luminous and fast rotating galaxies.

Distributions of K-band luminosities (left) and velocities of rotation (right) for low luminous galaxies of our sample. Orange - galaxies Irr+Sm, blue - dS, grey - dS with GD structure, taken separately.



HI content in dS galaxies





pink - dIrr, green - dSm, blue - dS galaxies. Asterisks – galaxies with GD spiral structure.

Straight lines mark the linear relationships and the ±1σ intervals for isolated galaxies in a wide range of L_K (the AMIGA sample).

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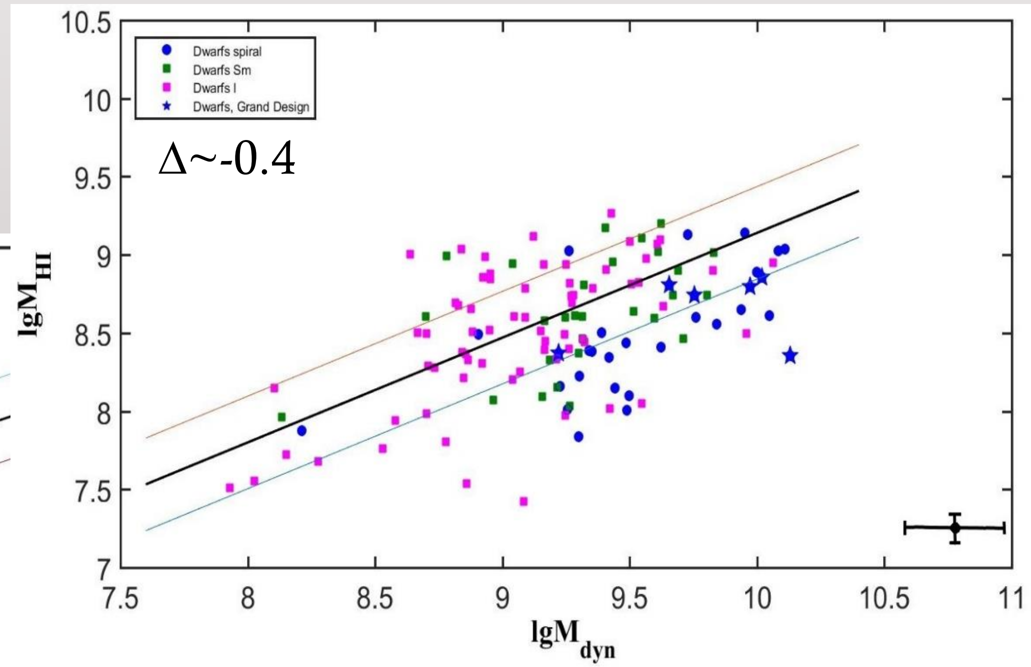
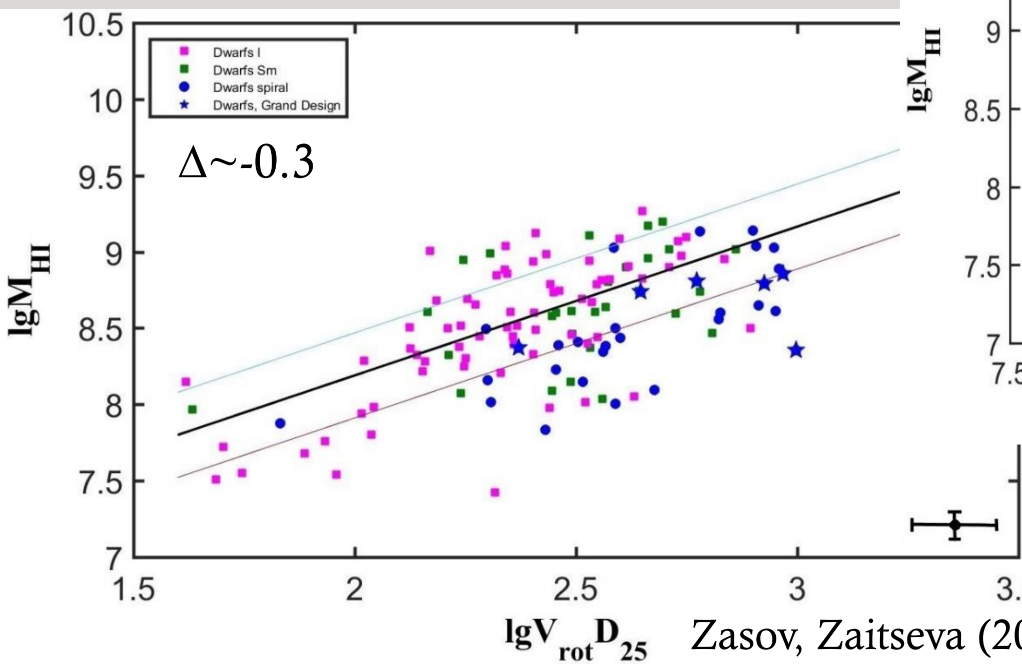


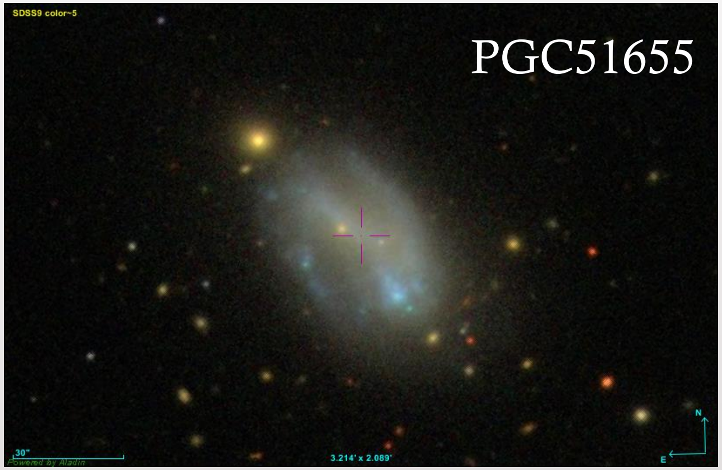


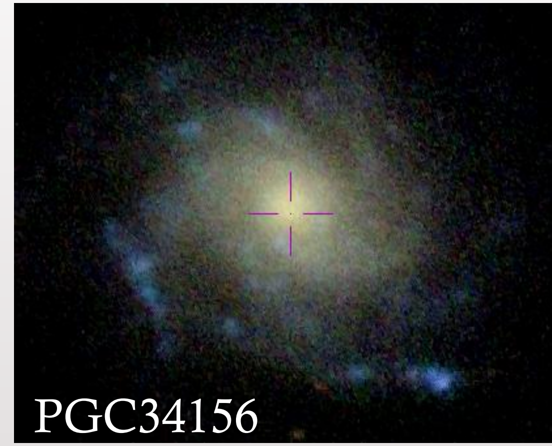
Zasov, Zaitseva (2017)

Parameters of GD dS galaxies

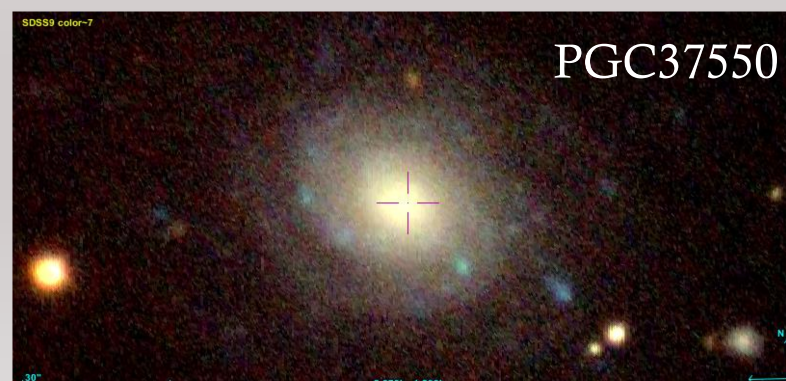
pgc	V, km/s	D_{25}, kpc	V_{rot}, km/s	M_{HI}/L_K	M_{HI}/M_{dyn}	Bar
10586	584	3,8	61	0,4	0,1	B
12961	1652	8,5	117	0,1	0,02	B
36137	1145	9,0	66	0,2	0,1	-
37132	921	9,6	97	1	0,07	B
49741	1619	8,8	95	0,8	0,07	-
51971	1528	4,0	111	1,2	0,1	B

A frequency of occurrence of barred galaxies





	Barred	Total
Spiral	30	46
Sm	23	34
Irr	45	73



Modelling

- We tried to find conditions of spiral arms formation in low-mass discy galaxies due to gravitational instability development in 2 component disks (stars+gas).
- Direct PP-method was used for this research. A total number of equal mass points is about 10^6.
- We used GPU programming methods to calculate gravitational forces between N-bodies of self-consistent galaxy model.

Stellar-gaseous disk dynamics model

numerical integration of a joint system of basic equations

Gas

$i = 1, \ldots, N_g$

$$\frac{d\mathbf{v}_i}{dt} = -\frac{\nabla p_i}{\rho_i} + \sum_{j=1, j\neq i}^{N} \mathbf{f}_{ij}$$

$$\frac{d\mathbf{r}_i}{dt} = \mathbf{v}_i$$

$$\frac{de_i}{dt} = -\frac{p_i}{\rho_i} \nabla \cdot \mathbf{v}_i$$

$$e_i = \frac{p_i}{(\gamma - 1)\rho_i}$$

Non-dissipative gas dynamics

Gravitational interaction

$$\mathbf{f}_{ij} = -G \frac{m_j (\mathbf{r}_i - \mathbf{r}_j)}{|\mathbf{r}_i - \mathbf{r}_j + \delta|^3}$$

$N = N_g + N_s$

Stars (collisionless N-body component)

$i = 1, \ldots, N_s$

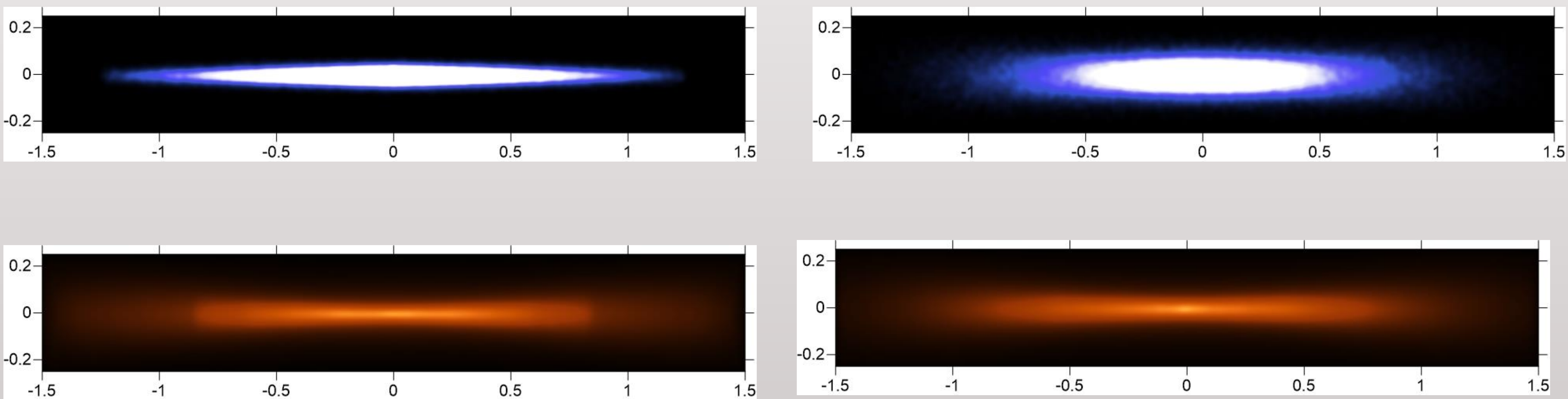
$$\frac{d\mathbf{v}_i}{dt} = \sum_{j=1, j\neq i}^{N} \mathbf{f}_{ij}$$

$$\frac{d\mathbf{r}_i}{dt} = \mathbf{v}_i$$

+ fixed potential of isothermal halo with given mass and density distribution law

Main varied parameters of the model

1) $z_0 = z_{01} + sr$ - average relative vertical scale 0.05 – 0.5
(normalized to a radial exponential scale)



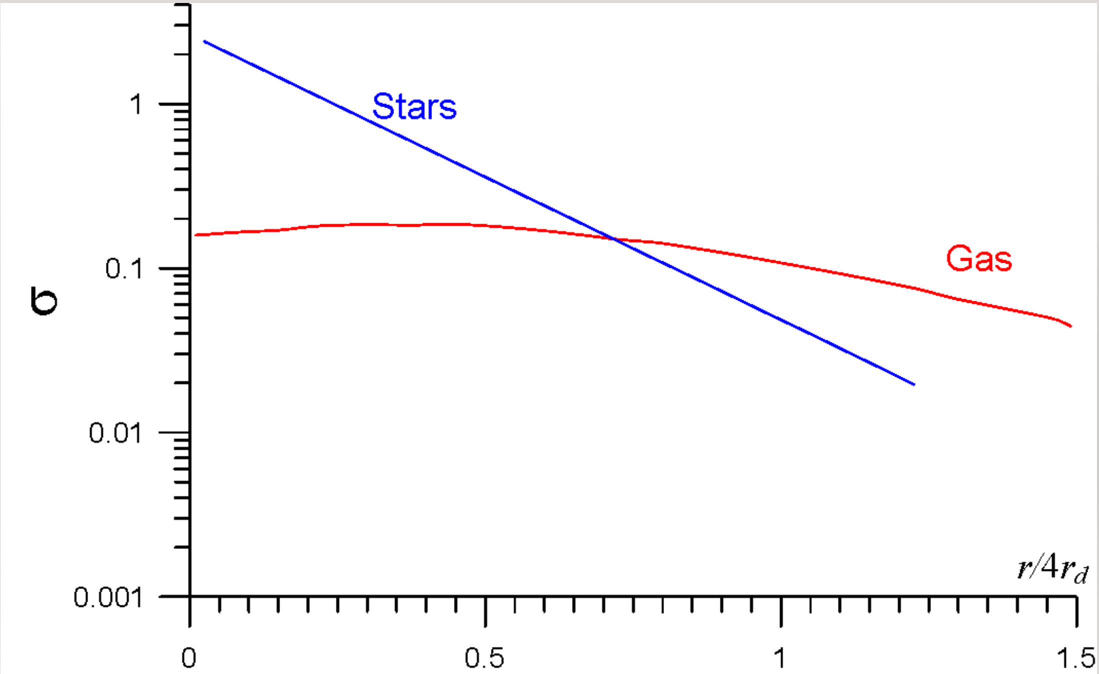
2) Velocity dispersion radial profiles of stellar disk
Parameter interval: from 10 km/s up to a half gas rotation speed

Main varied parameters of the model

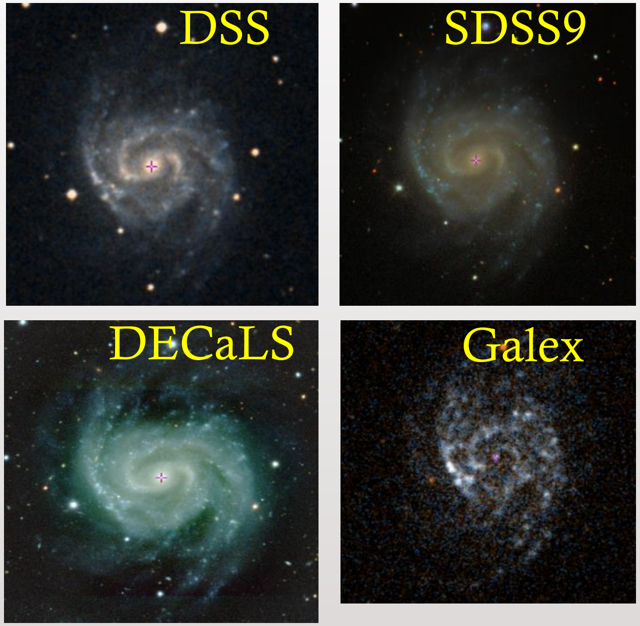
3) Stellar rotation speed V_{max}
Parameter interval: from 40 up to 100 km/s

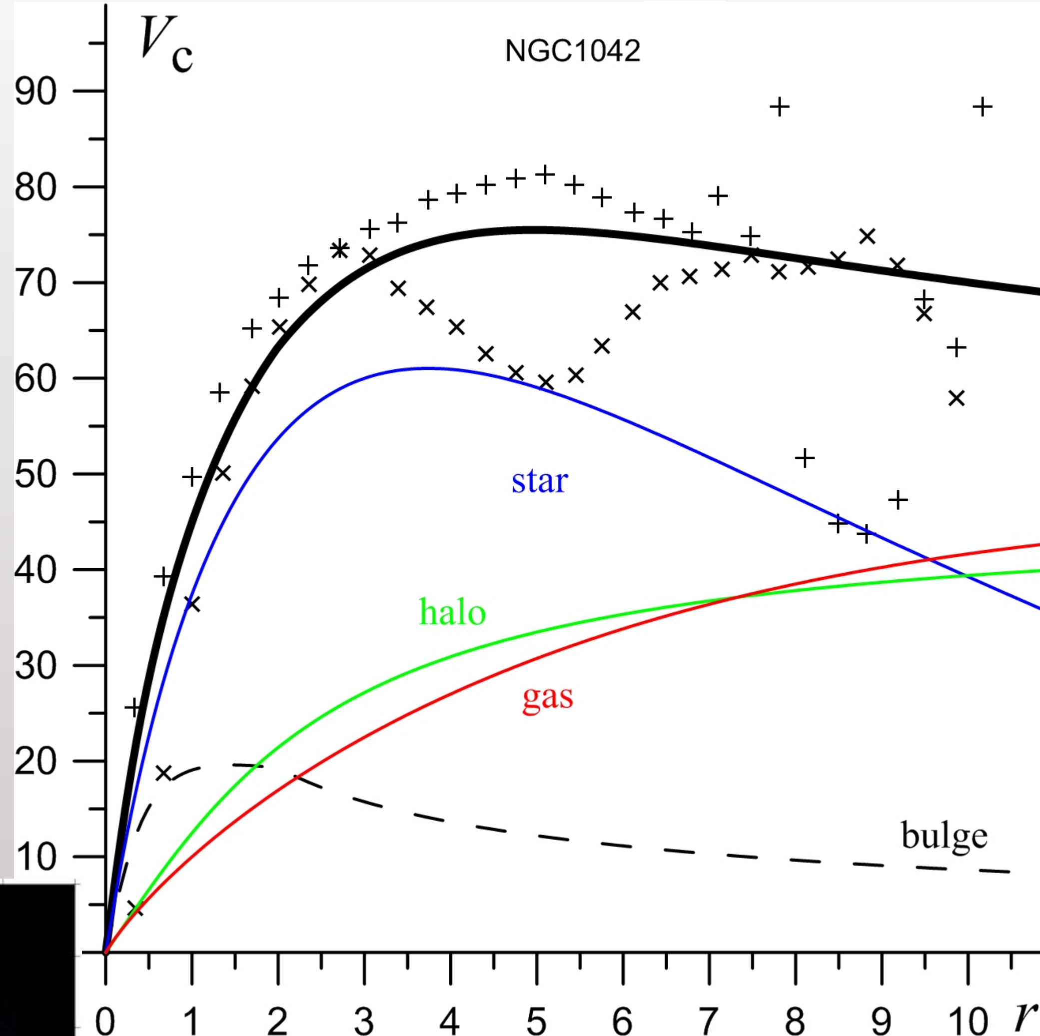
4) Central density of an exponential stellar disk
Typical values are 100 – 450 M_{sun} /pc²

5) The gas-to-star mass ratio of the disk: 20 – 100%.
Example of the initial surface density profiles:

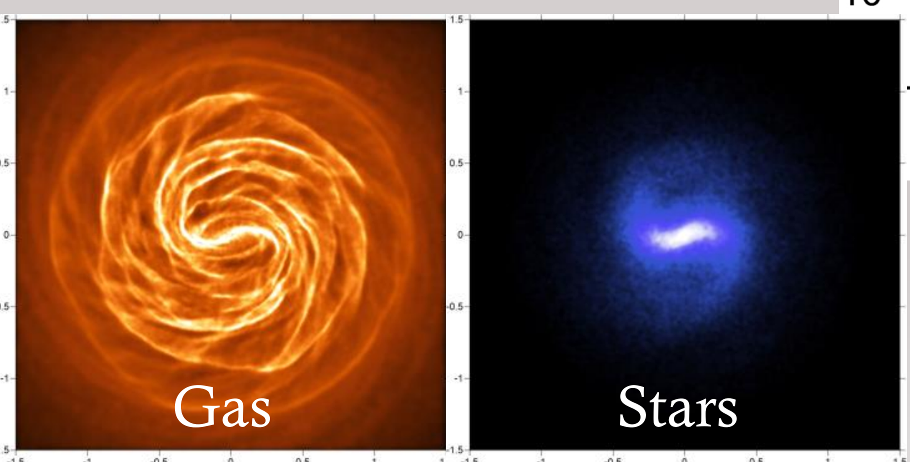


NGC 1042 (M_B=-17.5): clear spiral structure with small bar and powerful SF in spiral arms.





Rotation curve: D. Kornreich et al. (2000)

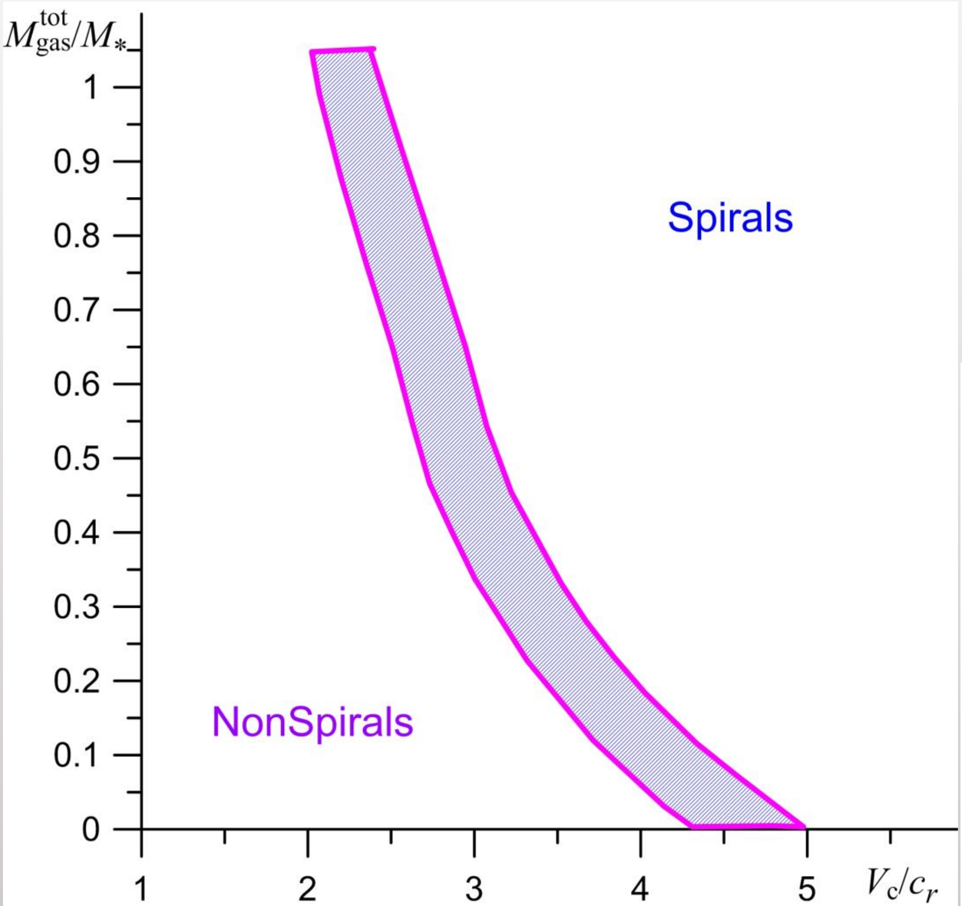


r < 7 kpc:

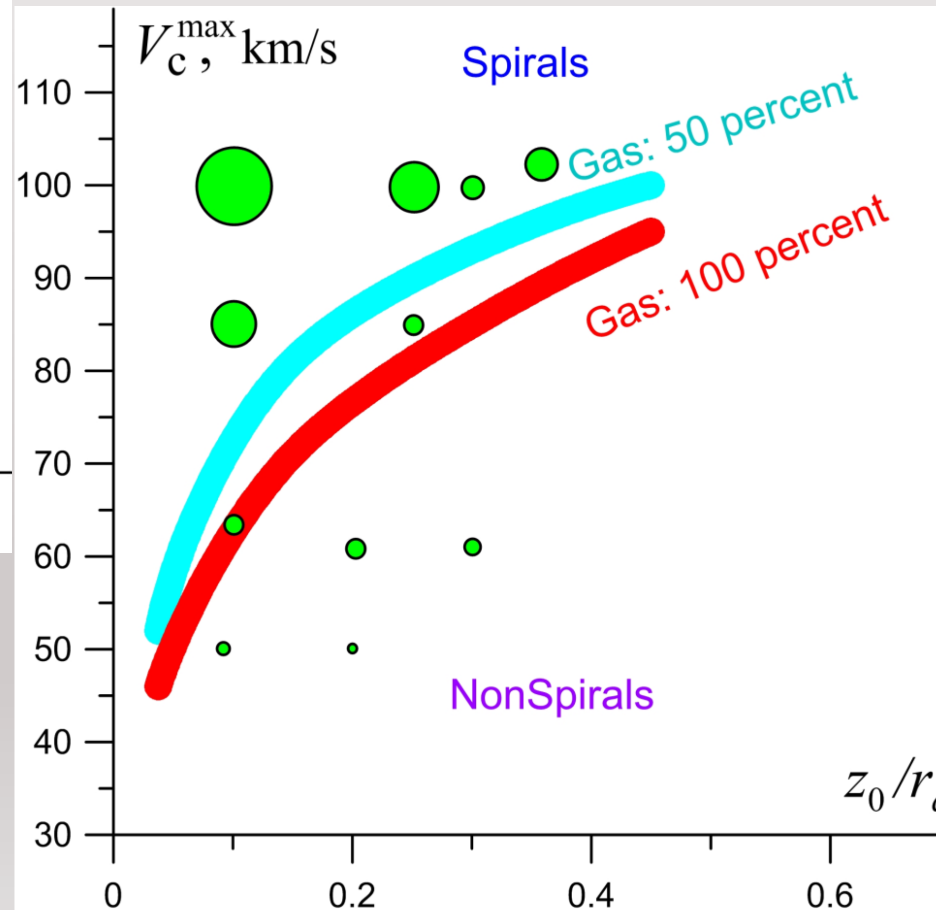
$M_s = 0.371\ 10^{10}$ $M_g = 0.199\ 10^{10}$

$M_h = 0.222\ 10^{10}$

Attempts to reproduce spiral structure

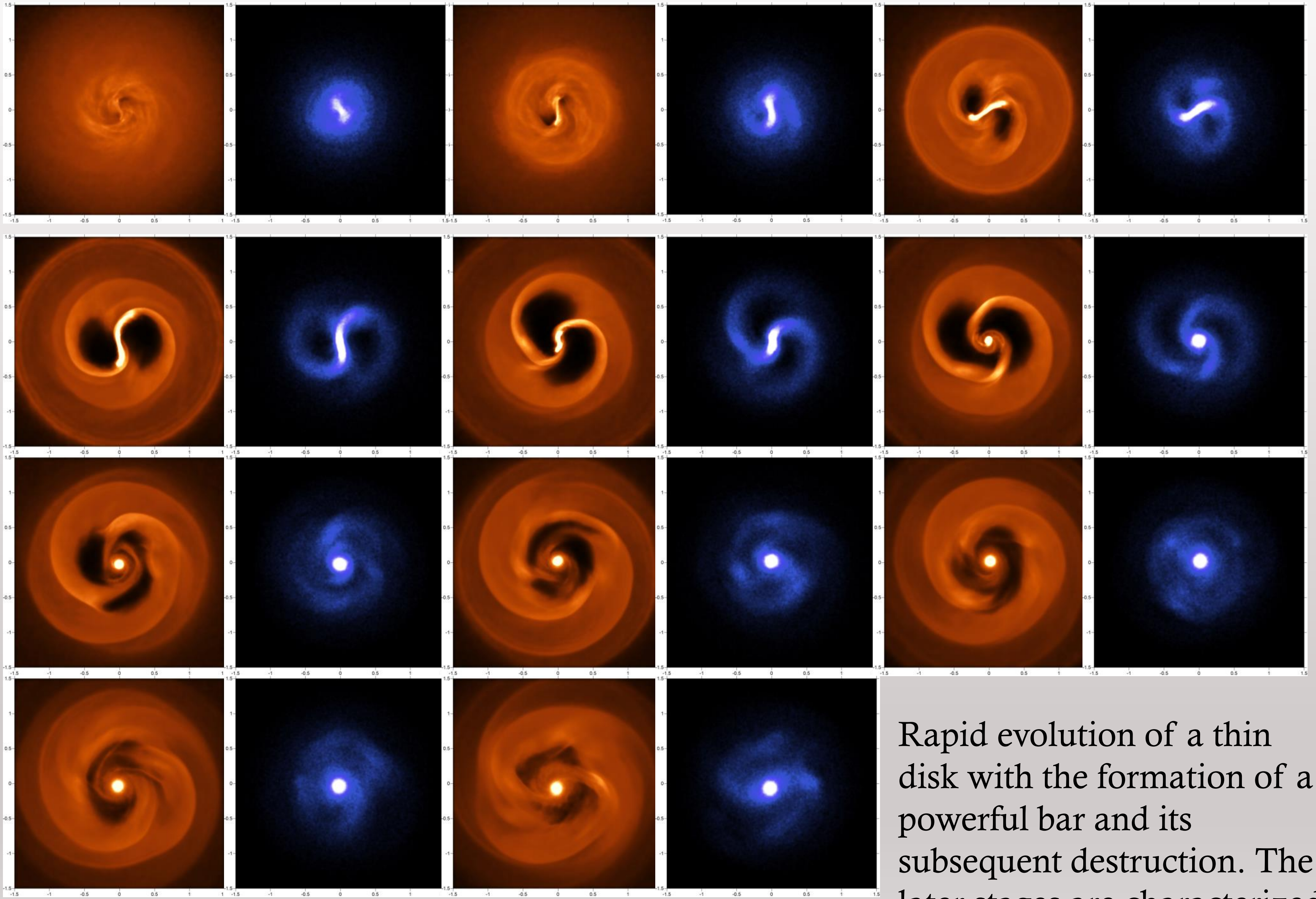


Regions at the parameter plane where spiral structure was reproduced in our models as a result of the gravitational instability development.



The size of the green circle is proportional to the maximum amplitude levels of the Fourier harmonic (mostly 2nd one).

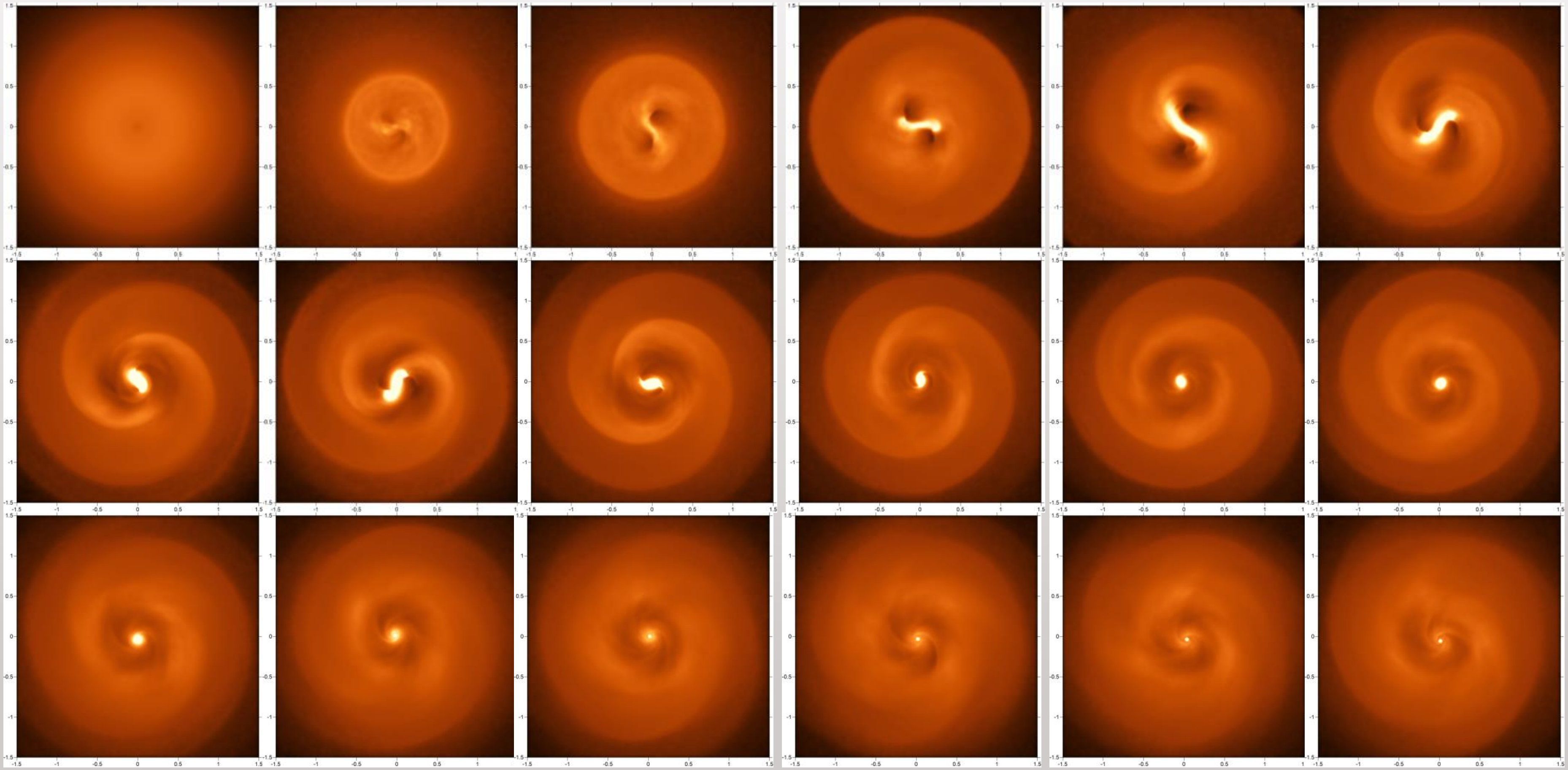
The example of spiral structure development and evolution (~10 periods of rotation)



Rapid evolution of a thin disk with the formation of a powerful bar and its subsequent destruction. The later stages are characterized by spirals without a bar.

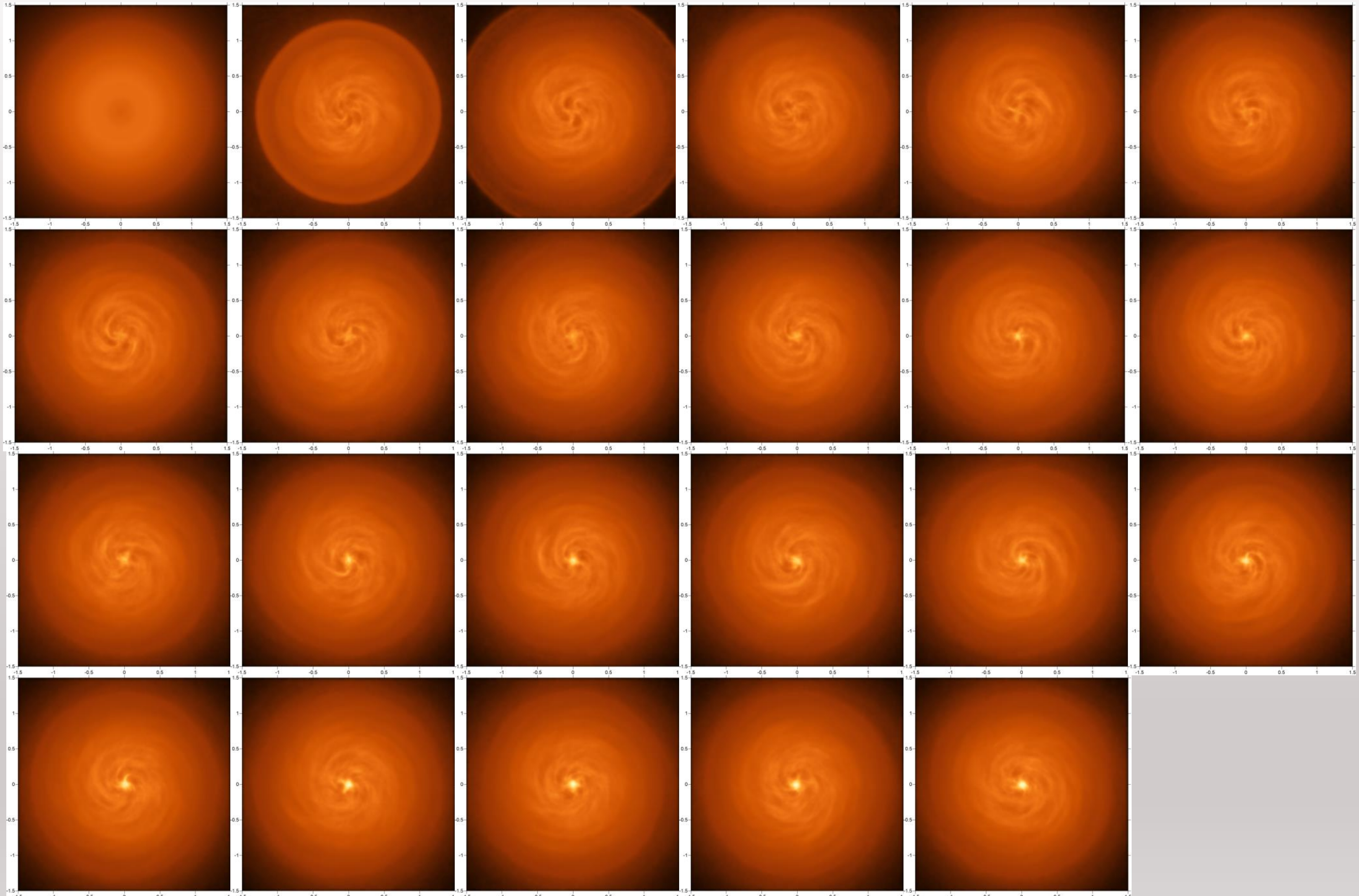
DW003b gas mass=stellar mass

A thicker stellar disk leads to a weaker structure (a gas only).



Dw005 gas mass=stellar mass

There is no clear spiral structure with significant amplitude in the case of even thicker stellar disk.



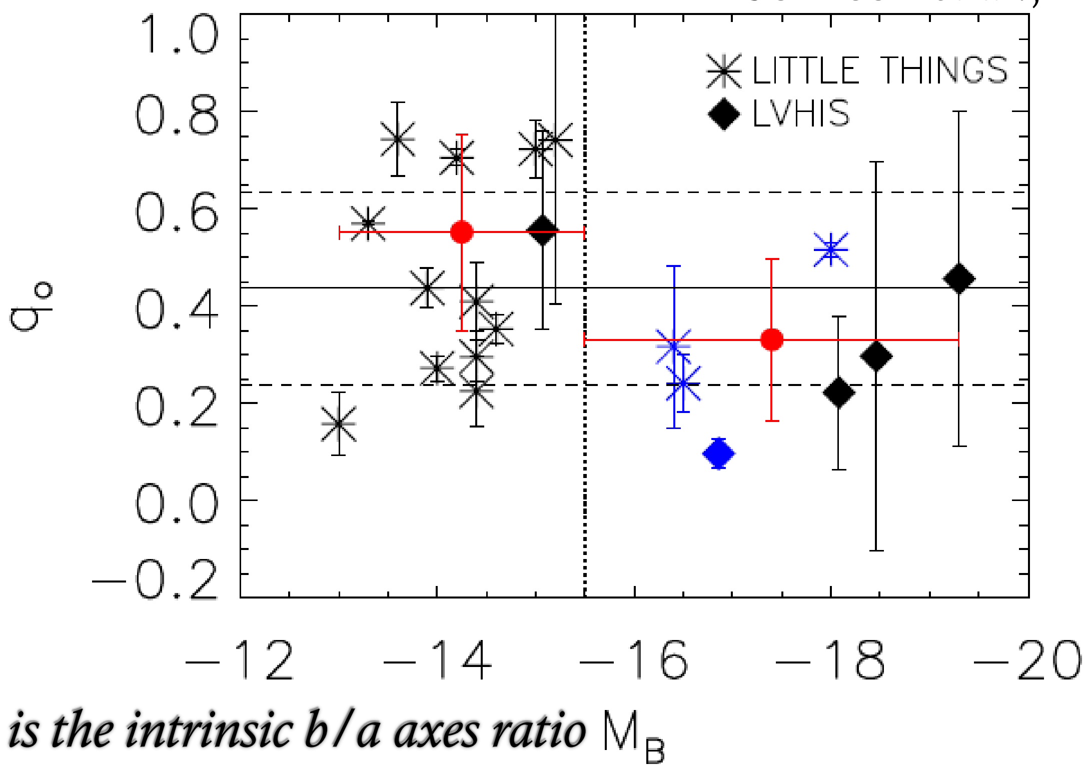
DW003e gas mass=stellar mass

Important facts:

Discs of dwarf galaxies appear to thicken with decreasing brightness.

- Johnson et al 2012, 2015, 2017
- Roychowdhury et al. , 2013
- Mosenkov et al., 2015
- Their "thickness-to-diameter" ratios are characterized by a large dispersion.

Johnson et al., 2017



q_0 is the intrinsic b/a axes ratio

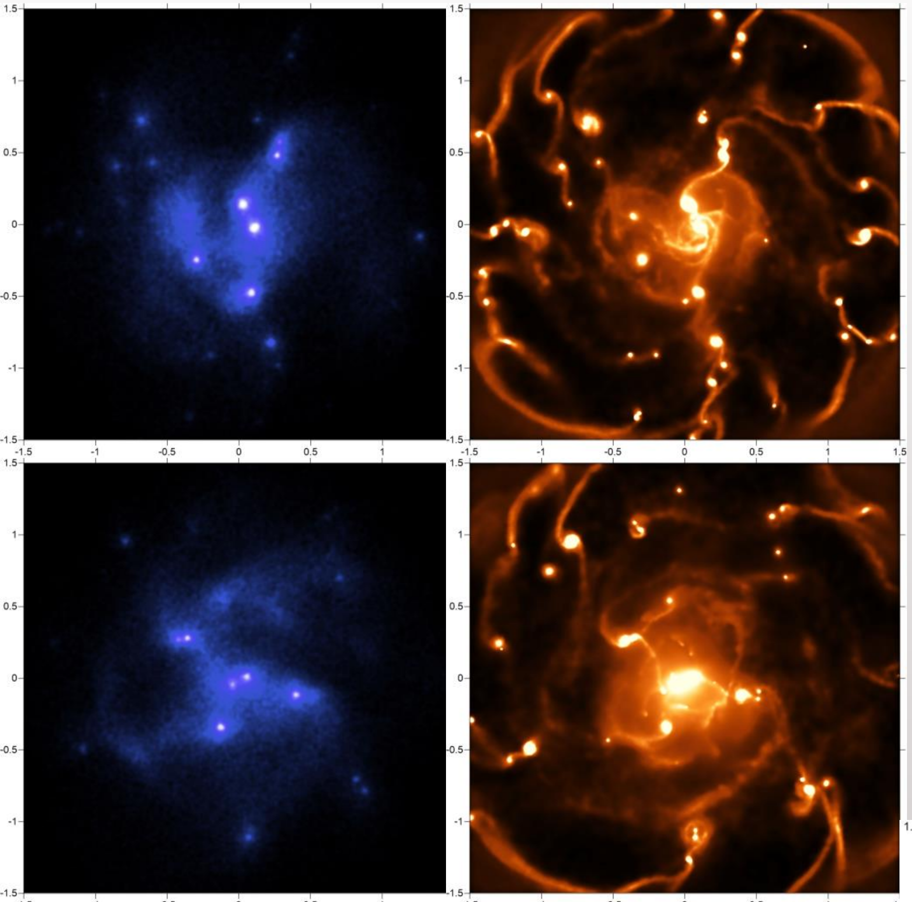
One can expect the formation of spiral structure in the most thin disks

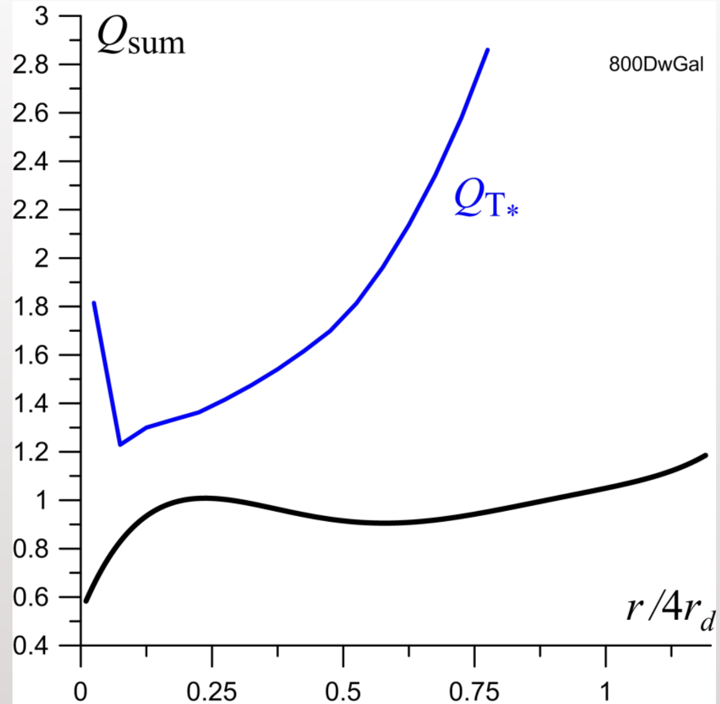
Conclusions:

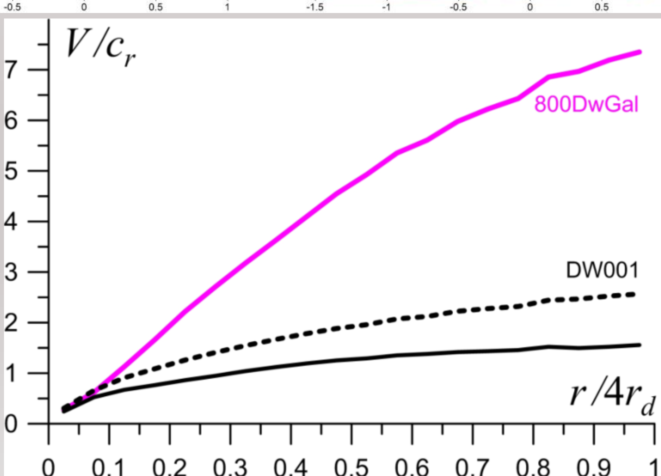
- We confirm that dS galaxies are among the more massive and fast rotation galaxies. A bulk of them have V_{rot}>50 km/s. In other words, they have relatively high luminosity and dynamical mass among dwarf galaxies.
- There is no correlation between dS fraction and the presence of a bar.
- HI mass is (in the mean) lower for dS galaxies comparing with other dwarfs with similar diameters, luminosities, dynamical masses and angular momentum. We argue that it corresponds to a fact, that formation of spiral arms requires relatively thin disks, e.g. low velocity dispersion and high rotation speed. In such cases a gas pressure is higher, and one can expect that gas consumption due to starformation if more effective.
- In general we conclude that dS galaxies present a fraction of low massive discy galaxies with the lowest disk thickness and relatively high V/C_r ratios.

Thank you for attention!

Stars 800DwGal Gas







Dw001