Механизмы формирования асимметричных спиральных галактик: численные модели N-тел

Mechanisms for the formation of asymmetric spiral galaxies:
numerical models of N-bodies

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Хоперсков С.А., Парижская обс.

«Современная звездная астрономия – 2017»,
Екатеринбург, 14-16 июня 2017, Уральский федеральный университет, 16 июня 2017
http://www.inasan.ru/scientific_activities/conferences/modern_stellar_astronomy_2017

Terminology:

Lopsided-galaxies

lop-sided (Большой англ.-русский словарь) = кривобокий, односторонний, искривленный, однобокий, перекошенный, несимметричный

Sa , Sb , Sc , Sd , Sdm Sm , Im

- One-arm spiral
- Offsets between the stellar bar and the discs
- Asymmetric bar
- Asymmetrical rotation curves

У **БМО** не совпадают:

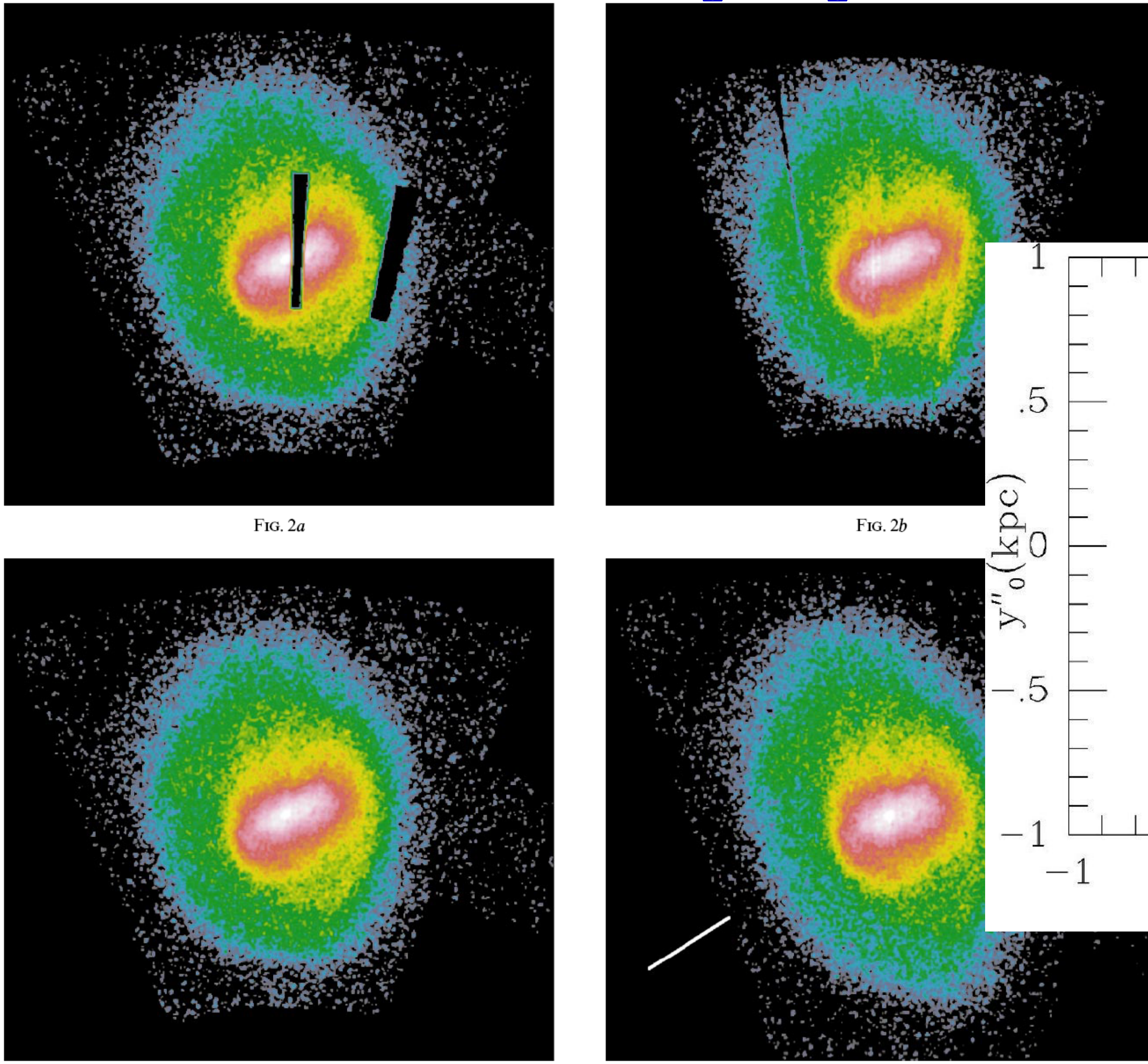
1) центр распределения яркости диска
2) центр планетарных туманностей
3) центр подсистемы сверхгигантов
4) центр *HI*
5) центр бара

[de Vaucouleurs & Freeman (1972), Zhao & Evans (2000), van der Marel (2001), Subramaniam & Subramanian (2009), D’Onghia & Fox 2015, …]

Large Magellanic Cloud

[van der Marel 2001]

внешние изофоты - 400 пк
кинематический центр HI
– 800 пк



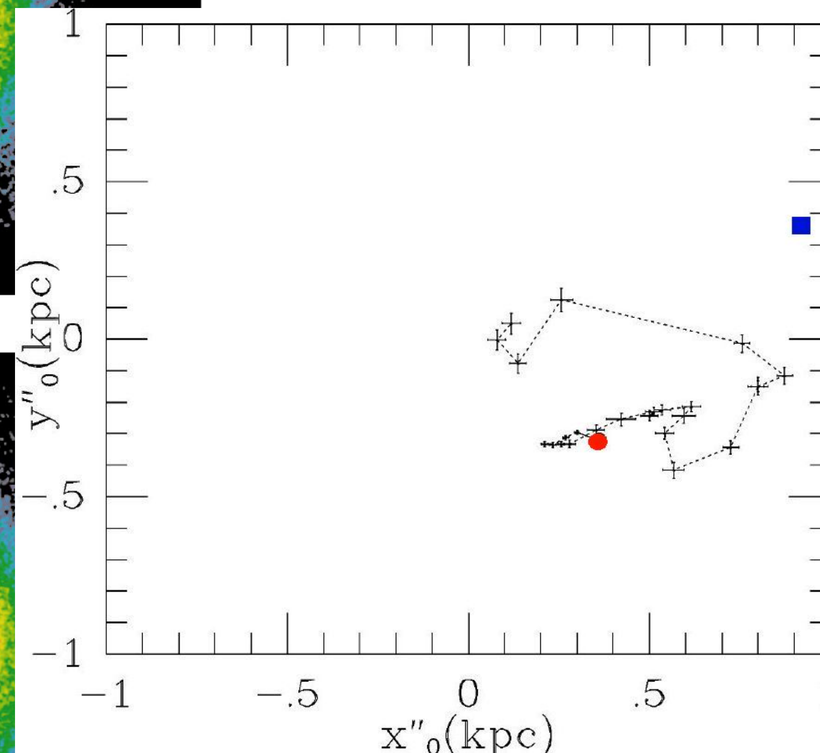
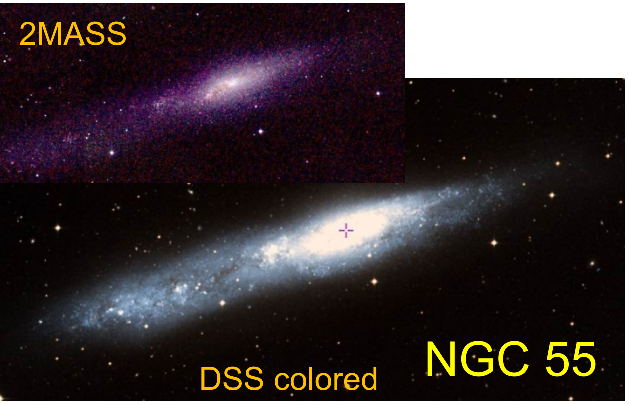


FIG. 2.—(*a–c*) Surface number density distribution on the sky of RGB and AGB stars in the LMC. North is up, and east is to the left. Each panel is 23°.55 × 21°.55. The Galactic foreground contribution was subtracted. (*a*) Stars from 2MASS that fall in the $(J-K_s, K_s)$ CMD region shown in the left panel of Fig. 1. The two dark vertical rectangles are regions missing from the 2MASS Second Incremental Data Release. (*b*) Stars from DENIS that fall in the $(I-J, J)$ CMD region shown in the right panel of Fig. 1. The features along lines of constant declination (which run close to vertical) are artifacts along a number of individual DENIS scan strips. (*c*), Same 2MASS surface density map as in (*a*) but with the unobserved regions filled in using the DENIS data in (*b*). (*d*) Face-on view of the LMC, deprojected using the viewing angles determined in Paper I and the approach described in § 4. The image is 20.95 × 19.18 kpc. The LMC disk is not circular in the disk plane but is instead considerably elongated. The line of nodes is indicated by white line segments; it lies at the same angle in the other panels of the figure.

Kim et al 1998, ApJ, 503, 674

r_d = 1.5 кпк

SBdm - SBm : NGC 55, 1313, 1507, 2188, 2537, 4027, 4618, 4525, 4631, 4945, 7741, LMC, SMC



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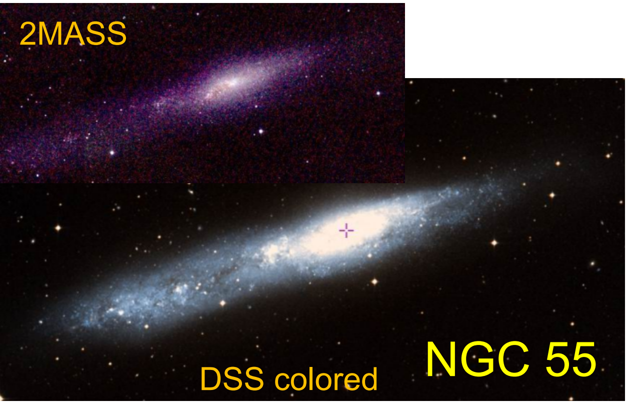
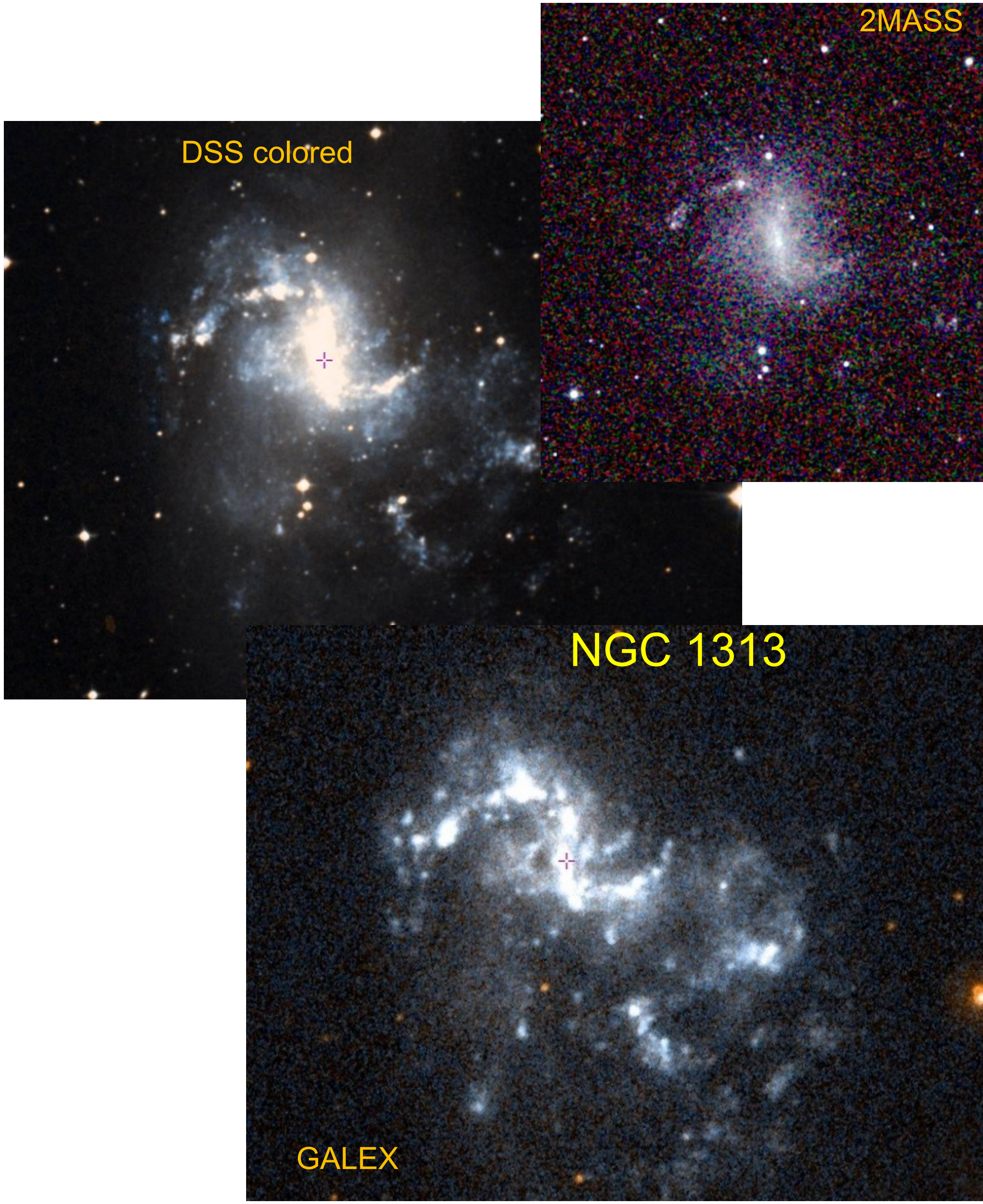
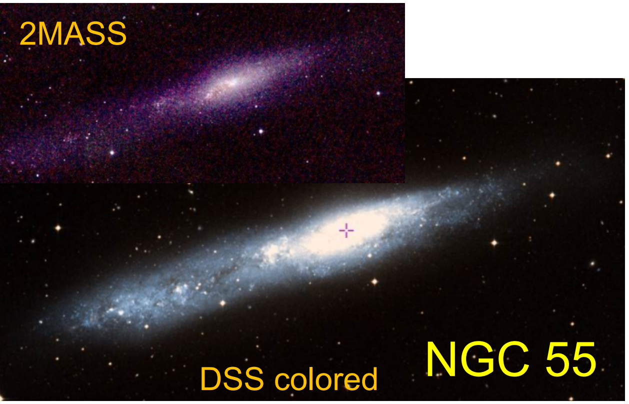
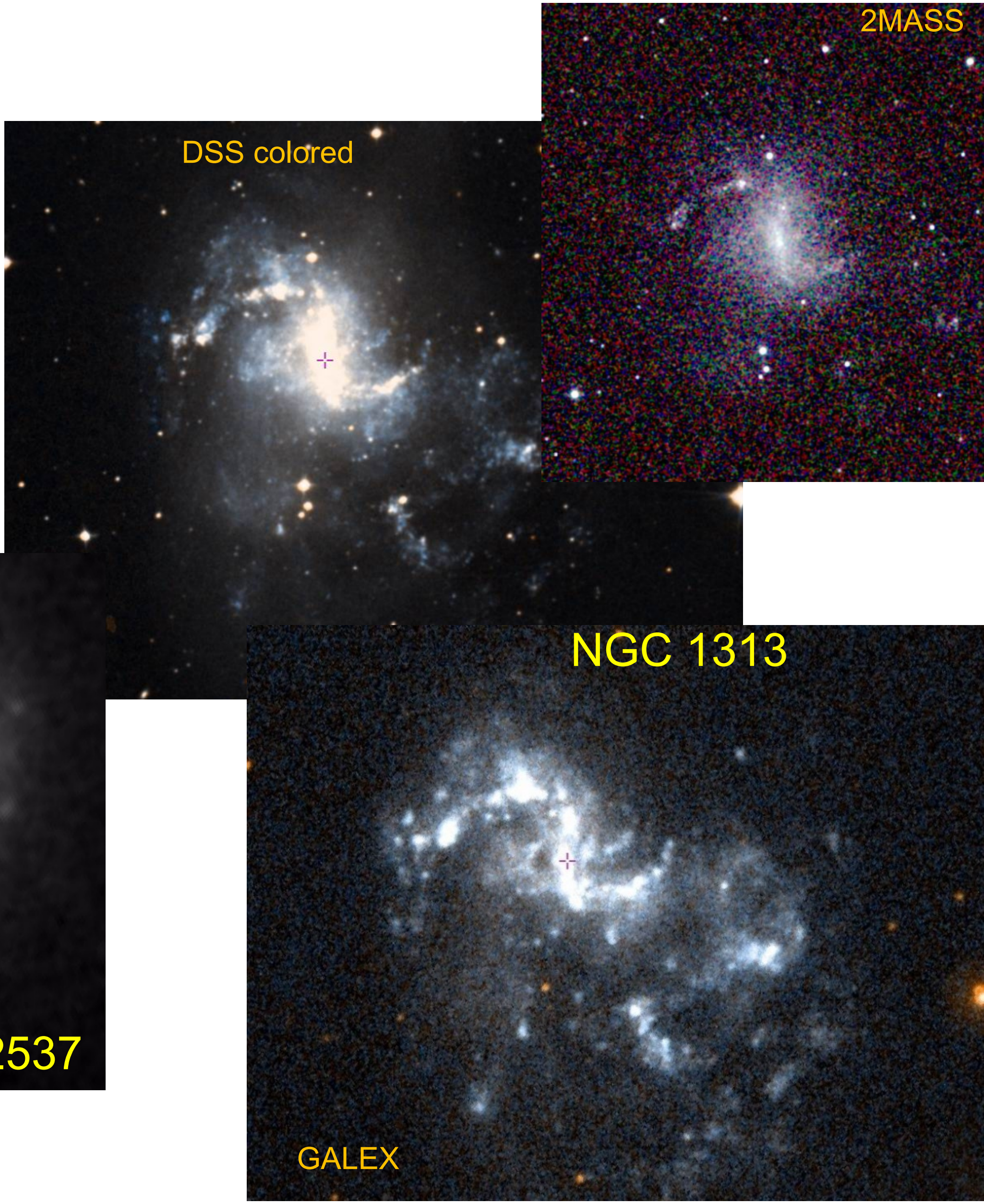
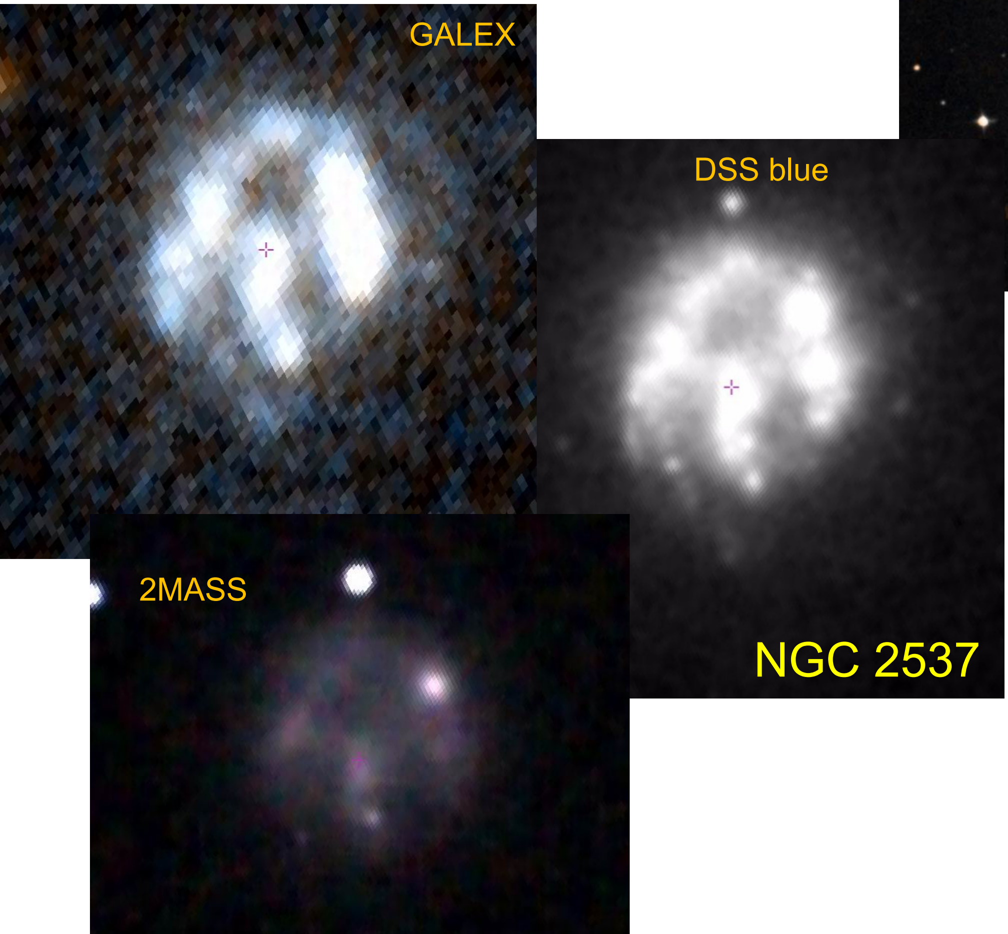




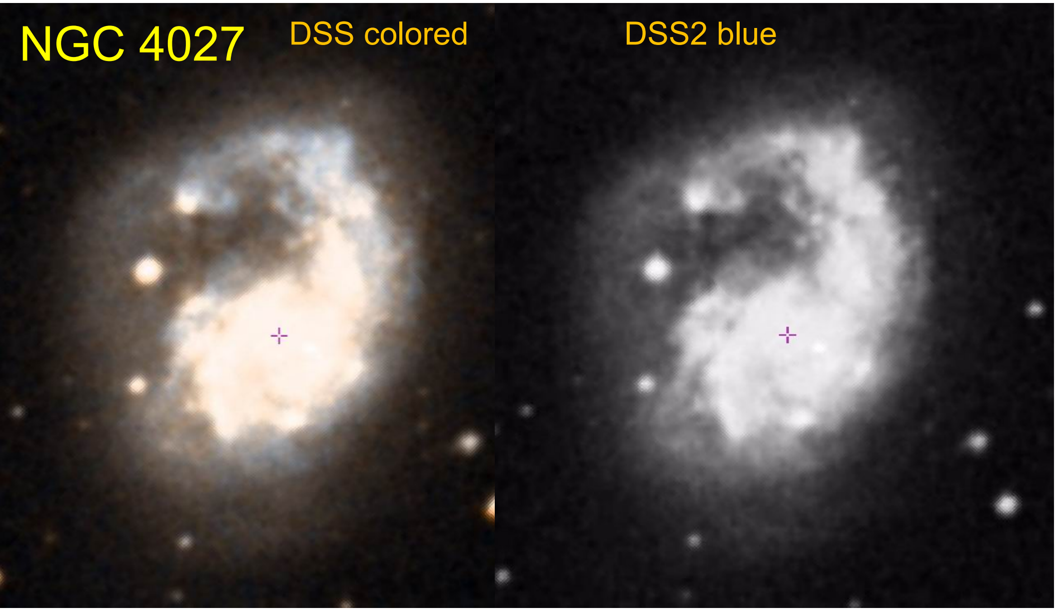
SBdm - SBm : NGC 55, 1313, 1507, 2188, 2537, 4027, 4618, 4525, 4631, 4945, 7741, LMC, SMC



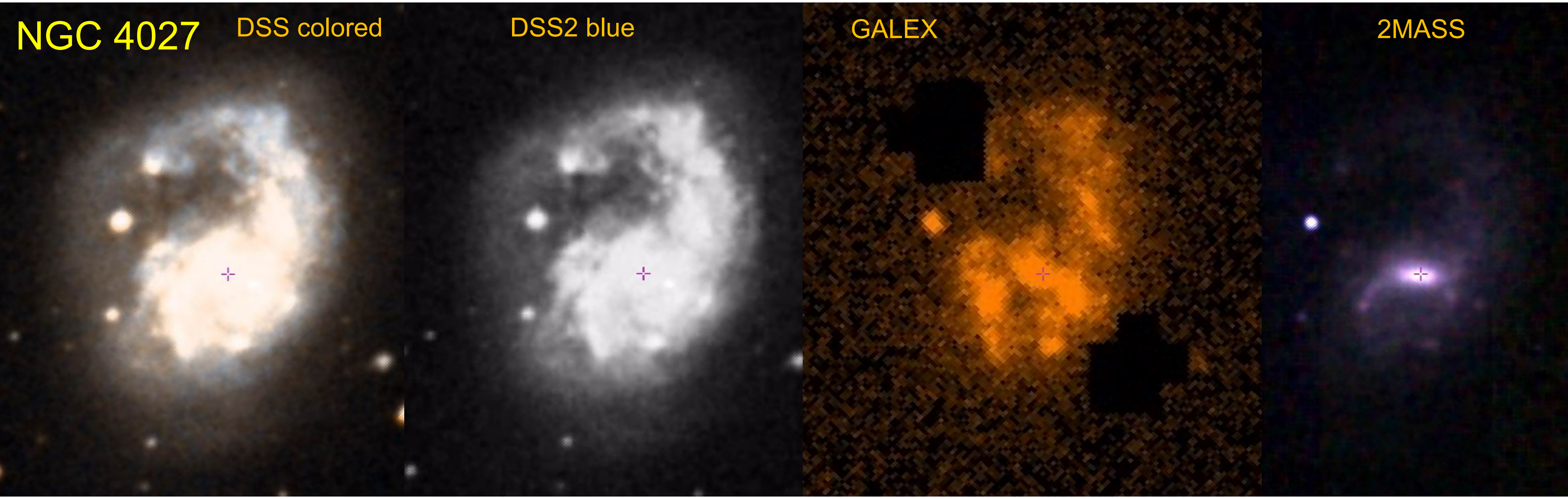




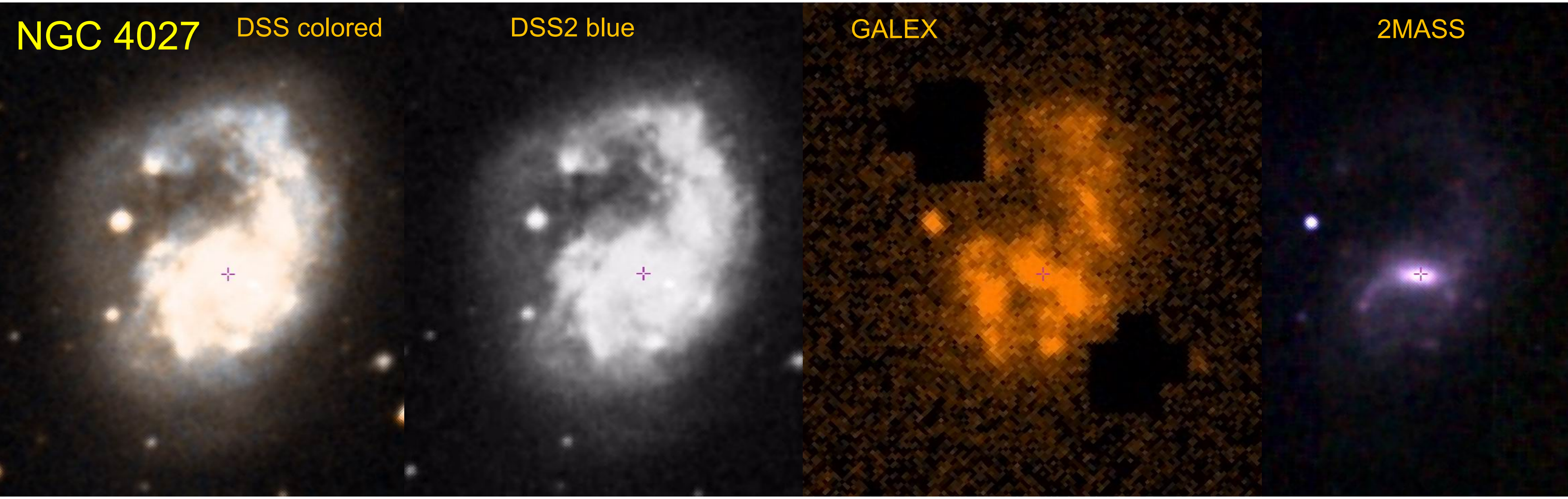
SBd - SBm : NGC 55, 1313, 1507, 2188, 2537, **4027**, 4618, 4525, 4631, 4945, 7741, LMC, SMC

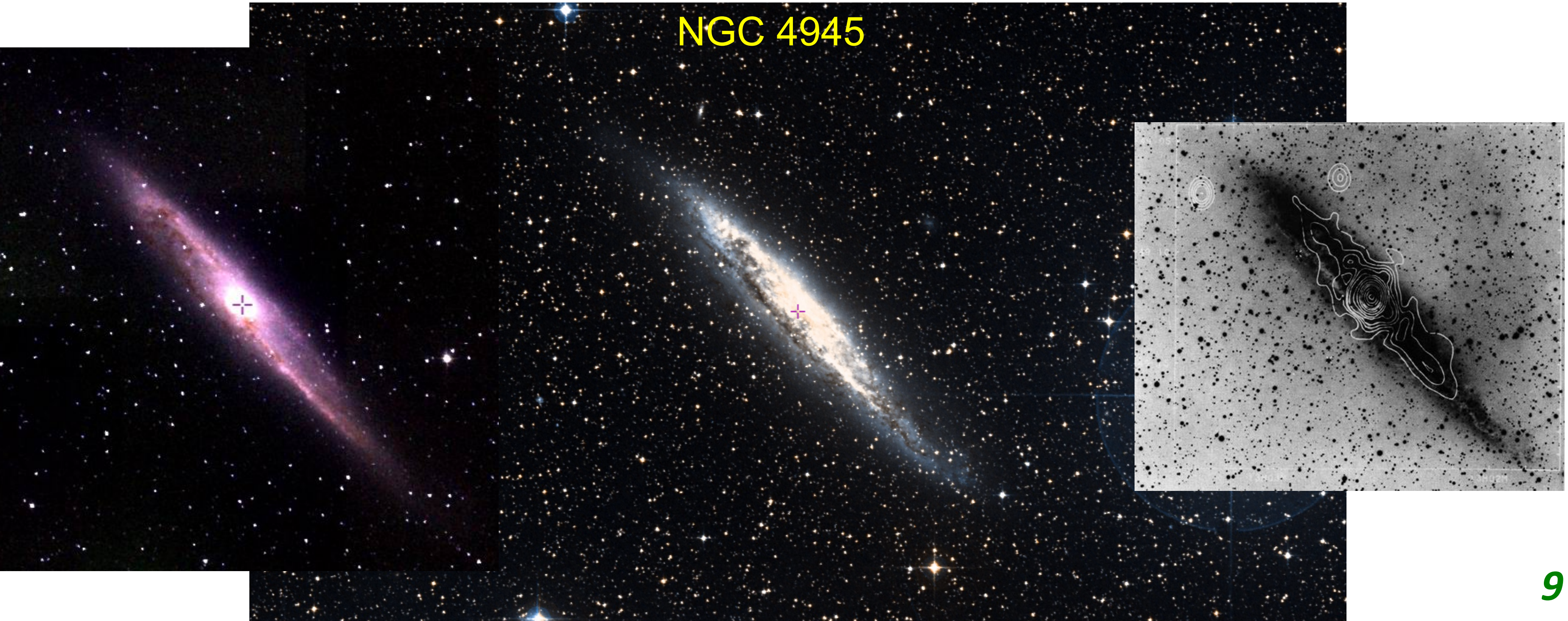


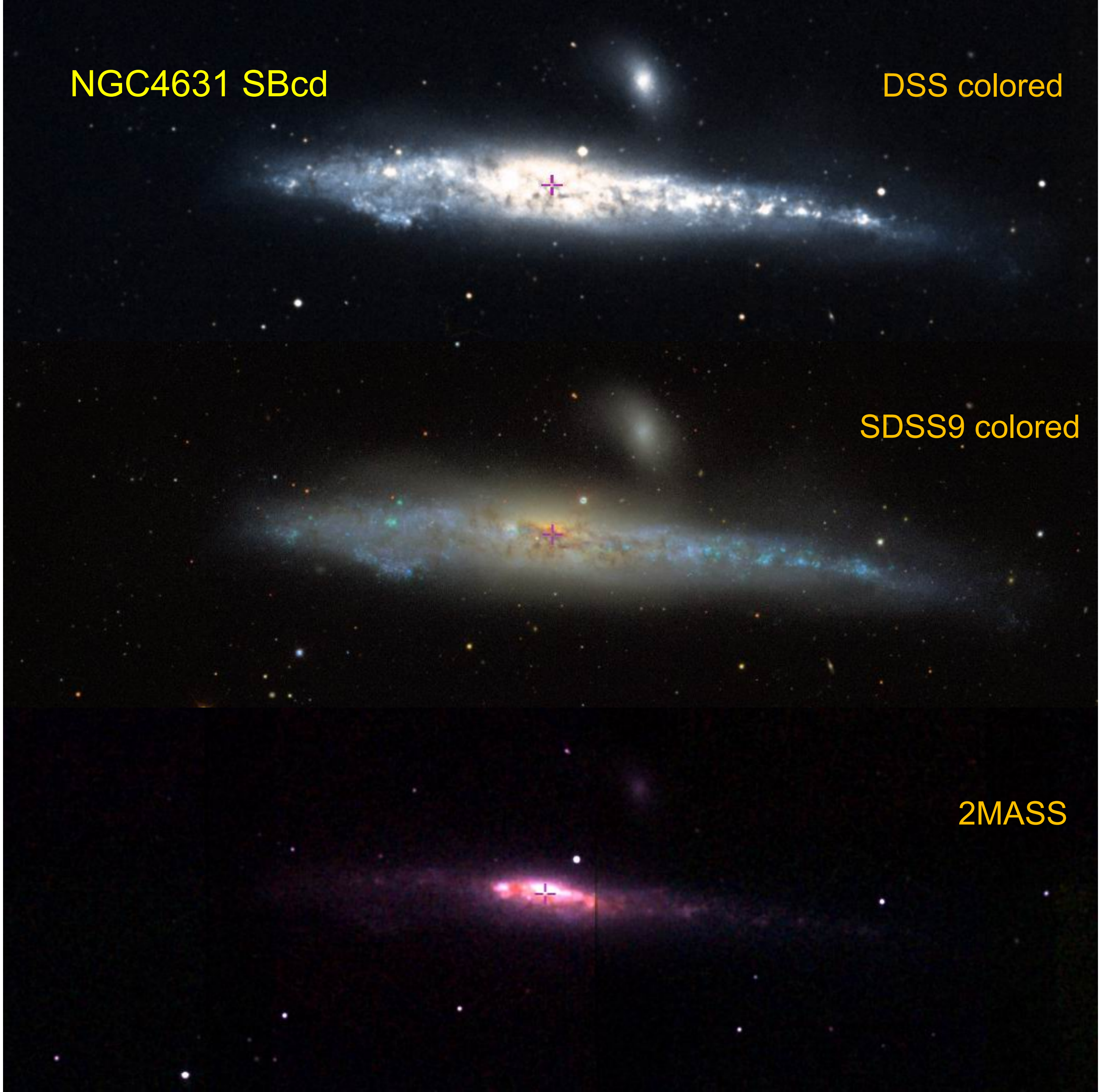
SBd - SBm : NGC 55, 1313, 1507, 2188, 2537, **4027**, 4618, 4525, 4631, 4945, 7741, LMC, SMC

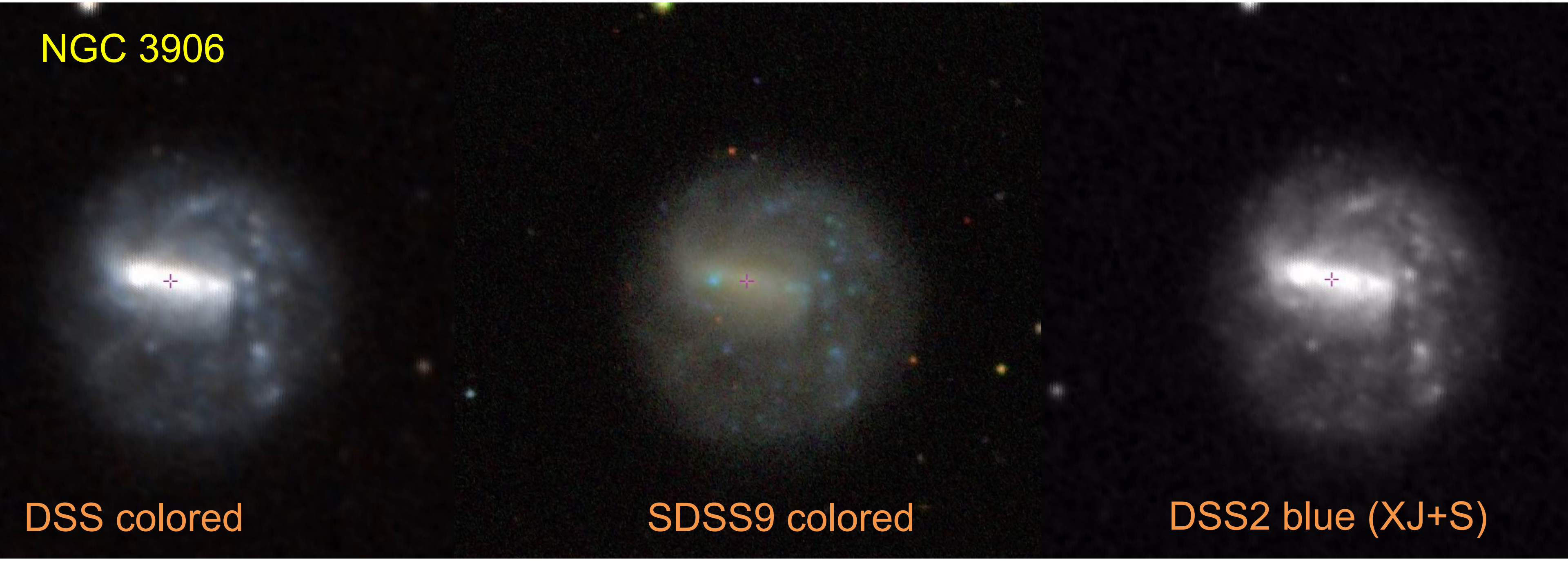


SBd - SBm : NGC 55, 1313, 1507, 2188, 2537, **4027**, 4618, 4525, 4631, 4945, 7741, LMC, SMC

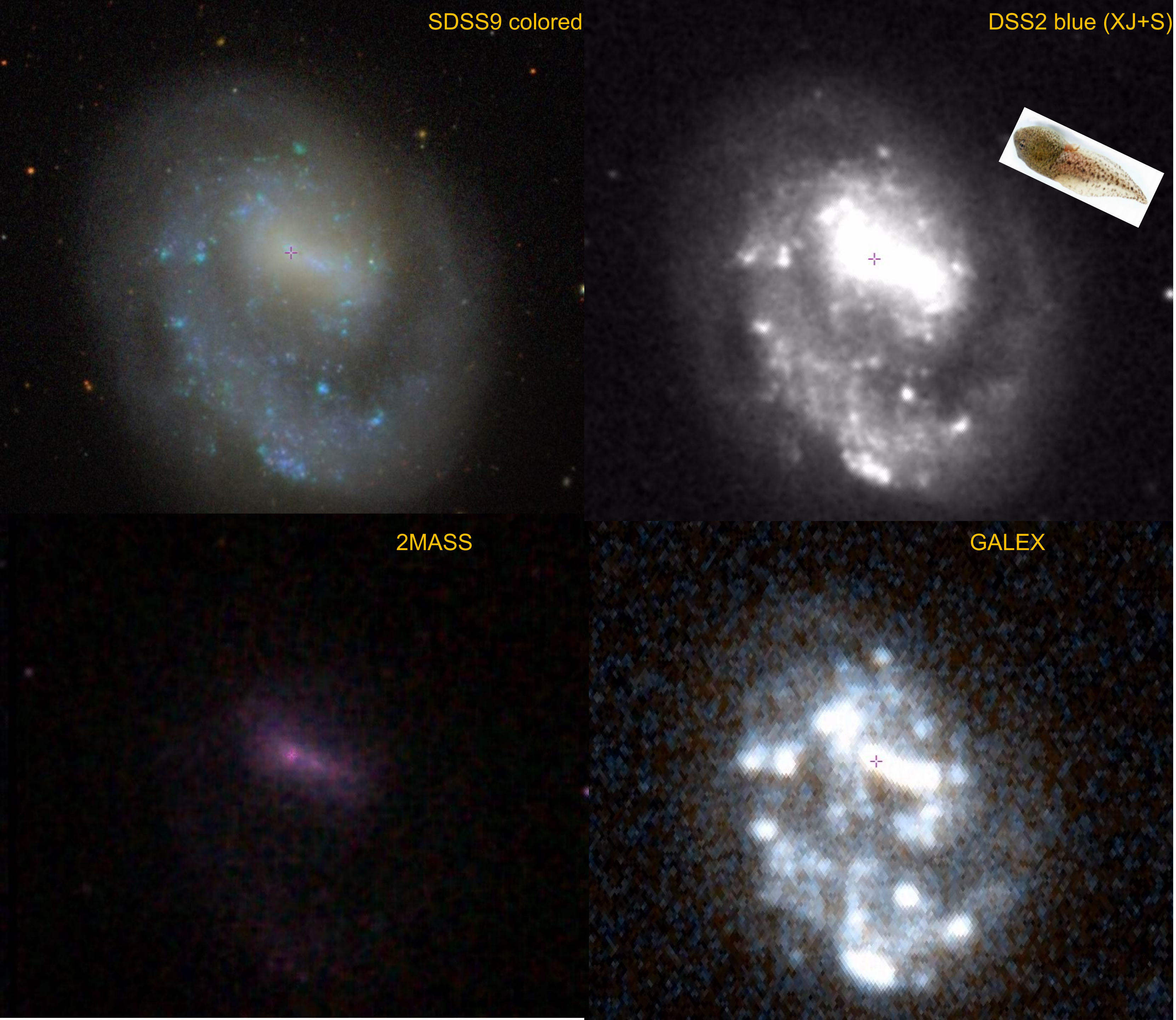





NGC4631 SBcd
DSS colored
SDSS9 colored
2MASS



[Swardt + (2015)]

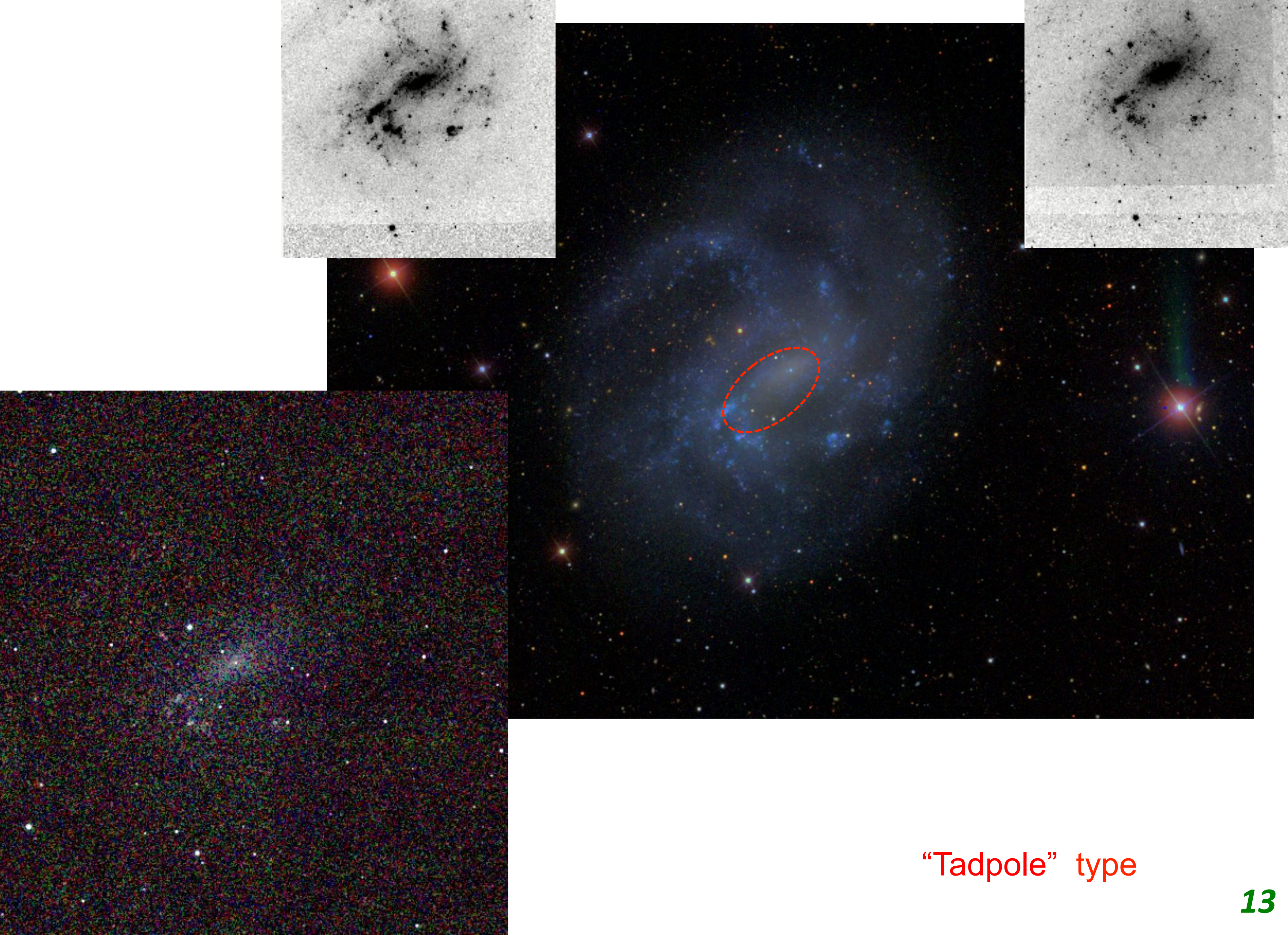


NGC4618
SBm

“Tadpole” type

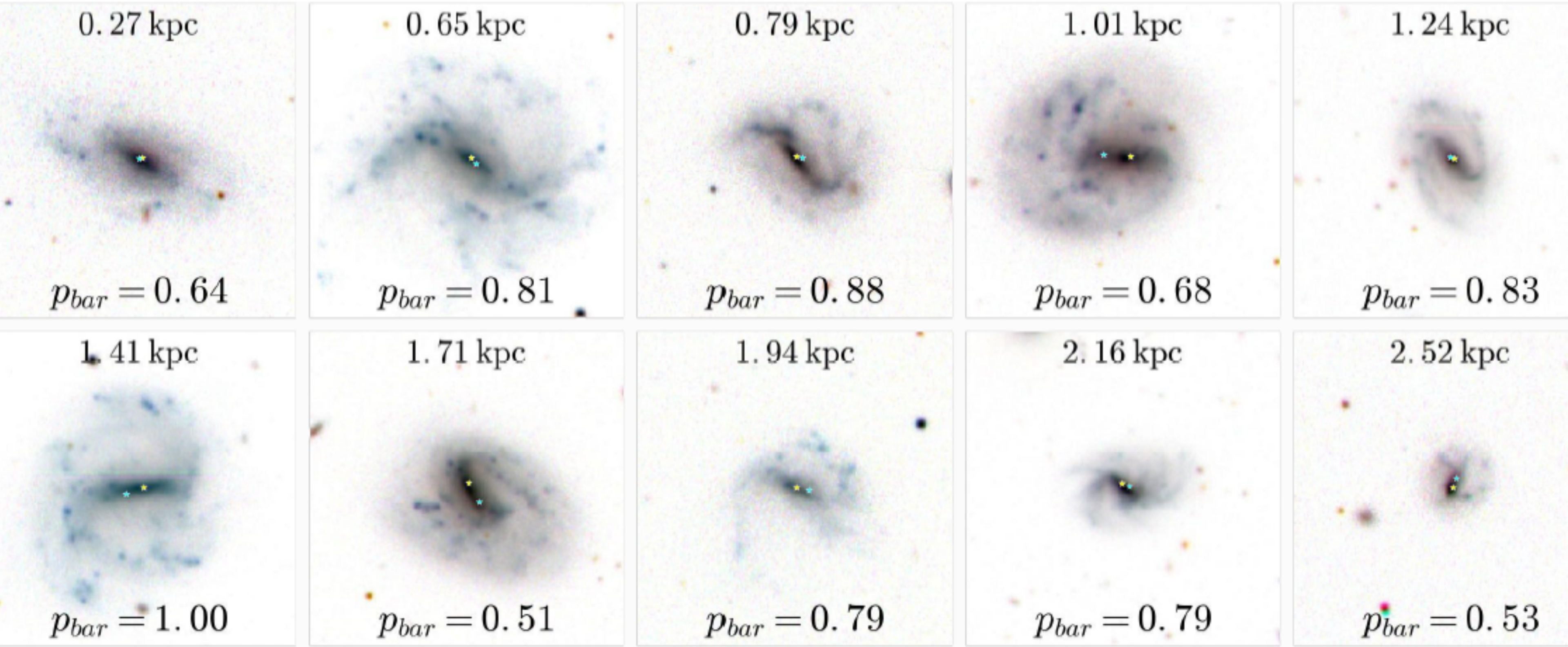
66 км/с

NGC 4395 SBm



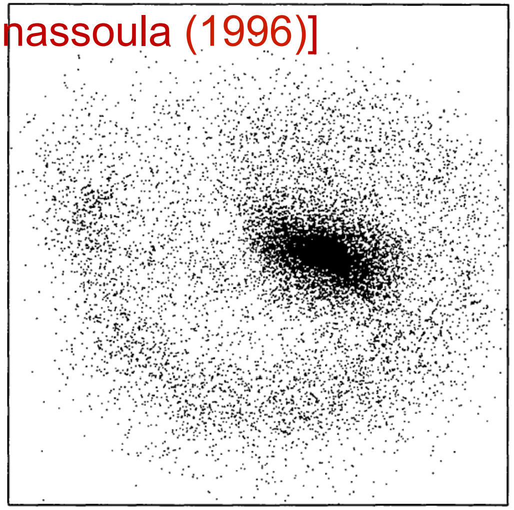
"Tadpole" type

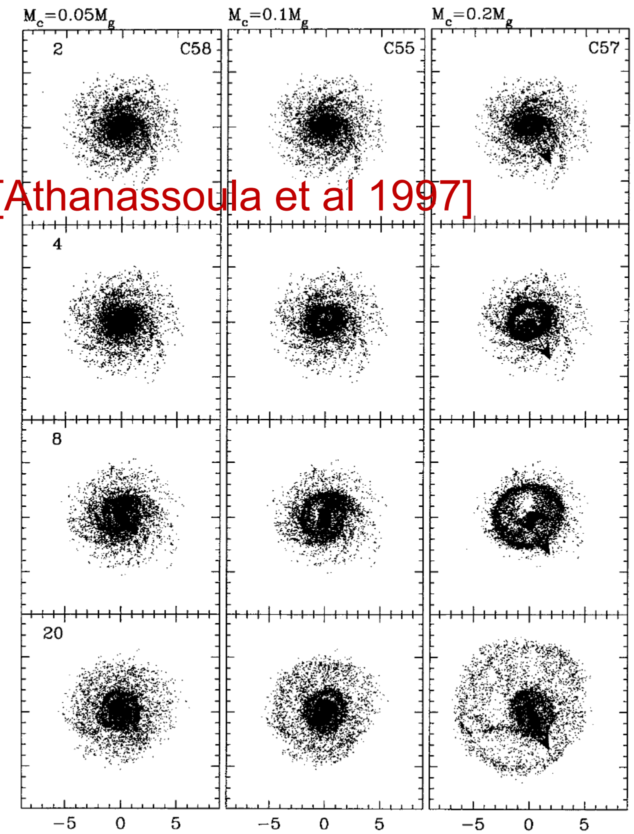
[Kruk +11, arXiv:1705.00007]



Formation lopsided SB-galaxies. Кто виноват ? Спутники ?

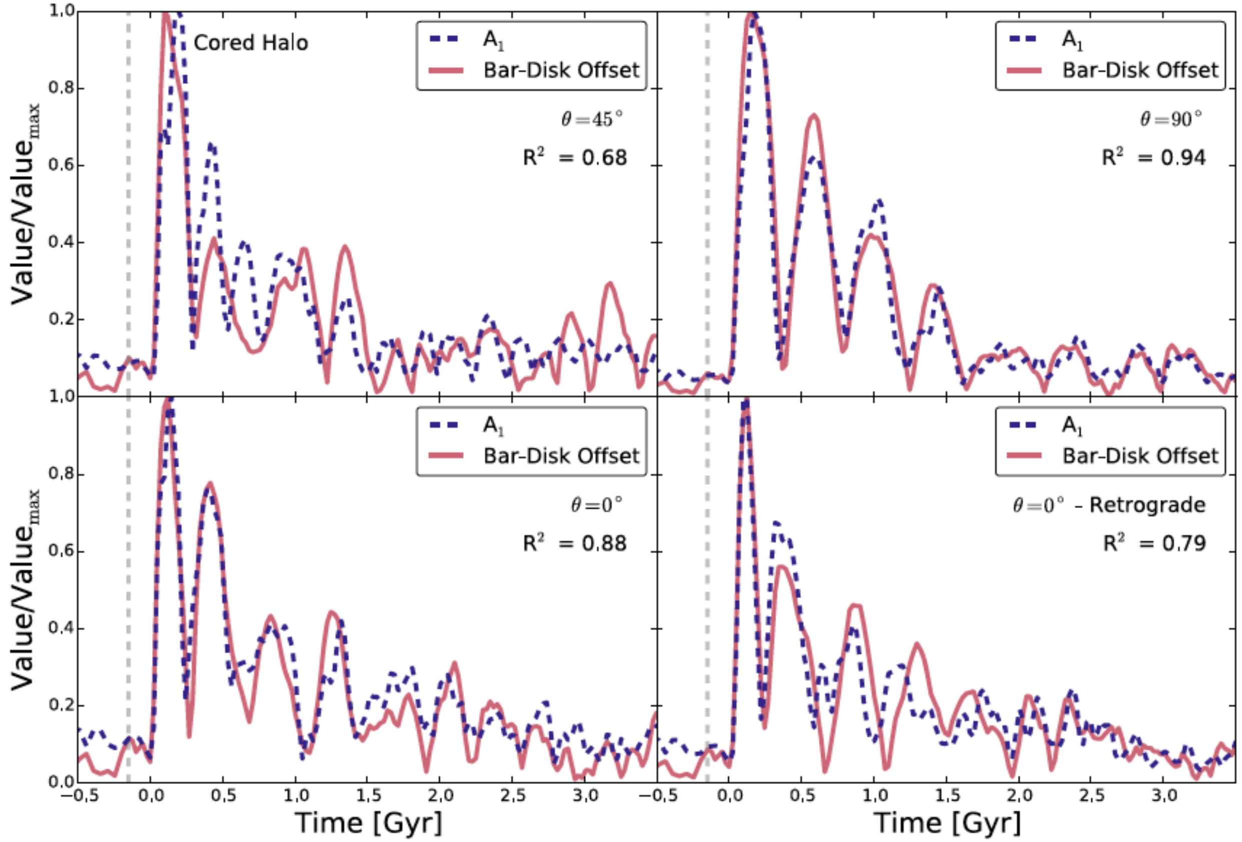
[Athanassoula (1996)]





[Athanassoula et al 1997]

[Pardy et al. (2016)]



Наблюдения

Galaxy Zoo: Finding offset discs and bars in SDSS galaxies

[Kruk +11, arXiv:1705.00007]

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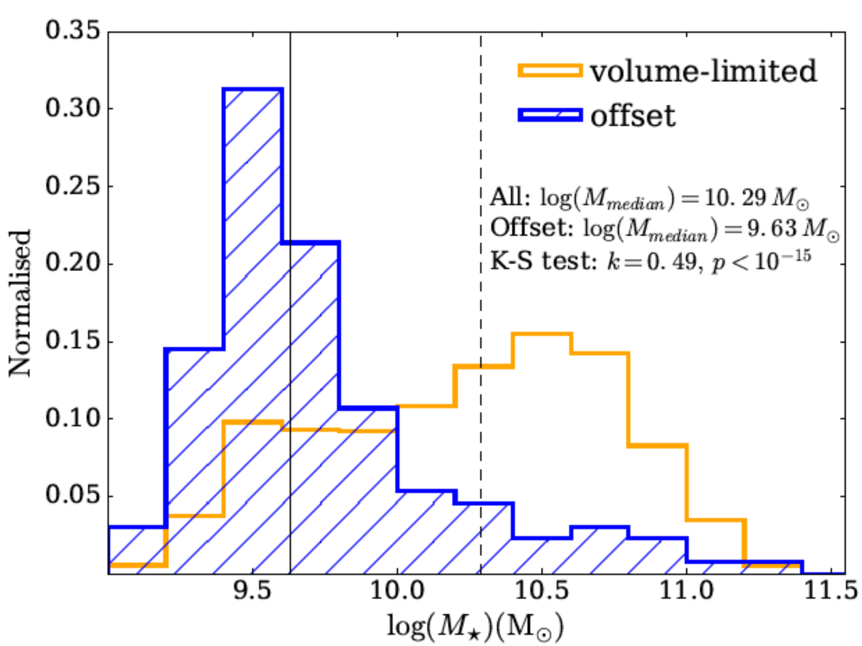
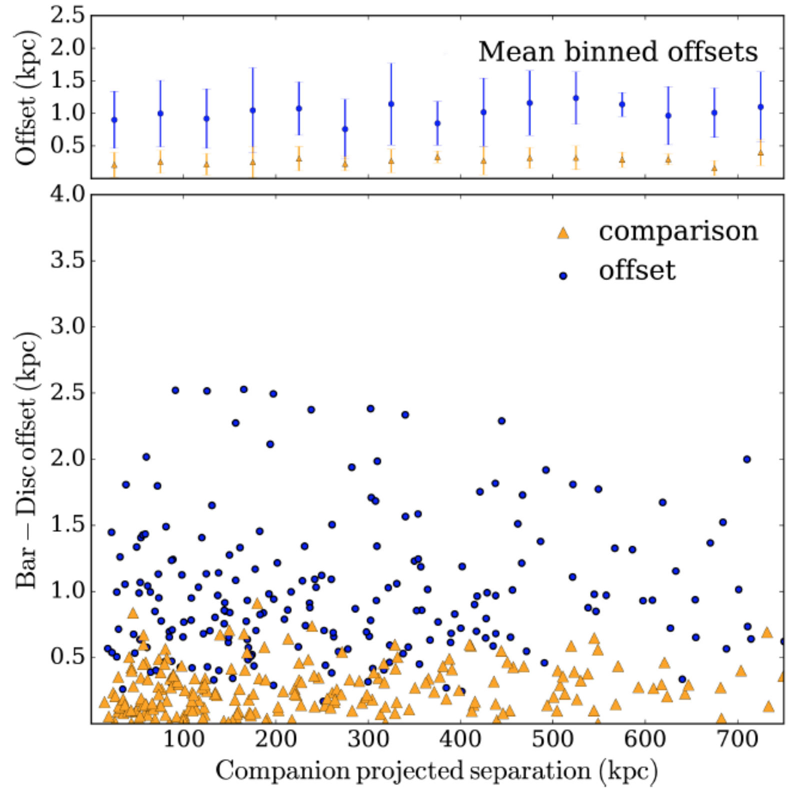
271 галактик позднего типа
(off-centre bar)

Sloan Digital Sky Survey (SDSS) DR7, Galaxy Zoo 2 (240419 галактик):
Bar-Disc Off-sets = 271.





Модели

$$\frac{d\mathbf{v}_i}{dt} = \mathbf{f}_i = -G\sum_{j=1, j\neq i}^{N} m_j \frac{\mathbf{r}_i - \mathbf{r}_j}{\left|\mathbf{r}_i - \mathbf{r}_j + \mathrm{e}\right|^3}$$

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

$$\frac{V_\varphi^2}{R} = -\frac{\partial \Psi}{\partial R} + \frac{C_R^2}{R}\left(1 - \frac{C_\varphi^2}{C_R^2} + \frac{R}{\rho C_R^2}\frac{\partial(\rho C_R^2)}{\partial R} + \frac{R}{C_R^2}\frac{\partial(V_R V_z)}{\partial z}\right)$$

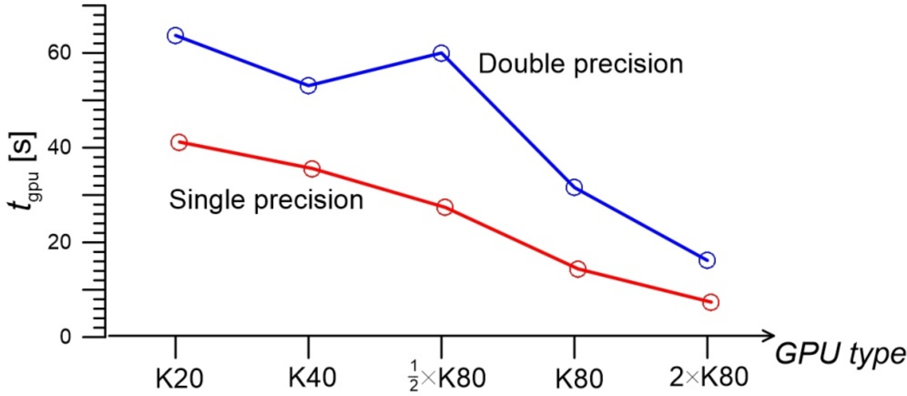
Live Halo

TreeCode-Up (Cloud-in-Cell, Triangular-Shaped-Cloud, P3M)

Particle – Particle:

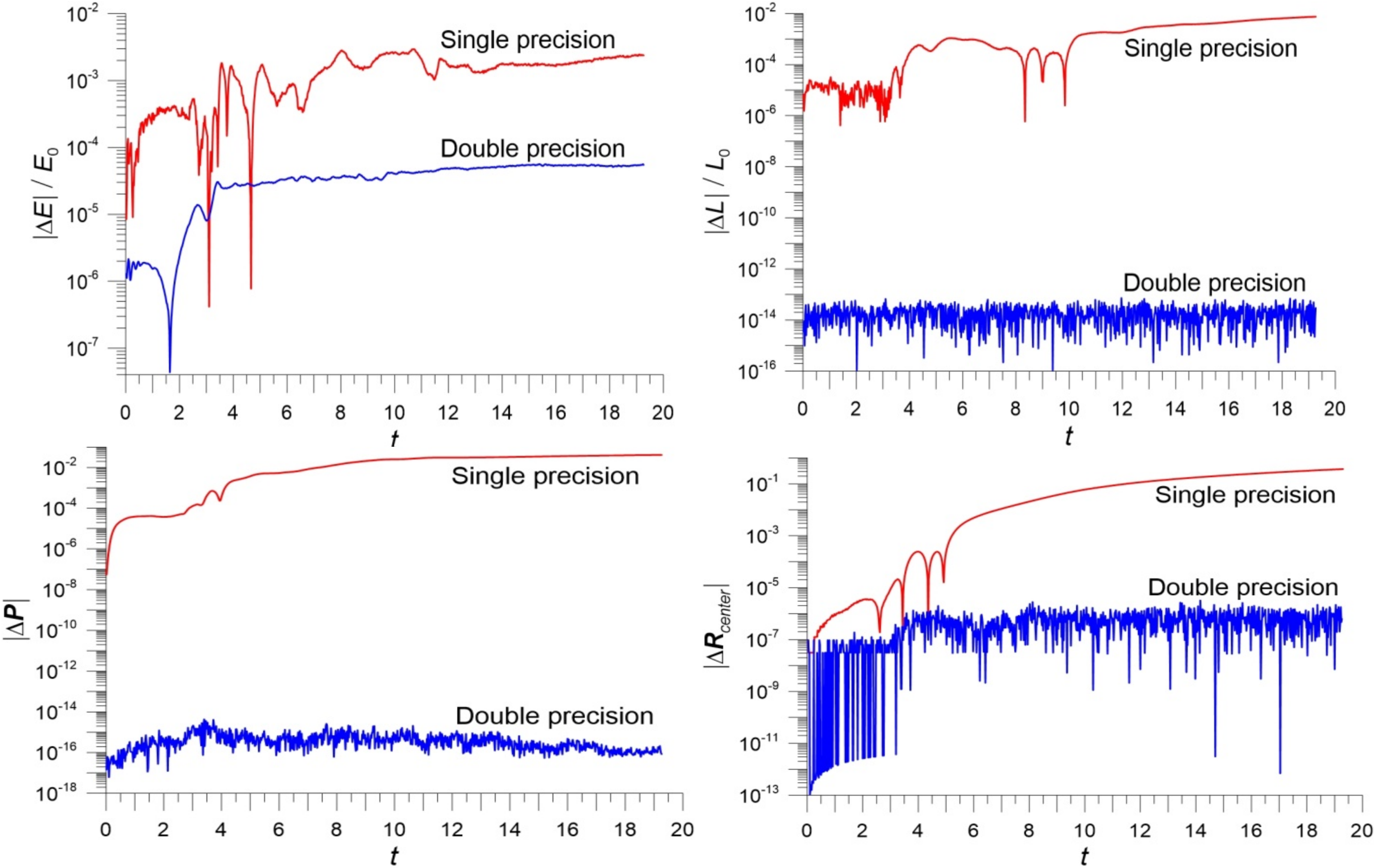
10^{18} - 2^{23}

GPU Nvidia Tesla computers: K20, K40, K80



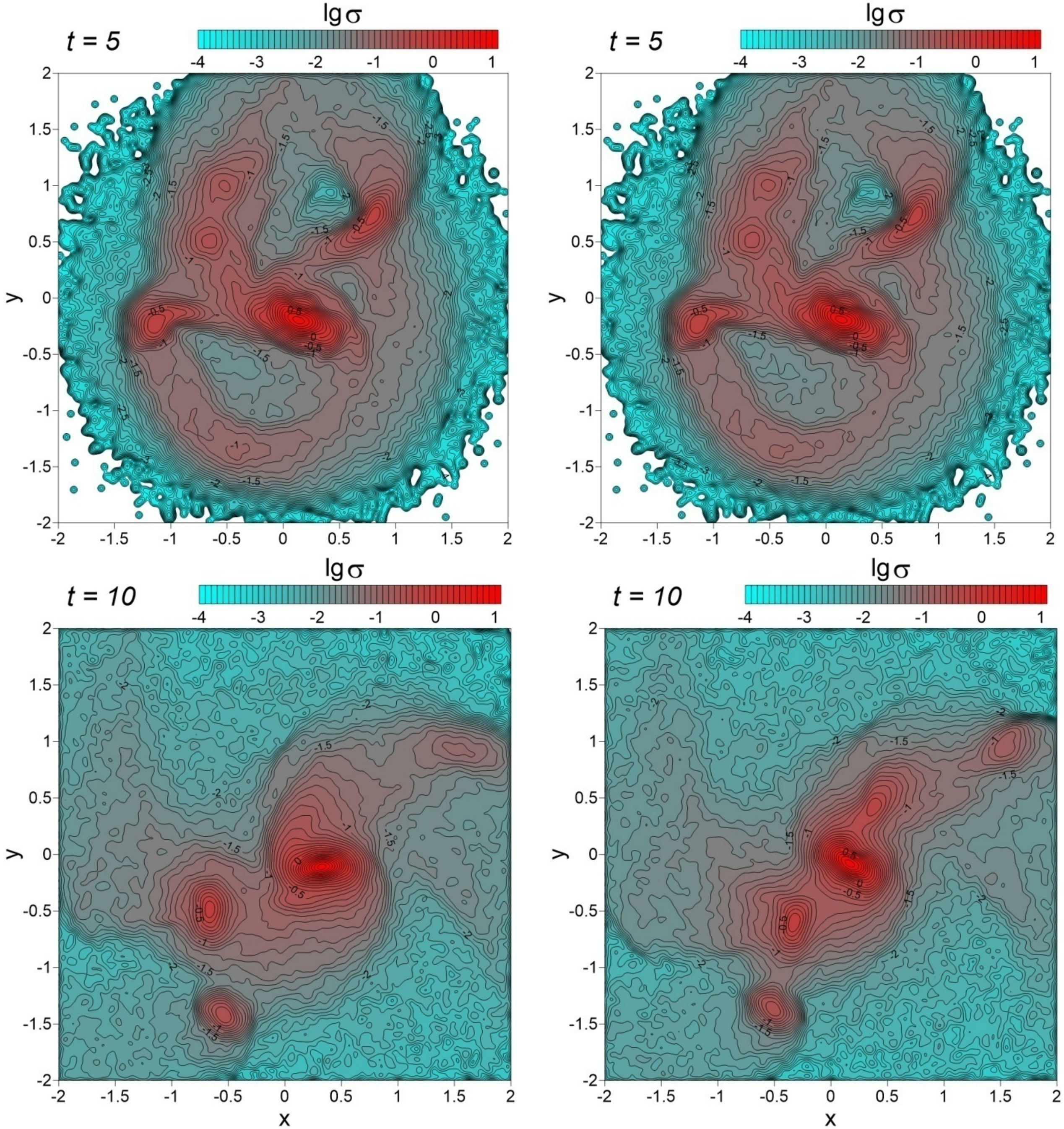
N ×1024	t_{gpu} [s], single precision			t_{gpu} [s], double precision		
	1×GPU	2×GPU	4×GPU	1×GPU	2×GPU	4×GPU
128	0.4	0.2	0.1	0.9	0.5	0.3
256	1.7	0.9	0.45	3.7	2	1
512	6.9	3.6	1.8	15	7.9	4
1024	27.4	14.4	7.4	60	31.6	16.2
2048	109.6	57.6	29.6	240	126.4	64.8
4096	438	230	118	960	506	259
8192	1754	922	474	3840	2022	1037

Модели

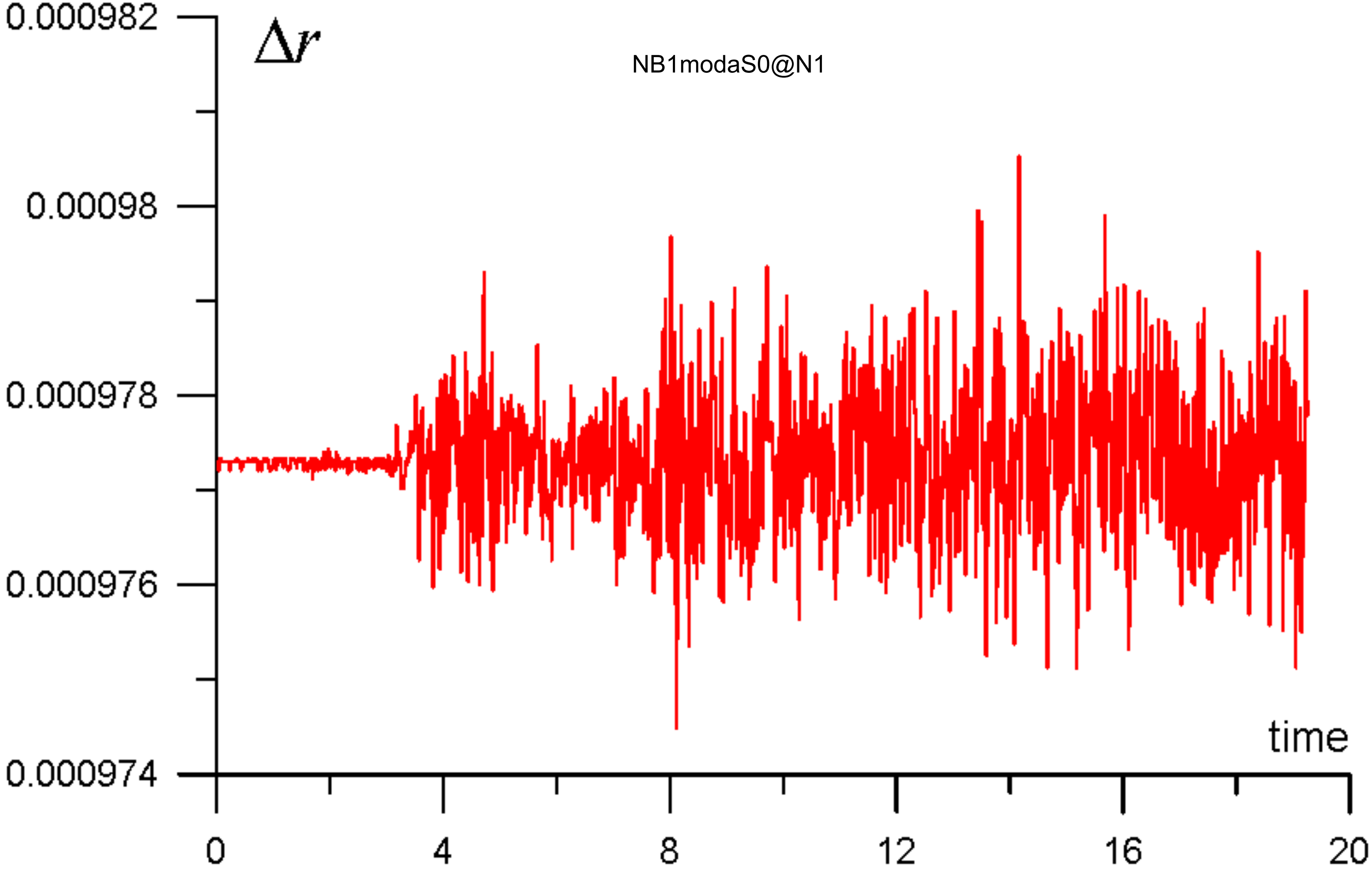


Single precision
Double precision
|ΔE| / E0
t
Single precision
Double precision
|ΔL| / L0
t
Single precision
Double precision
|ΔP|
t
Single precision
Double precision
|ΔR_center|
t

Модели



Модели

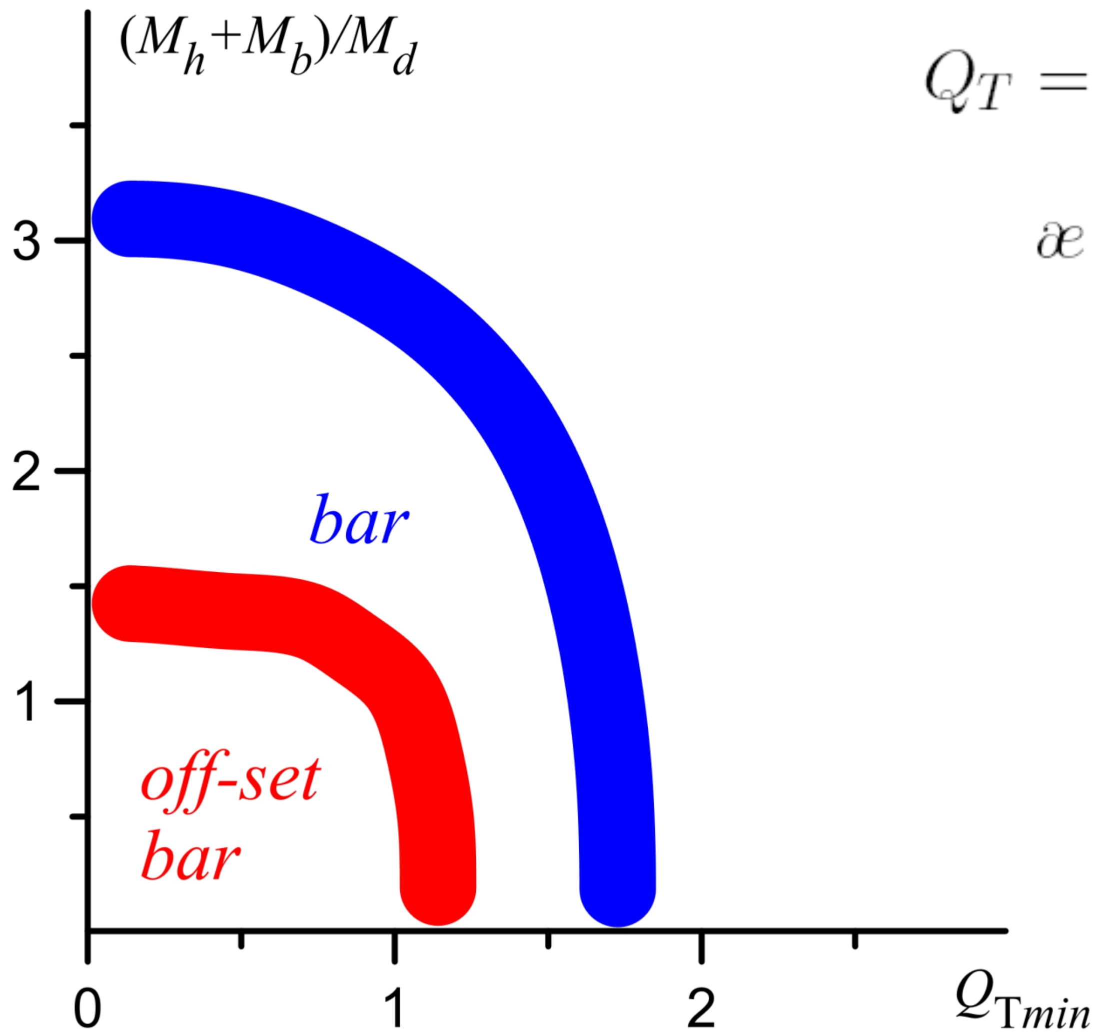


0.000982
0.00098
0.000978
0.000976
0.000974
Δr
NB1modaS0@N1
time
0
4
8
12
16
20

Как создать бар в численной модели N-тел ?

$M_h, a, M_b, b, M_d, r_d, c_r, c_\phi, c_z$

- Распределение массы в сфероидальной подсистеме (гало + балдж) + кинематика
- Распределение массы в дисковой компонента + кинематика



$$Q_T = \frac{c_r}{c_T} \qquad c_T = \frac{3.36 G\sigma}{æ}$$

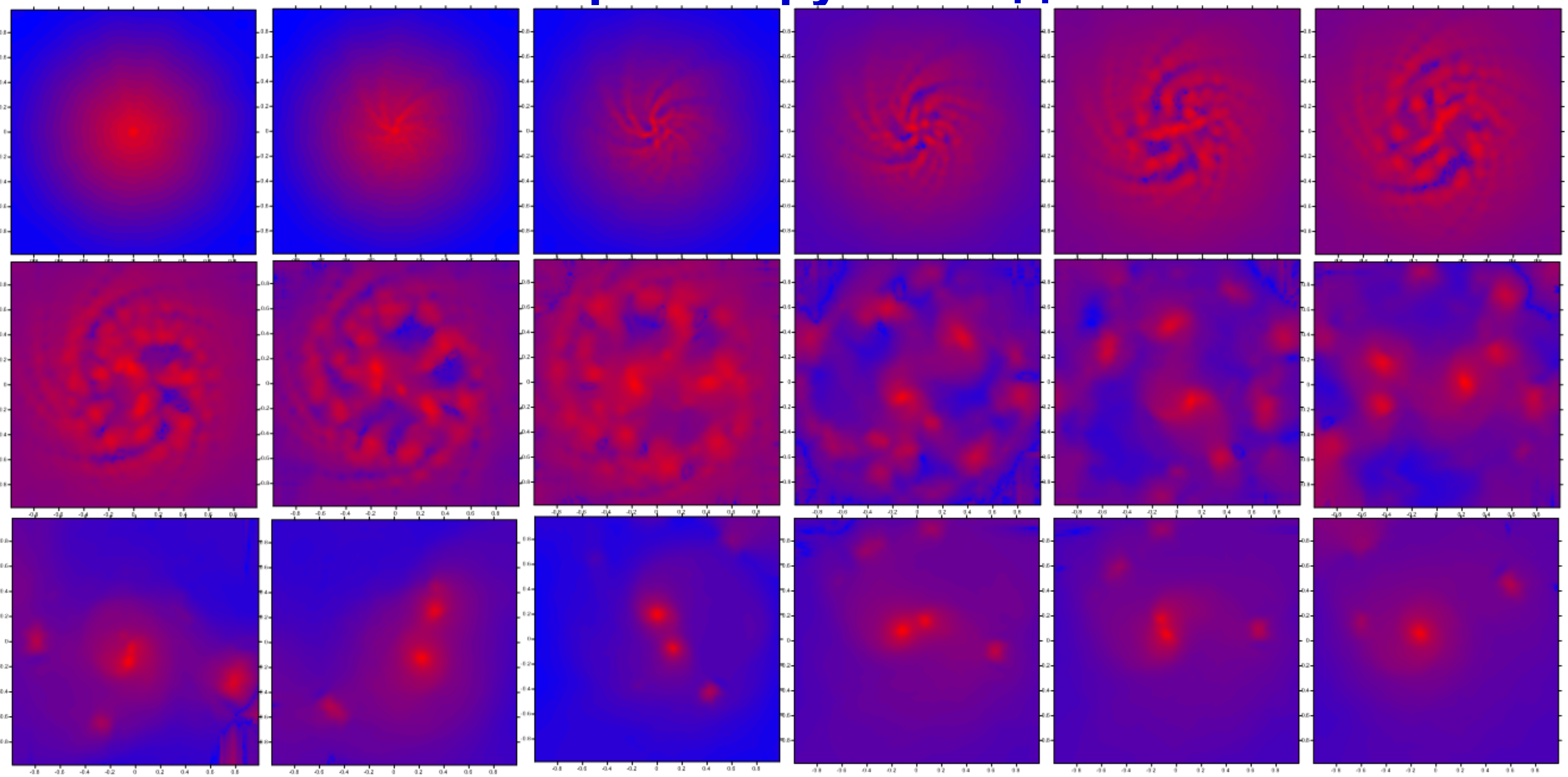
$$æ = 2\Omega\sqrt{1 + r\, d\Omega/2\Omega\, dr}$$

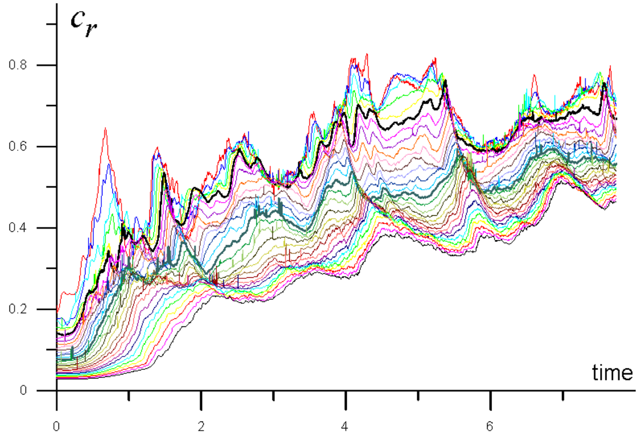
БМО: $M_h = 0.7M_d$, $a \sim R_d$

[Zasov & Khoperskov 2003]

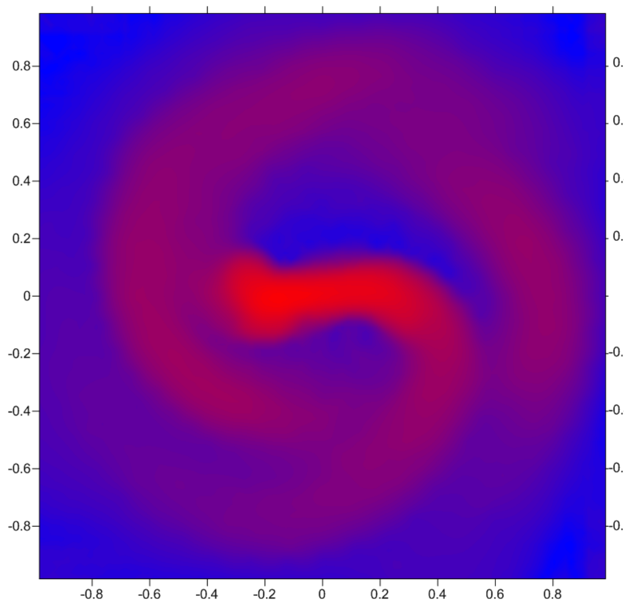
Самогравитирующий диск

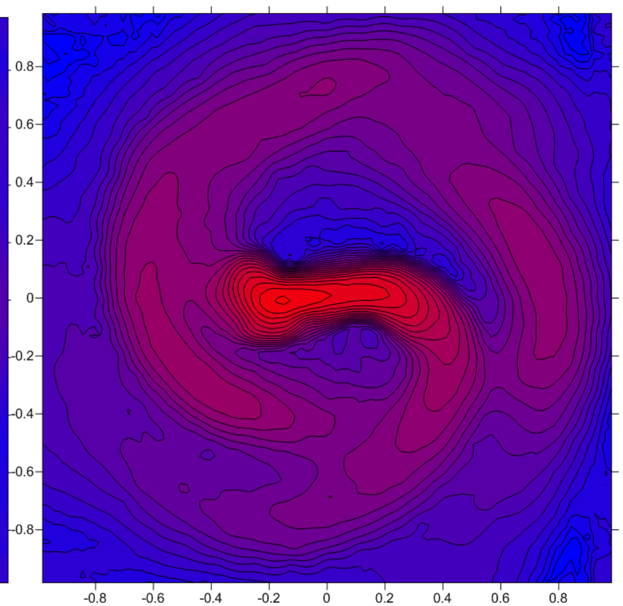
NB1moda00





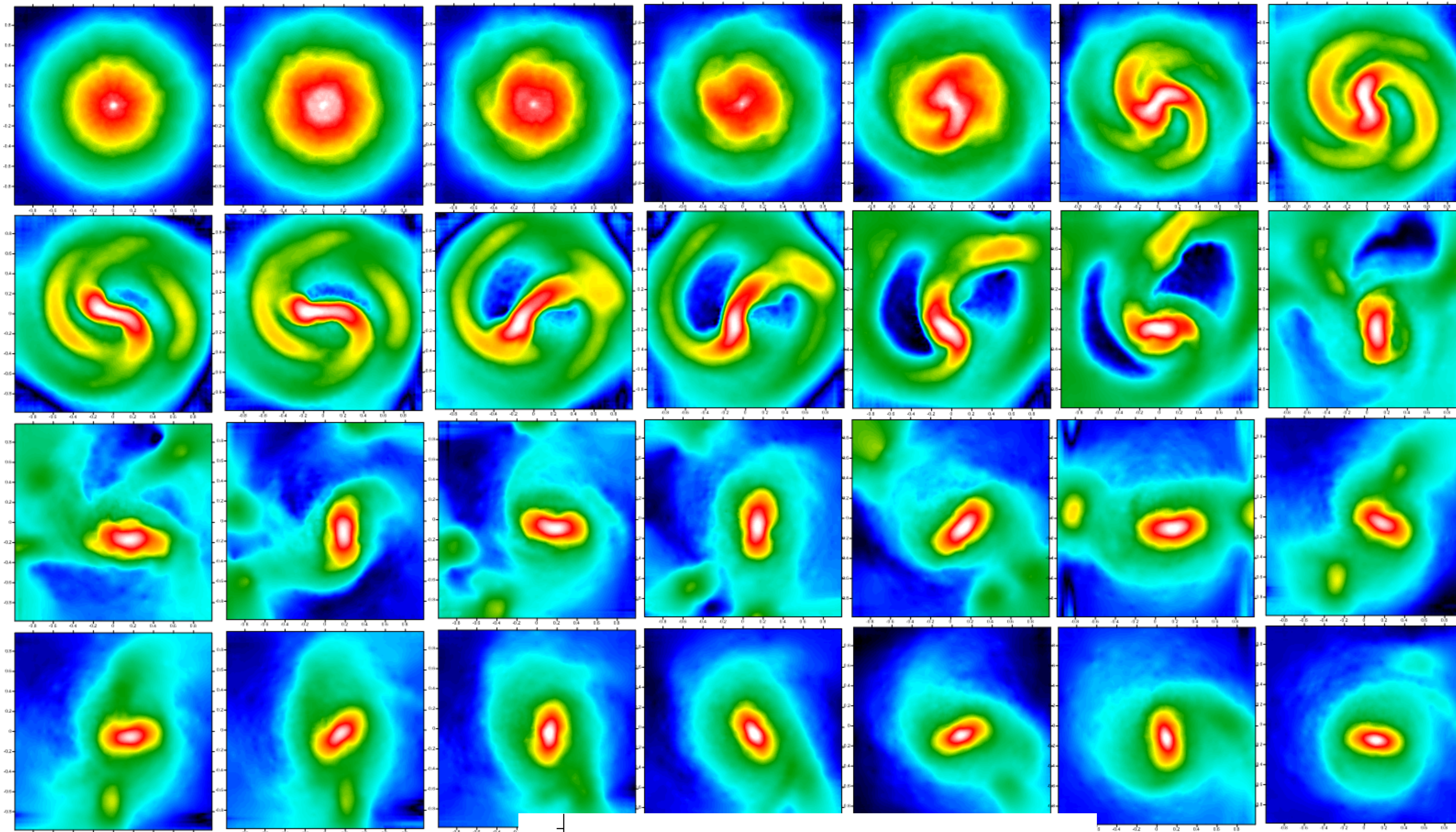
“Tadpole” structure formation

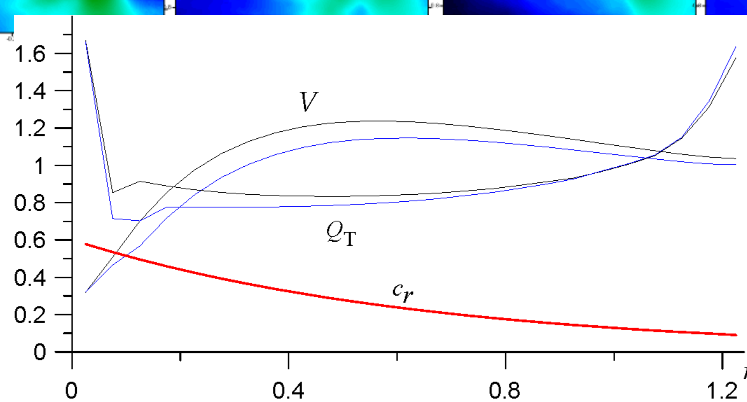




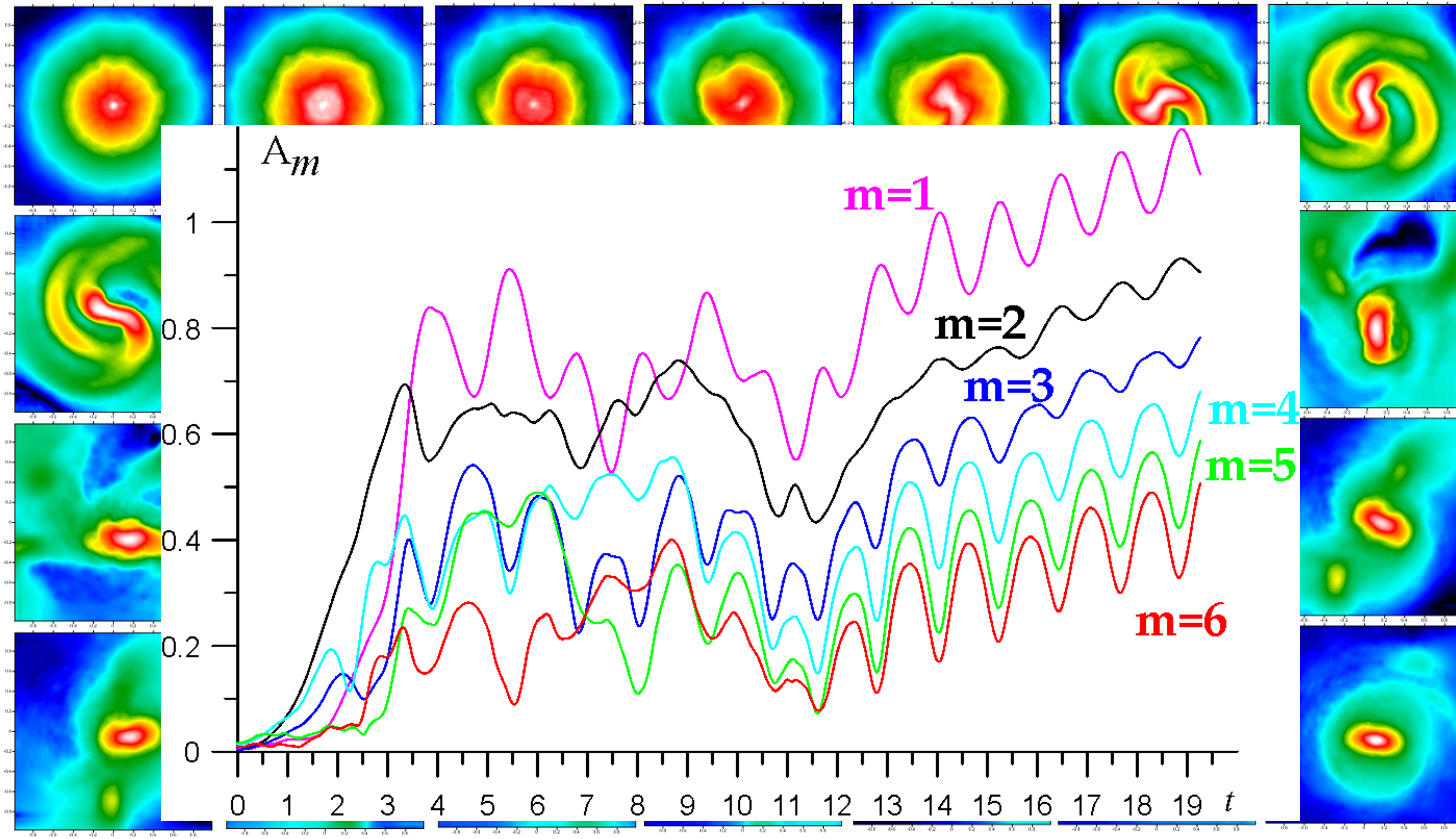
Tadpole structure

Breaking bar

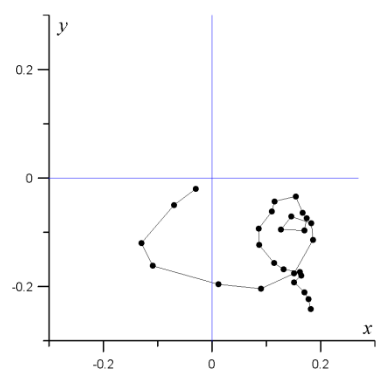




!!NB1modaS0@N1 Mh=0



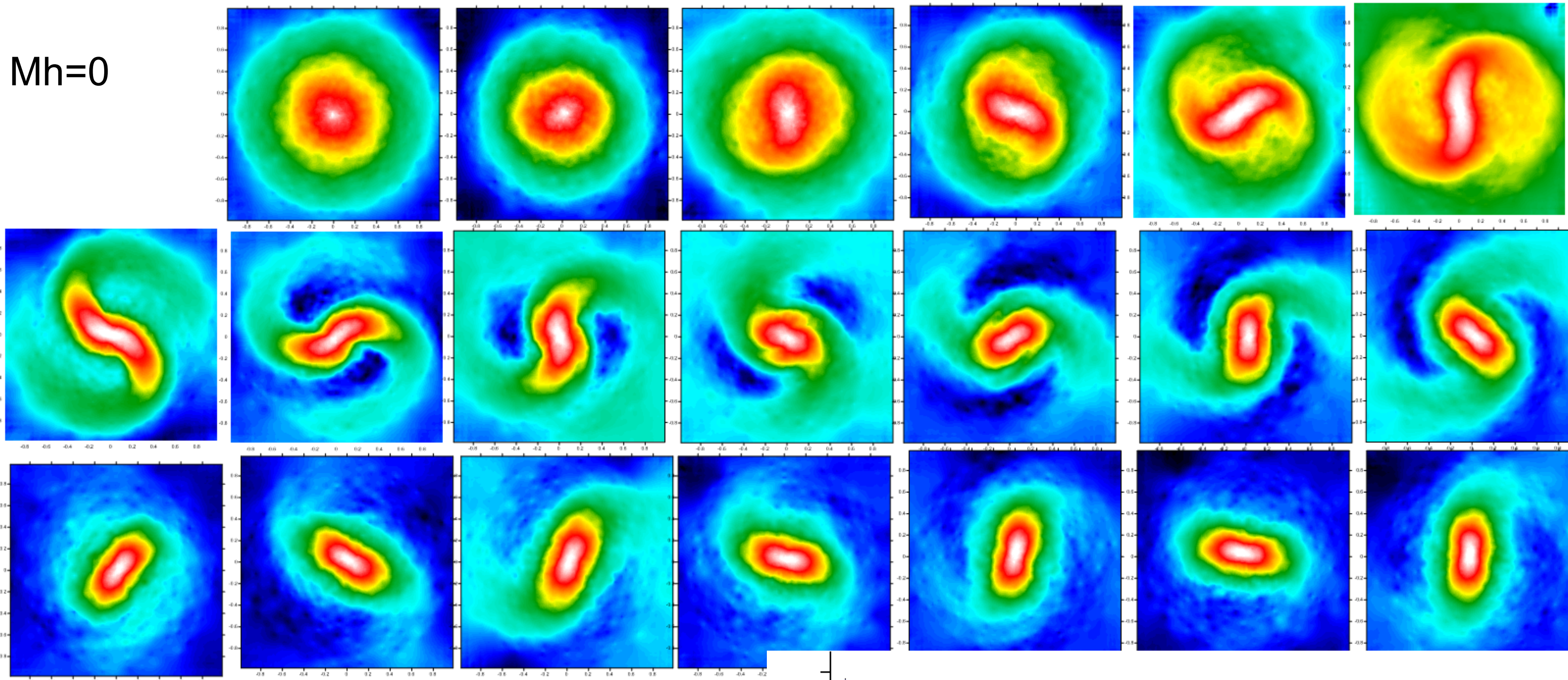
A_m
m=1
m=2
m=3
m=4
m=5
m=6
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 t

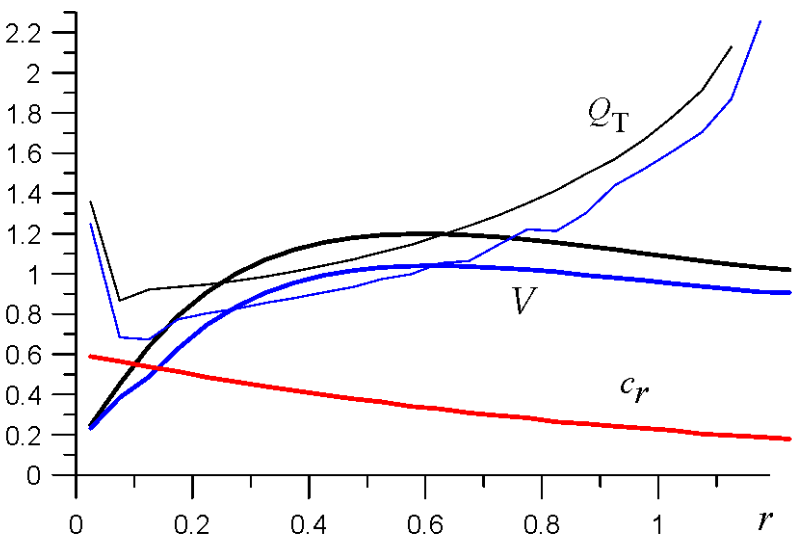


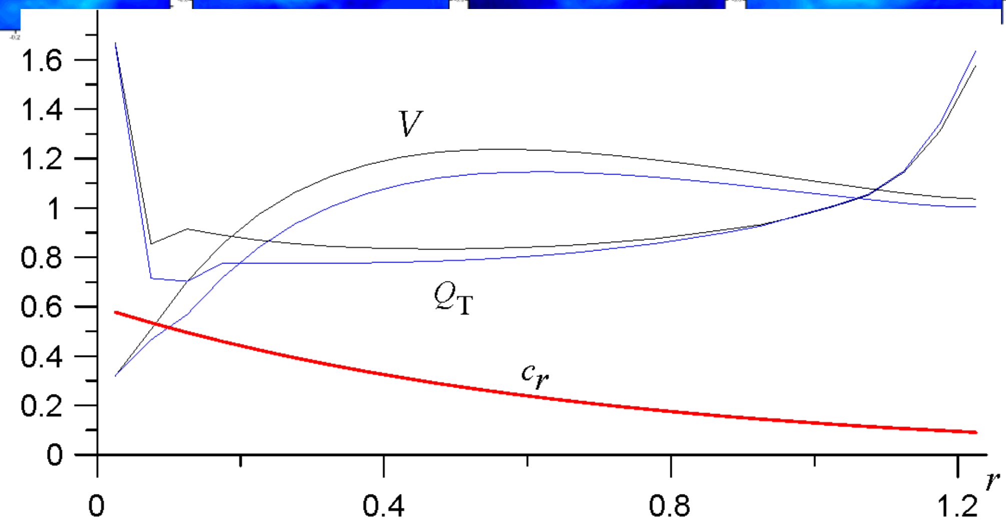
y
0.2
0
-0.2
-0.2
0
0.2
x

101NB1modaS0@cr06hotH05

Mh=0







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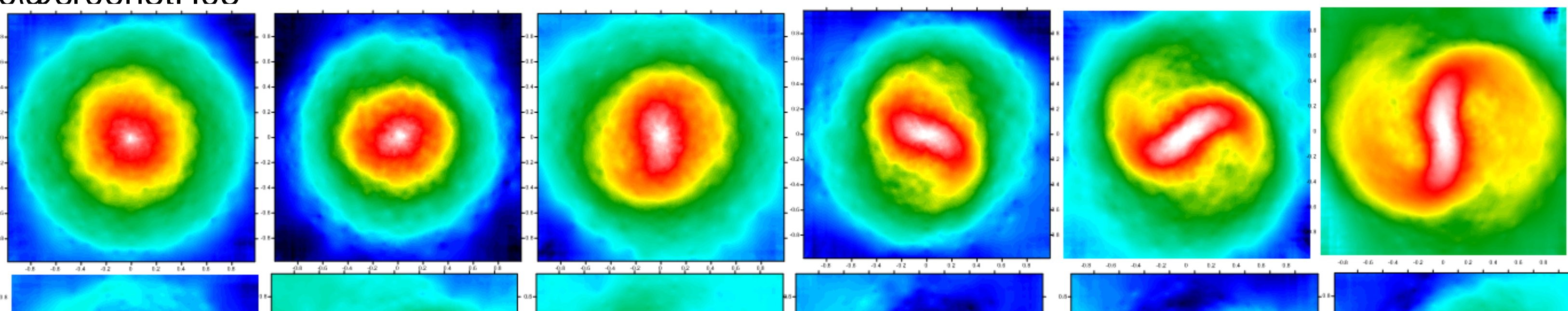
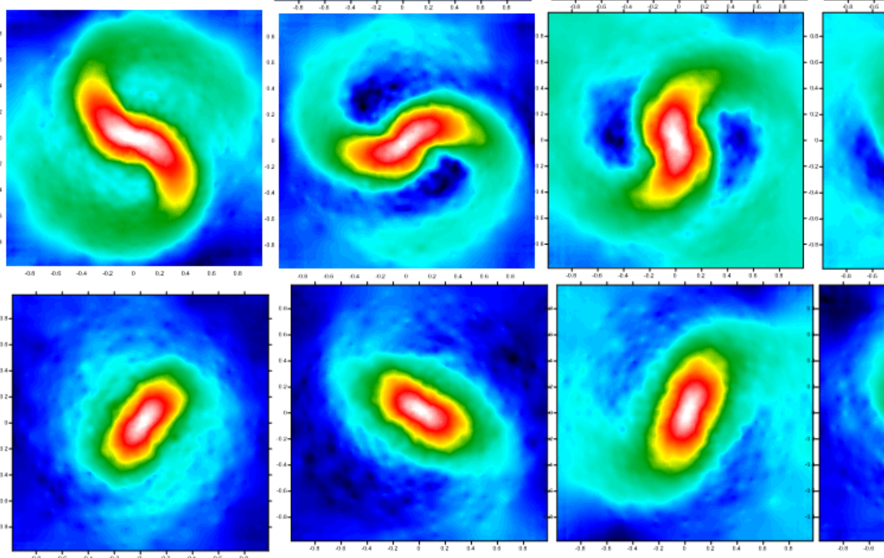
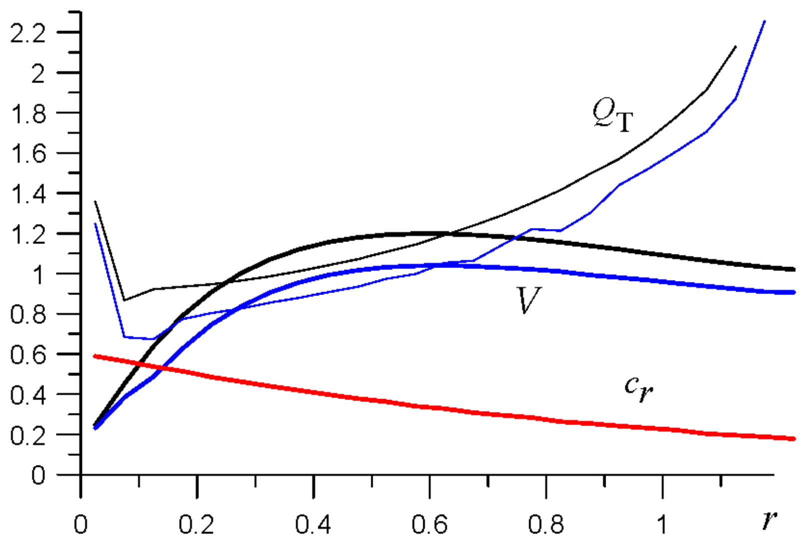
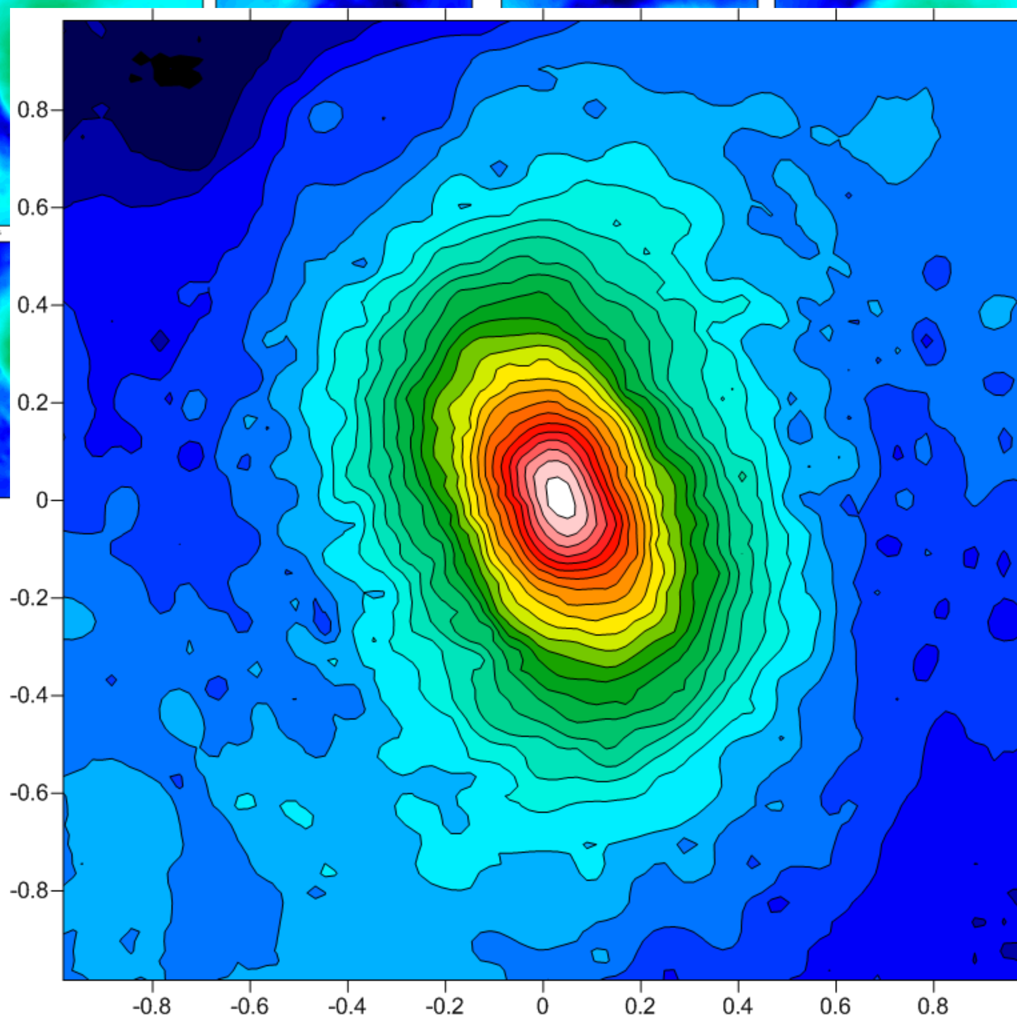
Mh=0

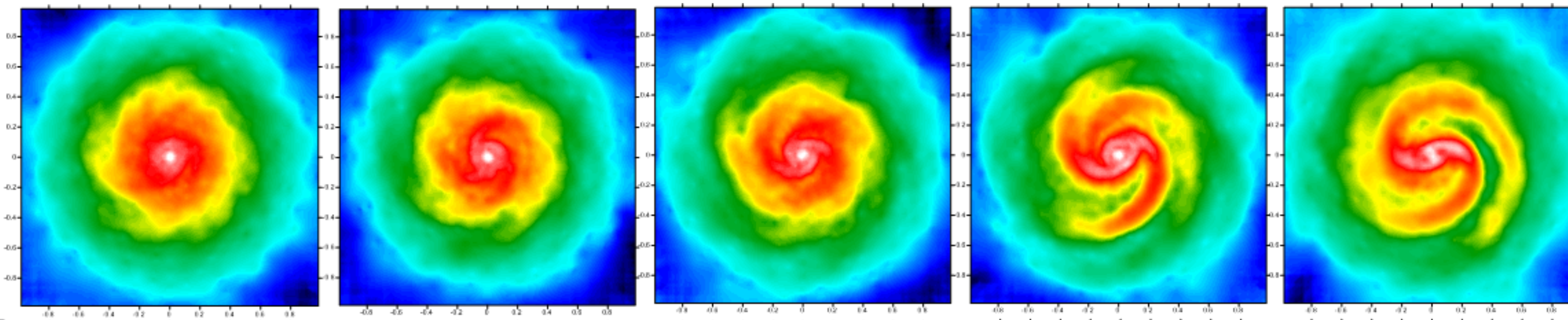


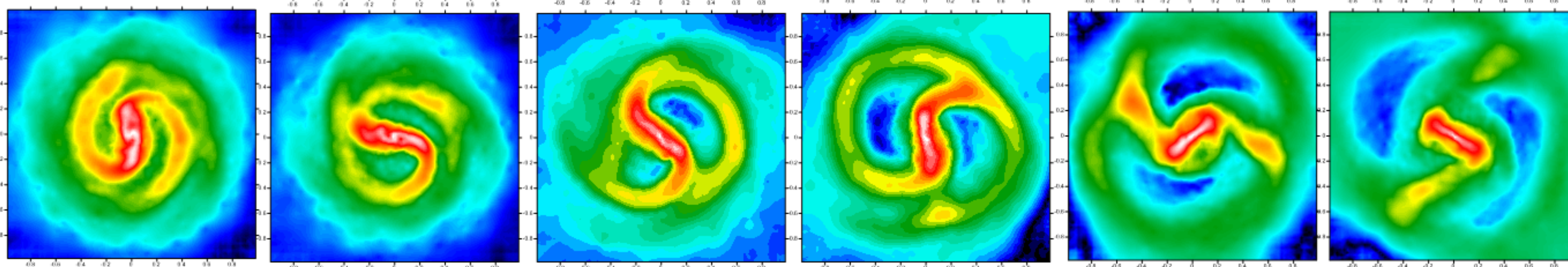


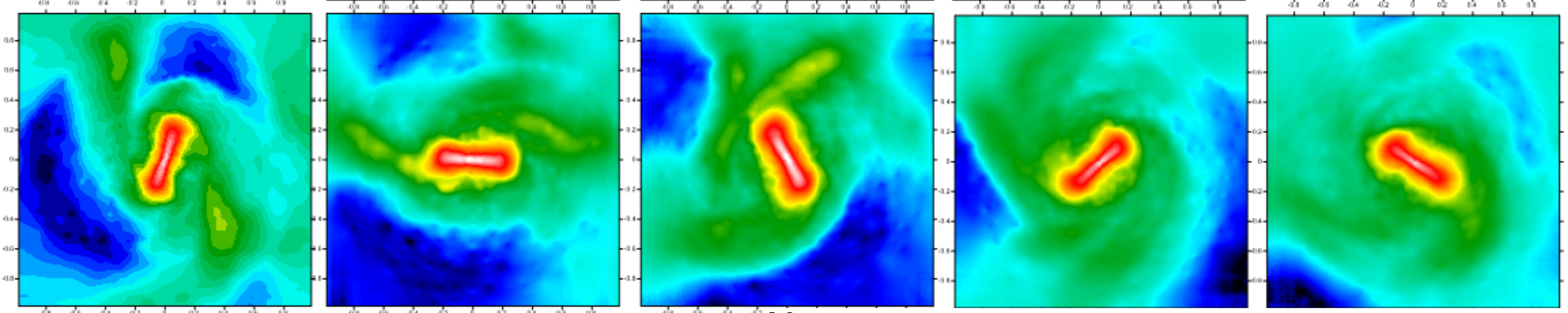




«202»







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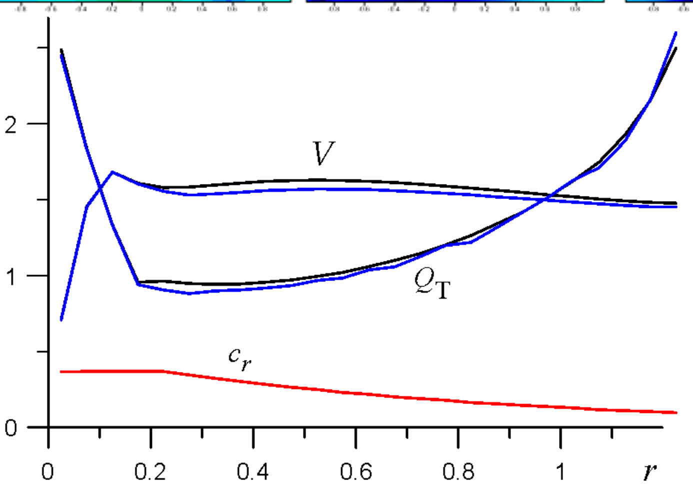
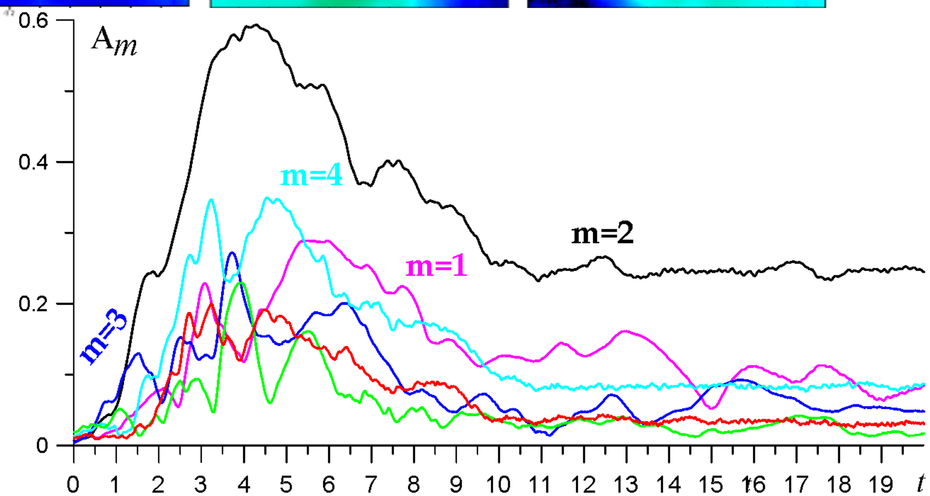
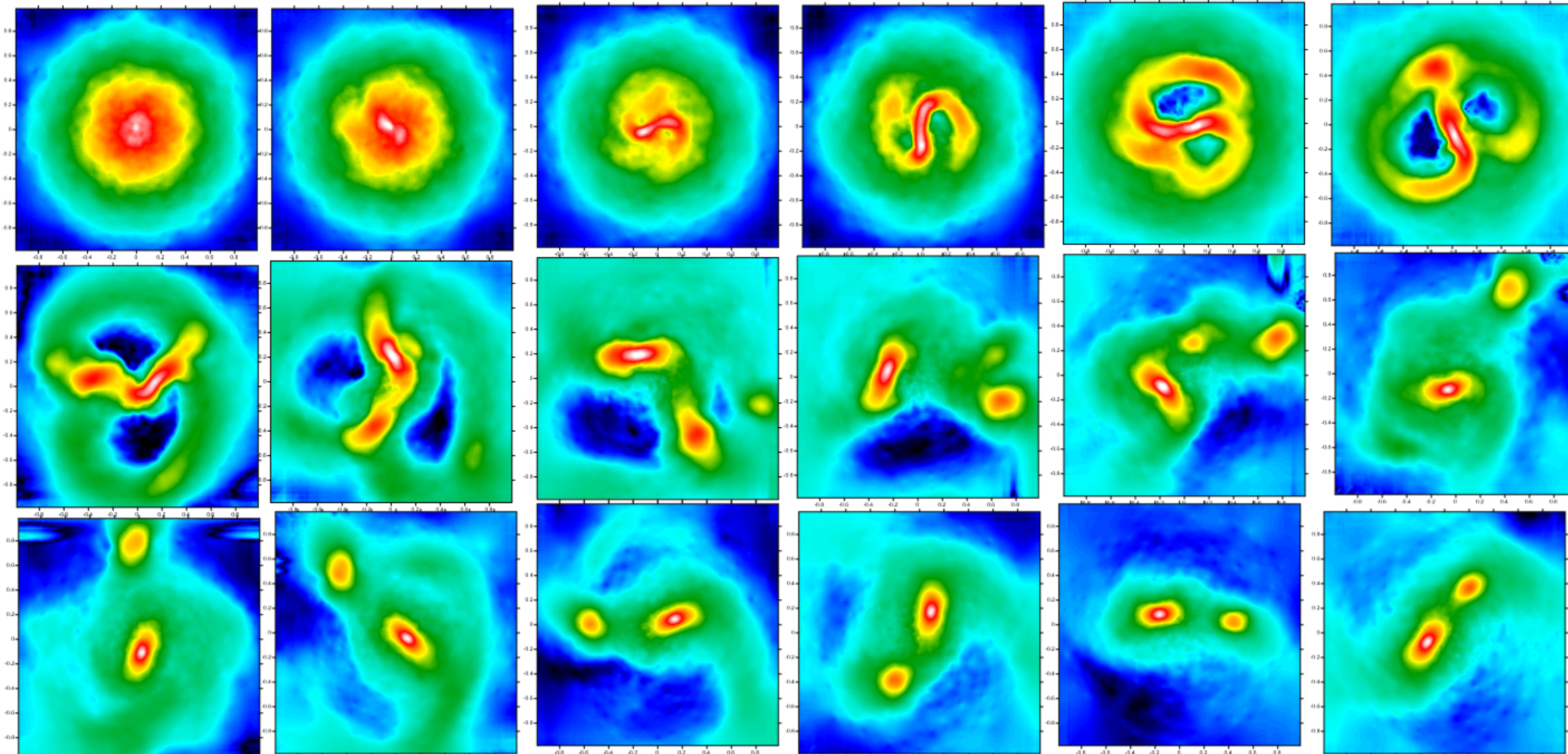
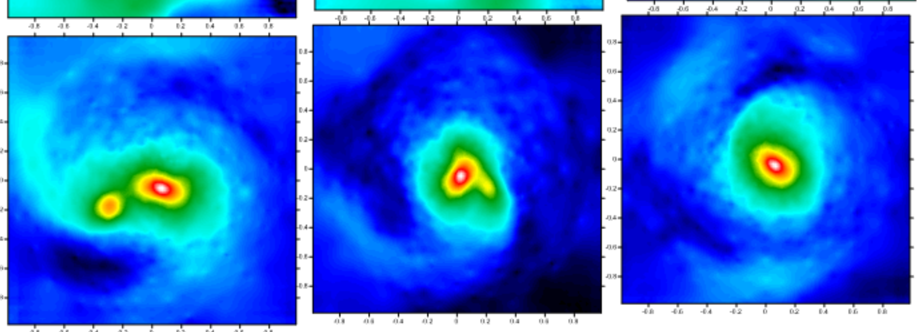
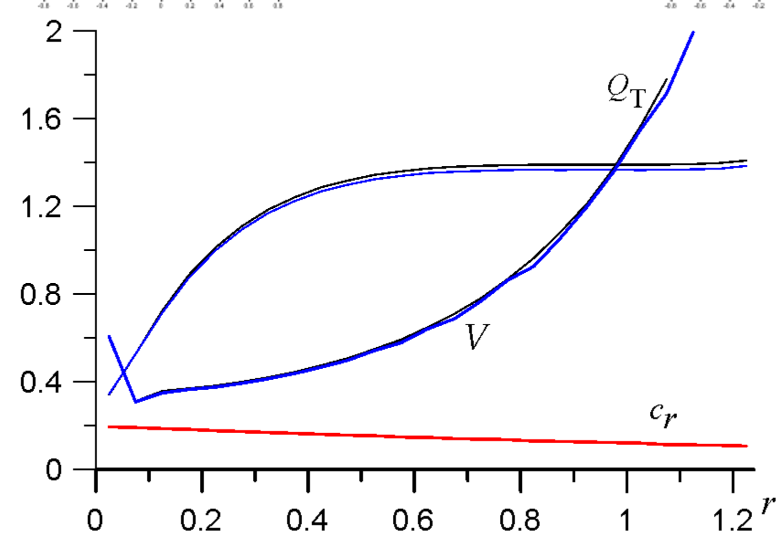
a=0.3
Mb=0.3
Md=1



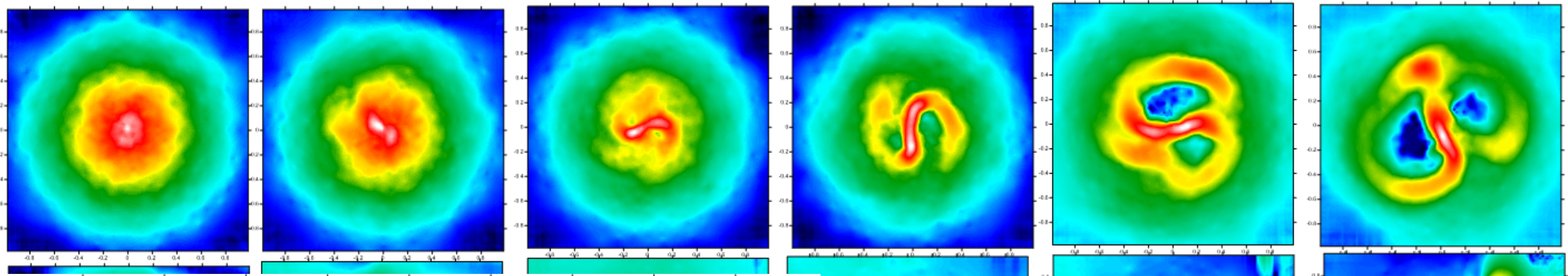


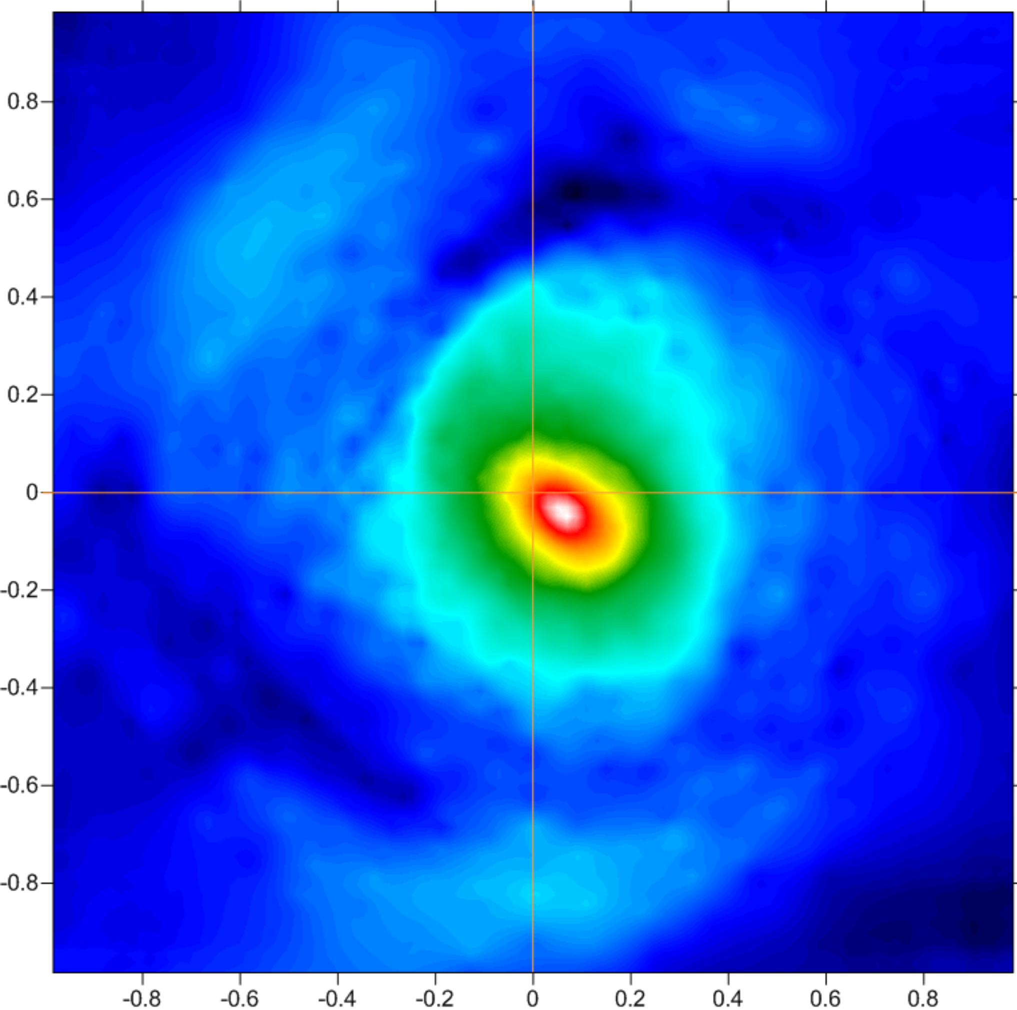


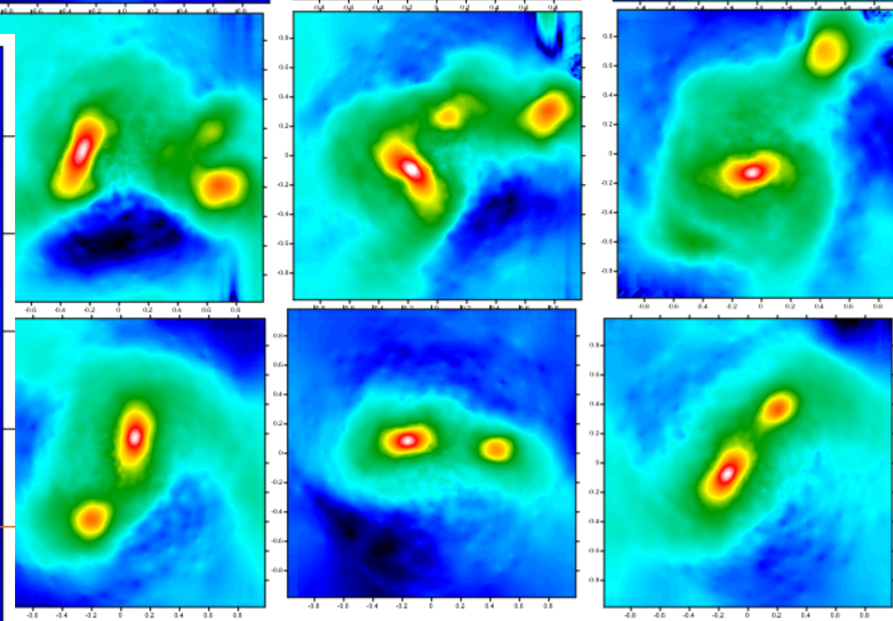


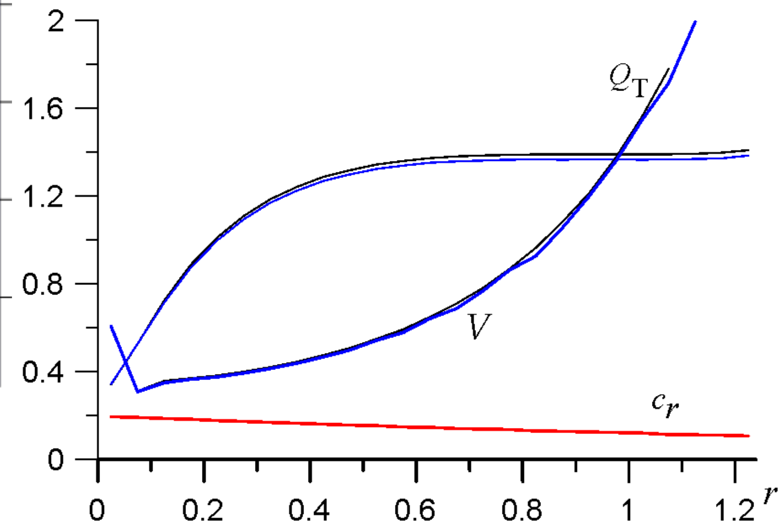


"510": Mh=0.7, a=1









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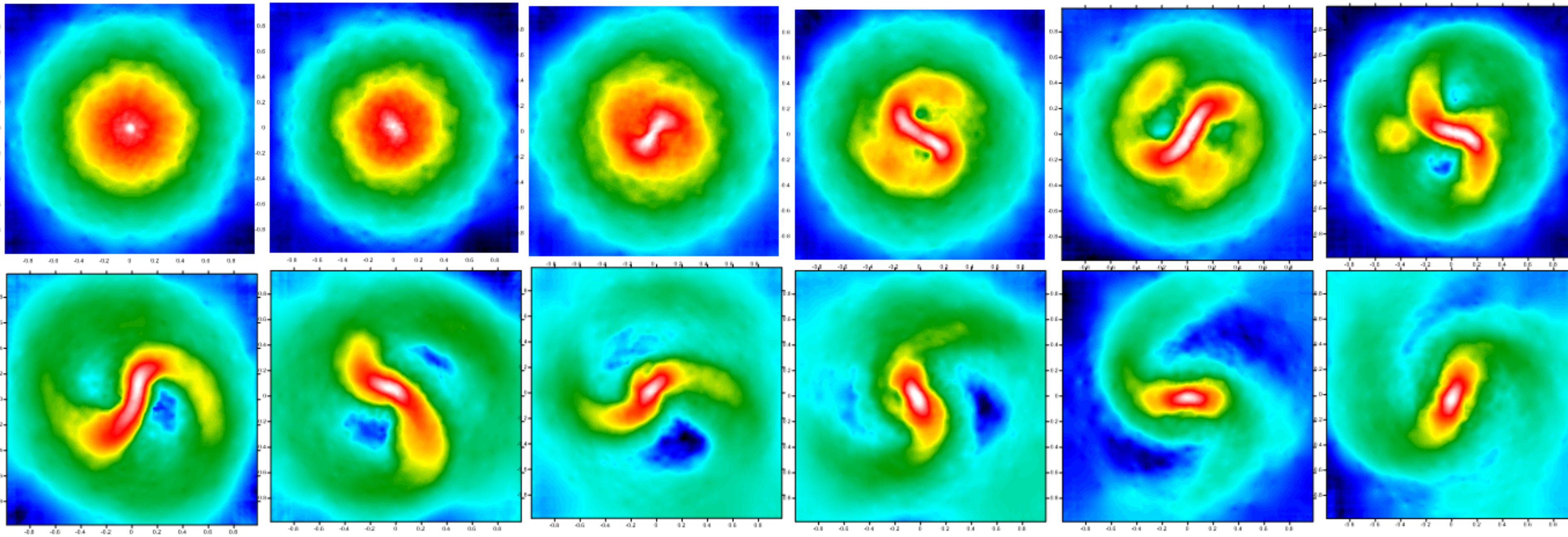

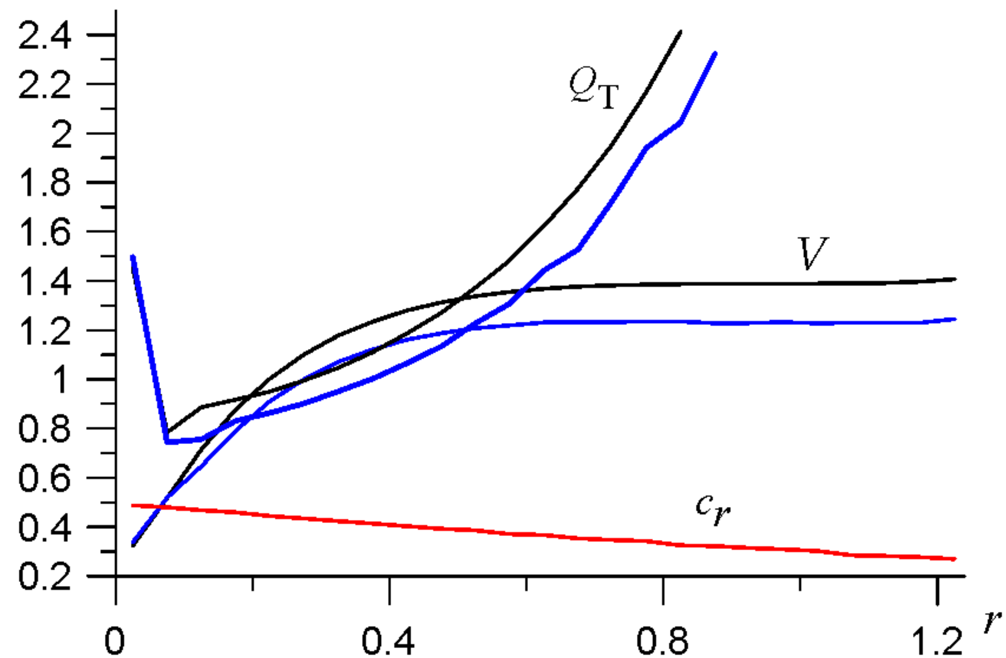

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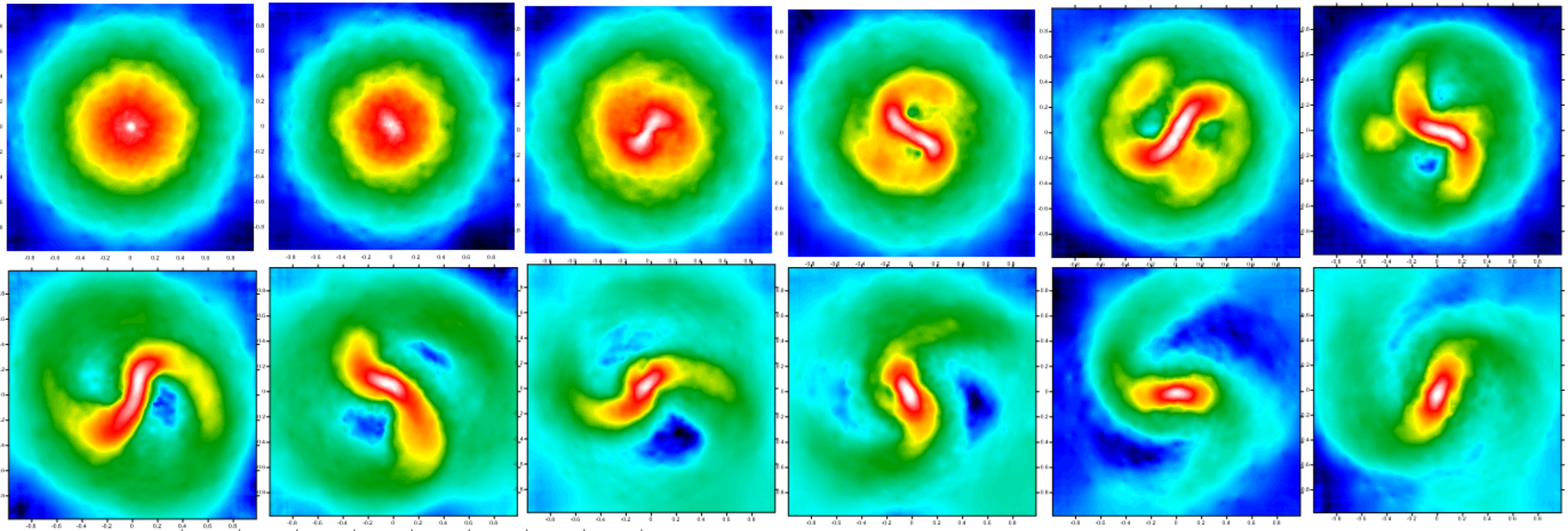

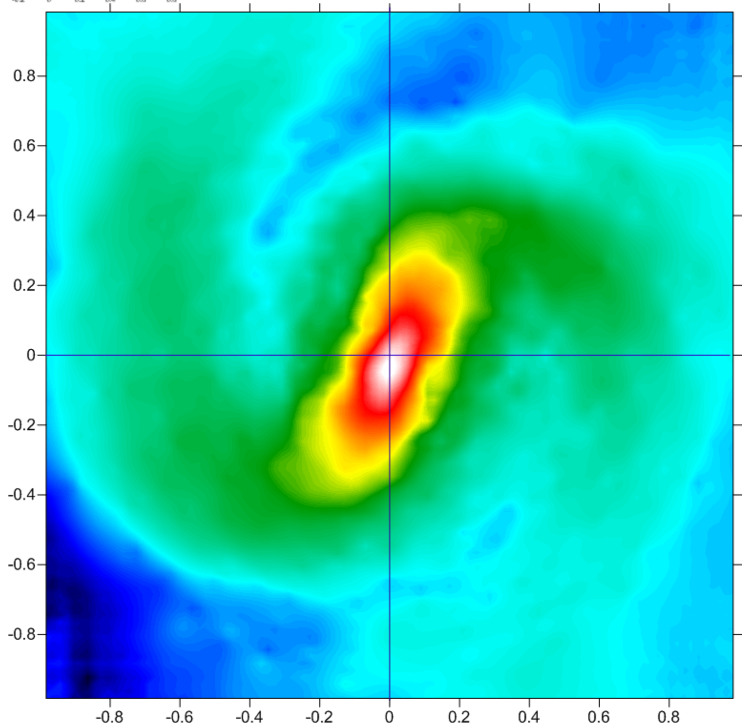

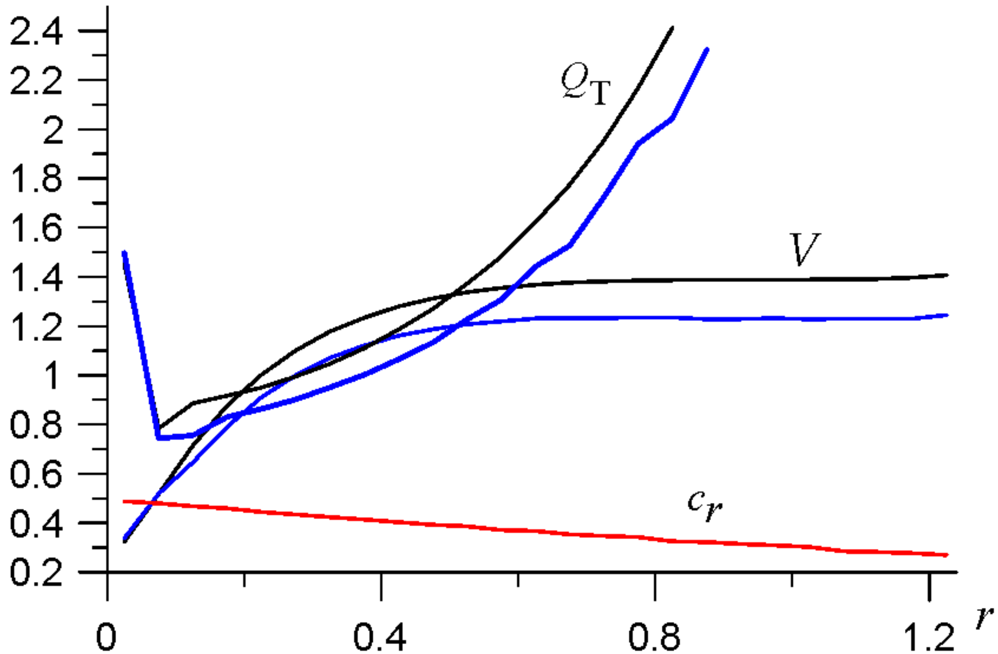

“**513**”: Mh=0.7, a = 1

Заключение

Симметричная изолированная галактика

Асимметричные галактики

Сильная гравитационная неустойчивость,
нелинейное взаимодействие бар-моды и однорукавной гармоники.

Условия для эффективного смещения бара относительно центра диска:

- Малая масса гало
- Большая шкала гало (рыхлое гало)
- Холодный диск
- Много холодного газа (??)