



Механизмы формирования асимметричных спиральных галактик: численные модели N-тел

Хоперсков А.В. (Волгоградский гос. университет)

Храпов С.С. (ВолГУ)

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 & Subramaniam (2009), D'Onghia & Fox 2015, ...]



Large Magellanic Cloud

[van der Marel 2001]

внешние изофоты - 400 пк
 кинематический центр HI
 - 800 пк

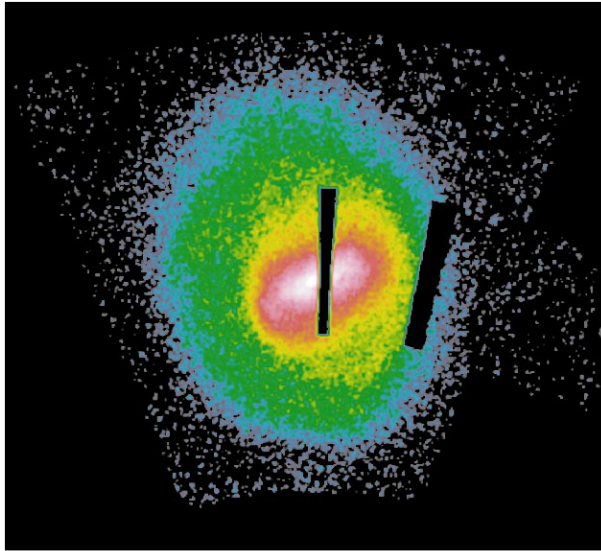


FIG. 2a

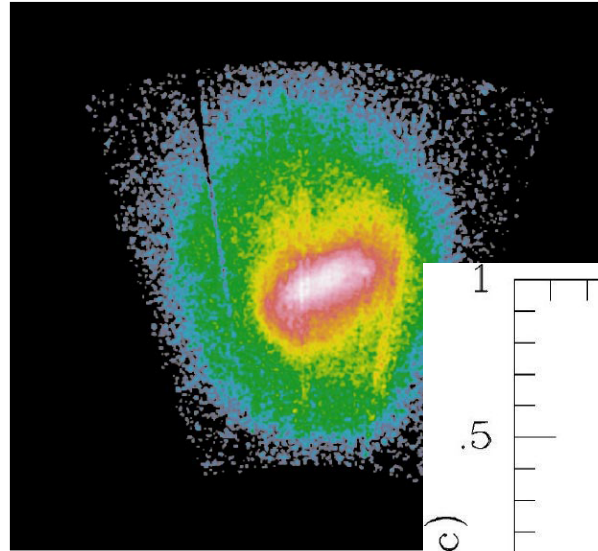


FIG. 2b

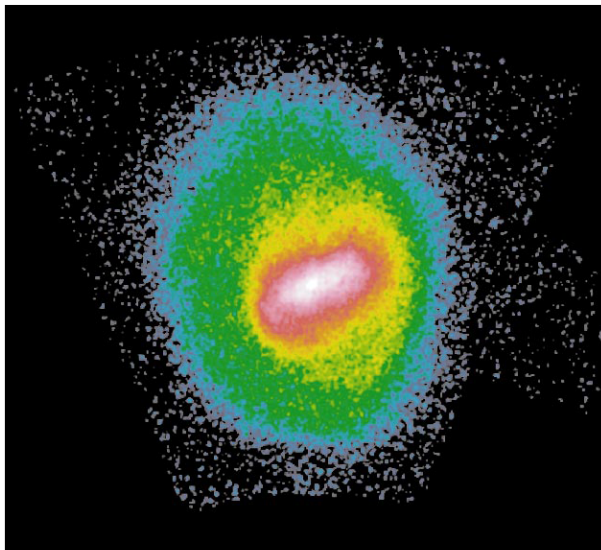


FIG. 2c

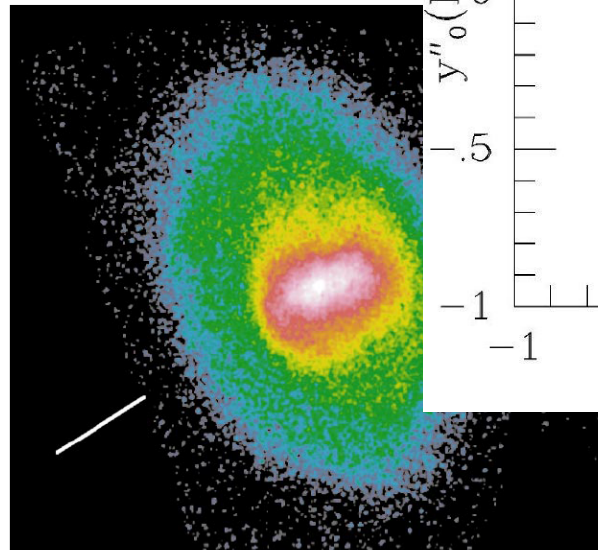
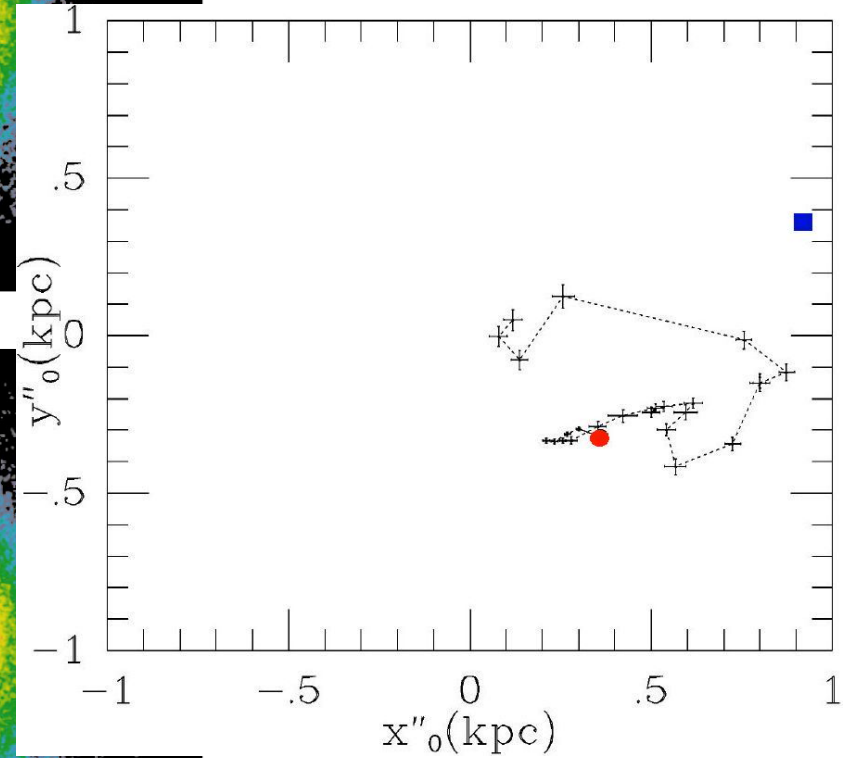


FIG. 2d

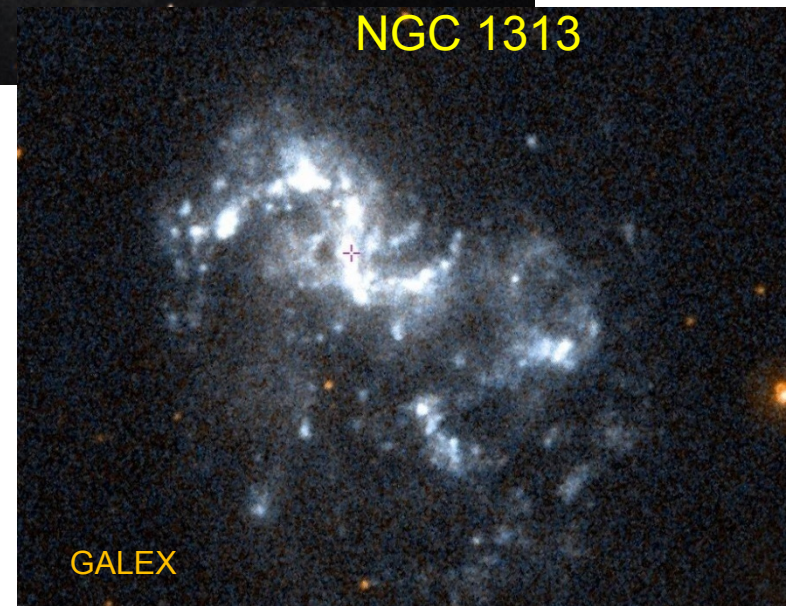
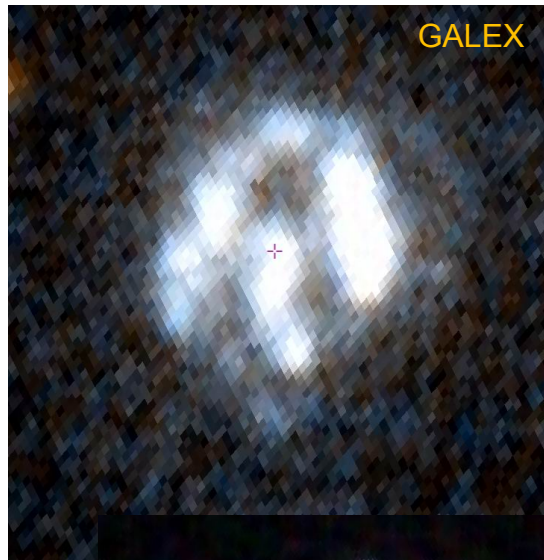
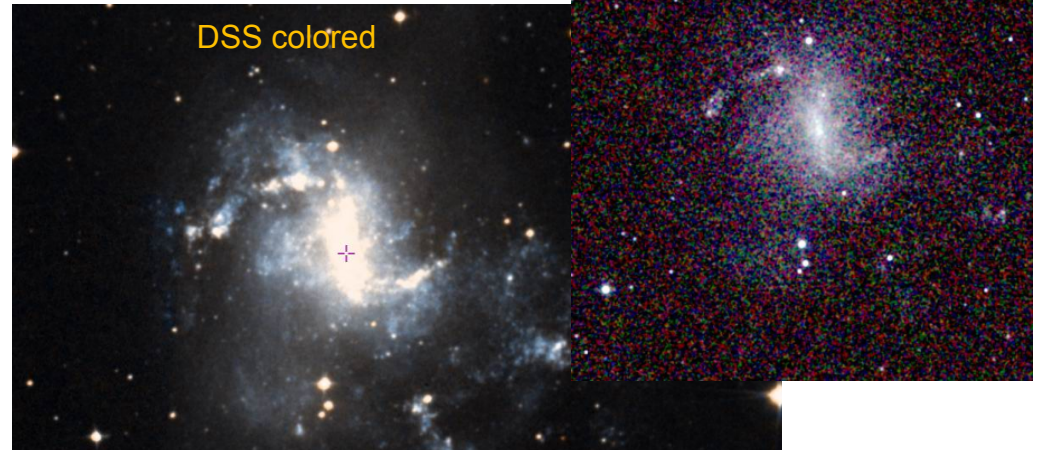
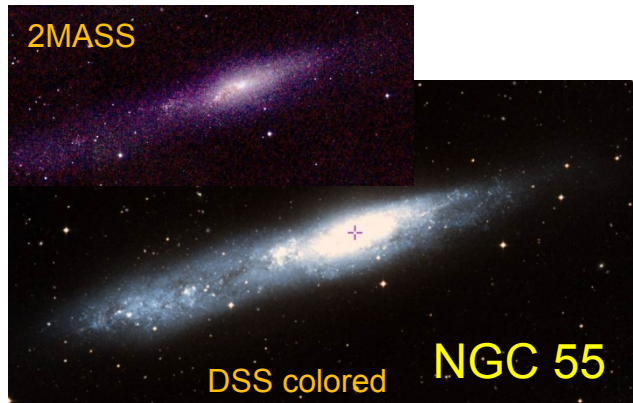


Kim et al 1998, ApJ, 503, 674

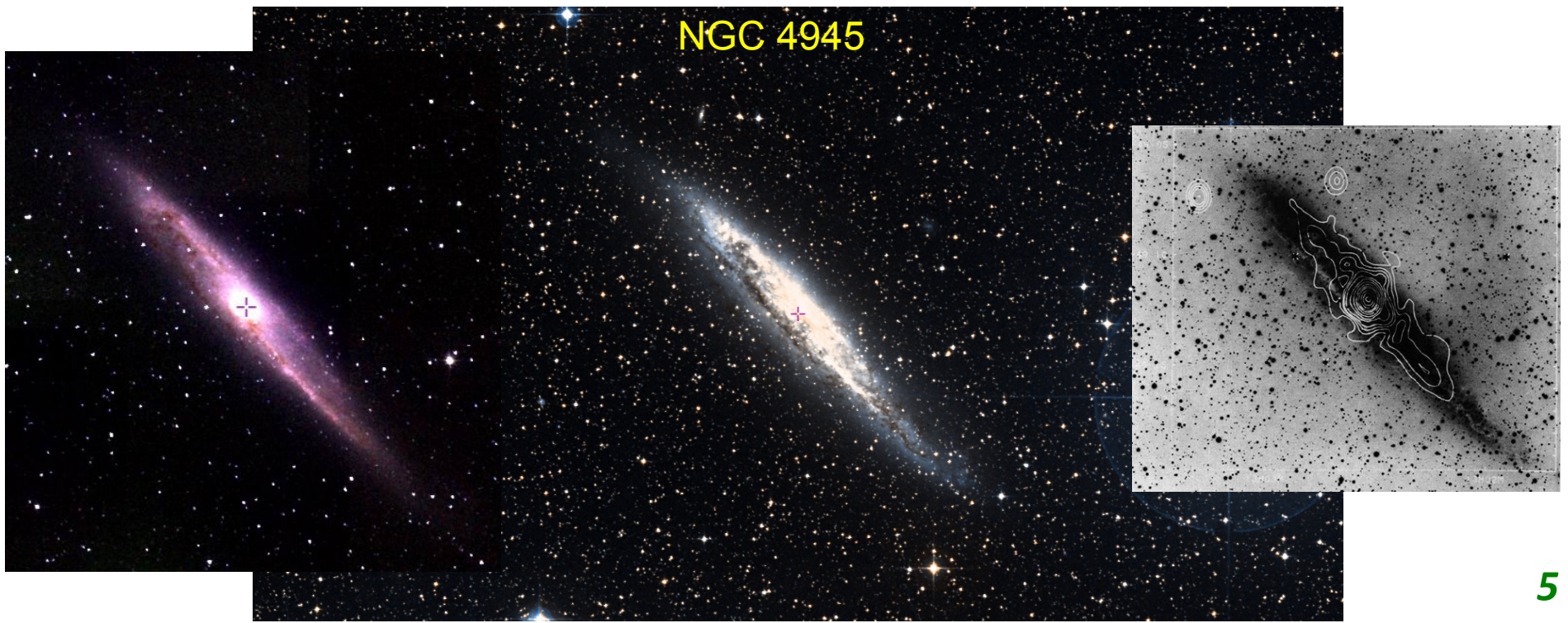
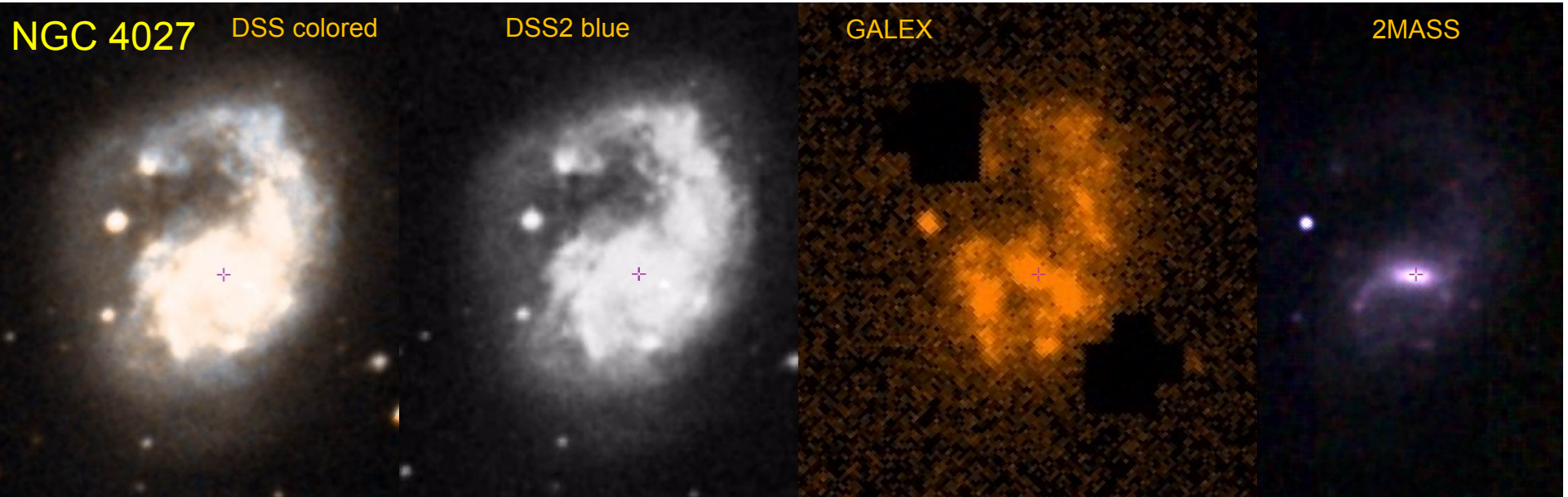
$$r_d = 1.5 \text{ кпк}$$

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 $23:55 \times 21:55$. 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.

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



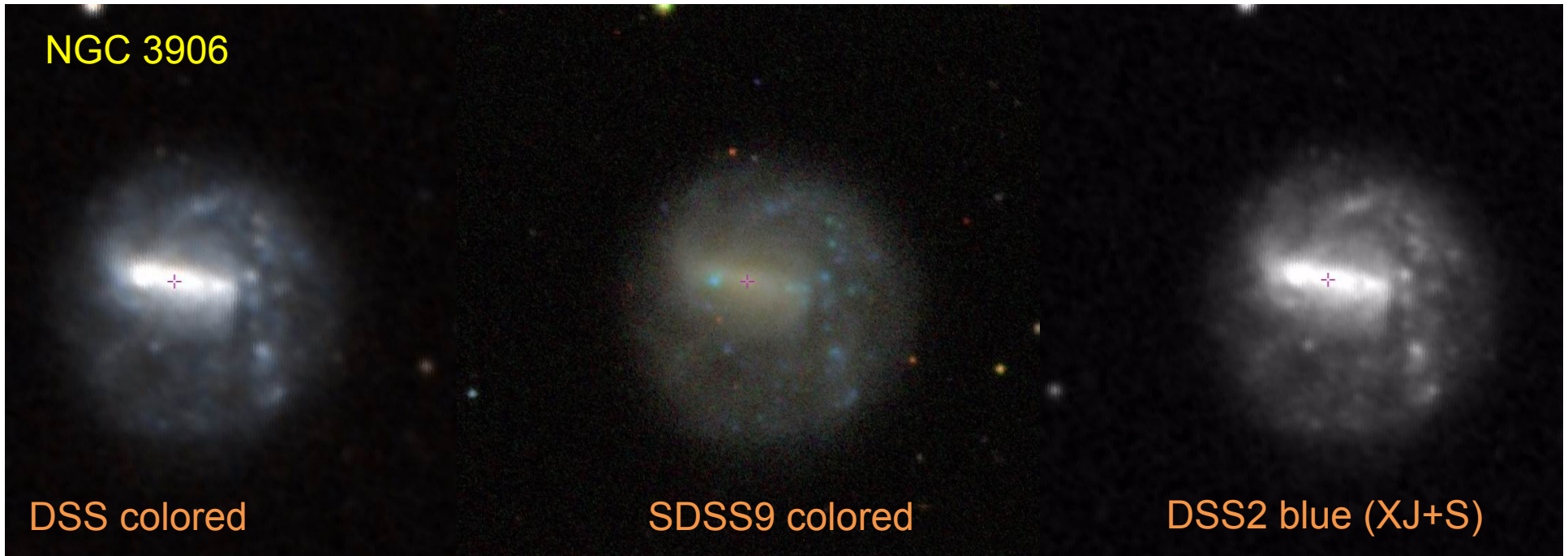
NGC4631 SBcd

DSS colored

SDSS9 colored

2MASS

NGC 3906



DSS colored

SDSS9 colored

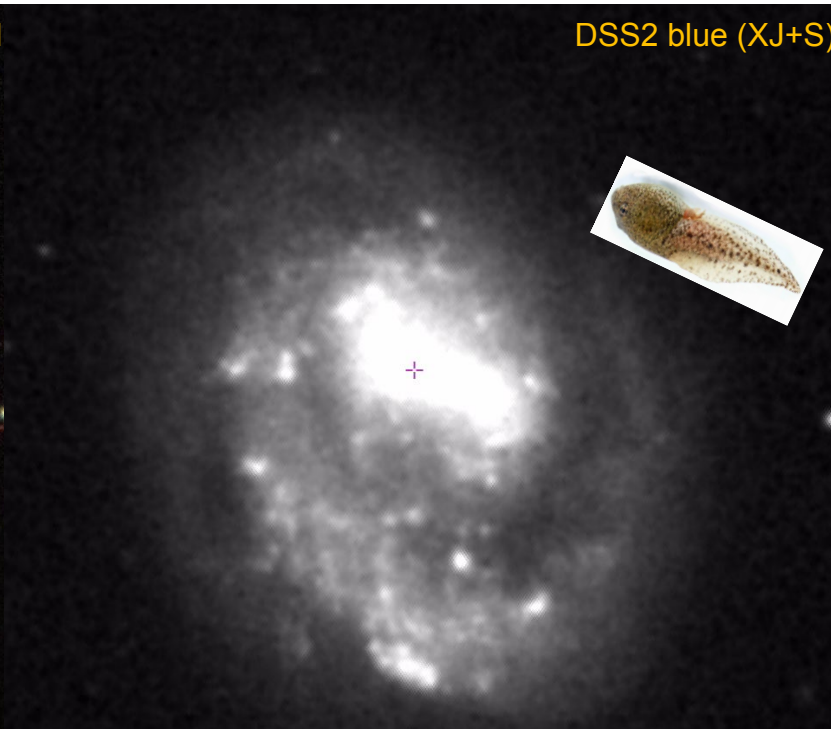
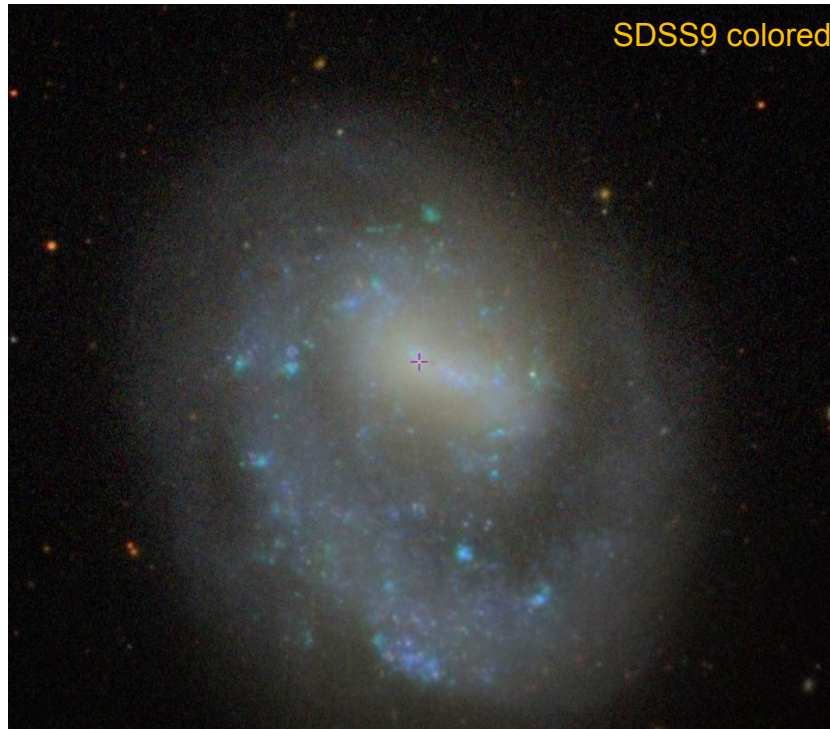
DSS2 blue (XJ+S)

[Swardt + (2015)]

SDSS9 colored

DSS2 blue (XJ+S)

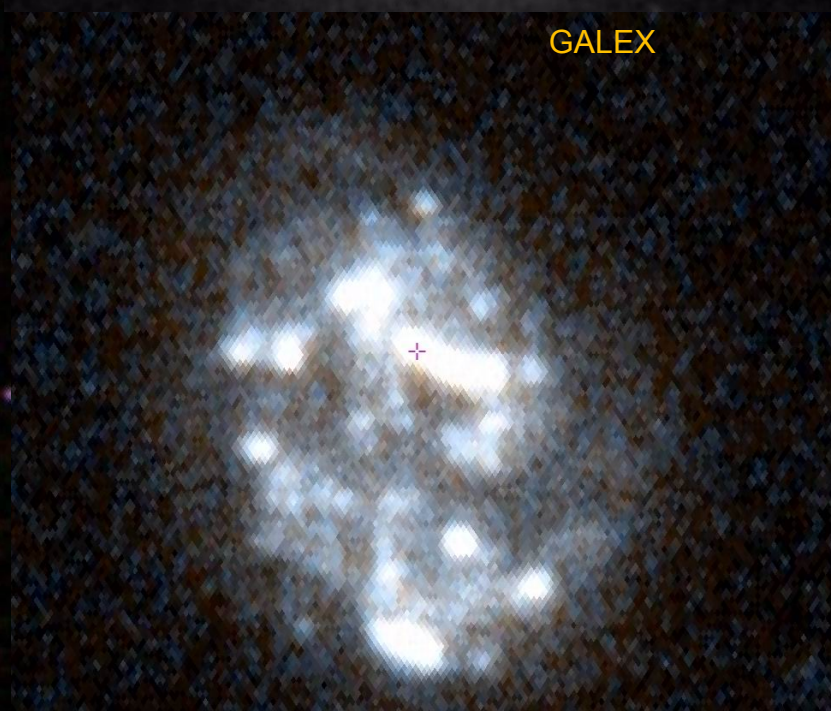
NGC4618
SBm



“Tadpole”
type

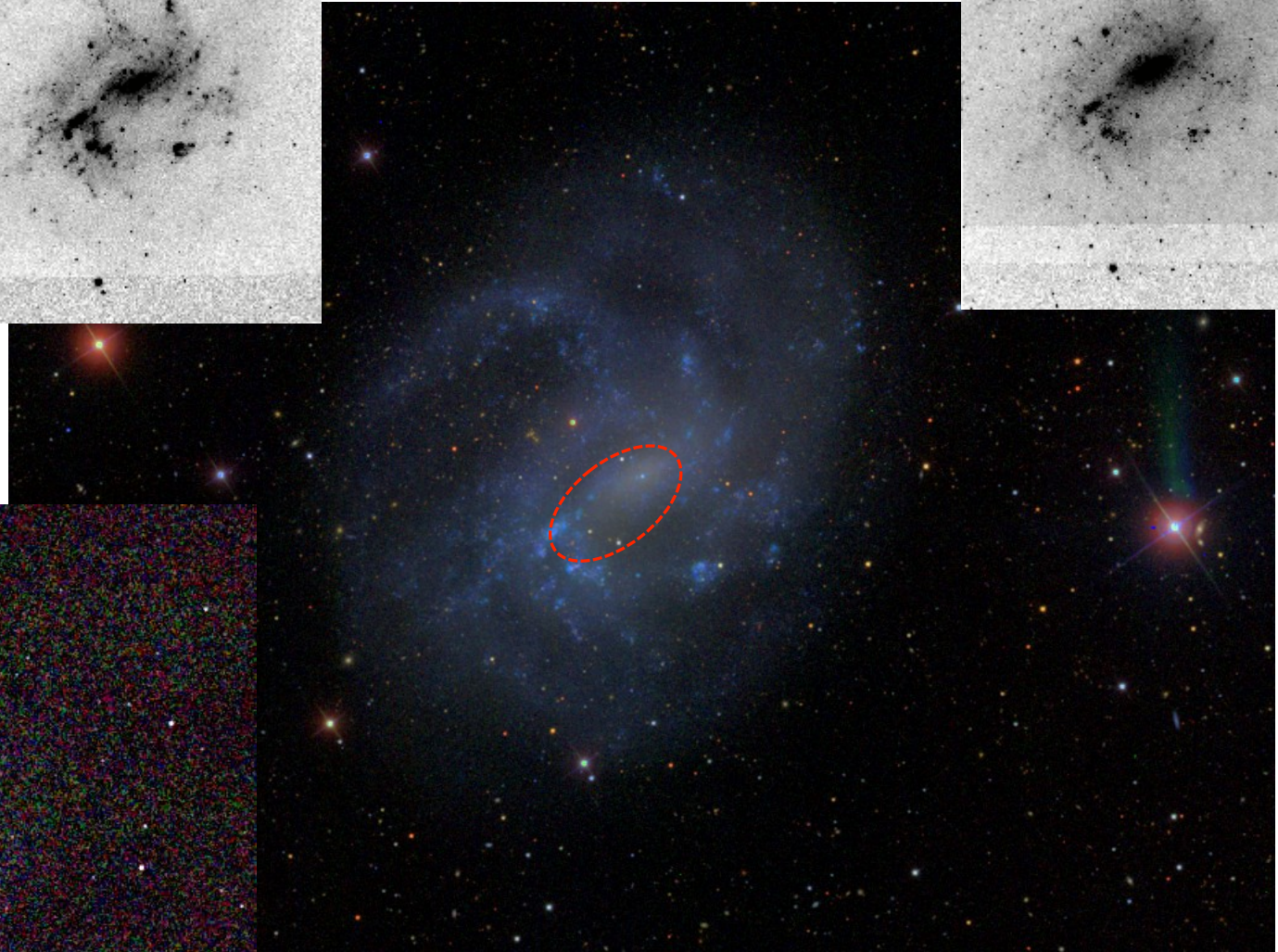
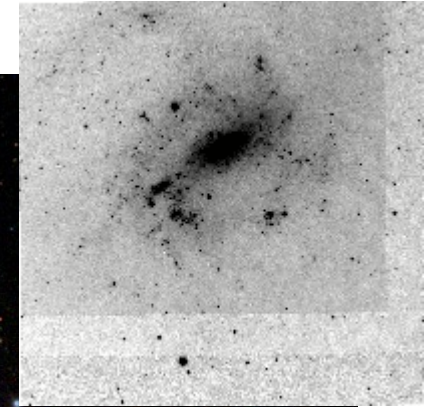
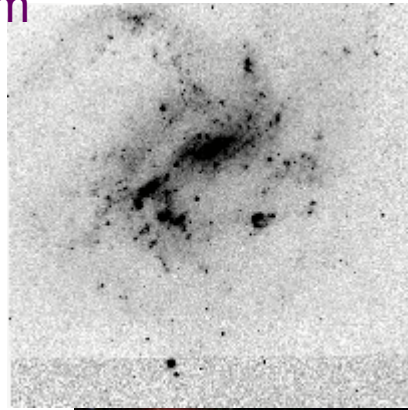
2MASS

GALEX



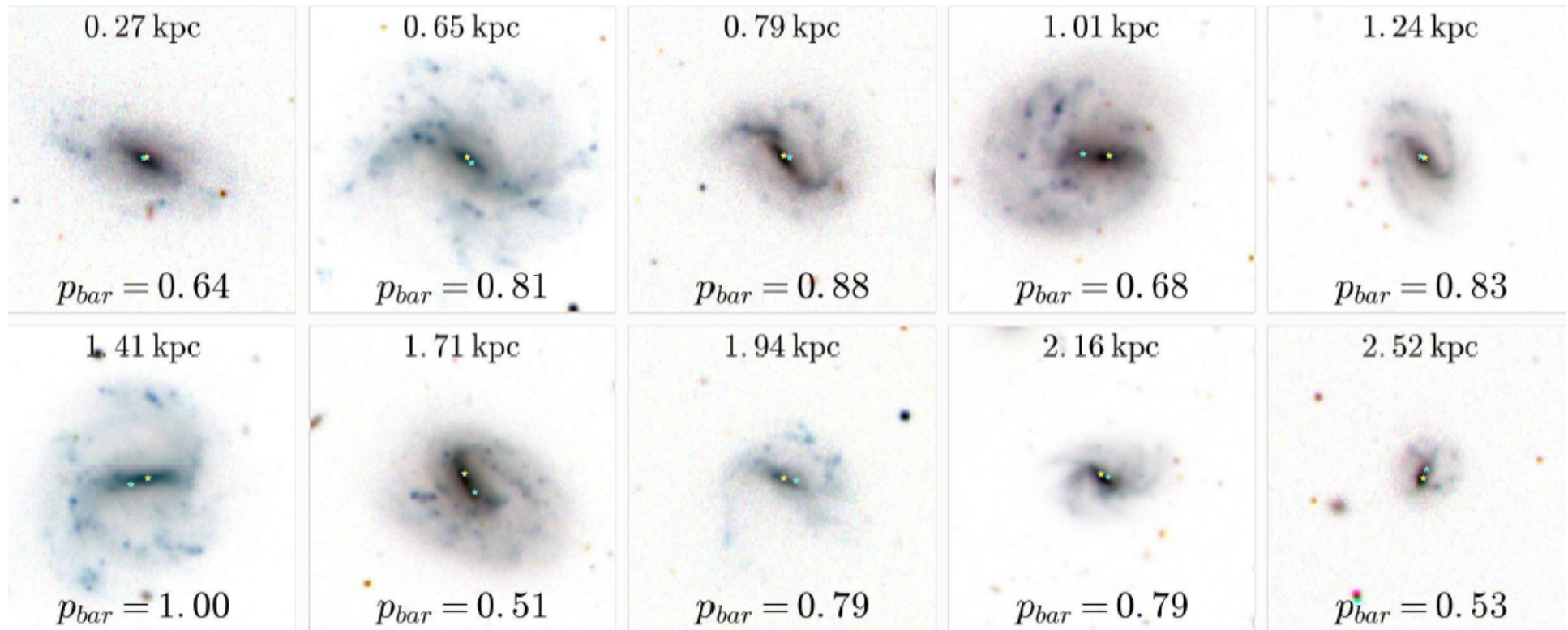
66 km/c

NGC 4395 SBm



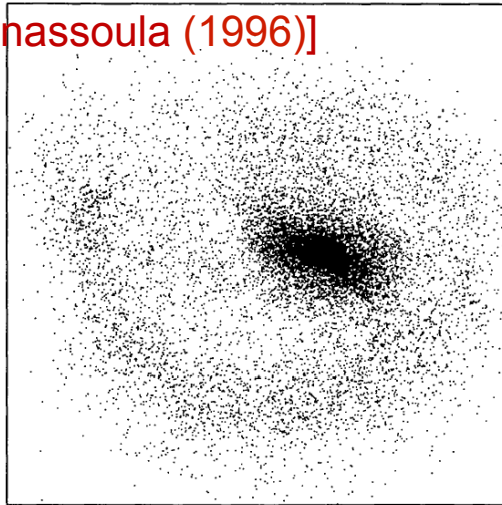
“Tadpole” type

[Kruk +11, arXiv:1705.00007]

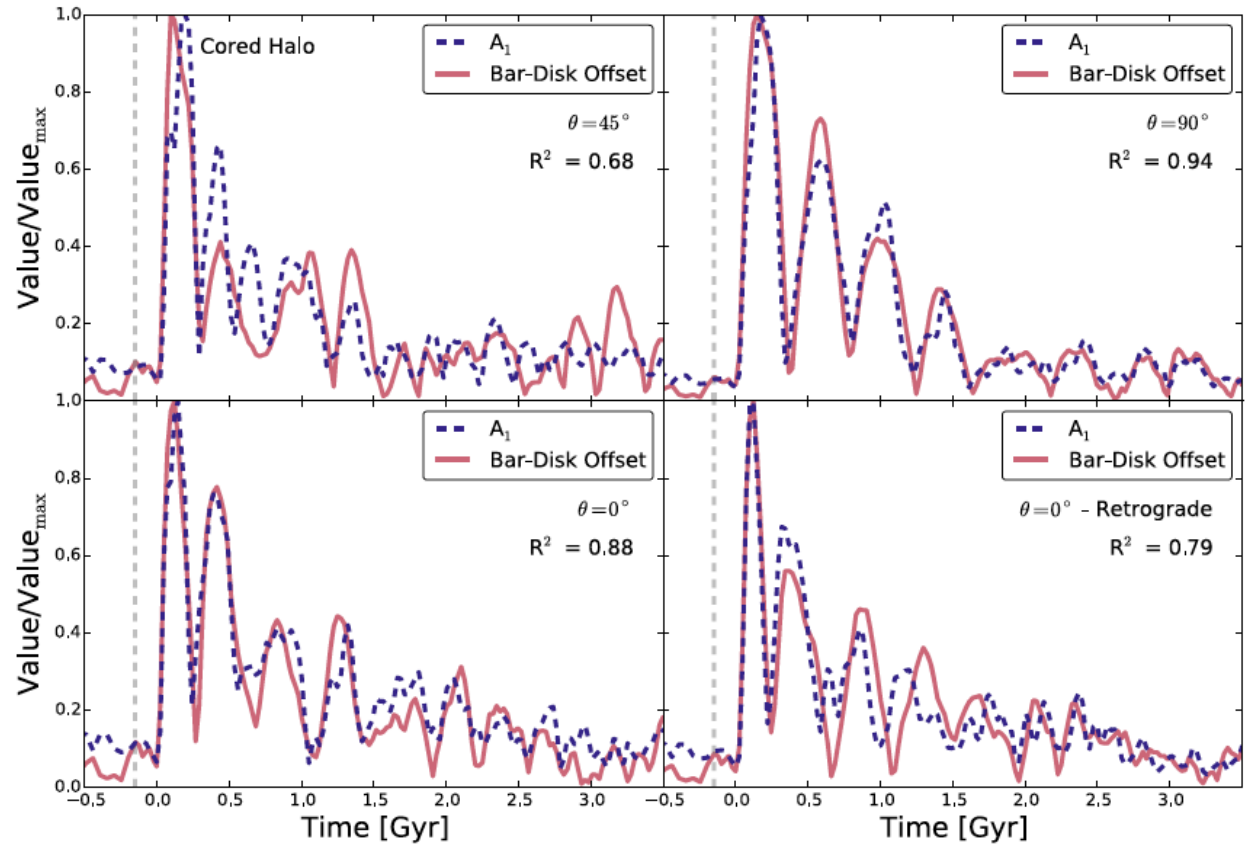


Formation lopsided SB-galaxies. Кто виноват ? Спутники ?

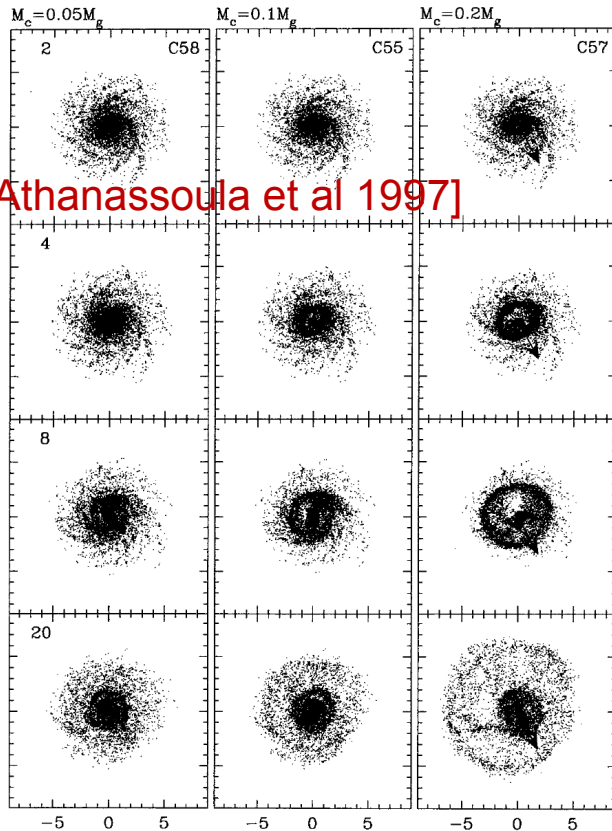
[Athanassoula (1996)]



[Pardy et al. (2016)]



[Athanassoula et al 1997]



Наблюдения

Galaxy Zoo: Finding offset discs and bars in SDSS galaxies

[Kruk +11, arXiv:1705.00007]

Sandor J. Kruk,^{1*} Chris J. Lintott,¹ Brooke D. Simmons,^{1,2†} Steven P. Bamford,³
Carolyn N. Cardamone,⁴ Lucy Fortson,⁵ Ross E. Hart,³ Boris Häußler,⁶
Karen L. Masters,⁷ Robert C. Nichol,⁷ Kevin Schawinski,⁸ Rebecca J. Smethurst^{1,3 ‡}

¹Oxford Astrophysics, Department of Physics, University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH, UK

²Center for Astrophysics and Space Sciences (CASS), Department of Physics, University of California, San Diego, CA 92093, USA

³School of Physics and Astronomy, The University of Nottingham, University Park, Nottingham NG7 2RD, UK

⁴Math and Science Department, Wheelock College, 200 The Riverway, Boston, MA 02215, USA

⁵School of Physics and Astronomy, University of Minnesota, 116 Church St. SE, Minneapolis, MN 55455, USA

⁶ESO - European Southern Observatory, Alonso de Cordova 3107, Vitacura, Santiago, Chile

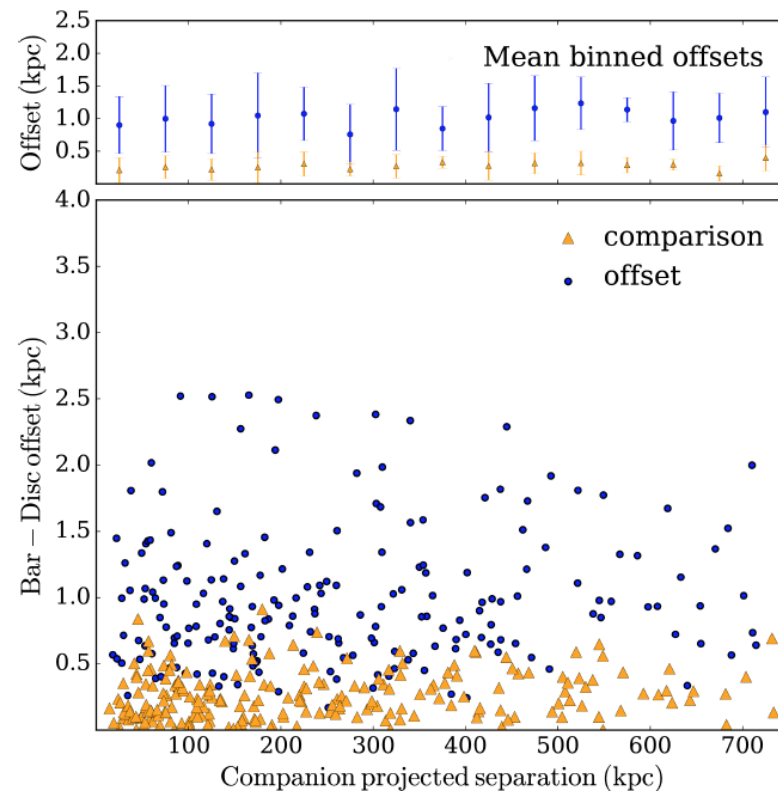
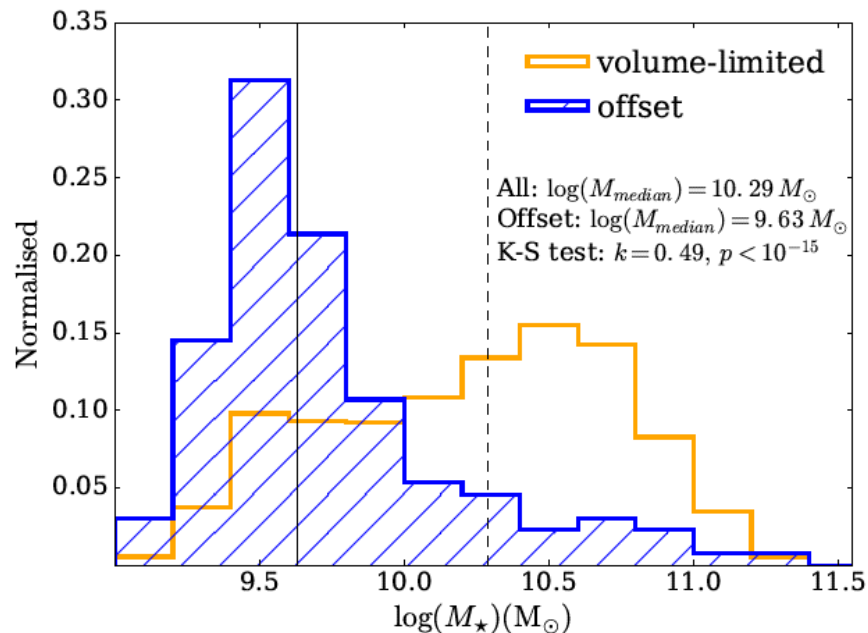
⁷Institute of Cosmology and Gravitation, University of Portsmouth, Dennis Sciama Building, Barnaby Road, Portsmouth, PO1 3FX, UK

⁸Institute for Astronomy, Department of Physics, ETH Zürich, Wolfgang-Pauli Strasse 27, CH-8093 Zürich, Switzerland

270 галактик позднего типа
(off-centre bar)

Sloan Digital Sky Survey (SDSS) DR7, Galaxy Zoo 2 (240419 галактик):

Bar-Disc Off-sets = 271.



Модели

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

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

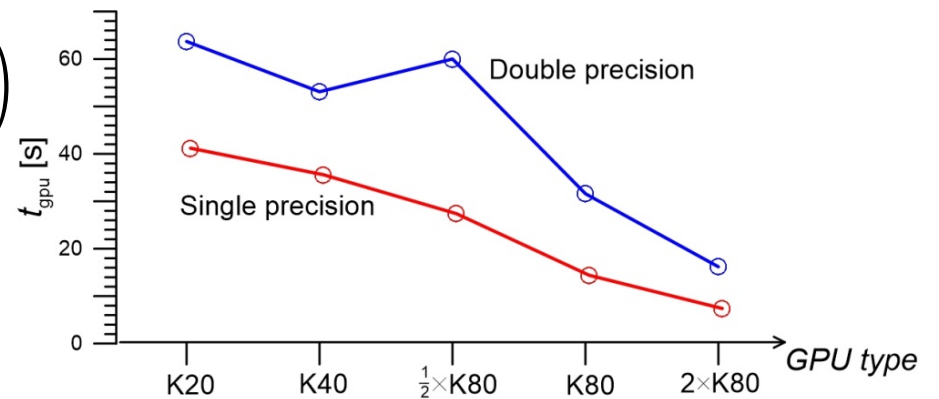
$$\frac{V_\phi^2}{R} = -\frac{\partial \Psi}{\partial R} + \frac{C_R^2}{R} \left(1 - \frac{C_\phi^2}{C_R^2} + \frac{R}{\rho C_R^2} \frac{\partial(\rho C_R^2)}{\partial R} + \frac{R}{C_R^2} \frac{\partial(V_R V_z)}{\partial z} \right)$$

Live Halo

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

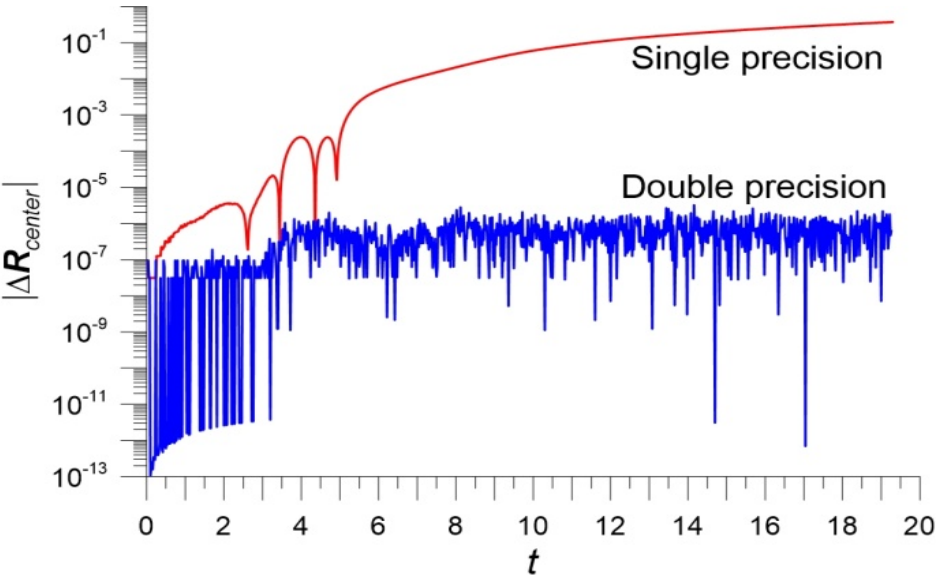
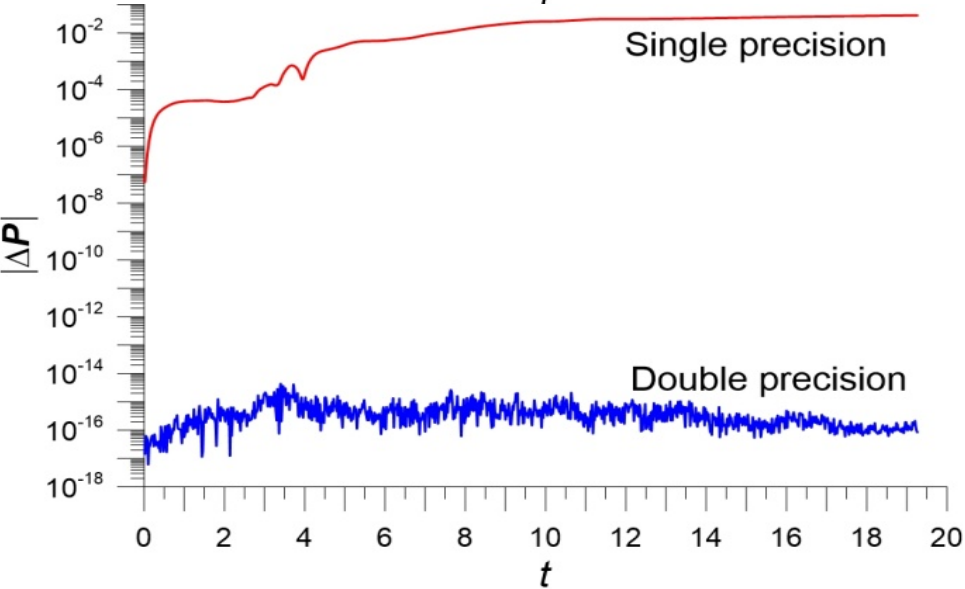
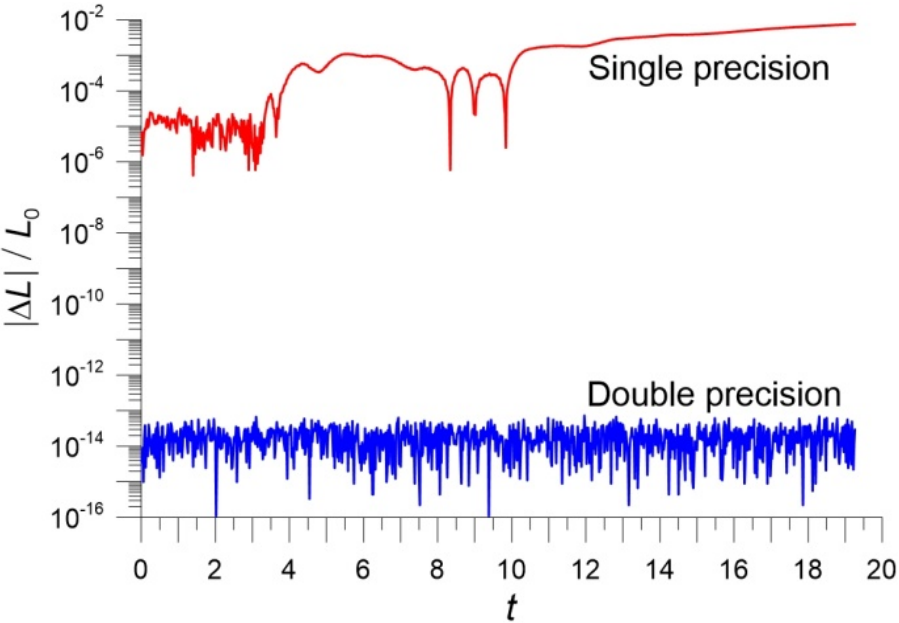
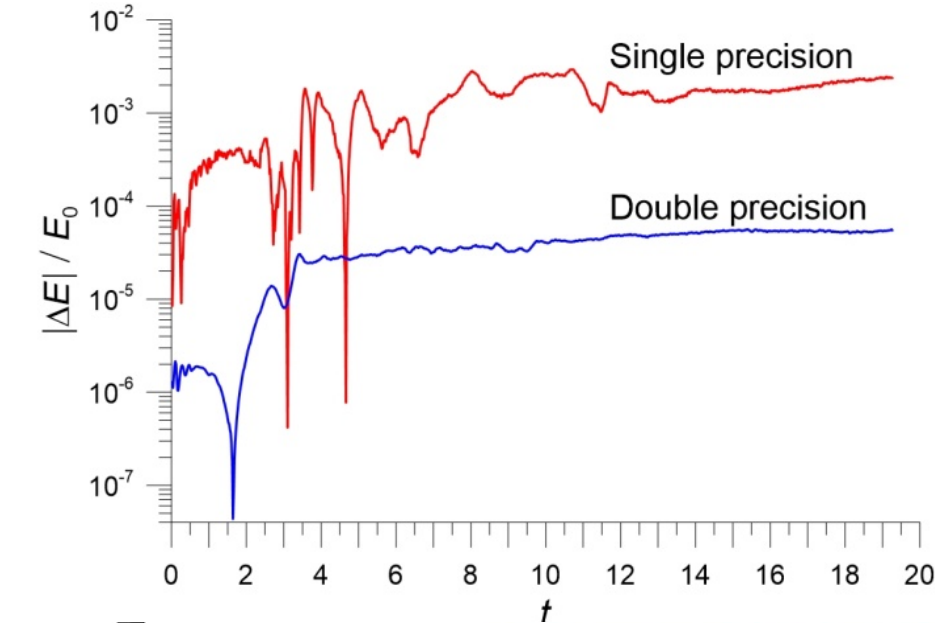
Particle – Particle:
 $10^{18} - 2^{23}$

GPU Nvidia Tesla computers: K20, K40, K80

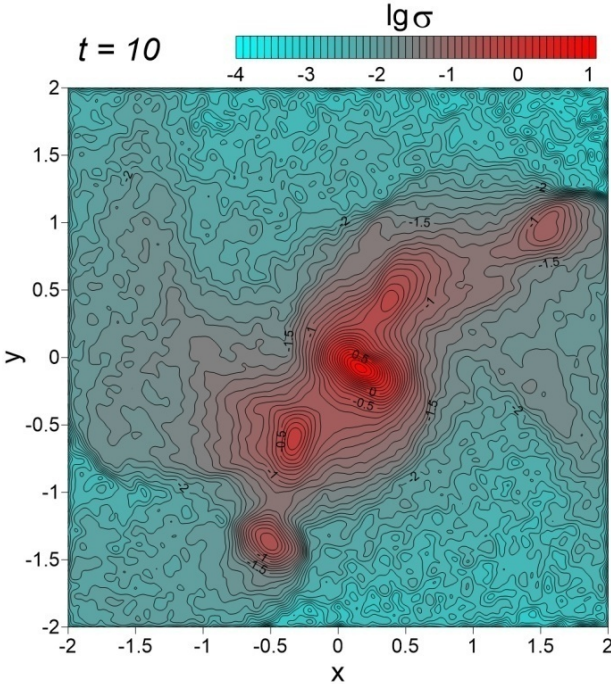
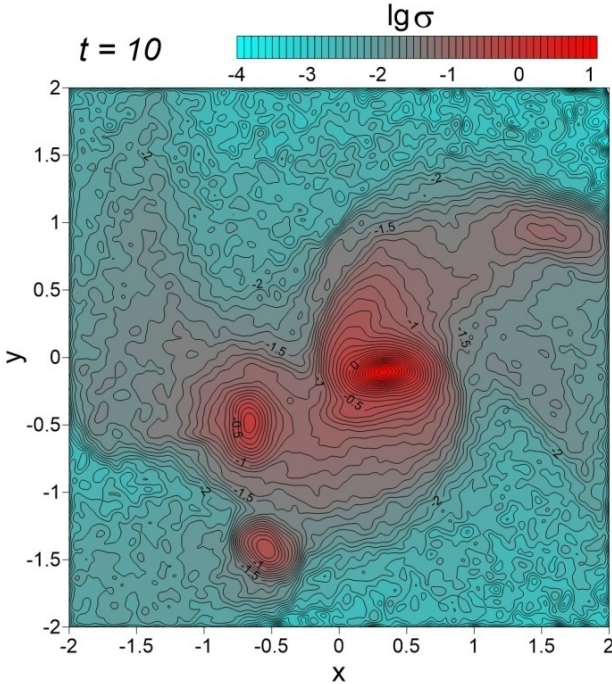
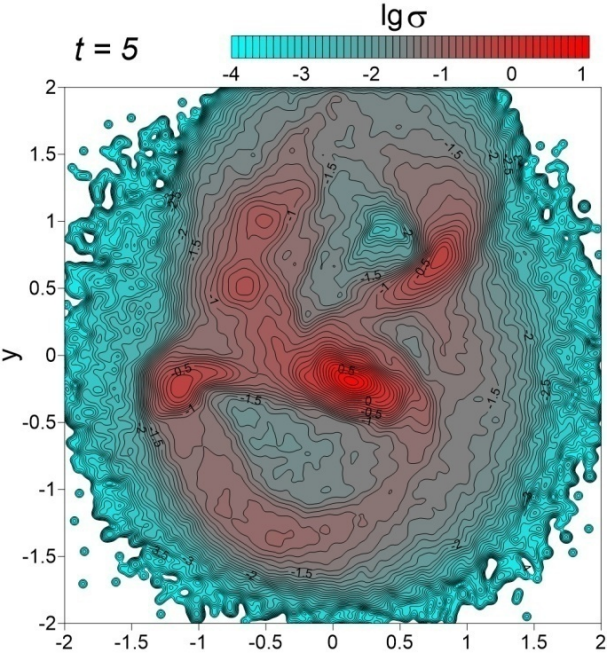
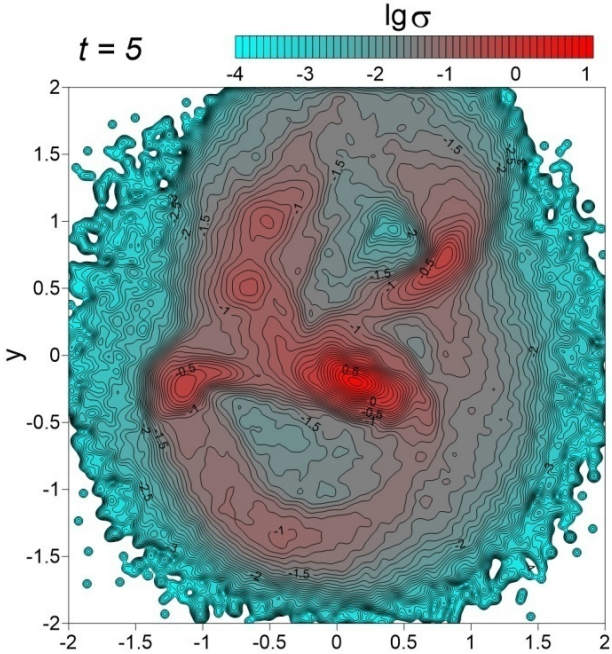


N ×1024	t_{gpu} [s], single precision			t_{gpu} [s], double precision		
	1×GPU	2×GPU	4×GPU	1×GPU	2×GPU	4×GPU
128	0.4	0.2	0.1	0.9	0.5	0.3
256	1.7	0.9	0.45	3.7	2	1
512	6.9	3.6	1.8	15	7.9	4
1024	27.4	14.4	7.4	60	31.6	16.2
2048	109.6	57.6	29.6	240	126.4	64.8
4096	438	230	118	960	506	259
8192	1754	922	474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

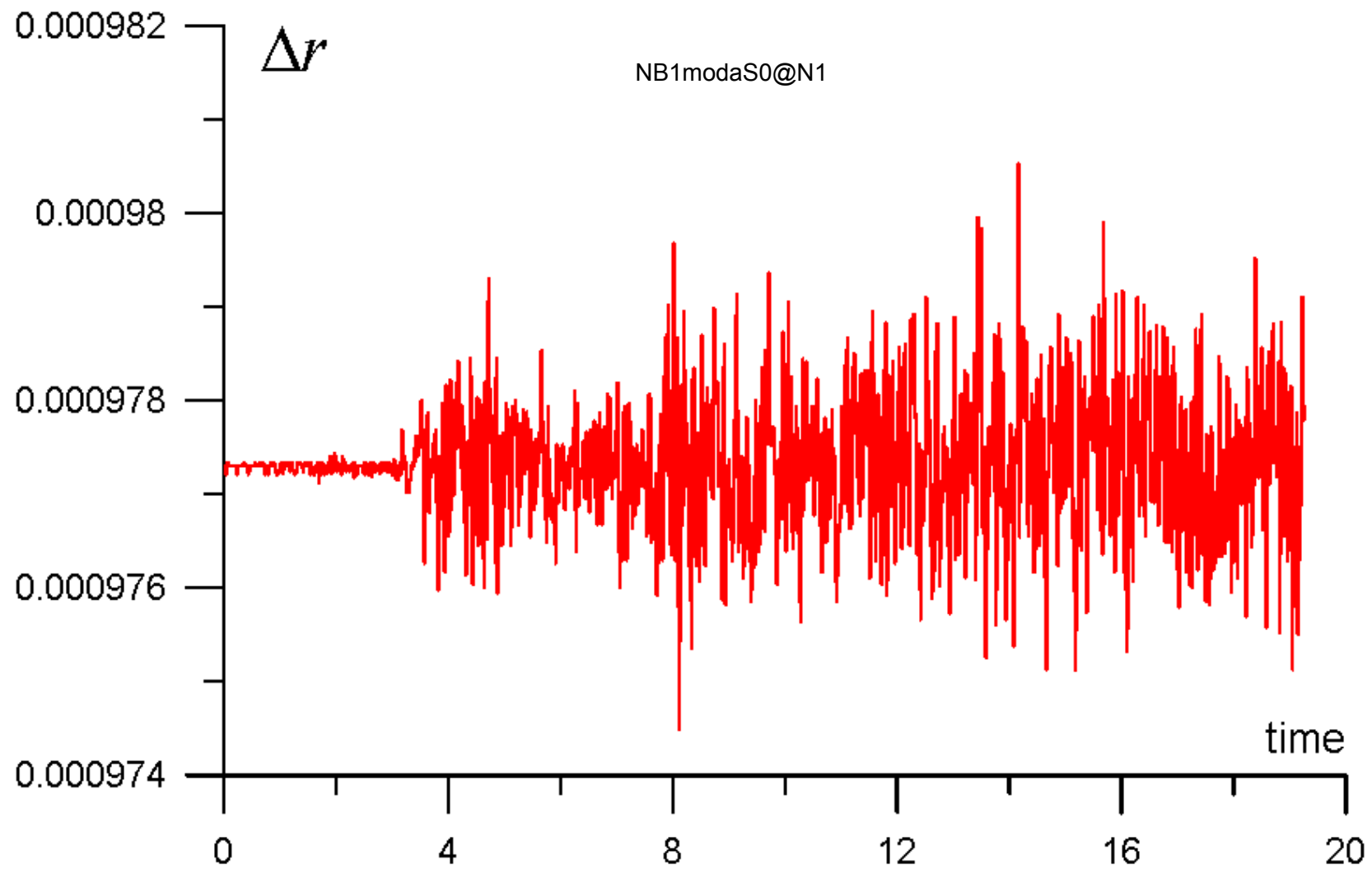
Модели



Модели



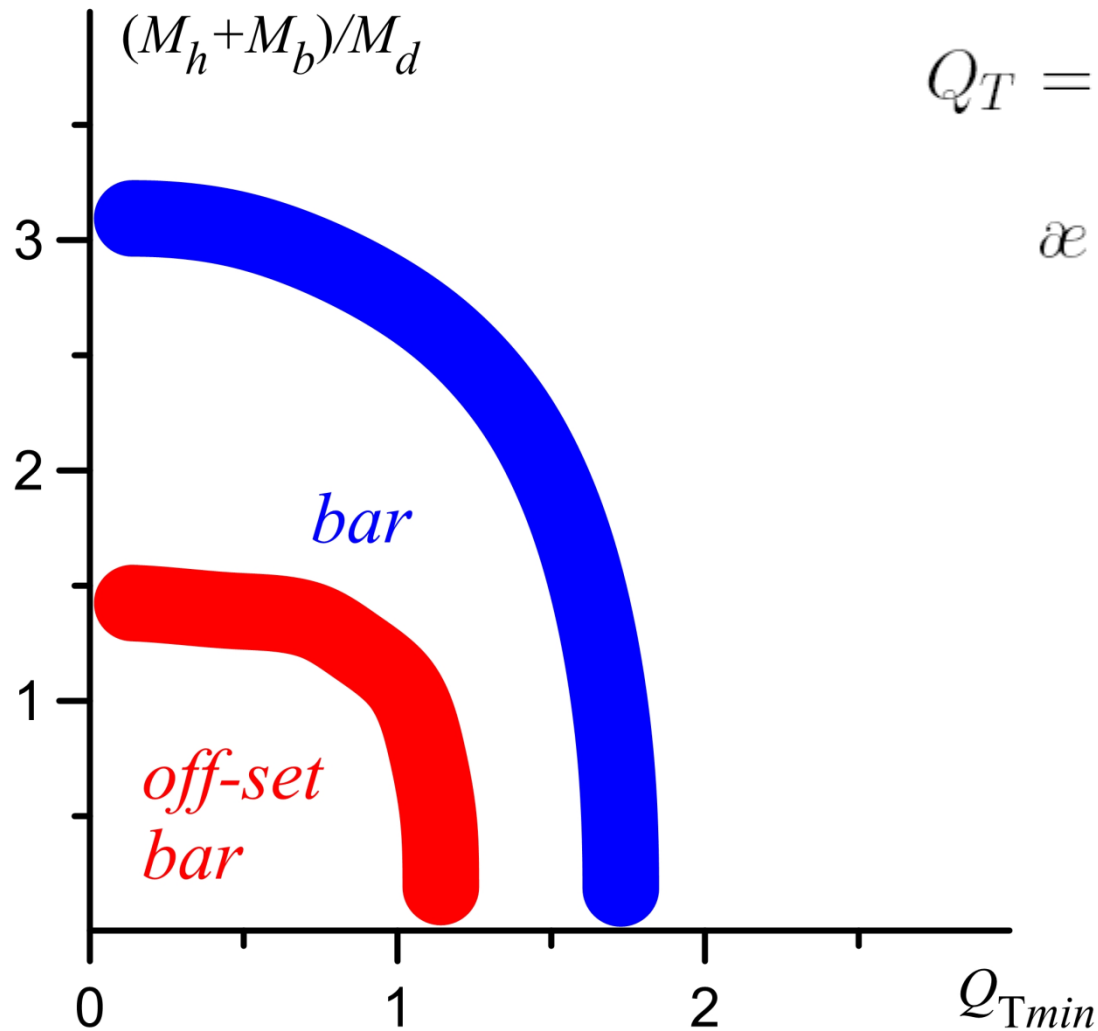
Модели



Как создать бар в численной модели N-тел ?

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

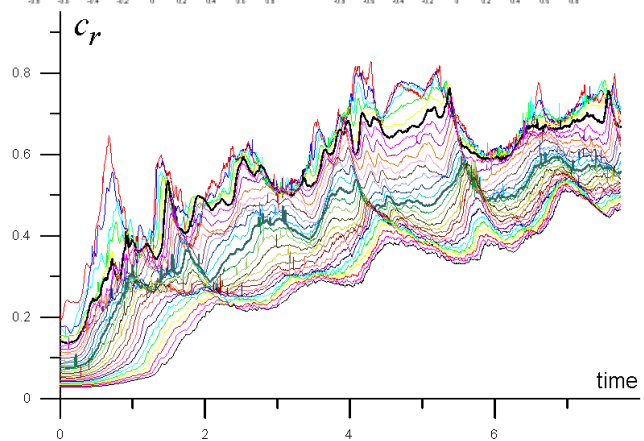
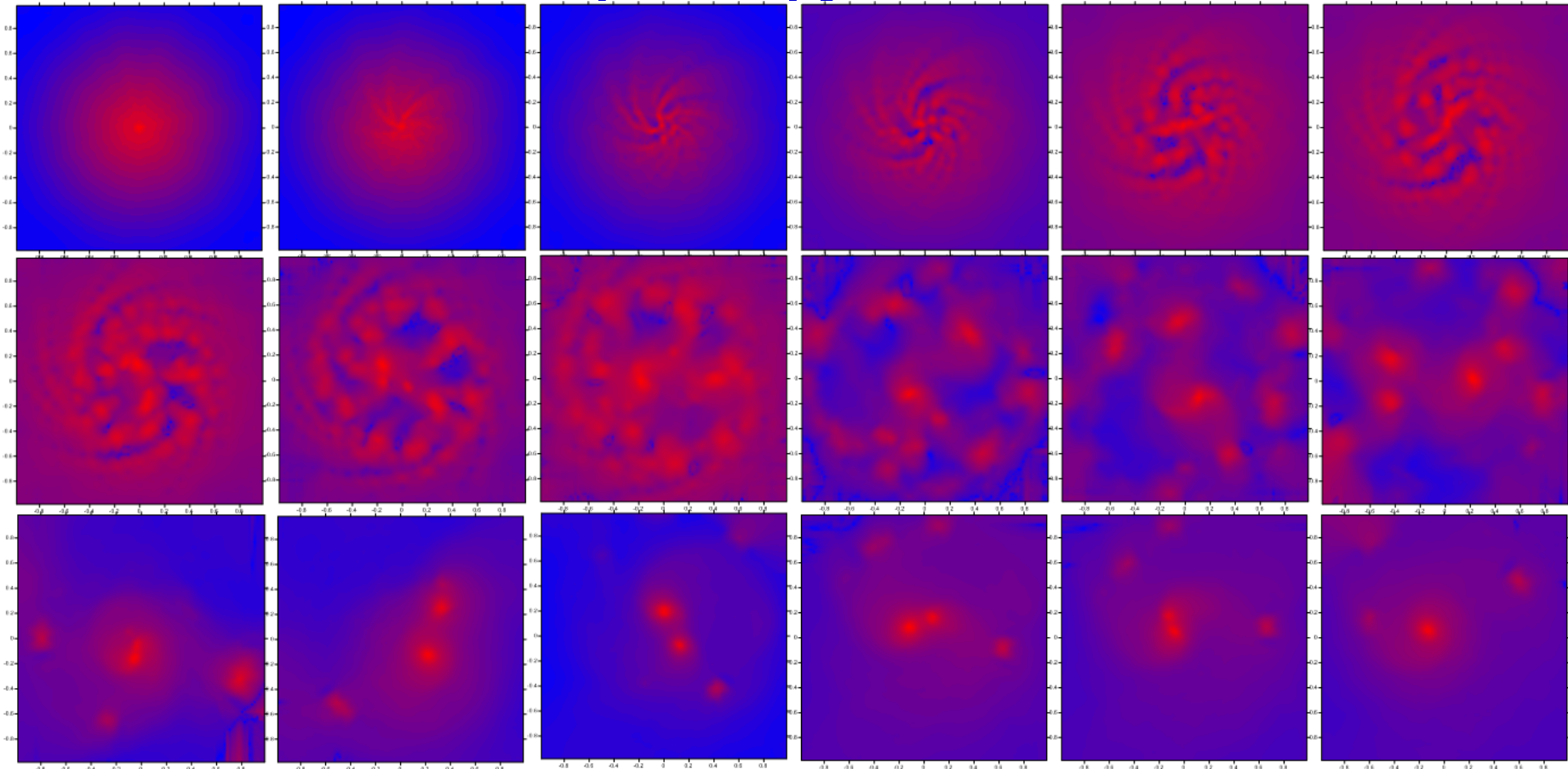
- Распределение массы в сфероидальной подсистеме (гало + балдж) + кинематика
- Распределение массы в дисковой компонента + кинематика



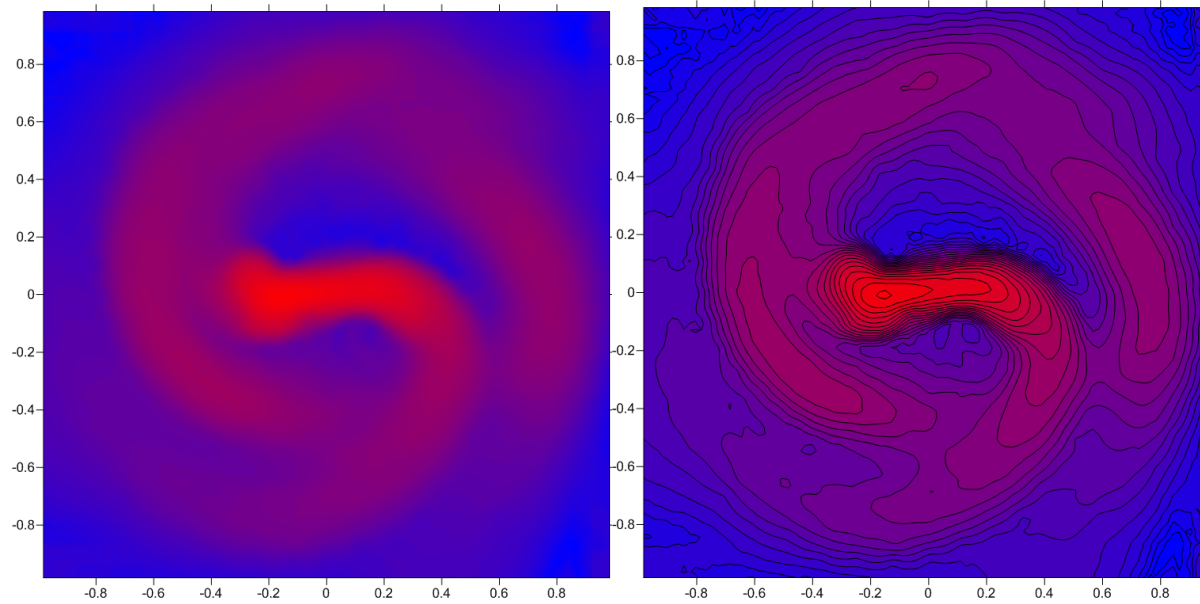
$$Q_T = \frac{c_r}{c_T} \quad c_T = \frac{3.36 G \sigma}{\alpha}$$
$$\alpha = 2\Omega \sqrt{1 + r \frac{d\Omega}{2\Omega dr}}$$

Самогравитирующий диск

NB1moda00



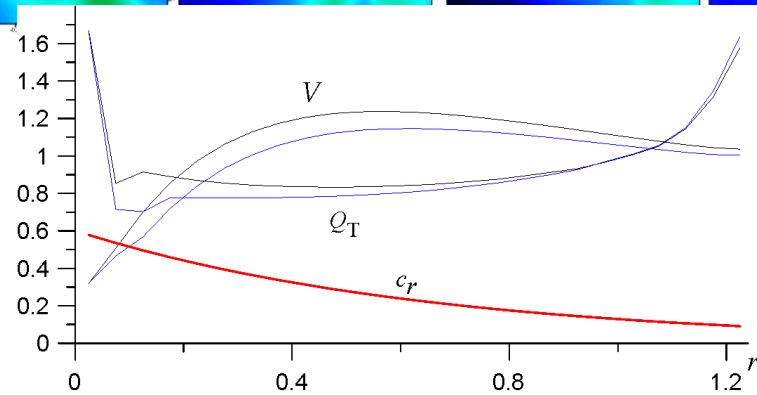
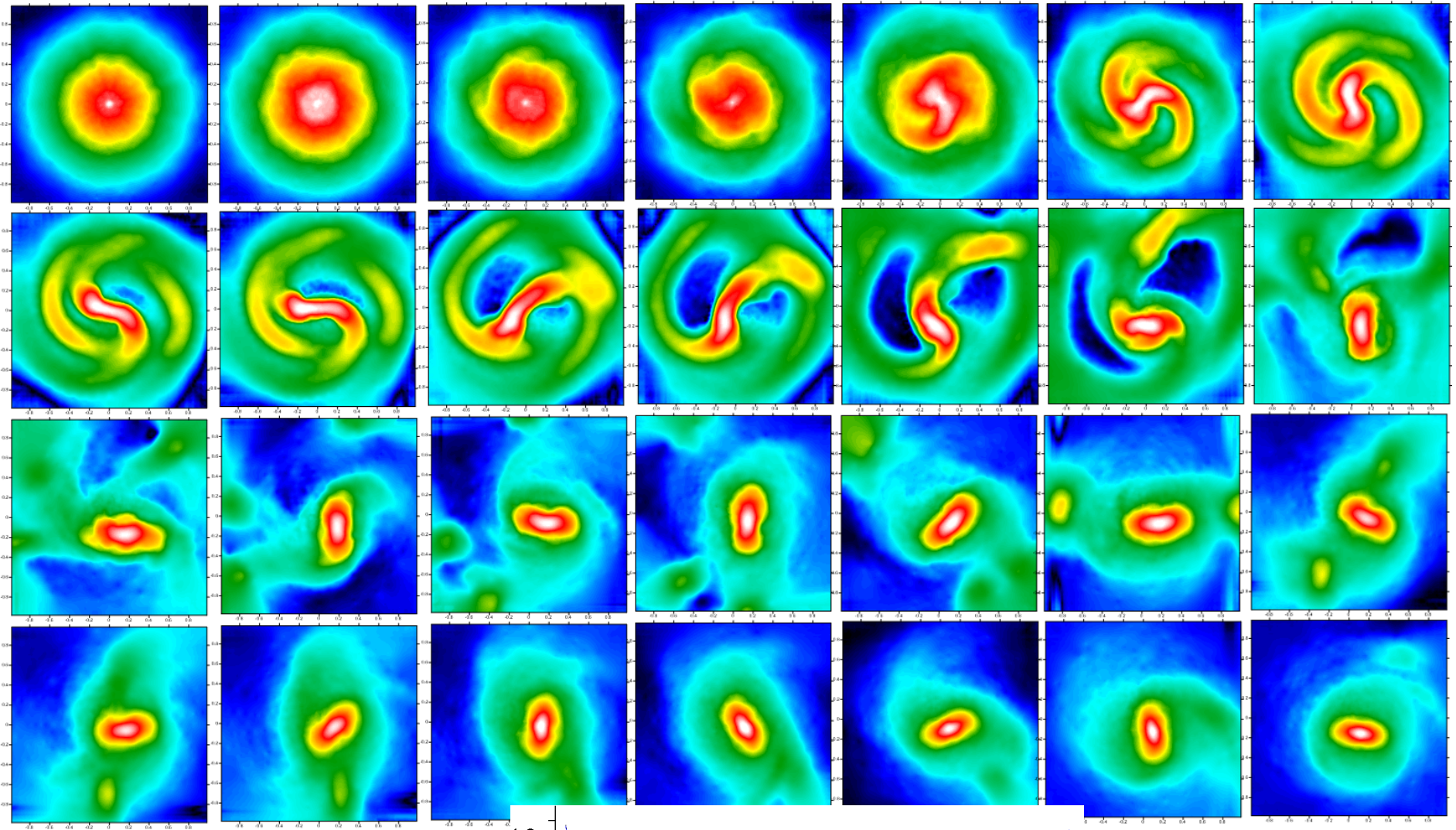
Tadpole structure formation



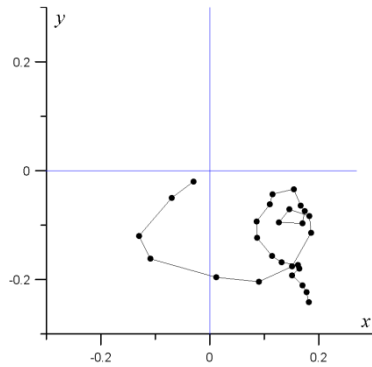
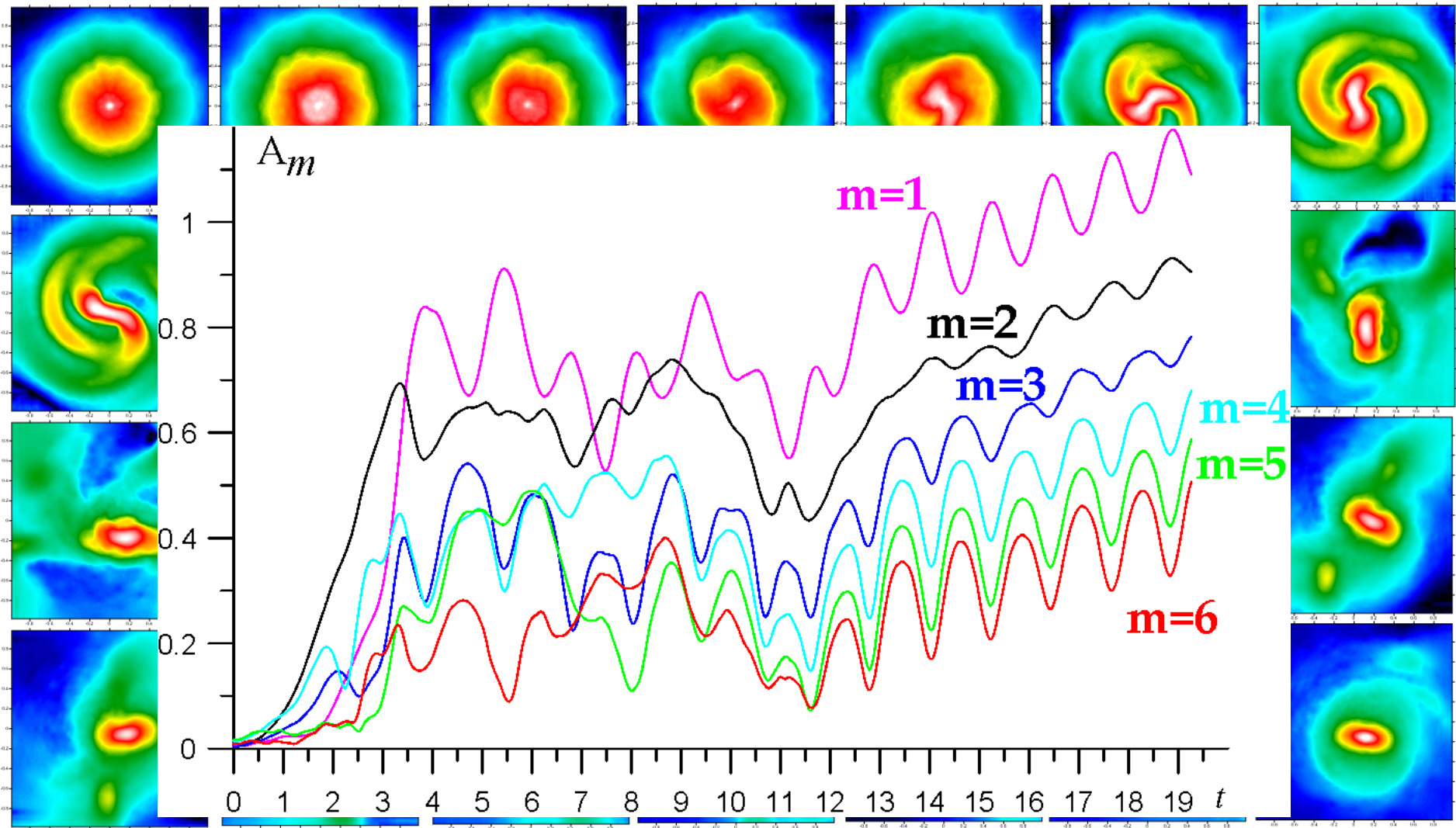
Tadpole structure

Breaking bar



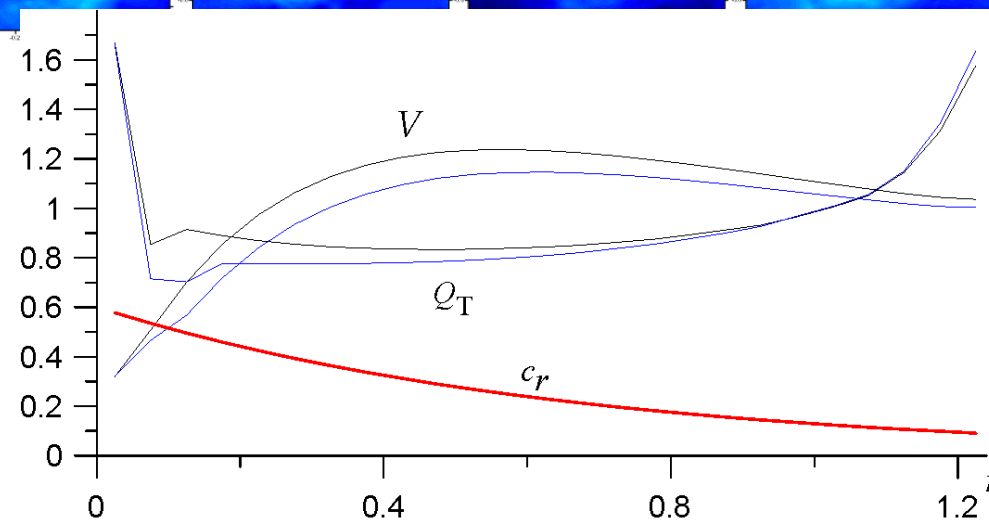
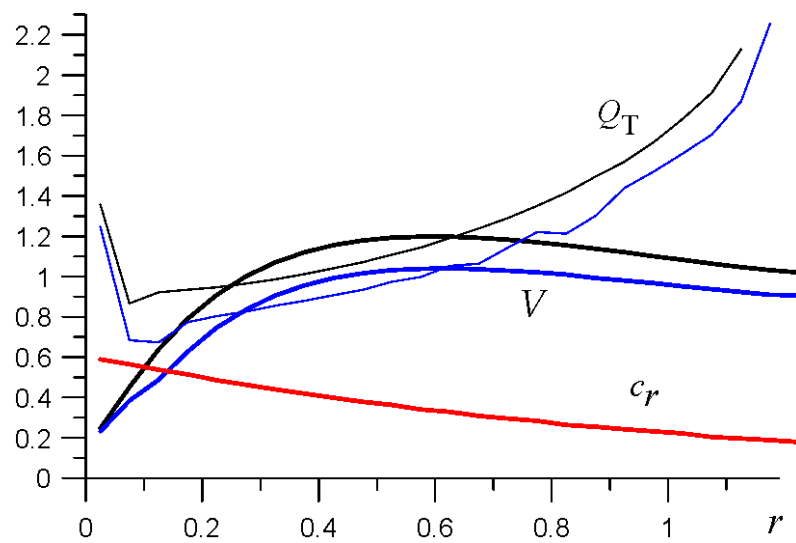
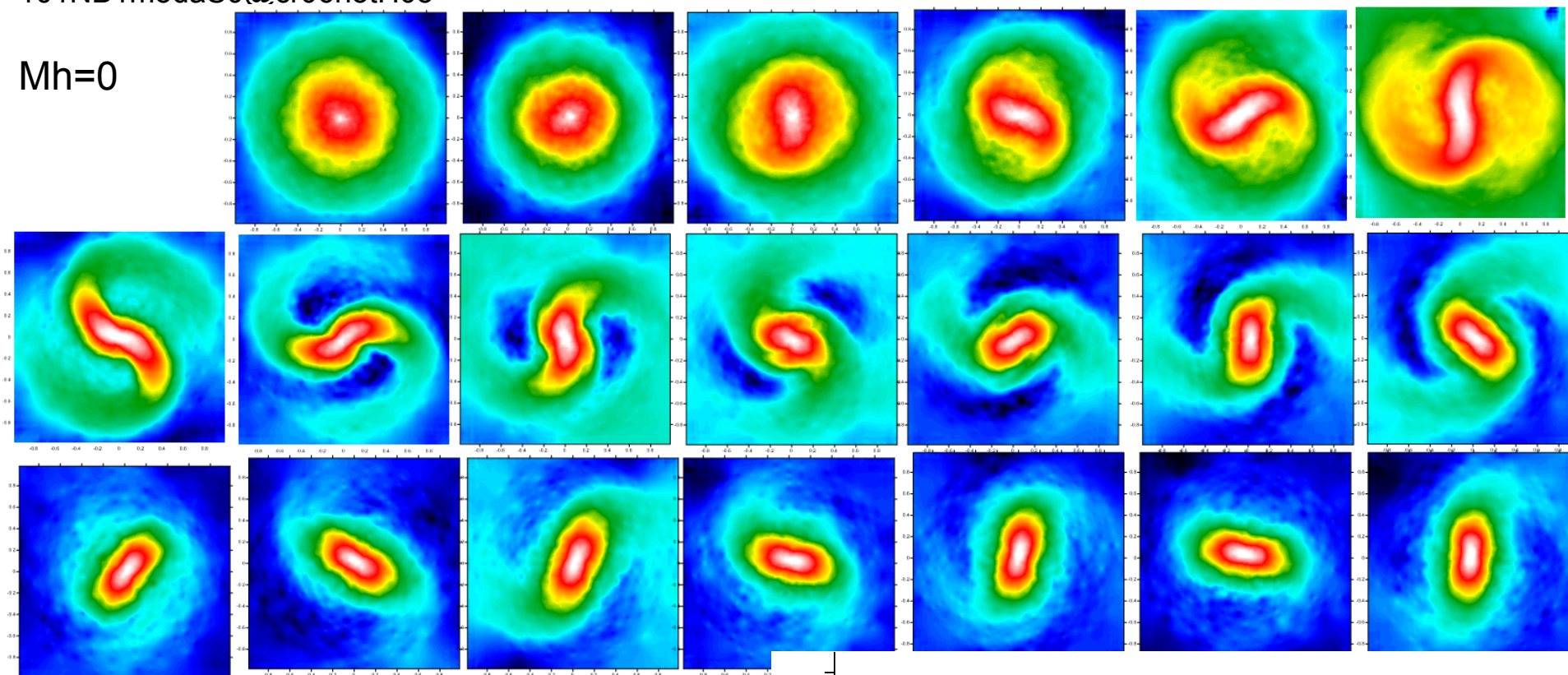


!!NB1modaS0@N1 Mh=0



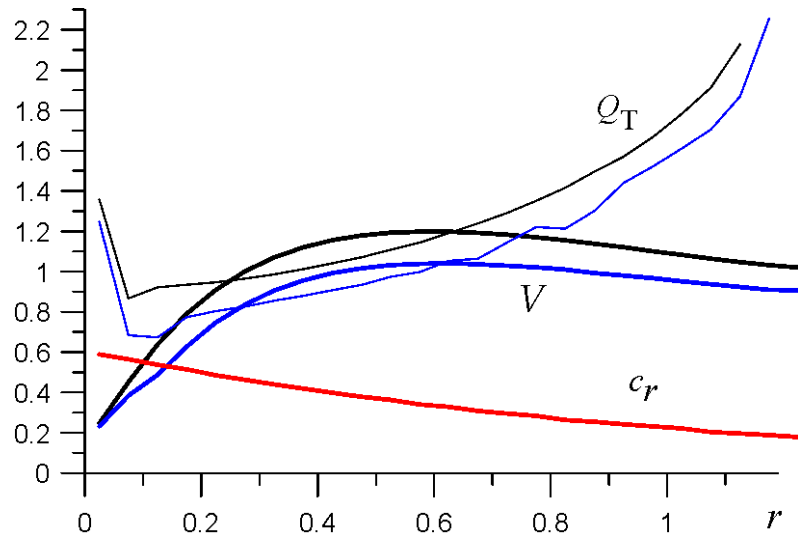
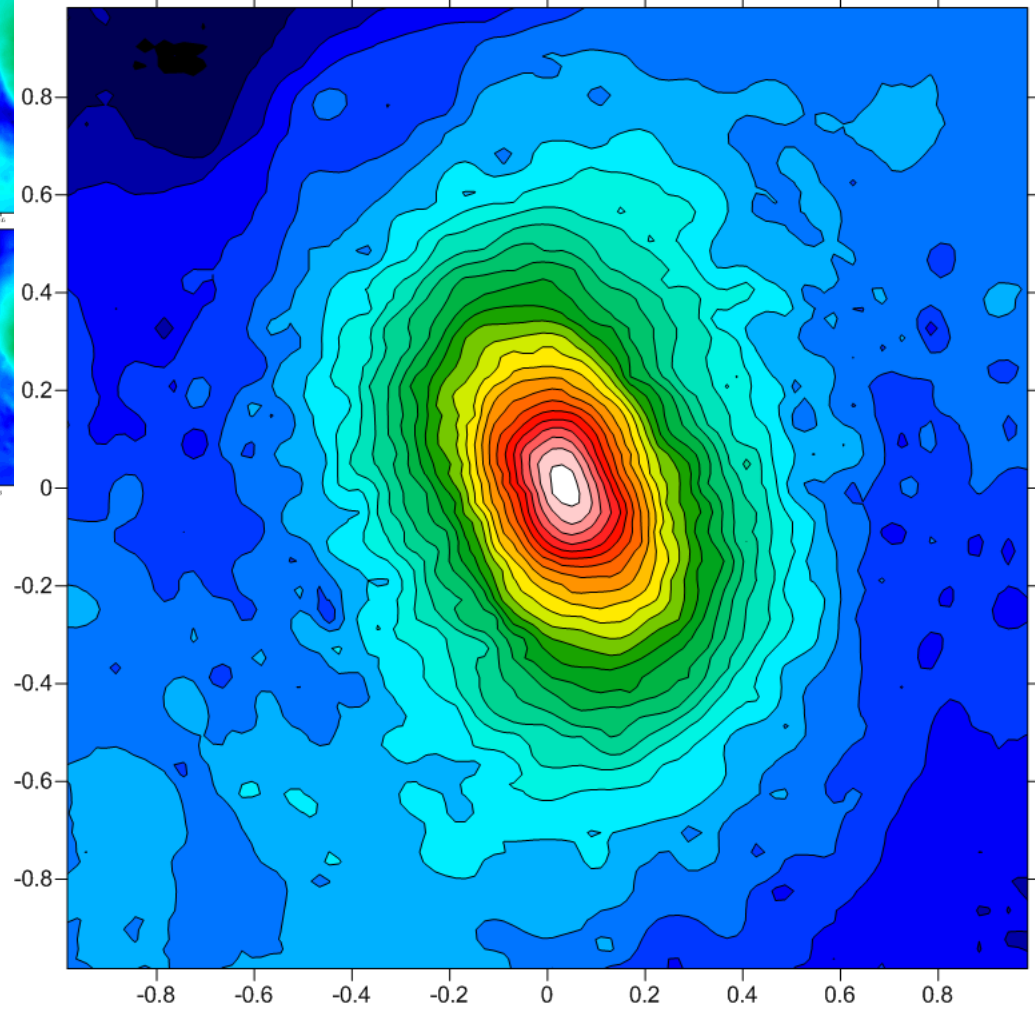
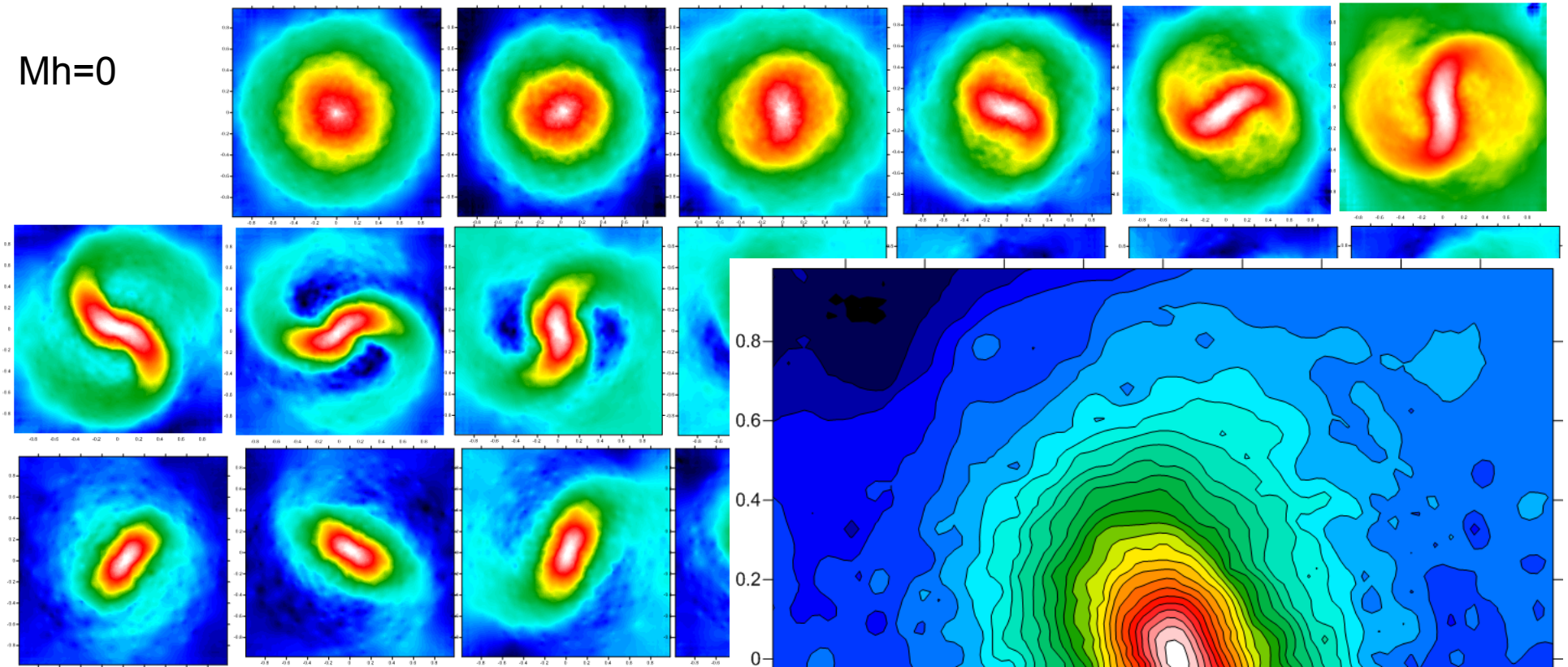
101NB1modaS0@cr06hotH05

Mh=0

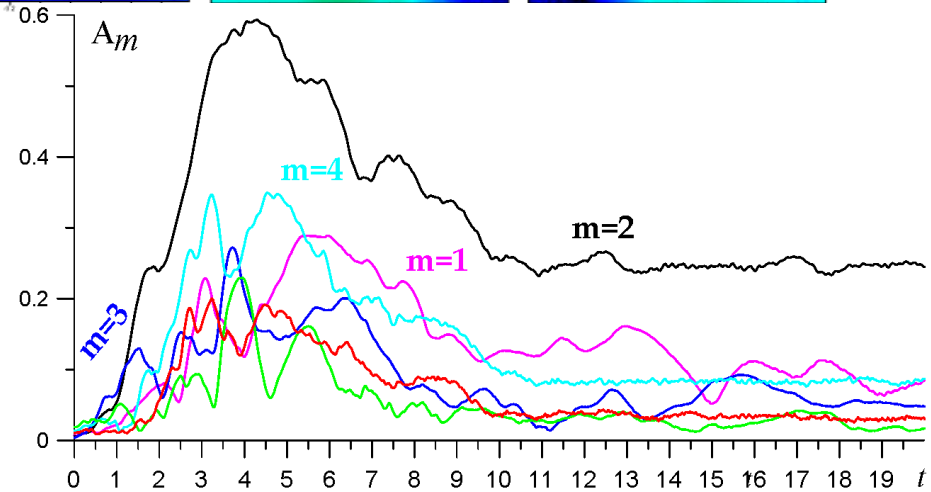
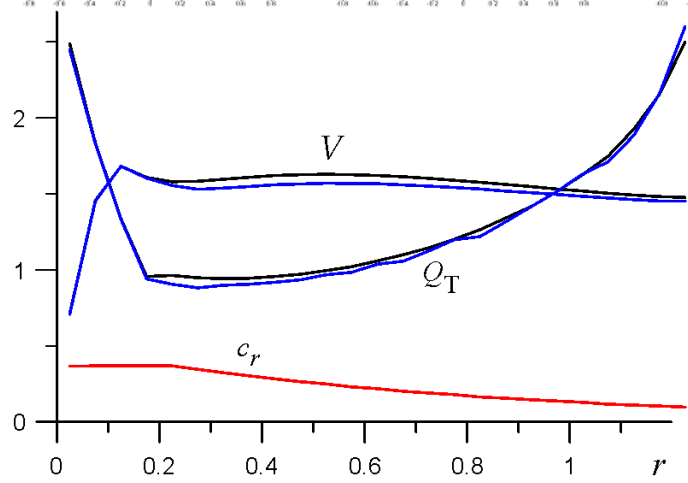
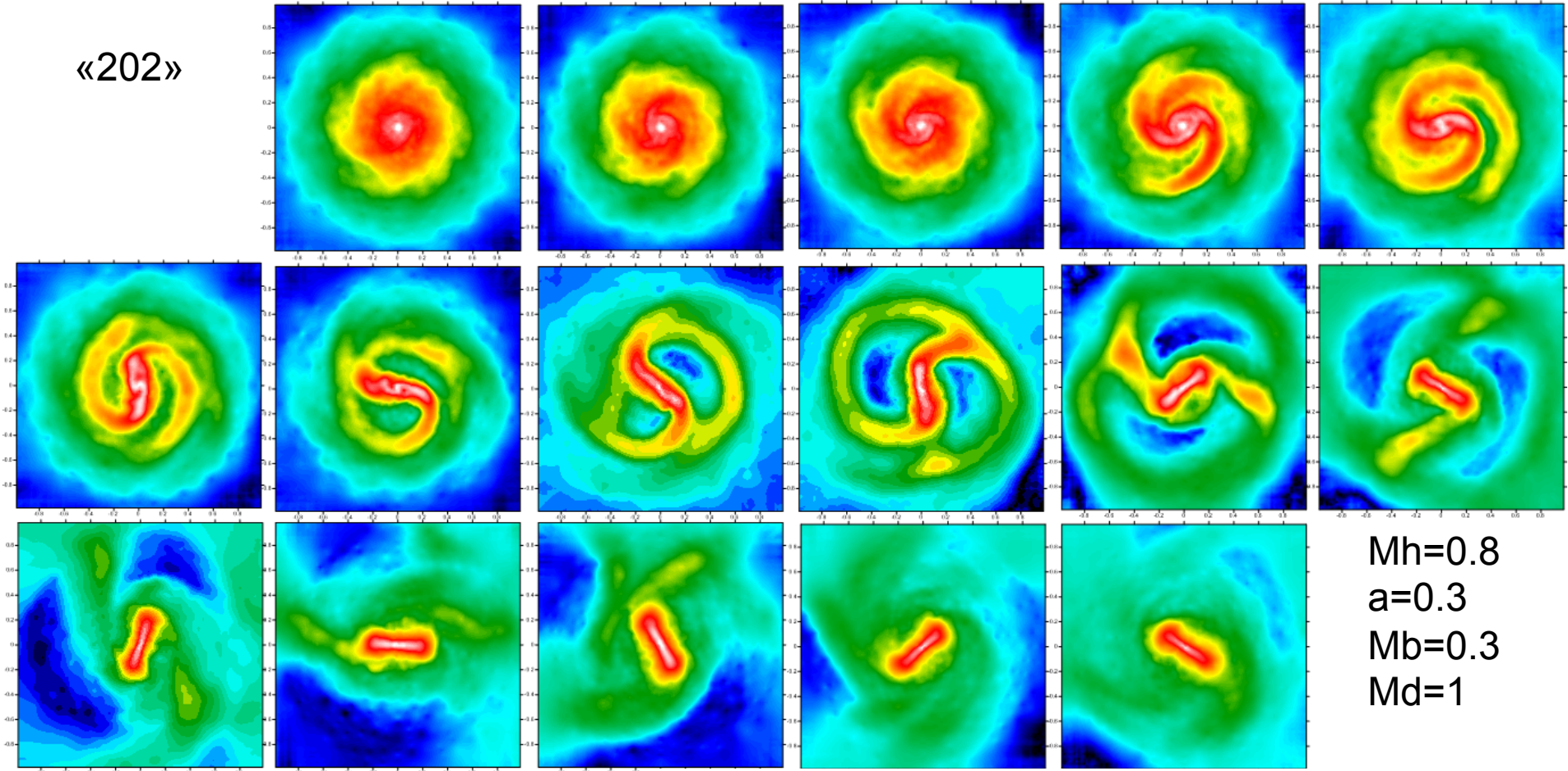


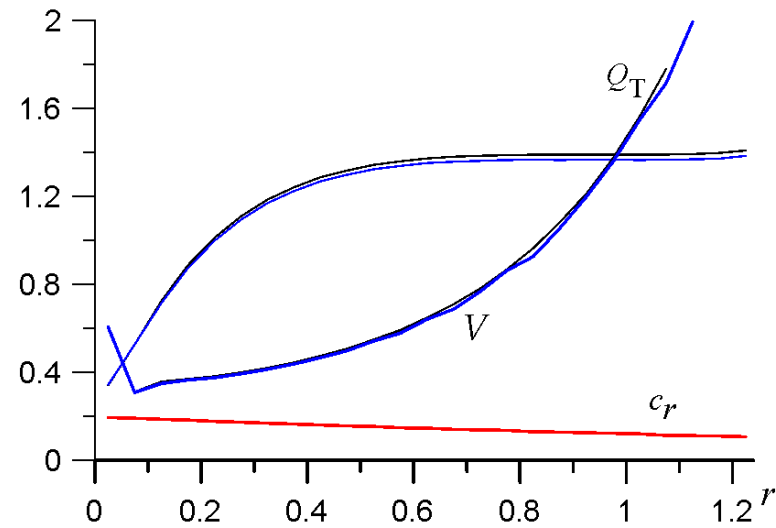
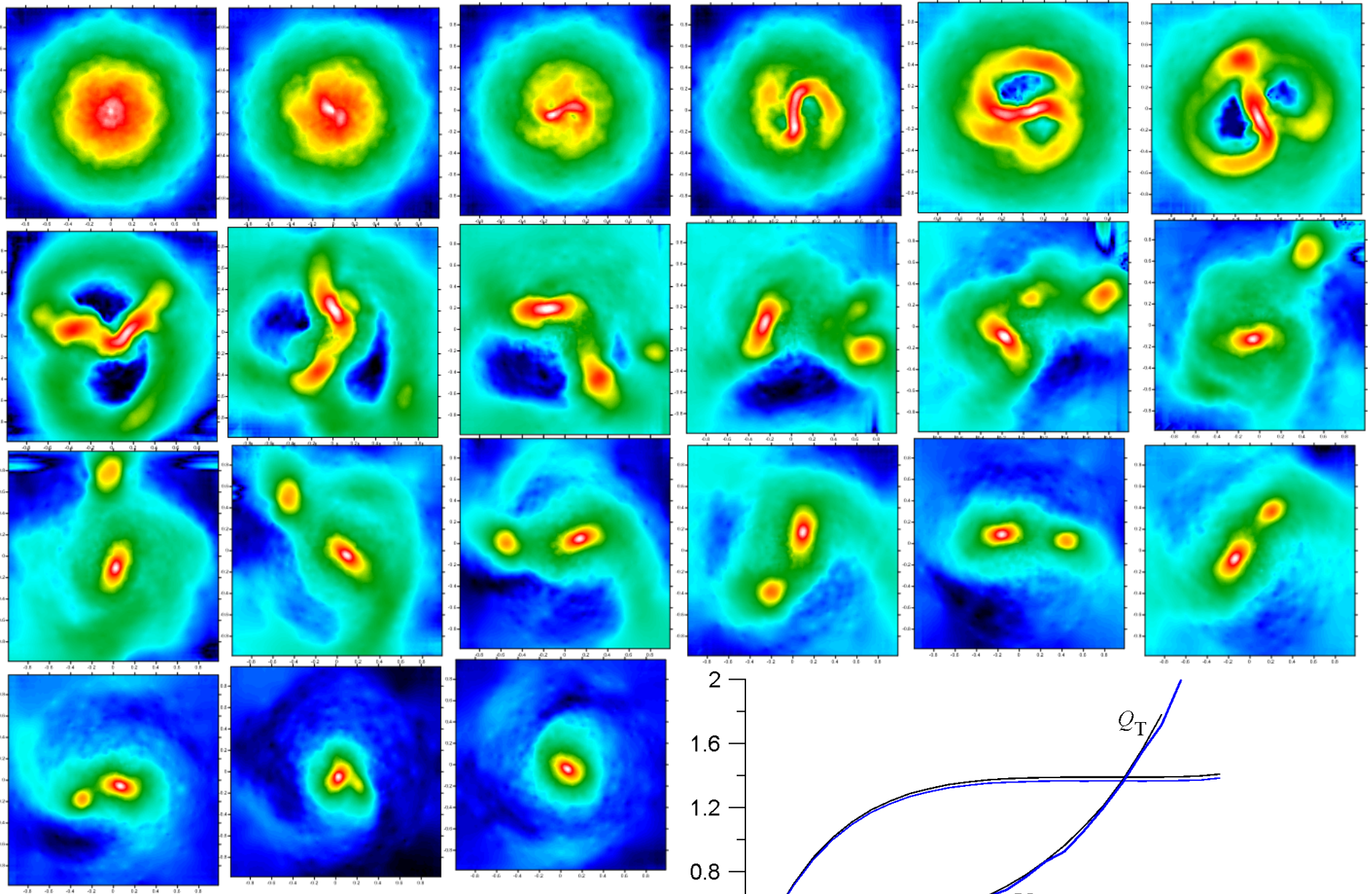
101NB1modaS0@cr06hotH05

Mh=0

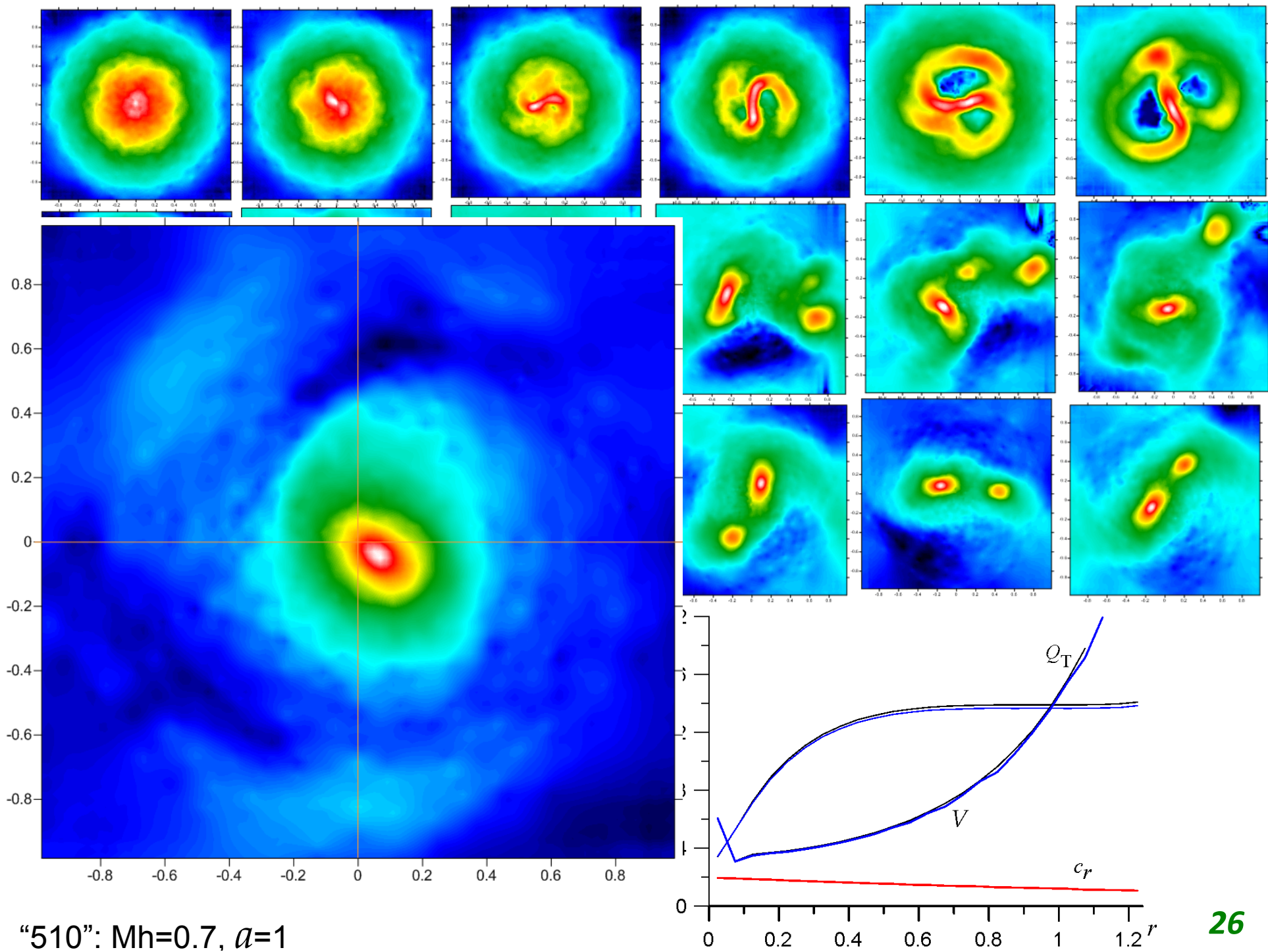


«202»

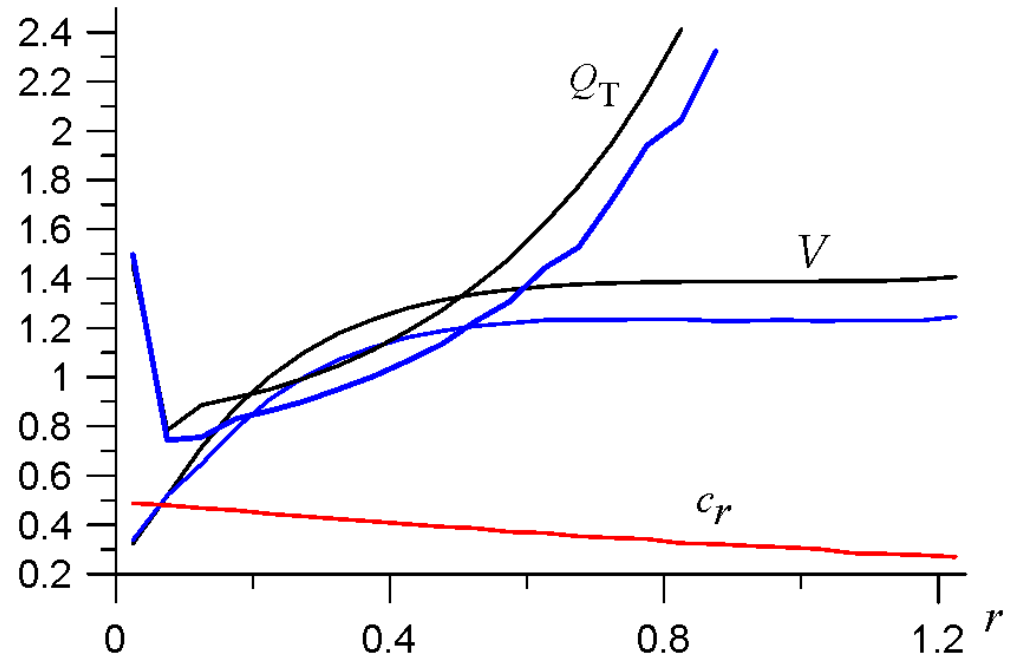
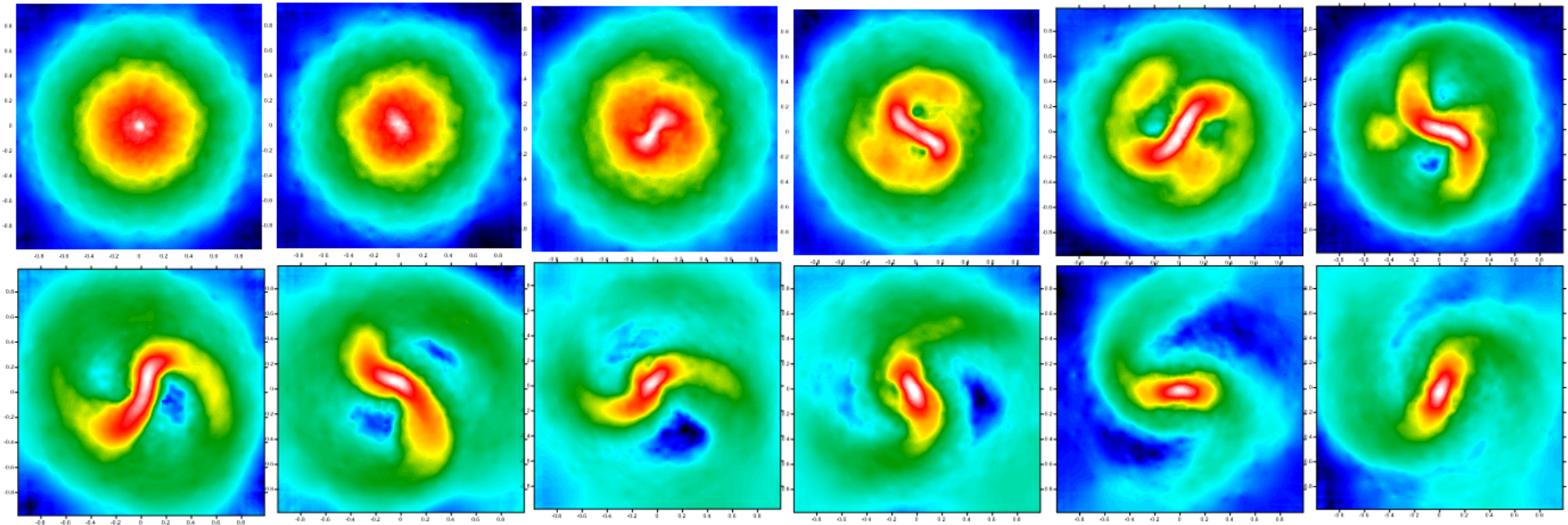




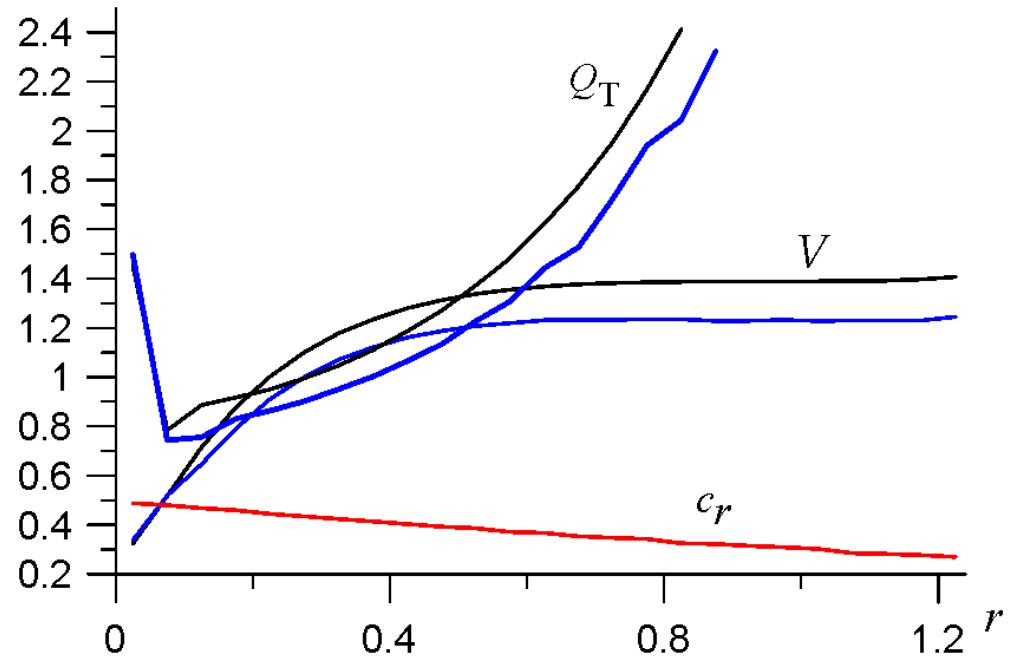
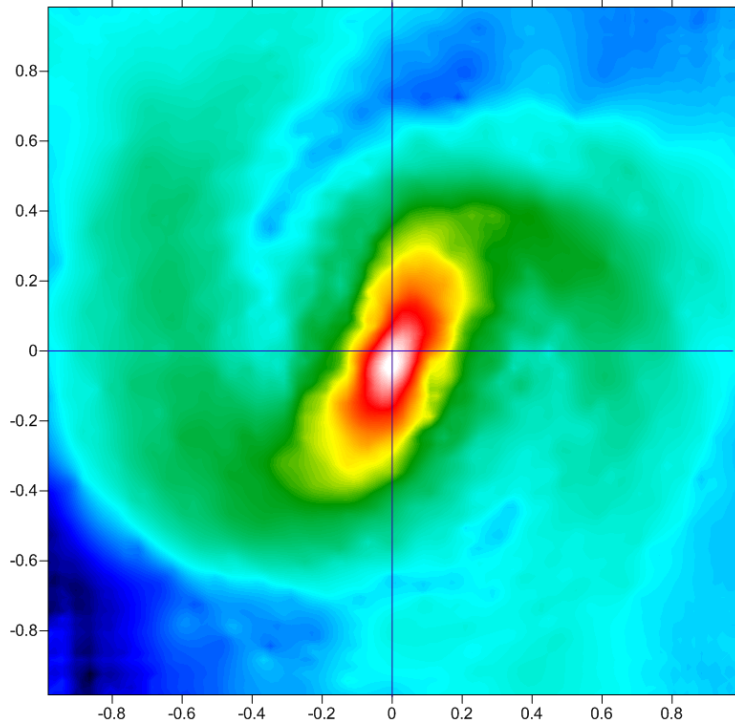
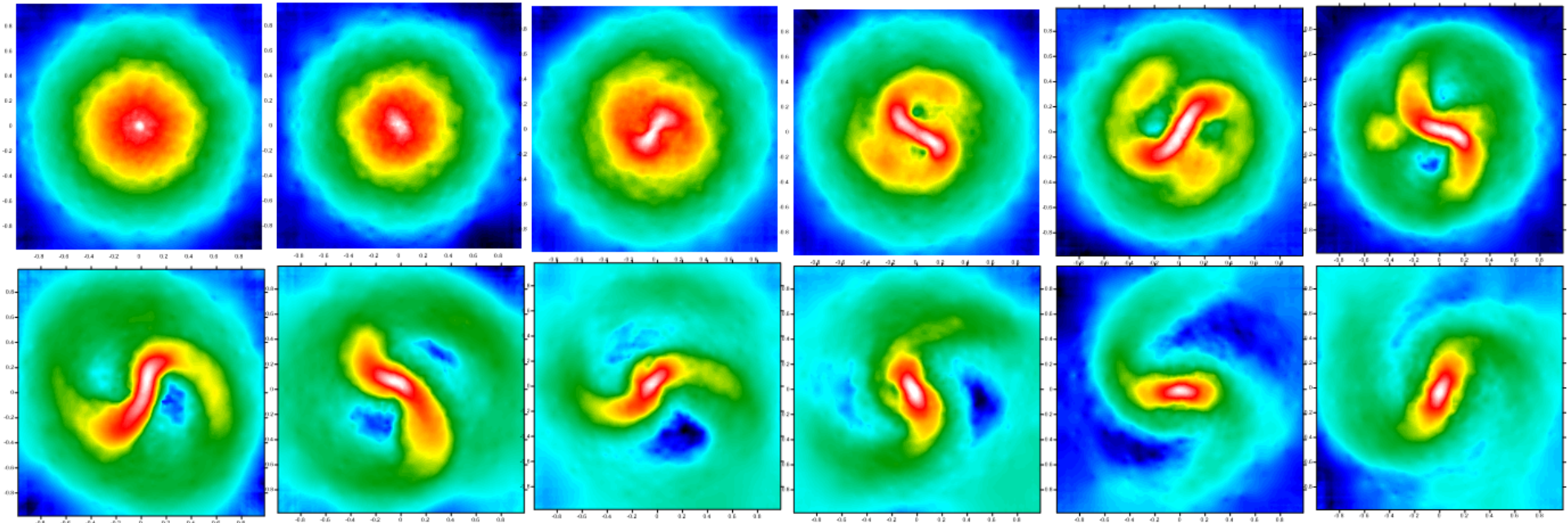
“510”: $Mh=0.7$, $a=1$



“510”: $Mh=0.7$, $a=1$



“513”: $Mh=0.7$, $a = 1$



“513”: $Mh=0.7$, $a = 1$

Заключение

Симметричная изолированная галактика

Асимметричные галактики

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

Условия для эффективного смещения бара относительно центра диска:

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

