Galaxy Rotation Curves from String Theory

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- Work in Progress with:
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  - Konstantin Savvidy, Nanjing University
  - Feng Xu

- String Theory is:
  - A theory of Everything?

    too many assumptions; everything seems possible!
  - A theory of Quantum Gravity?

    provides the needed fundamental theory for cosmology?

    yet to make contact with observation.
  - A theory good for Nothing?

    spectacular success in mathematics over the past decade.

    no experimental support whatsoever...

Pauli would have said, "It is not even WRONG!"

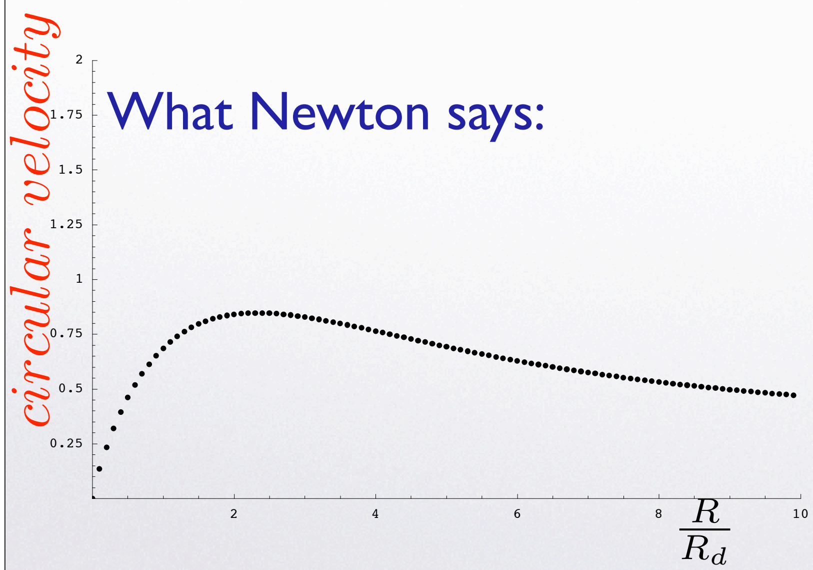
Breaking the "symmetry" between right and wrong...

Getting in touch with data is very rewarding by itself!

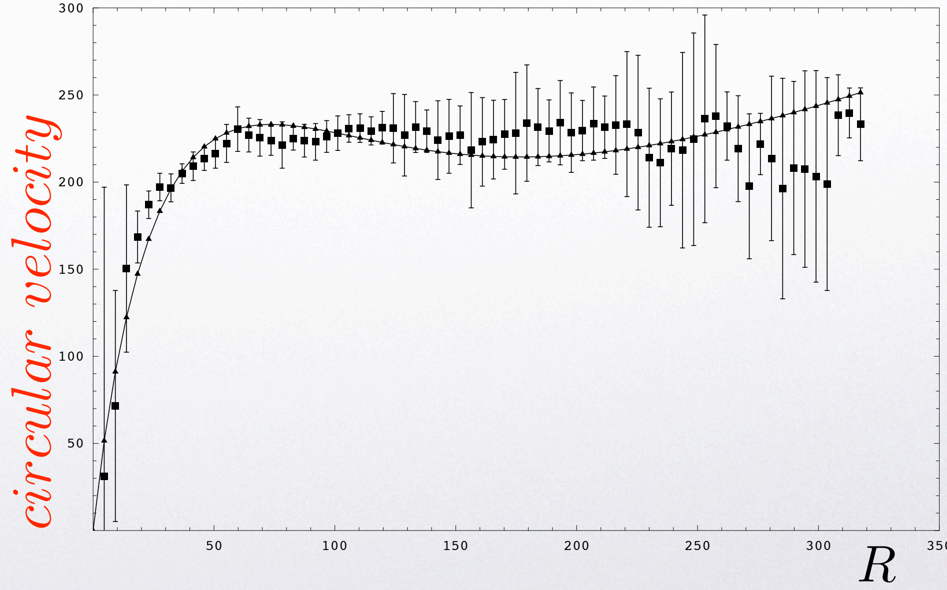
The Missing Mass Problem:

Young and bright stars in a spiral galaxy lie on a thin stellar disk.
They execute circular orbits around the center of the galaxy.

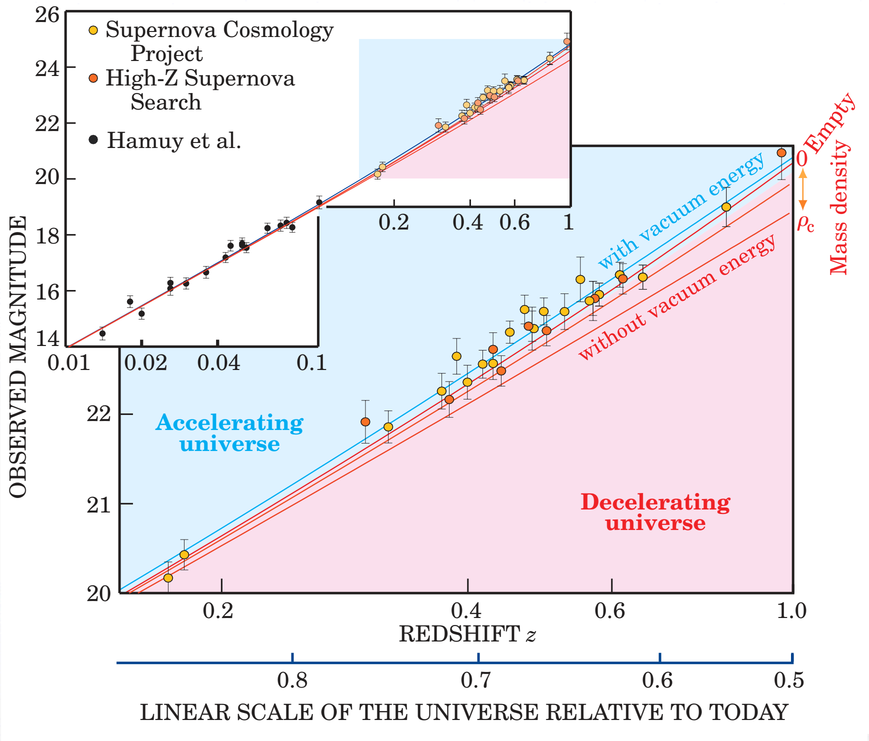
What Newton says:



What Nature does:



Dark Energy:



DM & DE are the two main roadblocks on our path to a comprehensive fundamental theory of Nature.

- Dark Matter:
  - baryonic or non-baryonic;
  - well-founded or exotic;
- MOND: modification of Newtonian dynamics at large scale;
- existent fields/long range force from String Theory; exploit their low energy implications.

point particle and gauge field:

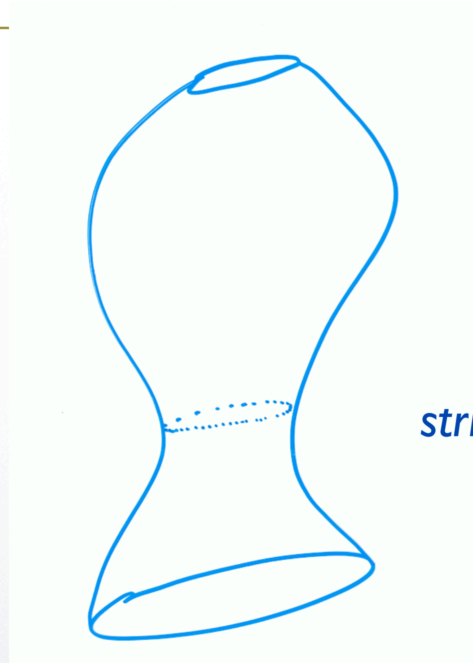
$\int A \cdot dX \qquad F = dA$

string and its gauge potential:

$\int B \cdot dS \qquad H = dB$

particle worldline

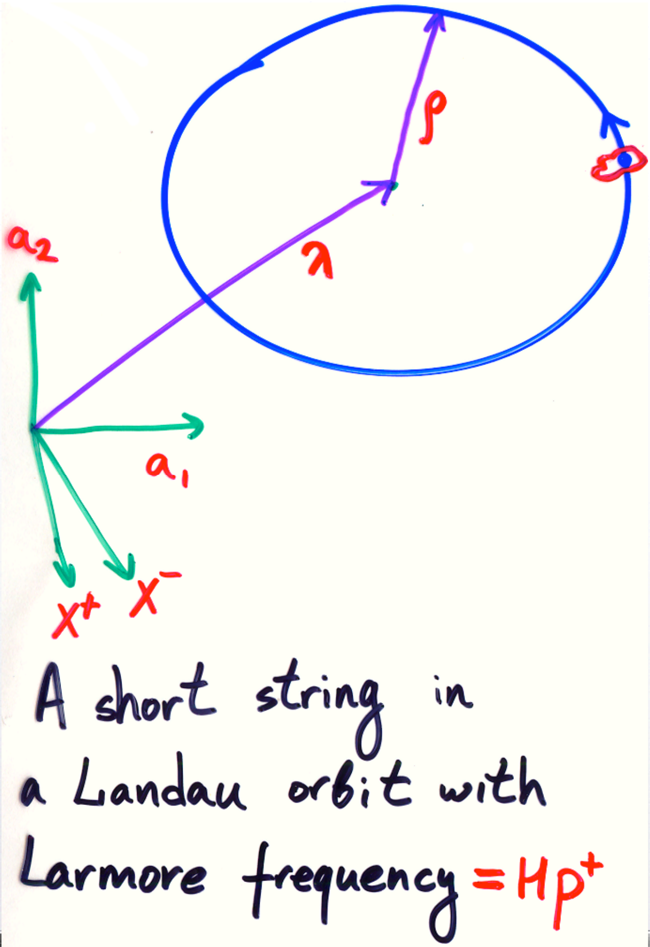
TIME



string worldsheet

If strings are indeed fundamental objects, then $B_{\mu\nu}$ will play a role as fundamental as A_μ does.

- plane-polarized gravitational fields:



centre of mass of the closed string follows the geodesic:

$$\begin{aligned} u &= u_0 + Hp^+\tau \\ a &= -\lambda + \rho\, e^{+iHp^+\tau} \\ \bar{a} &= -\bar{\lambda} + \bar{\rho}\, e^{-iHp^+\tau} \end{aligned}$$

⟹ "gravi-magnetic field"

In a leap of faith...

- If matter is indeed made of strings, they will *all* be charged under this "gravi-magnetic" field.
- In the presence of such background field, galaxies will execute Landau orbits.
- provides the extra centripetal force, which would otherwise be attributed to extra mass:

$$m\frac{v^2}{r} = QH_z v + \frac{G_N M m}{r^2}$$

extra mass ⟹ Dark Matter

Parametric Modeling of the Mass Distribution

- Van Der Kruit & Searle's Formula:

$$\rho(r,z) = \rho_0\, exp(-\frac{r}{R_d})sech^2(\frac{6z}{R_d})$$

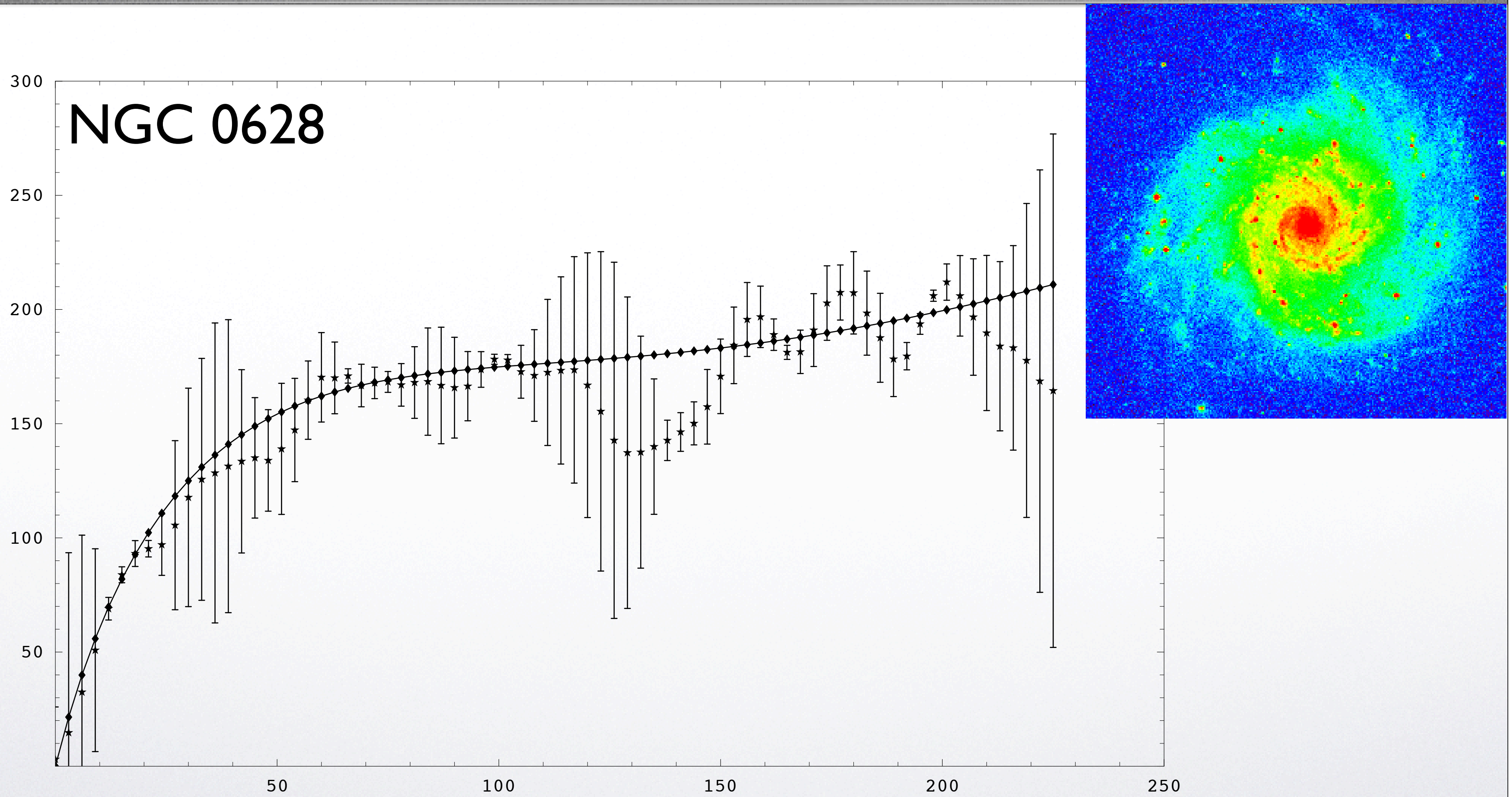
for the *visible* stellar disk and spheroid.

- introduce three parameters: Ω, ρ, and R_d.

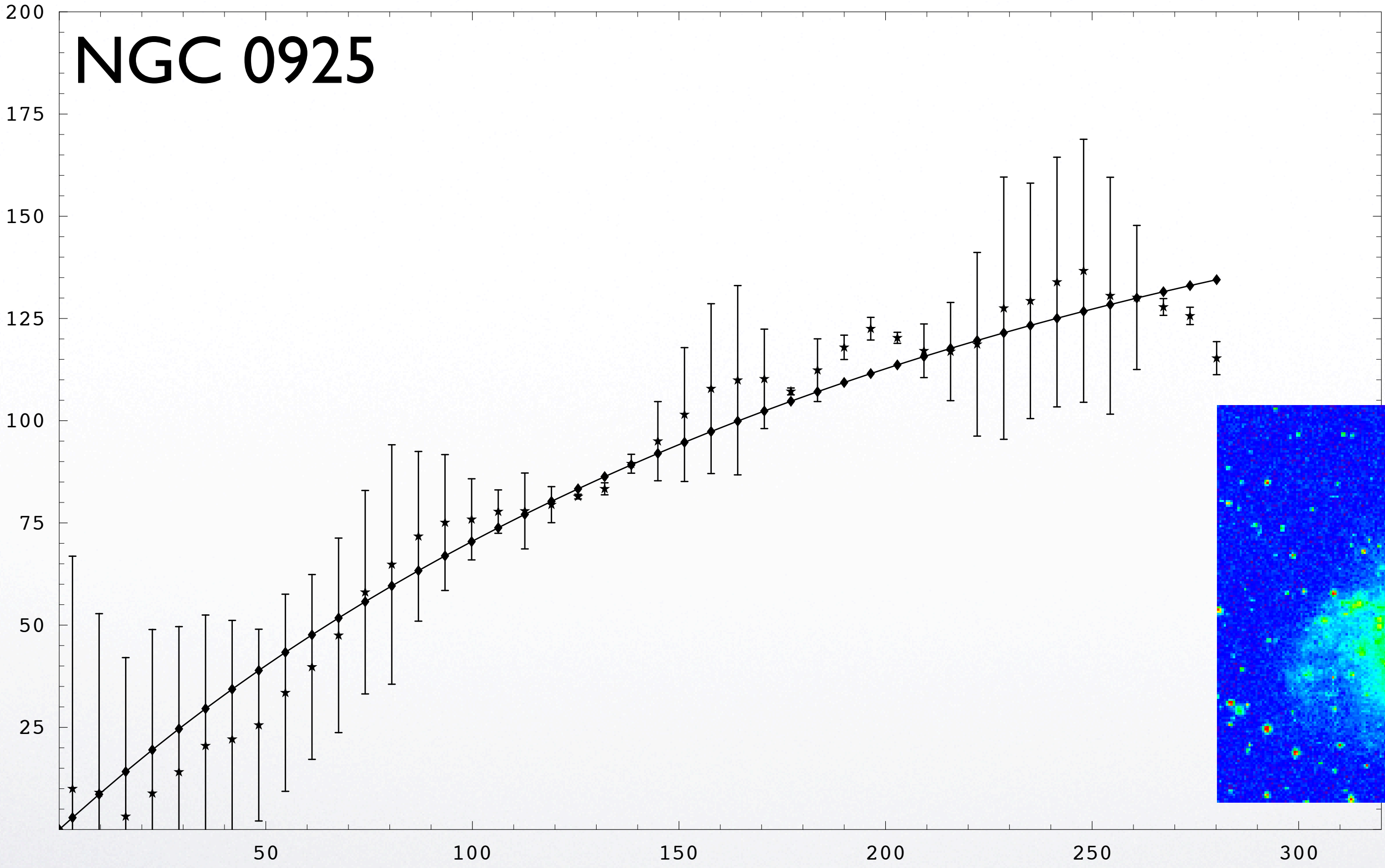
$$v^2 = R_{obs}\,\Omega\, v + R_{obs}\,\rho\tilde{E}(\tilde{r})$$

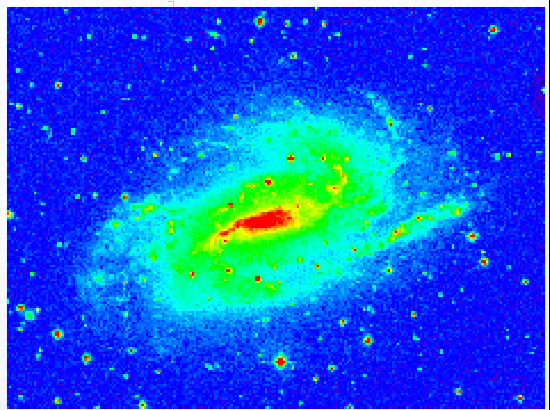
where $\tilde{E}(\tilde{r})$ is dimensionless.

- data: http://www.astro.umontreal.ca/fantomm/sings/index.htm

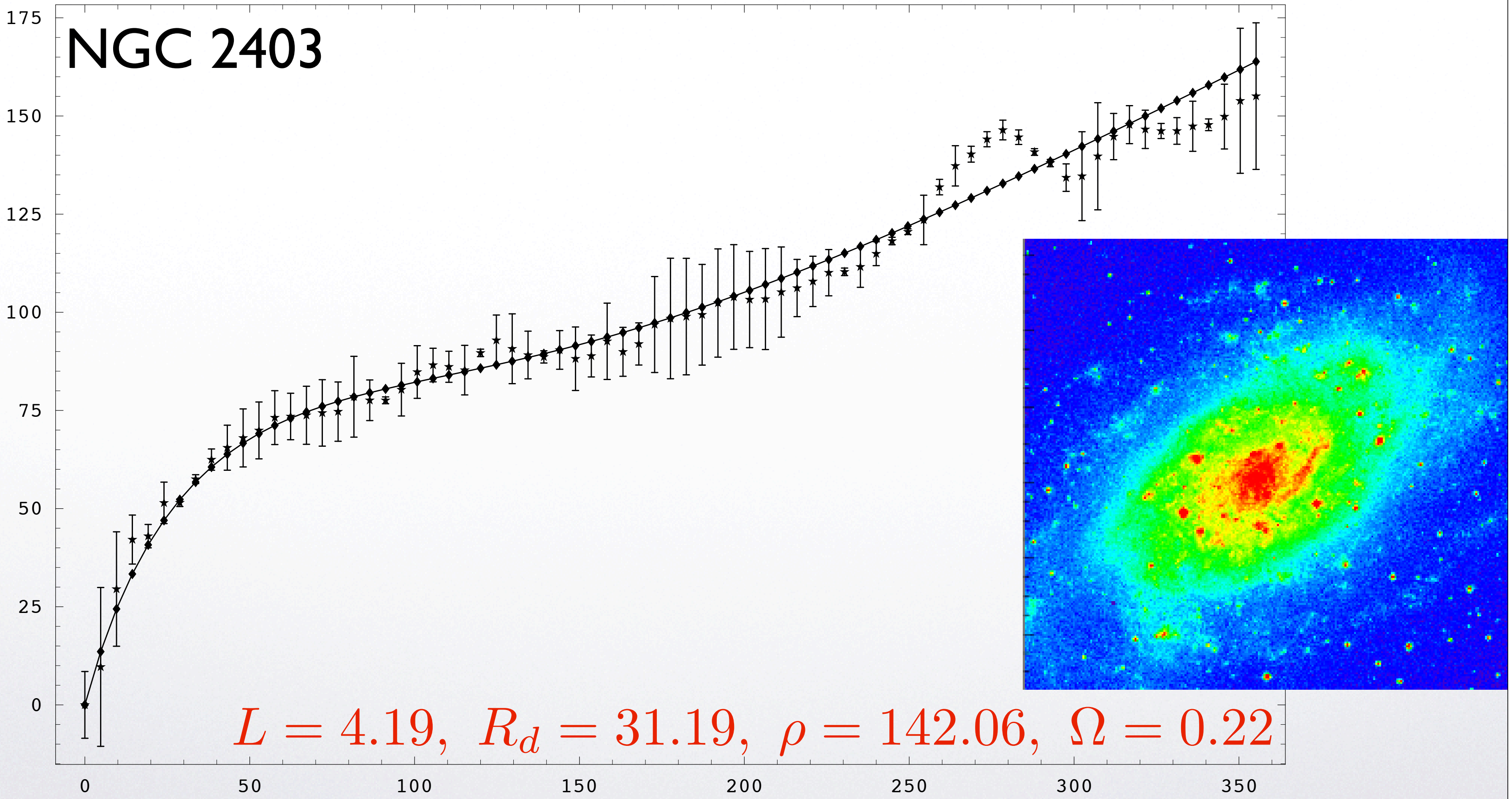


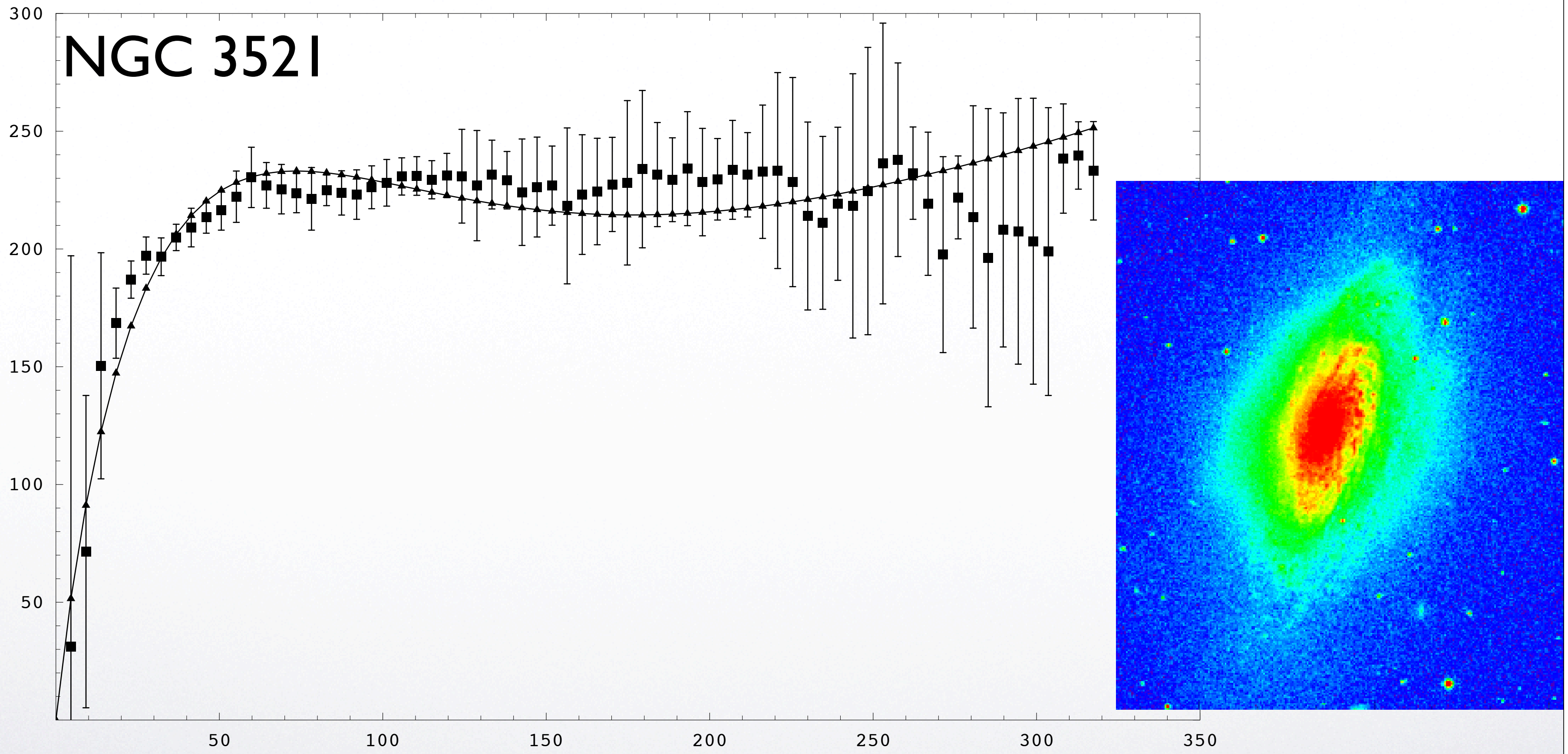
$$L = 1.29,\ \ R_d = 29.67,\ \ \rho = 847.01,\ \ \Omega = 0.39$$



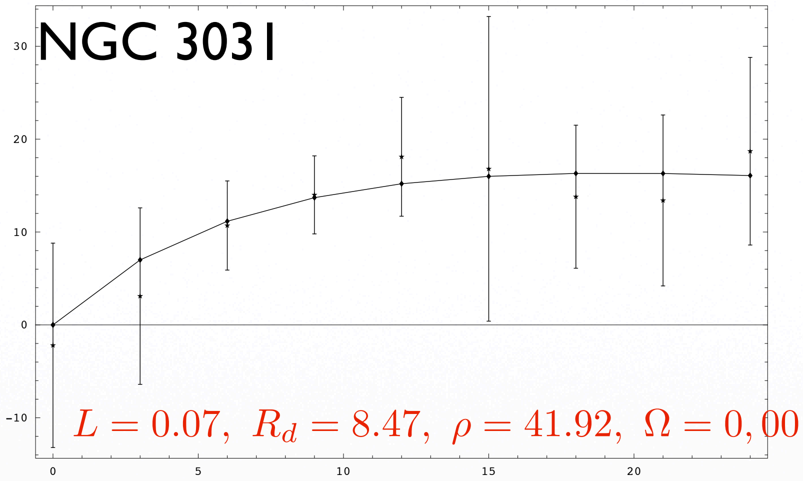


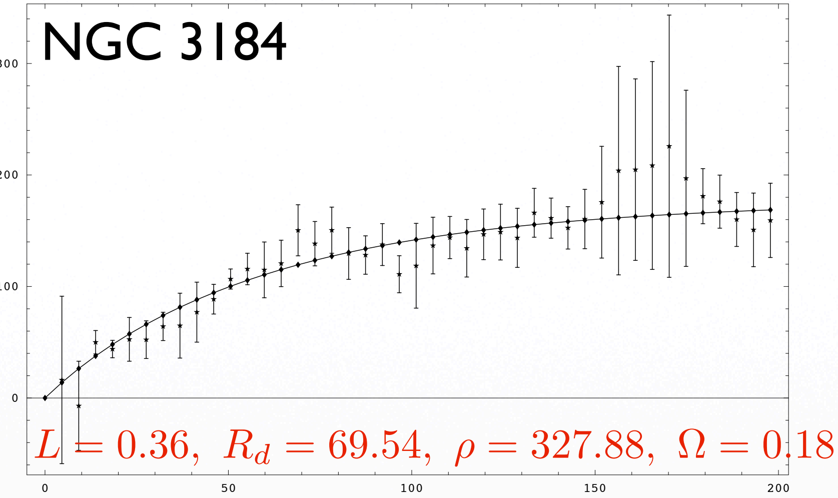
$$L = 2.52,\ \ R_d = 285.68,\ \ \rho = 128.63,\ \ \Omega = 0,00$$

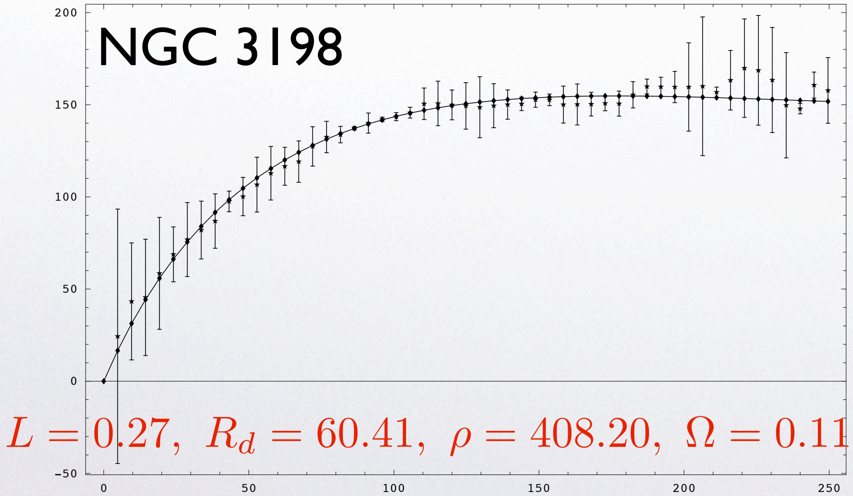

NGC 2403
$L = 4.19,\ R_d = 31.19,\ \rho = 142.06,\ \Omega = 0.22$
175
150
125
100
75
50
25
0
0
50
100
150
200
250
300
350

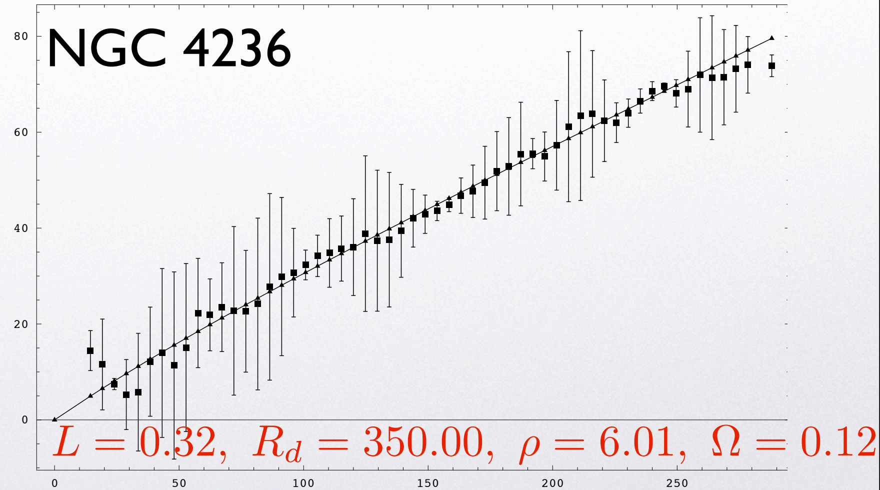


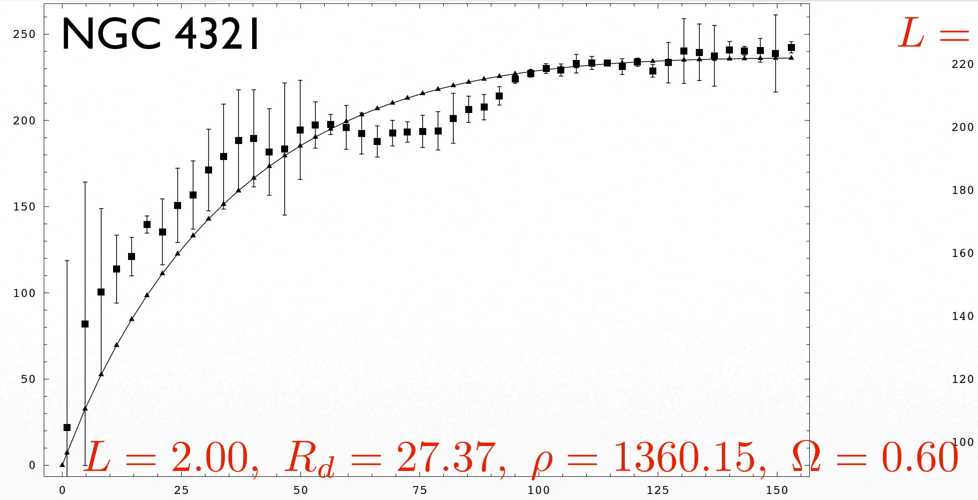
$$L = 0.51, \;\; R_d = 26.67, \;\; \rho = 2197.00, \;\; \Omega = 0.33$$

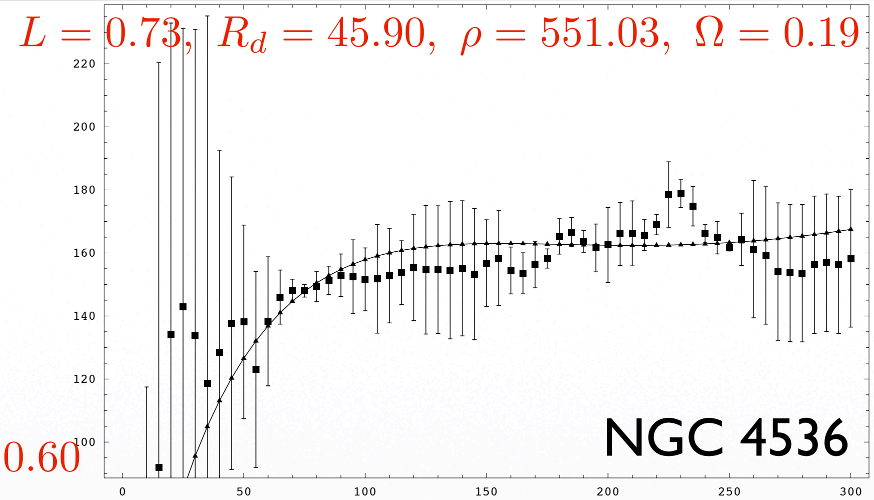

NGC 3031
$L = 0.07, \ R_d = 8.47, \ \rho = 41.92, \ \Omega = 0,00$

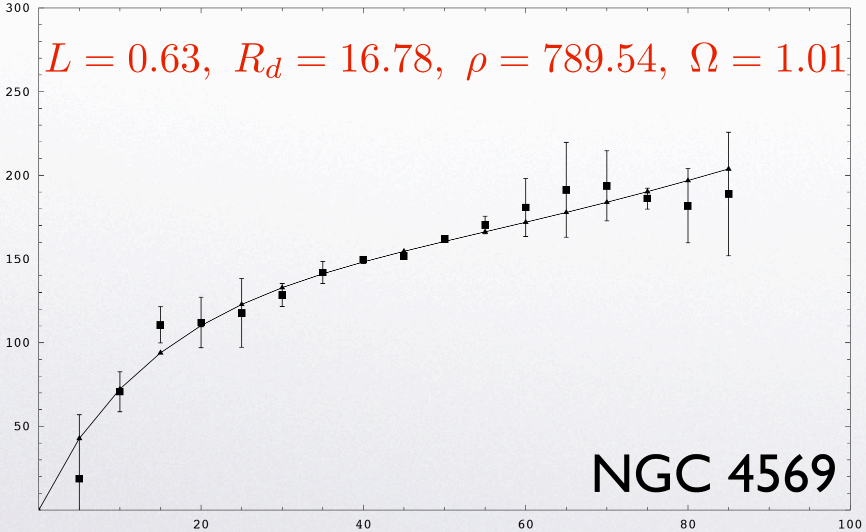

NGC 3184
$L = 0.36, \ R_d = 69.54, \ \rho = 327.88, \ \Omega = 0.18$

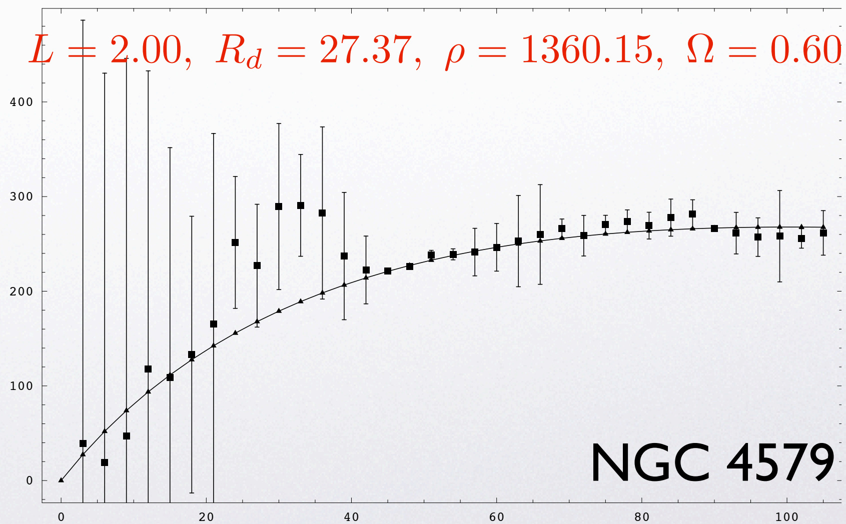

NGC 3198
$L = 0.27, \ R_d = 60.41, \ \rho = 408.20, \ \Omega = 0.11$

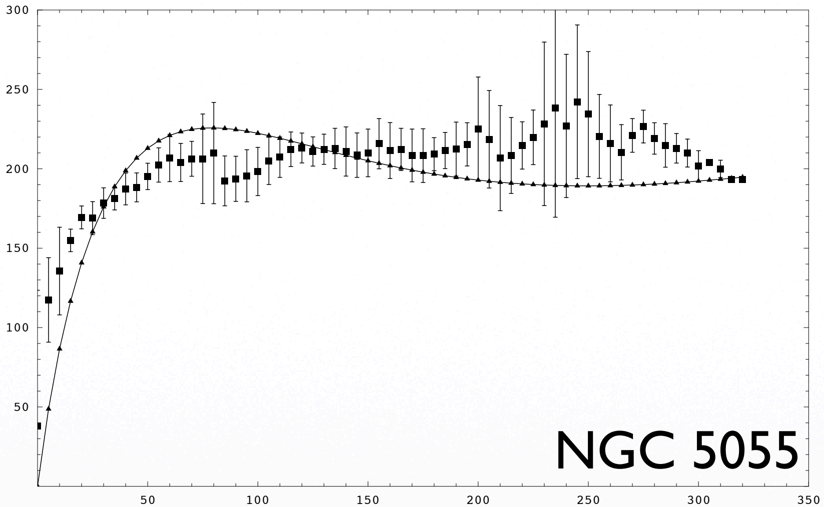

NGC 4236
$L = 0.32, \ R_d = 350.00, \ \rho = 6.01, \ \Omega = 0.12$

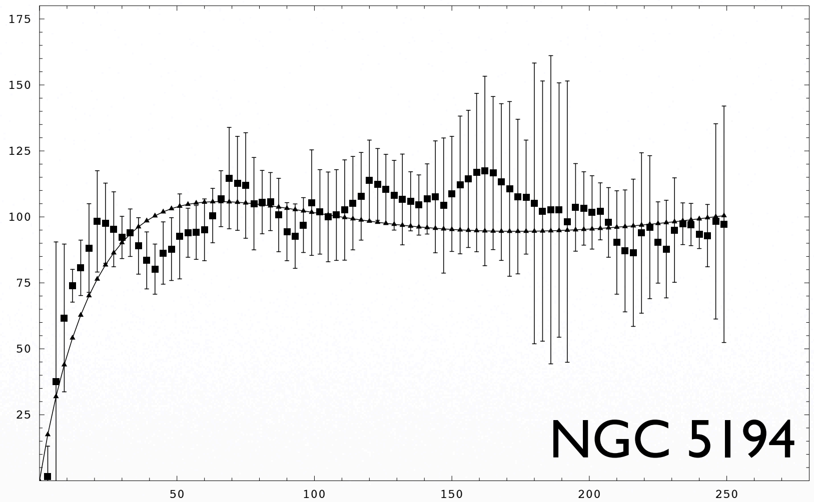

NGC 4321
$L = 2.00,\ R_d = 27.37,\ \rho = 1360.15,\ \Omega = 0.60$

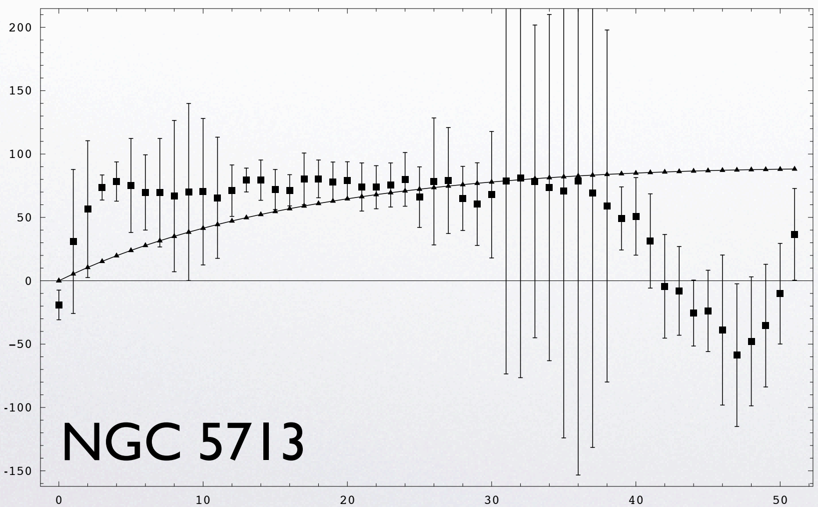

$L = 0.73,\ R_d = 45.90,\ \rho = 551.03,\ \Omega = 0.19$
NGC 4536

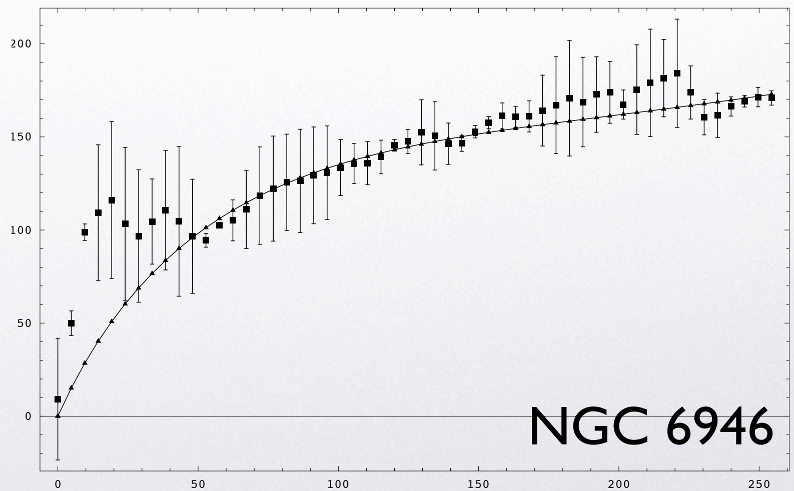

$L = 0.63,\ R_d = 16.78,\ \rho = 789.54,\ \Omega = 1.01$
NGC 4569


$L = 2.00,\ R_d = 27.37,\ \rho = 1360.15,\ \Omega = 0.60$
NGC 4579


NGC 5055
300
250
200
150
100
50
50
100
150
200
250
300
350


NGC 5194
175
150
125
100
75
50
25
50
100
150
200
250


NGC 5713
200
150
100
50
0
-50
-100
-150
0
10
20
30
40
50


NGC 6946
200
150
100
50
0
0
50
100
150
200
250

Galaxy	Likelihood	Rd	rho	Omega
ngc0628	1.29	29.67	847.01	0.39
ngc0925	2.52	285.68	128.63	0.00
ngc2403	4.19	31.19	142.06	0.22
ngc3031	0.07	8.47	41.92	0.00
ngc3184	0.36	69.54	327.88	0.18
ngc3198	0.27	60.41	408.20	0.11
ngc3521	0.51	26.67	2197.00	0.33
ngc4236	0.32	350.00	6.01	0.12
ngc4321	2.00	27.37	1360.15	0.60
ngc4536	0.73	45.90	551.03	0.19
ngc4569	0.63	16.78	789.54	1.01
ngc4579	0.50	43.88	2171.41	0.00
ngc5055	3.16	30.59	1914.81	0.21
ngc5194	0.60	24.35	507.39	0.15
ngc5713	2.72	20.00	454.78	0.00
ngc6946	5.75	56.81	293.73	0.23

$$\rho(r,z) = \rho_0\, exp(-\frac{r}{R_d})sech^2(\frac{6z}{R_d})$$

Galaxy	Rd	rho	Mass (M sun)2
ngc0628	29.67	847.01	4.19E+11
ngc0925	285.68	128.63	5.90E+12
ngc2403	31.19	142.06	7.77E+10
ngc3031	8.47	41.92	1.69E+9
ngc3184	69.54	327.88	8.91E+11
ngc3198	60.41	408.20	8.37E+11
ngc3521	26.67	2197.00	8.78E+11
ngc4236	350.00	6.01	4.13E+11
ngc4321	27.37	1360.15	5.72E+11
ngc4536	45.90	551.03	6.52E+11
ngc4569	16.78	789.54	1.24E+11
ngc4579	43.88	2171.41	2.35E+12
ngc5055	30.59	1914.81	1.01E+12
ngc5194	24.35	507.39	1.69E+11
ngc5713	20.00	454.78	1.02E+11
ngc6946	56.81	293.73	5.32E+11

$$G_{Newton} = 4.32 \times 10^{-6}(\frac{km}{s})^2 kpc/M_{sun}$$

Frank C. van den Bosch et al, astro-ph/9911372

Table 2. Parameters of best fits to HI surface brightness.

Galaxy	Σ_0 $M_\odot pc^{-2}$	R_d h_{70}^{-1} kpc	β	R_c h_{70}^{-1} kpc	$\log(M_{HI})$ h_{70}^{-2} $M_\odot$
(1)	(2)	(3)	(4)	(5)	(6)
F563-1	8.59	10.63	0.20	26.37	9.644
F568-1	4.55	1.97	3.43	16.98	9.674
F568-3	11.52	3.46	1.78	19.45	9.524
F568-V1	11.55	5.24	1.39	15.91	9.464
F574-1	2.16	3.13	3.51	18.71	9.649
F583-1	9.38	2.77	2.09	16.18	9.401
NGC 247	4.24	0.56	7.89	8.63	8.912
DDO 154	14.38	1.53	0.52	6.17	8.383
NGC 3109	8.28	3.08	0.32	12.92	8.713

Note. — Column (1) lists the name of the galaxy. Columns (2) through (5) list the best fitting parameters for the HI surface density, and column (6) lists the corresponding HI mass.

Table 3. Parameters of fits to rotation curves.

Galaxy (1)	Model (2)	α (3)	c (4)	V_{200} (5)	Υ_B (6)	$f_{\rm bar}$ (7)
F563-1	BF	2.00	5.2	73.5	0.0	0.039
F568-1	BF	1.97	5.8	64.0	6.2	0.369
F568-3	BF	1.18	3.4	127.7	0.5	0.010
F568-V1	BF	0.47	15.6	91.6	0.9	0.023
F574-1	BF	0.26	8.6	118.3	1.0	0.018
	a	1.30	8.6	76.4	1.0	0.067
	b	0.26	8.6	55.7	6.0	0.537
	c	0.80	2.0	278.8	1.0	0.001
F583-1	BF	0.00	20.6	65.7	0.0	0.035
NGC 247	BF	1.02	7.2	93.1	1.0	0.011
DDO 154	BF	0.00	14.7	44.0	0.0	0.011
NGC 3109	BF	0.00	10.2	101.6	0.0	0.002

Note. — Column (1) lists the name of the galaxy. Columns (2) lists the ID of the model, with 'BF' indicating the best-fit model (i.e., the one that minimizes $\chi^2_{\rm vel}$). For F574-1 three additional models are listed (a, b, and c) all of which fall within the 68.3 confidence level of the BF-model (see contour plots in Figure 4). Columns (3) through (5) list parameters of the model: c, Υ_B (in h_{70} $M_\odot/L_\odot$), and V_{200} (in $\rm km\,s^{-1}$). Finally, column (7) gives the resulting baryon fraction $f_{\rm bar} = (M_{\rm gas} + M_{\rm stars})/M_{200}$

Comments:

- only 3 parameters vs the usual 8
- masses of the galaxies obtained
  - cross-check with photometric method

    In progress
- effective field theory...

  In progress

I have pushed the limits of the model...

Perhaps a happy ending:

- Theoretically well-motivated, (very ordinary) Dark Matters:
  - black holes
  - small stars (not burning hydrogen)
- A little bit of String Gauge Fields

in a happy union!

fin

Thank You!