Dark matter Phase Transition constrained at Ec = 0.11 eV by LSB rotation curve

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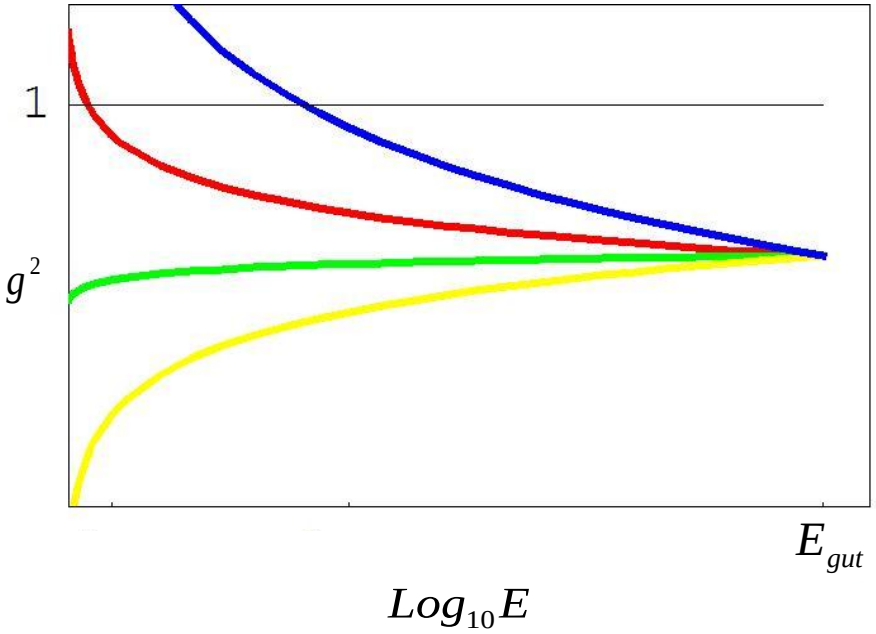
OUTLINE

- Motivation
- The BDM Model
- Mass Model
- Results
- Conclusion
- Reference

MOTIVATION

BOUND DARK MATTER

Evolution of coupling constant vs Energy, Λ



SU(3) Strong Interaction

SU(N) Dark Matter

SU(2) Weak Interaction

SU(1) E.M. Interac.

$$E_{gut} \cong 10^{16} GeV,$$

We propose an extra group SU(Nc) with Nf being the fundamental particles. The mass of the particles is given by the coupling force.

ONE LOOP EVOLUTION

$$\frac{1}{g^2(E)} = \frac{1}{g^2(E_{gut})} + \frac{b}{8\pi^2} Log[\frac{E}{E_{gut}}]$$

$$E_{gut} \cong 10^{16} GeV,$$

$$g^2(E_{gut}) \cong 1/2$$

$$b = 3N_c - N_f$$

MOTIVATION

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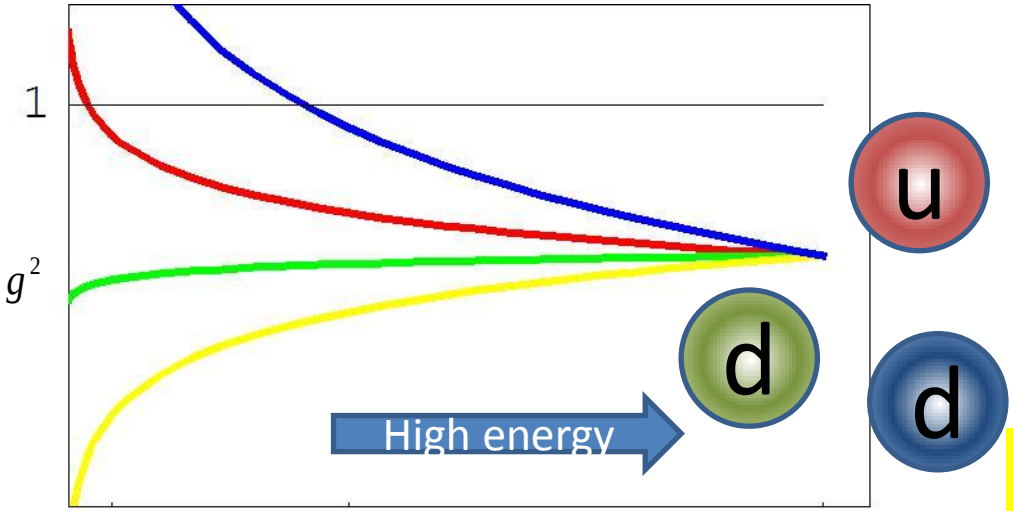

SU(3) Strong Interaction

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SU(1) E.M. Interac.

$E_{QCD} \cong 200\ MeV$ $\qquad$ $E_{gut} \cong 10^{16} GeV,$

$Log_{10}E$

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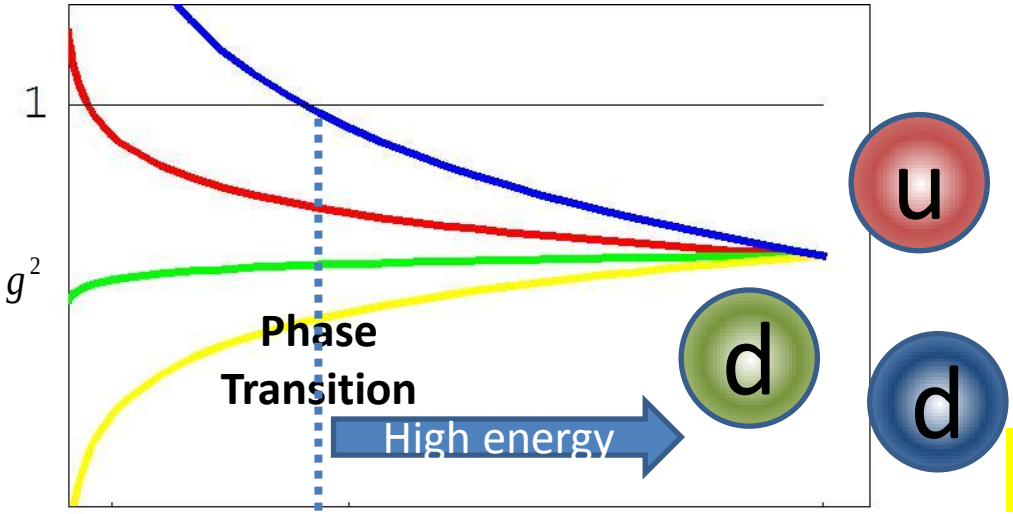

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$E_{QCD} \cong 200\ MeV$ $\qquad$ $E_{gut} \cong 10^{16} GeV,$

$Log_{10} E$

The condensation or phase transition scale is defined as the energy when the coupling constant becomes strong

$$g^2 >> 1$$

ONE LOOP EVOLUTION

$$\frac{1}{g^2(E)} = \frac{1}{g^2(E_{gut})} + \frac{b}{8\pi^2} Log[\frac{E}{E_{gut}}]$$

$$E_{gut} \cong 10^{16} GeV,$$

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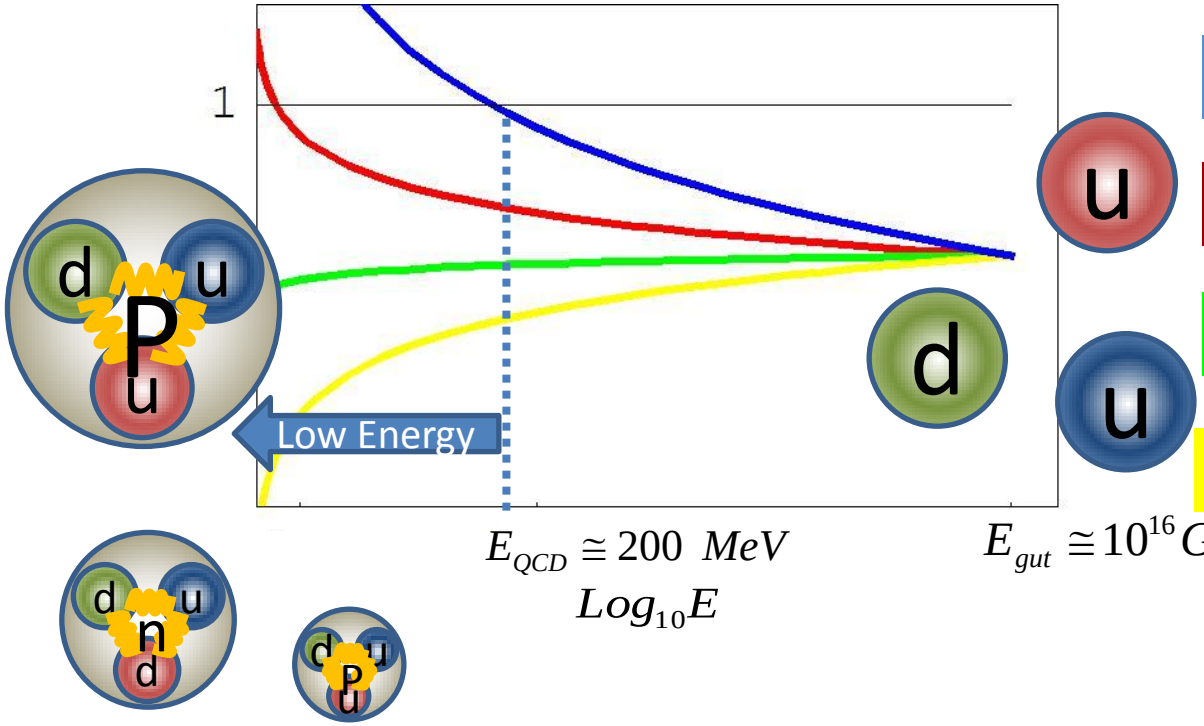
MOTIVATION

BOUND DARK MATTER

Evolution of coupling constant vs Energy, Λ



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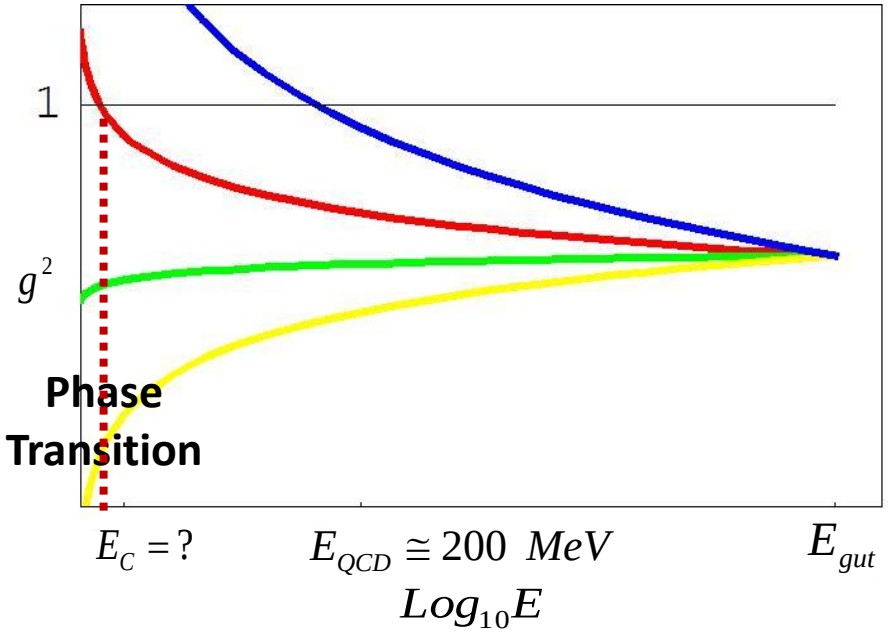
MOTIVATION

BOUND DARK MATTER

Evolution of coupling constant vs Energy, Λ



SU(3) Strong Interaction

SU(N) Dark Matter

SU(2) Weak Interaction

SU(1) E.M. Interac.

The value of Ec is determined by the particle physics model and constraint by the dark matter properties derived from cosmology.

ONE LOOP EVOLUTION

$$\frac{1}{g^2(E)} = \frac{1}{g^2(E_{gut})} + \frac{b}{8\pi^2} Log[\frac{E}{E_{gut}}]$$

$$E_{gut} \cong 10^{16} GeV,$$

$$g^2(E_{gut}) \cong 1/2$$

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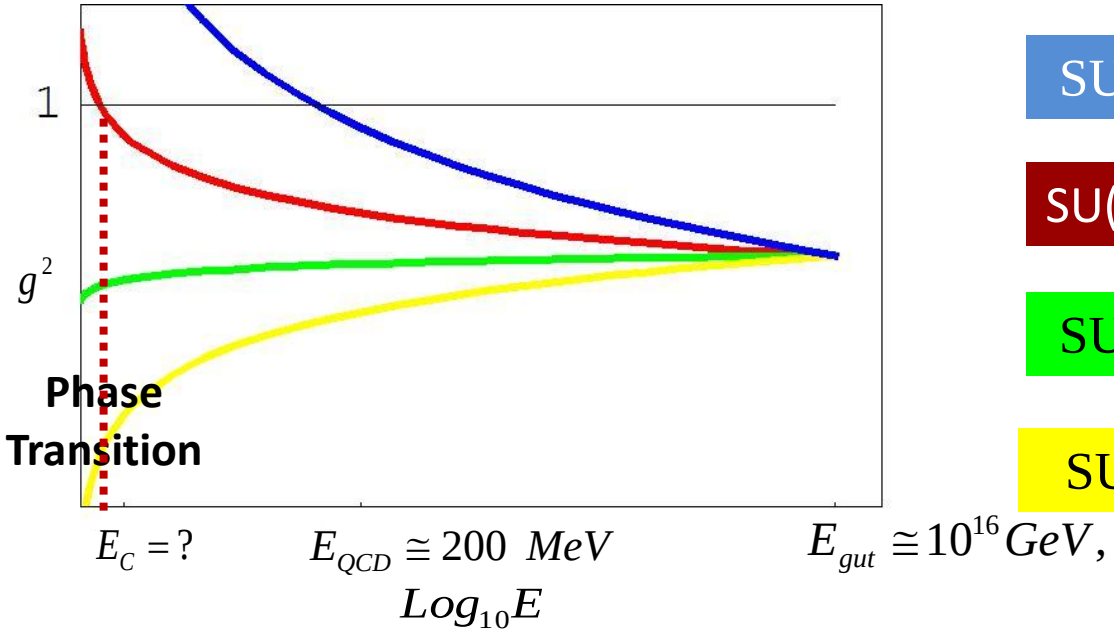
MOTIVATION

BOUND DARK MATTER

Evolution of coupling constant vs Energy, Λ



SU(3) Strong Interaction

SU(N) Dark Matter

SU(2) Weak Interaction

SU(1) E.M. Interac.

From gauge group dynamics we expect the mass of the confined particles is of the order of the transition energy

$$m_{bdm} = cE_c \qquad c \approx \vartheta(1-10)$$

e.g. proton m = 938 with E_{QCD} = 200 MeV, c = 4.6

THE MODEL

AT THE BEGINNING OF THE UNIVERSE

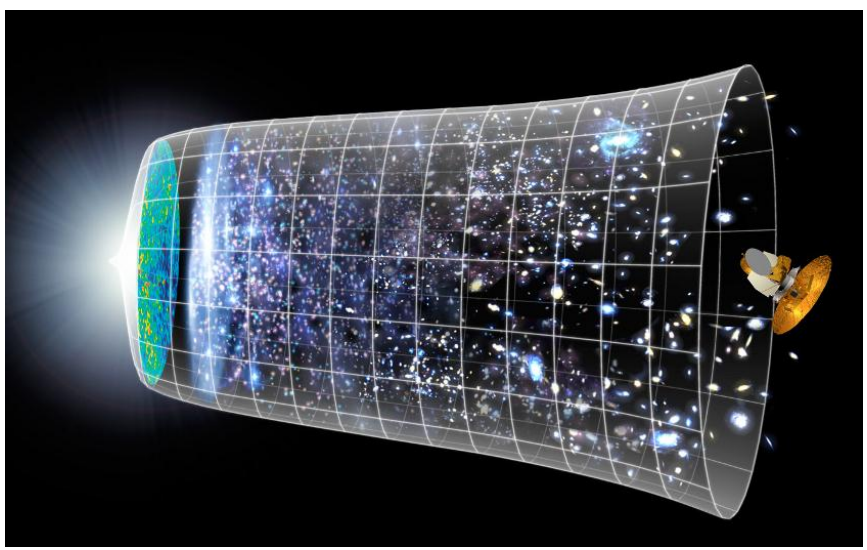
The BDM particles behaves as

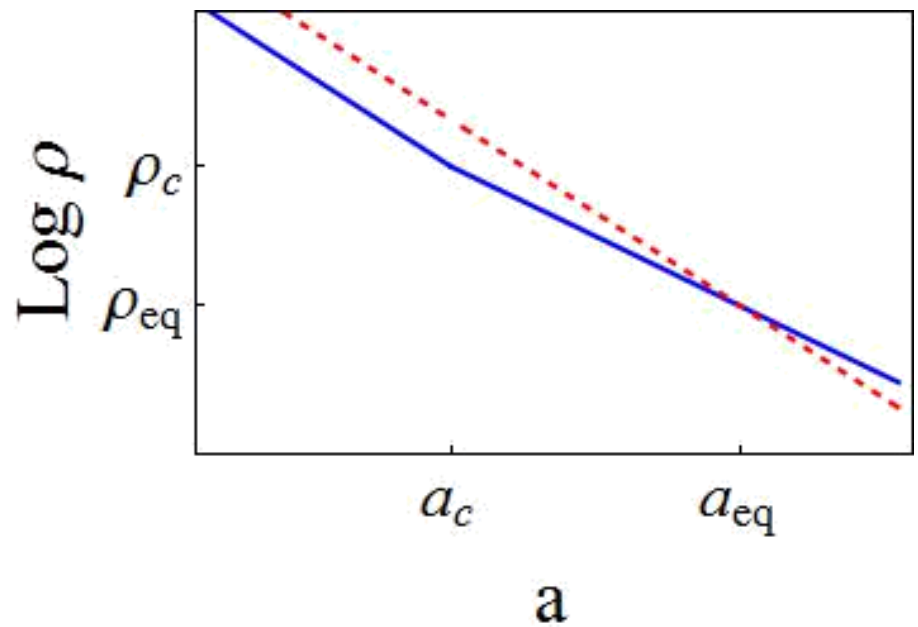
- Radiation
  Above the energy scale Ec.
  e.g HDM
  $$\rho \propto a^{-4} \geq \rho_c$$
  $$v \rightarrow c$$
- Matter
  Below the energy scale Ec
  e.g CDM
  $$\rho \propto a^{-3} \leq \rho_c$$
  $$v \rightarrow 0$$

We could find this behaviour in two situations:

1. **At the beginin of the Univers.**

$$Ec^4 = \rho_c$$





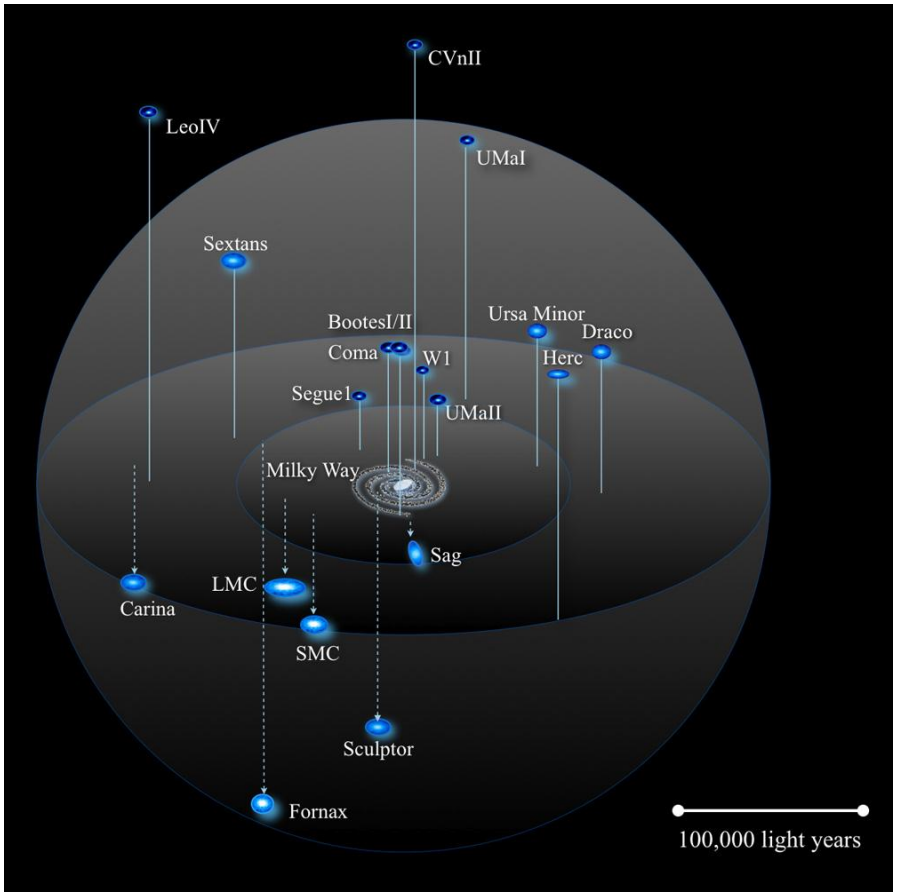
THE MODEL

AT THE BEGINNING OF THE UNIVERSE

We could find this behaviour in two situations:

1. **At the beginin of the Univers.**

Since the particles of BDM travel at the speed of light at energy densities above ρc there will be a cut at small scales in the power spectrum and BDM will erase inhomogeneities and inhibit structure formation for scales below the free streaming scale Lfs

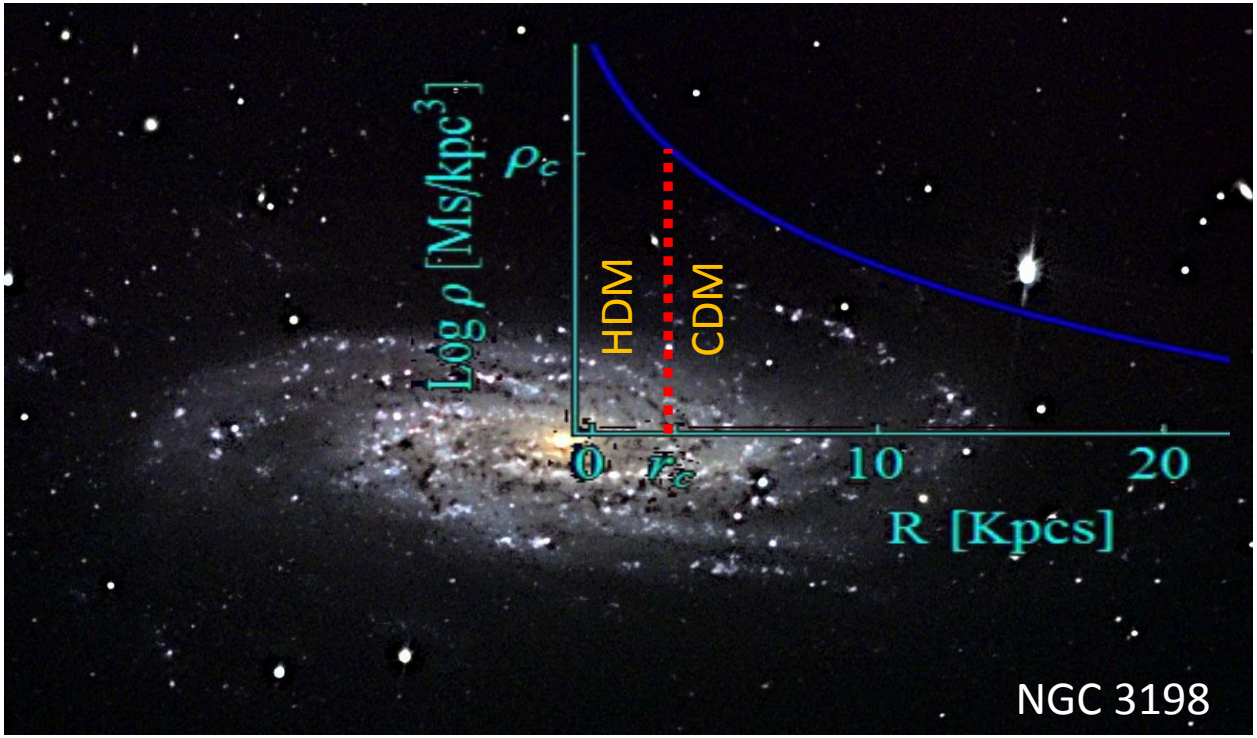


ΛCDM predicts an overpopulation of satellite galaxies around our own galaxy.

2. Inside of the galaxies.

BDM predicts a core in galaxies

A great number of rotation curves in dwarf and LSB galaxies fits better considering a dark matter halo with a core profiles than a cuspy profile.



THE MODEL

BOUND DARK MATTER

Halo profile: NFW

$$\rho_{NFW} = \frac{\rho_0}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2}$$

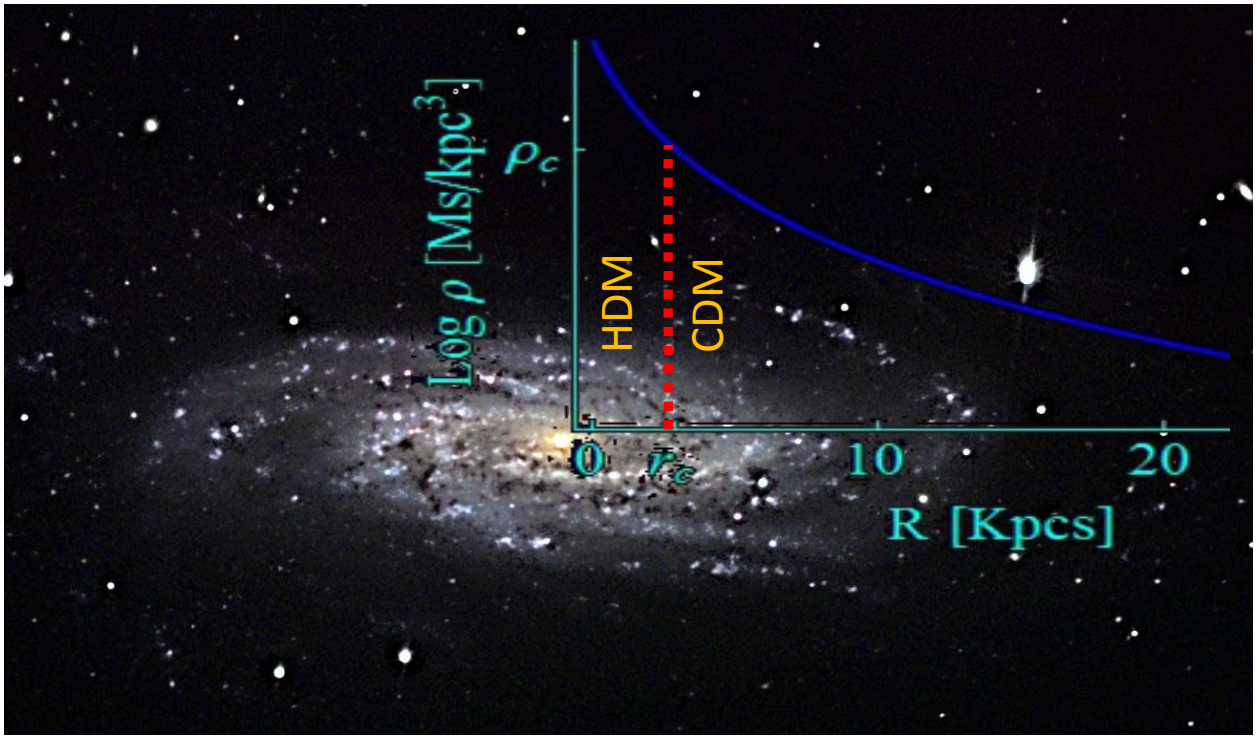
BDM

$$\rho_{BDM} = \frac{\rho_0}{\left(\frac{r_c}{r_s}+\frac{r}{r_s}\right)\left(1+\frac{r}{r_s}\right)^2}$$

The energy transition

$$Ec^4 = \rho_{BDM}(r = r_c) \equiv \rho_c$$

$$\rho_c = \frac{\rho_0 r_s}{2r_c}$$



THE MODEL

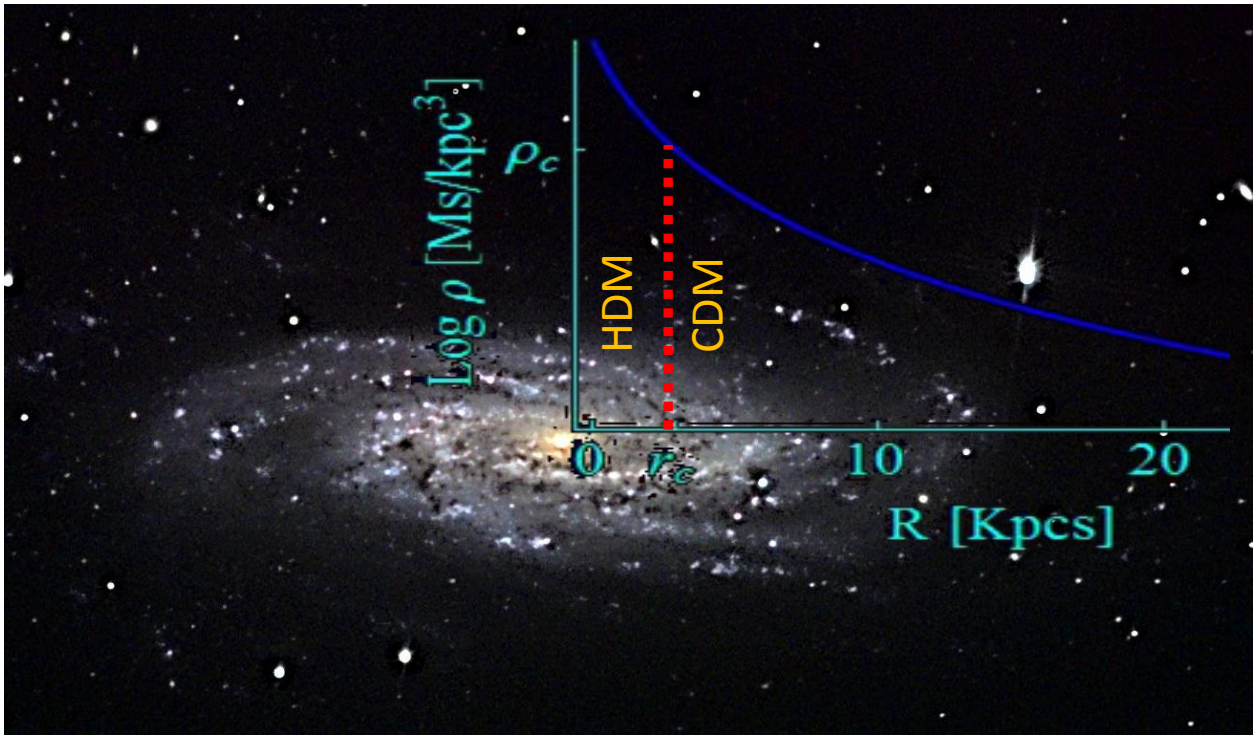
BOUND DARK MATTER

Pseudo-Isotermal

$$\rho_{ISO} = \frac{\rho_0}{1+\left(\frac{r}{r_s}\right)^2}$$

Perfil de Burkert

$$\rho_B = \frac{\rho_0}{\left(1+\frac{r}{r_s}\right)\left(1+\left(\frac{r}{r_s}\right)^2\right)}$$

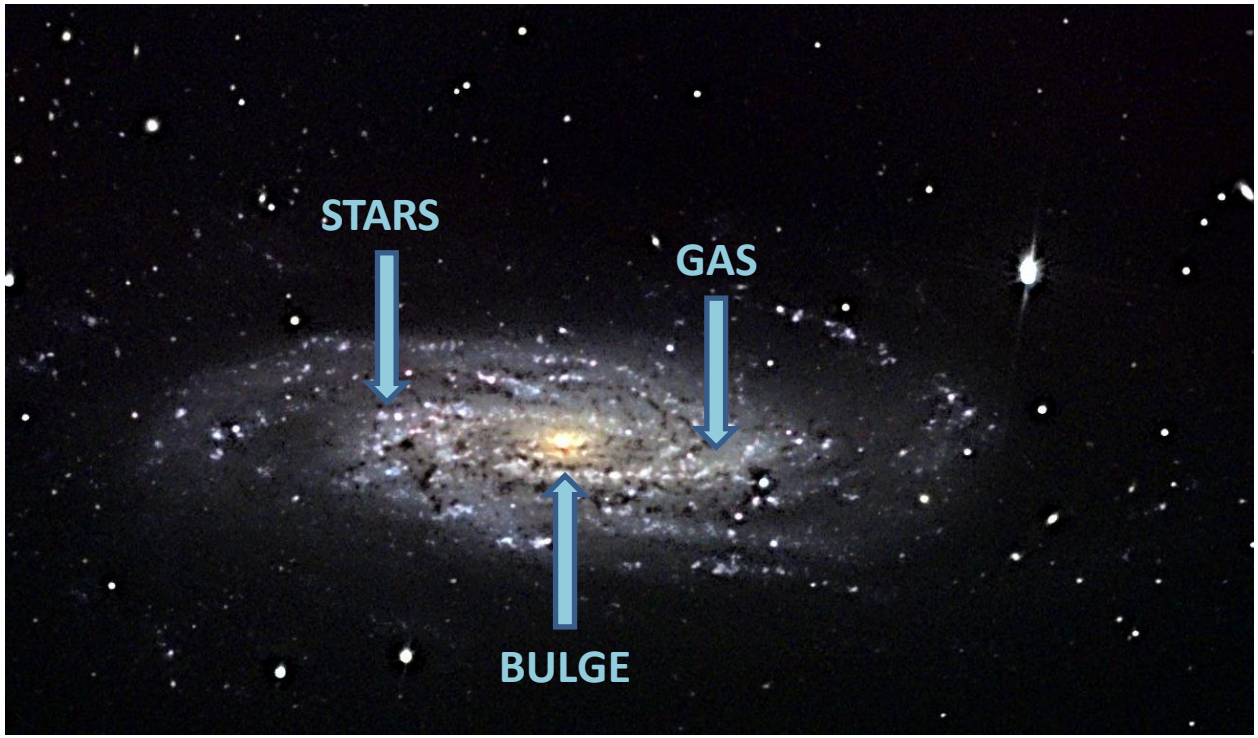


MASS MODEL

VISIBLE COMPONENTS

The visible component of a galaxy:

- STARS
- BULGE
- GAS

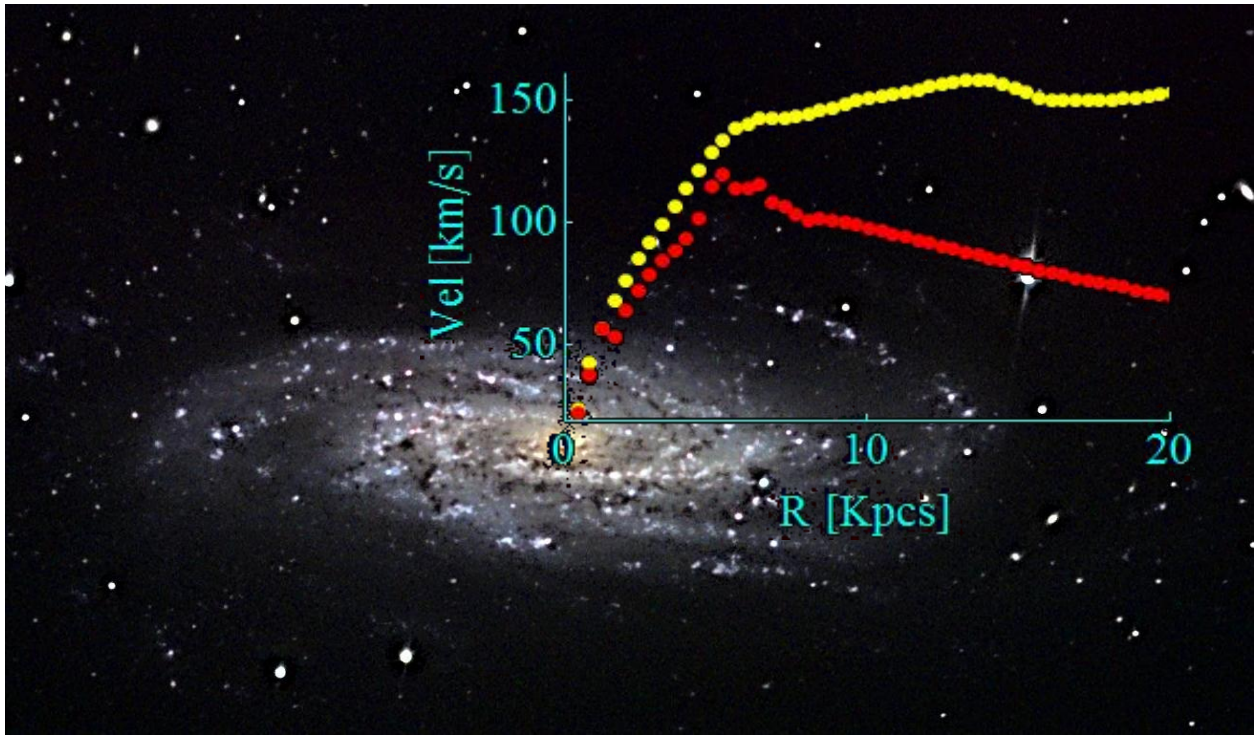


MASS MODEL

ROTATION CURVE OF THE VISIBLE COMPONENT

$$\Phi_T = \Phi_G + \Phi_*$$

$$V_{OBS}^2 = V_G^2 + \gamma_* V_*^2$$



MASS MODEL

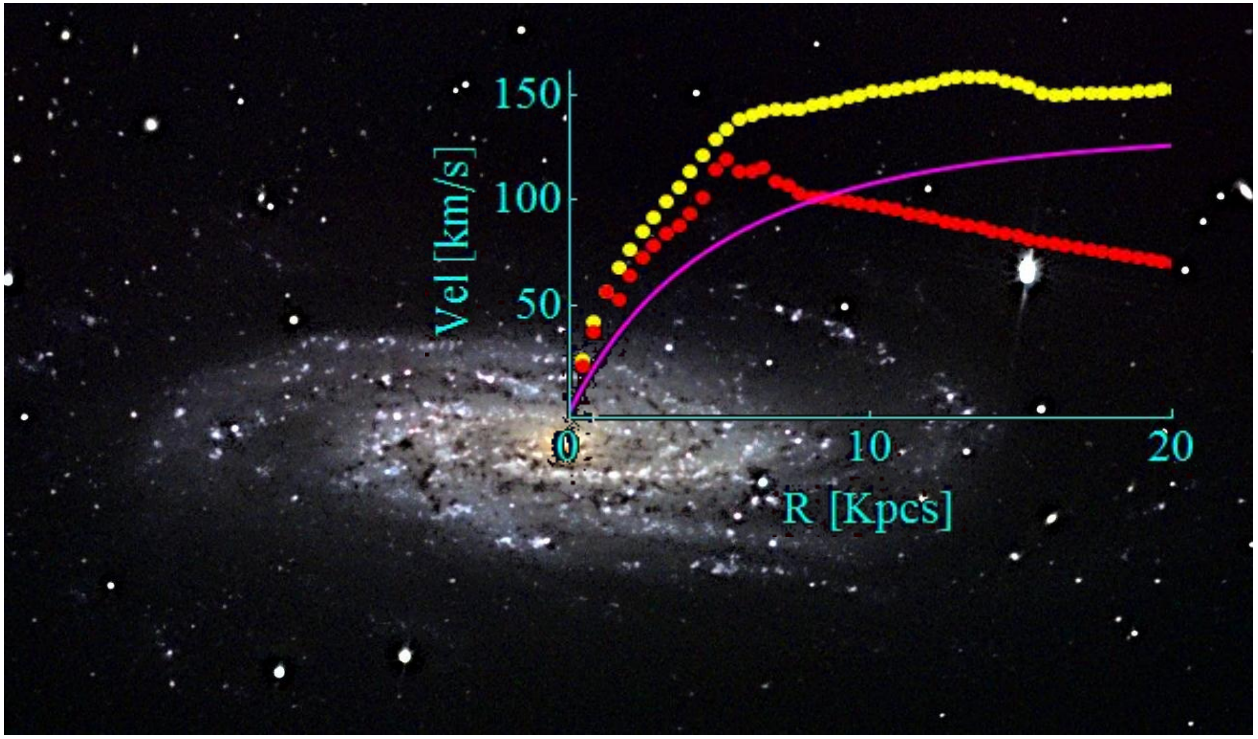
$$\Phi_T = \Phi_H + \Phi_G + \Phi_* \longrightarrow V_{OBS}^2 = V_H^2 + V_G^2 + \gamma_* V_*^2$$

V_G^2 → HI Observations

V_{OBS}^2 → Redshifts

V_*^2 → Photometric measurements (J-K Bands)

V_H^2 → BDM profiles



MASS MODEL

KROUPA, DIET-SALPETER & DETAILS

Stellar population syntesis models → Diet-Salpeter IMF. It settle down the maximum stellar contribution from the photometric constriction.

Stellar Population of the Milky Way → Kroupa IMF. Minimum contribution for stellar disk

$$\chi^2 = \sum_{i=1}^{n}\left[\frac{y_i - y_t(\alpha, x_i)}{\sigma_i}\right]^2$$

$$\log(\gamma^K) = 1.43(J-K) - 1.38$$

$$\gamma_*^{3.6} = 0.92\gamma_*^{K} - 0.05$$

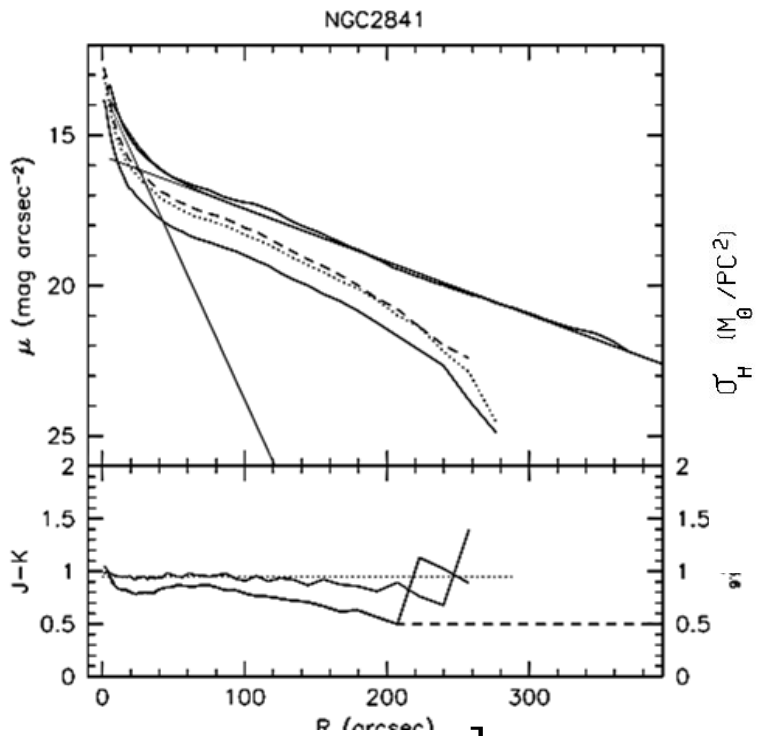
$$\gamma_{salpeter} = 1.4\gamma_{kroupa}$$

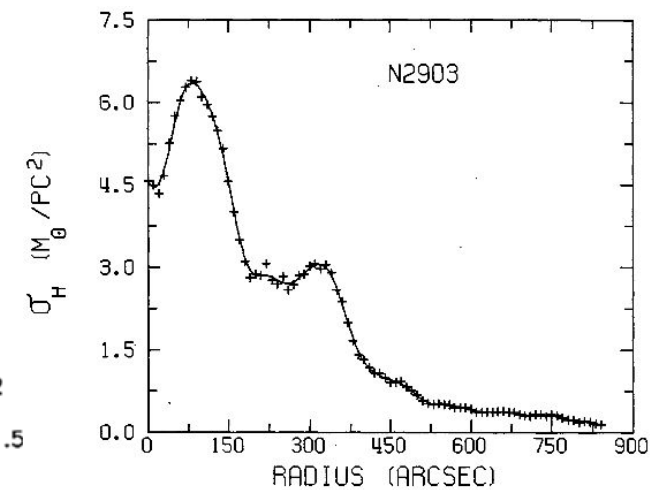
$$\gamma_{free}$$

$$\Sigma_*(r) = \Sigma_0 e^{-r/r_d}$$

$$\Sigma^{\lambda}{}_0 = \gamma^{\lambda} 10^{\frac{1}{2.5}\left(M_{\circ}{}^{\lambda} - \mu^{\lambda} - 5\right)}$$

$$V_*^2(y) = 4\pi G\Sigma_0 r_d^2 y^2\left[I_0(y)K_0(y) - I_1(y)K_1(y)\right]$$





$$\Phi_G(r) = -G\int_0^{\infty} dr' r' \Sigma_G(r') \int_0^{2\pi} \frac{d\theta}{|r - r'|}$$

$$\mu(r)^{\lambda} = \mu^{\lambda}{}_0 + 1.0857\frac{r}{r_d}$$

MASS MODEL

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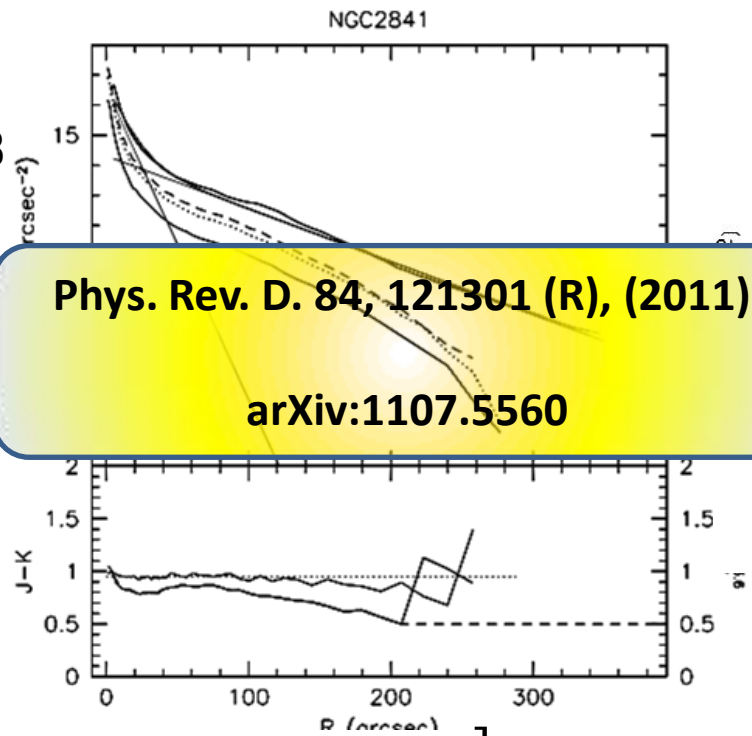
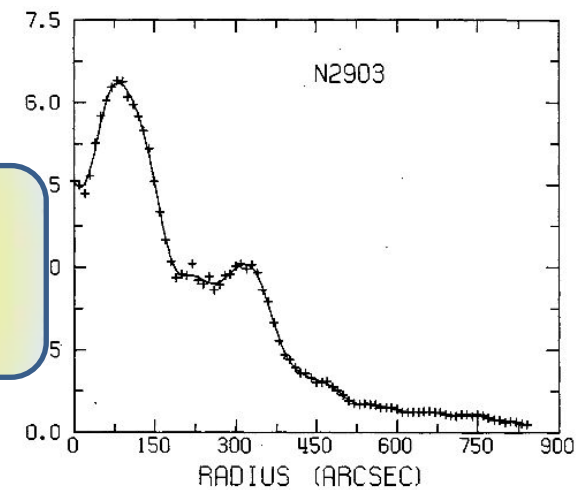


Phys. Rev. D. 84, 121301 (R), (2011)

arXiv:1107.5560



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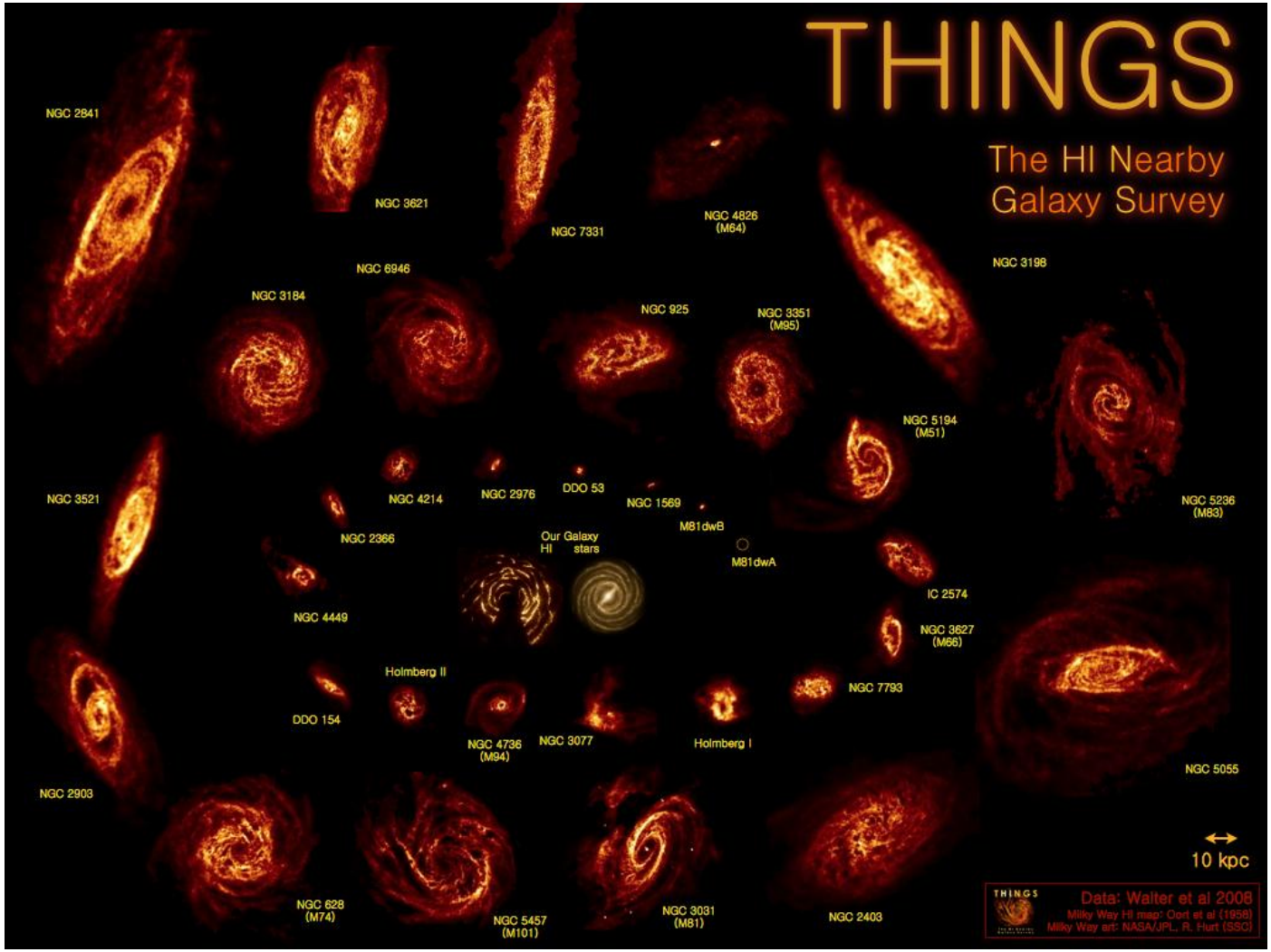
SAMPLE



- Great angular resolution
- Large number of galaxies
- All galaxies show circular movements
- None elongation in the DM halo.

PARTIAL RESULTS

$r_s > r_c \neq 0$

7/14 Galaxies

DDO 154, NGC 2841, NGC 3031
NGC 3621, NGC 4736, NGC 6946
NGC 7793

$r_{c \leq} 260\ pc \quad r_{s \approx} 5\ kpc \quad E_{c=} 0.11\ eV$

BDM ☺ NFW ☺
ISO ✖ BUR ✖

$r_s \cong r_c$

7/14 Galaxies

IC 2574, NGC 2366, NGC 2903,
NGC 2976, NGC 3198, NGC 3521,
NGC 925

$r_{s \leq} 5\ kpc$

Inner Analysis

BDM ☺ NFW ✖
ISO ☺ BUR ☺

$\frac{r_c}{r_s} \leq 10^{-6}$

3/14 Galaxies

NGC 2403, NGC 5055 y NGC 7331

Not enough inner data

BDM 〓 NFW 〓
ISO ✖ BUR ✖

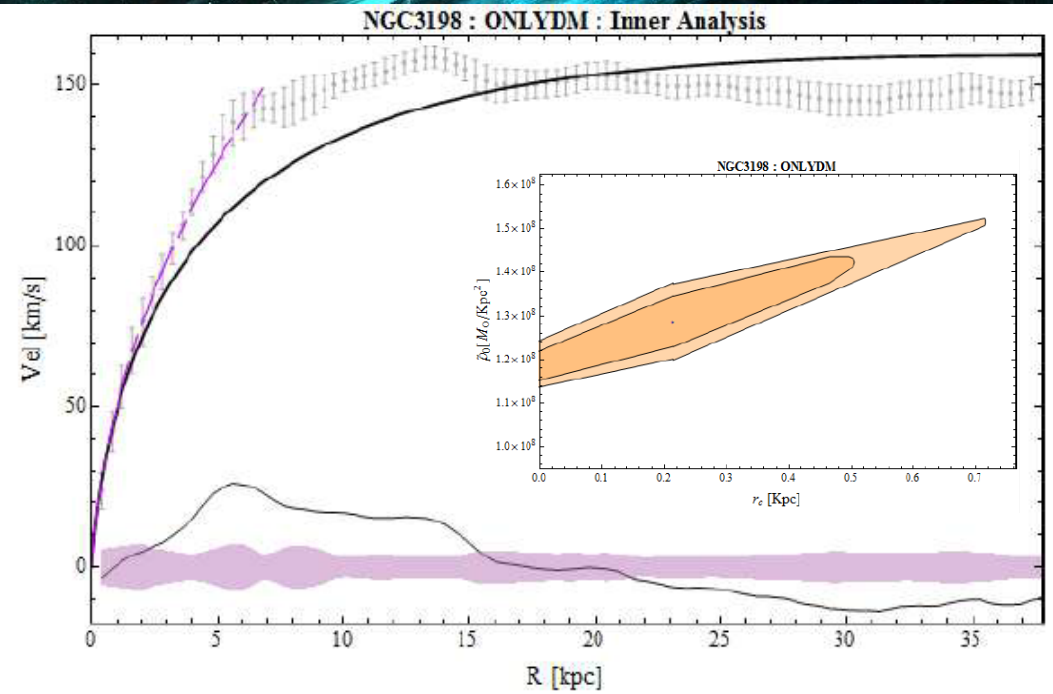
INNER ANALYSIS

$$\rho_{\text{int}} = \frac{\sigma_0}{(r_c + r)}$$

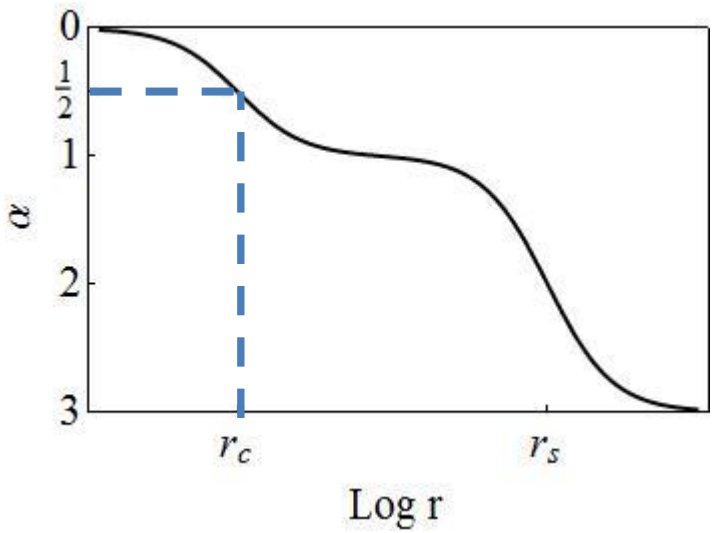
$$\sigma_0 = \rho_0 r_s$$

$$r_c \approx 1.3 \ kpc$$

$$E_c \approx 0.06 \ eV$$



(a) Fit and Difference



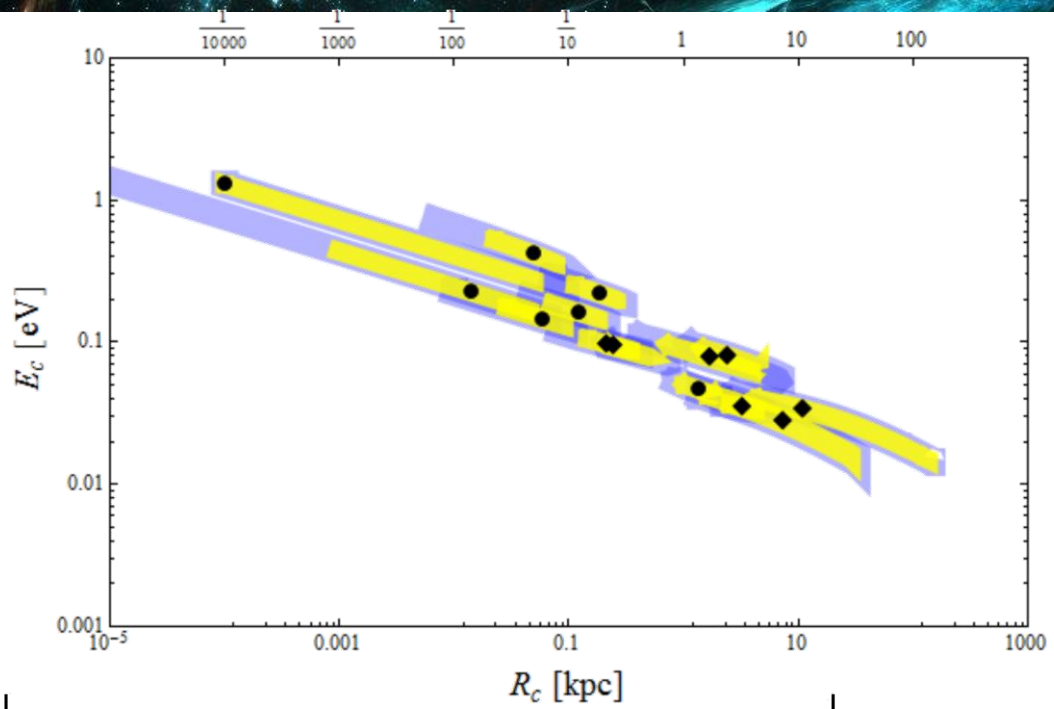
$$\alpha \equiv -\frac{d \log \rho}{d \log r} = \frac{r/r_c(1 + 3r/r_s + 2r_c/r_s)}{(1 + r/r_c)(1 + r/r_s)}$$

$$\rho_\alpha = \rho_0 r^\alpha$$

$$\alpha \begin{cases} 0 & r = 0 \\ ½ & r = r_c \\ 1 & r_c < r < r_s \end{cases}$$

$$\boxed{\alpha \leq 0.52}$$

PARTIAL RESULTS



	Energy E_c						Core r_c				
Mass Models	$\tilde{E}_{c_n}$	E_{c_-}	E_c	E_{c_+}	$\sigma(E_c)$	$\log_{10}\rho_c$	$\tilde{r}_{c_n}$	r_{c_-}	$\hat{r}_c$	r_{c_+}	$\sigma(r_c)$
Min.Disk	0.21	0.04	0.11	0.33	0.46	8.70	2.00	0.01	0.26	5.41	1.31
Min.Disk+gas	0.09	0.05	0.08	0.16	0.27	8.15	1.77	0.12	0.63	3.26	0.71
Kroupa	0.08	0.02	0.05	0.13	0.36	7.65	6.80	0.37	2.33	14.74	0.80
diet-Salpeter	0.13	0.01	0.03	0.30	0.95	6.44	6.58	0.15	3.01	61.76	1.31

RESULTS

$$Ec^4 = \rho_c = \frac{\rho_0 r_s}{2r_s}$$

$$\rho_{BDM} = \frac{\rho_c}{\left(1+\frac{r}{r_c}\right)\left(1+\frac{r}{r_s}\right)^2}$$

ONLY DM

8 Galaxies	$\chi^2_{BDM} < \chi^2_{NFW}$
8 Galaxies	$\chi^2_{BDM} \approx \chi^2_{NFW}$
2 Galaxies	$\chi^2_{BDM} > \chi^2_{NFW}$

KROUPA

6 Galaxies	$\chi^2_{BDM} < \chi^2_{NFW}$
7 Galaxies	$\chi^2_{BDM} \approx \chi^2_{NFW}$
4 Galaxies	$\chi^2_{BDM} > \chi^2_{NFW}$

Fixed-BDM Statistics

Mass Model	E_c	$\tilde{r}_c$	r_{c-}	r_c	r_{c+}	$\sigma(r_c)$	$\tilde{r}_s$	r_{s-}	r_s	r_{s+}	$\sigma(r_s)$
Min.Disk	0.11	0.81	0.11	0.46	1.85	0.61	4.72	0.52	2.64	13.44	0.71
Min.Disk+gas	0.08	1.86	0.42	1.3	4.04	0.49	3.04	1.03	2.41	5.62	0.37
Kroupa	0.05	3.22	0.94	2.32	5.73	0.39	7.71	2.03	5.22	13.46	0.41
diet-Salpeter	0.03	9.00	0.007	1.46	308.96	2.33	7.06	1.09	3.66	12.28	0.53

CONCLUSION

- The model predict a core of 0.23 - 2.3 kpc in the halo dark matter in galaxies.
- The BDM profile fits better (or equally well) than NFW profile.
- The energy transition Ec = 0.11 eV makes it interestings for the large scale structure with CAMB and COSMOMC.
- We end up with one fundamental constant from the theory, and two free parameters given by the morphology of the galaxies.

REFERENCES

- Galactic Phase Transition at Ec= 0.11 eV from Rotation Curves of Cored LSB and nonperturbative Dark Matter Mass.
  de la Macorra, **Mastache**, Cervantes.
  Phys.Rev. D84 (2011) 121301

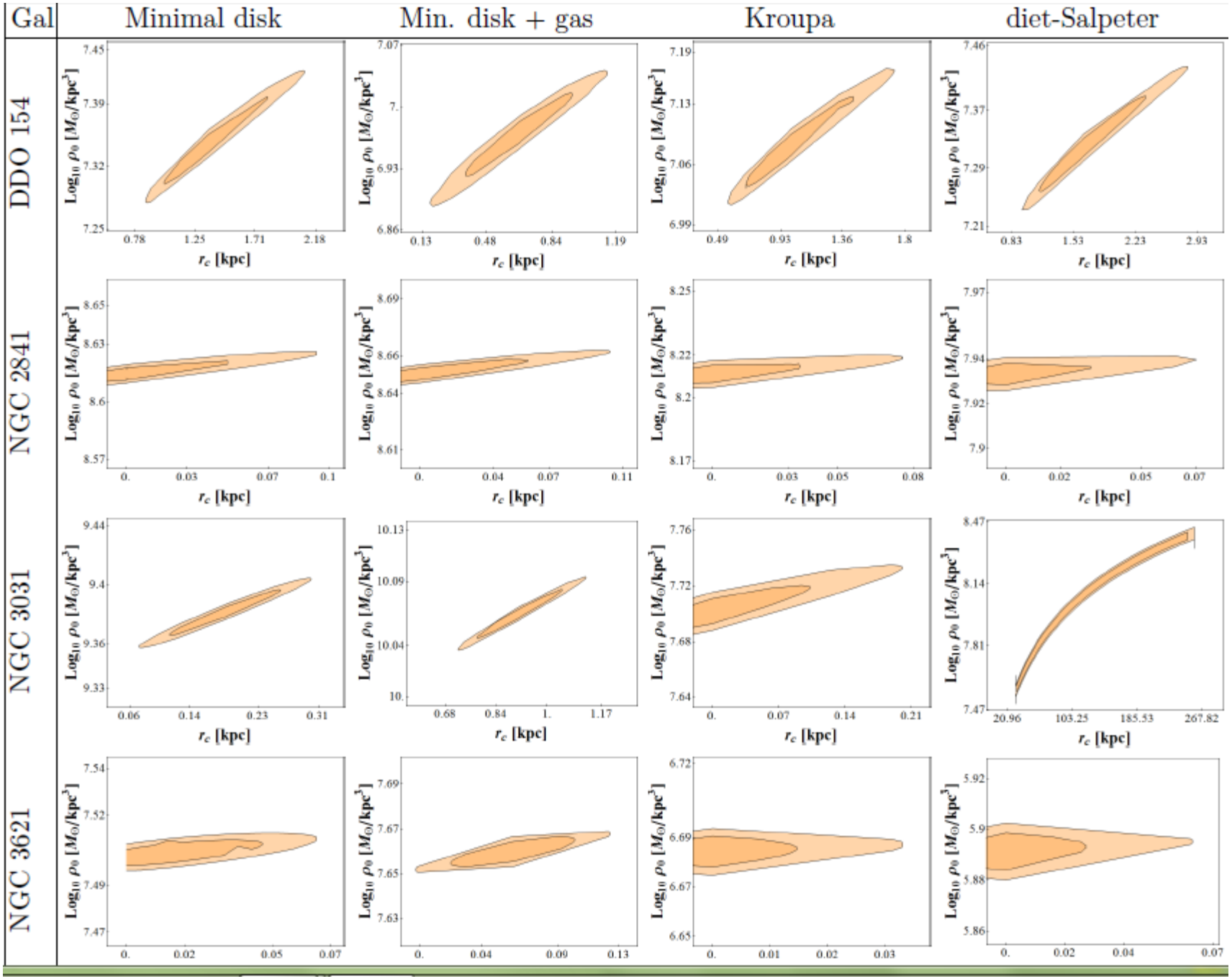
- Core-Cusp revisited and Dark Matter Phase Transition Constrained at 0.11 eV with LSB Rotation Curve.
  Mastache, de la Macorra, Cervantes
  arXiv:1107.5560v1

- BDM Dark Matter: CDM with a core profile and a free streaming scale
  Astropart.Phys. 33:195-200,2010.

- High-Resolution Rotation Curves and Galaxy Mass Models from THINGS.
  Astrophys. J. 136, 2648, 2008

Jach Dyos b'o'otik!!

(Thank you!!)


Gal
Minimal disk
Min. disk + gas
Kroupa
diet-Salpeter
DDO 154
NGC 2841
NGC 3031
NGC 3621
$\mathrm{Log}_{10}\ \rho_0\ [M_\odot/\mathrm{kpc}^3]$
r_c [kpc]

BDM

	Galaxia	MINIMAL DISK			MINIMAL DISK+GAS		
		r_c	$\log_{10}\rho_c$	E_c	r_c	$\log_{10}\rho_c$	E_c
G.A	DDO154	$1.35^{+0.04}_{-0.04}$	$7.20^{+6.18}_{-6.17}$	$0.05^{+0.001}_{-0.001}$	$0.66^{+0.04}_{-0.04}$	$7.42^{+6.54}_{-6.53}$	$0.05^{+0.002}_{-0.002}$
	NGC2841	$0.001^{+0.01}_{-0.01}$	$12.98^{+15.}_{-11.08}$	$1.29^{+0.004}_{-0.004}$	< 0.01	–	–
	NGC3031	$0.19^{+0.01}_{-0.01}$	$9.90^{+8.74}_{-8.02}$	$0.22^{+0.004}_{-0.001}$	$0.91^{+0.01}_{-0.01}$	$9.14^{+7.74}_{-7.73}$	$0.14^{+0.001}_{-0.001}$
	NGC3621	$0.01^{+0.01}_{-0.01}$	$9.94^{+9.87}_{-9.83}$	$0.22^{+0.05}_{-0.04}$	$0.06^{+0.01}_{-0.01}$	$9.36^{+8.76}_{-8.74}$	$0.16^{+0.01}_{-0.01}$
	NGC4736	$0.05^{+0.01}_{-0.01}$	$11.01^{+10.2}_{-8.9}$	$0.41^{+0.016}_{-0.001}$	$0.40^{+0.009}_{-0.005}$	$9.71^{+8.61}_{-7.61}$	$0.20^{+0.004}_{-0.0004}$
	NGC6946	$0.12^{+0.02}_{-0.01}$	$9.37^{+8.53}_{-8.46}$	$0.16^{+0.006}_{-0.005}$	$0.15^{+0.01}_{-0.01}$	$9.30^{+8.33}_{-8.32}$	$0.16^{+0.004}_{-0.004}$
	NGC7793	$0.06^{+0.01}_{-0.01}$	$9.18^{+8.51}_{-8.49}$	$0.15^{+0.007}_{-0.007}$	$0.06^{+0.01}_{-0.01}$	$9.21^{+8.56}_{-8.55}$	$0.15^{+0.008}_{-0.008}$
G.B	IC2574	$3.26^{+0.33}_{-0.33}$	$6.72^{+5.74}_{-5.72}$	$0.04^{+0.001}_{-0.001}$	$2.22^{+0.2}_{-0.2}$	$6.71^{+5.73}_{-5.76}$	$0.03^{+0.001}_{-0.001}$
	NGC2366	$7.40^{+0.74}_{-0.74}$	$6.32^{+5.68}_{-5.72}$	$0.03^{+0.002}_{-0.002}$	$3.23^{+0.3}_{-0.3}$	$6.02^{+6.03}_{-6.05}$	$0.02^{+0.006}_{-0.006}$
	NGC2903	$1.70^{+0.17}_{-0.17}$	$8.12^{+7.26}_{-7.26}$	$0.08^{+0.003}_{-0.003}$	$1.66^{+0.2}_{-0.2}$	$8.12^{+7.27}_{-7.27}$	$0.08^{+0.003}_{-0.003}$
	NGC2976	$0.25^{+0.025}_{-0.025}$	$8.44^{+7.46}_{-7.45}$	$0.09^{+0.003}_{-0.002}$	$0.20^{+0.02}_{-0.02}$	$8.31^{+7.52}_{-7.51}$	$0.09^{+0.004}_{-0.004}$
	NGC3198	$0.22^{+0.021}_{-0.021}$	$8.48^{+7.49}_{-7.49}$	$0.10^{+0.003}_{-0.003}$	$0.20^{+0.02}_{-0.02}$	$8.52^{+7.53}_{-7.53}$	$0.10^{+0.003}_{-0.003}$
	NGC3521	$2.42^{+0.242}_{-0.242}$	$8.15^{+7.36}_{-7.36}$	$0.08^{+0.003}_{-0.003}$	$5.32^{+0.5}_{-0.5}$	$8.47^{+7.0}_{-7.0}$	$0.10^{+0.001}_{-0.001}$
	NGC925	$11.01^{+1.1}_{-1.1}$	$6.65^{+5.87}_{-5.87}$	$0.03^{+0.001}_{-0.001}$	$8.02^{+0.7}_{-0.7}$	$6.52^{+5.92}_{-5.92}$	$0.03^{+0.002}_{-0.002}$