Structure Formation with Scalar Field Dark Matter

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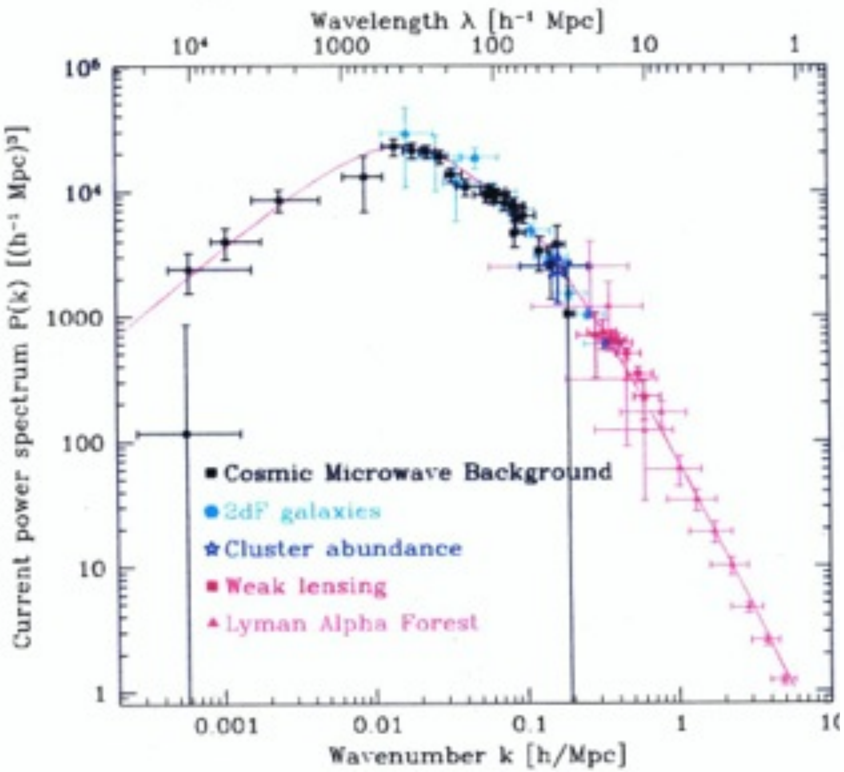
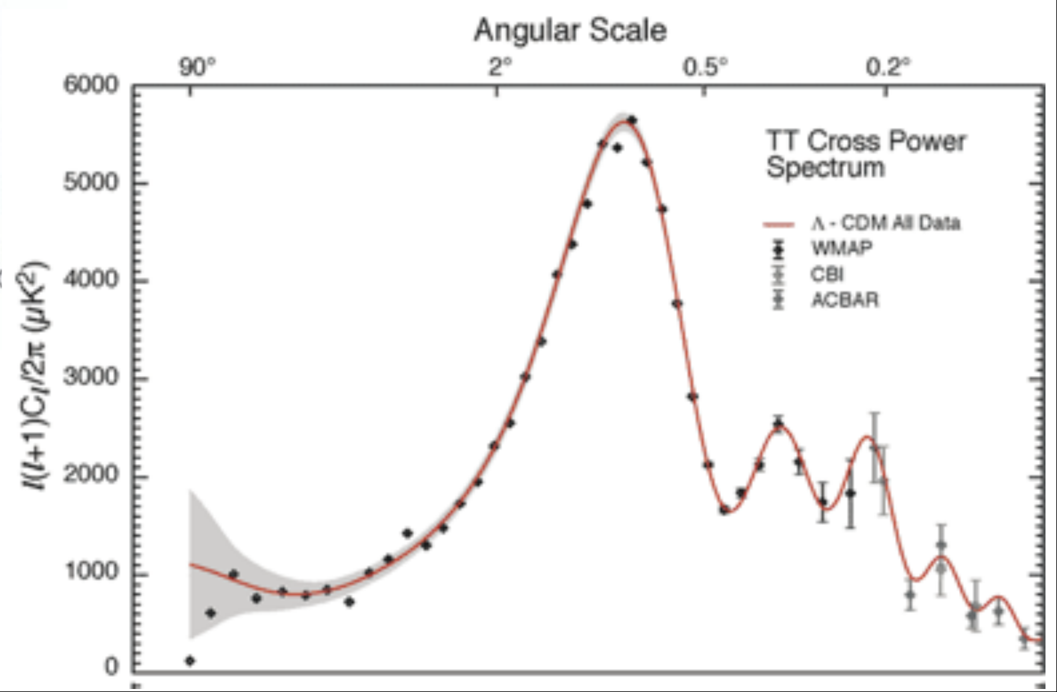
Some Problems of the LCDM

SFDM

The Standard Model of Cosmology: LCDM





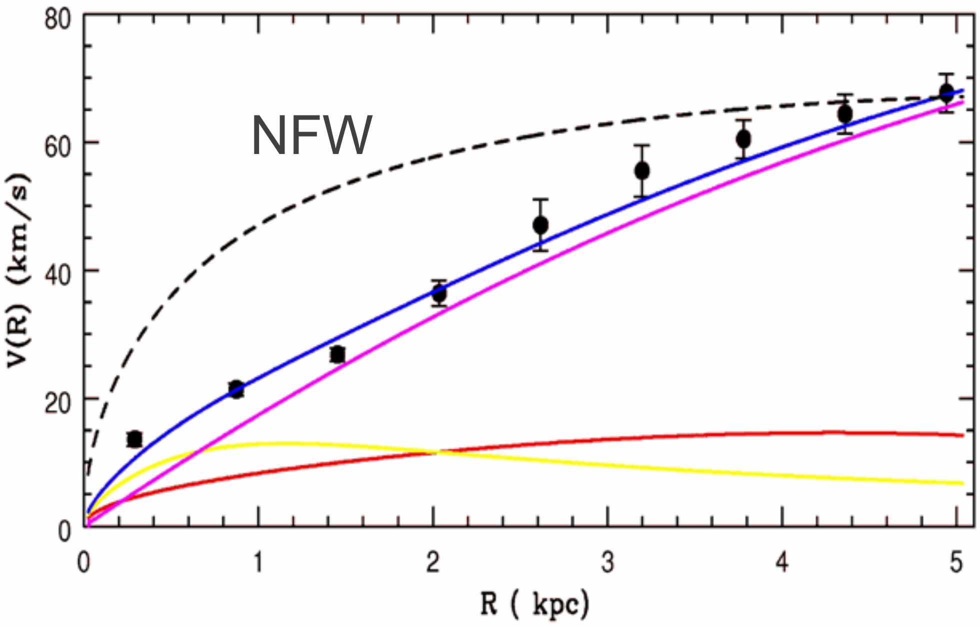
The Standard Model of Cosmology: Problems

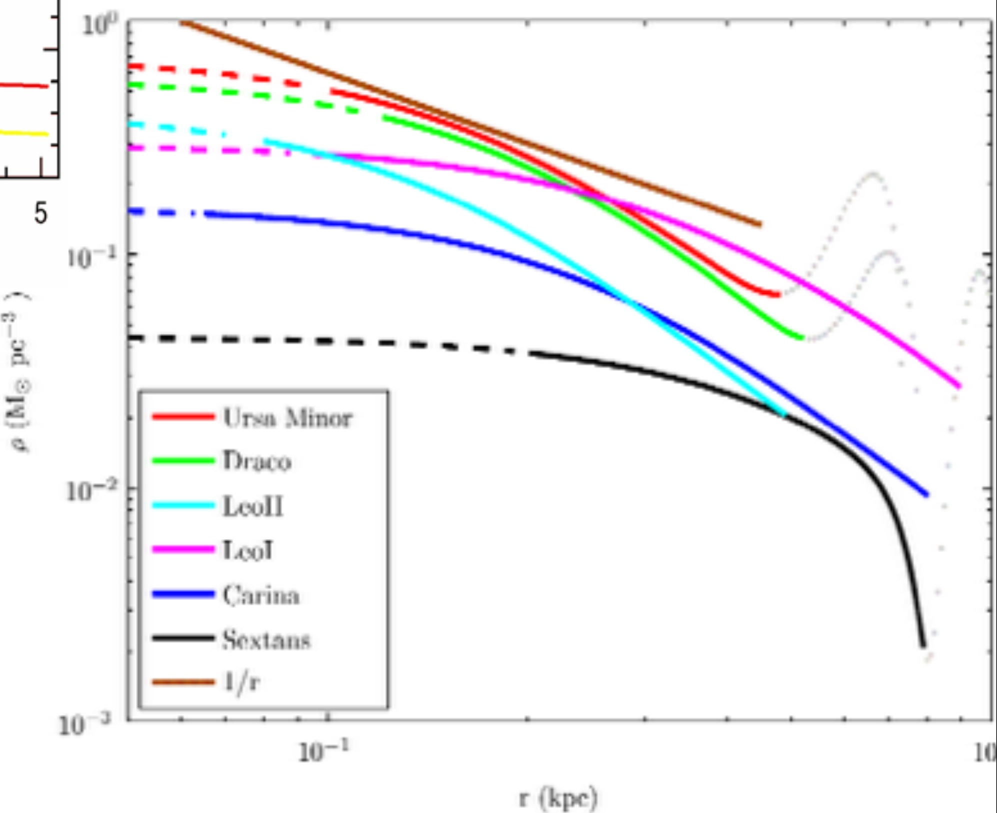
- Extreme fine tuning
- Coincidence
- Cuspy central density profiles
- Missing Satellites Problem
- Satellites stability
- Too big to fail
- No-detection of DM
- etc.

The Standard Model of Cosmology: Problems

- Cuspy central density profiles
- Missing Satellites Problem
- Satellites stability

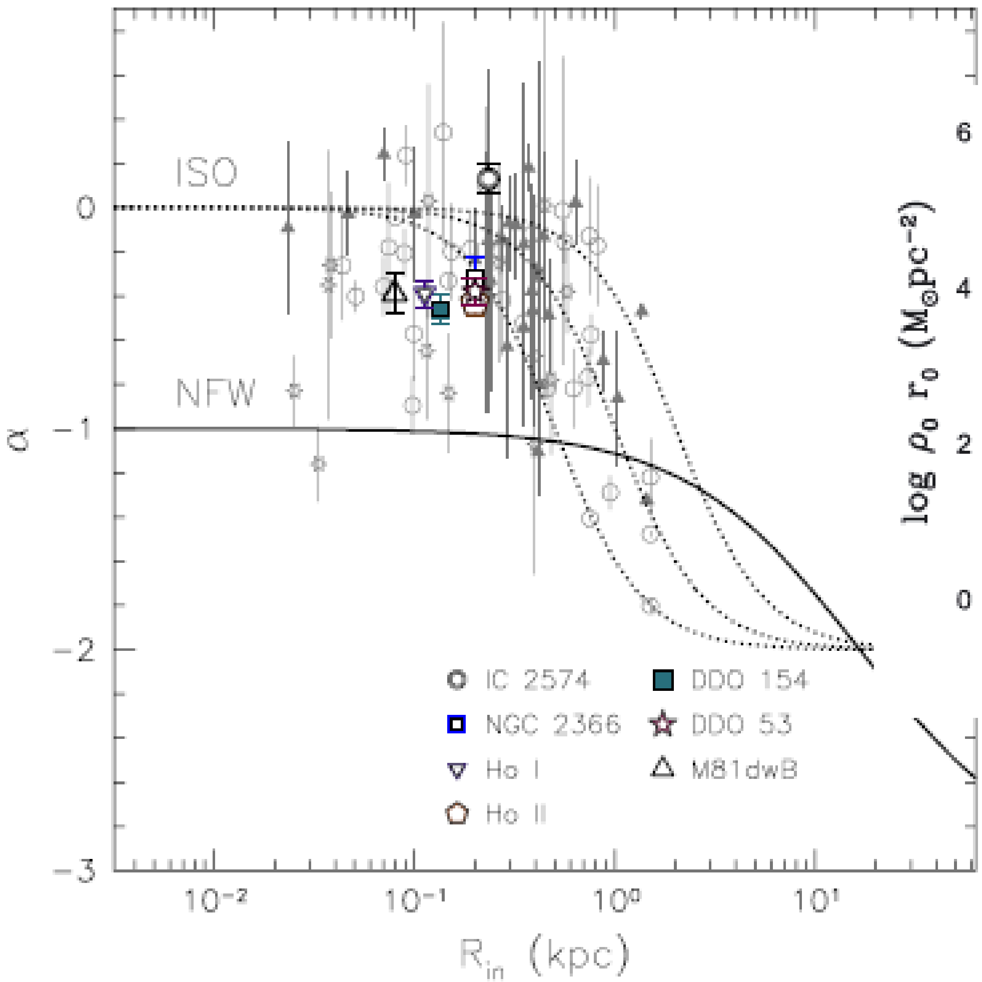
Galaxy's Center: Observations

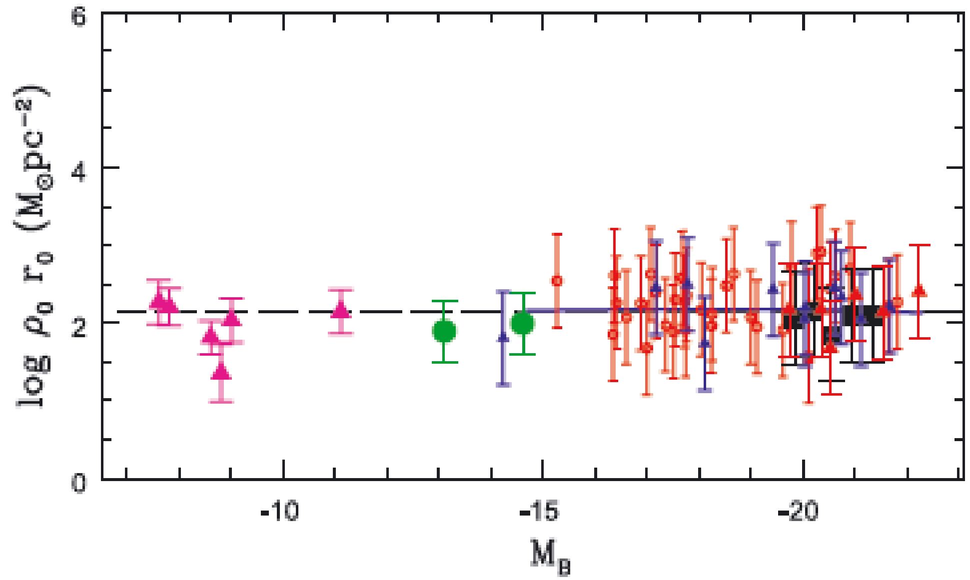




Galaxy's Center: Observations

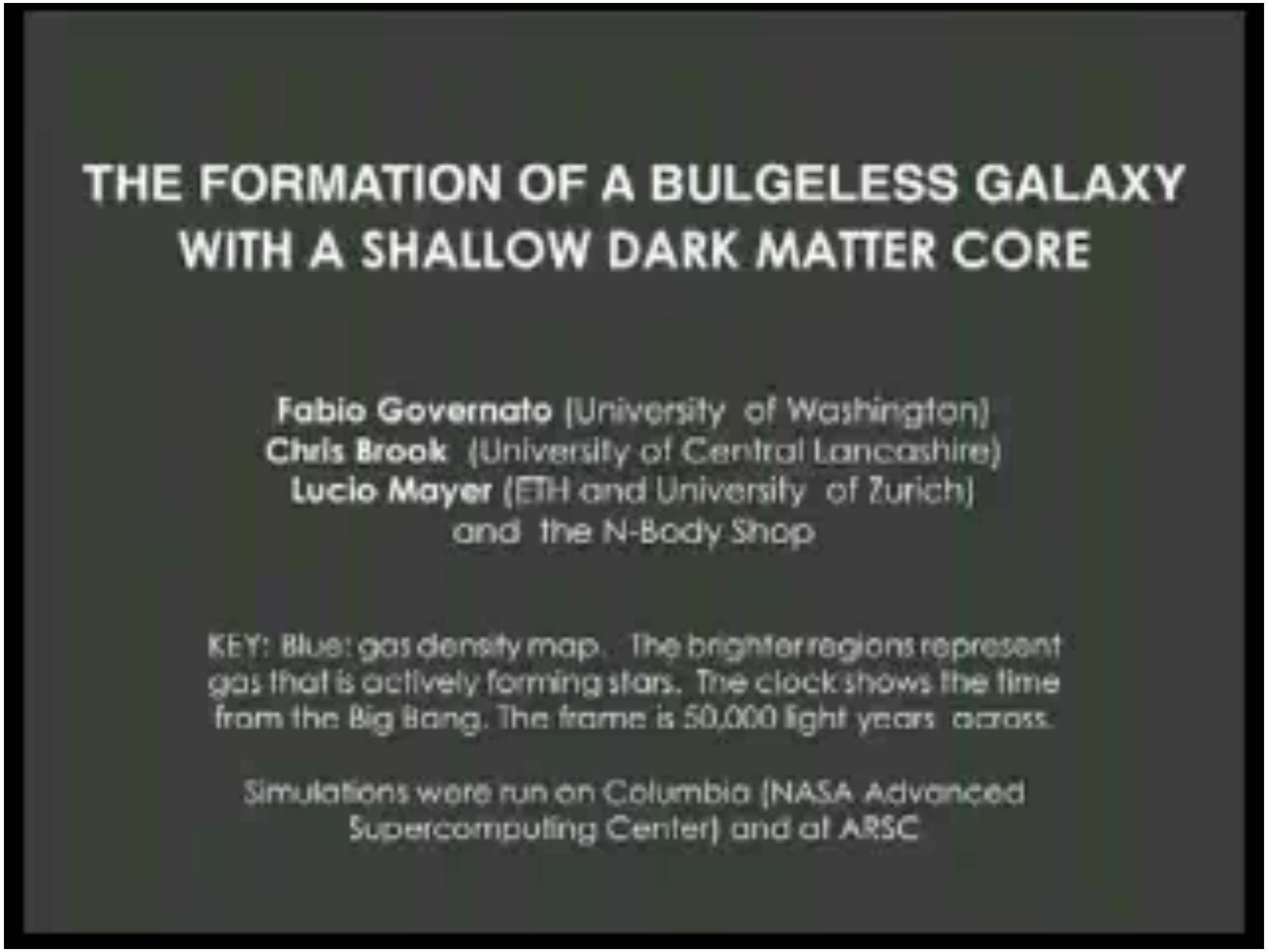
Gentile G., Tonini C. and Salucci P., A&A, 467, 925-931 (2007).





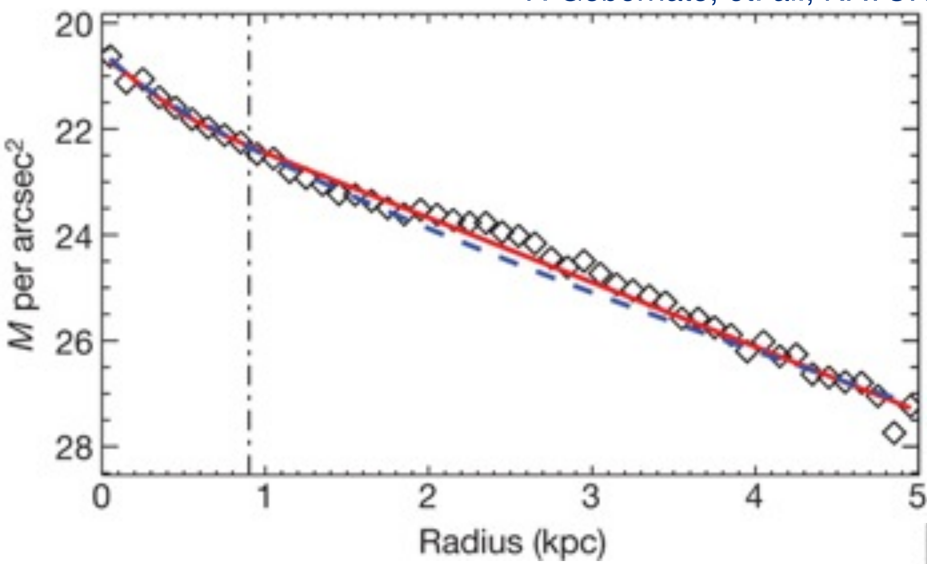
Galaxy’s Center: Simulations

F. Gobernato, et. al., NATURE, Vol 463, 14 January 2010



Galaxy's Center: Simulations

F. Gobernato, et. al., NATURE, Vol 463, 14 January 2010

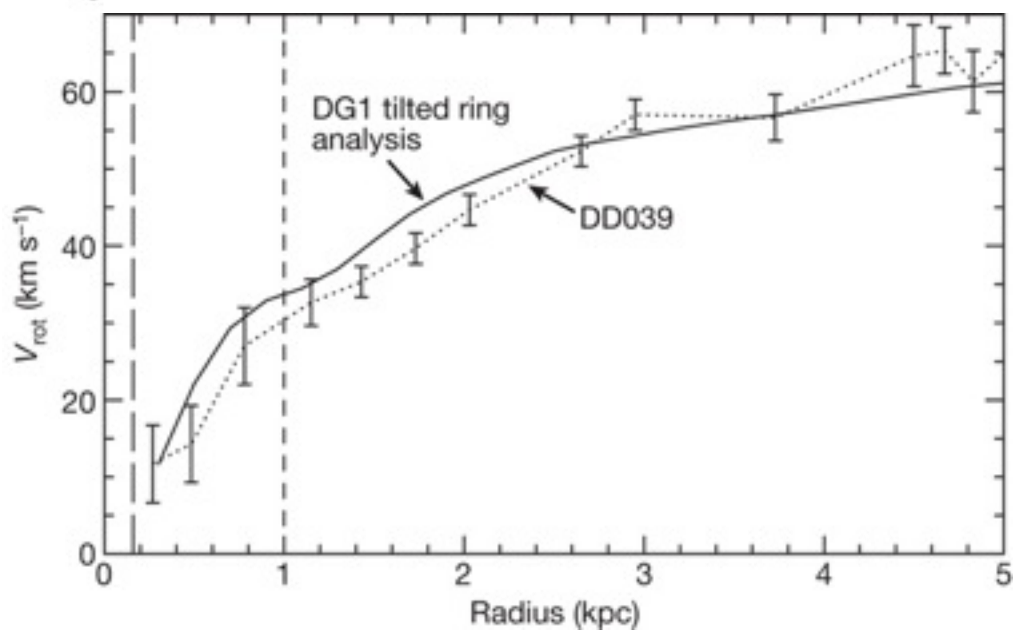


Einasto profile

$$\rho = \rho_0 e^{-A\, r^{\alpha}}$$

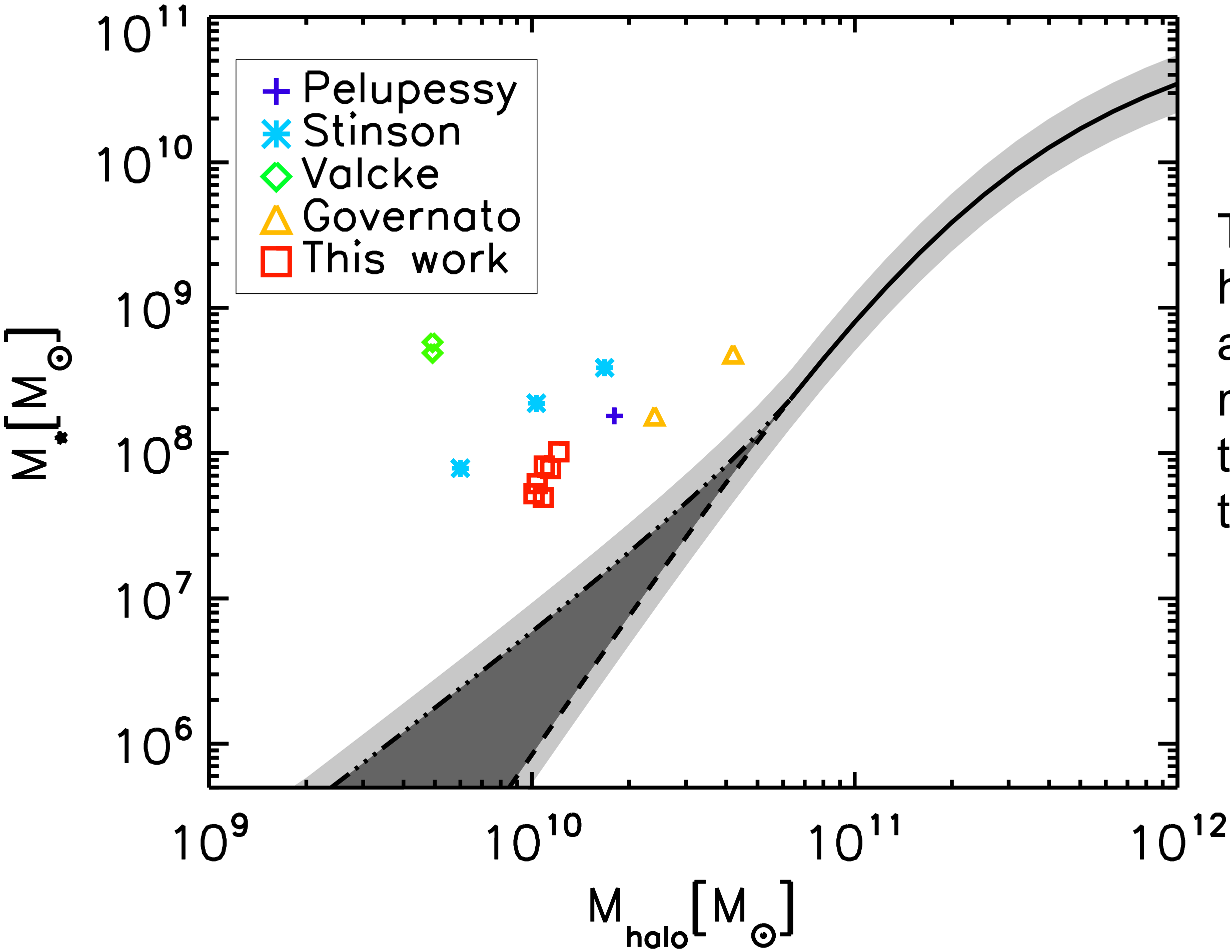
No evidence for internal features or star formation that could be the result of tidal processes or star formation induced by the cluster environment.

ej: Samantha J. Penny, Christopher J. Conselice, Sven De Rijcke and Enrico V. Held**:**
Mon. Not. R. Astron. Soc. 393, 1054–1062 (2009), etc.



Stellar Mass Predictions

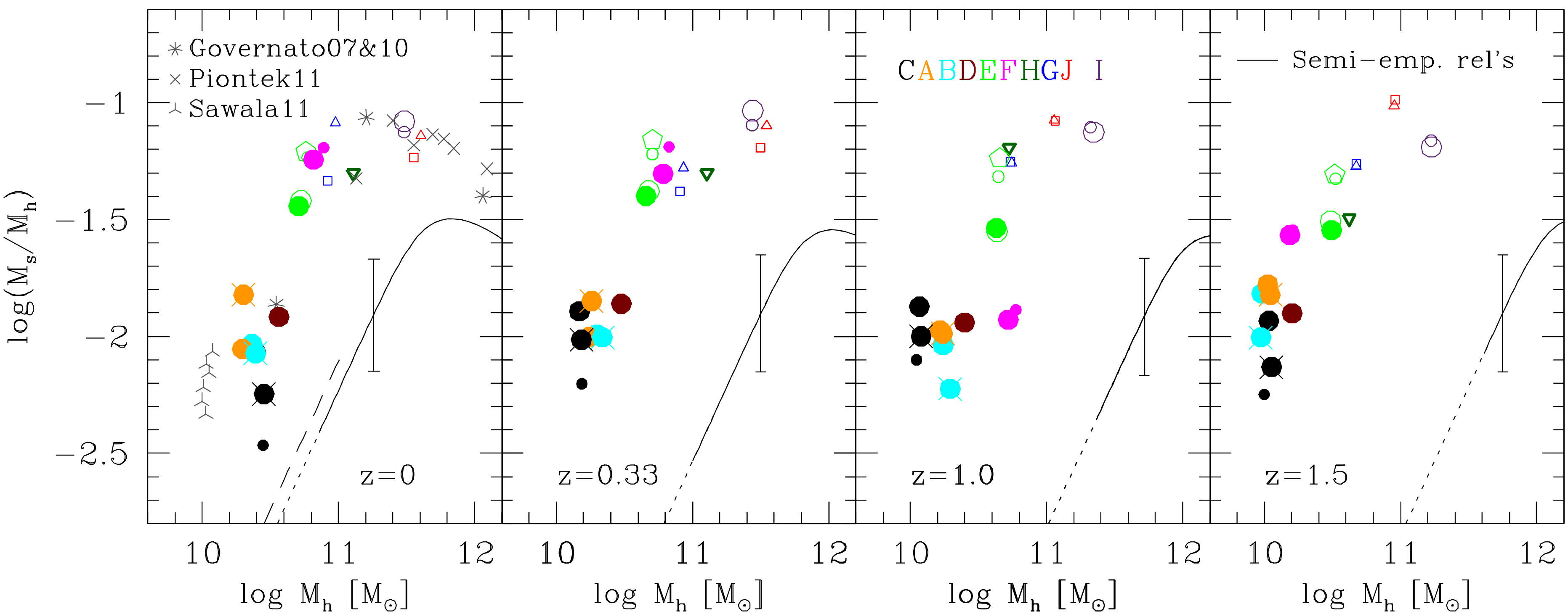
Till Sawala, Qi Guo, Cecilia Scannapieco, Adrian Jenkins and Simon White. Mon. Not. Roy. Astron. Soc. 413, (2011), 659



The dwarf galaxies formed in hydrodynamical simulations are almost two orders of magnitude more luminous than expected for haloes of this mass.

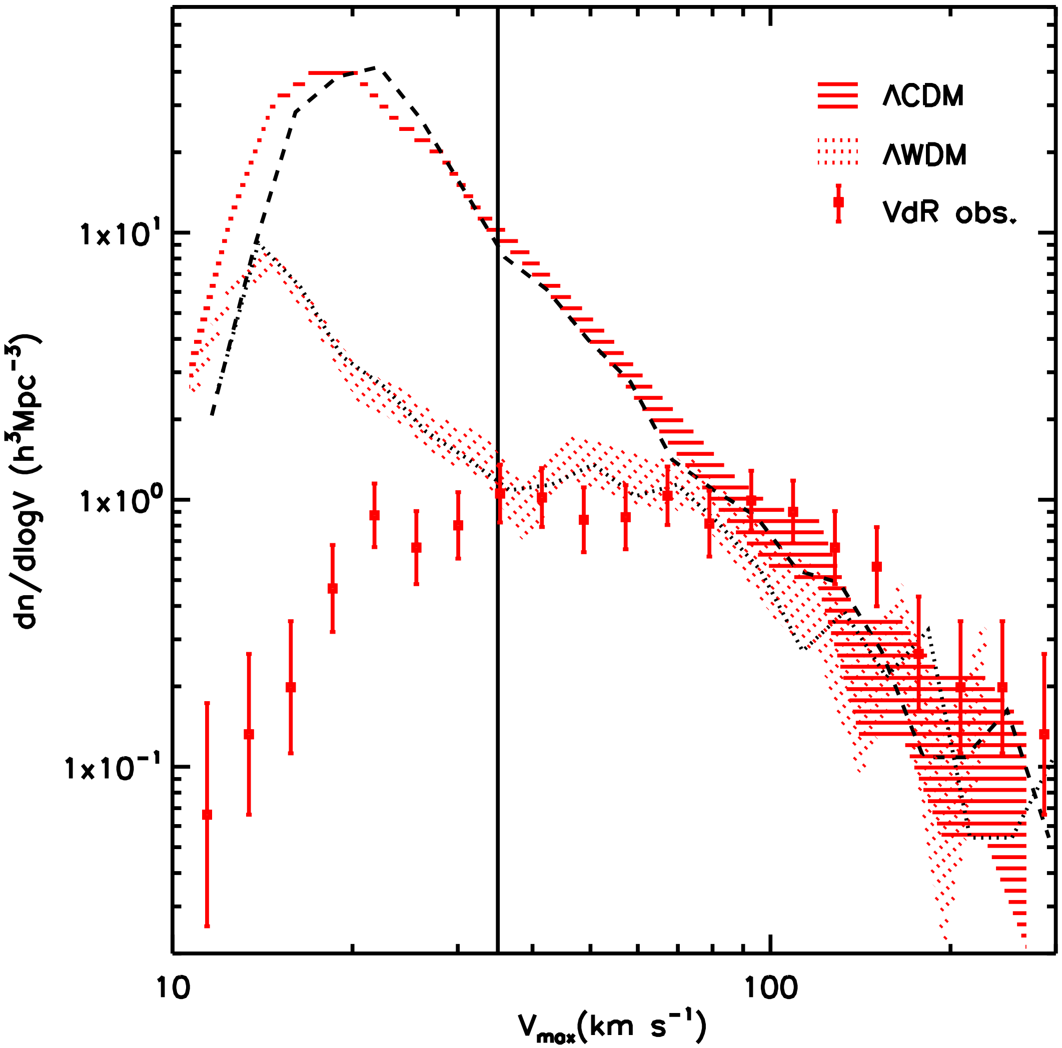
Stellar Mass Predictions

V. Avila-Reese, P. Colín, A. González-Samaniego, O. Valenzuela, C. Firmani, H. Velázquez, & D. Ceverino. The ApJ, 736:134, (2011)



Velocity predictions

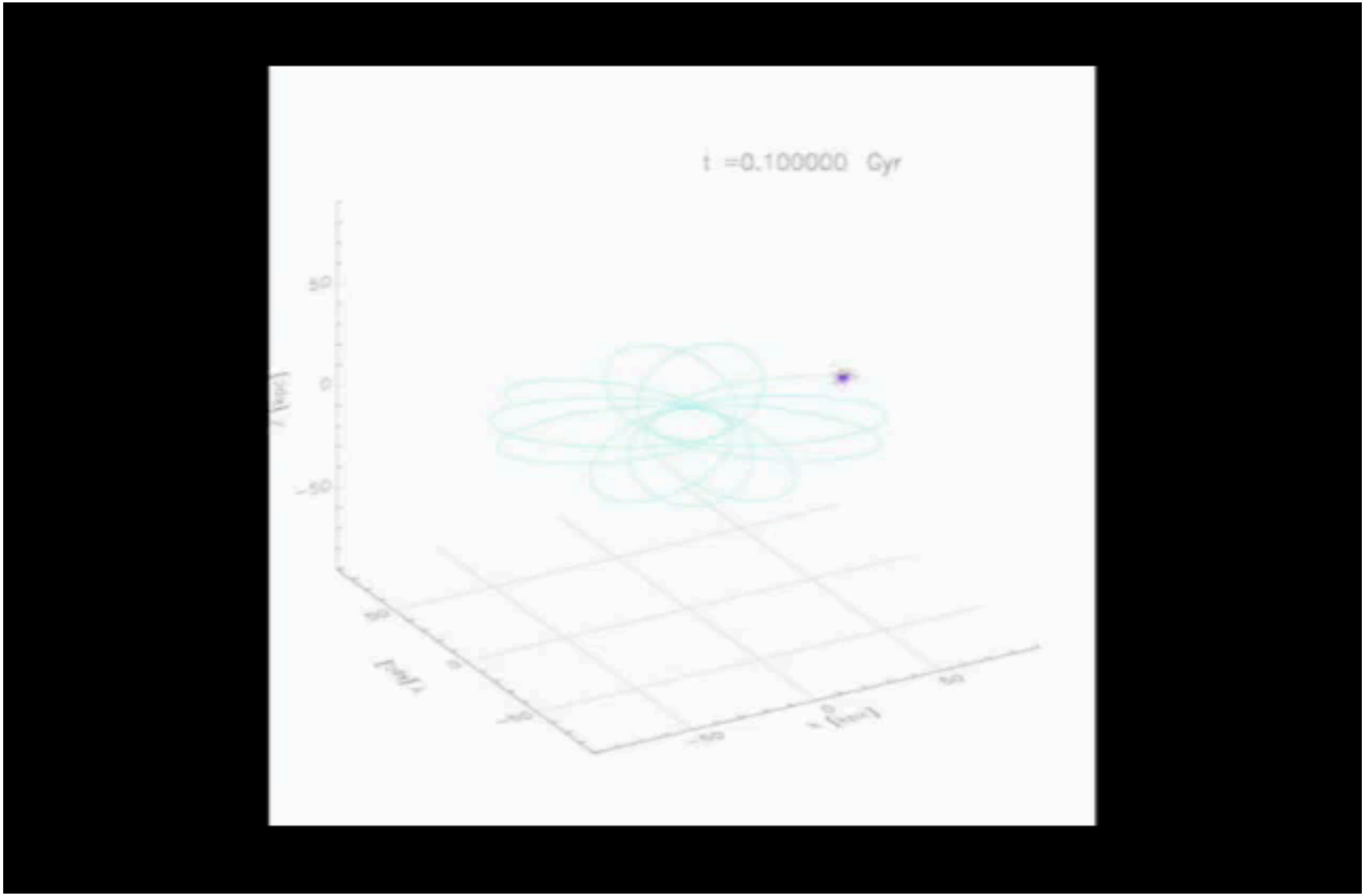
Jesús Zavala, et. al. ApJ, 700:1779–1793, 2009 August 1

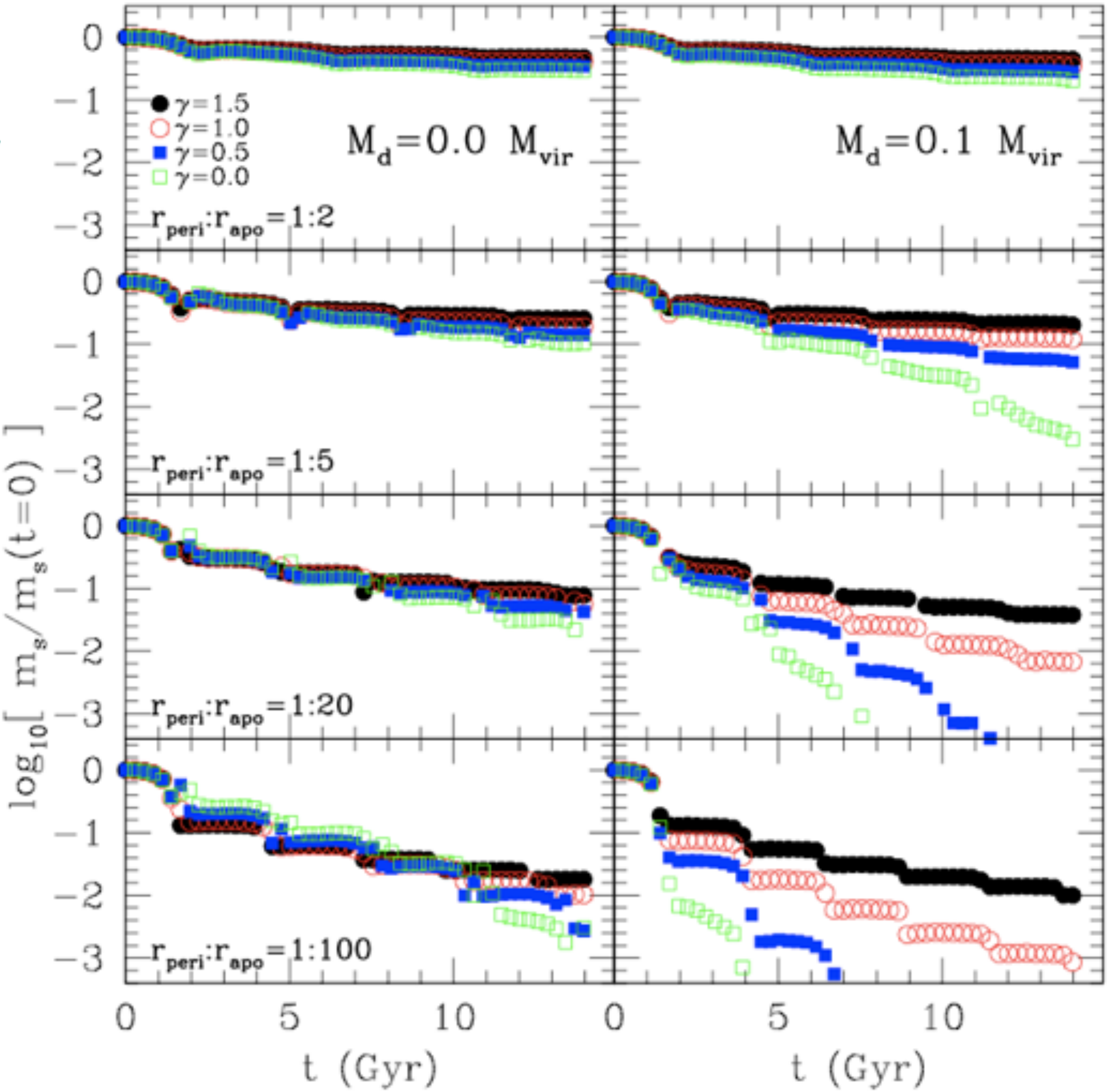


The simulation with CDM predicts a steep rise in the VF toward lower velocities; for Vmax = 35 km/s, it forecasts ~10 times more sources than the ones observed. If confirmed by the complete ALFALFA survey, these results indicate a potential problem for the CDM paradigm

Galactic Dynamics

J. Peñarrubia, A. J. Benson, M. G. Walker,G. Gilmore, A. W. McConnachie & L. Mayer. MNRAS 406(2010)1290





γ=1.5
γ=1.0
γ=0.5
γ=0.0
M_d=0.0 M_vir
M_d=0.1 M_vir
r_peri:r_apo=1:2
r_peri:r_apo=1:5
r_peri:r_apo=1:20
r_peri:r_apo=1:100
log_10[m_s/m_s(t=0)]
t (Gyr)
0
5
10
0
−1
−2
−3

The Cosmology

T. Matos and L. Ureña, Class. Q. Grav. 17(2000)L75

- Dark Matter: → $\frac{1}{2}m^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$
- Dark Energy: → Λ

- Baryons, Radiation,
- Neutrinos, etc.

- $\Omega_\Phi \sim 0.23$
- $\Omega_\Lambda \sim 0.73$
- $\Omega_b \sim 0.04$

Bose-Einstein Condensates

A Review on the Scalar Field/ Bose-Einstein Dark Matter model. Abril Suarez, Victor Robles and Tonatiuh Matos. arXiv:1302.0903

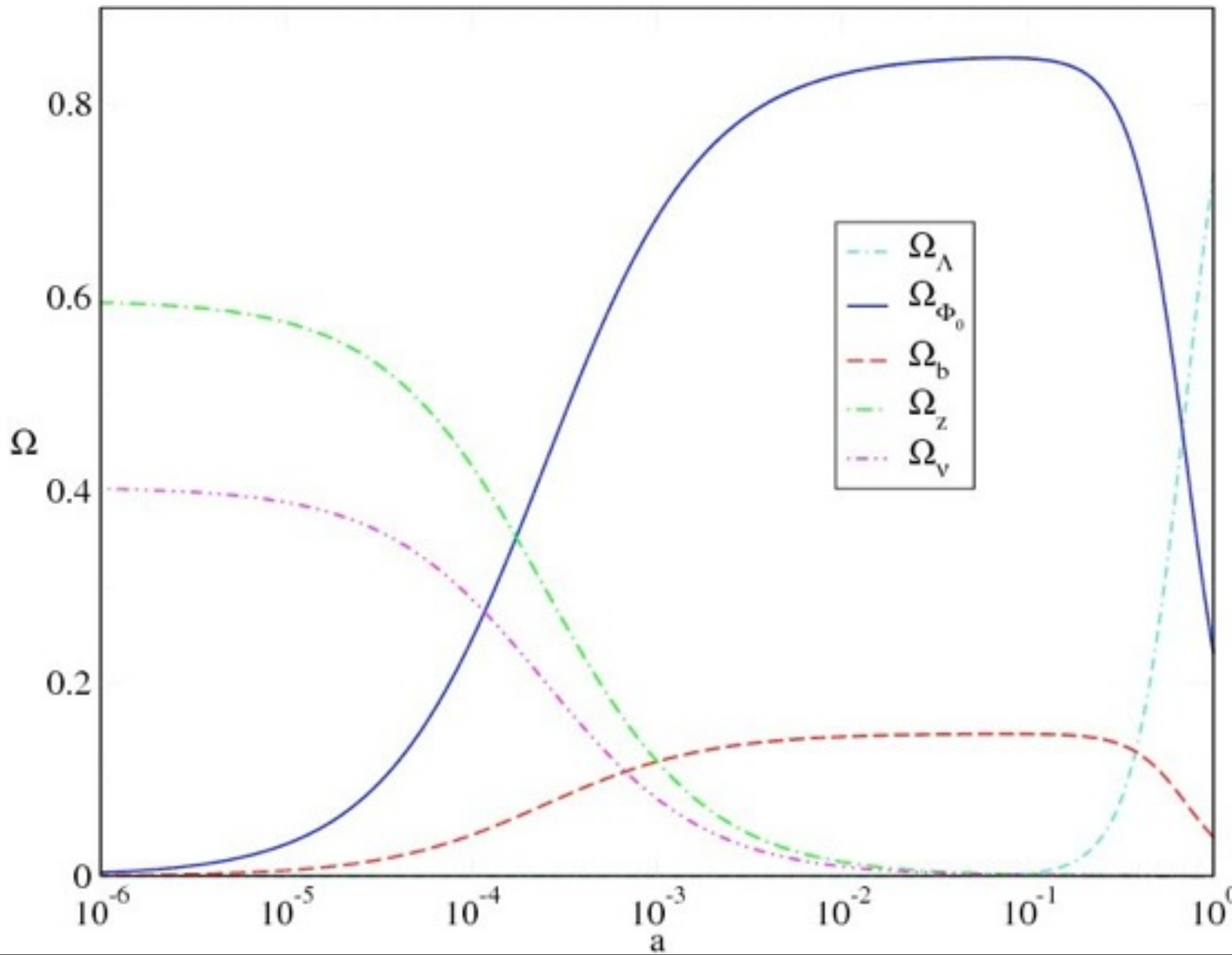
$$\Box\Phi + \frac{dV}{d\Phi} = 0$$

$$\ddot{\Phi} + 3H\dot{\Phi} + \frac{dV}{d\Phi} = 0$$

$$k_B T_c = \frac{2\pi\hbar^2}{m^{\frac{5}{3}}} \left(\frac{\rho}{g_{\frac{3}{2}}(1)} \right)^{\frac{2}{3}}$$

The Cosmology

Φ^2 as Dark Matter. T. Matos, A. Vázquez & J.A. Magaña. MNRAS, 389, (2009) 13957.

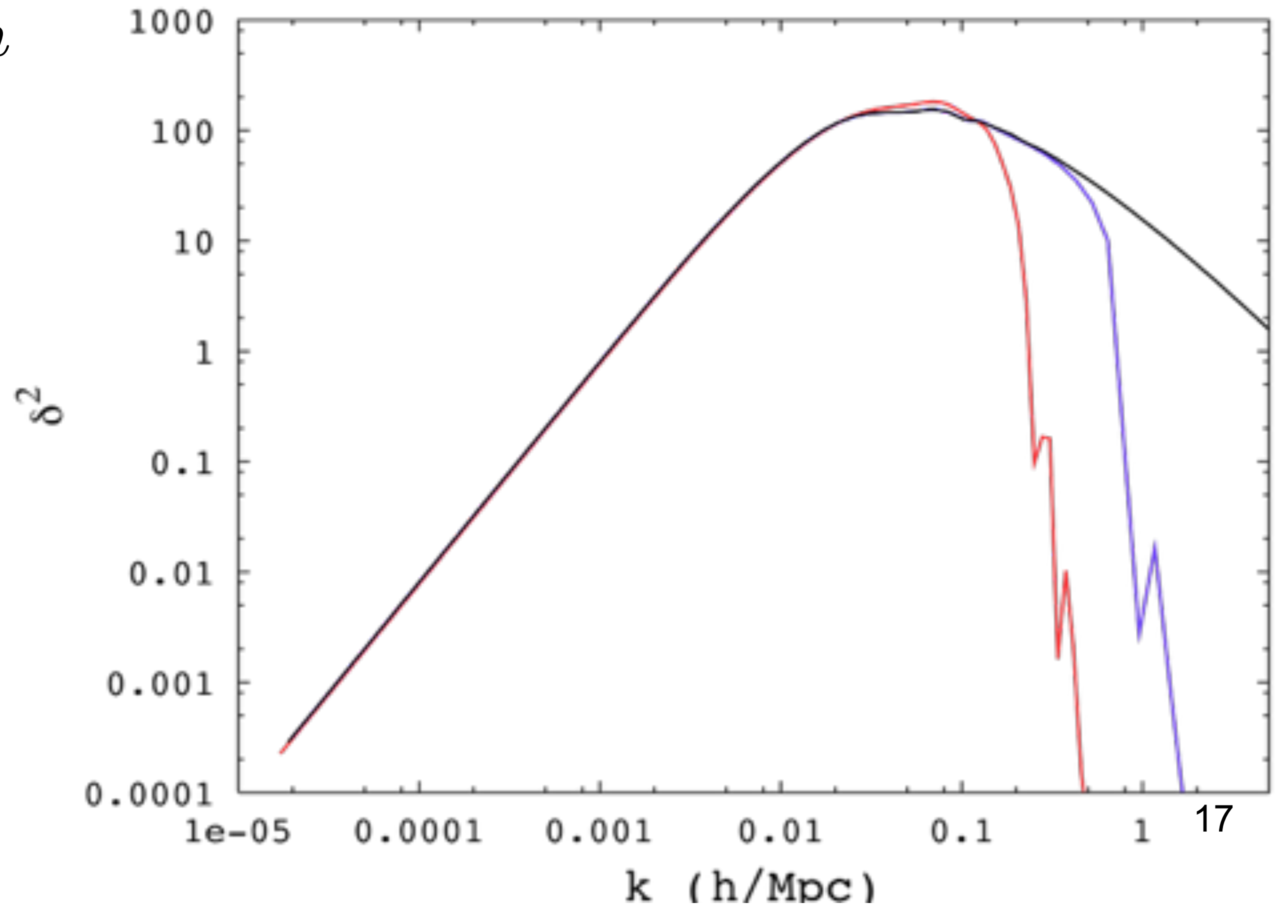


Natural Cut off

Tonatiuh Matos and Luis A. Ureña. Phys Rev. D63, (2001), 063506. Available at: astro-ph/ 0006024

$$\delta\ddot{\Phi}_k + 3H\delta\dot{\Phi}_k + \left(\frac{k^2}{a^2} + V_{,\Phi\Phi}\right)\delta\Phi_k + 2V_{,\Phi}\,\phi_k - 4\Phi_0\dot{\phi}_k = 0$$

In Φ_{min}



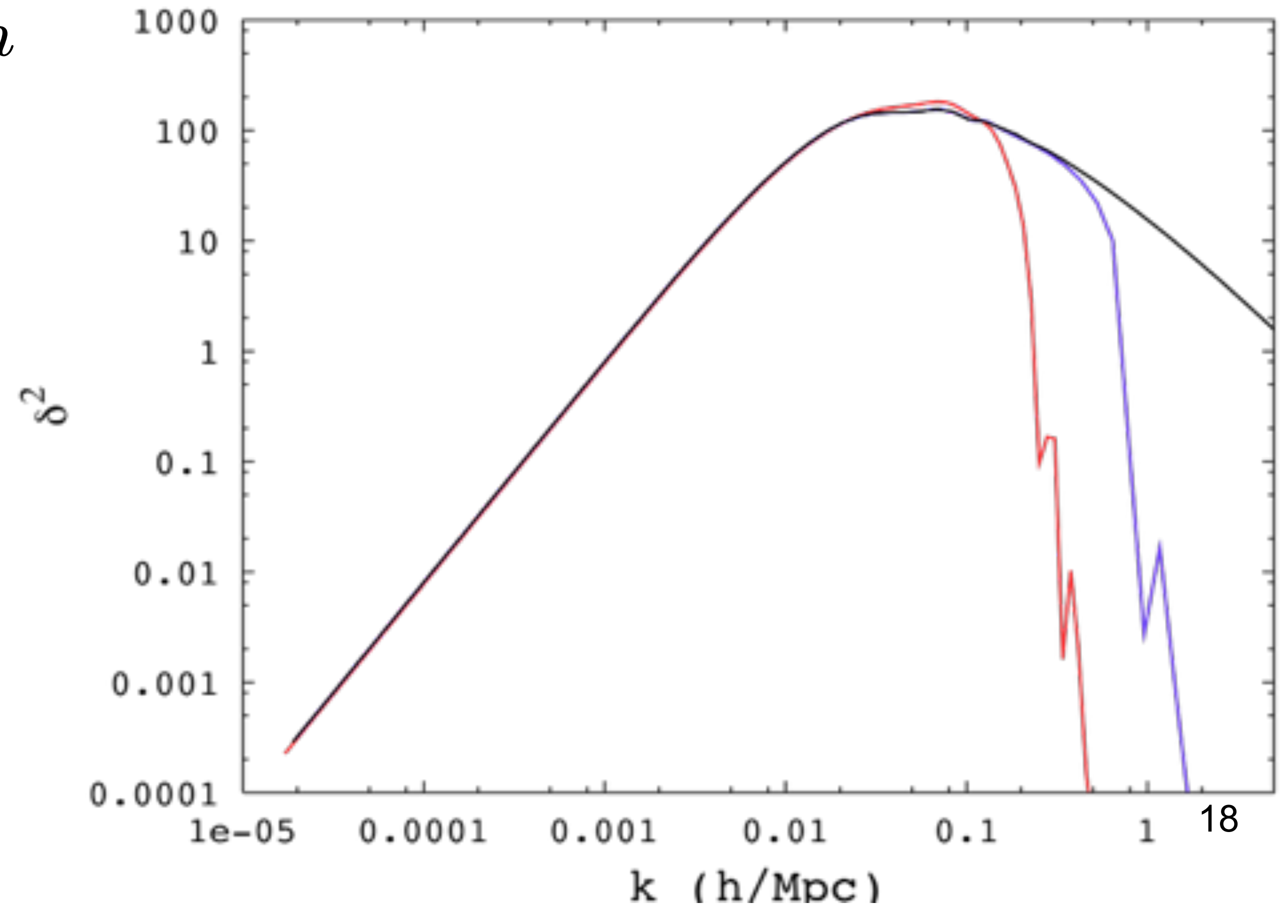
T << *T*c

Natural Cut off

Tonatiuh Matos and Luis A. Ureña. Phys Rev. D63, (2001), 063506. Available at: astro-ph/ 0006024

$$\delta\ddot{\Phi}_k + 3H\delta\dot{\Phi}_k + \left(\frac{k^2}{a^2} - m^2 + \frac{\lambda}{4}T^2\right)\delta\Phi_k = 4\Phi_0\dot{\phi}_k$$

In Φ_{min}



T << *T*$_c$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\delta\ddot{\Phi} + 3H\delta\dot{\Phi} - \frac{1}{a^2}\nabla^2\delta\Phi + V_{,\Phi\Phi}\,\delta\Phi + 2V_{,\Phi}\,\phi = 0$$

$$\delta\Phi = \sqrt{\hat{\rho}}\cos\left(\frac{mc^2\,t}{\hbar} + S\right)$$

$$\vec{v} \equiv \frac{\hbar}{m}\nabla S$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\vec{v} \equiv \frac{\hbar}{m}\nabla S$$

$$\begin{aligned}
\frac{\partial\hat{\rho}}{\partial t} &+ \frac{1}{a^2}\nabla\cdot(\hat{\rho}\vec{v}) + 3H\hat{\rho} \\
&- \frac{\hbar}{m}\hat{\rho}\left(\ddot{S} + 3H\dot{S}\right) - \frac{\hbar}{m}\dot{\hat{\rho}}\dot{S} = 0 \\
\frac{\partial\vec{v}}{\partial t} &+ \frac{1}{a^2}\vec{v}\nabla\cdot\vec{v} + \nabla\phi + \frac{\hbar^2}{2m^2}\nabla\left(\frac{\Box\sqrt{\hat{\rho}}}{\sqrt{\hat{\rho}}}\right) \\
&- \frac{\hbar}{m}\dot{S}\,\frac{\partial\vec{v}}{\partial t} = 0,
\end{aligned}$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\vec{v} \equiv \frac{\hbar}{m}\nabla S$$

$$\frac{\partial\hat{\rho}}{\partial t} \quad + \quad \frac{1}{a^2}\nabla\cdot(\hat{\rho}\vec{v}) + 3H\hat{\rho} = 0$$

$$\frac{\partial\vec{v}}{\partial t} \quad + \quad \frac{1}{a^2}\vec{v}\nabla\cdot\vec{v} + \nabla\phi + \frac{\hbar^2}{2m^2}\nabla\left(\frac{\Box\sqrt{\hat{\rho}}}{\sqrt{\hat{\rho}}}\right) = 0,$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\hat{\rho} = \hat{\rho}(t) \qquad S = S(t) \qquad \vec{v} \equiv \frac{\hbar}{m}\nabla S$$

$$\frac{\partial \hat{\rho}}{\partial t} + \frac{1}{a^2}\nabla \cdot (\hat{\rho}\vec{v}) + 3H\hat{\rho} = 0$$

$$\frac{\partial \vec{v}}{\partial t} + \frac{1}{a^2}\vec{v}\nabla \cdot \vec{v} + \nabla\phi + \frac{\hbar^2}{2m^2}\nabla\left(\frac{\Box\sqrt{\hat{\rho}}}{\sqrt{\hat{\rho}}}\right) = 0,$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\hat{\rho} = \hat{\rho}(t) \qquad S = S(t) \qquad \vec{v} \equiv \frac{\hbar}{m}\nabla S$$

$$\frac{\partial \hat{\rho}}{\partial t} + 3H\hat{\rho} = 0$$

$$\hat{\rho} \sim \frac{1}{a^3}$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\vec{v} \equiv \frac{\hbar}{m}\nabla S$$

$$\frac{\partial\hat{\rho}}{\partial t} + \frac{1}{a^2}\nabla\cdot(\hat{\rho}\vec{v}) = 0$$

$$\frac{\partial\vec{v}}{\partial t} + \frac{1}{a^2}\vec{v}\nabla\cdot\vec{v} + \nabla\phi + \frac{\hbar^2}{2m^2}\nabla\left(\frac{\Box\sqrt{\hat{\rho}}}{\sqrt{\hat{\rho}}}\right) = 0,$$

Structure Formation

Abril Suarez and TM MNRAS 311, (2011), 87

$$\begin{aligned}\hat{\rho} &= \hat{\rho}_0 + \rho_1(t)\exp(i\vec{k}\cdot\vec{x}/a)\\ \vec{v} &= \vec{v}_0 + \vec{v}_1(t)\exp(i\vec{k}\cdot\vec{x}/a)\\ \phi &= \phi_0 + \phi_1(t)\exp(i\vec{k}\cdot\vec{x}/a)\end{aligned}$$

$$\vec{v}_1 = \lambda\vec{k} + \vec{v}_2$$

$$\begin{aligned}\frac{\partial\rho_1}{\partial t} + 3H\rho_1 + i\frac{\hat{\rho}_0}{a^2}k^2\lambda &= 0\\ \frac{\partial\lambda}{\partial t} + i(\frac{v_q^2}{\hat{\rho}_0} - 4\pi G\frac{a^2}{k^2})\rho_1 &= 0,\end{aligned}$$

$$\delta = \frac{\rho_1}{\hat{\rho}}$$

SFDM

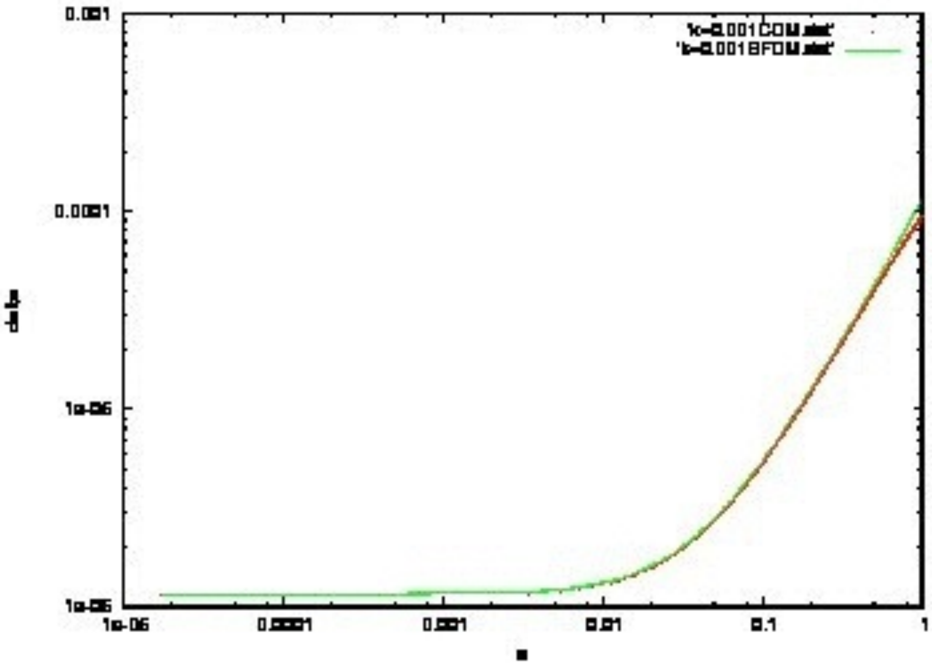
$$\frac{d^2\delta}{dt^2} + 2\,H\frac{d\delta}{dt} + \left(v_q^2\frac{k^2}{a^2} - 4\pi G\hat{\rho}_0\right)\delta = 0, \qquad v_q^2 = \frac{\hbar^2k^2}{4a^2m^2}$$

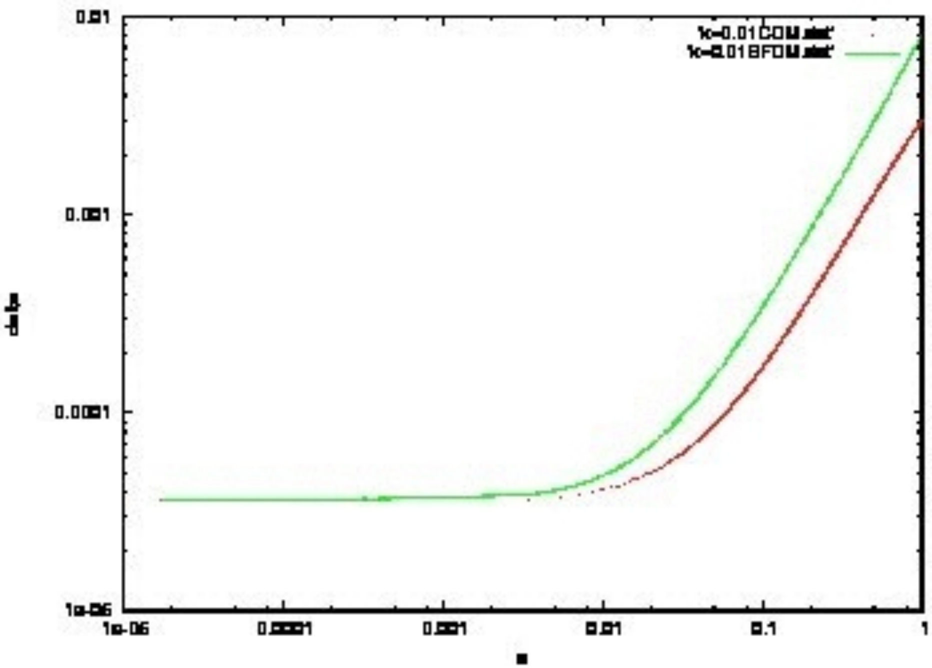
CDM

$$\frac{d^2\delta}{dt^2} + 2\,H\frac{d\delta}{dt} + \left(v_s^2\frac{k^2}{a^2} - 4\pi G\hat{\rho}_0\right)\delta = 0,$$

Structure Formation

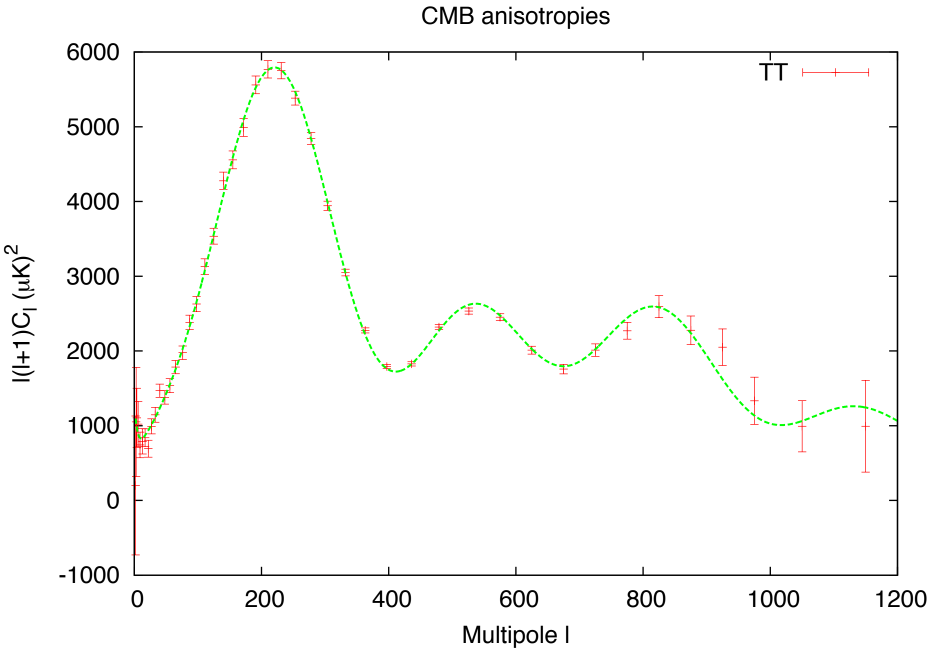
Abril Suarez and TM MNRAS 311, (2011), 87

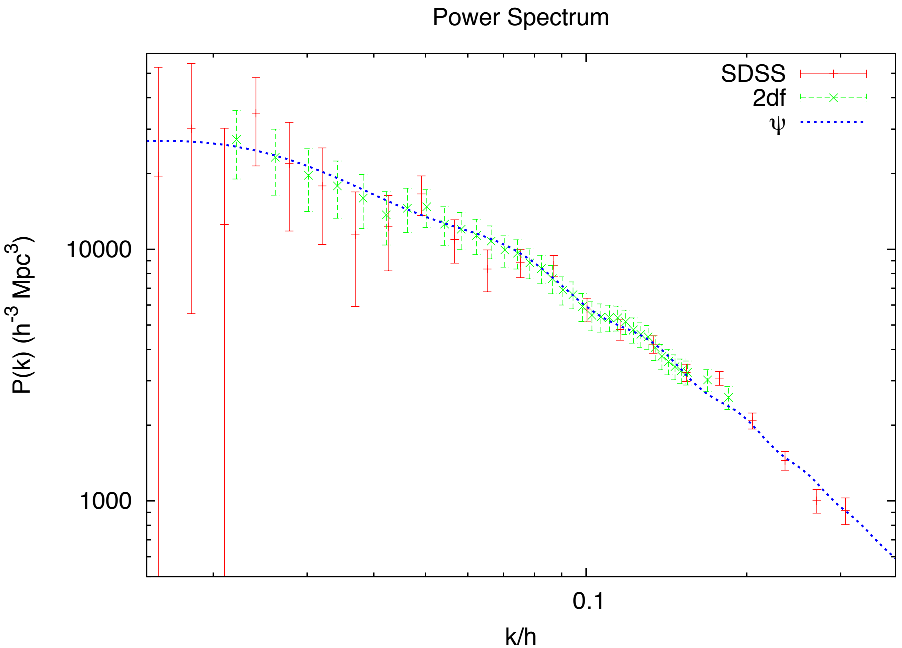




The Cosmology

I. Rodriguez, A. Pérez-Lorenzana, E. de la Cruz, Y. Giraud-Héraud and TM. Bosonic Cosmic Dark Matter. Phys. Rev. D87(2013)025009. arXiv:1110.2751





Scalar Field Fluctuation = Halo

J. Balakrishna, E. Seidel and W. Suen. PRD 58(1998)104004

M.Alcubierre, F. S. Guzmán, T. Matos, D. Núñez, L. A. Ureña and P. Wiederhold.
Galactic Collapse of Scalar Field Dark Matter. CQG 19(2002)5017. arXiv:gr-qc /0110102.

Pau Amaro-Seoane, Juan Barranco, Argelia Bernal and Luciano Rezzolla.
Constraining scalar fields with stellar kinematics and collisional dark matter. JCAP11 (2010)002

m ~ 1eV ⇨ $\lambda = 1 \times 10^{-6}$

$$M \sim 0.06\sqrt{\lambda}\,\frac{m_{pl}^3}{m^2}$$

$$T_c = \frac{2m}{\sqrt{\lambda}}$$

$$M \sim 10^{14}\,M_\odot$$

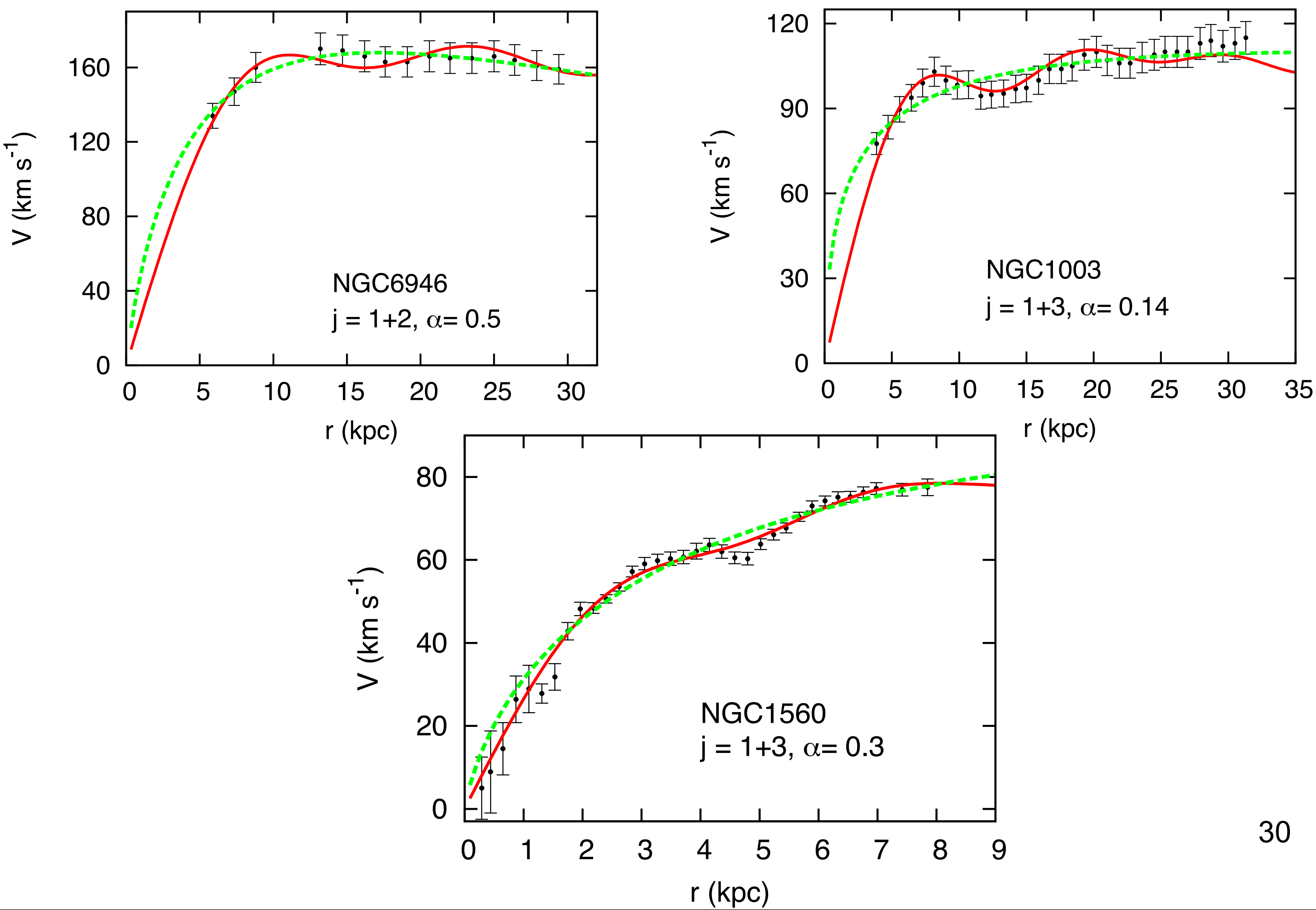
$$T_c \sim 2000\,eV$$

Axions vs SFDM

Barranco and Bernal, PRD 83,(2011)043525

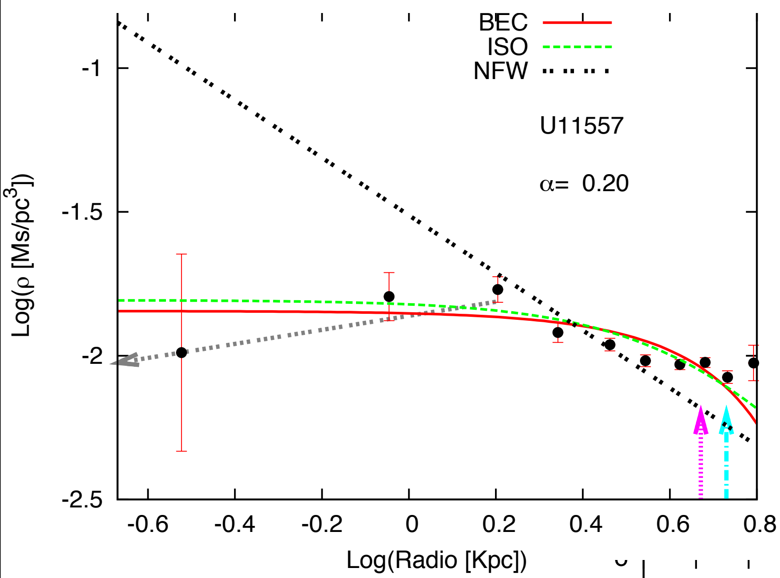
Galaxy Formation

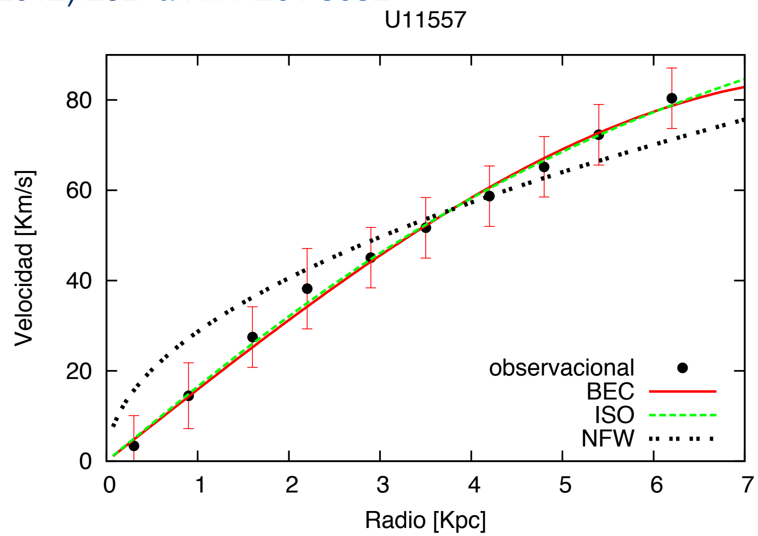
V. H. Robles and TM. MNRAS 392, (2012) in press. arXiv:1201.3032

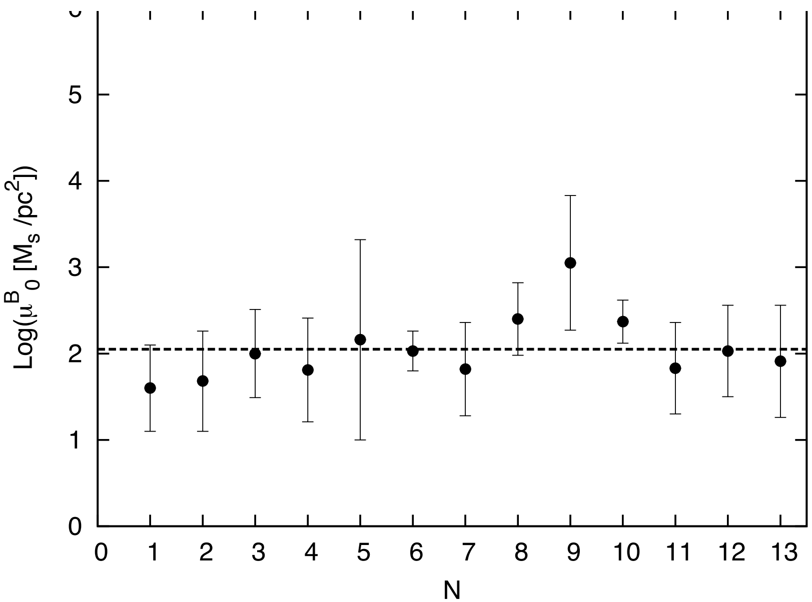


Galaxy Formation

V. H. Robles and TM. MNRAS 422, (2012) 282. arXiv:1201.3032







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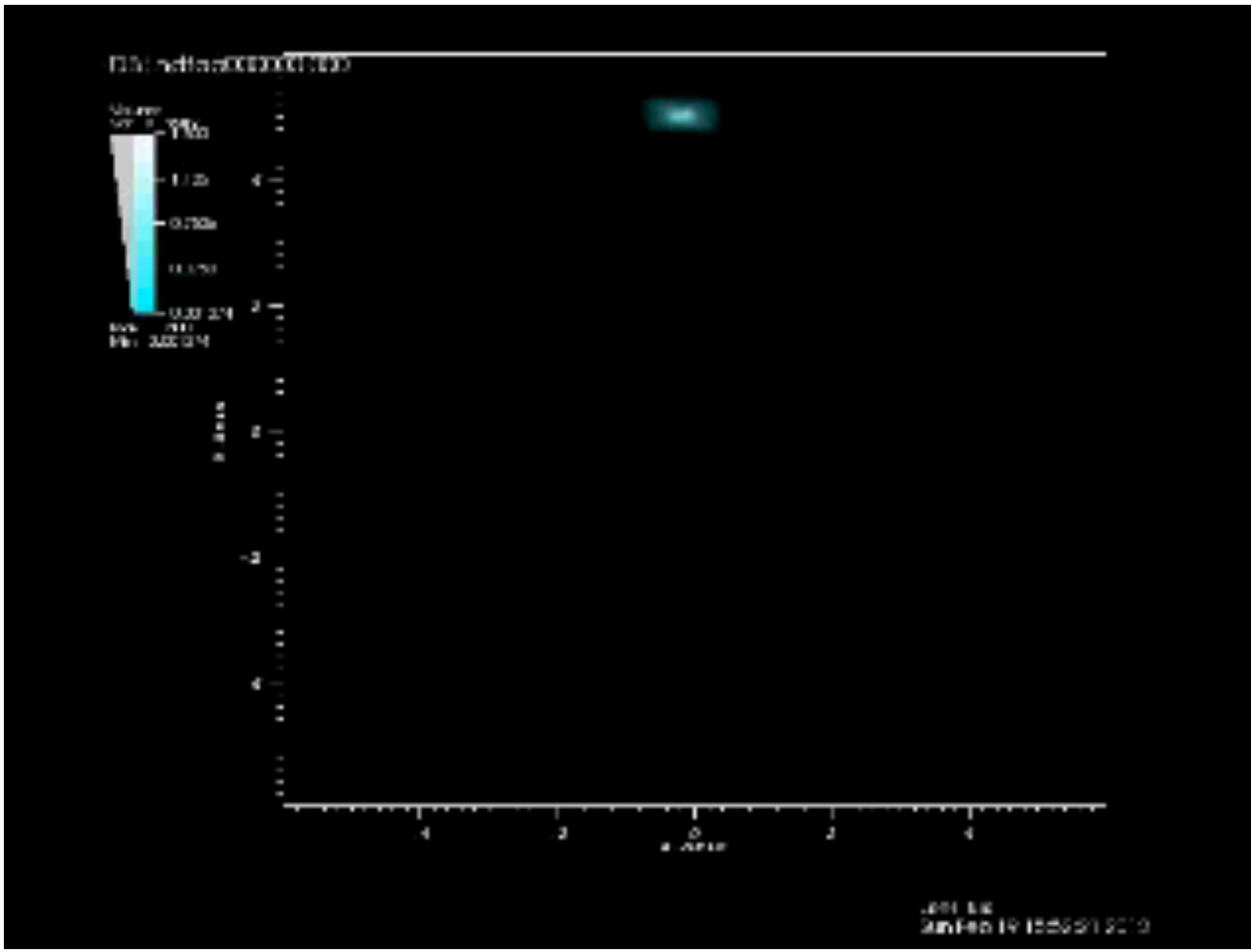
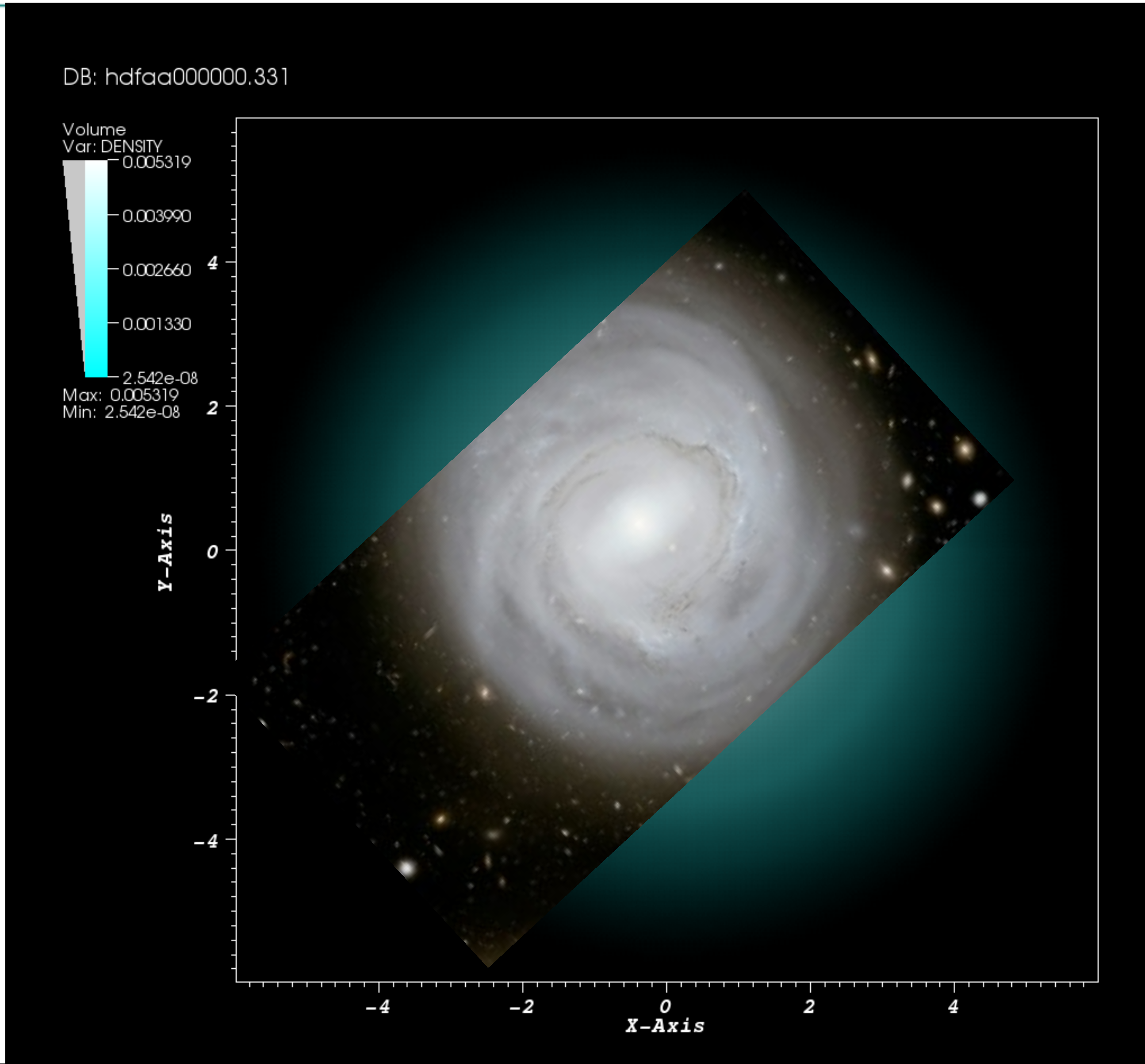
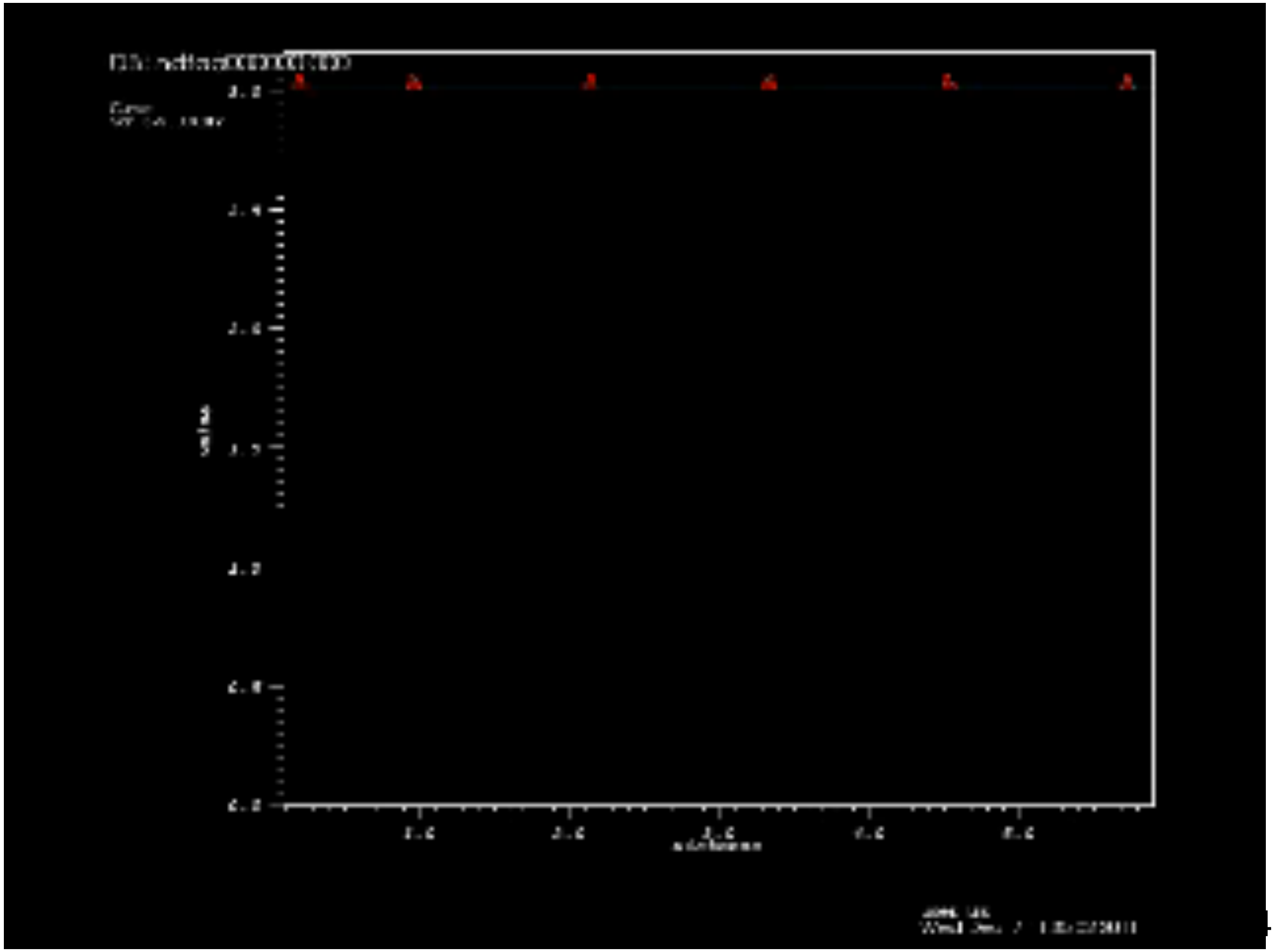
M.Alcubierre, F. S. Guzmán, T. Matos, D. Núñez, L. A. Ureña and P. Wiederhold.
Galactic Collapse of Scalar Field Dark Matter. CQG 19(2002)5017. arXiv:gr-qc /0110102.



Scalar Field Fluctuation=Halo

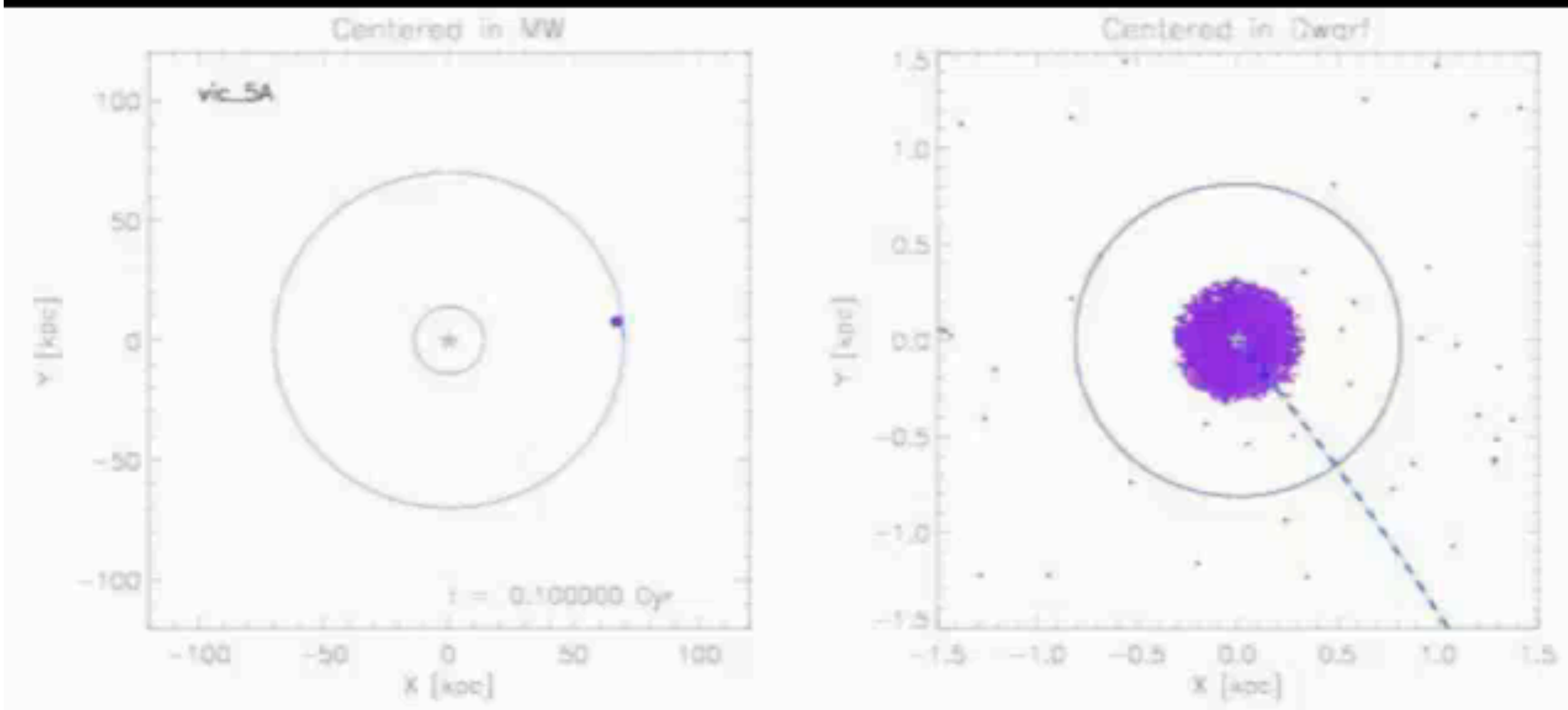


Scalar Field Fluctuation=Halo



Galactic Dynamics

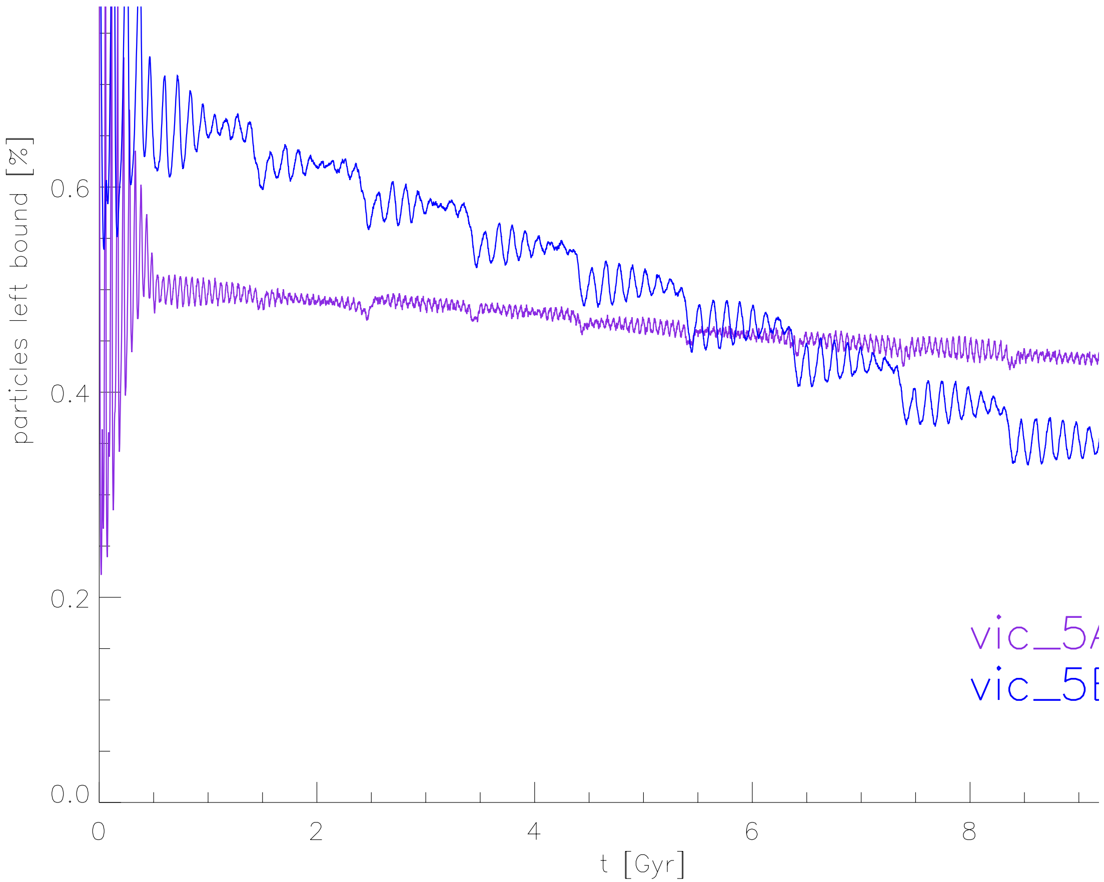
V. Lora, V. Robles, F.J. Sanchez-Salcedo and TM. In preparation



MW Potential + Dwarf DM Potential + Dwarf stellar component + Miyamoto-Nagai Disc
rho_Dwarf = 0.16 Msun/pc^3, peri = 14 kpc, apo = 70 kpc (Peri/Apo = 1/5)

Galactic Dynamics

V. Lora, V. Robles, F.J. Sanchez-Salcedo and TM. In preparation



SFDM

A brief Review of the Scalar Field Dark Matter model. Juan Magana, Tonatiuh Matos, Victor Robles, Abril Suarez. arXiv:1201.6107

Behaves like dust at cosmological level

Clusters form by hierarchy

Galaxies form by condensation of the SF

Haloes are BEC drops

MPS has a natural cut off

→

Same predictions for CMB and MPS

Same predictions for structure formation

Galaxies haloes form earlier and are similar

Galaxies are core

Substructure is restricted

Conclusion

- Scalar Field Dark Matter is so far an excellent candidate to be the Dark Matter in the Universe