Dynamics of BEC dark matter halos

Francisco Siddhartha Guzmán Murillo

UBC.ca + UMSNH.mx

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The Scalar Field Dark Matter model

The idea starts with an effective theory.
The Lagrangian density

$$L = -R + \partial^{\mu}\phi\partial_{\mu}\phi + V(\phi)$$

This was interpreted as an effective theory, that assumes the existence of a spinless particle represented by the scalar field.

The origin of the scalar field could have different roots, including particular *flavors* of string theory, other high-dimensional models (KK), a field coupled to EM, etc… it could also be associated to non-linear terms of ***R***, or the Einstein-frame version of Brans-Dicke theories…

guzman@ifm.umich.mx

The analysis of fluctuations

For the potential

$$V(\phi) = V_0[\cosh(\phi) - 1] \approx m^2\phi^2 + \cdots$$

the analysis of fluctuations, CMBR and Lambda, reveals that it shows the same properties of CDM with a BONUS: the mass is a parameter for the mass power spectrum.

The best fitting parameter of the spectrum happened to be

$$m \approx 10^{-23} eV$$

[T. Matos + L. A. Ureña-López 2000, 2001] [V. Sahni 2001]

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The cosmic SFDM vs LCDM

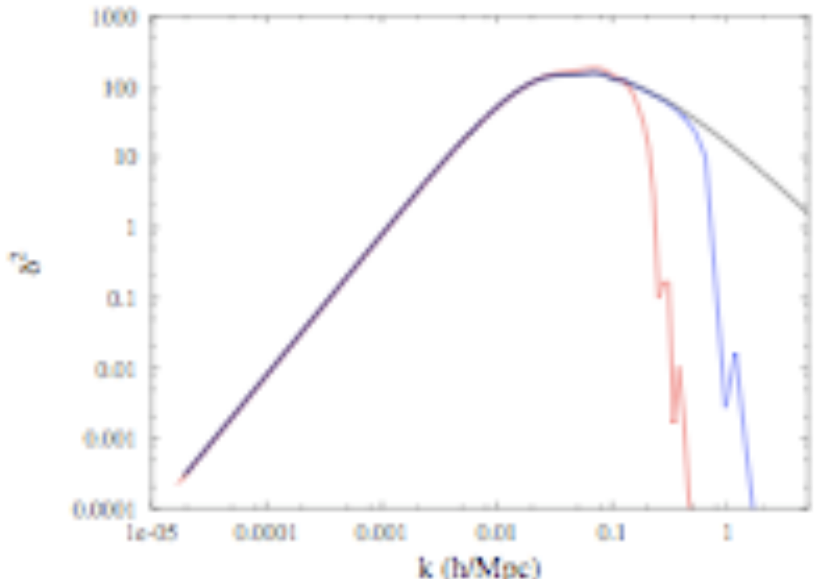
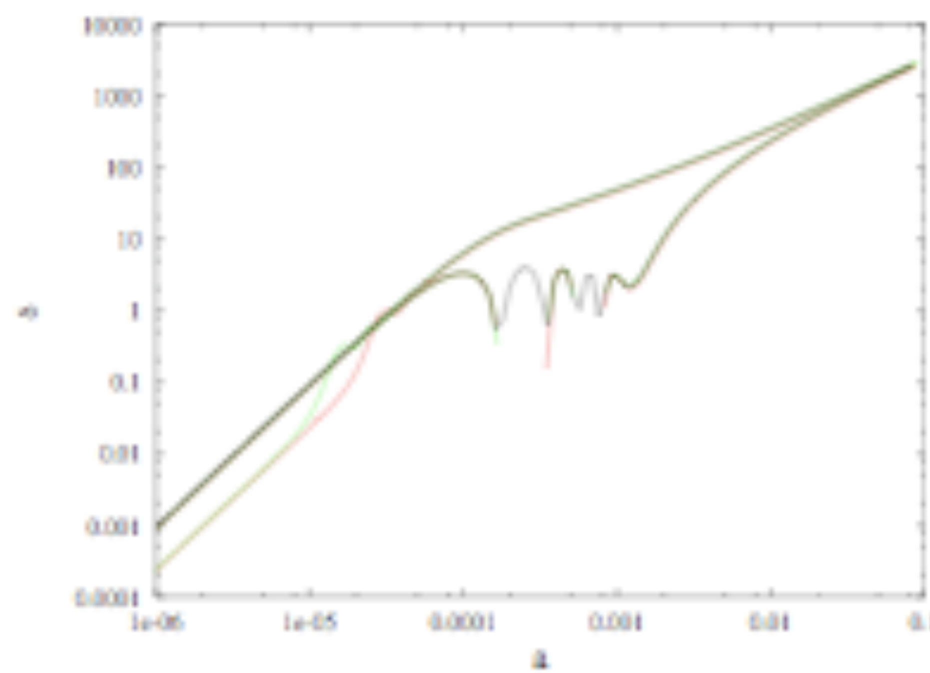


FIG. 5. Power spectrum at a redshift $z = 50$: ΛC
(black), and ΦCDM with $\lambda = 5$ (red) and $\lambda = 10$ (b
The normalization is arbitrary.



Can a SF work at galactic scale?

Are there solutions of the theory

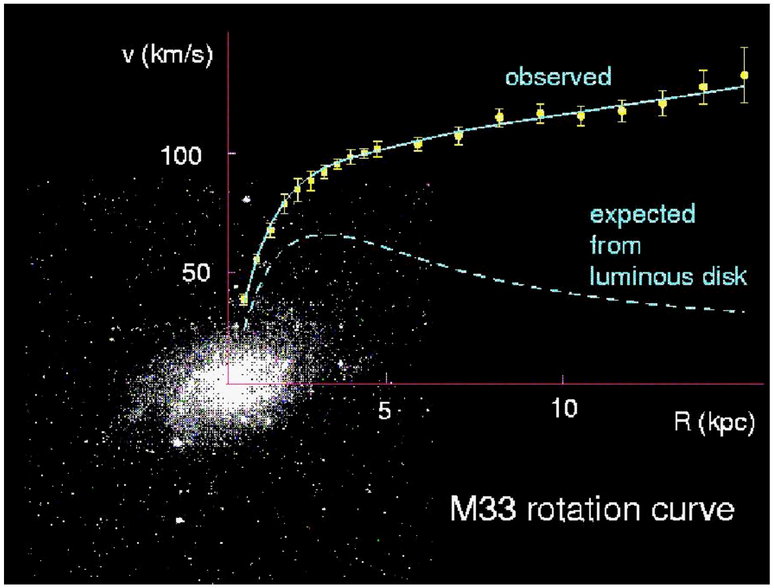
$$L = -R + \partial^{\mu}\phi\partial_{\mu}\phi + V(\phi)$$

That work at galactic scale?
- massless complex SF
- global monopoles
- Massive SF….. Etcetera….

$$G_{\mu\nu} = \kappa T_{\mu\nu}$$

$$T_{\mu\nu} = \phi_{,\mu}\phi_{,\nu} + \tfrac{1}{2} g_{\mu\nu} V(\phi)$$

$$T^{\mu\nu}{}_{;\mu} = 0$$



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Ideas at galactic scale

Guzmán Matos 2000: galactic rotation curves using an exact solution of the EKG with axial symmetry, static (very likely unstable and problems with singularity theorems).

Scalar I

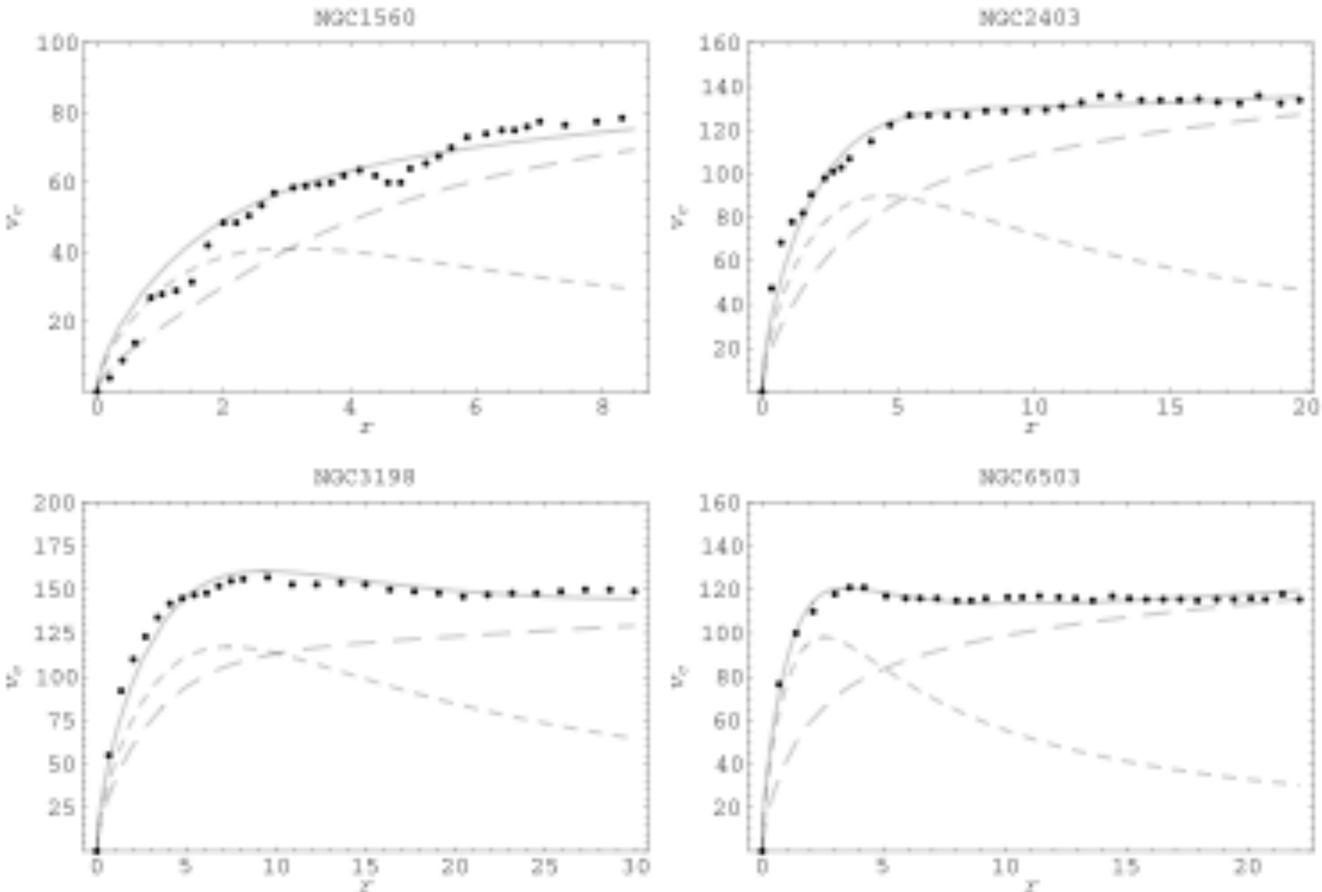
F. S

Scalar I

F. S

Scalar I

F. S



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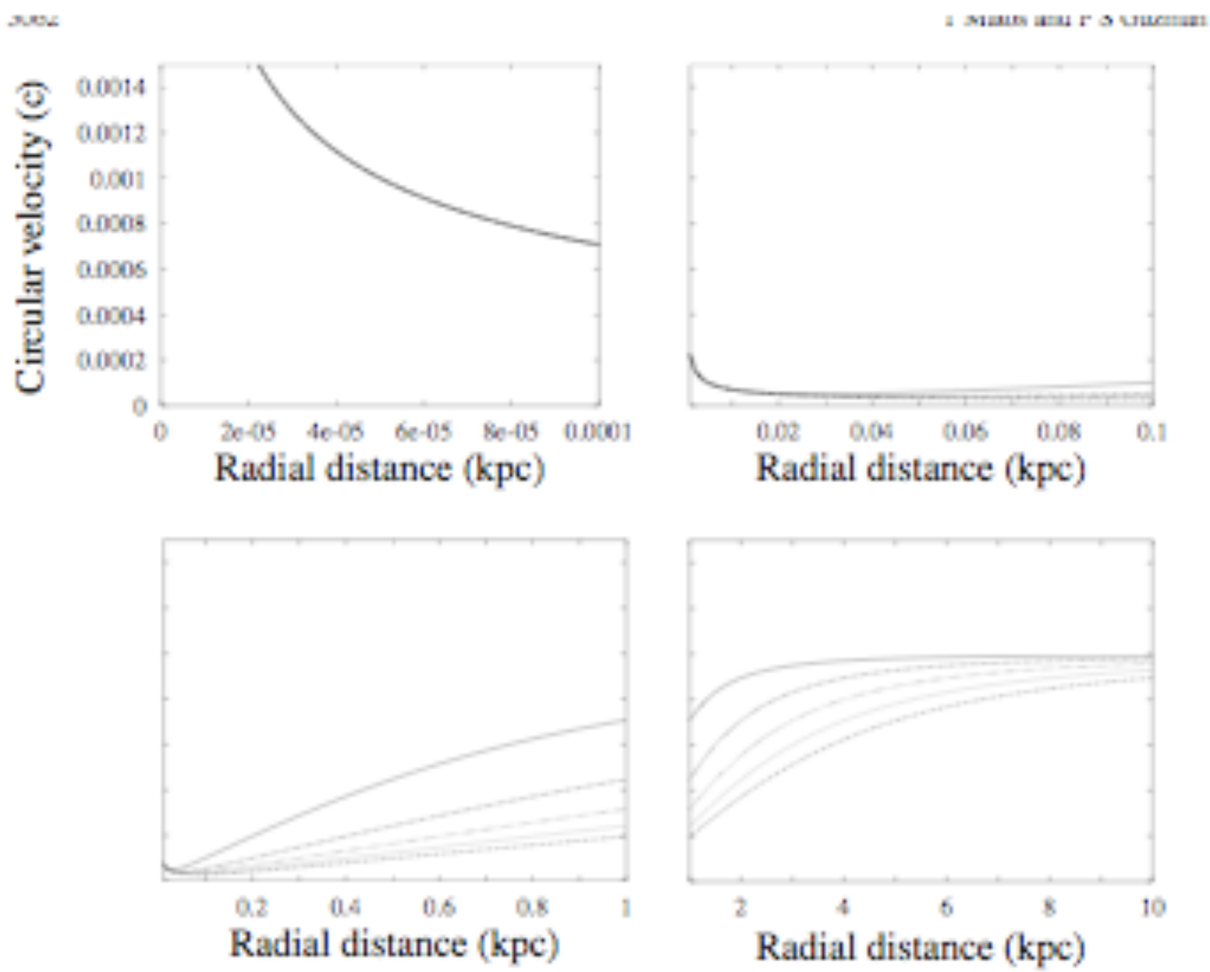
El modelo SFDM BEC

"On the Space Time of a Galaxy".

T. Matos and F. S. Guzmán. Class. Quantum Grav. 18 (2001) 5055-5064.



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Is the dynamics of SFDM appropriate?

Is there a Jeans type of collapse for the ultralight Scalar Field?

Ed Seidel and Ai Mo Suen showed in 1990 that there are long-lived solutions of the EKG for a real scalar field, that scale with *m*.

$$M \sim M_{pl}^2 / m$$

THESE solutions later called oscillatons show nice properties and looked interesting…

For *m ~ 10^(-23)eV*
the critical mass for collapse would be 10^(12) Solar Masses

We just did the exercise….

[Alcubierre, Guzmán and friends 2001]

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Could SFDM be sucked by a SMBH?

TRYING to *destroy* the model we asked the question of whether or not a scalar field survives to the presence of a SMBH. THEN WE SOLVED THE KG equation onto a fixed Schwarzschild black hole.

Ted Jacobson asked at some point.

Andrew Liddle + Urena-Lopez did as well. Scalar fields with wave-packet widths bigger than the Schwarzschild radius may be partially reflected.

It was shown numerically [Urena-Lopez & Fernandez 2010].

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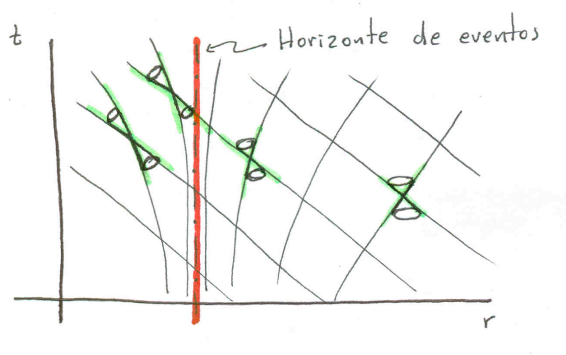
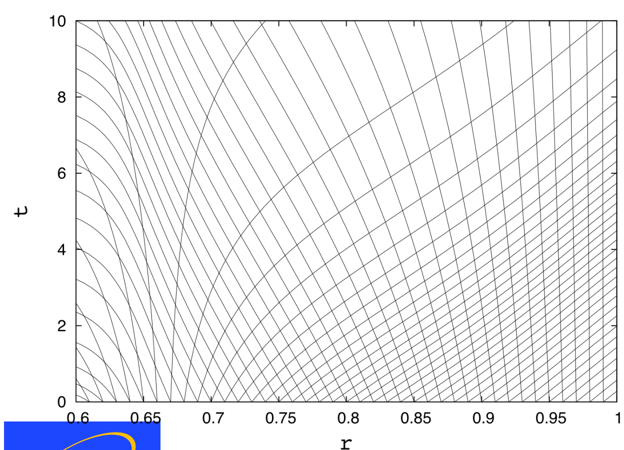
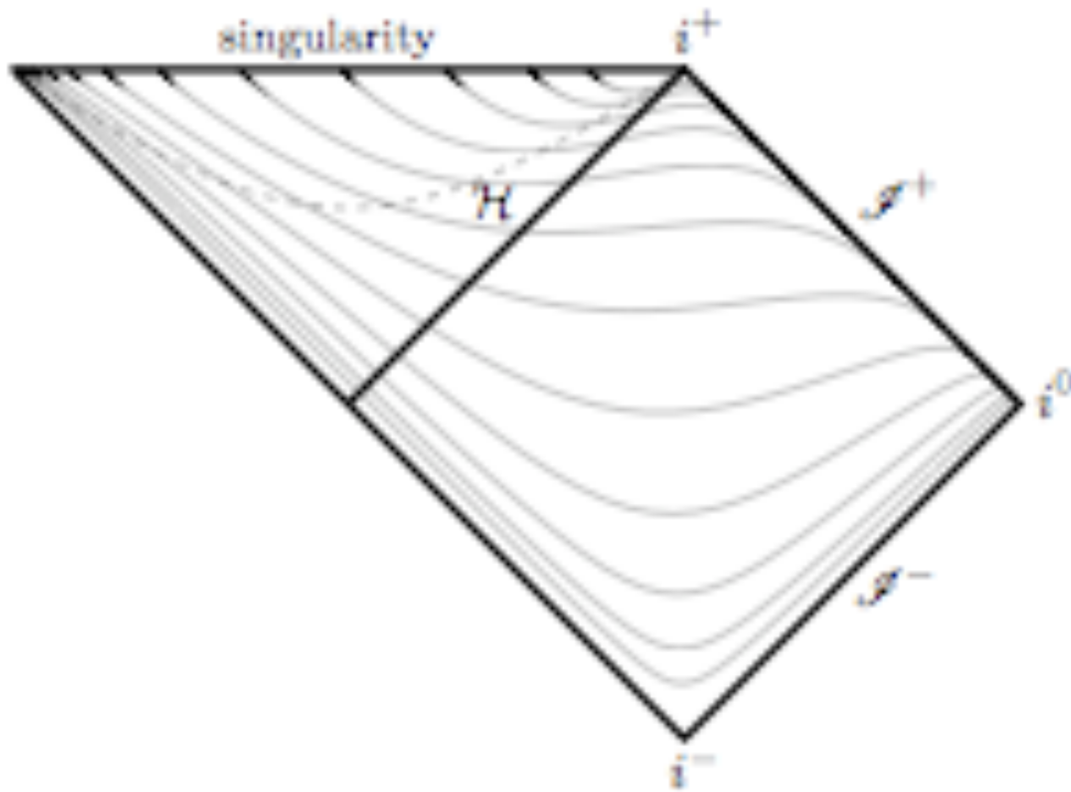
Could SFDM be sucked by a SMBH?
[Cruz-Guzman-Lora- JCAP 2010]

We tried to do it in the best possible way







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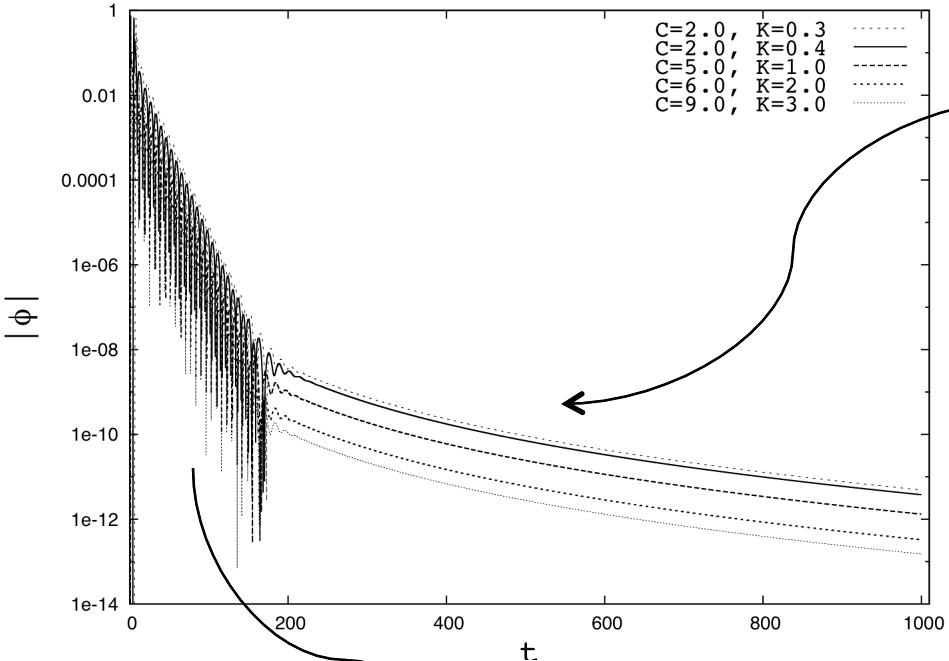
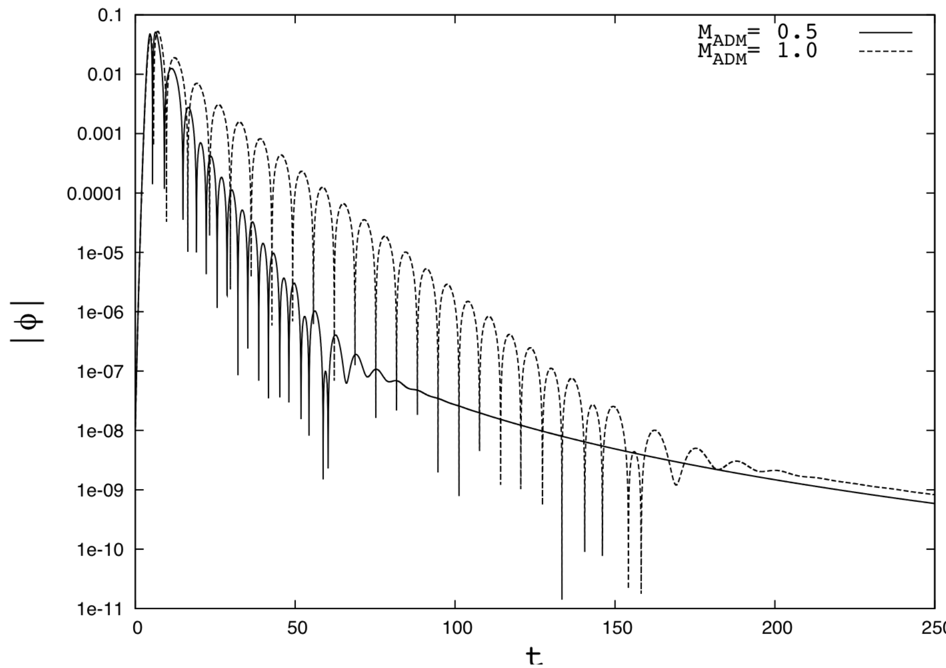
Results: QNM and tails



$$|\phi| \sim t^{p}$$



$$\phi = A e^{(\omega_R + i\omega_I)t}$$

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Results of these experiments

Generic behavior

For the case l=0 the most conservative detector measures an exponent p~4-6

For the case l=1 the most conservative detector measures an exponent p~5-8

For the case l=2 the most conservative detector measures an exponent p~6-9

In the three cases, this implies the density decreases to its half in less than a year for a Bhmass= 10^9 measurements made from near the Horizon up to 1000M

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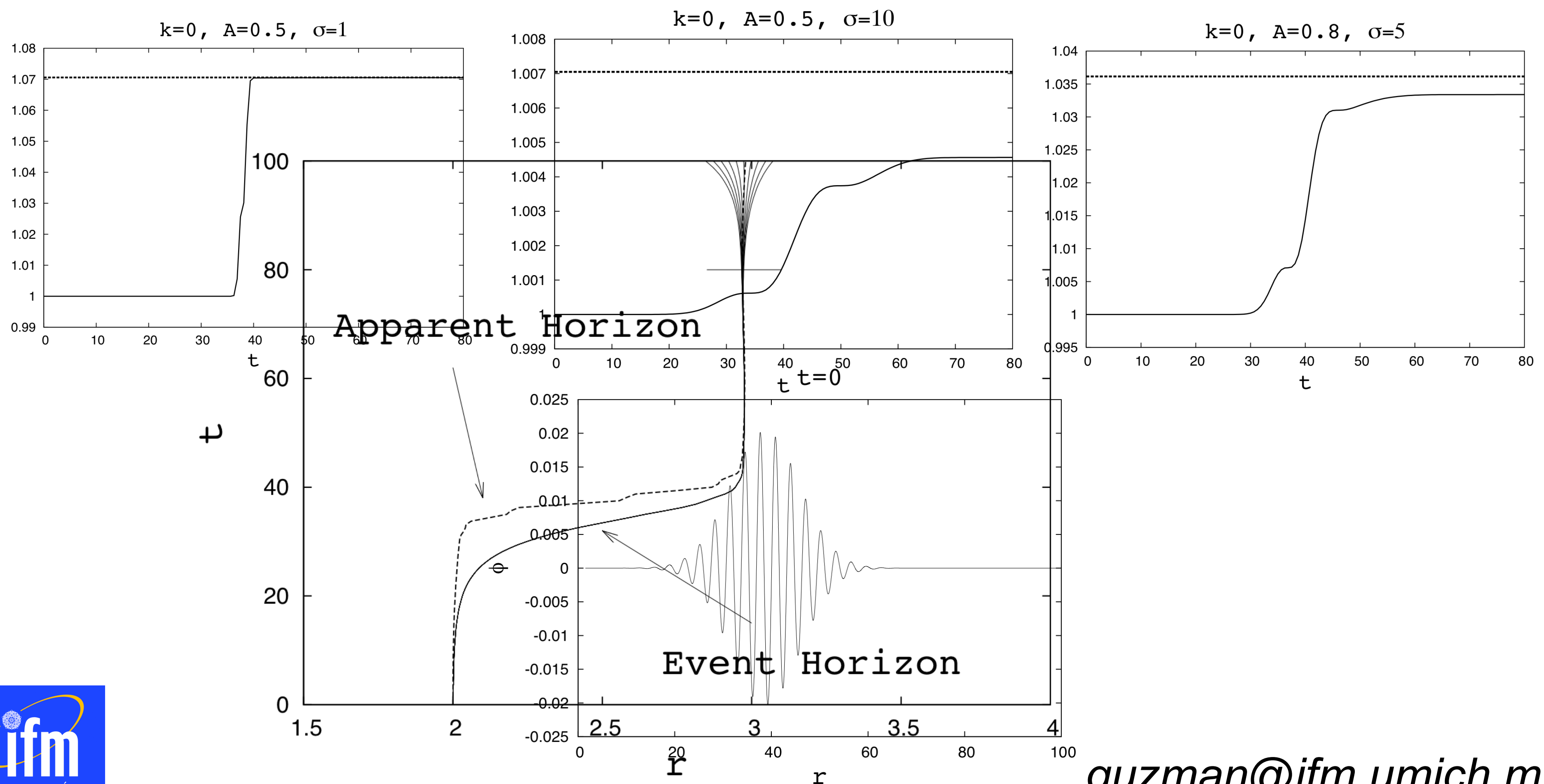
Could SFDM be sucked by a SMBH?
[Guzman & Lora Phys Rev D 2012]

We went back into the FULL NONLINEAR experiments: solve EKG for a black hole space-time.



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Einstein-Klein-Gordon is perhaps not the appropriate regime to study the dynamics of structures (EKG -> SP)

The correct gravitational regime for the evolution of structures (at least in the non-linear regime) is the Newtonian.

It was fine to solve the Einstein-Klein-Gordon system to model relativistic regimes (like the linear regime at early times).

It is nice to model strong field regimes.

HOWEVER galaxies are not a system with a strong surface gravitational field. [Could have been figured out before]

EKG -> Schroedinger-Poisson system in the low energy limit and weak gravitational field regime.

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The ultralight boson T_c for condensation(SP -> GPP)

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi + \frac{2\pi\hbar^2 a}{m^2}|\Psi|^2\,\Psi$$

$$\nabla^2 V = 4\pi G m |\Psi|^2$$

It happens that Schroedinger equation plays the role of the Gross-Pitaevskii equation, that rules a BEC in the mean field approximation with a point to point interaction among bosons.

The critical temperature for m~10^-23eV is of the order of TeV.

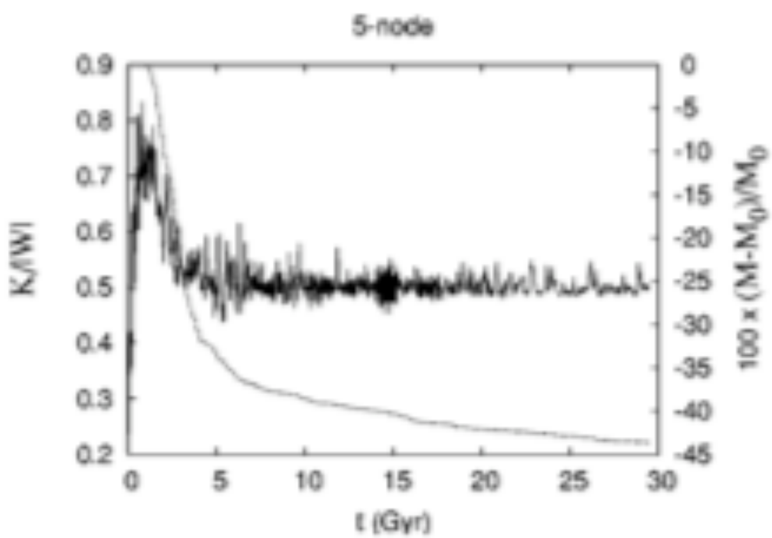
guzman@ifm.umich.mx

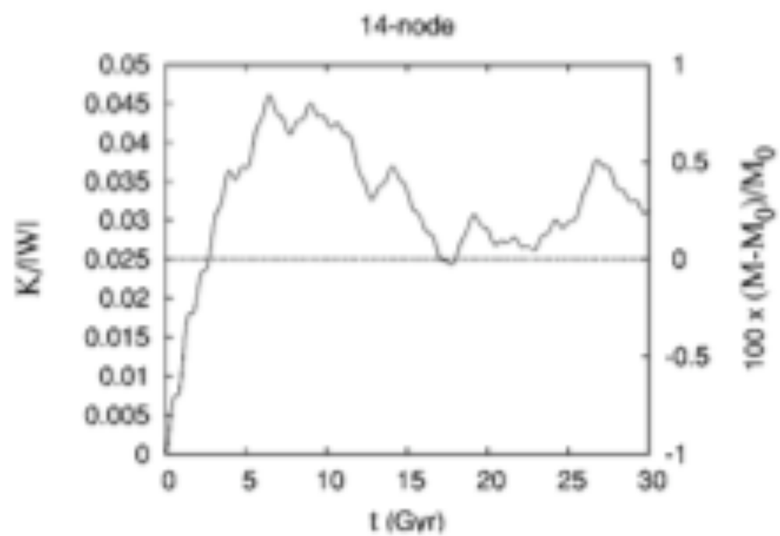
Vrialization of structures

"**Newtonian Collapse of Scalar Field Dark Matter**".

F. S. Guzmán and L. A. Ureña-Lopez. Phys. Rev. D 68 (2003) 024023.

Virialization time





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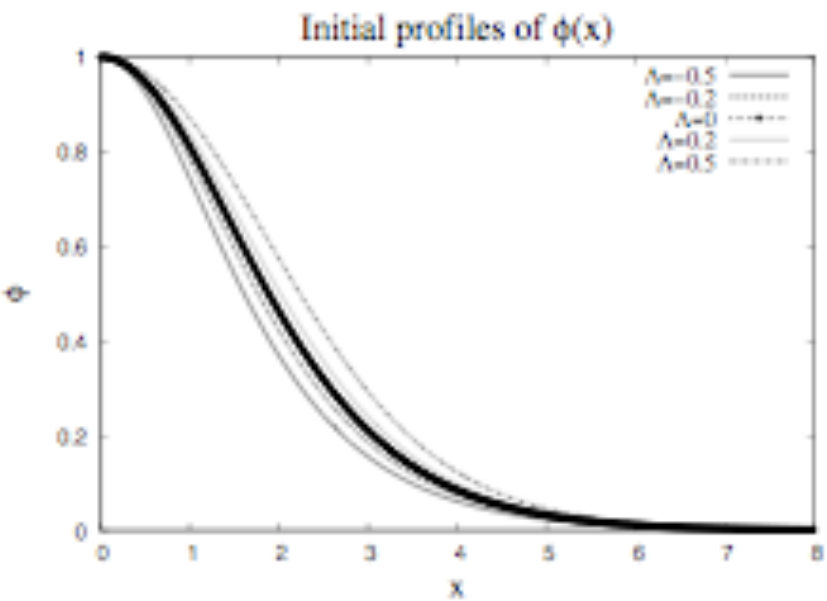
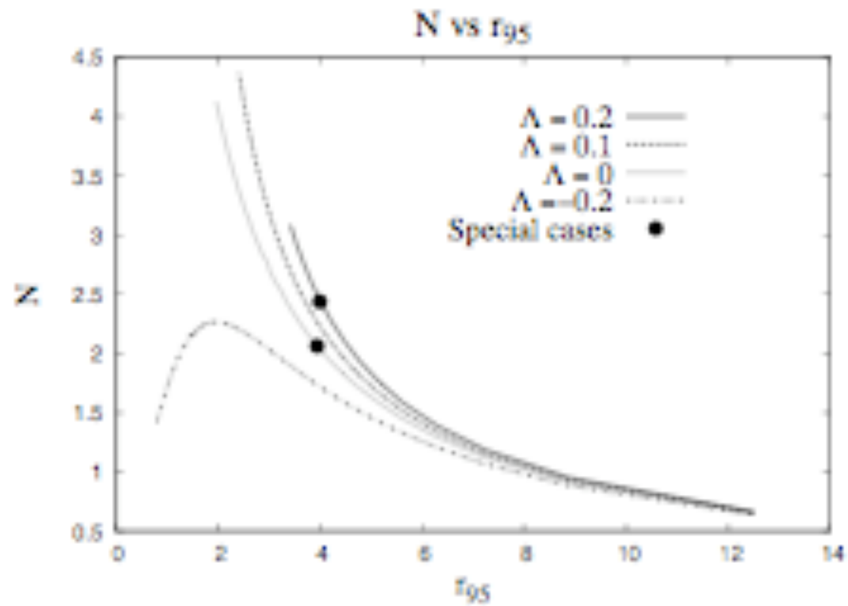
Solutions of the GPP system

Assume spherical symmetry.





Solve it. There is one solution for each central value of the wave function.

It can have nodes or not: like atoms solutions (called at some points ***gravitational atoms***). *[S-J Sin, Phys. Rev. D 50 (1994) 3650. S.U. Ji and S-J. Sin, Phys. Rev. D 50 (1994) 3655.] [R. Ruffini and S. Bonazolla, Phys. Rev. 187 (1969) 1767.]*

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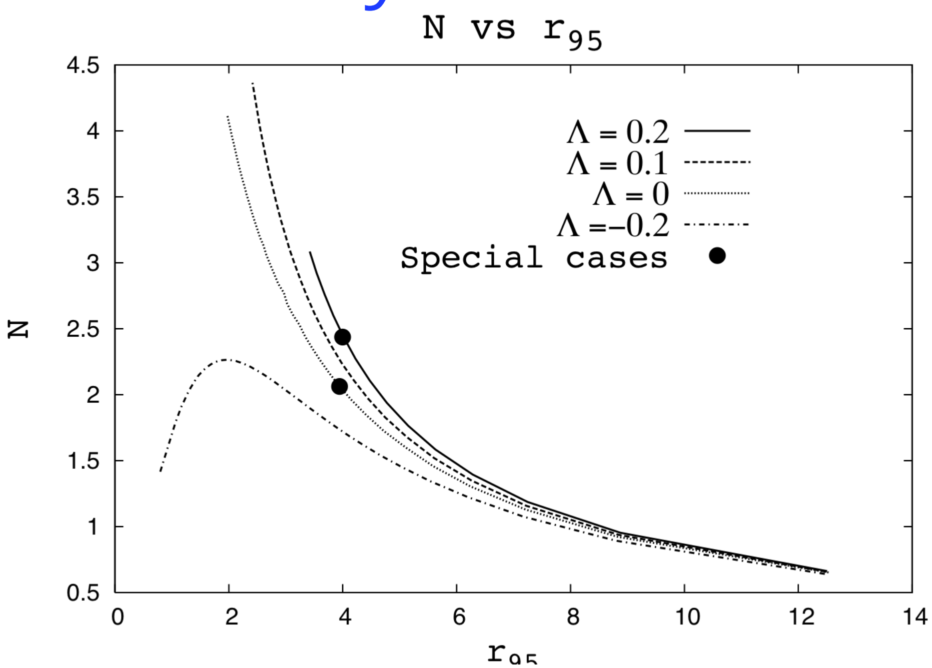
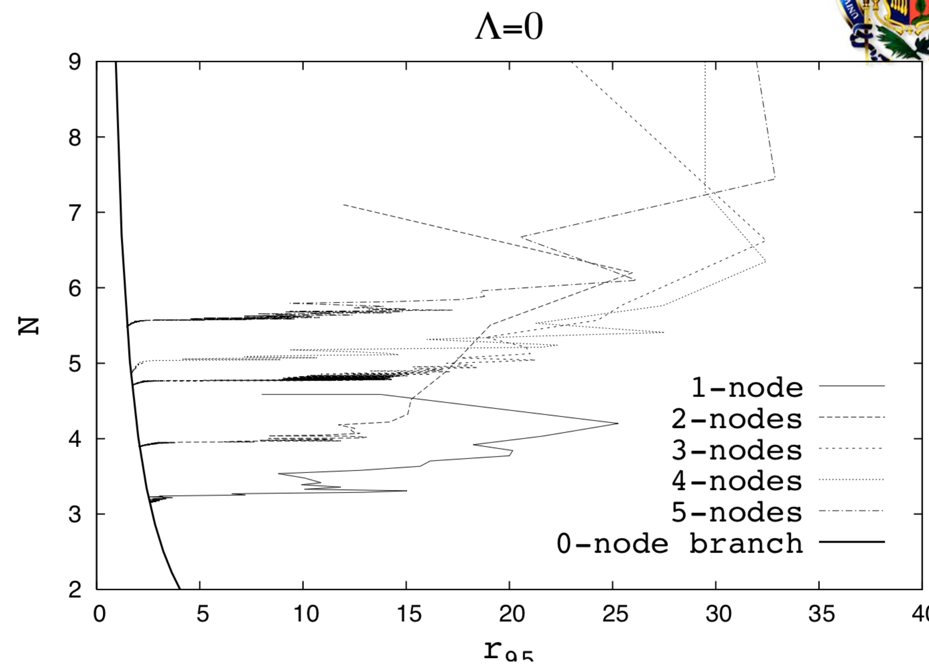
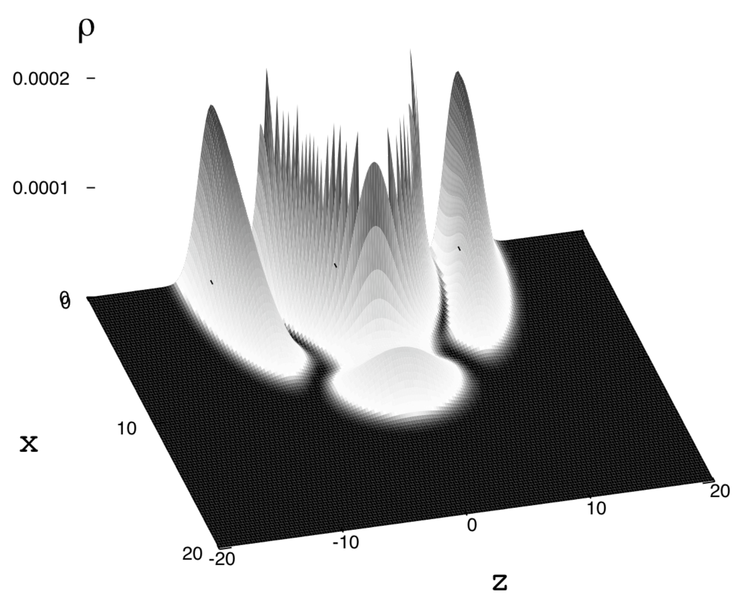
Stability of GPP solutions







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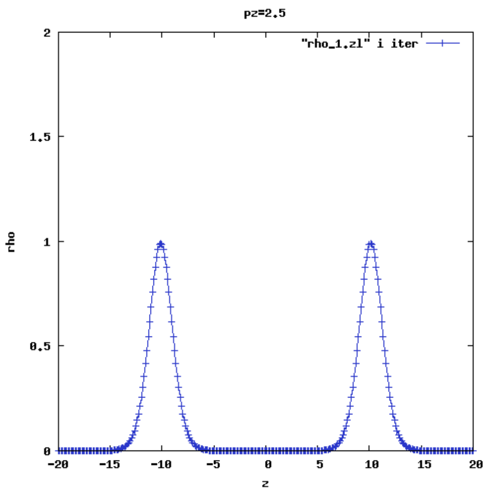
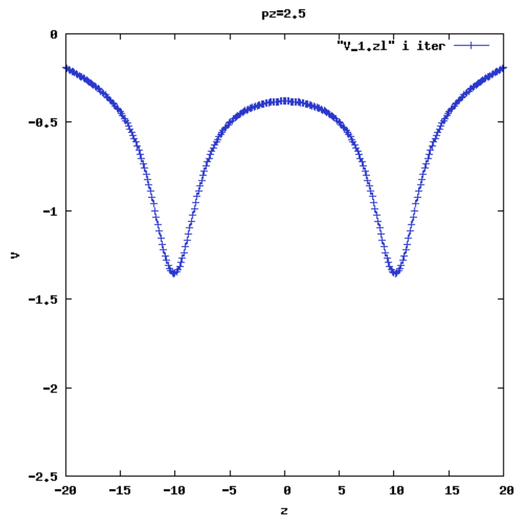
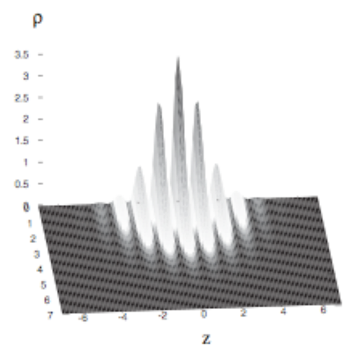
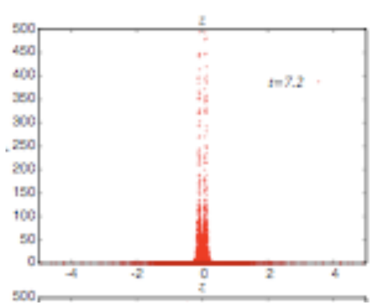
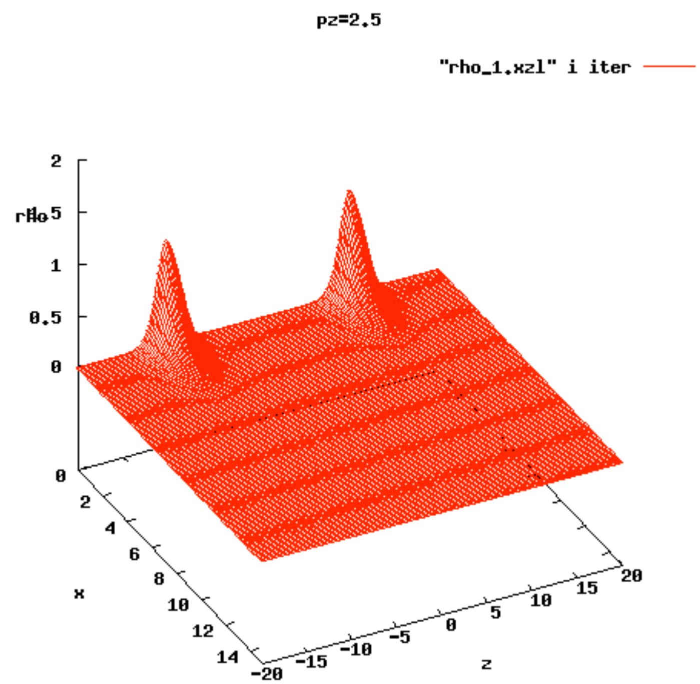
Even exploration of interaction











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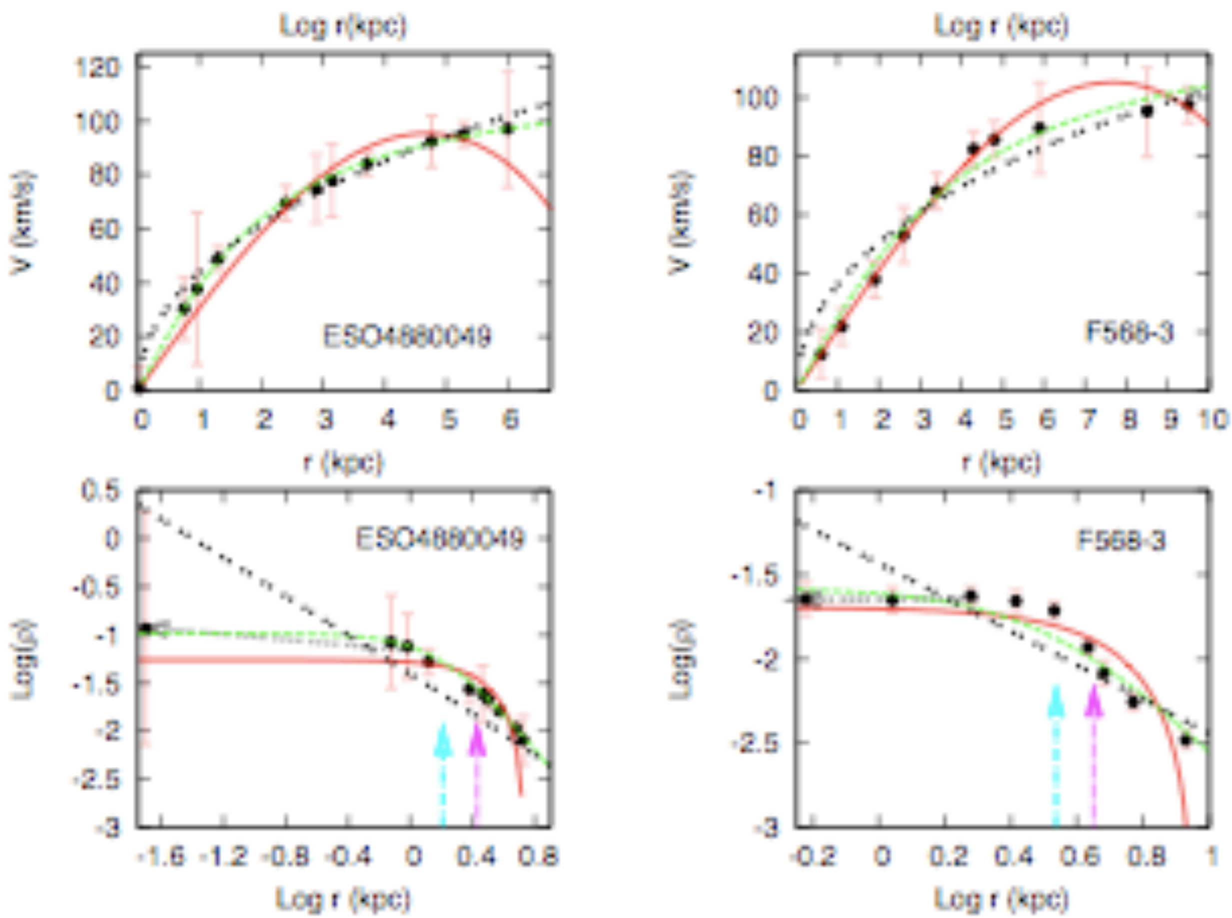
BEC galactic halos in the Thomas-Fermi limit

Bohemer-Harko JCAP 2007 (atomic gases)
Matos Robles MNRAS 2012 (ultralight stuff)

$$R = \pi \sqrt{\frac{\hbar^2 a}{G m^3}}$$

The density profiles are $\rho(r) = \rho_c \frac{\sin(\pi r / R)}{\pi r / R}$



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Their stability and failure in spherical symmet

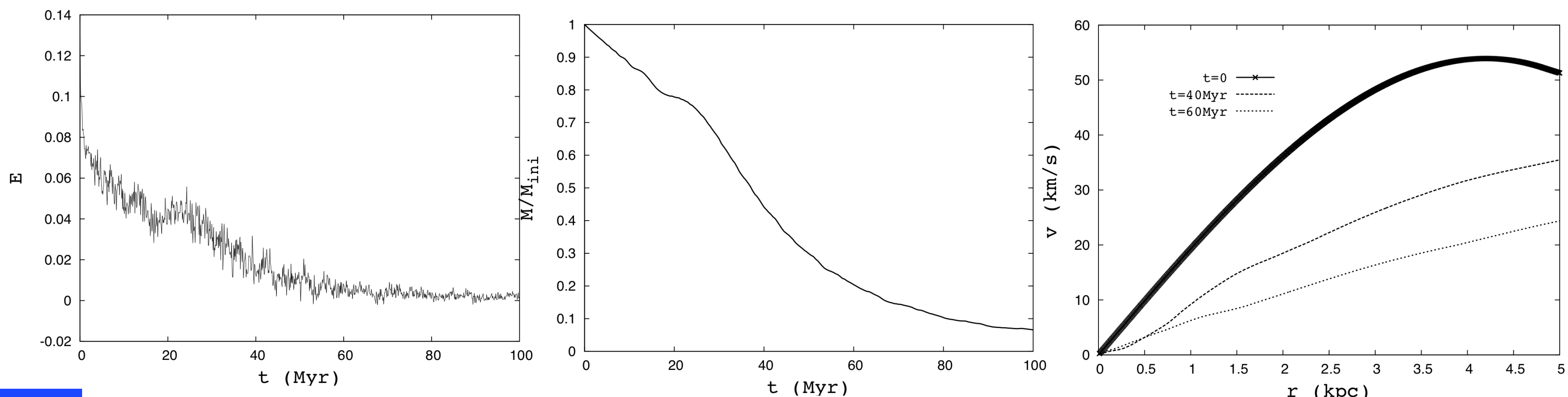
Plug in these halo density profiles into the GPP fully time-dependent GPP system.

We showed the total energy is positive.

That the Thomas-Fermi limit did not actually hold.

That the system was unstable.

[Guzman-Lora-Gonzalez-Rivera JCAP 2013]



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Status of spherical BEC halos

There are nice solutions to the GPP system

Stable
Attractors in time
However can only fit either cored or RCs and not both.

There are node solutions with nice RCs but unstable

In the Thomas-Fermi limit the model either does not really belong to this limit or requires atomic mass of the order of meV, which does not help at cosmic scale.

THEN spherical HALOS thus are just not nice.

We ADDED some rotation to see what happens.

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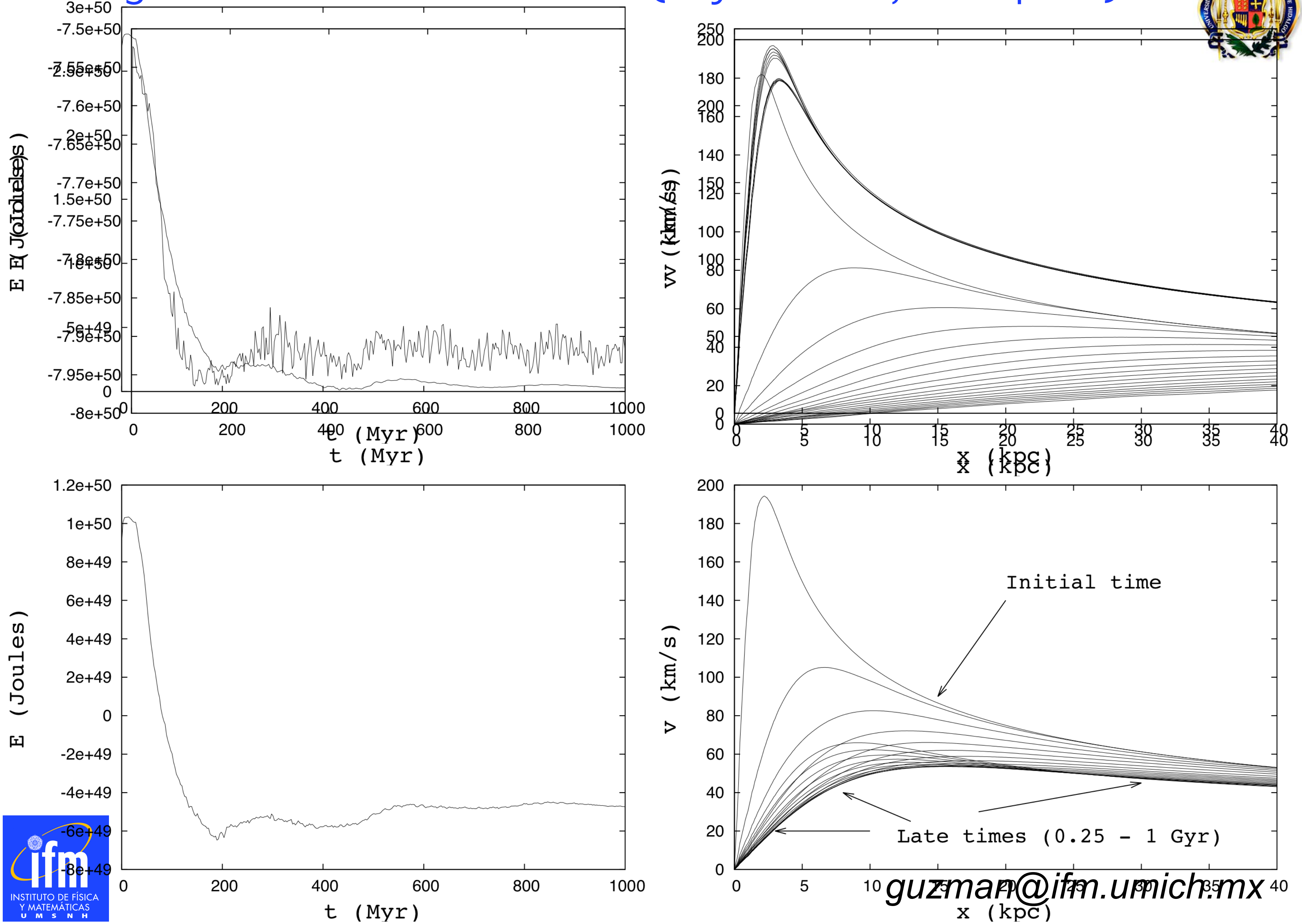
Adding rotation to BEC halos (Phys Rev D, accepted)



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Even beyond that

Galactic halos as vortices in BECondensates

Ultralight axionic dark matter

Feedback in cores

Trying to evolve a bunch of structures and analyze the structure growth process.

Adding finite temperature effects

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guzman@ifm.umich.mx

En blanco

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