Non-linear accretion of collisional dark matter onto a spherically symmetric supermassive black hole.

Miguel Gracia Linares[1],
F. D. Lora-Clavijo[2], F. S. Guzmán[1,3].
[1]Instituto de Física y Matemáticas - UMSNH,
[2]Instituto de Astronomía - UNAM, [3]Physics and Astronomy Department - UBC.
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Motivation.

- Actual mass of SMBHs in the center of galaxies?

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- Origin of SMBH seeds (PBHs)?

Abstract.

We present the accretion of collisional dark matter on a supermassive Schwarzschild black hole seed. The analysis is based on the numerical solution of the fully coupled system of Einstein-Euler equations for spherically symmetric flow. The dark matter is model as a perfect fluid that obeys an ideal gas equation of state.

- To observe how much a SMBH seed grows due to the dark matter acretion process.
- Analize how the density profile behaves at galactic core scales.

In order to solve the Eistein-Euler system we used:

- 3+1 space-time decomposition, described by the metric:

$$ds^2 = -(\alpha^2 - \beta^i \beta_i)dt^2 + 2\beta_i dx^i dt + \gamma_{ij} dx^i dx^j .$$

- We adopted ADM form Einstein's equation on spherically symmetric:

$$\begin{aligned}
\partial_t \gamma_{rr} &= -2\alpha K_{rr} + \beta\gamma'_{rr} + 2\beta'\gamma_{rr} \\
\partial_t \gamma_{\theta\theta} &= -2\alpha K_{\theta\theta} + \beta\gamma'_{\theta\theta} \\
\partial_t K_{rr} &= -\alpha'' + \alpha' \frac{\gamma'_{rr}}{2\gamma_{rr}} - \alpha \frac{\gamma''_{\theta\theta}}{\gamma_{\theta\theta}} + \frac{1}{2}\alpha \left(\frac{\gamma'_{\theta\theta}}{\gamma_{\theta\theta}}\right)^2 \\
&+ \alpha \frac{\gamma'_{rr}\gamma'_{\theta\theta}}{2\gamma_{rr}\gamma_{\theta\theta}} + 2\alpha \frac{K_{rr}K_{\theta\theta}}{\gamma_{\theta\theta}} - \alpha \frac{K^2_{rr}}{\gamma rr} + \beta K'_{rr} + 2\beta' K_{rr} \\
&+ 4\pi((S - \rho_{ADM})\gamma_{rr} - 2S_{rr}) \\
\partial_t K_{\theta\theta} &= -\alpha' \frac{\gamma'_{\theta\theta}}{2\gamma_{rr}} - \alpha \frac{\gamma''_{\theta\theta}}{2\gamma_{rr}} + \alpha \frac{\gamma'_{rr}\gamma'_{\theta\theta}}{4\gamma^2_{rr}} + \alpha \left(1 + \frac{K_{rr}K_{\theta\theta}}{\gamma_{rr}}\right) + \beta K'_{\theta\theta} \\
&- 8\pi(S_{\theta\theta} - \frac{1}{2}\gamma_{\theta\theta} S) - 4\pi\alpha\gamma_{\theta\theta}\rho_{ADM} ,
\end{aligned} \tag{1}$$

The matter source in the Einstein's equation are considerer in the terms S_{ij}, S and ρ_{ADM}.

- The fluid is describe by the relativistic Euler equations which have to be solve simultaneously with Einstein's equations. In spherically symmetric the system reduces to:

$$\partial_t \mathbf{u} + \partial_r \mathbf{F}^r(\mathbf{u}) = \mathbf{S} \tag{2}$$

con:

$$\mathbf{u} = \begin{bmatrix} D \\ J_r \\ \tau \end{bmatrix} = \begin{bmatrix} \sqrt{\gamma}\rho W \\ \sqrt{\gamma}\rho h W^2 v_r \\ \sqrt{\gamma}(\rho h W^2 - p - \rho W) \end{bmatrix},$$

$$\mathbf{F}^r = \begin{bmatrix} \alpha\left(v^r - \frac{\beta^r}{\alpha}\right) D \\ \alpha\left(v^r - \frac{\beta^r}{\alpha}\right) J_r + \alpha\sqrt{\gamma} p \\ \alpha\left(v^r - \frac{\beta^r}{\alpha}\right)\tau + \sqrt{\gamma}\alpha v^r p \end{bmatrix},$$

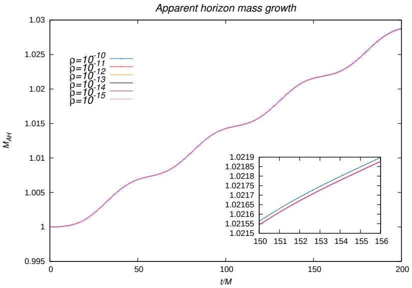
$$\mathbf{S} = \begin{bmatrix} 0 \\ \alpha\sqrt{\gamma} T^{\mu\nu} g_{\nu\sigma} \Gamma^{\sigma}{}_{\mu r} \\ \alpha\sqrt{\gamma}(T^{\mu 0}\partial_\mu \alpha - \alpha T^{\mu\nu}\Gamma^{0}{}_{\mu\nu}) \end{bmatrix}.$$

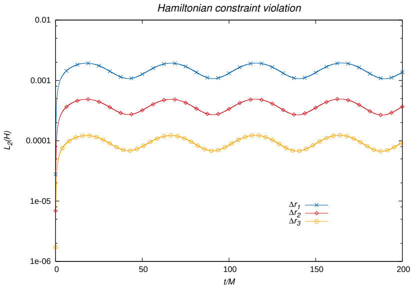
The Einstein-Euler system was numerically solved using:

- Finite diference method to discretize the spatial derivatives of the geometry variables.
- HRSC for the hydrodynamics variables.
  - Riemann solver: HLLE
  - Variable reconstruction: Linear piecewise (minmod)
- MOL for time evolution. RK3 integrator.
- Excision technique on the inner boundary.
- Constraint preserving boundary conditions for external boundary of geometry variables.

We obtained our results as follows:

1. Given values of Γ, v^r y ρ_0, we solved the system numerically.
2. We track the evolution of the apparent horizon mass. We found a linear growing behavior of the profile which we fit with the linear function $M_{AH} = At + C$ where A indicates the accretion rate.
3. In order to associate our numerical results to astrophysical scenarios we fix the physical evolution time to $10 Gyr$, the environment dark matter density to $\rho_0 = 100 M_\odot pc^{-3}$ and initial SMBHs seeds masses of $10^2 M_\odot$ - $10^9 M_\odot$.



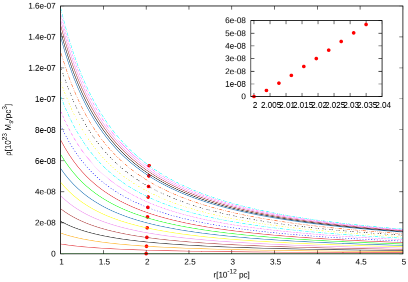


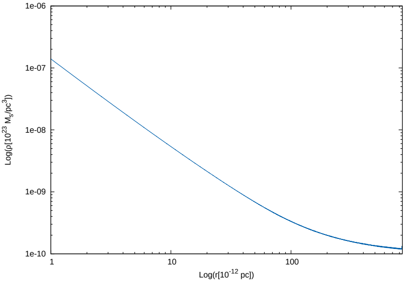
OUR RESULTS!

Table 1: Accreted mass by a SMBHs seed in 10*Gyr* .

Seed:	$M_{(1)} = 10^2 M_\odot$	$M_{(2)} = 10^3 M_\odot$	$M_{(3)} = 10^4 M_\odot$	$M_{(4)} = 10^5 M_\odot$	$M_{(5)} = 10^6 M_\odot$	$M_{(6)} = 10^9 M_\odot$
			Mass accreted in 10 Gyr ($\Gamma = 1{,}12$)			
$v^r = -0{,}1$	$2{,}49 \times 10^{-9} M_{(1)}$	$2{,}49 \times 10^{-8} M_{(2)}$	$2{,}49 \times 10^{-7} M_{(3)}$	$2{,}49 \times 10^{-6} M_{(4)}$	$2{,}49 \times 10^{-5} M_{(5)}$	$2{,}49 \times 10^{-2} M_{(6)}$
$v^r = -0{,}08$	$1{,}68 \times 10^{-9} M_{(1)}$	$1{,}68 \times 10^{-8} M_{(2)}$	$1{,}68 \times 10^{-7} M_{(3)}$	$1{,}68 \times 10^{-6} M_{(4)}$	$1{,}68 \times 10^{-5} M_{(5)}$	$1{,}68 \times 10^{-2} M_{(6)}$
			Mass accreted in 10 Gyr ($\Gamma = 1{,}1$)			
$v^r = -0{,}1$	$2{,}46 \times 10^{-9} M_{(1)}$	$2{,}46 \times 10^{-8} M_{(2)}$	$2{,}46 \times 10^{-7} M_{(3)}$	$2{,}46 \times 10^{-6} M_{(4)}$	$2{,}46 \times 10^{-5} M_{(5)}$	$2{,}46 \times 10^{-2} M_{(6)}$
$v^r = -0{,}08$	$1{,}66 \times 10^{-9} M_{(1)}$	$1{,}66 \times 10^{-8} M_{(2)}$	$1{,}66 \times 10^{-7} M_{(3)}$	$1{,}66 \times 10^{-6} M_{(4)}$	$1{,}66 \times 10^{-5} M_{(5)}$	$1{,}66 \times 10^{-2} M_{(6)}$
			Mass accreted in 10 Gyr ($\Gamma = 1{,}01$)			
$v^r = -0{,}1$	$2{,}08 \times 10^{-9} M_{(1)}$	$2{,}08 \times 10^{-8} M_{(2)}$	$2{,}08 \times 10^{-7} M_{(3)}$	$2{,}08 \times 10^{-6} M_{(4)}$	$2{,}08 \times 10^{-5} M_{(5)}$	$2{,}08 \times 10^{-2} M_{(6)}$
$v^r = -0{,}08$	$1{,}64 \times 10^{-9} M_{(1)}$	$1{,}64 \times 10^{-8} M_{(2)}$	$1{,}64 \times 10^{-7} M_{(3)}$	$1{,}64 \times 10^{-6} M_{(4)}$	$1{,}64 \times 10^{-5} M_{(5)}$	$1{,}64 \times 10^{-2} M_{(6)}$

Dark matter density profile





We study the behavior in time of the dark matter density profile on the CDM limit in two regions. After sometimes of evolution we found a static regime. We explore with function $\rho(r) \sim 1/r^k$ two regions:

1. Near the black hole seed which help us to understand how dark matter distribute around the black hole ($k \sim 1{,}5$).
2. The far region to see how cuspy is the profile in the center of the galaxie the values of $k < 0{,}3$ which correspond to a cored halo models.

CONCLUSIONS

- We presented a fully general relativistic treatment of the radial accretion of ideal gas to model dark matter accretion.
- Our results indicate that the amount of mass accreted by the black hole seed is a small portion of its orginal, for example for seed of $10^{-7} M_\odot$ is $10^{-3} M_\odot$ when for a seed of $100 M_\odot$ is $10^{-7} M_\odot$.
- The mass of SMBH has to be explained by other means.
- By assuming a density profile of $1/r^k$,we found near the black hole $k < 1{,}5$ in all cases, whereas in the far region $k < 0{,}3$ already at a distance of $10^{-5} pc$ from the black hole, which is consistent with cored halo models.
- Our result were submited to ApJ.