Dark matter dynamics in Galactic center

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Nbody 2008 Workshop, August 2008 Turku, Finland

Why the dark matter life and adventures in Galactic center are interesting?

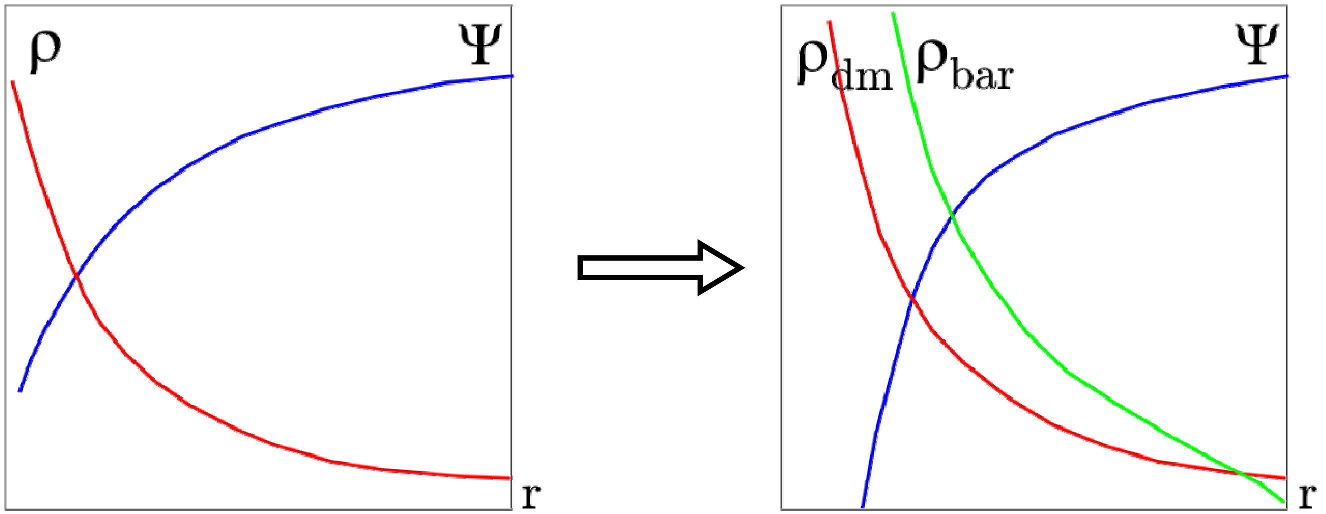
- There is much DM in the center: $\rho(r) \sim r^{-1}$ originally or even steeper after baryonic compression
- High density implies high annihilation rate: $J \sim \int \rho^2(r)\, d^3r$
- The distribution of DM changes greatly during galactic lifetime because of gravitational interaction with stars
- The supermassive black hole in galactic center is nourished by DM as well as by ordinary matter

What processes are significant for dark matter evolution in Galactic center?

- Baryonic compression

For circular orbits the angular momentum is conserved:

$$L^2 = v_{circ}^2 r^2 = M_{dm,in}(r)\, r \Rightarrow (M_{dm,fin}(r') + M_{bar}(r'))\, r'$$



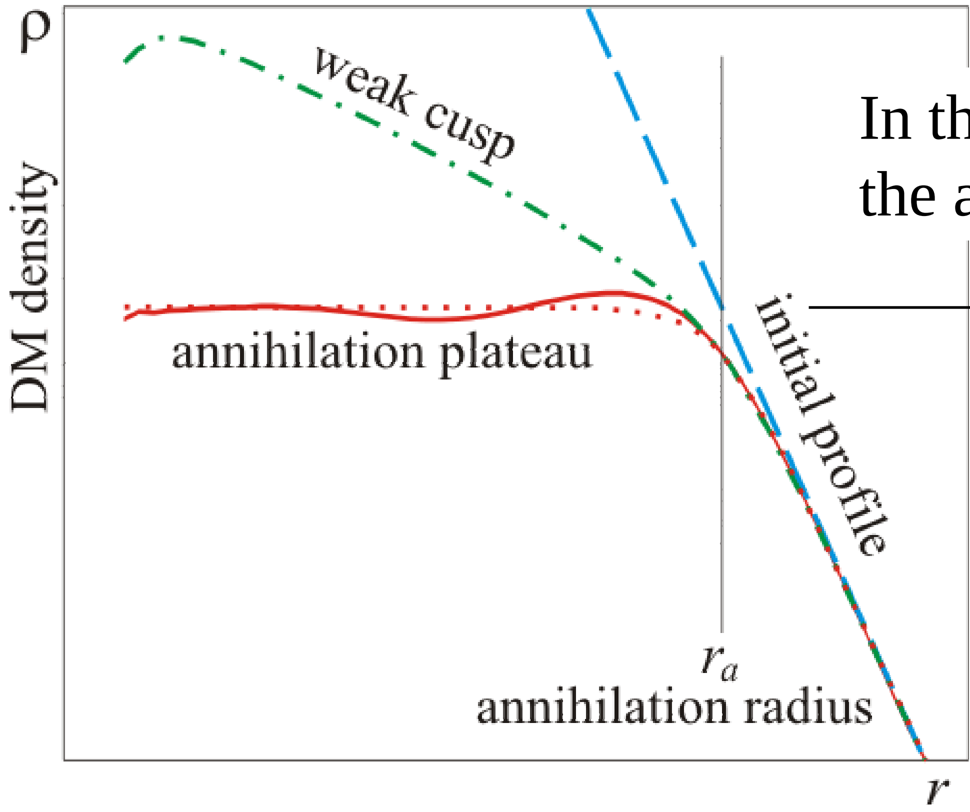
In general case, the radial action is also adiabatically conserved.

Blumenthal et al. 1986; Gondolo & Silk 1999; Sellwood & McGaugh 2005; Vasiliev 2006

What processes are significant for dark matter evolution in Galactic center?

- Dark matter annihilation near a black hole

DM density drops at small radii



In the case of circular orbits, the annihilation plateau is formed

$$\rho_a = \frac{m_\chi}{\langle \sigma v \rangle t}$$

In more realistic cases (e.g. isotropic velocity distribution) a weak cusp is formed

Vasiliev 2007

What processes are significant for dark matter evolution in Galactic center?

- Dark matter scattering by stars and absorption by SMBH

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relaxation

N-body simulations

Merritt, Harfst & Bertone 2007

Fokker-Planck modelling

Bahcall & Wolf 1976
Lightman & Shapiro 1977
Cohn & Kulsrud 1978

} stars

Merritt 2004
Ilyin, Zybin & Gurevich 2004
Bertone & Merritt 2005
Vasiliev & Zelnikov 2008

} dark matter

Fokker-Planck treatment of DM evolution

Assumptions:

- spherical symmetry:
  using variables E (energy) and L (angular momentum)
- single supermassive black hole in the galactic center
- orbit-averaged kinetic equation
  (distribution function changes slowly compared to dynamical time)
- Stationary stellar distribution

Additionally

evolution considered both within and outside SMBH radius of influence (r_h = 2 pc for Milky Way);
relaxation timescale t_r ~ 2.5 Gyr within r_h and quickly grows outside r_h

Fokker-Planck treatment of DM evolution

The kinetic equation:

$$\frac{\partial f(E,R,t)}{\partial t} = \mathcal{G}^{-1}\frac{\partial}{\partial \xi_\alpha}\left\{\mathcal{G}\left[D_{\alpha\beta}\frac{\partial f}{\partial \xi_\beta} - D_\alpha f\right]\right) - S_{ann}[f]\,, \qquad \mathcal{G} - \text{jacobian},$$

$\xi_\alpha = \{E, R\}$ are phase space variables: E is energy and
$R = \frac{L^2}{L_c(E)^2} \in [0..1]$ is scaled angular momentum squared
($L_c(E)$) is maximal angular momentum for given energy E).

D_α и $D_{\alpha\beta}$ are drift and diffusion coefficients due to scattering on stars.

$D_\alpha \propto \frac{m}{m_\star} \Rightarrow$ drift is insignificant for dark matter.

S_{ann} is orbit-averaged annihilation loss term.

Fokker-Planck treatment of DM evolution

The black hole imposes boundary condition at $R = R_{min}(E)$:

(capture boundary)

$$\left(f - \alpha R_{min} \frac{\partial f}{\partial R}\right)\Big|_{R=R_{min}} = 0 \, .$$

$$\alpha \approx \begin{cases} \sqrt{q} & , \quad q < 1 \, ; \\ q & , \quad q > 1 \, ; \end{cases}$$

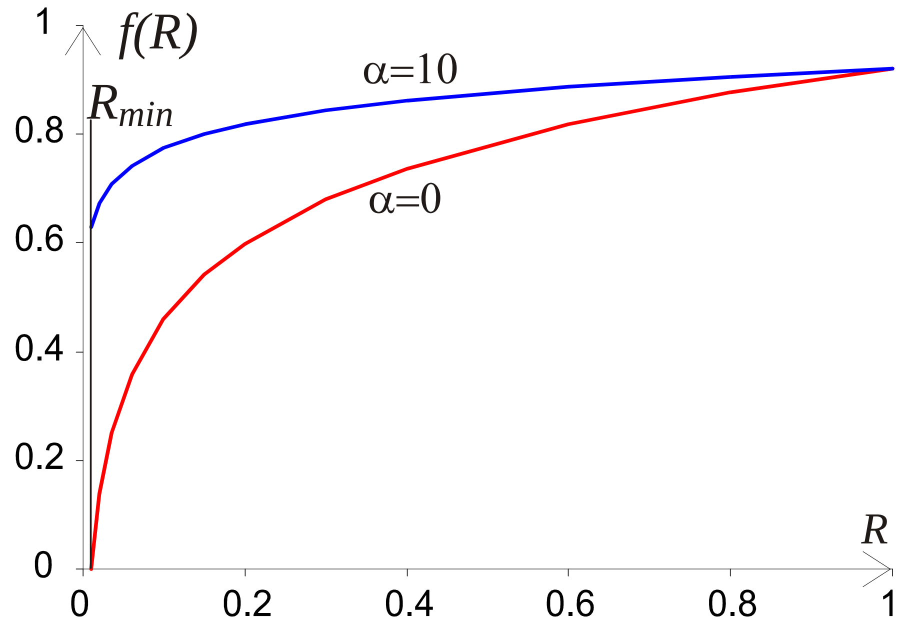
$$q = (D_{RR}/R)|_{R\to 0} \, T_{orb}(E)/R_{min}(E)$$

Low E: $q \ll 1$ (empty loss cone)

High E: $q \gg 1$ (full loss cone)

The distribution function at fixed E and small R is close to logarithm:

$$f(R) = f_{min} \cdot \left(1 + \frac{1}{\alpha} \ln \frac{R}{R_{min}}\right).$$



For stars this allows to reduce the equation to 1-dimensional (for energy only)

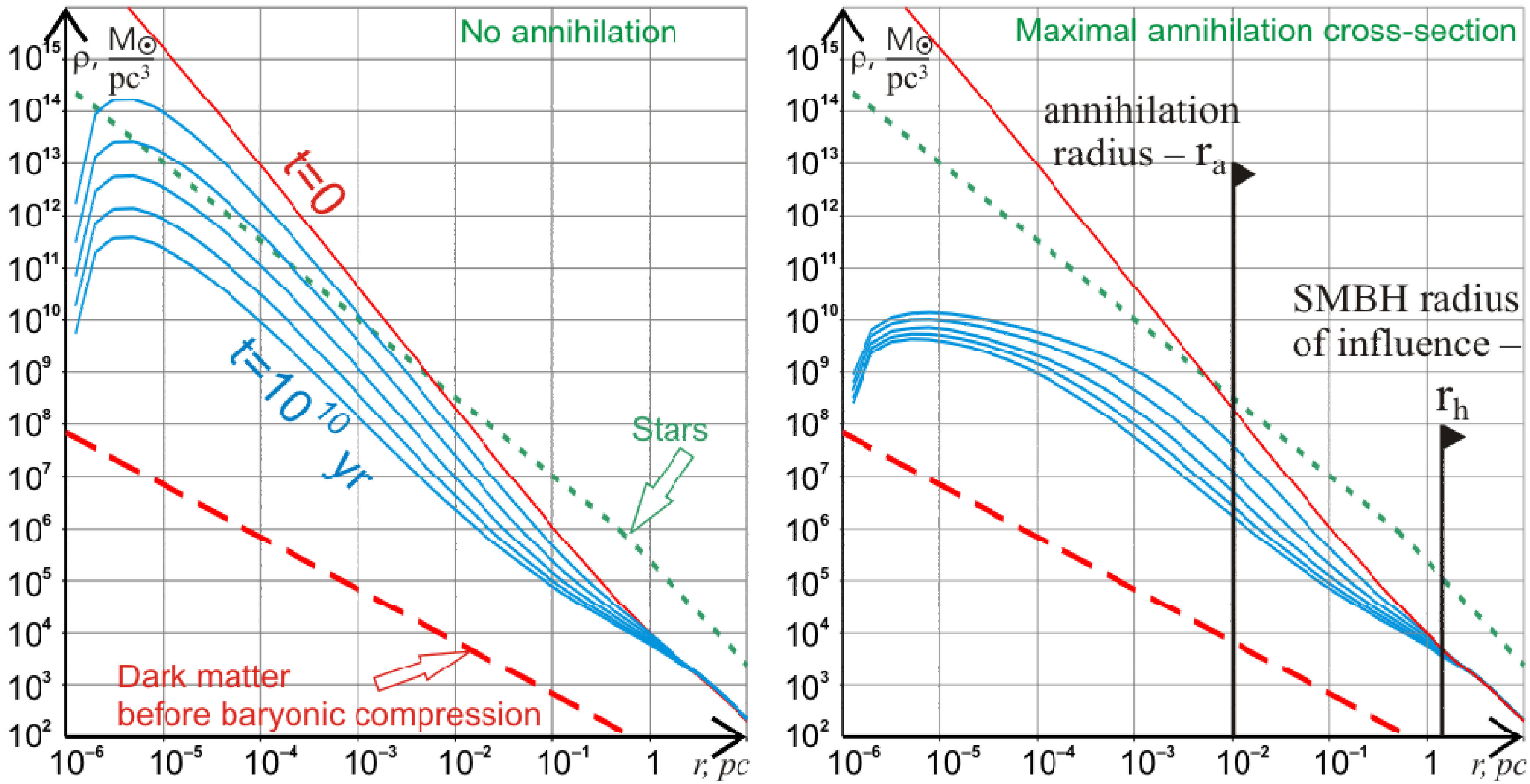
Fokker-Planck treatment of DM evolution

Main features of our consideration:

- two-dimensional (E and R):
  diffusion coefficients vary significantly with R, so R-averaging and reduction to one-dimensional equation for energy is questionable
- broad class of initial DM profiles (NFW, Moore, etc.)
  allows comparison of different models and detects common factors
- analytic approximations for early ($t \ll t_r$) and late ($t \gg t_r$) times;
  analytic consideration of 1-dim. simplified equations for E and R;
  full 2-dim. equation is solved numerically.

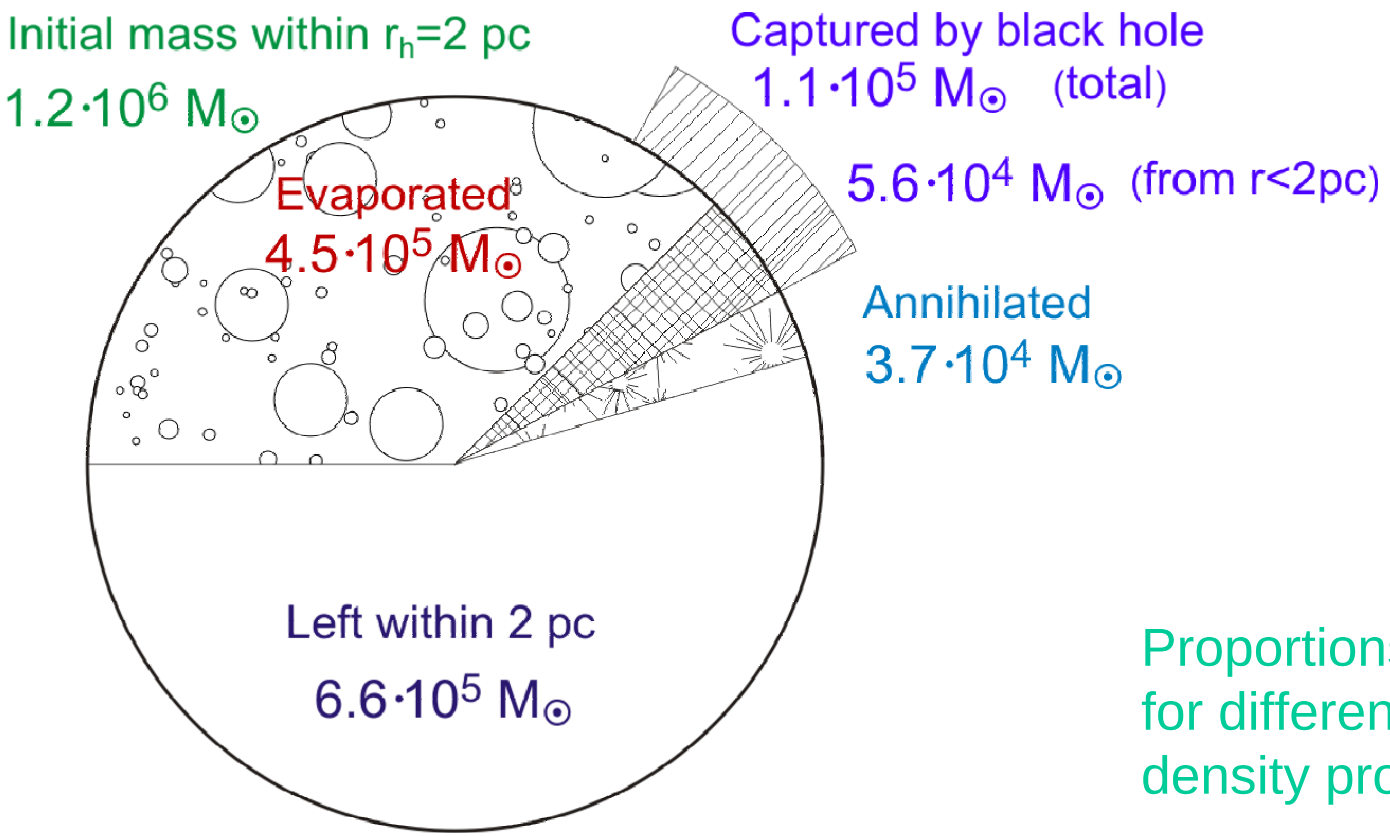
Main difference from stars: no (quasi)-stationary DM profile (as opposed to Bahcall-Wolf cusp) because of constant heating of DM particles by stars [energy equipartition of light (DM) and heavy (star) species]

Dark matter density evolution



example for initial DM profile of NFW ($\rho \sim r^{-1}$)

Dark matter budget after 10^{10} yr of evolution



Proportions are similar for different initial DM density profile models

example for initial DM profile of NFW ($\rho \sim r^{-1}$)

Conclusions

- Dark matter distribution in the Galactic center
  significantly evolved since Galaxy formation; the evolution is due to gravitational scattering on stars, capture by black hole and annihilation
- Evolution is followed by method of Fokker-Planck equation
  in two-dimensional phase space of energy and angular momentum
- Differences between various initial DM density profiles
  are greatly reduced after several relaxation times
- DM density determines intensity of annihilation radiation
  from the Galactic center; predictions from the calculations are consistent with observational constraints

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