Primordial black holes in an astrophysical context

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See also talks by Michele Cicoli, Steven Clark, Scott Watson

PRL 119, 041102 (2017) PHYSICAL REVIEW LETTERS

Dynamics of Dwarf Galaxies Disfavor Stellar-Mass Black Holes as Dark Matter

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(Received 5 April 2017; revised manuscript received 12 May 2017; published 24 July 2017)

PRL 119, 221104 (2017) PHYSICAL REVIEW LETTERS week ending 1 DECEMBER 2017

Maximum Redshift of Gravitational Wave Merger Events

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(Received 24 August 2017; published 30 November 2017)

Fundamental questions about primordial black holes

- When and how are they form?
- When and how can we infer their existence?
- Is dark matter primordial black holes?

What would it take to establish their existence?

- Direct observation (e.g., gravitational waves)
- Indirect observation (e.g., effects in the early universe, CMB, energetic backgrounds, lensing, stellar dynamics, merger rates, etc…)

PRL 119, 041102 (2017) PHYSICAL REVIEW LETTERS week ending 28 JULY 2017

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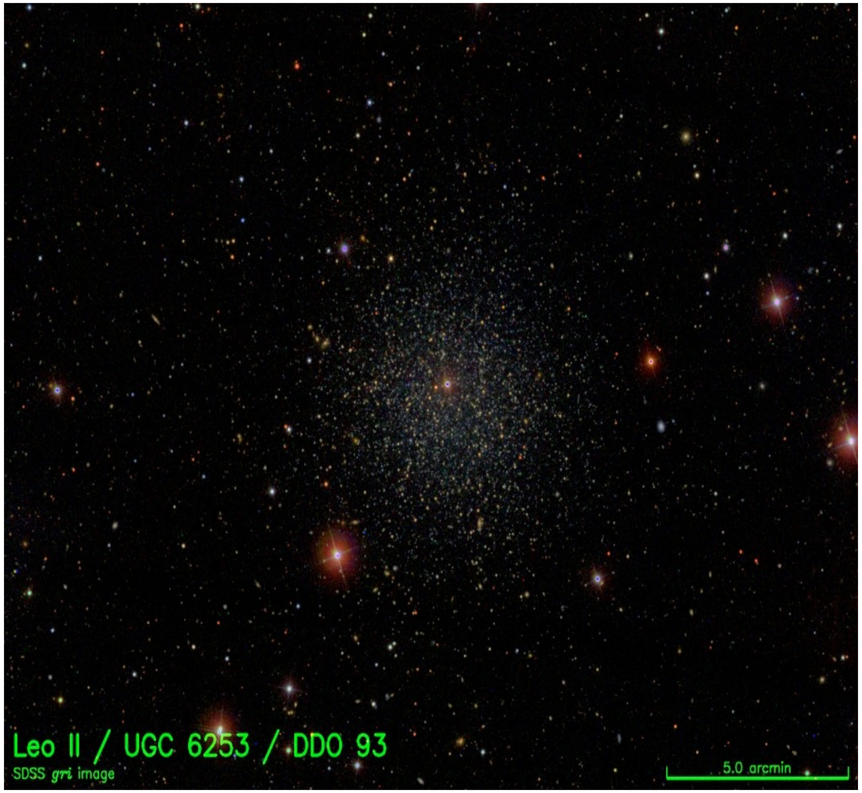
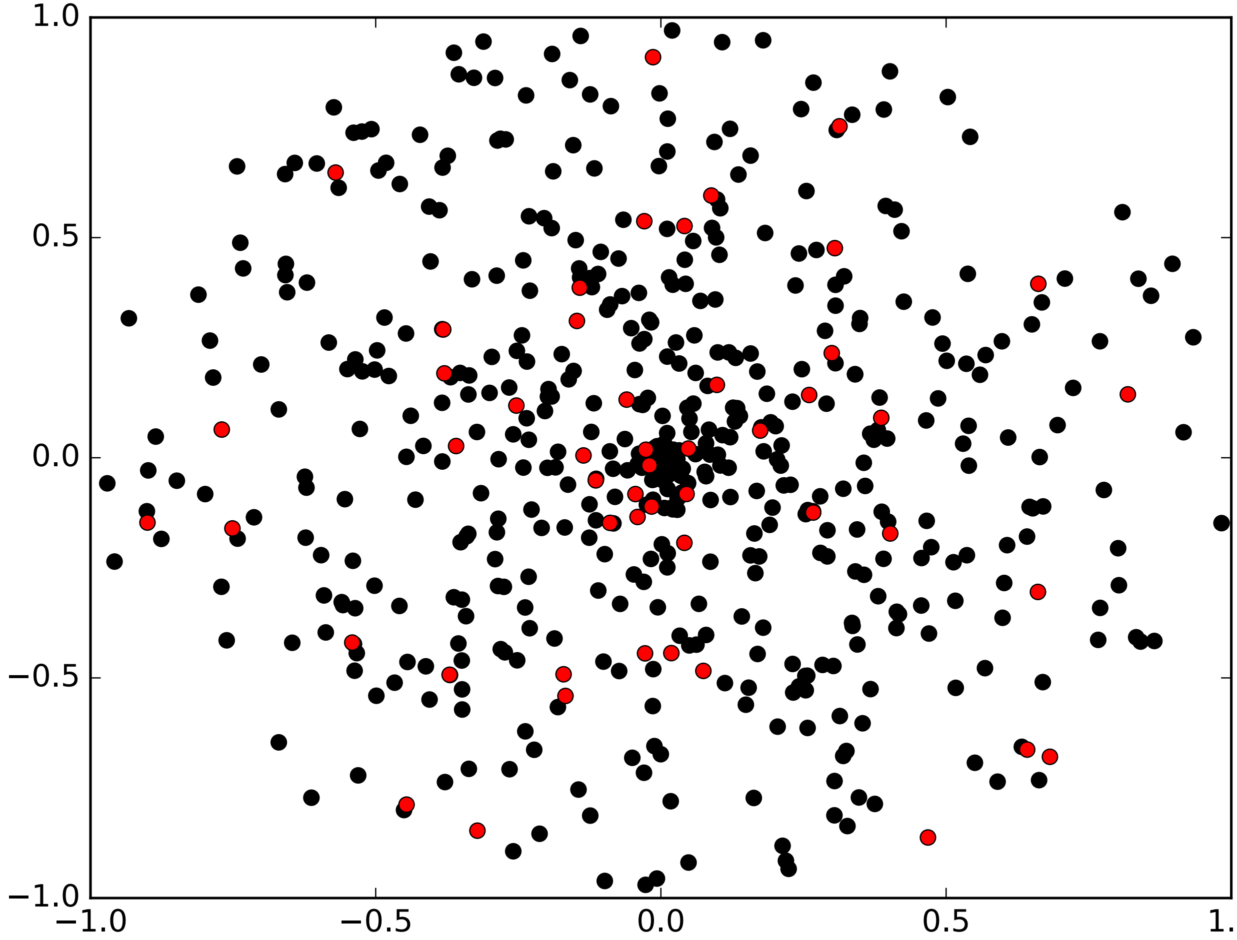
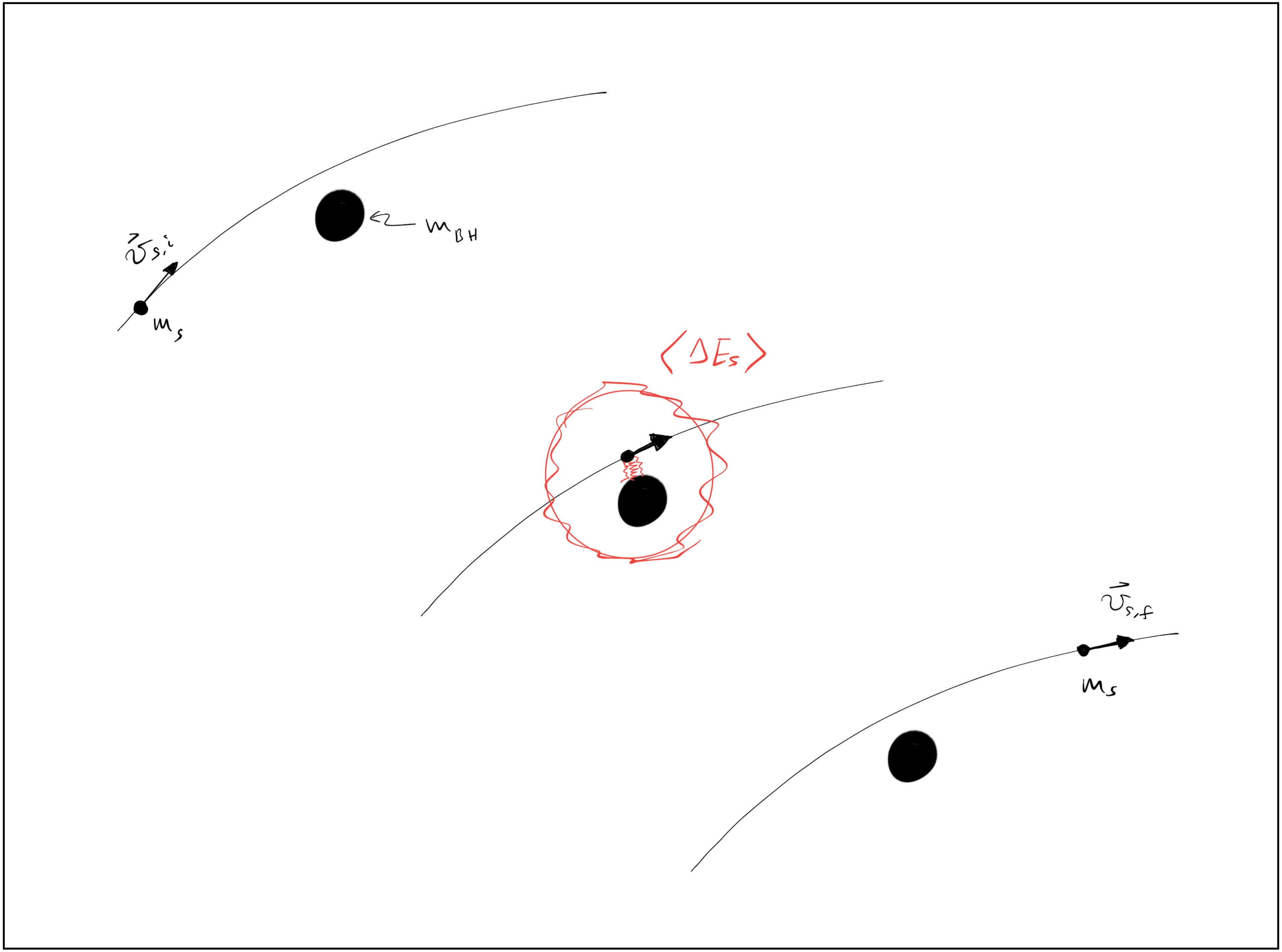
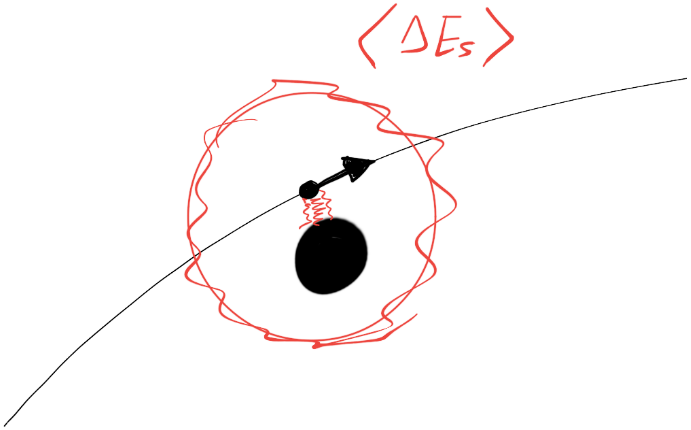


Dwarf galaxies: **Primordial black hole** dominated systems with few stars





$\vec{v}_{s,i}$
m_{BH}
m_s
$\langle \Delta E_s \rangle$
$\vec{v}_{s,f}$
m_s



Single interaction

$$\langle \Delta E \rangle_s \sim \frac{m_{\rm BH} n_{\rm BH}}{v_s} \, f\left(\frac{m_s}{m_{\rm BH}}\right)$$

Mean change of KE

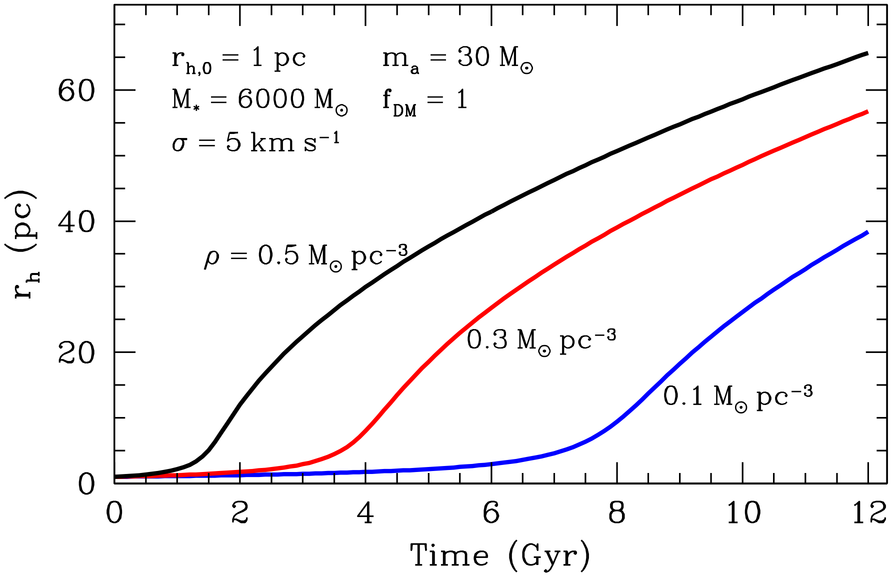
$$\frac{dE_s}{dt} \sim \frac{m_s \rho_{\rm BH}}{\sigma^3}\left[m_{\rm BH}\langle v_{\rm BH}^2\rangle - m_s\langle v_s^2\rangle\right]$$

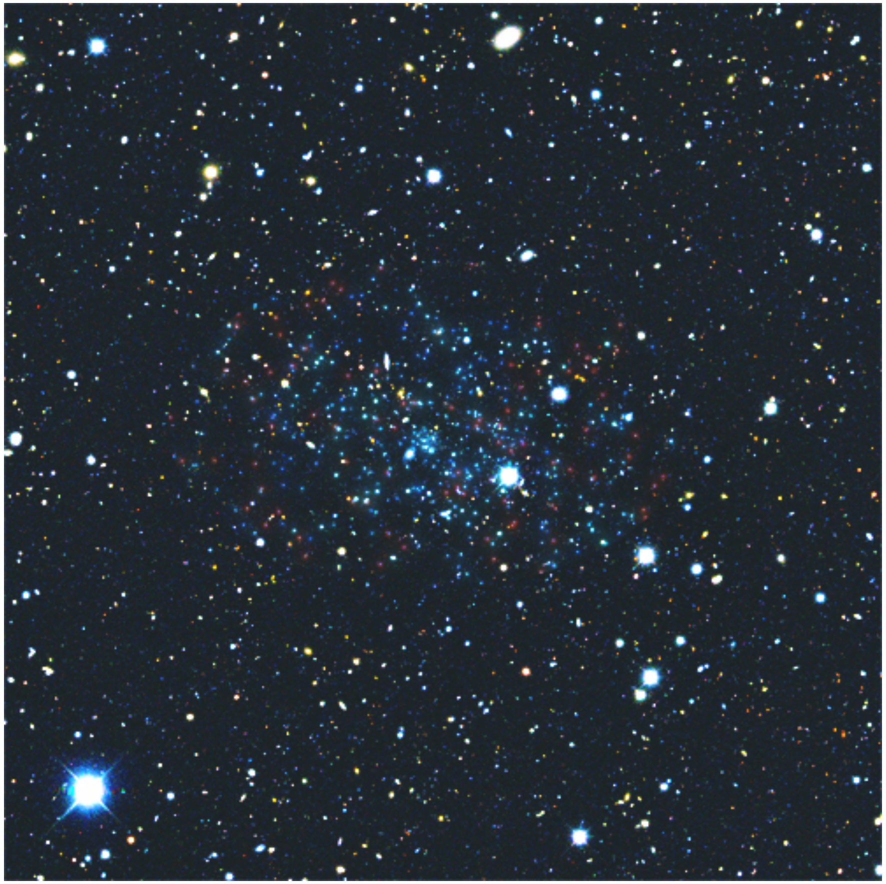
Eridanus II

Velocity dispersion unknown

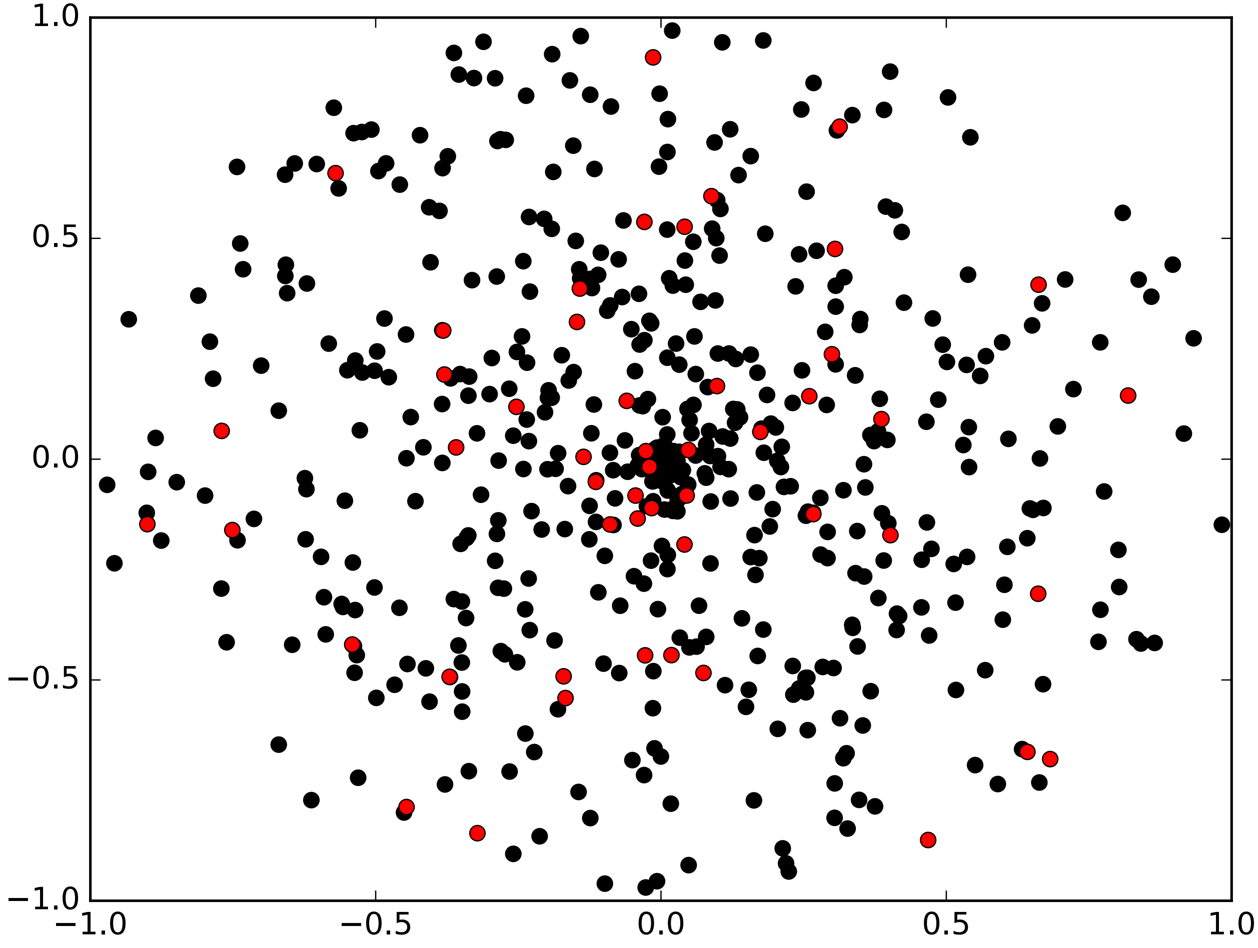
Dark matter distribution unknown

Use 1/2-light radius of the central cluster only

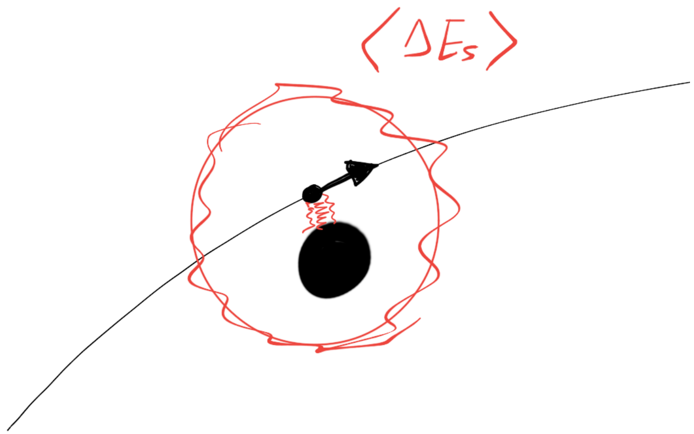




T. D. Brandt, Astrophys. J. Lett. **824**, L31 (2016)



1.0
0.5
0.0
−0.5
−1.0
−1.0
−0.5
0.0
0.5
1.0



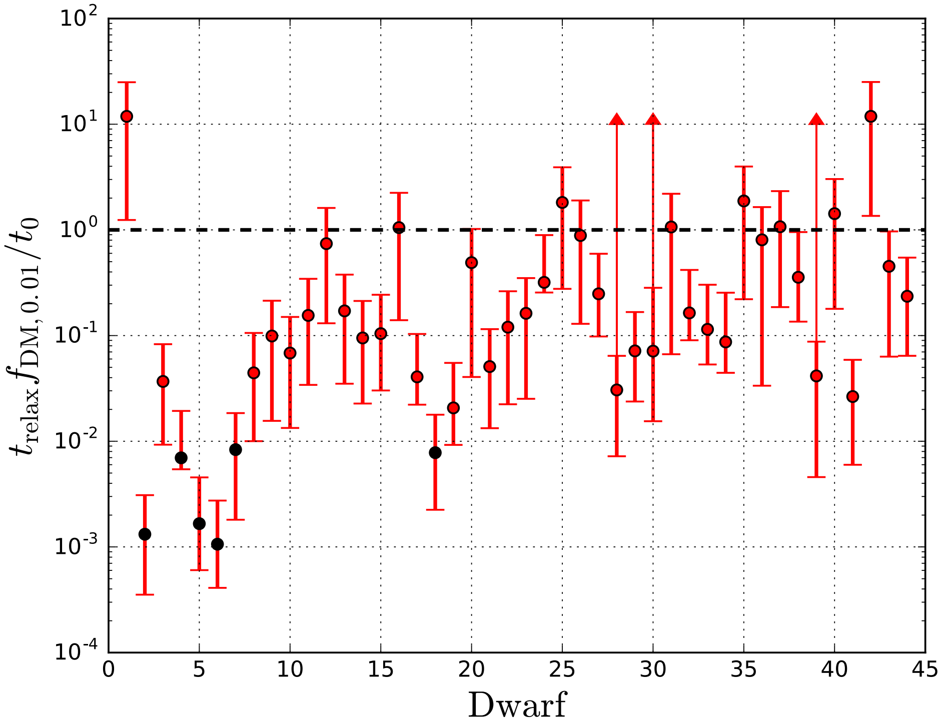
Time over which equipartition takes place

$$t_{\rm r} = \frac{E_s}{dE_s/dt}$$

Dwarfs with smallest relaxation time

Segue 1

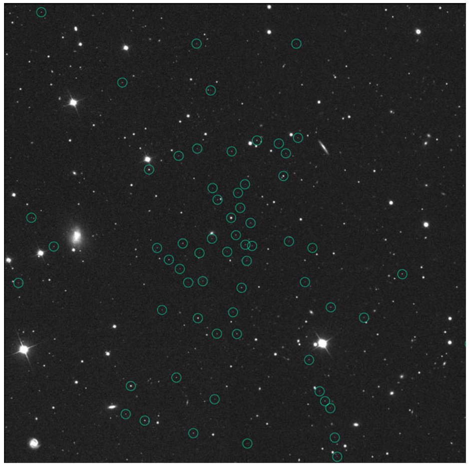
Boötes II
Segue II
Wilman 1
Coma Berenices
Canes Venatici II



The Astrophysical Journal, 733:46 (20pp), 2011 May 20 doi:10.1088/0004-637X/733/1/46

A COMPLETE SPECTROSCOPIC SURVEY OF THE MILKY WAY SATELLITE SEGUE 1: THE DARKEST GALAXY*

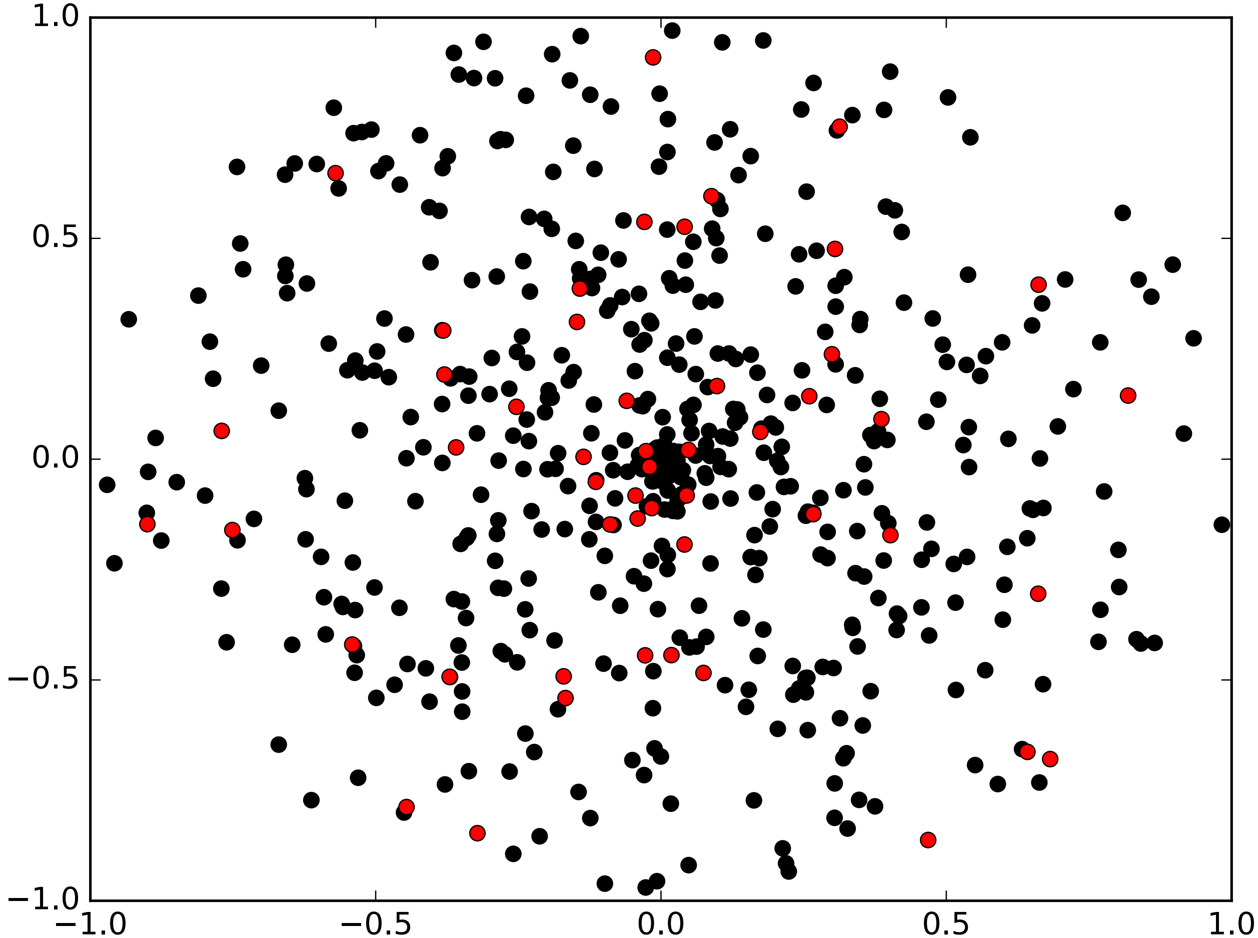
Joshua D. Simon[1], Marla Geha[2], Quinn E. Minor[3], Gregory D. Martinez[3], Evan N. Kirby[4,8], James S. Bullock[3], Manoj Kaplinghat[3], Louis E. Strigari[5,8], Beth Willman[6], Philip I. Choi[7], Erik J. Tollerud[3], and Joe Wolf[3]



The Astrophysical Journal, 801:74 (18pp), 2015 March 10 doi:10.1088/0004-637X/801/2/74

DWARF GALAXY ANNIHILATION AND DECAY EMISSION PROFILES FOR DARK MATTER EXPERIMENTS

Alex Geringer-Sameth[1,2], Savvas M. Koushiappas[1], and Matthew Walker[2]



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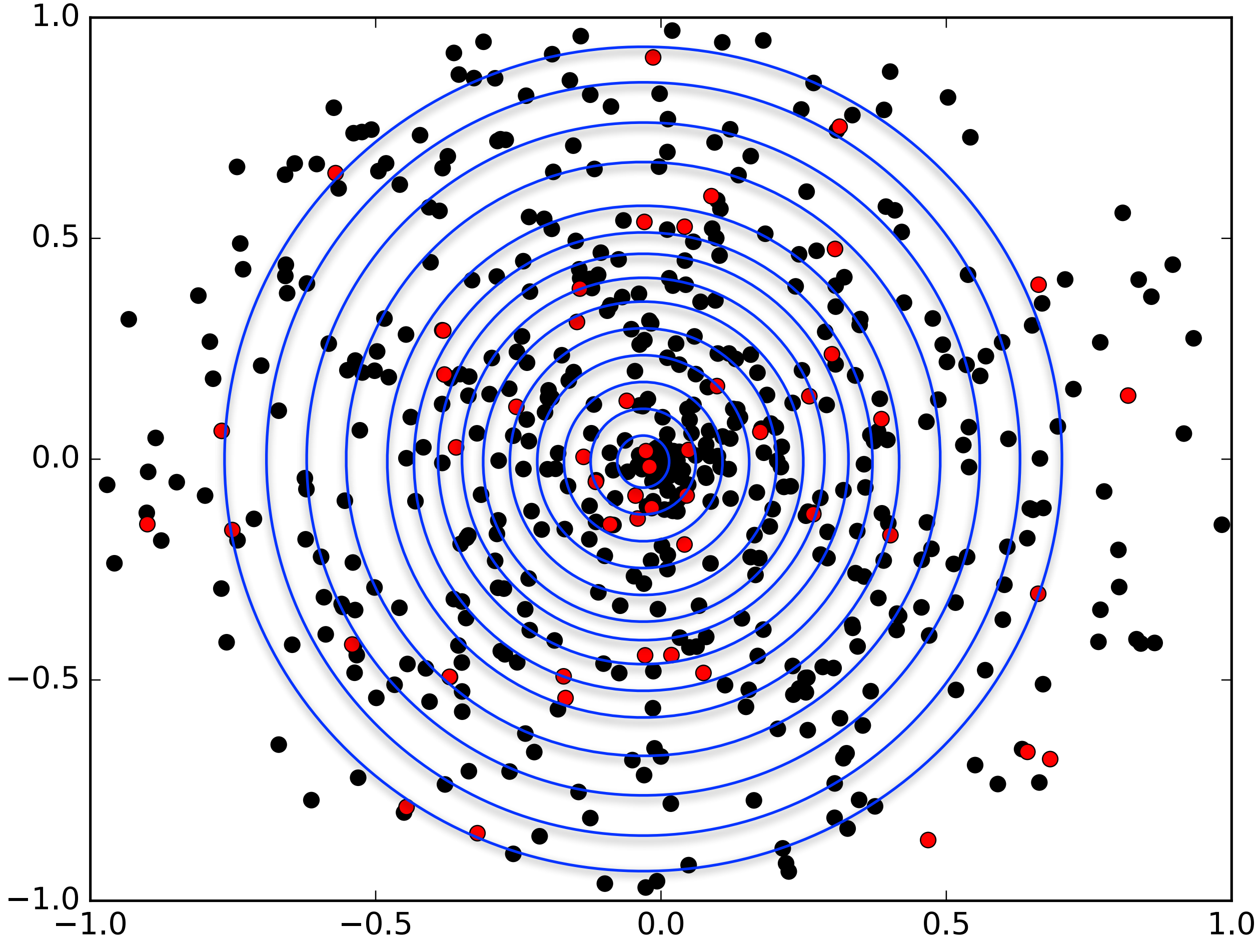

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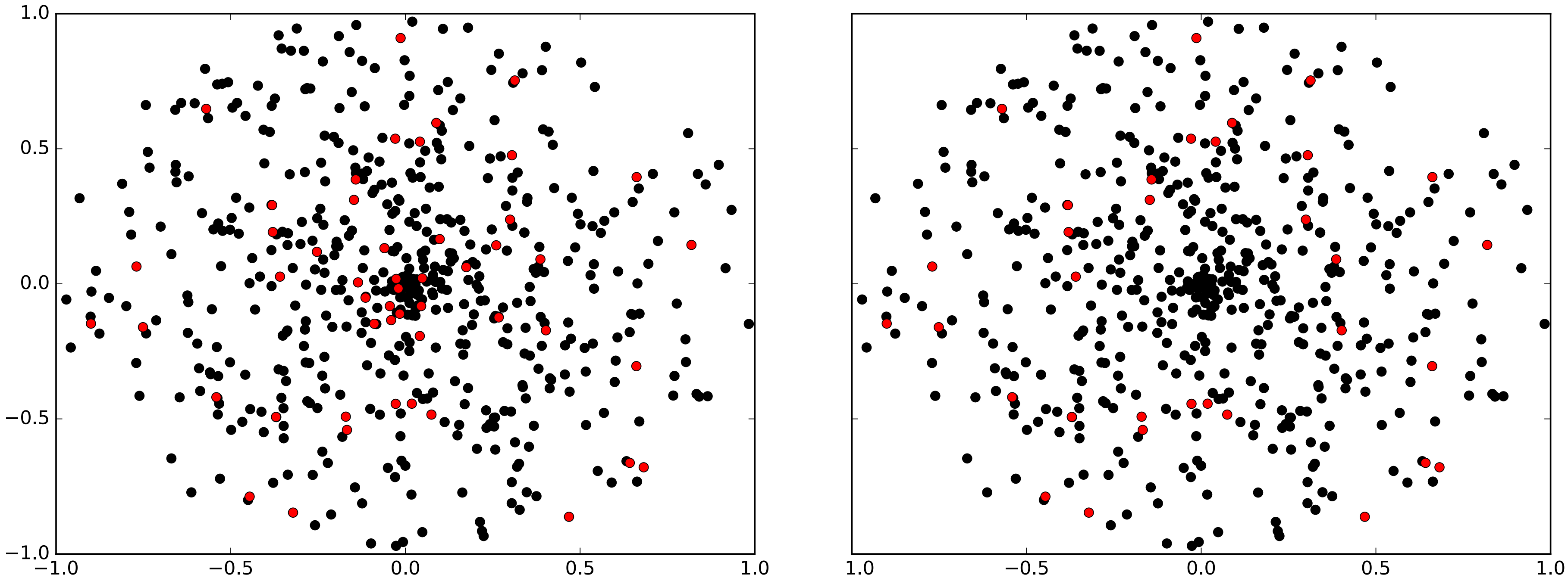
Equipartition leads to the depletion of stars from the center of the dwarf



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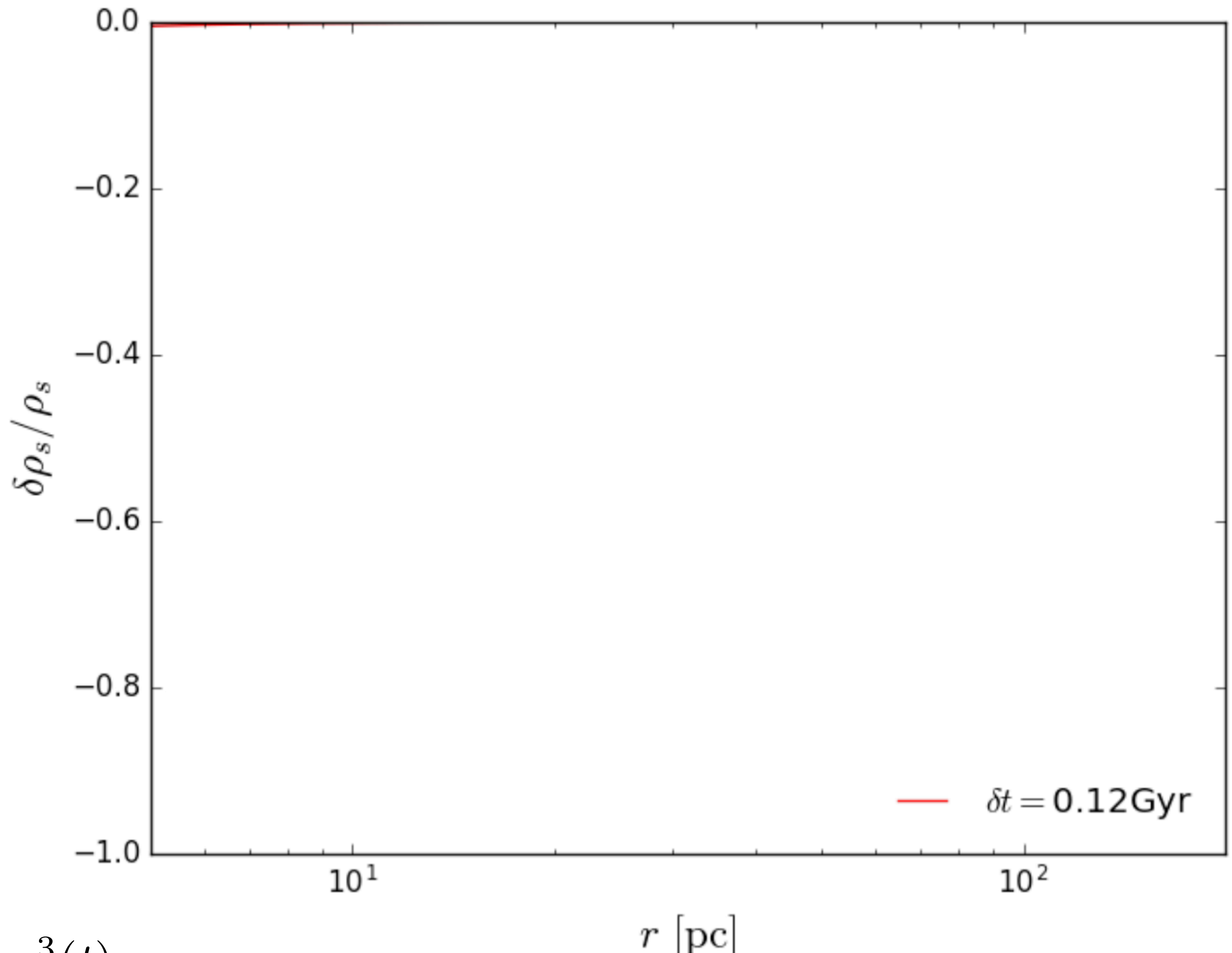
Evolution of density profile when 1% of dark matter is in 20 solar mass black holes



$$\frac{\delta\rho_s}{\rho_s} = \frac{r^3(t)}{r^3(0)} - 1$$

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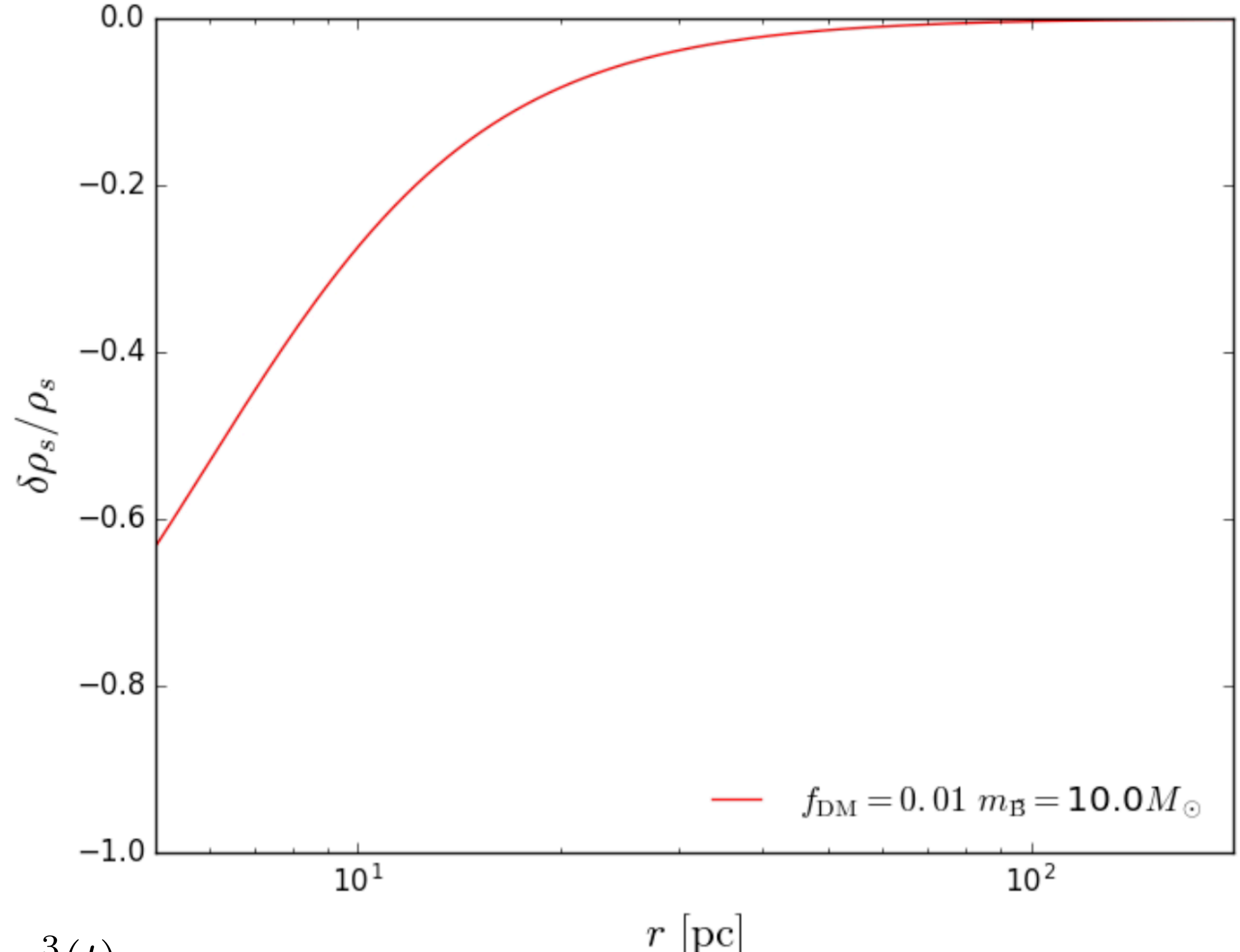
Evolution of density profile over 12 Gigayears



$$\frac{\delta\rho_s}{\rho_s} = \frac{r^3(t)}{r^3(0)} - 1$$

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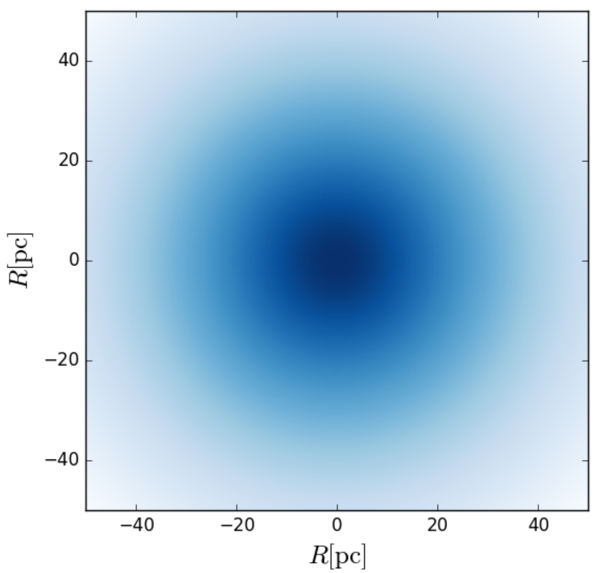
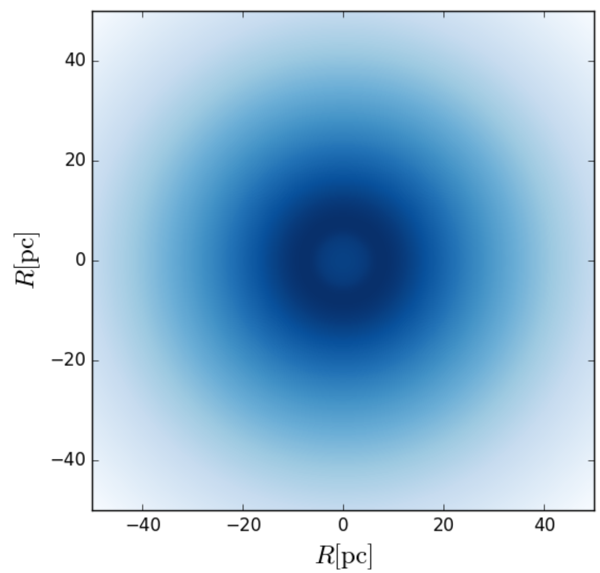
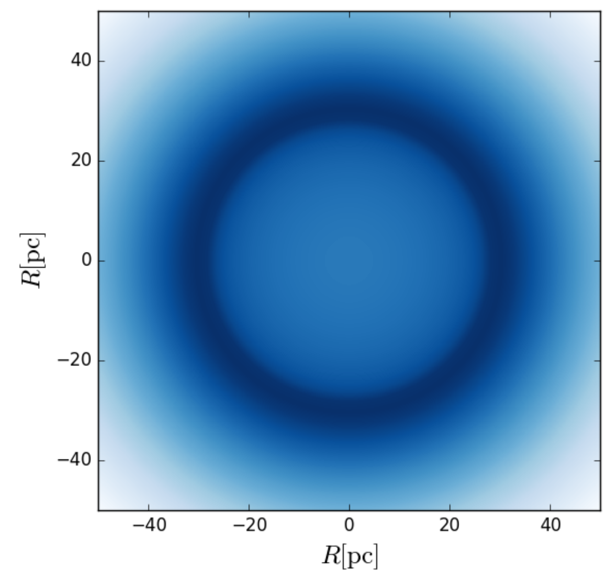
No black holes



1% dark matter in
10 solar mass black holes



10% of dark matter in
30 solar mass black holes



Both of these consistent with current observations

Ruled out

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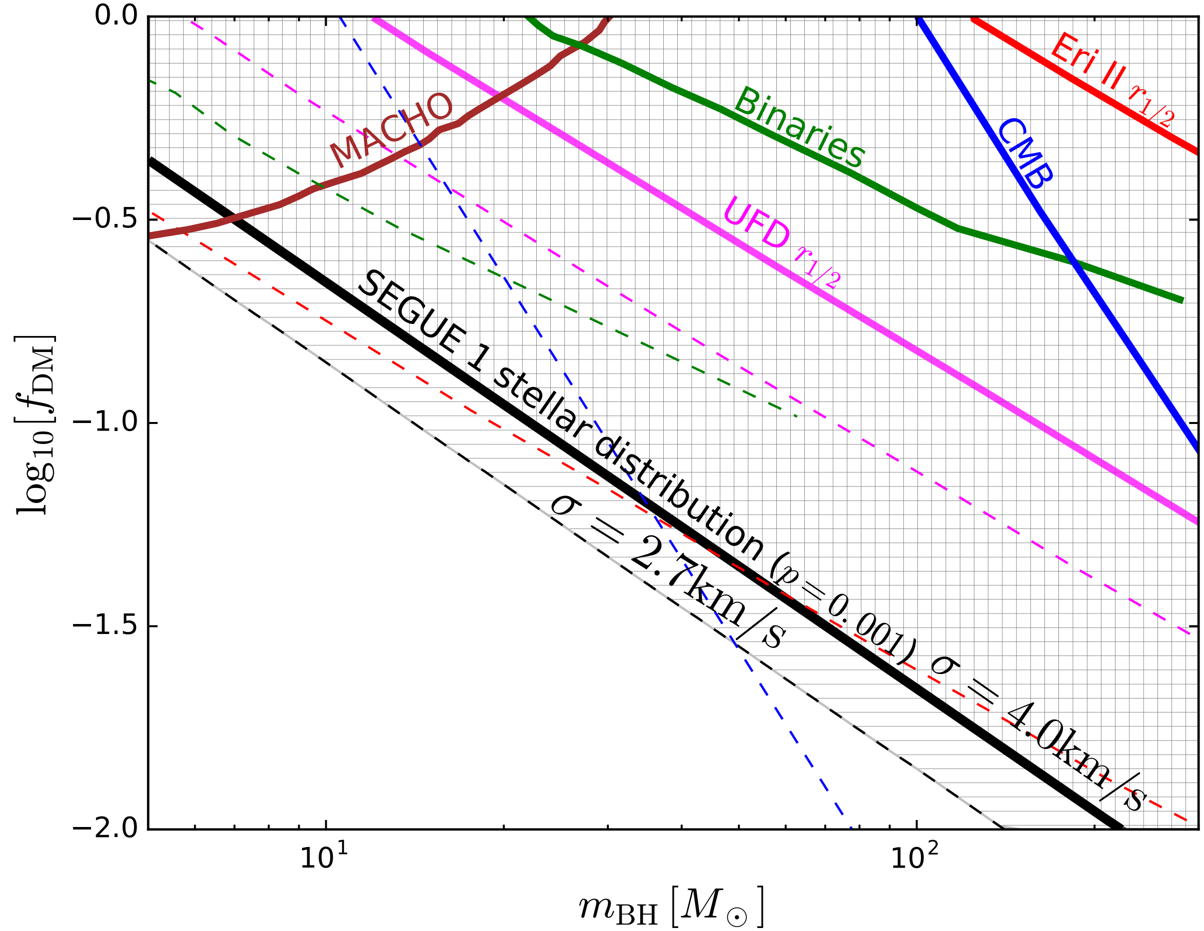
Primordial black hole constraints from the whole stellar population of Segue 1



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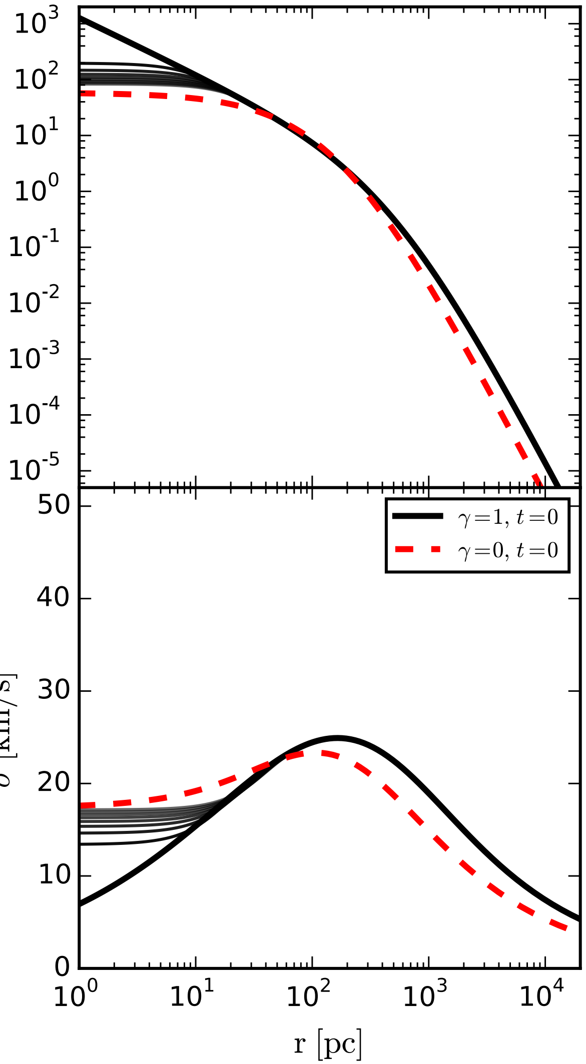
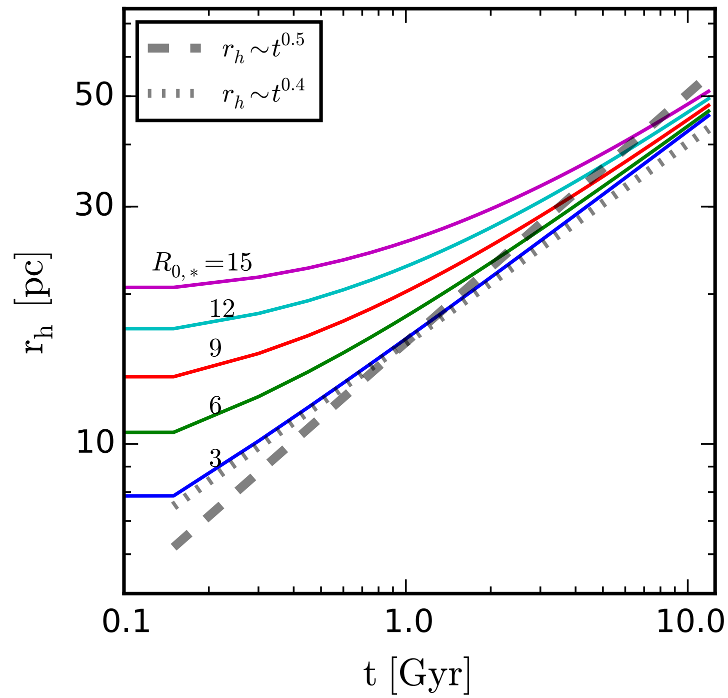
Fokker-Planck treatment of the same problem



1. arXiv:1710.05032 [pdf, other]
Primordial Black Holes as Dark Matter: Constraints From Compact Ultra-Faint Dwarfs
Qirong Zhu, Eugene Vasiliev, Yuexing Li, Yipeng Jing



How to distinguish primordial from baryonic black holes

PRL **119,** 221104 (2017) PHYSICAL REVIEW LETTERS week ending 1 DECEMBER 2017

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(Received 24 August 2017; published 30 November 2017)

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How to distinguish primordial from baryonic black holes

- Black holes must be formed.

- Black holes must find a way to get close enough so that gravitational waves can take-over as the dominant energy loss mechanism.

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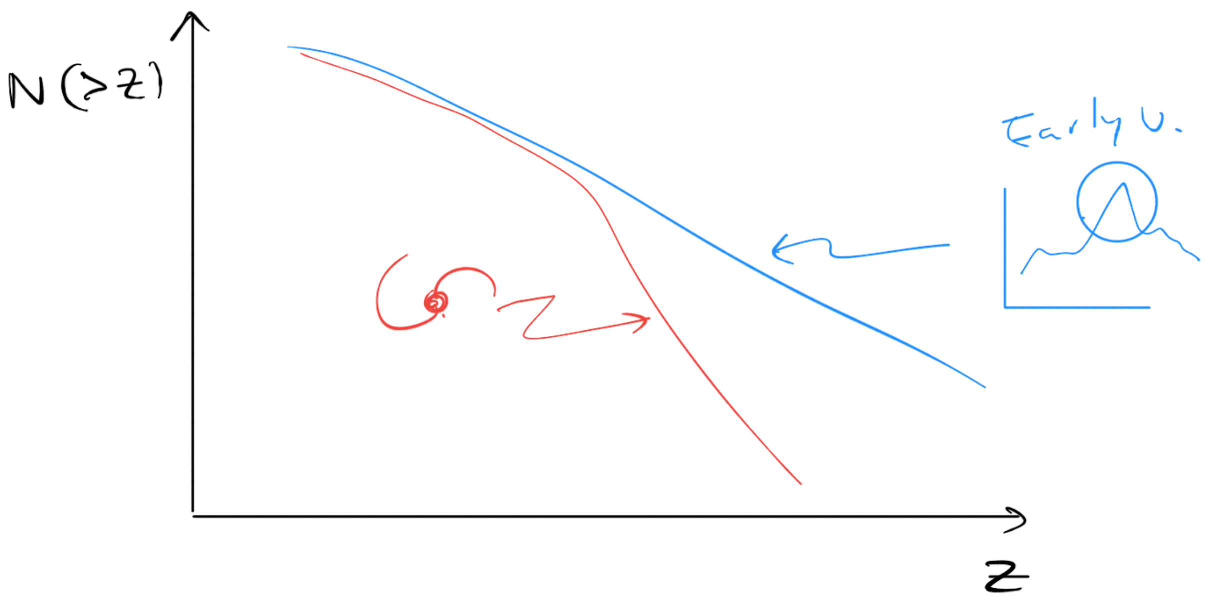

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How to distinguish primordial from baryonic black holes

$$\mathcal{N}(>z) = \int_z^{\infty} \frac{d\mathcal{R}}{dz}\, dz$$

How many DM Halos

Rate of gas inflow

Fraction of gas that cools to form black holes

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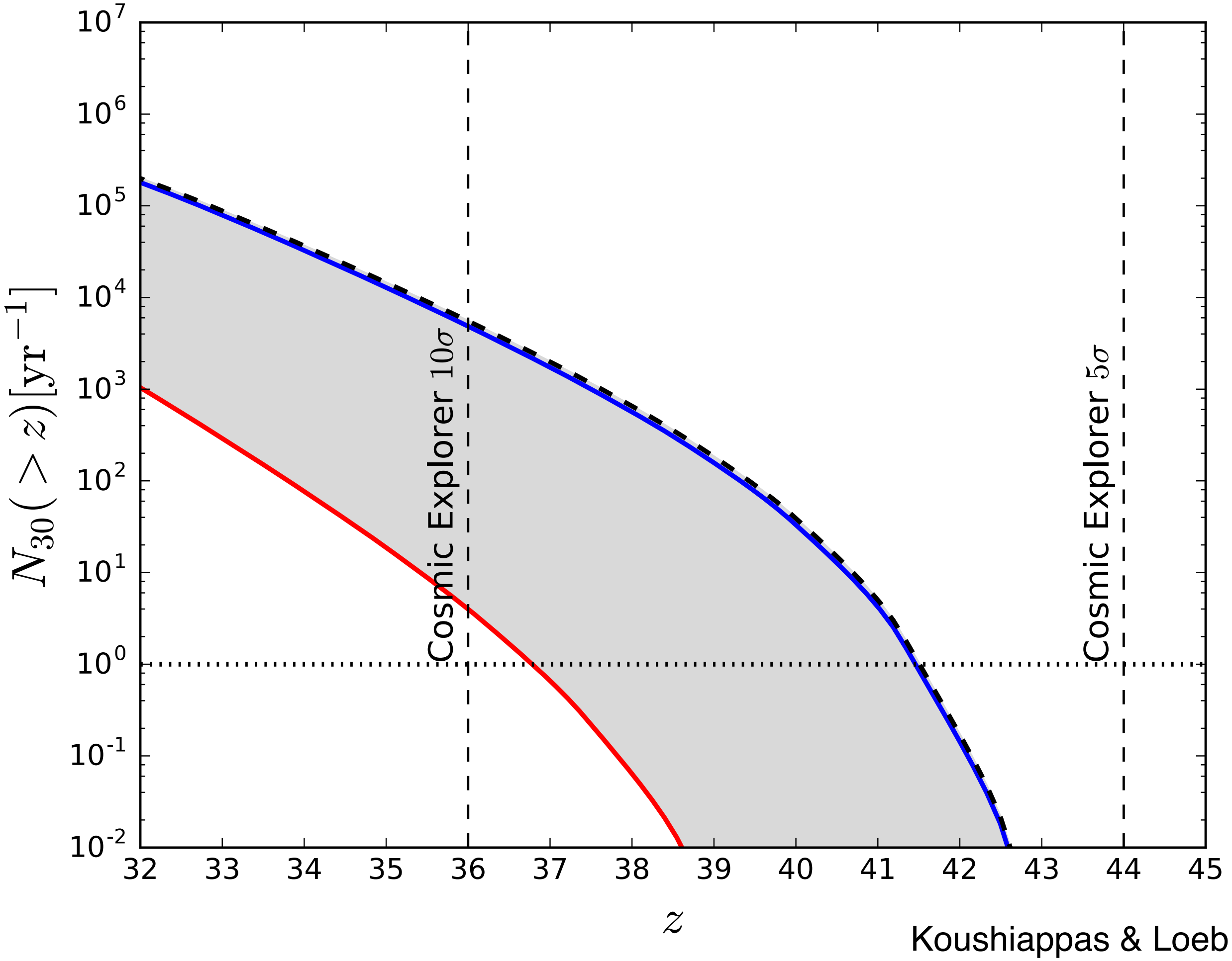
Rate of black hole merger events

Define maximum redshift

$$\mathcal{N}(z = z_{\max}) = 1\,\mathrm{yr}^{-1}$$



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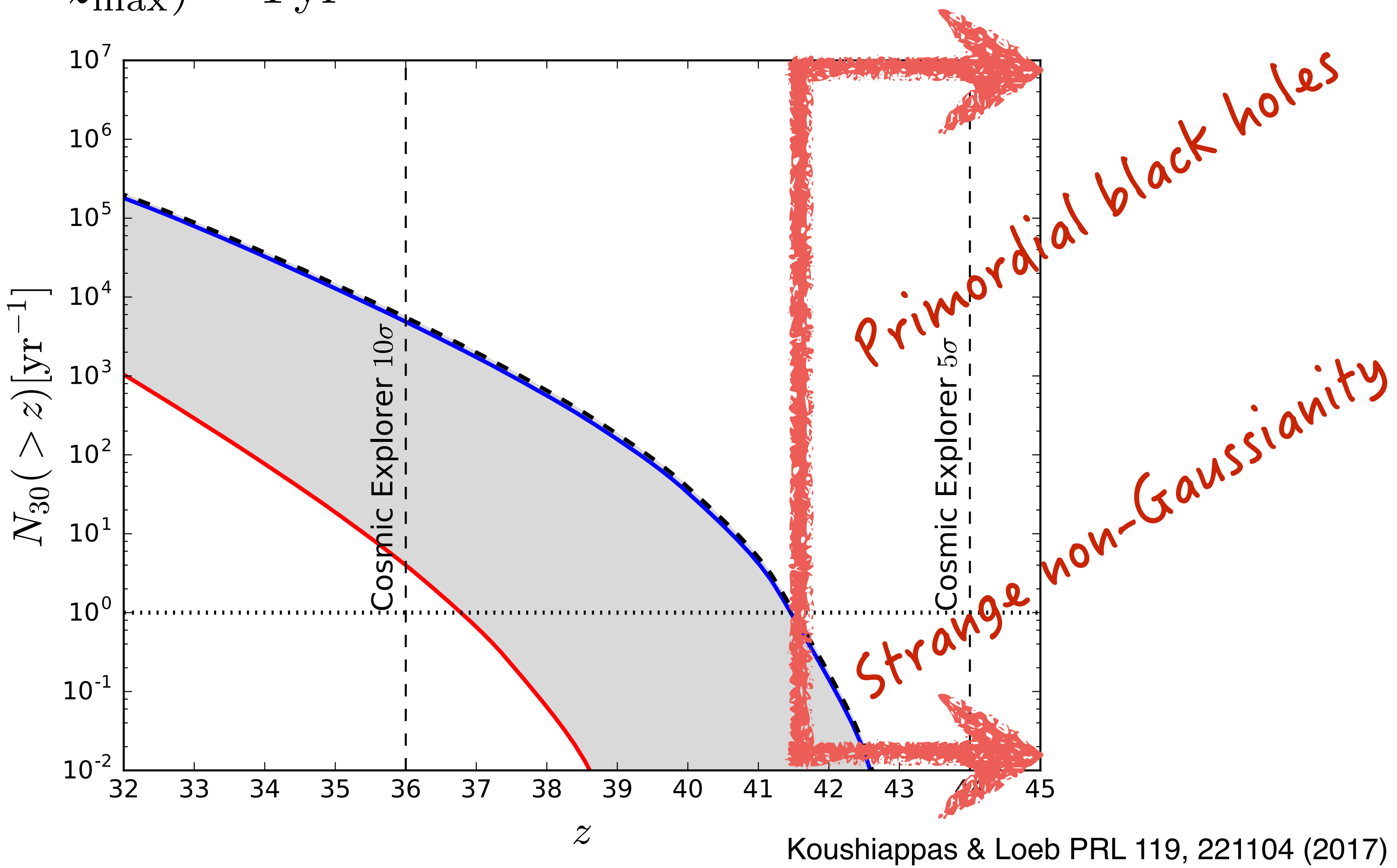

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Four things to take away

1. Black holes as dark matter lead to a depletion of stars in the center and the appearance of a ring in the projected stellar surface density profile.

2. Current observations rule out the possibility that more than 4% of the dark matter is composed of black holes with mass of few tens of solar masses.

3. Next generation of large aperture telescopes could improve these constraints.

4. Event rate of more than 1 per year from redshifts greater than ~ 40 must be due to either primordial black holes or some strange non-gaussianity.