Dark matter annihilation in the Galaxy

Veniamin Berezinsky[⋆‡]
Vyacheslav Dokuchaev[⋆] Yury Eroshenko[⋆]

[⋆]Institute for Nuclear Research, RAS, Moscow

[†]Laboratori Nazionali del Gran Sasso, Italy

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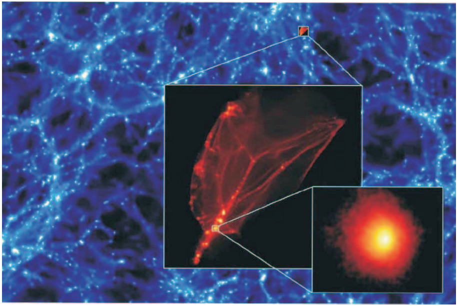
DM clumps

- Standard cosmological scenario with an inflationary-produced primordial fluctuation spectrum
- Spike in the spectrum of perturbations
- Clumps from isothermal fluctuations
- Clumps seeded by topological defects
- Various DM models

Numerical simulations



3 kpc 60 pc 0.024 pc

$N = 62 \cdot 10^6$, $m = 1.2 \cdot 10^{-10} M_\odot$, $z = 350 \to 26$

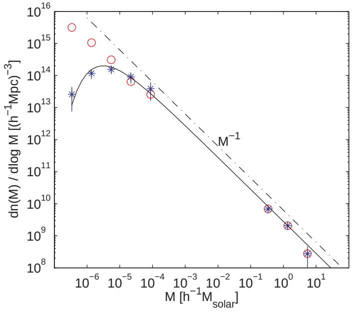
(Diemand, Moore, Stadel, 2005)

- Integral mass function and number density of clumps

$$\xi_{\rm int}\frac{dM}{M} \simeq 0.02(n+3)\,\frac{dM}{M}$$

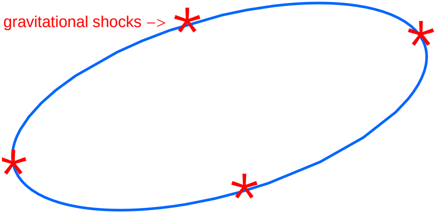
$$n_{\rm cl}(M,R)d\ln M d\ln R = \frac{\rho_{\rm DM}(r_\odot)}{M}\xi(M,\nu)d\ln M d\nu$$

(Berezinsky, Dokuchaev, Eroshenko, 2003, 2006, 2008)



(Diemand, Moore, Stadel, 2005)

Remnants (cores) of clumps



$\sum_j (\Delta E)_j \sim |E|$ - rough criterium for destruction

Gradual mass loss $\rightarrow$ remnants of clumps. Core size = ?

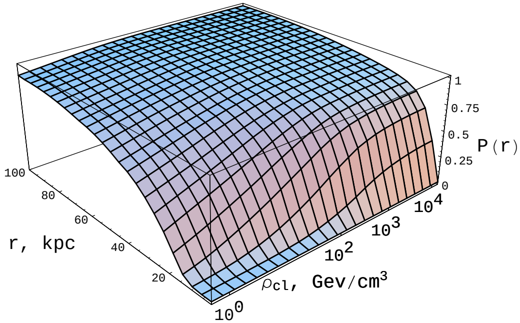
$R_c/R \simeq 10^{-5}$ (Gurevich, Zybin, 1995)

$R_c/R \simeq 0.01$ (Diemand, Moore, Stadel, 2005)

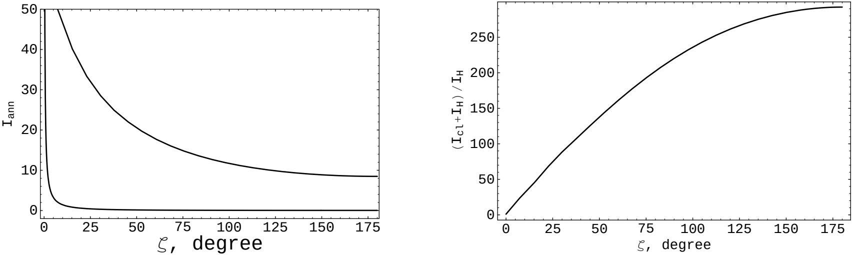
$$\rho_{\rm int}(r) \propto r^{-\beta}, \quad \dot{N} \propto \int_0^r 4\pi r'^2 dr' \rho_{\rm int}^2(r')$$

There is no dependence on r if $\beta > 3/2$ and $R_c/R \ll 1$!

Survival probability

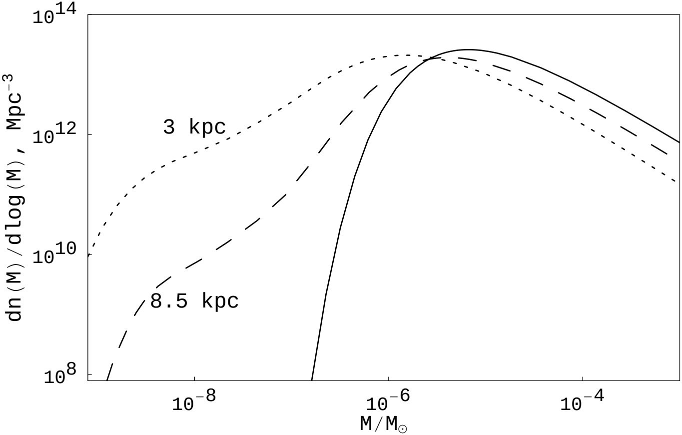


Fraction of survived clumps with $M = 10^{-6} M_\odot$ and $\nu = 2$ in dependence of clump density $\rho_{\rm cl}$ in GeV cm^{-3}.



Left: The annihilation signal (upper curve) as a function of the angle ζ between the line of observation and the direction to the Galactic center. Right: amplification of the signal $(I_{\rm cl} - I_{\rm H})/I_{\rm H}$.

Transformation of the mass function



Numerically calculated modified mass function of clump remnants for galactocentric distances 3 and 8.5 kpc. The solid curve shows the initial mass function.

Despite the small survival probability of clumps during early stage of hierarchial clustering, they provide the major contribution to the annihilation signal (in comparison with the unclumpy DM). The amplification (boost-factor) can reach 10^2 or even 10^3 depending on the initial perturbation spectrum and minimum mass of clumps. This boost-factor must be included in calculations of the annihilation signals. These remnants of DM clumps form the low-mass tail in the standard mass distribution of small-scale clumps extended much below $M_{\rm min}$ of the standard distribution. The numerical estimate of the boost-factor for DM particle annihilation inside clumps is very model-dependent. It depends on nature of DM particles and on their interaction with ambient plasma. The spectral index of density perturbation n_p affects strongly the boost-factor.

Loops length distribution

Cosmological phase transitions $\rightarrow$ network of cosmic strings $\rightarrow$ interconnections $\rightarrow$ transient stage $\rightarrow$ scaling regime $\rightarrow$ closed loops with $l \simeq \alpha c t$, where $\alpha \simeq 0.1$.

$$dn_{\rm loop} = \frac{N dl}{c^{3/2} t^{3/2} l^{5/2}}, \quad \text{where } N \sim 2$$

(Olum, Vilenkin, 2006)

The loops distribution is translated to DM clumps distribution.

Formation of DM clumps at RD stage

- Initial speed of the loops and rocket effect.
  $\langle v_i^2 \rangle^{1/2} \simeq 0.15c$ (Allen, Shellard,1990)
  Probability of low velocity loop formation: $P_{\rm lv} \simeq 2 \times 10^{-7}$.
- Formation of DM clumps at RD stage (Kolb, Tkachev, 1994)

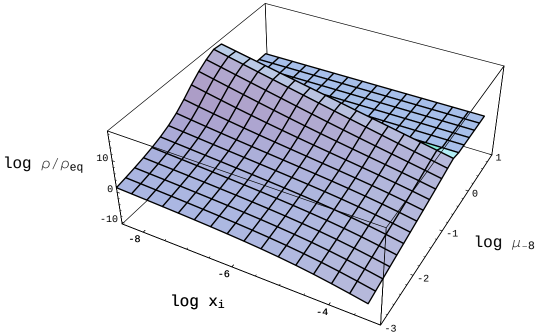
$$x(x+1)\frac{d^2b}{dx^2} + \left[1 + \frac{3}{2}x\right]\frac{db}{dx} + \frac{1}{2}\left[\frac{1+\Phi}{b^2} - b\right] = 0,$$

where $x = a(\eta)/a_{\rm eq}$, $r = a(\eta)b(\eta)\xi$, ξ is the comoving coordinate.

- Continuous evaporation and fast decay approximations.

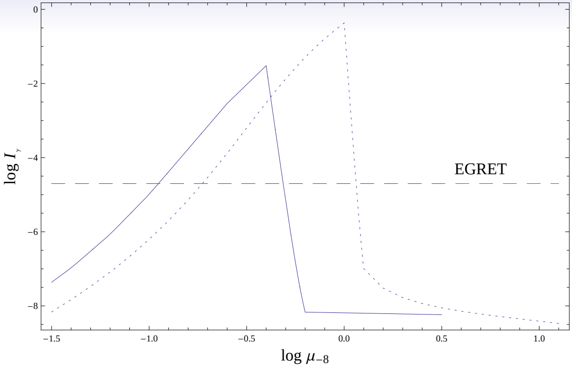
$$\frac{dM_l}{dt} = -\frac{\Gamma G\mu^2}{c}, \quad \tau \simeq lc/(G\mu\Gamma)$$

- Adiabatic expansion of clumps $M_{\rm tot}R = const$



Clump density ρ in the units of density at matter-radiation equality $\rho_{\rm eq}$ in dependence on the loop birth moment $x_i = a(t_i)/a_{\rm eq}$ and parameter $\mu_{-8} = G\mu/(10^{-8}c^2)$. The break of the surface down to value $\rho = 140\rho_{\rm eq}$ corresponds to the proximity of turnaround and loop decay moments.

$\mu \equiv M_l/l$, for the grand-unification-scale $G\mu/c^2 \sim 10^{-6}$
Restrictions:
$G\mu/c^2 \leq 2 \times 10^{-7}$ – CMB
$\leq 10^{-7}$ – pulsar timing and nucleosynthesis
$\leq 3 \times 10^{-8}$ – stars in the first DM haloes seeded by the loops
Search for gravitational wave bursts from strings by LIGO



The annihilation signal (in units cm^{-2} s^{-1} sr^{-1}) from clumps in dependence on string parameter $\mu_{-8} = G\mu/(10^{-8}c^2)$ is shown by solid line. The horizontal dashed line shows the EGRET data $I_\gamma \simeq 2 \times 10^{-5}$ cm^{-2}s^{-1}sr^{-1}. Dotted line - continuous evaporation approximation.

100 GeV neutralino DM is incompatible with range of strings parameters $1 \times 10^{-9} < G\mu/c^2 < 5 \times 10^{-9}$