

Title: Astroparticle Physics & Theory: WIMP Paradigm

Date: Jul 06, 2015 11:00 AM

URL: <http://pirsa.org/15070014>

Abstract:



(3) Black Hole $\sim 4 \times 10^6 M_{\odot}$

(4) Dark Matter Halo



$R \sim 200 \text{ kpc}$

$M \sim 10^{12} M_{\odot}$

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gravitational interactions

Exercise | Stars are good tracers for DM

actions

CAUTION
DO NOT TOUCH THE BOARD SURFACE
OR THE BOARD FRAME
OR THE BOARD MOUNTING BRACKET

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Exercise | Stars are good tracers for DM

Time btwn collisions

$$R \sim R_0 \sim 2 \times 10^8 \text{ pc}$$

$$v \sim 50 \text{ km/s} \sim 3 \times 10^{-14} \text{ pc/s}$$

Mean free path $\lambda \sim \frac{1}{n\sigma}$

$$n \sim 0.6 \text{ pc}^{-3}$$

$$\sigma \sim \pi R_0^2 \sim 10^{15} \text{ pc}^2$$

$$\lambda \sim 10^{15} \text{ pc}$$

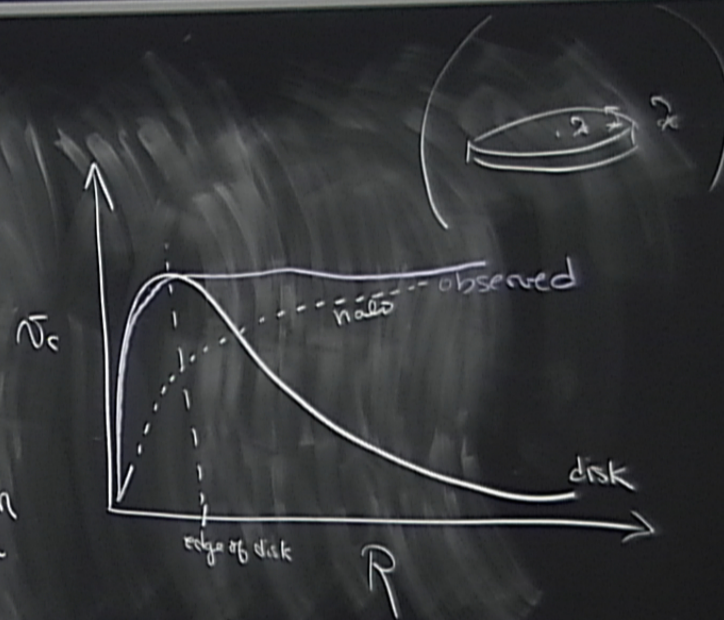
Time btwn collisions
for 2 stars

ROTATION CURVES

30's: Zwicky

1939: Babcock Rotation Curves

1970's: Rubin + Ford } Rotation Curve
Whitehurst }



Interpretations = (1) Missing non-visible mass
(2) Newton's laws must be notified

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MOND

[www.slac.stanford.edu/
~mperkin/GCI15](http://www.slac.stanford.edu/~mperkin/GCI15)

effective force law

$$\vec{F} = M \vec{a} \mu\left(\frac{a}{a_0}\right)$$

$\mu(x)$ interpolates

$$x \sim a/a_0 \gg 1, \mu \rightarrow 1$$

$$x \sim a/a_0 \ll 1, \mu \rightarrow x$$

$$F = ma$$

$$F = ma^2/a_0$$

disk
→

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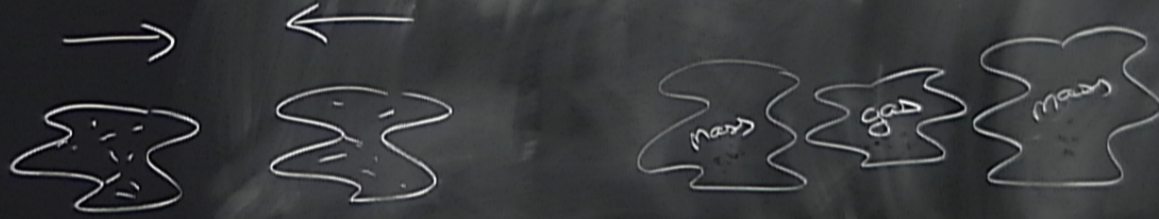
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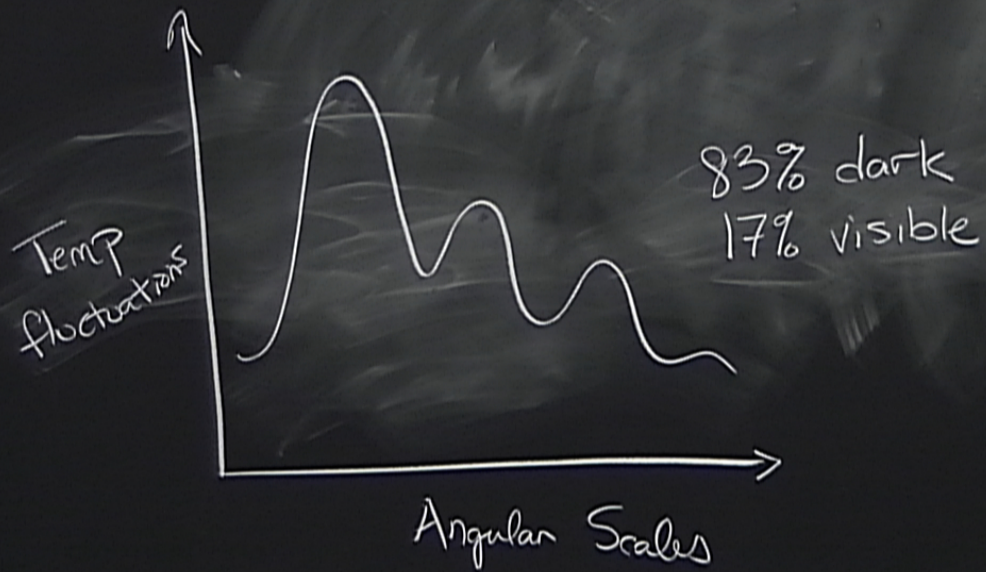
$$F = ma$$

$$F = m\vec{a}^2/a_0$$

$\mu \approx 10^{-10} \text{ pc}^{-2}$



reactions



Collisionless Boltzmann Eqn

$$\frac{\partial f}{\partial t} + \dot{\mathbf{q}} \cdot \frac{\partial f}{\partial \mathbf{q}} + \dot{\mathbf{p}} \cdot \frac{\partial f}{\partial \mathbf{p}} = 0$$

"DM fluid"

Jeans Thm | steady-state soln to must be
a function of integrals of motion (I)

$$\frac{d}{dt} I(\bar{x}, \bar{v}) = 0 \quad \text{ex: } H = \frac{1}{2} v^2 + \Phi$$

Collisionless Boltzmann Eqn

$$\frac{\partial f}{\partial t} + \dot{\mathbf{q}} \cdot \frac{\partial f}{\partial \mathbf{q}} + \dot{\mathbf{p}} \cdot \frac{\partial f}{\partial \mathbf{p}} = 0$$

"DM fluid"

Jeans Thm | steady-state soln to must be

H, L_z a function of integrals of motion (I)

H, L $\frac{d}{dt} I(\bar{x}, \bar{v}) = 0$ ex: $H = \frac{1}{2} v^2 + \Phi$

Exercise | Show that the mean velocity
vanishes \Leftrightarrow velocity dispersion is isotropic
 $f(\frac{1}{2}v^2 + \phi) \quad \Leftrightarrow \quad \sigma_{ij}^2 = \langle v_i v_j \rangle$



Assumptions: DM is collisionless, equilibrium, isotropic

Claim: $\rho \sim 1/R^2 \iff f(v) \sim \exp\left(\frac{\psi - \frac{1}{2}v^2}{\sigma^2}\right)$

Proof: Relate ρ to ψ $\rho \propto e^{\psi/\sigma^2}$

Use Poisson's eqn \Rightarrow

$$\rho(R) = \frac{\sigma^2}{2\pi G R^2}$$

Numerical Simulations

[www.slac.stanford.edu/
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Hierarchical Merging

- initial density perturbations collapse
small, low-mass halos
- over time,

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If it is necessary to clean
the board, please use the
chalk eraser only.

Numerical Simulations

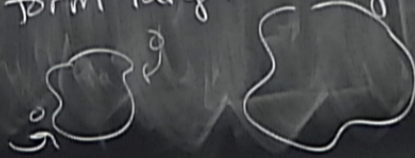
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Hierarchical Merging

→ initial density perturbations collapse
small, low-mass halos

→ over time, merging together to
form larger + larger halos
"fossil structure"

\rightarrow
 \rightarrow
 \rightarrow



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cold dark matter : non-relativistic during structure formation ($\lambda \ll D_{\text{galaxy}}$)

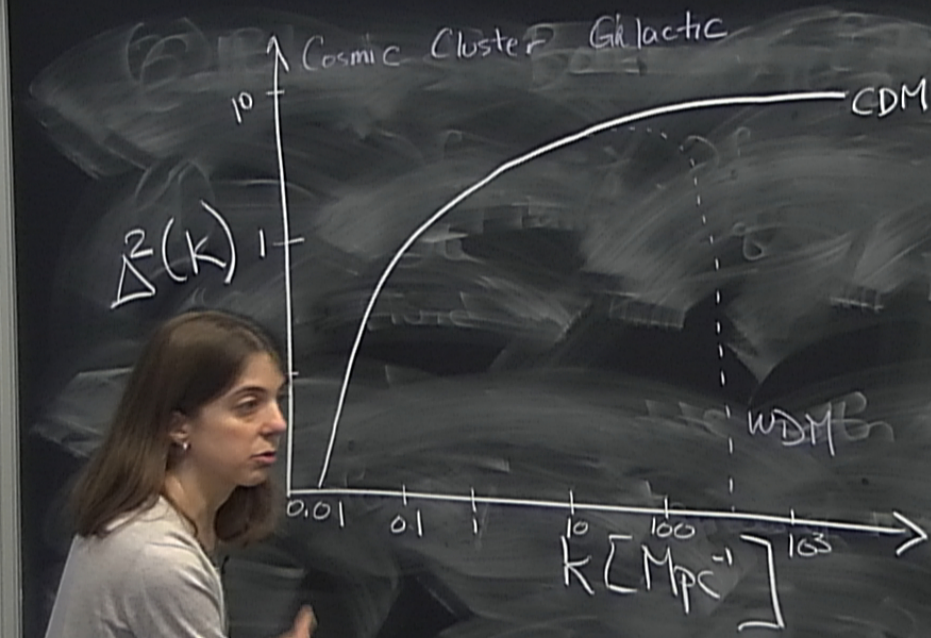
warm dm : intermediate

hot dark matter : relativistic ($\lambda \gg D_{\text{galaxy}}$)

cold dark matter : non-relativistic during structure formation ($\lambda \ll D_{\text{galaxy}}$)

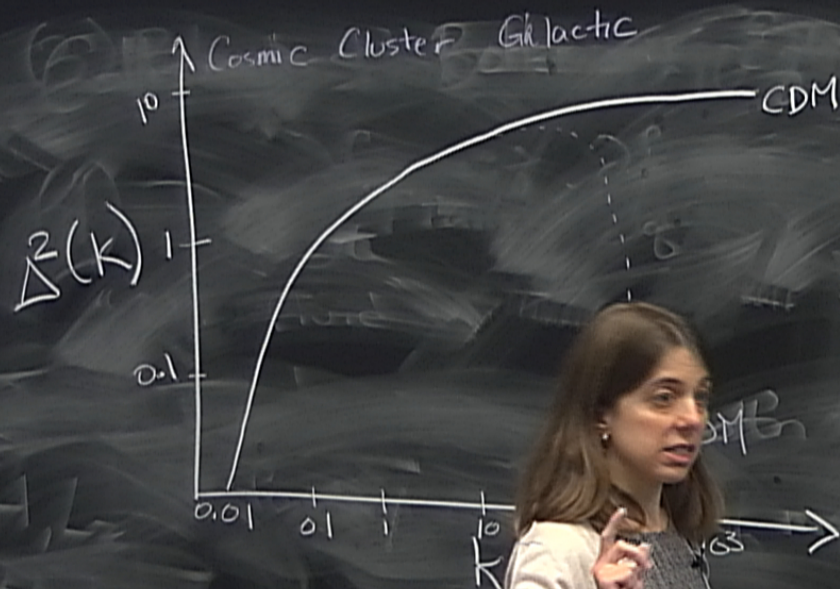
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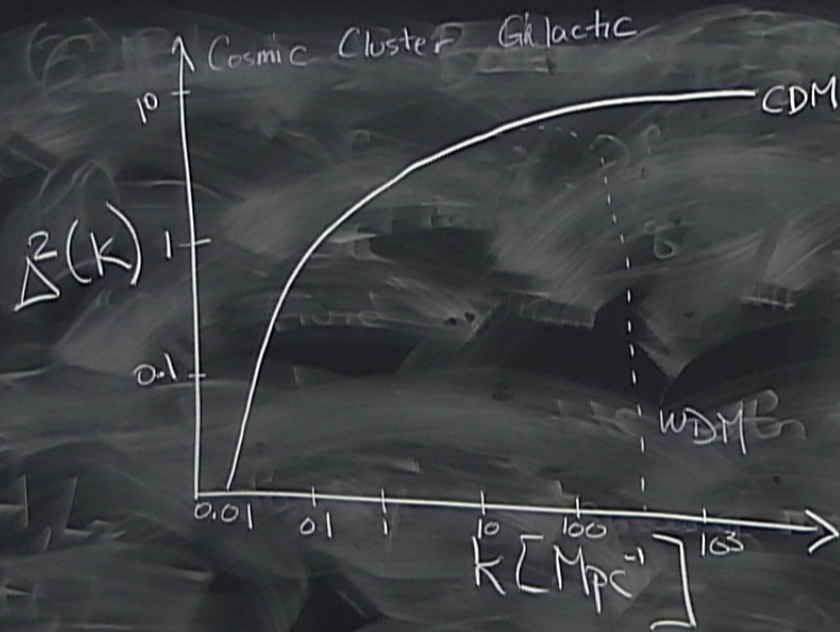
$$\Delta^2(k) = 4\pi \left(\frac{k}{2\pi}\right)^3 P(k)$$

200 kpc



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Substructure in the MW-like galaxies

- self-bound subhalos

$$\frac{dN}{dM} \sim M^{-1.9}$$

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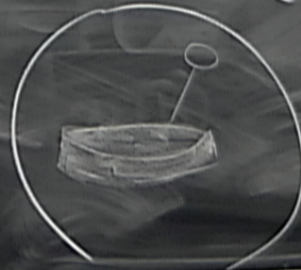
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→ more clumpiness further away from GC

- tidal streams

- dark disk

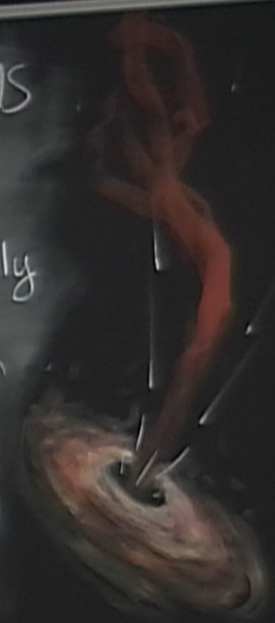
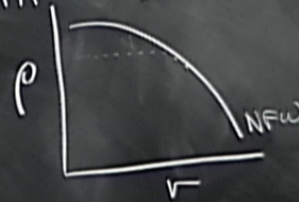


MYSTERIES FROM DM-ONLY SIMULATIONS

- Missing Satellites Problem

Sim find more subhalos than we actually observe

- CUSP/CORE CONTROVERSY: sim tend to find "cuspy" density dist



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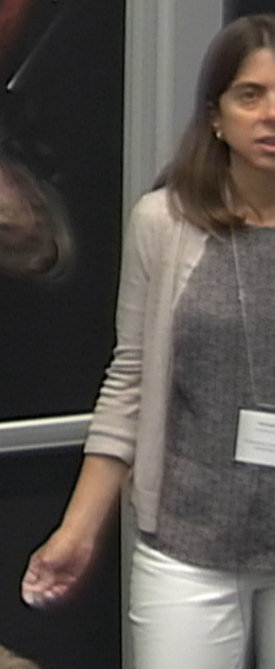
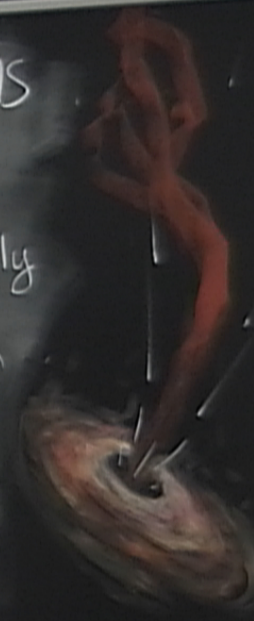
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density dist



- TOO BIG TO FAIL PROBLEM: sim find more very massive halos than are actually observed



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PLEASE ASK THE PRESENTER

Substructure in the MW-like galaxies

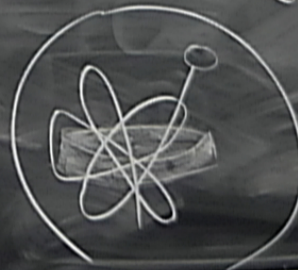
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