

Title: Explorations in Particle Theory-15

Date: Apr 24, 2015 09:00 AM

URL: <http://pirsa.org/15040024>

Abstract:

Last tutorial

Today

2-3:30pm

Problem Set 3.

Due next Fri

Last tutorial

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Problem Set 3

Due next Fri

Lab test:

$$\left(\frac{\Theta_{eff}}{f_a} + \frac{a}{f_a} \right) \text{Tr} \tilde{G} \tilde{G}$$

$$\downarrow d_h \sim 10^{-16} \Theta \text{ e-cm}$$



$$d_h \sim \frac{a \Theta}{f_a} \cos(\theta_{eff}) \text{ e-cm} (\times 10^{-16})$$

$$\sim 10^{-35} \cos(\theta_{eff}) \text{ e-cm}$$

Open Questions in DM

- Assumed conventional DM
→ cold, collisionless, ...
- Propose models for DM
and try to test them.

Last tutorial

1st day

10pm

Set 3

next Fri

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Two hints for interesting DM physics

- ① Small-scale structure anomalies

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Two hints for interesting DM physics

- Small-scale structure anomalies
- The DM-baryon coincidence

stions in DM

① Small-scale structure

Break down of predictions of Λ CDM model on subgalactic scales.

i) Missing Satellites Problem (1998)

physics
anomalies

stions in DM

entional DM
collision

els for

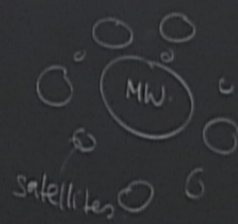
to

physics
anomalies
idence.

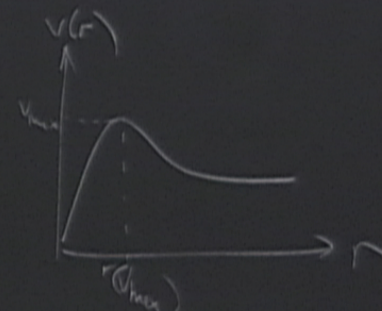
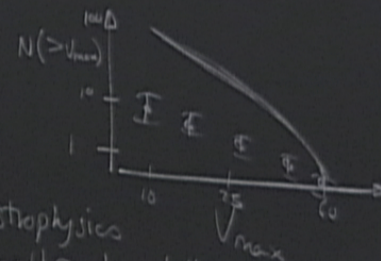
① Small-scale structure

Break down of predictions of CDM model on subgalactic scales.

i) Missing Satellites Problem (1998)



N-body simulations



Proposed solution: high-E astrophysics
can strip gas out of small protosatellites.

predictions in DM

collisionless DM

models for DM

to test them

interesting DM physics

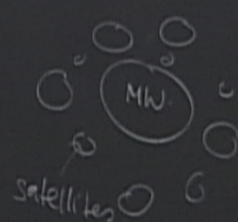
scale structure anomalies

M-baryon coincidence

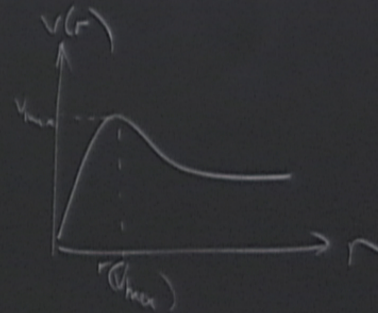
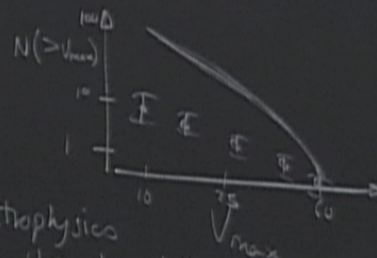
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N-body simulations

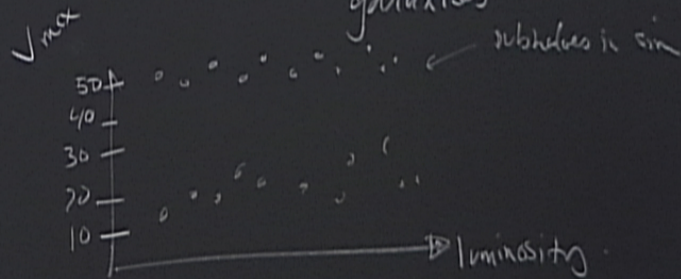


Proposed solution: high-E astrophysics
can strip gas out of small proto-satellites

ii) "Too Big to Fail" Problem (2011)

For big satellites, "gas stripping" doesn't work

→ too big to fail to form luminous galaxies.



iii) Cusp-core Problem (90s)

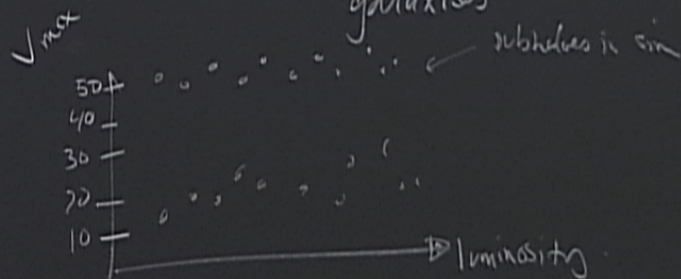
N-body simulations

NFW profile $\rho(r) \propto \left(1 + \frac{r}{R_s}\right)^{-2}$
 $R_s \sim (MW)$

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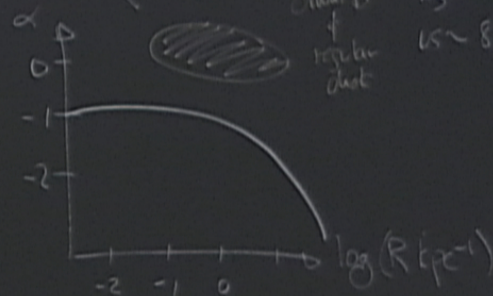
$$\text{NFW profile } \rho(r) = \rho_0 \left(\frac{R_s}{r} \right) \left(1 + \frac{r}{R_s} \right)^{-2}$$

$$\rho \sim r^{-1}$$

dark matter
+ regular dust

$$R_s \sim 20 \text{ kpc (MW)}$$

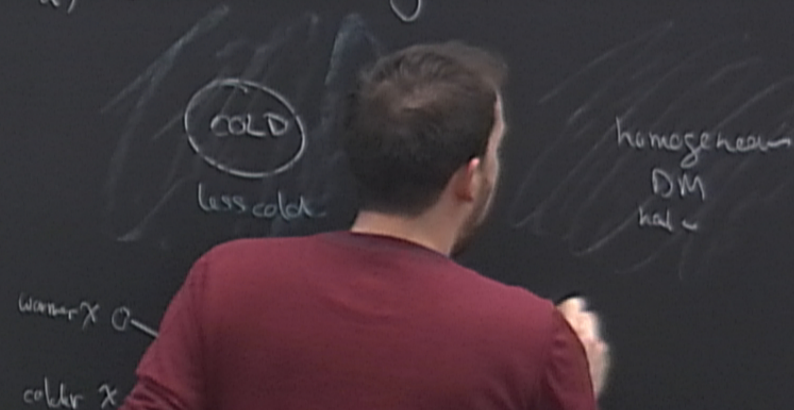
$$R_s \sim 8 \text{ kpc}$$



Possible resolutions

- 1) N-body simulations conventionally don't include baryons.
 - supernovae lead to ejection of baryonic matter, pulls DM.
 - does it work in DM-dominated like dwarfs?
- 2) Astrophysics.
- 3) New DM physics!

a) self-interacting DM

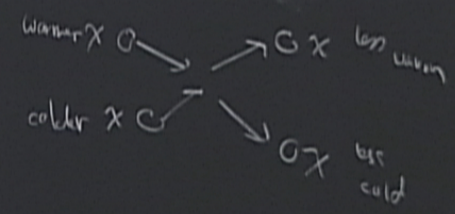
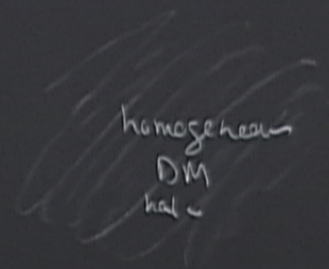
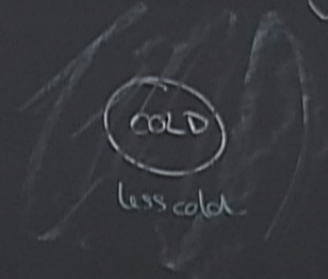


conventionally
anyons.

ad to ejection of
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in DM-dominated

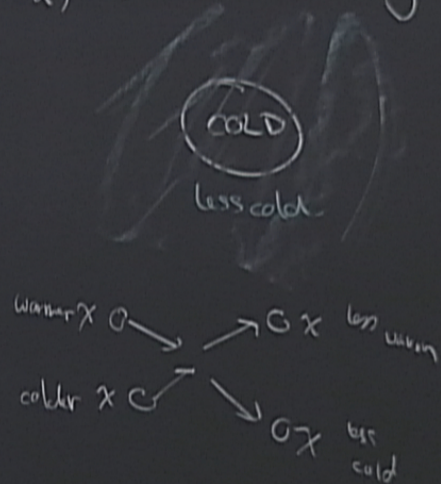
a) self-interacting DM



→ suppresses structure
on small scales.

conventionally
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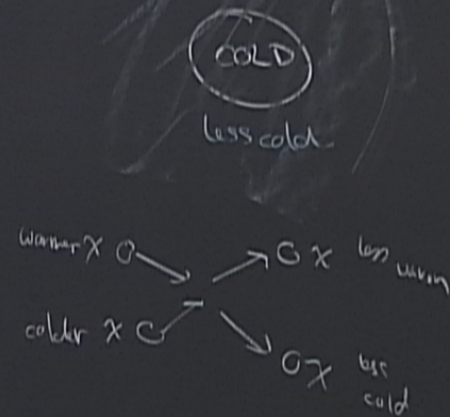


homogeneous
 DM
 halo
 → suppresses struc
 on small scales

$$\frac{\sigma_T}{m} \quad 0.1 - 10 \text{ cm}^2/\text{g}$$

! QCD-scale

a) self-interacting DM



homogeneous DM halo
→ suppresses structure on small scales.

$$\frac{\sigma_T}{m_\chi} \sim 0.1 - 10 \text{ cm}^2/\text{g}$$

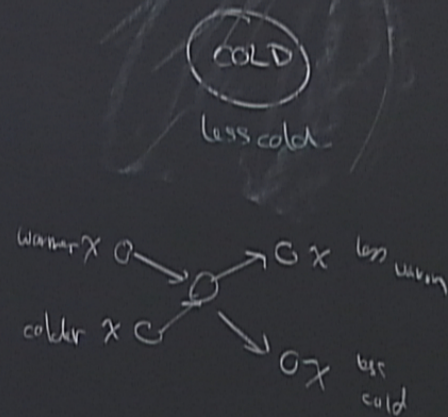
HUGE! QCD-scale σ

Bullet cluster: excluded.

$$\frac{\sigma_T}{m_\chi} \lesssim 0.1 - 1 \text{ cm}^2/\text{g}$$

WIMP $O(100 \text{ GeV})$, $m_\chi \sim 1 \text{ MeV}$ mediator.
→ highly v -dependent σ

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homogeneous
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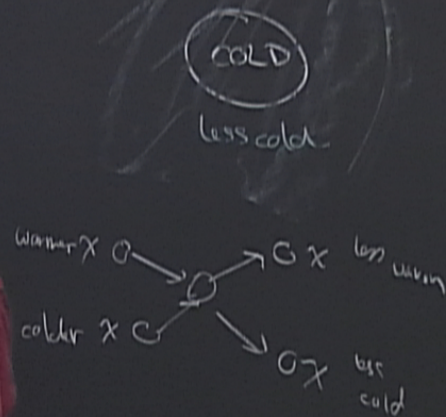
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b) Warm DM.

$\rightarrow$ clumping is harder

$\rightarrow$ more homogeneous / less structured halo

$$m_\chi^{\text{thermal}} \sim \text{keV}$$

Lyman- α forest.

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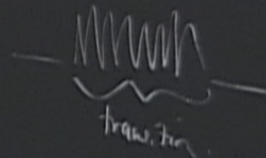
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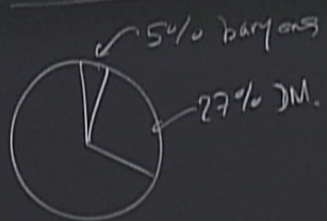
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Lyman- α forest.

 $\rightarrow m_\chi^{\text{thermal}} \sim \text{few keV}$

⑦ The DM-Baryon Coincidence

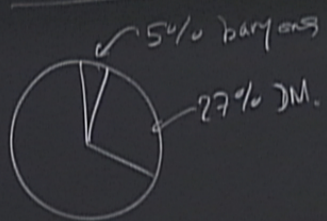


DM: WIMP miracle
or
freeze-in
or
misalignment

Baryons: $n_B > n_{\bar{B}}$

$Y_B^\infty = Y_B - Y_{\bar{B}}$ at
early
times

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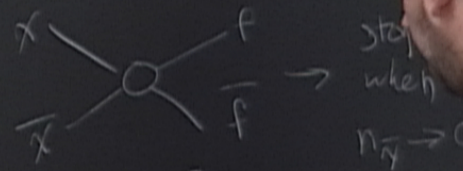
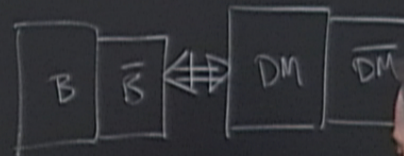


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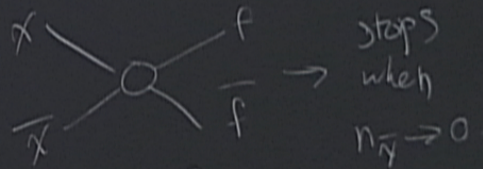
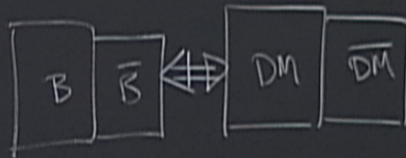
Asymmetric DM.



$$\mathcal{L} = \frac{1}{\Lambda^5} \chi^3_{\text{odd}} + \text{h.c.}$$

Possible resolution:

Asymmetric DM.



$$\mathcal{L} = \frac{1}{\Lambda^5} \underbrace{X^3}_{\text{odd}} + \text{h.c.}$$

$\underbrace{\Lambda^5}_{\text{U(1)}_{\text{DM}}}$ $\underbrace{\text{odd}}_{\text{U(1)}_B}$

$\text{U(1)}_{B-\text{DM}}$

$$P(\text{odd} \rightarrow \bar{X}\bar{X}\bar{X}) \sim n_B$$

$$P(\bar{\text{odd}} \rightarrow XXX) \sim n_{\bar{B}}$$

$$\neq 0$$

$$n_B - n_{\bar{B}} \sim n_{\text{DM}} - n_{\bar{\text{DM}}}$$

$n_B > n_{\bar{B}}$
 $\Rightarrow Y_B - Y_{\bar{B}}$ at
 early
 times

$$\rho_B = m_B n_{\Delta B}$$

$$\rho_X = m_X n_{\Delta X}$$

$$= 5 \rho_B \rightarrow m_X = 5 m_B \left(\frac{n_{\Delta X}}{n_{\Delta B}} \right) \sim 1$$

$$m_X = 5 \text{ GeV}$$

Properties

- no indirect detection!
→ CMB, Fermi all gone
- larger $\langle \sigma v \rangle$ than in freeze-out

$$\Omega_{DM}^{fo} \sim \frac{1}{\langle \sigma v \rangle}$$

$$\Omega_{DM}^{ADM} \sim Y_X - Y_{\bar{X}}, \text{ independent}$$

$n_{\Delta B}$
 $\times n_{\Delta X}$
 $\rho_B \rightarrow m_X = 5 m_B \left(\frac{n_{\Delta X}}{n_{\Delta B}} \right)$
 $m_X = 5 \text{ GeV}$

Properties:

- no indirect detection!
 $\rightarrow$ CMB, Fermi all gone
- large $\langle \sigma v \rangle$ then in freeze-out

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detection!
 Fermi all gone
 > than in
 re-out

$\int_{DM}^{ADM} \sim Y_x - Y_{\bar{x}}$, independent of $\langle \sigma v \rangle$

Summary:

DM is:

- particle
- neutral (...?)
- collisionless (...?)
- stable (...?)
- cold (...?)

New ideas for theory

- missing something really big?
paradigm shift?

- missing connections with SM
(naturalness, flavour, ...)

New ideas for experiment

- clear signals that we haven't thought of?

Particle physics connections with DM

- "conventional" particle physics
- cosmology
-

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Particle physics connections with DM

- "conventional" particle physics
- cosmology
- astrophysics
- nuclear physics
- atomic & optical physics
- formal developments

