Synthesized Constraints on Dark Matter

Dan Coe

KISS Dark Matter Workshop 7/13/09
What can we accomplish during this WORKshop?

• “Can we update the Bernard Carr plots?”
  – James Taylor
  – Carr94 (ARA&A): observations ➔ MACHO constraints

• Synthesize current DM constraints
• Evaluate future prospects for constraints
• Strategize future research and experiments
## Current dark matter constraints

<table>
<thead>
<tr>
<th>Observable</th>
<th>Constraint</th>
<th>Method</th>
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</thead>
<tbody>
<tr>
<td>Mass</td>
<td>100 GeV WIMP? $10^{-5}$ eV axion?</td>
<td>theory, $\Omega_{\text{DM}}, \Omega_{\text{b}}$</td>
</tr>
<tr>
<td>DM-baryon scattering x-sect</td>
<td>$&lt; 10^{-42}$ cm$^2$/g (10$^{-6}$ pb)</td>
<td>CDMS-II, XENON100, etc. (“direct” detection)</td>
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<tr>
<td>DM-DM scattering x-section</td>
<td>$&lt; 1$ cm$^2$/g</td>
<td>Bullet Cluster</td>
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<tr>
<td>DM-DM self-annihilation x-sect</td>
<td>low high?</td>
<td>CMB: reionization optical depth</td>
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<tr>
<td>Thermal velocity</td>
<td>mostly cold</td>
<td>Large scale structure</td>
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<td>Density fluctuations</td>
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<tr>
<td>other?</td>
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Connect observations to DM constraints

Strong gravitational lensing

Matter power spectrum

DM particle constraints

warm decays
OMEGA Mission Concept
Moustakas et al.
(Bolton, Bullock, Cheng, Coe, Fassnacht, Keeton, Kochanek, Lawrence, Marshall, Metcalf, Natarajan, Peterson, Wambsganns)

- Dedicated space-based observatory monitoring ~100 time delay lenses
- ~1.5-m mirror, near-UV -- near-IR + spectra
- Precise measurements of fluxes, positions, and time delays
- Constraints on nature of dark matter particle from small-scale power cutoff
Power spectrum suppressed on small scales by warm DM or DM decay
If DM turns out to be gravitinos, strong gravitational lensing could be the only method capable of constraining it. If DM turns out to be gravitinos, strong gravitational lensing could be the only method capable of constraining it.
Many ways to constrain DM properties

• Astronomical observations
  – CMB, gravitational lensing, LSS, substructure, SZ

• “Indirect” detection (DM self-annihilation products)
  – $e^+e^-$: EGRET, HEAT, PAMELA, ATIC, H.E.S.S., Fermi
  – $\gamma$-rays: VERITAS, Fermi, MAGIC
  – $\nu$ (neutrinos): IceCube, ANTARES, Super-Kamiokande

• “Direct” detection (“catching” DM particles)
  – CDMS-II, XENON100, CREST, EDELWEISS, DAMA/LIBRA

• “Production” in particle accelerators
  – Tevatron, LHC, ILC
LM, AB, & MK began making lists

DM properties / variations
• DM–DM elastic scattering ($\sigma_{\text{DM}}(v)$)
• DM–baryon interactions ($\sigma_{\text{DM}-n}$)
• Finite velocity dispersion ($Q_{\text{prim}}$)
• Late–time decays – NLSP–LSP ($\Delta m/m$)
• Broken scale invariance
• Small-scale primordial non–Gaussianity; $f_{\text{NL}}(k)$
• Cold + hot (massless) dark matter
• Equivalence principle violating dark matter (or long–range DM–DM interaction)
• Dark U(1)
• Warm dark matter; $m_{\text{DM}}, \theta$
• Enhanced ?????????

Measurements
• $\Omega_{\text{DM}}$
• Strong lensing (substructure; halo shapes; dwarfs)
• Q (LSBs; ellipticals)
• Dwarf galaxy abundances
• Dark matter cusps (Q?)
• Lyman–alpha forest
• 21cm P(k)
• Diffuse X–ray
• Elliptical galaxy shape distributions
• Dwarf galaxy mass function
• Substructure from annihilation (gamma–ray, e's etc.)
• Milky Way substructure
• Tidal tails
• Cluster weak lensing
• Caustics

from Moustakas, Kaminkowski, Benson chalkboard talk 6/4/09
Let’s make the connections

**DM properties / variations**

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Connections: observations to DM constraints
Thank you for your input so far, and we look forward to more!

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### One matrix or several?

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<thead>
<tr>
<th>Properties</th>
<th>Observations</th>
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#### Single

<table>
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<tr>
<td>WIMP</td>
<td>X</td>
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<td>axion</td>
<td>X</td>
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<td>gravitino</td>
<td>X</td>
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#### One for each candidate?
Dark Matter candidates

- particles
  - thermal
    - WIMPs
      - SUSY
  - non-thermal
    - neutrinos
    - axions
    - gravitinos

- MACHOs
- modified gravity
From each experiment / observation, 1-D constraints on individual variables

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<td>Mass</td>
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<td>DM-baryon cross section: scattering</td>
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<td>DM-DM cross section: elastic scattering</td>
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What about correlations?
From each experiment / observation, 2-D constraints on pairs of variables
From each experiment / observation, multi-dimensional constraints on variables

Techniques to probe large parameter spaces:

Monte Carlo Markov Chains

Fisher matrices
How best to combine constraints from multiple experiments?

- Fisher matrices?
- Simple and efficient way of exploring large parameter spaces
- e.g., cosmological parameters: $(h, \Omega_m, \Omega_{de}, \Omega_k, w_0, w_a)$
- Alternative: MCMC
From each experiment / observation, a Fisher matrix of constraints and correlations.
From each experiment / observation, a Fisher matrix of constraints and correlations for Dark Matter properties?
From each experiment / observation, full probability matrix, explored with MCMC for Dark Matter properties?
Can DM constraints be well approximated by Gaussian uncertainties?
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Can DM constraints be well approximated by Gaussian uncertainties?
Can DM constraints be well approximated by Gaussian uncertainties?

• In WIMP mass – DM-baryon cross section space, *maybe*

• How about in other parameter spaces?

• Let’s find out…
By drawing connections,
We are not just collecting butterflies

- The goal is to inform future research and experiments
Dark Matter Task Force?

- Analogous to the Dark Energy Task Force
- Determine potential constraints from various methods
- Prioritize!
Pick constraints that rule out candidates
Tasks

• Define most fundamental & useful DM property parameter space
• How narrow / broad?
• Connect observations to properties
Questions to discuss

• Our priorities at this meeting?
• Does spreadsheet sound useful?
• Separate spreadsheets for WIMPs, axions, etc.?
• Will a Fisher matrix analysis (assuming Gaussian uncertainties) make sense?
• Dark Matter Task Force?

We look forward to your input both online and in person at this WORKshop
I propose we try doing this for WIMPs and take it from there...

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<th>B</th>
<th>C</th>
<th>D</th>
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Exotic Dark Matter Theories

Which theories should we astrophysicists pay attention to?
Include these properties in simulations of structure formation?

• Modified Gravity (MOND / TeVeS / MoG / STVG)
• Inelastic Dark Matter (multiple particles with mass splitting)
• Dark Matter – Dark Energy combined theories
• Exciting Dark Matter (XDM)
The observed power spectrum is reproduced by theory on an enormous range of scales, given the concordance cosmology.
Future high-resolution minimal-assumption cluster mass maps
Resolution improves with density of multiple images