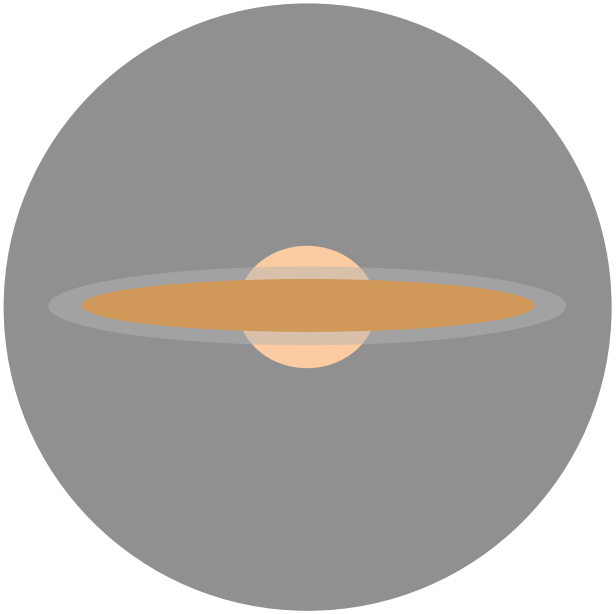
Dark Disks

Invisibles, Madrid
June 25th 2015



Matthew McCullough

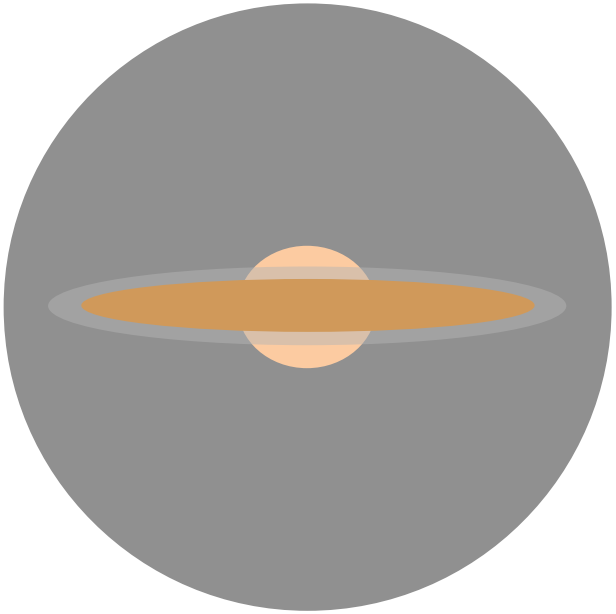
CERN

Dark Disks

(and other Dark exotica)

Invisibles, Madrid

June 25th 2015



Matthew McCullough

CERN

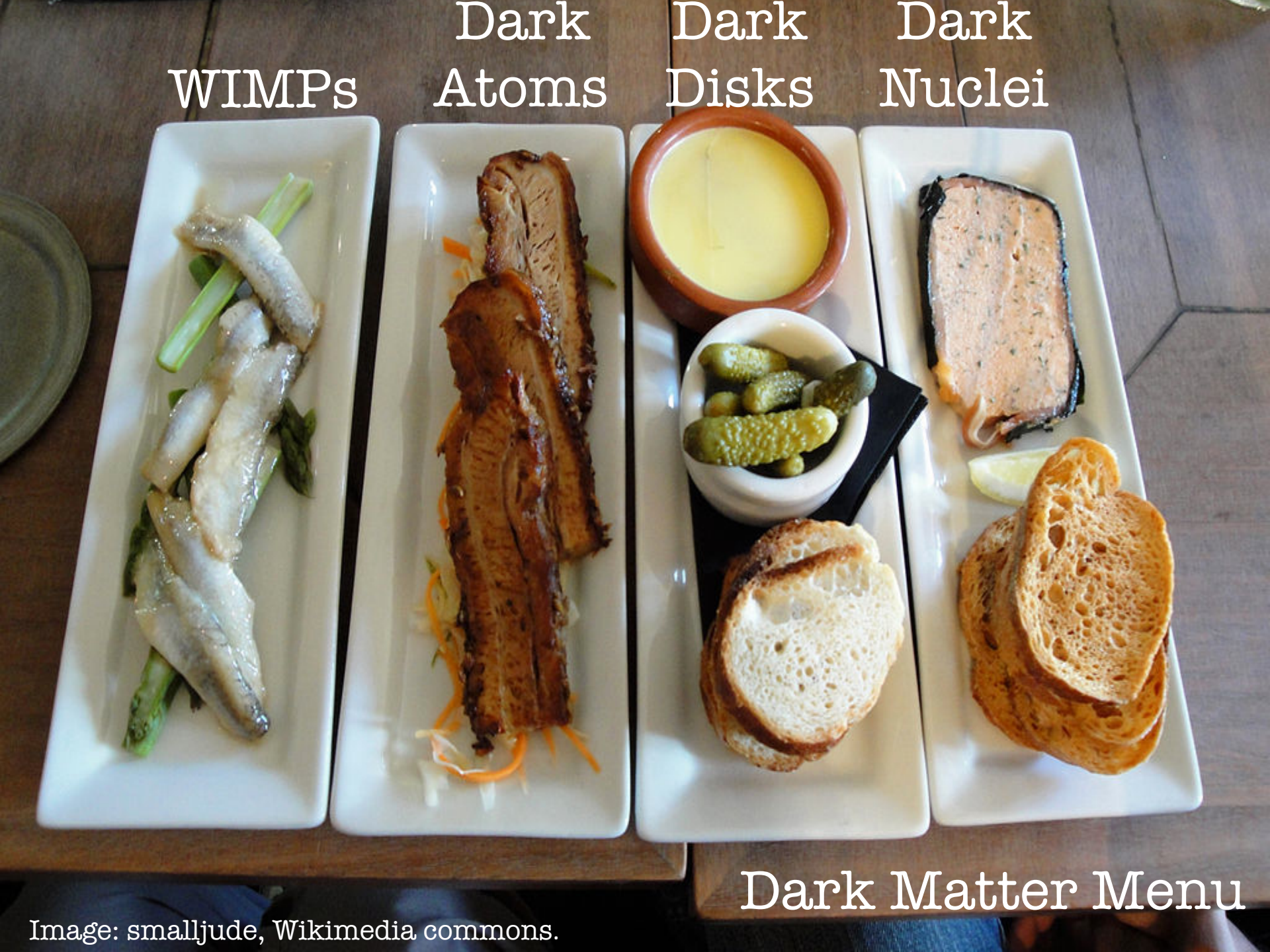
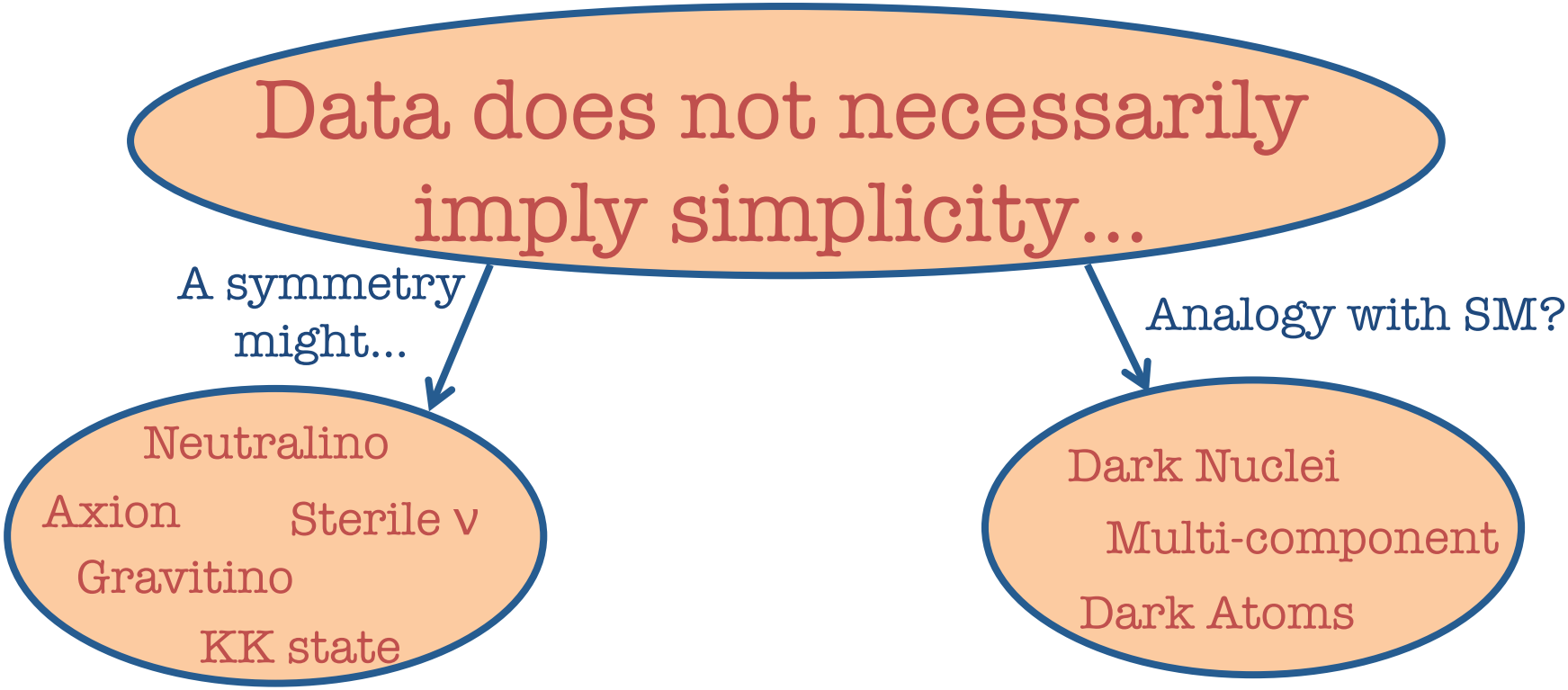
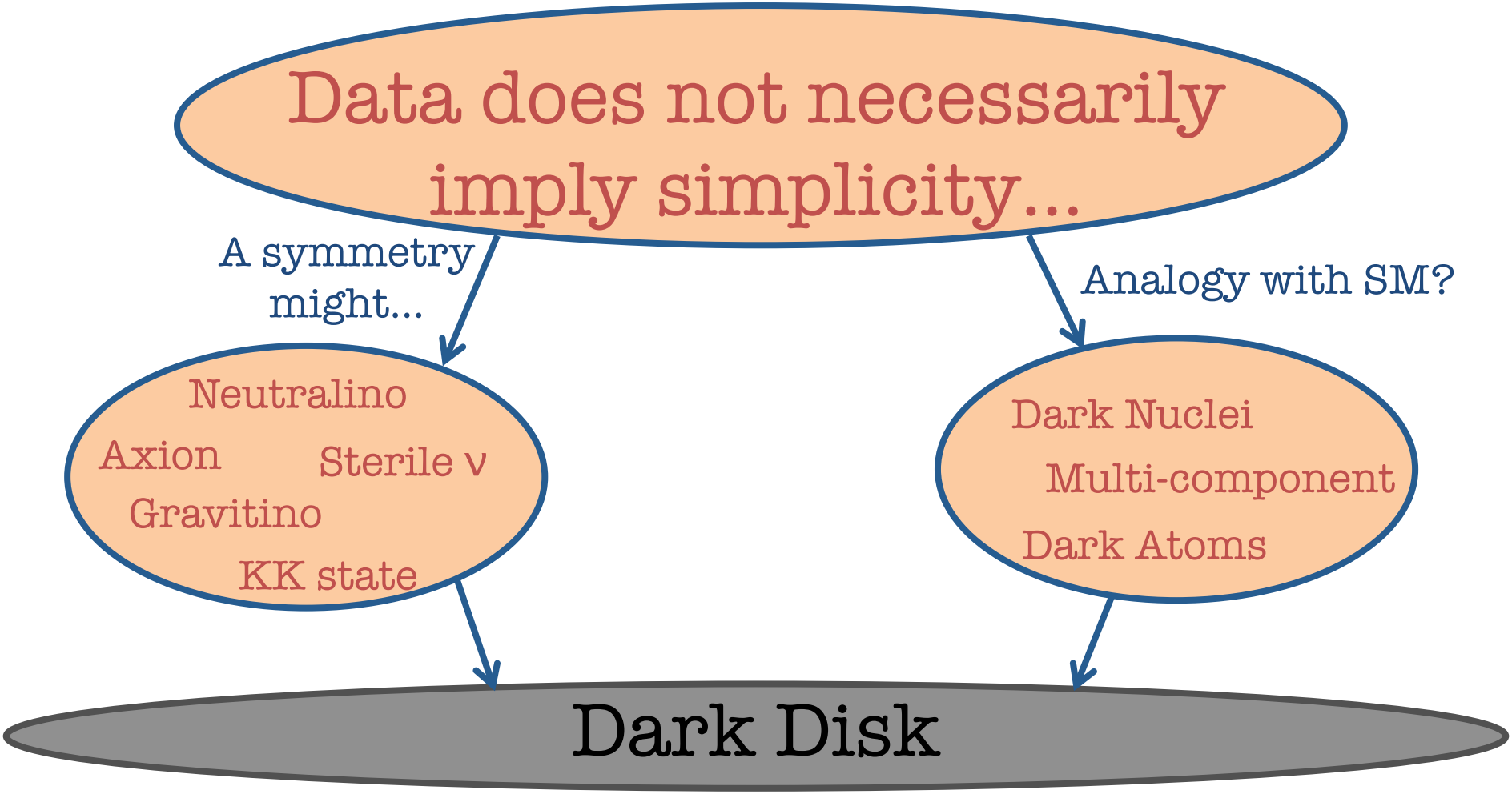


Image: smalljude, Wikimedia commons.

Dark Sector


Data does not necessarily imply simplicity...
A symmetry might...
Analogy with SM?
Neutralino
Axion
Sterile ν
Gravitino
KK state
Dark Nuclei
Multi-component
Dark Atoms

Dark Sector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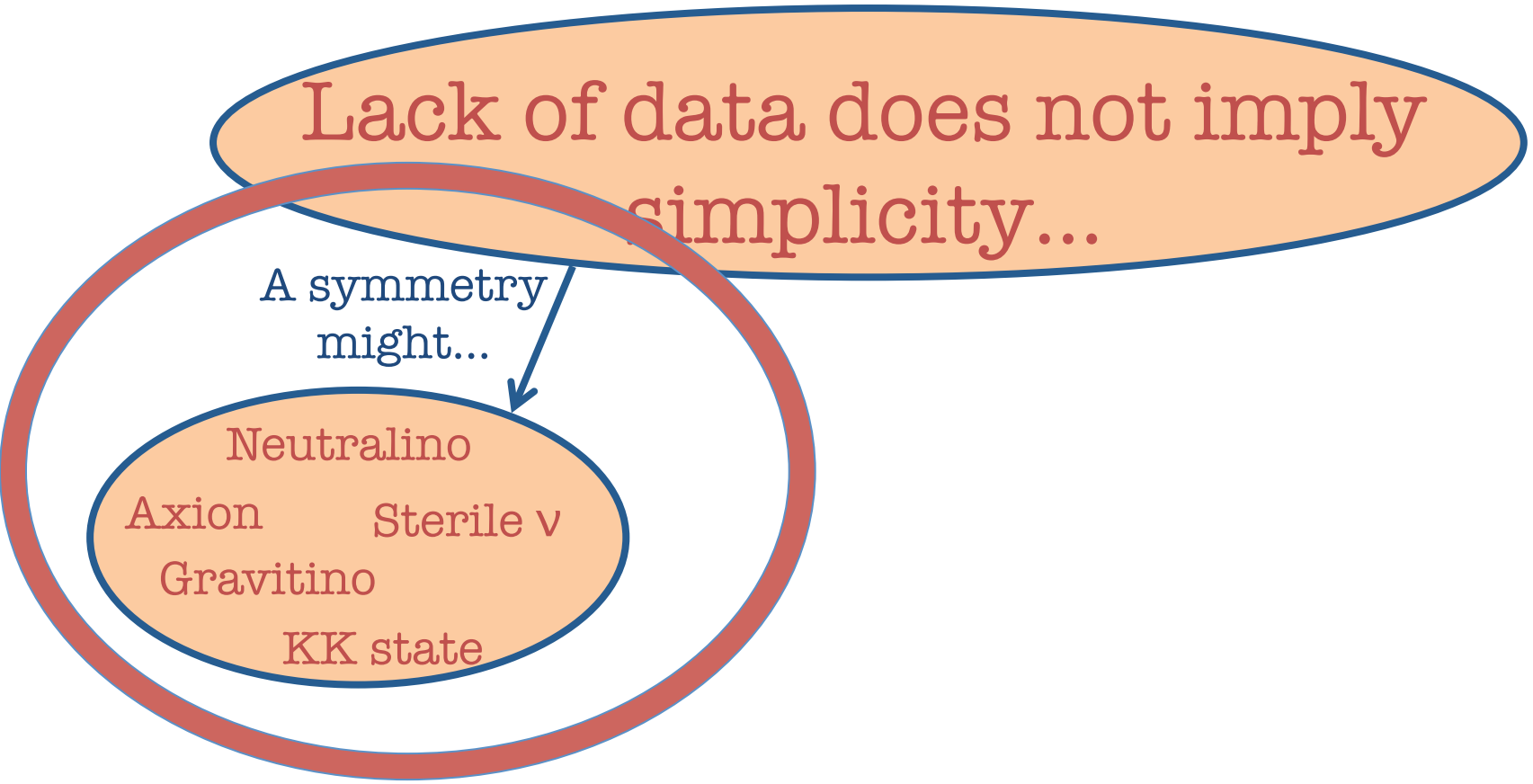
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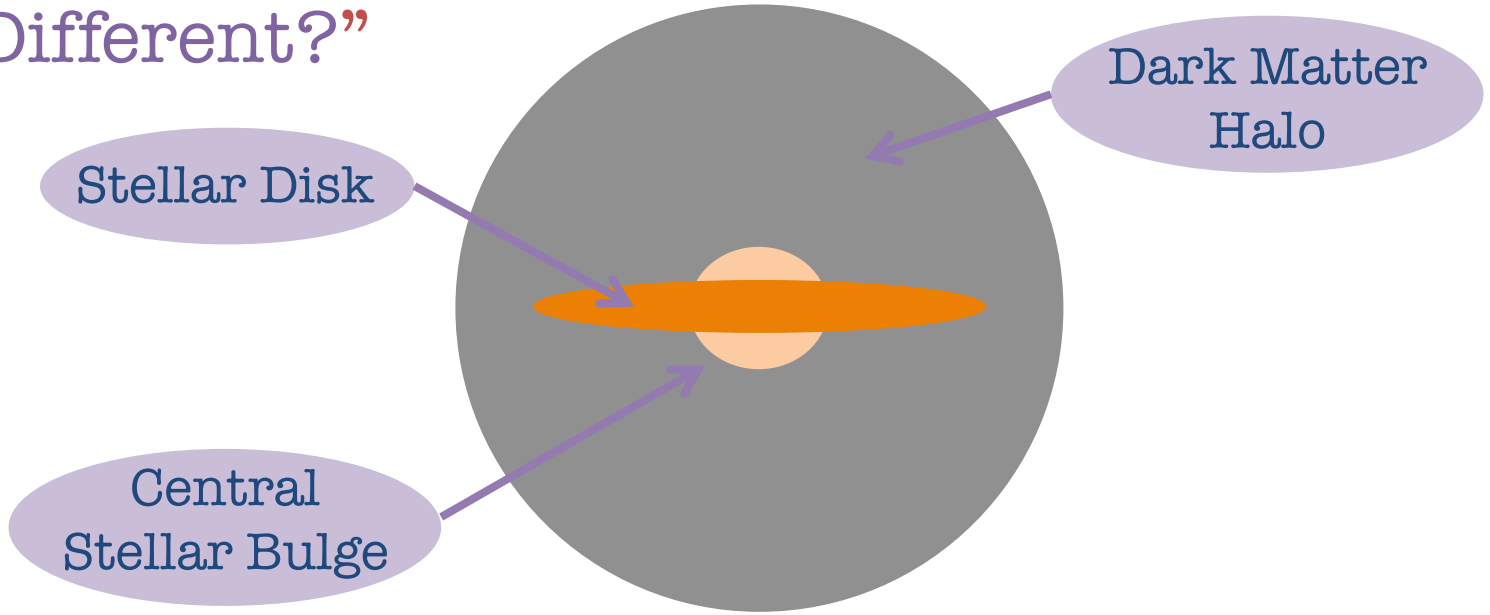
KK state

WIMP Disks

Considered in context of standard Cold Dark Matter WIMP paradigm for some time...

Lake 1989: "Must the Disk and Halo Dark Matter be Different?"



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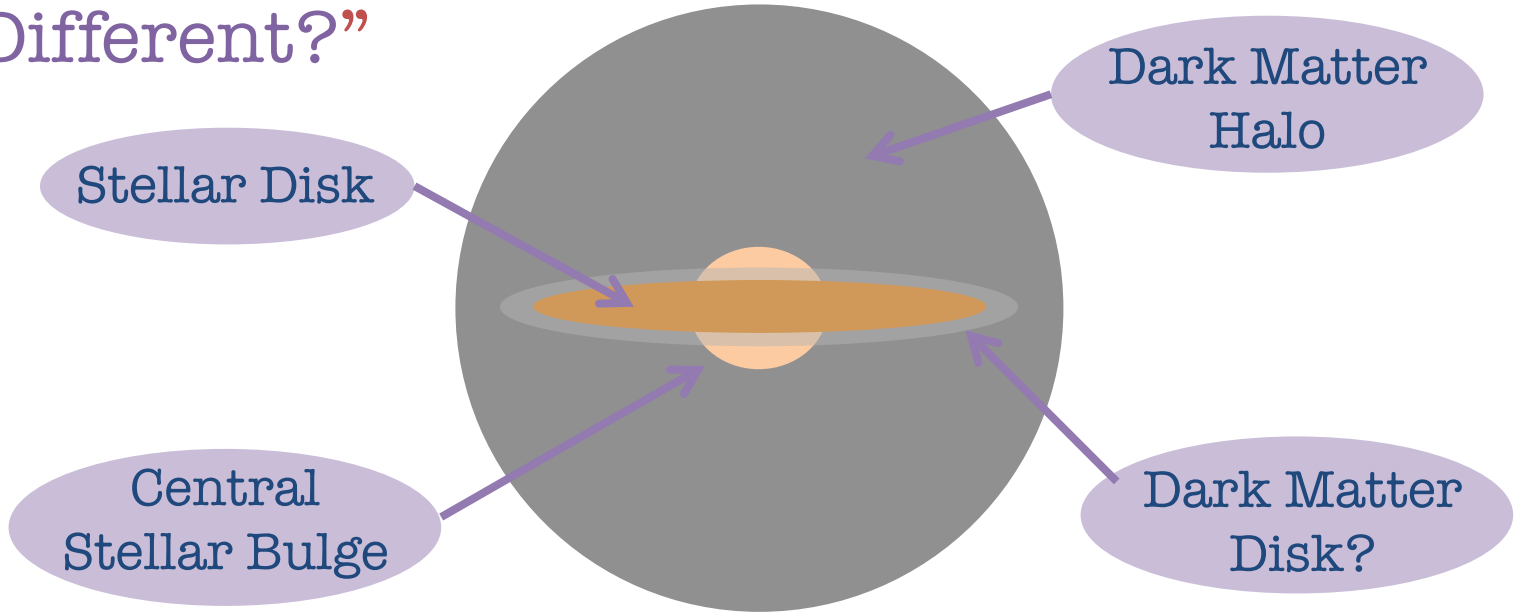


Can show up in modern simulations:

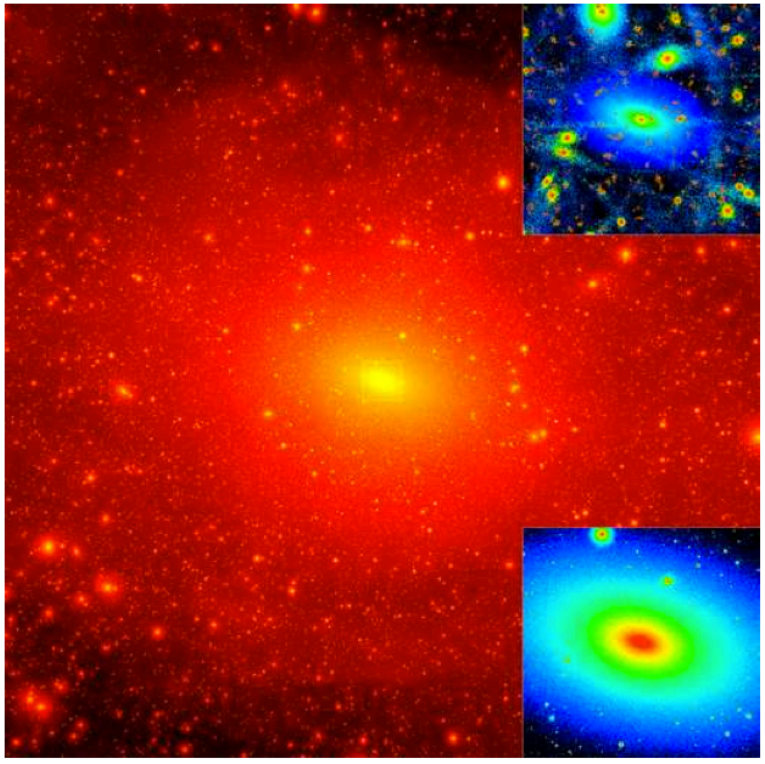
- Read, Lake, Agertz, Debattista (0803.2714)

WIMP Disks

How could they form? Lake 1989: "Must the Disk and Halo Dark Matter be Different?"

This image not a dark disk, but pretty. 800kpc and 40 kpc.

From Diemand, Kuhlen, et al. 0805.1244



Can result from hierarchical structure formation leading to mergers of subhalos into halo.

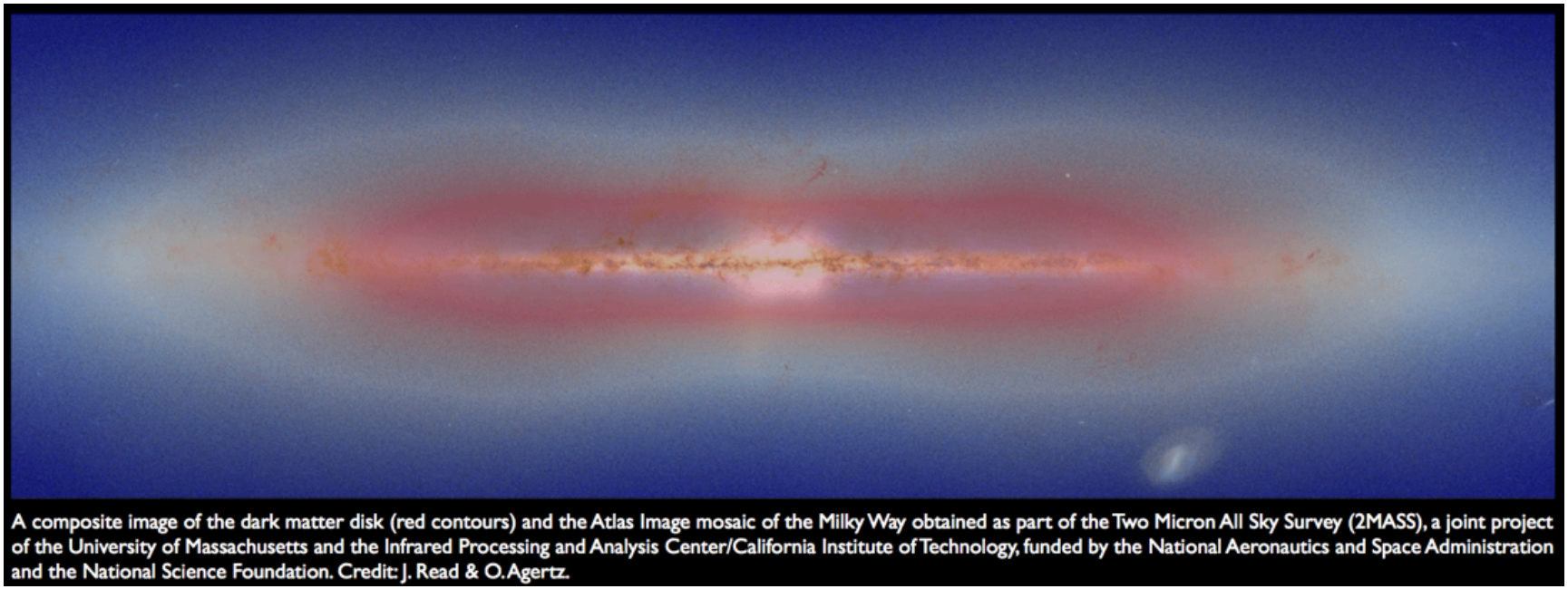
Can show up in modern simulations:

- Read, Lake, Agertz, Debattista (0803.2714)
- However, see Cooper, Cole, Frenk, White, et al. (0910.3211)

WIMP Disks

What do they look like?

In a magazine they look like this:



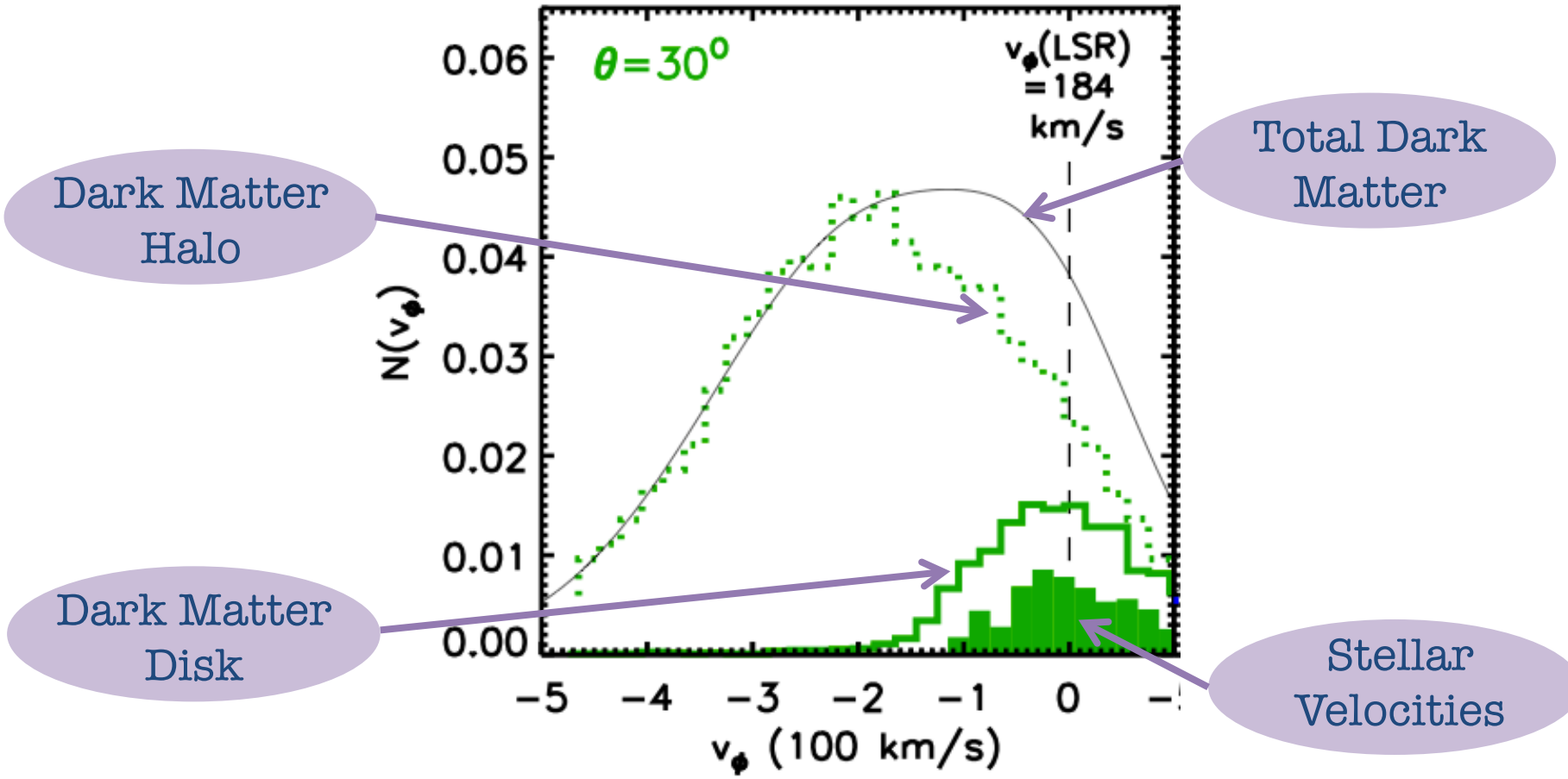
A composite image of the dark matter disk (red contours) and the Atlas Image mosaic of the Milky Way obtained as part of the Two Micron All Sky Survey (2MASS), a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Credit: J. Read & O. Agertz.

www.universetoday.com (Nancy Atkinson)

- "Dark Matter Halos? How About Disks, Too"

WIMP Disks

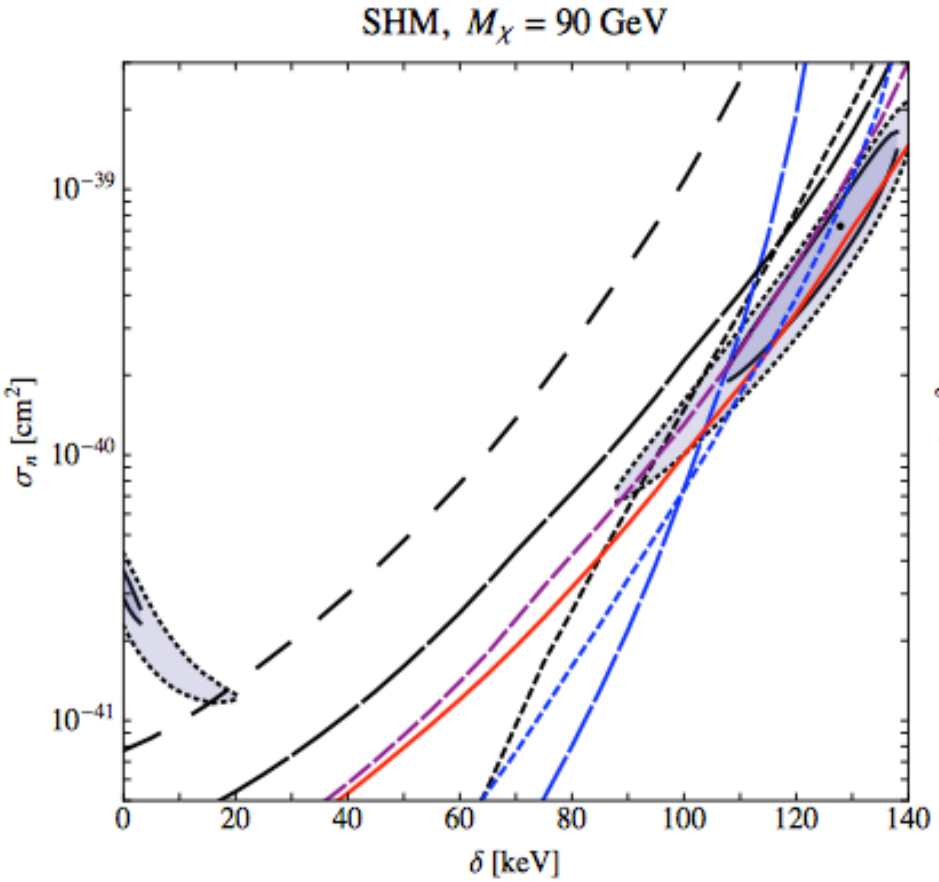
In a paper they look like this:

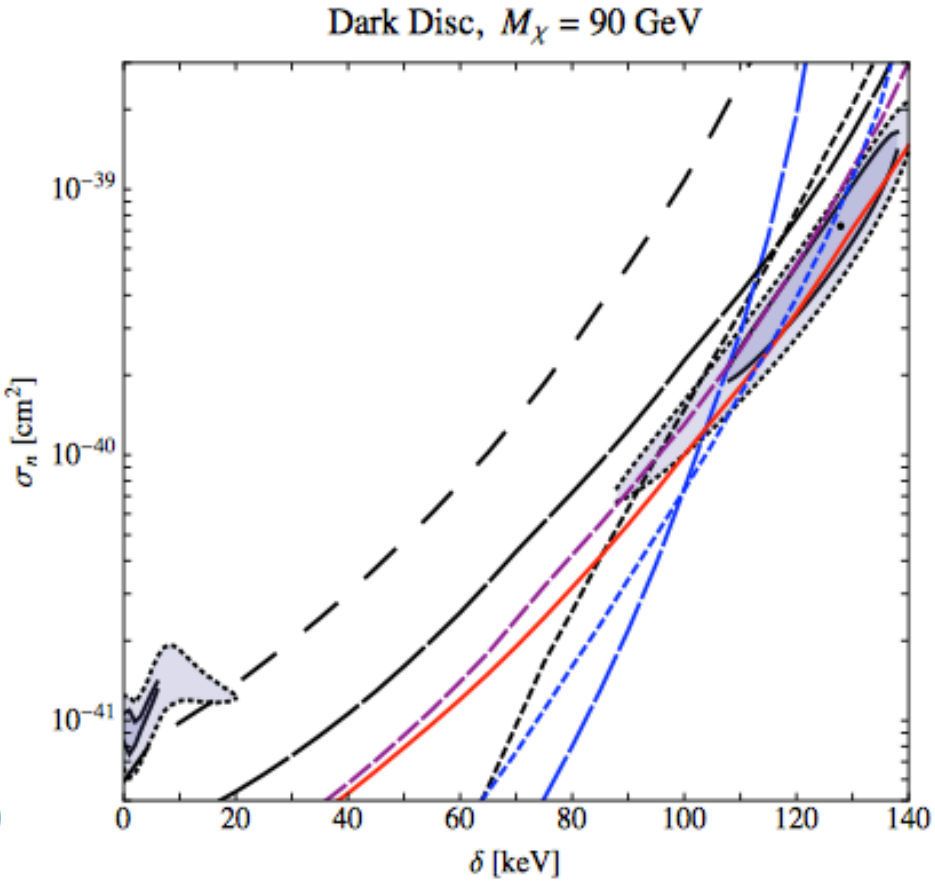


- Purcell, Bullock, Kaplinghat (0906.5348)

Detecting WIMP Disks

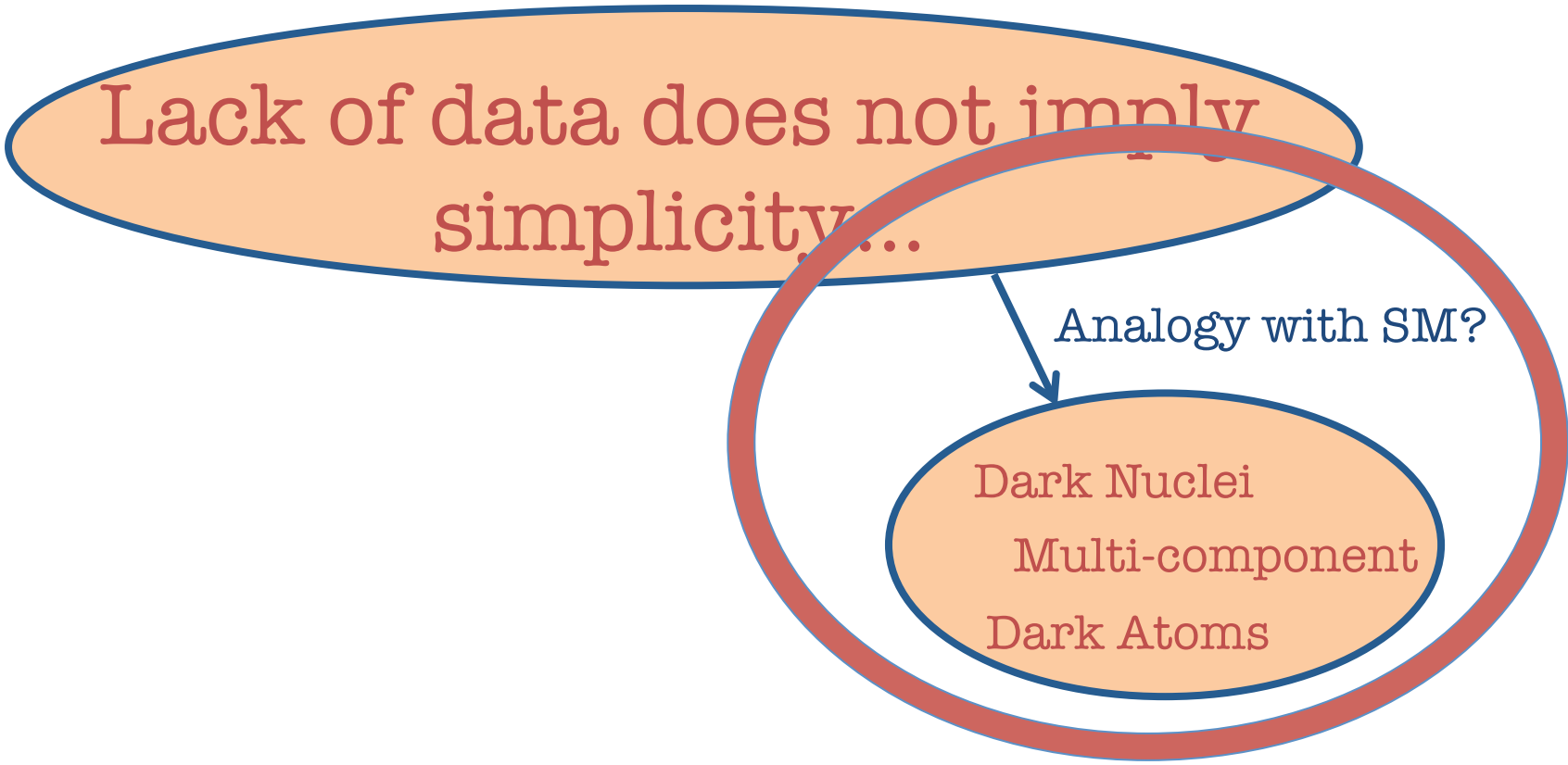
Modifications to exotic scattering candidates as well. Old paper on inelastic dark matter:





- March-Russell, McCabe, MM (0812.1931)

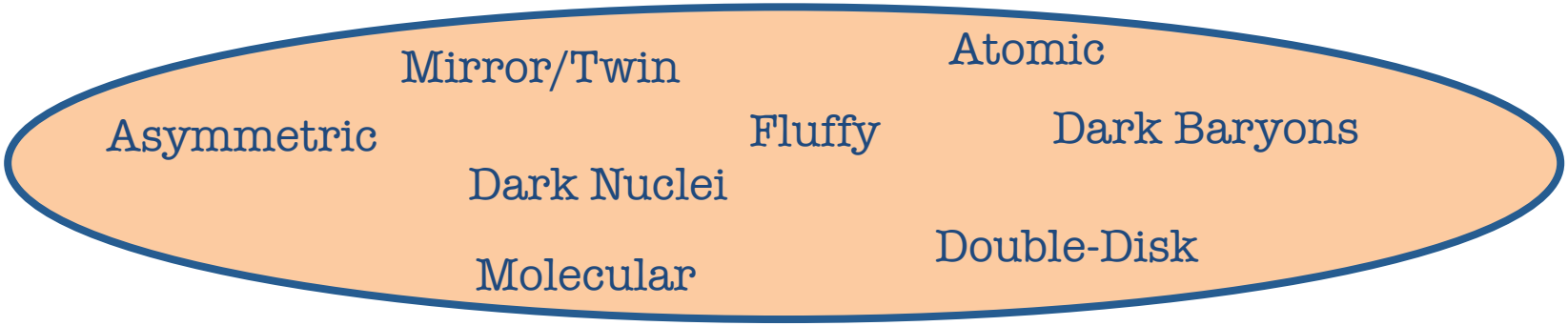
Dark Sector


Lack of data does not imply
simplicity...
Analogy with SM?
Dark Nuclei
Multi-component
Dark Atoms

Subcomponent Disks

WIMPs are interesting. However…

- The dark sector may be a cocktail of states



- Subcomponent with self-interactions, "Partially Interacting Dark Matter"
- Possibilities rich: Fan, Katz, Randall, Reece.
- Focus here: "Double Disk Dark Matter"

Subcomponent Disks

Consider a simple subcomponent model:

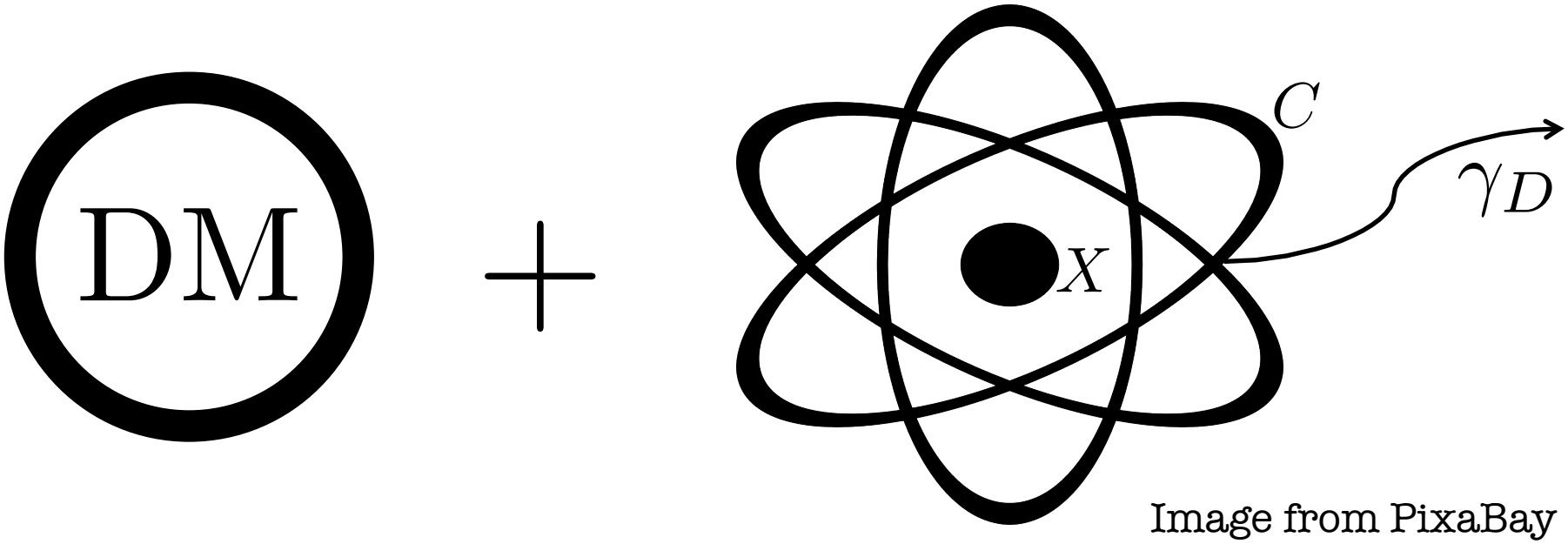


Image from PixaBay

Could have a DM subcomponent like a dark atom. Plausible possibility. Phenomenology potentially rich.

Dark Atoms: Kaplan, Krnjaic, Rehermann, Wells. Cline, Liu, Xue.
Dark Atom Subcomp: Fan, Katz, Randall, Reece.

Subcomponent Disks

Cooling allows DDDM to collapse into a disk. Details different from SM as no supernova feedback etc. Can cool to a temperature

$$T_{cool} \sim 0.1\, E_{Binding}$$

And the thickness of the resulting dark disk can be quite small

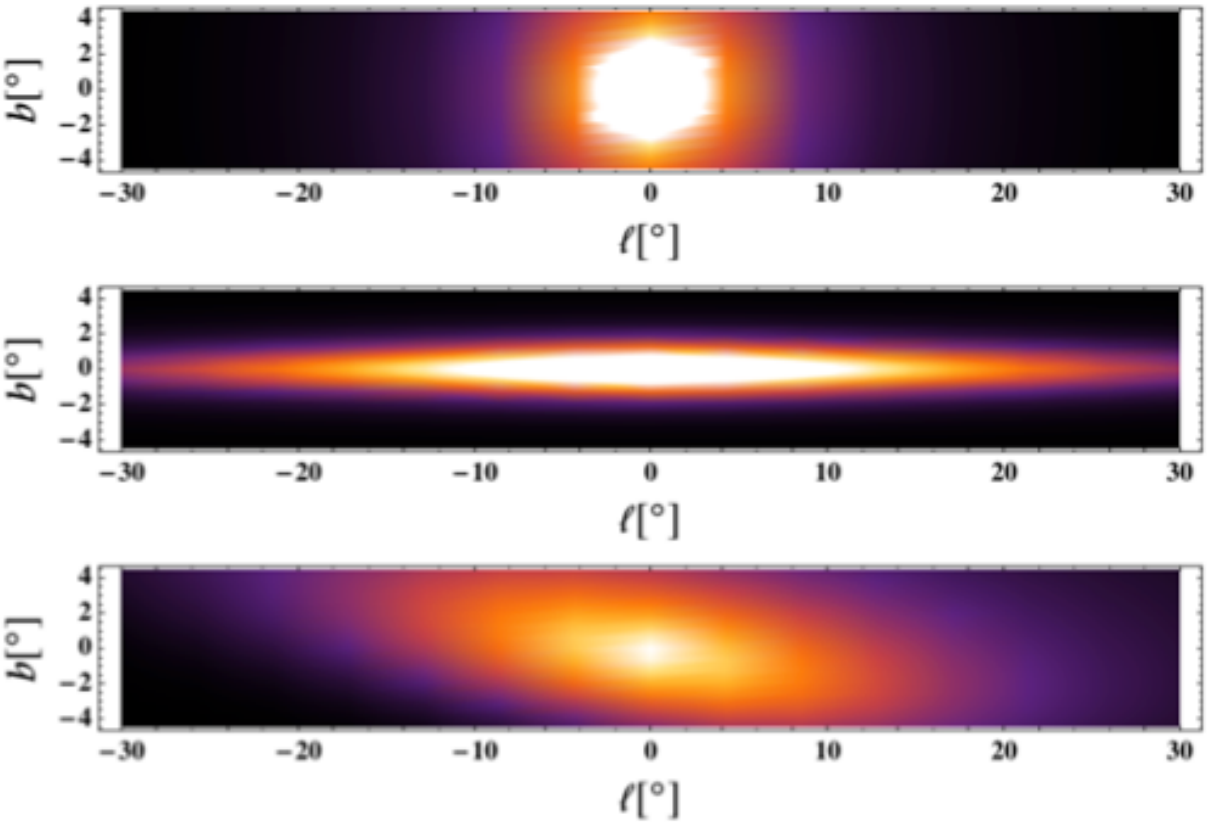
$$z_d \approx 2.5\mathrm{pc} \left(\frac{\alpha_D}{0.02}\right)^2 \frac{m_C}{10^{-3}\mathrm{GeV}} \frac{100\mathrm{GeV}}{m_X}$$

Thus an entirely different mechanism leads to a very different disk from the WIMP disk scenario.

Fan, Katz, Randall, Reece

Subcomponent Disks

Implications for standard searches could be significant.



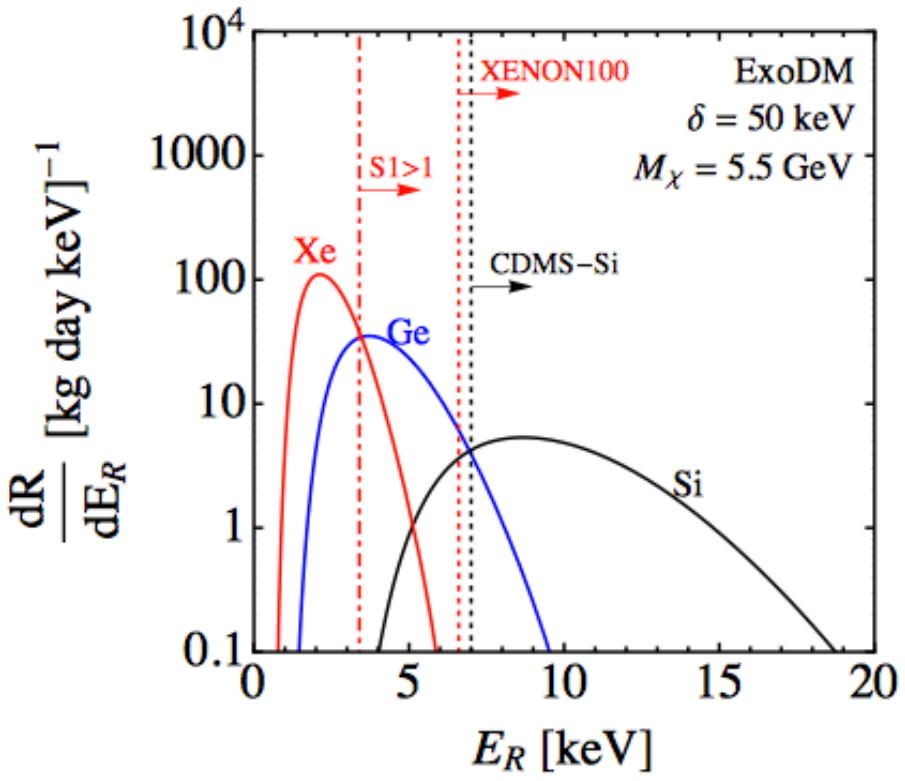
Spectacular modifications of indirect detection signature morphology.

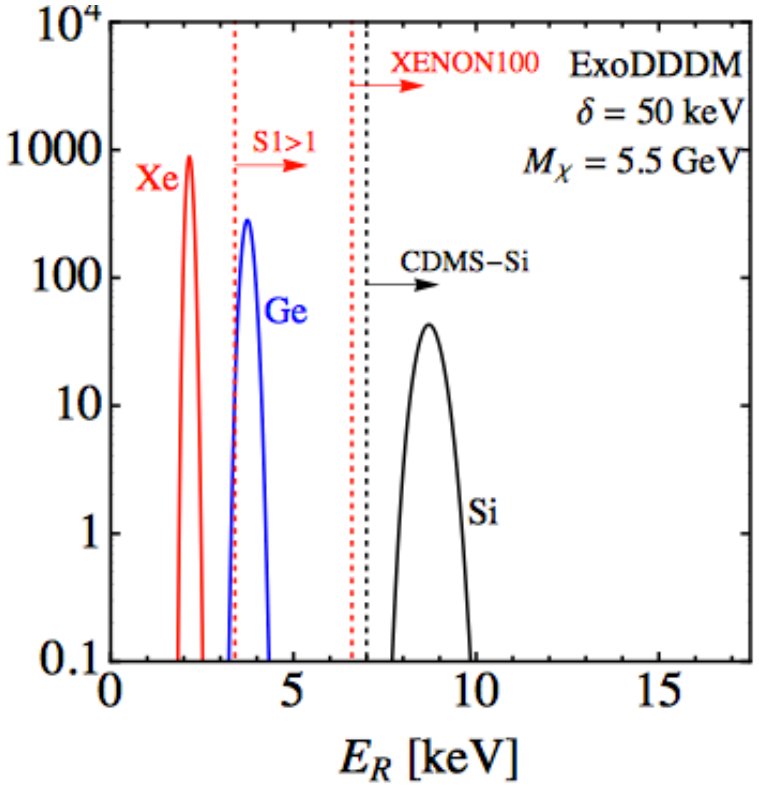
Including possible tilted disks.

Fan, Katz, Randall, Reece

Subcomponent Disks

Or for exotic models, such as exothermic scattering, could lead to very exotic direct detection signatures.





ExoDDDM, MM, Randall, 2013

Subcomponent Disks

Hipparcos (GAIA Future) local star velocity surveys

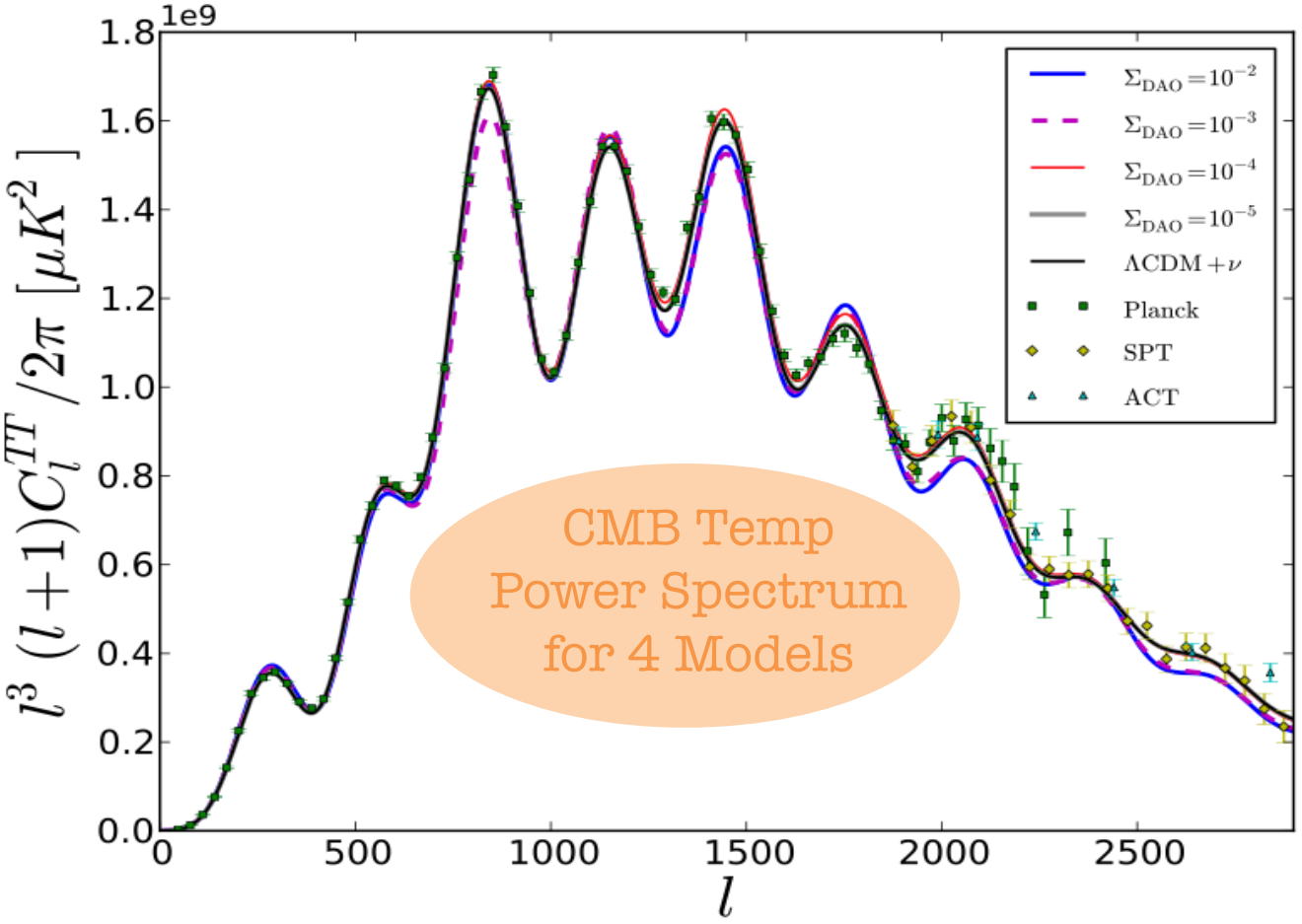
SEE POSTER: ERIC KRAMER.

Complex Subcomponents

If subcomponent behaves like matter, similar cosmological effects. Cyr-Racine, de Putter, Raccanelli, Sigurdson 2013

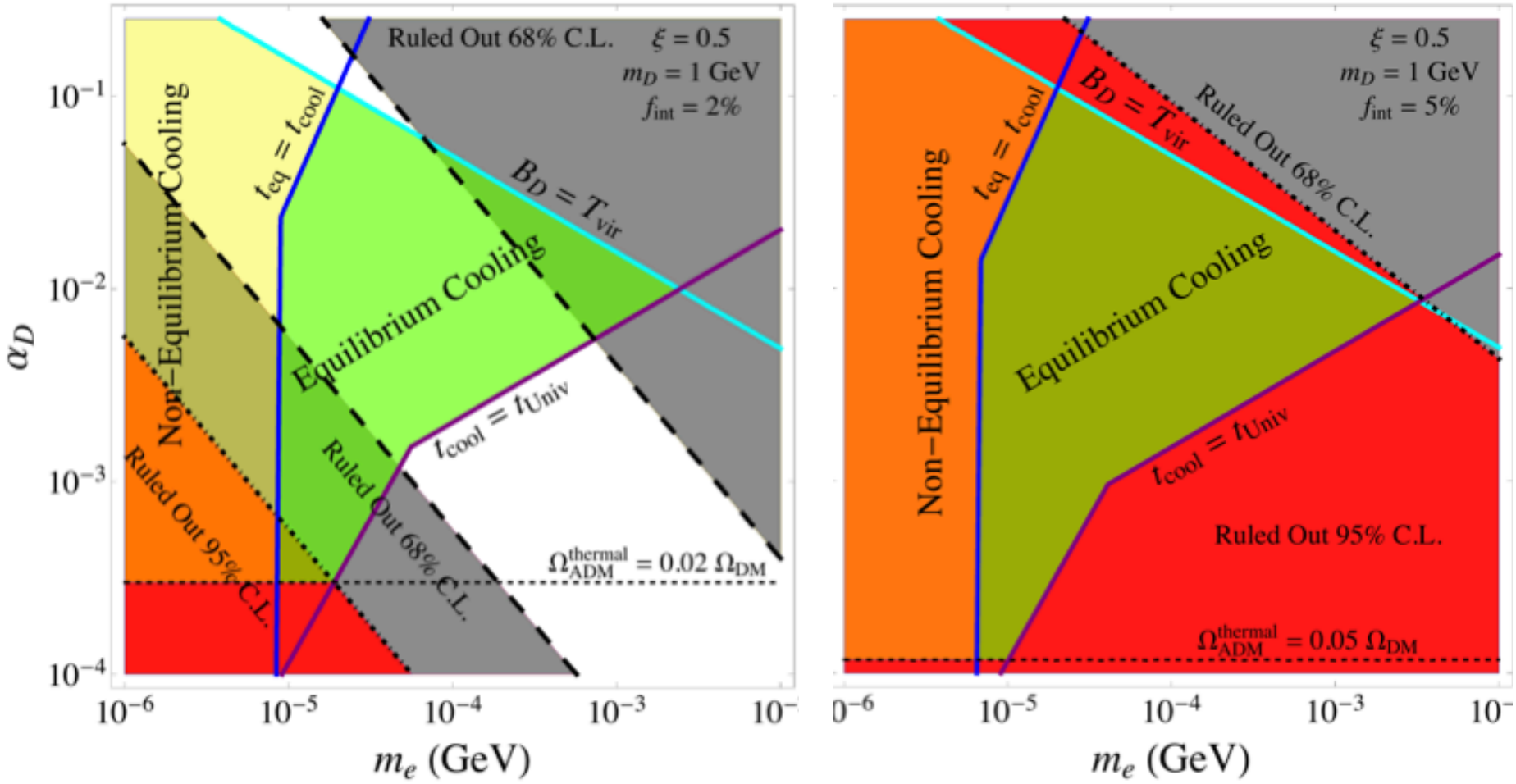
Should have "Dark Acoustic Oscillations".

Observable in CMB BG and lensing, BAO data from SDSS, BOSS Power Spectrum



Subcomponent Disks

Planck+WP+High-l+BAO+Lens constraints:



Also: Buckley, Zavalla, Cyr-Racine, Sigurdson, Vogelsberger, 2014

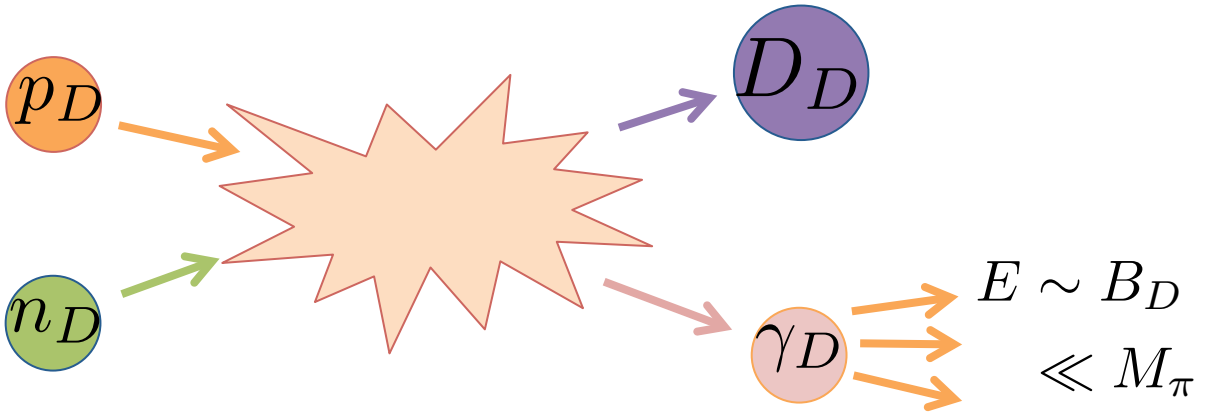
Segue

Other dark exotica

Dark Nuclei

Usual lore for asymmetric DM: no annihilation means no indirect detection!

Dark nuclei:



Dark nucleosynthesis preserves dark baryon-number and can lead to indirect detection signatures! (SM analogy useful here)

"Dark Nuclei" Detmold, MM, Pochinsky 1406.2276

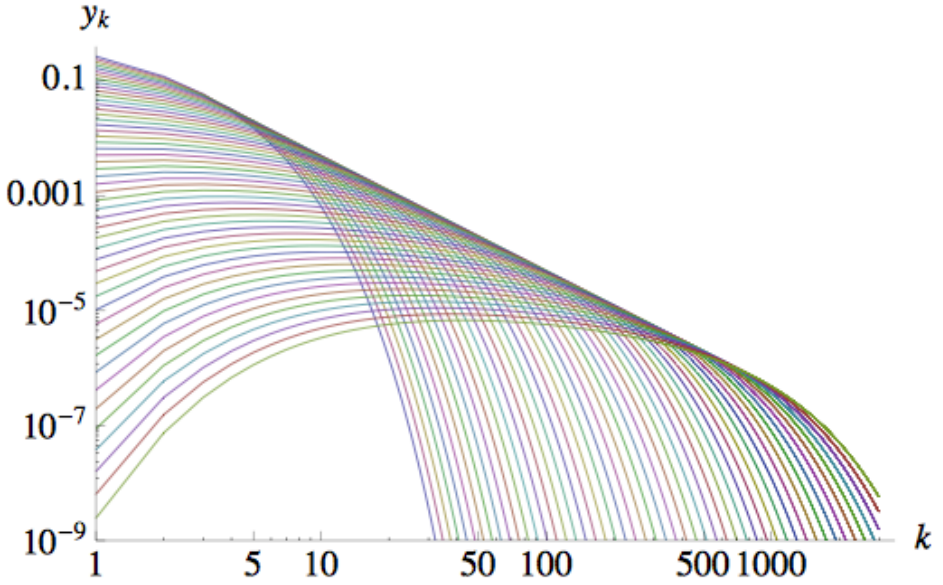
Large Dark Bound States

A number of works have considered bound states of elementary and composite dark sector states.

- Wise & Zhang. Krjaic & Sigurdson. Hardy, Lasenby, March-Russell, & West.

Distribution of states with dark nuclei number k.

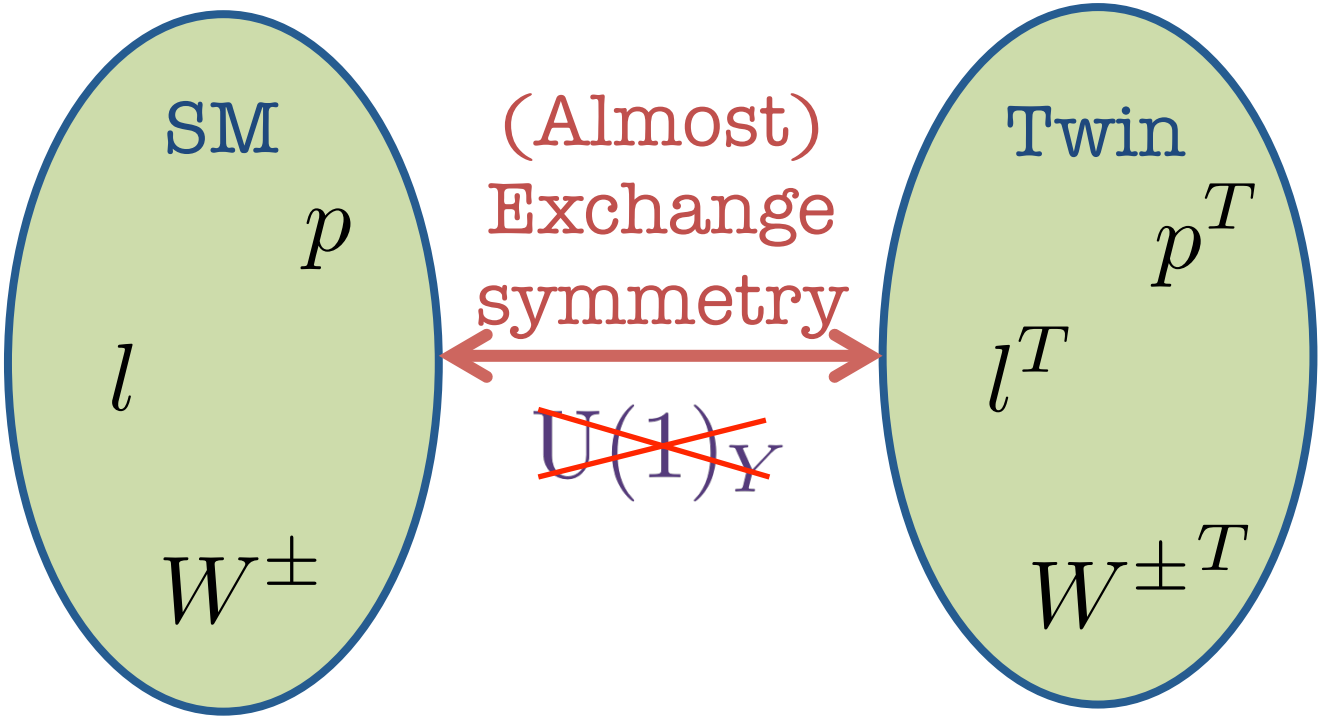
Significant modifications of standard signals.



"Nuggets" of dark matter possible, total mass far exceeding usual unitarity bounds.

Twin Miracle

Take analogy between SM and DM to an extreme level (for a reason: Little Hierarchy Problem)



Miracle: Twin weak interactions similar to SM

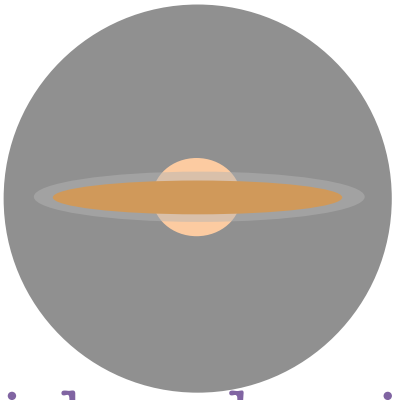
Asymmetry: Mass scale for ADM now motivated!

Craig & Katz. Garcia Garcia, Lasenby, & March-Rusell. Farina.

Conclusions

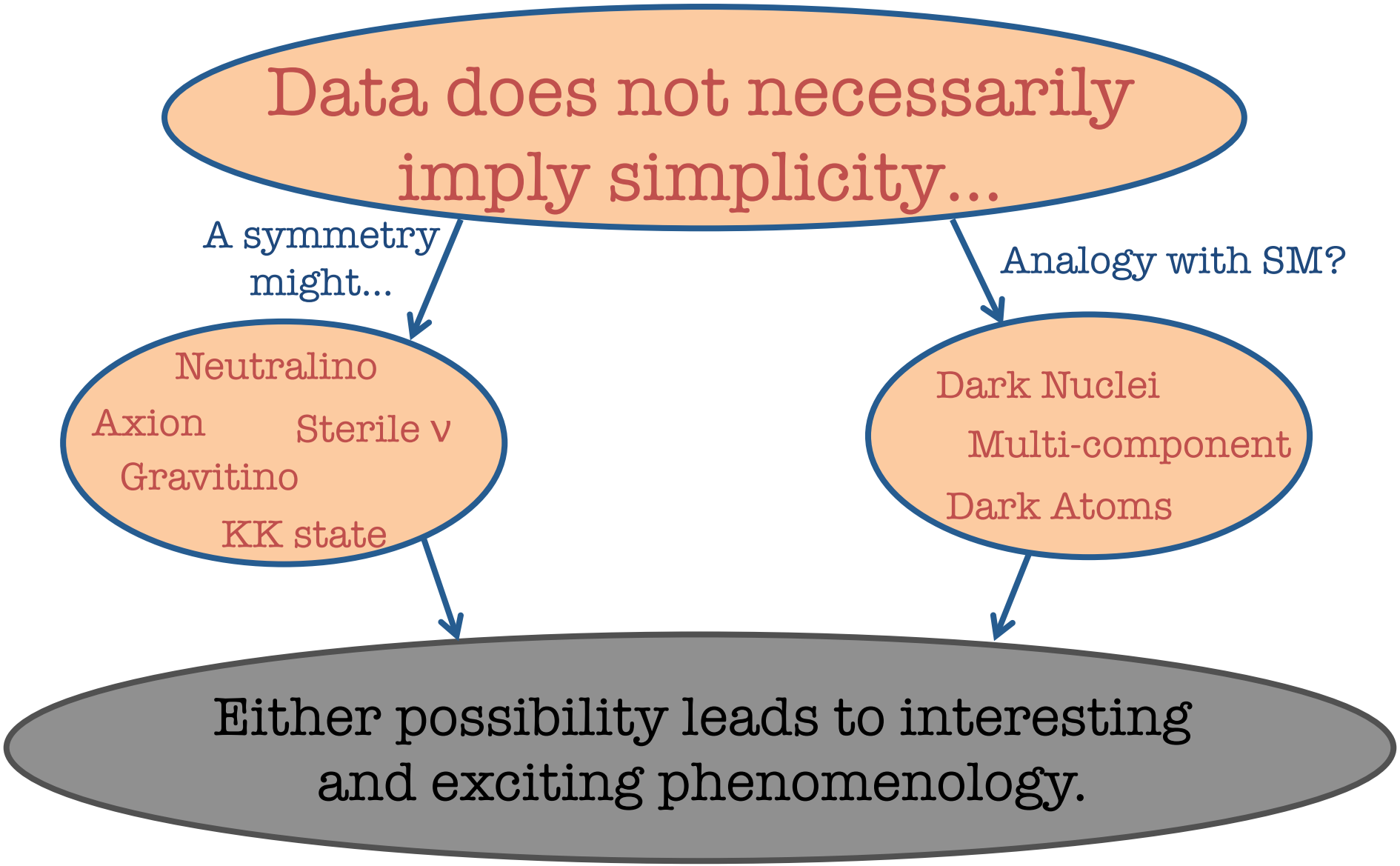
Dark Disks: plausible dark matter substructure

- WIMP Disks: possible consequence of hierarchical structure formation
  - Modifications to dark matter detection



- Subcomponent disks: plausible prediction of non-minimal dark subcomponent scenarios
  - Dramatic consequences for detection
  - Already driving new signatures, new applications for precision cosmology

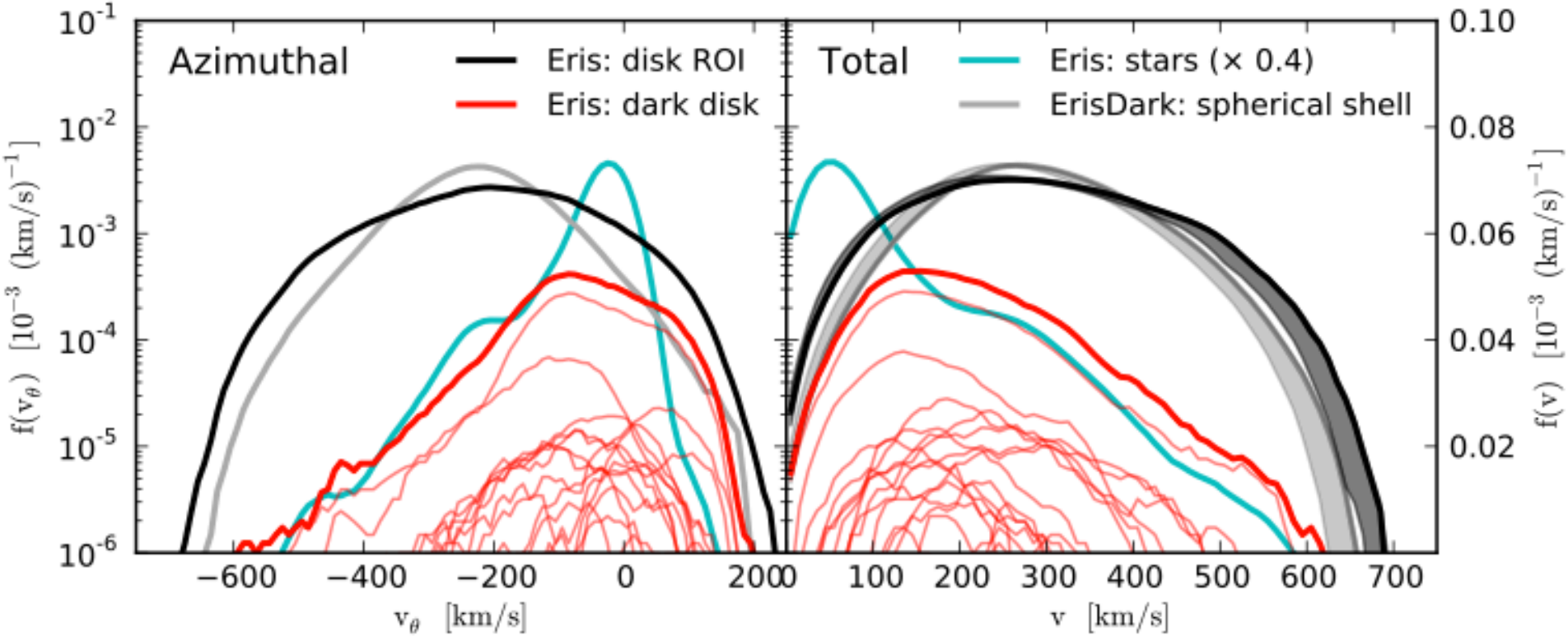
Conclusions



Backup Slides

WIMP Disks

In a paper they look like this:

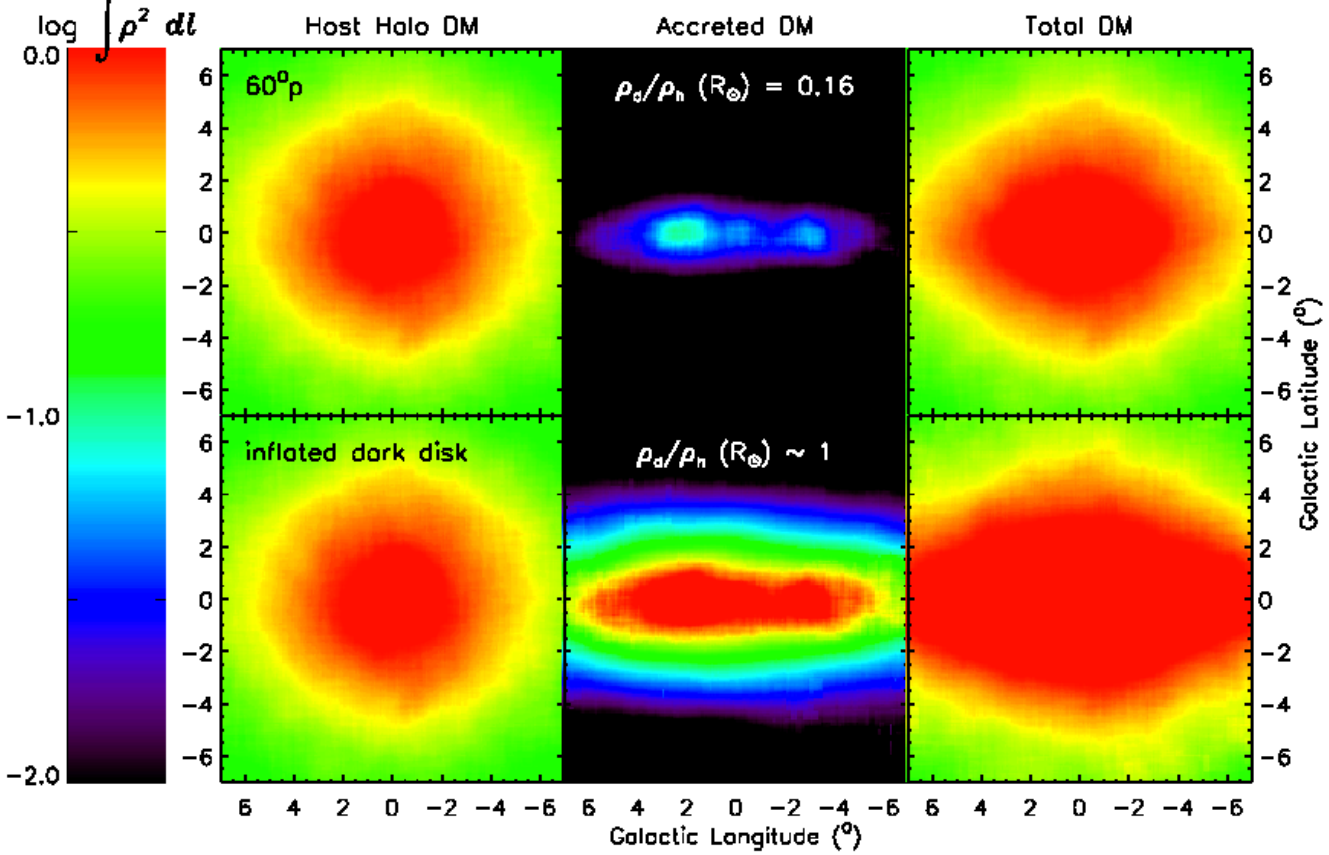


Notice that dark disk does not dominate DM density anywhere.

- Pillepich, Kuhlen, Guedes, Madau (1308.1703)

Detecting WIMP Disks

Indirect Detection modified



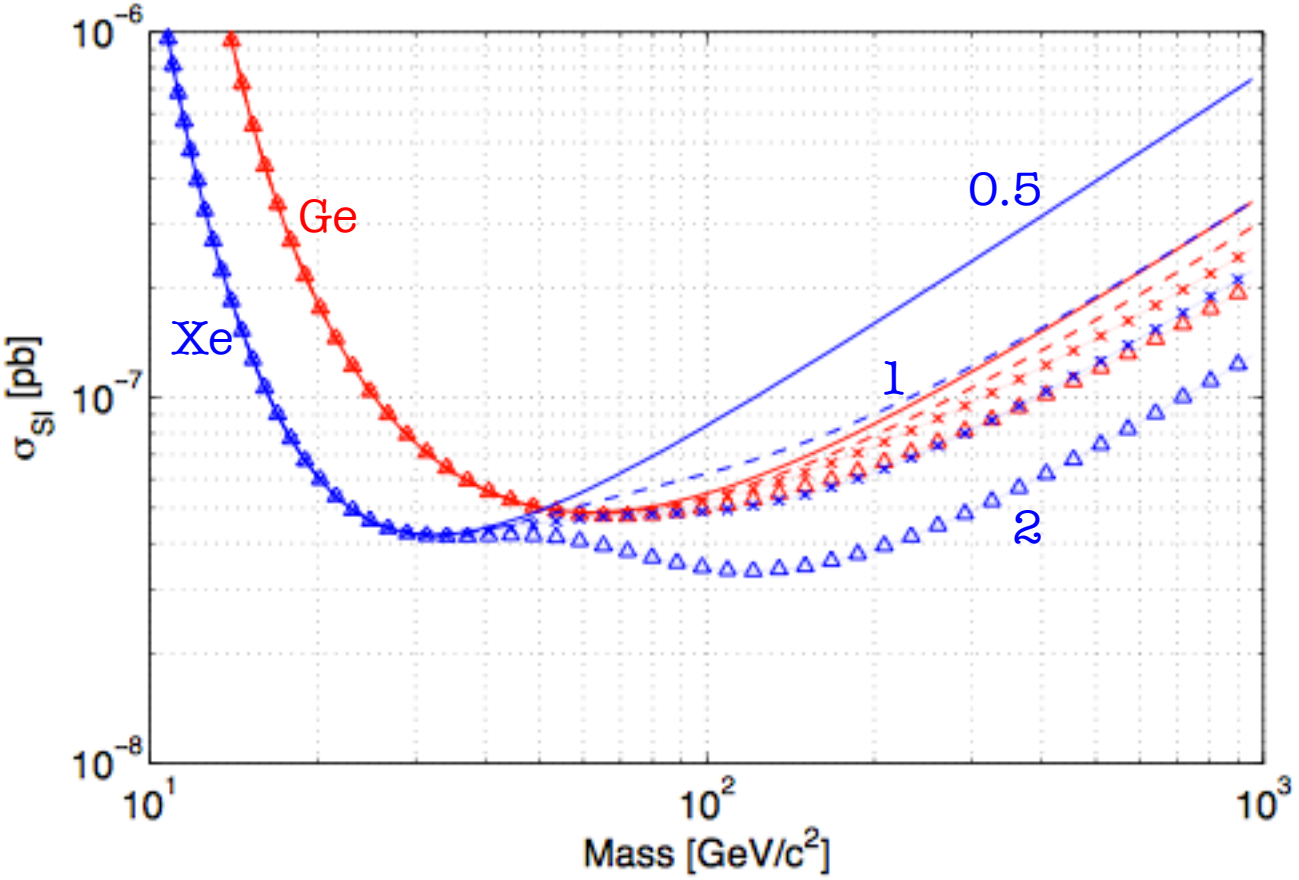
Signatures in gamma rays depend on line-of-sight density integral.

Morphology may be significantly influenced.

- Purcell, Bullock, Kaplinghat (0906.5348)

Detecting WIMP Disks

Direct Detection signatures modified due to enhanced low-velocity component.



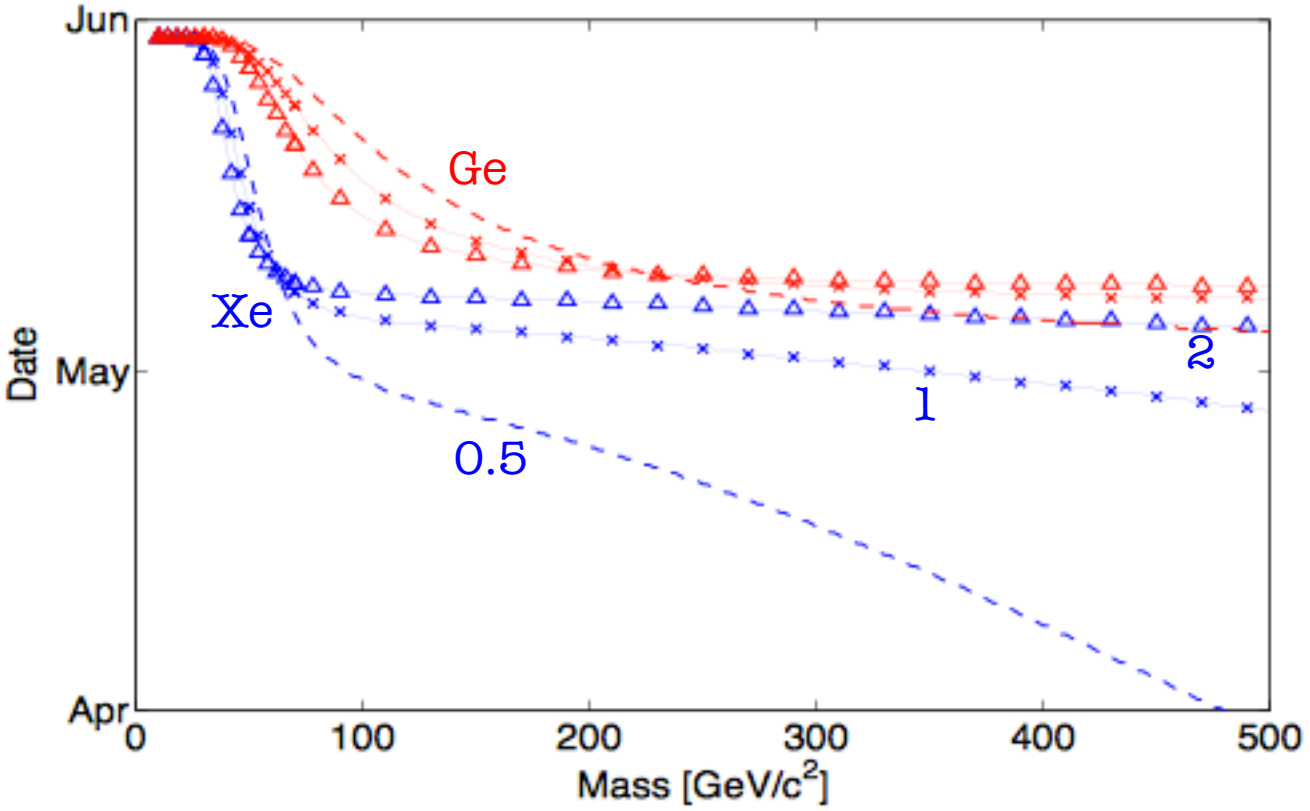
Total scattering rate enhanced, especially for heavier DM.

Changes cross section limits.

- Bruch, Read, Baudis, Lake (0804.2896)

Detecting WIMP Disks

Direct Detection signatures modified due to enhanced low-velocity component.



Peak phase of modulation altered for high masses.

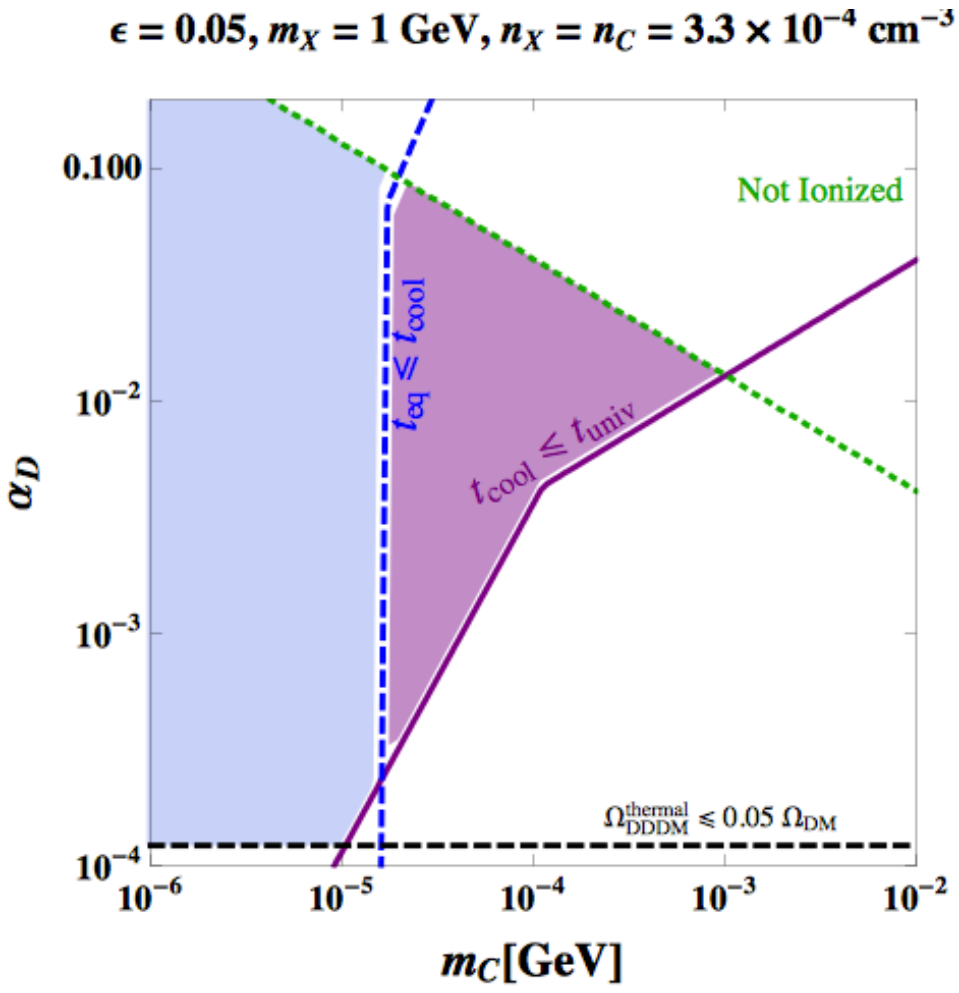
- Bruch, Read, Baudis, Lake (0804.2896)

Subcomponent Disks

Annihilation into dark photons efficient, so imagine an asymmetric scenario (like SM!).

DDDM can cool adiabatically via Compton and Bremsstrahlung.

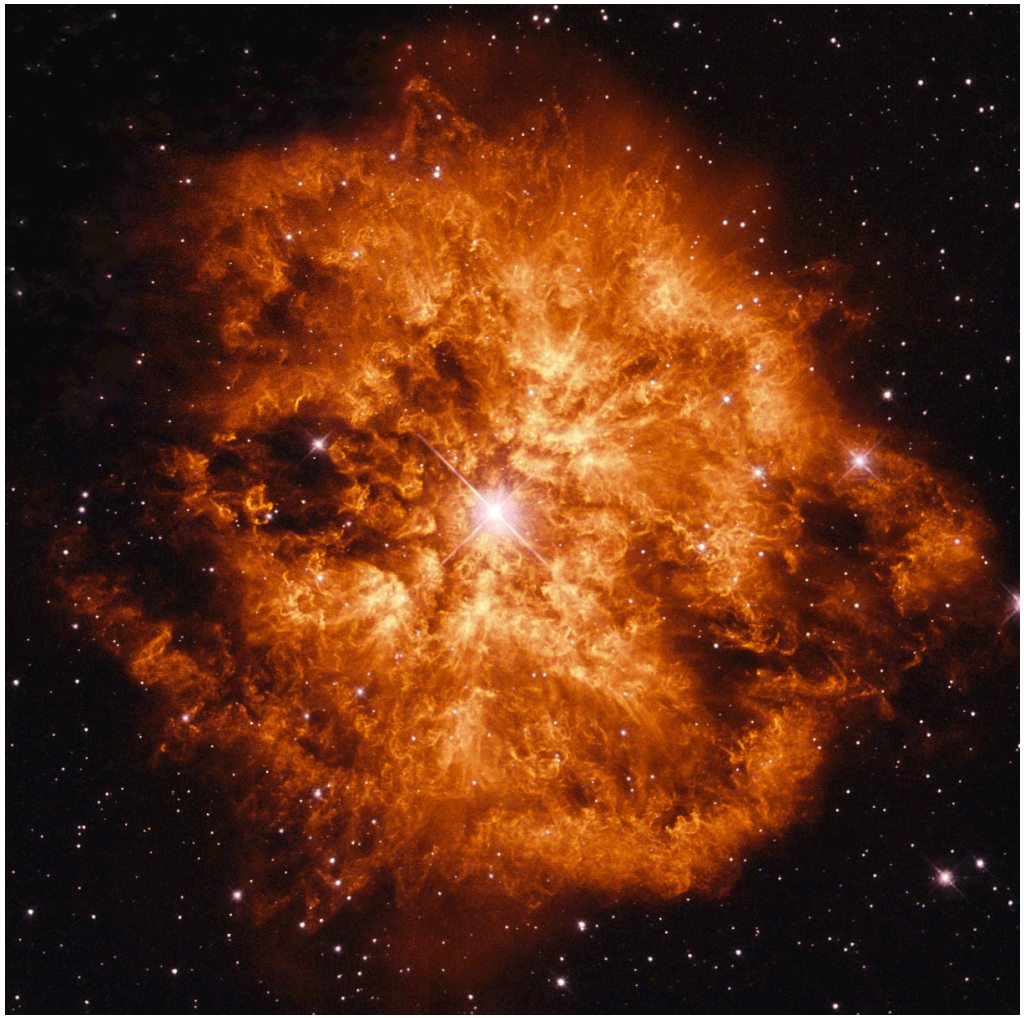
This allows for different structure within the DM halo and a significantly modified cosmology.



Fan, Katz, Randall, Reece

Subcomponent Disks

Wolf-Rayet Stars and Gamma Ray Bursts



In galaxy merger events Wolf-Rayet Stars form (think 20 M_{Sun}!).

Wolf-Rayet believed to be progenitors of Black Holes.

Blandford-Znajek mechanism: Magnetic flux threads BH, spin-down via emission of radiation jets.

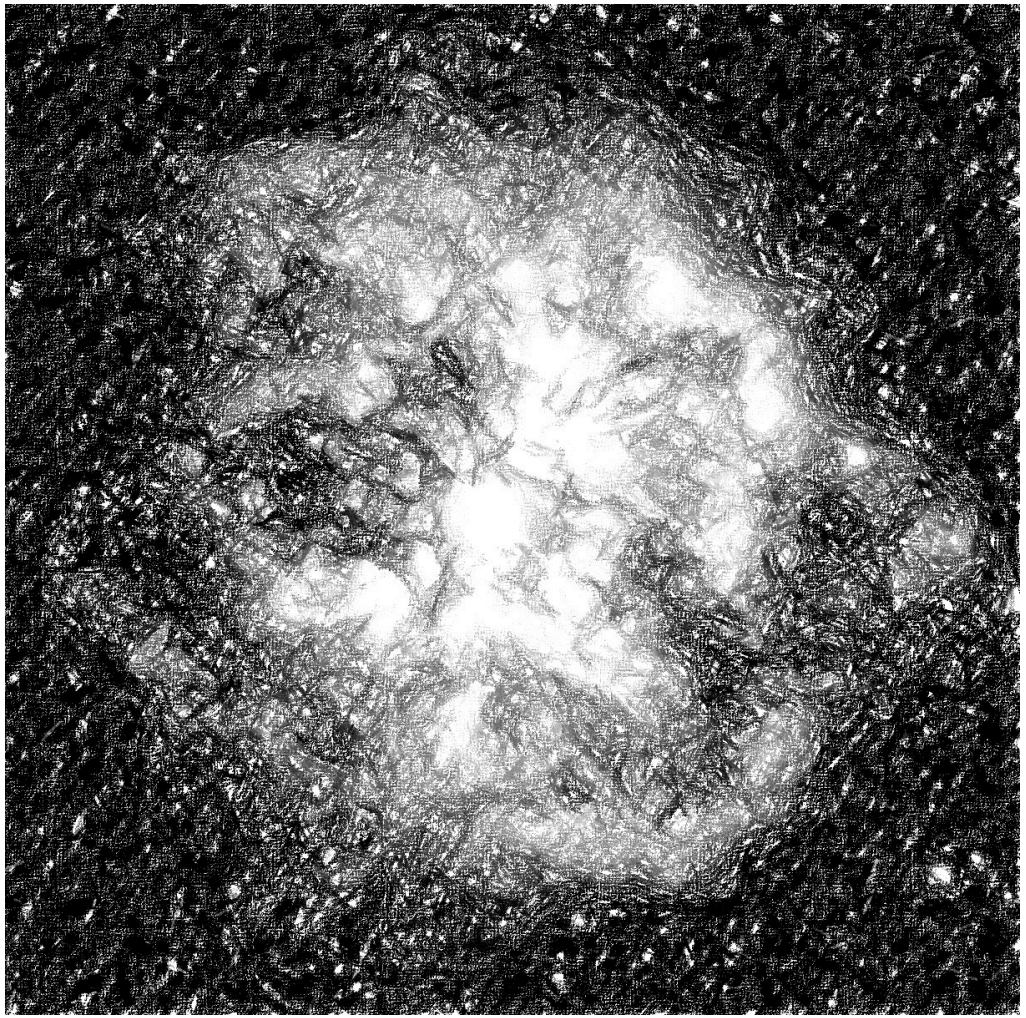
Subcomponent Disks

Fischler, J&D Lorshbough 2015

If merger involved significant amounts of DM, subcomponents would also be in merger region.

Dark magnetic field threads BH and... Dark Gamma Ray Burst!

Mismatch between spin-down and observed GRB energy outflow.

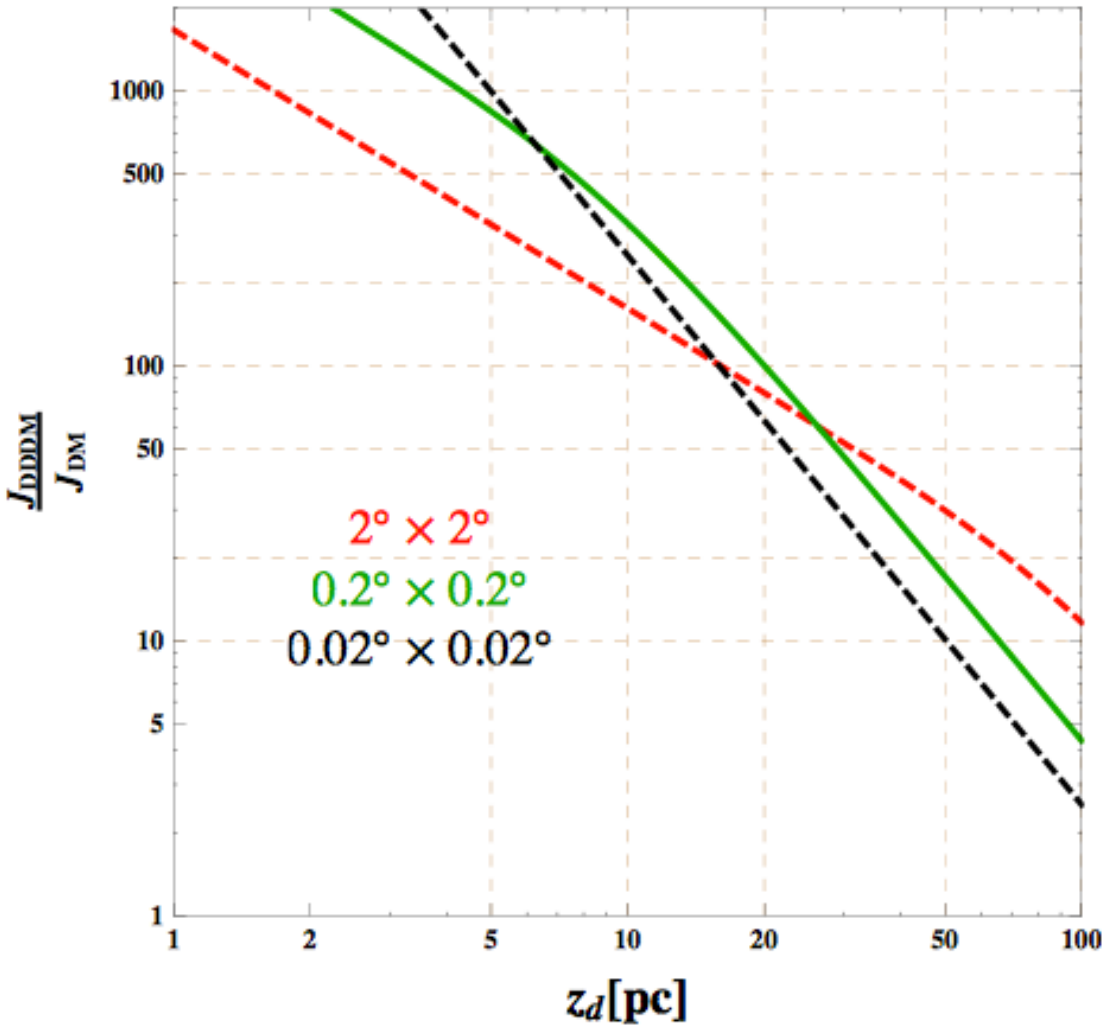


Subcomponent Disks

Implications for standard searches could be significant.

Large boost factors for indirect detection due to high density of disk.

Also possible Sommerfeld enhancement.

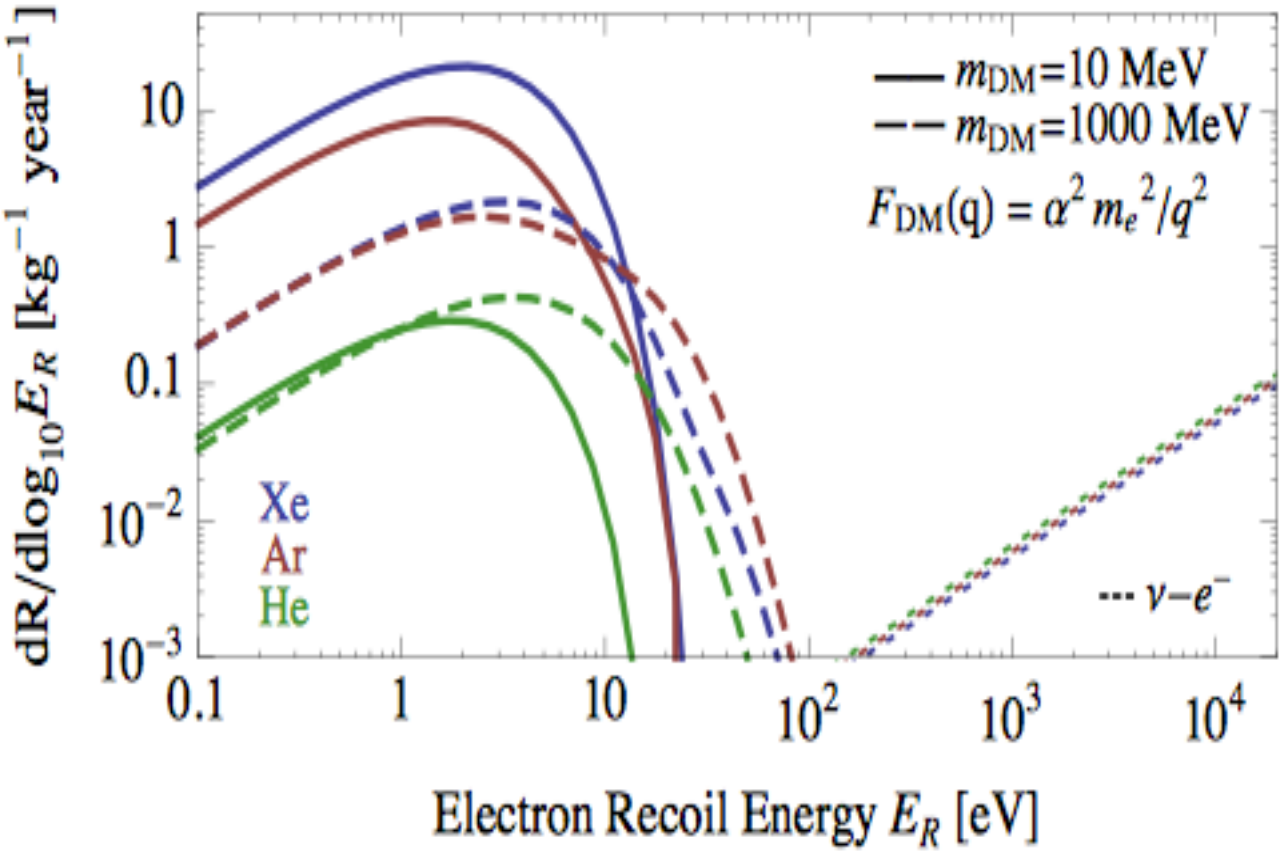


Fan, Katz, Randall, Reece

Subcomponent Disks

Dark Disk likely co-rotating with stellar disk: Small relative velocity and dispersion suppress direct detection.

Perhaps show up in low-threshold experiments, such as proposed by Essig, Mardon, Volansky.



Fan, Katz, Randall, Reece

Subcomponent Disks

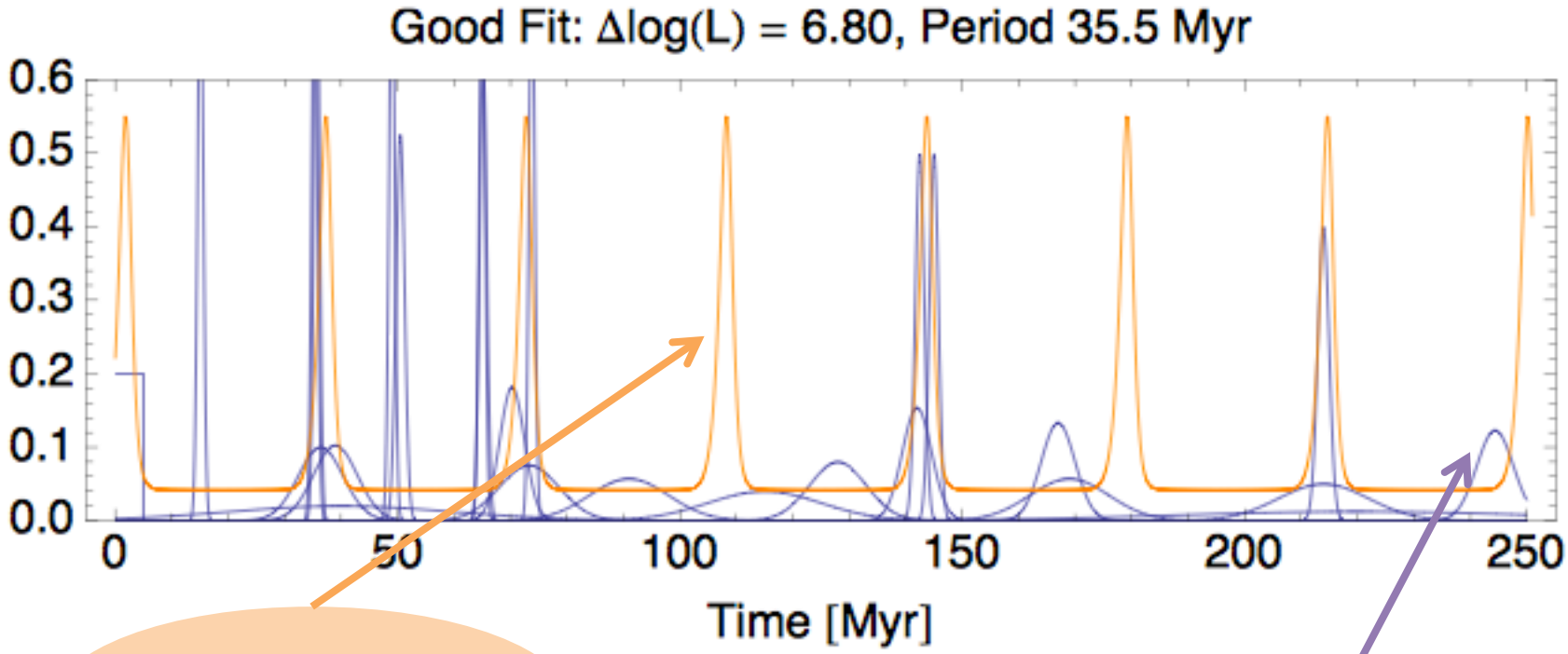
Periodic Comet Impacts

- Possible 35 Myr period in comet impacts, noted in 1984. Statistical significance small.

- Some possible explanations…
  - Nearby star "Nemesis Hypothesis"
  - Tidal stripping of Oort cloud by periodic potential of motion through galactic disk
- Latter taken seriously by serious people

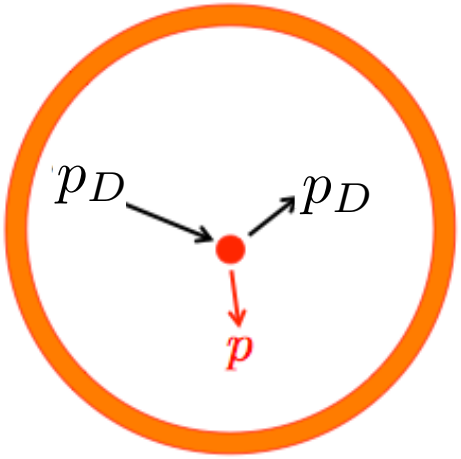
Subcomponent Disks

If stellar disk could do it, then why not a dark disk? Randall and Reece 2014.



Dark Nuclei

Components may be captured in Sun via scattering:



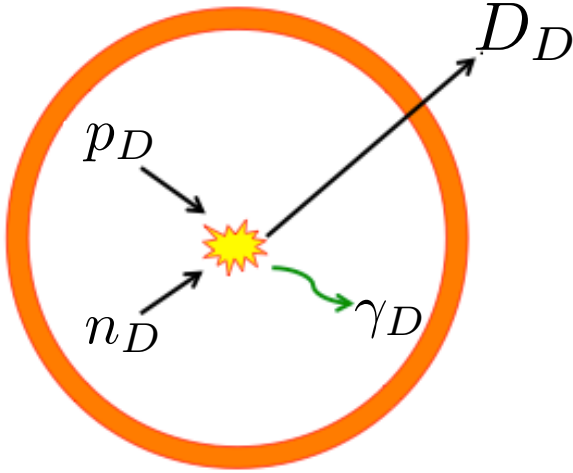
Standard scenario:

- Symmetric: May annihilate leading to detectable neutrinos
- Asymmetric: No annihilation, DM just builds up!

Dark nuclei:

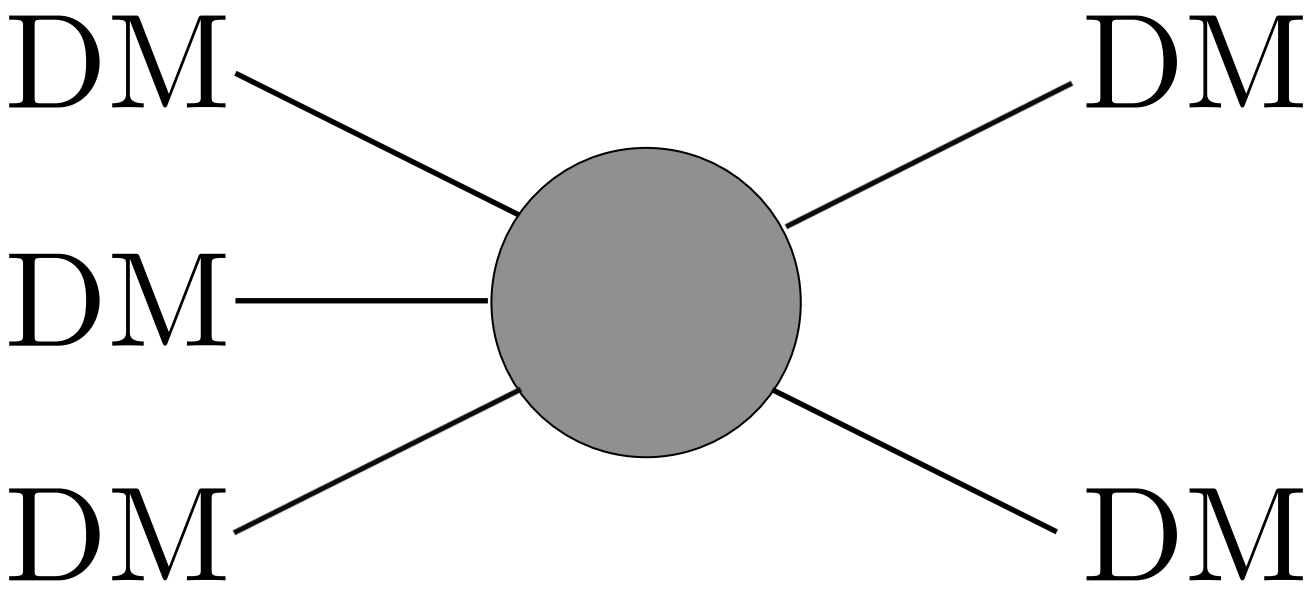
- Symmetric: May also annihilate leading to detectable neutrinos
- Symm and Asymm: Dark nucleo may **eject dark nucleus from star**!

$$\beta_D \sim B_D/M_D \gtrsim 0.01 > \beta_{\rm Escape}$$



SIMP Miracle

"Strongly Interacting" abundance miracle:
Hochberg, Kuflik, Murayama, Volanksy, Wacker.



Emerges naturally in scenarios where the DM is a bound state of strongly coupled sector.