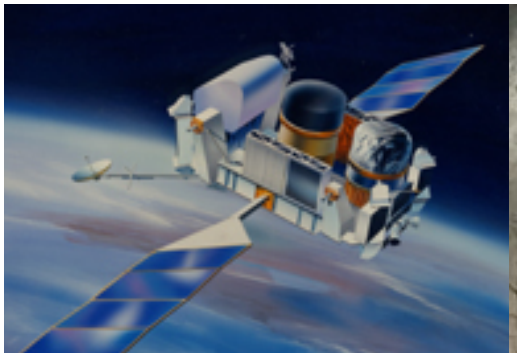
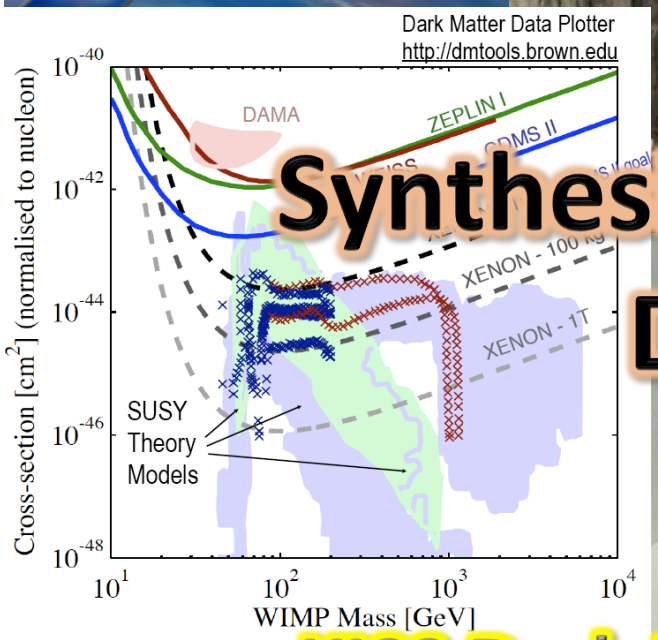
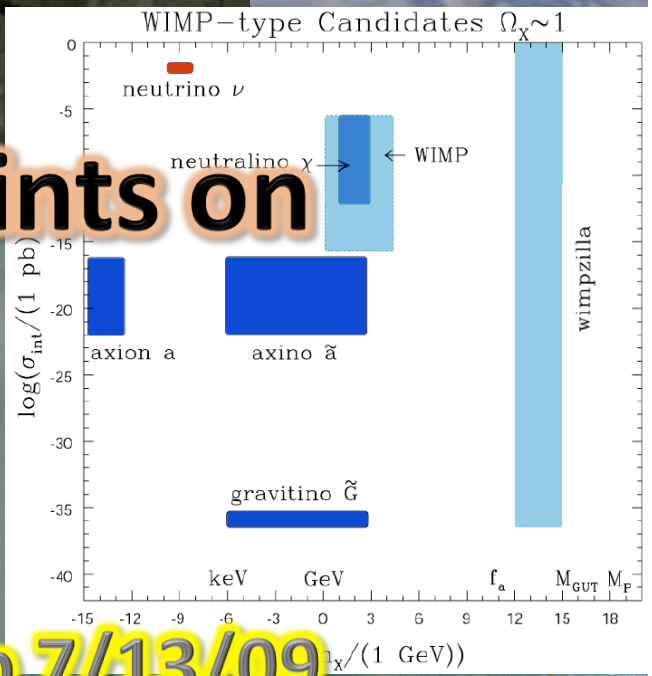


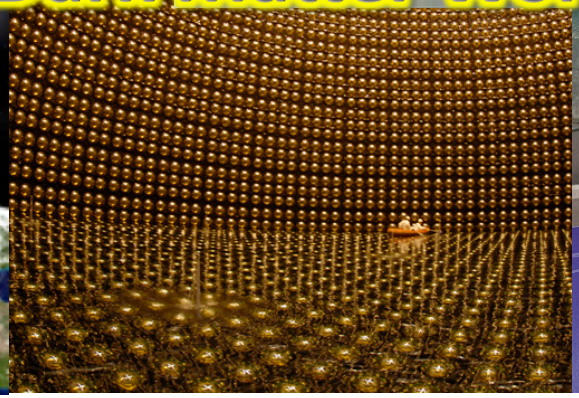


Synthesized Constraints on Dark Matter

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

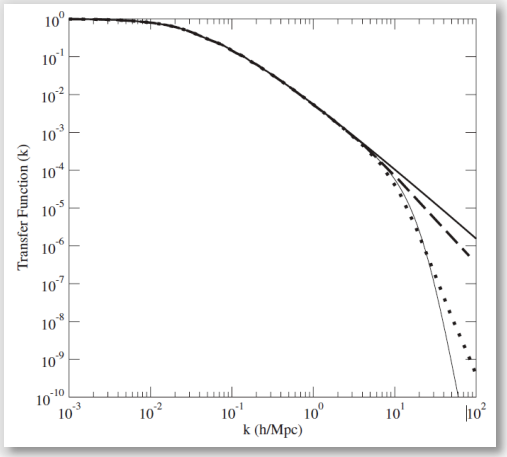
Observable	Constraint	Method
Mass	100 GeV WIMP? 10^{-5} eV axion?	theory, Ω_{DM}, Ω_b
DM-baryon scattering x-sect	<~ 10^{-42} cm^2/g (10^{-6} pb)	CDMS-II, XENON100, etc. ("direct" detection)
DM-DM scattering x-section	<~ 1 cm^2/g	Bullet Cluster
DM-DM self-annihilation x-sect	low high?	CMB: reionization optical depth PAMELA & ATIC ("indirect" detection)
Thermal velocity	mostly cold	Large scale structure
Density fluctuations		
other?		

Connect observations to DM constraints

Strong gravitational lensing

?

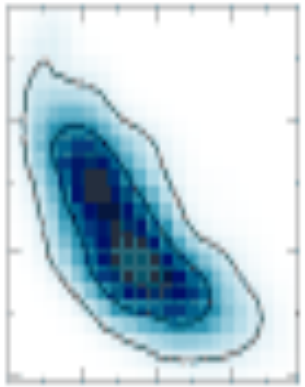
Matter power spectrum



?

DM particle constraints

decays



warm

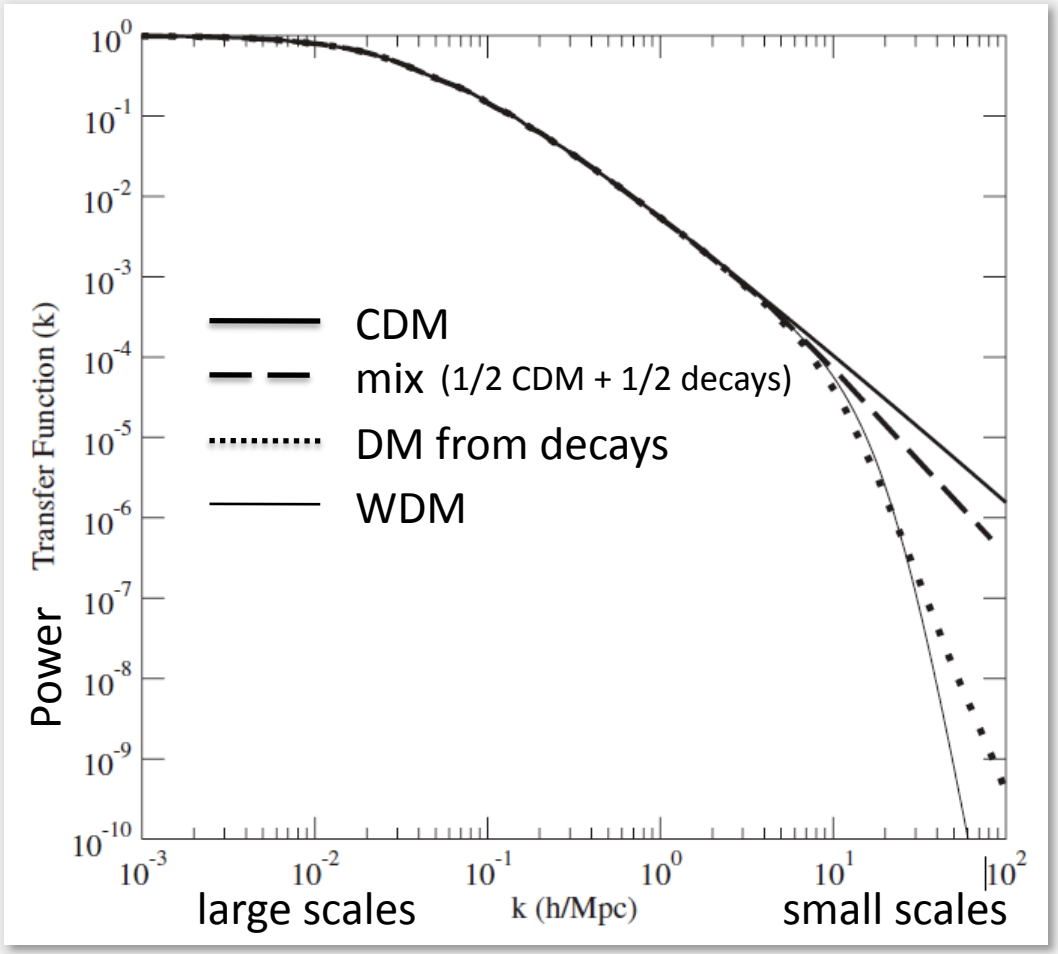
OMEGA Mission Concept

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



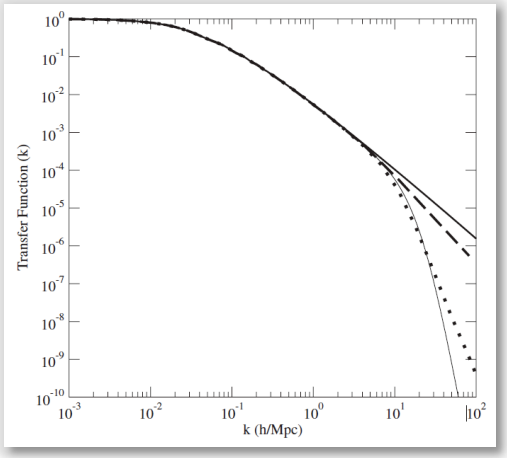
Kaplinghat05

If DM turns out to be gravitinos, strong gravitational lensing could be the only method capable of constraining it

Strong gravitational lensing

?

Matter power spectrum



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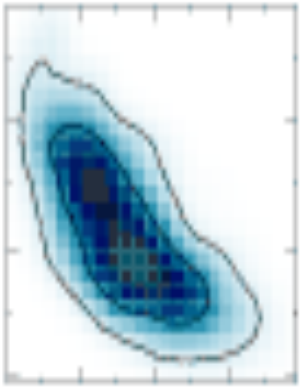
DM particle constraints

decays



warm

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
  - γ-rays: VERITAS, Fermi, MAGIC
  - ν (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 ($\sigma_{DM}(v)$)
- DM-baryon interactions (σ_{DM-n})
- Finite velocity dispersion (Q_{prim})
- Late-time decays - NLSP-LSP ($\Delta m/m$)
- Broken scale invariance
- Small-scale primordial non-Gaussianity; $f_{NL}(k)$
- Cold + hot (massless) dark matter
- Equivalence principle violating dark matter
  (or long-range DM-DM interaction)
- Dark U(1)
- Warm dark matter; m_{DM}, θ
- Enhanced ????????

Measurements

- Ω_{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

- DM-DM elastic scattering ($\sigma_{DM}(v)$)
- DM-baryon interactions ($\sigma_{DM\text{-}n}$)
- Finite velocity dispersion (Q_{prim})
- Late-time decays - NLSP-LSP ($\Delta m/m$)
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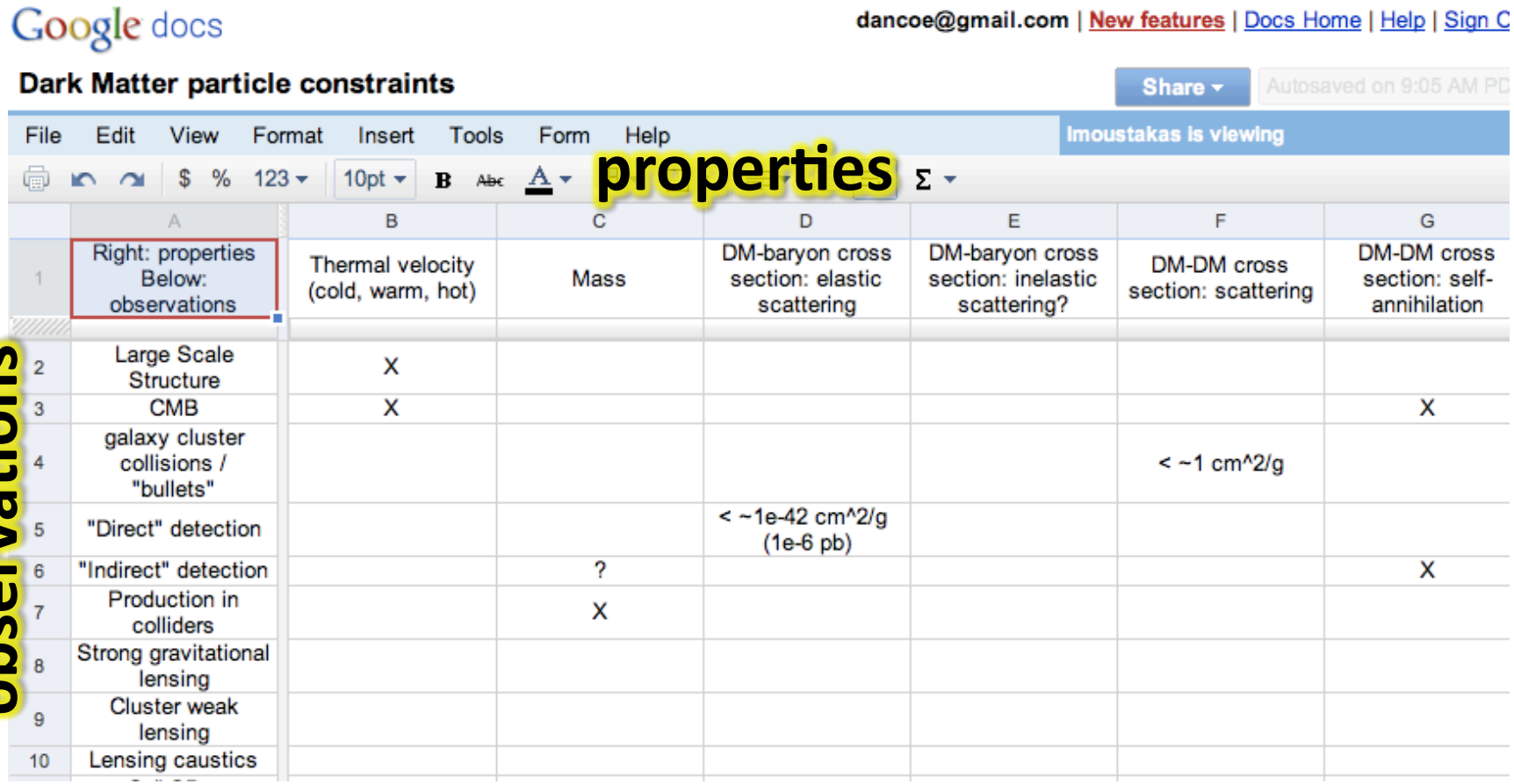
from Moustakas, Kaminkowski, Benson chalkboard talk 6/4/09

Connections: observations to DM constraints

Thank you for your input so far, and we look forward to more!



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Dark Matter particle constraints

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properties

observations

	A	B	C	D	E	F	G
1	Right: properties Below: observations	Thermal velocity (cold, warm, hot)	Mass	DM-baryon cross section: elastic scattering	DM-baryon cross section: inelastic scattering?	DM-DM cross section: scattering	DM-DM cross section: self-annihilation
2	Large Scale Structure	X					
3	CMB	X					X
4	galaxy cluster collisions / "bullets"					< ~1 cm^2/g	
5	"Direct" detection			< ~1e-42 cm^2/g (1e-6 pb)			
6	"Indirect" detection		?				X
7	Production in colliders		X				
8	Strong gravitational lensing						
9	Cluster weak lensing						
10	Lensing caustics						

One matrix or several?

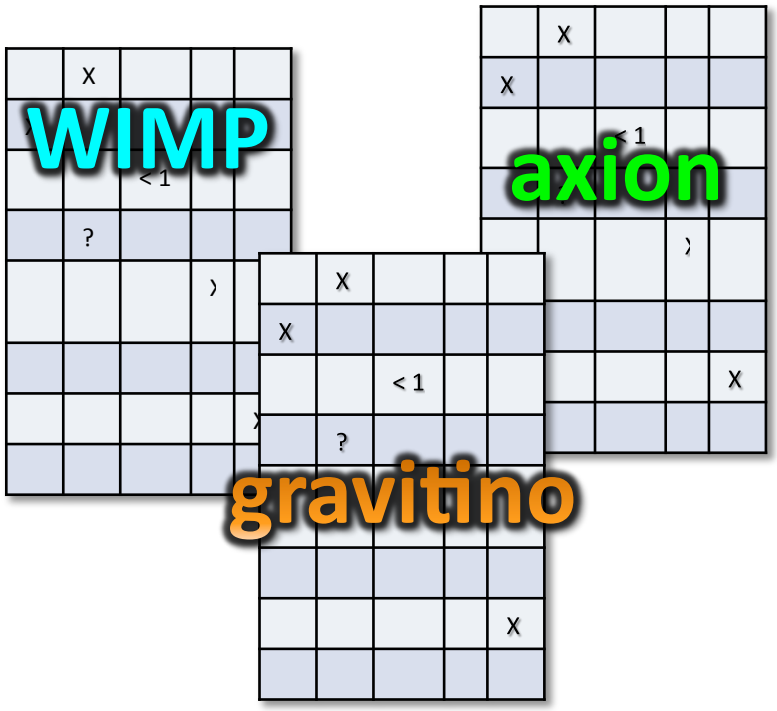
Single

Properties

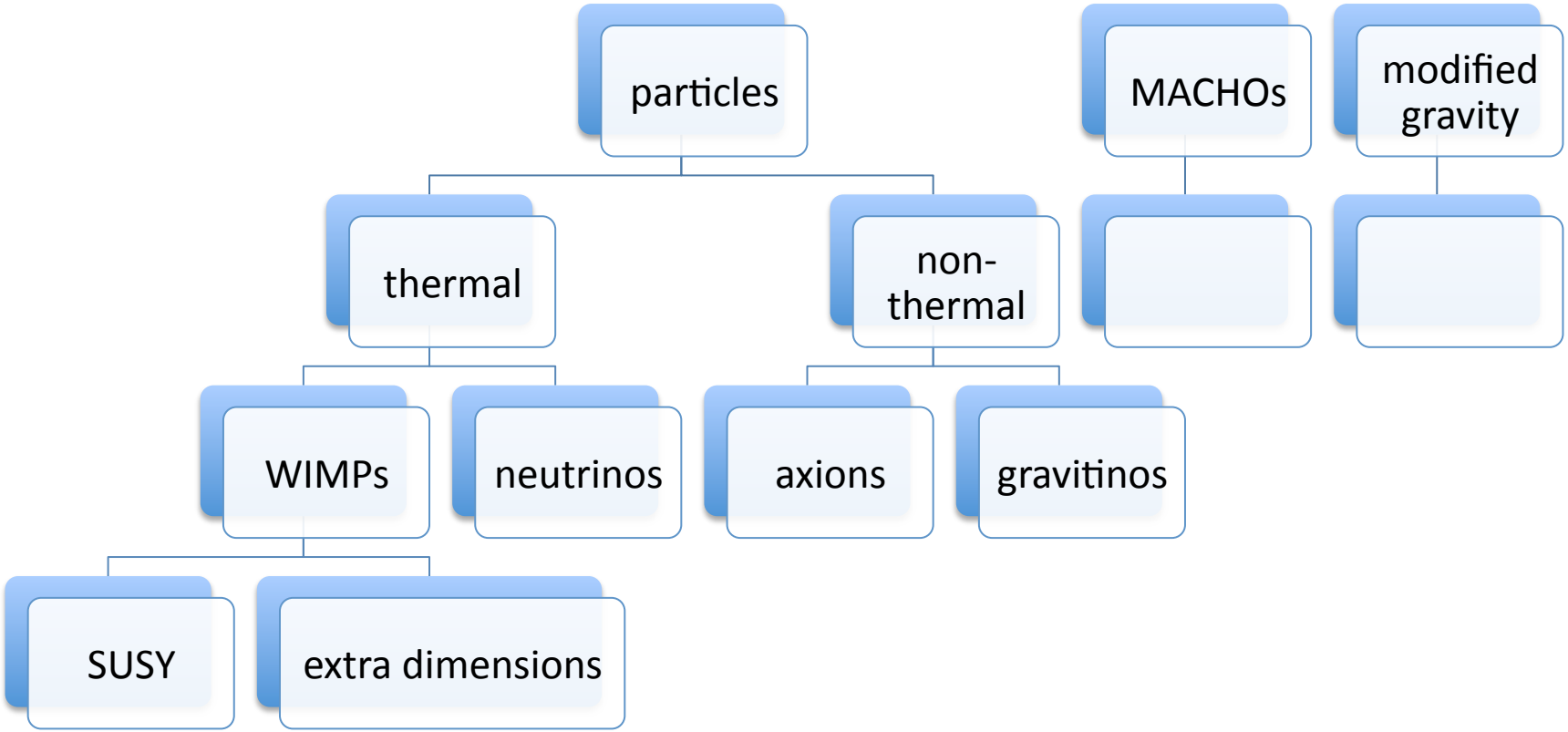
Observations

	X			
X				
		< 1		
	?			
			X	
				X

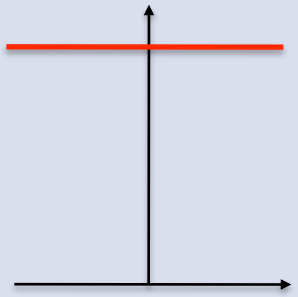
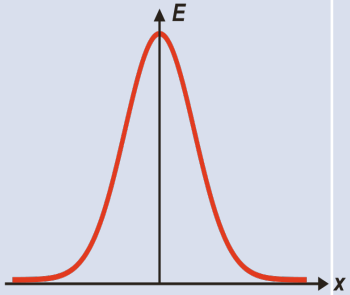
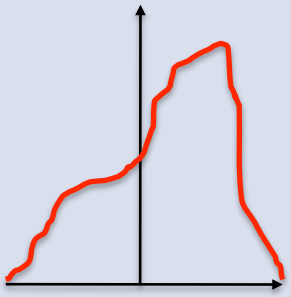
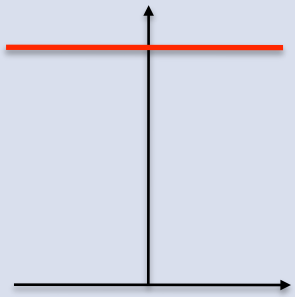
One for each candidate?



Dark Matter candidates



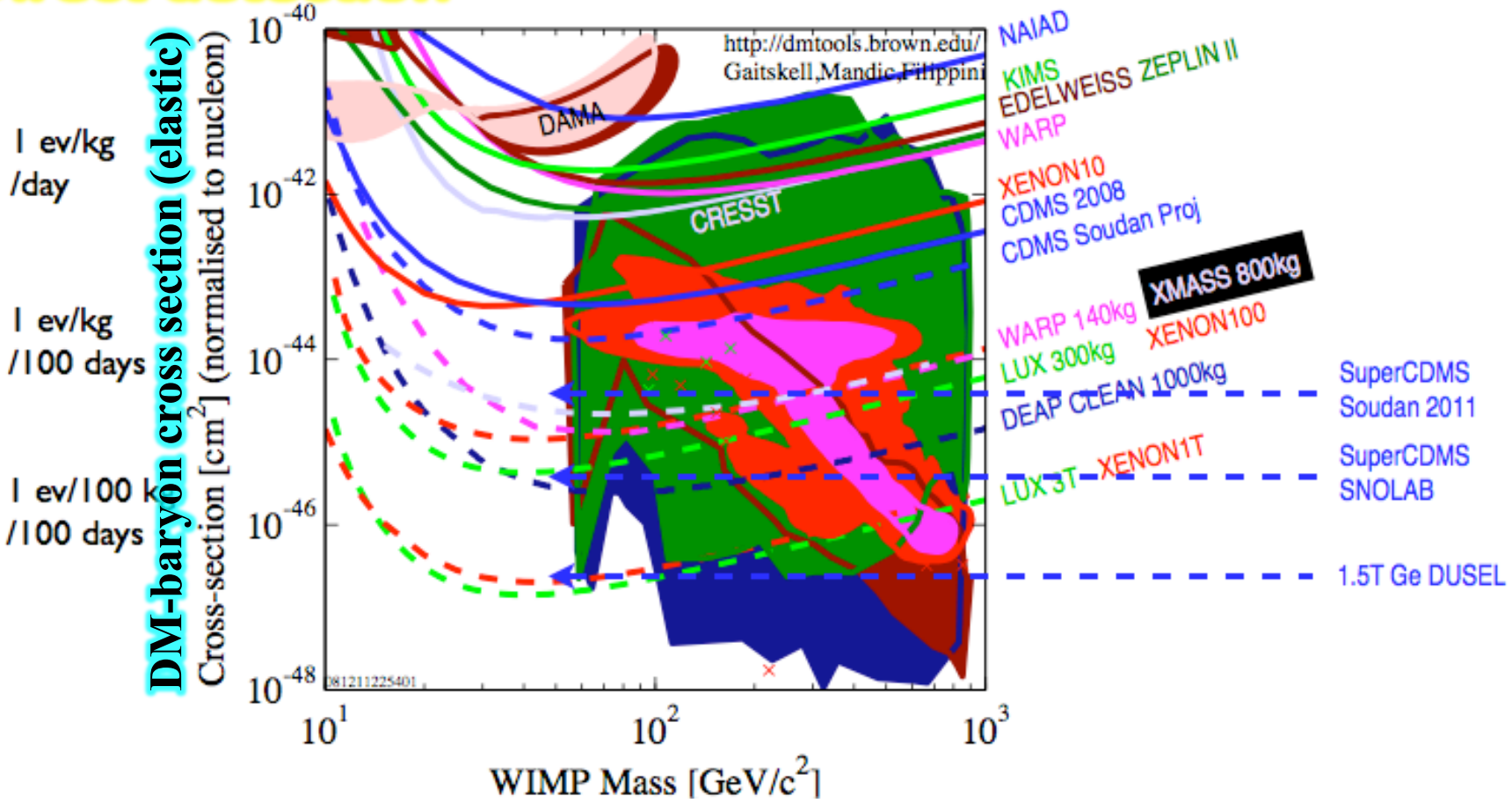
From each experiment / observation, 1-D constraints on individual variables

	Thermal velocity	Mass	DM-baryon cross section: scattering	DM-DM cross section: elastic scattering
Direct detection				

What about correlations?

From each experiment / observation, 2-D constraints on pairs of variables

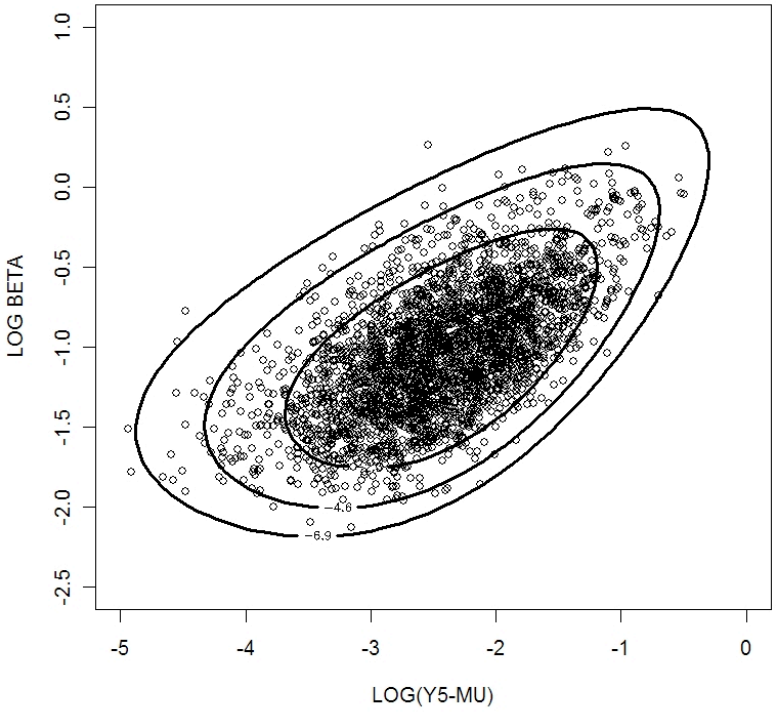
Direct detection



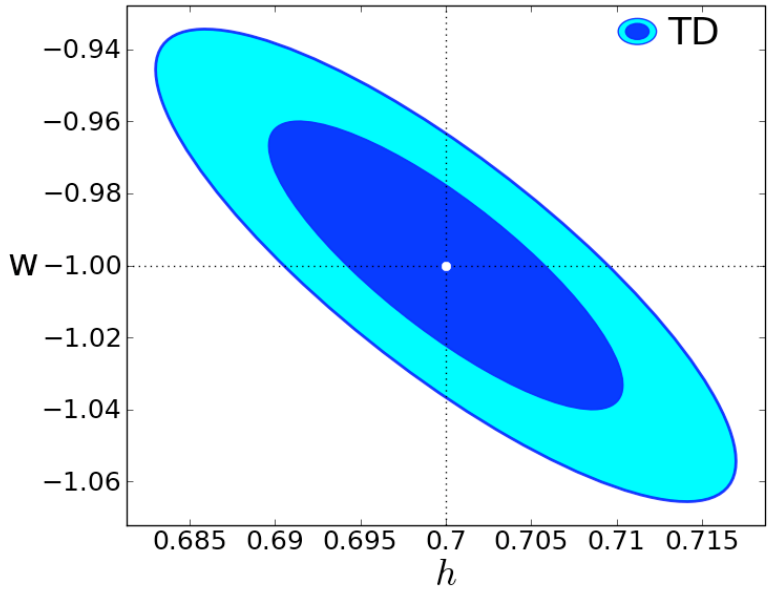
From each experiment / observation, multi-dimensional constraints on variables

Techniques to probe large parameter spaces:

Monte Carlo Markov Chains

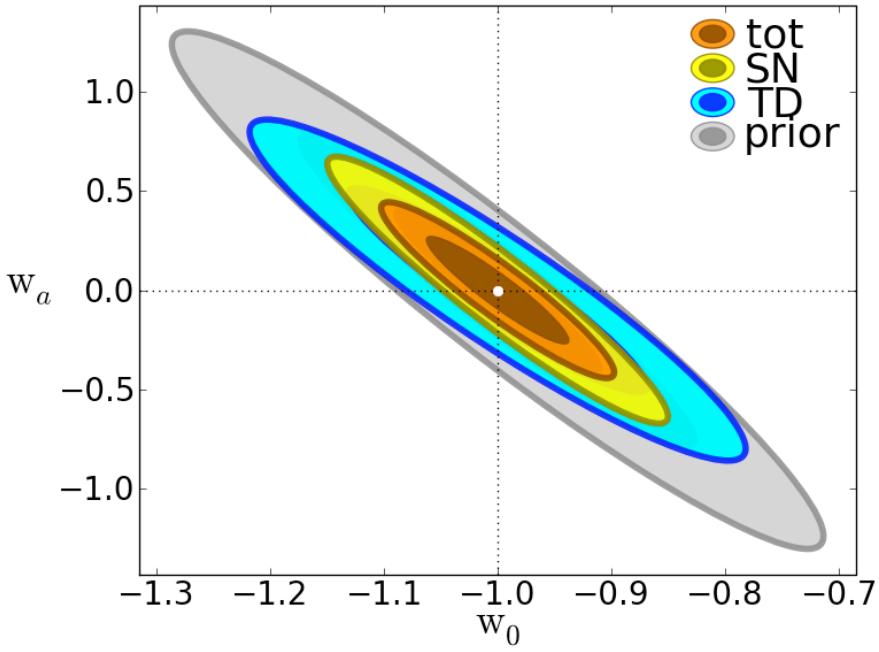


Fisher matrices

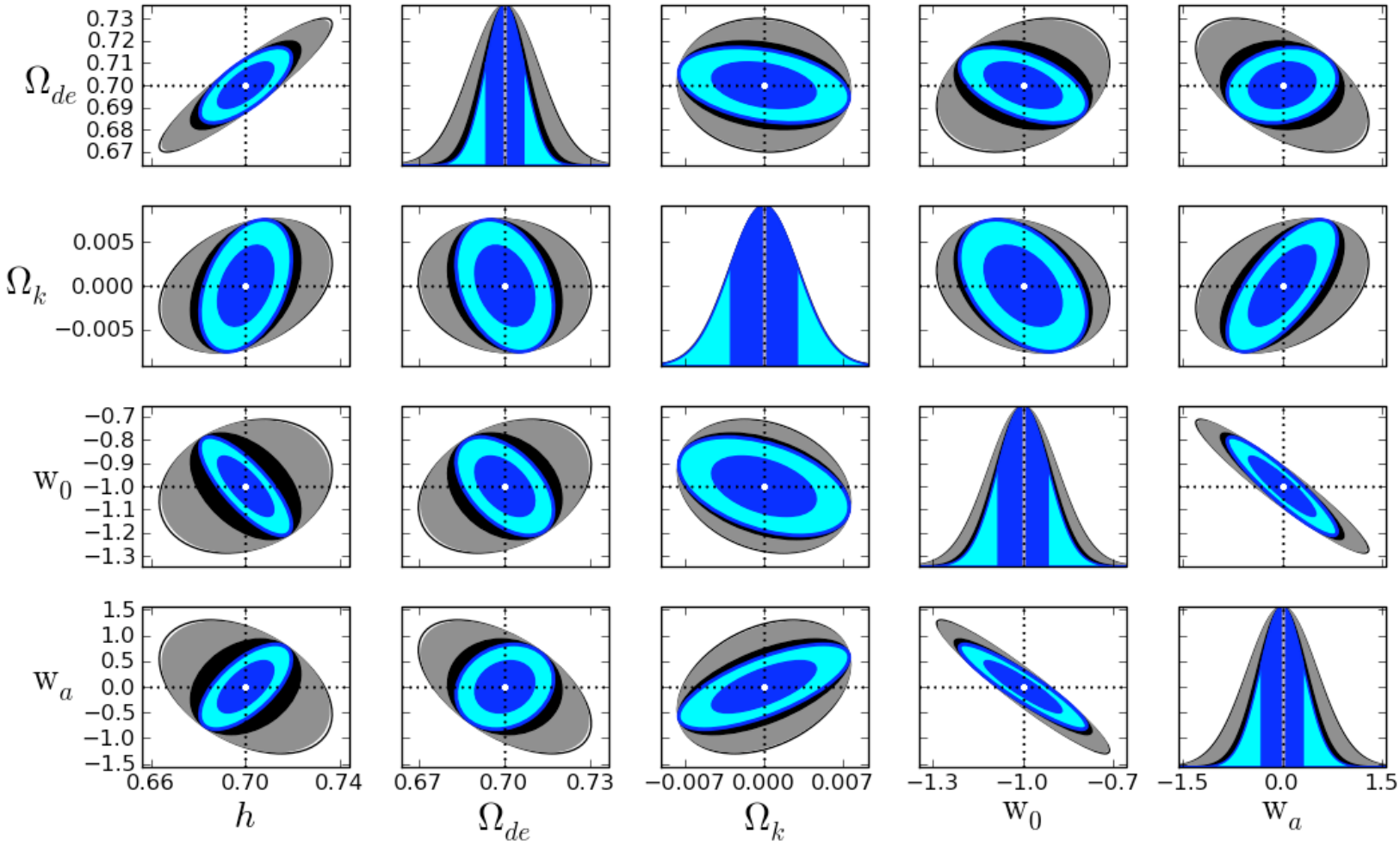


How best to combine constraints from multiple experiments?

- Fisher matrices?
- Simple and efficient way of exploring large parameter spaces
- e.g., cosmological parameters: (h, Ω_m, Ω_{de}, Ω_k, w_0, w_a)
- Alternative: MCMC

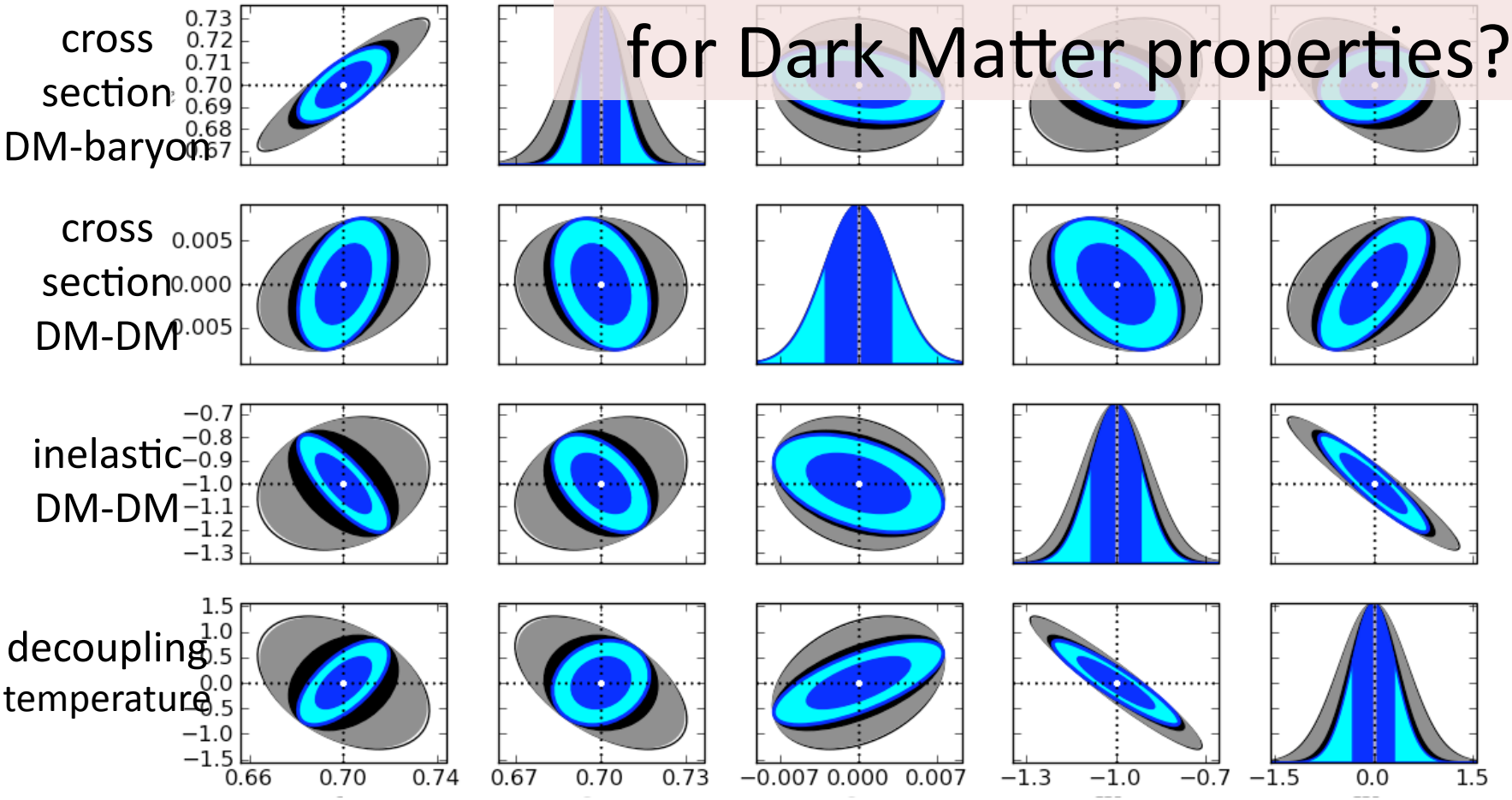


From each experiment / observation, a Fisher matrix of constraints and correlations

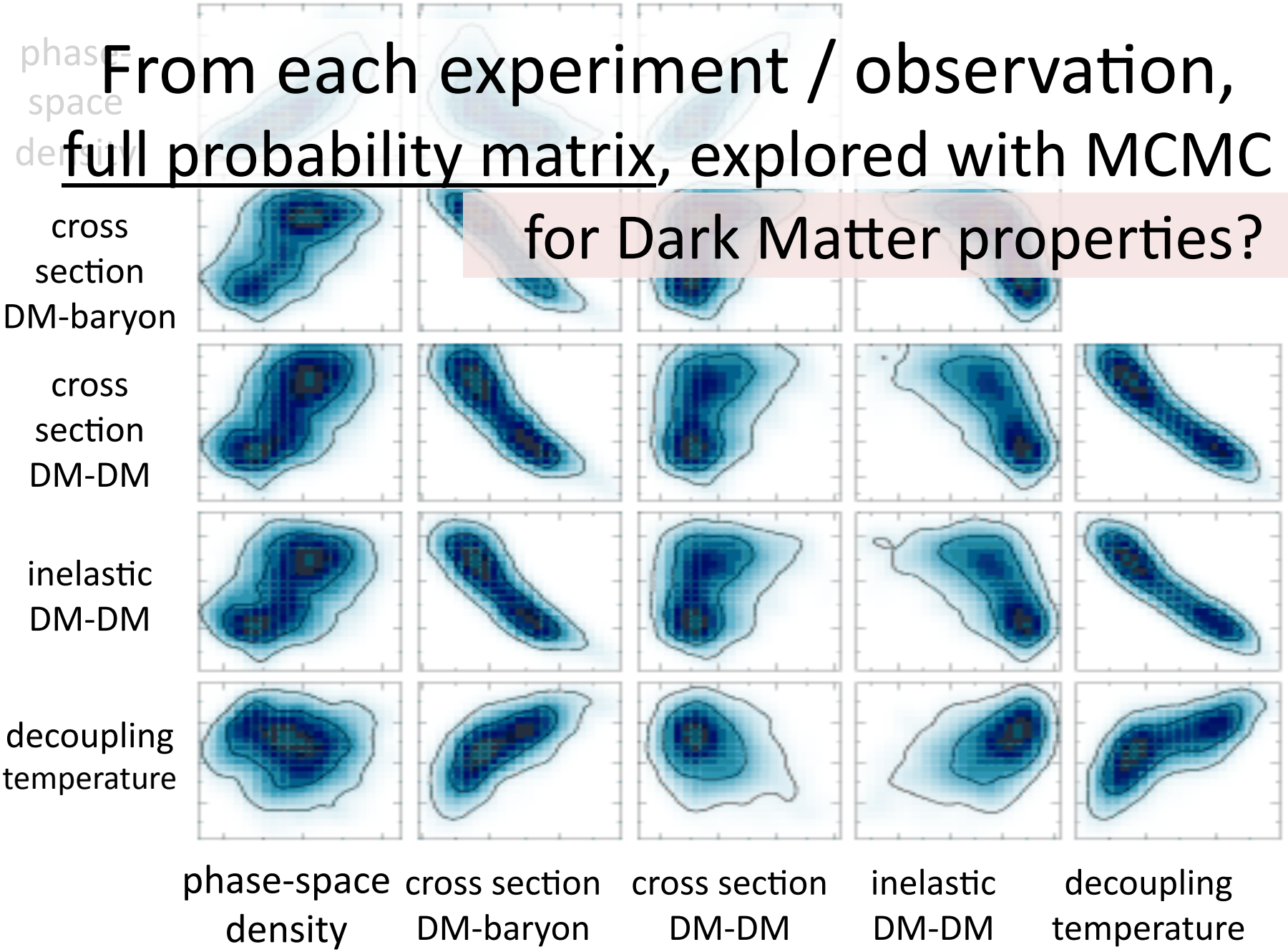


Cosmological Constraints from Gravitational Lens Time Delays (Coe09)

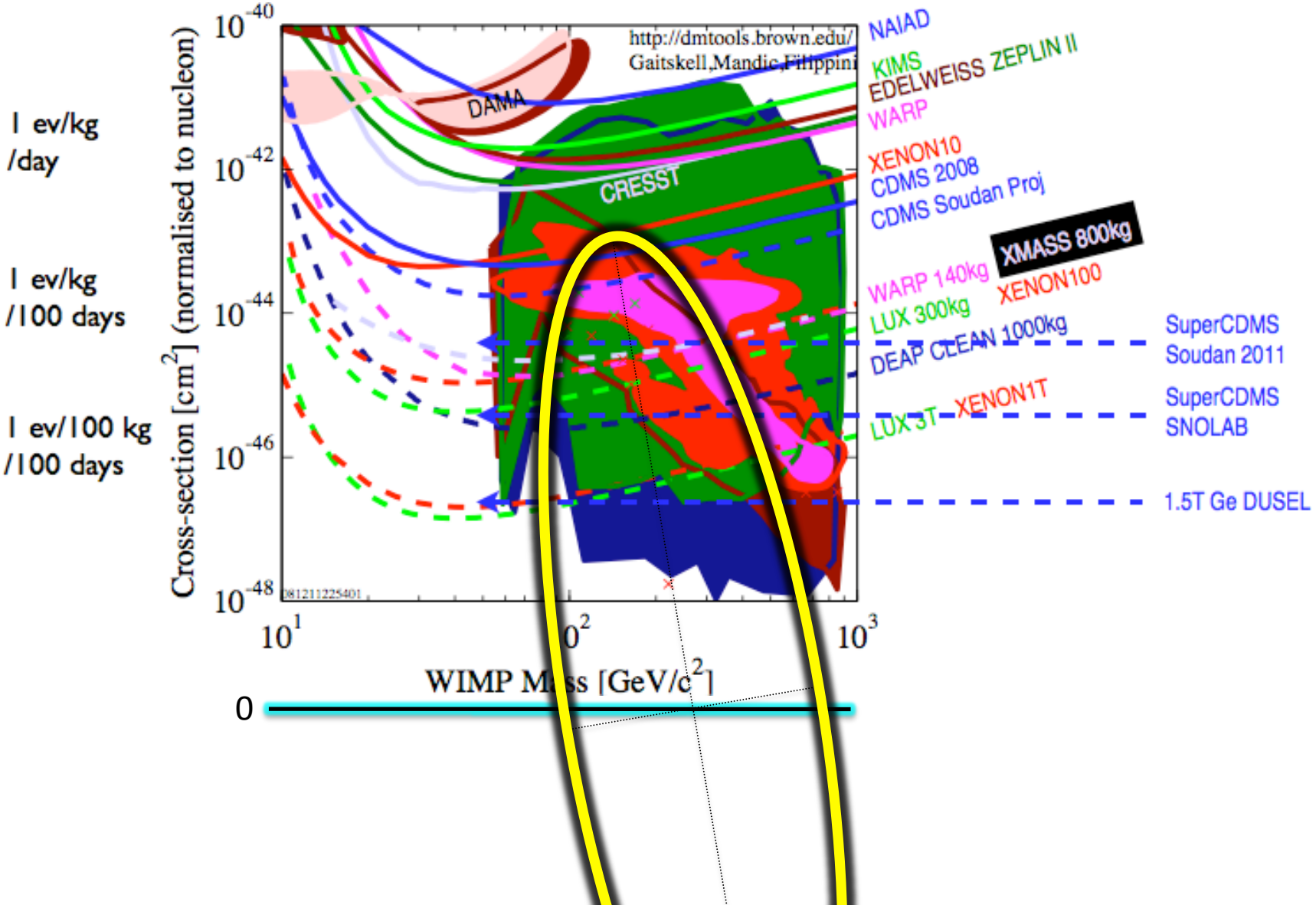
From each experiment / observation, a Fisher matrix of constraints and correlations for Dark Matter properties?



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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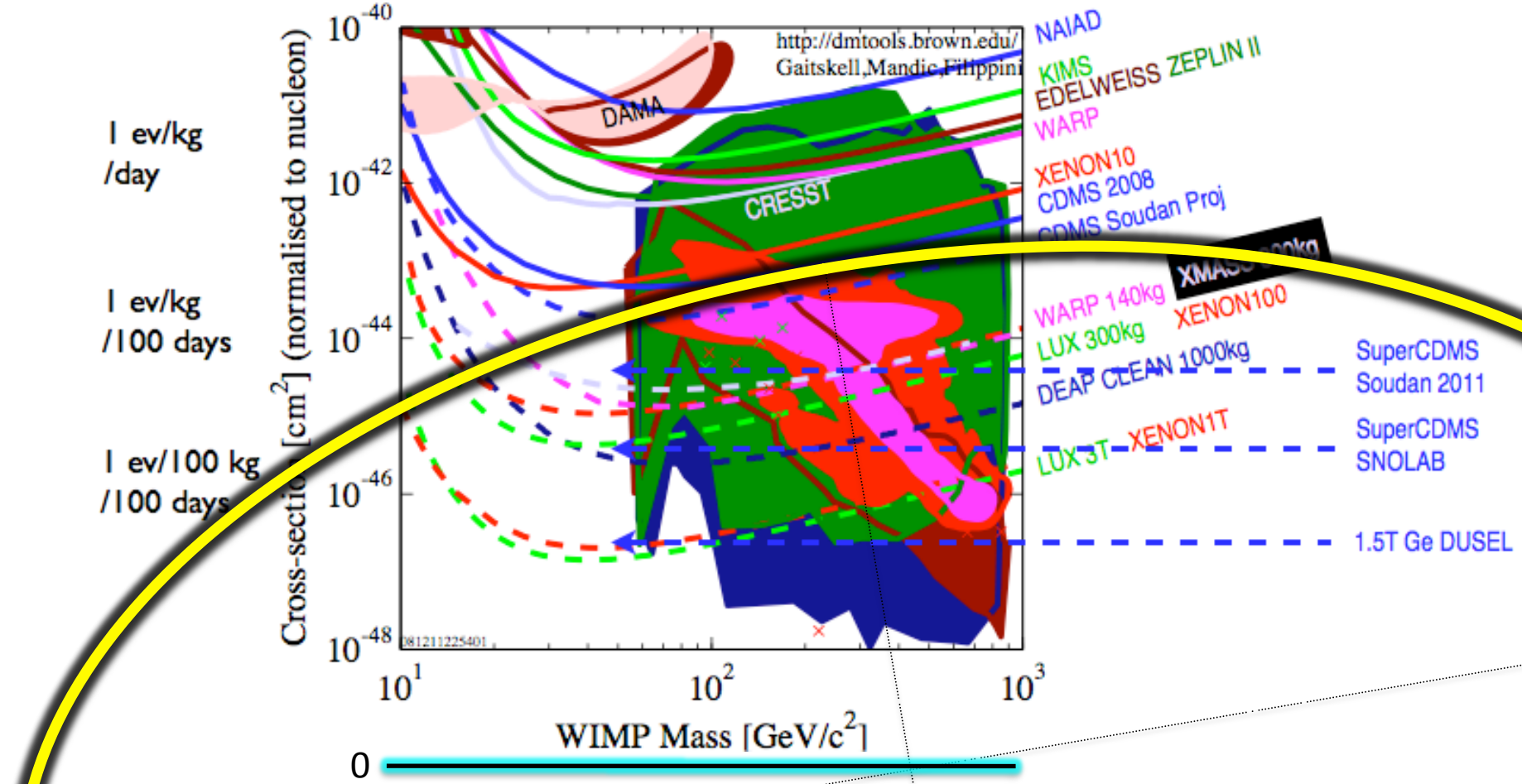

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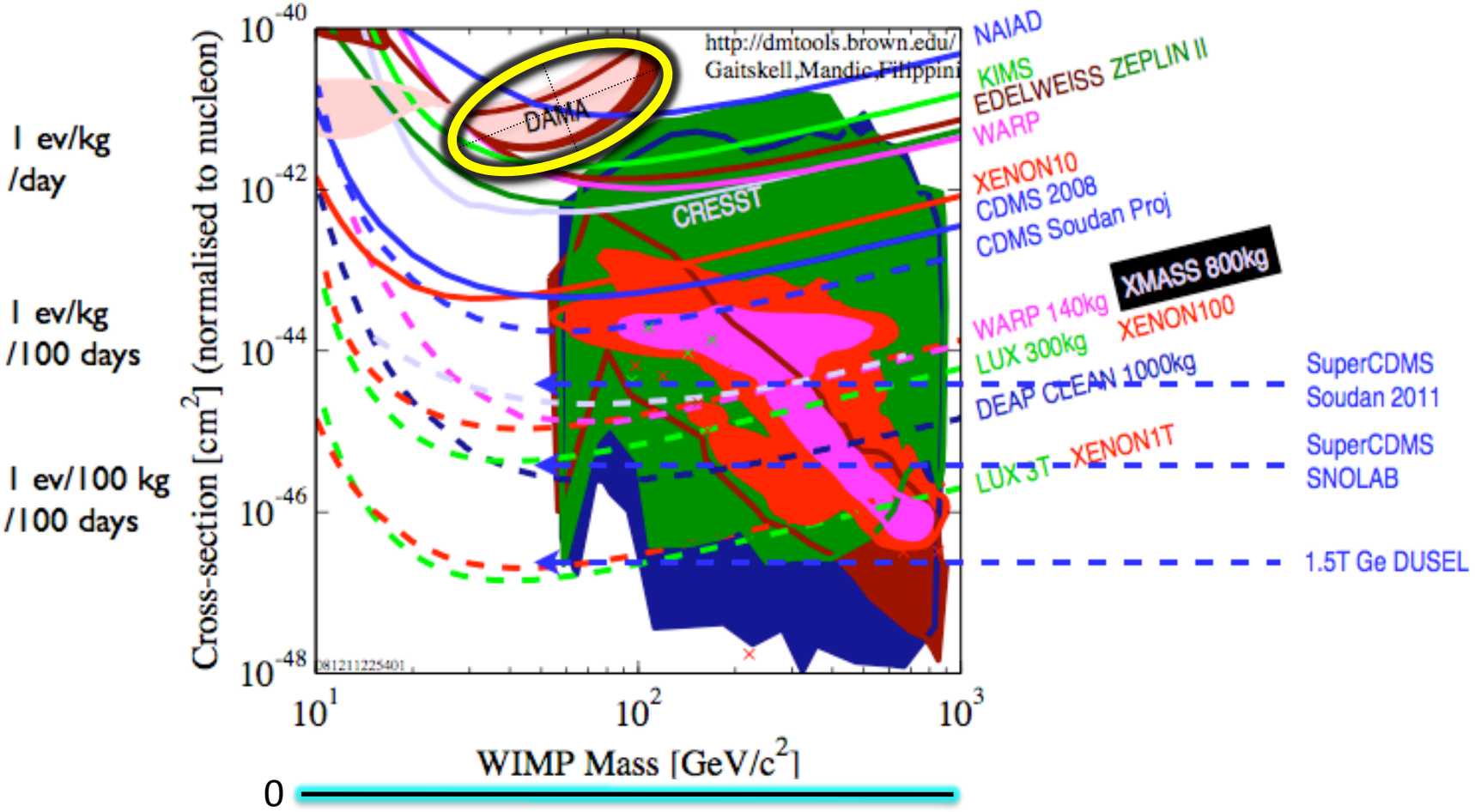
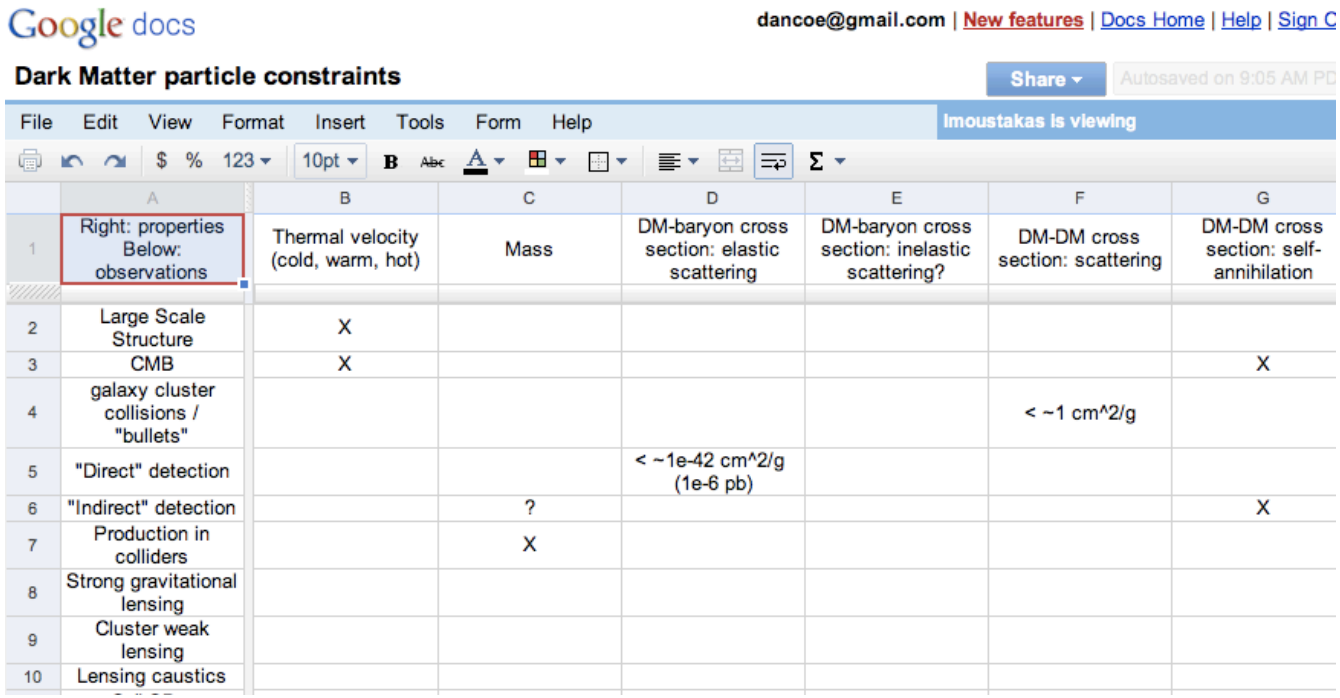


Can DM constraints be well approximated by Gaussian uncertainties?

- 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



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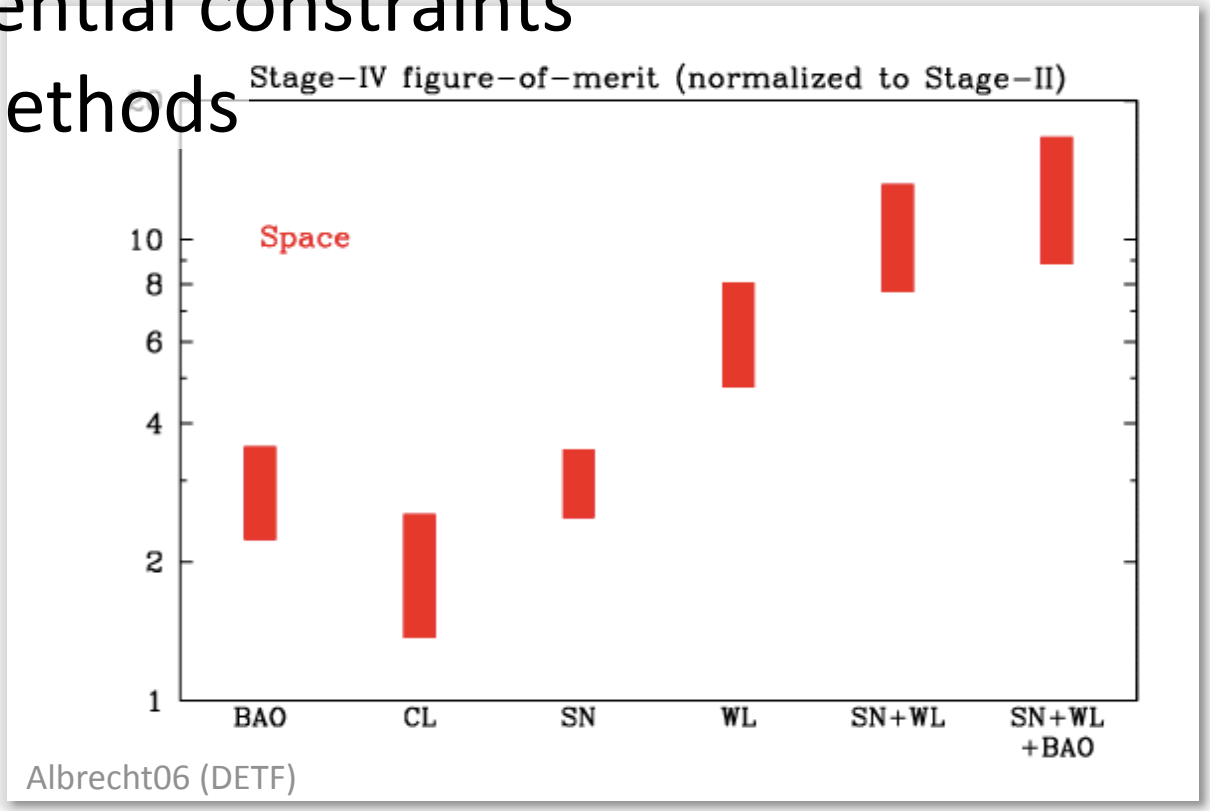
6	"Indirect" detection		?				X
7	Production in colliders		X				
8	Strong gravitational lensing						
9	Cluster weak lensing						
10	Lensing caustics						

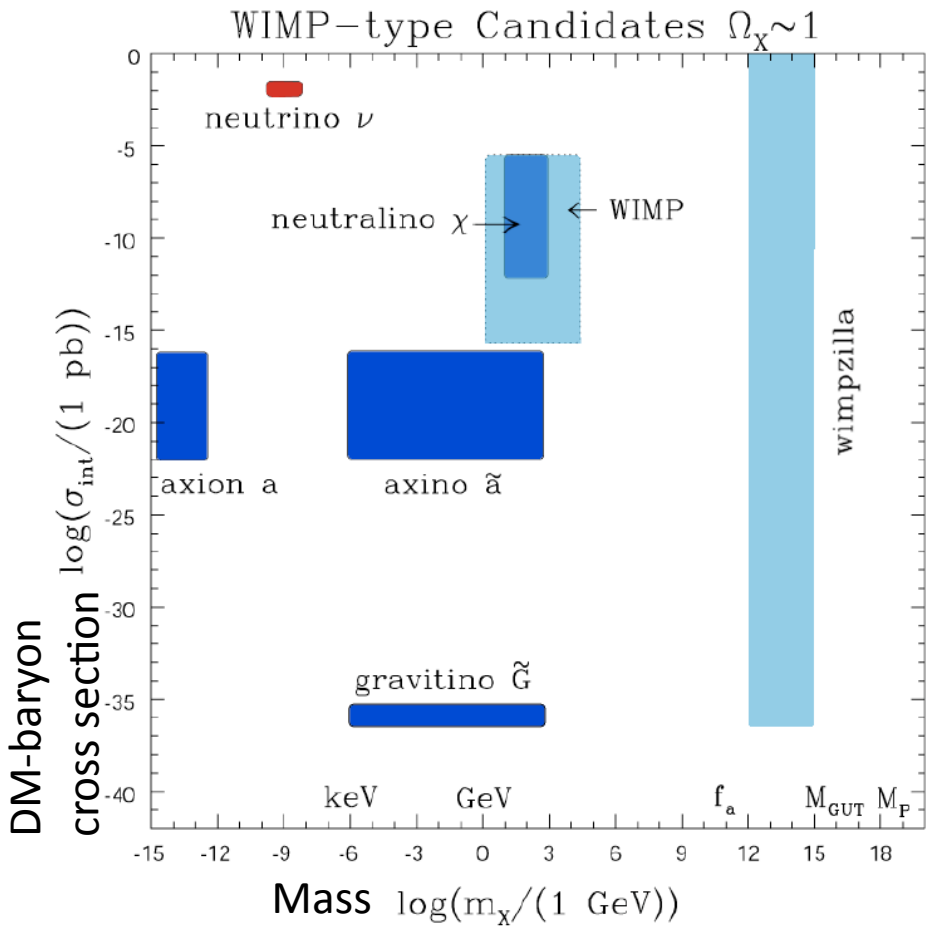
Dark Matter Task Force?

- Analogous to the Dark Energy Task Force
- Determine potential constraints from various methods
- Prioritize!



Albrecht06 (DETF)

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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properties

observations

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10	Lensing caustics						

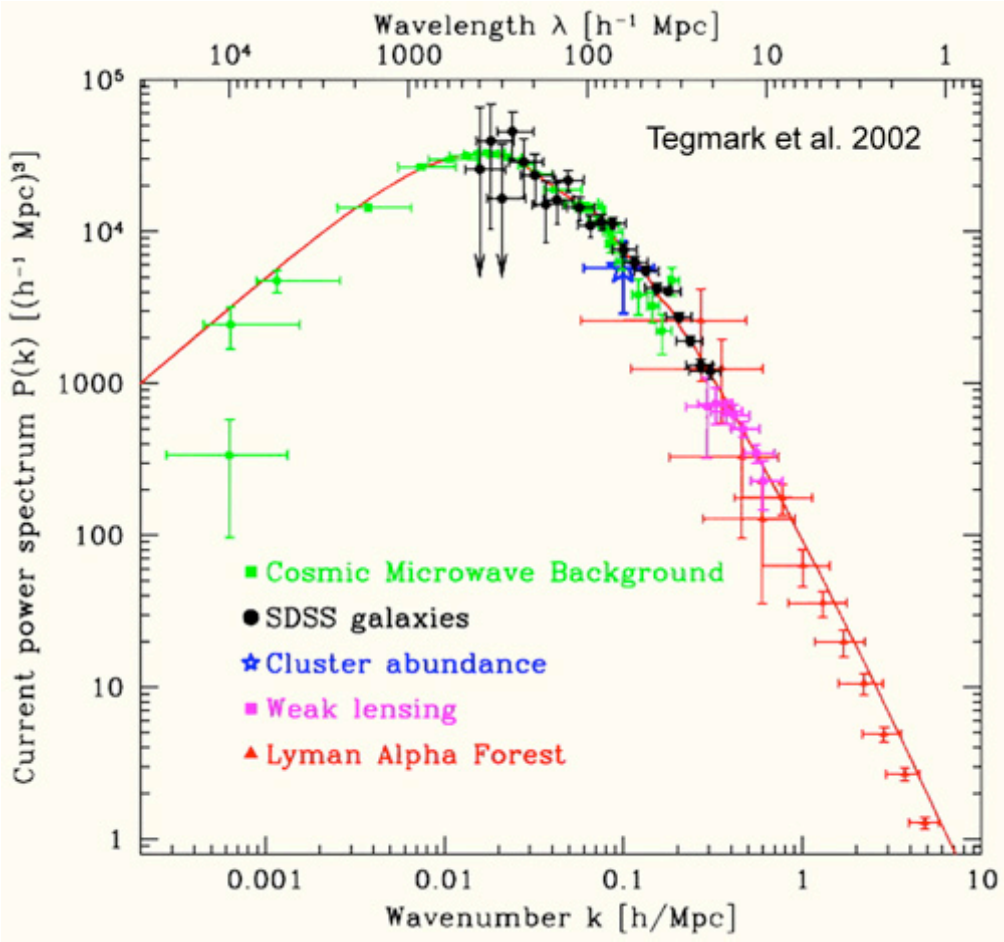
Exotic Dark Matter Theories

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

LensPerfect