Bullet-proof tests for indirect signals of dark matter

Tim Wiser

SITP, Stanford University

May 4
Pheno 2015

arXiv:1502.03824 (to appear in PRD)

with Peter Graham, Surjeet Rajendran, and Ken Van Tilburg

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Gravitational interactions $\implies$ lensing maps of DM

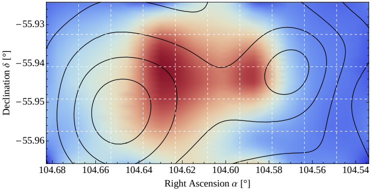
Merging Clusters

Lensing maps often reveal separation of DM and ICM:

Bullet Cluster

- Dramatic proof of collisionless particle DM
- ...but far away (1.5 Gpc) and small (3 arcmin)

Lensing: Clowe et al., X-ray: XMM-Newton



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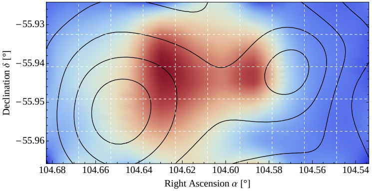

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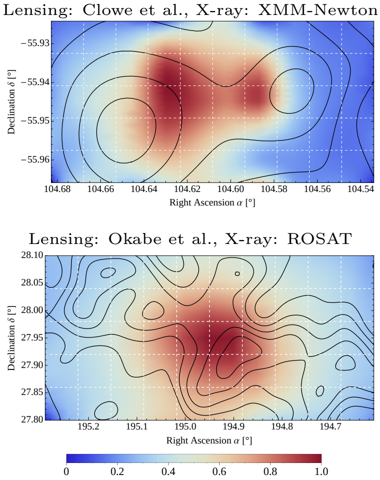

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How to apply lensing maps/merging clusters to indirect DM detection?

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Paper: 2 tests ("Method A" for decays; "Method B" for (e.g.) annihilations) and 1 boost ("Method C")

This talk: Method A (simplest, relevant for 3.55 keV)

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  - — Lensing measures surface mass density κ
  - — DM decay flux: $\frac{dN}{d\Omega} \propto \int_{\text{l.o.s.}} \rho \, dl = \kappa$
- Typical astrophysical alternatives distributed like the intracluster medium (ICM), not galaxies
  - — X-ray: ICM emission lines
  - — γ ray: cosmic ray–ICM scattering (not yet observed)

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Likelihood ratio test: favor DM over ICM when

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- x_i photons per bin, N total photons
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$$\Longrightarrow \Lambda = \frac{1}{2N^{3/2}} \sum_i \frac{(g_i - f_i)}{b_i^2} x_i^2$$

Power of Test

Expected value of Λ depends on spatial profile of excess

$$T = \sqrt{\sum_i \frac{(g_i - f_i)^2}{b_i}} \qquad \text{“discrimination factor”}$$

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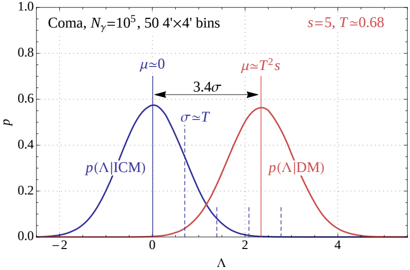
So a 5σ excess in Coma becomes a 3.4σ statement about origin, 3σ becomes 2σ, etc.



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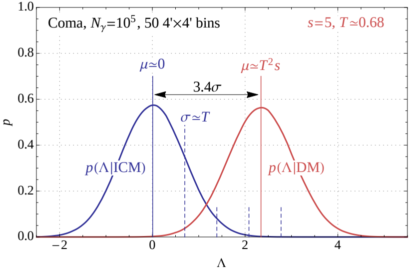

3.55 keV line is visible in Coma+2 others at $> 4\sigma$*... (Bulbul et al.)*

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  - Small enough to resolve DM structures
- Power of test (T) determined only by *geometry* of cluster (DM and ICM)
- Robust against uncertainties in spatial distributions
  - For Coma cluster, lensing uncertainty important only for excesses $\sim 15\sigma$

Conclusions

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  - Coma is close and moderately separated
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- Geometry of cluster determines $T = \frac{\text{test sigma}}{\text{excess sigma}}$
  - We calculated $T \gtrsim \frac{2}{3}$ for Bullet and Coma Clusters
- Can check 3.55 keV line in Coma with data on tape

A brief advertisement for the rest of our paper

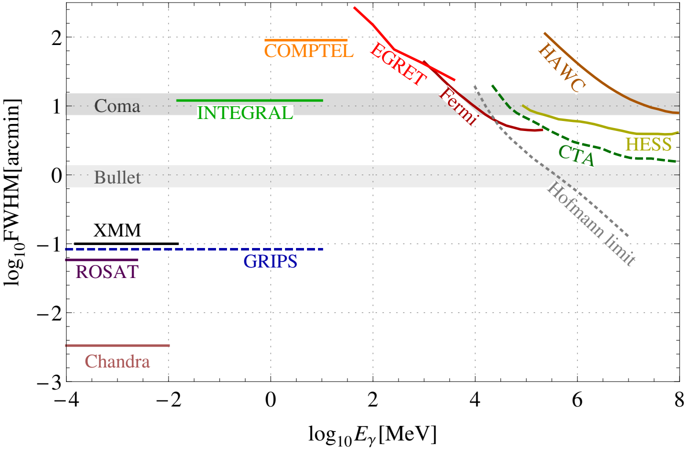
- Method B: Fit excess to linear combination of templates (good for annihilating DM; retains good sensitivity)
- Method C: Reweight to strengthen limits on DM (optimal reweighting gains about 20% in Coma)

Questions?

T values

		X-ray	gamma ray
DM decay signal	g_i	lensing map κ	
alternative	f_i	$n_{\rm ICM}^2$	$n_{\rm CR} n_{ICM}$
background	b_i	$n_{\rm ICM}^2$	uniform
	$\delta\theta$	T	
Bullet Cluster	$12''$	0.79	0.67
	$30''$	0.74	0.62
	$2.5'$	0.12	0.11
Coma Cluster	$4'$	0.68	0.59

Angular resolutions



Method B: Annihilating DM

DM annihilations are another important case, but the spatial distribution of the signal is unknown (not measured by lensing)

$$\frac{dN}{d\Omega} \propto \int_{\mathrm{l.o.s}} \rho^2 \, dl \neq f(\kappa)$$

Take some inspiration from simulations:

- Flux = smooth (NFW) + clumpy (substructure)
- Relative contribution unknown ($\frac{\text{clumpy}}{\text{smooth}} \sim 2$–$1000$)
- Relate spatial profiles of each to surface mass density using simulations
- Extrapolate relation to merging clusters

Then *fit* the profile of observed excess to linear combination of smooth + clumpy + ICM (our "Method B")

Method B: Results for Coma