Galaxy clusters for Dark Matter indirect detection: stacking vs. single-source

C. Combet, LPSC

D. Maurin (LPSC)
E. Nezri (LAM)
E. Pointecouteau (IRAP)
J. Hinton & R. White (UoL, UK)

Charbonnier, Combet, Maurin, CPC 183, 656, arXiv:1201.4728

Combet et al., PRD 85, 063517, arXiv:1203:1164

Nezri et al., arXiv:1203.1165

Maurin et al., arXiv:1203:1166

Gamma-ray flux from DM annihilation

The γ-ray flux is given by

$$\frac{d\Phi}{dE}(E,\phi,\theta,\Delta\Omega) = \frac{d\Phi^{\rm pp}}{dE}(E) \times \Phi^{\rm astro}(\phi,\theta,\Delta\Omega)$$

Particle physics

Astrophysics

Weakly Interacting Massive Particles

m_{WIMP} ~ 100 GeV – 100 TeV

$$\frac{d\Phi^{\rm pp}}{dE} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m^2_{\rm WIMP}} \cdot \sum_f \frac{dN^f}{dE} B_f$$

$$\text{J} \equiv \Phi^{\rm astro} = \int_{\Delta\Omega}\int_0^{l_{\rm max}} \rho^2(l,\Omega)\, dl\, d\Omega$$

Detection or non-detection

→ Need $\Phi^{\rm astro}$ to put any constraints on DM candidate

Gamma-ray flux from DM decay

The γ-ray flux is given by

$$\frac{d\Phi}{dE}(E,\phi,\theta,\Delta\Omega) = \frac{d\Phi^{\rm pp}}{dE}(E) \times \Phi^{\rm astro}(\phi,\theta,\Delta\Omega)$$

Particle physics

Astrophysics

Weakly Interacting Massive Particles

m_{WIMP} ~ 100 GeV – 100 TeV

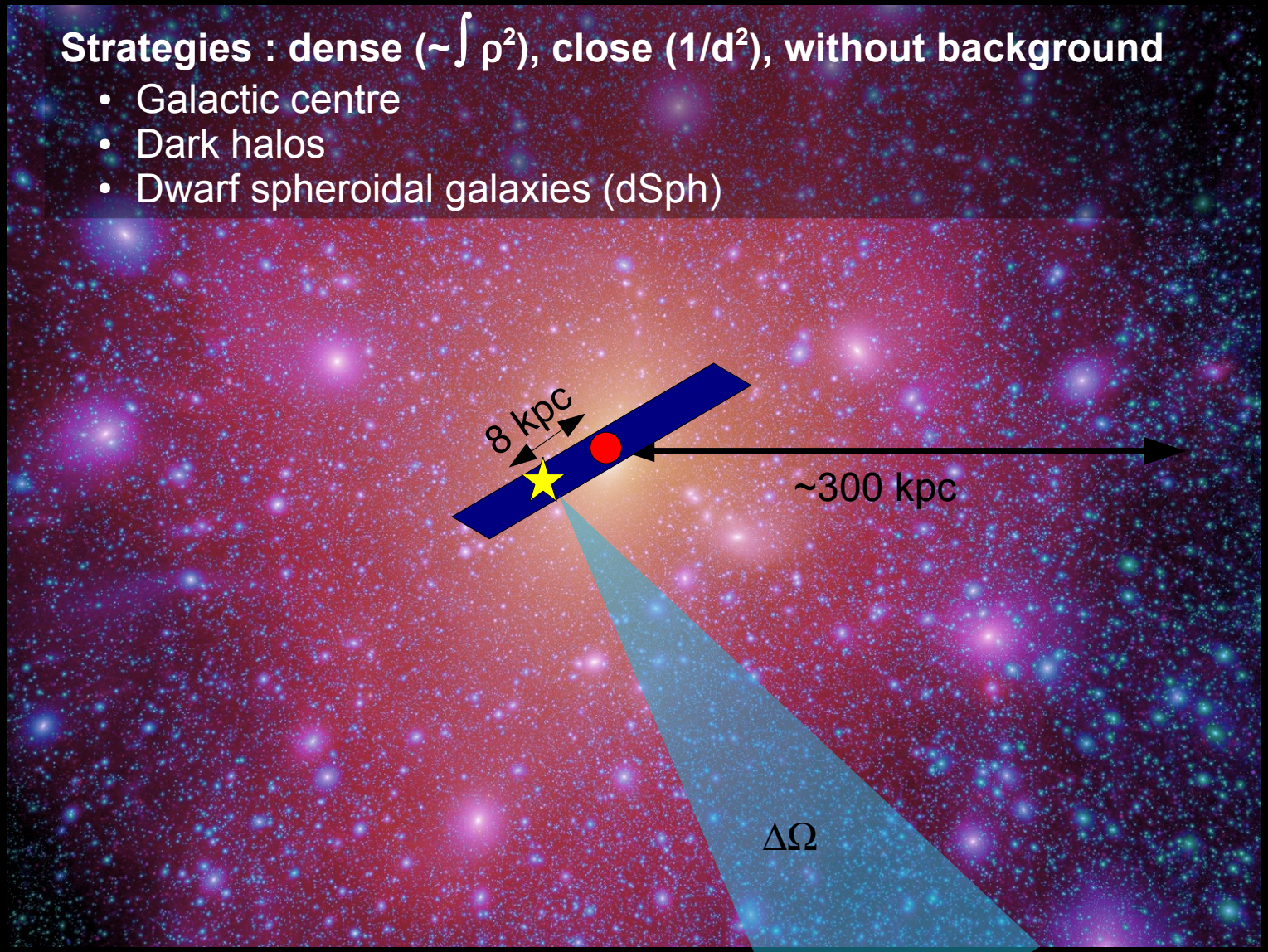
$$\frac{d\Phi^{PP}}{dE} = \frac{2}{4\pi}\frac{\Gamma}{m^2_{\rm WIMP}}\delta\left(1-\frac{2E}{m_{\rm WIMP}}\right) \qquad D \equiv \Phi^{\rm astro} = \int_{\Delta\Omega}\int_0^{l_{\rm max}} \rho(l,\Omega)\,dl\,d\Omega$$

Detection or non-detection

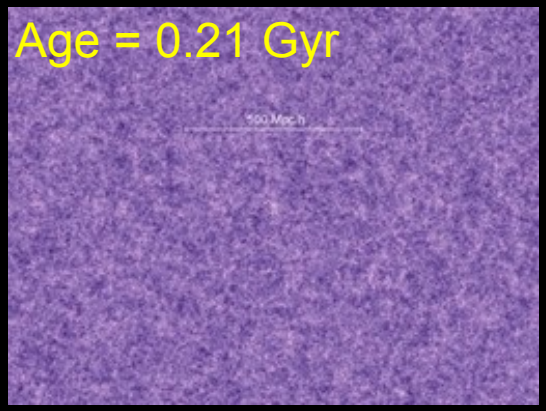
→ Need $\Phi^{\rm astro}$ to put any constraints on DM candidate

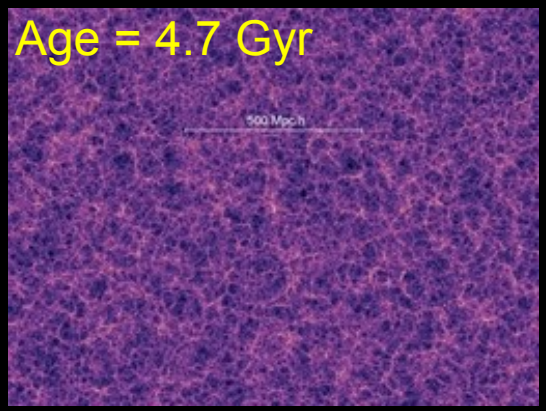
Where to look ? 1. Galactic scale

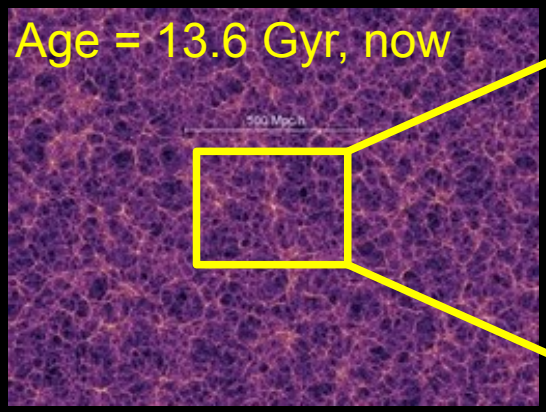
Aquarius – Springel et al (2008) – MW-like halo - ΛCDM



2. And further: galaxy clusters





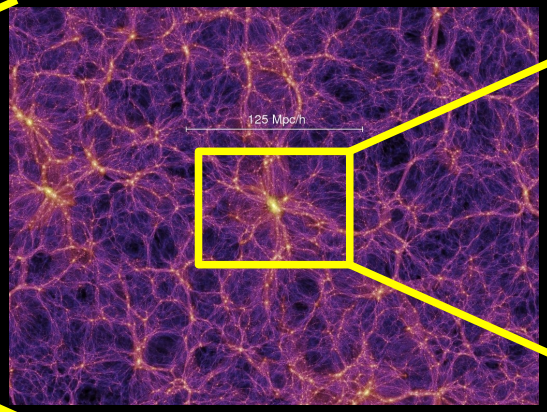


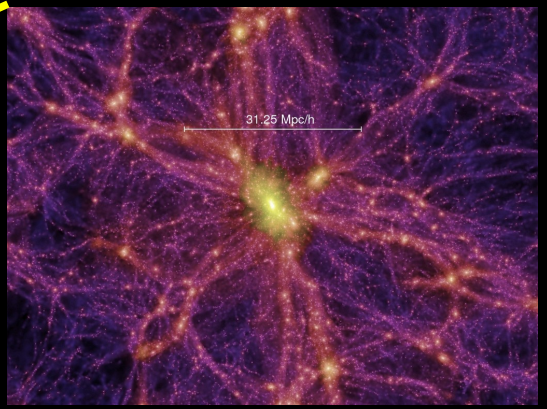
t

Galaxy clusters have a huge DM content ($10^{14} - 10^{15}$ Msun)
→ interesting for indirect detection

But CR-induced emission could be a strong contaminant

Spectrum, signal spatial distribution and associated multi-λ emissions could help distinguish CR from DM (e.g. *Jeltema, Kehayias & Profumo 2009, Maurin et al. 2012*)





Millenium run – Springel et al. (2005)

DM searches in galaxy clusters

- So far, non-detections only:

Observations

→ MAGIC: *Aleksic et al. (2010)* – Perseus

→ HESS: *Abramowski et al (2012)* – Fornax

→ Fermi: *Yuan et al. (2010), Ackermann et al. (2010), Huang et al. (2012), Zimmer et al. (2012), Han et al. (2012)*

- Modeling:

→ Theory, sims.: *Jeltema et al. (2009*), *Pzinke et al. (2011), Cuesta et al. (2011), Sanchez-Conde et al. (2011)*

- X-ray catalogue: best up until recently, HIFLUGCS ~ 100 objects

Best targets: Coma, Fornax, AWM7, Virgo...
No detection → Constraints on cross-section (annihil.) or lifetime (decay)

Since 2011, MCXC meta-catalogue: ~ 1700 objects → "statistics" become possible

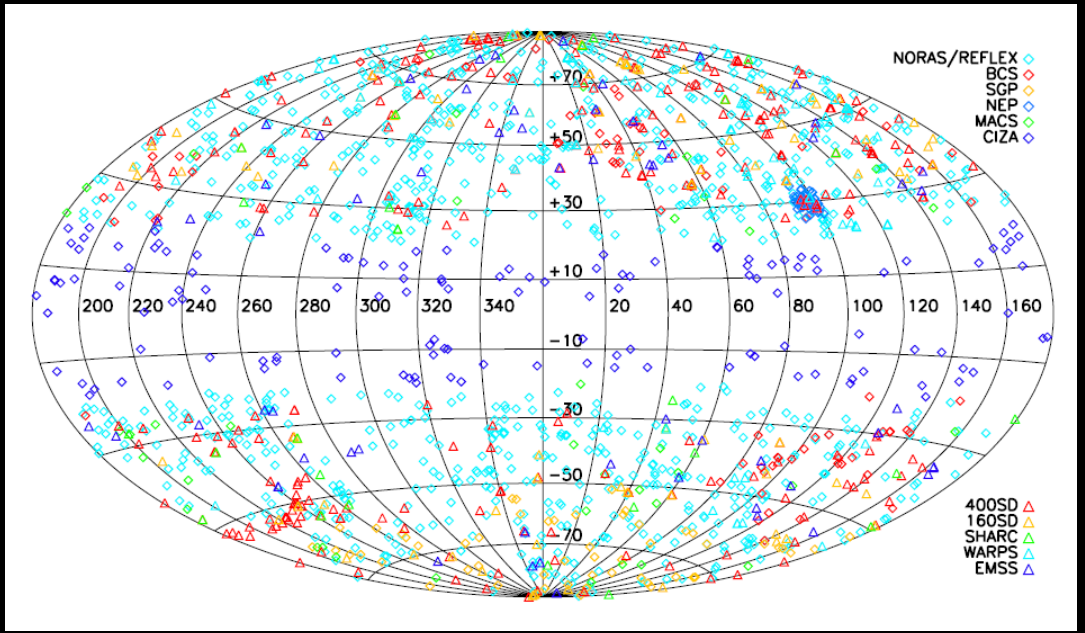
MCXC : Piffaretti et al. (2011)

Catalogue Sub-catalogues	No. of clusters Input	No. of clusters MCXC
NORAS/REFLEX	889	878
NORAS	445	437
REFLEX	444	441
400SD	266	257
400SD_SER	242	237
400SD_NONSER	24	20
160SD	199	90
BCS	312	80
BCS	205	47
eBCS	107	33
SGP	157	55
SHARC	69	29
SHARC_BRIGHT	37	14
SHARC_SOUTH	32	15
WARPS	159	78
WARPS	34	11
WARPSII	125	67
NEP	63	48
MACS	51	39
MACS_MJFV	23	18
MACS_BRIGHT	22	15
MACS_DIST	6	6
CIZA	130	128
CIZAI	73	72
CIZAII	57	56
EMSS	102	61
EMSS_1994	81	47
EMSS_2004	21	14
TOTAL	2397	1743

Meta-catalogue of 1743 X-ray detected clusters

- Most data from ROSAT All Sky Survey
- Extraction and homogenisation
- Provides R_{500} and M_{500} for all objects

For the first time, number of objects is high enough to start studying the statistics

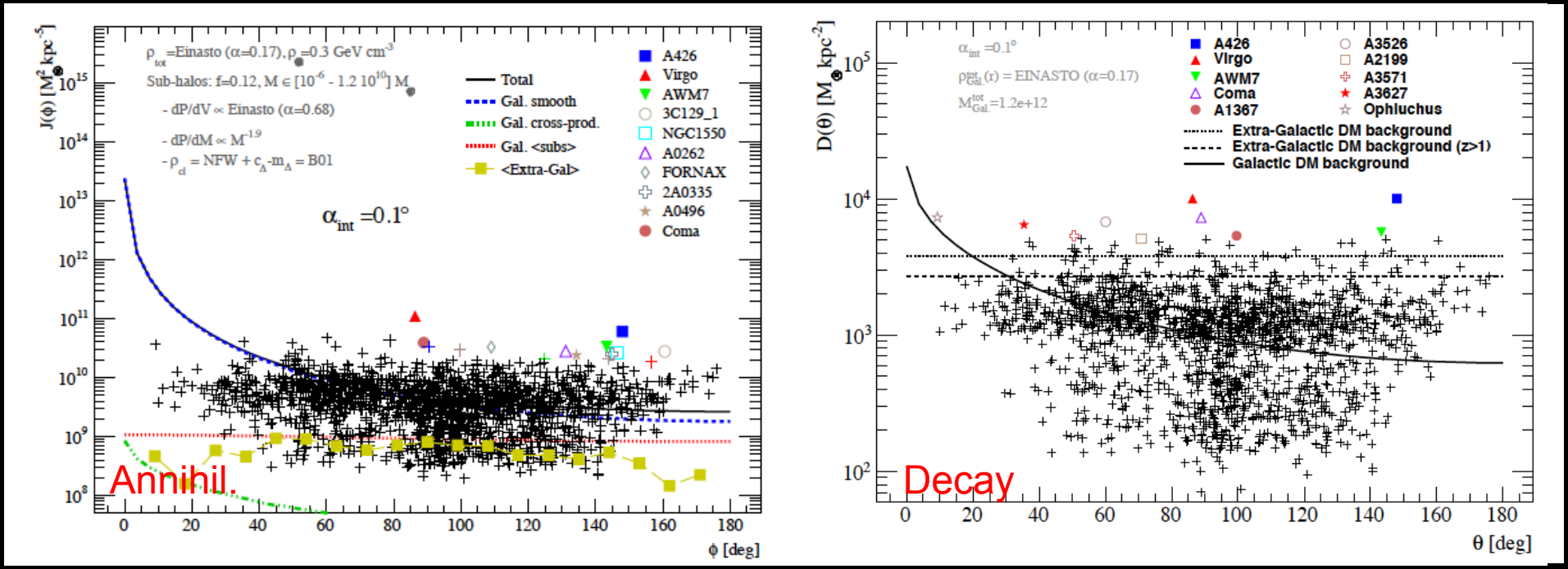


Modeling annihilation/decay - Φ^{astro}

- Cluster DM profile poorly constrained
- Assume NFW profile for all MCXC clusters $\rho(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$
- Calculate normalisation and scale radius from R_{500} and M_{500}
- Compute J or D for all MCXC clusters

Modeling annihilation/decay - Φ^{astro}

- Cluster DM profile poorly constrained
- Assume NFW profile for all MCXC clusters $\rho(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$
- Calculate normalisation and scale radius from R_{500} and M_{500}
- Compute J or D for all MCXC clusters



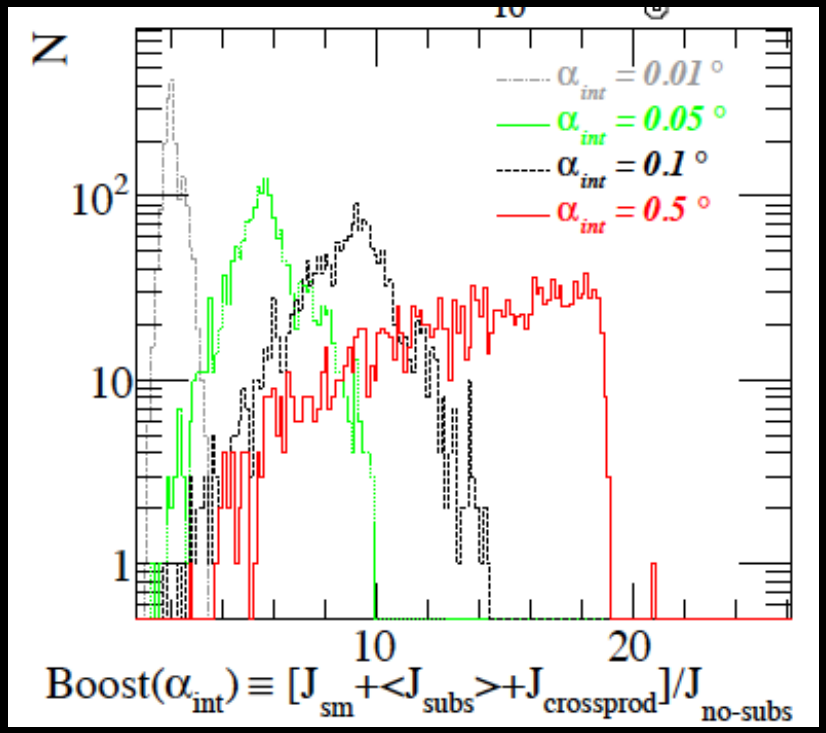
Can stacking help?

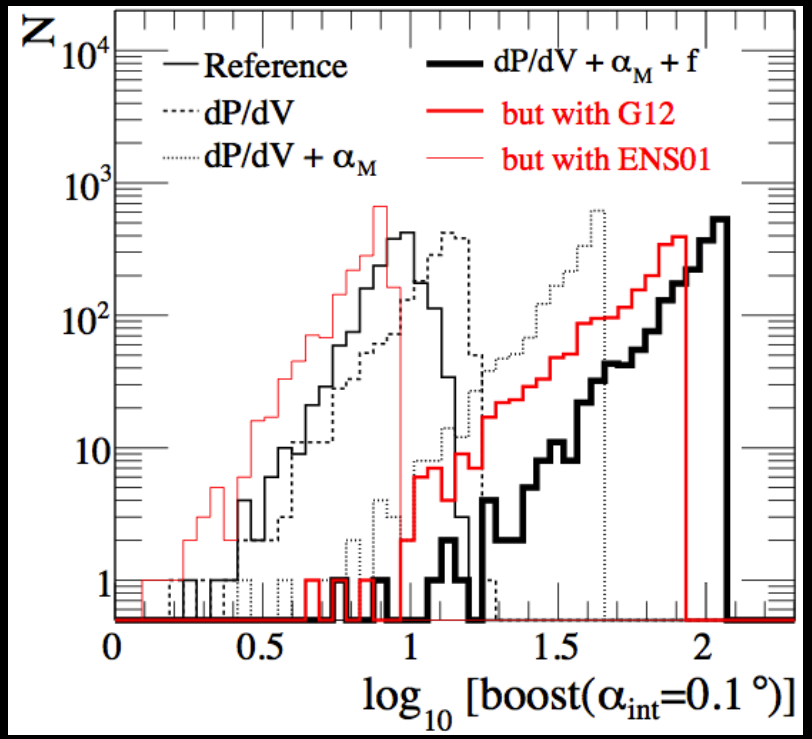
Annihilation: sub-structures

- N-body sims → spatial distribution of substructures dP/dV, mass distrib. dP/dM
- Boost from substructures: $\int \rho^2 \neq \left(\int \rho\right)^2$ (no boost for decay)
- Boost depends on integration angle, mass range for the clumps, dP/dV, dP/dM

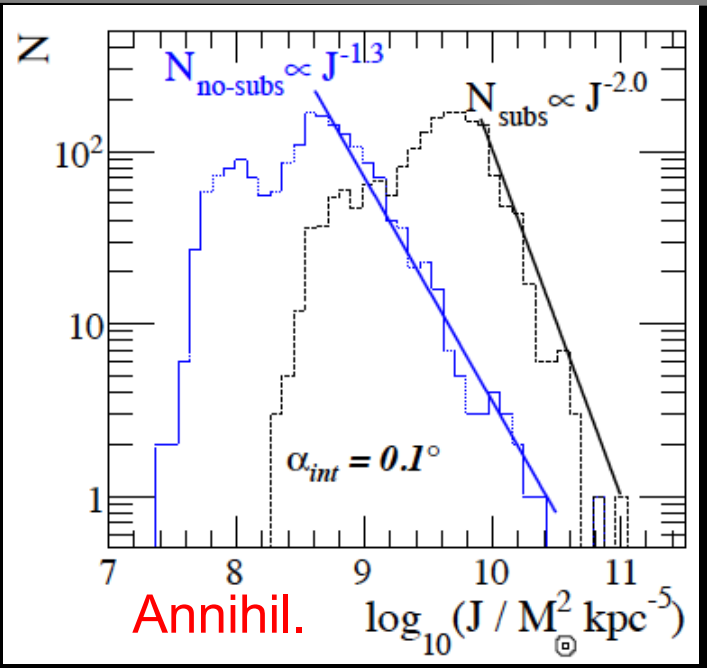
  → large uncertainties

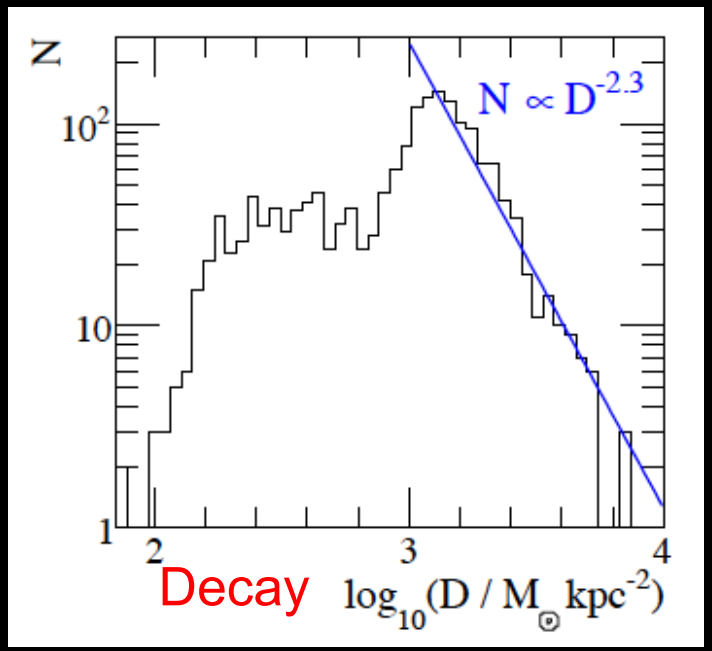
  → Working with conservative parameters





Stacking potentially useful?





Annihilation:

- If no clumps → stacking is pointless
- With substructures → stacking could be interesting as

$$N \propto J^{-2}$$

Decay: $N \propto D^{-2.3}$

- Stacking looks promising

But need consider instrumental response
Answer depends on type of detector

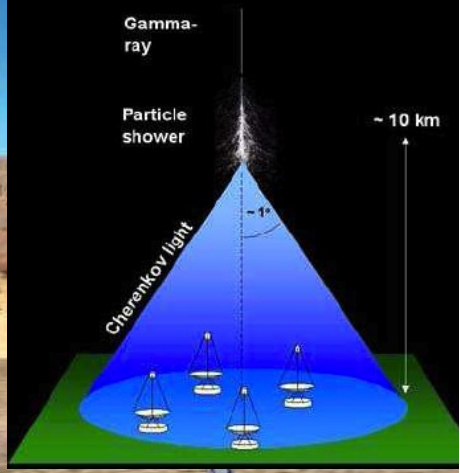
Fermi and CTA

Fermi

- Space-borne
- Energy range: 30 MeV – 300 GeV
- Resolution: 1° – 0.1°
- Fullsky

CTA – Cherenkov Telescope Array

- Ground based
- Energy range: 100 GeV → 100 TeV
- Resolution: 0.2° – 0.02°
- CR contamination → background limited



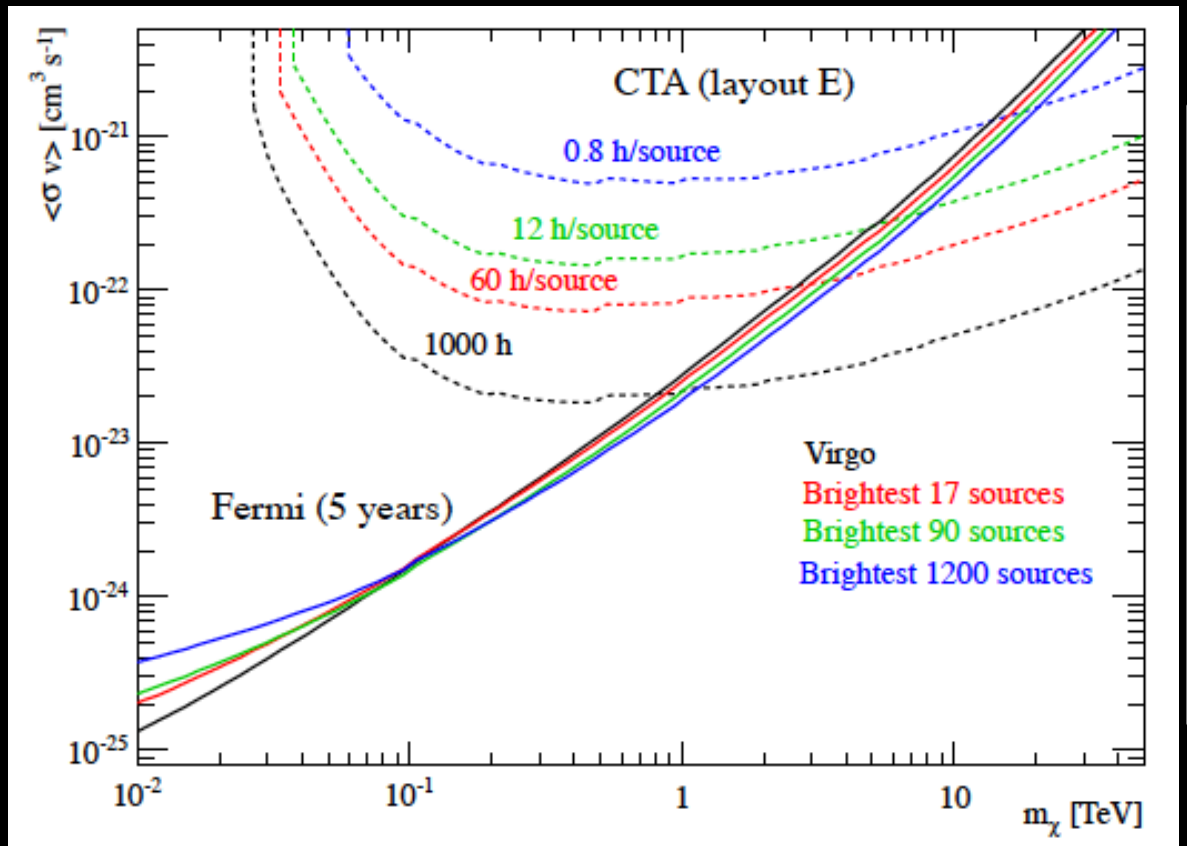
Stacking if annihilation

$$\langle \sigma v \rangle \propto m_\chi^2 \cdot J(\alpha_{\rm int}) \cdot \underline{\rm Sensib}(E, \alpha_{\rm int}) \cdot \frac{dN^{pp}}{dE}$$

From instrument characteristics

Choose spectrum from PP

→ Stack sources according to S/N consideration (PSF, integration angle)



- Stacking worsens prospects for CTA as need to adapt total observation time to each source
- At low masses, Fermi-LAT has poor resolution → background-limited. Stacking does not help.
- Above 0.1 TeV, a slight improvement can be achieved by stacking (x 1.7)

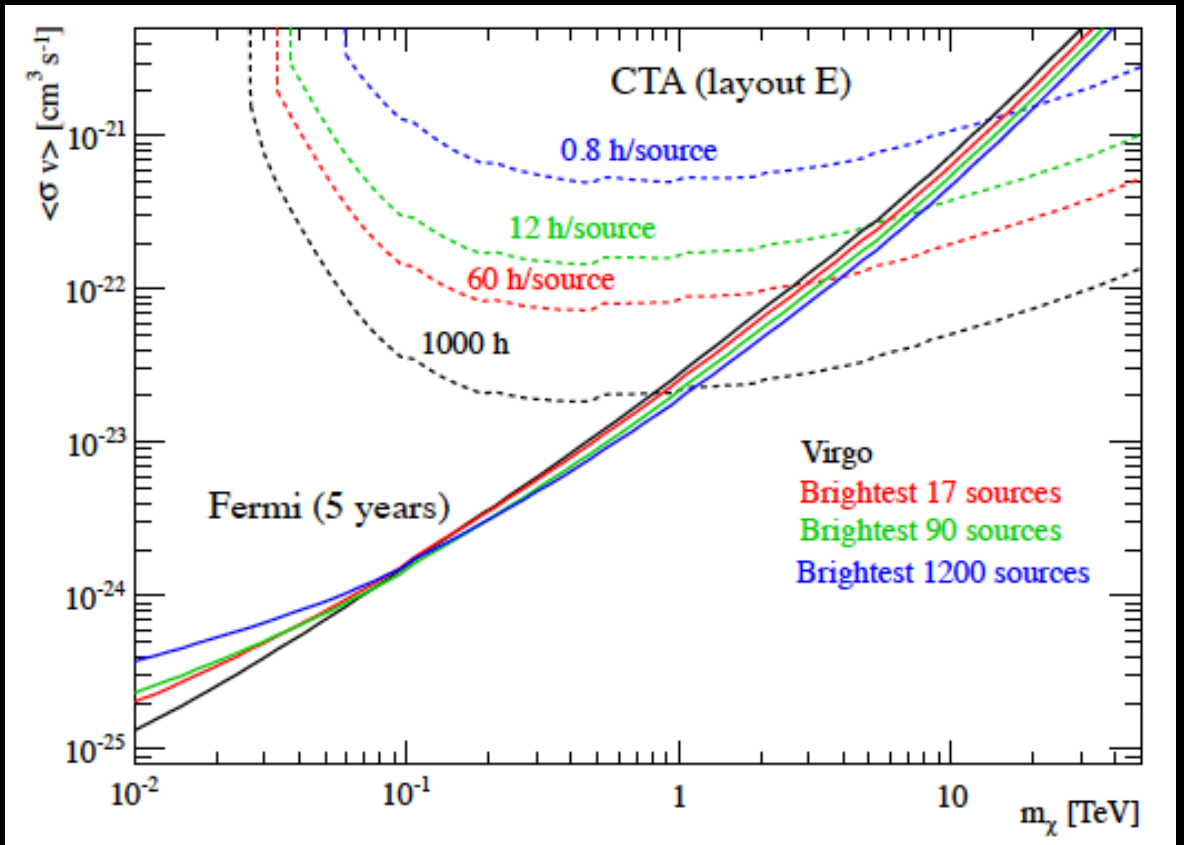
Stacking if annihilation

$$\langle \sigma v \rangle \propto m_\chi^2 \cdot J(\alpha_{\rm int}) \cdot \underline{\rm Sensib}(E, \alpha_{\rm int}) \cdot \frac{dN^{pp}}{dE}$$

From instrument characteristics

Choose spectrum from PP

→ Stack sources according to S/N consideration (PSF, integration angle)



- Boost from sub-structures can lower the limit
- $\langle\sigma v\rangle \sim 10^{-26}$ cm^3/s may be within reach... (e.g. Huang et al (2012))

Conclusions

- Galaxy clusters are interesting DM indirect detection targets
  Alternative to dSph (see Charbonnier et al., 2011)
- Individual DM profiles are poorly-constrained
  → Stacking is a way to wash out uncertainties
- Annihilation: Log J – log N, stacking looks promising but

  → For pointed observations (CTA), single-object observation is a better strategy

  → It is marginally beneficial for all-sky observatories (e.g. Fermi), x 1.7
- Decay: initial study shows that stacking should yield a factor ≥ 5 improvement
- Stacking also investigated as discriminant between DM and cosmic ray-induced gamma-ray emission