Looking Under a Better Lamppost:

MeV Scale Dark Matter Candidates

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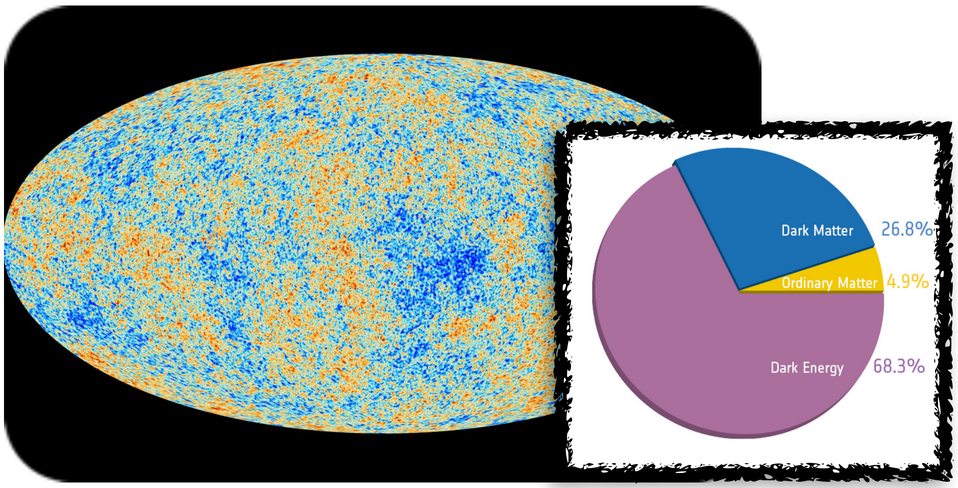
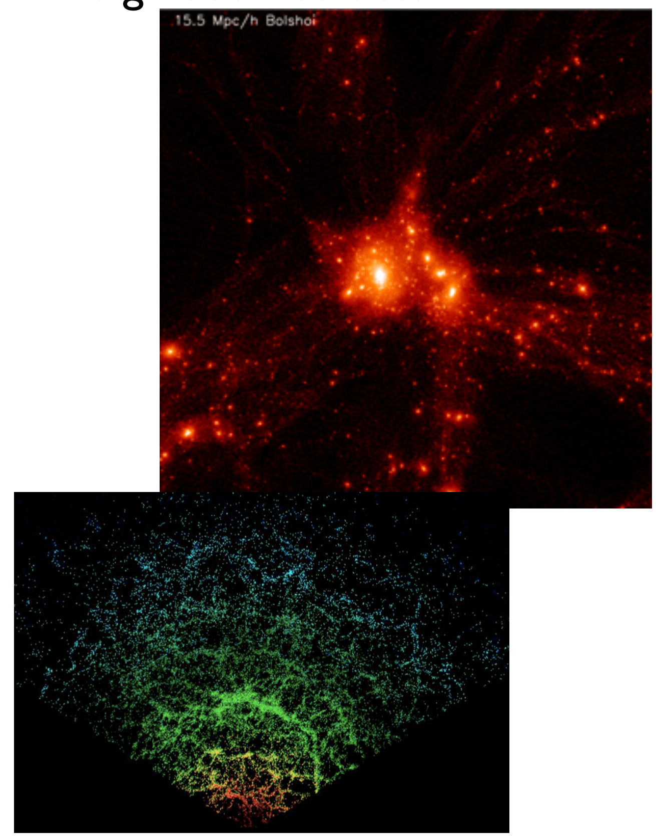
AMEGO Splinter Session
AAS 2020

What Do We Know about Dark Matter?

Cosmic Microwave Background



Large Scale Structure

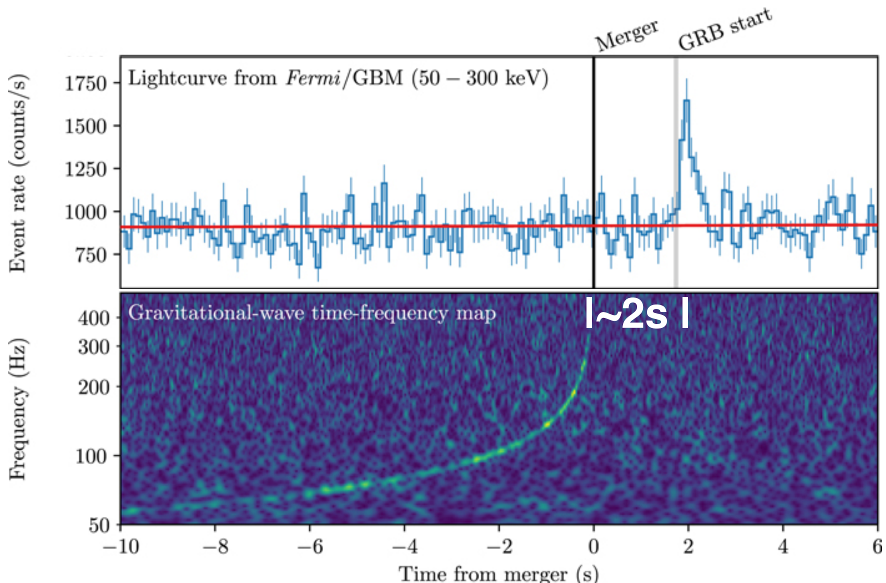


Lensing/The Bullet Cluster

Planck Collaboration, 2013; SubbaRao et al. (2008); J. Primack et al.,2011; NASA, APOD, 2006 August 24, J. A. Tyson et al., Astrophys.J.498:L107,1998

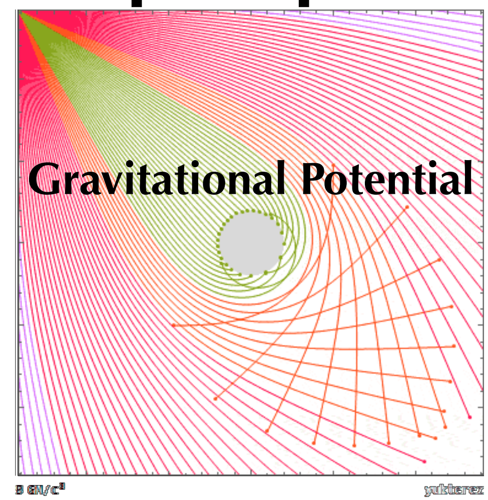
Modified Gravity?

GW170817/GRB170817A



ApJ, 848:L13, 2017

Test of Weak Equivalence principle



Boran et al., PRD 97, 041501 (2018),

Gravitons and photons travel in space-time in the same way

***SN1987a found the same thing for neutrinos and photons**

Dark Matter Candidates

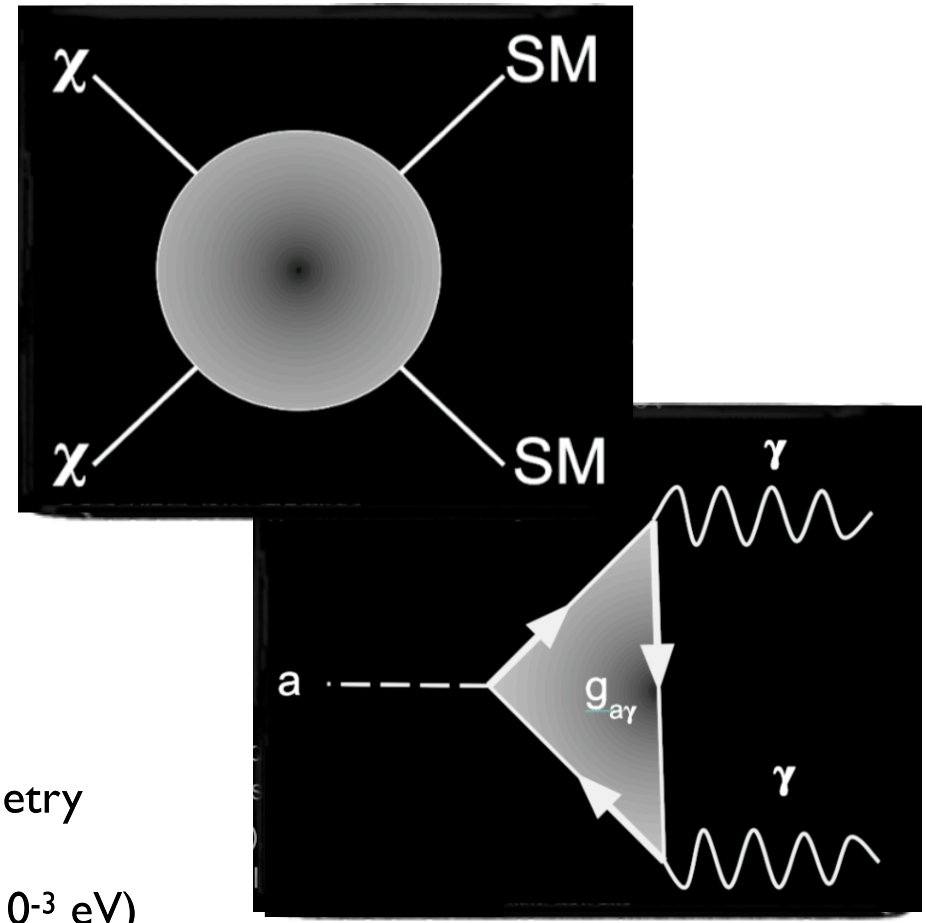
Weakly Interacting Massive Particles (WIMPs)

Lower bounds:

- ~10 GeV if mediated by Weak force (Lee-Weinberg bound)
- ~few MeV limited # neutrinos - thermal relic (Ho & Scherrer)

Upper bounds:

- ~120 TeV (Unitarity bound)

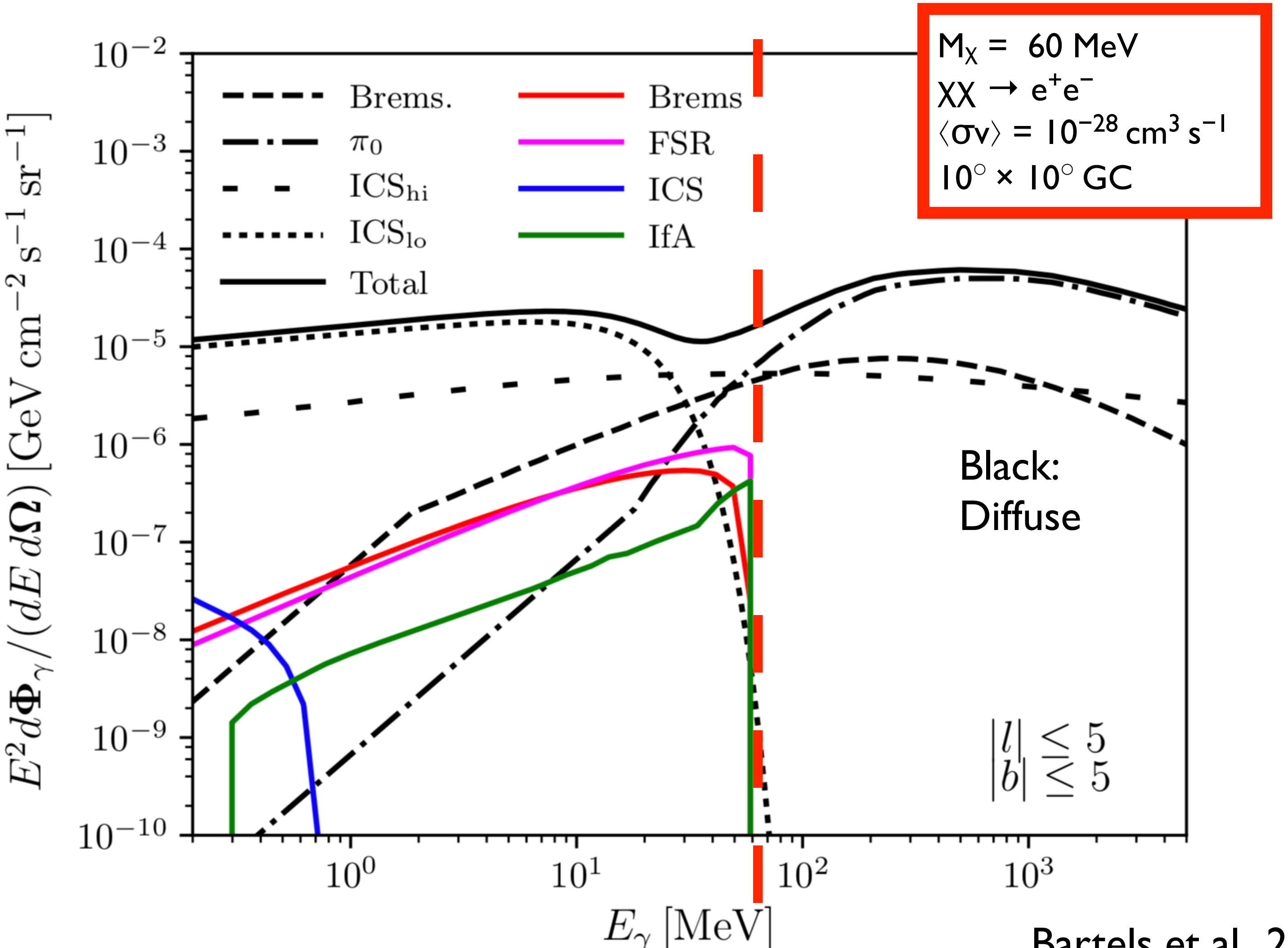


Weakly Interacting Sub-eV Particles (WISPs)

Axion-like particles (WISPs) - any U(1) symmetry breaking

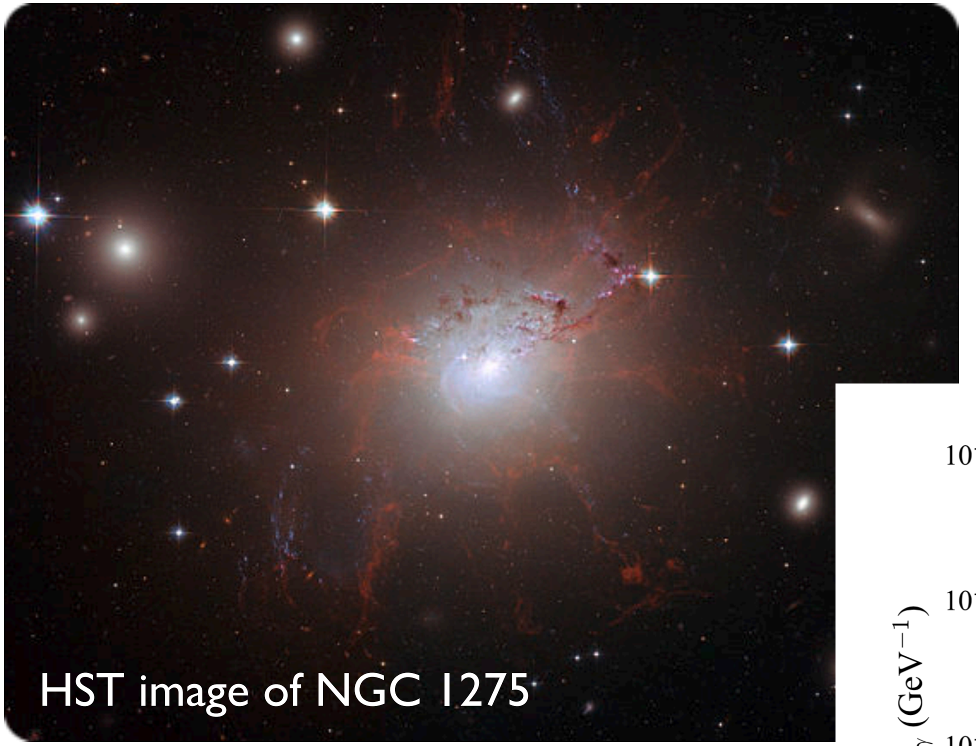
Bounds: 10^{-3} neV to 10^{-3} eV (Axions: 10^{-5} to 10^{-3} eV)

What do you get from MeV WIMP annihilation?



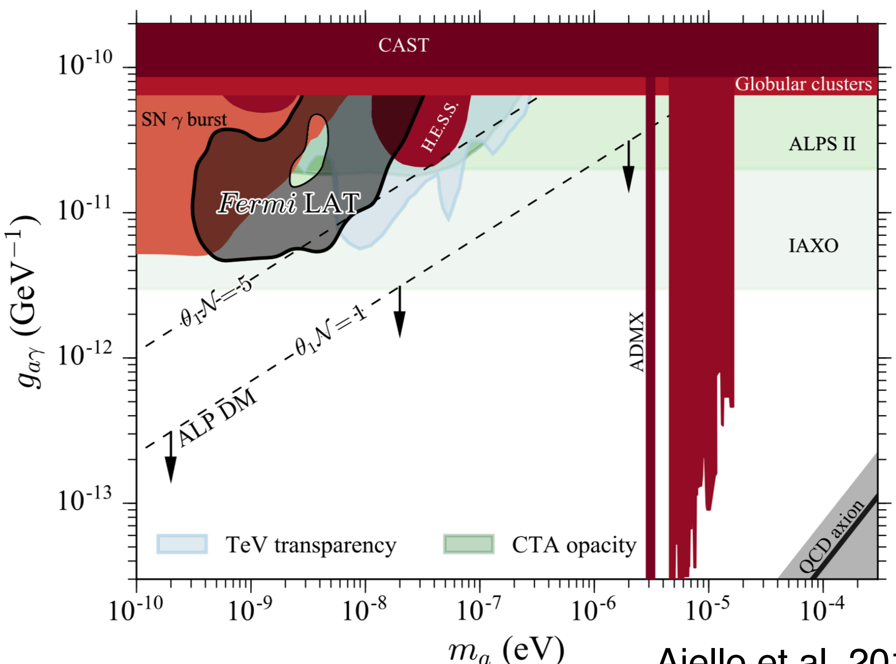
Bartels et al., 2017

How do you observe WISPs in the MeV regime?



- Central radio galaxy of Perseus cluster
- Bright γ-ray emitter
- Central B field of cluster: 25 μG

Taylor et al. 2006



Ajello et al. 2016

Observational Requirements

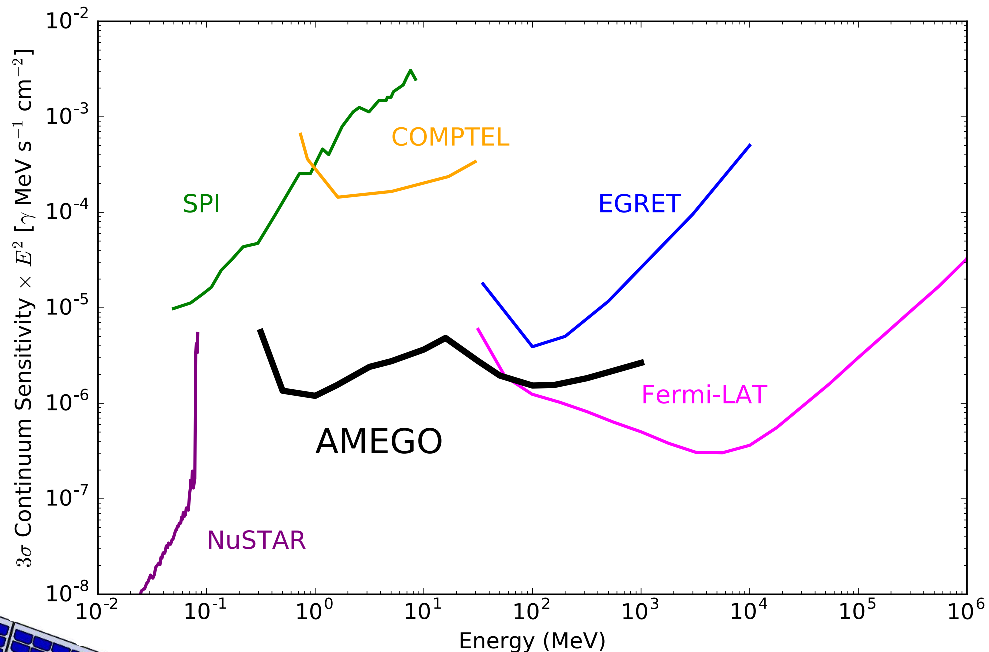
Weakly Interacting Massive Particles (WIMPs)

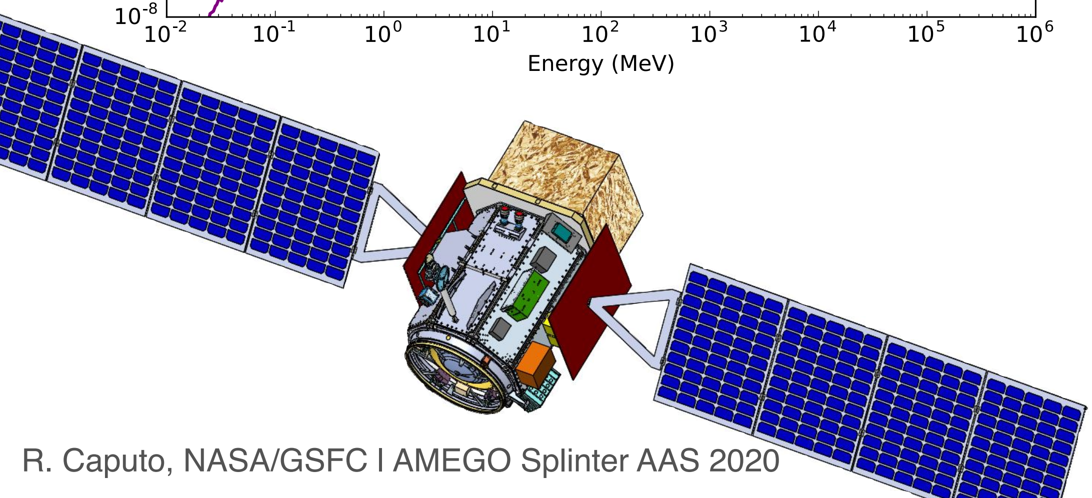
- Wide Field-of-View and Exposure time similar to LAT
- High angular resolution (<3°) at 1 GeV at Galactic Center

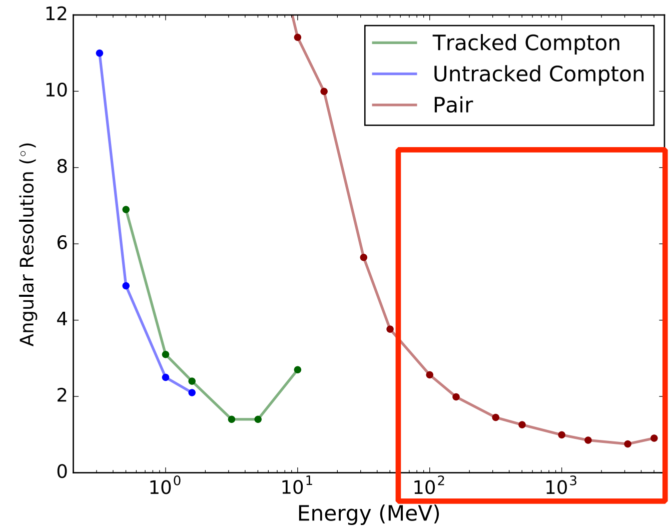
Axion-like and Weakly Interacting Sub-eV Particles (WISPs)

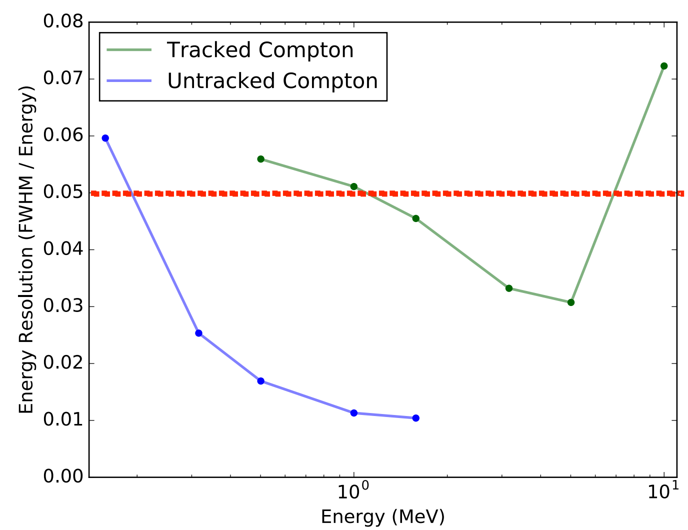
- Energy resolution of <5% from 1-100 MeV
- Wide Field-of-View for transient searches

AMEGO Performance

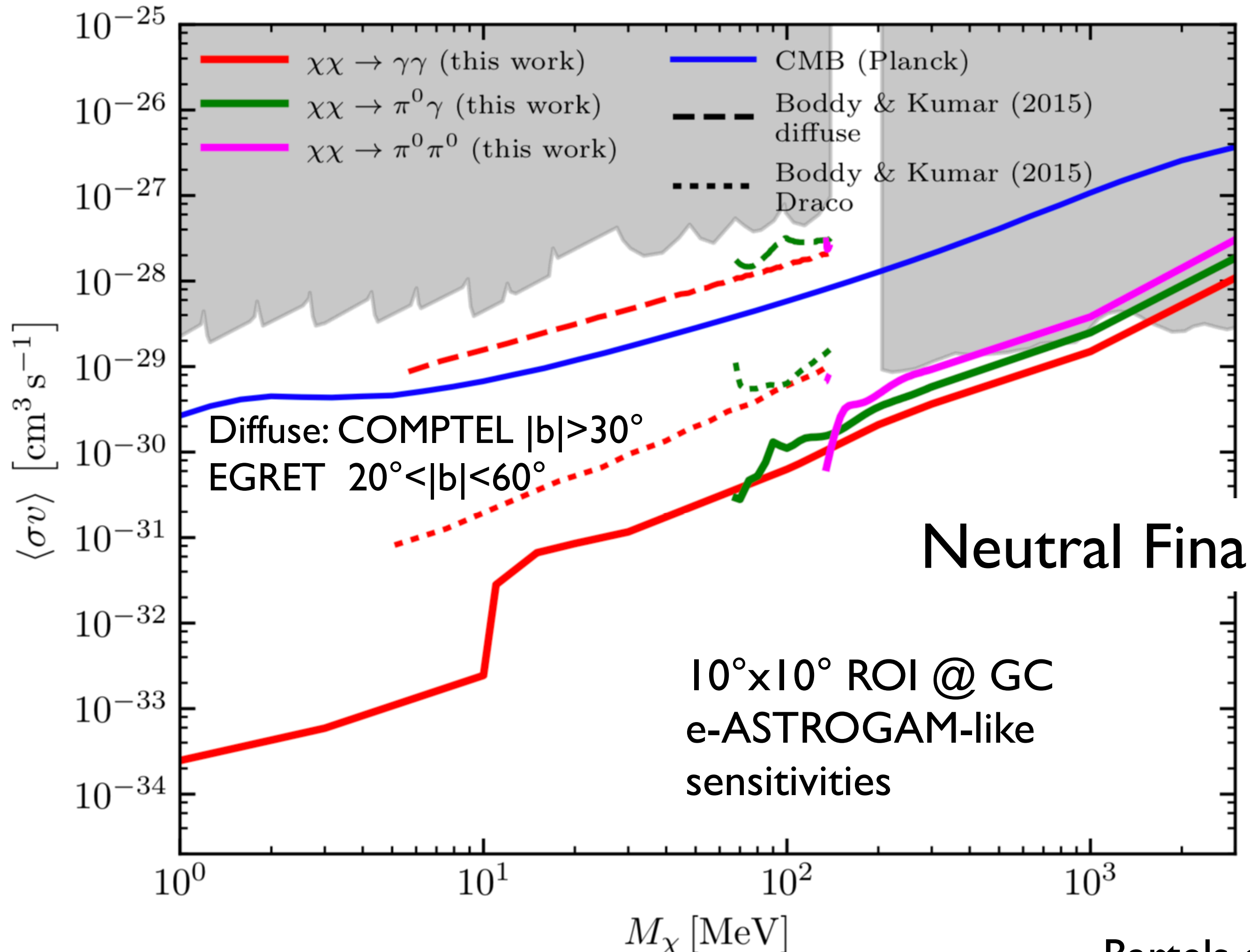








WIMP Annihilation Sensitivity

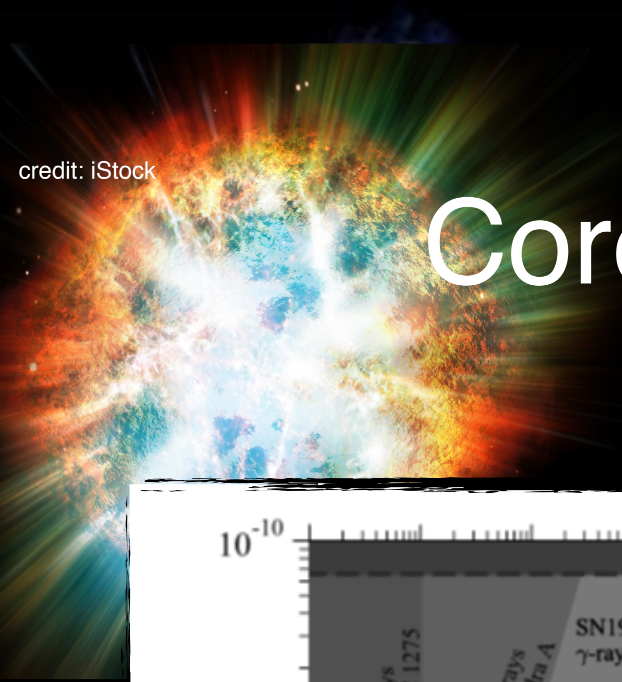


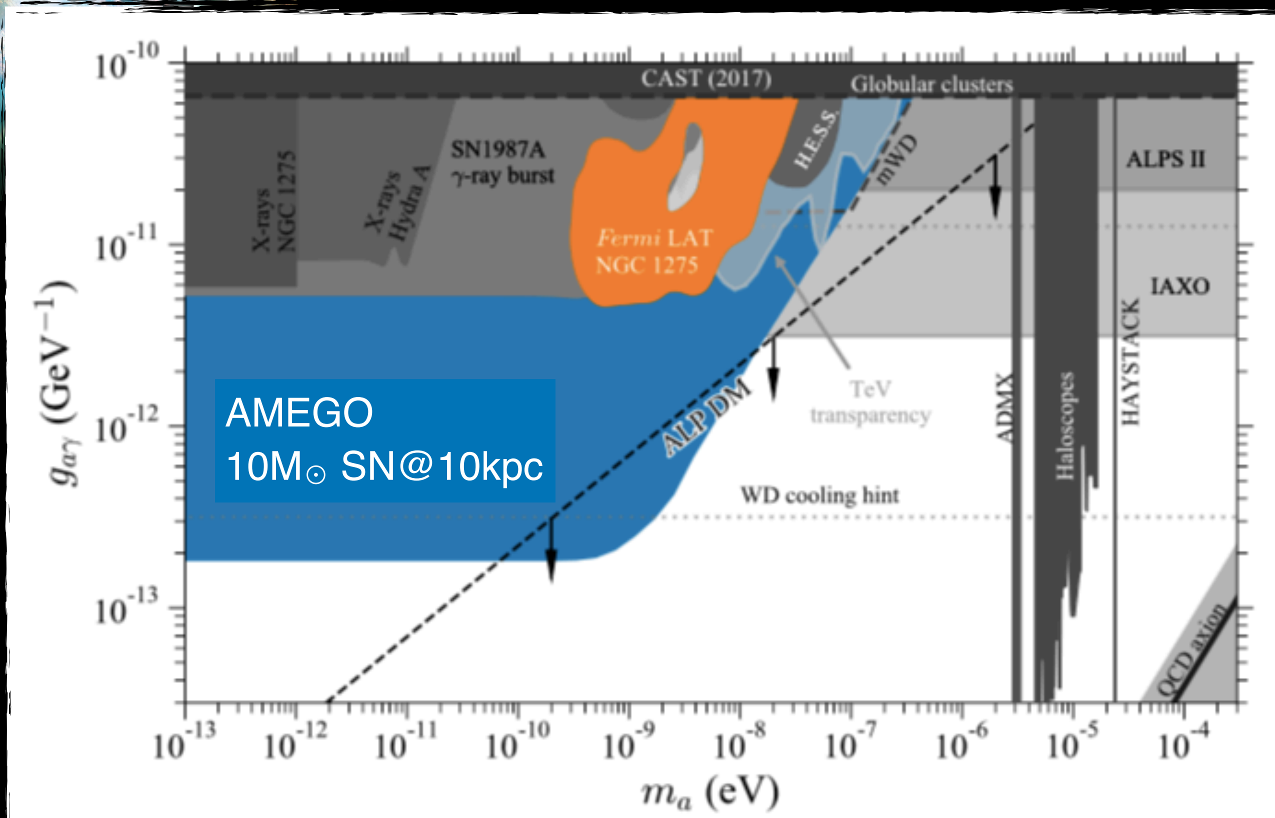
Diffuse:
Fermi-LAT |b|>20°

Neutral Final States

Bartels et al., 2017

Axions Produced in Core-Collapse Supernovae



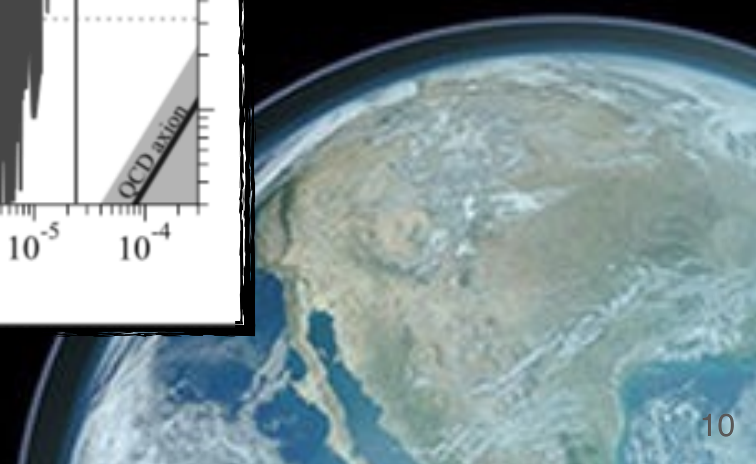


Produced ~10s with neutrinos

Peak ~60 MeV

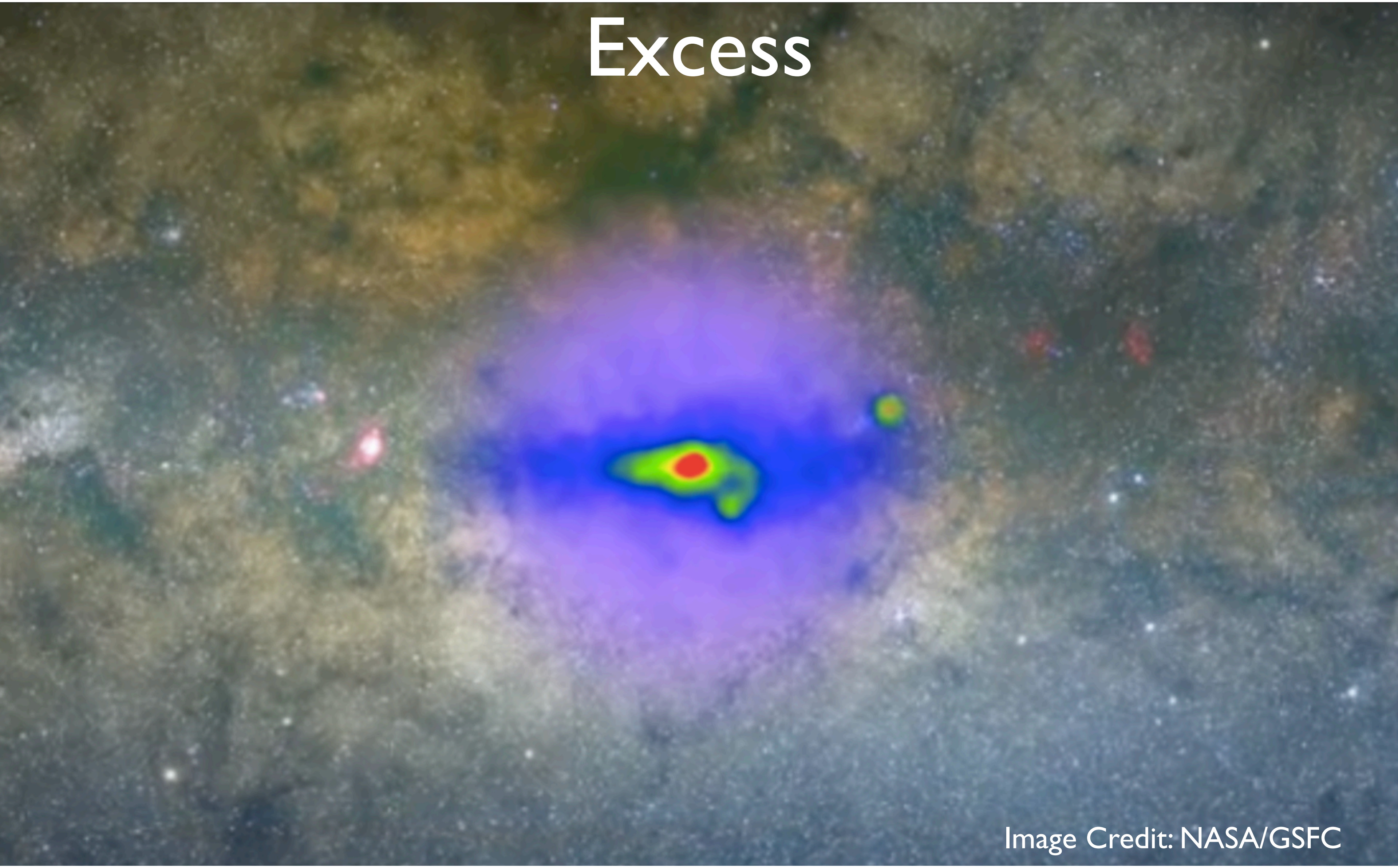
Flux $\propto g_{a\gamma}{}^4$

Payez et al., 2015
Meyer et al., 2017



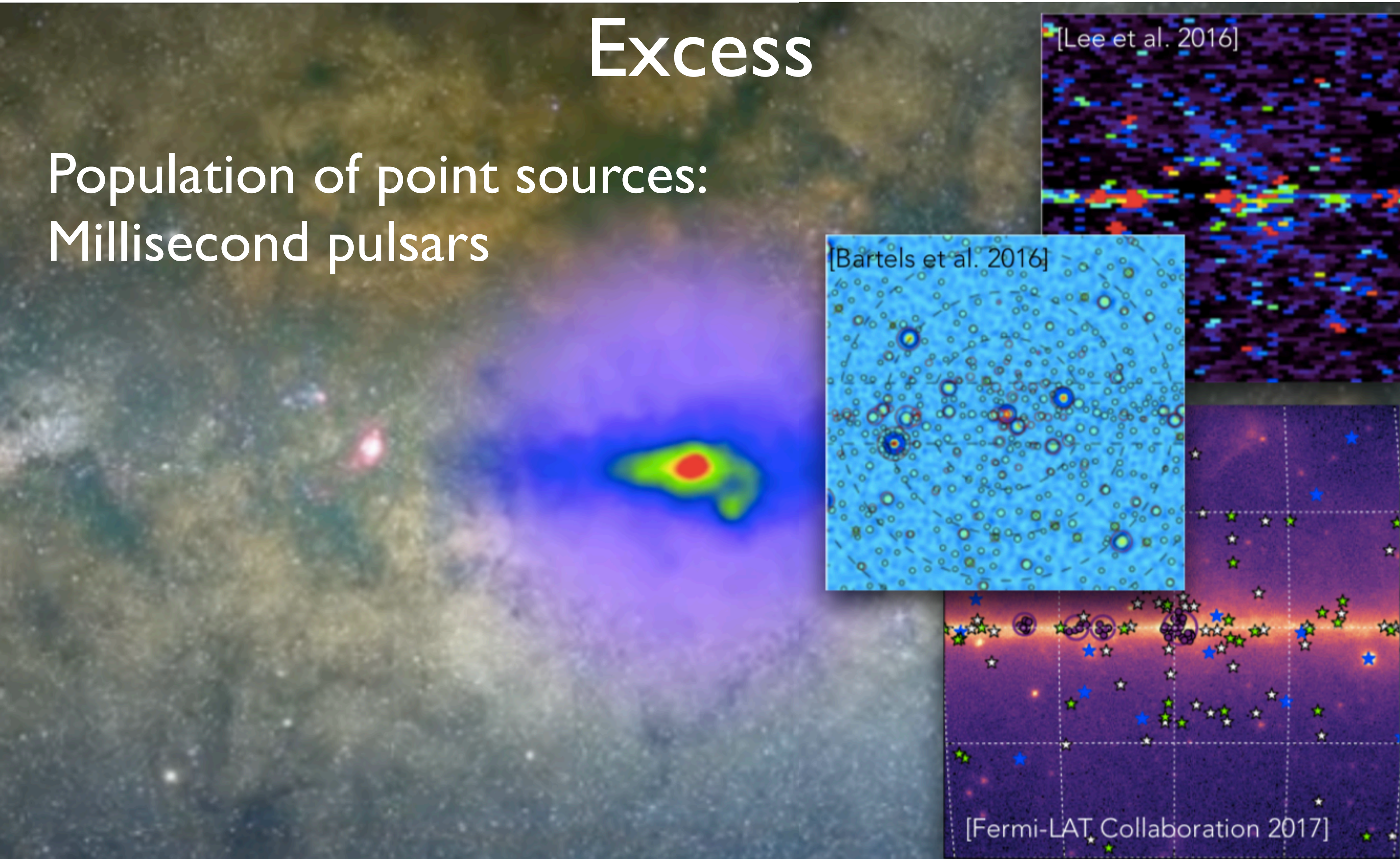
But wait, there's more…

Probing the Galactic Center

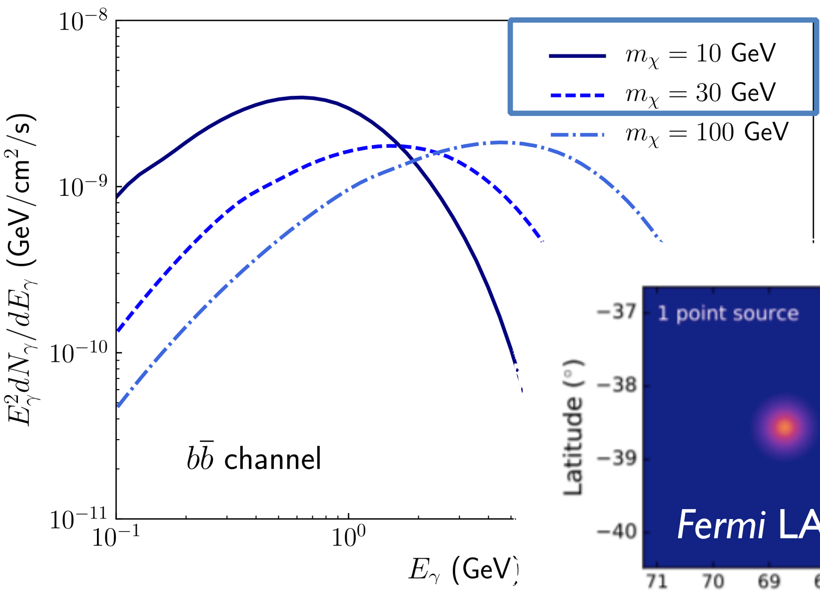


Probing the Galactic Center Excess

Population of point sources:
Millisecond pulsars

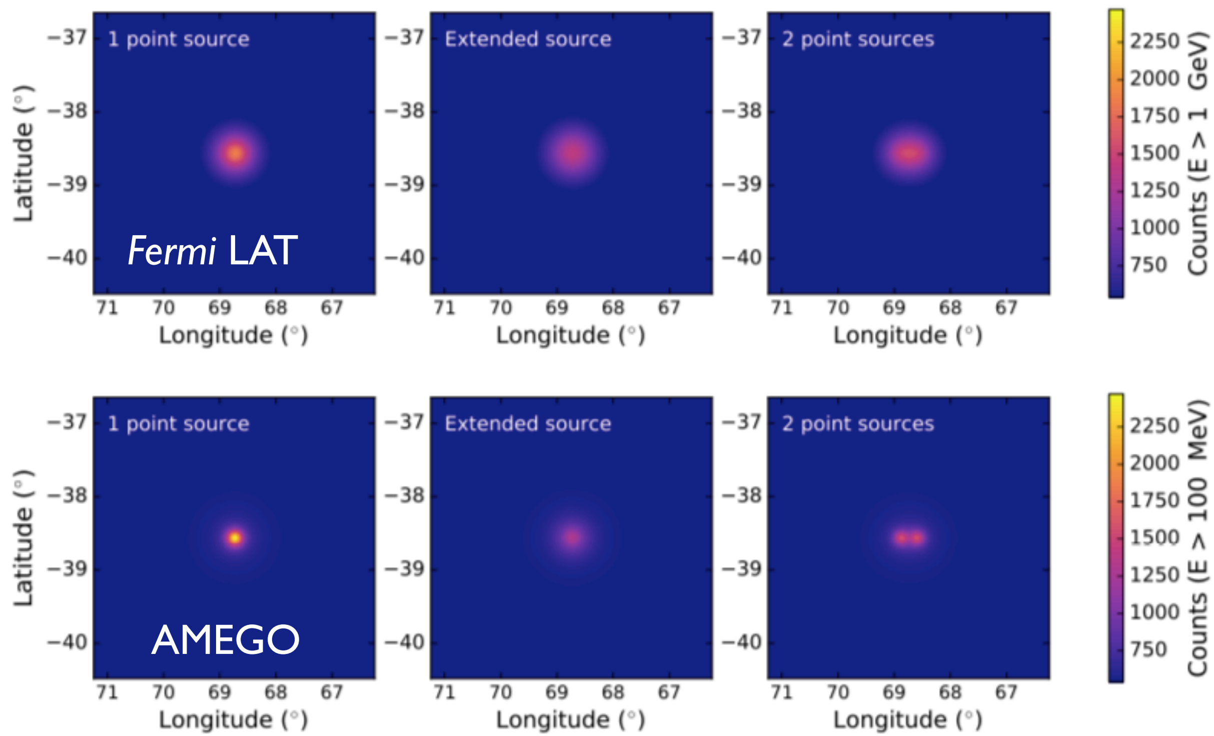


Complementarity in the γ-ray Sky



Relevant for extended sources and Galactic Center

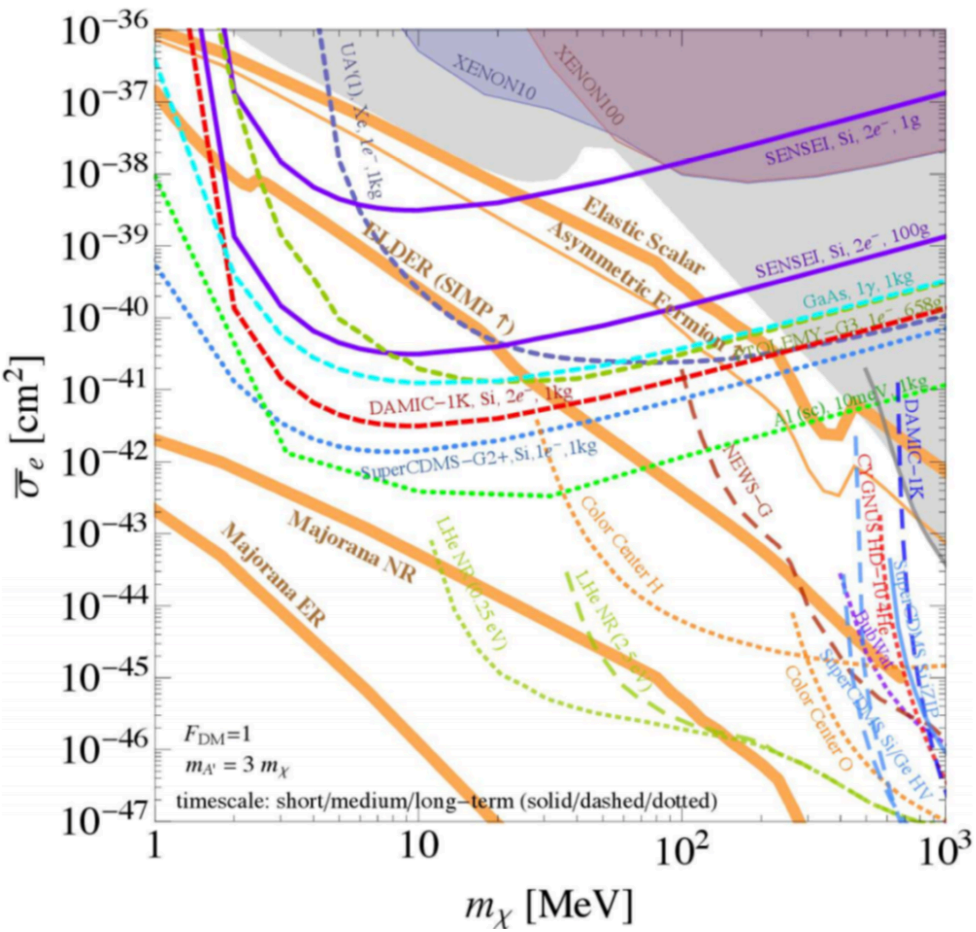
Separated by 0.28°

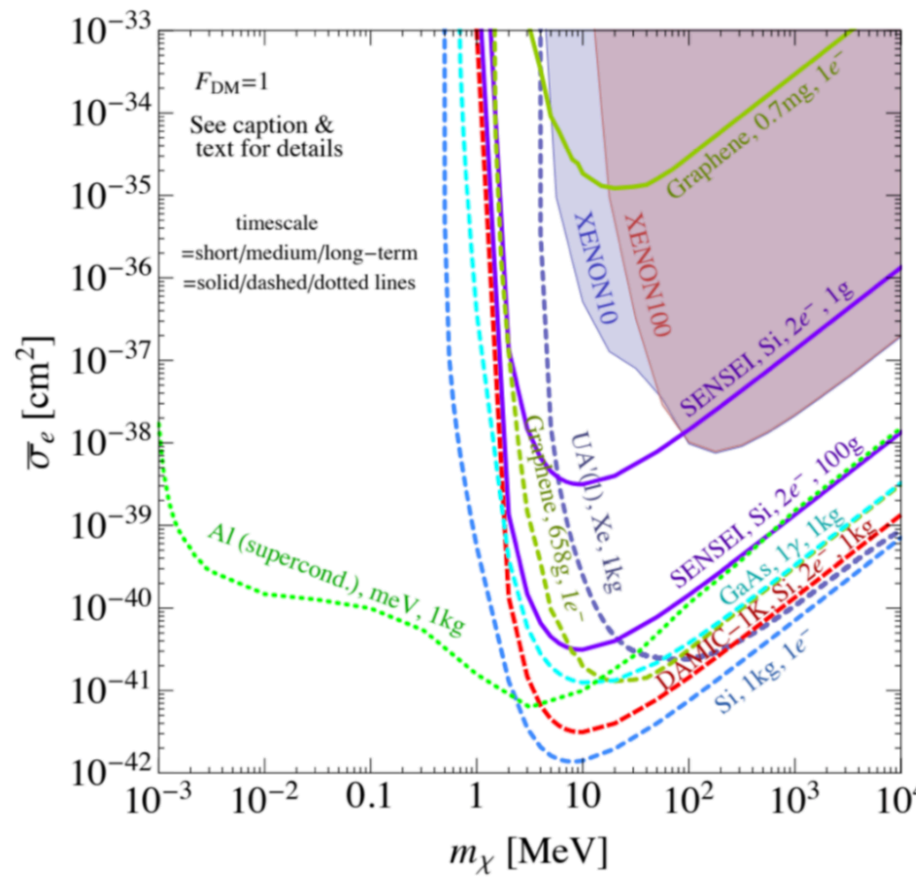


Chou et al. arXiv: 1709.08562

The Future is bright in the MeV band…

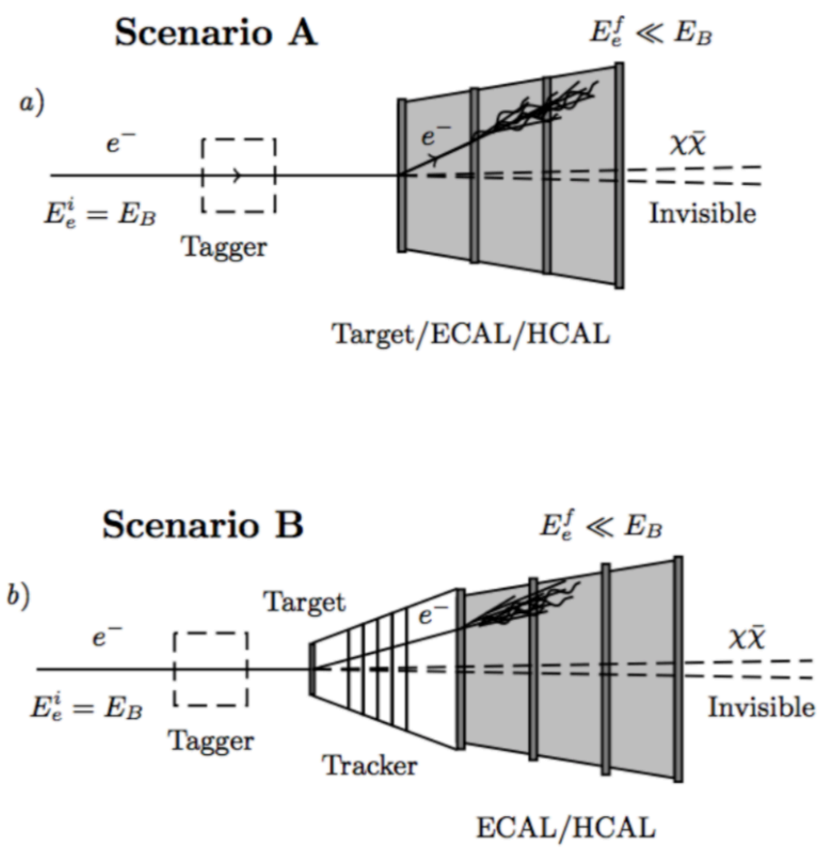
Complementarity: Direct Detection

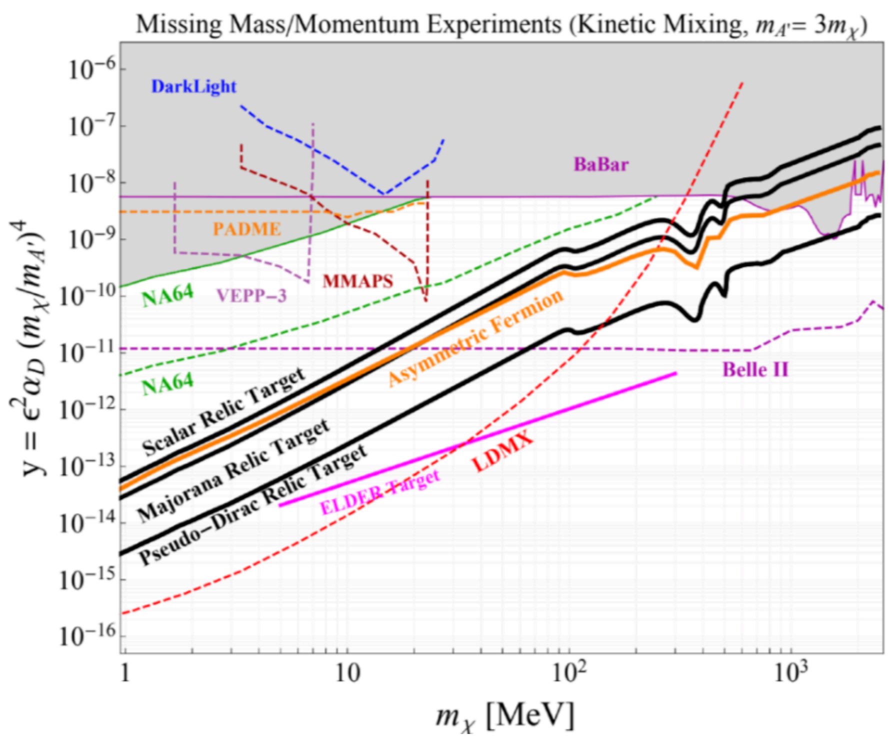




Cosmic Visions White-paper

Complementarity: Fixed-Target





Izaguirre et al. 2015

The Future is bright in the MeV band…

Well motivated discovery space in direct, collider and indirect dark matter searches for broad range of different dark matter candidates

Backups

Dark Matter Annihilation

How low (in mass) can you go?

$\chi\chi \rightarrow \gamma\gamma$: Accessible at all energies

$\chi\chi \rightarrow \gamma\pi^0$: Accessible if $\sqrt{}$COM interaction > m_{π^0}

$\chi\chi \rightarrow \pi^0\pi^0$: Accessible if $\sqrt{}$COM interaction > $2m_{\pi^0}$

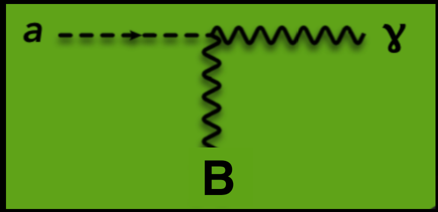
$\chi\chi \rightarrow \bar{\ell}\ell$: Accessible if $\sqrt{}$COM interaction > m_ℓ

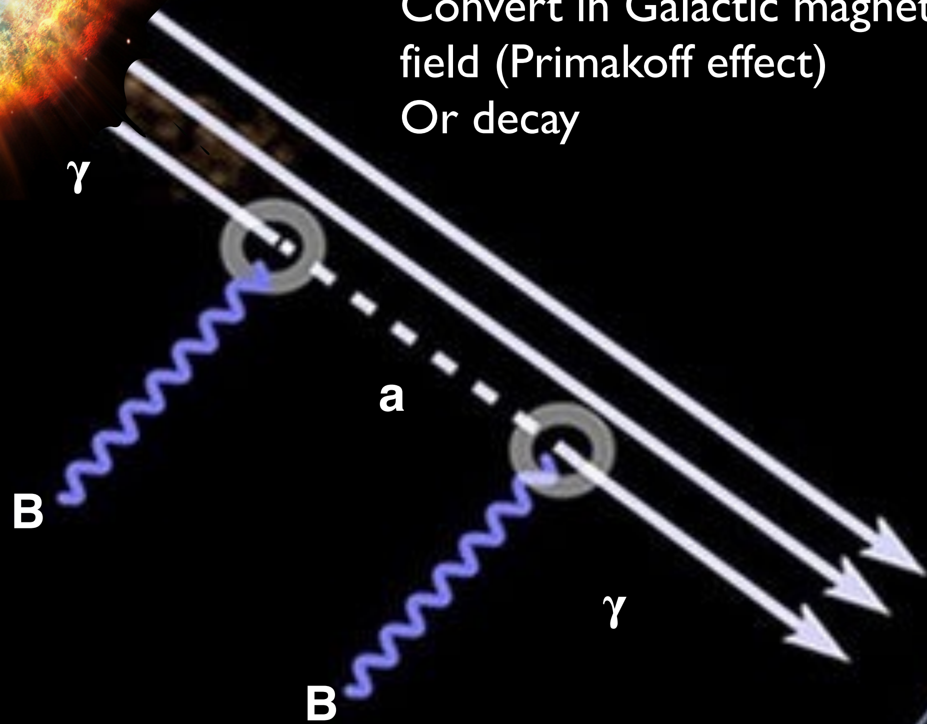
$\chi\chi \rightarrow \phi\phi$ and $\phi \rightarrow e^+e^-$: Additional mediators, cascade annihilation

Inspired by Boddy & Kumar 2015

Axions and Axion-like Particles

Convert in Galactic magnetic field (Primakoff effect)
Or decay

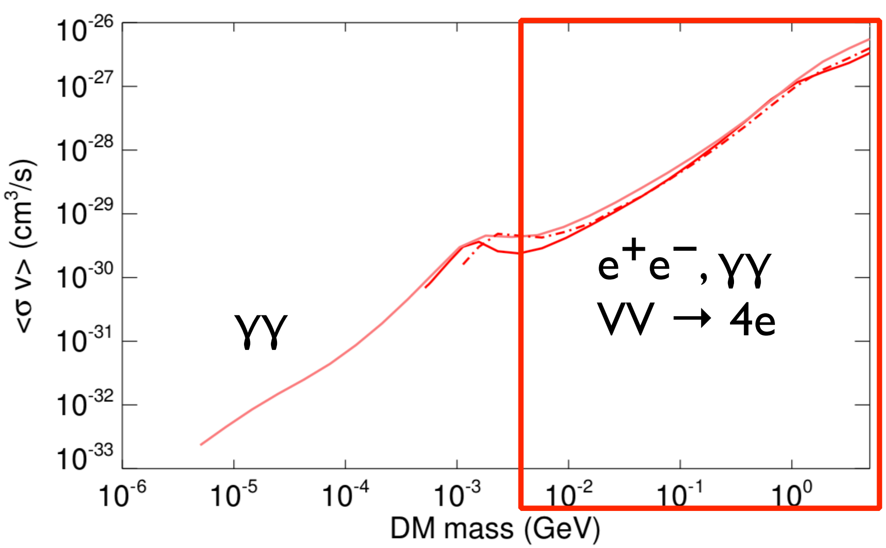




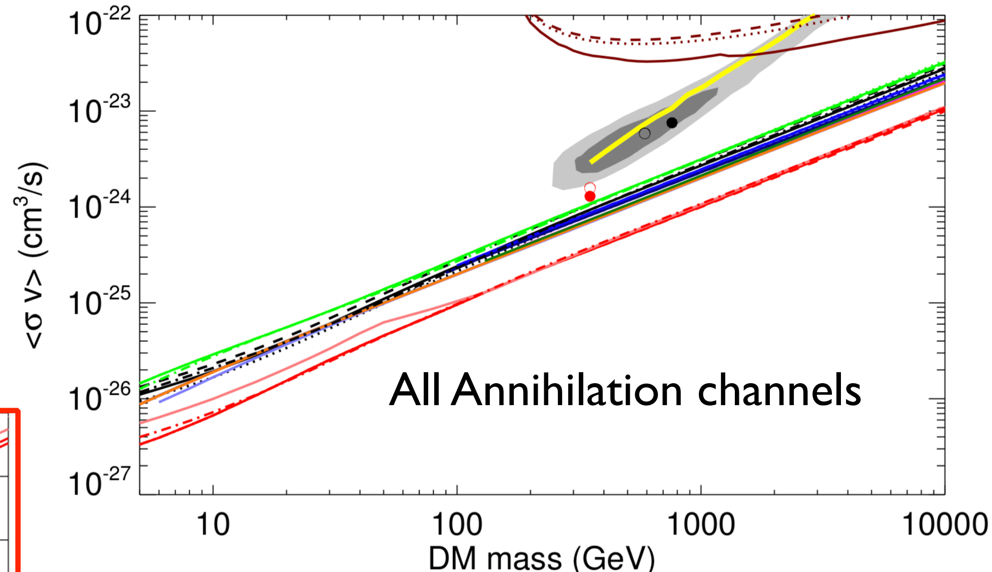
[Peccei & Quinn 77; Wilczek 78; Weinberg 78; Preskill et al. 83; Abbott & Sikivie 83; Witten 84; e.g. Arvanitaki et al. 09; Cicoli et al. 12; Arias et al. 2012; Raffelt & Stodolsky 1988]

Dark Matter Annihilation Limits from CMB

Light Dark Matter Annihilation more constrained than heavier Dark Matter



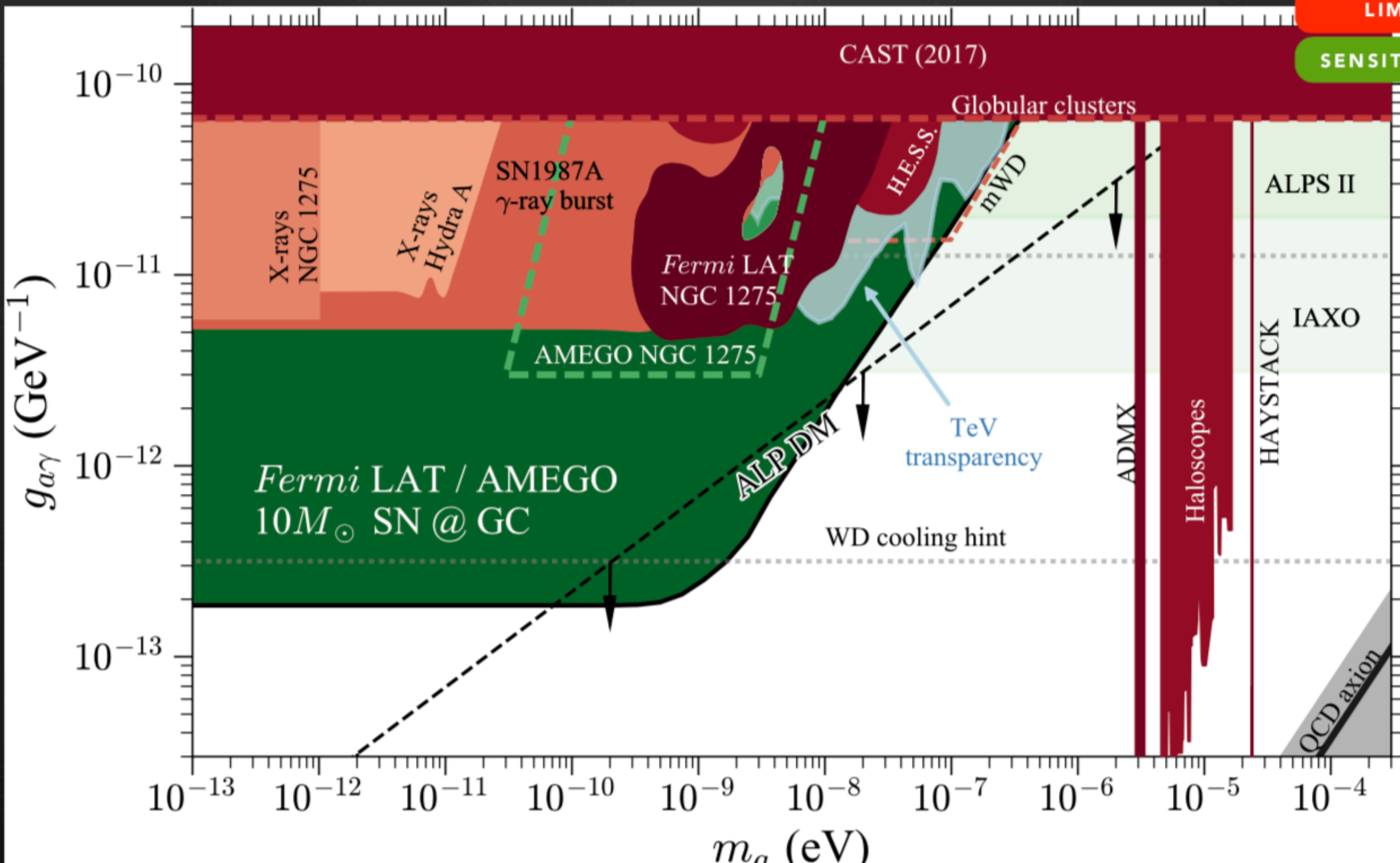
Slatyer 2016



Weak-Scale cross sections constrained

s-wave constraints can be avoided if p-wave (velocity dependent) annihilation

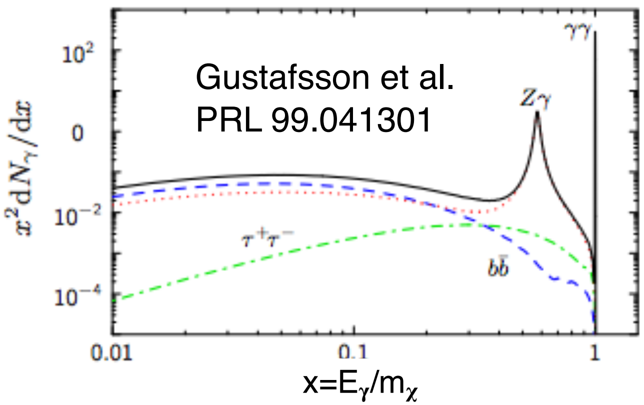
Axion/ALP Dark Matter Sensitivities

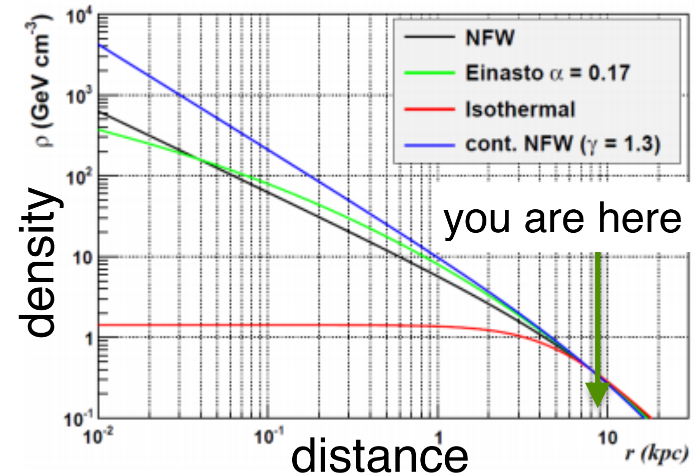


Courtesy M. Meyer

Indirect Searches: γ-rays

Observed = Particle Properties x Astrophysics Properties





$$\Phi_\gamma(E,\psi) = \frac{1}{4\pi}\frac{\langle\sigma_\chi v\rangle}{2m_\chi^2} N_\gamma(E) \times J(\psi)$$

cross section

mass

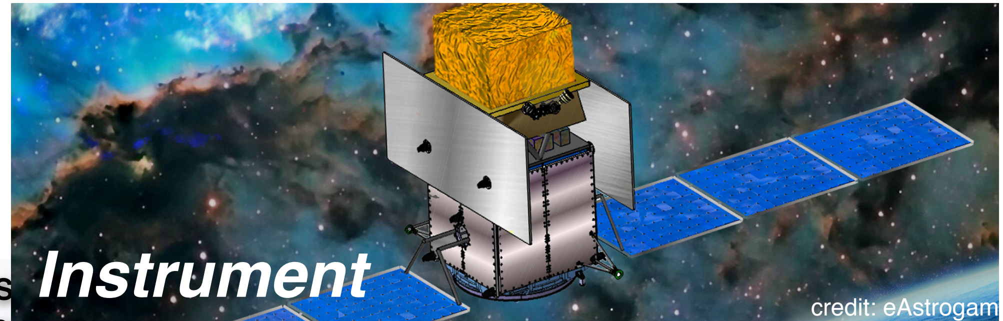
photons

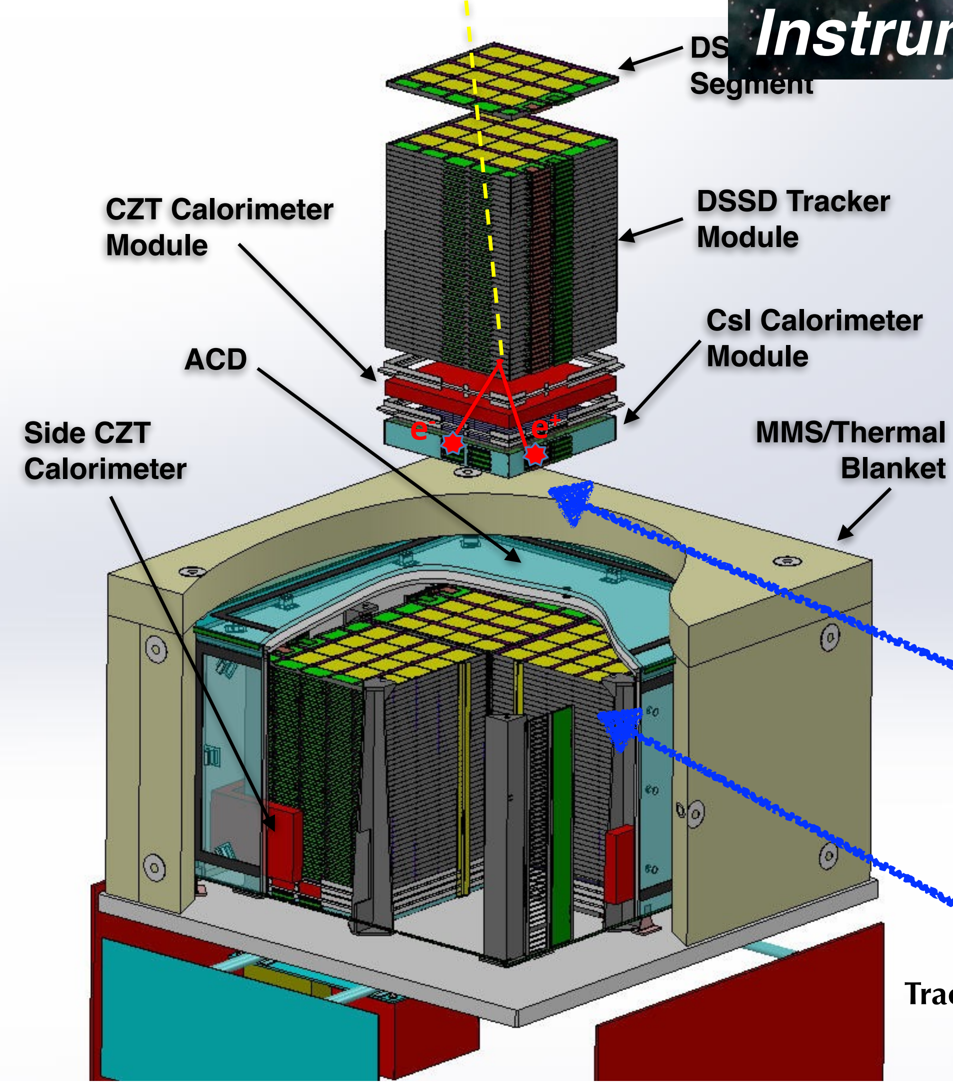
J-Factor: ~ ∫ρ²

(solid angle, line of sight)

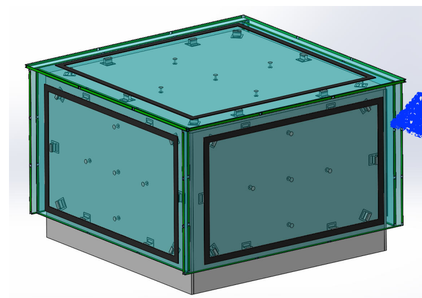
L. Bergstrom et al., ApJ. 9:137-162, 1998

AMEGO

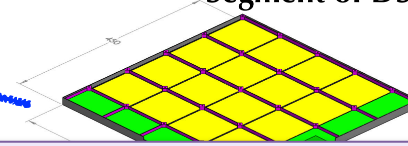




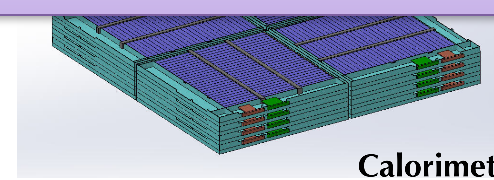
Anti-Coincidence Detector plastic scintillator



Segment of DSSD tracker



Sister Instrument: e-ASTROGAM

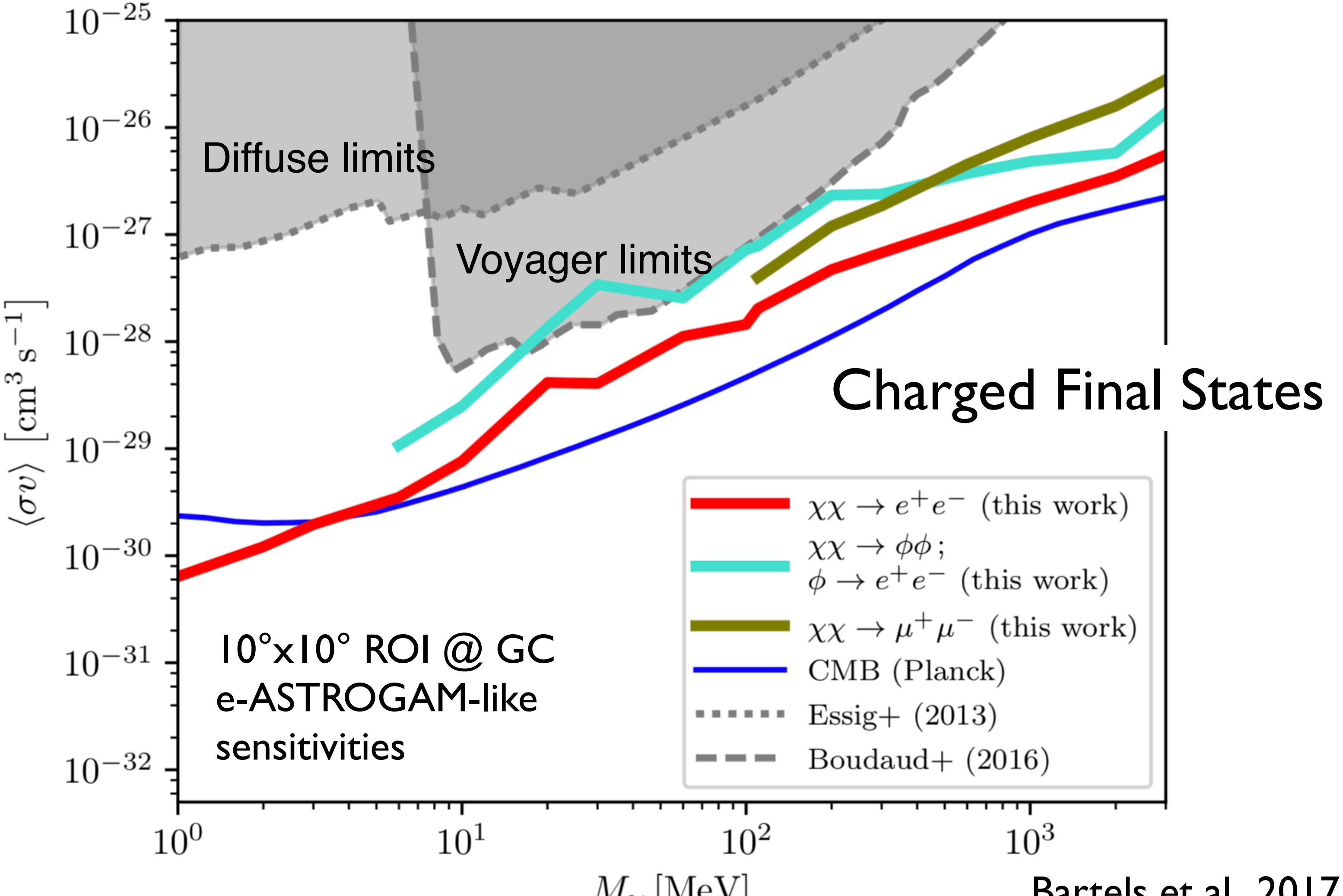


Tracker and Calorimeter Towers

Calorimeter:
4 layers/tower
16 total

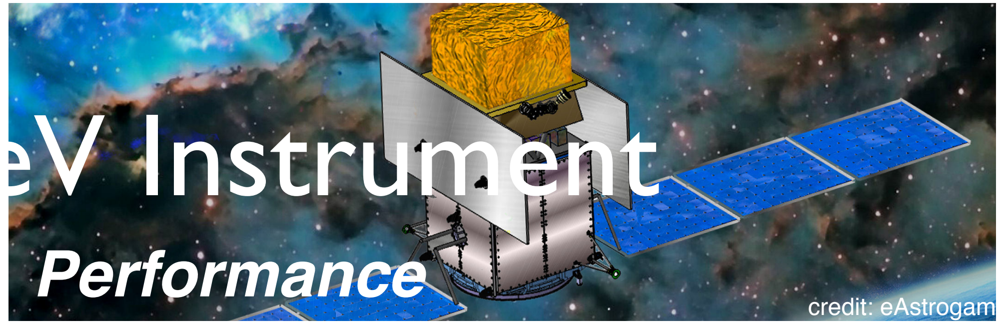
Spacecraft

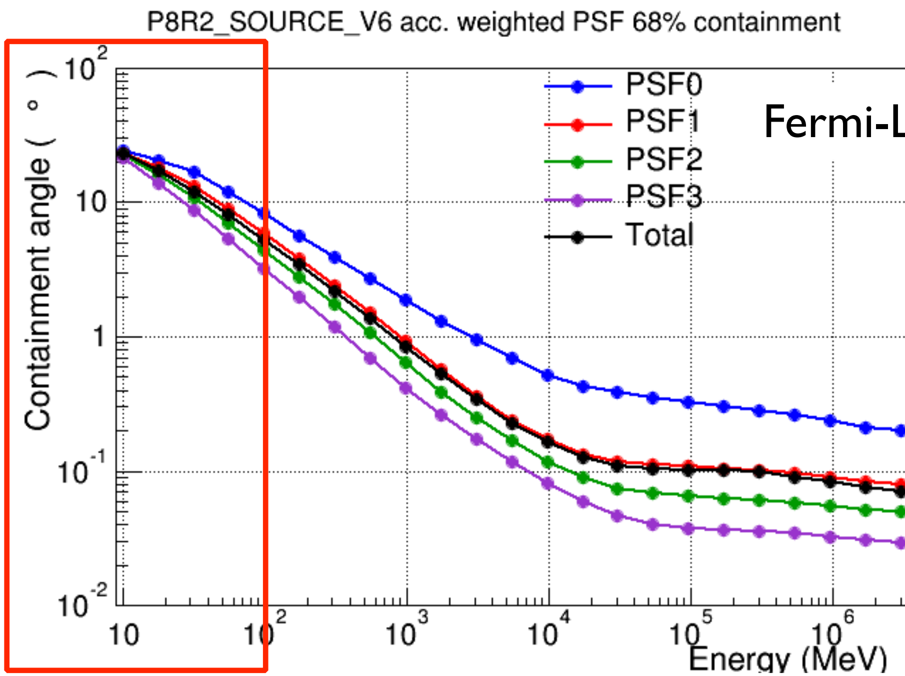
Dark Matter Annihilation Sensitivity



Bartels et al., 2017

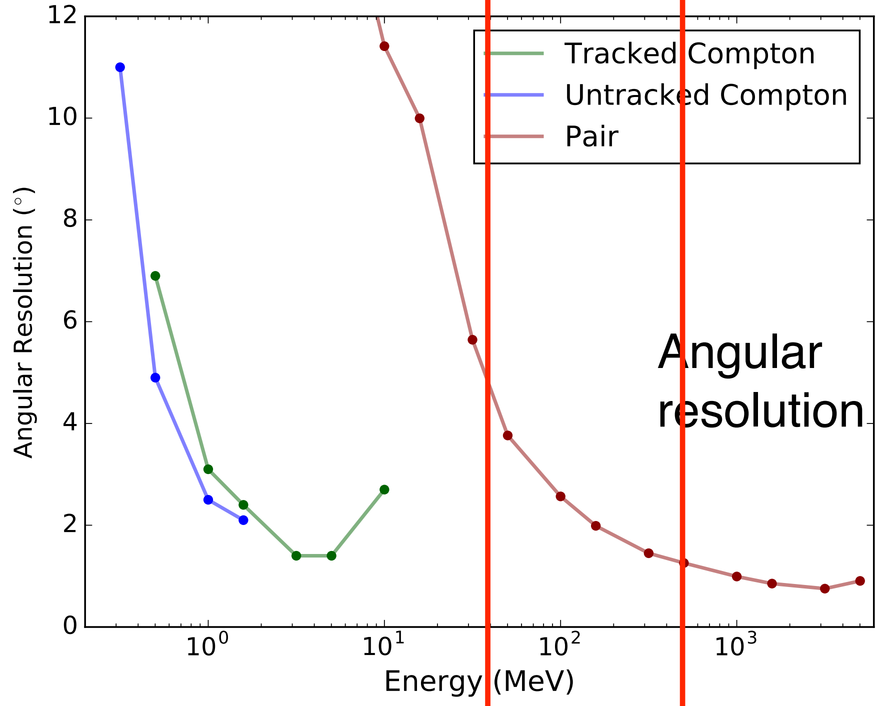
Future MeV Instrument Performance





Fermi-LAT Performance

AMEGO Performance



Angular resolution

RC, et al., PoS (ICRC2017) 783