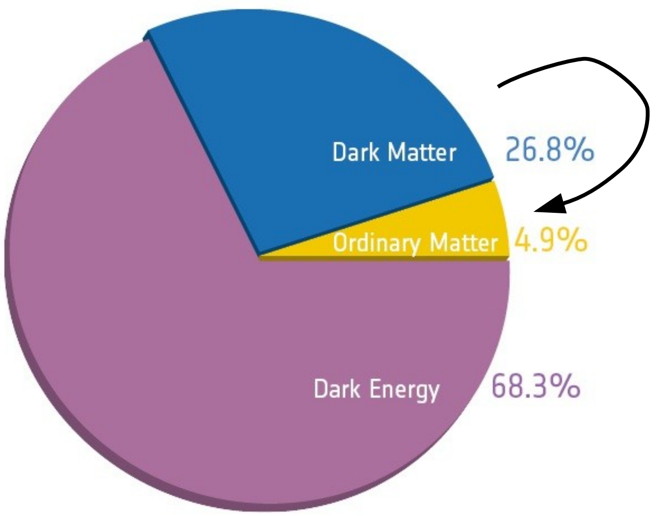
(Brief) indirect DM detection overview



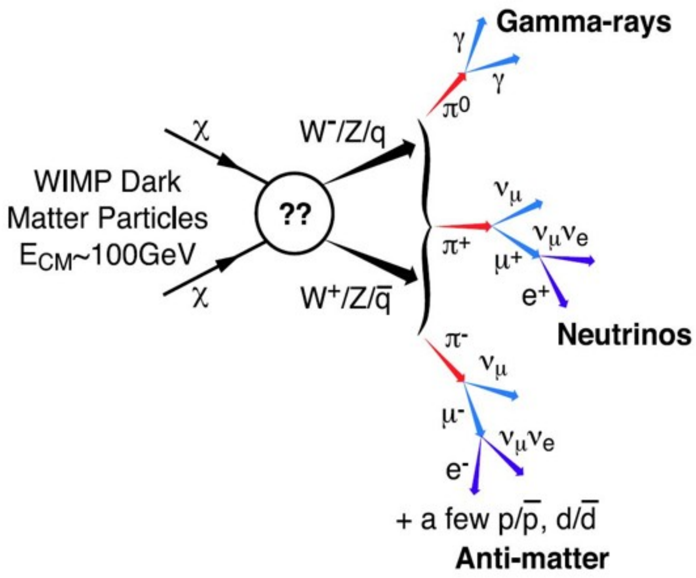
$$\frac{\dot{\rho}_\chi}{\rho_\chi} \sim 10^{-10} H_0$$

Christoph Weniger
GRAPPA, Institute of Physics
University of Amsterdam (UvA)

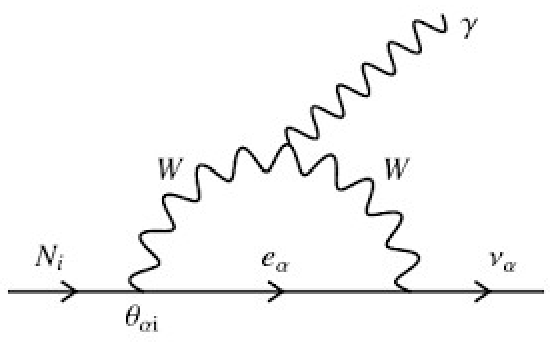
13 May 2019
Update of the European Strategy for Particle Physics
Granada

Energy transfer mechanisms

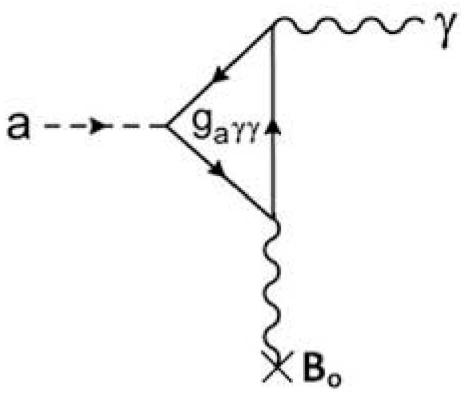
1) Self-annihilation
(e.g. WIMPs)



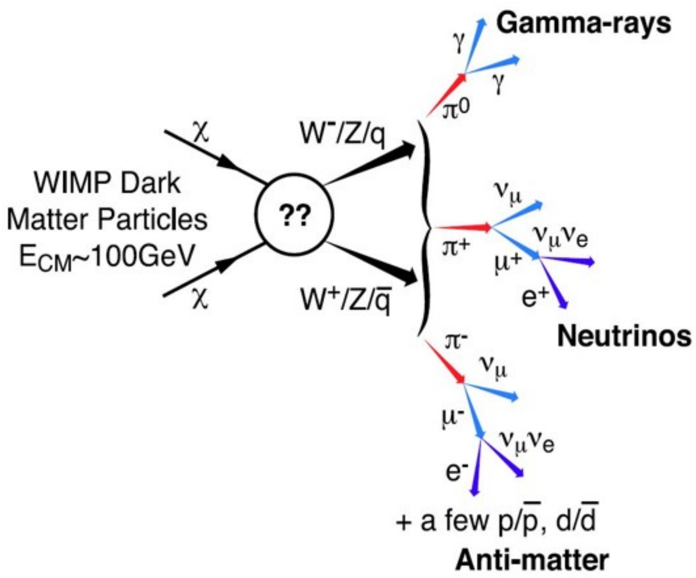
2) Decay
(e.g. sterile neutrinos)



3) Conversion
(e.g. axions)



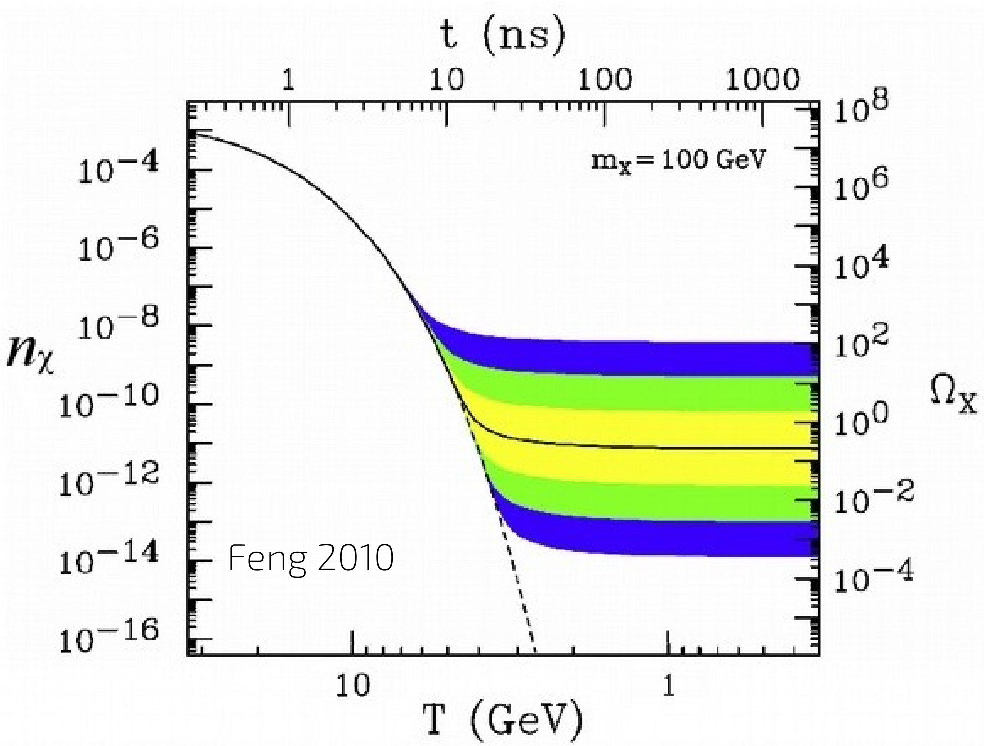
1) Dark matter self-annihilation



The annihilation cross section

s-wave annihilation $(\sigma v \approx \mathrm{const})$

→ Direct link between relic density and velocity weighted cross section today



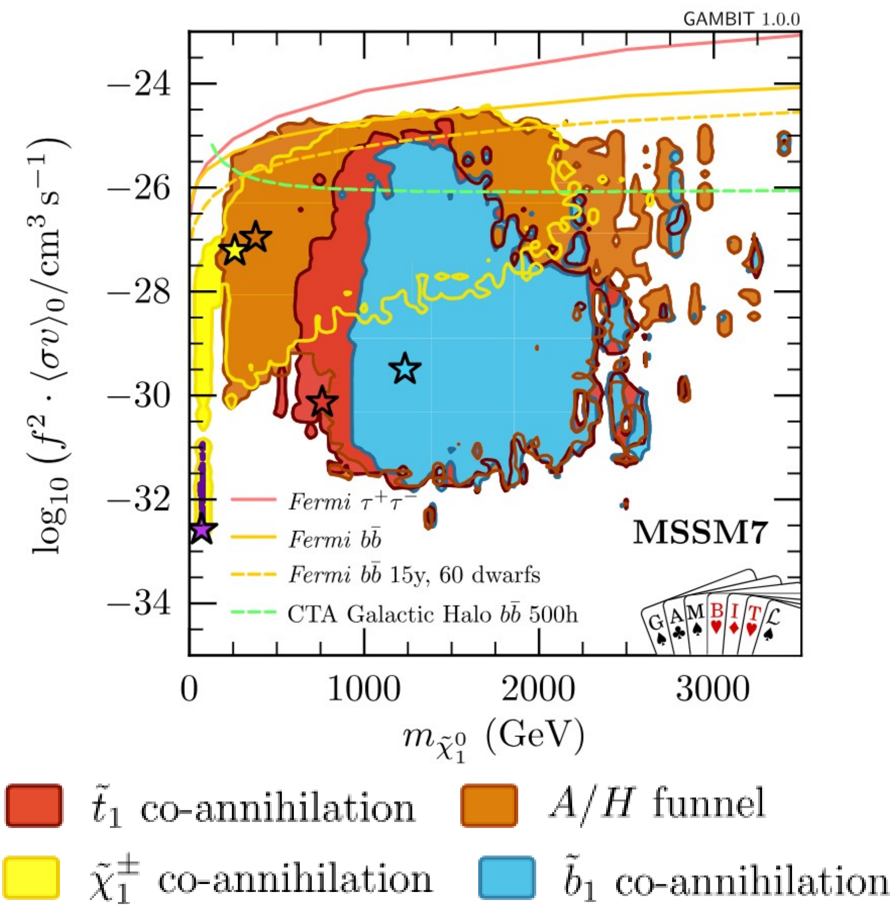
$$\frac{\Omega_\chi h^2}{0.1} \approx \frac{3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

s-wave: $\langle \sigma v \rangle_{T\sim\mathrm{GeV}} = (\sigma v)_{v=0}$

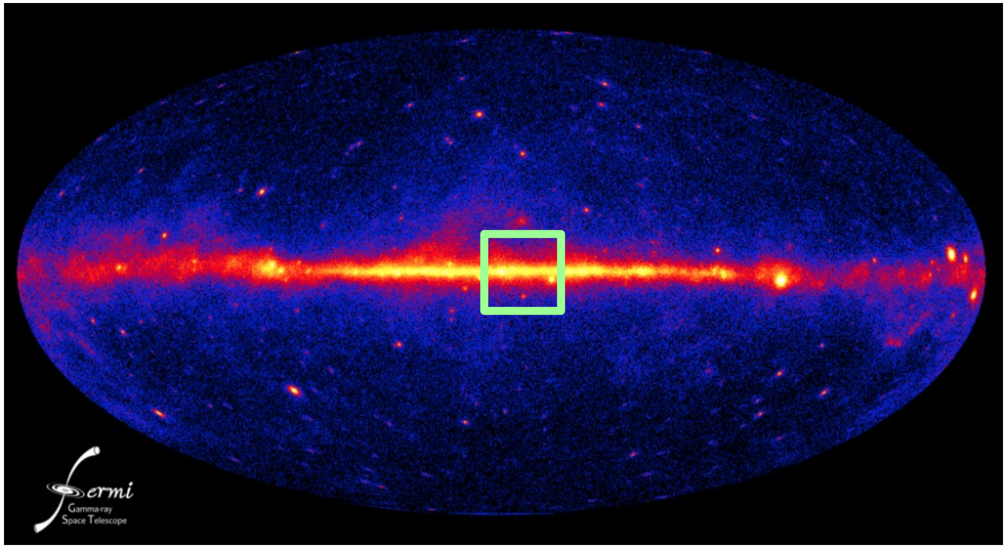
in general

$$\langle \sigma v \rangle_{T\sim\mathrm{GeV}} \neq (\sigma v)_{v=0}$$

Example MSSM7
(rescaled by DM fraction)

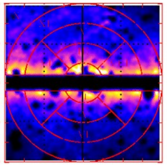


Fermi LAT - Galactic center GeV excess



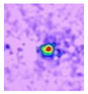
Different groups, different ROIs

$40^\circ \times 40^\circ$



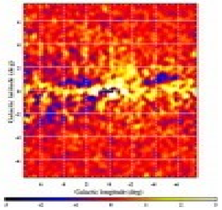
Calore+14

$7^\circ \times 7^\circ$

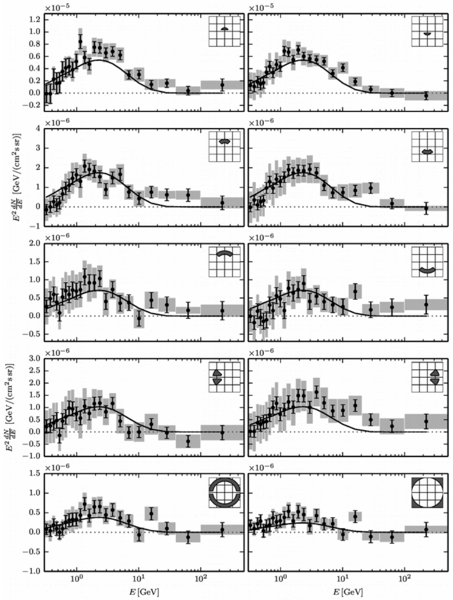


Daylan+ 14 (GC analysis)

$14^\circ \times 14^\circ$



Ajello+15

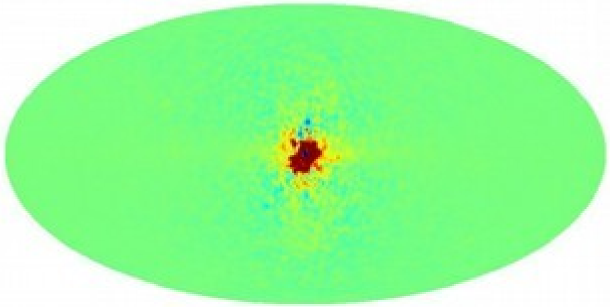


The Fermi GeV bulge emission

- Initial claims by Goodenough&Hooper (2009) [see also Vitale&Morselli (2009)]
- Controversial discussion in the community for six years
- In 2015, existence of “GeV excess” finally got the blessing from the Fermi LAT collaboration
- **Is it a DM signal?**

… Hooper & Linden 11; Boyarsky+ 11; Abazajian & Kalpinghat 12; Hooper & Slatyer 13; Gorden & Macias 13; Macias & Gorden 13; Huang+ 13; Abazajian+ 14; Daylan+ 14; Zhou+ 14; Calore+ 14; Huang+15; Cholis+ 15; Bartels+ 15; Lee+ 15, …)

Information field theory:



Huang+ 15

Fermi LAT - My take on the GeV excess

Situation

- Thousands of (hypothetical) millisecond pulsars in the Galactic bulge could potentially cause the emission (spectrum works) Abazajian 2010
- Production plausibly related to disruption of globular clusters Brandt & Kocsis 2015

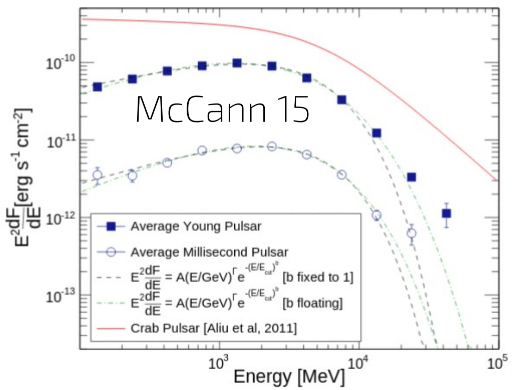
Photon clustering

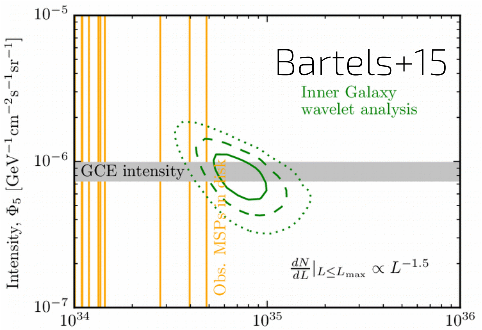
- Point source origin of emission suggests clustering of photons, supported by waveflet fluctuation analysis
- Non-Poissonian template fit results recently retracted (but not relevant for wavelet analysis) Lee+15, see also Leane+19

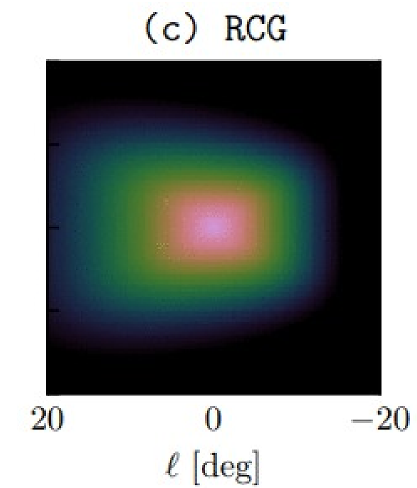
Spatial distribution

- Excess emission appears to trace stellar mass in Galactic bulge rather than a spherical (DM) profile → Suggests astrophysical origin Bartels+18

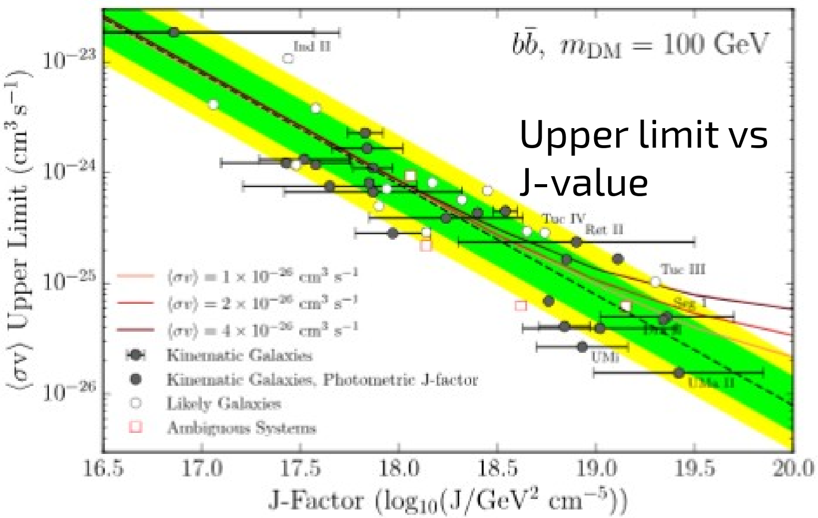
But: Situation remains unclear, difficult to make definitive statements with photon data alone → Radio searches (MeerKAT should find ~10 bulge MSPs within 100 h in a dedicated survey, maybe 2019/2020?) Calore+15

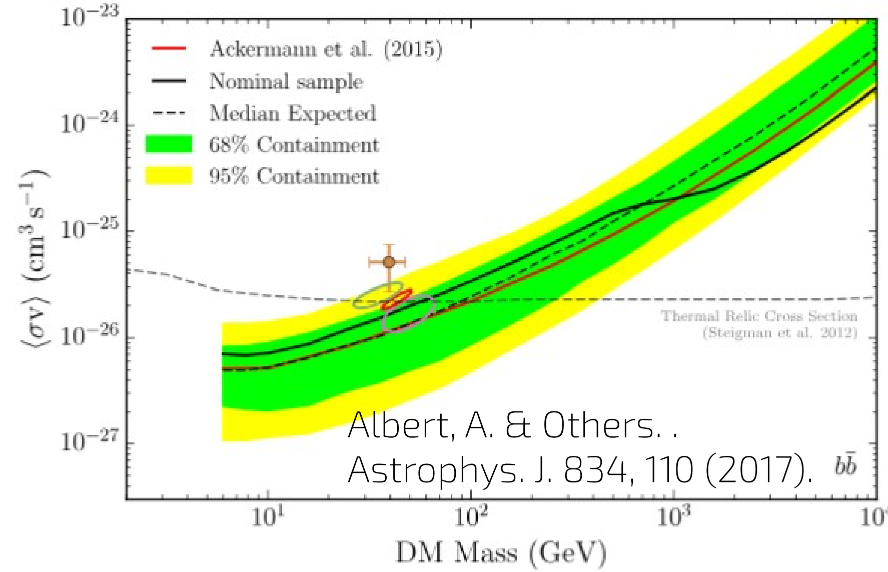






Fermi LAT - Dwarf Spheroidal Galaxies





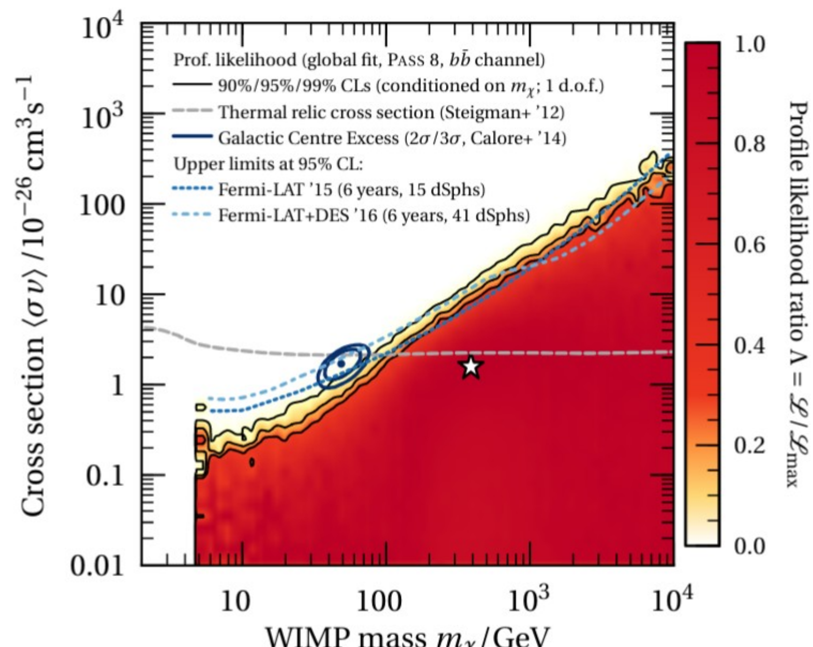
Latest Fermi coll. limits from 39 dSphs, only for half o them the J-value is kinematically determined

→ GeV excess OK (thanks to excesses in 4 dSphs)

Recent analysis of 27 dSphs with J-value, using Bayesian and Frequentist methods, long tail J-value priors → GeV excess in tension [Hoof+ 2018]

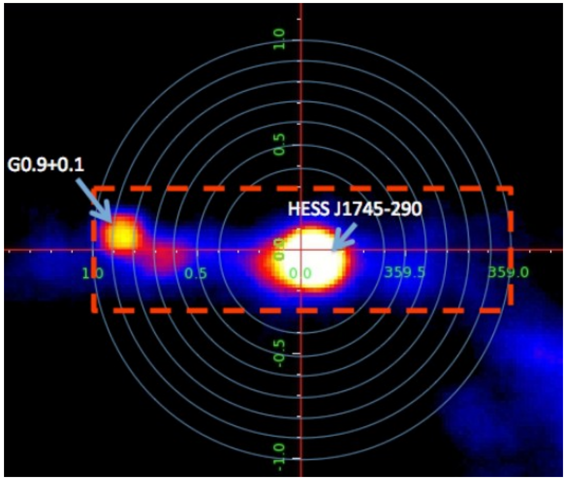
Ongoing J-values discussion

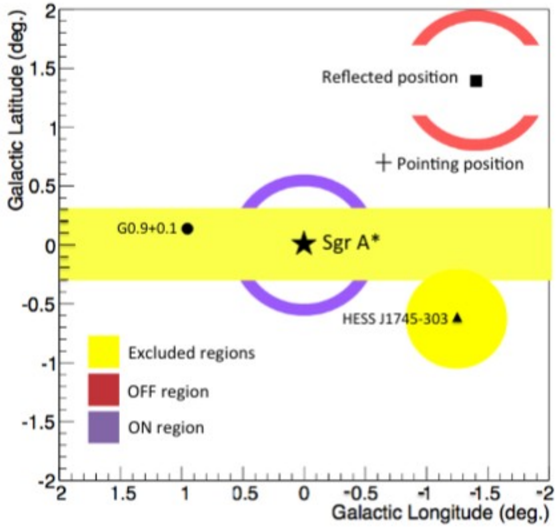
- Ongoing discussion about "J-values" in the literature [e.g. Bonnivard+ '15, Geringer-Sameth+ '15, Charbonnier+ '11, Walker+ '11]
- Impact of tri-axiality somewhere around factor 2 [Bonnivard+ '15, Hayashi+ '16]
- Non-parametric approach can reduce J-values by up to factor four [Ullio & Valli 2015]



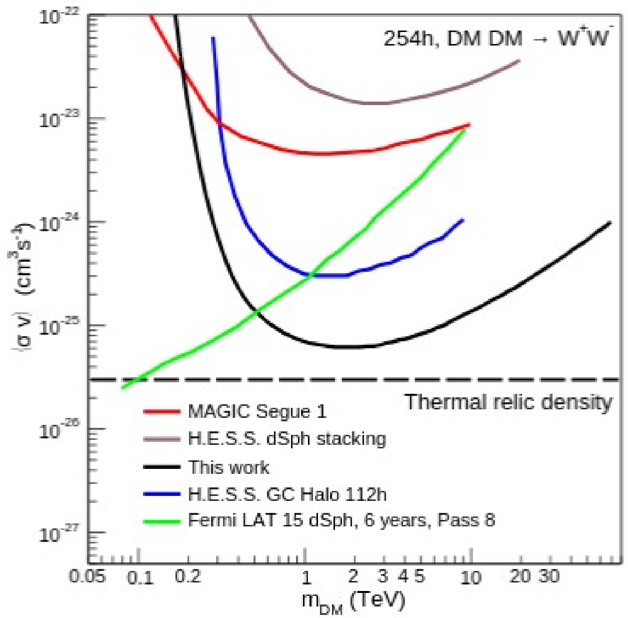
Hoof, S., Geringer-Sameth, A. & Trotta, R.arXiv [astro-ph.CO] (2018).

H.E.S.S. - Galactic center



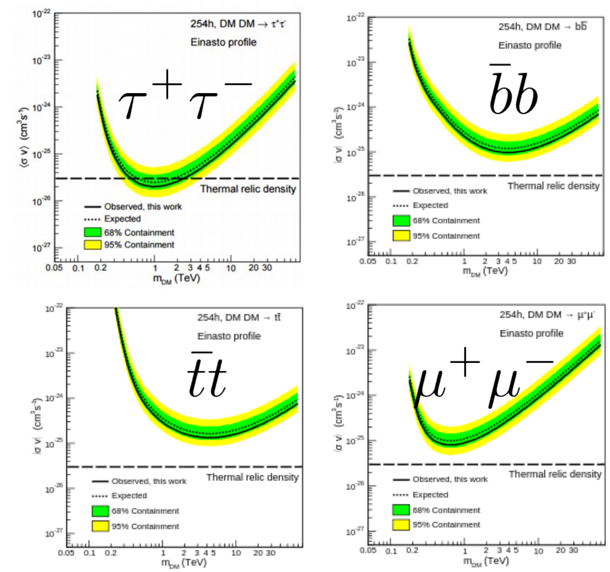


Abdallah, H. et al. Phys. Rev. Lett. 117, 111301 (2016).

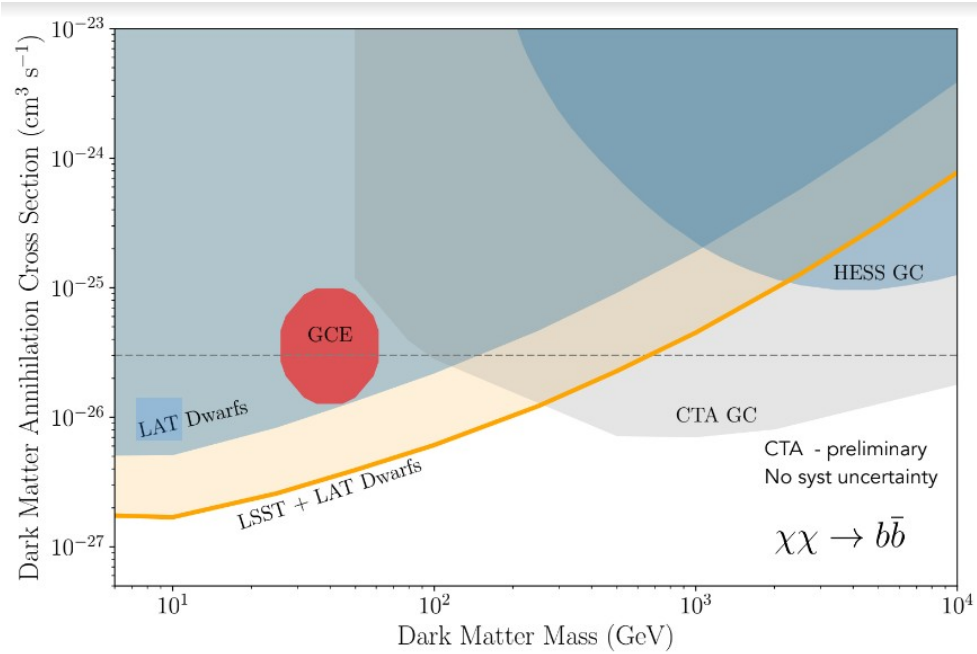


DM searches with Cherenkov telescopes

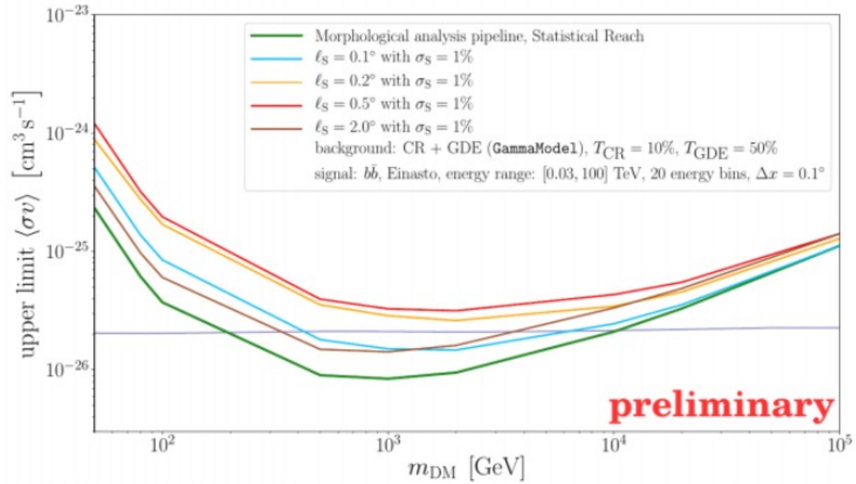
- Large CR backgrounds imply that brightest targets are best → GC
- Strongest limits from HESS GC halo observations, recent updates use improved stat. method (HESS 2016)
- Relevant limits at ultra-high-energy gamma rays (m>100 TeV) come from IceCube [e.g., Murase & Beacom 2012]
- Constraints practically disappear for cored profiles



Outlook GeV - TeV energies



From Drlica-Wagner, A. & Others. arXiv [astro-ph.CO] (2019). See also Carr, J. & Others. PoS ICRC2015, 1203 (2016).



- Obtaining subthermal constraints is challenging, requires understanding bkgs at ~1% level

Silverwood, H., CW, Scott, P. & Bertone, G. JCAP 1503, 055 (2015); Balázs, C. et al. 2017; Pierre, M., Siegal-Gaskins, J. M. & Scott, P. 2014

See Lisanti's talk for Wino DM

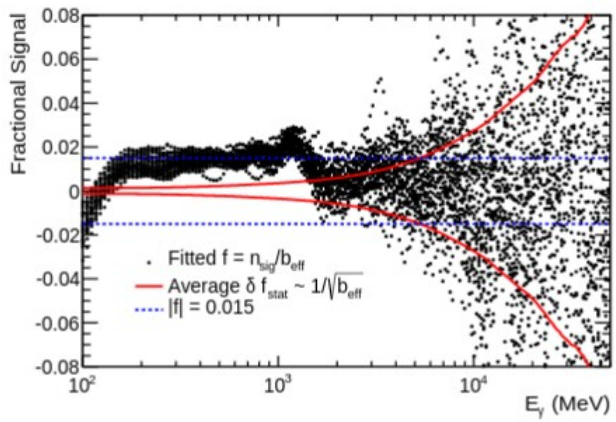
General high energy prospects:

- Above m~100 TeV, HAWC will improve limits from observations of dSph & GC (Abeysekara+ 2014; Proper+ 2015)
- LHAASO (~2022) will dominate above m~100 TeV in the long run (e.g. Knödlseder 2016)
- CTA (~2025) will improve HESS limits by factor up to 10 (Silverwood+ 2015, Doro+ 2013, Carr+ 2015, Lefranc+ 2015)

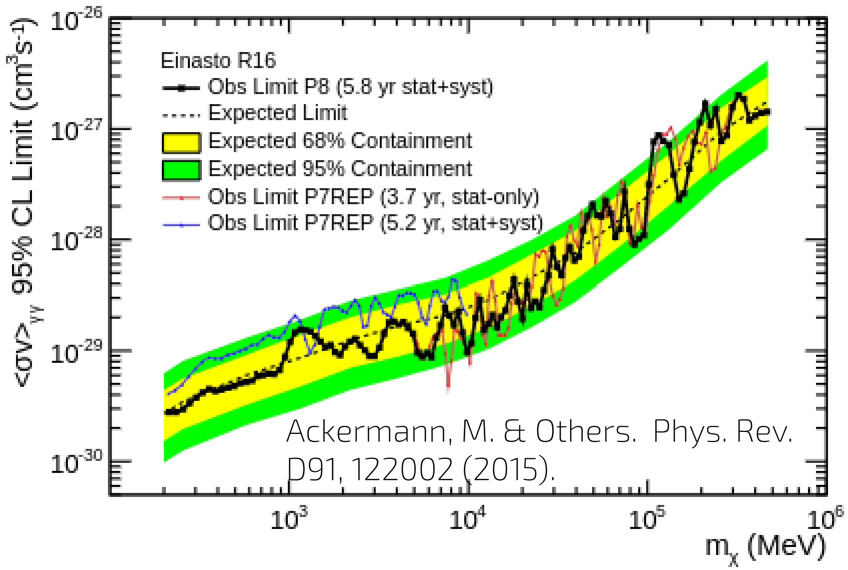
Line constraints in general

$\chi\chi \to \gamma\gamma$

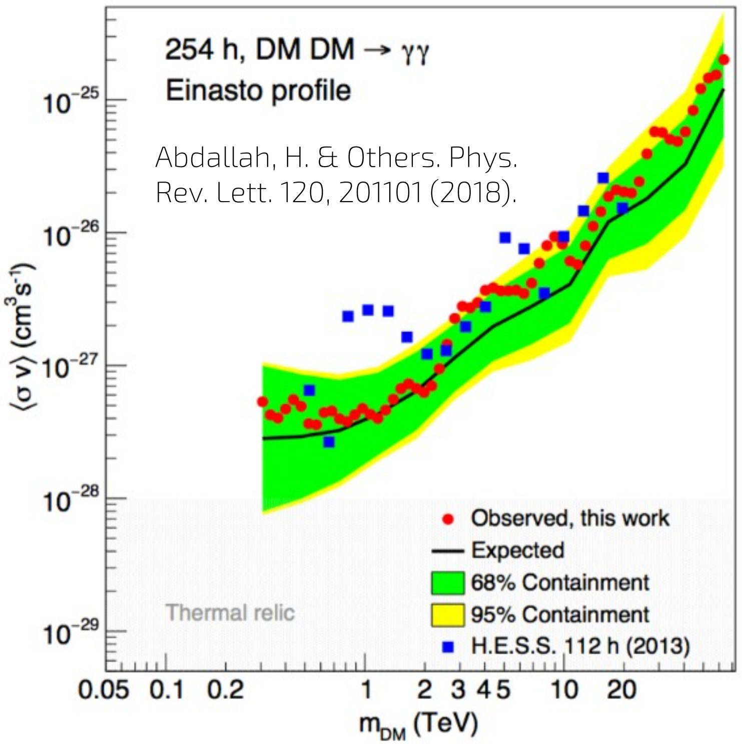
- Gamma ray lines, virtual internal Bremsstrahlung, etc, would provide clear discoveries against astro bkgs
- Observational constraints are usually strongest from the Galactic center (highest statistics, ~no bkg confusion)
- Branching ratios small as well → Only in exceptional cases the leading constraint



Systematics dominated below 3 GeV

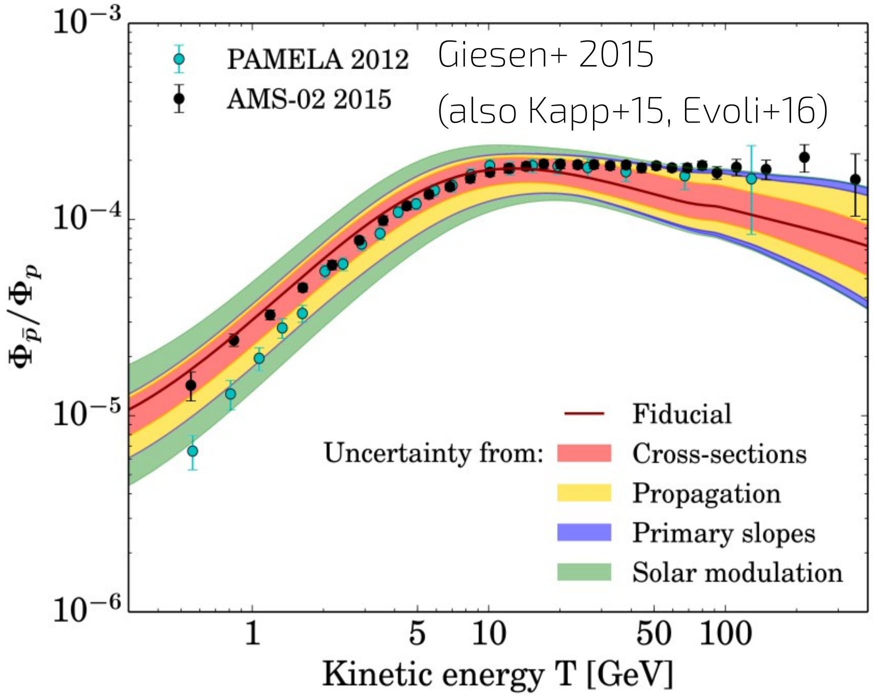


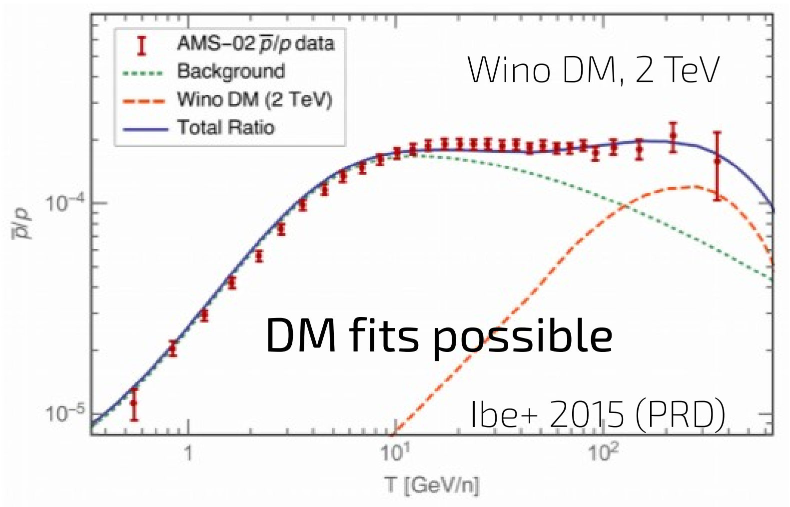
Ackermann, M. & Others. Phys. Rev. D91, 122002 (2015).

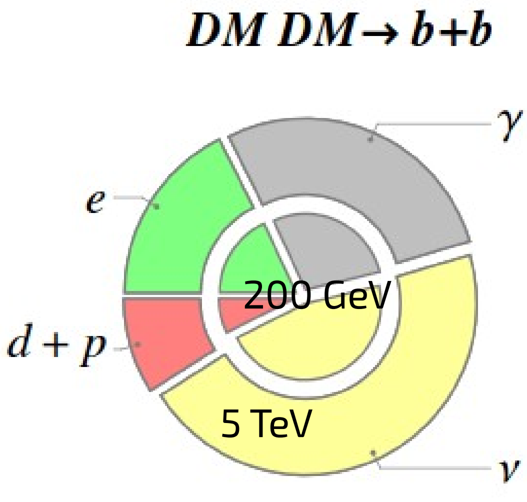


Abdallah, H. & Others. Phys. Rev. Lett. 120, 201101 (2018).

DM searches with anti-protons







Cirelli et al. (2010) "PPPC4DMID"

Anti proton constraints

- Background of secondary anti-protons can be predicted within factor of a few
- AMS-02 measurements marginally consistent with secondary background (Giesen+ 15; Evoli+ 15)
- Hard to exclude astro explanation for excesses above secondaries (e.g. nearby SNR; e.g. Kachelriess+ '15, non-universal diffusion, etc)

See also: Winkler+ 17; Carlson+14; Cirelli+14; Jin+15; Ibe+15; Hamaguchi+15; Lin+15; Kohri+15; Balazs&Li15; Doetinchem+15; Fornengo+13

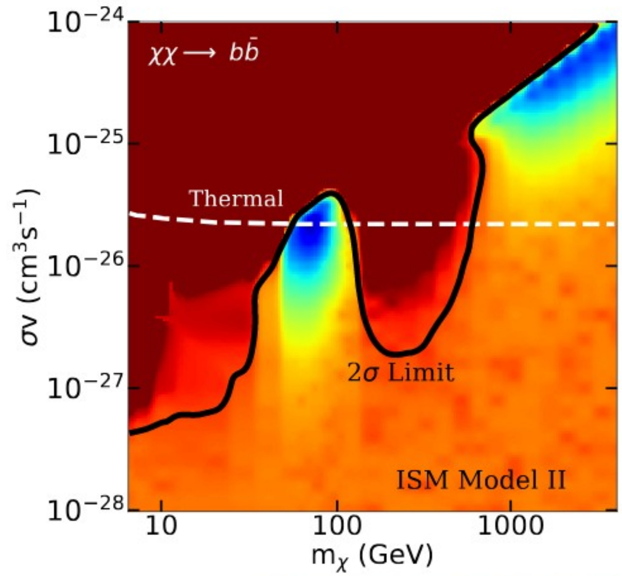
Anti-proton ~15 GV excess?

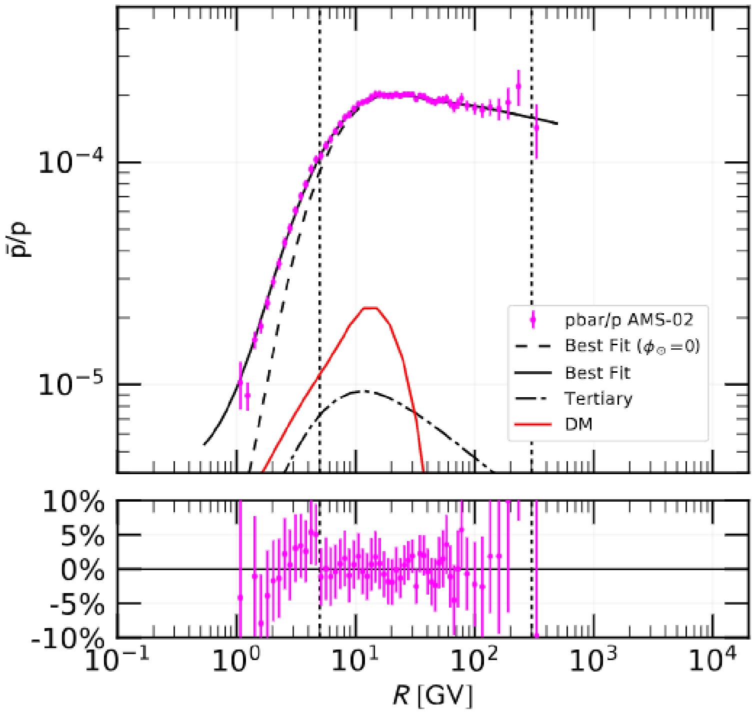
Cuoco+ 2019

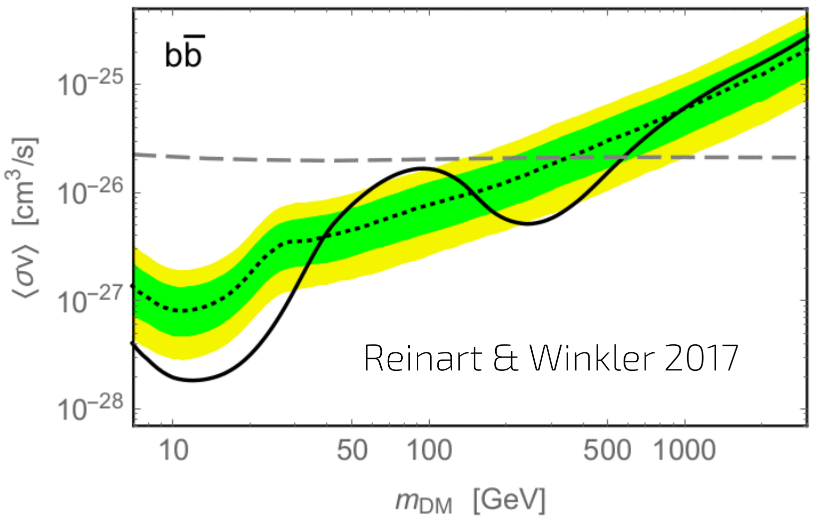
- First identified in Cuoco+ 2017, with ~4 sigma significance
- After new systematic checks, still at few sigma level
  - Marginalizing over pbar production cross section reduces significance
  - Correlated instrumental systematics are important, of same order as excess, but correlation structure is now publically available

Cholis+ 2019

- Check time-/charge-dependend diffusion
- Confirm excess with even higher significance (though no marginalization over all parameters)





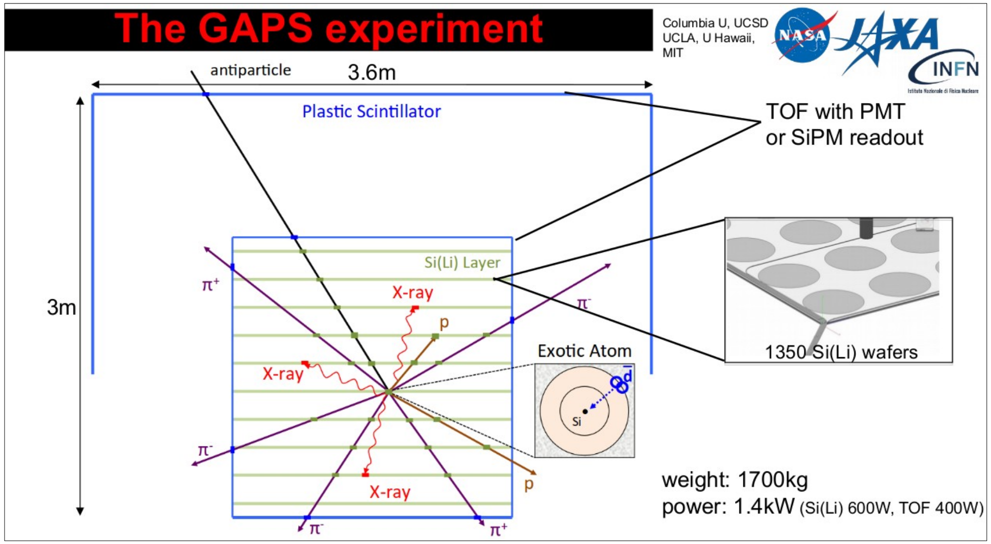


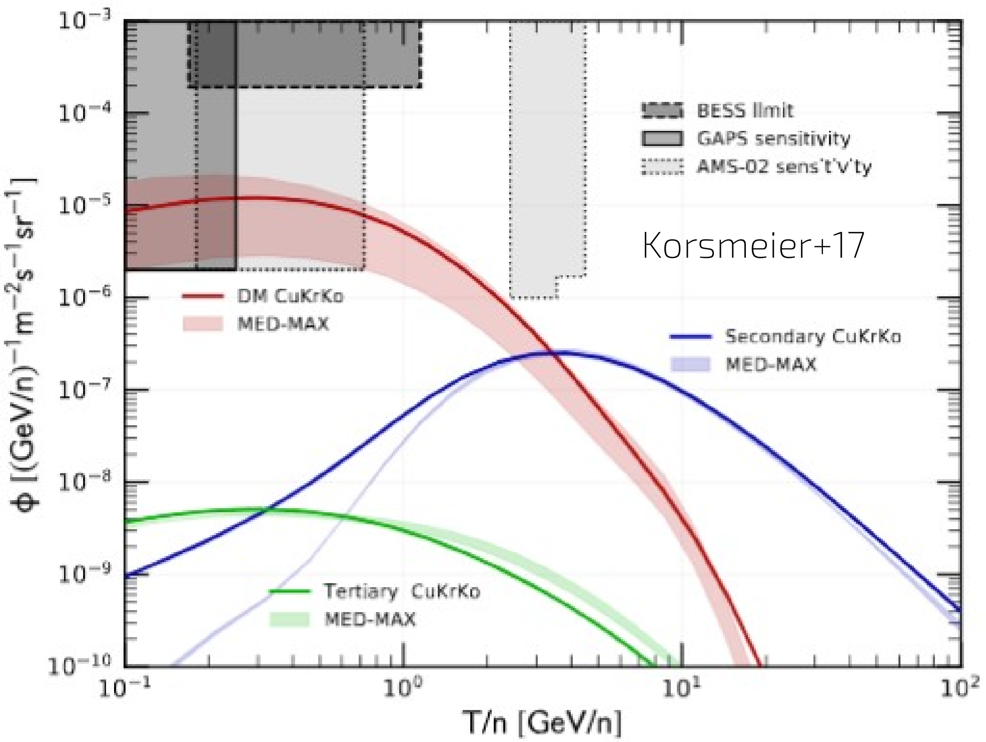
Outlook - GAPS

Searches for **anti-deuterons** with exotic atom formation

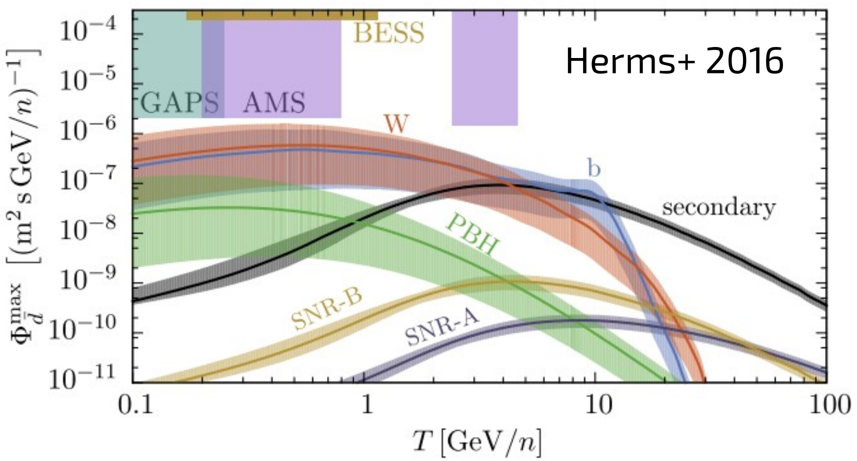
Supported by USA, Italy, Japan. First flight planned for ~2021.

Credit: P. von Doetinchem





See also Aramaki+ 2016

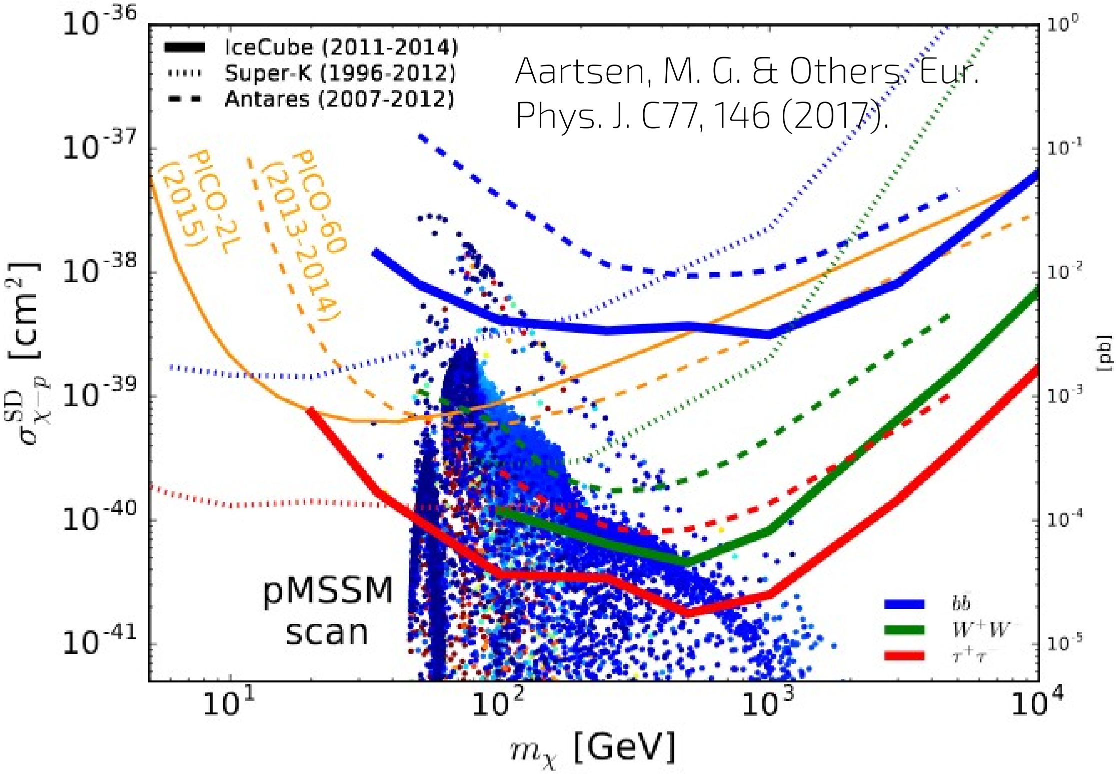


Sever constraints on the range of detectable models comes from AMS-02 anti-protons.

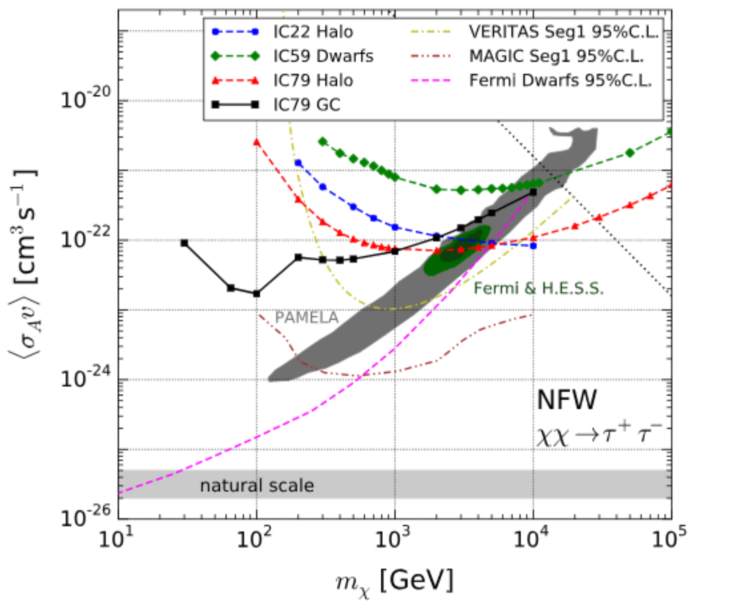
Neutrinos

DM annihilation of WIMPs **captured in the Sun**

→ Flux depends on WIMP-proton scattering (in equilibrium)



DM annihilation in MW

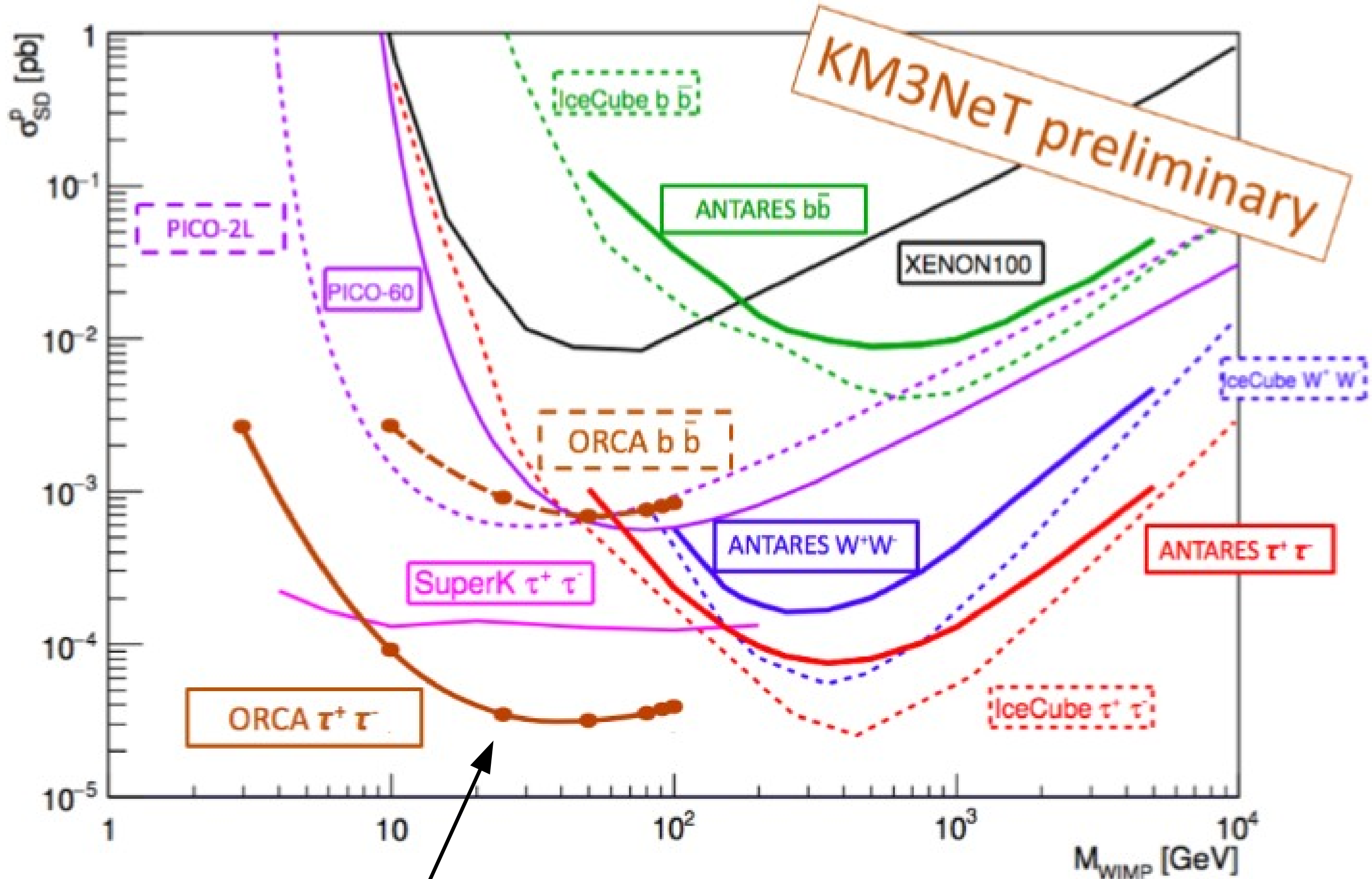


Aartsen, M. G. & Others. Eur. Phys. J. C75, 492 (2015).

Situation

- Most stringent bounds on spin-dependent scattering cross-section in the 10 GeV to multiple TeV range come from neutrino telescopes (IceCube, Super-K)
- However, searches for signal from GC not very competitive since neutrinos usually accompanied by photons etc

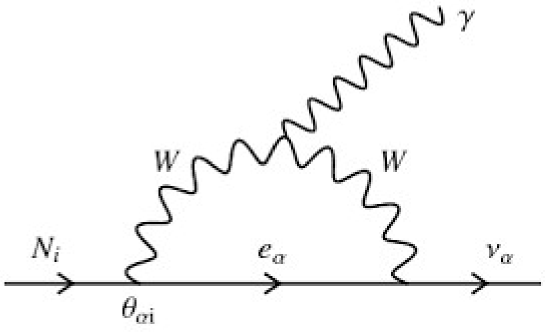
KM3NeT prospects (ORCA)



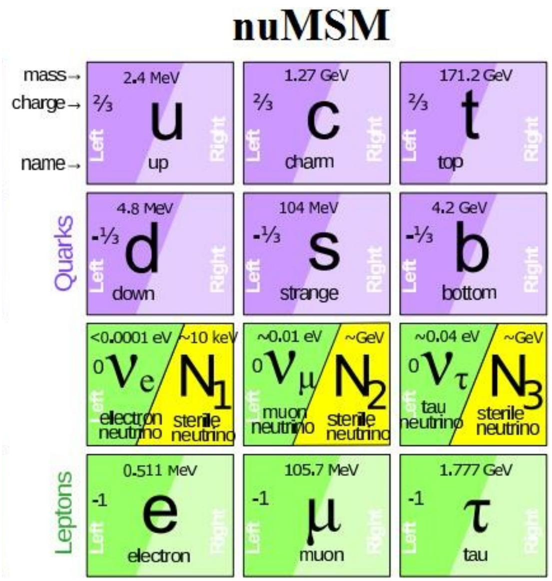
3 years data taking

Coyle+2017

2) Dark matter decay



Sterile neutrino DM searches - Status

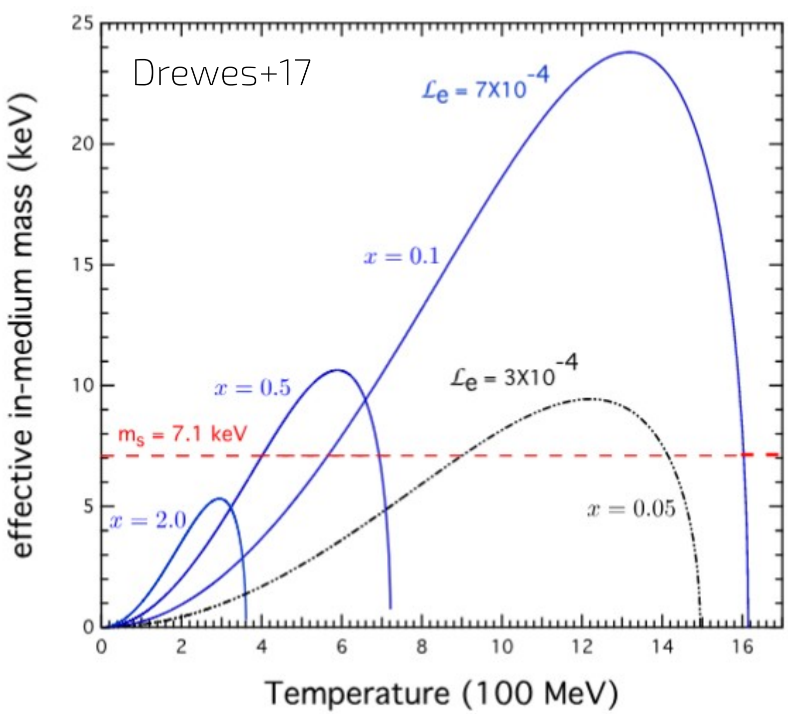


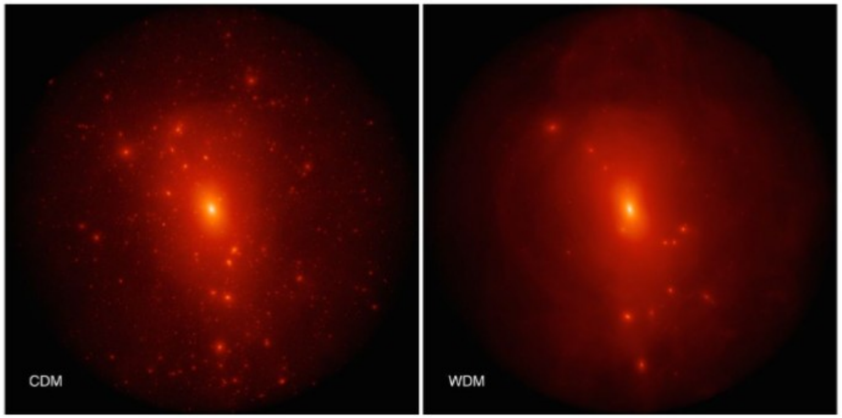
Sterile neutrino dark matter

- Lightest right-handed neutrino can play the role of DM
- Production through active-neutrino mixing, via scattering or oscillation → Warm dark matter

$$\rho = \begin{pmatrix} \rho_{\nu\nu} & \rho_{\nu N} \\ \rho_{N\nu} & \rho_{NN} \end{pmatrix}$$

- Lepton-asymmetry in primordial plasma can cause resonant enhancement of production
  → Cold component

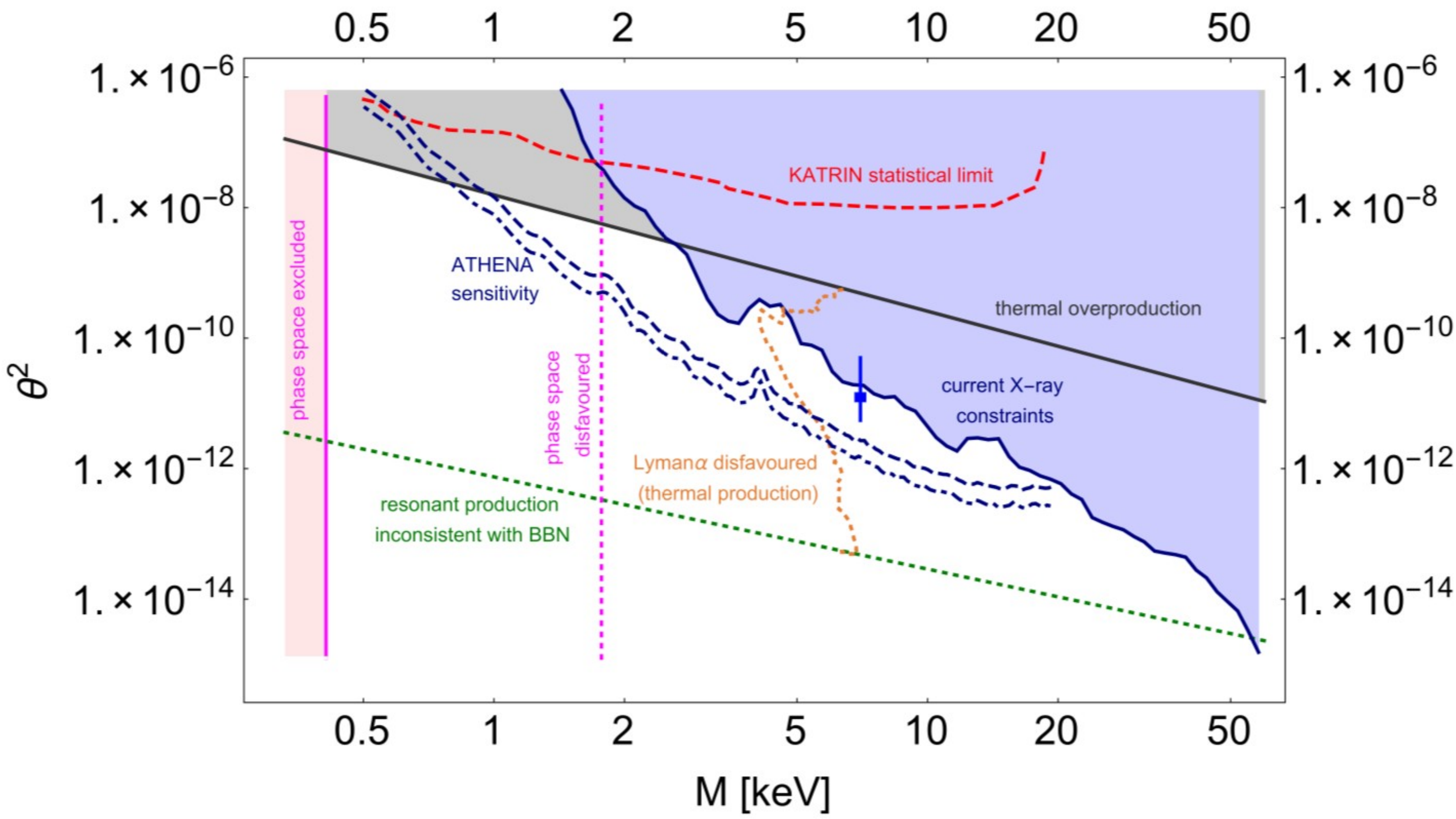




Suppression of small scale structure

Lovell+11; Drewes+17

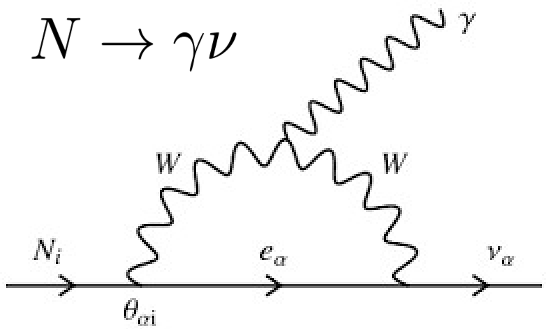
Sterile neutrino DM searches - Status

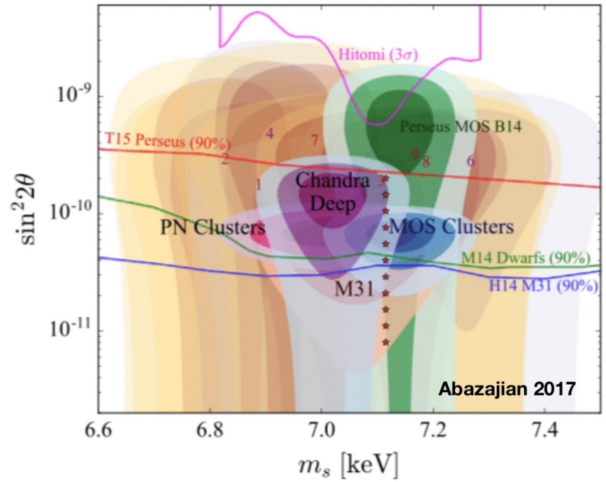


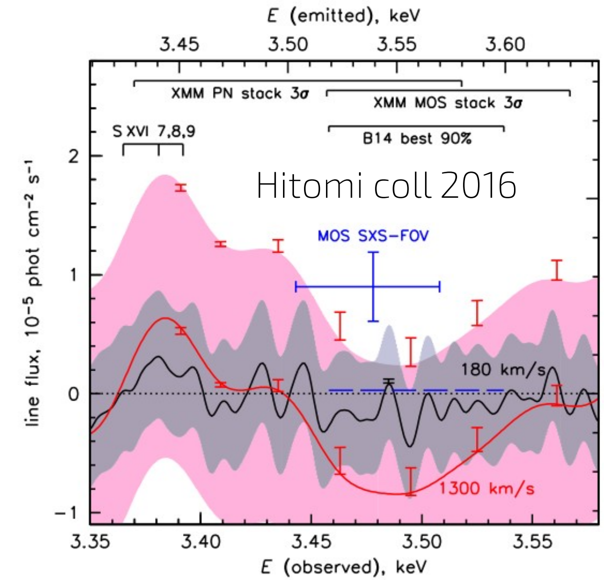
Credit: Ruchaysky

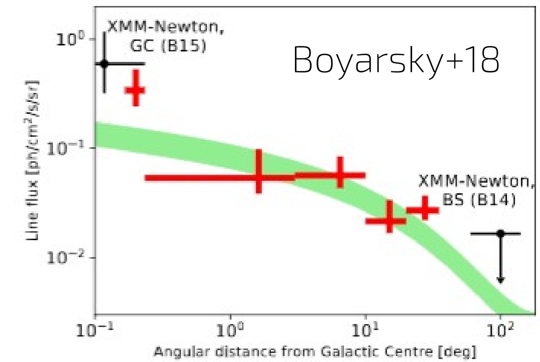
The 3.5 keV feature

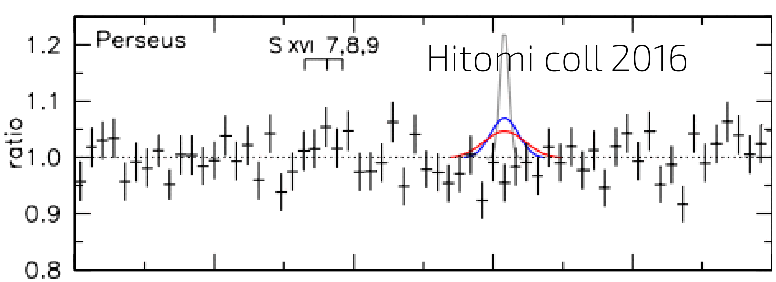
$N \to \gamma\nu$











Situation

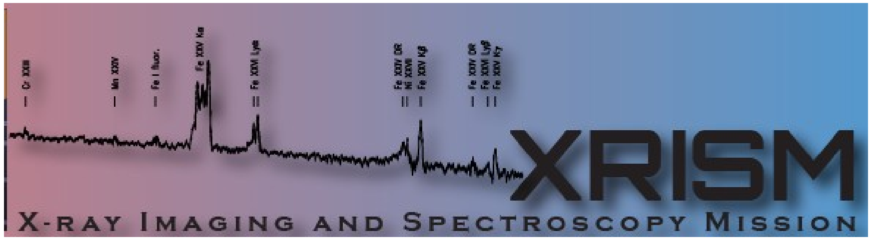
- Found in 4 different detectors
  XMM-MOS/PN, Chandra, Suzaku, NuStar
  [Boyarsky+14, Bulbul+14, ...]
- Found / hinted for in multiple targets
  Milky Way & Andromeda, Perseus cluster, Draco dSph, stacked clusters, COSMOS & Chandra deep fields
- However: Results are somewhat analysis- and target dependent, need to get bkgs right etc
  Non-detections in some deep field analysis, nearby galaxies
  [Anderson+15, Dessert+18, Boyarsky+18]
- Hitomi observations disfavour Potassium line interpretation (or other narrow lines)
  Still possible: Sulphor ion charge exchange?
  [Gu+15&17, Shah+16]

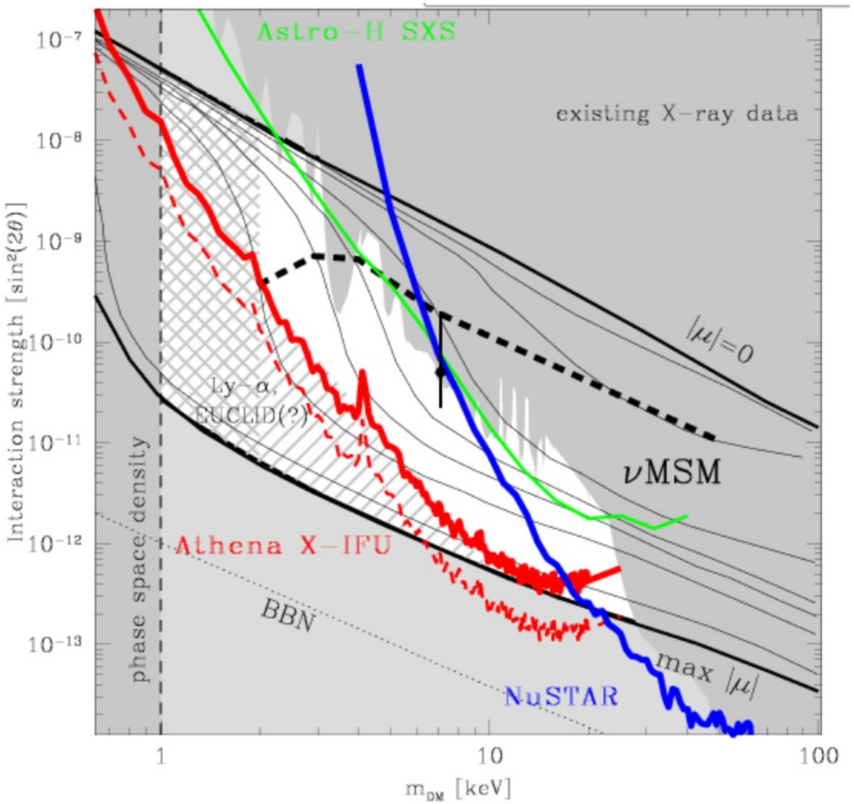
Prospects

- Hitomi: Initial observations (before satellite desintegrated) demonstrated power of spectrometers to probe DM interpretation
- XRISM (Hitomi replacement, scheduled for launch in 2021)

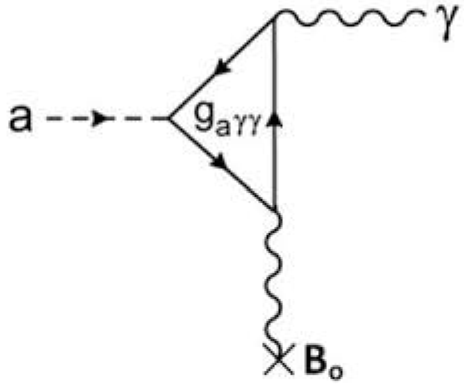
  → Check line width (10x difference expected between atomic and DM lines in Perseus)

  → Resolve atomic lines
  → Measure position
  → Measure actual line flux from many targets
- Athena+ (~2028)
  Large X-ray imaging & spectrometer mission
  → Will allow "dark matter astronomy", if DM lines are confirmed

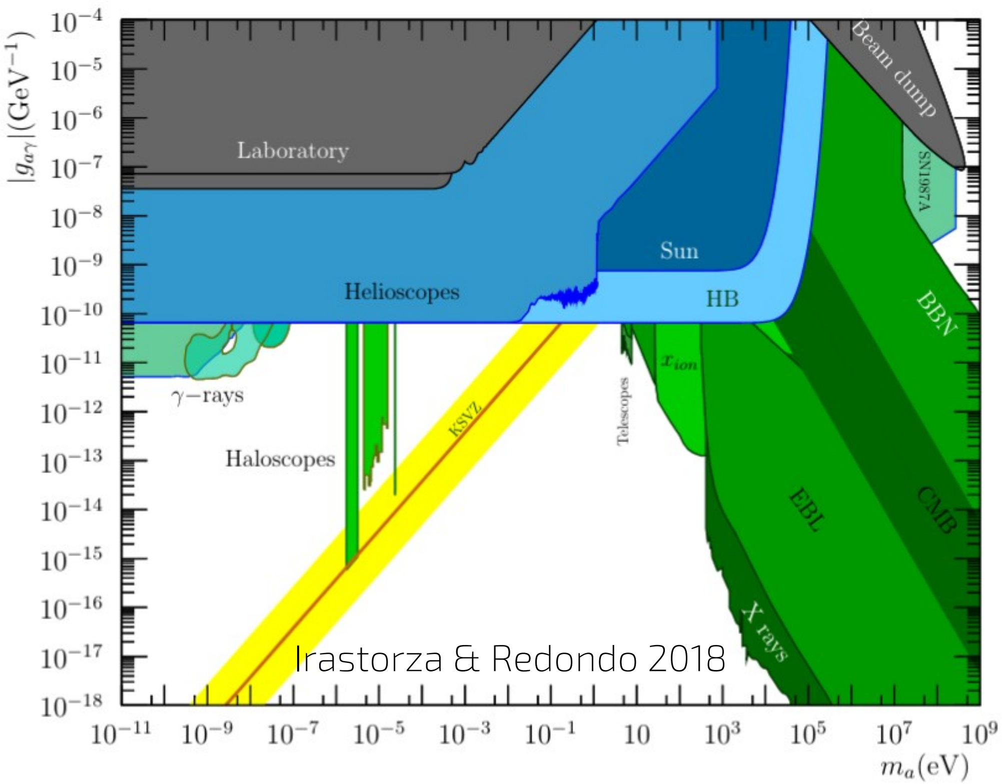




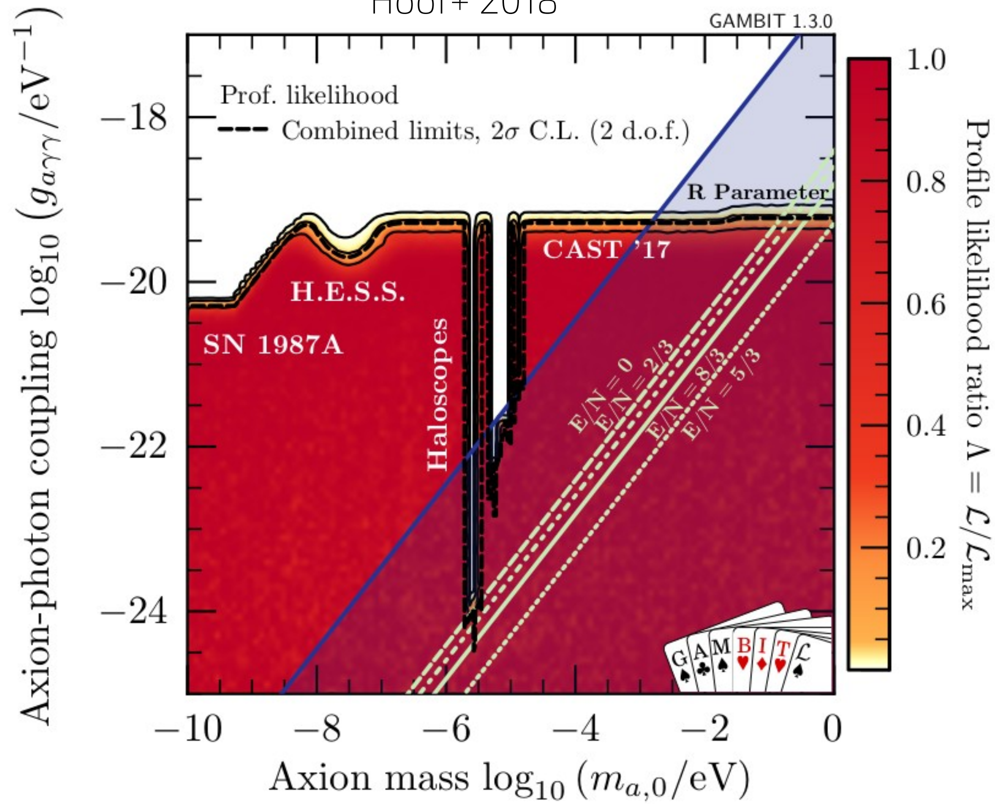
3) Dark matter conversion



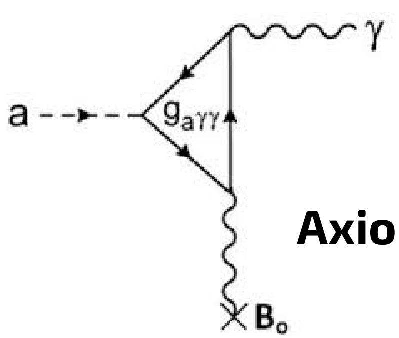
Axion Dark Matter - Status



Hoof+ 2018

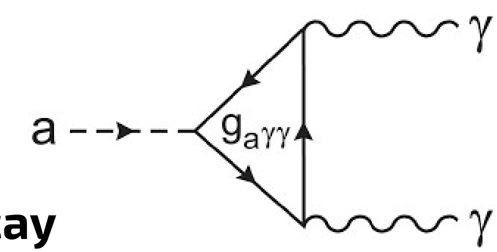


$$\mathcal{L}_a^{\mathrm{int}} = -\frac{g_{a\gamma\gamma}}{4} A F_{\mu\nu} \widetilde{F}^{\mu\nu}$$



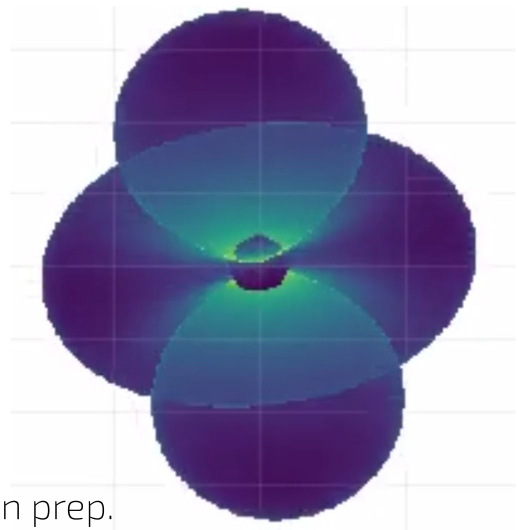
Axion-photon conversion

Axion decay
& stimulated emission

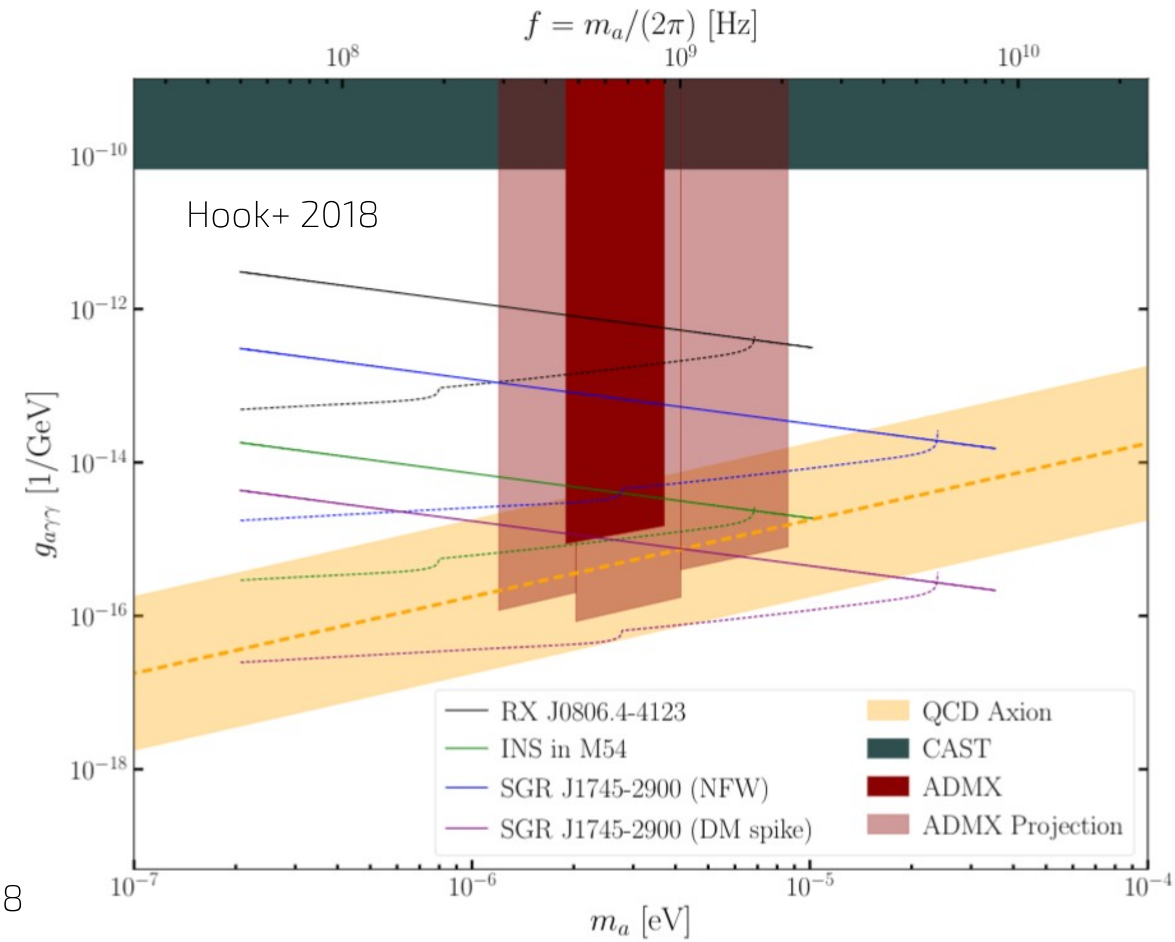


Radio searches for axions - Sensitivity

Ray-tracing simulation of DM axion-photon conversion signal from neutron stars



See also Pshirkov 2009; Kelley & Quinn, 2017; Safdi+18



- Searches have clear discovery potential for QCD axions, but constraints will depend on our understanding of neutron star magnetospheres.
- Other targets: Dwarf spheroidals, white dwarfs (X-ray)

  Safdi+19; Caputo+18

Some ongoing searches (all this year)

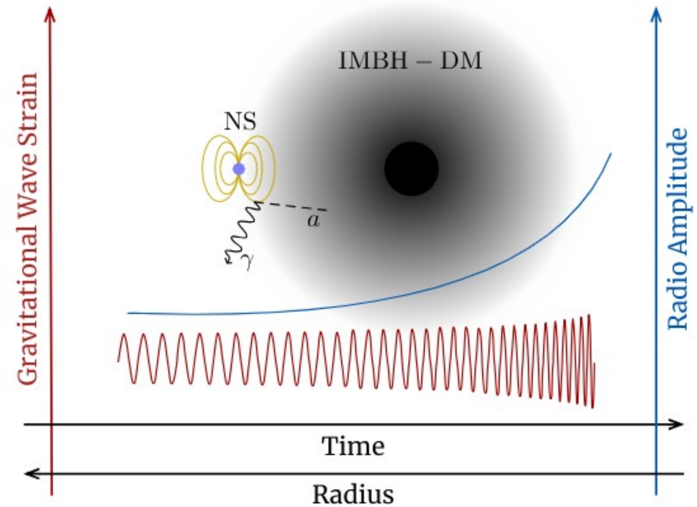
- Effelsberg telescope
- Greenbank telescope
- Murchison Widefield array
- Sardinia radio telescope

Probing axion DM with GWs & radio?

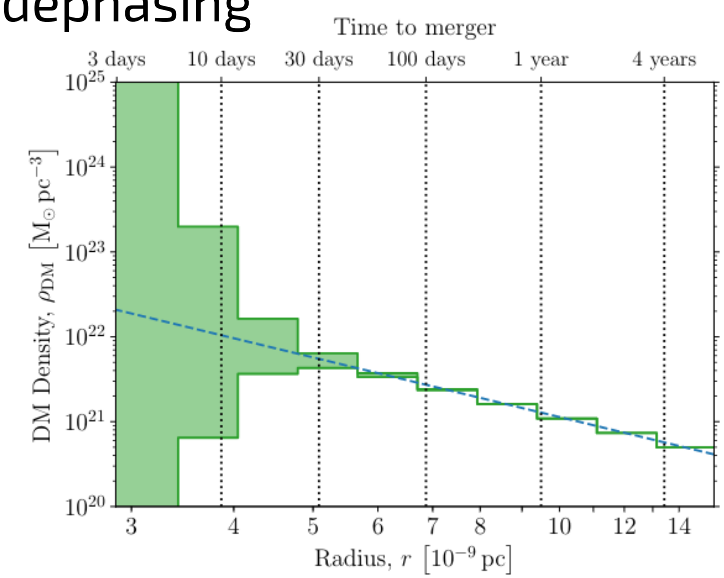
Grav. Wave (LISA) & radio observation

- De-phasing of GW signal
  → Measurement of DM spike profile
- Radio observations
  → Probing axion-photon conversion

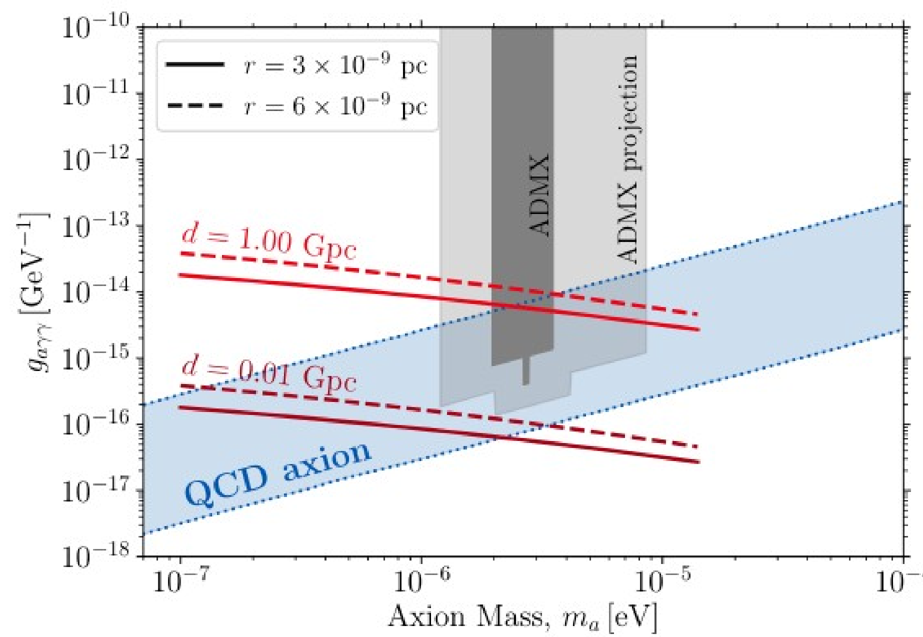
Tom Edwards+, to appear tomorrow



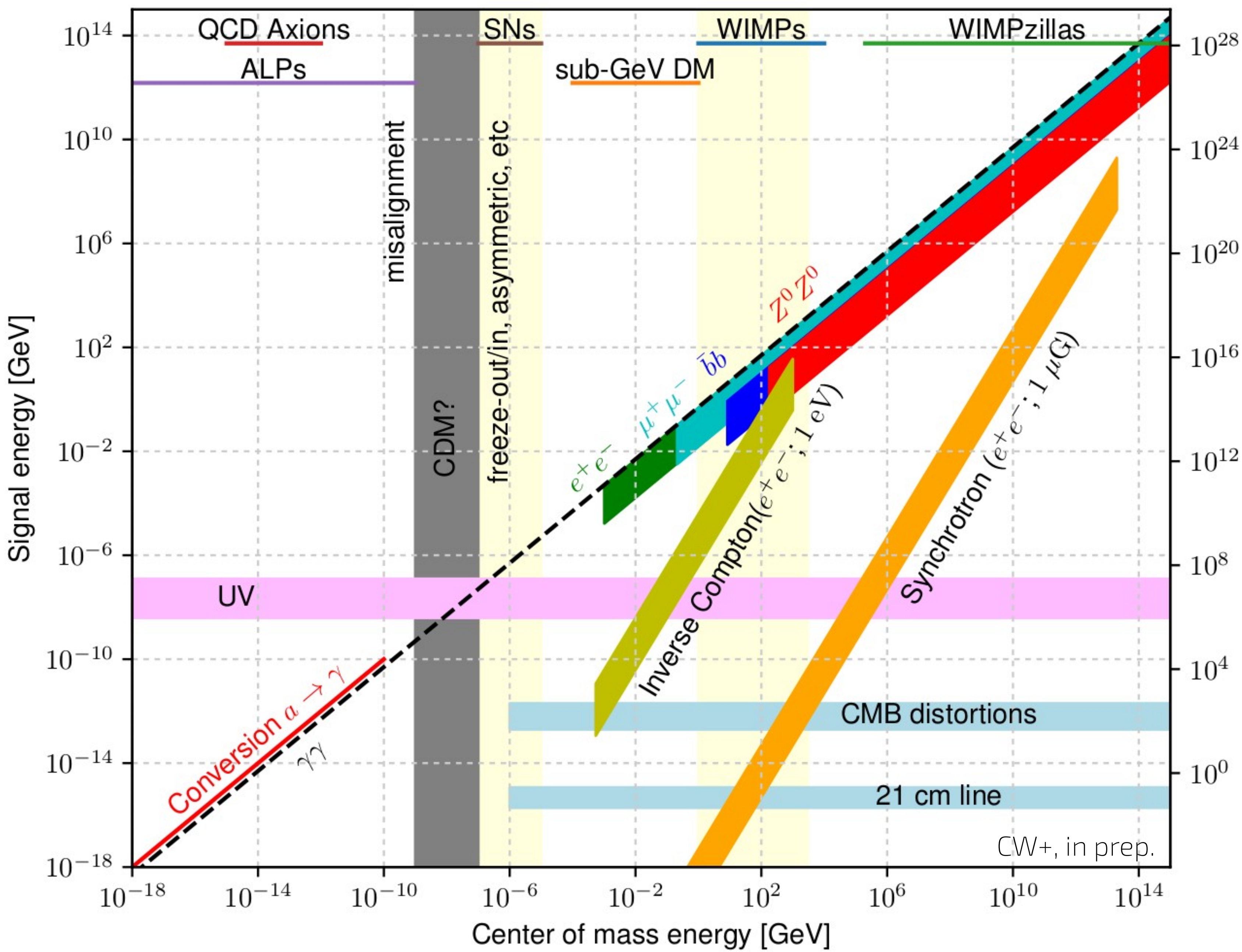
DM profile reconstruction uncertainties from dephasing



Reach SKA (100h)



Emission energy vs. DM mass



LHAASO (~2021)

CTA (~2025)

KM3NeT-ORCA (construction)

GAPS (~2021)

AMEGO (proposed)

XRISM (~2022)

SKA (~2025)

Conclusions

- Indirect dark matter searches make slow but steady progress
- Annihilation searches are approaching the thermal cross-section, exclude s-wave annihilation below ~100ish GeV (depending on channel)
- Most robust constraints from dSphs, despite J-value discussion, but also lines and positrons; pbar or Fermi halo are stronger, but more prone to systematics
- 10 years after its discovery, the Fermi GeV excess is still around, and arguably caused by MSPs. But situation remains unclear (pbar excess, Fermi data not conclusive → Radio searches badly needed)
- Various upcoming or proposed missions (CTA, AMEGO, …) will probe sub-thermal cross-section below and above Fermi energy range
- Sterile neutrinos: 3.5 keV feature remains largely consistent with DM interpretation, but astrophysical causes hard to exclude → XRISM will bring resolution in the next years
- Conversion of axion DM into photons can be probed with radio observations, X-ray, gamma-rays. This is largely unexplored, lots of progress to be expected during upcoming years

Thank you!