

CAP Congress - June 2014 - Sudbury

Recent Developments in Astroparticle Physics

Adam Ritz

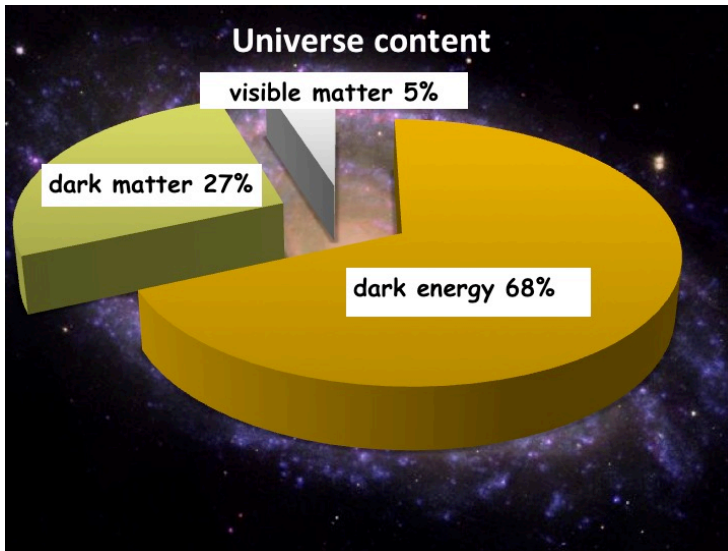
University of Victoria



Astroparticle Physics

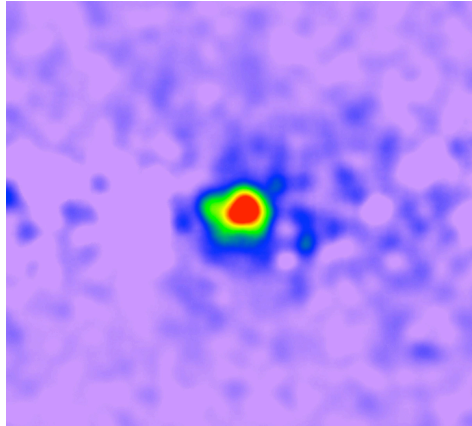
- Fundamental physics in (and from) the cosmic laboratory
 - New physics
 - e.g. dark matter, ...
 - New regimes
 - e.g. (very) high energy accelerators,

← A working definition of “astroparticle physics” for this talk

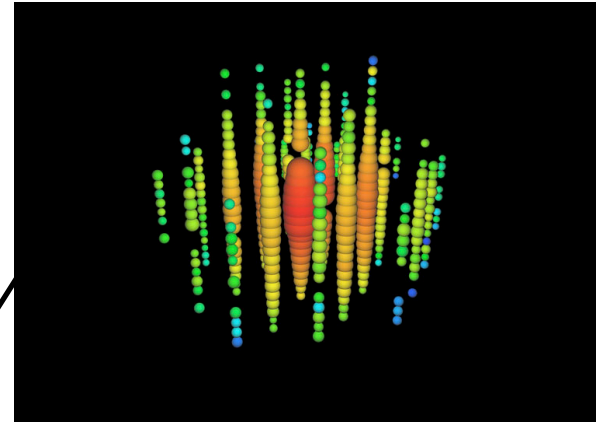


Large and active experimental and theoretical field. This overview will be a bit biased, focussing mainly on searches for dark matter

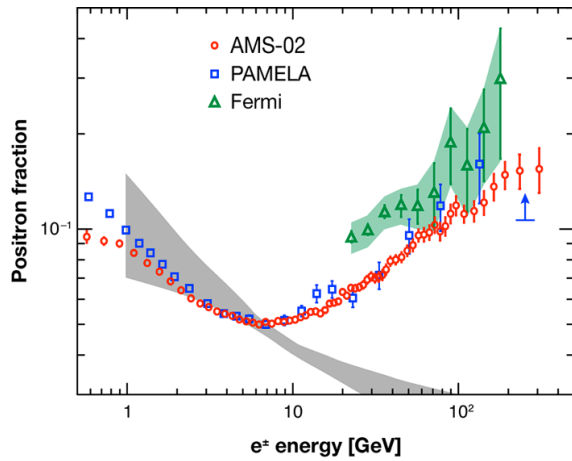
2013-14 News items



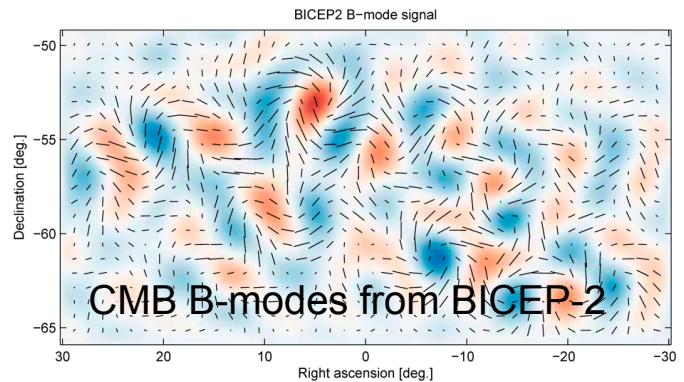
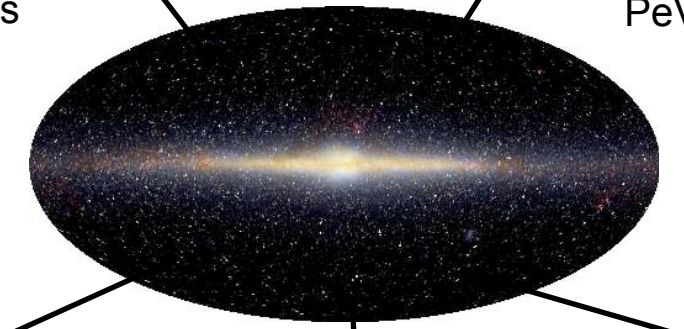
DM indirect γ -ray signals



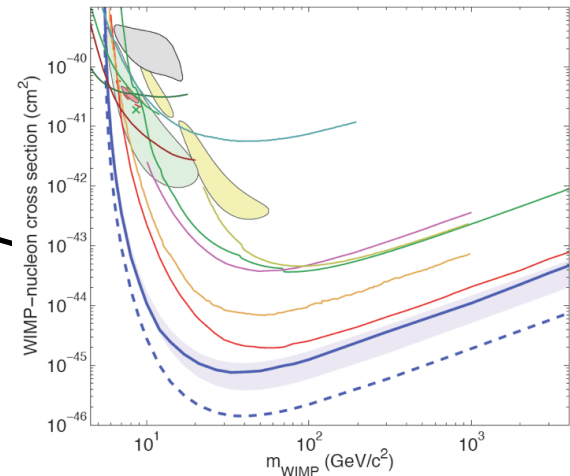
PeV neutrinos in IceCube



Cosmic ray positron fraction

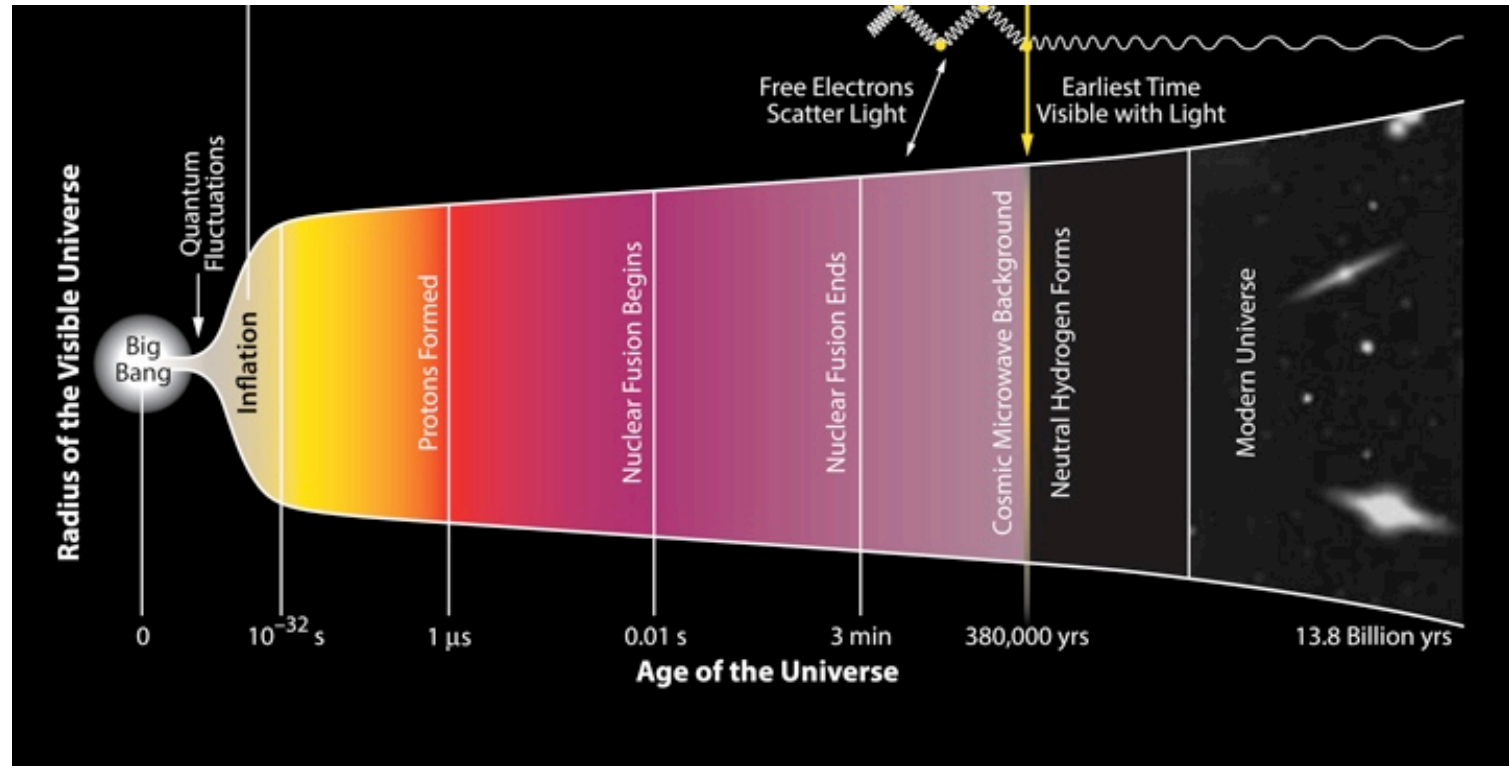


CMB B-modes from BICEP-2

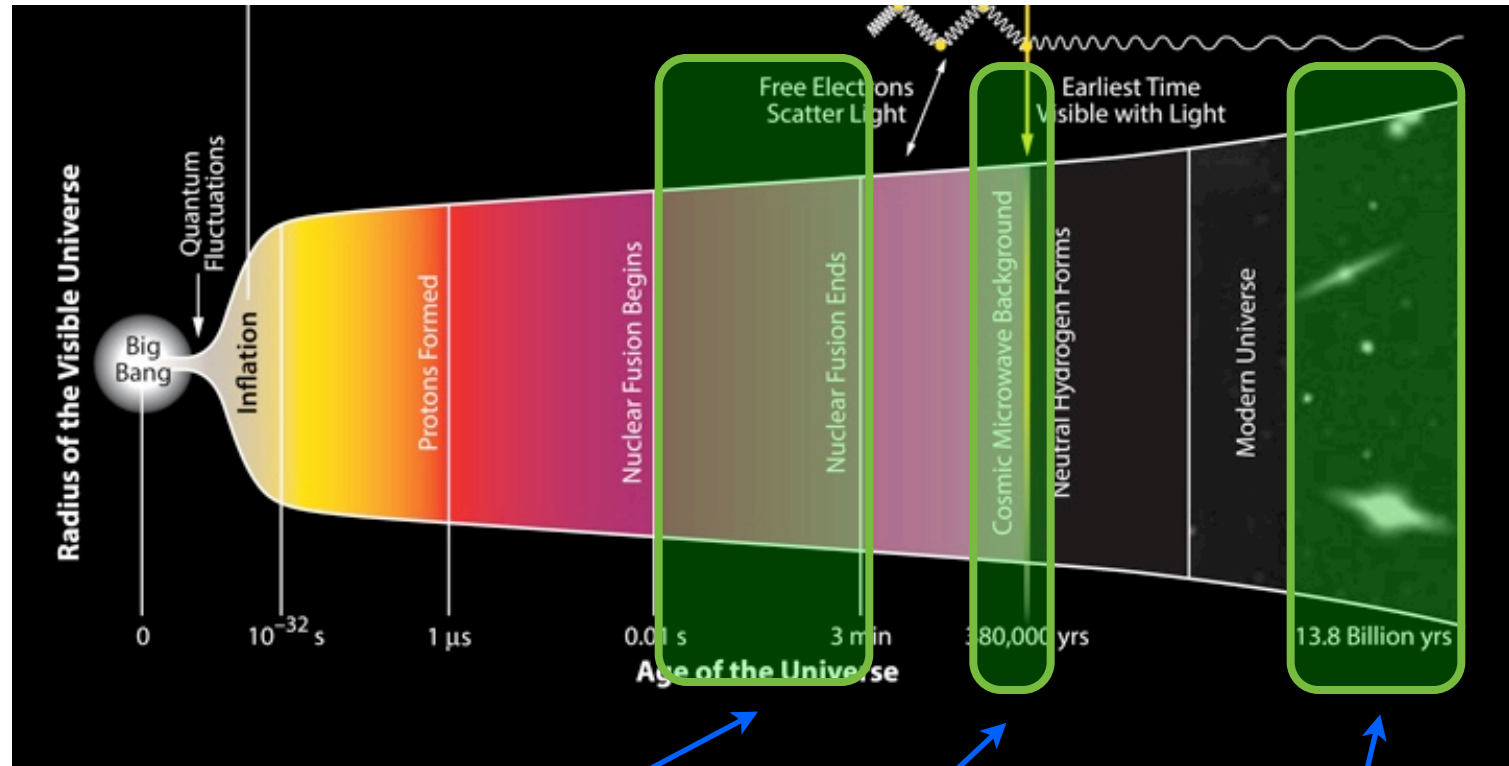


DM Direct detection limits

News items - chronological



News items - chronological

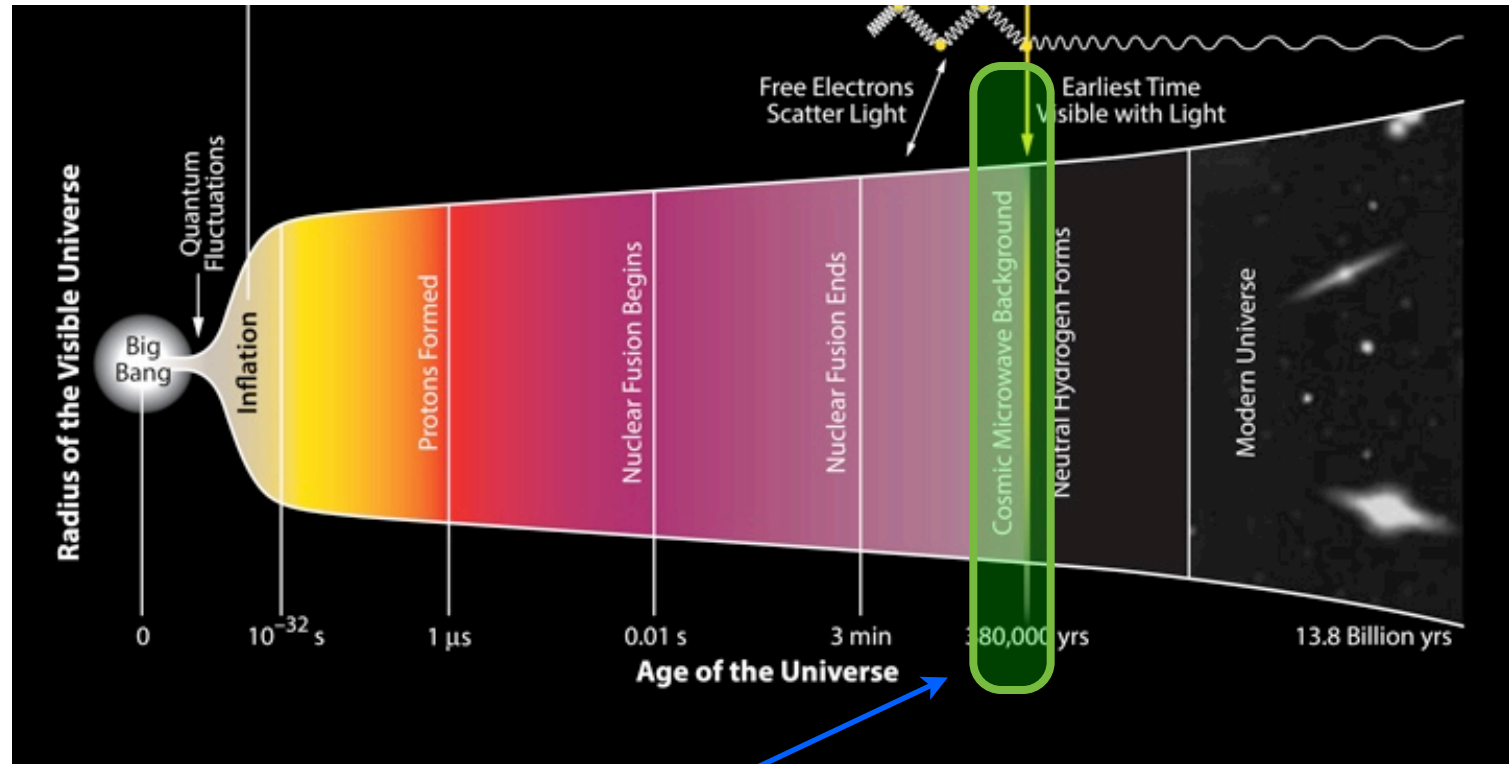


Precision BBN

Precision CMB

Multi-messenger
astronomy

News items - chronological

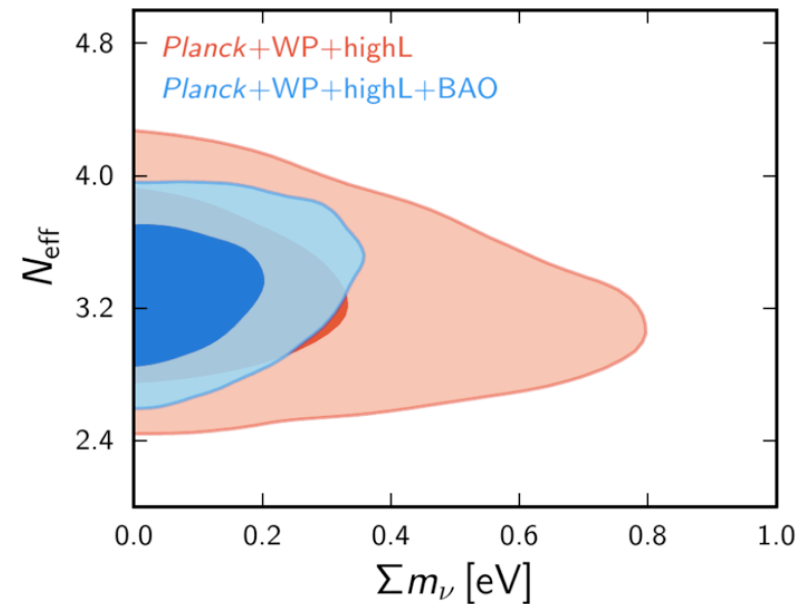
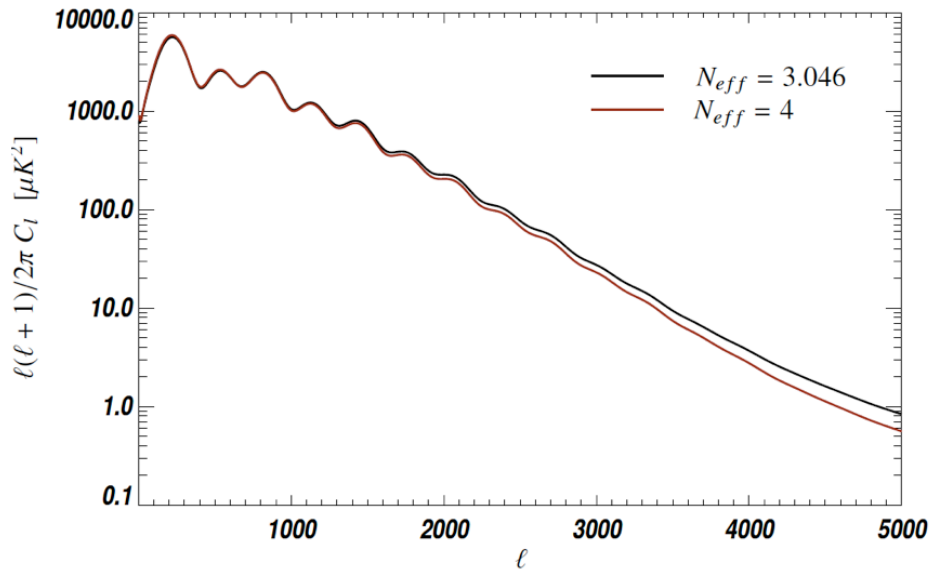


Precision CMB - focus on sensitivity to new degrees of freedom (Planck, BICEP2)

CMB sensitivity to light degrees of freedom

Important test of new light (relativistic) degrees of freedom, that affect the energy density during radiation domination

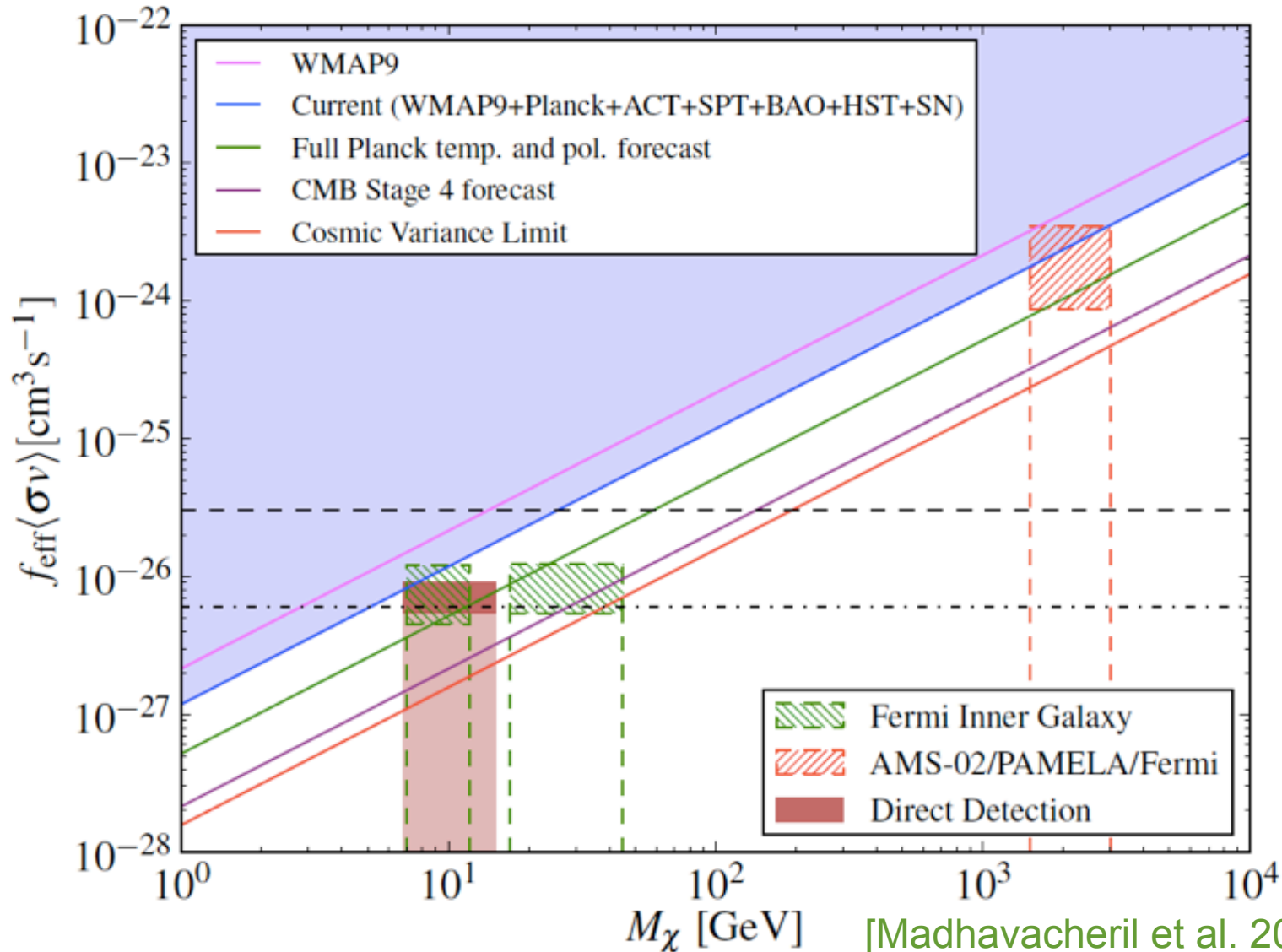
$$\rho_\nu \propto N_{\text{eff}} T^4$$



[Planck 2013]

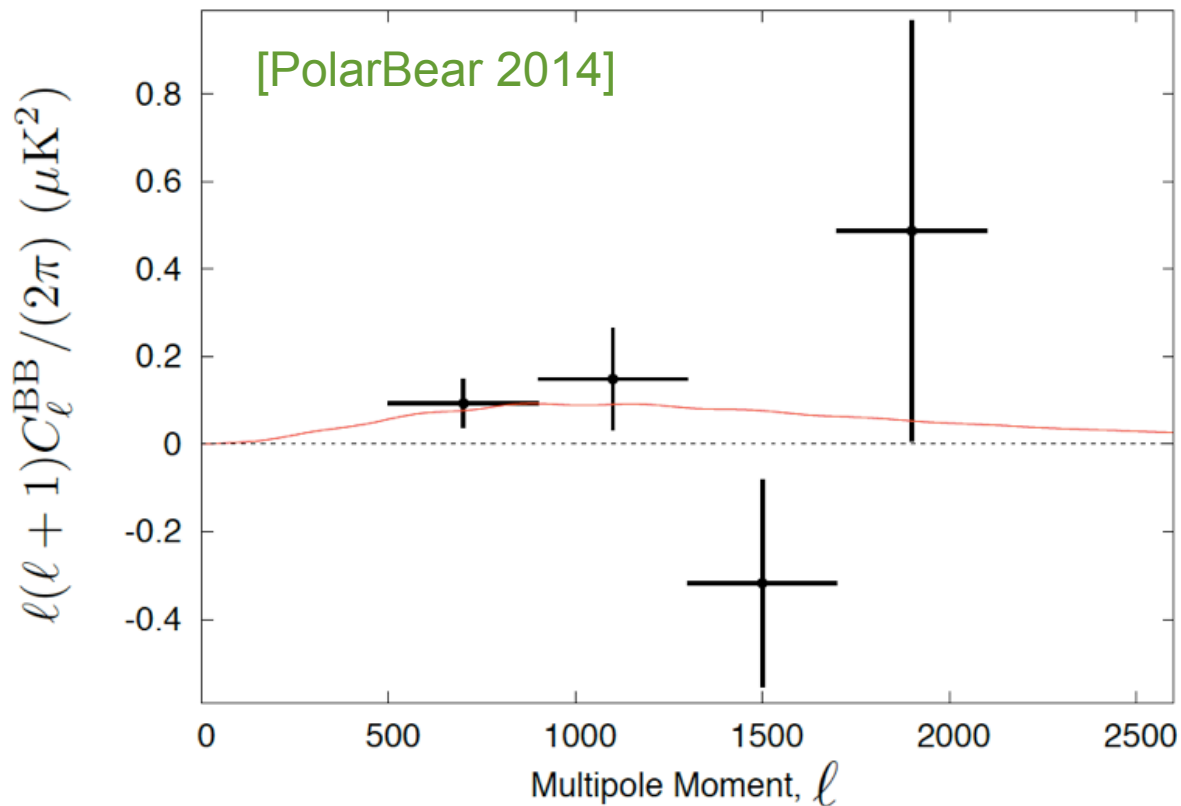
CMB sensitivity to DM annihilation

Sensitivity to residual DM annihilation around recombination



CMB B-modes

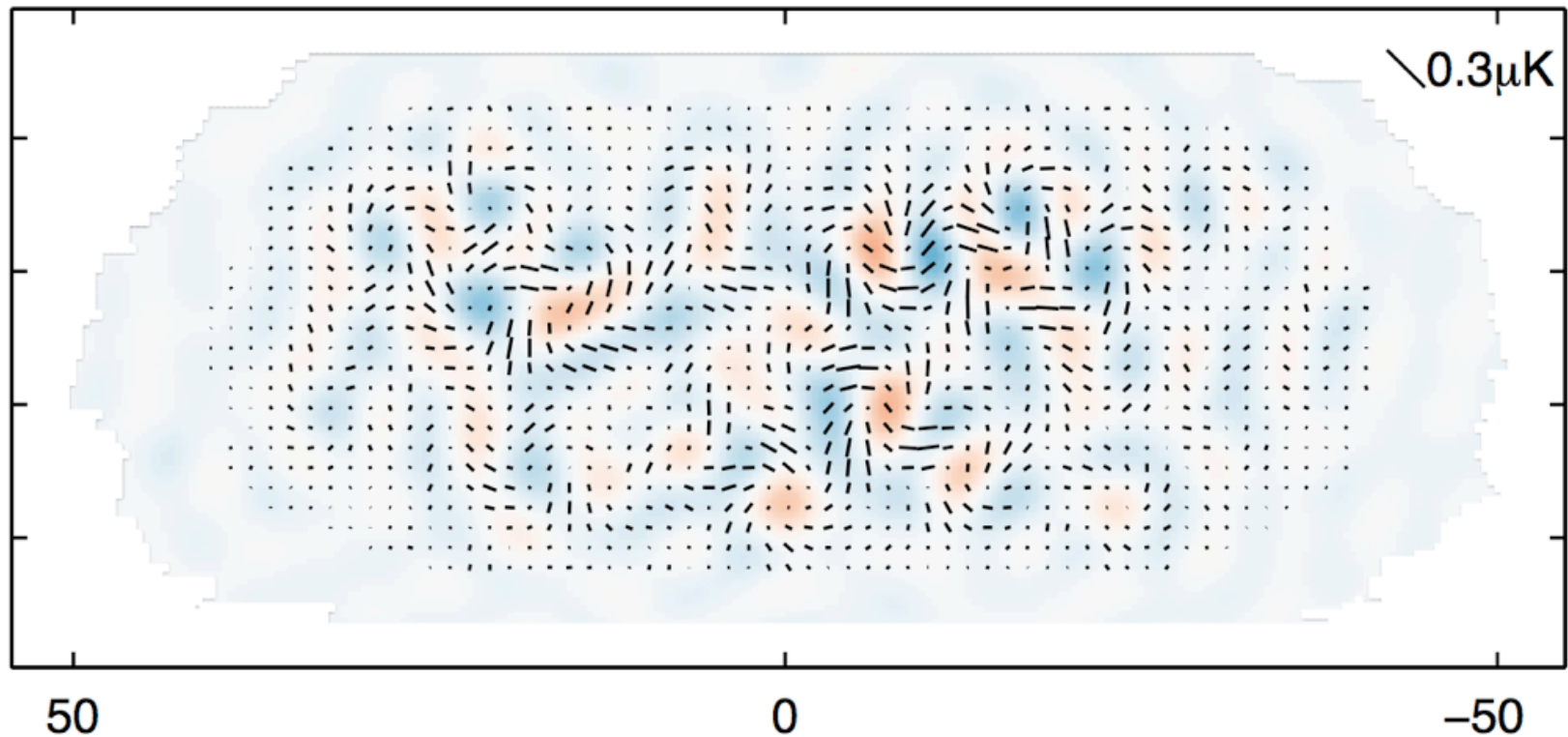
- First observation of lensed B-modes
 - EB correlation from SPTPol
 - BB from PolarBear



CMB B-modes

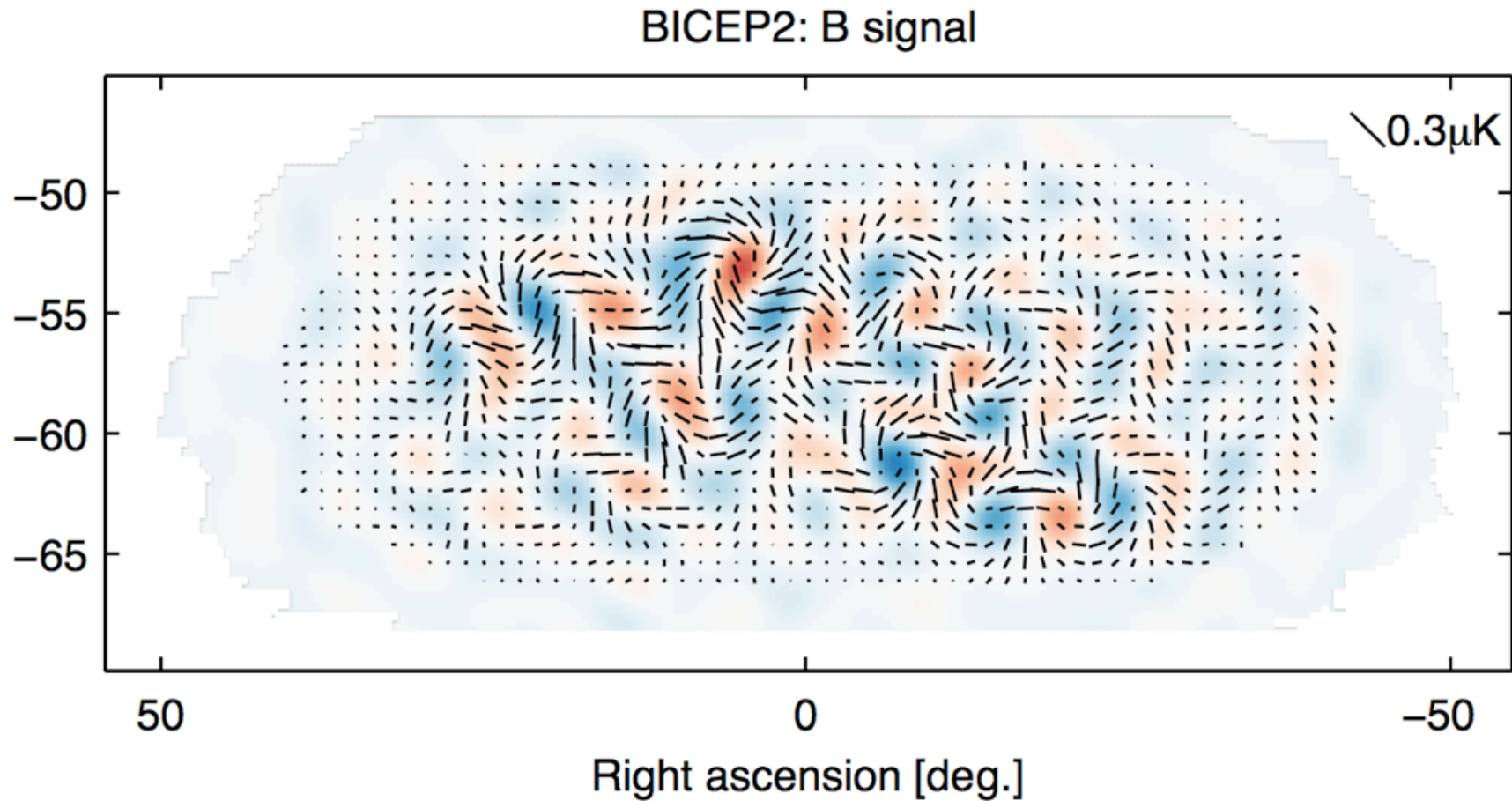
- First observation of lensed B-modes
- First claimed observation of primordial B-modes from BICEP2

Simulation: B from lensed- Λ CDM+noise



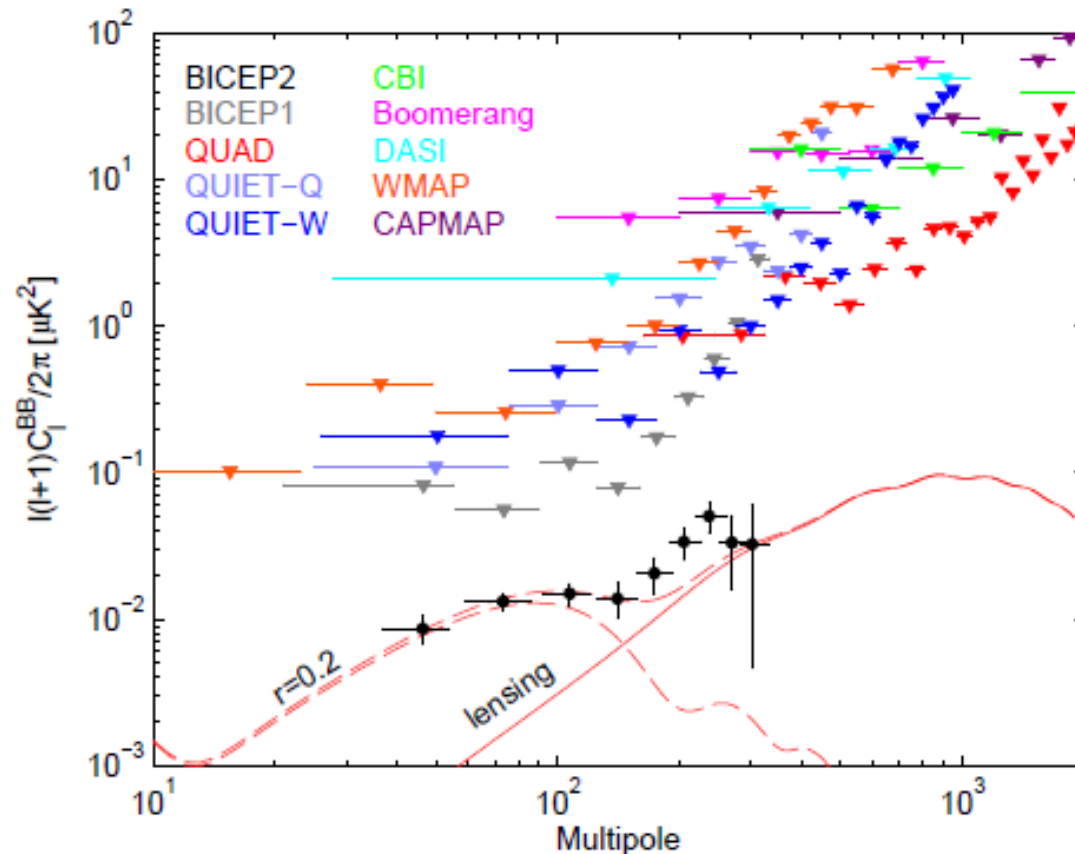
CMB B-modes

- First observation of lensed B-modes
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CMB B-modes

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 - assumes foregrounds, e.g. from dust, are negligible (to be checked!)



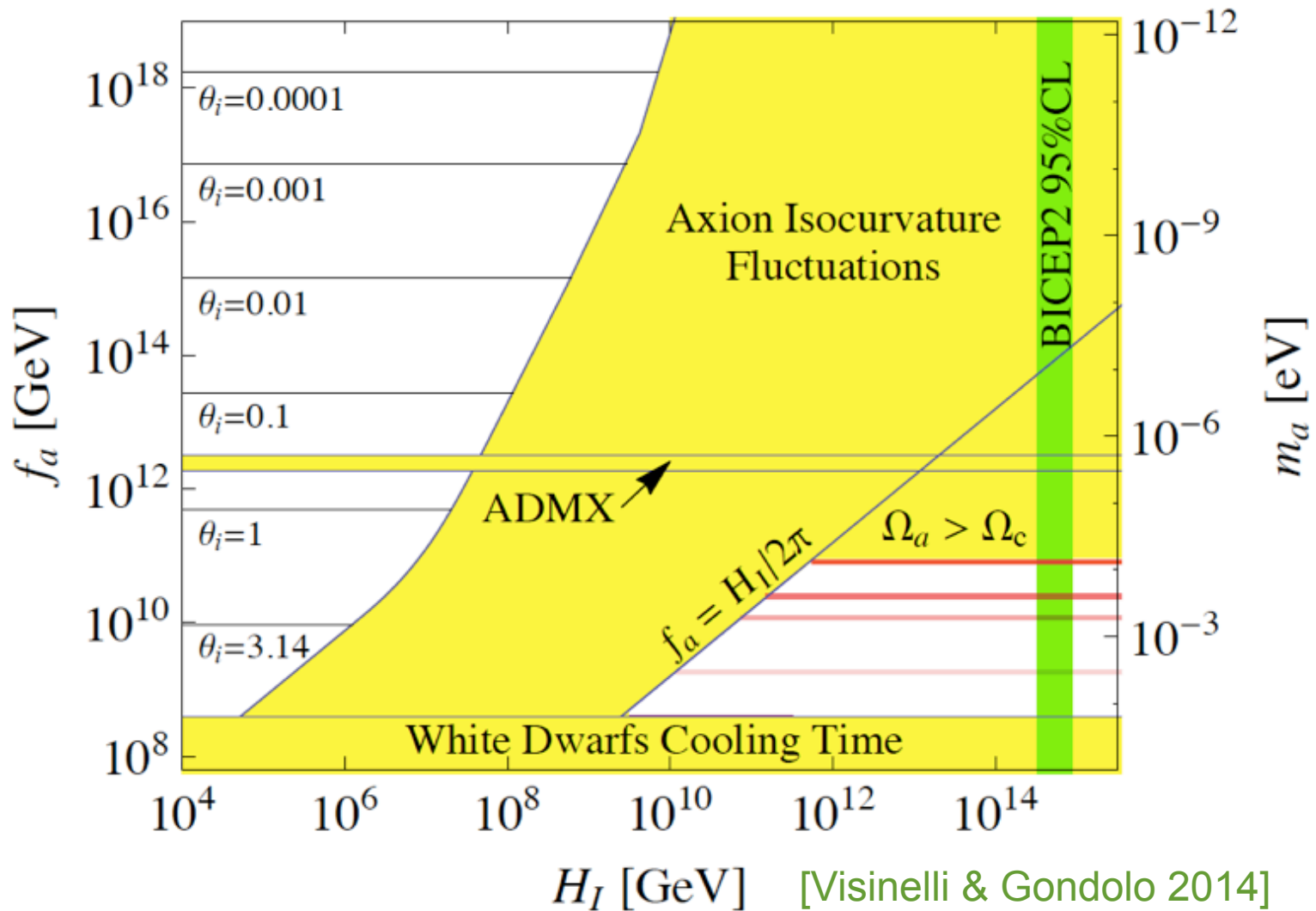
CMB B-modes

- First observation of lensed B-modes
- First claimed observation of primordial B-modes from BICEP2
 - assumes foregrounds, e.g. from dust, are negligible (to be checked!)
 - If primordial, the signal appears consistent with gravitational waves generated during inflation with a simple $V \sim m^2\phi^2$ inflaton potential
 - Inflation at the GUT energy scale of 10^{16} GeV!

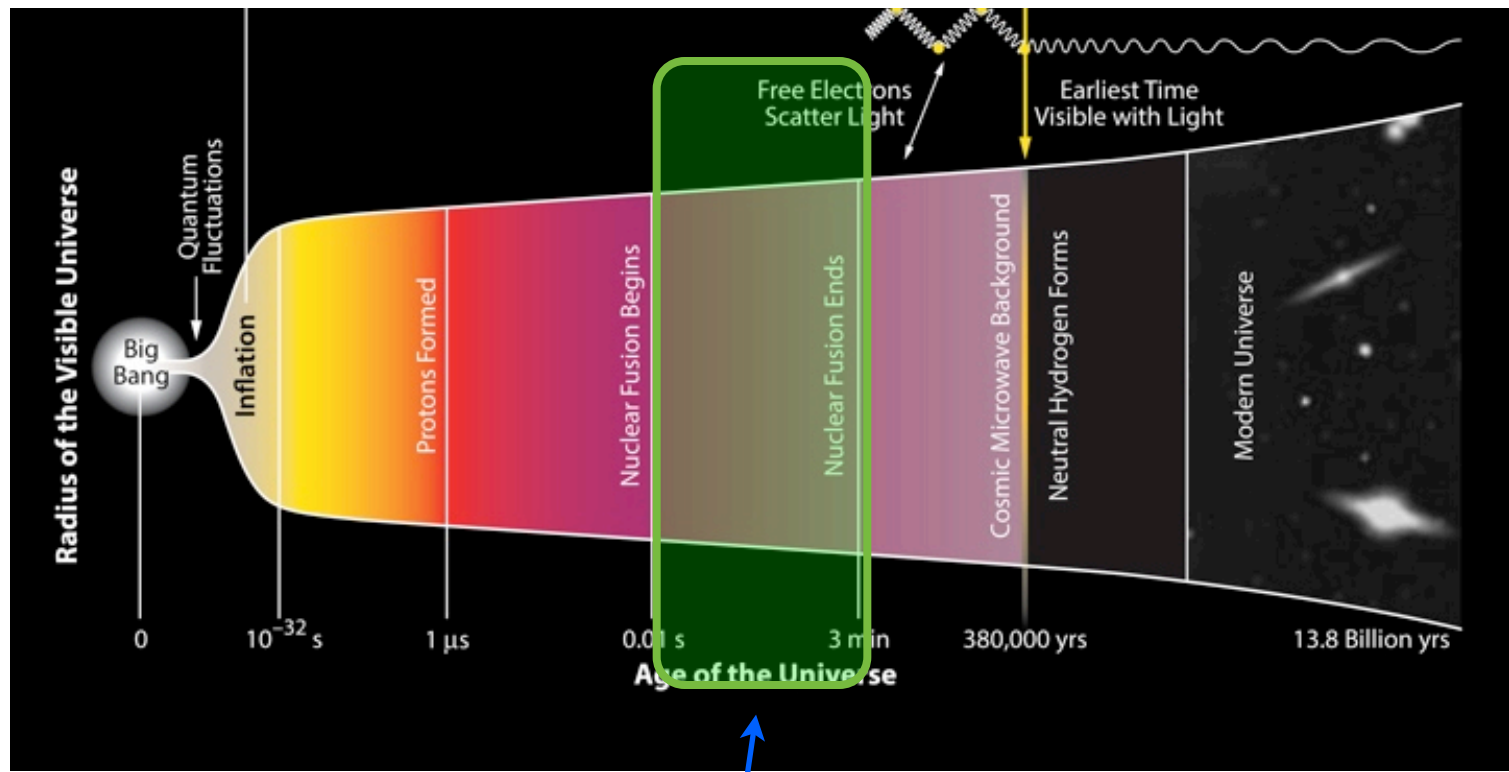
$$r = 0.14 \left(\frac{H}{10^{14} \text{ GeV}} \right)^2$$

High inflationary scale vs axion DM

Any “measurable” value of r would point against high scale axion DM due to the constraints on isocurvature perturbations



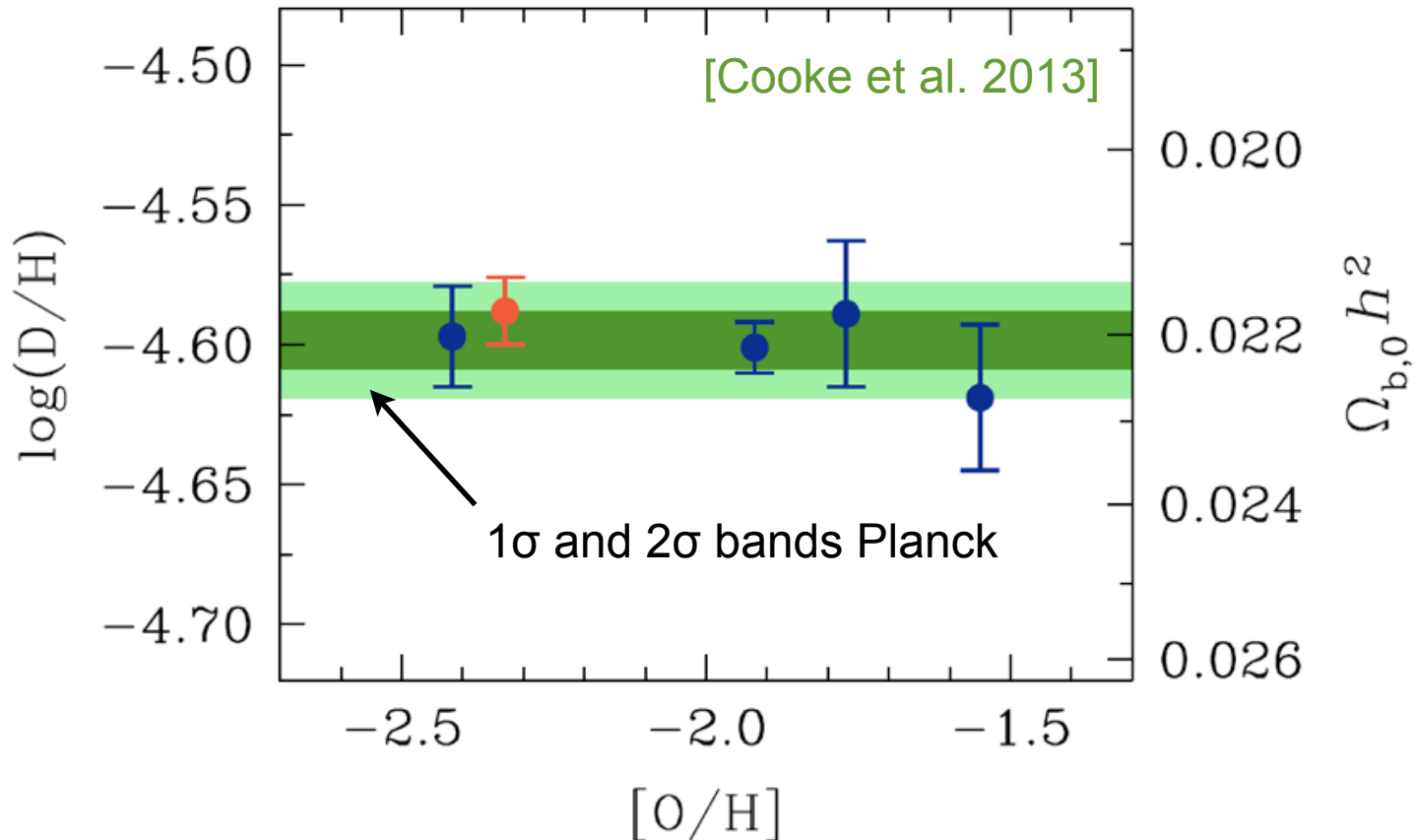
News items - chronological



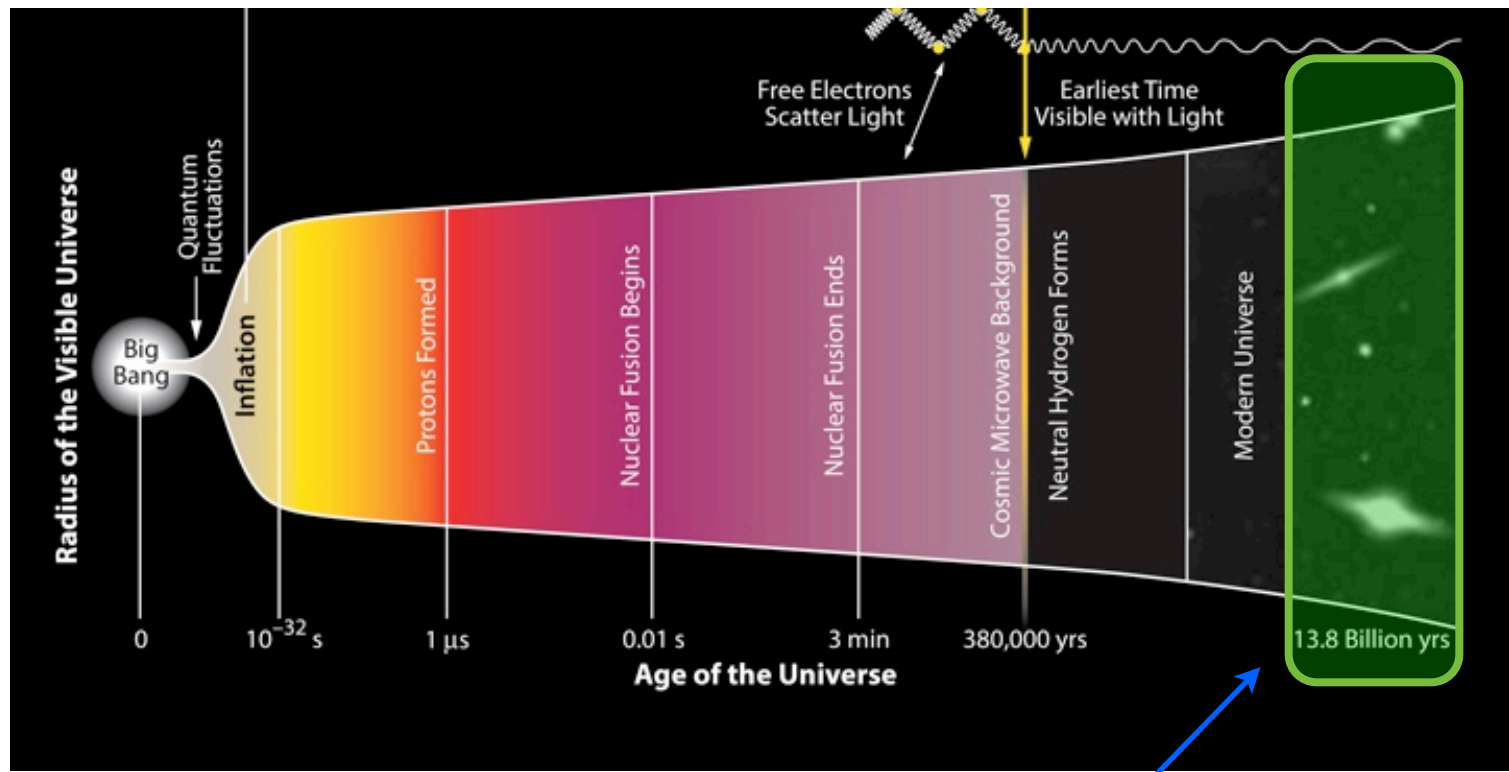
Precision BBN

Precision BBN

- Recent determinations of the BBN Deuterium abundance from BBN, using absorption in metal-poor high- z Lyman- α systems
 - percent-level consistency of baryon abundance with CMB



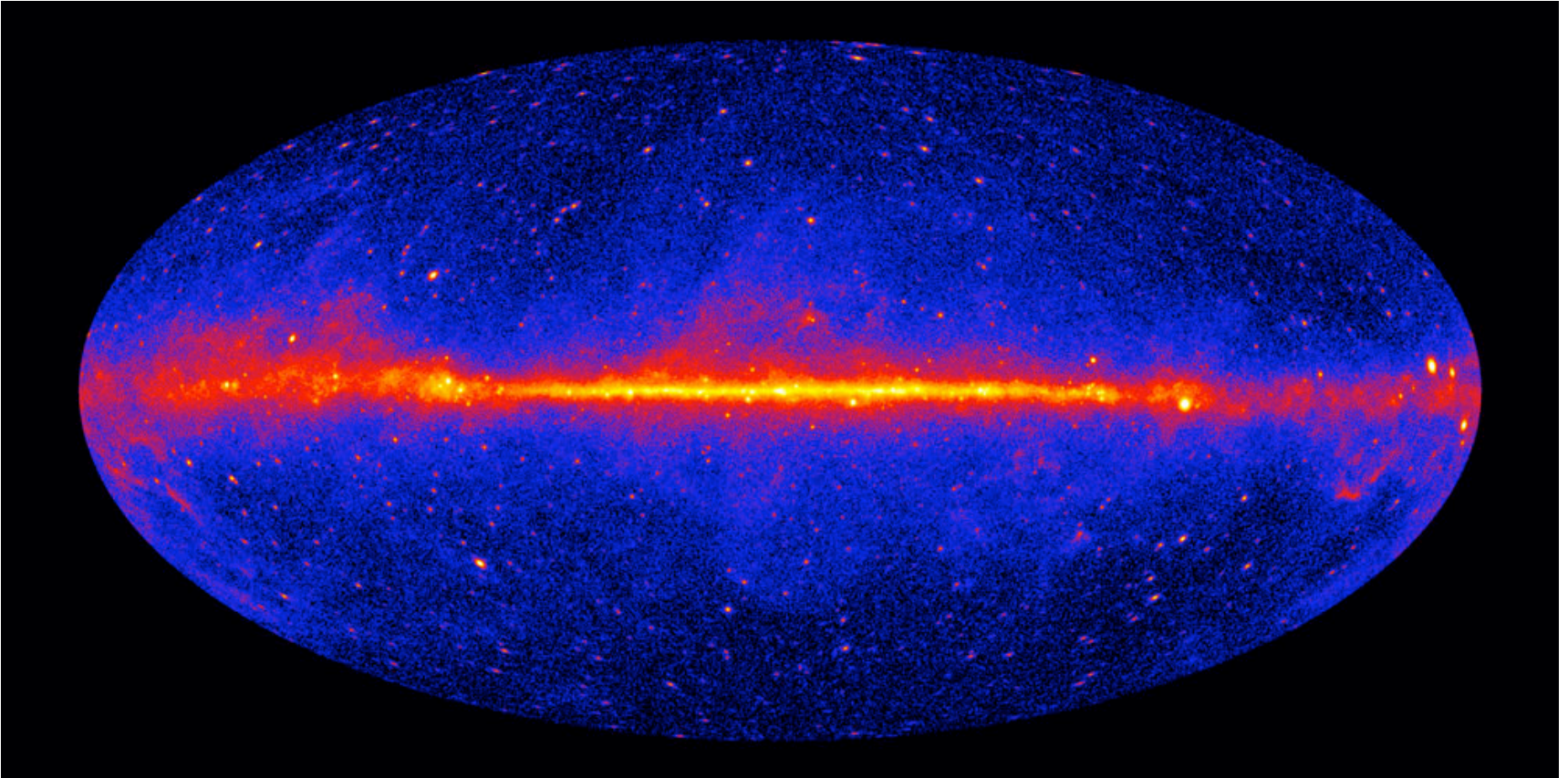
News items - chronological



DM in the late universe

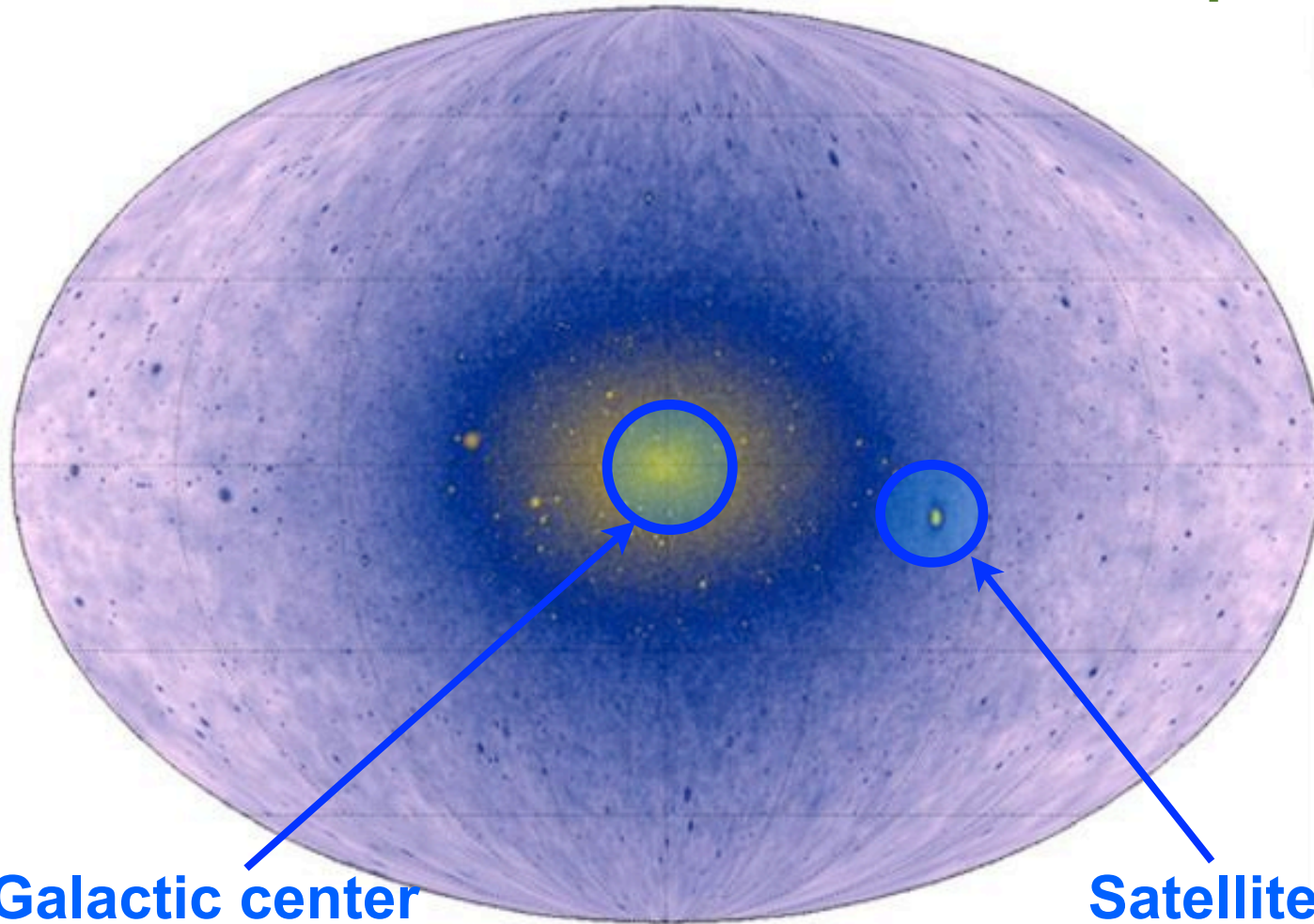
Indirect DM detection

- results from the Fermi satellite



Indirect DM detection

[Kuhlen et al]



Galactic center

highest rate, but many other sources including transients

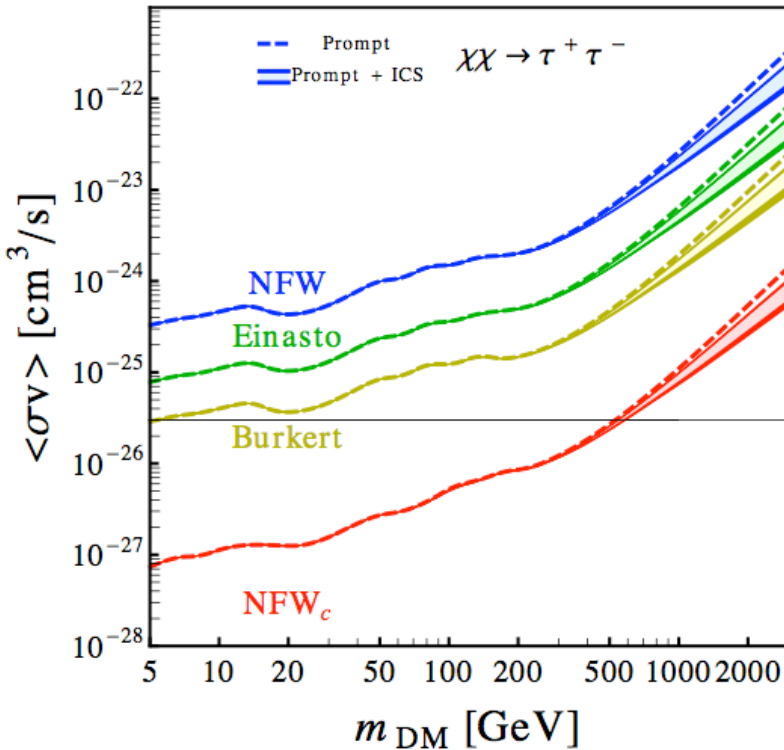
Satellites

low background, but astrophysical uncertainties

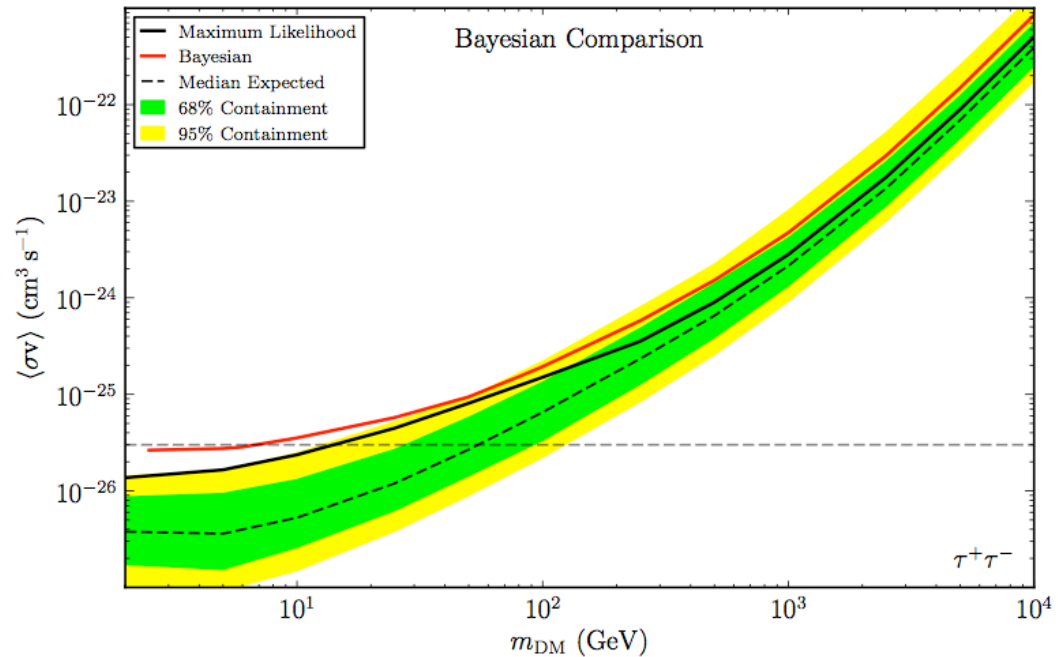
Indirect DM detection

- results from the Fermi satellite
 - annihilation constraints now close to the s-wave benchmark from thermal freeze-out

$$\Omega_{\text{DM}} h^2 \sim 0.1 \left(\frac{3 \times 10^{-26} \text{cm}^3 \text{s}^{-1}}{\langle \sigma v \rangle} \right)$$



From regions around the galactic center



Combined limits from 15 dwarf spheroidal satellites

Indirect DM detection

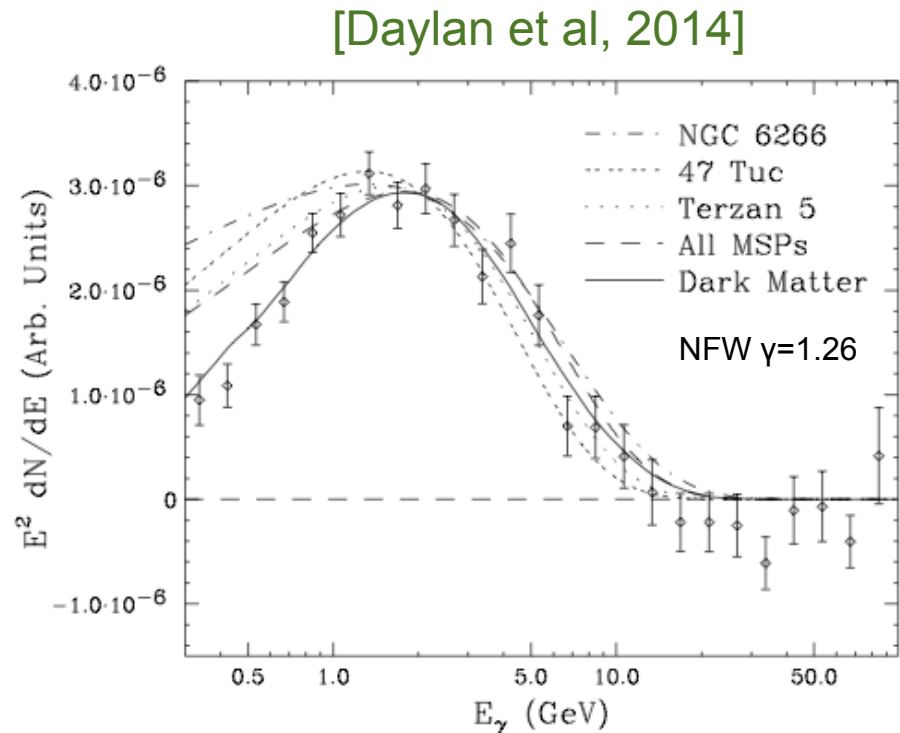
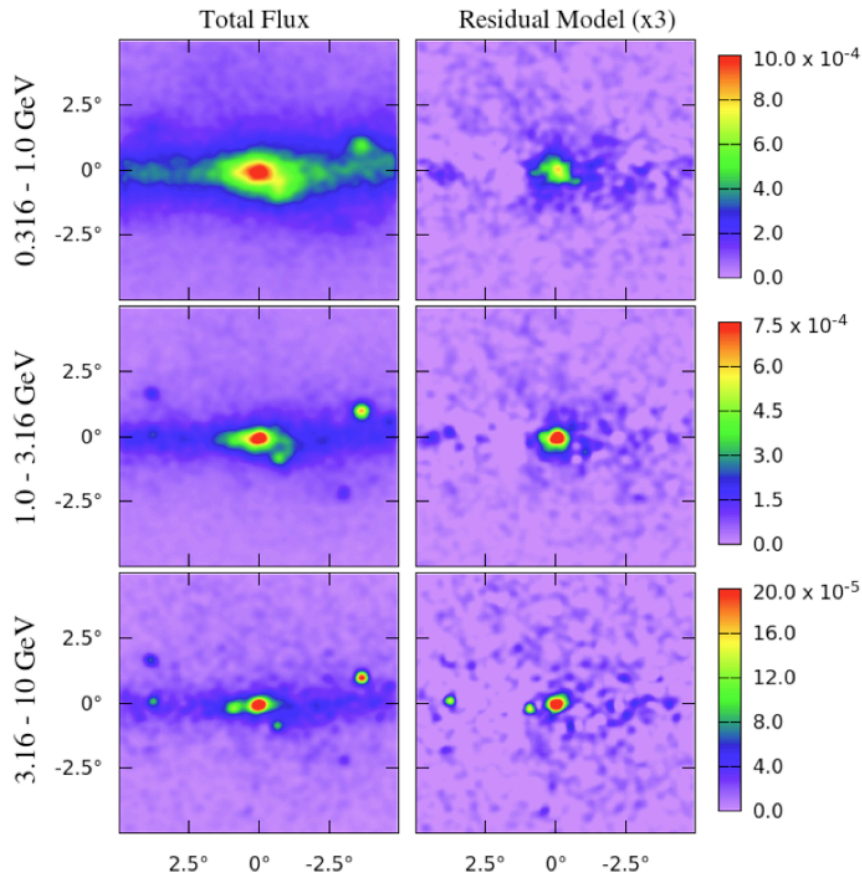
Identifying astrophysical signatures of DM annihilation...



The signatures are photons, cosmic rays, etc, and there are usually many astrophysical backgrounds...

Indirect DM detection

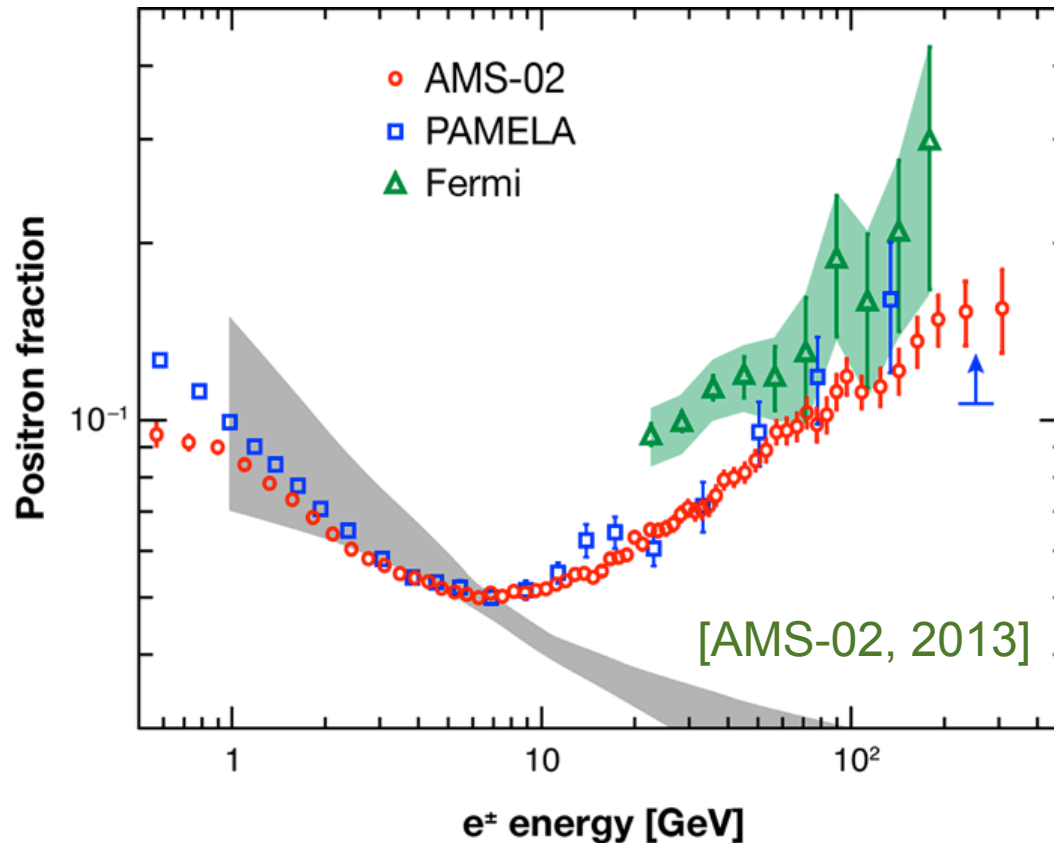
- Hints from the galactic center...?
 - DM annihilation or astrophysics? (e.g. MSPs, transients,...)



- Also, a claim of new 3.57 keV x-ray line in clusters... [Bulbul et al, 2014]
- (earlier hints of a 130 GeV line are dissipating) 22

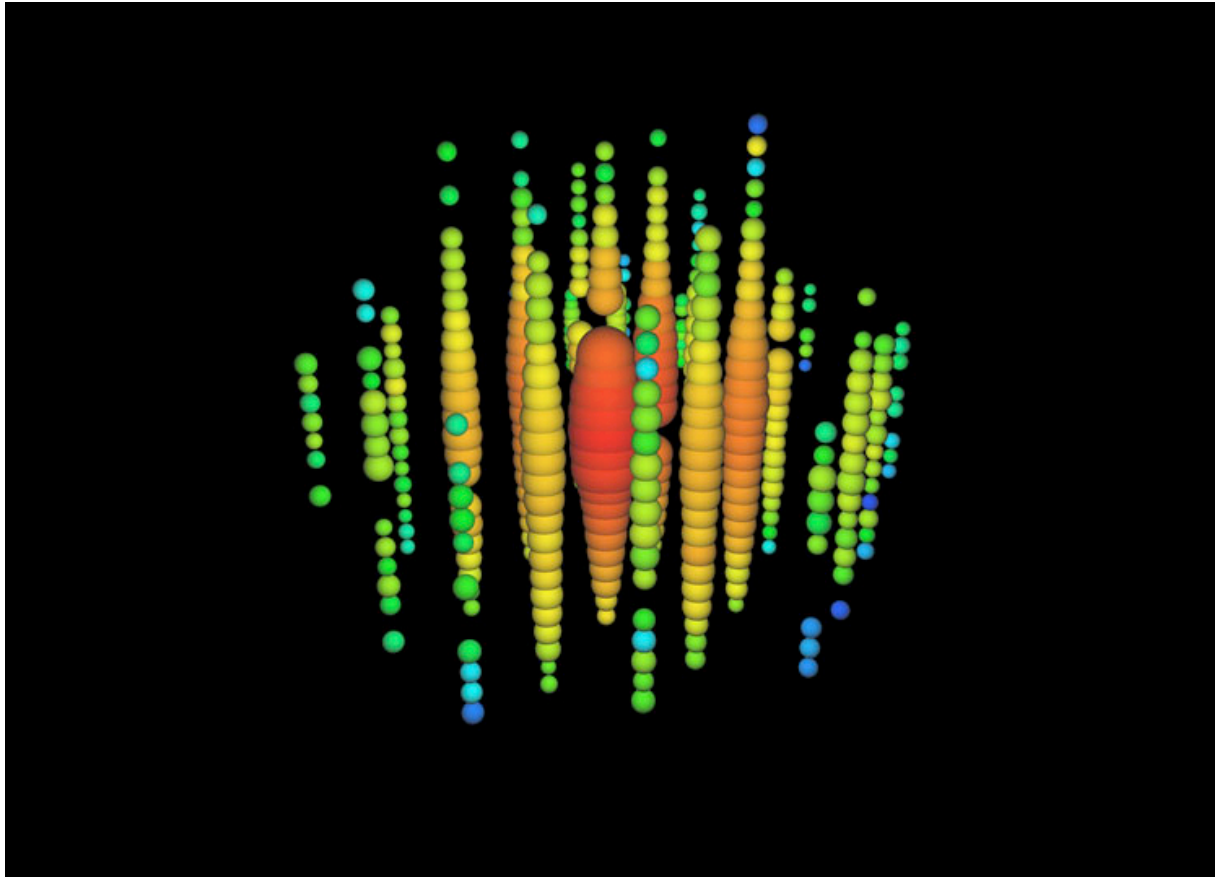
Indirect DM detection

- AMS-02 verified the anomalous rise in the cosmic ray positron fraction = $e^+/(e^++e^-)$
 - dark matter annihilation or a local source (e.g. pulsars)?



PeV (astrophysical) neutrinos

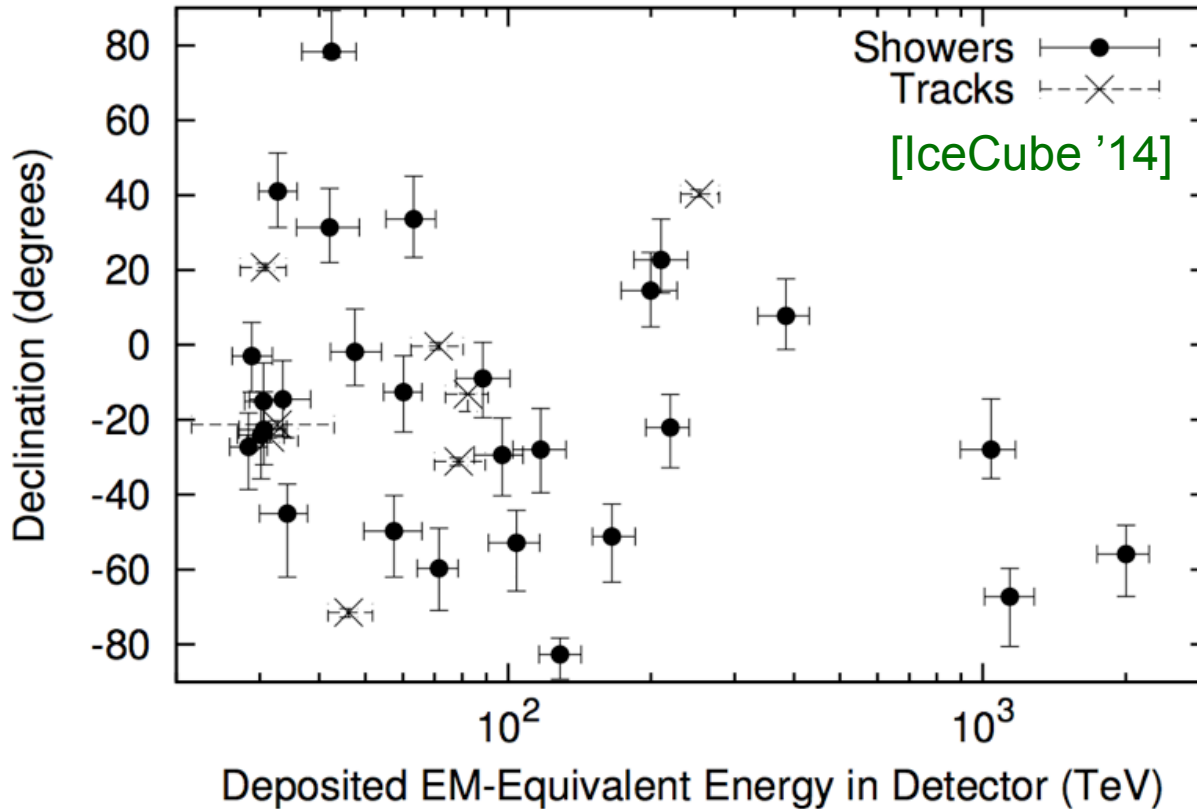
- First observation of astrophysical neutrinos



[IceCube '14]

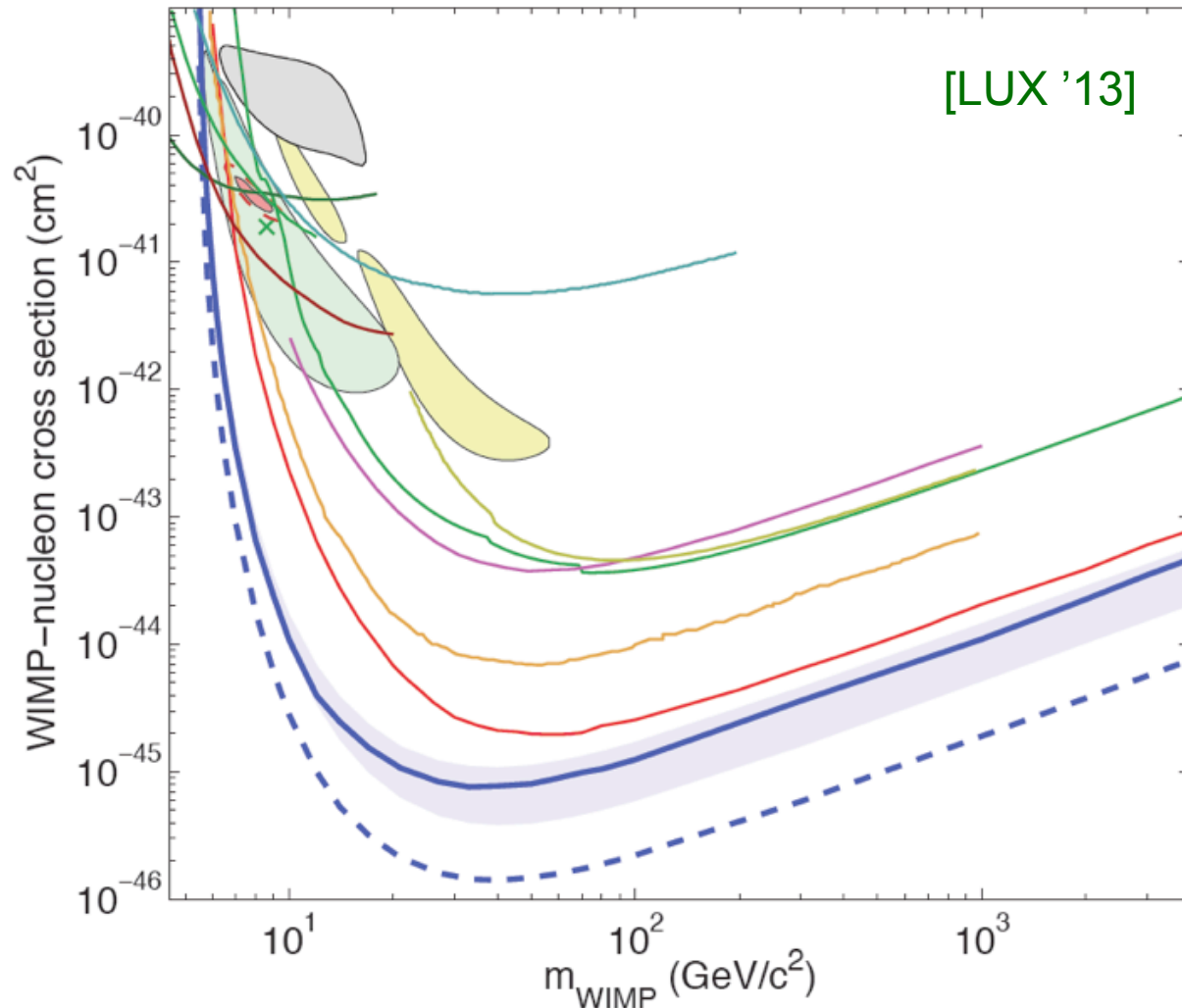
PeV (astrophysical) neutrinos

- First observation of astrophysical neutrinos



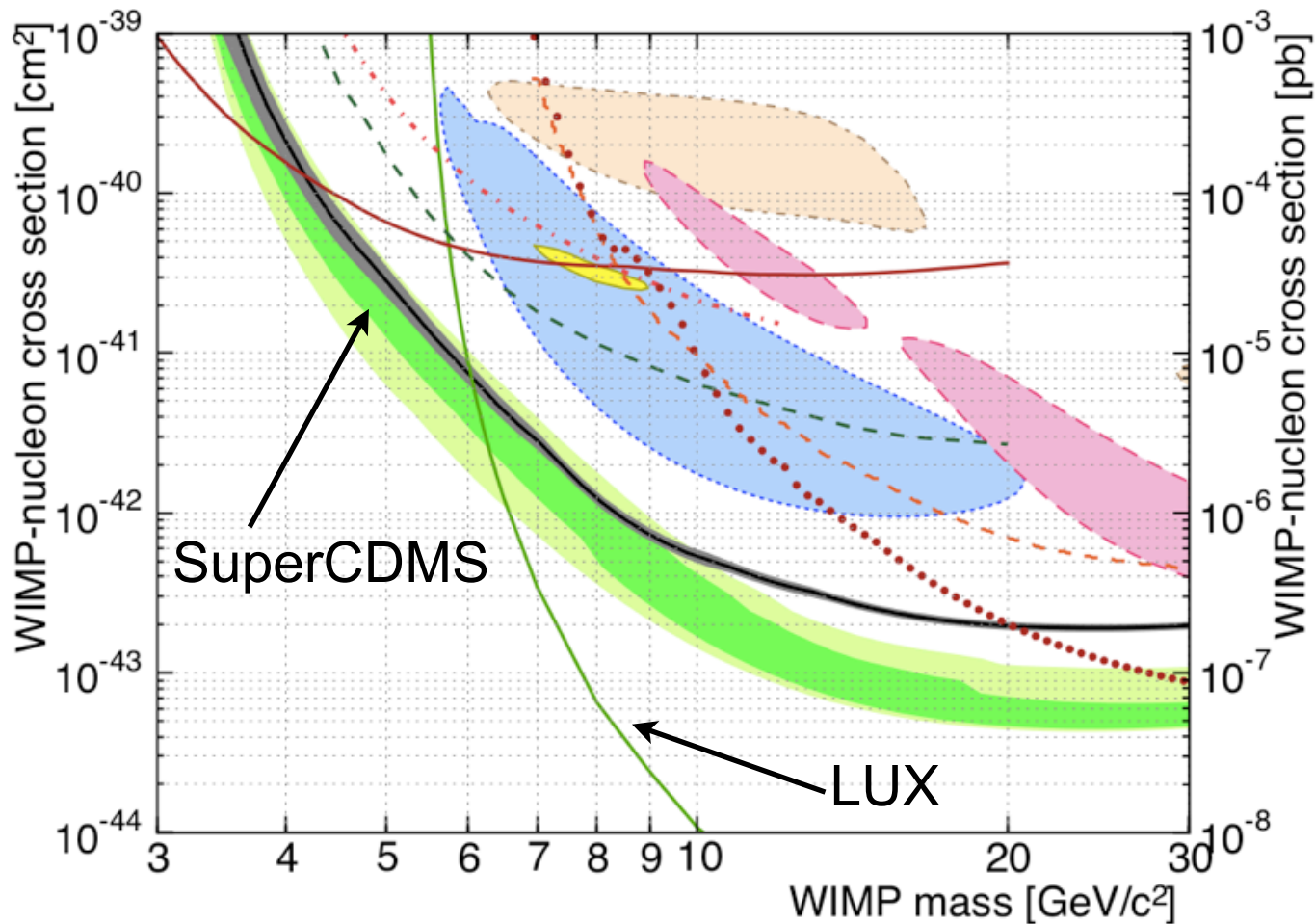
- 37 events (background ~ 10), flavor universal and isotropic in direction
- expect to be linked to high-energy cosmic rays...

Direct DM detection



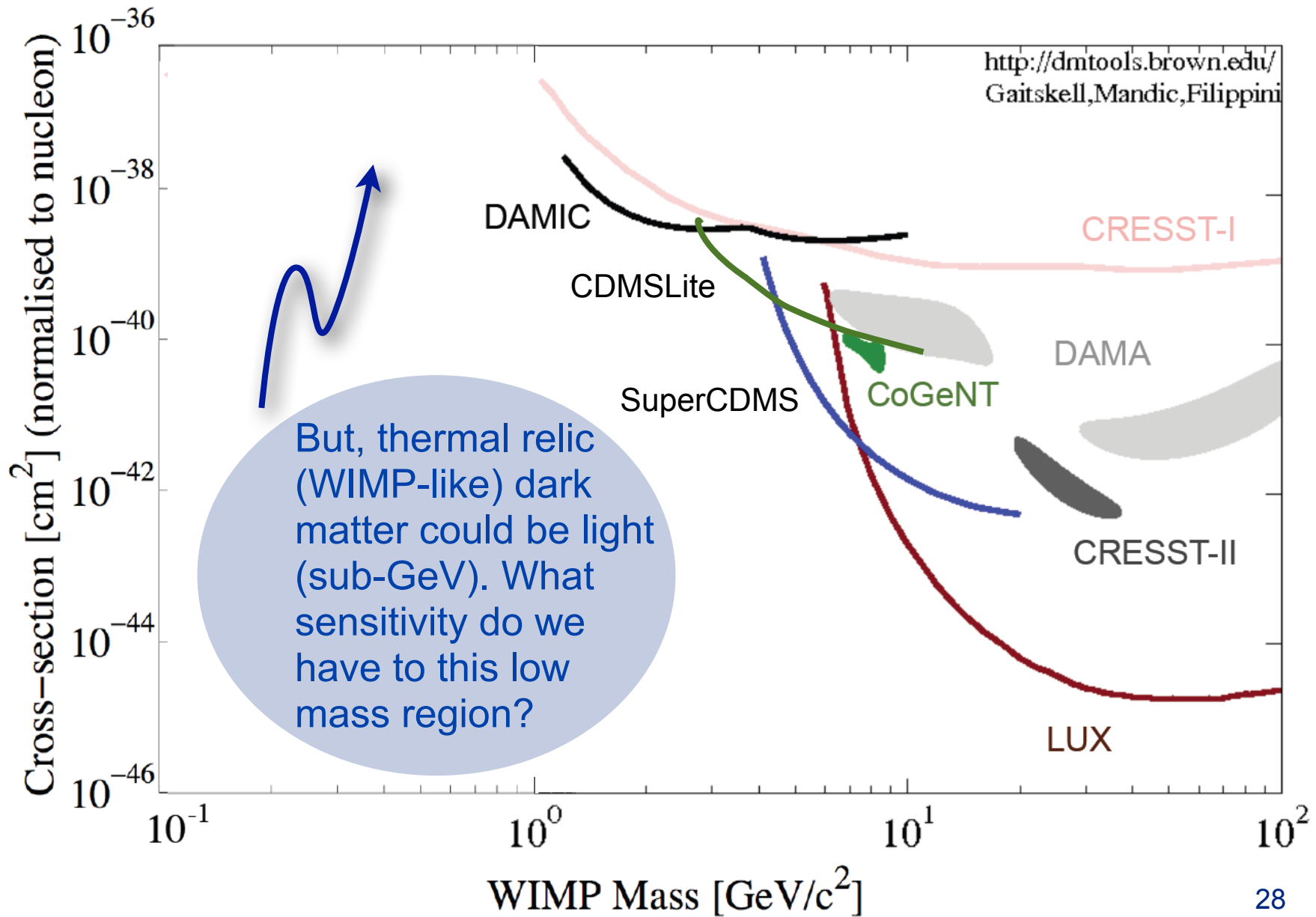
Impressive direct detection sensitivity to thermal relic (WIMP) dark matter in the halo with O(GeV - TeV) mass, and spin-independent scattering with nuclei.

Direct DM detection - low mass

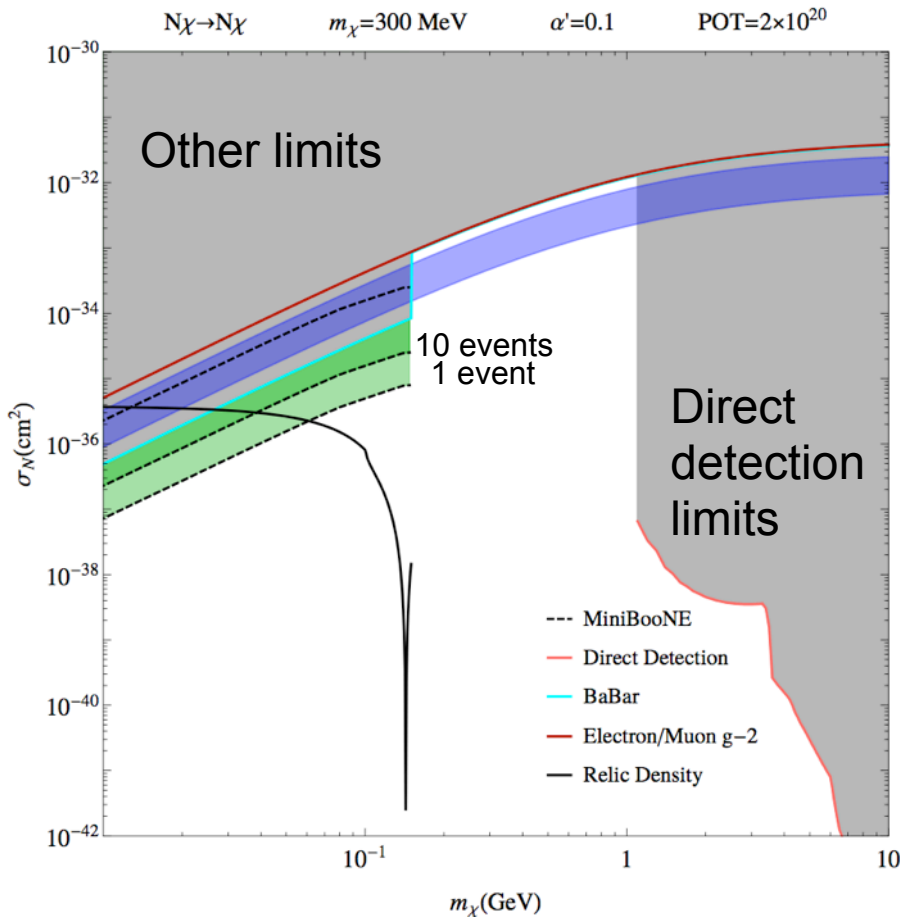
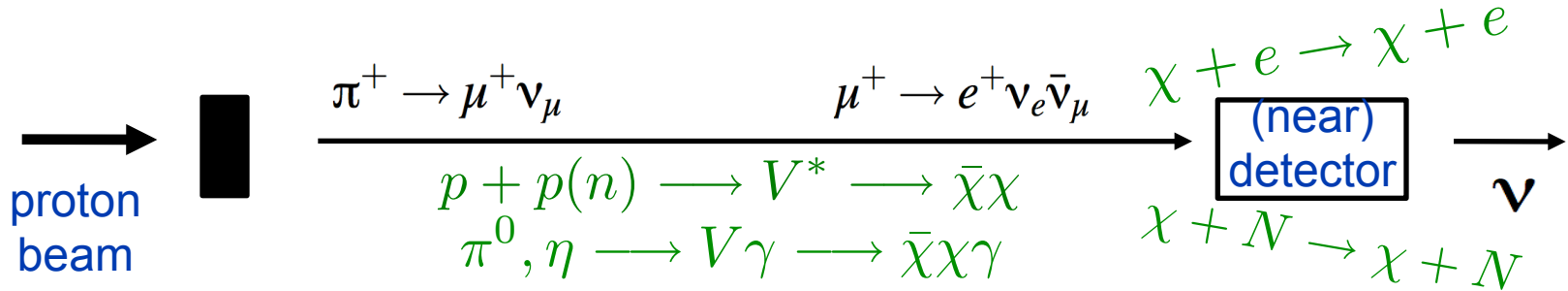


Candidate events from DAMA, CoGeNT, CRESST, CDMS(Si)
not confirmed by LUX, SuperCDMS, CDMSLite

Direct DM detection - low mass



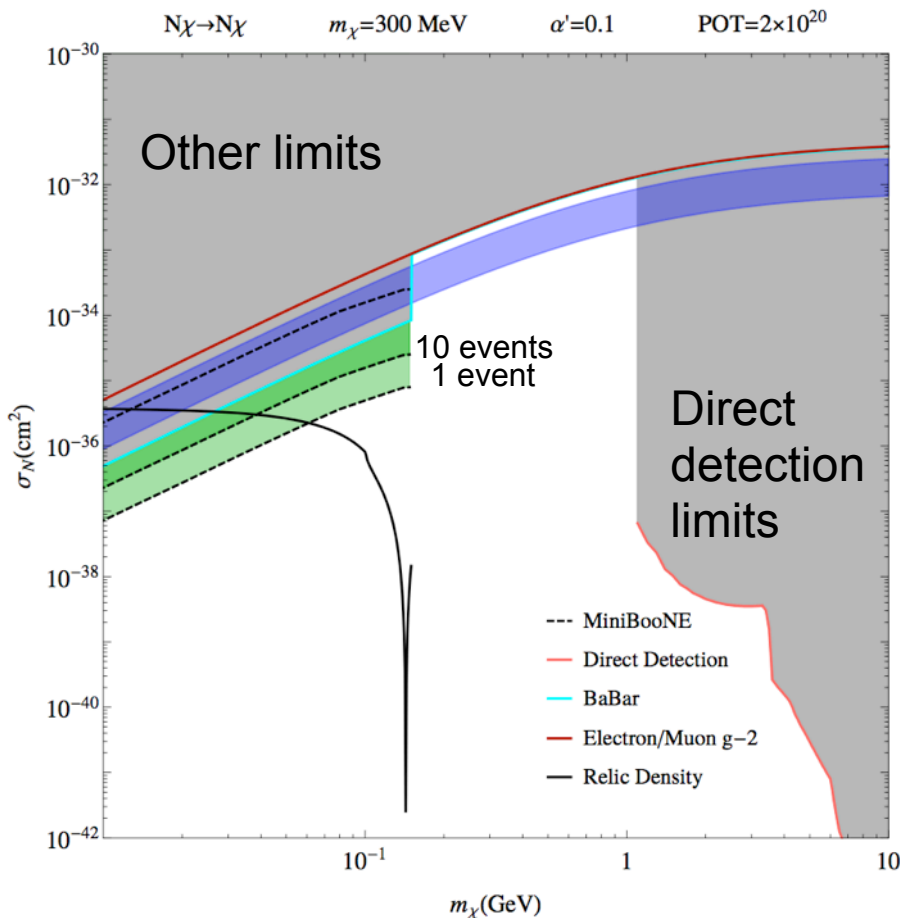
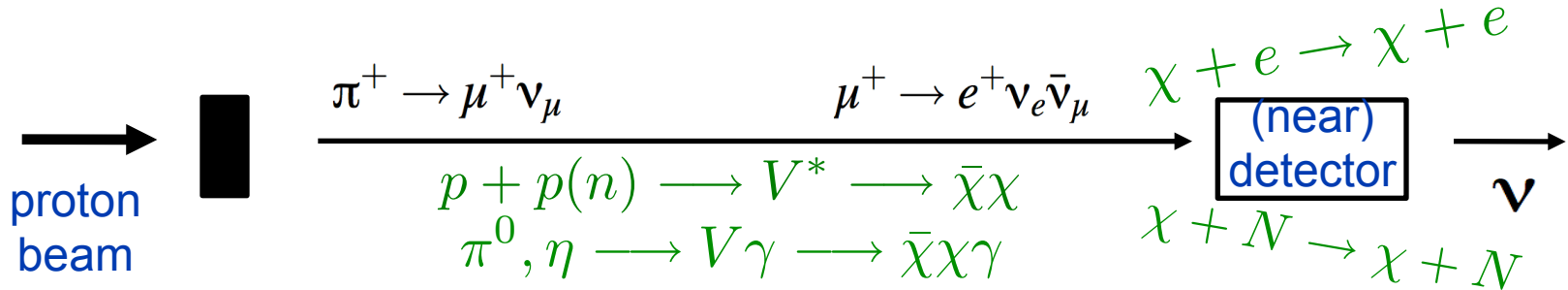
Fixed target DM searches - Neutrino Beams



Sensitivity within search currently underway at MiniBooNE (run as a beam dump to reduce neutrino background)

[deNiverville et al '11,
 Dharmapalan et al '12;
 Batell, deNiverville et al '14]

Fixed target DM searches - Neutrino Beams



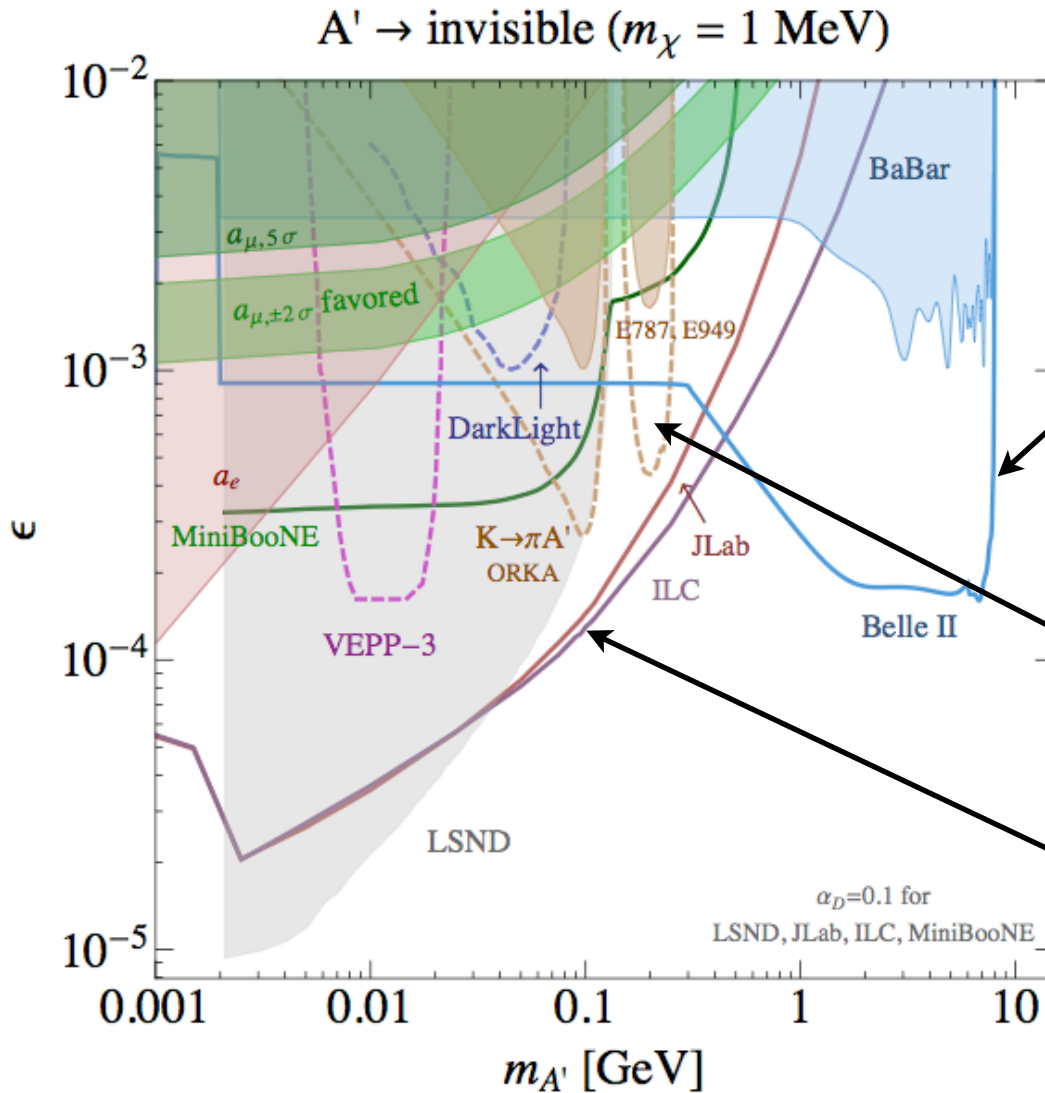
Sensitivity within search currently underway at MiniBooNE (run as a beam dump to reduce neutrino background)

[deNiverville et al '11, Dharmapalan et al '12; Batell, deNiverville et al '14]

Proposal to use T2K/SuperK (exploiting timing cuts) to explore higher mass range

[CAP talk by C. Nantais]

Other probes of light DM



[Snowmass NLWCP
WG, Essig, Jaros,
Wester et al '13]

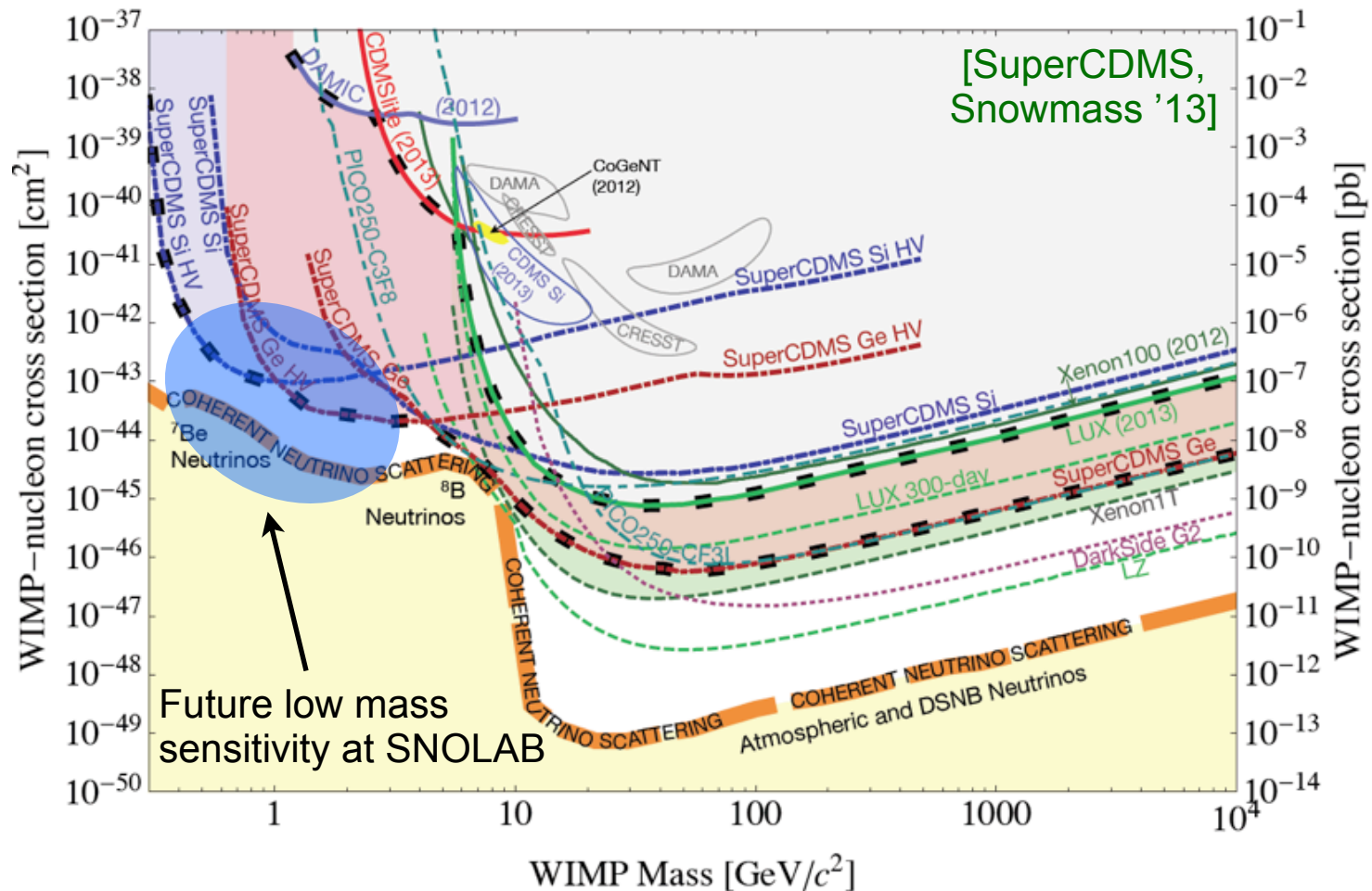
Monophotons at
BaBar, and possibly
Belle-II? [Essig et al '13]

Rare decays

Electron fixed target
proposal at JLab
[Izaguirre et al '13]

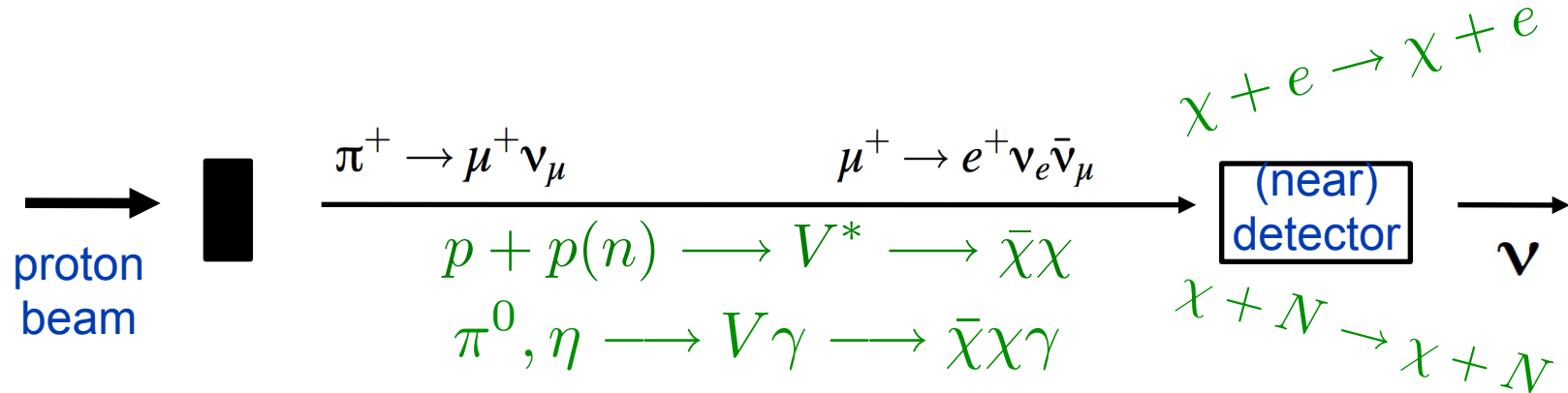
In place of conclusions...

- As we're in Sudbury, can't over-emphasize the global importance of SNOLAB for observational astroparticle physics, with neutrino and direct detection dark matter searches.



Extra slides

Fixed target DM searches - Neutrino Beams



Can use the neutrino (near) detector as a dark matter detector, looking for recoil, but now from a relativistic beam. E.g.

- LSND - 800 MeV beam, 10^{23} POT, detector at 30m
- MiniBooNE - 9 GeV beam, 650 ton detector at 500m
- T2K - 30 GeV beam, off-axis detectors, near (280m), far (Super-K)
- (CHARM, MINOS, NOvA, LBNE,...)

Fixed target DM searches - Neutrino Beams

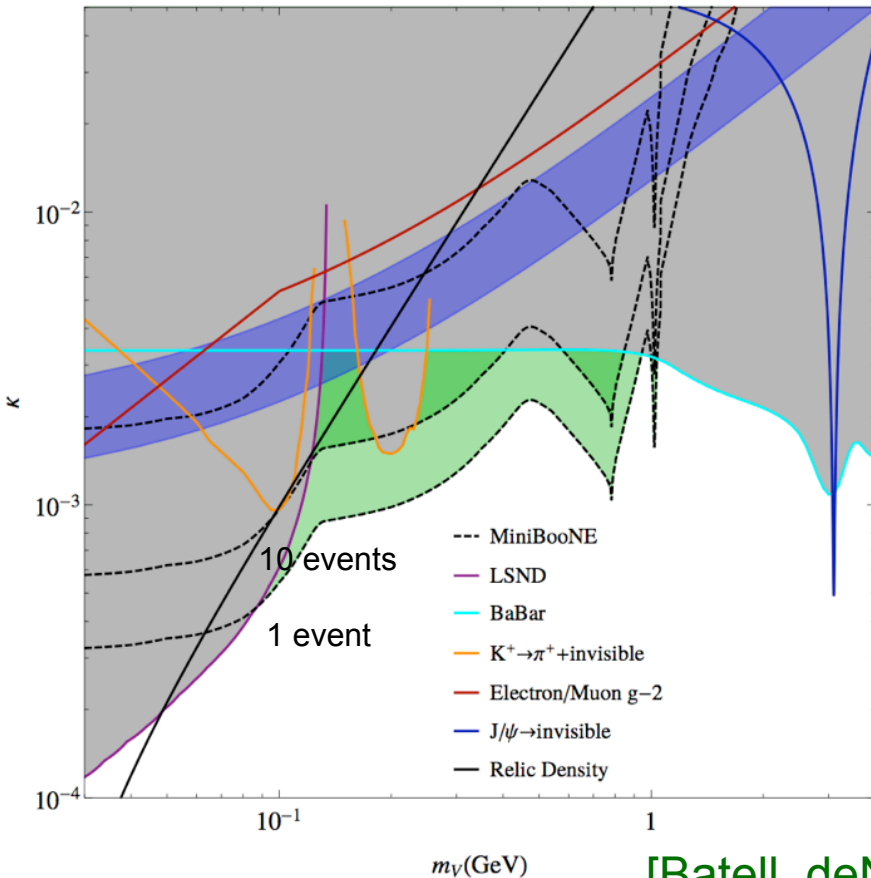
$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} - \frac{1}{2}m_V^2V_\mu^2 + |D_\mu\chi|^2 - m_{\text{DM}}^2|\chi|^2 + \dots$$



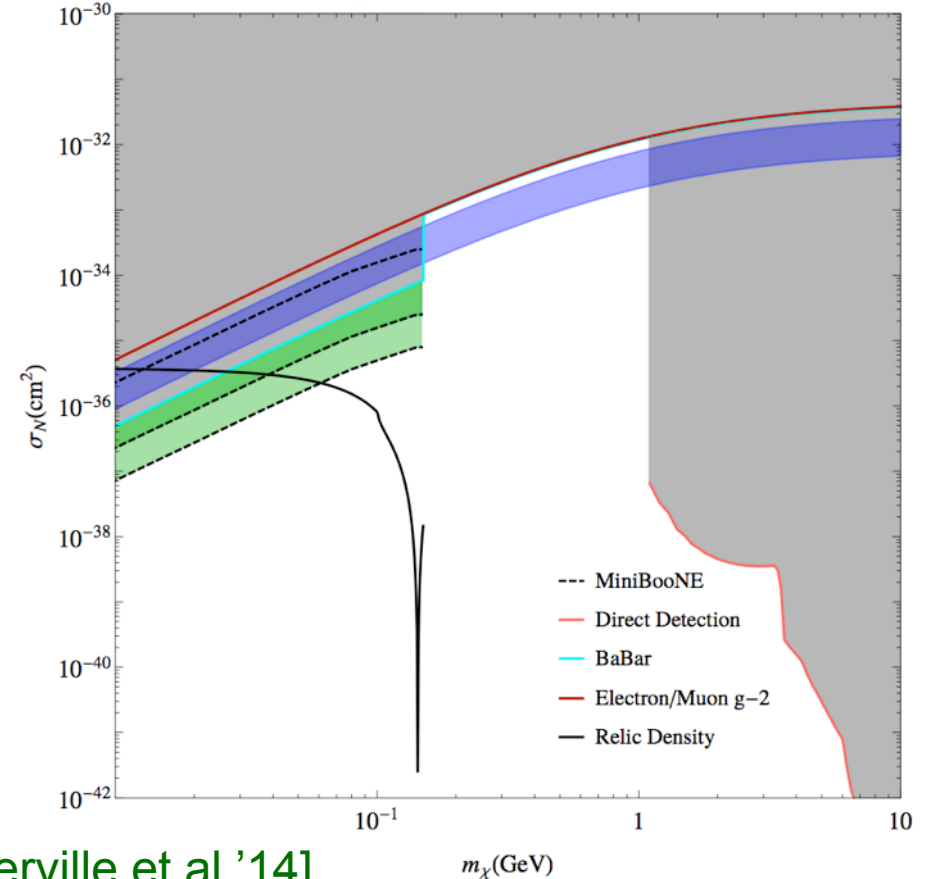
$$\mathcal{L}_{\text{int}} = -\kappa e V_\mu J_{\text{em}}^\mu$$

DM candidate,
coupled through
U(1)'

$N\chi \rightarrow N\chi$ $m_\chi = 10 \text{ MeV}$ $\alpha' = 0.1$ $\text{POT} = 2 \times 10^{20}$



$N\chi \rightarrow N\chi$ $m_\chi = 300 \text{ MeV}$ $\alpha' = 0.1$ $\text{POT} = 2 \times 10^{20}$



[Batell, deNiverville et al '14]