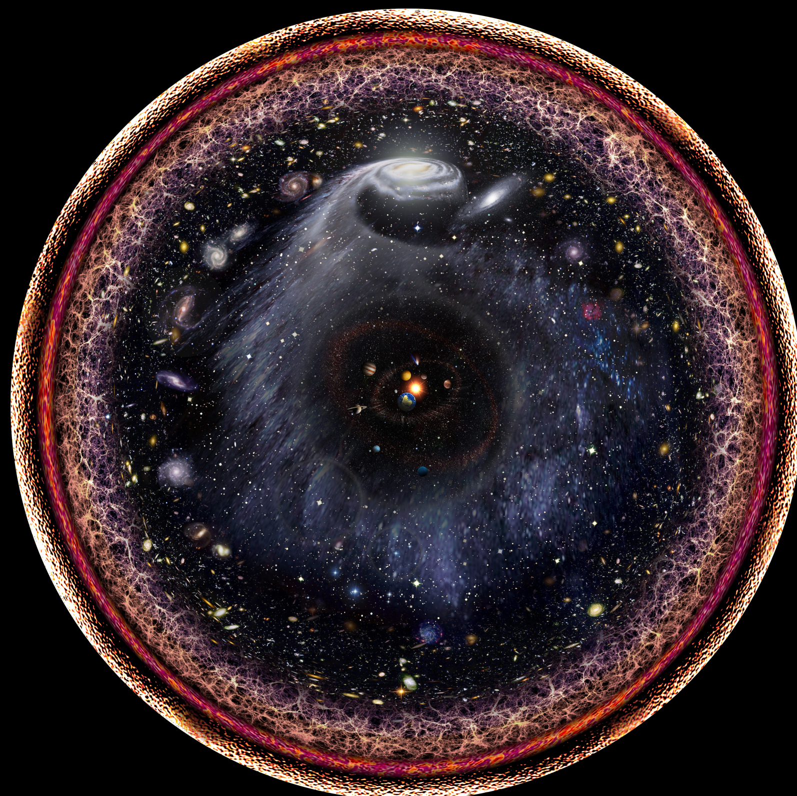
Cosmological searches for dark matter-baryon interactions



Vera Gluscevic

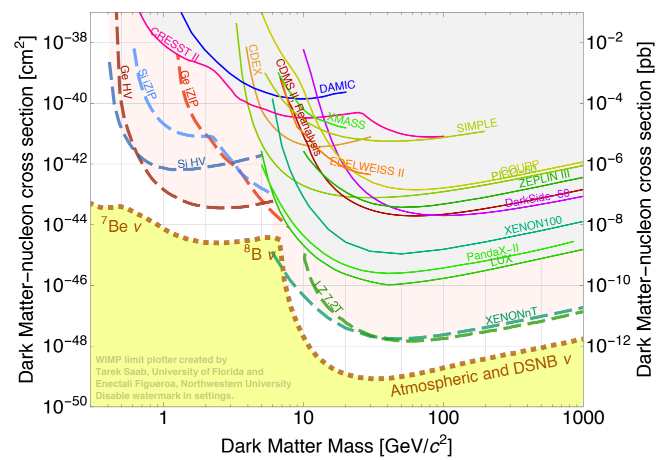
Eric Schmidt Fellow, Institute for Advanced Study

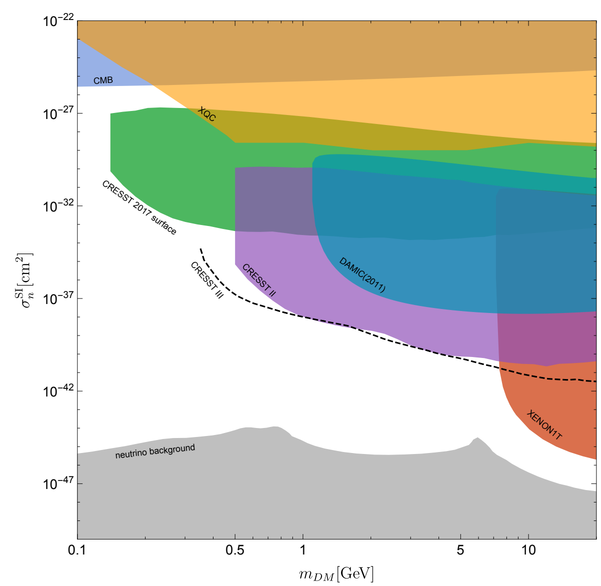
Image credit: Budassi

CIPANP 2018

Caveats of low-energy searches

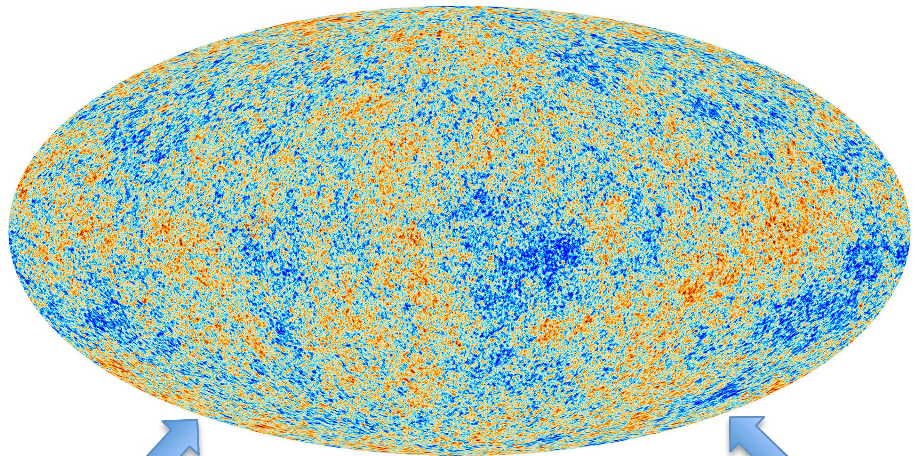
- DD has a ceiling.
- Masses << GeV are still poorly explored.
- Assumptions about <u>local</u> astrophysics of DM.
- Limited ability to pin down nature of the interaction. [see arXiv 1506.04454]



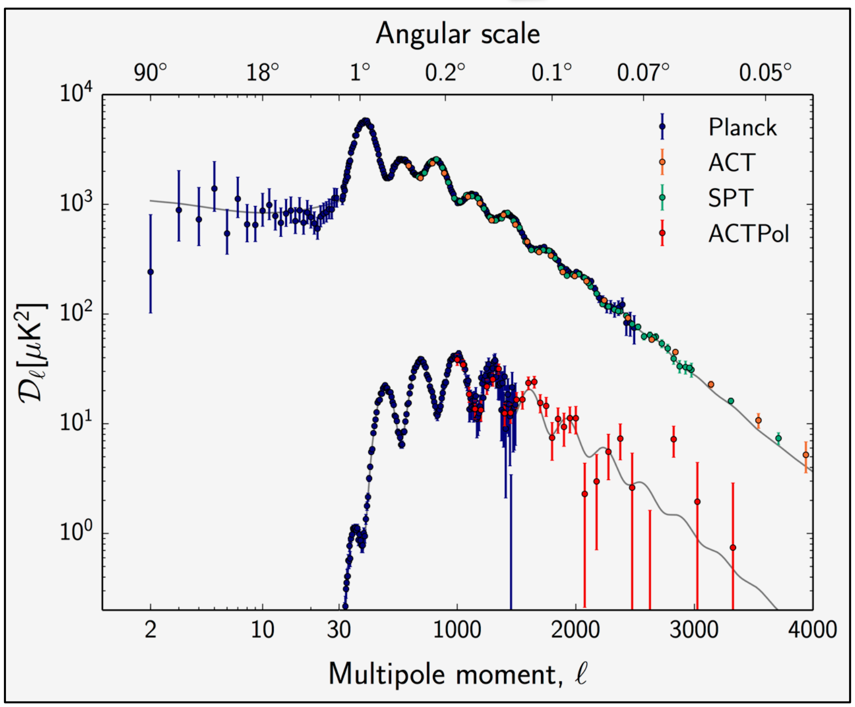


Emken and Kouvaris, 2018

Cosmic microwave background [CMB]

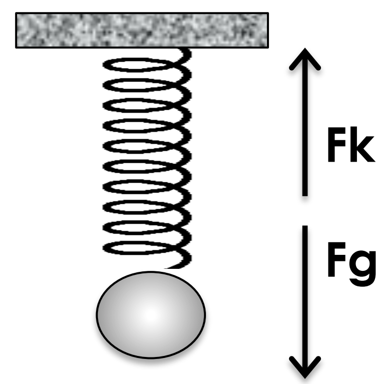


Power spectrum



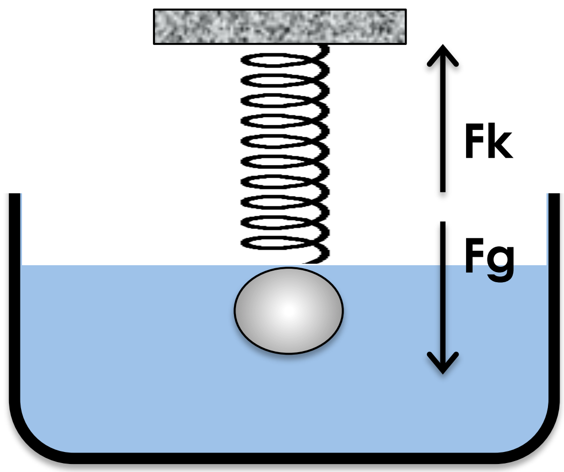
Plot by E. Calabrese
(for ACTPol)

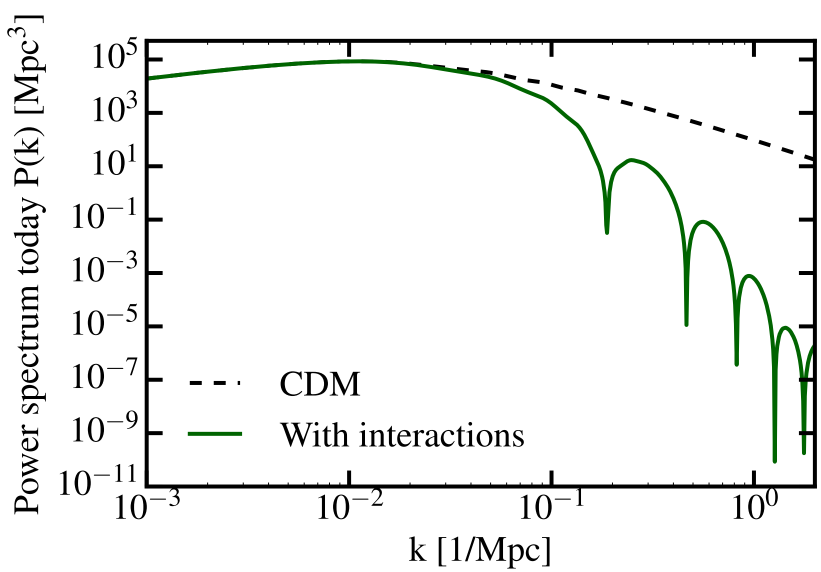
Acoustic oscillations



With dark matter-proton scattering:

scattering →drag force→ suppression of small scales

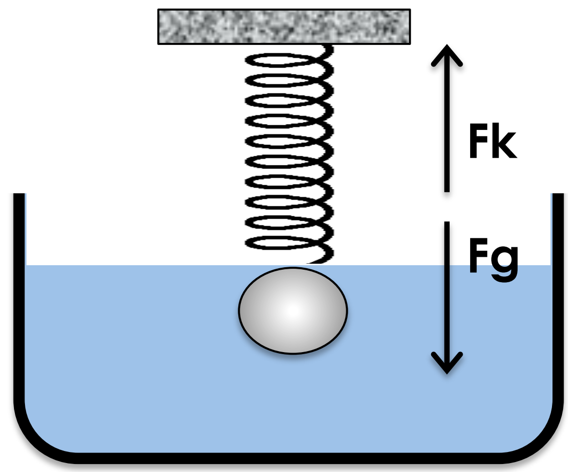




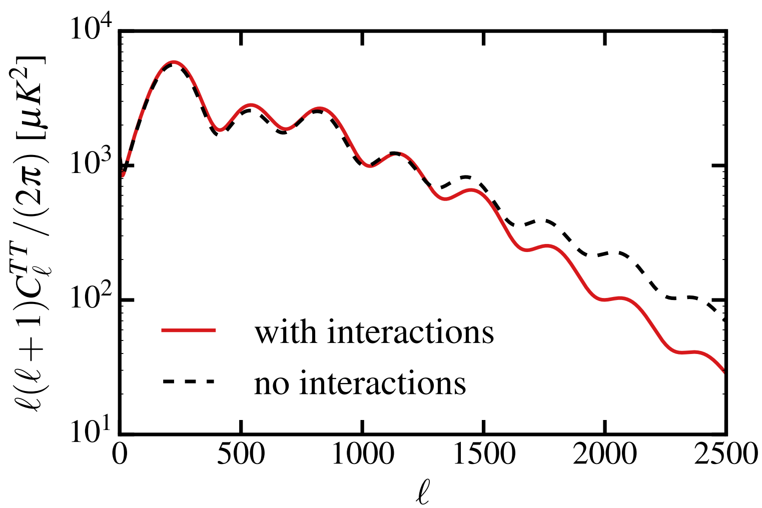
Boddy and VG (2018).

With dark matter-proton scattering:

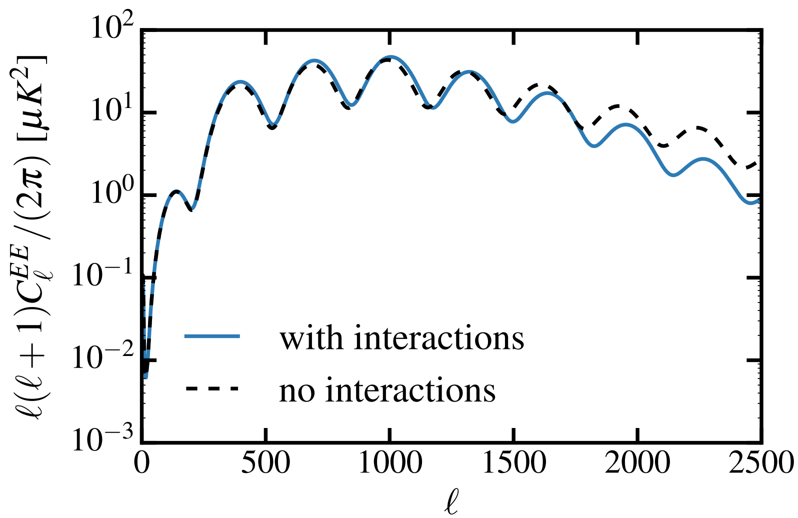
scattering →drag force→ suppression of small scales



Temperature



Polarization



VG and Boddy (2017), Boddy and VG (2018); Previous work: Chen et al (2002), Sigurdson et al (2004); Dvorkin et al (2014); etc.

Scattering in the early universe

Momentum transfer between baryon-photon fluid and DM affects perturbations and thermal history:

$$\dot{\delta}_\chi = -\theta_\chi - \frac{\dot{h}}{2}, \qquad \dot{\delta}_b = -\theta_b - \frac{\dot{h}}{2},$$

$$\dot{\theta}_\chi = -\frac{\dot{a}}{a}\theta_\chi + c_\chi^2 k^2 \delta_\chi + \underline{R_\chi \left(\theta_b - \theta_\chi\right)},$$

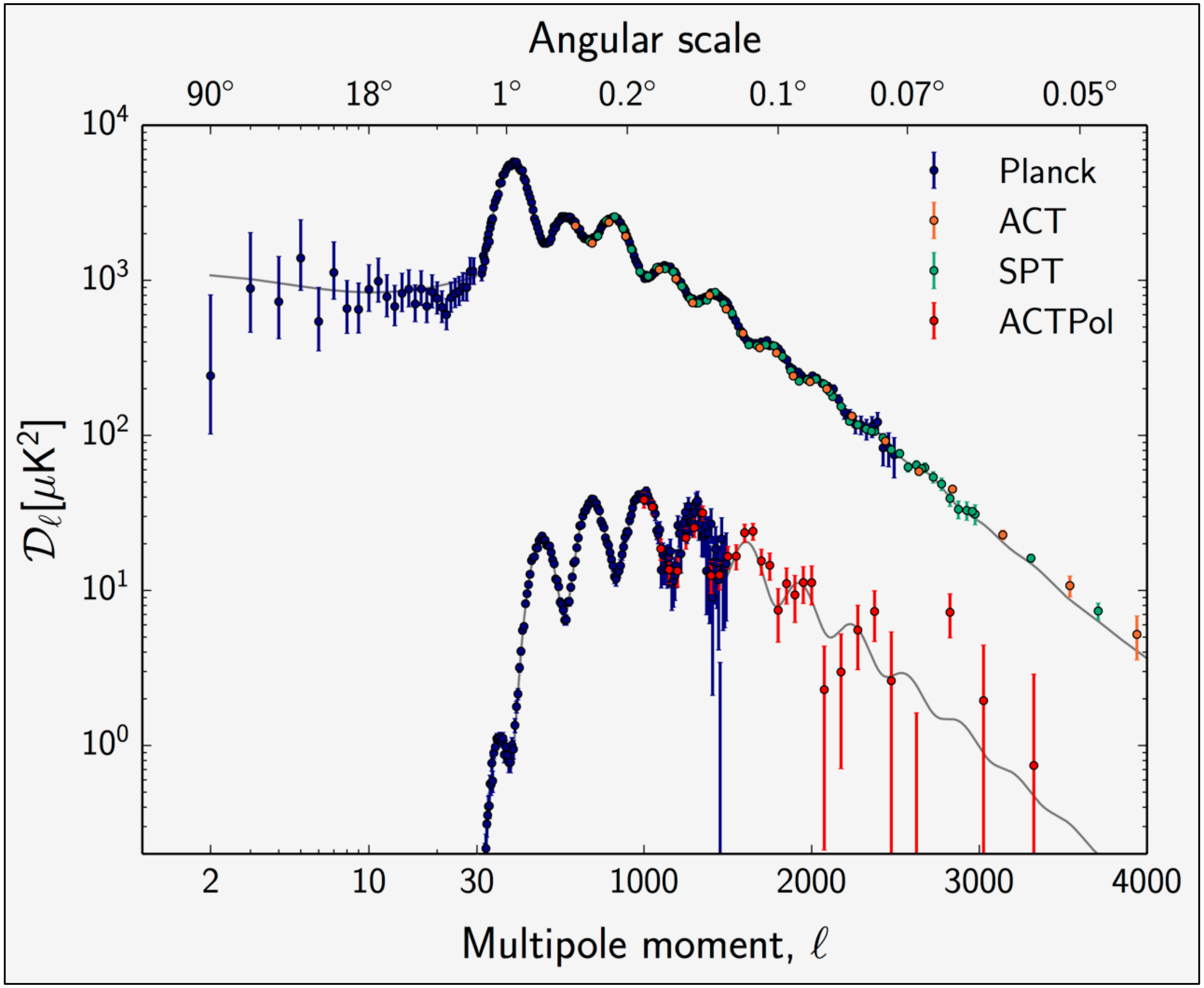
$$\dot{\theta}_b = -\frac{\dot{a}}{a}\theta_b + c_b^2 k^2 \delta_b + R_\gamma \left(\theta_\gamma - \theta_b\right) + \underline{\frac{\rho_\chi}{\rho_b} R_\chi \left(\theta_\chi - \theta_b\right)}$$

$$\dot{T}_\chi = -2\frac{\dot{a}}{a}T_\chi + \underline{2R'_\chi (T_b - T_\chi)}$$

$$\boxed{R_\chi = \frac{a\, c_n\, \rho_b\, \sigma_0}{m_\chi + m_{\rm H}} \left(\frac{T_b}{m_{\rm H}} + \frac{T_\chi}{m_\chi}\right)^{\frac{n+1}{2}} \mathcal{F}_{\rm He}}$$

Gluscevic and Boddy (2017), Boddy and Gluscevic (2018),
Chen et al (2002), Sigurdson et al (2004); Dvorkin et al (2014); etc.

Data

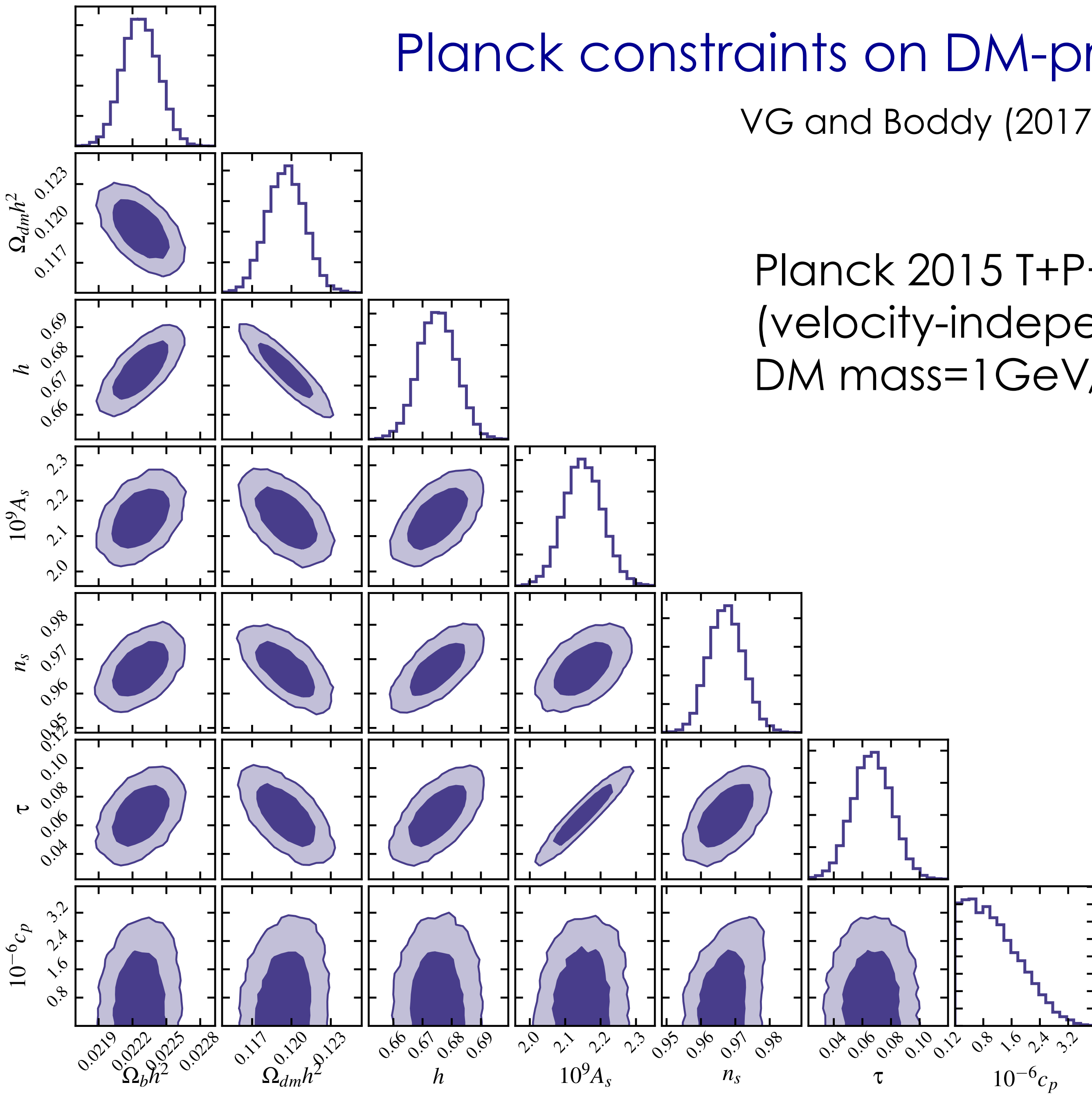


Plot by E. Calabrese [for ACTPol]

Planck constraints on DM-proton scattering

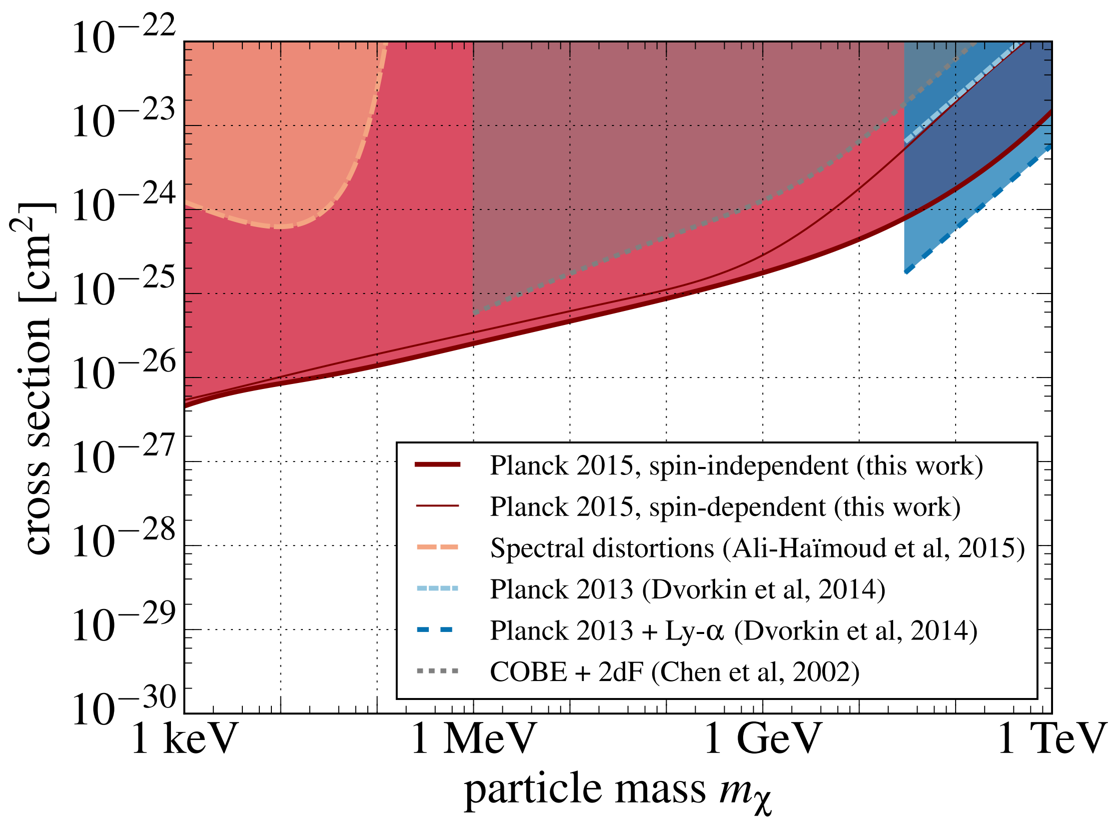
VG and Boddy (2017), Boddy and VG (2018)

Planck 2015 T+P+lensing
(velocity-independent scattering,
DM mass=1GeV, include He):



Cosmological exclusion curves

v-independent DM scattering with proton: 95% confidence upper limit



VG and Boddy (2017)

High cross sections, down to mass ~keV!

Non-relativistic EFT

[Fan et al, 2010; Fitzpatrick et al, 2012; Anand et al, 2013]

$$\mathcal{O}_1 = 1_\chi 1_N$$

$$\mathcal{O}_3 = \vec{S}_N \cdot \left(\frac{i\vec{q}}{m_N} \times \vec{v}^\perp\right)$$

$$\mathcal{O}_4 = \vec{S}_\chi \times \vec{S}_N$$

$$\mathcal{O}_5 = \vec{S}_\chi \cdot \left(\frac{i\vec{q}}{m_N} \times \vec{v}^\perp\right)$$

$$\mathcal{O}_6 = -\left(\vec{S}_\chi \cdot \frac{i\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$

$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$

$$\mathcal{O}_9 = \vec{S}_\chi \cdot \left(\vec{S}_N \times \frac{i\vec{q}}{m_N}\right)$$

$$\mathcal{O}_{10} = \vec{S}_N \cdot \frac{i\vec{q}}{m_N}$$

$$\mathcal{O}_{11} = \vec{S}_\chi \cdot \frac{i\vec{q}}{m_N}$$

$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left(\vec{S}_N \times \vec{v}^\perp\right)$$

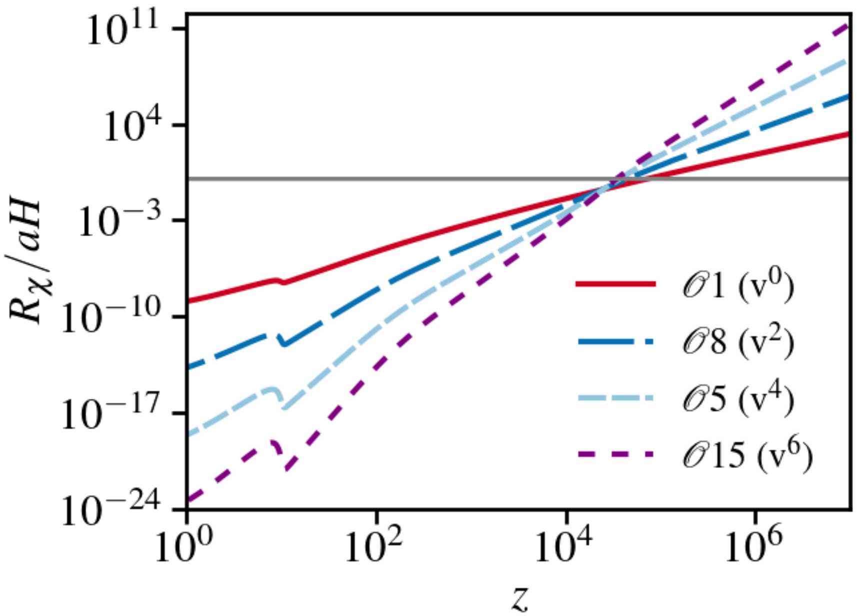
$$\mathcal{O}_{13} = \left(\vec{S}_\chi \cdot \vec{v}^\perp\right)\left(\vec{S}_N \cdot \frac{i\vec{q}}{m_N}\right)$$

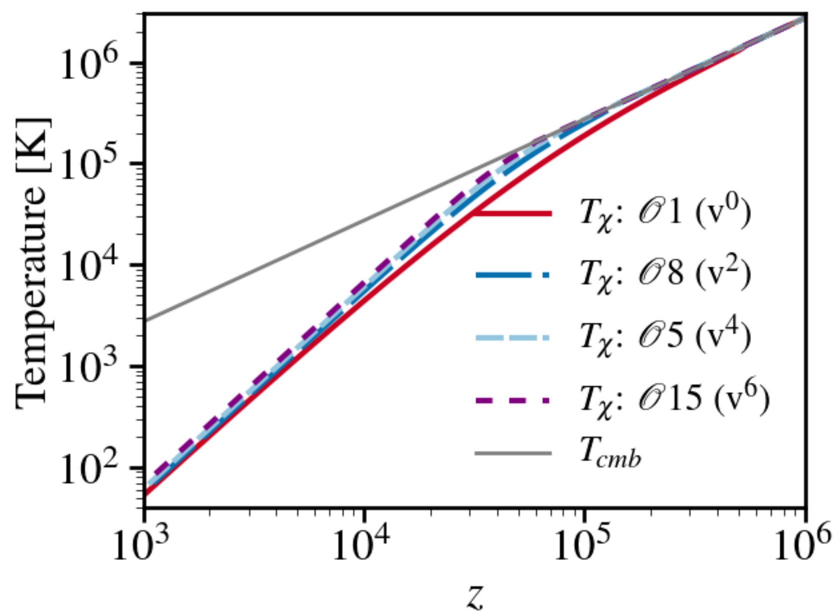
$$\mathcal{O}_{14} = \left(\vec{S}_\chi \cdot \frac{i\vec{q}}{m_N}\right)\left(\vec{S}_N \cdot \vec{v}^\perp\right)$$

$$\mathcal{O}_{15} = \left(\vec{S}_\chi \cdot \frac{i\vec{q}}{m_N}\right)\left[\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{i\vec{q}}{m_N}\right]$$

Momentum transfer

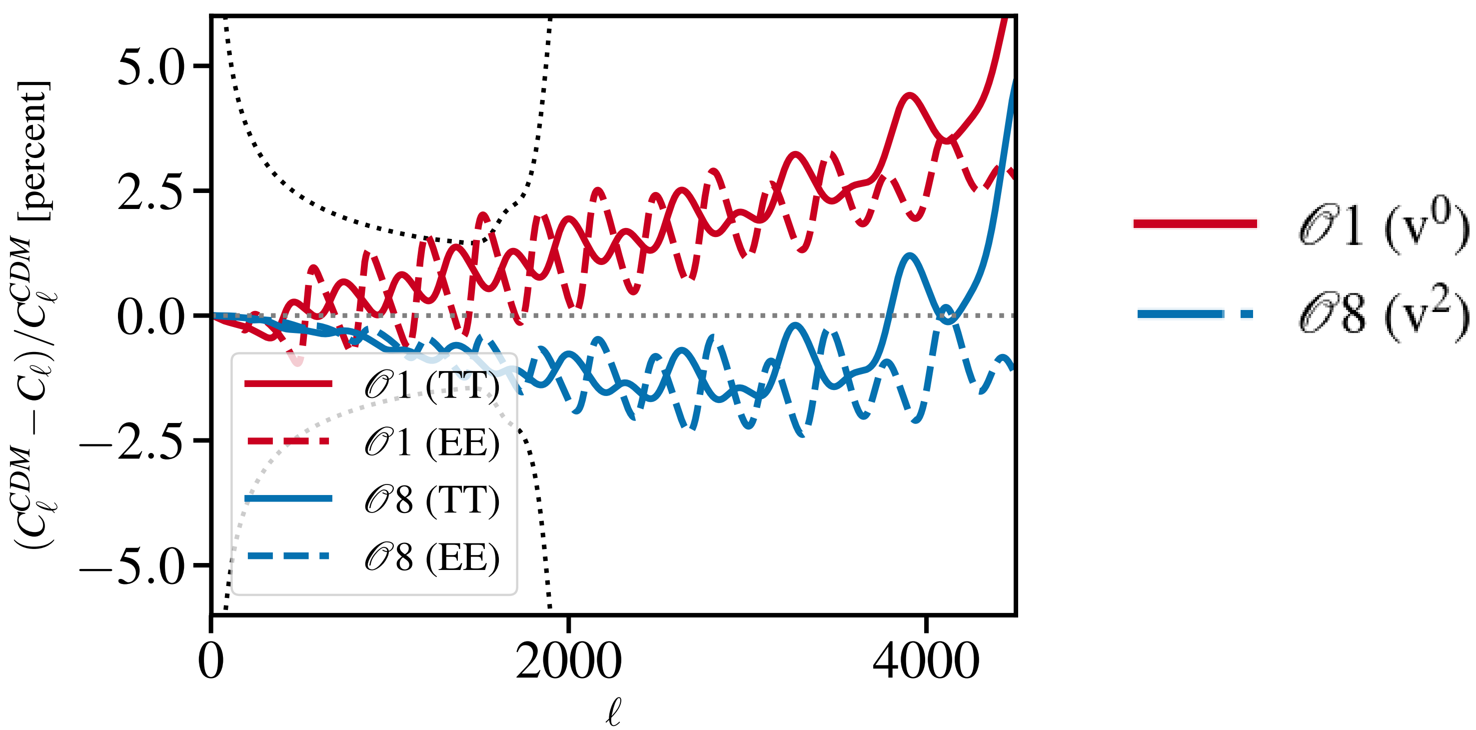
✧ Each operator -> cross section with a different dependence on relative particle velocity, different thermal history:



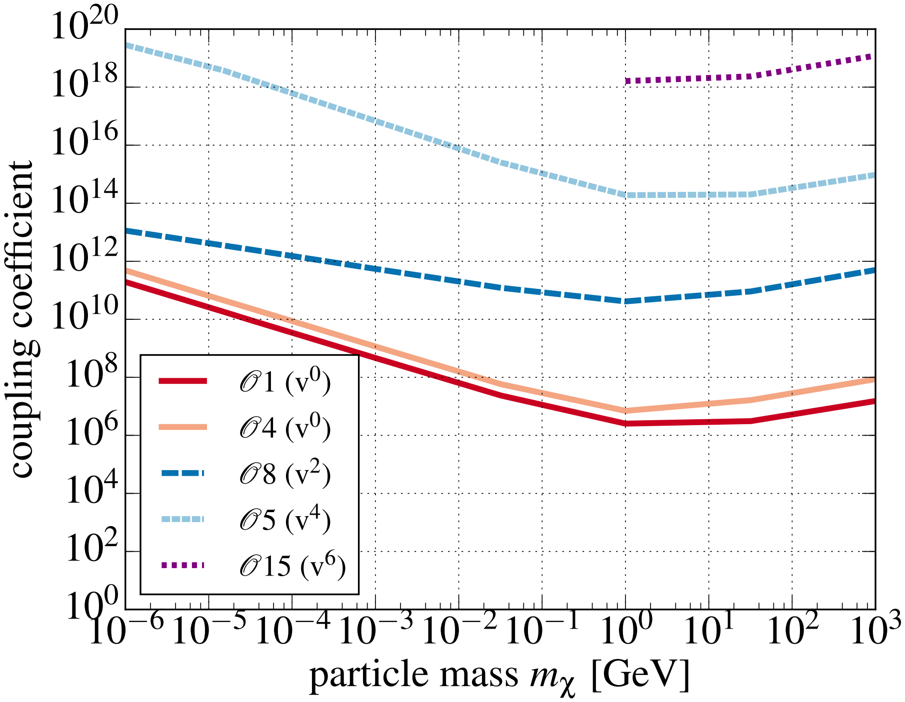


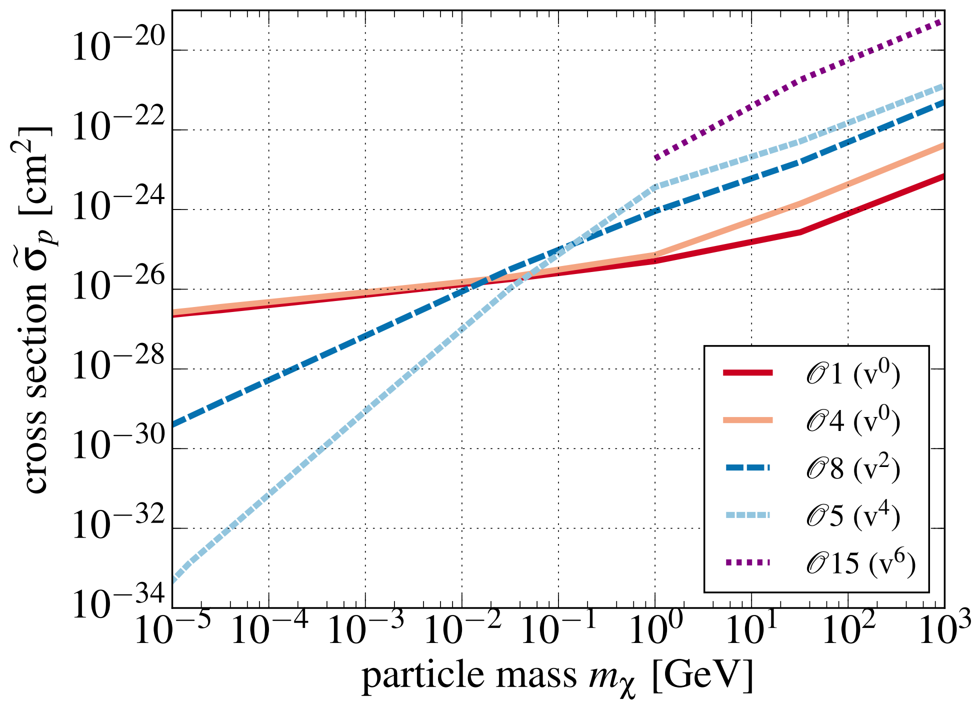
CMB observables

✧ Each operator -> cross section with a different dependence on relative particle velocity, different thermal history:



Cosmological constraint on DM-baryon EFT





Boddy and VG (2018)

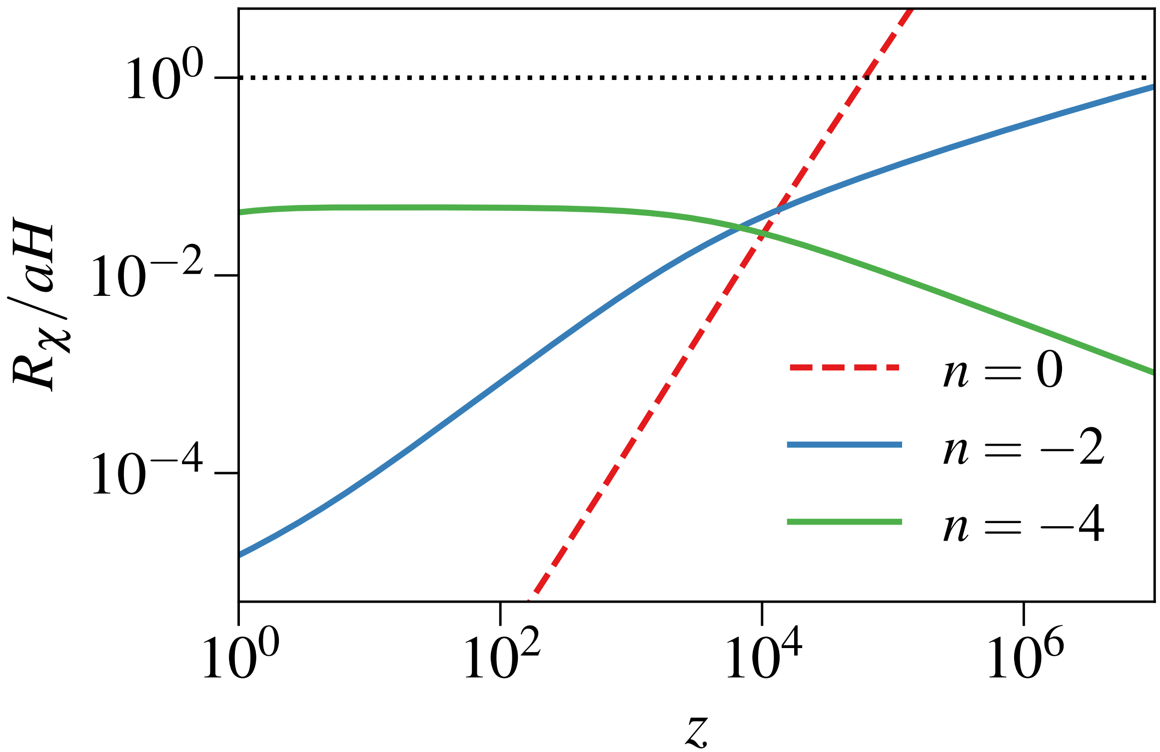
Other scattering scenarios

$\sigma \sim \sigma_0 \, v^n$

Dvorkin+ (2014); Xu+ (2018); Slatyer+ (2018)

Late-time: n <-2

Early-time: n≥-2



Boddy, VG, Poulin, + (coming up)

Late-time scattering: relative bulk velocity

Tseliakhovitch and Hirata (2010)

Problem: non-linear equations

$$\dot{\delta}_\chi = -\theta_\chi - \frac{\dot{h}}{2}, \qquad \dot{\delta}_b = -\theta_b - \frac{\dot{h}}{2},$$

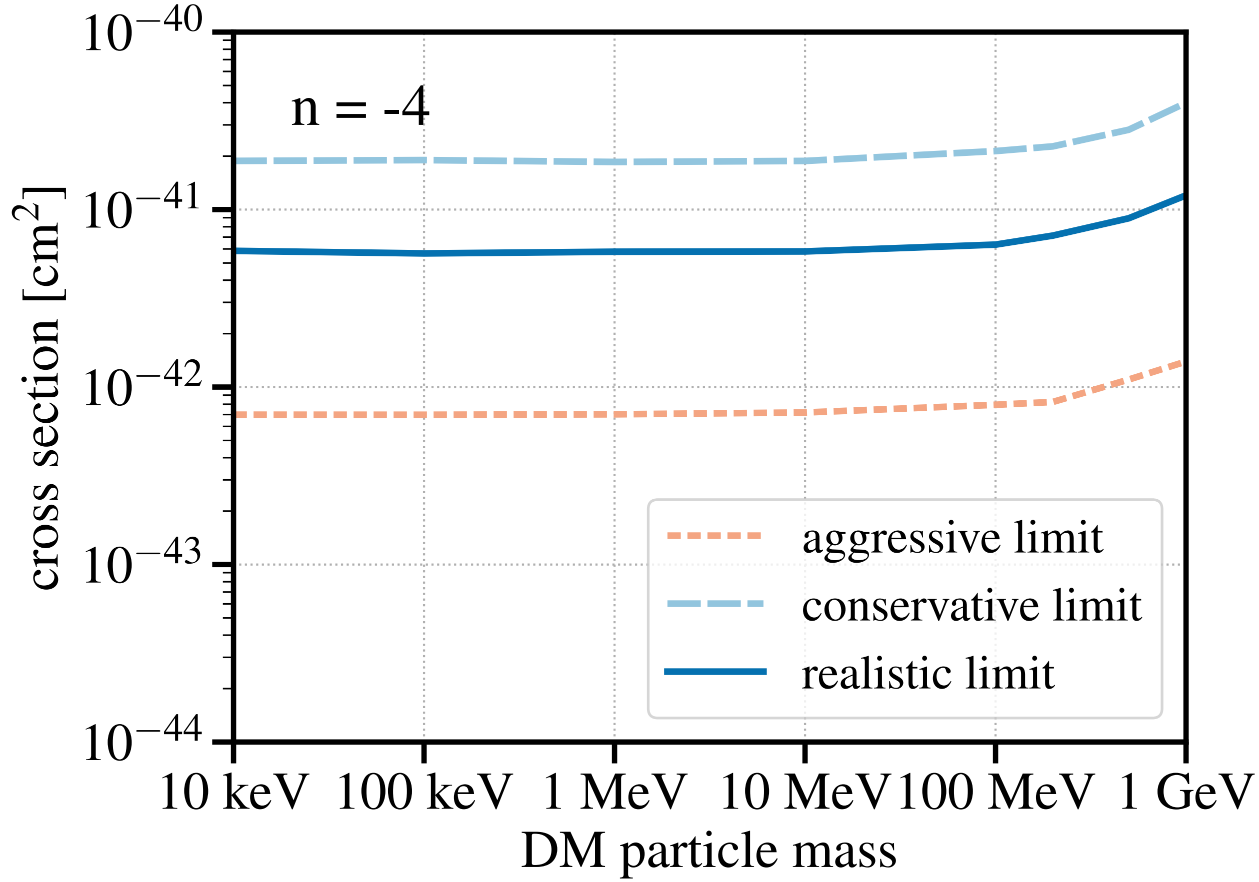
$$\dot{\theta}_\chi = -\frac{\dot{a}}{a}\theta_\chi + c_\chi^2 k^2 \delta_\chi + R_\chi \left(\theta_b - \theta_\chi\right),$$

$$\dot{\theta}_b = -\frac{\dot{a}}{a}\theta_b + c_b^2 k^2 \delta_b + R_\gamma \left(\theta_\gamma - \theta_b\right) + \frac{\rho_\chi}{\rho_b} R_\chi \left(\theta_\chi - \theta_b\right)$$

$$R_\chi = \frac{a\, c_n\, \rho_b\, \sigma_0}{m_\chi + m_{\rm H}} \left(\frac{T_b}{m_{\rm H}} + \frac{T_\chi}{m_\chi}\right)^{\frac{n+1}{2}} \mathcal{F}_{\rm He}$$

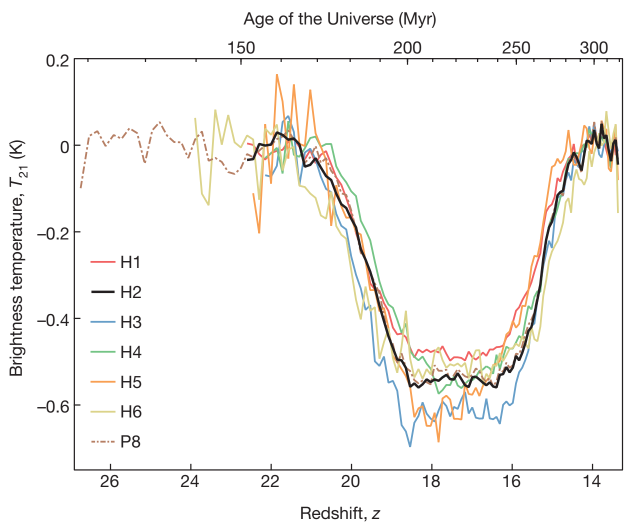
Only for Vbulk << Vthermal

v^{-4} scattering: Planck limits



Boddy, VG, Poulin, + (coming up)

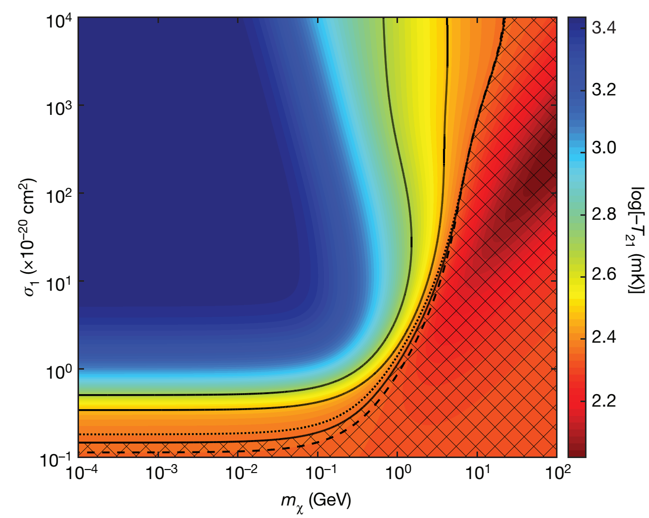
What about EDGES?



Bowman+ (2018)

?

- Systematics?
- Foregrounds?
- Astrophysics?
- **Cold baryons?**

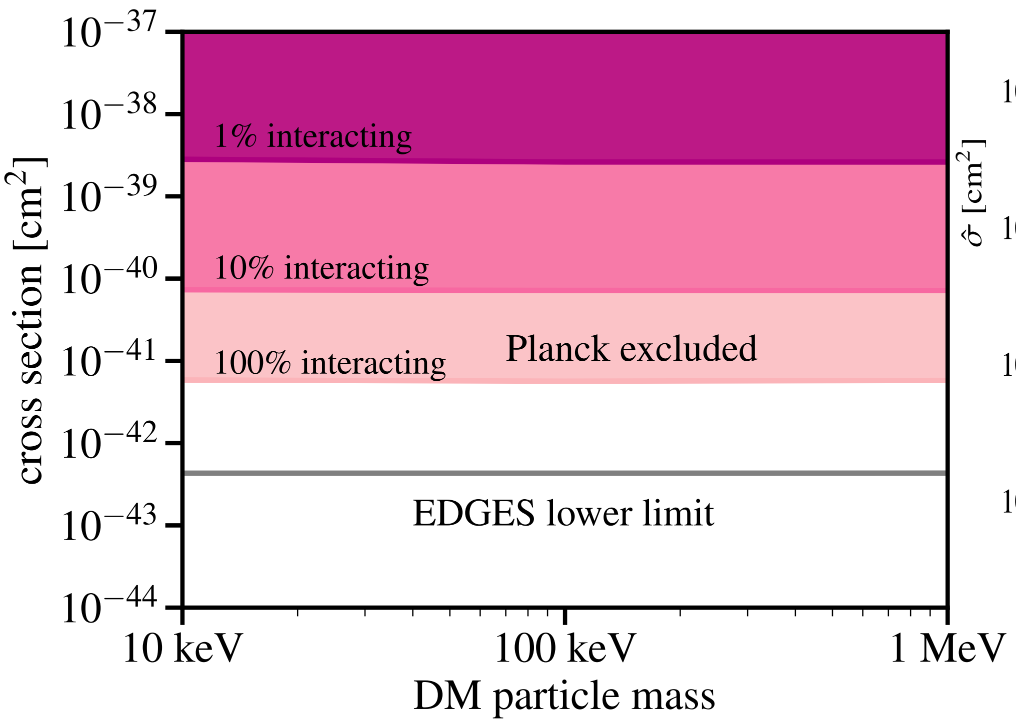


Barkana (2018)

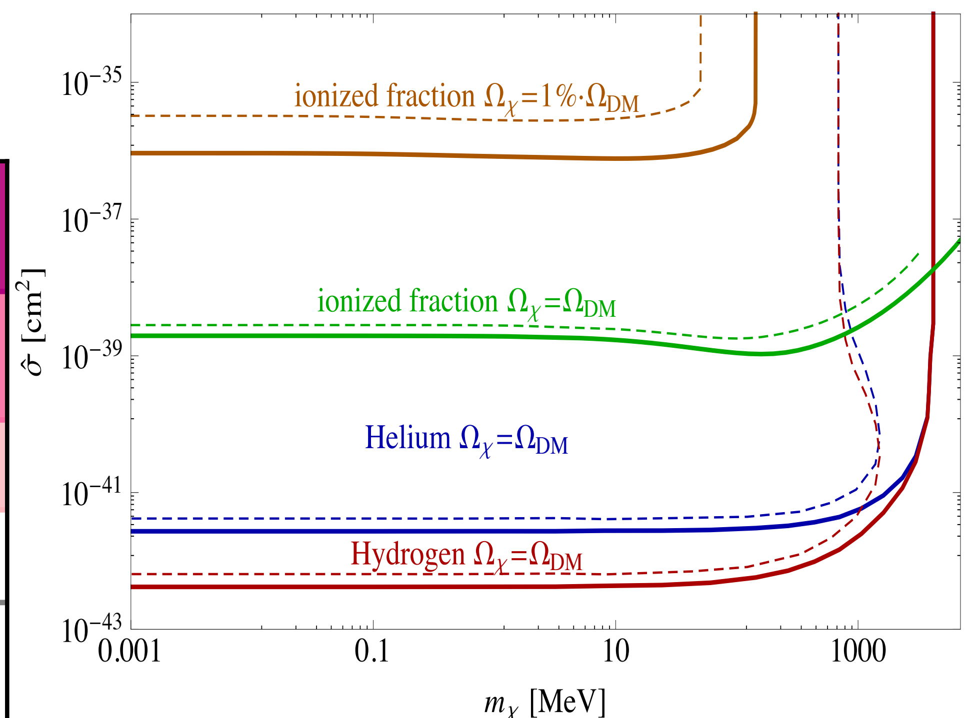
Order of business: **Is it in the sky? Is it cosmological? Is it DM?**

EDGES: v^{-4} and millicharge

From CMB limits on momentum-transfer: EDGES cannot be 1% of millicharged DM, but could be 100% with some other v^{-4} interaction.



Boddy, VG, Poulin, + (coming up)

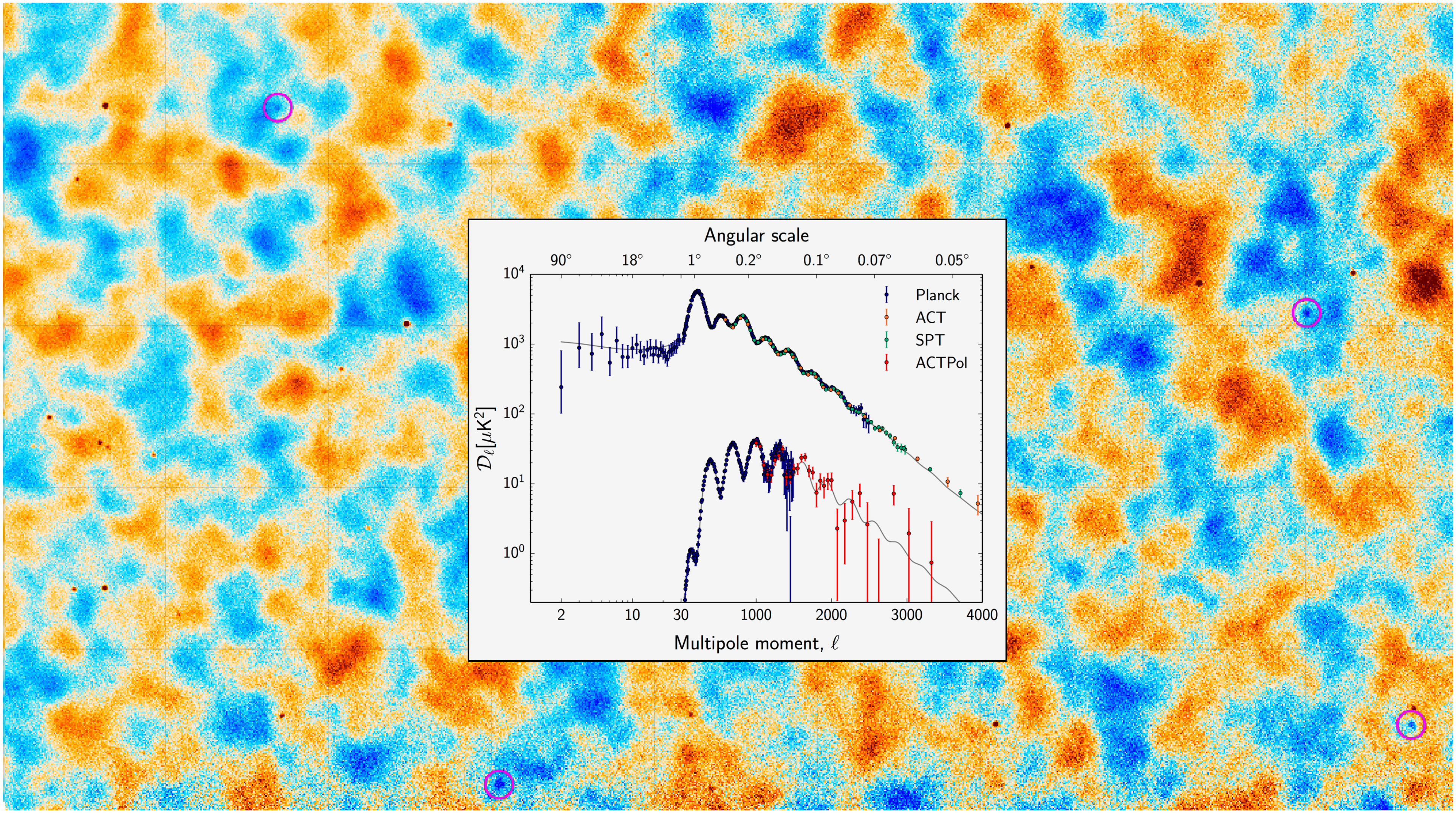


Barkana+ (2018)

What’s coming?

Data

Atacama Cosmology Telescope [ACT]

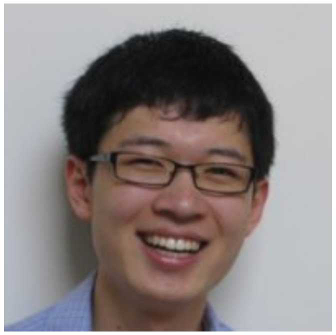


Louis et al 2016

The Simons Observatory

- A five year $45M+ program to advance technology and infrastructure in preparation for CMB-S4.
- Will eventually lead to the merging of the ACT and POLARBEAR/Simons Array projects.
- Tentative plans include:
  - Major site infrastructure
  - New telescopes with space for more future telescopes.
  - CMB-S4 class receivers with partially filled focal planes.

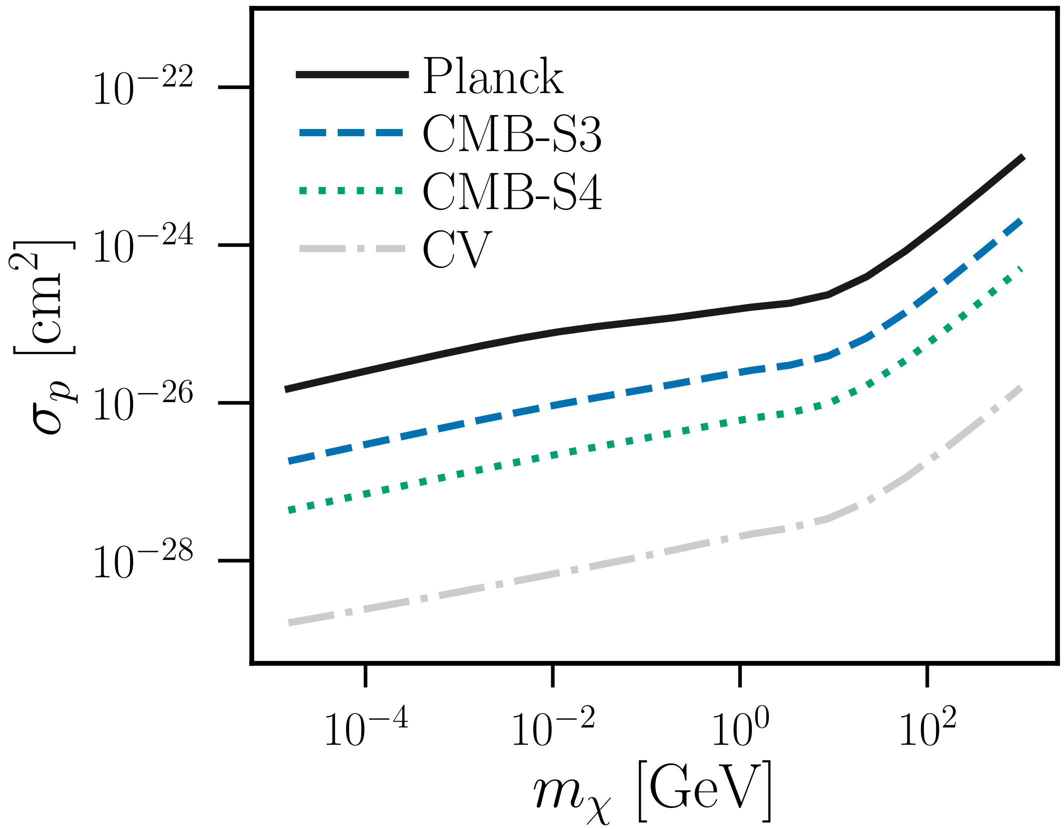
Forecasts



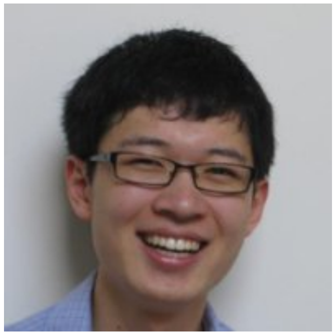
Zack Li (Princeton)

Large gain with next-stage CMB experiments.

[Li, VG, +, coming up]



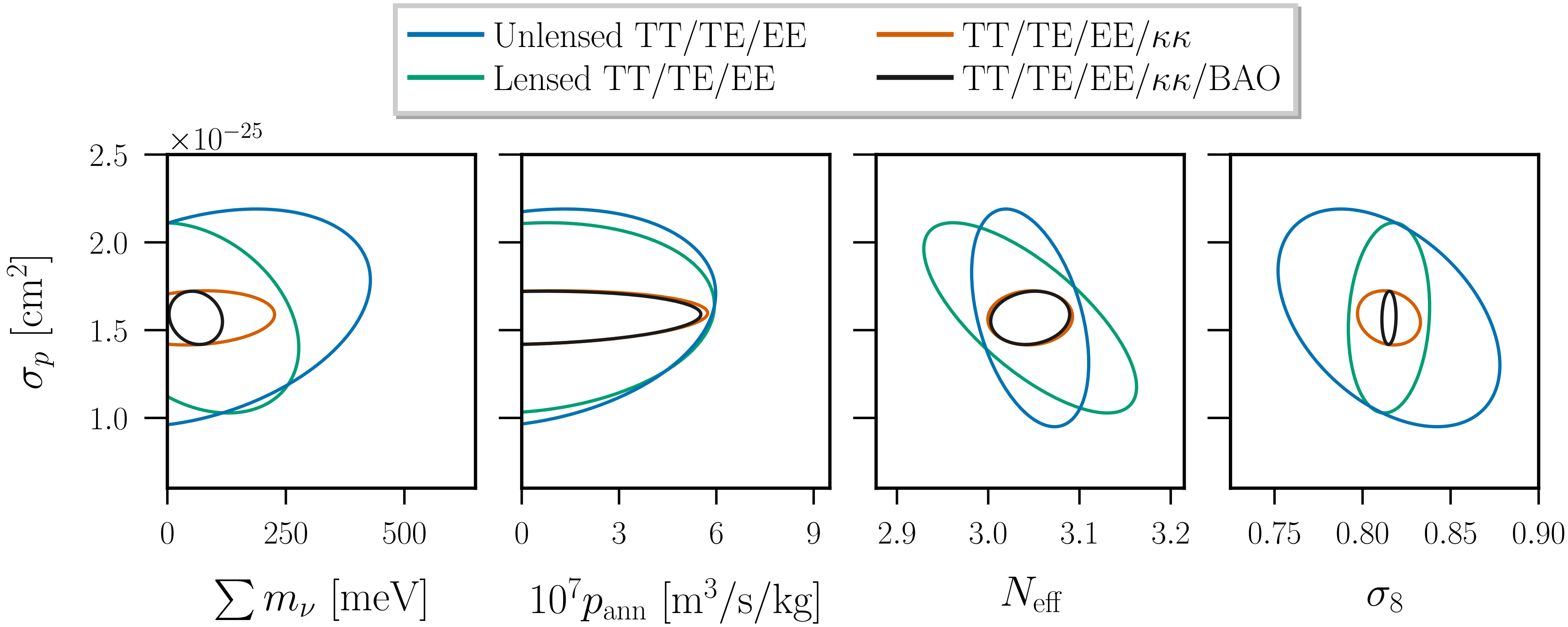
Distinguishability?



Zack Li (Princeton)

DM-baryon scattering does **NOT** look like neutrino mass, DM annihilations, Neff, nor LCDM parameters, once lensing is included in analyses.

[Li, VG, +, coming up]



What's coming?

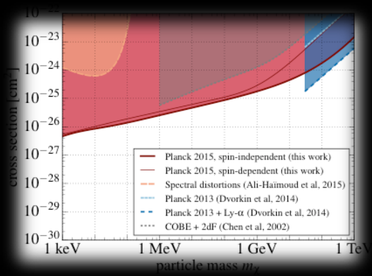
Analysis

Work in progress

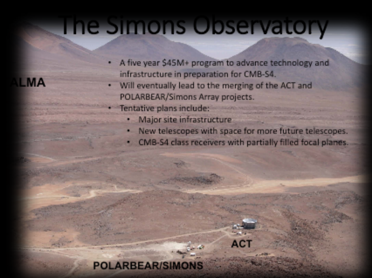
(with K. Boddy, Z. Li, M. Madhavacheril, the ACTPol collaboration)

- Cross-correlation with large-scale structure.
- Scattering with electrons (better sensitivity to lower mass).
- Constrain specific well-motivated models.
- **Ultimate goal: combine analyses of experimental and observational data, find and confirm the signal, robustly test DM physics.**

Summary

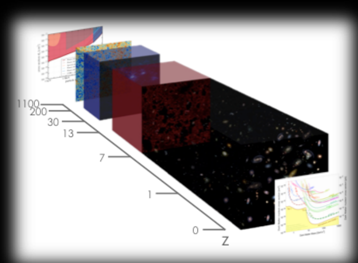


- ✓ CMB and cosmology probe vast parameter space (sub-GeV mass and large cross sections).



- ✓ Abundance of new data on the horizon:

  CMB, galaxy surveys, 21-cm experiments, direct detection, LHC, fixed targets, +



- ✓ Synthesizing information is important to guide searches and will be essential post-discovery.