Title: Ultralight axions and Future CMB experiments

Speakers: Renee Hlozek

Collection: PI-CITA Day 2019

Date: April 02, 2019 - 12:00 PM

URL: http://pirsa.org/19020045

@reneehlozek

primordial fluctuations

large scale B-modes
→ tensor-to-scalar ratio (BB)

damping tail
→ primordial power on small scales (TE, TT, EE)
→ primordial bispectrum (f_{NL} via TTT,TTE,… + lens/kSZ)

relativistic species

damping tail
→ N_{eff} (TE, TT, EE)

reionization

sources
→ duration of reionization (kSZ)
→ mean free path of photons (kSZ)

neutrino mass

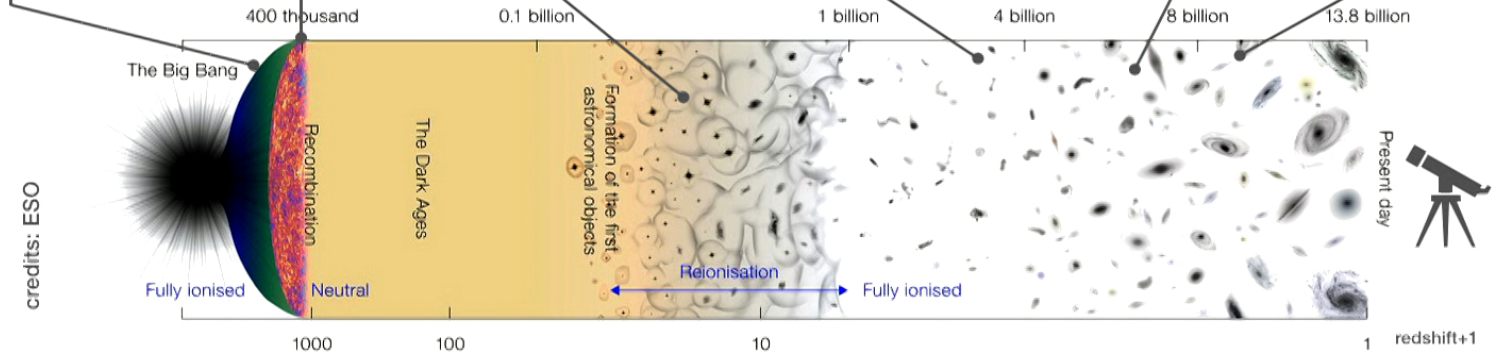
lensing potential (TT+EB), tSZ
→ Σm_ν

galaxy evolution

tSZ, kSZ
→ non-thermal pressure (tSZ+kSZ)
→ feedback efficiency (tSZ +kSZ)

dark energy

tSZ, lensing
→ σ_8 at z=2-3 (lensing, tSZ)
→ growth of structure (kSZ)



credits: ESO

Additional science includes (but is not limited to):
- helium fraction, cosmic birefringence, primordial magnetic fields
- high-redshift clusters
- dark matter annihilation and interactions
- isocurvature
- calibration of multiplicative shear bias (e.g., for LSST)
- new sample of dusty star-forming galaxies
- transient sources
- cosmic infrared background

Slide credit: Colin Hill

SO forecast paper 1808.07445

SO surveys

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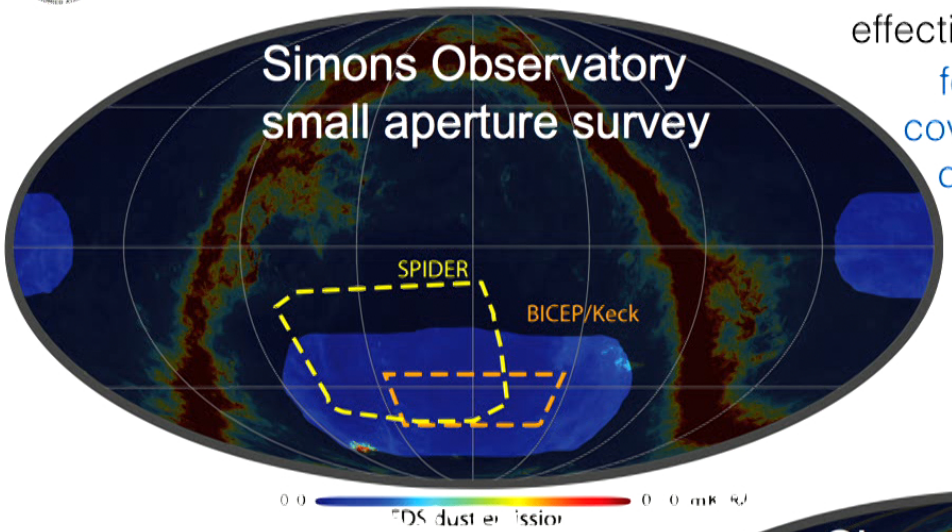


effective f_{sky} ~ 10%

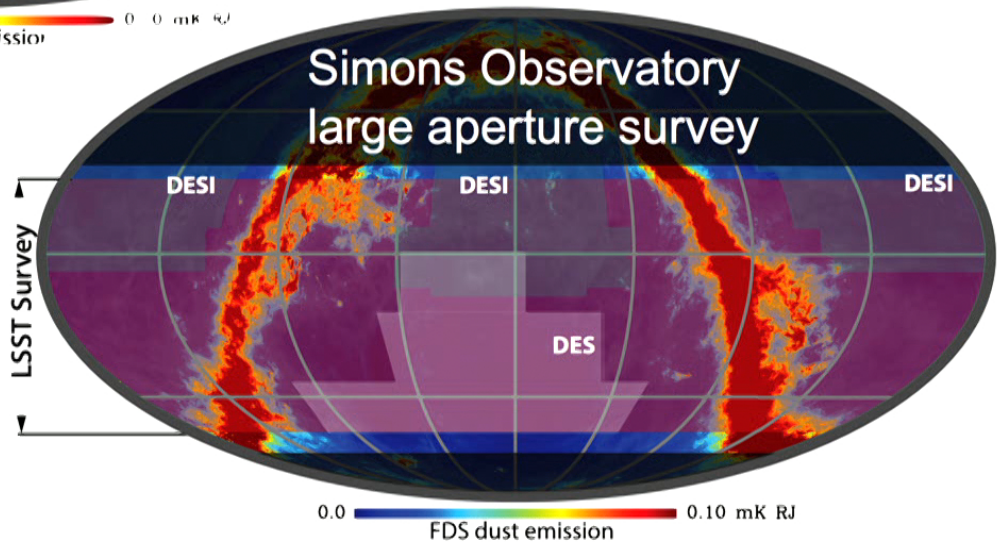
for SO noise and coverage, dedicated delensing survey not required

	Freq. [GHz]	SATs ($f_{sky} = 0.1$) FWHM (′)	Noise (baseline) [μK-arcmin]	Noise (goal) [μK-arcmin]
LF	27	91	35	25
	39	63	21	17
MF	93	30	2.6 | 2 μK-amin	1.9
	145	17	3.3	2.1
HF	225	11	6.3	4.2
	280	9	16	10

effective f_{sky} ~ 40%

maximal overlap w/ LSST, large overlap w/ DESI

LAT ($f_{sky} = 0.4$) FWHM (′)	Noise (baseline) [μK-arcmin]	Noise (goal) [μK-arcmin]
7.4	71	52
5.1	36	27
2.2	8.0 | 6 μK-amin	5.8
1.4	10	6.3
1.0	22	15
0.9	54	37



Simons Observatory Site

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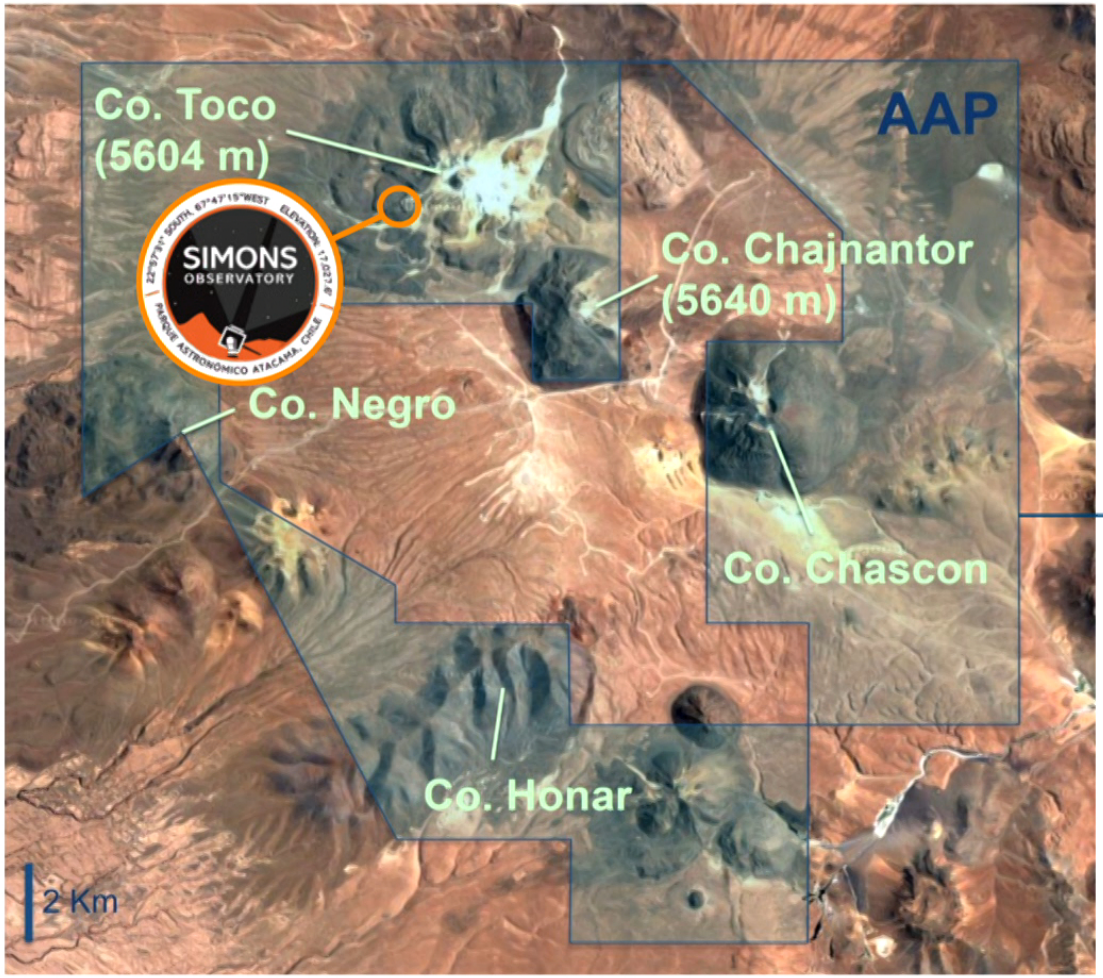

Parque Astronómico Atacama

Slide credit: Colin Hill

Simons Observatory Instruments & Technology

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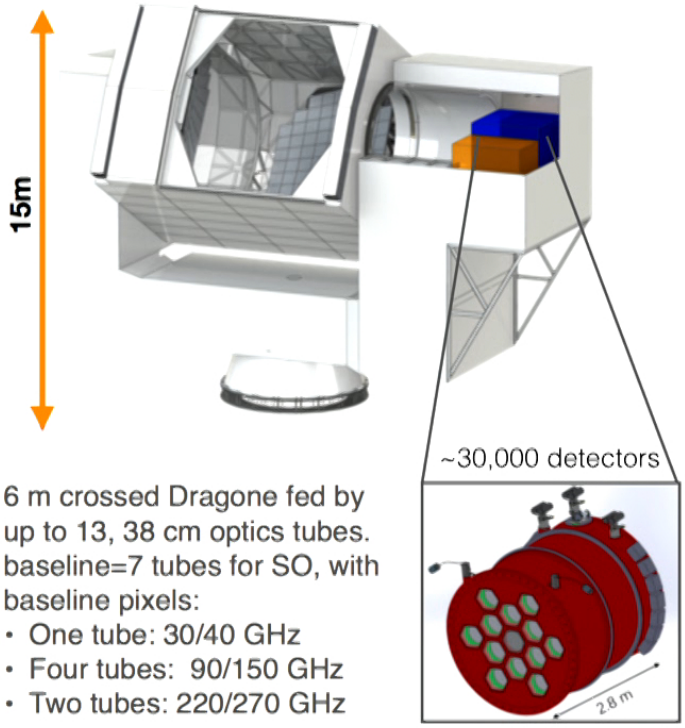
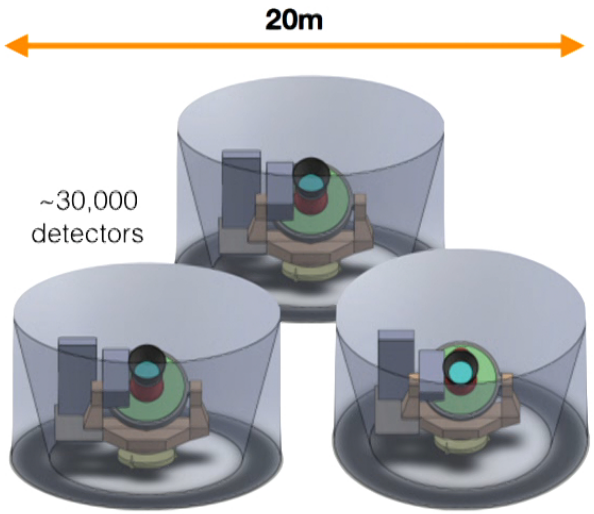
large aperture telescope



6 m crossed Dragone fed by up to 13, 38 cm optics tubes.
baseline=7 tubes for SO, with baseline pixels:

- One tube: 30/40 GHz
- Four tubes: 90/150 GHz
- Two tubes: 220/270 GHz

small aperture telescopes



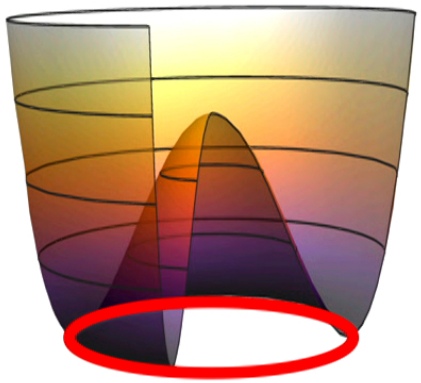
Three 42 cm diameter refractors,
baseline dichroic pixels:
30/40 | 90/150 | 90/150 | 220/270 GHz

FIRST LIGHT IN 2021

Slide credit: Colin Hill

Ultralight axions

Axions originally solved the CP problem - but we are considering the ultralight axions (ULAs) that may arise from string theory.



$$\theta = \phi / f_a$$

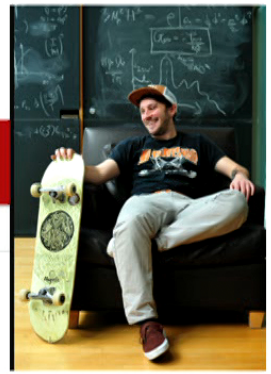
arXiv.org > hep-th > arXiv:0905.4720

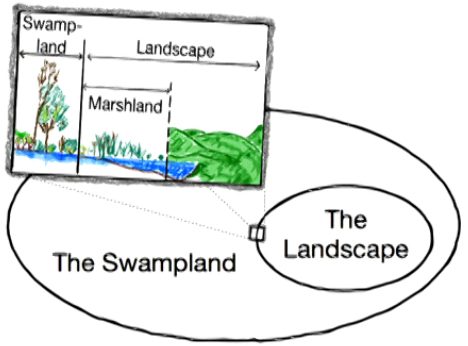
High Energy Physics - Theory

String Axiverse

Asimina Arvanitaki, Savas Dimopoulos, Sergei Dubovsky, Nemanja Kaloper, John March-Russell

Ultralight axions





arXiv.org > hep-th > arXiv:1903.12643

High Energy Physics - Theory

The Marshland Conjecture

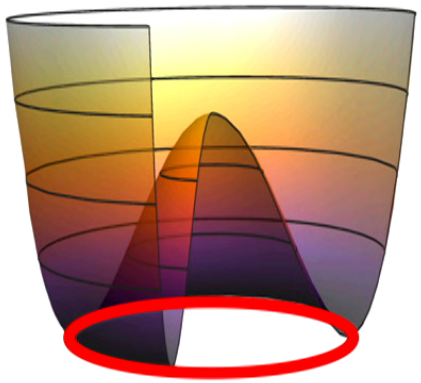
David M.C. Marsh, J.E. David Marsh

(Submitted on 29 Mar 2019)

We posit the existence of the Marshland within string theory. This region is the boundary between the landscape of consistent low-energy limits of quantum gravity, and the swampland of theories that cannot be embedded within string theory because they violate certain trendy and obviously uncontroversial conjectures. The Marshland is probably fractal, and we show some pretty pictures of fractals that will be useful in talks. We further show that the Marshland contains theories with a large number of light axions, allowing us to cite lots of our own papers. We show that the Marshland makes up most of the volume of the landscape, and admits a novel, weakly broken $\mathbb{Z}_2$ Marshymmetry that we find strong evidence for by considering a carefully crafted example.

Ultralight axions

Axions originally solved the CP problem - but we are considering the ultralight axions (ULAs) that may arise from string theory.



$\theta = \phi / f_a$

Axion dynamics specified by the scalar field potential:

$$\ddot{\phi}_0 + 2\mathcal{H}\dot{\phi}_0 + m_a^2 a^2 \phi_0 = 0$$

Simple harmonic oscillator

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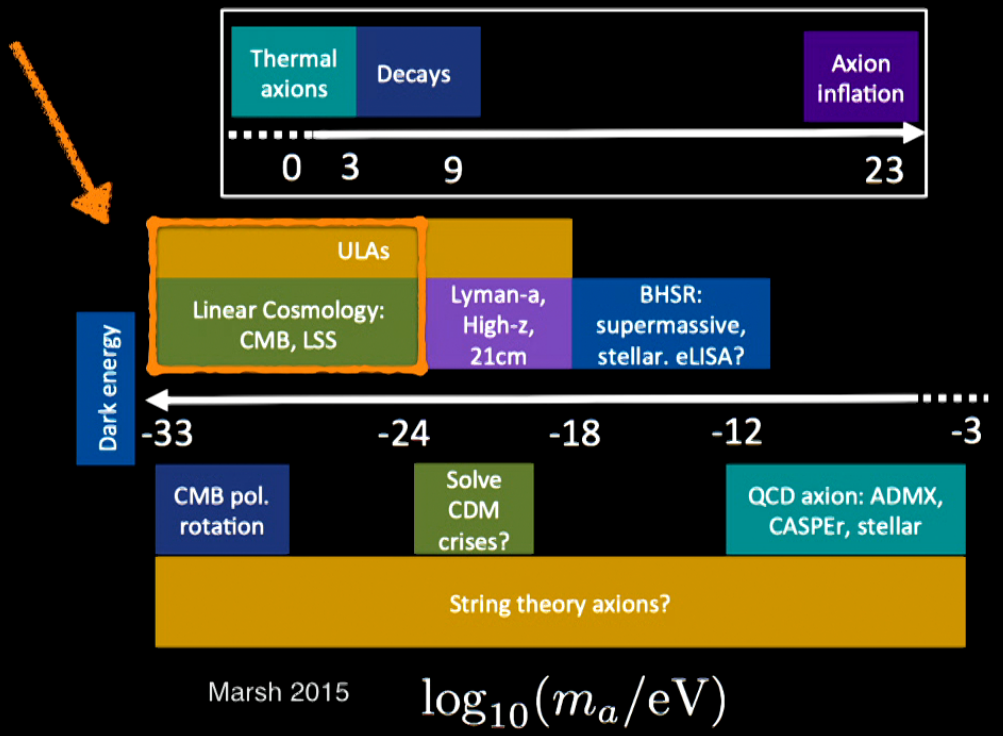
$$\rho_a = \dot{\phi}^2/2 + m_a^2\phi^2/2 \sim \begin{cases} \text{const. for } H \gtrsim m_a\,, \\ 1/a^3 \quad \text{for } H \lesssim m_a\,. \end{cases}$$

Why should you care about axions?

- Depending on their mass - axions look like Dark Energy or Dark Matter



Marsh 2015 $\log_{10}(m_a/\mathrm{eV})$

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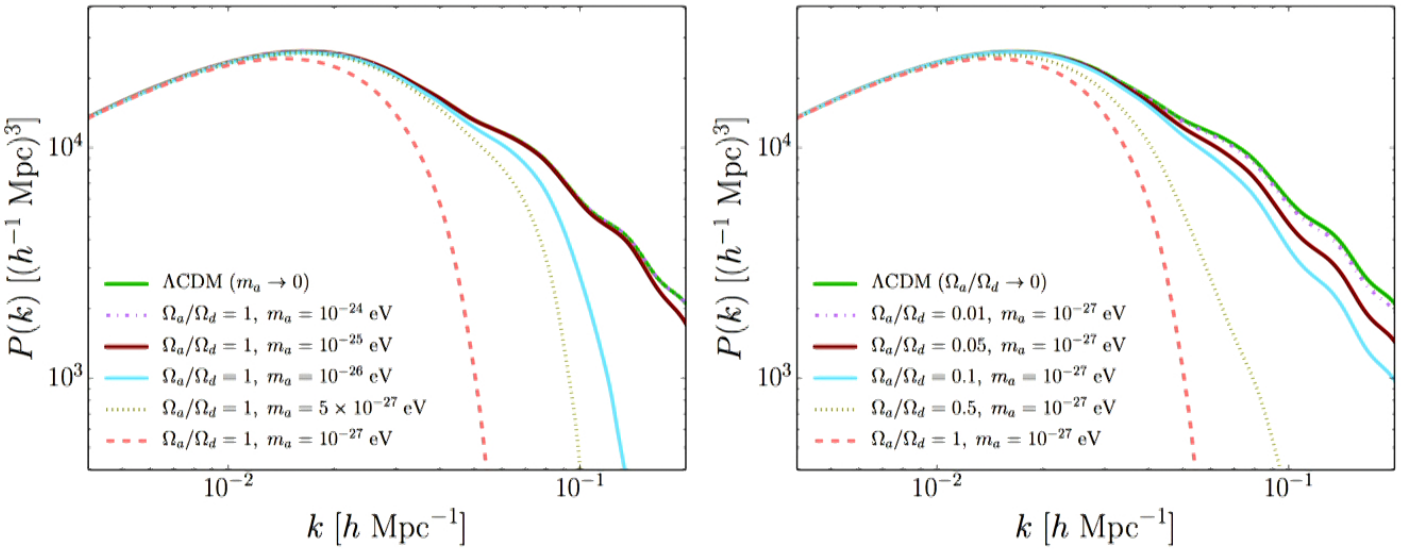


Hložek et al. 2015

ULAs	vs	WDM
Ultra-light axions		Warm DM
Non-thermal misalignment		Relativistic at early times
$H > m_a \Rightarrow w_a \approx -1$		$T > m_W \Rightarrow w_W \approx 1/3$

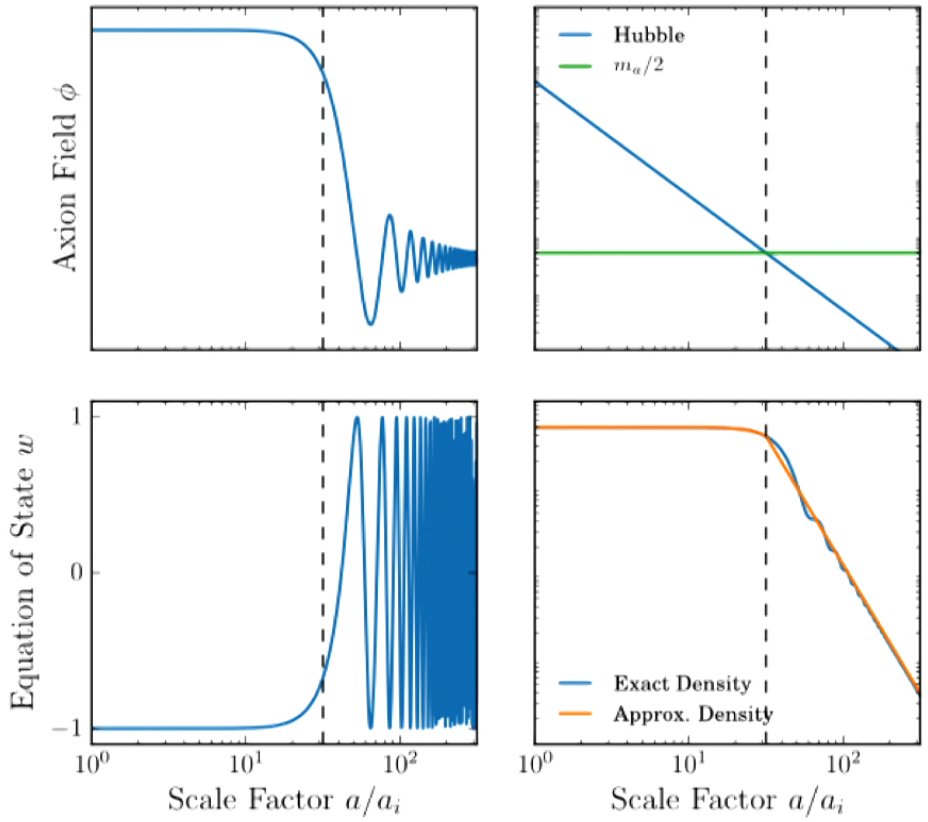
→ Structure suppressed on scales k ~ aH at transition

$$T \sim \sqrt{M_{pl} H} \Rightarrow m_W \sim \sqrt{M_{pl} m_a}$$

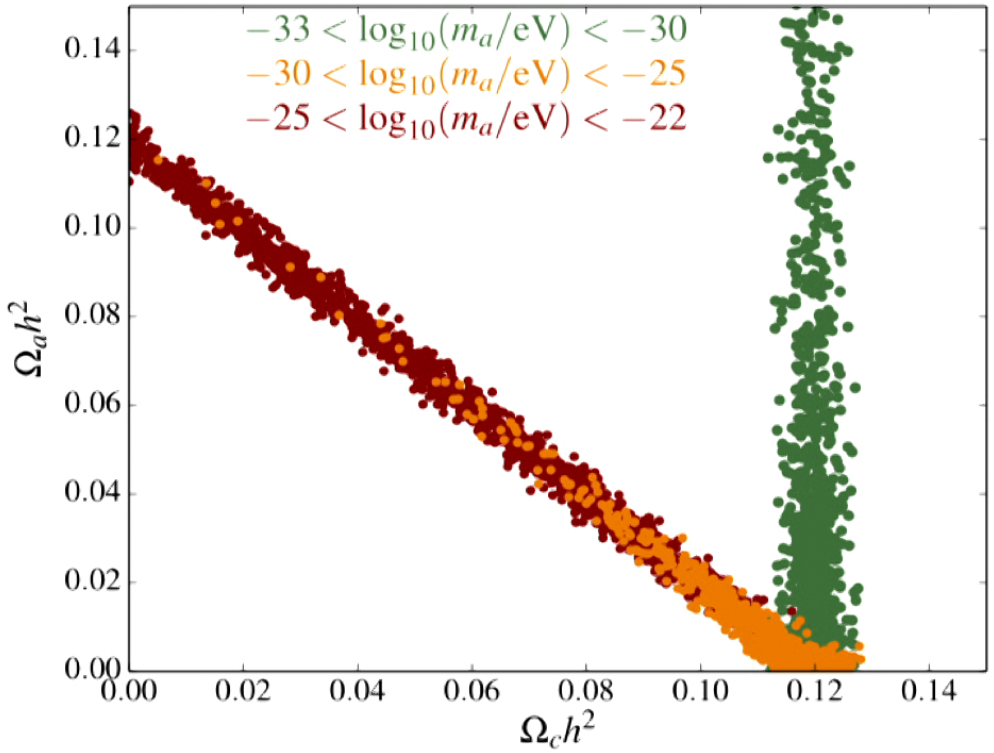
Sound-speed + Jeans scale —> scale-dep. growth	Free-streaming —> “initial” condition

Misalignment production of DM

Exact solution for $H \sim t^p$ (fluid domination.) in terms of Bessel functions.

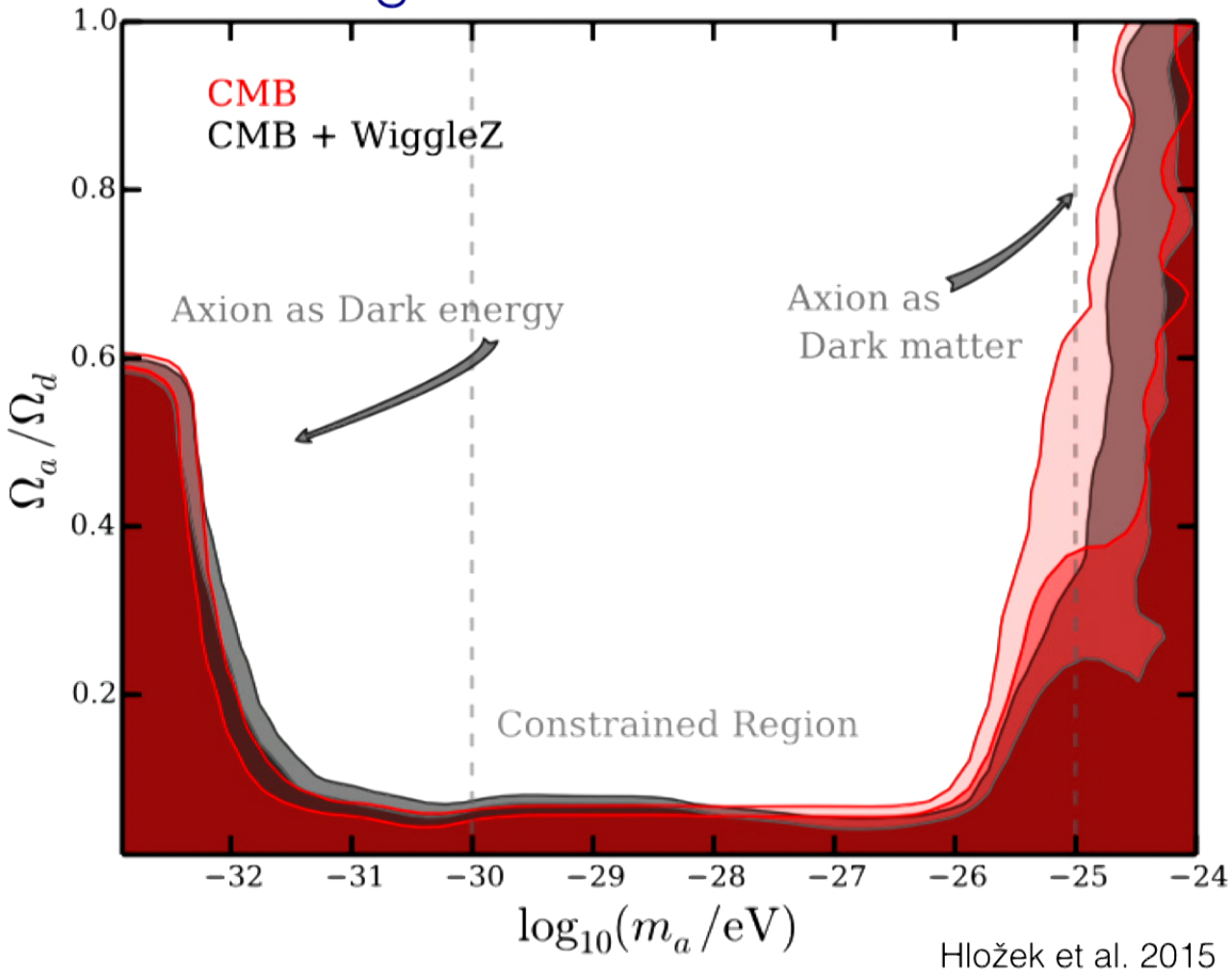


A challenging parameter space

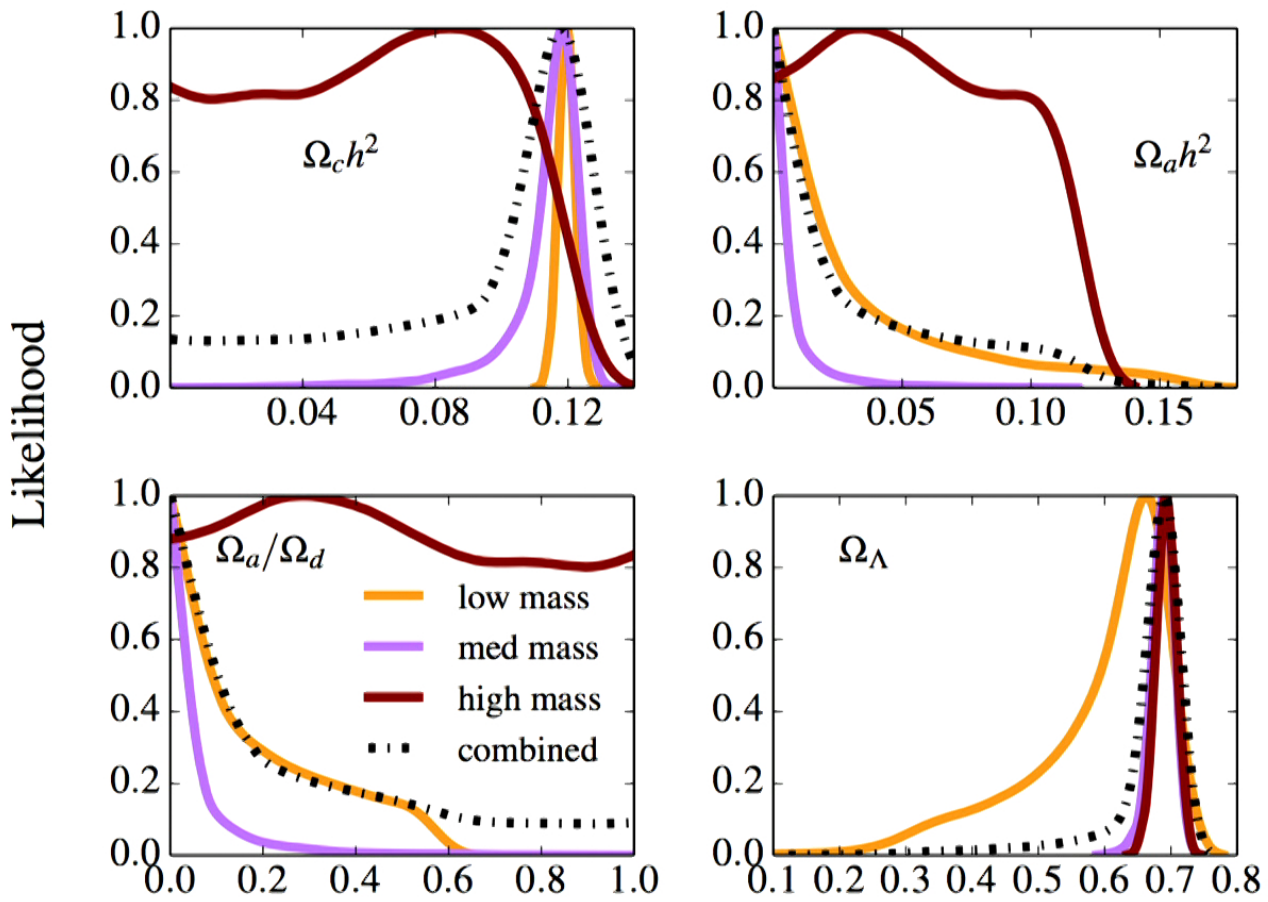


Hložek et al. 2015

Ultralight axions: *Planck* results



Hložek et al. 2015



Hložek et al. 2015

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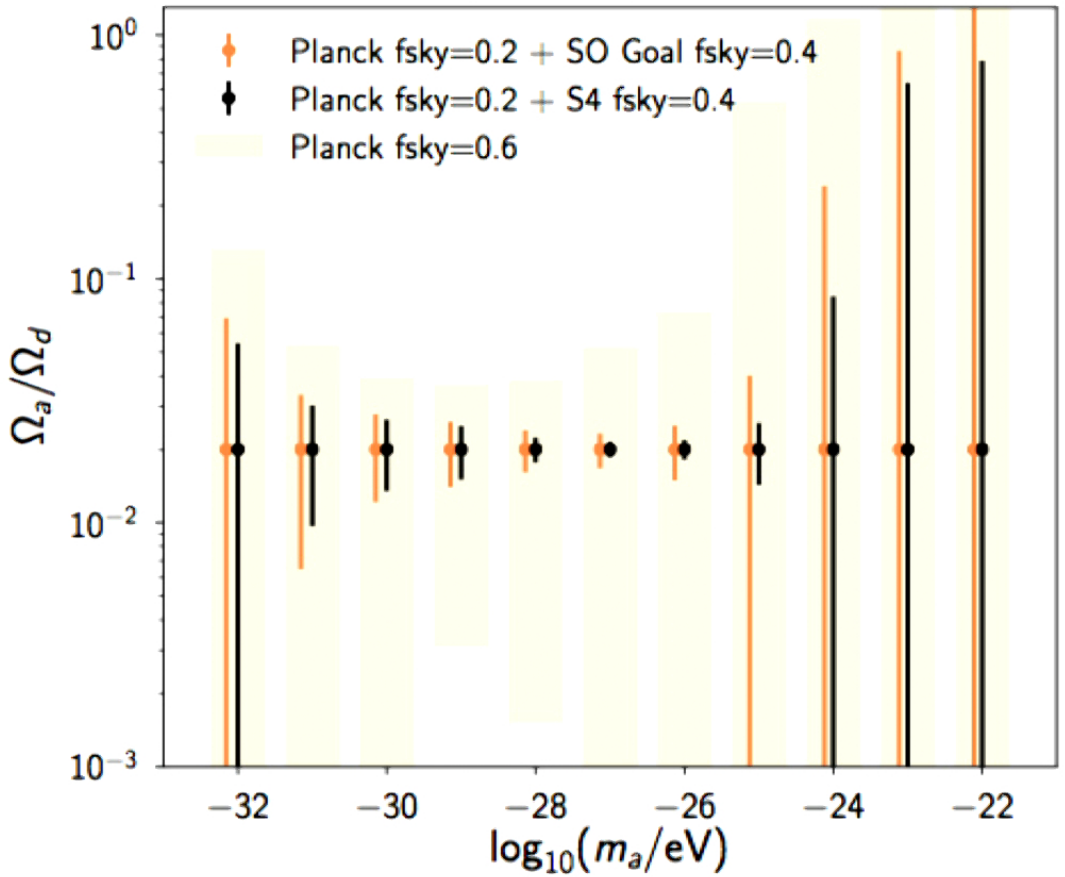
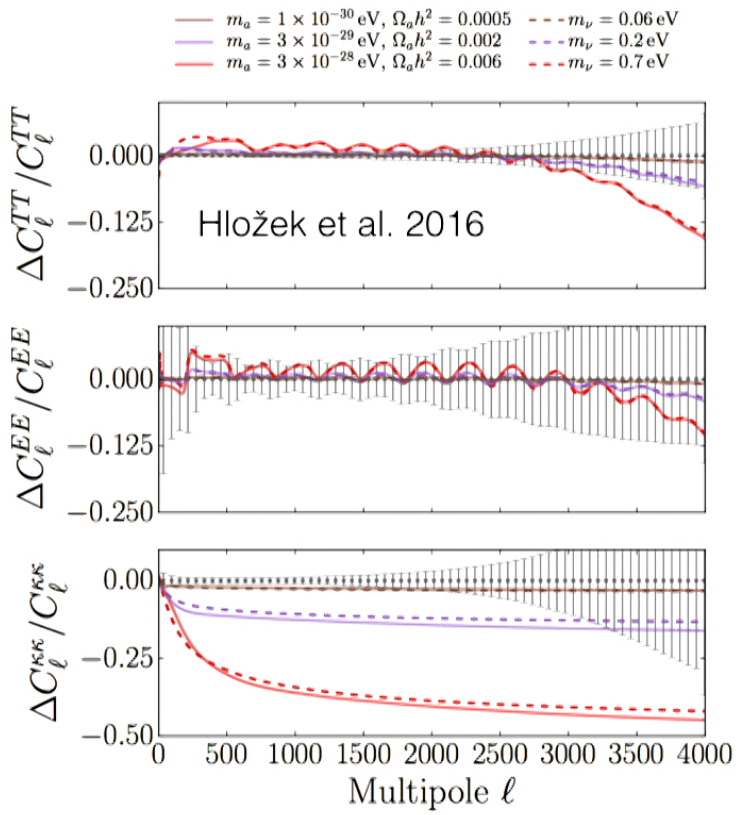
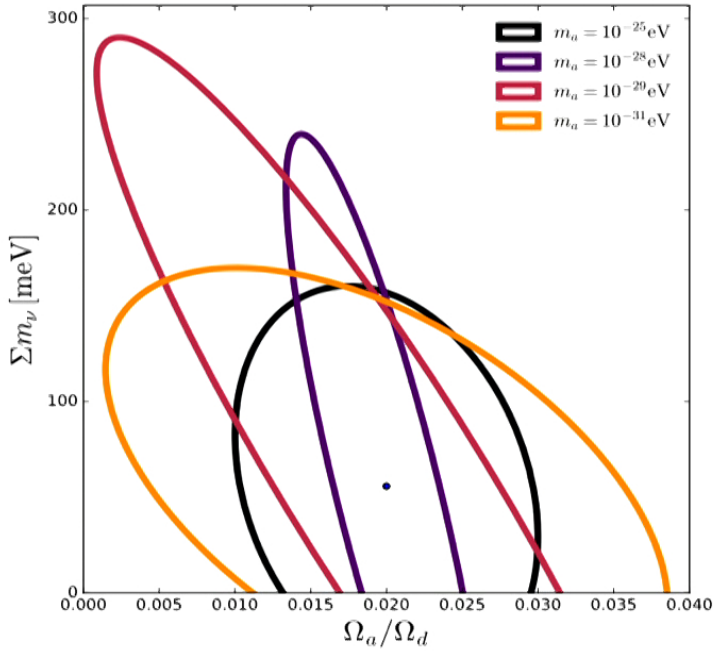
Ultralight axions: SO forecast



(SO forecasts from Ade++2018)



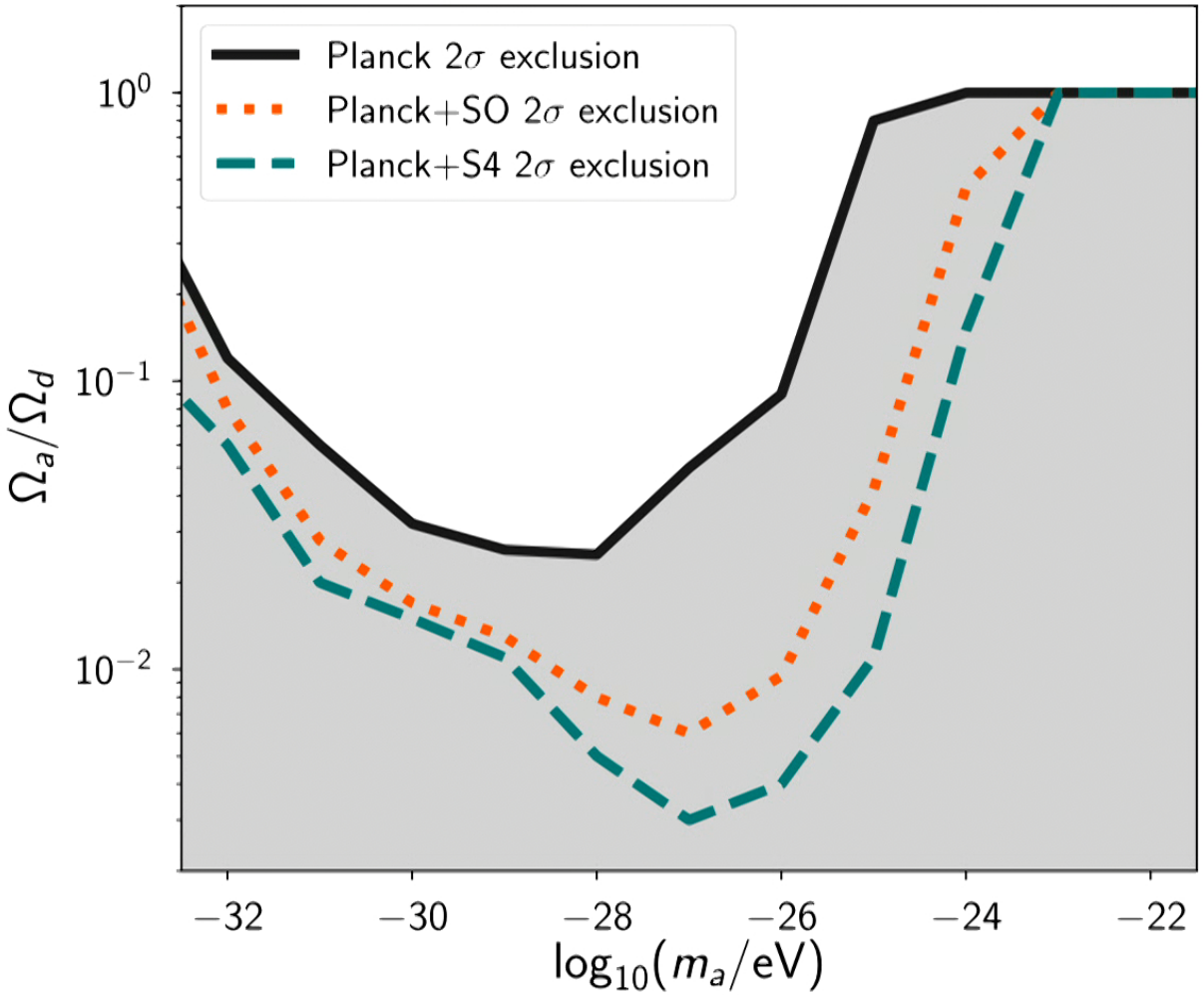
Axions are degenerate with massive neutrinos



$$\Omega_{\rm a} = \left[\frac{a^{-2}}{2}\dot{\phi}_0^2 + \frac{m_a^2}{2}\phi_0^2\right]_{m_a=3H} a_{\rm osc}^3/\rho_{\rm crit}$$

$$\Omega_\nu h^2 = \frac{\Sigma m_\nu}{93.14\text{eV}}$$

Ultralight axions: exclusion



New constraints on axion models

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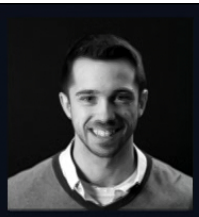
Can we compute non-linear clustering of axions to compare with data?



1LPT Toy Model

(now with FDM and baryons)

$$\nabla^2_{\mathbf{q}}\phi^{(1)} = \delta$$

$$\mathbf{v} = -\mathcal{H}\frac{d\ln D}{d\ln a}\nabla_{\mathbf{q}}\phi^{(1)}$$

$k_0 \propto \sqrt{\frac{\hbar}{m}}$

$B = \frac{4}{3}\kappa(6\pi G)^{-1/3}; \quad P = \kappa\rho^{4/3}$

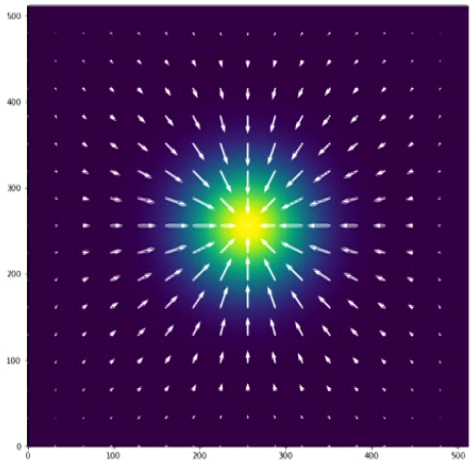
$D_{\rm FDM}(k,a) \approx \Theta(|\mathbf{k}| - |\mathbf{k_0}|)D_{\rm CDM}(a)$

$D_{\rm b}(k,a) = t^{-1/6+\sqrt{25/36-B|\mathbf{k}|^2}}$

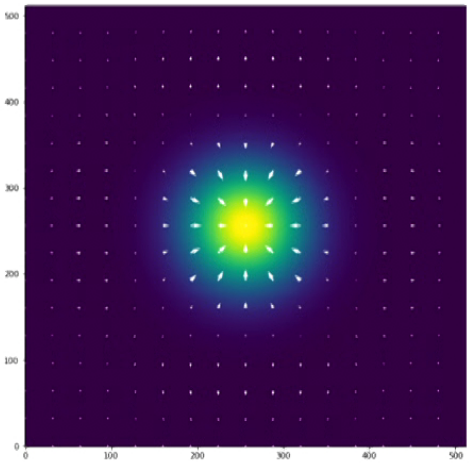
$D_{\rm CDM}(a) \propto a$

Can we compute non-linear clustering of axions to compare with data?

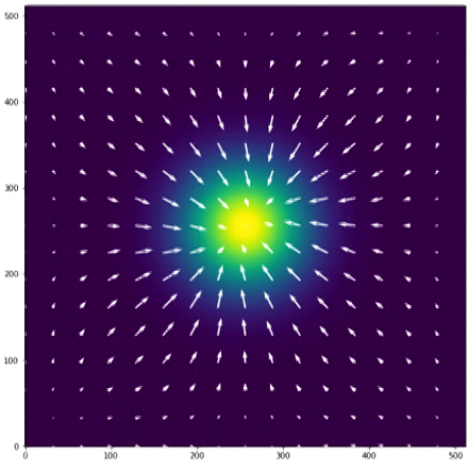
CDM

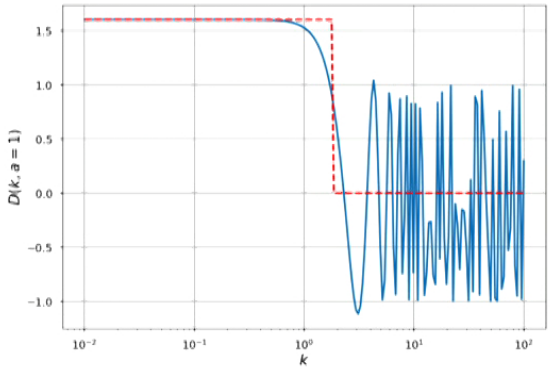


FDM



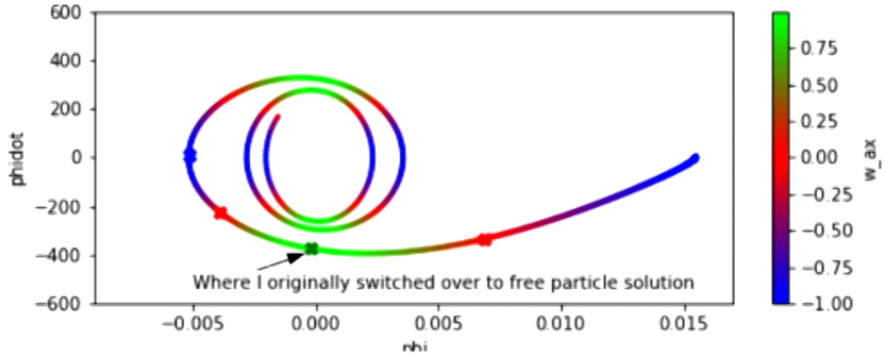
Baryons

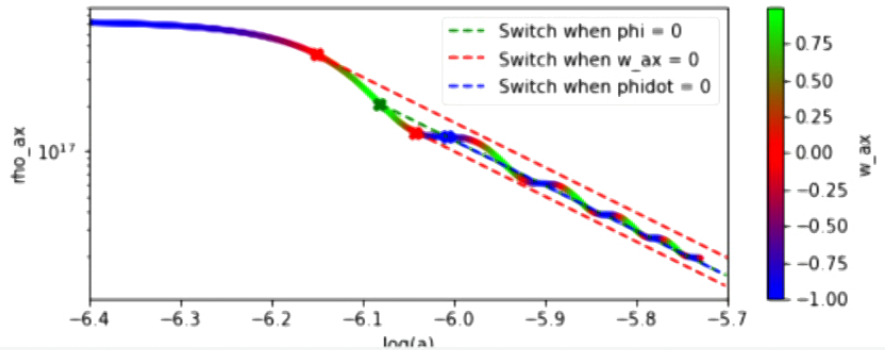




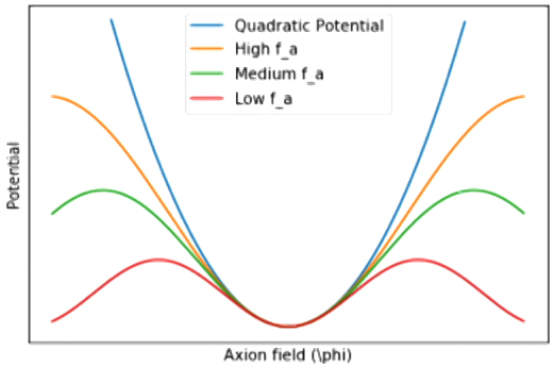
Can we constrain the symmetry breaking scale rather than using simple potential?

$$\ddot{\phi}_0 + 2\mathcal{H}\dot{\phi}_0 + m_a^2 a^2 \phi_0 = 0$$





$$V(\phi) = \Lambda_a^4 \left[1 - \cos\left(\frac{N_{\rm DW}\phi}{f_a}\right)\right]$$



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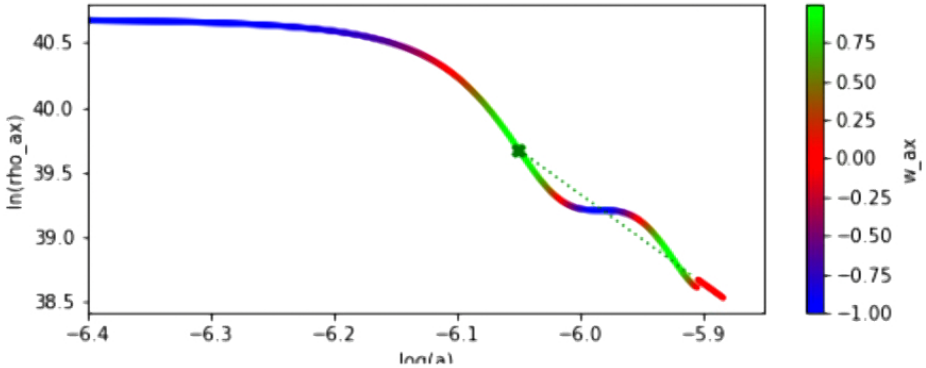

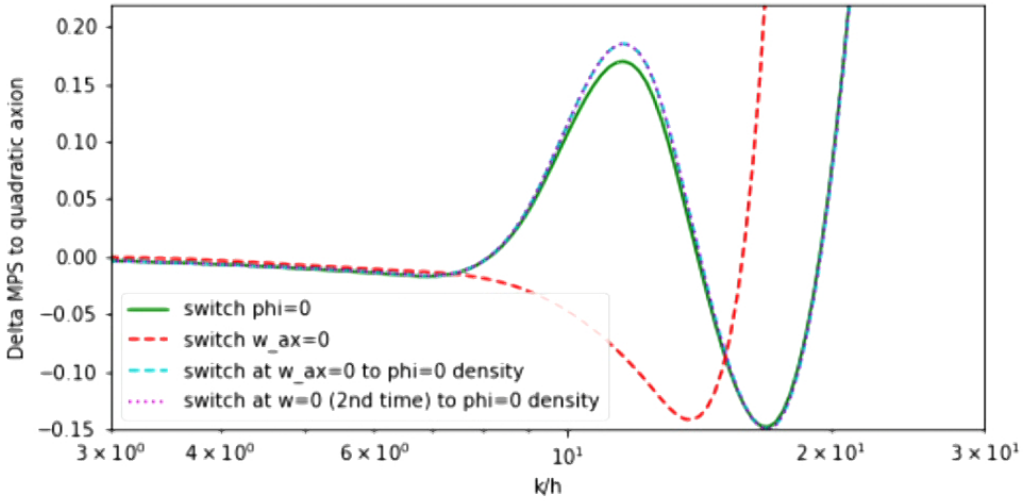

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Simons Observatory Outlook

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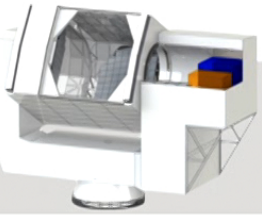


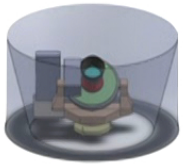
Large Aperture telescope construction by VERTEX

Large Aperture Receiver Design | Manufacture | Cryo-genic test | integration and test | ship and testing

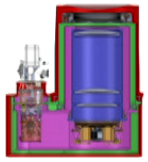
scientific observations

2018 2019 2020 2021 2026

First SAT on sky 2020



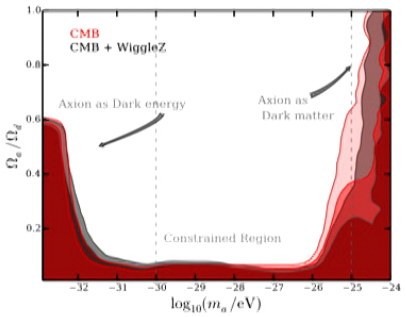
Small Aperture Platform Design | Platform Fabrication | accep -tance test | ship | install and test

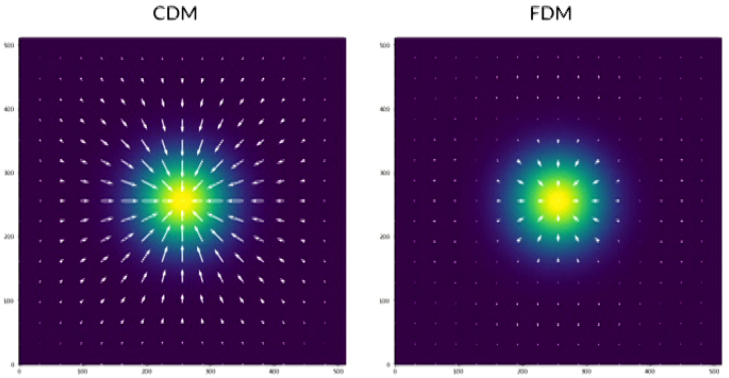


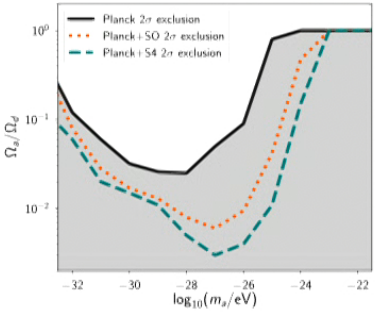
Small Aperture Camera Design | Manufacture | Cryo-genic test | integration and test | ship and testing

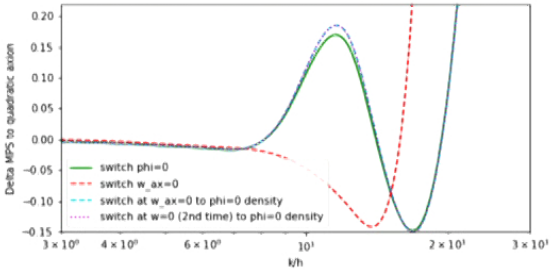
scientific observations

- site design and construction
- analysis pipeline development
- calibration strategy
- etc.









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