Searching for interacting dark sectors in cosmology

Gustavo Marques-Tavares

Department of Physics & Astronomy
THE UNIVERSITY OF UTAH

Related to past and current work done with


Buen-Abad


Chacko

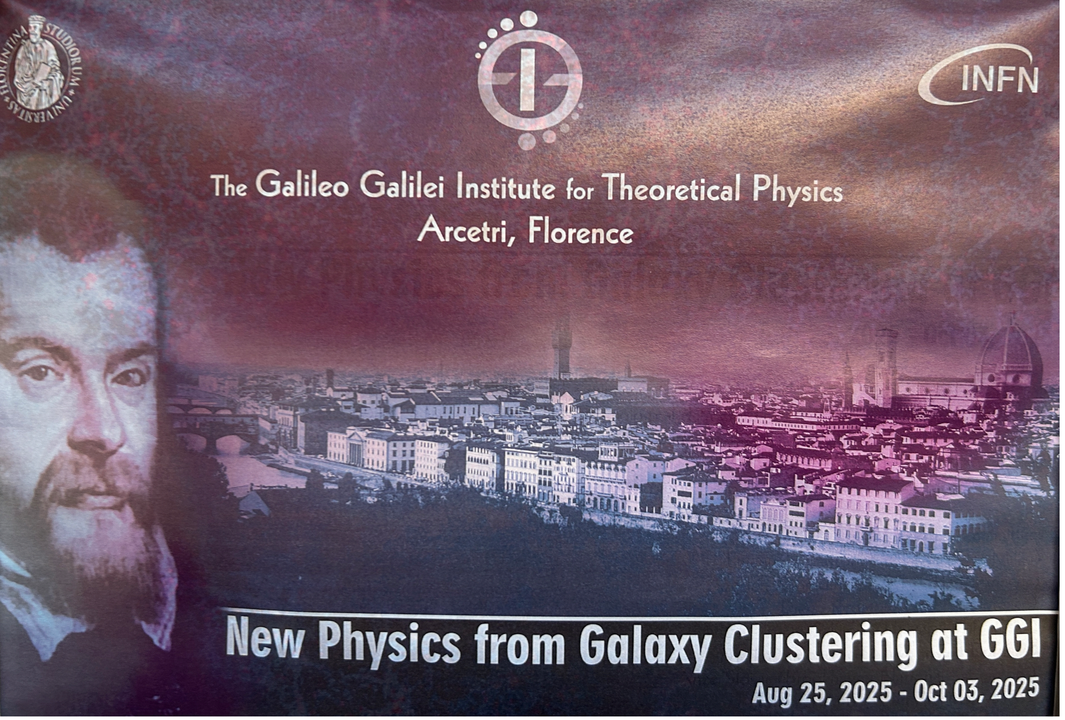

Cvetko

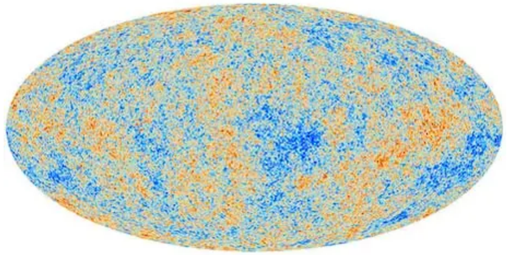

Flood

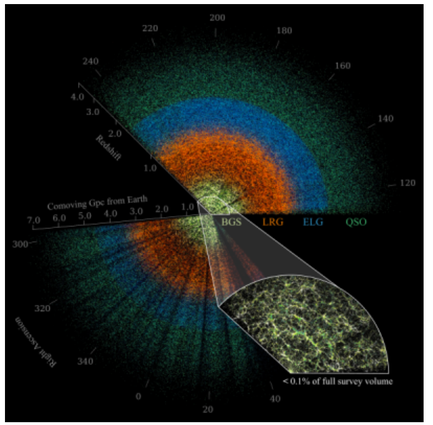

Joseph


Kilic

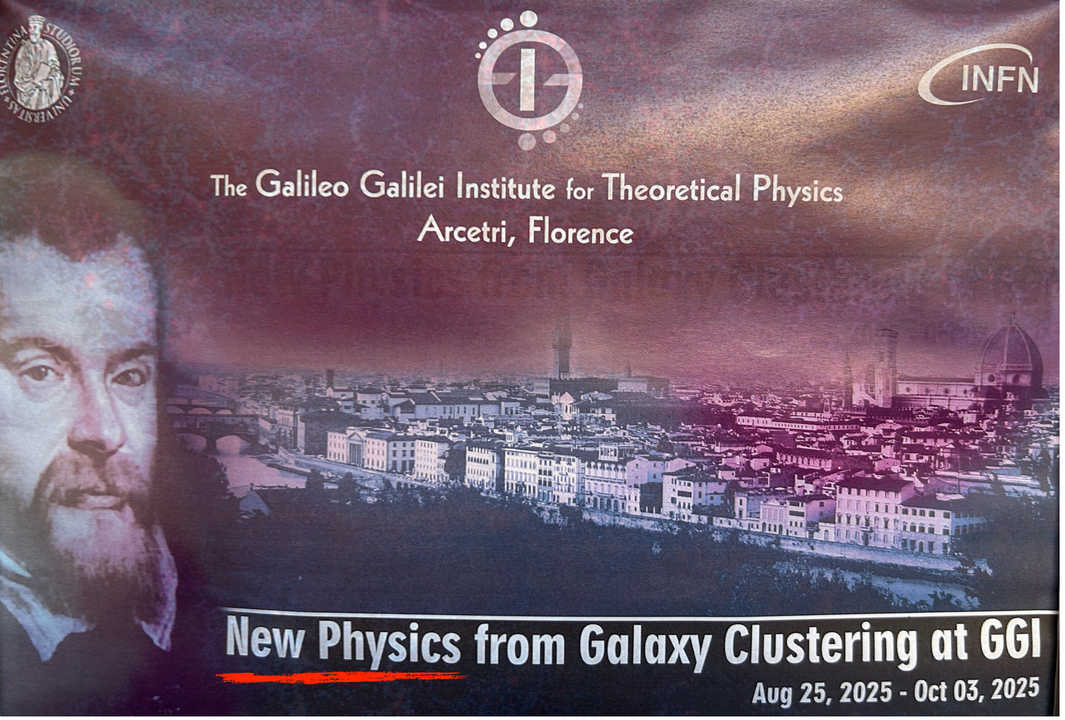

Youn

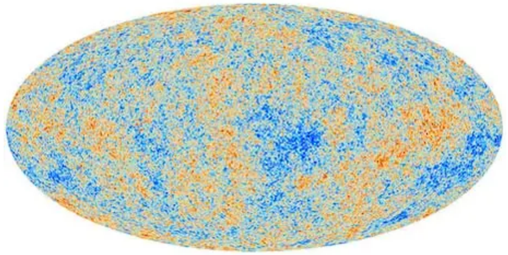


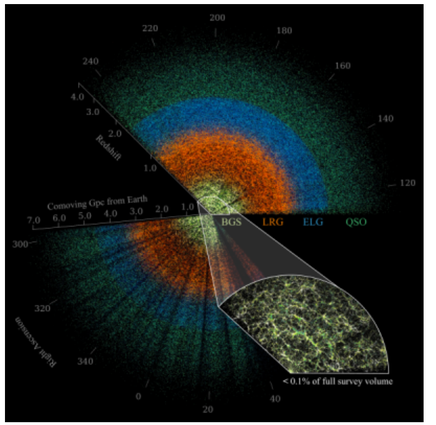




Inflation + Λ CDM + Gravity



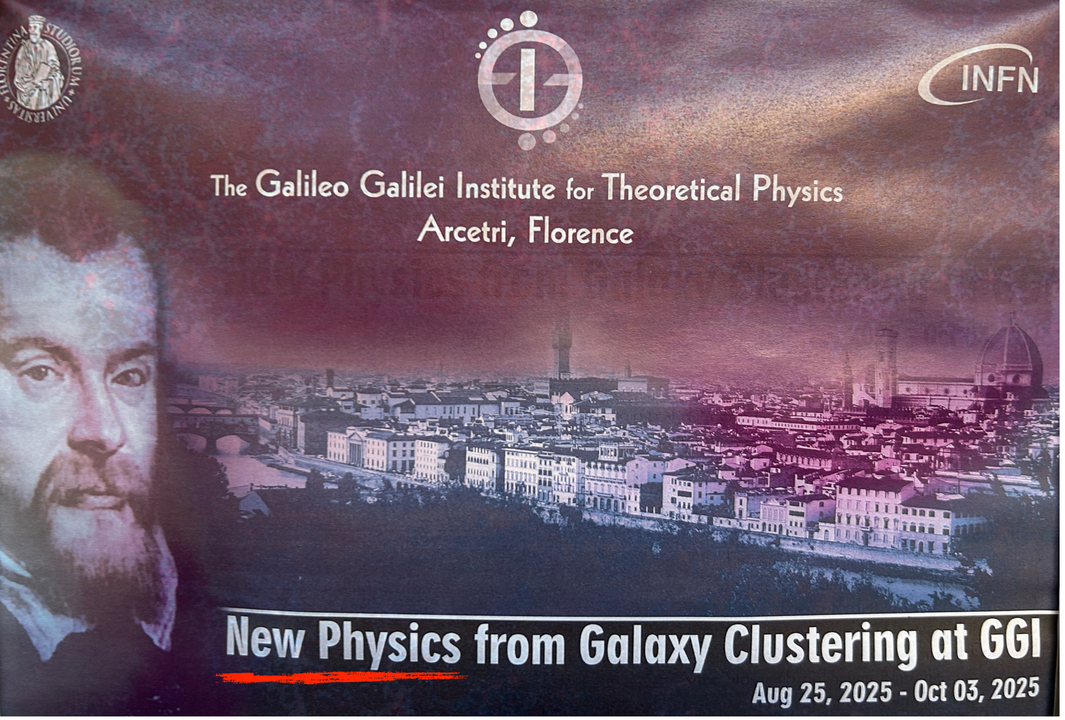


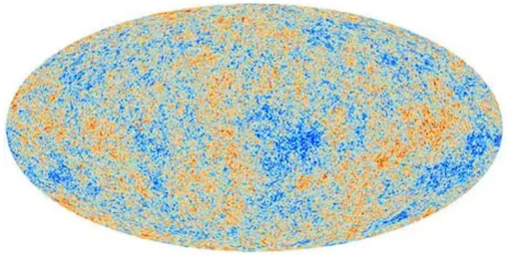


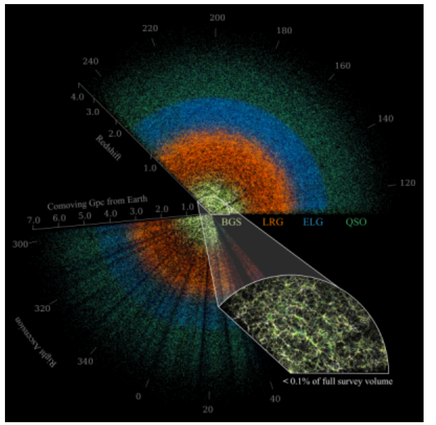
Inflation + Λ CDM + Gravity

Apparent cosmologist's prior on new physics

* counter example: Erminia's talk







Inflation + ΛCDM + Gravity

- Much easier to find models with new signatures
- Often more visible effects at LSS than CMB

★ Will consider dark matter with dynamics: ΛiDM ?

What kind of dark matter interactions?

- To affect $k \lesssim 1$ Mpc^{-1} → Generally implies light mediator: $m \lesssim$ keV

- Cosmology of at least two “dark” species: dark matter + mediator

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- Cosmology of at least two “dark” species: dark matter + mediator

- **Simplicio:** Isn’t this light mediator condition designed to make the signal visible?

- **Salviati:** Most signals we are (will be) sensitive to will require some coincide/tuning so they happen somewhere between equality and today.

- **Sagredo:** Boh, two dark species seems reasonable.

** - GMT: hope I will still be allowed back to GGI*

Coherent long range interactions

If all particles have the “same charge”, this leads to macroscopic forces, similar to gravity ⟶ go talk to the organizers!

Unveiling dark fifth forces with linear cosmology

Maria Archidiacono, Emanuele Castorina, Diego Redigolo and Ennio Salvioni

Published 24 October 2022 • © 2022 The Author(s)

Journal of Cosmology and Astroparticle Physics, Volume 2022, October 2022

Citation Maria Archidiacono *et al* JCAP10(2022)074

DOI 10.1088/1475-7516/2022/10/074

Unveiling Dark Forces with Measurements of the Large Scale Structure of the Universe

Salvatore Bottaro [1], Emanuele Castorina [2], Marco Costa [3], Diego Redigolo [4], and Ennio Salvioni [5]

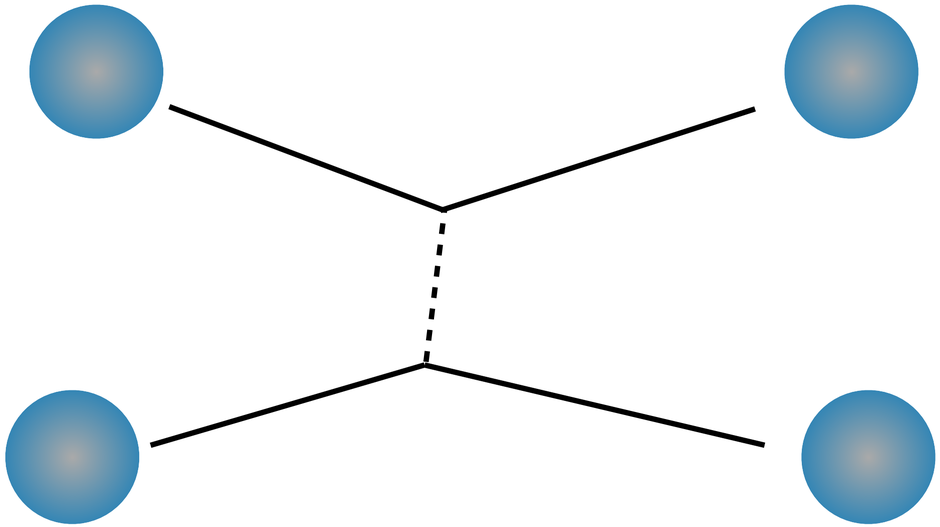
Show more

Phys. Rev. Lett. **132**, 201002 – **Published 17 May, 2024**

DOI: https://doi.org/10.1103/PhysRevLett.132.201002

Dark matter self-interactions

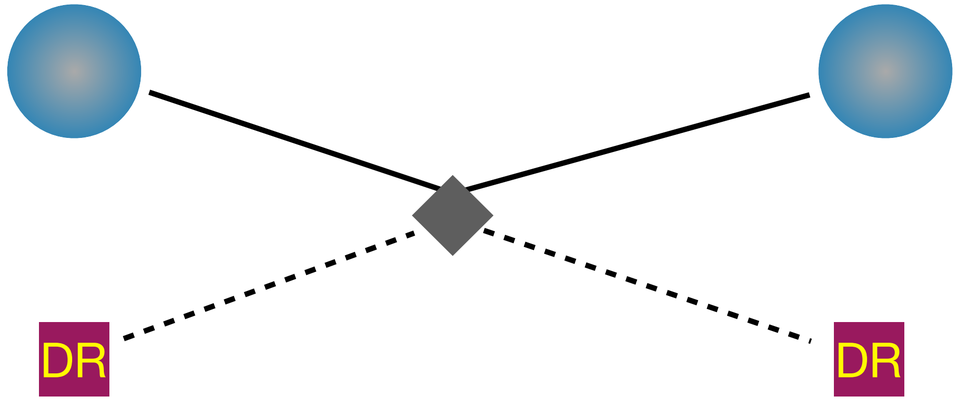
- Effects dominated by interactions between individual particles:



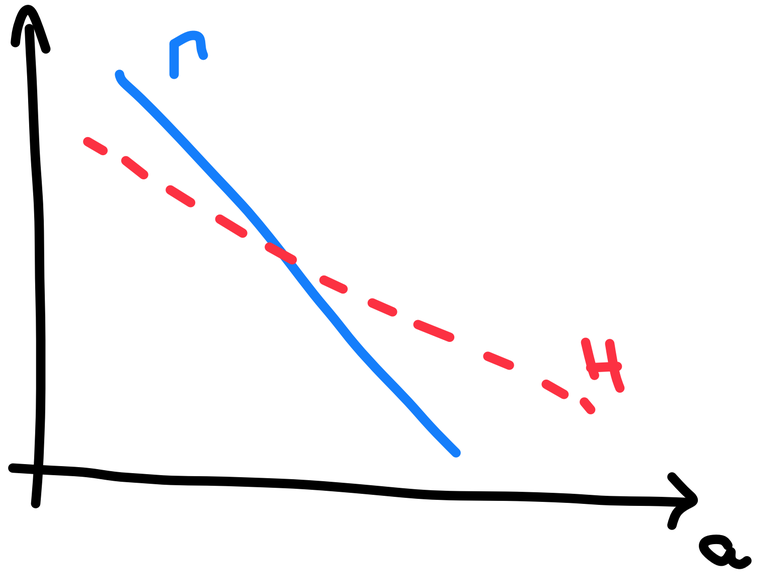
- Dark matter self-interactions: no effects at the linear cosmology level. Lots of studies about impacts to effects in halos (core-cusp, diversity…). Not obvious if any interesting signatures at large scales

Since we have two species, there are more possibilities

Dark matter - dark radiation interactions

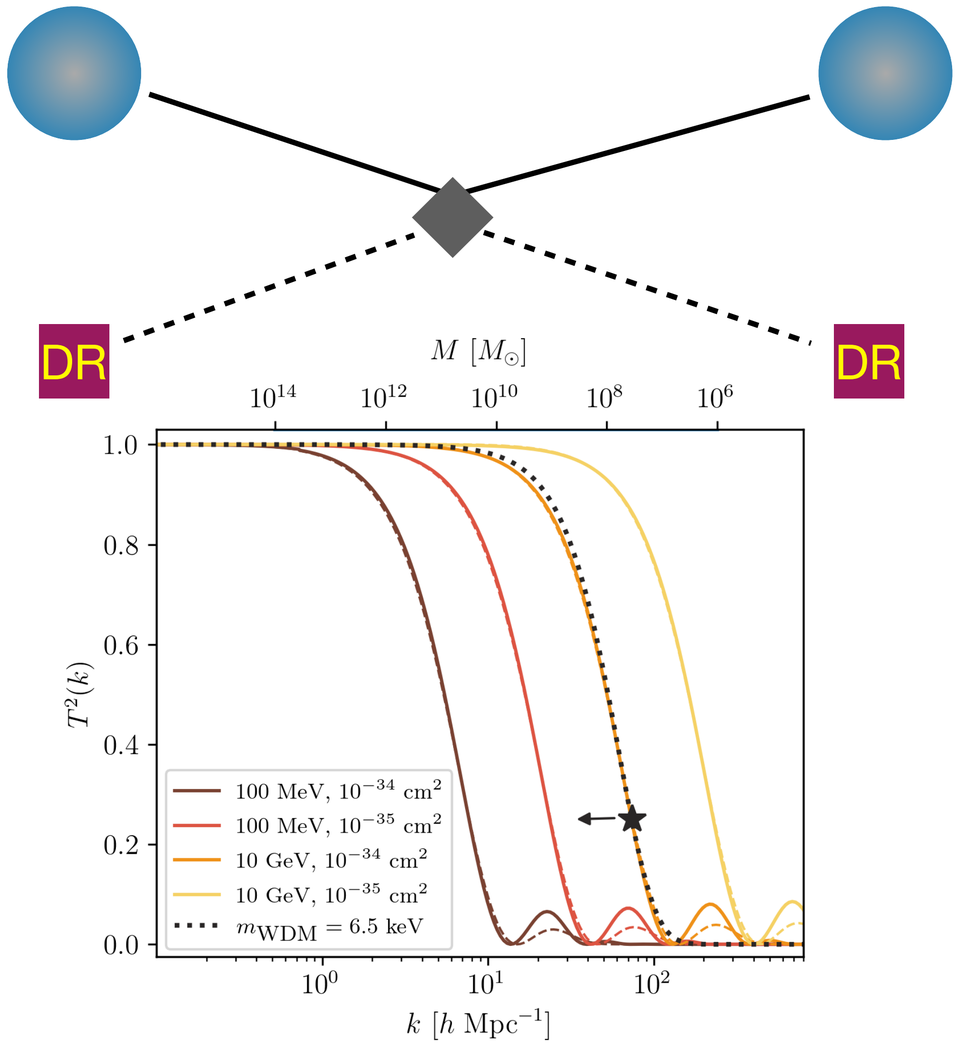


$$\Gamma \propto T^n$$



*Cyr-Racine, Sigurdson, Zavala, Vogelsberger, *Phys.Rev.D* 93 (2016) 12, 123527

Dark matter - dark radiation interactions



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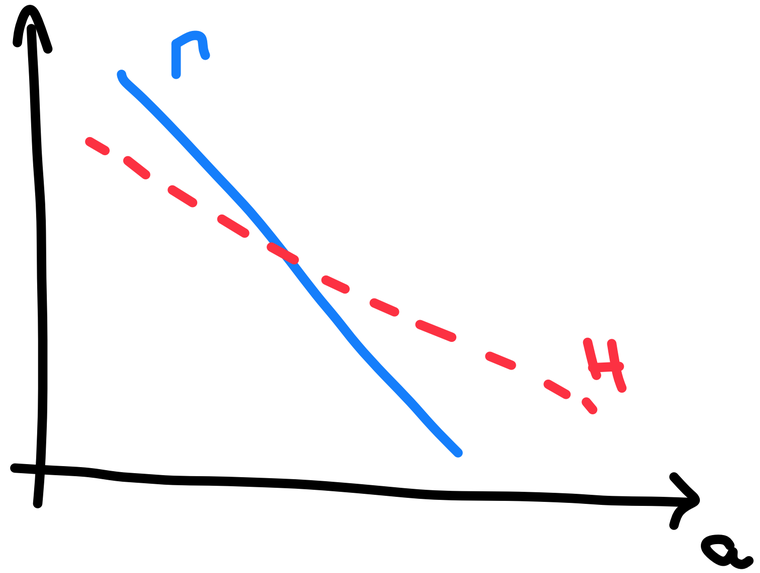
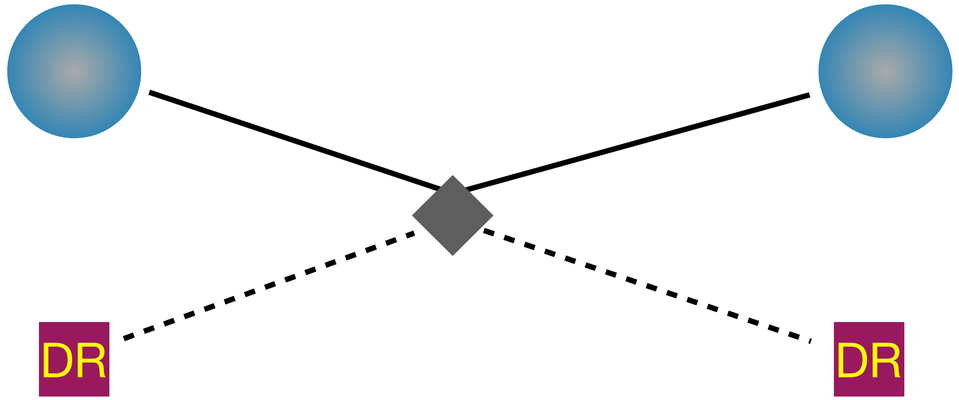


- Crumrine, Nadler, An, Gluscevic, *Phys.Rev.D* 111 (2025) 2, 023530

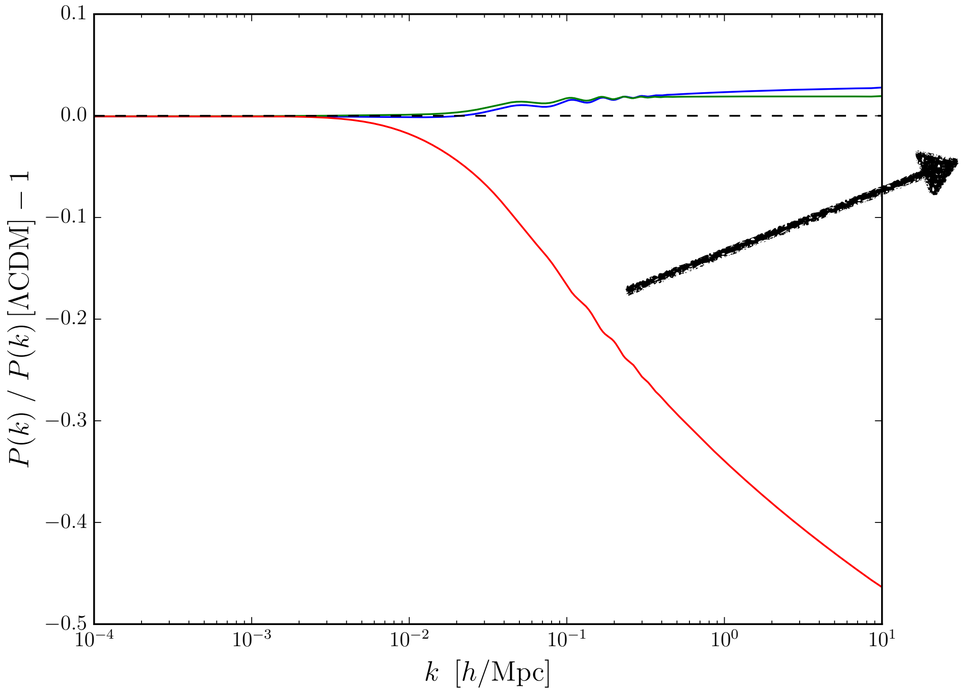
*See also Matteo and Ely's talks

Dark matter - dark radiation interactions



$$\Gamma \propto T^2$$

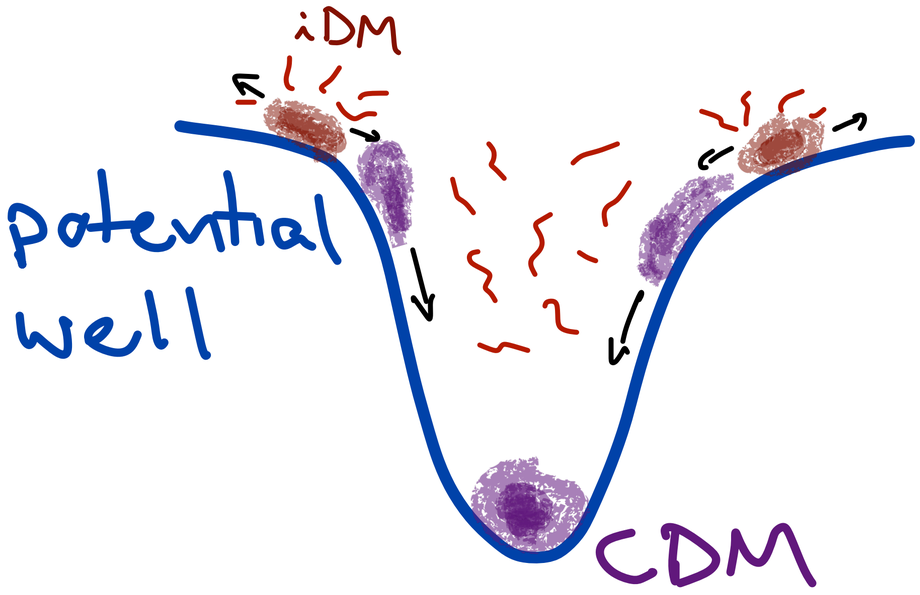
$$\frac{\Gamma}{H} \sim \text{const}$$



$$\sim \frac{\Gamma}{H} \log k$$

- Buen-Abad, **GMT**, Schmaltz, *Phys.Rev.D* 92 (2015) 2, 023531;
- Lesgourgues, **GMT**, Schmaltz, *JCAP* 02 (2016) 037;
- Buen-Abad, Schmaltz, Lesgourgues, Brinckmann, *JCAP* 01 (2018) 008
- Rubira, Mazoun, Garny, *JCAP* 01 (2023) 034;
- Joseph, Aloni, Schmaltz, Sivarajan, Weiner, *Phys.Rev.D* 108 (2023) 2, 023520

Sharper small feature: CDM + iDM

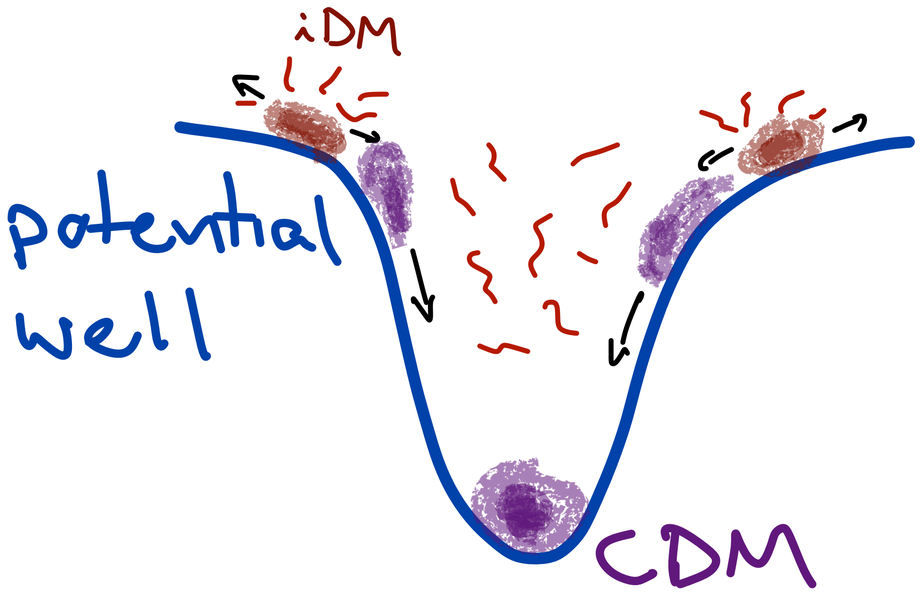


- iDM and dark radiation tightly coupled

$$\delta''_{\rm idm} + \frac{R}{1+R}\mathscr{H}\delta'_{\rm idm} + c_s^2 k^2 \delta_{\rm idm} = \cdots$$

$$R = \frac{3\rho_{\rm idm}}{4\rho_{\rm DR}} \qquad c_s^2 = \frac{1}{3(1+R)}$$

Sharper small feature: CDM + iDM



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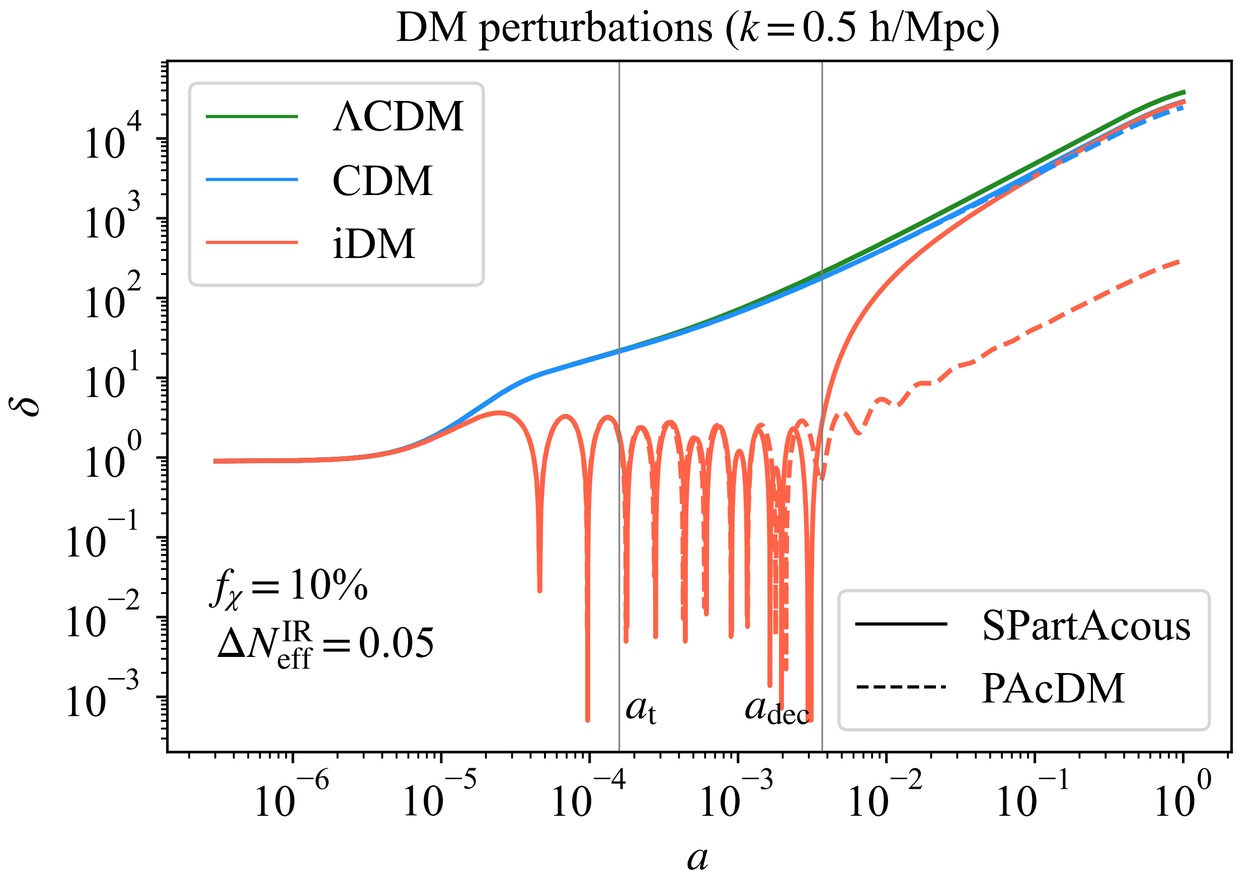
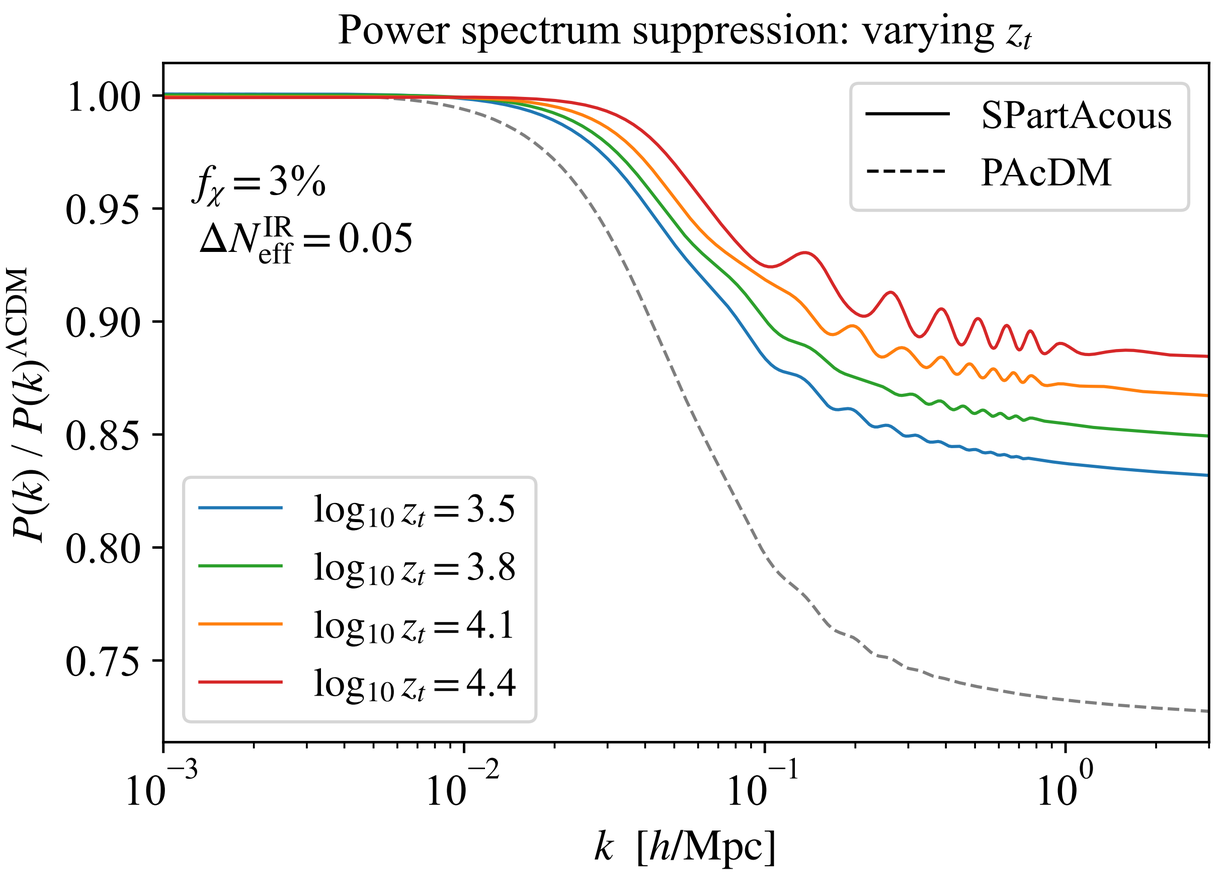
$$R = \frac{3\rho_{\rm idm}}{4\rho_{\rm DR}} \qquad c_s^2 = \frac{1}{3(1+R)}$$

- Even if $\Gamma/H \gg 1$, perturbations entering the horizon after R >> 1 grow like CDM
- If decoupling happens, $\Gamma/H \ll 1$, perturbations at all scales can grow

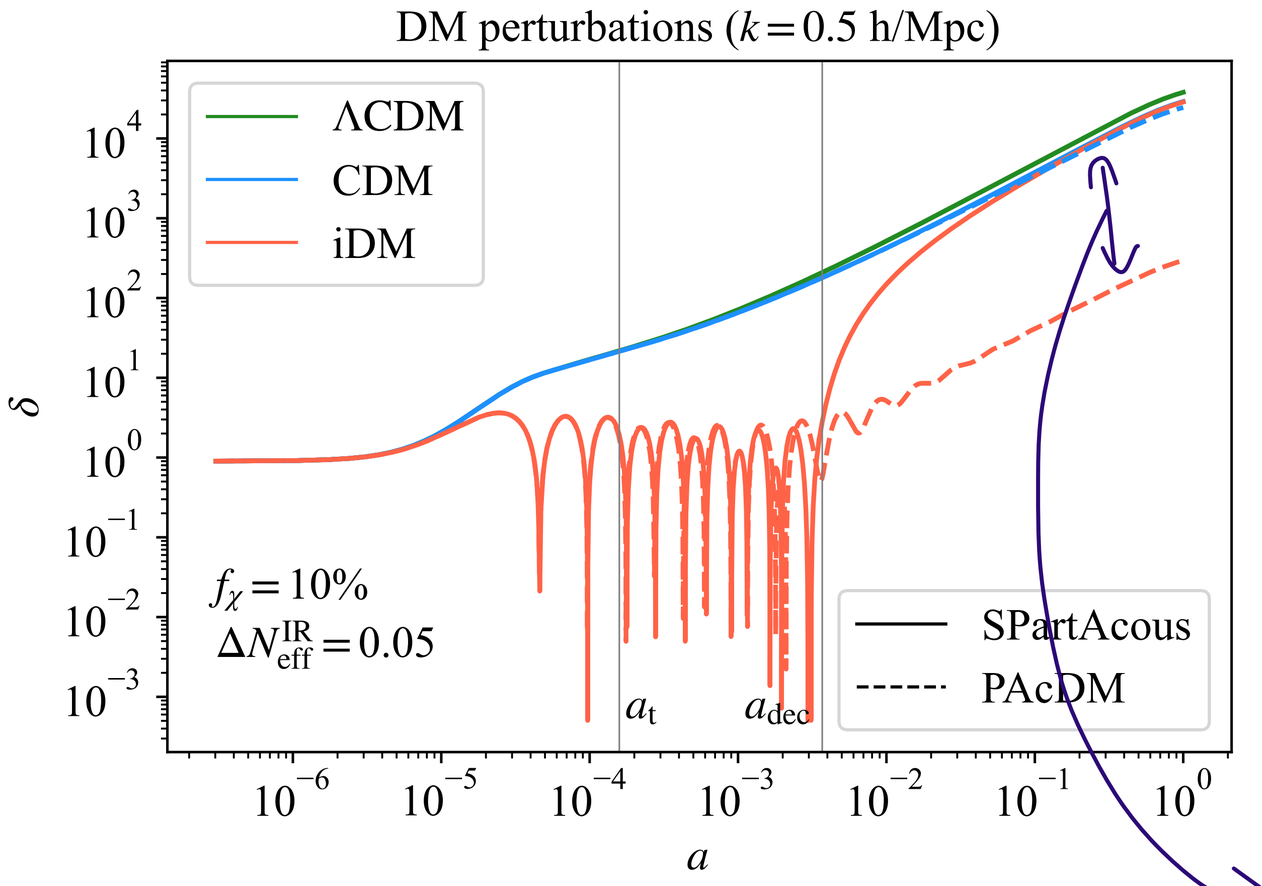
iDM + CDM structure growth

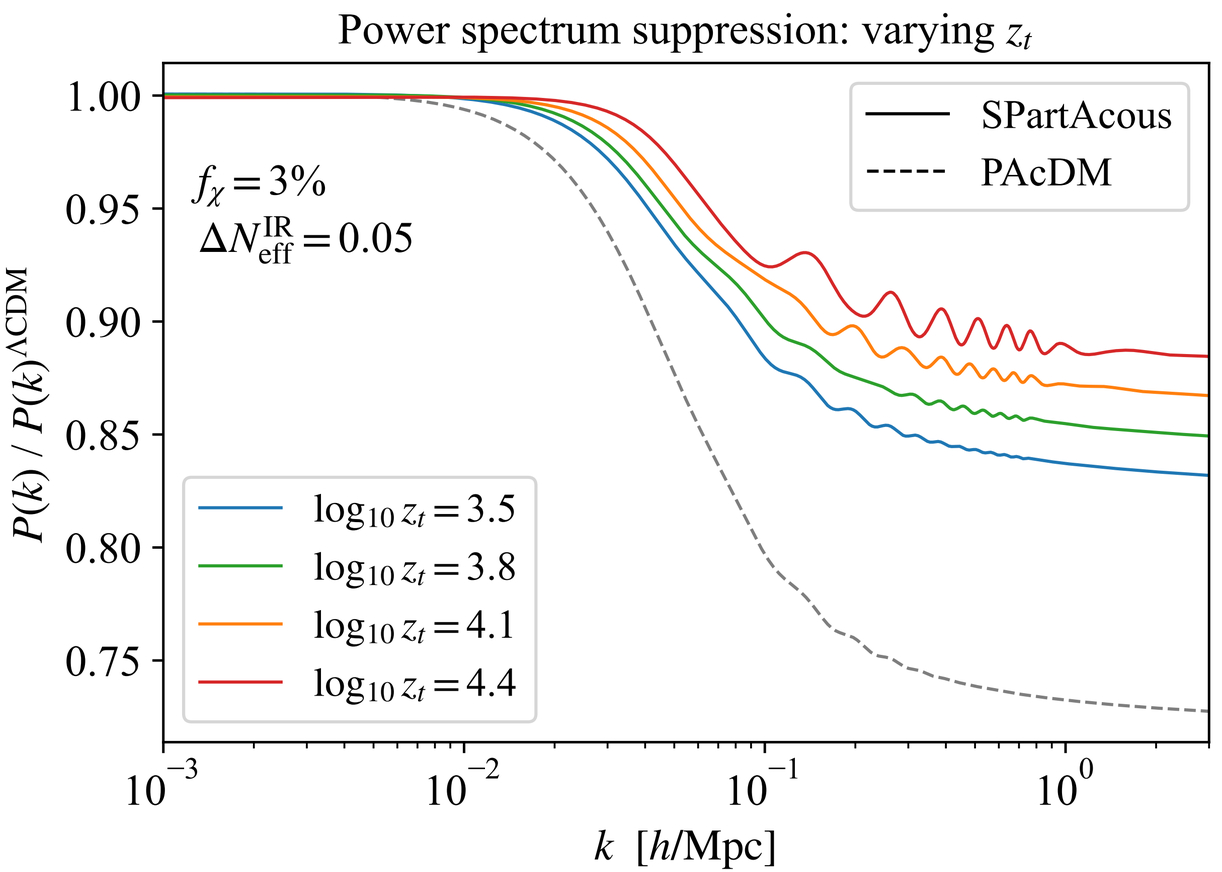




- Chacko, Cui, Hong, Okui, Tsai, *JHEP* 12 (2016) 108
- Buen-Abad, Chacko, Kilic, **GMT**, Youn, *JHEP* 06 (2023) 012
- Buen-Abad, Chacko, Kilic, **GMT**, Youn, *JCAP* 11 (2023) 005

iDM + CDM structure growth





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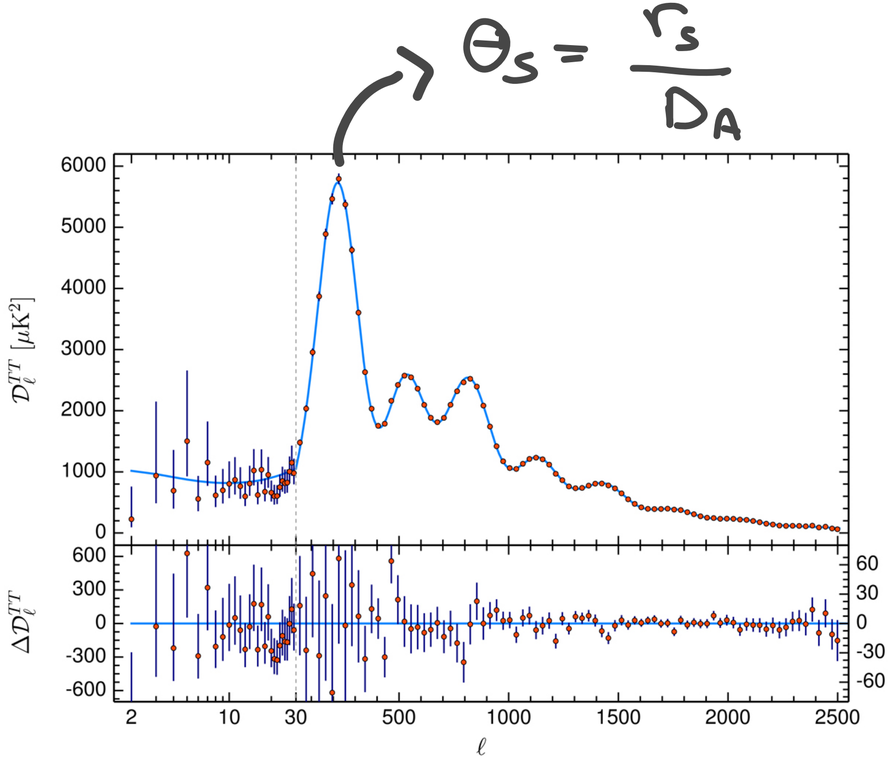
- Buen-Abad, Chacko, Kilic, **GMT**, Youn, *JCAP* 11 (2023) 005

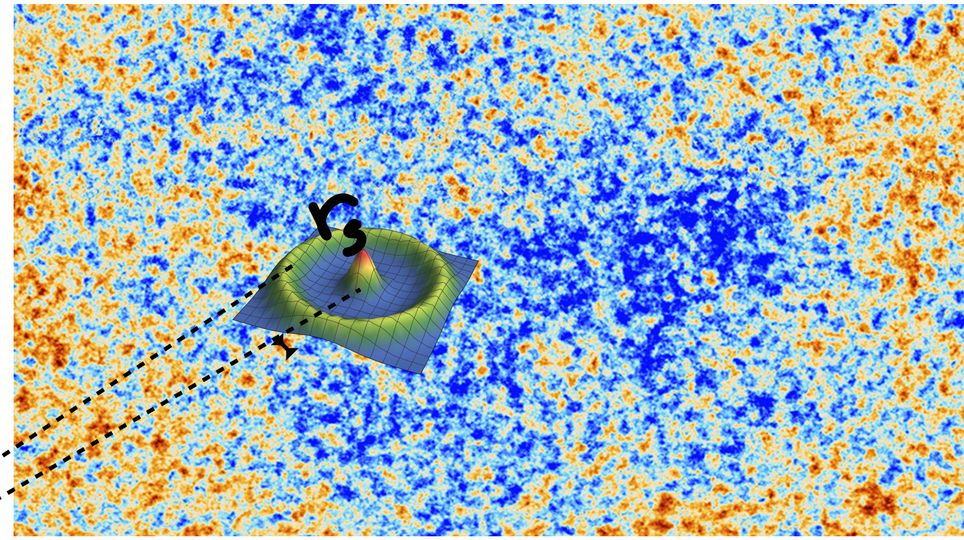
when to keep information about relative density field? (see Safak and Francesco's talks)

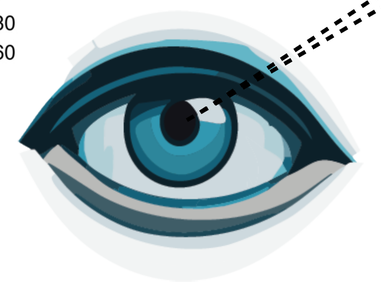
Guilty of signal model building.

Let me confess to also trying to solve anomalies

H0, sound horizon, etc





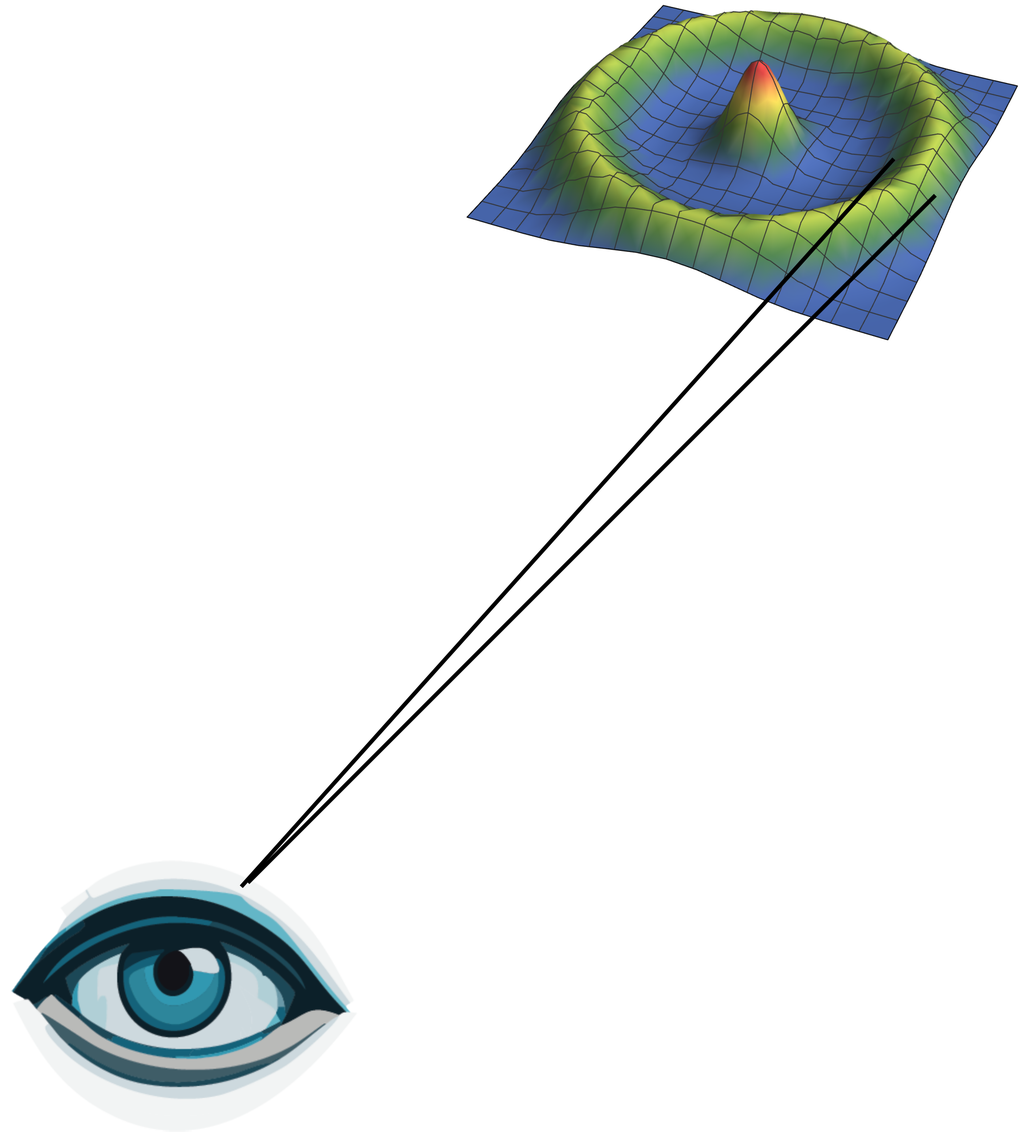


Dark radiation increases H(z) pre-recombination ⇒ raises H_0

* will take dark-radiation to be self-interacting to help more

See Julien's talk

Challenge: diffusion scale



$$r_d^2 \approx \pi^2 \int_0^{a_*} \frac{da}{a^2 H} \frac{\lambda}{a} \propto \frac{1}{H_*}$$

$$r_s \propto \frac{1}{H_*}$$

$$r_d \propto \sqrt{\frac{1}{H_*}}$$

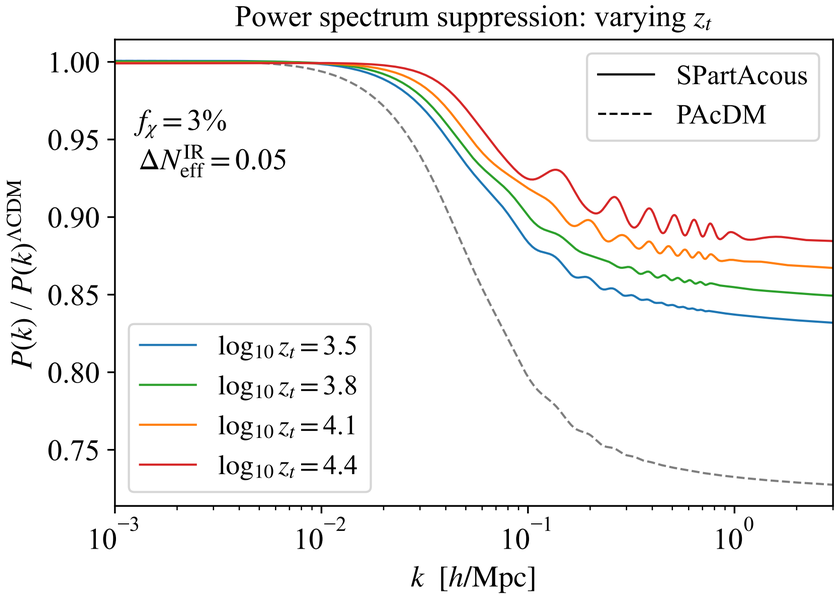
Silk damping moves to larger scales

$$C_l \propto e^{-\frac{l^2}{l_d^2}}$$

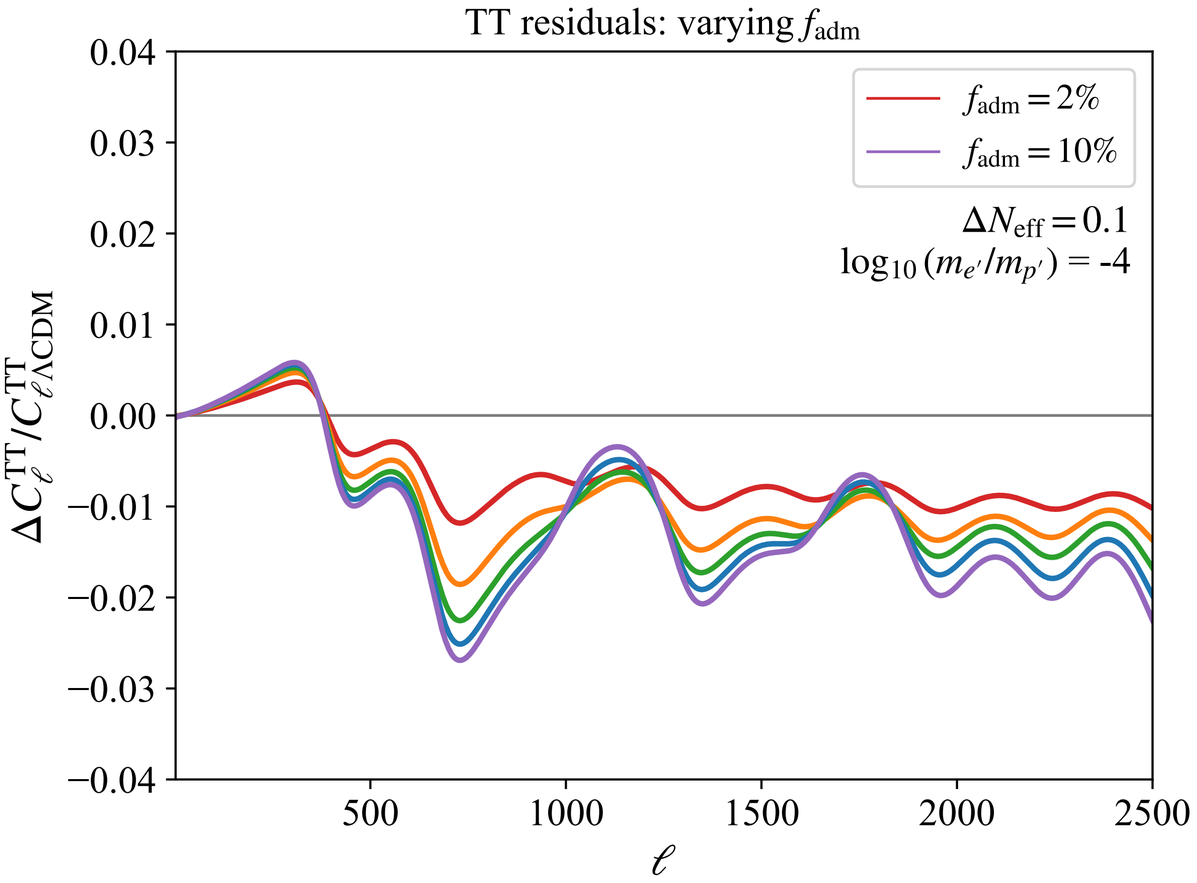
Enhacing power at small scales

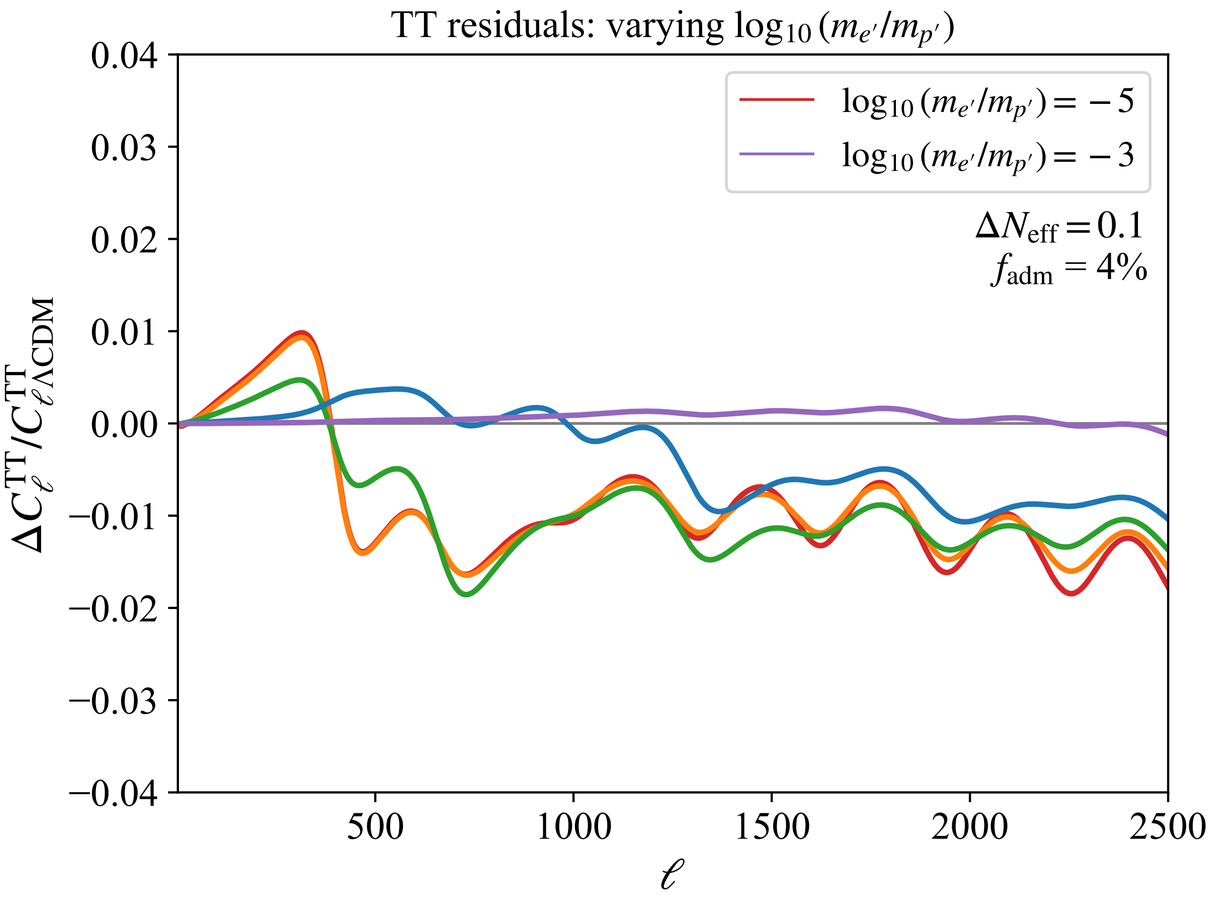
- Within LCDM, can enhance n_s: tradeoff more power at high l ⇒ less at low l
- Could also change He abundance (hard to change it enough to work)

Can new physics add an scale dependent effect?



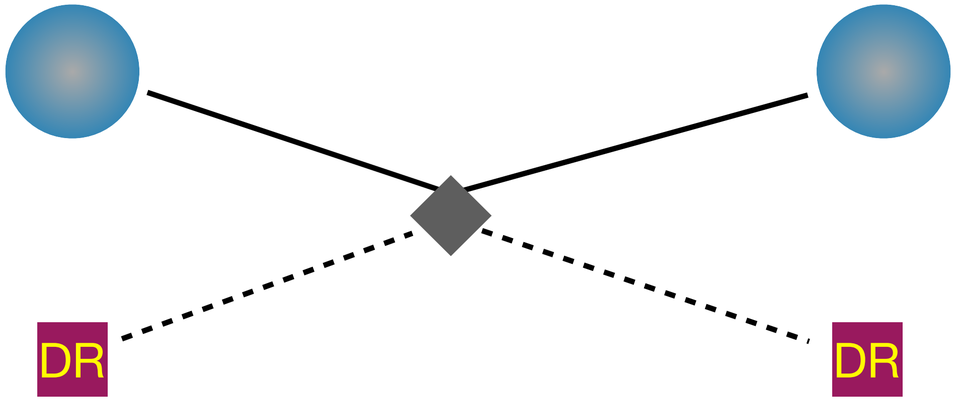
Dark interactions and CMB





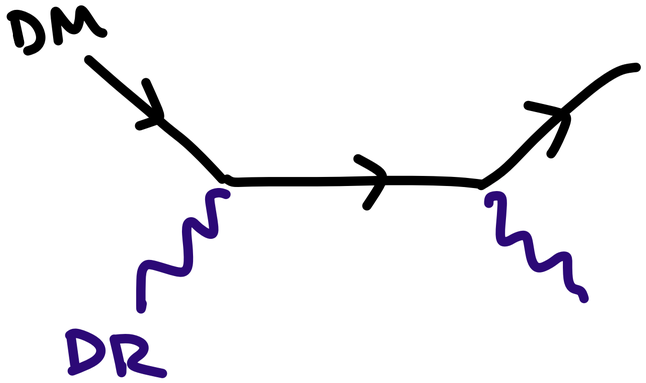
- Buen-Abad, **GMT**+++, *JHEP* 07 (2025) 084

Phenomenological interacting dark sectors

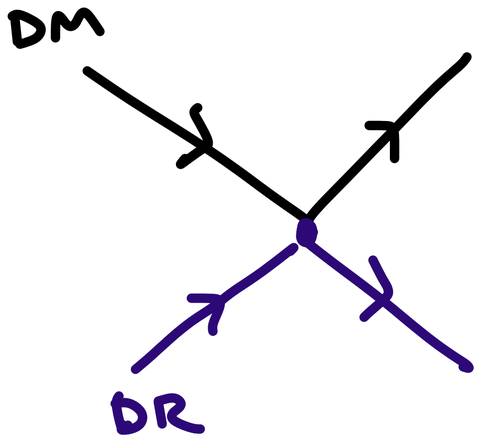


$$\Gamma \propto T^{2+n}$$

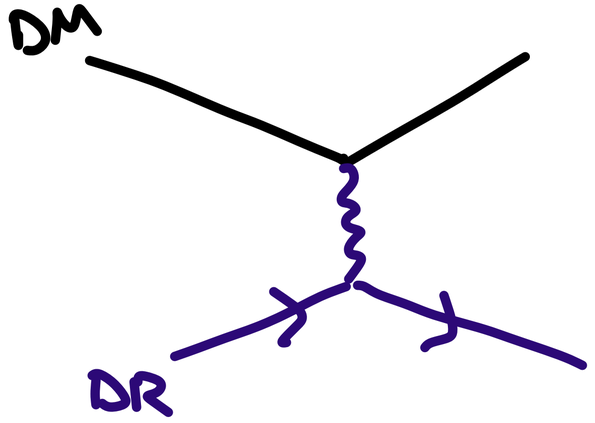
$n = 2$



$n = 4$



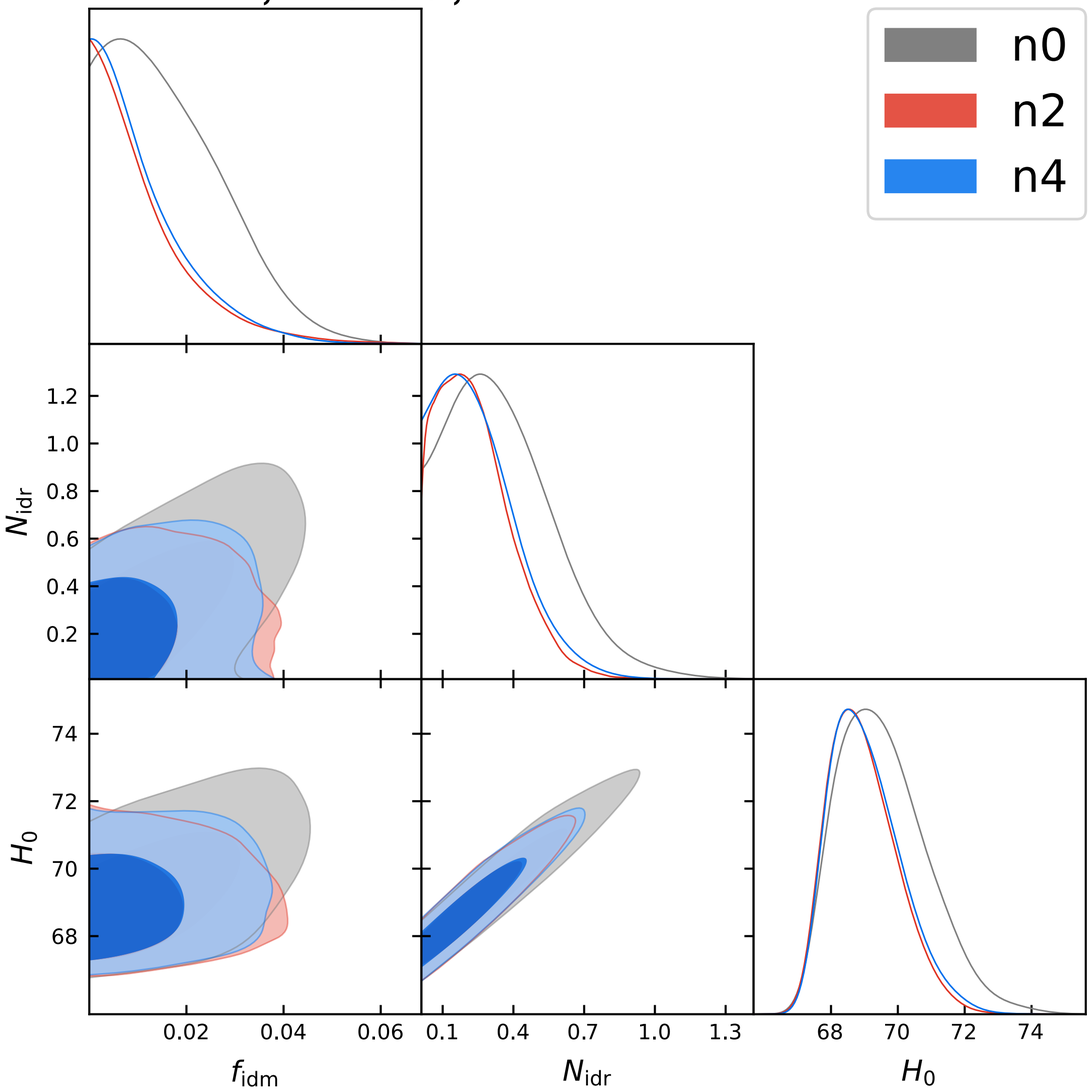
$n = 0\,*$



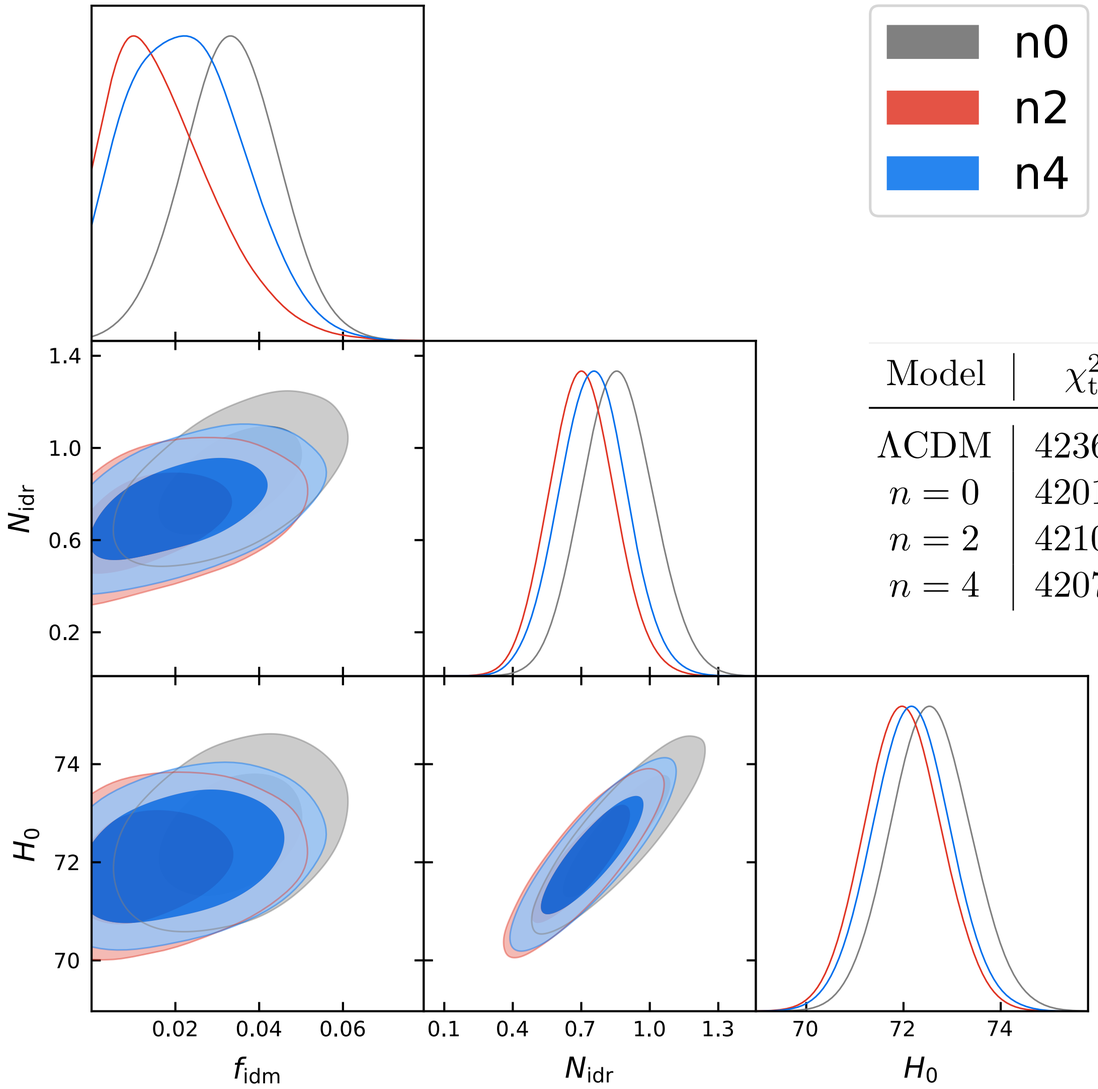
$$\Gamma \propto T^2 e^{-B_d/T}$$

3 relevant parameters: N_{idr}, f_{idm}, z_{dec}

Planck, BOSS, Pantheon+



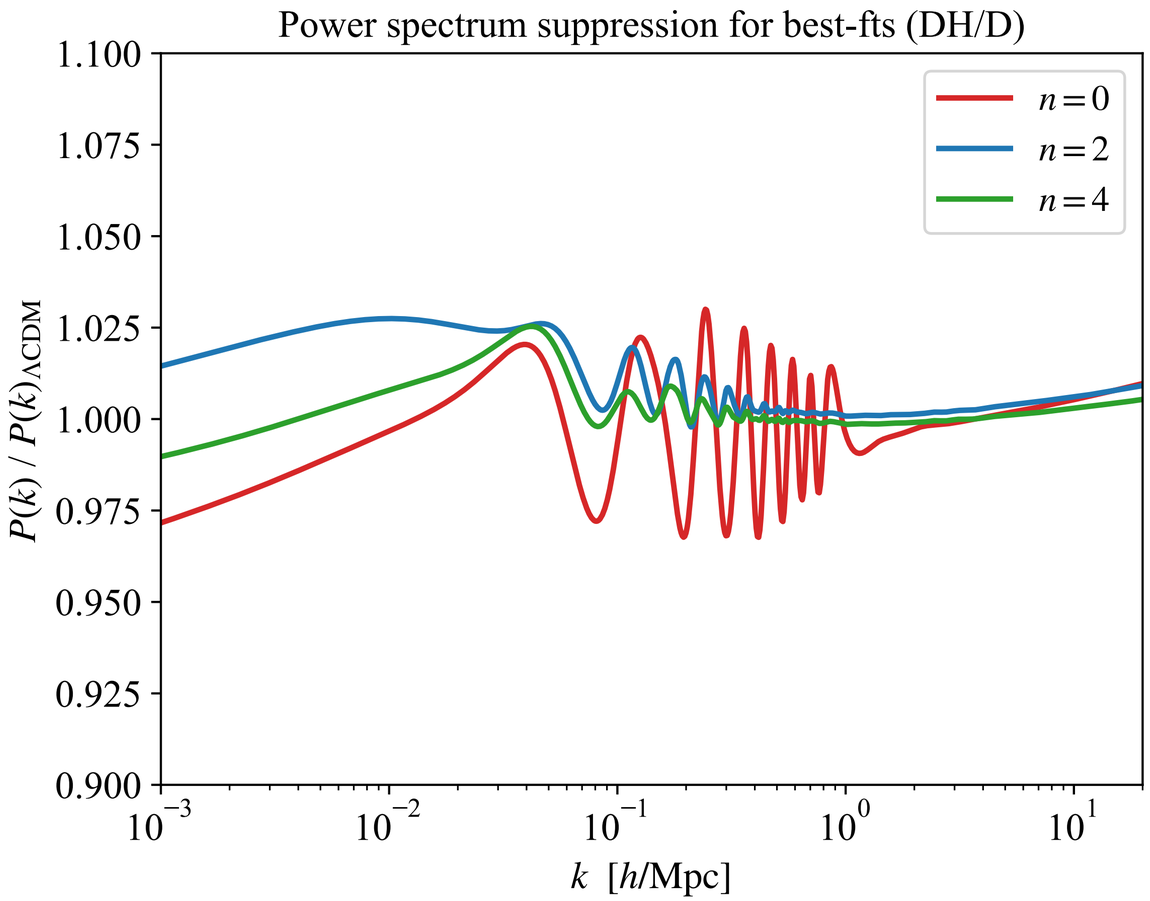
+ SH0ES



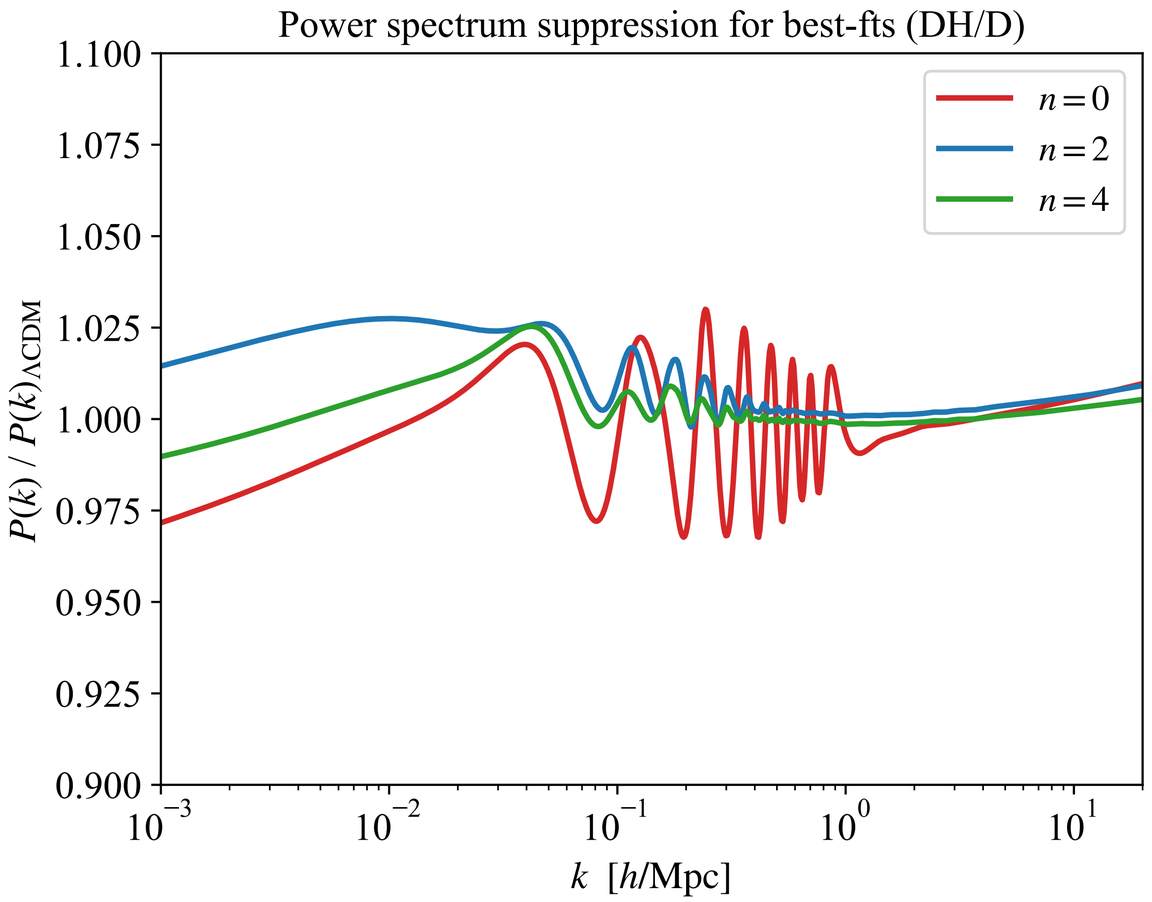
Model	$\chi^2_{\rm tot}$	$\chi^2_{\rm CMB}$
ΛCDM	4236.49	2769.00
$n = 0$	4201.81	2767.40
$n = 2$	4210.21	2773.20
$n = 4$	4207.34	2771.89

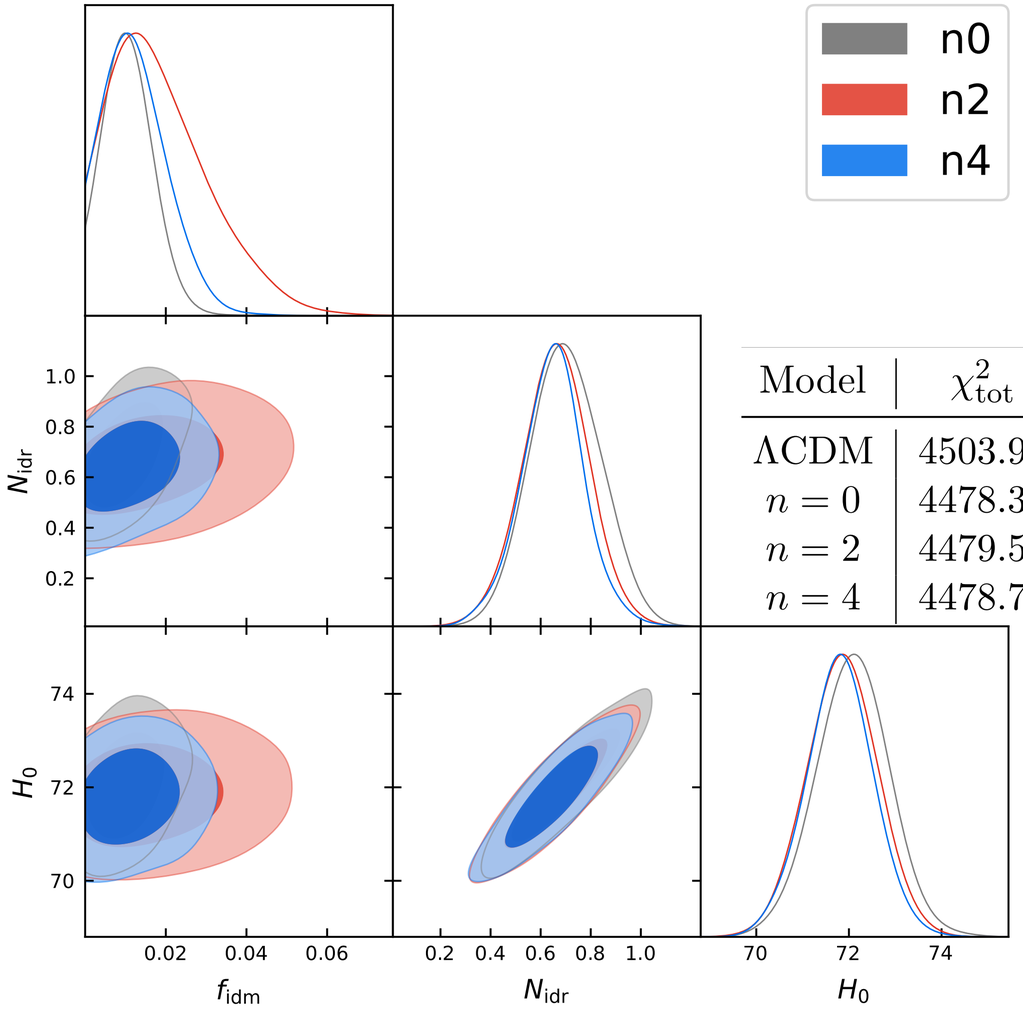
*Buen-Abad, Chacko, Flood, Kilic, **GMT**, Youn, *(in preparation)*

What about the power spectrum?



What about the power spectrum?





Model	χ^2_{tot}	χ^2_{CMB}
ΛCDM	4503.91	2768.93
$n=0$	4478.36	2769.42
$n=2$	4479.55	2772.22
$n=4$	4478.70	2771.21

+ BOSS FS with PyBird

*Buen-Abad, Chacko, Flood, Kilic, **GMT**, Youn, *(in preparation)*

Seems like we have sensitivity to O(1%) features in the power spectrum!

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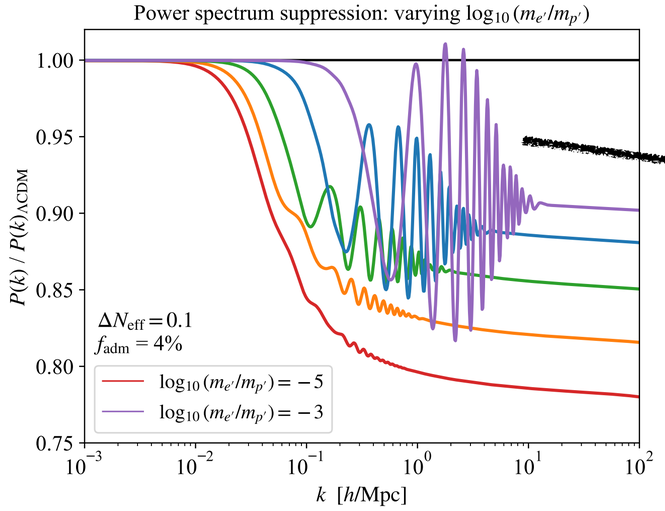
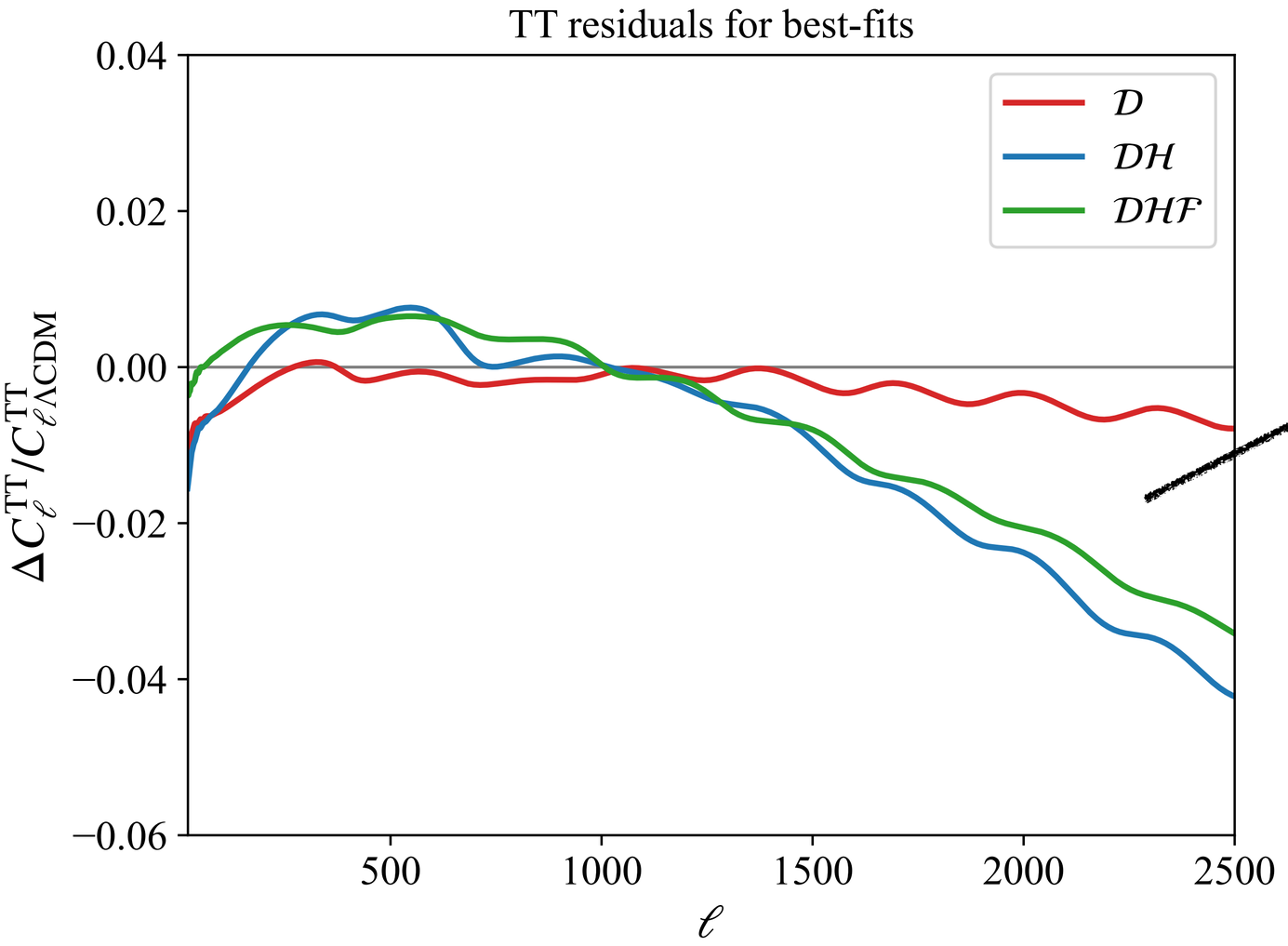


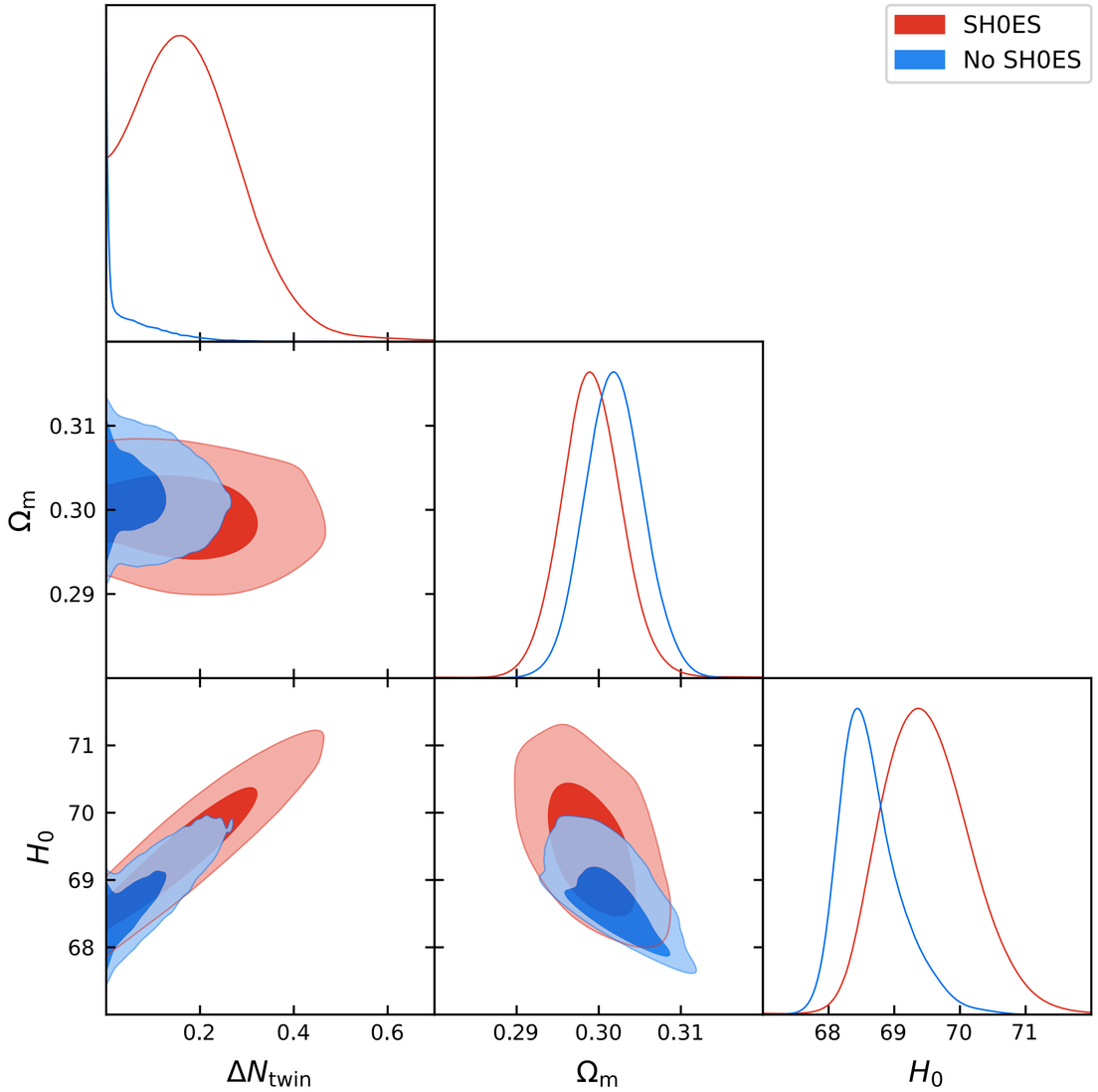
* Inspired by Sam's talk, but not primordial and linear in k

I didn’t forget about Erminia’s talk



At smaller scales difference between interacting DS and LCDM becomes more pronounced

Preliminary ACT



not looking promising to solve H_0

* Cvetko, Joseph, **GMT**, *In Preparation*

Summary

- Dark matter interacting with dark radiation leads to interesting features in the power spectrum
- Relaxes the bound on Neff (also other shifts, like Ω_m)
- BOSS full shape seems sensitive to O(1%) features in power spectrum at k = 0.1
- ACT might effectively rule out “simple” interacting dark sectors as solutions to H_0
- Interactions in the dark sector still a useful framework to consider well defined signal targets for upcoming surveys. Maybe natural simplified models approach for a large class of LSS signatures?

Summer Aspen 2026

JUNE 14 - JULY 5

New Synergies: Crafting the Next Generation Narrative for Cosmology and Particle Physics

Application deadline January 15