The role of CMB spectral distortions in the Hubble tension

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Based on
Lucca 2020 [2008.01115]
(and Lucca et al. 2019 [1910.04619])

In collaboration with
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Presentation for the
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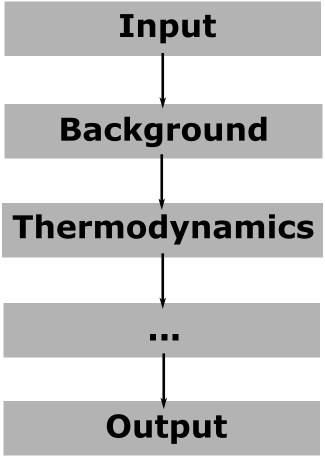
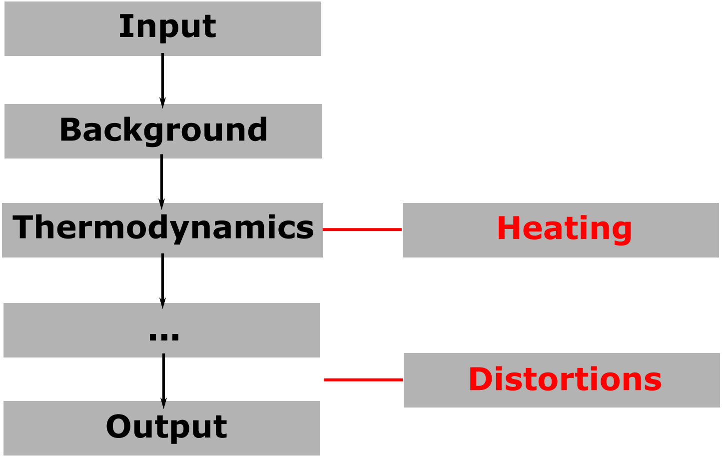
The numerical implementation

The structure of CLASS:



See `http://class-code.net` for more details

The structure of CLASS **in the new version 3.0**:



See Lucca et al. '19 for more details (**release paper**)

The new heating module:

- Inclusion of **straightforward energy injection scenarios** such as
  - DM decay or annihilation (Poulin et al. '16 [1610.10051])
  - PBHs evaporation or accretion (Ali-Haïmoud & Kamionkowski '16 [1612.05644], Stöcker et al. '18 [1801.01871], Poulin et al. '20 [2002.10771])

  as well as **"non-injected" sources** of SDs such as (Chluba & Sunyaev '12 [1109.6552], Chluba '13 [1304.6121], Chluba '16 [1603.02496])
  - Dissipation of acoustic waves
  - Adiabatic cooling of electrons and baryons
  - Sunyaev-Zeldovich effect

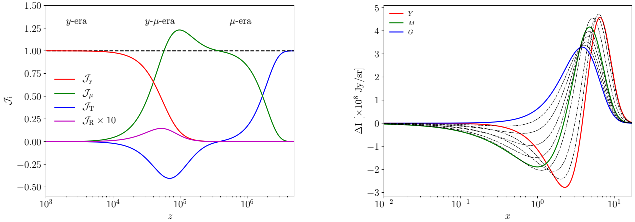
  (Only Cosmic Recombination Radiation missing to complete ΛCDM)
- Careful **distinction between injected and deposited energy**: different schemes for injection efficiency and deposition fractions (Chen & Kamionkowski '03 [astro-ph/0310473], Slatyer '16 [1211.0283], Galli et al. '13 [1306.0563])

The new distortions module:

- Based on the **Green's function approximation** (i.e. assuming that the thermalization problem can be linearized, Chluba '13 [1304.6120])

$$\Delta I(\nu, z_0) = \int_{z_0}^{\infty} G_{\rm th}(\nu, z') \frac{\mathrm{d}Q(z')/dz'}{\rho_\gamma(z')} \mathrm{d}z' \quad \text{with}$$

$$G_{\rm th}(\nu, z') = \mathcal{G}(\nu)\mathcal{J}_g(z') + \mathcal{M}(\nu)\mathcal{J}_\mu(z') + \mathcal{Y}(\nu)\mathcal{J}_y(z') + R(\nu, z')$$



Adapted from Lucca et al. '19

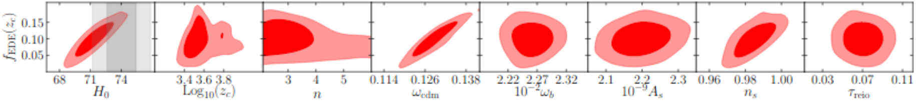
- **Complete freedom in** the choice of the **detector specifics**, fundamental to determine branching ratios and residuals exactly (Chluba & Jeong '13 [1306.5751], Fu et al. '20 [2006.12886])

Forecasting cosmological constraints with MontePython:

- Assuming an experiment has measured ΔI, which cosmological parameters can we constrain?
  → Use **MontePython to create mock likelihoods**
  1. Create fiducial (ΛCDM) with CLASS
     → *observed* SD
  2. For each step in the MCMC, update the cosmological parameters of given model using CLASS
     → *predicted* SD
  3. Compare *prediction* and *observation* for each step
     → confidence levels for each parameter
- State-of-the-art implementation of galactic and extra-galactic **foregrounds** (Schöneberg et al. '20 [2010.07814], based on Abitbol et al. '17 [1705.01534])

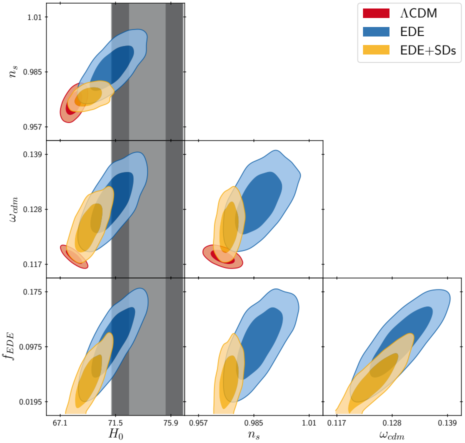
The Hubble tension and the role of SDs

- Growing consensus around the idea that **for a solution** to the Hubble tension **to be successful it needs to modify the expansion history** of the universe just **before recombination** (Knox & Millea '19 [1908.03663])
- The **new physics** often **needs to be compensated for by significant shifts in** the standard ΛCDM **parameters**
- **If one of these parameters is n_s, SDs can** place an independent prior on it and thereby **test the model's ability to solve the tension** (even if the model itself does not directly create any SDs)
- This is precisely the case for Early Dark Energy (see e.g., the introduction of Hill et al. '20 [2003.07355])



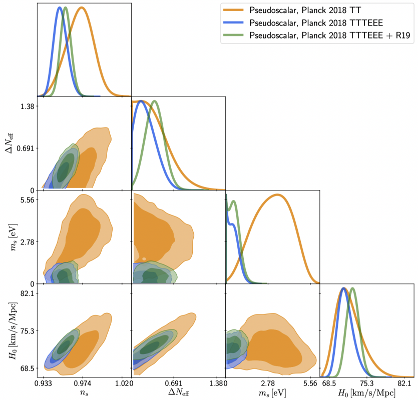
Adapted from Smith et al. '19 [1908.06995]

Proof of principle applied to Early Dark Energy



Adapted from Lucca '20

Possible other interesting applications: neutrino physics



Adapted from Archidiacono et al. '20 [2006.12885] but see also case of self-interacting neutrinos (Kreisch et al. '19 [1902.00534]) and interacting majoron-neutrinos (Escudero & Witte '19 [1909.04044])

Possible other interesting applications: modified gravity

Baseline + H_0

Parameter	GR-ΛCDM	type I RRVM	type I RRVM$_{\rm thr.}$	type II RRVM	BD-ΛCDM
H_0 (km/s/Mpc)	$68.75^{+0.41}_{-0.36}$	$68.77^{+0.49}_{-0.48}$	$68.14^{+0.43}_{-0.41}$	$70.93^{+0.93}_{-0.87}$	$71.23^{+1.01}_{-1.02}$
ω_b	$0.02240^{+0.00019}_{-0.00021}$	$0.02238^{+0.00021}_{-0.00023}$	$0.02243^{+0.00019}_{-0.00018}$	$0.02269^{+0.00025}_{-0.00024}$	$0.02267^{+0.00026}_{-0.00023}$
ω_{dm}	$0.11658^{+0.00080}_{-0.00083}$	$0.11661^{+0.00084}_{-0.00085}$	$0.12299^{+0.00197}_{-0.00203}$	$0.11602^{+0.00162}_{-0.00163}$	$0.11601^{+0.00161}_{-0.00157}$
$\nu_{\rm eff}$	-	$-0.00005^{+0.00040}_{-0.00038}$	$0.02089^{+0.00553}_{-0.00593}$	$0.00038^{+0.00041}_{-0.00044}$	-
$\epsilon_{\rm BD}$	-	-	-	-	$-0.00130\pm^{+0.00136}_{-0.00140}$
$\varphi_{\rm ini}$	-	-	-	$0.938^{+0.018}_{-0.024}$	$0.928^{+0.024}_{-0.026}$
φ_0	-	-	-	$0.930^{+0.022}_{-0.029}$	$0.919^{+0.028}_{-0.033}$
$\tau_{\rm reio}$	$0.050^{+0.008}_{-0.007}$	$0.049^{+0.009}_{-0.008}$	$0.058^{+0.008}_{-0.009}$	0.052 ± 0.008	0.052 ± 0.008
n_s	$0.9718^{+0.0035}_{-0.0038}$	0.9714 ± 0.0046	$0.9723^{+0.0040}_{-0.0039}$	$0.9868^{+0.0072}_{-0.0074}$	$0.9859^{+0.0073}_{-0.0072}$
σ_8	0.794 ± 0.007	0.795 ± 0.013	0.770 ± 0.010	$0.794^{+0.013}_{-0.012}$	$0.792^{+0.013}_{-0.012}$
S_8	$0.788^{+0.010}_{-0.011}$	0.789 ± 0.013	0.789 ± 0.011	$0.761^{+0.018}_{-0.017}$	$0.758^{+0.019}_{-0.018}$
r_s (Mpc)	$147.97^{+0.29}_{-0.31}$	$147.94^{+0.35}_{-0.36}$	$147.88^{+0.33}_{-0.29}$	$143.00^{+1.54}_{-1.96}$	$142.24^{+1.99}_{-2.12}$
$\chi^2_{\rm min}$	2302.14	2301.90	2288.82	2296.38	2295.36
ΔDIC	-	-2.36	+10.88	+5.52	+6.25

Adapted from talk by J. de Cruz Perez at the MG16 meeting (MC3 session) based on Sola et al. '20 [2006.04273]

Summary

Summary of the new public CLASS+MontePython implementation:

- State-of-the-art features such as
  1. many standard and exotic sources of SDs
  2. exact solution of the (linearized) thermalization problem
  3. total freedom in choice of detector settings
  4. galactic and extra-galactic foregrounds
- Ready to be used
  1. to explore synergy between CMB anisotropies and SDs
  2. for mission specific forecasts

Summary of the role of SDs in the Hubble tension:

- SDs are well-known to be able to set strong bounds on n_s
- If a model significantly affects this parameter in the attempt to solve the H_0 tension SDs would be a very powerful tool to constrain it