

The synergy between CMB spectral distortions and anisotropies

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Based on:

Lucca et al. 2019 [1910.04619], Fu et al. 2020 [2006.12886],
Lucca 2020 [2008.01115], and Schöneberg et al. 2020 [2010.07814]

In collaboration with:

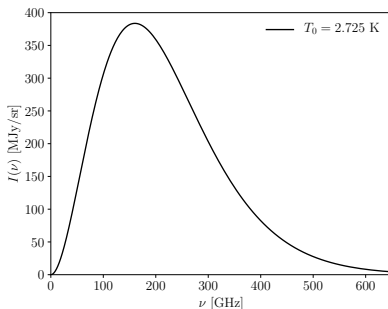
Elia S. Battistelli, Jens Chluba, Hao Fu, Silvia Galli,
Deanna C. Hooper, Julien Lesgourgues, and Nils Schöneberg

Presentation for
PONT 2020

What are SDs?

Step 1:

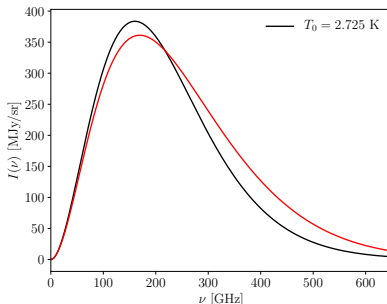
- ▶ Forget about the whole universe and everything that there is in it, including the CMB: all we need fits in a **box with a hole**
- ▶ Let's fill the box with only two types of particles, **electrons and photons**, which are **in thermal equilibrium**
- ▶ Then, if you look at the energy spectrum of the photons, you should see this:



→ Pure black body (BB) spectrum

Step 2:

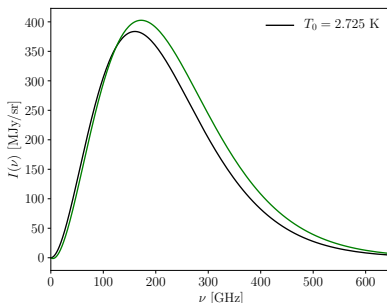
- ▶ Let's now imagine to **heat up** one side of **the box** for a tiny amount of time
- ▶ In this time interval we are then effectively heating up the photons that hit the wall
- ▶ Then, if you look at the energy spectrum of the photons, you should see this (red curve):



→ **Shift of low energy photons to higher energies**

Step 3:

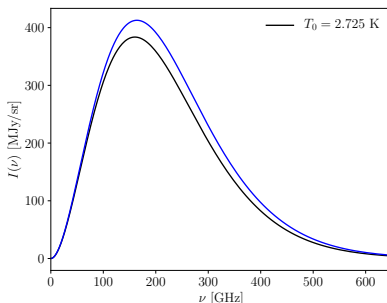
- ▶ Let's introduce in the box a scattering process such as Compton scattering
- ▶ Given enough time, the **scatterings** between photons and electrons will **redistribute** the "injected" **energy**
- ▶ Then, if you look at the energy spectrum of the photons, you should see this (green curve):



- **Overall shift of the spectrum**
- Not yet a BB:
too many high-energy photons

Step 4:

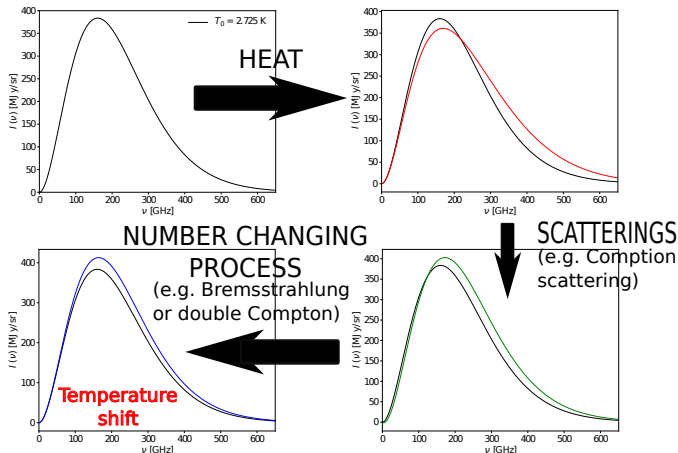
- ▶ Let's introduce in the box a **number changing process** such as Bremsstrahlung ($\gamma + e \rightarrow \gamma + \gamma + e$)
- ▶ Given enough time, the few **high energy photons** will transform **in** many **lower energy photons**
- ▶ Then, if you look at the energy spectrum of the photons, you should see this (blue curve):



→ **BB restored but with increased temperature!**

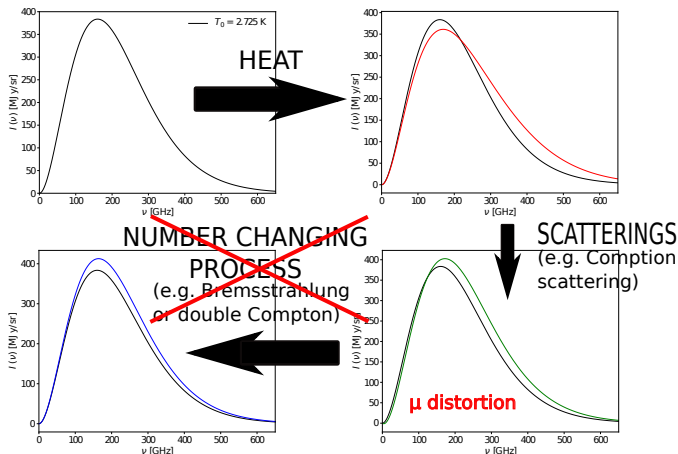
Step 5:

- ▶ Let's allow the box to **expand**, like the universe!
- ▶ At first **everything** is **efficient** → **Temperature shift**



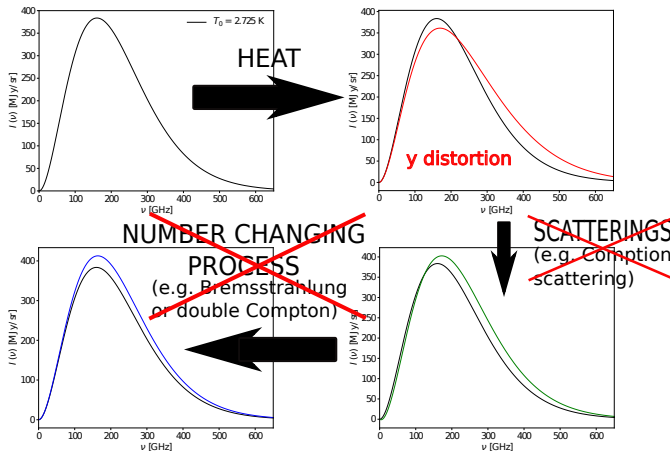
Step 5:

- ▶ Then **Bremsstrahlung becomes inefficient** (at $z \simeq 10^6$)
→ μ distortion



Step 5:

- ▶ Then **Compton scattering becomes inefficient** (at $z \simeq 10^4$)
→ y distortion



In summary:

- ▶ SDs are deviations from a pure BB in the CMB energy spectrum (caused by the inefficiency of scattering and number-changing processes)
- ▶ SDs are very sensitive to energy injections
- ▶ Since the primordial SD signal is frozen at decoupling, SDs are a fantastic window into the early universe

→ All implemented in CLASS v3.0: **First code able to evaluate CMB power spectra, SDs and much more with a single run!**

See also Chluba '13 [1304.6120], Chluba&Jeong '14 [1306.5751]

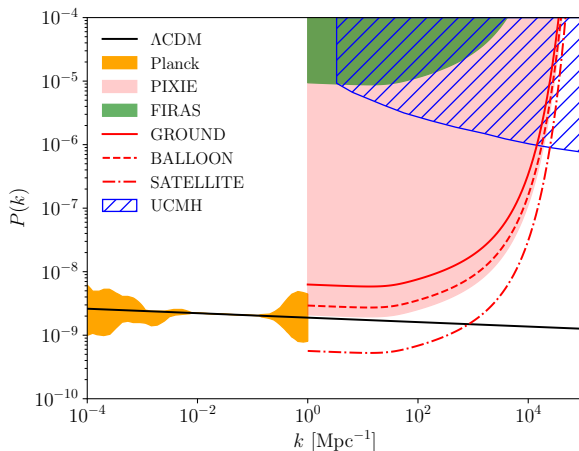
What are possible sources of SDs?

- ▶ In Λ CDM:
 1. Adiabatic cooling of electrons and baryons
 2. **Dissipation of acoustic waves** ($\rightarrow \{n_s, A_s\}$)
 3. Sunyaev-Zeldovich effect
 4. ...
- ▶ In exotic scenarios:
 1. Non-standard **inflationary scenarios**
 2. **DM decay** or annihilation
 3. **PBHs evaporation**
 4. ...

See also Chluba&Sunyaev '12 [1109.6552], Chluba '13 [1304.6121]
Chluba '16 [1603.02496], Poulin et al. '17 [1610.10051],
Stöcker et al. '18 [1801.01871], Hart et al. '20 [2006.04826]

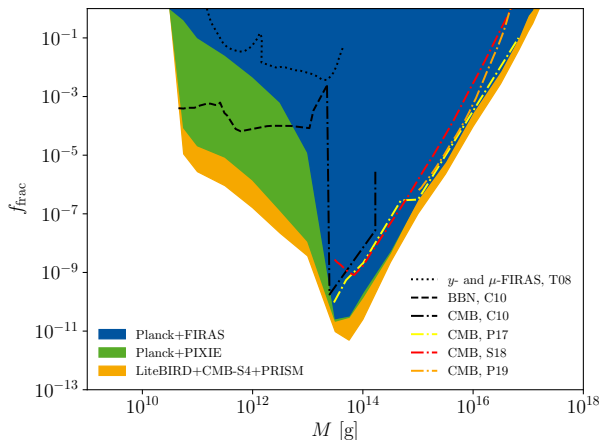
Concrete examples

1) Λ CDM (considering different experimental setups)



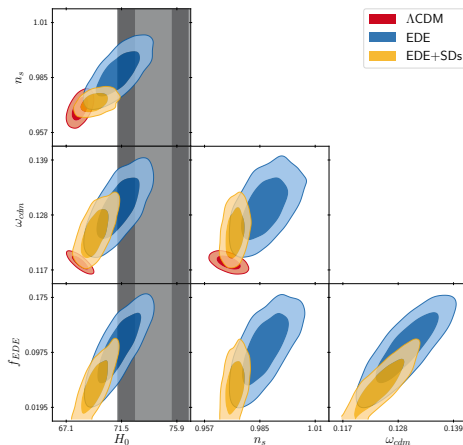
From Fu et al. '20 [2006.12886]

2) Evaporating PBHs (similar results also for decaying DM)



From Lucca et al. '19 [1910.04619]

3) Hubble tension (proof of principle applied to Early Dark Energy)



From Lucca '20 [2008.01115]

What can still be done?

- ▶ Improve CLASS implementation even further including e.g.
COSMOSPEC, Chluba&Ali-Haïmoud '16 [1510.03877]
SZPACK, Chluba et al. '12 [1205.5778]
DARKAGES, Stöcker et al. '18 [1801.01871]
- ▶ Constrain a variety of new models such as
Primordial Magnetic Fields (relevant also for the H_0 tension [2004.09487]) and
Non-standard DM interactions (e.g. with photons or baryons)
- ▶ Apply "Hubble tension idea" to other models like
Self-interacting neutrinos [1902.00534] and
Interacting majoron-neutrinos [1909.04044]