A new approach to linear cosmological perturbations in massive neutrino species

Based on: Phys. Rev. D 104, 083535 (2104.00703)
Phys. Rev. D 108, 023505 (2303.09580)

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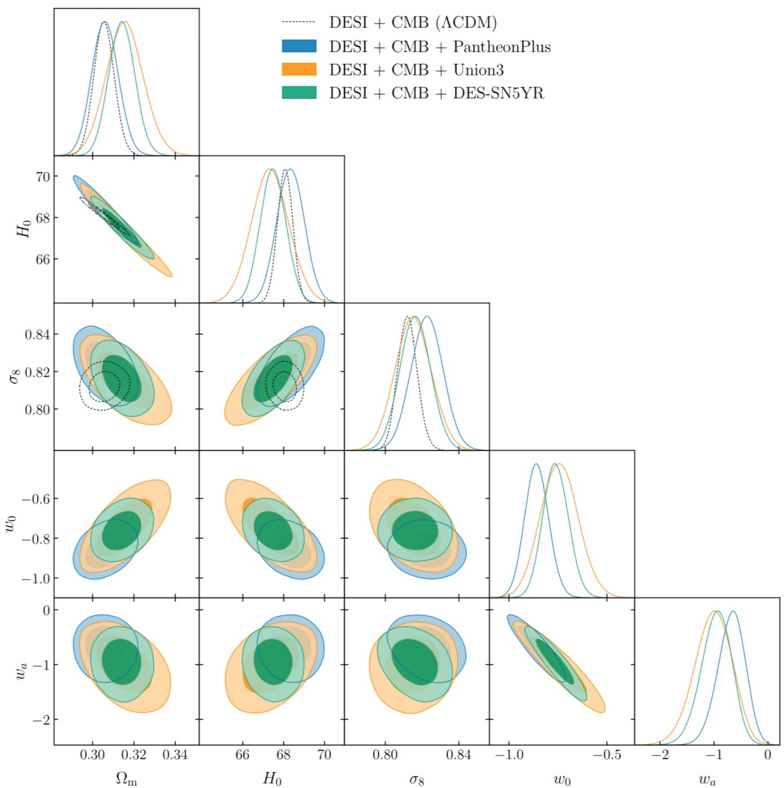
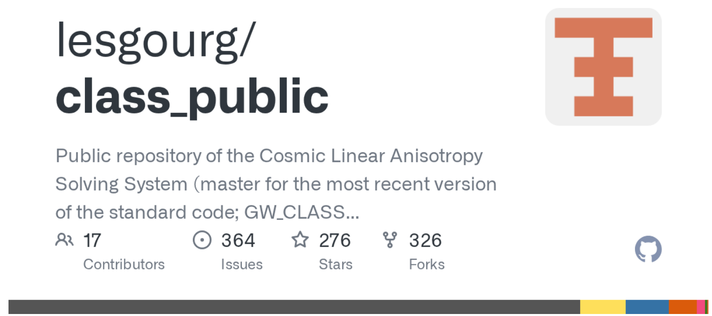
GGI Symposium
Sep 30th

Motivation



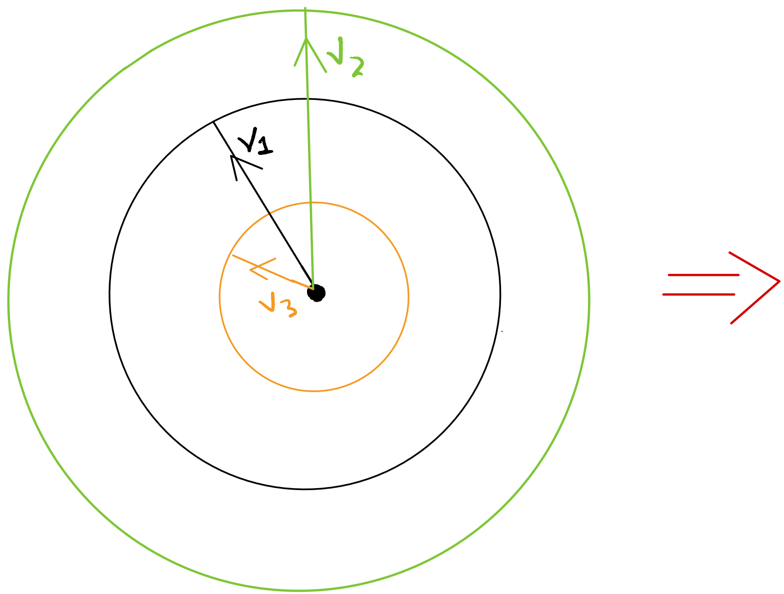
Taken from: DESI Full-Shape (2411.12022)

It is expensive to turn on massive neutrinos!



$$t(M_\nu) \sim 2t(M_\nu = 0)$$

The culprit: Velocity dispersion



$$\frac{\partial f}{\partial t} + \frac{d\vec{x}}{dt} \cdot \frac{\partial f}{\partial \vec{x}} + \frac{d\vec{p}}{dt} \cdot \frac{\partial f}{\partial \vec{p}} = 0$$

Solve for $f(t, \vec{x}, \vec{p})$

for each p separately

We care about integrated quantities

$$E_p = \sqrt{p^2 + m_\nu^2}$$

- $f \sim \sum_\ell f_\ell P_\ell(\hat{k} \cdot \hat{p}) \implies F_\ell \sim \int d^3\vec{p}\; f_\ell E_p v_p^\ell$

Multipole expansion

$$v_p = \frac{p}{E_p}$$

$$F_0 \sim \int d^3\vec{p}\; f_0 E_p \sim \rho$$

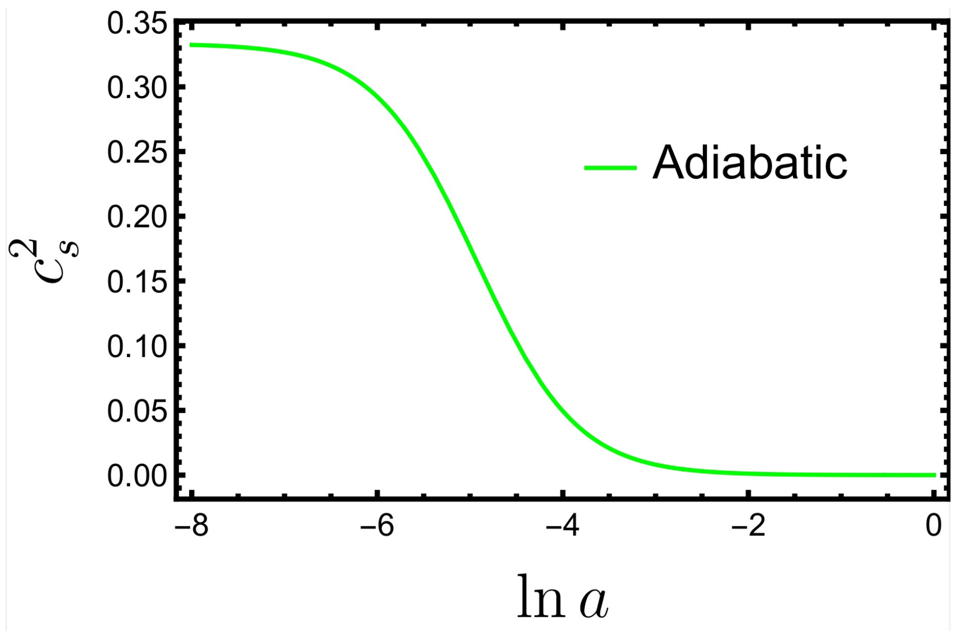
$$F_1 \sim \int d^3\vec{p}\; f_1 v_p \sim v$$

$$\vdots$$

- $G_{\mu\nu} = 8\pi G T_{\mu\nu} \longrightarrow$ Various momentum integrations per time step!

A useful tool: Fluid approximation

- Based on mass conservation and momentum balance. Need to approximate the fluid sound speed and shear stress.



- Integral part of CLASS!

A different route: Generalized Boltzmann Hierarchy

$$F_{\ell,n} \sim \int d^3\vec{p}\; f_\ell E_p v_{\mathrm{p}}^{2n+\ell}$$

Add velocity weights!

$$\Downarrow$$

$$\frac{d}{dt}F_{\ell,n} = \sum_{\substack{\ell'=\ell-1,\ell,\ell+1 \\ n'=n,n+1}} c_{\ell',n'}(t)F_{\ell',n'} + \text{Source terms}$$

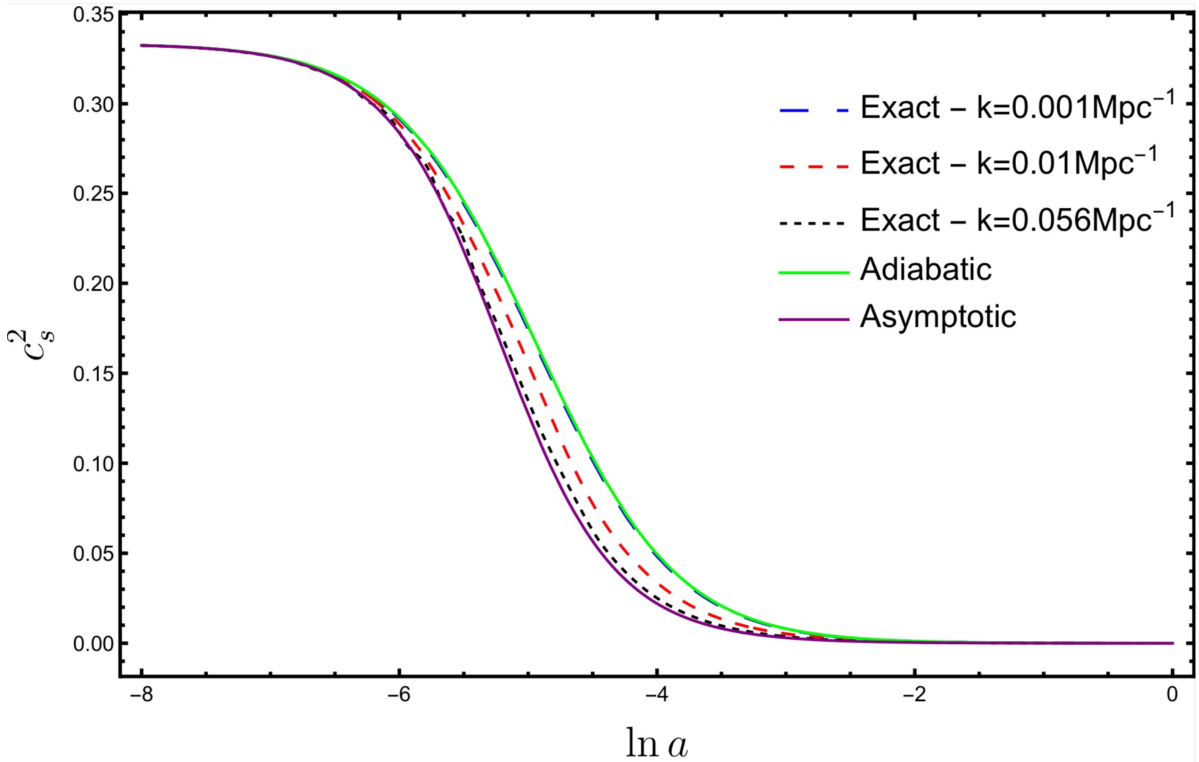
Main features

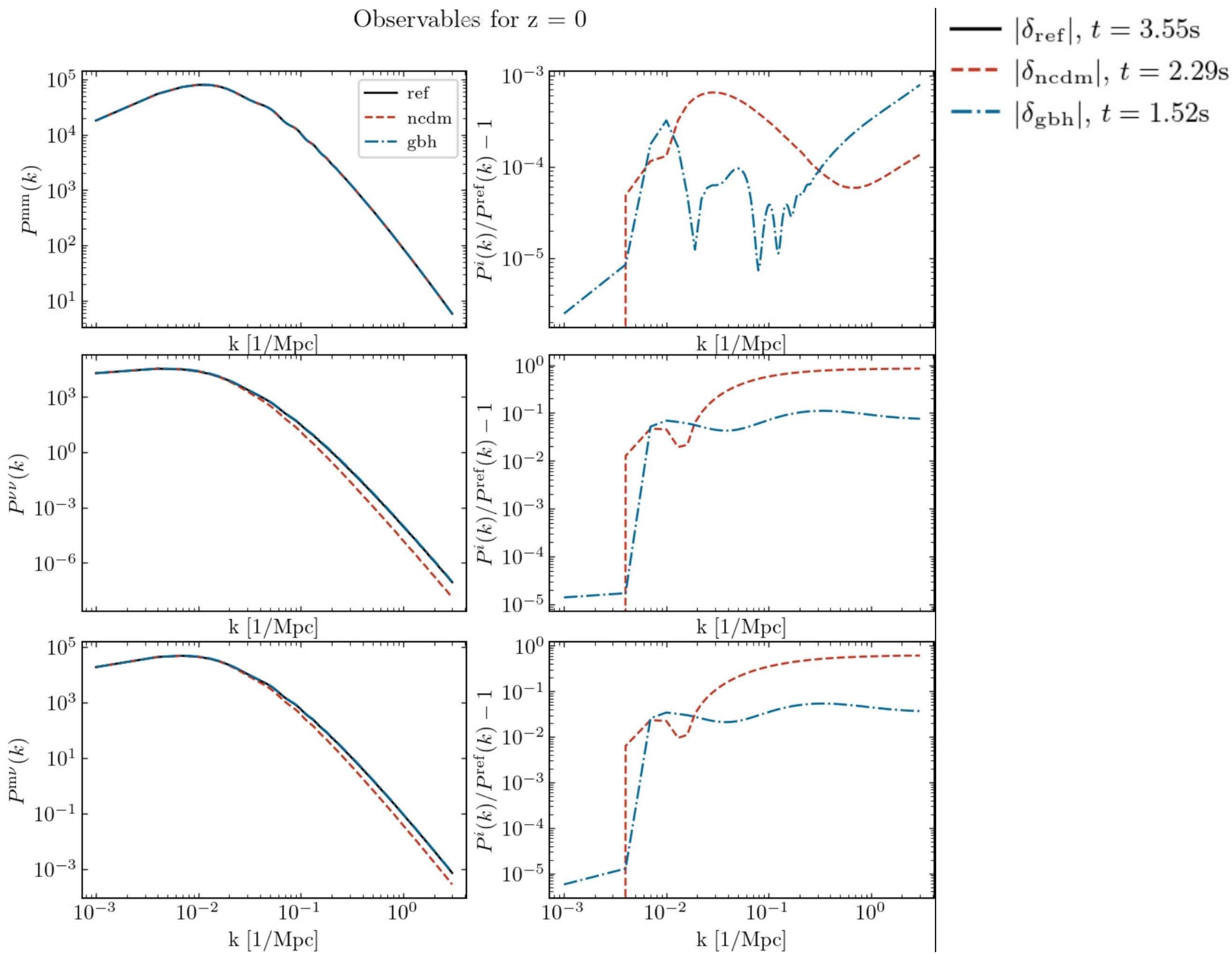
- Physical interpretation: higher $n \equiv$ probing faster moving particles

- $+$ truncation scheme $=$ System of $\sim n_{\max} \times l_{\max}$ ODE's

- No momentum integrals whatsoever. NDsolve? 

Dispersive fluid approximation




Observables for z = 0
$|\delta_{\rm ref}|$, $t = 3.55$s
$|\delta_{\rm ncdm}|$, $t = 2.29$s
$|\delta_{\rm gbh}|$, $t = 1.52$s
ref
ncdm
gbh
$P^{\rm mm}(k)$
$P^{\nu\nu}(k)$
$P^{\rm m\nu}(k)$
$P^i(k)/P^{\rm ref}(k) - 1$
k [1/Mpc]

Takeaways

- The GBH effectively integrates out the momentum dependence, is much simpler and faster than traditional methods.

- Fluid approximation becomes significantly more accurate when the dispersive nature of the neutrino fluid is accounted for.

- The coupled GBH + dispersive FA is more accurate and more efficient than standard methods!

- Simple and flexible framework for general ncdm species with nonstandard properties? Stay tuned…

Grazie!