Early Dark Energy meets massive Neutrinos arXiv:2207.01501 [1]

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Tensions in Cosmology Corfu
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IPA

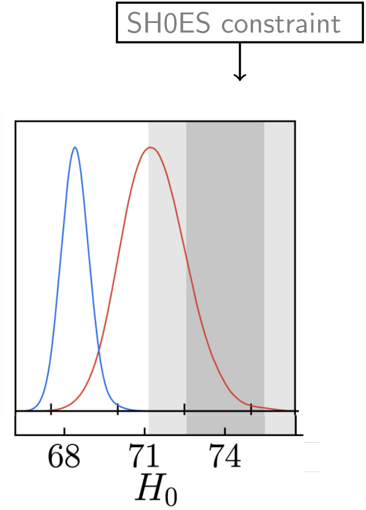
[1] A.R, L.Herold (MPA Garching), S.Vagnozzi (Cambridge), B.Sherwin (Cambridge), E.Ferreira (Tokyo)

The EDE model increases inferred H_0

$\theta_s = \frac{r_s}{D(z_*)}$ well constrained by CMB

$D(z_*) = \int_0^{z_*} dz \frac{1}{H(z)}$, $r_s = \int_{z_*}^{\infty} dz \frac{c_s(z)}{H(z)}$

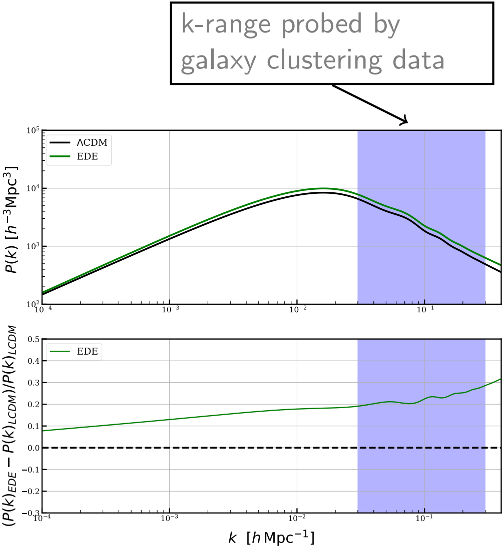
- EDE: add scalar field to ΛCDM
- Field held up by Hubble friction in early Universe $\rightarrow$ acts as DE and accelerates expansion prior to z_* $\rightarrow$ reduced r_s
- Maintaining θ_s $\rightarrow$ increased H_0



ΛCDM fit to Planck+BAO+SN1A+SH0ES
EDE fit to Planck+BAO+SN1A+SH0ES
Smith *et al.*, PRD 101 (2020) 6, 063523

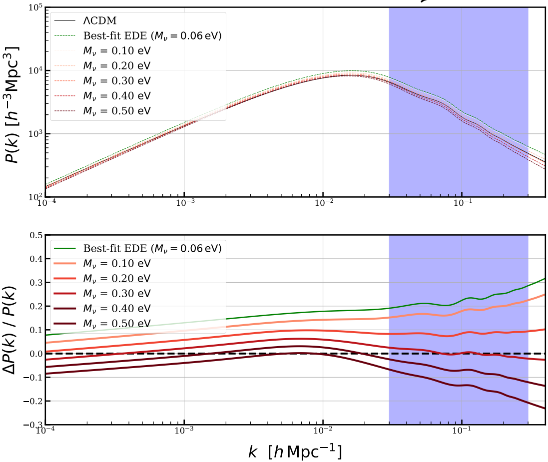
Motivation: EDE meets LSS data

- Maintaining fit to CMB in EDE scenario requires $\omega_{cdm} \uparrow$
- This leads to increased clustering amplitude $\rightarrow$ inconsistency with LSS data
- Previous works [Hill(2020), Ivanov(2020)] find no evidence for EDE resolving H_0 tension when LSS data included in analysis



EDE with massive neutrinos

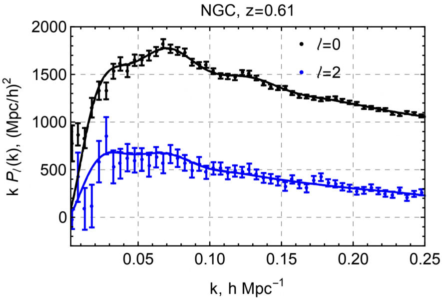
k-range probed by galaxy clustering data



Datasets

Planck (TTTEEE+lensing)

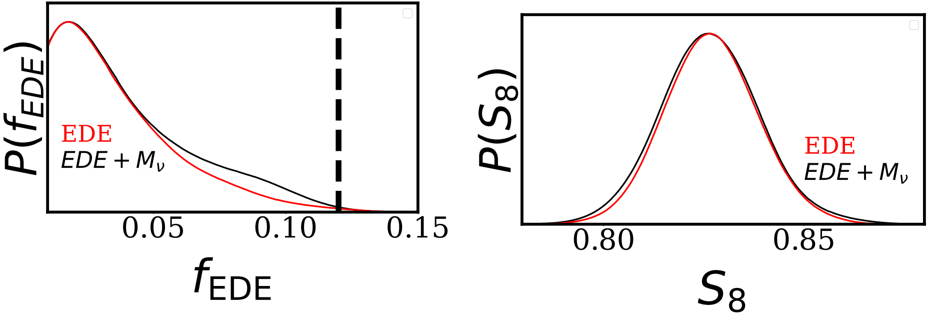
BOSS DR12 full-shape + re-constructed BAO'



https://github.com/Michalychforever/CLASS-PT

Ivanov(2020)

Massive neutrinos and EDE I: Bayesian results



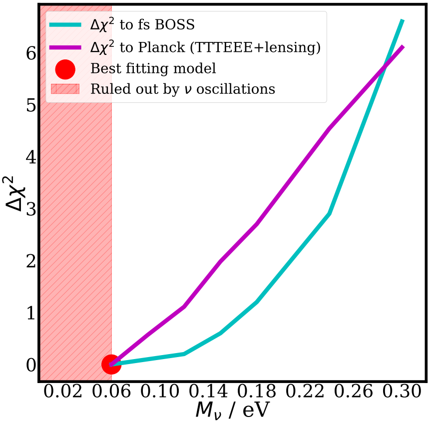
- Bayesian constraints show very little impact of freeing M_ν in the EDE model
- Caveat: recent evidence for prior volume effects impacting EDE constraints (see Laura Herold talk!)

A.R, L.Herold, S.Vagnozzi, B.Sherwin, E.Ferreira, arXiv:2207.01501 (submitted to MNRAS)

Massive neutrinos and EDE II: Frequentist results

Frequentist analysis: fix M_ν to 7 values in range $0.06 < M_\nu/eV < 0.3$ and find bestfit parameters and χ^2

- $M_\nu = 0.06eV$ gives global best fit in frequentist setting: no preference for increased M_ν
- Why does BOSS not favour high M_ν in EDE scenario?
  - Raised M_ν leads to worse fit to geometrical scales in clustering data due to background expansion effect
  - Outweighs any 'benefit' of M_ν reducing clustering amplitude



A.R, L.Herold, S.Vagnozzi, B.Sherwin, E.Ferreira, arXiv:2207.01501

Conclusions

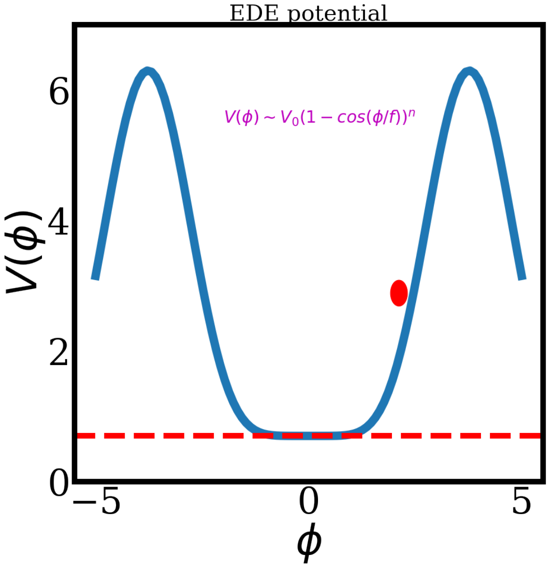
In this work we explored an extended Early Dark Energy model with a free neutrino mass

- These results show raising M_ν cannot effectively reduce excess clustering in the EDE model
- Geometrical information in BOSS likelihood gives strong constraints on M_ν: likely to be the case for any early-time extension to ΛCDM
- Further work: a) Consider other datasets e.g. ACT/WL b) explore other mechanisms to reduce clustering (decaying DM, DM-DR interactions etc.)

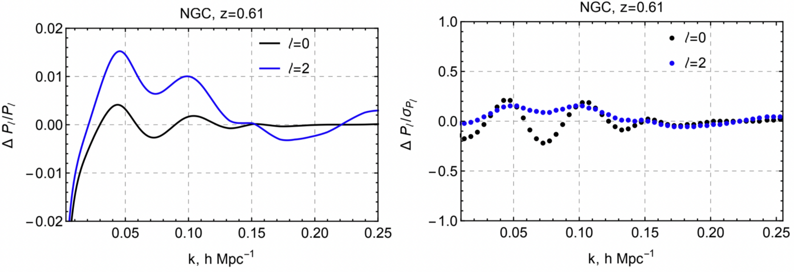
If you want to know more please read our paper: arXiv:2207.01501

EXTRA SLIDE1: EDE potential and physics

- Axion EDE field ϕ, $V_0 = m^2 f^2$
- Modified axion potential broken by 'non-perturbative instanton effects' to give this specific form
- Uncoupled DE model: effect on other fields via background effects
- $\phi'' + 2aH\phi' + m^2 a^2 \frac{dV}{d\phi} = 0$: held up by Hubble friction in early Universe $\rightarrow$ acts as DE



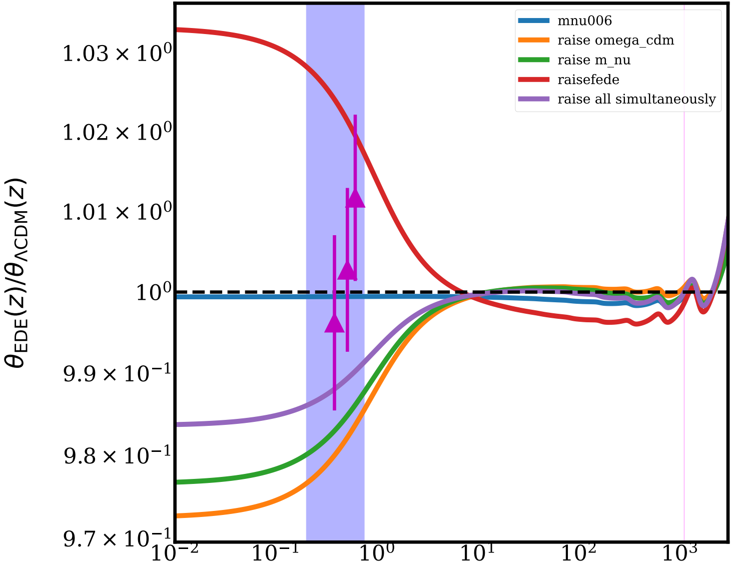
EXTRA SLIDE2: sensitivity to clustering amplitude



Credits: Ivanov *et al.*, PRD 102 (2020) 10, 103502

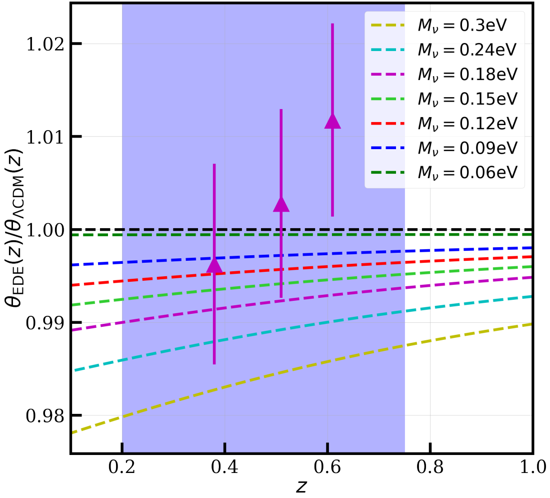
EXTRA SLIDE3: EDE + M_ν reason for hope?

$M_\nu - f_{EDE}$ symbiotic?



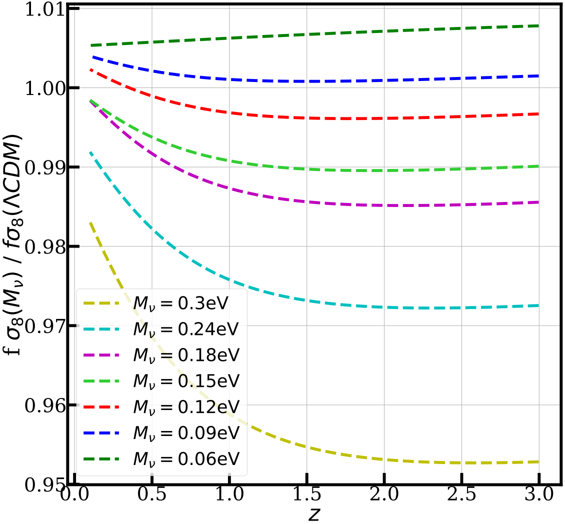
EXTRA SLIDE 4: BACKGROUND IMPACT OF M_ν

- $\theta = r_s(drag)/D(z)$: characterises position of BAO feature in galaxy clustering data
- Background effects of M_ν lead to a worse fit to BAO position than in baseline EDE model
- BOSS(fs) + BAO likelihood more sensitive to geometry information than overall clustering amplitude



AR, arXiv:2207.01501

EXTRA SLIDE 6: $f\sigma 8$



EXTRA SLIDE 7: PVEs