Fundamental Physics and Cosmology with Fast Radio Bursts

GERMAN CENTRE FOR COSMOLOGICAL LENSING

Robert Reischke

with Steffen Hagstotz and Robert Lilow

Paris-Saclay Astroparticle Symposium 2022

Menu du jour

RUHR
UNIVERSITÄT
BOCHUM

1. Dispersion Measure Correlations
2. Equivalence Principle Tests with FRBs
3. Cosmological Prospects

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1. **Dispersion Measure Correlations**
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FRB statistics

Consider angular clustering

Correlate positions

$$\left\langle \delta^{\mathrm{FRB}}_{\ell m} \delta^{\mathrm{FRB}}_{\ell' m'} \right\rangle = C^{\mathrm{FRB}}(\ell) \delta^{\mathrm{K}}_{\ell \ell'} \delta^{\mathrm{K}}_{m m'}$$

Sparse, noisy distances, shot-noise dominated

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Correlate Dispersion Measure

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Sparse, noisy distances, signal dominated

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Sparse, noisy distances, signal dominated

FRB statistics

Correlate dispersion measure

$$C^{\mathrm{DM}}(\ell) = \frac{2}{\pi}\int k^2 \mathrm{d}k \int \mathrm{d}\chi_1 \int \mathrm{d}\chi_1 W(\chi_1) W(\chi_2) \sqrt{P_{\mathrm{e}}(k,\chi_1) P_{\mathrm{e}}(k,\chi_2)}\, j_\ell(k\chi_1) j_\ell(k\chi_2)$$

FRB statistics

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Redshift distribution, ionisation history

FRB statistics

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Matter power spectrum, electron bias

FRB statistics

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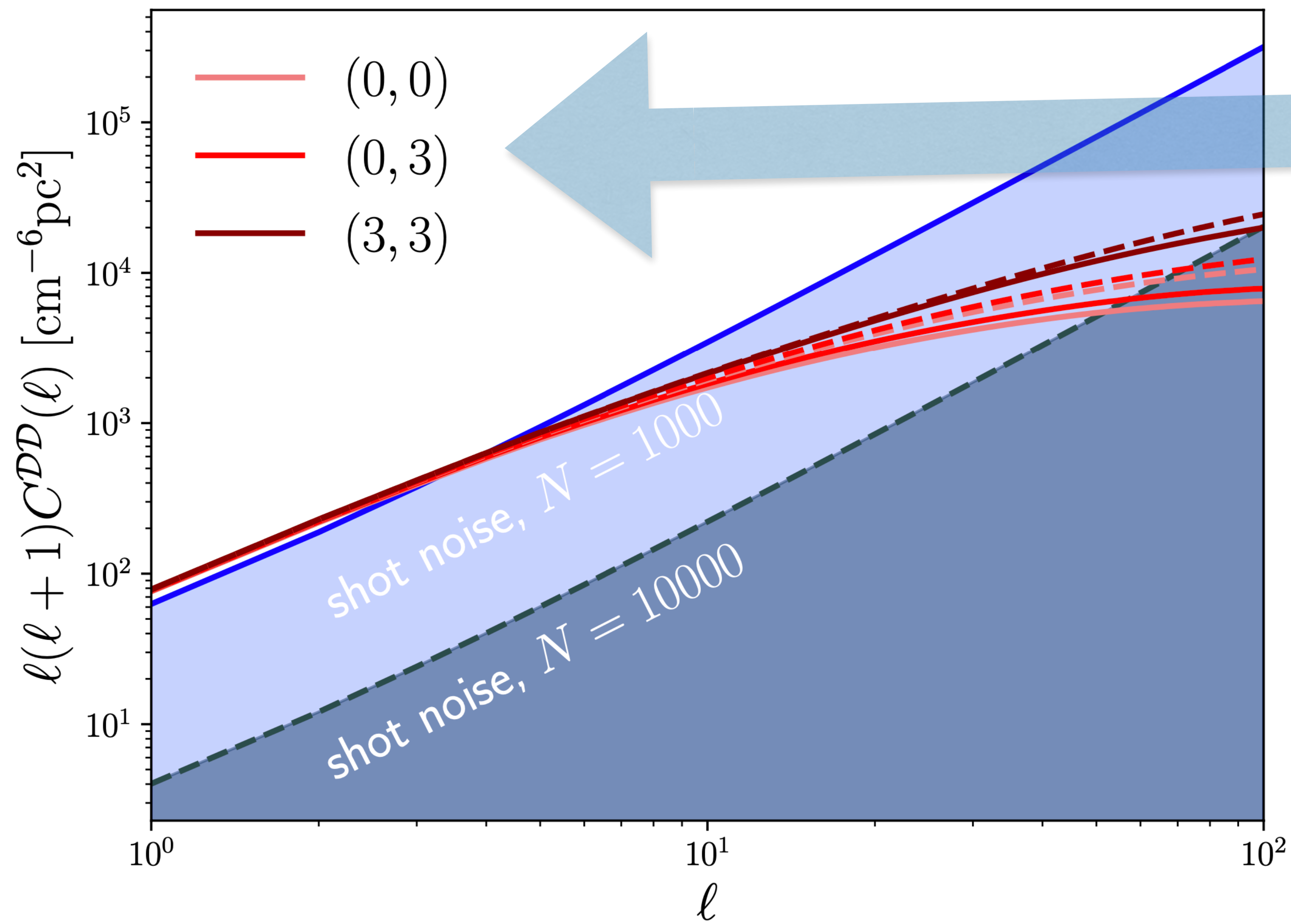
Redshift distribution, ionisation history

Matter power spectrum, electron bias

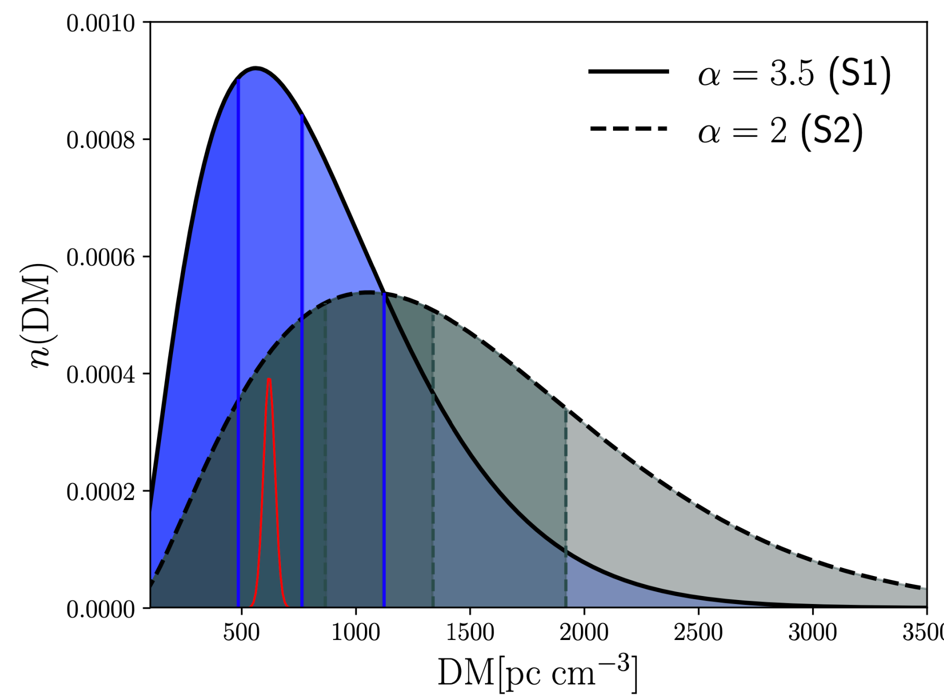
- DM correlations - Masui & Sigurdson (1506.01704)
- Cross-correlations with galaxy surveys - Rafiei-Ravandi, Smith & Masui (1912.09520)
- Primordial non-Gaussianity - RR, Hagstotz, Lilow (2007.04054)
- Shapiro delay tests of GR - RR, Hagstotz, Lilow (2102.11554)
- …

FRB statistics

Tomographic dispersion measure spectra



Use (homogeneous) dispersion measure as distance proxy



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Equivalence principle

- If EP is broken, photons of different frequencies would pick up an additional (to ν^{-2} scaling) delay

$$\Delta t = \Delta t_{\mathrm{DM}} + \Delta t_{\mathrm{grav}}$$

- So far what has been assumed is the classical Shapiro delay expression

$$t_{\mathrm{grav}} = -\frac{1+\gamma}{c^3}\int_{\boldsymbol{r}_\mathrm{e}}^{\boldsymbol{r}_\mathrm{o}} \mathrm{d}\lambda\, U(\boldsymbol{r}(\lambda))$$

- Idea: assume to know a subset of potentials along line-of-sight

- Put upper limits on $\Delta\gamma$

Problems

- Adding structure increases the limit monotonically
- In a cosmological setting the standard expression diverges due to boundary conditions
- Should rather use

$$\Delta t_{\rm grav} = \frac{\Delta\gamma}{c^3}\int {\rm d}\chi a(\chi)\phi(\hat{\boldsymbol{x}}\chi)$$

- New problem: no longer upper bound since ϕ fluctuates

Equivalence principle tests

- True observable: time delay between frequency arrival $\Delta t = \Delta t_{\mathrm{DM}} + \Delta t_{\mathrm{grav}}$

- Shapiro delay

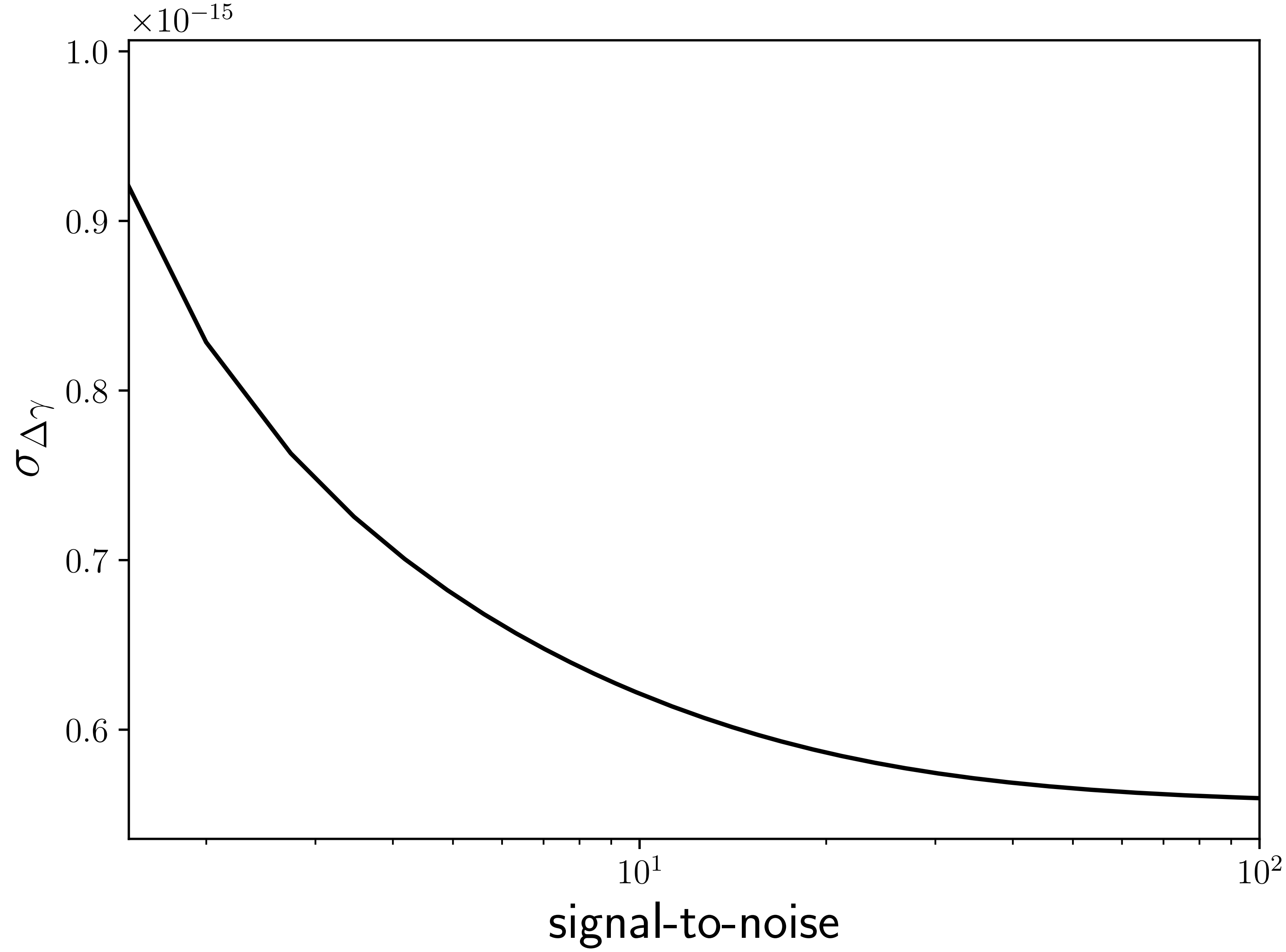
Possible frequency dependence

$$\Delta t_{\mathrm{grav}} = \frac{\Delta\gamma}{c^3}\int \mathrm{d}\chi a(\chi)\phi(\hat{\boldsymbol{x}}\chi)$$

- Can imprint additional correlations when interpreted as DM signal

Equivalence principle tests

RR, Hagstotz, Lilow, 2102.11554



- Events ~ms, line of sight ~Gpc
- Any $\Delta\gamma$ would completely dominate the correlation signal
- Any detection puts tight constraints on the EP

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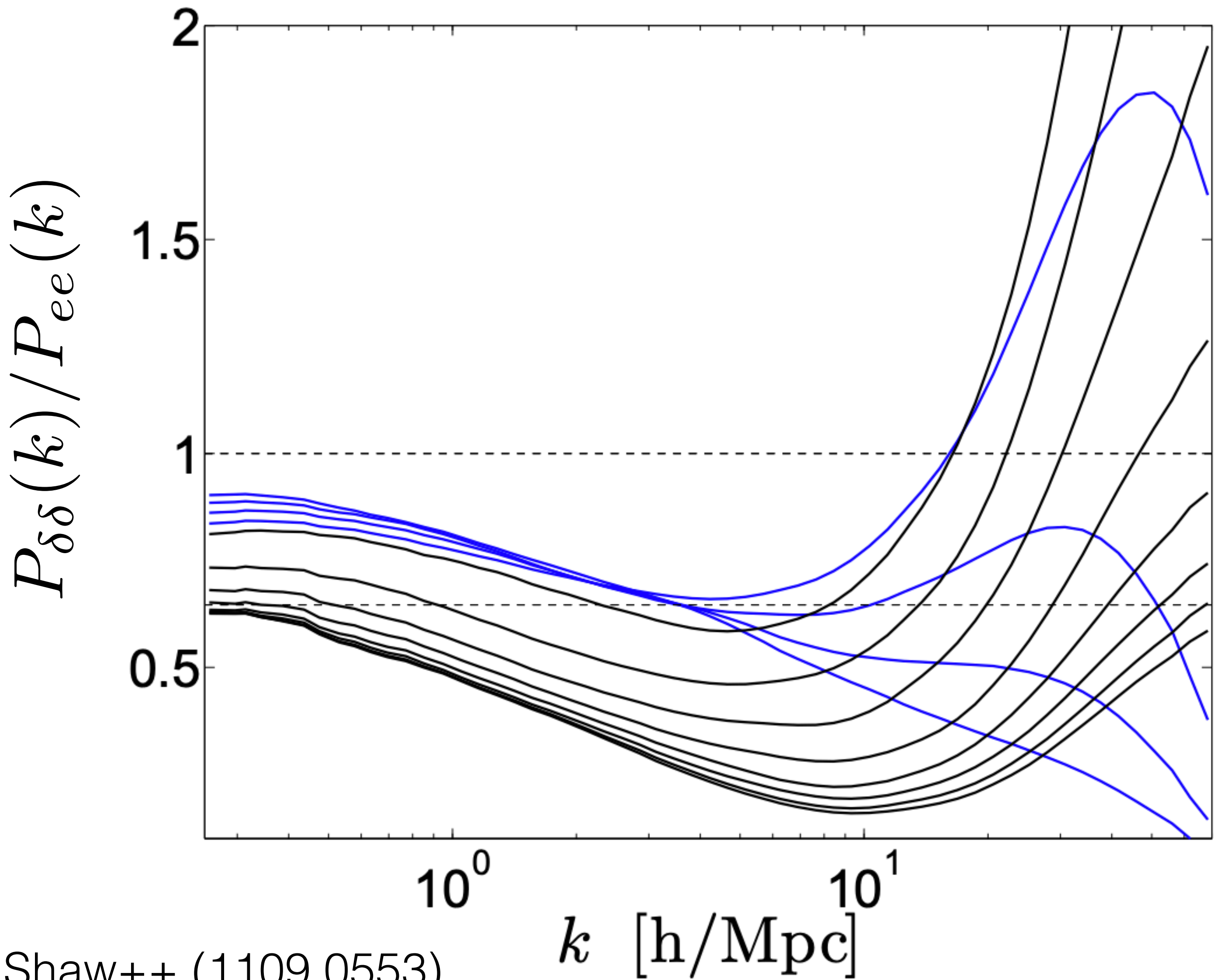
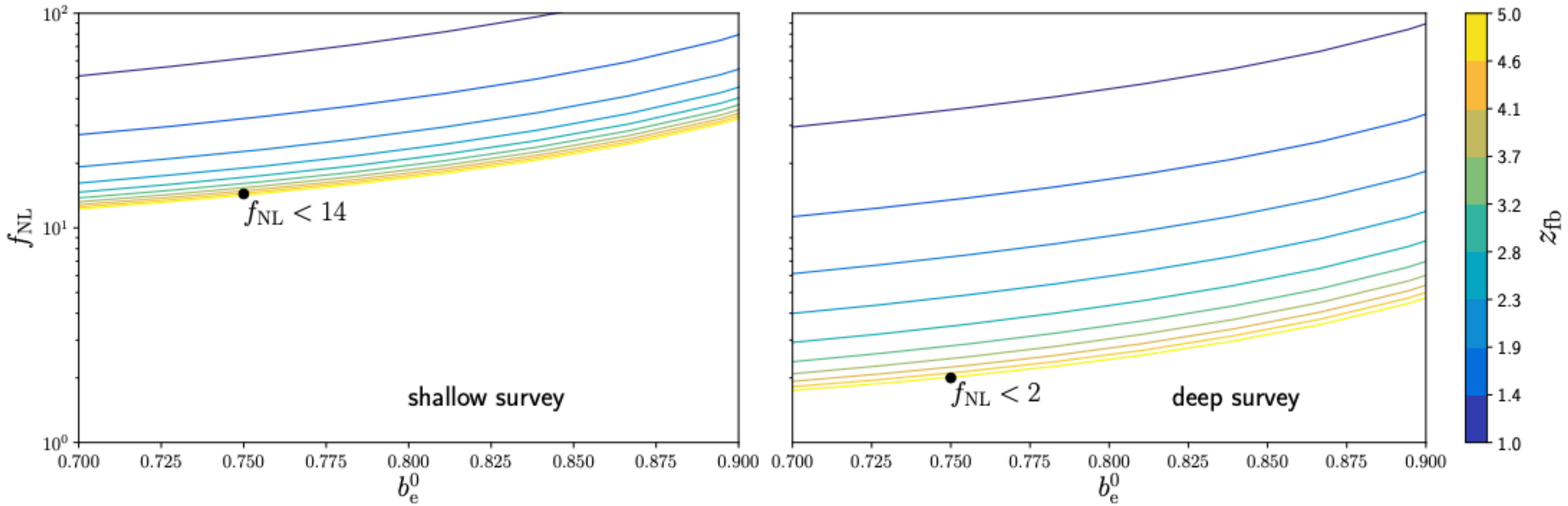
Electron bias



Shaw++ (1109.0553)

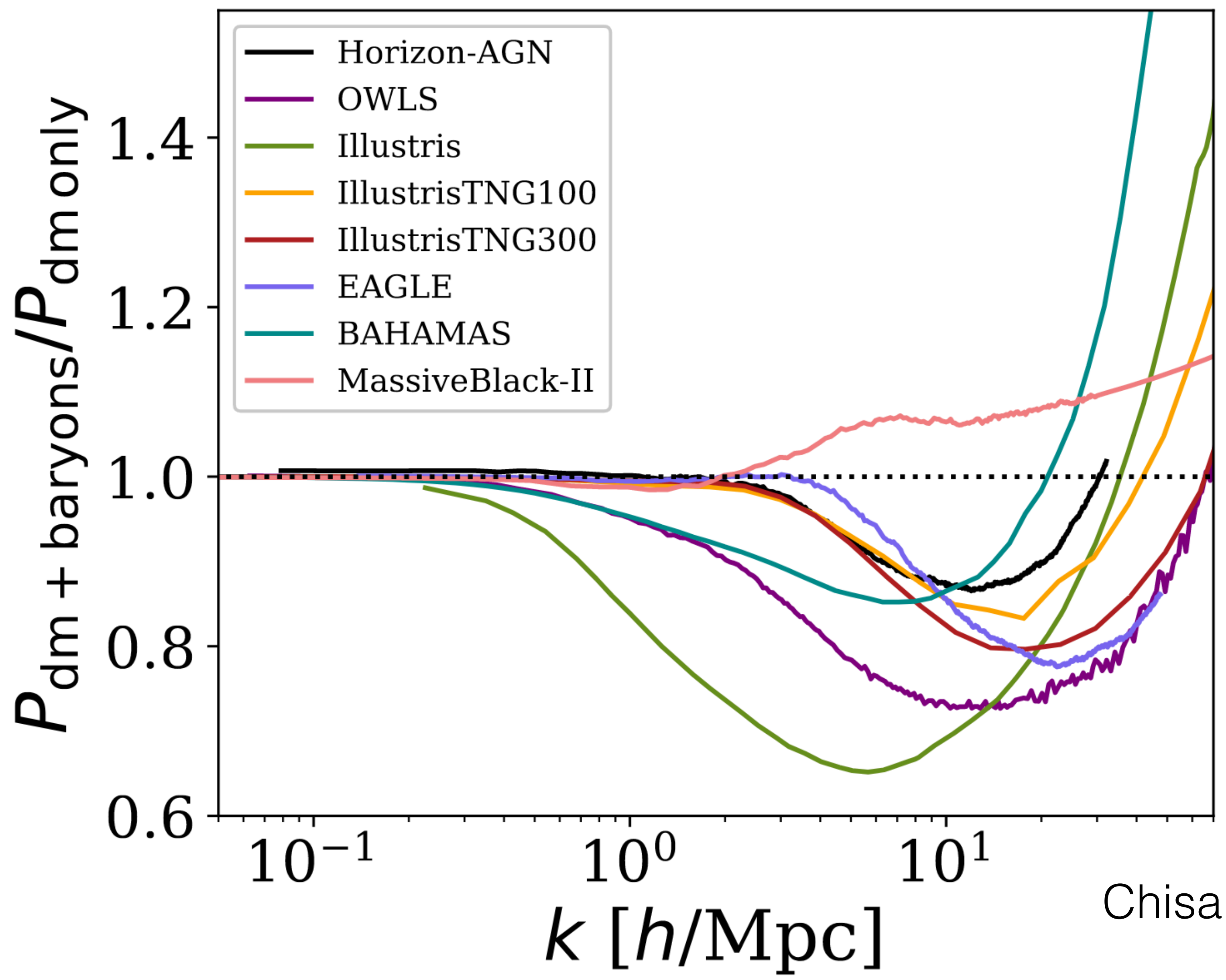
- Feedback pushes gas out of halos
- Free electrons anti-correlated with halos on large scales

Effect of feedback



For now, electron feedback is the largest uncertainty. Can we turn this around to test feedback models with cross-correlations?

Baryonic Feedback



Chisari++ (1905.06082)

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Summary

Fast Radio Bursts …

- are a rising probe of the large-scale structure with thousands of new detections to be expected in the future

- can probe fundamental physics as soon as a correlation is detected

- serve as a test of cosmology both on the background as well as the perturbation level

- potentially provide insights on baryonic feedback