Baryonic Feedback with Fast Radio Bursts and SKA

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SKA cosmology SWG Meeting
Nice - November 6 I 2024

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Menu du jour

1. Dispersion measure
2. Observing the cosmological background
3. Observing cosmological perturbations

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1. **Dispersion measure**
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Robert Reischke

Fast Radio Bursts

- Mechanism still debated
- First discovered in archival data 2007
- Short (~ms), bright (~Jy) radio transients
- Frequencies 300 Mhz - 8 Ghz
- Extragalactic
- About 800 known events, soon several 1000s
- Some repeating

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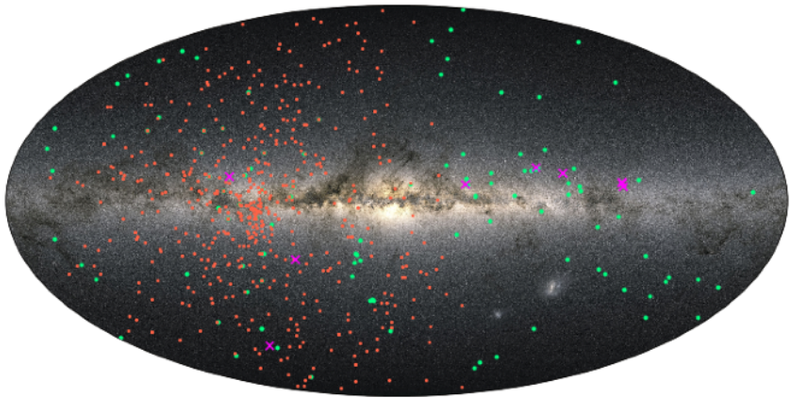
Known FRBs



- Until now: detections mostly incidental
- Expect rates of $10^3 - 10^4$ / sky / night
- Now: dedicated searches ongoing

CHIME

ASKAP

DSA-110

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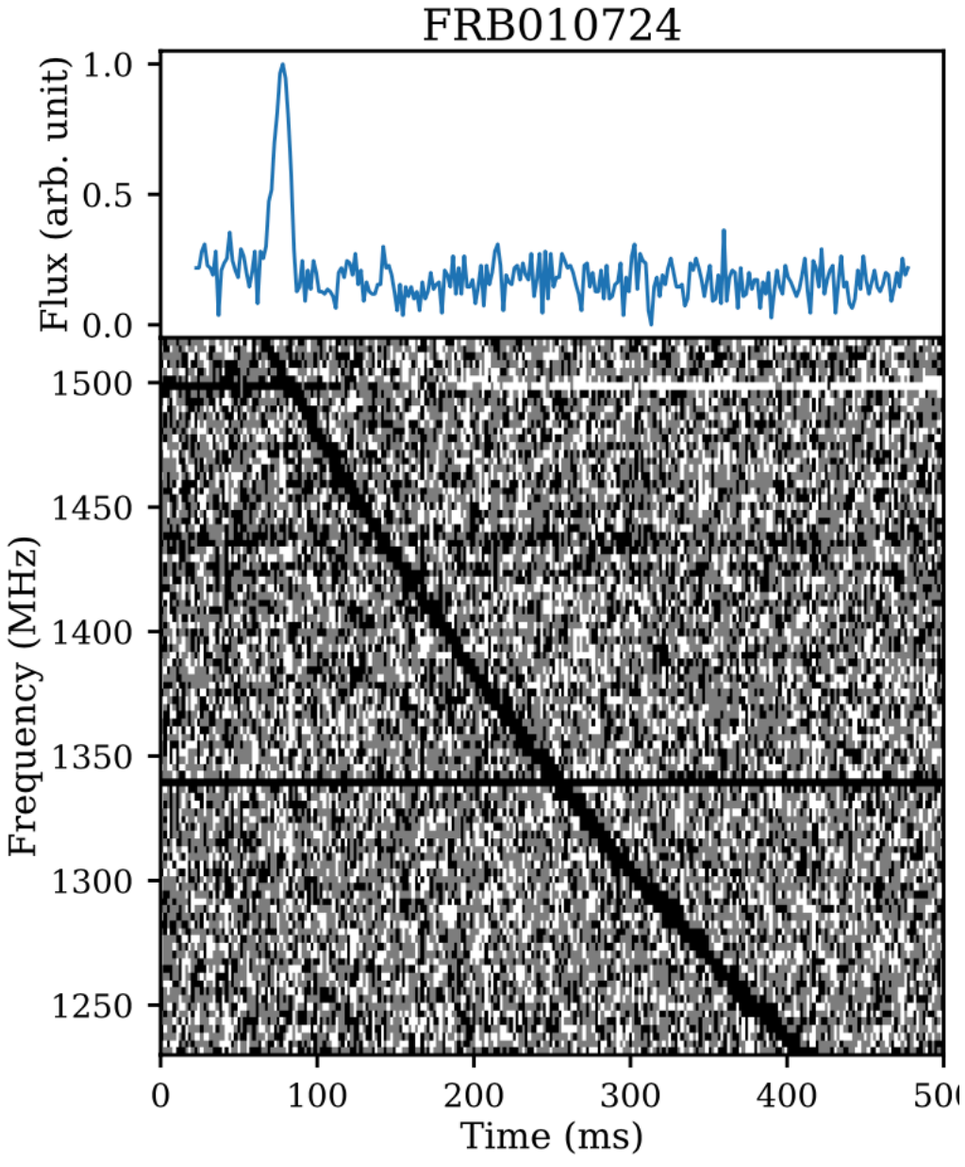
Dispersion measure



Lorimer et al 2007
Cordes & Chatterjee 2019

- Radio signals undergo dispersion
- Pulse delay $\Delta t \sim \nu^{-2}$
- Depends on integrated electrons along LoS

$$\mathrm{DM} = \int \frac{n_e}{1+z} \mathrm{d}l$$

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Dispersion measure

$$\mathrm{DM_{obs}}(\mathbf{x}, z) = \mathrm{DM_{MW}}(\mathbf{x}) + \mathrm{DM_{LSS}}(z, \mathbf{x}) + \mathrm{DM_{host}}(z)$$

Milky Way models
Can be checked with Pulsars
Quite accurate!

Host halo models
Depends on galaxy types?
Location of FRBs?

Redshift scaling:

$$\propto \mathrm{const.} + \int_0^z \mathrm{d}z' \frac{1+z'}{E(z')} + \frac{1}{1+z}$$

Statistics can tell contributions apart

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Dispersion measure

$$\mathrm{DM}_{\mathrm{obs}}(\mathbf{x}, z) = \mathrm{DM}_{\mathrm{MW}}(\mathbf{x}) + \mathrm{DM}_{\mathrm{LSS}}(z, \mathbf{x}) + \mathrm{DM}_{\mathrm{host}}(z)$$

$$\mathrm{DM}_{\mathrm{LSS}} = \int \mathrm{d}l \frac{n_e}{1+z}$$

$$n_e \approx F(z)\frac{\rho_b}{m_p} = F(z)\frac{\bar{\rho}_b}{m_p}\left[1 + b_e \delta_m\right]$$

Distance measure
Need redshifts
(Part II)

Baryon fraction
Need redshifts

Ionisation history
Need redshifts

Density field
(Part III)

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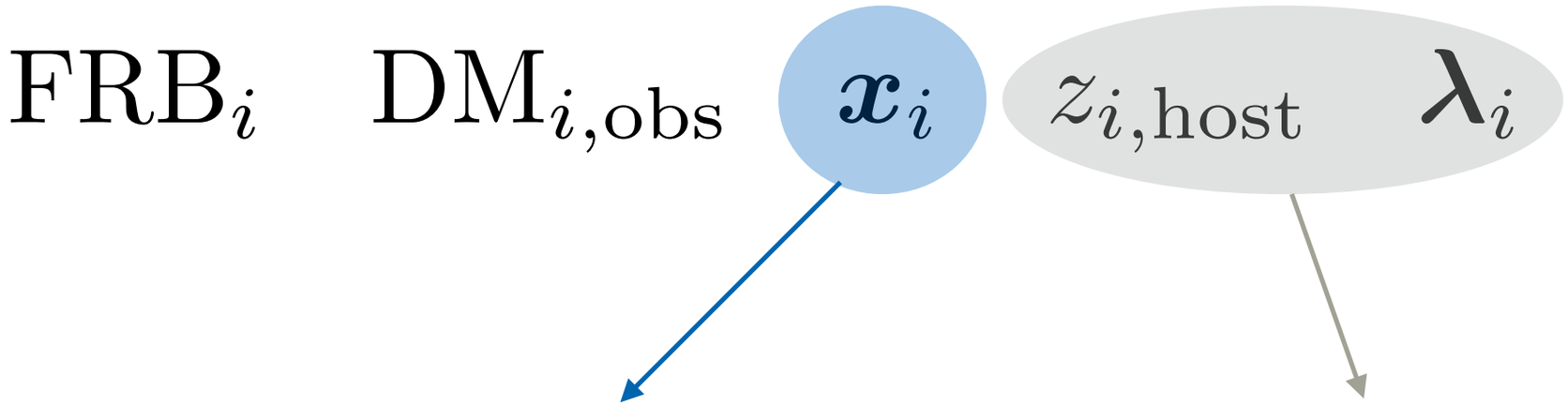
Starting point



Position
(If host known,
very accurate)

Host redshift and
other properties

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Distance scale

Mean LSS dispersion:

$$\langle \mathrm{DM_{LSS}} \rangle(z) = \int \mathrm{d}l \frac{n_e}{1+z}$$

$$\langle b_\mathrm{e} \delta_\mathrm{m} \rangle = 0$$

$$n_e \approx \chi_e \frac{\bar{\rho}_\mathrm{b}}{m_p}$$

$$= \frac{3\Omega_\mathrm{b} H_0}{8\pi G m_\mathrm{P}} \chi_\mathrm{e} f_\mathrm{IGM} \int^z \frac{1+z'}{E(z')} \mathrm{d}z'$$

- Perfect degeneracy at the background level
- Combine with prior on baryon density $\Omega_\mathrm{b} h^2$ (from CMB or BBN)

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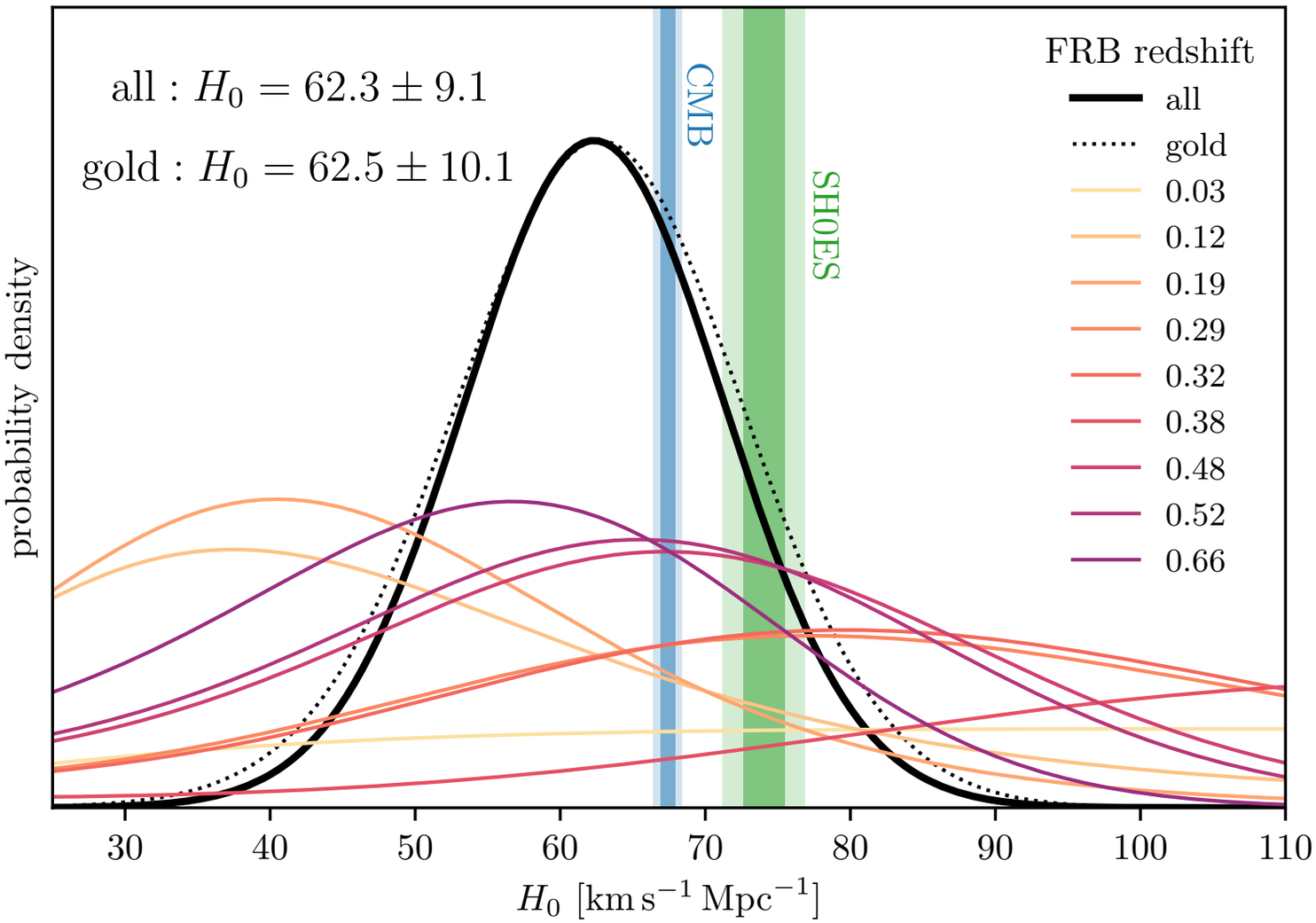
Distance scale



Events at large z most important

Uncertainty in host DM dominates error

arxiv:2104.04538

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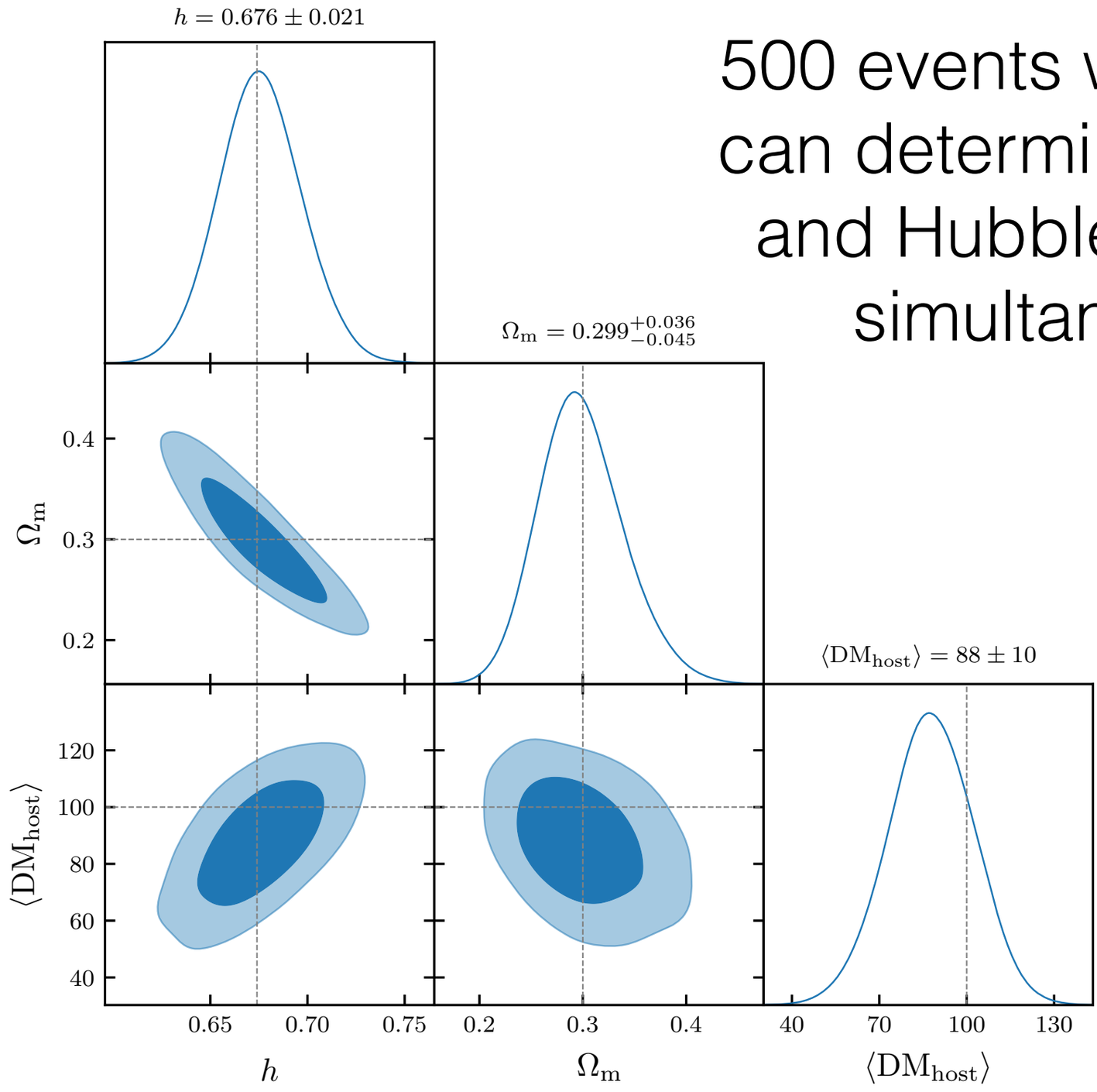
Distance scale



500 events with host ID can determine host DM and Hubble constant simultaneously

arxiv:2104.04538

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Correlated events

Nearby lines of sight
traverse similar structures
→ correlated DM

→ probe statistical properties
of electron distribution

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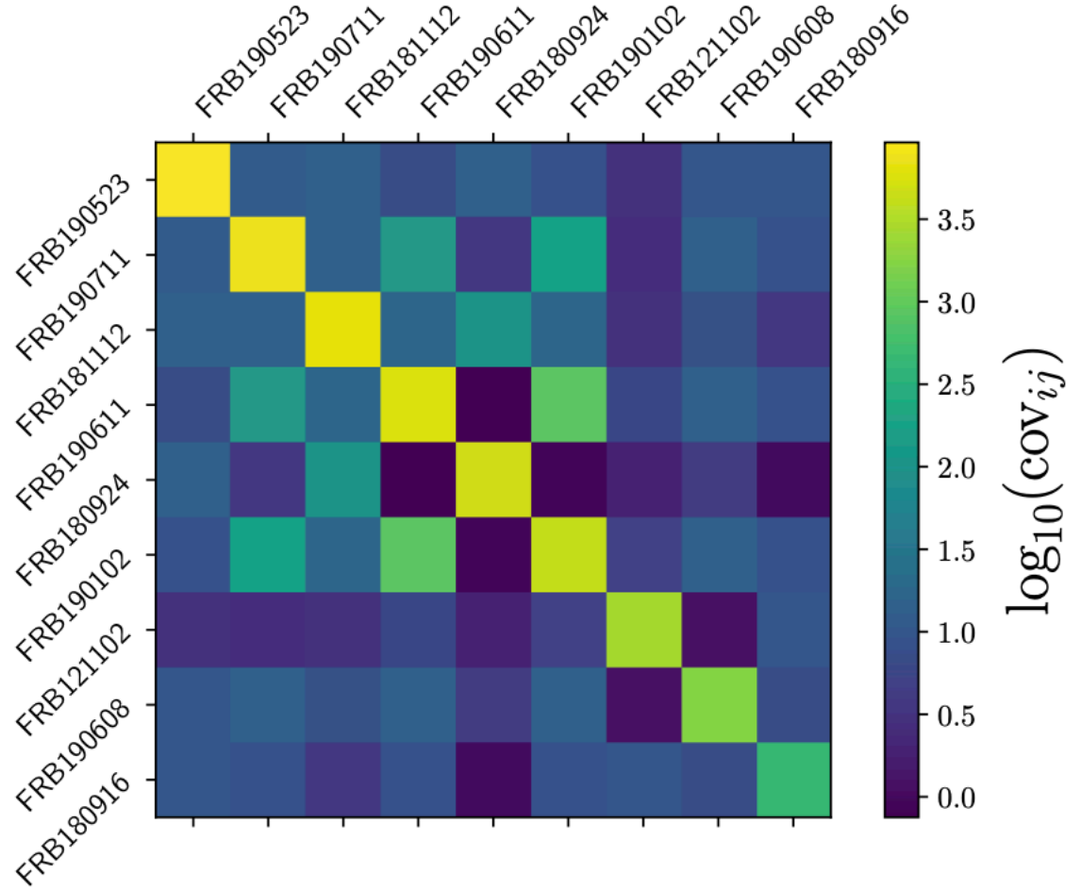
Correlated events

Nearby lines of sight traverse similar structures → correlated DM



arxiv:2301.03527

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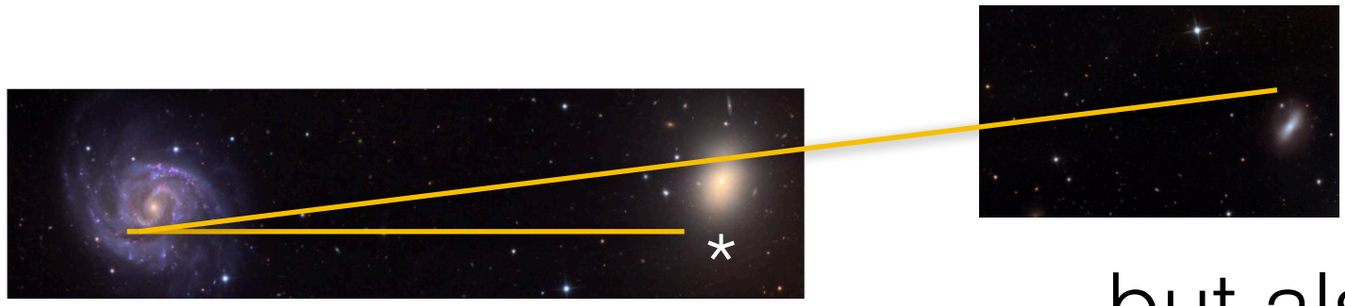
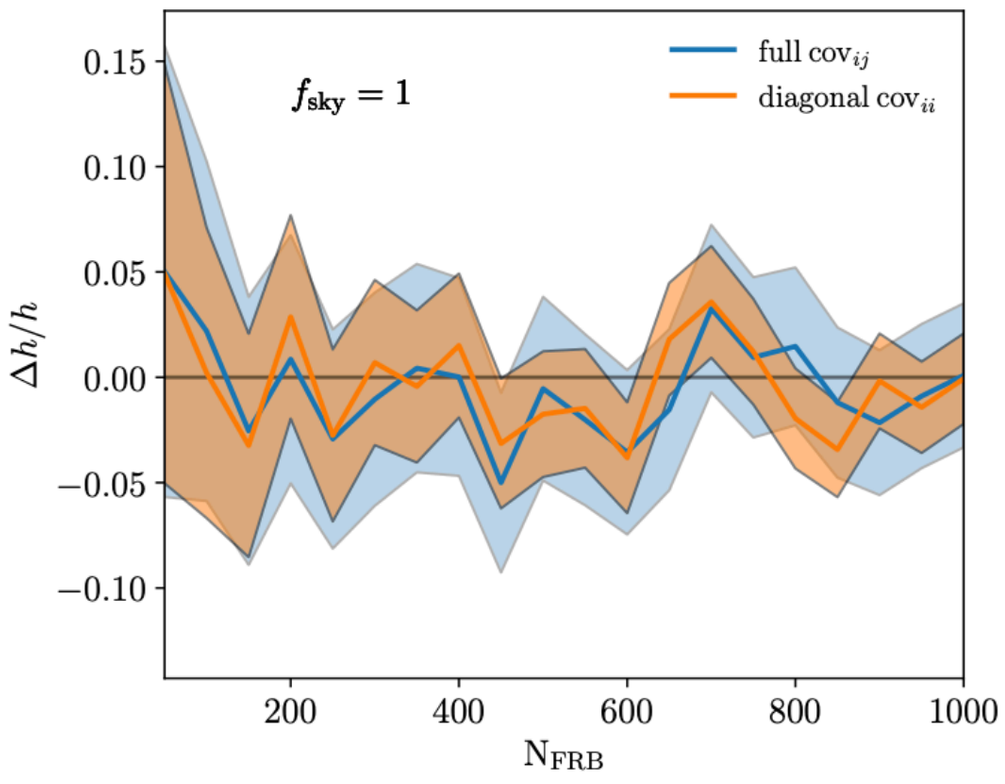
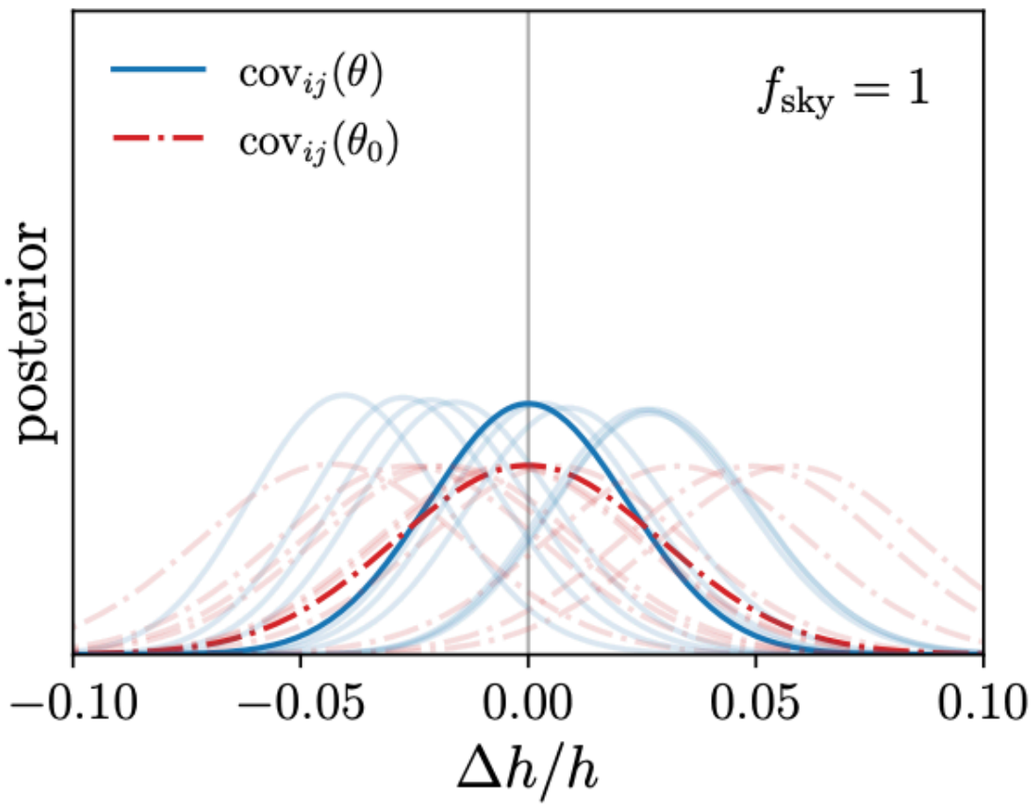
Correlated events



…but also is a source of information





Correlation becomes important for few 100s FRBs/sky..

$\mathrm{cov}(H_0, \Omega_m, \ldots)$

arxiv: 2301.03527

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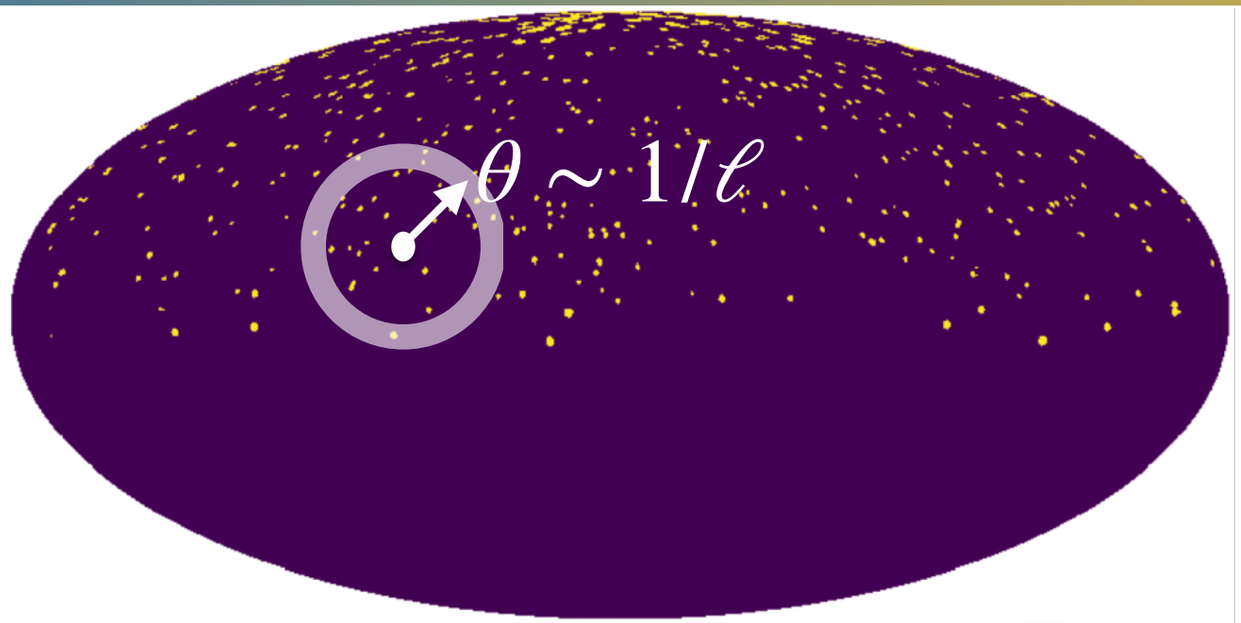
DM correlations



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

Redshift distribution, ionisation history

Matter power spectrum, electron bias

A very biased list of what you can do with FRBs

- Shapiro delay tests of GR (2102.11554, 2302.10072)
- PNG or GR (2007.04054, 2409.11163)
- Tests of baryonic feedback (2309.09766)
- Simulation-based inference (2410.07084)

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DM correlations

Correlate FRBs

$$C_\ell = \langle \delta_\ell^{\rm FRB}\, \delta_{\ell'}^{\rm FRB} \rangle$$

Bad galaxy survey

Sparse, noisy distances, shot-noise dominated

Correlate dispersion measure

weak lensing on steroids*

$$C_\ell = \langle {\rm DM}_\ell\, {\rm DM}_{\ell'} \rangle \sim \int {\rm d}\chi \Big[\ldots P_{ee}(k) \Big] + \frac{\sigma^2_{\rm host}}{\bar{n}}$$

*(but still sparse)

signal ~ noise

Because $\mathrm{DM}_{\rm LSS}(z) \sim \mathrm{DM}_{\rm host}$

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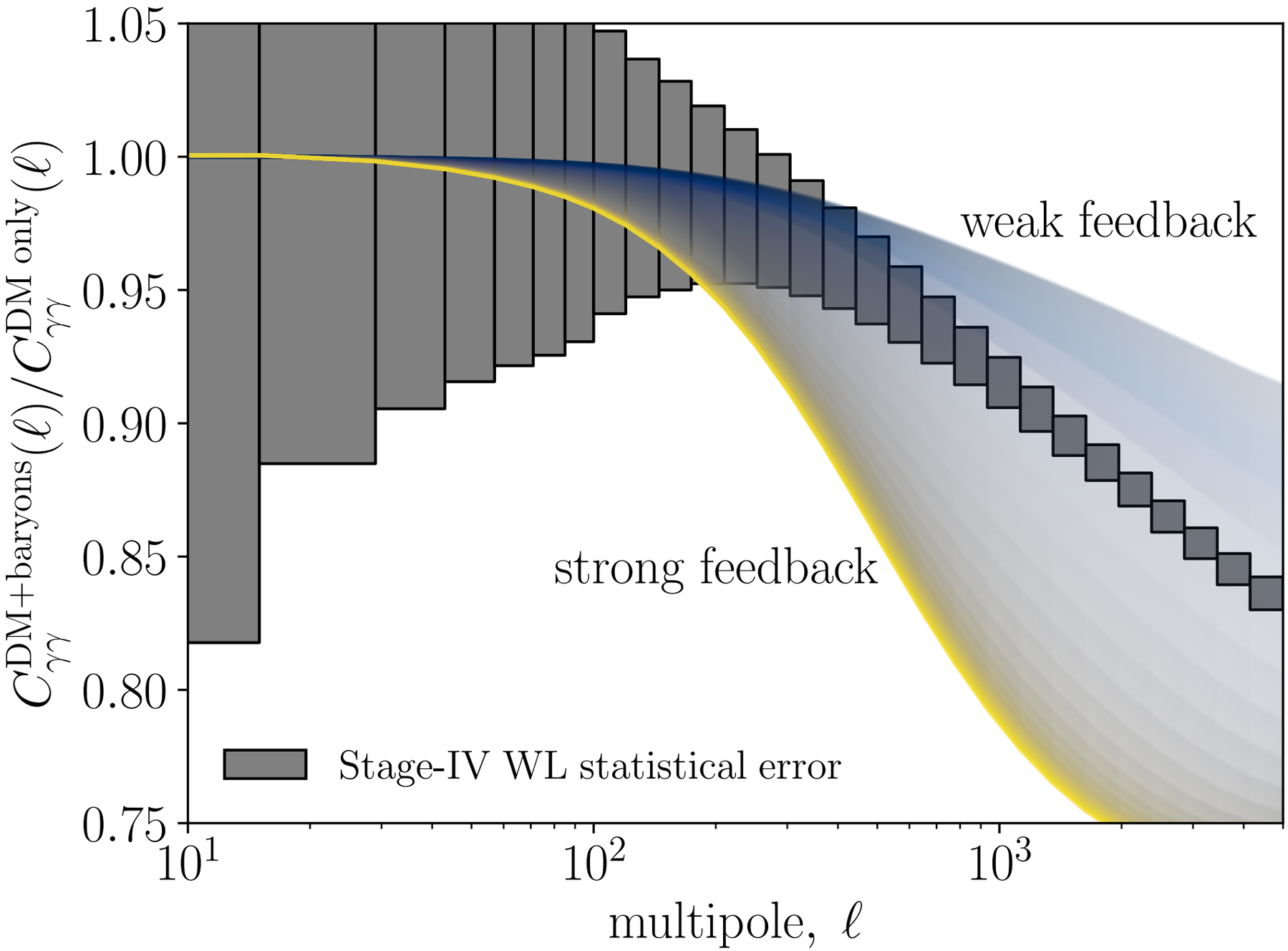
Baryonic Feedback



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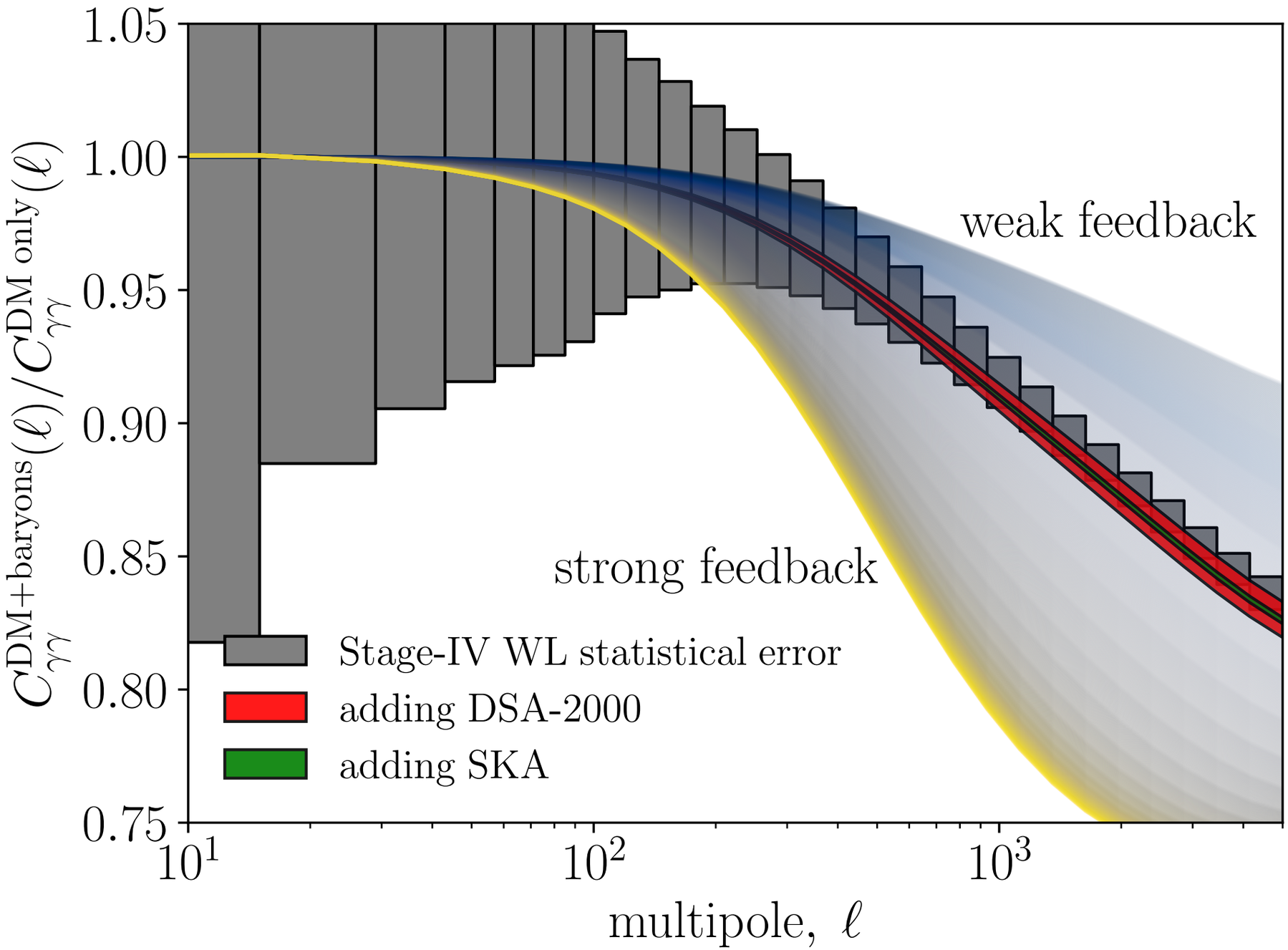
Baryonic Feedback



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Summary

- FRBs can provide independent measurement of the Hubble constant

- Can provide tests of ionisation history and ISM/IGM transition

- Currently limited by statistics, SKA will improve numbers of current flagships by an order of magnitude

- Direct measurement of baryons to constrain feedback, key for upcoming LSS surveys

- Correlations allow powerful tests of fundamental physics

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