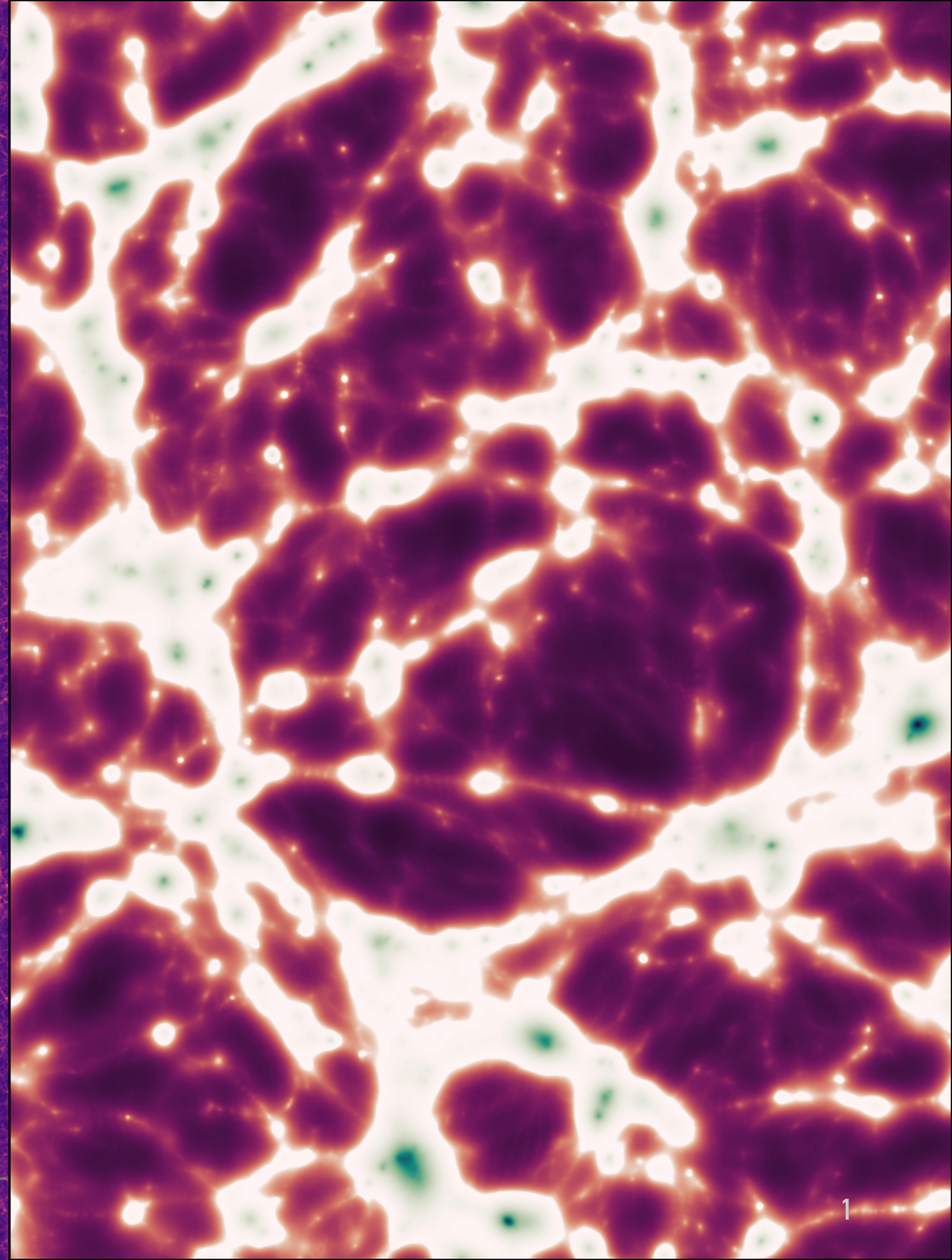
LATE-TIME DOMAIN WALLS IN COSMOLOGICAL SIMULATIONS

Exploring phenomenological consequences



SOME CLAIMED TENSIONS AND PROBLEMS

Phenomenology

- Supermassive black hole growth & formation
- Hubble parameter (Riess 2022..)
- Cosmic dipole magnitude (Secrest 2021..)
- Quasar- and large scale structure dipoles
- Small scale crises
- σ_8 / Ω_m parameters (Peracaula 2019..)
- Early galaxies (JWST 2023..)
- Stochastic gravitational wave spectrum (NANOGRAV 2023..)
- Vaucoueurs local supercluster flat patterns (Peebles 2023), giant arc (Lopez 2022), big ring (Lopez 2024)
- Plane of satellites of the milky way (Naik 2022, Sales 2023)
- Anomalous ISW from large voids (Kovács 2019..)

Theory

- Quantum gravity
- Coincidence problem
- Λ smallness problem

Name	Mean z	Size Mpc
HCB Great Wall	~ 2	2000–3000
Giant GRB Ring	0.82	1720
Correlated LQG orientations	1.0–1.8	1600
U1.27, Huge-LQG	1.27	1240
Coherent quasar polarisation[3]	1–2	1000
U1.11	1.11	780
U1.28, CCLQG	1.28	630
Sloan Great Wall	0.073	450
South Pole Wall	0.04	420
Blazar LSS	~ 0.35	350
Local void	< 0.07	300
BOSS Great Wall (BGW)	0.47	250
Great Wall	0.029	240
Saraswati supercluster	0.28	200
CMB anomalies		
Acceleration anisotropy		
Cluster anisotropy		
Quasar dipole	0.5–2.0	
Statistical power, LRGs	~ 0.6	1000

(Lopez et al. 2021)

(cred: Michael Kramer)

(cred: NANOGrav collaboration)

SOME CLAIMED TENSIONS AND PROBLEMS

Phenomenology

- Supermassive black hole growth & formation
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- Stocha
- Vaucou
  giant a
- Plane c
- Anoma

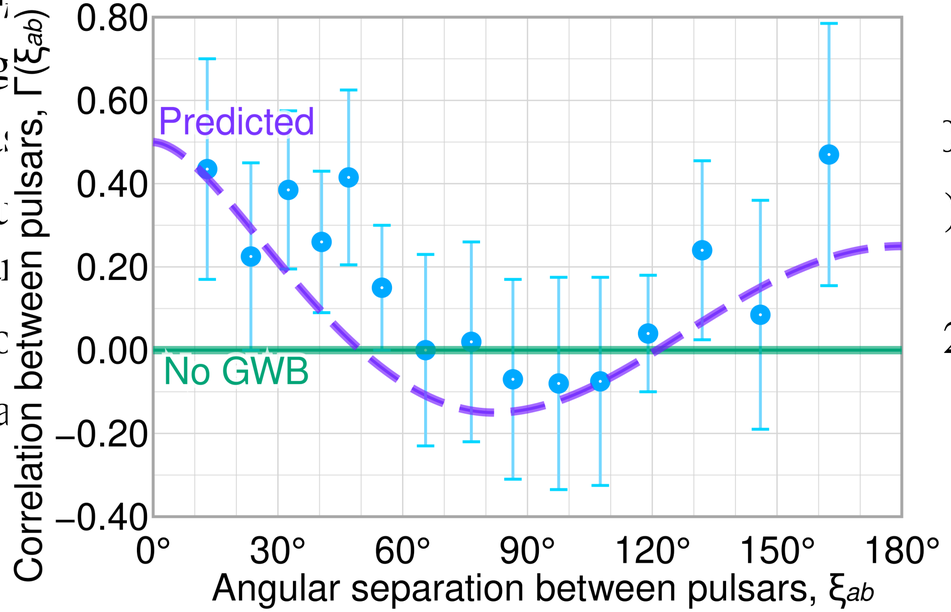
Theory

- Quantum gravity
- Coincidence problem
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)23..)

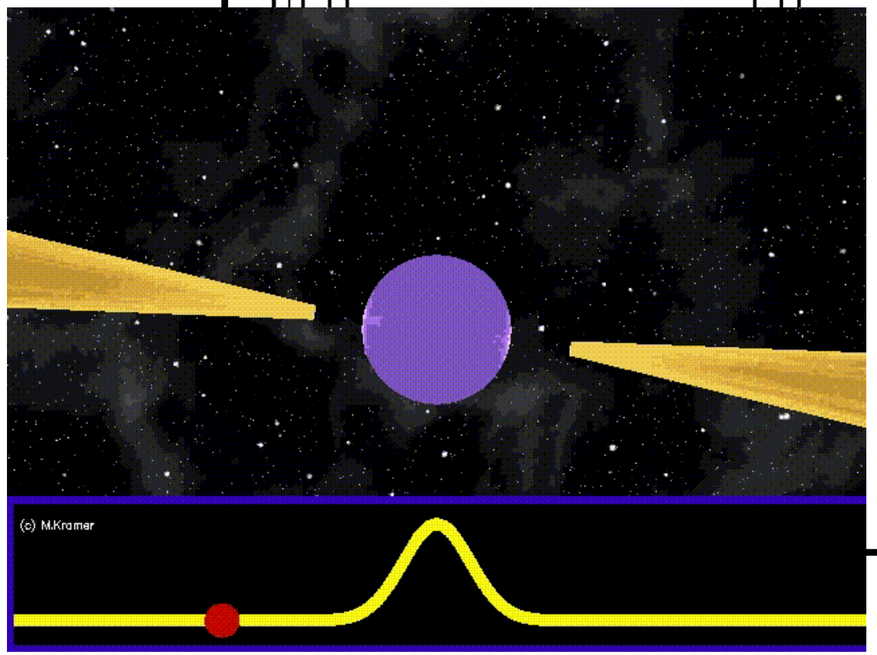
),

23)



(cred: NANOGrav collaboration)

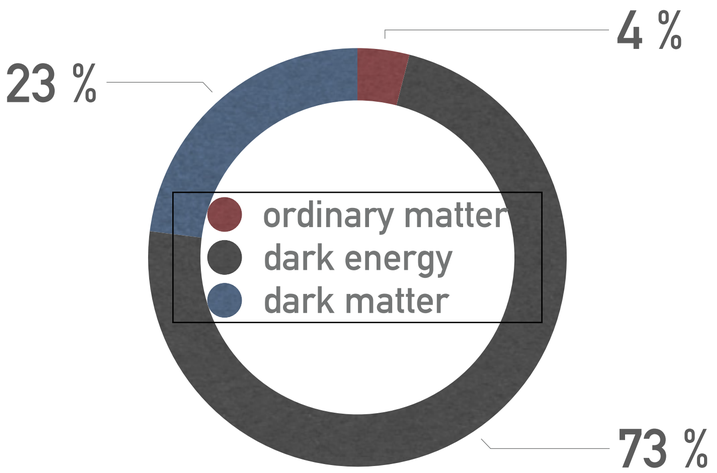
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		300
		250
		240
		200
		1000

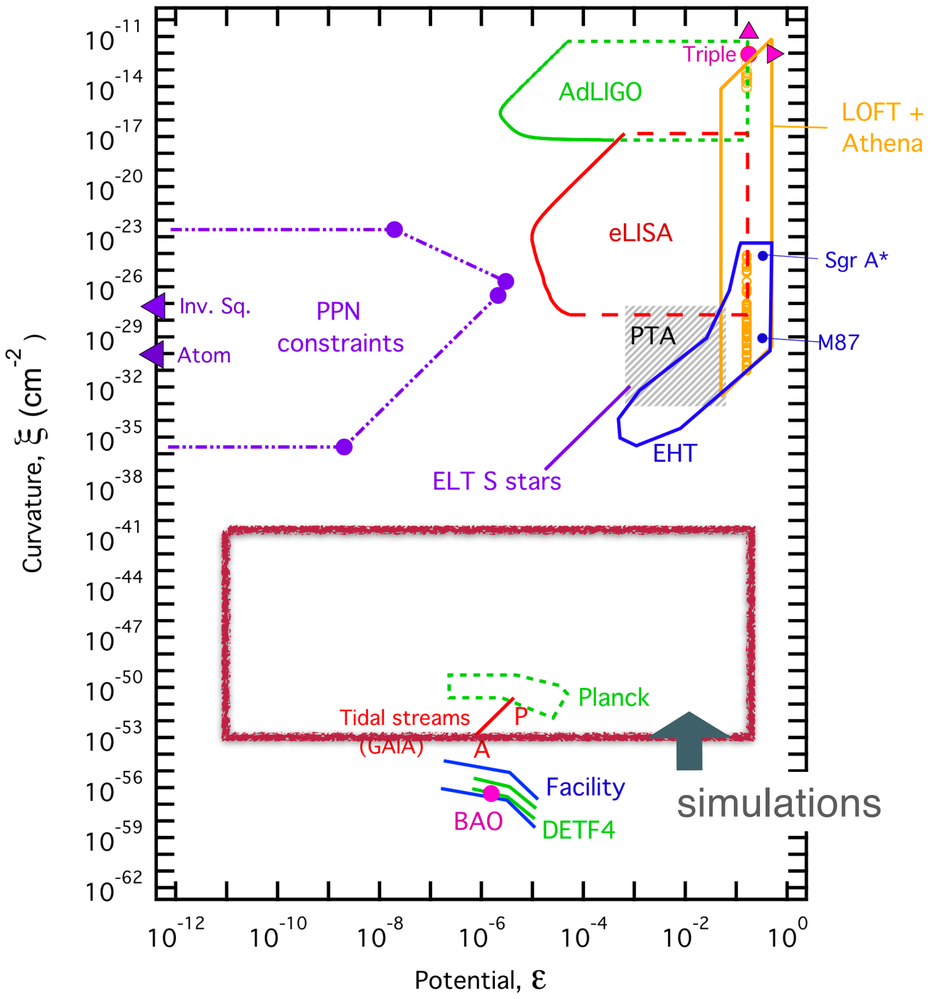


(cred: Michael Kramer)

WHY N-BODY SIMULATIONS?

- Non-linearities
- Emulating surveys
- Sandbox for exploring physics





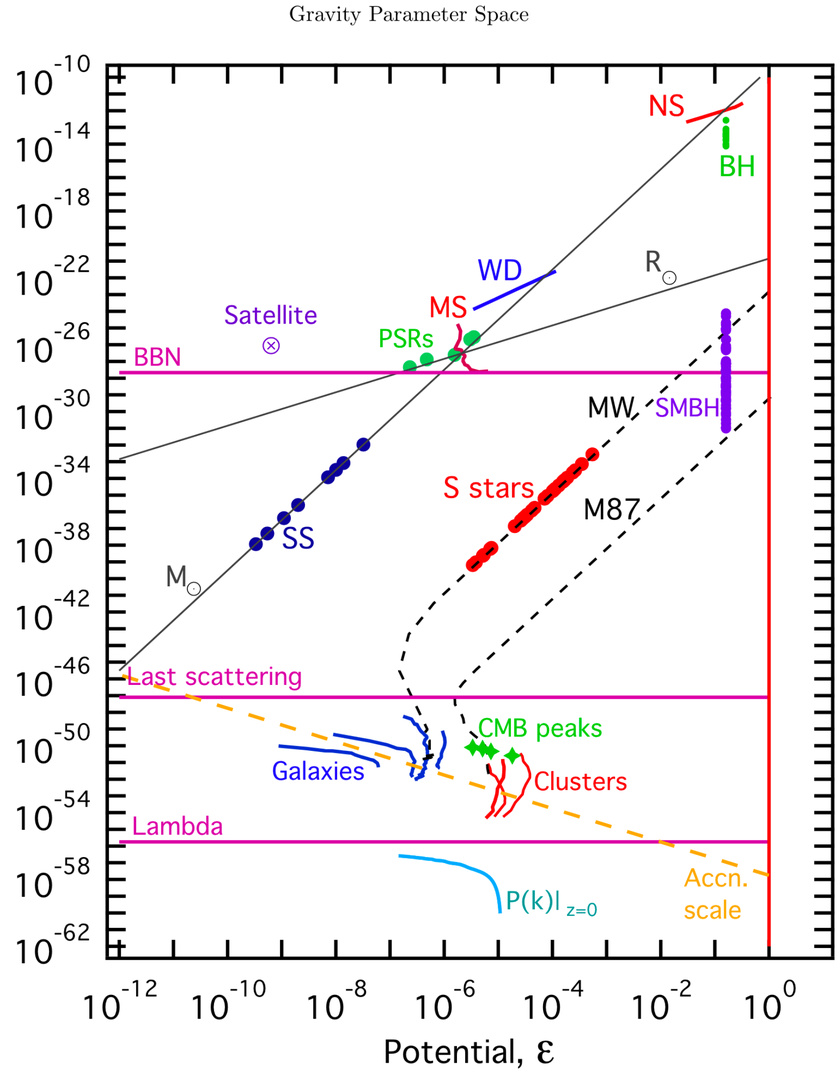


Image credit: Baker et al. (2015)

SYMMETRON DARK ENERGY (Hinterbichler & Khoury 2010)

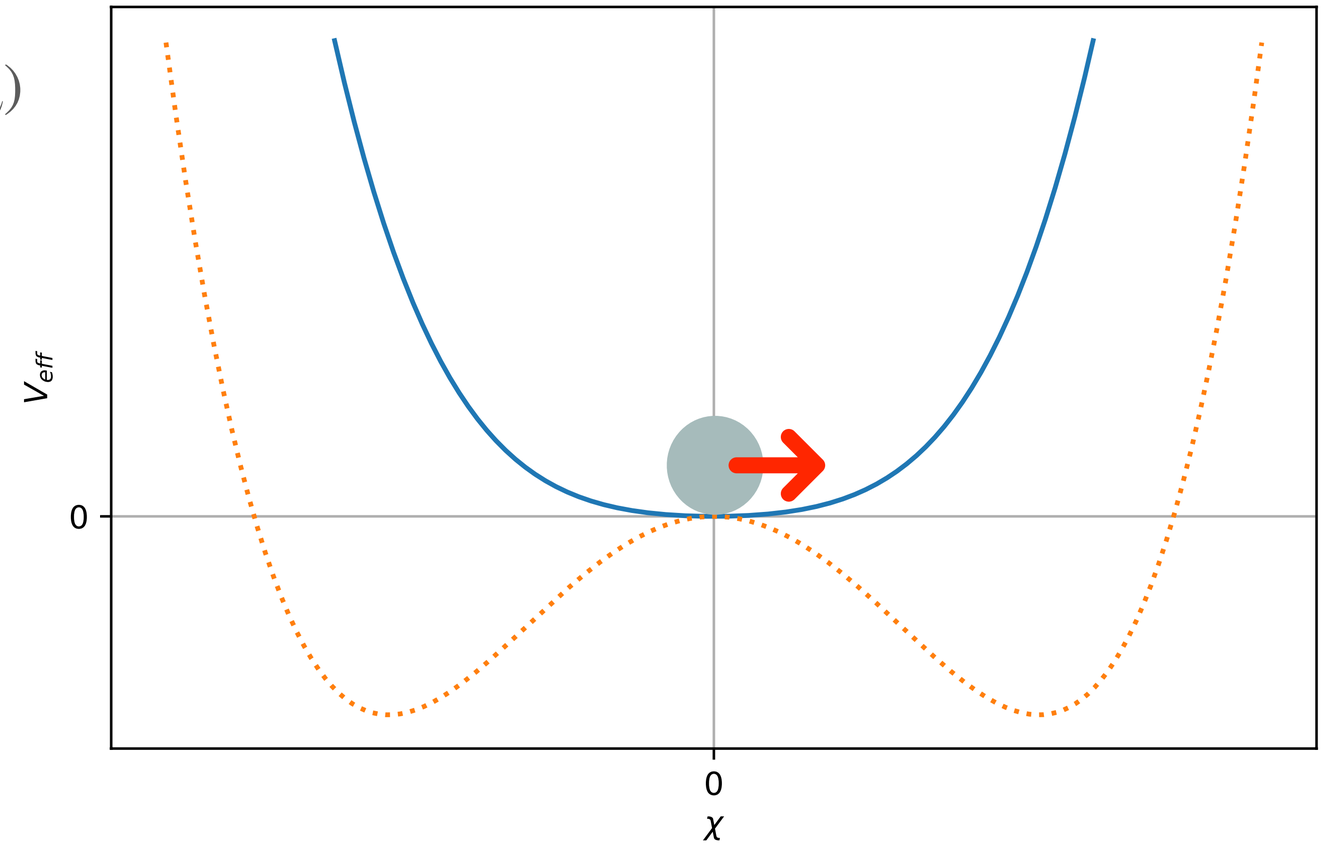
$$\mathscr{L} = -\frac{1}{2}\left(\partial\phi\right)^2 - V(\phi) + \mathscr{L}_m(\psi_i, \tilde{g}_{\mu,\nu})$$

$$\tilde{g}_{\mu\nu} = A^2(\phi) g_{\mu\nu}$$

$$A(\phi) = 1 + \frac{1}{2}\left(\frac{\phi}{M}\right)^2$$

$$V_{eff} = V_0 - \tfrac{1}{2}\mu^2\phi^2 + \tfrac{1}{4}\lambda\phi^4 - A(\phi)T$$

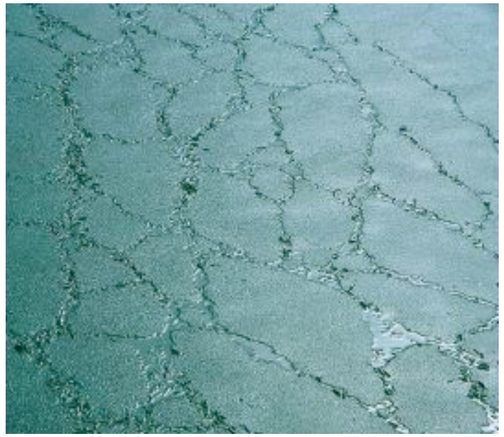
$$\partial^2_\phi V|_{\phi=0} \propto \frac{\rho}{\mu^2 M^2} - 1$$



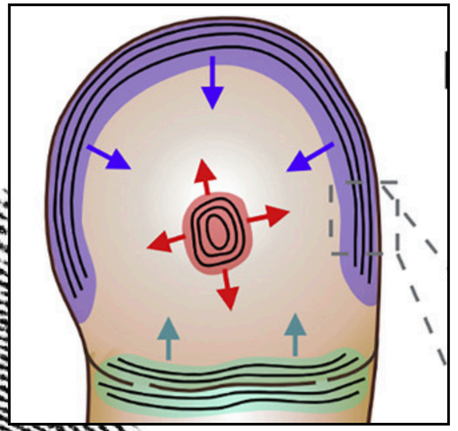
TOPOLOGICAL DEFECTS

IN COSMOLOGY …

- Topological inflation (Vilenkin 1994, Linde&Linde 1994)
- Seeding initial anisotropy (Kibble 1976, Durrer et al. 2001, Hindmarsh 2019)
- Skeleton for structure (Shellard et al. 1987, Naik & Burrage 2022)
- Late-time tensions (Desmond et al. 2019, Perivolaropoulos&Skara 2022)





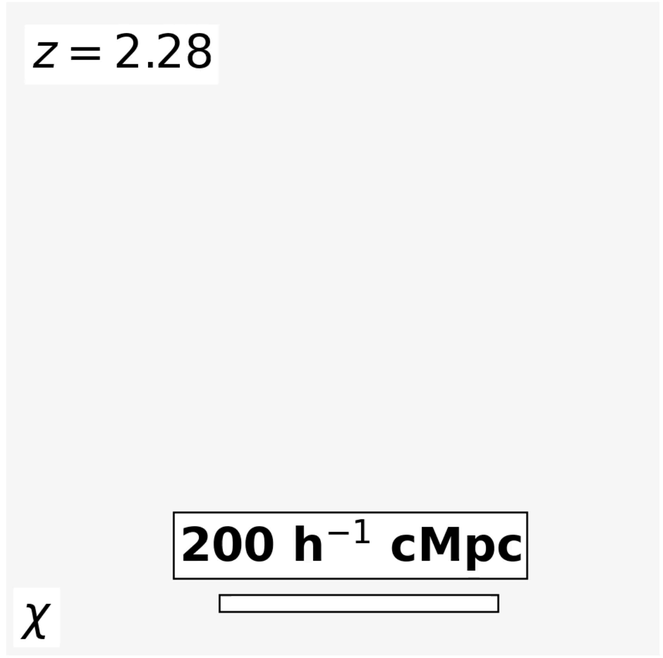


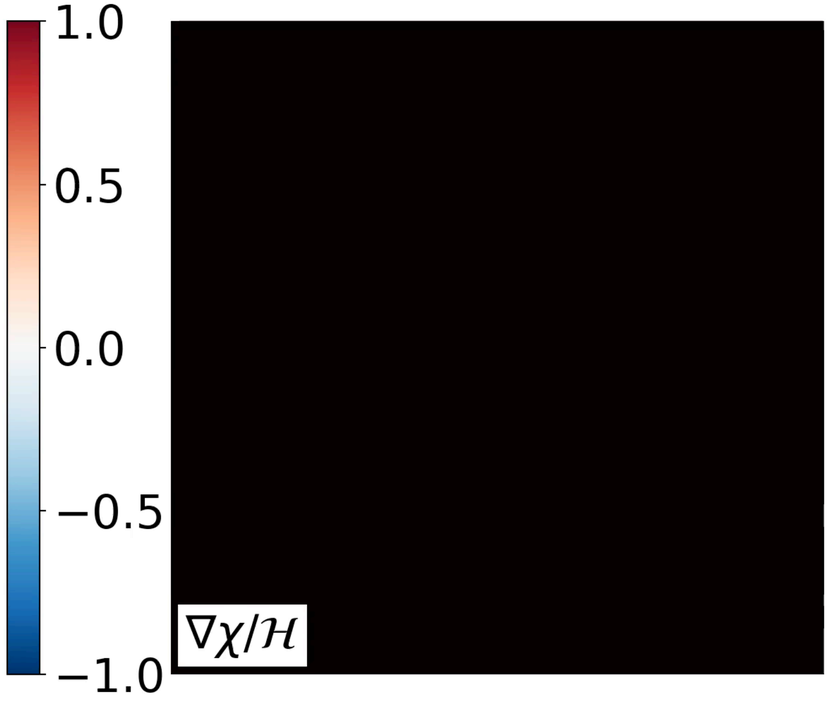


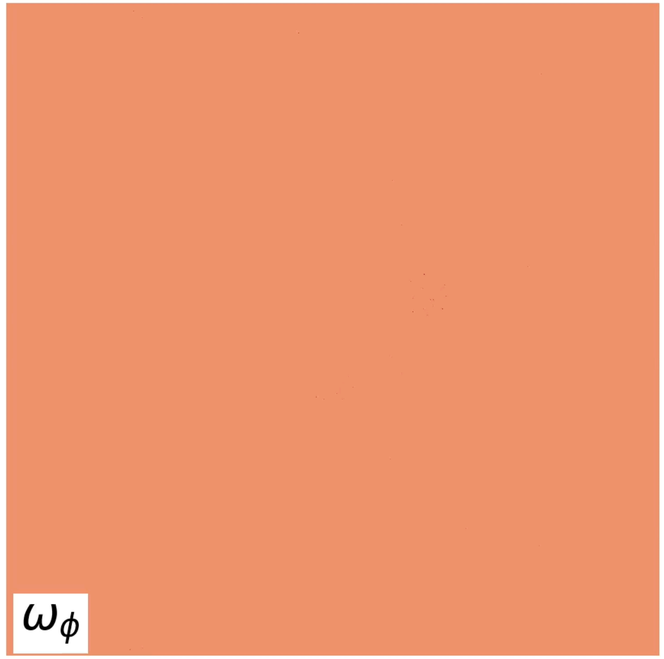
- Finger prints (Glover et al. 2023, Penrose 1979)
- Hydra morphology (Maroudas-Sacks et al. (2020))
- Plate tectonics (Cordier et al. (2014))
- Frustrated magnets and spin liquids
- Growth of bacteria colonies (Basaran et al. (2022))

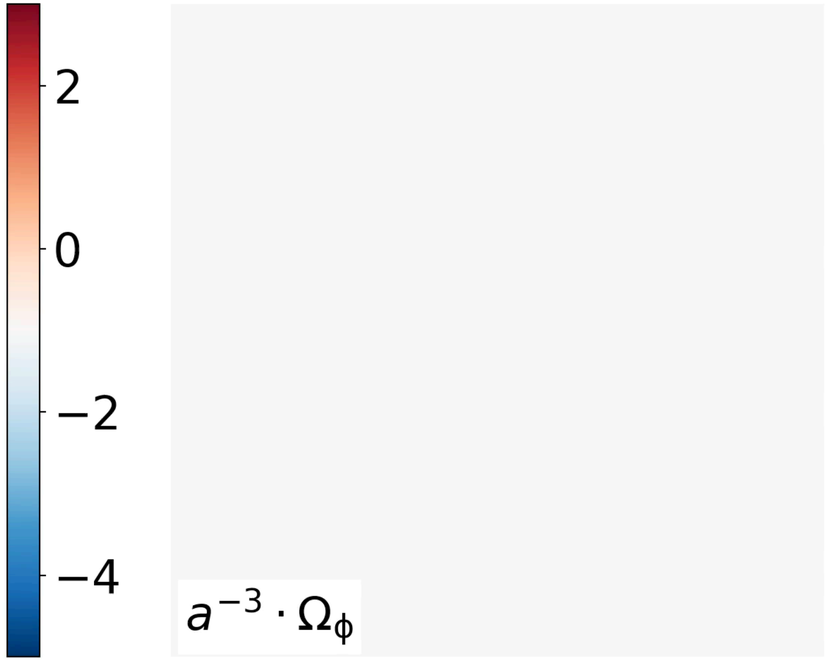
$(L_C, z_*, \beta_*) = (1\,\mathrm{Mpc/h}, 2, 1)$

(Ø.C., Farbod Hassani, David Mota)









Guide:

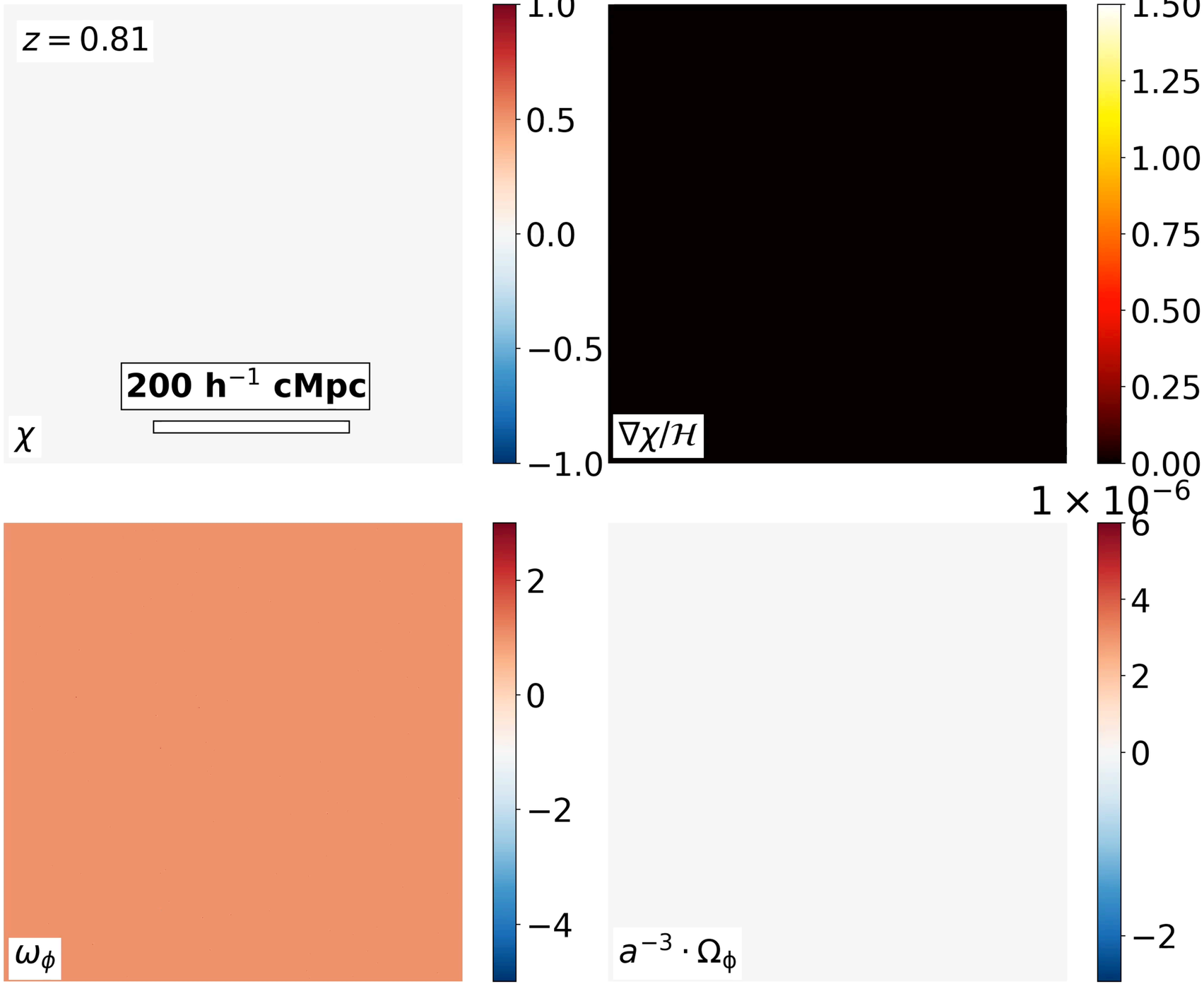
$z = 2 \rightarrow t = 3.3\,\mathrm{Gyr}$

$z = 0 \rightarrow t = 13.8\,\mathrm{Gyr}$

$200\,\mathrm{h}^{-1}\mathrm{cMpc} = 1\,\mathrm{Gly}$

$(L_C, z_*, \beta_*) = (1\,\mathrm{Mpc/h}, 0.1, 8)$

(Ø.C., Farbod Hassani, David Mota)



Guide:

$z = 0.8 \rightarrow t = 6.8\,\mathrm{Gyr}$

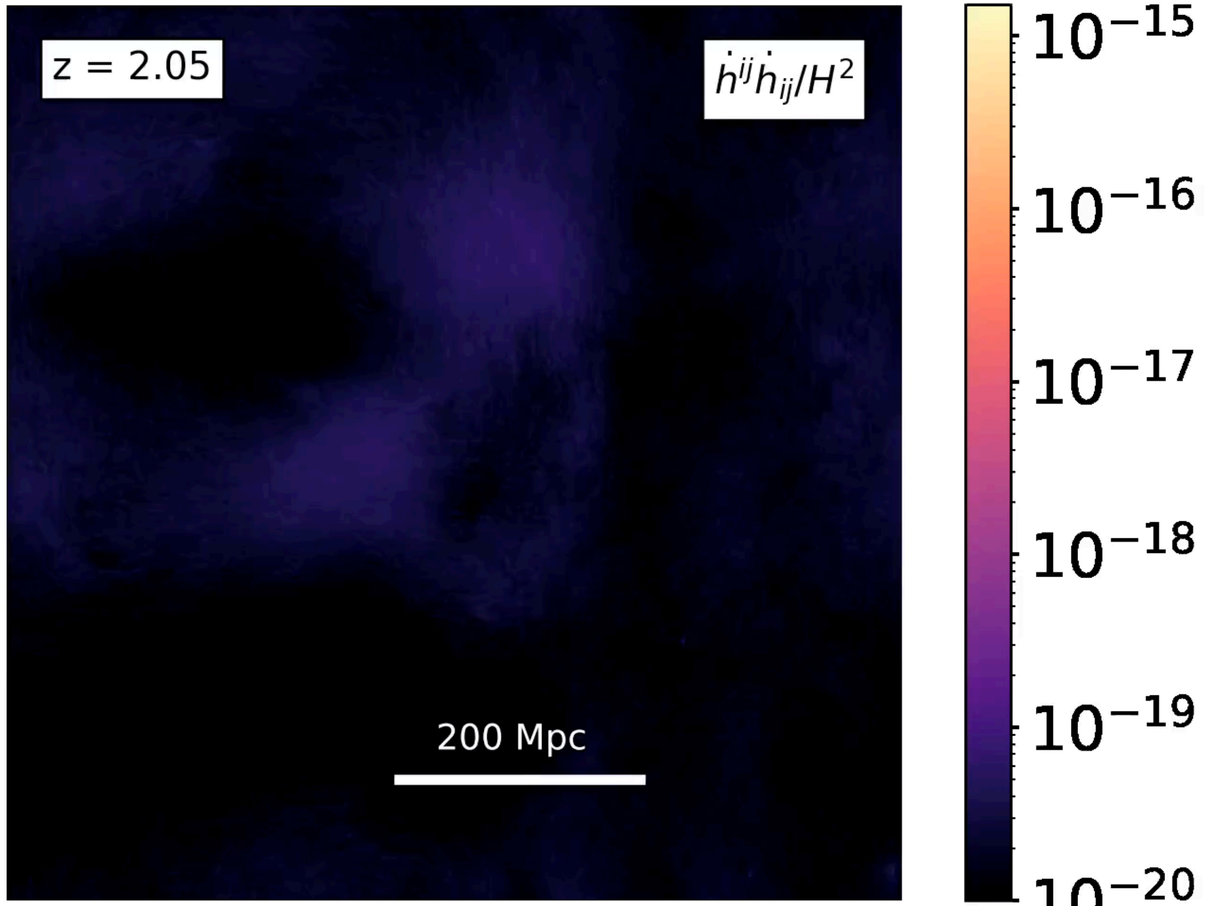
$z = 0.0 \rightarrow t = 13.8\,\mathrm{Gyr}$

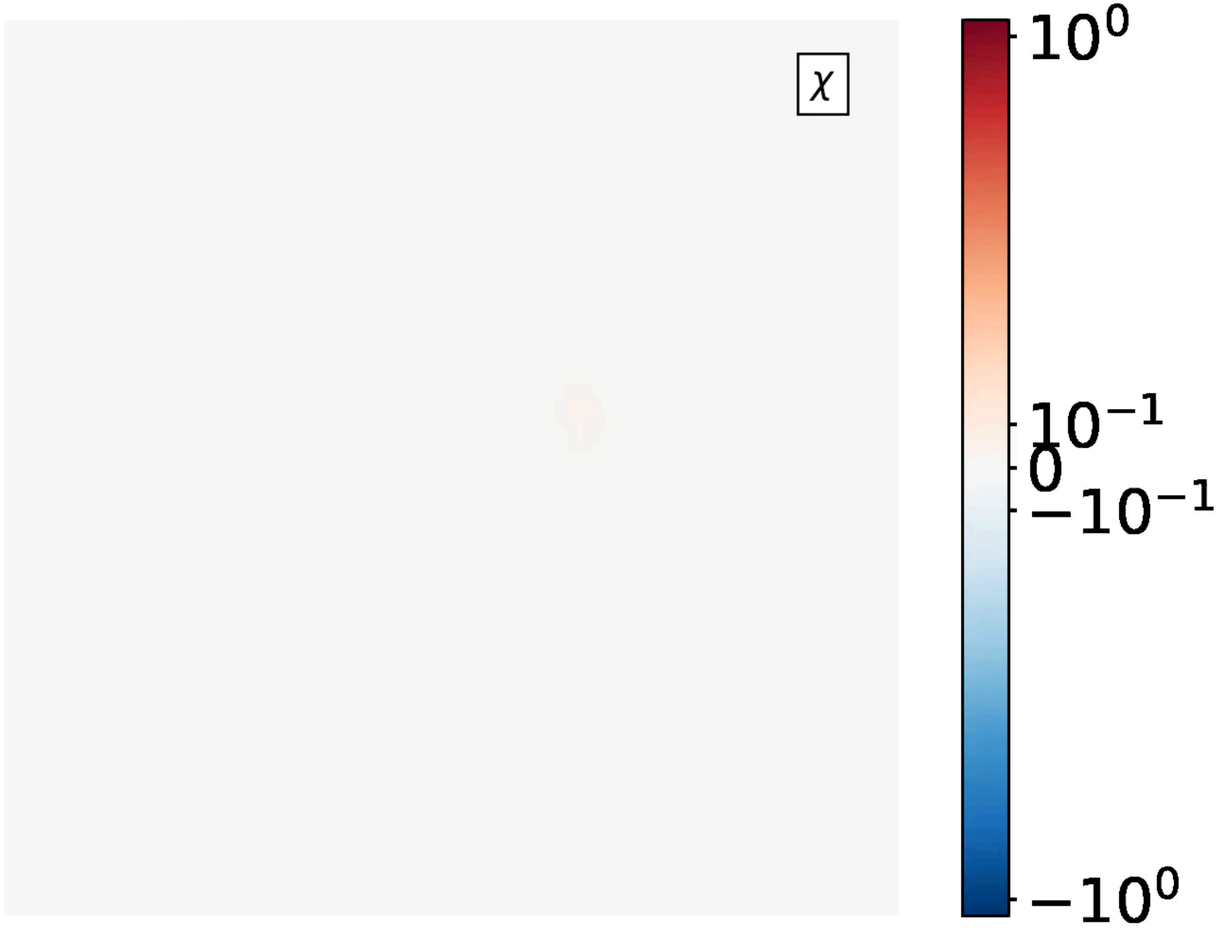
$200\,\mathrm{h}^{-1}\mathrm{cMpc} = 1\,\mathrm{Gly}$

VISUALISATION OF GRAVITATIONAL WAVES

$(L_C, z_*, \beta_*) = (1\,\mathrm{Mpc/h}, 2, 1)$

(Ø.C., Julian Adamek, Farbod Hassani, David Mota)

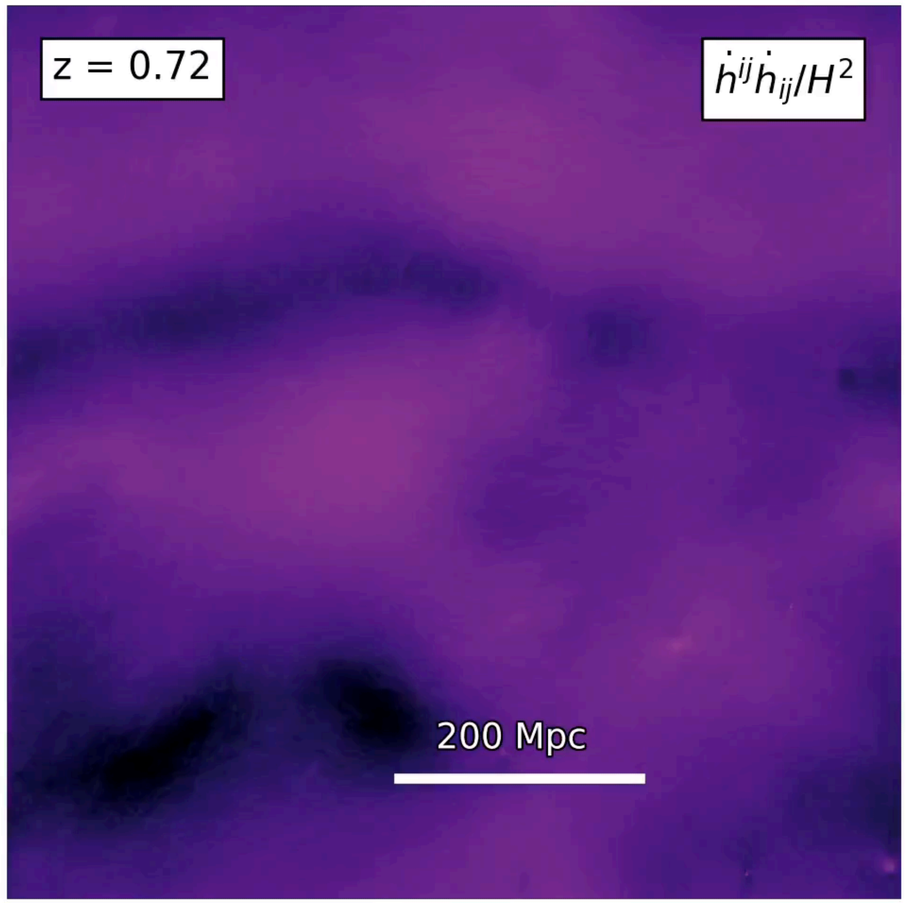


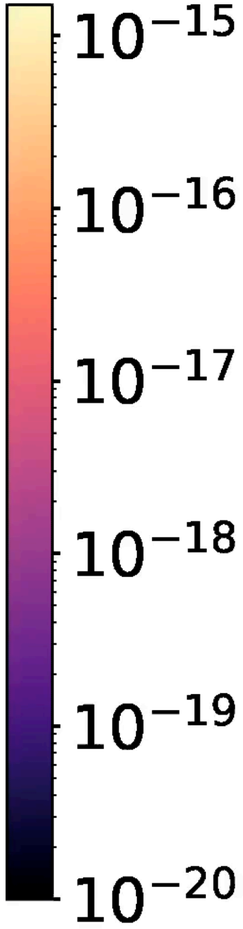


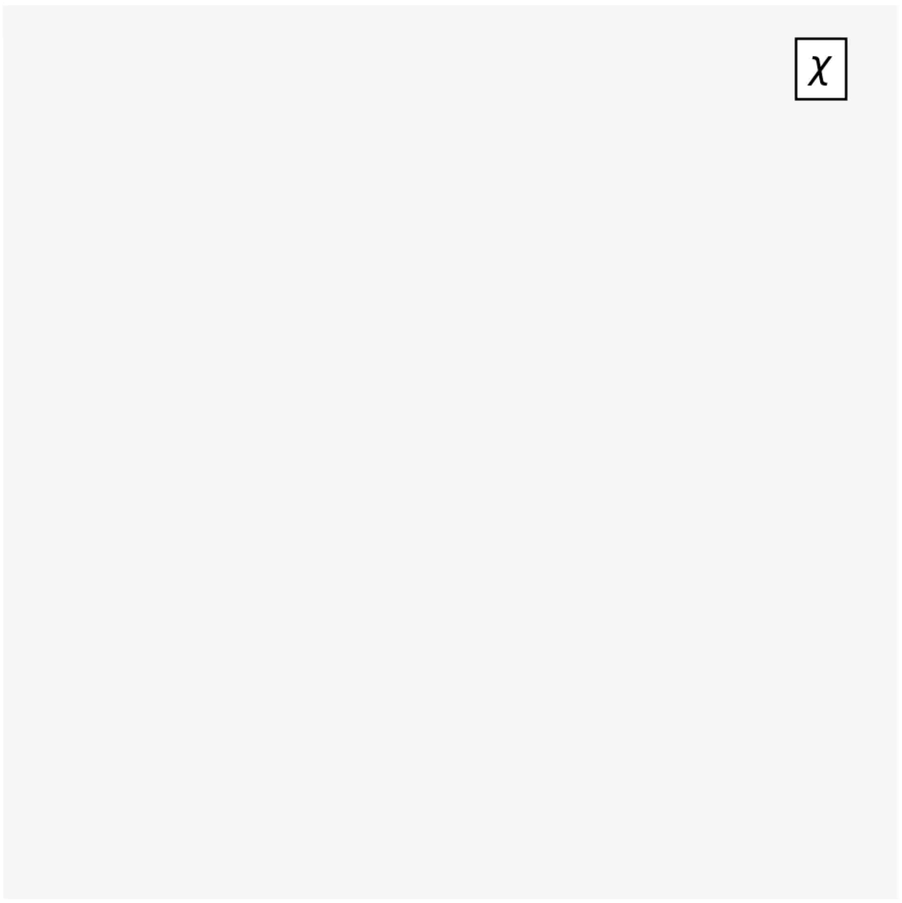
VISUALISATION OF GRAVITATIONAL WAVES

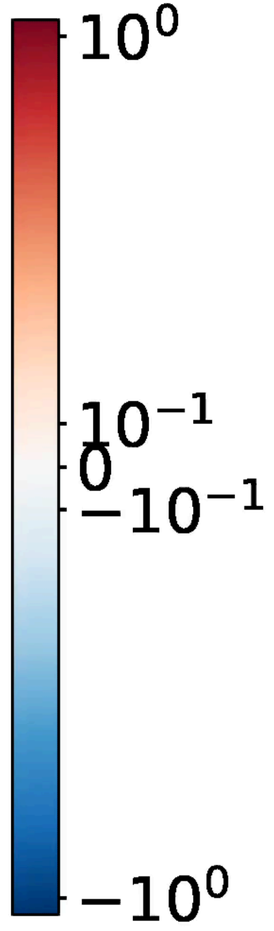
$(L_C, z_*, \bar{\beta}, \Delta\beta/\bar{\beta}) = (1\,\mathrm{Mpc/h}, 0.1, 8, 10\%)$

(Ø.C., Julian Adamek, Farbod Hassani, David Mota)



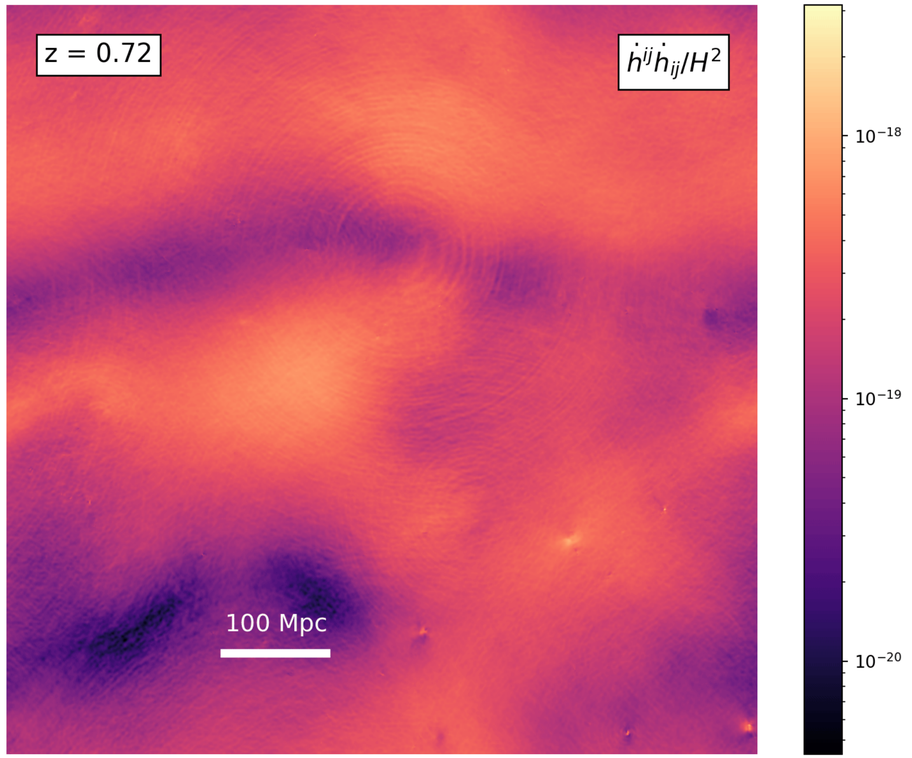


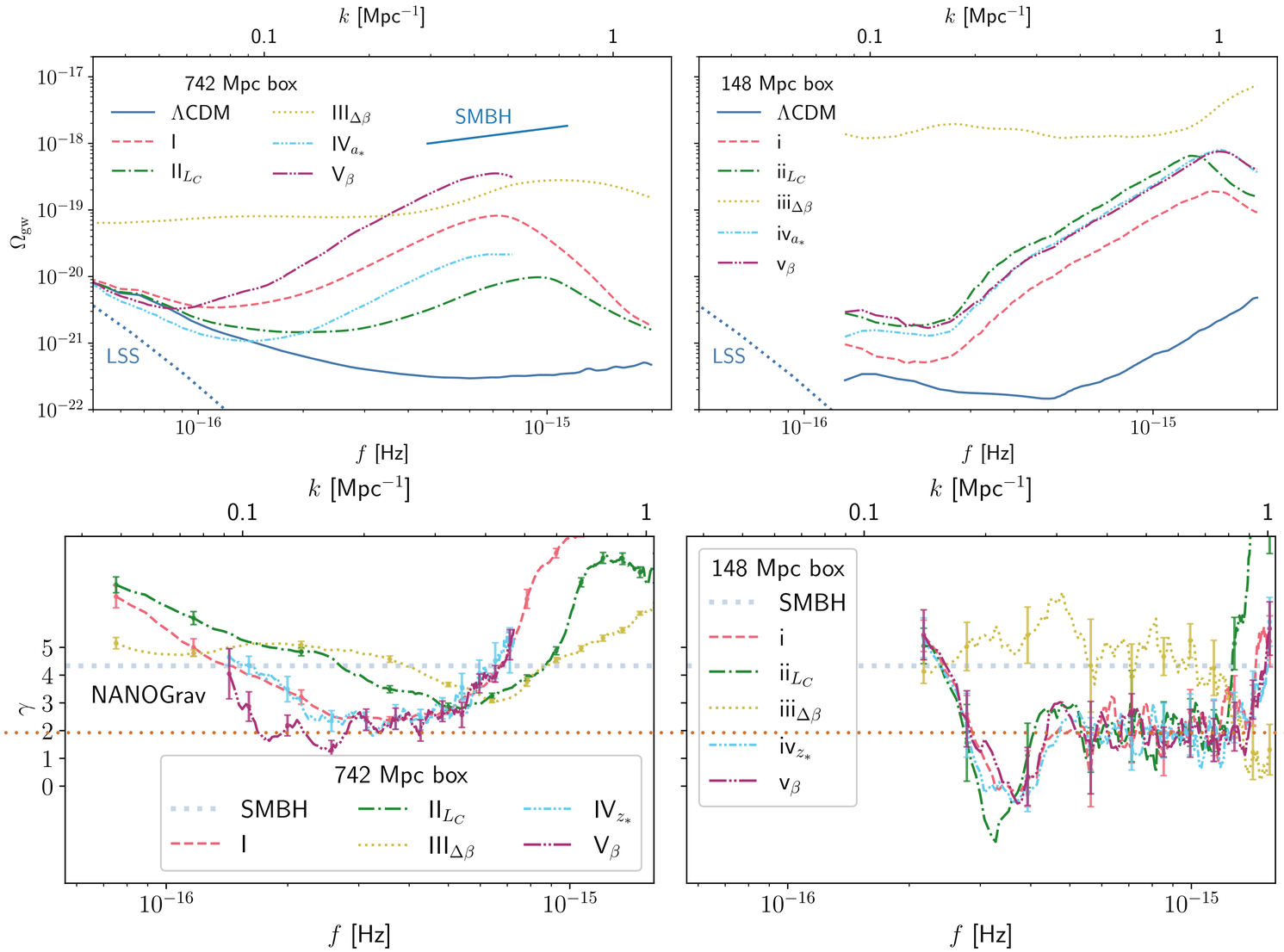




Simulations of stochastic gravitational waves

- First late-time simulation of cosmological sources
- Prospects for further investigations





$$\tilde{h}_{ij}'' + 2\mathscr{H}\tilde{h}_{ij}' + c^2k^2\tilde{h}_{ij} = \frac{16\pi G}{c^2}\left(P_i^l P_j^m - \frac{1}{2}P_{ij}P^{lm}\right)\tilde{T}_{lm}$$

(Standard case: $\gamma_{\rm DW} \sim 2$)

(Ø.C., Julian Adamek, Farbod Hassani, David Mota)

THANK YOU

Papers:

arxiv:2405.00668

arXiv:2401.02410

arXiv:2401.02409

arxiv:2302.07857

animations and more:

https://oyvindchristiansen.com/projects/symmetron_resolve

https://oyvindchristiansen.com/projects/symmetron_GWs