Isobaric reconstruction of BAO from simulated Galaxy & 21cm intensity mapping merged filed

A presentation for Galaxy Evo. Group meeting, SYSU

Narrator: Tian-cheng Luan

2023.12.14

A pdf version of this prep can be download here:

Outline

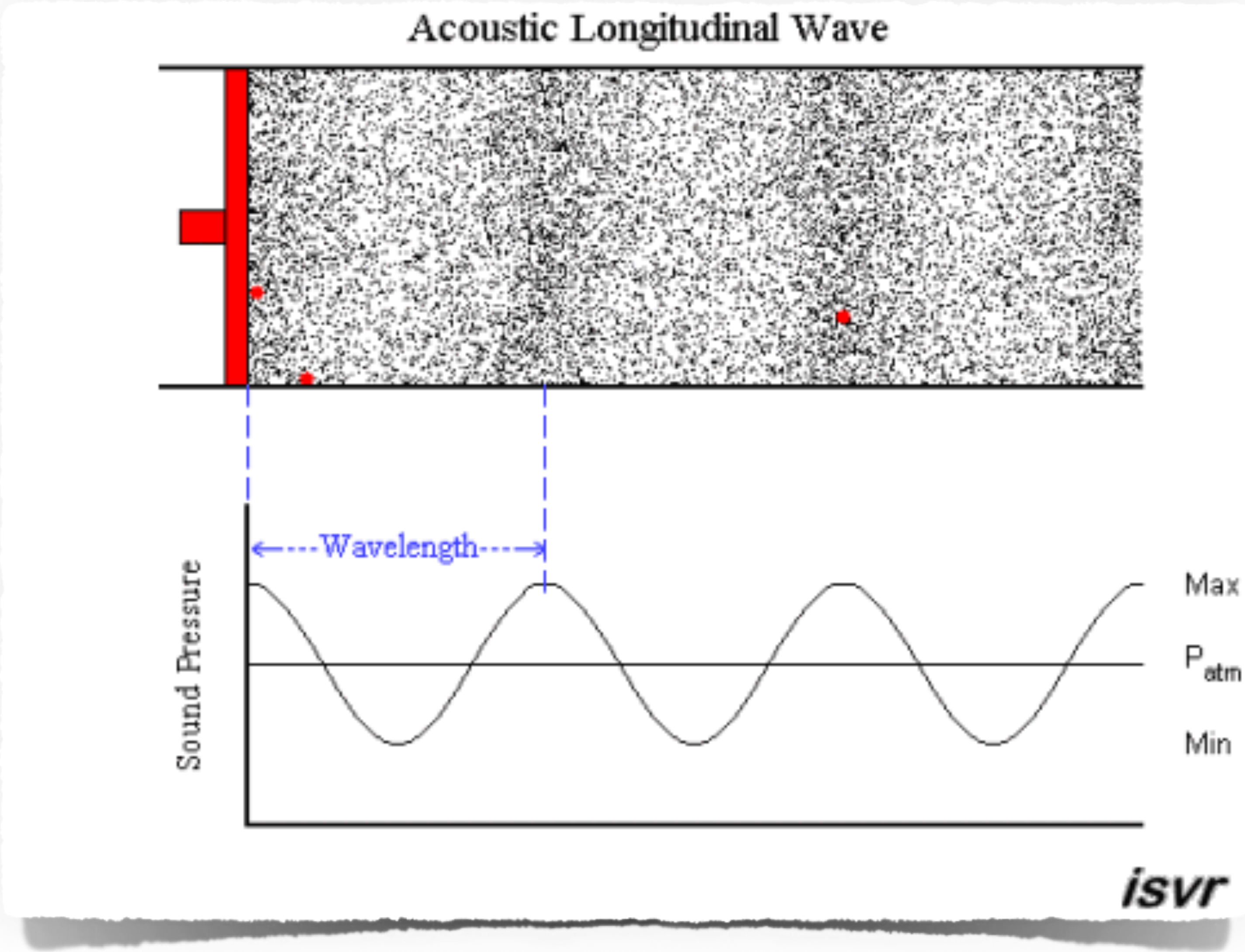
- So what is BAO?
- Why reconstruction?
- Why use HI & Galaxy?

A pdf version of this prep
can be download here:

What is Baryon Acoustic Oscillations(BAO)

The propagation of a typical sound wave:

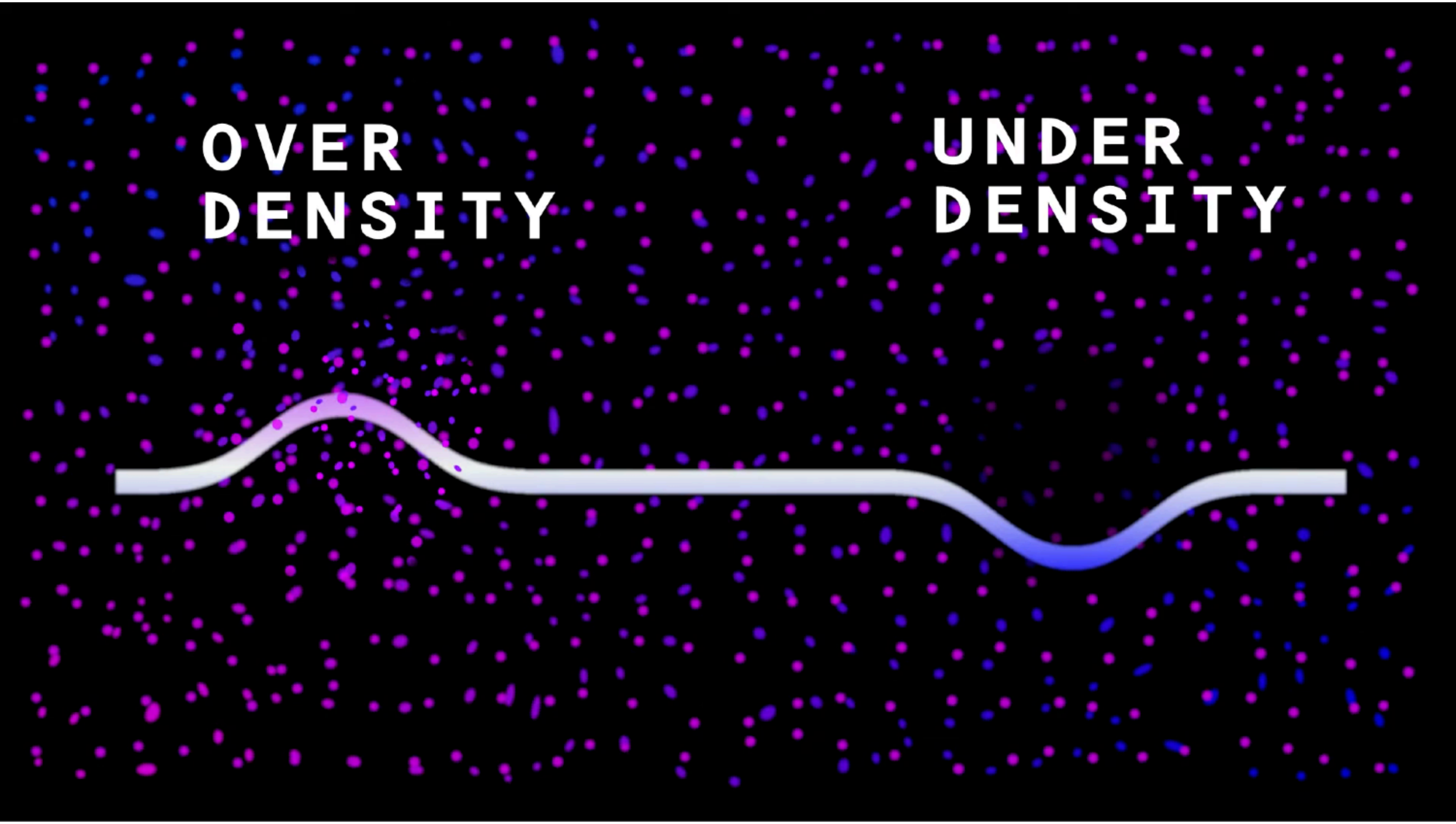
Pressure !



Credit: Online

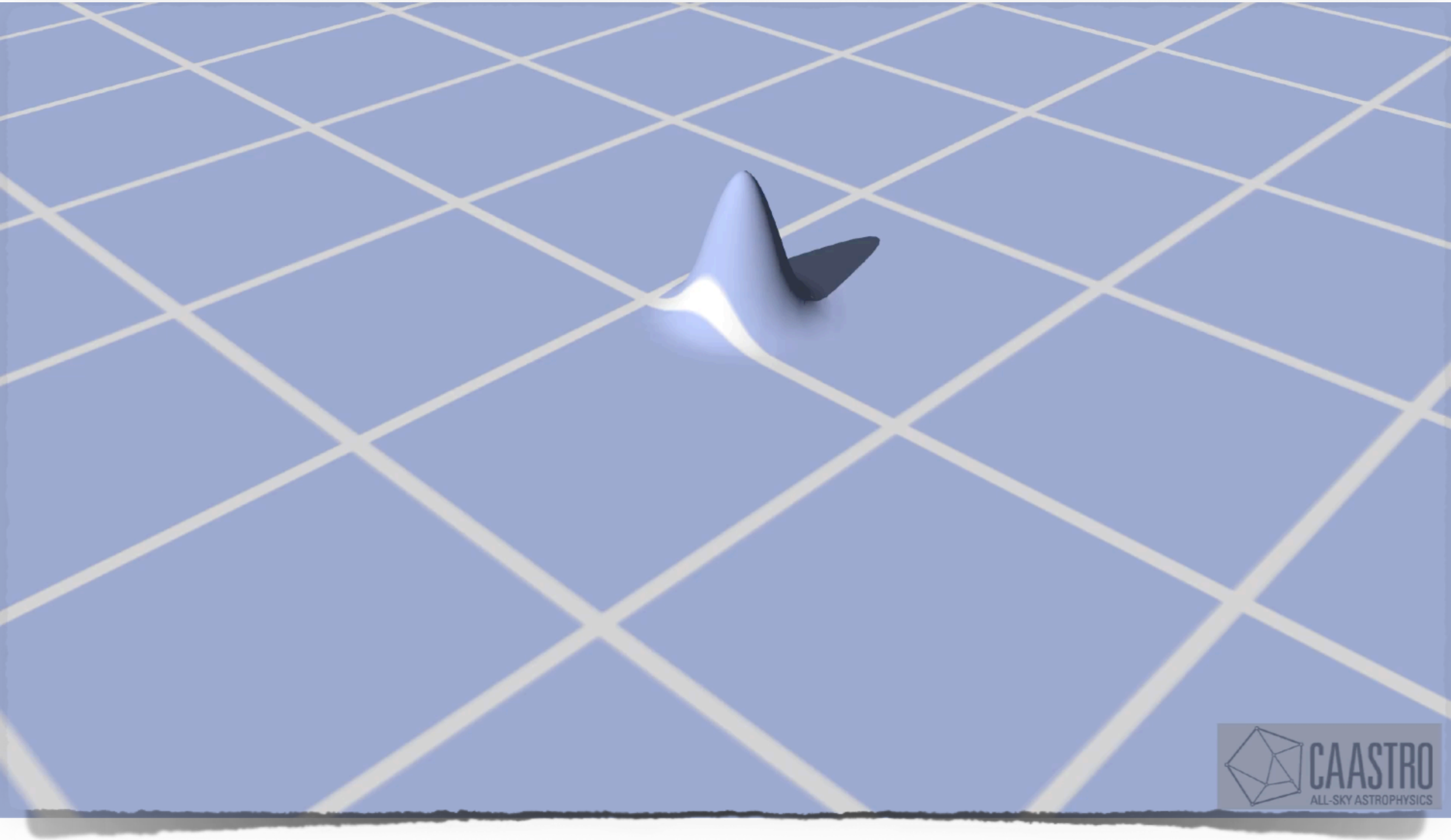
What is Baryon Acoustic Oscillations(BAO)

Pressure vs Gravity



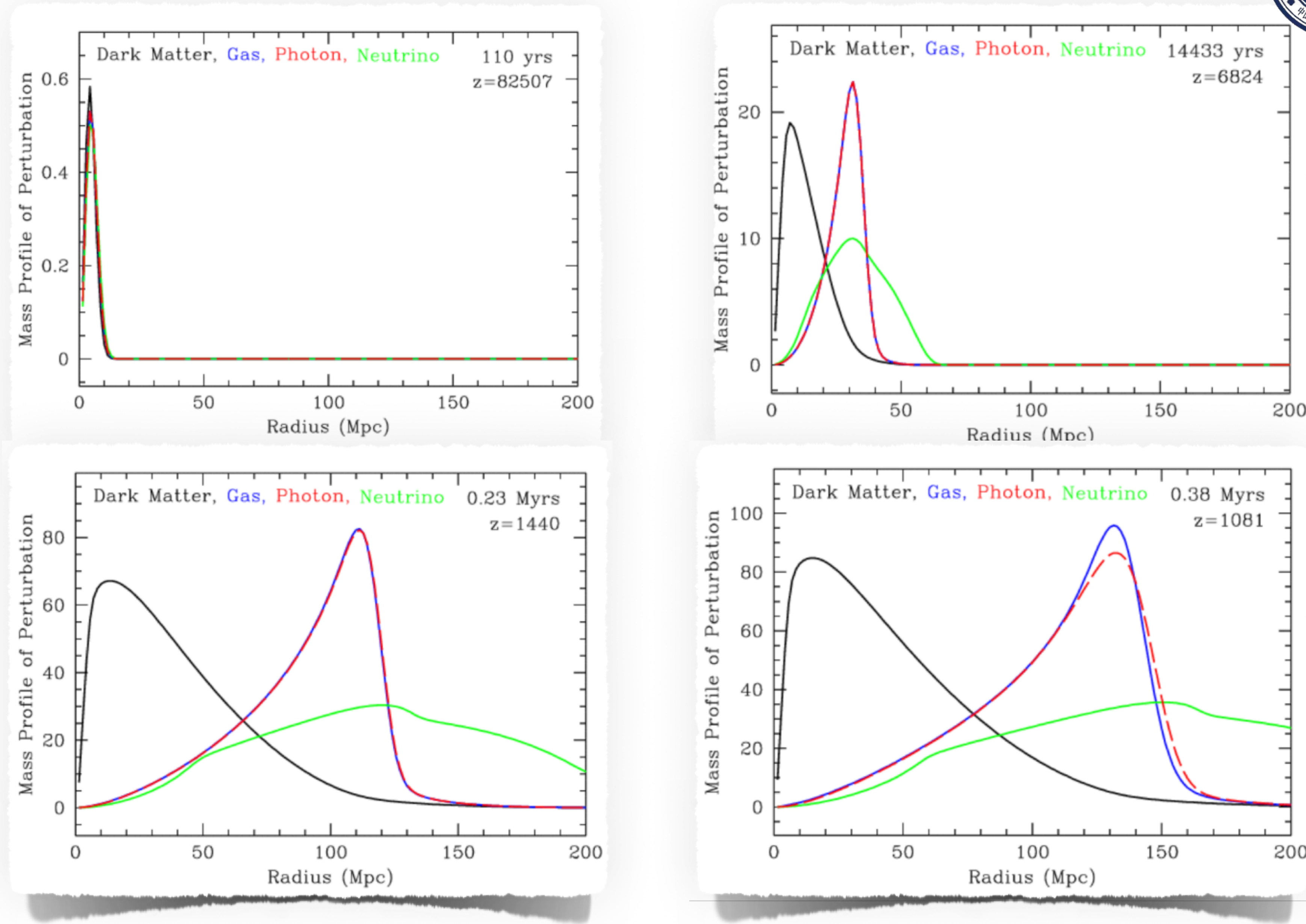
Video: https://www.youtube.com/watch?v=d-_pDO9jsjk

What is Baryon Acoustic Oscillations(BAO)



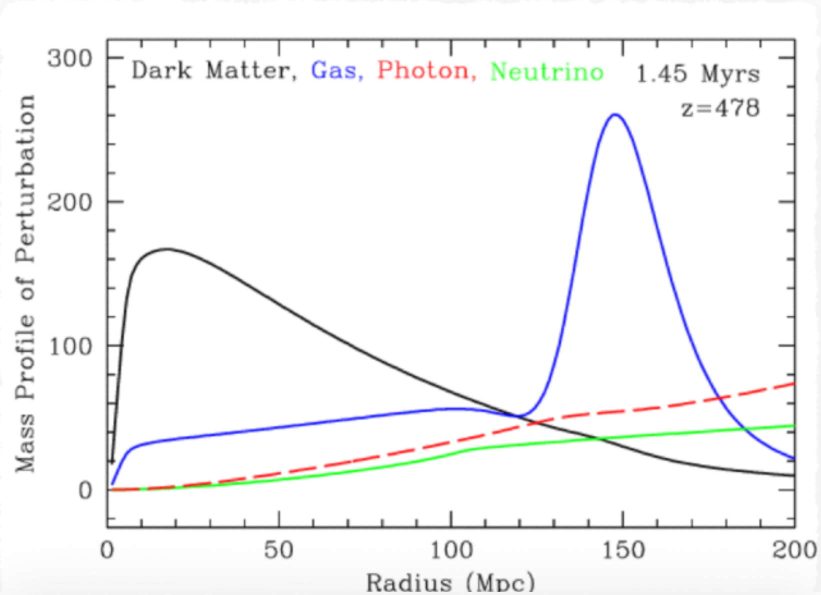
Video: https://www.youtube.com/watch?v=jpXuYc-wzk4

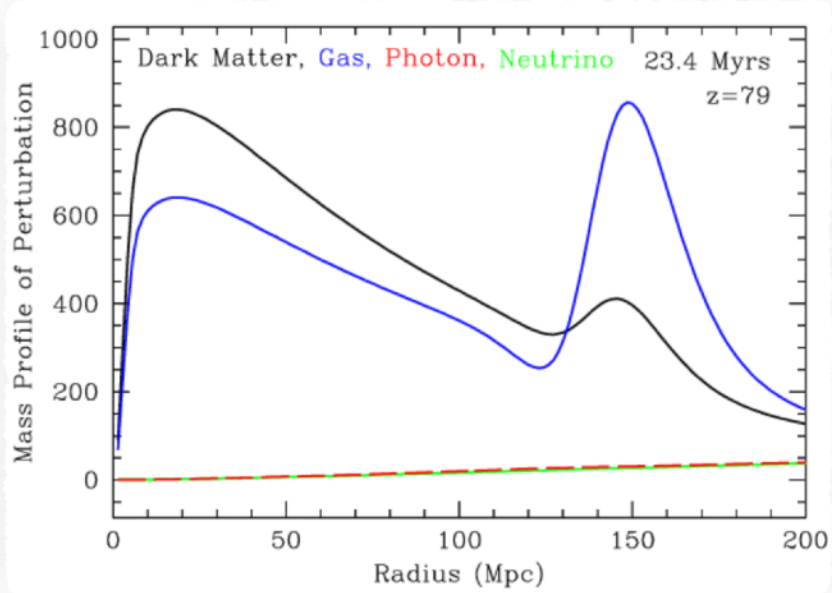
What is Baryon Acoustic Oscillations(BAO)

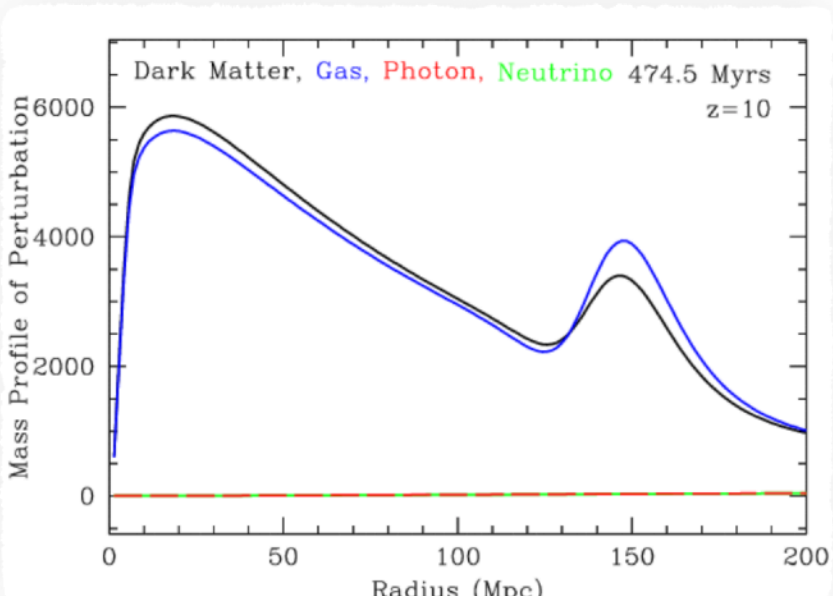


Credit: Daniel Eisenstein

What is Baryon Acoustic Oscillations(BAO)

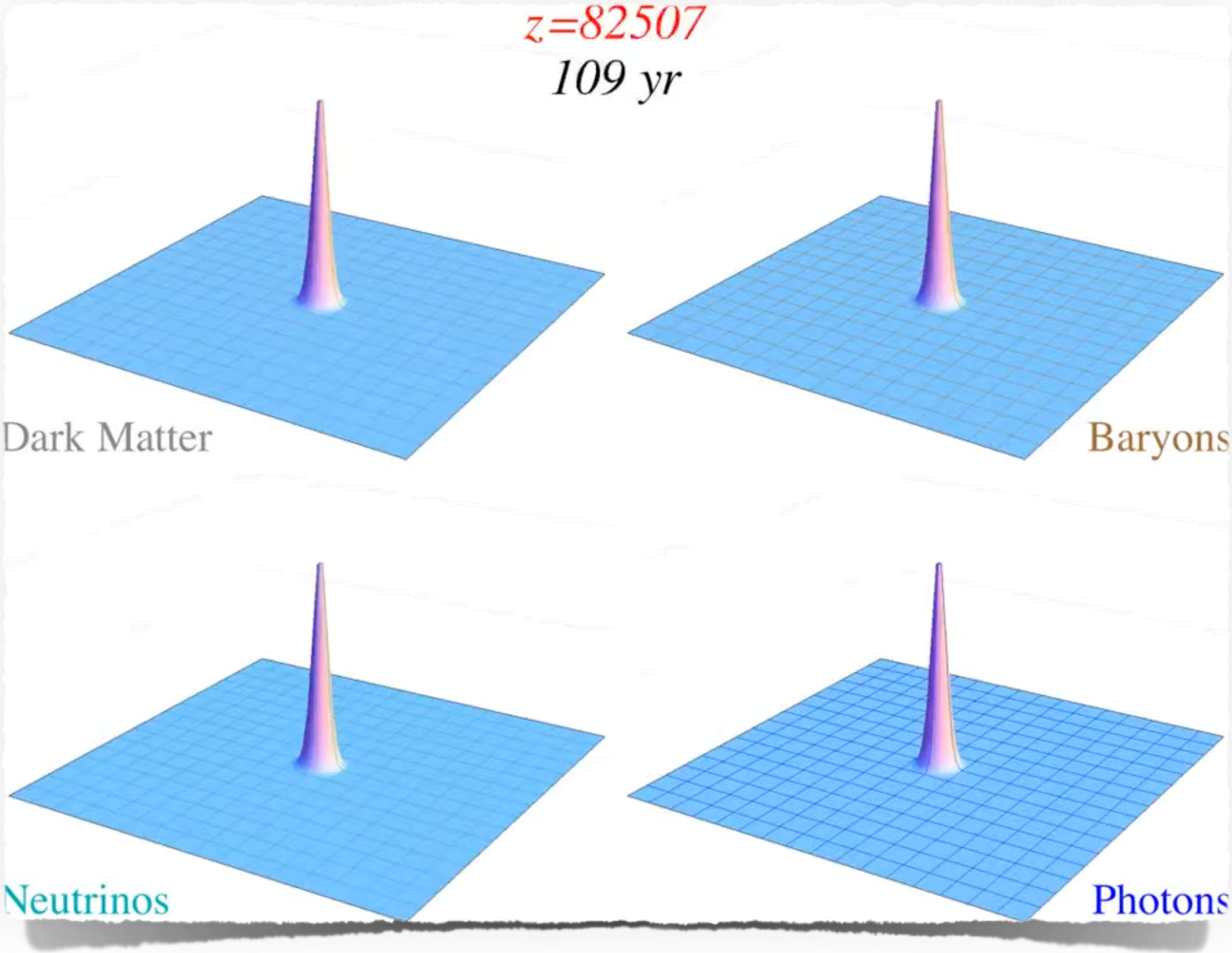






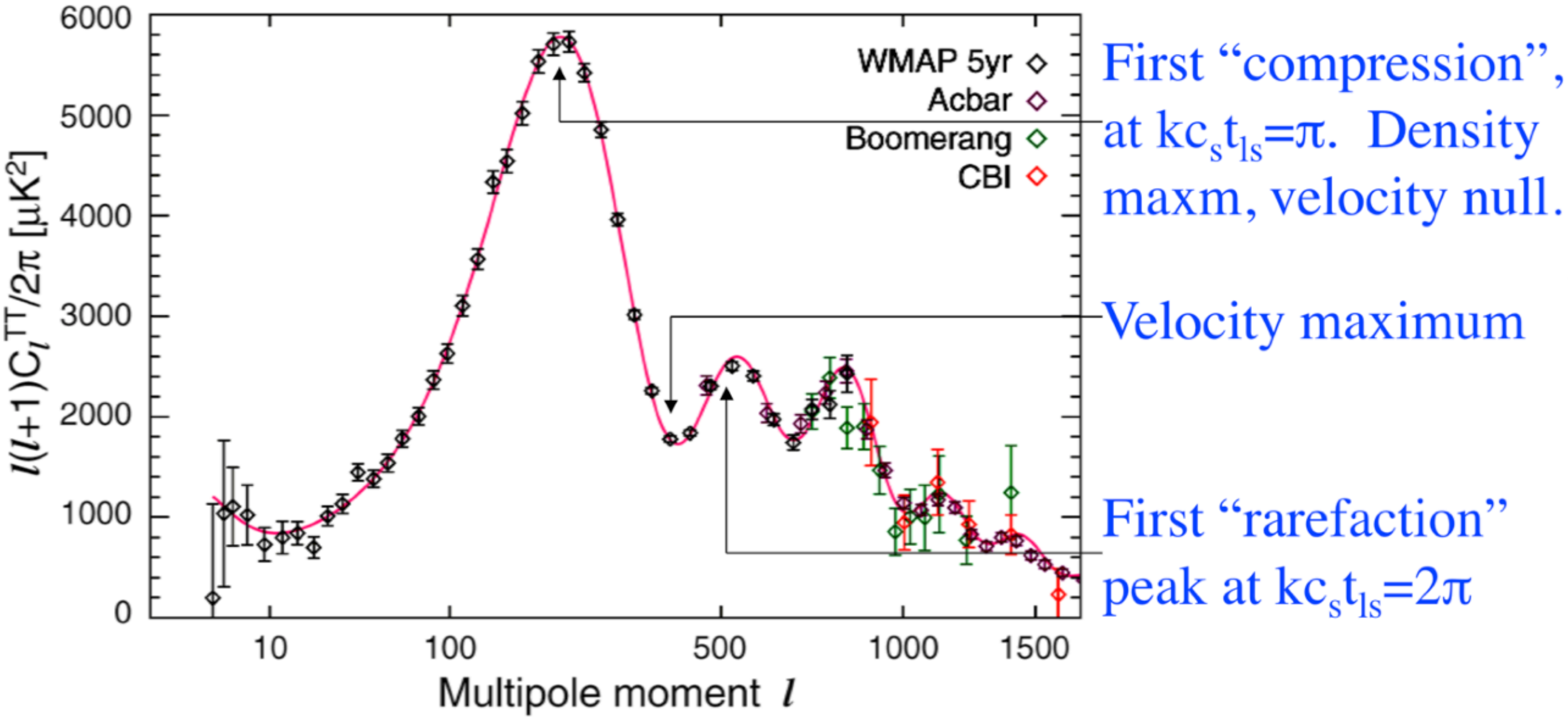
Credit: Daniel Eisenstein

What is Baryon Acoustic Oscillations(BAO)



Video: https://www.youtube.com/watch?v=GPiQVRS8kCg

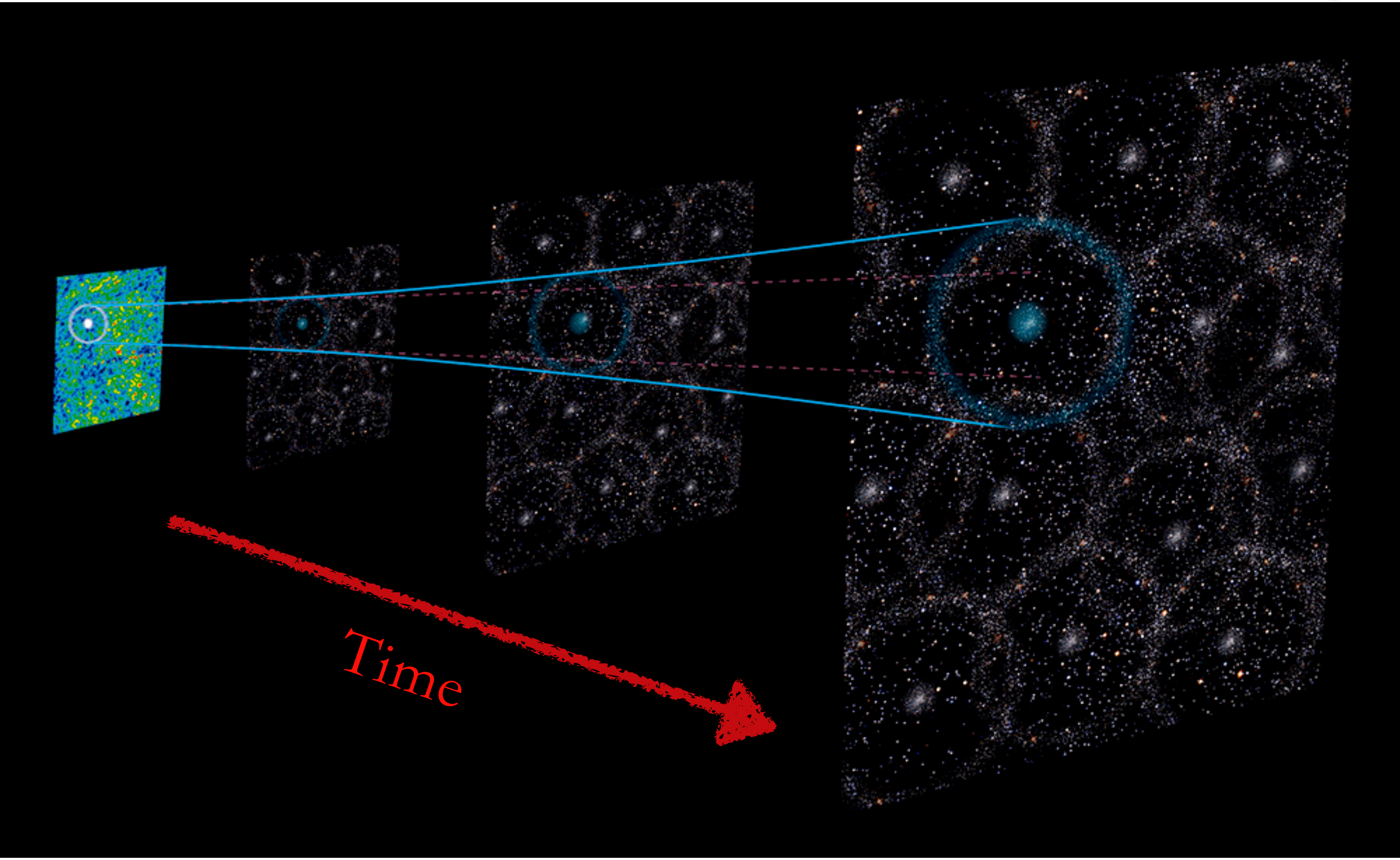
BAO & CMB



Acoustic scale is set by the *sound horizon* at last scattering: $s = c_s t_{ls}$

Credit: White Martin

BAO: Stand ruler to constrain DE



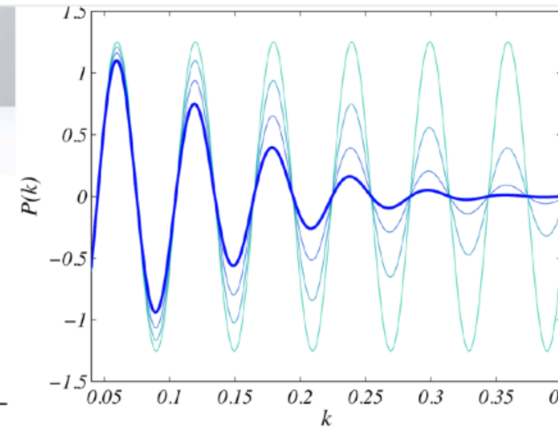
Credit: Gabriela Secara, Perimeter Institute

Why we need reconstruction?

A pdf version of this prep
can be download here:

Why reconstruction

Baryonic Acoustic Oscillation



- Nonlinear coordinate transform:

$$\det\left(\frac{\partial x_i}{\partial q_j}\right) = \det\left(\delta_{ij} + \partial_i \Psi_j\right) = \frac{\bar{\rho}}{\rho} = \frac{1}{1+\delta_\rho}$$

- or $$1 + \delta_m(\mathbf{x}) = \int d^3\mathbf{q}[1 + \delta_0(\mathbf{q})]\delta_D(\mathbf{x} - \mathbf{q} - \mathbf{\Psi}(\mathbf{q})).$$

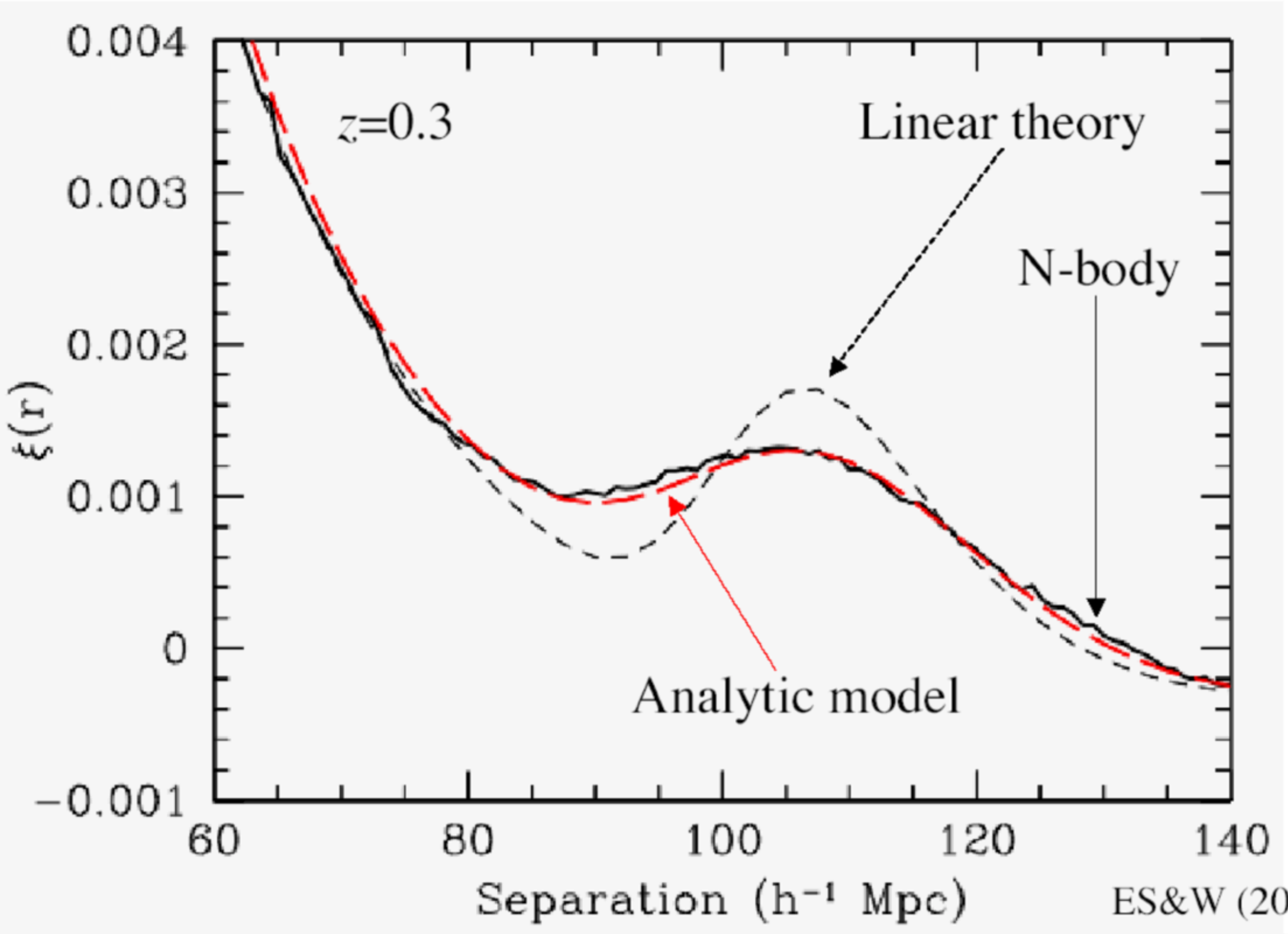
- in Fourier space $$\delta(\mathbf{k}) \equiv \int \frac{d^3x}{(2\pi)^3}\delta(\mathbf{x})e^{i\mathbf{k}\cdot\mathbf{x}} = \int \frac{d^3q}{(2\pi)^3}e^{i\mathbf{k}\cdot\mathbf{q}}[e^{i\mathbf{k}\cdot\Psi(\mathbf{q})} - 1],$$

- Power spectrum $$P_{\rm nl}(k) = \int \frac{d^3r}{(2\pi)^3}e^{i\mathbf{k}\cdot\mathbf{r}}\left[\langle e^{i\mathbf{k}\cdot\Delta\mathbf{\Psi}}\rangle - 1\right] = G^2(k)P_{\rm ini}(k) + P_{\rm mc}(k),$$

$$\mathrm{Wig}(k) = \frac{P_{\rm nl}(k)}{P_{\rm sm}(k)} - 1 \approx \exp(-k^2\sigma_v^2)\ \mathrm{Wig}_{\rm ini}(k)$$

Why reconstruction

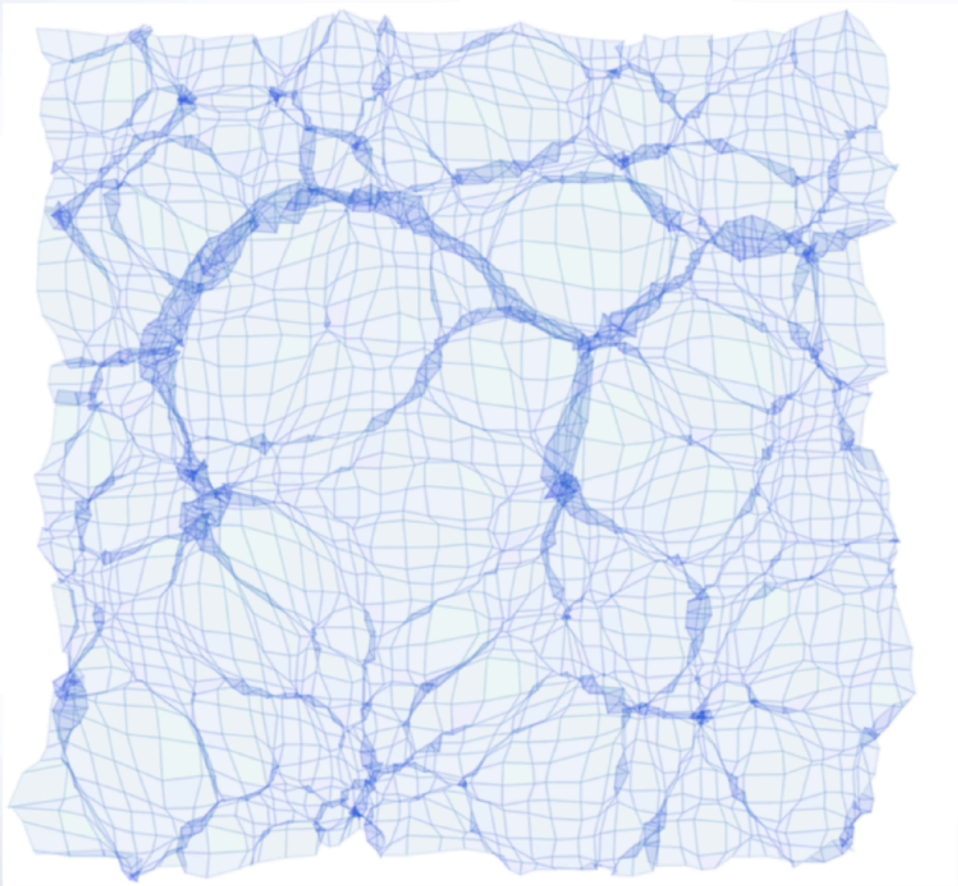
Non-linearities



ES&W (2007)

Why reconstruction

Large-scale Structure & Origami



A dark-matter sheet distorted and folded according to the Zel'dovich approximation. The darkness of the color at each position gives the number of streams there.

Why reconstruction

Reconstruction

- Take differentiation of the coordinate transform (local)

$$d_\tau \left[\rho\left(\boldsymbol{x}\left(\mathbf{q}\right)\right)\det\left(\frac{\partial x_i}{\partial q_j}\right)\left(\mathbf{q}\right)\right] = 0$$

- —> continuity equation (curvilinear coordinate)

$$\partial_\mu\left(\rho\sqrt{g}e_i^\mu\delta^{i\nu}\partial_\nu\left(d_\tau\phi\right)\right) = \partial_\mu\left(\rho\sqrt{g}e_i^\mu\left(d_\tau x^i\right)\right) = d_\tau\rho$$

- iterative solution

$$\boxed{\phi^{rec}(\boldsymbol{\xi})} = \sum_i^{iters} d\phi^{(i)}\left(\boldsymbol{\xi}\right.$$

$$P_{\rm nl}(k) = \int \frac{d^3r}{(2\pi)^3} e^{i\mathbf{k}\cdot\mathbf{r}}\left[\langle e^{i\mathbf{k}\cdot\Delta\boldsymbol{\Psi}}\rangle - 1\right]$$

- multi-grid, moving mesh PDE solver

Zhu et al. (2017), Yu et al. (2017), Pan et al. (2017), *XW et al. (2017, 2019)*

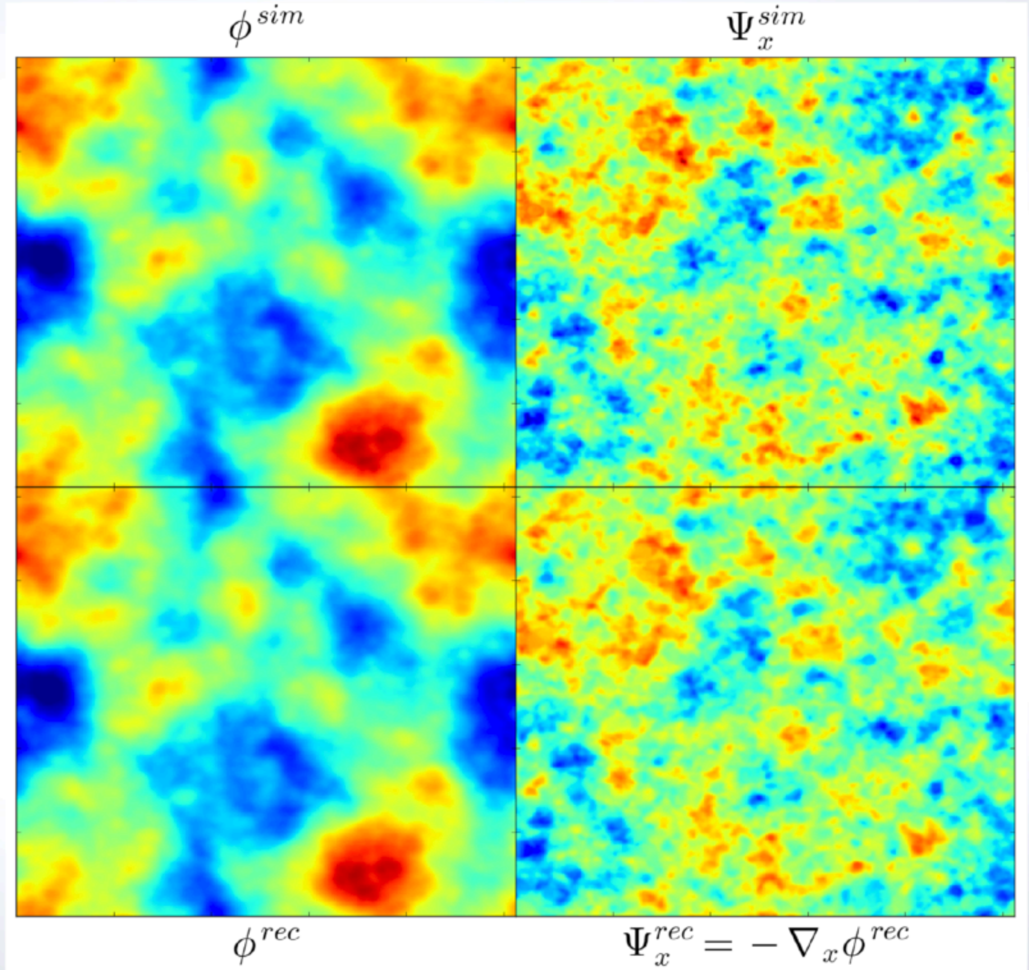
Inheriting from Prof. Wang’s Presentation

Why reconstruction

Solving the Displacement

Simulation

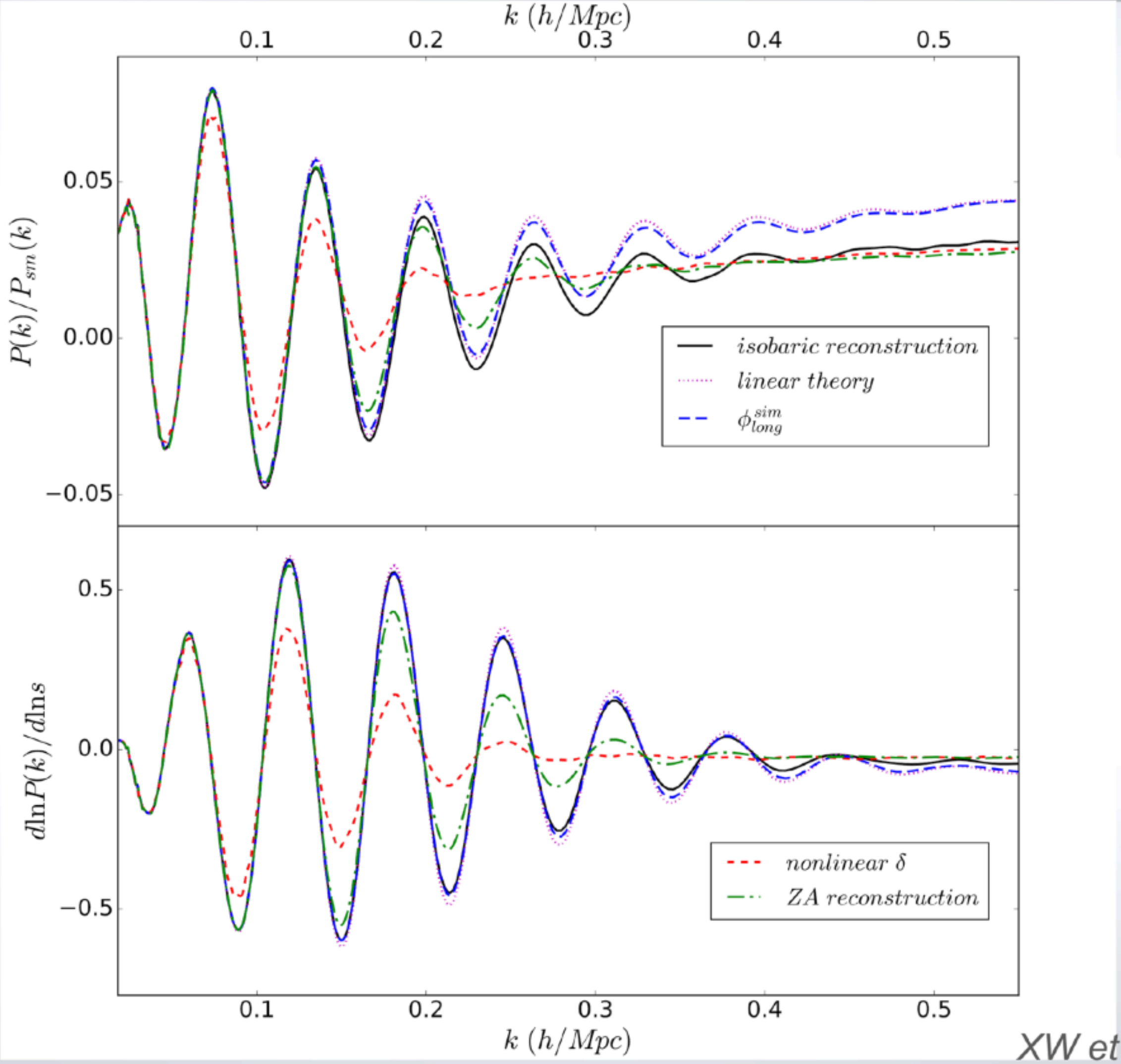
Reconstruction



XW et al. (2017)

Why reconstruction

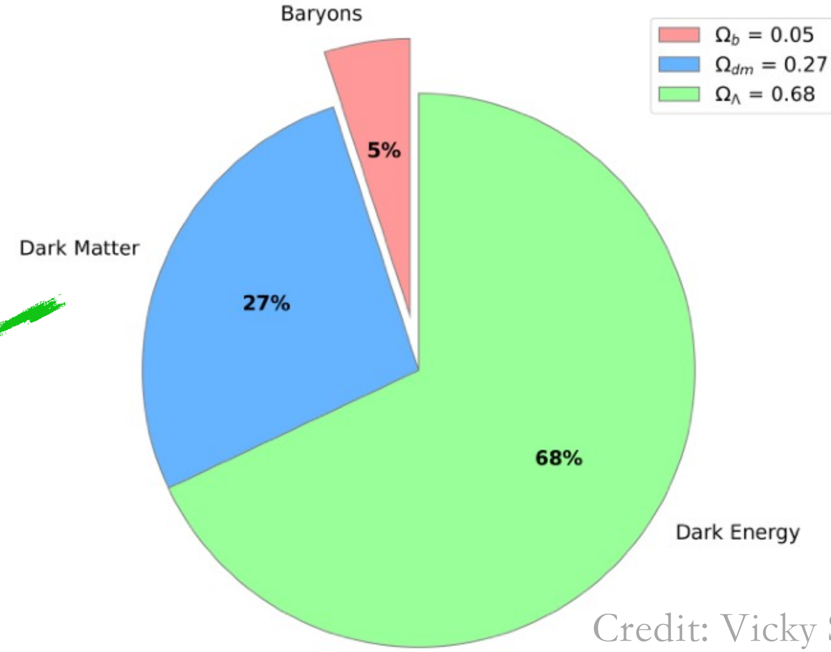
Reconstruction



XW et al. (2017)

So, why HI and Galaxy?

Why use HI & Galaxy?

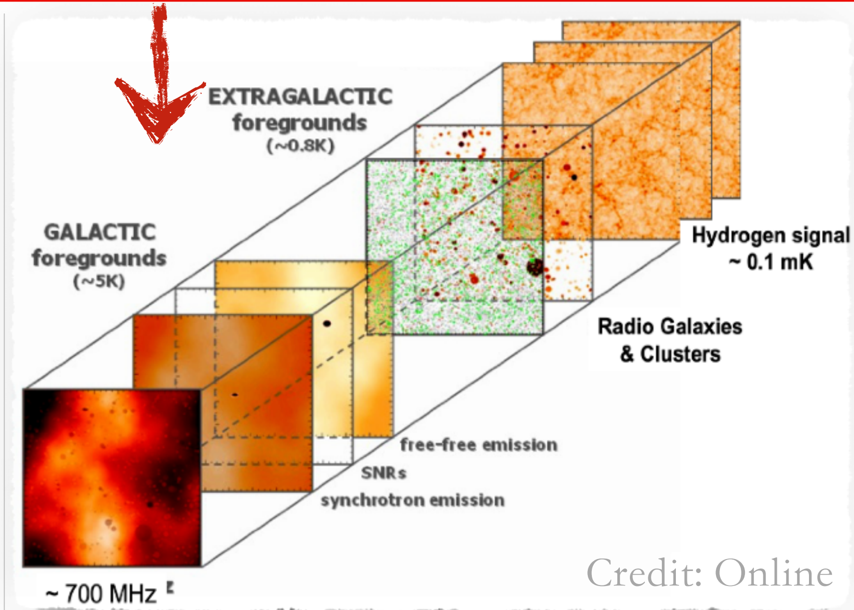


Credit: Vicky Scowcroft

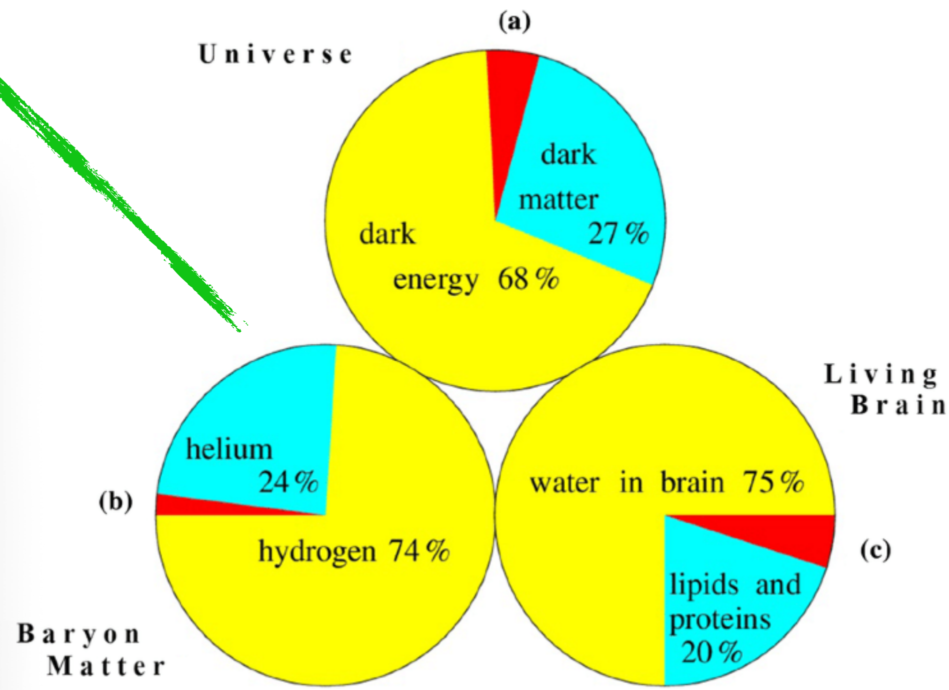
- Abundance of HI

but……

- Foreground contamination



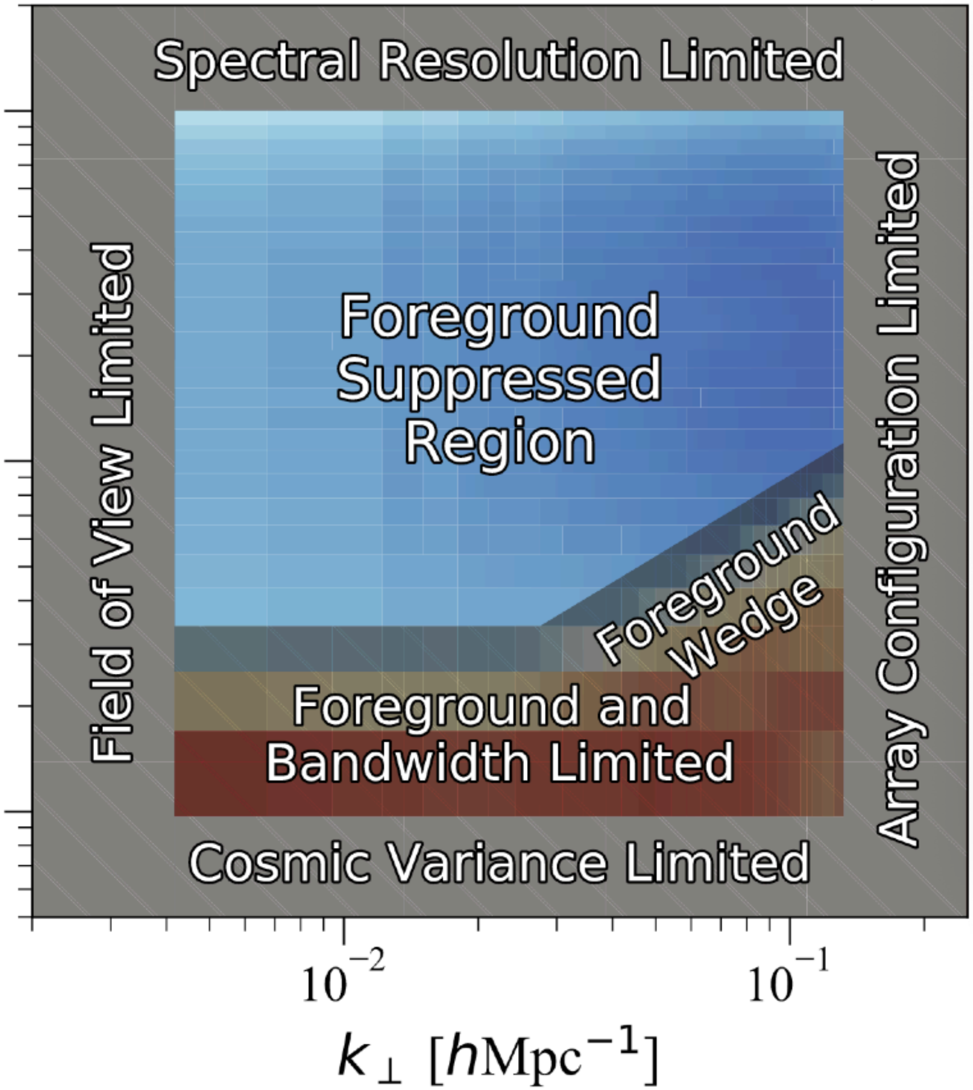
Credit: Online

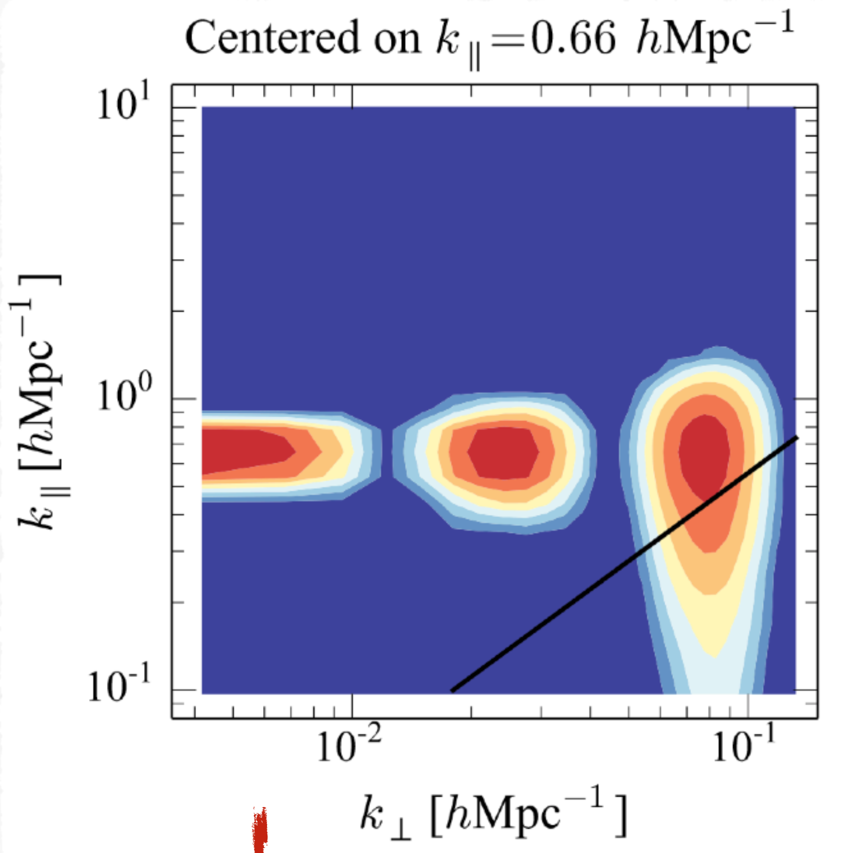


Credit: Valeriy Sbitnev

HI foreground: Mode mixing of the interferometer (foreground wedge)

DOI: 10.1088/1538-3873/ab5bfd

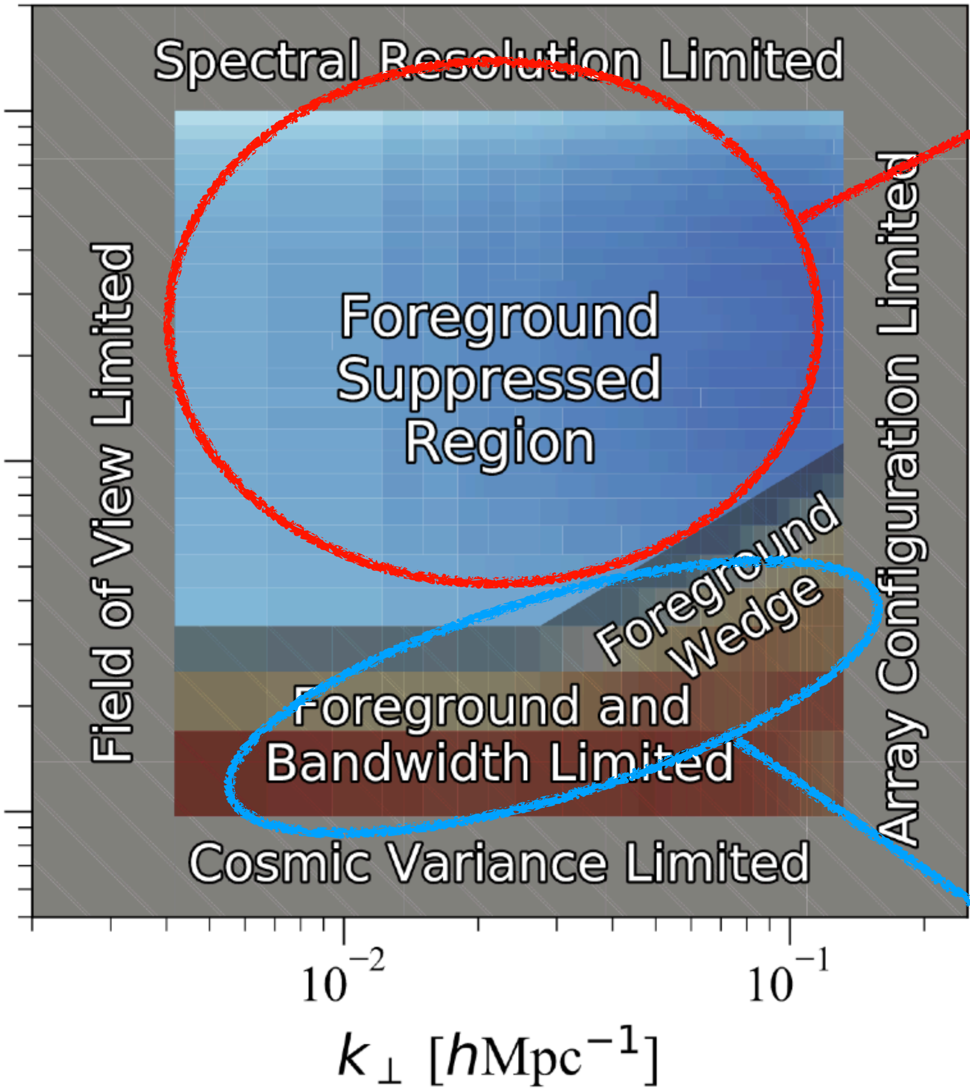




$$k_\parallel = k_\perp \frac{H_0 D_c E(z)\theta_0}{c(1+z)}$$

The $k_\parallel$ at higher $k_\perp$ will be mixed with lower value by window function

HI foreground: Mode mixing of the interferometer (foreground wedge)



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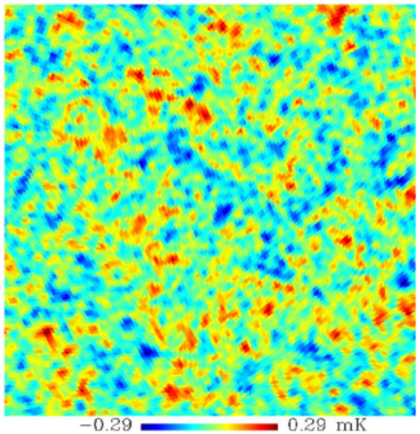
21cm intensity mapping



DOI:10.1093/mnras/stx2621

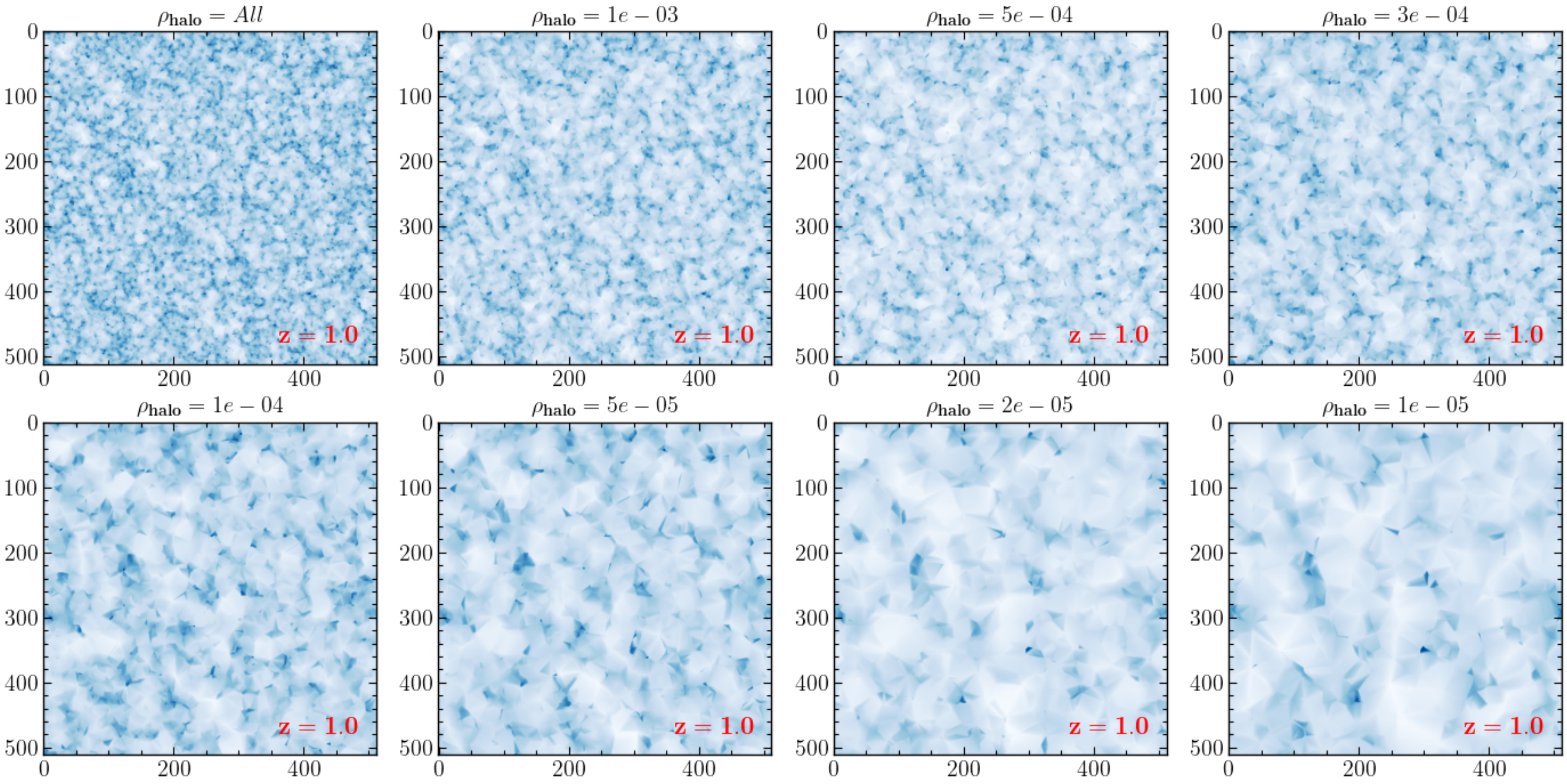
+

Credit: SDSS

Galaxy(Halo)

How to set Galaxy (Halo) map?

DM map $\xrightarrow{\text{Halo finder algorithm}}$ Halo catalog $\xrightarrow{\text{Halo number density } \rho_{halo}}$ Halo map

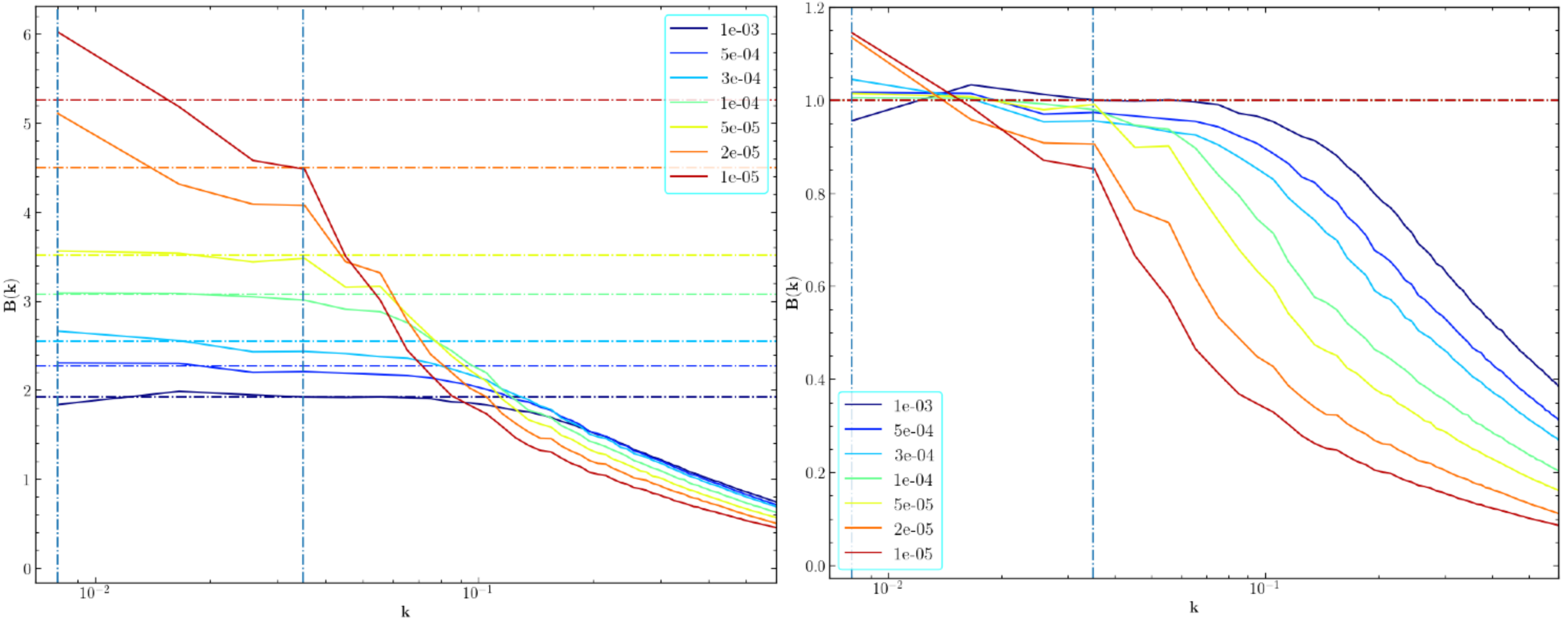


How to set Galaxy (Halo) map?

De-biasing:

$$B(k) = \sqrt{P_{halo}(k)/P_{DM}(k)}$$

$$\boxed{\rho_\delta} = \frac{\frac{\rho}{\rho_{mean}} - 1}{\delta} + 1 \quad \text{, where} \quad \delta = \frac{1}{N} \sum_{b(k)<k_{max}} B(k)$$



How to set HI 21cm map?

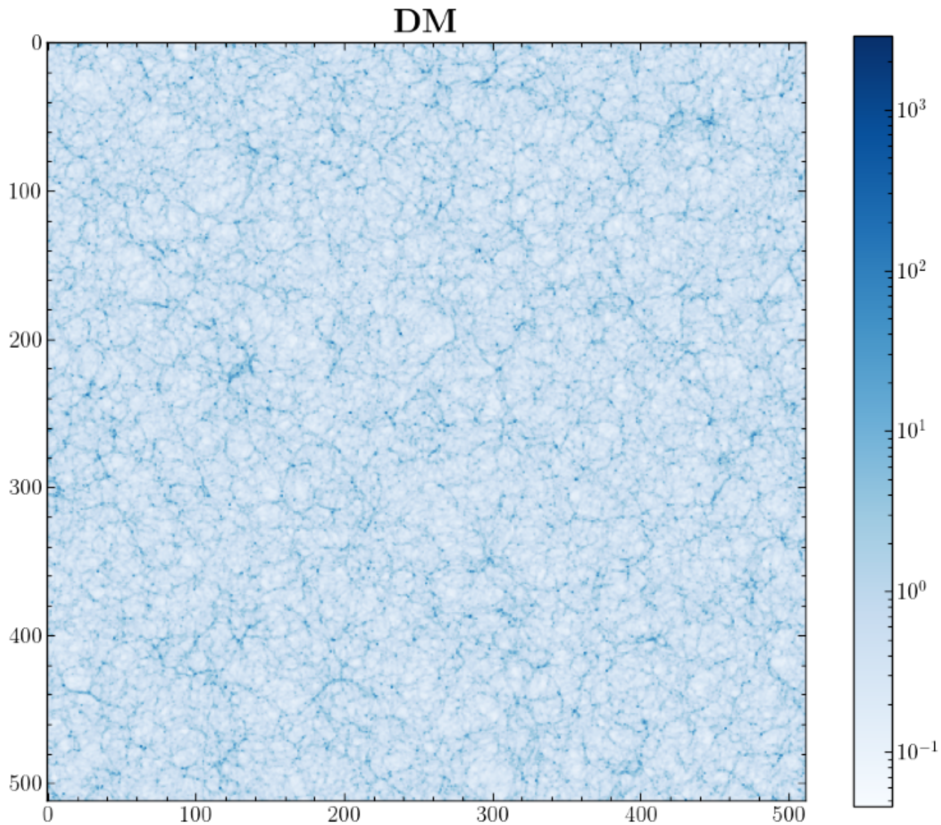
DM map

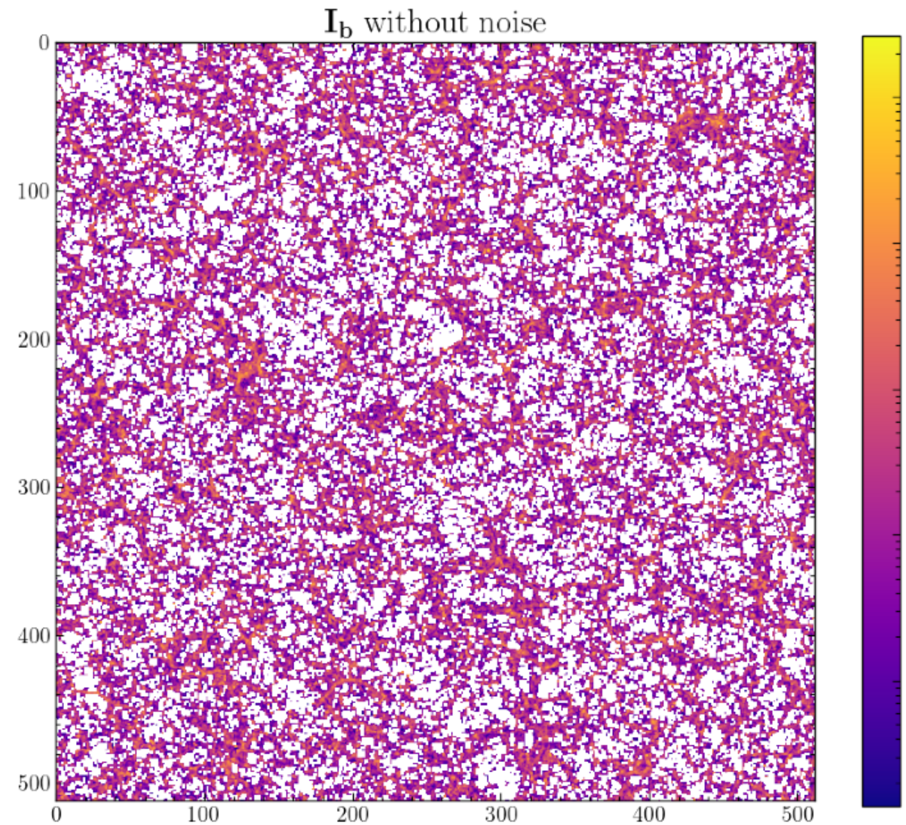
Halo map

Using empirical relation between HMF & HI mass function

Plz refer: DOI: 10.3847/1538-4357/aadba0

HI map

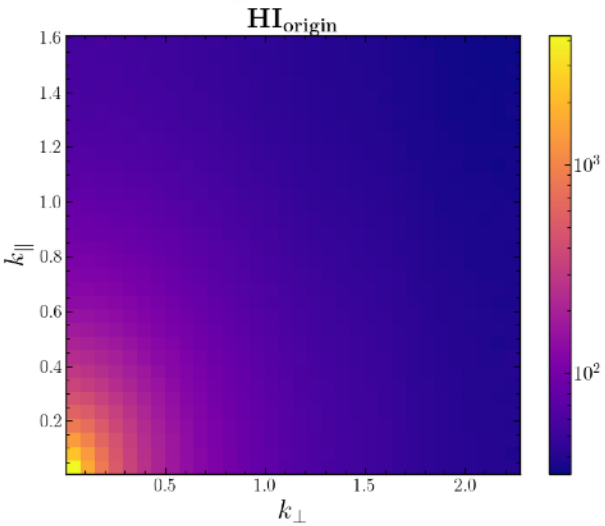


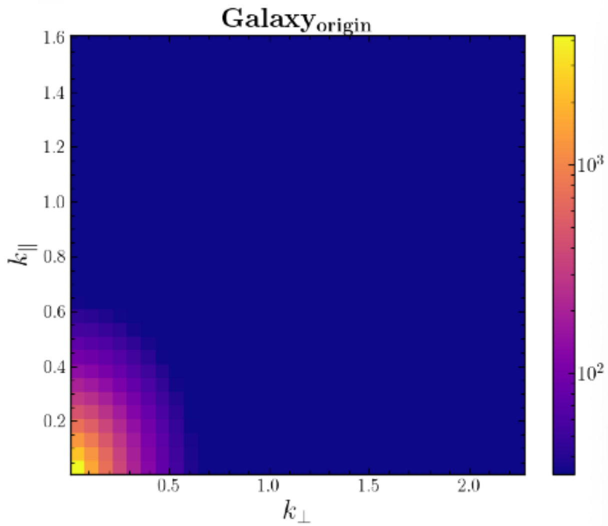


Merging HI & Galaxy map in Fourier space

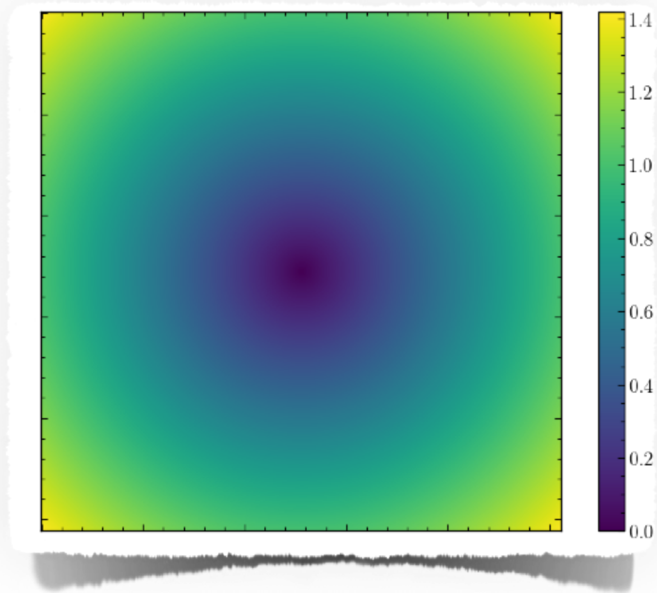
$$k_{\parallel} = k_{\perp} \frac{H_0 D_c E(z) \theta_0}{c(1+z)}$$

Origin cylindrical fourier plane:

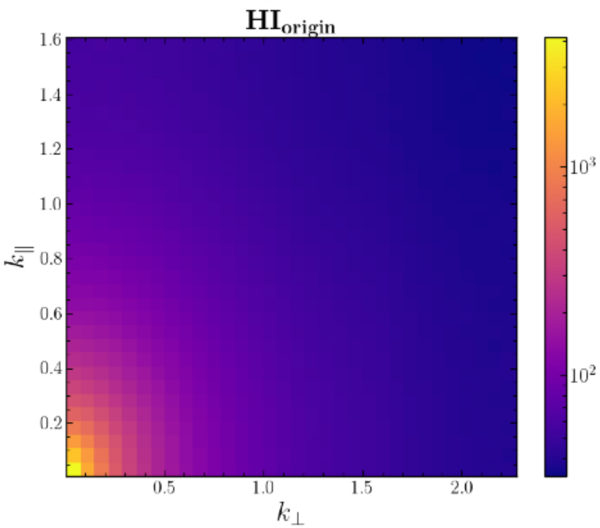


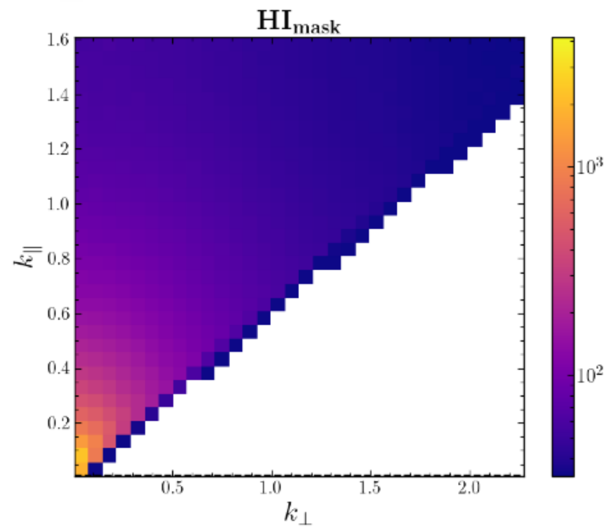


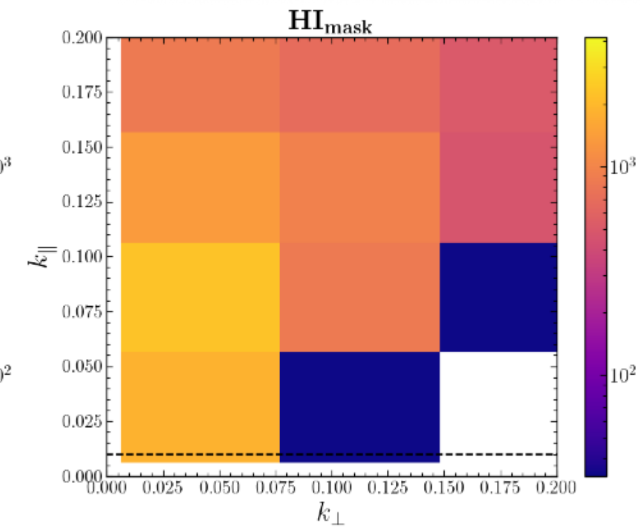
Wedge slice:



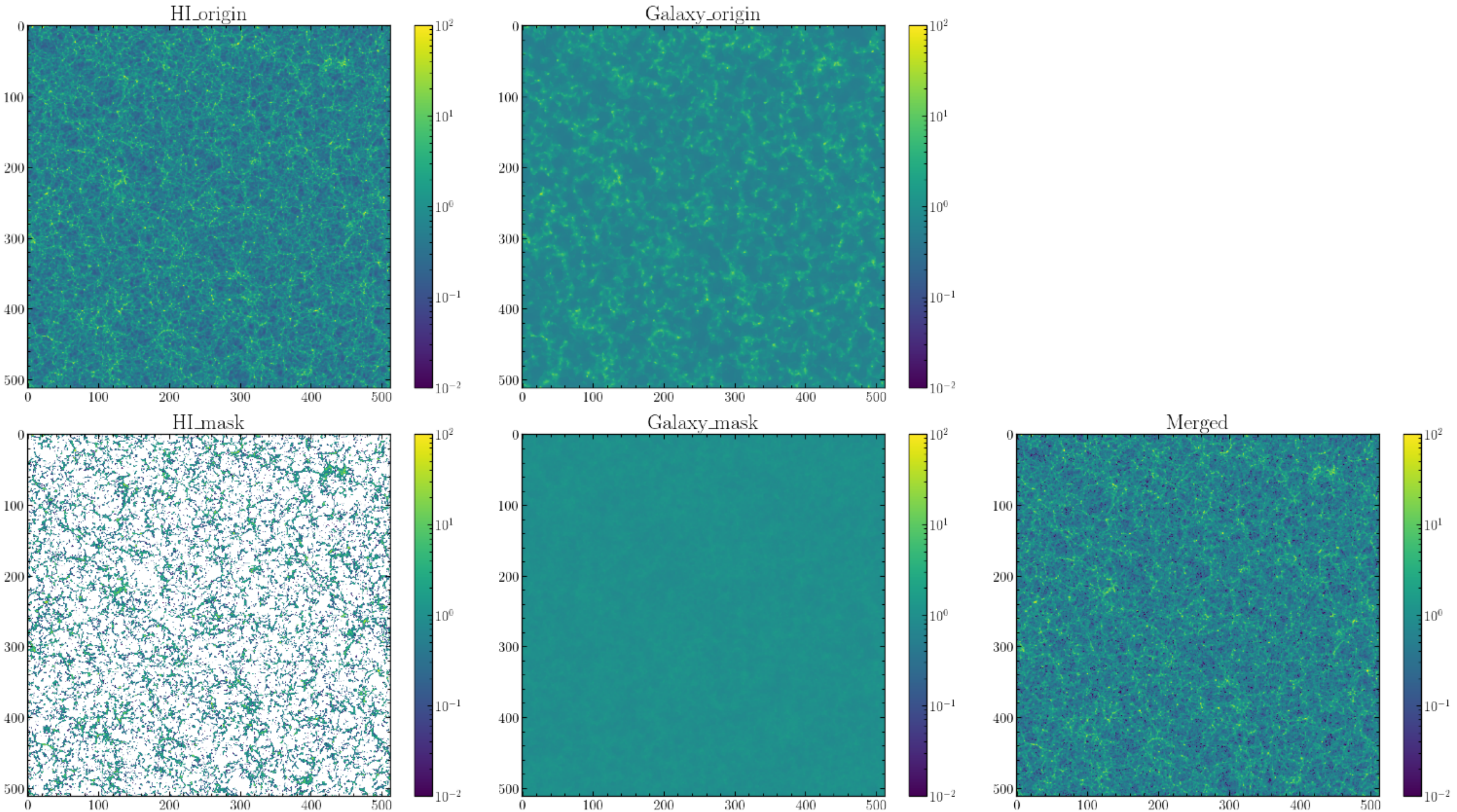
Masked cylindrical fourier plane:







Merging HI & Galaxy map in Fourier space



Conclusion

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can be download here:

Motivation:

1. Stand ruler to constrain DE
2. To constrain cosmological parameters

Reconstruction:

1. Methodology
2. Practicability?

HI & Galaxy merged map:

1. Why use HI?
2. Why merged? (HI foreground)
3. How to implement

Thanks for your patience ☺

Credit: Gabriela Secara