Intensity mapping observables of cosmology

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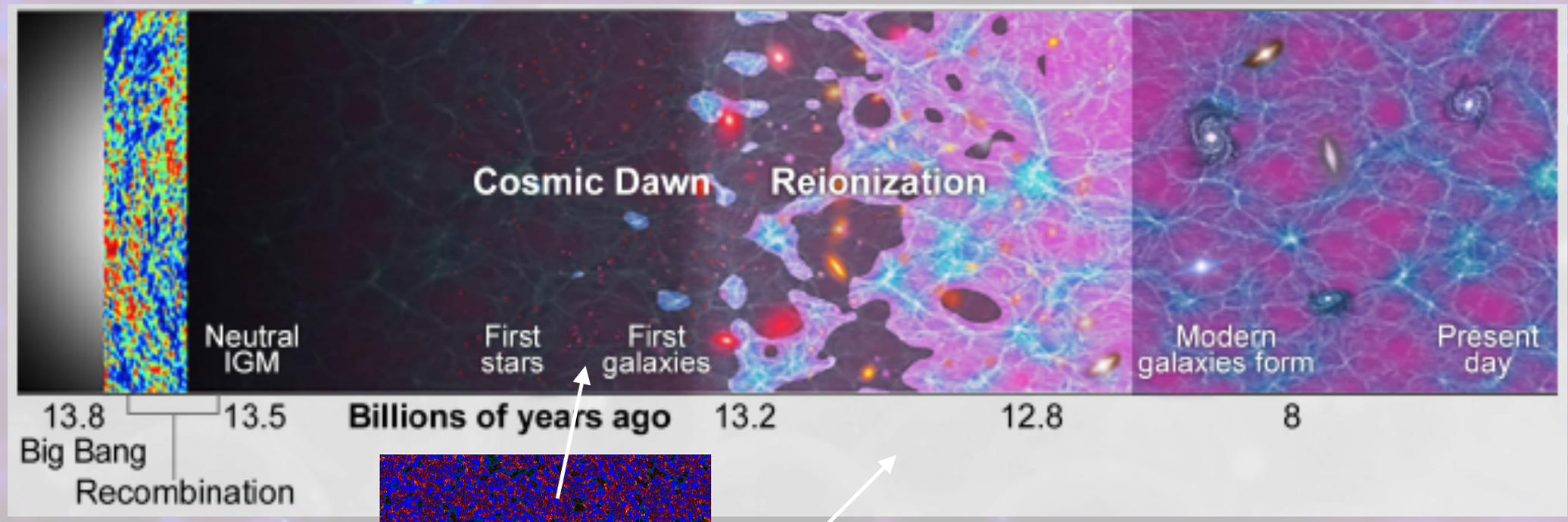
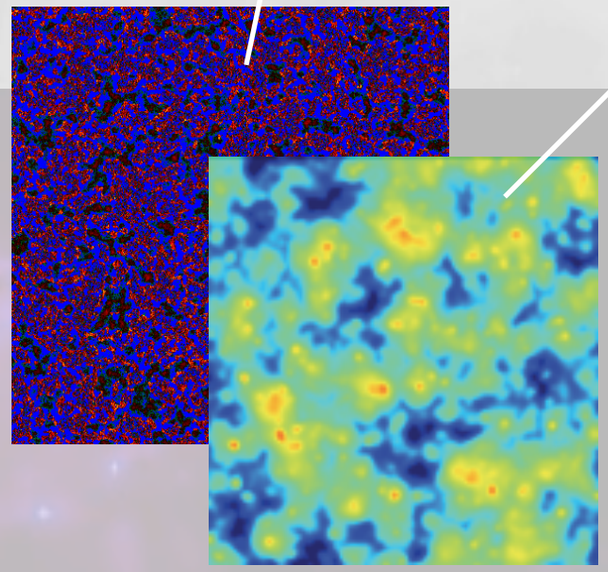
Mostly based on: CH+ ApJ, 848 (2017), Heneka & Amendola JCAP10(2018)004, Liu+ JCAP accepted (2020)
arXiv: 1611.09682, 1805.03629, 1910.02763, see also: 1805.11044, 1903.03144, 1903.03629, 1903.11744
Collaborators: **Luca Amendola, Xue-Wen Liu**, Asantha Cooray, Andrei Mesinger

Motivation

Goal: Push measurements to tomography, up to high redshifts, for mapping of large number of modes and time evolution during structure formation





Create radio and near-IR spectroscopic legacy surveys

What astrophysics? Reionization model?
What cosmology? Structure growth?

Motivation

What is the (large scale) structure of the Universe?

What are properties of radiating sources?

To find out, we can identify individual sources of emission.

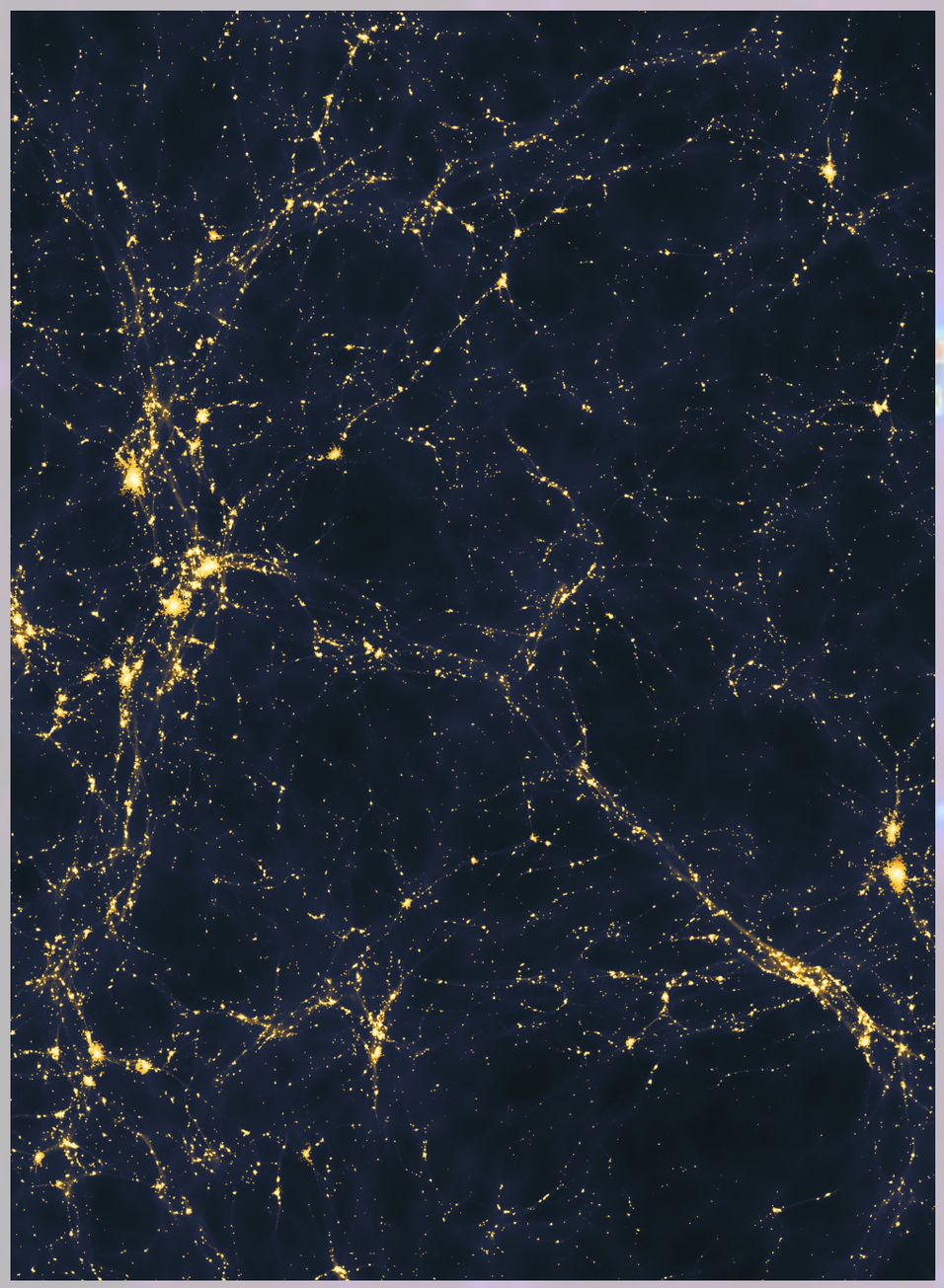


Image: Courtesy of Asantha Cooray

Motivation

What is the (large scale) structure of the Universe?

What are properties of radiating sources?

To find out, we can identify individual sources of emission.

OR

We can sum the emission in larger areas and measure fluctuations.

Example: Planck satellite for the CMB

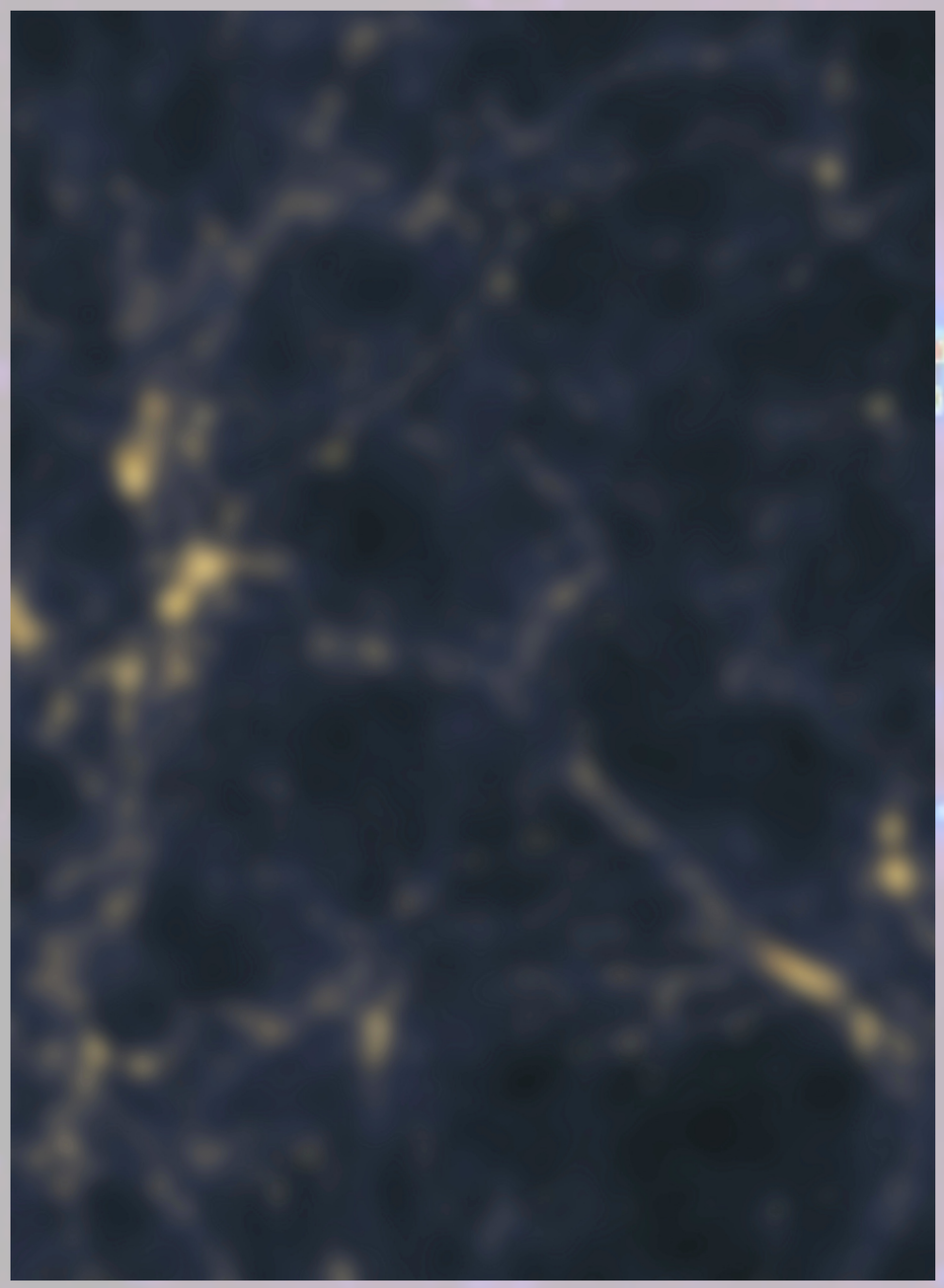
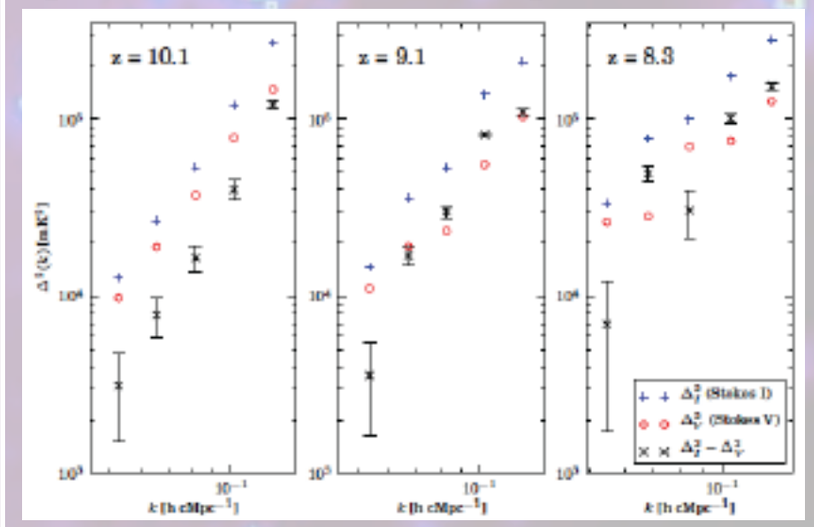


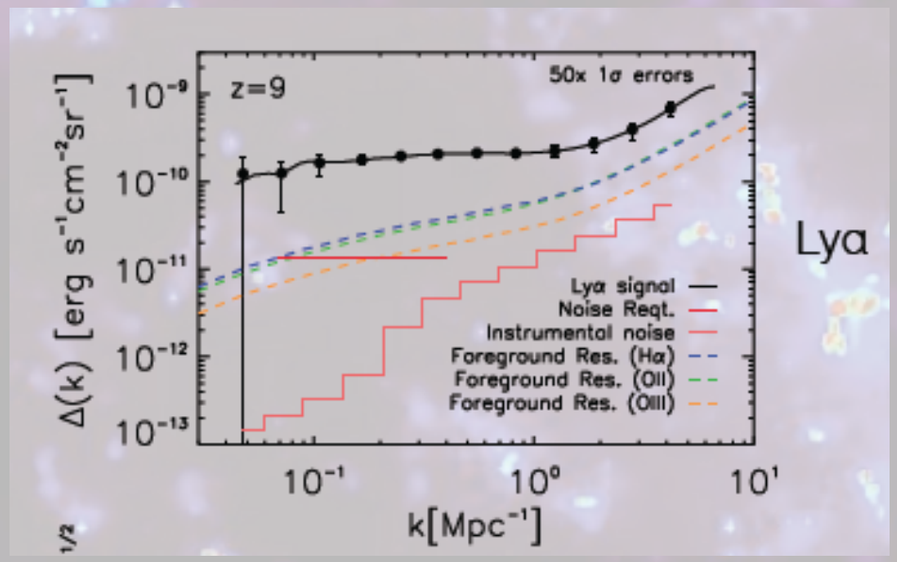
Image: Courtesy of Asantha Cooray

Is this measurable?

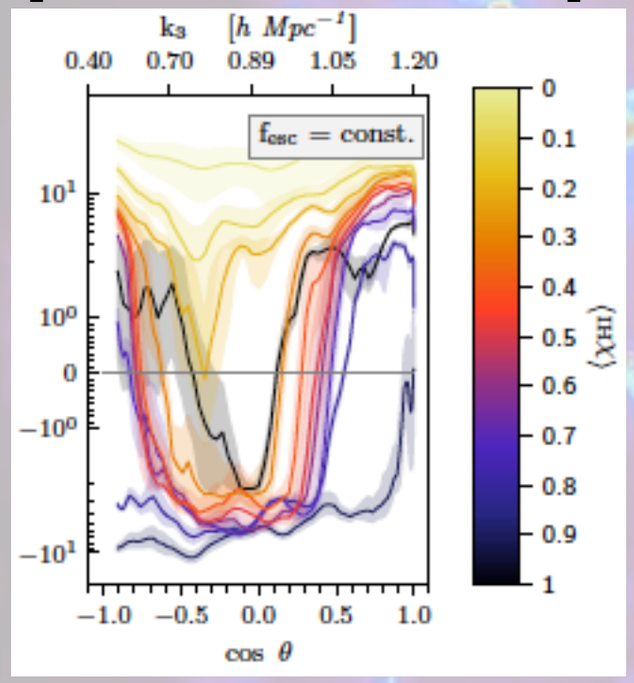
Power spectra
LOFAR 21cm
upper limits
[Patil et al. 2017]



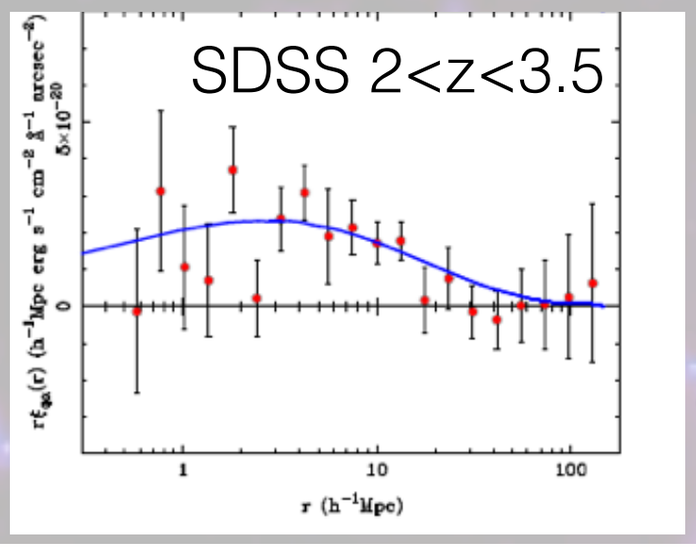
Multi-line Tomography
SPHEREx, CDIM
[Cooray+, Heneka 2019]



3pt / Bispectrum
[Hutter et al. 2019]



+(Global signal)
EDGES
[Bowman et al. 2018]

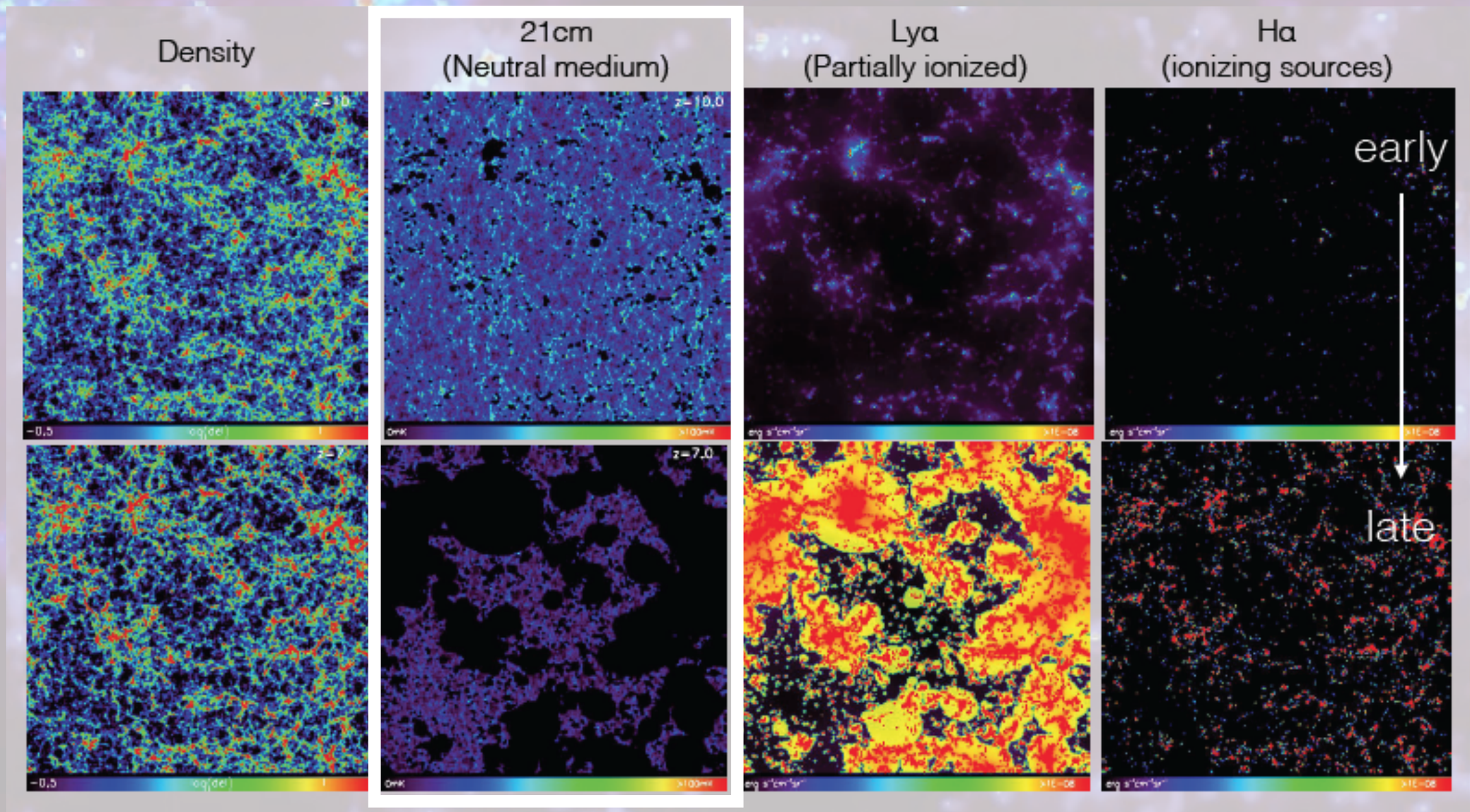


Cross-correlation
Lya IM
quasar-Lya cross
[Croft et al. 2016]

Multi-Line Intensity Mapping

[CDIM Science Report, Cooray+, Heneka 2019]

Gain complementary information on **LSS**, IGM, sources:



Optical Emission lines = near-IR lines during reionization (high redshift)

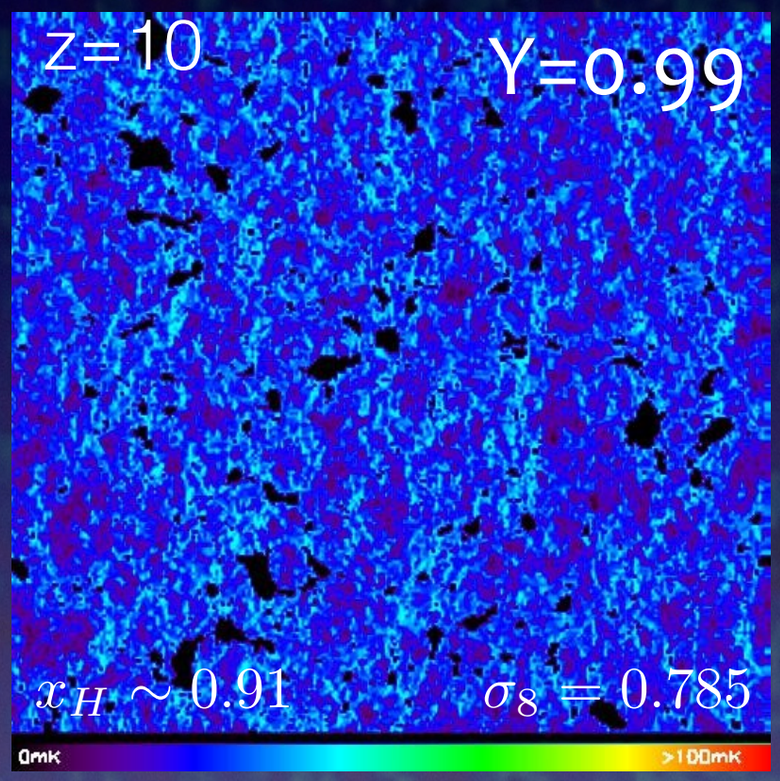
→ constrain **cosmology**, ability to distinguish beyond LCDM?

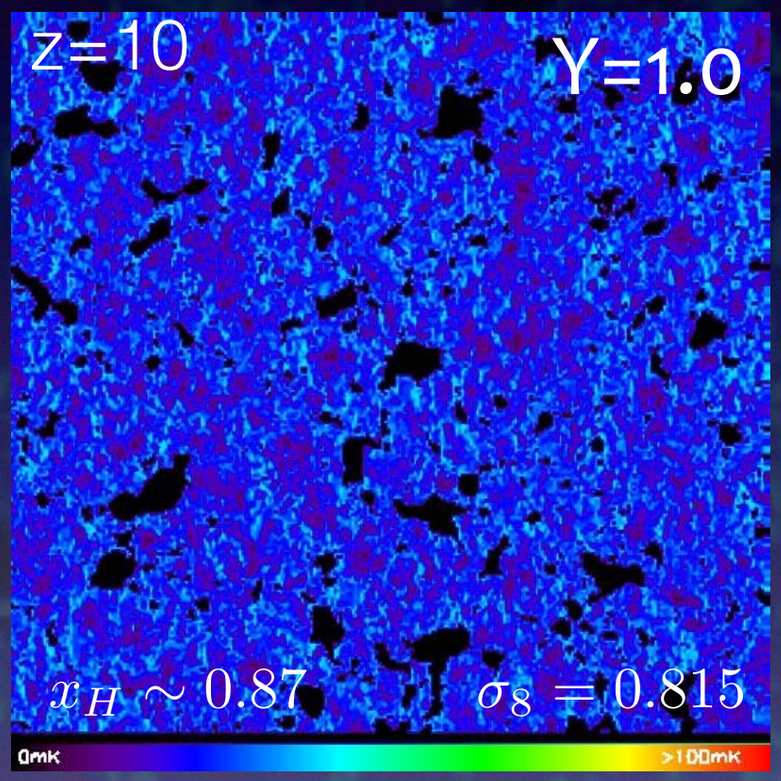
Beyond GR: What to learn from 21cm P(k)

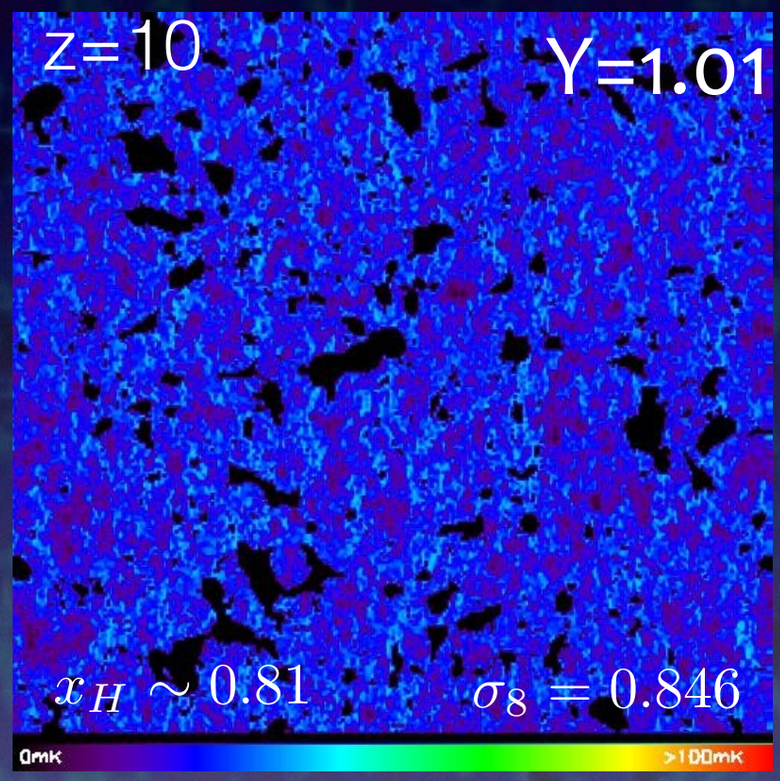
Starting with a general modification to GR:

Y ~ effective G, $\alpha = \delta'_{in}/\delta_{in}$

GR:
$Y = 1 \quad \alpha = 1$







[Normalized to same growth at CMB]

Offset 21-cm brightness temperature δT_b

$$\delta T_b(\nu) = \frac{T_S - T_\gamma}{1+z}\left(1 - e^{-\tau_{\nu_0}}\right)$$

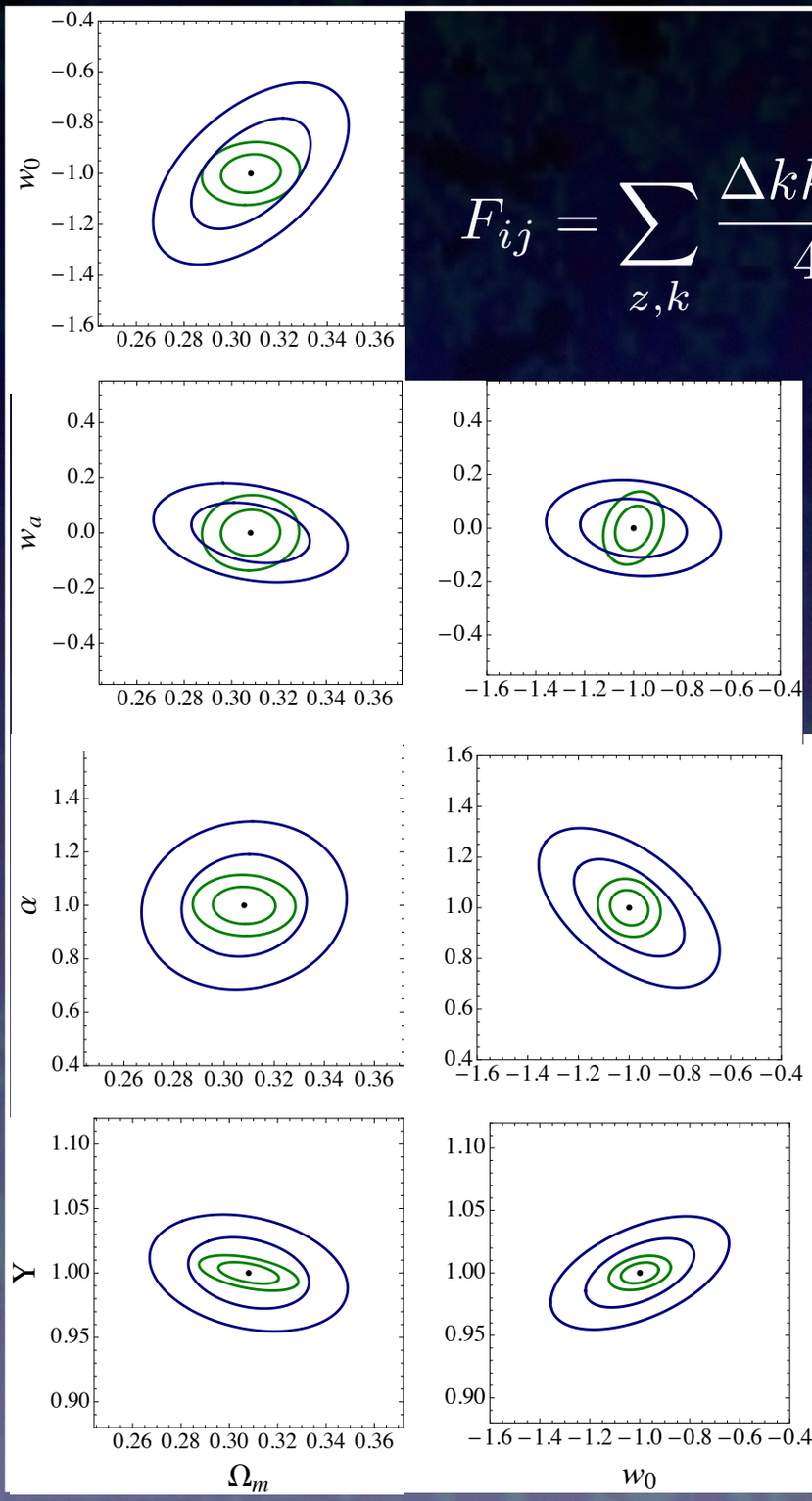
$$\propto x_{HI}\,(1+\delta_{nl})\left(\frac{H}{\mathrm{d}v_r/\mathrm{d}r + H}\right)$$

$$\delta''_m + \left(2 + \frac{E'}{E}\right)\delta'_m = \frac{3}{2}\frac{\delta_m}{a^3 E^2}\Omega_{m,0} Y$$

with IC: $\alpha = \delta'_{in}/\delta_{in}$

C. Heneka & L. Amendola, 2018

Fisher (SKA): $\Omega_{\rm m}$, w_0, w_a, Y, α



$$F_{ij} = \sum_{z,k} \frac{\Delta k k^2 V_{\rm sur}}{4\pi^2} \frac{\partial \Delta^2_{21}(z,k)}{\partial p_i} Cov^{-1}(z,k) \frac{\partial \Delta^2_{21,l}(z,k)}{\partial p_j}$$

+ foreground removal

$$k_\parallel \leq \frac{d_c E(z) \theta_0}{d_H (1+z)} k_\perp$$

$\Delta\Omega \sim 0.008$ (0.016)

$\Delta w_0 \sim 0.05$ (0.144)

$\Delta w_a \sim 0.06$ (0.072)

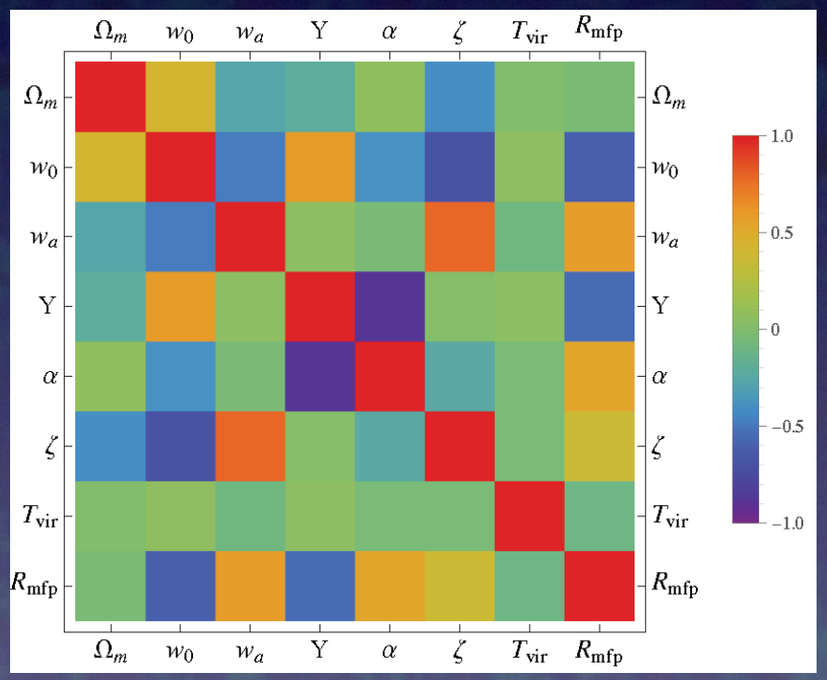
$\Delta Y \sim 0.006$ (0.018)

$\Delta\alpha \sim 0.06$ (0.126)

[For 5 z-bins z=6-10]

Fisher (SKA): $\Omega_{\rm m}$, w_0, w_a, Y, α

$$P_{ij} = \frac{C_{ij}}{\sqrt{C_{ii}C_{jj}}}$$



For cosmological parameters only:

$\Delta Y \sim 0.006$

$\Delta\alpha \sim 0.06$

'the optimist'

Plus reionization parameters:

$\Delta Y \sim 0.013$

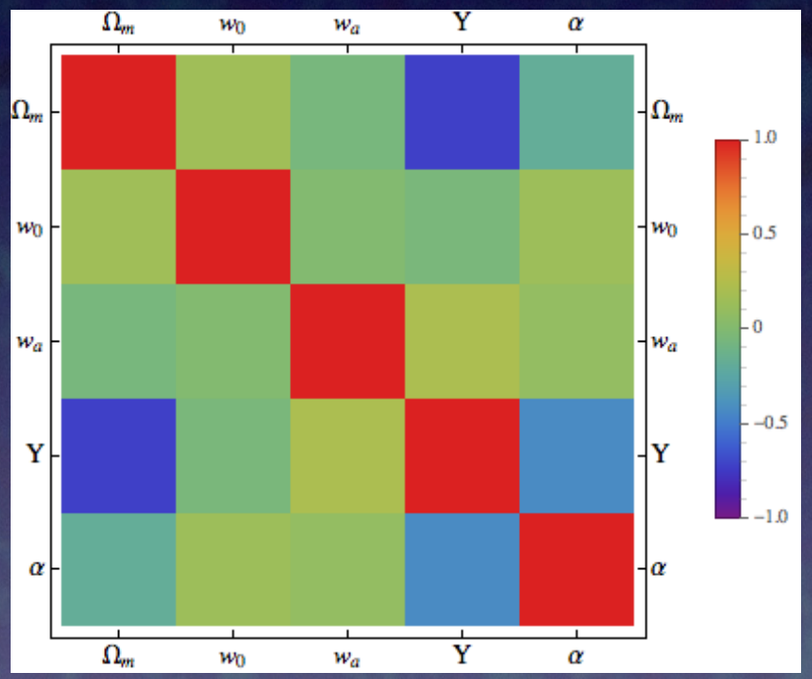
$\Delta\alpha \sim 0.119$

+ order % errors
on other parameters

Tomography is key!

Fisher (SKA): $\Omega_{\rm m}$, w_0, w_a, Y, α

$$P_{ij} = \frac{C_{ij}}{\sqrt{C_{ii}C_{jj}}}$$



From cosmological parameters only:

$\Delta Y \sim 0.006$

$\Delta\alpha \sim 0.06$

Cut non-linear scales:

$\Delta Y \sim 0.12$

$\Delta\alpha \sim 0.88$

Shot-noise high-k cut:

$\Delta Y \sim 0.04$

$\Delta\alpha \sim 0.34$

Important to model
(mildly) non-linear scales!

Beyond GR: What to learn from 21cm P(k) + global signal

Choose a coupled quintessence setup:

Q ~ coupling to DM,

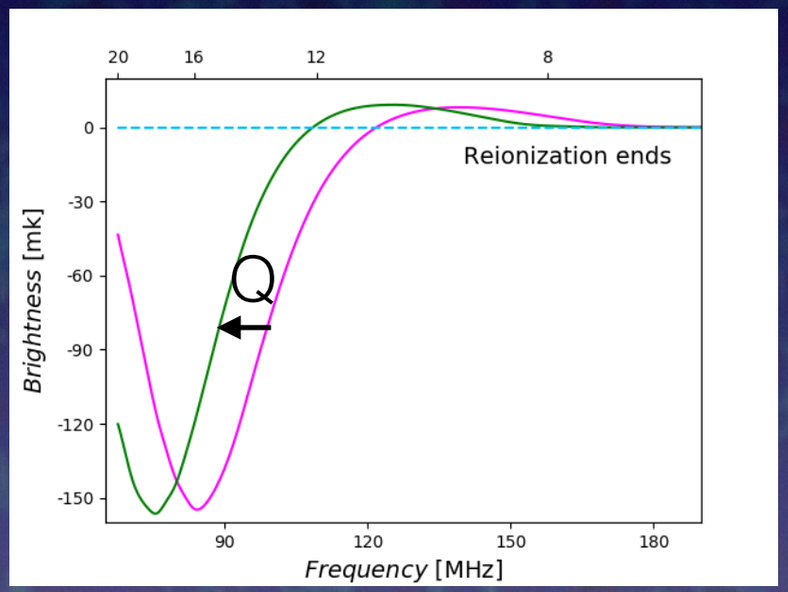
$$\nabla_\mu T^\mu_{\nu(\phi)} = -I_{\rm int}$$

$$\nabla_\mu T^\mu_{\nu({\rm dm})} = +I_{\rm int}$$

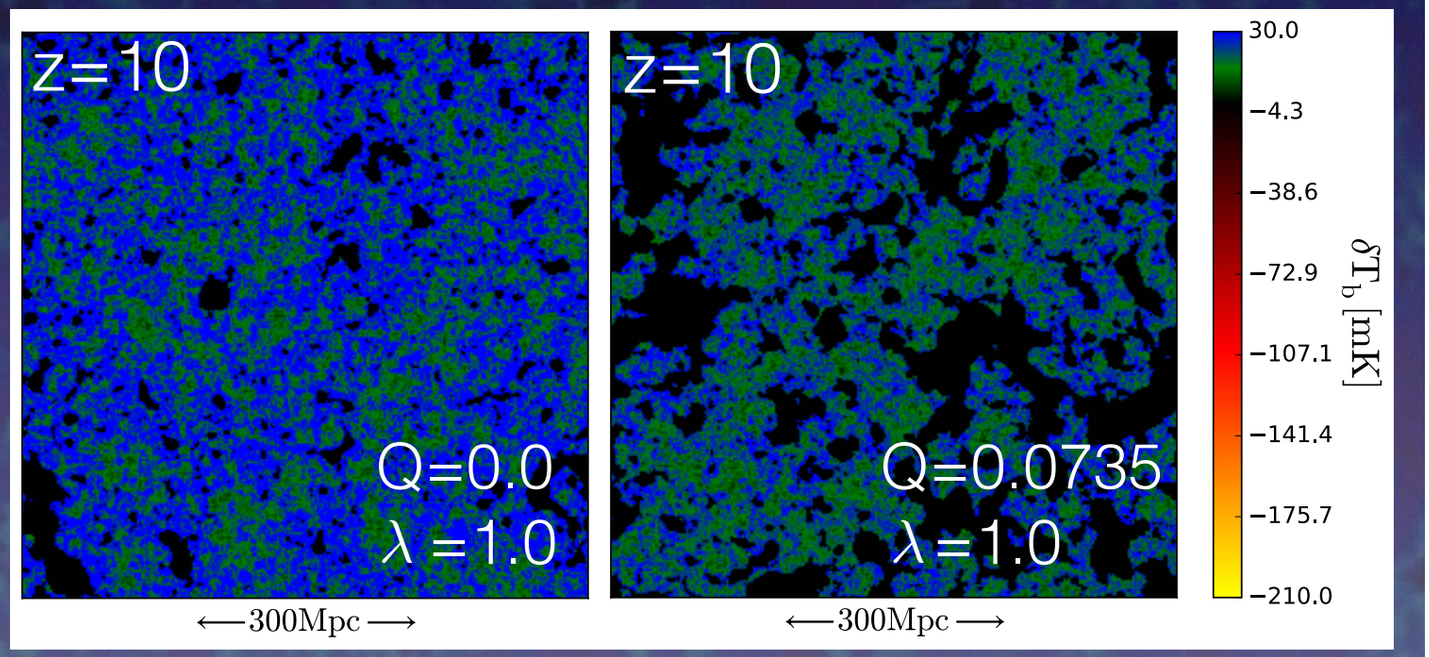
$$I_{\rm int} = Q T_{\rm dm} \nabla_\nu \phi$$

λ~exp. potential

$$V(\phi) = V_0 e^{-\lambda\phi}$$



[Normalized to same growth at CMB]



Fisher forecast for

1) fiducial global experiment
2) power spectra (SKA)

Liu, Heneka, Amendola, 2020

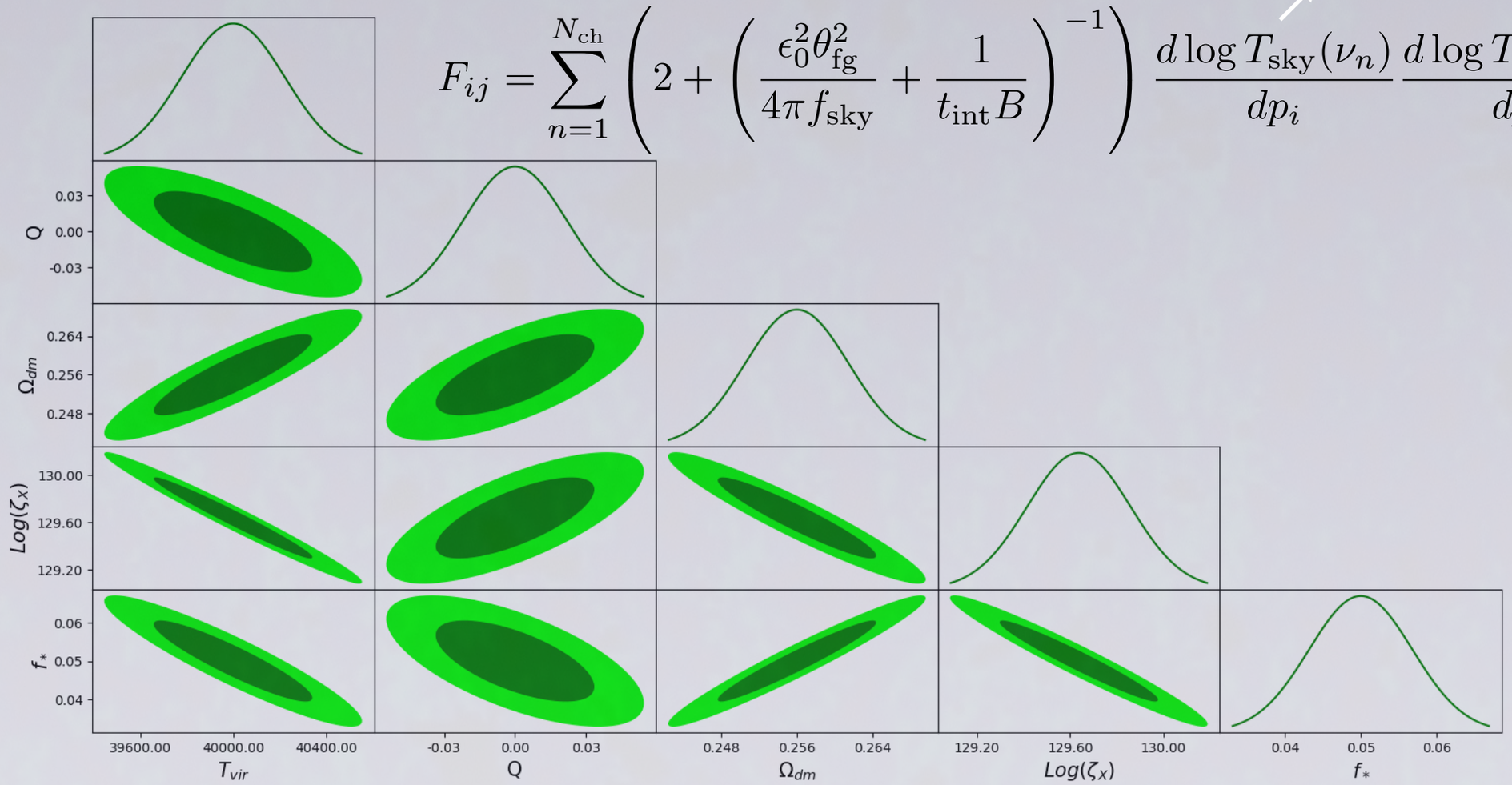
Beyond GR: What to learn from 21cm P(k) + global signal

Fisher forecast for
1) fiducial global experiment
2) power spectra (SKA)

1) global

$$T_{\rm sky}(\nu) = T_{\rm fg}(\nu) + T_{\rm b}(\nu)$$

$$F_{ij} = \sum_{n=1}^{N_{\rm ch}} \left(2 + \left(\frac{\epsilon_0^2 \theta_{\rm fg}^2}{4\pi f_{\rm sky}} + \frac{1}{t_{\rm int} B} \right)^{-1} \right) \frac{d \log T_{\rm sky}(\nu_n)}{dp_i} \frac{d \log T_{\rm sky}(\nu_n)}{dp_j}$$



[For 6 z-bins z=15-20]

Beyond GR: What to learn from 21cm P(k) + global signal

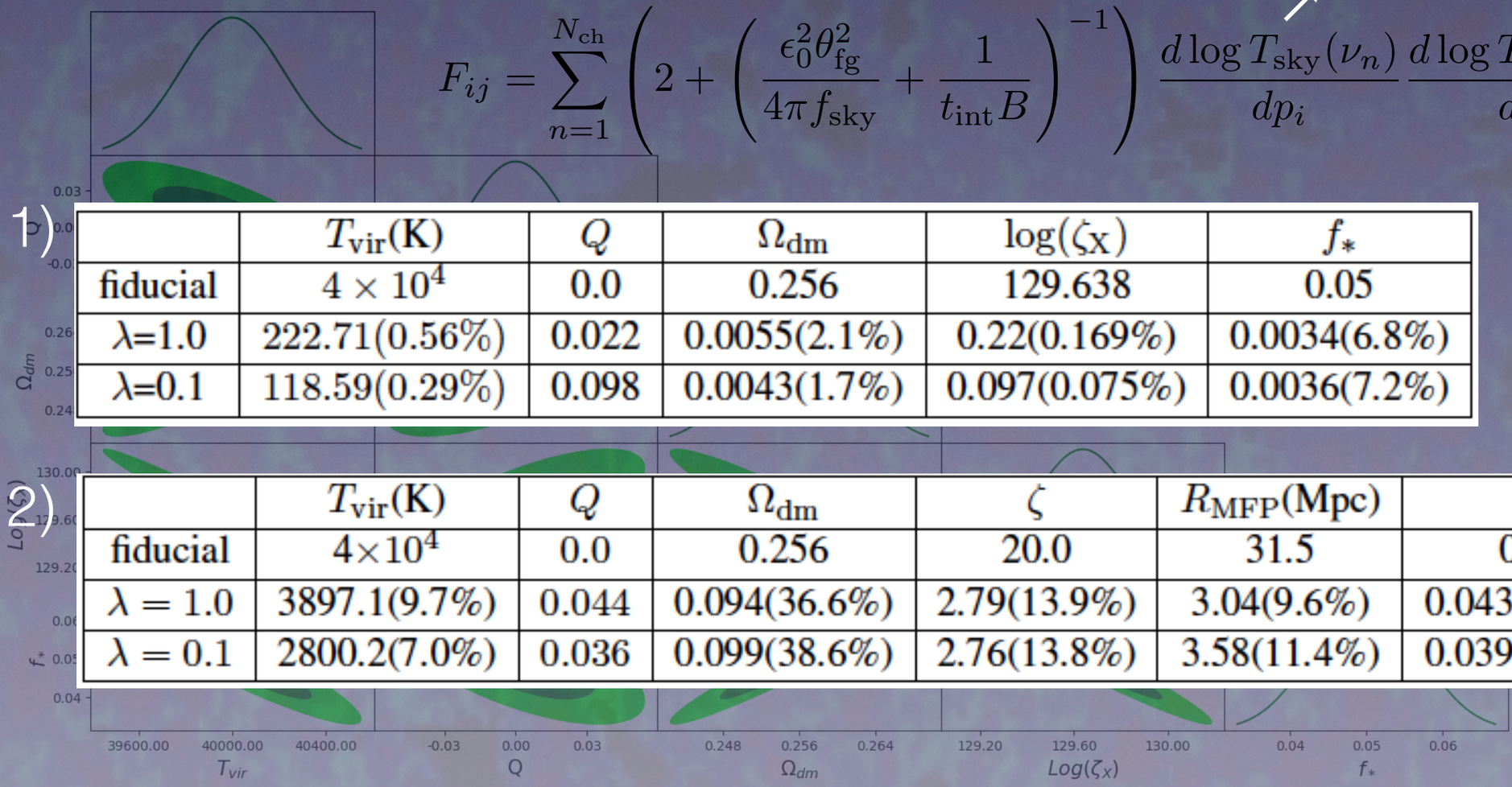
Fisher forecast for
1) fiducial global experiment
2) power spectra (SKA)

Main take away →

- global signal improves constraints $\Omega_{\rm dm}$
- similar constraints on Q
- only mildly dependent on λ

$$T_{\rm sky}(\nu) = T_{\rm fg}(\nu) + T_{\rm b}(\nu)$$

$$F_{ij} = \sum_{n=1}^{N_{\rm ch}} \left(2 + \left(\frac{\epsilon_0^2 \theta_{\rm fg}^2}{4\pi f_{\rm sky}} + \frac{1}{t_{\rm int} B} \right)^{-1} \right) \frac{d \log T_{\rm sky}(\nu_n)}{dp_i} \frac{d \log T_{\rm sky}(\nu_n)}{dp_j}$$



1)

	$T_{\rm vir}$(K)	Q	$\Omega_{\rm dm}$	$\log(\zeta_{\rm X})$	f_*
fiducial	4×10^4	0.0	0.256	129.638	0.05
λ=1.0	222.71(0.56%)	0.022	0.0055(2.1%)	0.22(0.169%)	0.0034(6.8%)
λ=0.1	118.59(0.29%)	0.098	0.0043(1.7%)	0.097(0.075%)	0.0036(7.2%)

2)

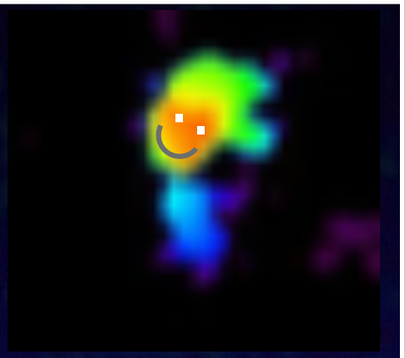
	$T_{\rm vir}$(K)	Q	$\Omega_{\rm dm}$	ζ	$R_{\rm MFP}$(Mpc)	f_*
fiducial	4×10^4	0.0	0.256	20.0	31.5	0.05
$\lambda = 1.0$	3897.1(9.7%)	0.044	0.094(36.6%)	2.79(13.9%)	3.04(9.6%)	0.043(85.9%)
$\lambda = 0.1$	2800.2(7.0%)	0.036	0.099(38.6%)	2.76(13.8%)	3.58(11.4%)	0.039(77.9%)

Liu, Heneka, Amendola, 2020

Conclusion & Outlook

- Avenue to constrain cosmology / MG

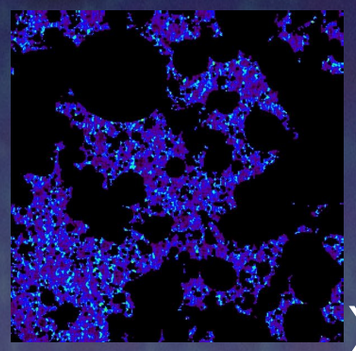
  %-precision even for extended models within reach
- Tomography lifts degeneracies with astrophysics
- Important to model (mildly) non-linear scales



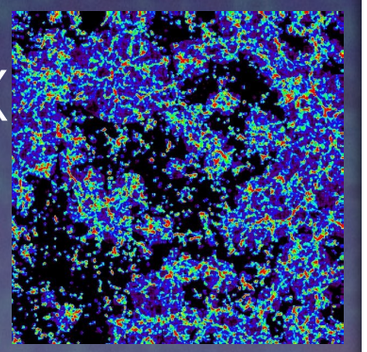
Thank you!

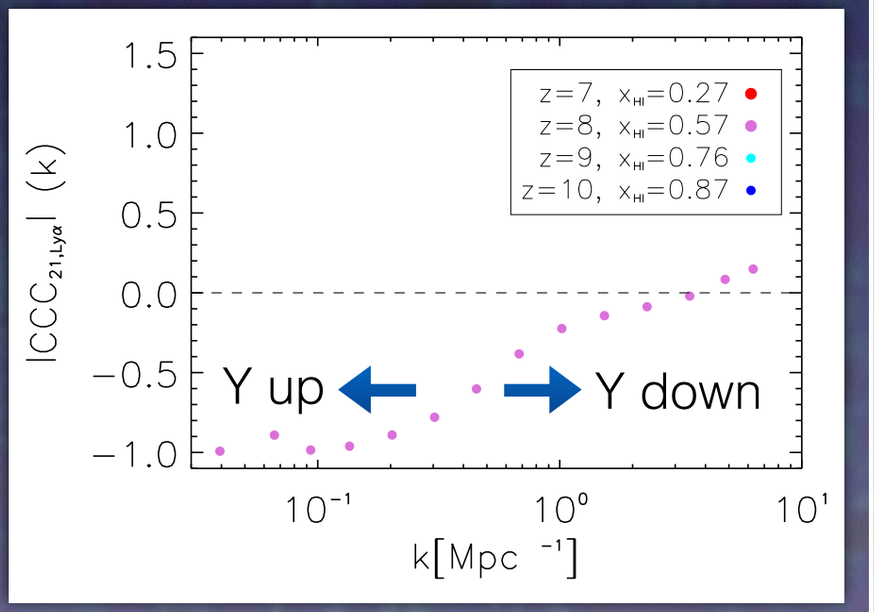
Ongoing & Upcoming:

- Test scale-dependency
- Combine with other lines
- Model the (mildly) non-linear regime



X





[Heneka, in prep.]

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