Weak lensing and higher-point statistics

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with
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based on arXiv:1803.04975 and work in progress

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L'institut Canadien d'astrophysique théorique

CCA Intensity Mapping Workshop
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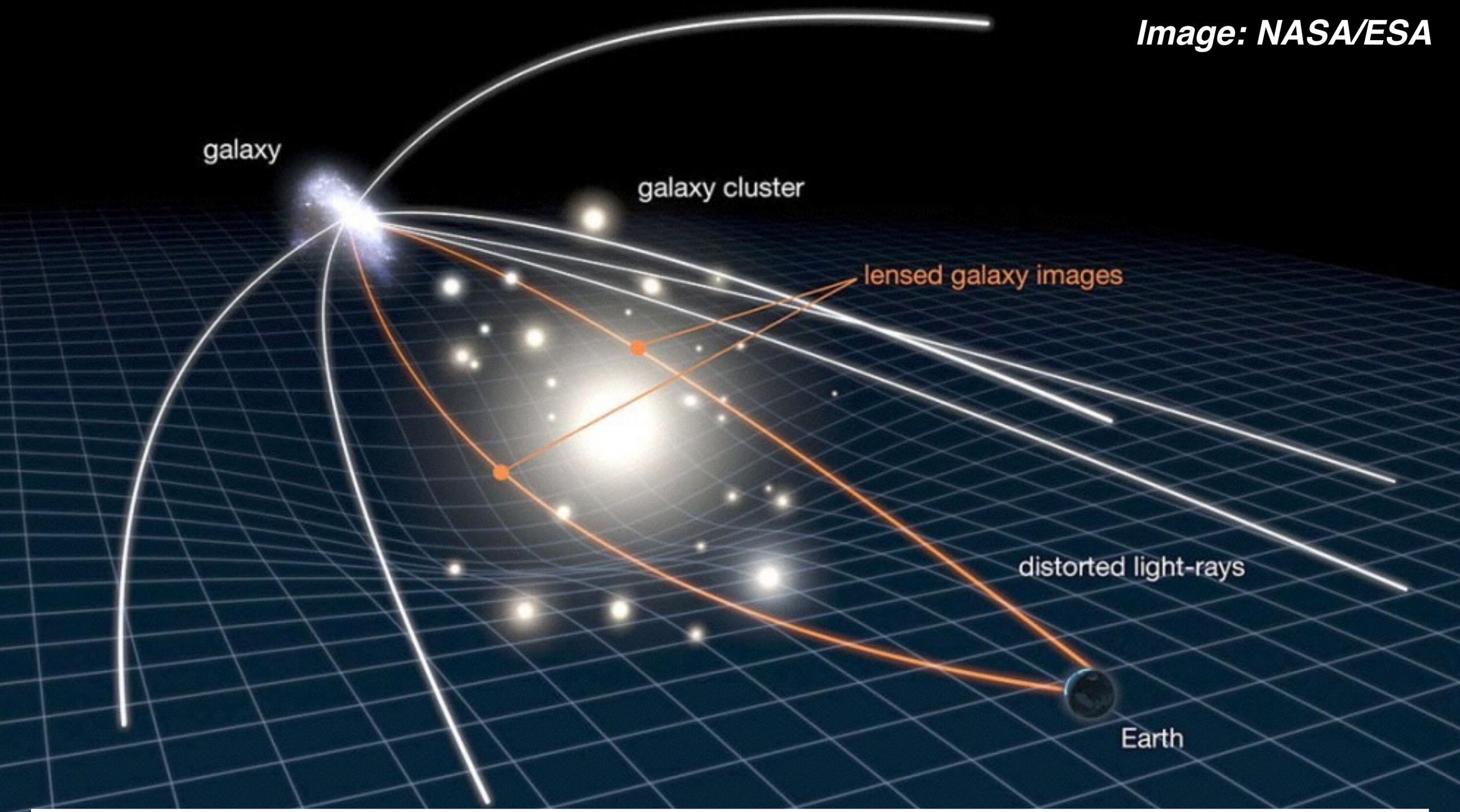
Gravitational lensing: basic picture



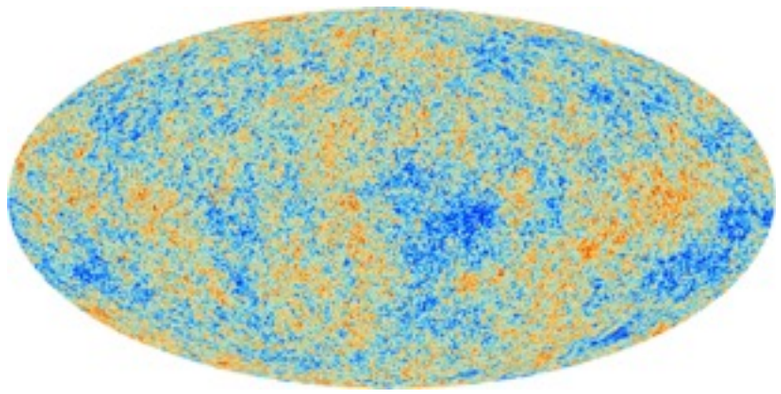
Directly traces low-redshift structure

→ Neutrino masses, structure growth, cross-correlations

CMB lensing vs. LIM lensing

CMB lensing:

Single
2d map



Intrinsic statistics:
linear, Gaussian

Techniques/instruments:
well-established

LIM lensing:

Full
3d map

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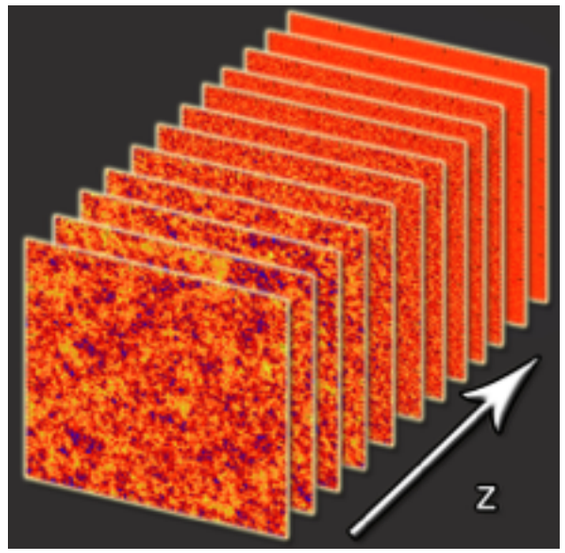
- reduce noise
- tomography

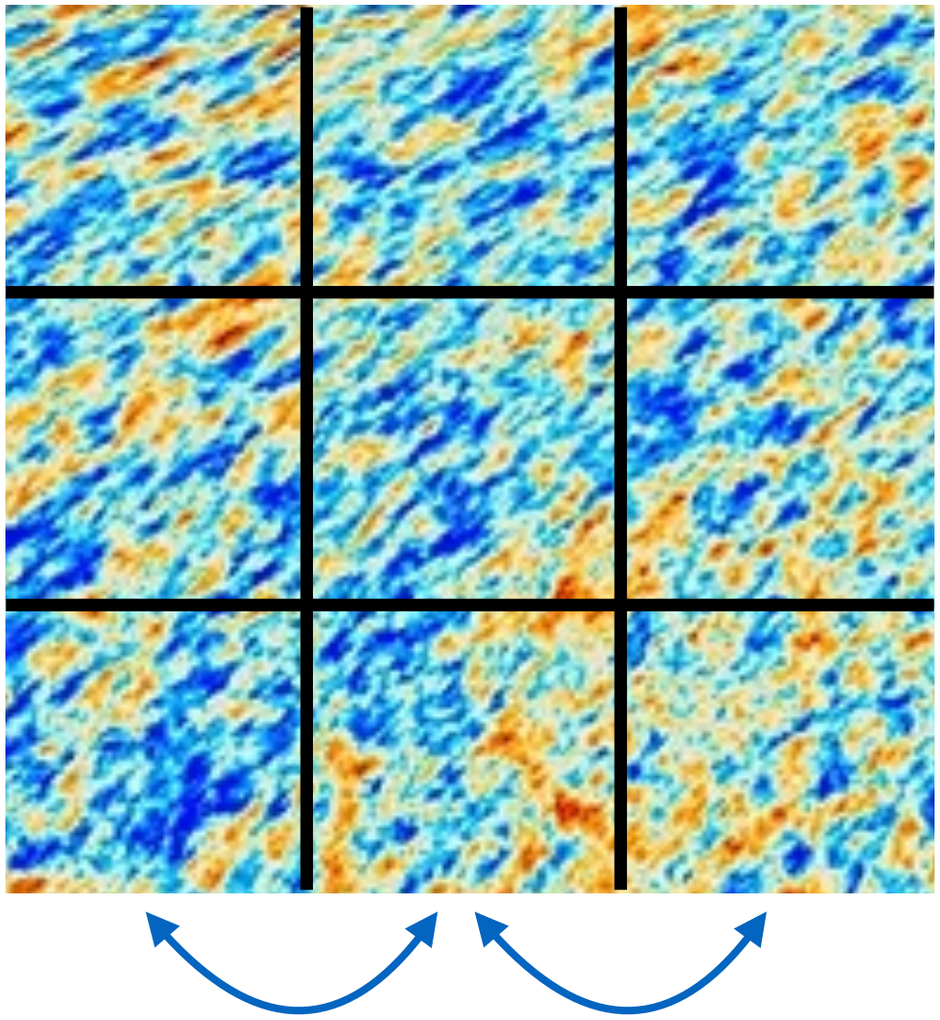


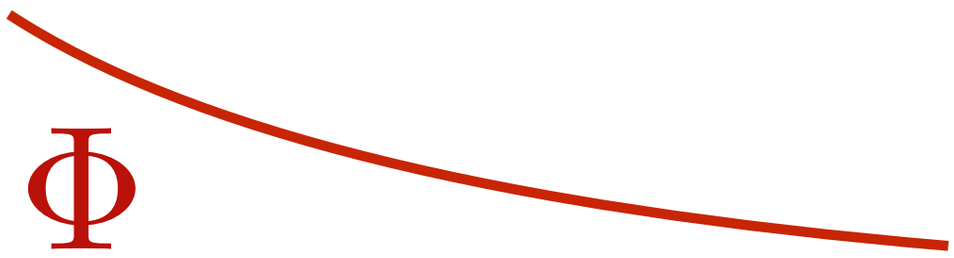
Intrinsic statistics:
nonlinear, non-Gaussian

Techniques/instruments:
in progress

Images: ESA; Romeo et al. 2017

Measuring lensing





Grav. potential of foreground lenses
distorts and correlates
local power in map

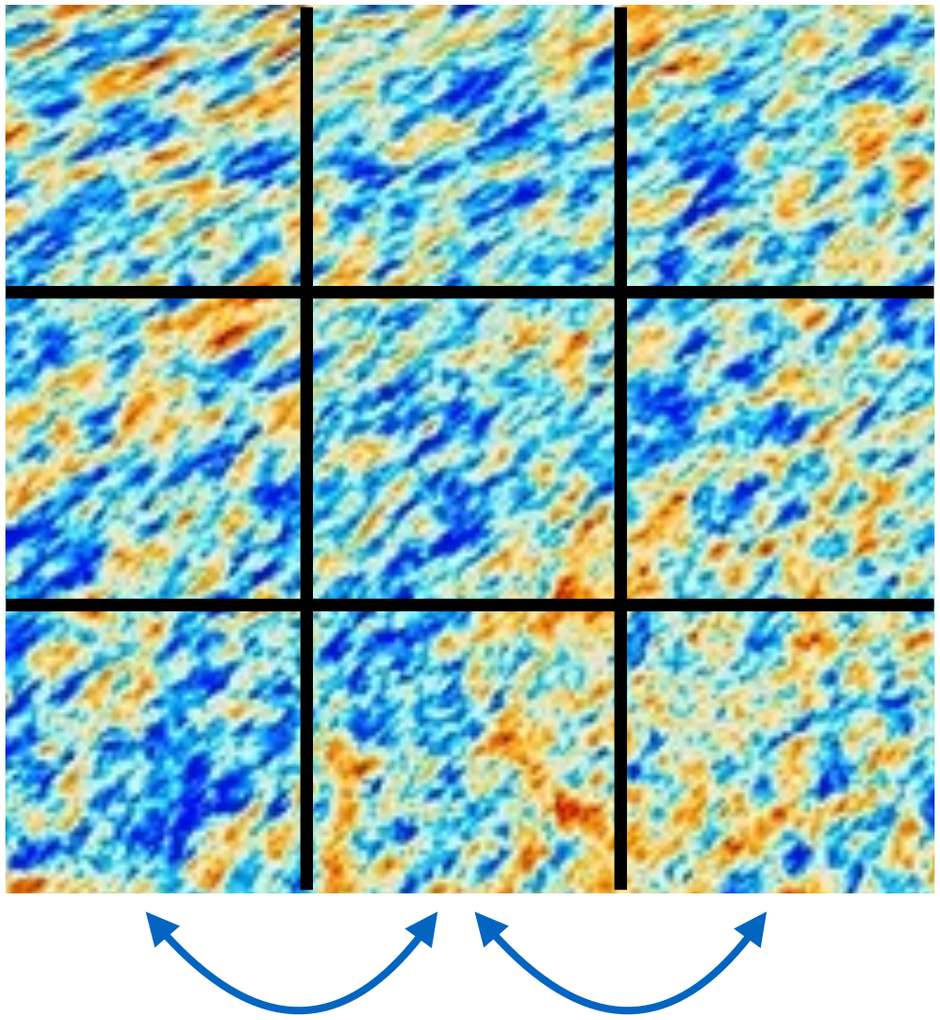
Power ~ T^2

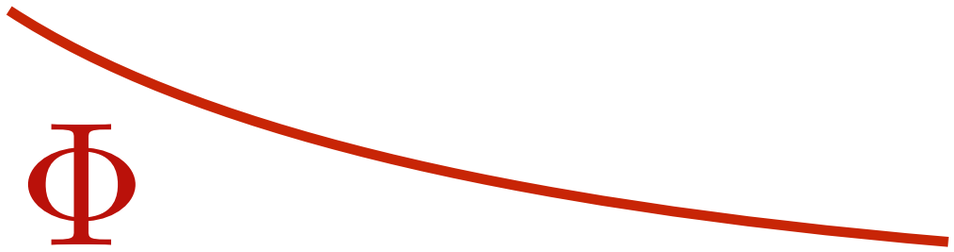
Correlated power: $\langle T^2\, T^2 \rangle \neq 0$

→ 4-point T correlations

Hu 2001

Measuring lensing





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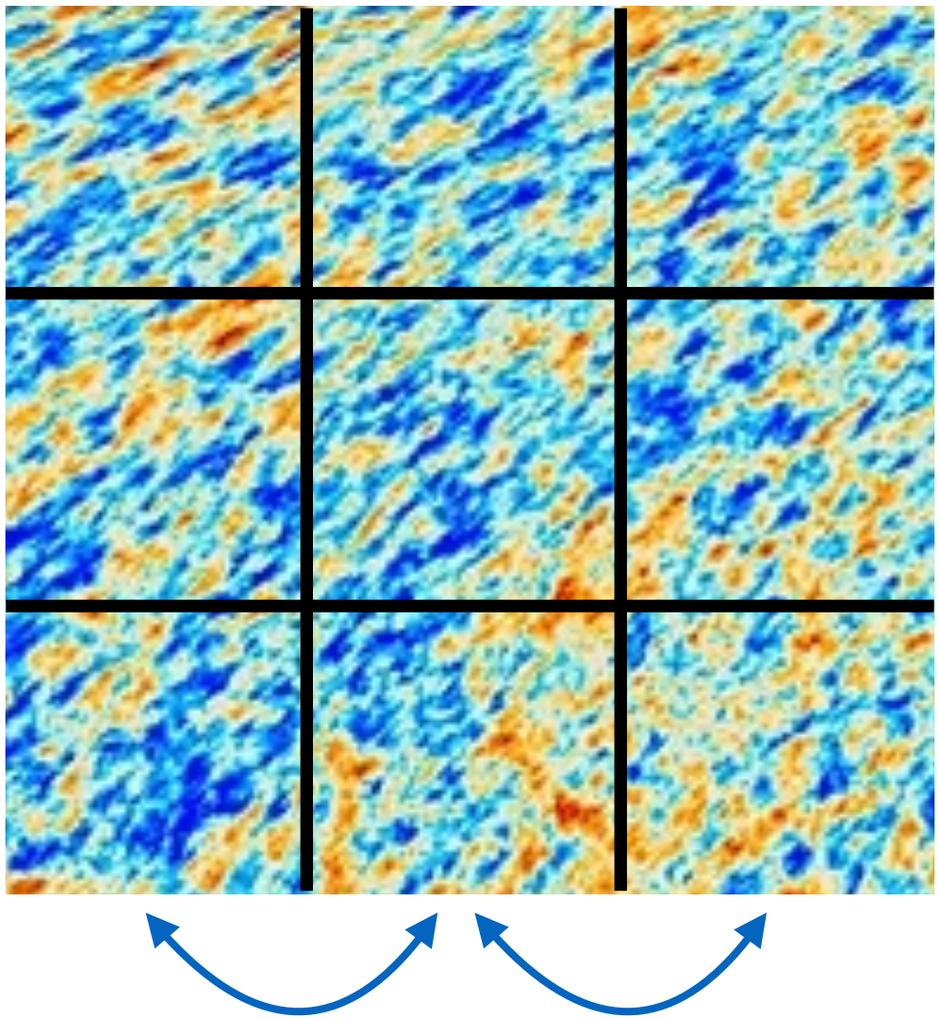
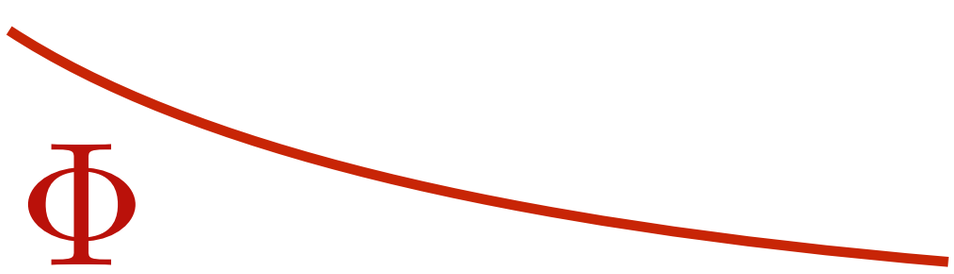
Map of ϕ (projected grav. potentials)

Power spectrum of ϕ

Hu 2001

Measuring lensing





Hu 2001

Grav. potential of foreground lenses
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→ 4-point T correlations

In a line intensity map, $\langle T^2\, T^2 \rangle \neq 0$
even without lensing

↓

Extra bias + noise,
but partially removable

SF et al. 2018

Forecasts for 21cm surveys

S/N on lensing power spectra for 21cm surveys

	z	width of each band [MHz]	$f_{\rm sky}$	$\langle\kappa\kappa\rangle$	$\langle\kappa g_{\rm LSST}\rangle$	$\langle\kappa\gamma_{\rm LSST}\rangle$
SKA1-Low	$6 < z < 14$	5	27 deg^2	3.6	26	13
CHIME	$1.1 < z < 2.5$	25	0.5	0.25	34	27
HIRAX	$1.35 < z < 2.5$	25	0.5	0.93	45	34

lensing auto spectrum

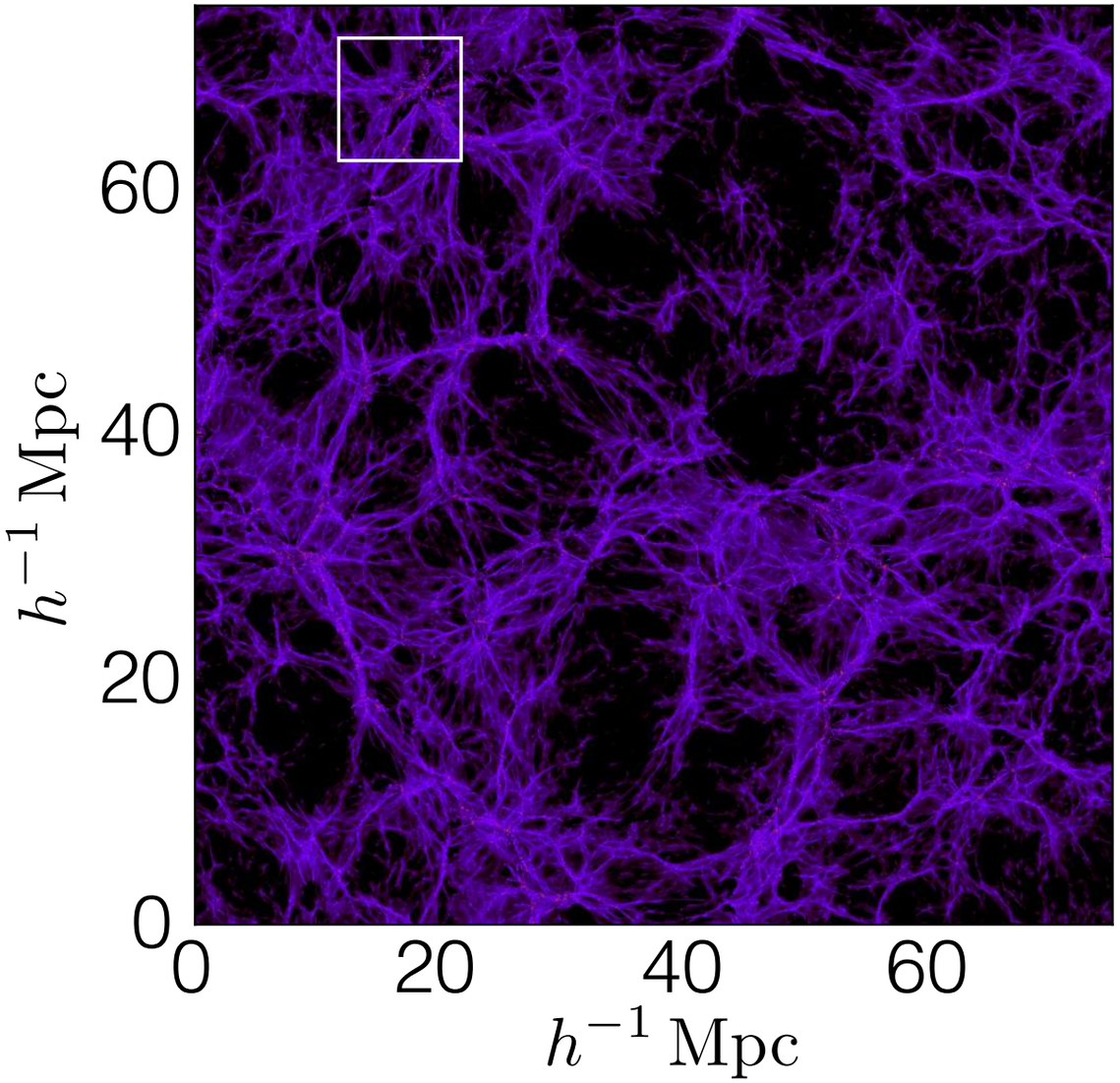
lensing x ~LSST galaxy clustering

lensing x ~LSST galaxy lensing

Caveat emptor:

- assume $T \sim b\,\delta_{\rm matter}$
- only consider 4-pt function from gravitational clustering
- assume foregrounds removed above some $k_{\parallel \rm min}$

Intensity maps are non-Gaussian (even without lensing)



There is more information beyond 2-pt statistics

e.g. $\left\langle \delta(\vec{k}_1)\delta(\vec{k}_2)\delta(\vec{k}_3) \right\rangle$

Villaescusa-Navarro et al. 2018

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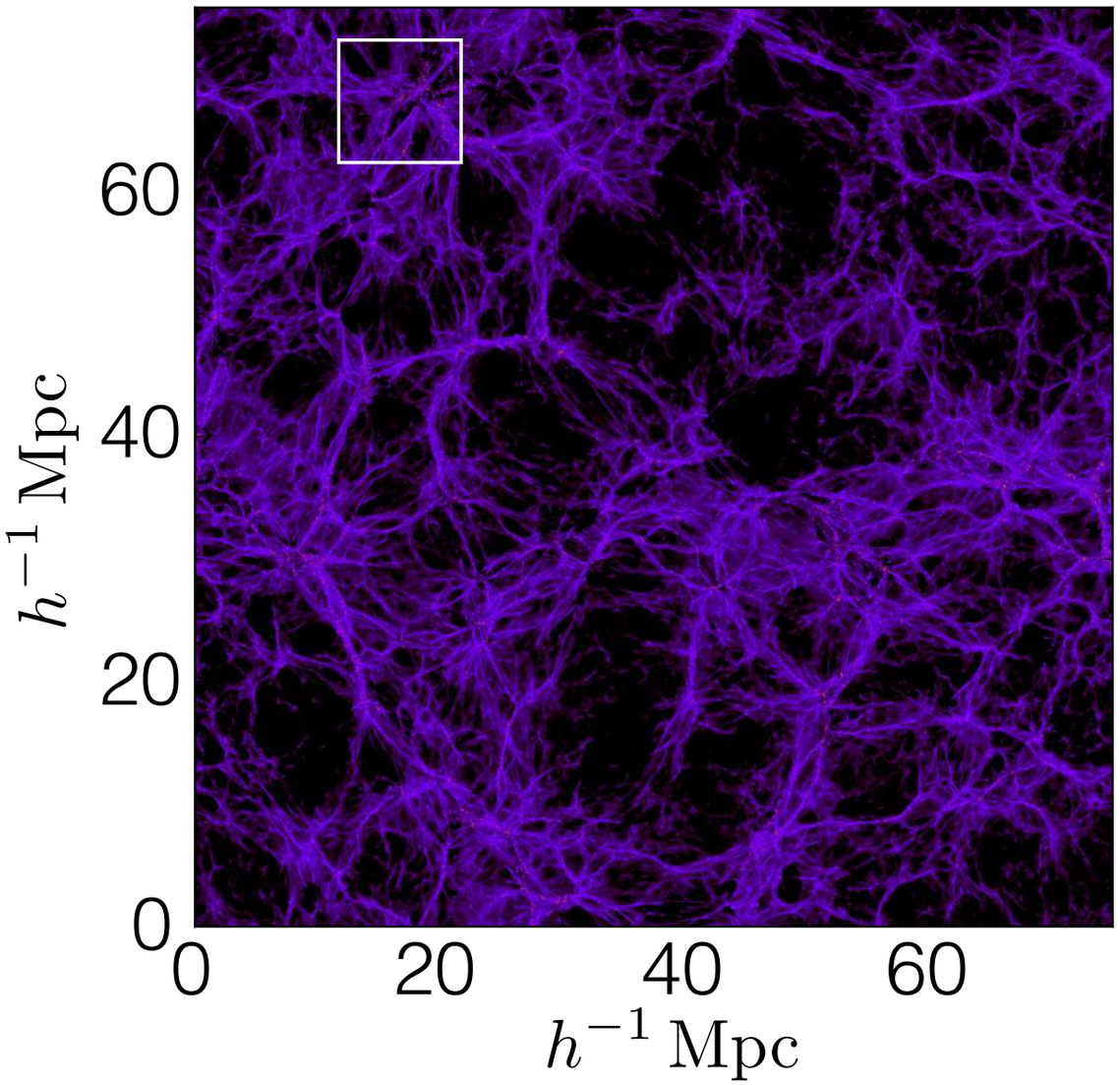

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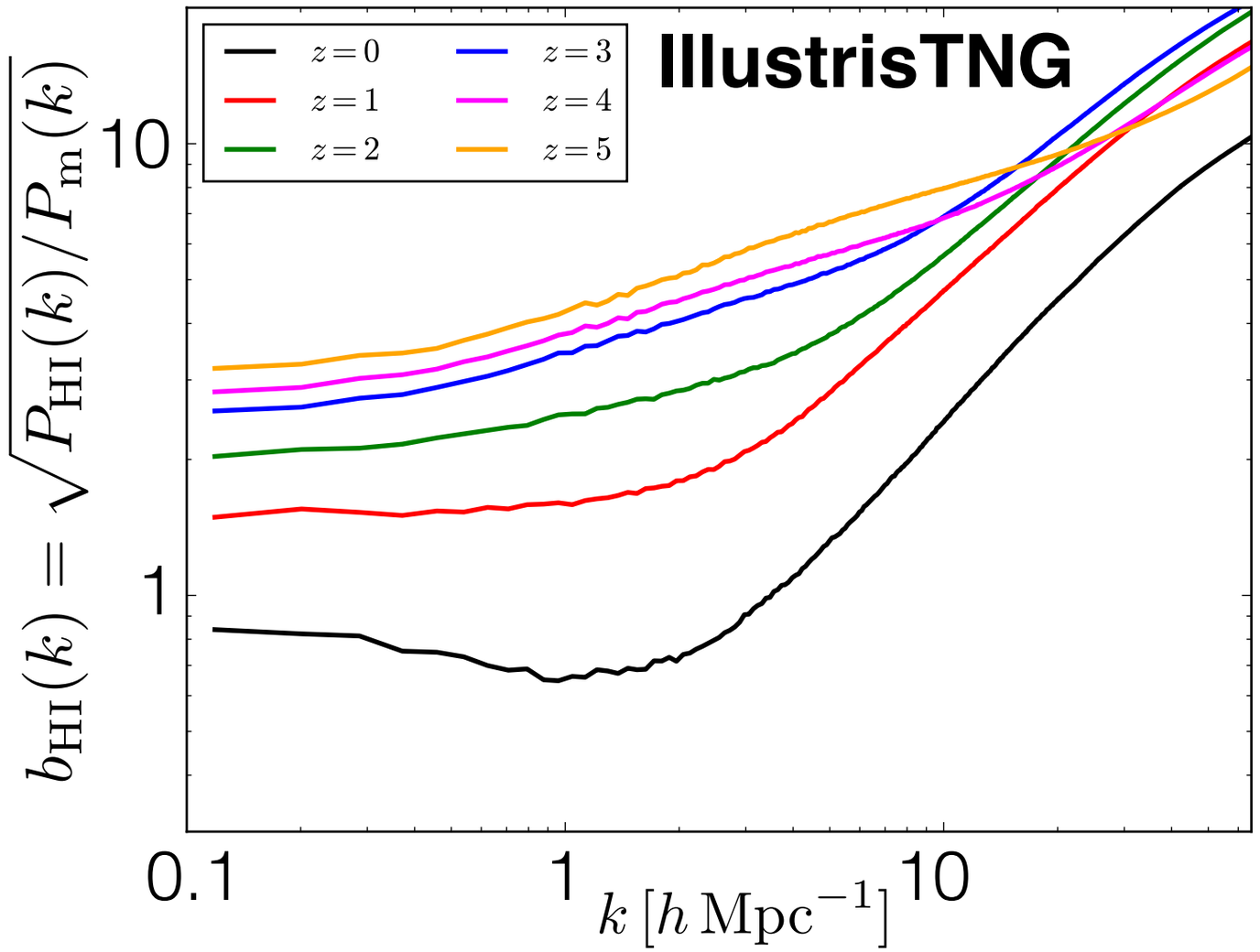
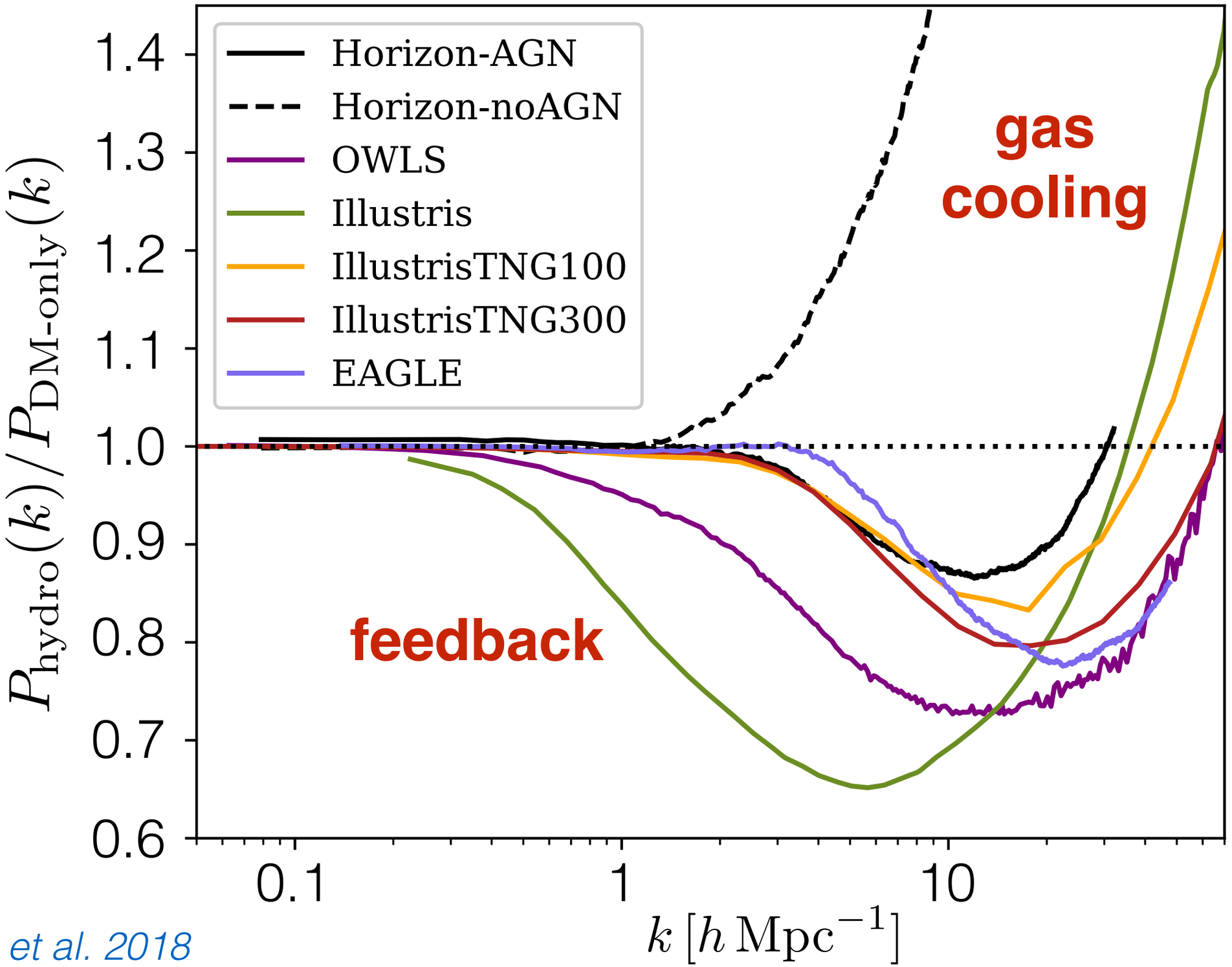
What can hydro sims teach us about the 3-pt function?

Villaescusa-Navarro et al. 2018



What do baryons do to the matter 2-pt function?

Different simulations give different results



Chisari et al. 2018

What do baryons do to the matter 3-pt function?

Old Illustris

PRELIMINARY

Preliminary plot removed in public version :)

What do baryons do to the matter 3-pt function?

IllustrisTNG

Preliminary plot removed in public version :)

What do baryons do to the matter 3-pt function?

IllustrisTNG

Preliminary plot removed in public version :)

- How do other triangle shapes look?
- How do other sims look?
- Can we model this?

Conclusions

- Techniques from CMB lensing can also be applied to line intensity maps

  see also: Zahn & Zaldarriaga 2006; Lu & Pen 2008; Pourtsidou & Metcalf 2014; Romeo et al. 2017; Schaan, Ferraro & Spergel 2018; ***SF et al. 2018***

- First detections of lensing cross-correlations may be possible in near-future surveys, *contingent on control of systematics*

- Simulations will be invaluable in guiding modeling efforts for higher-point statistics

Extra Slides

Forecasts for 21cm surveys

S/N on lensing or tidal reconstruction power spectra			
quantity / experiment	CMB S4	21-cm-S2, no wedge	21-cm-S2, with wedge
lensing x ~LSST g	367	676	358
lensing x ~LSST shear	178	367	173
lensing auto	353	216	8
tidal rec. auto	-	2240	266

21cm-S2: $2 < z < 6$, 256 x 256 6m dishes, 5 years

- Generally, strongest signal from highest z
- No need to bias-harden in cross-correlations

CMB-S4: assumed 1’ beam, $f_{sky} = 0.4$, noise = 2μK-arcmin