Anisotropic assembly bias

in theory, simulations and data

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with Will Percival & Neal Dalal

LBL Research Progress Meeting, October 15th, 2020

arXiv:1906.11823
arXiv:2004.07240

Outline

- ^j §}nL«H§_nj
- 8j_ n§}nq_H \9en 9 0h@e´ @_9 _j _h«e9§_nj
- 8j_ n§}nq_H X9e92´ 9 0h@e´ @_9 _j ?m~~ 9hqe0
- Gnj 0x«0jH0 rTn} KN~^s : ~«h h9}´

Overview

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Overview

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Overview

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Overview

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Overview

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Overview

¯0 \9®0 9 ®0}´ «HH0 T«e GK g hnL0e L0 H}_@_j X §\0 ª j_®0} 0

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Gg ? h09 «}0h0j§ §_ee Lnh_j9§0 §\0 Hnj §}9_j§ nj Hn hnenX_H9e q9}9h0§0}

?«§ d9}X0] H9e0 ~§}«H§«}0 _ ¨K Ś 0²q0H§0L §n «e§_h9§0e´ \9®0 hn}0 Hnj §}9_j_jX qn°0}

ª qHnh_jX X9e9²´ }0L _T§ «}®0´ rKN~^J N«He_Ls °_ee }09H\ «jq}0H0L0j§0L q}0H_ _nj

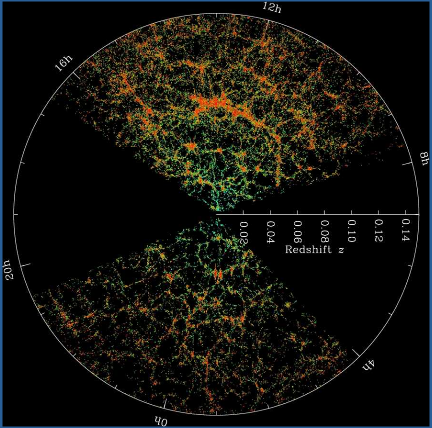
Large-scale structure

m®0}L0j _§´ »0eLI

$_h(^2) = \; _h(^2)/ \; _h \quad 1$

pn°0} q0H§}«hI

$p_h(\mathbf{c}_o; \mathbf{c}_©) \; / \; h \; _h(\mathbf{c}_o) \; _h(\mathbf{c}_©) i$



SDSS

Large-scale structure

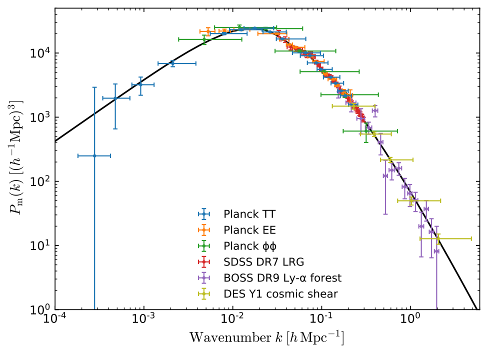
m®O}LOj _§´ »OeLI

h(²) = h(²)/ h 1

pn°O} qOH§}«hI

p h(cₒ; c©) / h h(cₒ) h(c©)i

Gn hnenX_H9e p}_jH_qeOI p h(c)



Planck, 2018

Large-scale structure

m®0}L0j _§´ »0eLI

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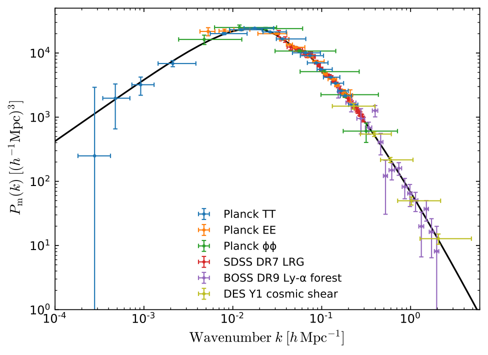
Gn hnenX_H9e p}_jH_qe0I p h (c)

[n°0®0} °0 j0_§\0} n@ 0}®0 L9}c

h9§§0} jn} }09e] q9H0 qn _§nj ²

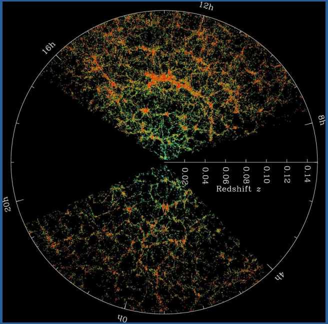


Planck, 2018

Linear bias and redshift-space distortions

Galaxies, halos, voids, 21cm, Ly forest ... all biased tracers of matter in real space, observed in redshift-space

$$_X(c) = @_X \; _h(c) \quad (\;) \quad p_X(c) = @_X^2 p \; _h(c)$$



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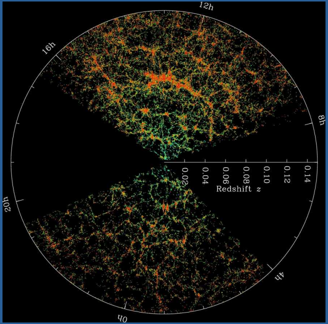
@X e_j09} H9e9} @_9 nT 0uXu X9e9²_0



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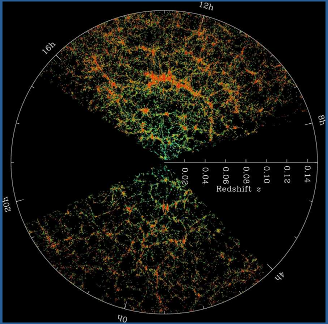
$@_X$ e_j09} H9e9} @_9 nT OuXu X9e9²_0

$@_X$ L0q0jL nj \9en h9 : }0L _T§I

- massive objects more biased
- objects more biased earlier



SDSS

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- massive objects more biased
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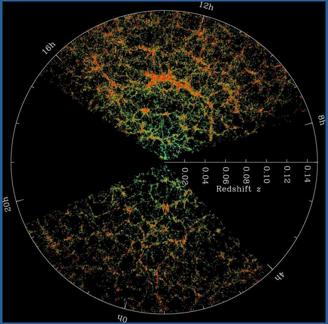
^j }0L _T§] q9H0J e_j09} §\0n}´ Tn} h9§§0}I

$$_h(c; \;\;) = (1 + T\;\;^2) \;\; _h(c)\mathrm{J} \qquad = c_k/c$$



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$@_X$ e_j09} H9e9} @_9 nT OuXu X9e9²_0

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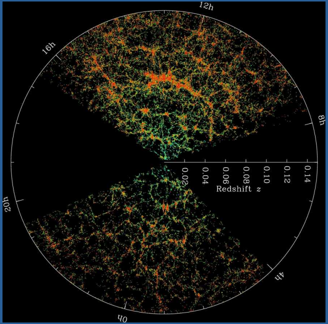
Nx«_®9e0jH0 q}_jH_qe0 Q) jn ®0enH_§´ @_9

$$ {}_X(c; \;) = (@_X + T \;^2) \; {}_h(c) $$



SDSS

Galaxy power spectrum in redshift-space

Linear theory: $p_X(c;\ ) = (@_X + T\ ^2)^2 p_h(c)$

Use Legendre expansion into multipoles:

$$p_{`}(c) = \frac{2` + 1}{2} \int_{1}^{1} p_X(c;\ ) L_{`}(\ ) L$$

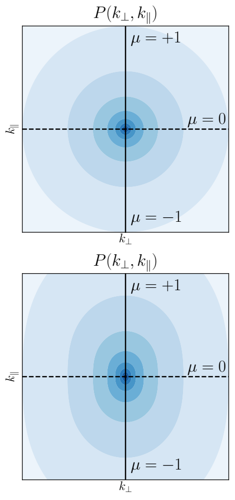
$$p_0(c) = \ @_X^2 + \frac{2}{3} T @_X + \frac{1}{5} T^2 \ \ p_h(c)$$

$$p_2(c) = \ \frac{4}{3} @_X T + \frac{4}{7} T^2 \ \ p_h(c)$$

Measuring $p_0 : p_2$ gives $@_X : T$

Note quadrupole $p_2 \ / \ T$

In real-space $p_2 = 0$



Galaxy power spectrum in redshift-space

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$$p_{\cdot}(c) = \frac{2` + 1}{2} \int_{1}^{1} p_X(c;\ ) L_{\cdot}(\ ) L$$

$$p_0(c) = \left(@_X^2 + \frac{2}{3} T @_X + \frac{1}{5} T^2 \right) p_h(c)$$

$$p_2(c) = \left(\frac{4}{3} @_X T + \frac{4}{7} T^2 \right) p_h(c)$$

Measuring $p_0 : p_2$ gives $@_X : T$

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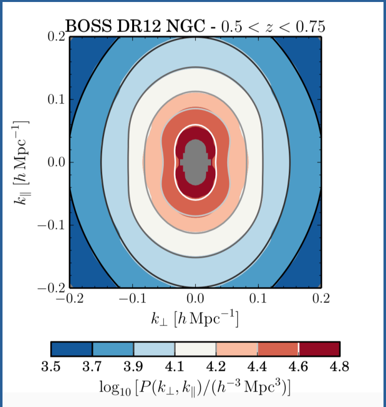


Alam+2016

Growth rate T

One of the key parameters

$$T \quad \frac{L \ln K(9)}{L \ln 9}$$

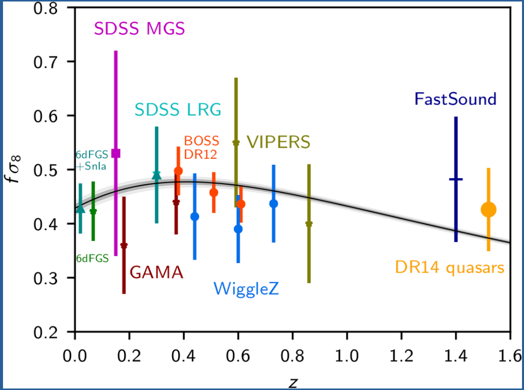
W| q}0L_H§_njI $T = \quad {}_{\mathrm{m}}(¶)^{0:55}$

^h qn}§9j§ Tn}I

- Testing Gravity
- Constraining neutrino masses
- Testing dark energy models
- ...

G«}}0j§e´ 5 10 t

S«§«}0 «}®0´ rKN~^J N«He_Ls 0²qOH§0L §n }09H\ 1 5 t q}0H_ _nj

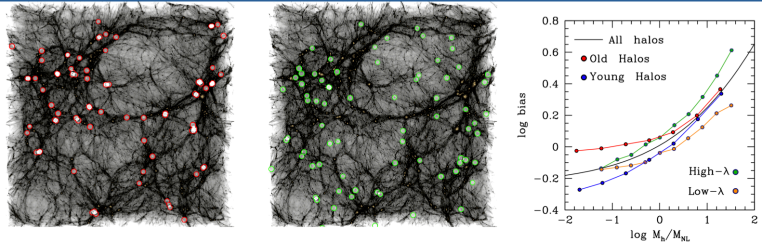


Planck, 2018

Assembly bias

Bias depends on other *H9e9}* properties, for fixed halo mass and redshift

- Formation history
- Age
- Spin
- Concentration
- Shape ...



Wechsler+, 2018

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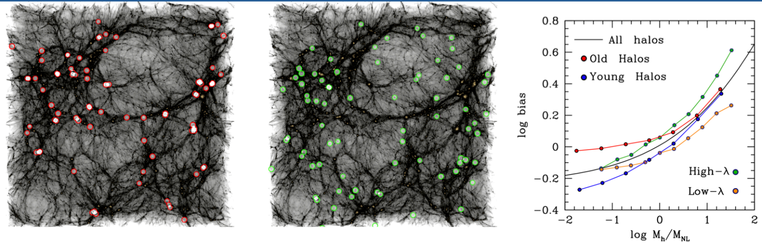


Wechsler+, 2018

K0§0H§0L _j _h «e9§_nj J jn Hnj®_jH_jX 0®_L0jH0 _j L9§9

Non-scalar bias

8§ §\0 e_j09} e0®0e _j $_h$ °0 « «9ee´ 9 «h0I $_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c)$

Non-scalar bias

8§ §\0 e_j09} e0®0e _j h °0 « «9ee´ 9 «h0I X(c) = (@X + T 2) h(c)

¦ \0}0] 9jn§\0} §0}h e_j09} _j h Ś §}9H0e0 q9}§ nT §\0 §_L9e »0eLI

_a(2) = (r _ r a r 2 _a/3) h(2) ( ) _a(c) = (c _c_a/c2 _a/3) h(c)

Non-scalar bias

8§ §\0 e_j09} e0®0e _j $_h$ °0 « «9ee´ 9 «h0I $_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c)$

¦ \0}0ļ 9jn§\0} §0}h e_j09} _j $_h$ Ś §}9H0e0 q9}§ nT §\0 §_L9e »0eLI

$_{\_a}(^2) = (\,r\,\_\,r_a\,r\ ^2\quad _{\_a}/3)\ _h(^2)\quad (\ )\quad _{\_a}(\mathbf{c}) = (c\_c_a/c^2\quad _{\_a}/3)\ _h(\mathbf{c})$

$$_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c) + @_{\_a}\ _{\_a}(\mathbf{c})$$

Non-scalar bias

8§ §\0 e_j09} eO®Oe _j $_h$ °0 « «9ee´ 9 «h0I $_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c)$

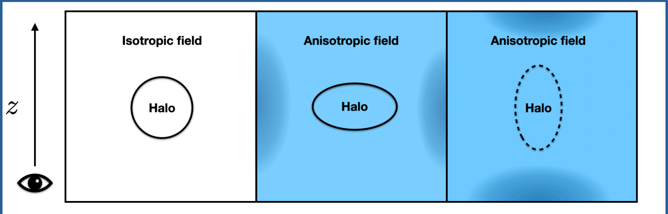
¦ \0}0ļ 9jn§\0} §0}h e_j09} _j $_h$ Ś §}9H0e0 q9}§ nT §\0 §_L9e »0eLI

$_{\_a}(^2) = (\ r\ \_\ r_a\ r\ \ ^2\ \ _{\_a}/3)\ _h(^2)\ \ (\ )\ \ _{\_a}(\mathbf{c}) = (c\_c_a/c^2\ \ _{\_a}/3)\ _h(\mathbf{c})$

$$_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c) + @\_a\ \ _{\_a}(\mathbf{c})$$

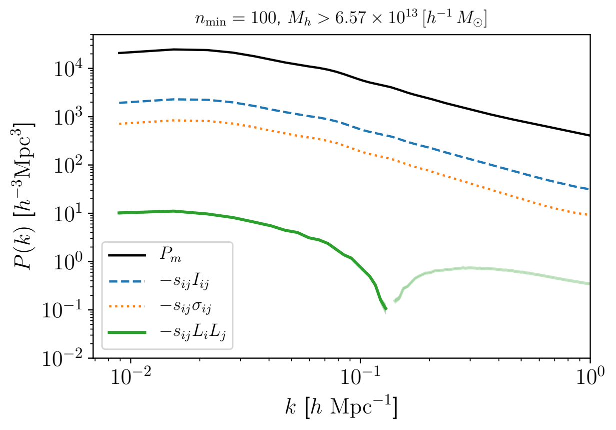
mje´ jnj] H9e9} q}nq0}§_0 H9j Hn}}0e9§0 °_§\ §_L9e »0eL

- projected sizes, velocity dispersion & angular momentum



How correlated are halos & tidal field?

We use 1000 Quijote N-body sims (Villaescusa-Navarro+, 2019) to measure cross-correlations



8mv©·ok

Non-scalar bias

8§ §\0 e_j09} e0®0e _j h °0 « «9ee´ 9 «h0I $_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c)$

¦ \0}0l 9jn§\0} §0}h e_j09} _j h Ś §}9H0e0 q9}§ nT §\0 §_L9e »0eLI

$_a(^2) = (\, r\,\_\,r_a\,r\ ^2\ \ _a/3)\ _h(^2)\ \ (\ )\ \ _a(\mathbf{c}) = (c\_c_a/c^2\ \ _a/3)\ _h(\mathbf{c})$

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mje´ jnj] H9e9} q}nq0}§_0 H9j Hn}}0e9§0 °_§\ §_L9e »0eL

- projected sizes, velocity dispersion & angular momentum

Non-scalar bias

8§ §\0 e_j09} e0®0e _j $_h$ °0 « «9ee´ 9 «h0I $_X(\mathbf{c}) = (@_X + T\ ^2)\ _h(c)$

¦ \0}0l̥ 9jn§\0} §0}h e_j09} _j $_h$ Ś §}9H0e0 q9}§ nT §\0 §_L9e »0eLI

$$_{\_a}(^2) = (\,r\,\_r_a\,r\ \ ^2\ \ \ _{\_a}/3)\ \ _h(^2)\ \ (\ )\ \ \ _{\_a}(\mathbf{c}) = (c\,\_c_a/c^2\ \ \ _{\_a}/3)\ \ _h(\mathbf{c})$$

$$_X(\mathbf{c}) = (@_X + T\ ^2)\ \ _h(c) + @_{\_a}\ \ _{\_a}(\mathbf{c})$$

mje´ jnj] H9e9} q}nq0}§_0 H9j Hn}}0e9§0 °_§\ §_L9e »0eL

– projected sizes, velocity dispersion & angular momentum

8¶_h«§\9e ´h h0§}´ : $@_x$ $@_{¶¶}$

$$_X(c;\ \ ) = (@_X + T\ ^2)\ \ _h(c) + @_{¶¶}(\ ^2\ \ \ 1/3)\ \ _h(c)$$

$$= \ @_X\ \ \ @_x/3 + (T + @_x)\ \ ^2\ \ \ _h(c)$$

Non-scalar bias

– projected sizes, velocity dispersion & angular momentum

Anisotropic assembly bias (AB)

$$_X = (@_X + T \;\; ^2) \;\; _h \quad Q) \qquad _X = (@_X \quad @_x/3 + (T + @_x) \;\; ^2) \;\; _h$$

Anisotropic assembly bias (AB)

$${}_X = (@_X + T\ {}^2)\ {}_h\quad Q)\qquad {}_X = (@_X\quad @_x/3 + (T + @_x)\ {}^2)\ {}_h$$

p9}9h0§0} $@_x$ _ §\0 **anisotropic assembly bias**

Anisotropic assembly bias (AB)

$$_X = (@_X + T \quad ^2) \quad _h \quad Q) \qquad _X = (@_X \quad @_x/3 + (T + @_x) \quad ^2) \quad _h$$

p9}9h0§0} $@_x$ _ §\0 **anisotropic assembly bias**

~n«}H0 nT 9j_ n§}nq´ _j §\0 }09e q9H0 qn°0} q0H§}«h

Anisotropic assembly bias (AB)

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p9}9 h 0§0} $@_x$ _ §\0 **anisotropic assembly bias**

~n«}H0 nT 9j_ n§}nq´ _j §\0 }09e q9H0 qn°0} q0H§}«h

8LL_§_nj9e n«}H0 nT 9j_ n§}nq´ _j §\0 }0L _T§] q9H0

Anisotropic assembly bias (AB)

$$ _X = (@_X + T \; ^2) \; _h \quad Q) \qquad _X = (@_X \quad @_x/3 + (T + @_x) \; ^2) \; _h $$

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8LL_§_nj9e n«}H0 nT 9j_ n§}nq´ _j §\0 }0L _T§] q9H0

i n§0 $@_x$ _ q0}T0H§e´ L0X0j0}9§0 °_§\ T R

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$$_X = (@_X + T\ ^2)\ _h\ \ Q)\qquad _X = (@_X\ \ @_x/3 + (T + @_x)\ ^2)\ _h$$

p9}9 h0§0} $@_x$ _ §\0 **anisotropic assembly bias**

~n«}H0 nT 9j_ n§}nq´ _j §\0 }09e q9H0 qn°0} q0H§}«h

8LL_§_nj9e n«}H0 nT 9j_ n§}nq´ _j §\0 }0L _T§] q9H0

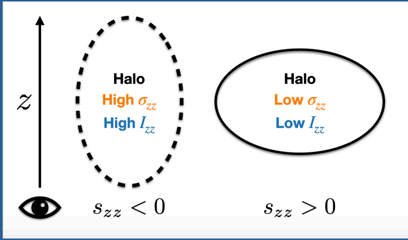
i n§0 $@_x$ _ q0}TOH§e´ L0X0j0}9§0 °_§\ T R

$@_x$ = 0 _TI

- Selection independent of halo orientation, e.g. projected size, velocity dispersion, angular momentum
- *n}* if observed tracer and host halo randomly misaligned

Halo selection based on tensor properties

Selection on radial halo extent & velocity dispersion oK in **real space**



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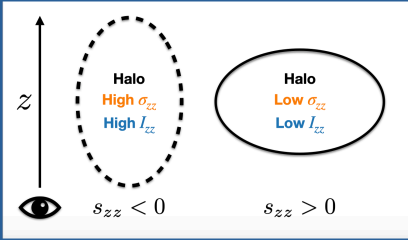

Real-space $p_2 = T = 0$

$p_2 \neq 0 \rightarrow \partial_x \neq 0$

Halo selection based on tensor properties

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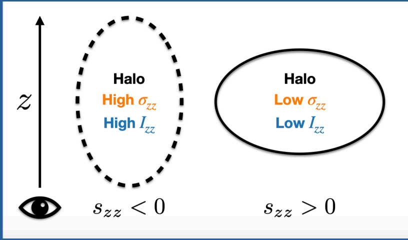
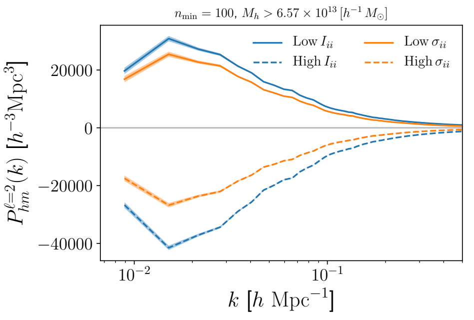




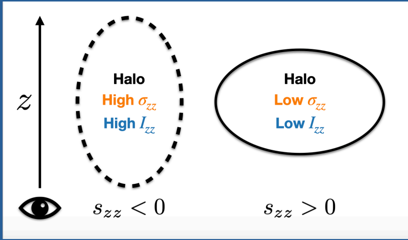
AO+2019

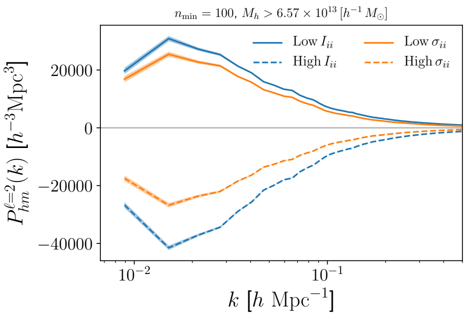
Real-space p_2 = T = 0

p_2 6= 0 ! @$_x$ 6= 0

Halo selection based on tensor properties

Selection on radial halo extent & velocity dispersion oK in **real space**





AO+2019

Real-space $p_2 = T = 0$

$p_2 \not\in 0$! $@_x \not\in 0$

Halos: $@_x$ 1 2

Redshift-space T 0:7

What about real galaxies?

When split on orientation dependent quantities, do galaxies show different clustering strength?

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When split on orientation dependent quantities, do galaxies show different clustering strength?

Baryon Oscillation Spectroscopic Survey
BOSS DR12 galaxy sample

10^6 X9e9²´ }0L _T§

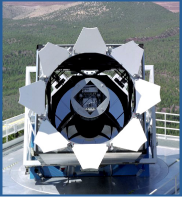
$0{:}15 <$ ¶ $< 0{:}7$

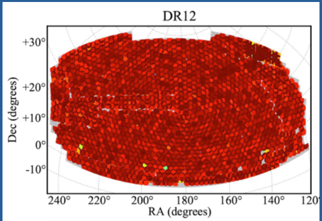
d«h_jn« }0L X9e9²_0 J @X 2

Nee_q§_H9e J g \ 10^{13} g / \

W9e9²´ 9 h qe0

- LOWZ $(0{:}15 <$ ¶ $< 0{:}43)$
- CMASS $(0{:}43 <$ ¶ $< 0{:}7)$





SDSS

How do we look for AB?

Main idea – split on orientation ($_{\star}$) $\rightarrow$ look for differences in anisotropy (∂_x)

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Subsamples matching $j(¶)$ have matching T

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Galaxy Properties from Portsmouth Group

– velocity dispersion $_?$ (1D)
– stellar mass $g_?$

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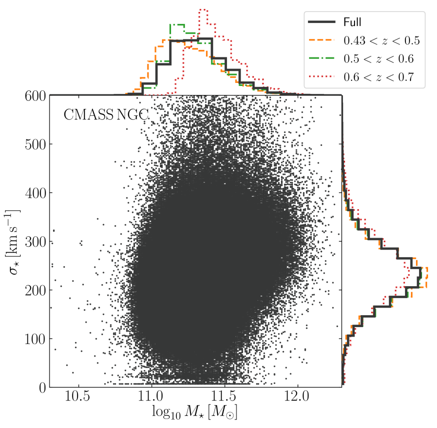

How do we look for AB?

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Subsamples matching j(¶) have matching I

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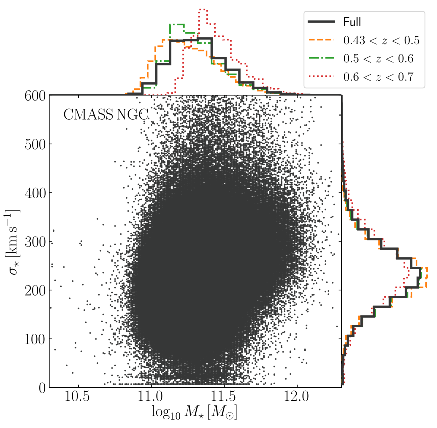
Mismatch p_2 ! evidence $@_x$ 6= 0

Galaxy Properties from Portsmouth Group

- velocity dispersion $_?$ (1D)
- stellar mass g $_?$

Split on $_?$ = split on orientation & galaxy mass ($^2_?$ / g $_?$)



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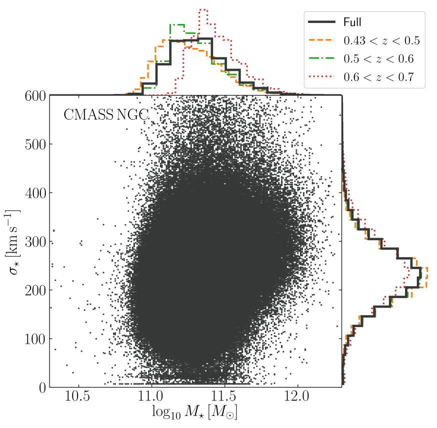
Galaxy Properties from Portsmouth Group

- velocity dispersion ? (1D)
- stellar mass g ?

Split on ? = split on orientation & galaxy bias @$_X$(g ?) ! different p_0 & p_2



How do we look for AB?

Main idea – split on orientation (?) ! look for differences in anisotropy (@x)

Subsamples matching j(¶) have matching T

Subsamples can have different @X & @x

Find subsamples matching p_0 & j(¶)!

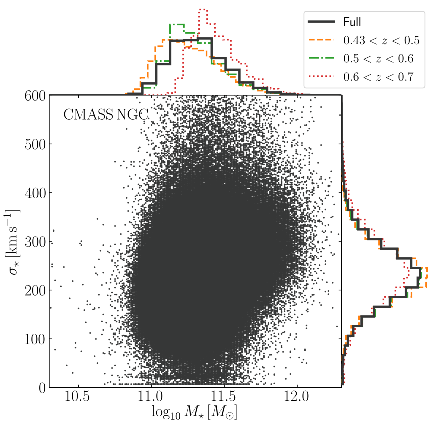
Mismatch p_2 ! evidence @x ≠ 0

Galaxy Properties from Portsmouth Group

- velocity dispersion ? (1D)
- stellar mass g ?

Split on ? = split on orientation & galaxy bias @X(g ?) ! different p_0 & p_2

Use g ? to remove mass (@X) dependence



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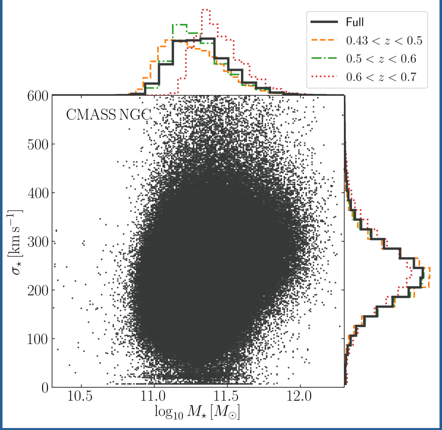
Galaxy Properties from Portsmouth Group

- velocity dispersion ? (1D)
- stellar mass g ?

Split on ? = split on orientation & galaxy bias @$_X$(g ?) ! different p_0 & p_2

Make subsamples with either

- high g ?, low ? n}
- low g ?, high ?



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- Galaxy Properties from Portsmouth Group
  - velocity dispersion $_?$ (1D)
  - stellar mass $g_?$
- Split on $_?$ = split on orientation & galaxy bias $@_X(g_?)$! different p_0 & p_2
- Make subsamples with either
  - high $g_?$, low $_?$ $n\}$
  - low $g_?$, high $_?$

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[n° Ln °0 h9§H\ j(¶)y

- Need to account for ¶-evolution
- Work with percentiles
- Compute percentiles in 30 ¶-bins
- Split on percentiles in each ¶-bin
- Q) matching j(¶)

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[n° Ln °0 h9§H\ hnjnqn℮0 y

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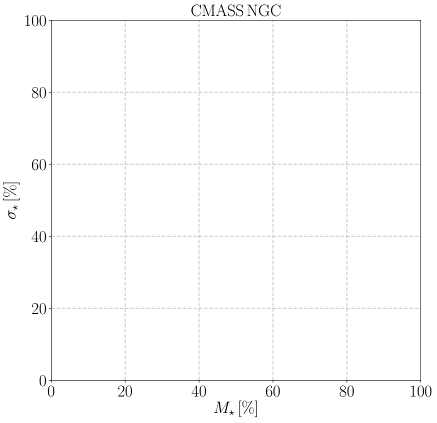
[n° Ln °0 h9§H\ hnjnqn℮0 y

– Grid of 25 ($_?$; g $_?$) subsamples



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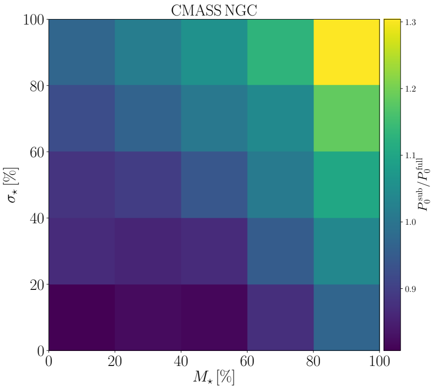
[n° Ln °0 h9§H\ hnjnqne0 y

- Grid of 25 (?; g ?) subsamples
- Measure mean amplitude



>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q!`BH2QMQ! FB7Q`M /Bz2`2M+(2 b#[)BM MBbQi`QT

am#b KTH2b K(Mx)+? B2M;K i+?7BM;

am#b KTH2b + M ? #p2 #[Bz2`2Mi

6BM/ bm#b KTH2b K(Mx)+? 5BM;

JBbK iS2?? 2pB/2M+#[62

>Qr /Q r2 K i+? KQMQTQH2b\

:`B/ Q7(k;8J?) bm#b KTH2b

J2 bm`2 K2 M KTHBim/2

GQ(r?; J?) HQr KTHBim/2

>B;(??; J?) ?B;? KTHBim/2

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q`B2QMQ FB7QM /Bz2`2M+(2 b#[)BM MBbQi`QT

am#b KTH2b K(Mx)+?BM2;K i+?BM;

am#b KTH2b + M ?#p2 #[Bz2`2Mi

6BM/ bm#b KTH2b K(M*)5BM;

JBbK iS2? 2pB/2M#[+62

>Qr /Q r2 K i+? KQMQTQH2b\

:`B/ Q7(k;8J?) bm#b KTH2b

J2 bm`2 K2 M KTHBim/2

"mi r2 r Mi K i+?BM; KTHBim/25

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q`B2QMQ F B7QM /Bz2`2M+(2 b#[)B M MBbQi`QT

- am#b KTH2b K(x)+? B M ;K i+?B M ;
- am#b KTH2b + M ? #p2 #[Bz2`2Mi
- 6BM/ bm#b KTH2b K(x)+? B M ;
- JBbK i+?2 2pB/2M+2

>Qr /Q r2 K i+? KQMQTQH2b\

6BM HHv b2H2+i b KTH2b rBi?,

?B;?2 - HQr

HQr - ?B;?

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q`BH2QMQ F B7QQM /Bz2`2M+(2 b#[)BM MBbQi`QT

am#b KTH2b K(Mx)+? BM2 ;K i+?7BM;

am#b KTH2b + M ? #p2 #[Bz2`2Mi

6BM/ bm#b KTH2b K(Mx)+5BM;

JBbK iS2? 2pB/2M#[+620

>Qr /Q r2 K i+? KQMQTQH2b\

6BM HHv b2H2+i b KTH2b rBi?,

?B;J?? - HQ?r

HQJr? - ?B;??

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q` B2QMQ FB7Q`M /Bz2`2M+( b#[)BM MBbQi`QT

am#b KTH2b K(Mx)+? BM2 ;K i+?BM;

am#b KTH2b + M ?#p2 #[Bz2`2Mi

6BM/ bm#b KTH2b K(Mx)5BM;

JBbK iS[2]? 2pB/2M#[+62

q? i #Qmi [m /`mTQH2b\

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M)Q` B2QMQ F B7QM /Bz2`2M+2 b#[)BM MBbQi`QT

am#b KTH2b K(x)+? BM ;K i+?BM;

am#b KTH2b + M ?#p2 #[Bz2`2Mi

6BM/ bm#b KTH2b K M(x) 5BM;

JBbK i$_2 ? 2pB/2M#[+20

q? i #Qmi [m /`mTQH2b\

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q($M_?$)Q:`BH2QMQ FB7QM /Bz2`2M+(b#[)BM MBbQi`QT

am#b KTH2b K(Ix)+?BpM2 ;K i+?7BM;

am#b KTH2b + M ?#p2 #[Bz2`2Mi

6BM/ bm#b KTH2S_0 KM(Ix)5BM;

JBbK iS_2? 2pB/2M#[+62 0

J i+?S_0 M(Ix)! K i+?S_2

R e

>Qr /Q r2 HQQF 7Q` "\

J BM B/2 bTHBi Q(M?)Q!`B?2QMQ F B7QQM /Bz2`2M+(2 b#[)BM MBbQi`QT

am#b KTH2b K(Mx)+?BM;K i+?7BM;

am#b KTH2b + M ? #p2 #[Bz2`2Mi

6BM/ bm#b KTH2b0 K M(x) 5BM;

JBbK iS2? 2pB/2M#[+62 0

J i+?S0 M(x) ! K i+?S2

JBbK iS2!? 2pB/2M#[+62 0

Re

_2bmHib *J aaL:*

PYkyky

R d

_2bmHib GPqw L:*

PYkyky

.2i2+iBQM bB;MB}+ M+2

Ib2 KQ+F ; H tv + i HQ;b

aTHBi 2 +? KQ+F BM irQ ` M/QK bm#b KTH2b

*`Qbb@+Q``2H i2 2 +? bm#b KTH2 rBi? 7mHH KQ+F

JBMBKBx2 $S^{bm#,1}$ ` $S^{bm#,2}$

J i+?BM; KQMQ$_0$ TQ$_1$ H2b

rBi?1BMi HH b+ H2b

.Bz2`2Mi [m /`m$_2$ T6 QH2b

K Mvöb r v5

4) #$_[$ 6 0 #2ir22M bm#b KTH2b

.2i2+iBQM bB;MB}+ M+2

lb2 KQ+F ; H tv + i HQ;b

aTHBi 2 +? KQ+F BM irQ ` M/QK bm#b KTH2b

*`Qbb@+Q``2H i2 2 +? bm#b KTH2 rBi? 7mHH KQ+F

JBMBKBx2 $S = S^{bm\#,1}$ ` $S^{bm\#,2}$

J i+?BM; KQMQ$_0$TQ$_1$H2b

rBi?1BMi HH b+ H2b

.Bz2`2Mi [m /`m$_2$T6QH2b

K Mvöb r v5

4) #[6 0 #2ir22M bm#b KTH2b

*QK#BM2/ /2i2+iBQM bB;MB}+

5 mbBRM$_{k}$ t_{i}; 0:15 ?JT +[1]

PYkyky

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 " E

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 "

q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
Qi?2` i? M ? HQK bb

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 " E

q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
Qi?2` i? M ? HQ K bb

Pm` /2i2+iBQM Bb i?2 }`bi iQ52t+22/ i?2 I

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 " E

q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
Qi?2` i? M ? HQ K bb

Pm` /2i2+iBQM Bb i?2 }`bi iQ5 2t+22/ i?2 F

q2 QMHv K2#bQm7 2bm#b KTH2b- MQi#i5?2 7

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 " E

q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
Qi?2` i? M ? HQ K bb

Pm` /2i2+iBQM Bb i?2 }`bi iQ52t+22/ i?2 H

q2 QMHv K2 #bQm`7 2bm#b KTH2b- MQi#i5?2 7

6Q` "Paa ; H tB2b r2 }M/ bm#b0K1TH02b rB

.Bb+mbbBQM

- q2 T`2b2Mi bB;MB}+Mi 2pB/2M+2 Q7 " E
- q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
  Qi?2` i? M ? HQ K bb
- Pm` /2i2+iBQM Bb i?2 }`bi iQ 52t+22/ i?2 K
- q2 QMHv K2#bQm7 2bm#b KTH2b- MQi i#i5?2 7
- 6Q` "Paa ; H tB2b r2 }M/ bm#b 0K1TH02b rB
- 6Q` ? HQb BM bBKb r2 7QmM#/ b1m#2b KTH

.Bb+mbbBQM

q2 T`2b2Mi bB;MB}+ Mi 2pB/2M+2 Q7 " E

q2 b?Qr +Hmbi2`BM; Q7 ; H tB2b /2T2M/
Qi?2` i? M ? HQ K bb

Pm` /2i2+iBQM Bb i?2 }`bi iQ52t+22/ i?2 H

q2 QMHv K2#bQm7 2bm#b KTH2b- MQ i#i5?2 7

6Q` "Paa ; H tB2b r2 }M/ bm#b 0K1TH0:2b rB

6Q` ? HQb BM bBKb r2 7QmM#/ b1m#2b KTH

JBb HB;MK2Mi Q7 ; H tB2b M/ ? HQb /2

kR

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

- 6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b
- 6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b

6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/

6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

- 6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b
- 6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/ =
- 6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5
- 1G:b +QMi B4M /KmQbì2 7 +2@QM i? M 2/;2 QM ; H tB2b

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

- 6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b
- 6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/
- 6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5
- 1G:b +QMi BM 4) /KQbi2 7 +2@QM i? M 2/;2 QM ; H tB2b
- >Qr2p2`- 1G:b HB;M2/ r2 F2` i? M G_:b

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

- 6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b
- 6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/
- 6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5
- 1G:b +QMi BM /mbi2 7 +2@QM i? M 2/;2 QM ; H tB2b
- >Qr2p2`- 1G:b HB;M2/ r2 F2` i? M G_:b
- q2 `2 +m``2MiHv HQQFBM; BMiQ 1G: i `;2ib iQ b22 ?Q

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b

6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/

6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5

1G:b +QMi BM /KQbi 2 7 +2@QM i? M 2/;2 QM ; H tB2b

>Qr2p2`- 1G:b HB;M2/ r2 F2` i? M G_:b

q2 `2 +m``2MiHv HQQFBM; BMiQ 1G: i `;2ib iQ b22 ?Q

.1aA GmKBMQmb _2/ : H tB2b UG_:bV

*QMb2[m2M+2b 7Q` .1aA

J BM [m2biBQMb, Ab i `;2i b2H2+iBQM Q7 s Q`B2Mi iBQM /2T2

.1aA 1KBbbBQM GBM2 : H tB2b U1G:bV

6B#2` K ;MBim/2 pbX KQ/2H K ;MBim/2b
6 BMi ; H tB2b M2 ` i?2 /2i2+iBQM i?`2b?QH/ +QmH/
6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5
1G:b +QMi B4M /KQi2 7 +2@QM i? M 2/;2 QM ; H tB2b
>Qr2p2`- 1G:b HB;M2/ r2 F2` i? M G_:b
q2 `2 +m``2MiHv HQQFBM; BMiQ 1G: i `;2ib iQ b22 ?Q

.1aA GmKBMQmb _2/ : H tB2b UG_:bV

aBKBH ` iQ "Paa- #2ii2` K2 bm`2K2Mi Q7 "

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- 6 BMi ; H tB2b `2 HbQ KQ`2 MmK2`Qmb5
- 1G:b +QMi B4M /Kmbi2 7 +2@QM i? M 2/;2 QM ; H tB2b
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- `2 G_:b /mbi 7`22\

Pi?2` +QMb2[m2M+2b

:`QmTbf+Hmbi2`b 7QmM/ BM `2/b?B7i@

Other consequences

W}n«q ¤He« §O} Tn«jL _j }OL _T§] q9HO

- ... in simulations exhibit strong AB signal in their clustering

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W}n«q ¤He« §0} Tn«jL _j }0L _T§] q9H0

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Gn«eL @0 9j _ «0 Tn} |~K °_§\ ©oHh ^j§0j _§´ g9qq_jX

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i nj] H9e9} \9en q}nq0}§_0 9}0 Hn}}0e9§0L ° _§\ e9}X0] H9e0 §_L9e »0eL

m}_0j §9§_nj L0qu 0e0H§_nj 0¸0H§ 9jL §_L9e 9e_Xj h0j§ nT \9en ¤X9e9²_0 I

$X = (@x \quad @x/3 + (T + @x) \quad ^2) \quad h$

¯0 »jL §0}h e_c0 $@_x$ q}0 0j§ _j _h «e9§_nj 9jL ?m~~ X9e9²_0

- ~qe_§ X9e9²_0 @9 0L nj e_j0 nT _X\§ ®0enH_§´ L_ q0} _nj ? 9jL g ?
  Ś ~_h qe0 §0 § Ś «@ 9h qe0 h9§H_jX p_0 Q) h9§H_jX p_2

W9e9²´ He« §0}_jX L0q0jL nj n§\0} enH9e q}nq0}§_0 J jn§ a« § \9en h9 I

First detection of galaxy assembly bias to exceed 5 **!**

Problem for RSD since $@_x$ **completely degenerate with** T **!**

d|W J NdW J X}n«q ¤He« §0} J ©oHhJ ®n_L J 0§Hu 0e0H§_nj 0¸0H§ y

Other splits and approaches

We find no signal when splitting on projected physical size $|_0$ & $g_?$

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AO+2020

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AO+2020

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  - Perhaps explaining previous results...

AO+2020

Summary

i nj] H9e9} \9en q}nq0}§_0 9}0 Hn}}0e9§0L °_§\ e9}X0] H9e0 §_L9e »0eL

m}_0j§9§_nj L0qu 0e0H§_nj 0¸0H§ 9jL §_L9e 9e_Xj h0j§ nT \9en ¤X9e9²_0 I

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¯0 »jL §0}h e_c0 $@_x$ q}0 0j§ _j _h«e9§_nj 9jL ?m~~ X9e9²_0

- ~qe_§ X9e9²_0 @9 0L nj e_j0 nT _X\§ ®0enH_§´ L_ q0} _nj ? 9jL g ? Ś ~_h qe0 §0 § Ś «@ 9h qe0 h9§H_jX p_0 Q) h9§H_jX p_2

W9e9²´ He« §0}_jX L0q0jL nj n§\0} enH9e q}nq0}§_0 J jn§ a« § \9en h9 I

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