SubHalo Abundance Matching for eBOSS Galaxies

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- Principles
  - Galaxy Bias Models
  - SubHalo Abundance Matching Description
  - Two-point Correlation Function
- SHAM implementation
- Results
- Conclusions and Outlooks

SHAM Principles: Galaxy Bias

✓ self-consistent framework

Theories: DM

validate

Simulations

SHAM Principles: Galaxy Bias

✓ self-consistent framework

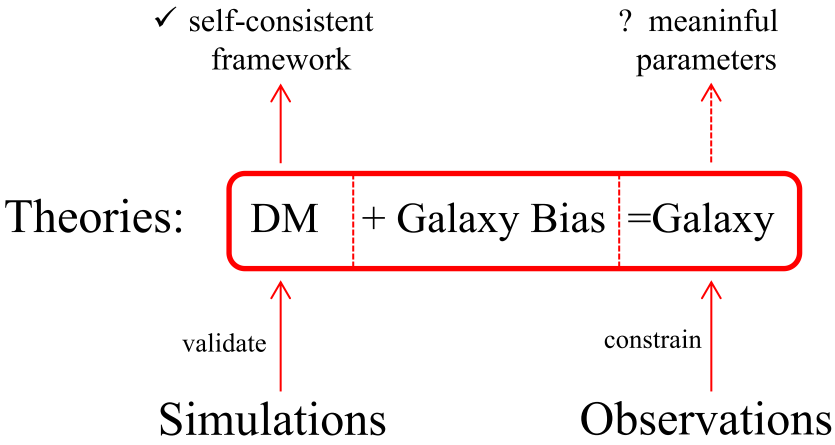
? meaninful parameters

Theories: DM | Galaxy

validate: Simulations → DM

constrain: Observations → Galaxy

SHAM Principles: Galaxy Bias



SHAM Principles: Galaxy Bias

✓ self-consistent framework

✓ reliable link

✓ meaningful parameters

Theories: DM + Galaxy Bias =Galaxy

validate

constrain

Simulations

Observations

SHAM Principles: Galaxy Bias

✓ self-consistent framework

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validate

calibrate

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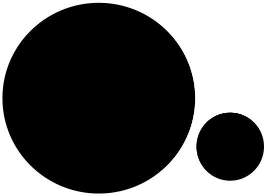
Simulations **SHAM** Observations

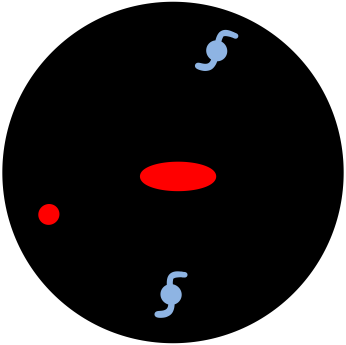
SHAM Principles: Galaxy Bias Models



Halo/Subhalo Simulations

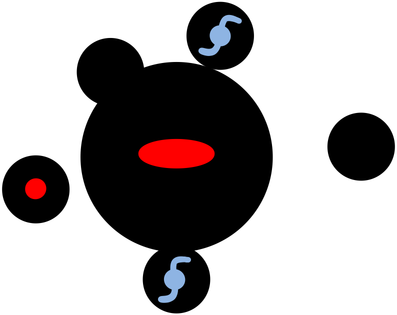
ELG/LRG Observations

SHAM Principles: Galaxy Bias Models



HOD

$P(N|M_{halo})$



SHAM

$P(M_{(sub)halo})$

SHAM Principles: SHAM Descriptions

Select halos (i.e., galaxies) so that they:

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- Have **the same number density** as observations

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Select halos (i.e., galaxies) so that they:

- Have **the same number density** as observations
- Match the **galaxy probability distribution function** (P.D.F)

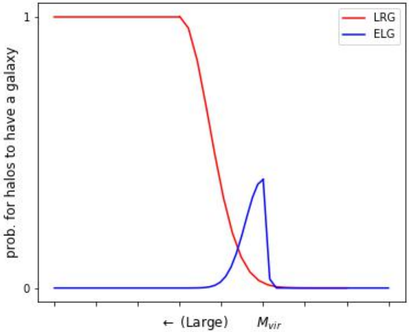


Fig 1. The ideal probability distribution function for halos with a certain mass to have a galaxy inside

SHAM Principles: SHAM Descriptions

The most massive halos: all have an LRG, no one hosts an ELG

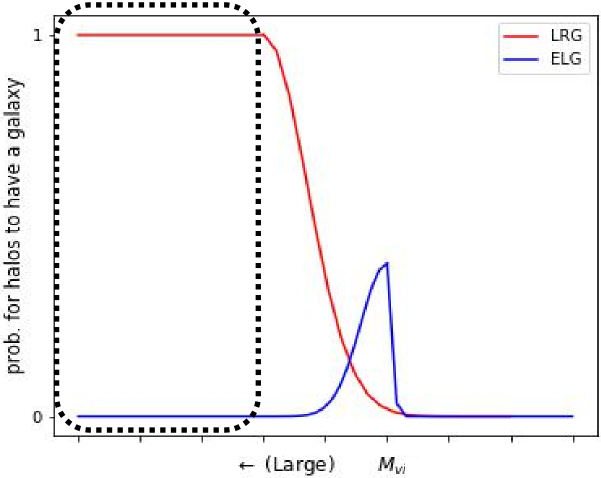
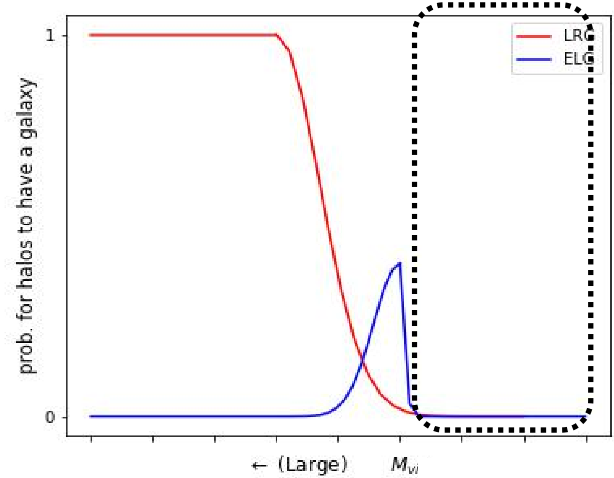


Fig 1. The ideal probability distribution function for halos with a certain mass to have a galaxy inside

SHAM Principles: SHAM Descriptions

The lightest halos: no galaxy

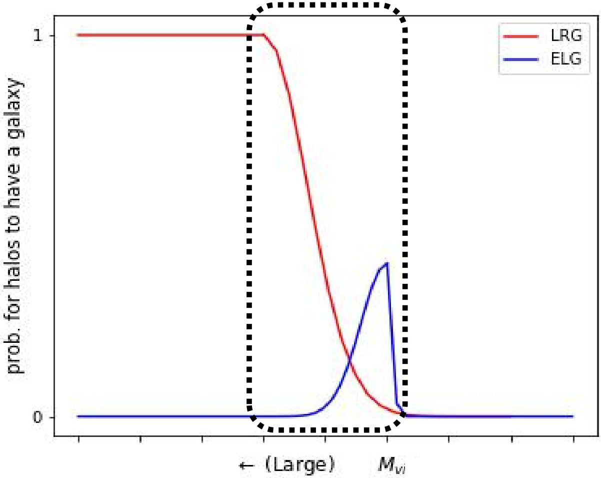


*** mention the linear bias here**

Fig 1. The ideal probability distribution function for halos with a certain mass to have a galaxy inside

SHAM Principles: SHAM Descriptions

Intermediate halos: physical processes lead to Stochasticity



*** mention the stochastic bias here**

Fig 1. The ideal probability distribution function for halos with a certain mass to have a galaxy inside

SHAM Principles: SHAM Descriptions

Select halos (i.e., galaxies) so that they:

- Have **the same number density** as observations
- Match the **galaxy probability distribution function** (P.D.F)
- Agree with the observed **two-point correlation functions** (2PCF) on **5-25 Mpc/h**

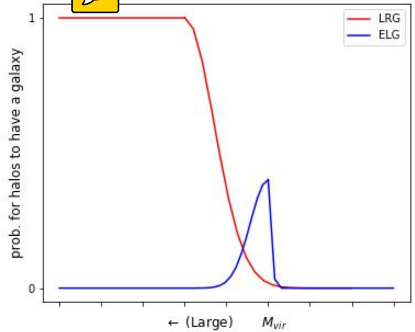
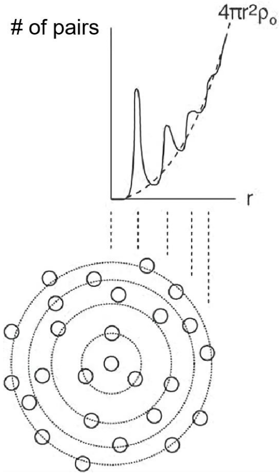


Fig 1. The ideal probability distribution function for halos with a certain mass to have a galaxy inside

SHAM Principles: 2PCF



For SHAM galaxies:

$$\xi_{PH}(s,\mu) = \frac{DD(s,\mu)}{RR(s,\mu)} - 1$$

(Peebles & Hauser 1974)

For eBOSS galaxies:

$$\xi_{LS}(s,\mu) = \frac{DD(s,\mu) - 2DR(s,\mu) + RR(s,\mu)}{RR(s,\mu)}$$

(Landy & Alexander 1993)

Ref 1. Peebles, P. J. E., & Hauser, M. G. 1974, The Astrophysical Journal Supplement Series, 28, 19
Ref 2. Landy, S., & Alexander, S. 1993, the astropysical journal, 412, 64

Figure from LASTRO Tea-Time Talk: Cosmology with large-scale structures

SHAM Principles: 2PCF(*b*) with RSD

density contrast in the real space:

$$\delta(\boldsymbol{x}) = \frac{\rho(\boldsymbol{x}) - \bar{\rho}(\boldsymbol{x})}{\bar{\rho}(\boldsymbol{x})}$$

the linear galaxy bias in the real space:

$$\delta_{gal}(\boldsymbol{x}) = b \times \delta_{halo}(\boldsymbol{x})$$

density contrast in the redshift space:

$$\delta_{obs}(\boldsymbol{x}) = \delta(\boldsymbol{x}) - \frac{\partial_d (\boldsymbol{v} \cdot \boldsymbol{n})}{H}$$

(Kaiser 1987)

correlation function in the redshift space:

$$\xi_{gal}(\boldsymbol{s}) = <\delta_{obs}(\boldsymbol{x})\delta_{obs}(\boldsymbol{x}-\boldsymbol{s})>$$

$$\xi_0(\boldsymbol{s}) \propto f(b^2, b)$$

$$\xi_2(\boldsymbol{s}) \propto f(b)$$

(Hamilton 1992)

Ref 1. Kaiser, N. 1987, Monthly Notices of the Royal Astronomical Society, 227, 1
Ref 2. Hamilton, A. J. S. 1992, The Astrophysical Journal, 385, L5

SHAM Principles: 2PCF(*b*) with RSD

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peculiar velocity's effects

density contrast in the redshift space:

$$\delta_{obs}(\boldsymbol{x}) = \delta(\boldsymbol{x}) - \frac{\partial_d \boxed{(\boldsymbol{v} \cdot \boldsymbol{n})}}{H}$$

(Kaiser 1987)

correlation function in the redshift space:

$$\xi_{gal}(\boldsymbol{s}) = <\delta_{obs}(\boldsymbol{x})\delta_{obs}(\boldsymbol{x}-\boldsymbol{s})>$$

stronger bias impacts on the monopoles

$$\boxed{\begin{aligned} \xi_0(\boldsymbol{s}) &\propto f(b^2, b) \\ \xi_2(\boldsymbol{s}) &\propto f(b) \end{aligned}}$$

(Hamilton 1992)

Ref 1. Kaiser, N. 1987, Monthly Notices of the Royal Astronomical Society, 227, 1
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- Principles
- SHAM implementation
  - Data Descriptions
  - SHAM using V_{peak}
  - SHAM model Calibration
- Results
- Conclusions and Outlooks

SHAM Implementation: Data Description

the (Sub)Halo catalogue:

the UNIT simulation

Box size: 1^3 $(Gpc/h)^3$

Employed snapshots z=0.859 and z=0.702

V_{peak}: the peak maximum circular velocity over the mass accretion history

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eBOSS observations:

PIP+ANG weighted galaxy pair counts

ELG at $0.6<z<1.1$, $z_{eff}=0.845$, $n_{eff}= 2.93e^{-4}$ (Gpc/h)$^{-3}$

LRG at $0.6<z<1.0$, $z_{eff}=0.698$, $n_{eff}= 6.26e^{-5}$ (Gpc/h)$^{-3}$

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Covariance matrices:

EZmocks

1000 realisations for one tracer in one galactic cap

SHAM Implementation: SHAM using V_{peak}

Massive Truncation: probable absence of eBOSS heavy galaxies

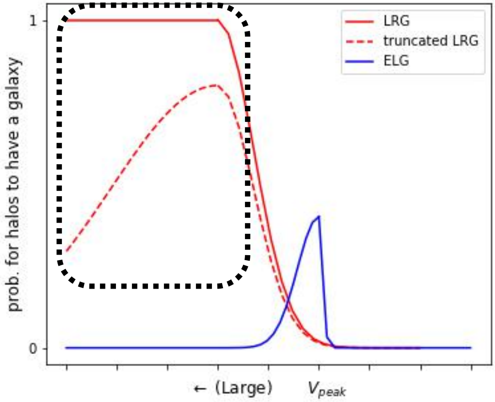


Fig 2. The eBOSS galaxy P.D.F compared with the ideal one

mention the target selection effect

SHAM Implementation: SHAM using V_{peak}

eBOSS LRGs and ELGs have the same SHAM model

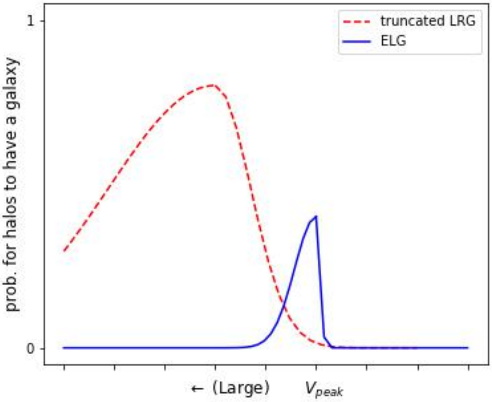
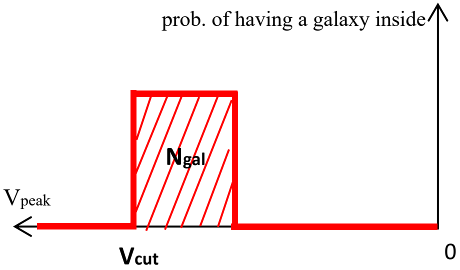


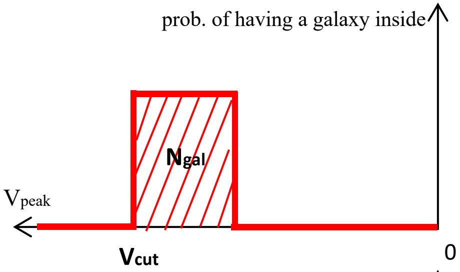
Fig 3. The eBOSS galaxy P.D.Fs

SHAM Implementation: SHAM using V_{peak}

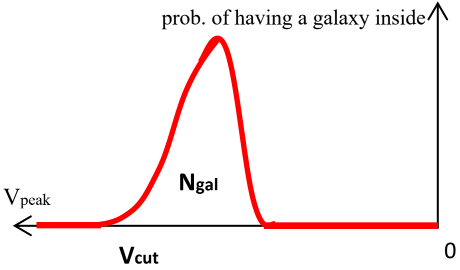


Simply Cut at V_{cut}

SHAM Implementation: SHAM using V_{peak}



Simply Cut at V_{cut}



Scattering with $N(0, \sigma^2)$
Massive-end cut at V_{cut}

SHAM Implementation: SHAM using V_{peak}

SHAM processes:

- Scattering V_{peak} of (sub)halos with $N(0,\sigma^2)$
- Truncate the massive end of V_{peak}^{scat} at V_{cut}
- Select the N_{gal}-th largest $V_{peak}^{scat,cut}$ as galaxies

  ($N_{gal} = n_{eff}*(1\mathrm{Gpc}/h)^3$)

SHAM Implementation: SHAM using V_{peak}

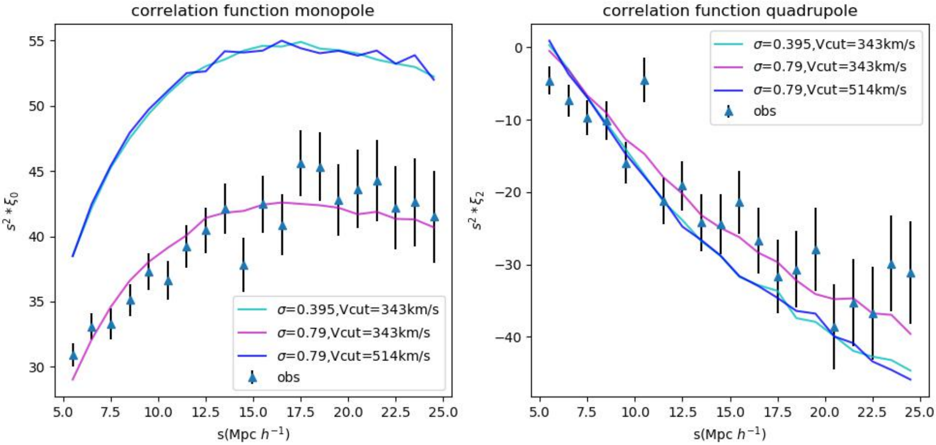


Fig 4. The impacts of σ and Vcut on the 2PCF monopole (left), quadrupole (right) and the Vpeak PDF (the next page)

SHAM Implementation: SHAM using V_{peak}

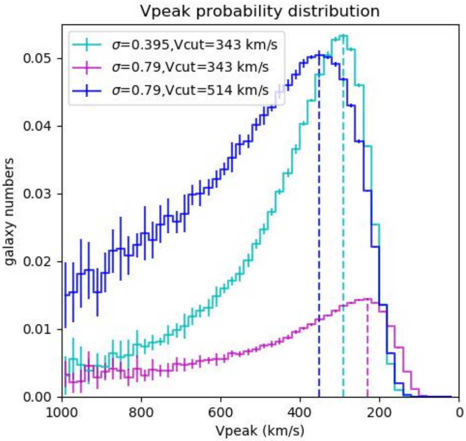


Fig 4. The impacts of σ and Vcut on the Vpeak PDF

mention the possible degeneracy here

SHAM Implementation: Calibration

(Sub)Halos

$\downarrow$ SHAM selection (σ, V_{cut})

SHAM galaxy catalogue & 2PCF

SHAM Implementation: Calibration

(Sub)Halos

$\downarrow$ SHAM selection (σ, V_{cut})

SHAM galaxy catalogue & 2PCF

$\downarrow$ Reduce the statistical fluctuation from $N(0,\sigma^2)$

Average over the 2PCFs of 20 catalogues for a single (σ, V_{peak})

SHAM Implementation: Calibration

(Sub)Halos

↓ SHAM selection (σ, V_{cut})

SHAM galaxy catalogue & 2PCF

↓ Reduce the statistical fluctuation from $N(0,\sigma^2)$

Average over the 2PCFs of 20 catalogues for a single (σ, V_{peak})

↓ calculate χ^2 with the observations

Monte-Carlo Nested Samping (Multinest) to obtain the best parameters

(iminuit as a reference)

Contents:

Results: ELG NGC 2PCF

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.513^{+0.433}_{-0.081}$	268^{+124}_{-30}	52.296	1.376

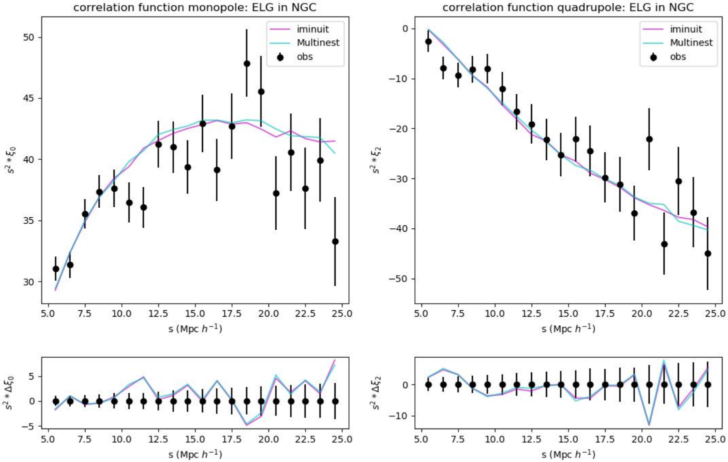


Fig 5. The correlation functions of eBOSS SHAM ELGs in NGC

Results: ELG NGC P.D.F

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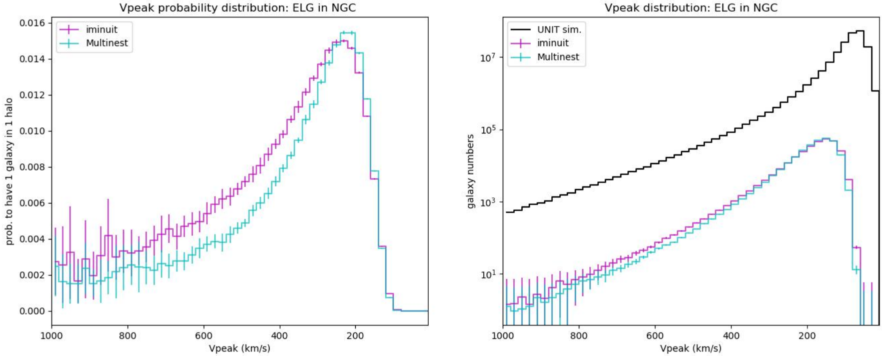
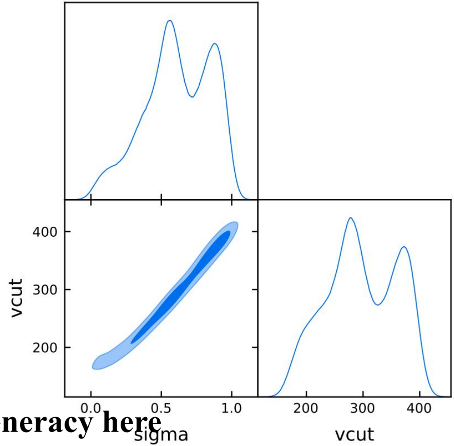


Fig 6. The probability distribution function of eBOSS SHAM ELGs in NGC

Results: ELG NGC Posterior

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.513^{+0.433}_{-0.081}$	268^{+124}_{-30}	52.296	1.376



mention the degeneracy here

Fig 7. The posterior distributions of eBOSS SHAM ELGs in NGC

Results: ELG SGC 2PCF

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.790^{+0.200}_{-0.285}$	342^{+58}_{-61}	51.526	1.356

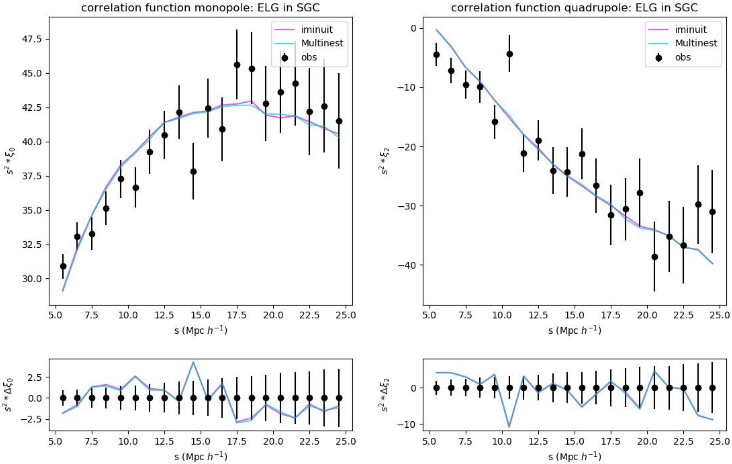


Fig 8. The correlation functions of eBOSS SHAM ELGs in SGC

Results: ELG SGC P.D.F

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.790^{+0.200}_{-0.285}$	342^{+58}_{-61}	51.526	1.356

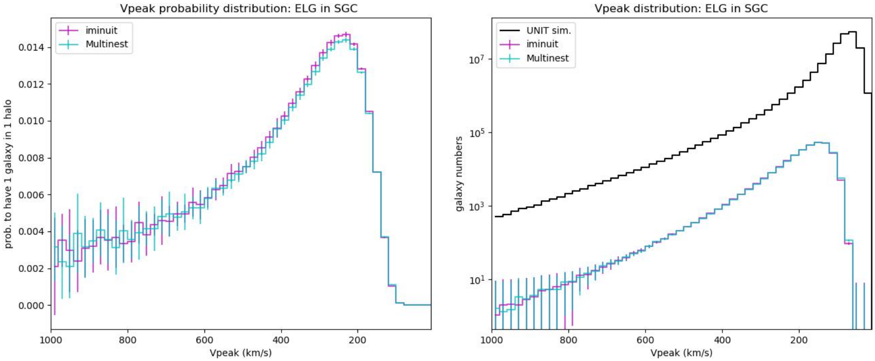


Fig 9. The probability distribution function of eBOSS SHAM ELGs in SGC

Results: ELG SGC Posterior

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.790^{+0.200}_{-0.285}$	342^{+58}_{-61}	51.526	1.356

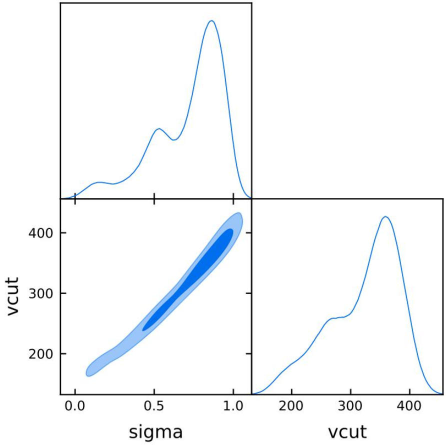


Fig 10. The posterior distributions of eBOSS SHAM ELGs in SGC

Results: LRG NGC 2PCF

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.800^{+0.035}_{-0.056}$	1167^{+29}_{-63}	72.785	1.915

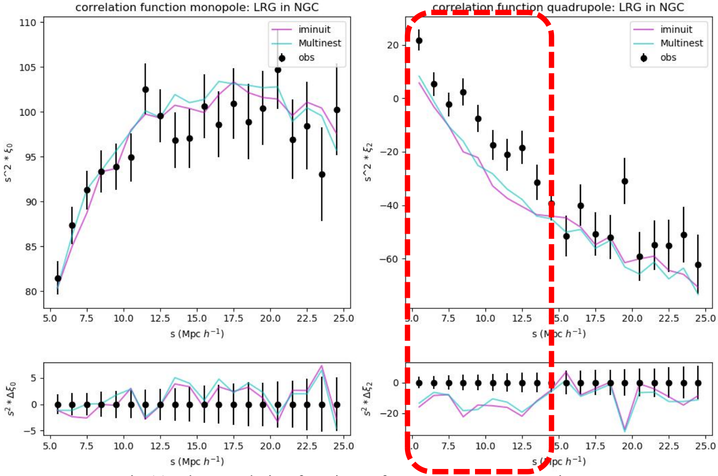
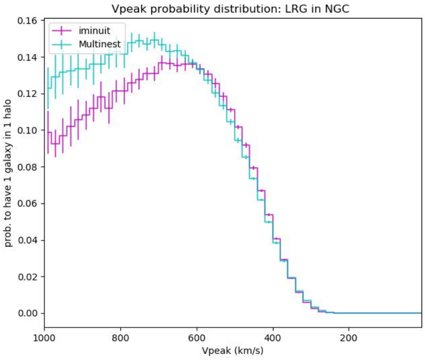


Fig 11. The correlation functions of eBOSS SHAM LRGs in NGC

Results: LRG NGC P.D.F

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.800^{+0.035}_{-0.056}$	1167^{+29}_{-63}	72.785	1.915



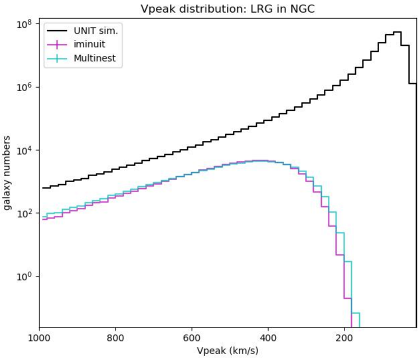


Fig 12. The probability distribution function of eBOSS SHAM LRGs in NGC

Results: LRG NGC Posterior

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.800^{+0.035}_{-0.056}$	1167^{+29}_{-63}	72.785	1.915

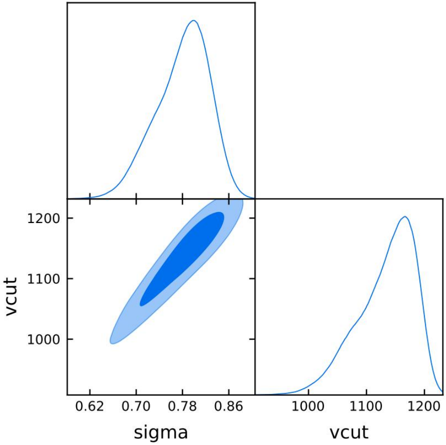


Fig 13. The posterior distributions of eBOSS SHAM LRGs in NGC

Results: LRG SGC 2PCF

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.710^{+0.144}_{-0.029}$	994^{+167}_{-12}	54.593	1.437

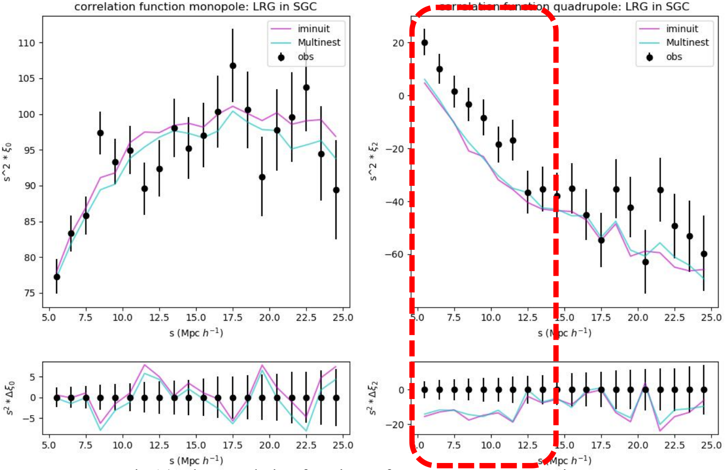


Fig 14. The correlation functions of eBOSS SHAM LRGs in SGC

Results: LRG SGC P.D.F

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.710^{+0.144}_{-0.029}$	994^{+167}_{-12}	54.593	1.437

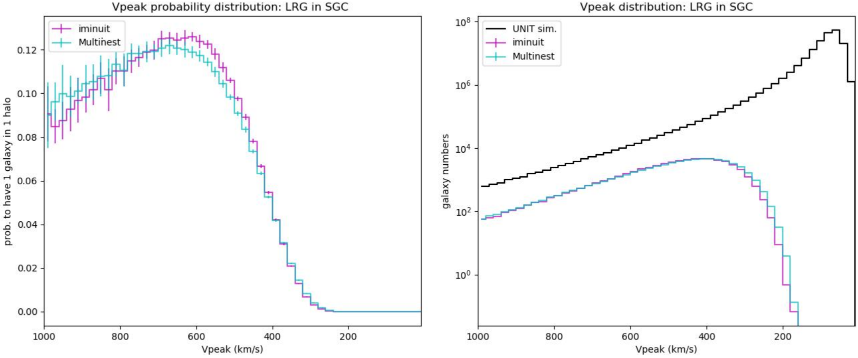


Fig 15. The probability distribution function of eBOSS SHAM LRGs in SGC

Results: LRG SGC Posterior

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
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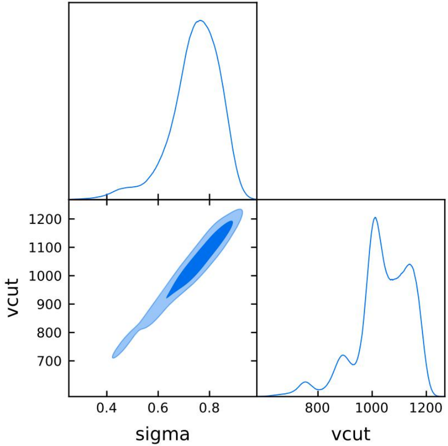

Fig 16. The posterior distributions of eBOSS SHAM LRGs in SGC

Results: LRG SHAM Improvement

$$\Delta v = c\Delta z(1+z)$$

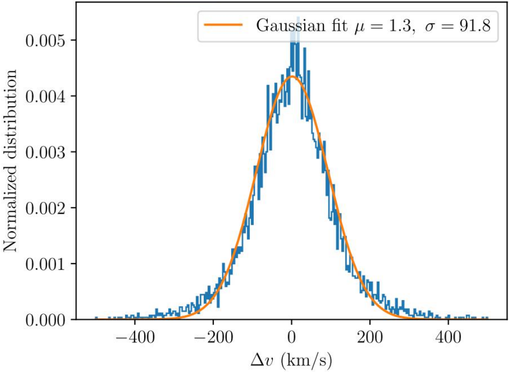

Fig 17. The redshift uncertinty of eBOSS LRG observation pairs, Figure 2 of Ross et al. (2020)

Results: LRG SHAM Improvement

Δv modelled by a **Gaussian smearing** $N(0, 91.8^2)$ on the **peculiar velocity**

* the Peculiar velocity not sensitive to the galaxy bias

⇨the **Quadrupole shifts larger** than the monopole shift (?)

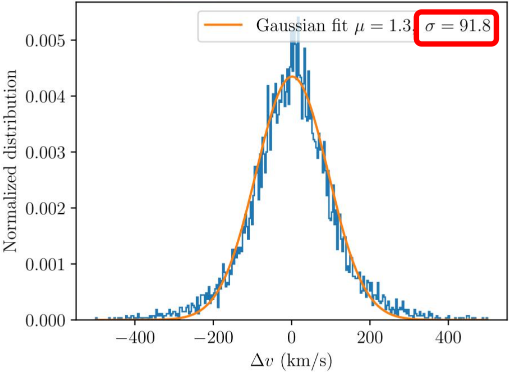

Fig 17. The redshift uncertinty of eBOSS LRG observation pairs, Figure 2 of Ross et al. (2020)

Results: LRG SHAM Improvement

σ	V_{peak} (km/s)	χ^2	Reduced χ^2
$0.800^{+0.035}_{-0.056}$	1167^{+29}_{-63}	72.785	1.915
0.806	1170	33.910	0.916

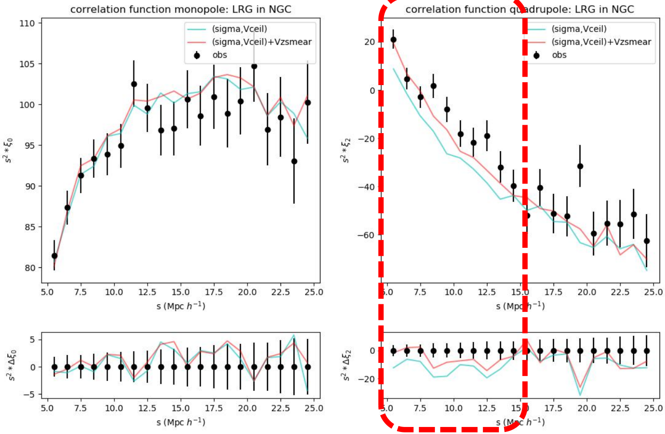

Fig 18. The peculiar-velocity-smeared SHAM LRG in NGC

Contents:

- Principles
- SHAM implementation
- Results
- Conclusions and Outlooks

Conclusions:

- ✓ Applyed SHAM on UNIT (sub)halo catalogue
- ✓ Reproduced the 2PCF of eBOSS LRG and ELG respectively

	σ	V_{peak} (km/s)	χ^2	Reduced χ^2
ELG NGC	$0.513^{+0.433}_{-0.081}$	268^{+124}_{-30}	52.296	1.376
ELG SGC	$0.790^{+0.200}_{-0.285}$	342^{+58}_{-61}	51.526	1.356
LRG NGC	$0.800^{+0.035}_{-0.056}$	1167^{+29}_{-63}	72.785	1.915
LRG SGC	$0.710^{+0.144}_{-0.029}$	994^{+167}_{-12}	54.593	1.437

- ✓ Improved the LRG SHAM by adding the redshift uncertainty effect

Outlooks:

- ✓ Reliable eBOSS LRG & ELG SHAM models
- ☐ Robust SHAM models
  - ☐ Implement (σ, σ_{pec}, V_{cut}) SHAM models
  - ☐ Test the three-parameter model in different redshift bins
- ☐ Multi-tracer SHAM
  - ☐ 'generate' multiple tracers simultaneously
  - ☐ difficulty: overlapped distribution function
- ☐ Cross-Correlation between tracers

Thanks!