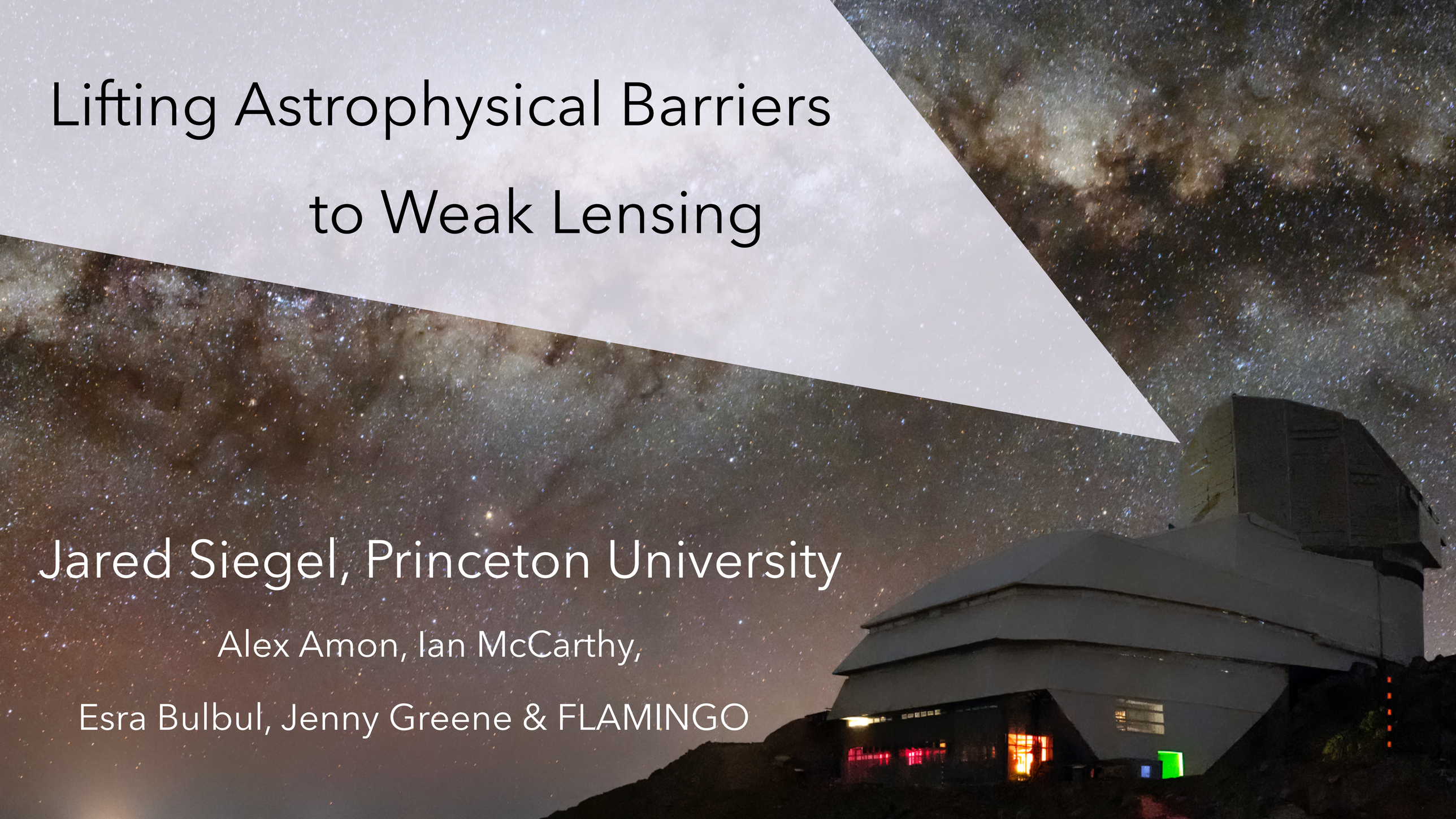
Lifting Astrophysical Barriers to Weak Lensing



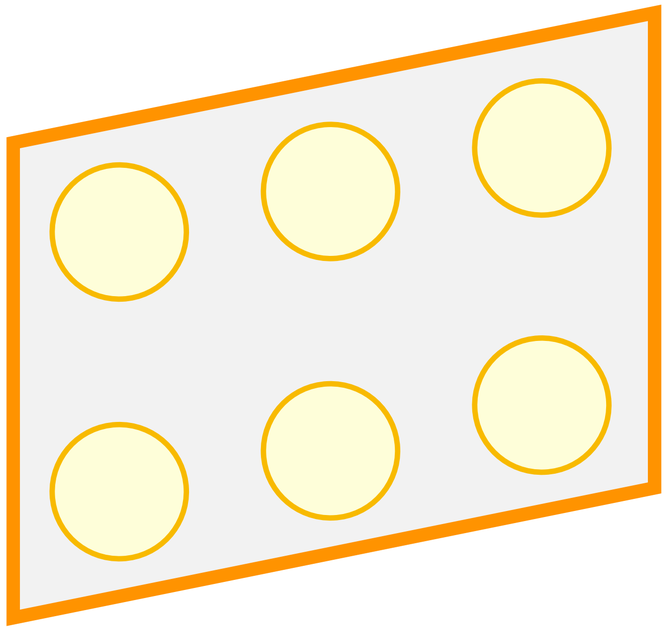
Jared Siegel, Princeton University

Alex Amon, Ian McCarthy,

Esra Bulbul, Jenny Greene & FLAMINGO

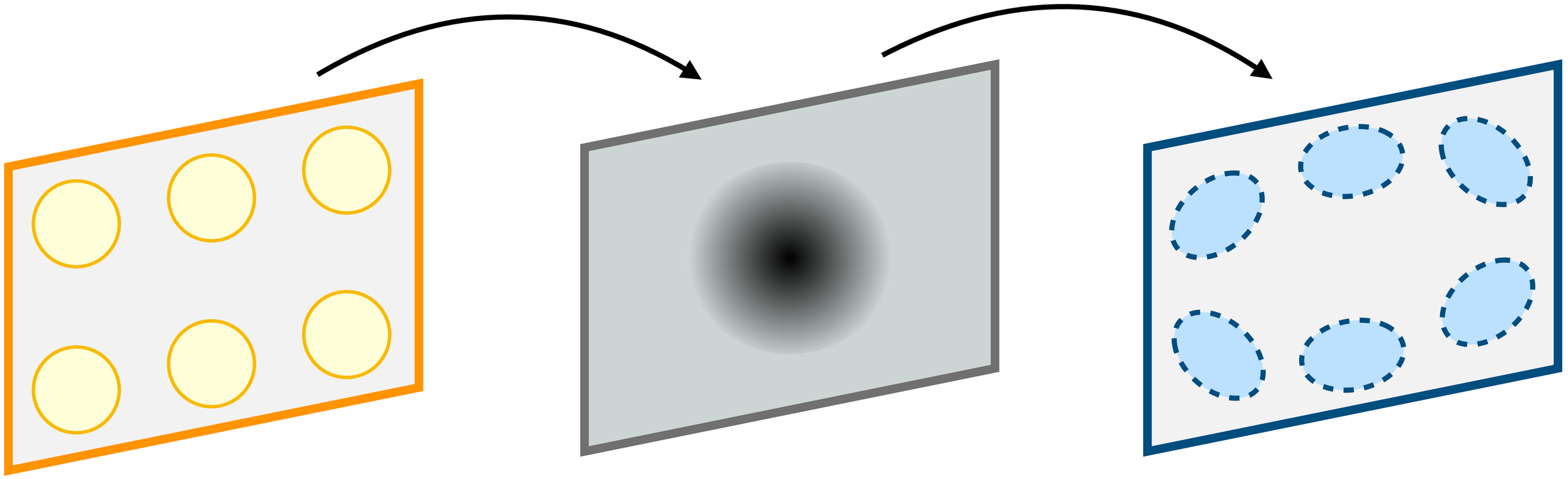
Weak Lensing Cosmology

Weak Lensing Cosmology



Background Galaxies

Weak Lensing Cosmology

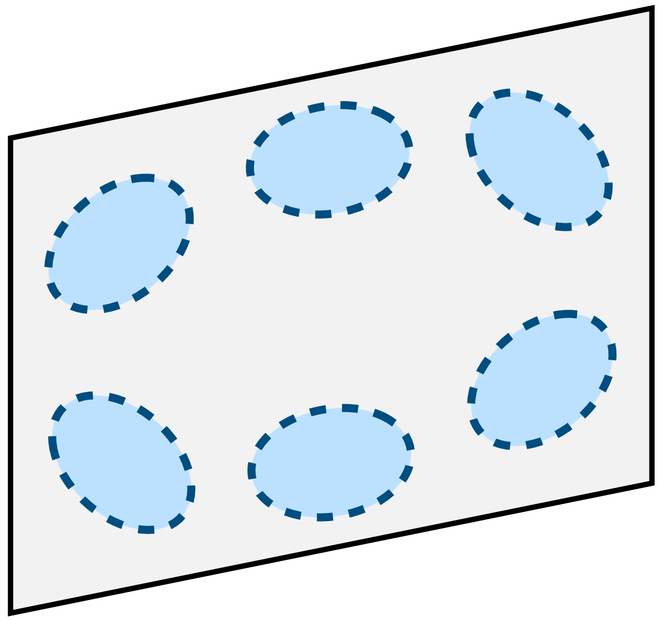


Background Galaxies

Intervening Matter

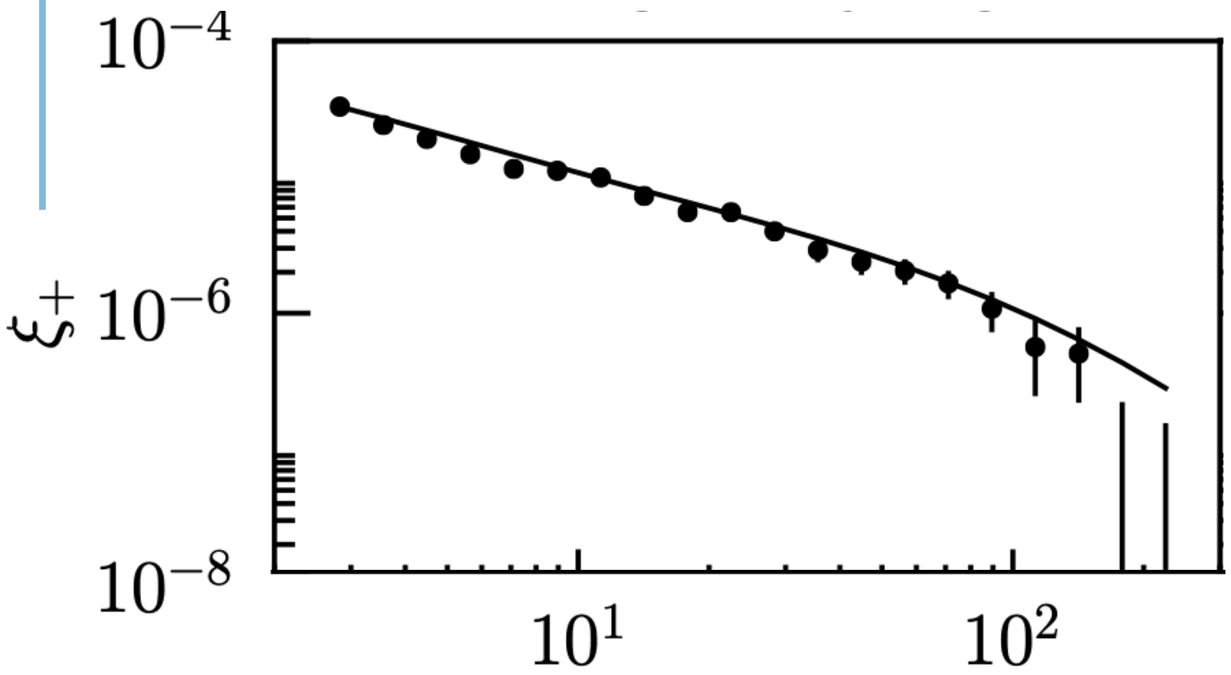
Lensed Galaxy Images

Weak Lensing Cosmology



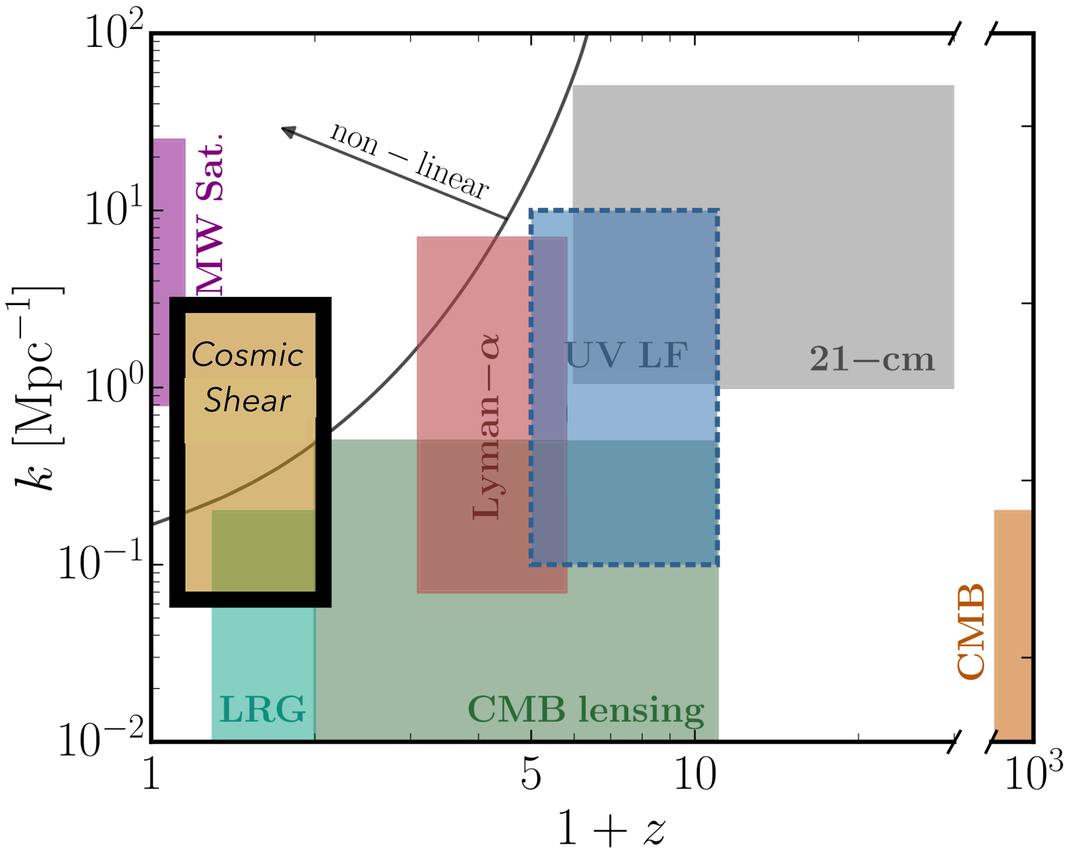
Lensed Galaxy Images

Shear Two-point Correlation



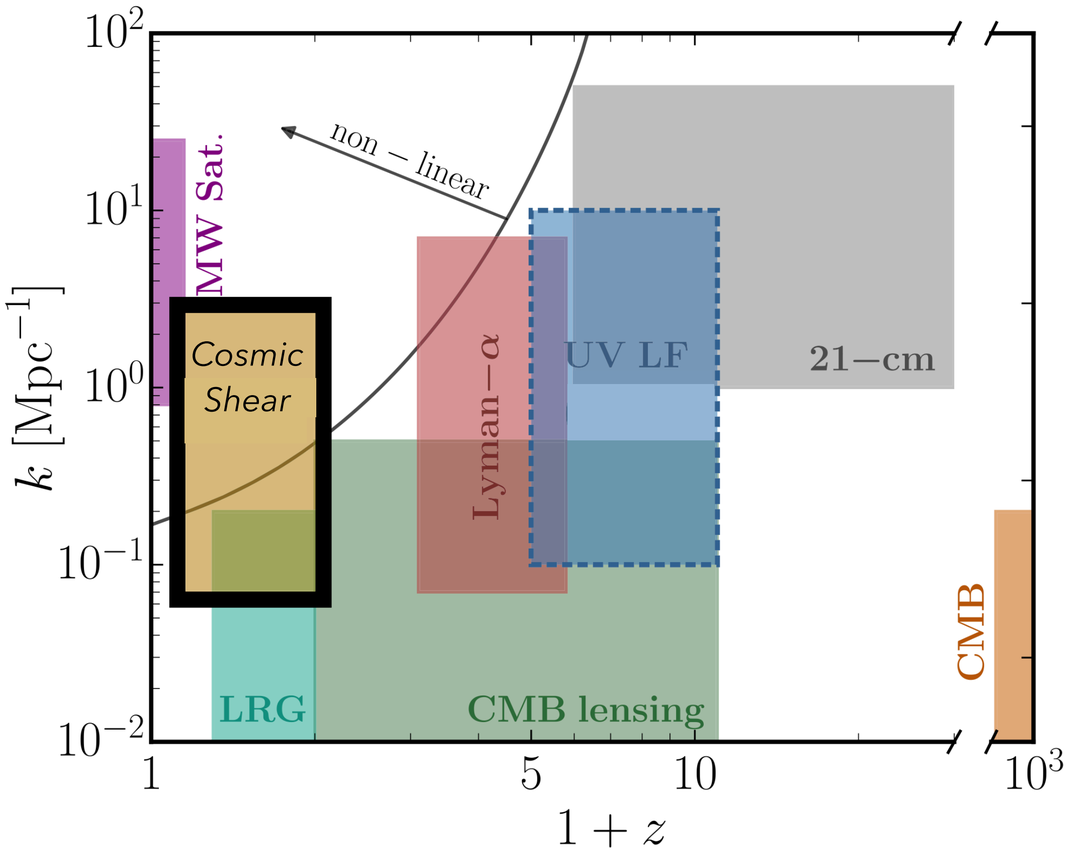
Angular Scale [arcmin]

Weak Lensing Cosmology

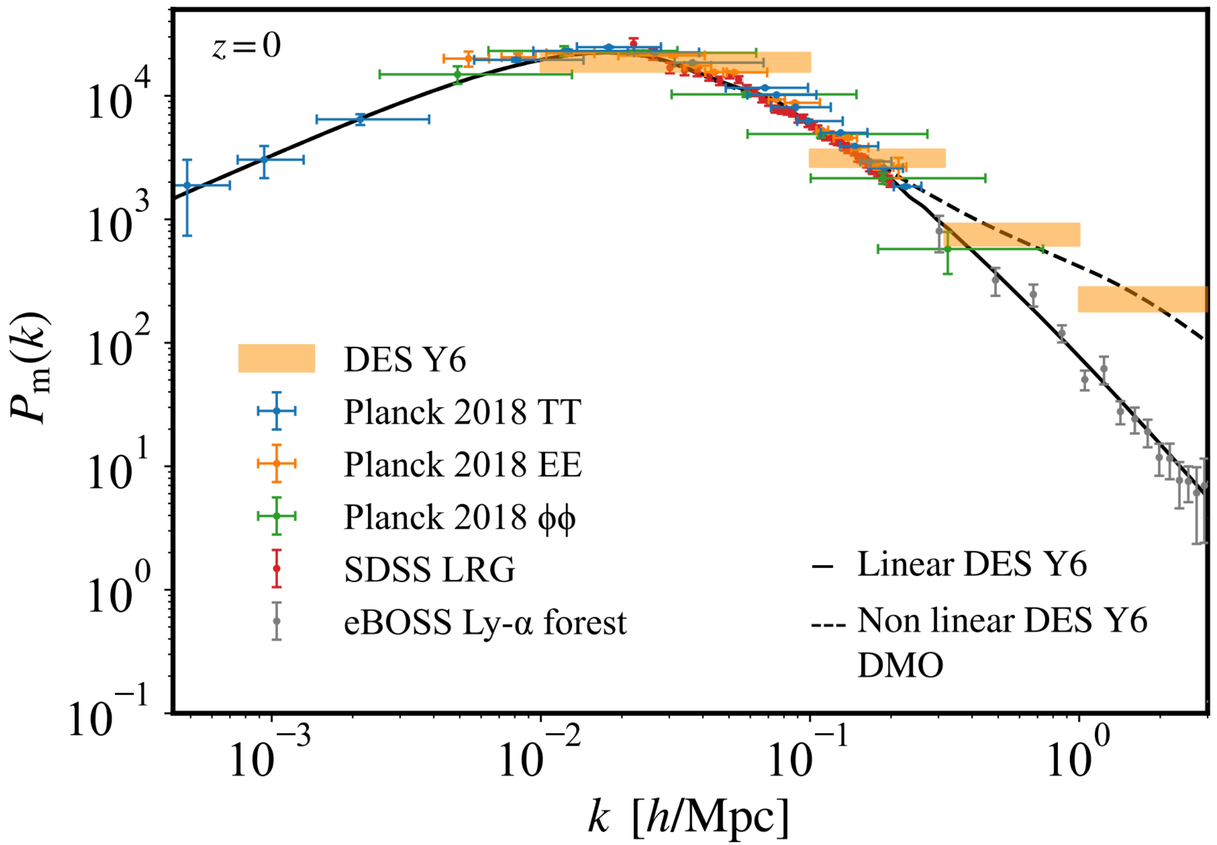


Adapted from Sabti + 22

Weak Lensing Cosmology



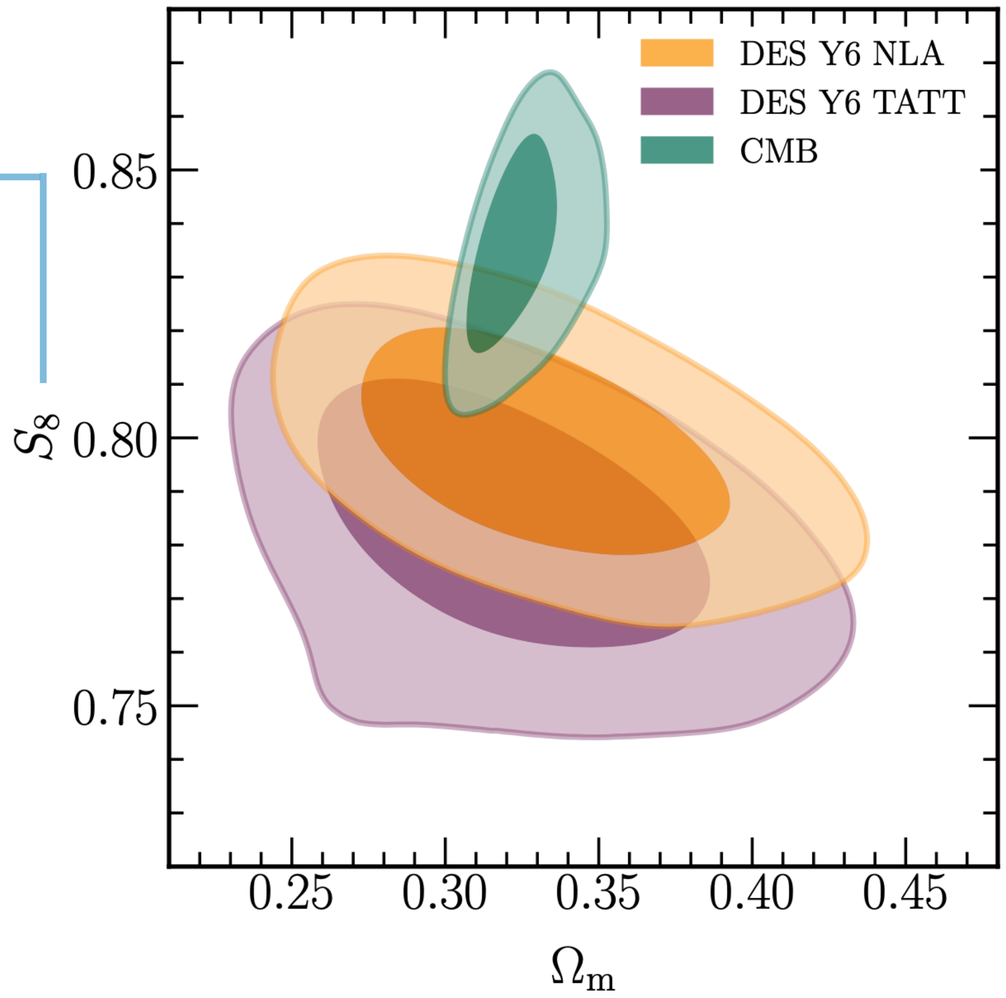
Adapted from Sabti + 22



DES Y6 arxiv:2602.10065

Weak Lensing Cosmology

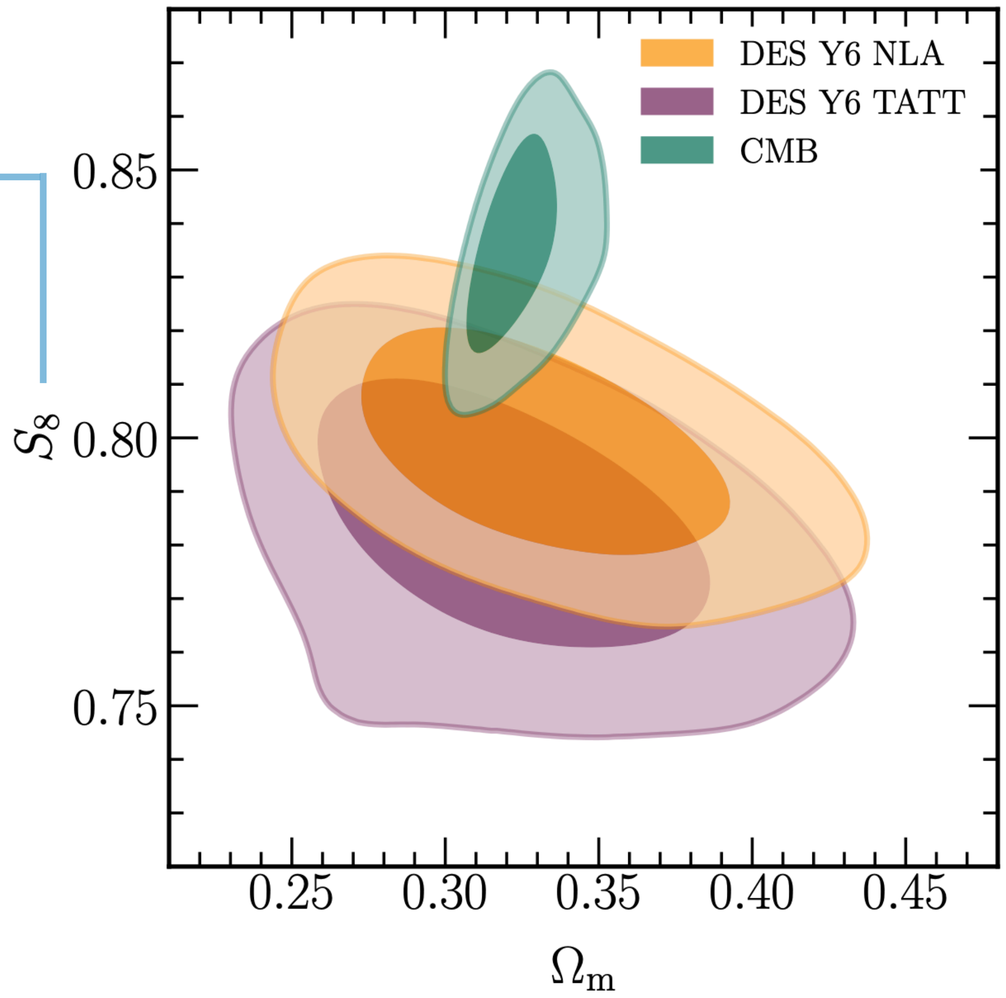
$$S_8 = \sigma_8 \sqrt{\Omega_{\rm m}/0.3}$$



DES Y6 Cosmic Shear

Weak Lensing Cosmology

$$S_8 = \sigma_8 \sqrt{\Omega_\mathrm{m}/0.3}$$



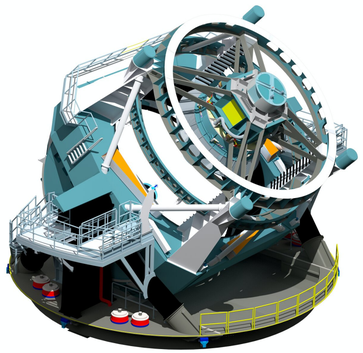
Planck + ACT + SPT

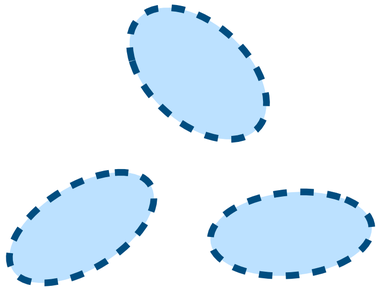
Dark Energy Survey Y6

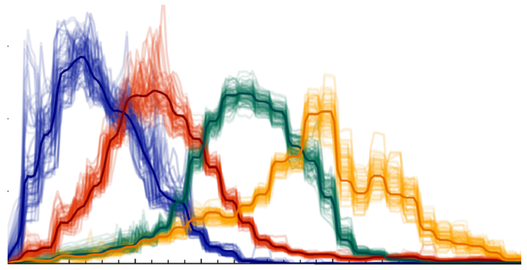
140 million galaxies

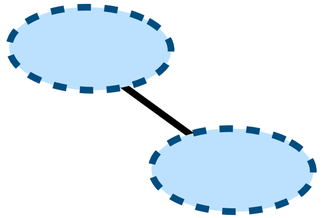
DES Y6 Cosmic Shear

Weak Lensing Cosmology



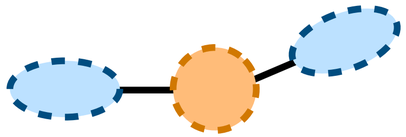






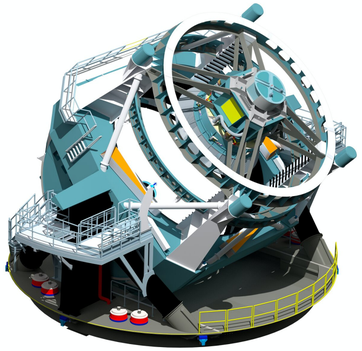
Shape Catalog | Redshift bins | 2-point statistics | Cosmology

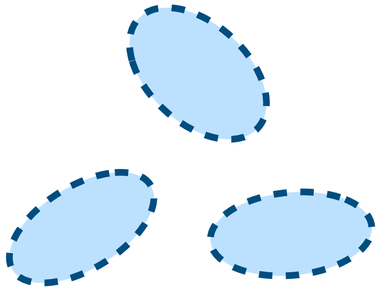
Weak Lensing Cosmology

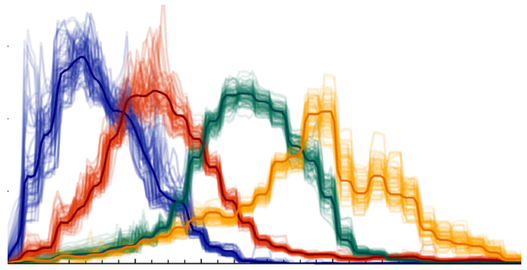


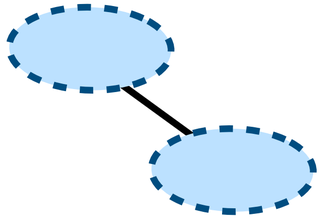
Intrinsic Alignments

Baryon Feedback









Shape Catalog

Redshift bins

2-point statistics

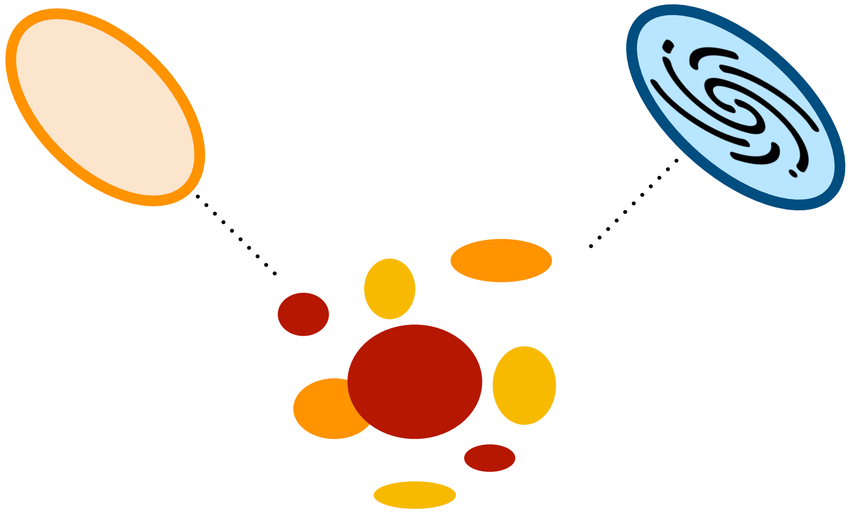
Cosmology

Astrophysical Barriers

Intrinsic Alignments

Galaxy shapes are influenced

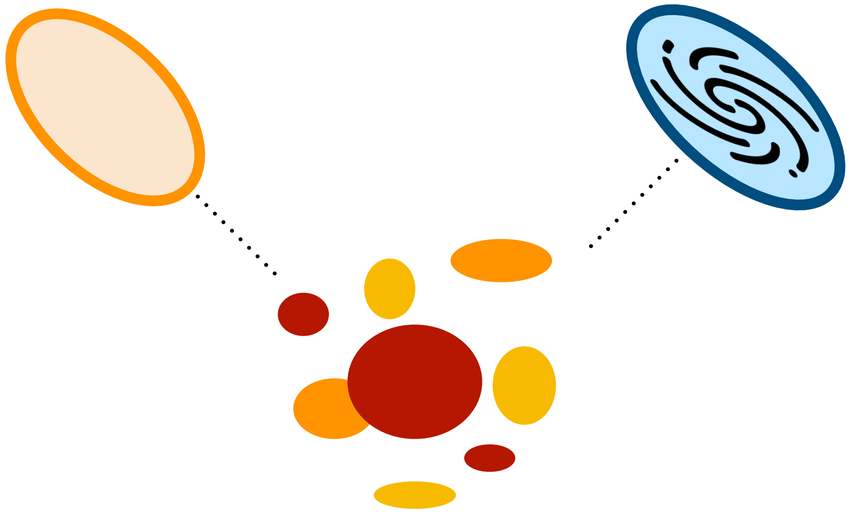
by their local environments



Astrophysical Barriers

Intrinsic Alignments

Galaxy shapes are influenced by their local environments



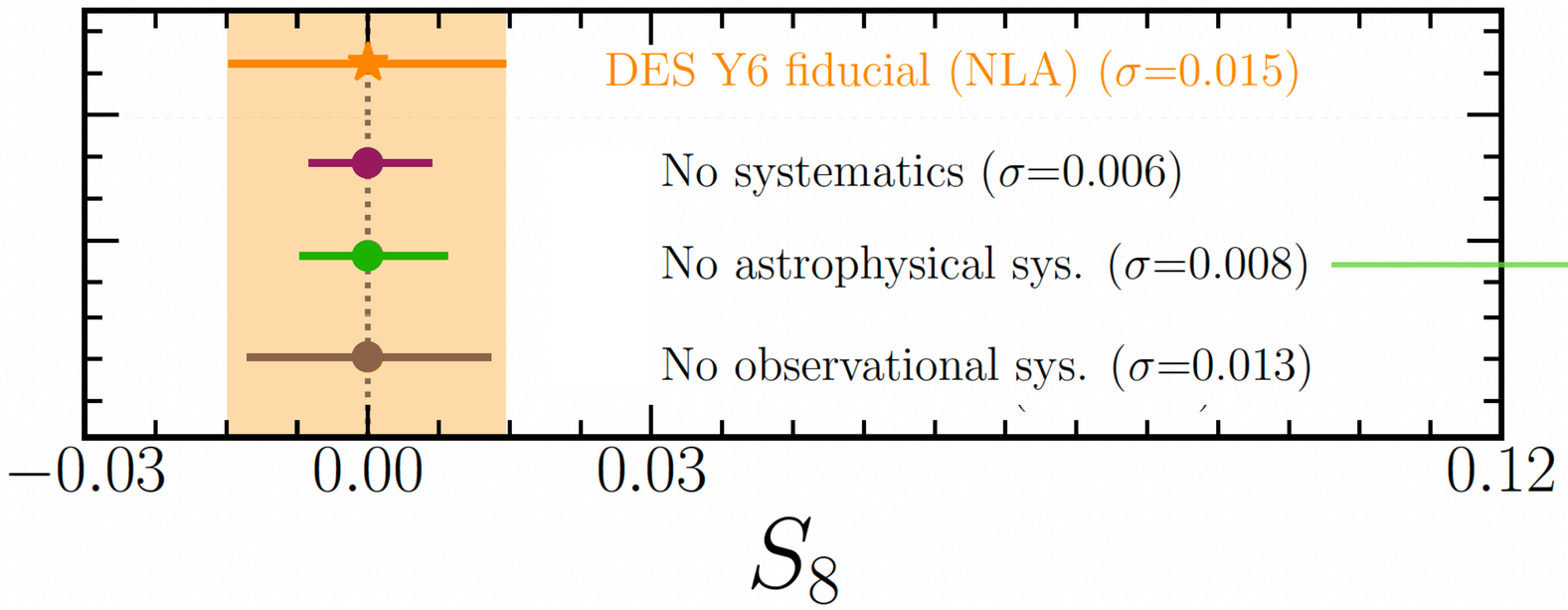
Baryon Feedback

Redistribution of matter by AGN and supernova

What limits cosmic shear?

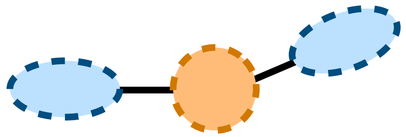
What limits cosmic shear?

2 × loss in precision from astrophysical uncertainties



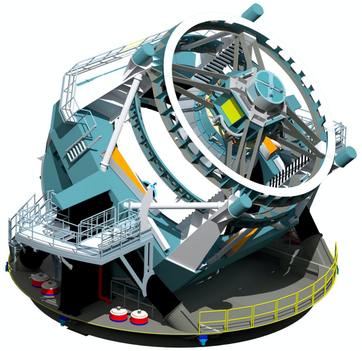
DES Y6 Cosmic Shear Plots courtesy of Masaya Yamamoto

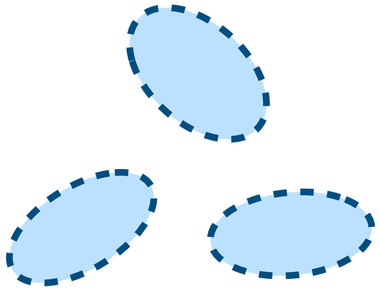
Unlocking Small Scale Shear

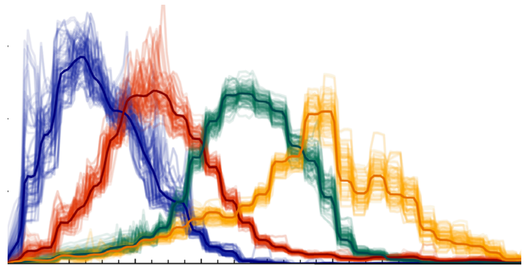


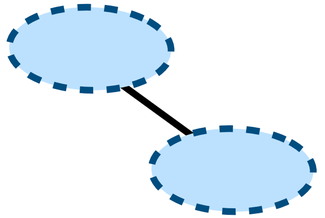
Intrinsic Alignments

Baryon Feedback









Shape Catalog

Redshift bins

2-point statistics

Cosmology

Data-driven Astrophysical Priors

Intrinsic Alignments

Baryon Feedback

Data

Priors

Cosmology

Data-driven Astrophysical Priors

	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	kSZ + X-ray + GGL Siegel + 25b
Priors		
Cosmology		

Data-driven Astrophysical Priors

	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	kSZ + X-ray + GGL Siegel + 25b
Priors	McCullough, Siegel + in prep	Siegel + 25c
Cosmology		

Data-driven Astrophysical Priors

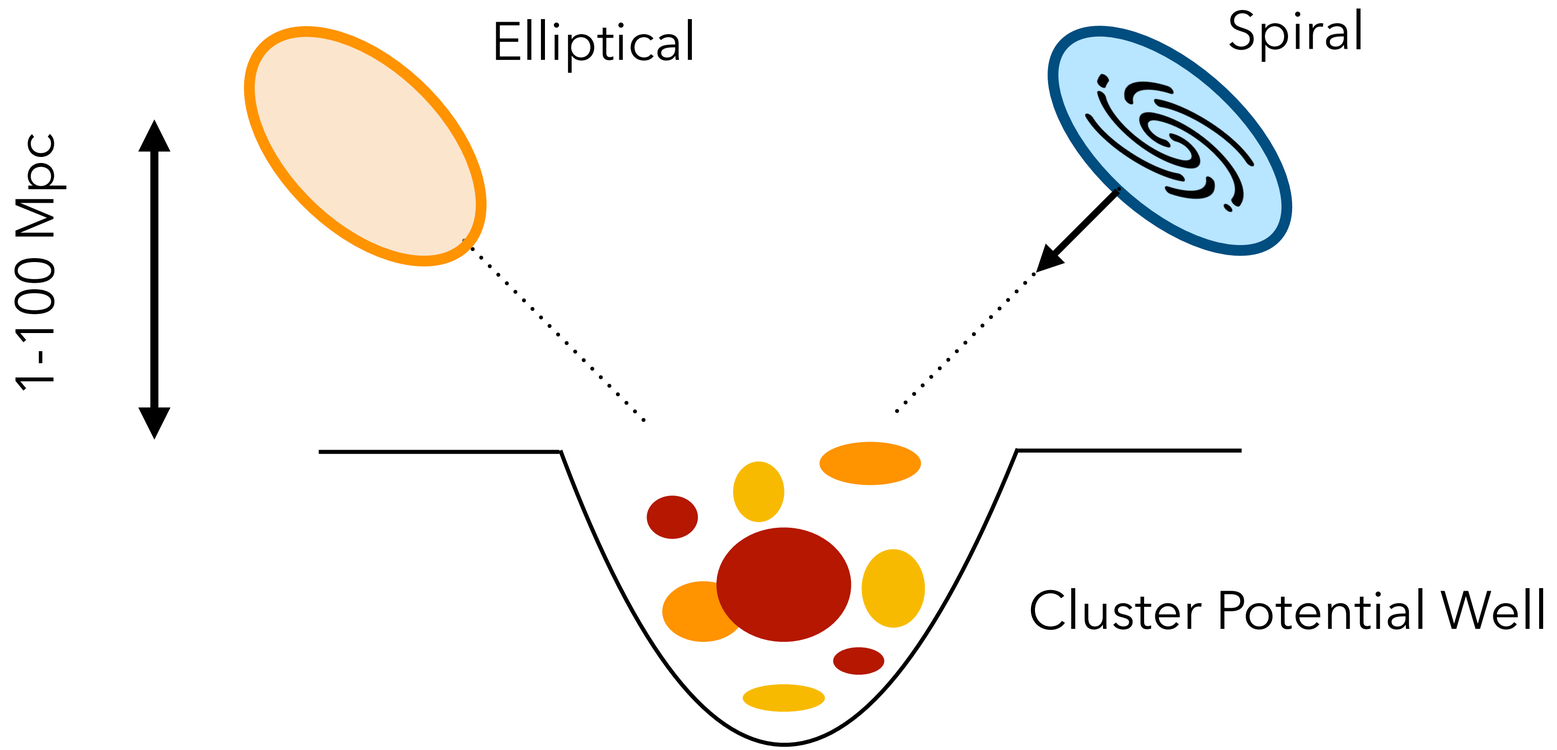
	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	kSZ + X-ray + GGL Siegel + 25b
Priors	McCullough, Siegel + in prep	Siegel + 25c
Cosmology	DES Y3 Small Scale Reanalysis (Bigwood, McCullough, Siegel + 25)	

Intrinsic Alignments

Intrinsic Alignments

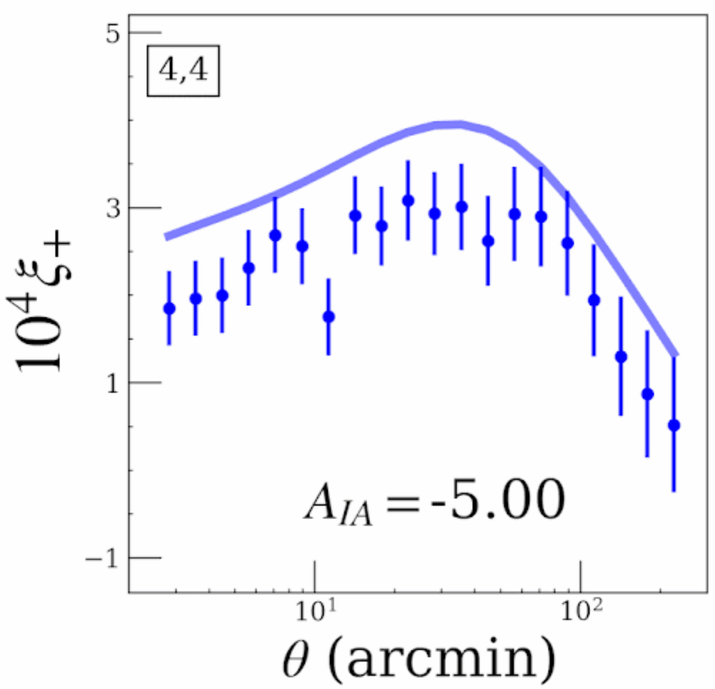
Correlations between galaxy shapes

and their local environments



Intrinsic Alignments

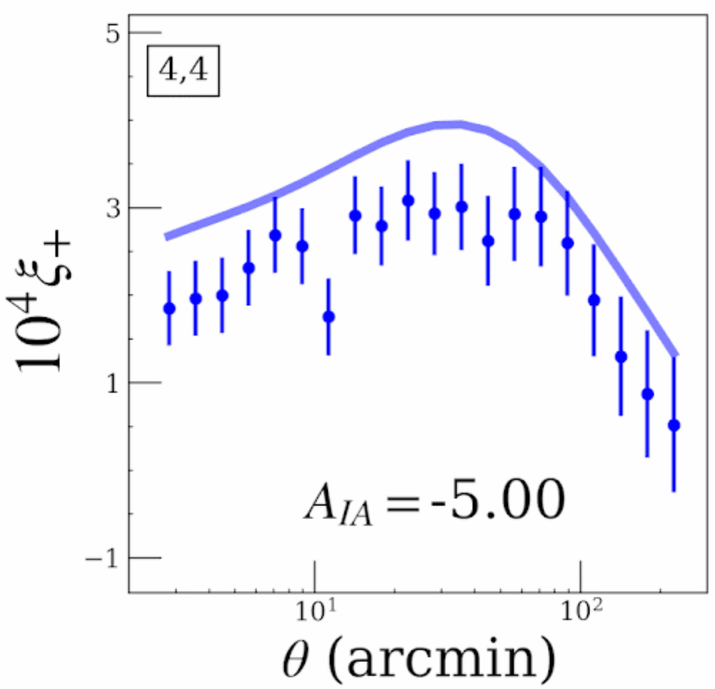
Alignments are a source of uncertainty and potential bias



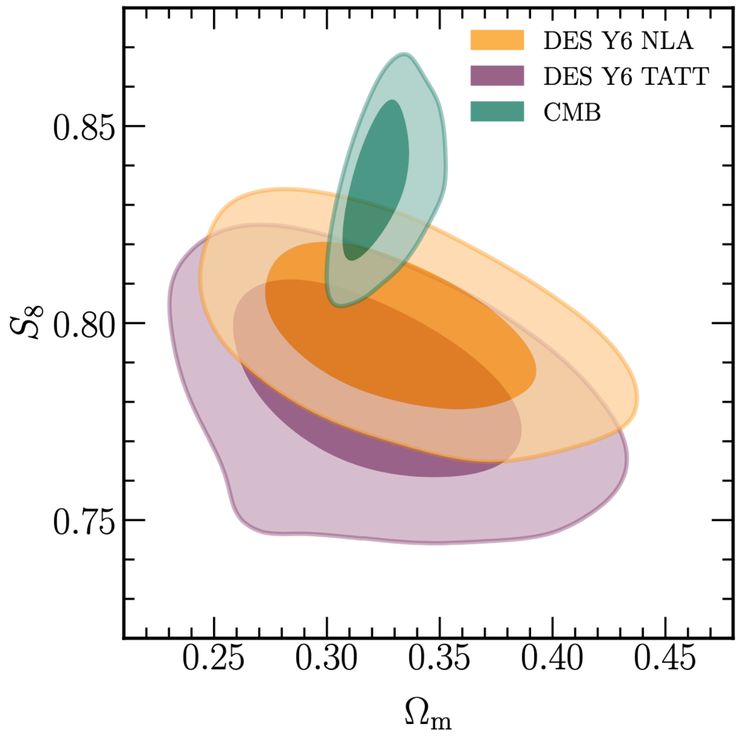
Courtesy of Jamie McCullough

Intrinsic Alignments

Alignments are a source of uncertainty and potential bias



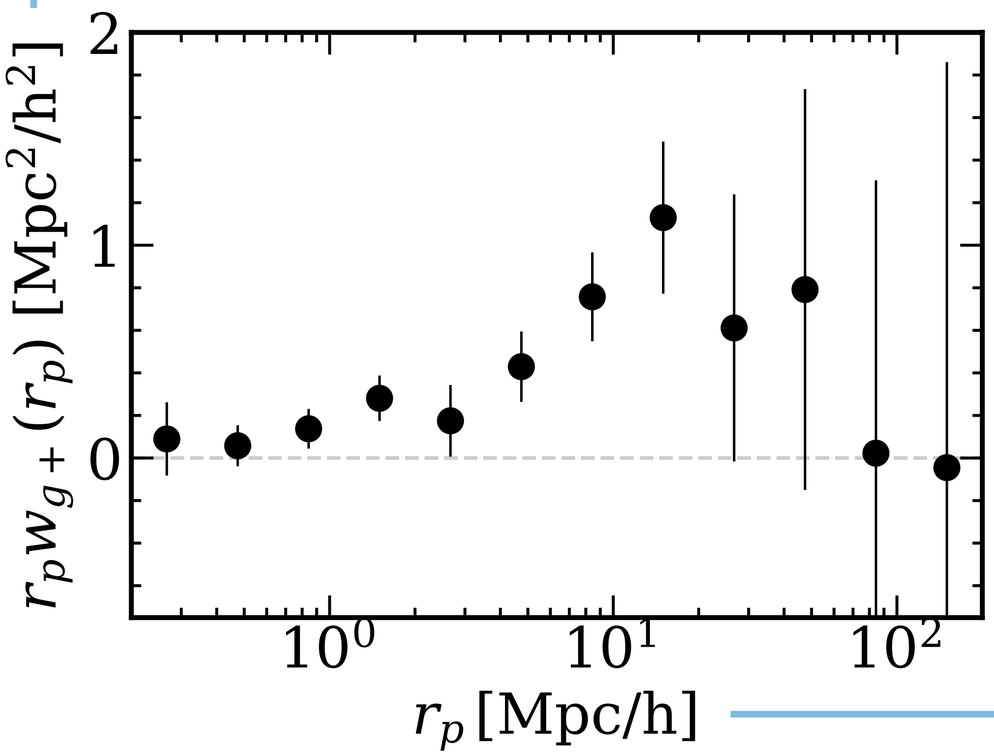
Courtesy of Jamie McCullough



DES Y6 Cosmic Shear

Intrinsic Alignments: Measurements

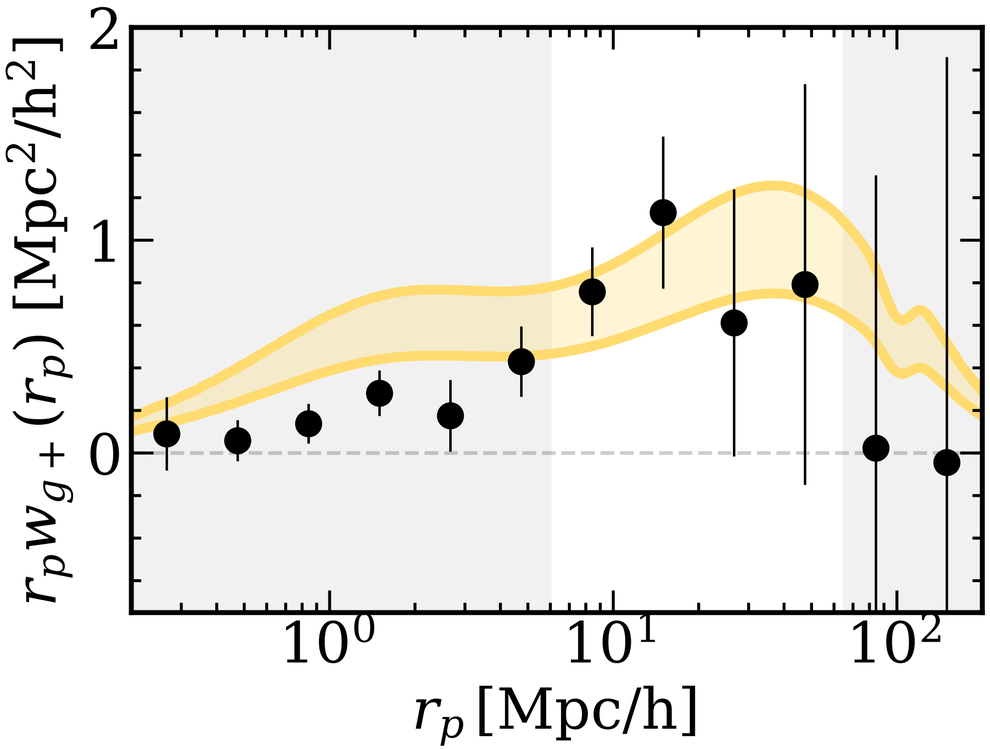
Correlation between galaxy shapes and positions



Comoving Distance

Intrinsic Alignments: Modeling

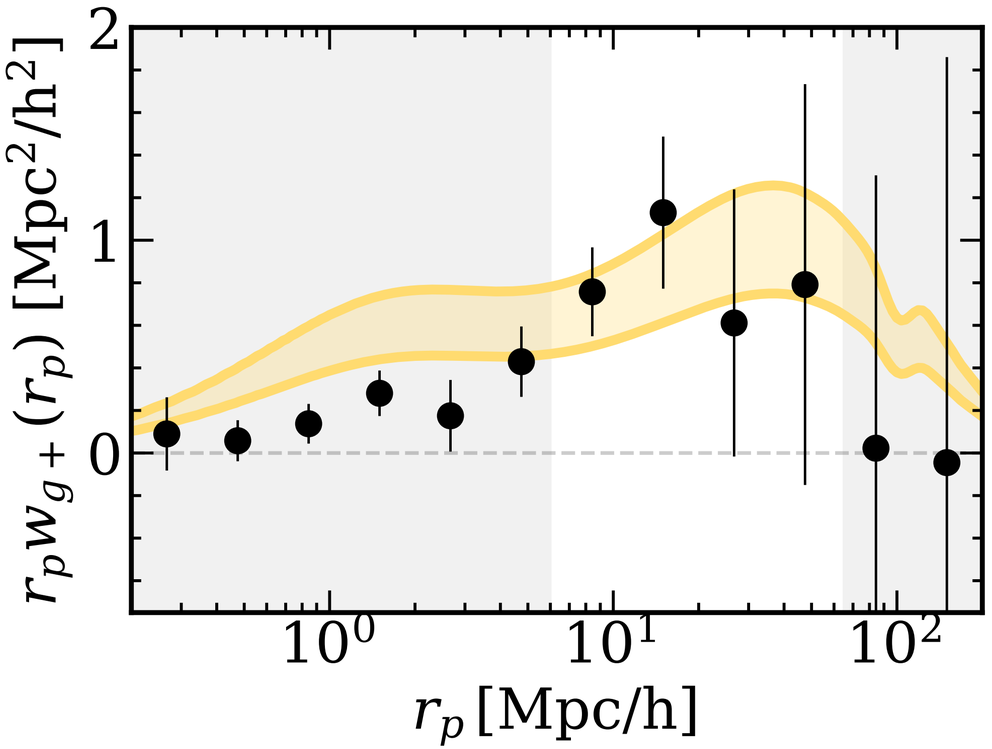
Non-linear Linear Alignment



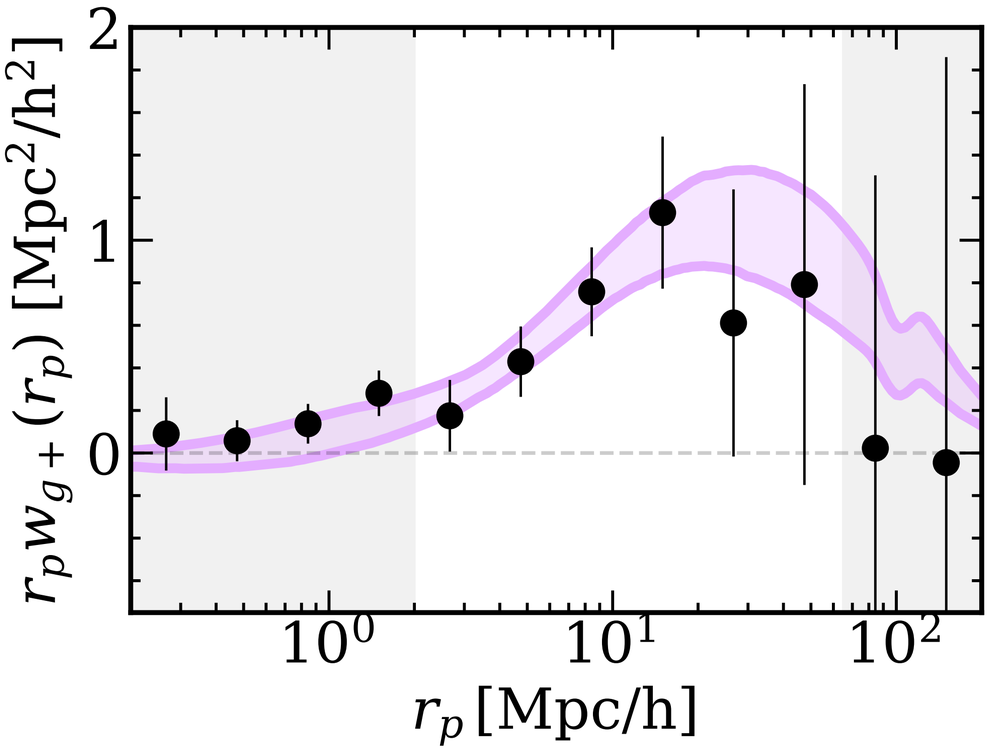
See Lamman+24 & Blazek+25

Intrinsic Alignments: Modeling

Non-linear Linear Alignment



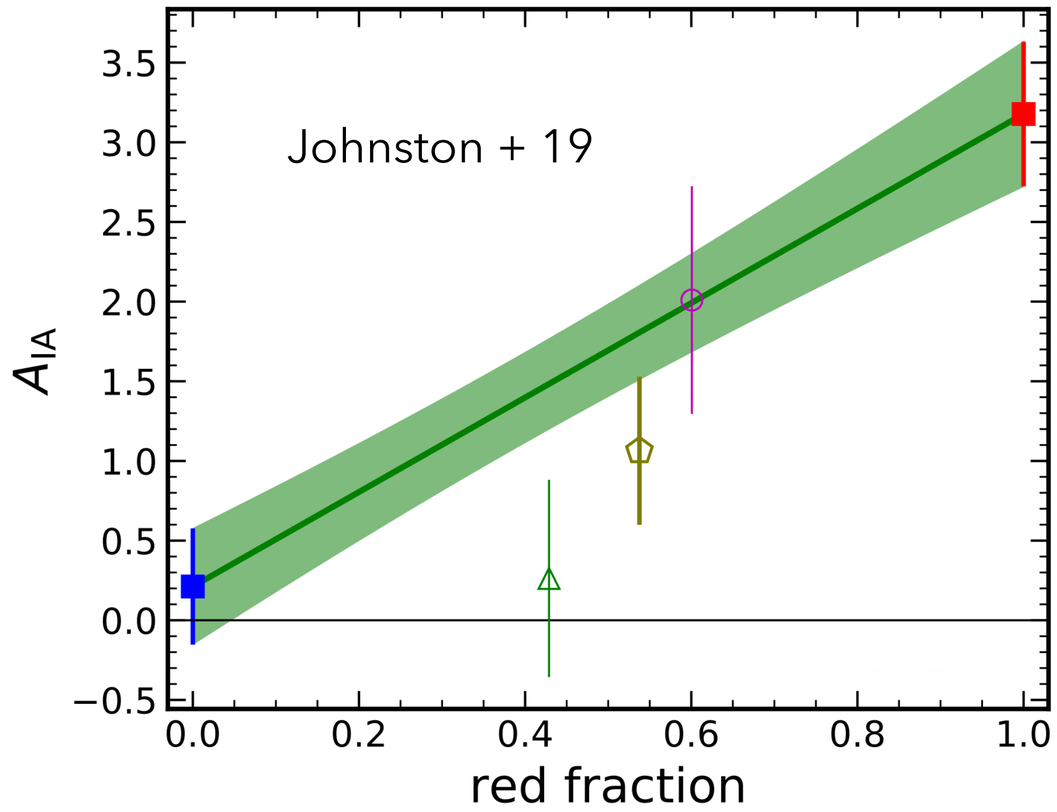
Tidal Alignment and Tidal Torquing



See Lamman+24 & Blazek+25

Intrinsic Alignments: Demographics

Direct measurements reveal how IA depends on galaxy type

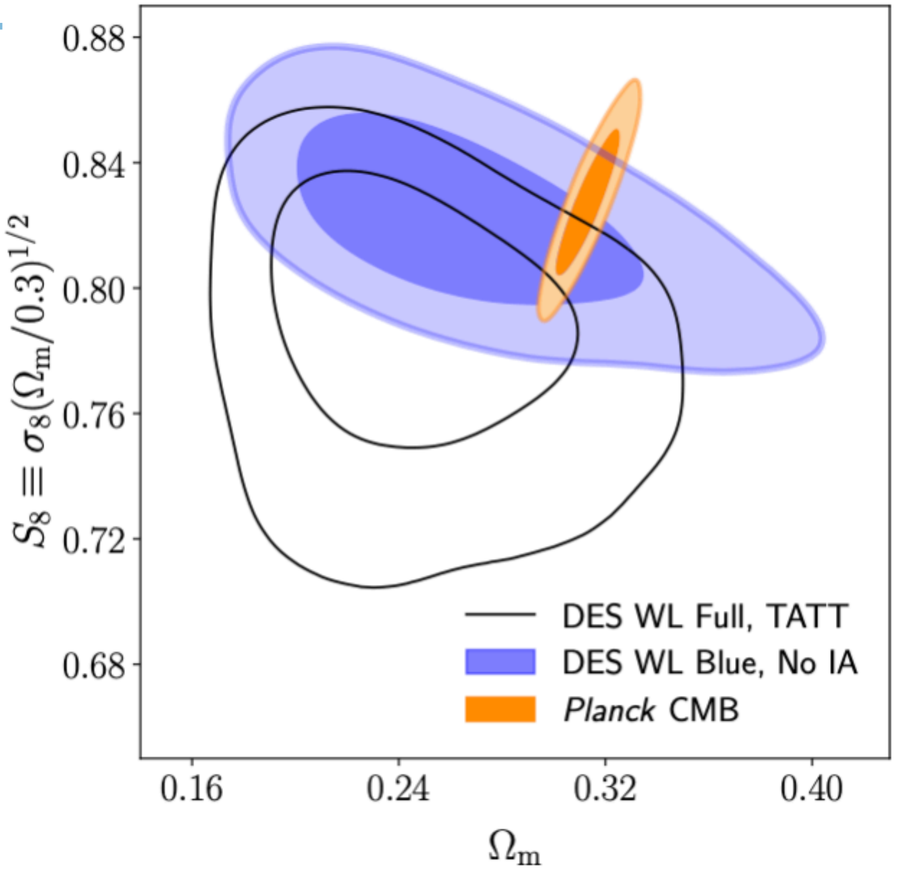


Tailored IA

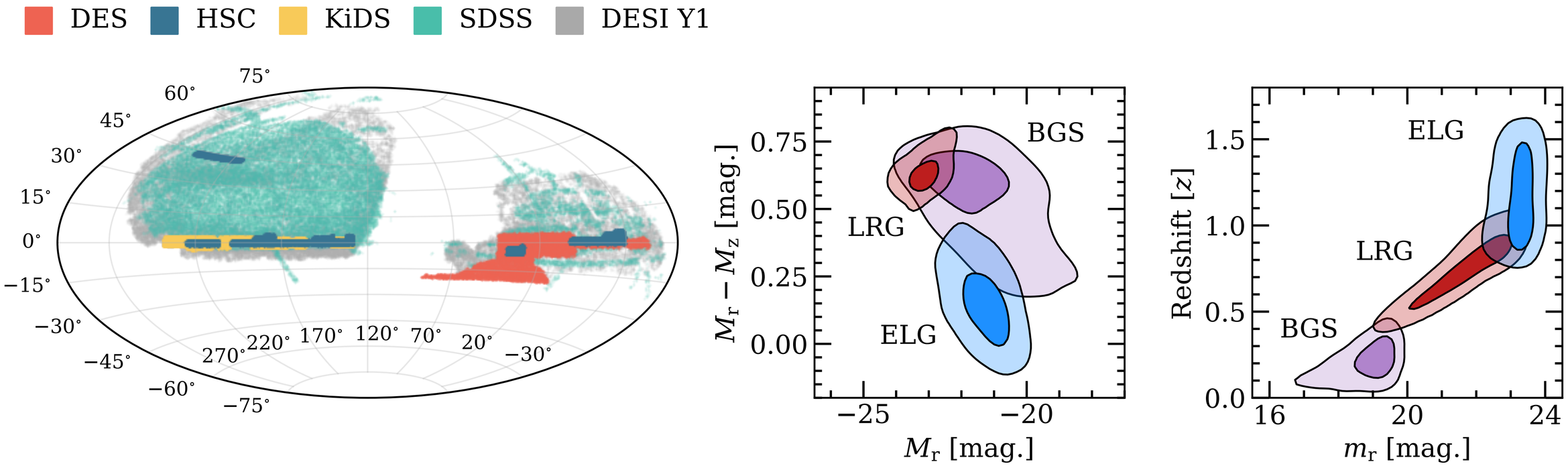
Blue Shear

DES Y3 reanalysis using a pure star forming shape catalog (70% of galaxies)

McCullough + 24

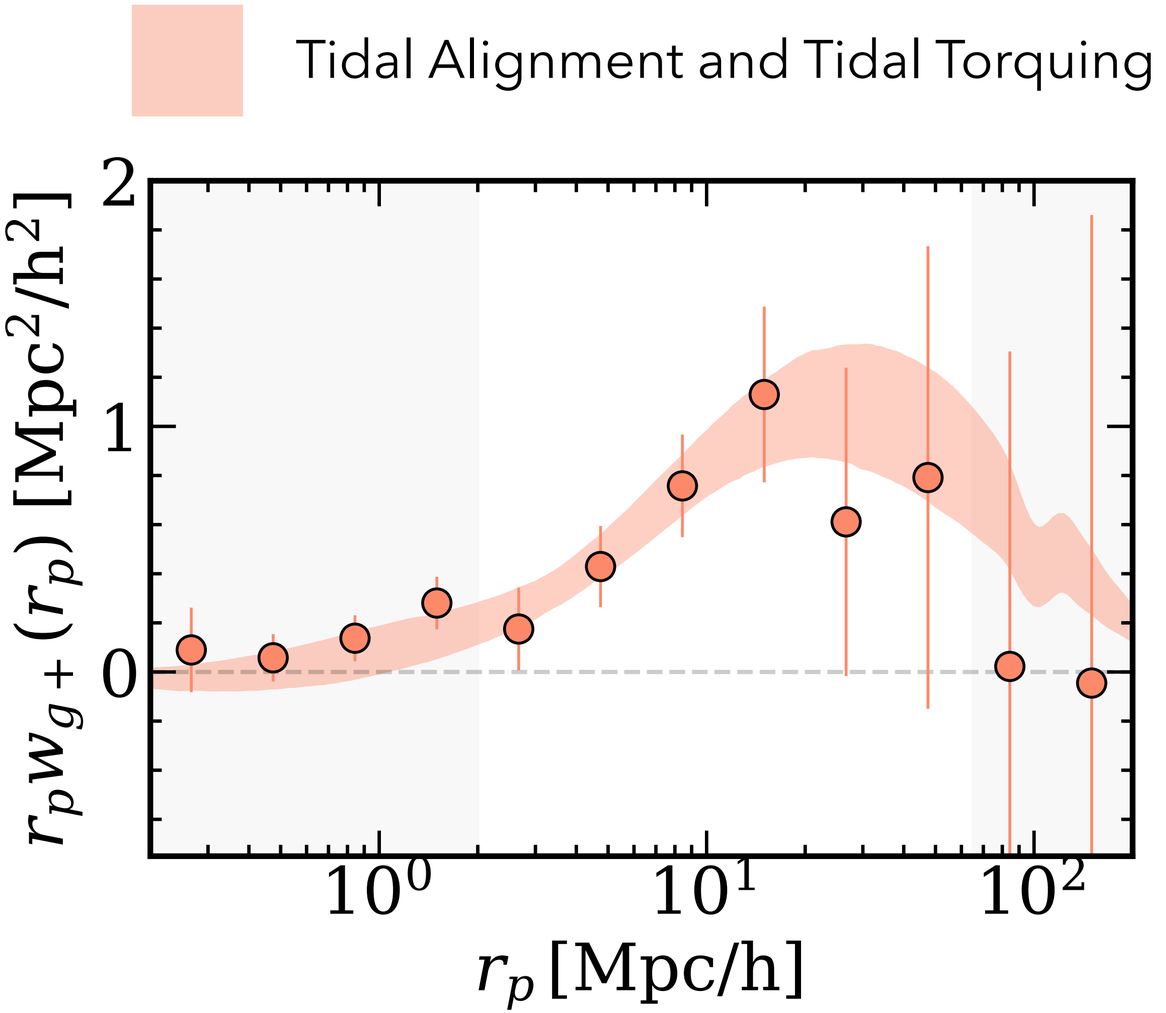


Direct Measurements with DESI



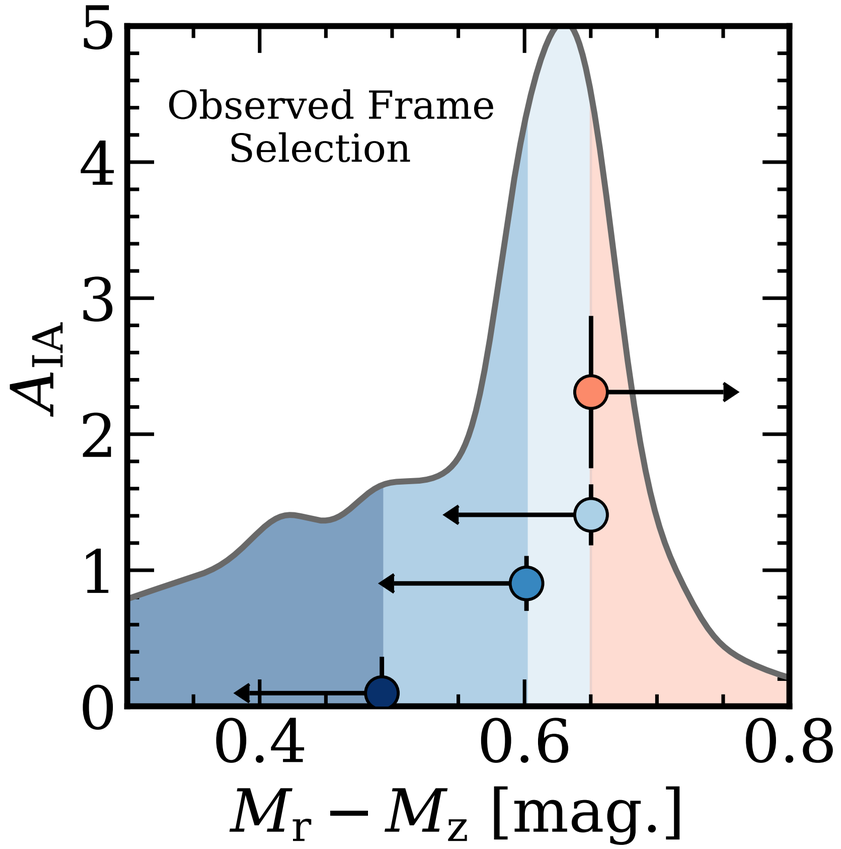
How does alignment depend on galaxy type, mass, and redshift?

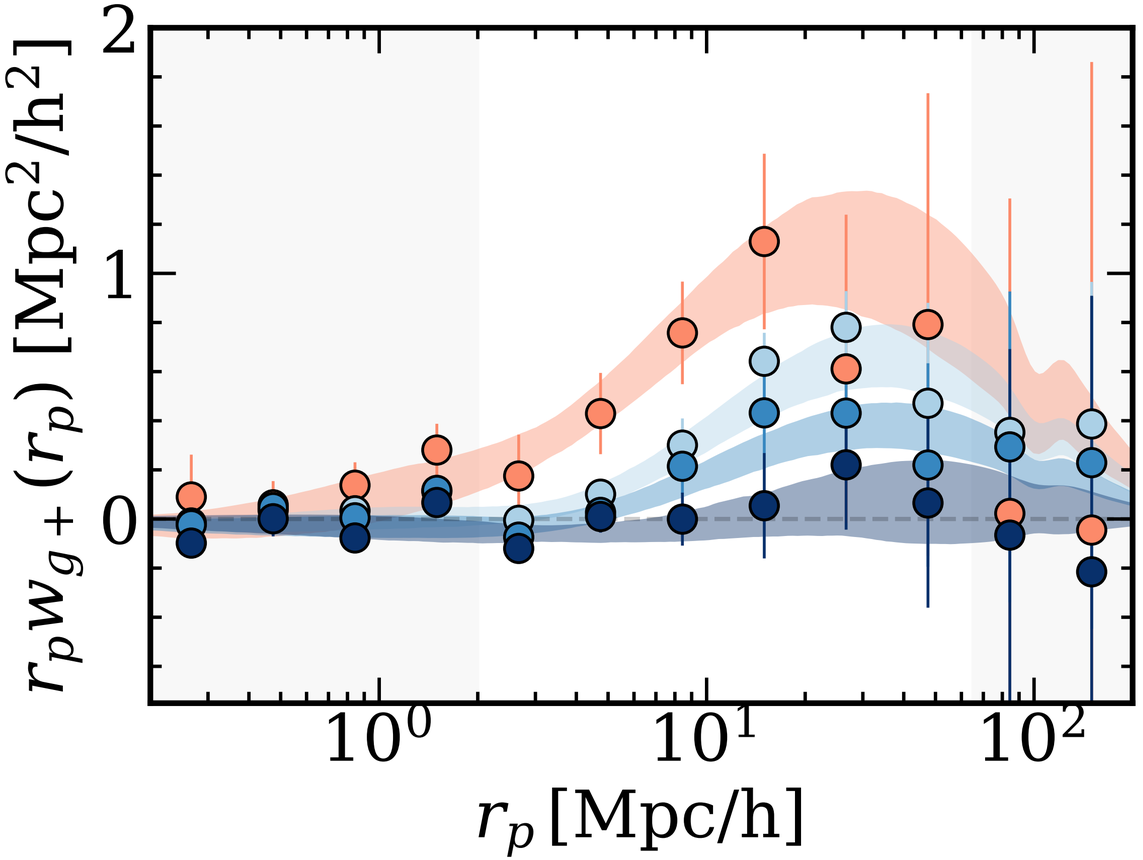
Intrinsic Alignments: DESI DR1



Intrinsic Alignments: DESI DR1

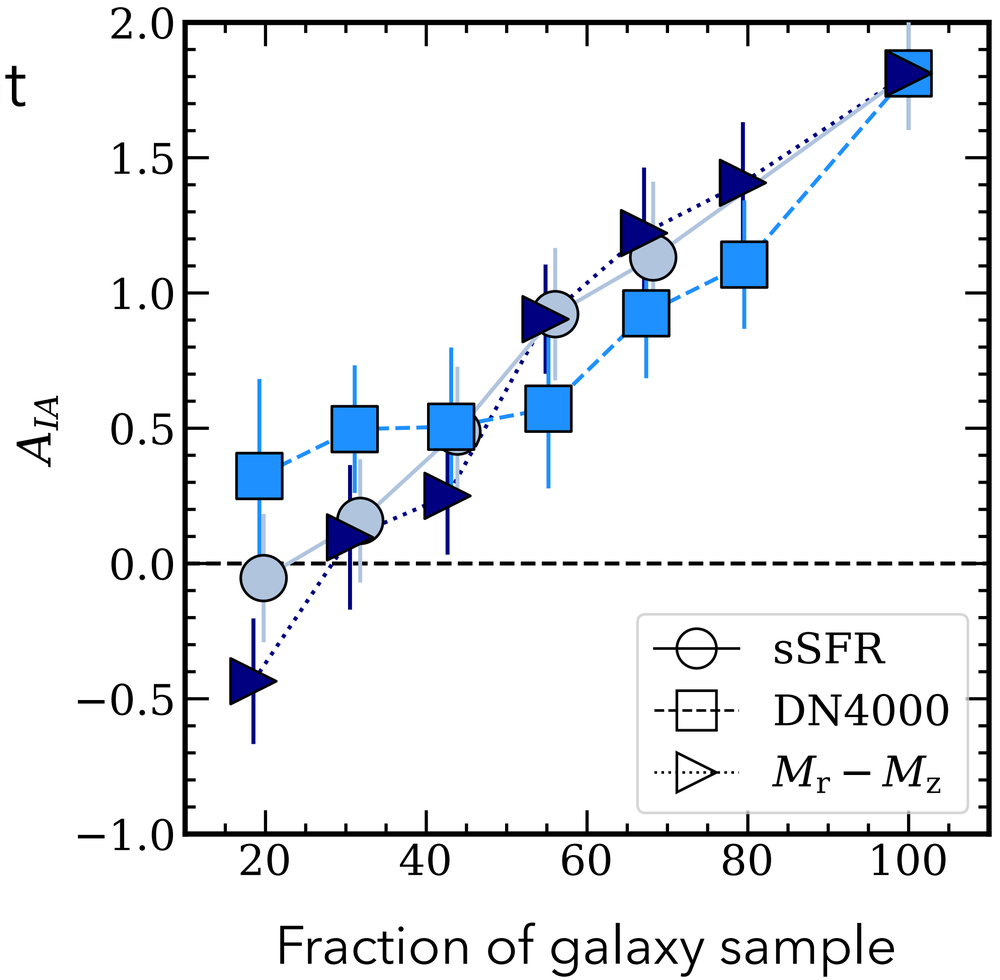
Blue star forming galaxies are minimally aligned





Intrinsic Alignments: DESI DR1

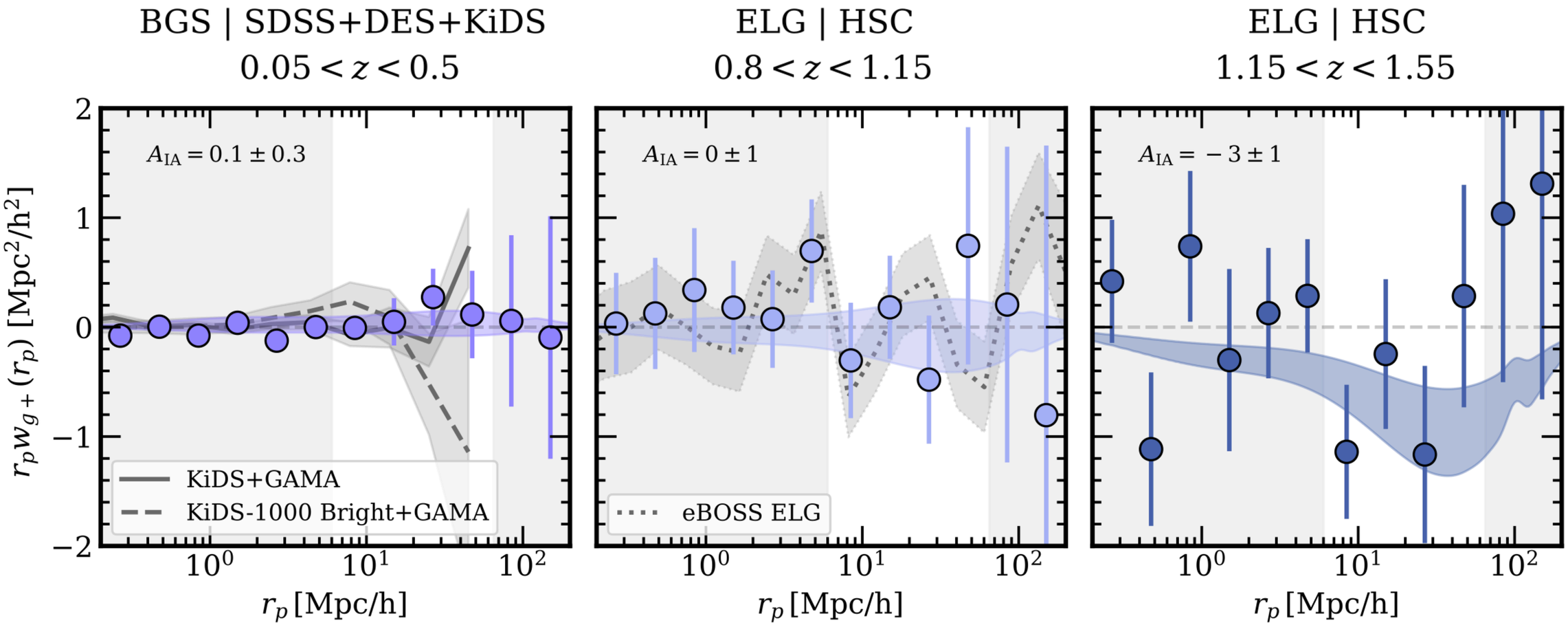
More Alignment



Fraction of galaxy sample

Pure Blue Sample ⟷ Blue+Red Sample

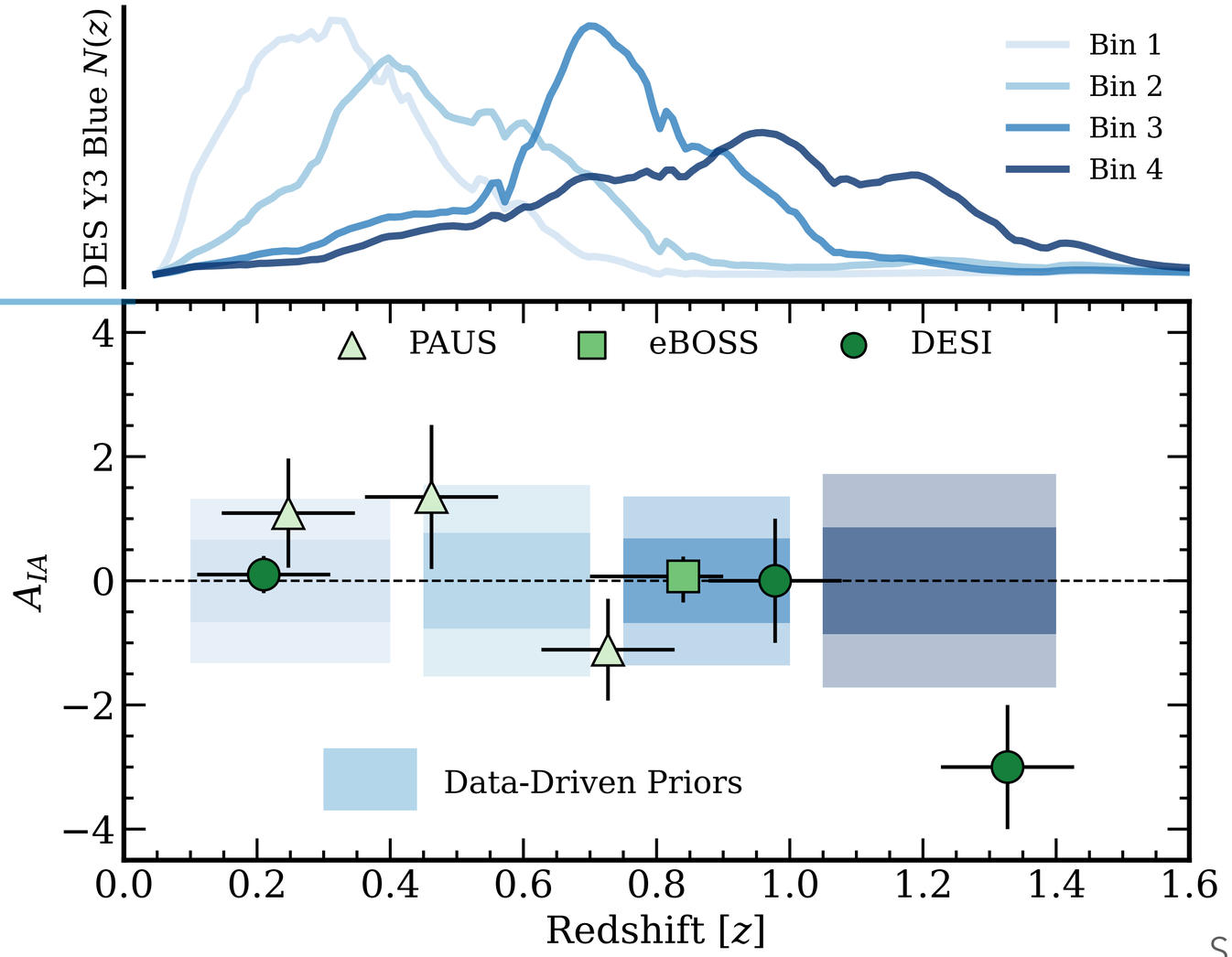
Intrinsic Alignments: DESI DR1



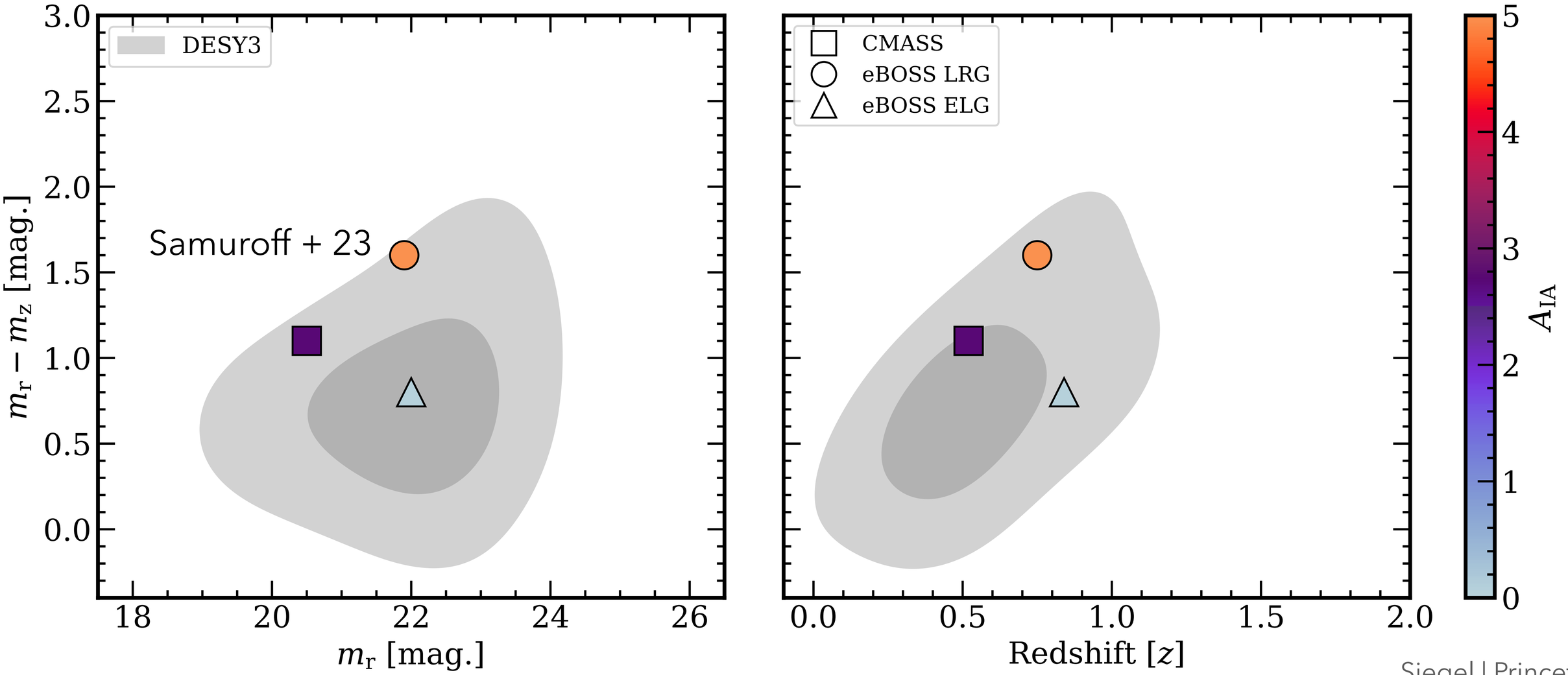
Tailored IA

Priors

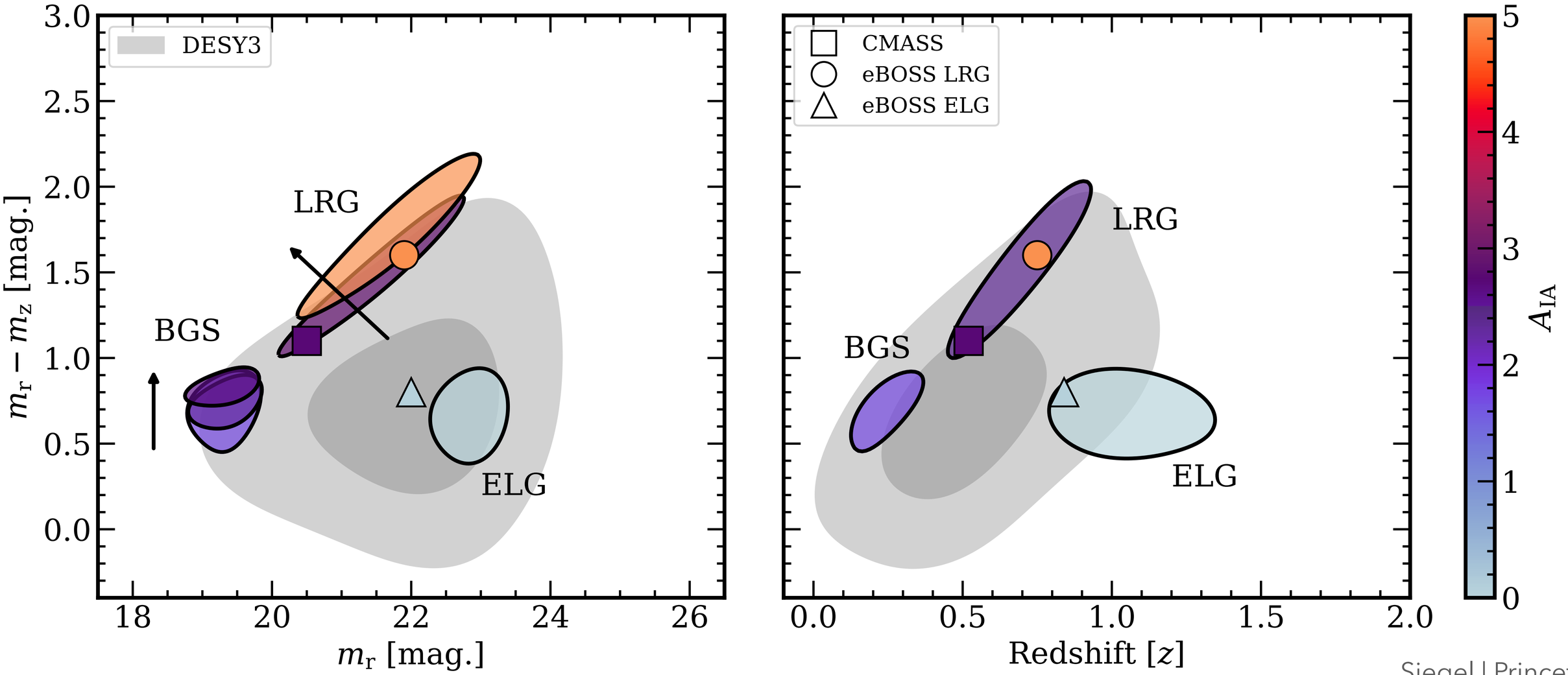
McCullough + in prep



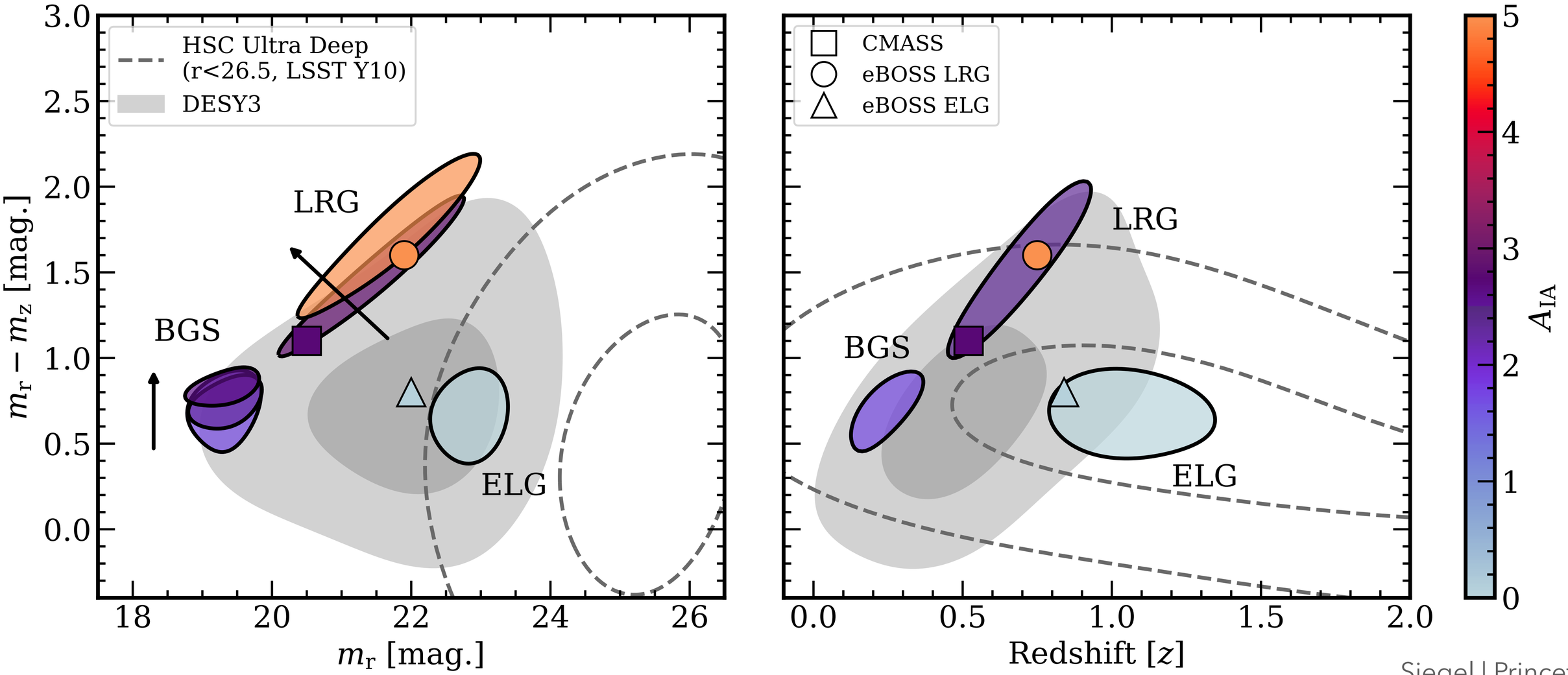
Tailored IA


DESY3
Samuroff + 23
$m_r - m_z$ [mag.]
m_r [mag.]
3.0
2.5
2.0
1.5
1.0
0.5
0.0
18
20
22
24
26
CMASS
eBOSS LRG
eBOSS ELG
Redshift [z]
0.0
0.5
1.0
1.5
2.0
A_{IA}
5
4
3
2
1
0

Tailored IA


DESY3
LRG
BGS
ELG
$m_r - m_z$ [mag.]
m_r [mag.]
CMASS
eBOSS LRG
eBOSS ELG
LRG
BGS
ELG
Redshift [z]
A_{IA}

Tailored IA


HSC Ultra Deep
(r<26.5, LSST Y10)
DESY3
LRG
BGS
ELG
$m_r - m_z$ [mag.]
m_r [mag.]
CMASS
eBOSS LRG
eBOSS ELG
Redshift [z]
A_{IA}

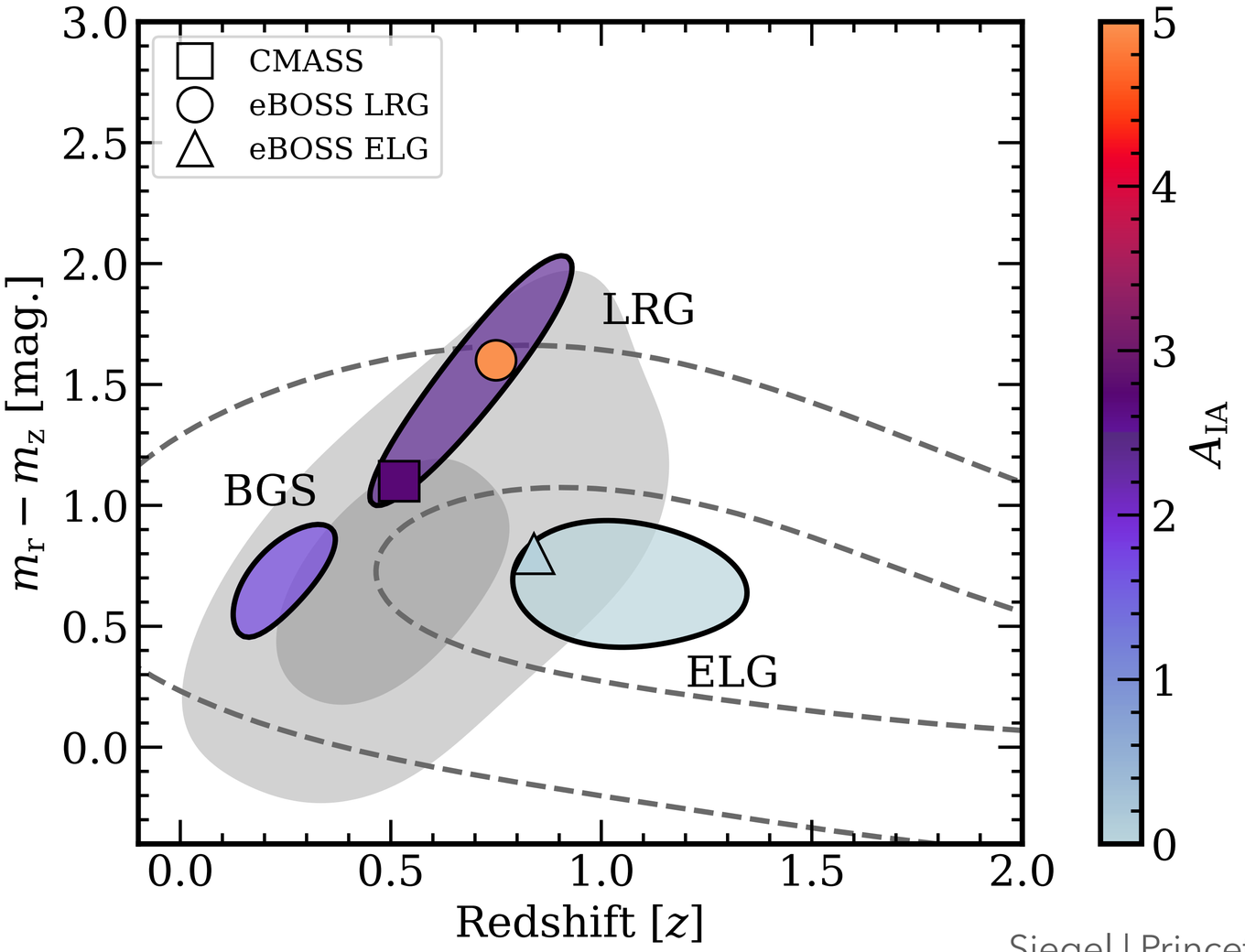
Tailored IA

What's next?

DESI DR2

LSST DP2

DESI II



Data-driven Astrophysical Priors

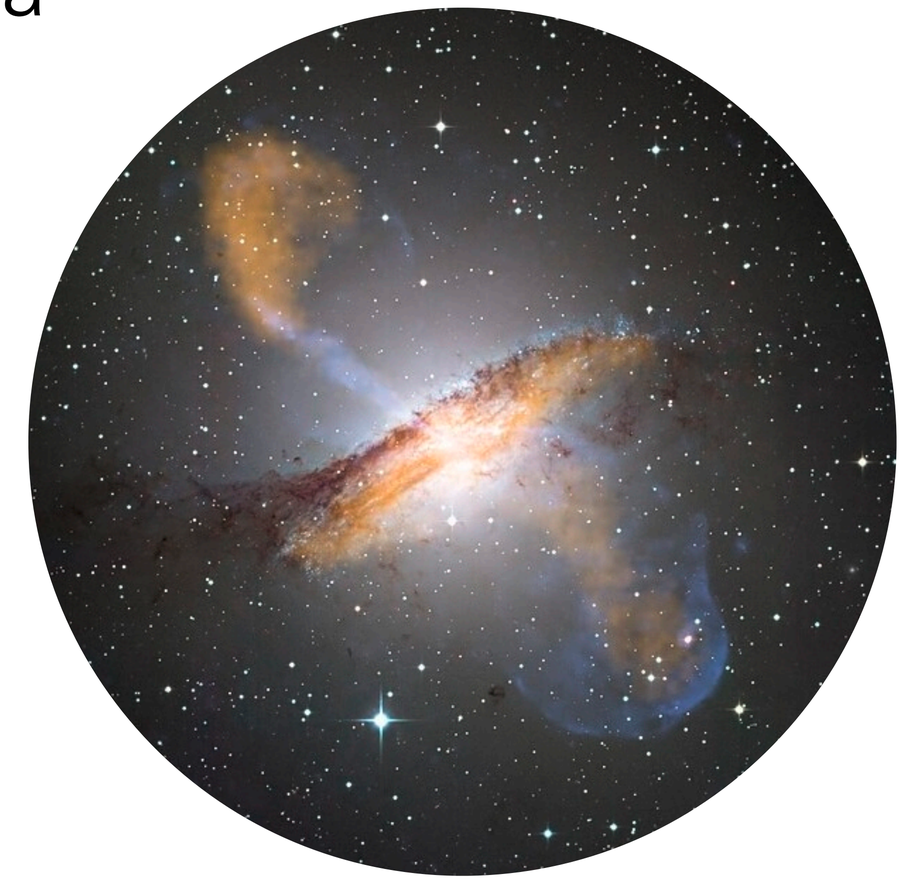
	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	
Priors	McCullough, Siegel + in prep	
Cosmology		

Data-driven Astrophysical Priors

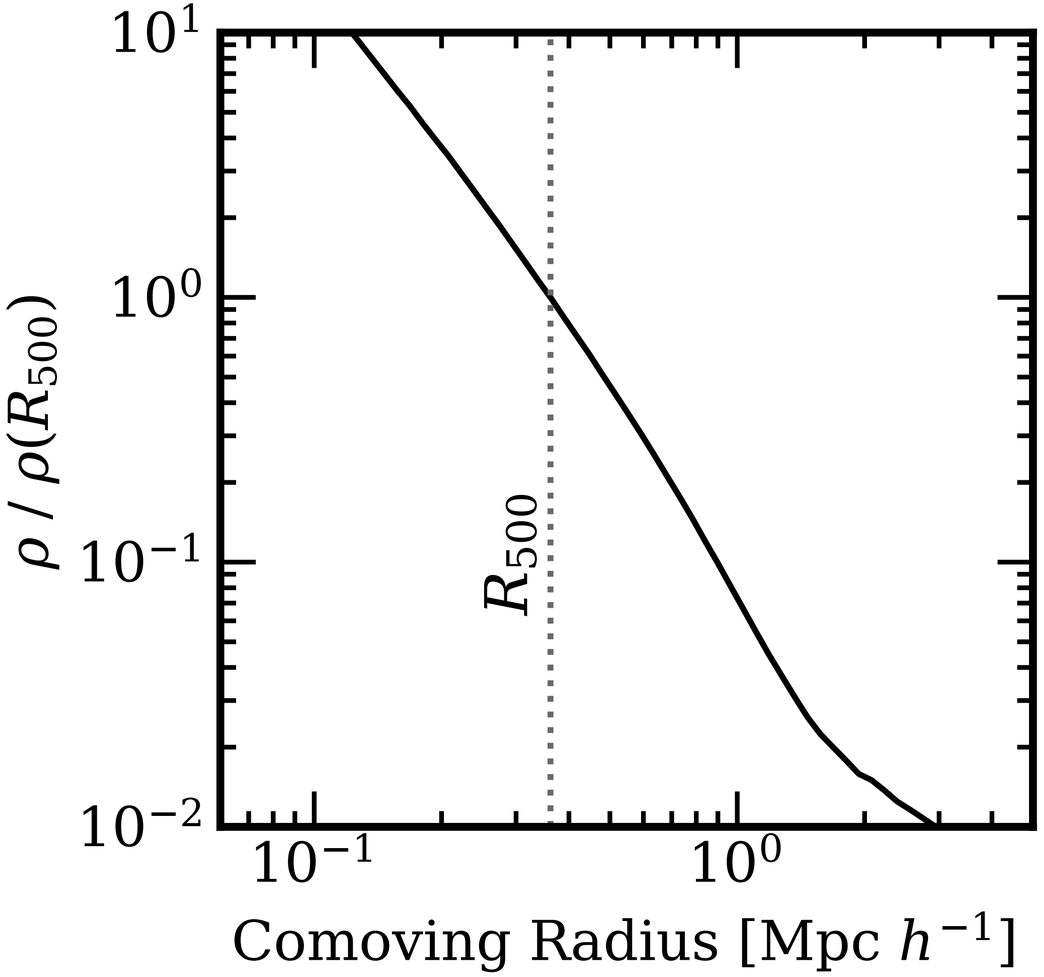
	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	kSZ + X-ray + GGL Siegel + 25b
Priors	McCullough, Siegel + in prep	Siegel + 25c
Cosmology		

Baryon Feedback

Redistribution of matter by supernova and Active Galactic Nuclei (AGN)



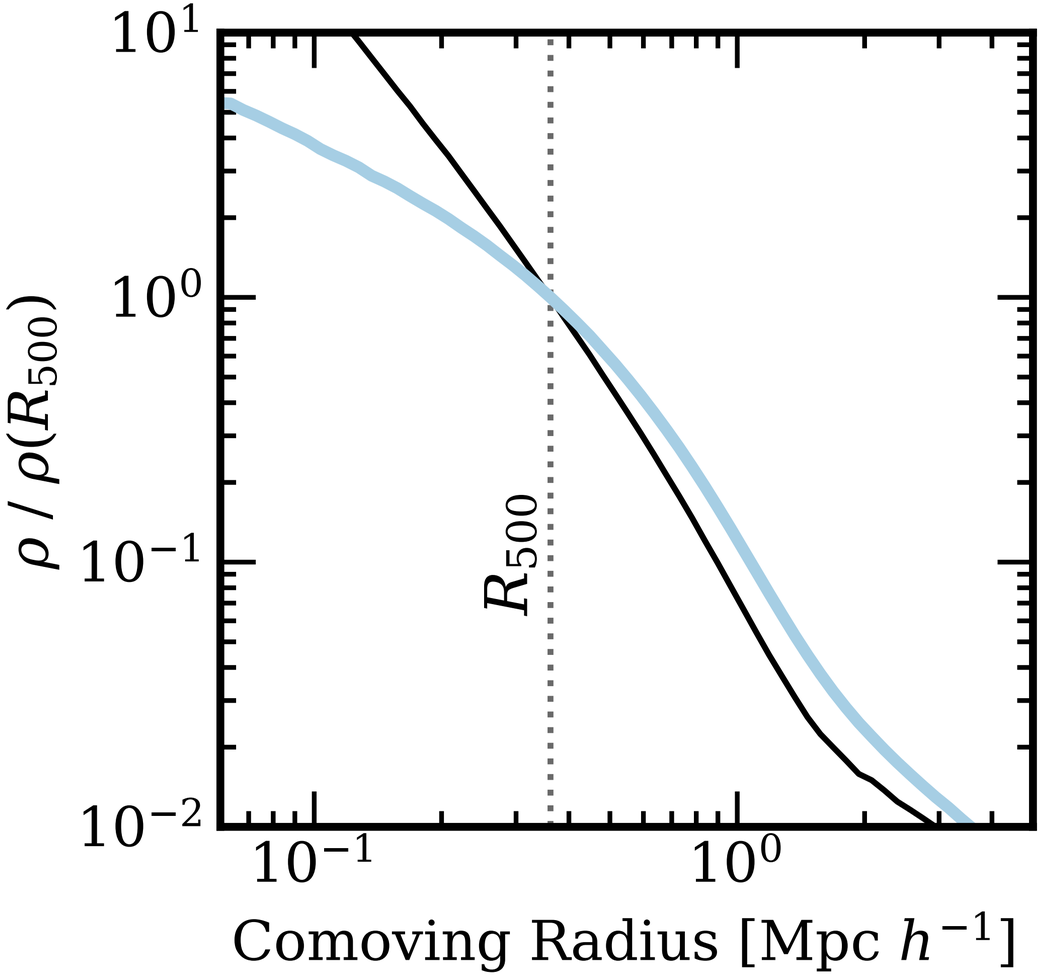
Baryon Feedback



Total matter

Schaye et al. 2023

Baryon Feedback

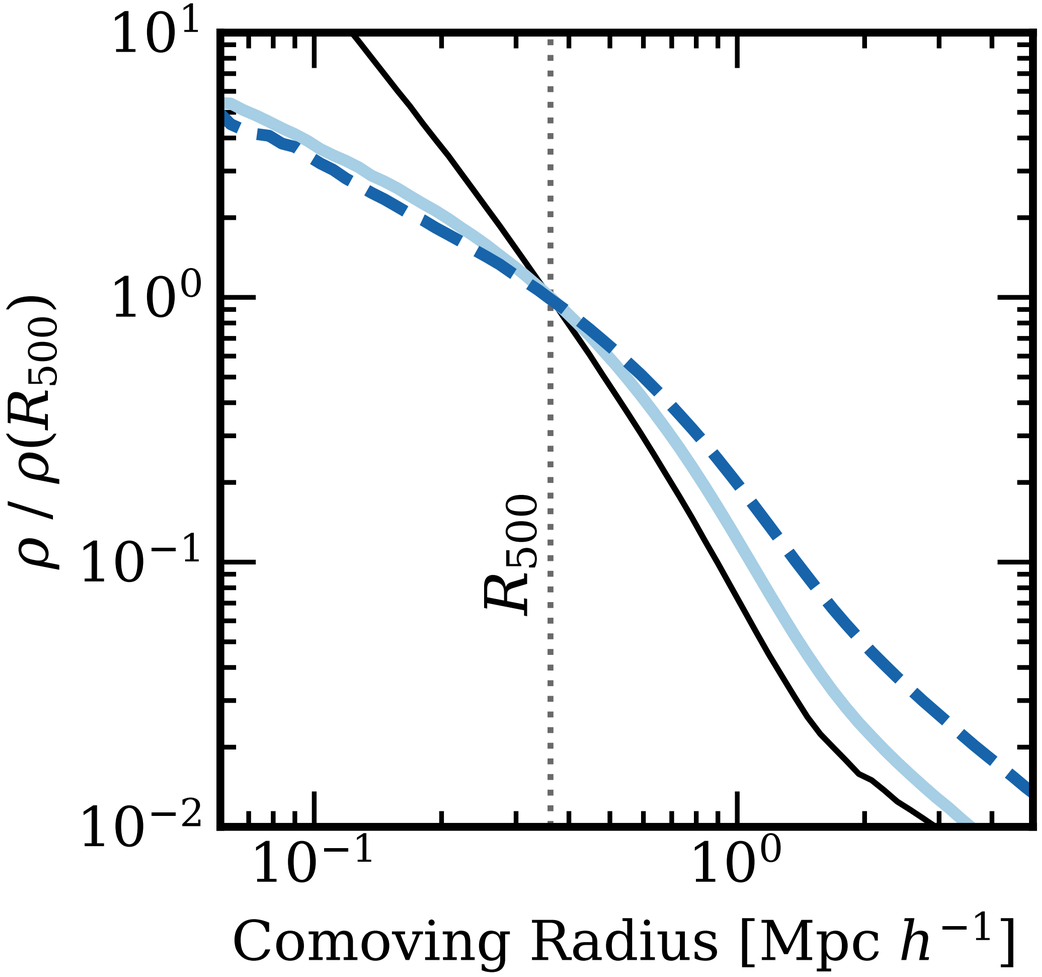


Total matter

Hot Gas | Fiducial AGN

Schaye et al. 2023

Baryon Feedback



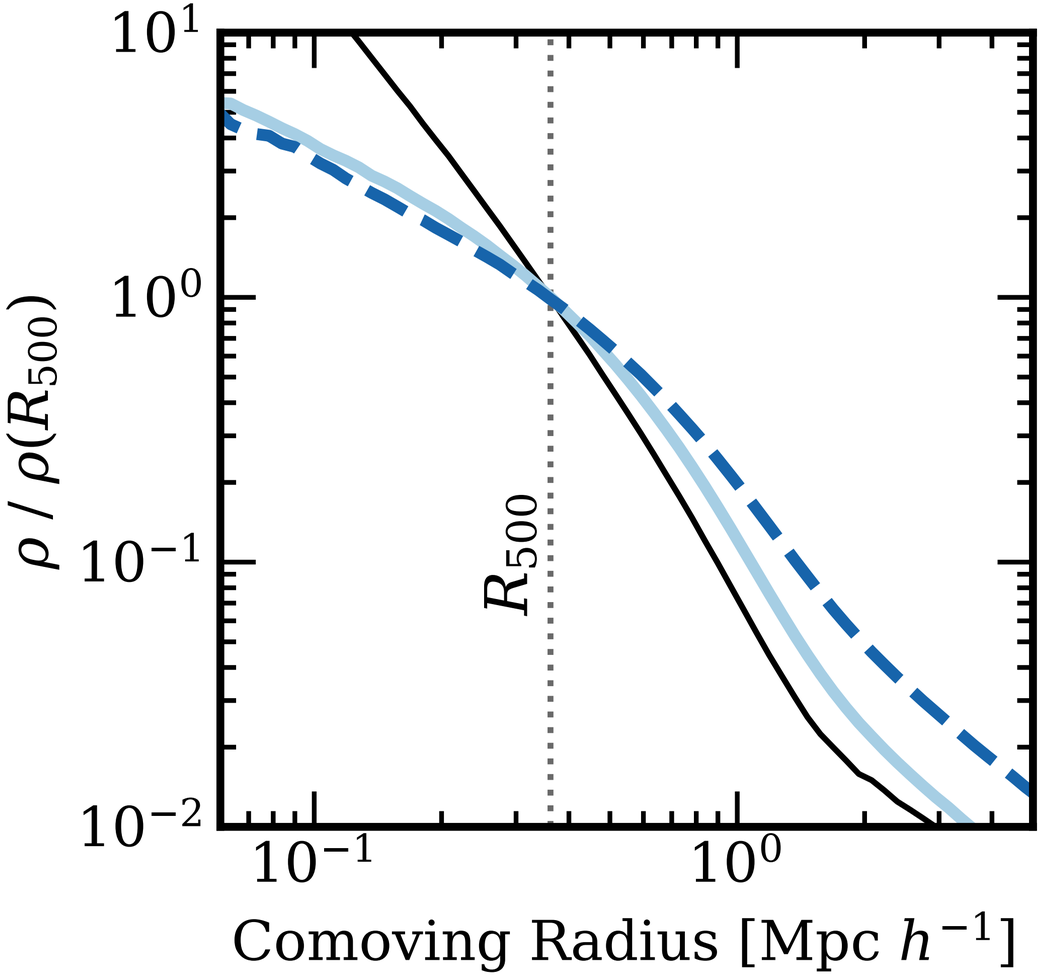
Total matter

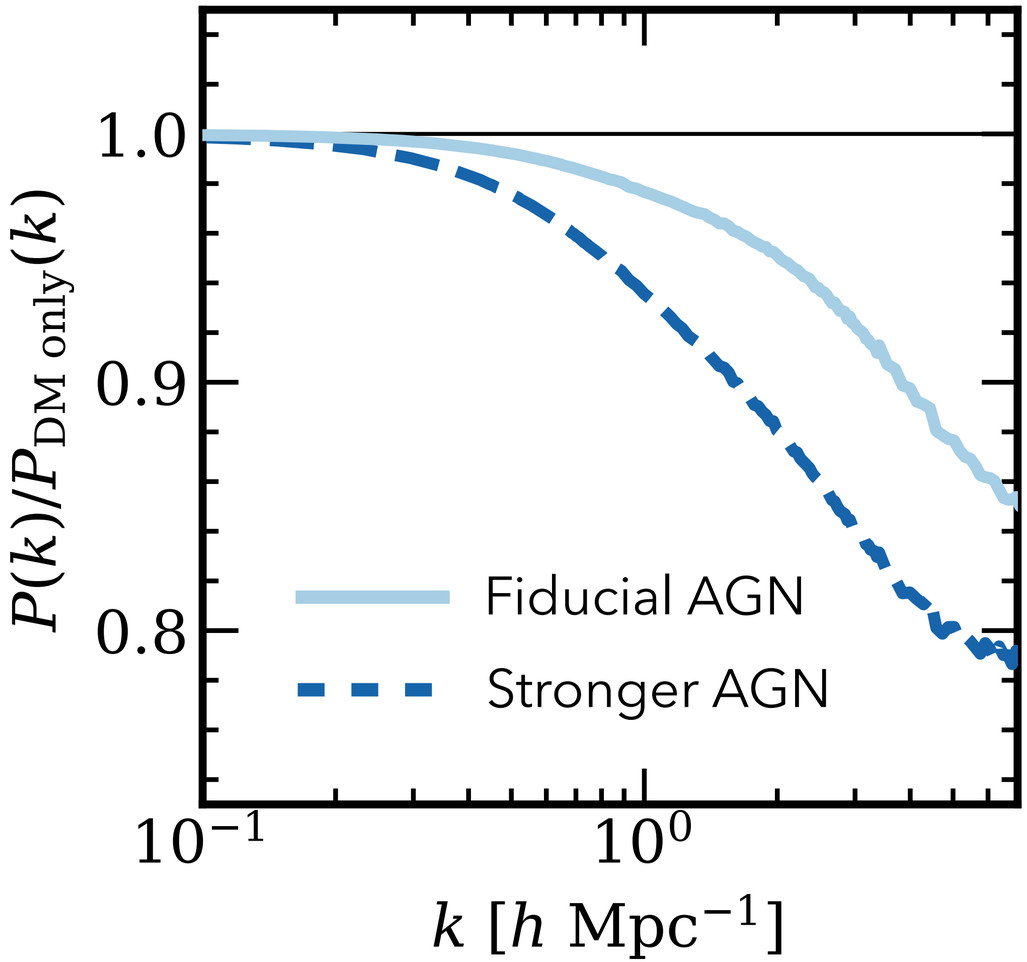
Hot Gas | Fiducial AGN

Hot Gas | Stronger AGN

Schaye et al. 2023

Baryon Feedback

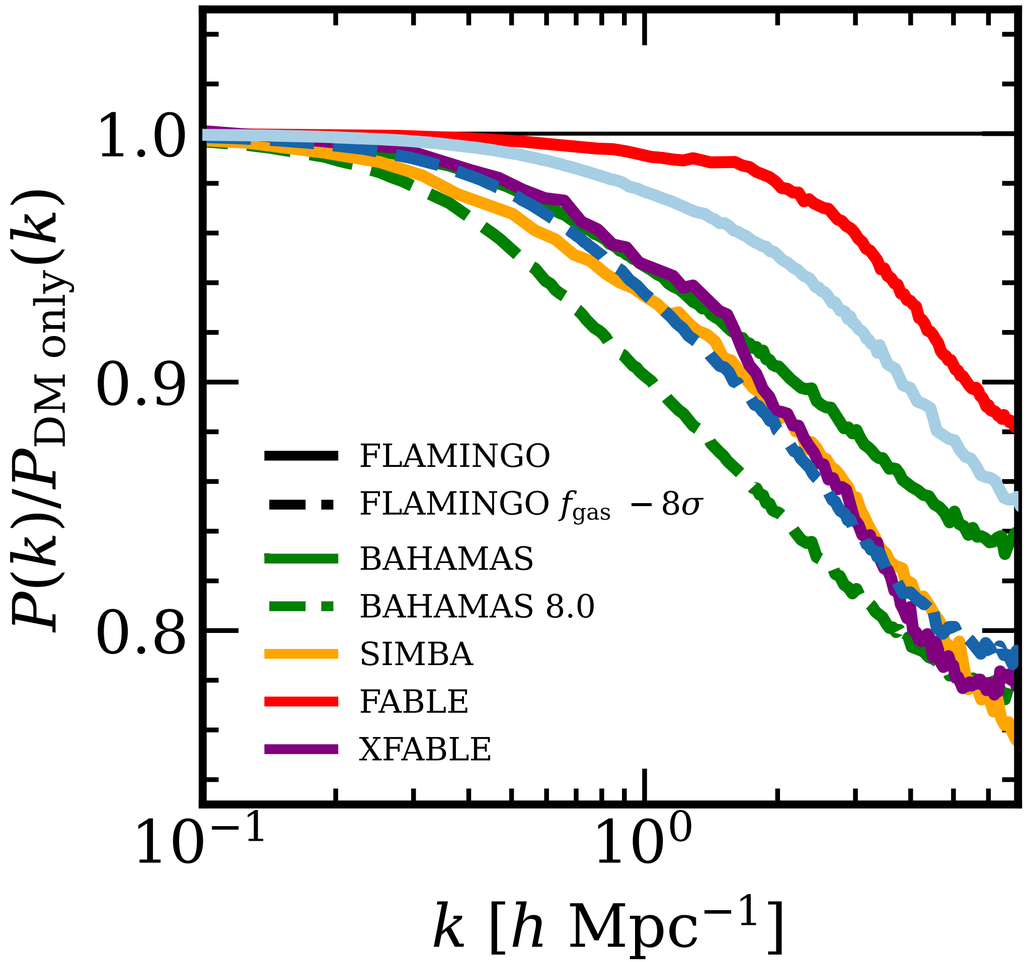




Schaye et al. 2023

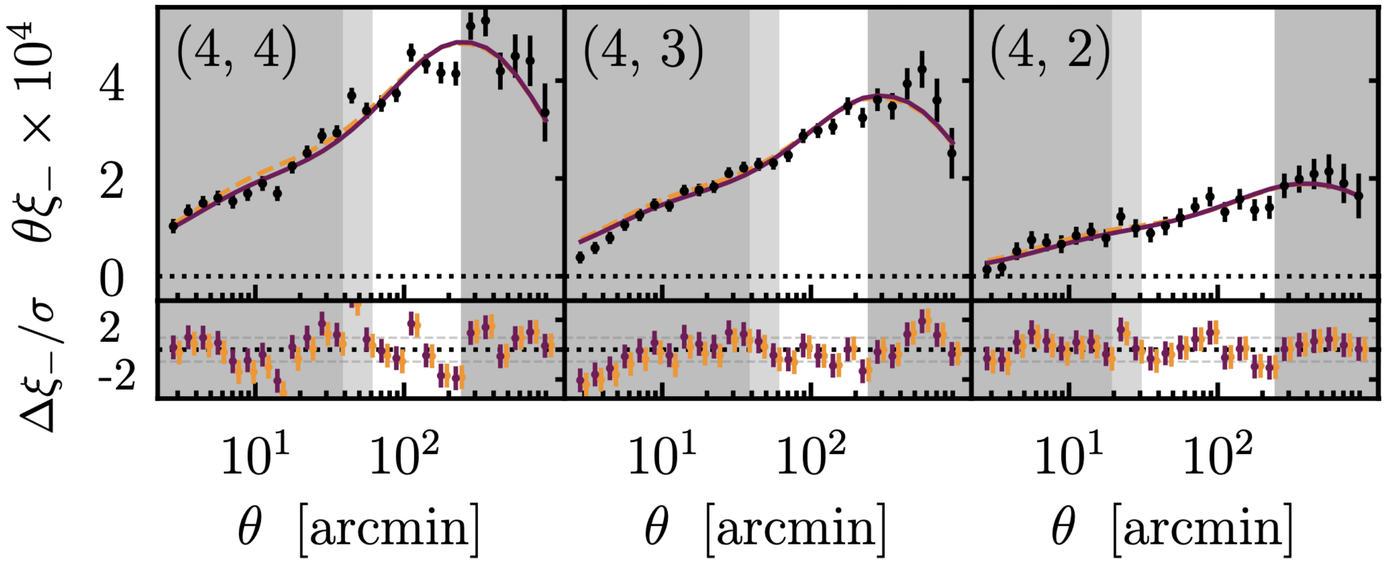
Baryon Feedback

Simulation Predictions



Baryon Feedback

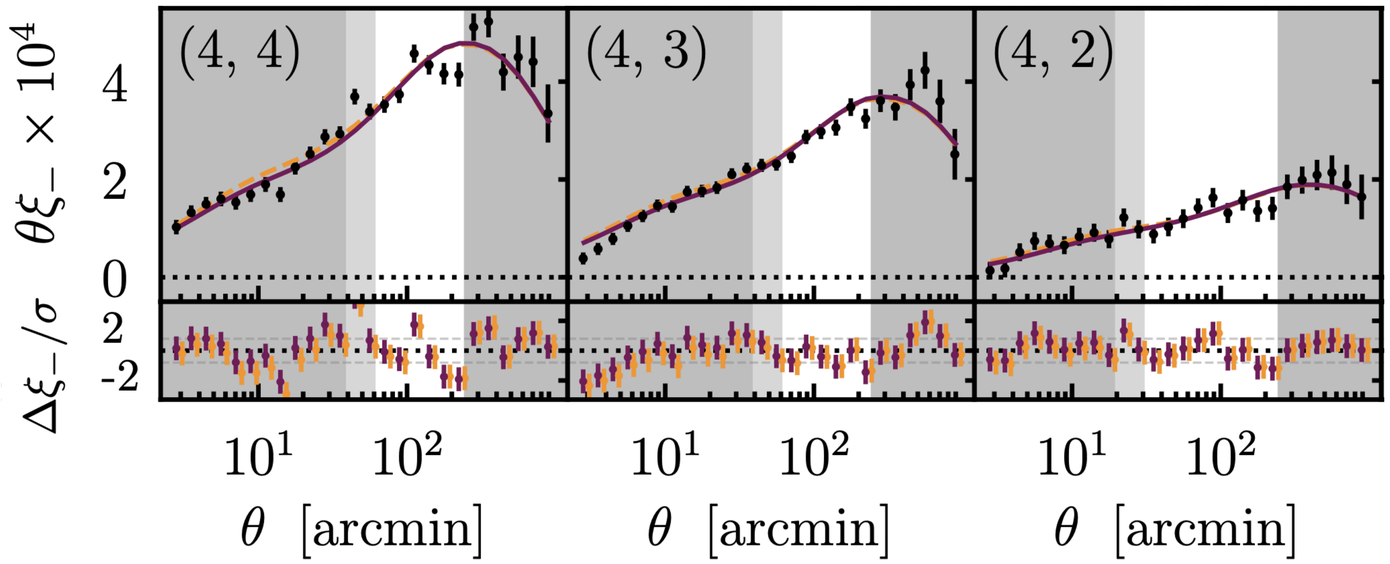
Baryon feedback is a source of **uncertainty** and a potential **bias** for cosmic shear

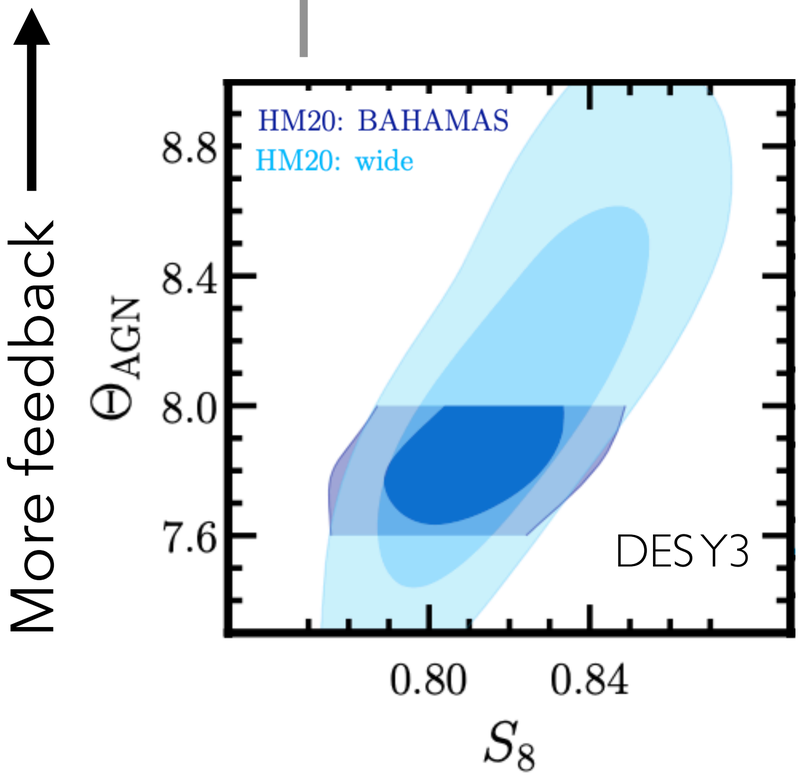


DES Y6 Cosmic Shear

Baryon Feedback

Baryon feedback is a source of **uncertainty** and a potential **bias** for cosmic shear



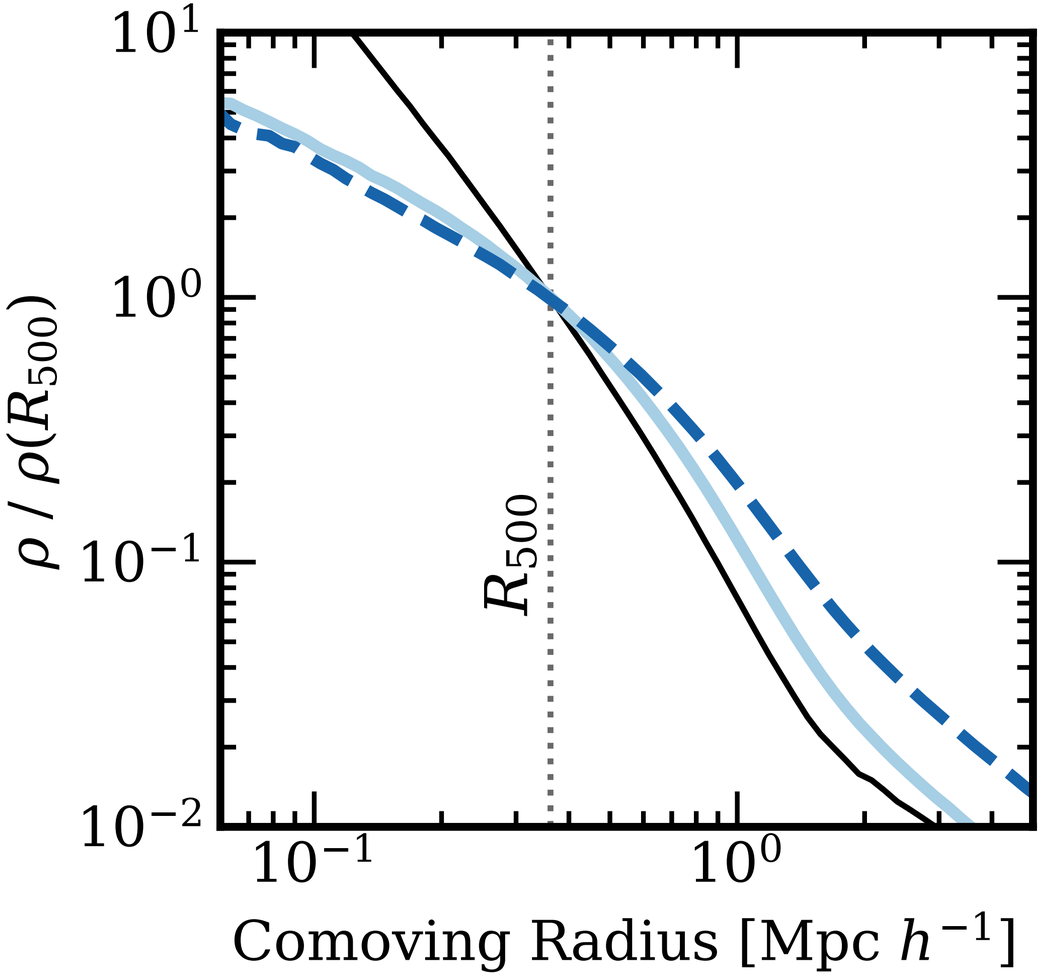


DES Y6 Cosmic Shear

Bigwood+24

How do we measure feedback?

How do we measure feedback?



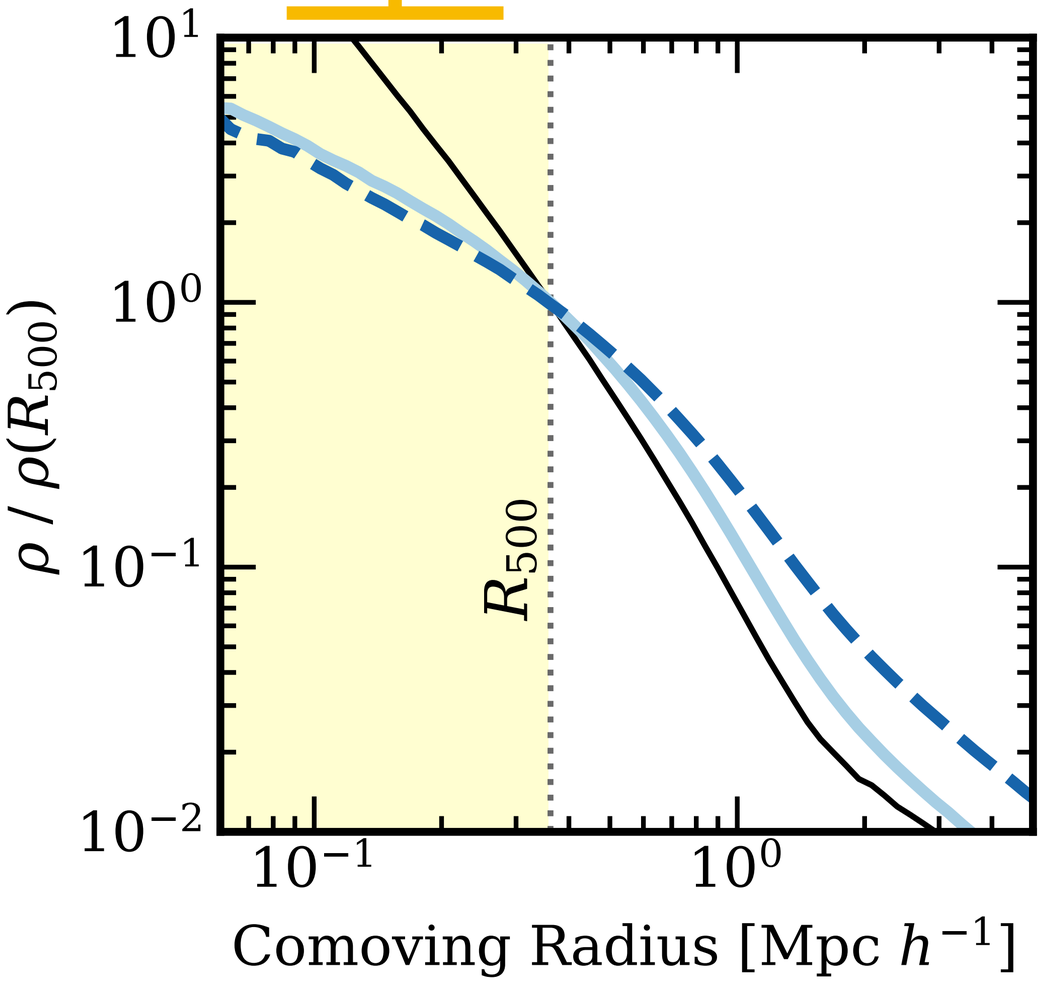
Total matter

Hot Gas | Fiducial AGN

Hot Gas | Stronger AGN

Schaye et al. 2023

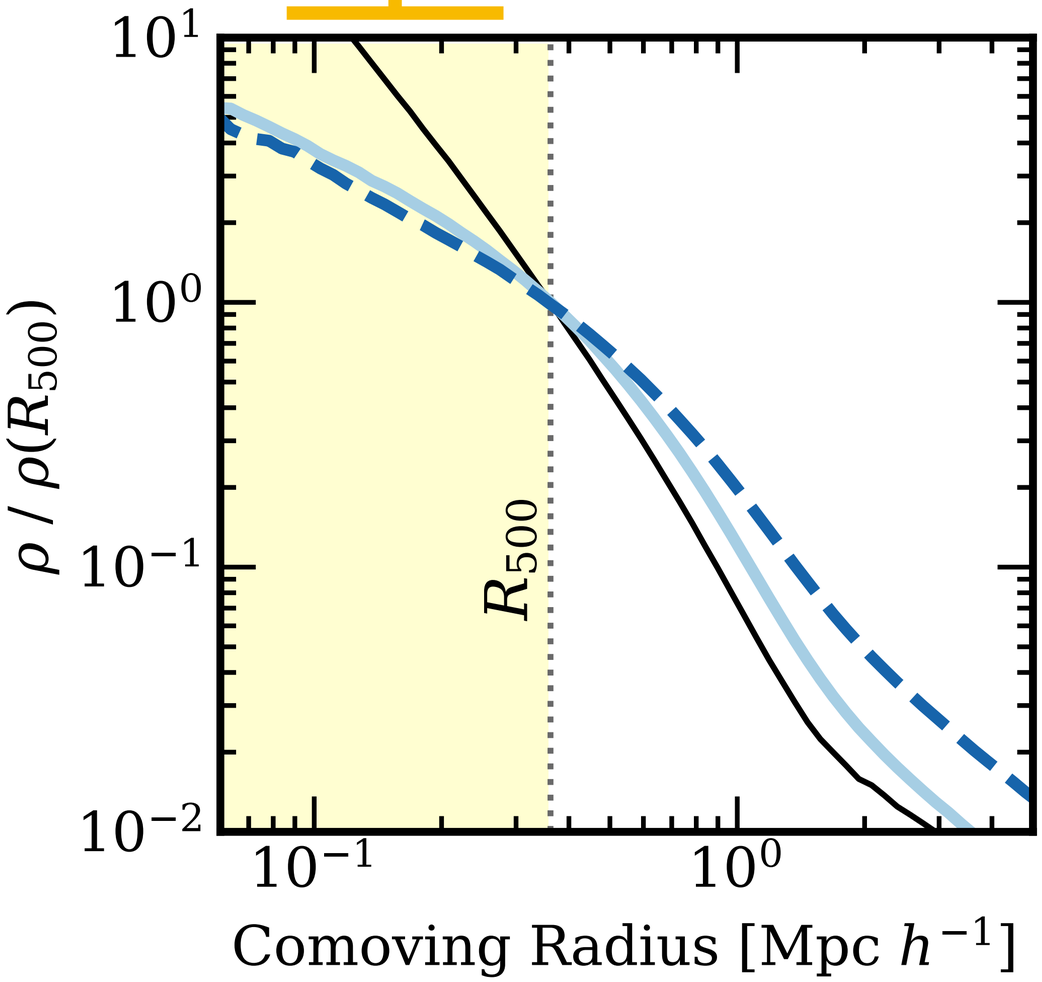
How do we measure feedback?

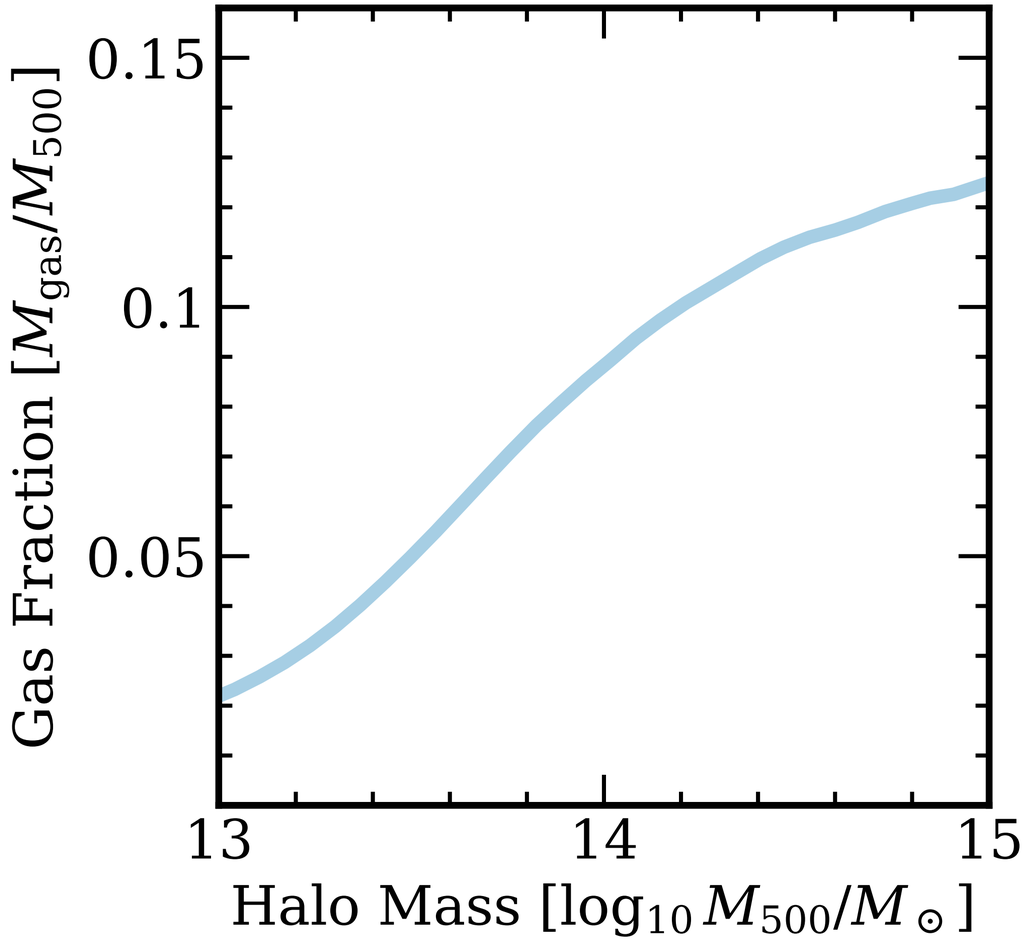


X-ray Hot Gas Fractions

eROSITA

How do we measure feedback?





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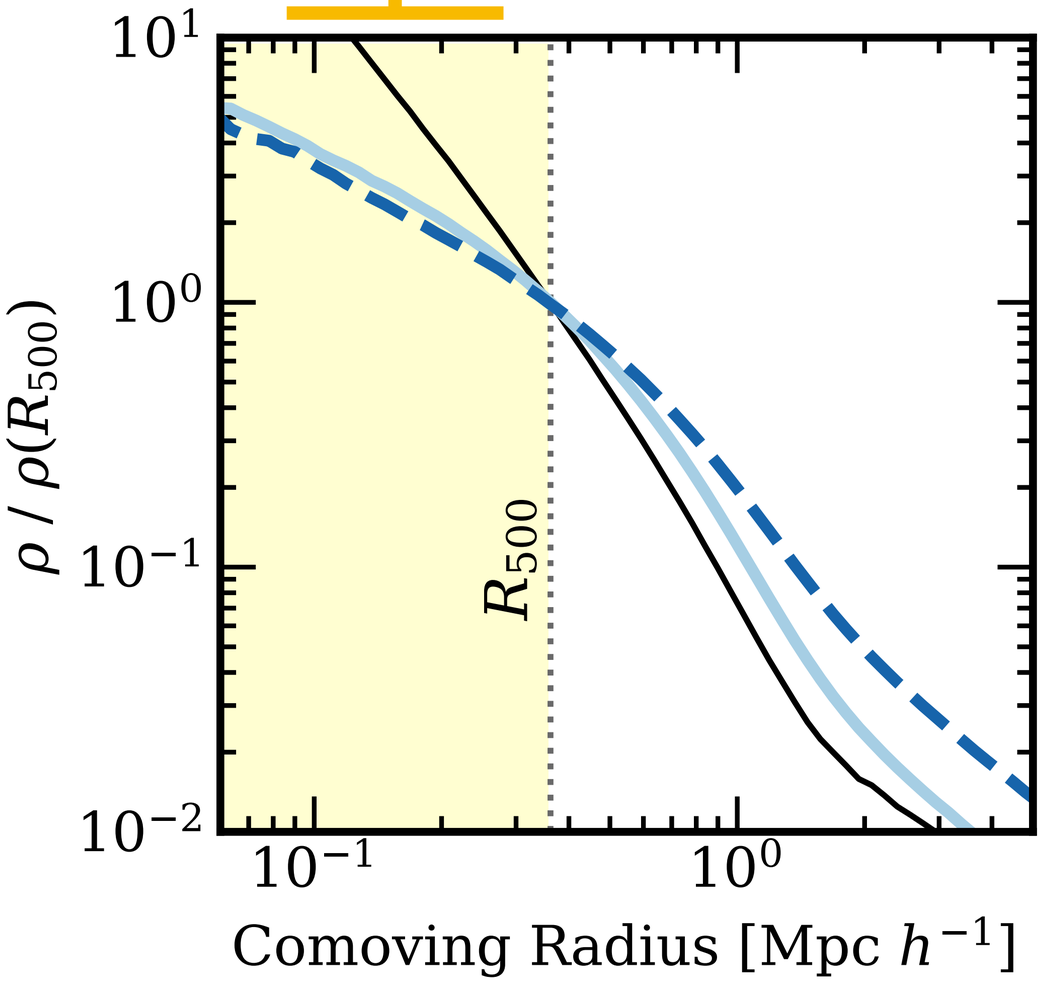

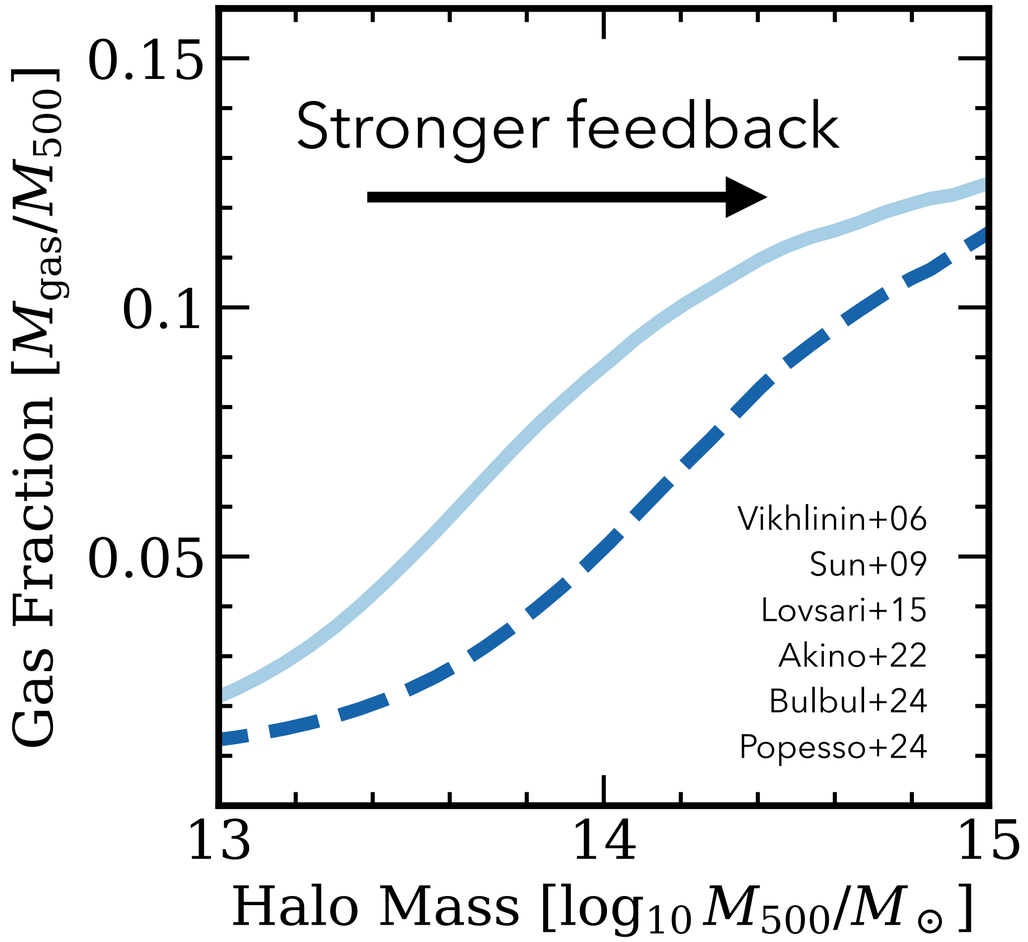

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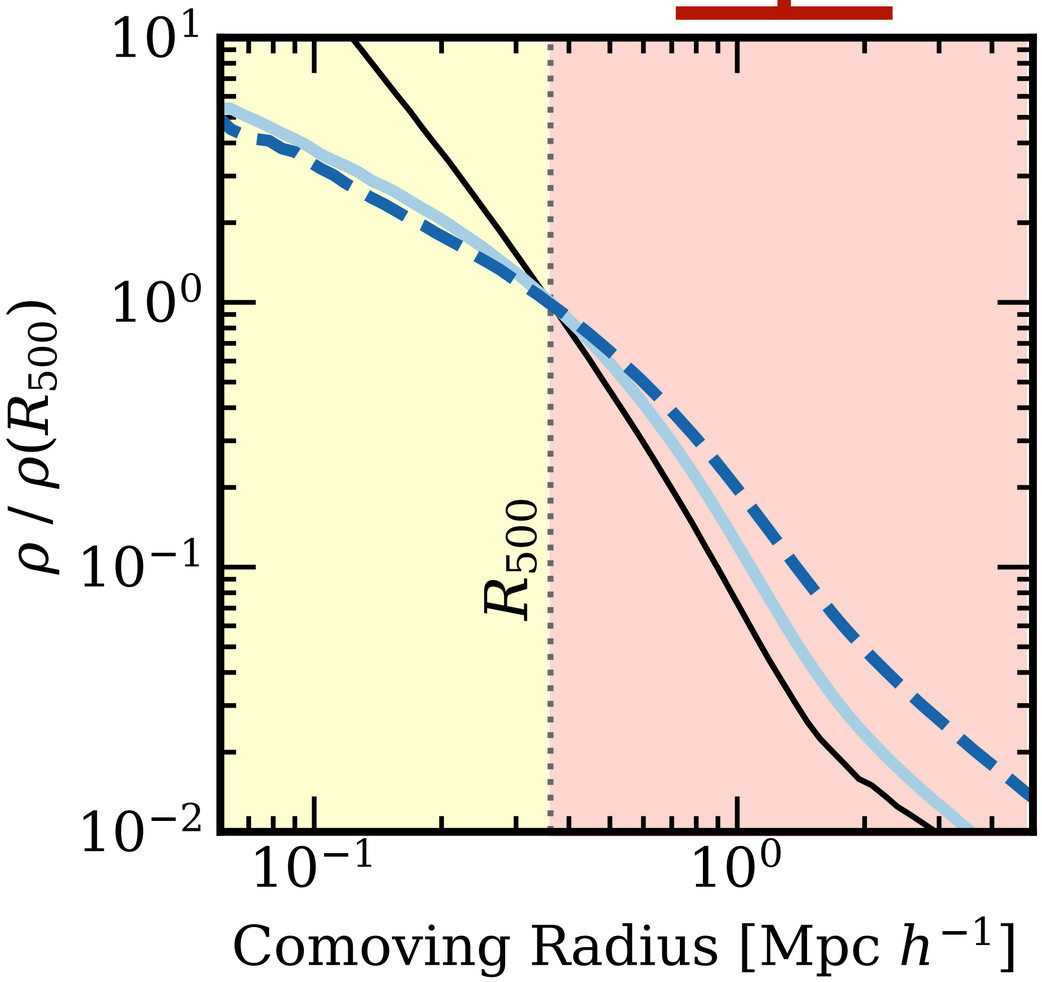
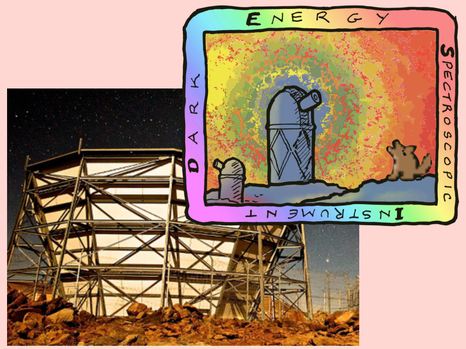


kSZ Effect



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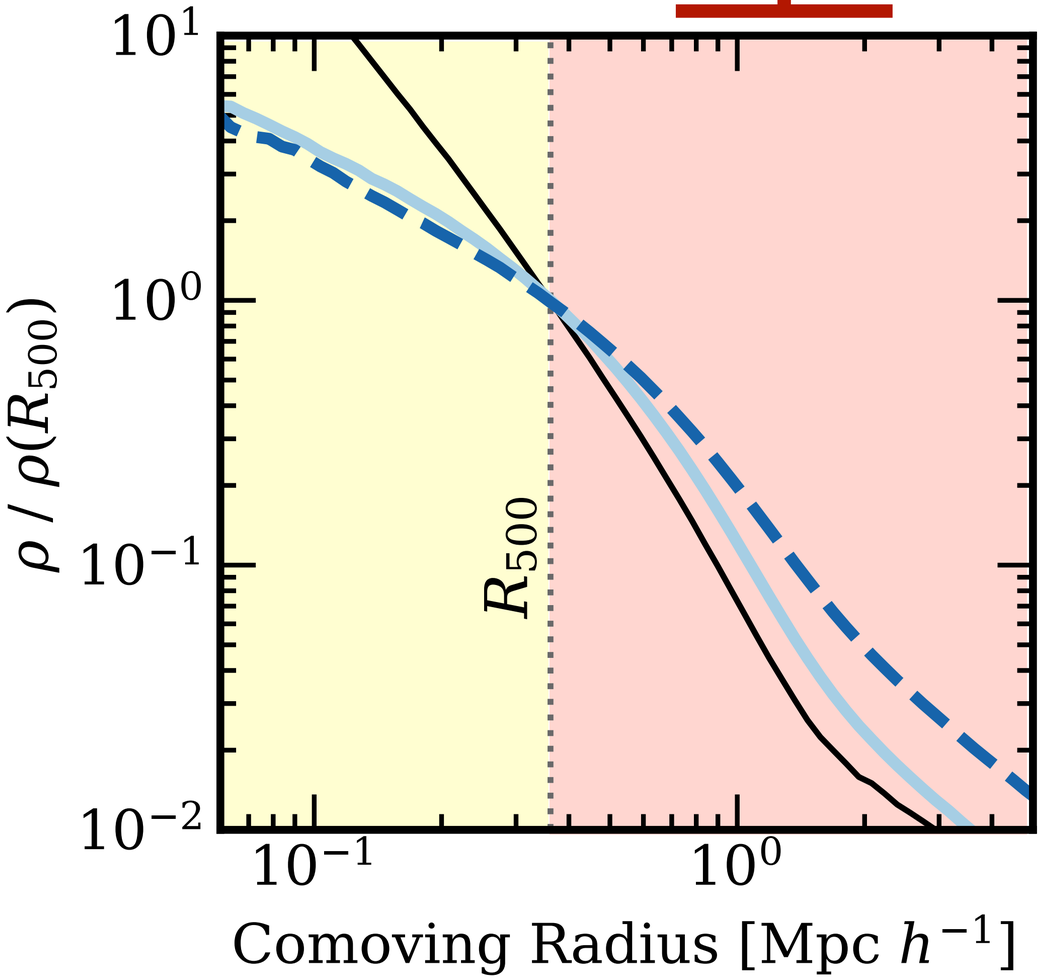

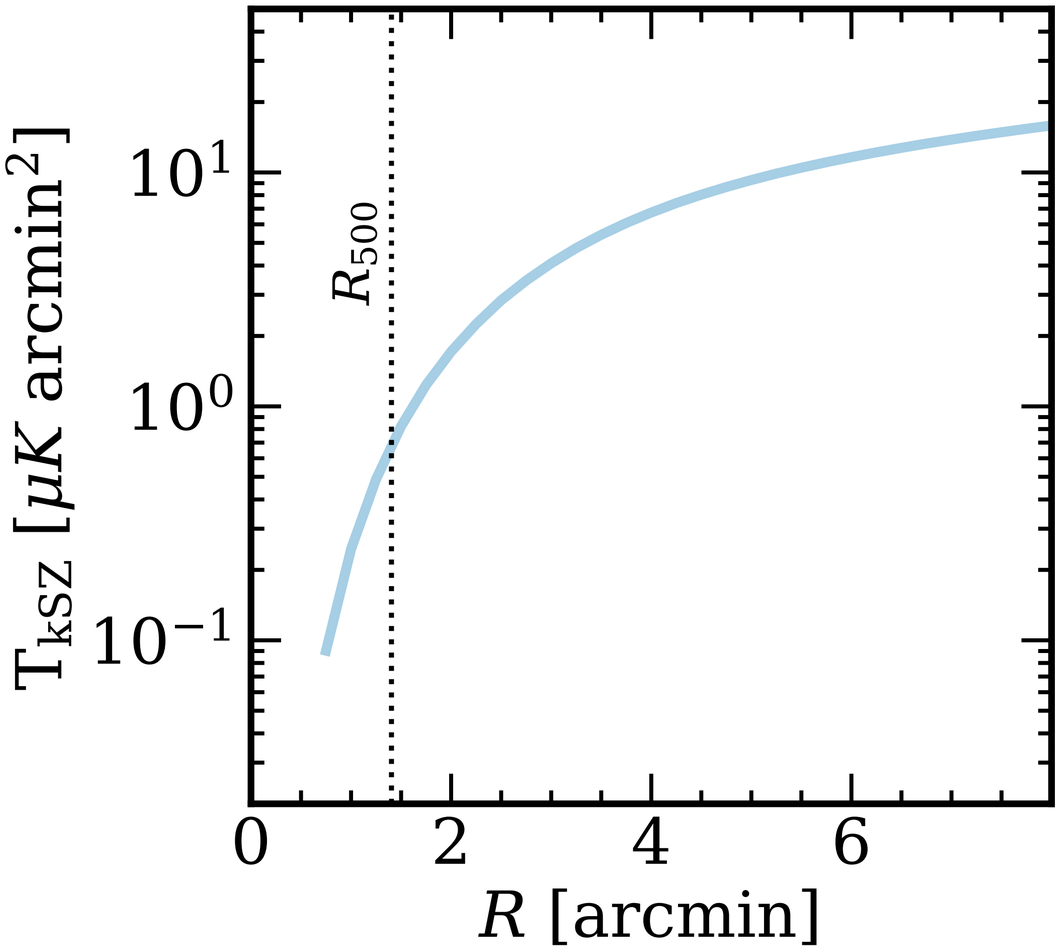

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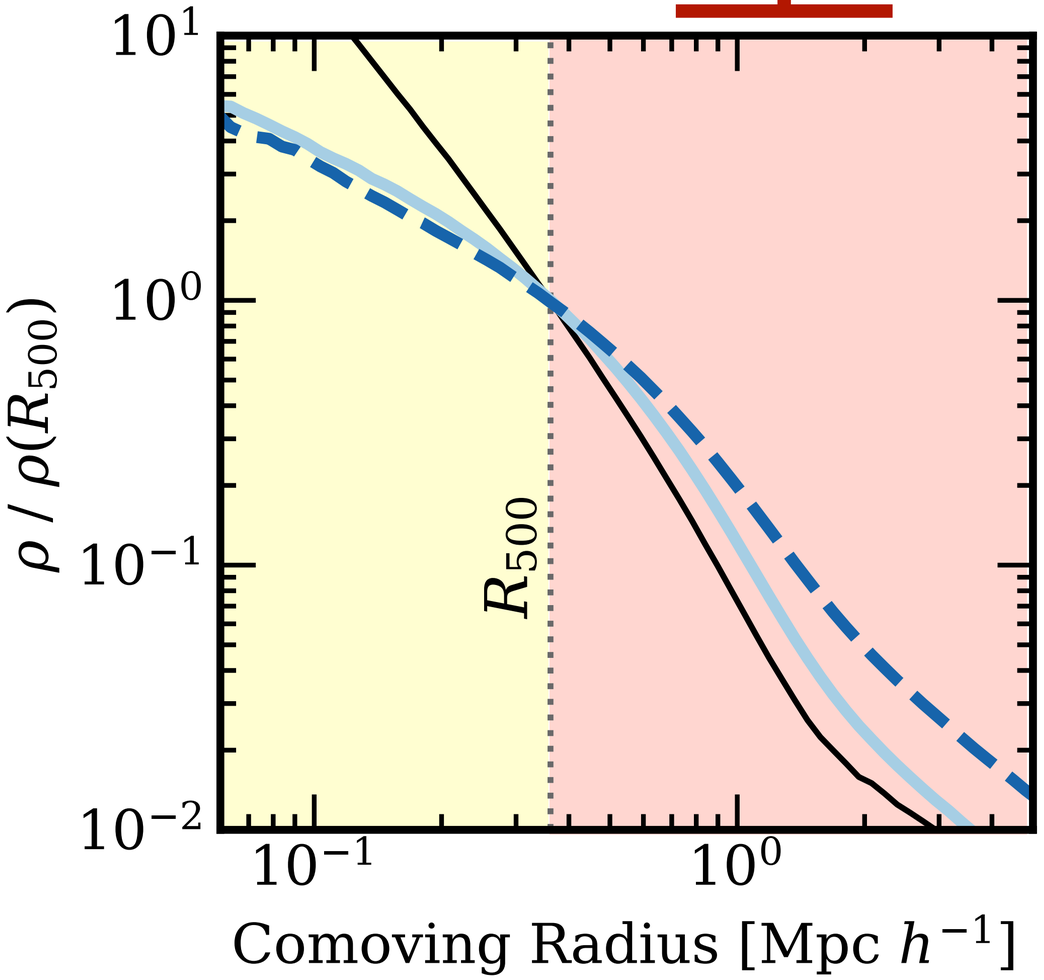

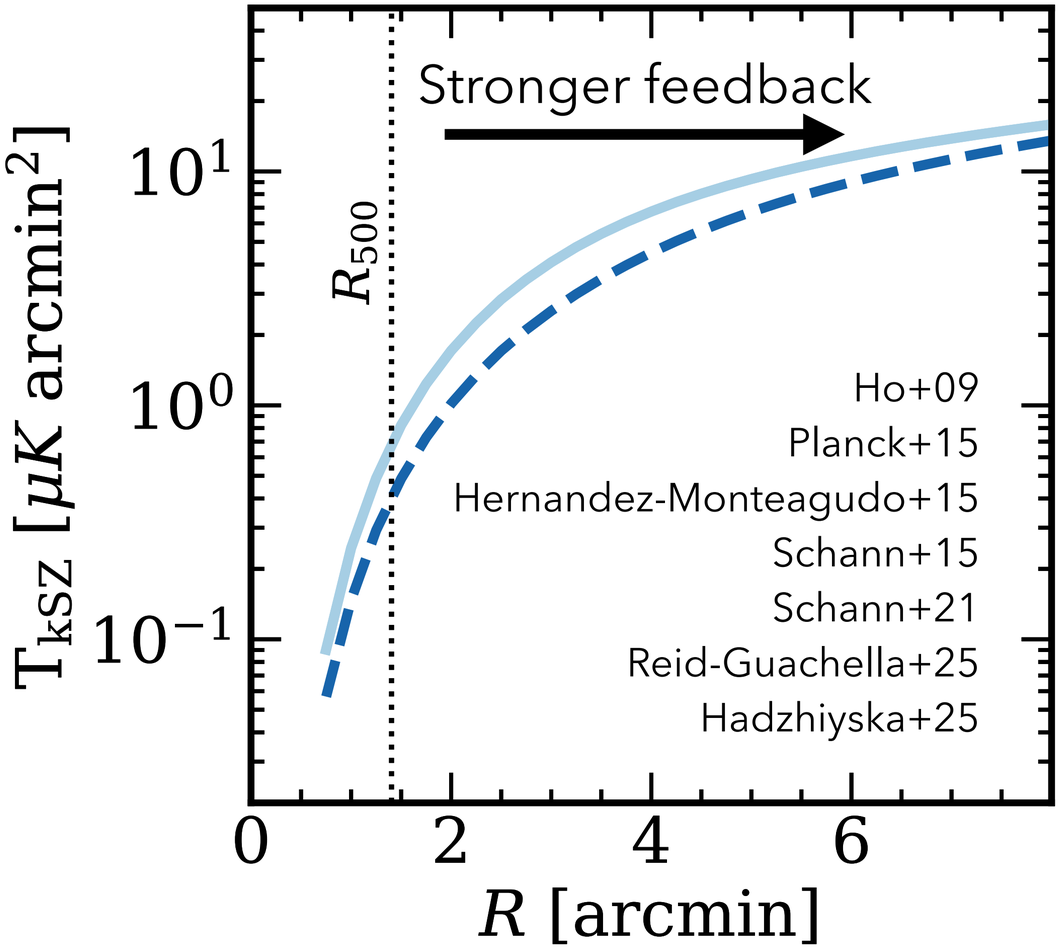

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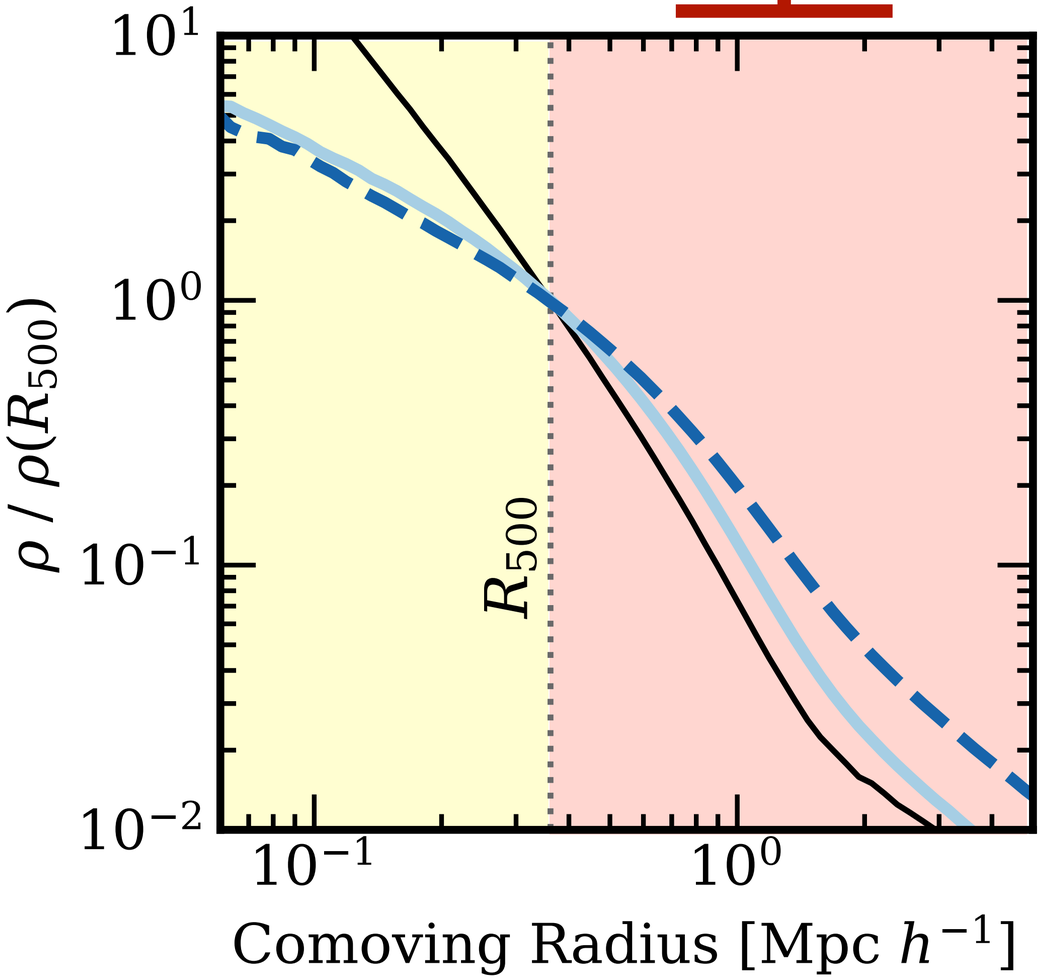

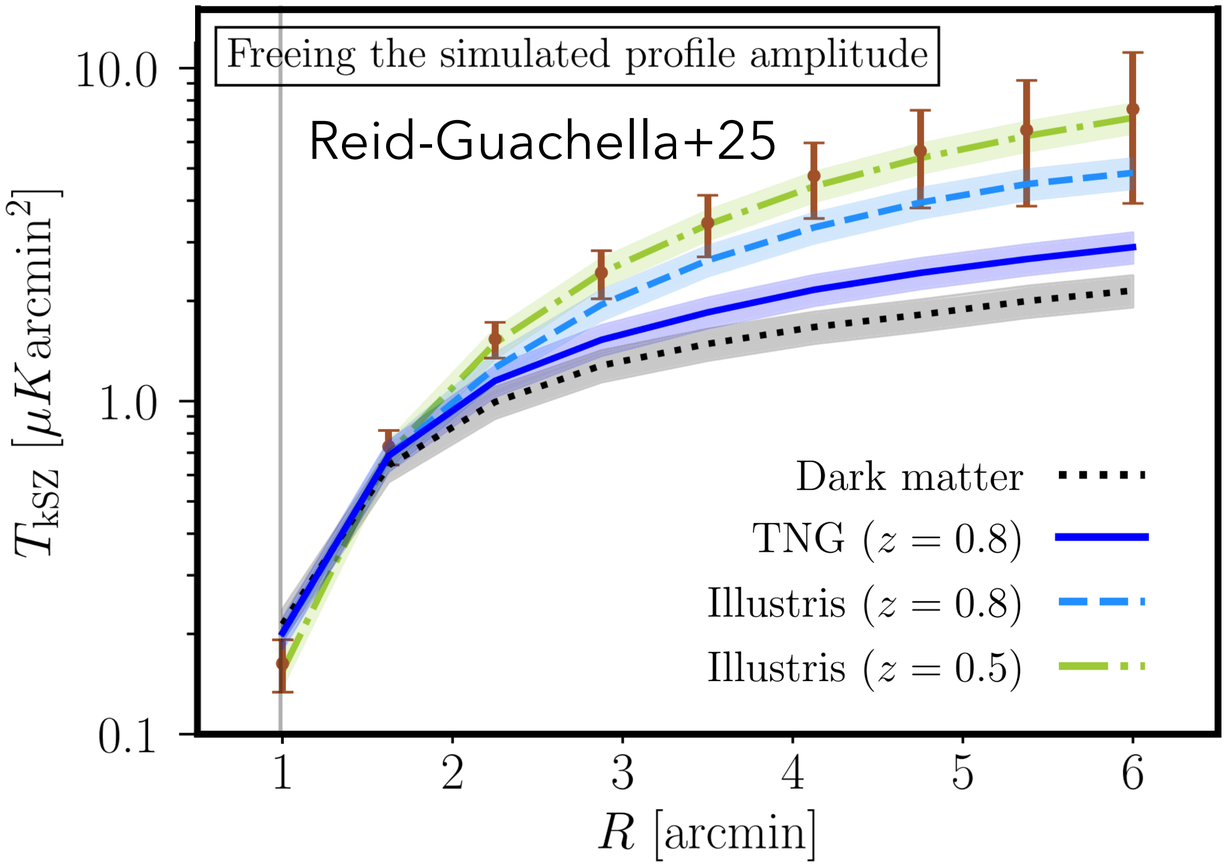

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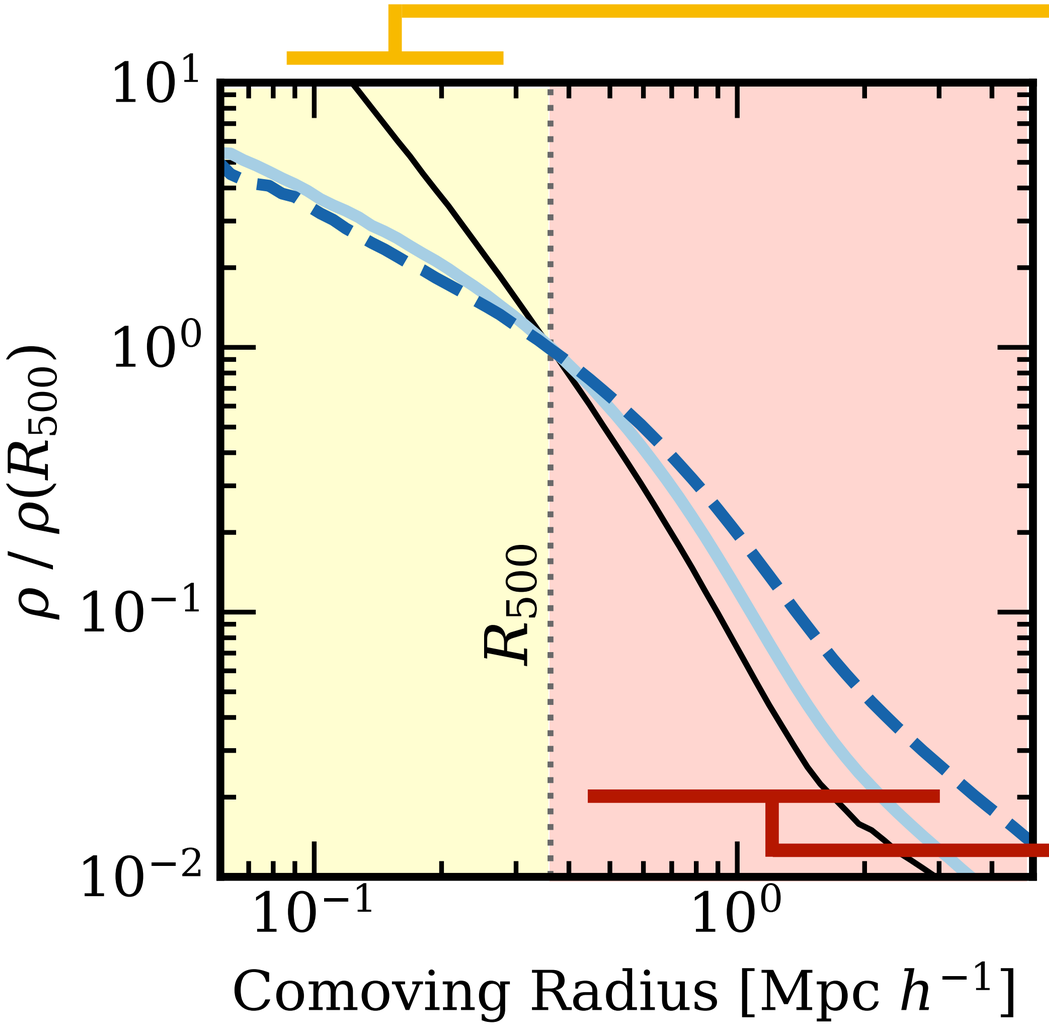
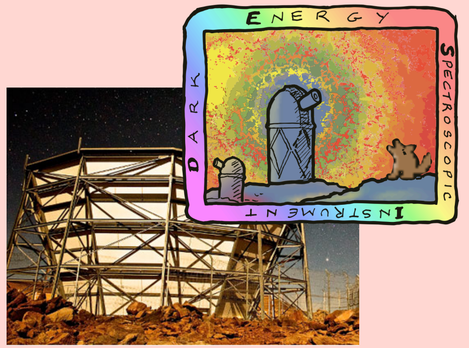


X-ray Hot Gas Fractions

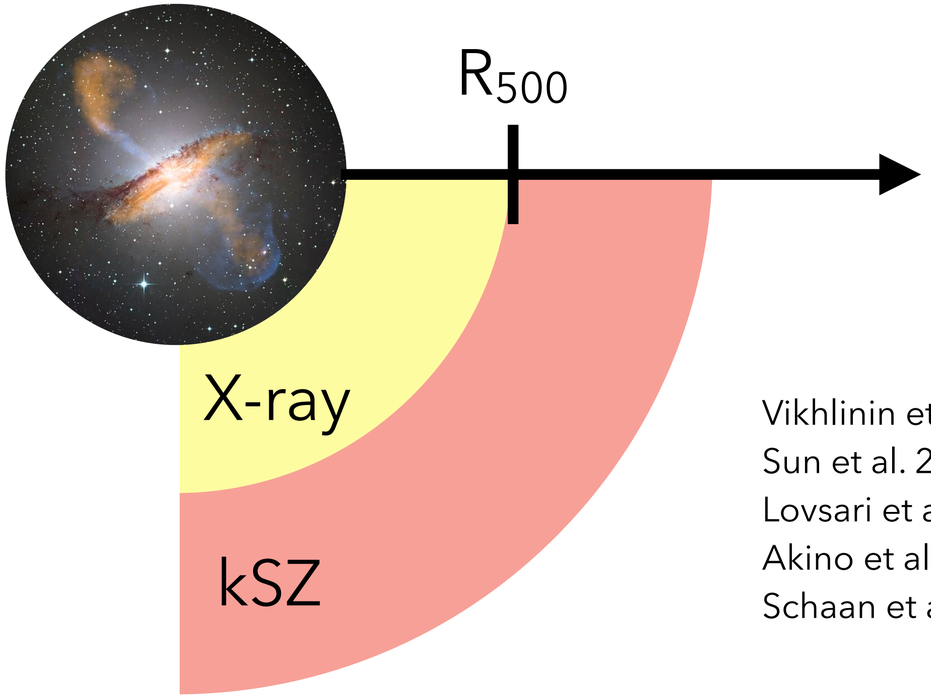
eROSITA

kSZ Effect



How do we measure feedback?

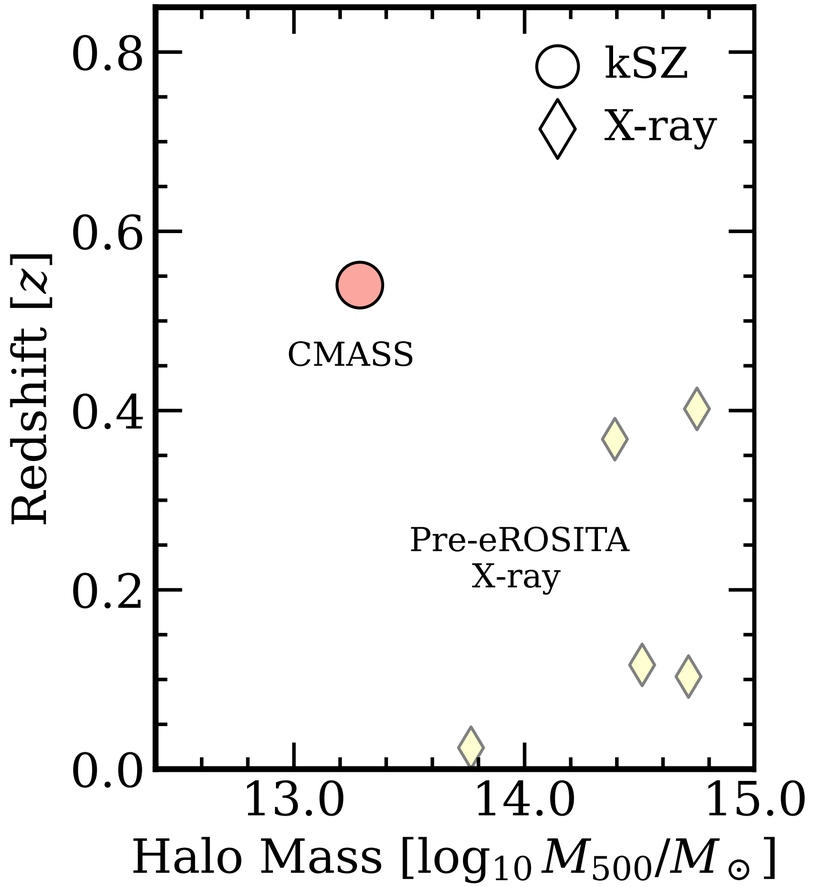
Are we explaining all scales?



Vikhlinin et al. 2006
Sun et al. 2009
Lovsari et al. 2015
Akino et al. 2022
Schaan et al. 2021

all masses?

all redshifts?



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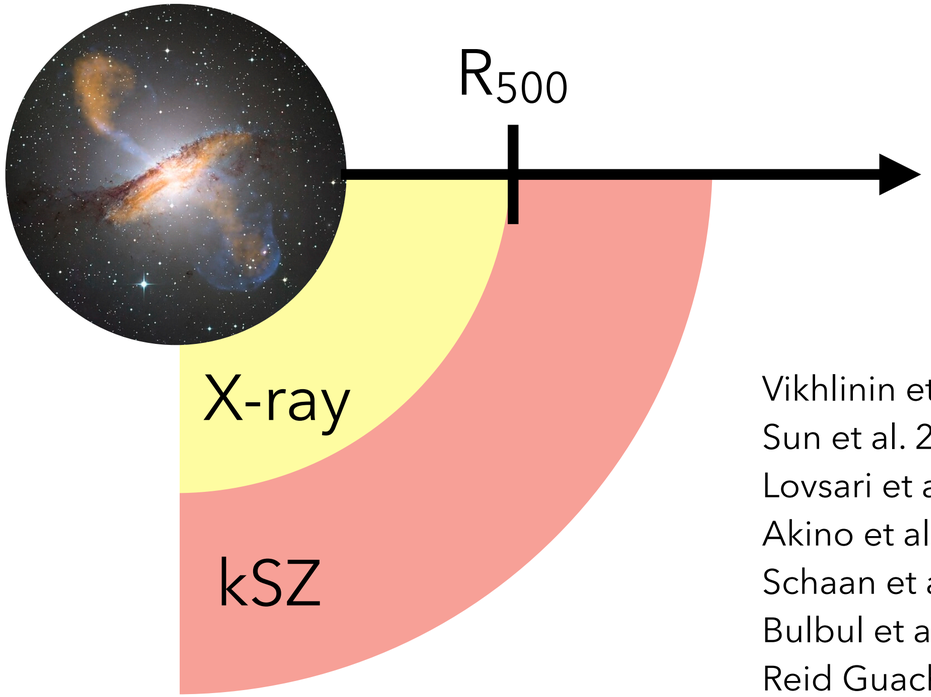

Vikhlinin et al. 2006
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Bulbul et al. 2024
Reid Guachalla et al. 2025

all masses?

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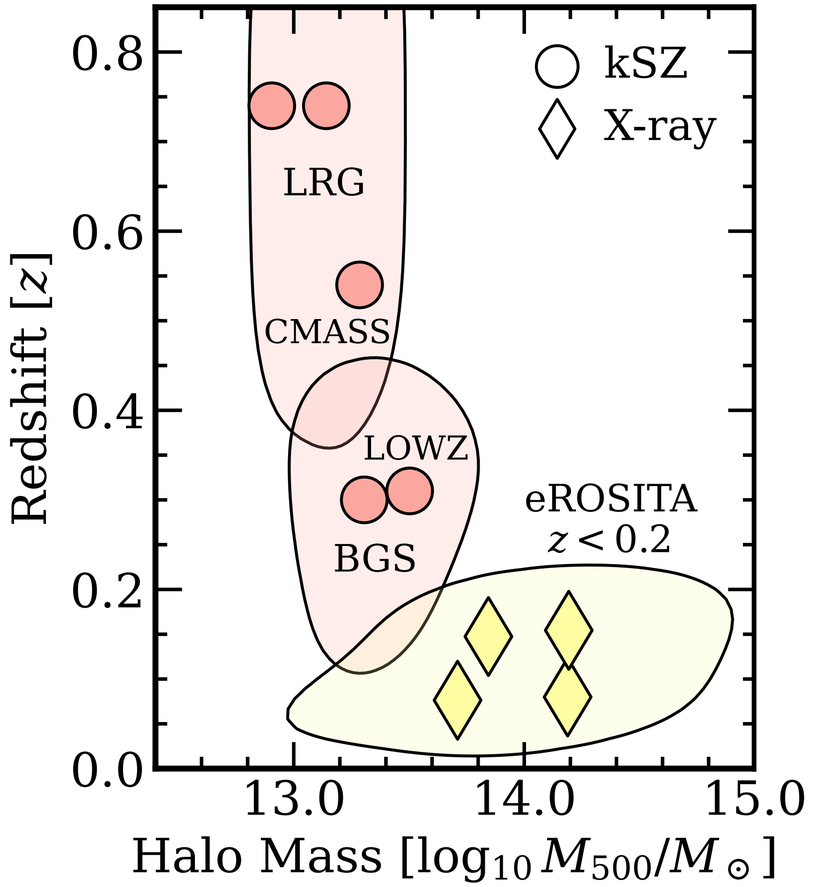


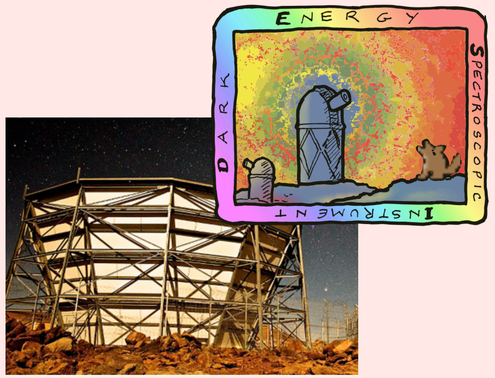
How do we measure feedback?

X-ray Gas Fraction

Bulbul + 2024

+

Kinetic SZ Effect

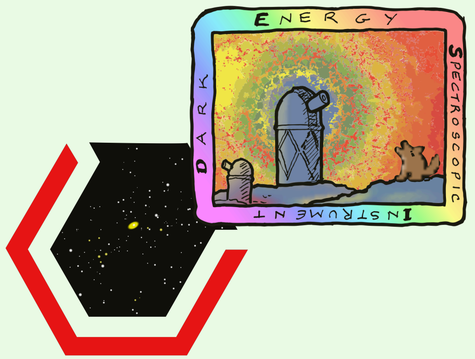


Schaan +21

Ried Guachalla + 25

+

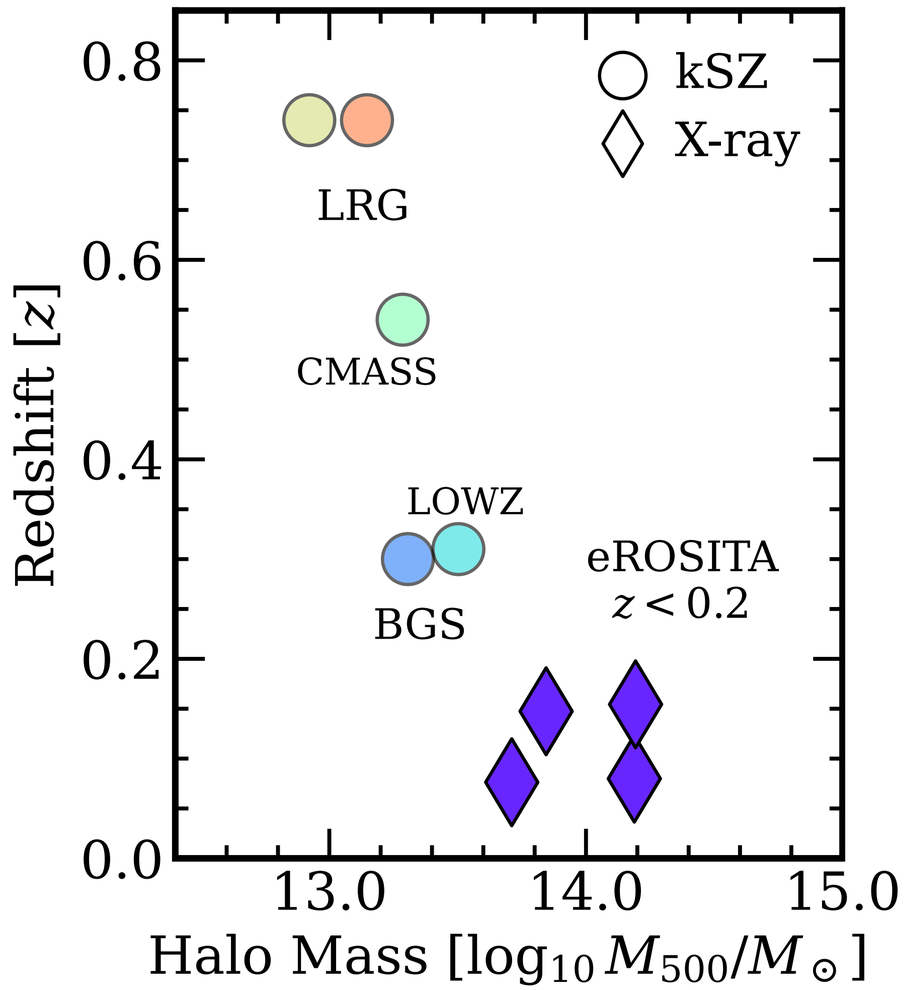
Galaxy-Galaxy Lensing

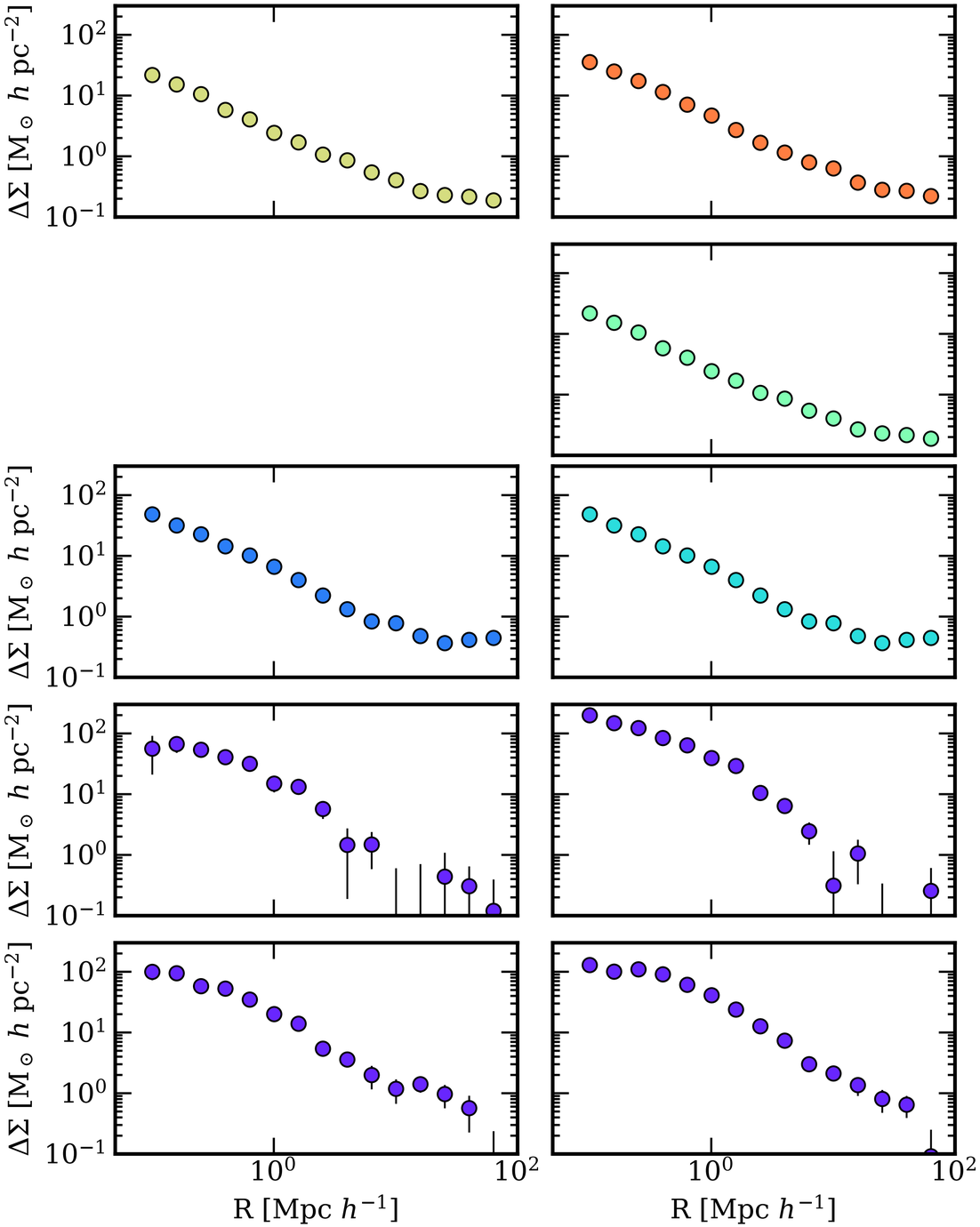


McCarthy + 24

Siegel + 25

Galaxy–Galaxy Lensing





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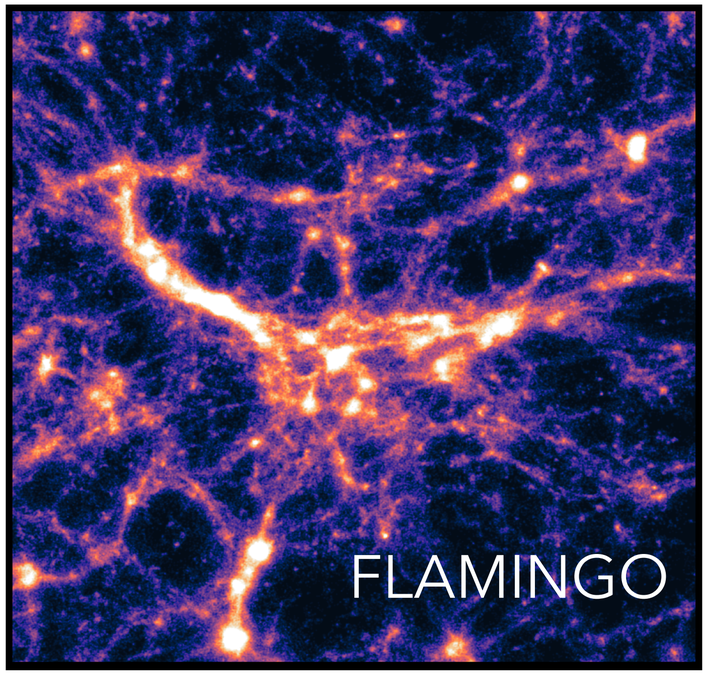
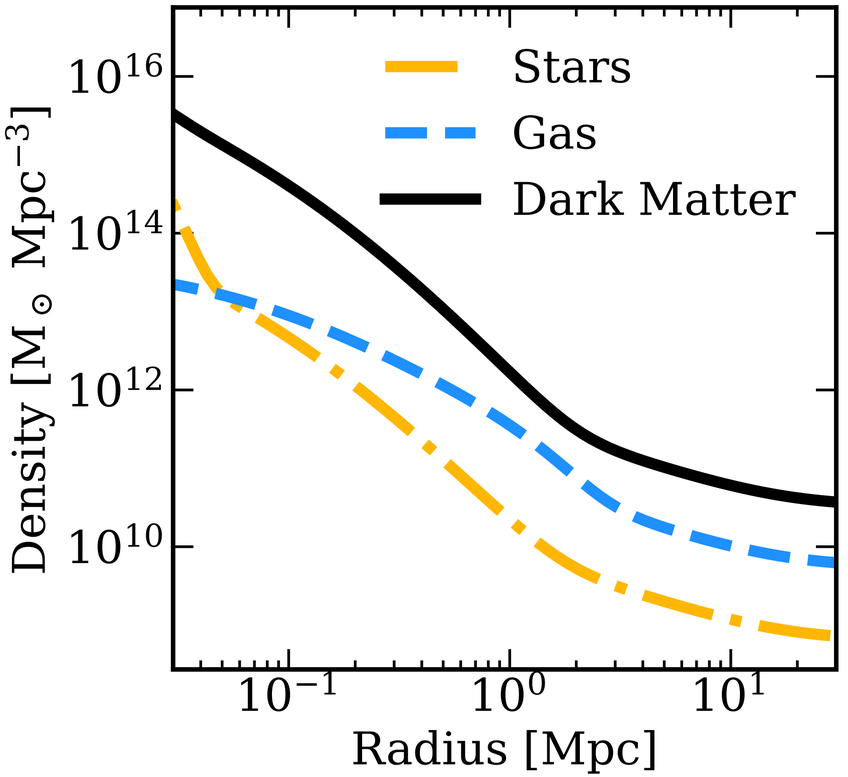


Hydrodynamical Simulations

Siegel + 25b arXiv:2509.10455



Semi-analytic Modeling

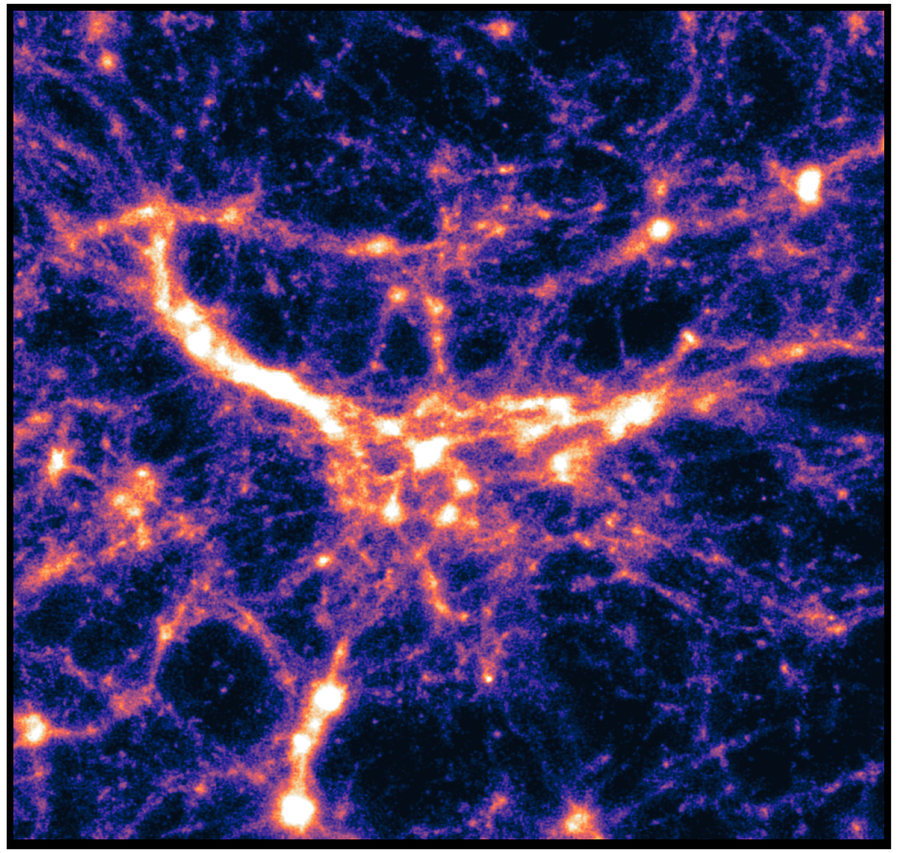
Siegel + 25c arXiv:2512.02954

FLAMINGO simulations

$1\ \mathrm{Gpc}^3$ boxes

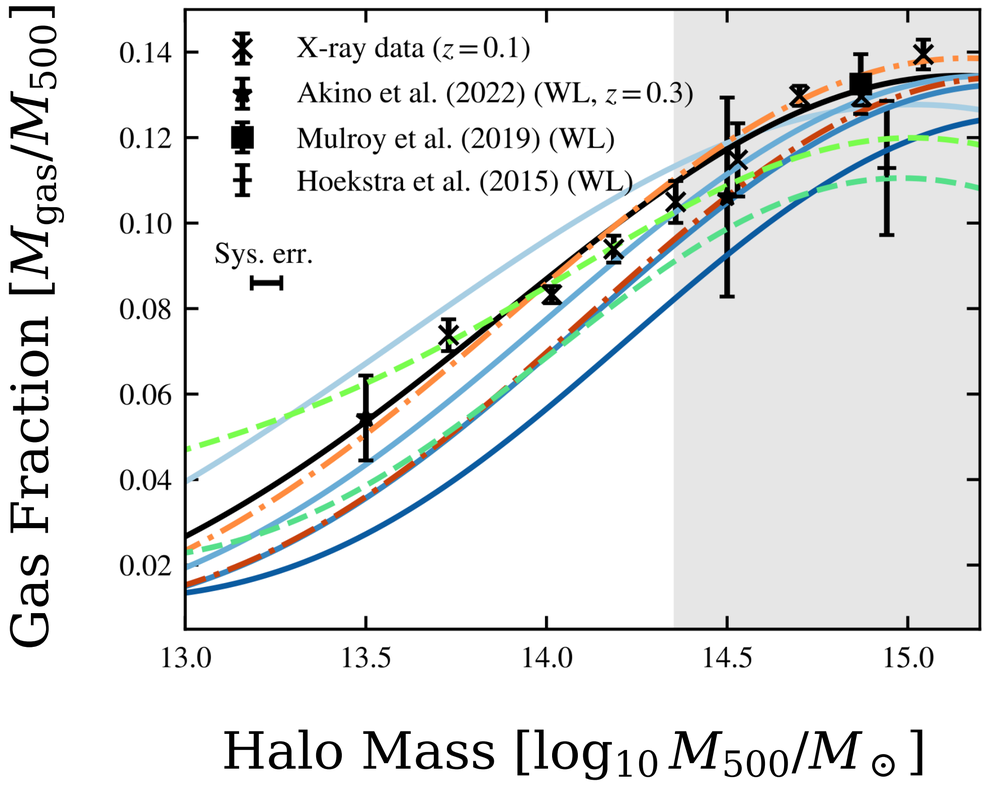
Calibrated to SHMR &
group and cluster gas fractions

8 different feedback variants

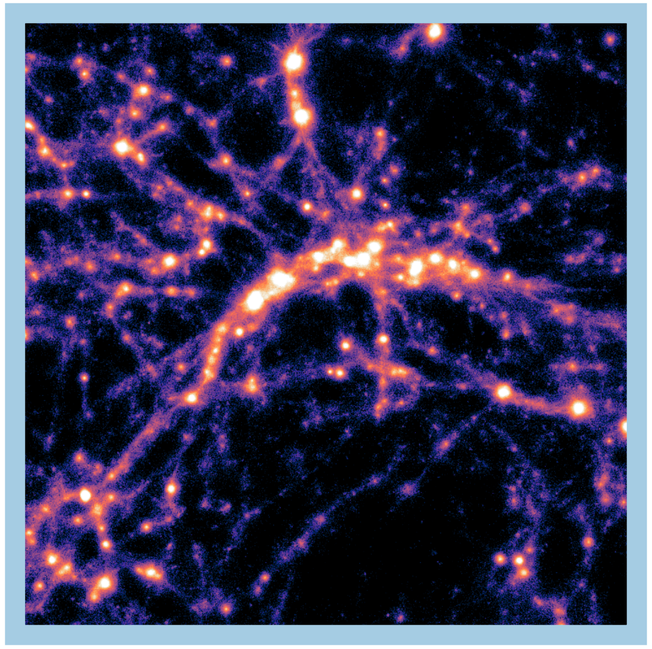


Schaye et al. 2023

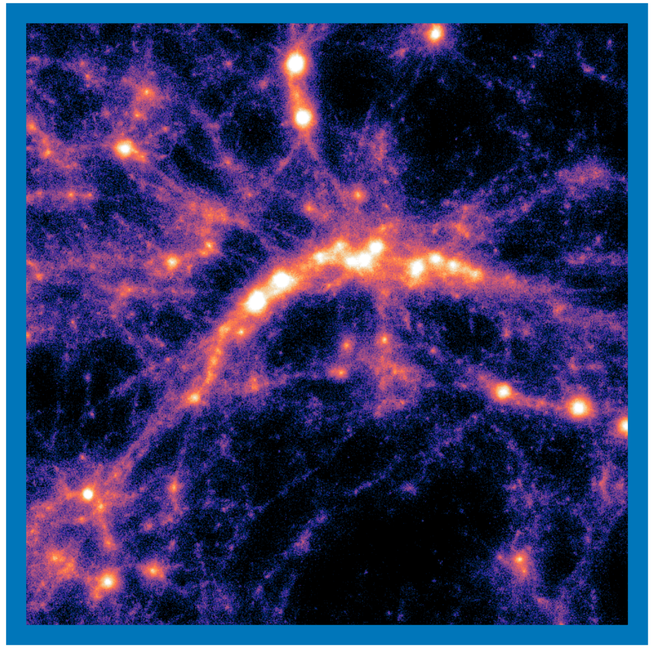
FLAMINGO simulations



Weak Feedback



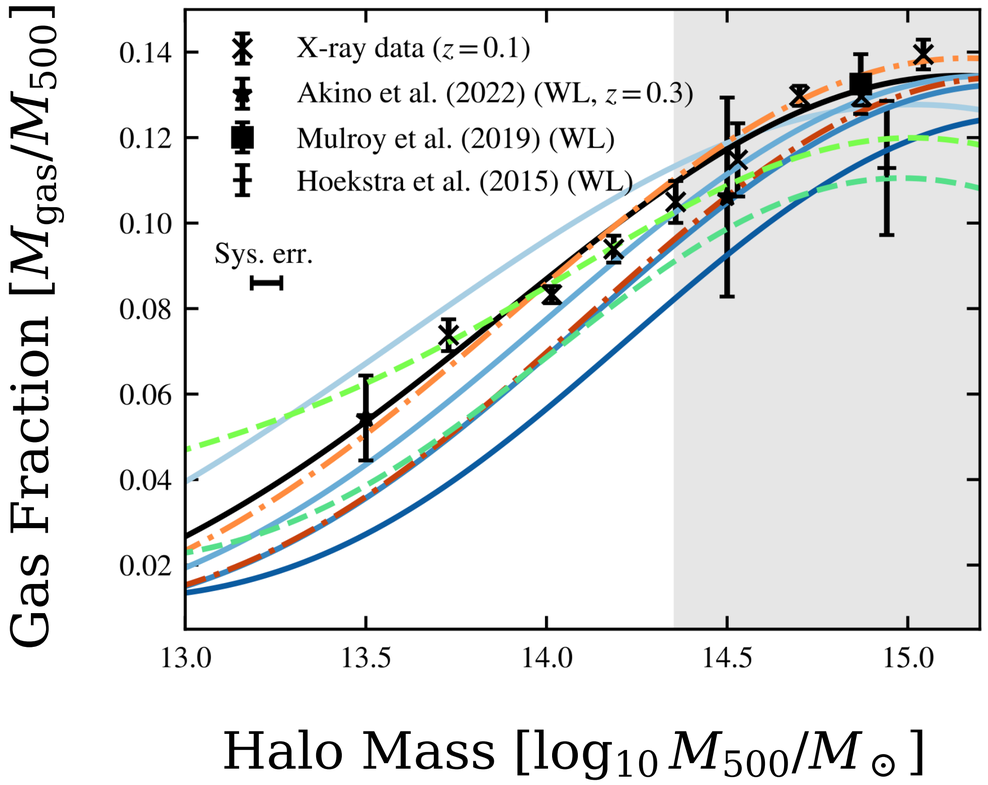
Strong Feedback



100 Mpc

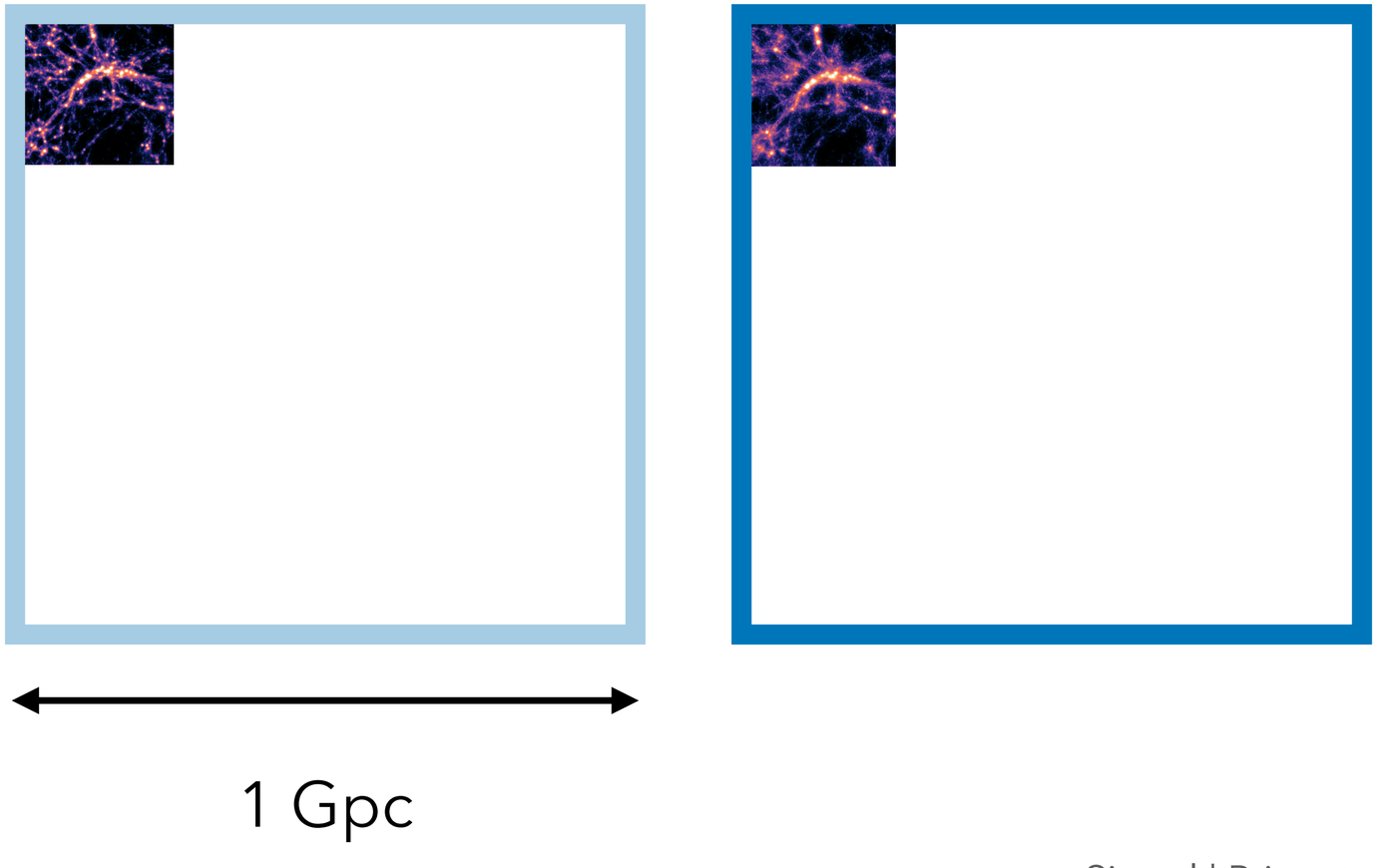
Schaye et al. 2023

FLAMINGO simulations



Weak Feedback

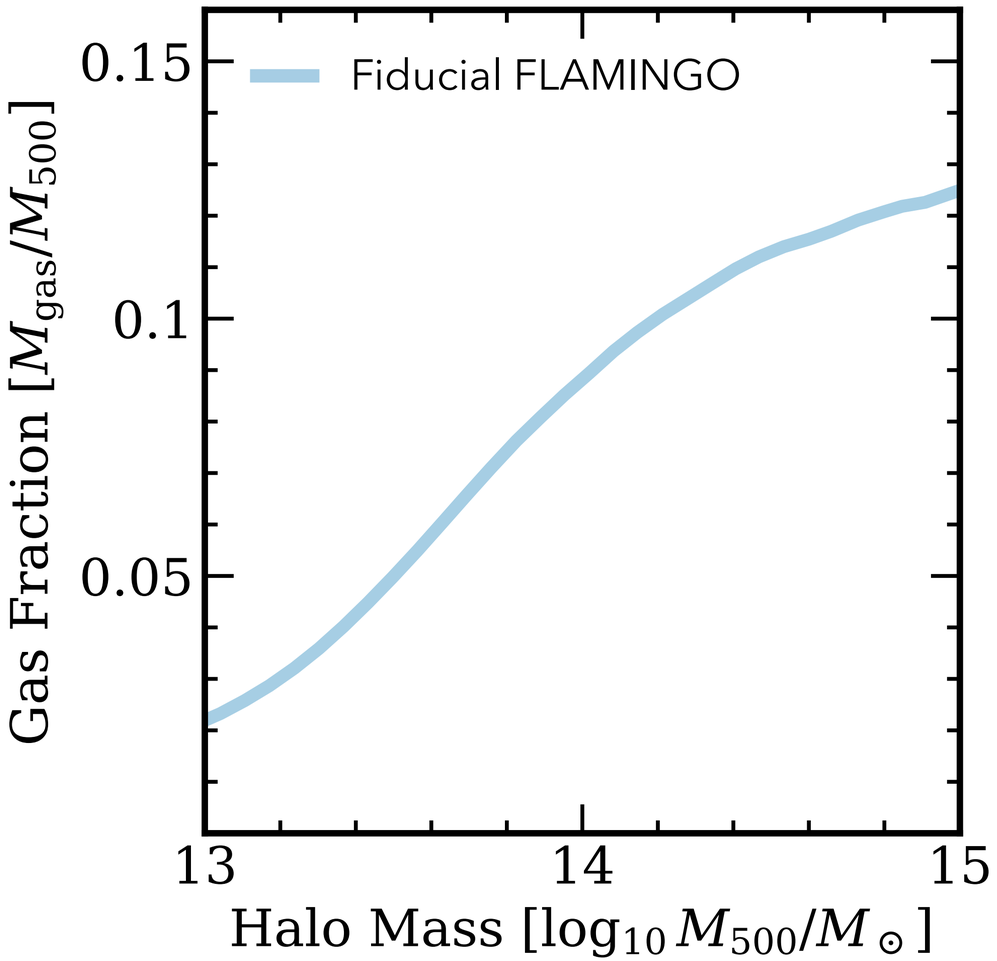
Strong Feedback



Schaye et al. 2023

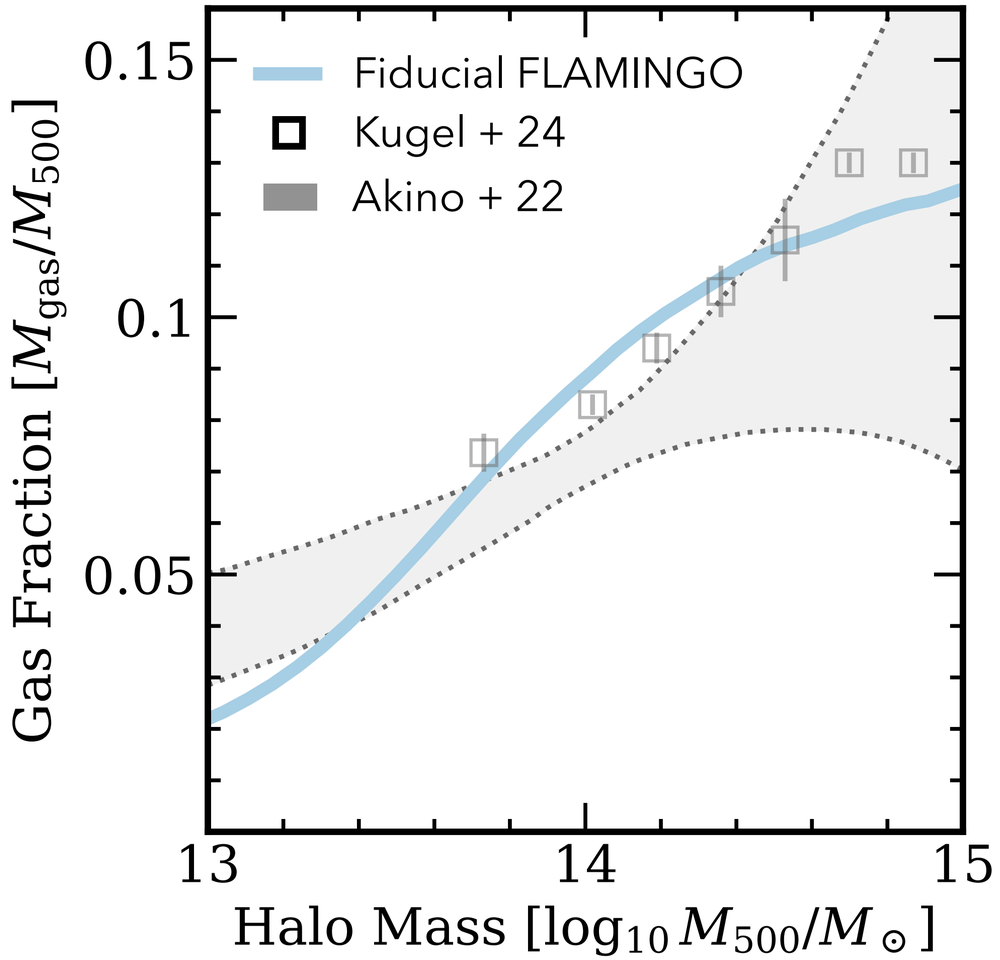
X-ray Gas Fraction

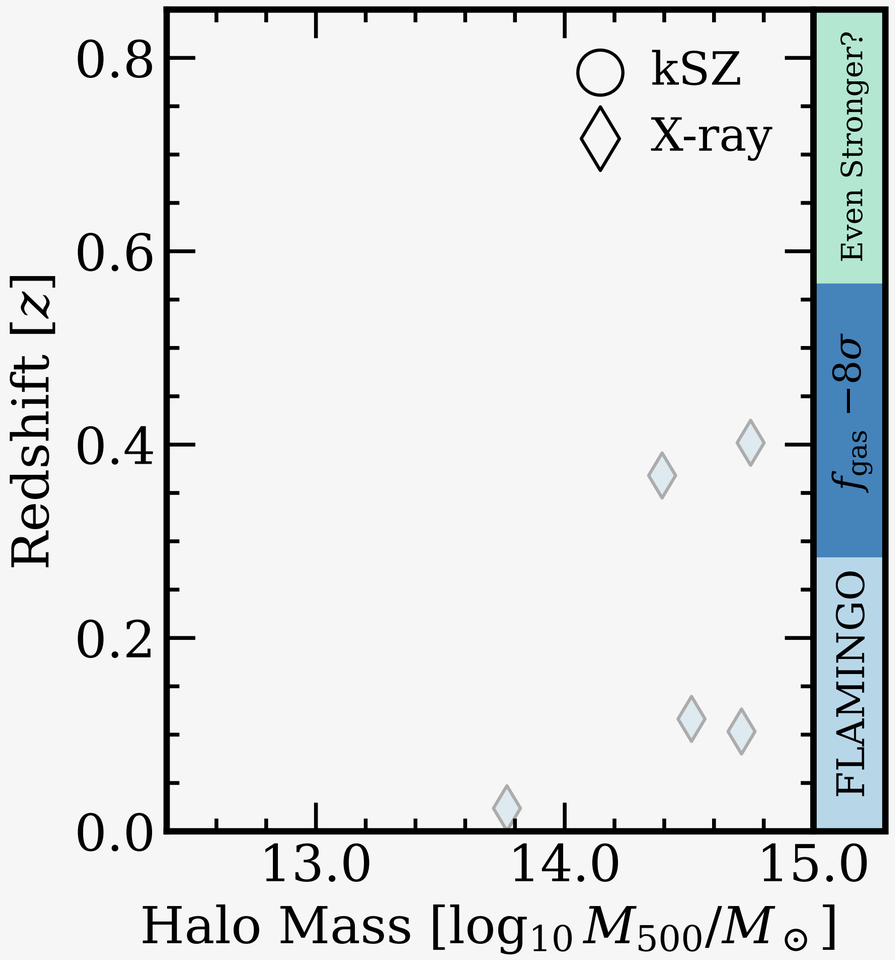
eROSITA+WL Gas Fractions



X-ray Gas Fraction

eROSITA+WL Gas Fractions





X-ray Gas Fraction

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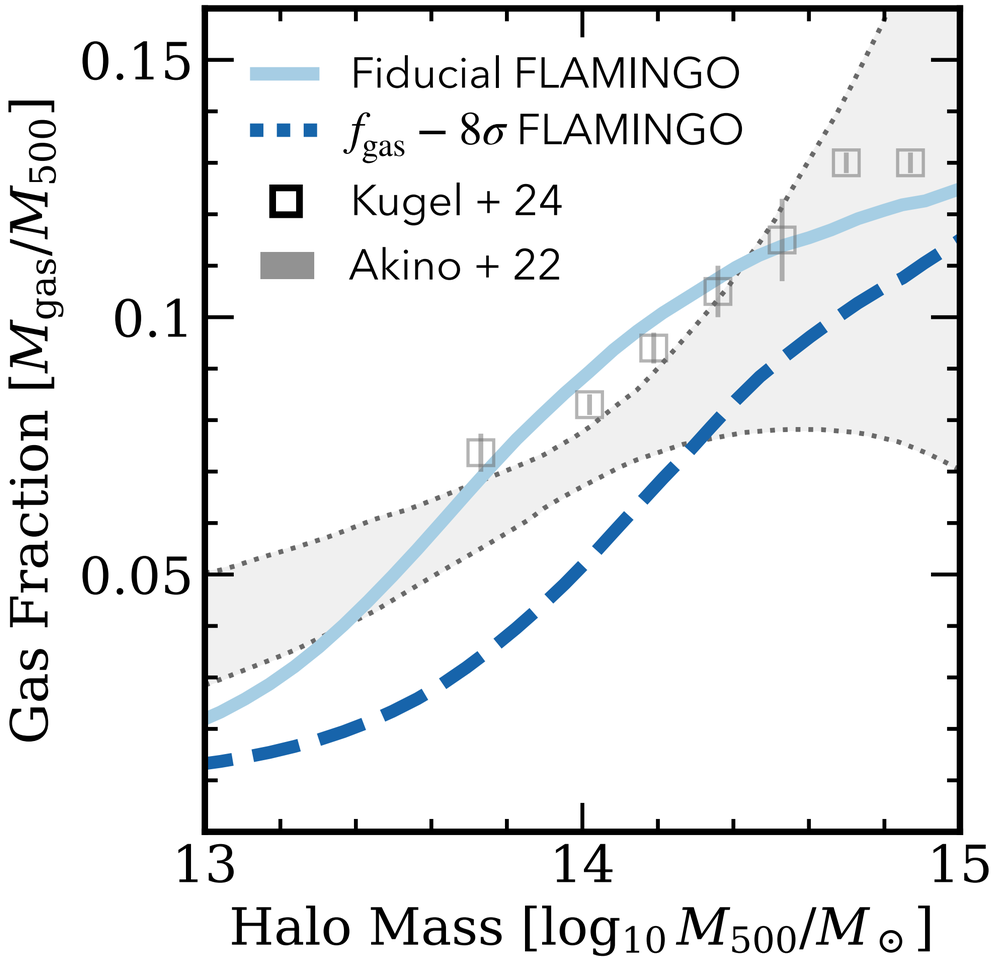
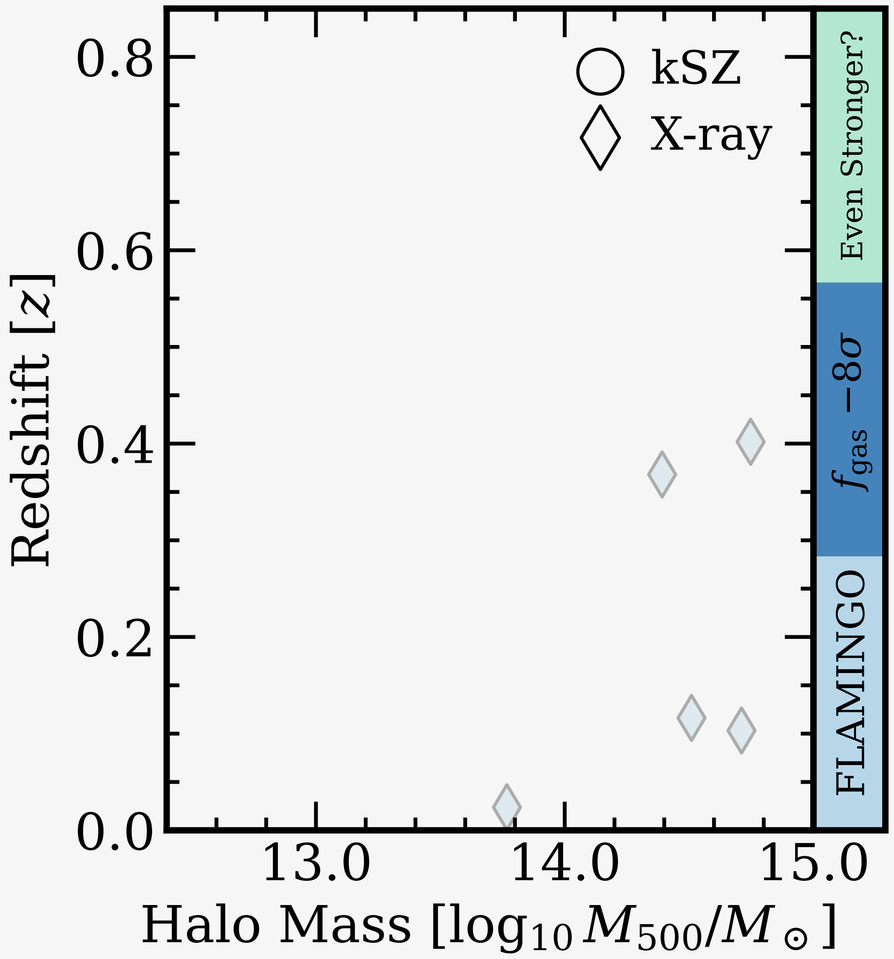
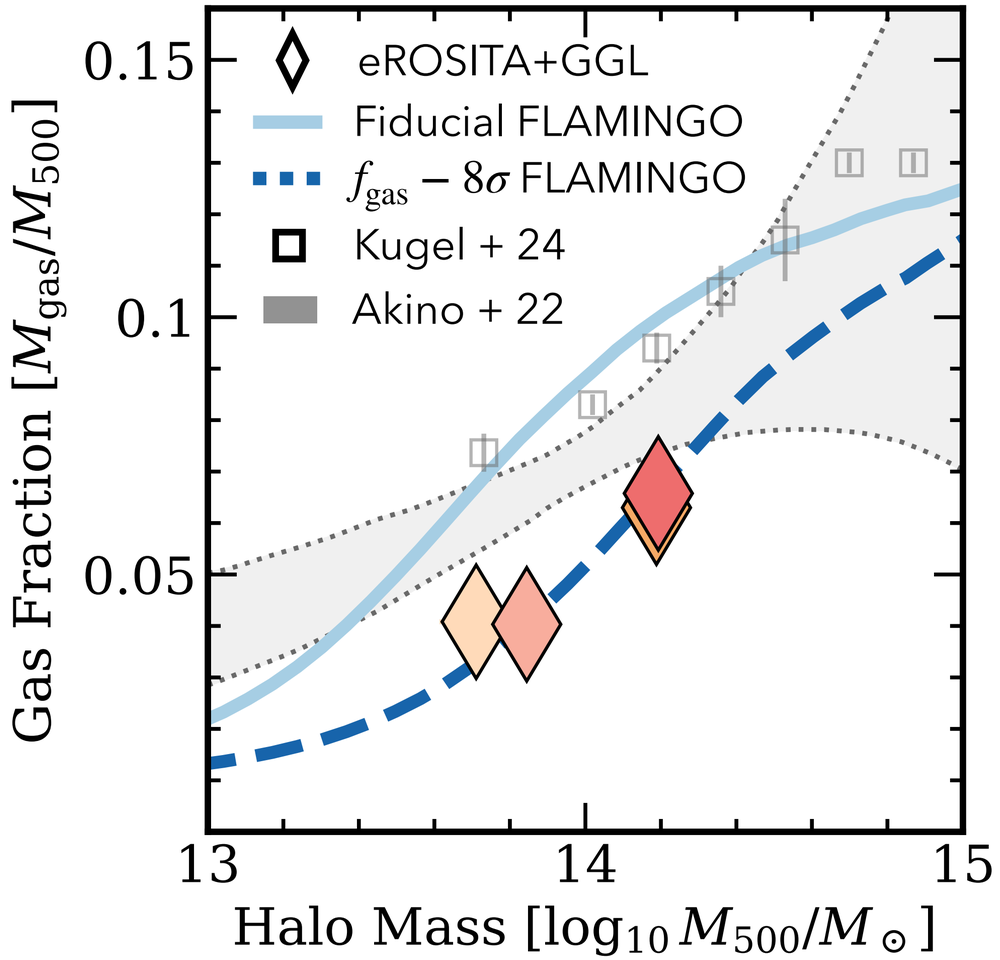
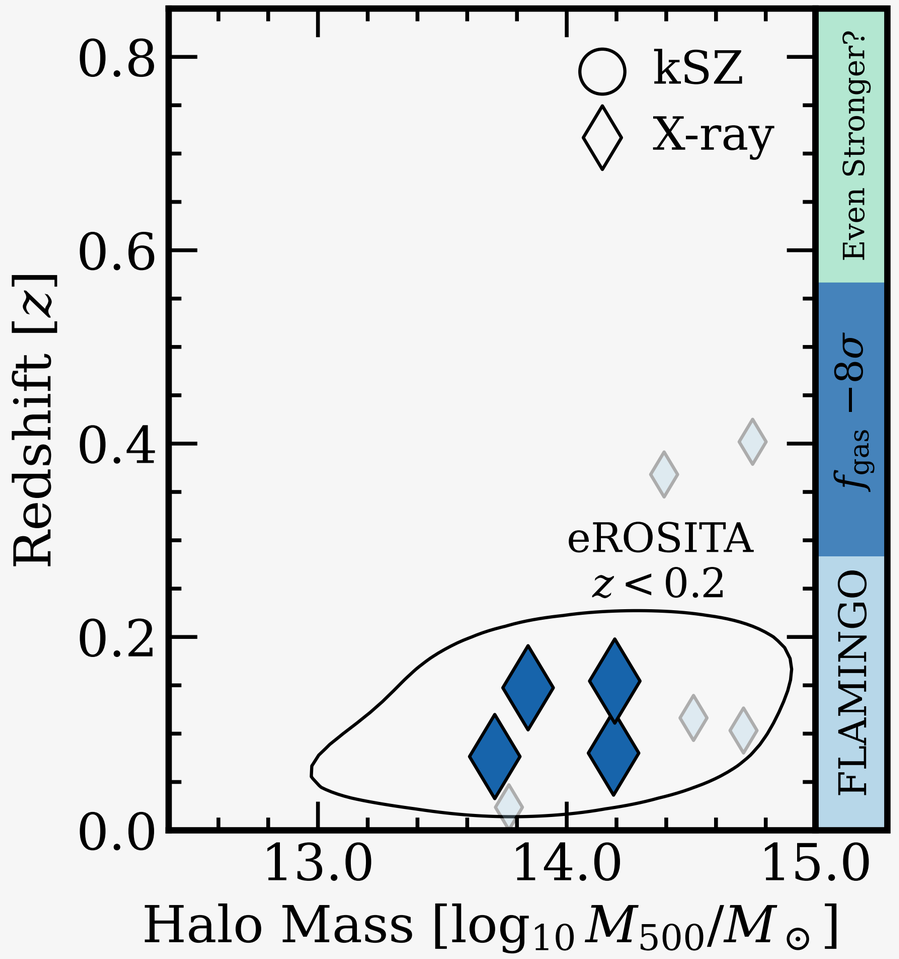




X-ray Gas Fraction

eROSITA+WL Gas Fractions

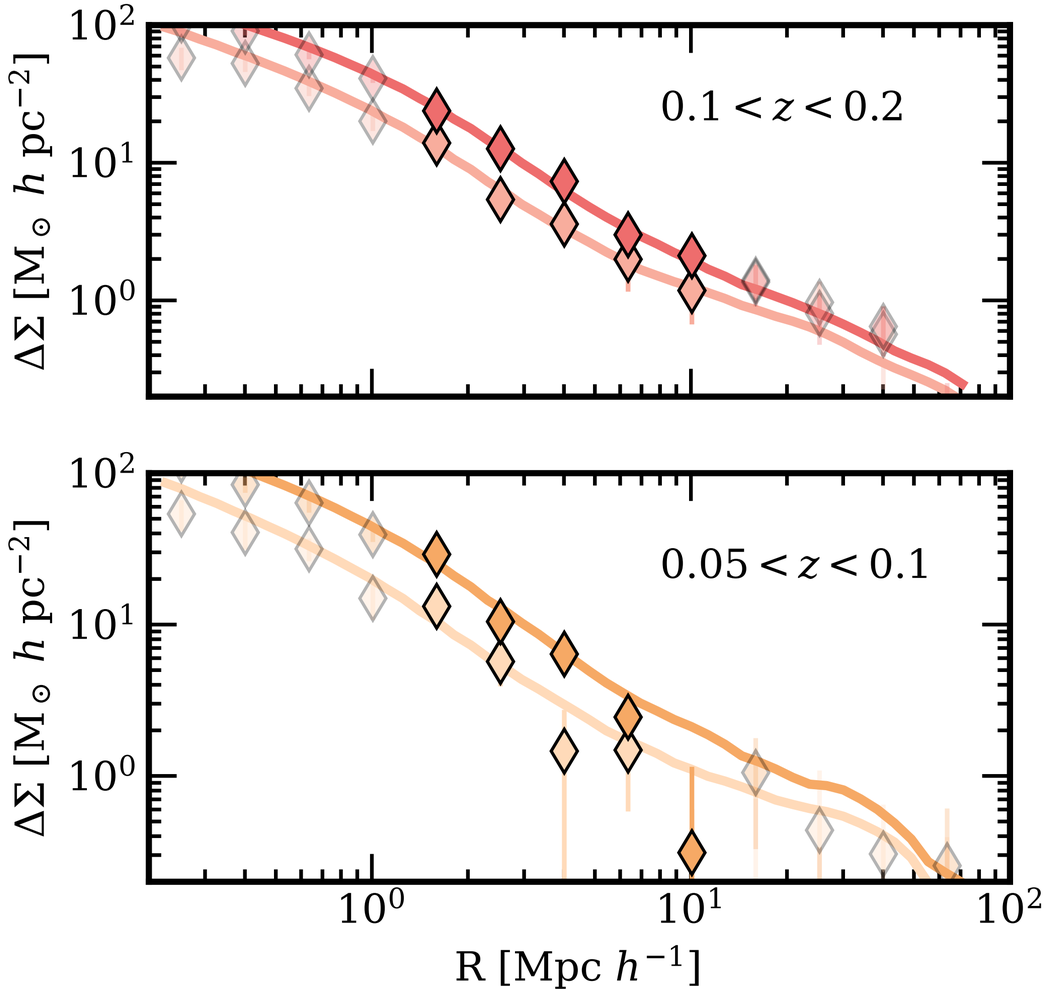


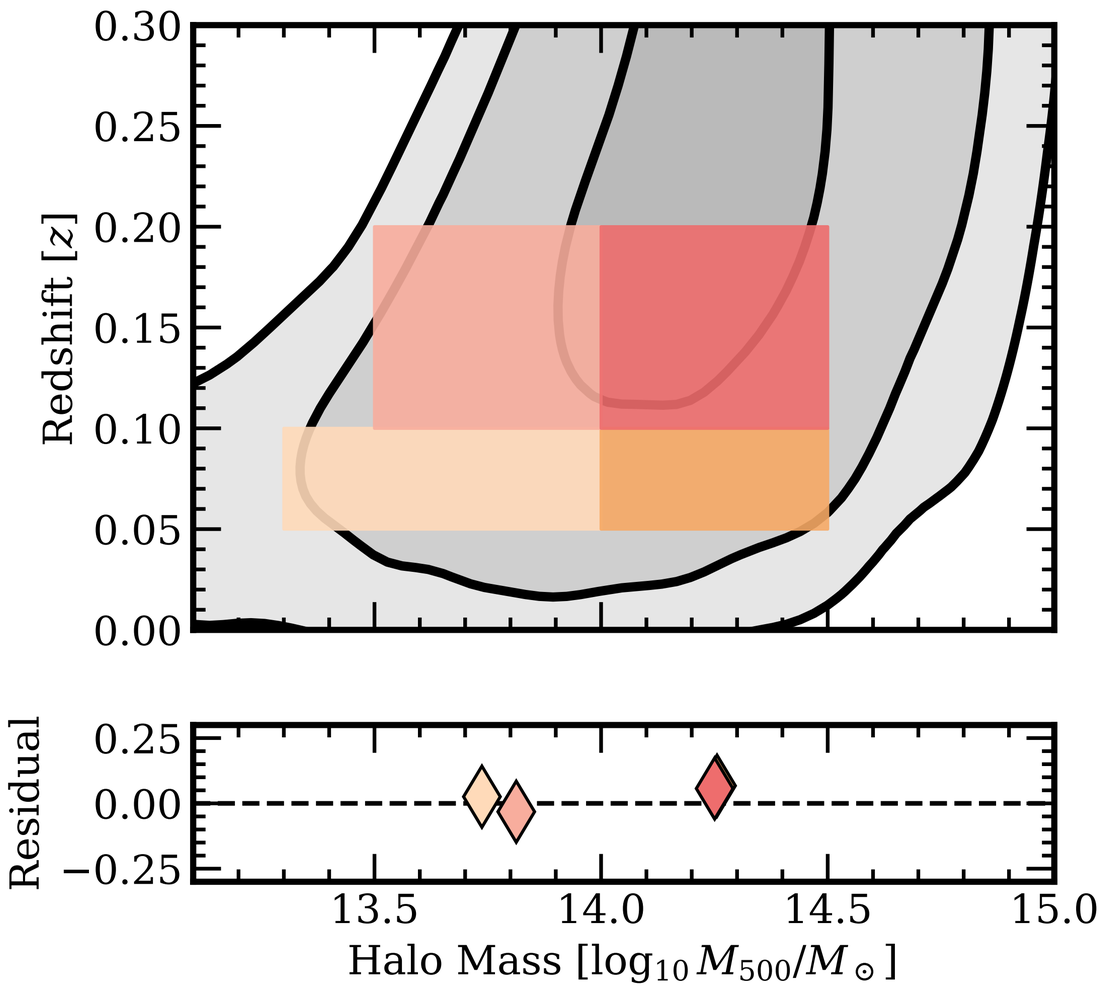


X-ray Gas Fraction

eROSITA

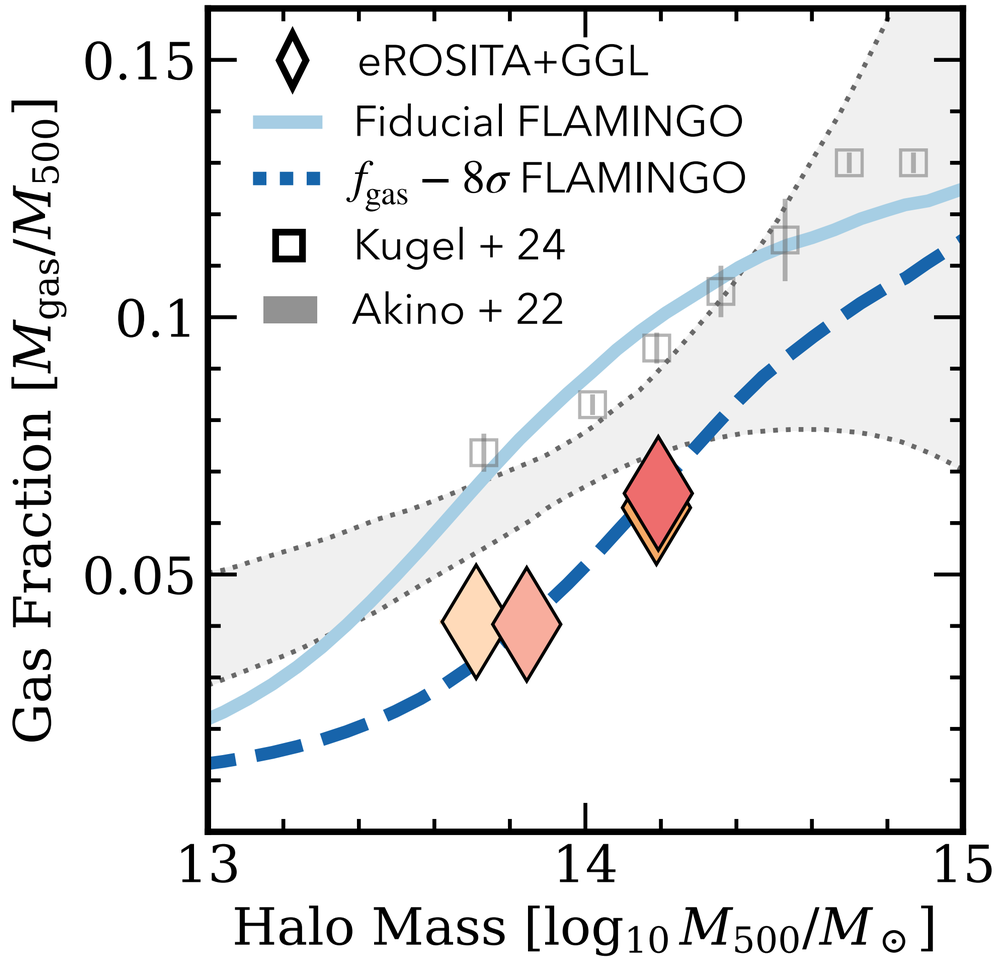
Halo Mass Measurements

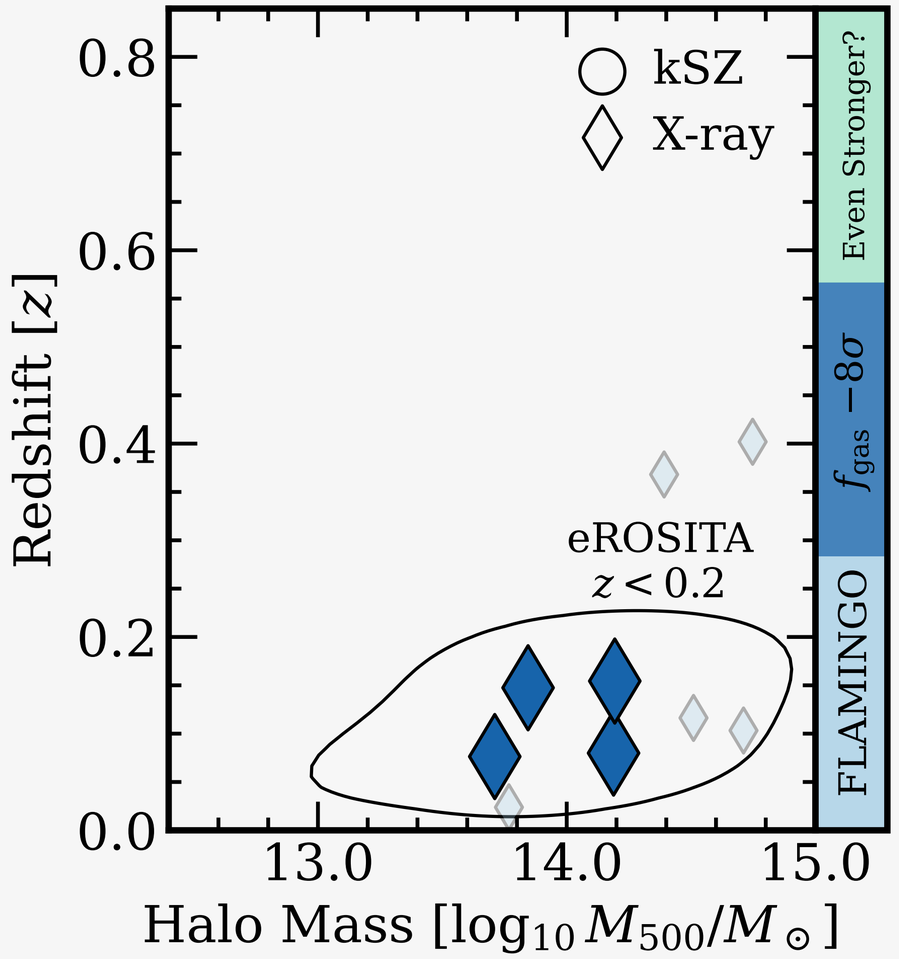




X-ray Gas Fraction

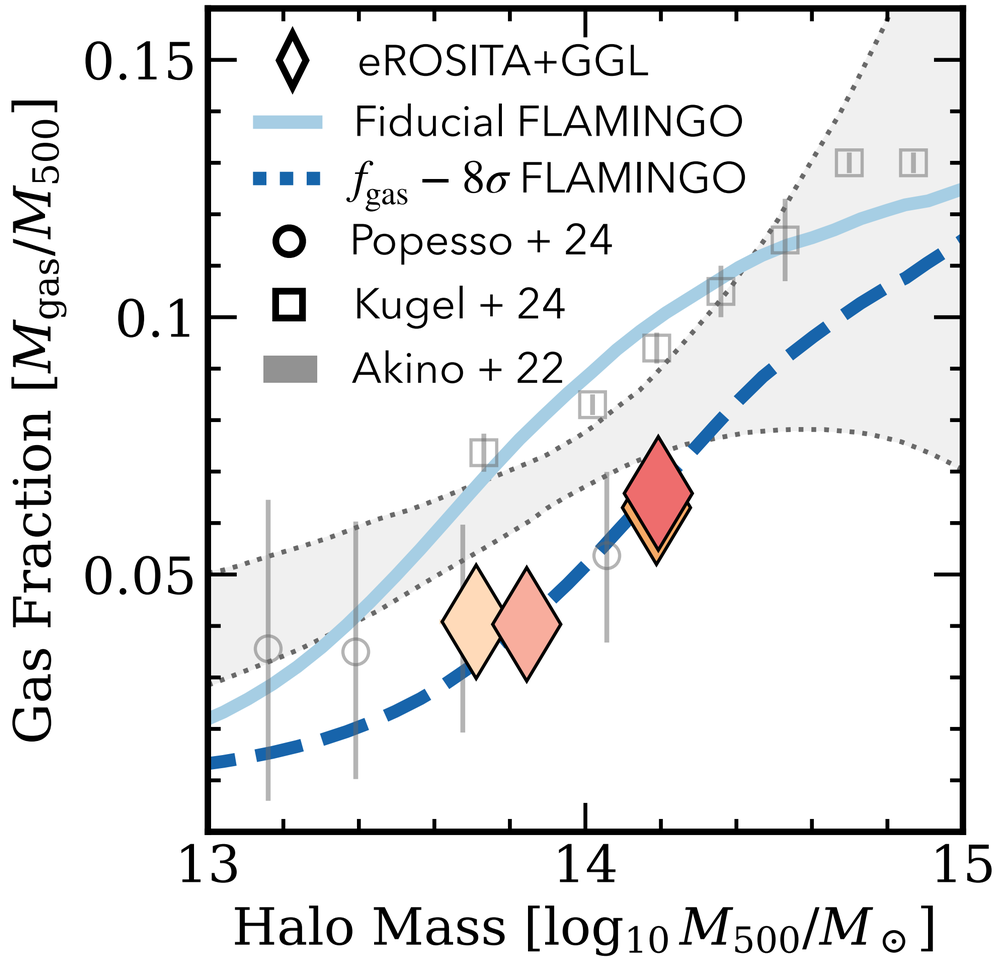
eROSITA+WL Gas Fractions

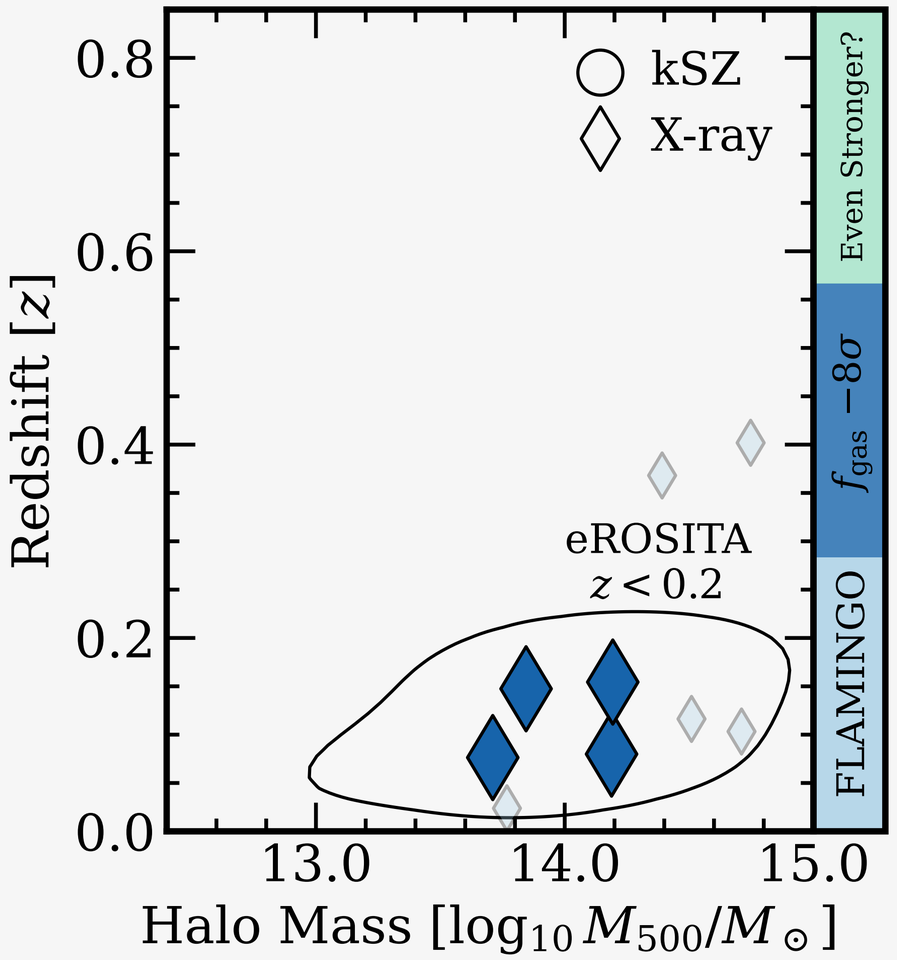




X-ray Gas Fraction

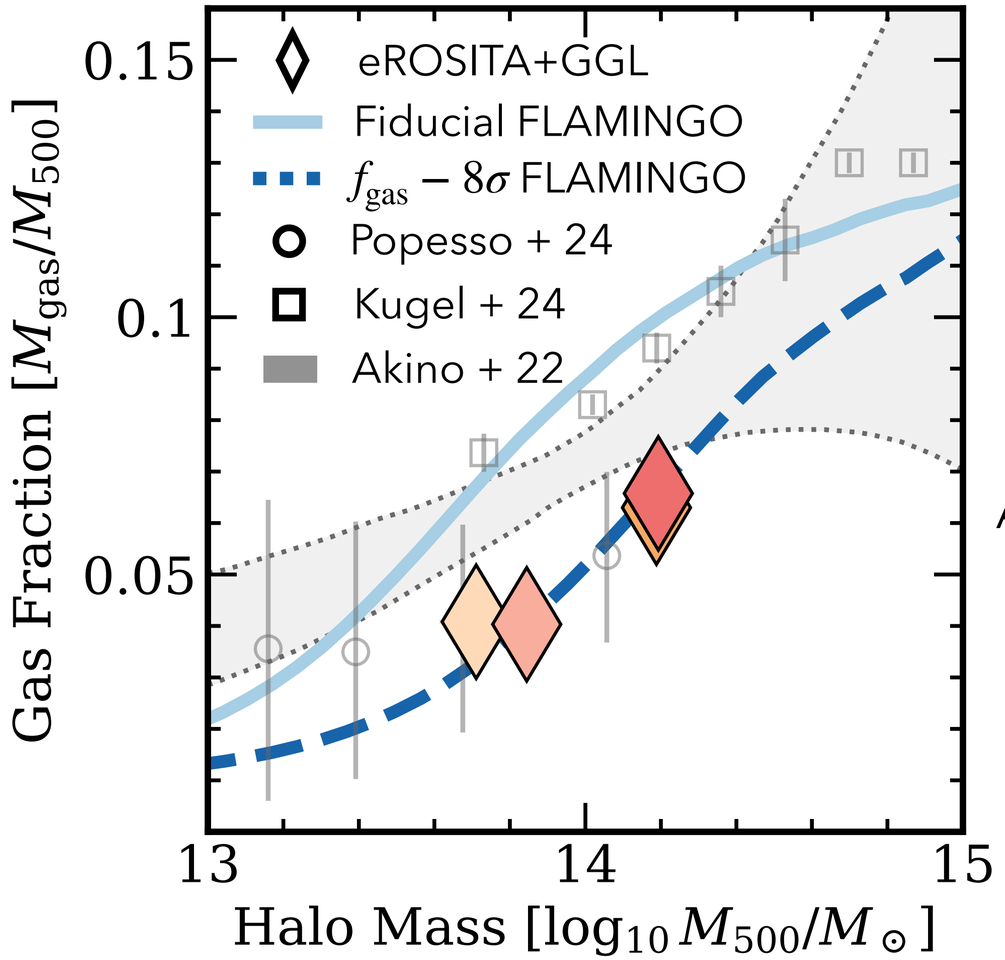
eROSITA+WL Gas Fractions



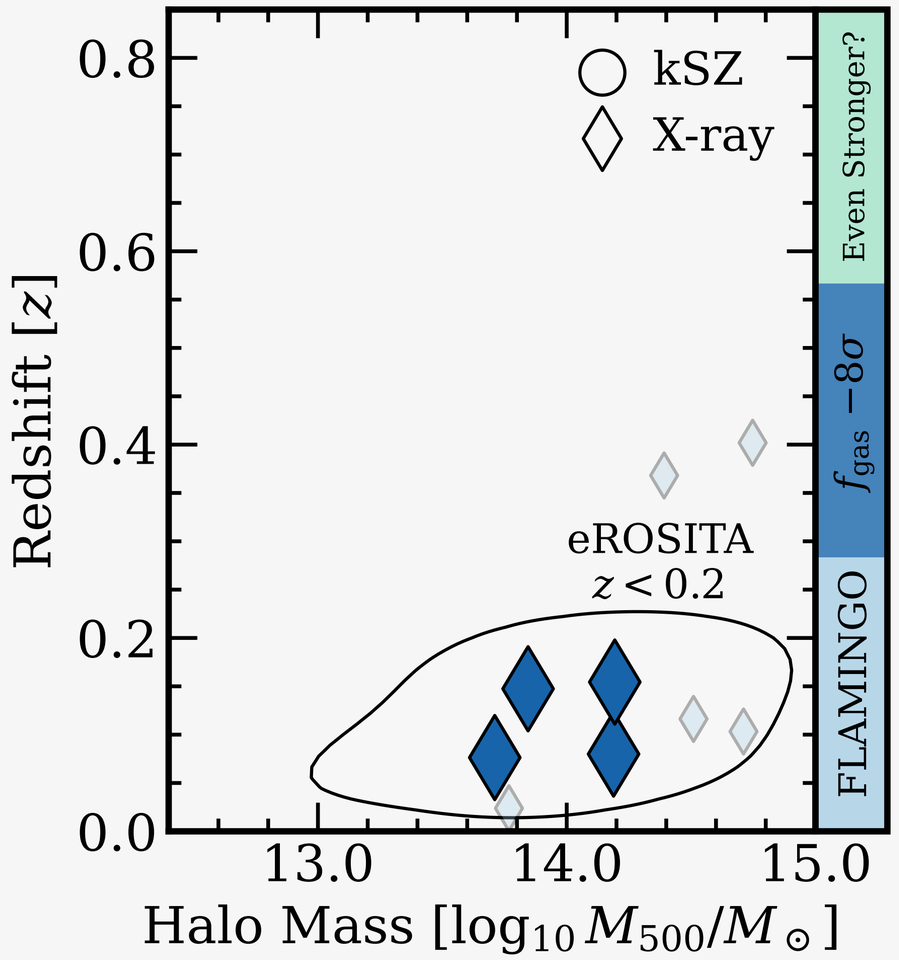


X-ray Gas Fraction

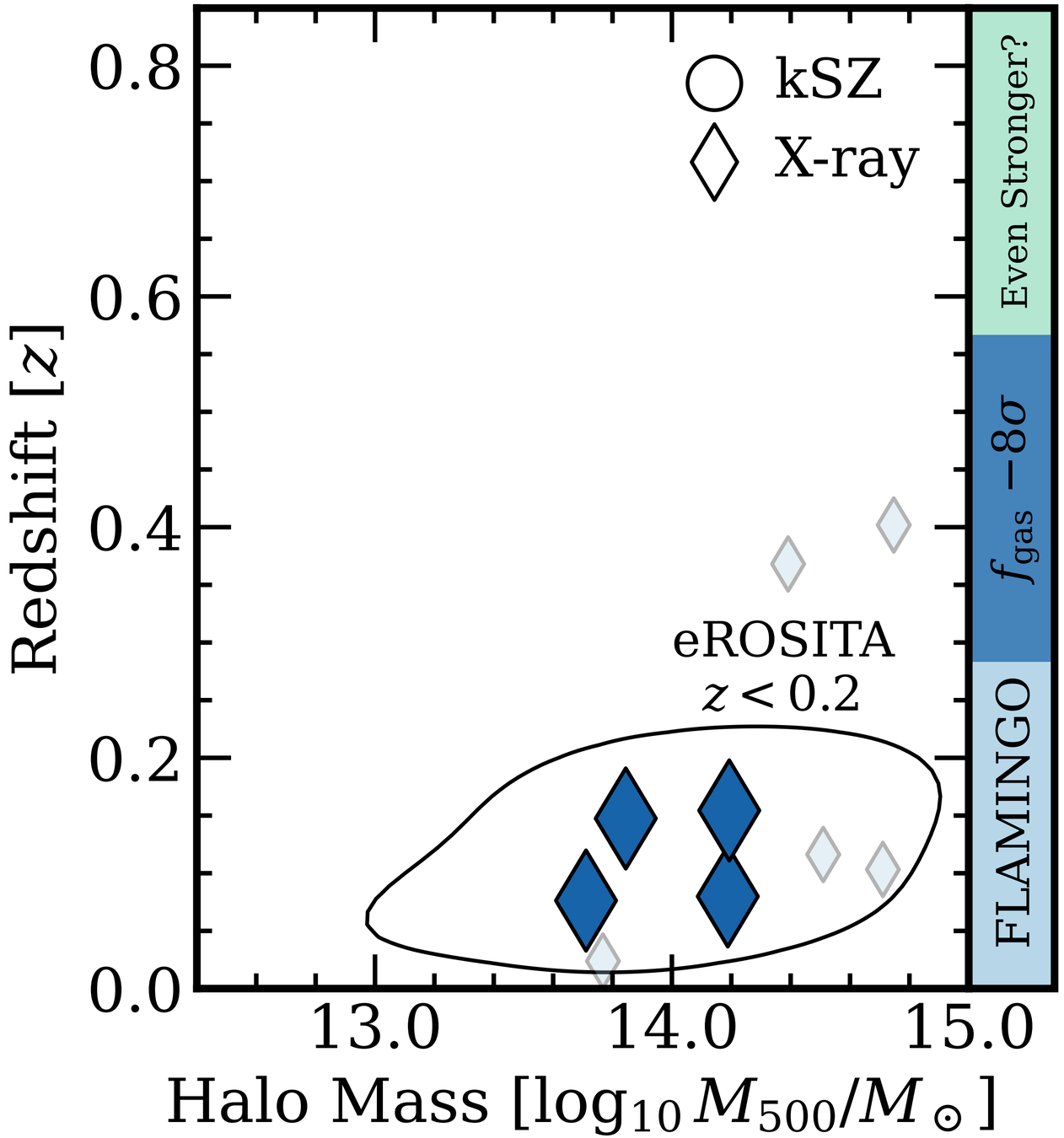
eROSITA+WL Gas Fractions



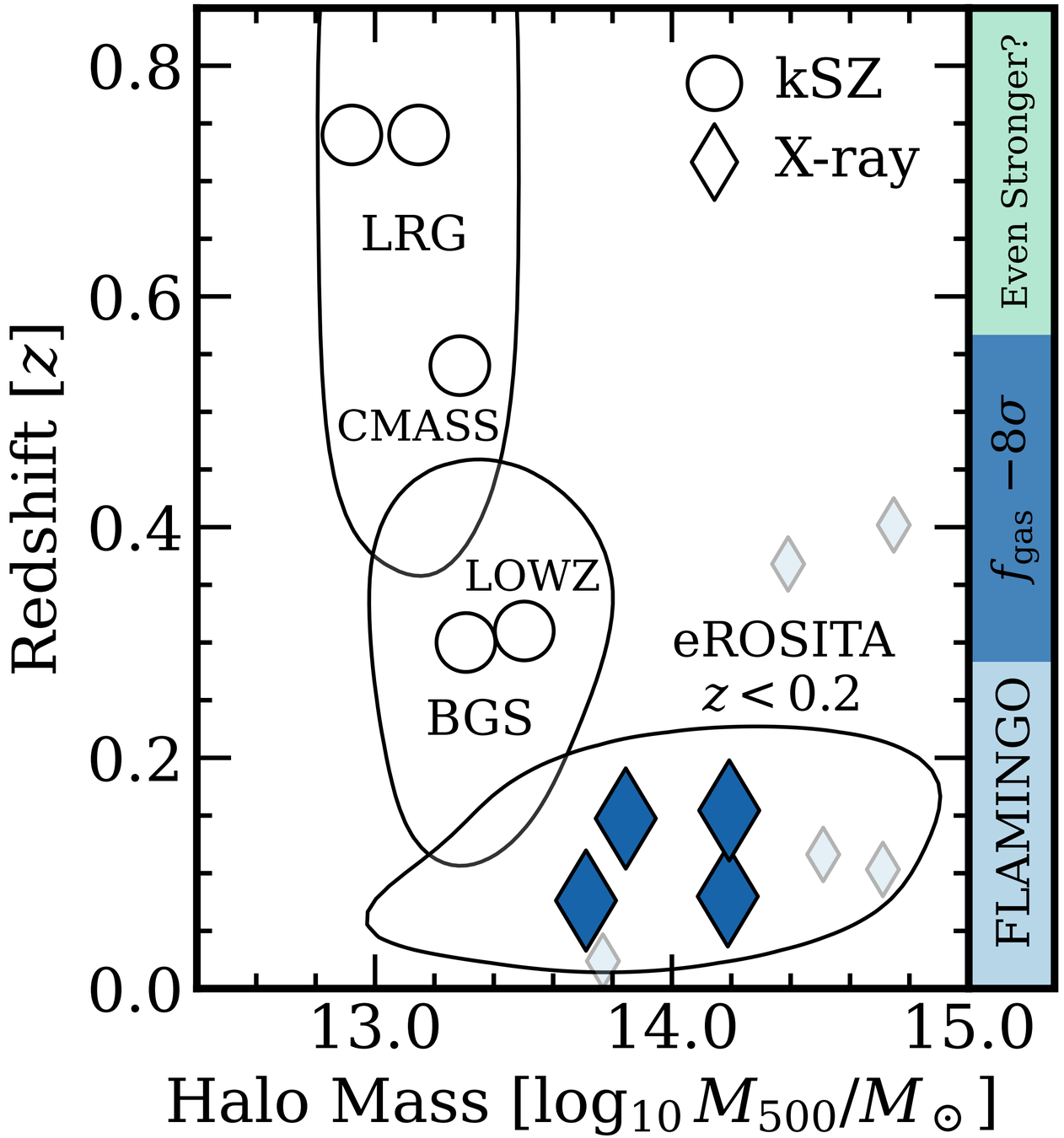
Also see:
Seppi+22
Popesso+24
Marini+24
Ding+in prep

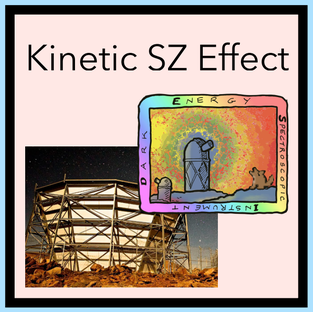


Landscape of Feedback

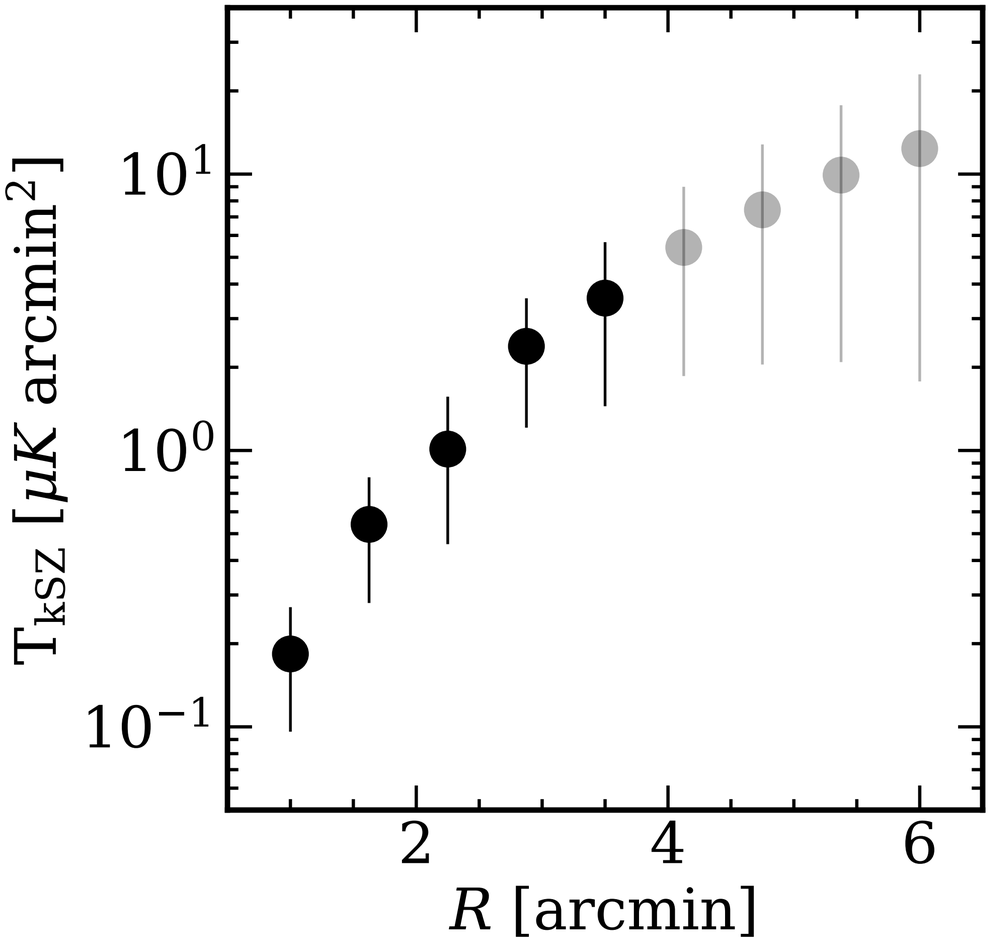


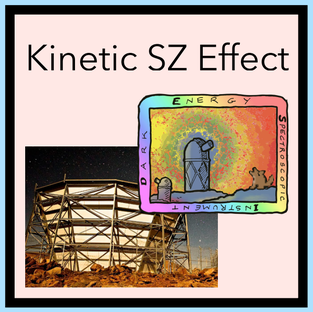
Landscape of Feedback



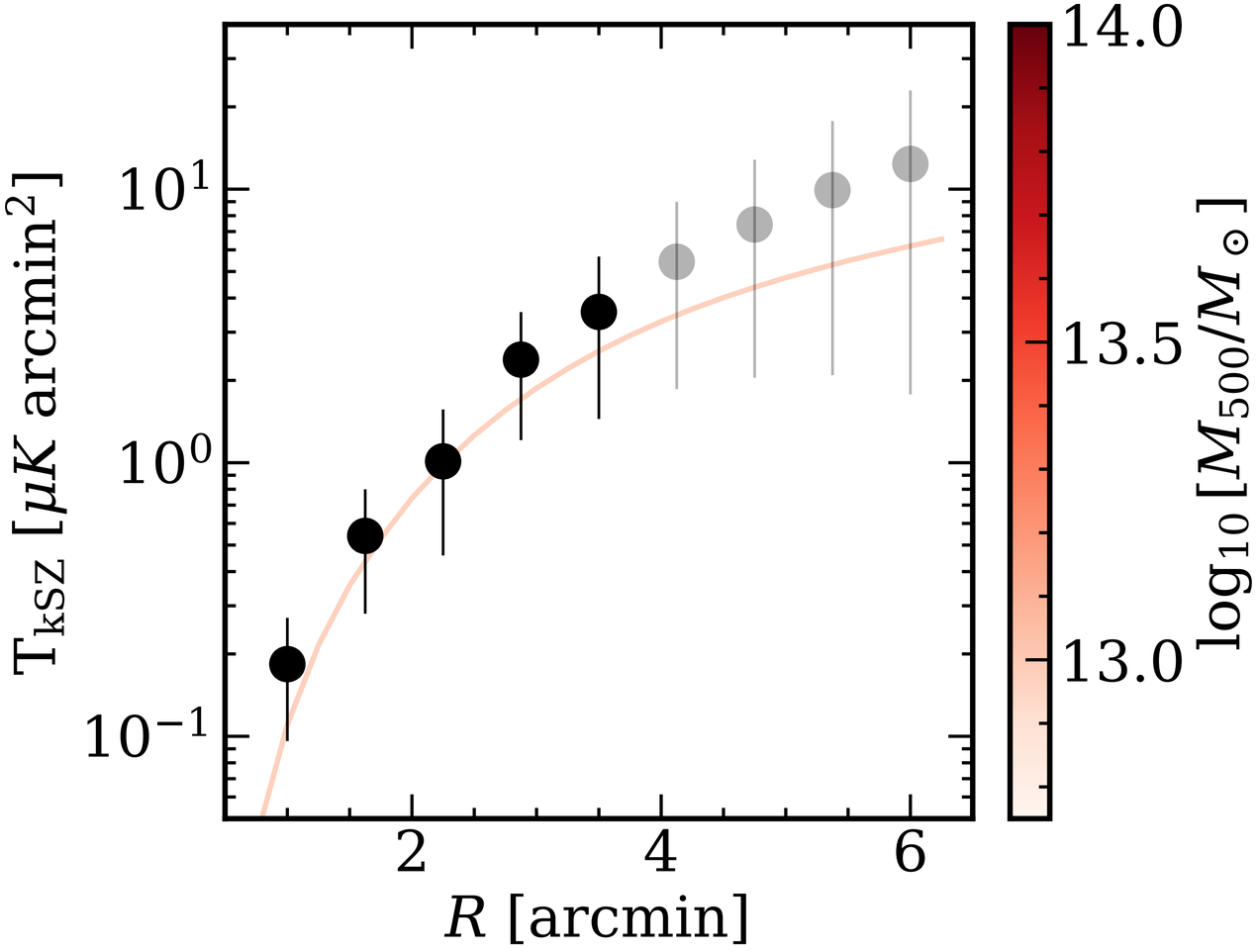


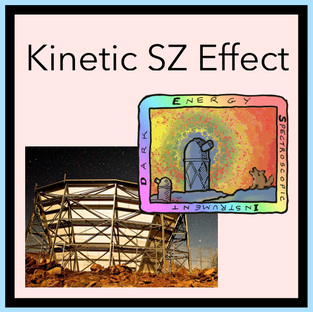
Like-with-like kSZ Analysis



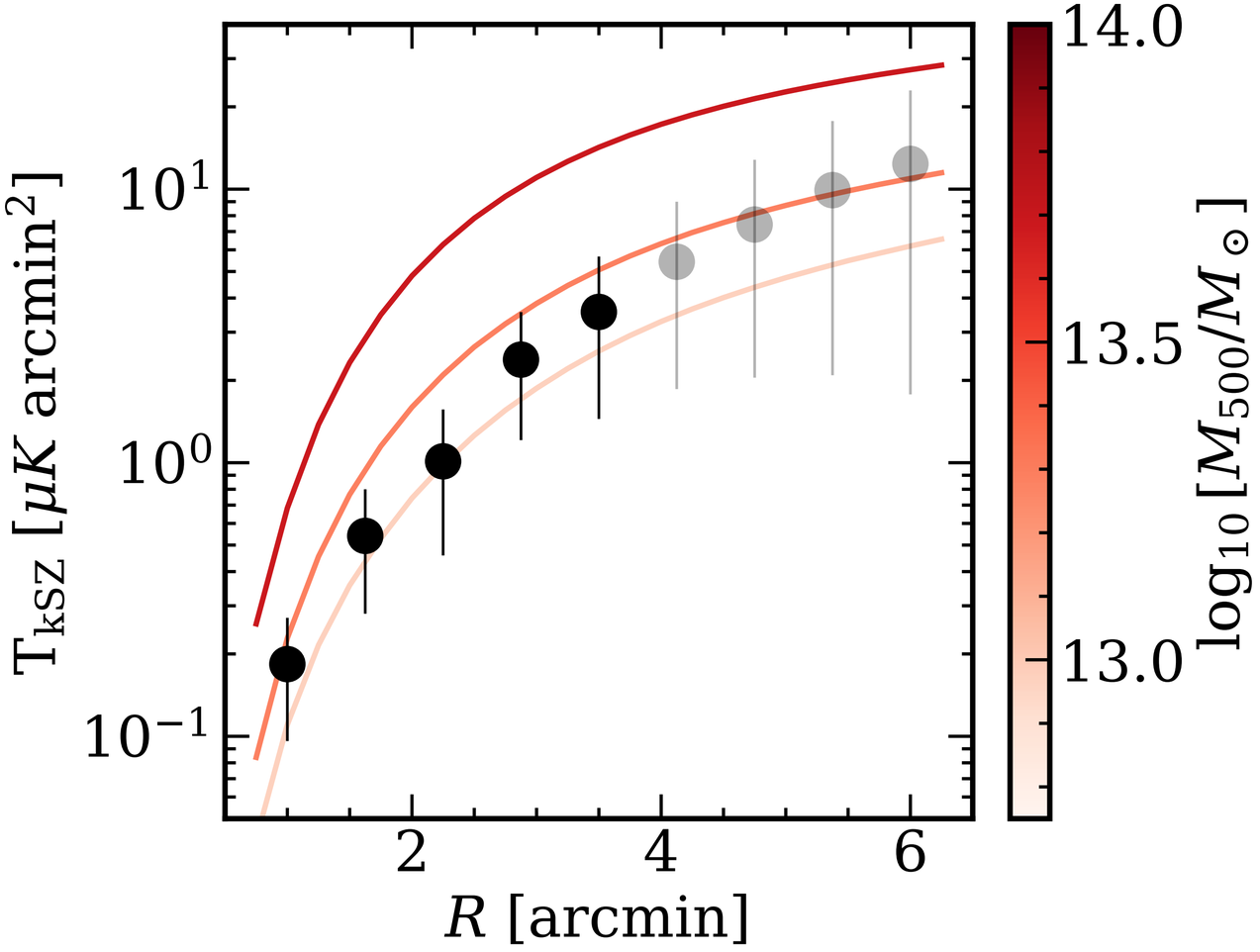


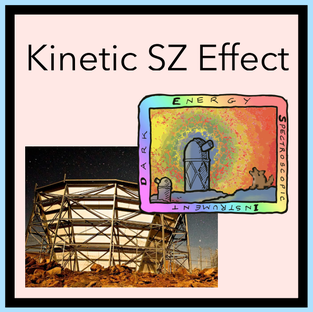
Like-with-like kSZ Analysis



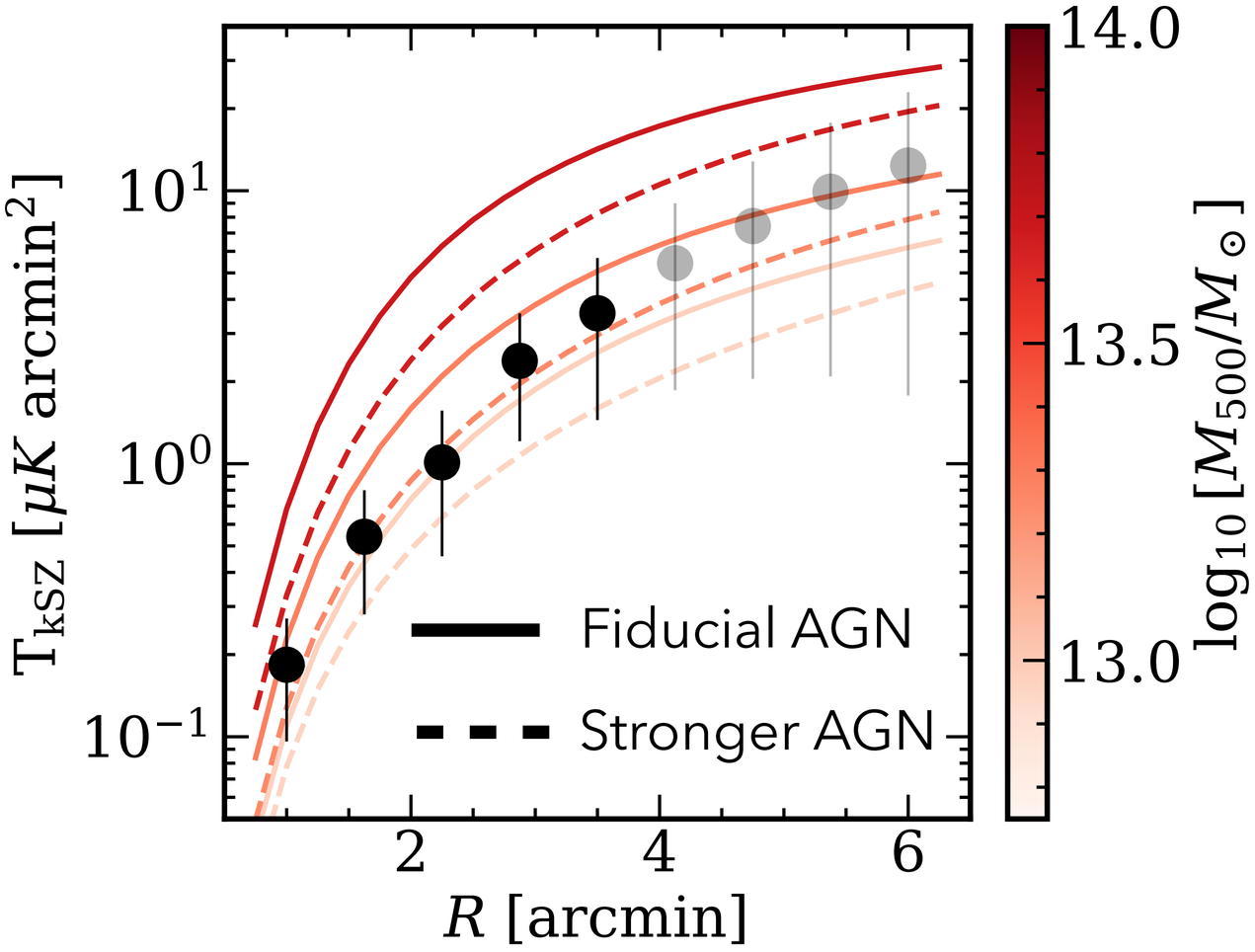


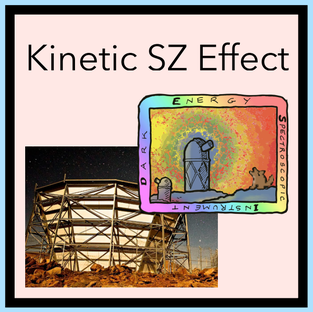
Like-with-like kSZ Analysis





Like-with-like kSZ Analysis





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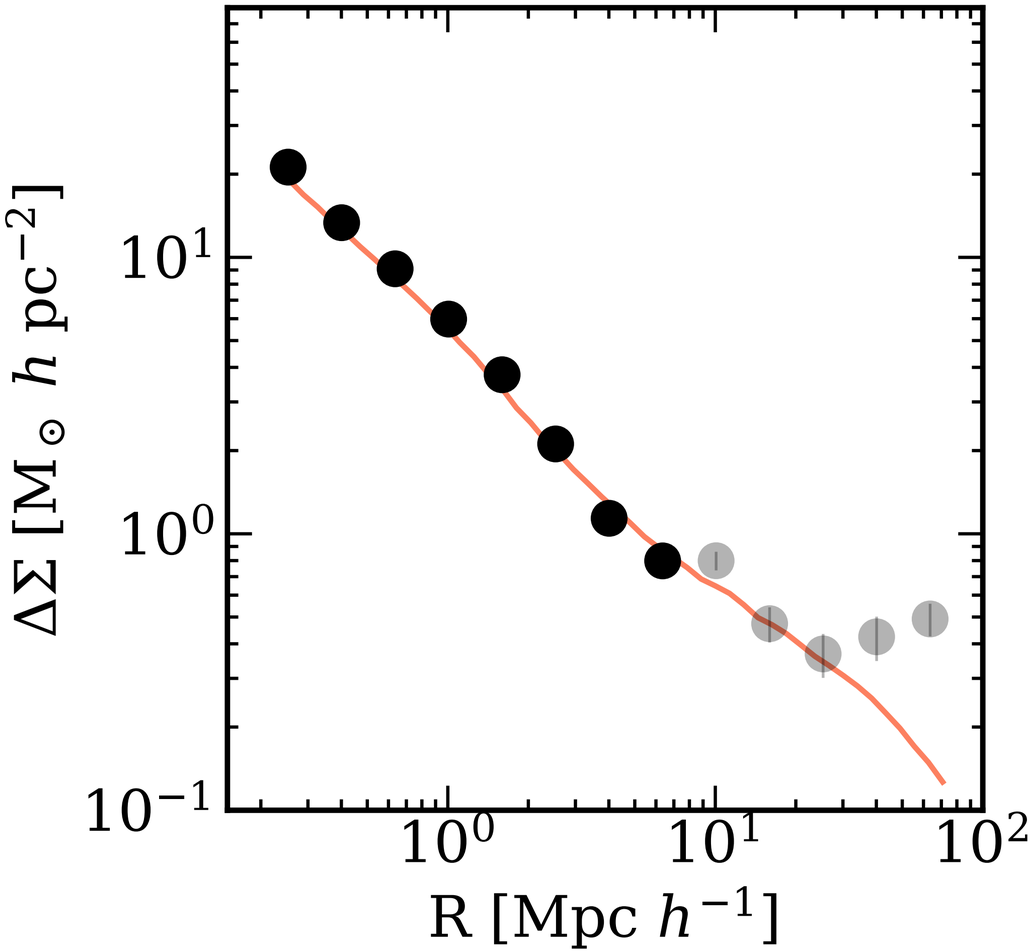
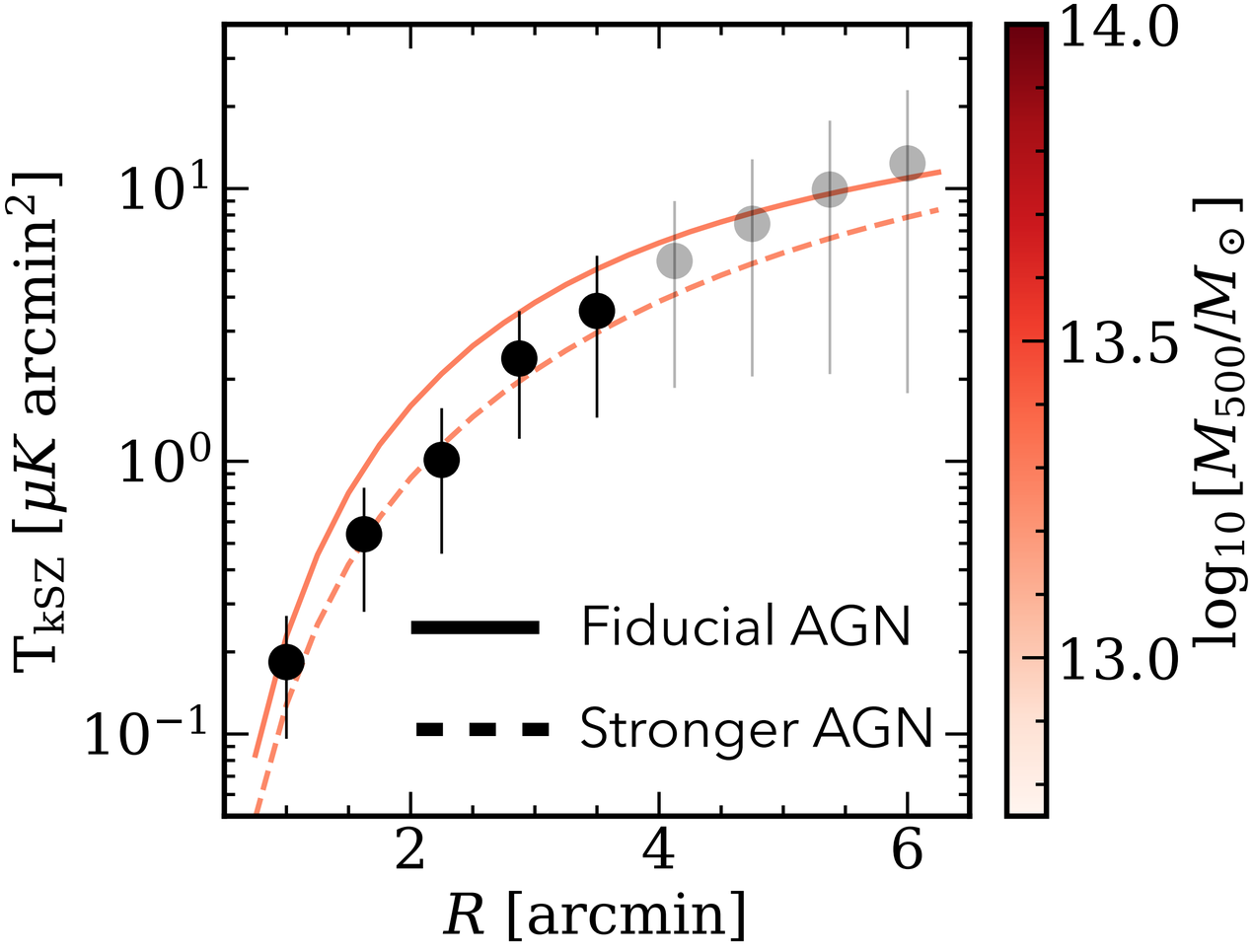
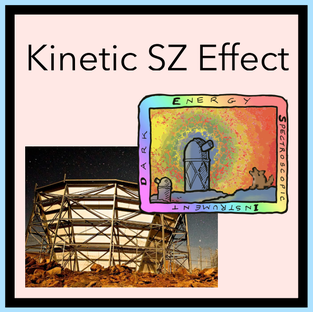
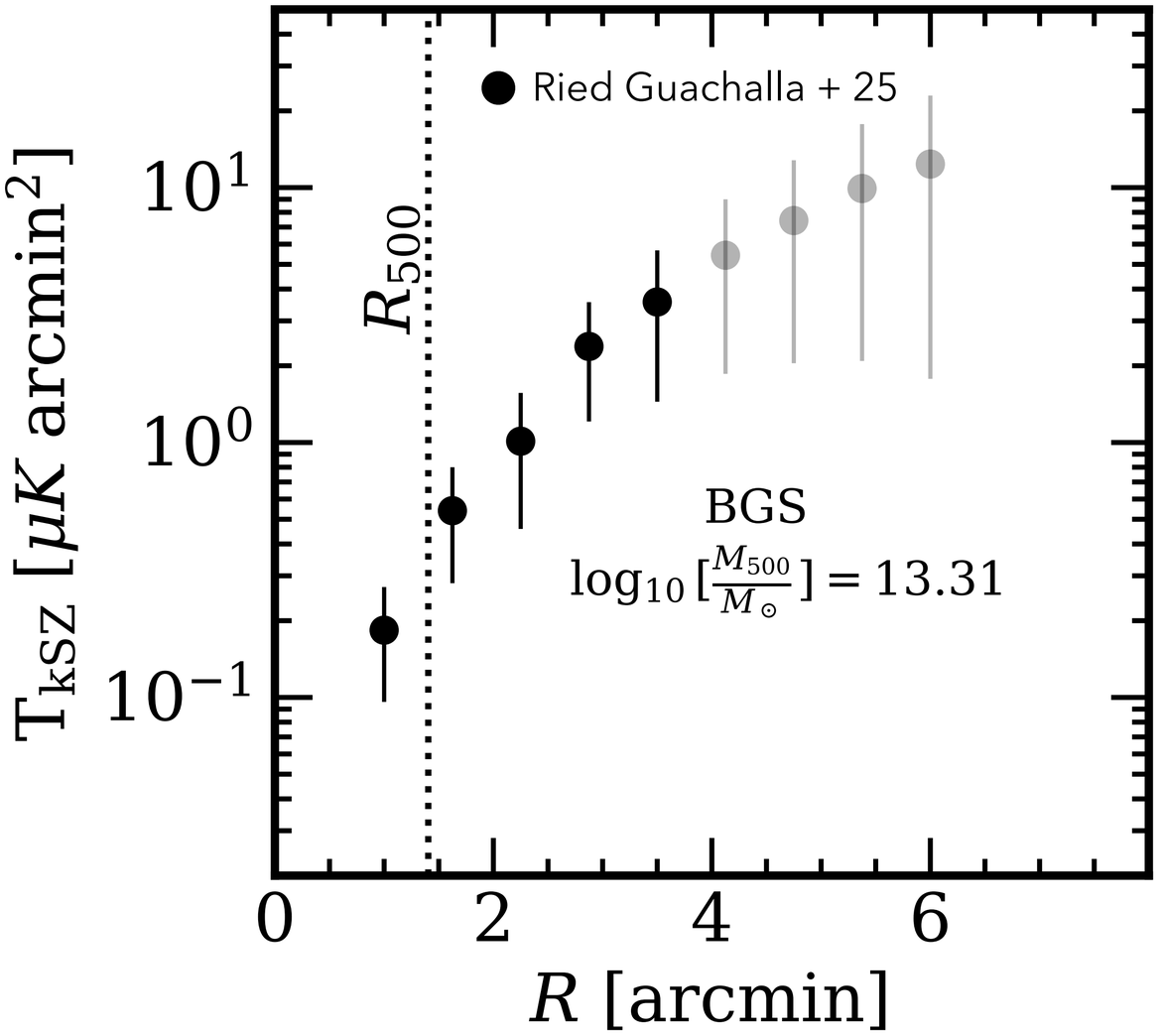
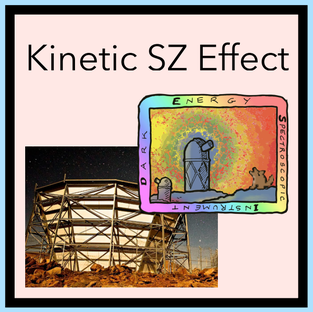




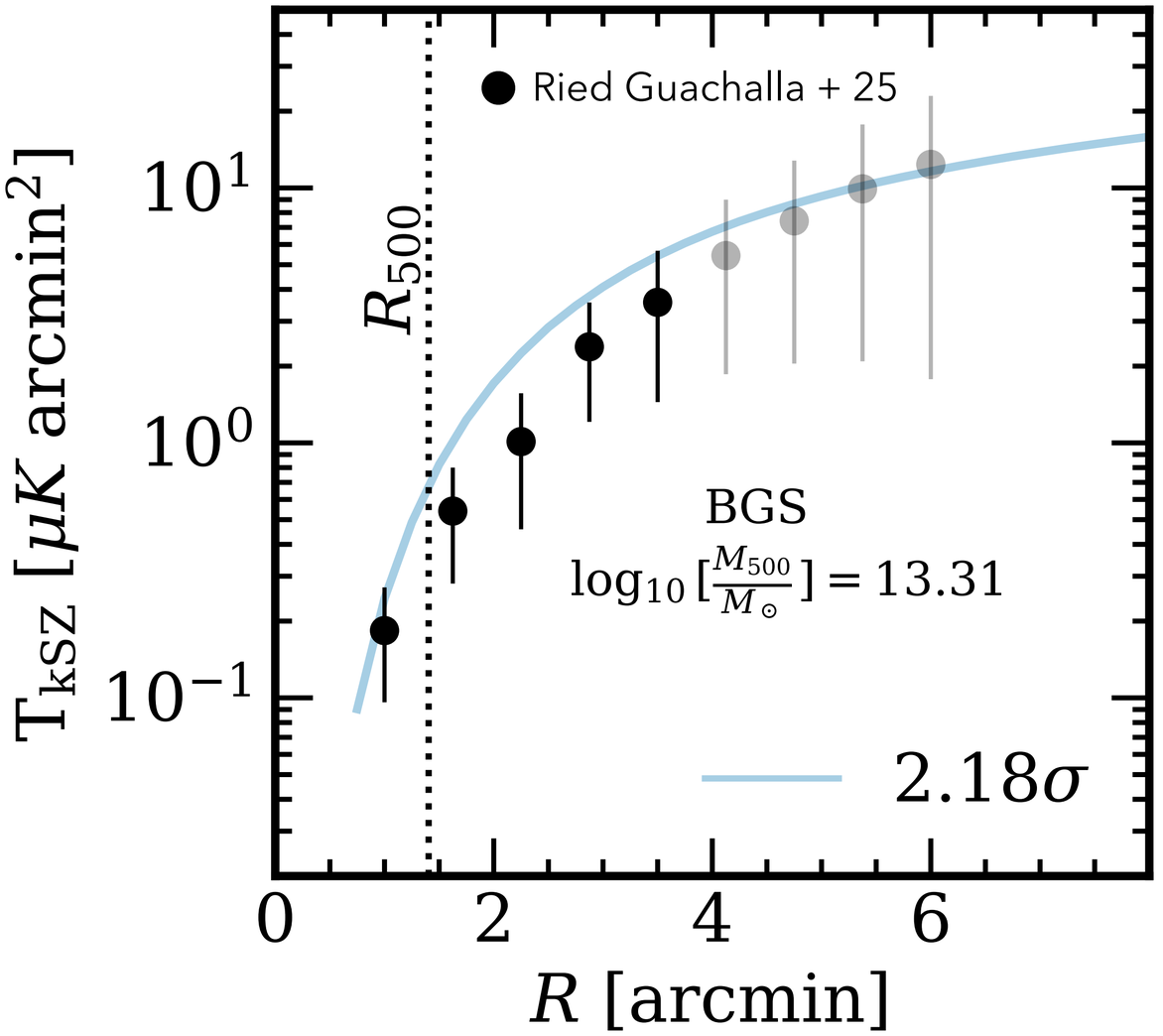


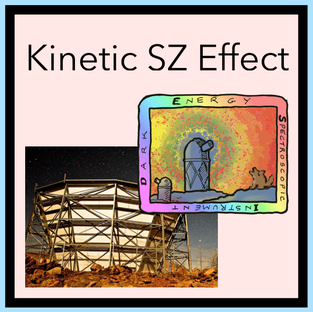
SDSS/DESI+ACT kSZ





SDSS/DESI+ACT kSZ





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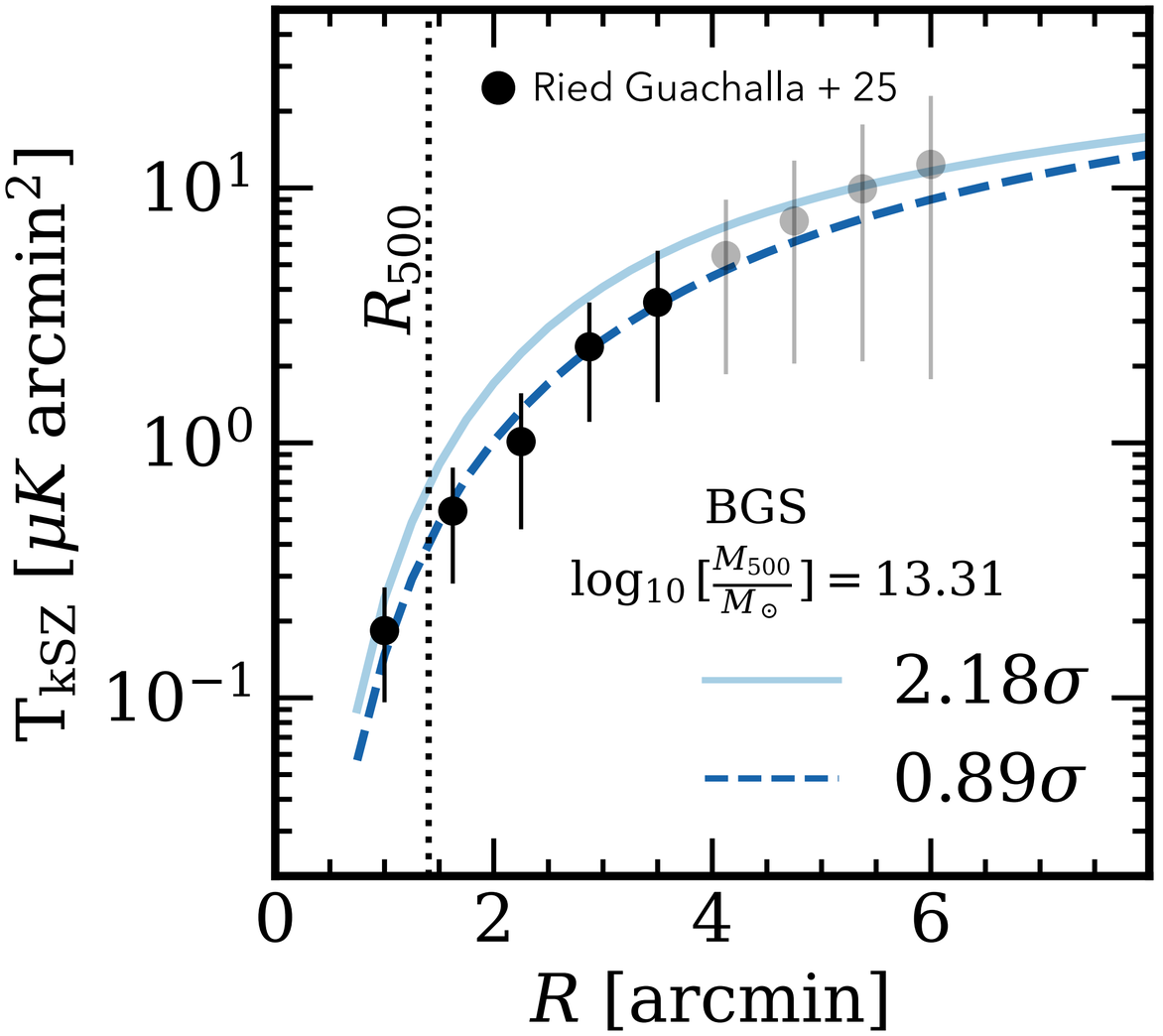
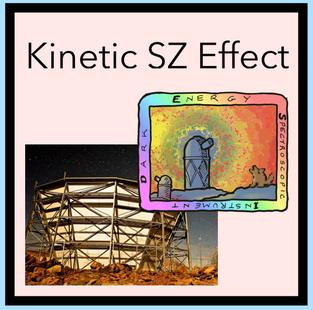
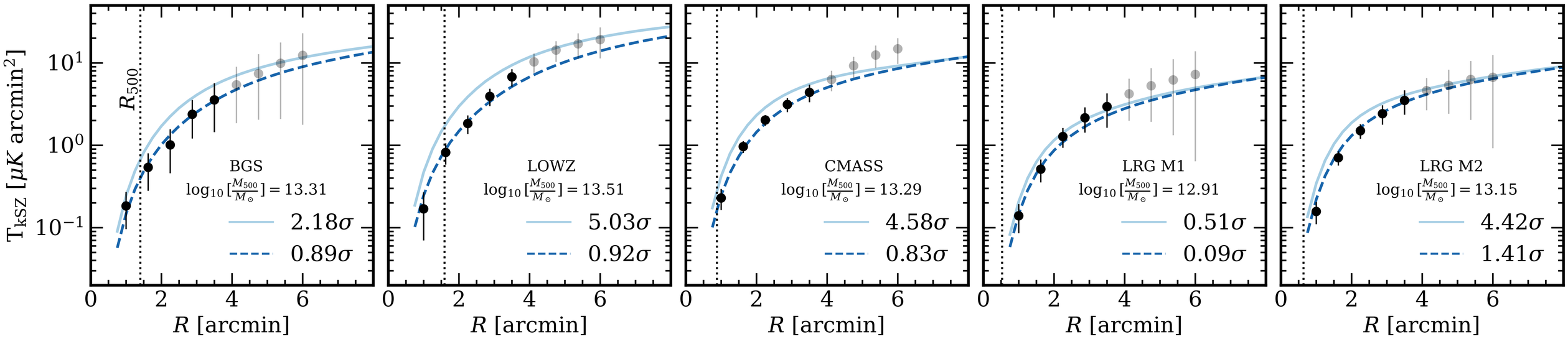




SDSS/DESI+ACT kSZ



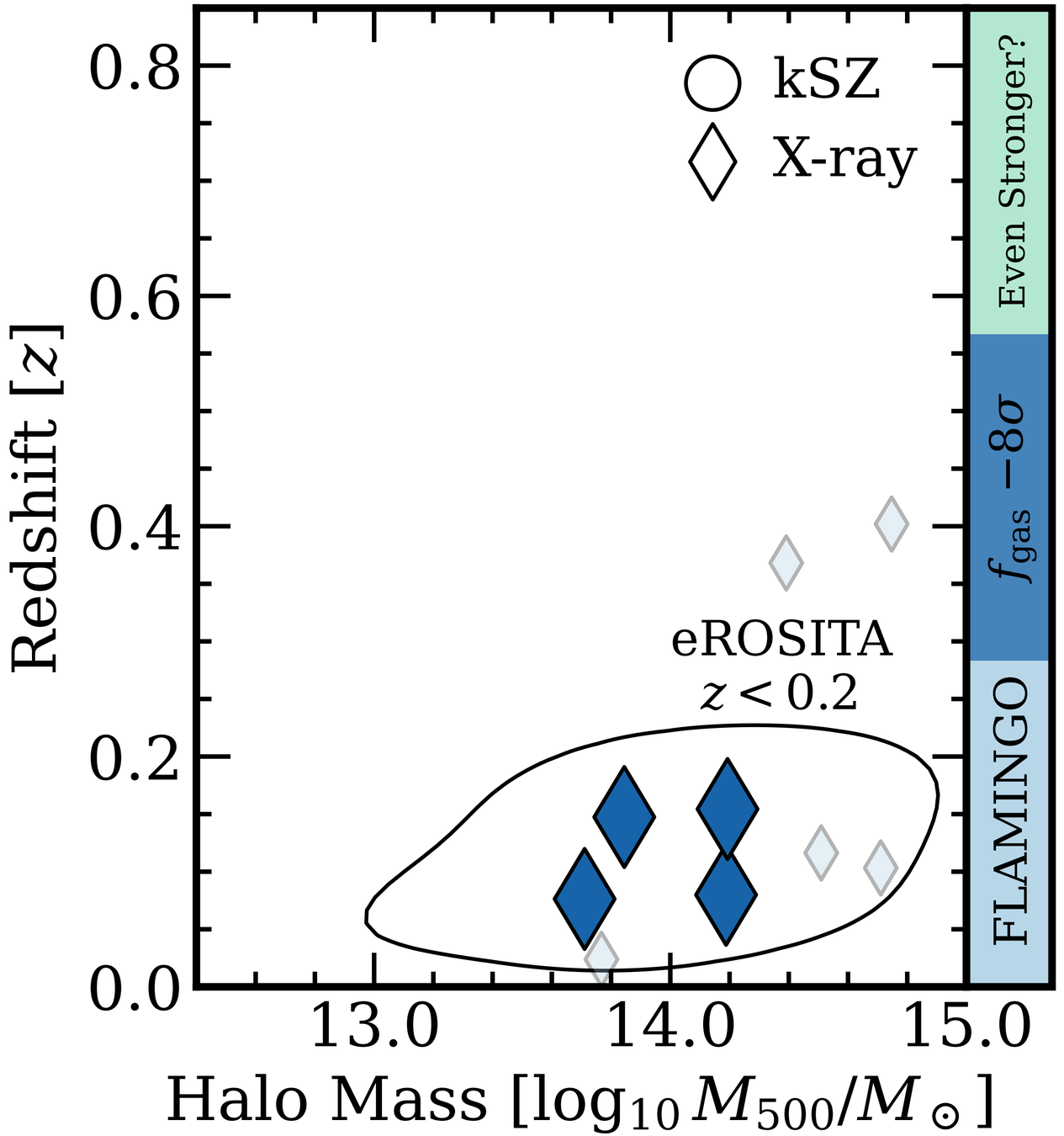
McCarthy+24

Siegel+25

Hadzhiyska+24

Ried Guachalla + 25

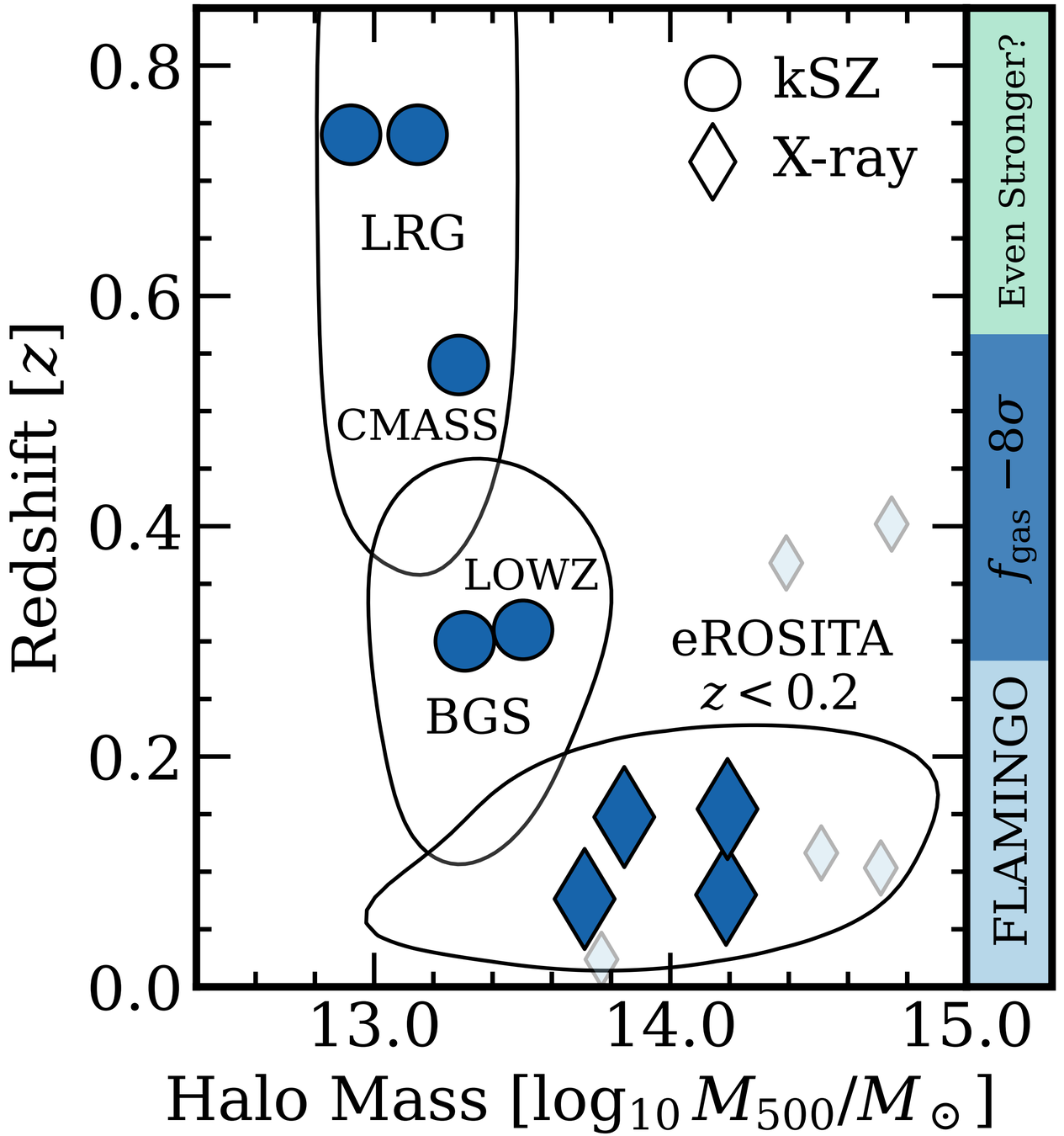
Landscape of Feedback



McCarthy+24 arXiv:2410.19905

Siegel+25 arXiv:2509.10455

Landscape of Feedback

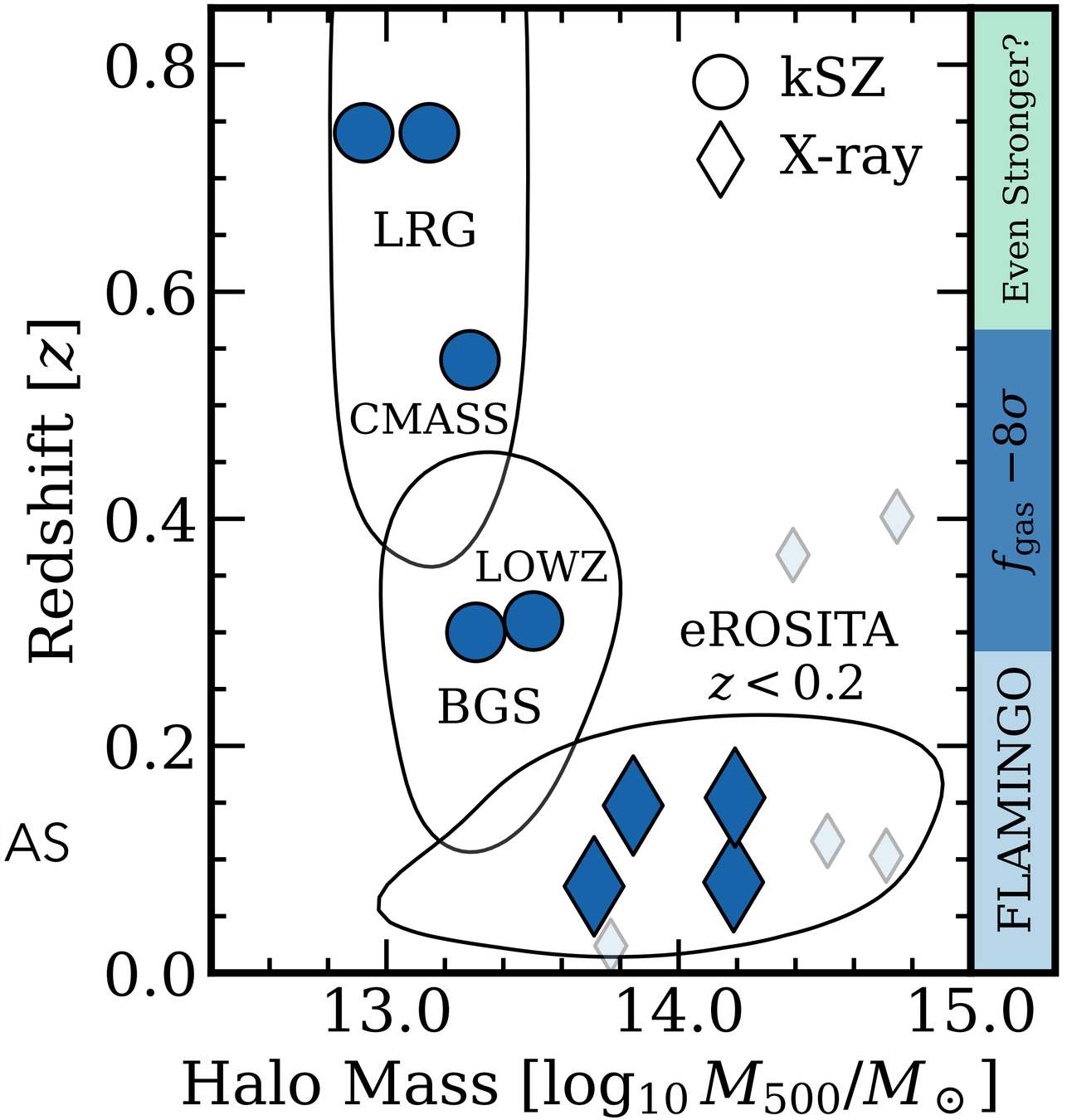


McCarthy+24 arXiv:2410.19905

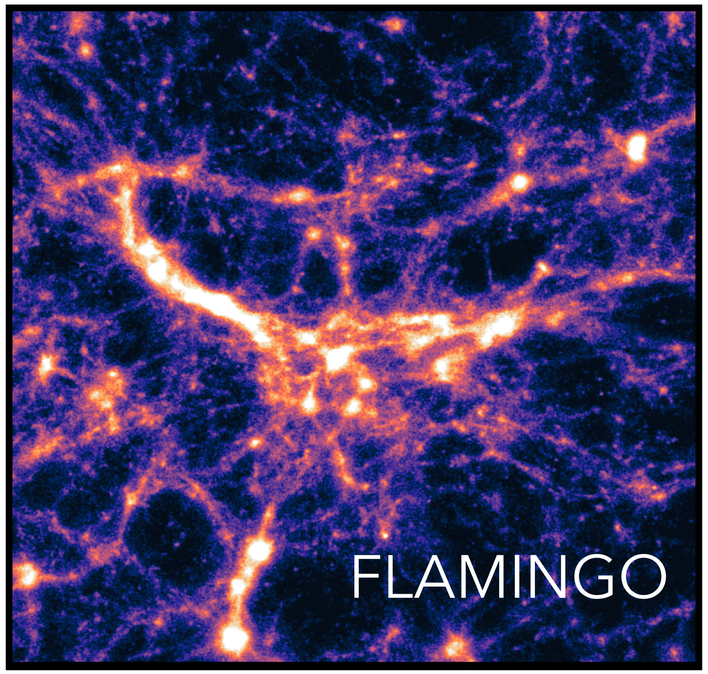
Siegel+25 arXiv:2509.10455

Landscape of Feedback

Bigwood+25: FABLE, SIMBA, BAHAMAS

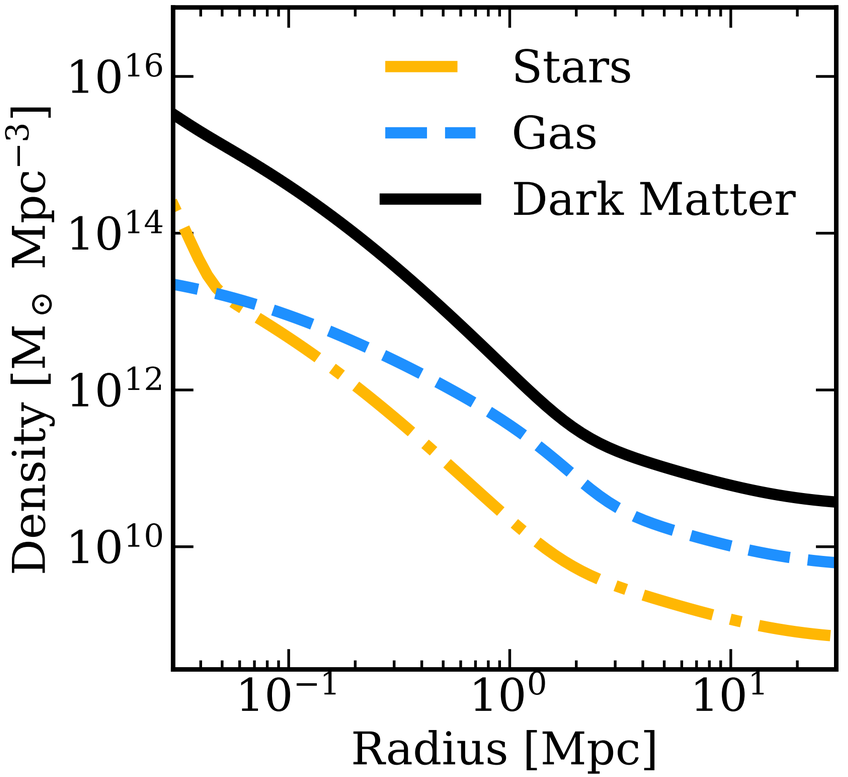


How do we measure feedback?



Hydrodynamical Simulations

Siegel + 25b arXiv:2509.10455

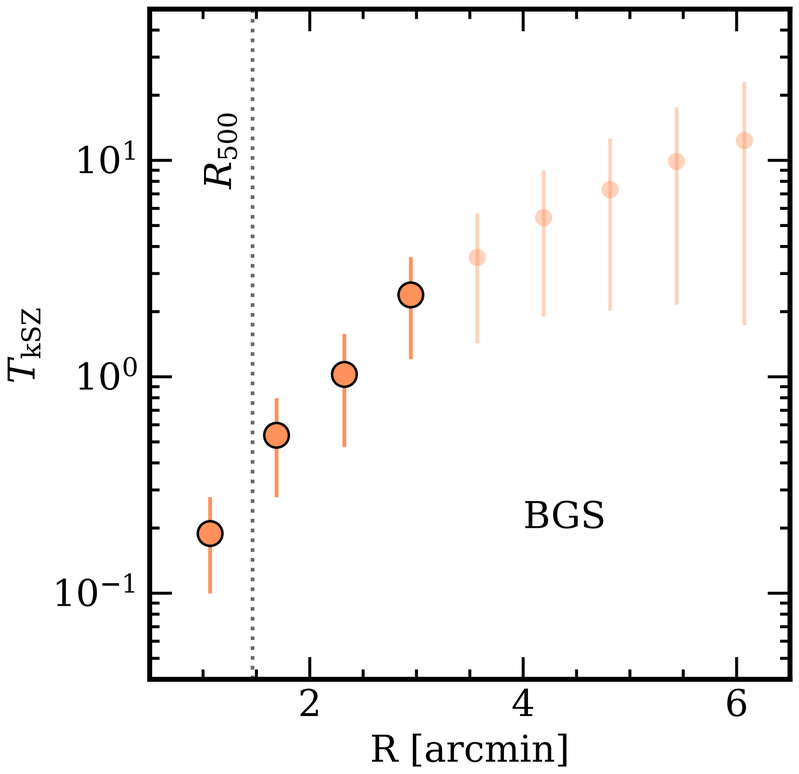


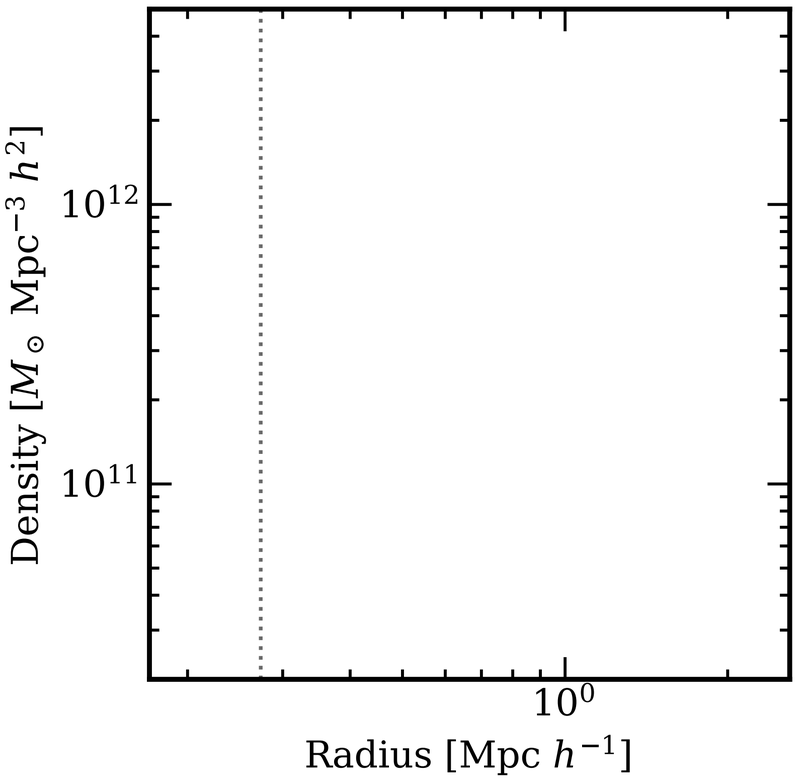
Semi-analytic Modeling

Siegel + 25c arXiv:2512.02954

Building a Complete Picture

Semi-Analytic Modeling



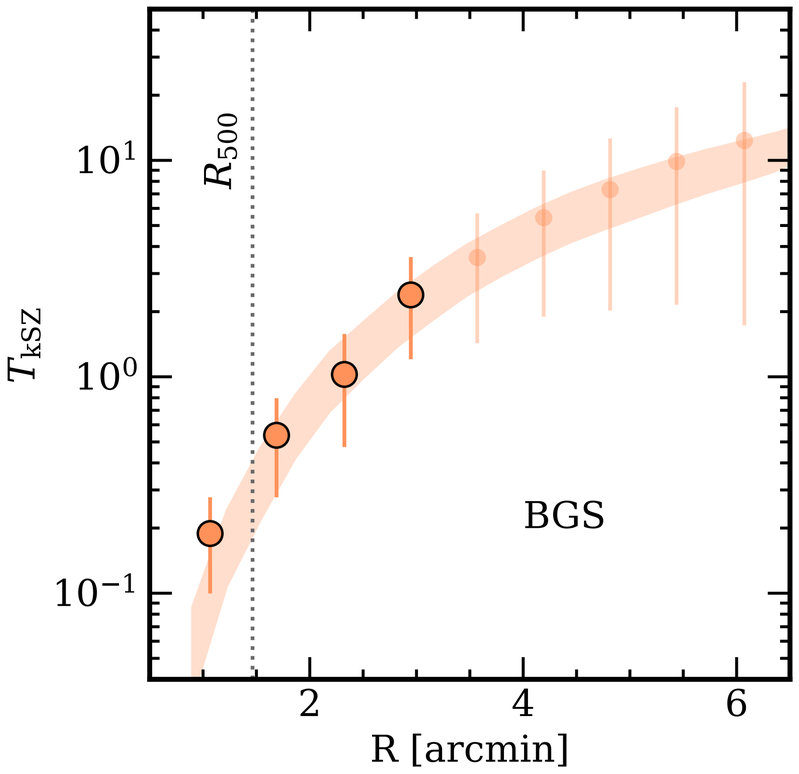


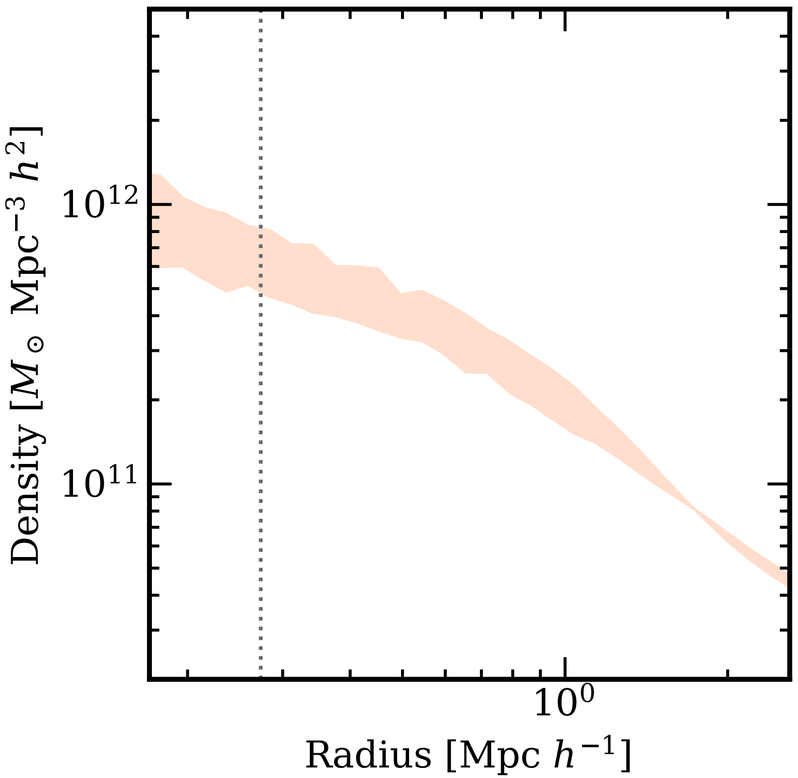
$$\rho(r \mid \theta, M_{500}, z)$$

Schneider & Teyssier (2015)
Giri & Schneider (2021)
Oppenheimer et al. (2025)
Kovac et al. (2025)

Building a Complete Picture

Semi-Analytic Modeling





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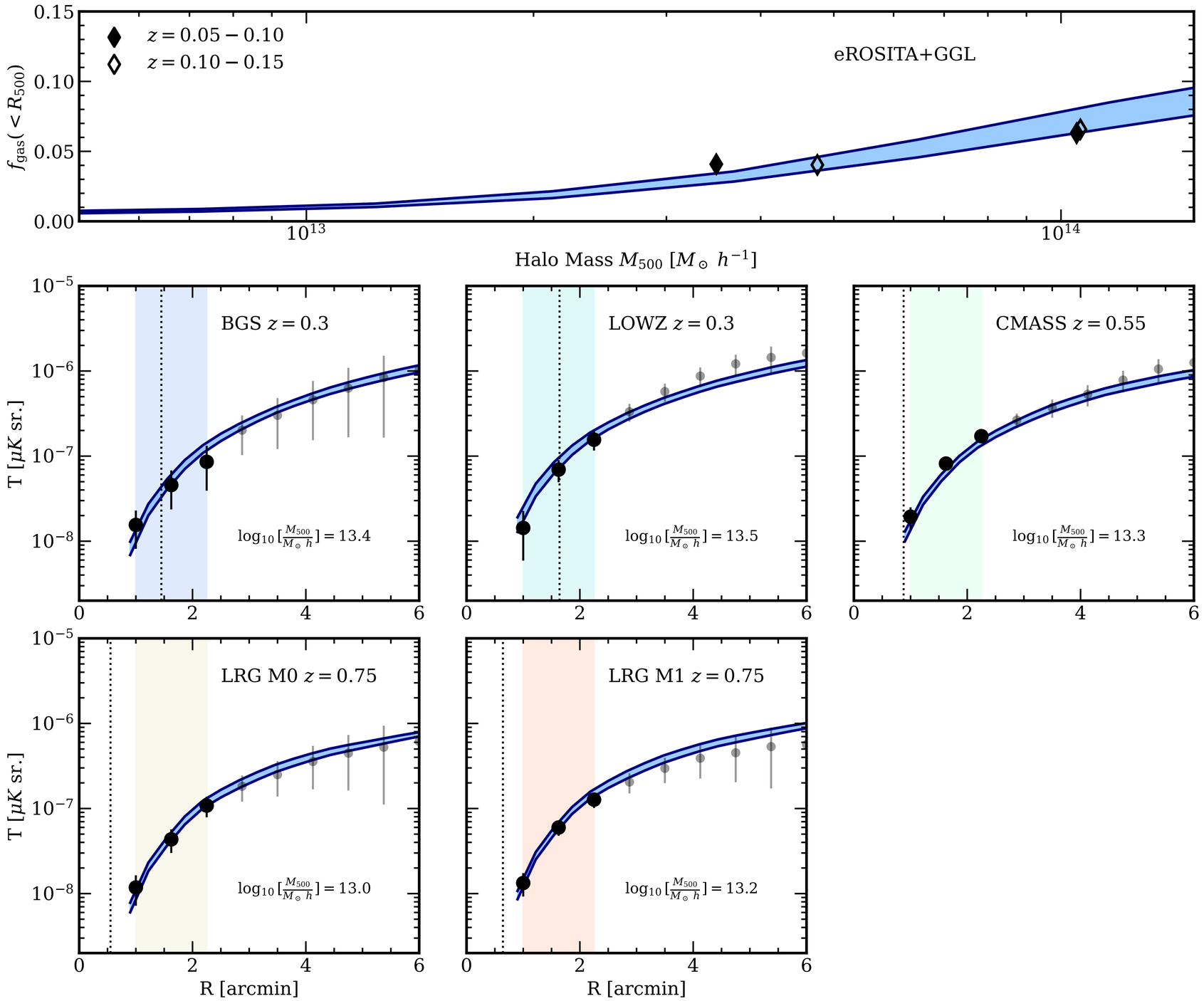
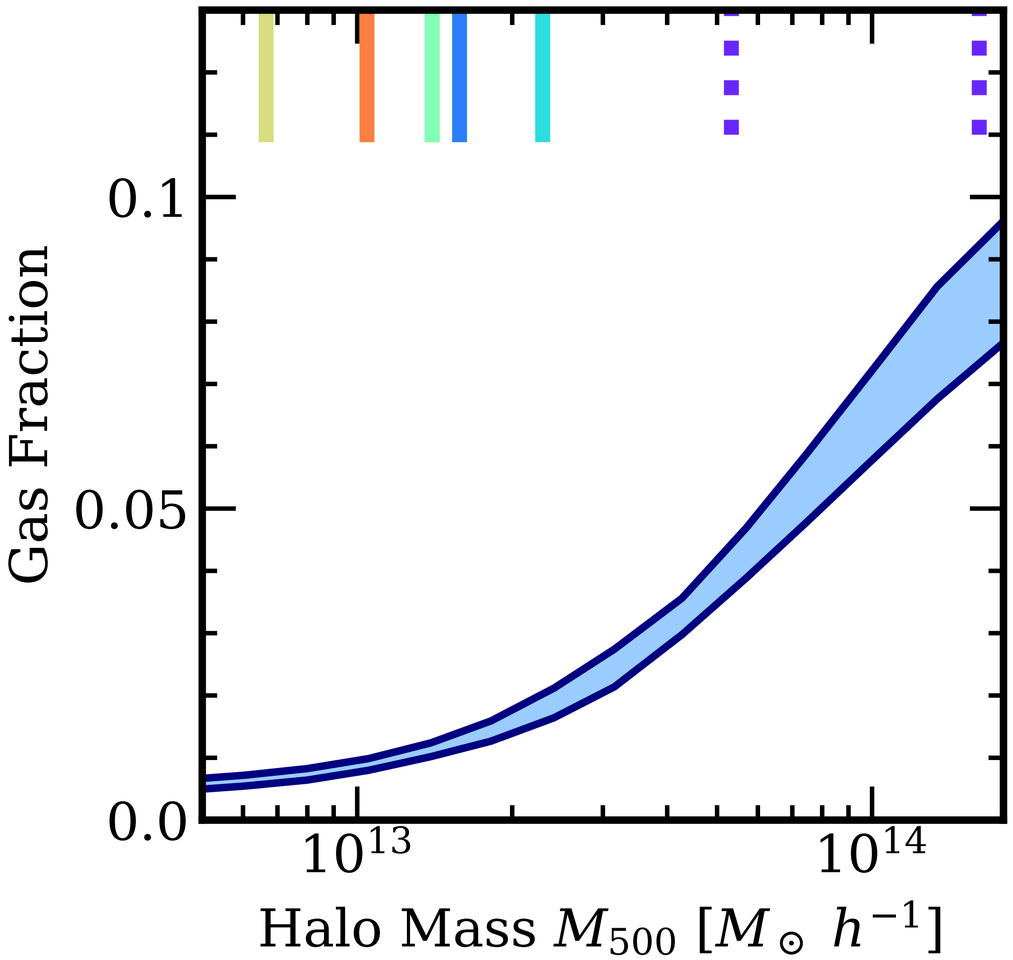
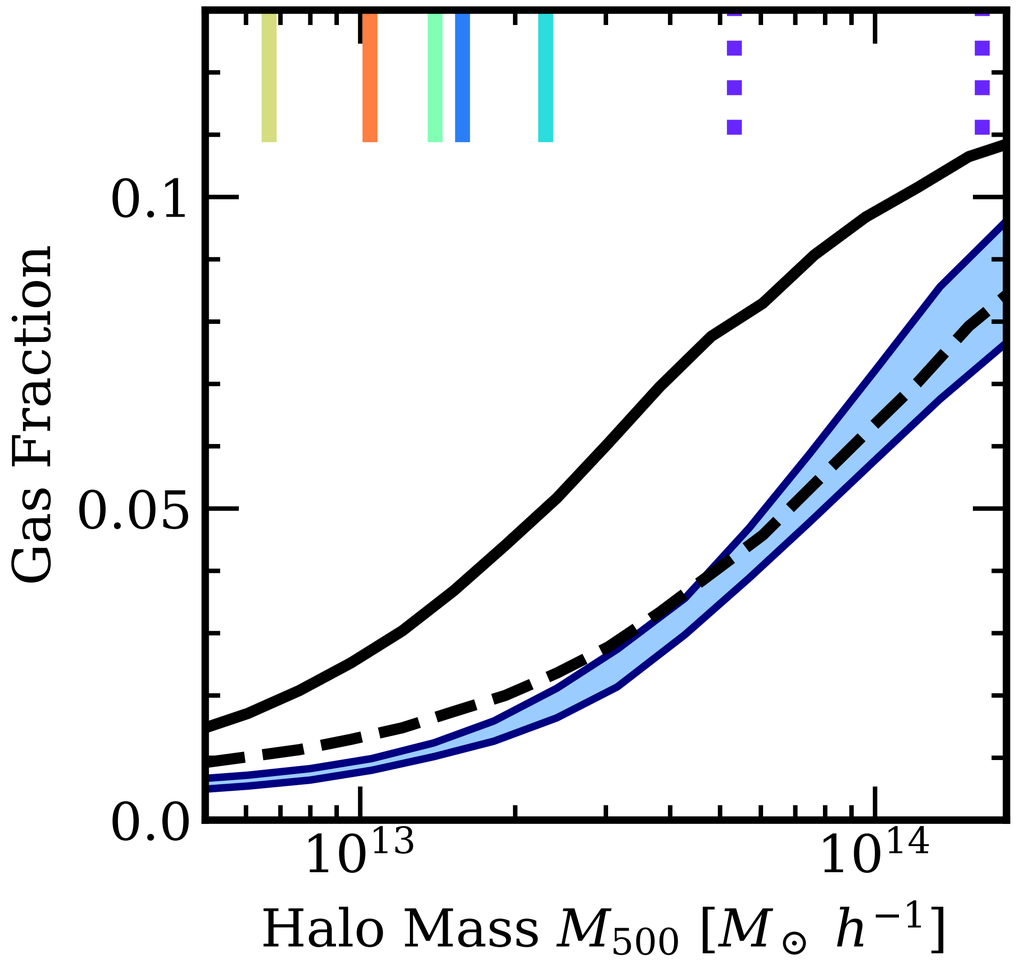
X-ray & kSZ Joint Fit



Building a Complete Picture



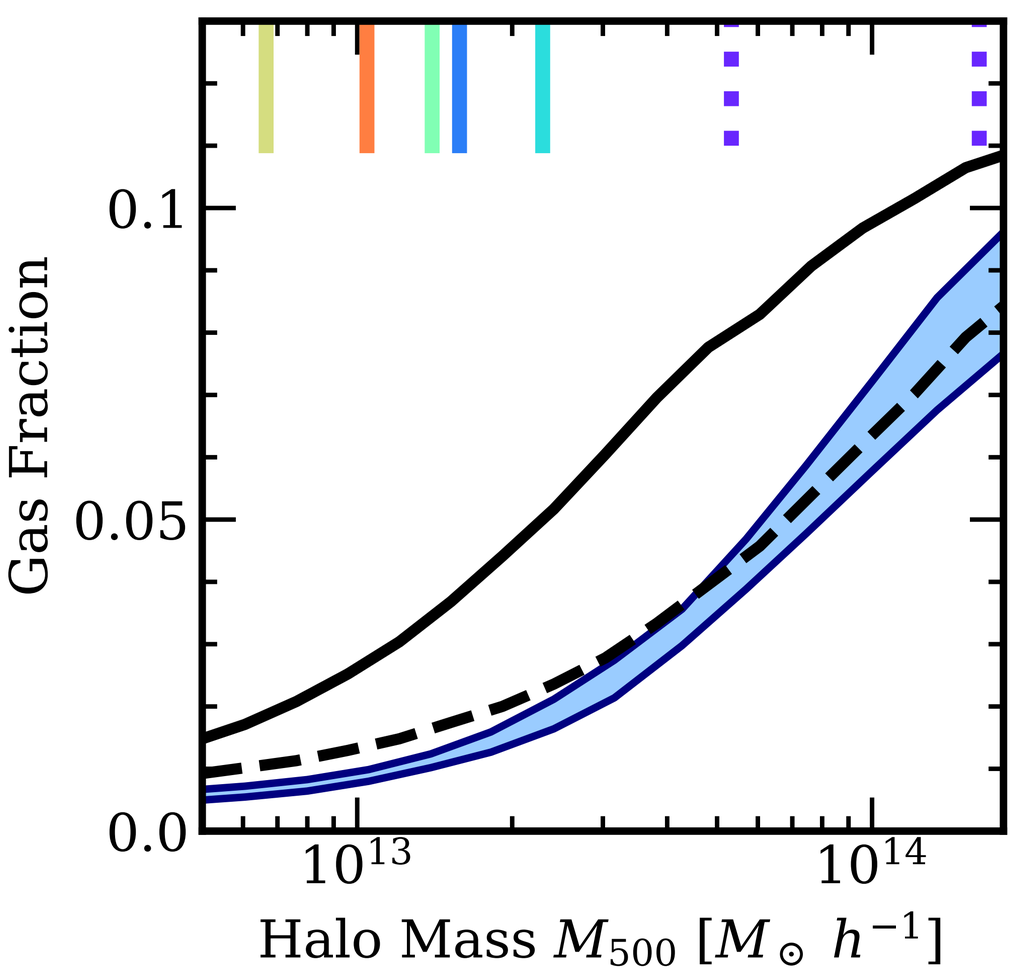
Building a Complete Picture

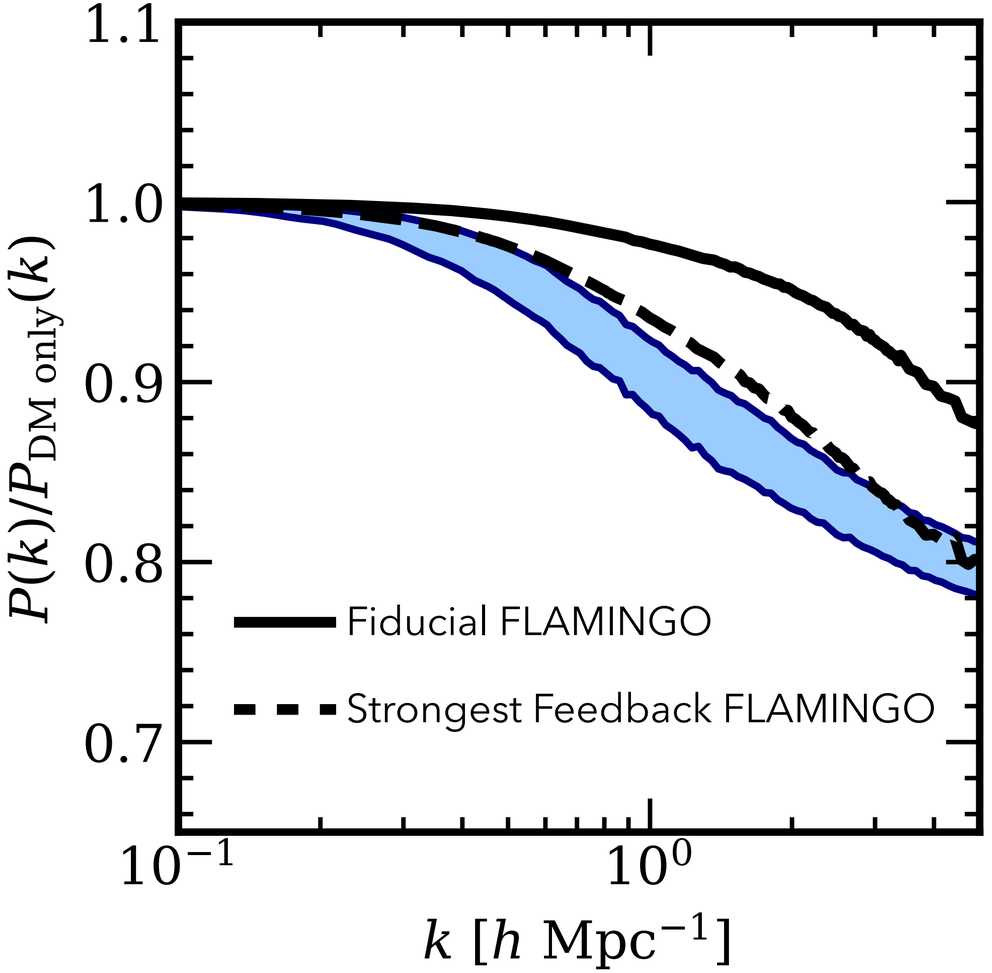


Fiducial FLAMINGO

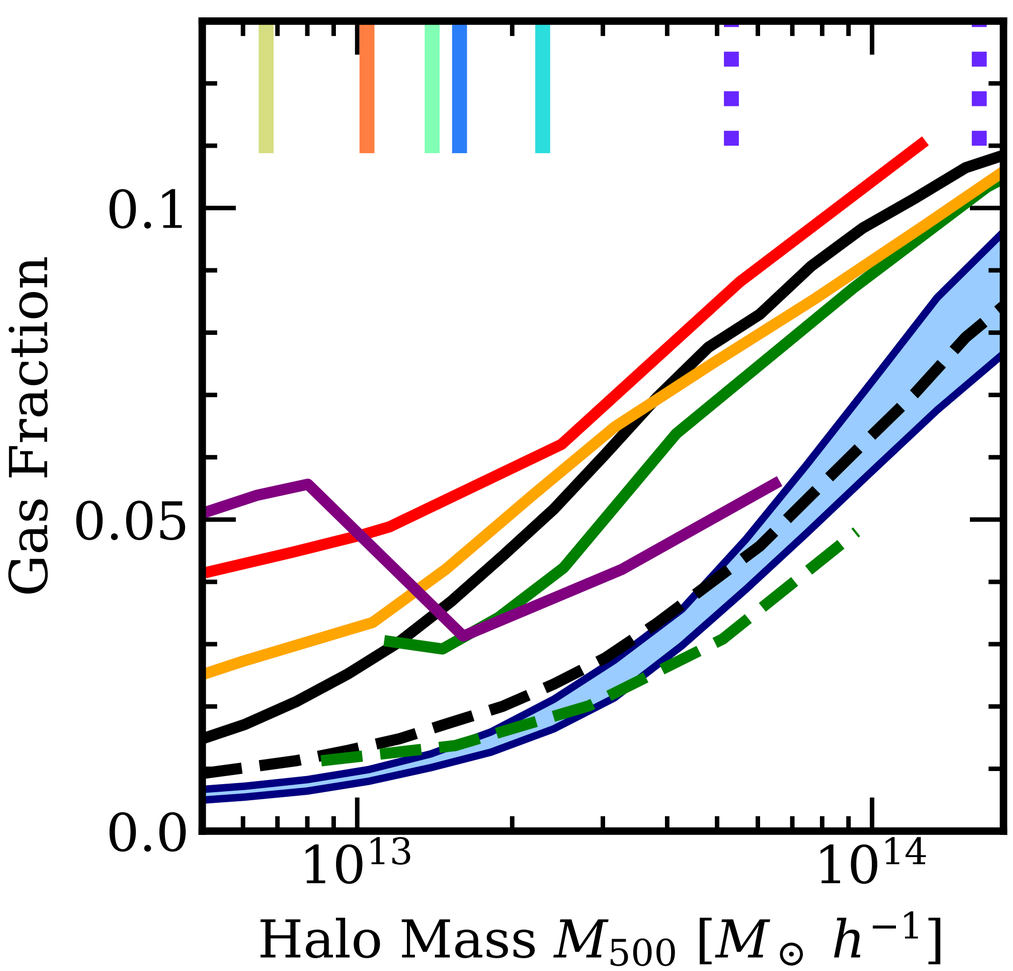
Strongest Feedback FLAMINGO

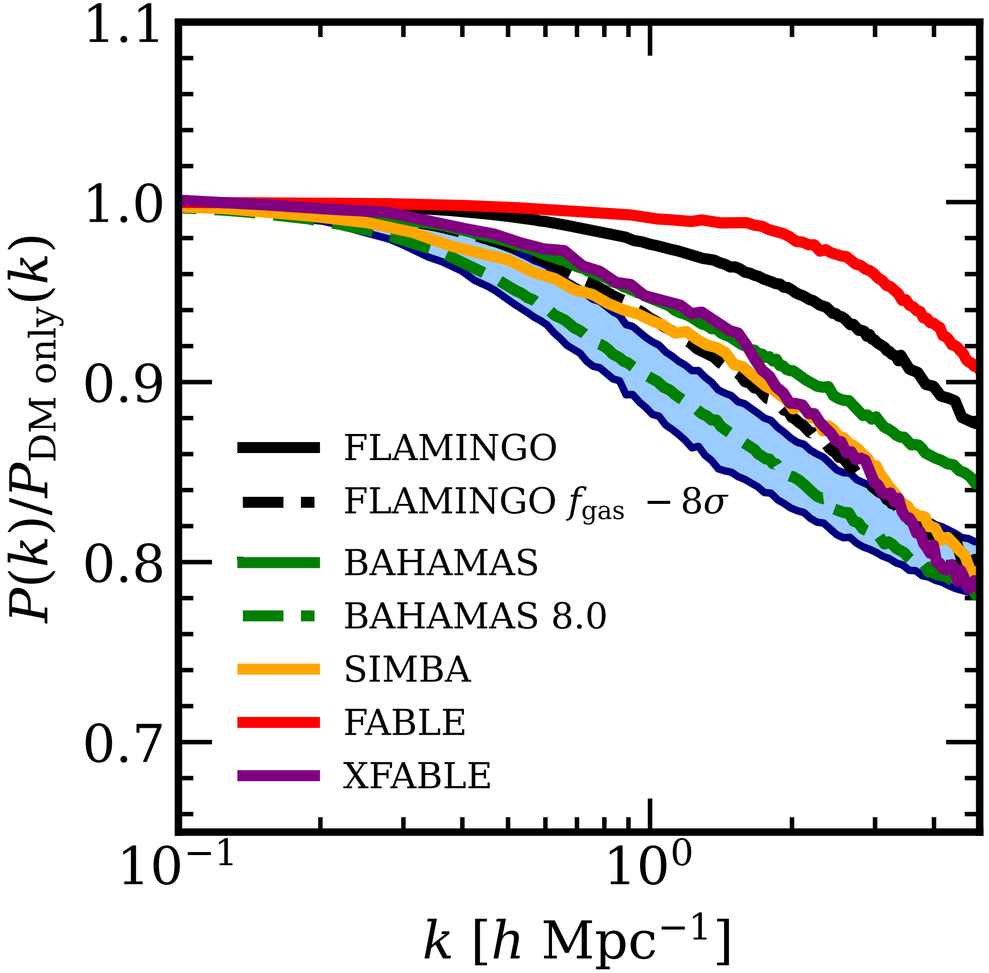
Building a Complete Picture



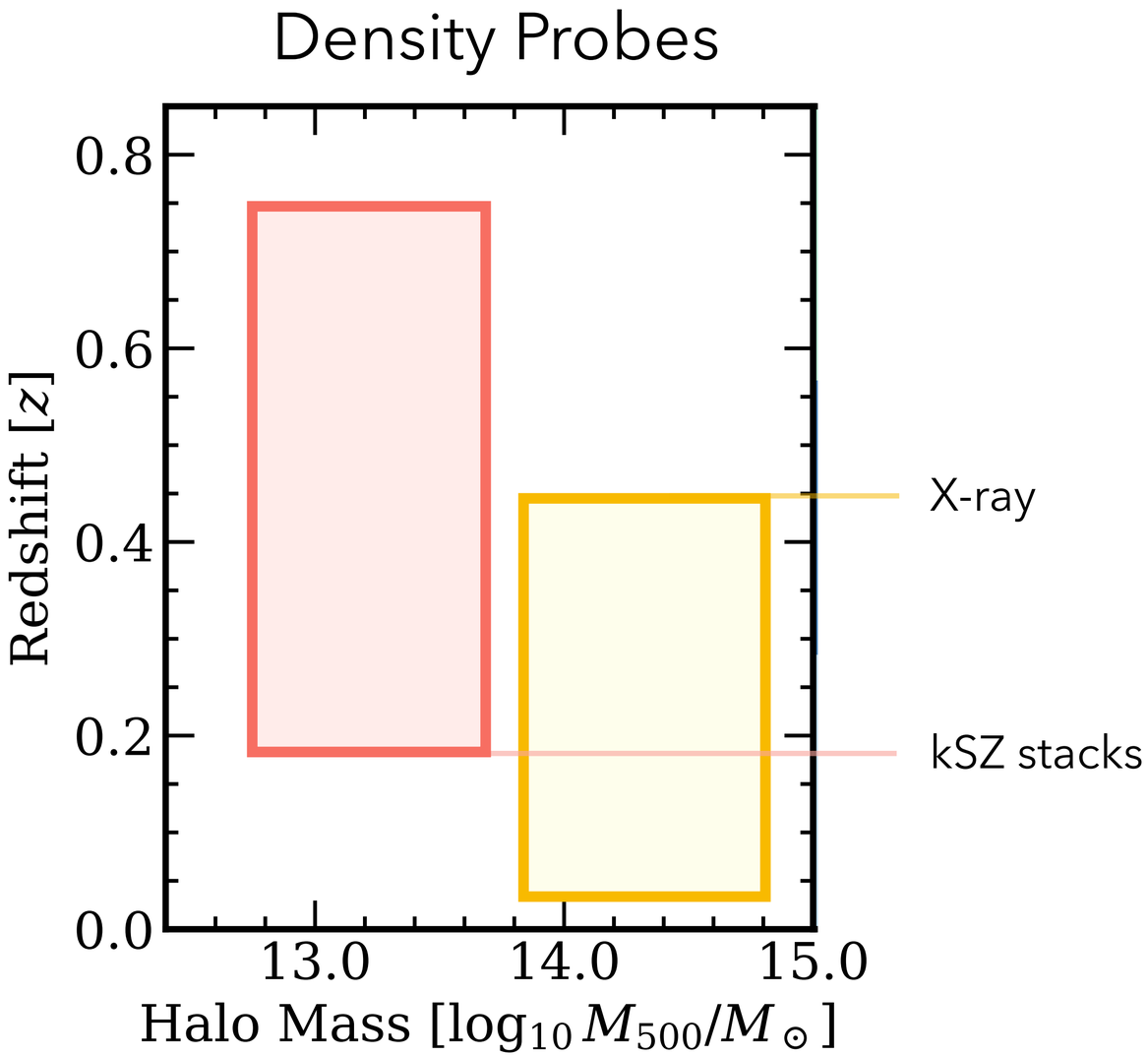


Building a Complete Picture





Landscape of Feedback Measurements



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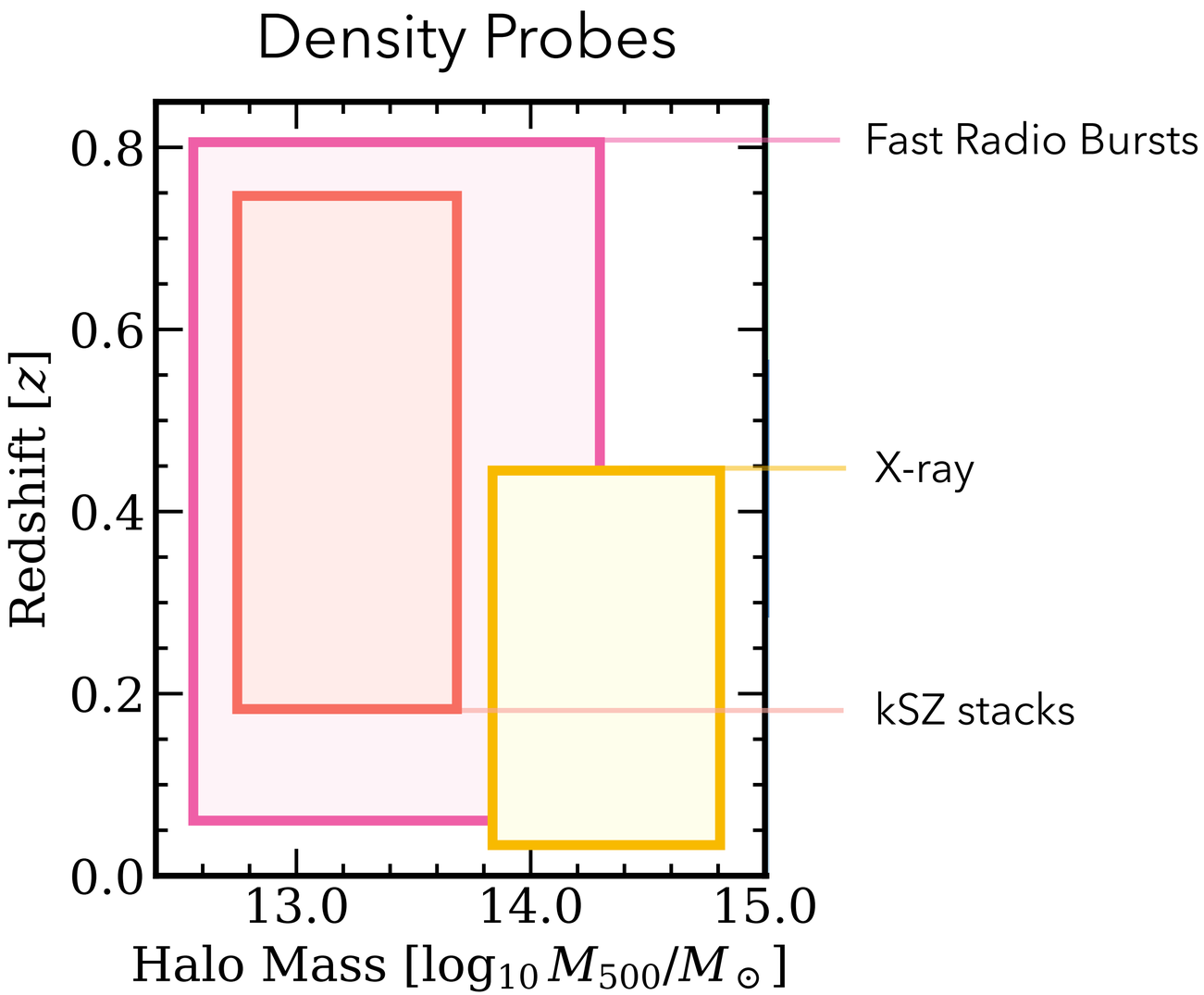
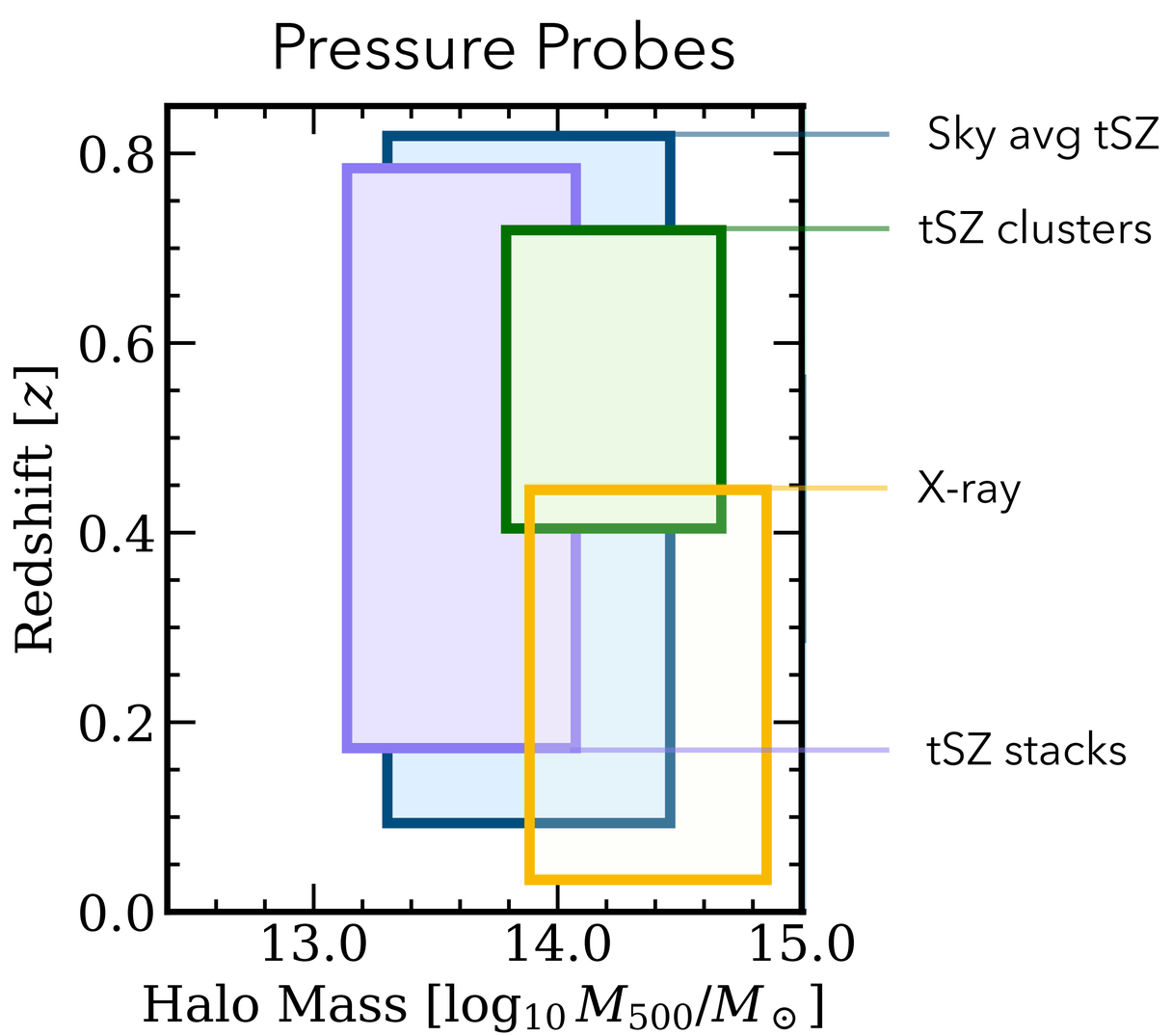
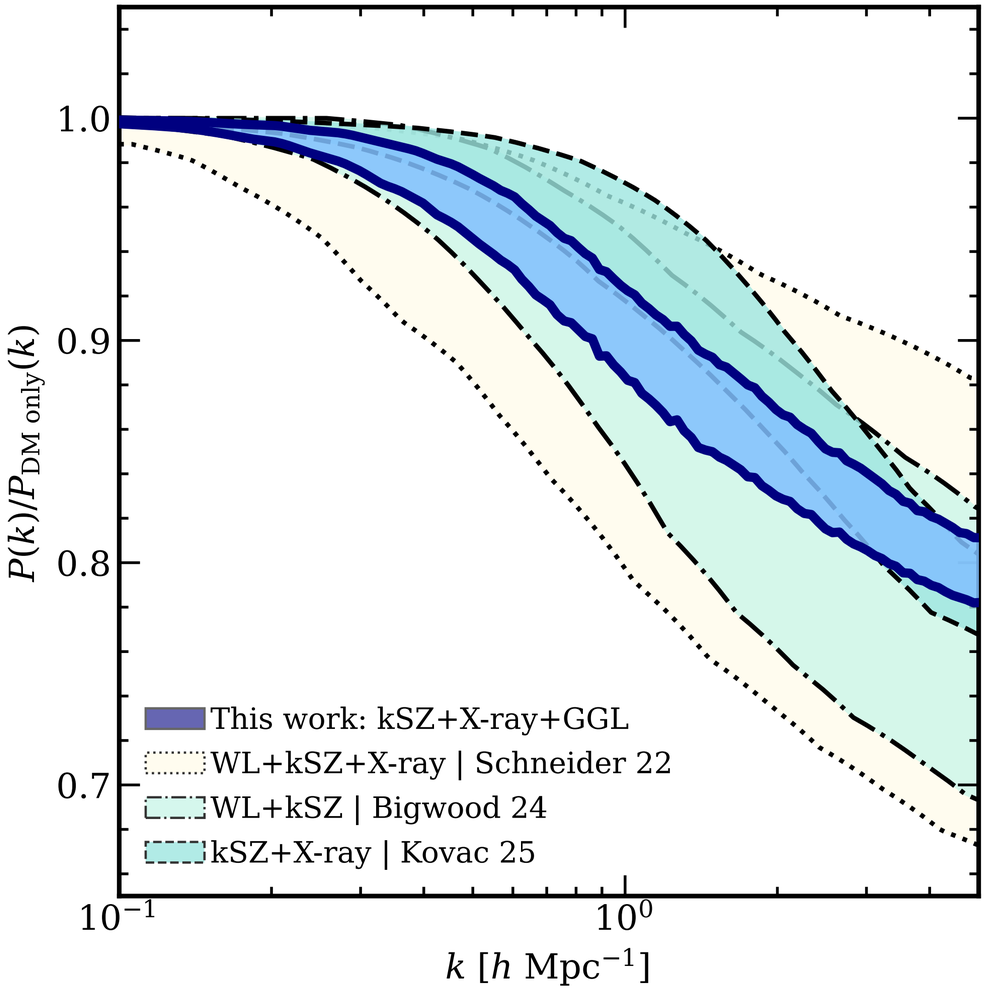
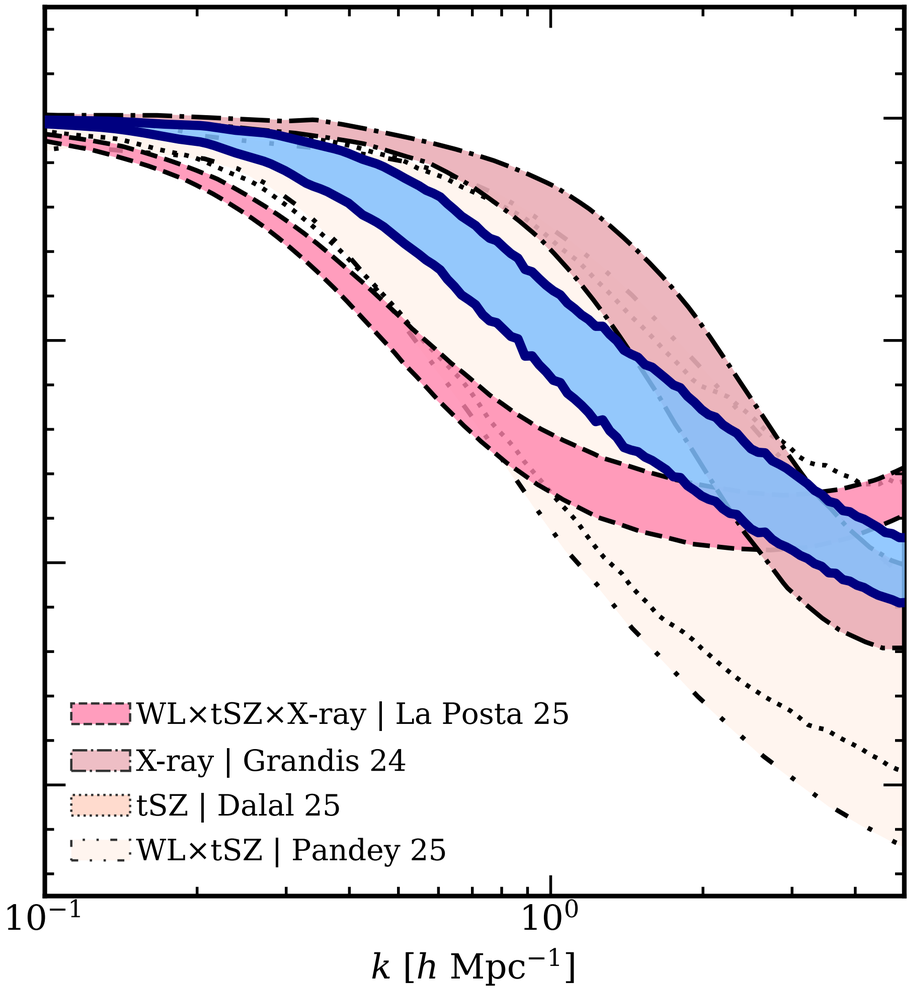




Landscape of Feedback Measurements





Data-driven Astrophysical Priors

	Intrinsic Alignments	Baryon Feedback
Data	DESI measurements Siegel, McCullough + 25a	kSZ + X-ray + GGL Siegel + 25b
Priors	McCullough, Siegel + in prep	Siegel + 25c
Cosmology		

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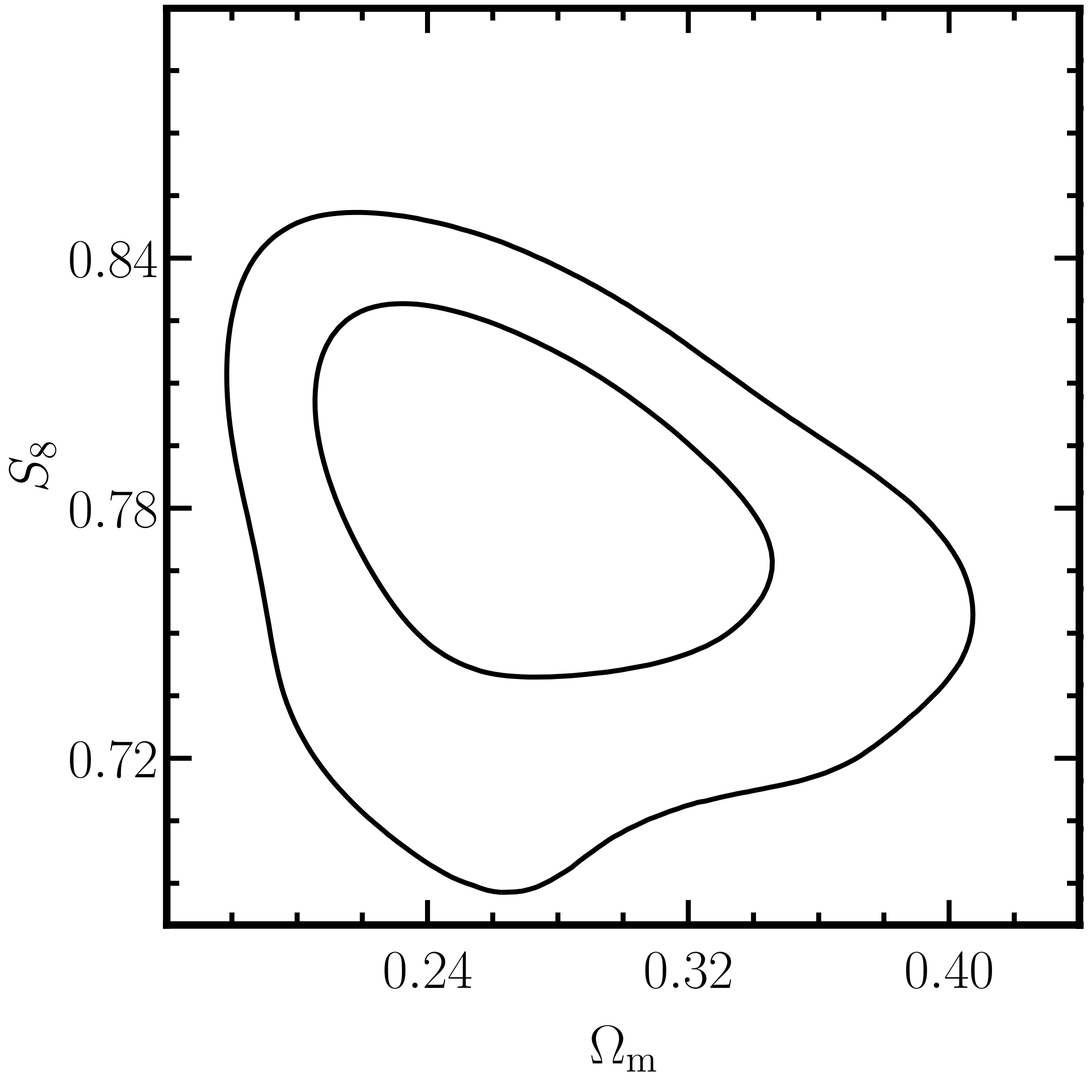
Cosmology	DES Y3 Small Scale Reanalysis (Bigwood, McCullough, Siegel + 25)	

Data-driven Lensing



DES Y3

Amon + 22

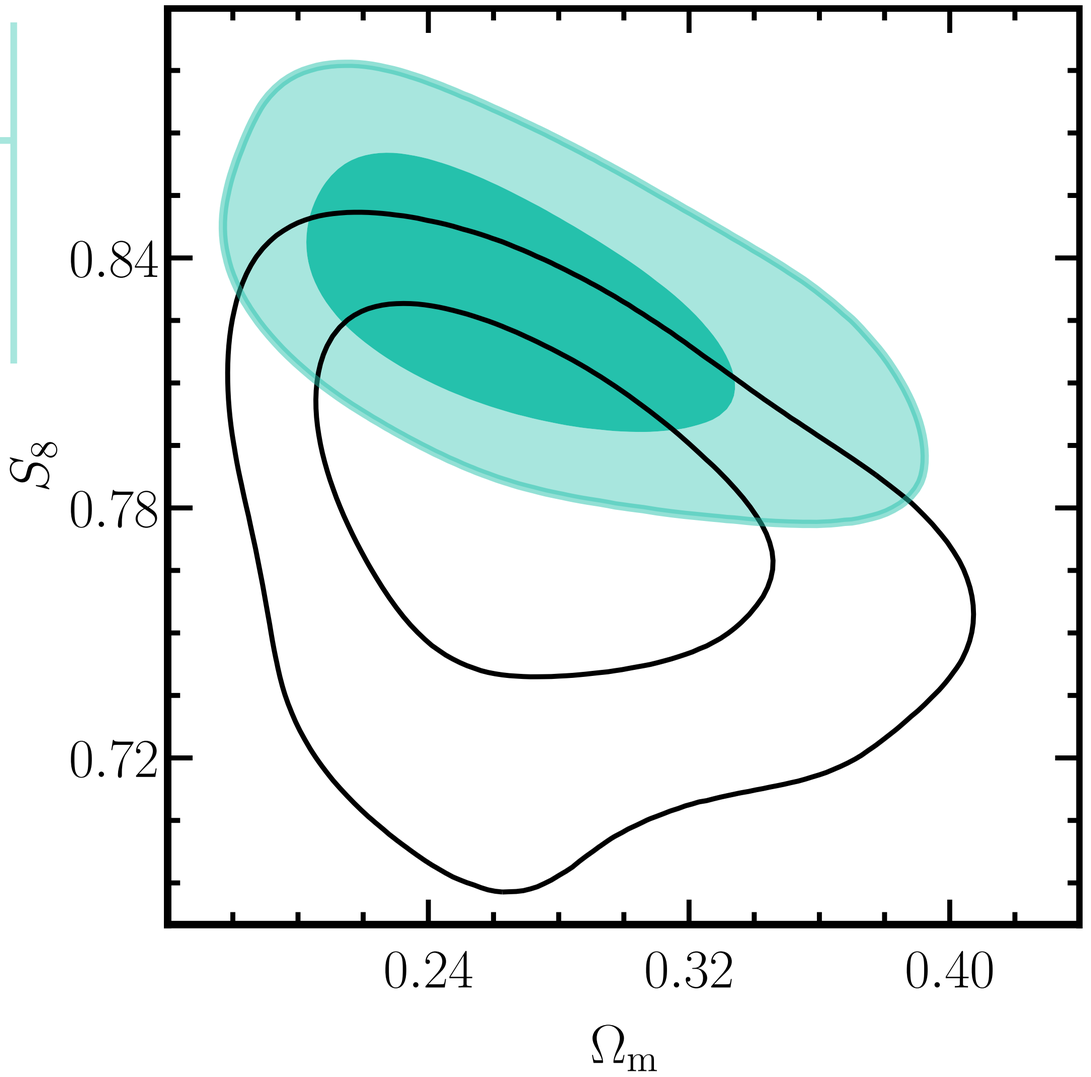
Data-driven Lensing

Small Scale Reanalysis

Blue galaxy sample

IA priors

Feedback priors



DES Y3

Amon + 22

Bigwood, JM, Siegel + 25
arXiv:2512.04209

Data-driven Lensing

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Blue galaxy sample

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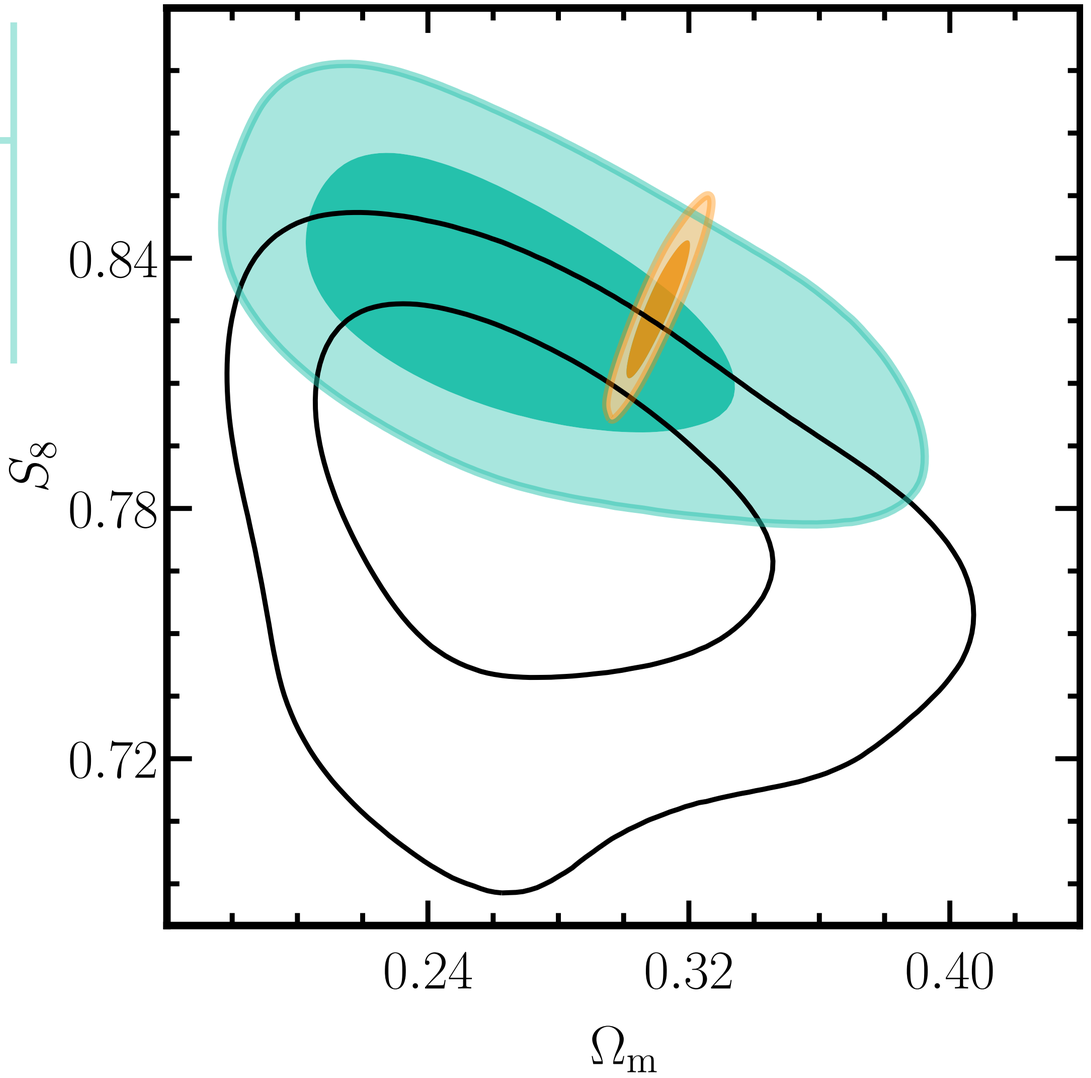
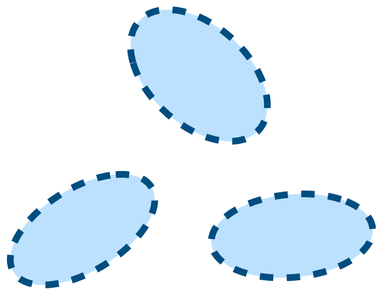


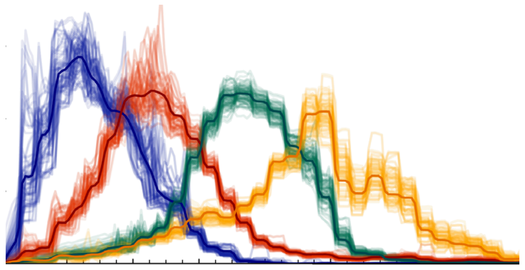
ACT + Planck

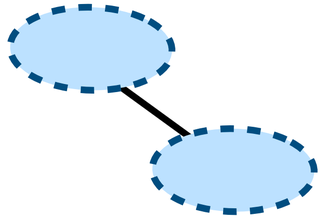
Louis + 25

DES Y3

Amon + 22





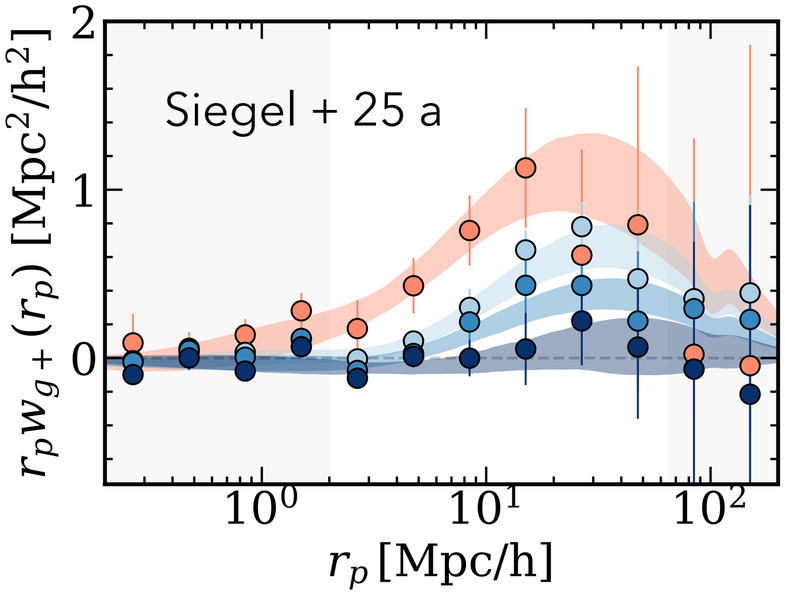


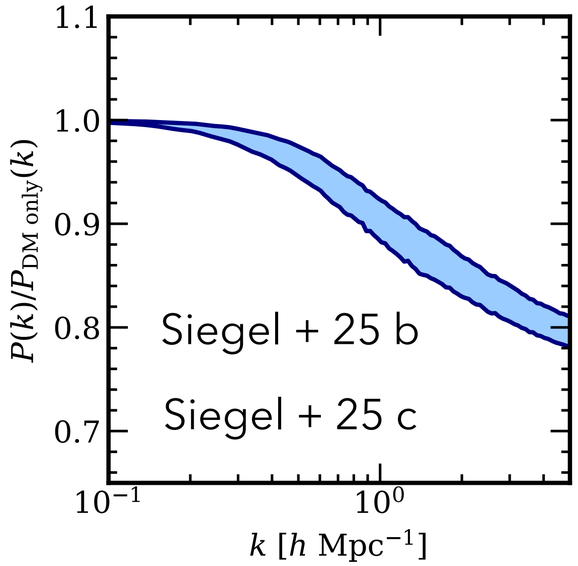
Shape Catalog

Redshift bins

2-point statistics

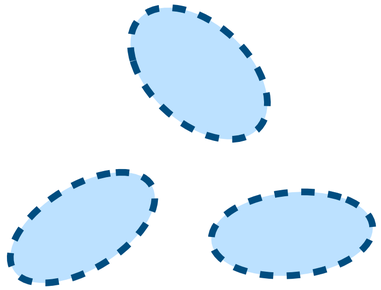
Cosmology

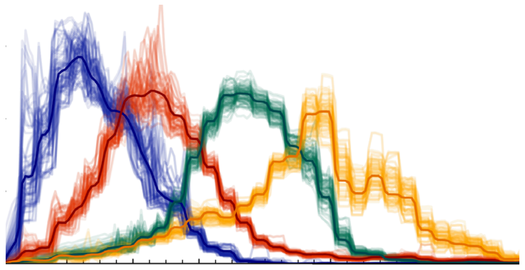


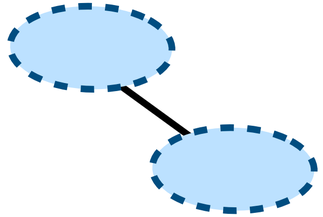


Intrinsic Alignments

Baryon Feedback







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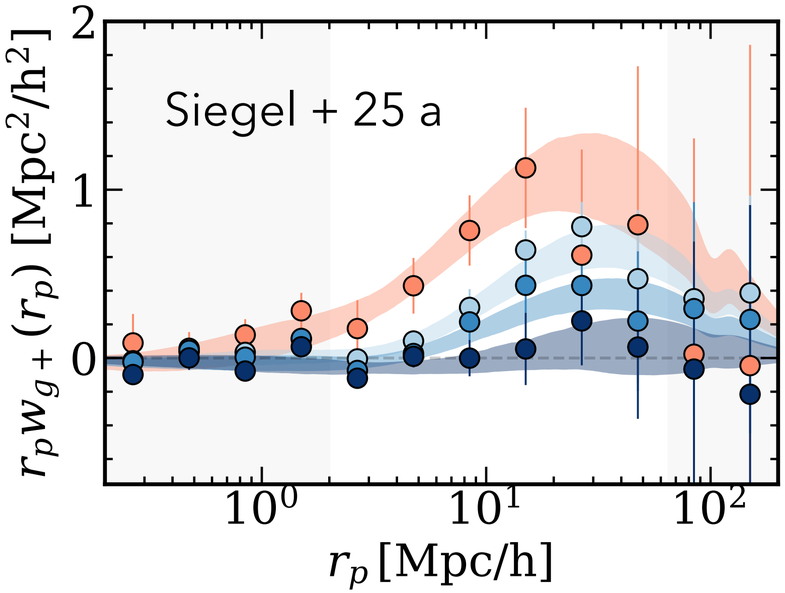
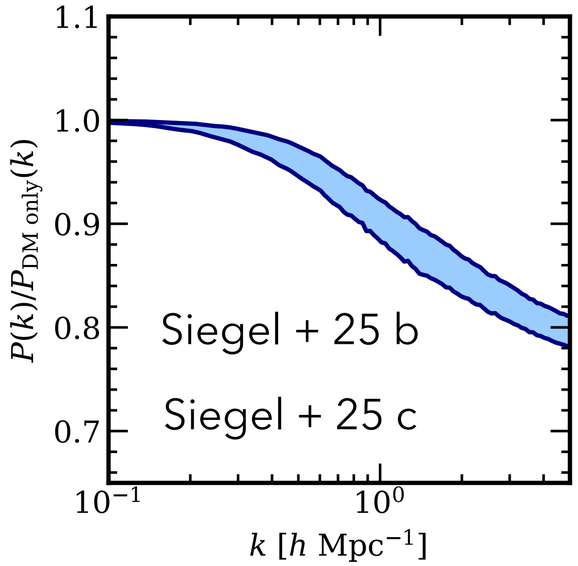
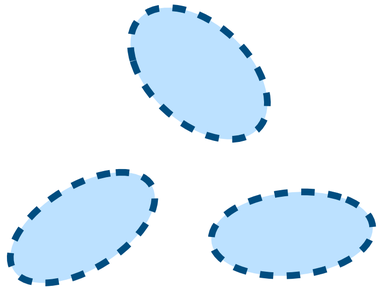
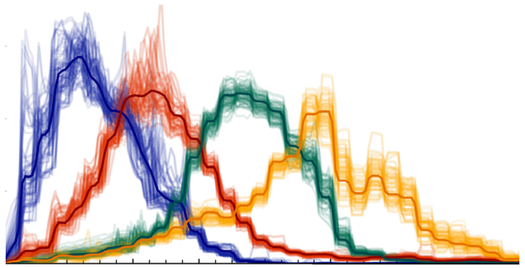


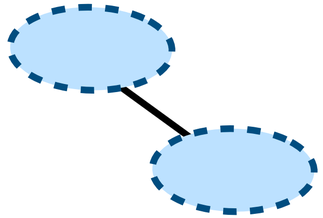


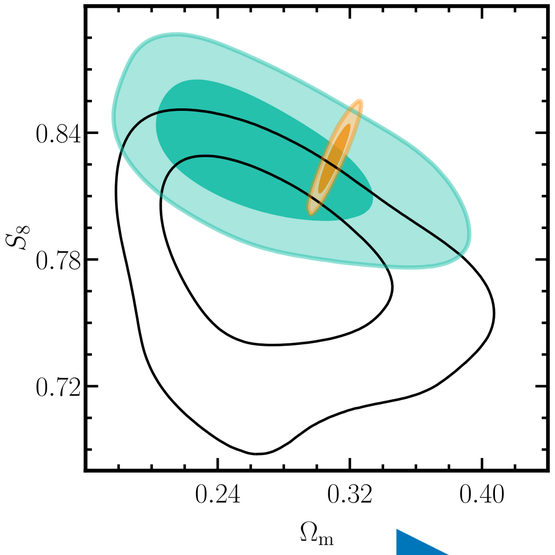
Intrinsic Alignments

Baryon Feedback







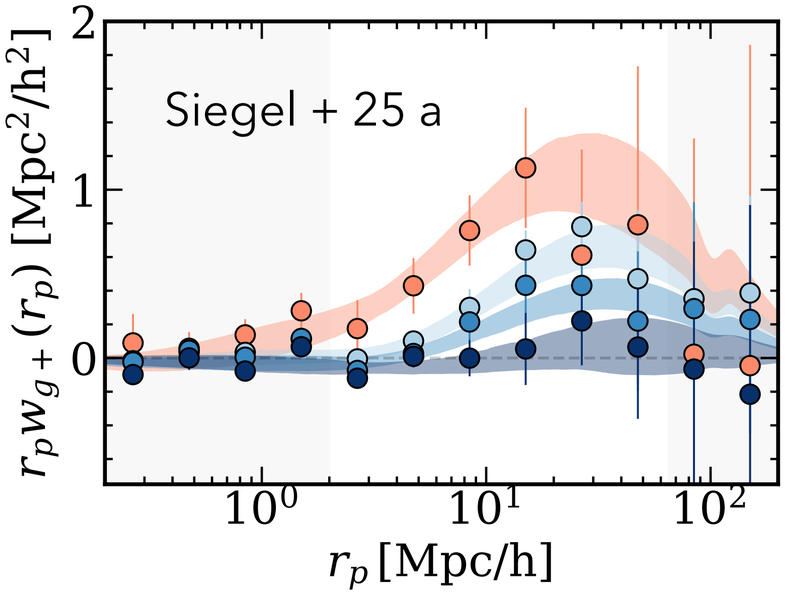


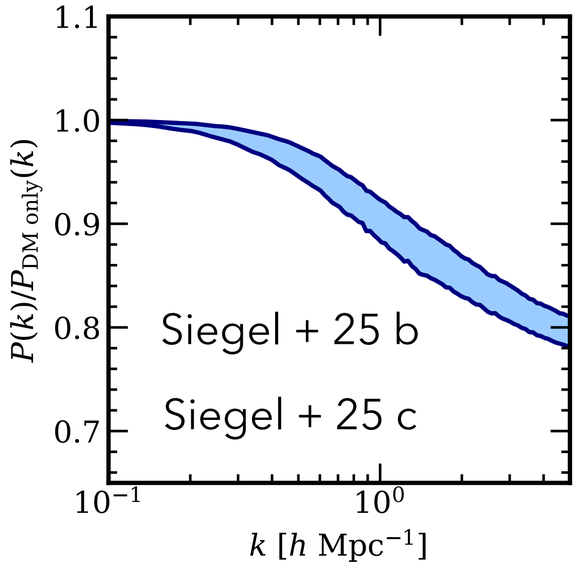
Shape Catalog

Redshift bins

2-point statistics

Cosmology





Intrinsic Alignments

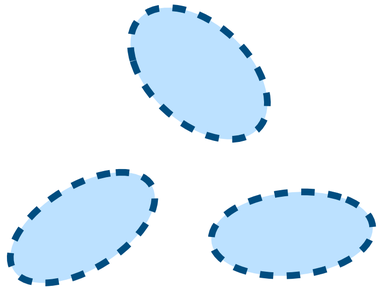
Baryon Feedback

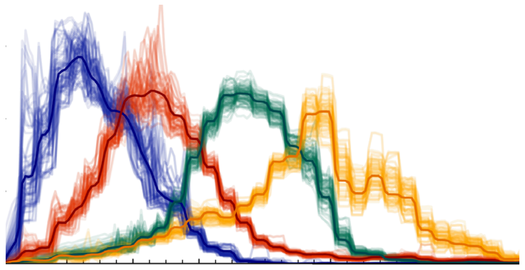
DES Y6 Small Scales

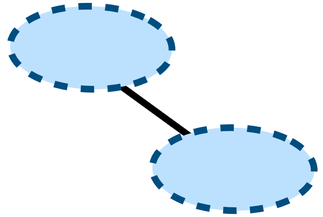
Blue galaxy sample

IA + Baryon Priors

Siegel + in prep







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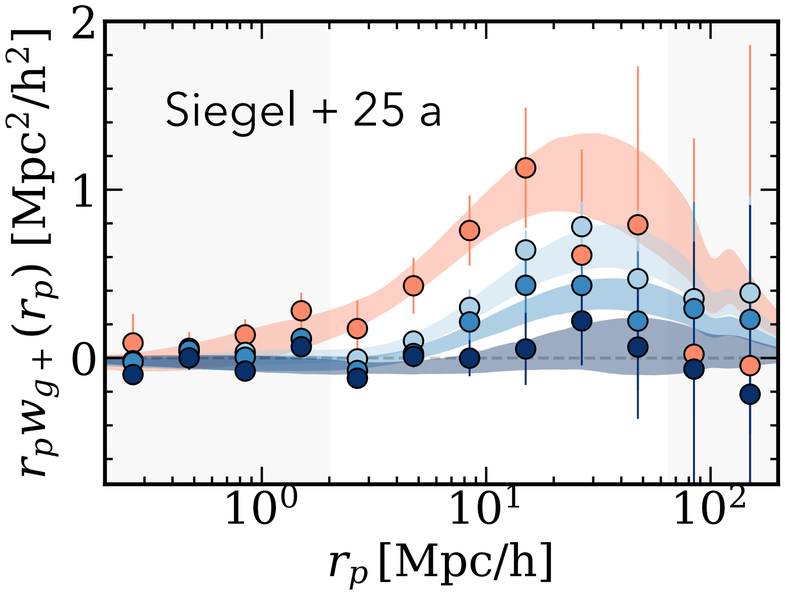

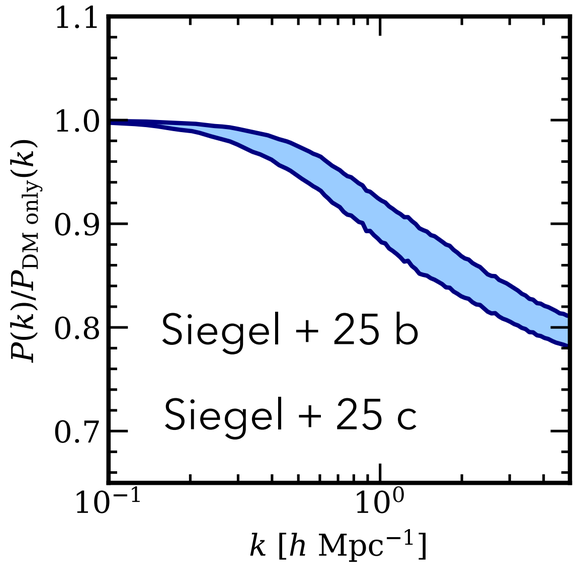

Physics of Feedback

Next generation simulations

Test mechanisms of efficient gas expulsion

Future probes: FRB & SO

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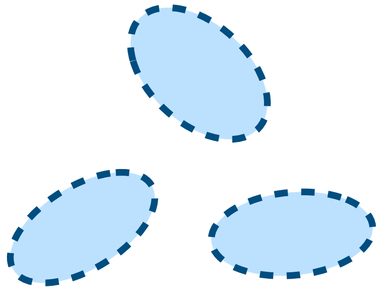

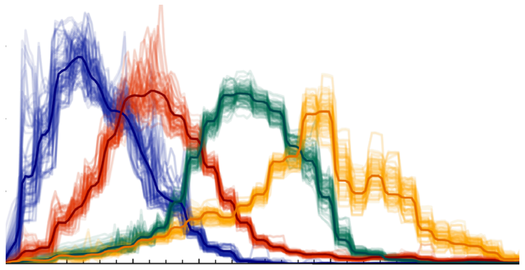

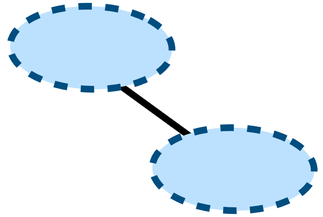

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