The Impact of Galaxy Formation on Galaxy Biasing, and Informative Priors for Primordial non-Gaussianity Constraints

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arxiv.org/abs/2602.04987

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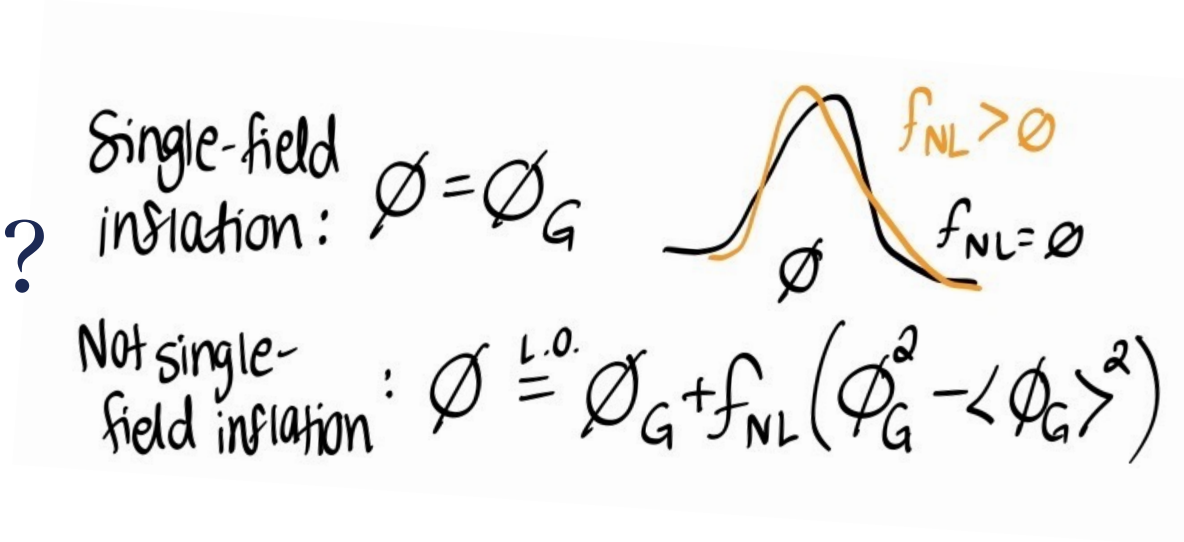
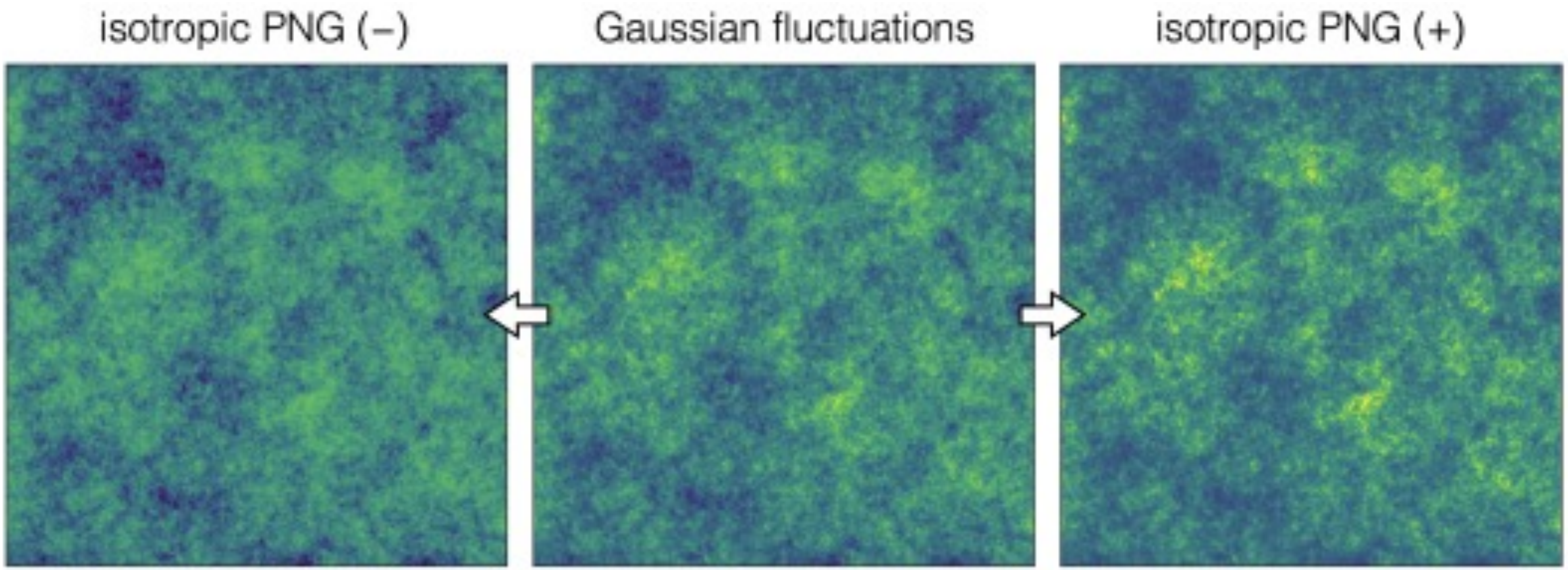
April 21st, 2026 | BCCP/Cosmology Seminar

better galaxies = better cosmology

How non-Gaussian were the primordial energy fluctuations? How did inflation occur?





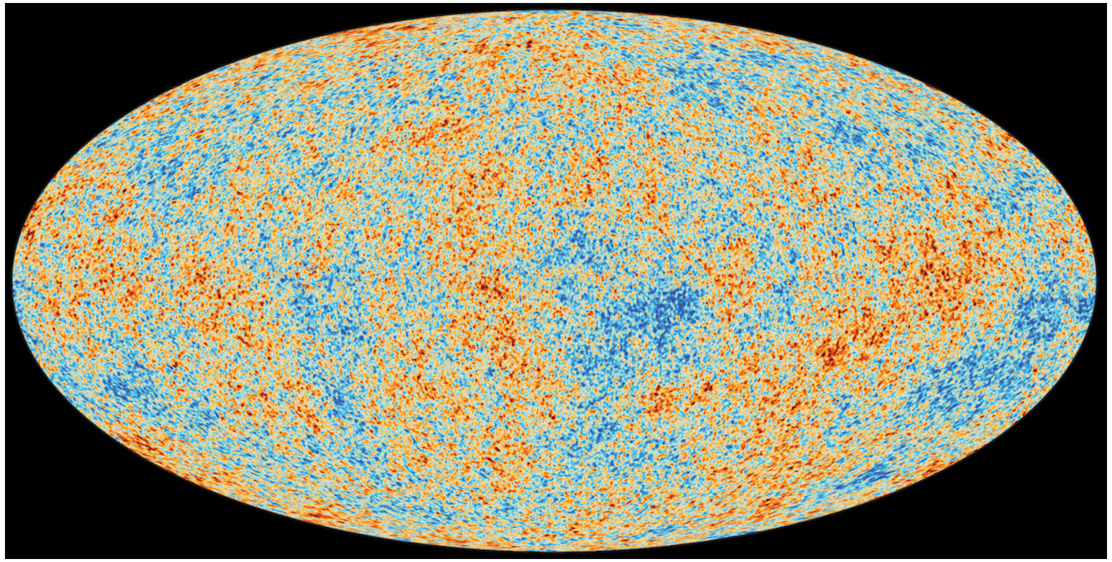
https://www.ipmu.jp/en/20231221-Non-Gaussianity , based off Kurita & Takada 2023

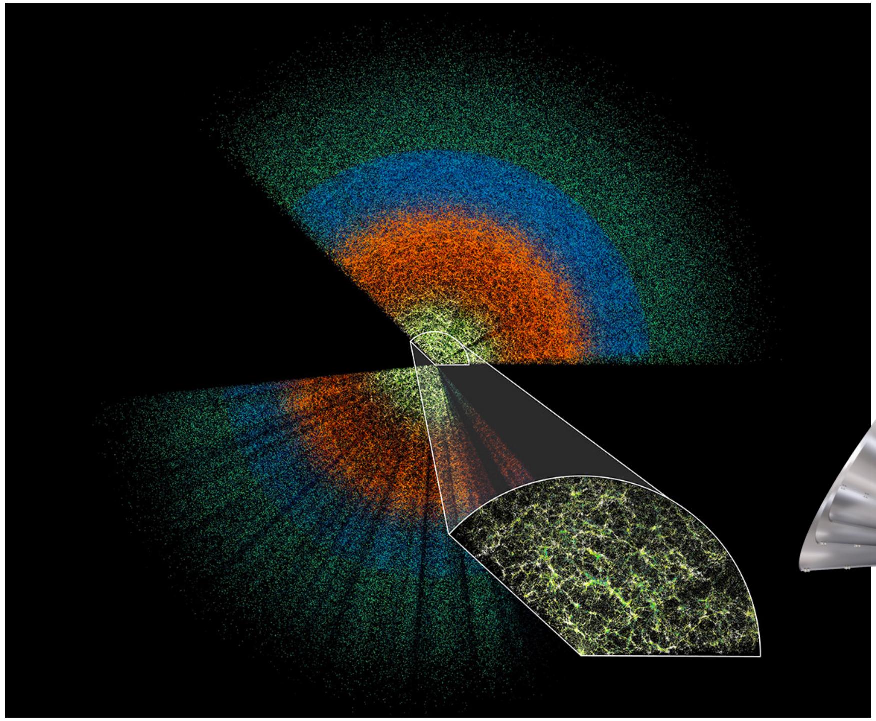
f_{NL} measures local primordial non-Gaussianity

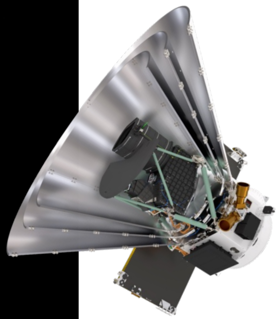
Measuring non-zero f_{NL} helps constrain the process of inflation

$f_{NL} = -0.9 \pm 5.1$ *(68%)*

but I can't go past k ~0.05 h^{-1} Mpc and I'm nearing my cosmic variance limit ☹







That's okay—I'll use galaxy clustering past k > 0.3 h^{-1} Mpc and reduce that error bar to within ±1!

f_{NL} is **completely degenerate** with galaxy bias parameters in analyses of galaxy clustering!

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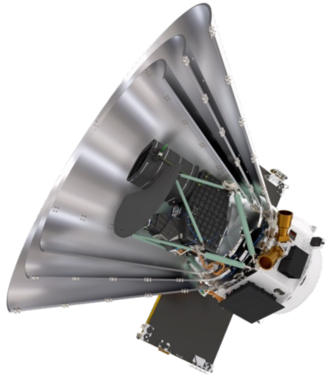

$$\delta_g(\vec{k},z) \overset{\text{L.O.}}{=} b_1(z)\,\delta_m(\vec{k},z) + b_\phi(z)\, f_{NL}^{loc}\, \phi(\vec{k},z) + \varepsilon(z)$$

galaxy density contrast

matter density contrast

primordial gravitational potential

random noise

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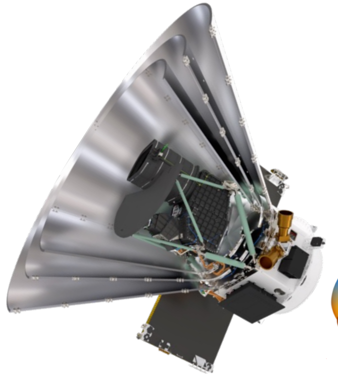

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galaxy density contrast — matter density contrast — primordial gravitational potential — random noise

$$\hookrightarrow \delta_g(\vec{k},z) \equiv \frac{n_g(\vec{k},z)}{\bar{n}_g(\vec{k},z)} - 1\,;\quad \frac{\text{local}}{\text{mean}} \text{ comoving galaxy densities}$$

f_{NL} is **completely degenerate** with galaxy bias parameters in analyses of galaxy clustering!

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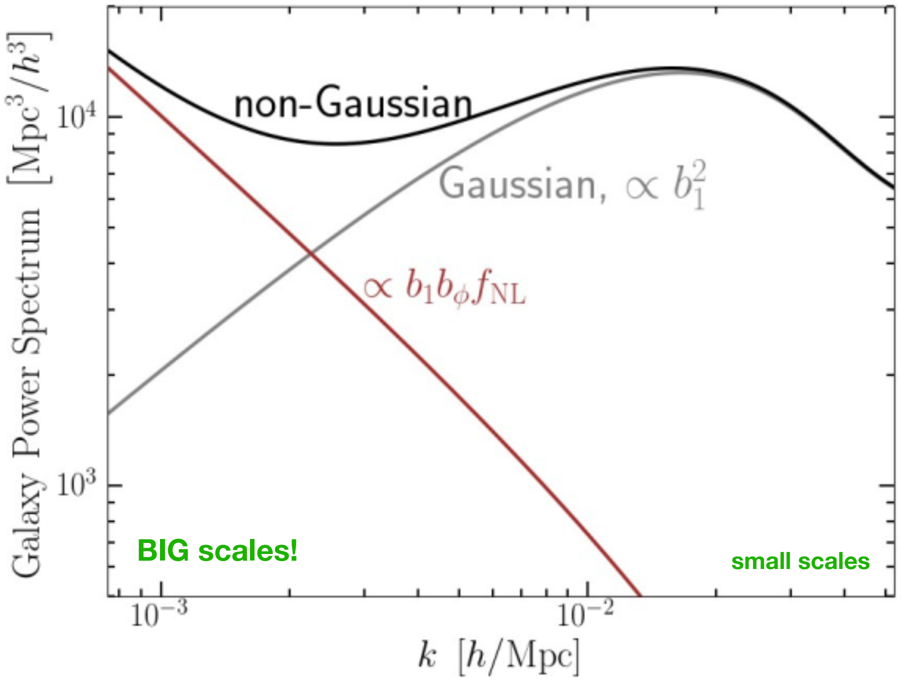
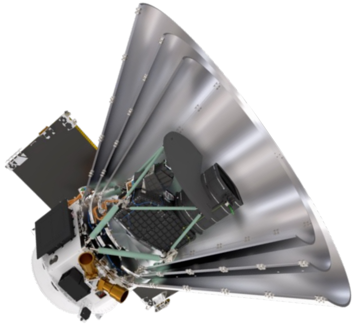
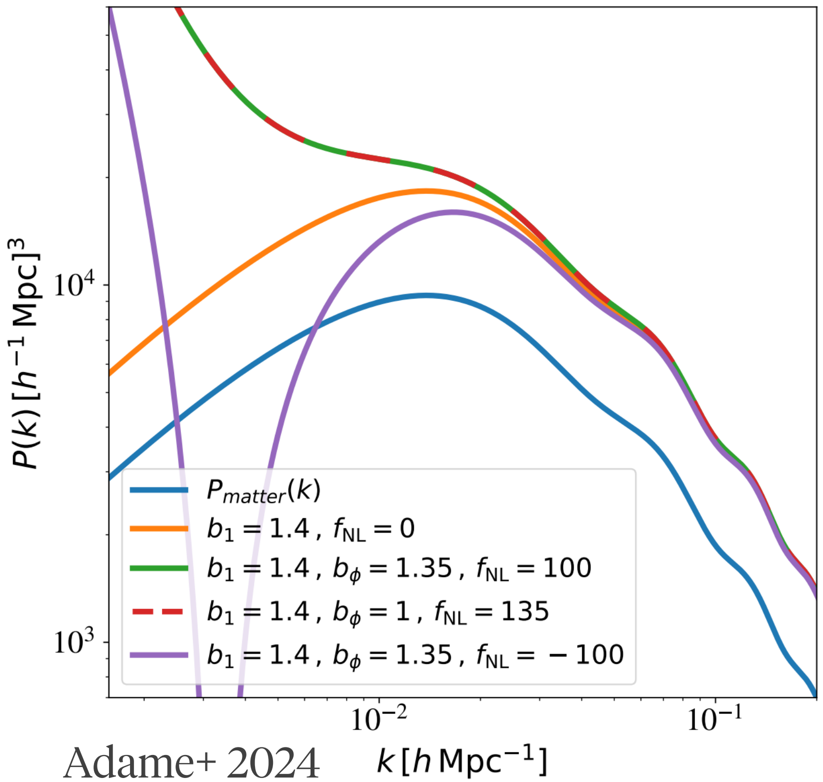
$$P_{gg}(\vec{k},z) \overset{L.O.}{=} P_{mm}(\vec{k},z)\left\{b_1^2 + \frac{2 b_1 b_\phi f_{NL}}{\mathcal{M}(\vec{k},z)} + \frac{b_\phi^2 f_{NL}^2}{\mathcal{M}(\vec{k},z)^2}\right\} + P_{\varepsilon\varepsilon}$$

galaxy power spectrum — matter power spectrum







Adame+ 2024

Can we get around the degeneracy of b_1 b_ϕ f_{NL} ?

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Let's try what works for halos:

"universality relation"

$$b_\phi(z) = 2\delta_c(\ b_1(z) - 1\ )$$

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Issue 1: not perfect for simulated halos

Issue 2: priors on b_1 and b_ϕ are ***supremely*** important for your final f_{NL} constraint

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Can we actually constrain $f_{\rm NL}$ using the scale-dependent bias effect?

An illustration of the impact of galaxy bias uncertainties using the BOSS DR12 galaxy power spectrum

Alexandre Barreira[a,b]

[a]Excellence Cluster ORIGINS, Boltzmannstraße 2, 85748 Garching, Germany
[b]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Same BOSS galaxy data, different priors for b_ϕ and b_1

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↓

$f_{NL} = 16 \pm 16$ ***or***

$f_{NL} = 230 \pm 226$

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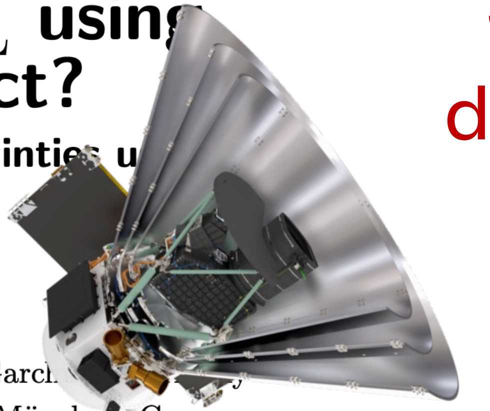

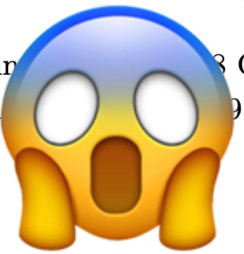

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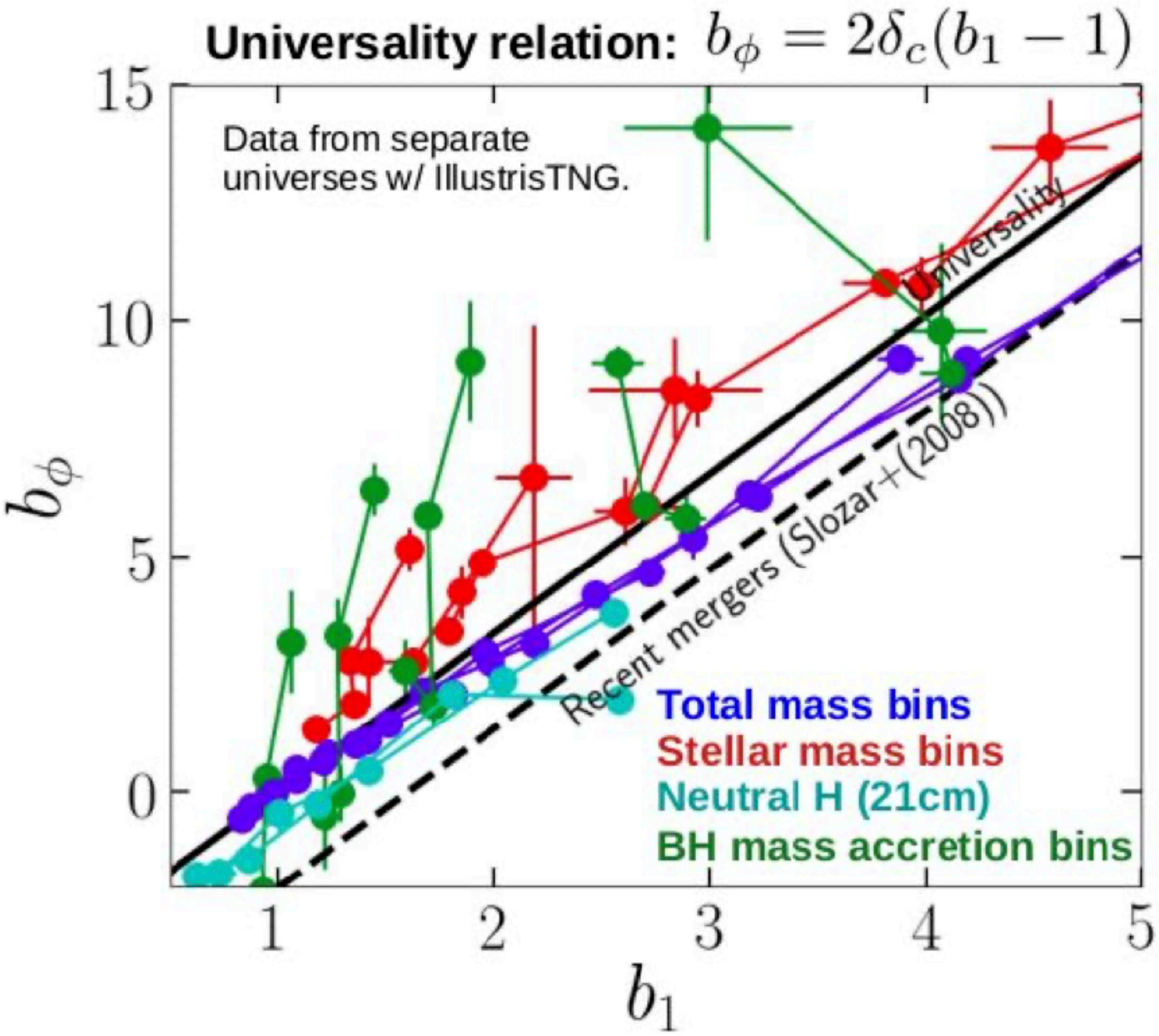
Can galaxy simulations help?



Barreira++ arXiv:2006.09368 , arXiv:2107.06887 , arXiv:2112.03253

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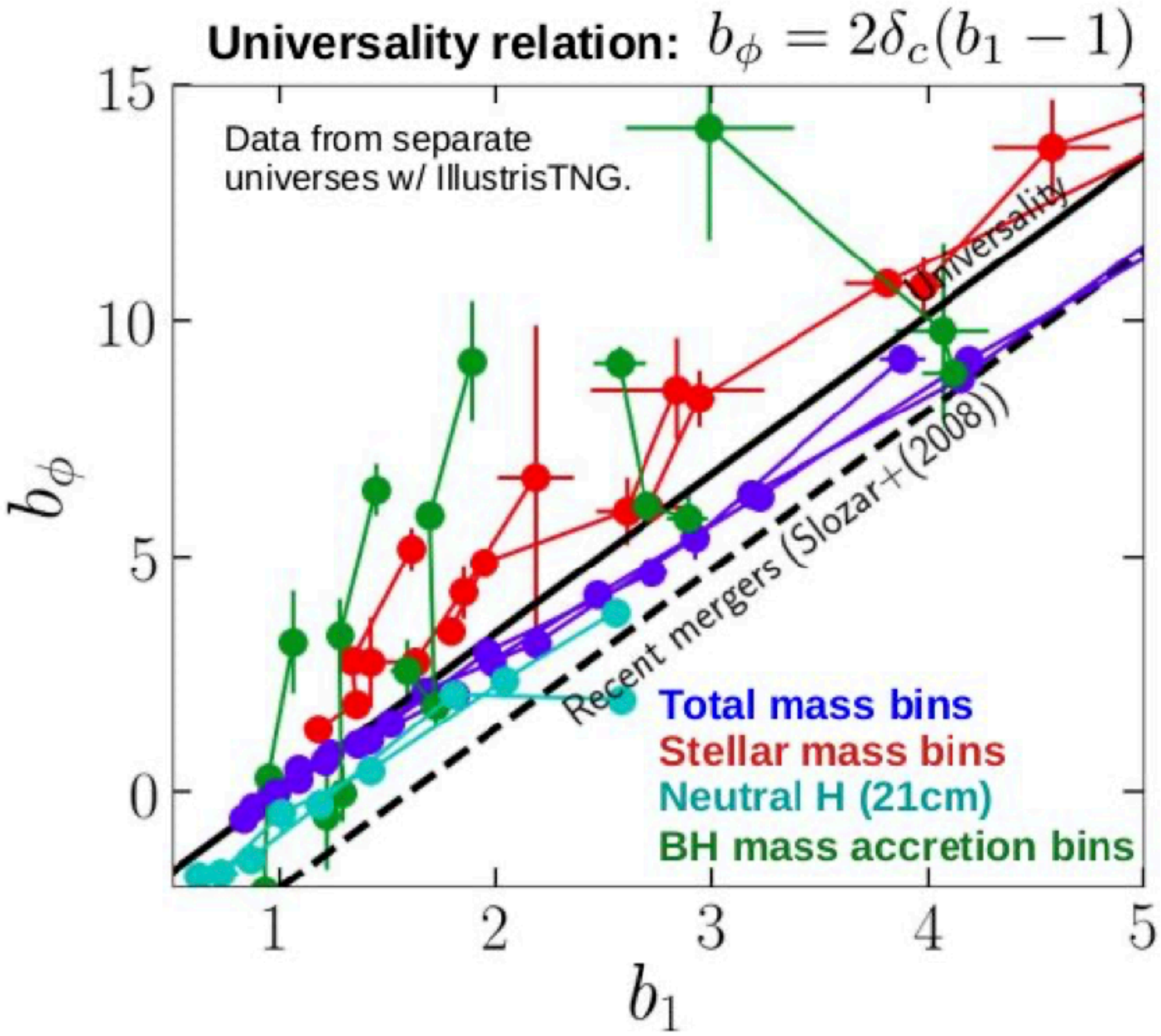

What about different parameters within the same galaxy model?

What about other galaxy models?

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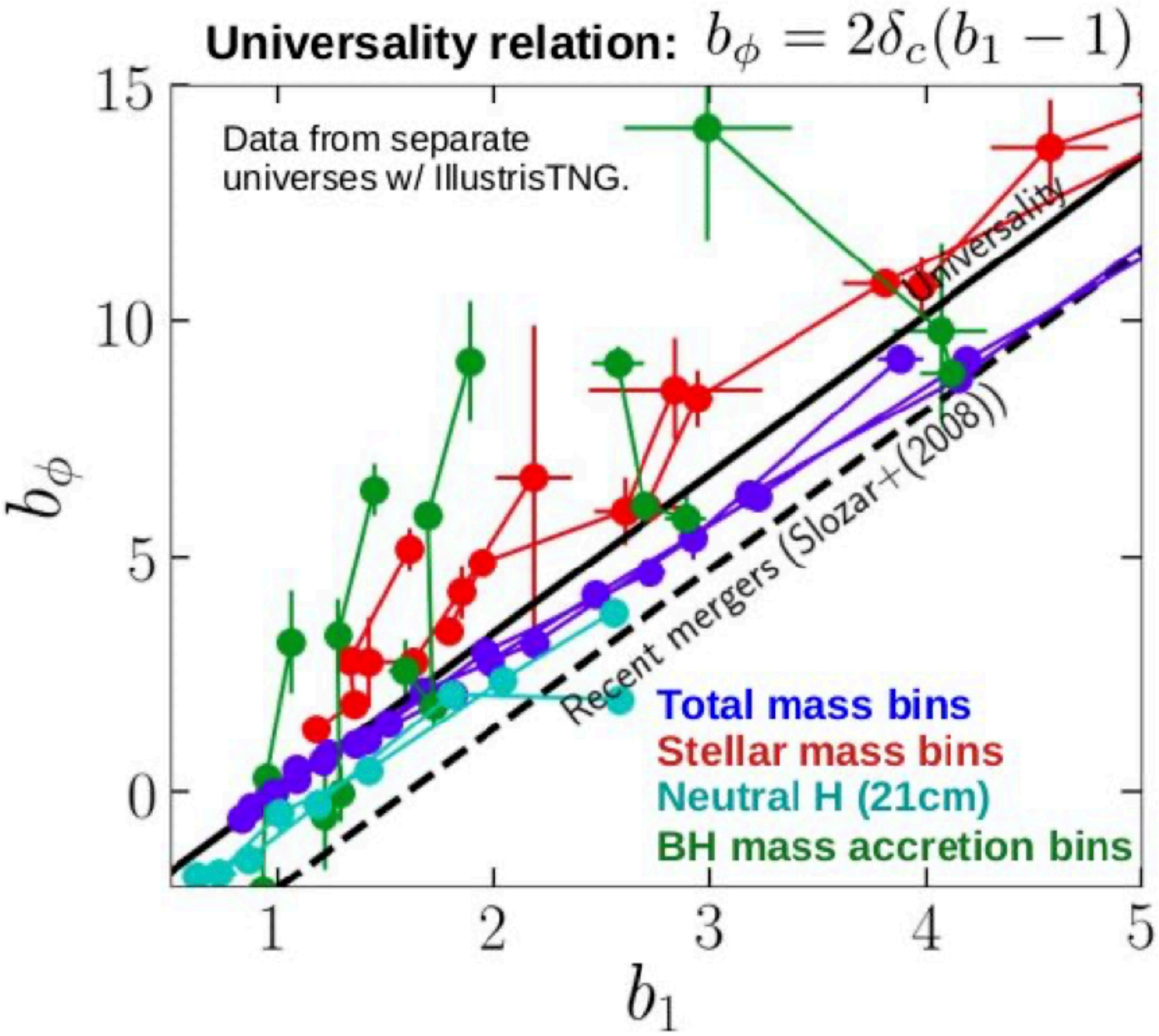

What about different parameters within the same galaxy model?

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How much better could our cosmology be if we quantify our ignorance around galaxy formation?

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Let's pin down b_ϕ with the Santa Cruz Semi-Analytic Model for Galaxy Formation

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Separate Universe simulations to measure b_ϕ

$(205\ h\text{-}1\ cMpc)^3$, $N=1280^3$, same initial conditions, different σ_8

+

Several dozen unique runs of the SC-SAM

Vary 3 parameters for SN & AGN feedback (see Perez, Genel, + 2023)

Separate Universes method for measuring galaxy bias

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$$\delta_g(\vec{k},z) \overset{\text{L.O.}}{=} b_1(z)\,\delta_m(\vec{k},z) + b_\phi(z)\, f_{NL}^{loc}\, \phi(\vec{k},z)$$

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The local structure formation response to long-wavelength perturbations is <u>equivalent</u> to structure formation in a different cosmology

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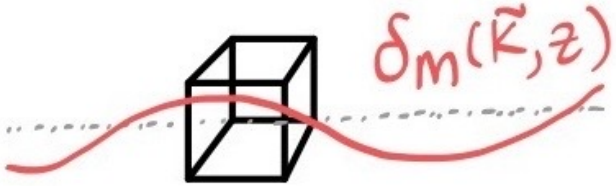
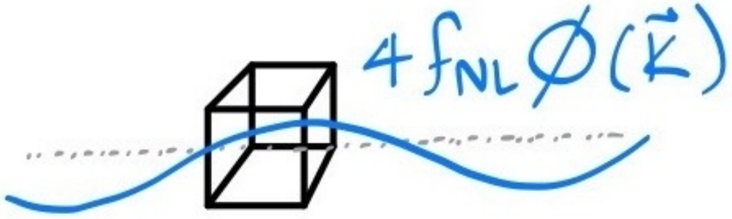
$$b_1 \equiv \frac{d\ln(n_g(z))}{d\delta_L(z)} \qquad b_\phi \equiv 4\frac{d\ln(n_g(z))}{d\delta A_s}$$





The local structure formation response to long-wavelength perturbations is <u>equivalent</u> to structure formation in a different cosmology

Bias → the response of galaxy density to a different cosmology!

a.k.a. "Separate Universes"

(from the peak background split)

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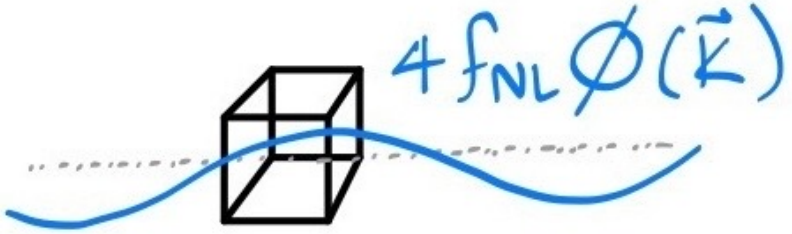
$$b_\phi \equiv 4\,\frac{d\ln(n_g(z))}{d\,\delta A_s} \rightarrow 4 f_{NL}\,\phi_L$$



b_ϕ → how galaxy counts/density respond to changing the primordial power spectrum (A_s or σ_8)

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A_{SN1} x, $+A_{SN2}$

$$\dot{m}_{\mathrm{out}} = \epsilon_{\mathrm{SN}} \left(\frac{V_0}{V_{\mathrm{c}}}\right)^{\alpha_{\mathrm{rh}}} \dot{m}_*,$$

⬆ mass outflow rate due to SN & massive stars

⬇ mass ejected by an AGN in radio jets

A_{AGN1} x

$$\dot{m}_{\mathrm{radio}} = \kappa_{\mathrm{radio}} \left[\frac{kT}{\Lambda(T, Z_{\mathrm{h}})}\right] \left(\frac{M_{\mathrm{BH}}}{10^8\ \mathrm{M}_\odot}\right)$$

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→

Understand how b_ϕ and b_ϕ (b_1) varies with galaxy selection across different parametrizations of one galaxy formation model

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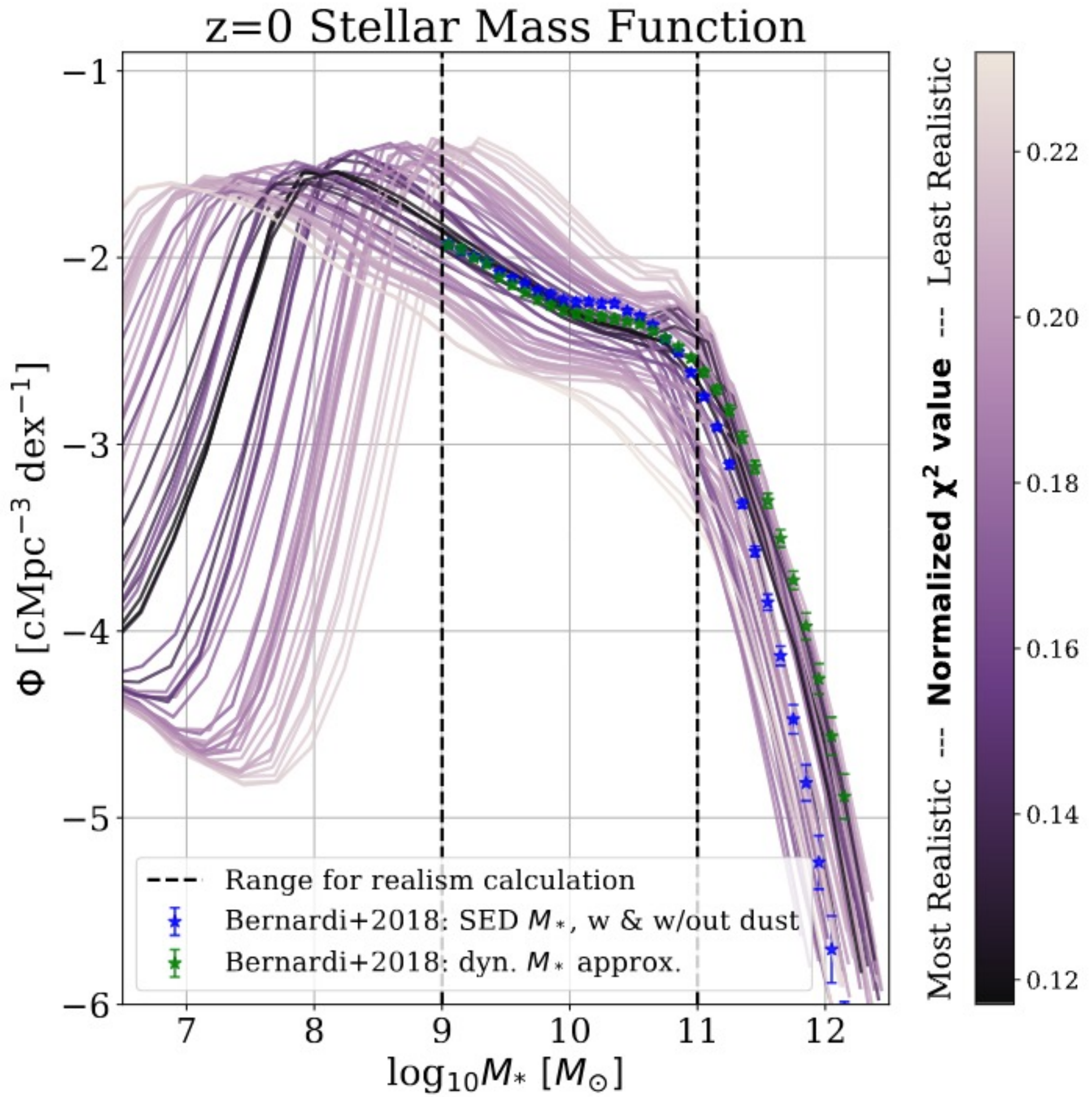
↑

Do we agree with the IllustrisTNG findings, and the few others measured for SAMs? Let's get physically-motivated b_ϕ priors for f_{NL} analyses?

How “realistic” is a given SAM parametrization?



Here, we compare to z=0 stellar mass function between $9 < \log_{10}(M_{star}) < 11$

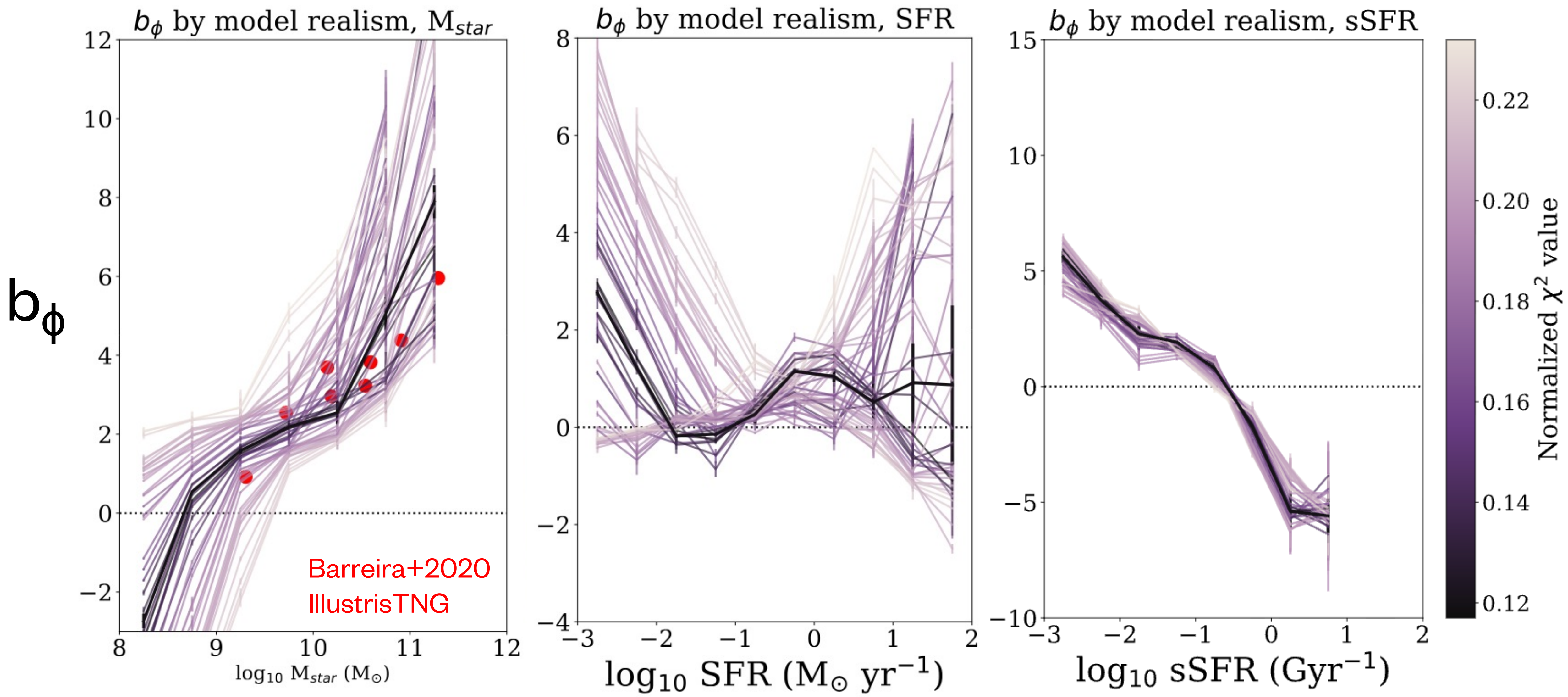
Light- to-stellar mass is hard science

Black → beige is most to least ‘realistic’

Even extreme parameters can yield realistic SMFs in unique combinations!

b_ϕ different galaxy selections, z=1

b_ϕ → how galaxy counts/density respond to changing the primordial power spectrum (A_s or σ_8)



Why? The galaxy-halo connection!

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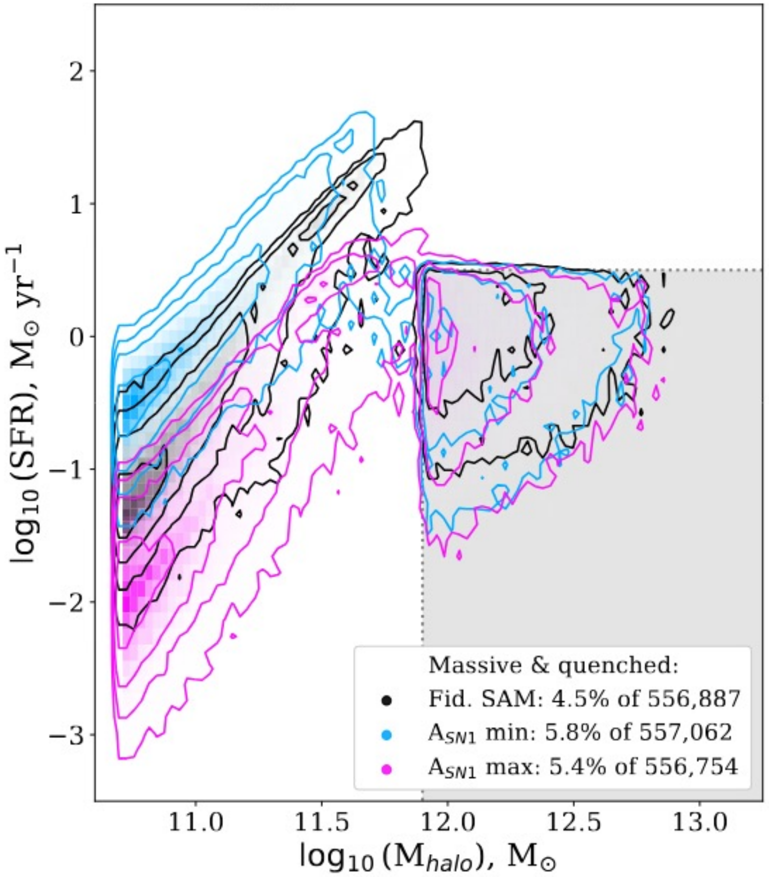
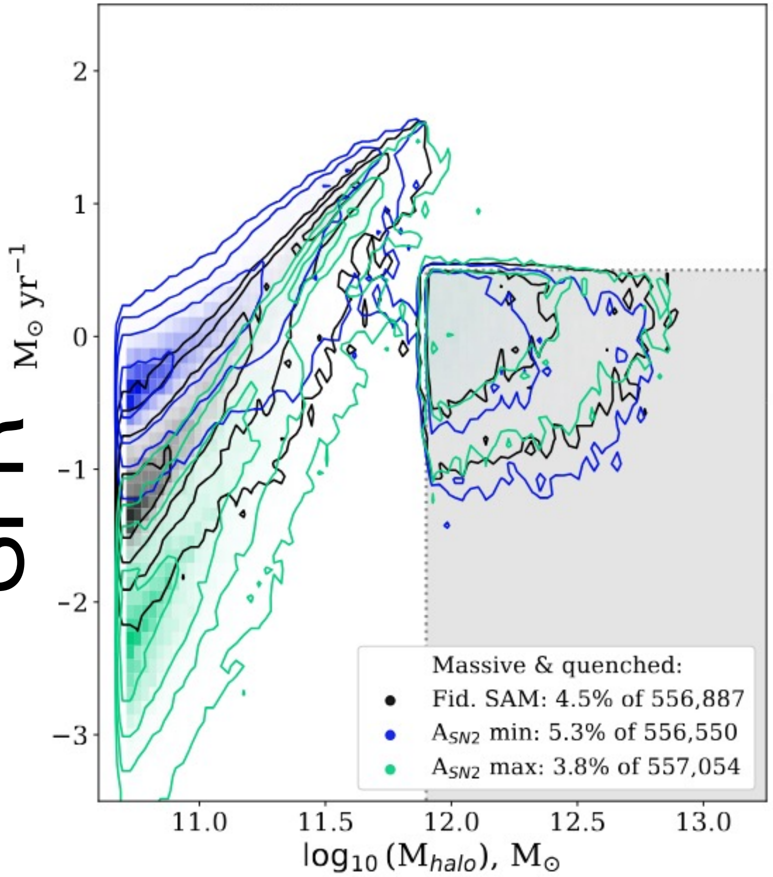
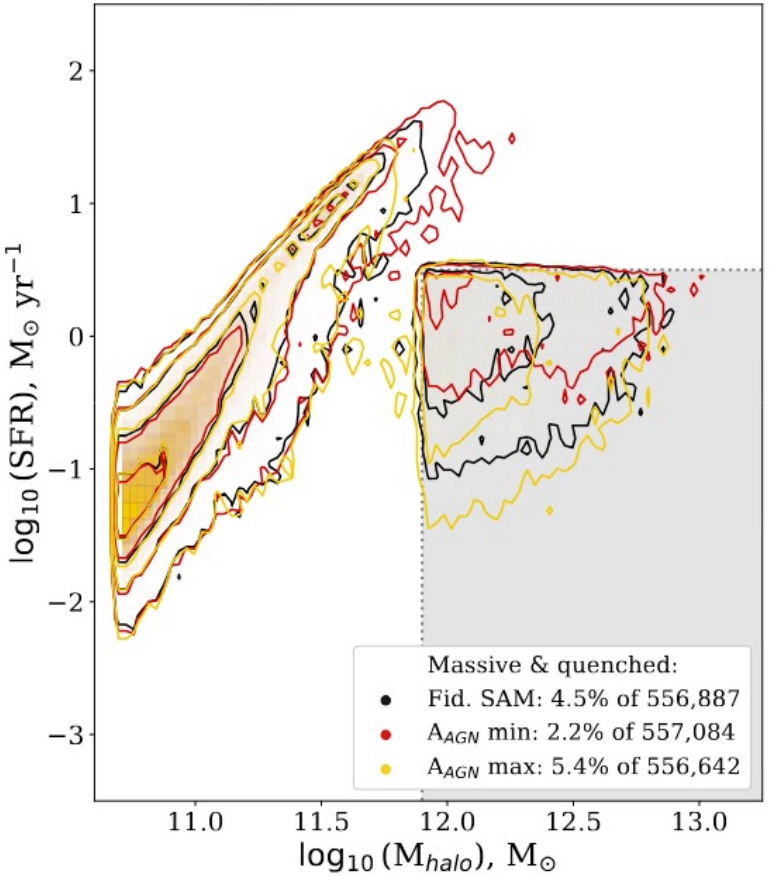


SFR



Halo Mass



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⬆ mass outflow rate due to SN & massive stars

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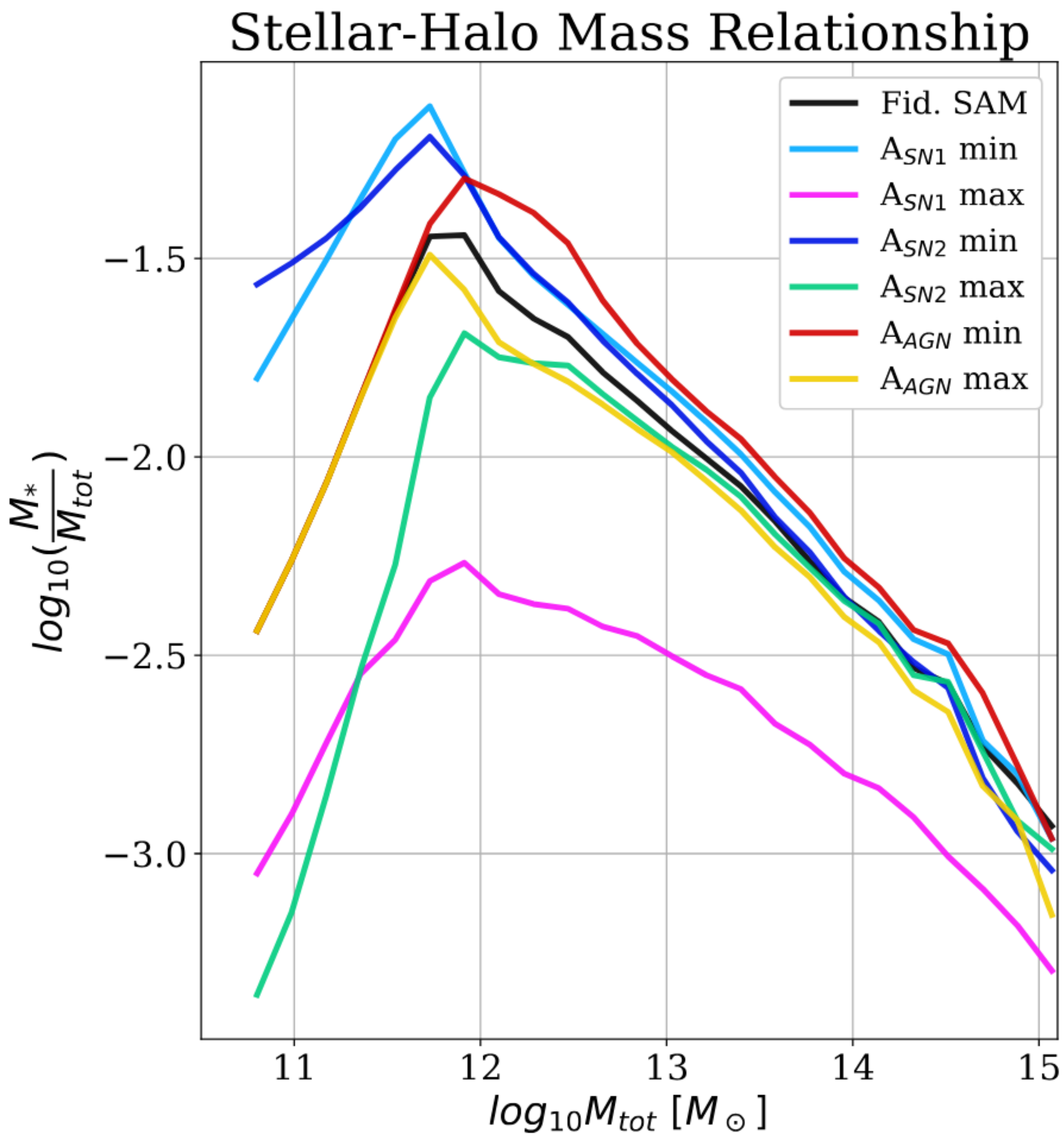

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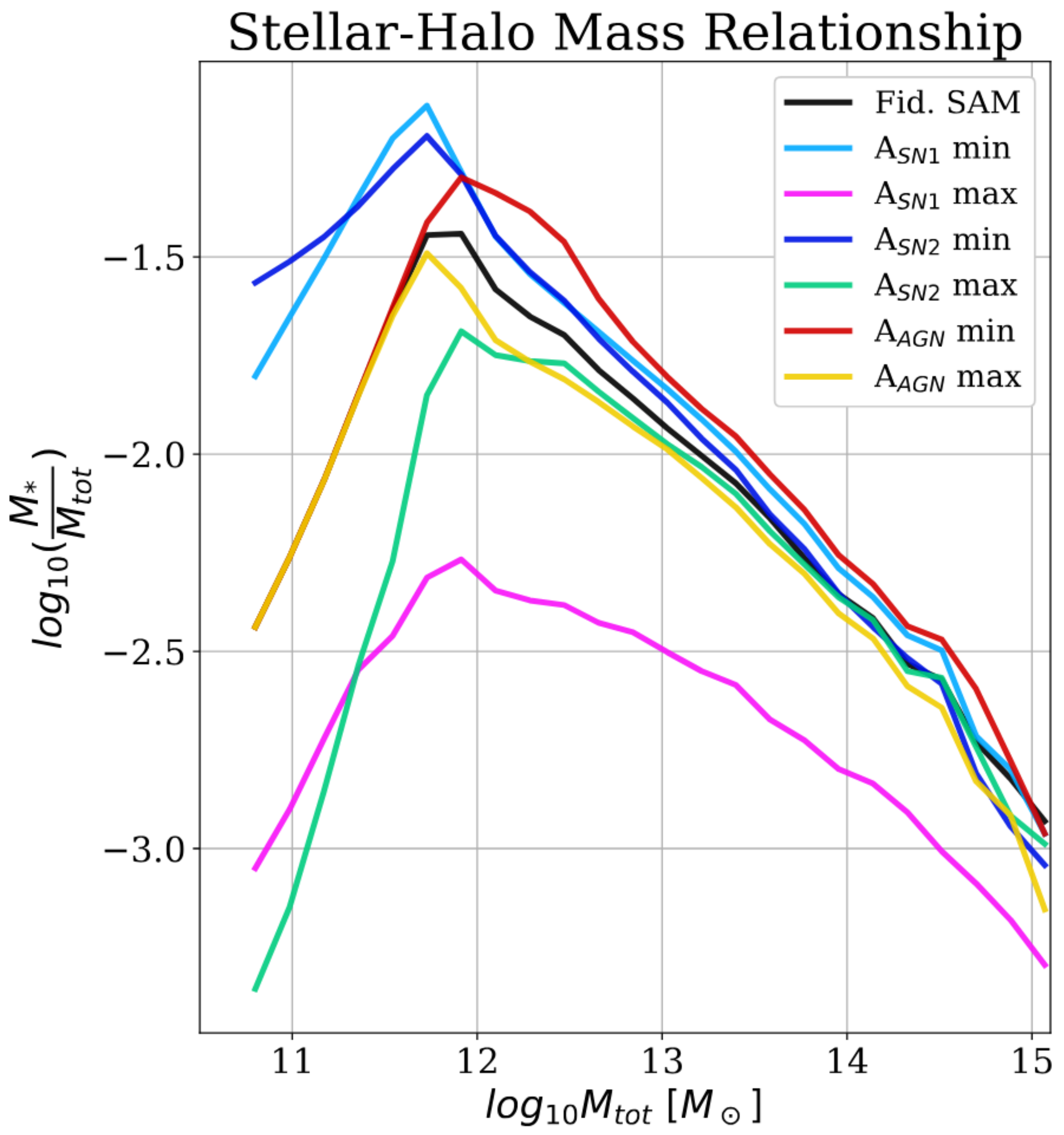
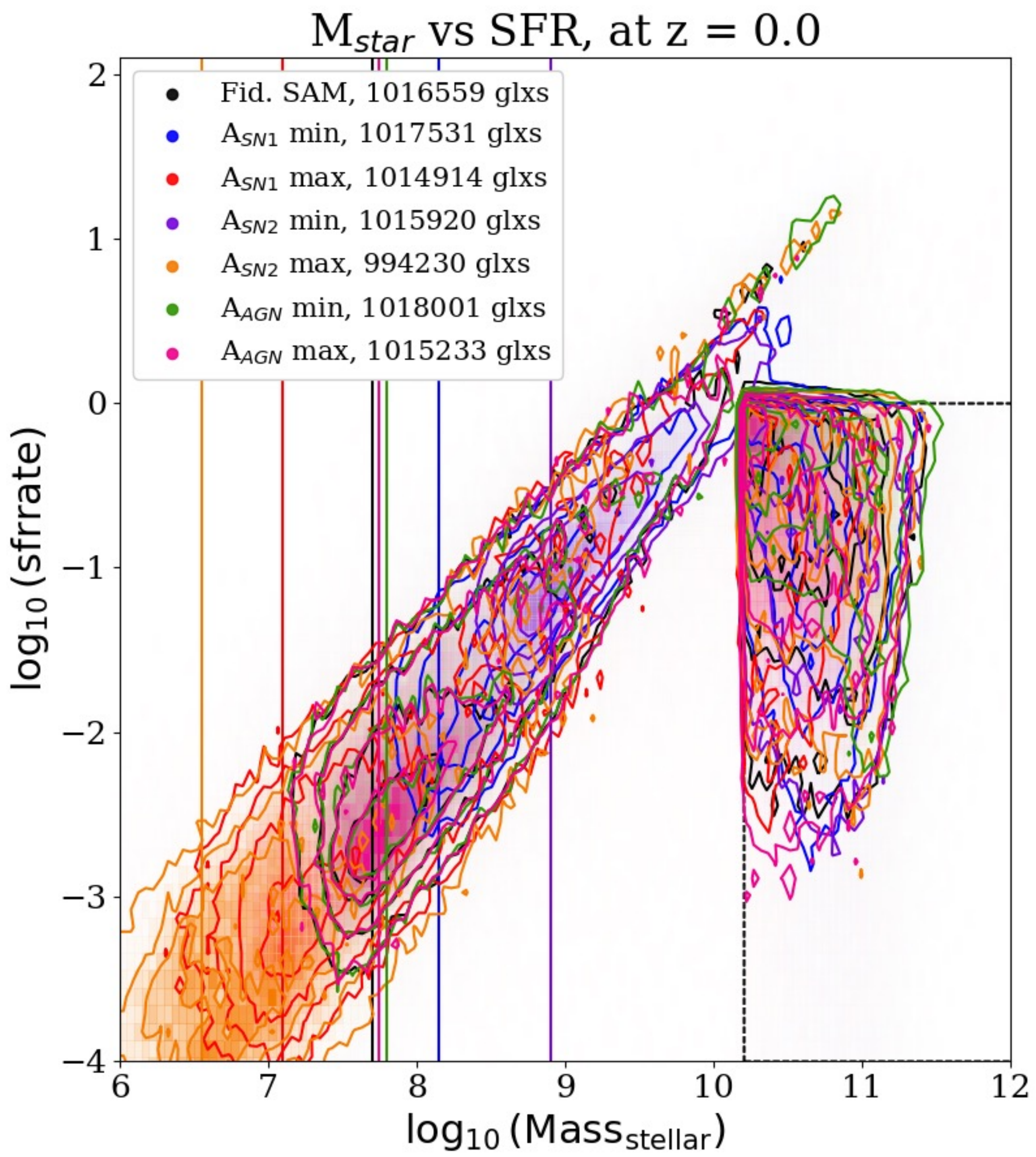
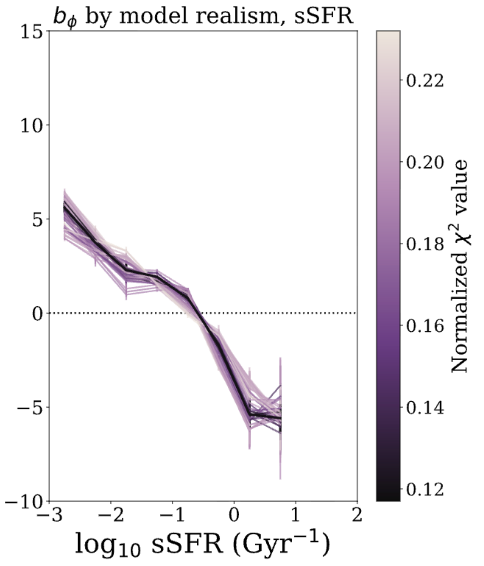
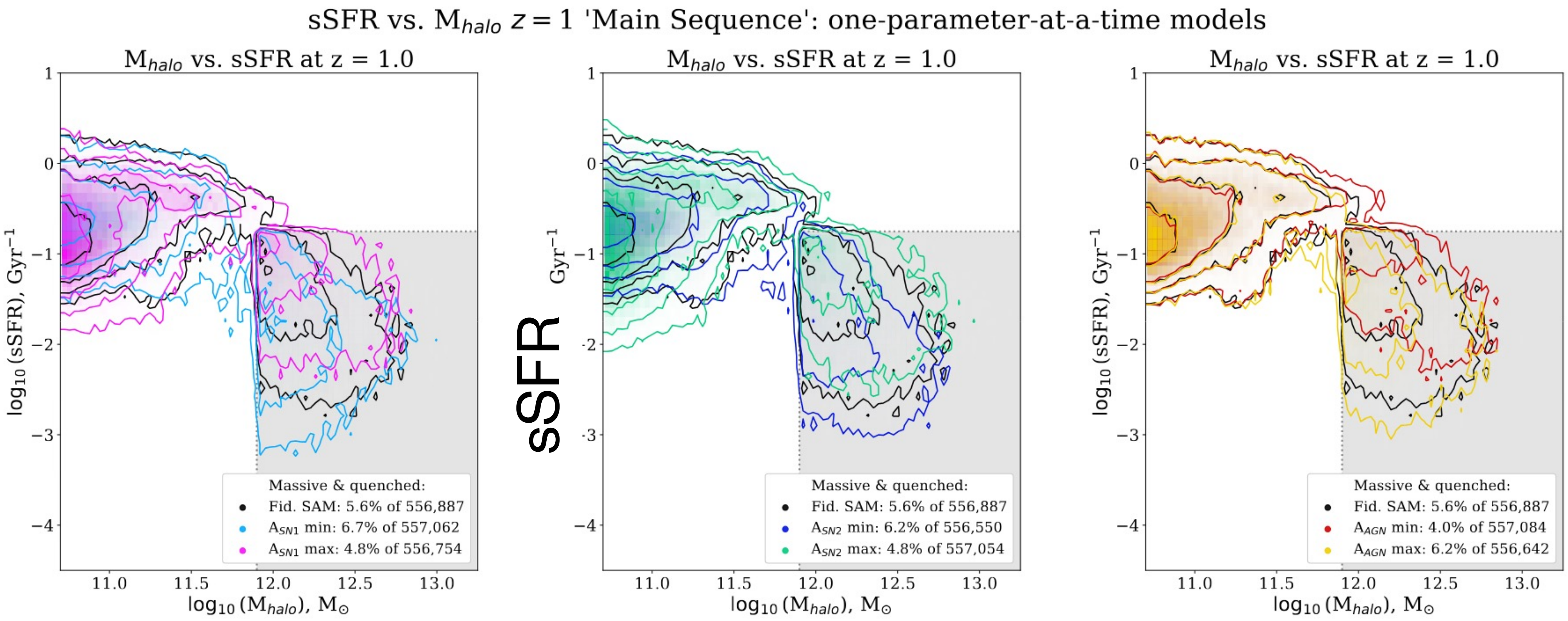




Why? The galaxy-halo connection!

Regulated sSFR- M_{halo} makes b_ϕ(sSFR) standard



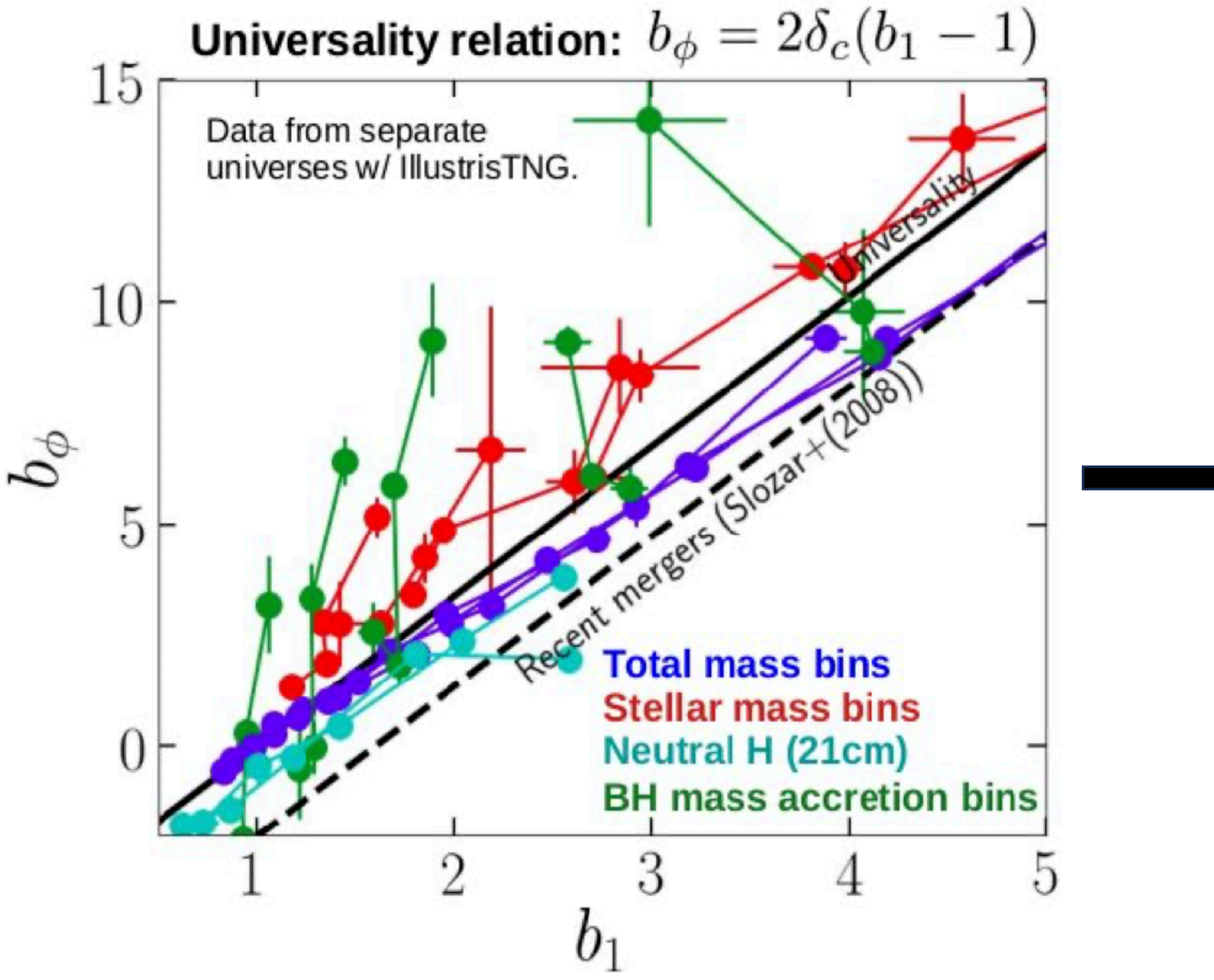


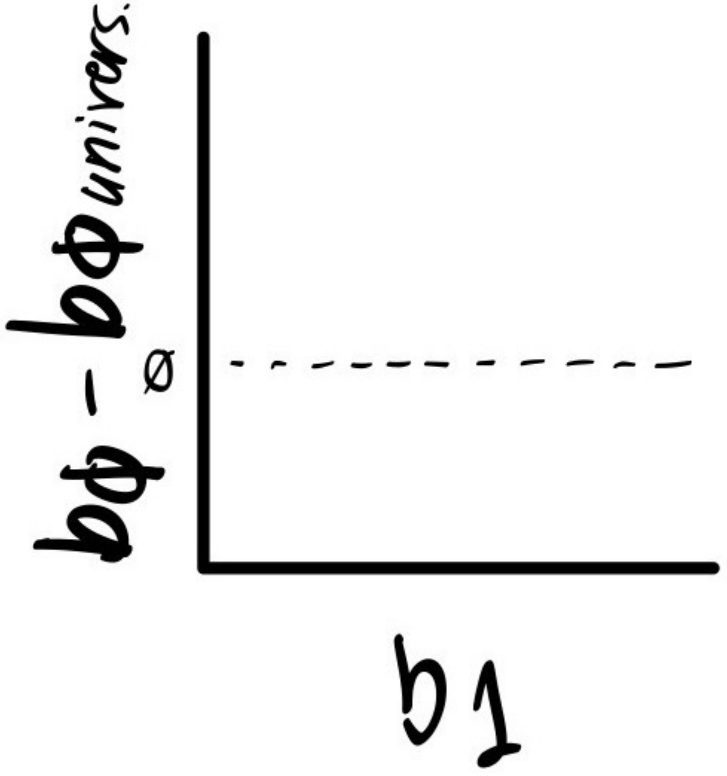
sSFR

Halo Mass

(The SC-SAM is correctly regulating star formation even as the parameters go wild)

(b_ϕ - $b_{\phi,\text{ universality}}$) vs. b_1





If universality describes well, points will clump near 0!

Barreira++ arXiv:2006.09368 , arXiv:2107.06887, arXiv:2112.03253

b_ϕ vs. b_1 for M_{star}, SFR, sFR

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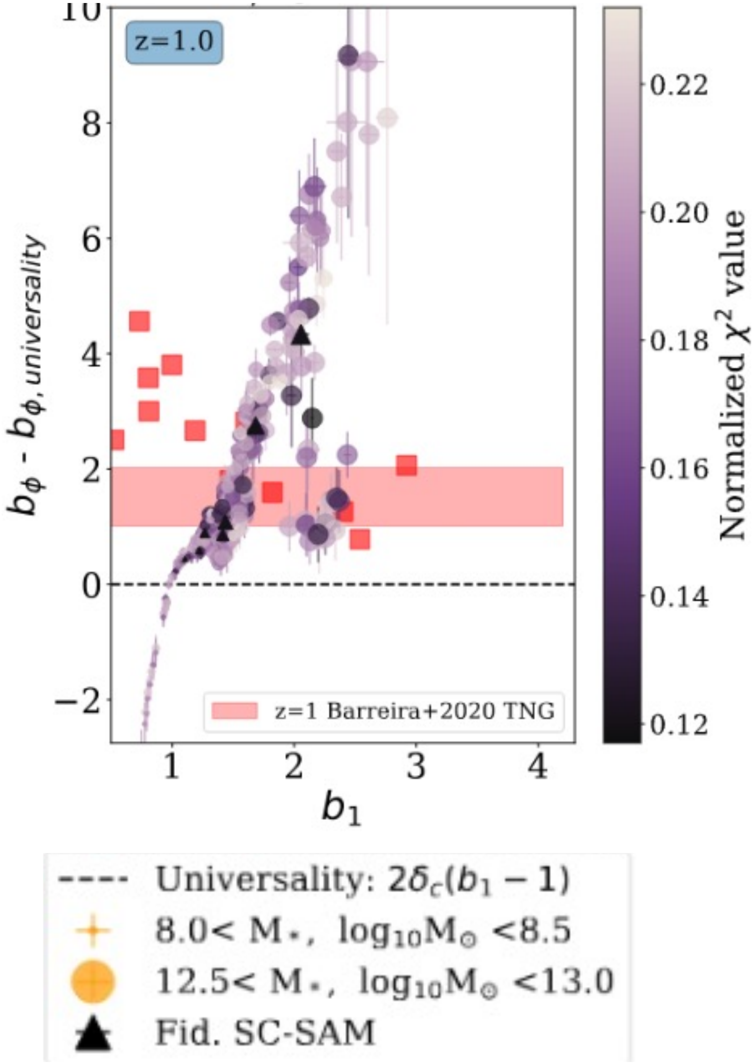
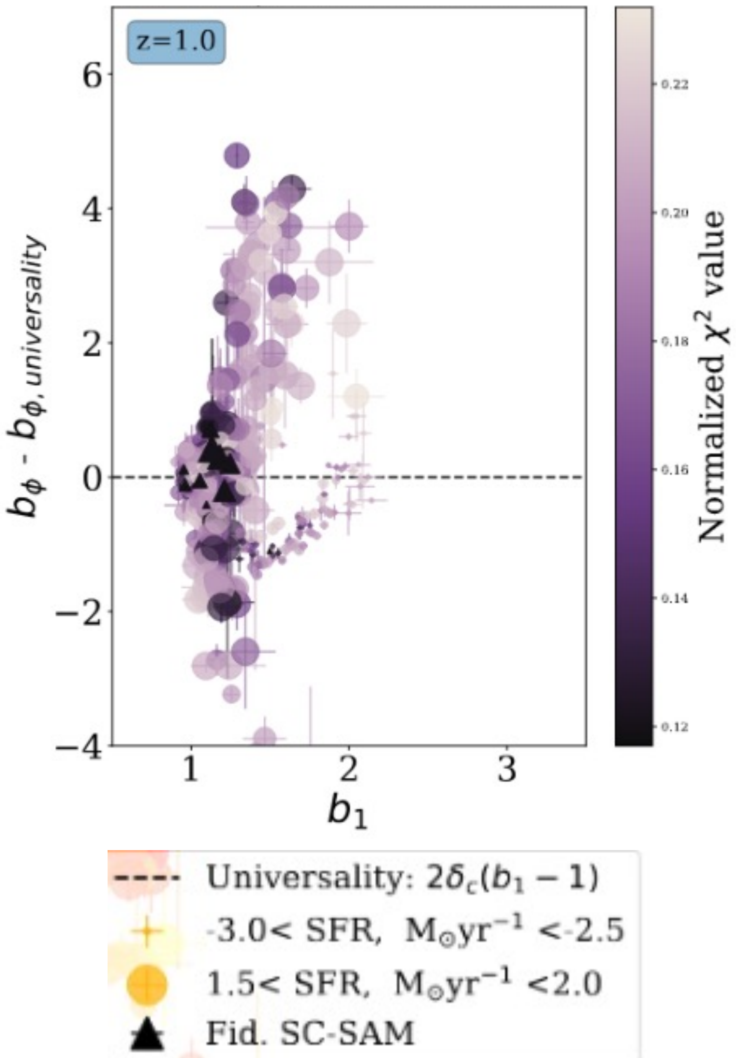
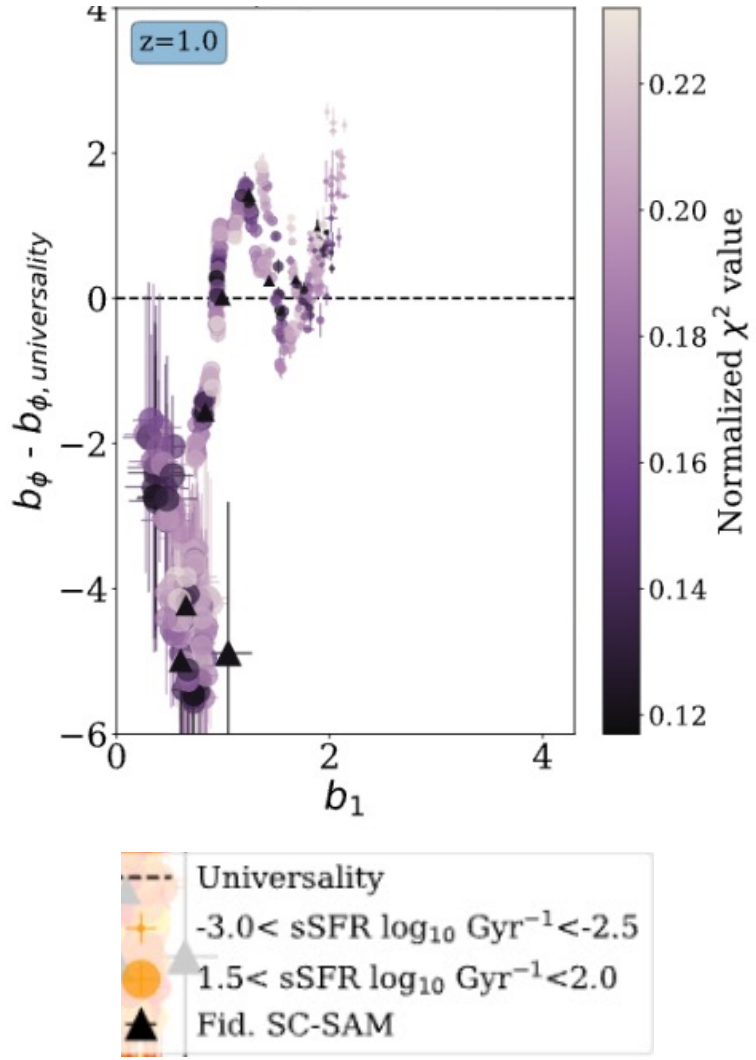
Stellar Mass selections



Instan. SFR selections



Specific SFR selections



What about other galaxy models?

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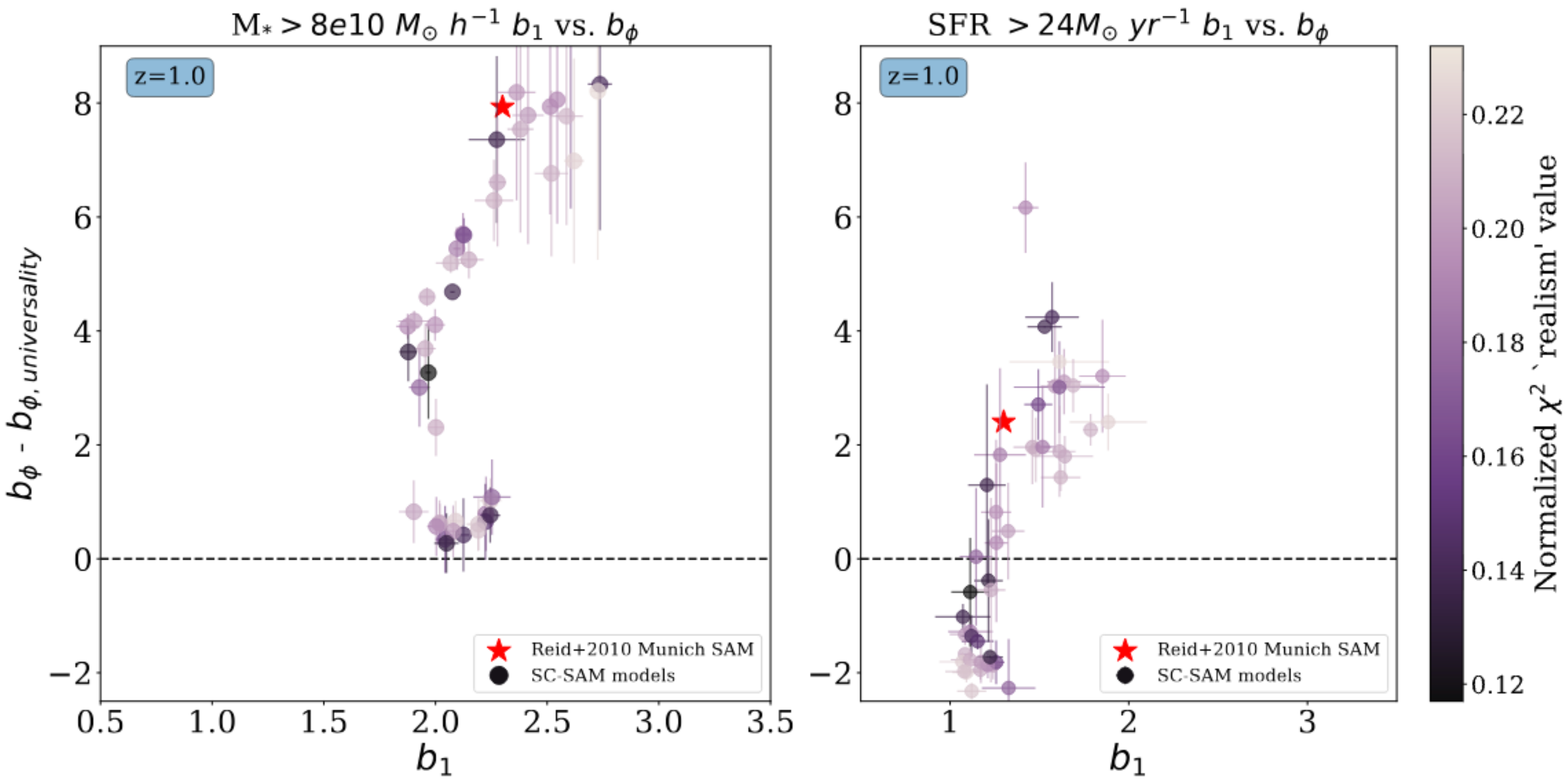
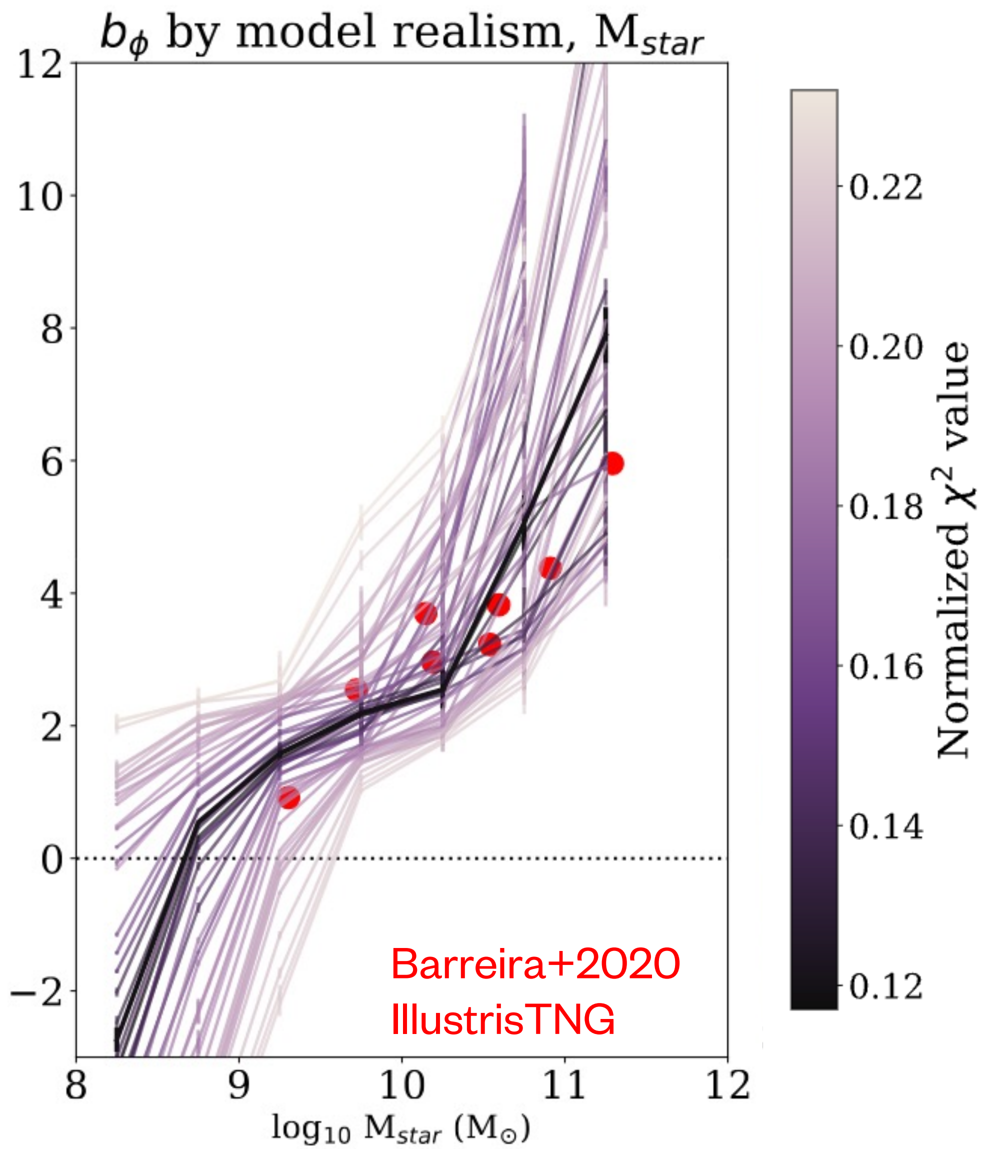
High mass galaxies   Strongly star forming galaxies



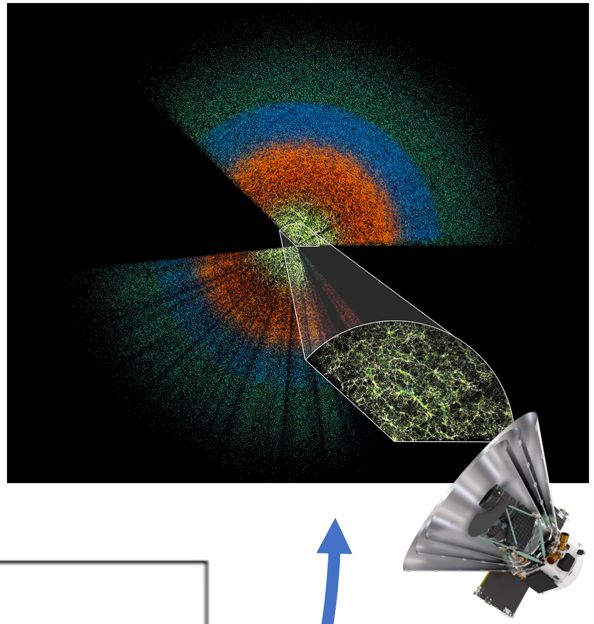
Reid et al. (2010) measure non-Gaussian assembly bias in the Munich SAM

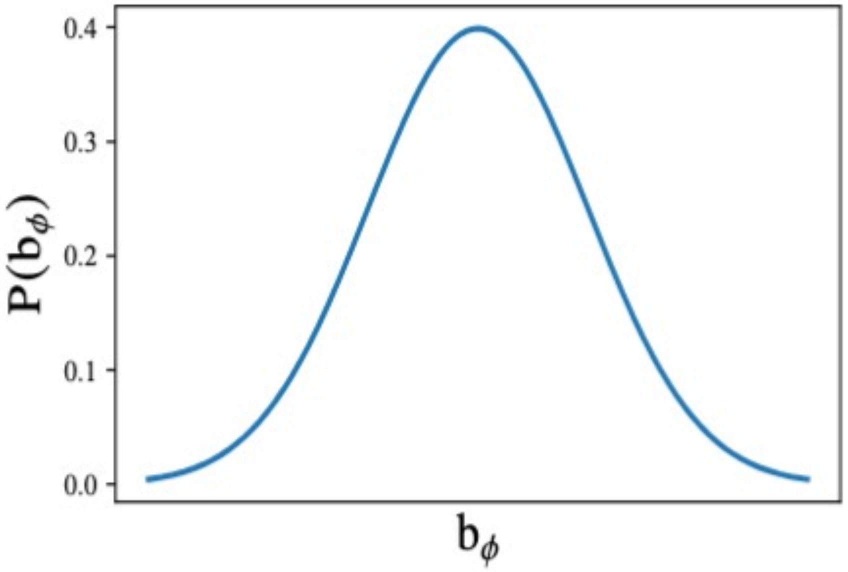
Next: get useful priors for f_{NL} studies



b_ϕ

But not all those models are realistic! The prior should reflect that.



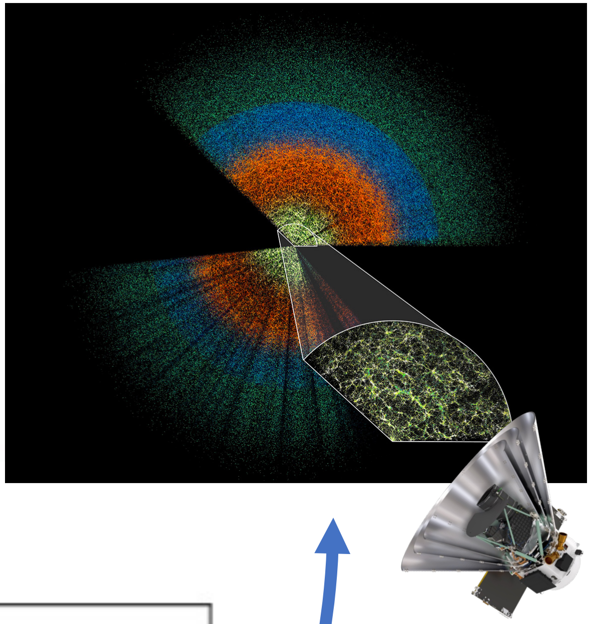


Galaxies selected by e.g. high stellar mass or SFR

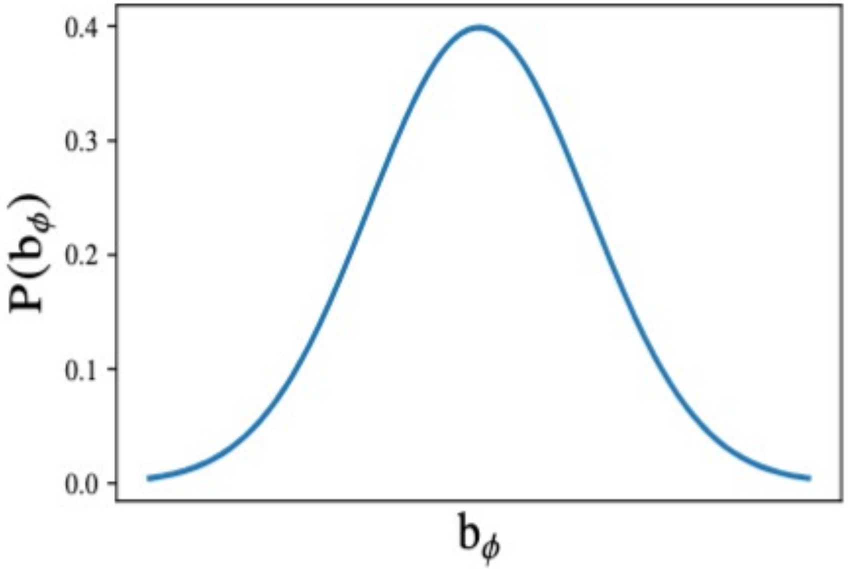
Next: get useful priors for f_{NL} studies

$$p(b_\phi | \mathrm{Obs}) = \int d\Theta_{GF}\; p(b_\phi | \Theta_{GF})\; p(\Theta_{GF} | \mathrm{Obs})$$

- prior on b_ϕ, for some selection, given a comparison observation
- galaxy formation parameters
- b_ϕ for some set of params
- realism of a set of params conditioned on some observable



Galaxies selected by e.g. high stellar mass or SFR



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Next: get useful priors for f_{NL} studies:

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$$p(b_\phi \mid \mathrm{Obs}) = \int d\Theta_{GF}\; p(b_\phi \mid \Theta_{GF})\; p(\Theta_{GF} \mid \mathrm{Obs})$$

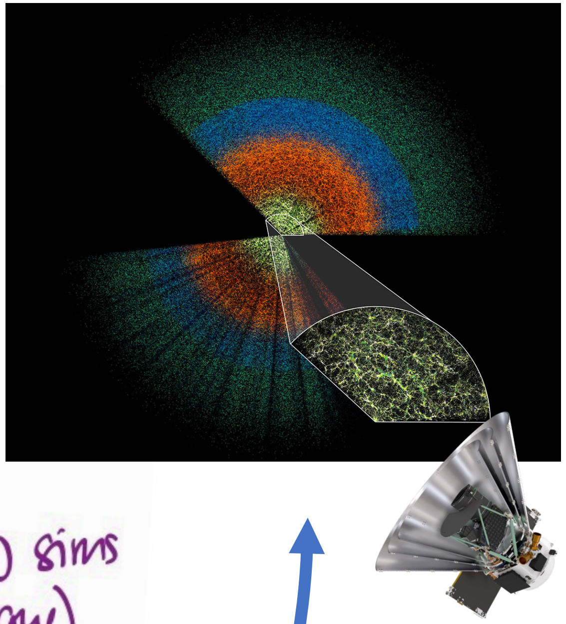
prior on b_ϕ, for some selection, given a comparison observation

galaxy formation parameters

b_ϕ for some set of params
⇓
use separate universe SC-SAM simulations + b_ϕ's

realism of a set of params conditioned on some observable
⇓
use full CAMELS-SAM $L=100\ h^{-1}$Mpc suite of 1000 sims (marginalize over cosmology)

b_ϕ prior marginalized over galaxy formation



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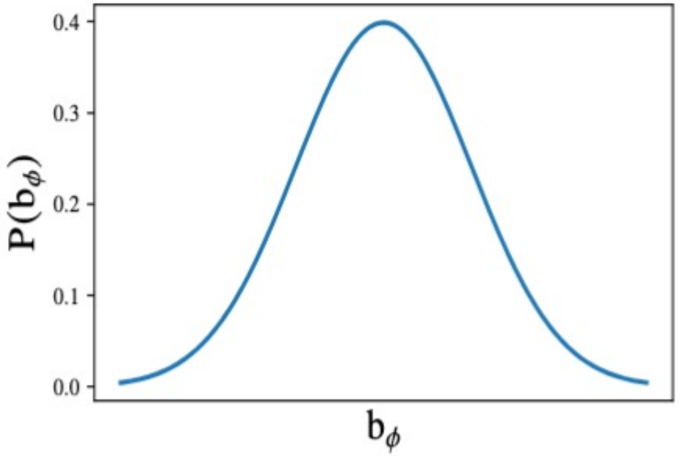

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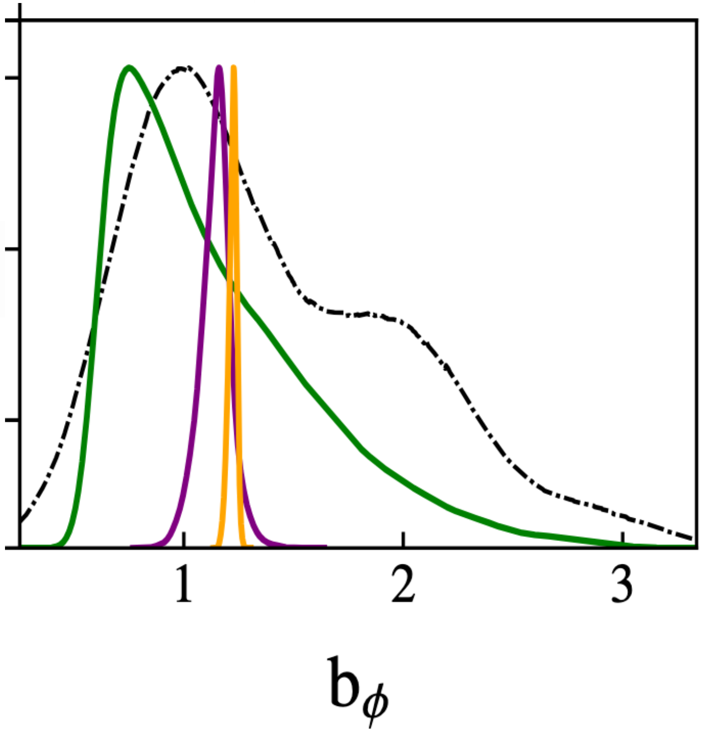
DARK ENERGY SPECTROSCOPIC INSTRUMENT

Preliminary results: this leads to significant narrowing in the b_ϕ prior, $\sigma_{b\phi}$ reduced by ~90%!

But it depends on the observable, limited by the fewer Sep. Univ. SC-SAMs

DESI ELG-like selection in stellar mass and specific SFR



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b_ϕ Priors Conditioned on Observed Data

Metric	$\langle b_\phi \rangle_{SU}$	$\langle b_\phi \rangle_{\chi^2\{Obs\}}$			$p(b_\phi\|\{Obs\})$		
		SMF	SHMR	$M_* - Z_*$	SMF	SHMR†	$M_* - Z_*$
$\langle b_\phi \rangle$	1.43	1.20	1.41	1.39	1.15	1.25	1.15
σ_{b_ϕ}	0.69	0.48	0.58	0.62	0.08	0.02	0.45

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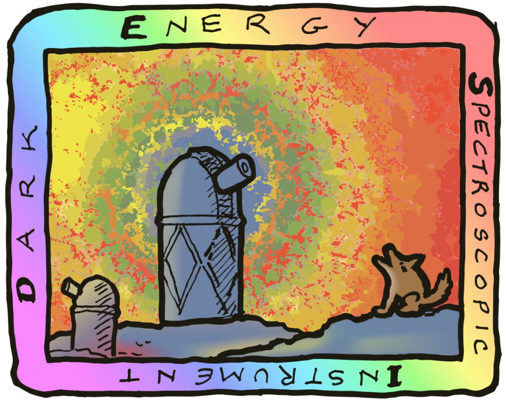

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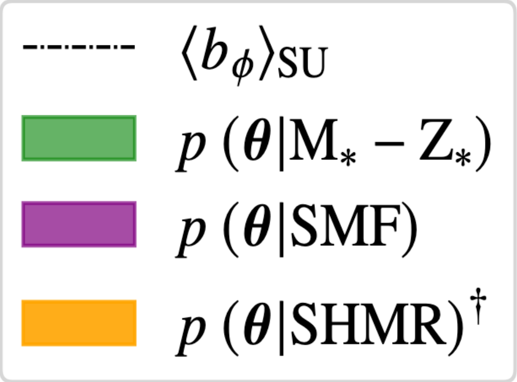
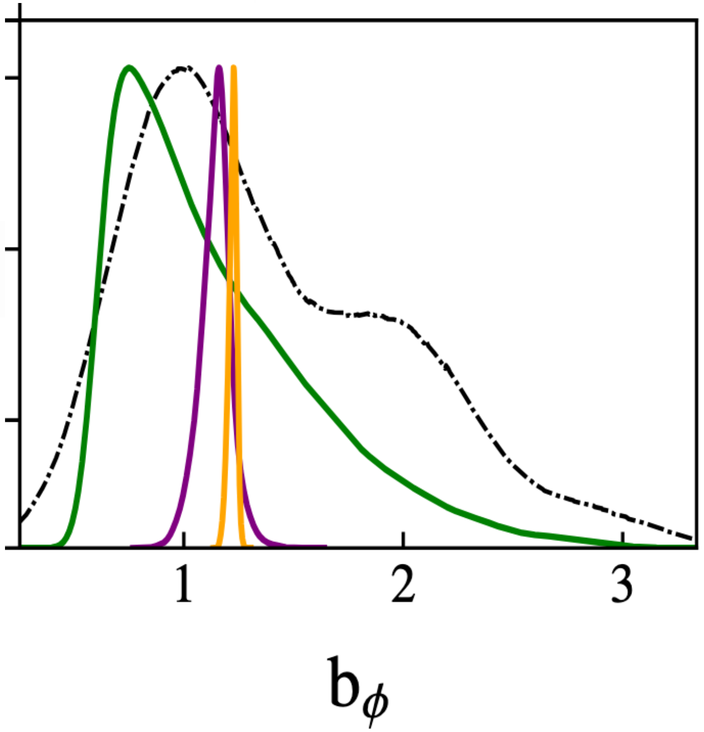
DESI ELG-like selection in stellar mass and specific SFR





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Summary & Takeaways: arxiv.org/abs/2602.04987

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- f_{NL} will not be well constrained until we better understand how galaxy formation affects galaxy bias parameters!
- With separate universe simulations and the Santa Cruz SAM, we measure non-Gaussian galaxy bias b_ϕ across several dozen parametrizations varying SN and AGN feedback
- All selections strongly diverge from the universality relation:
  - Our stellar mass findings aligns well with previous IllustrisTNG b_ϕ measurements, but diverge a bit in $b_\phi(b_1)$
  - SFR selections yield chaotic b_ϕ and $b_\phi(b_1)$
  - sSFR seems robust to galaxy formation parameterizations, likely due to regulated star formation in the SC-SAM
- We agree with the $b_\phi\,(b_1)$ measured in the Munich SAM—but we need more galaxy formation models!
- We can get much narrower priors for b_ϕ by conditioning on how realistic a particular SC-SAM parametrization is given some observable (Moore, LAP, & Krause in final prep)

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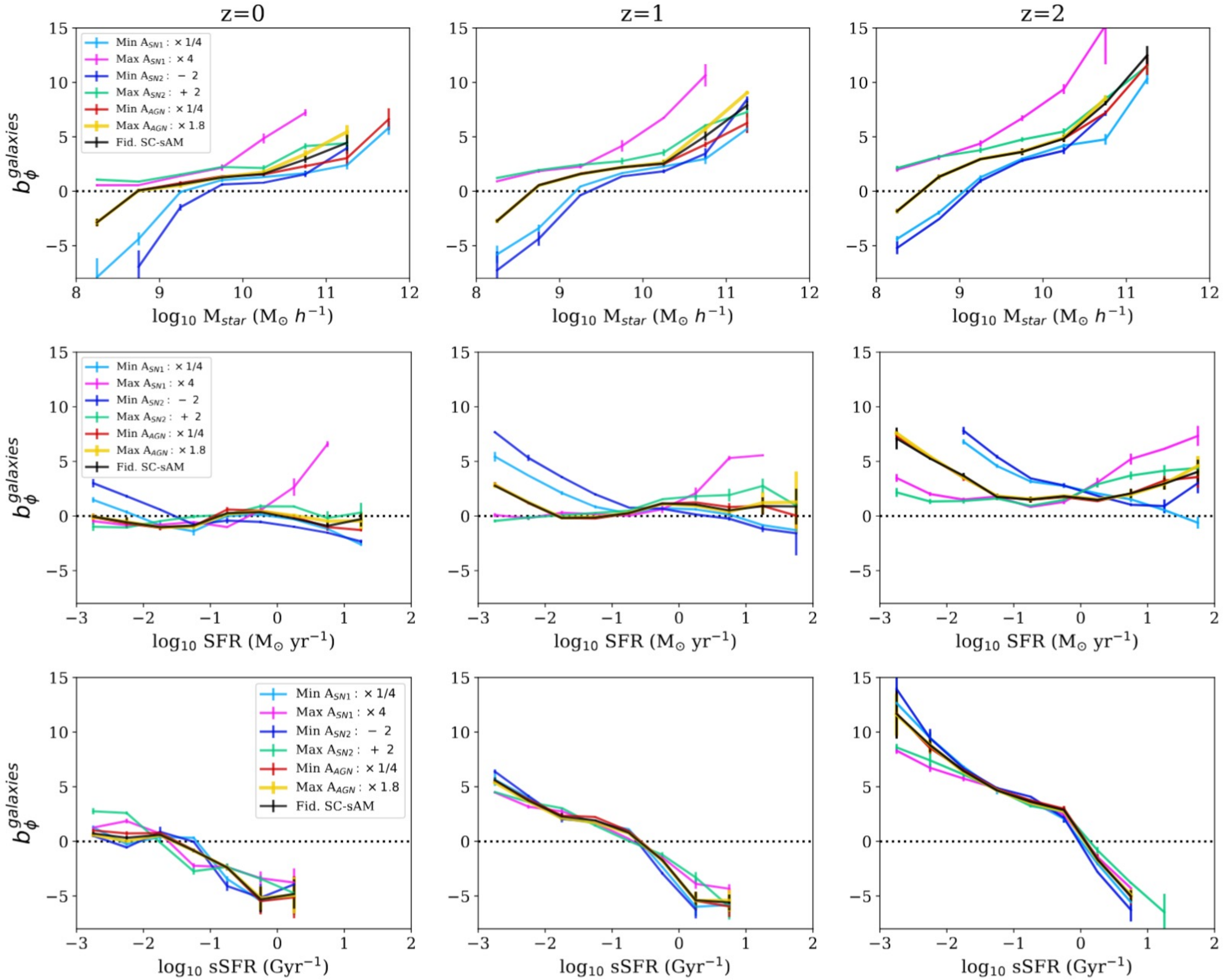

Redshift evolution of b_ϕ? Effect of individual parameters?