Backlighting the Baryons

Plenary Summary Report

Alexie Leauthaud and Simone Ferraro

Introduction/Motivation

Why care about the gas?

NASA, ESA, DePasquale, Wheatley, Levay

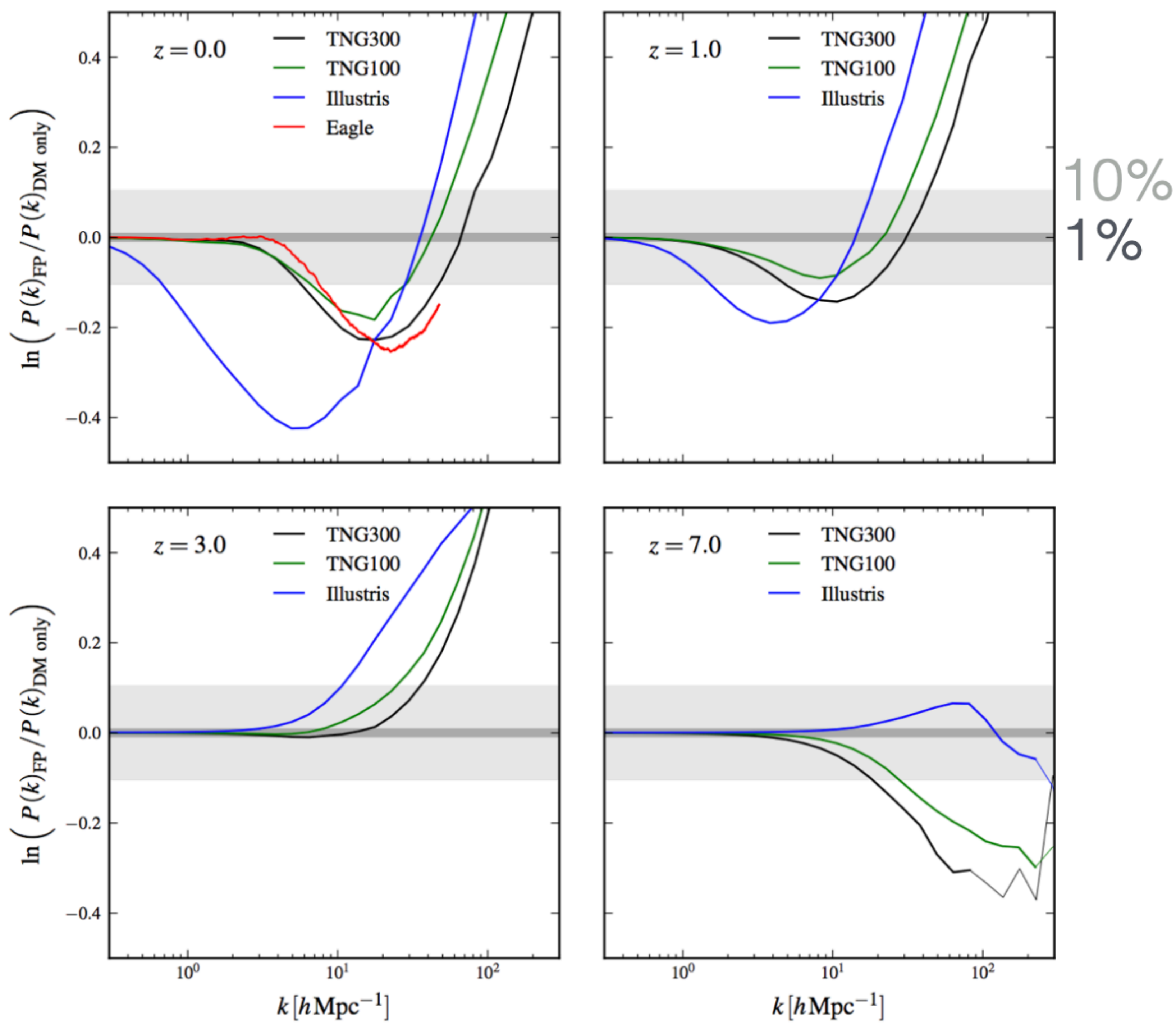
Galaxies surrounded by vast gaseous halos

Gas is more extended than dark matter,
due to feedback in galaxy formation
→ Key astrophysical unknown!

Main limiting theoretical systematic for galaxy lensing

Slide: Emmanuel Schaan

Effect of baryons on P(k)

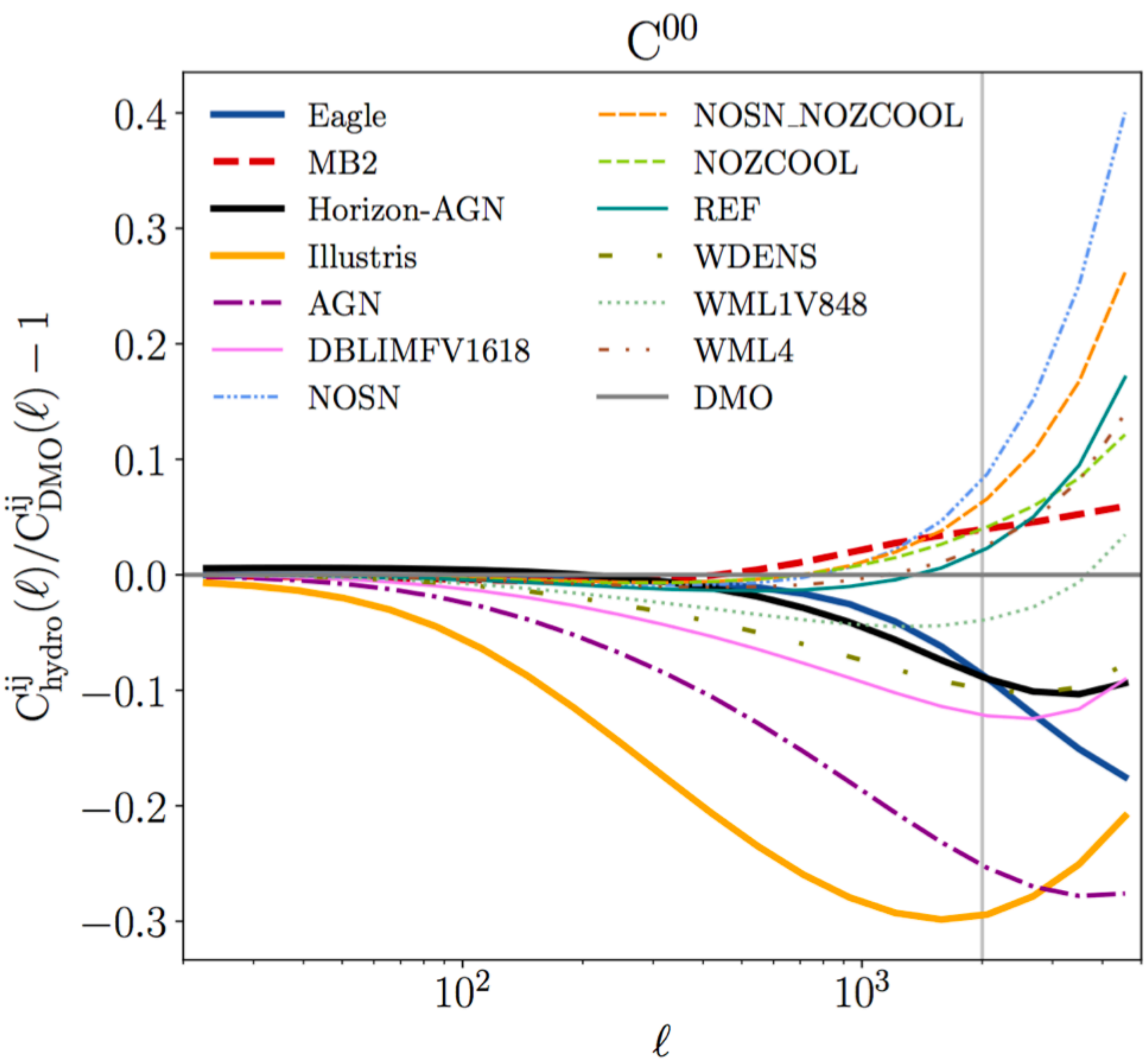


Springel+ (2017)

Slide: Colin Hill

Implications

If not modeled accurately, these effects bias parameter inference from, e.g., the weak lensing power spectrum



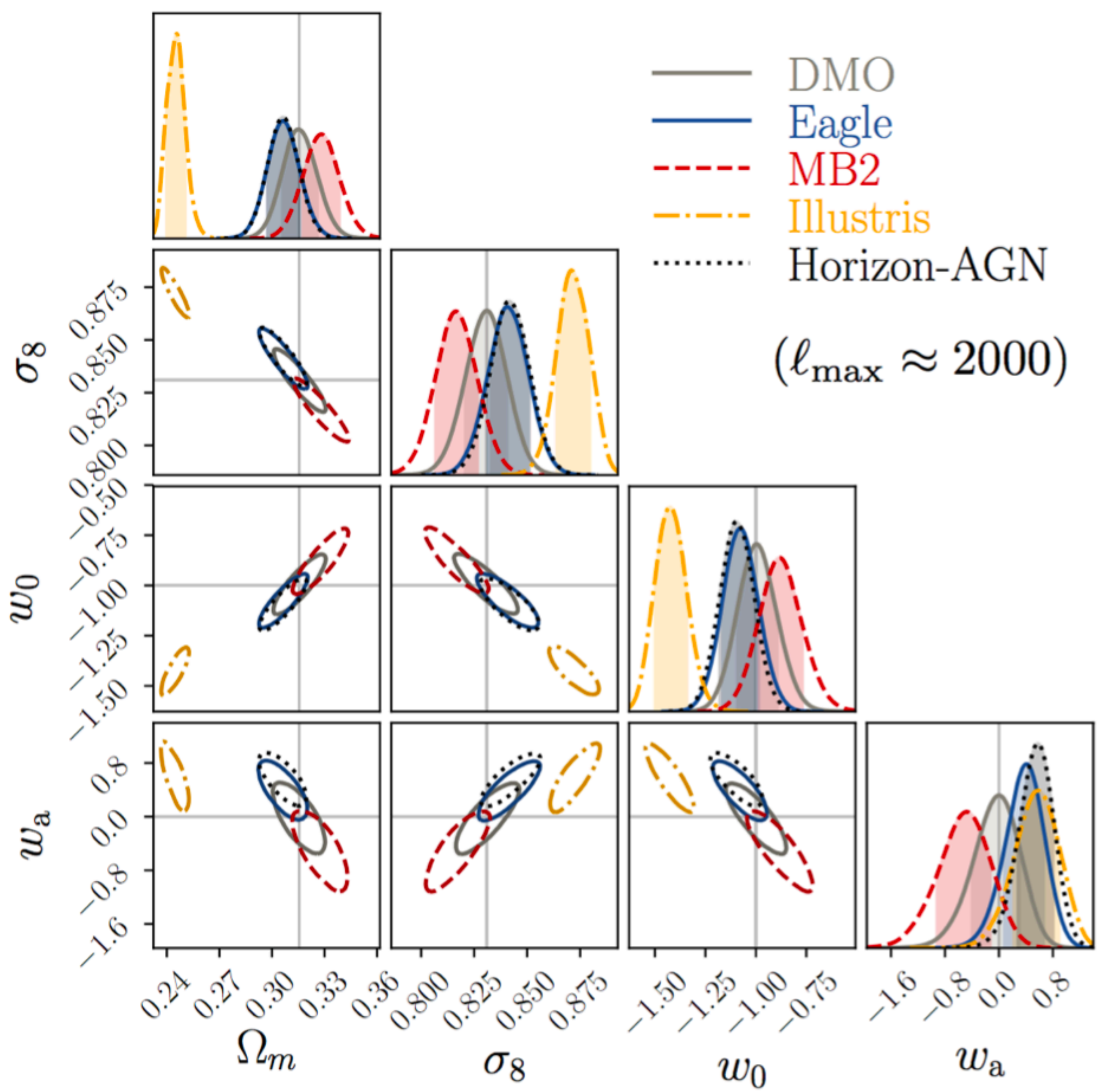
WL power spectrum for tomographic bin at z~0.25

Huang+ (2018)

Slide: Colin Hill

Implications

If not modeled accurately, these effects bias parameter inference from, e.g., the weak lensing power spectrum

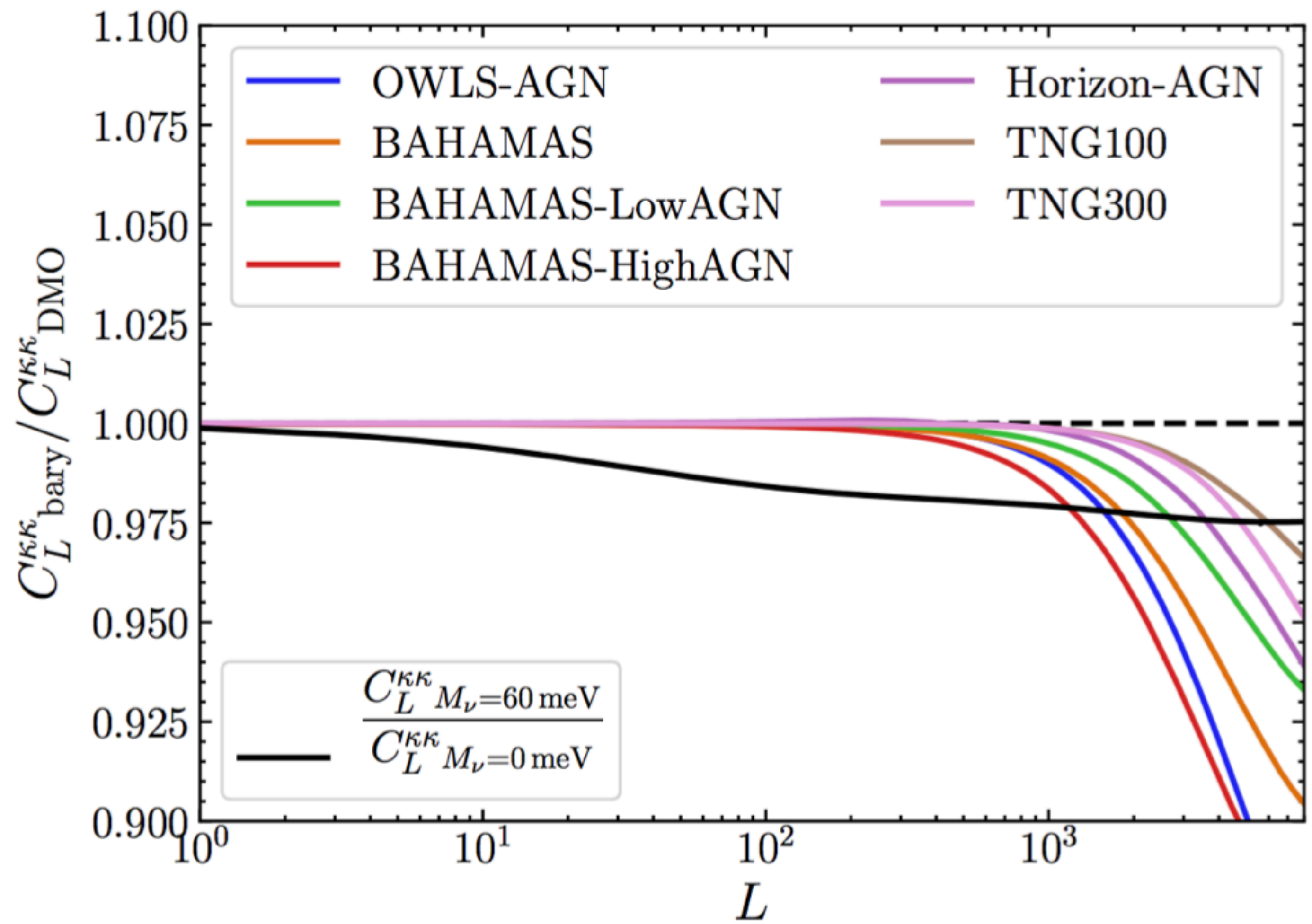


Huang+ (2018)

Slide: Colin Hill

Effect on CMB lensing

Similar to galaxy WL case, inaccurate modeling of baryonic effects can bias inference of (e.g.) Σm_ν from CMB lensing power spectrum

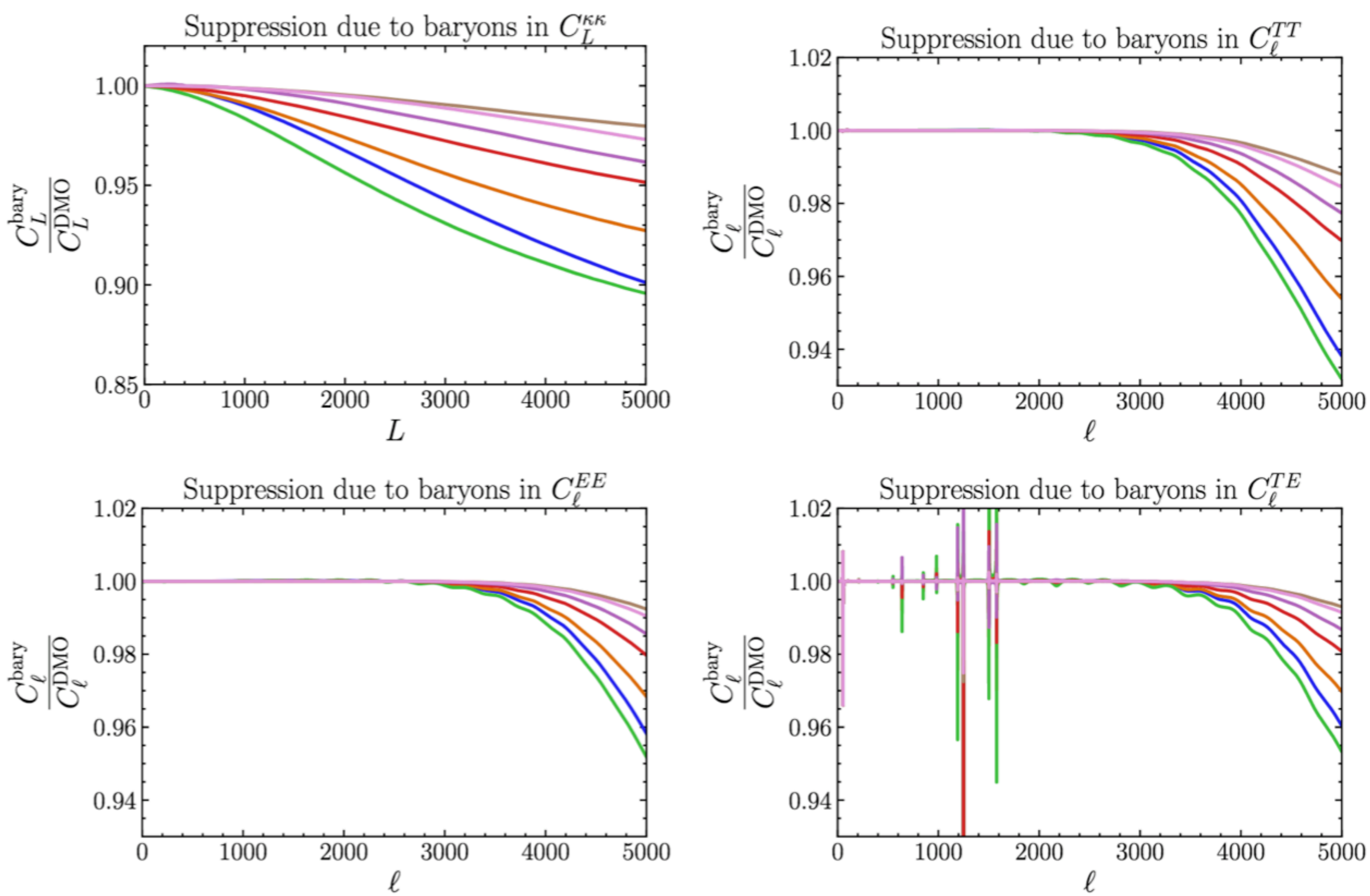


McCarthy, Foreman, & van Engelen (2020)

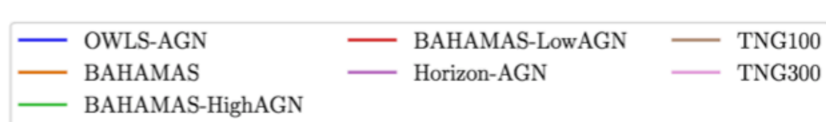
Slide: Colin Hill

Effect on primary TT/TE/EE spectra

Via lensing, baryons can even affect the primary TT/TE/EE power spectra!



Seven hydro sims:



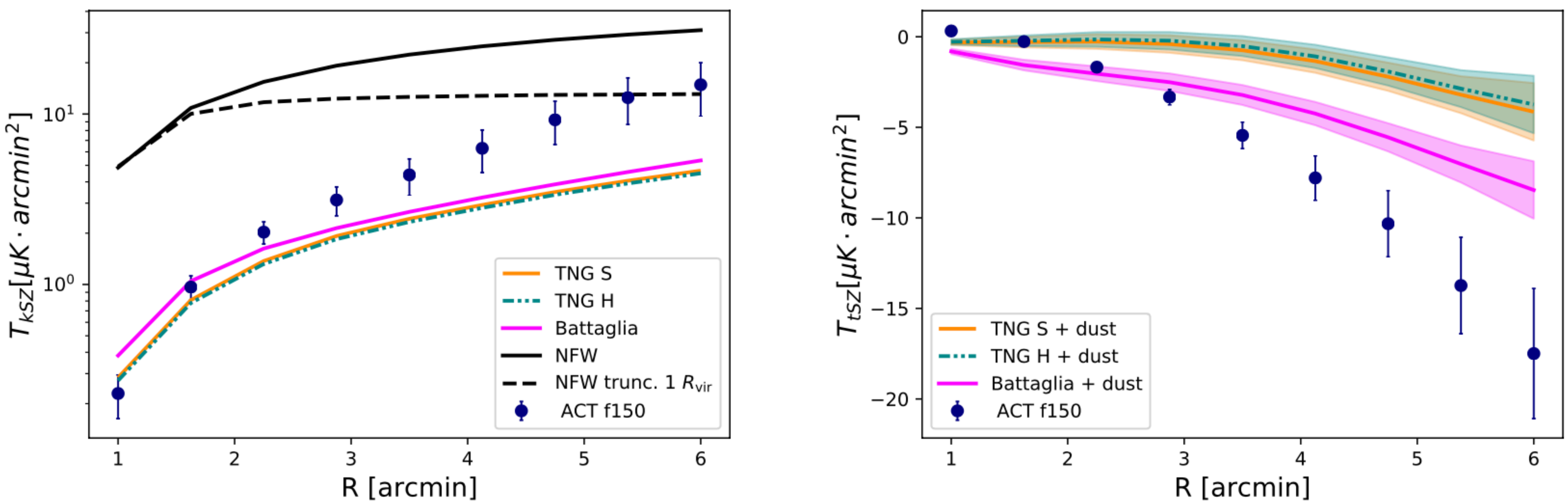
McCarthy, JCH, & Madhavacheril (2021)

Impacts CMB-S4 and Simons Observatory, but not current data sets.

Slide: Colin Hill

Results

Constraints from kSZ BOSS+ACT+ PLANCK



Amodeo Battaglia Schaan Ferraro & ACT 20

New territory: low halo masses, outside virial radius

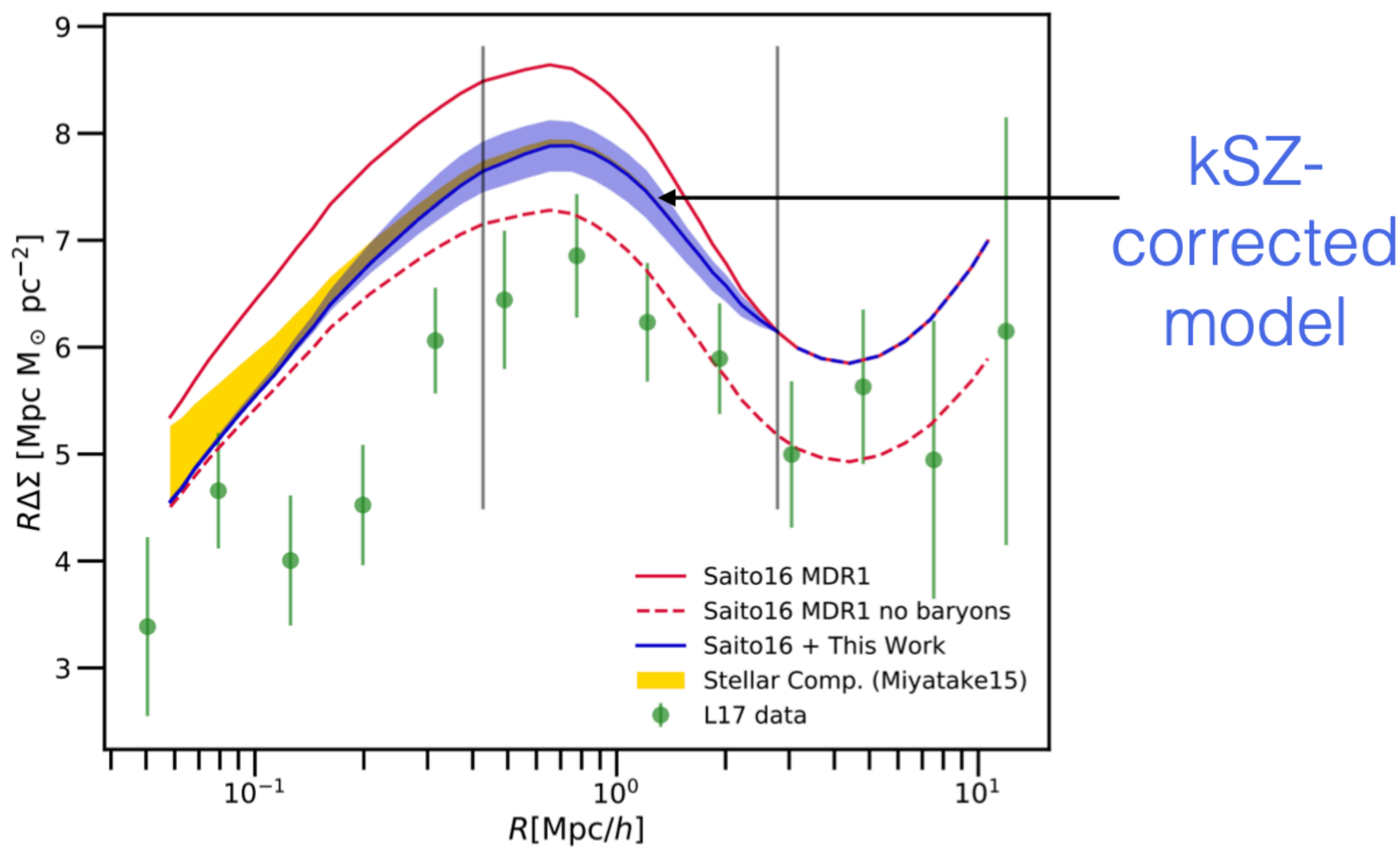
Data suggests hotter gas in the outskirts

Informs subgrid feedback prescriptions in hydro sims

Slide: Emmanuel Schaan

Implications for “lensing is low”

kSZ tomography directly images the ionized gas distribution



For galaxy-galaxy lensing (g x κ), kSZ measures **exactly** the dominant baryonic correction (where the gas is located!): example shown here for CMASS g-g lensing

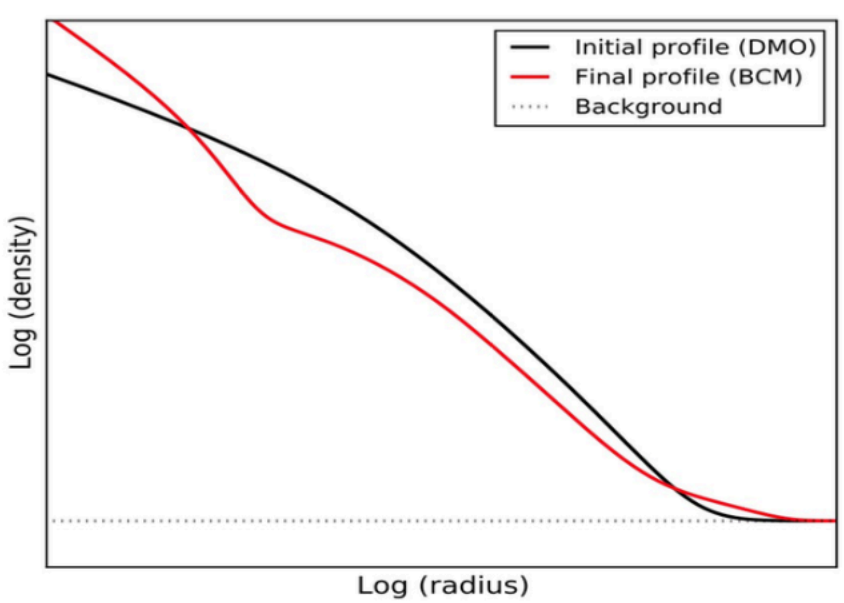
Amodeo+ (2021); see also Schaan+ (2021)

Slide: Colin Hill

Mitigation Strategies for WL

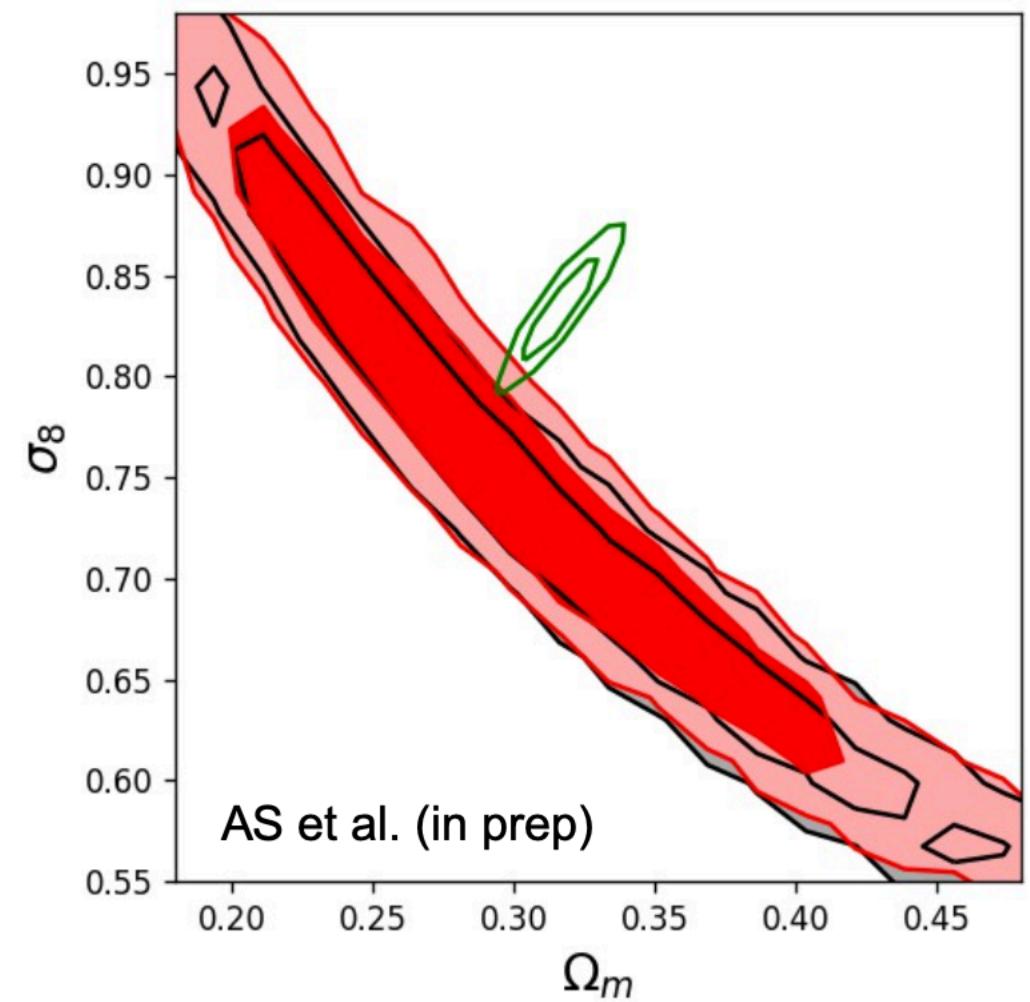
1. Simulations with free parameters
2. Parametrization of halo profiles
3. Baryonification

Parametrisation of halo profiles



$$\rho_{\rm tot}(r) = \rho_{\rm dm}(r) + \rho_{\rm gas}(r) + \rho_{\rm star}(r)$$

(AS & Teyssier 2015, AS et al 2019, Arico et al 2019, Lu & Haiman 2021)



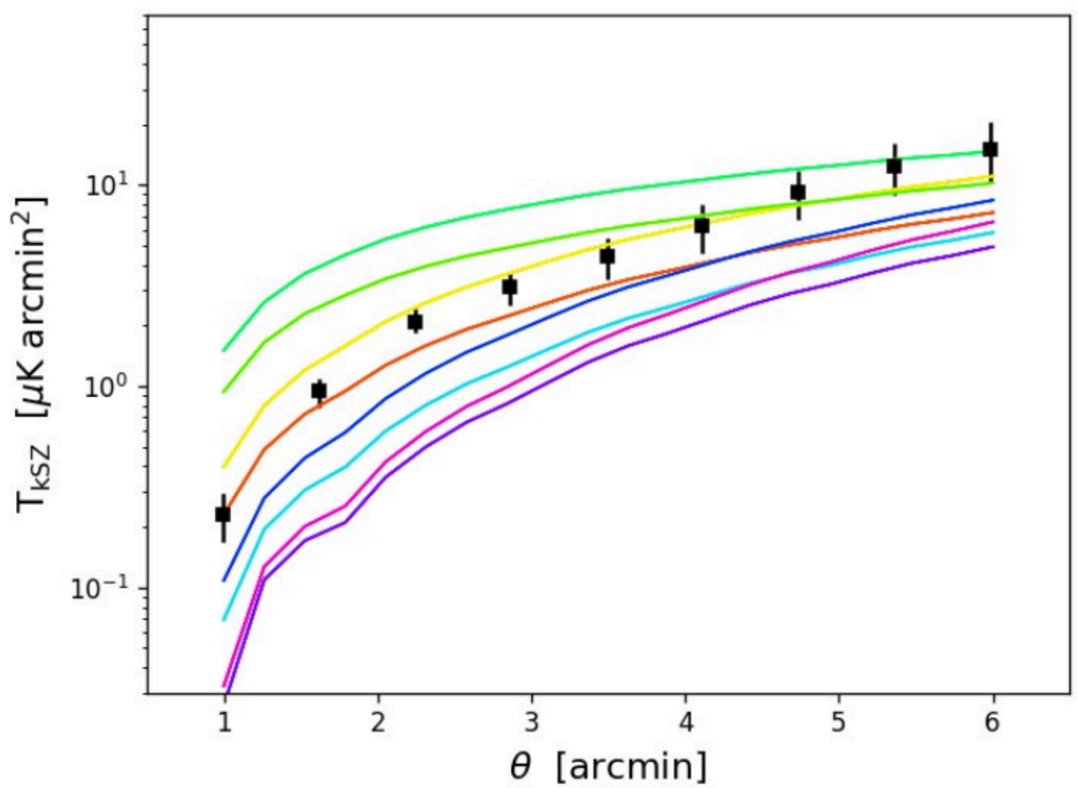
Baryonification model with 5 free parameters

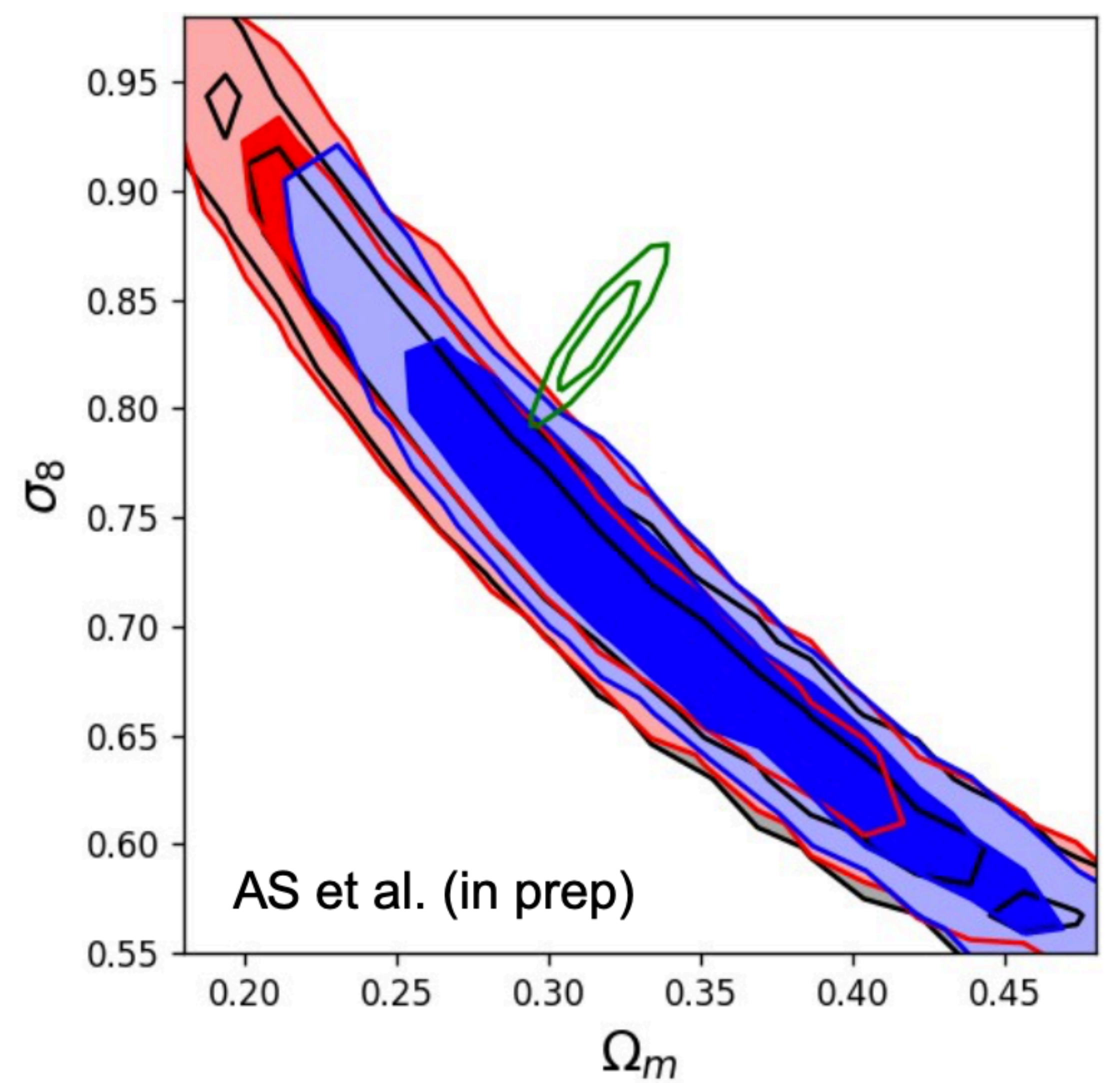
Slide: Aurel Schneider

Baryonification

Combining with kSZ profiles (ACT)

(see Amodeo et al 2020, Schaan et al 2020)





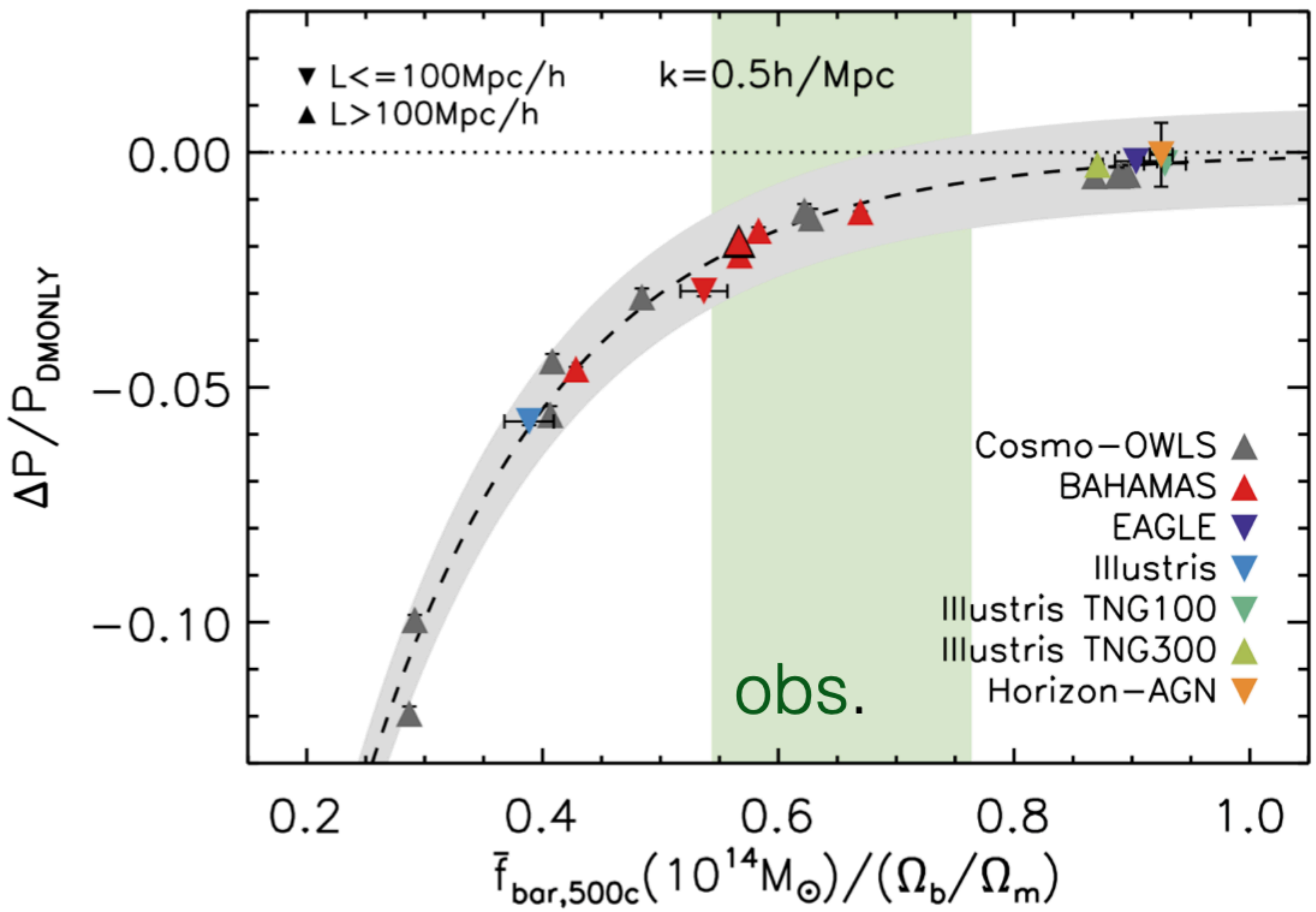
Baryonification model

with 5 free parameters

Slide: Aurel Schneider

Baryonic Corrections

Perhaps only a single-variable model is needed (on relevant scales)



At k = 0.5 h/Mpc, the baryonic suppression in P(k) is predicted simply by the mean baryon fraction in ~10^{14} M_{sun} halos

M. van Daalen, I.G. McCarthy, & J. Schaye (2020)

Slide: Colin Hill

Mitigation Strategies for Impact on CMB lensing

1) Explicitly cut all TT data at ell>3000 (w/ small penalty in final parameter error bars) — 13% increase in $\sigma(N_{eff})$ for S4

2) Marginalize over parameters describing baryonic effects

— but pay a penalty in parameter error bars: 13% increase in $\sigma(N_{eff})$ for S4 [coincidentally same as above]

3) Delens the T and E-mode maps using the reconstructed κ map (and/or external tracers like the CIB)

—> Most robust, data-driven approach, and can actually improve the error bars on parameters [Green et al. (2016)]

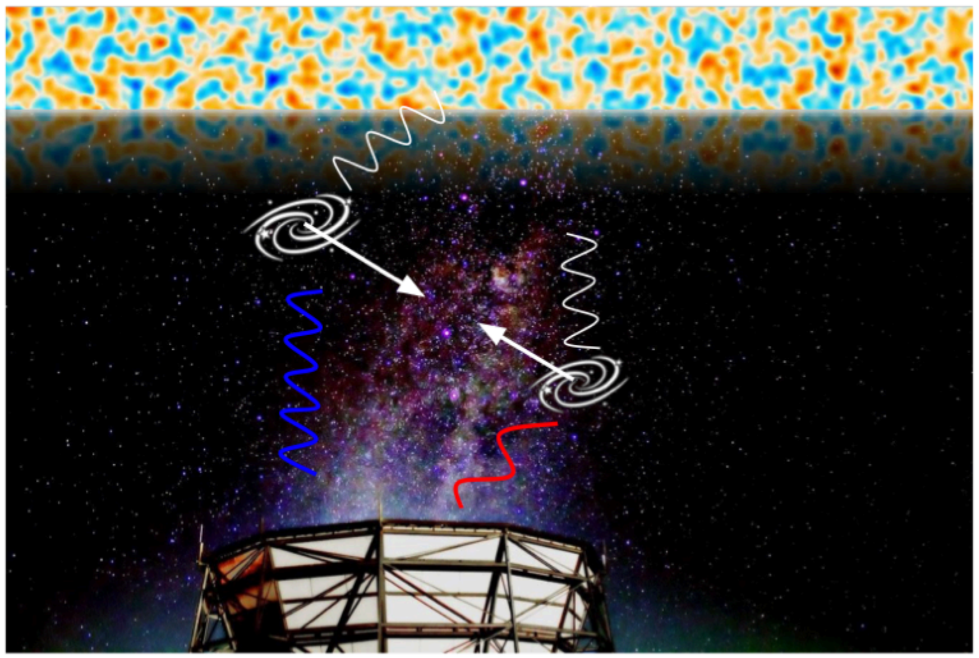
—> Challenge: need very high-L κ information!

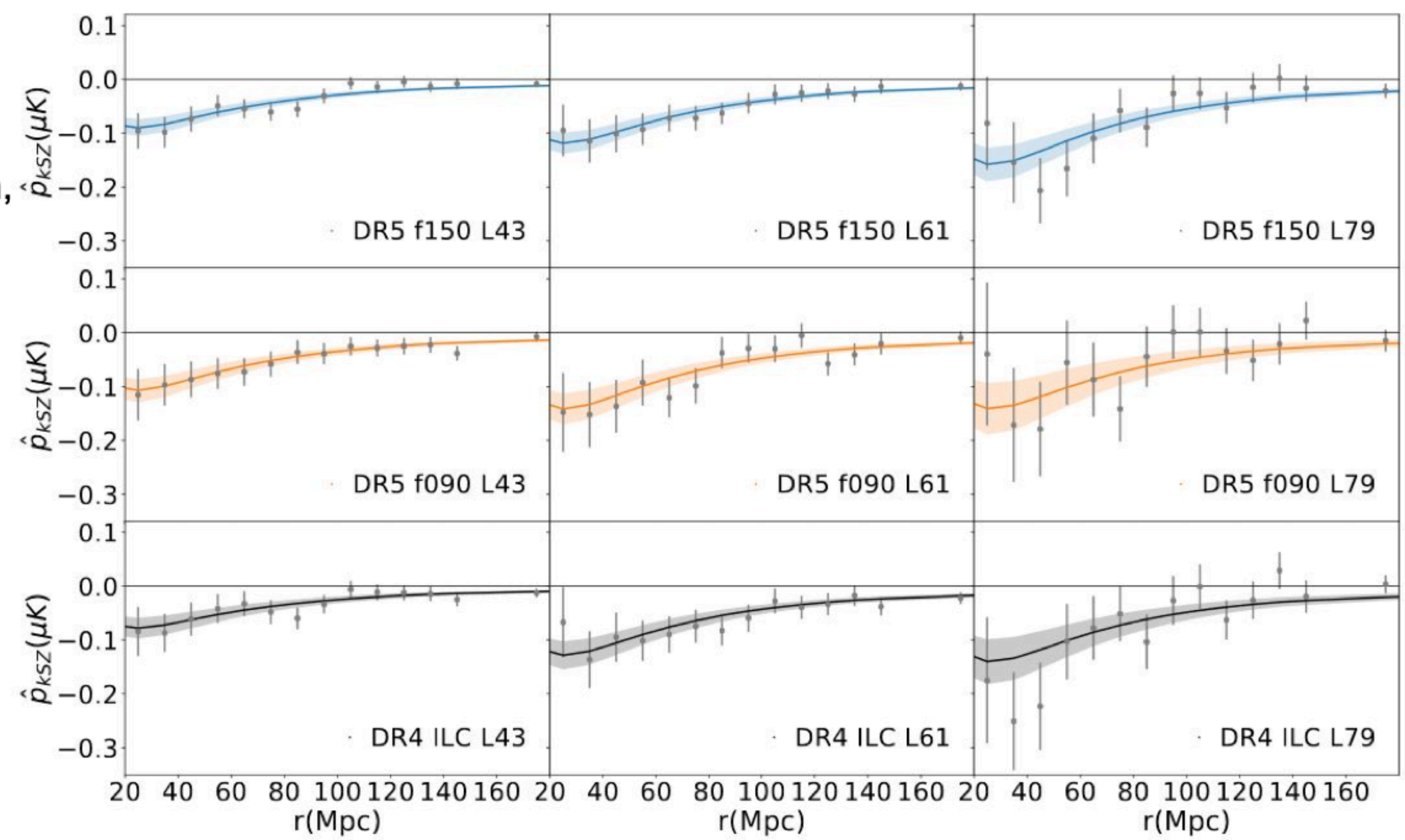
McCarthy, JCH, & Madhavacheril (2021)

Slide: Colin Hill

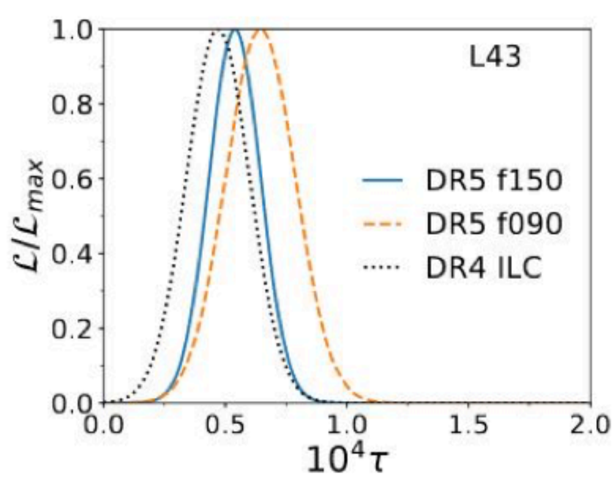
Pairwise kSZ: ACT+Planck & SDSS

Goal: Constrain neutrinos, sigma8, f, dark energy, models of modified gravity, baryon content





- 5.4σ detection
- Fits to model yield estimate of optical depth, trace baryon content
- Consistent across maps



Vavagiakis, Gallardo, Calafut, Amodeo et. al. 2021, arXiv:2101.08373

V. Calafut, P. A. Gallardo, E. M. Vavagiakis, et al. 2021 (PRD, 2101.08374)

Slide: Eve Vavagiakis

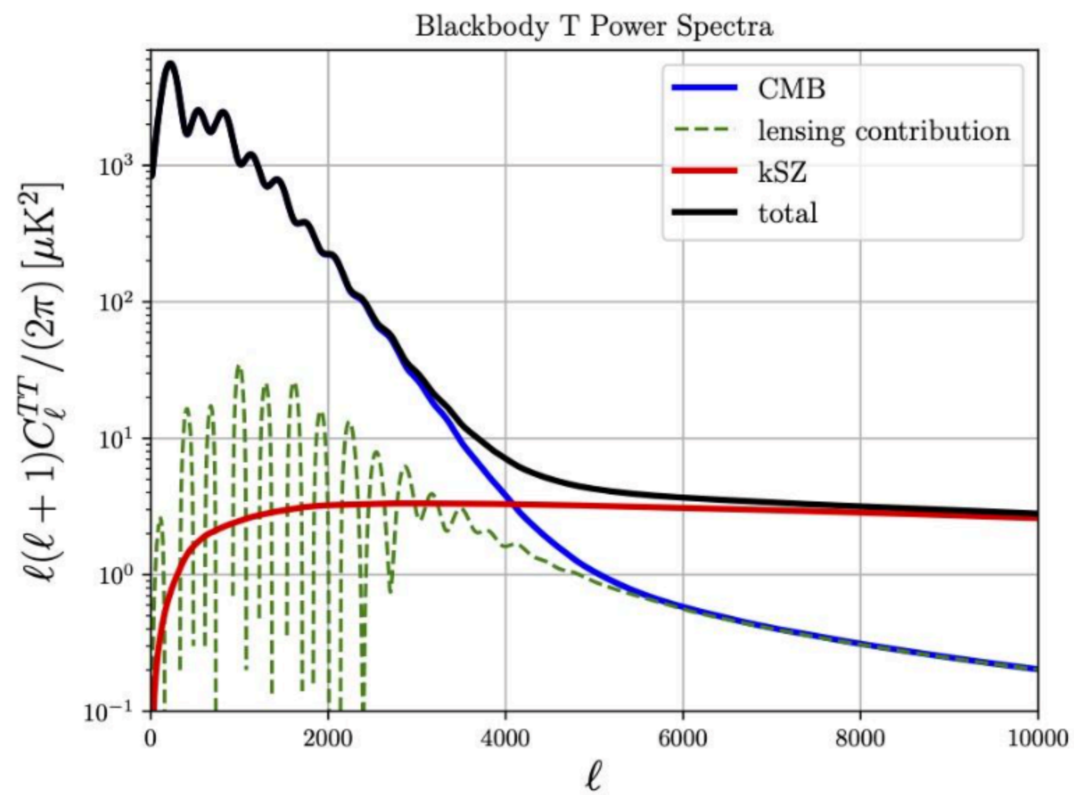
Projected Field kSZ

Idea: **foreground-cleaned** blackbody CMB temperature map contains kSZ information

kSZ signal traces the overall mass distribution, and thus can be detected by cross-correlating it with any large-scale structure (LSS) field

1. Construct a clean T map and apply Wiener filter
2. Cross-correlate with *projected* (2D) galaxy number density map
3. But <T x g> vanishes!
4. Solution: measure <T^2 x g>

No redshift estimates needed!

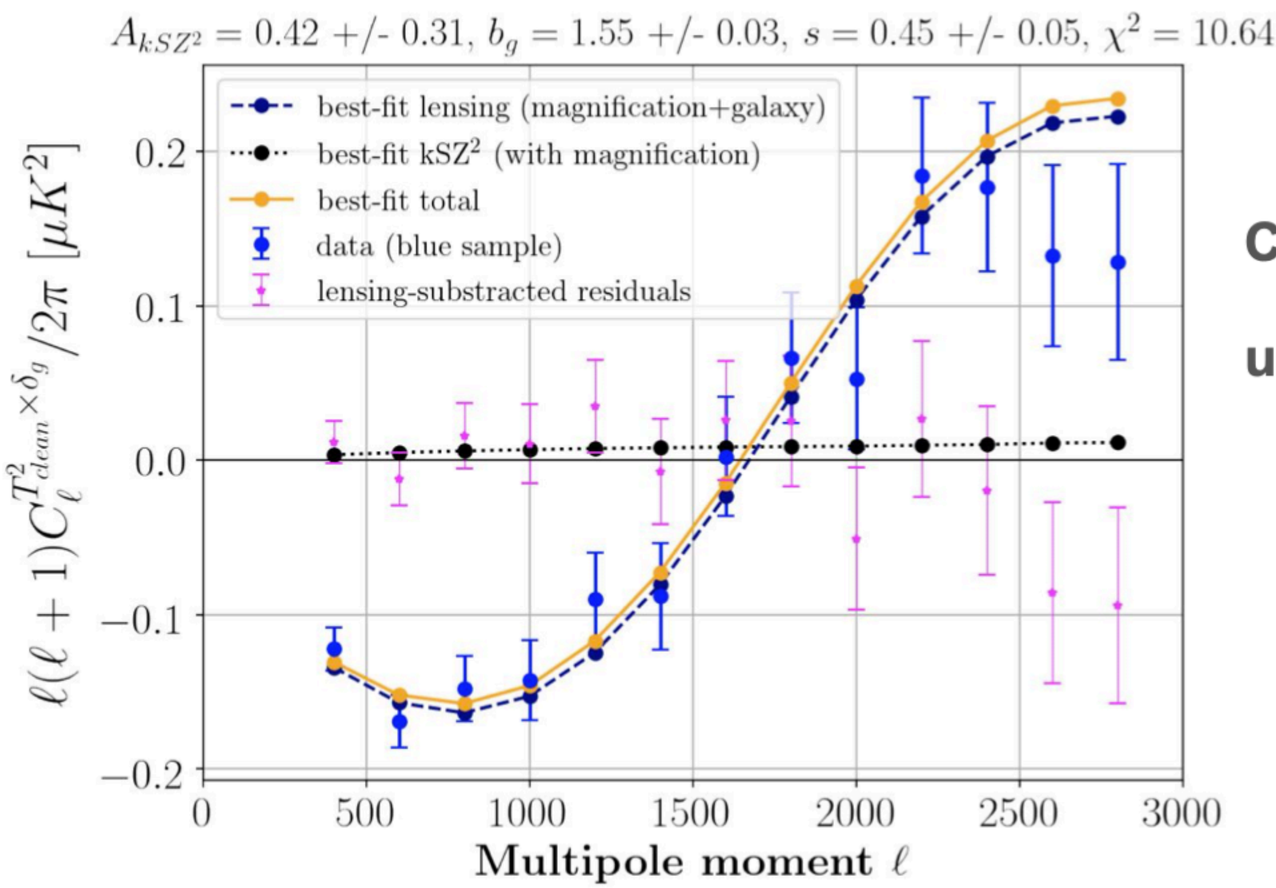


Credits: Colin Hill
kSZ power spectrum from Battaglia et al simulations

Dore+2004, DeDeo+2005, Hill+2016, Ferraro+2016, Kusiak+2021

Slide: Ola Kusiak

Projected Field kSZ with unWISE



CMB: LGMCA map again + Planck SMICA map

unWISE catalog (Krolewski et al. 2020):

- Based on WISE and NEOWISE
- 3 subsamples: blue (z=0.6), green (z=1.1), and red (z=1.5)
- Over 500 million galaxies on the full sky

Uses photometric samples and n(z) distirbution.

Blue (z~0.6): $(f_b/0.158)\ (f_{free}/1.0) = 0.65$ +/- 0.24

Green (z~1.1): $(f_b/0.158)\ (f_{free}/1.0) = 2.24$ +/- 0.23

Red (z~1.5): $(f_b/0.158)\ (f_{free}/1.0) = 2.87$ +/- 0.56

S/N = 5.5

No missing baryons!

Kusiak+2021

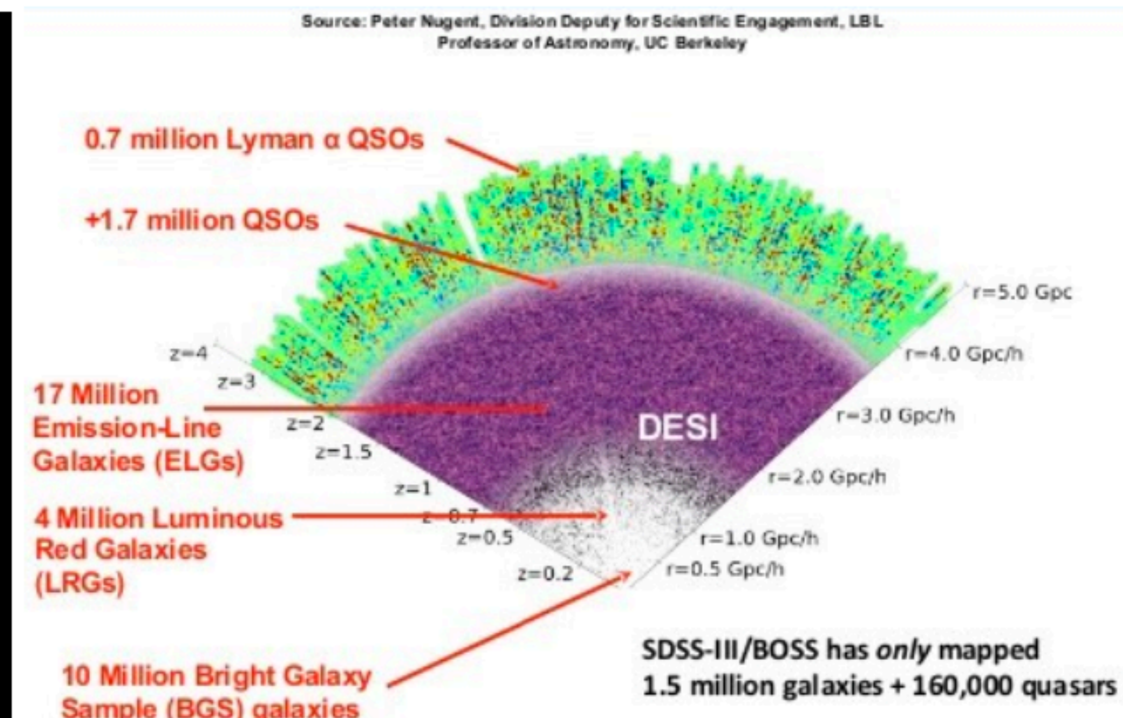
Slide: Ola Kusiak

Looking Forward

DESI has started!

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science



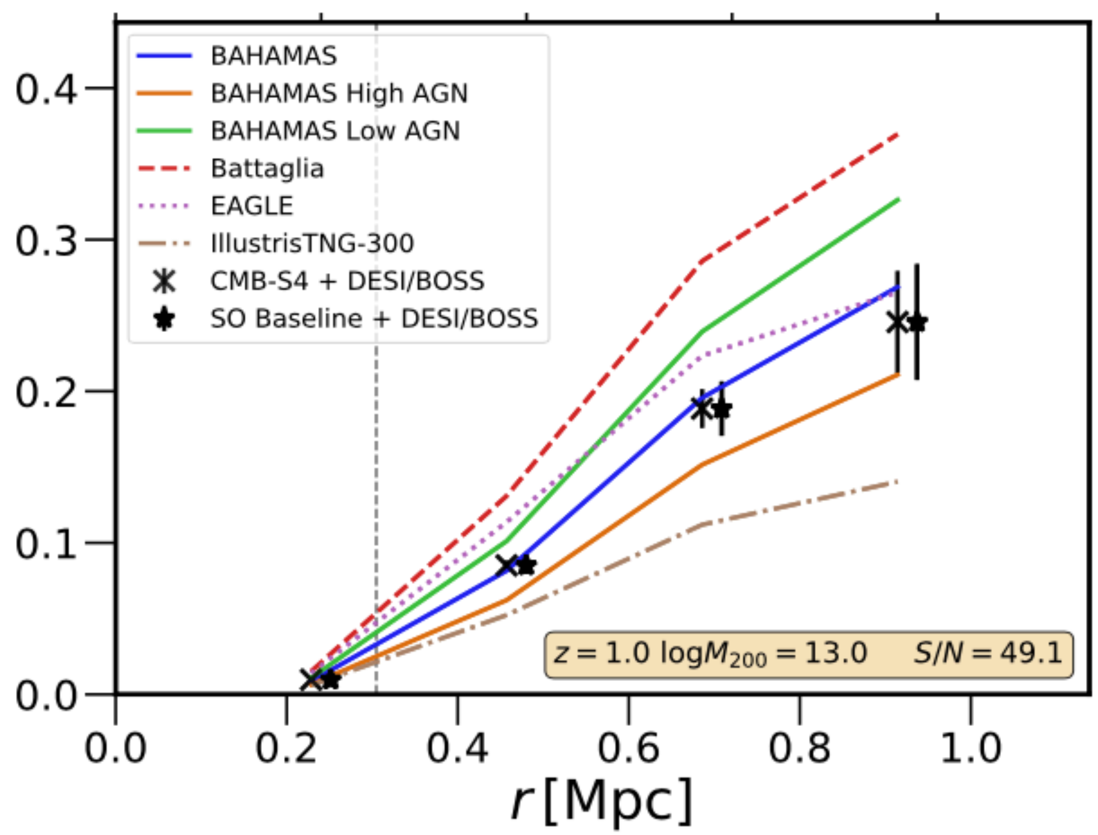
Commissioning complete, main survey ongoing until 2025
5k fiber spectrograph on 4m Mayall telescope
35M redshifts over 14k deg^2

In 2.5 months, DESI gathered as many redshifts as BOSS+eBOSS in 10 years!

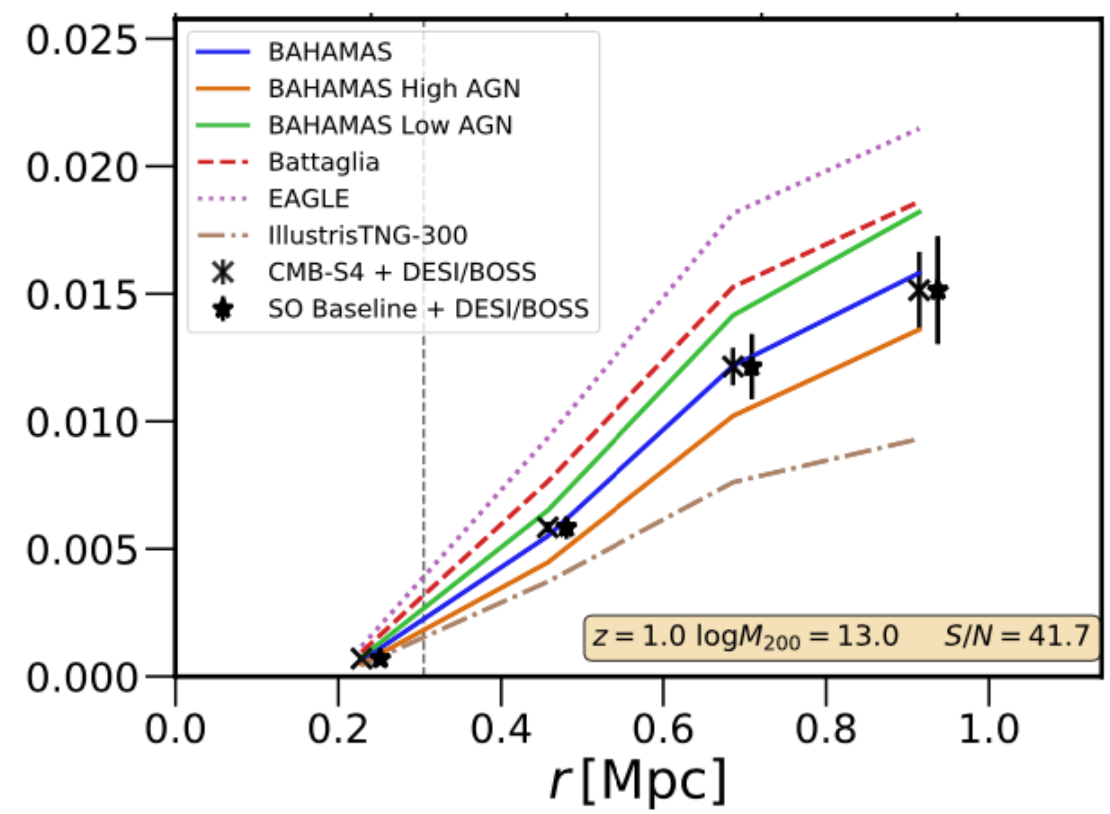
Slide: Emmanuel Schaan

CMB S4 and DESI

kSZ cumulative profile



tSZ cumulative profile



CMB S4 DSR, Battaglia+17

and lensing profiles for the same halos!

Slide: Emmanuel Schaan

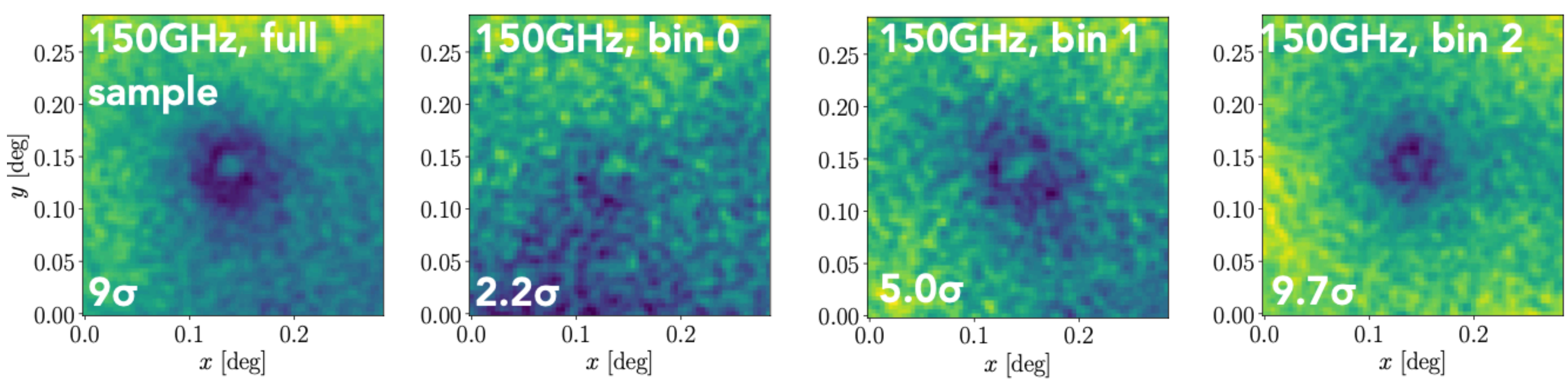
Joint Analysis tSZ + lensing

S Amodeo, A Amon, F Ardila, H Aung, N Battaglia, J deRose, S Ferraro, S Huang, J Lange, A Leauthaud, D Nagai, A Roman, E Schaan, A Schneider

Joint analysis of tSZ, gg lensing, RSD for BOSS galaxies

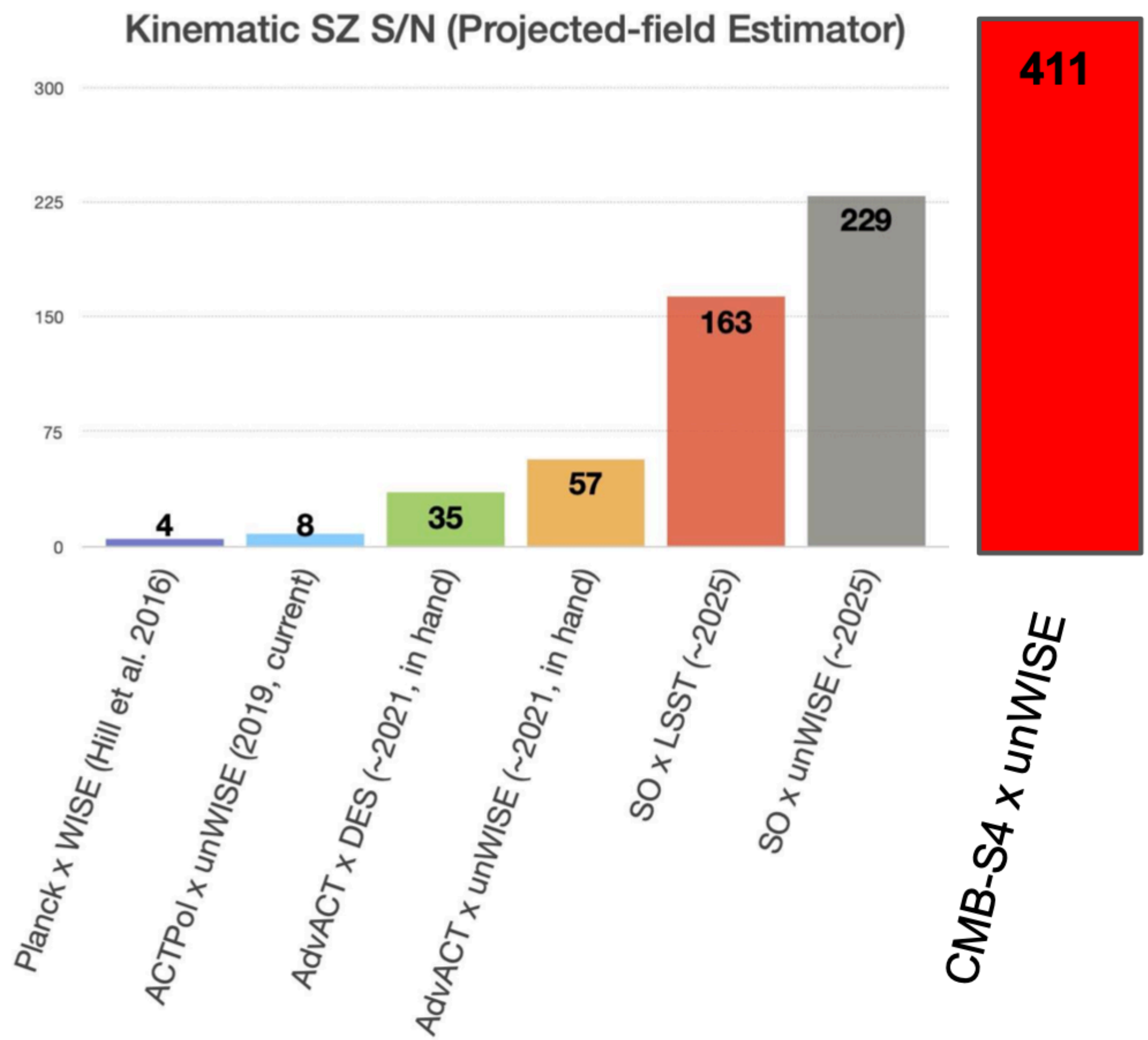
Investigate low lensing tension depending on host halo mass

3 Stellar mass bins = [$10^{11.4}$ - $10^{11.57}$[,
[$10^{11.57}$ - $10^{11.75}$[,
[$10^{11.75}$ - $10^{13.0}$]



Slide: Emmanuel Schaan

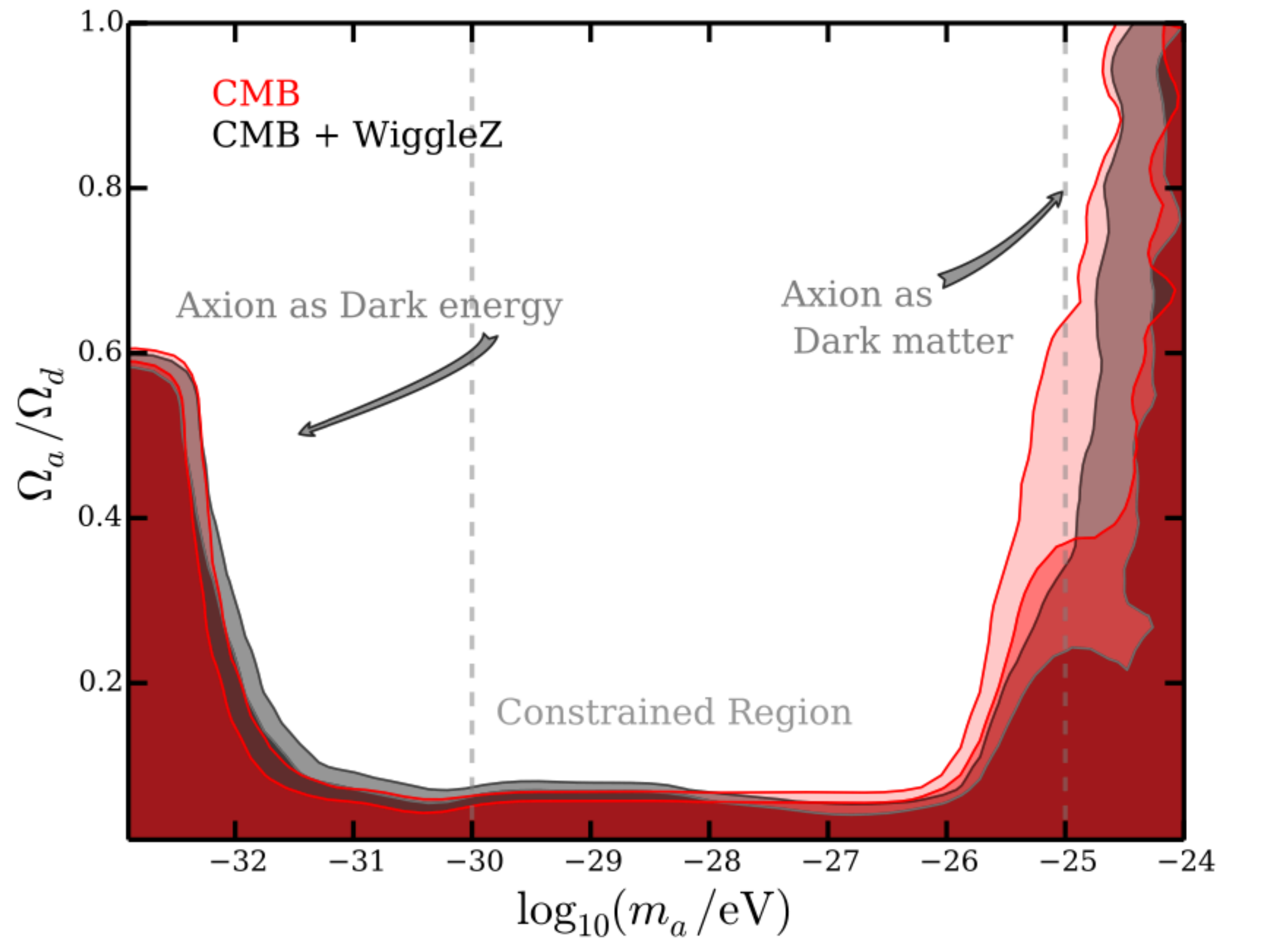
Projected Field kSZ



Ferraro+2016

Slide: Ola Kusiak

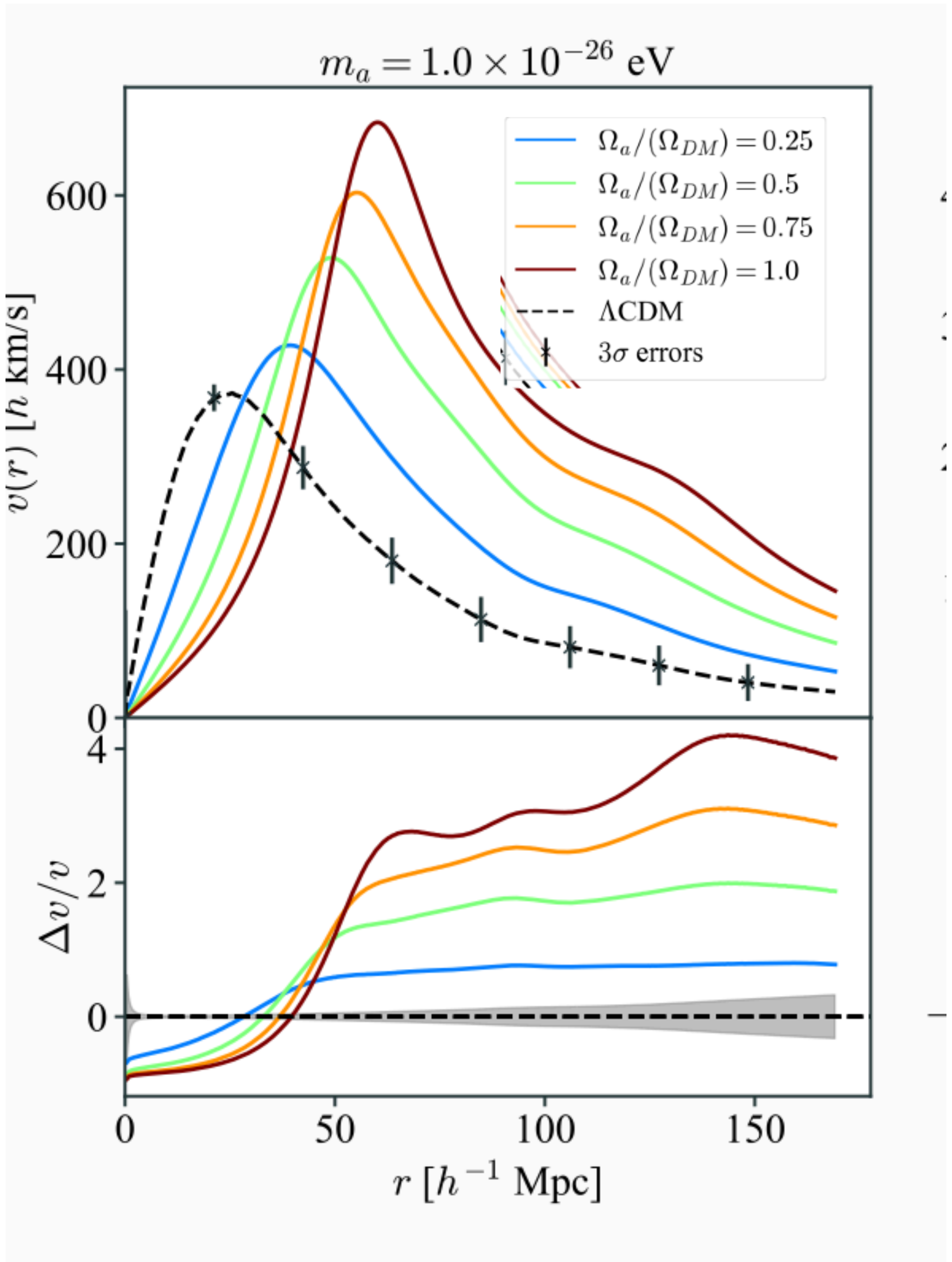
Constraining Ultra Light Axions with kSZ



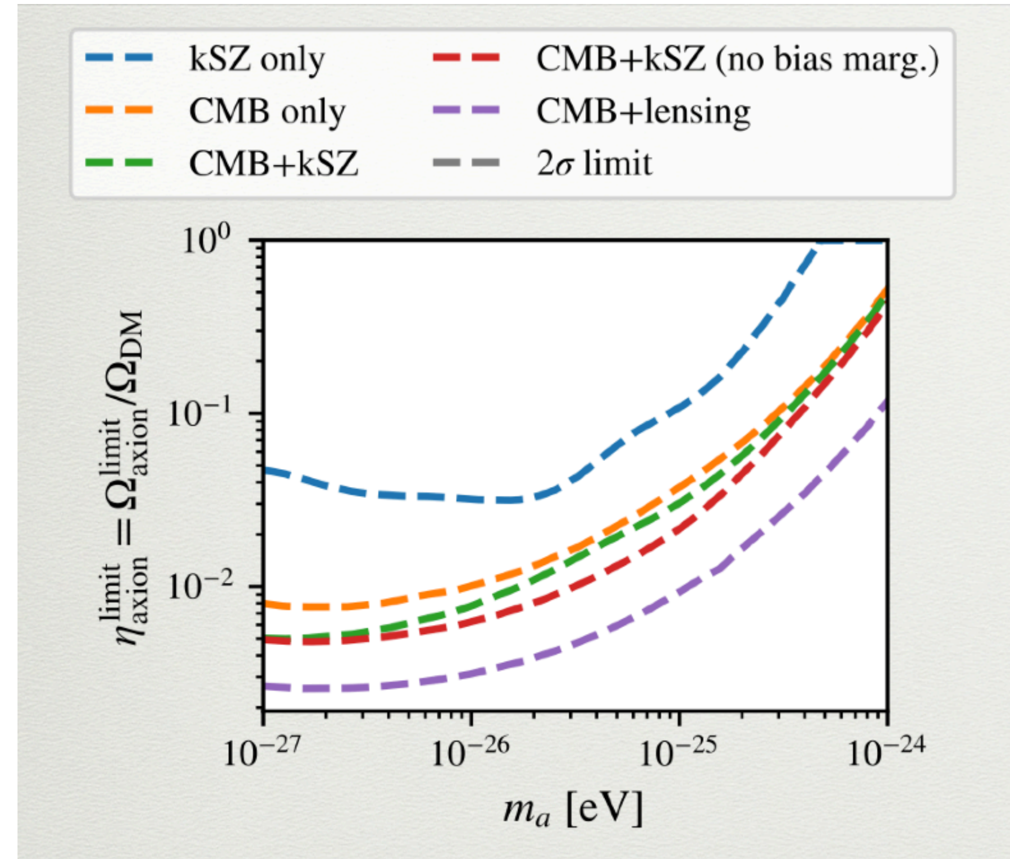
- **Strong constraints from primary CMB :Hlozek ++ (2014,2017), Cookmeyer ++ (2019).**
- **Computed using axion CAMB (Grin et al. 2013)**

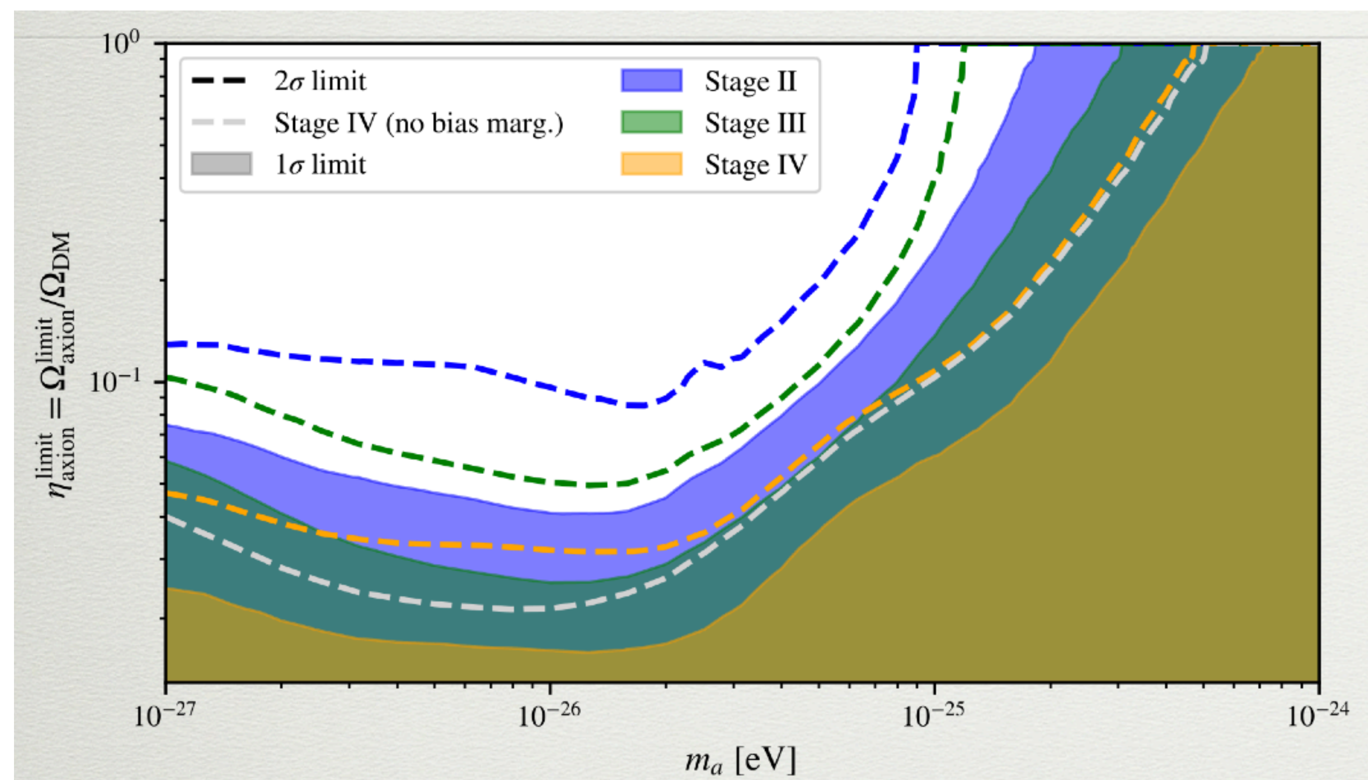
Slide: Daniel Grin

Predicted Constraints



Impact of ultra light axions on pairwise velocities

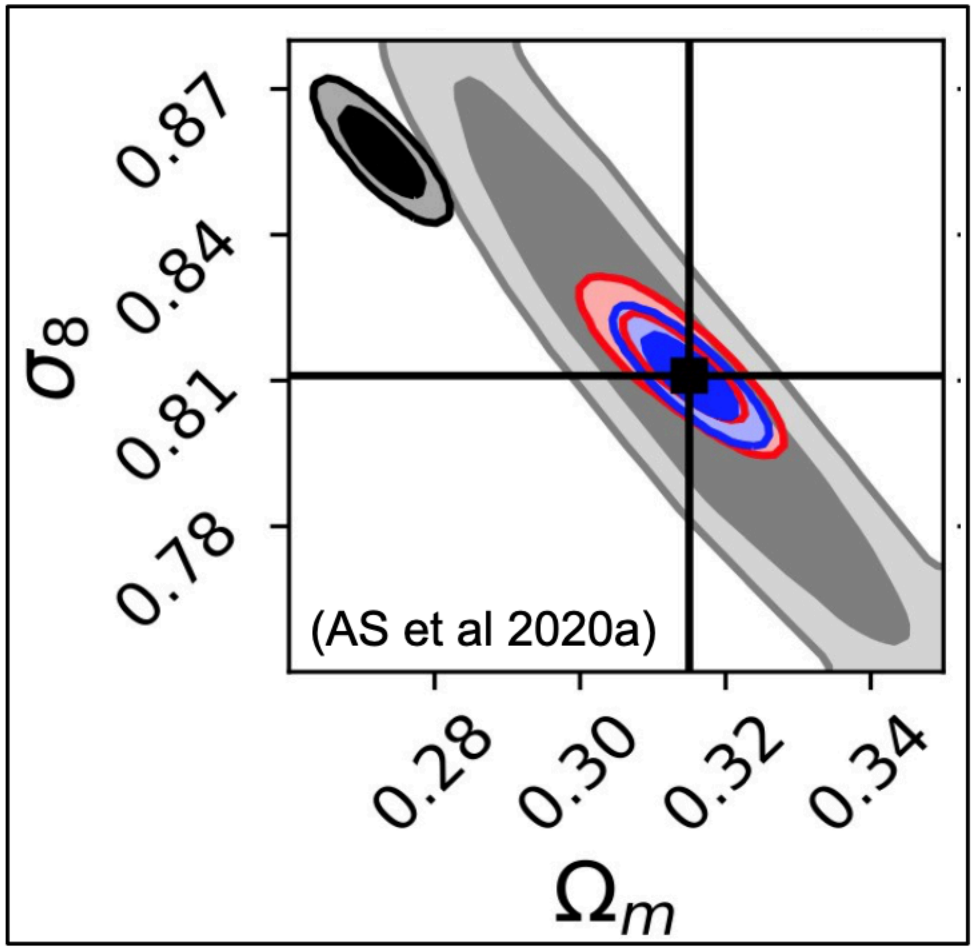


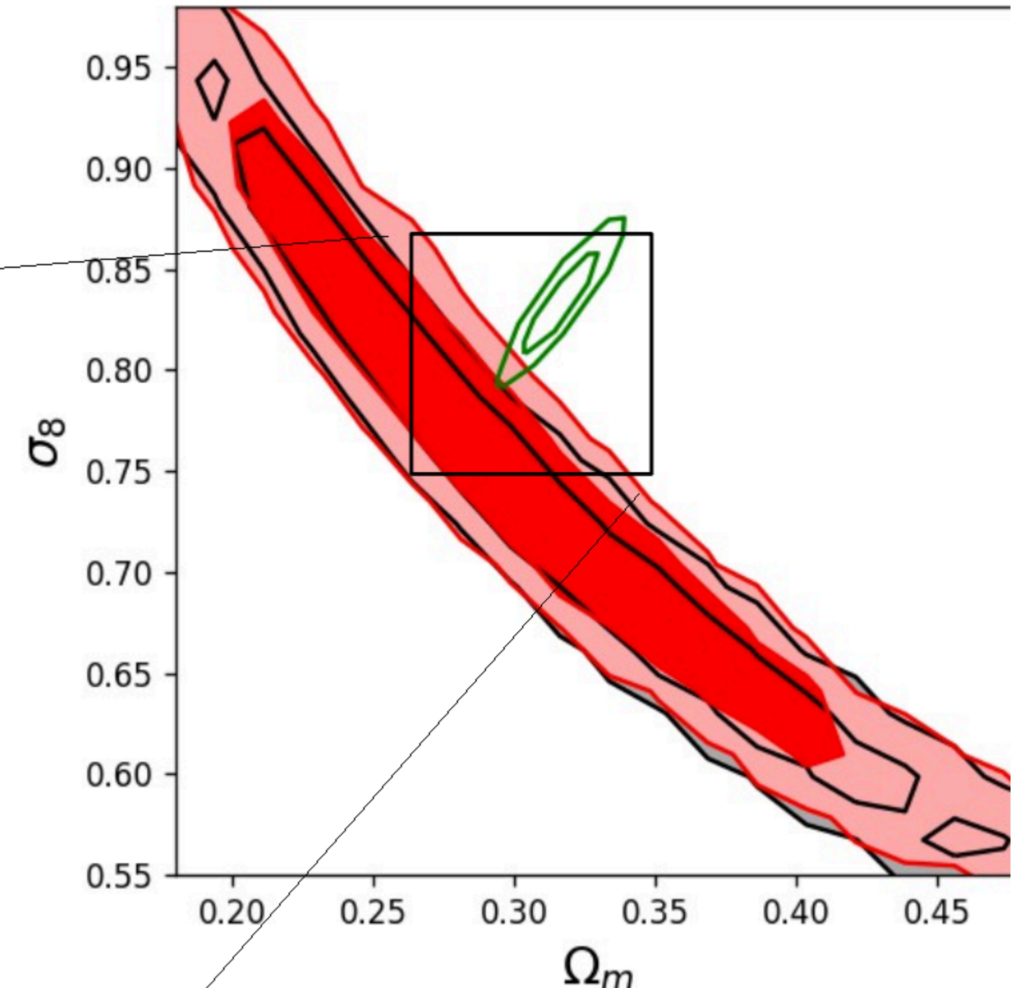


Slide: Daniel Grin

Baryonic effects for Euclid

Marginalised baryonic params (red)
Fixed baryonic params (blue)
Ignoring baryons (black)

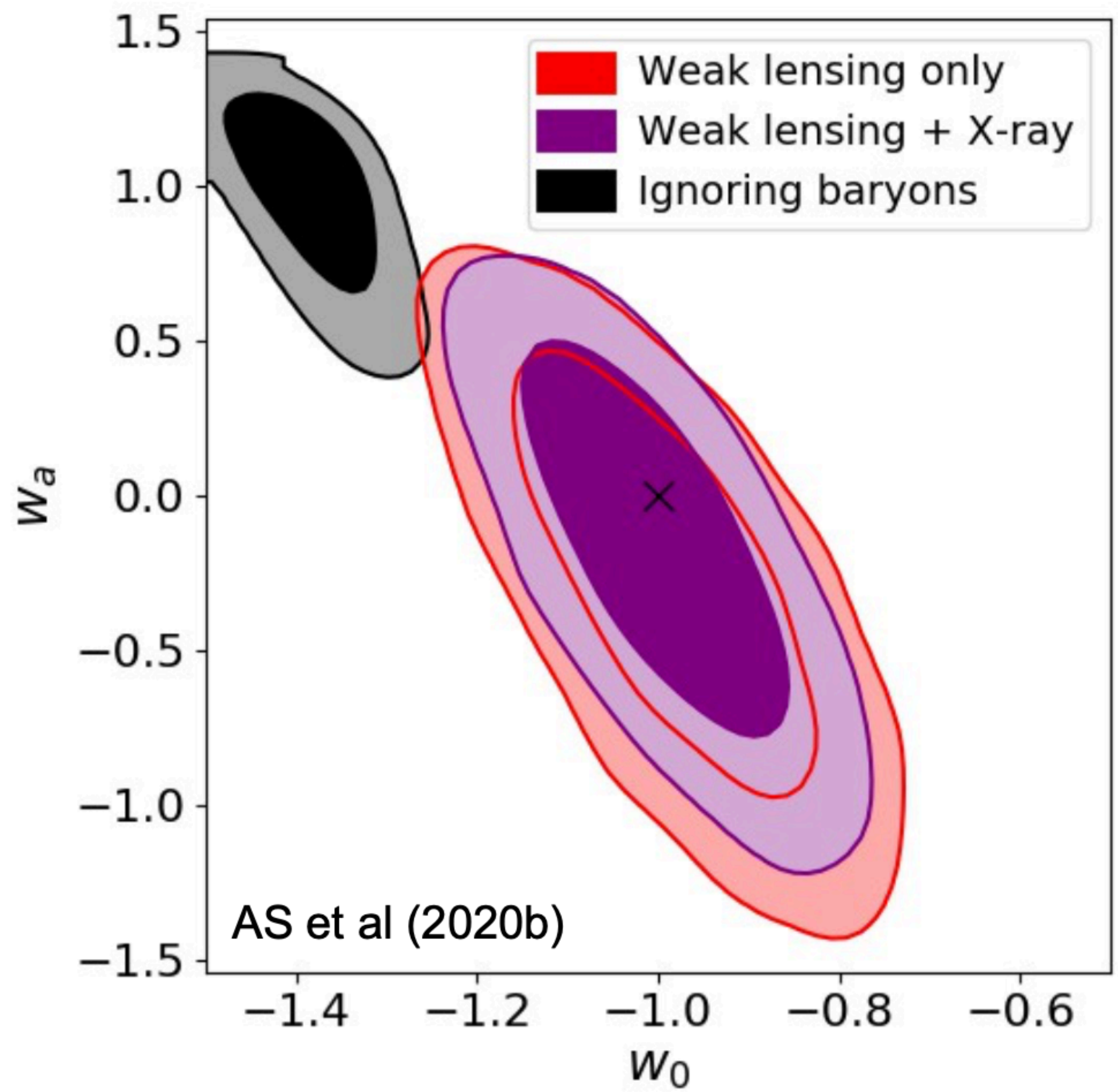




Slide: Aurel Schneider

Cannot ignore baryons!

wCDM cosmology

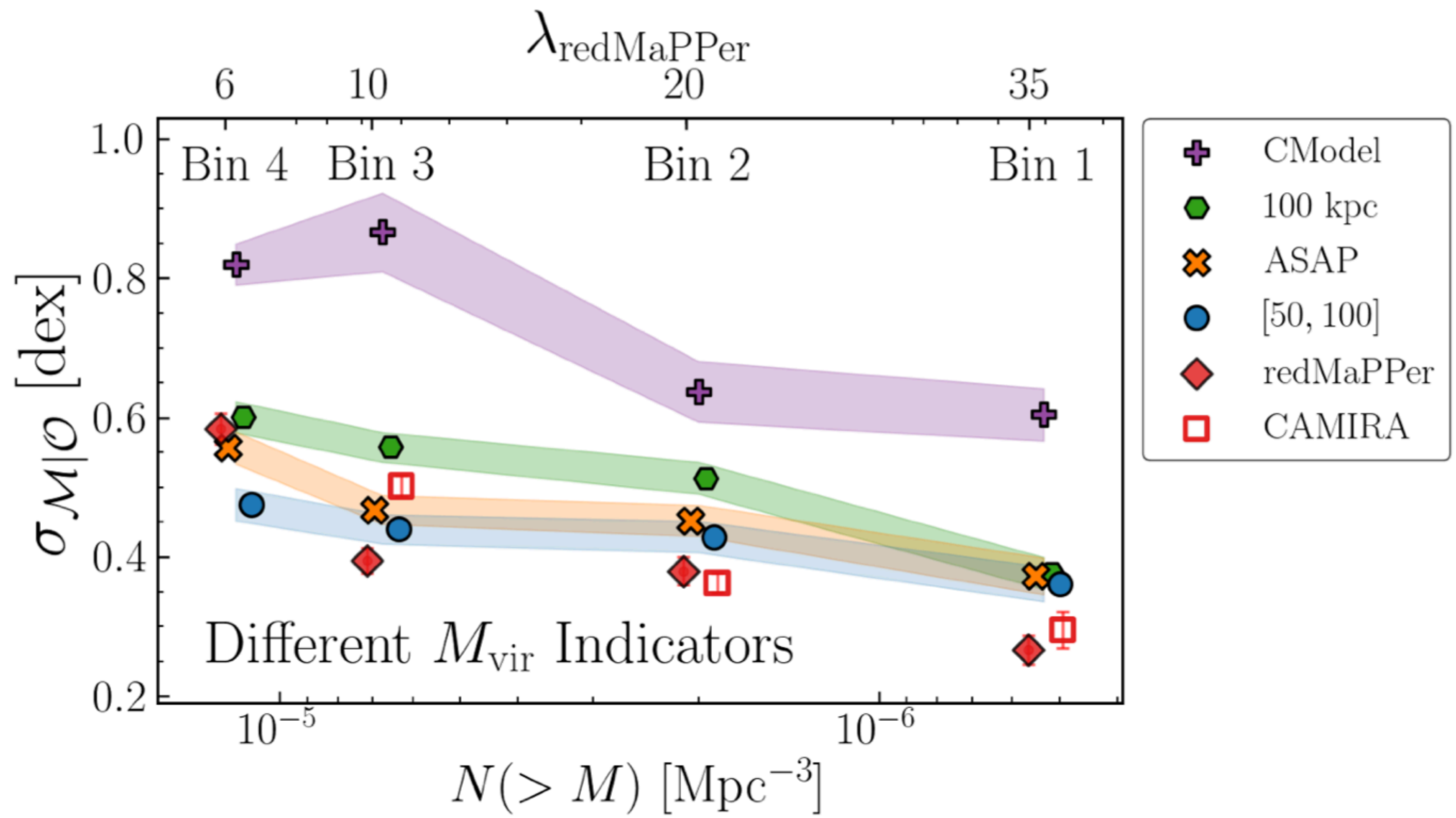


Slide: Aurel Schneider

New Frontiers

Larger overlap between surveys and new methods for finding dark matter halos will allow for the calibration of baryonic effects as a function of halo mass.

Galaxy outer mass



A number of advantages: no evidence for mis-centering or projections effects. Working to make this tracer available for DESI.

Huang et al. 2021, on the arXive in September

Slide: Alexie Leauthaud

Discussion

No missing baryons in projected field kSZ?
Too early to say.

A lot of discussion on how baryons impact the primary CMB (short answer: from CMB lensing and Alens).

kSZ : spectroscopic samples versus photometric samples?
Loose a factor of 2 in S/N with photometric samples and harder to model. But sample sizes are significantly larger.

A lot of excitement about DESI!
Many opportunities afforded by DESI x ACT then DESI x SO.
Needs cross collaborative groups working on joint simulations and joint mock challenges.