COSMOLOGY FROM WEAK LENSING ALONE AND IMPLICATIONS FOR THE HUBBLE TENSION

Based on arXiv:2104.12880

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WHO AM I?

Post-doc at the Institute for Astronomy, University of Edinburgh.

Recent work:

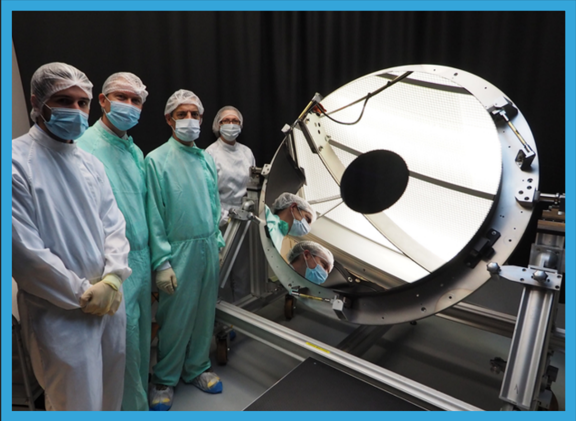
- *Weak lensing and galaxy clustering analysis techniques*
- *Gravitational wave source populations, primordial black holes*

Less recent work:

- *21cm intensity mapping, CMB lensing, relativistic effects in cosmology, non-linear modelling, …*

Member of ESA *Euclid* Consortium:

- Co-lead of Weak Lensing Estimators Work Package and Pre-Launch Key Project
- Euclid UK Coordination Group

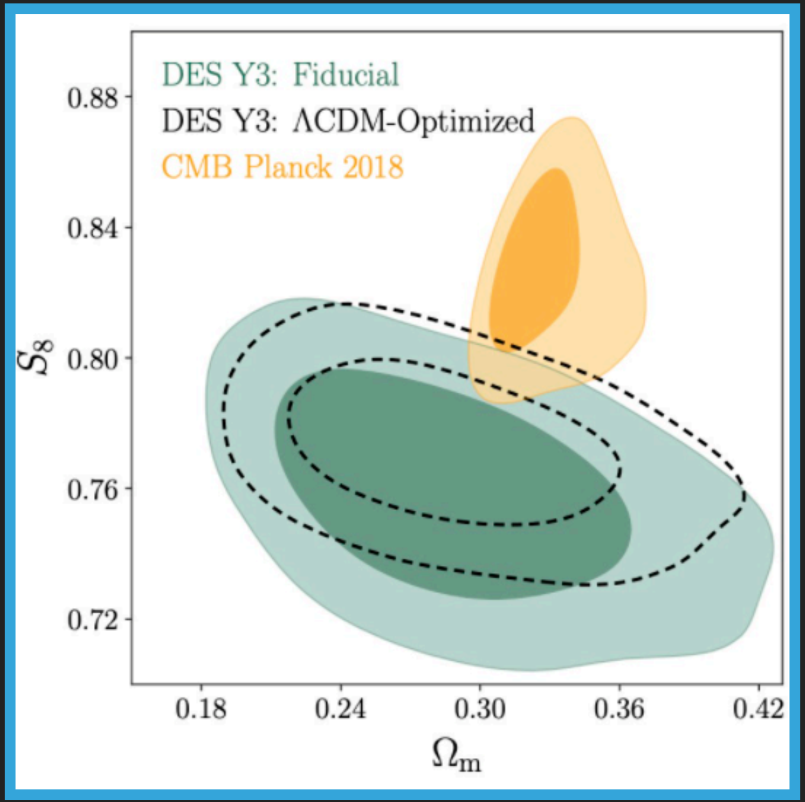


OUTLINE OF THIS TALK

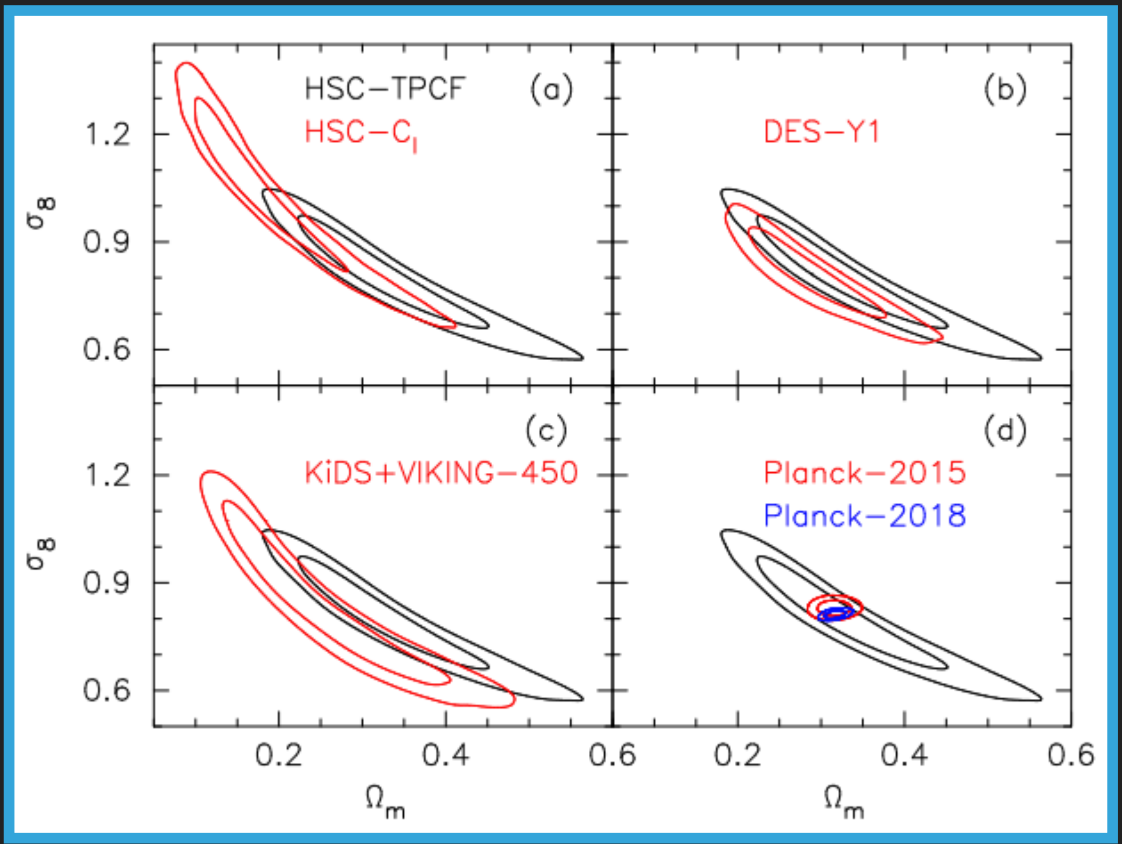
- CURRENT STATE OF COSMIC SHEAR COSMOLOGY
- WHAT DOES WEAK LENSING TELL US ABOUT THE UNIVERSE?
- WHAT DOES WEAK LENSING NOT TELL US ABOUT THE UNIVERSE?
- WHAT CAN WEAK LENSING TELL US ABOUT THE HUBBLE CONSTANT?

LATEST RESULTS FROM COSMIC SHEAR

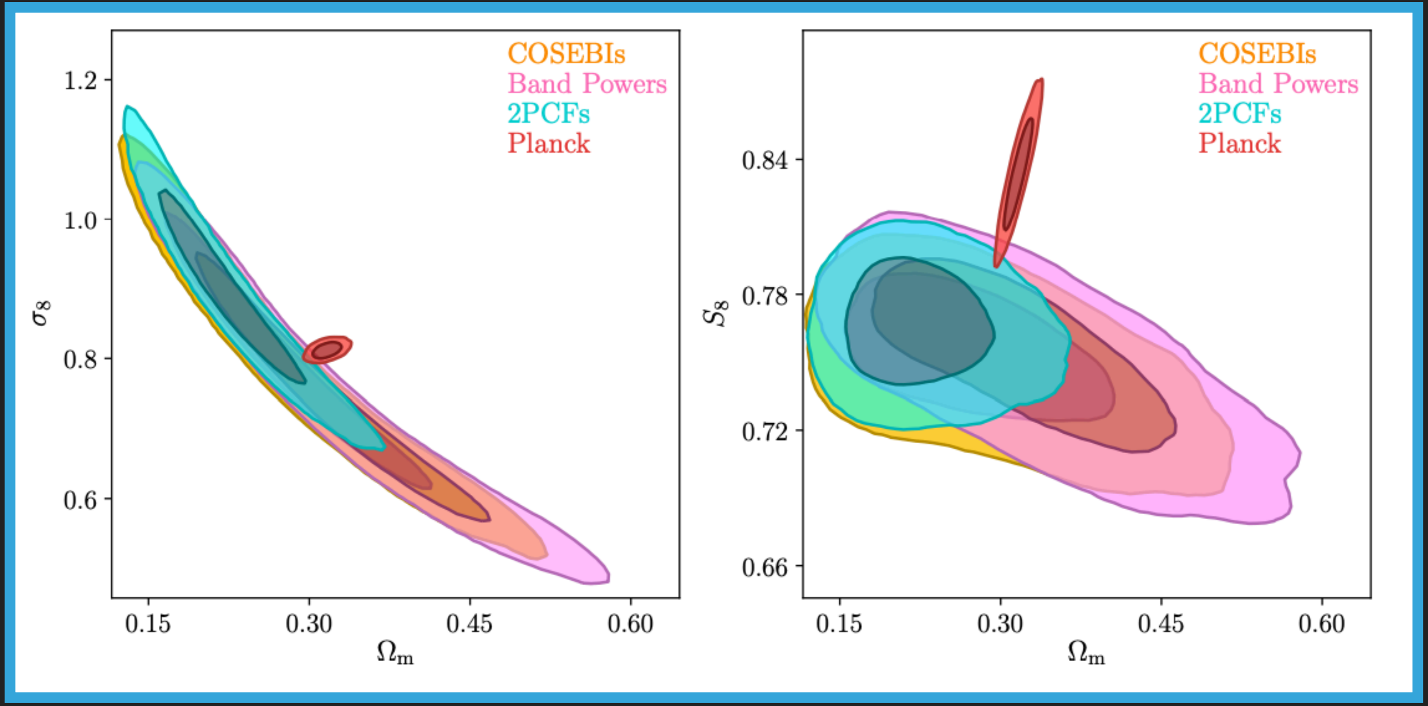
$$S_8 \propto \sigma_8 \Omega_m^{0.5}$$



DES Collaboration, Amon et al. 2021



HSC Collaboration, Hamana et al. 2019 (Erratum 2022)



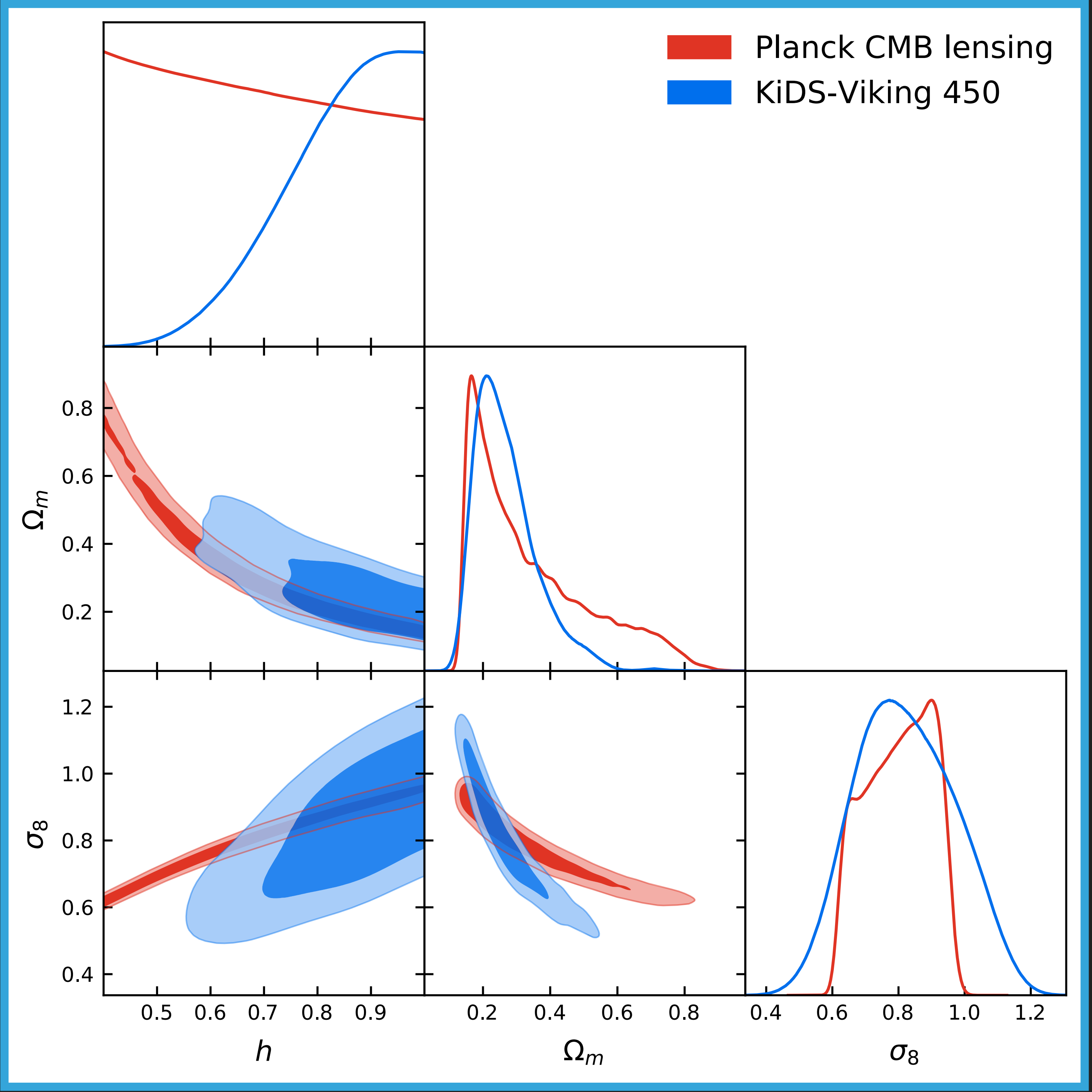
KiDS Collaboration, Asgari et al. 2020

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

Constrain well the combination

$$S_8 \propto \sigma_8 \Omega_m^{0.5}$$

Poor constraints on almost every other parameter combination



COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

CMB lensing

Constrain well **two** of the combinations

We understand this! →

$\sigma_8 h^{-0.5}$	Small-scale amplitude
$\Omega_m^{0.6} h$	Peak in the matter power spectrum (in projection)
$\sigma_8 \Omega_m^{0.25}$	Amplitude and shape

Galaxy weak lensing

Constrain well the combination

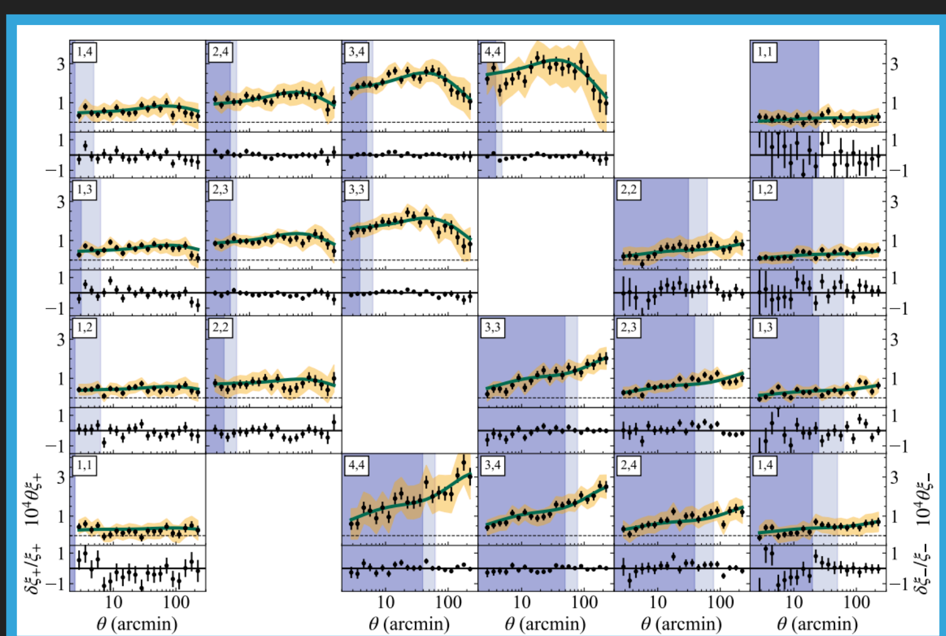
Do we understand this? →

$$\boxed{S_8 \propto \sigma_8 \Omega_m^{0.5}}$$

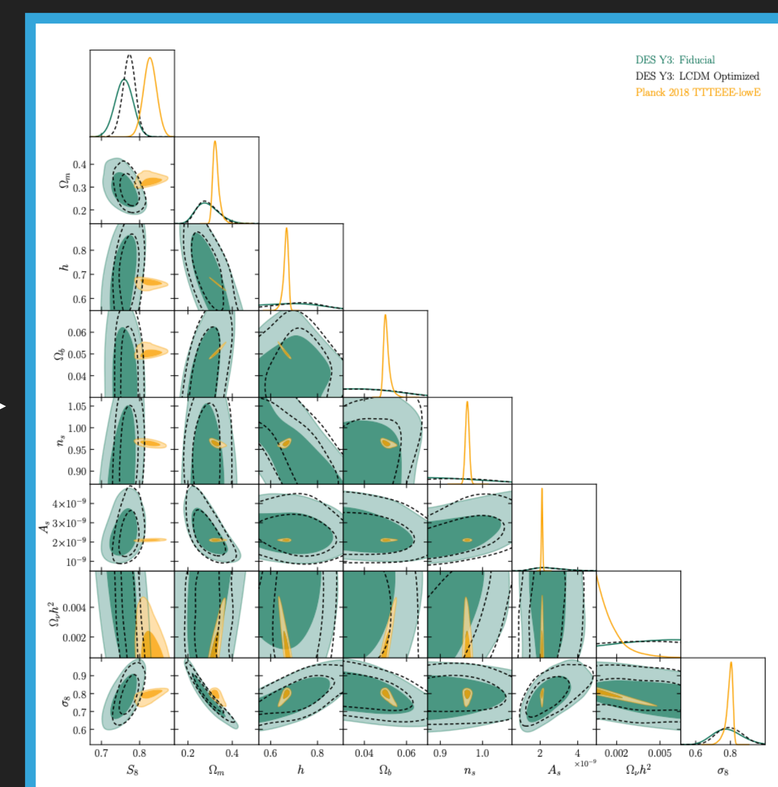
Poor constraints on almost every other parameter combination

WHY IS IT IMPORTANT TO UNDERSTAND WHERE PARAMETER INFORMATION COMES FROM?

1) A sanity check on parameter posteriors



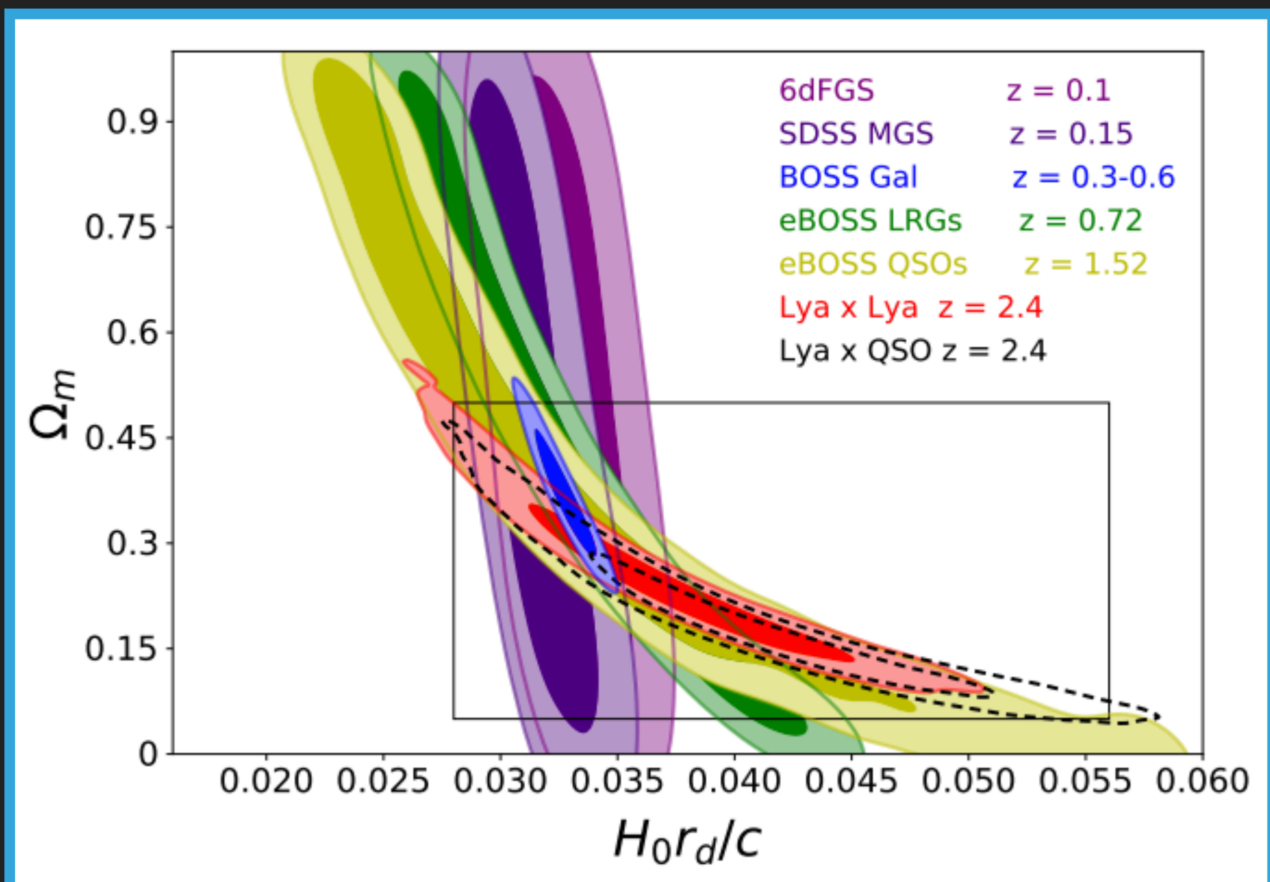
?



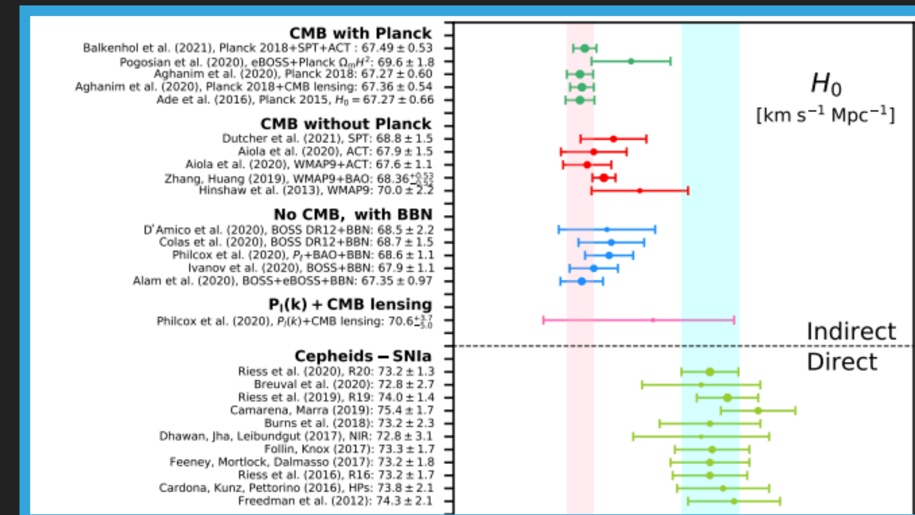
DES Collaboration, Amon et al. 2021

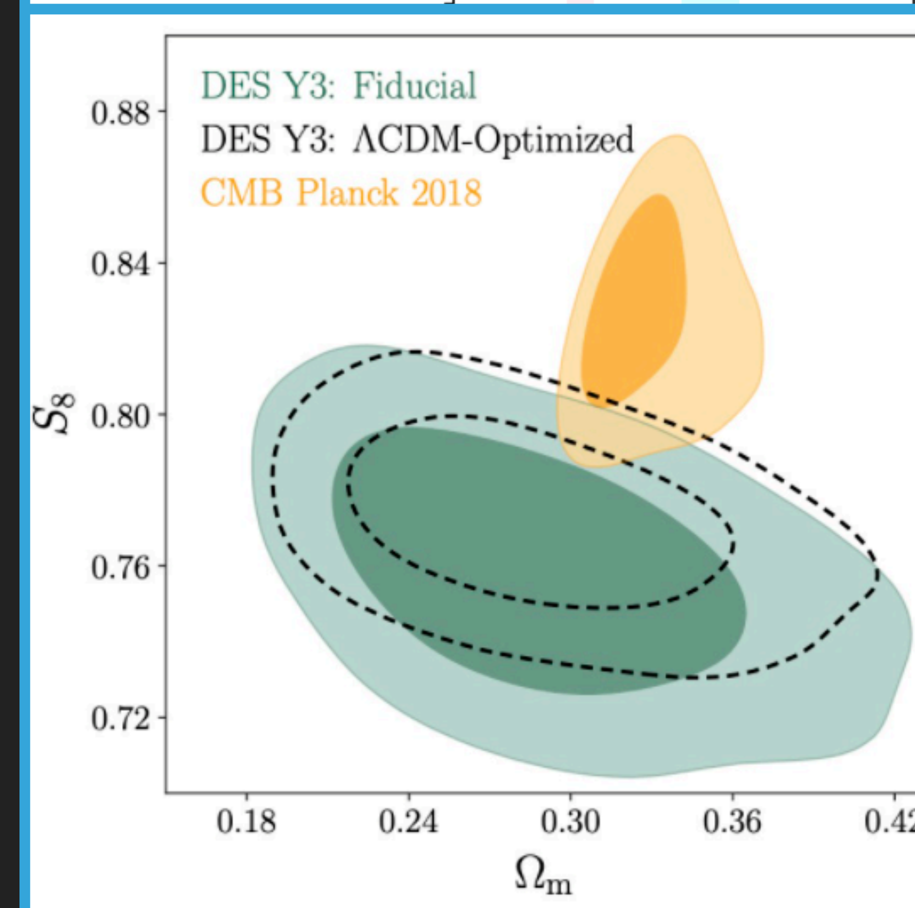
WHY IS IT IMPORTANT TO UNDERSTAND WHERE PARAMETER INFORMATION COMES FROM?

2) Lambda-CDM may need modifying



Cuceu et al. 2019





Di Valentino et al. 2021, Amon et al. 2021

QUESTIONS

1) **Where** does parameter information come from in weak lensing? Why are some parameter combinations constrained well and some not so well?

2) *Tensions:* Why does weak lensing tell us about S8 and not H0?

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

$$C_\ell^{\gamma\gamma} = \frac{9}{4}\Omega_m^2 H_0^4 \int_0^{z_s} \frac{\mathrm{d}z}{H(z)} \left[\frac{r(z_s) - r(z)}{r(z_s)}\right]^2 (1+z)^2 P_m\left(\frac{\ell}{r(z)}; z\right)$$

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Gravitational potential gradients cause deflection.
Gradients in the deflection cause shear.

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

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Gravitational potential gradients cause deflection.
Gradients in the deflection cause shear.

Shear distortions are the net effect of many small deflections along the photon path

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

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$$\sim \frac{\Omega_m^2}{\ell^3} \int_0^{z_s} \frac{\mathrm{d}z}{H(z)/H_0} \left[\frac{r(z_s) - r(z)}{r(z_s)}\right]^2 (1+z)^2 [H_0 r(z)]^3 \Delta_m^2\left(\frac{\ell}{r(z)}; z\right)$$

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COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\rm max}} {\rm d}z\; F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

$$\Delta^2(k) \equiv \frac{k^3}{2\pi^2}P_m(k)$$

The dimensionless matter power spectrum with k in h/Mpc units

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The dimensionless matter power spectrum with k in h/Mpc units

Physically: lensing introduces no new length scales on top of those already present in the matter distribution.

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\max}} \mathrm{d}z\ F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

Usual hand-wavy argument: $\Delta^2 \sim \sigma_8^2$

$$\implies C_\ell \sim \sigma_8^2\Omega_m^2$$

i.e. gets the dependence wrong!

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\max}} \mathrm{d}z \; F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

More precise: Jain & Seljak 1997 $\quad \xi_+(\theta) \sim \sigma_8 \Omega_m^\alpha$

Using linear theory and the Peacock & Dodds 1996 formula for the non-linear P(k)

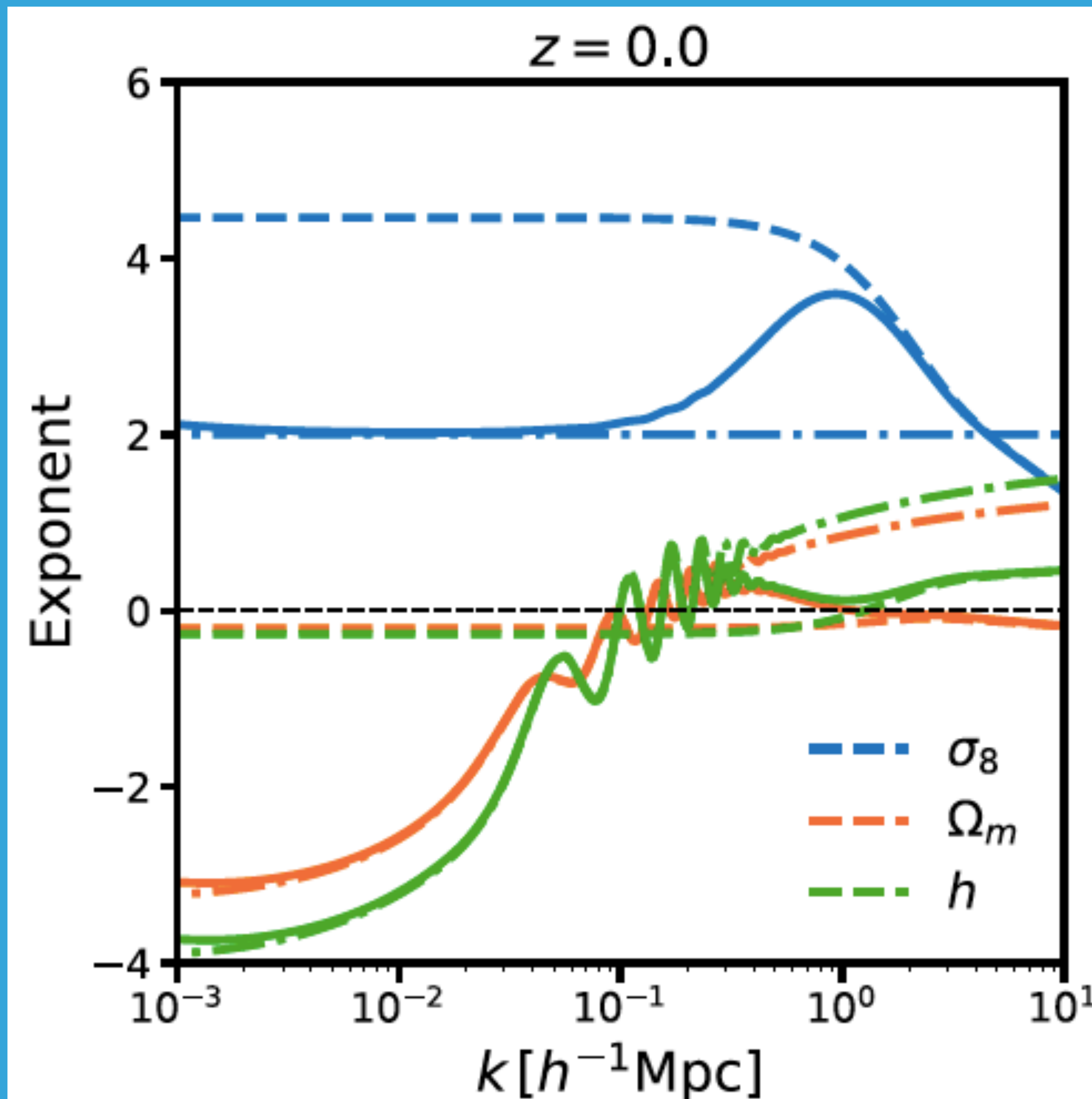
$\alpha \lesssim 0.5 \qquad \theta \lesssim 2'$

$\alpha \approx 0.7 \qquad \theta > 10'$

See also: Kaiser 1992, Villumsen 1996, Bernardeau, van Waerbeke, Mellier 1997

PARAMETER SENSITIVITY IN THE HALO MODEL

$$\lim_{k\to 0} \Delta^2_{1H}(k) = \frac{(k/h)^3}{2\pi^2}\frac{h^3}{\bar{\rho}^2}\int_0^\infty M^2 n(M)\mathrm{d}M$$



$$\lim_{k\to 0} \Delta^2_{1H}(k) \propto (k/h)^3 \sigma_8^{4.3}$$

Most of the contribution to the 1-halo amplitude at z=0 comes from Lagrangian scales around 8 Mpc/h.

$$\Delta^2(k/h) \sim \sigma_8^\alpha \Omega_m^\beta h^\gamma$$

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\max}} \mathrm{d}z\, F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

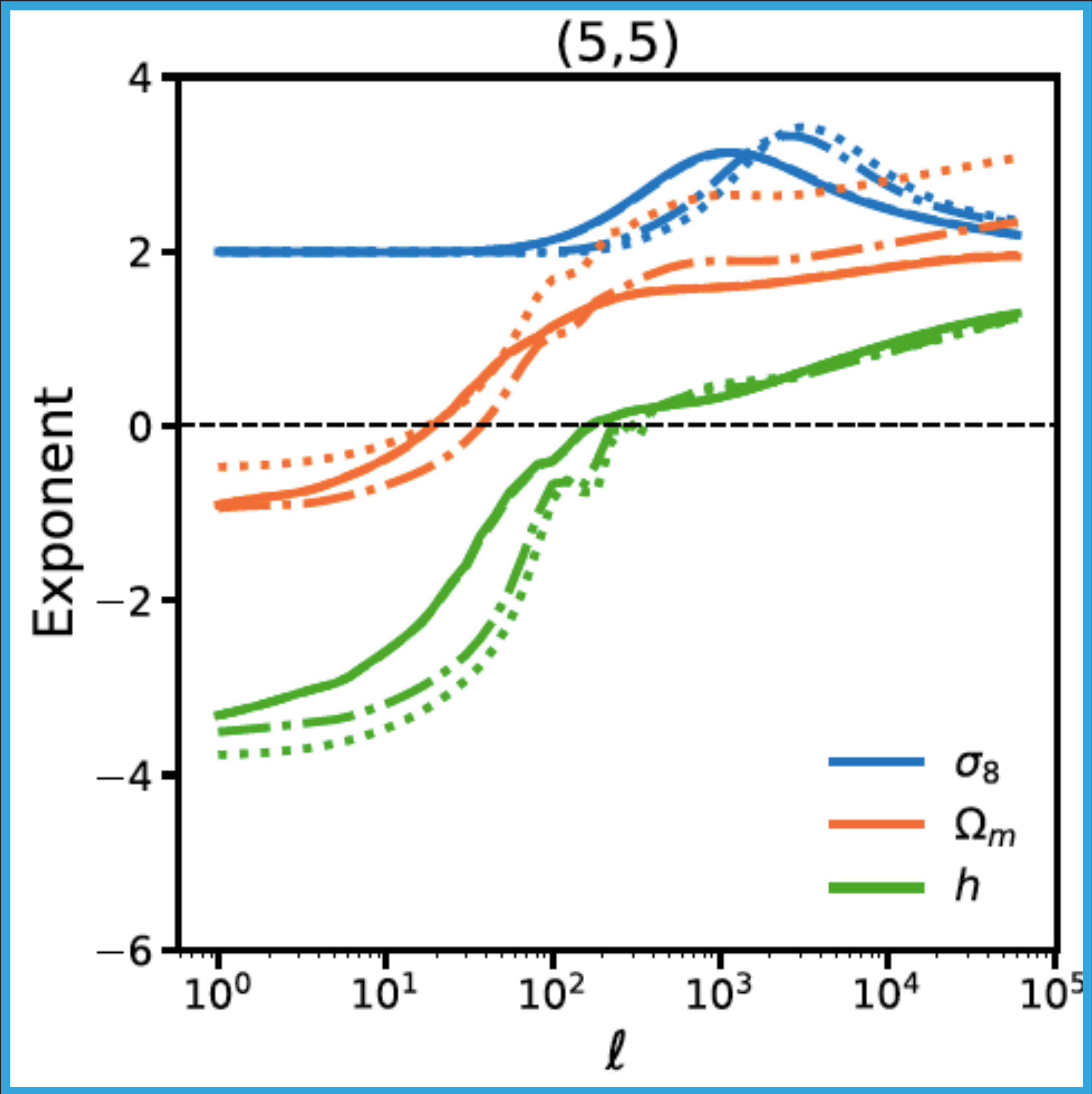
$$\lim_{k\to 0} \Delta^2_{1H}(k) \propto (k/h)^3 \sigma_8^{4.3}$$

$$\implies C_\ell^{\gamma\gamma} \propto \Omega_m^2 \sigma_8^{4.3} \sim S_8^4$$

On quasi-linear and 1-halo scales, h-dependence drops out completely and dependence is entirely on S8

(Not perfect due to baryon smoothing, finite-redshift effects, 1-halo shape effects, etc.)

COSMOLOGICAL INFORMATION CONTENT OF WEAK LENSING



AH 2021

$$C_\ell \sim \sigma_8^\alpha \Omega_m^\beta h^\gamma$$

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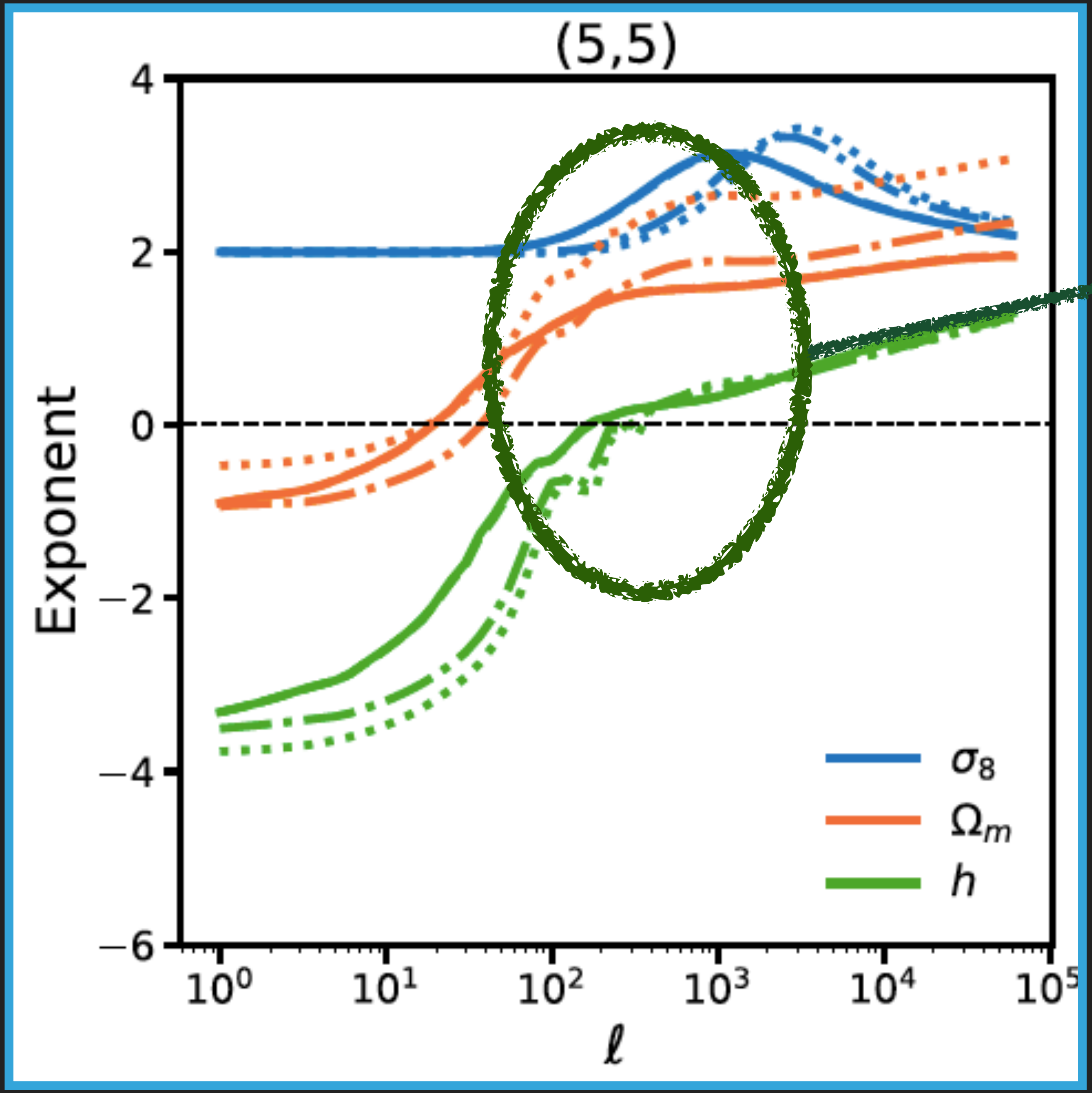

AH 2021

Most of the S/N in current surveys comes from here

$$C_\ell \sim \sigma_8^\alpha \Omega_m^\beta h^\gamma$$

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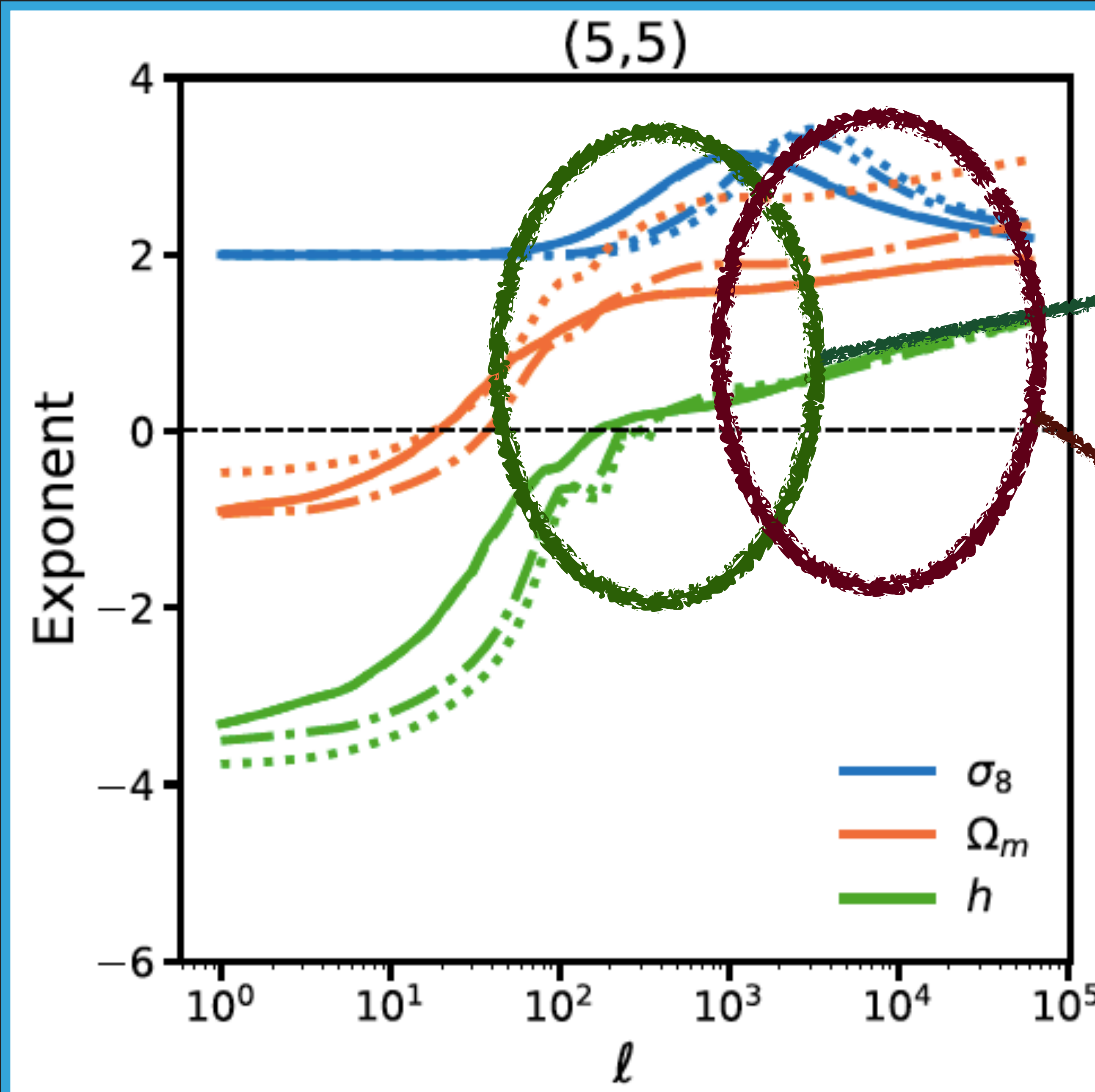

AH 2021

Most of the S/N in current surveys comes from here

Contaminated by baryon feedback!

$$C_\ell \sim \sigma_8^\alpha \Omega_m^\beta h^\gamma$$

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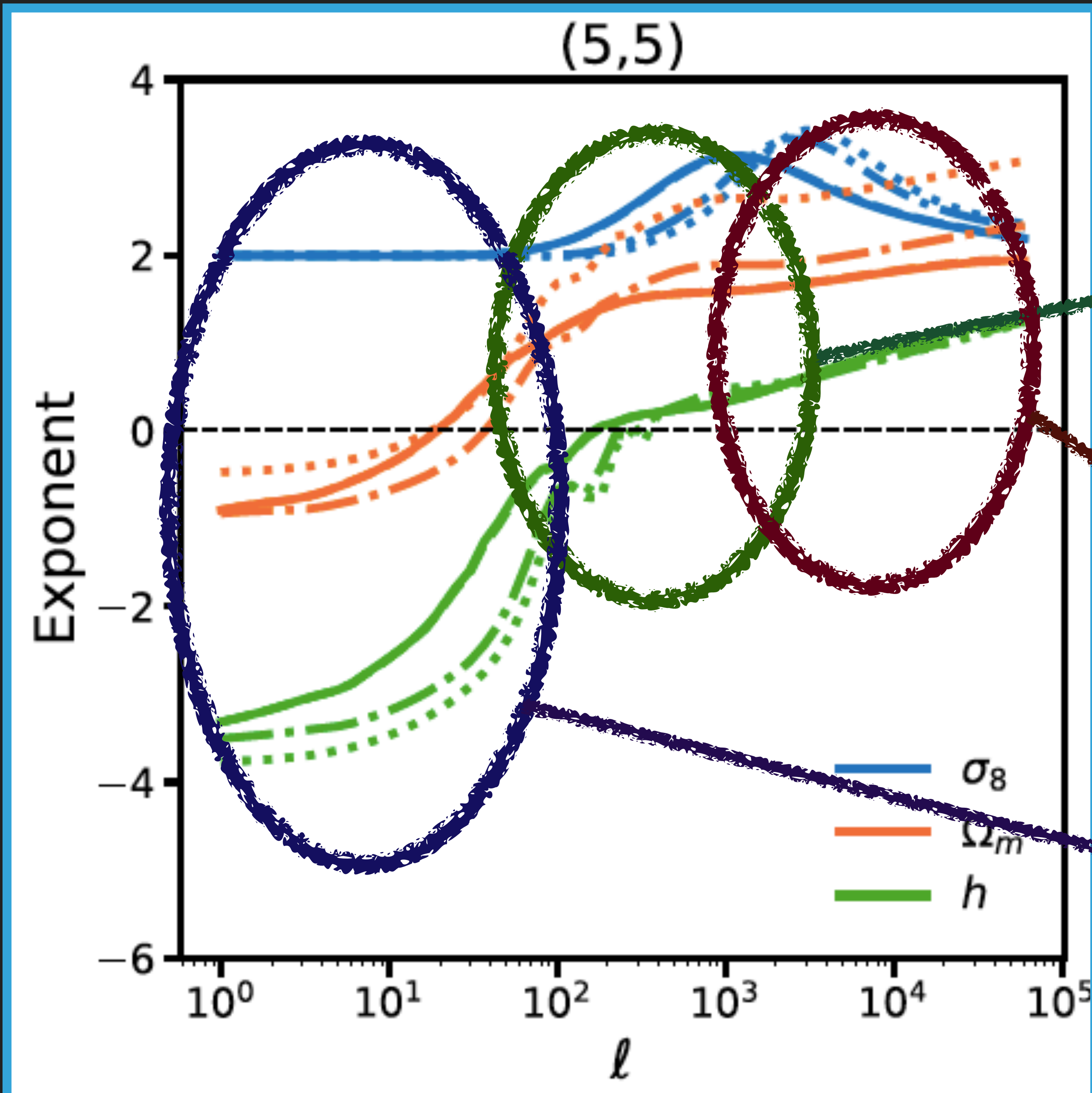

Most of the S/N in current surveys comes from here

Contaminated by baryon feedback!

Future wide surveys: break degeneracies! (Known for at least ~ 20 years)

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$$C_\ell \sim \sigma_8^\alpha \Omega_m^\beta h^\gamma$$

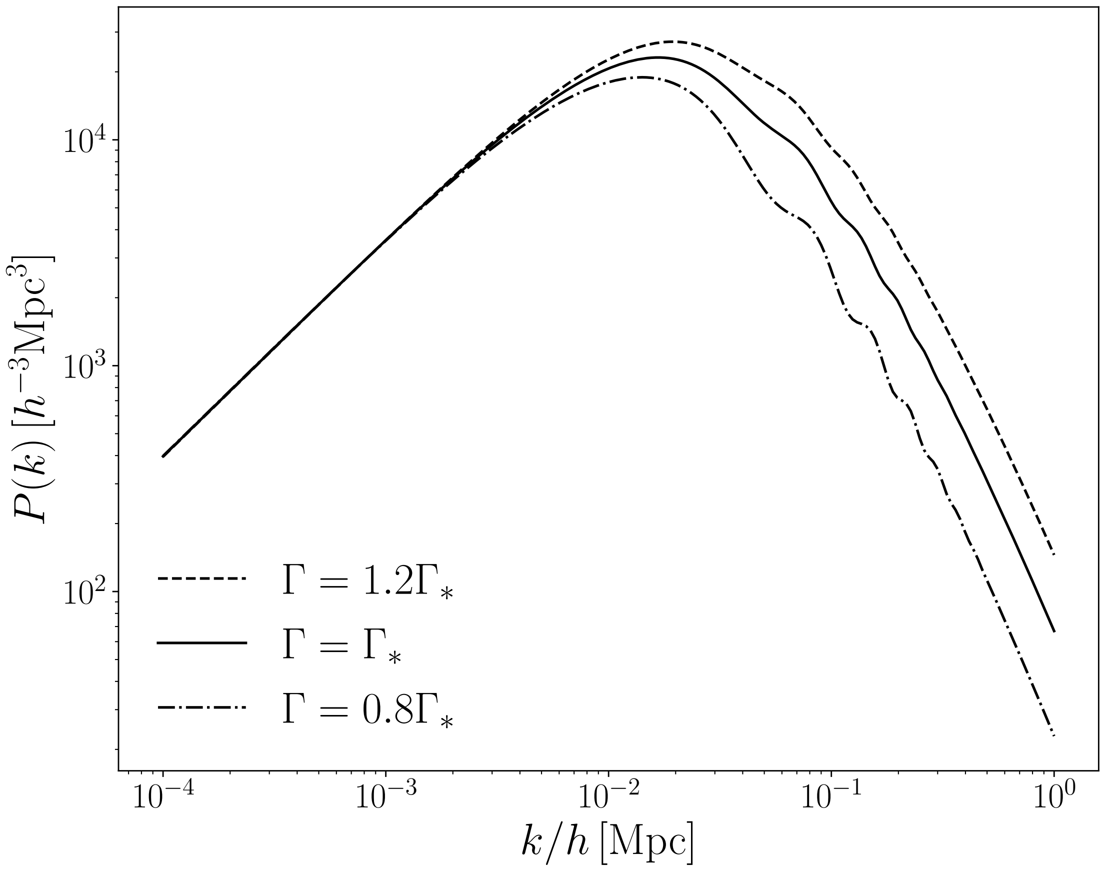
WHY SO INSENSITIVE TO H0?

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\max}} \mathrm{d}z\, F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

Fixing Ω_m to keep the lensing pre-factors fixed

$\Longrightarrow \Gamma \equiv \Omega_m h$ changes

(the horizon scale at matter-radiation equality in h/Mpc units a.k.a. the "shape parameter")



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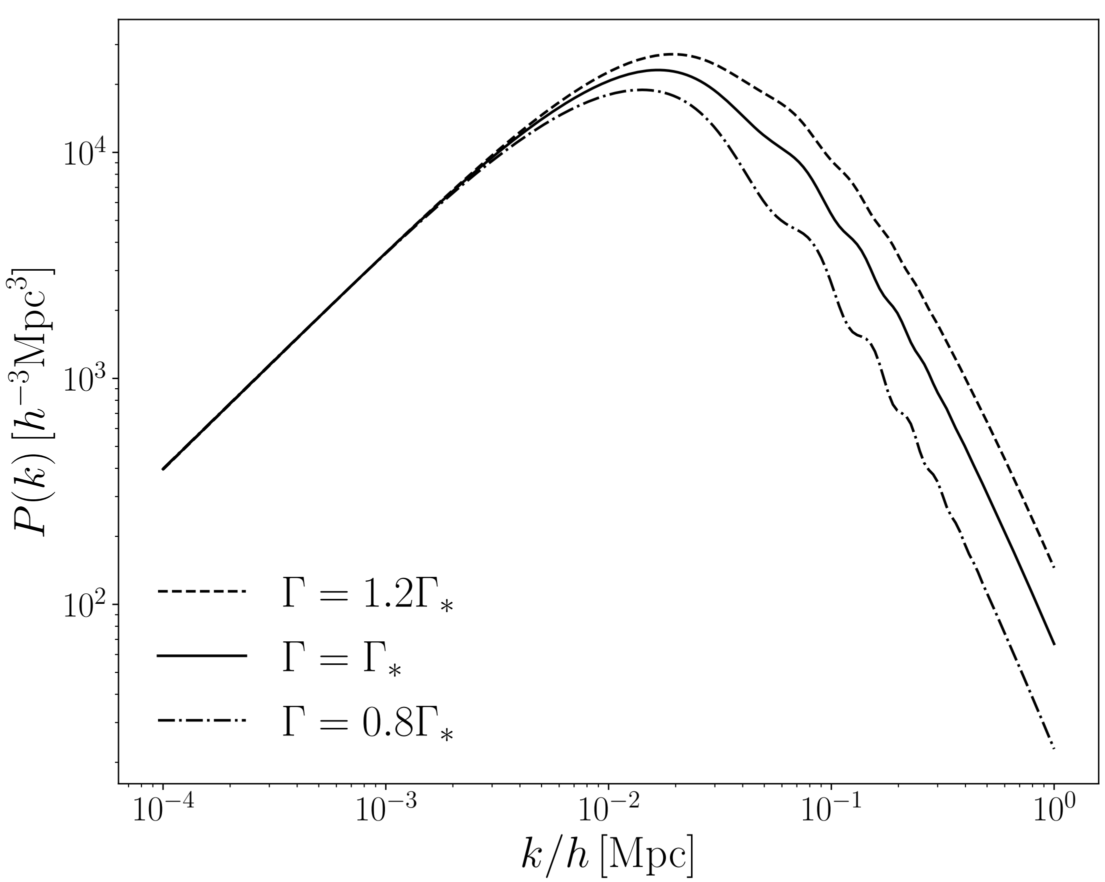


H_0 changes the small-scale amplitude at fixed A_s

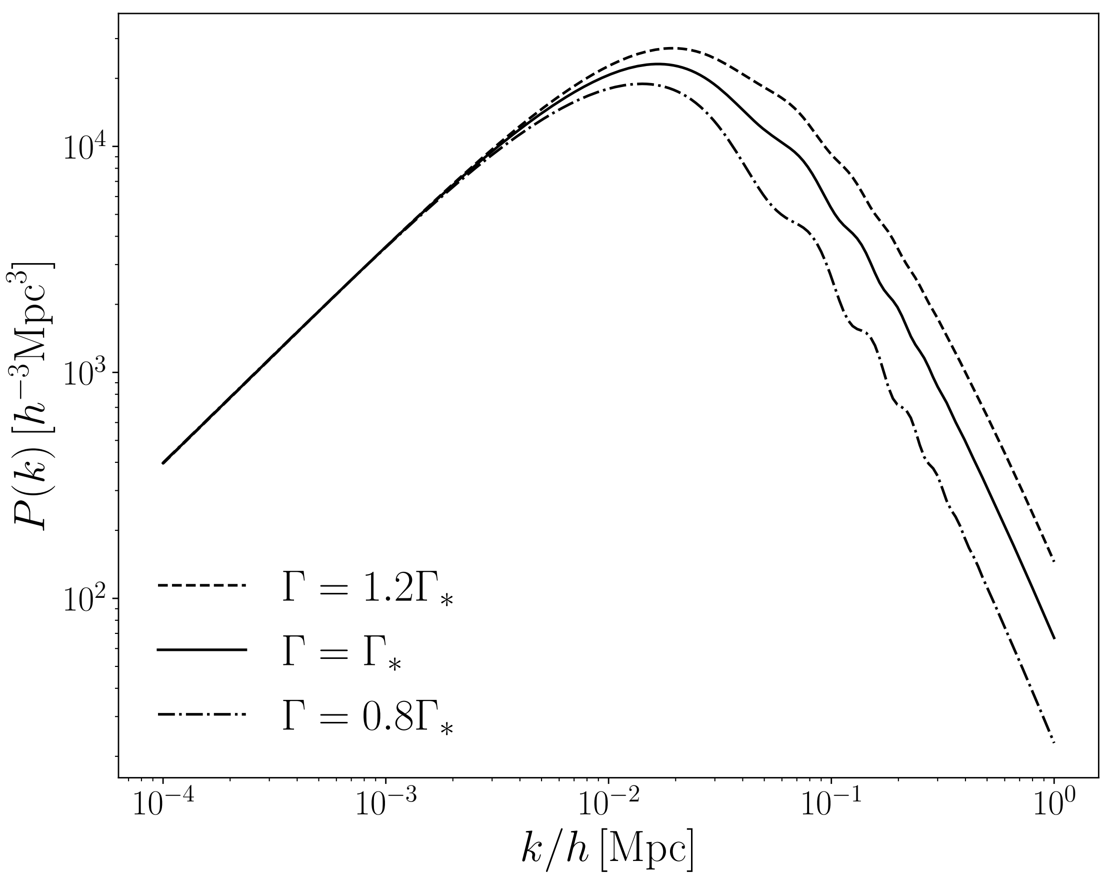
But the amplitude is also controlled by Ω_m and A_s or σ_8.

WHY SO INSENSITIVE TO H0?

$$C_\ell^{\gamma\gamma} \sim \ell^{-3}\Omega_m^2 \int_0^{z_{\max}} \mathrm{d}z\, F(z)\Delta^2\left(k/H_0 = \frac{\ell}{z}; z\right)$$

Fixing Ω_m to keep the lensing pre-factors fixed

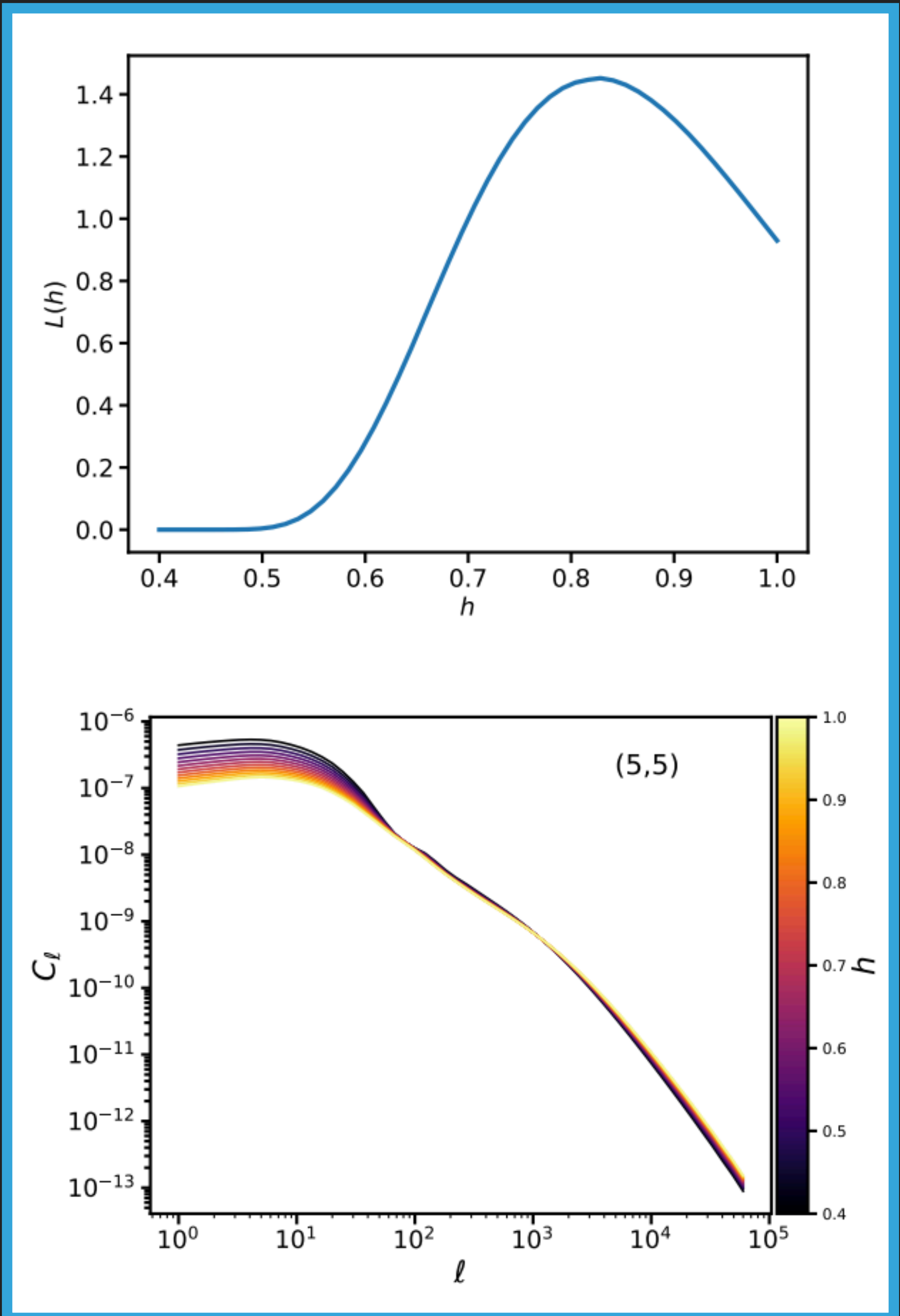
$$\implies \Gamma \equiv \Omega_m h \quad \text{changes}$$



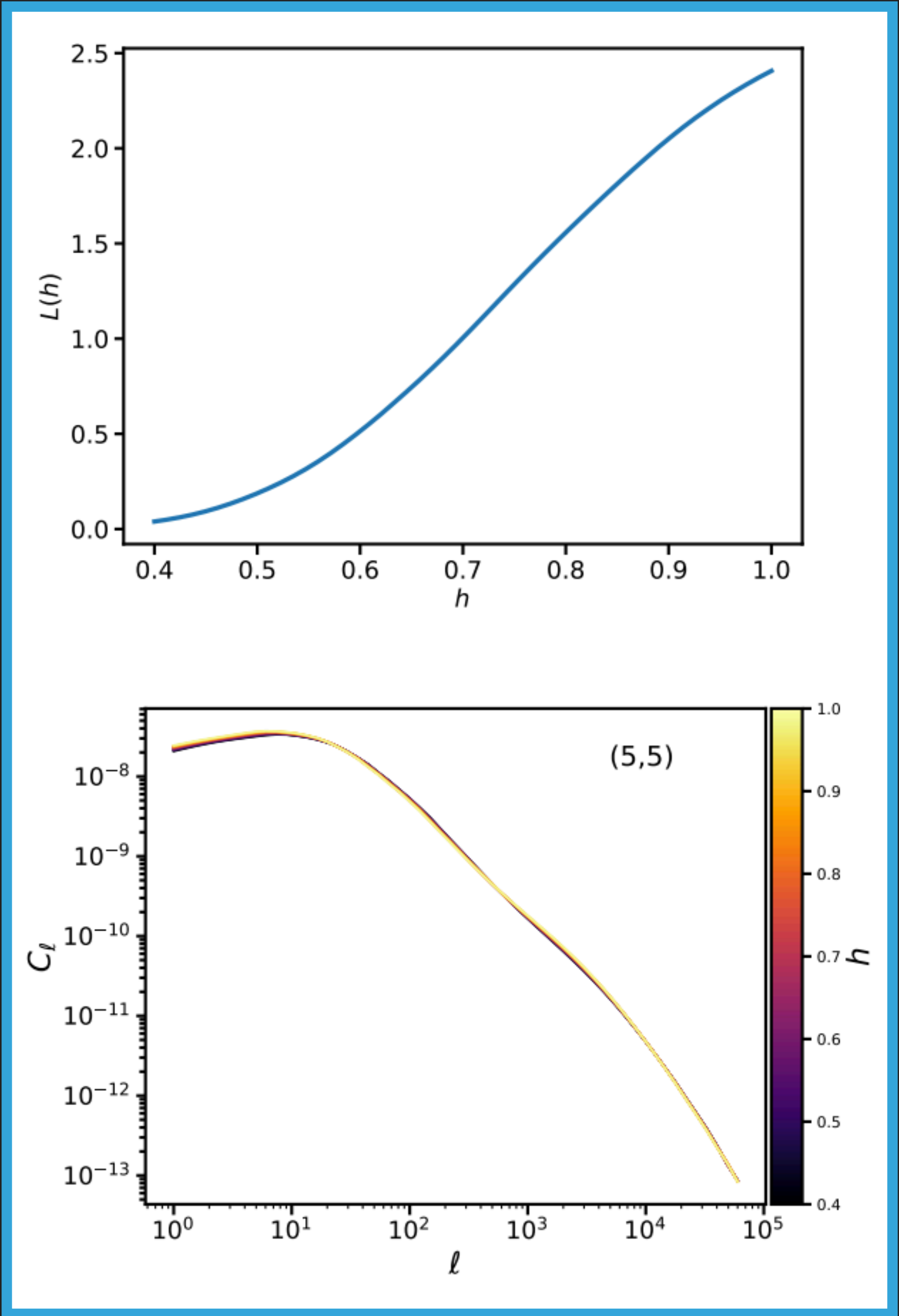
H_0 changes the small-scale amplitude at fixed A_s

Fixing the small-scale amplitude leaves only subtle changes to the shape - not well measured by current surveys!

H0 INFORMATION IN KV450

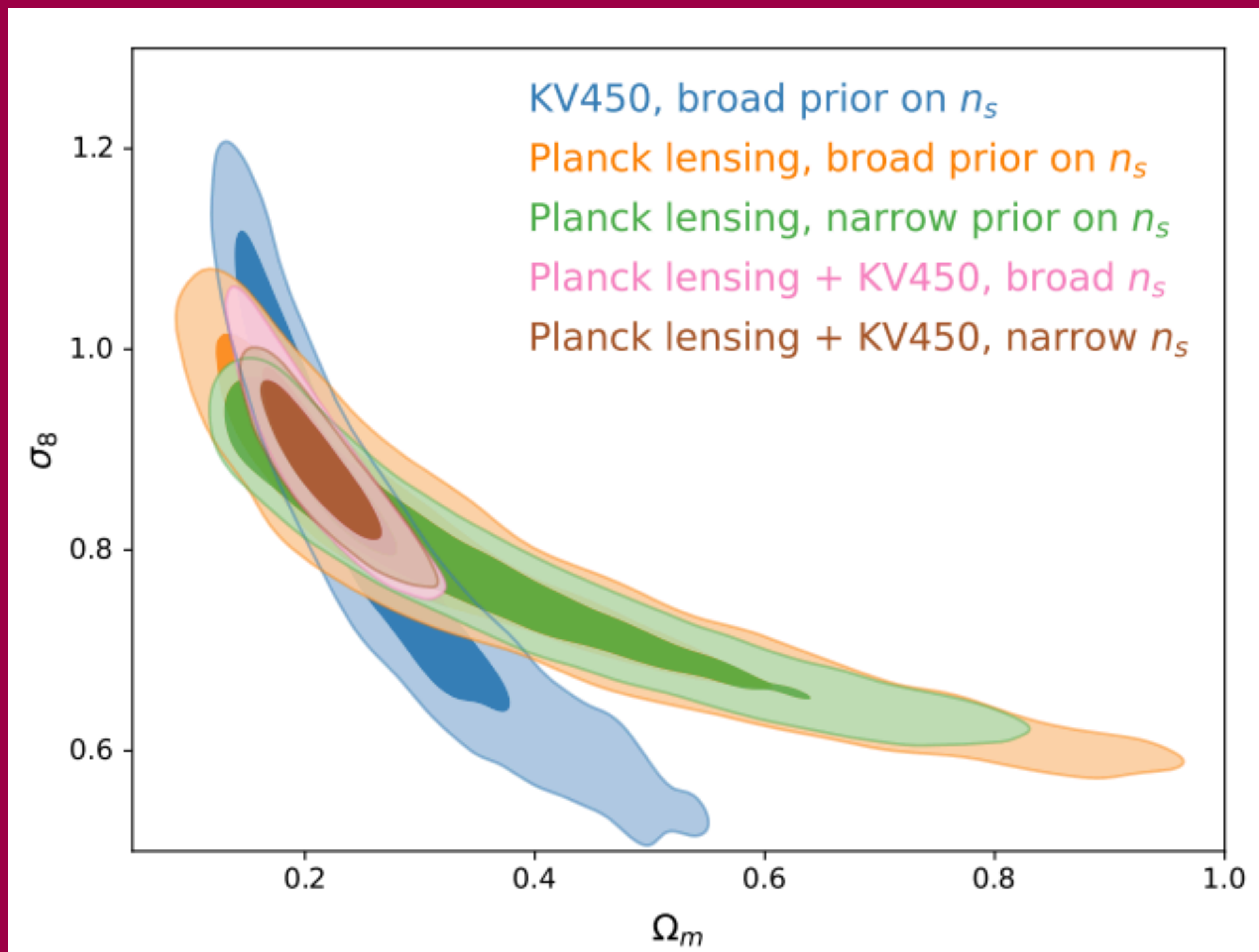


Fixed σ_8 and Ω_m



Fixed S_8 and $\Omega_m h^2$

WHAT *CAN* WEAK LENSING TELL US ABOUT H0?



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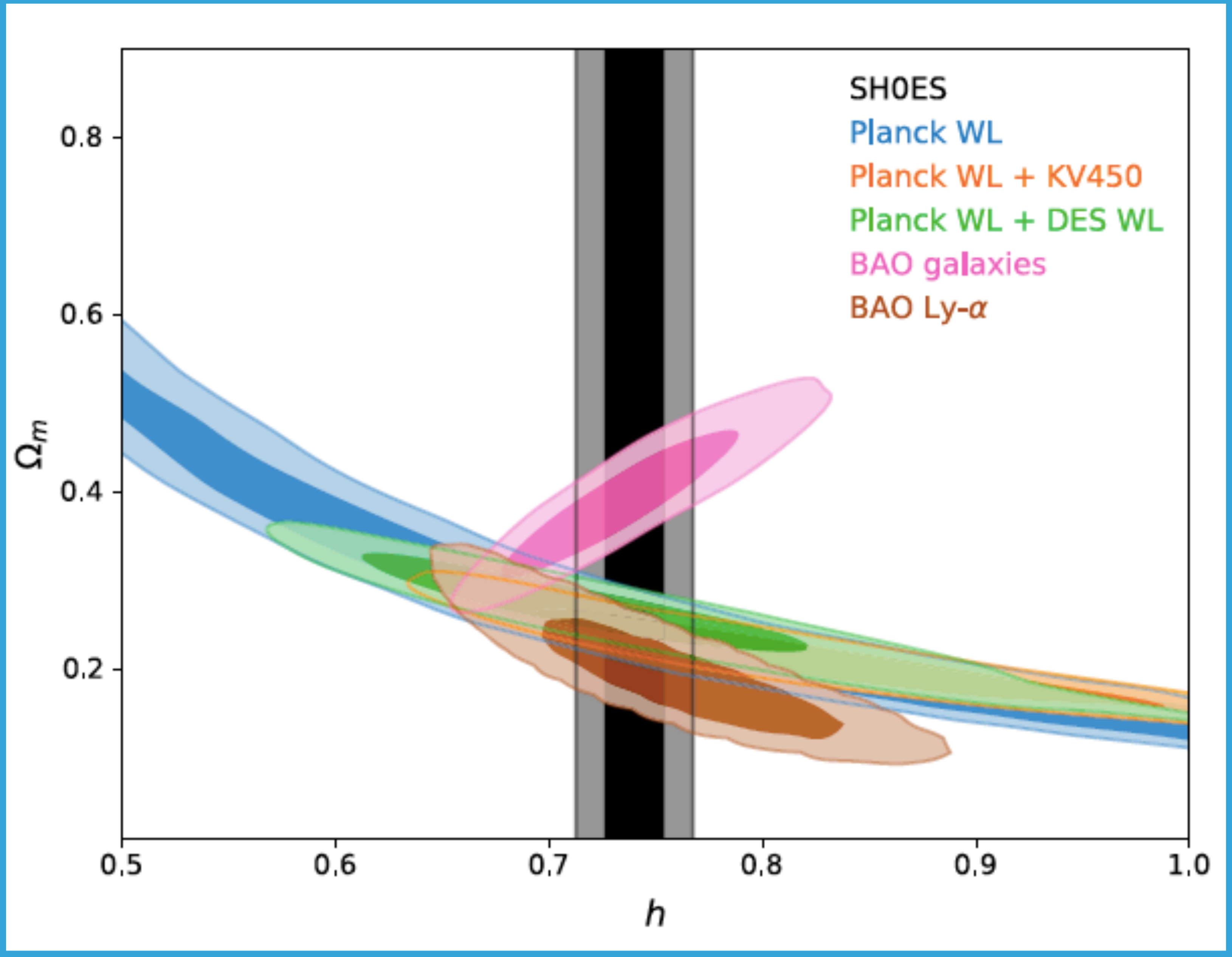
Combined weak lensing probes give us Ω_m

Combine with *BAO+BBN*, which give contours in the Ω_m - H_0 plane.

CMB-independent probe of *H0*
Addison+ 2013,
Auborg+ 2015 (DES)

WHAT *CAN* WEAK LENSING TELL US ABOUT H0?



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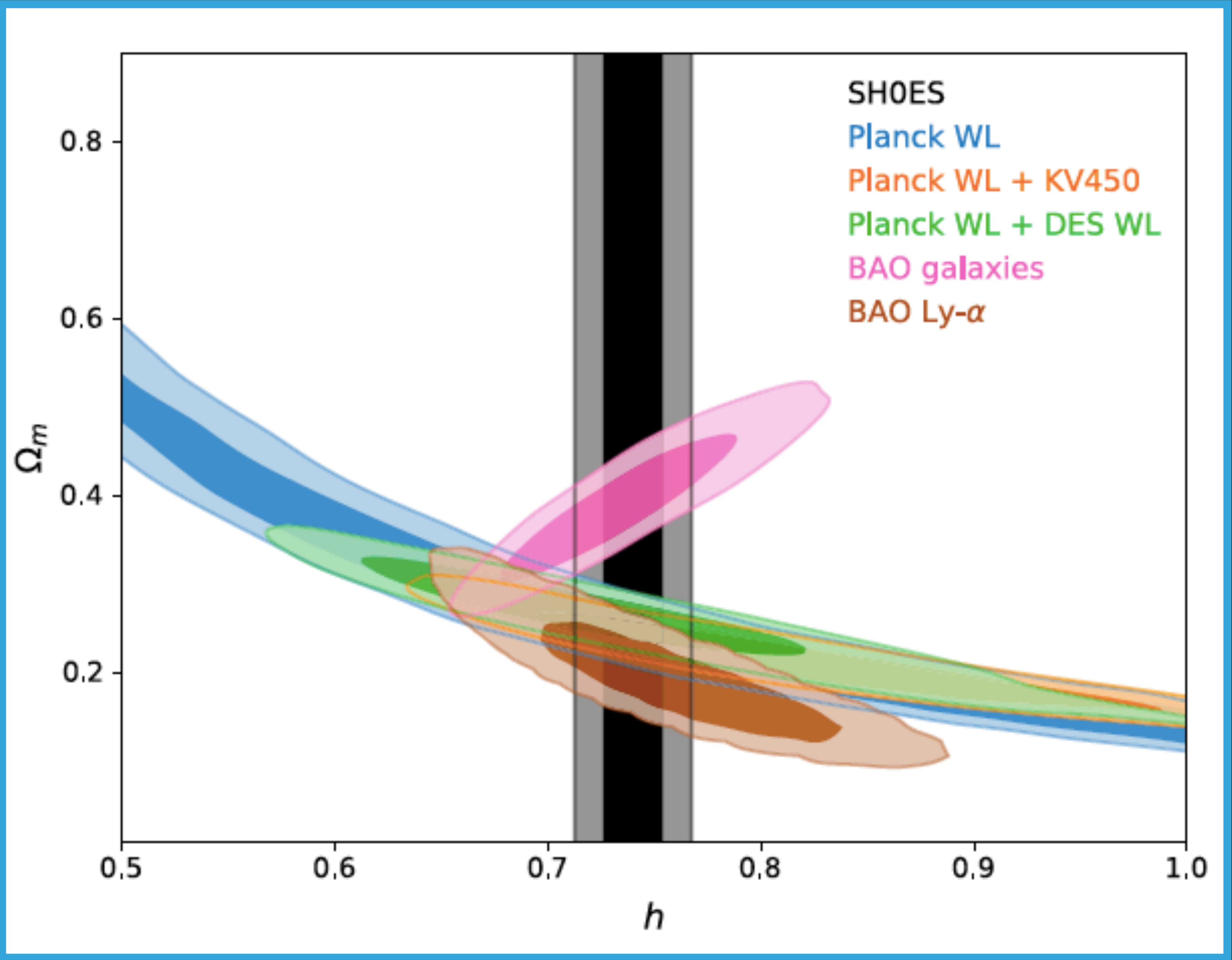
Galaxy lensing adds basically nothing to H0 from CMB lensing + BAO.

Do get separate Ω_m and σ_8 constraints.

BAO + BBN + WL: $H_0 = 67.4 \pm 0.9\,\mathrm{km s^{-1} Mpc^{-1}}$

WHAT *CAN* WEAK LENSING TELL US ABOUT H0?



AH 2021

Galaxy lensing adds basically nothing to H0 from CMB lensing + BAO.

Do get separate Ω_m and σ_8 constraints.

BAO + ~~BBN~~ + WL: $H_0 = 70.0 \pm 6.5\,\mathrm{km s^{-1} Mpc^{-1}}$

S8 and nothing else - same story in ~10 years time?

NEAR-FUTURE WEAK LENSING SURVEYS

Vera C. Rubin Observatory:

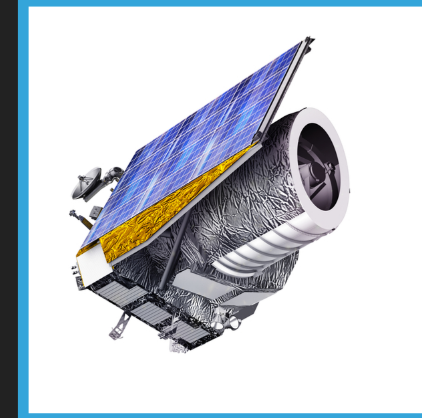
The Legacy Survey of Space and Time (LSST)

8.4m M1

18,000 sq deg: WL, GC, 3x2pt

n_eff ≈ 30 galaxies per sq arcmin.

EUCLID



1.2m primary mirror made from silicon carbide.

Two instruments: Visible light camera (VIS) and Near-Infrared camera (NISP).

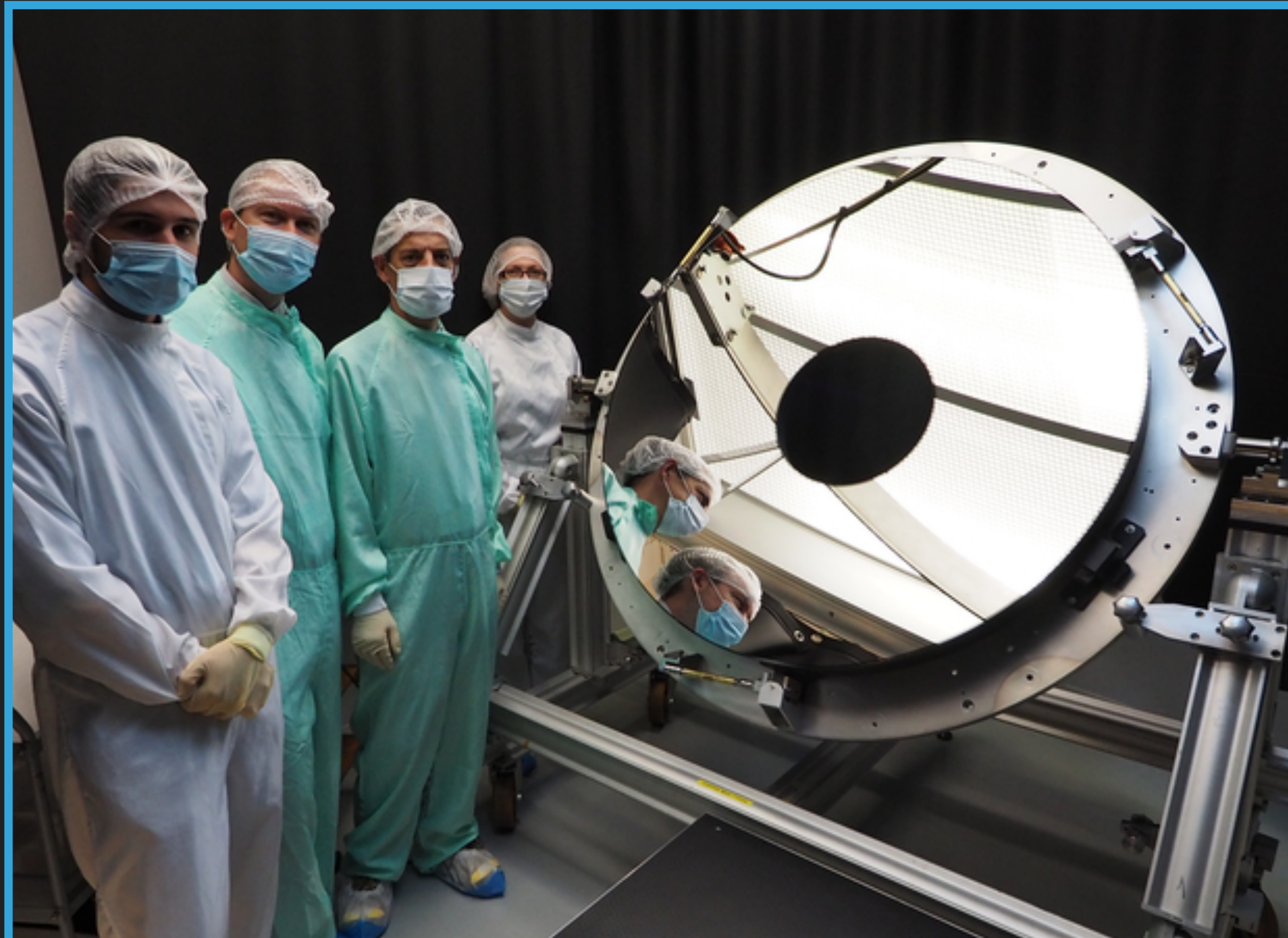
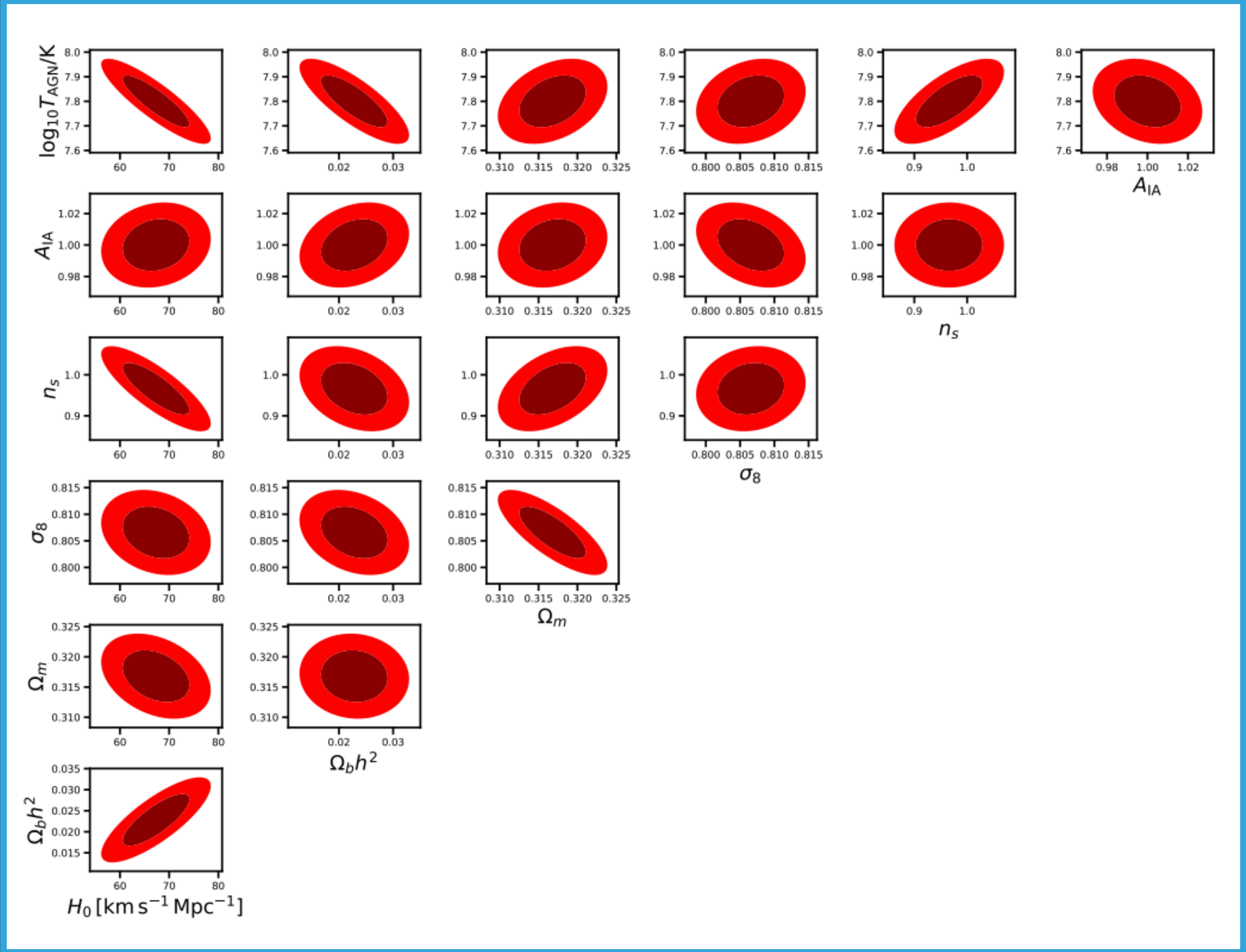


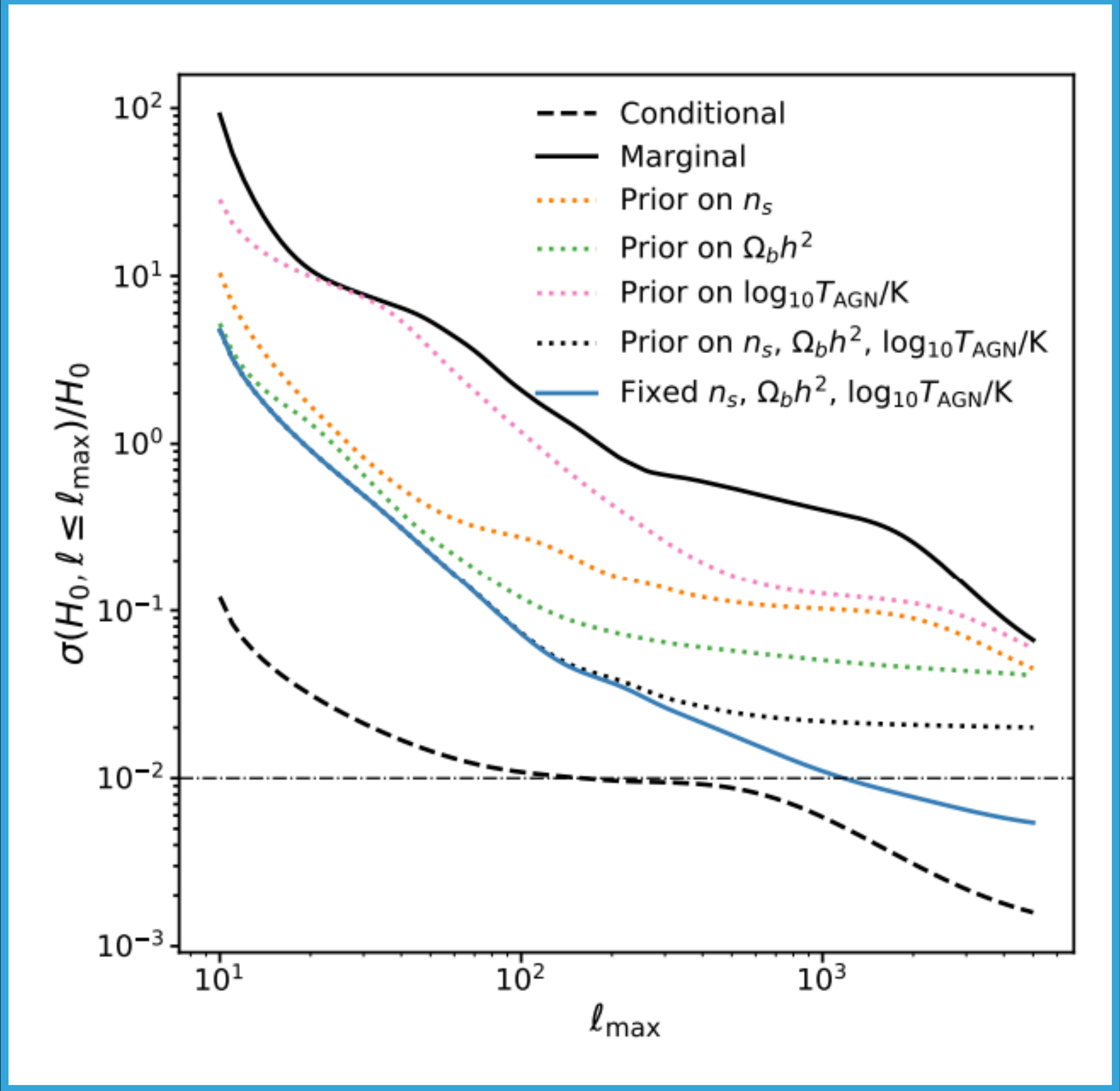
Image credit: ESA

Launch date: 2023

EUCLID-LIKE FORECAST FOR LCDM



EUCLID-LIKE FORECAST ON H0



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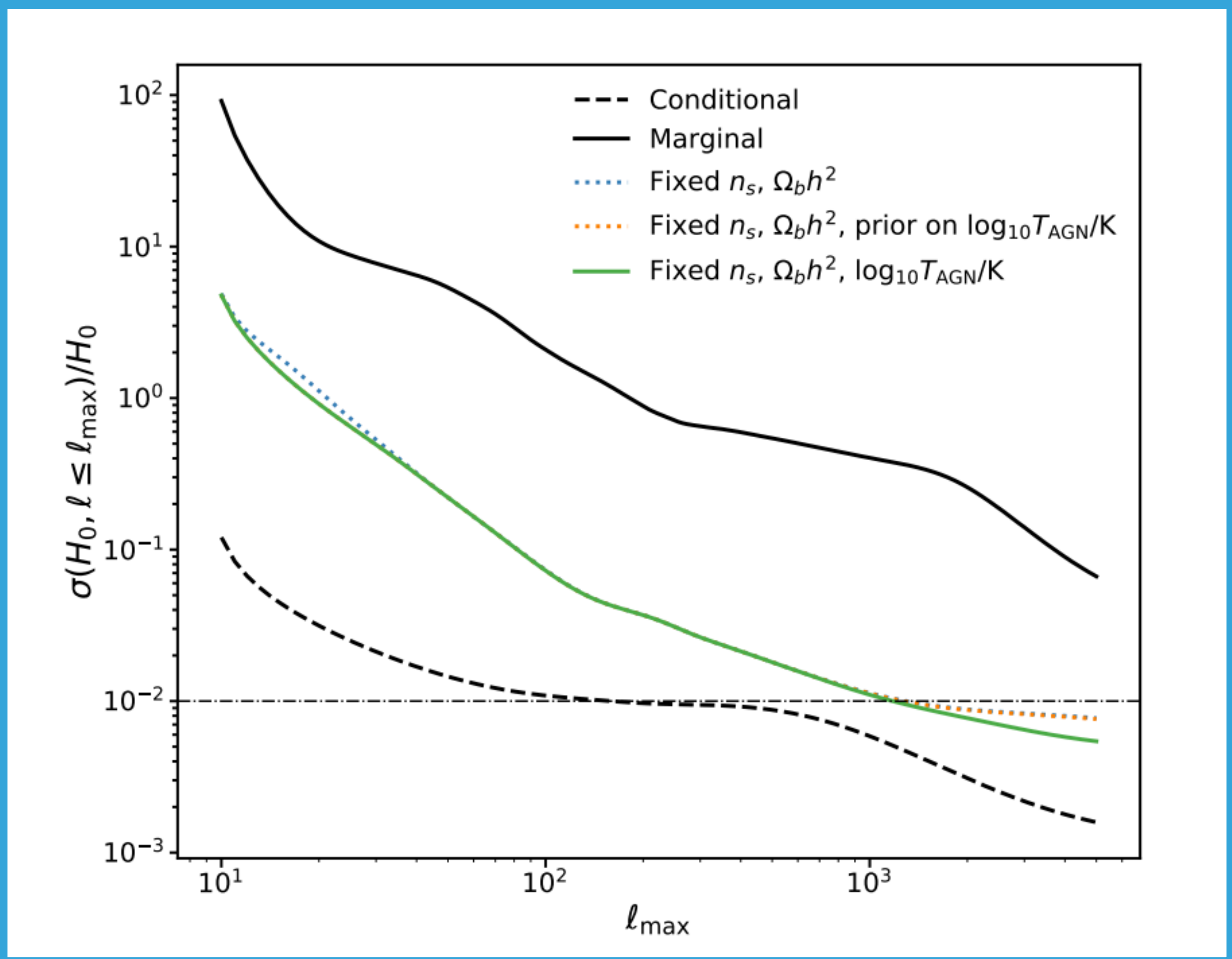
EUCLID-LIKE FORECAST ON H0



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For 1% H0 from lensing need *at least*:

- to know ns to current (Planck) precision
- assume BBN
- Use all modes out to lmax=5000

H0 information coming from broadband shape of the power spectrum - many degeneracies!

CONCLUSIONS

- Current lensing surveys alone give good constraint on S8 but weak/no constraint on H0.

- Have shown why current lensing data constrain S8 well and H0 poorly, using **analytic arguments** based on the halo model.

- Cleanest probe of H0 is the matter-radiation equality scale seen in projection, followed by subtle effects on the shape of the spectrum: partially degenerate with baryon feedback. Looks like Euclid will have a tough job of getting <1% H0 from lensing alone!

arXiv:2104.12880

IF YOU ENJOYED THIS, YOU MAY ALSO LIKE...

Astrophysics > Cosmology and Nongalactic Astrophysics

[Submitted on 8 Feb 2022]

The non–Gaussian likelihood of weak lensing power spectra

Alex Hall, Andy Taylor

arXiv:2202.04095

Theory + simulations paper:

- Derive the leading-order correction to the power spectrum likelihood from non-Gaussianity (non-linearity) in the shear field.
- Provide (first?) rigorous justification for the use of a Gaussian likelihood for power spectra in wide cosmic shear surveys (or 3x2pt).