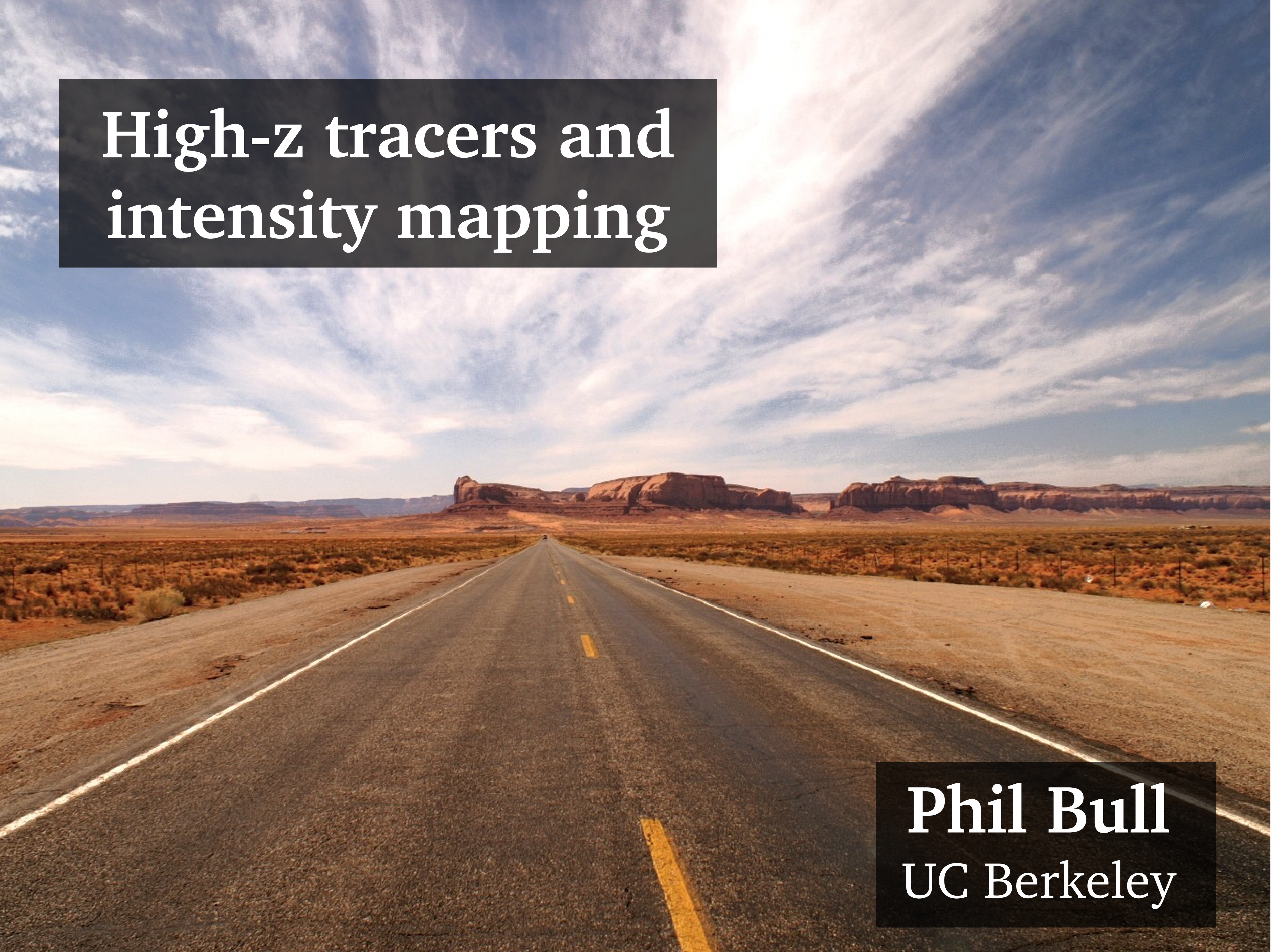


High-z tracers and intensity mapping

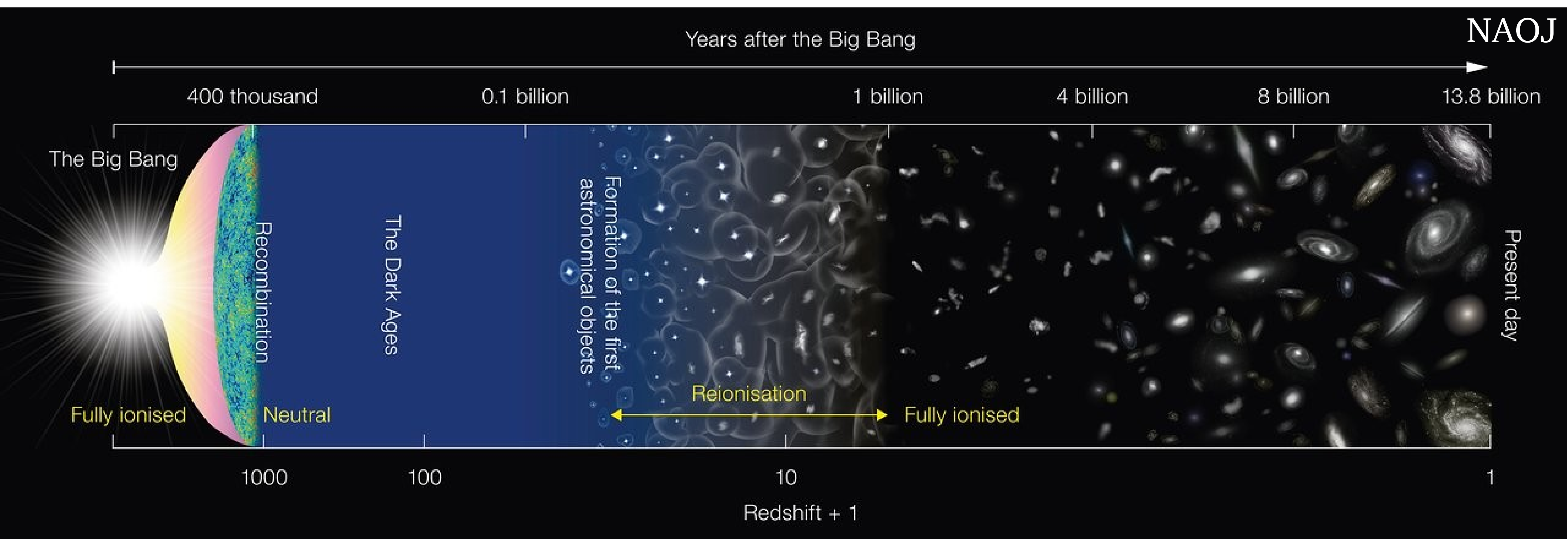
Phil Bull
UC Berkeley

Why high redshifts?

Are there reasons to make *cosmological* observations in the $2.5 < z < 6$ window?

z < 2: Cosmic acceleration, tests of GR

z > 6: EoR / dark ages / CMB



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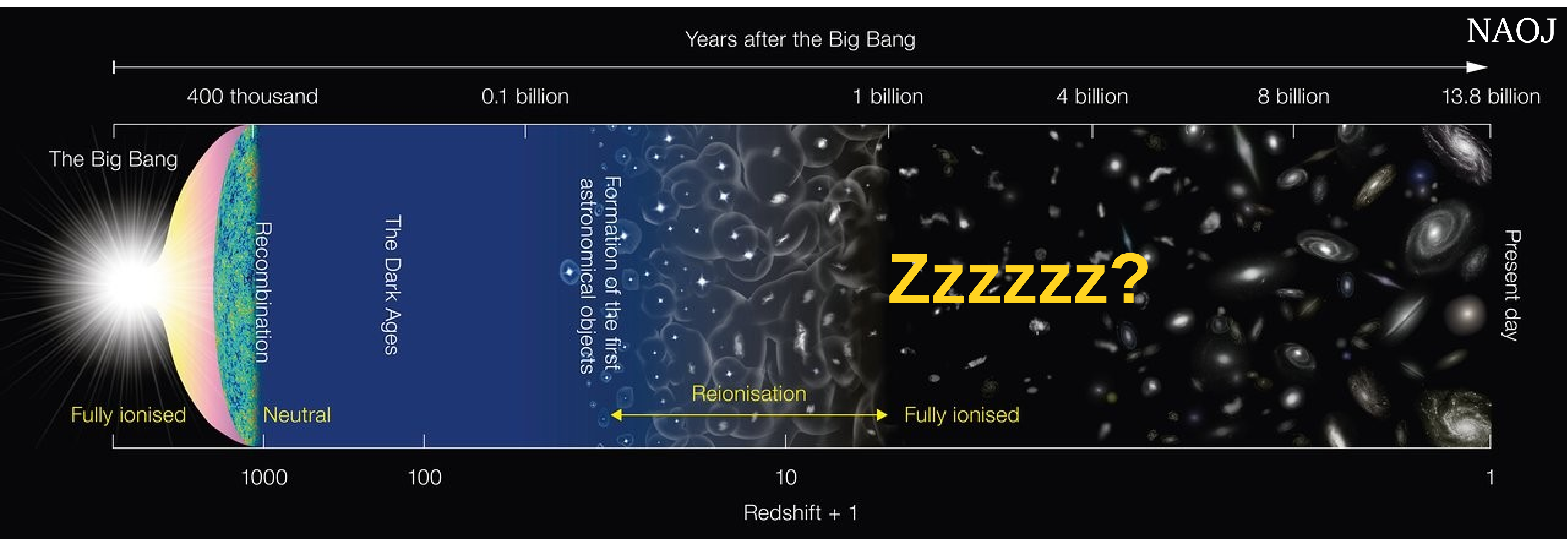


Why high redshifts?

Are there reasons to make *cosmological* observations in the $2.5 < z < 6$ window?

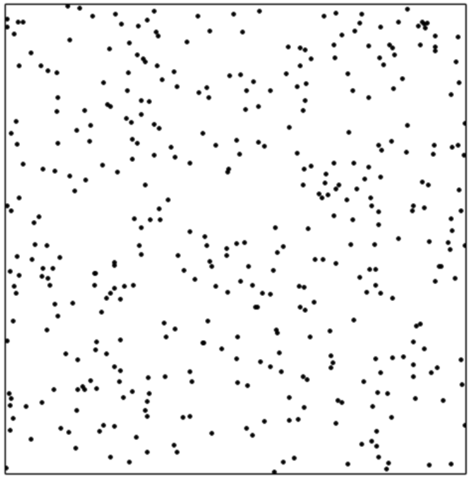
Actually, yes:

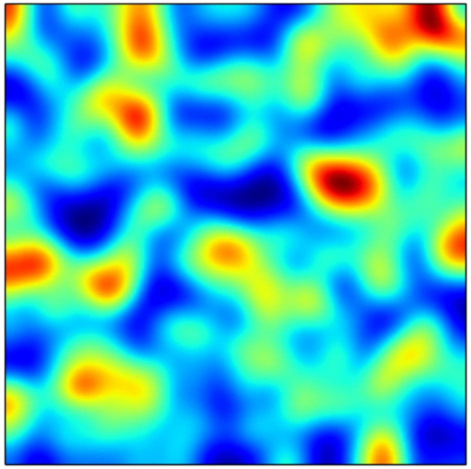
- Early-ish dark energy and tests of GR
- Spatial curvature and primordial non-Gaussianity
- Independent neutrino mass measurement
- Einstein-de Sitter is a useful reference point!

21cm intensity mapping

Use the combined line emission from many galaxies to map large-scale structure in 3D

Sacrifice resolution for sensitivity





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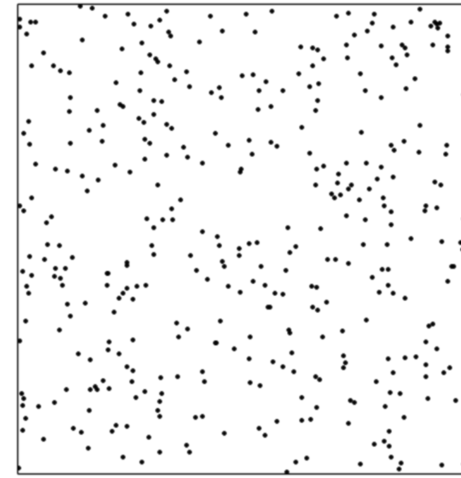
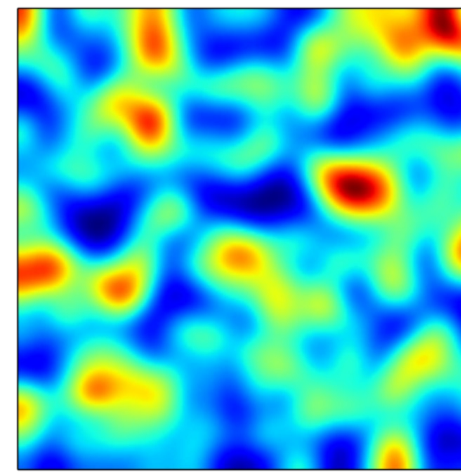




Use the combined line emission from many galaxies to map large-scale structure in 3D

Sacrifice resolution for sensitivity

Advantages of 21cm IM:

- Access high redshifts (straightforward to build wideband receivers at < 1 GHz)
- Access large volumes (sacrifice resolution for survey speed and sensitivity to large scales)
- HI is ubiquitous: relatively unbiased, $\sim$linear tracer out to $z \sim 6$

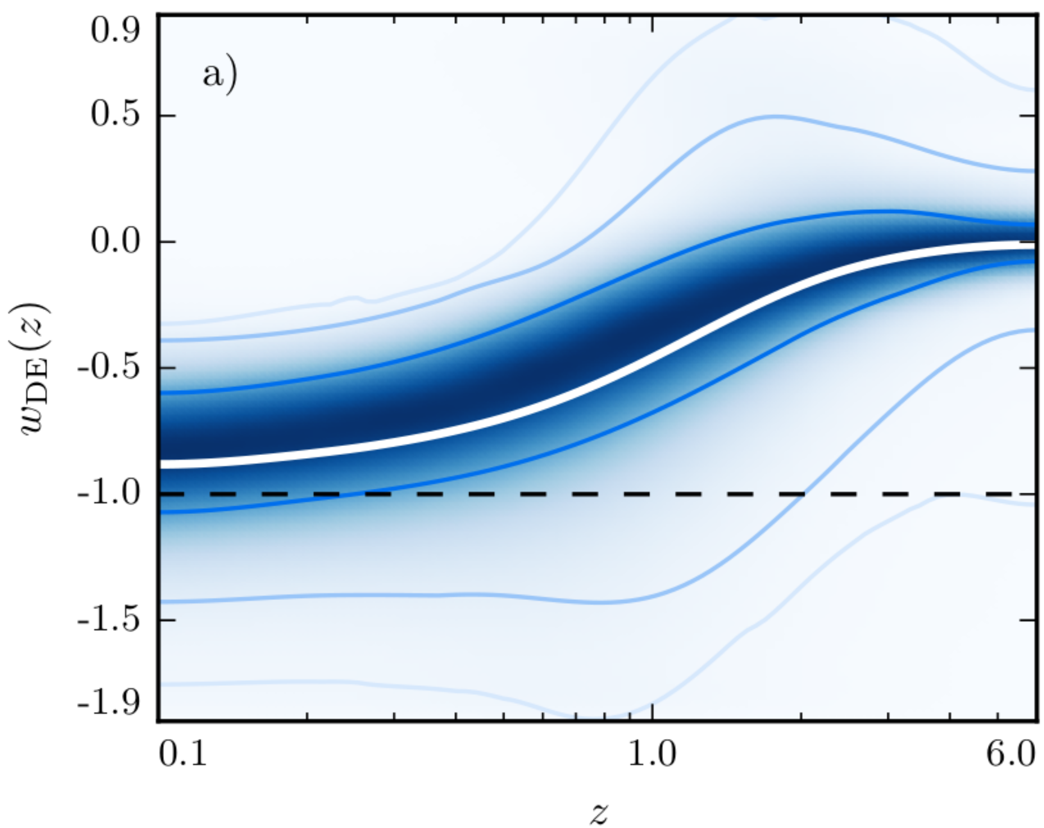
Typical dark energy behaviours

DE/MG models often exhibit "tracking" behaviour, where w(z) becomes much less negative at high z (e.g. w → 0)

Monte Carlo exploration of entire Horndeski class:

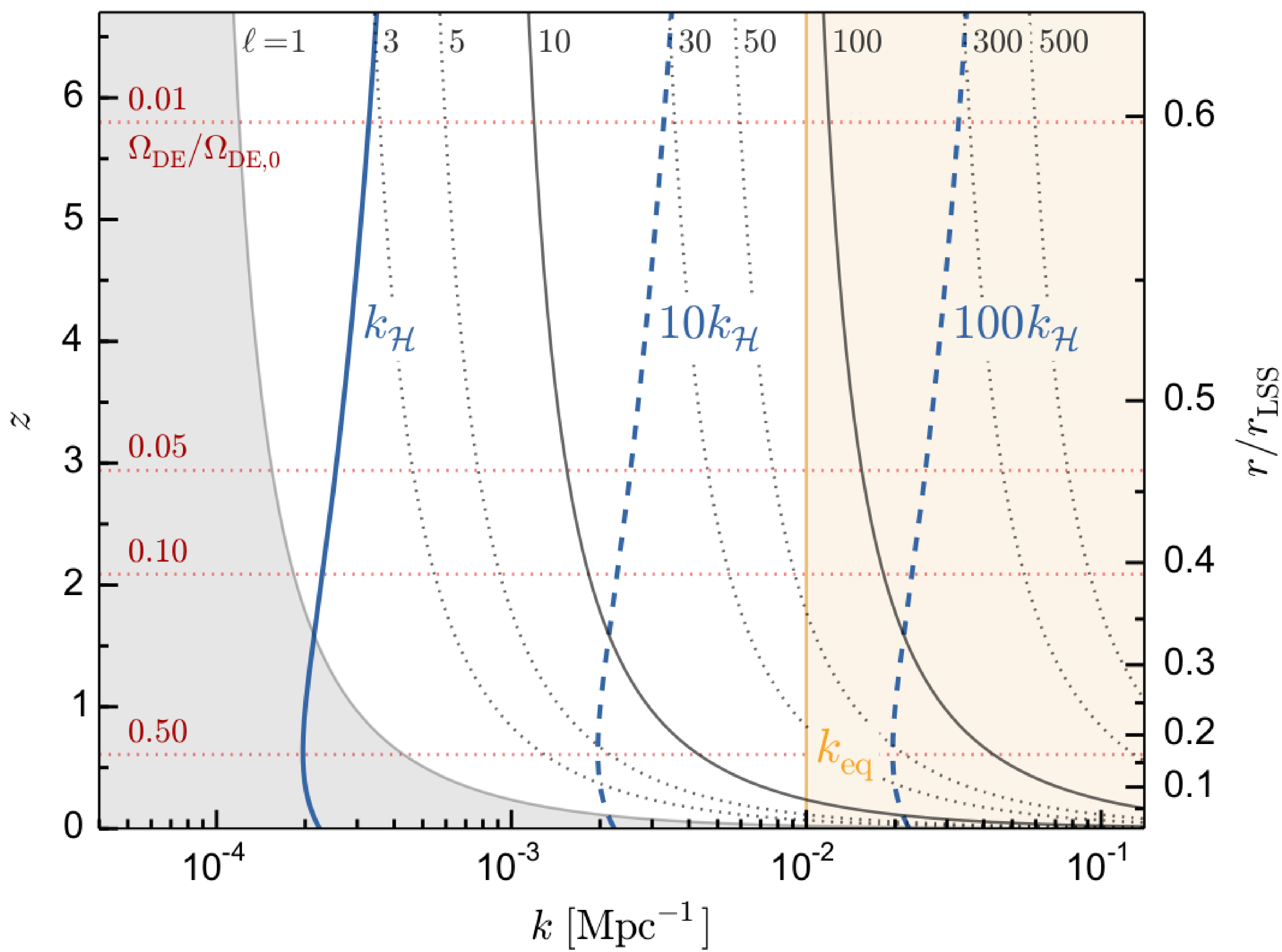
Equation of state of dark energy

$w(z) = P / \rho$



Raveri, **PB**, Pogosian, Silvestri (2017)

Where's left to look?



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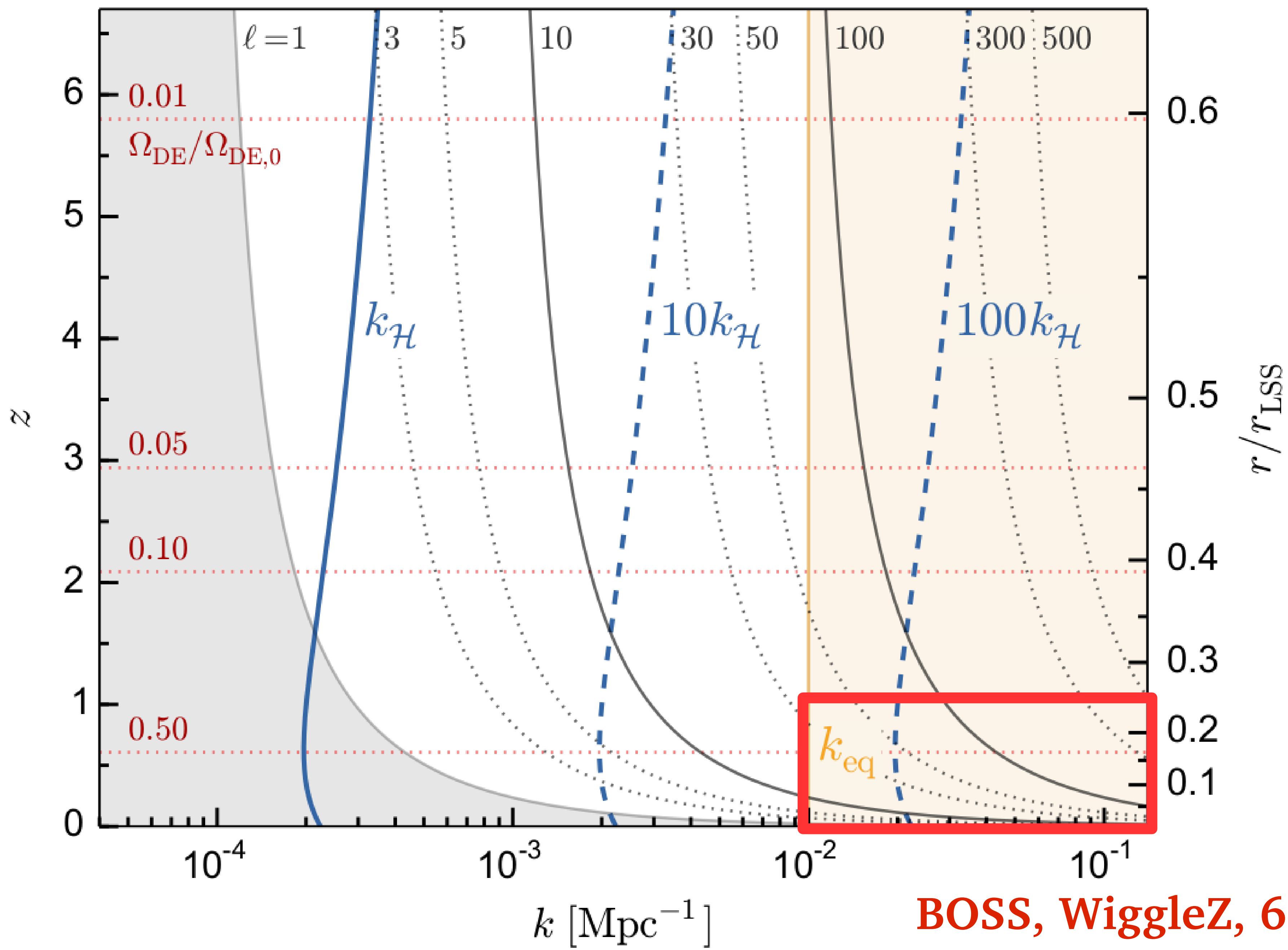

BOSS, WiggleZ, 6dF…

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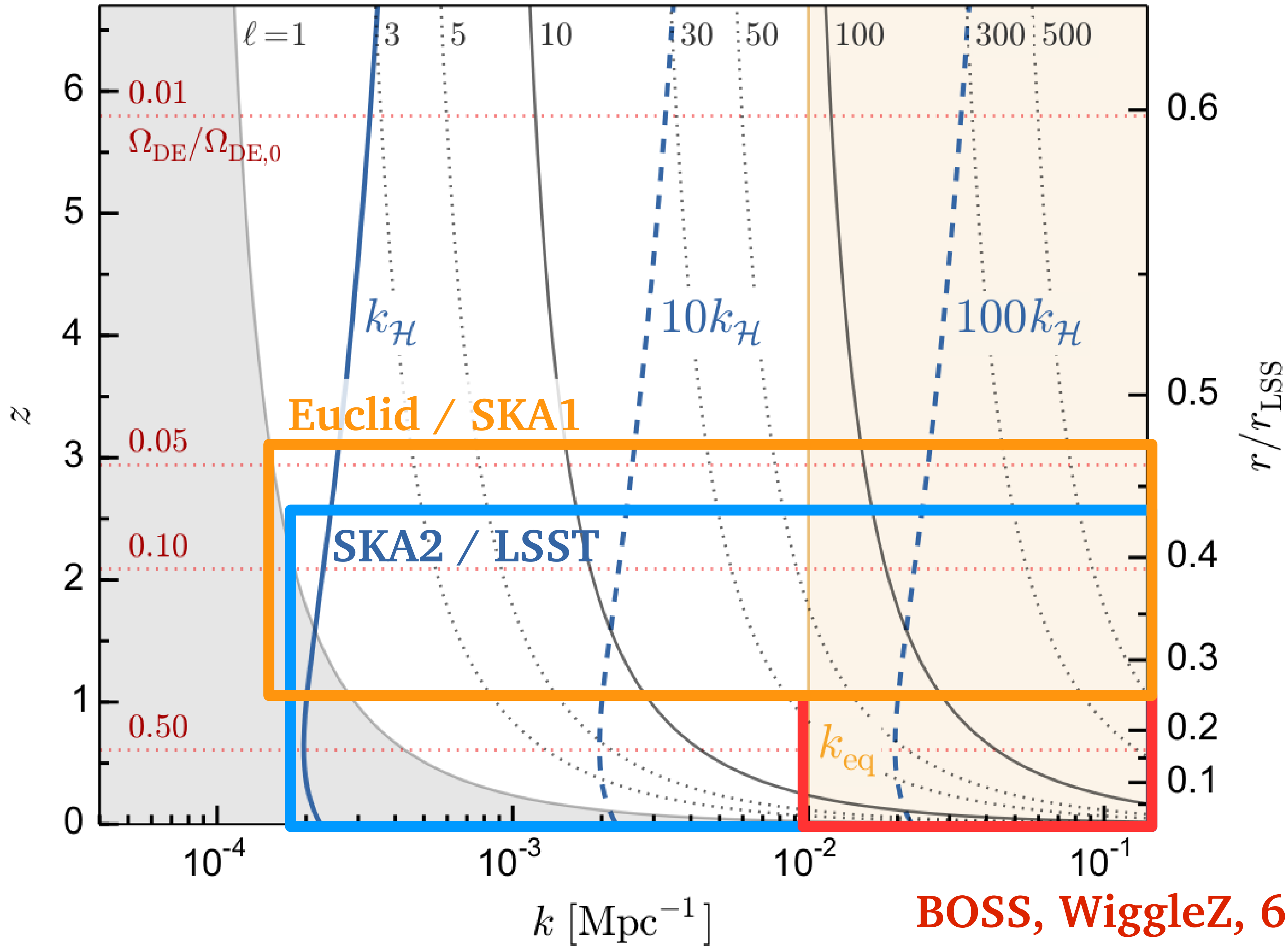


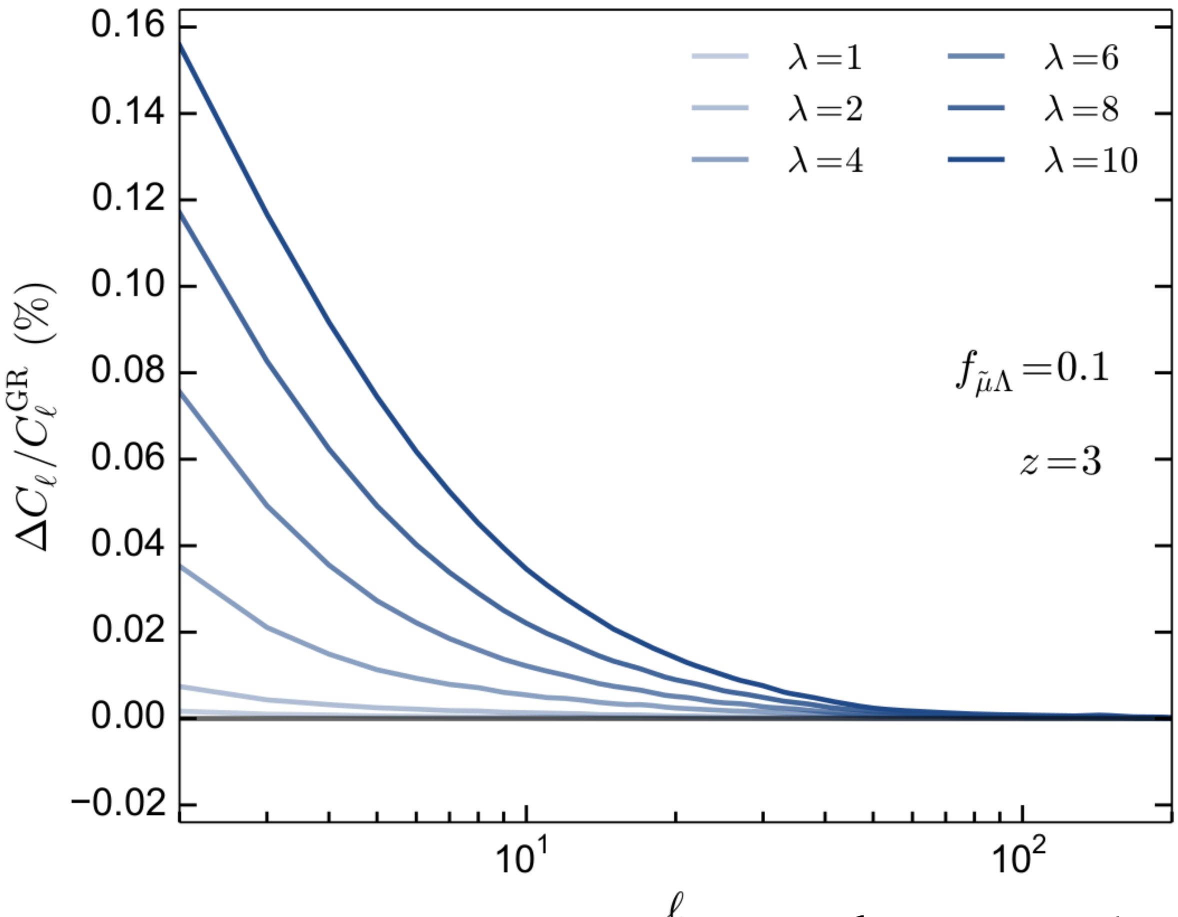
BOSS, WiggleZ, 6dF...

Hubble-scale deviations from GR

What if MG **only** affects Hubble-scale physics?

Fractional change in galaxy power spectrum for a 10% modification to GR <u>only</u> at $k < \lambda H$

Also severely hampered by cosmic variance...

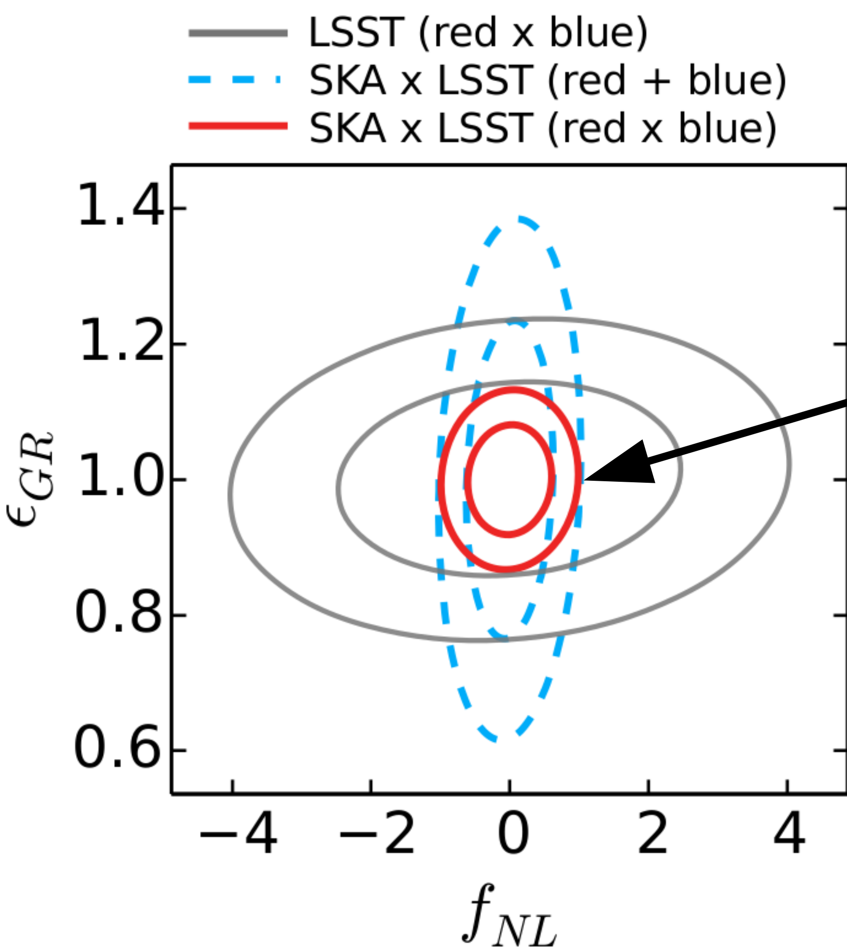


T. Baker & **PB** (2016)

Multi-tracer cosmology

Well-matched pairs of galaxy samples can reduce errors significantly below single-tracer cosmic variance limit

Seljak (2009)



Large bias ratio between 21cm IM + optical galaxies → **tighter constraints**

Alonso & Ferreira (2016) [adapted]

Spatial curvature

Most inflation models predict very low curvature

→ Detecting curvature falsifies them! (e.g. eternal inflation)

Curvature related to no. of e-folds. Short inflation = more chance of seeing anomalies (c.f. CMB)? (Aslanyan & Easther 2015)

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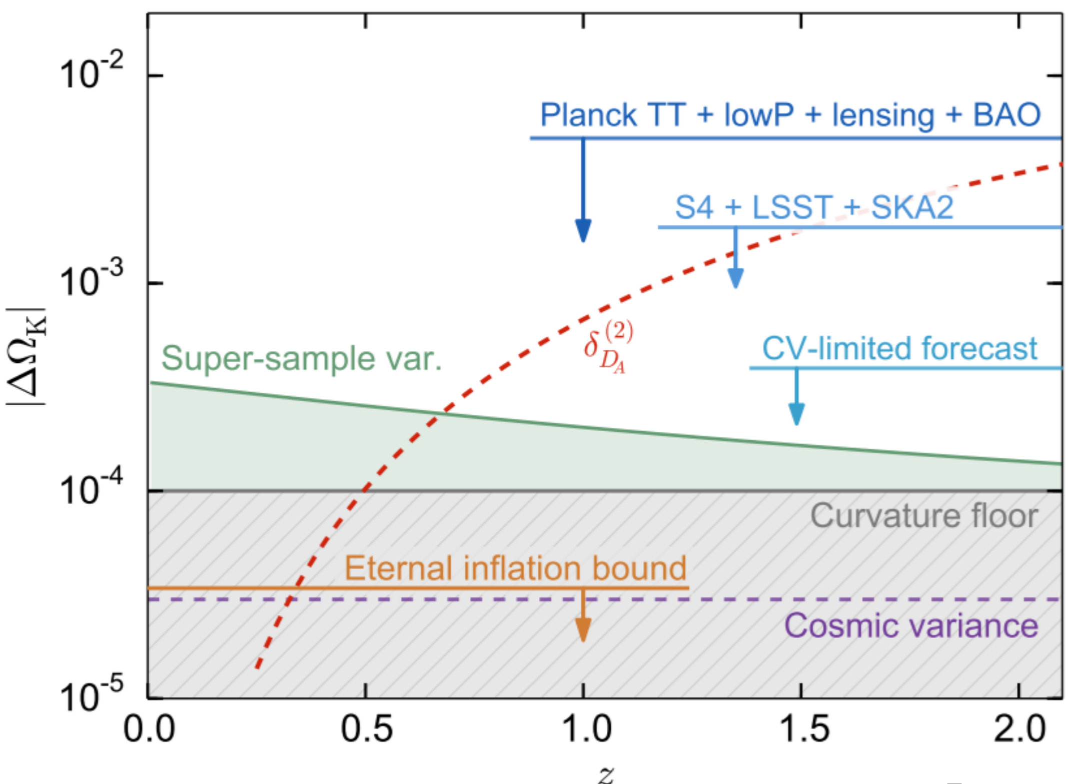
How far away are we from the cosmic variance limit?



Leonard, **PB**, Allison (2016)

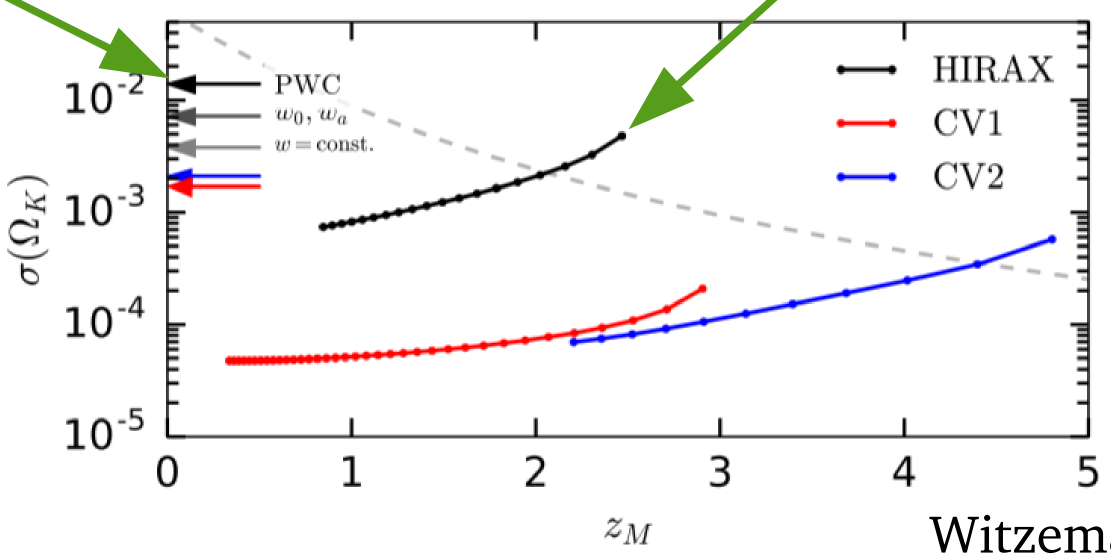
Spatial curvature

Degeneracy with low-z dark energy w(z) behaviour

Can we avoid this complexity and make a "pure" curvature measurement?

Marginalise over **arbitrary** DE models

"Avoid" DE by only using $z > z_M$



Witzemann, **PB** + (2017)

Similar arguments with other parameters

→ "Cleaner" measurements in the EdS regime?

Massive neutrinos

Significant fraction of HI is in low-mass halos

Massive neutrinos suppress small-scale power

→ HI goes into higher-mass halos; affects bias, mean signal etc.

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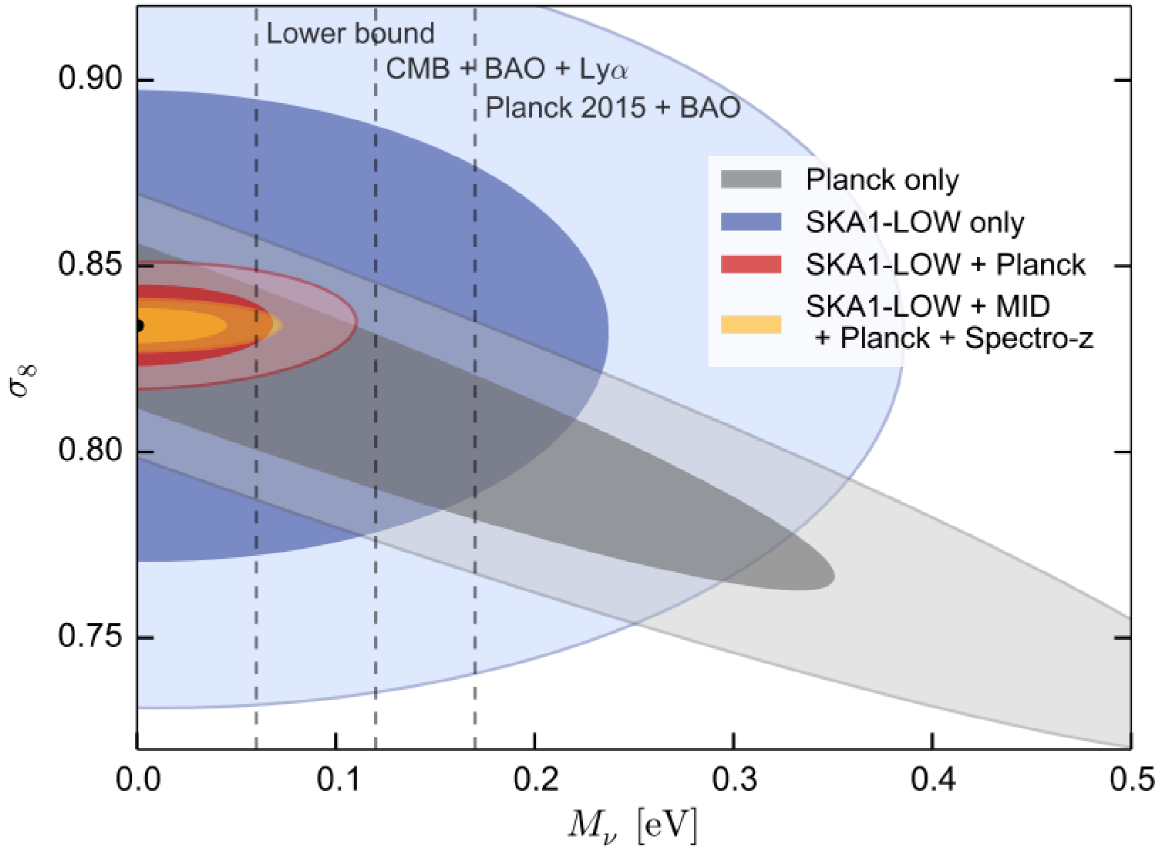
Useful bounds from high-z IM (3 < z < 6):



Villaescusa-Navarro, **PB**, Viel (2015)

Summary

New handles on cosmology

Unique predictions at high z and large scales

- Broad class of DE/MG models predict “tracking” at $z > 1$
- New physics at ∼Hubble scale? (MG, primordial NG)
- **Need multi-tracer**; 21cm IM is excellent counterpart

Validation of lower-z results

Is low-z cosmology providing a consistent picture?

- Compare low-z vs. high-z curvature, neutrino mass etc.
- IM has completely different systematics