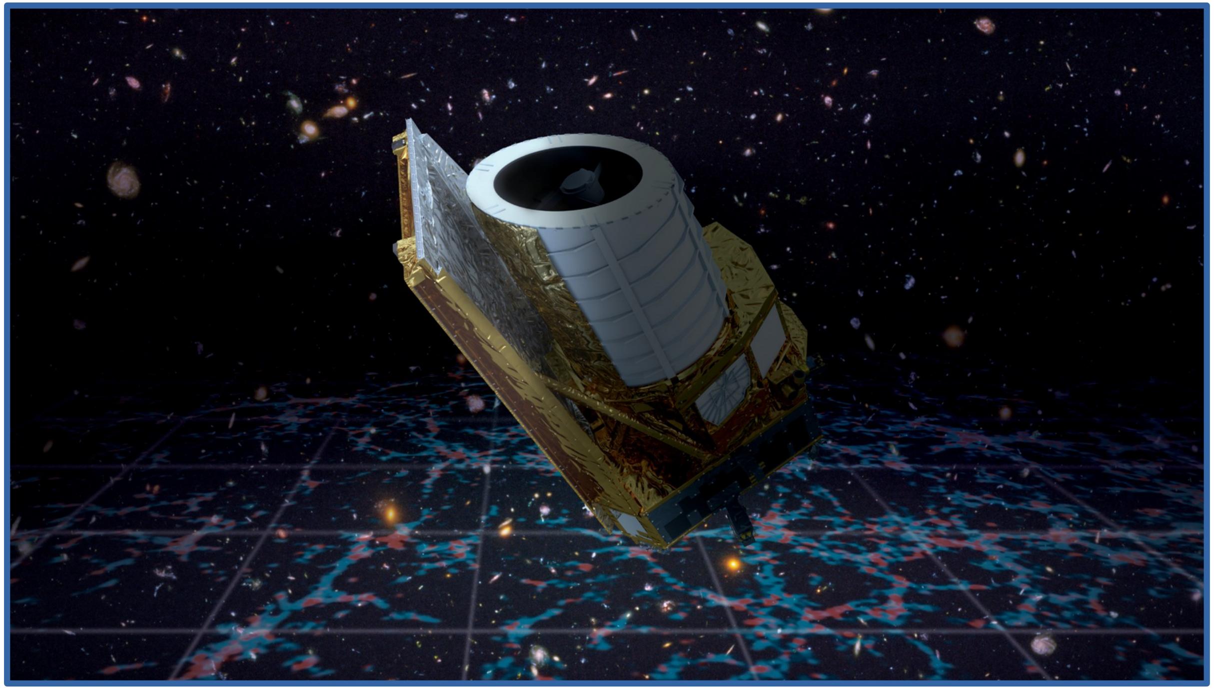
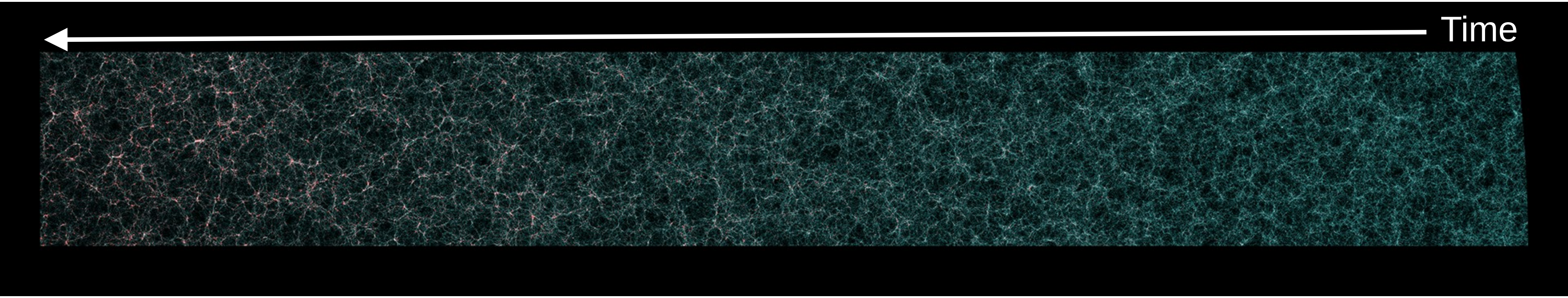
Euclid Preparation: Sensitivity to Neutrino Parameters



Sefa Pamuk @ NOW2024: Neutrino Oscillation Workshop

The Large Scale Structure



Credits: J. Carretero, P. Tallada, S. Serrano

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Imprints of the early universe are visible in the large scale structure.

To first order the power spectrum can be predicted using linearized Einstein equations.

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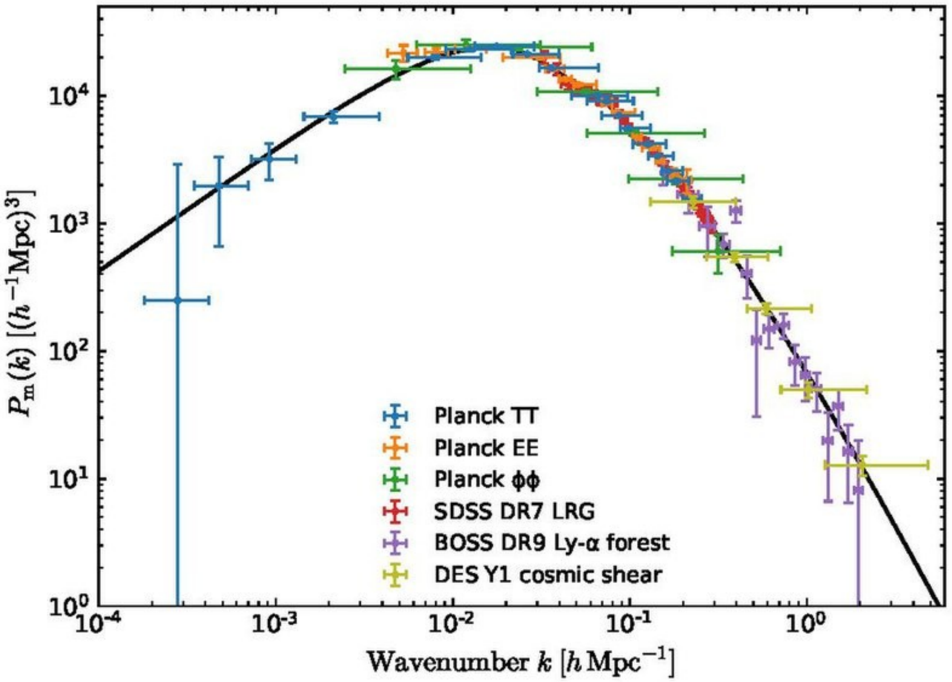
To first order the power spectrum can be predicted using linearized Einstein equations.

We can predict the corrections to using numerical simulations and perturbation theory.

Different probes can be used to probe the spectrum on a large range of scales.



Ade et al. [Planck 2018]

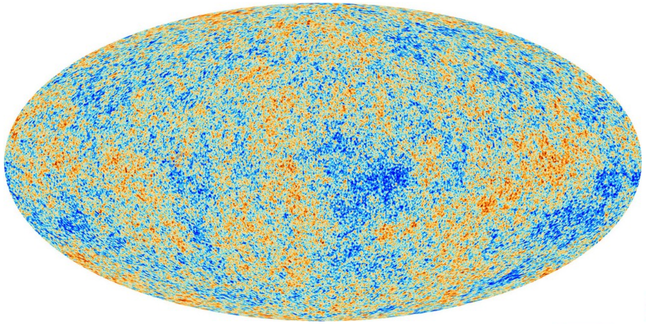
The Effective Number of Neutrinos

Cosmological probes have access to the effective number of neutrinos N_{eff} .

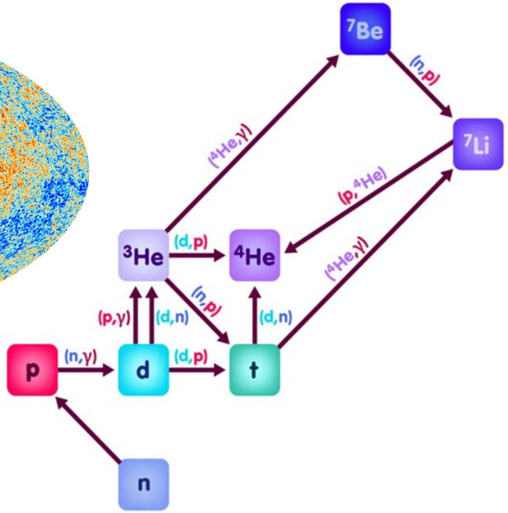
It includes any additional thermalised, feebly-interacting, ultra-relativistic relic species.

This parameter enters the expansion history of the universe making it accessible trough different probes.

- Big bang nucleosynthesis (abundance of light elements)
- Cosmic microwave background anisotropies (expansion speed at recombination, effect of the perturbations on the polarization)
- Changes the size of cosmological standard rulers



Credits: Planck Colaboration, ESA



Khoddam et al.

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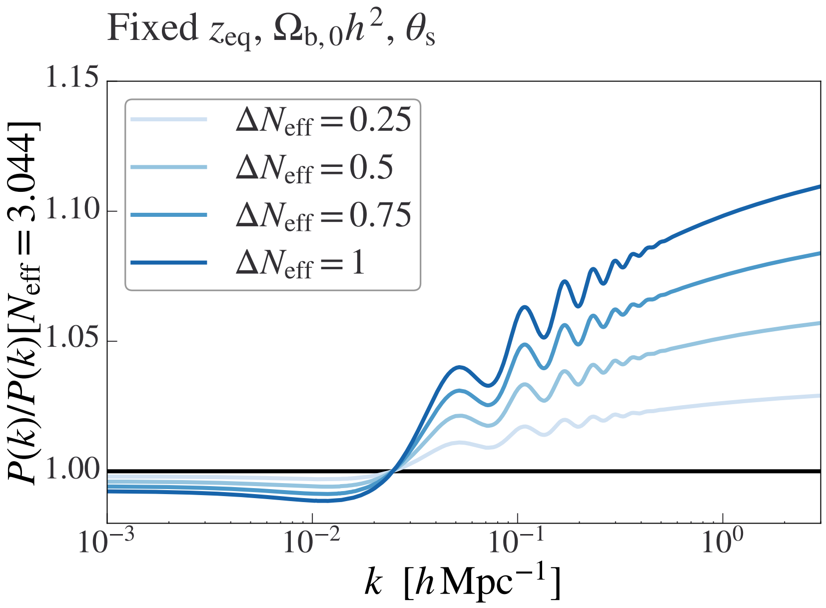
Deviations from $N_{\rm eff} \approx 3$ indicate deviations from the standard model e.g. additional light sterile neutrinos or other decoupled light particles.



Archidiacono et al. [Euclid 2024]

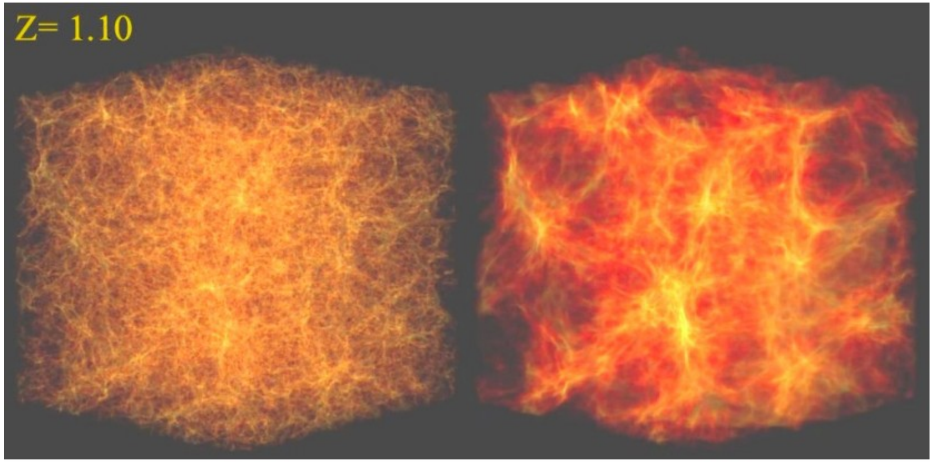
The Cosmological Neutrino Mass

Cosmological neutrinos are produced ultra relativistically early in the universe.

They become non-relativistic after recombination.

They can only start clustering afterwards and only on very large scales due to high thermal velocity.

Universe w/o massive neutrinos w/ 15% massive neutrinos



Credit: Troels Haugbølle

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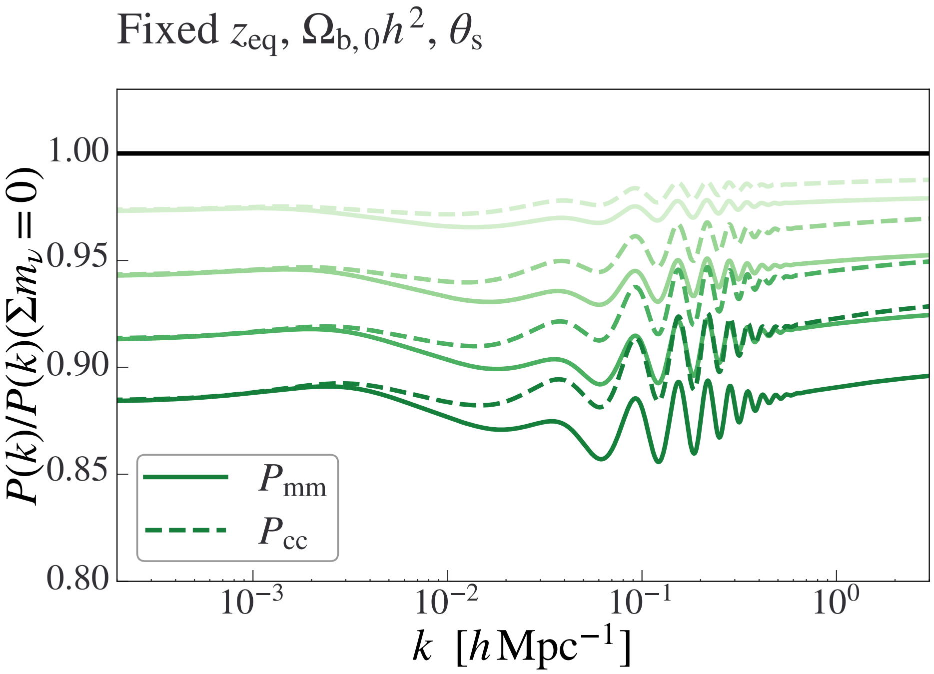
Overall suppression of the growth is proportional to the total neutrino mass.

Splitting of the 3 masses not resolvable with *Eucild* .

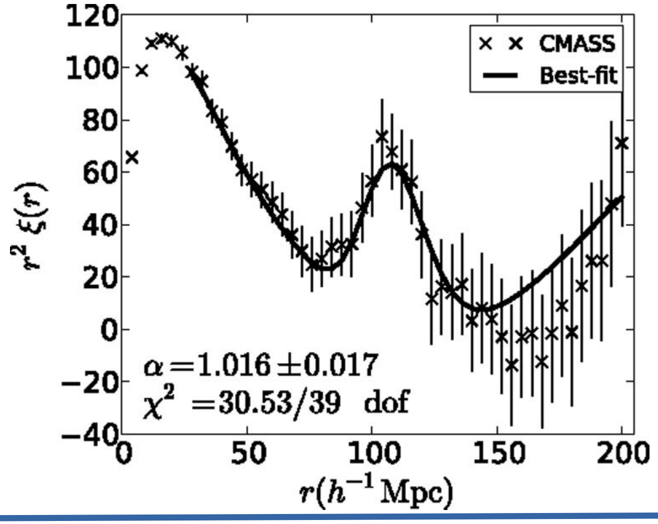


Archidiacono et al. [Euclid 2024]

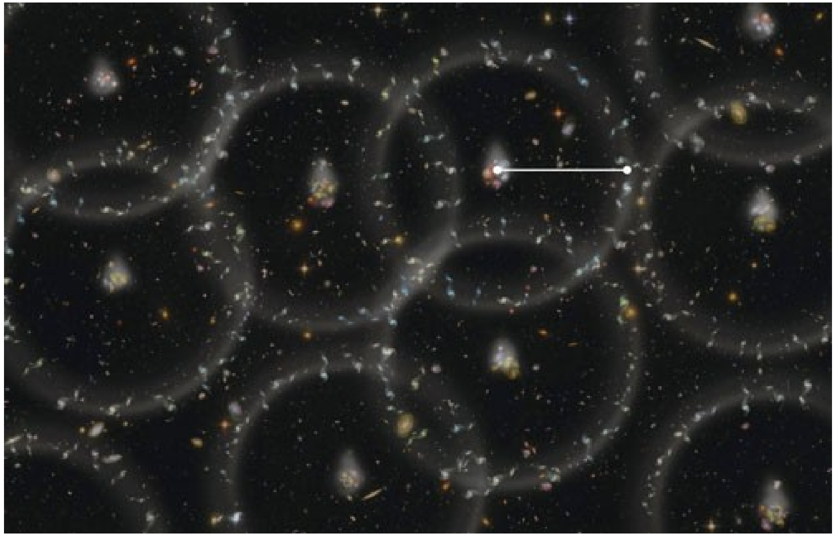
The Observables

Baryon Acoustic Oscillations

- Perturbations in the primordial plasma excite sound waves
- They are frozen after the recombination era
- Remains in the distribution of galaxies and cosmic microwave background anisotropies as a standard ruler



Anderson et al. (2012)



Credits: BOSS colaboration

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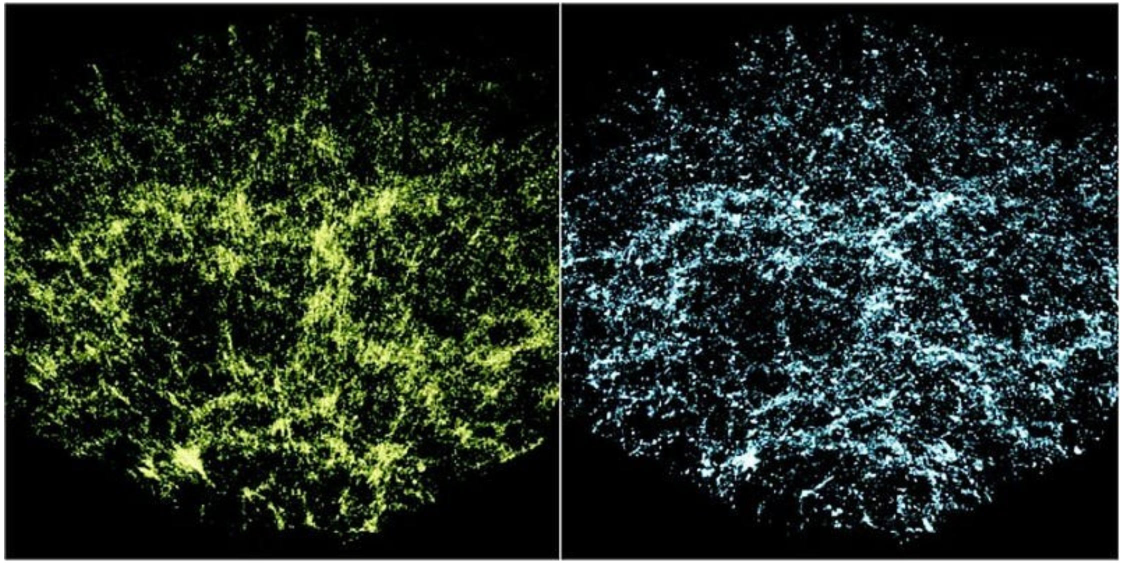
Redshift space distortions

- As matter falls into over-densities the peculiar velocities make the distribution look anisotropic
- Amplitude of the anisotropy is given by the growth rate of structure



M.U. Subbarao et al. (2008)

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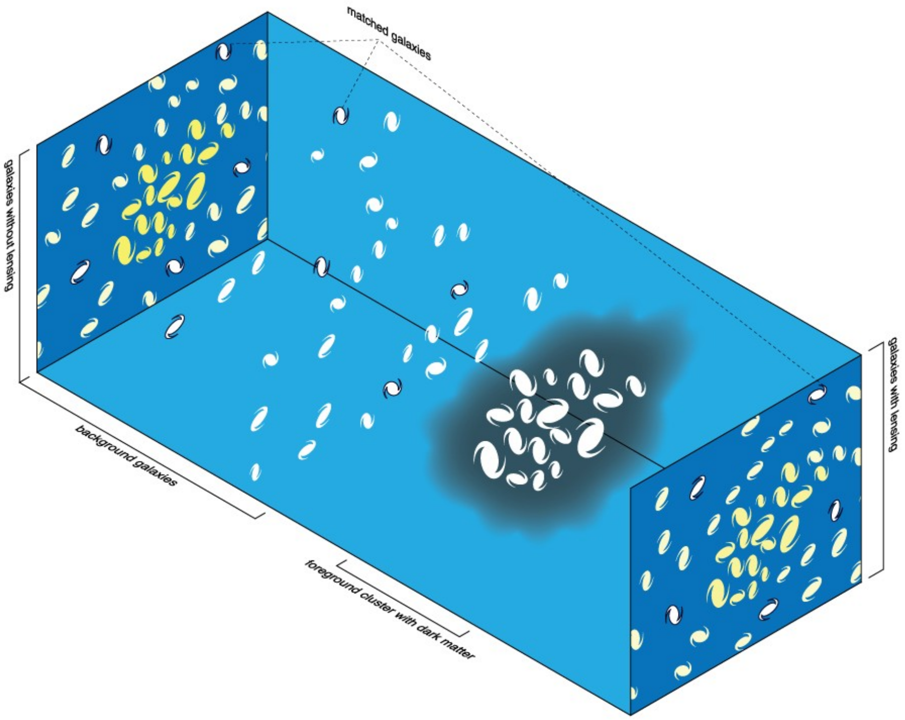
Cosmic shear

- Massive foreground cluster lenses the images of background galaxies
- Able to measure the amplitude of the matter perturbations between observer and background



Credits: Michael Sachs

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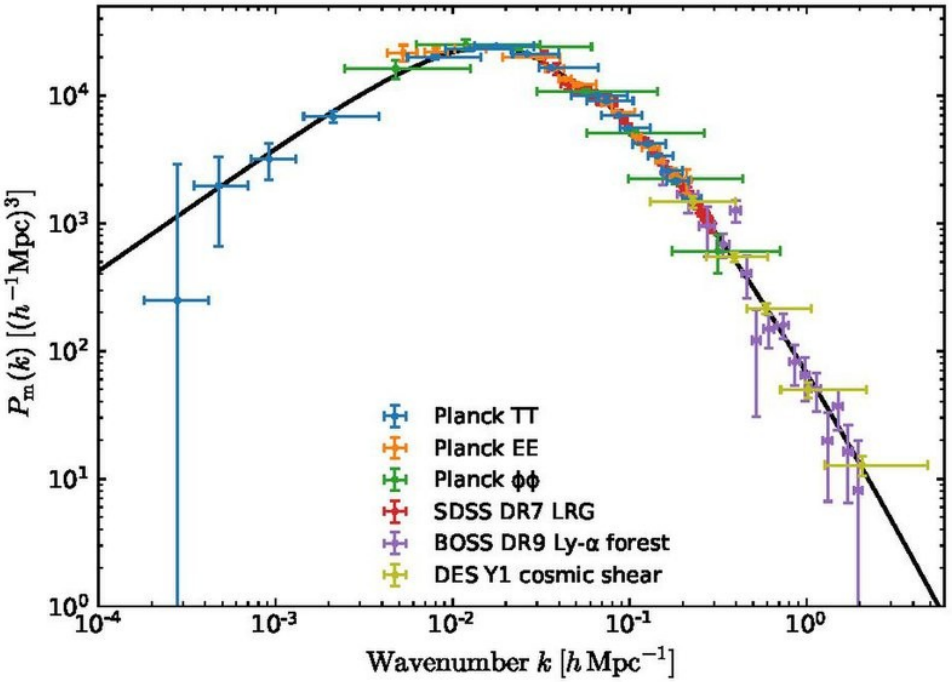
Combination will help us measure the power spectrum on a wide range of scales



Ade et al. [Planck 2018]

The Observer

***Euclid* mission's observational goals**

- catalogue ~1 billion galaxies
- cover ~1/3 of the sky
- measure redshifts and shapes of galaxies from up to 10 billion years ago

***Euclid* mission's scientific goals**

- expansion rate of the universe
    - dark energy equation of state
- growth of structure
    - cosmological neutrinos
    - deviations from GR
    - dark matter properties

Credit: SpaceX

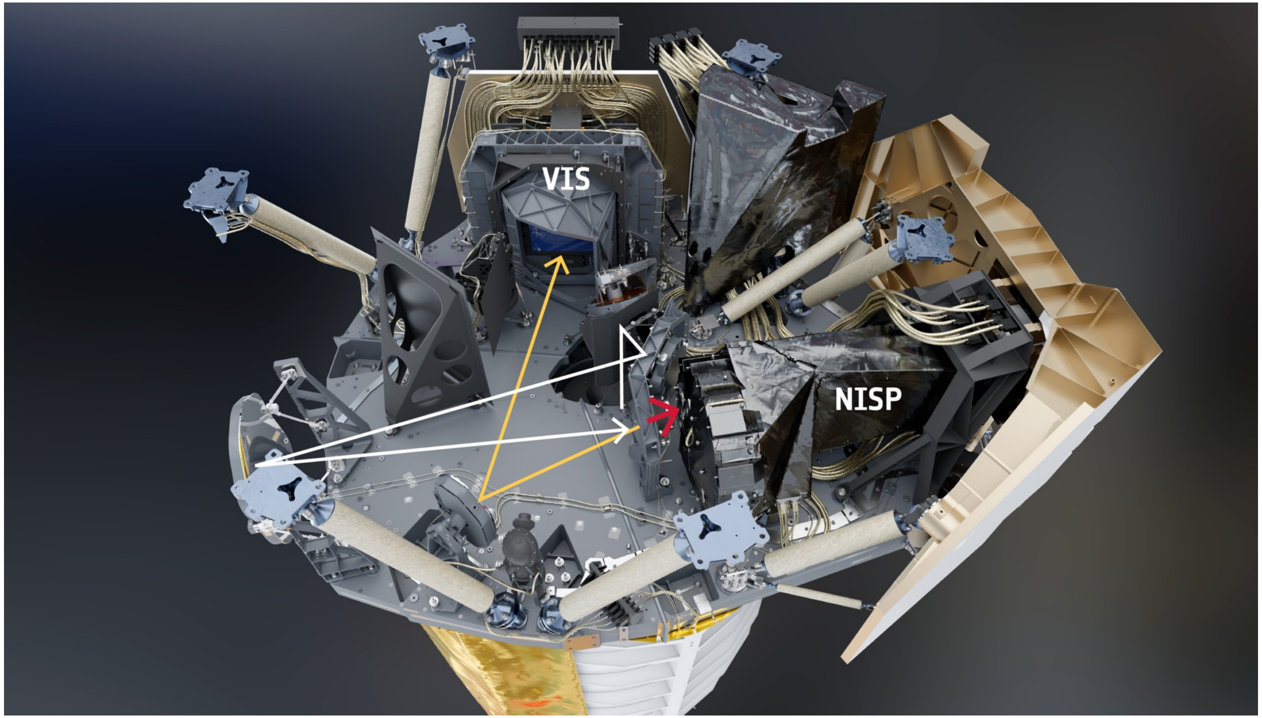
The Observer

The main probes

- spectroscopic redshifts
  - galaxy map (→ 3D space)
- photometric redshifts
  - galaxy map (→ angular space)
  - cosmic shear map (→ angular space)

Additional probes

- cluster and void number counts
- quasar catalogue



Credit: Airbus, ESA

The Forecast

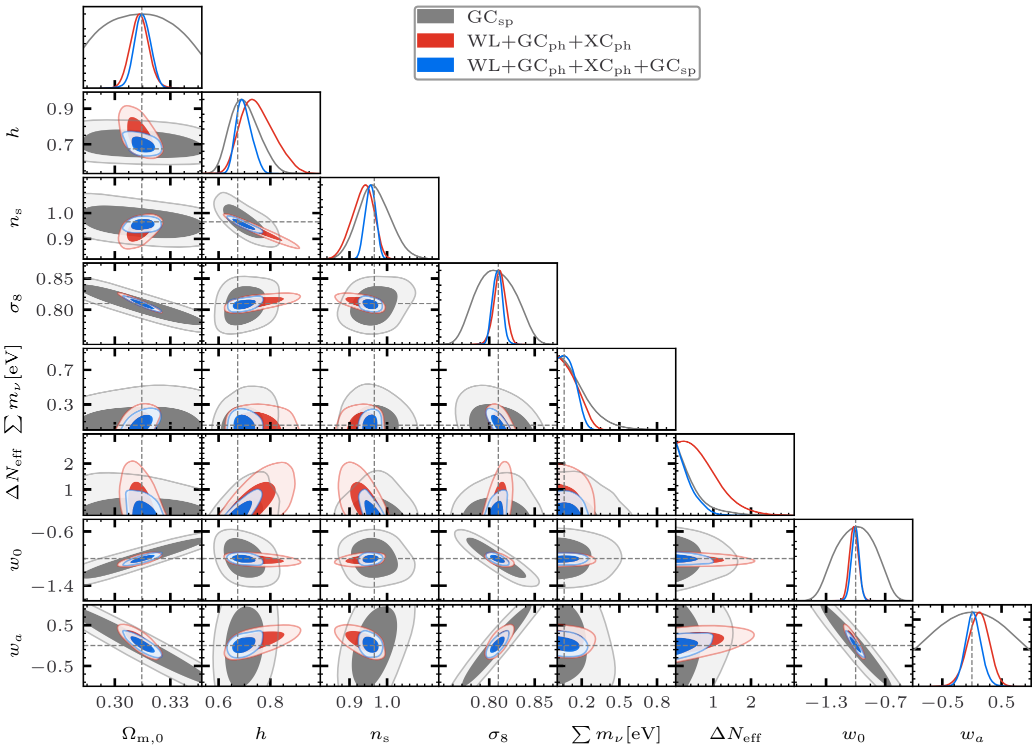
The forecast is done using Markov chain Monte Carlo methods

We see that the two Euclid instruments are complimentary and can be combined to break degeneracies

- Especially in the local expansion speed h and N_{eff}

We can also see from the contours that the dynamical dark energy parameters do not correlate with the neutrino parameters

$w_0 w_a\mathrm{CDM}+\sum m_\nu+\Delta N_{\mathrm{eff}}$



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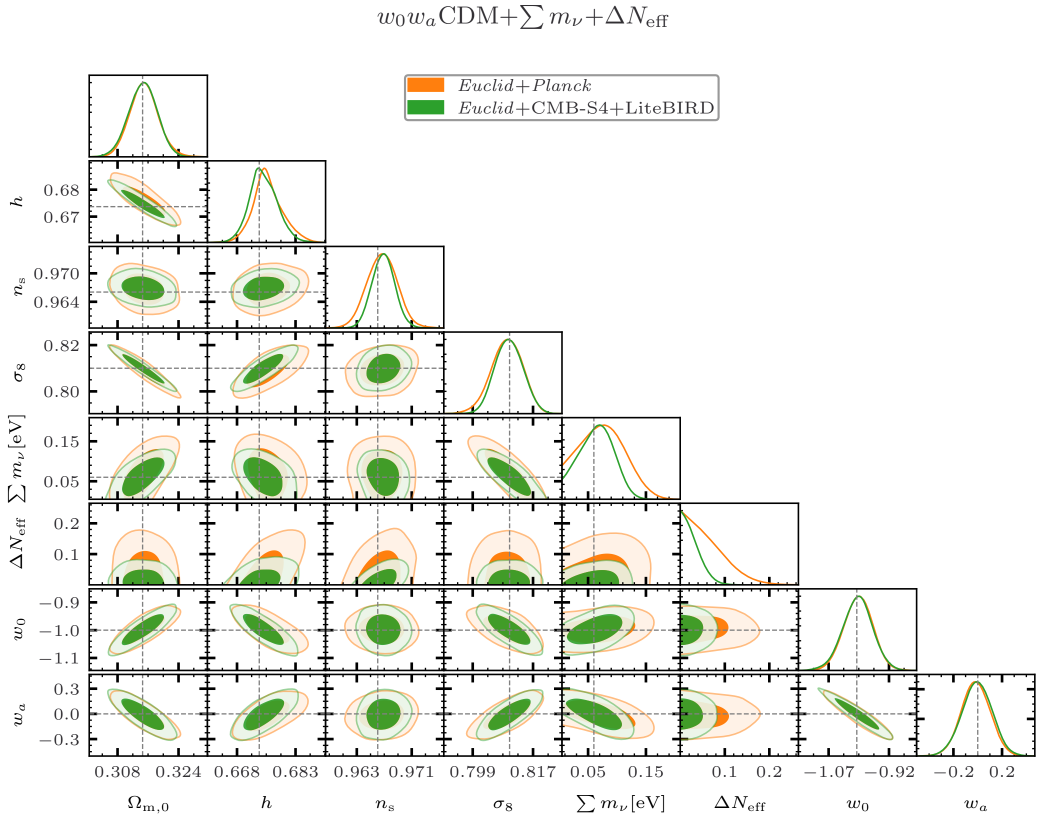
Combination with cosmic microwave background data further helps breaking degeneracies

- Euclid data breaks degeneracy of h and $\sum m_\nu$ present in CMB only
- CMB spectra is used to fix the primordial amplitude making Euclid very sensitive to the neutrino mass
- Euclid on the other hand helps breaking the degeneracy of h and N_{eff}



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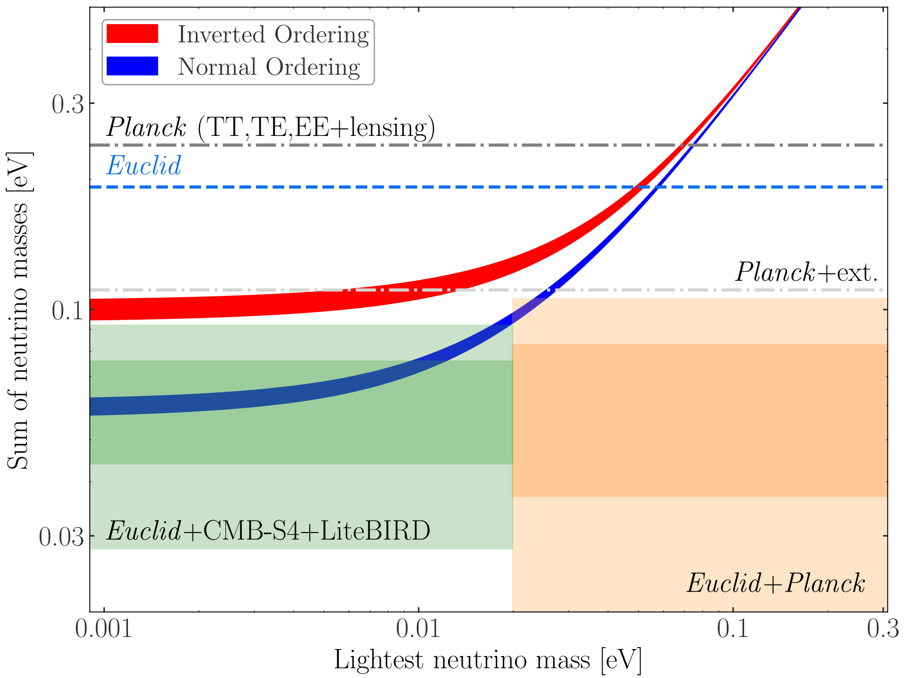

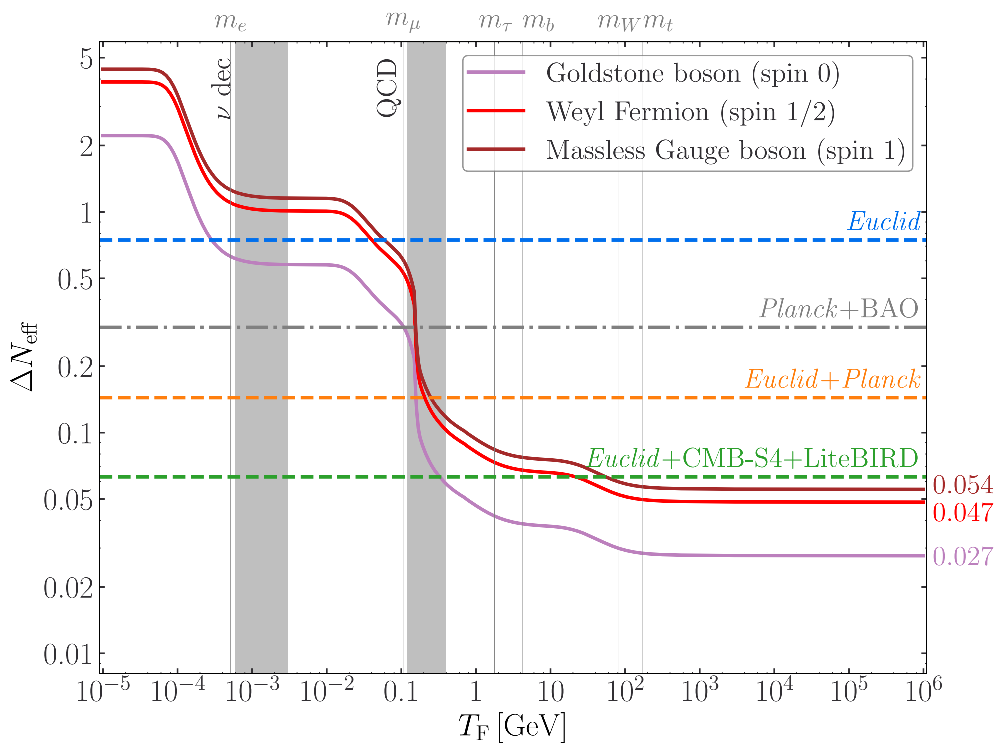

Conclusions

$\Lambda\mathrm{CDM} + \sum m_\nu + \Delta N_{\mathrm{eff}}$							
	$\Omega_{\mathrm{m},0}$	$100\,\Omega_{\mathrm{b},0}$	h	n_{s}	σ_8	$\sum m_\nu[\mathrm{meV}]$	ΔN_{eff}
Euclid-only							
$\mathrm{WL}+\mathrm{GC}_{\mathrm{ph}}+\mathrm{XC}_{\mathrm{ph}}+\mathrm{GC}_{\mathrm{sp}}$	0.0026	0.19	0.023	0.012	0.0039	< 220	< 0.746
Euclid+CMB							
Euclid+*Planck*	0.0022	0.037	0.0028	0.0021	0.0031	25	< 0.144
Euclid+CMB-S4+LiteBIRD	0.0019	0.025	0.0018	0.0016	0.0025	16	< 0.063

- Cosmology is a powerful tool to make measurements on neutrino parameters
- The Euclid probes show remarkable complementarity with each other and with CMB data
- Euclid + Planck are forecast to be able to measure a non zero neutrino mass with a >95% confidence
- This combination will also be able to exclude additional ultra-relativistic relics decoupled before the QCD transition
- The constrains will be even better with future CMB stage 4 experiments