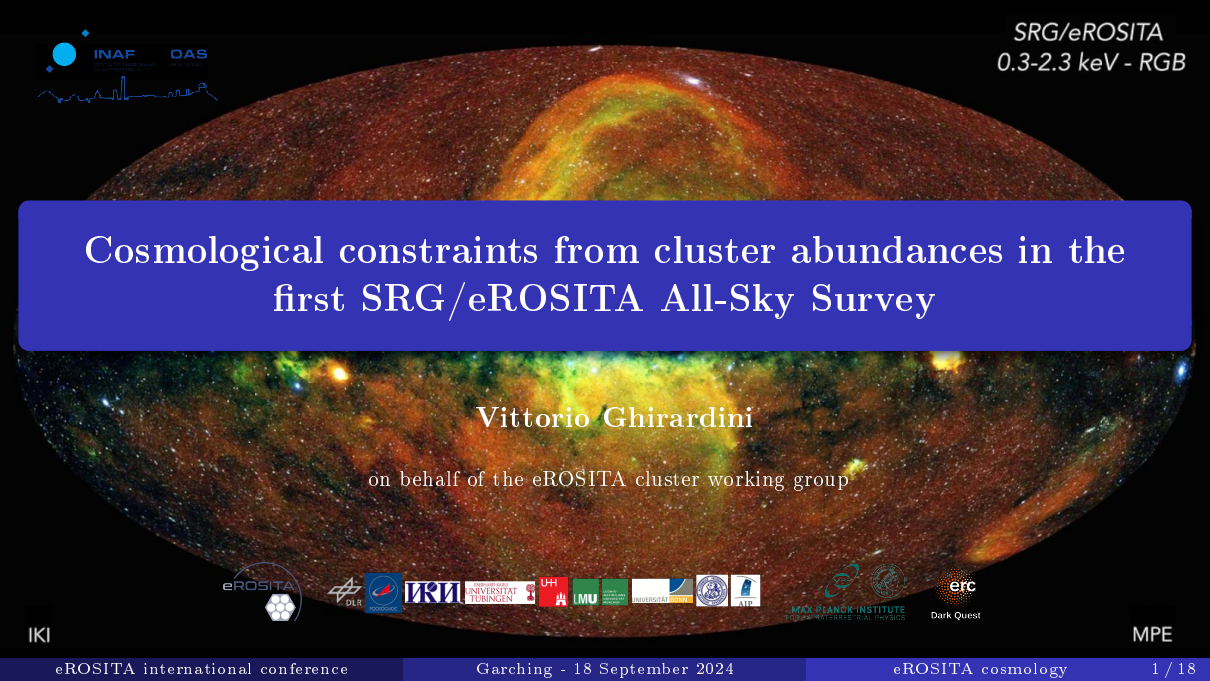


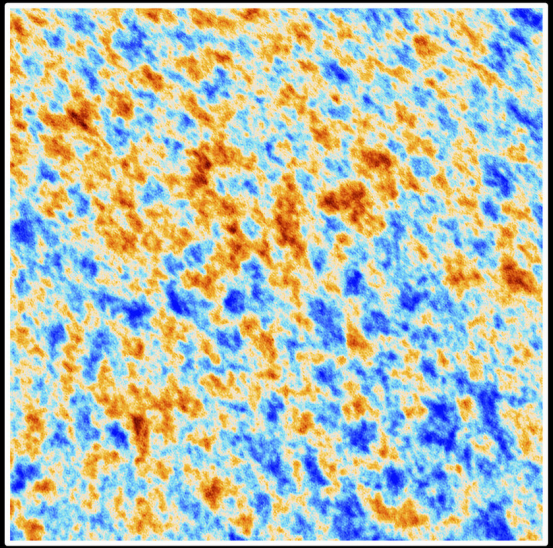
Cosmological constraints from cluster abundances in the first SRG/eROSITA All-Sky Survey

Vittorio Ghirardini

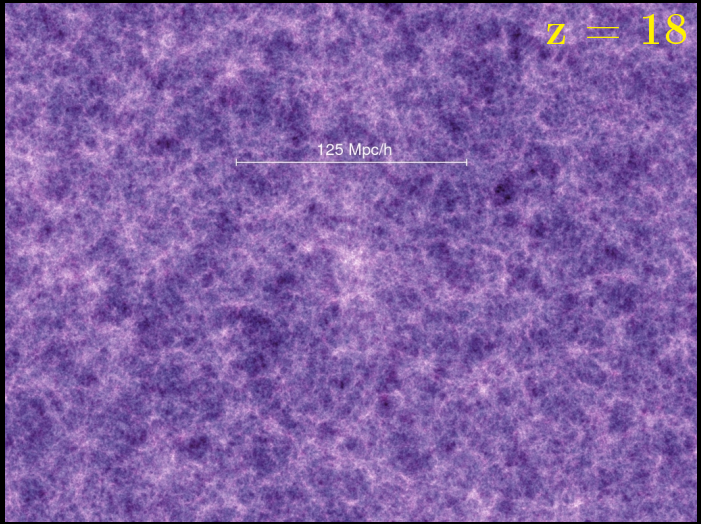
on behalf of the eROSITA cluster working group

IKI MPE

Clusters are powerful cosmological probes

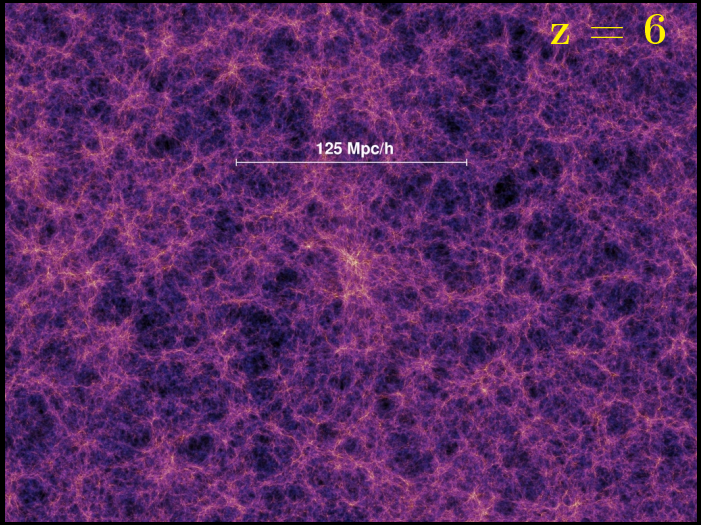


Clusters are powerful cosmological probes



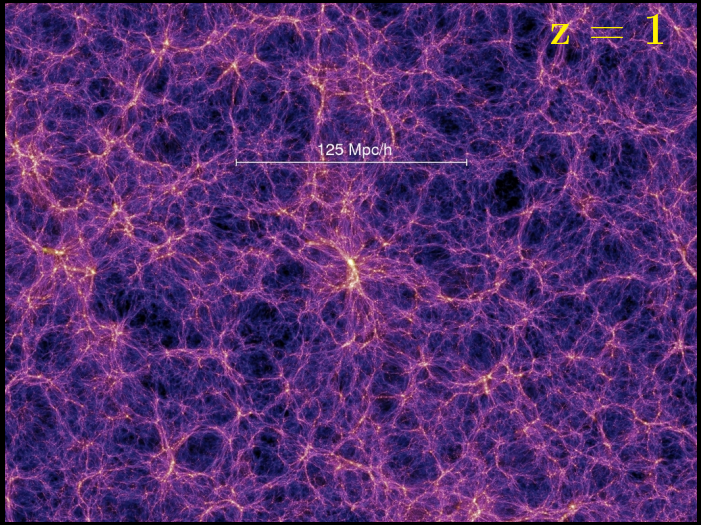
Millenium, Springel et al. 2006

Clusters are powerful cosmological probes



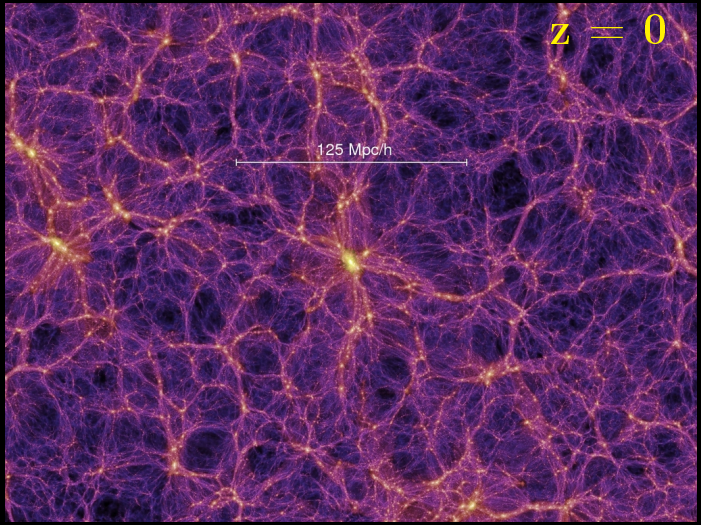
Millenium, Springel et al. 2006

Clusters are powerful cosmological probes



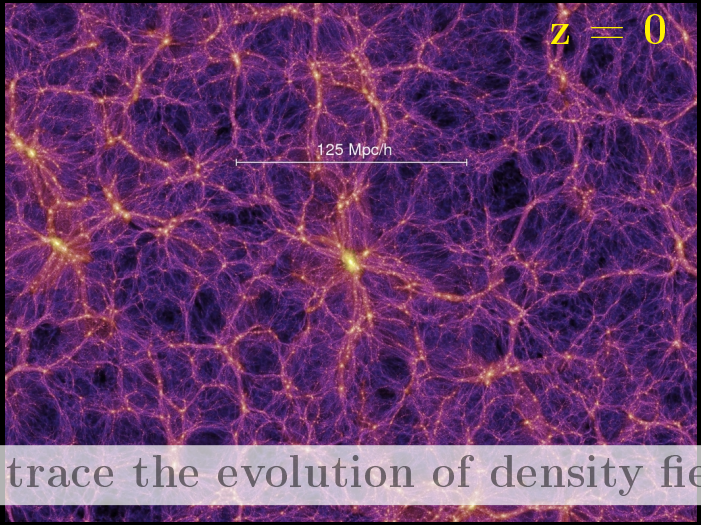
Millenium, Springel et al. 2006

Clusters are powerful cosmological probes



Millenium, Springel et al. 2006

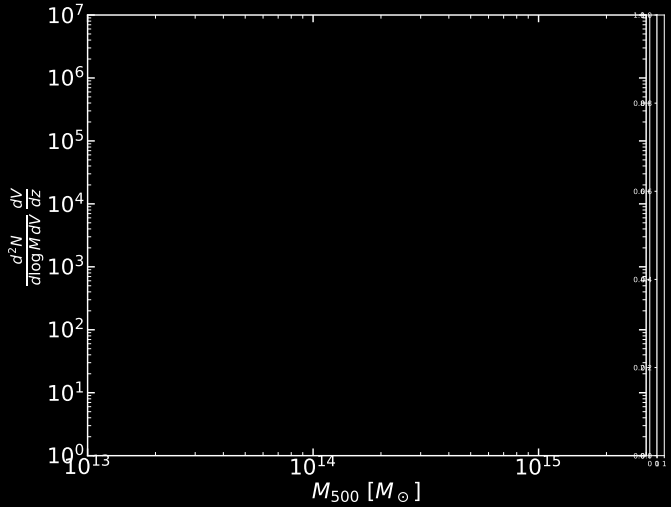
Clusters are powerful cosmological probes



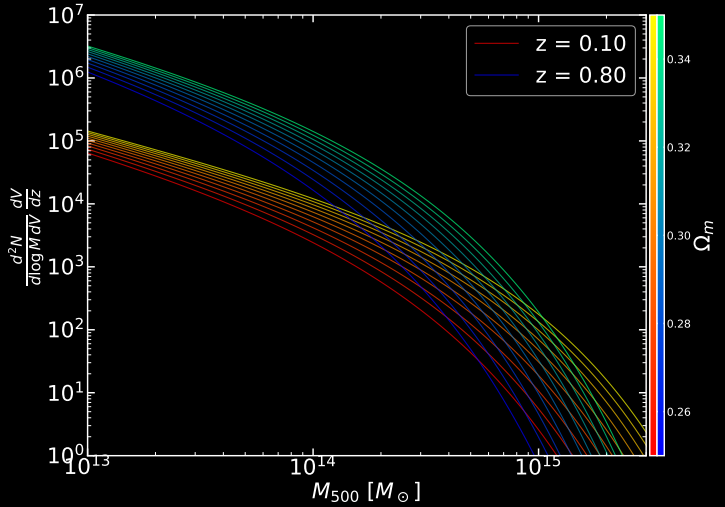
Clusters trace the evolution of density field peaks

Millenium, Springel et al. 2006

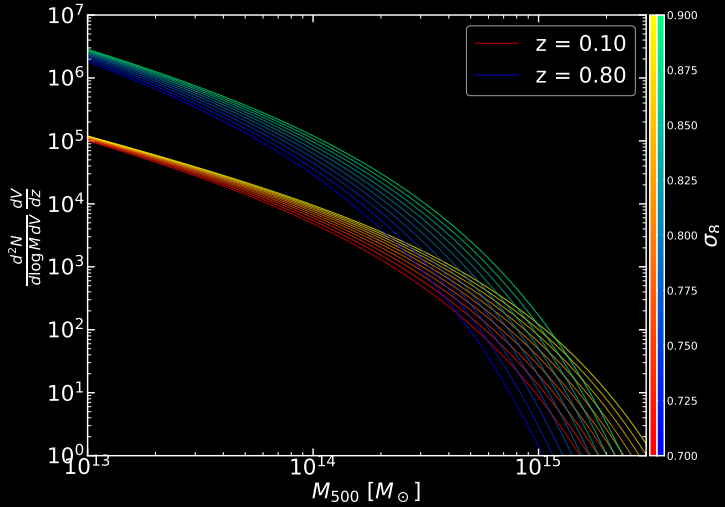
Halo Mass Function



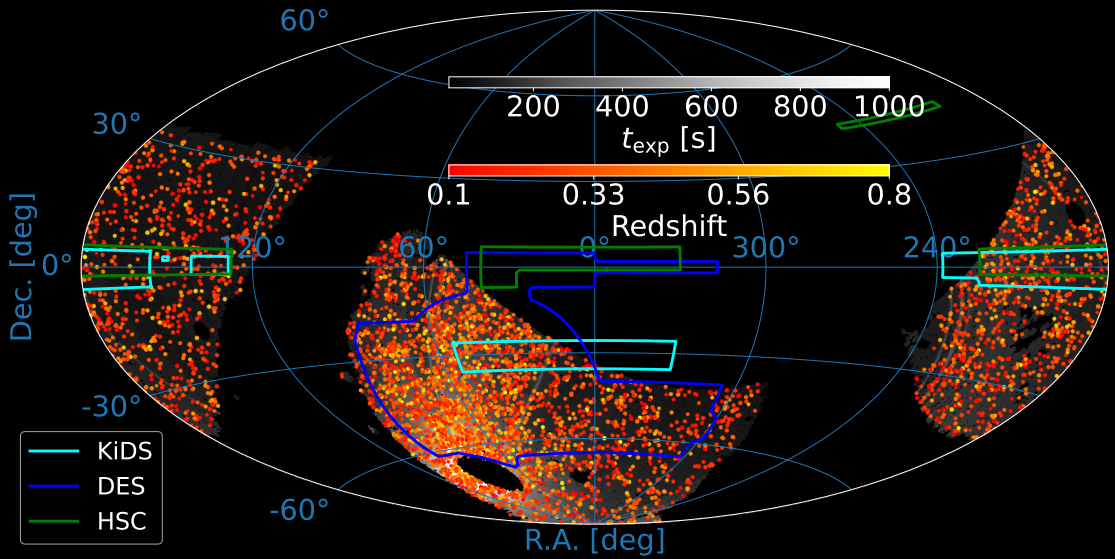
Halo Mass Function



Halo Mass Function



eROSITA_DE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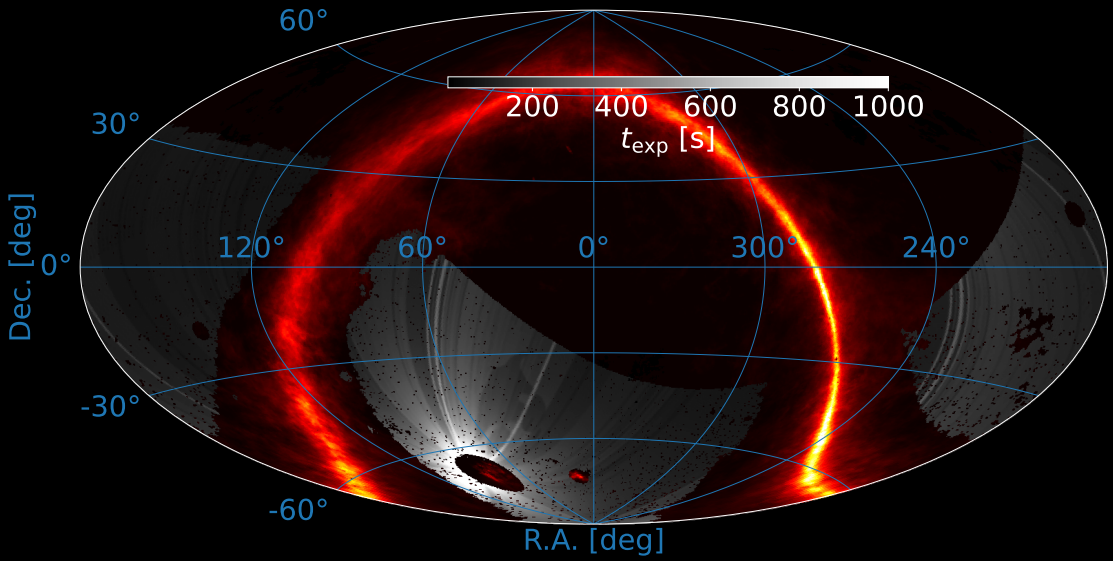
Redshift
KiDS
DES
HSC

eROSITA_DE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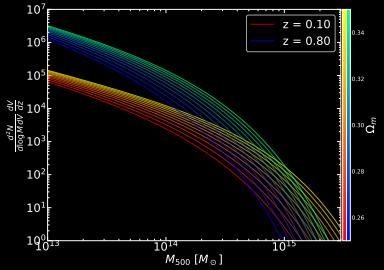
t_{exp} [s]

Forward model



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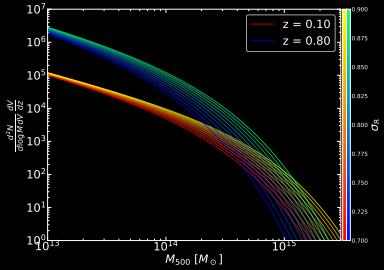
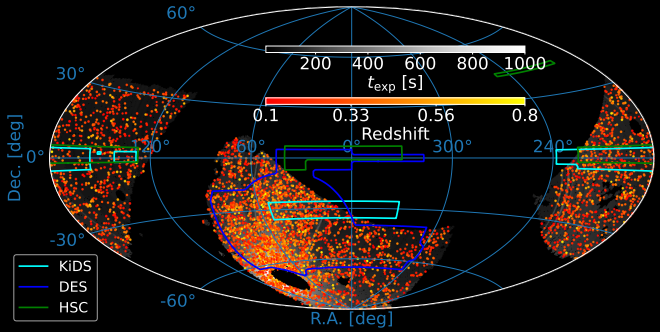
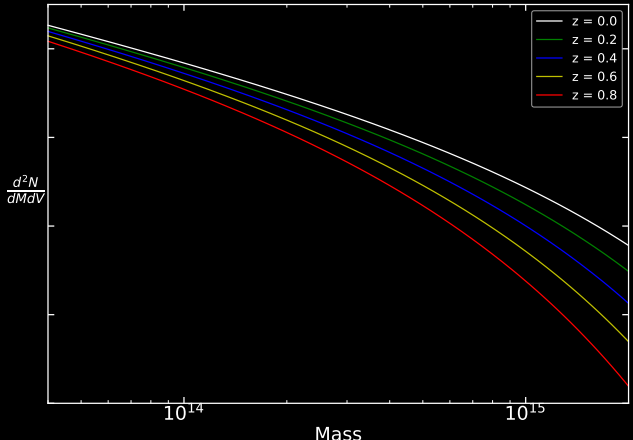




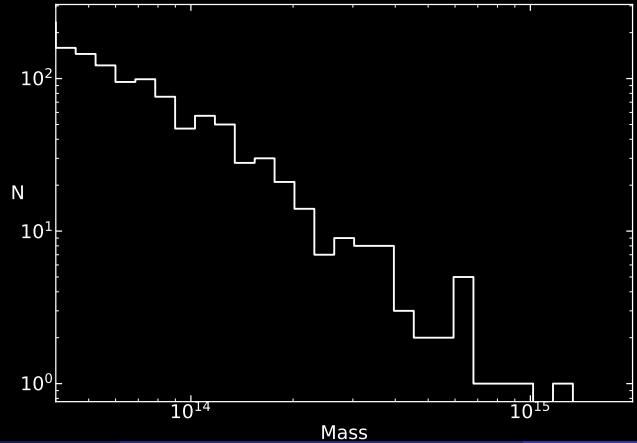
Forward model – Halo Mass Function

$$\underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}}$$



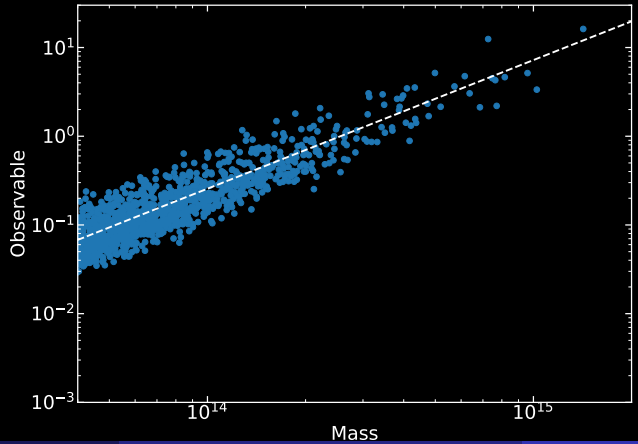
Forward model – Halo Mass Function

$$\underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}}$$



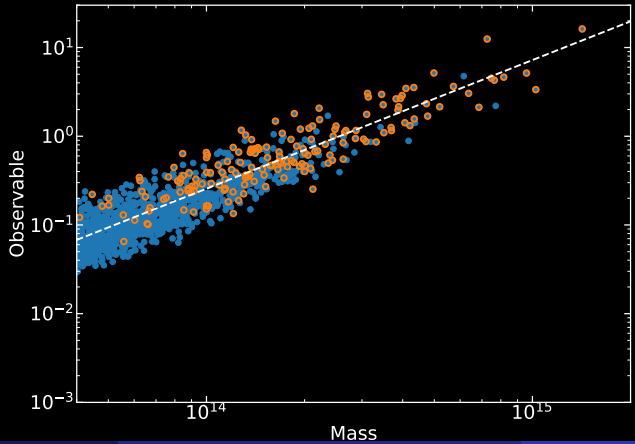
Forward model – Scaling relation

$$\underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}}\underbrace{\frac{dM}{d\bar{X}}(z,\theta_p)}_{\text{astrophysics}}$$



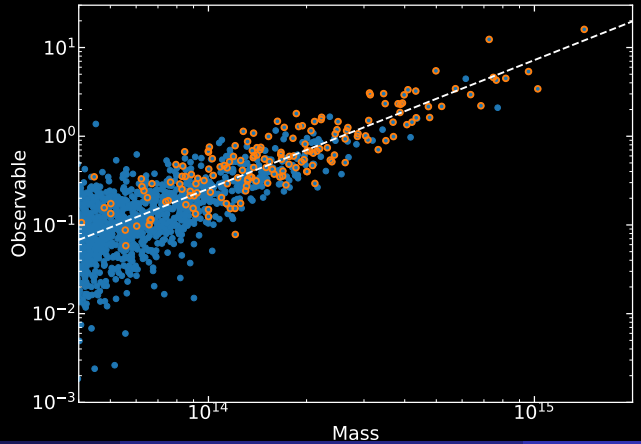
Forward model – Selection function

$$\underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}}\underbrace{\frac{dM}{d\bar{X}}(z,\theta_p)}_{\text{astrophysics}}\underbrace{P(I|\bar{X},M,z,\theta_s)}_{\text{selection function}}$$



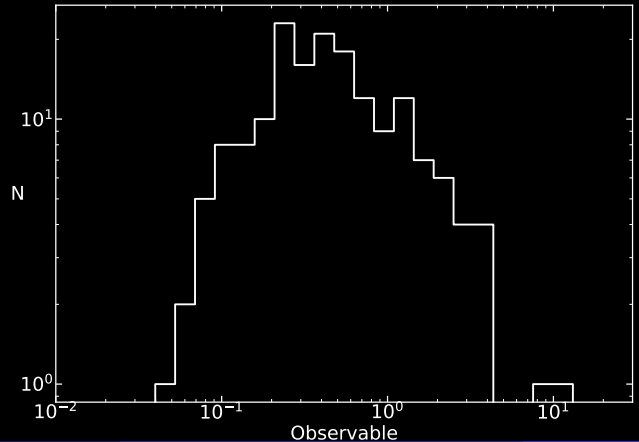
Forward model – Measurement uncertainty

$$\underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}}\underbrace{\frac{dM}{d\bar{X}}(z,\theta_p)}_{\text{astrophysics}}\underbrace{P(I|\bar{X},M,z,\theta_s)}_{\text{selection function}}\underbrace{P(\hat{\bar{X}}|\bar{X})}_{\text{uncertainty}}$$



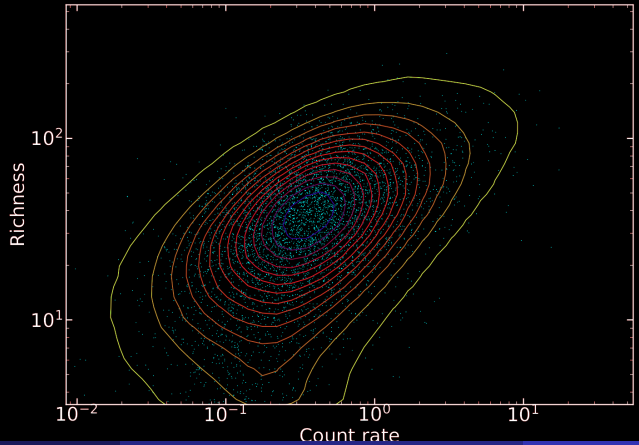
Forward model – Marginalization

$$\iint \underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}} \underbrace{\frac{dM}{d\bar{X}}(z,\theta_p)}_{\text{astrophysics}} \underbrace{P(I|\bar{X},M,z,\theta_s)}_{\text{selection function}} \underbrace{P(\hat{\bar{X}}|\bar{X})}_{\text{uncertainty}} \underbrace{dMdX}_{\text{marginalize}}$$

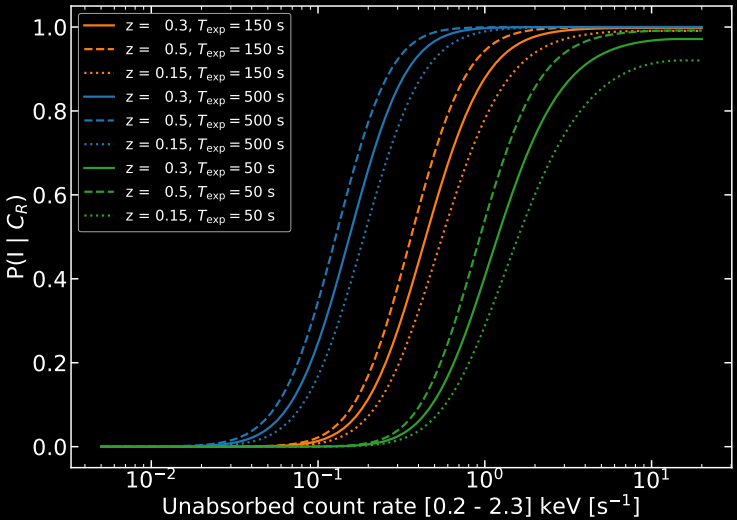


Forward model – Multiple observables

$$\iint \underbrace{\frac{d^2N(M,z,\theta_c)}{dMdV}\frac{dV}{dz}(\theta_c)}_{\text{cosmology dependence}} \underbrace{\frac{dM}{d\bar{X}}(z,\theta_p)}_{\text{astrophysics}} \underbrace{P(I|\bar{X},M,z,\theta_s)}_{\text{selection function}} \underbrace{P(\hat{\bar{X}}|\bar{X})}_{\text{uncertainty}} \underbrace{dMd\bar{X}}_{\text{marginalize}}$$



Selection Function



Comparat+2020, Seppi+2022, Clerc+2024

Scaling relations

$$\frac{dM}{d\bar{X}}(z, \theta_p) \quad : \quad M \overset{\frown}{\qquad} \bar{X}$$

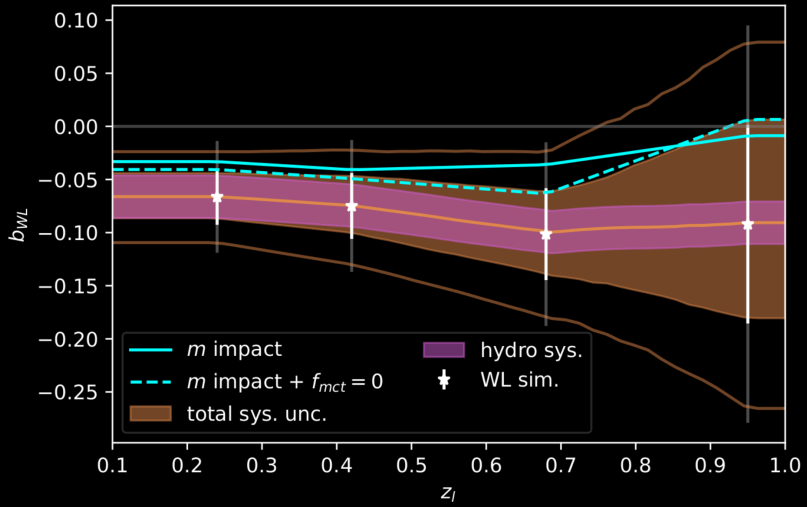
- Self-similarity of cluster properties
  - Kaiser 1986
- $\langle \bar{X} \rangle \sim M^{\alpha}$
  - $L_X \sim M^1$
  - $T_X \sim M^{2/3}$

- Uncertainties in the mass - observable relation are the dominant source of systematics for cluster cosmology

Weak lensing mass proxy

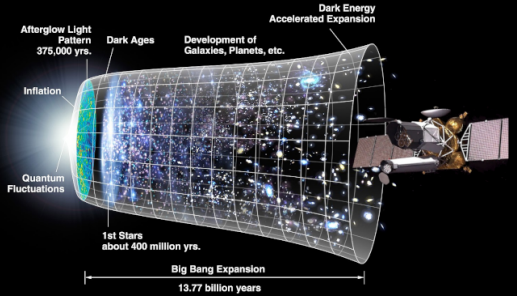
- All mass proxy are biased!
- The factors contributing to the WL bias are under control
  - Triaxiality
  - Substructures
  - Mis-centering
  - Baryonic effects
  - Uncorrelated structures
- They can be calibrated using simulations

Weak lensing mass proxy



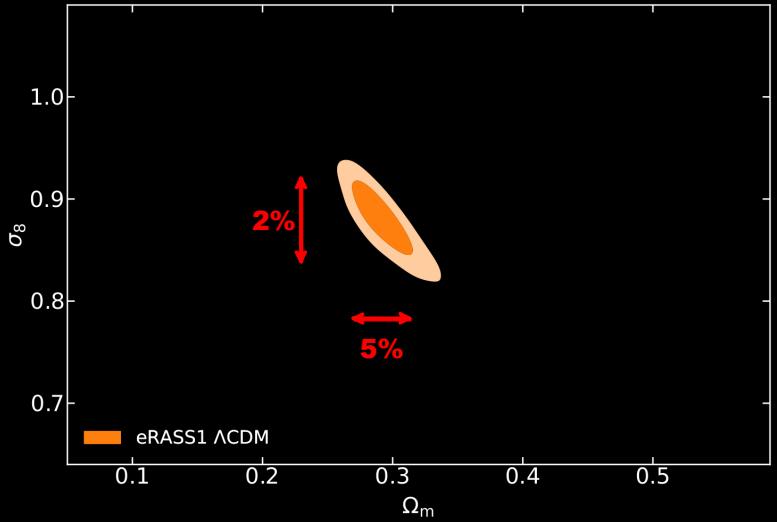
Grandis+24

Results: ΛCDM

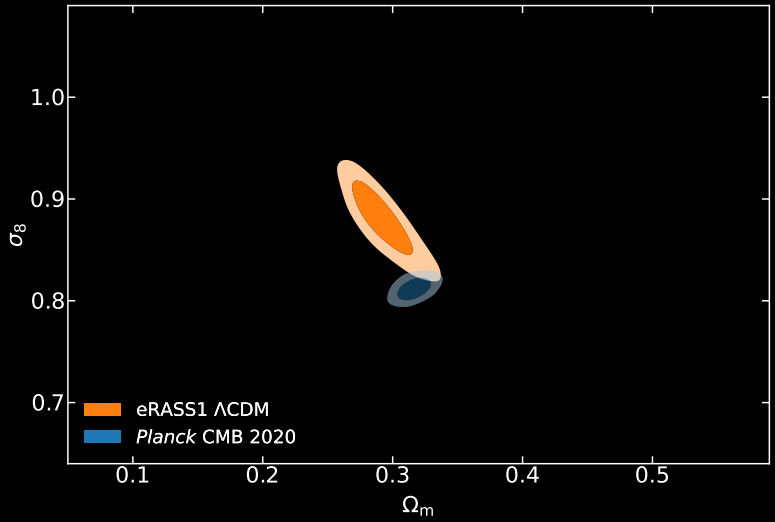


- $\Omega_{\rm m}$: mean matter density at present time
- σ_8: the amplitude of mass density fluctuations
- $S_8 = \sigma_8 \sqrt{\frac{\Omega_{\rm m}}{0.3}}$: clumpiness of structure

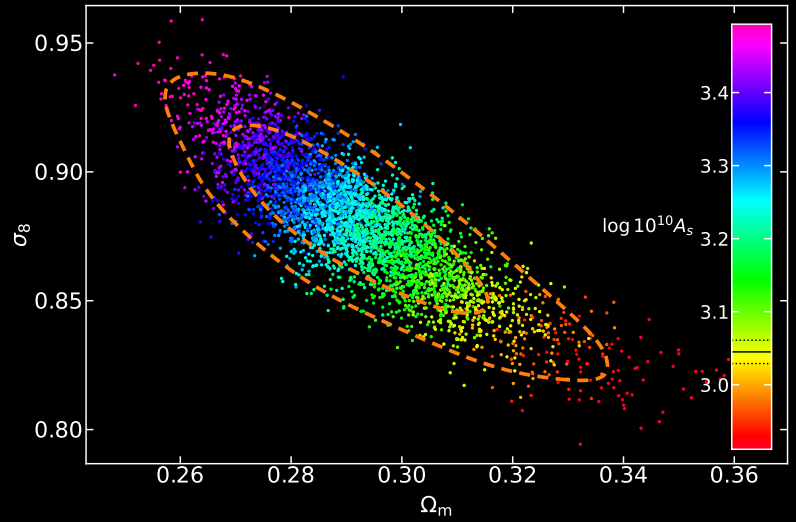
ΛCDM results



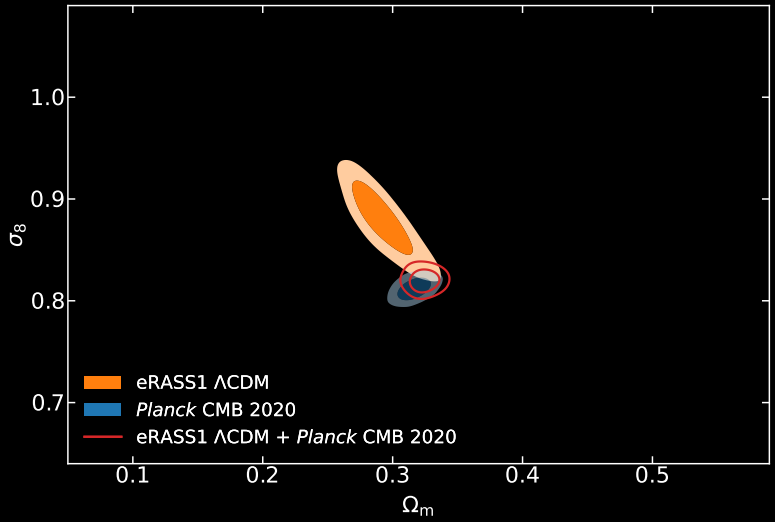
ΛCDM results



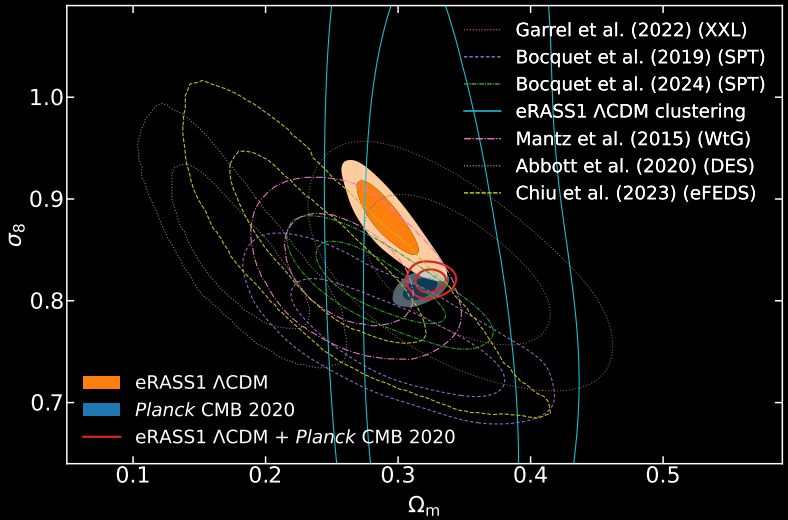
Can we combine?



ΛCDM results



ΛCDM results



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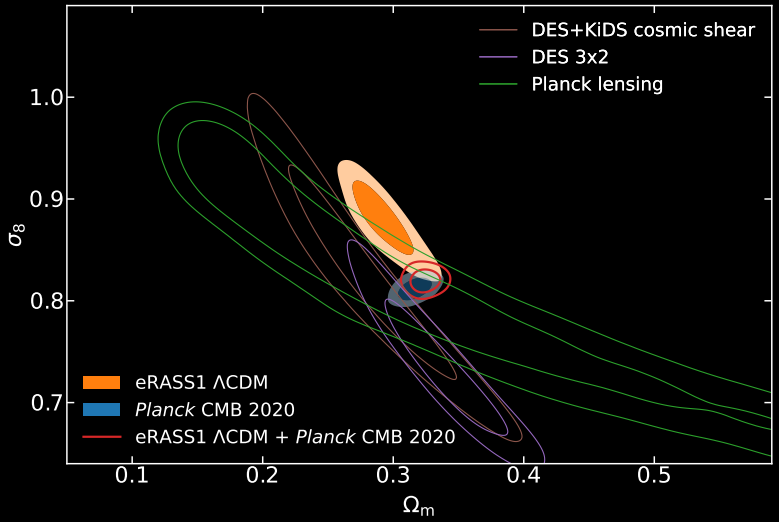
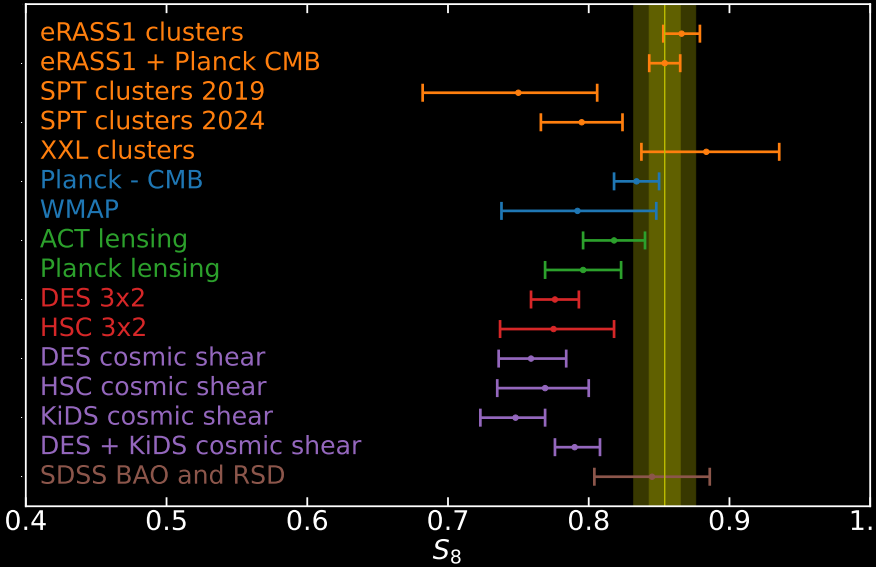


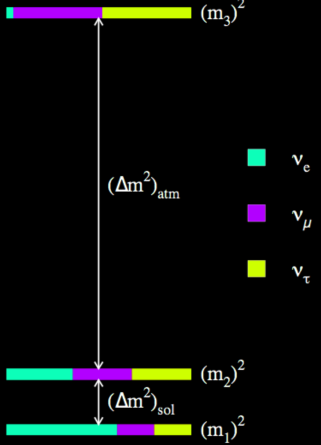
ΛCDM results - S_8

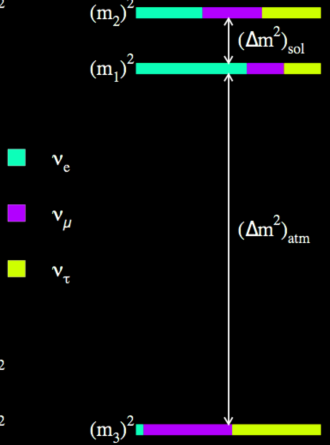


Results: νCDM

- $\sum m_\nu$: sum of neutrino masses

Neutrino mass hierarchy





Direct experiments

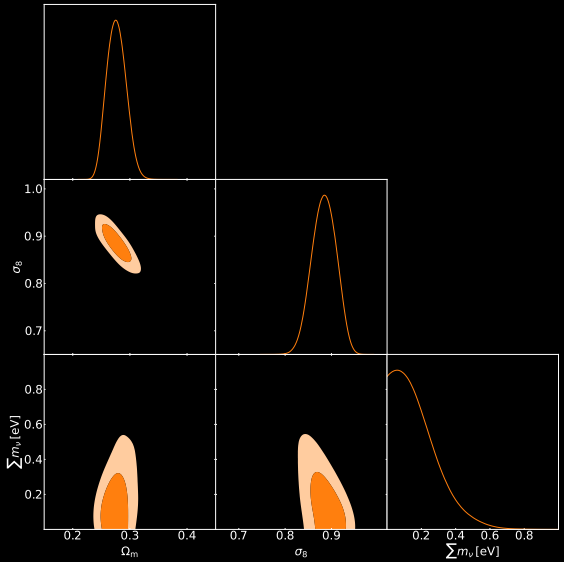
- Oscillations:
  $\sum m_\nu > 0.059$ eV (normal)
  $\sum m_\nu > 0.101$ eV (inverted)
- Tritium decay:
  $\sum m_\nu < 1.1$ eV

Indirect experiments

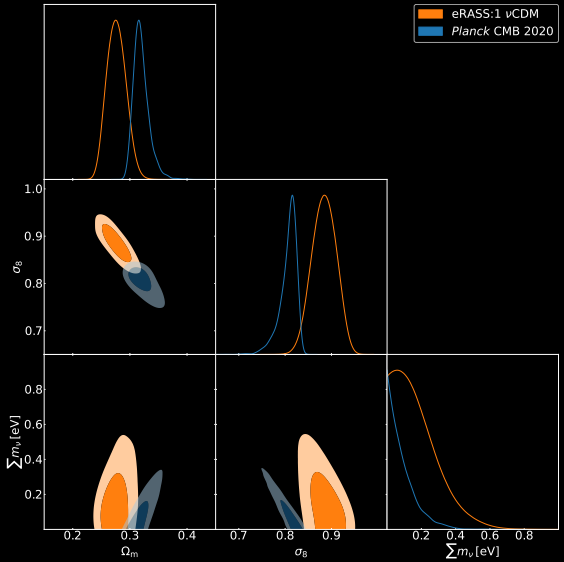
- Planck CMB:
  $\sum m_\nu < 0.26$ eV
- Planck CMB + BAO/Lyα:
  $\sum m_\nu < 0.15$ eV

Tanabashi+18, Vagnozzi+17, Rossi+15, Aker+19, Planck+20

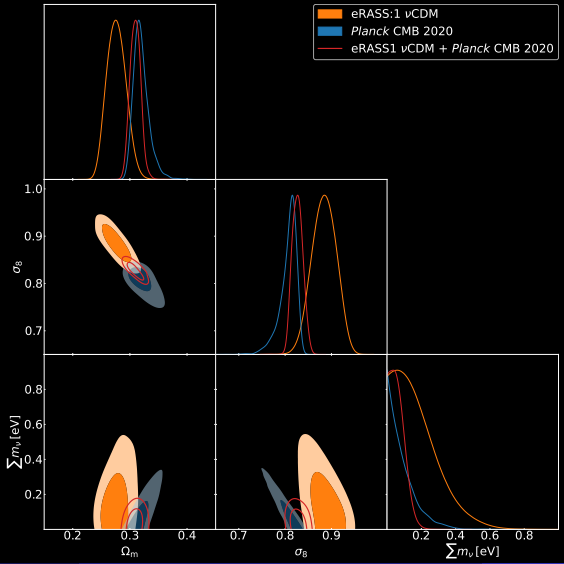
νCDM results



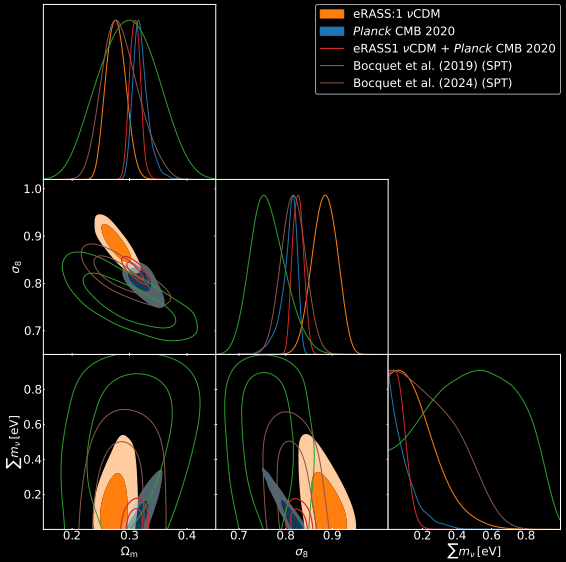
νCDM results



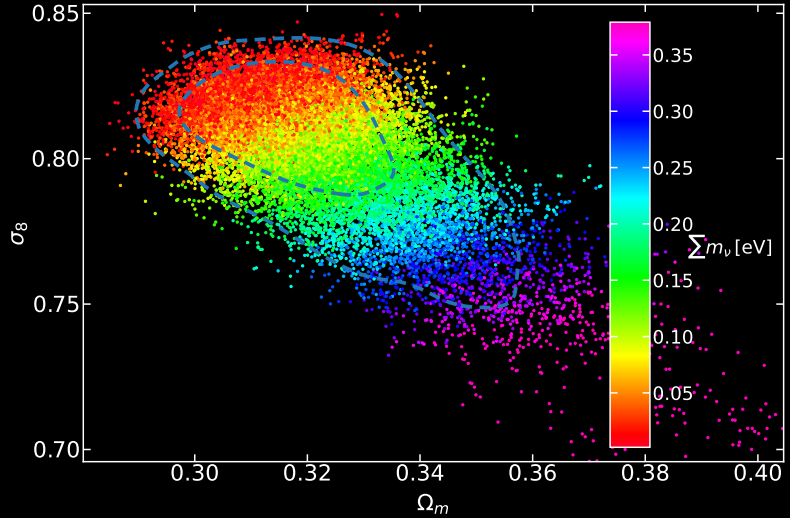
νCDM results



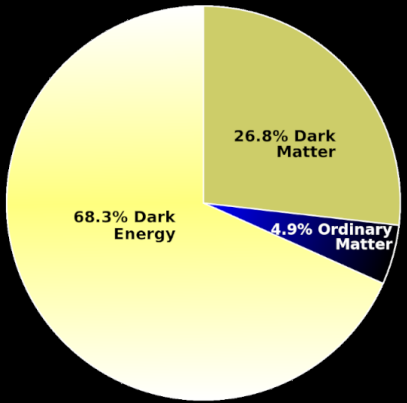
νCDM results



Why is Planck combination still powerful?

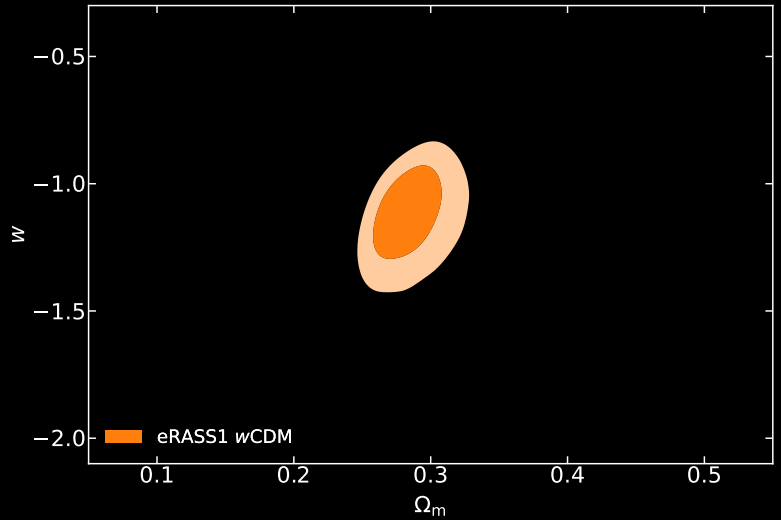


Results: wCDM

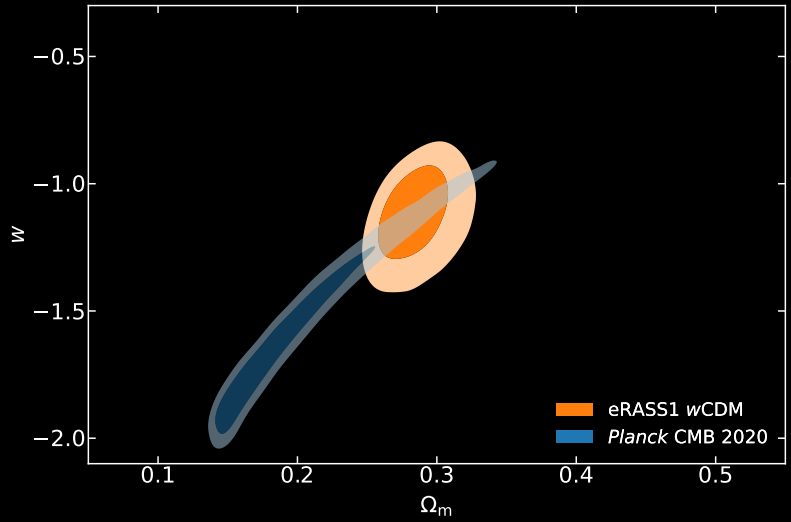


- w: P/ρ equation of state

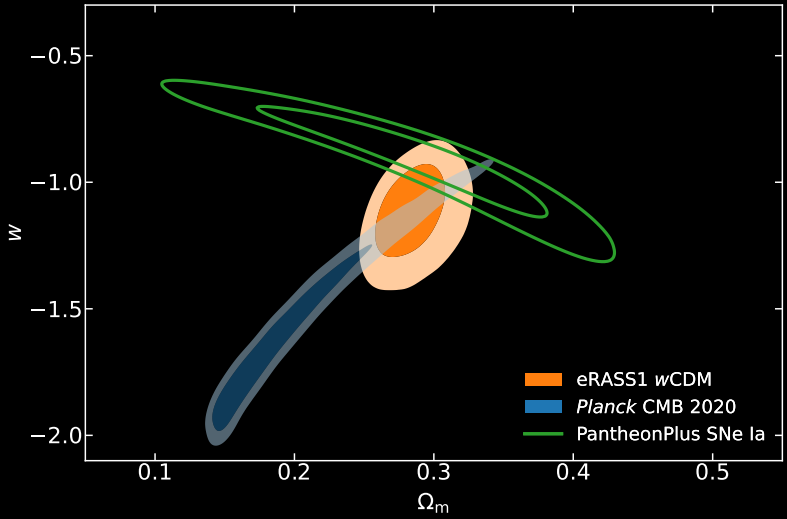
wCDM results



wCDM results



wCDM results



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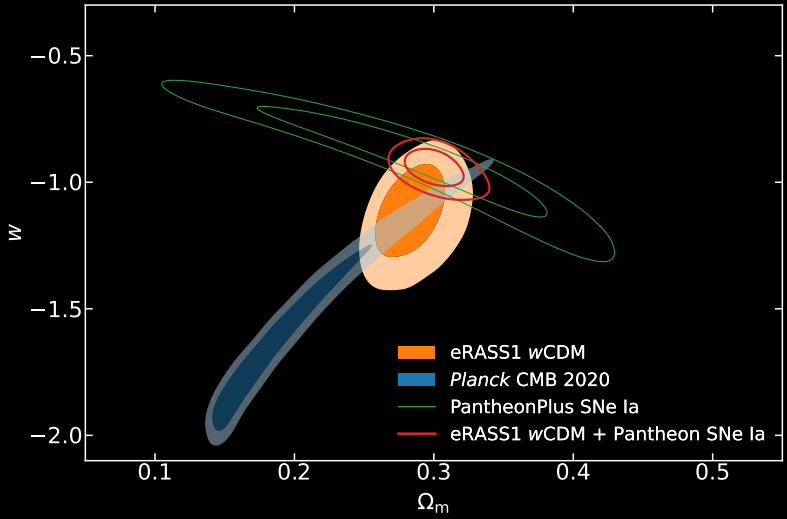
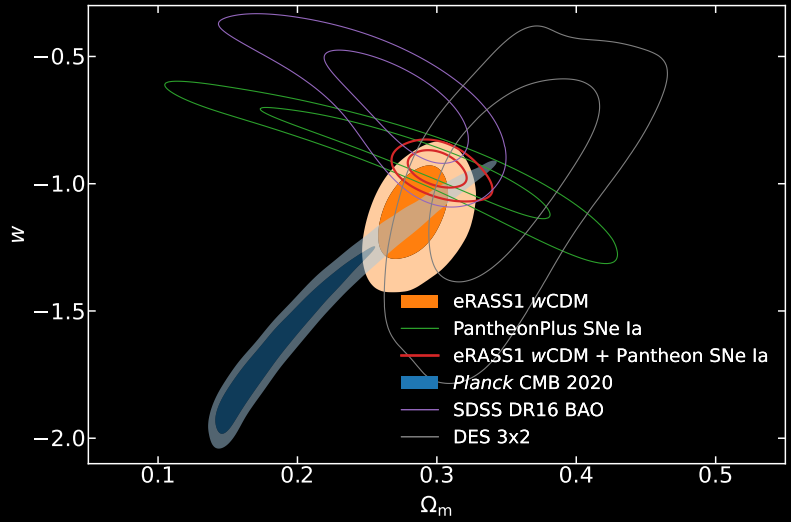


wCDM results



Takeaway messages – why these results matter?

- Clusters are precision cosmological probes
- All late-time parameters have been measured with high precision
- We do not find any tension with ΛCDM
- We are in tension with cosmic shear experiments on S_8
- Neutrino constraints are competitive, and probe combination is powerful
- Dark energy equation of state is consistent with -1
- Future eROSITA surveys will return ground-breaking results on cosmology