Constraint on Mass of Light Gravitino from CMB Lensing and Cosmic Shear

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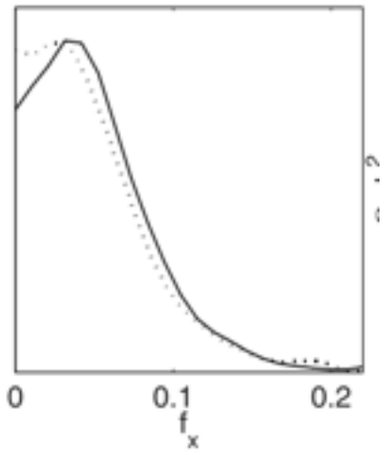
Introduction

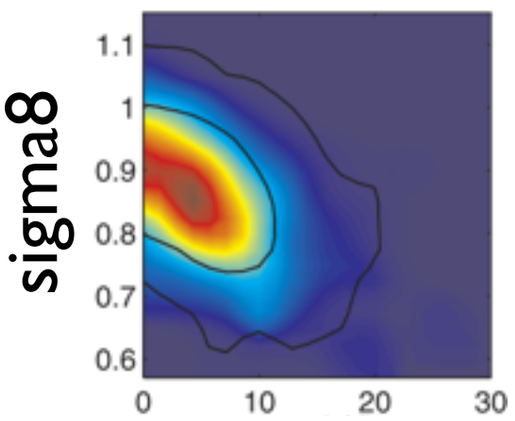
- **Gravitino**: supersymmetric partner of graviton.
  Gravitinos have no charge and spin-3/2. **Candidate of dark matter**
  Supersymmetric models predict gravitino mass of $\mathcal{O}(\mathrm{eV} - \mathrm{GeV})$

- **Light gravitinos:** $m_{3/2} \sim 10\ \mathrm{eV}$
  In this mass range, the theory is free from gravitino problem and suitable for baryogenesis.



- **Collider experiments (e.g., LHC)** place the constraint on lower-bound of light gravitino mass. And **cosmological observations** constrain it as upper-bound.
  Recent constraint from Lyman-alpha forests.

$$m_{3/2} < 16\ \mathrm{eV}\ (95\%\ \mathrm{C.L.})$$



Viel+ 2005

Effects on Large-Scale Structure

- **1. Change of matter-radiation equality**

  Light gravitinos act as a radiation component in early Universe and can change the total energy content characterized by **the effective degree of freedom**.

  ➡But this effect cannot be probed, since the abundance of light gravitinos is small.

$$\frac{\rho_{3/2}}{\rho_\nu} = \left(\frac{T_{3/2}}{T_\nu}\right)^4 = \left(\frac{g_{*\nu}}{g_{*3/2}}\right)^{4/3}$$

fixed at 90 (Pierpaoli+ '98)

- **2. Suppression of small scale fluctuations via free-streaming**

  Light gravitinos travel freely after decoupling and **smooth out small scale fluctuations**.

  The characteristic scale of free-streaming effects is

$$k_{\rm FS} = \left(\frac{4\pi G\bar{\rho}a^2}{v_{\rm th}^2}\right)^{1/2}\Bigg|_{a=a_{\rm eq}} \simeq 0.27\ {\rm Mpc}^{-1}\ \left(\frac{m_{3/2}}{10\ {\rm eV}}\right)^{1/2}$$

Kamada+ (2014)

Observational Probes

➡We have to rely on probes which are sensitive to the free-streaming scale of light gravitinos.

- **CMB Lensing**

  Gravitational lensing of CMB photons by large-scale structure.

  Lensing potential: comoving distance to the LSS (z~1000)

  $$\phi(\hat{n}) = -2\int_0^{\chi_*} d\chi' \, \frac{f_K(\chi_* - \chi')}{f_K(\chi_*) f_K(\chi')} \Psi$$

  ensity

  most sensitive at $z \simeq 2.0$

- **Cosmic Shear**

  Weak gravitational lensing of distant galaxies

  Convergence: comoving distance to the source galaxy (z~1)

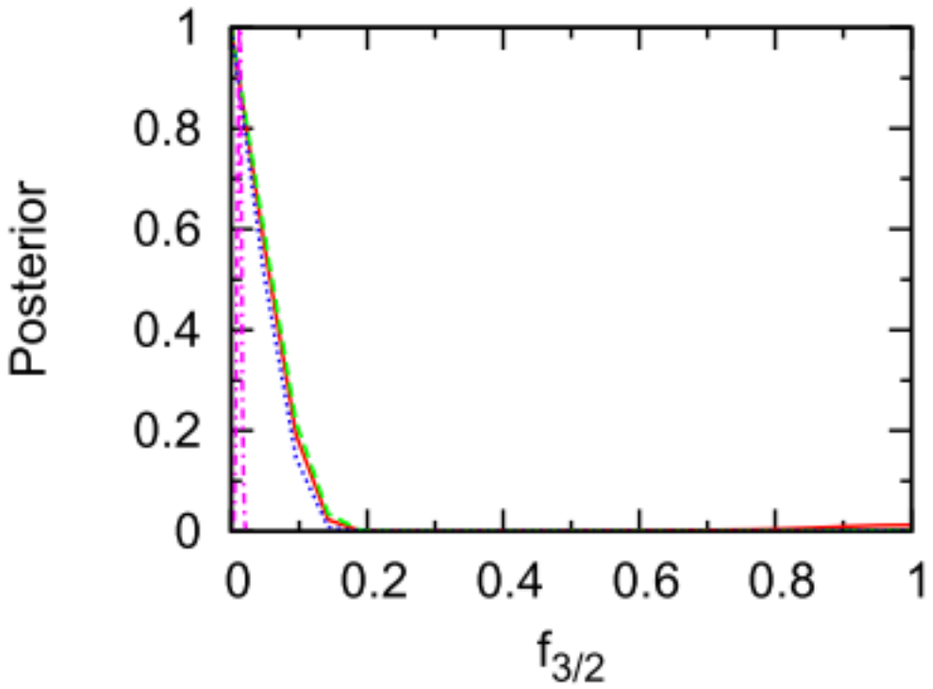
  $$\kappa(\hat{n}) = \frac{1}{c^2}\int_0^{\chi} d\chi' \, \frac{f_K(\chi - \chi') f_K(\chi')}{f_K(\chi)}$$

  most sensitive at $z \simeq 0.5$

Statistics: $C_\ell^{\phi\phi}$, $C_\ell^{\phi T}$, $P_\ell^{\kappa\kappa}$

Forecasts

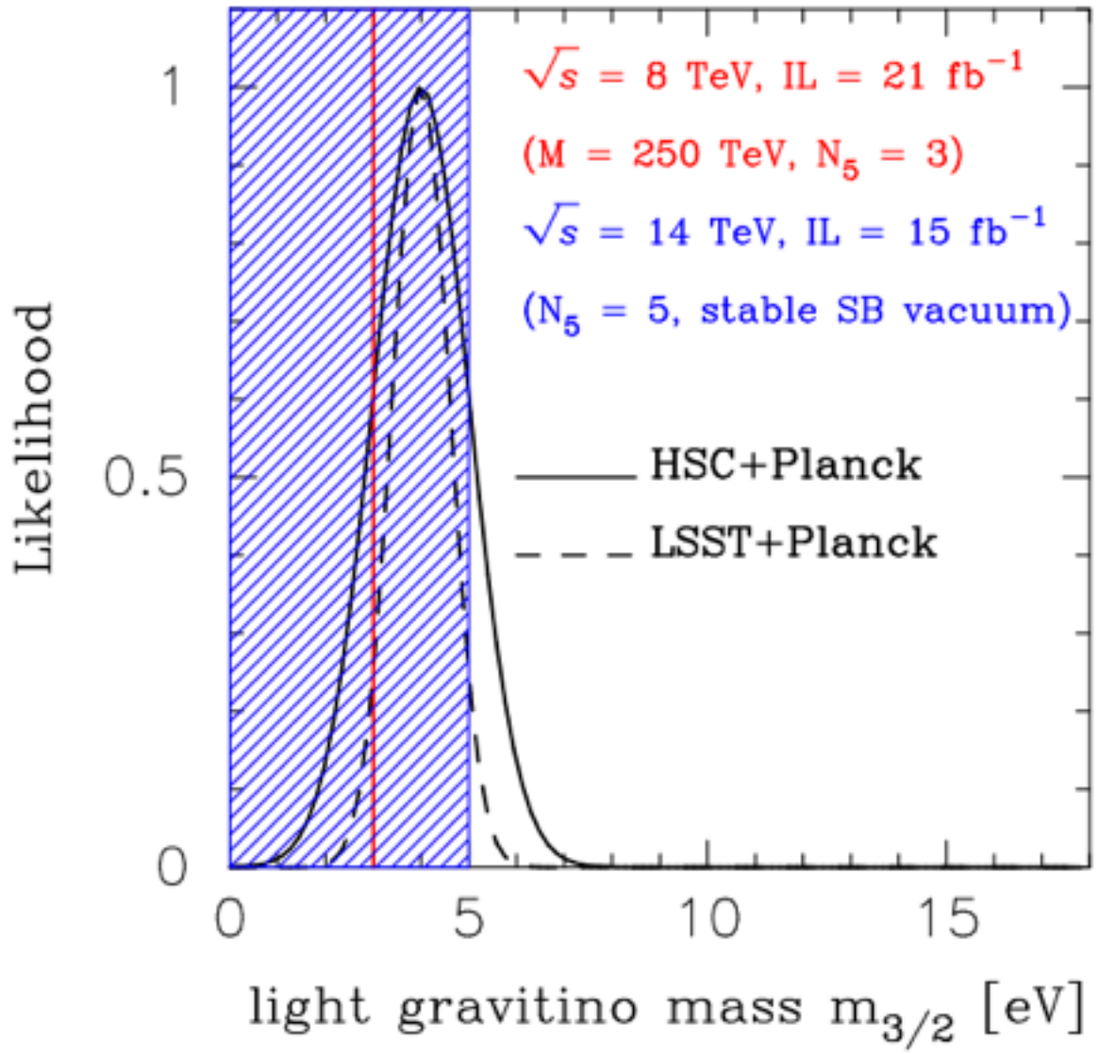
- CMB Lensing
  Ichikawa+ 2009



$$\delta m_{3/2} = 1.6 \text{ eV}$$

For POLARBEAR + Planck lensing

- Cosmic Shear
  Kamada, Shirasaki, Yoshida 2014



$$\delta m_{3/2} = 1 \text{ eV}$$

For HSC + Planck TT

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Methods

- **Linear Boltzmann Code**
  CLASS (Lesgourgues+ 2011, Blas 2012,
  and Lesgourgues+ 2011 for non-cold relics)
  with Halofit (Takahashi+ 2012) and
  warm component correction (Bird+2012)

➡NOTE: The correction term is calibrated in

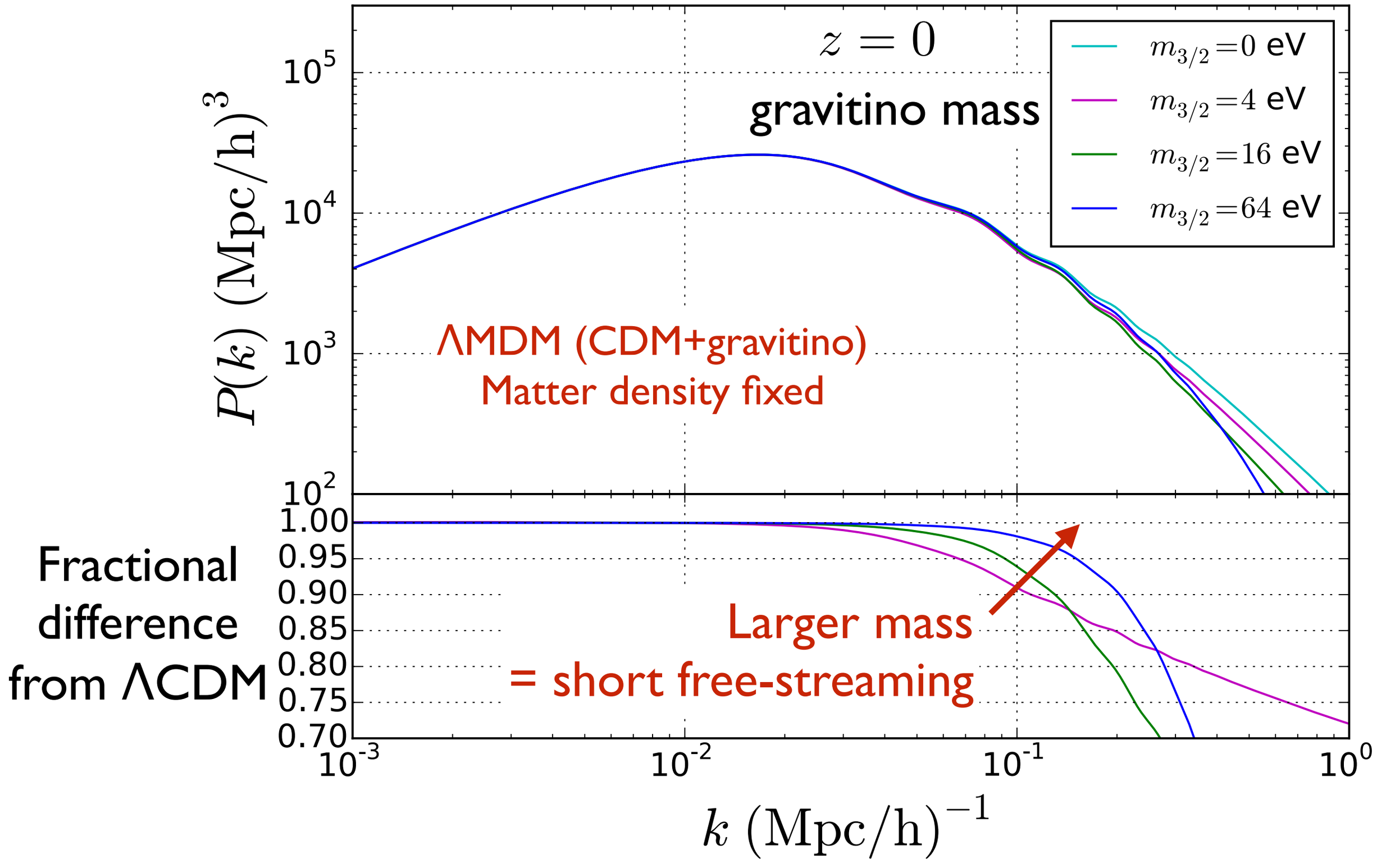
$$0\ \mathrm{eV} \leq m_{3/2} \leq 4.95\ \mathrm{eV}$$

✓We assume **no massive neutrinos**,
which are strongly degenerate with light gravitinos,
for a conservative constraint of light gravitino mass.

- **MCMC Sampler**
  MontePython (Audren+ 2013)
  with ΛMDM (cold dark matter+gravitino) cosmology

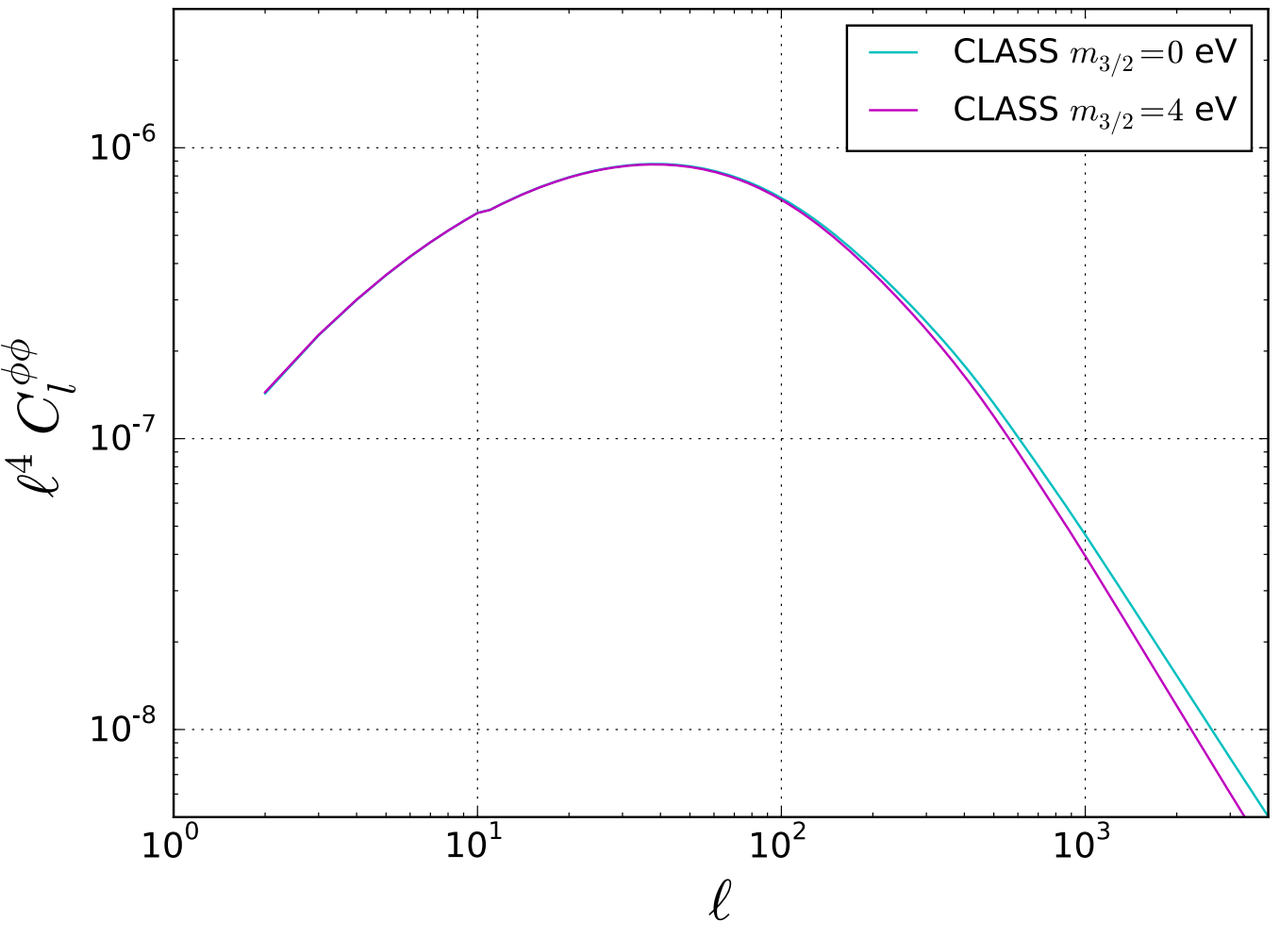
$$(\Omega_{\mathrm{cdm}}h^2, \Omega_{\mathrm{b}}h^2, 100\theta_s, \ln(10^{10}A_s), n_s, \tau_{\mathrm{reio}}, m_{3/2})$$

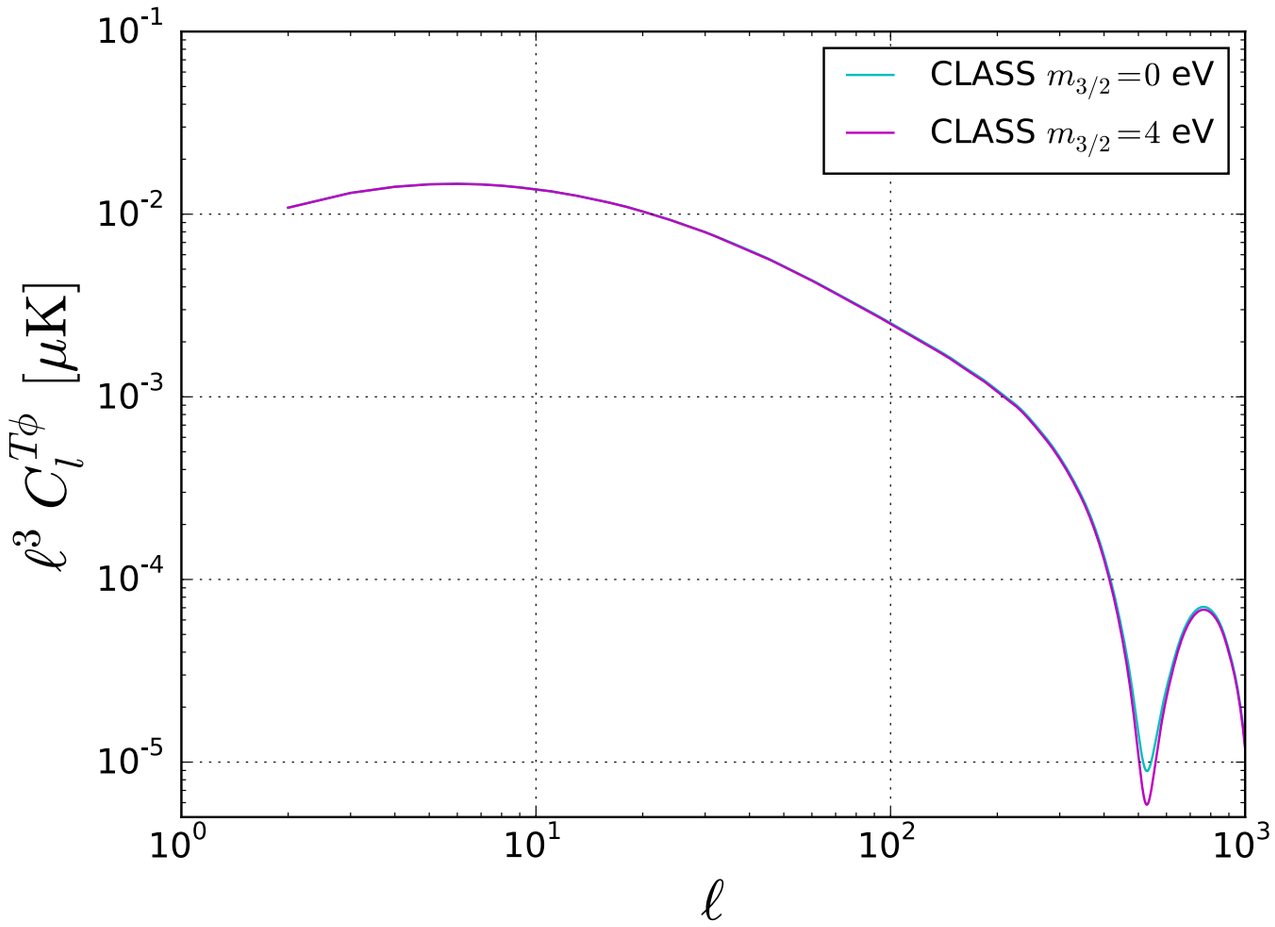
Linear Matter Power Spectra



Spectra of CMB Lensing

- ✓ Auto- and cross-spectra of CMB lensing

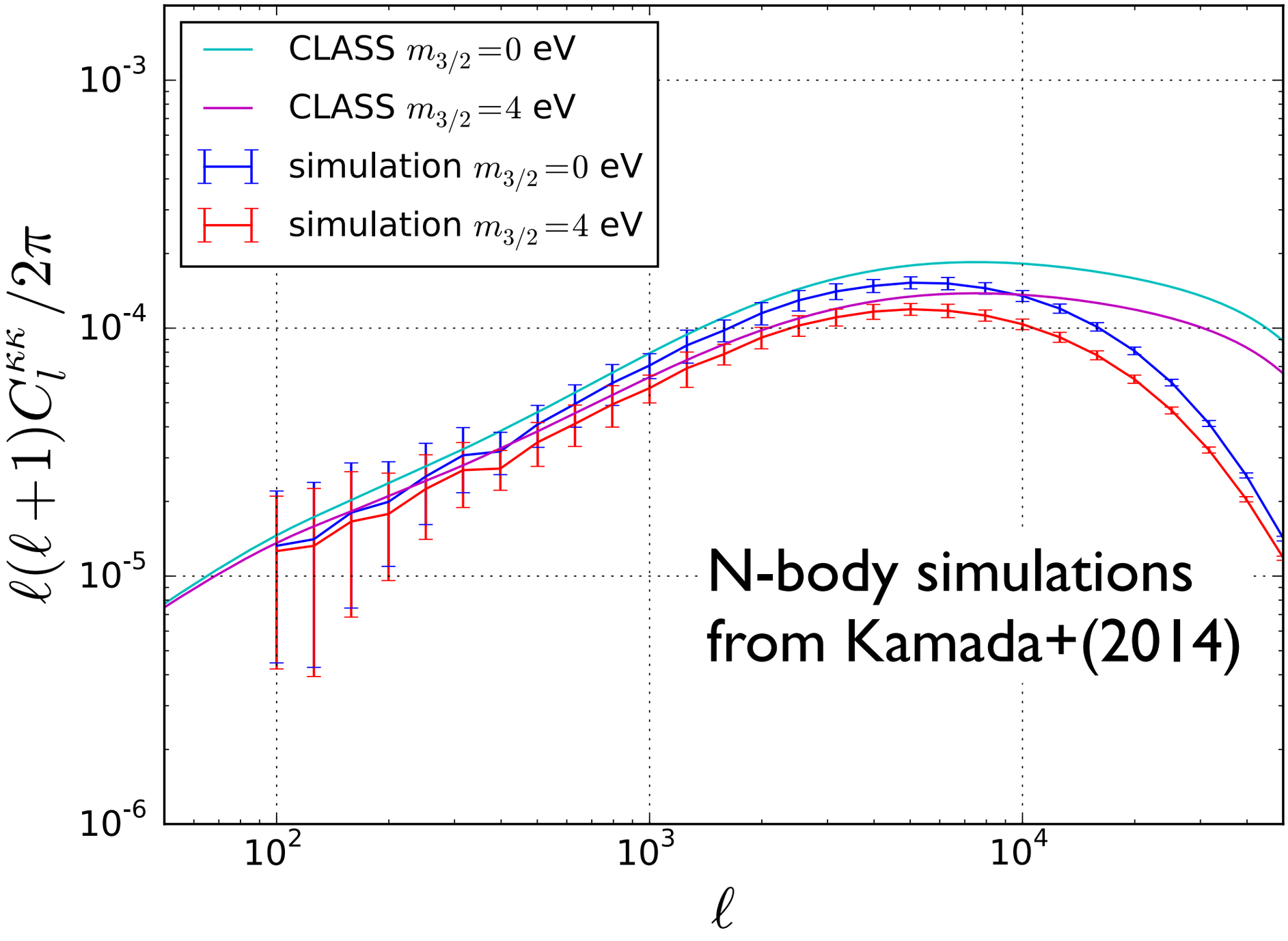




- ✓ Suppression of fluctuations by light gravitinos is imprinted in lensing spectra.

Spectra of Cosmic Shear

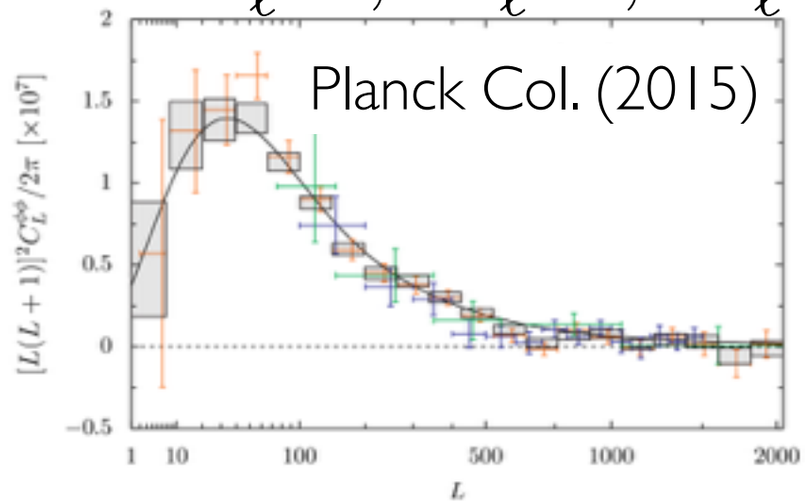
- ✓ Comparison with N-body simulations



Data Sets

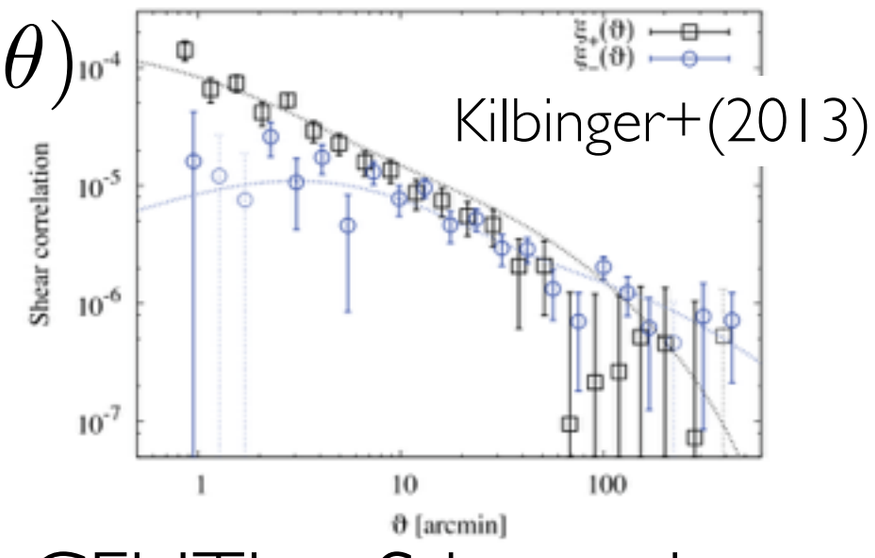
- **1. Planck base**
  Angular power spectra of temperature and polarization.

$$C_\ell^{TT},\ C_\ell^{TE},\ C_\ell^{EE}$$



- **2. Planck lensing (CMB lensing)**
  CMB lensing power spectra $C_\ell^{\phi\phi}\ C_\ell^{T\phi}$

- **3. CFHTLenS (Cosmic shear)**
  The two point correlation functions $\xi_\pm(\theta)$
  Survey area covers 154 deg^2



- **4. BOSS**
  To enhance convergence of chains when CFHTLenS is used, we add BAO scale into analysis from Anderson+ 2011

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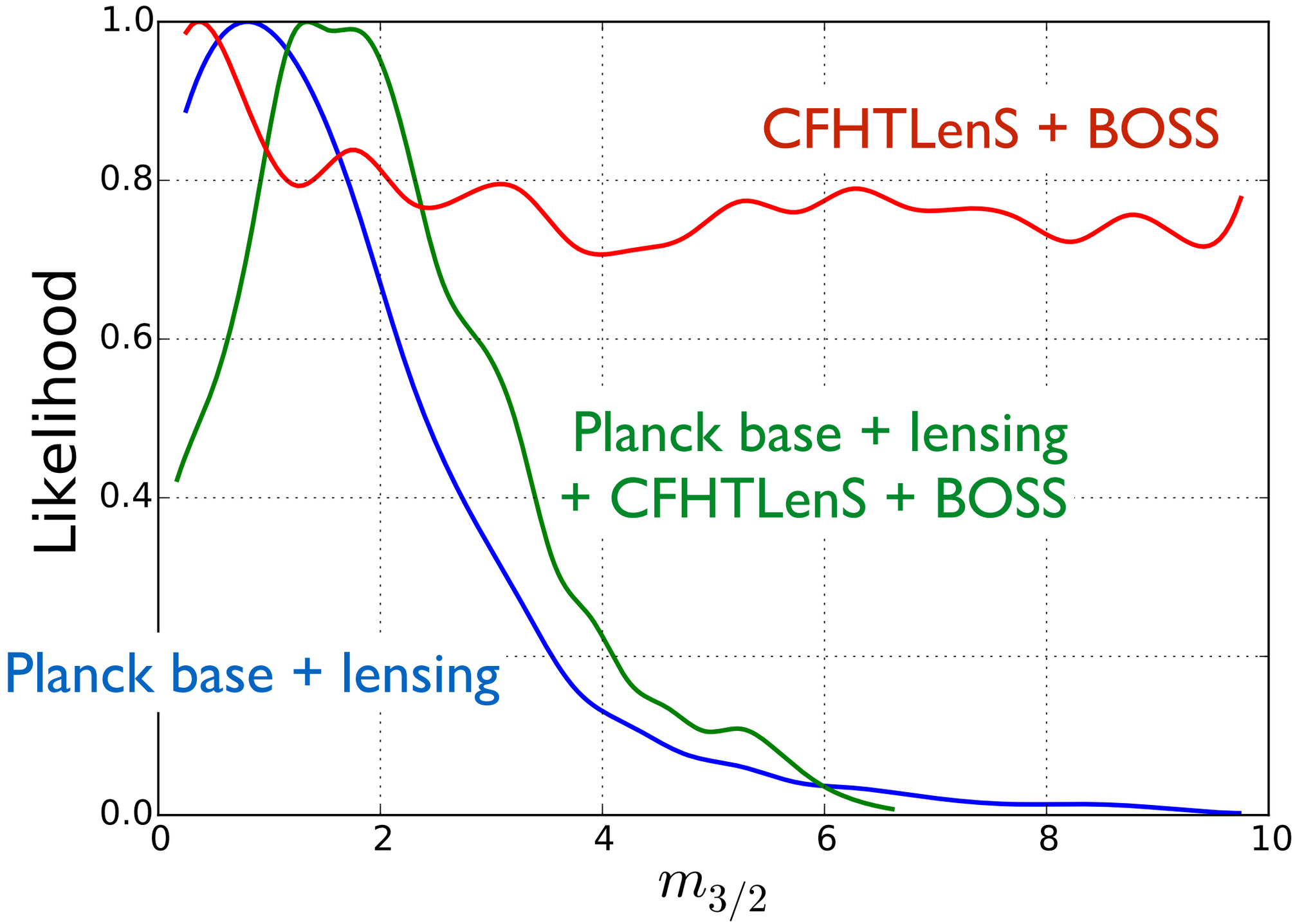
Light Gravitino Mass



KO+, in prep

Matter Density - Sigma8

Planck base + lensing
+ CFHTLenS + BOSS

Planck base + lensing

CFHTLenS + BOSS

Inclusion of light gravitinos

KO+, in prep

✓ Lower sigma8 is preferred. Confidence regions are approaching.

Summary

- Light gravitino is one of possible candidates of dark matter.
- Due to the free-streaming of light gravitinos, small scale fluctuations are suppressed.
- From CMB lensing and cosmic shear, we constrain the gravitino mass
- Light gravitinos reduce sigma8 and the tension is somewhat mediated.

Appendix