Weak lensing tomography with neutrinos

Ivan Debono[1]*, Alexandre Réfrégier[1], Anaïs Rassat[1], Adam Amara[2]

[1] *CEA Saclay, IRFU, Service d'Astrophysique, F-91911, Gif-sur-Yvette, FRANCE;* [2] *ETH Zurich, SWITZERLAND*

*Email: ivan.debono@cea.fr

In the generally accepted concordance model of the universe, the mass-energy content is made up of cold dark matter, baryonic matter, massive neutrinos and dark energy. Current observational data are consistent with dark energy in the form of a cosmological constant but future surveys will be needed to study its nature. The determination of the nature of dark energy is potentially made more difficult when one includes the effect of massive neutrinos, which also modify the matter power spectrum. Weak lensing has established itself as a method for probing cosmological parameters by measuring the mass distribution at low redshift. Here, we use Fisher analysis with an all sky weak lensing tomography survey to constrain the parameters for an extended QCDM cosmological model, including massive neutrinos and a running of the spectral index α. We examine the impact of their presence on the precision with which we can constrain the dark energy equation of state parameter w_n and its evolution w_a. We also study the constraints on neutrino mass which can be obtained using weak lensing, and the degeneracies between neutrino mass, dark energy and the primordial power spectrum as they manifest themselves in cosmological observations.

Cosmology

We consider a FRW universe, with a flat geometry, where the mass-energy content is made up of cold dark matter, baryonic matter, massive neutrinos, and dark energy. The dynamical dark energy equation of state is parametrised by

$$w(a) = w_n + (a_n - a)w_a$$

where the scale factor $a = (1+z)^{-1}$.

We also relax our assumptions on the shape of the primordial power spectrum by using a running spectral index

$$n_s(k) = n_s(k_0) + \frac{1}{2}\frac{\mathrm{d}n_s}{\mathrm{d}\ln k}\ln\left(\frac{k}{k_0}\right),$$

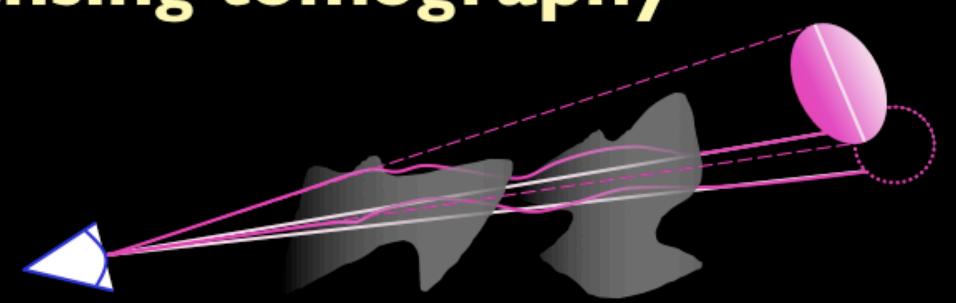
where k_0 is the pivot scale and $\alpha = \mathrm{d}n_s/\mathrm{d}\ln k$ is the running.

We assume three neutrino species, each with a mass m_i, with the most massive (non-relativistic) neutrino species being degenerate, so that the total neutrino mass is $m_\nu = N_\nu m_i$ where N_ν is the number of massive neutrino species.

Our most general parameter space is therefore

$$\mathbf{P} \equiv \{\Omega_m, \Omega_b, h, w_a, w_n, n_s, \alpha, \Omega_\nu, N_\nu, \sigma_8, \tau\}$$

Weak lensing tomography



As a photon travels from a distant galaxy to an observer, its path is deviated by inhomogeneities caused by large-scale structure. In our study, we use tomographic cosmic shear, with the background lensed galaxies divided into 10 redshift bins. Cosmological models are then constrained by the power spectrum corresponding to the correlations of shears within and between bins. The linear power spectrum is calculated using an Eisenstein & Hu (1999) transfer function. The 3D power spectrum is projected onto a 2D lensing correlation function using the Limbers equation. The galaxies are assumed to be distributed according to the following probability distribution function:

$$P(z) = z^\alpha \exp\left[-\left(\frac{z}{z_0}\right)^\beta\right],$$

where $\alpha = 2$ and $\beta = 1.5$, and z_0 is determined by the median redshift of the survey, z_m.

Fisher analysis

We use the Fisher matrix formalism to make predictions of the cosmological parameter errors within our model. The Fisher matrix is defined as the second derivative of the likelihood surface about a maximum. For the shear power spectrum this is given by

$$F_{\alpha\beta} = f_{\rm sky}\sum_l \frac{(2l+1)\Delta l}{2}\mathrm{Tr}\left[D_{l\alpha}\widetilde{C}_l^{-1}D_{l\beta}\widetilde{C}_l^{-1}\right]$$

where the sum is over bands of multipole l of width Δl, Tr is the trace, $f_{\rm sky}$ is the fraction of sky covered by the survey, and $D_{l\alpha}$ are the derivative matrices. We assume the likelihood to have a Gaussian distribution, with zero mean. The observed power spectra for each pair i, j of redshift bins are written as the sum of the lensing and noise spectra:

$$\widetilde{C}_l^{ij} = C_l^{ij} + N_l^{ij}.$$

The errors for each parameter are predicted by marginalising over all other parameters. To measure the quality of the survey, we use the Figure of Merit (FOM) proposed by the Dark Energy Task Force (Albrecht et al. 2006), proportional to the inverse of the area of the 2σ ellipses in the $w_a - w_n$ plane:

$$\mathrm{FOM} = \frac{1}{4\Delta w_p \Delta w_a}.$$

FIG. 1: Small-scale power suppression effect of massive neutrinos on the matter power spectrum

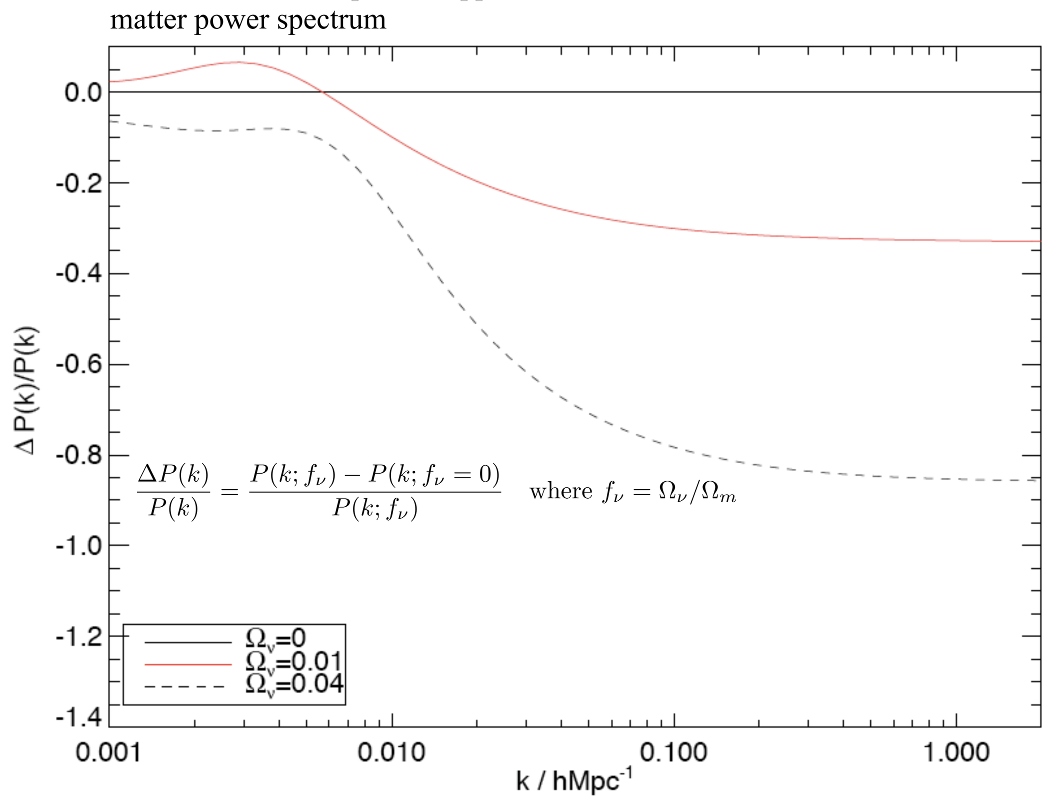


FIG. 2: The effect of massive neutrinos on the lensing power spectrum, for three cosmological models.

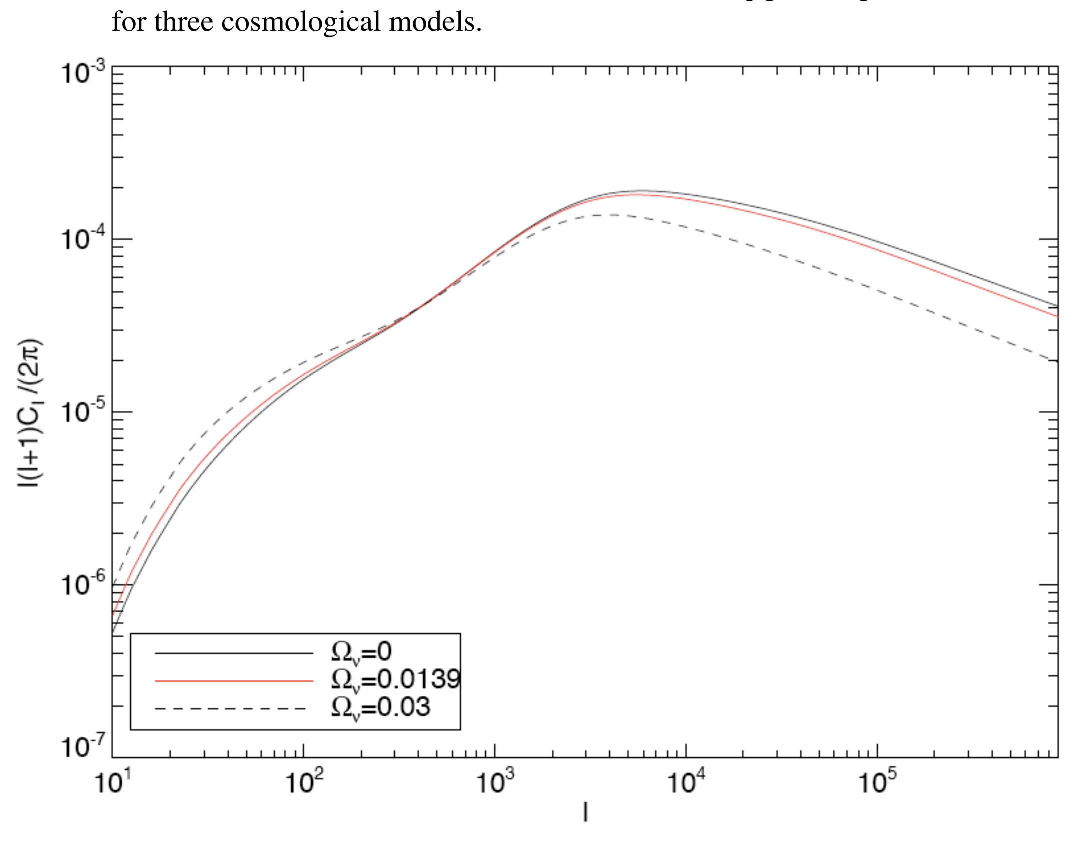


FIG. 3: Dark energy for a number of fiducial cosmologies with a different neutrino mass fraction, using a DUNE fiducial survey. In the Fisher matrix calculation, the neutrino fraction Ω_ν and the number of massive neutrinos N_ν are kept fixed. The ellipse contours represent the 68% confidence limits. The FOM for the zero neutrino case is 22.10.

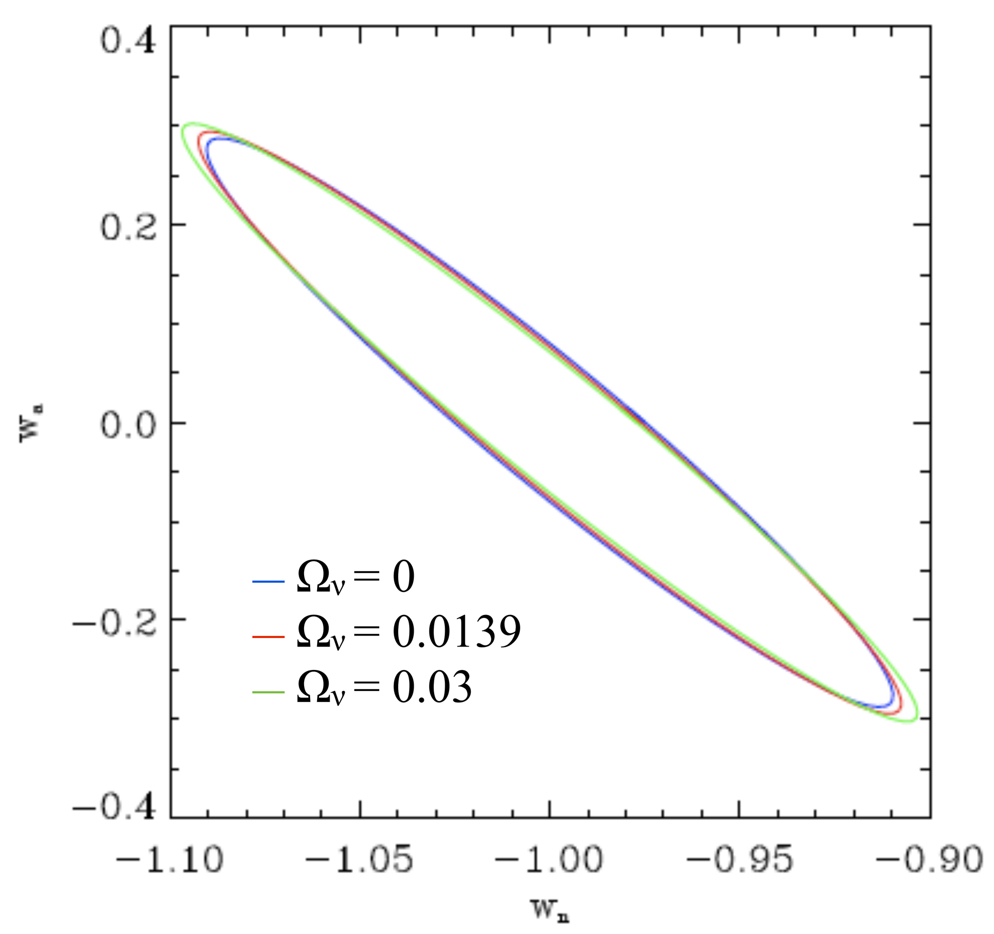
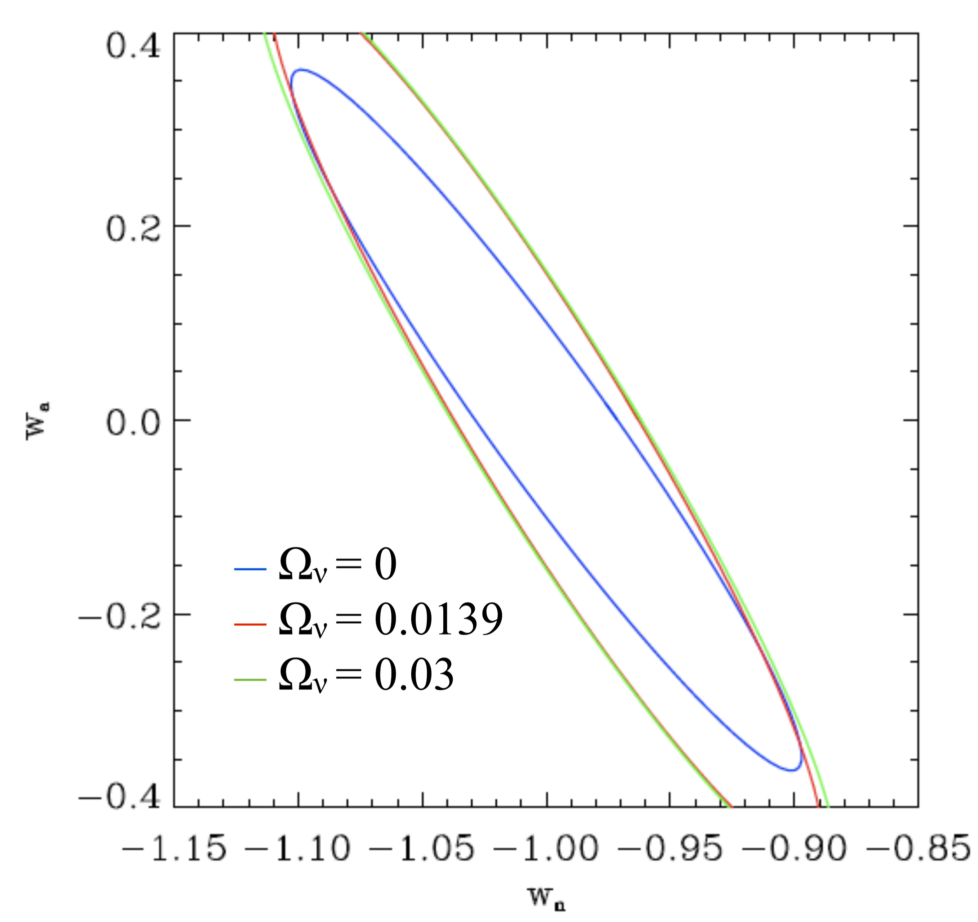


FIG. 4: Dark energy constraints for the same fiducial cosmologies as in Fig. 3, marginalising over all parameters, including neutrino fraction and number of massive neutrino species. The FOM for each model is 15.43, 11.45 and 10.50 respectively.



Fiducial cosmology

$\{\Omega_m = 0.27, \Omega_b = 0.04, h = 0.71, w_0 = -1, w_n = 0, n_s = 1, \alpha = 0,$
$\Omega_\nu = 0.0139^*, N_\nu = 3, \sigma_8 = 0.8, \tau = 0.09\}$

$*$ This corresponds to $m_\nu = 0.66$eV