Neutrino mass from CMB observation

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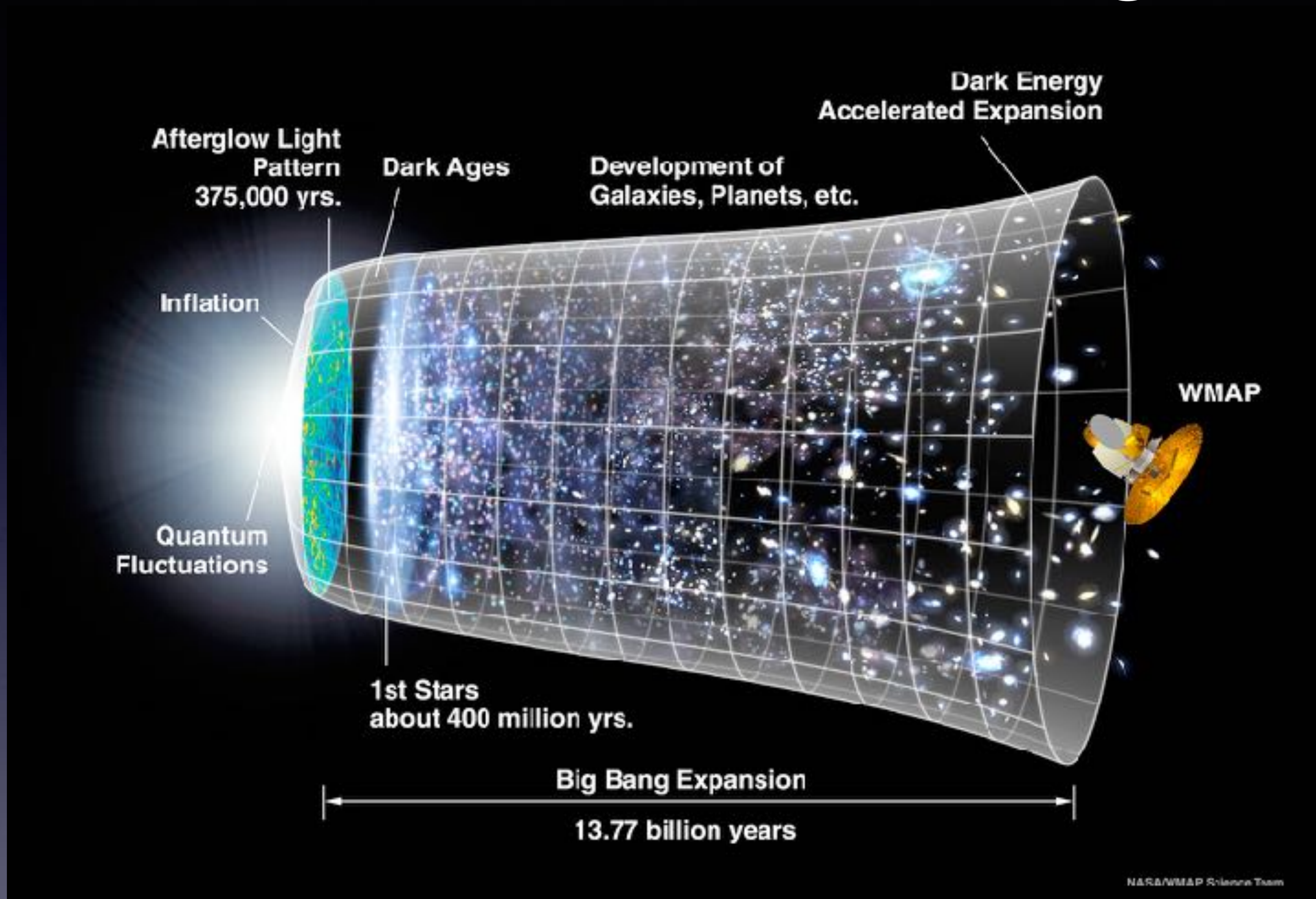
Outline

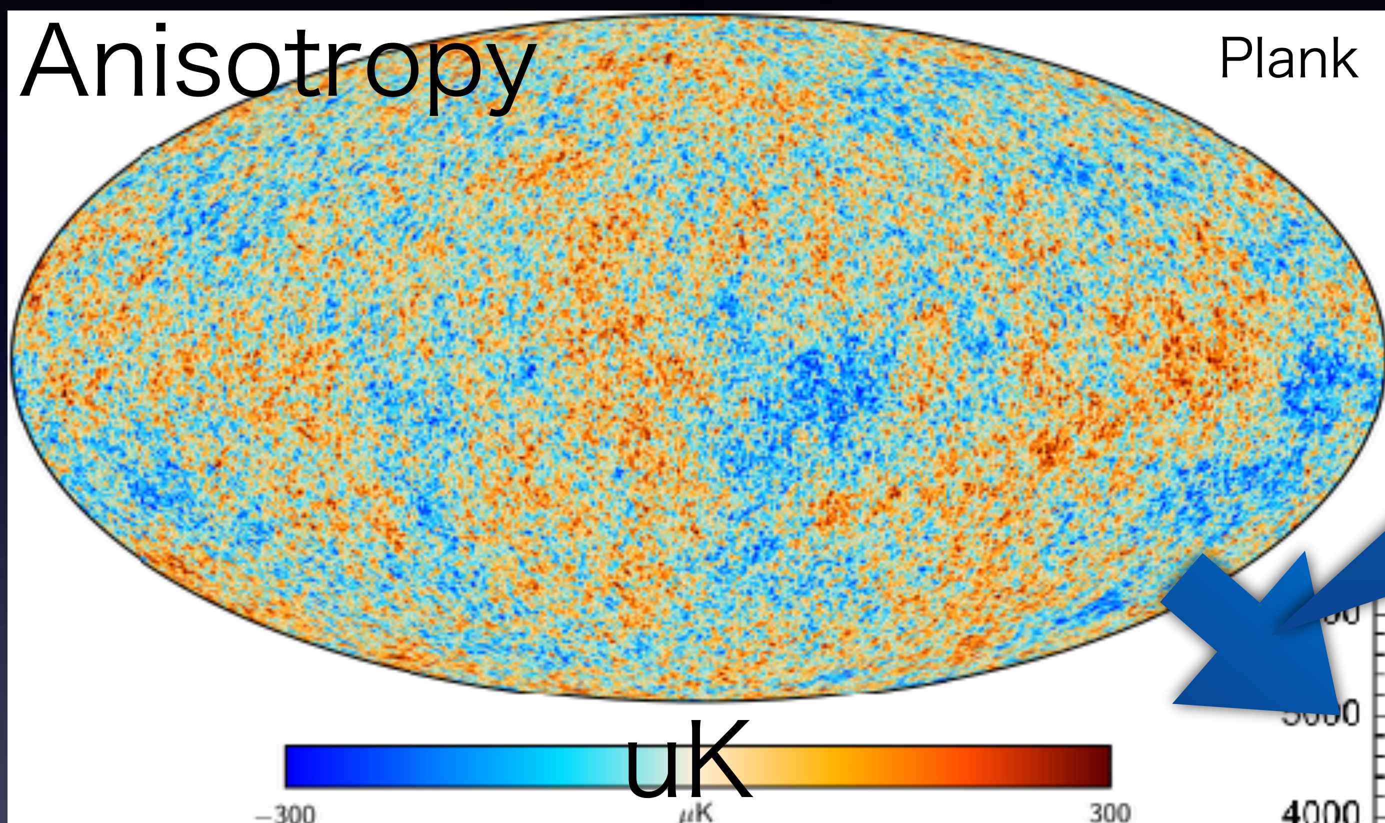
- Cosmic Microwave Background
  - How we get the parameters
- Polarization of CMB and Gravitational lensing
- Neutrinos in gravitational potential
- Sum of neutrino mass in B-mode spectrum
- CMB experiments: now and future

Cosmic Microwave Background

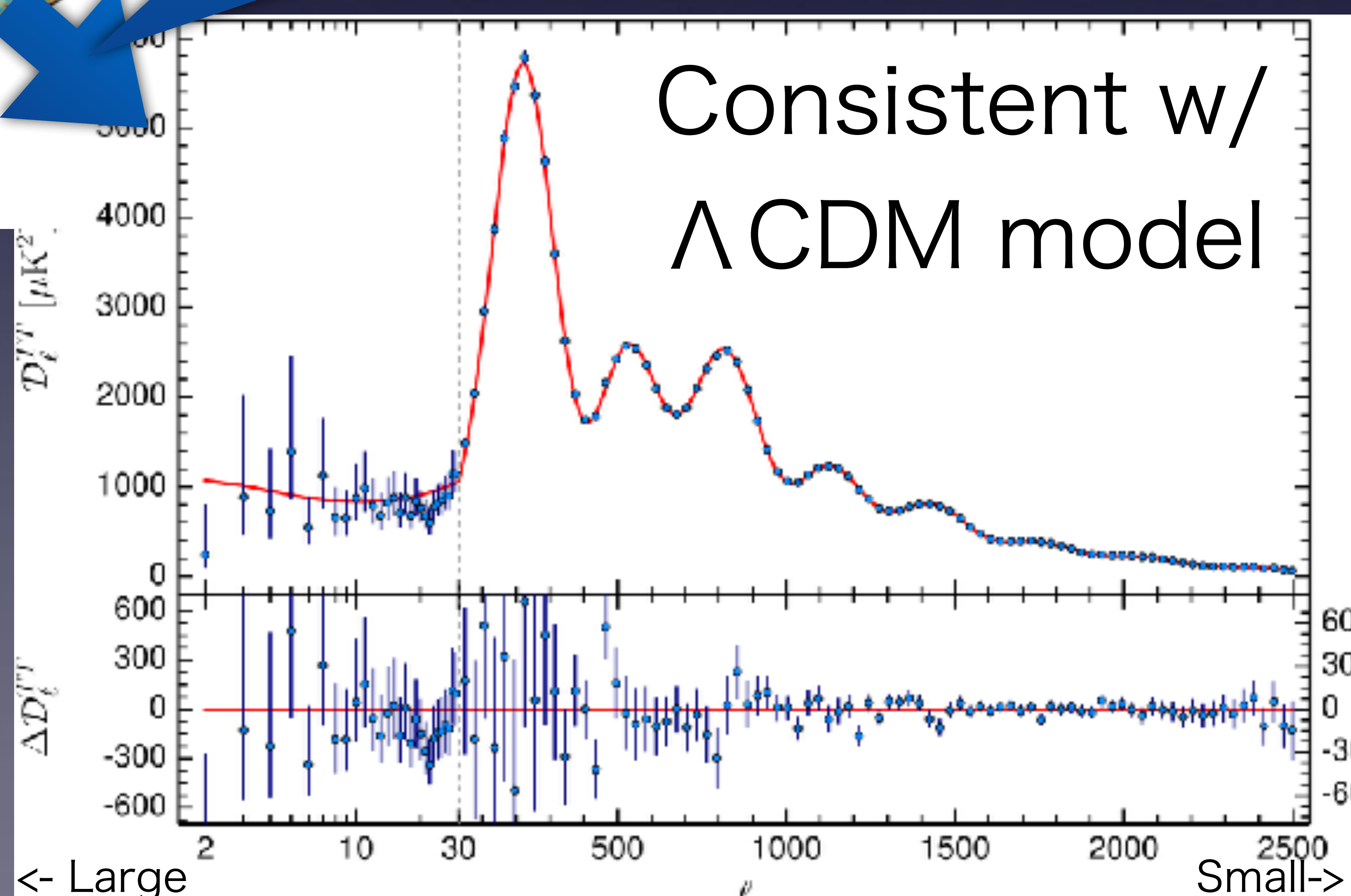


- Baby(375,000 years old !!) picture of our universe
  - 2.725K almost uniform black body radiation now
- Discolored by the 13.8 billion years of history

Extract cosmic parameters

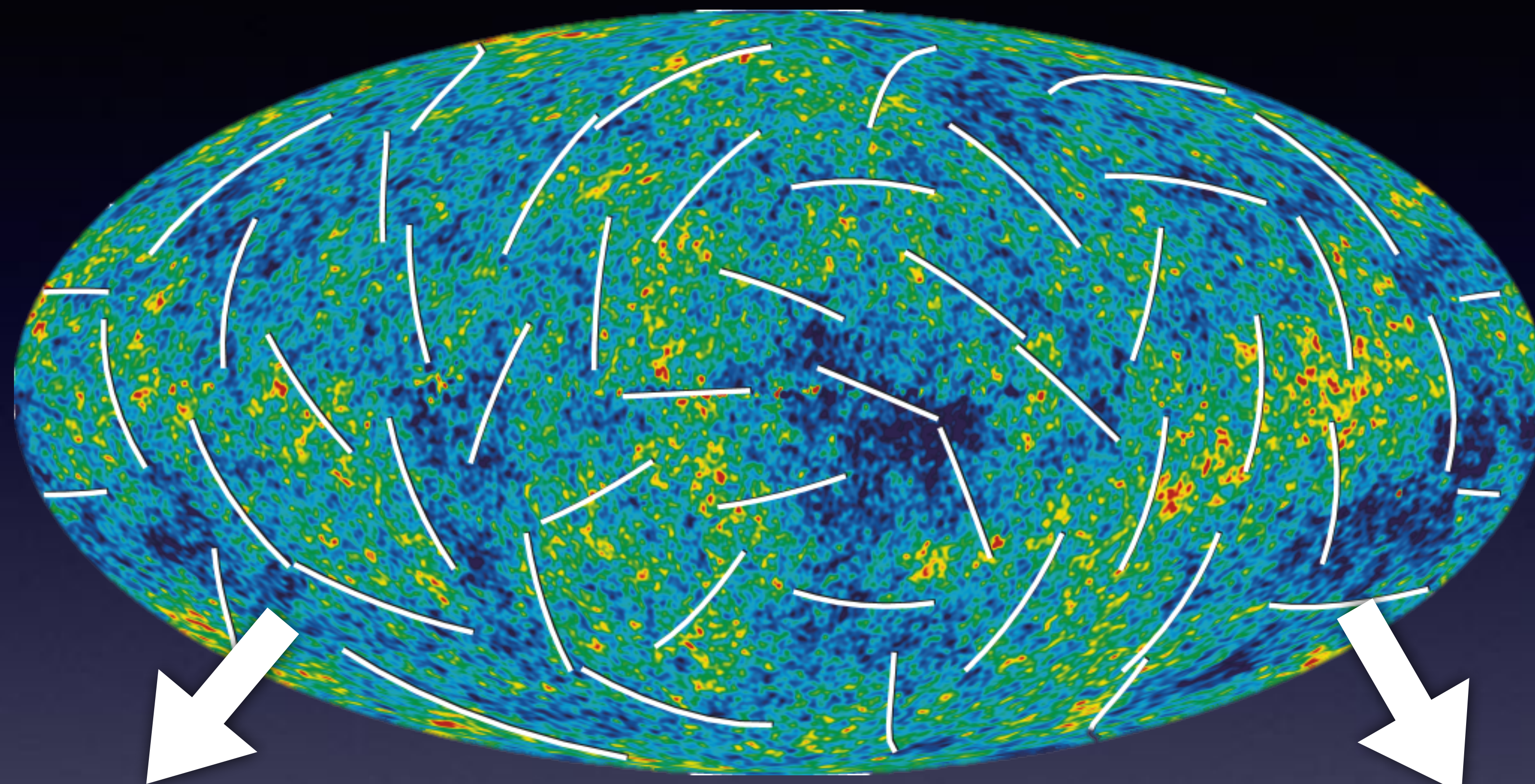


Spherical harmonic Transform
(2D Fourier transform)



Parameter	*Planck* TT+lowP+lensing
$\Omega_b h^2$ baryon density	0.02226 ± 0.00023
$\Omega_c h^2$ CDM density	0.1186 ± 0.0020
$100\theta_{MC}$ sound horizon at last scattering	1.04103 ± 0.00046
τ Re-ionization optical depth	0.066 ± 0.016
$\ln(10^{10} A_s)$ primordial curvature perturbation	3.062 ± 0.029
n_s Scalar spectral index	0.9677 ± 0.0060

Polarization pattern on CMB

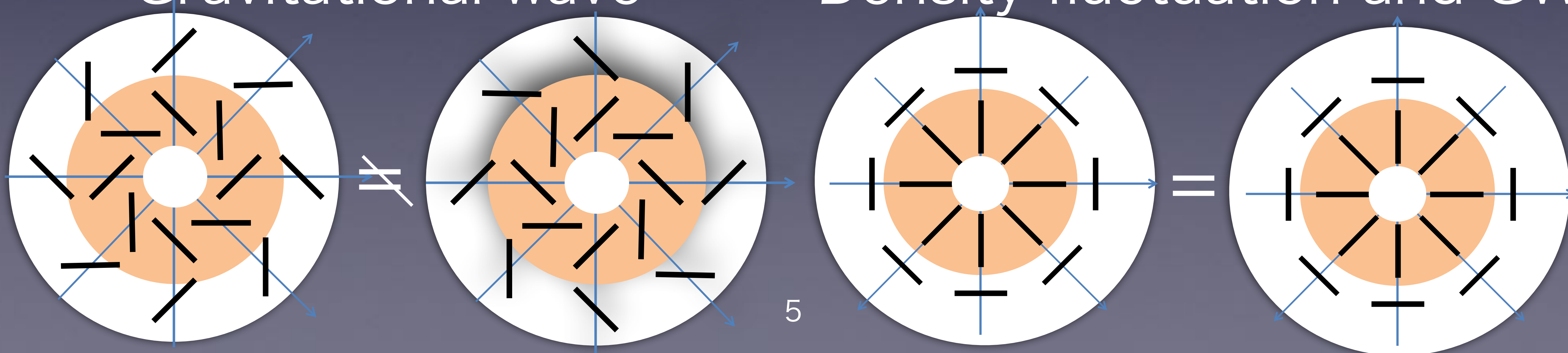


B-mode: parity odd

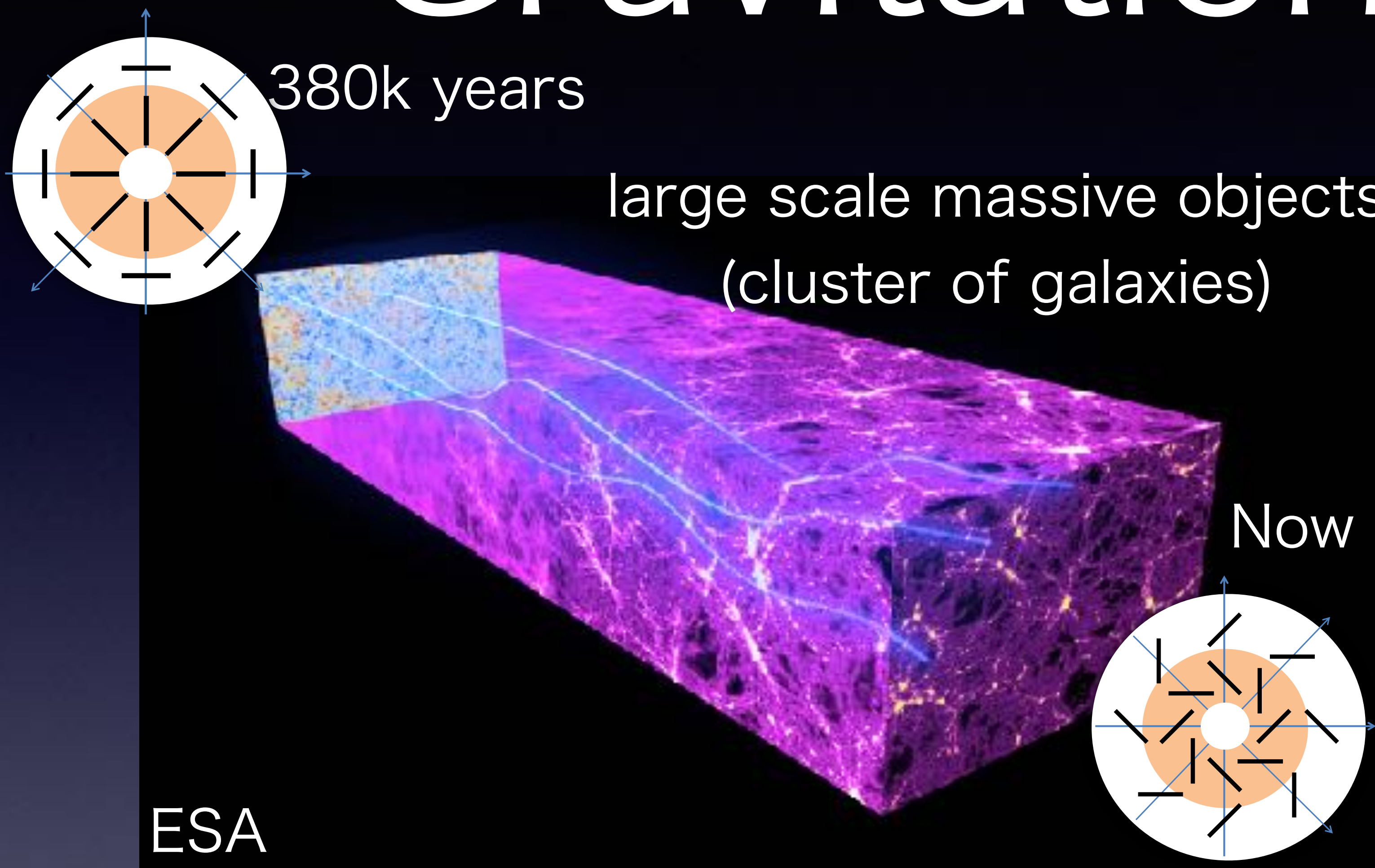
Gravitational wave

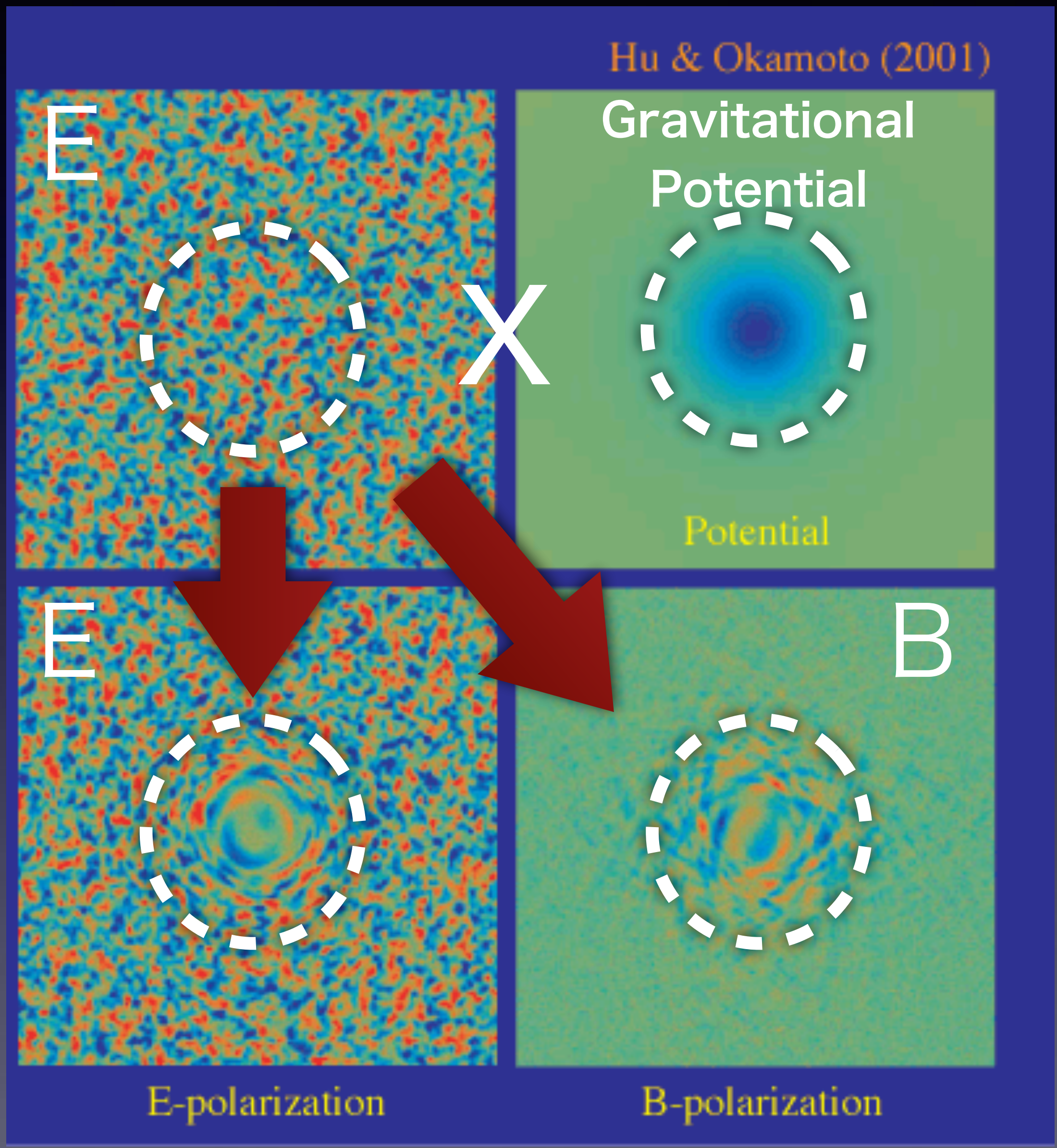
E-mode: parity even

Density fluctuation and GW



Gravitational lens



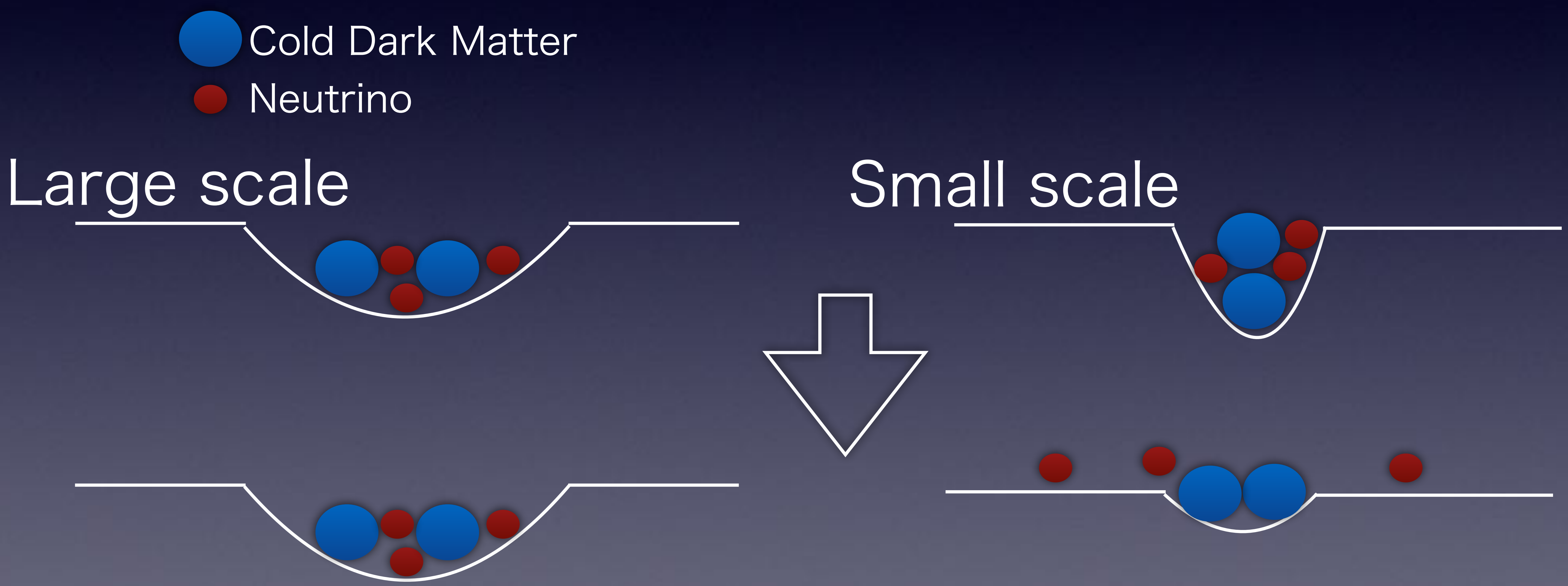


- Massive objects bend the photon
- Generates B-mode from E-mode !!

-> Lensing effect is a good probe of massive objects

Neutrino in gravitational potential

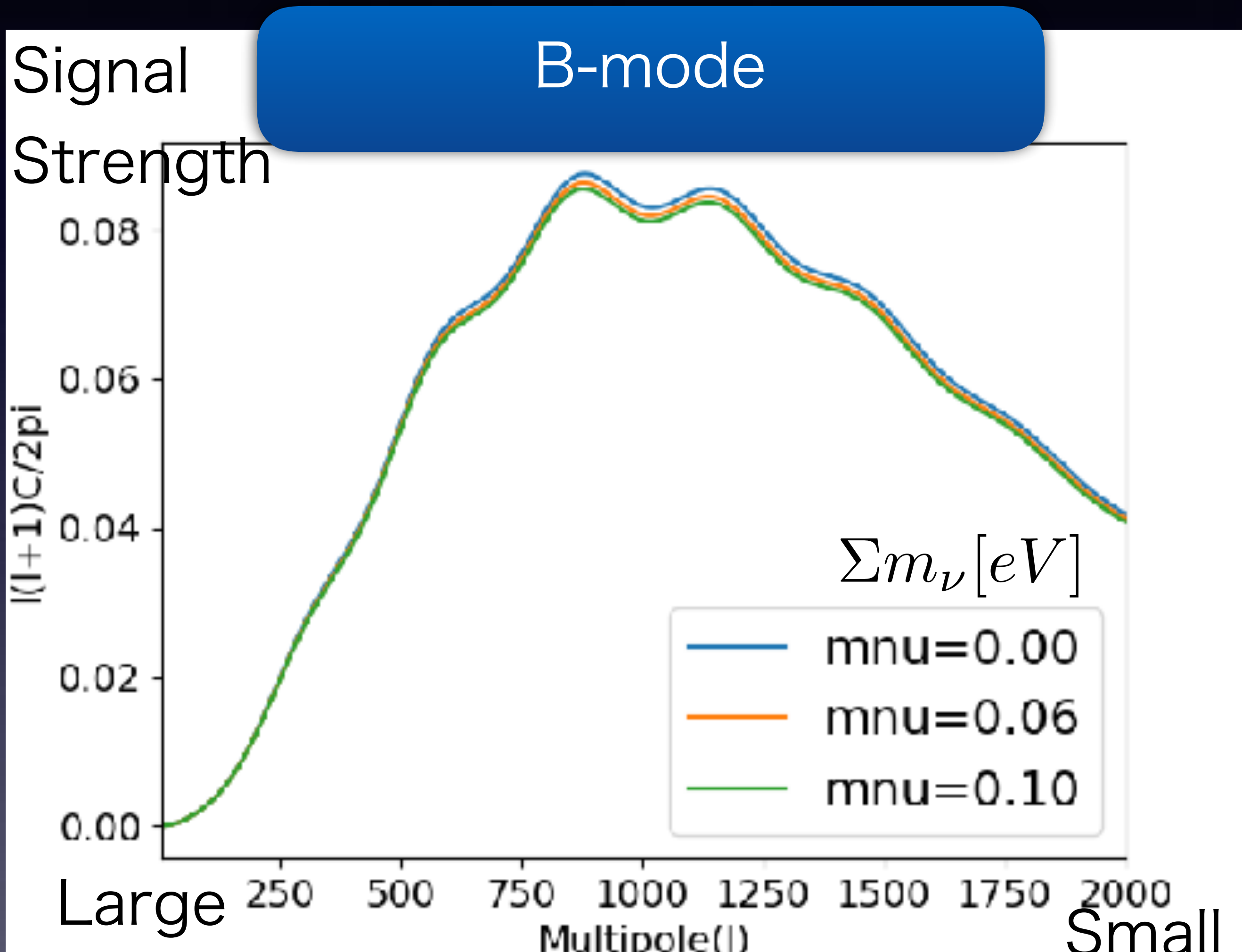
Neutrinos are only HOT massive particle in SM

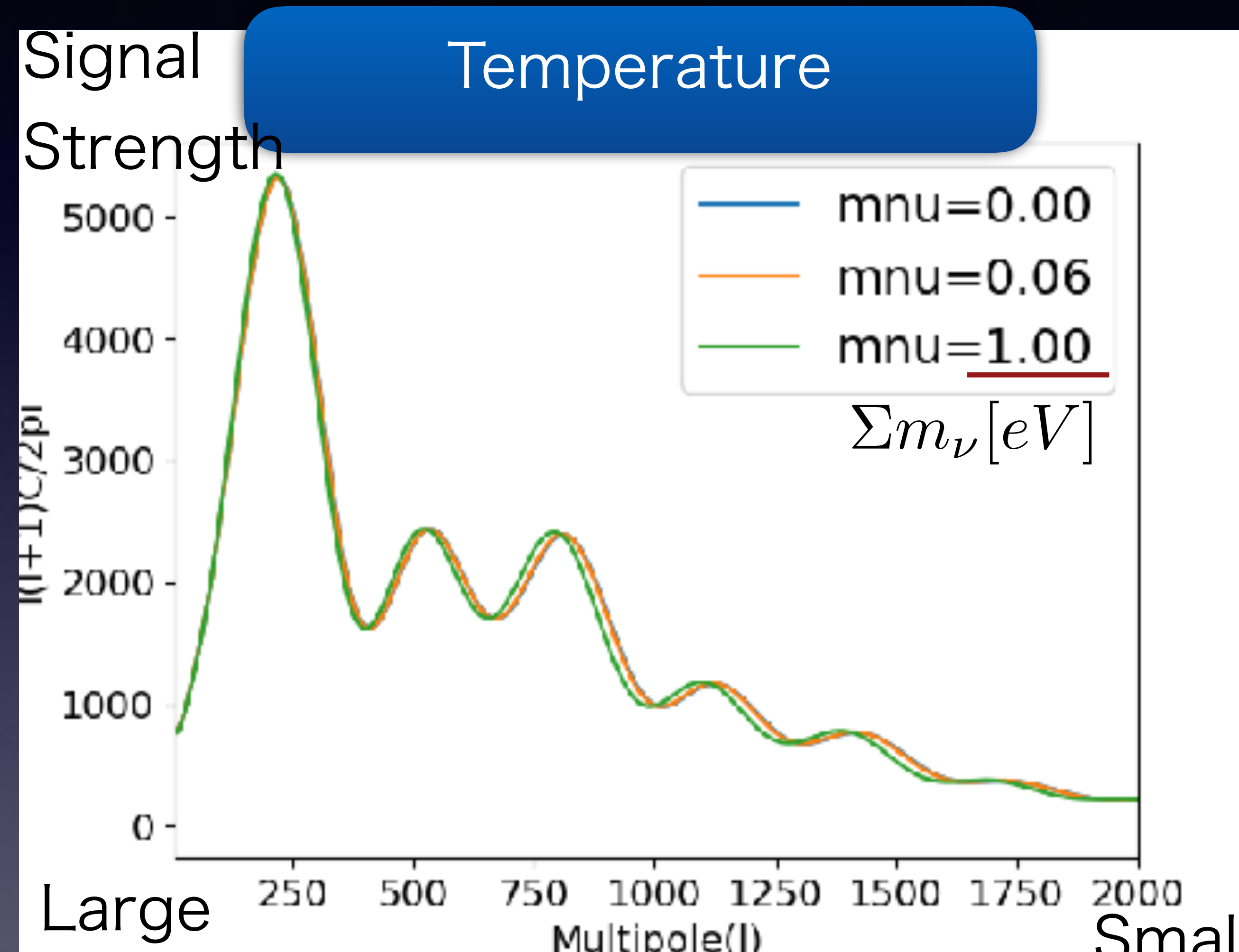


Neutrino cannot stay in small potential wall

Small scale structure is washed out

Σm_ν in CMB spectrum





Lensing B-mode is sensitive to the neutrino mass

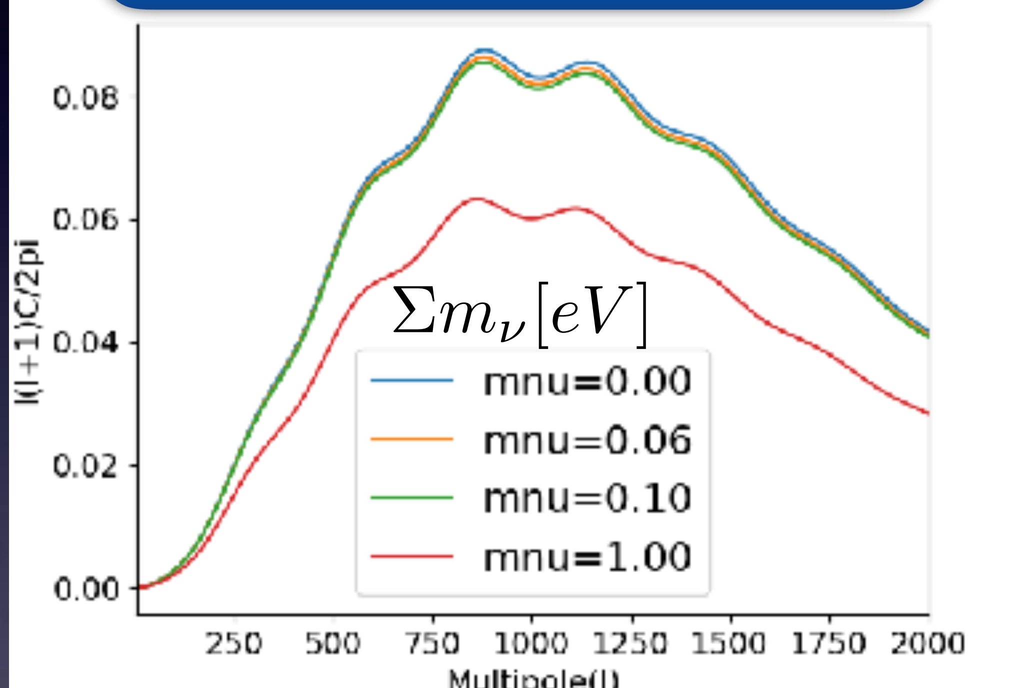
Less correlated to other cosmological parameters

Simulated by CAMB: http://camb.info/

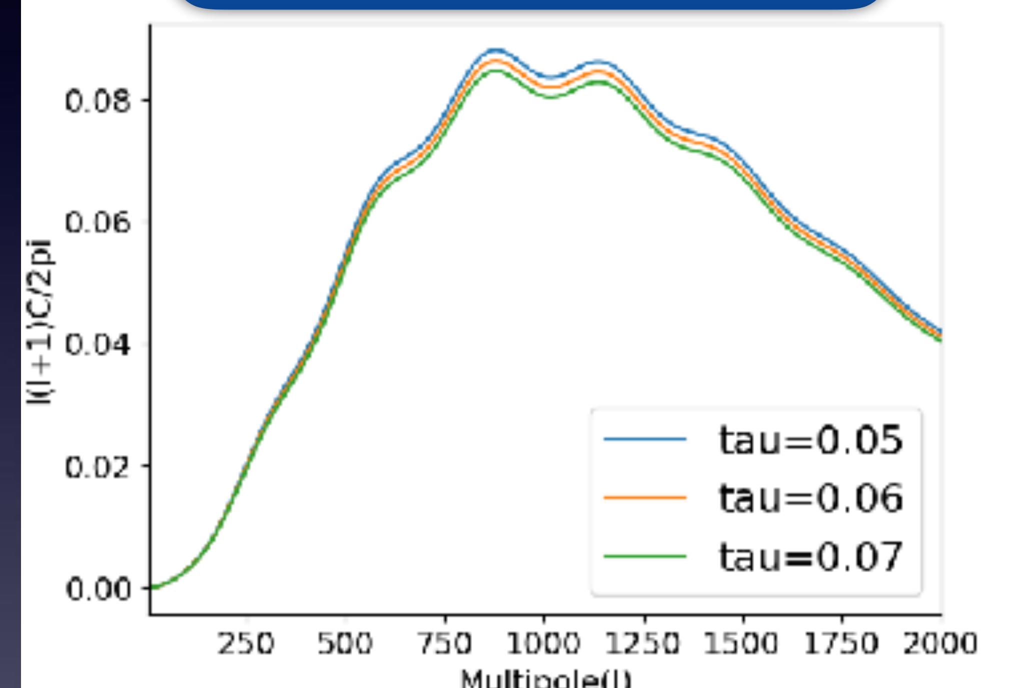
Separation of τ and Σm_ν

B-mode

Sum of Neutrino mass



Tau(optical depth)



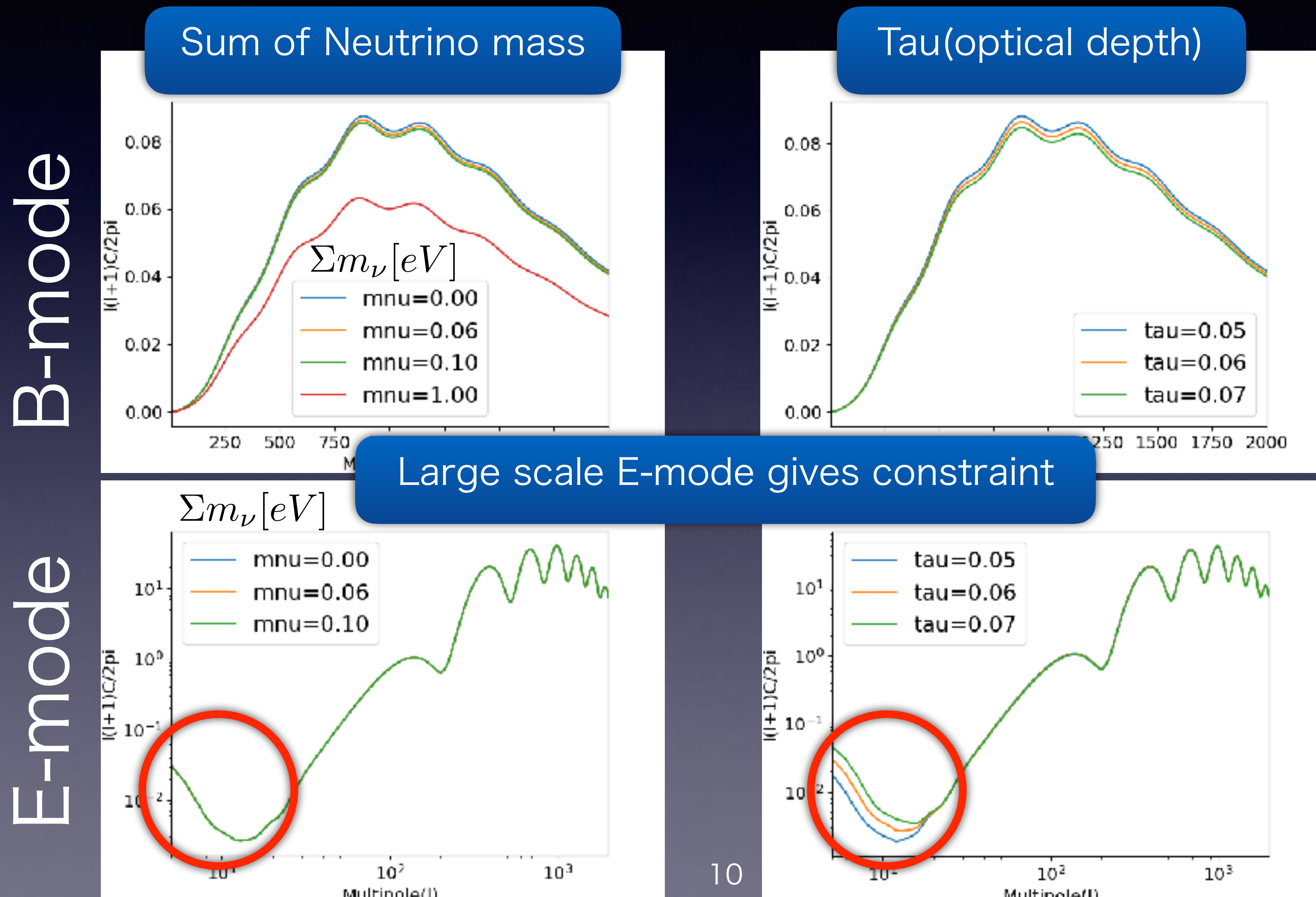
Unfortunately, Σm_ν and τ show similar effect on B-mode spectrum

Tau: Transparency of re-ionization era caused by first stars

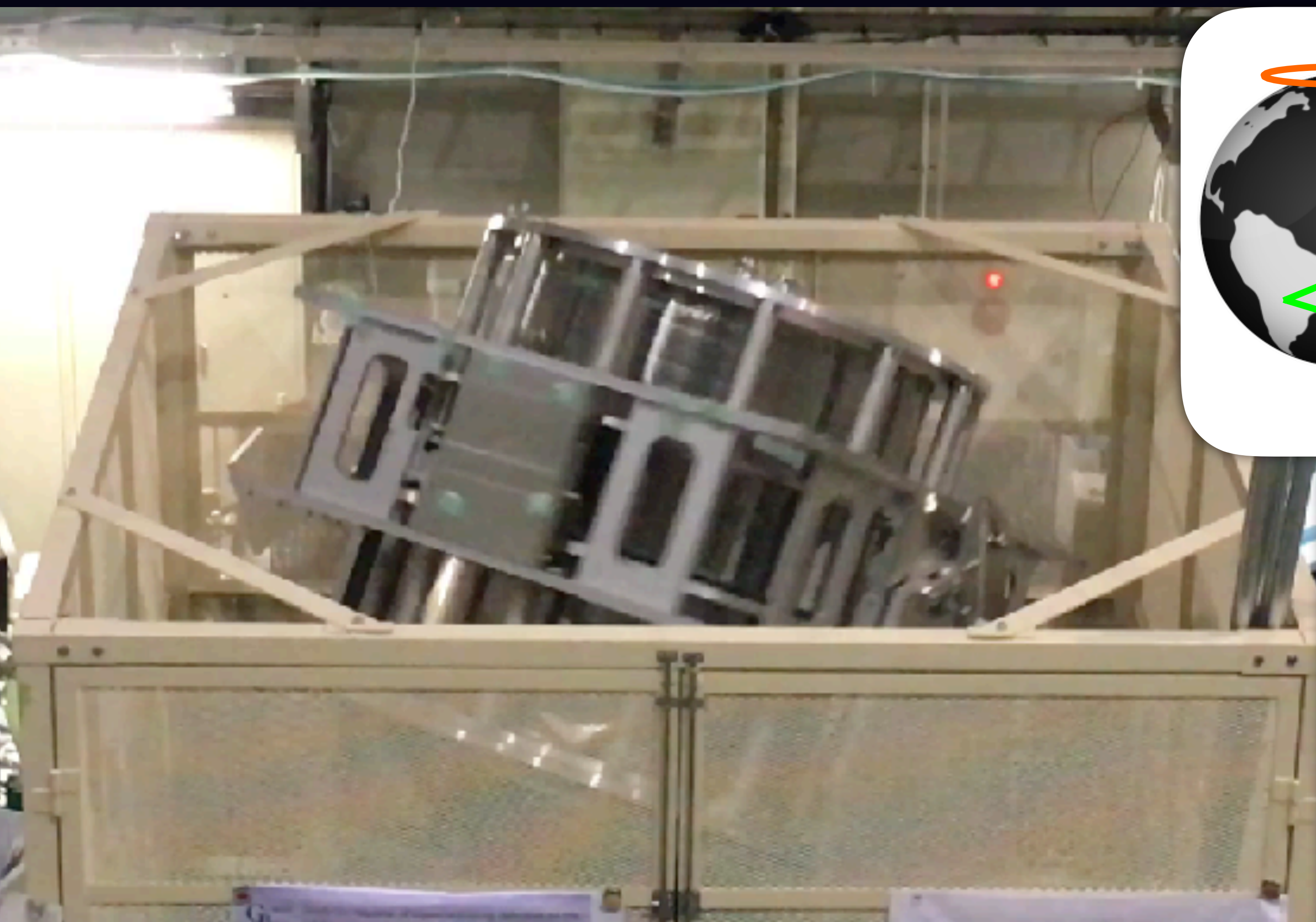
We need an additional constraint !

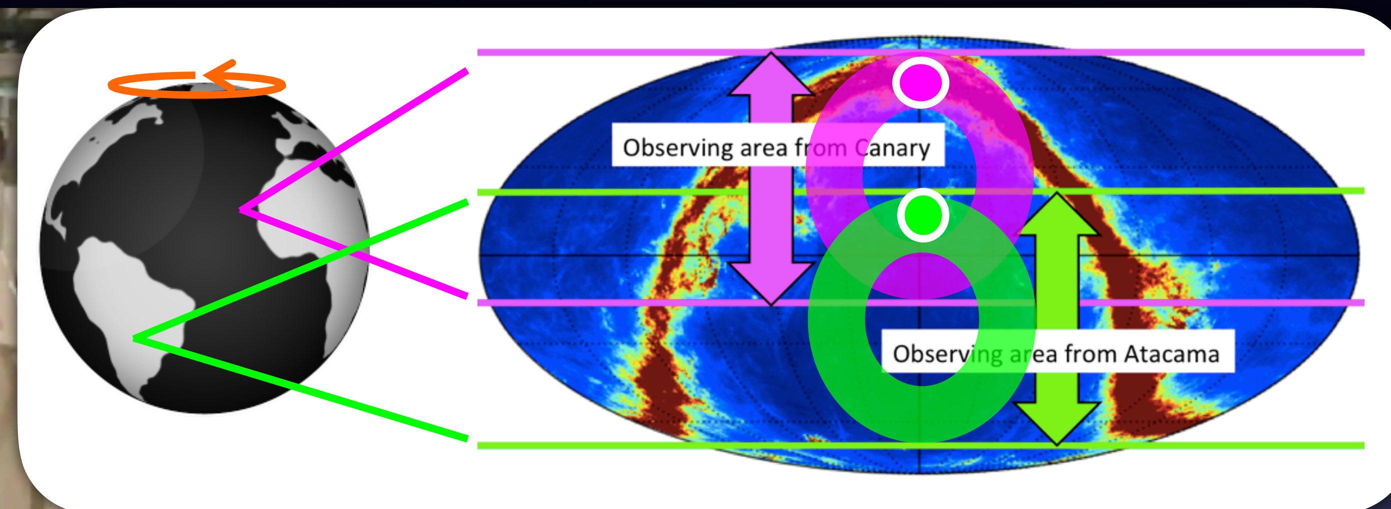
Simulated by CAMB

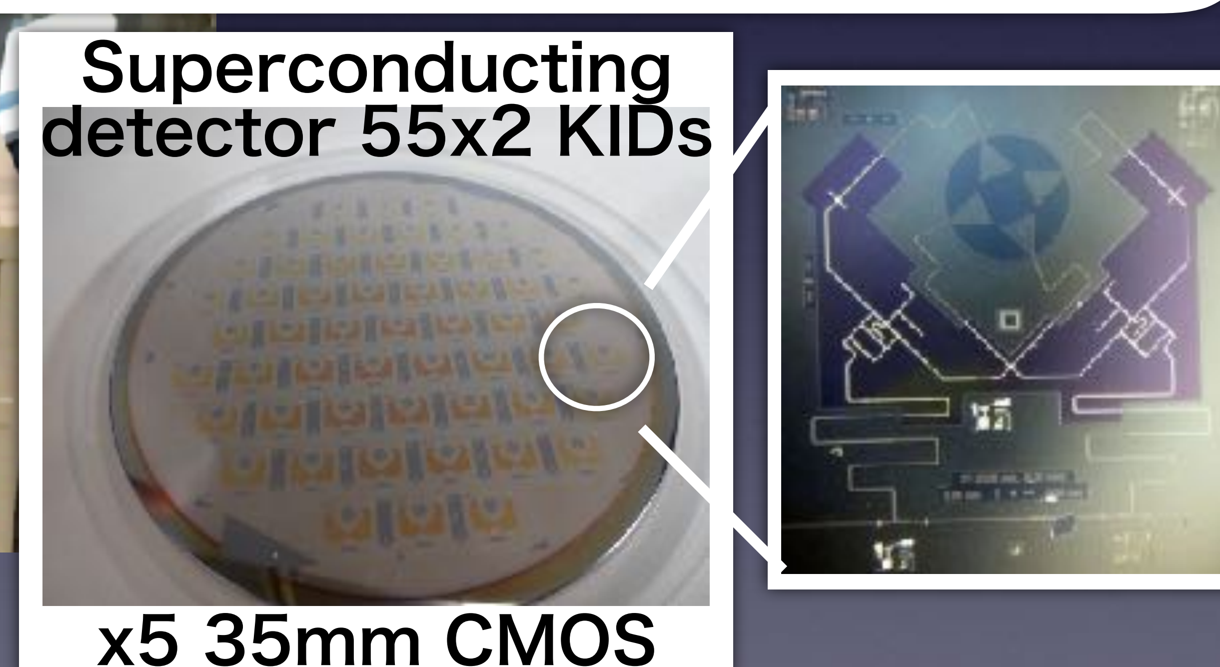
Separation of τ and Σm_ν



GroundBIRD



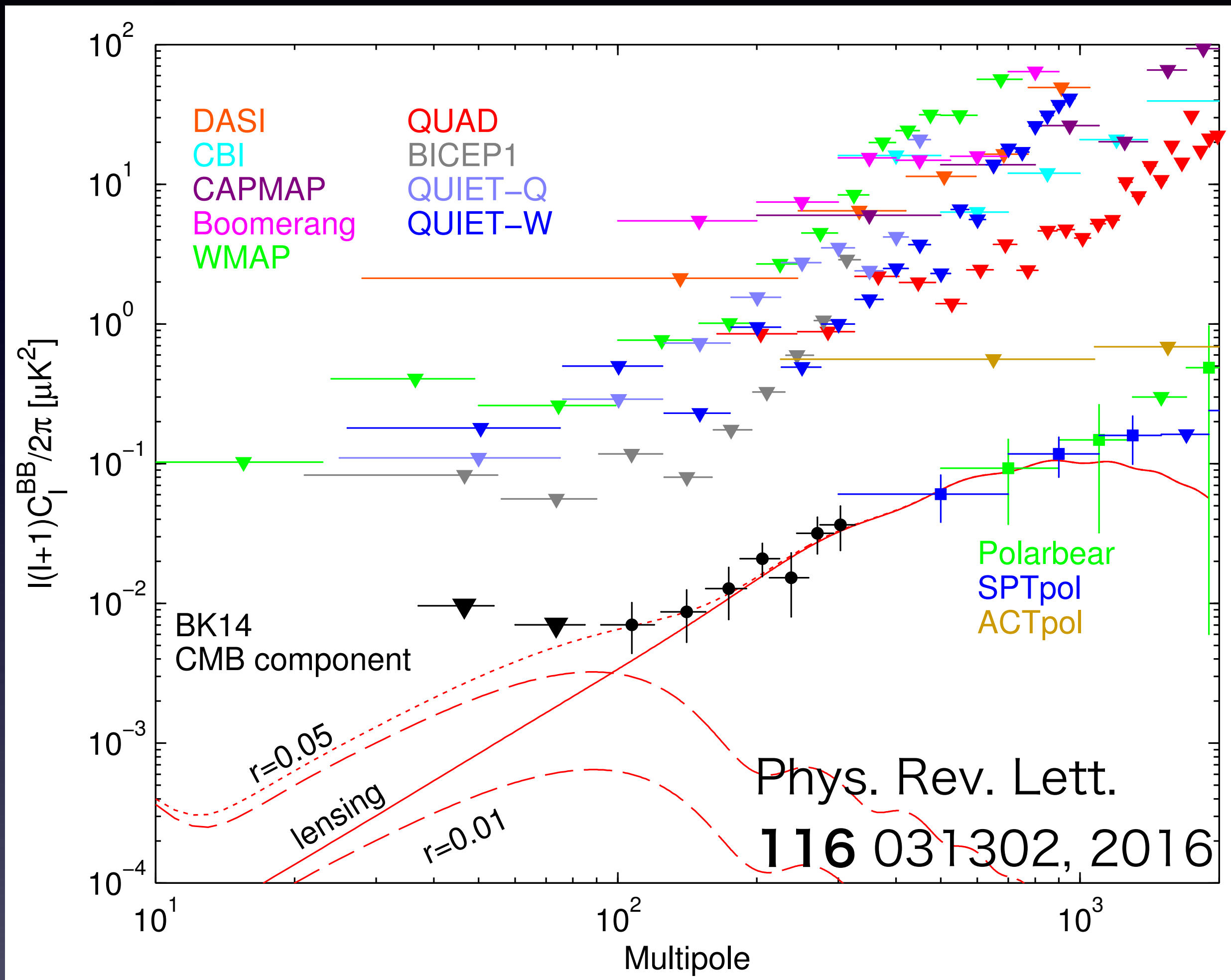




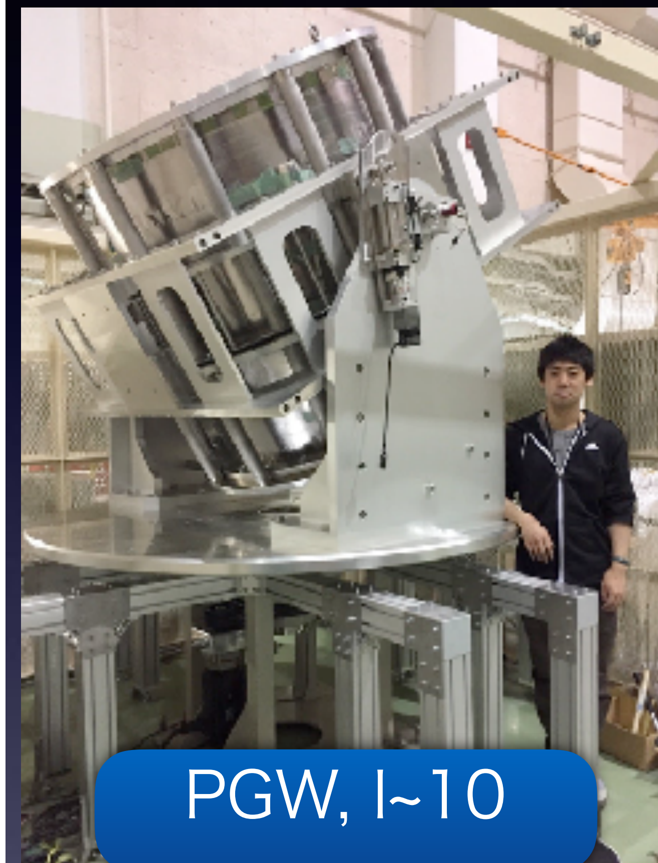
- 20 rpm rotational stage & 1kHz data taking
- Primary, secondary mirror are cooled at 4K
- Superconducting Kinetic Inductance Detector(KIDs)

Scan half the sky !!
Sensitivity to low l(>6)
B-modes and E-modes

Ground-based telescopes



GroundBIRD

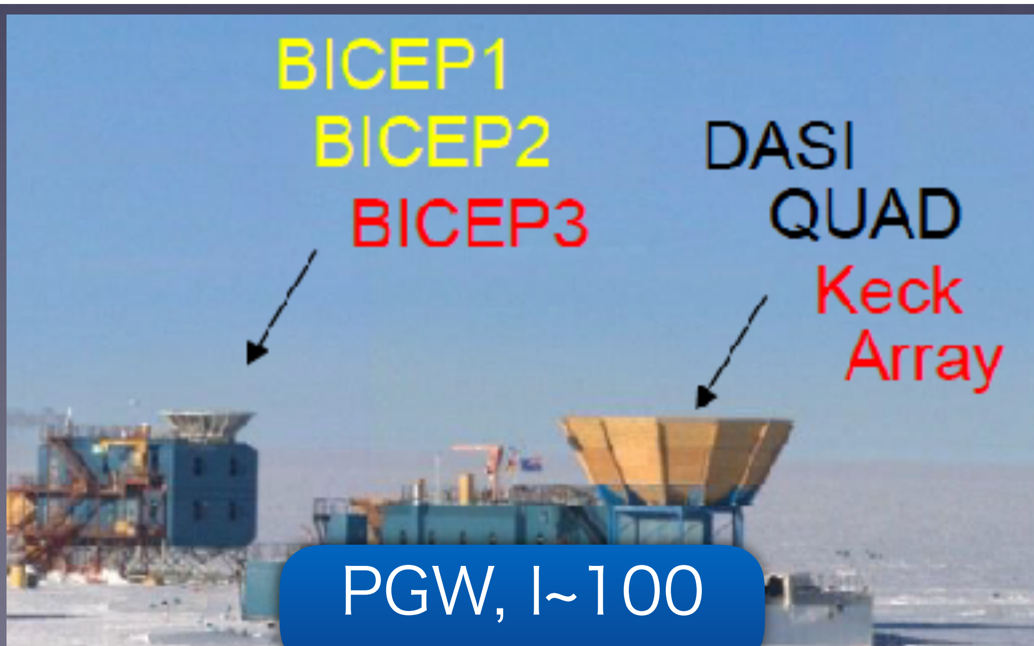


All of them employ

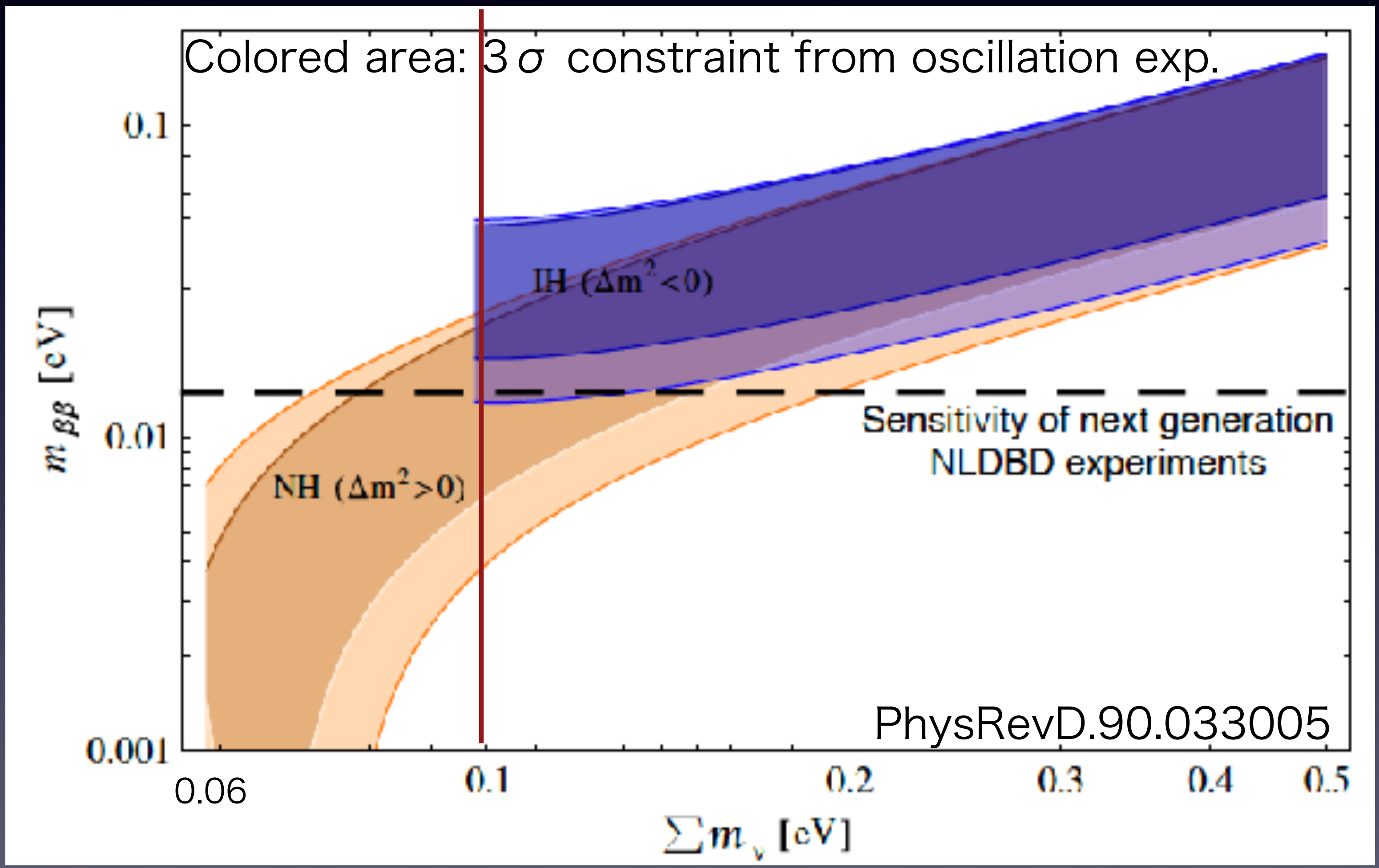
- Superconducting sensor array ~1000pix

Difference

- Target angular scale (Primordial or lensing)
  => scan area
  => telescope size



Future experiments and expected results



If CMB exp. observe the high mass(>0.1eV) neutrino
Neutrino less double beta decay exp.
Observe at same mass -> Majorana !
Reject that mass point -> Dirac !!
CMB cannot observe -> Normal !!!

CMB-S4 (U.S.)

- 2020 ~
- Telescope array
    - Combination of existing experiments
- 100,000 sensors !
- Expected sensitivity

$$\sigma\left(\Sigma m_\nu\right) = 16\ \mathrm{meV}$$
$$\sigma\left(\mathrm{N}_{eff}\right) = 0.020$$

Summary

- The lensing B-modes are good probe to measure the mass distribution
- The neutrinos contributes growth of large scale structure
- The lensing B-modes are sensitive to neutrino mass
- The large scale E-modes contributes to solve the correlation
- Many experiments are already running and lensing b-modes are already observed
- Future experiments will be able to measure $\sigma\left(\Sigma m_\nu\right) = 16\ \mathrm{meV}$