Pushing the limit:

BigBoss and

neutrino mas

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Big Boss

From Wikipedia, the free encyclopedia

Big Boss may refer to:

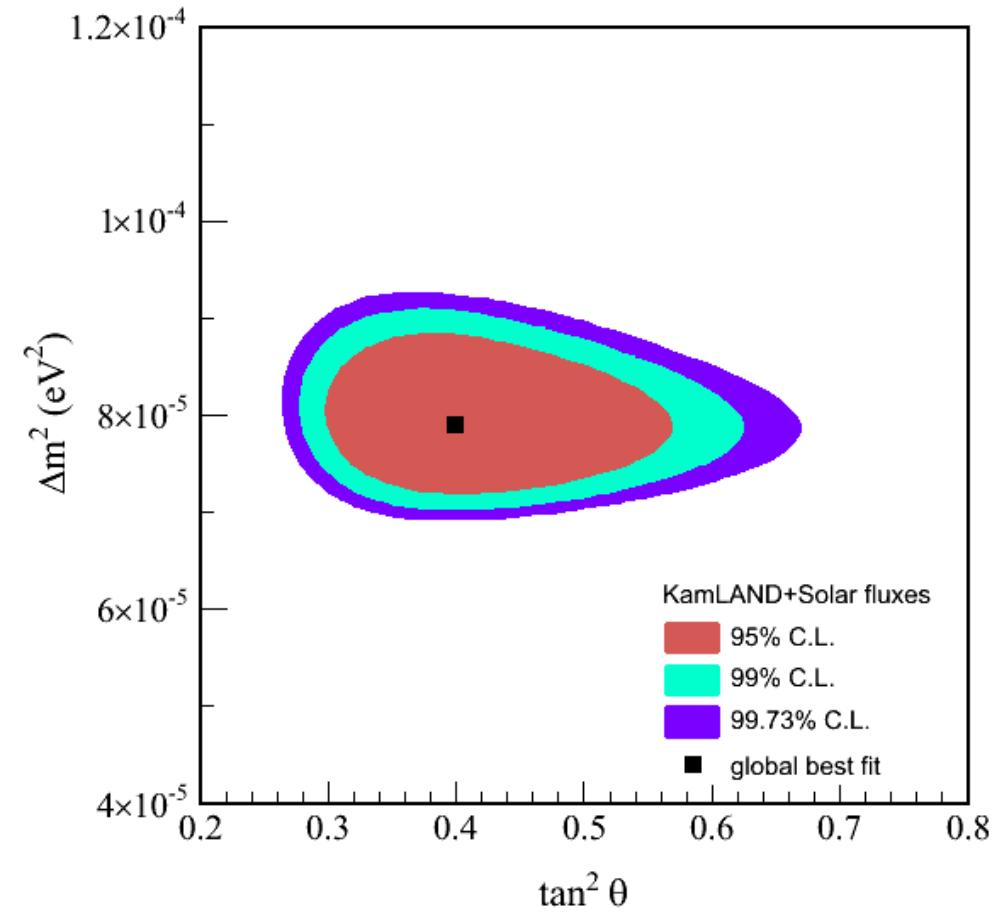
- Big Boss (*Metal Gear*), a fictional character from the *Metal Gear* video game series.
- *The Big Boss*, a film starring Bruce Lee
- Big Boss (*C.O.P.S.*), a fictional character from the toyline *C.O.P.S.*
- *Bigg Boss*, the Indian version of the international reality television series *Big Brother*.
- Big Boss (musician), metal singer from Czech Republic
- Ray Traylor, professional wrestler known as "The Big Boss Man"
- *Big Boss*, a 1995 Telugu film

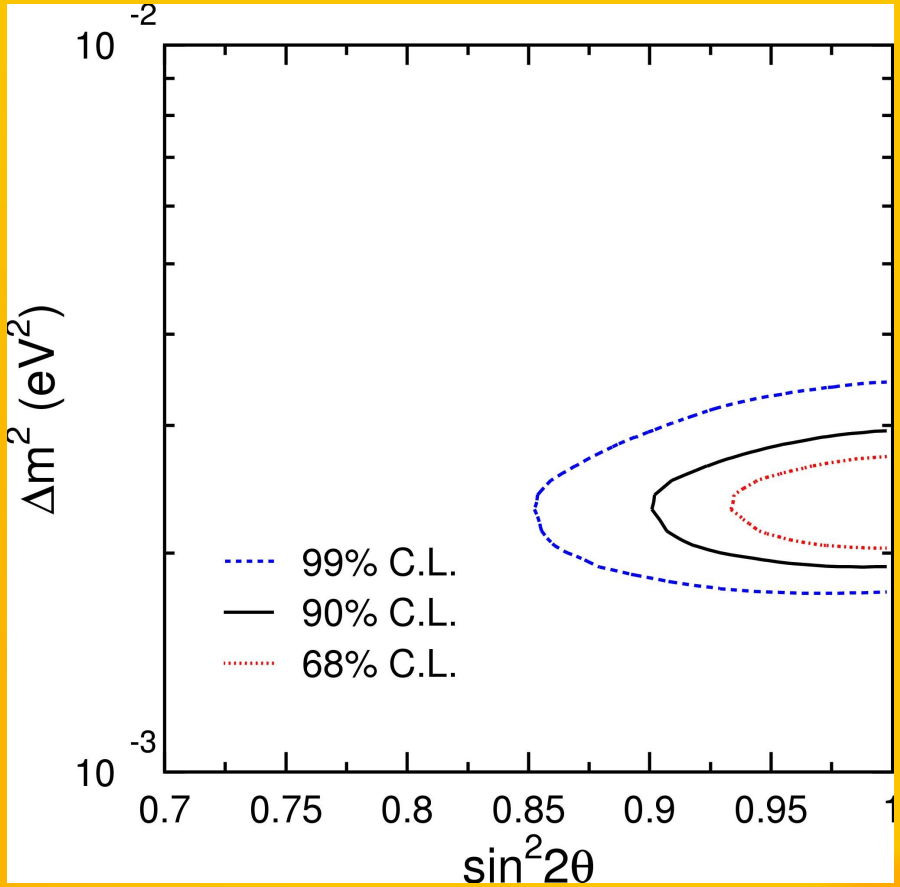
The protagonist of the Metal Gear series is a soldier without equal. He's saved the world multiple times and is a master of military combat, stealth tactics, and weapons.

Neutrinos

- Neutrinos Oscillate → must have mass → standard model of particle physics is incomplete
- Particle physics probes neutrinos in two ways:
  - Mass squared differences via oscillations: have detection
  - Absolute mass via tritium beta decay: don't have detection

Neutrino oscillations





Solar neutrinos:

$$\Delta m^2_{12} = m^2_2 - m^2_1 =\sim 5 \times 10^{-5}\mathrm{eV}^2$$

Atmospheric neutrinos:

$$|m^2_3 - m^2_2| =\sim 2.5 \times 10^{-3}\mathrm{eV}^2$$

Neutrinos in cosmology

* Assuming massless, they are like photons but
  - fermions rather than bosons:
    * Contribute 7/8 of energy density at the same temperature
  - decouple before electron - positron annihilation:
    * Their temperature can be calculated assuming conservation of entropy; one gets

$$T_\nu = \left(\frac{4}{11}\right)^{(1/3)} T_{CMB} \sim 1.95\ K$$

or 56/cm^3 <- cf 10^10/cm^3 for direct detection

Neutrinos in cosmology

- Next assume they are massive, but light enough so that they were still ultra-relativistic at the time of decoupling
- Their energy density today is

  number density x mass x c squared
- Hence, one can derive:

$$\omega_\nu = \Omega_\nu h^2 = \frac{\sum_i m_i}{92.4 \text{ eV}}$$

- Need 16 eV per neutrino species to close the Universe!

Neutrinos in cosmology

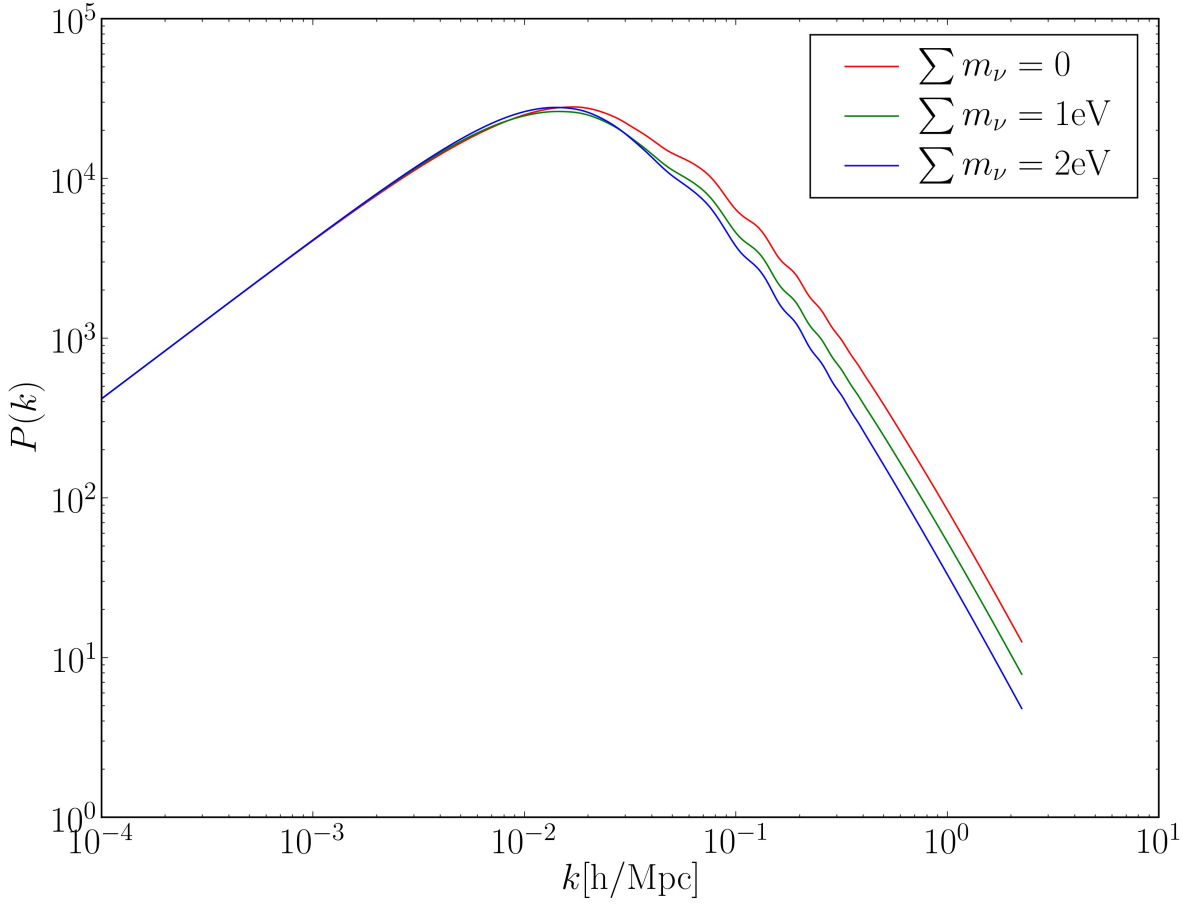
- Could neutrino be dark matter? NO!
  - Neutrino would be relativistic early on, erasing structure on scales smaller than free-streaming scale

$$k_{fs} \sim 10\ Mpc^{-1} \left(\frac{m_{nu}}{1\ keV} \right)$$

  - exponential supression characteristic of **HOT D.M.**
  - not observed, DM is cold as far as we can tell
- Standard model is therefore:

Perfectly cold dark matter + 3 essentially massless nu

Neutrinos in cosmology

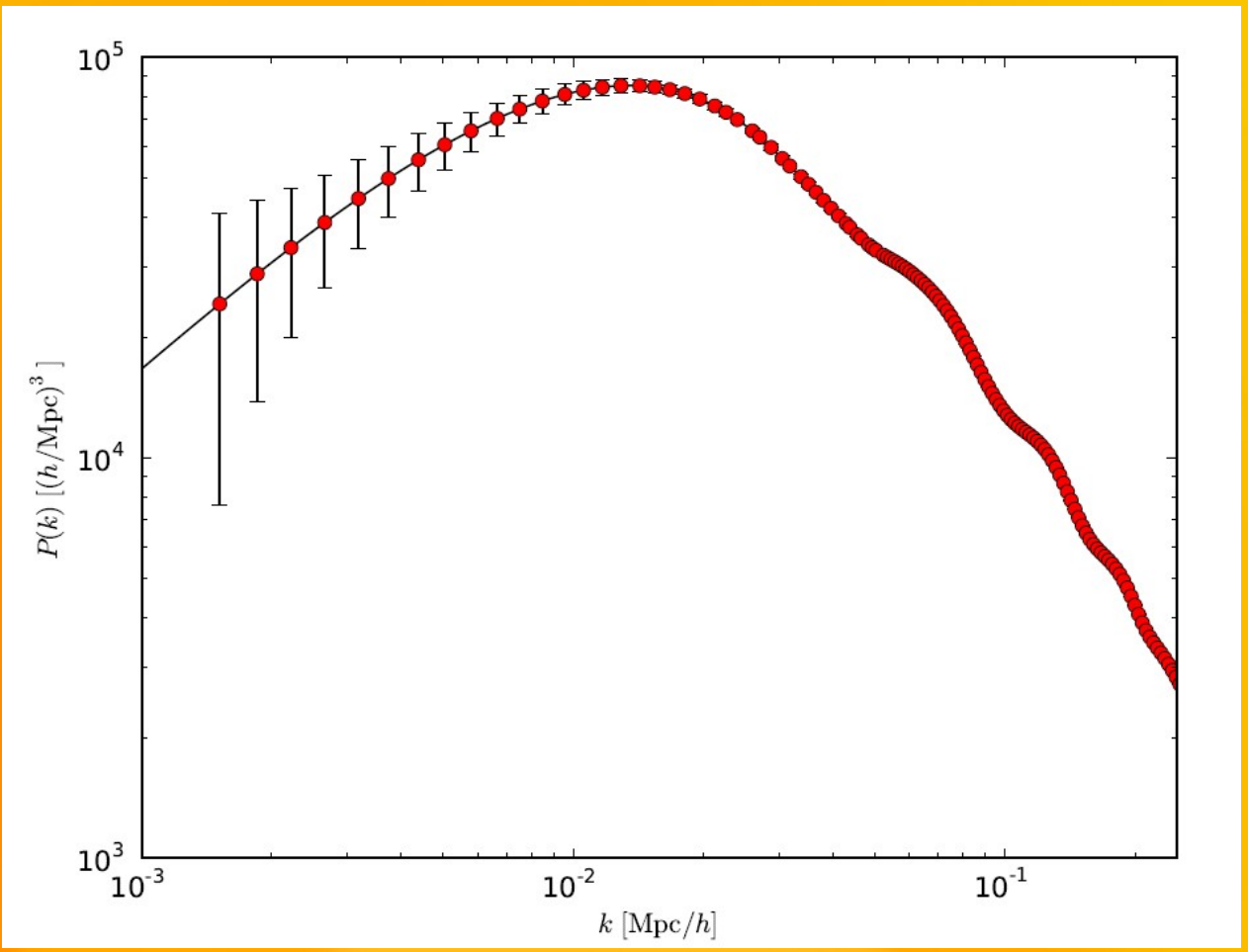


- Massive neutrinos + cold dark matter don't produce and exponential cut-off
- A suppression on small-scales still present
- Can put limits on neutrino mass!

Mass limits

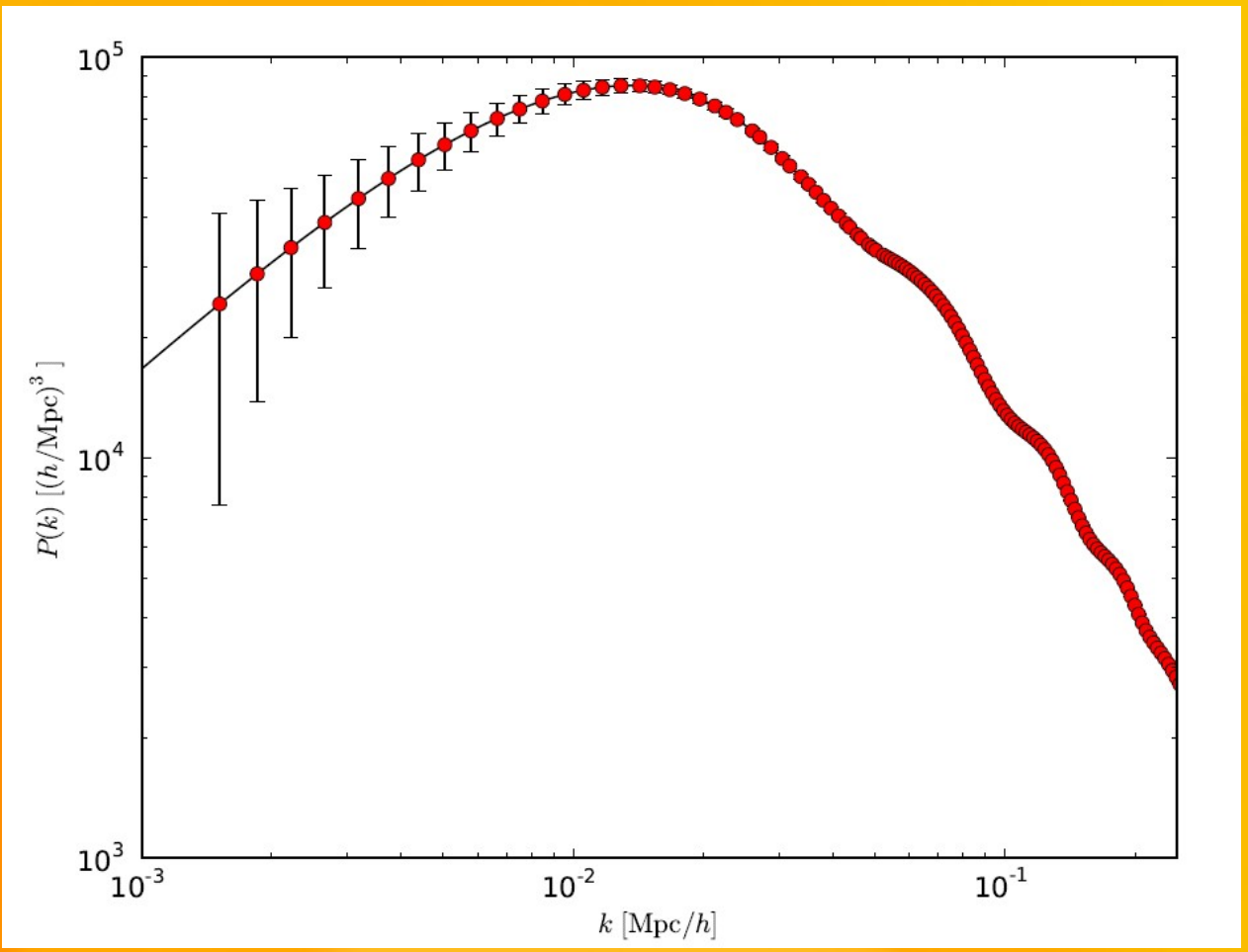
2dF + WMAP	Hannestad et al 03	<1.0 eV
SDSS +WMAP	Tegmark et al 04	<1.7 eV
WMAP + 2dF + SDSS	Crotty et al	<1.0 eV
WMAP + SDSS + Ly−α	Seljak et al 04	<0.43 eV
		$0.56^{+0.3}_{-0.2}$ eV
Clusters+WMAP	Allen et al 04	
WMAP3 + everything + Ly−α	Seljak, McDonald, AS 06	<0.17 eV
WMAP3 + SDSS, conservative	Zunckel & Ferreira 07	<2.2 eV
WMAP5	Dunkley 08	<1.3 eV
WMAP5+BAO+SN	Komatsu 08	<0.6 eV
WMAP5 + MaxBCG	Vikhlinin 09	<0.33 eV
WMAP5 + MaxBCG+H0+...	Reid 09	<0.3 eV

BigBoss Linear PS



- Errorbars: impressive
- Goes to very large scales: more linear
- Goes to higher redshift: more linear

BigBoss Linear PS



- Limit on sum of neutrino masses: 0.01eV–0.03eV
- Guaranteed detection?
- How to make it beliveable?

Nu mass from galaxies

- We don't measure the DM field, we measure galaxies
- Light neutrinos do relativistic-non-relativistic transition at:

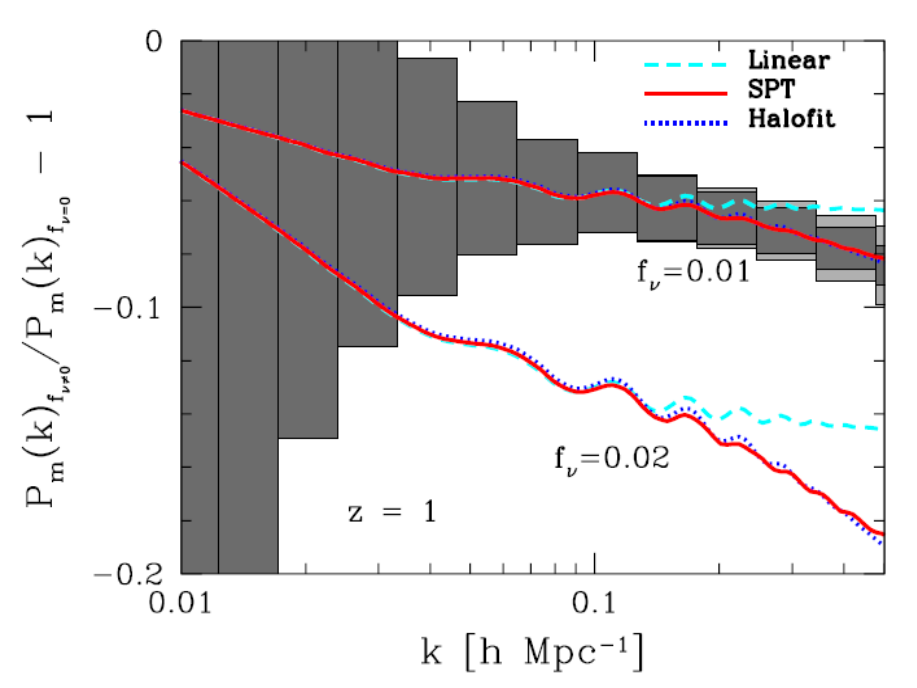
$$1 + z_{\rm NR} = 640 \left(\frac{\sum m_\nu}{1\,{\rm eV}} \right)$$

- Non-linear structure formation might be somewhat affected by presence of neutrinos

Saito et al

- Develop a 2nd order perturbation theory in presence of neutrinos.

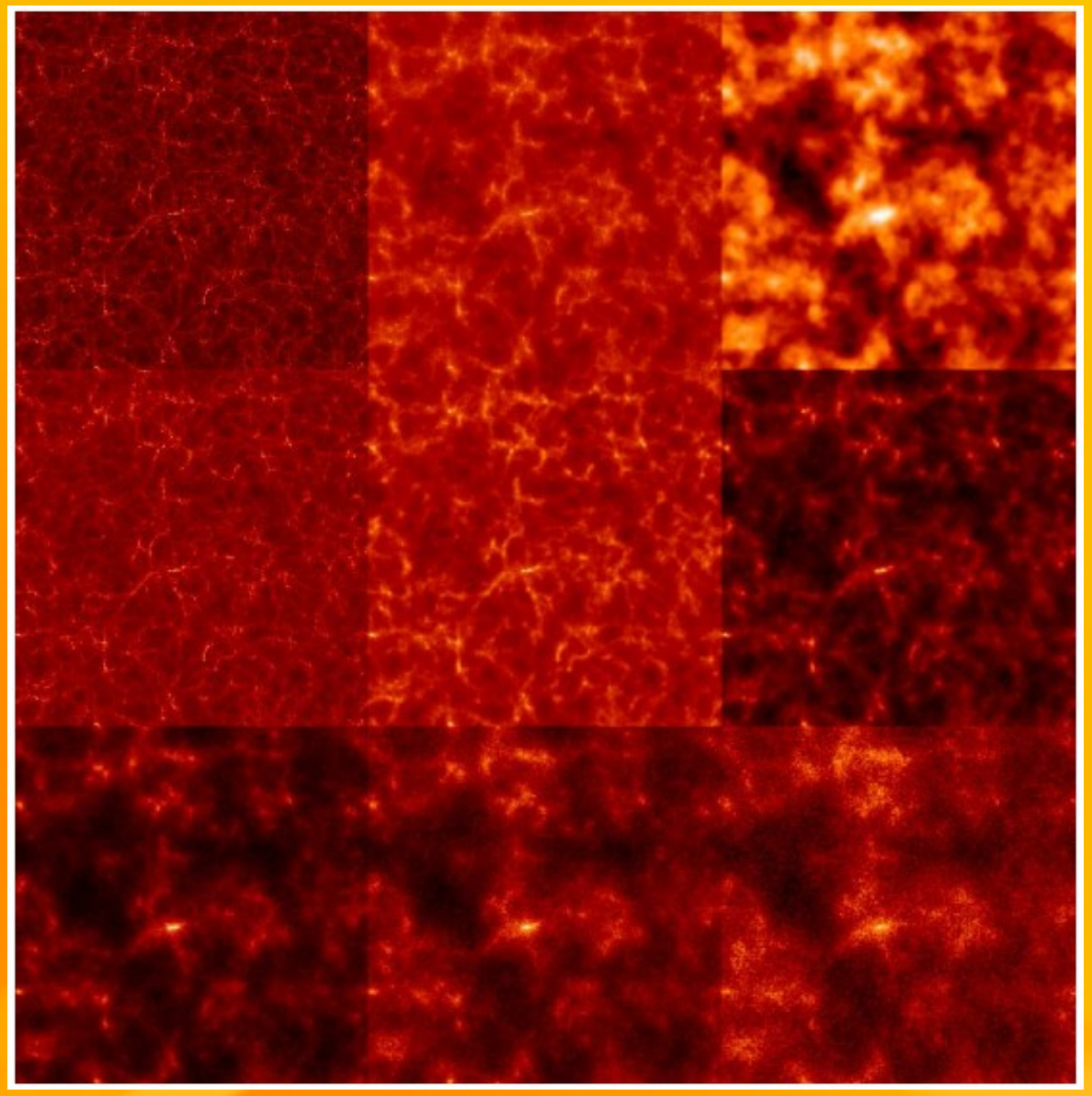
$$P_{\rm m}^{\rm NL}(k;t) = f_{\rm cb}^2\, P_{\rm cb}^{\rm NL}(k;t) + 2 f_{\rm cb} f_\nu\, P_{\rm cb\nu}^{\rm L}(k;t) + f_\nu^2\, P_\nu^{\rm L}(k;t),$$



Brandbyge & Hannestad

- Developed a hybrid scheme capable of simulating neutrinos.
- Follow the full momentum distributions on a Eulerian grid.
- As lower energies become non-relativistic, they are converted to particles
- Get halos which you can paint with gals

Brandbyge & Hannestad



CDM, nu part, nu grid.

q/T = 1,2,3

q/T = 5,7,10

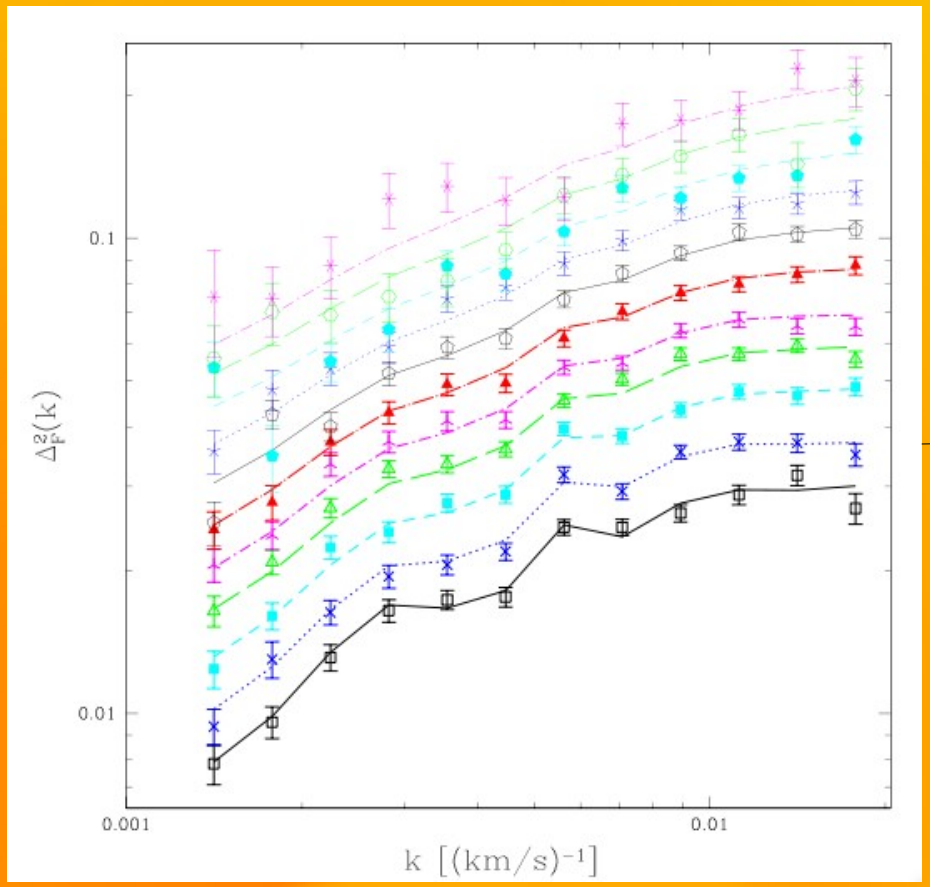
Neutrino mass from BB gals

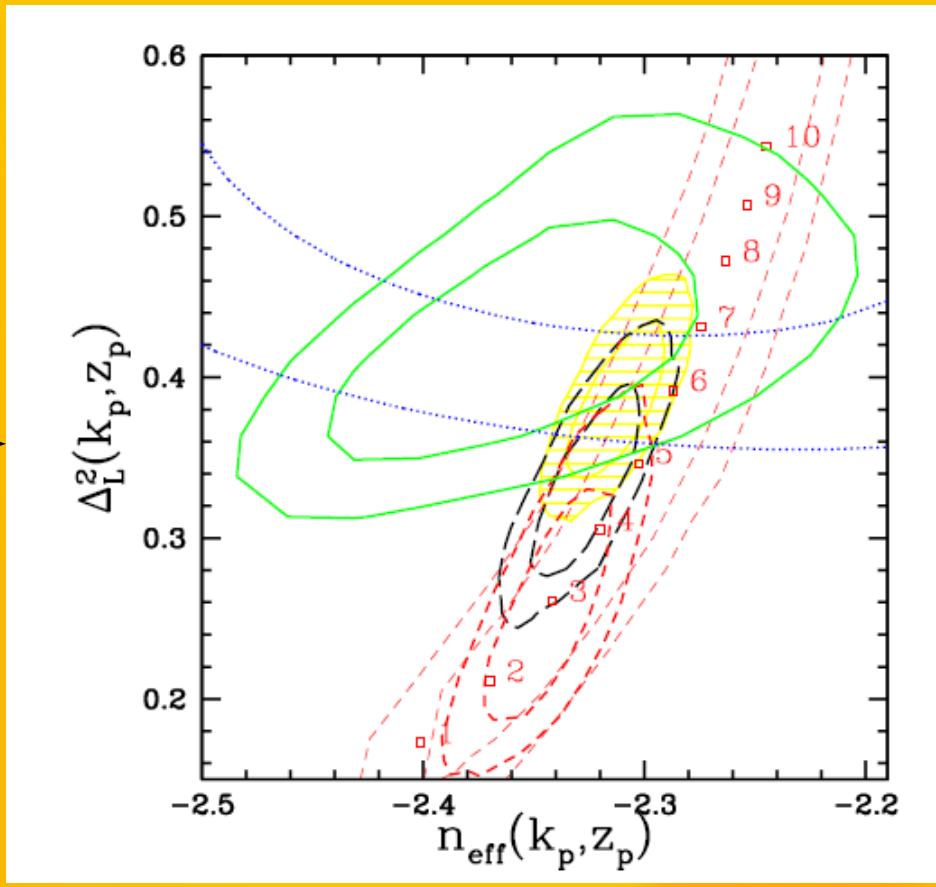
- Most signal from similar k-range as BAO: understanding of how galaxies occupy halos will likely be there
- There are subtle differences in structure formation with neutrinos: these will have to be simulated to death
- If it works, we have realistic chances of a detection

Neutrino mass from LyΔ

- Cannot use large scale modes: UV fluctuations and continuum uncertainties likely swamp the signal
- Must rely on small scale flux power spectrum:
  - Measure the amplitude of fluctuations

Ly-α: Flux power spectrum



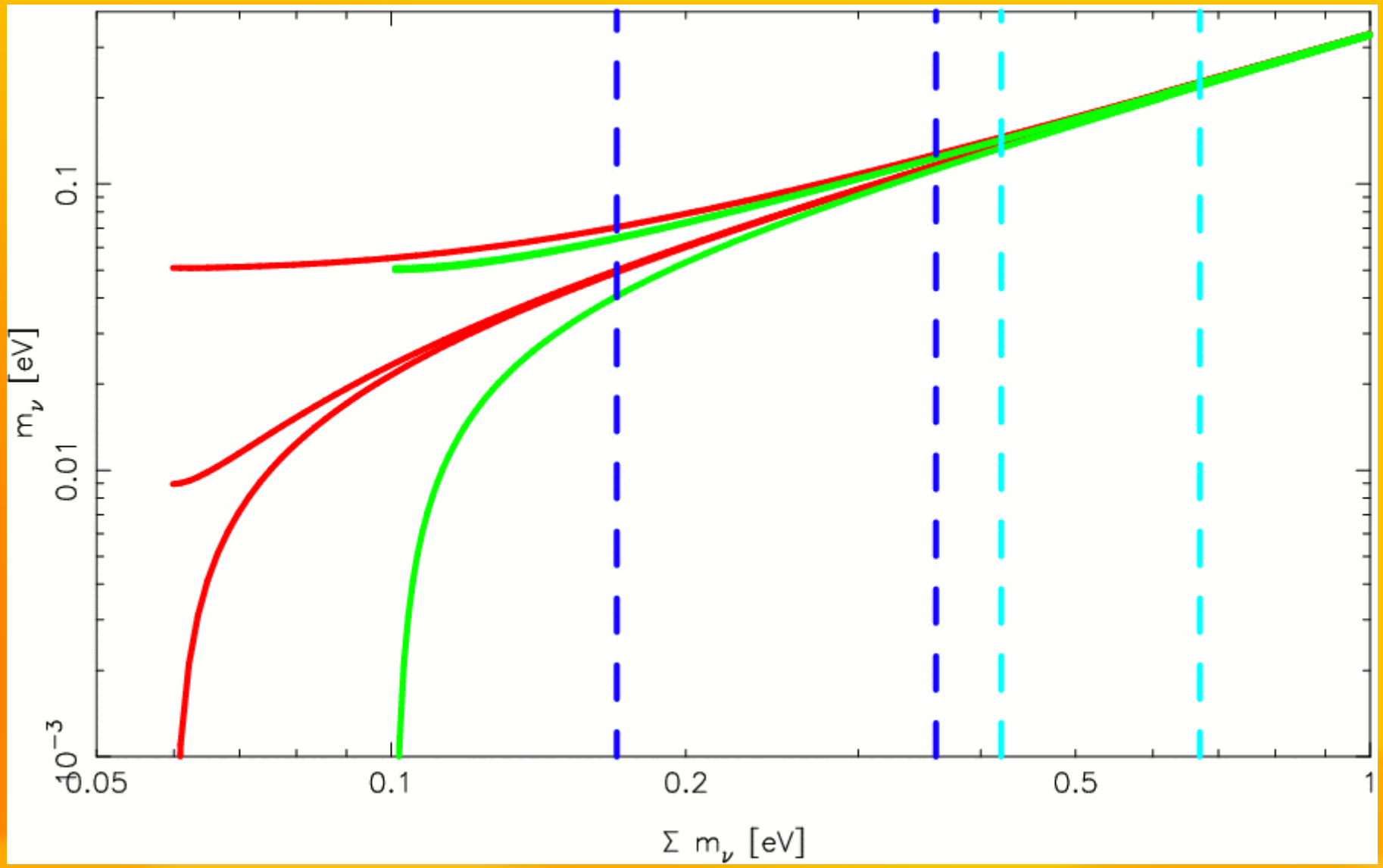


Flux PS

- McDonald et al, 2006

Measurement of linear PS

Mass hierarchies



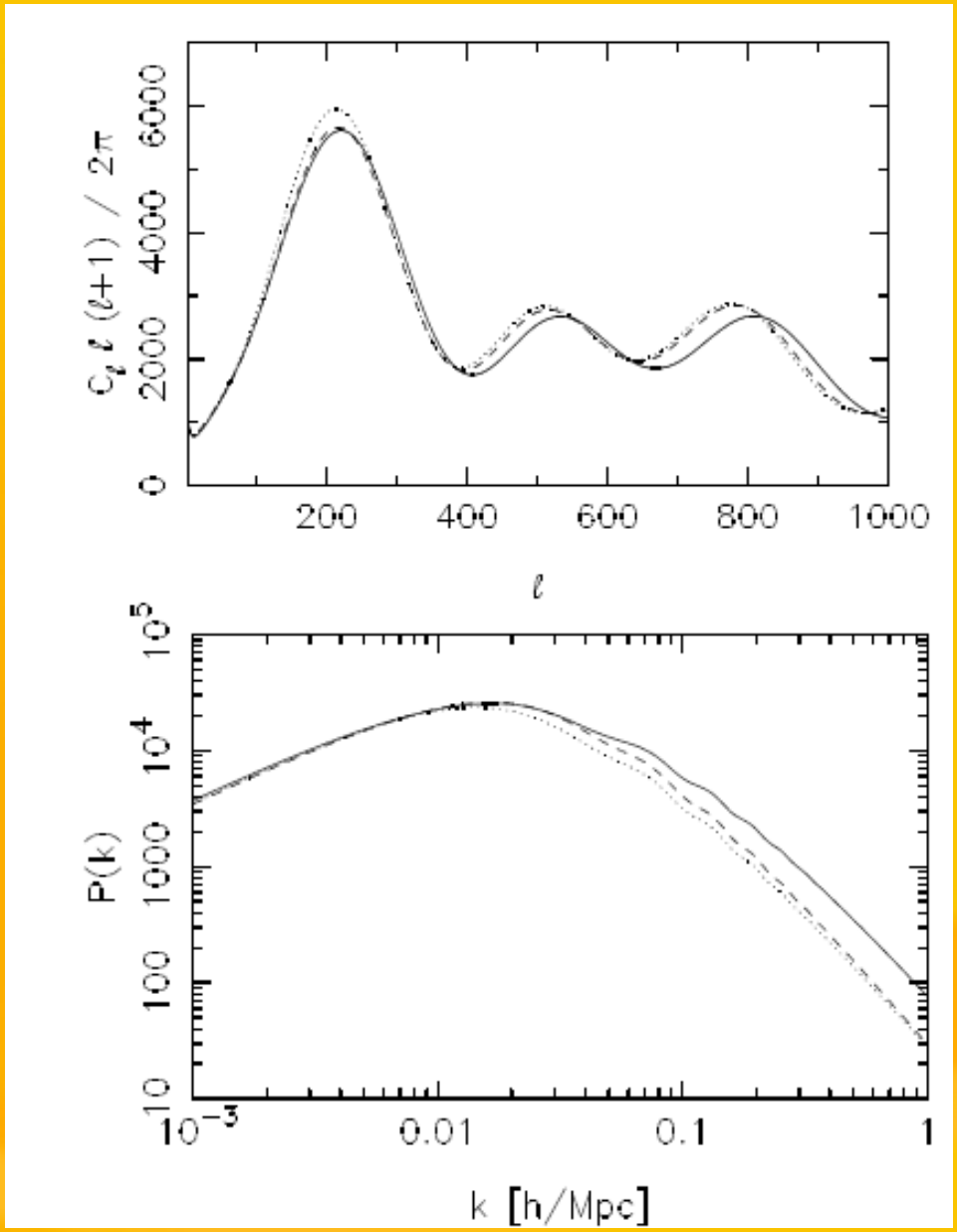
- Better than Fisher matrix!!

Nu mass from BB LyA

- SDSS: 3k analysed, 10k available
- BOSS: 160k, BIGBOSS: 1000k quasars
- Do we want fewer, but higher SNR quasars?
- Computers have grown, can do better sims even today
- Will we get away with amplitude/slope parametrisation

Neutrino mass difference

- Signal is there in principle (Lesgourgues 2003, Slosar 2006)
- I claimed undetectable
- I also didn't believe in 5% of all available volume...
- See e.g. de Bernardis (young one) et al.



Other things

- Number of relativistic species N_nu
- Light sterile neutrinos (?!)
- Sterile neutrino as a DM candidate under revised cooled scenarios
- Cosmological axions