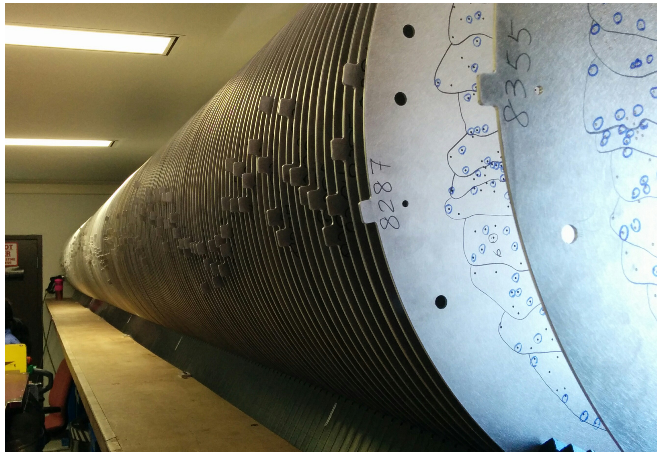
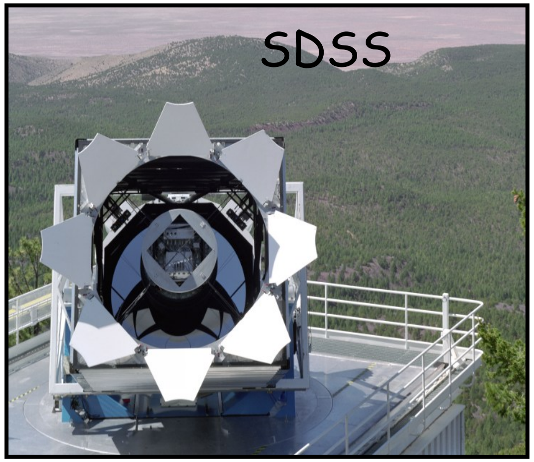
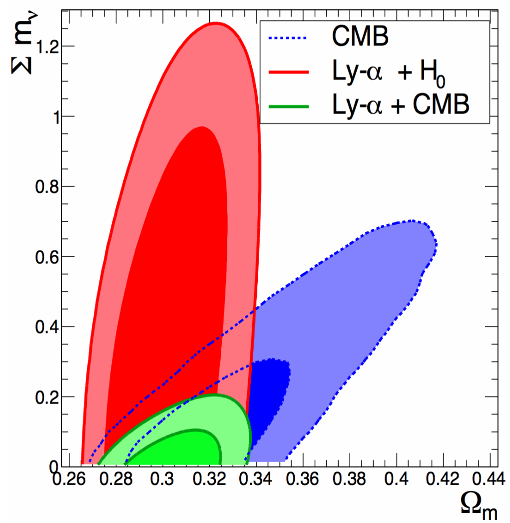
Measuring Σm_ν with drilled plates







Contributing persons:

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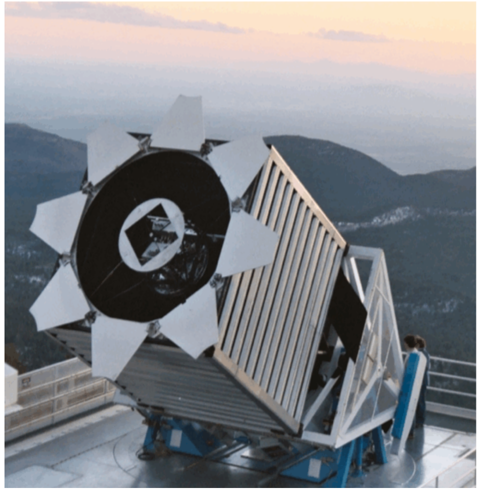
SPP Apero   Saclay   February 13, 2015

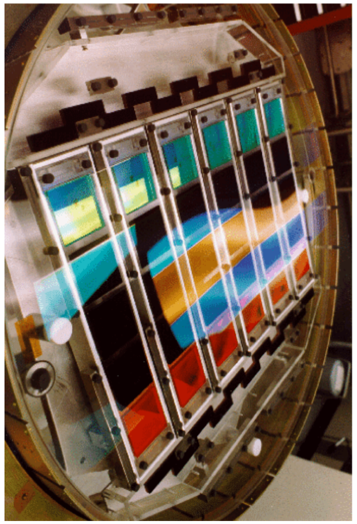
Why do we need plates?

SDSS/BOSS



SDSS Survey

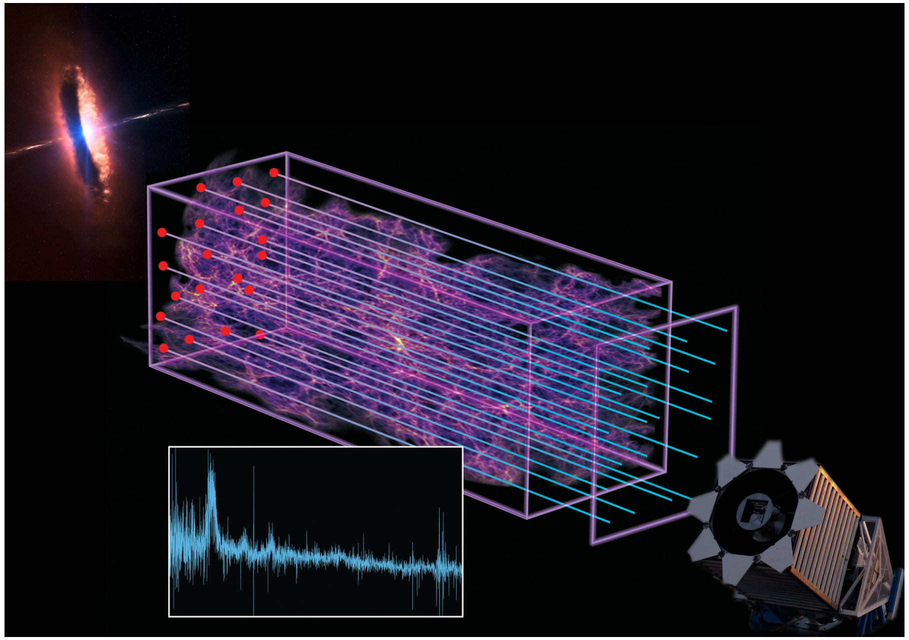
- 2.5m Sloan telescope with a wide FoV ~ 7 deg^2
- **(α,δ) positions:** 5 filter camera
- z **position:** Spectrograph ~1000 simultaneous spectra



BOSS tracers

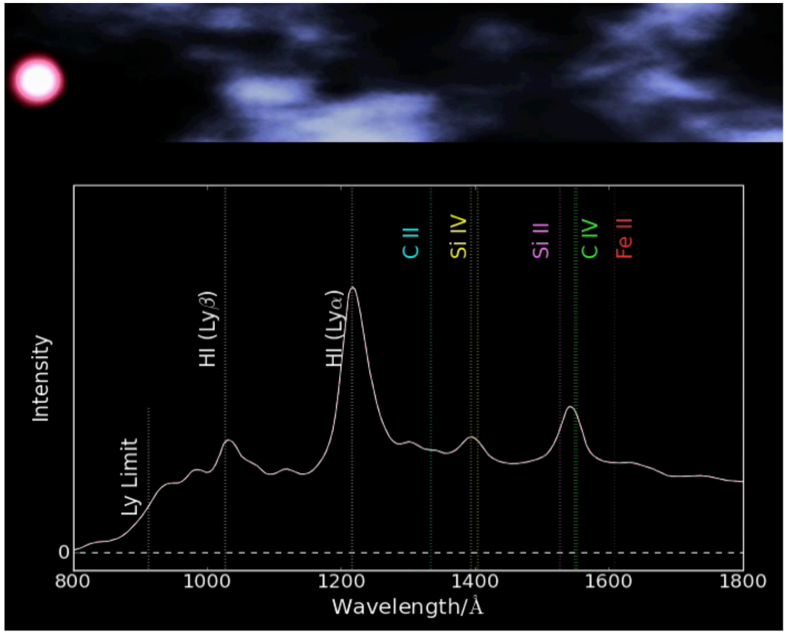
- 1.5 millions of Luminous Red Galaxies (light emitted 6 billions years ago, z~0.6)
- 180 000 quasars (light emitted 11 billions years ago, z~2.4) with Ly-α forests

Ly-α forests, matter tracers



Principles

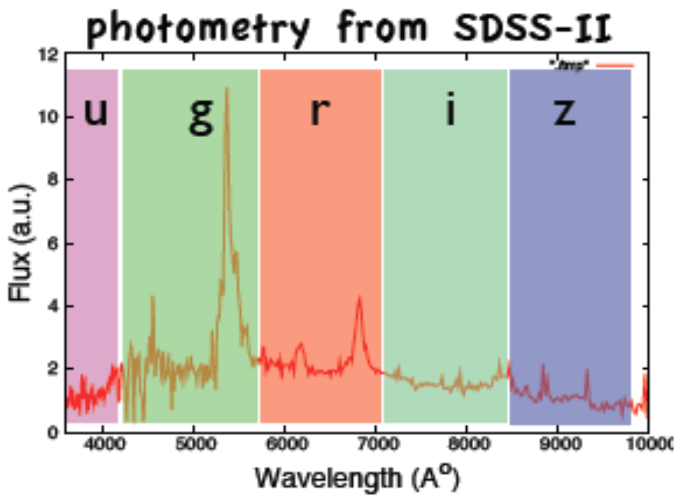
- Use Ly-α forests of quasars (2.2<z<4)
- HI absorption in IGM along the line of sight of QSOs
- We expect low density gas (IGM) to follow the dark matter density



1D power spectrum

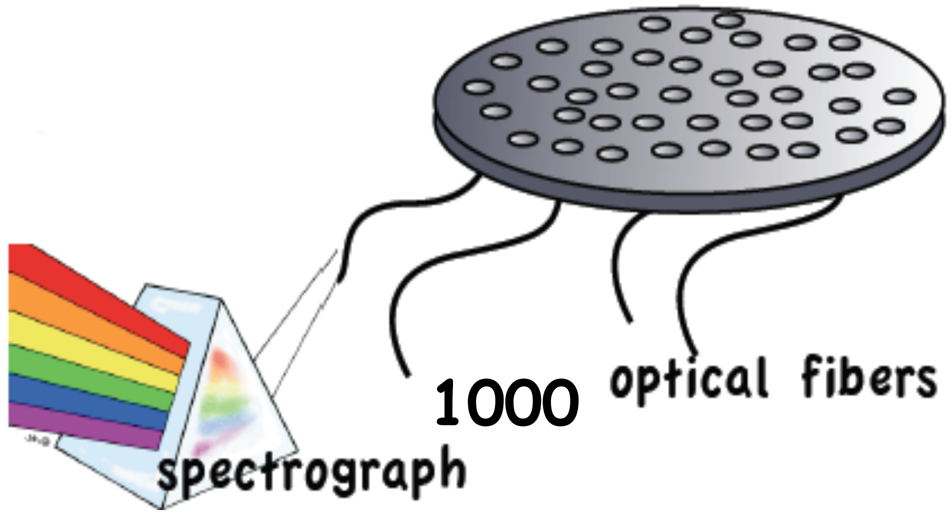
- Correlation between the pixels of a line of sight
- Proxy of the matter down to scale 1 Mpc

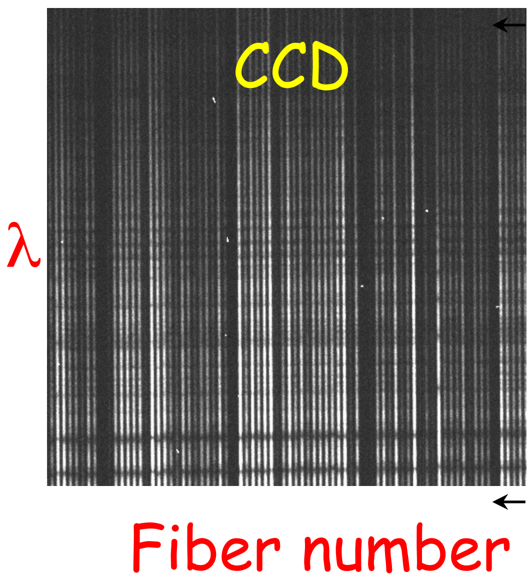
BOSS Observation Strategy



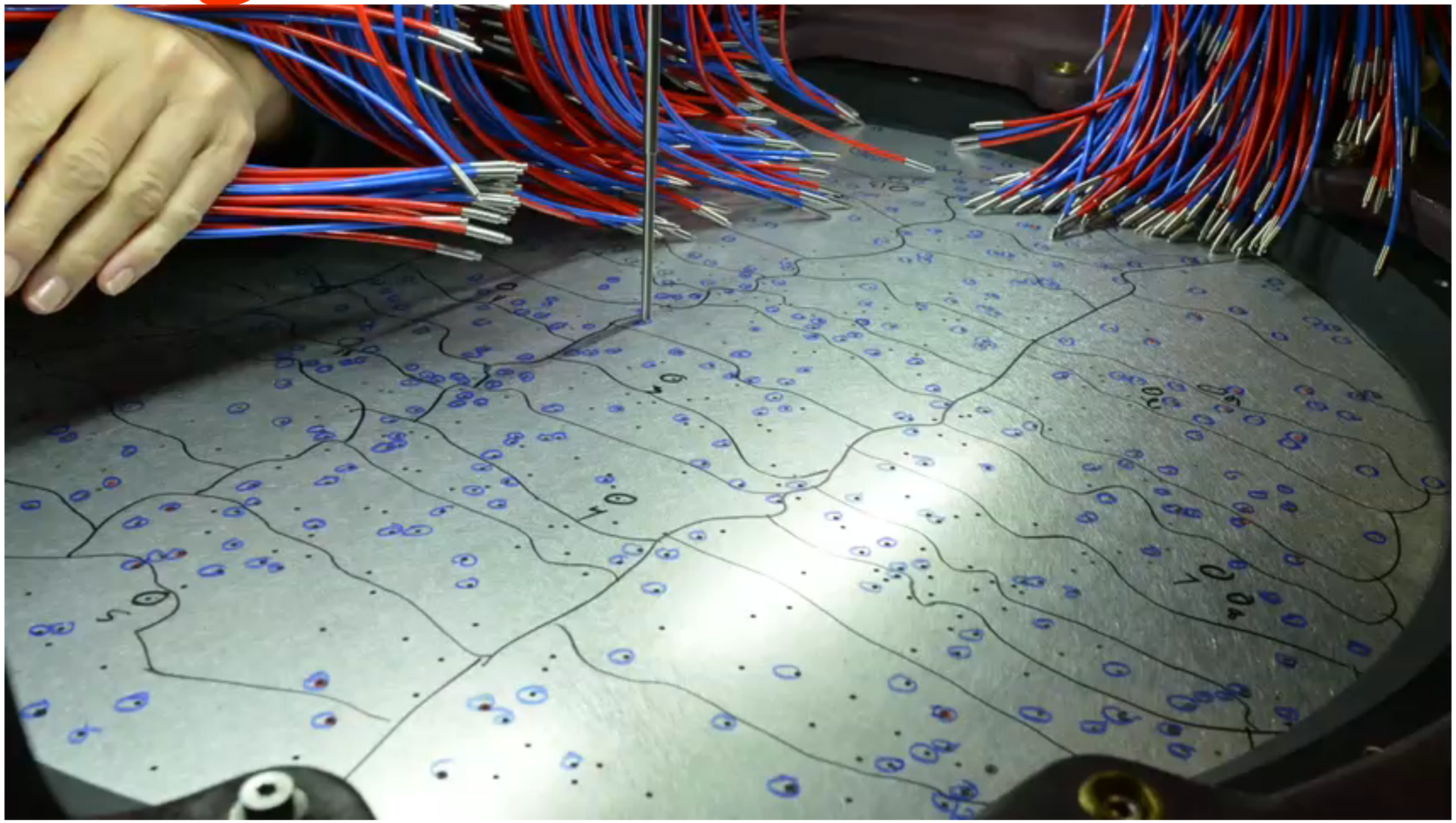
List of targets

SDSS J112253.51+005329.8
SDSSp J120441.73-002149.6
SDSSp J130348.94+002010.4
SDSSp J141205.78-010152.6
SDSSp J141315.36+000032.1
....





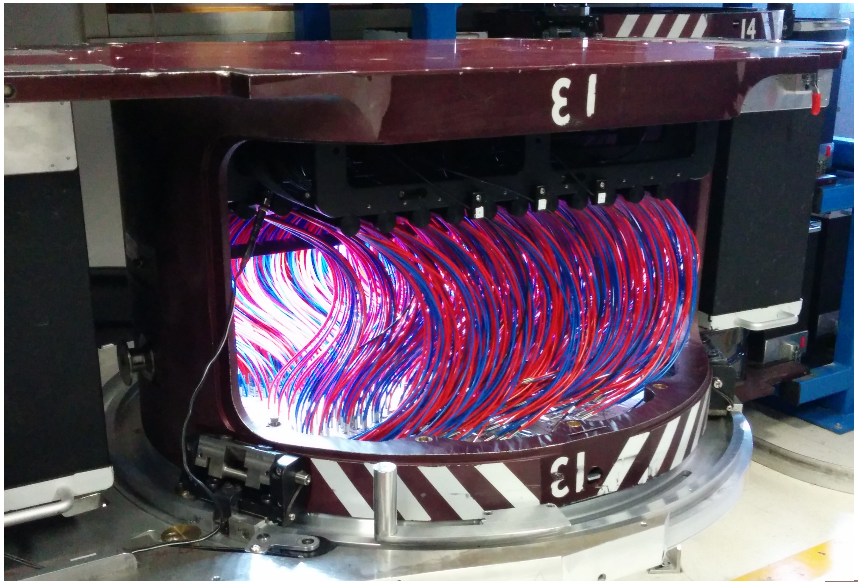
Plug and Observe



Several steps (~3 months)

- Target selections (~40 QSOs deg^{-2} and ~150 galaxies deg^{-2})
- Drill plates (1000 holes per plate)
- Plug plates on cartridges during day

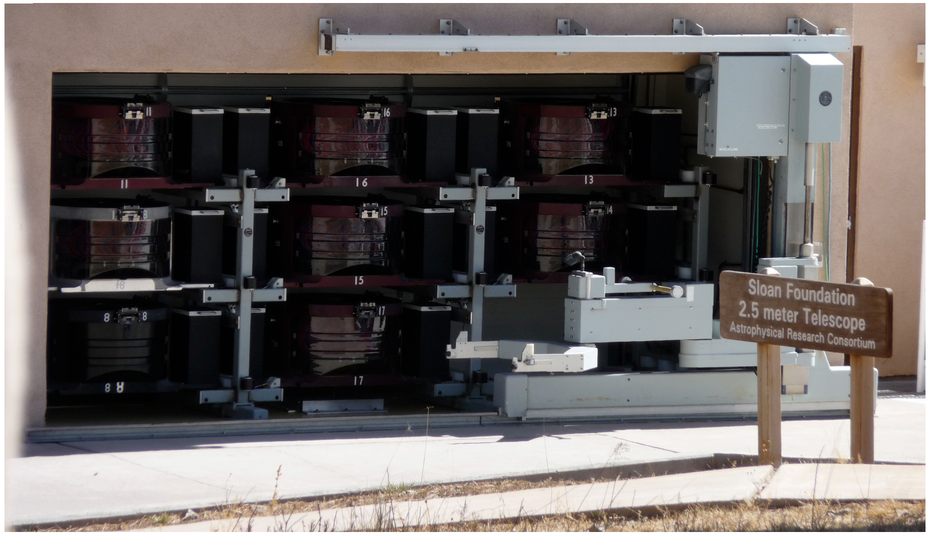
Observations at APO



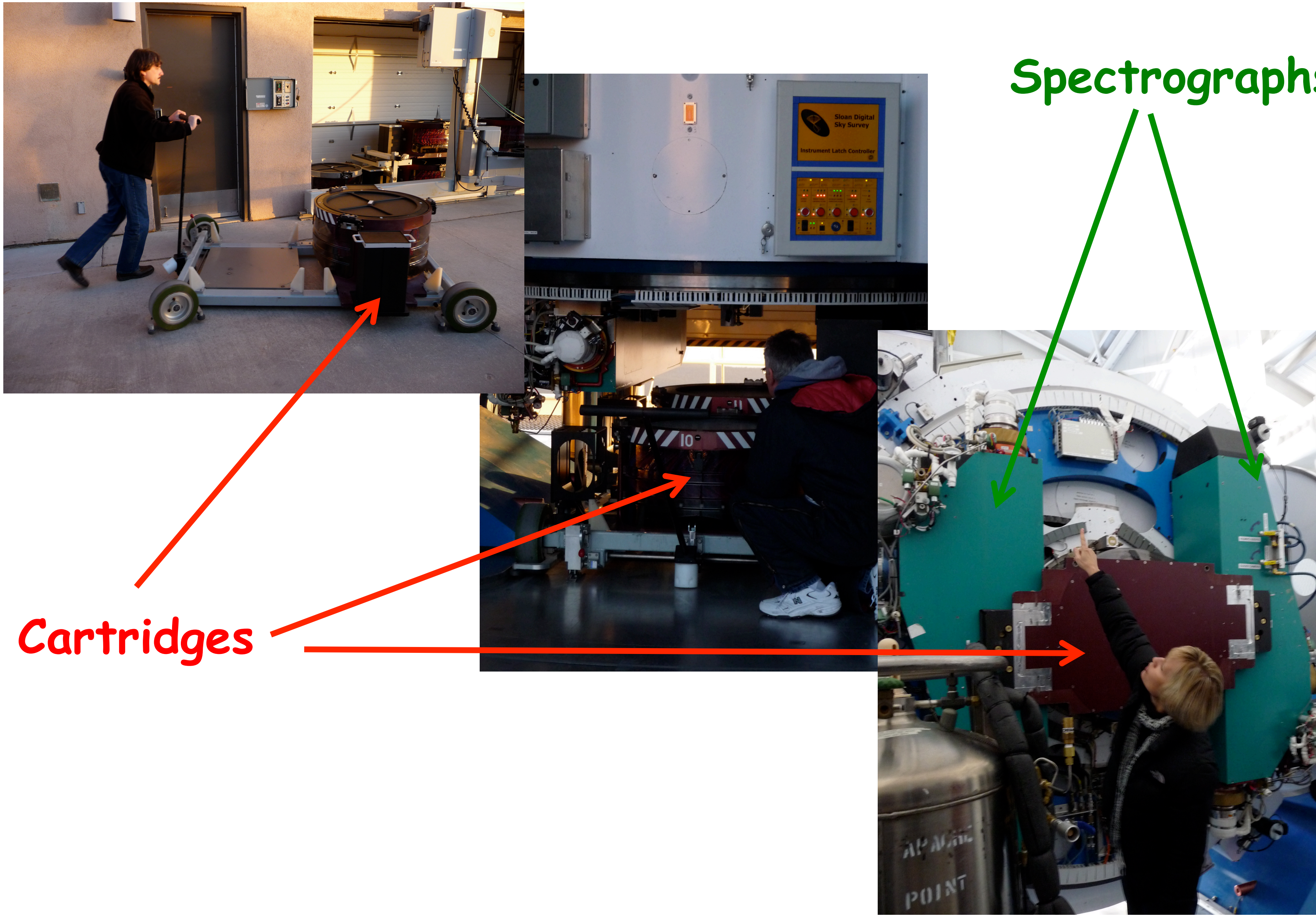
Cartridges

- Plugged during day
- 30 mns to 45 mns per cartridge
- Observation of 5-9 cartridges per night.

Cartridges stored for night observations



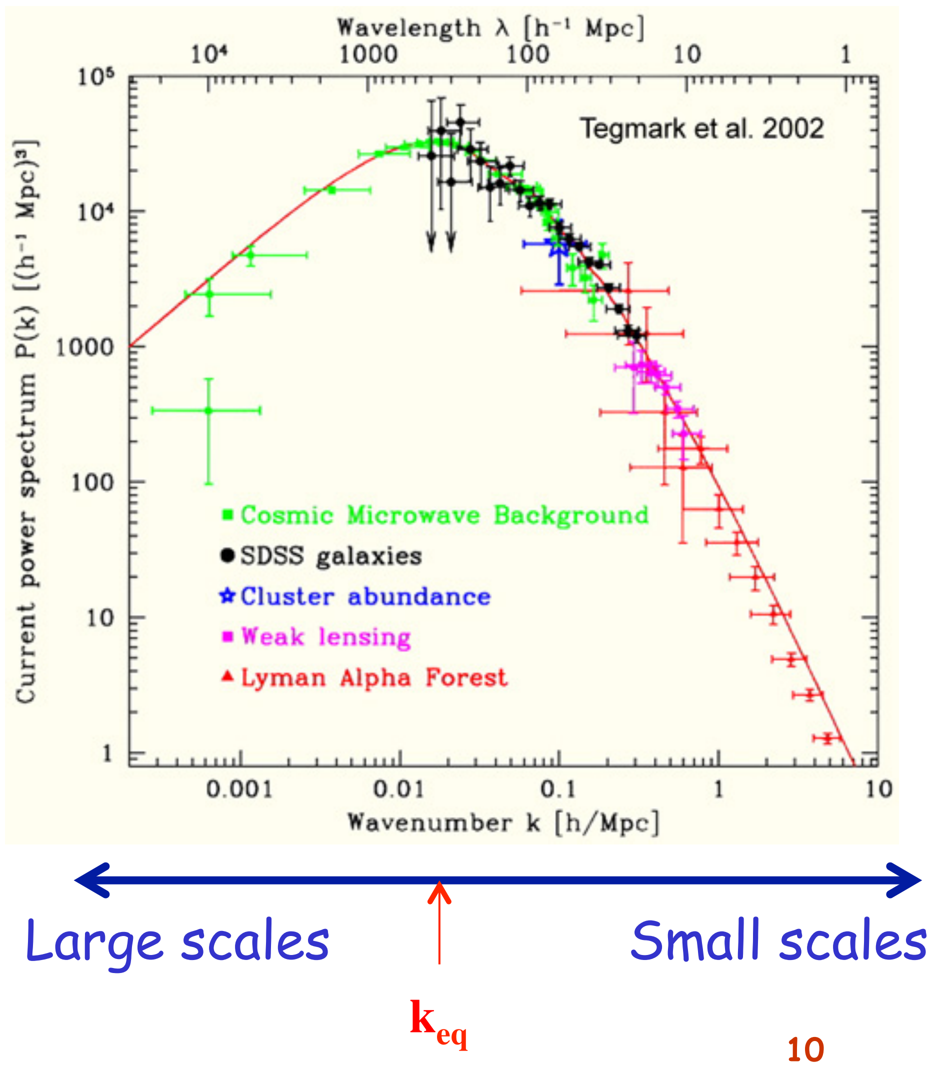
Observations at APO



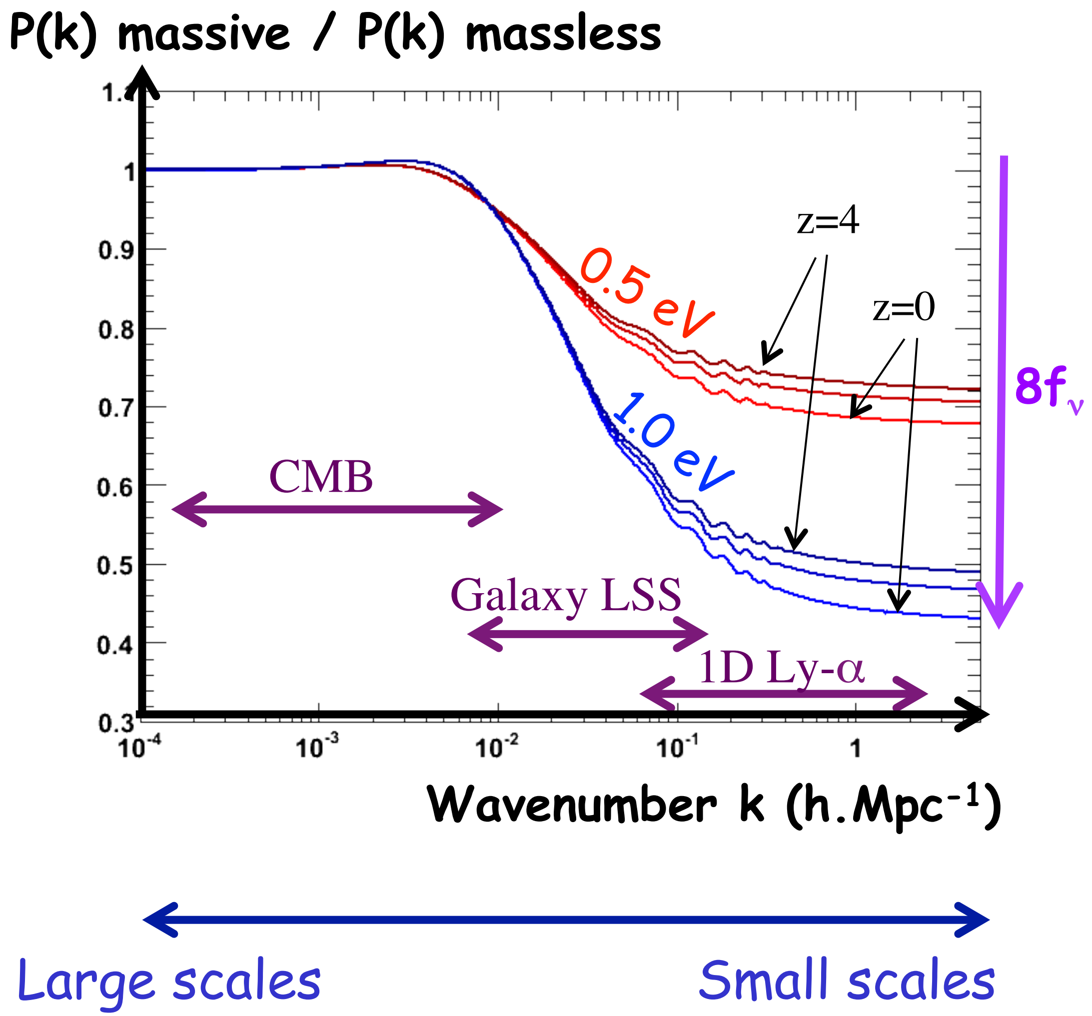
Measuring neutrinos masses

Matter power spectrum

- Analogy with sound: higher at certain frequencies
- Real space ⟹ k-space (Mpc^{-1})
- First observation of "total" power spectrum with different tracers of the matter



Impact of neutrino masses

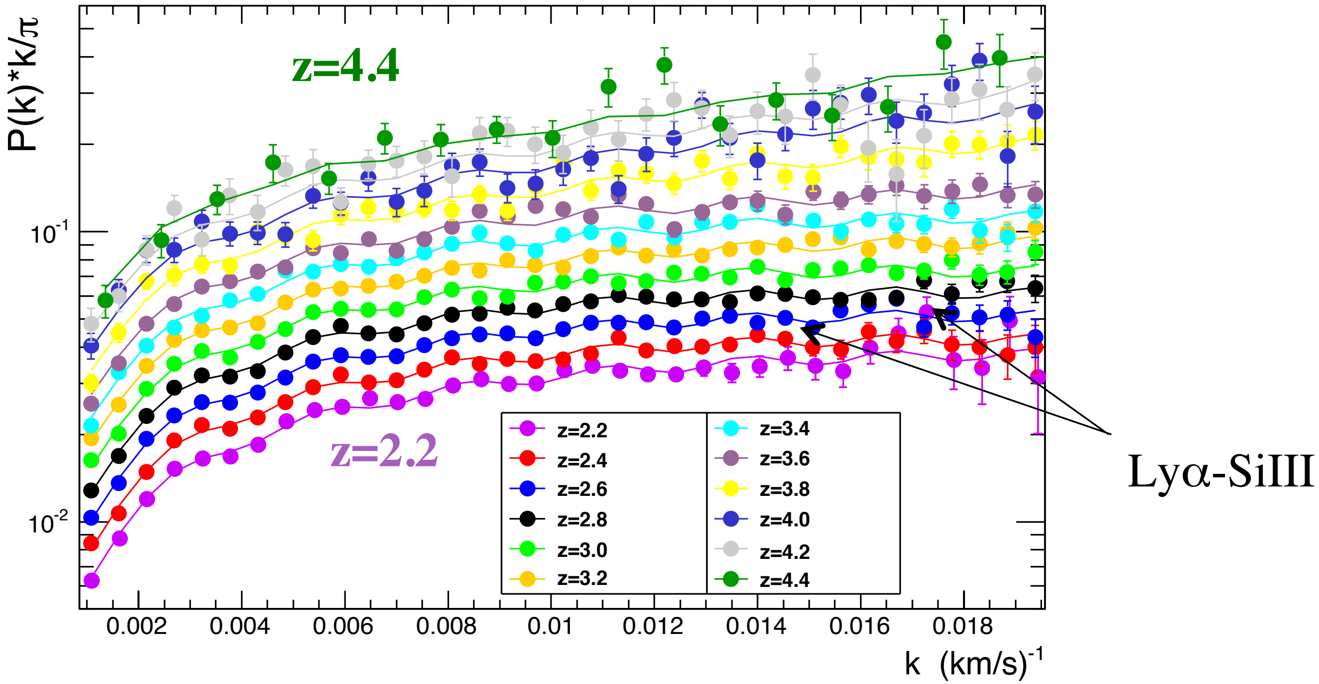


- Free-streaming ⇒ suppression of small scales
- Suppression factor ⇔ Σm_ν
- Independent measurements (CMB, Galaxies, 1D Ly-α)
- Suppression is z-dependent

Ly-α:
- Access to small scales (max effect) +
- Large z-range [2.1 ; 4.5] +
- Caveat: non-linear regime and power spectrum of flux (not mass density) —

⇒ **Hydro/N body simulations**

1D Power Spectrum

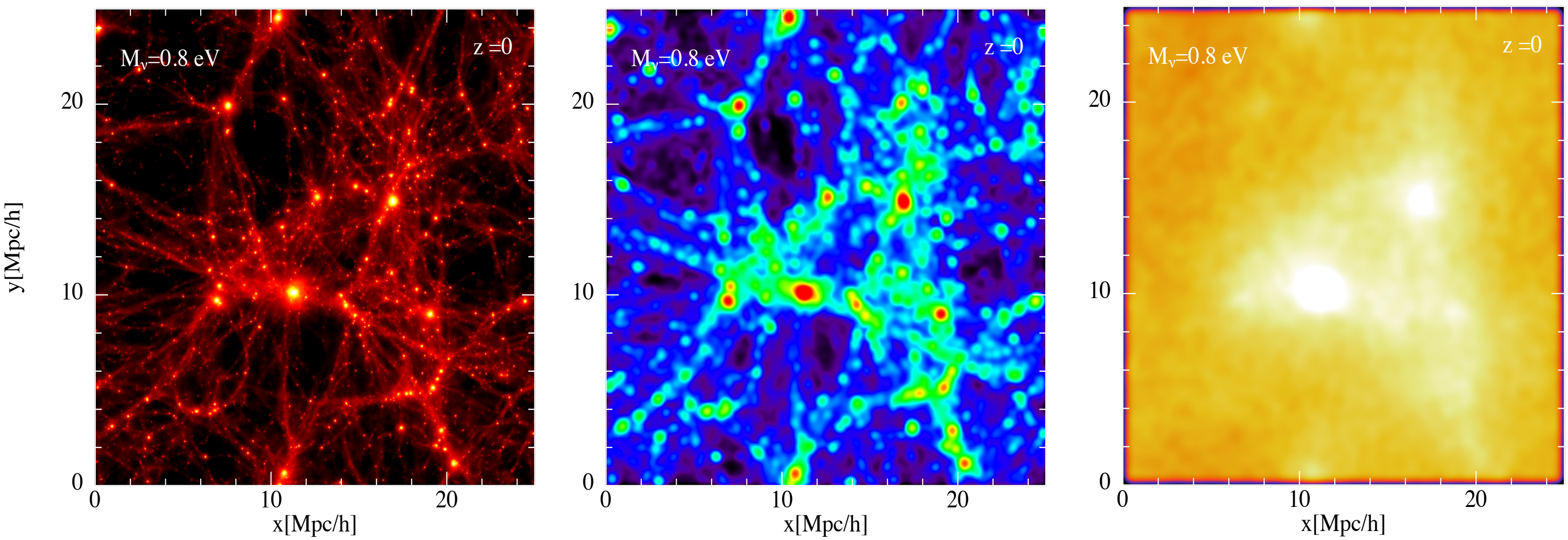


- First year of observation:
  14000 QSOs selected out of 60000
- Detailed study of spectrograph resolution, noise, lines of sky, correlation with other absorbers…
- Need simulations to come back to linear matter power spectrum

Hydro-dynamical simulations

- **3 Species:** dark matter + baryons
+ 3 degenerate-mass neutrinos
- **Methodology:**
  - Linear (CAMB) to z=30
  - Simulations from z=30 to z=2.0
  - Hydro/N-body simulations

Baryons   Dark matter   Neutrinos



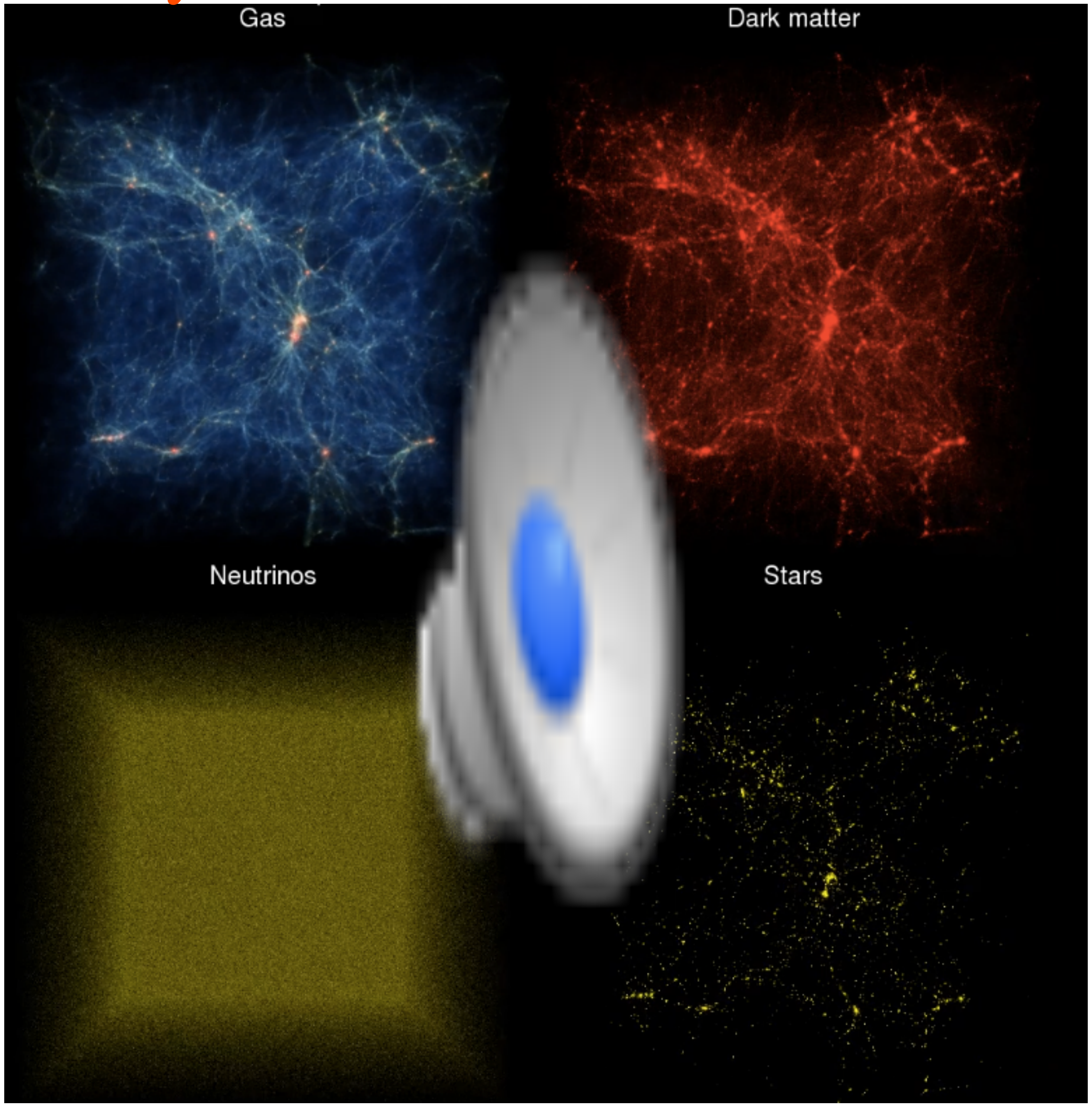
@ G. Rossi

Hydro-dynamical simulations

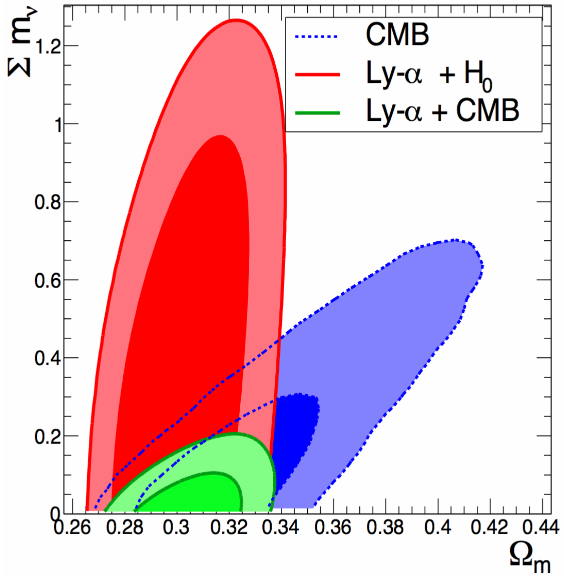
$z = 15 \rightarrow 0$

3 species
- Baryons
- Dark matter
- Neutrinos

Stars formed from baryons



Constraint on Σm_n



Limits:

- With Ly-α alone:
  $\Sigma m_\nu < 1.1$ eV @95%CL
- With CMB alone:
  $\Sigma m_\nu < 0.66$ eV @95%CL
- Combined with CMB (Planck 2013 + ACT + SPT + WMAP polarization)
  $\Sigma m_\nu < 0.15$ eV @95%CL

Parameter	Ly-α + $H_0^{gaussian}$ ($H_0 = 67.4 \pm 1.4$)	Ly-α + Planck	Ly-α + CMB	Ly-α + CMB + BAO
n_s	0.928 ± 0.012	0.958 ± 0.006	0.953 ± 0.005	0.954 ± 0.005
H_0 (km/s/Mpc)	67.2 ± 1.4	67.9 ± 1.0	68.0 ± 1.0	67.8 ± 0.5
$\sum m_\nu$ (eV)	< 1.1 (95%)	< 0.22 (95%)	< 0.15 (95%)	< 0.14 (95%)
σ_8	0.846 ± 0.039	0.822 ± 0.018	0.832 ± 0.009	0.837 ± 0.011
Ω_m	0.296 ± 0.017	0.296 ± 0.016	0.303 ± 0.014	0.308 ± 0.007

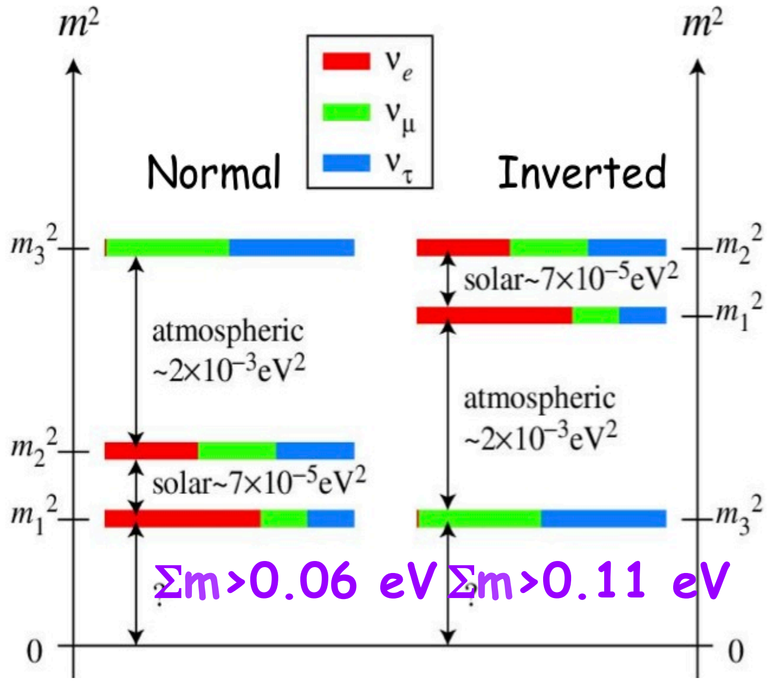
Neutrino mass hierarchy

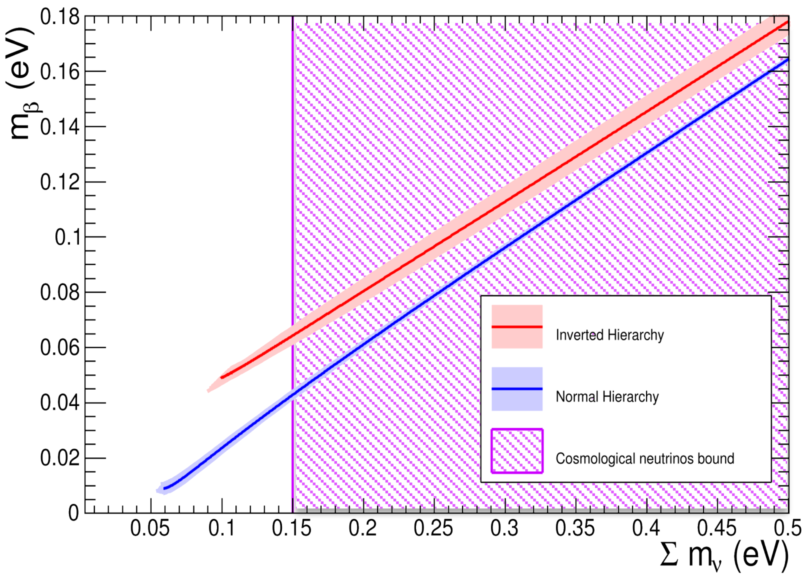
- Particle physics experiments measure the Δm^2 with mixing
- Cosmology measures Σm_ν
- Two possible ordering (NH / IH)

⟾ Measurement of absolute masses

Direct measurement with β-decays:

KATRIN: $^3H \longrightarrow {}^3He + e^- + \nu_e$





With Σm_ν < 0.15 eV @95%CL

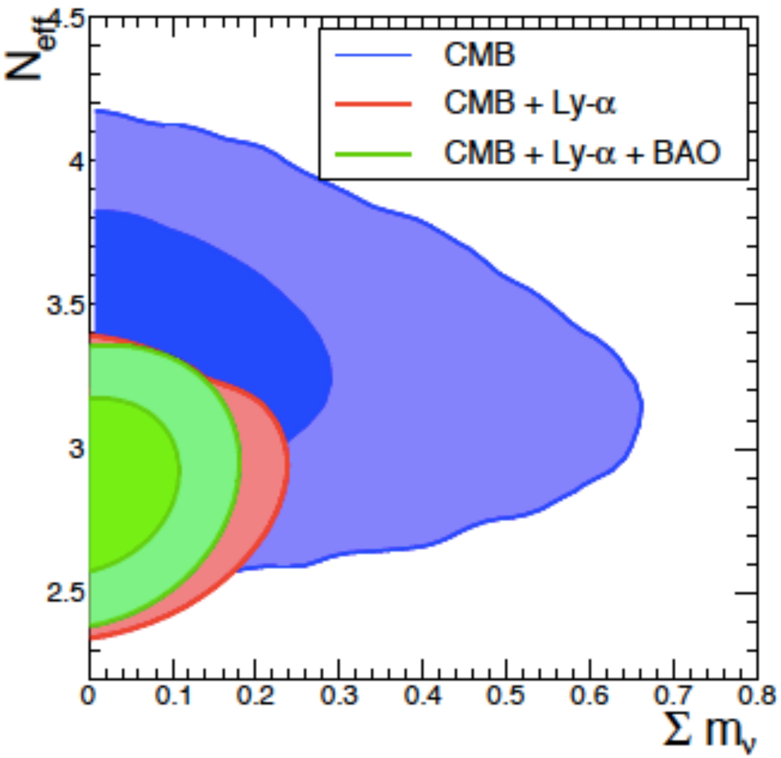
- NH is favored
- Prediction for m_β below KATRIN sensitivity : 0.2eV

Dark radiation - N_{eff}

$$\rho_R = \rho_\gamma + \rho_\nu = \left[1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right]\rho_\gamma$$

Sensitivity to the number of neutrino species

- Full degeneracy in Lya data alone
- Constraint when combining Lya and CMB

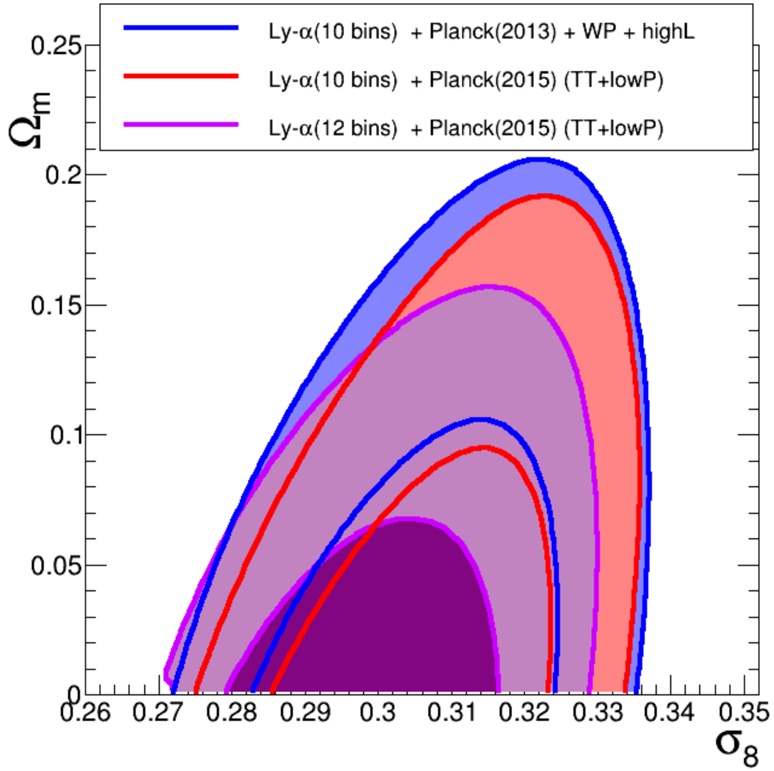


$N_{eff} = 2.91\ ^{+0.21}_{-0.22}$ (95% CL)

$\Sigma m_\nu < 0.15$ eV (95% CL)

$\Rightarrow N_{eff} = 4$ excluded at $> 5\sigma$

The future is already here! Results with Planck 2015



Limits on Σm_ν

- Ly-α with Planck 2013 + ACT + SPT + WMAP polarization)
  Σm_ν <0.15 eV @95%CL
- New Ly-α analysis with Planck 2015
  Σm_ν <0.11 eV @95%CL

New research fields:

- WDM with sterile neutrinos
- Inflation with n_s running