# Some remarks about precision cosmology

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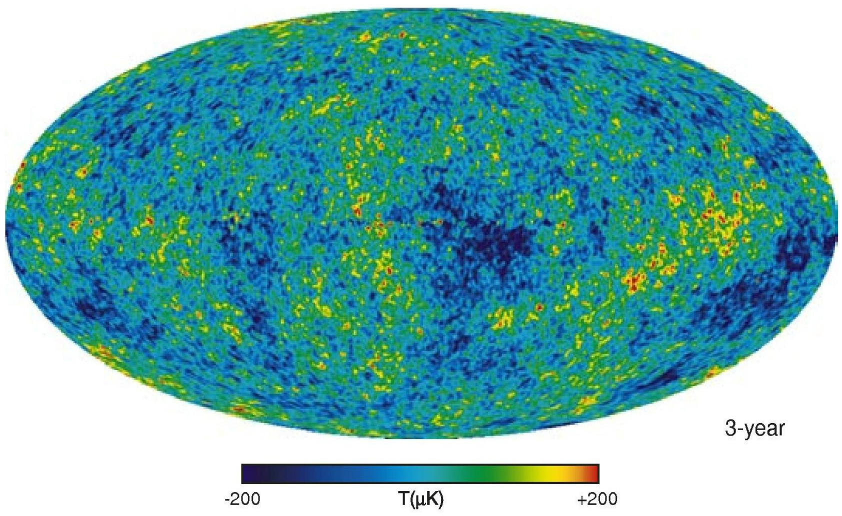
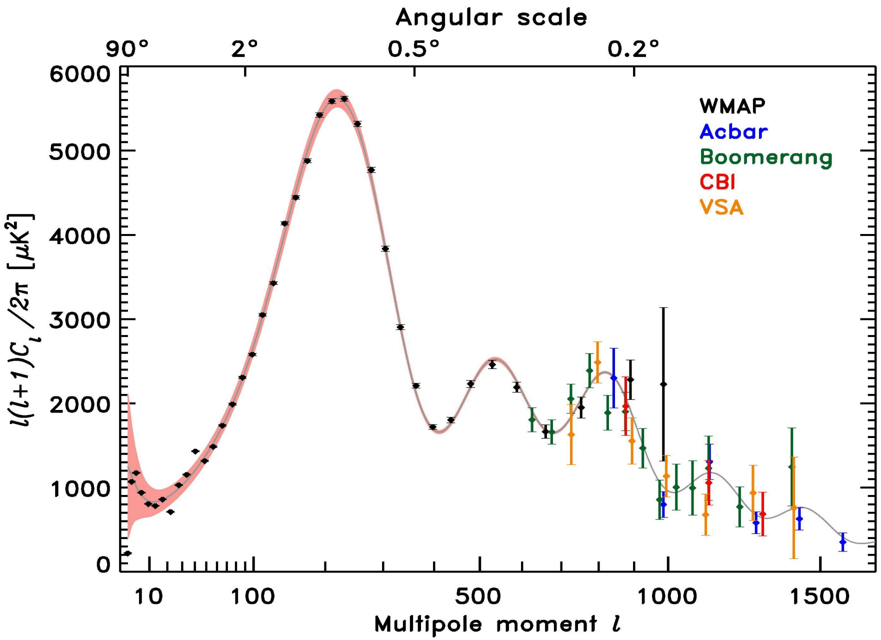
# Disclaimer...

- This talk is **not** about neutrino mass bounds from cosmology.
  - Go to S. Pastor's lectures.
- ... rather some hints on how to interpret cosmological parameter estimates and errors.
  - Why you should always use them with caution.

# Precision cosmological probes...

- **Cosmic microwave background (CMB) anisotropies:**

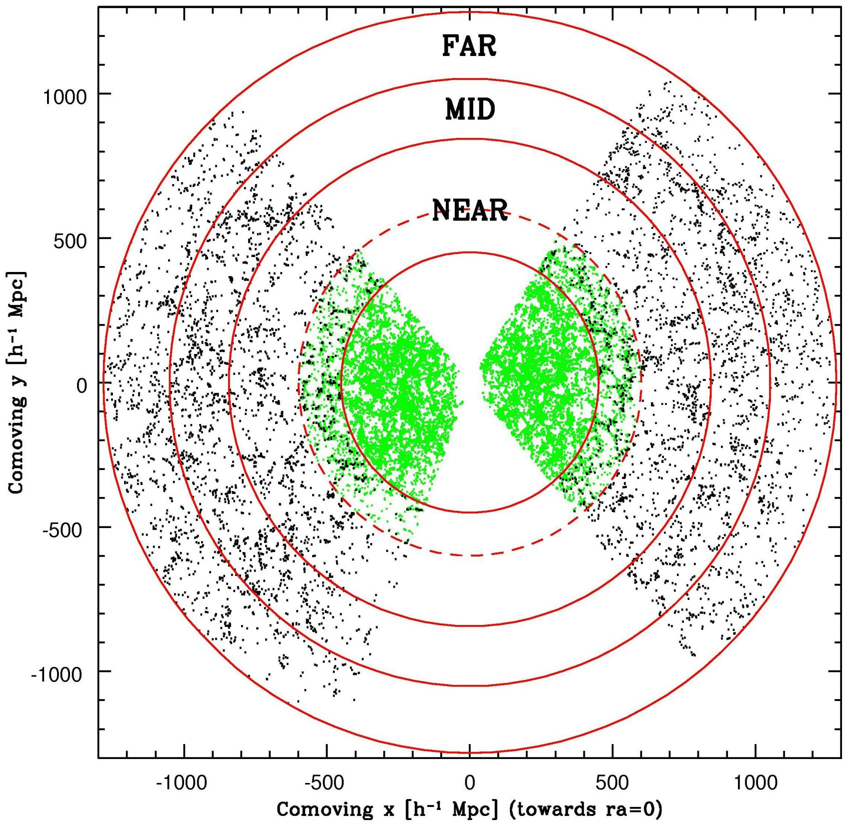


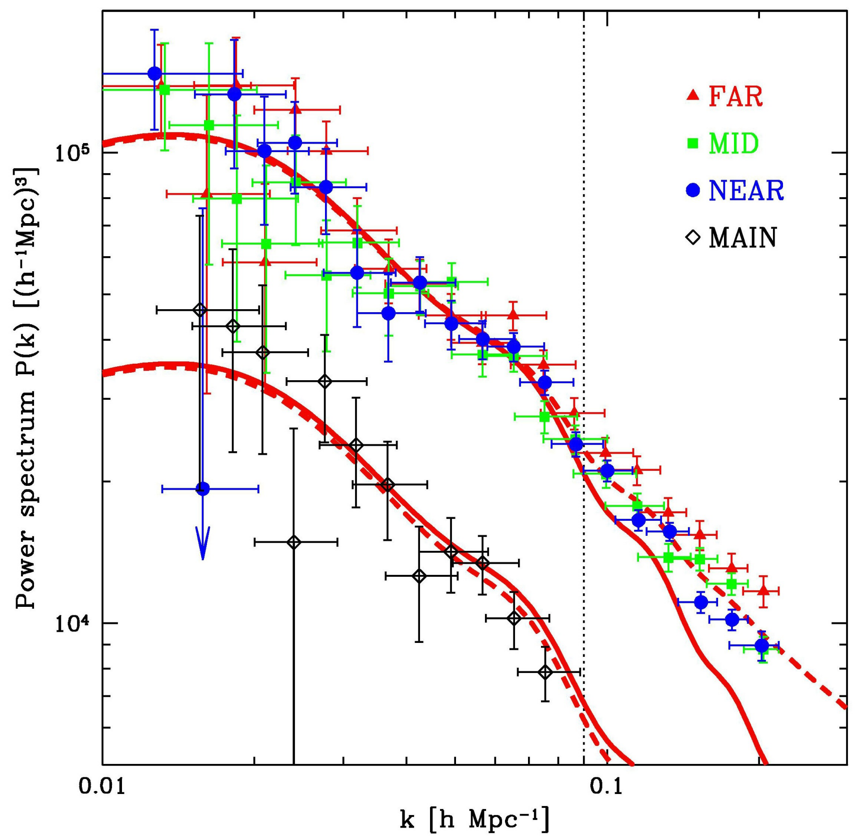




[Hinshaw et al. (WMAP) 2006]

# Precision cosmological probes...

- **Large-scale structure (LSS) power spectrum:**

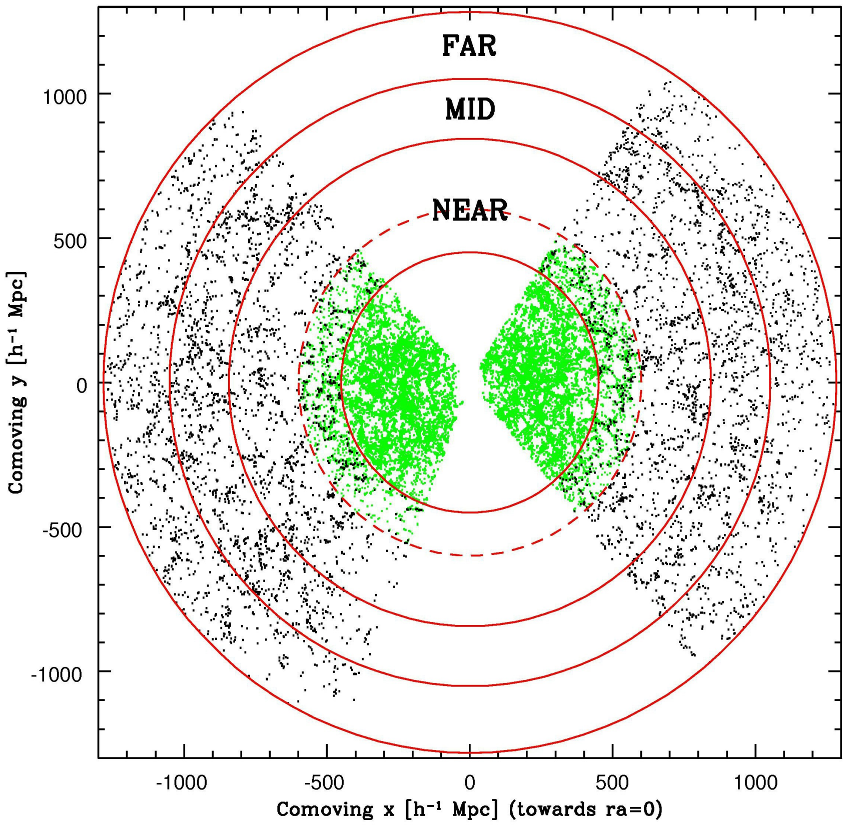


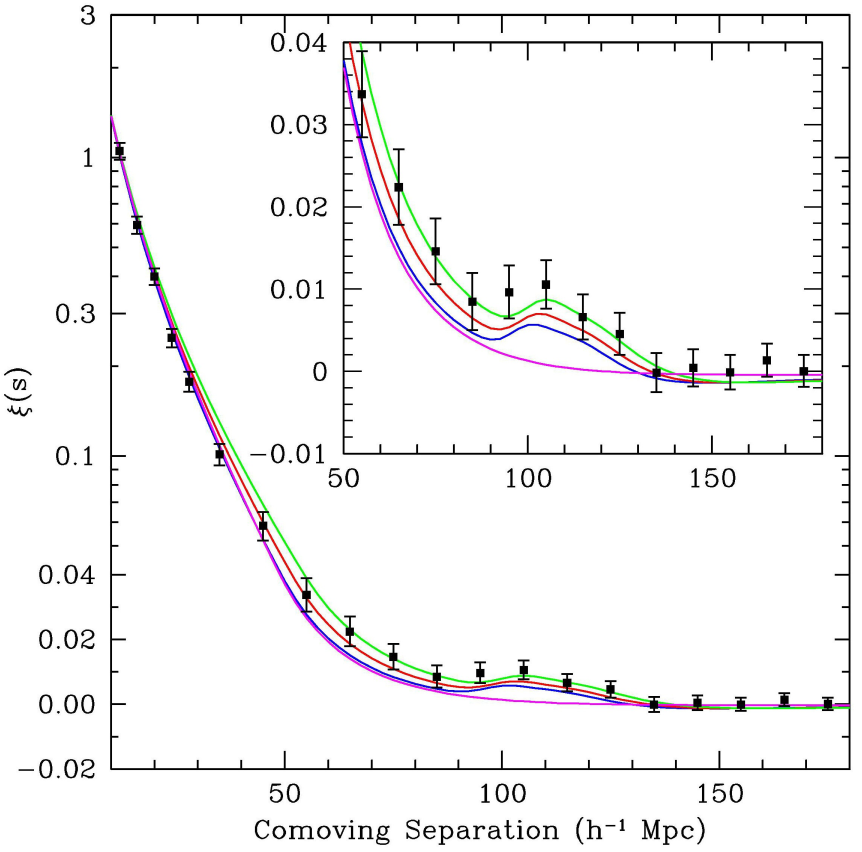




[Tegmark et al. (SDSS) 2006]

# Precision cosmological probes...

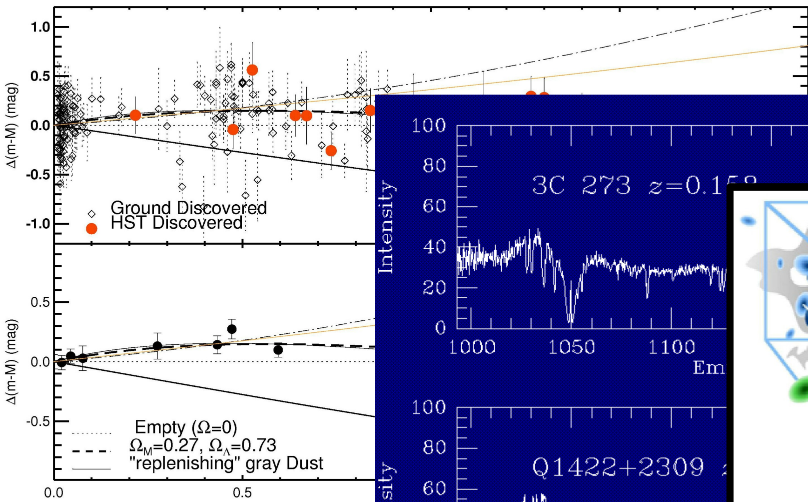
- **Baryon acoustic oscillations (BAO) peak:**



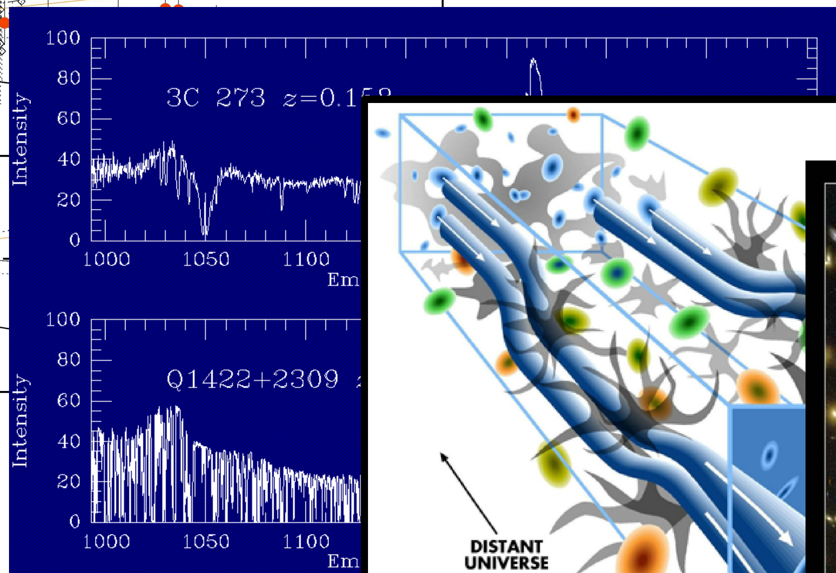




[Eisenstein et al. 2004]

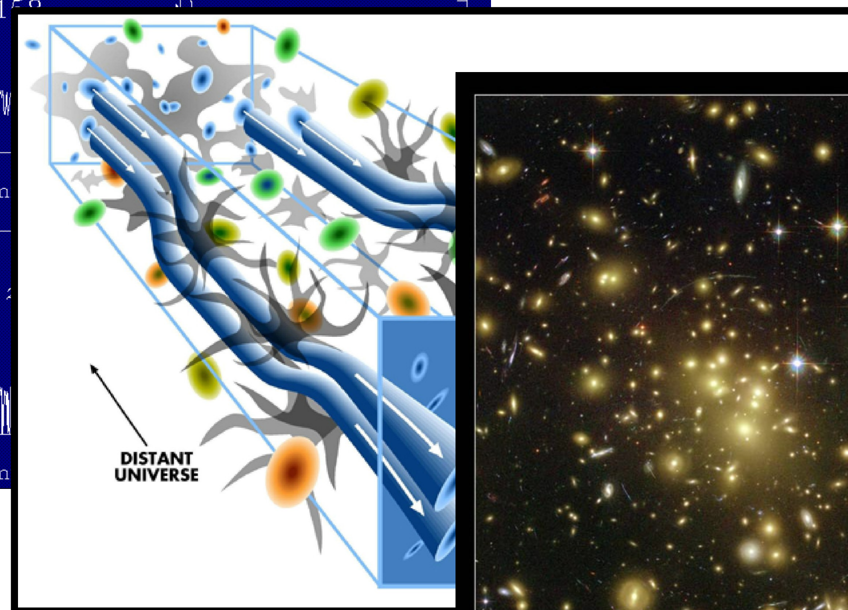
# Precision cosmological probes...



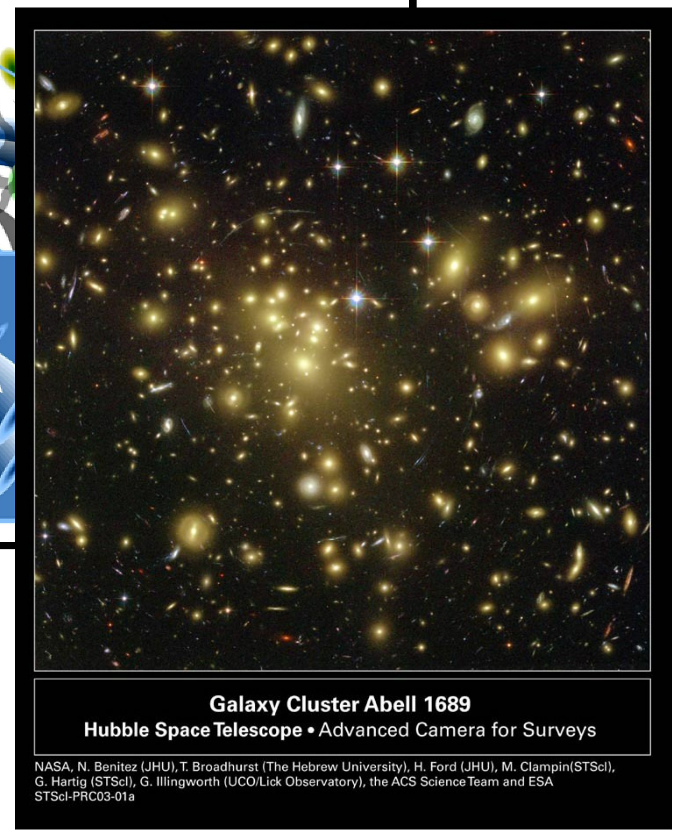

Supernova Ia




Lyα forest




Weak lensing




Strong lensing

# Cosmological model...

- **Six "vanilla" parameters + spatial flatness give a reasonable description of all data.**

| | CMB (+LSS) |
|---|---|
| – Baryon density, $\Omega_b h^2$=0.0222 | ± 4% (3%) |
| – Matter density (baryon+DM), $\Omega_m h^2$=0.127 | ± 8% (3%) |
| – Hubble parameter, h=0.7 | ± 5% (3%) |
| – Scalar perturbation spectral index, $n_s$=0.95 | ± 2% (2%) |
| – Fluctuation amplitude, $\sigma_8$=0.74 | ± 7% (5%) |
| – Optical depth to reionisation, $\tau$=0.09 | ± 30% (30%) |

[Spergel et al. (WMAP) 2006; Tegmark et al. (SDSS) 2006]

***"Vanilla rules OK."*** [Tegmark et al. (SDSS) 2006]

# Why vanilla...

- **Vanilla = a *minimal* set of parameters that describe the data.**
- **Many more parameters can affect cosmology, but...**
  - ...discarded because of no “substantial” improvement in the goodness-of-fit.

| | $\Delta\chi^2$ w.r.t. vanilla CMB (+LSS) |
|---|---|
| • Nonzero spatial curvature | -2.0 (0.0) |
| • Massive neutrinos | -1.0 (-0.5) |
| • Dark energy equation of state, w≠-1 | -1.0 (-0.9) |
| • Primordial gravity waves/tensors | 0.0 (-0.5) |
| • Running spectral index | -3.6 (-2.4) |

[Tegmark et al. (SDSS) 2006]

→ Occam's razor: less is better.

# Why NOT vanilla...

- **Where do you draw the line?**
  - What $\Delta\chi^2$ is "large enough"?
- **Vanilla ≠ a physical model.**
  - Product of a data modelling exercise.
  - Not guaranteed to make physical sense, e.g.,
    - Finite neutrino mass. [not a vanilla parameter]
- **A lot of assumptions about what we don't know!**

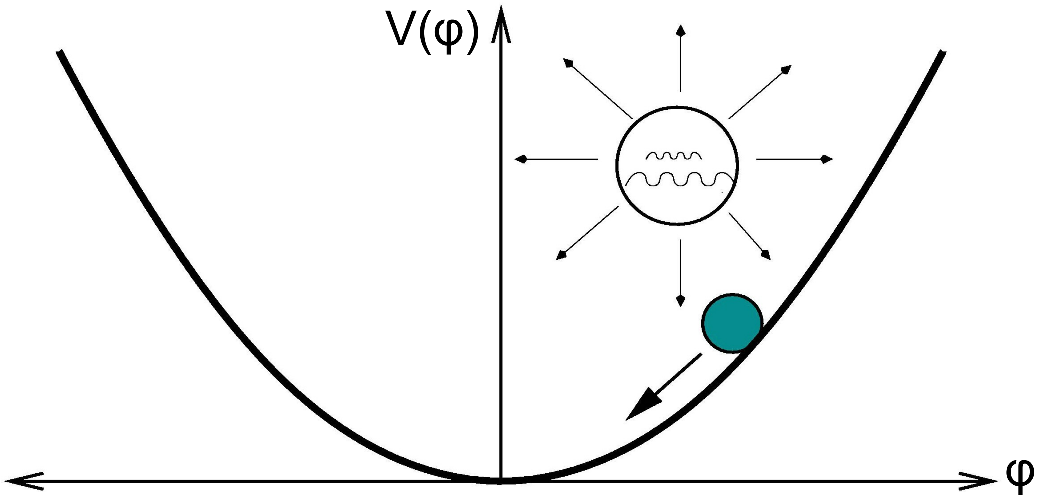
→ Artificially small parameter errors.

→ Misleading constraints on *fundamental physics*.

# Why NOT vanilla...

- Example 1: **inflation models.**
- Example 2: **dark matter density.**
- Example 3: **neutrino mass.**
- Example 4: **dark energy parameters.**

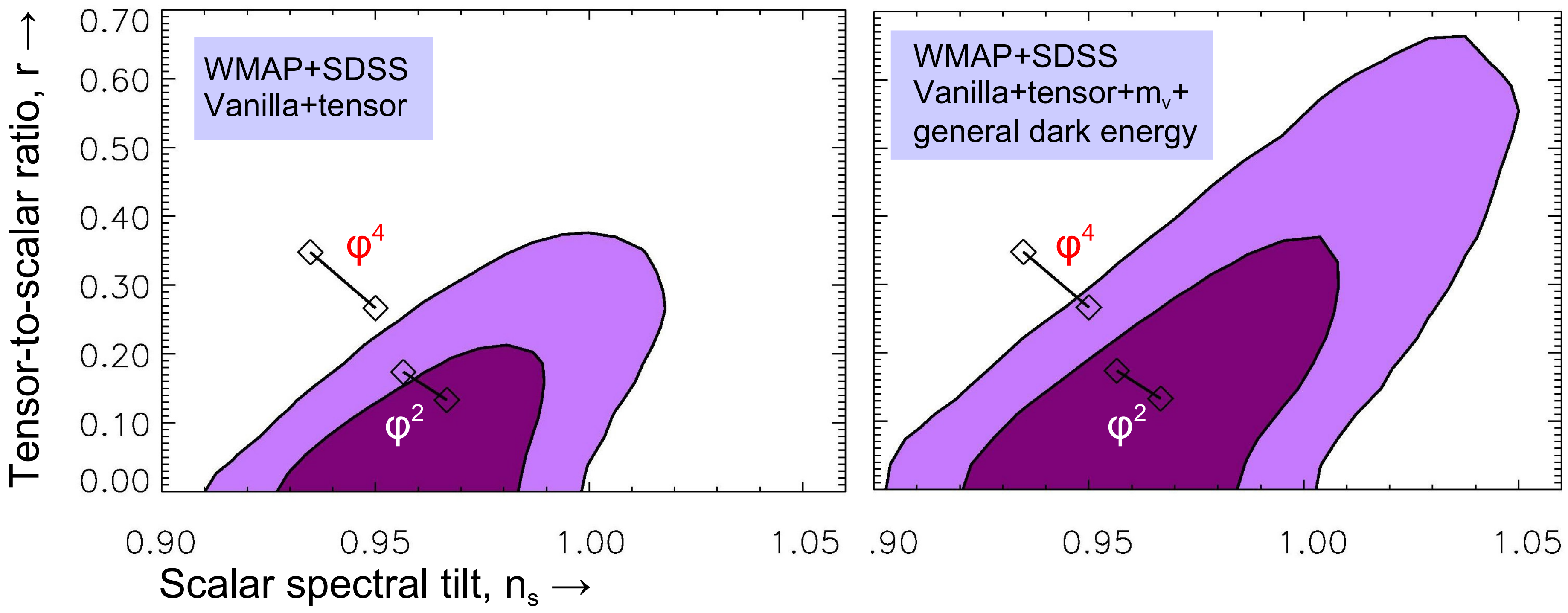
# Example 1: inflation models...




- **Inflation generates two fluctuation spectra:**
  - Scalar fluctuations ↔ matter density perturbations.
  - Tensor fluctuations ↔ gravity waves.
- **Spectral shapes and amplitudes depend on V(φ).**

→ Spectral tilt and tensor-to-scalar ratio as model identifiers.

- **Large field chaotic inflation, $V(\varphi) \sim \varphi^{\alpha}$:**




- **$\varphi^4$ is OK!!** [Hamann, Hannestad, Sloth & Y$^3$W 2006]
  - Contrary to previous conclusions.
    [e.g., Spergel et al. 2006; Tegmark et al. 2006; Kinney, Kolb, Melchiorri & Riotto 2006; etc]
  - If $\varphi^4$ is the true model of inflation, then $\Sigma m_\nu = 0.3 \rightarrow 0.5$ eV.

# Example 2: dark matter density...

- Vanilla, WMAP+SDSS:

$$\mathbf{0.097 < \Omega_{CDM}h^2 < 0.113 \quad (95\%\ C.L.)}$$

[Tegmark et al. (SDSS) 2006]

- Vanilla+($r,m_\nu,w,\Omega_k,\alpha_s$), WMAP+SDSS+SNIa+BAO:

$$\mathbf{0.094 < \Omega_{CDM}h^2 < 0.136 \quad (95\%\ C.L.)}$$

[Hamann, Hannestad, Sloth & $Y^3$W 2006]

→ Factor of two difference in the allowed ranges!!

(How many dark matter models have we saved?)

# Example 3: neutrino mass...

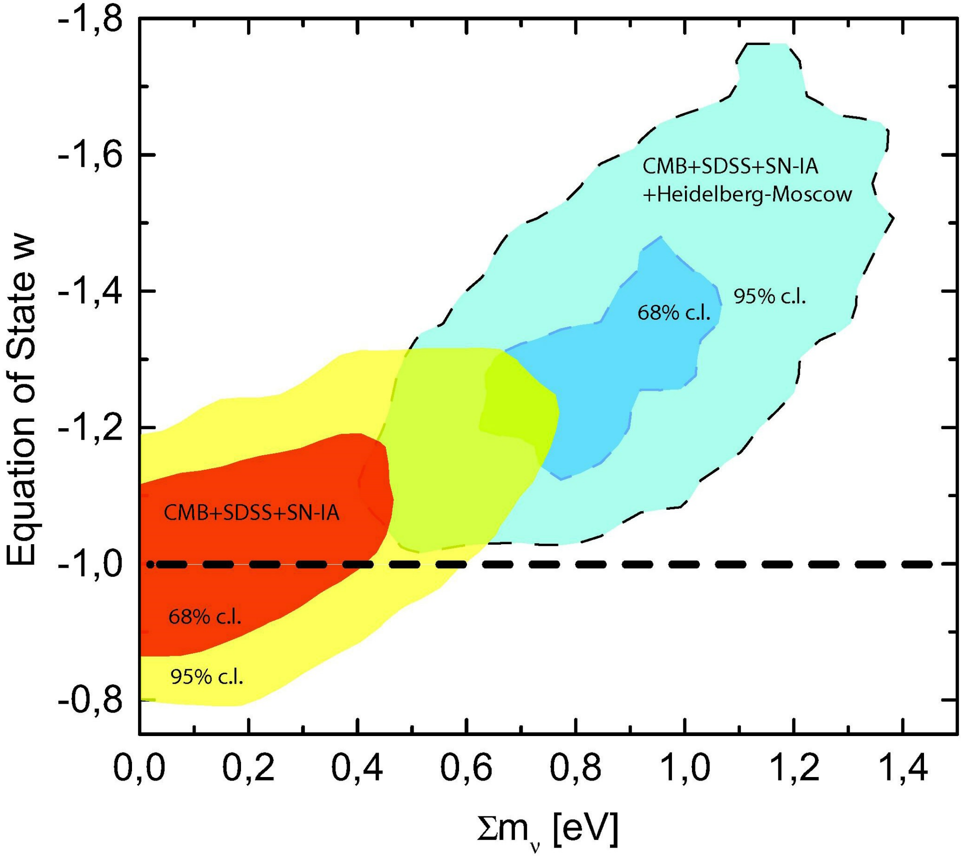
95% C.L. bounds on $\Sigma m_\nu$

| | vanilla+($m_\nu$,$N_\nu$,w,$\alpha_s$) | vanilla+$m_\nu$ |
|---|---|---|
| CMB+LSS+SNIa | **1.72 eV** | 0.70 eV |
| CMB+LSS+SNIa+BAO | **0.62 eV** | 0.48 eV |
| CMB+LSS+Lyα | **0.83 eV** | 0.35 eV |
| CMB+LSS+Lyα+BAO | **0.49 eV** | 0.27 eV |

[Goobar, Hannestad, Mörtsell & Tu, 2006]

# Example 4: dark energy parameters...

- **If the Heidelberg-Moscow 0νββ claim is correct [$0.43<m_\nu/\mathrm{eV}<0.81$ (2σ)], then...**




- CMB+SDSS+SNIa+HM:

**$-1.67 < w < -1.05$ (2σ).**

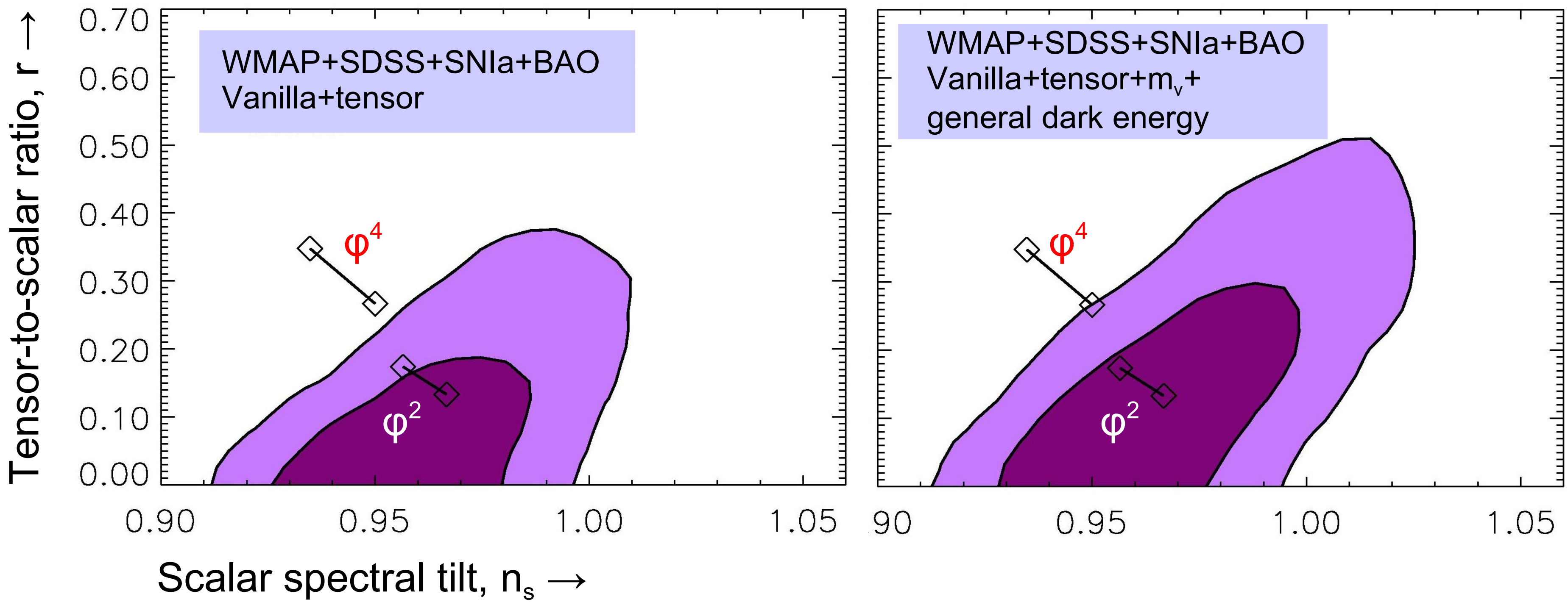
→ Cosmological constant is disfavoured at 95% C.L.!

[De La Macorra, Melchiorri, Serra & Bean 2006]

# Summary...

- **Cosmological parameter estimates and errors are model dependent.**
  - Many published limits are derived under very restrictive conditions which may not be physically well-motivated.
- **Use limits with extreme caution.**
  - Read the fine prints.
  - Do not over-interpret limits.
  - When in doubt, use the most conservative limits available.
- **We have “saved” a class of inflation models, by including uncertainties in the neutrino mass and dark energy.**

- **Large field chaotic inflation, $V(\varphi) \sim \varphi^\alpha$:**

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