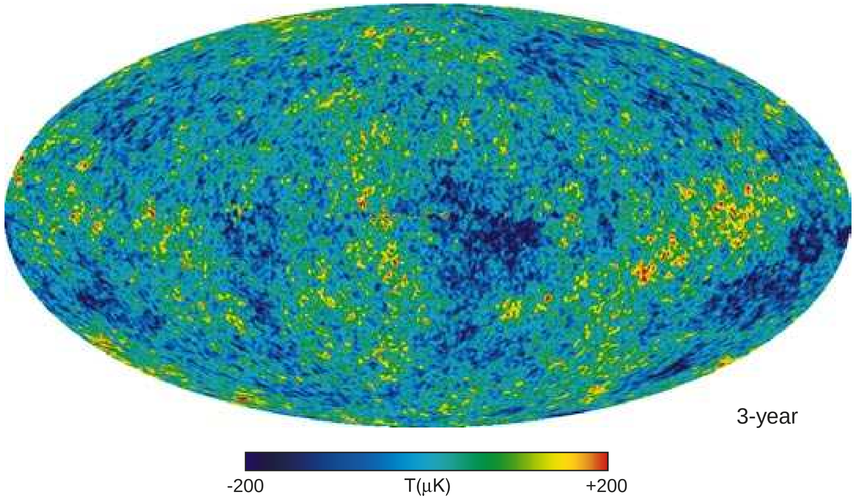
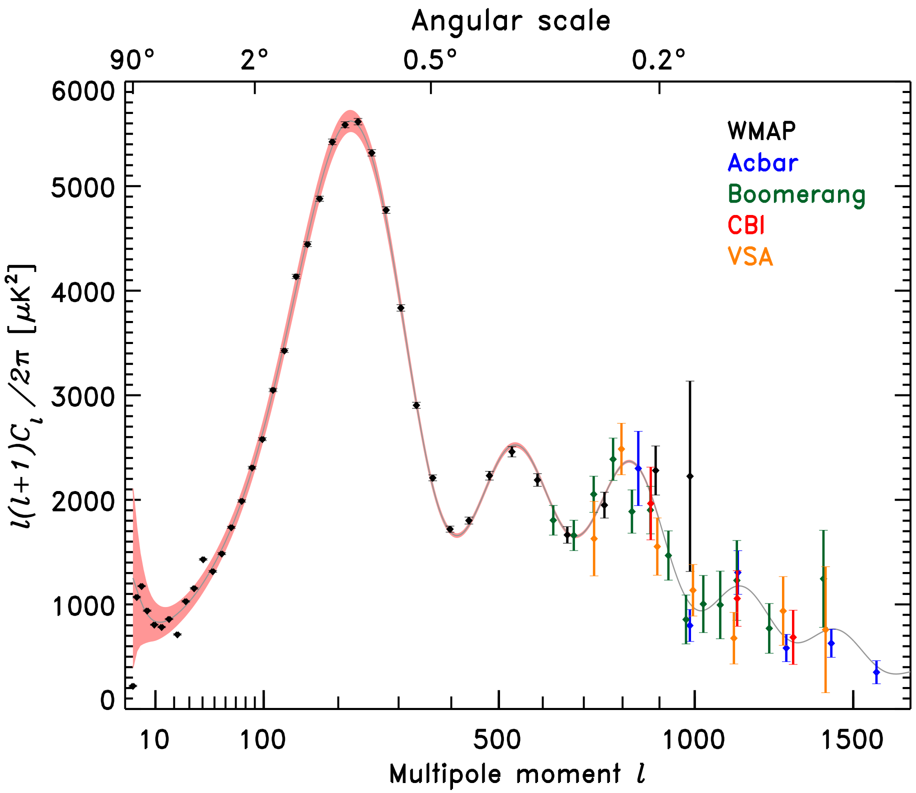
Neutrinos and precision cosmology

Yvonne Y. Y. Wong

Precision cosmological probes . . .

Cosmic microwave background (CMB) anisotropies

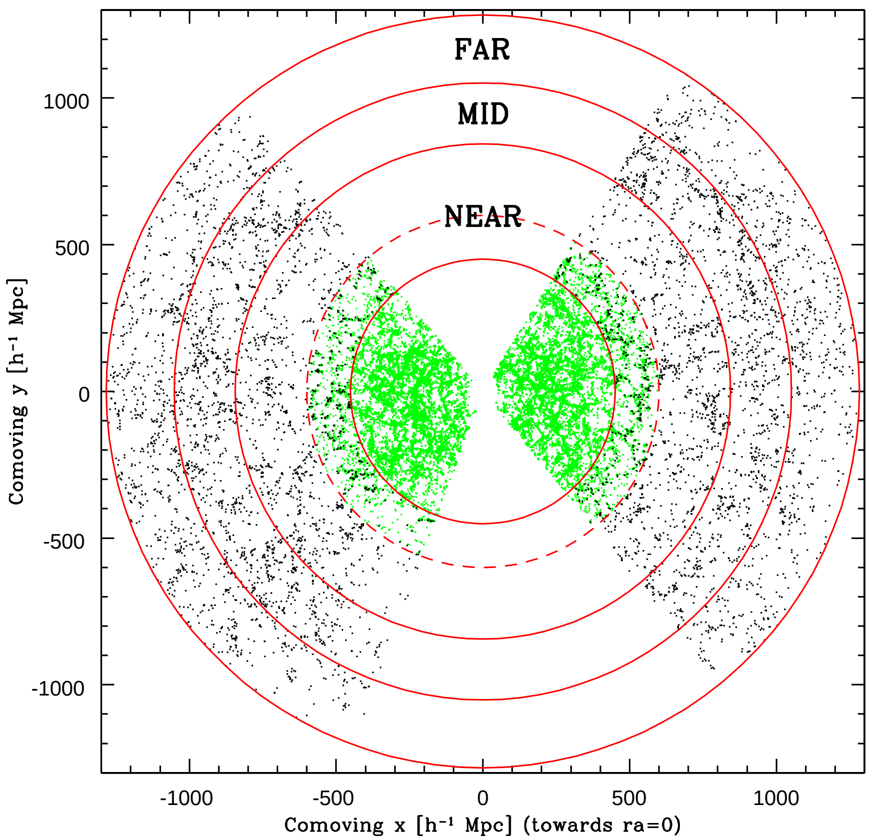


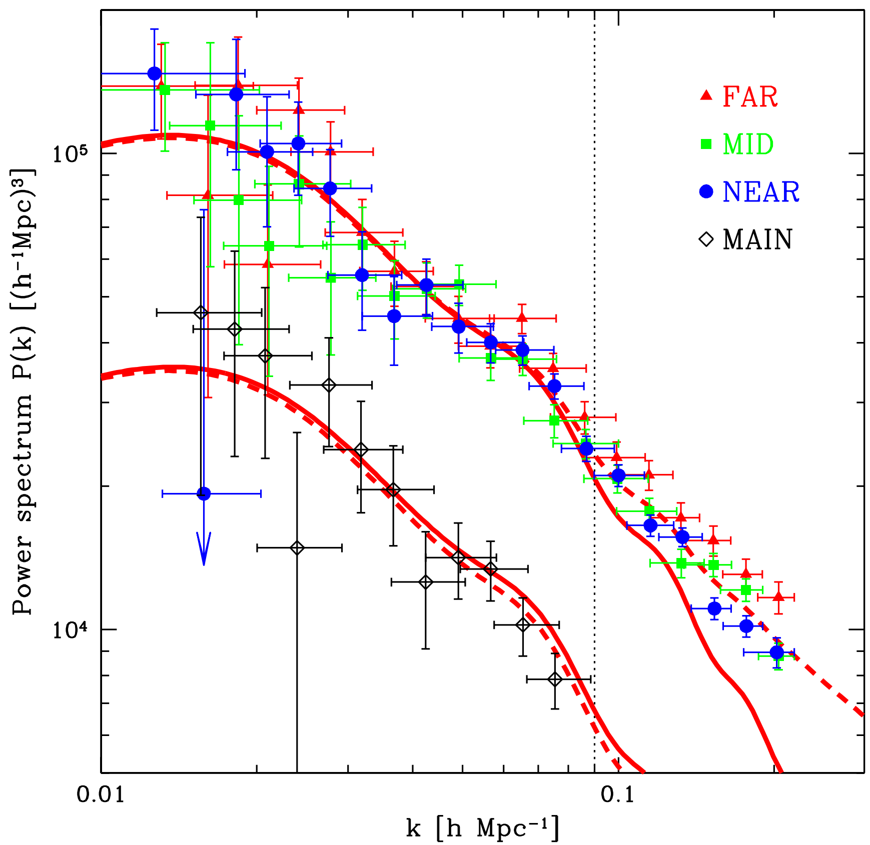


[Hinshaw et al. (WMAP collaboration), 2006]

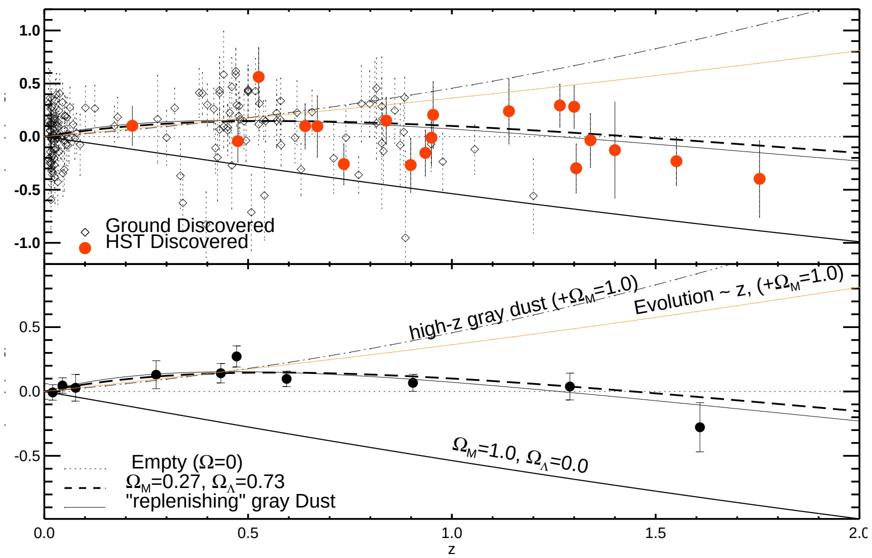
Precision cosmological probes . . .

Large-scale structure (LSS) power spectrum

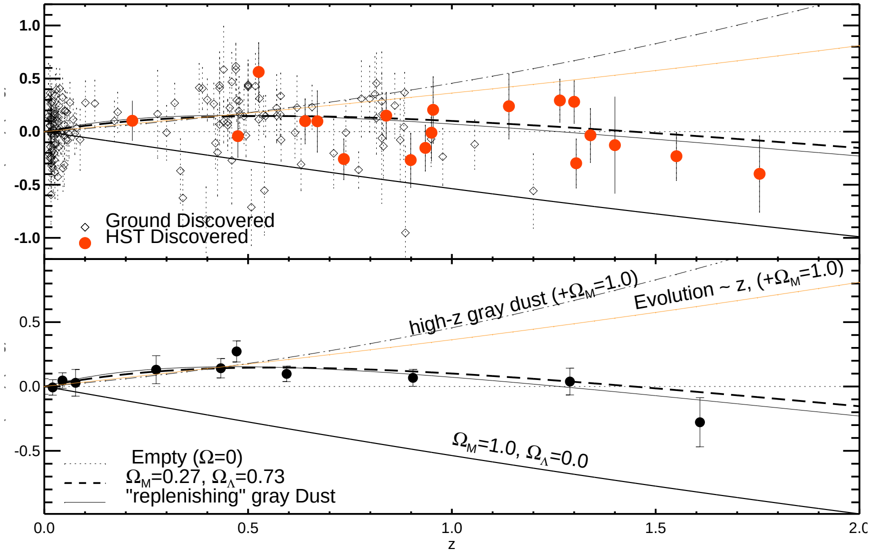




[Tegmark et al. (SDSS collaboration), 2006]



[Riess et al. (Supernova Search Team), 2004]



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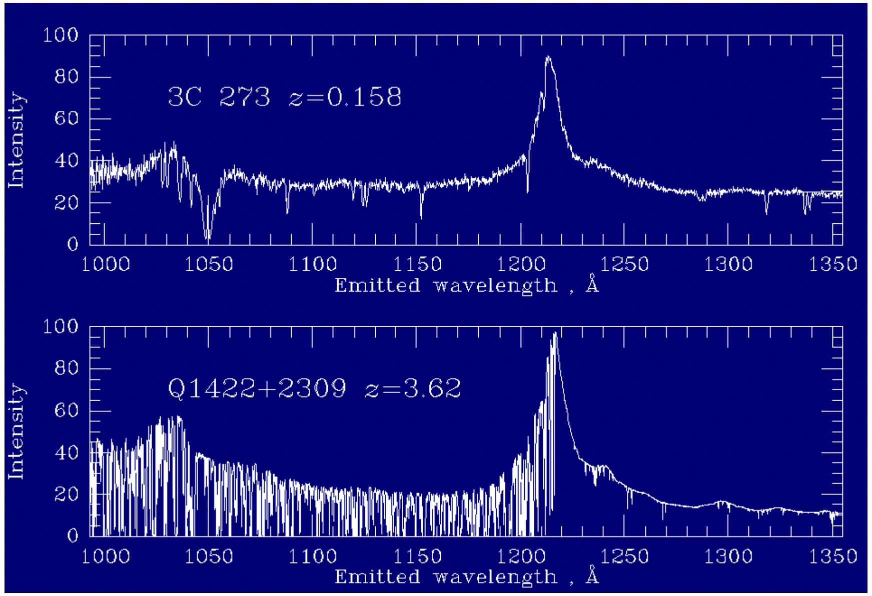
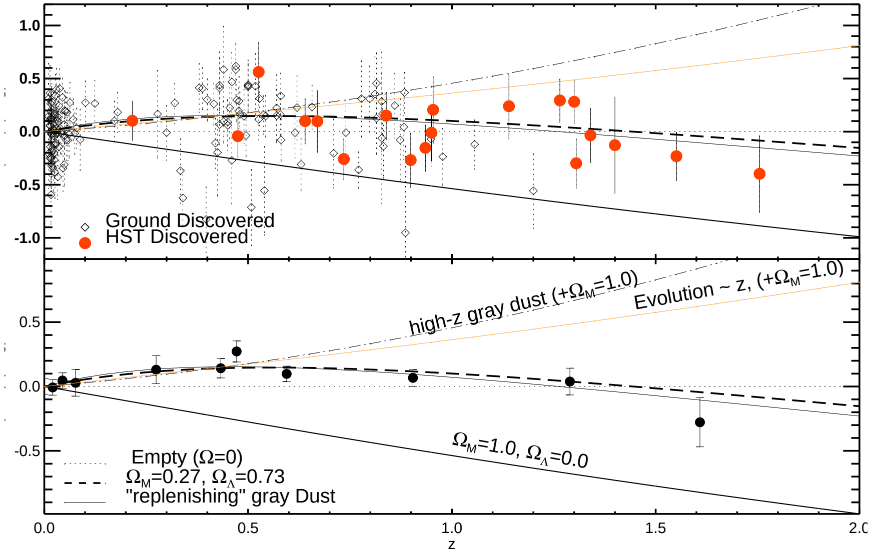


[www.astr.ua.edu/keel/agn/]



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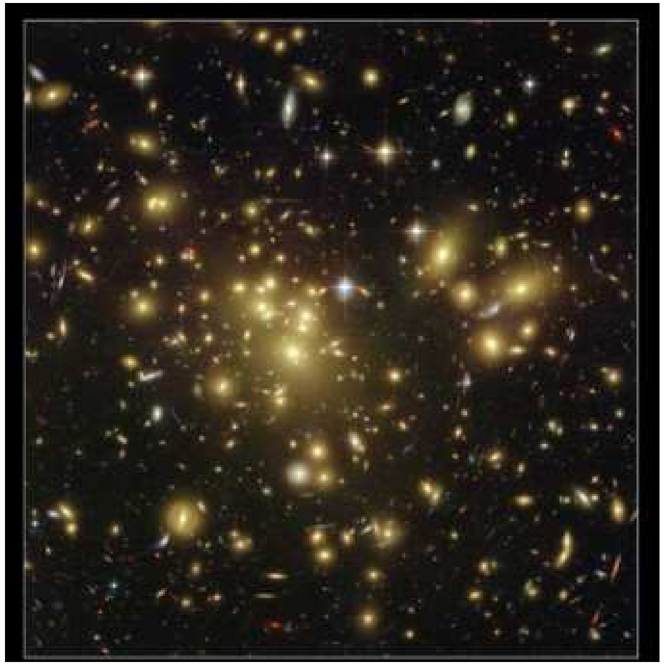

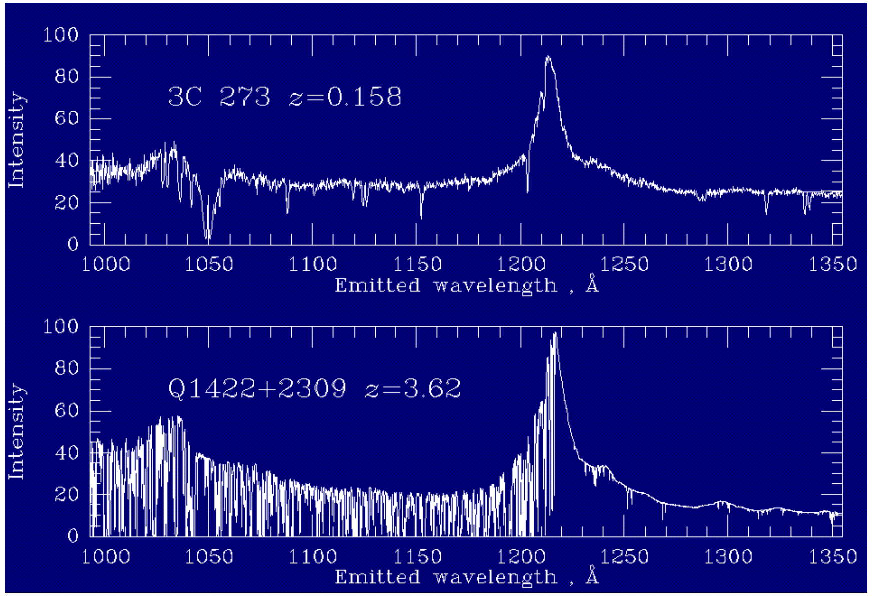

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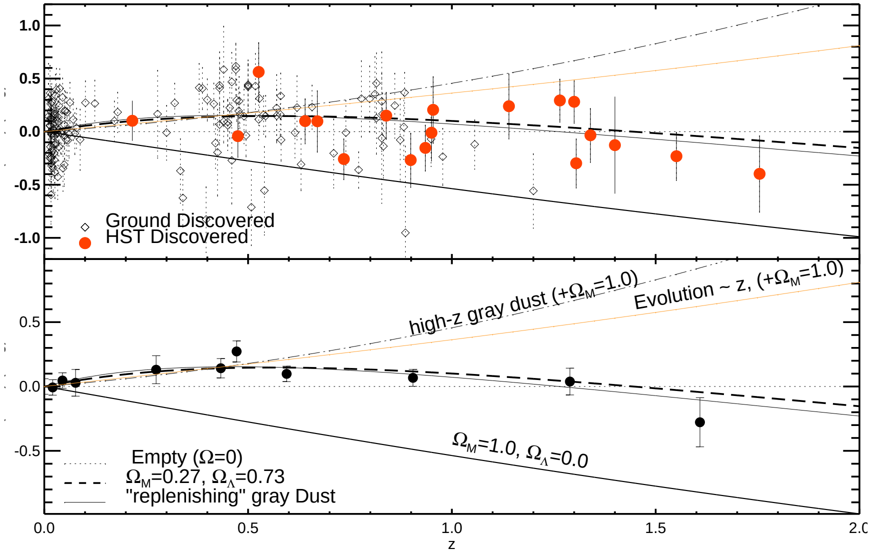

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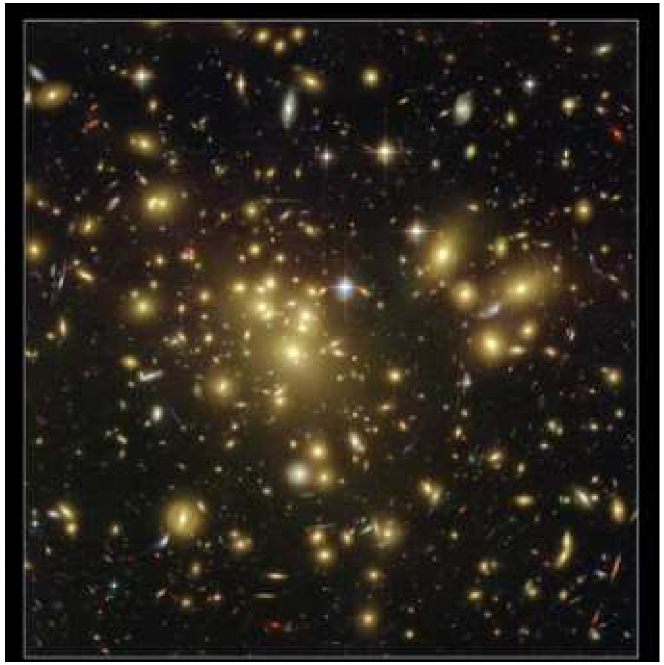
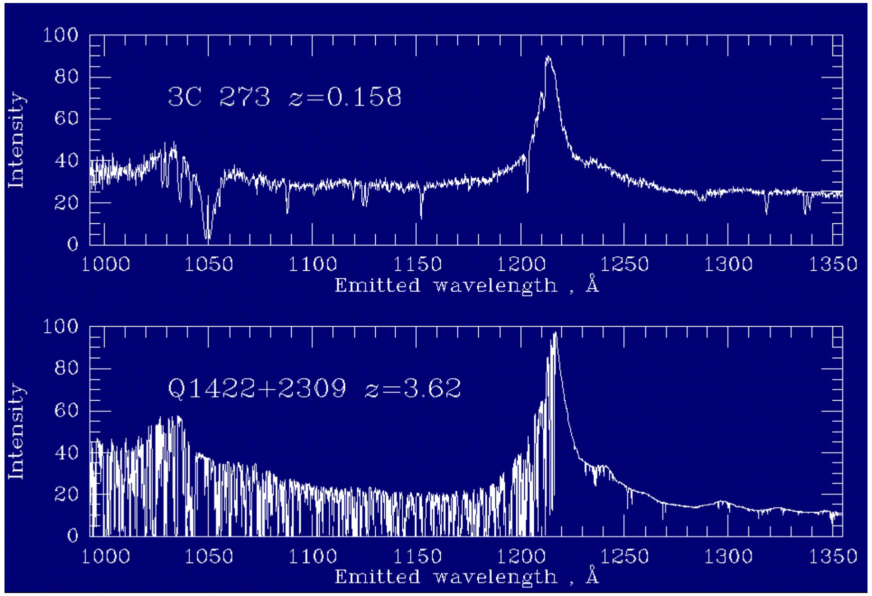
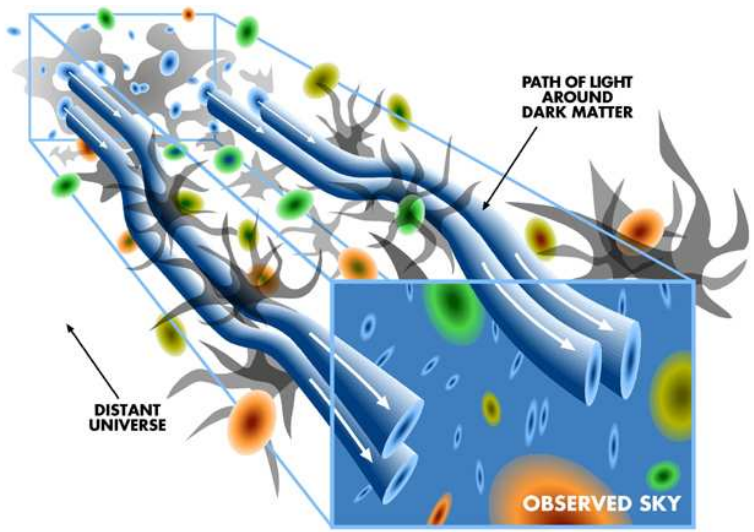






[www.astr.ua.edu/keel/agn/]

Cosmological model ...

Six "vanilla" parameters give a reasonable description of all data.

	CMB	(+LSS)
• Baryon density, $\Omega_b h^2 = 0.0222$.	$\pm$ 4 %	(3 %)
• Matter density (dark matter+baryon), $\Omega_m h^2 = 0.127$.	$\pm$ 8 %	(3 %)
• Hubble parameter, $H_0 = 0.73$.	$\pm$ 5 %	(3 %)
• Scalar perturbation spectral index, $n_s = 0.954$.	$\pm$ 2 %	(2 %)
• Fluctuation amplitude, $\sigma_8 = 0.74$.	$\pm$ 7 %	(5 %)
• Optical depth to reionisation, $\tau = 0.09$.	$\pm$ 30 %	(30 %)

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

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

The vanilla myth ...

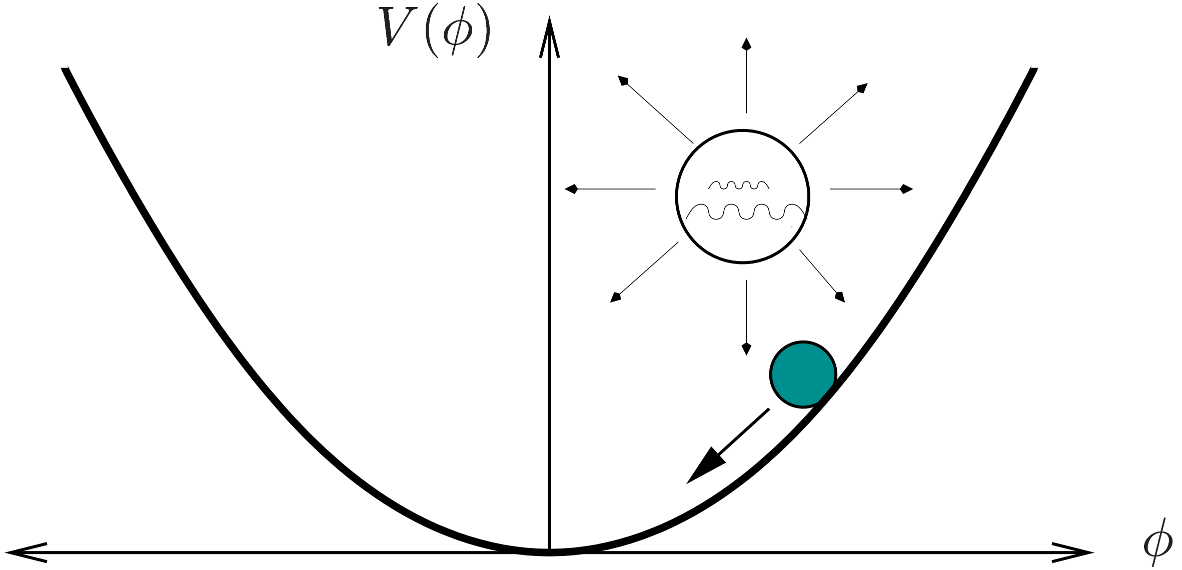
- Vanilla assumptions:
  - Zero spatial curvature. JUSTIFIABLE (inflation)
  - Adiabatic initial conditions. JUSTIFIABLE (single-field inflation)
  - Cold dark matter. JUSTIFIABLE (small-scale structures)
  - Cosmological constant, $w = -1$. BARELY ACCEPTABLE
  - Known helium fraction, $Y_{\rm He} = 0.24$. BARELY ACCEPTABLE
  - No primordial gravity waves, $r = 0$. BAD IDEA (inflation)
  - Massless neutrinos, $m_\nu = 0$. VERY BAD IDEA
  - et cetera.

Bad assumptions = Artificially tight bounds + Biased estimates.

$\Downarrow$

Bad for constraining *fundamental physics*.

Example: inflation models . . .



- Inflation generates two fluctuation spectra:
  - Scalar fluctuations $\Rightarrow$ Matter density perturbations.
  - Tensor fluctuations $\Rightarrow$ Primordial gravity waves.

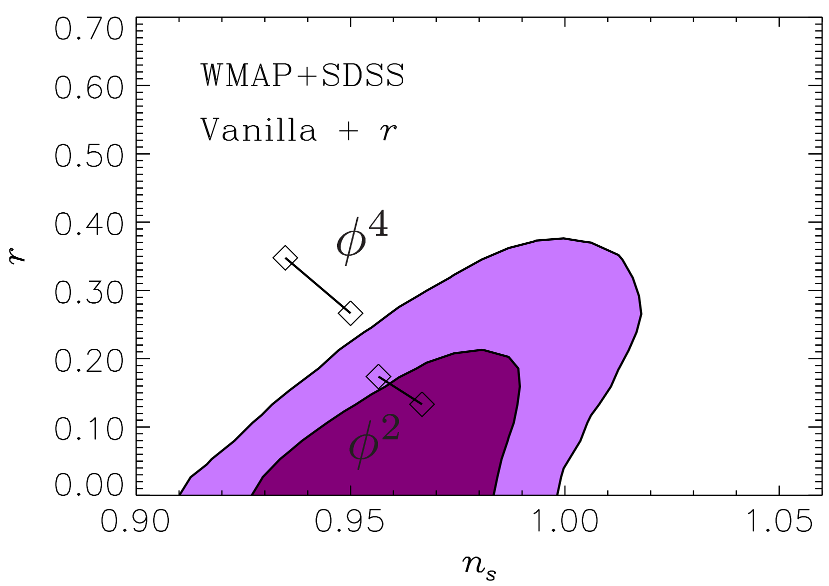
- Spectral shape and amplitude depend on $V(\phi)$.

$\Rightarrow$ **Spectral tilt and tensor-to-scalar ratio as model identifiers.**

Large-field chaotic inflation, $V(\phi) \propto \phi^\alpha$

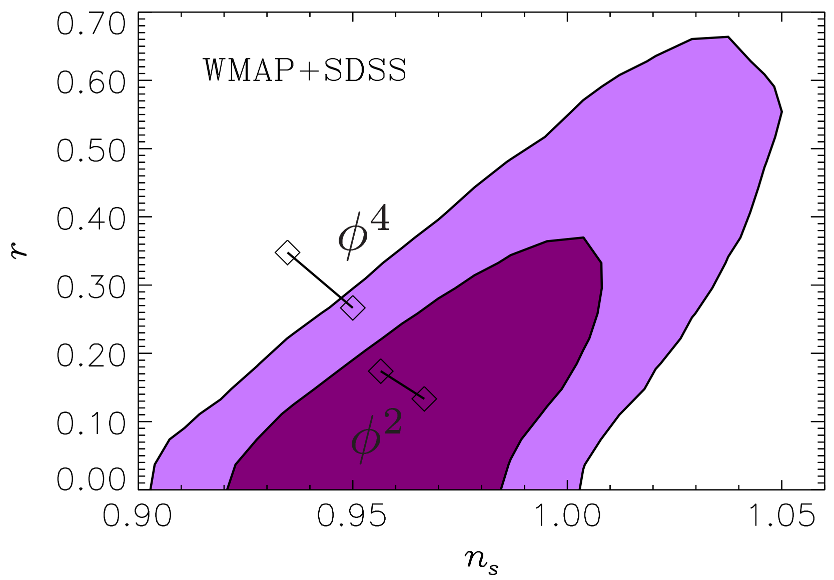
Tensor-to-scalar ratio ⟶

Vanilla+tensor



Scalar spectral tilt ⟶

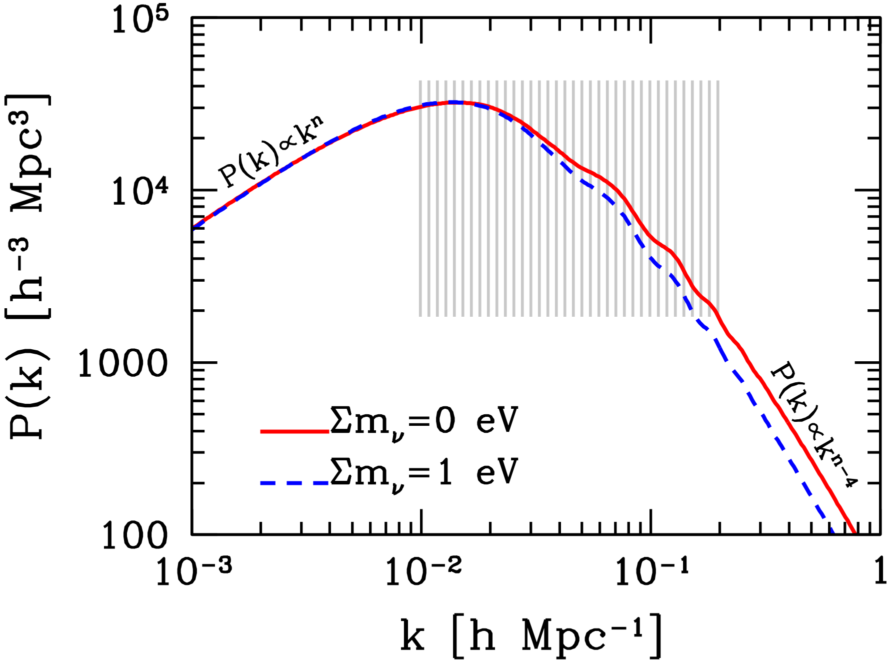
Vanilla+tensor+m_ν+ general dark energy



⇒ ϕ^4 is OK. [Hamann, Hannestad, Sloth & Y^{3}W, 2006]

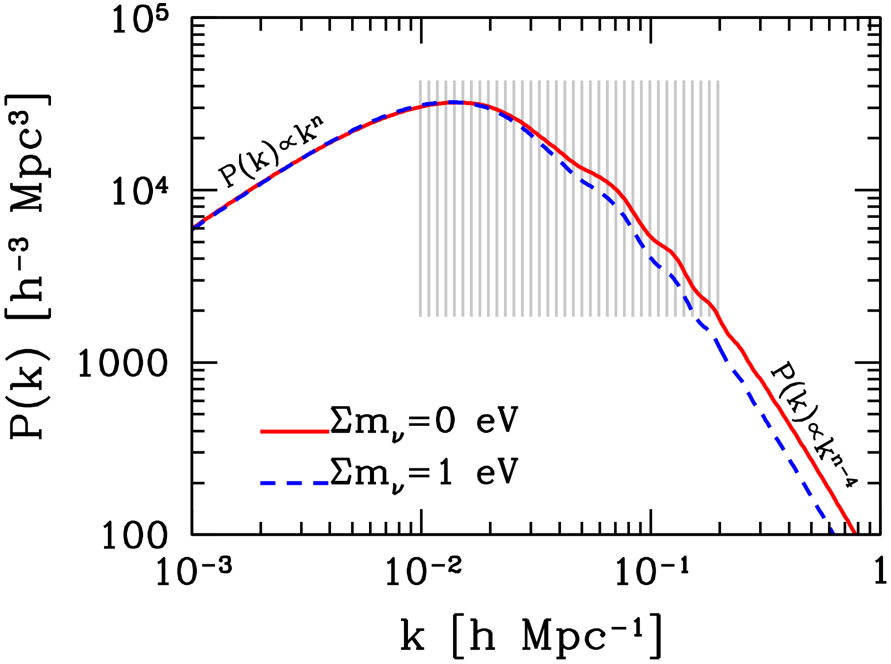
- Contrary to previous conclusions. [e.g., Spergel et al., 2006; Tegmark et al., 2006; Kinney, Kolb, Melchiorri & Riotto, 2006; Easther & Peiris, 2006; Martin & Ringeval, 2006; Finelli, Rianna & Mandolesi, 2006; etc.]
- Corresponding limit on neutrino mass: $\sum m_\nu < 0.6$ eV.

How does it happen?

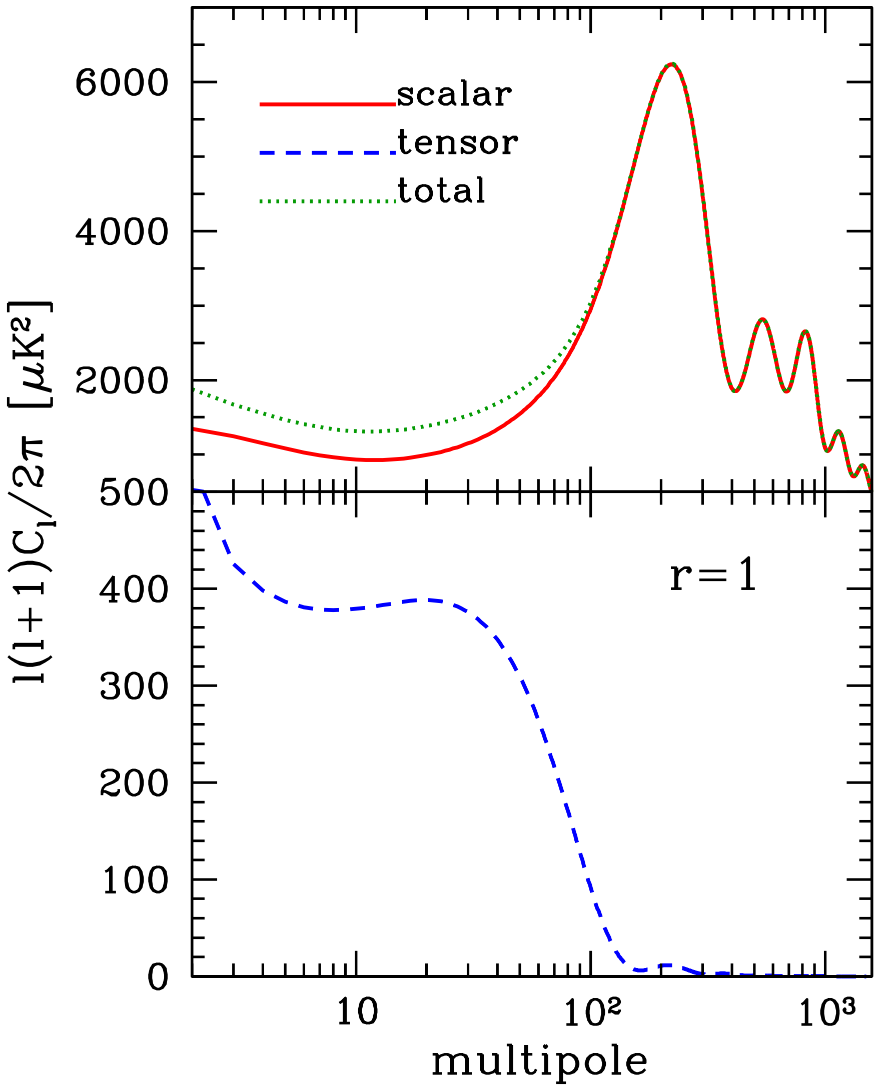


1. $m_\nu \uparrow, n_s \uparrow$ in LSS.

How does it happen?



1. $m_\nu \uparrow, n_s \uparrow$ in LSS.



2. $n_s \uparrow, r \uparrow$ in CMB.

Dark matter too . . .

- Vanilla, WMAP+SDSS:

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

[Tegmark (SDSS collaboration), 2006]

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

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

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

Summary . . .

- Most published cosmological constraints are derived under very restrictive conditions.
  - Some are justifiable; some are plain wrong.

- Use limits with EXTREME CAUTION.
  - Do not over-interpret them.

- We have "saved" a class of inflation models, by including uncertainties about the neutrino mass and dark energy.

- Have you killed your model for the wrong reasons?