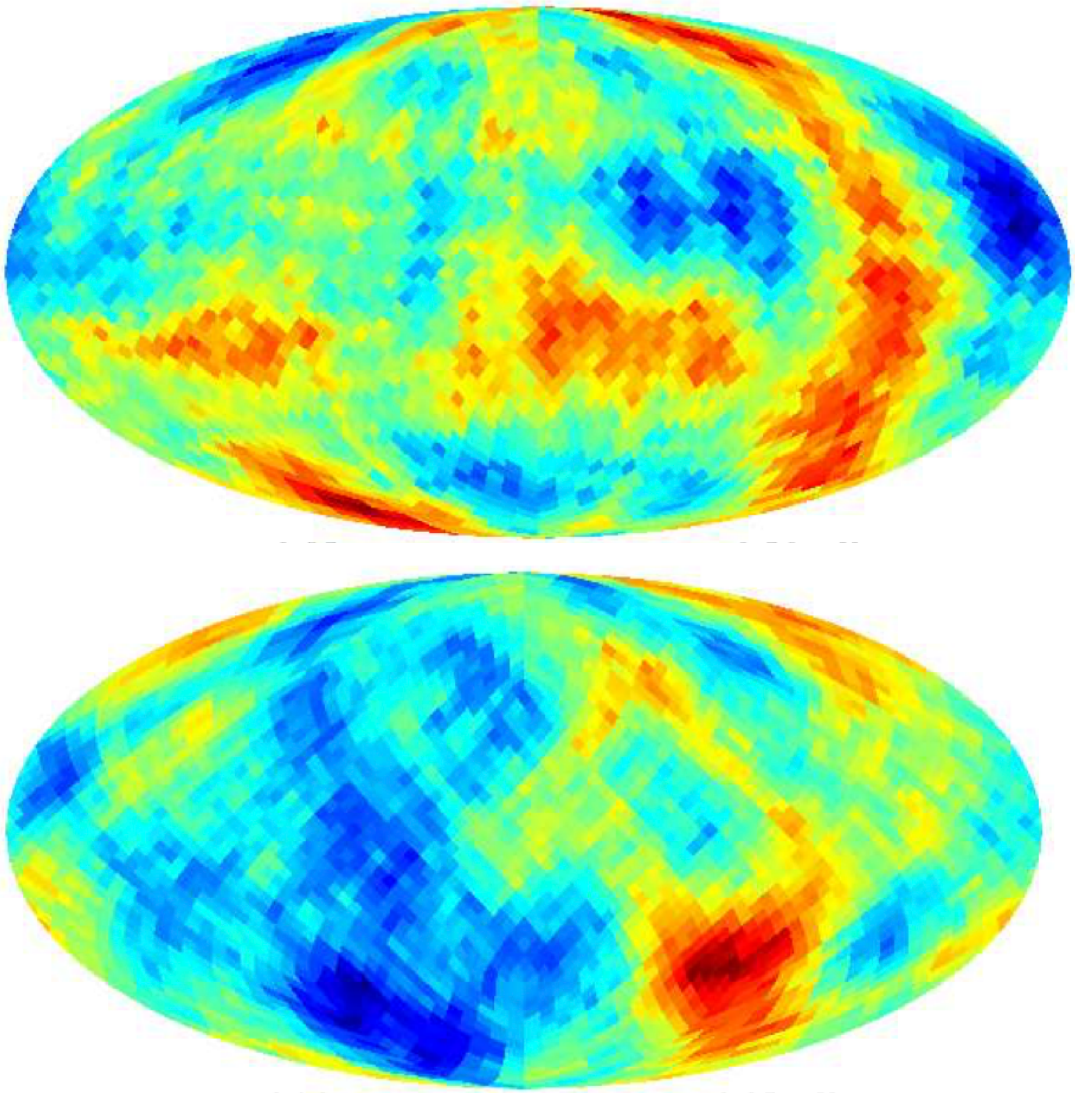
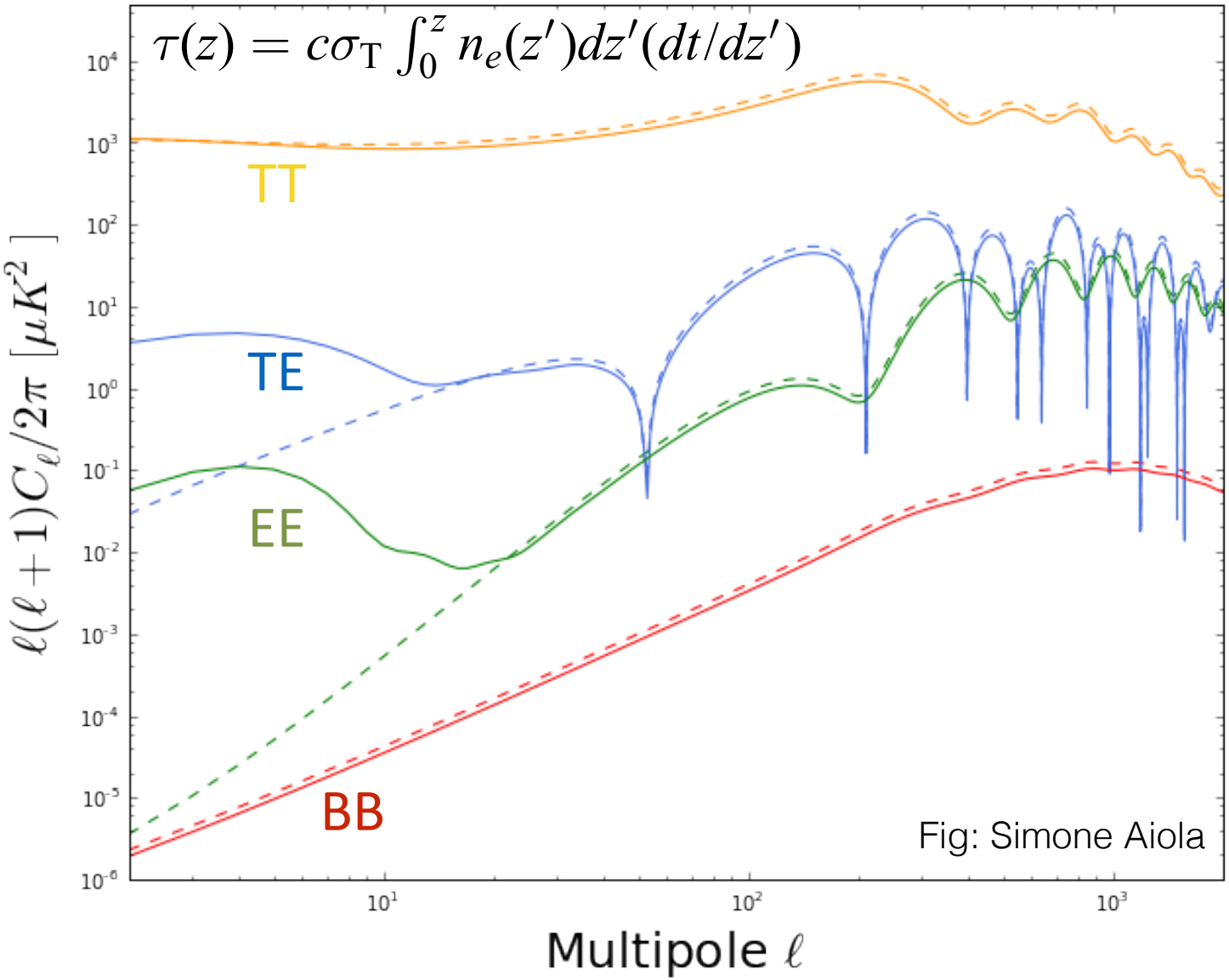


Large-scale EE and tau

Jo Dunkley
University of Oxford

Effect of reionization on the CMB

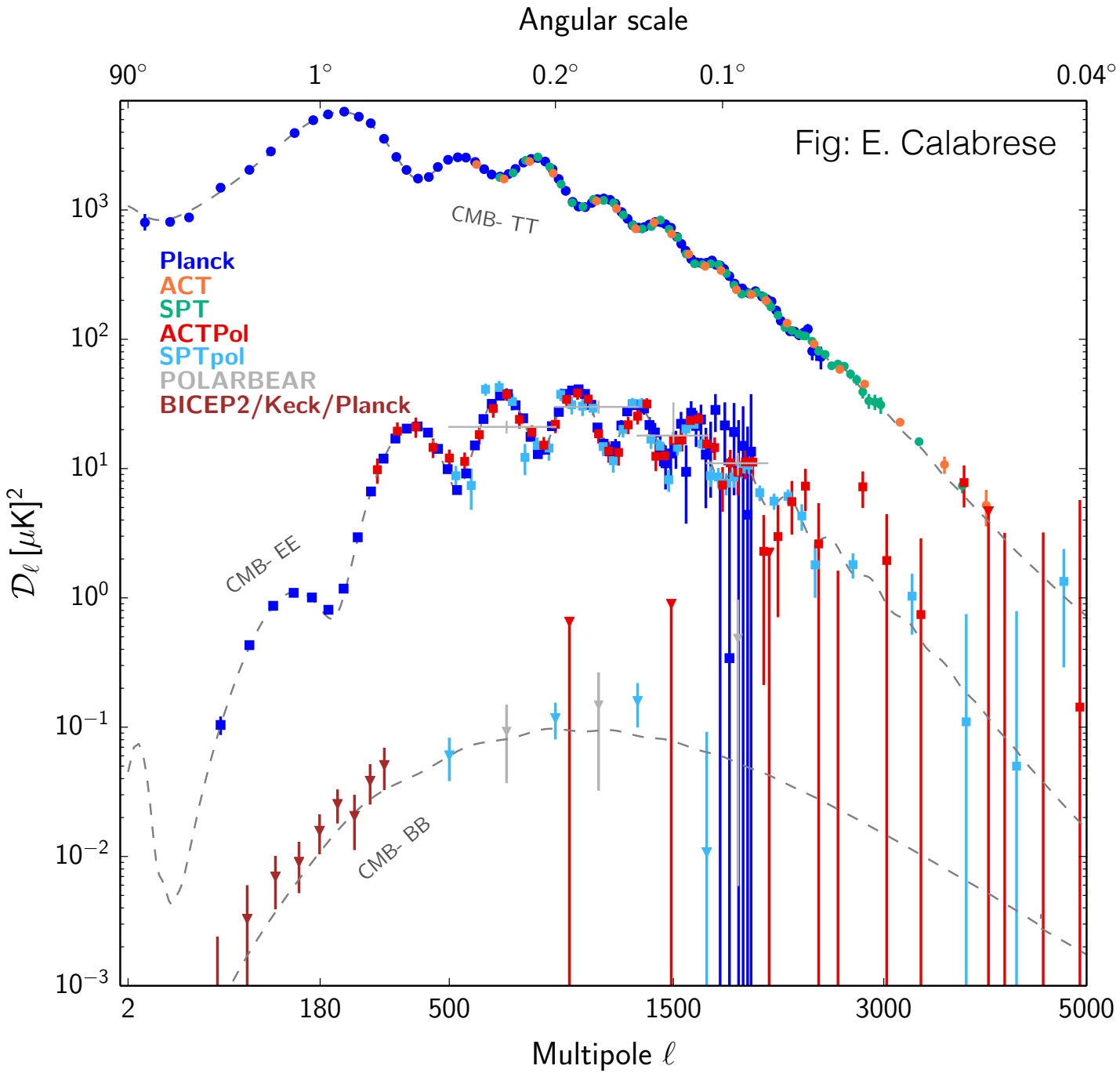


What reionization questions?

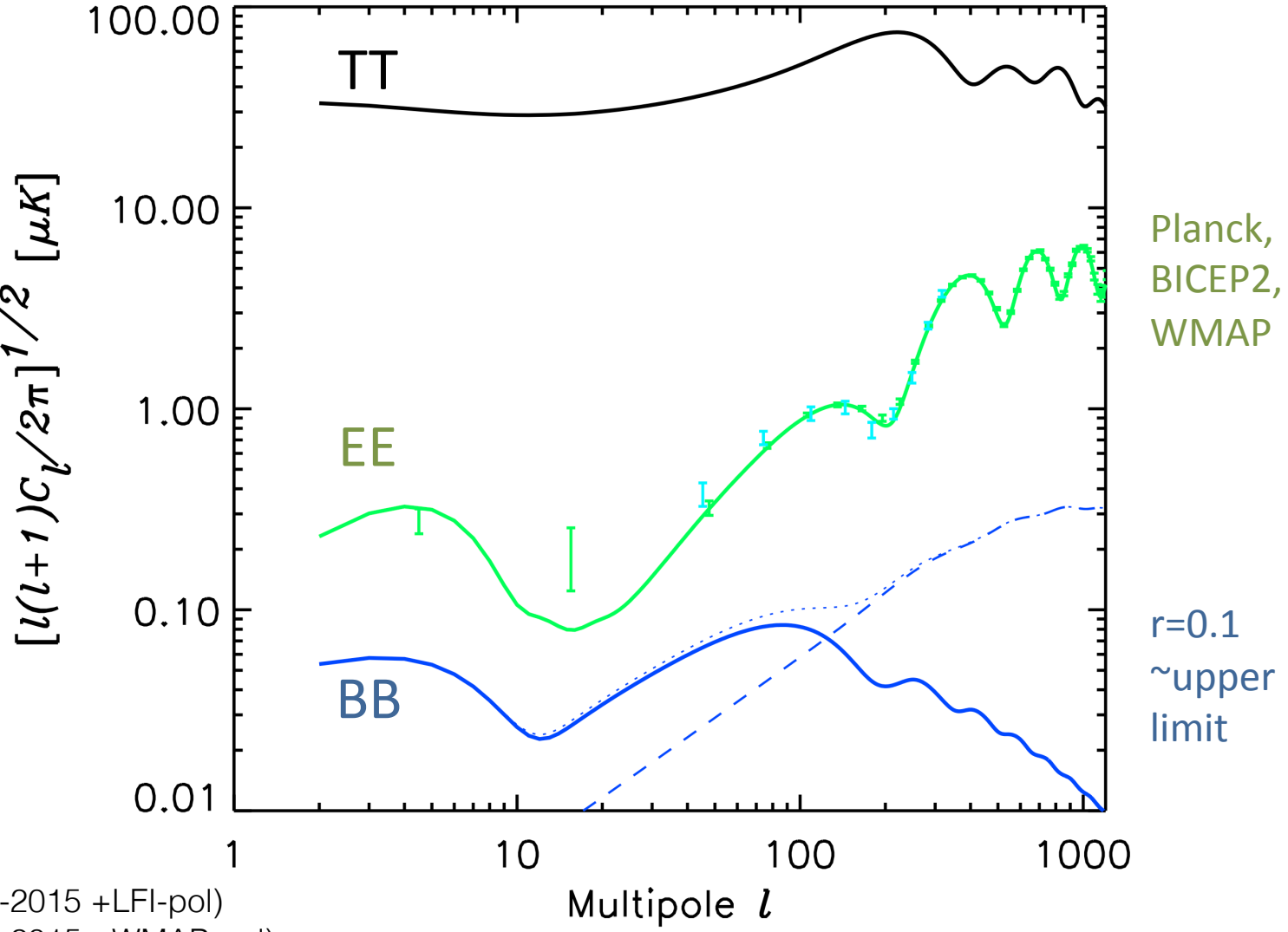
- When does the entire volume of the inter-galactic medium become filled with ionized gas?
- How extended is the reionization process?

- What does this tell us about the first generation of ionizing sources, and on the surrounding IGM, including the impact of feedback

Current CMB polarization data



Large-scale E-mode data



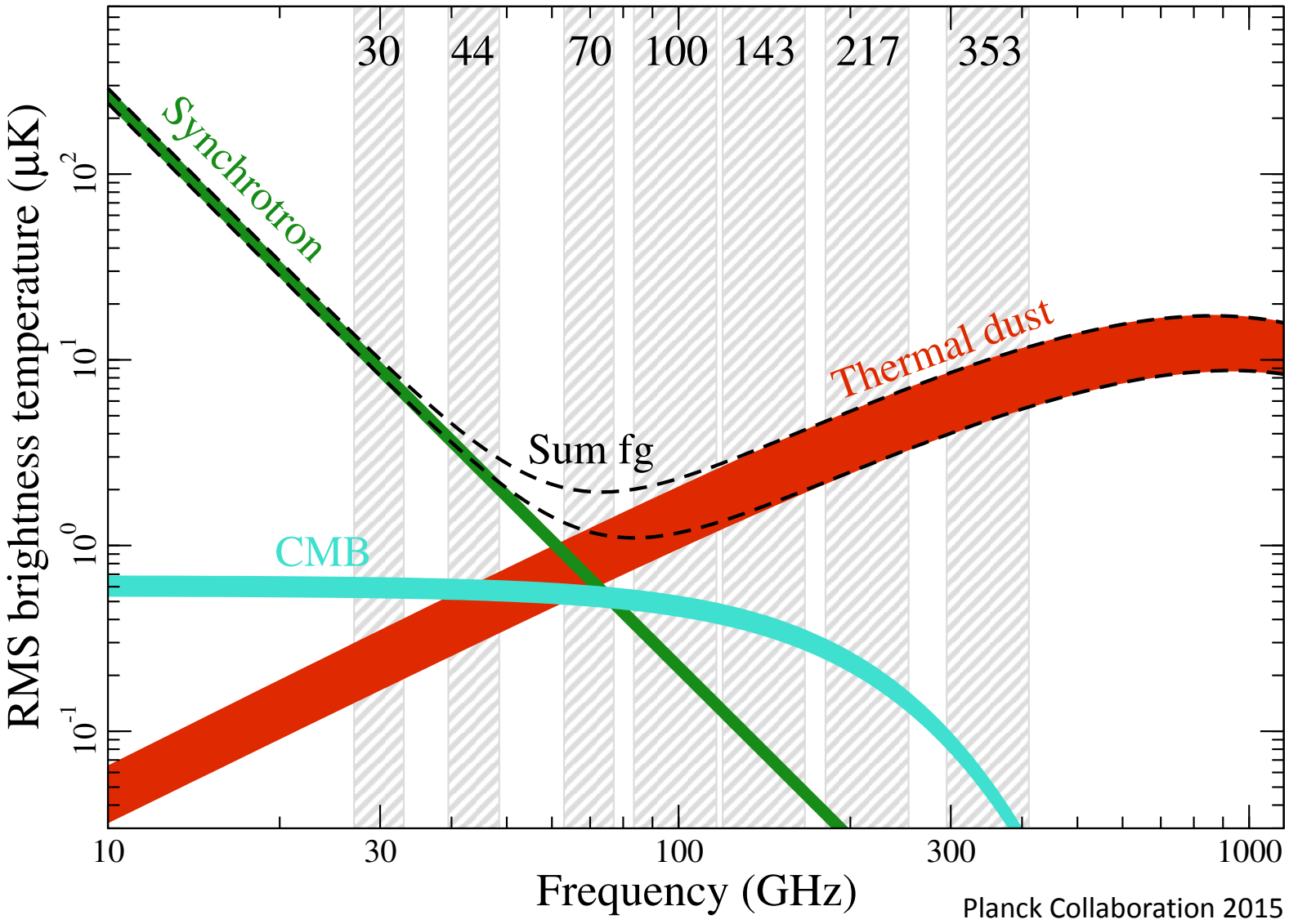
Planck, BICEP2, WMAP

r=0.1 ~upper limit

tau = 0.078 ± 0.019 (Planck-2015 +LFI-pol)
tau = 0.071 ± 0.013 (Planck-2015 +WMAP-pol)

Current tightest limits from WMAP (+Planck dust: down ~1-sigma with better dust removal)
LFI 70 GHz consistent but larger errors; Planck HFI analysis underway - see Monday talks!
Systematics are challenging.

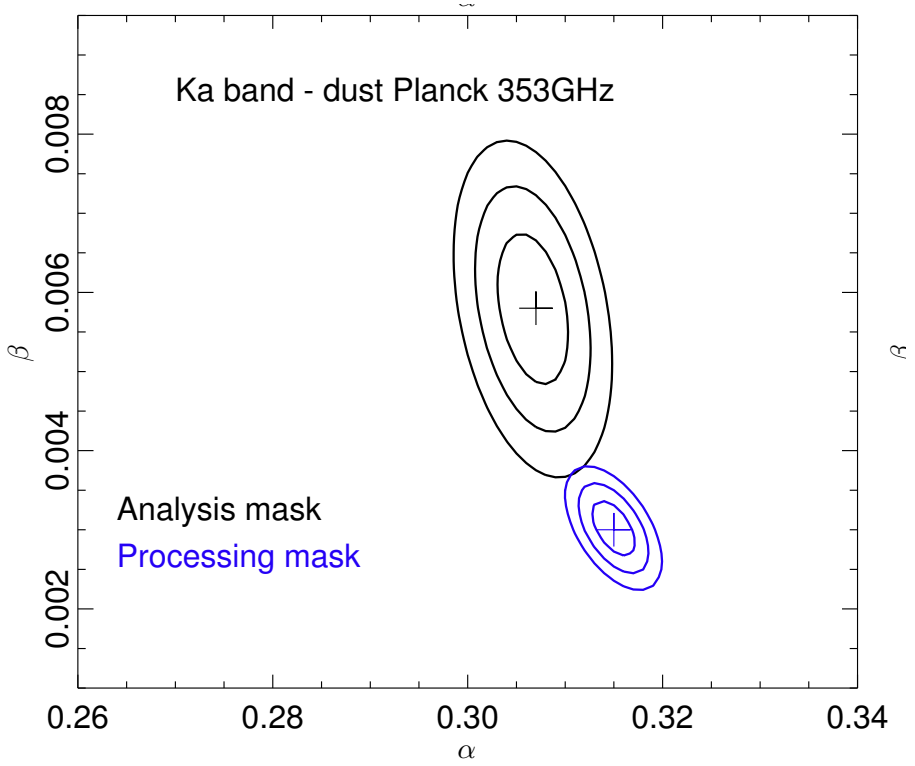
Foregrounds matter for EE too



Typically subtract global synchrotron and dust templates from the CMB bands

Foregrounds matter for EE too

Galactic foreground uncertainty still not fully understood/characterized for cleaning WMAP Q/U maps



Planck Collaboration 2013

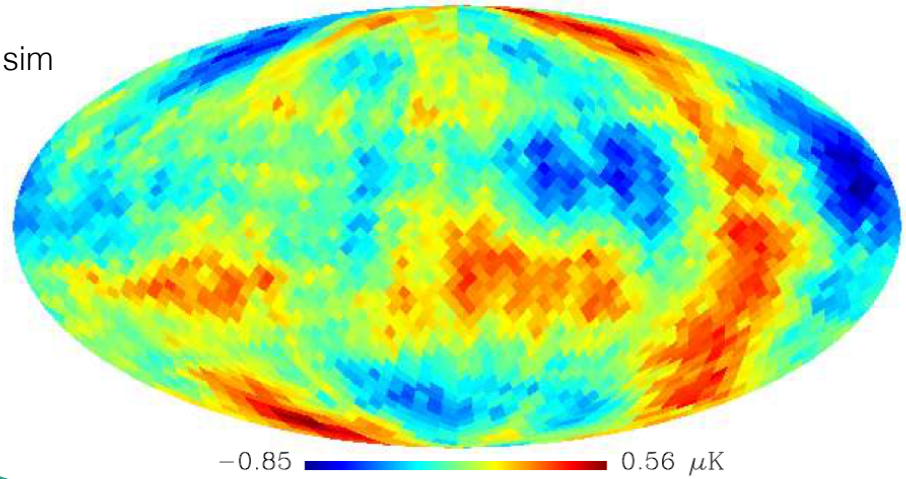
Worries with current model

- use spatially invariant scaling from global synchrotron and dust templates
- ignore scale-dependent spatial correlation between dust and pol
- ignore polarized AME

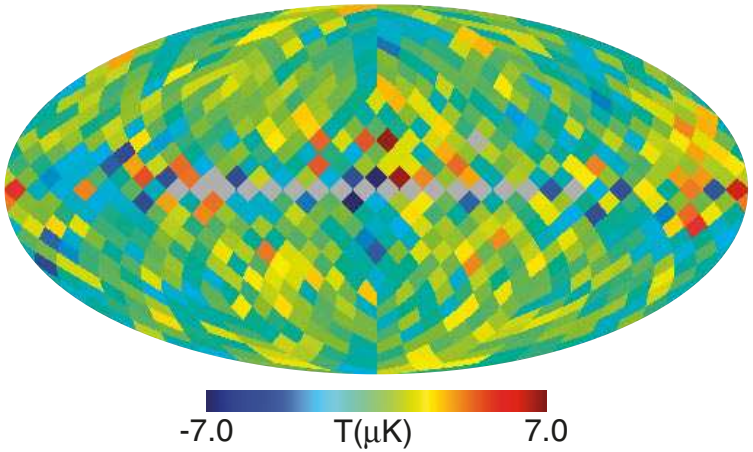
What is the ‘correct’ current constraint on optical depth?

What would we like to measure?

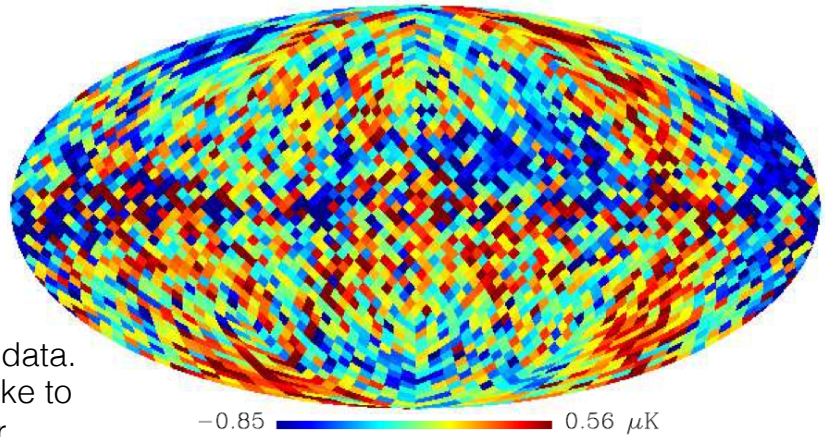
Q signal sim



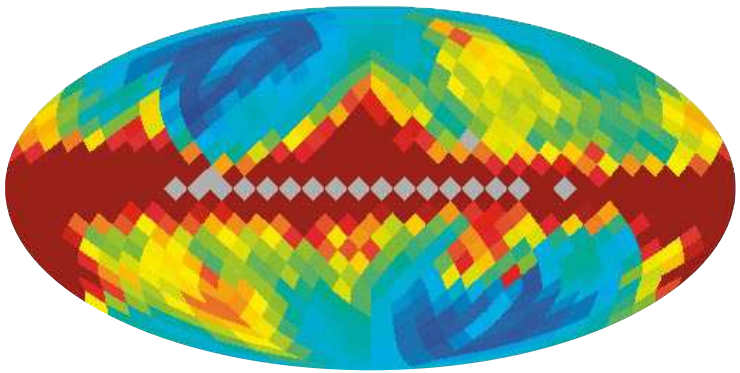
WMAP5 Q data

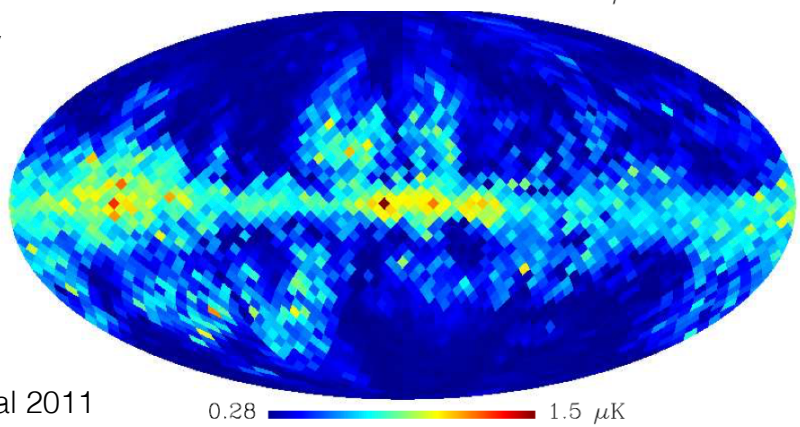


‘Planck’ Q recovered sim (Blue book white noise)



This is better than current data. Even beyond this would like to lower noise and lower foreground uncertainty





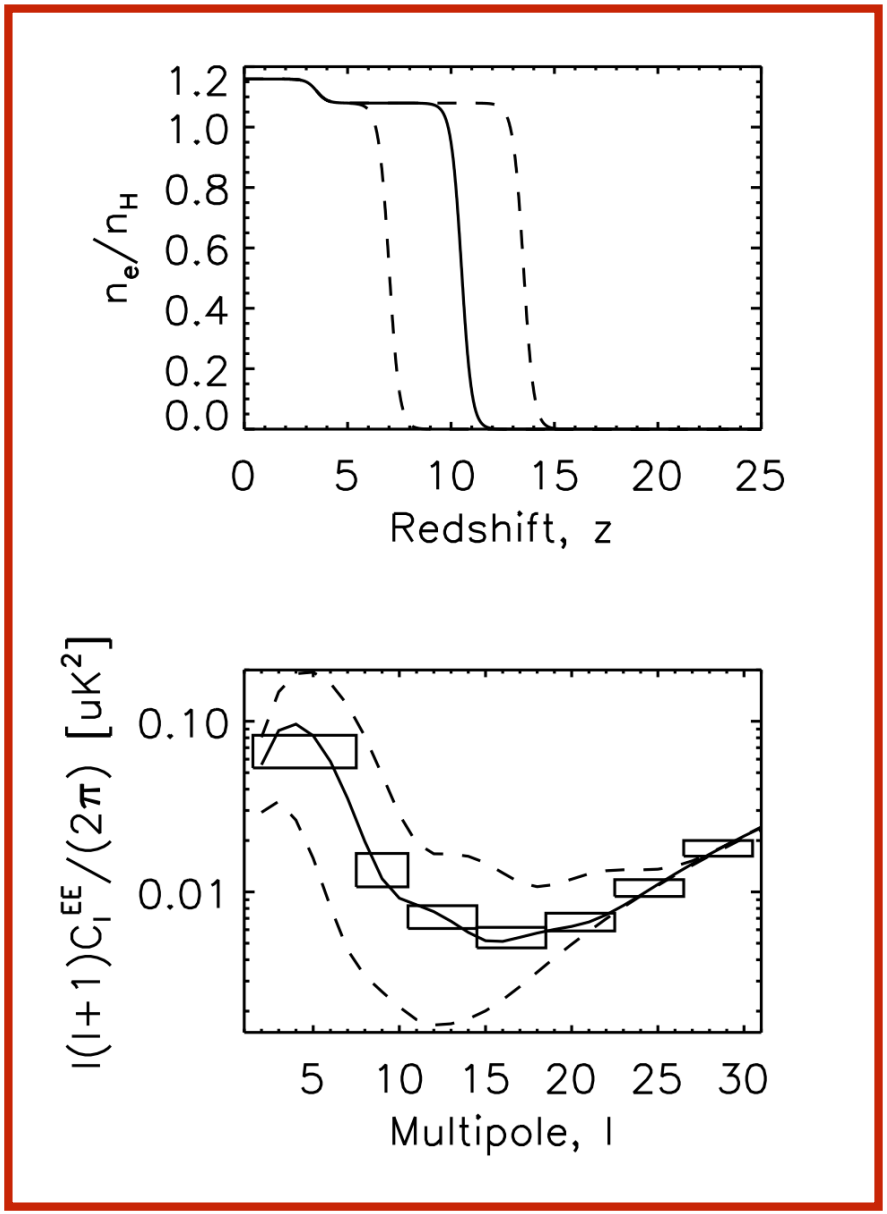
Dunkley et al 2009, Armitage-Caplan et al 2011

Improvements on tau/As

Sigma(tau) from large-scale EE:
2013 WMAP >= 0.013
2015 Planck LFI >= 0.019
2016? Planck HFI >= 0.005
2025? 'CV' sigma >= 0.002

This will be a valuable measurement for the reionization community

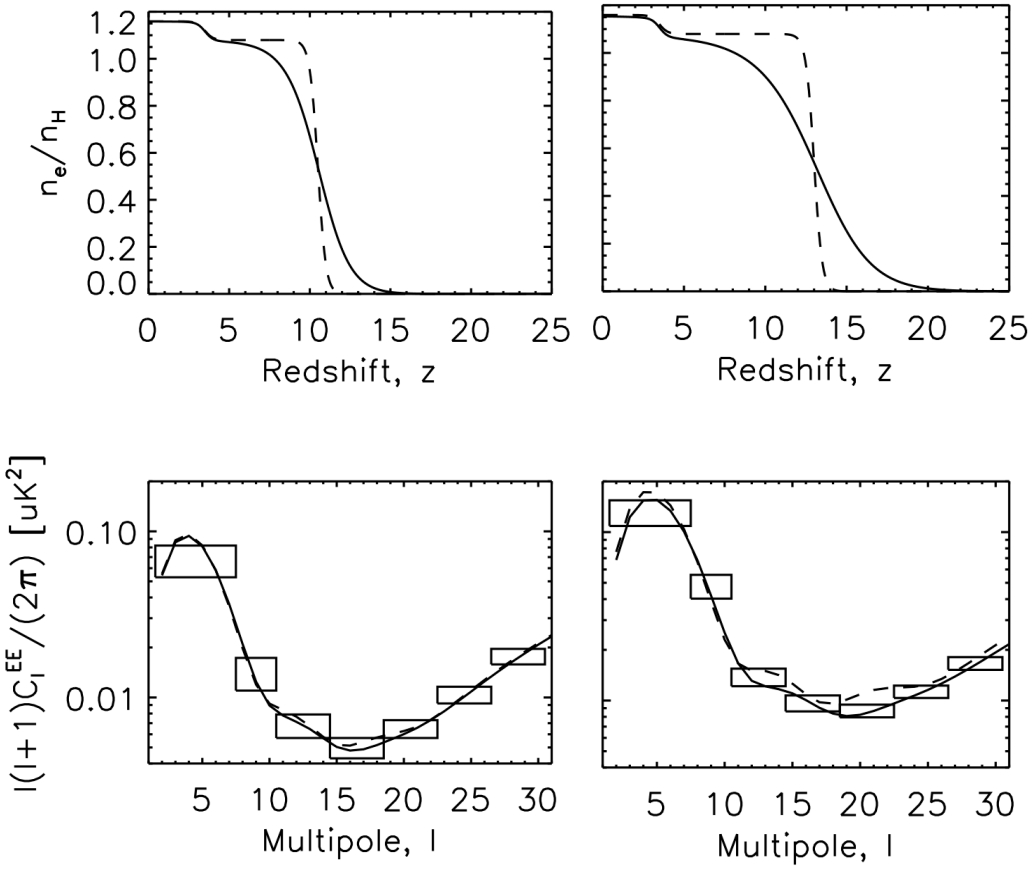
Primordial amplitude As:
similar scaling

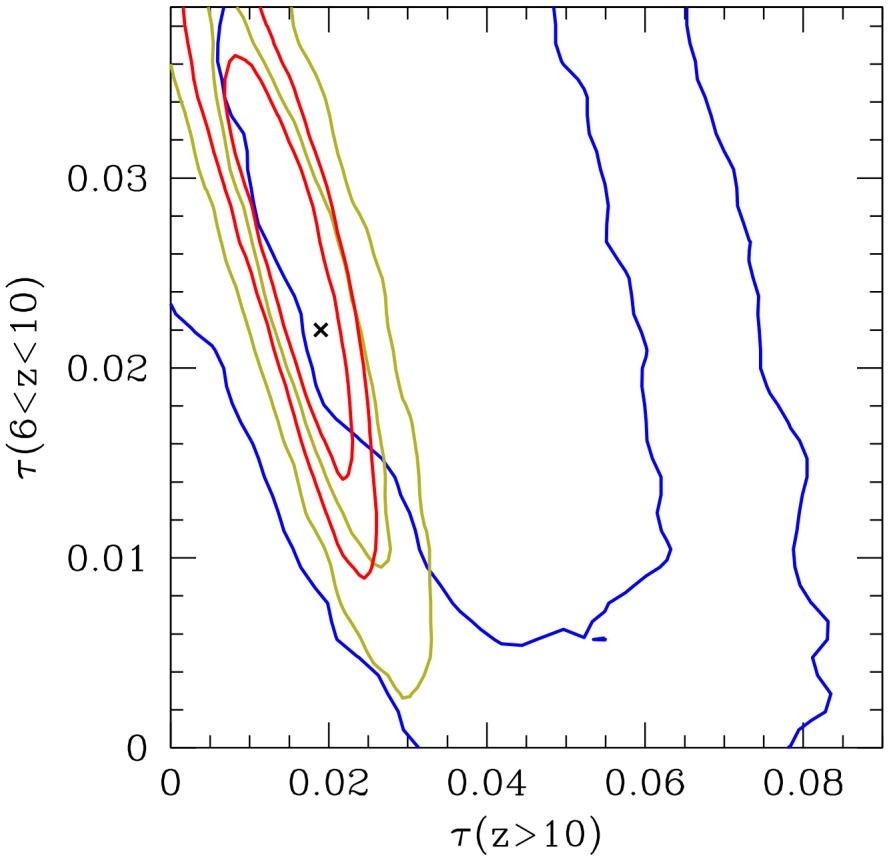


CMBPol White Paper, Zaldarriaga et al 2008

Measuring reionization history

CMBPol White Paper, Zaldarriaga et al 2008





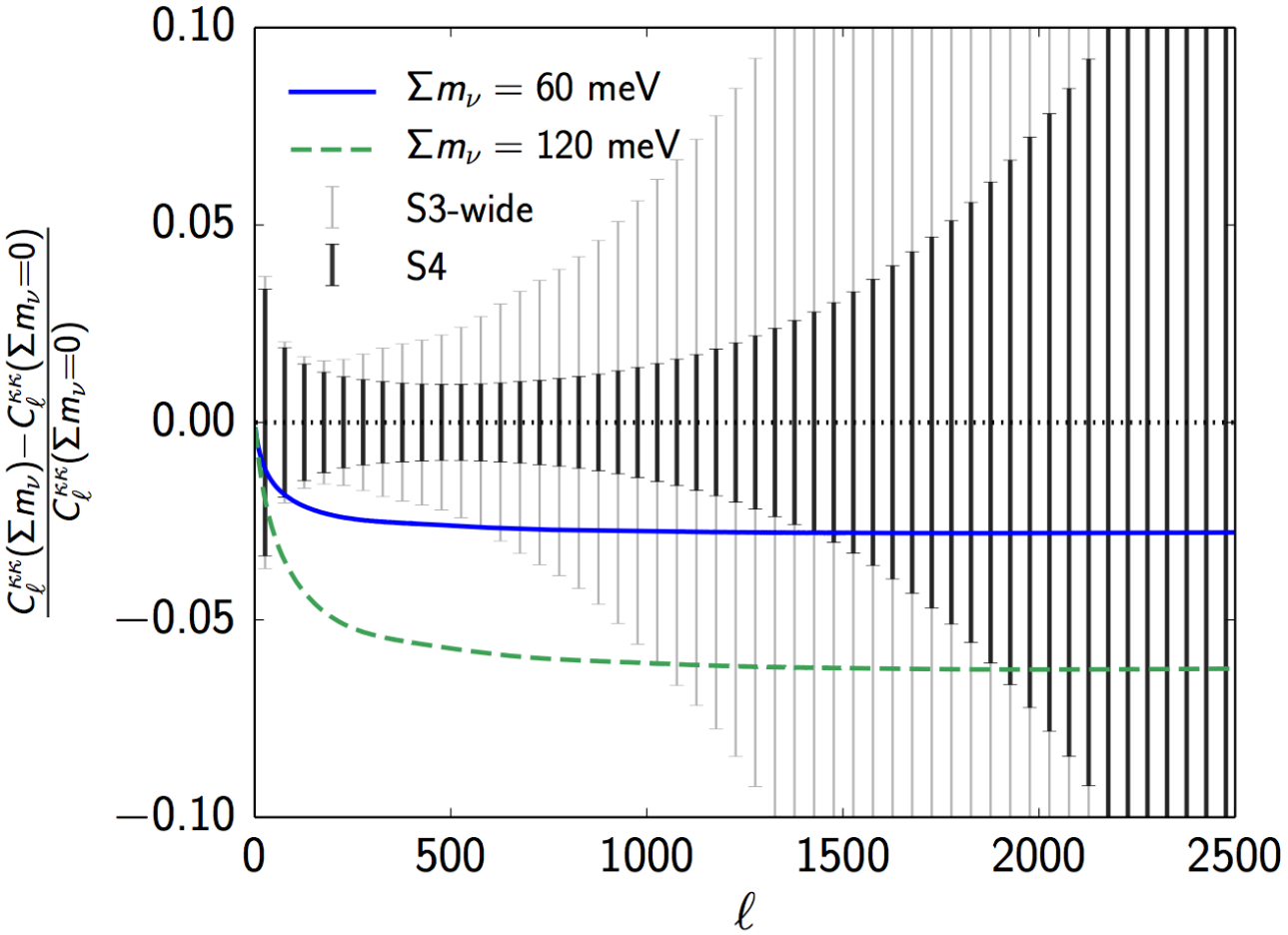
- Can distinguish very different durations, but not strong constraint on duration (and depends on actual value of tau) - kSZ will do that better
- Could make at least two-bin measurements of optical depth
- How many principal components? 1-2 for WMAP, 2-3 for Planck-HFI?, 4-5 for CV

To use growth of structure, want primordial amplitude

Structure probes like CMB lensing measure amplitude of structure at late times.

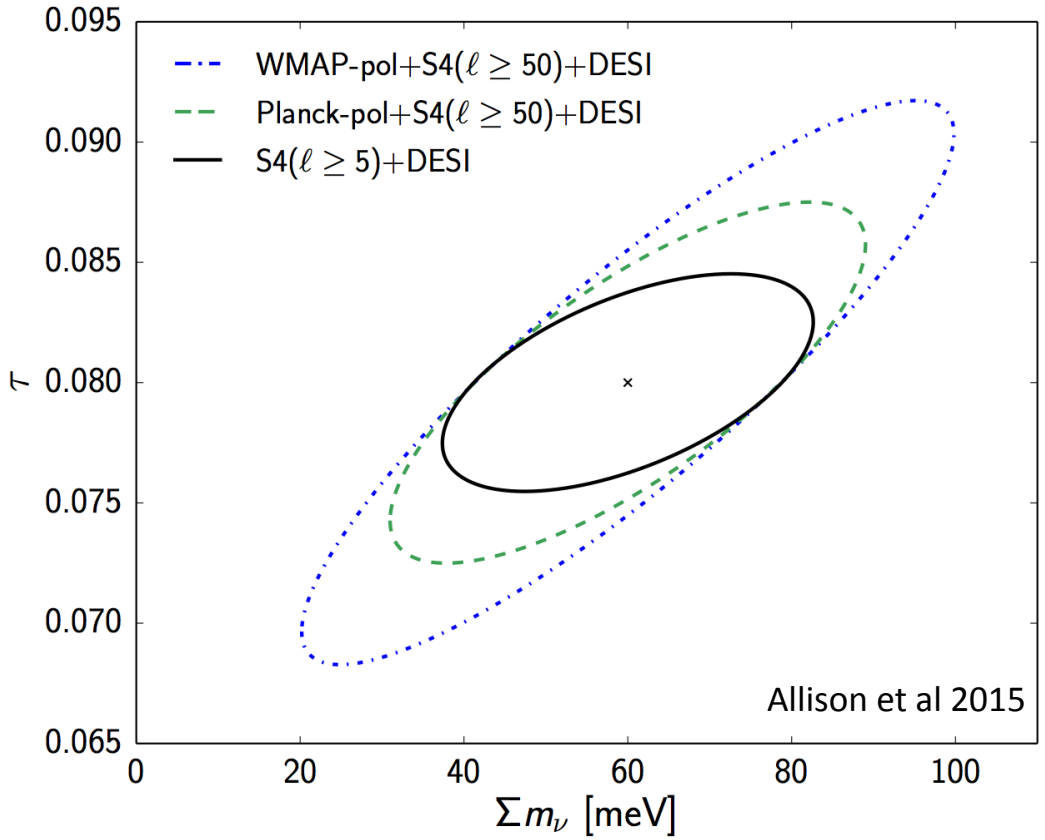
For example, neutrino mass suppresses structure. Also curvature and w ne -1.

Constraints limited by knowledge of primordial amplitude, as non-LCDM effects mostly look like a change in amplitude.



Allison et al 2015

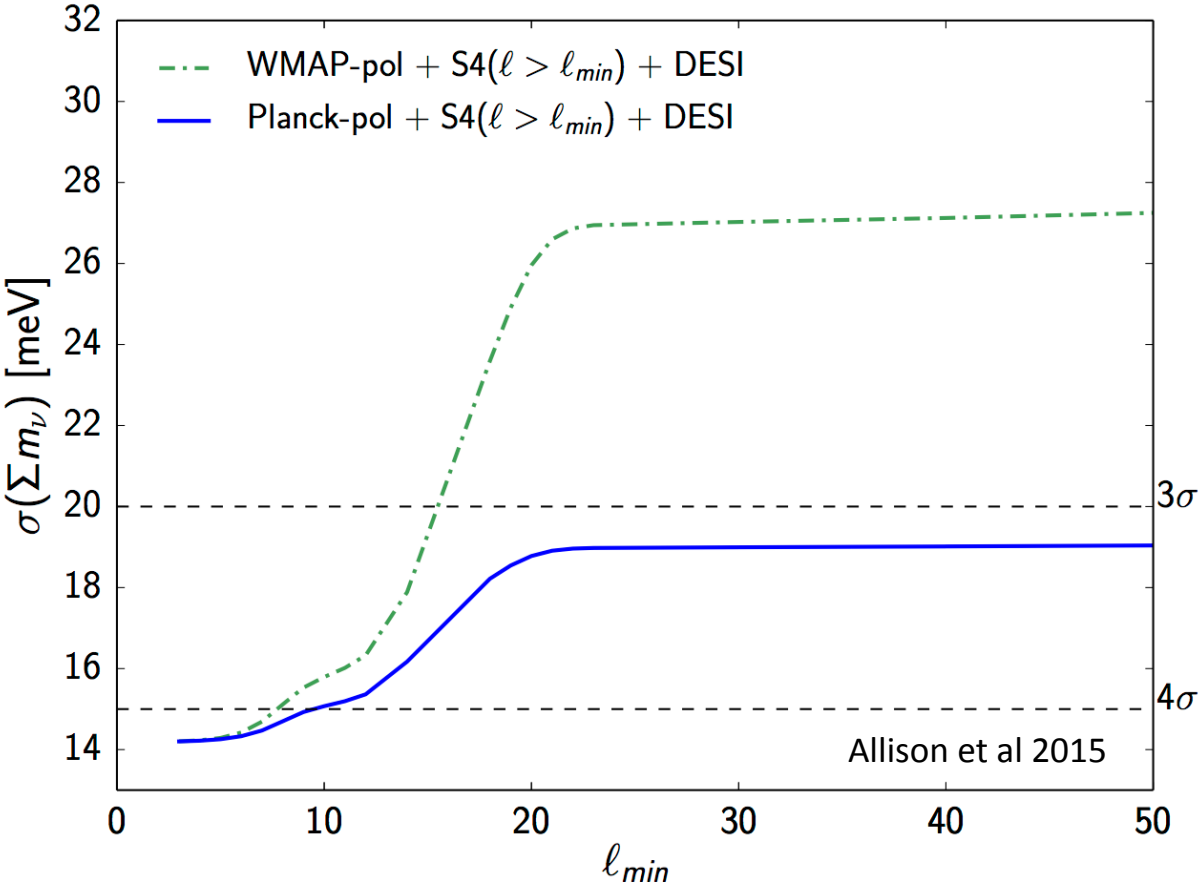
Impact of tau on neutrino mass forecasts



Improved tau measurement could halve (or more) constraints on late-time parameters
Similar degeneracies seen for e.g. curvature/dark energy/anything that affects growth.

Q. Are our standards different for fundamental physics parameters versus ‘astrophysical’ parameters?

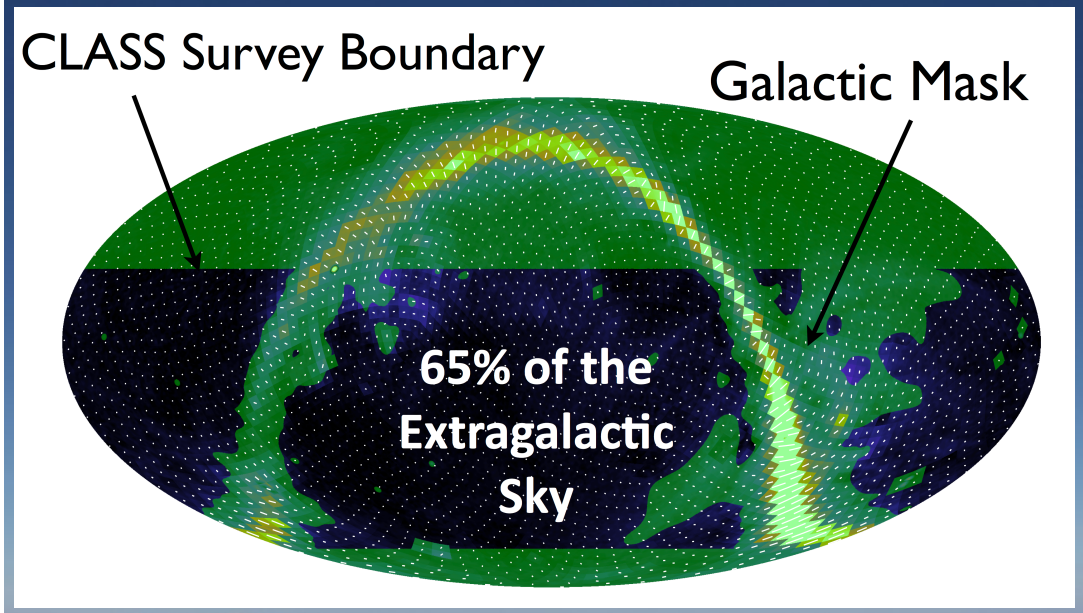
How low in ell do we need?



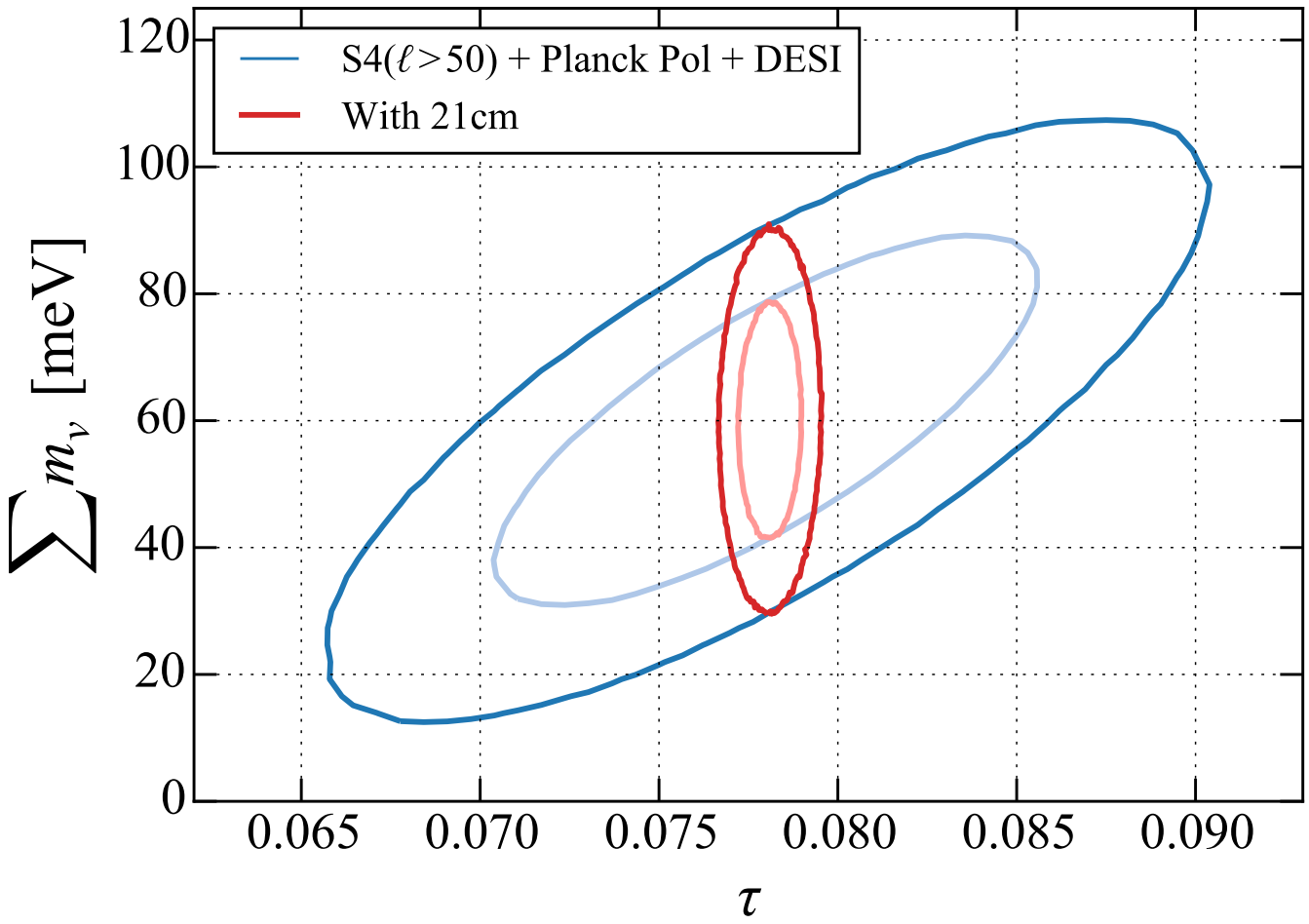
- Need to get to large scales, but l~10-15 is pretty good. However, that is a challenge from the ground or from balloons. NB. Planck-pol' is not at this level yet

- If you want to improve neutrino mass measurements beyond nominal S3 levels, an improved tau measurement helps **more** than decreasing small-scale Q/U noise below 10 uK/arcmin

Prospects from Atacama Desert



Will tau be measured by 21cm before CMB?



Forecast for HERA from Liu et al 2015; in principle yes but foregrounds will be significant and field still developing.

Status/opinion

- Even if Planck had reached Blue-book noise levels, there would remain improvements to be made in large-scale EE (and TE). Sigma(tau) —> 0.002. Current limits are sigma(tau)>=0.013.
- Planck has not yet demonstrated systematics-free large-scale polarisation performance from HFI, although see Monday's talks for an update.
- The large-scale foregrounds are still not fully characterized, even for EE.
- We need better tau measurement to fully exploit growth measurements for neutrino mass and curvature.
- There is also other interesting physics at l<~50 scales that are hard to reach from the ground. See Cora's talk, plus isocurvature fluctuations that can be seen at large scales in EE.
- Ground- and balloon-based experiments may improve on Planck-tau before 2025 (CLASS, Spider). But, their frequency coverage will be limited and angular reach not yet known.
- ***We need a better 2<l<~50 EE measurement. To make it robustly, we need multi-frequency data from space, designed to minimize large-scale polarization systematics. LiteBIRD is already more than a 1-parameter experiment.***