Topic: Methods

Parametric fitting

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Designing future CMB Experiments Workshop

Foregrounds versus systematics

- For Planck, the most difficult problem was not to remove synchrotron or thermal dust, but to disentangle instrumental systematics from foregrounds
  - The calibration process is “disturbed” by the presence of foregrounds
  - To calibrate the instrument, one needs to know what the sky is, but in order to know what the sky is, one needs well calibrated data
- Should assume that the same will be true for any future experiment as well
  - If one is lucky, and the systematics are low, then that is good, but one shouldn’t count on it
- If that is the case, one will need a detailed and realistic astrophysical model, not only Taylor-expansion approximations
  - For a true polarimeter-based experiment, this requires only estimation of synchrotron and thermal dust (and possibly polarized AME++) => moderate frequency range
  - For total-power experiments, one needs to decompose the temperature sky also into free-free, AME, CIB, zodi etc… => widest possible frequency range allowed by budget/power/focal plane

From Wednesday’s foreground session

Parametric fitting

- Parametric fitting is often implemented through Bayesian methods
- Assume that the data may be written as the sum of signal and noise,

$$\mathbf{d}_\nu = \mathbf{s}_\nu + \mathbf{n}_\nu$$

where the signal may be written on the following form

$$\mathbf{s}_\nu(\theta) = s_\nu(\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu)$$

Bandpass

Monopole/dipole

$$= g_\nu \sum_{i=1}^{N_{\mathrm{comp}}} \mathbf{F}_\nu^i(\beta_i, \Delta_\nu)\mathbf{a}_i + \mathbf{T}_\nu \mathbf{m}_\nu$$

Calibration

Spectral index

Signal amplitude

- The posterior distribution reads

Likelihood

$$P(\theta|\mathbf{d}) = \frac{P(\mathbf{d}|\theta)P(\theta)}{P(\mathbf{d})} \propto \mathcal{L}(\theta)P(\theta)$$

Prior

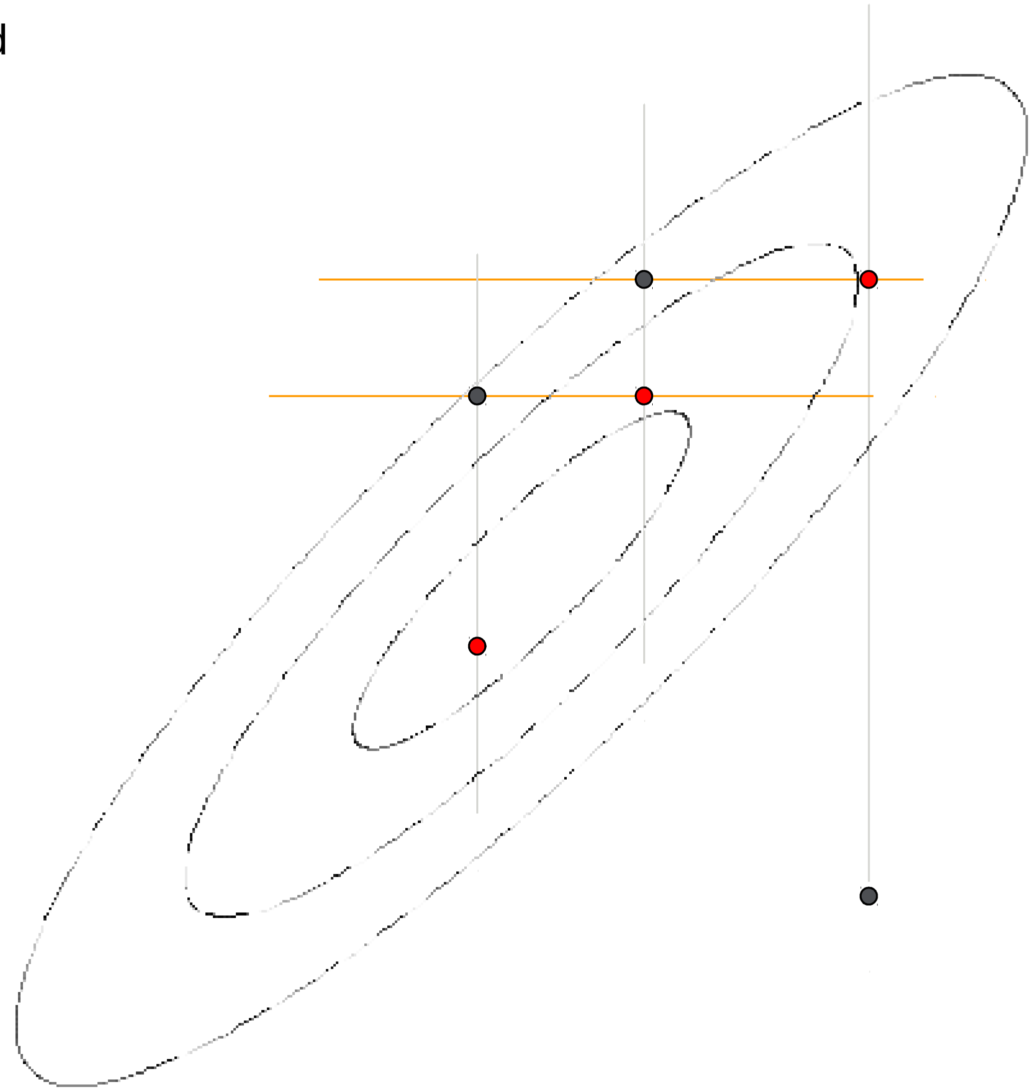
- If the noise is very nearly Gaussian distributed, then the likelihood is given by

$$\mathcal{L}(\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu) \propto e^{-\frac{1}{2}\sum_\nu [\mathbf{d}_\nu - \mathbf{s}_\nu(\theta)]^t \mathbf{N}^{-1} [\mathbf{d}_\nu - \mathbf{s}_\nu(\theta)]}$$

Gibbs sampling

- The posterior contains millions of correlated and non-Gaussian parameters. How is it possible to map out this distribution?
- Answer: Gibbs sampling
  - Rather than sampling from or maximizing the full joint distribution, iterate over conditionals
- We apply this to our problem in terms of the following Gibbs chain:

$$
\begin{aligned}
\mathbf{a}_i &\leftarrow P(\mathbf{a}_i|\beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
\beta_i &\leftarrow P(\beta_i|\mathbf{a}_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
g_\nu &\leftarrow P(g\nu|\mathbf{a}_i, \beta_i, \mathbf{m}_\nu, \Delta_\nu, C_\ell) \\
\mathbf{m}_\nu &\leftarrow P(m_\nu|\mathbf{a}_i, \beta_i, g_\nu, \Delta_\nu, C_\ell) \\
\Delta\nu &\leftarrow P(\Delta_\nu|\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, C_\ell) \\
C_\ell &\leftarrow P(C_\ell|\mathbf{a}_i, \beta_i, g_\nu, \mathbf{m}_\nu, \Delta_\nu)
\end{aligned}
$$



Gibbs sampling for future experiments

- It is easy to fit for astrophysical foreground parameters with ideal sky maps without systematics

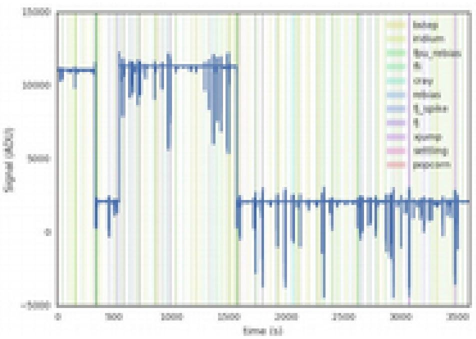
- The difficult part is to account simultaneously for foregrounds and instrumental effects
  - Bandpass mismatch, calibration, ADC correction etc.

- In practice, one has to iterate between low-level TOD processing and map making and high-level component separation
  - Done by LFI, HFI and NPIPE in latest Planck processing

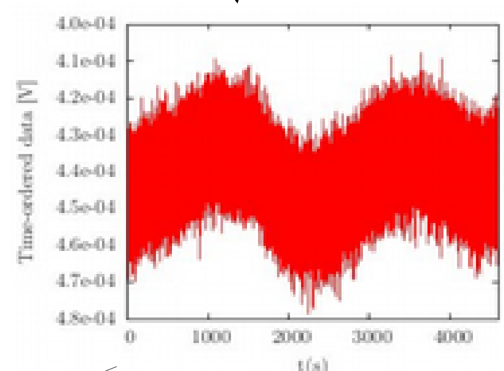
- Ideal solution: Build one big Gibbs sampler including both low- and high-level data processing (“time-domain Gibbs sampling”)
  - No need for human interaction between different processing steps

Classic linear analysis pipeline

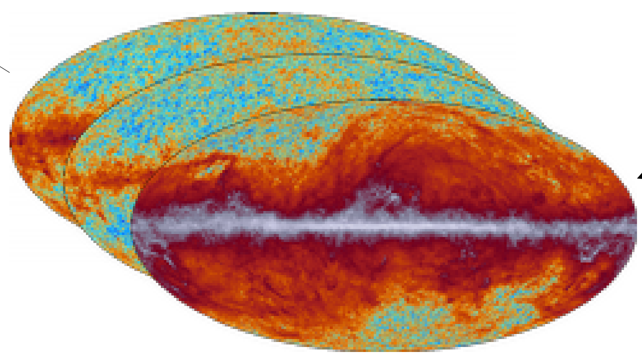
Observations



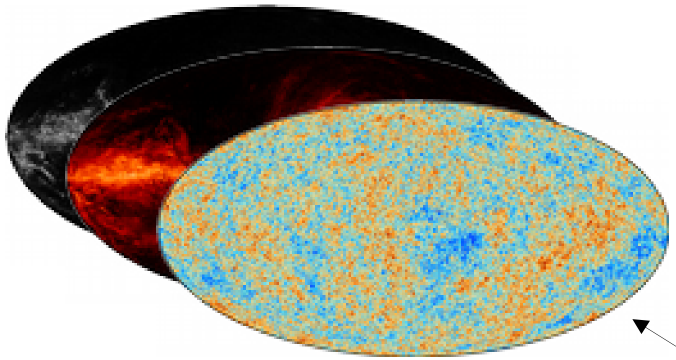
Calibration



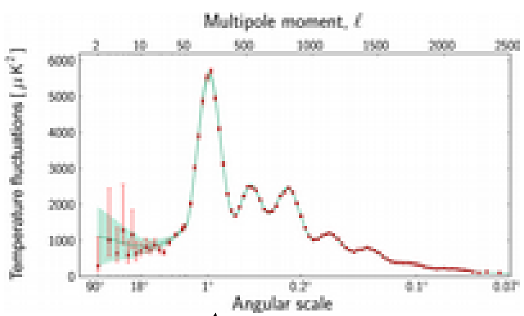
Map making



Component separation



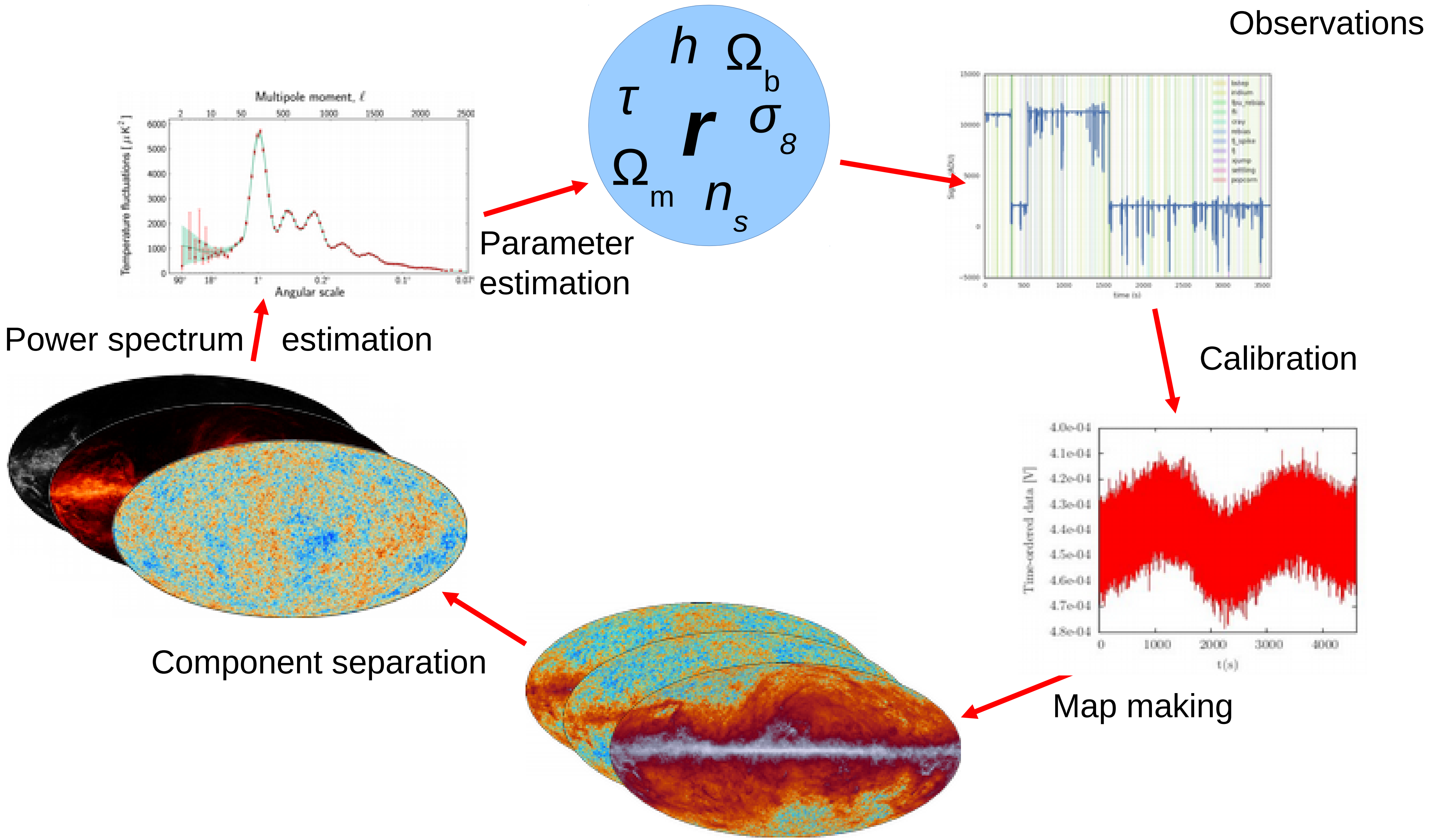
Power spectrum estimation



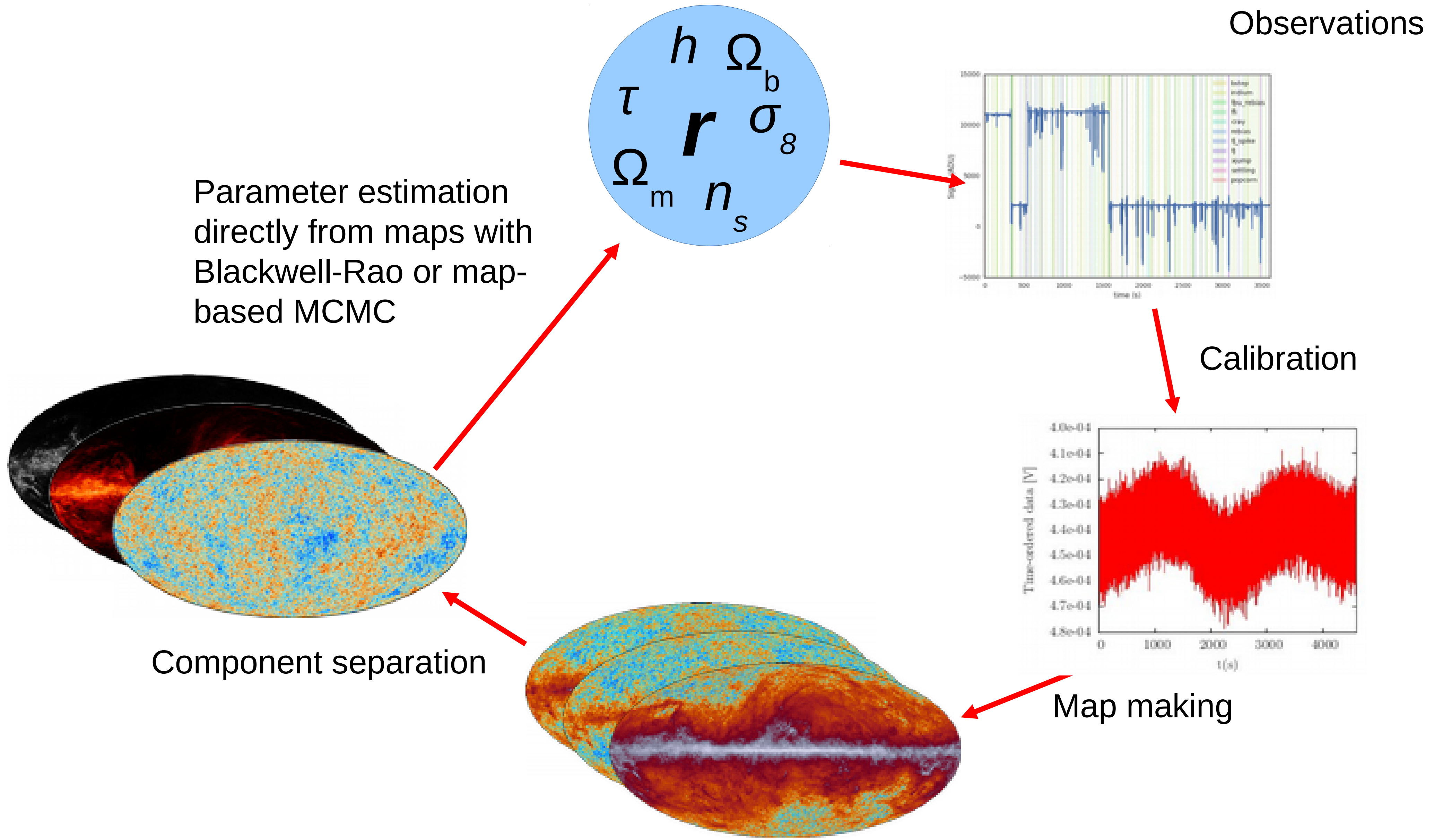
Parameter estimation

h Ω_b τ $\boldsymbol{r}$ σ_8 Ω_m n_s

Iterative analysis pipeline



Iterative analysis pipeline



‘Out-of-the-box’ discussion topics

- Analysis of spectra vs maps vs timestreams
- Uncertainties through Gibbs sampling vs from simulations
- Separate low-l and high-l analysis vs joint
- Parameters directly from maps/TODs vs likelihood