GLCW 2010

Probing the Epoch of Inflation by Deep Small-sky CMB Polarization Observations

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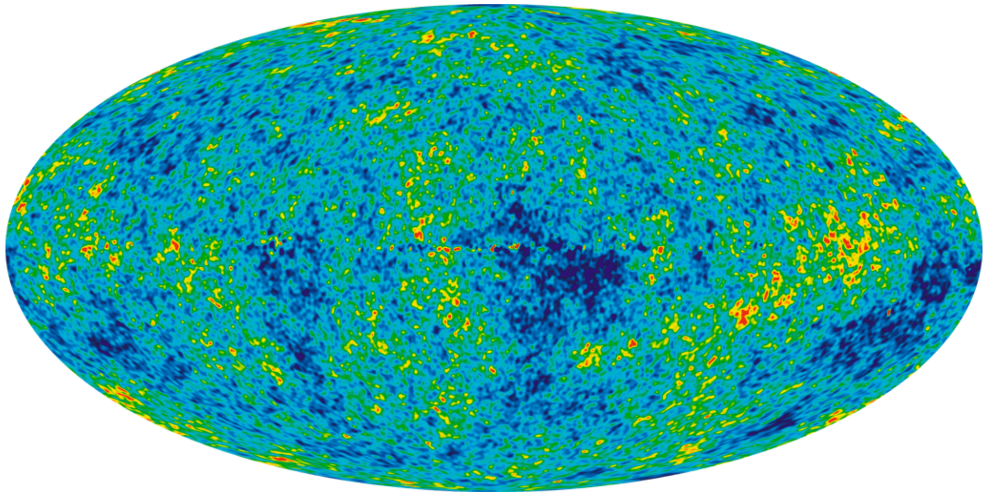
Cosmic Microwave Background (CMB) Radiation

- relic radiation from very young universe (379,000 yrs old)
- polarized
- described by 3 Stokes parameters:
  T (Temperature) Q,U (Polarization)
- very close to uniform in all directions
- small anisotropies contain a lot of cosmological information

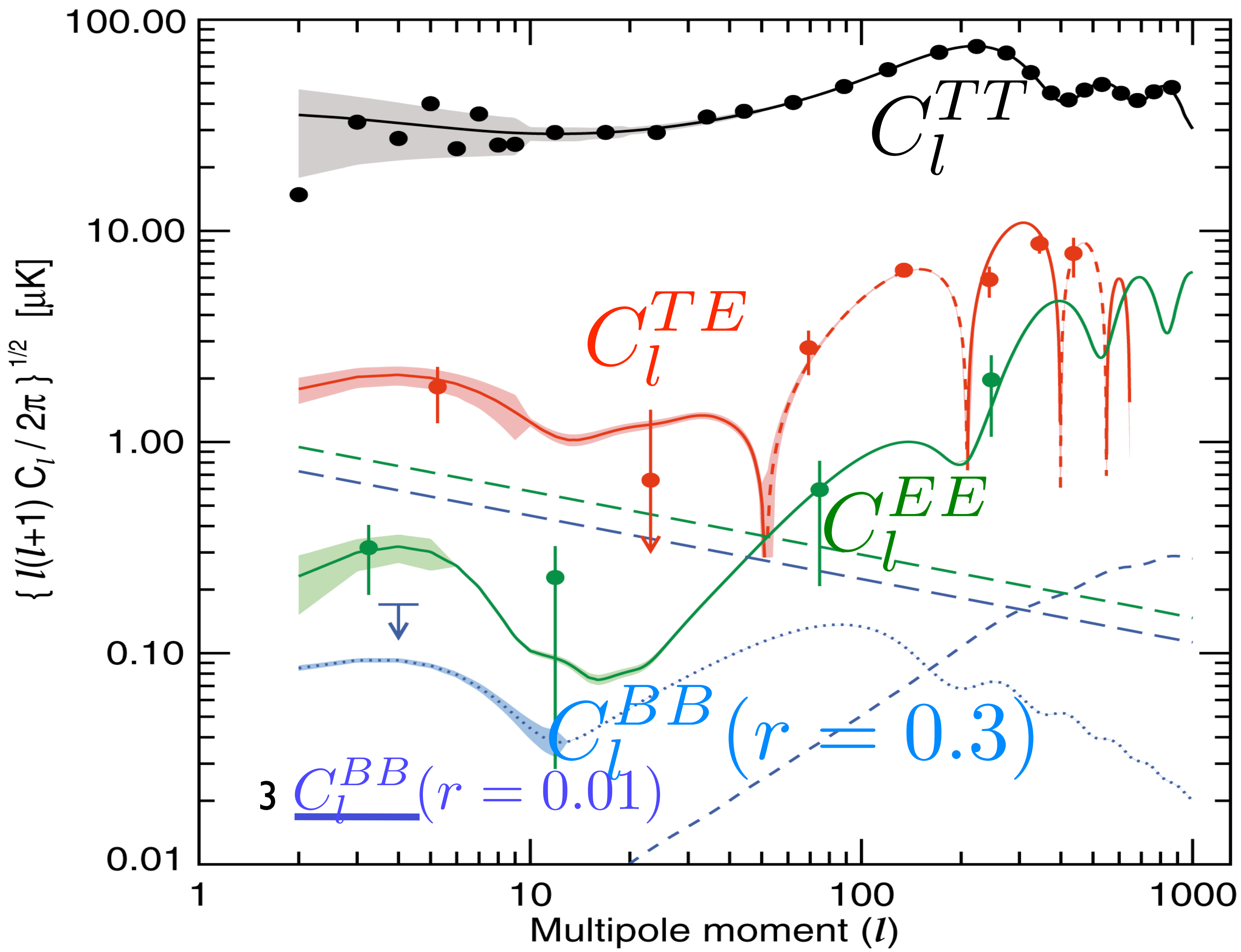


Cosmic Microwave Background Radiation

power spectra of fluctuations in
temperature (T) map and polarization (Q, U) maps

$$C_l^{TT}, C_l^{TE}, C_l^{EE}, C_l^{BB}$$

E-mode B-mode



Lyman A. Page

B-modes: probing energy scale of inflation

- (cosmic) B-mode ***only*** produced by gravity waves (on large scales), a necessary by-product of inflation.

amplitude of B-modes

$$V^{1/4} \sim 10^{16}\mathrm{GeV}\left(\frac{r}{0.01}\right)^{1/4}$$

inflationary potential

detection of large B-modes (r ~ 0.01 or larger)

↓

inflation happened at large energy scales (GUT scales?)
as predicted by standard inflation scenarios
strong confirmation of these theories

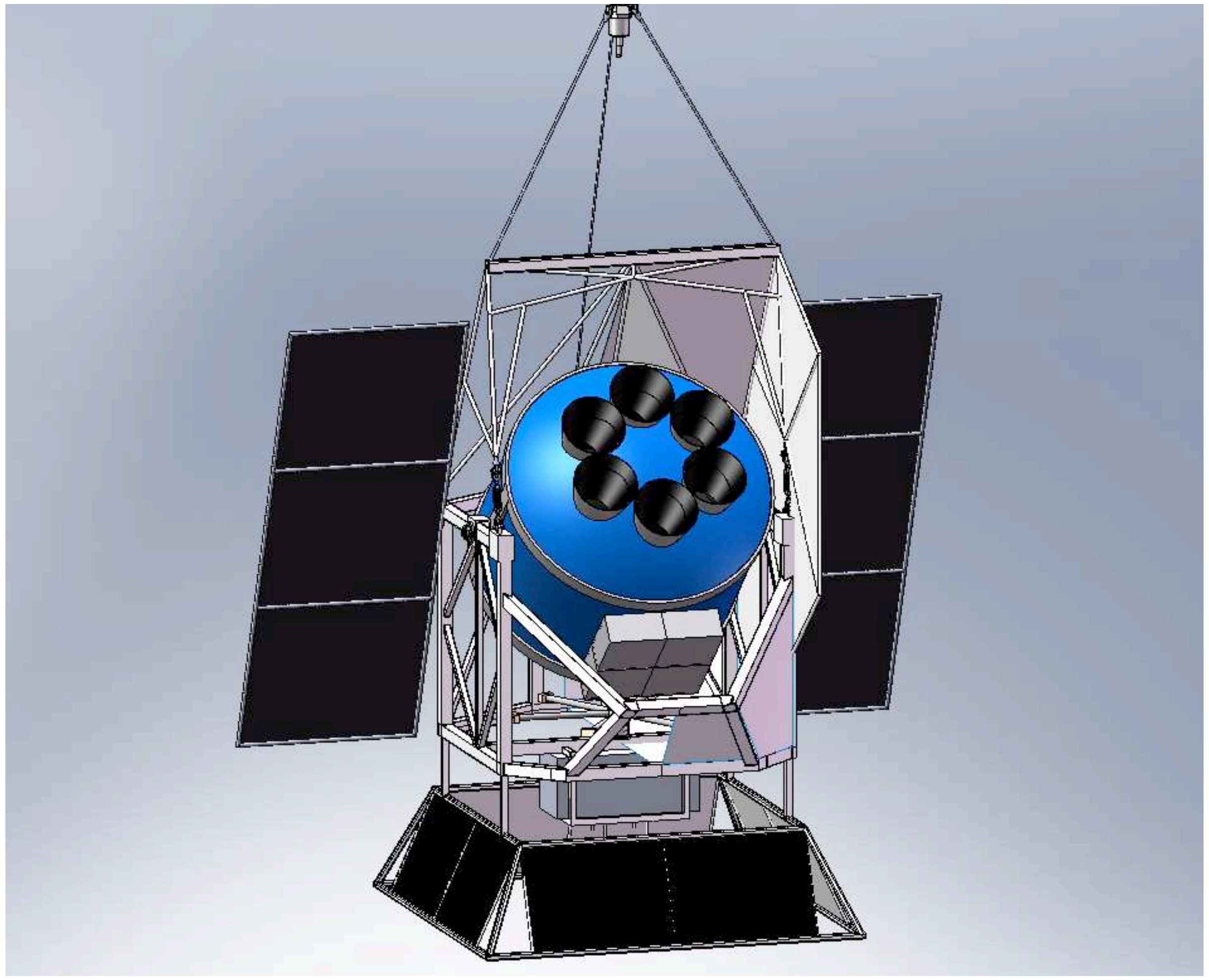
B-modes Experiments

BICEP, QUIET, EBEX, KECK, ABS, Planck, Spider, ...

Spider

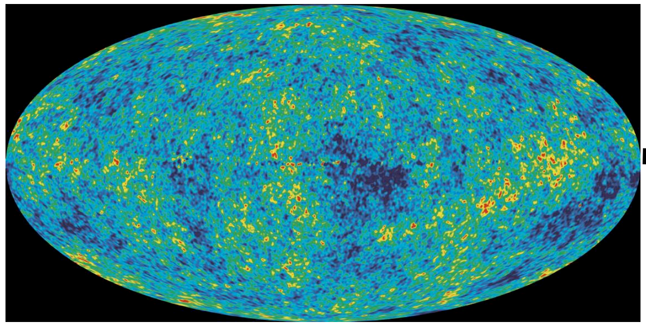
balloon-borne experiment to measure the polarization of CMB

LDB flight (20-40 days), December 2011 (Antarctica)



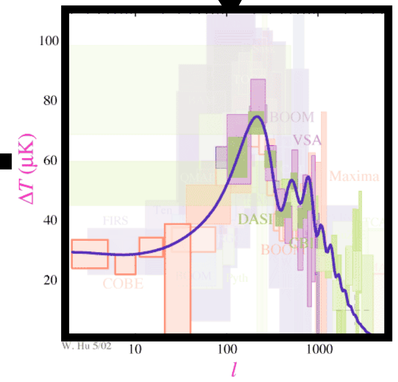
GOAL:
what is the optimum sky coverage for measuring r?

CMB Analysis Pipeline



foregrounds subtraction

power spectra estimation



model testing

parameters

$(\tau, r, \ldots)$

amplitude of gravity waves

- Signal is tiny. Very precise measurements are needed.

Sources of "*noise*"

- ✦ instrument noise
- ✦ cosmic variance: we only have one CMB sky.
- ✦ galactic foregrounds

✦ E/B mixing?

Part of E-mode polarization looks like B-mode.

a geometrical effect due to observing finite sky patches and absent in ideal full sky experiments.

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Avoid E/B mixing ?

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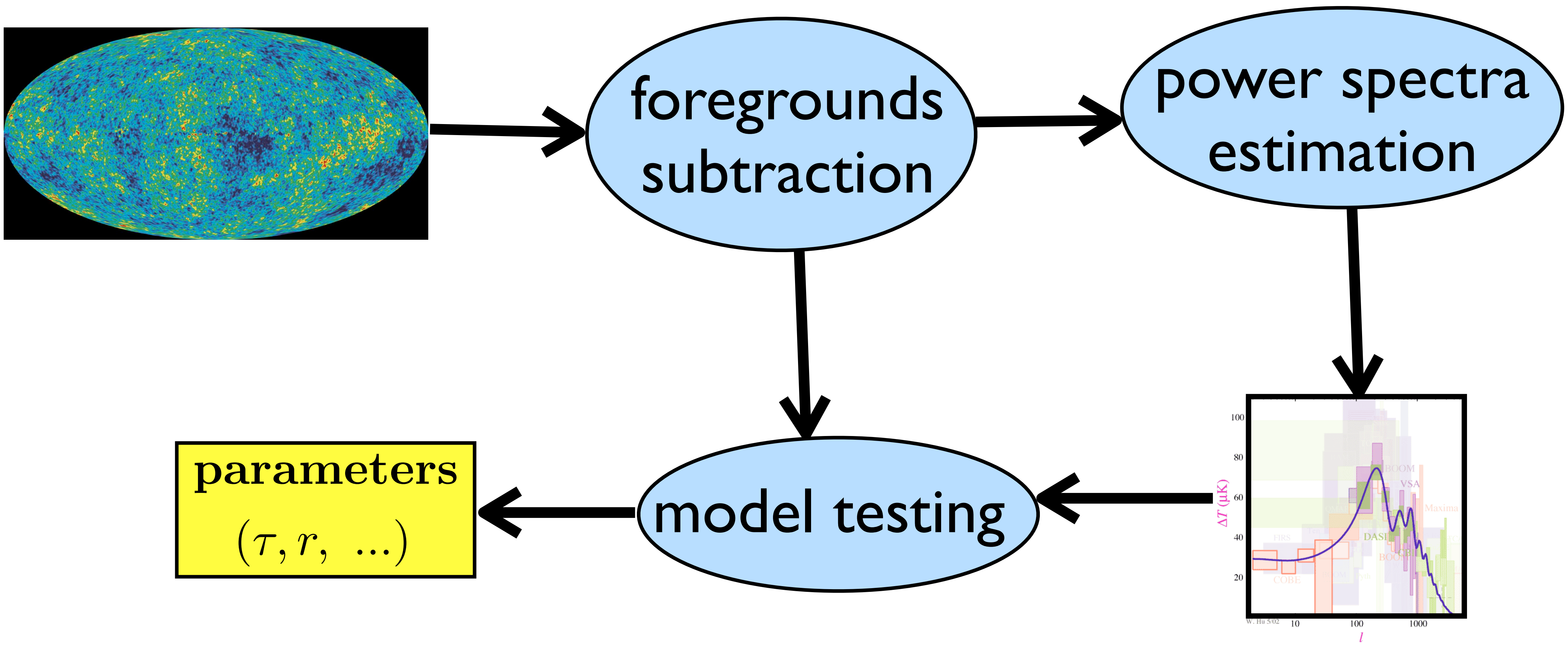
CMB Analysis Pipeline



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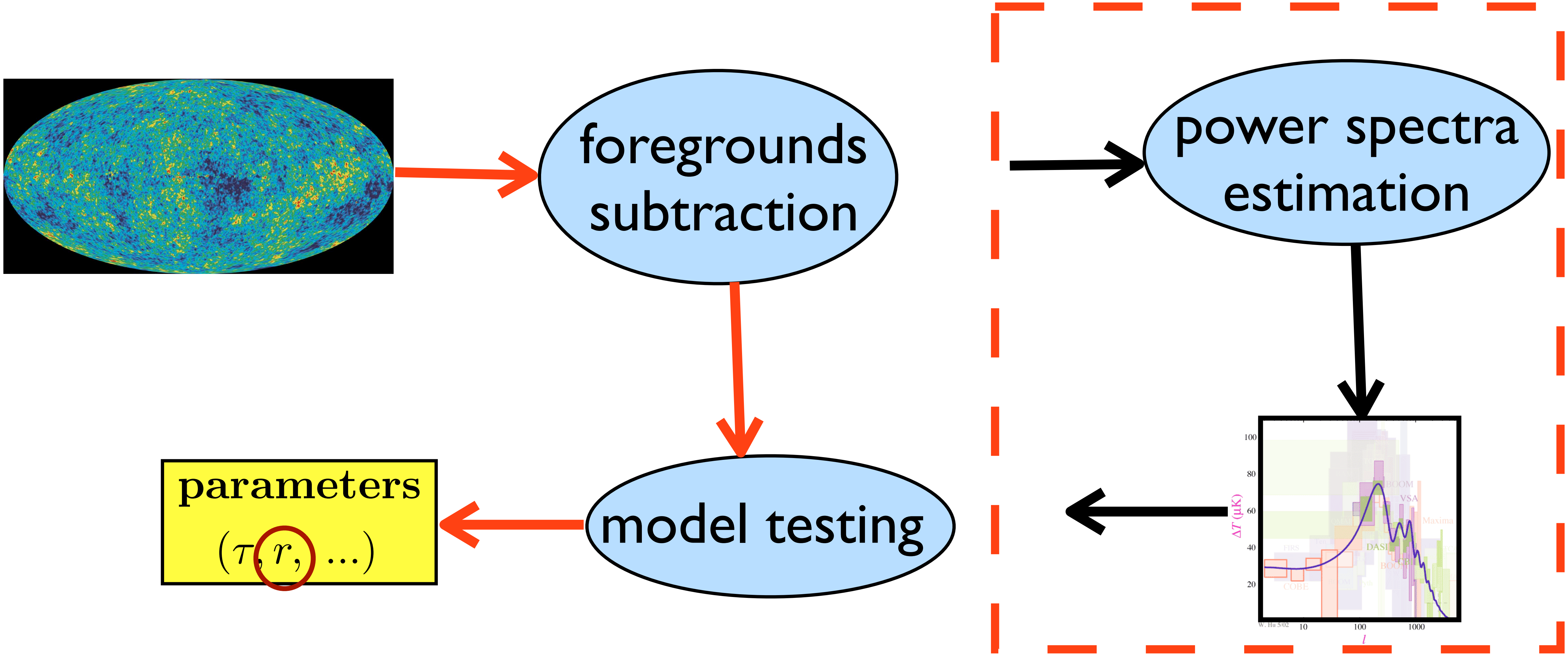
CMB Analysis Pipeline



Map-based likelihood estimator

Map-based maximum likelihood estimator

likelihood $$\mathcal{L}_\Delta(\alpha) \equiv P(\Delta|\alpha) = \frac{1}{(2\pi)^{\frac{N}{2}}|C|^{\frac{1}{2}}} e^{-\frac{1}{2}\Delta^T C^{-1}\Delta}$$

here: r

map $$\Delta = s + n$$

covariance matrix $$C = <\Delta\Delta^\dagger>$$

temperature, polarization
and the cross correlations

$$= C_T + C_N$$

$$= <ss^\dagger> + <nn^\dagger>$$

instrument noise +
uncertainty in foregrounds subtraction

Naturally and optimally deals with the E/B mixing problem
and does the best theoretically possible job.

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Goal

Optimizing sky coverage for measuring r

Simulations/Results

1- Observe a portion of the sky with *Spider* (beam, instrument sensitivity, ...).
How well is the input model recovered?

2- Challenges:

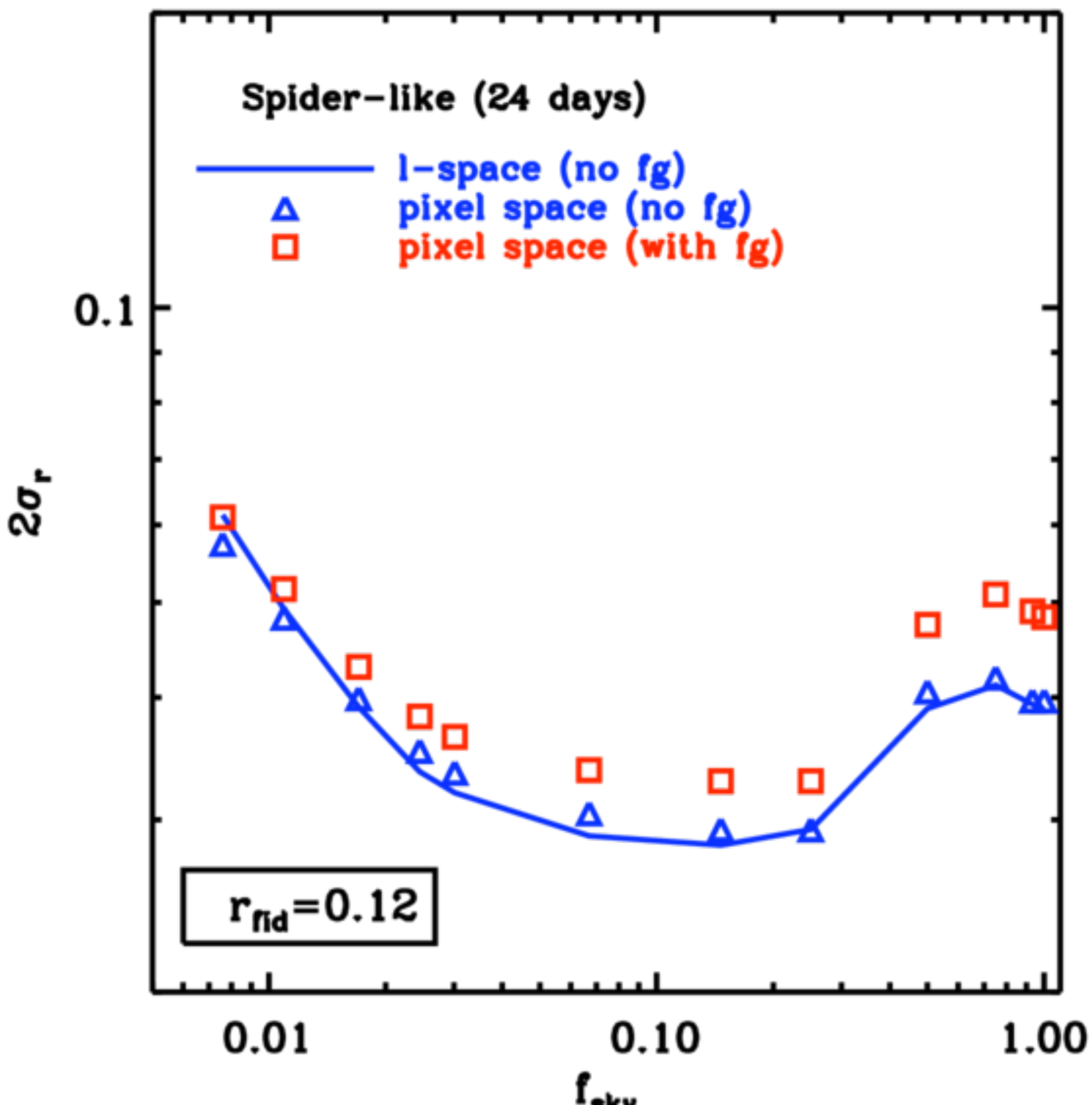
- the signal we are after is *very weak*.
- dealing with huge matrices.

CMB sky simulated with r=0.12

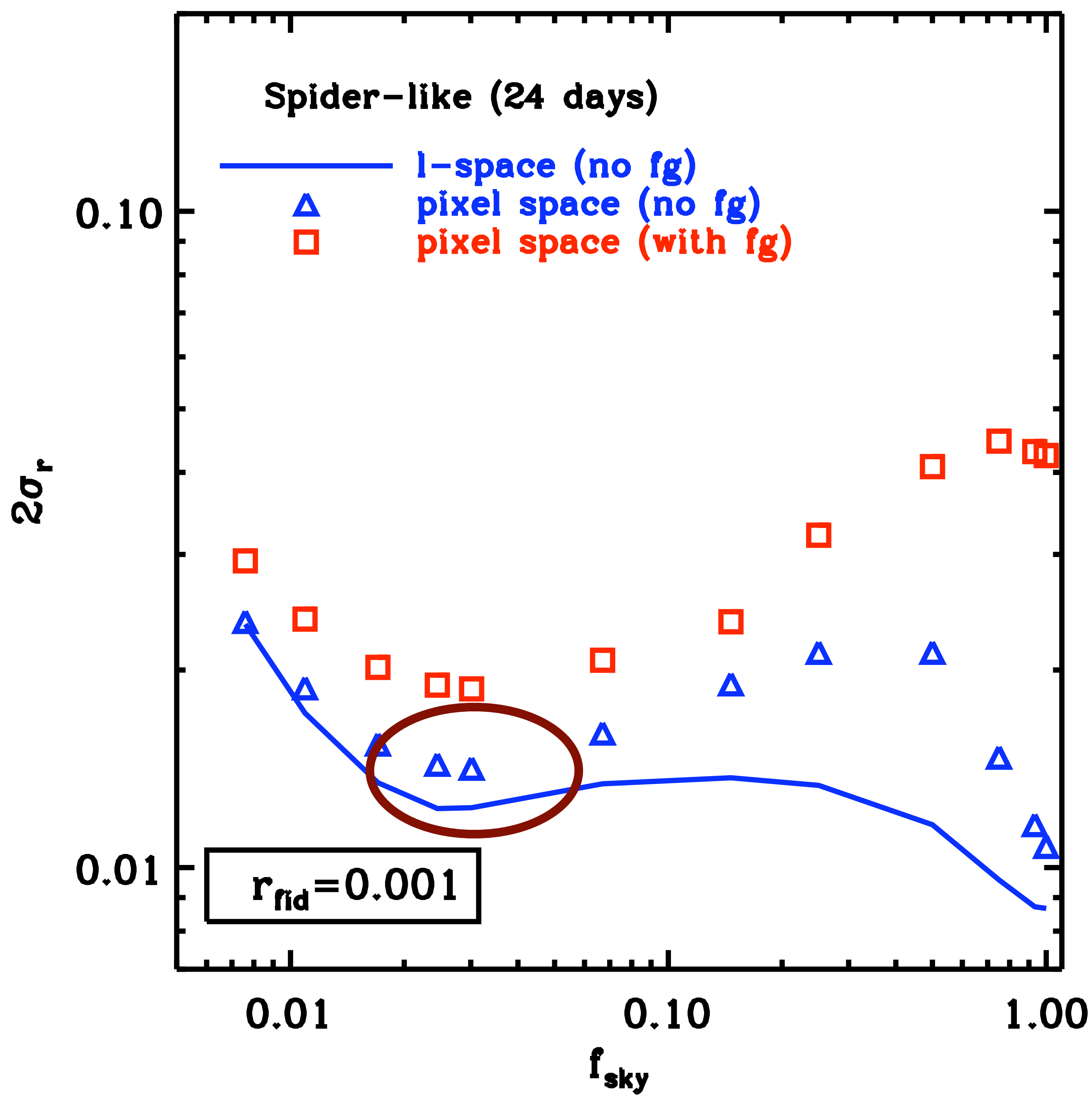
as predicted by $V \propto m^2\phi^2$

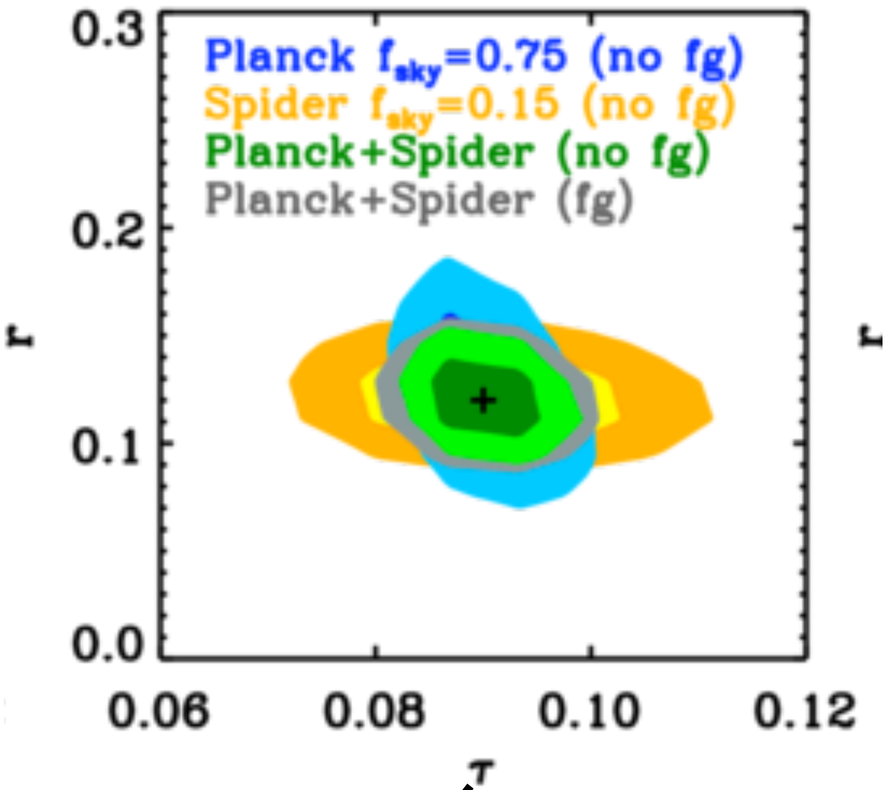
How well can we measure r for different sky cuts?

(with the same observation time)

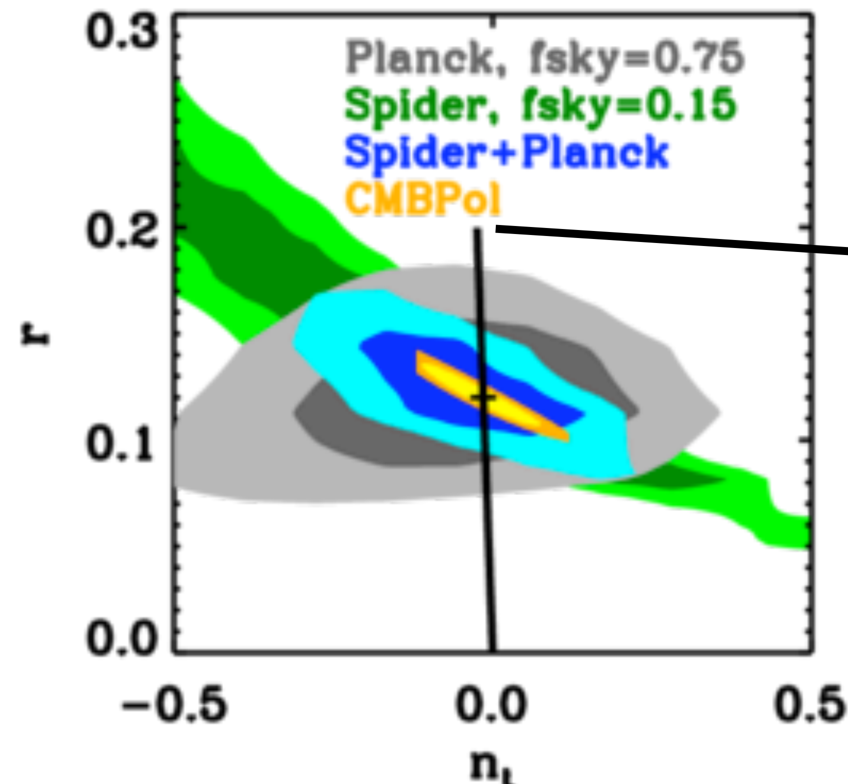


CMB sky simulated with r~0 .
What is upper bound on r for different sky cuts?





optical depth to reionization



consistency line
(slow-roll inflation)

tilt parameter

tells us about the shape of the tensor perturbation.

r tells only about the amplitude.

Summary

In experiments with small sky coverage, E/B mixing introduces non-negligible errors in measuring the gravity wave amplitude.

To avoid these errors, r can be measured directly using a *map-based* likelihood analysis on a feasible time-scale thanks to large parallel computations.

This method naturally and optimally deals with E/B mixing. Recovery of r to better than ± 0.02 seems feasible (with foregrounds ignored.)

Cosmic Microwave Background Radiation

power spectra of fluctuations in temperature (T) and polarization (Q, U)

$$\delta T(\hat{\mathbf{n}}) = \sum_{lm} a^T_{lm} Y_{lm}$$

$$Q + iU(\hat{\mathbf{n}}) = \sum_{lm} {}_2a_{lm} \, {}_2Y_{lm}$$

$$Q - iU(\hat{\mathbf{n}}) = \sum_{lm} {}_{-2}a_{lm} \, {}_{-2}Y_{lm}$$

$$a^E_{lm} = -({}_2a_{lm} + {}_{-2}a_{lm})/2$$

$$a^B_{lm} = i({}_2a_{lm} - {}_{-2}a_{lm})/2$$

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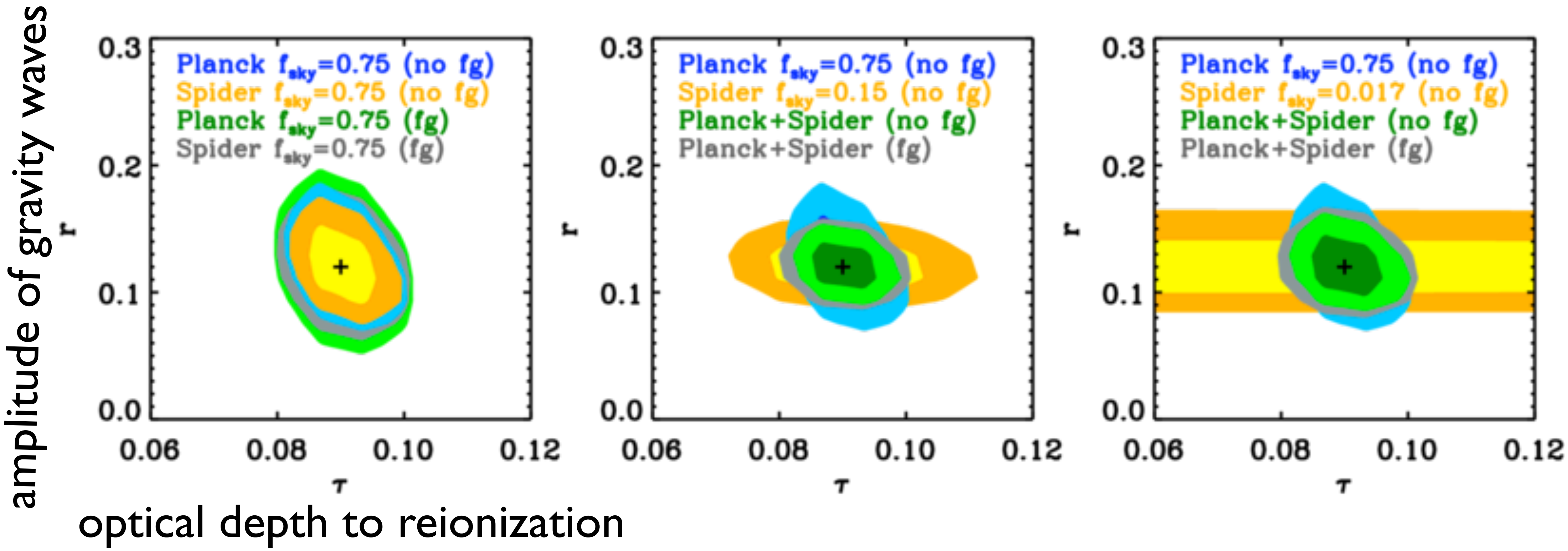
Planck + Spider



➡ small sky Spider + (full sky) Planck