CMB Foregrounds in the Planck Era

(almost...)

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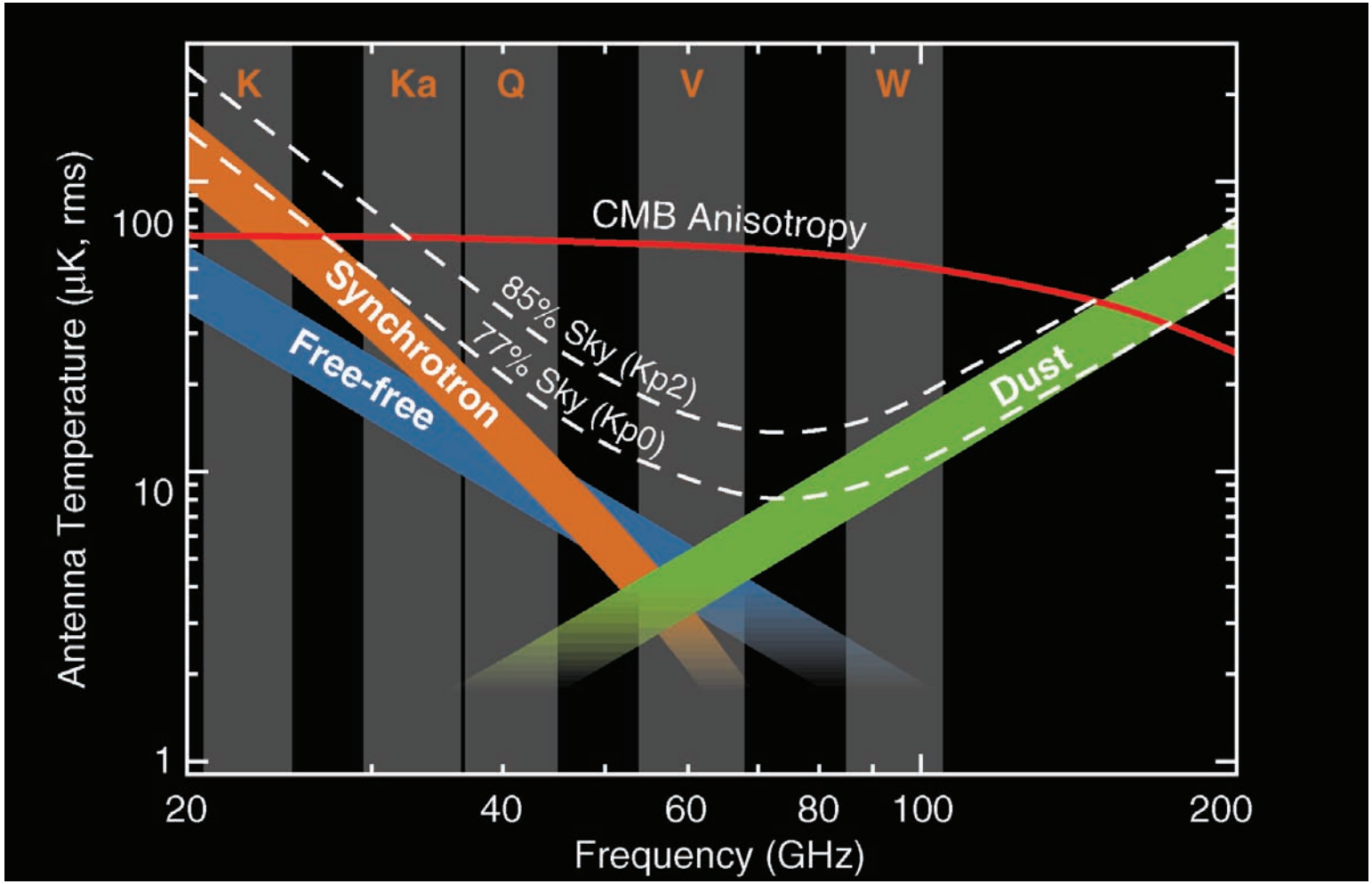
Overview

- Our knowledge of foregrounds will improve significantly in several big steps over the next 1.5 years, and some smaller ones
- The first Planck results will be released 21 March
  - 15.5 months of data (out of 29 total for HFI, $\sim$50 for LFI)
  - Temperature only
  - Unprecedented effort on diffuse component separation
- Within a few months Planck expects to submit several papers on foreground polarization
- The second Planck release will be probably mid 2014
  - Full data
  - Temperature and polarization
- A number of sub-orbital experiments is providing useful and very low noise data on small(er) regions of the sky

Overview — cont'd

- But there's a lot we already know
- Today I'll concentrate on extracting a few key points that are relevant for experimental design, based on what we already know
  - No simulations
  - No estimates of how well we can ultimately do
  - Concentrate on relative difficulty, about what's harder and what's easier to do
- Diffuse foregrounds only
  - Residual discrete foregrounds are complicated, important, and a subject in their own right. They need to be handled in a different way.

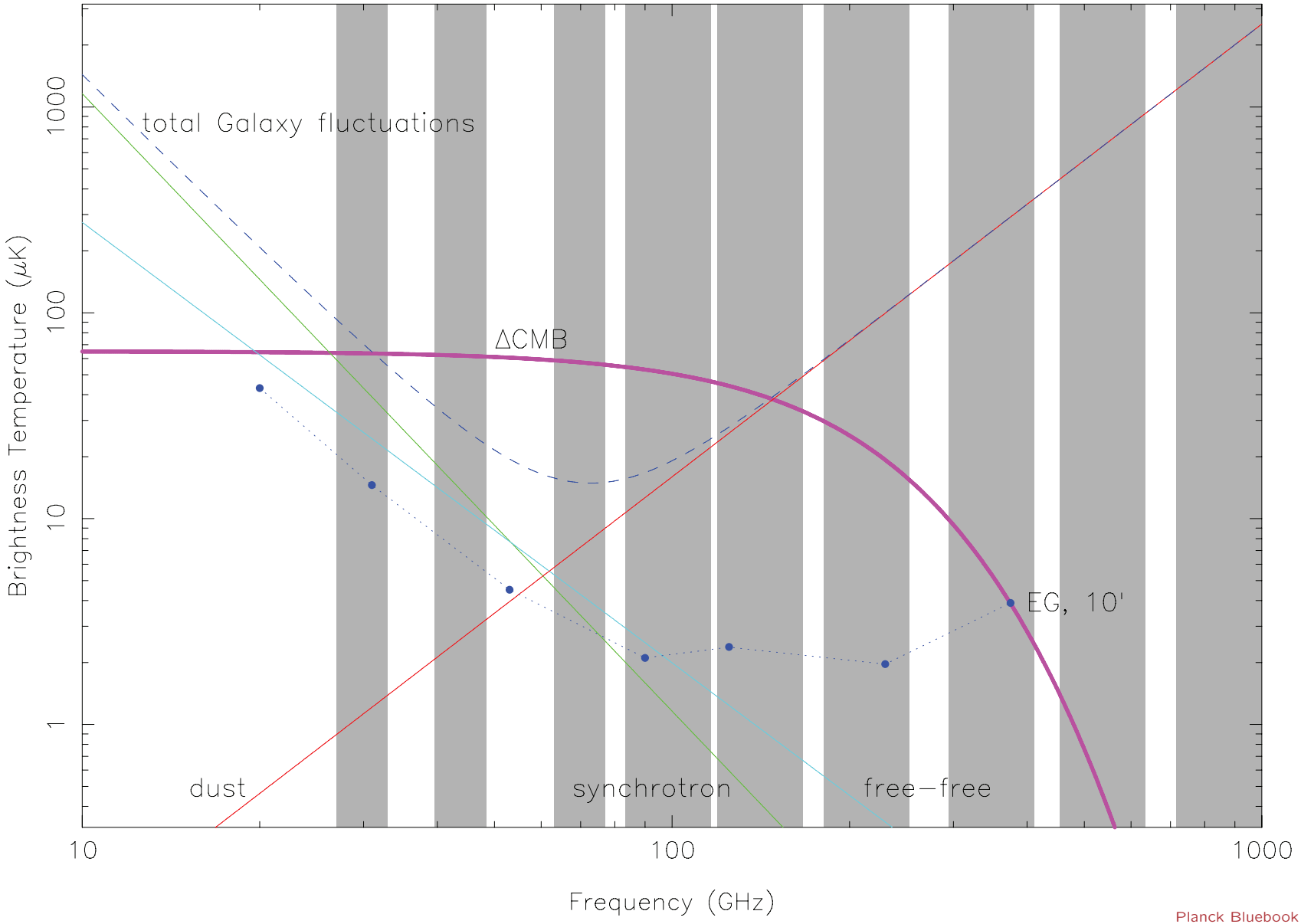
Foregrounds; WMAP Frequency Range



- This is temperature. Life is easy. Sort of. But. . .

N.B.—"Dust" is a frequency-dependent mixture of Galactic dust and the CIB. Spinning dust emission is not separated out.

Foregrounds; Planck Frequency Range



Planck Bluebook

A List of Diffuse Foregrounds

- Synchrotron (2 spatially-varying parameters, minimum)
- Free-free (1)
- Spinning dust ("anomalous microwave emission" = AME) (≥ 2, next slide)
- Thermal dust (3)
- Cosmic infrared background
  - Resolution-dependent; becomes a discrete-source foreground as resolution increases.
  - Isotropic
- Line emission
  - HI
  - CO
  - etc.

A&A 536, A20 (2011)

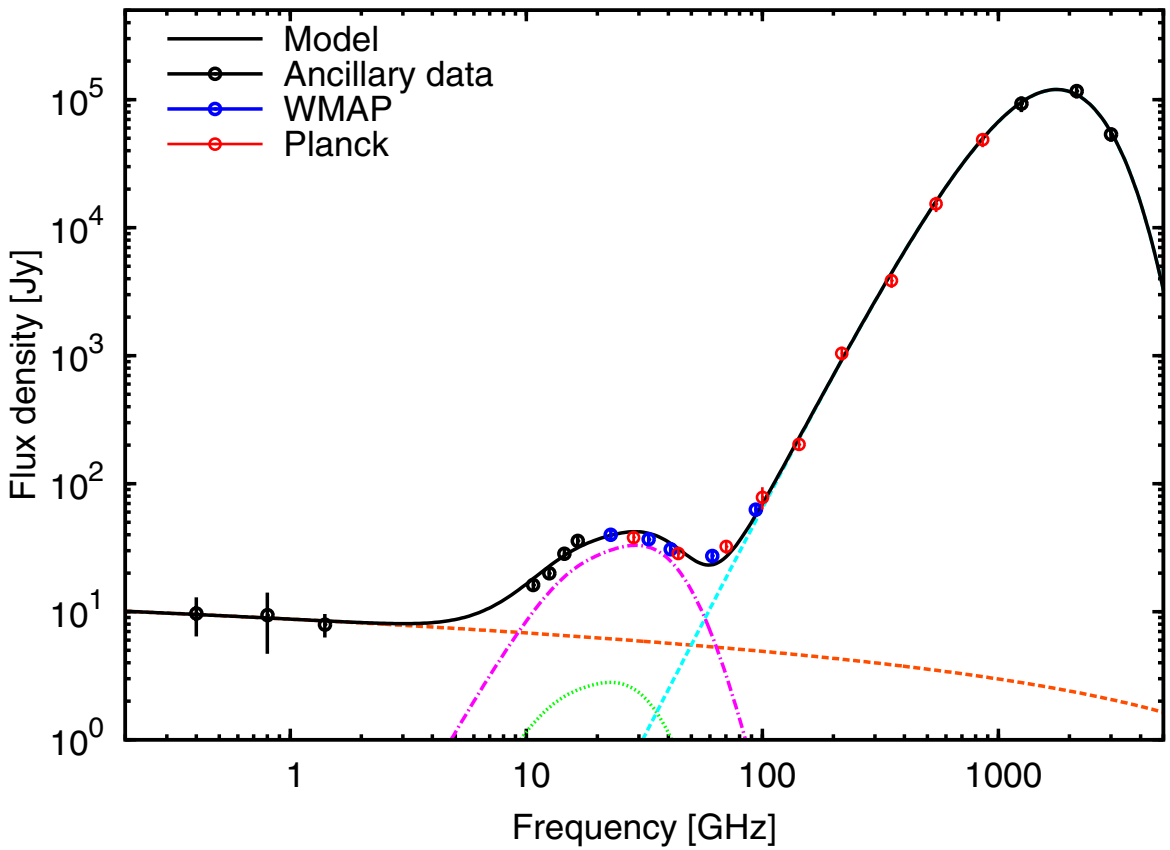


Fig. 4. Spectrum of AME-G160.26−18.62 in the Perseus molecular cloud. The best-fitting model consisting of free-free (orange dashed line), spinning dust, and thermal dust (light blue dashed line) is shown. The two-component spinning dust model consists of high density molecular gas (magenta dot-dashed line) and low density atomic gas (green dotted line).

Foreground Polarization

- From WMAP, e.g., Macellari et al. MNRAS 418, 888, 2011
  - Synchrotron: 5–40%, higher at high latitudes. Average for $|b| > 20^\circ$ is 19.3%
  - Free-free and anomalous dust relatively unpolarized
- From Archeops, e.g., Ponthieu et al. A&A 444, 327, 2005
  - Dust: 5–10%, even higher
  - "We have extrapolated our results to the reference frequency 100 GHz. . .The upper limit on the E and B modes becomes 0.2 $\mu\mathrm{K}^2_{\mathrm{CMB}}$. These values show that even at 100 GHz where dust radiation is expected to be lower than the CMB, its polarization may be very significant compared to the CMB and should be subtracted with care from the observations."
- Whereas for the CMB, polarization fractions are low (E) and really low (B).

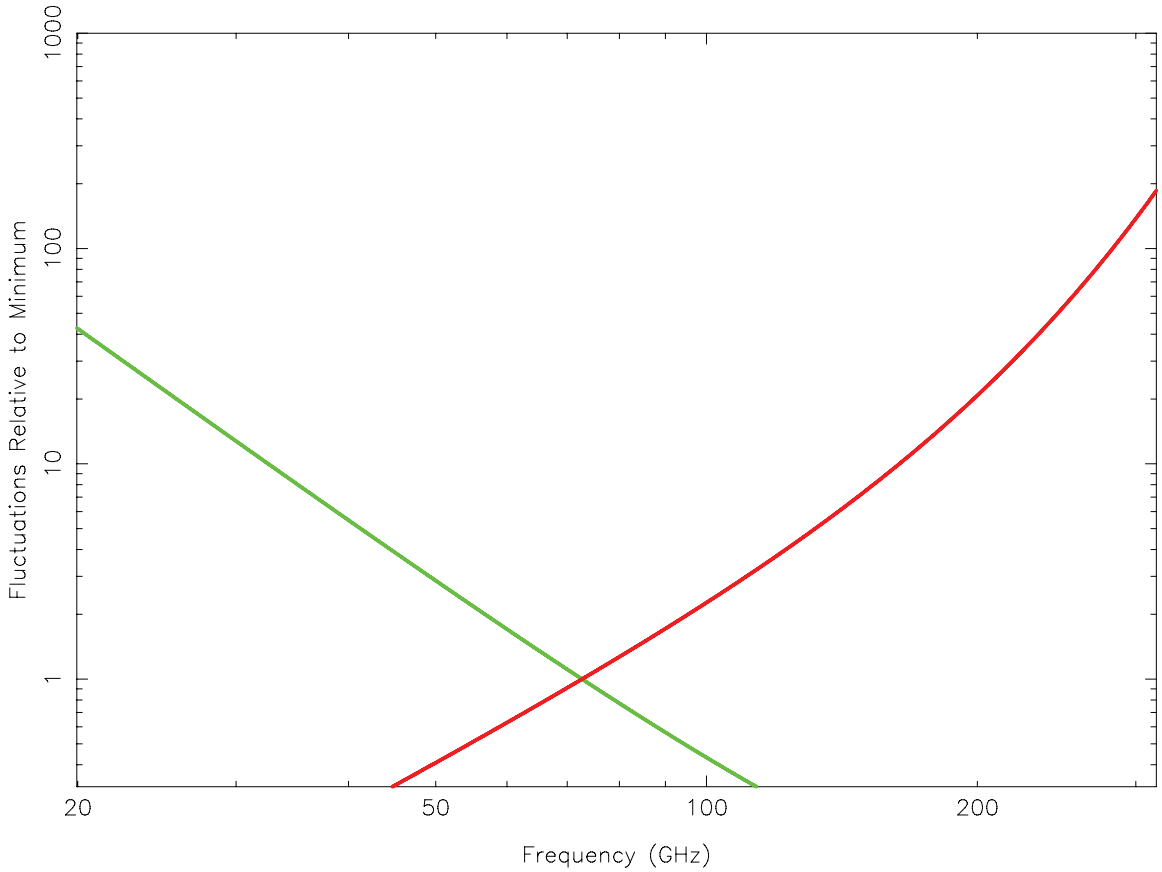
THERE IS NO ESCAPE FROM FOREGROUNDS IN POLARIZATION!!!

Detection of Polarization

- Real instruments have some "leakage" from temperature to polarization
- 1% is a rough order of magnitude
- $\Rightarrow$ even unpolarized foregrounds contribute to the polarized signal
  - Sure, measure the sky, measure the leakage, remove it
  - But there is always some residual error, and the stronger the starting foreground signal the more the error

Foregrounds—again

- Look at level of "low frequency" and "high frequency" foreground fluctuations relative to their values at the foreground minimum:



- These are seriously steep functions of frequency!

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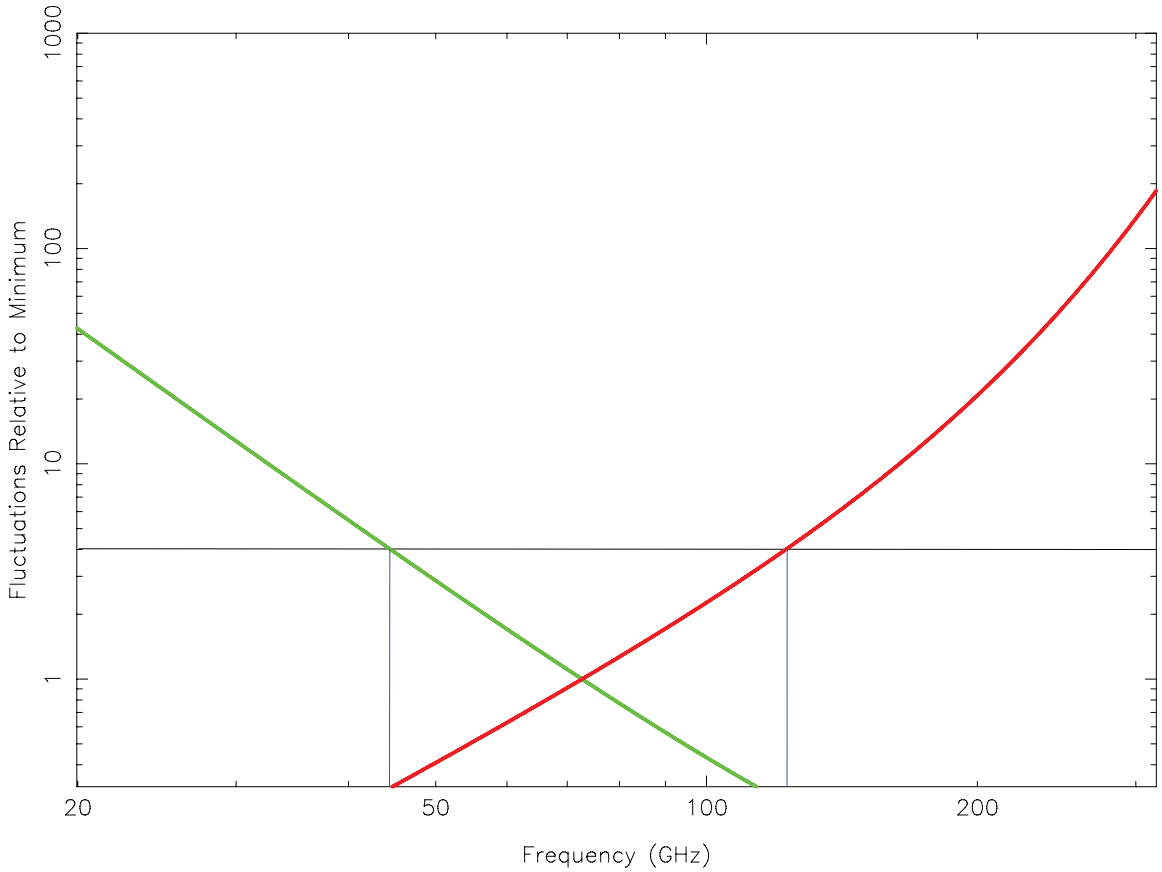
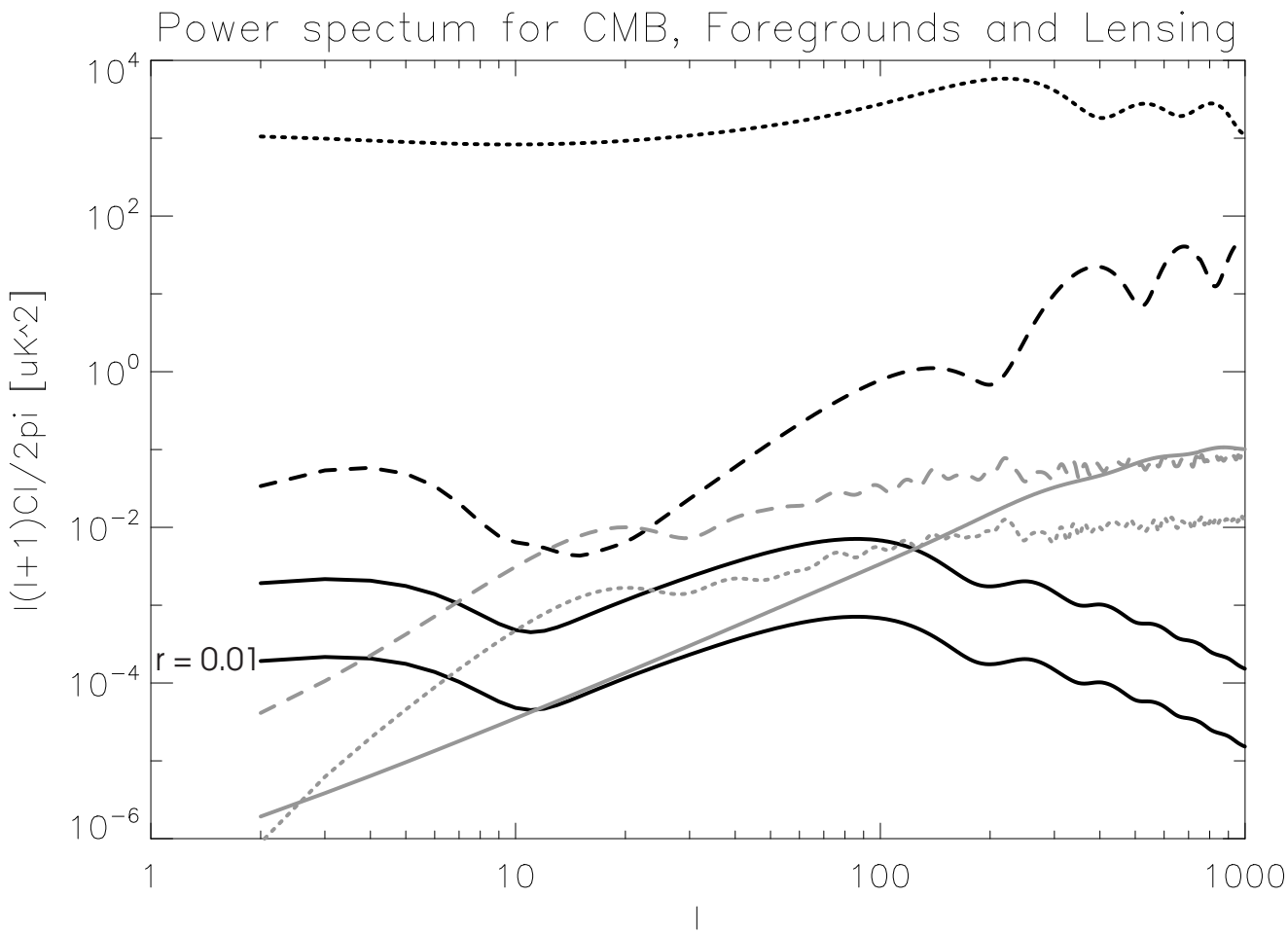


- These are seriously steep functions of frequency!


No foregrounds yet. So far so good!



CLOVER/North

Temperature (black dotted), E-mode (black dashed), and Bmode (black solid; upper: $r = 0.1$, lower: $r = 0.01$) for the CMB. Weak gravitational lensing (grey solid), Galactic synchrotron (grey dashed), and thermal dust (grey dotted) emission at 100 GHz. The levels of the galactic emission are based on very simple models, for rough comparison only, and are calculated in regions of low emission.

What About...?

- "Observe above (below) the frequency minimum. Better to observe one foreground well than many."
  - Foregrounds increase so rapidly away from the minimum ($\sim \nu^{-3}$, $\sim \nu^{2}$) that this is asking a lot
- "Dust isn't highly polarized."
  - Archeops!
- "Observe in really clean patches of sky."

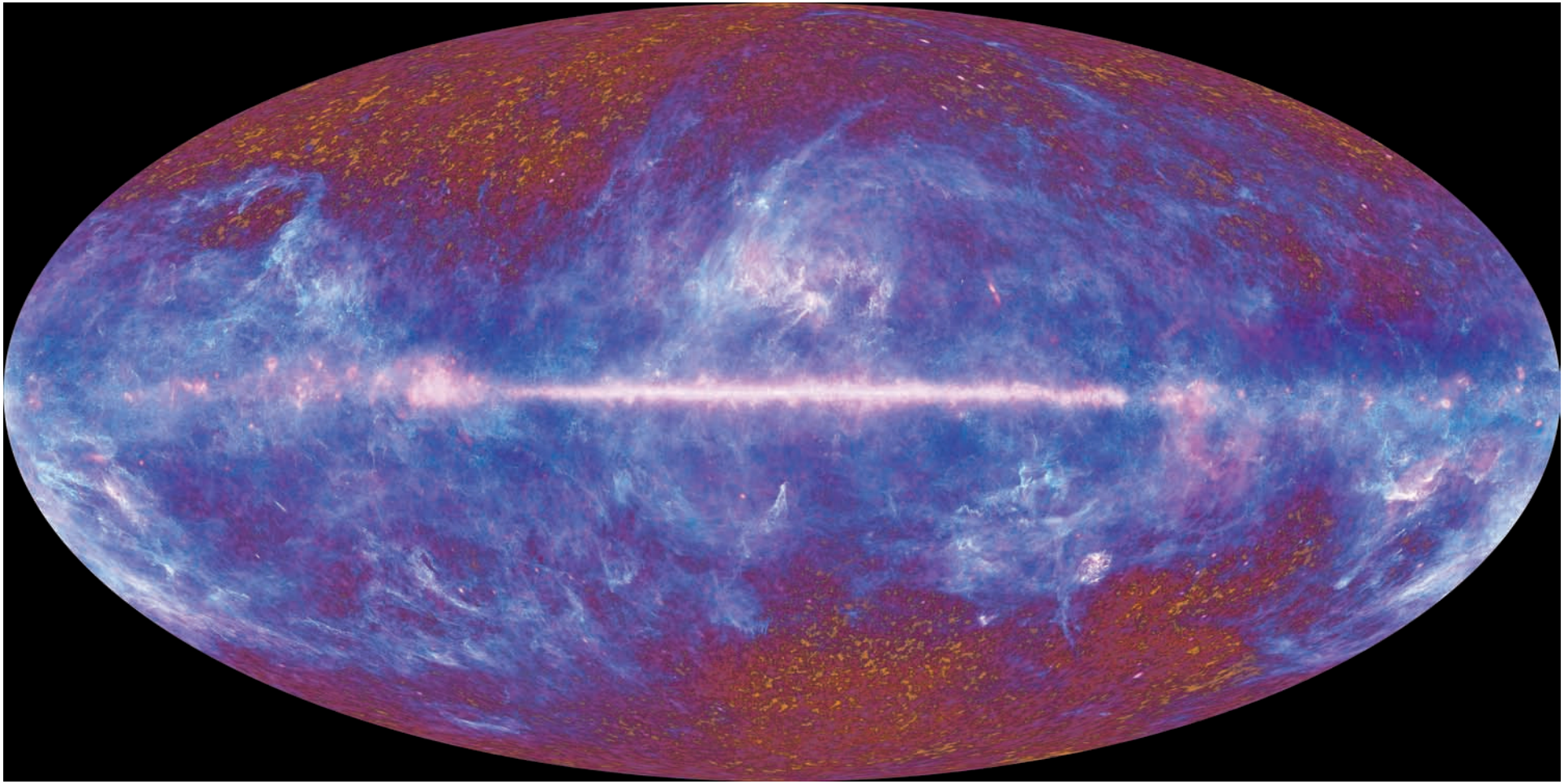
Foregrounds—cont'd

- "Observe in really clean patches of sky."

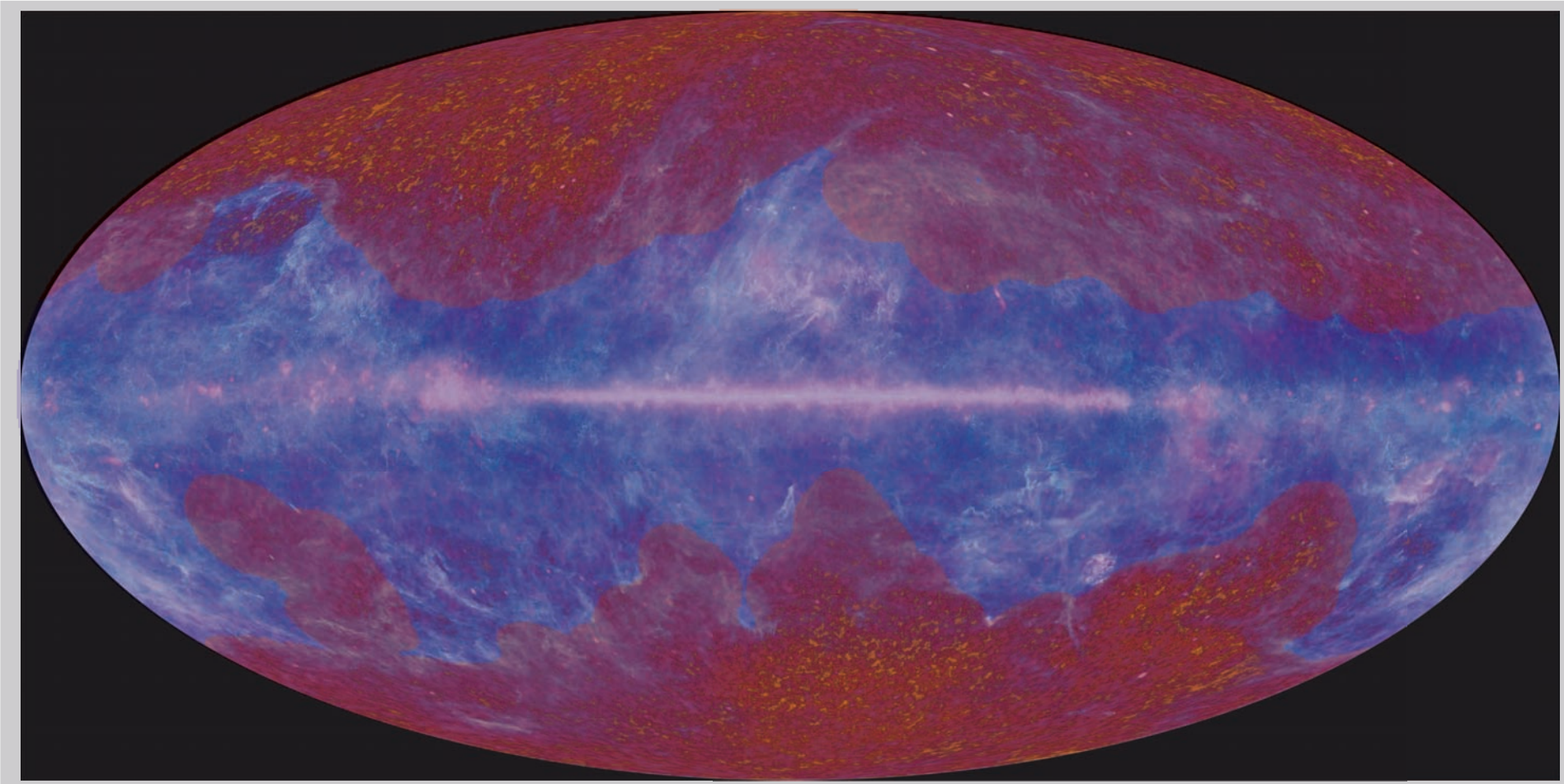
LET'S TAKE A LOOK.

Thanks to Ingunn Wehus for the masks, etc.

Planck Multi-frequency Combination 2010

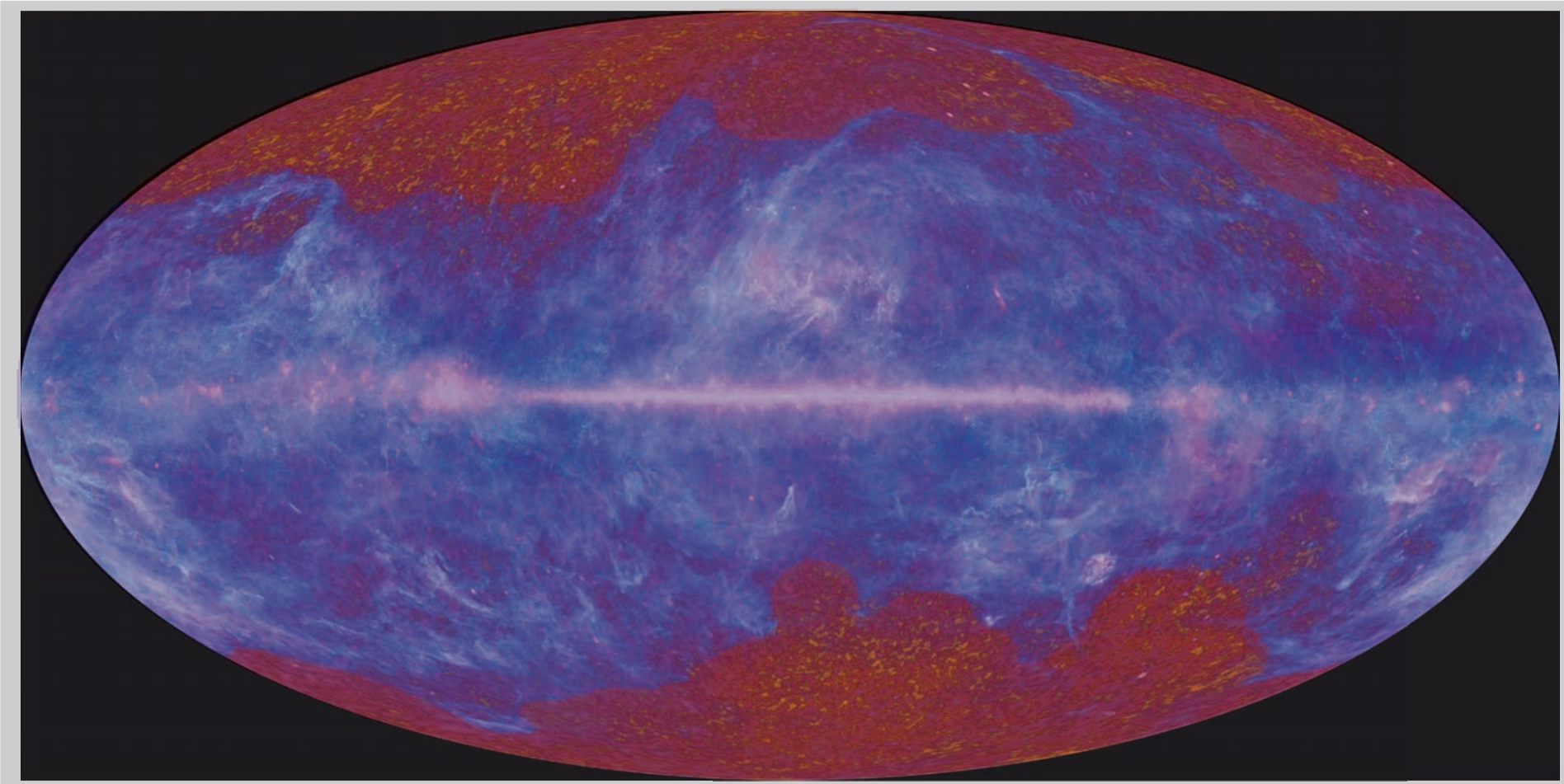


Mask Leaving 52% of Sky



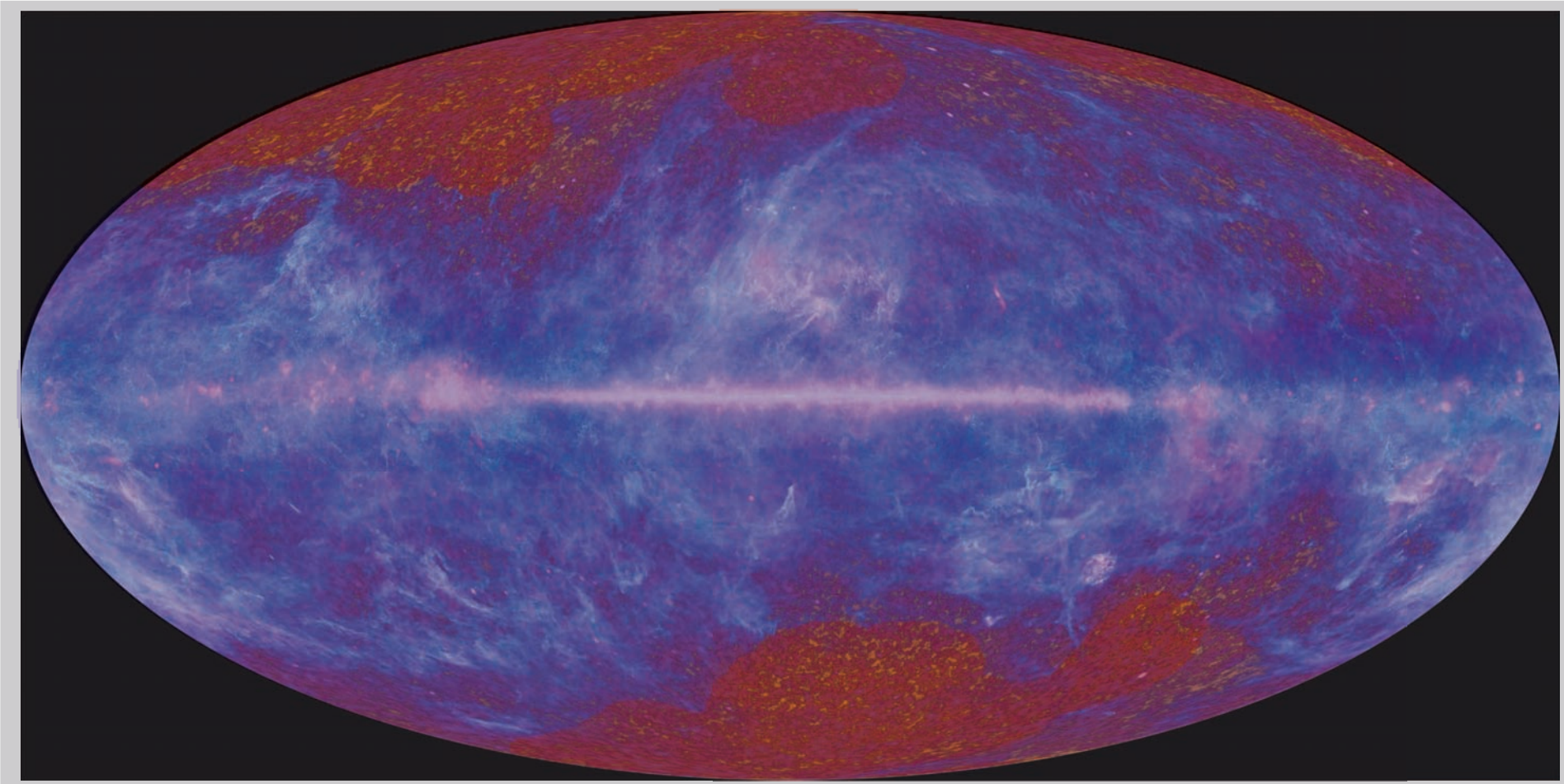
- Boundary level $\gtrsim 1500\,\mu$K

Mask Leaving 25% of Sky



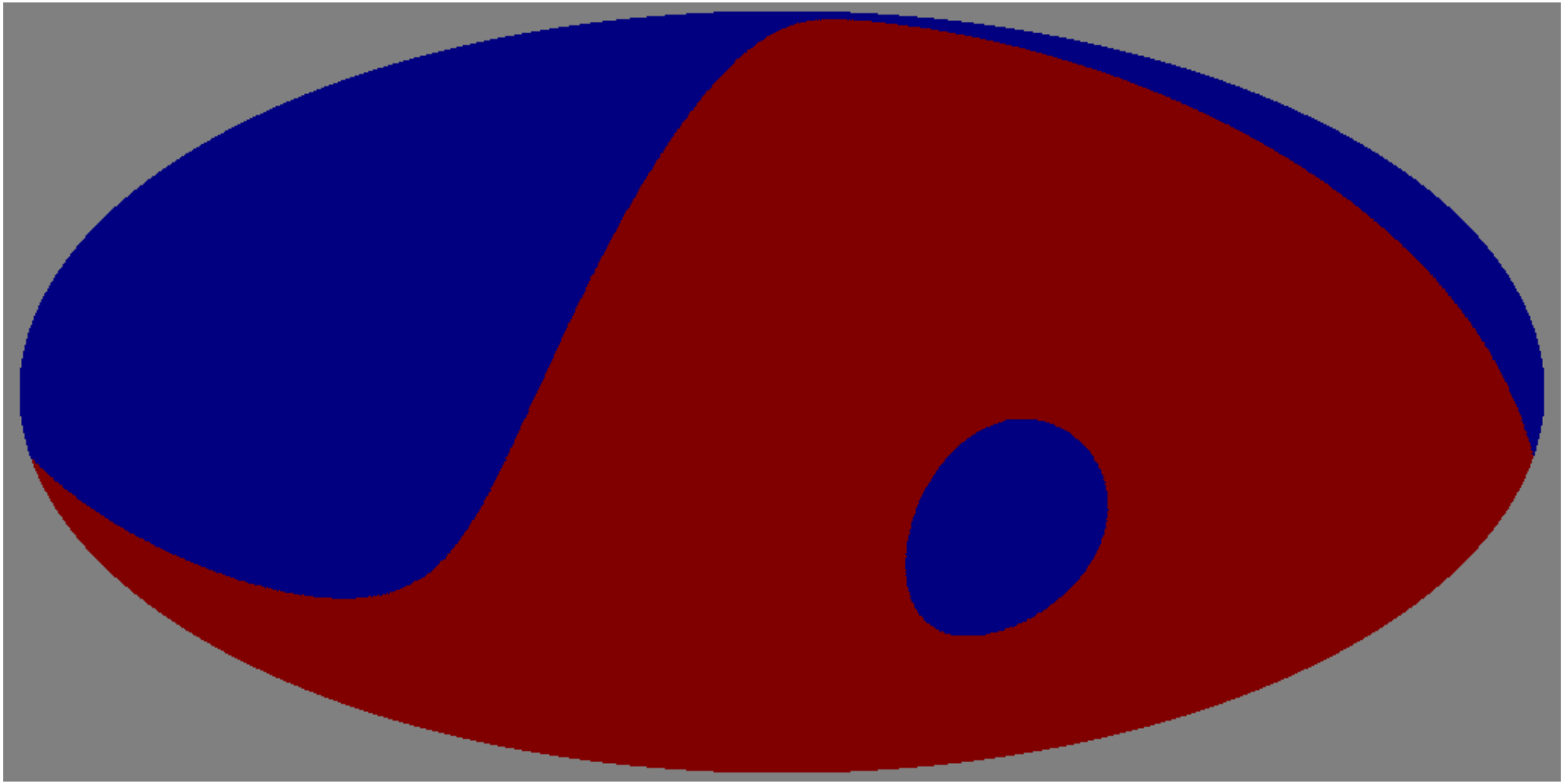
- Boundary level $\approx 900\,\mu$K

Mask Leaving 15% of Sky

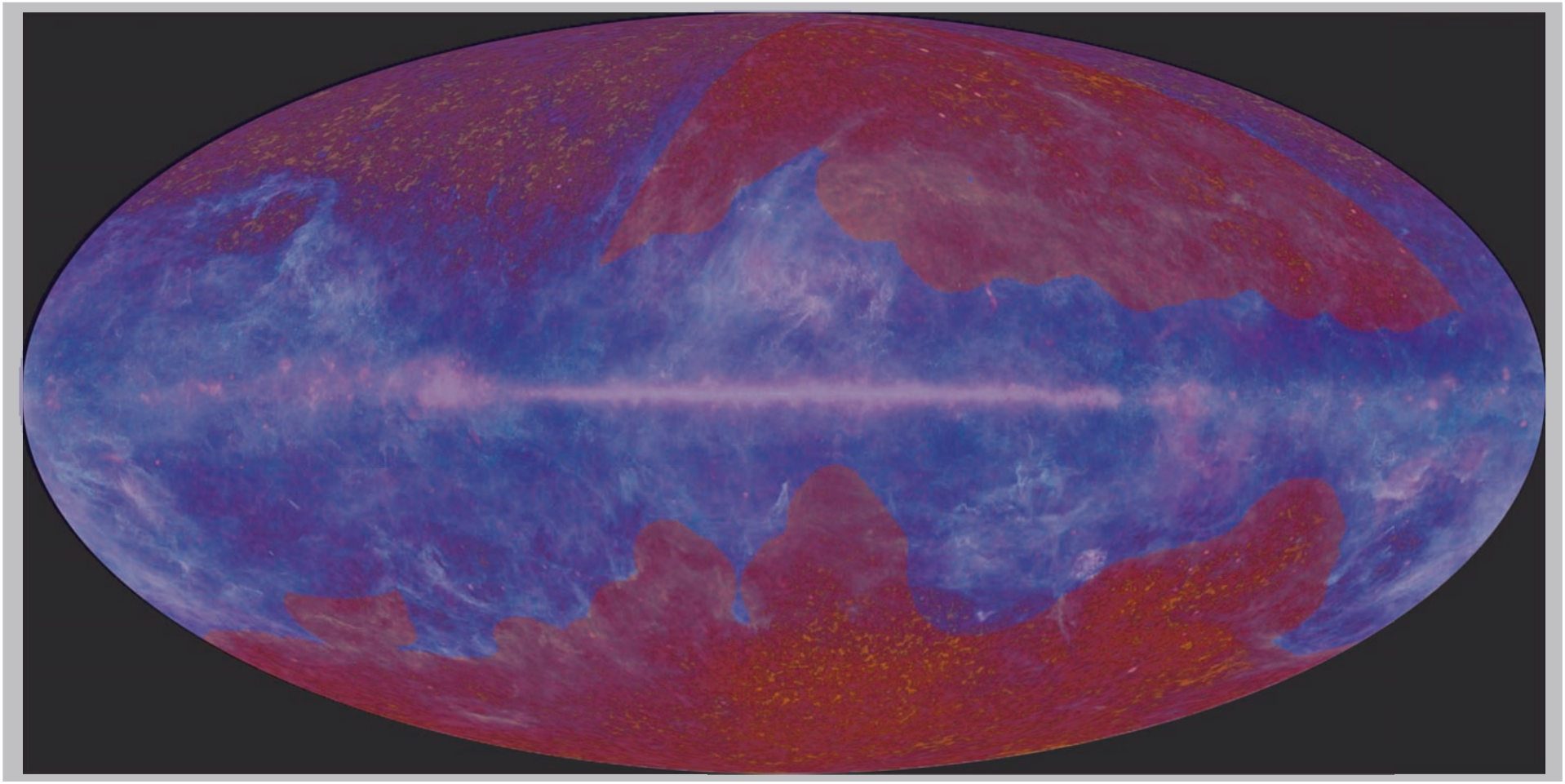


- Boundary level $\approx 450\,\mu$K

Sky Visibility from Atacama, $\geq 45^\circ$ elevation

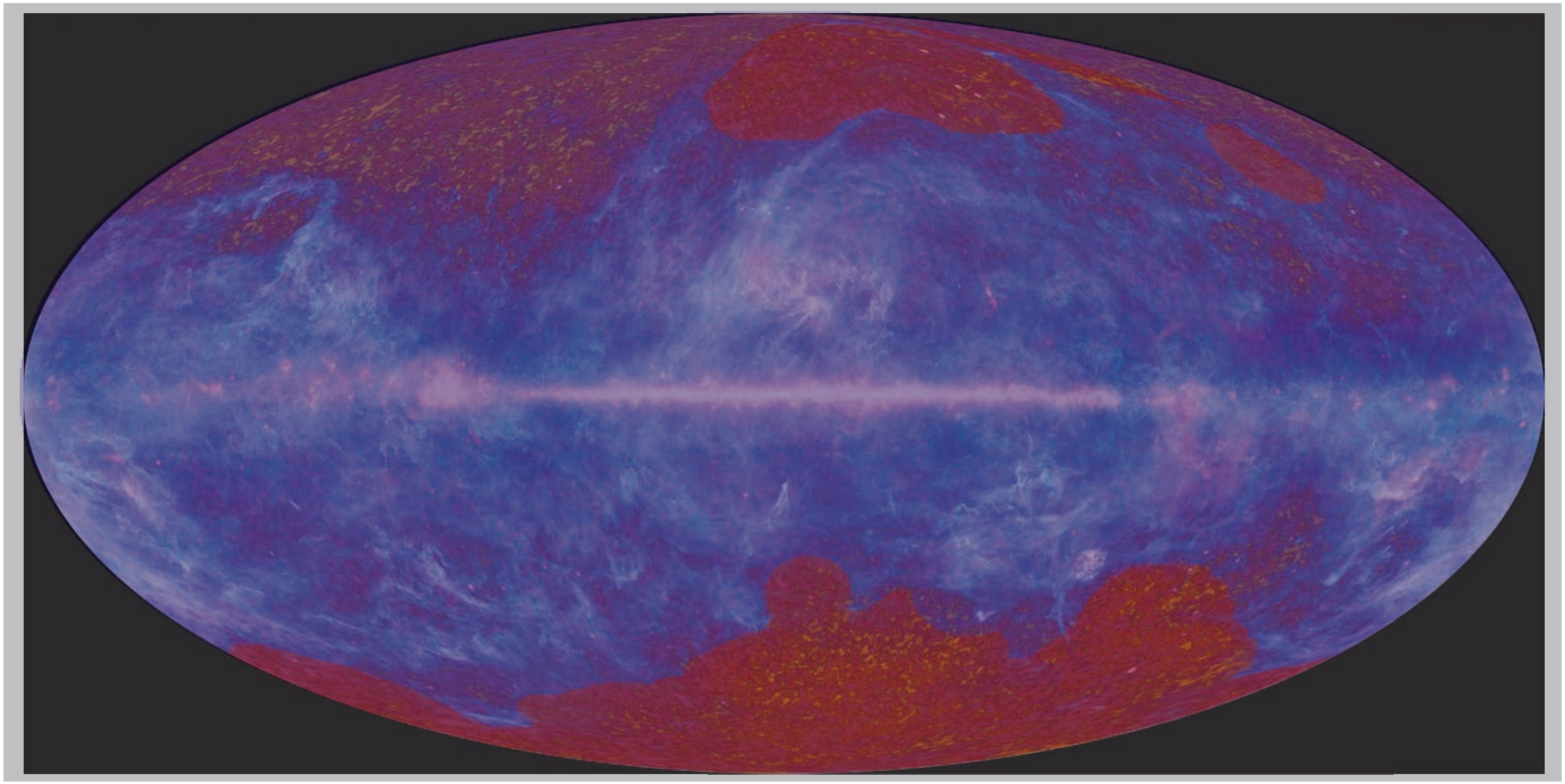


Atacama + 52% Mask



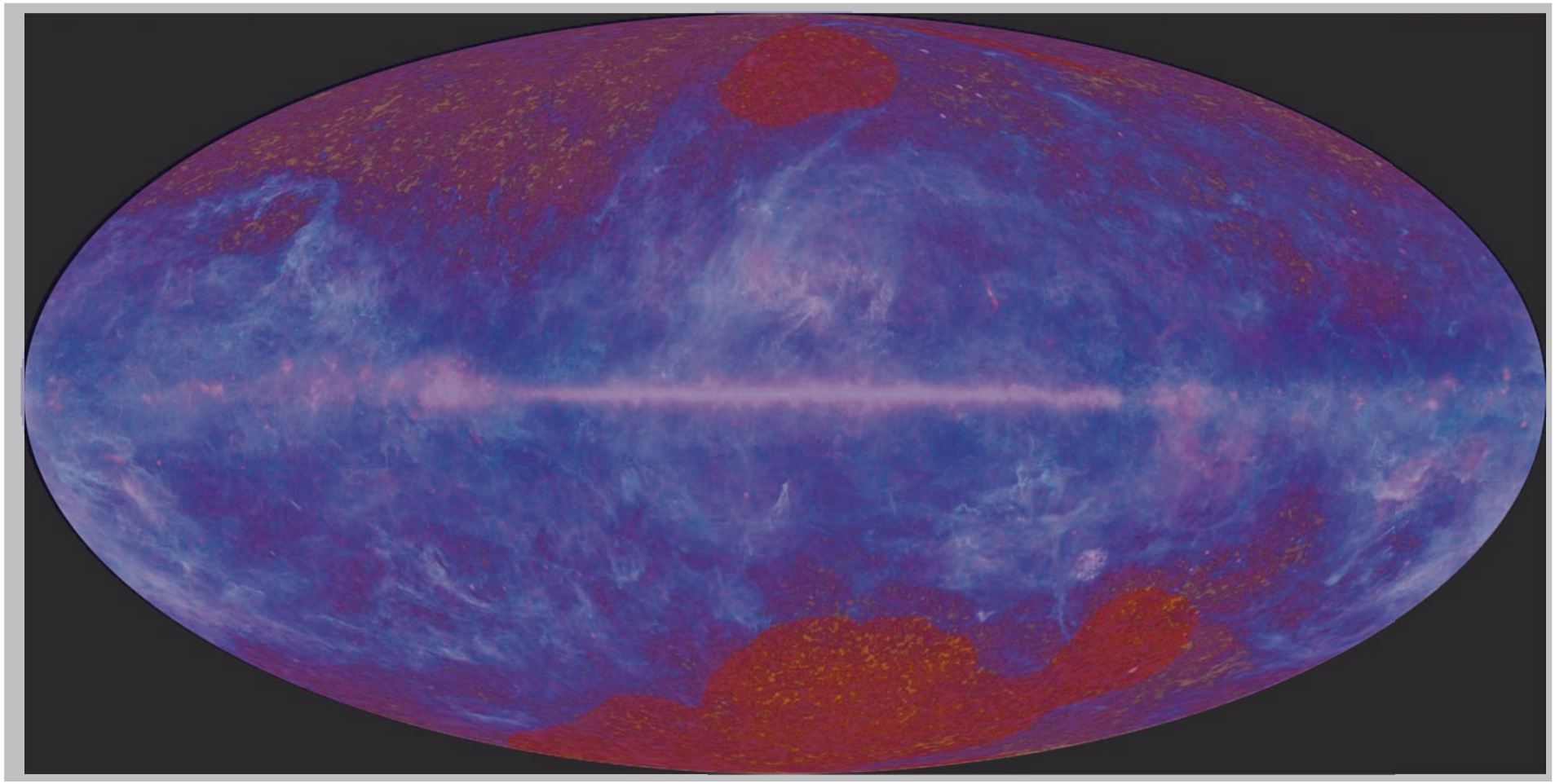
- 35% of sky available and outside of mask

Atacama + 25% Mask



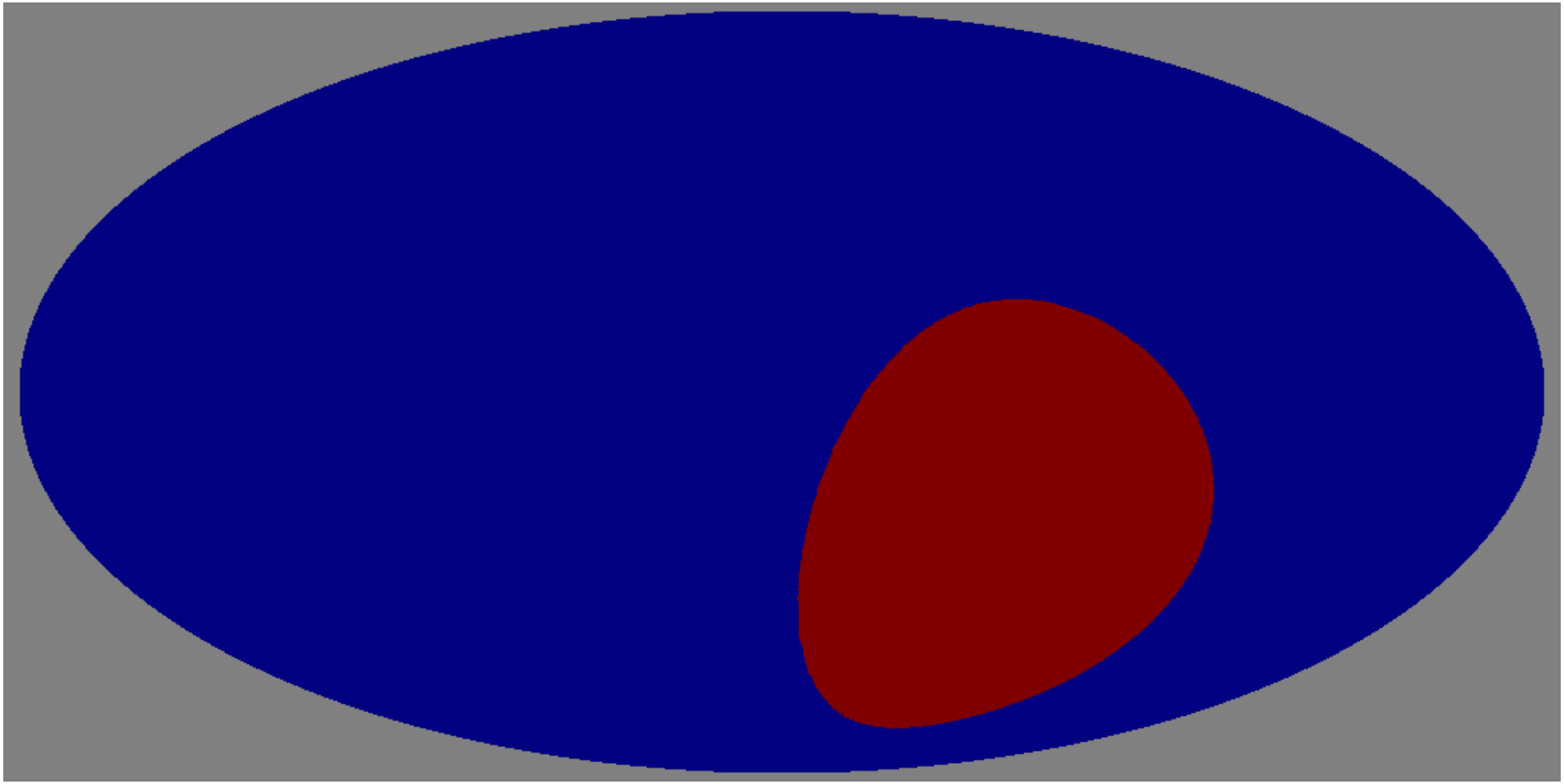
- 15% of sky available and outside of mask

Atacama + 15% Mask

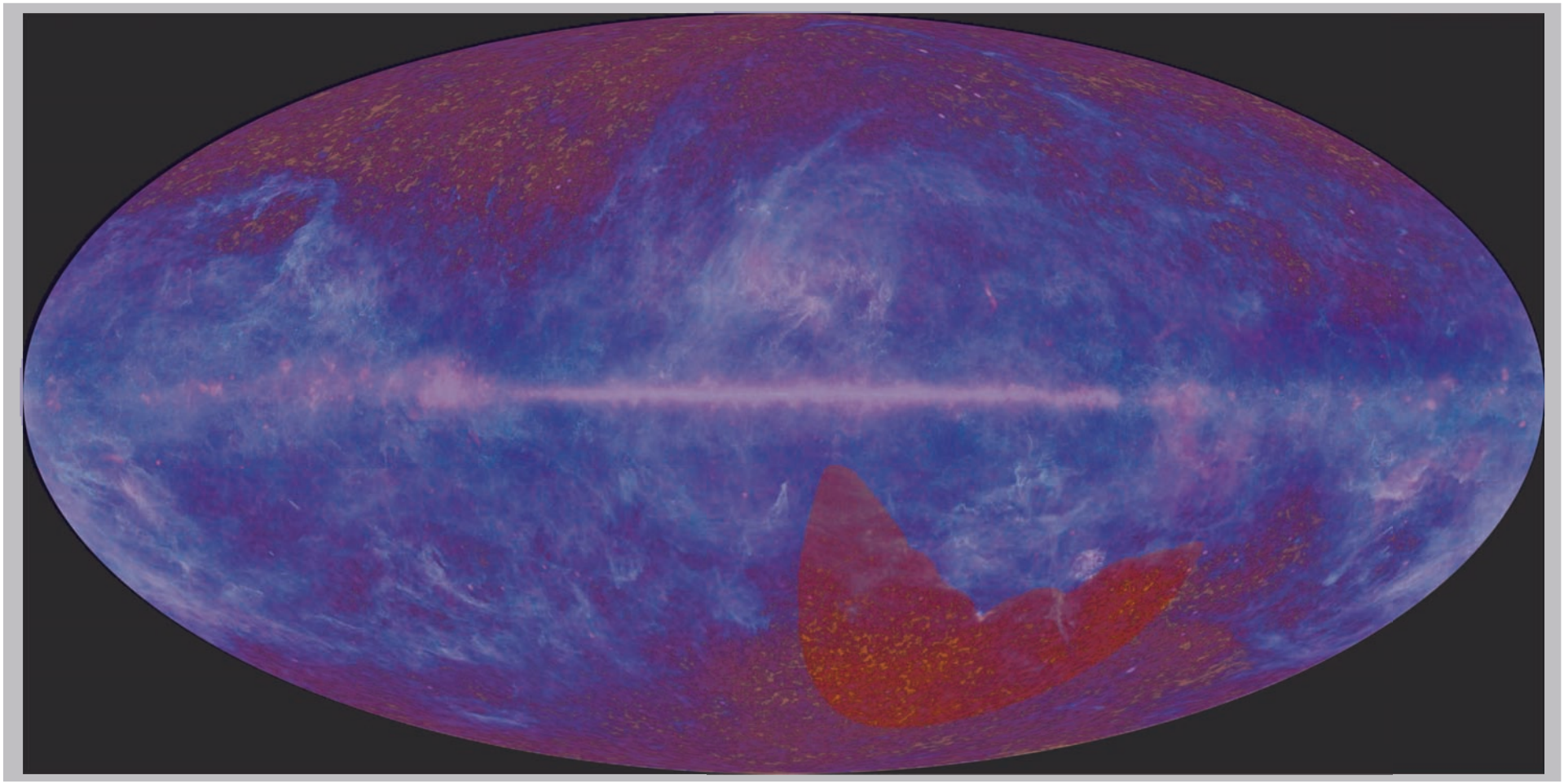


- 8% of sky available and outside of mask

Sky Visibility from South Pole, $\geq 45^\circ$ elevation

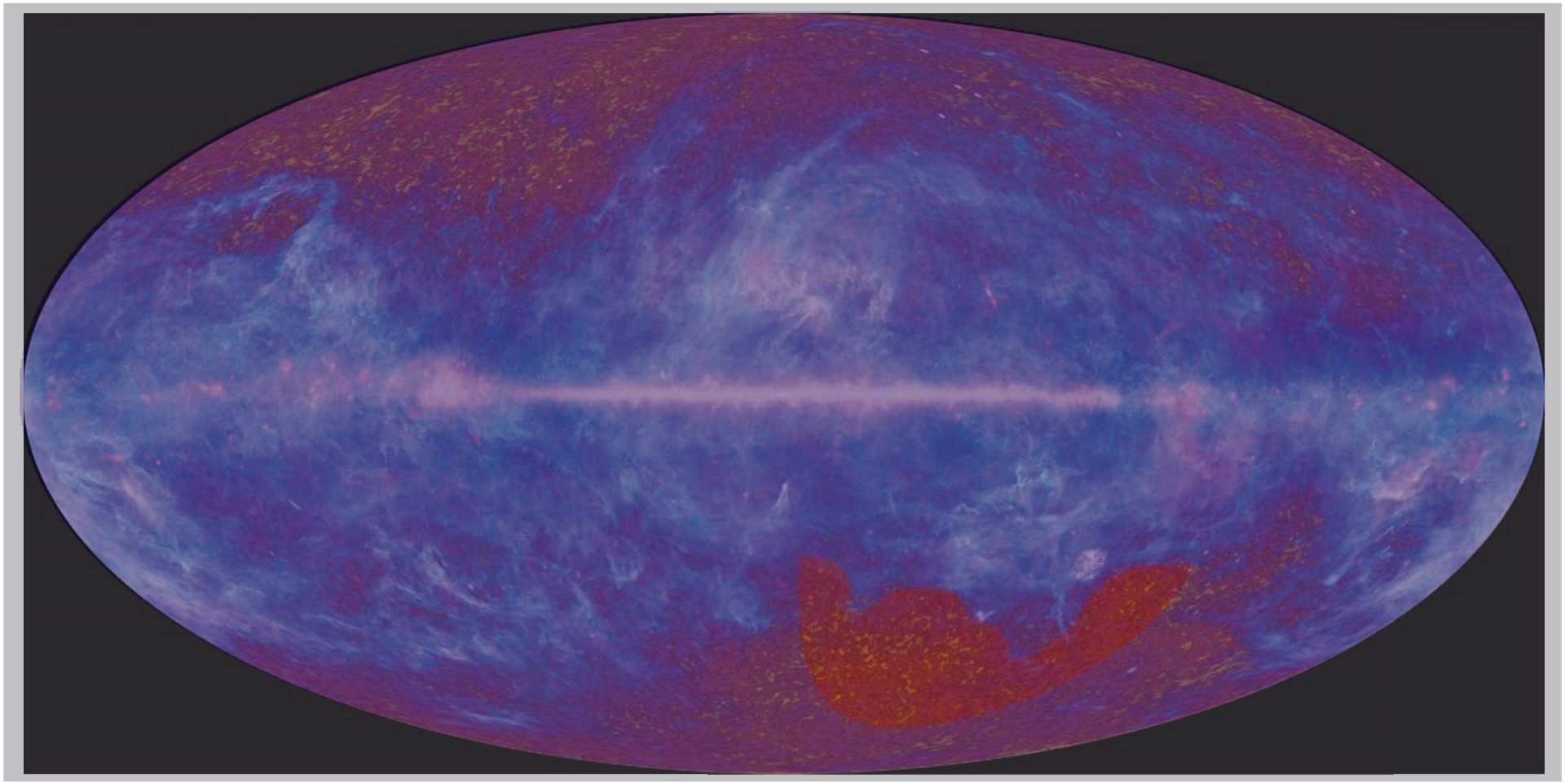


South Pole + 52% Mask



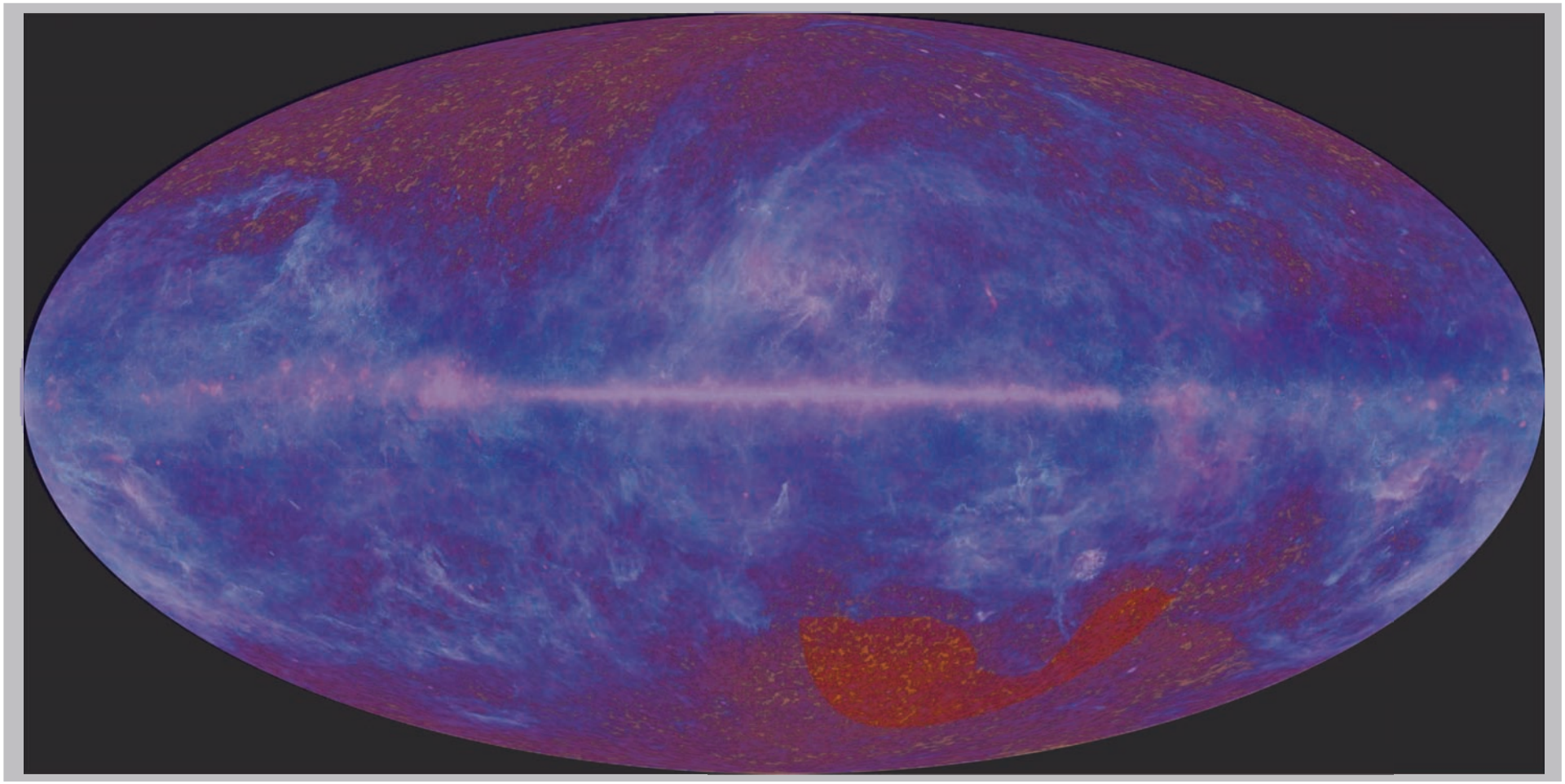
- 6% of sky available and outside of mask

South Pole + 25% Mask



- 4% of sky available and outside of mask

South Pole + 15% Mask



- 3% of sky available and outside of mask

Summary

- Foregrounds are everywhere. There are regions where they are low relative to other parts of the sky, but not relative to a B-mode signal. There is no escape from serious foreground separation. Because of $T \,\mathrm{to}\, P$ leakage, can't ignore unpolarized foregrounds.
- Foregrounds go up fast as sky fraction is increased. (Increased mapping speed generally means increased sky fraction.)

THE MORE SKY IS OBSERVED, THE BRIGHTER THE FOREGROUNDS THAT HAVE TO BE DEALT WITH

- Foregrounds go up really fast away from the frequency minimum

SHIFTING AWAY FROM THE MINIMUM TO AVOID DEALING WITH EXTRA COMPONENTS IS A LOSING STRATEGY

THE FURTHER FROM THE MINIMUM ONE OBSERVES, THE MORE ONE LEARNS ABOUT FOREGROUNDS RATHER THAN THE CMB

Summary — cont'd

- Design experiments for it

Observe the minimum — 70–100 GHz or so

Observe both sides of the minimum

- Some Planck results on polarized foregrounds should be available by summer, and can be included in the report.