Observational constraints on the types of cosmic strings

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Outline

- *Cosmic string in cosmology and methods of its detection*
- String traces in CMBR data: *theory*
- Contribution of cosmic strings' energy into total energy of the Universe (WMAP, Planck): *observations*
- Solitary string and modified Haar step function: *effective method to search*
- **WMAP and Planck data analysis: cosmic string candidates**
- which type and how many?

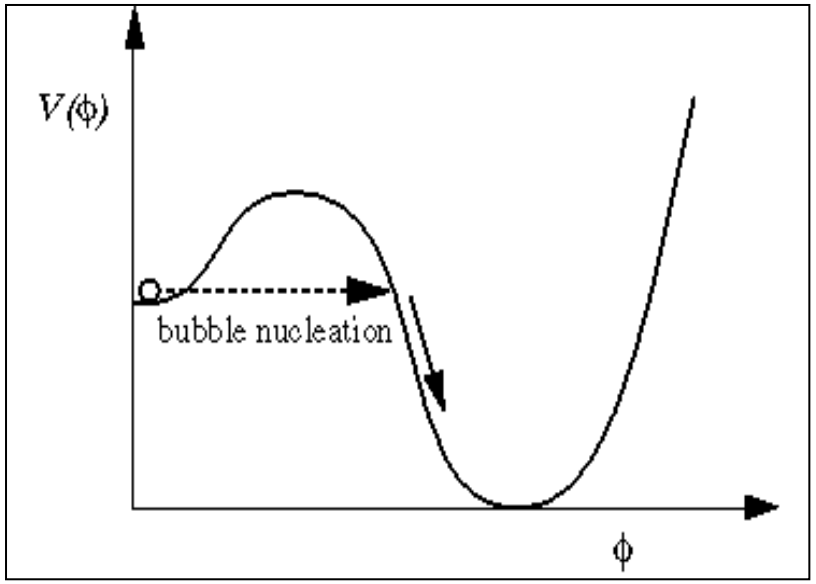
Cosmic string basis

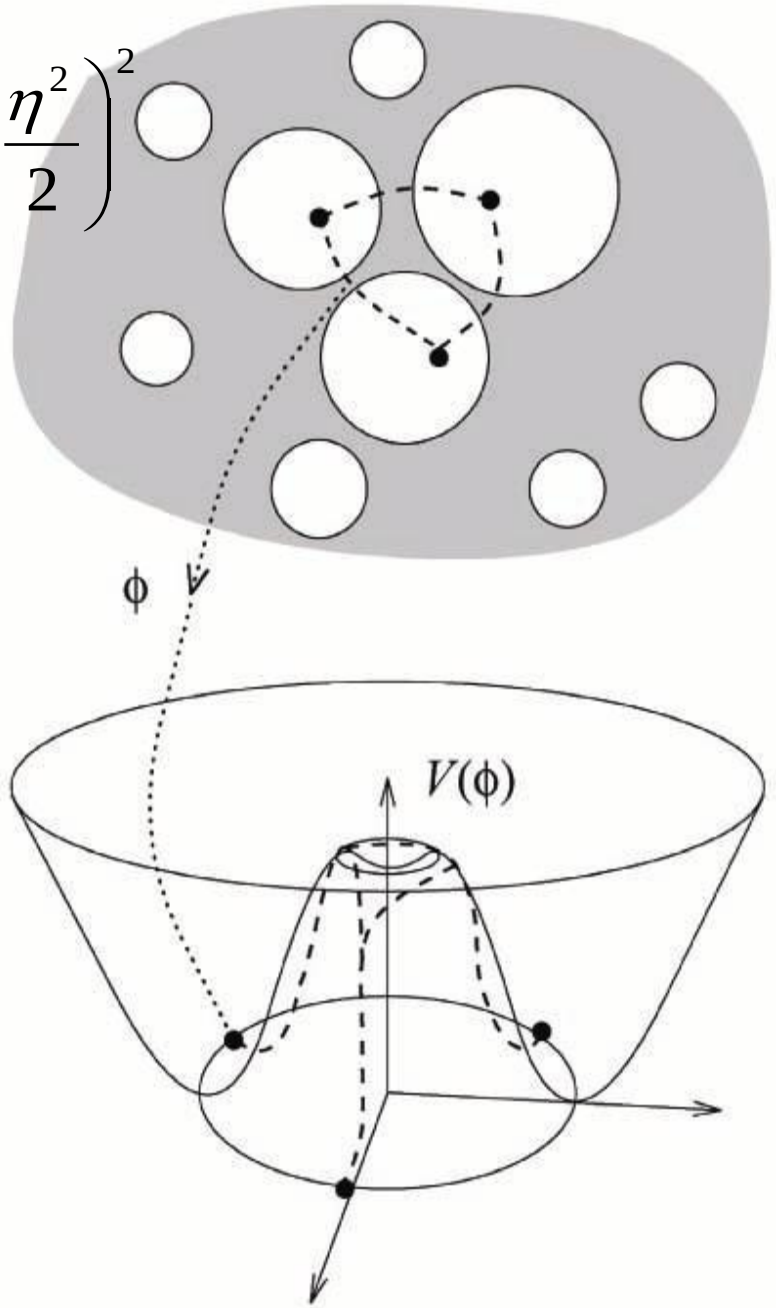
$$L = D^{\mu}\phi^{*} D_{\mu}\phi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \lambda\left(\phi^{*}\phi - \frac{\eta^{2}}{2} \right)^{2}$$

$$\left|\langle\phi\rangle\right|^{2} = \frac{\eta^{2}}{2}$$

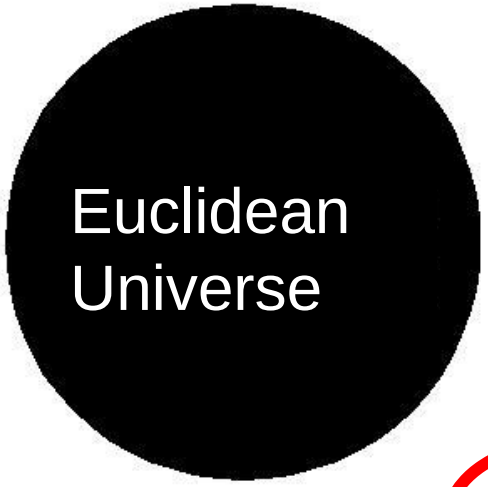
$$\langle\phi\rangle = \frac{\eta}{\sqrt{2}} \exp\{i\alpha(x)\}$$

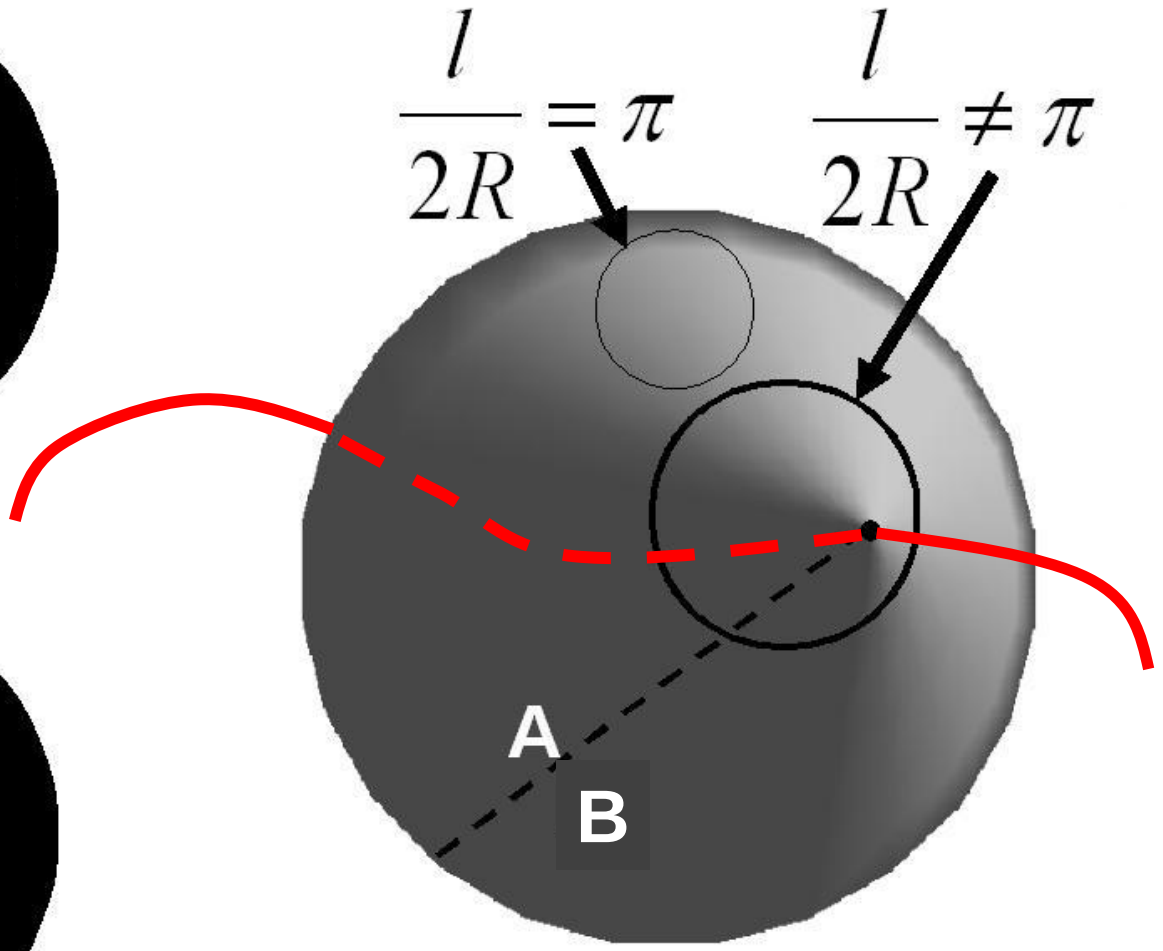
$$\mu \sim \eta^{2}$$

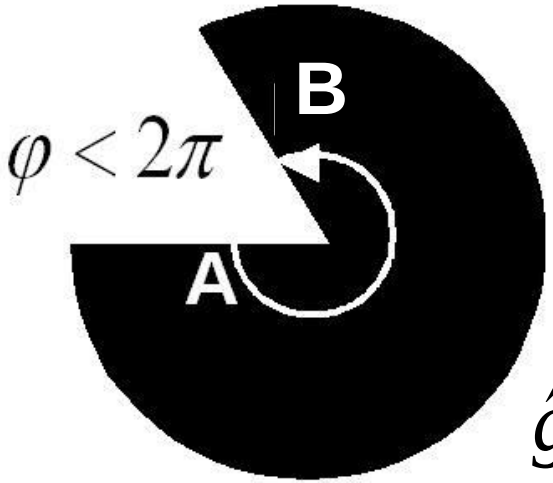




Cosmic string in the Universe







$$\hat{g}_{\mu\nu} = \eta_{\mu\nu} = diag(1,-1,-1,-1)$$

$$0 \le \varphi \le 2\pi - \Delta\theta, \quad \Delta\theta = 8\pi G\mu$$

Modern methods of cosmic string detection

- Optical surveys

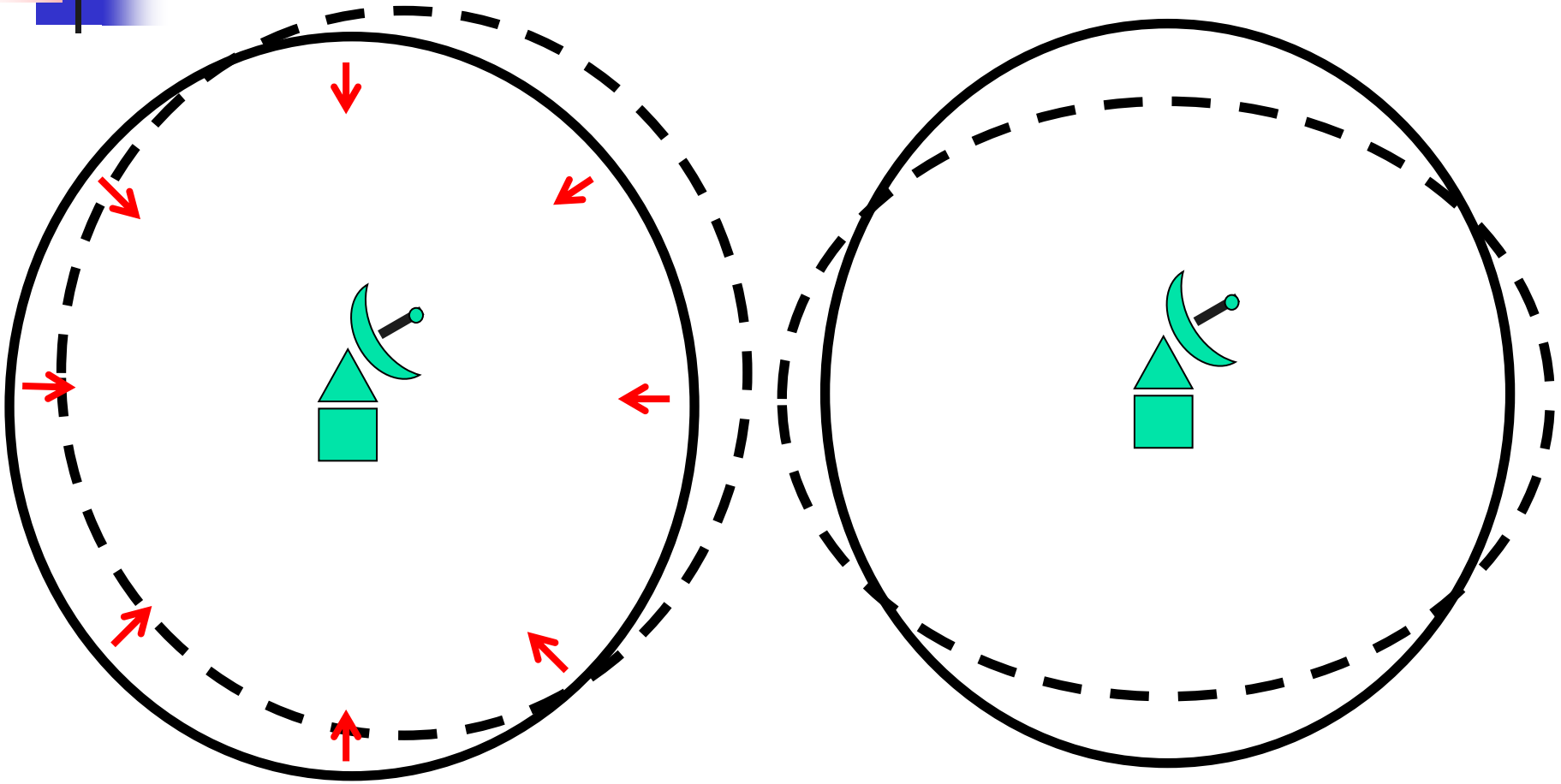
  Looking for gravitational lensing events

- Radio surveys

  The investigations of the structure of CMBR anisotropy in WMAP and Planck data

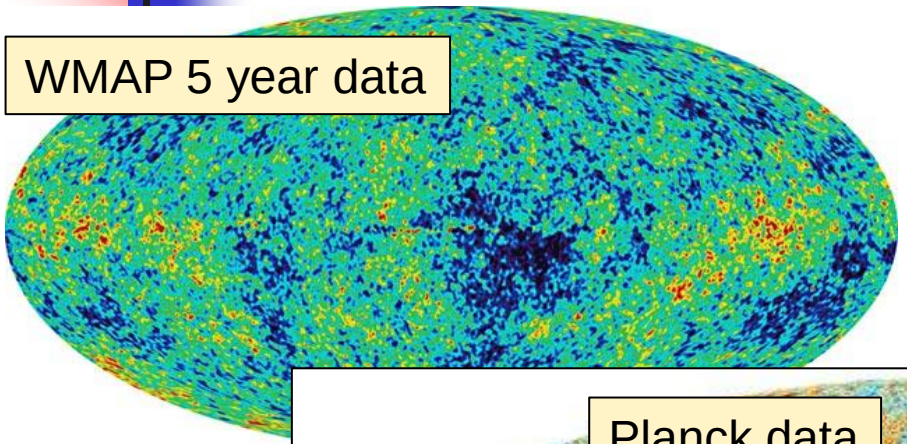
- Gravitational radiation from string loops
- Interaction of string and black hole
- Decay of heavy particles emitted by string
- String + string interaction
- ...

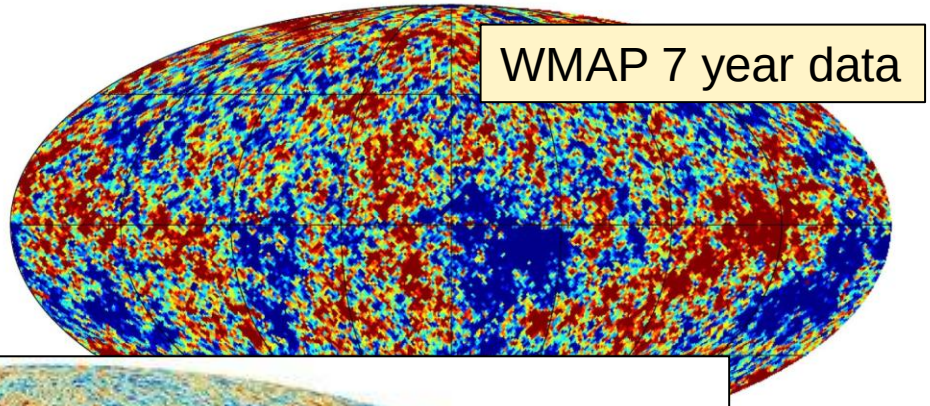
CMBR anisotropy

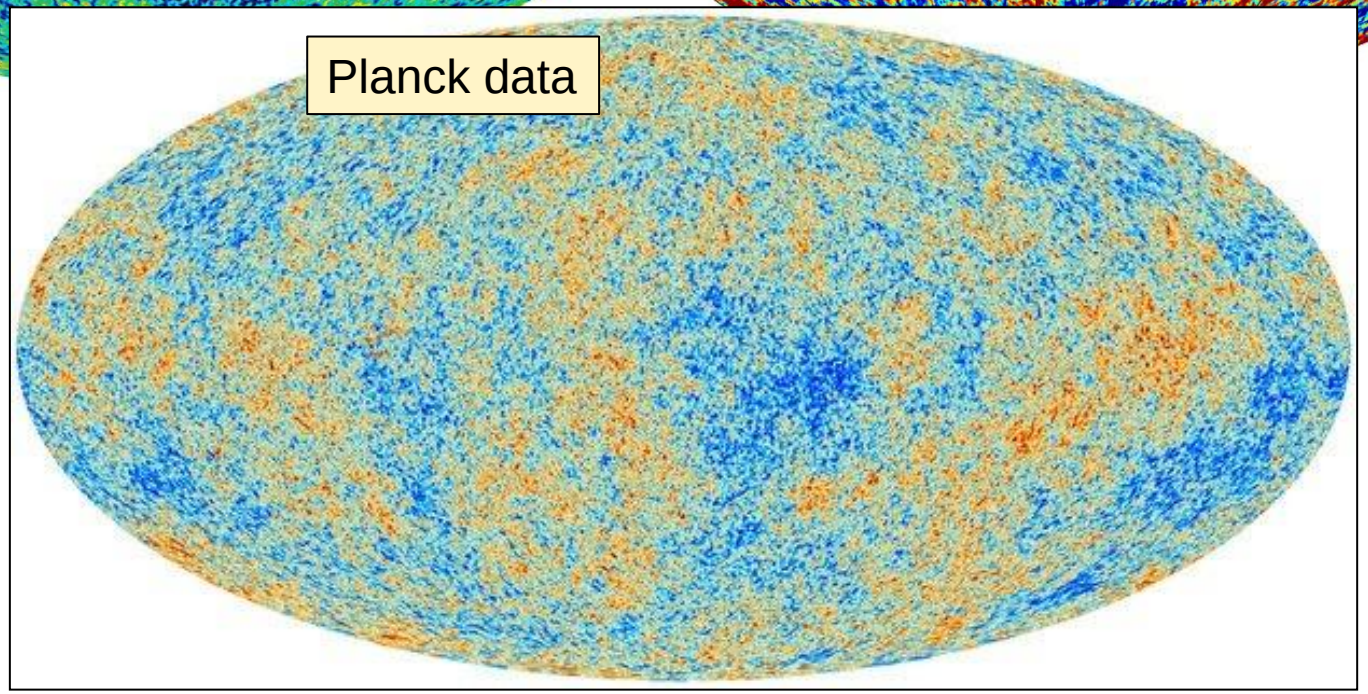


The surface of last scattering

CMBR anisotropy



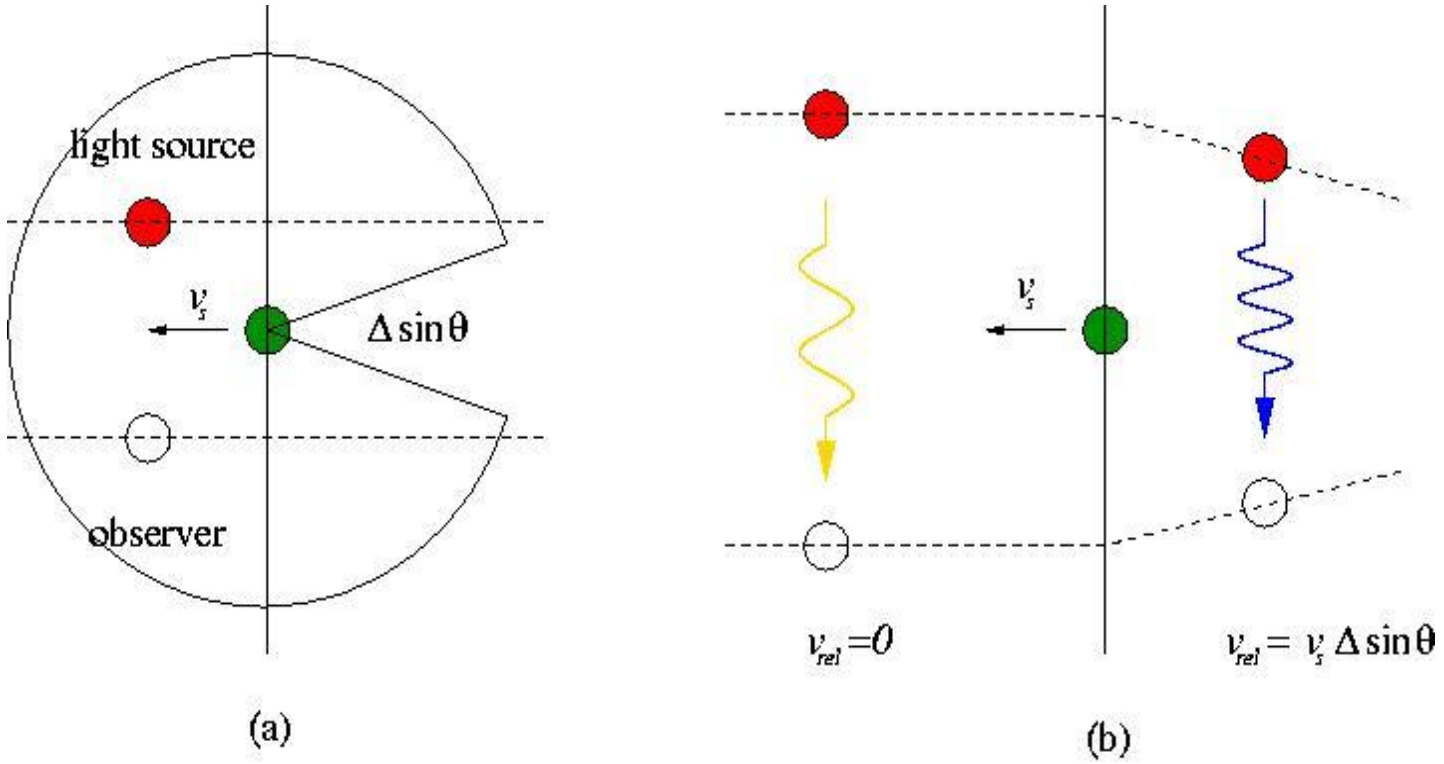




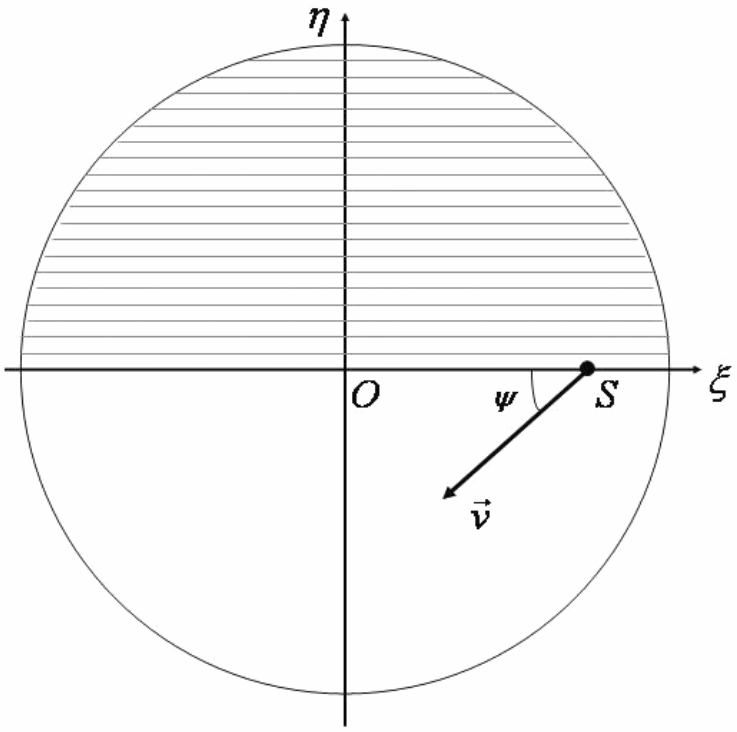
CMBR anisotropy induced by a cosmic string

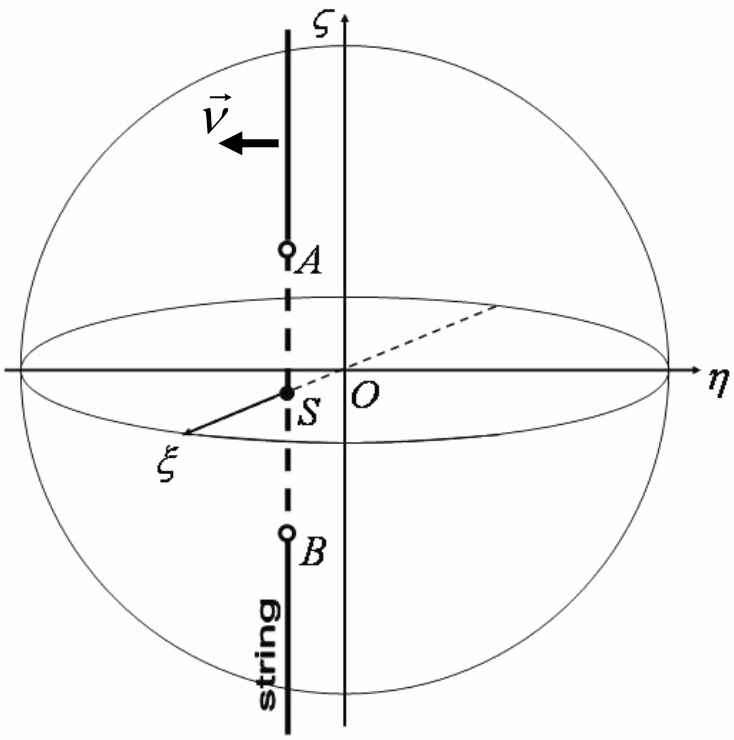
The Kaiser-Stebbins effect

Moving string produces red or blue shifts of photon frequency



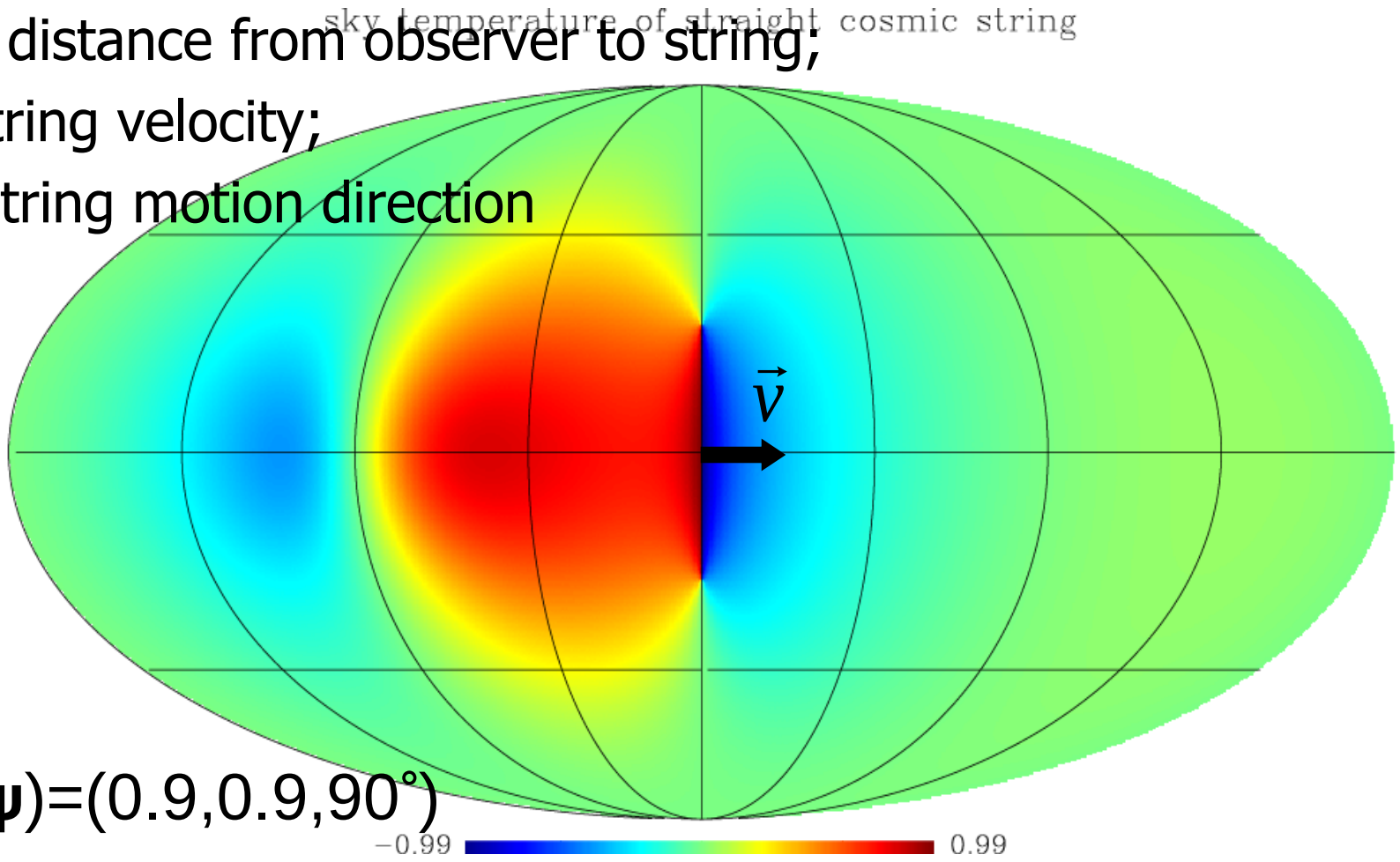
The simple simulation of a straight cosmic string moving with constant velocity





CMBR anisotropy induced by straight moving cosmic string. Simulations

- **OS** – distance from observer to string;
- **v** – string velocity;
- **ψ** – string motion direction

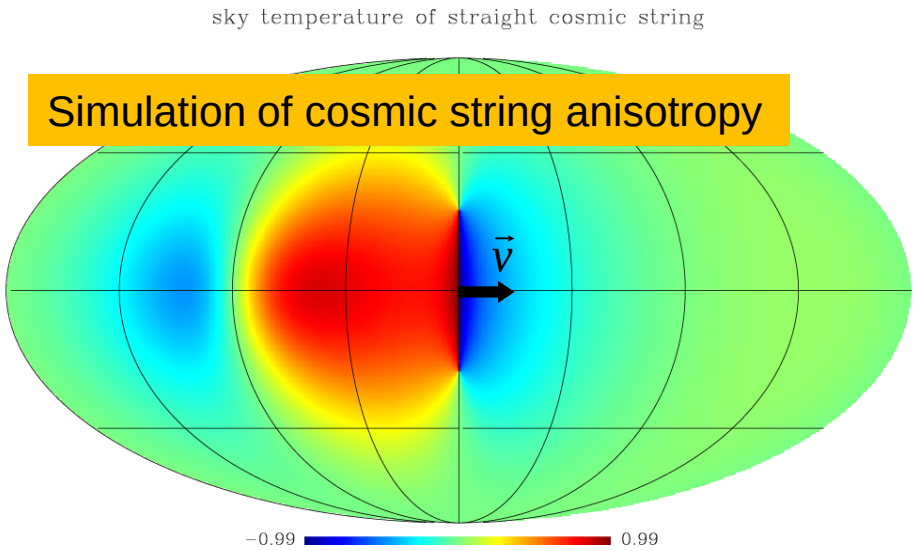


(**OS**,**v**,**ψ**)=(0.9,0.9,90°)

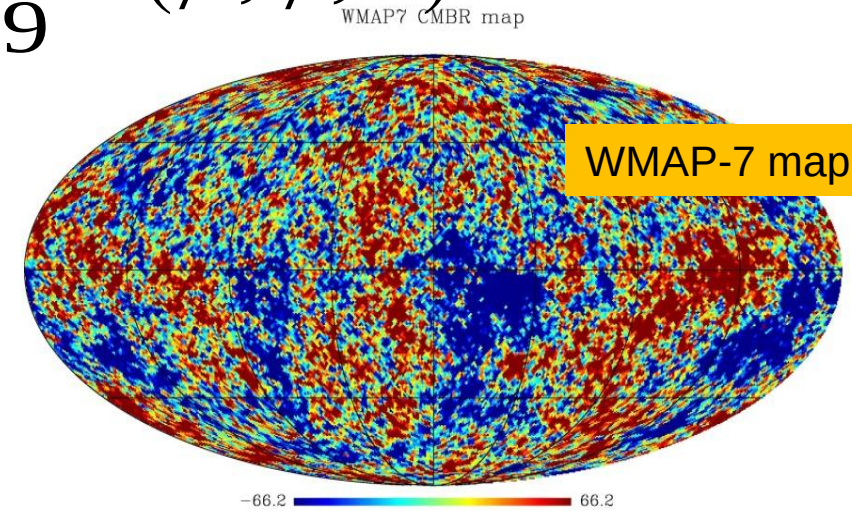
Amplitude of cosmic string anisotropy

$$\frac{\delta T}{T} \approx 8\pi G \mu \gamma \frac{v}{c}$$

$$\delta T = 27\ \mu\mathrm{K} \cdot \frac{\Delta\theta}{2''} \frac{v}{0.9} F(\psi, \varphi, \theta)$$



Simulation of cosmic string anisotropy



WMAP-7 map

$$\delta T \approx 100\ \mu K$$

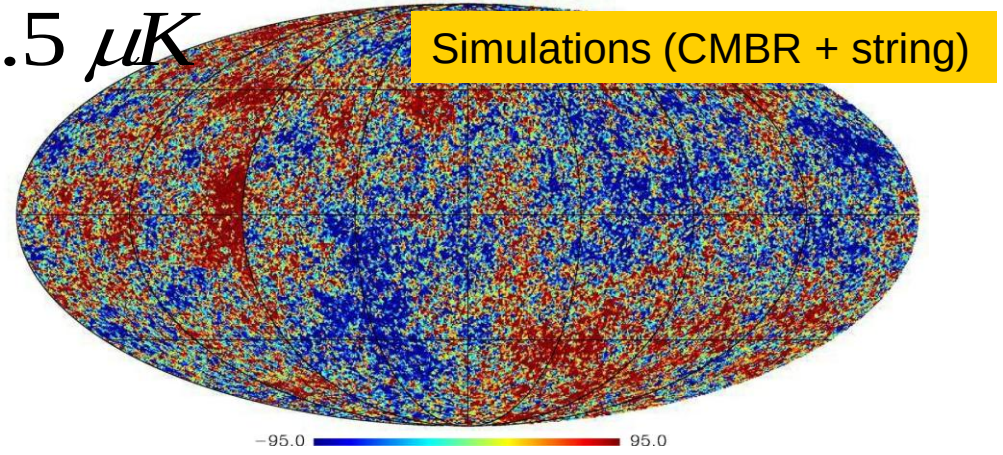
What strings are “observable”?

The upper bound on string deficit angle. The induced anisotropy (*amplitude of spot*) is compared with anisotropy due adiabatic fluctuations and could be detected.

$$\Delta\theta = 6'' \quad \Rightarrow \quad \delta T \approx 81\,\mu K$$

The low observational limit due the available resolution (*HST*) in optical searching of gravitational lensing events of galaxies by cosmic strings. “Superlight” strings could exist but can not be detected.

$$\Delta\theta = 0''.1 \quad \Rightarrow \quad \delta T \approx 1.5\,\mu K$$



What WMAP and Planck tell us about cosmic strings?

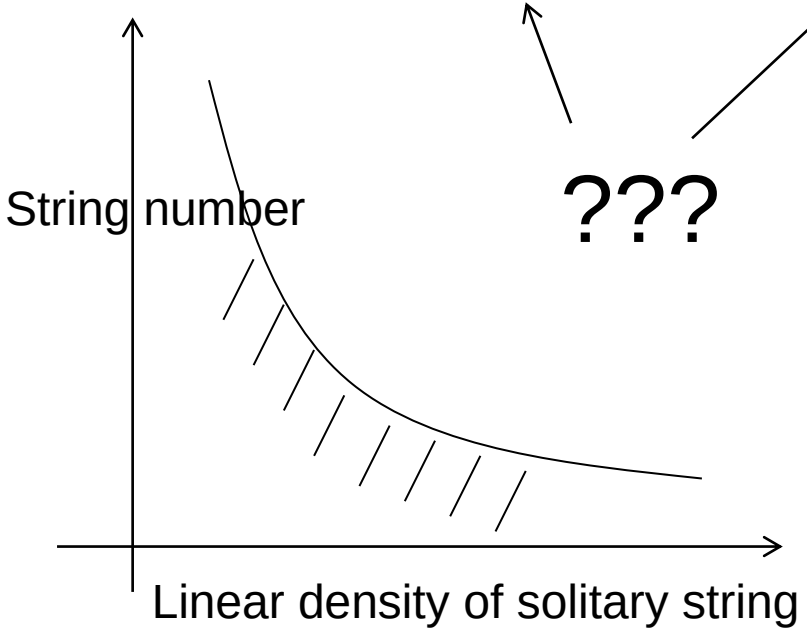
Cosmic string network model	Data	Cosmic string tension (upper bound) $\left(\frac{G\mu}{c^2}\right)_{\text{network}} \cdot 10^{-7}$
Nambu-Goto	Planck + WP	**1.5**
Abelian-Higgs field theory	Planck + WP	**3.2**
Abelian-Higgs mimic	Planck + WP	**3.6**
Semilocal cosmic string	Planck + WP	**11.0**
Global texture	Planck + WP	**10.6**

String network and solitary strings.

Simple model of homogeneous distribution

$$\left(\frac{G\mu}{c^2}\right)_{\text{solitary}} \cdot \sqrt{N} = \left(\frac{G\mu}{c^2}\right)_{\text{network}}$$

???



Numbers from WMAP and Planck

It is normalization of power spectrum produced by cosmic string network to be consistent with CMBR data. This value gives us the upper limit to estimate the fraction of energy in string with respect to the total energy of the Universe.

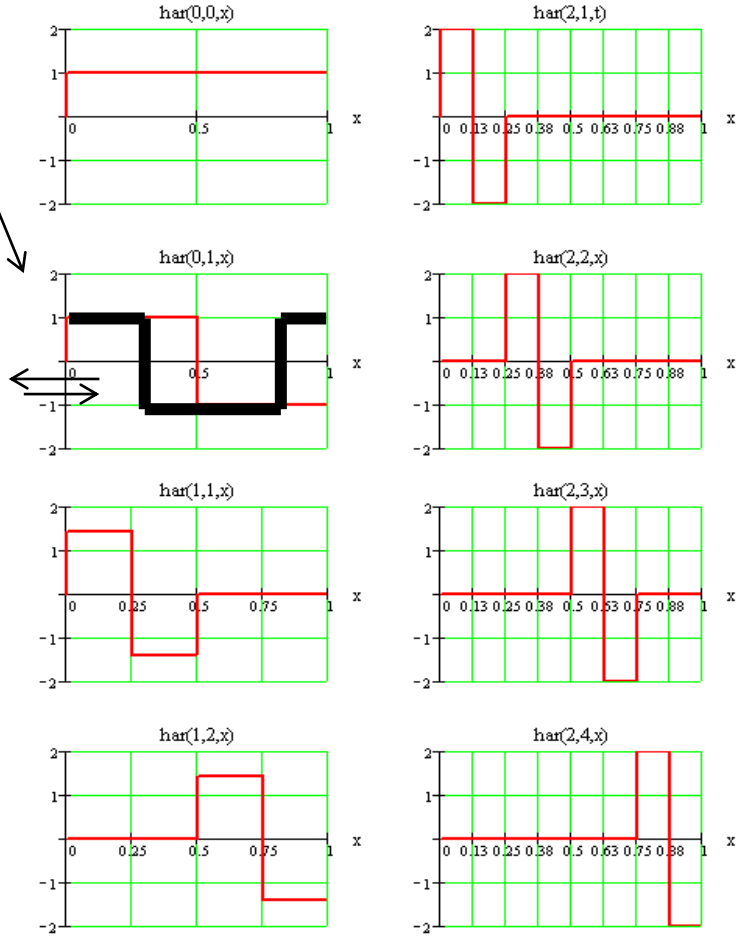
Planck data analysis

- Modified Haar functions with cyclic shift

$\{\psi_{ni}\}$ $[0,1]$ $a \in [0,1/2]$

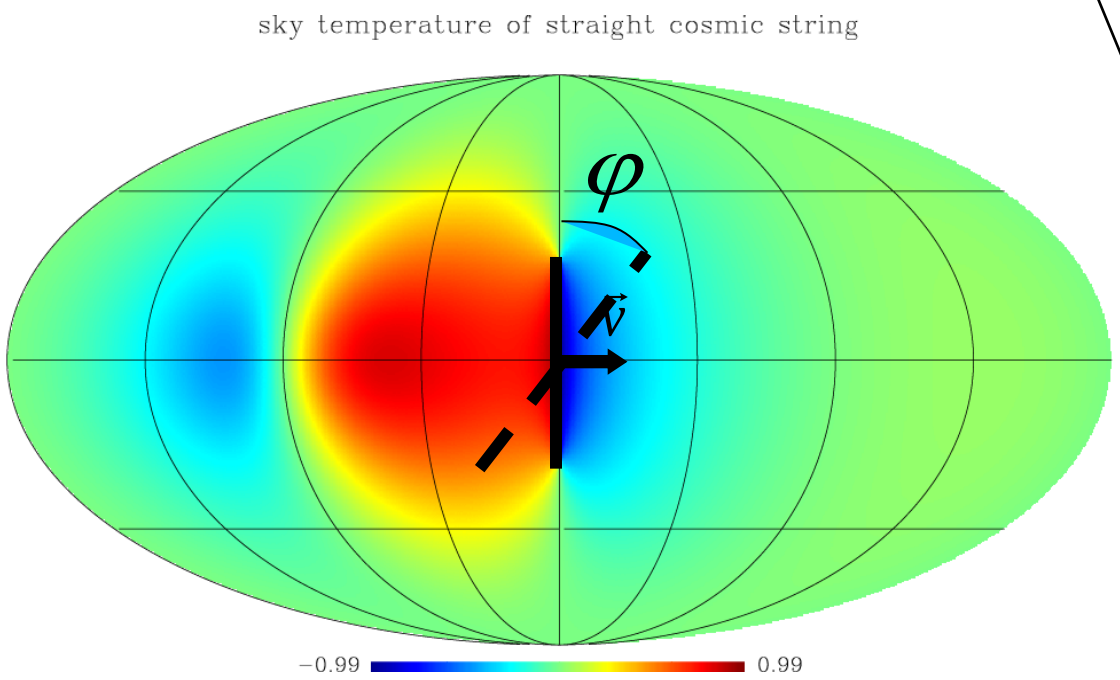
$$\begin{cases} 0 < a < 1 - i/2^n \\ 1 - i/2^n < a < 1 - i/2^n + 1/2^{n+1} \\ 1 - i/2^n + 1/2^{n+1} < a < 1 - i/2^n + 1/2^n \\ 1 - (i-1)/2^n < a < 1/2 \end{cases}$$

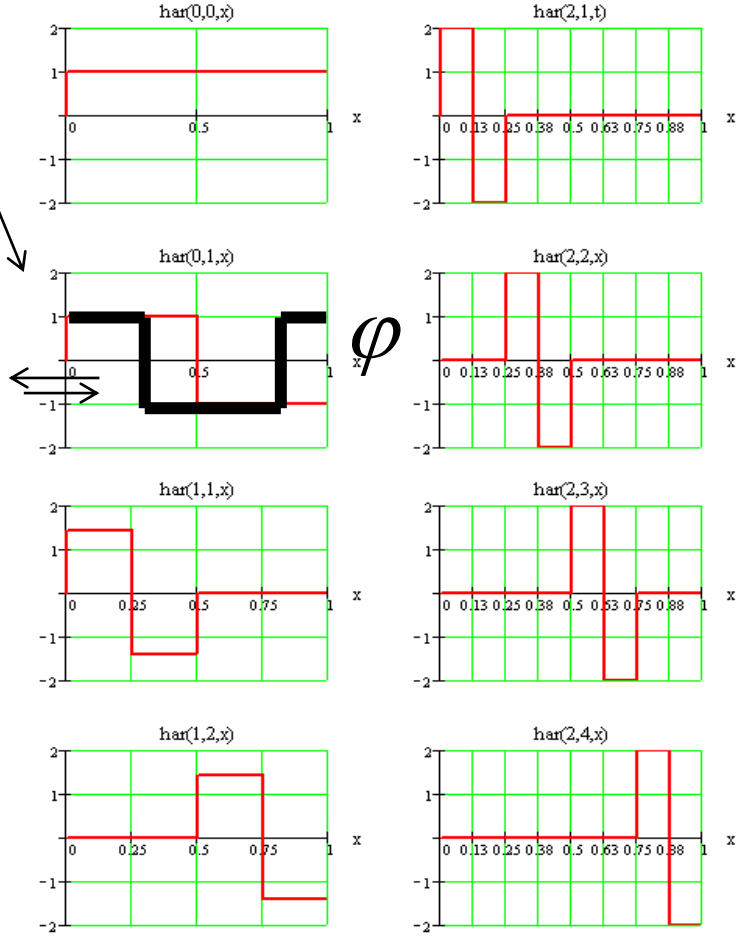
$$\psi_{ni}^{(a)} = \begin{cases} 2^{n/2}, \dfrac{i-1}{2^n} + a < x < \dfrac{i-1}{2^n} + a + \dfrac{1}{2^{n+1}}, \\ -2^{n/2}, \dfrac{i-1}{2^n} + a + \dfrac{1}{2^{n+1}} < x < \dfrac{i}{2^n} + a, \\ 0, x \notin \left[\dfrac{i-1}{2^n} + a; \dfrac{i}{2^n} + a \right]. \end{cases}$$



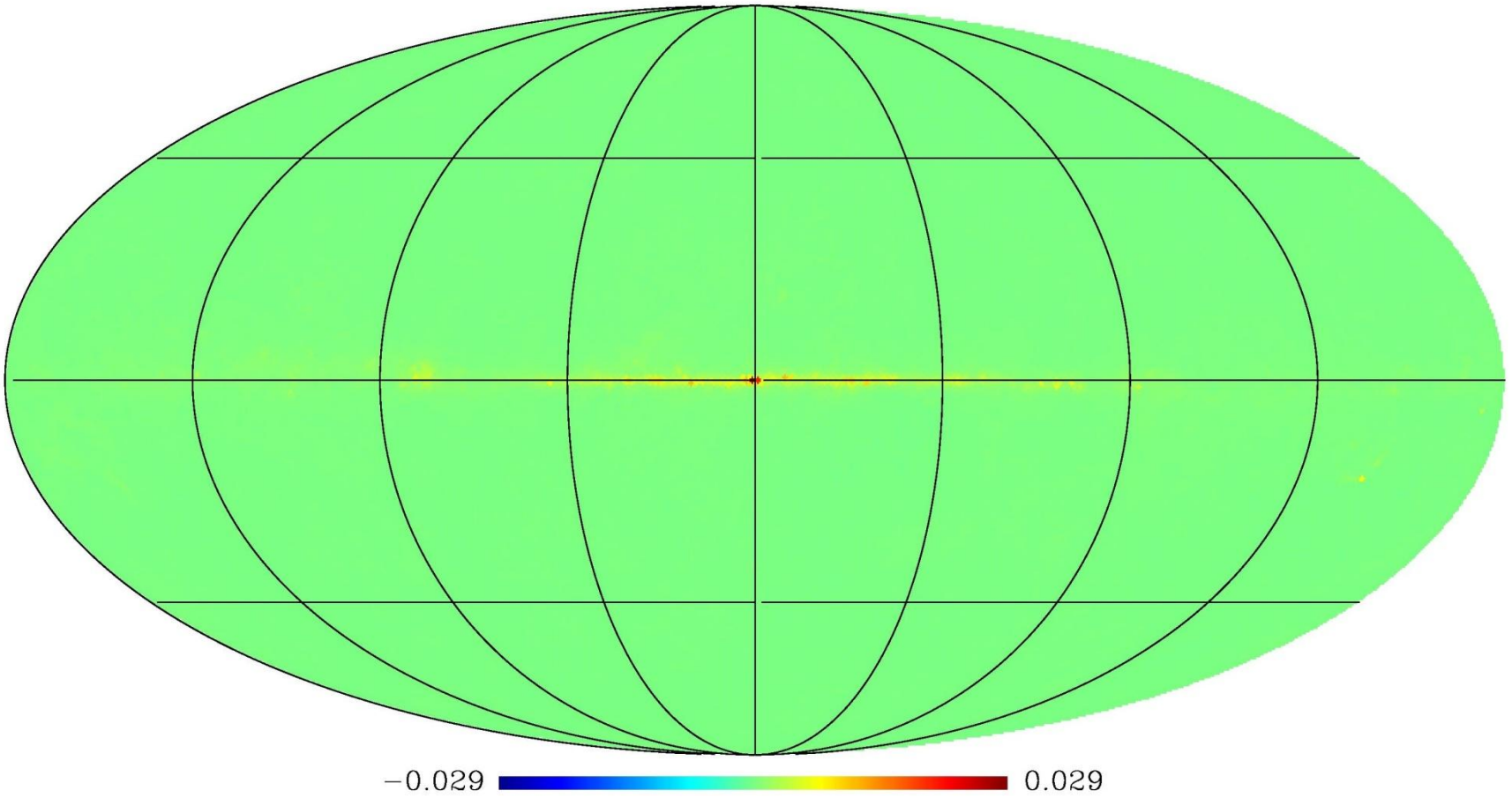
Planck data analysis

- Modified Haar functions with cyclic shift



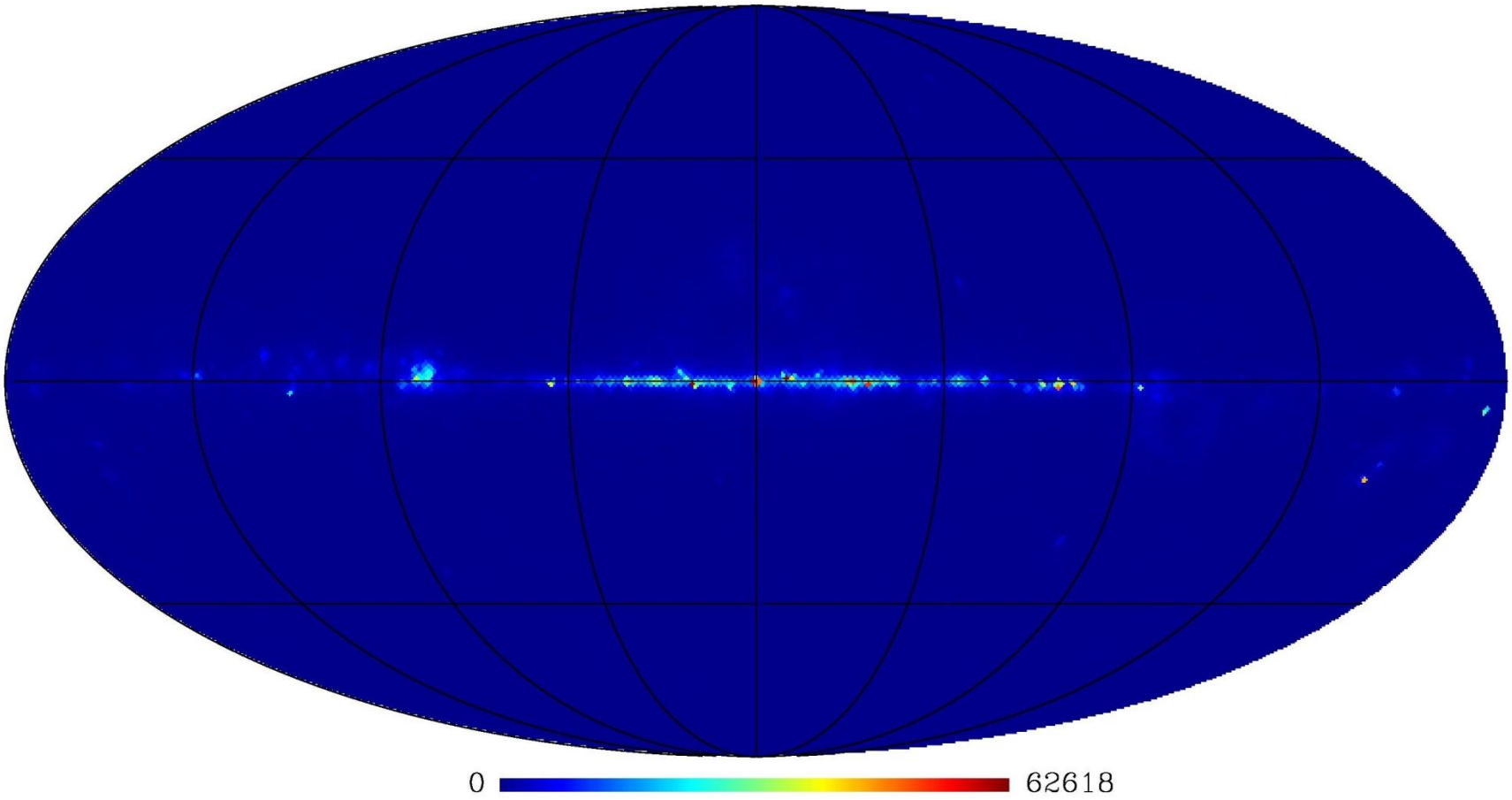


Planck original 100GHz map (units [K])

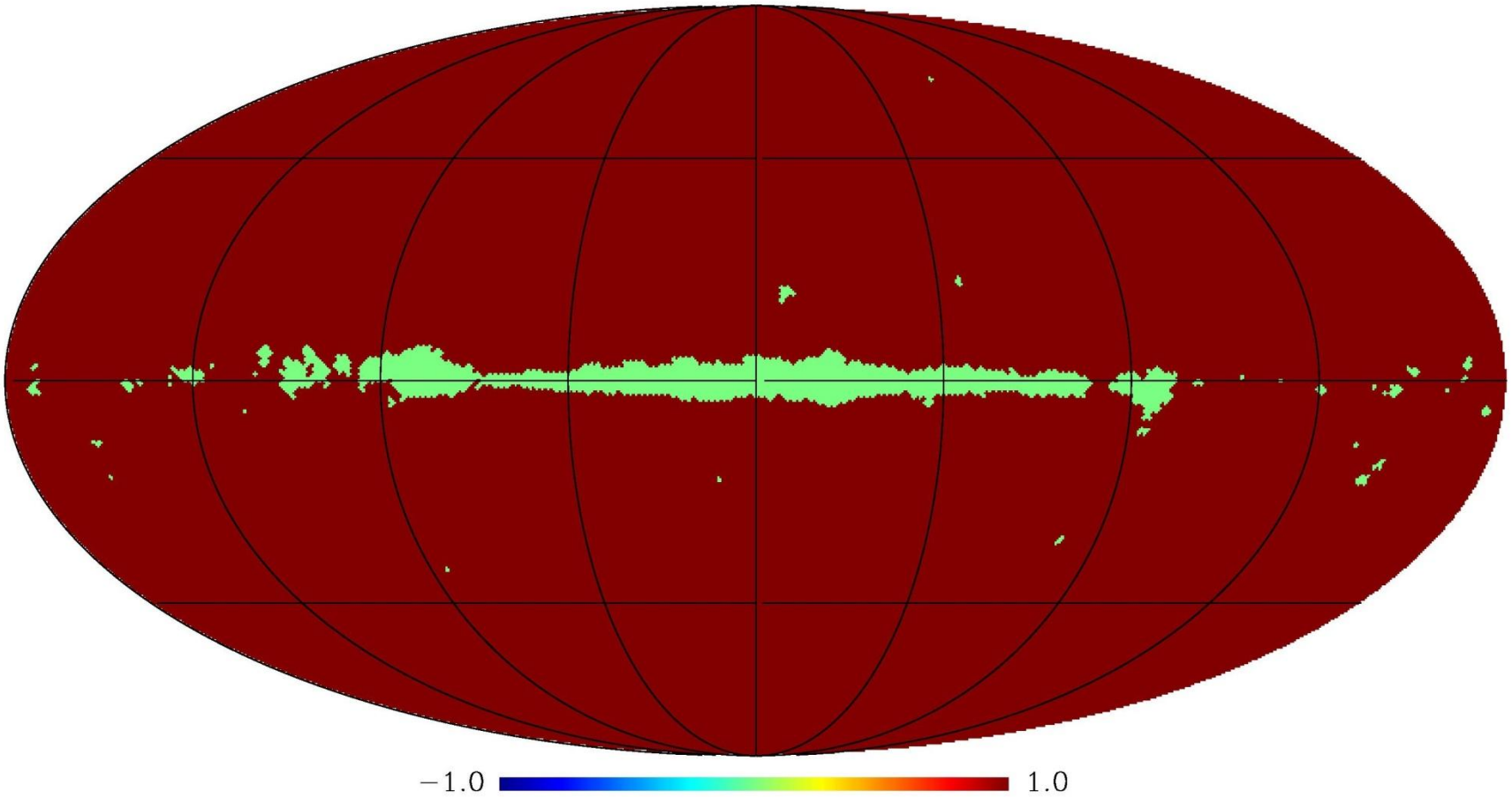


...we have six independent Planck maps, from 100GHz to 857GHz

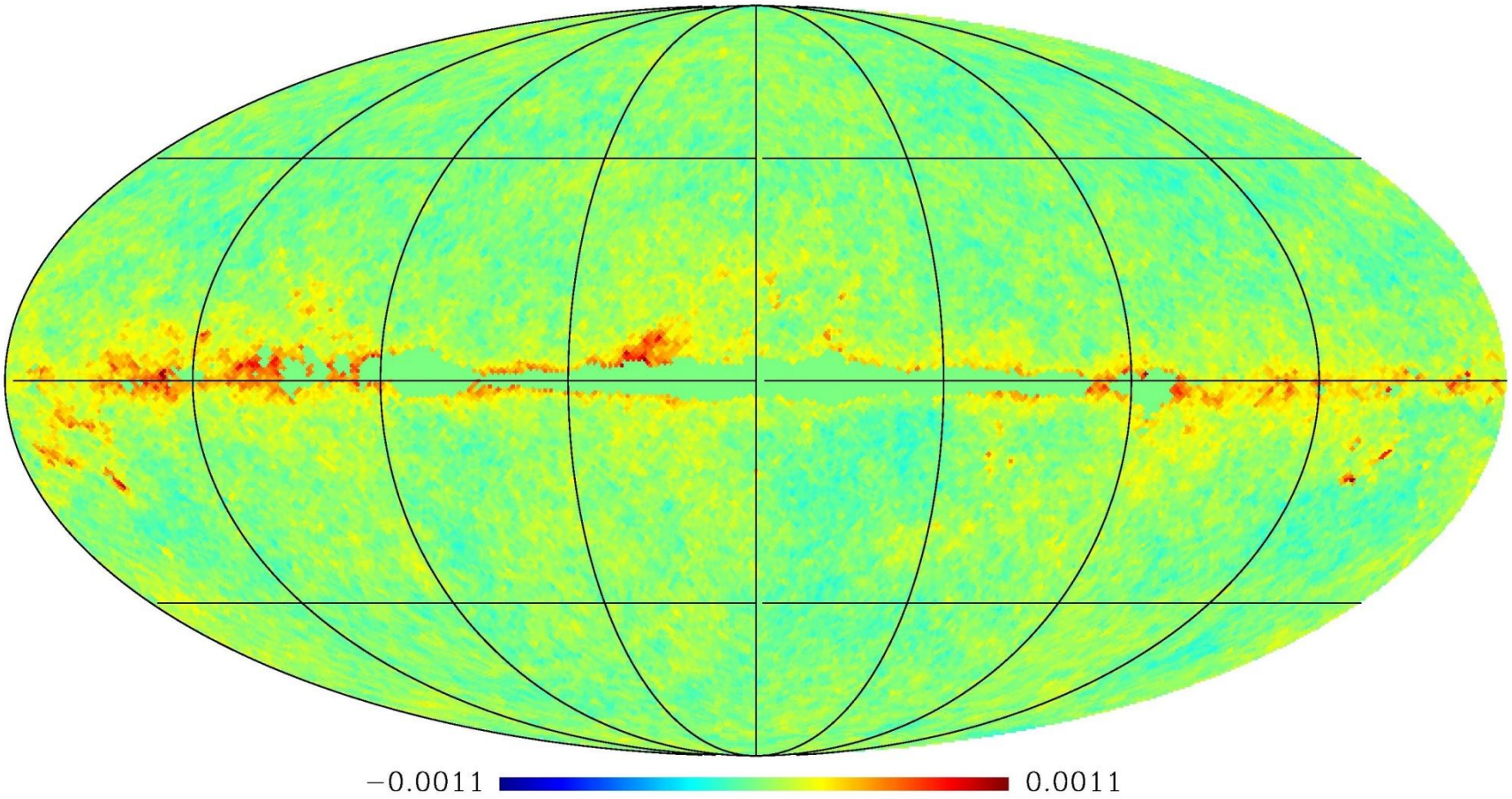
Planck low-frequency synchrotron map



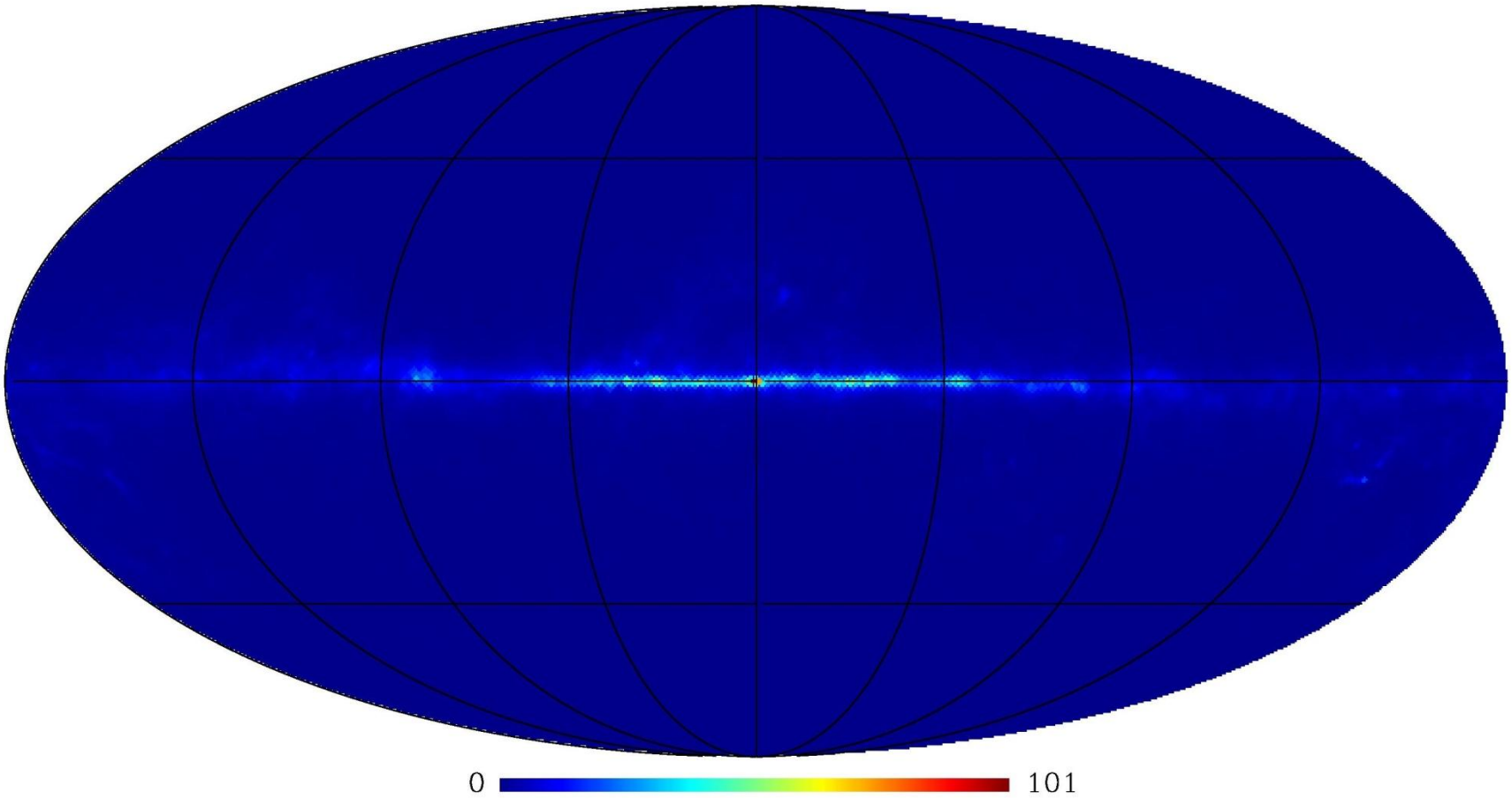
1σ synchrotron filter



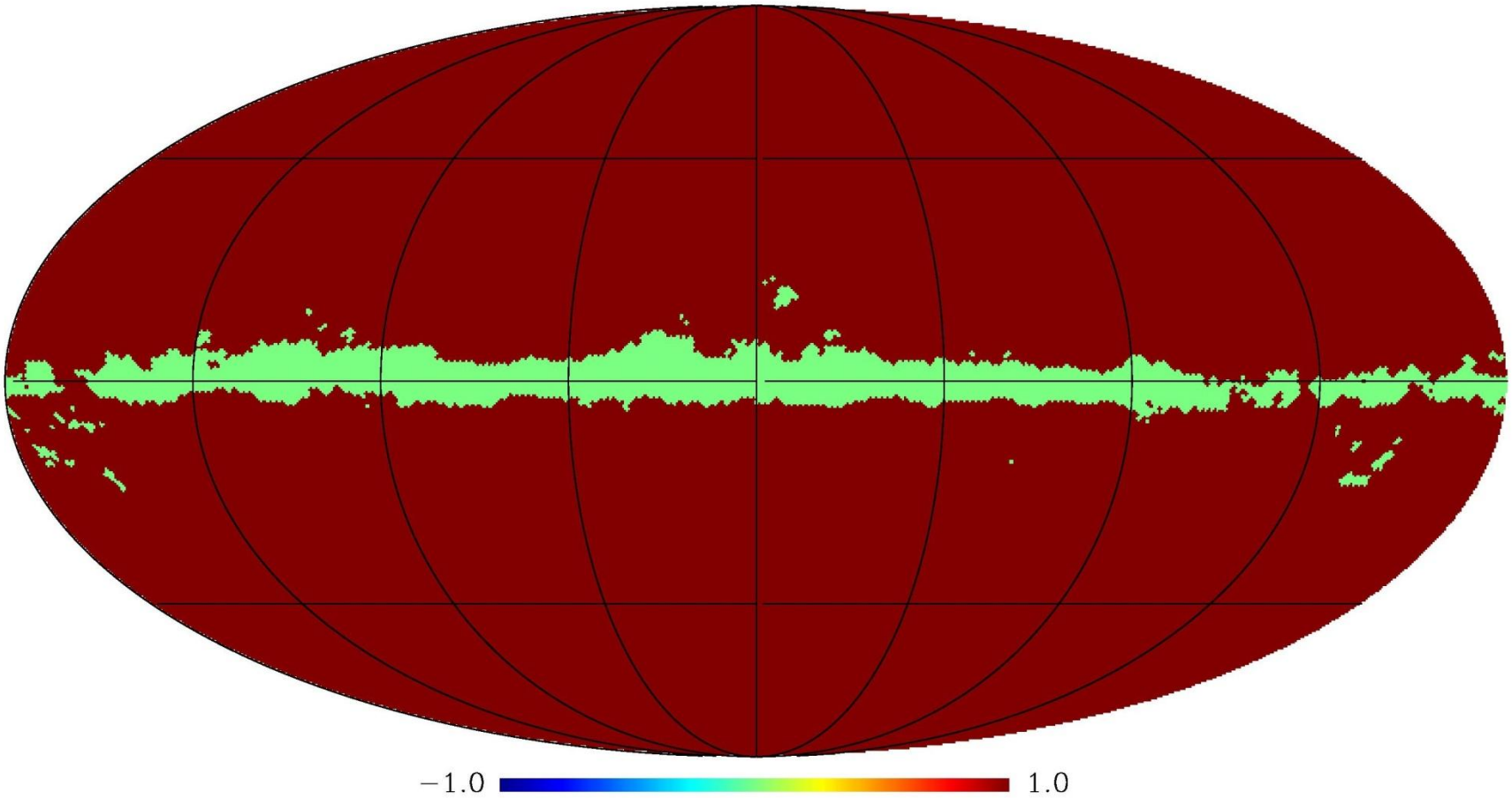
Planck 100GHz filtered map (units [K])



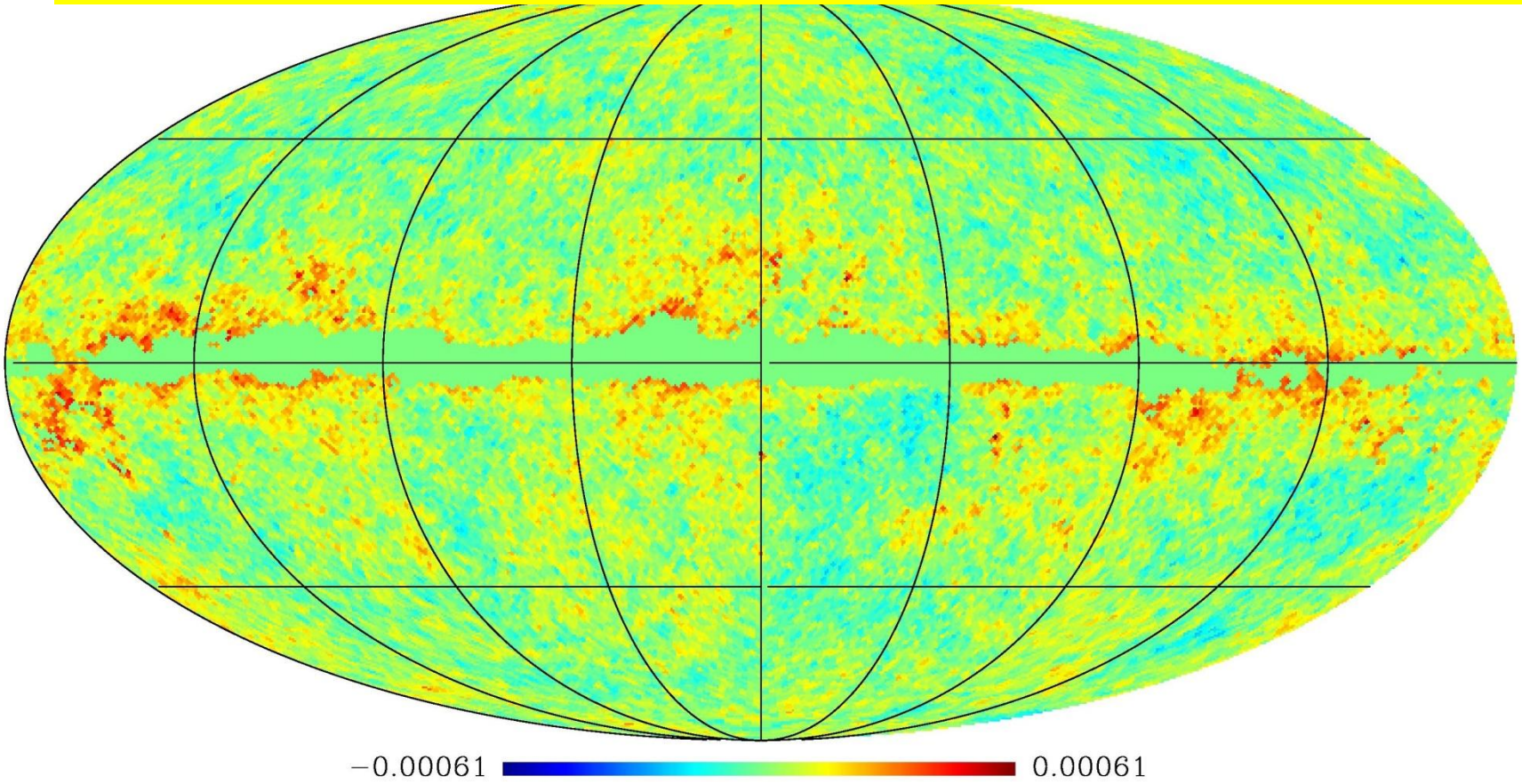
Planck low-frequency dust map



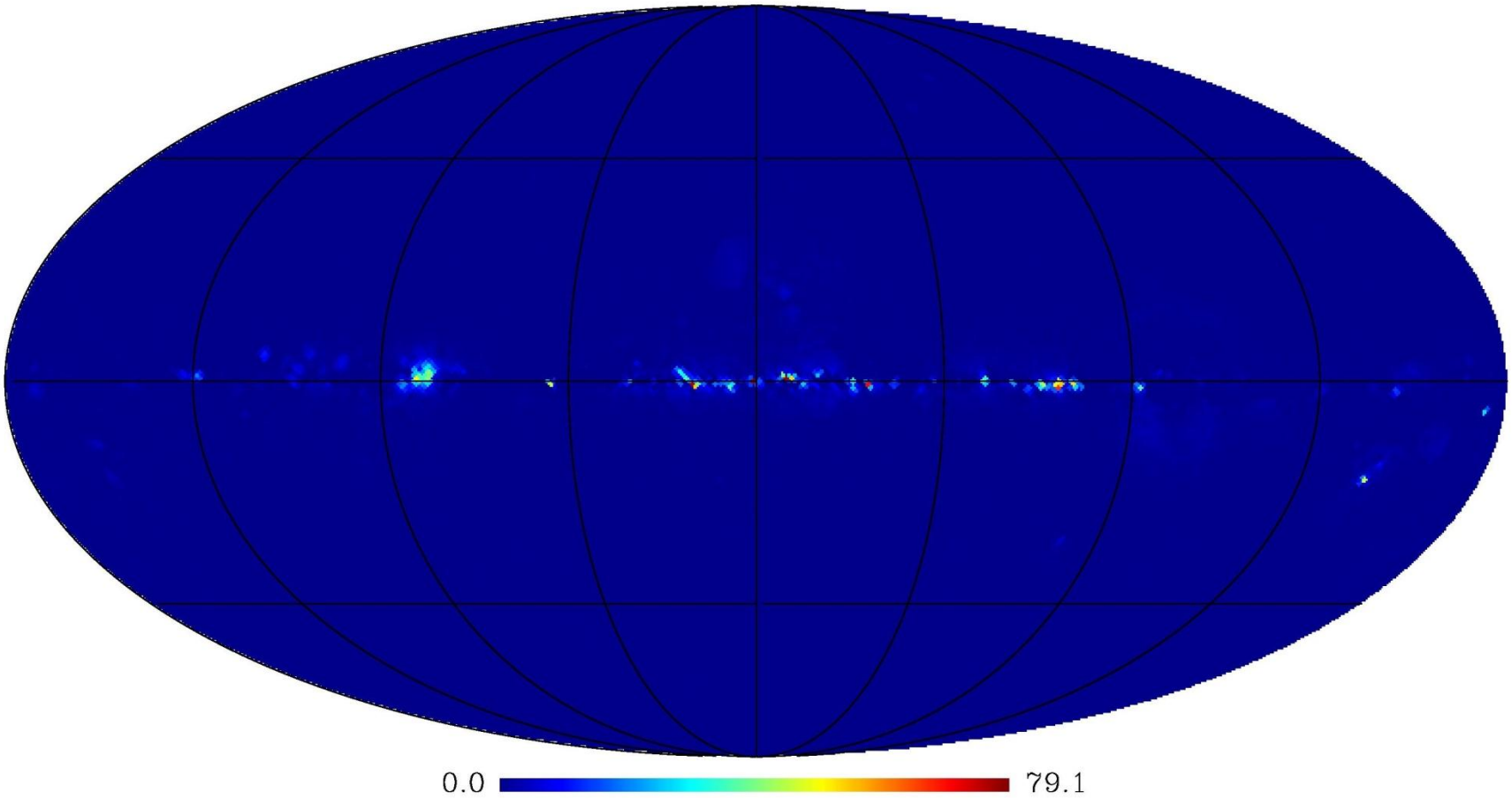
1σ dust filter



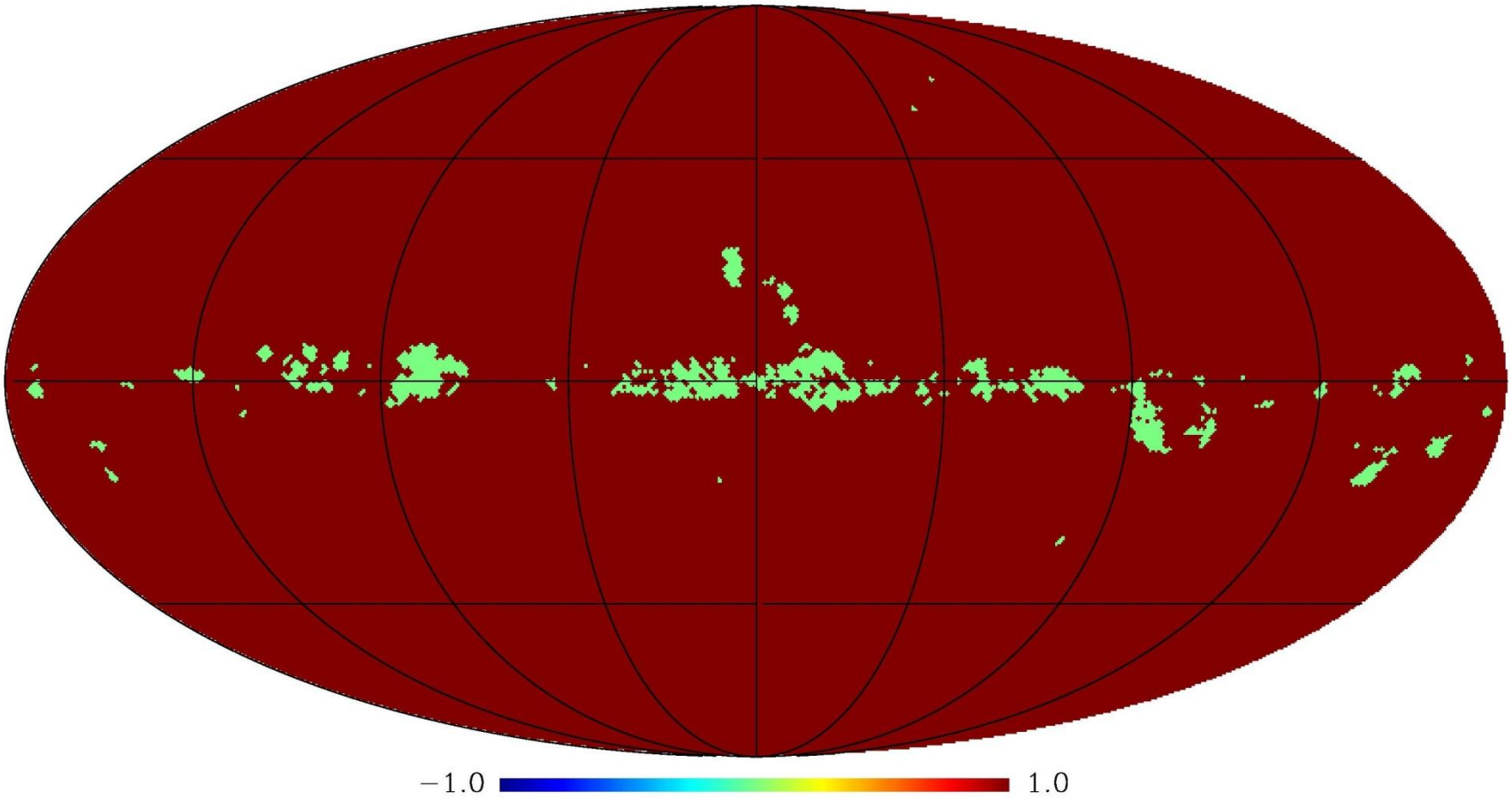
Planck 100GHz filtered map (using both dust and synchrotron filters; units [K])



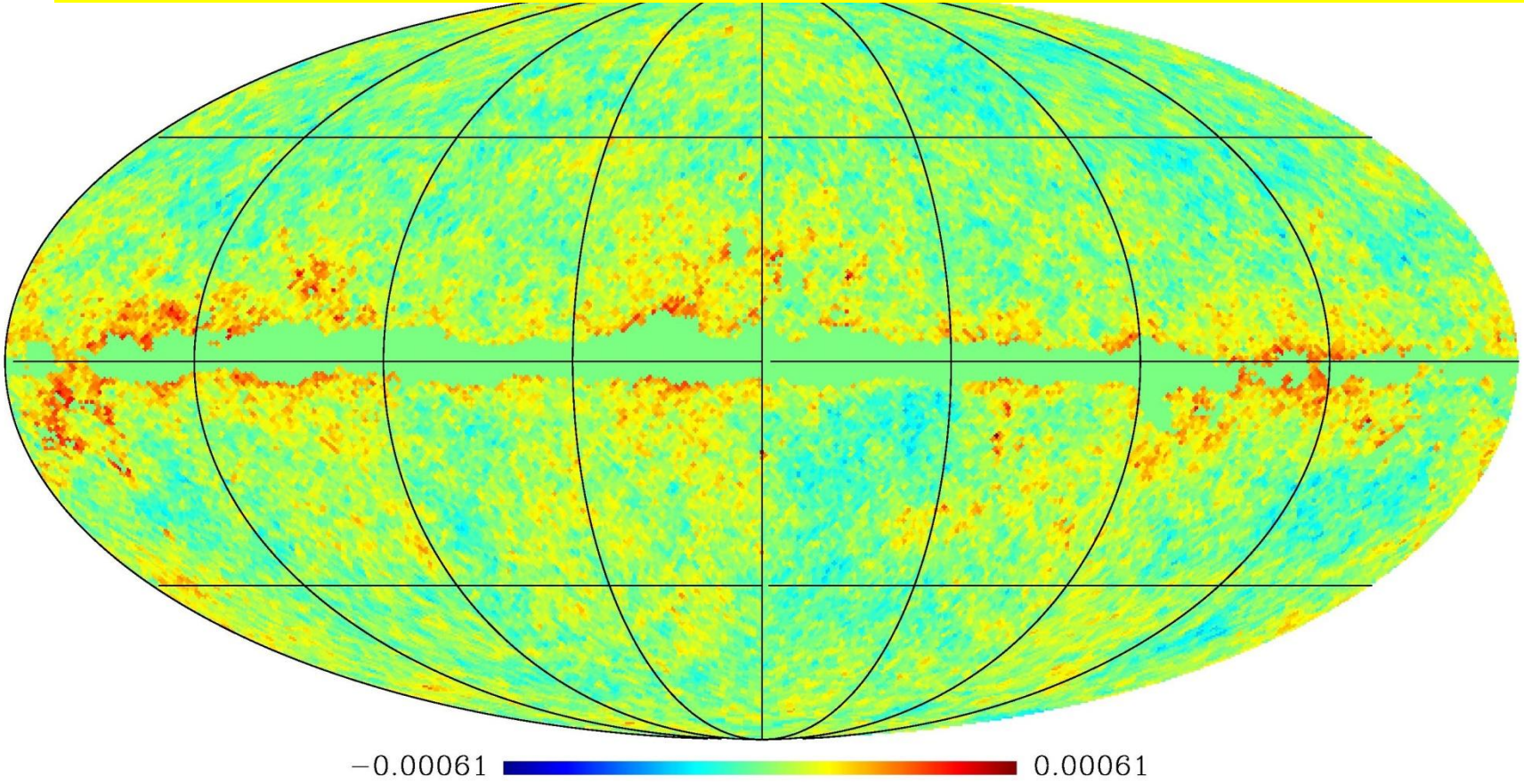
WMAP free-free K-map



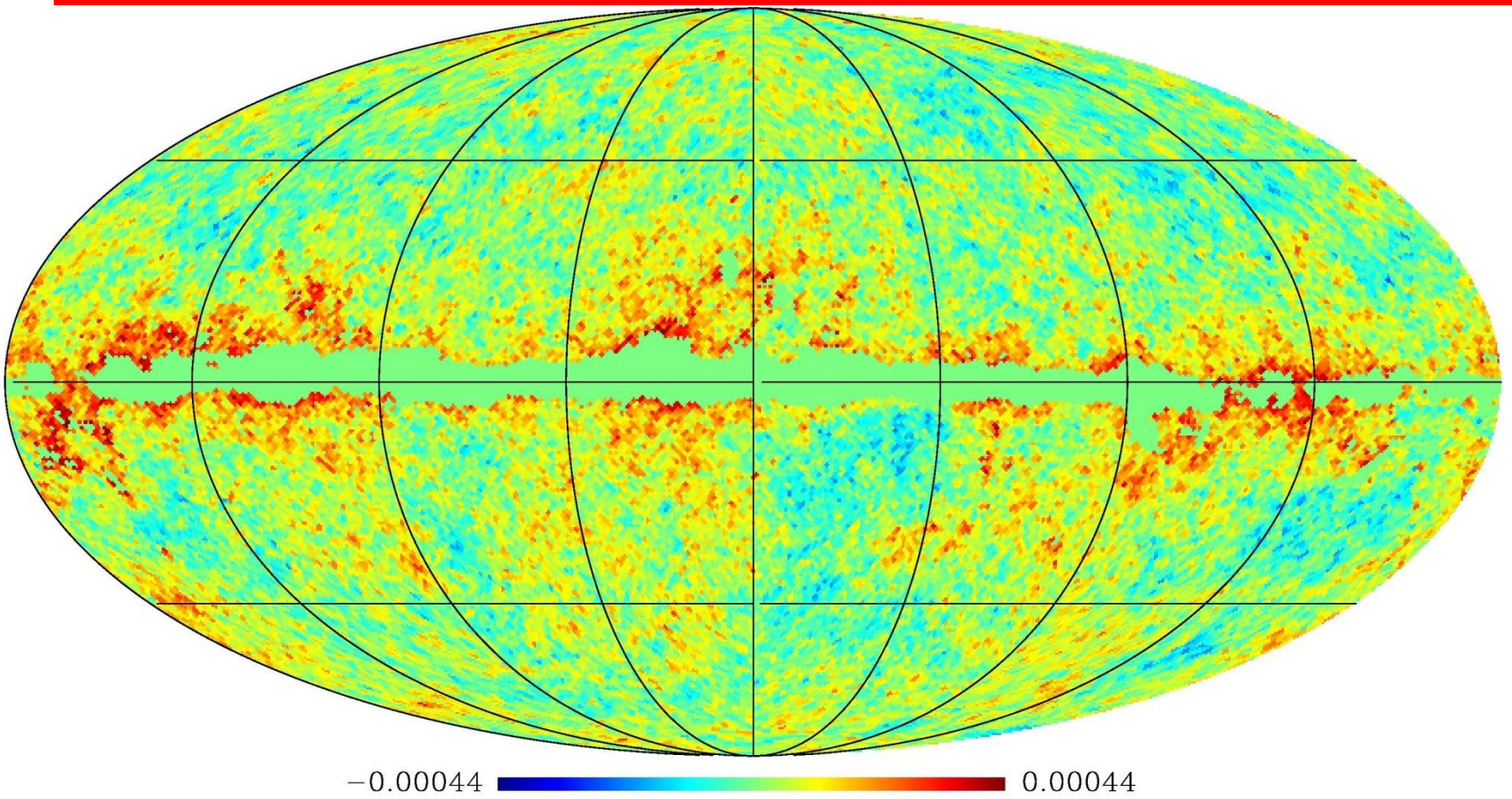
1σ WMAP free-free K-map



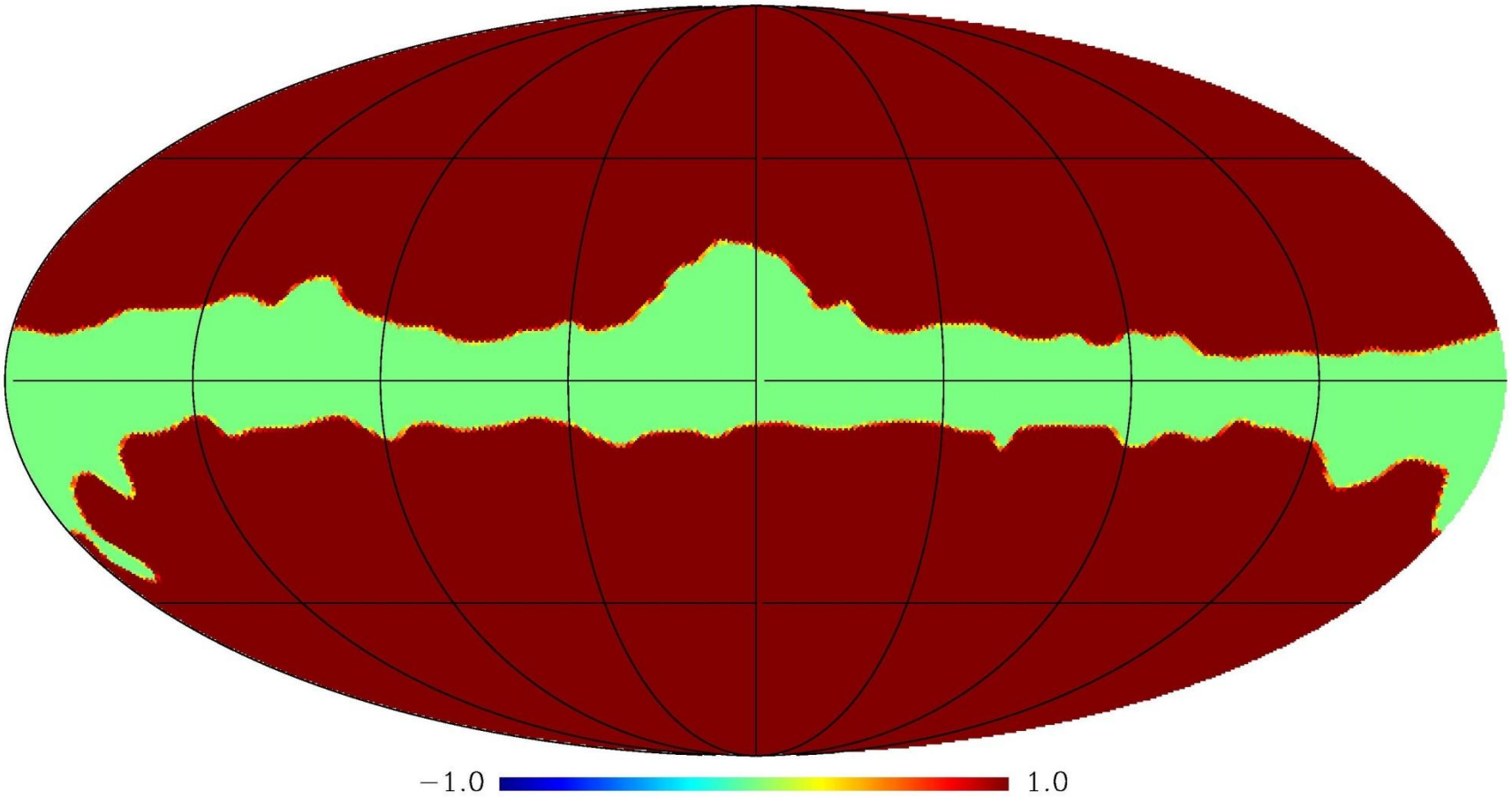
Planck 100GHz filtered map (using both dust and synchrotron filters + free-free WMAP7 filter; units [K])



Planck 100GHz filtered map (using both dust and synchrotron filters + free-free WMAP7 filter + marg.correction; units [K])

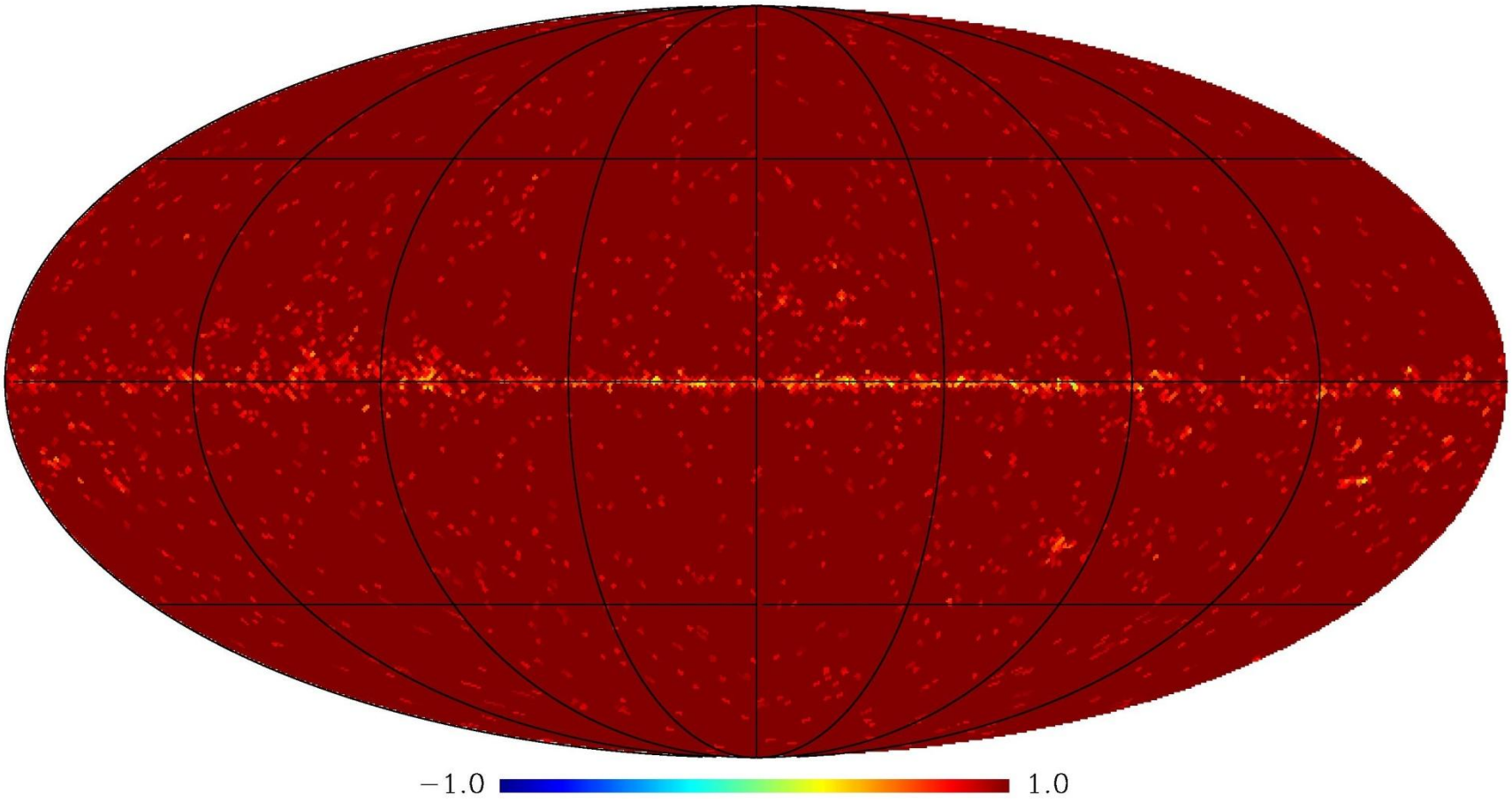


Planck mask to extract Galaxy (70% sky coverage)

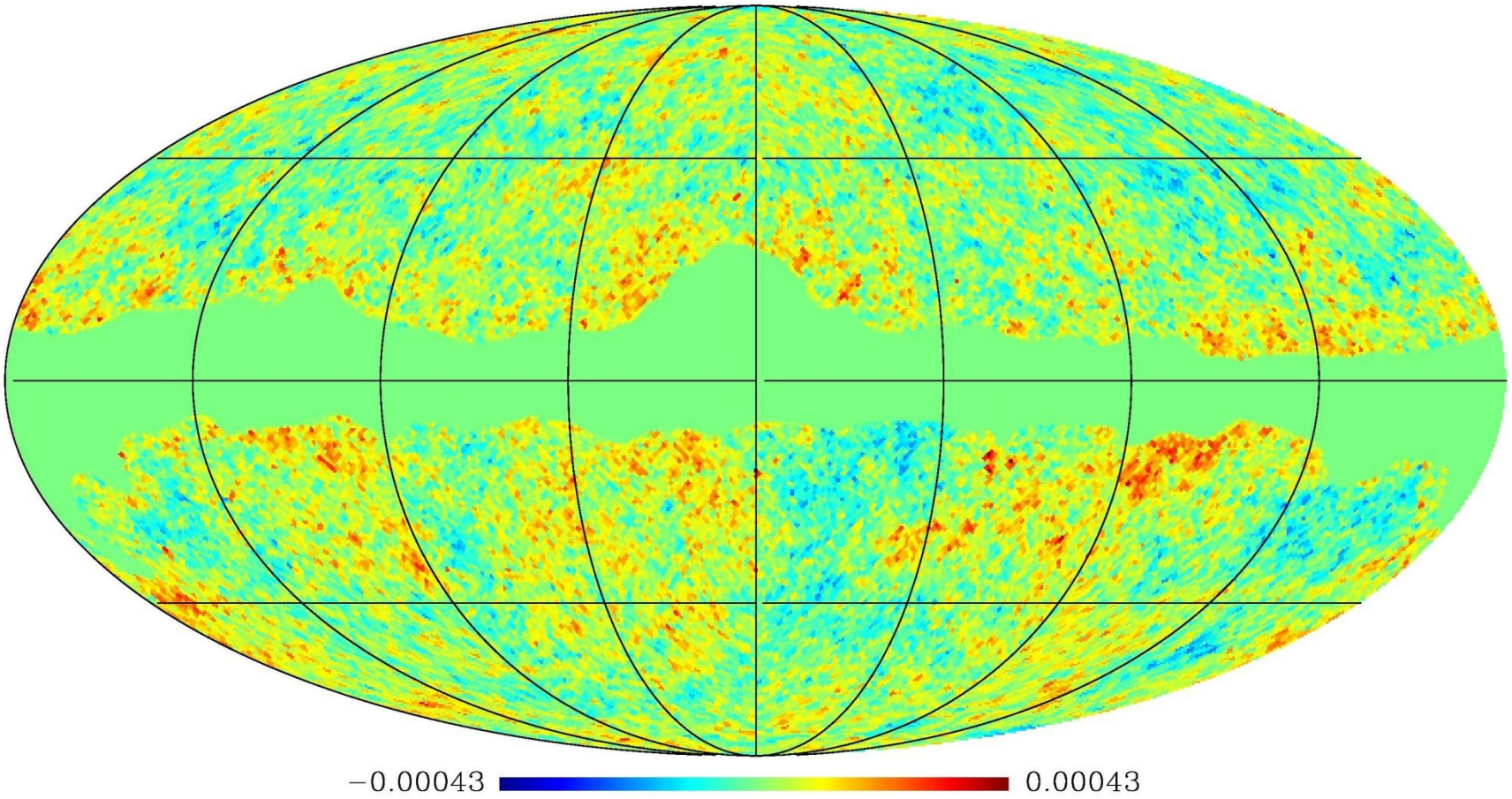


…recommended by Planck collaboration.
There is also 90%, 97%, and 99% sky coverage

Planck point source mask (100GHz, 5σ)



Planck 100GHz filtered map (units [K])

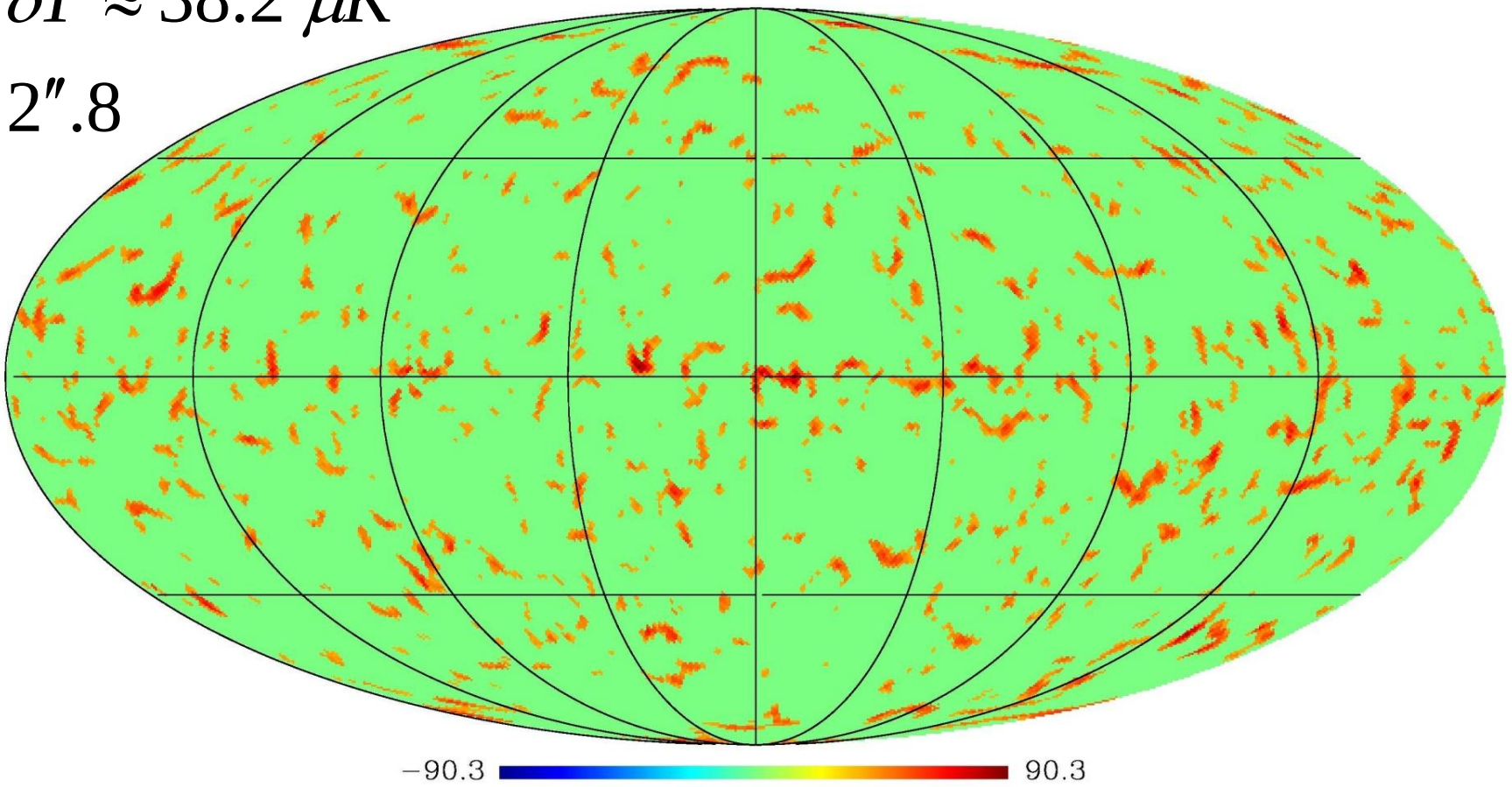


3σ

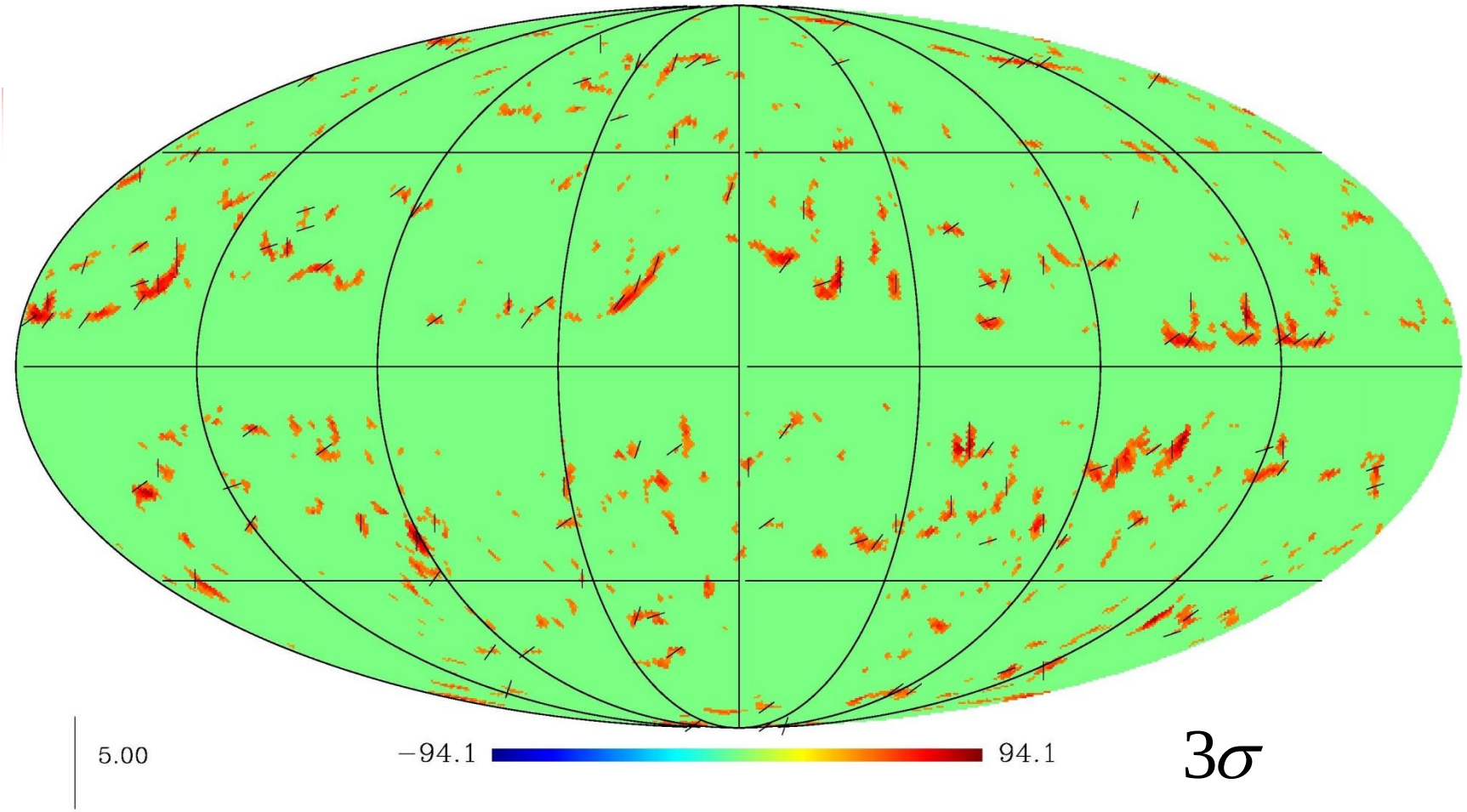
$\delta T \approx 38.2\ \mu K$

$2''.8$

Preliminary locations of string candidates.
WMAP ILC CMBR map after *Haar* analysis



Preliminary locations of string candidates. **PLANCK** filtered CMBR map after *Haar* analysis



3σ

$\delta T \approx 38.2\ \mu K$

$2''.8$

2σ

$\delta T \approx 25.3\ \mu K$

$1''.9$

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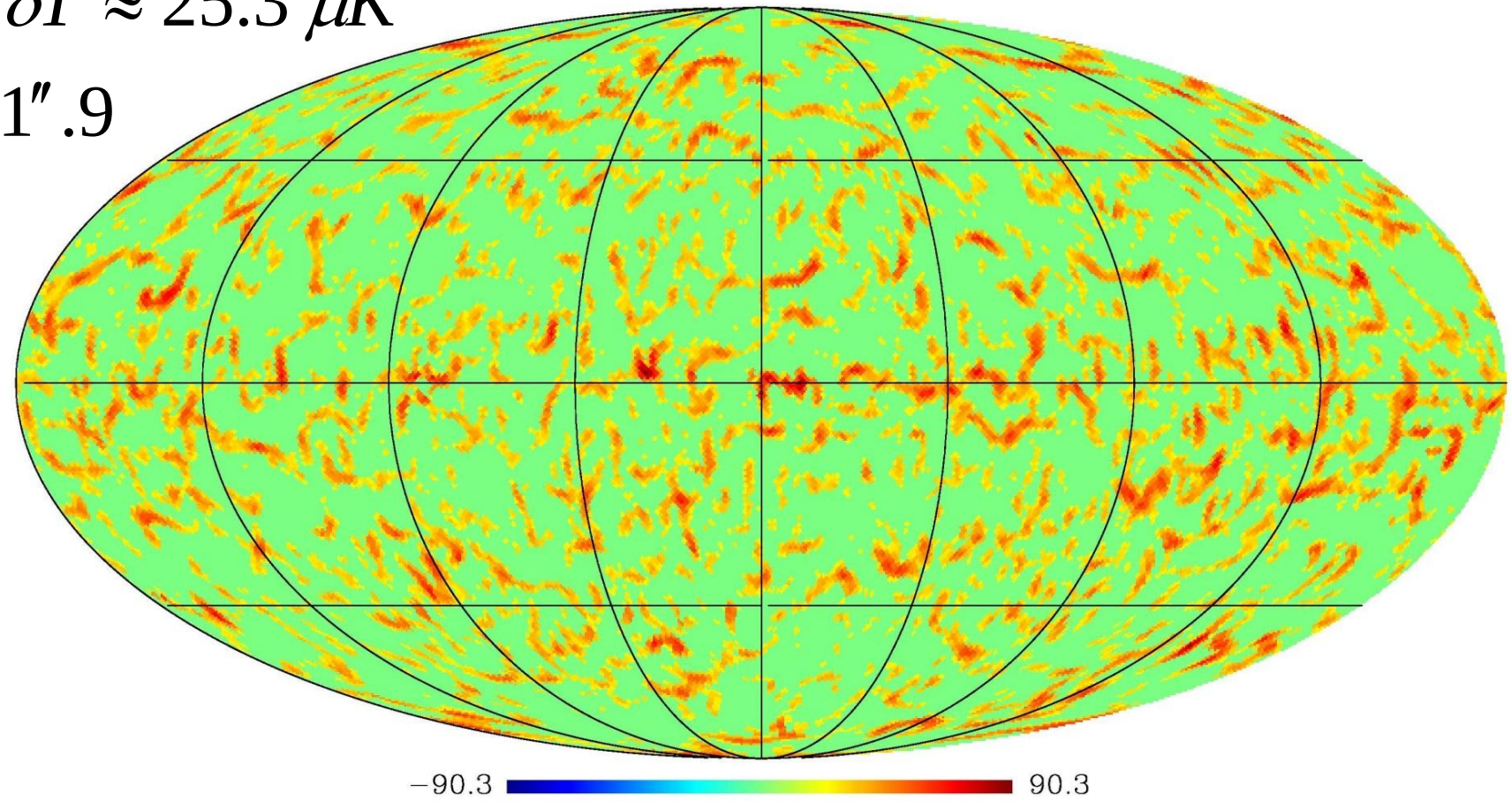
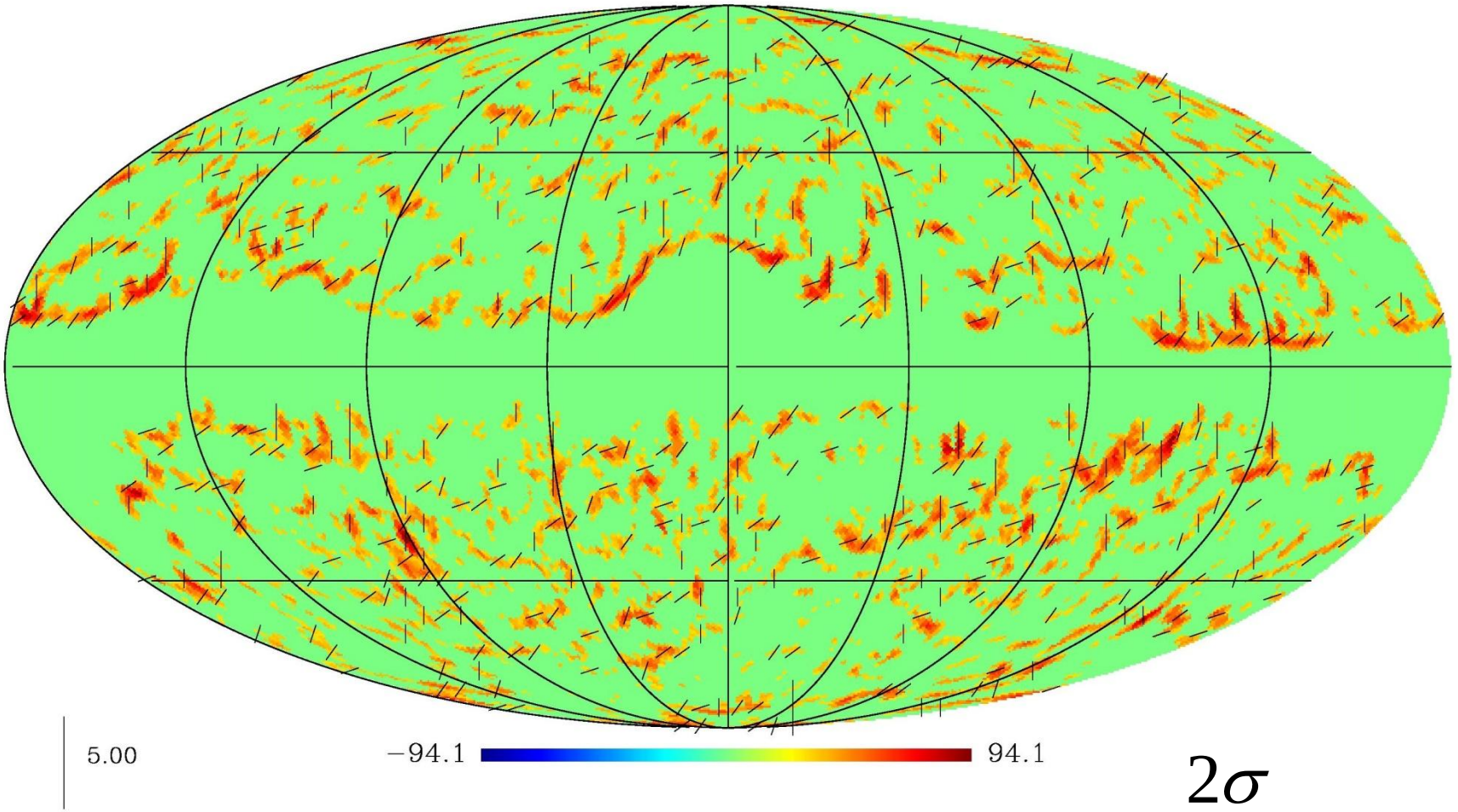


Preliminary locations of string candidates. **PLANCK** filtered CMBR map after *Haar* analysis



2σ

$\delta T \approx 25.3\ \mu K$

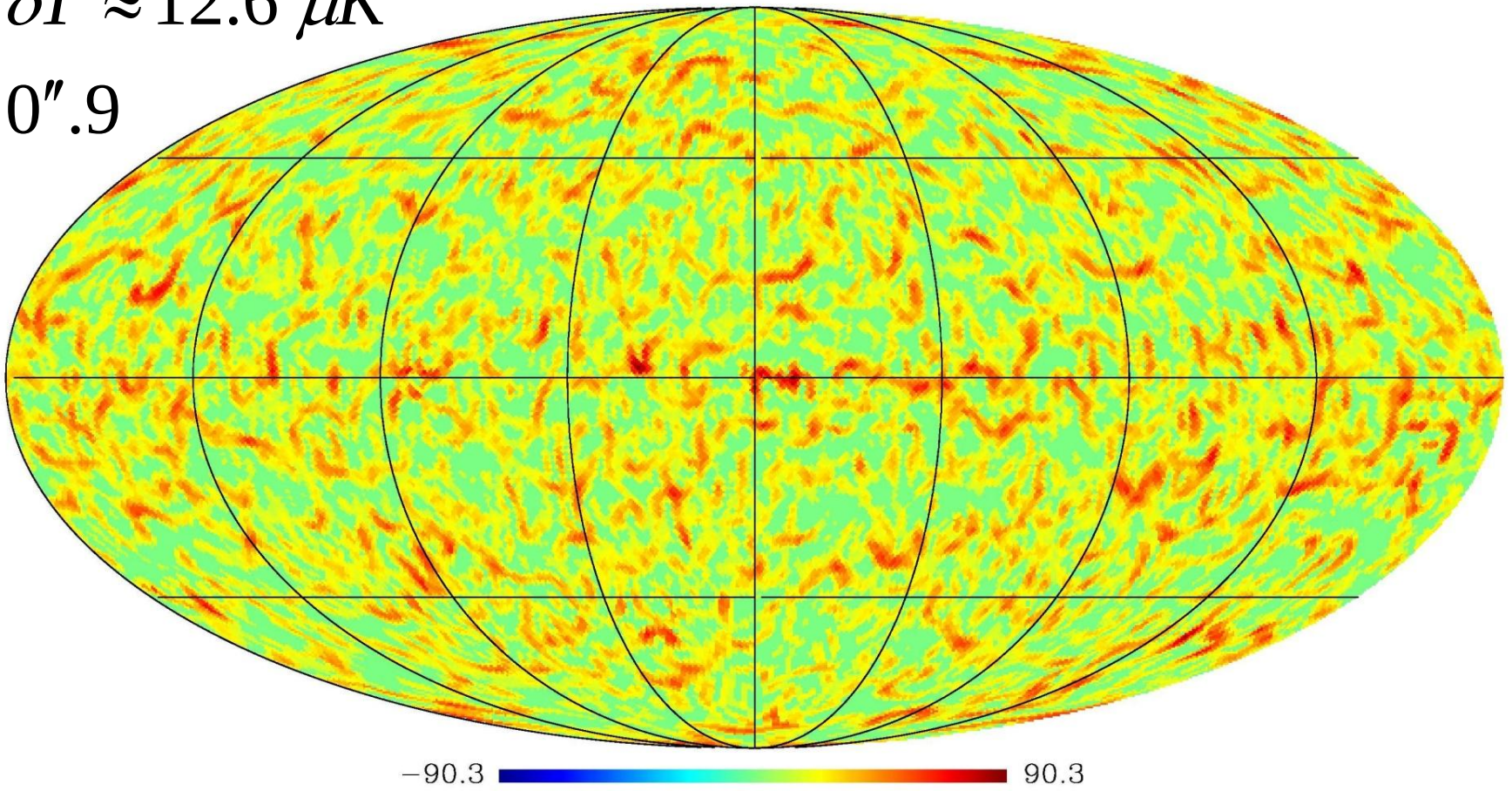
$1''.9$

1σ

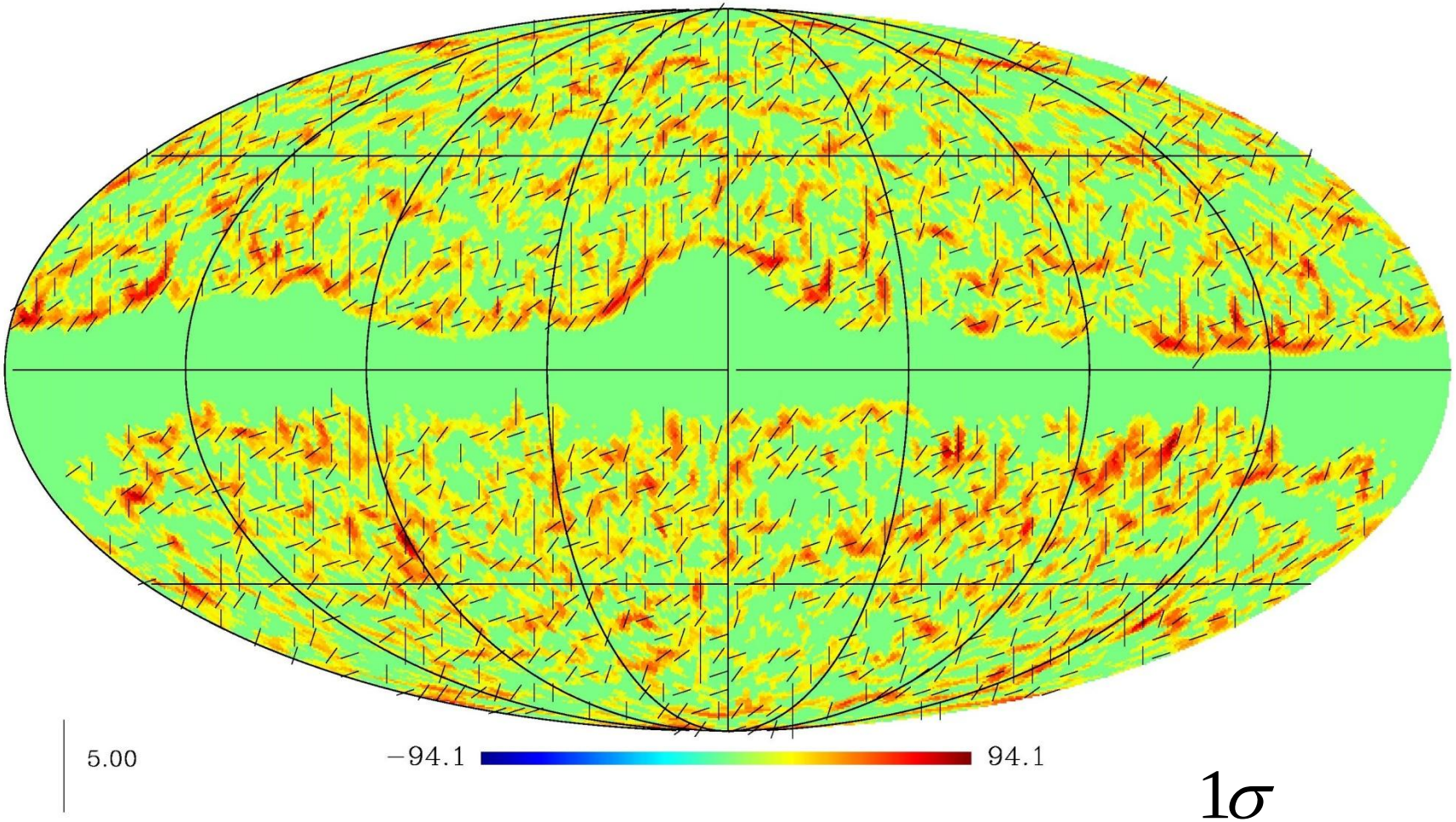
$\delta T \approx 12.6\ \mu K$

$0''.9$

Preliminary locations of string candidates.
WMAP ILCCMBR map after *Haar* analysis



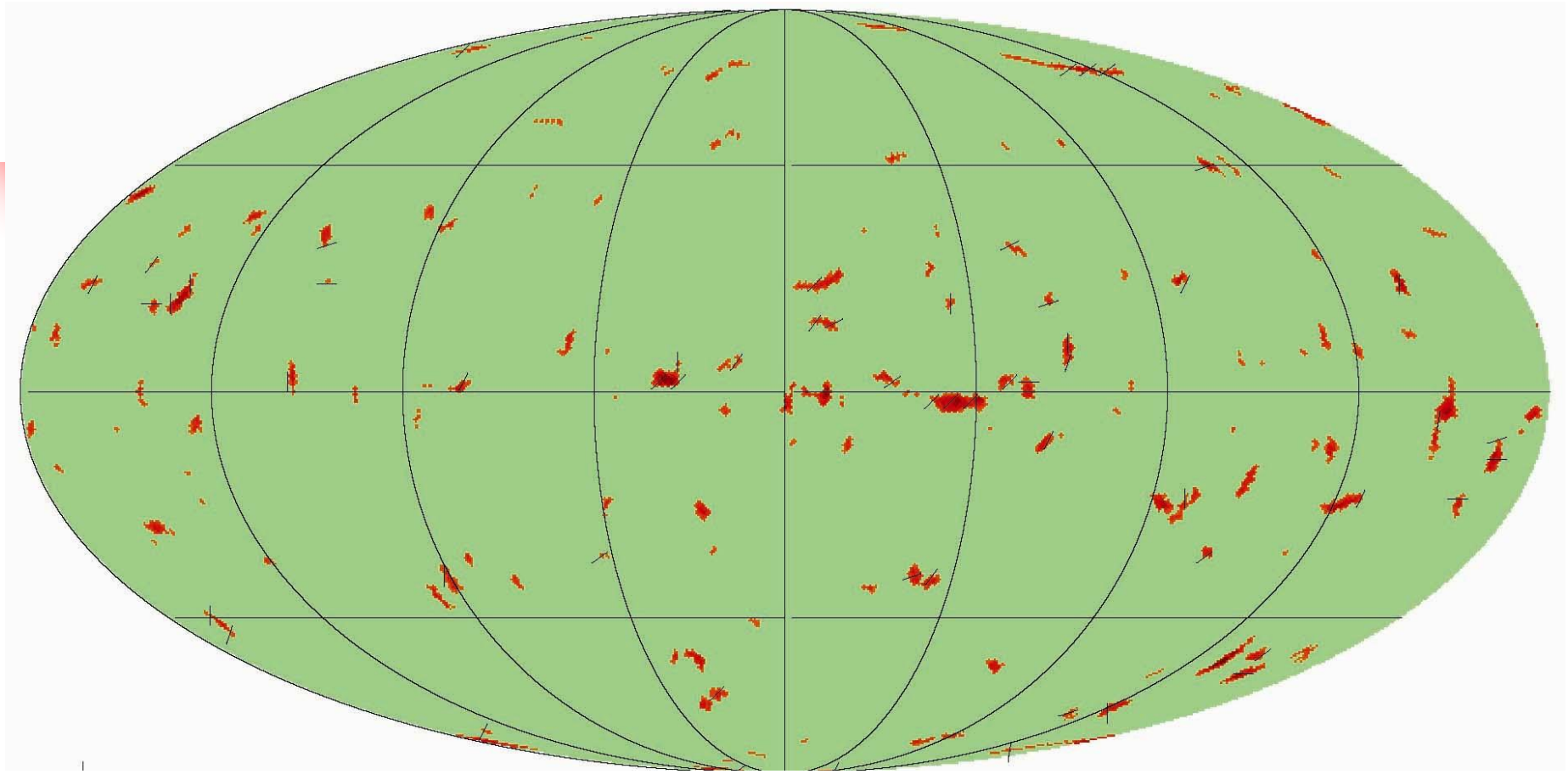
Preliminary locations of string candidates. **PLANCK** filtered CMBR map after *Haar* analysis



1σ

$\delta T \approx 12.6\ \mu K$

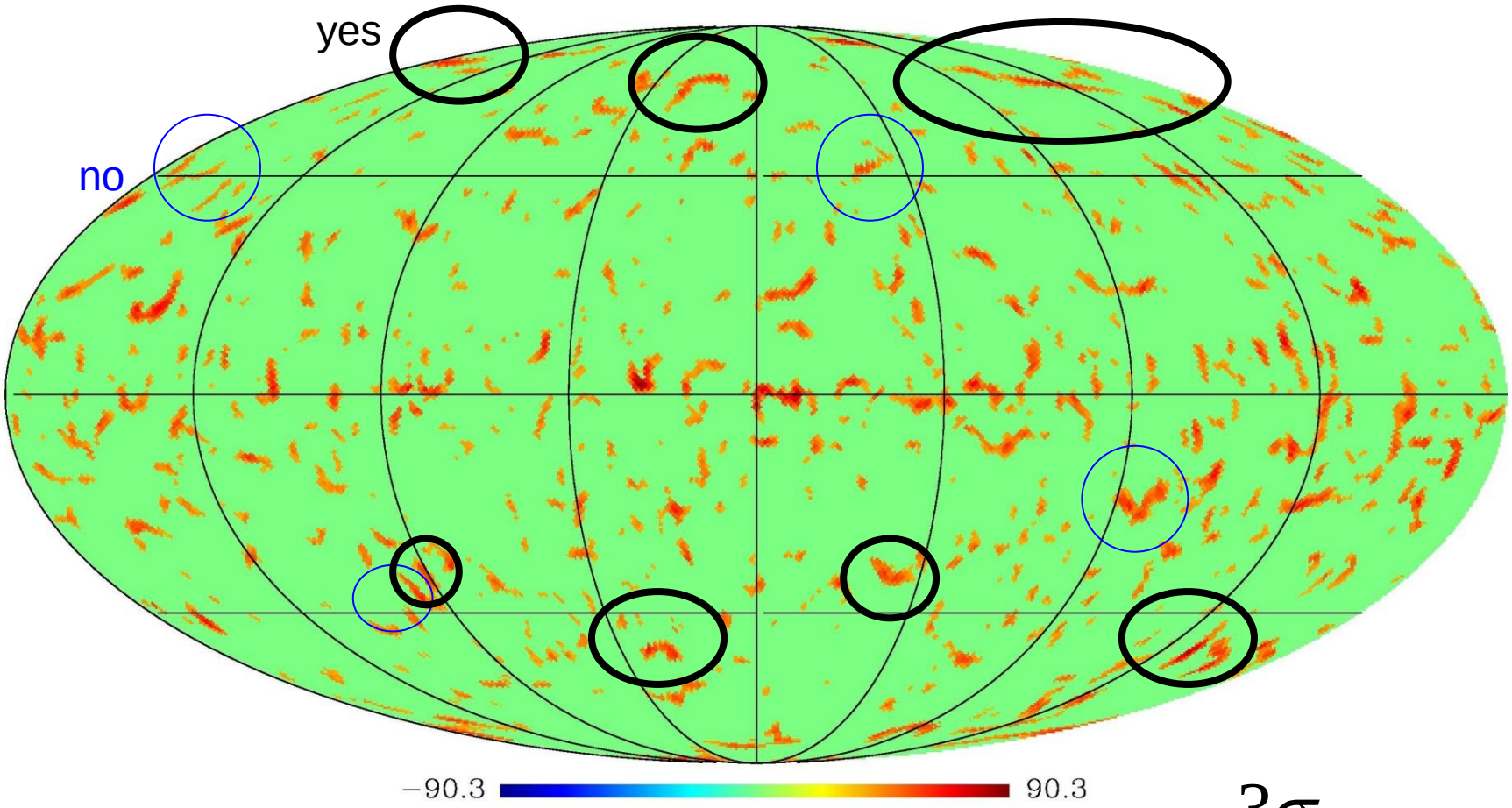
$0''.9$



The upper limit on cosmic string anisotropy "jump"

$$\delta T \approx 40\ \mu K$$

WMAP

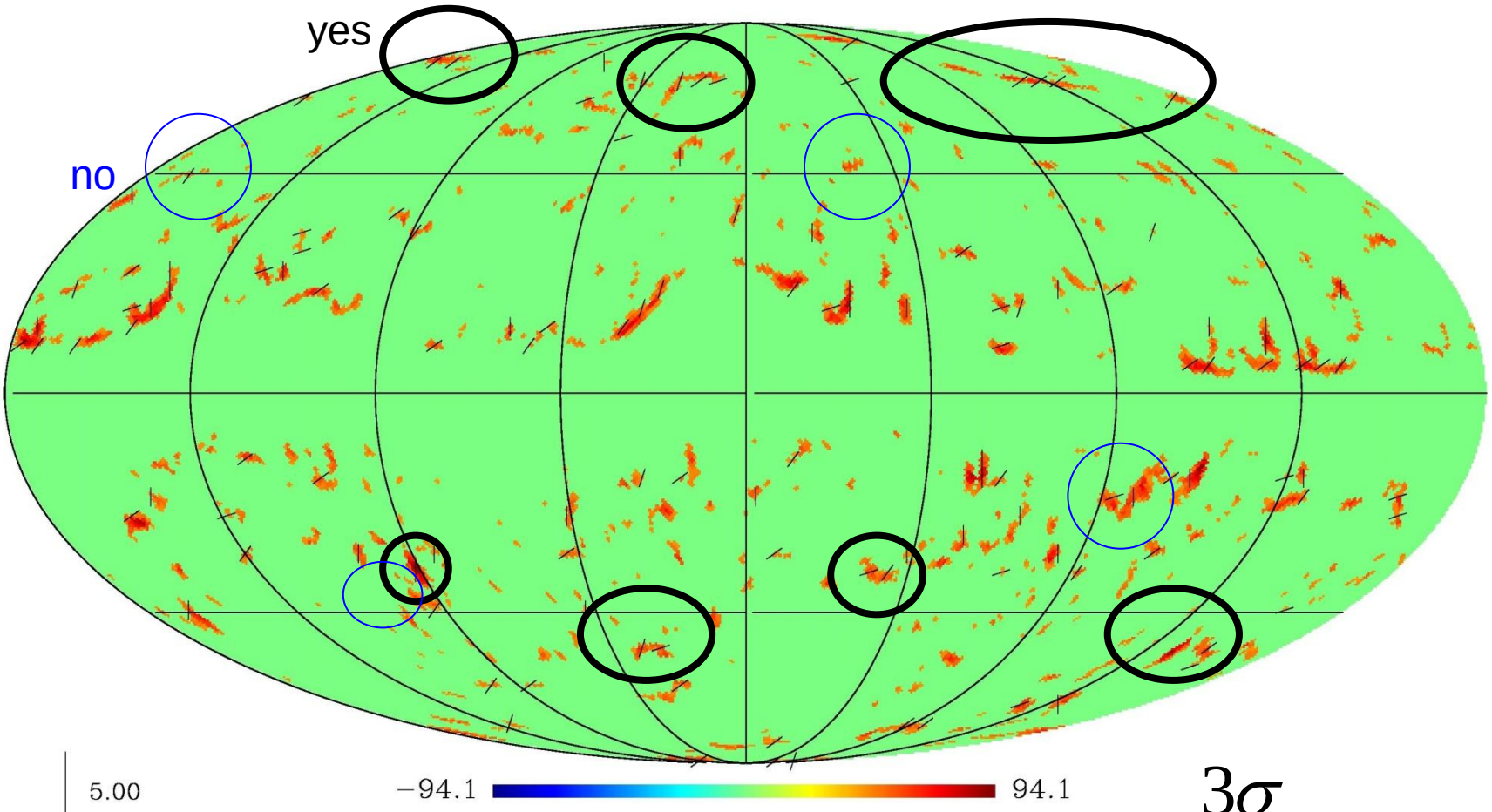


3σ

$\delta T \approx 38.2\ \mu K$

$2''.8$

Planck



We consider a detection to be positive if we find:

1) a continuous line;
2) at least three correlated vector of temperature gradients;
3) it remains in all bands.

3σ

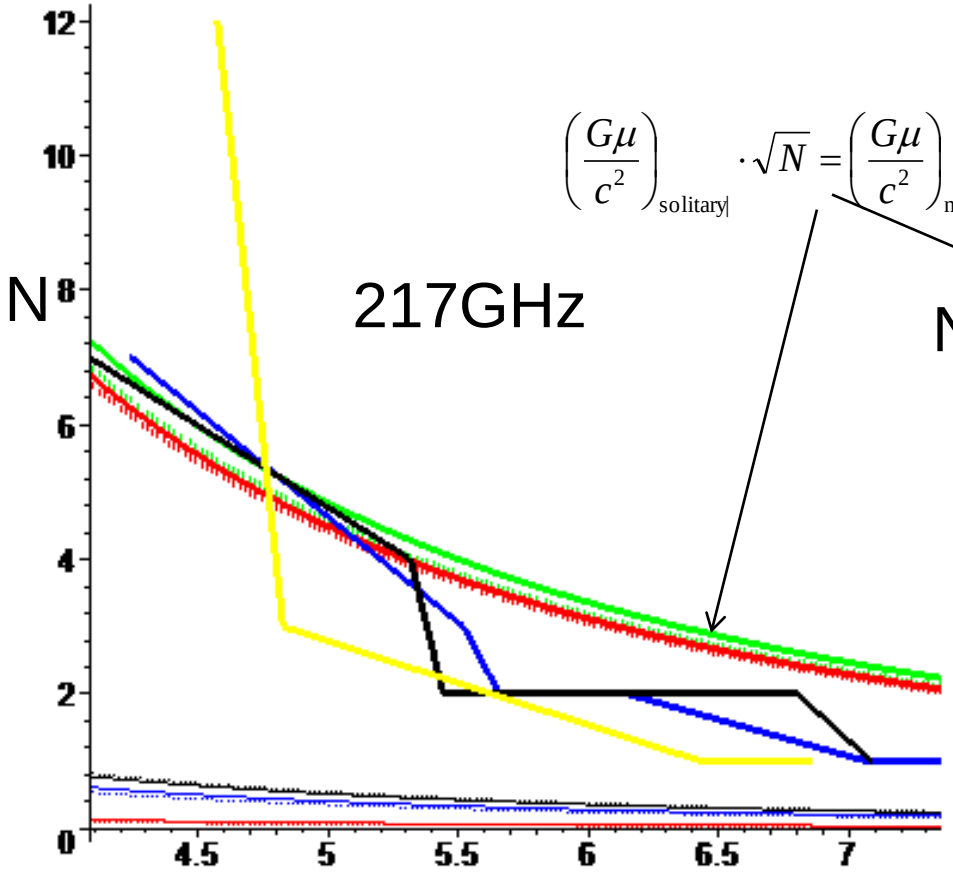
$\delta T \approx 38.2\ \mu K$

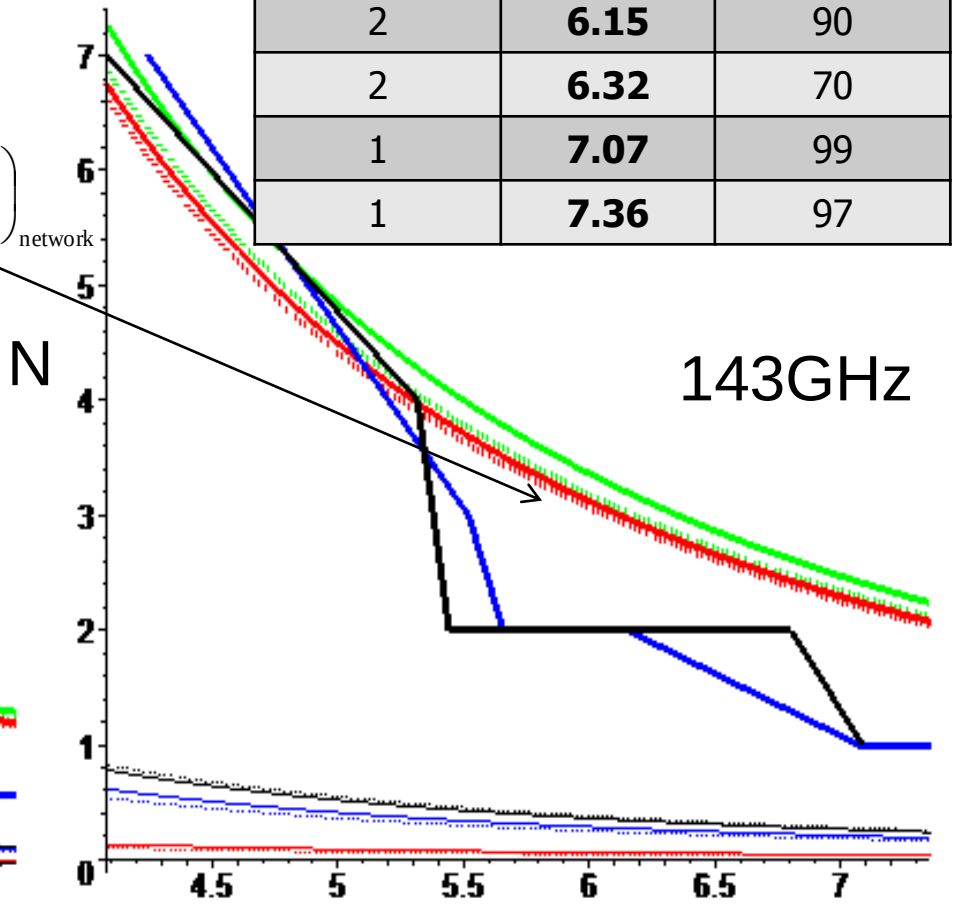
$2''.8$

Cosmic string candidates

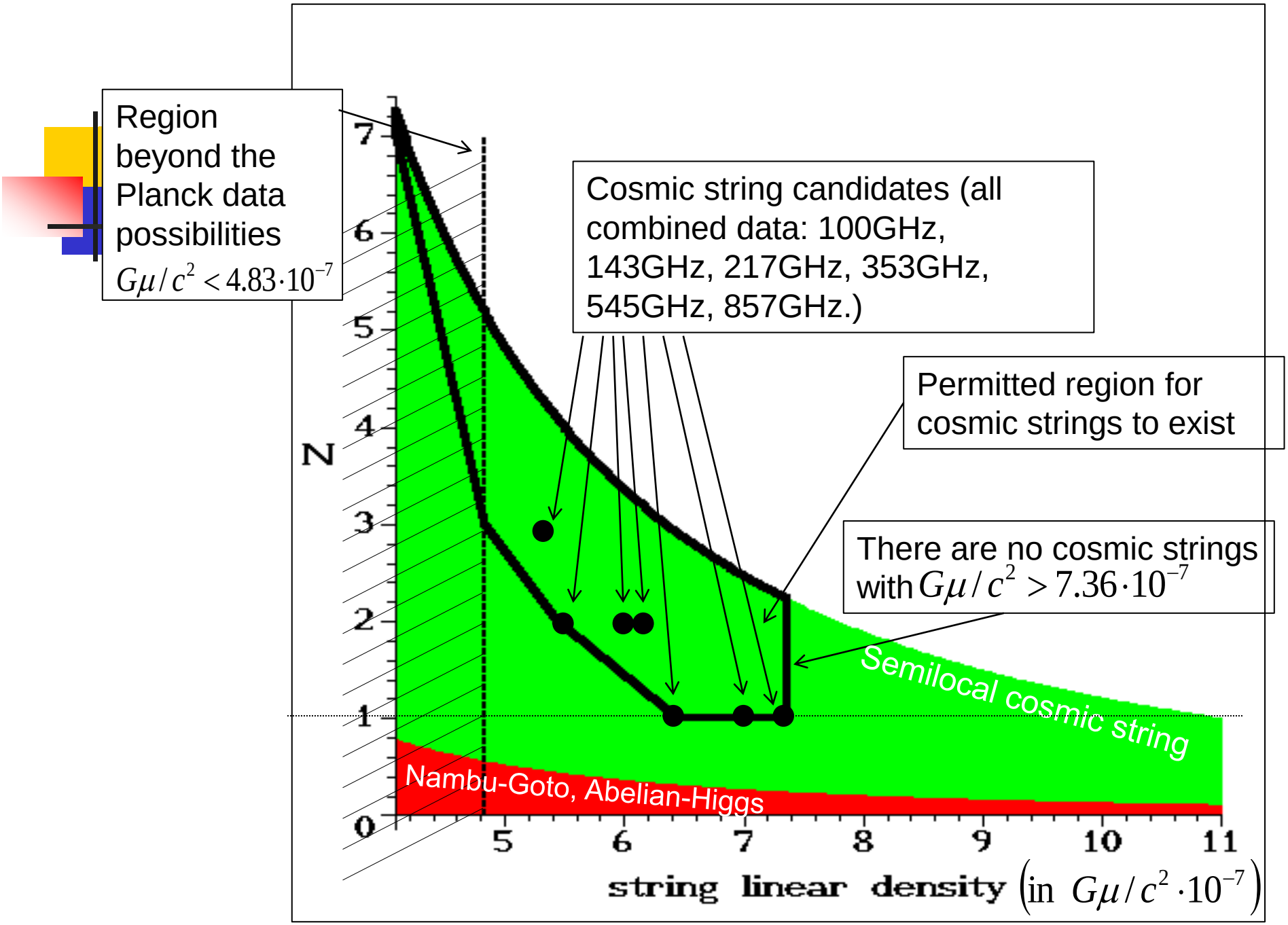
Cosmic string candidate number (143GHz)	Cosmic string tension	Sky coverage Filter
3	**5.52**	97
2	**5.66**	99
2	**6.15**	90
2	**6.32**	70
1	**7.07**	99
1	**7.36**	97

$$\left(\frac{G\mu}{c^2}\right)_{\text{solitary}} \cdot \sqrt{N} = \left(\frac{G\mu}{c^2}\right)_{\text{network}}$$

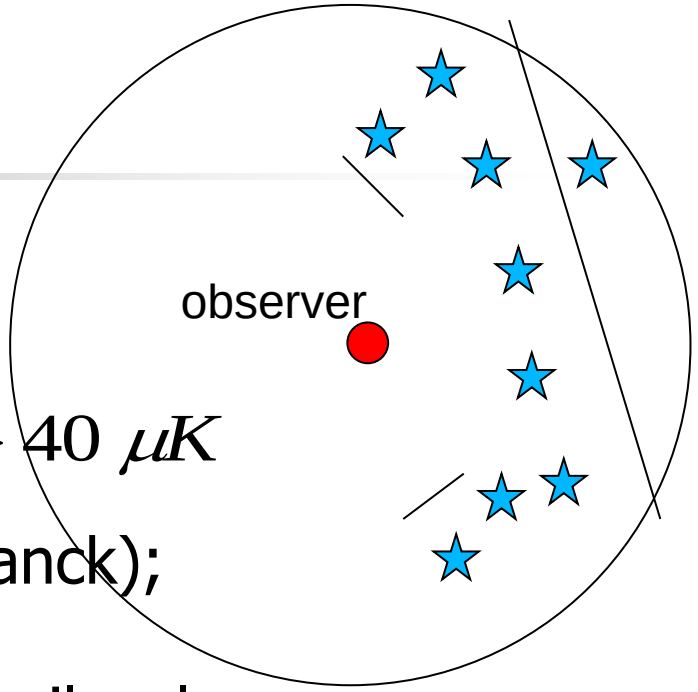




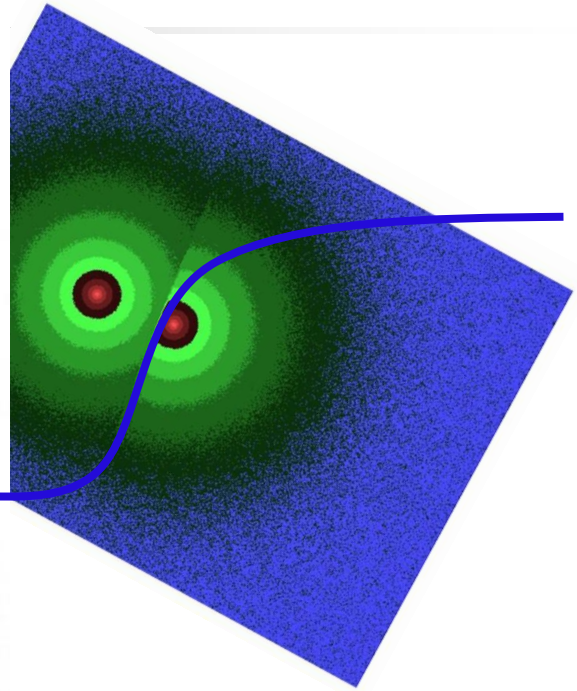
string linear density $\left(\text{in } G\mu/c^2 \cdot 10^{-7}\right)$


Region beyond the Planck data possibilities
$G\mu/c^2 < 4.83\cdot10^{-7}$
Cosmic string candidates (all combined data: 100GHz, 143GHz, 217GHz, 353GHz, 545GHz, 857GHz.)
Permitted region for cosmic strings to exist
There are no cosmic strings with $G\mu/c^2 > 7.36\cdot10^{-7}$
Semilocal cosmic string
Nambu-Goto, Abelian-Higgs
N
0
1
2
3
4
5
6
7
5
6
7
8
9
10
11
string linear density $\left(\text{in } G\mu/c^2\cdot10^{-7}\right)$

Conclusions



- There are no cosmic strings with $\delta T > 40\ \mu K$ (or with $G\mu/c^2 > 7.36 \cdot 10^{-7}$ from two independent data set by WMAP and Planck);
- There at least from 1 up to 6 heavy semilocal cosmic string candidates which have to be confirmed by independent optical data;
- There are neither Nambu-Goto nor Abelian-Higgs cosmic strings (under simple assumption of homogeneous distribution of cosmic strings).



Thank you for attention!