



Universidad
Católica del Norte



lawphysics
Latin American Webinars on Physics

Astroparticle physics

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Winter School HEP-PUC 2019 “Topics on Graviticulas”



The Plan

1. Astroparticles
2. Cosmic-rays
3. Neutrinos
4. Gamma-rays
5. Gravitational Waves

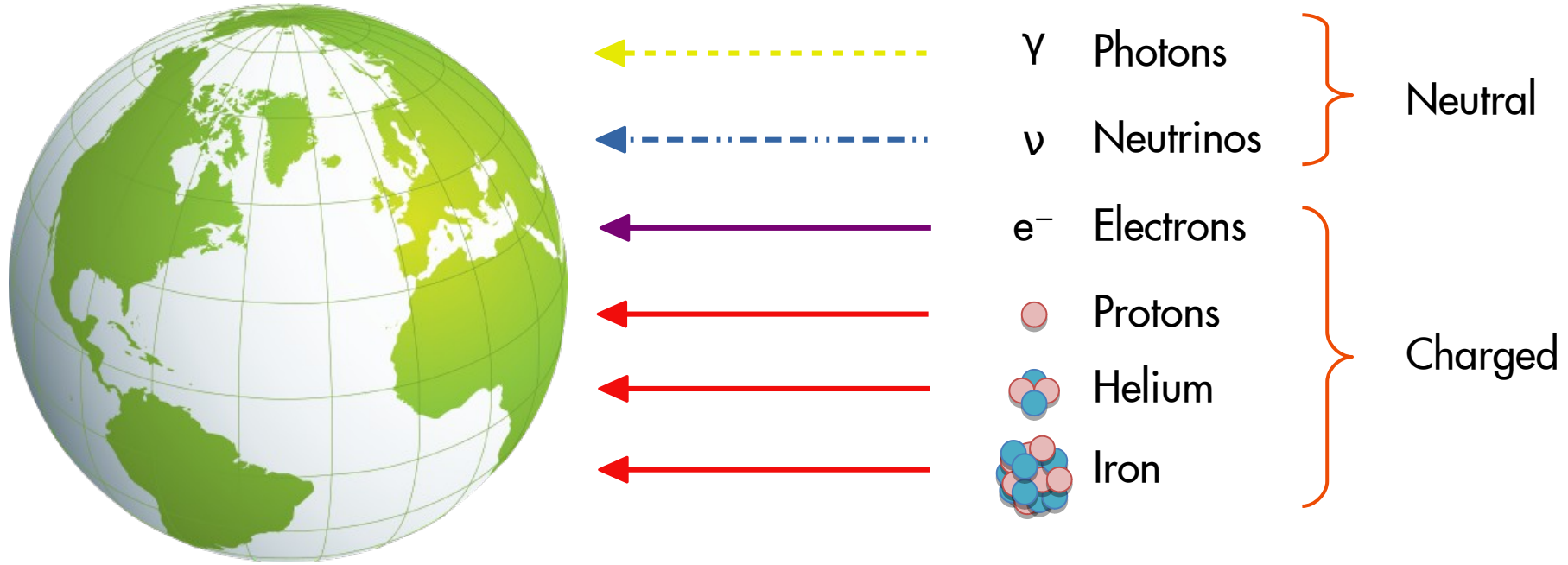
Dark Matter
Astrophysical Sources

Gamma-rays

and other wavelengths

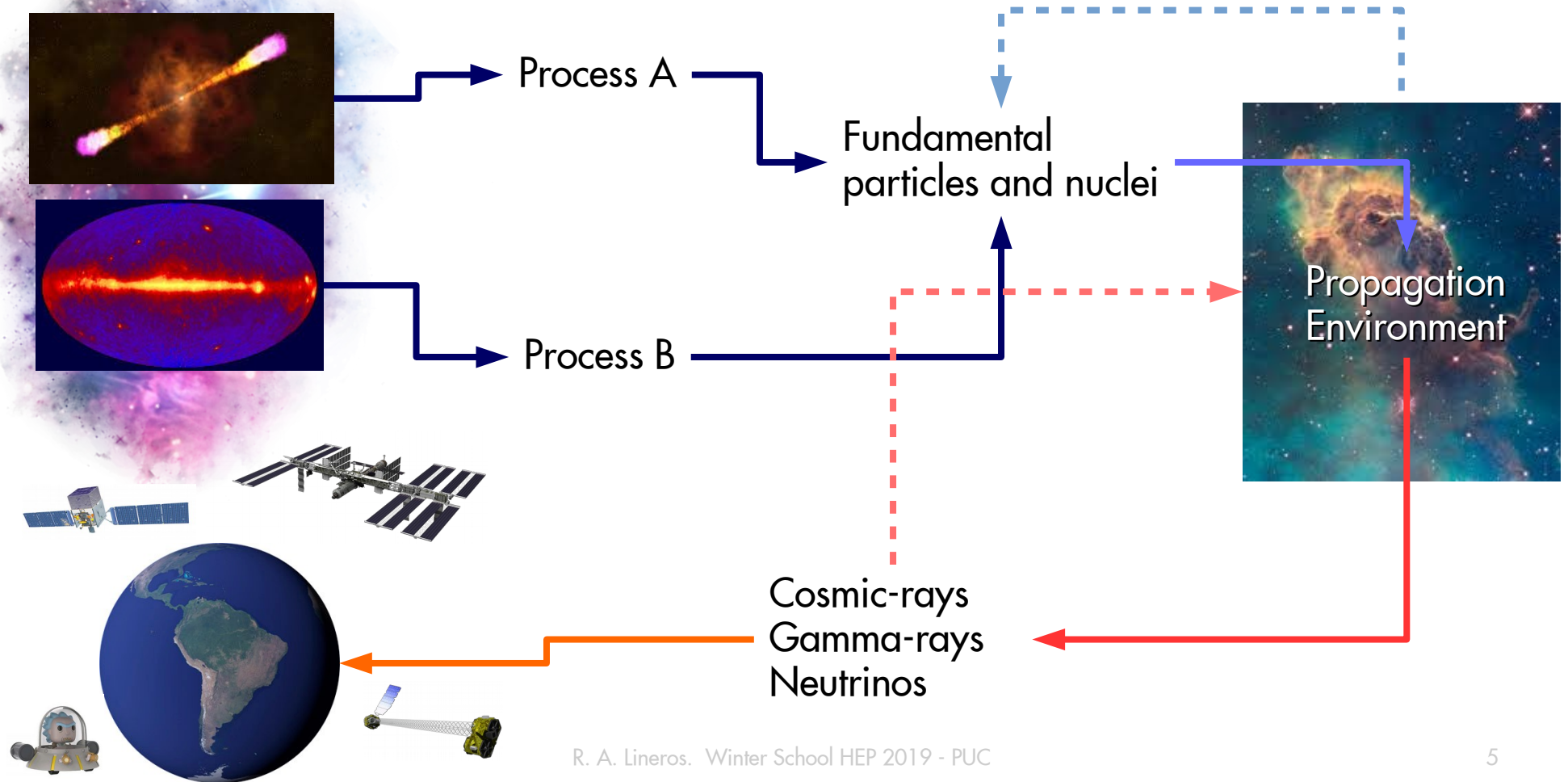


Particles from outer space



Any electrically charged particle may interact with photons

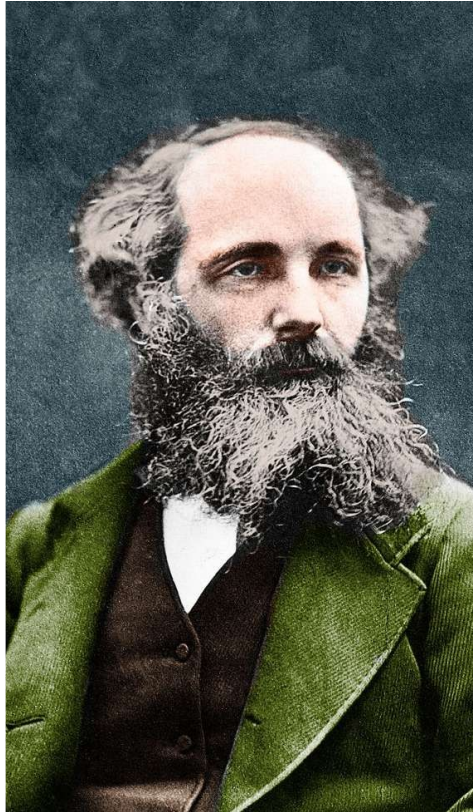
Multimessengers



Photon Physics



Maxwell's equations



Unified description of phenomena related to Electricity and Magnetism

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

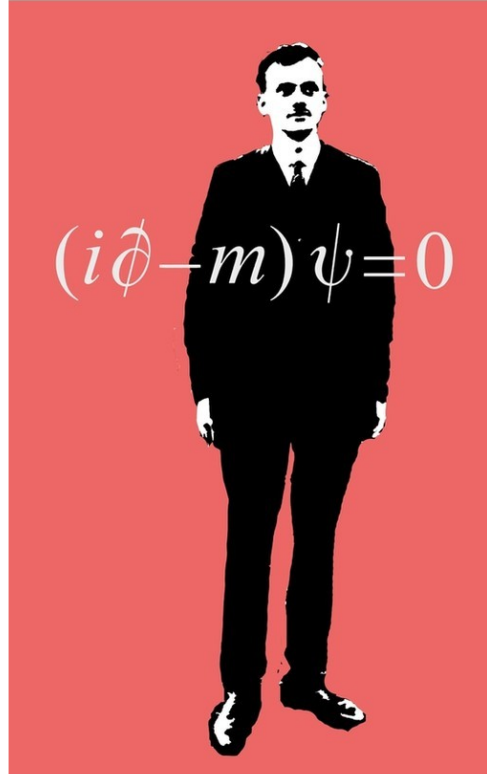
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

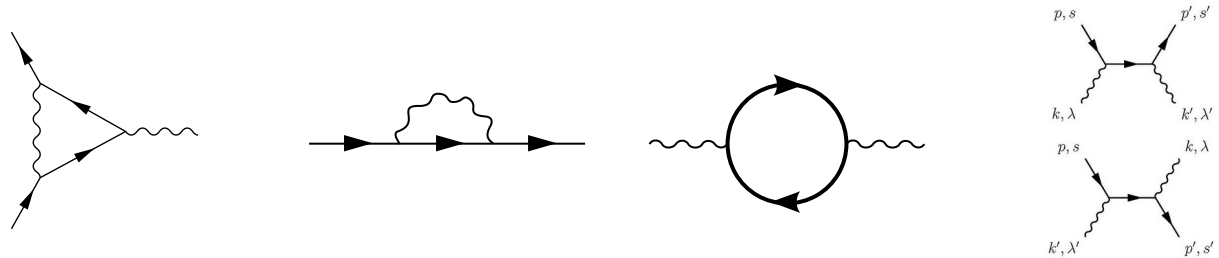
They describe most of the classical aspects of modern physics

Quantum electrodynamics



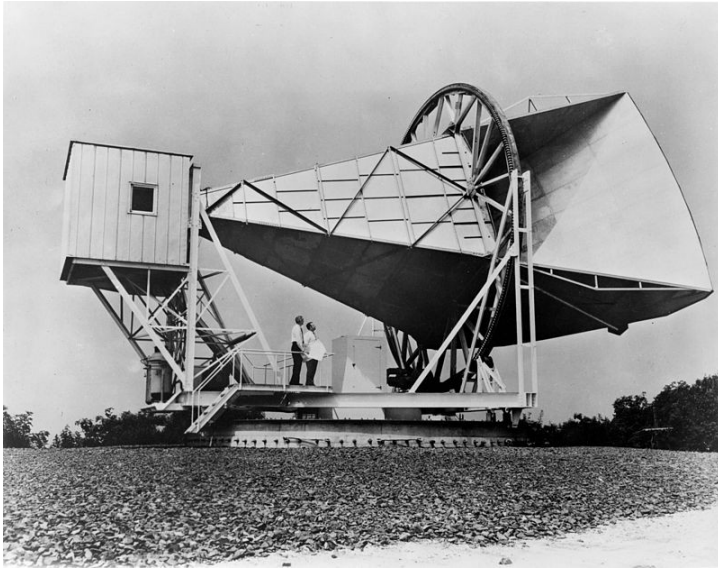
A description of the quantum nature of interactions between electromagnetic fields and electric charges.

$$\mathcal{L} = \bar{\psi} (i\gamma^\mu D_\mu - m) \psi - \frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

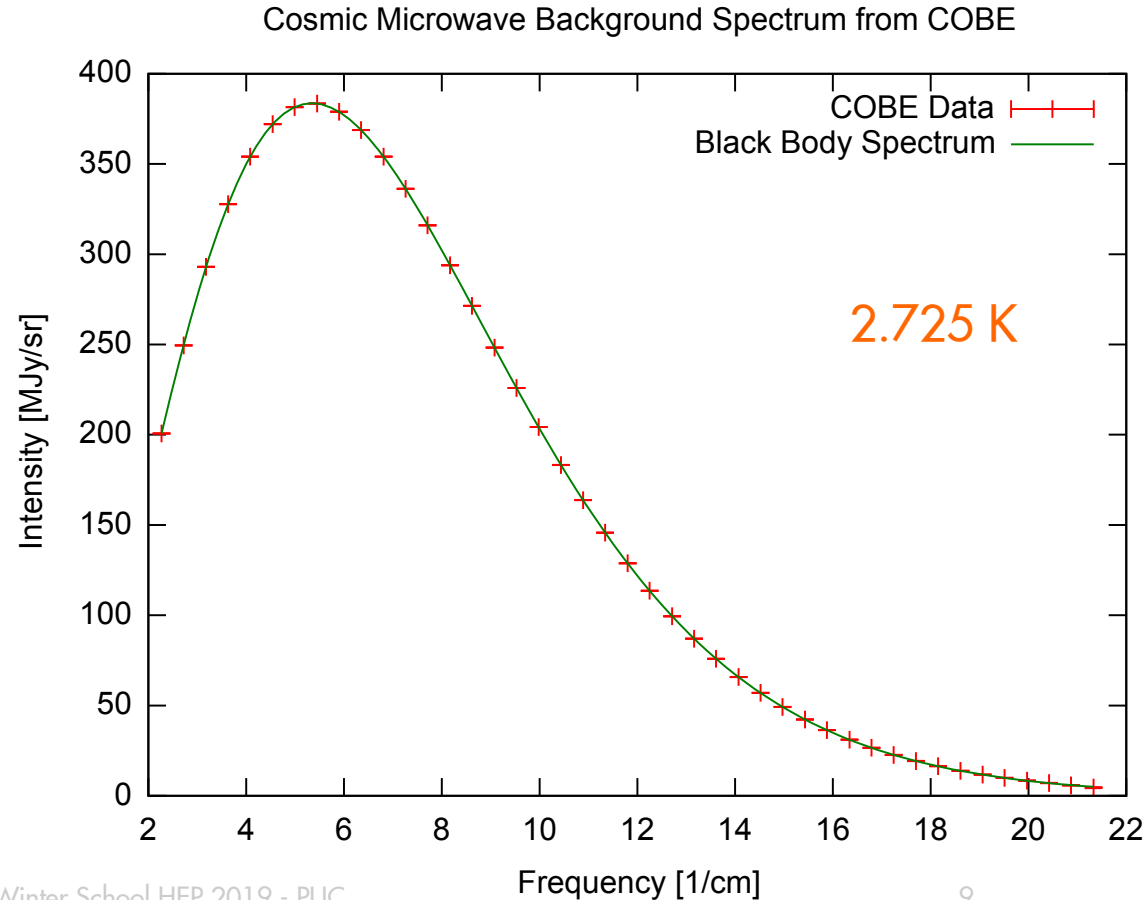


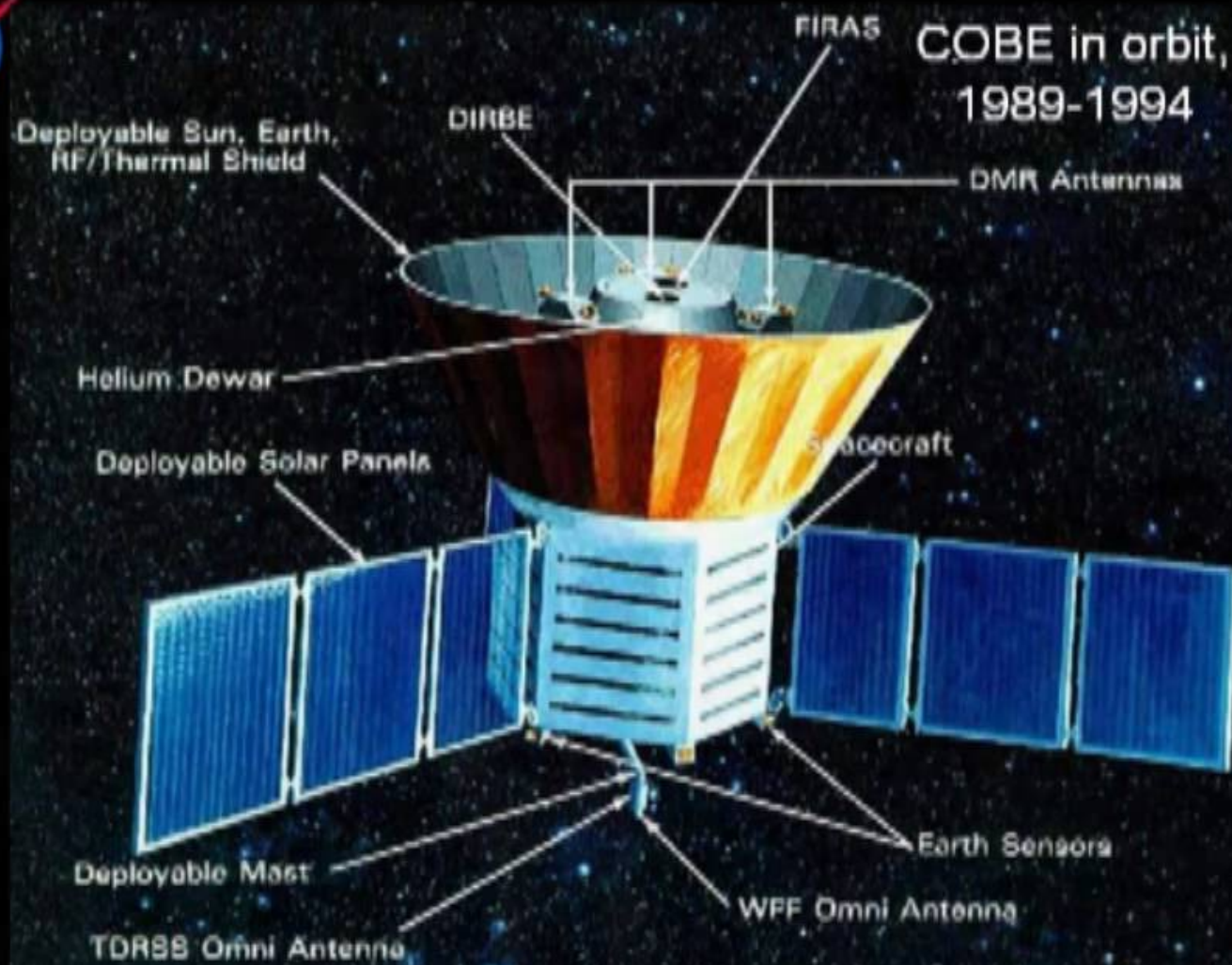
One of the foundational column to build the Standard Model

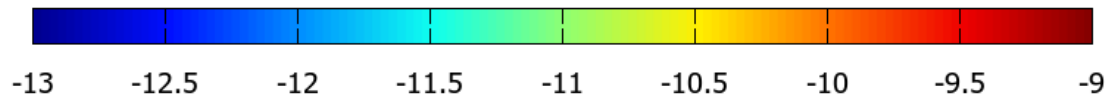
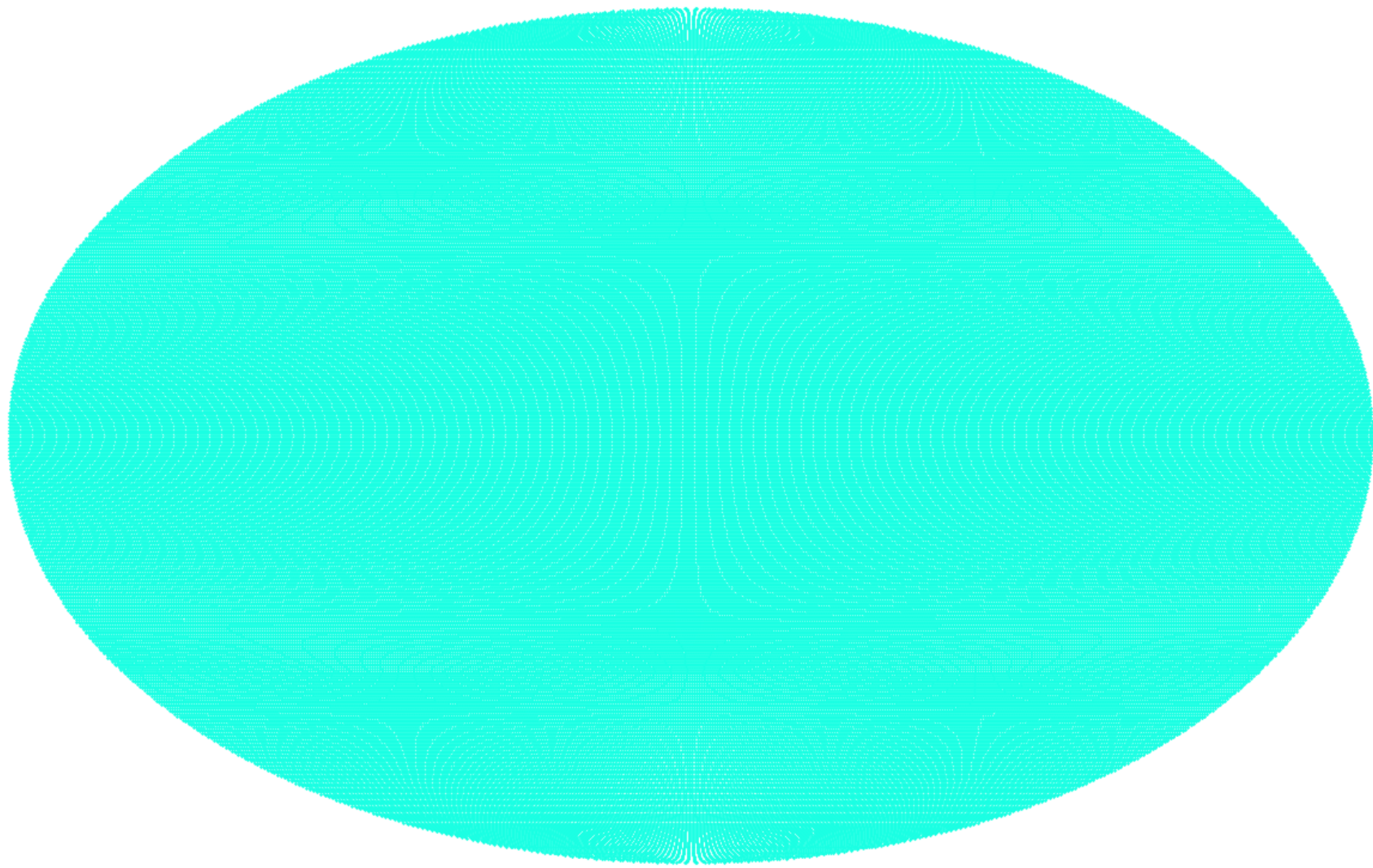
Cosmic Microwave Background

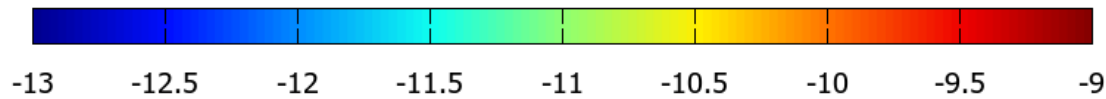
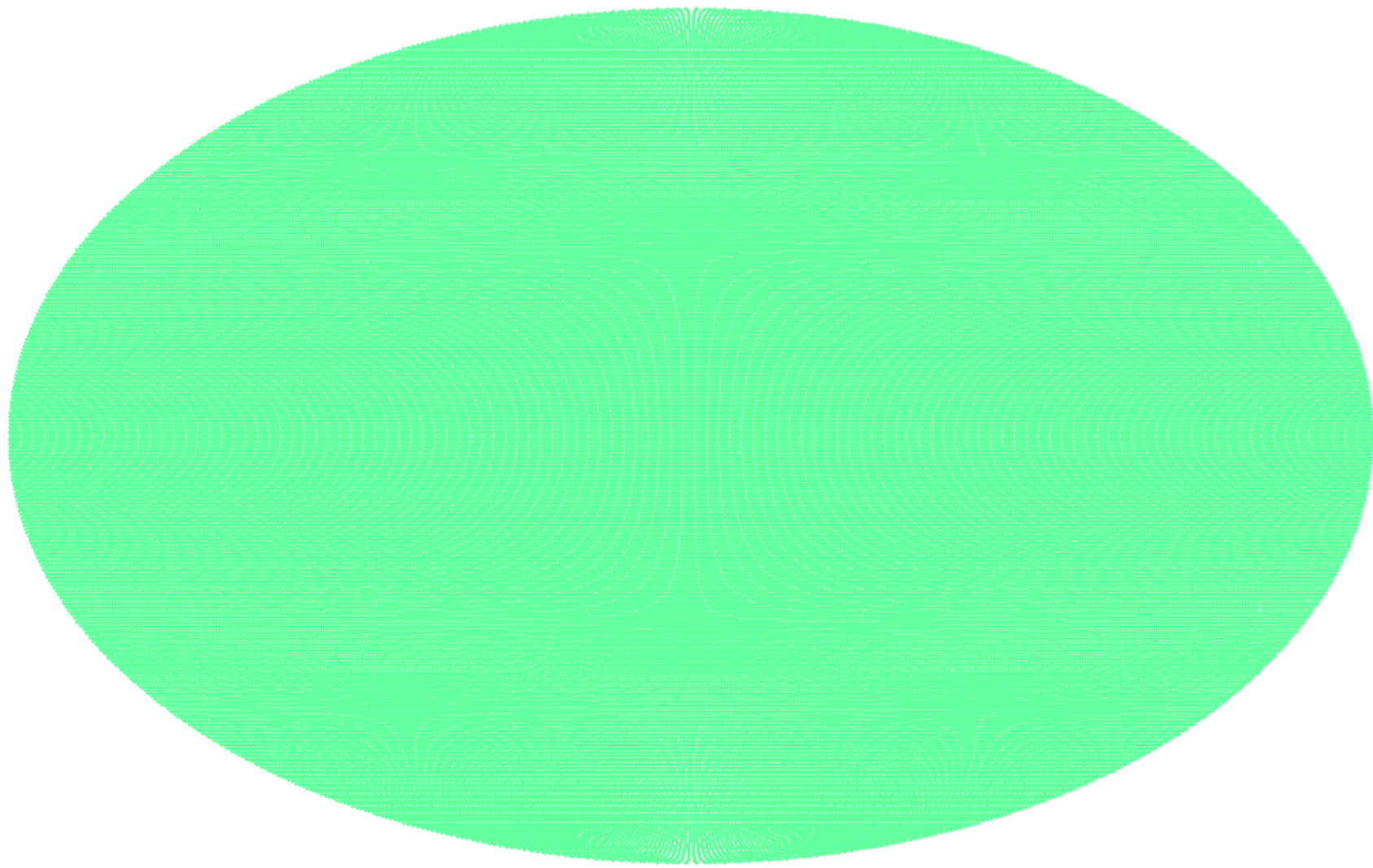


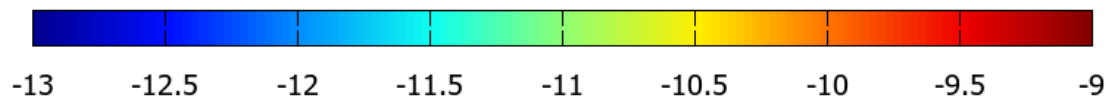
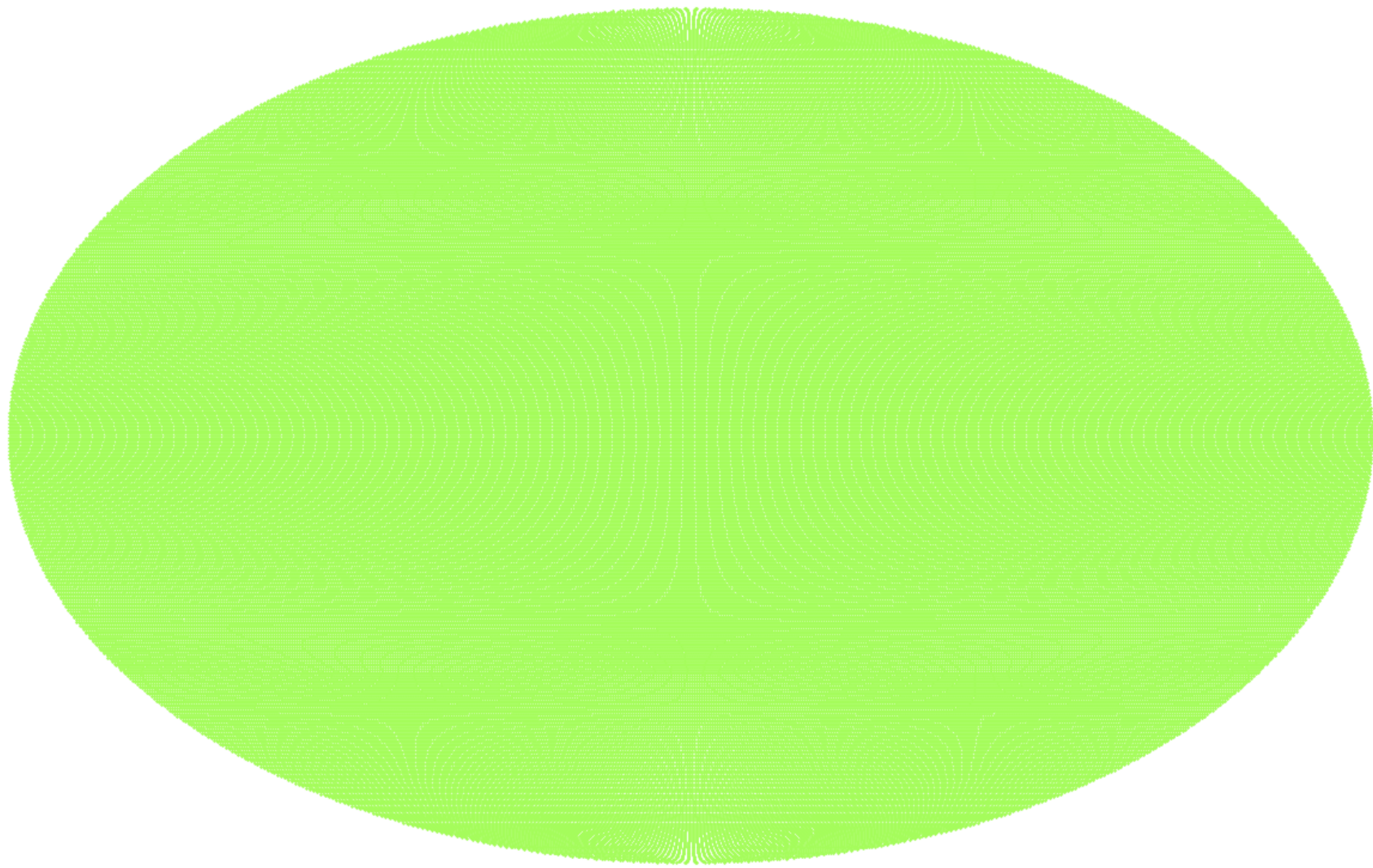
The Holmdel Horn Antenna on which Penzias and Wilson discovered the cosmic microwave background.

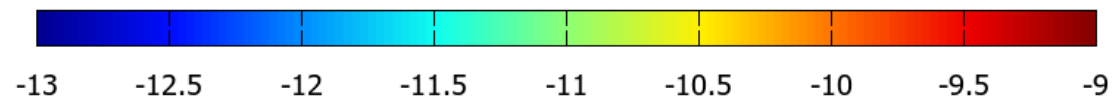
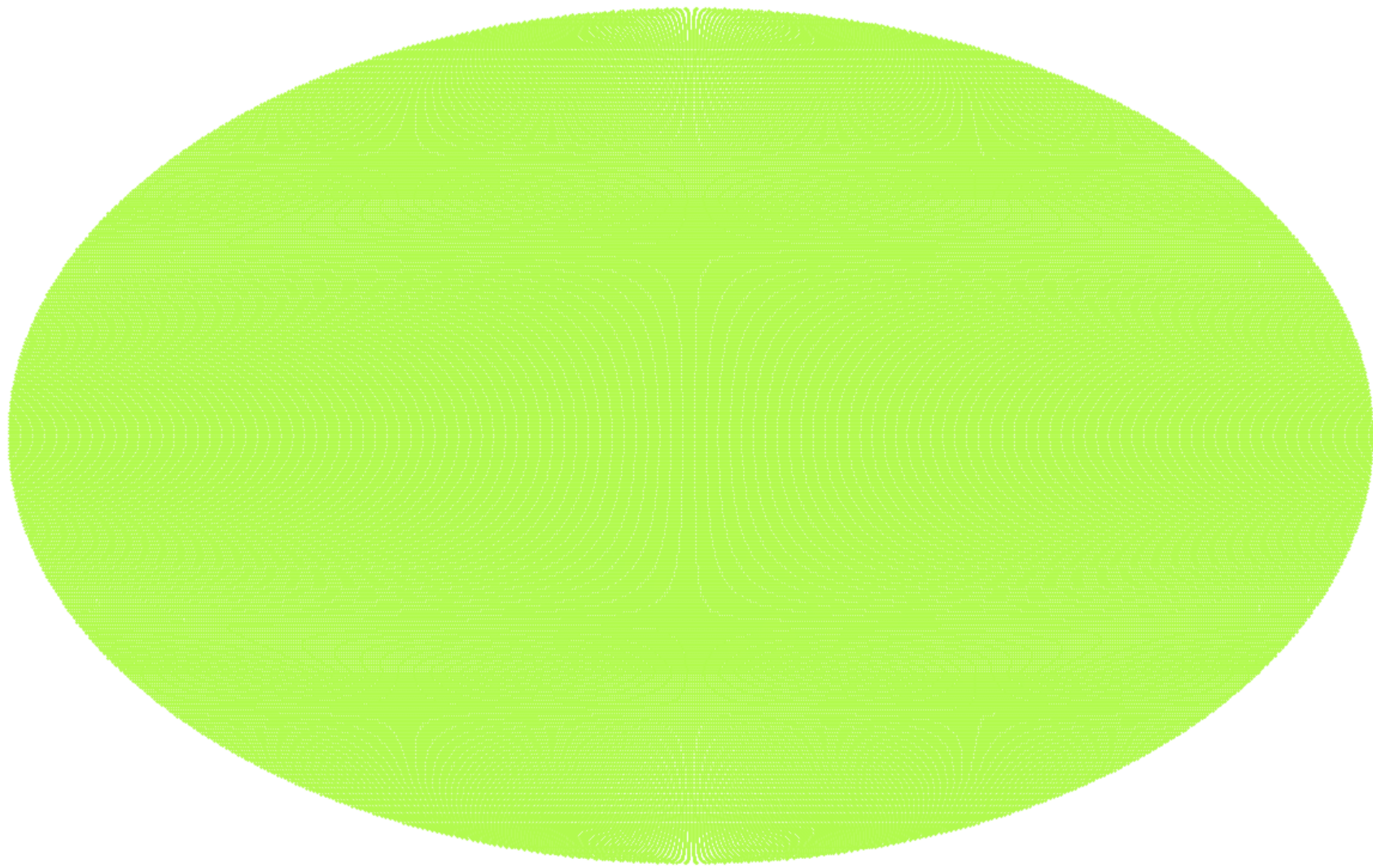


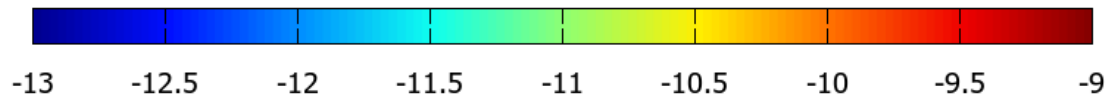
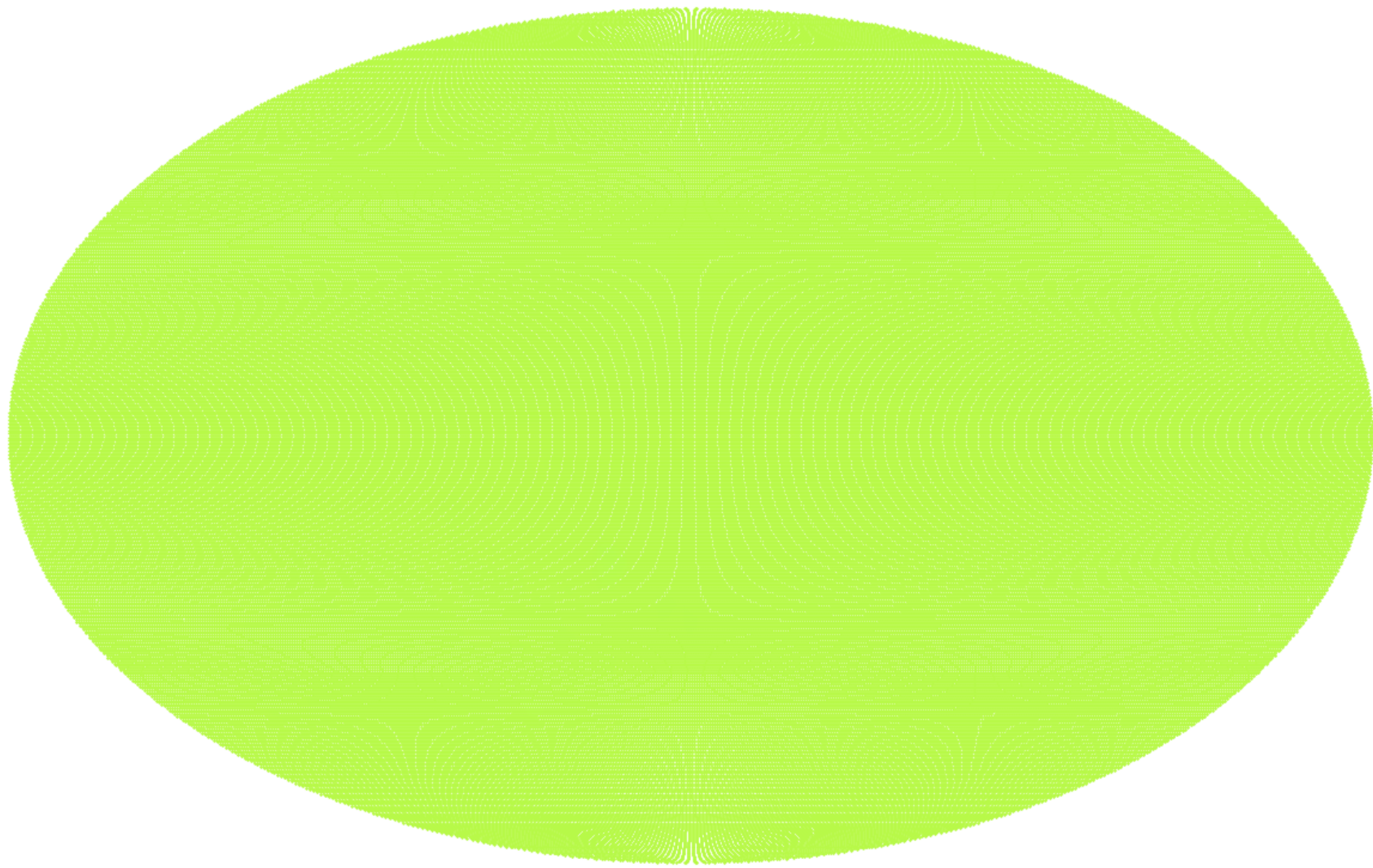


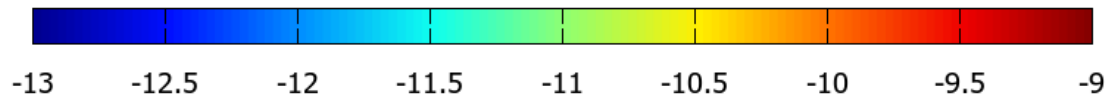
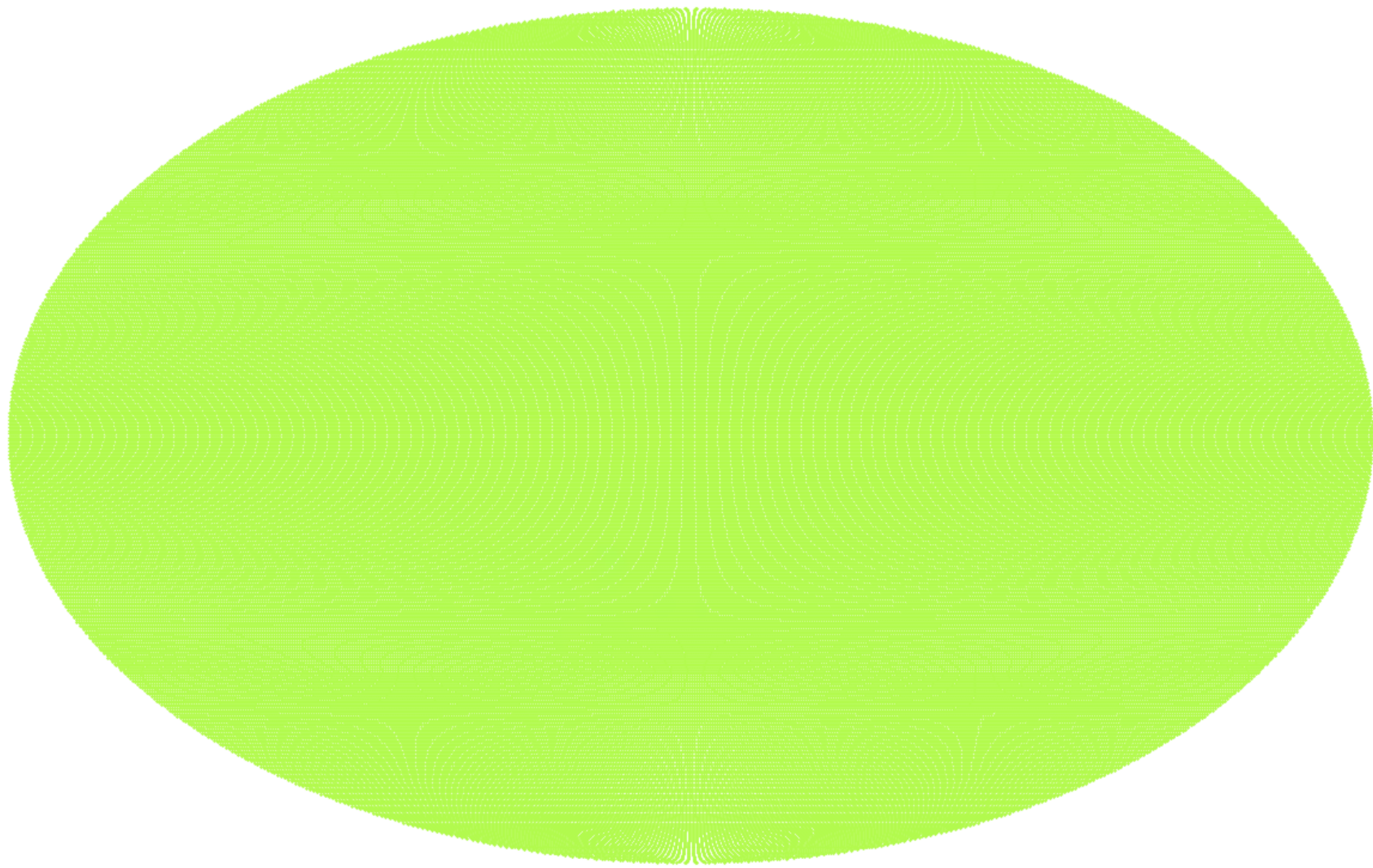


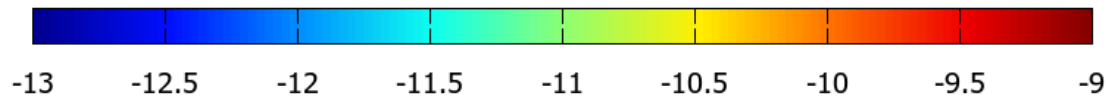
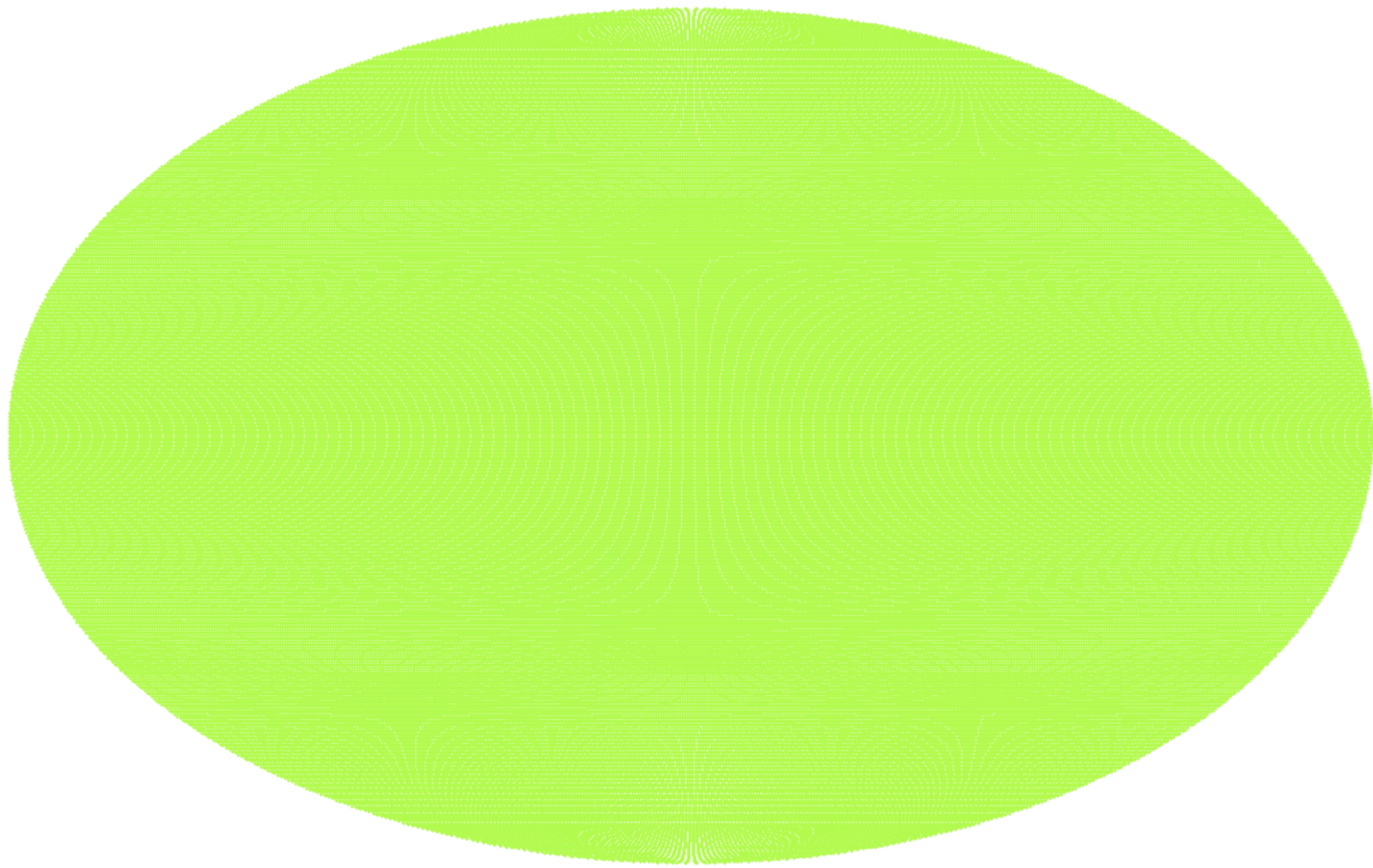


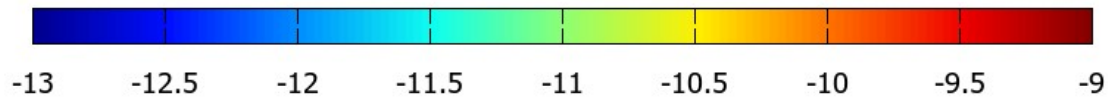
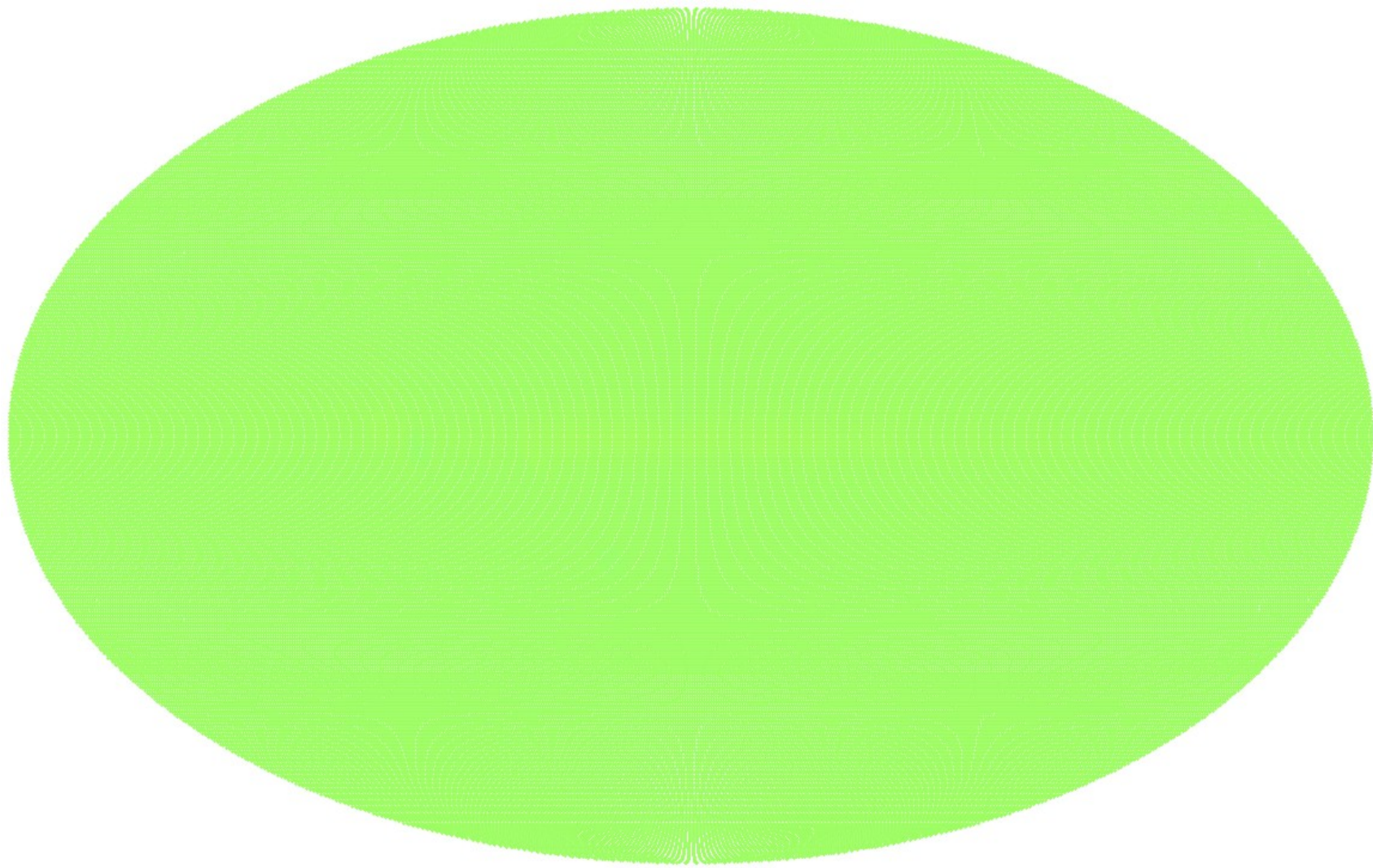


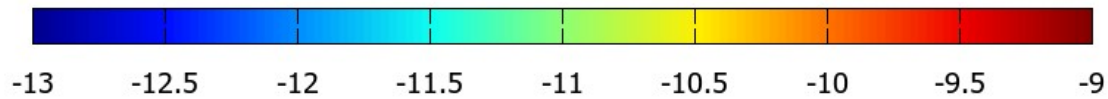
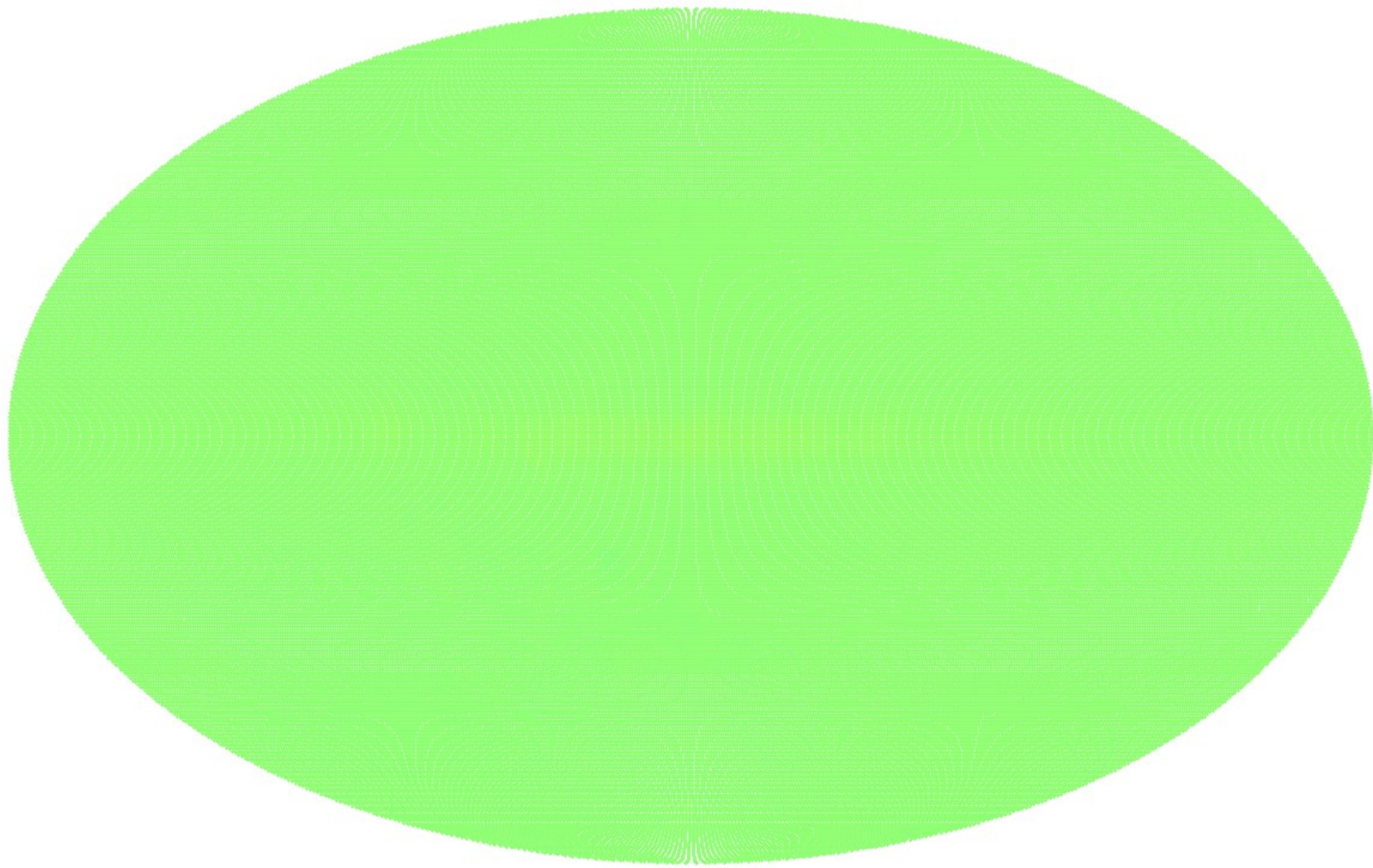


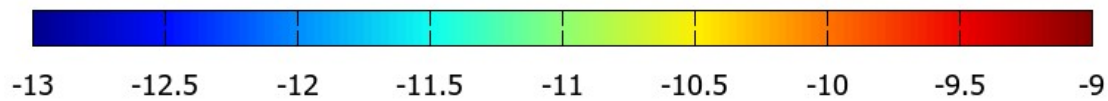
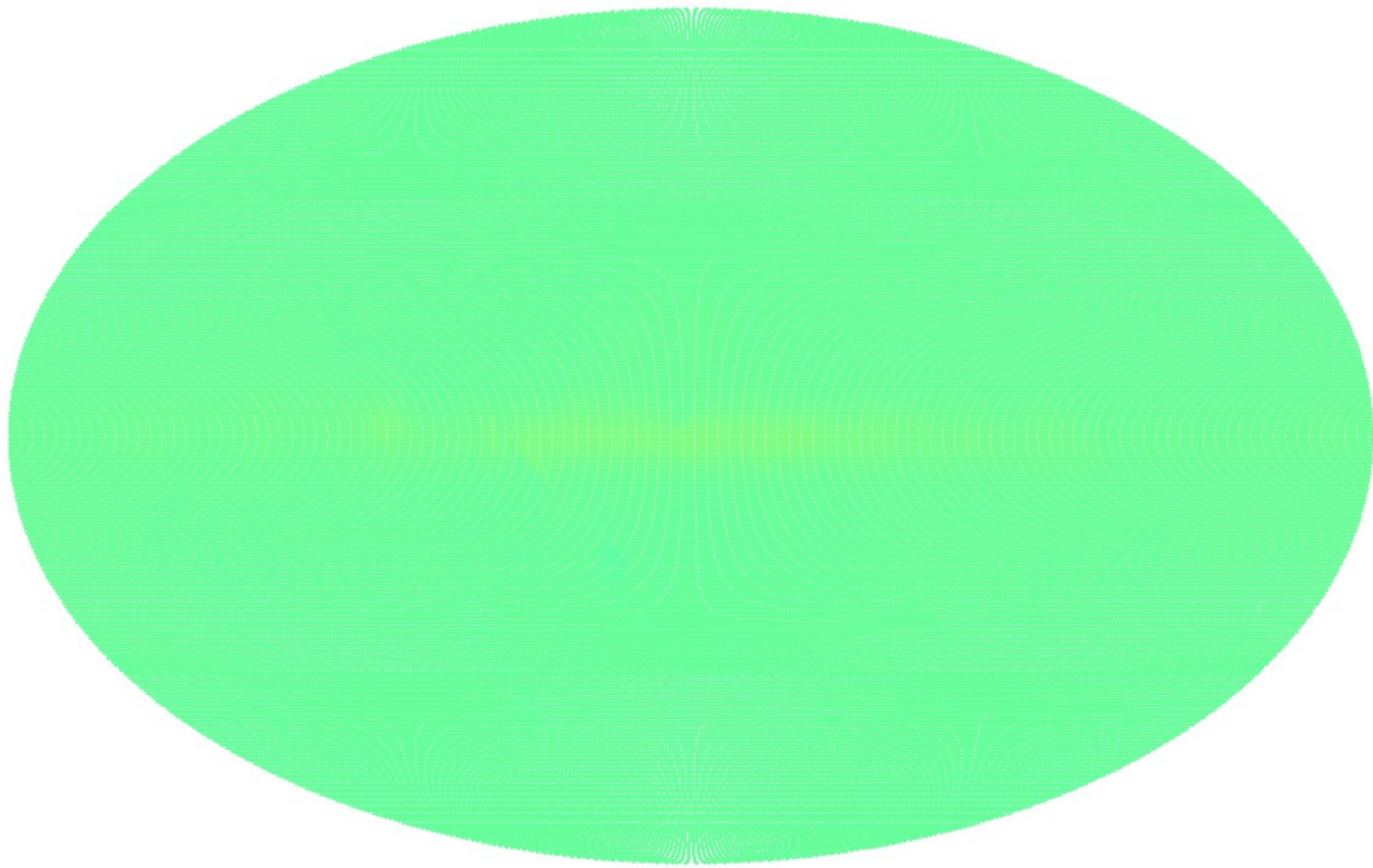


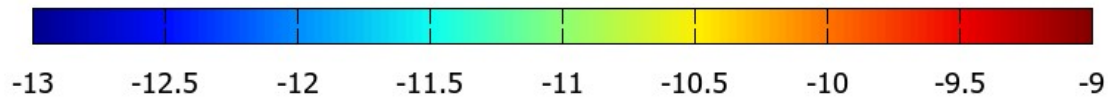
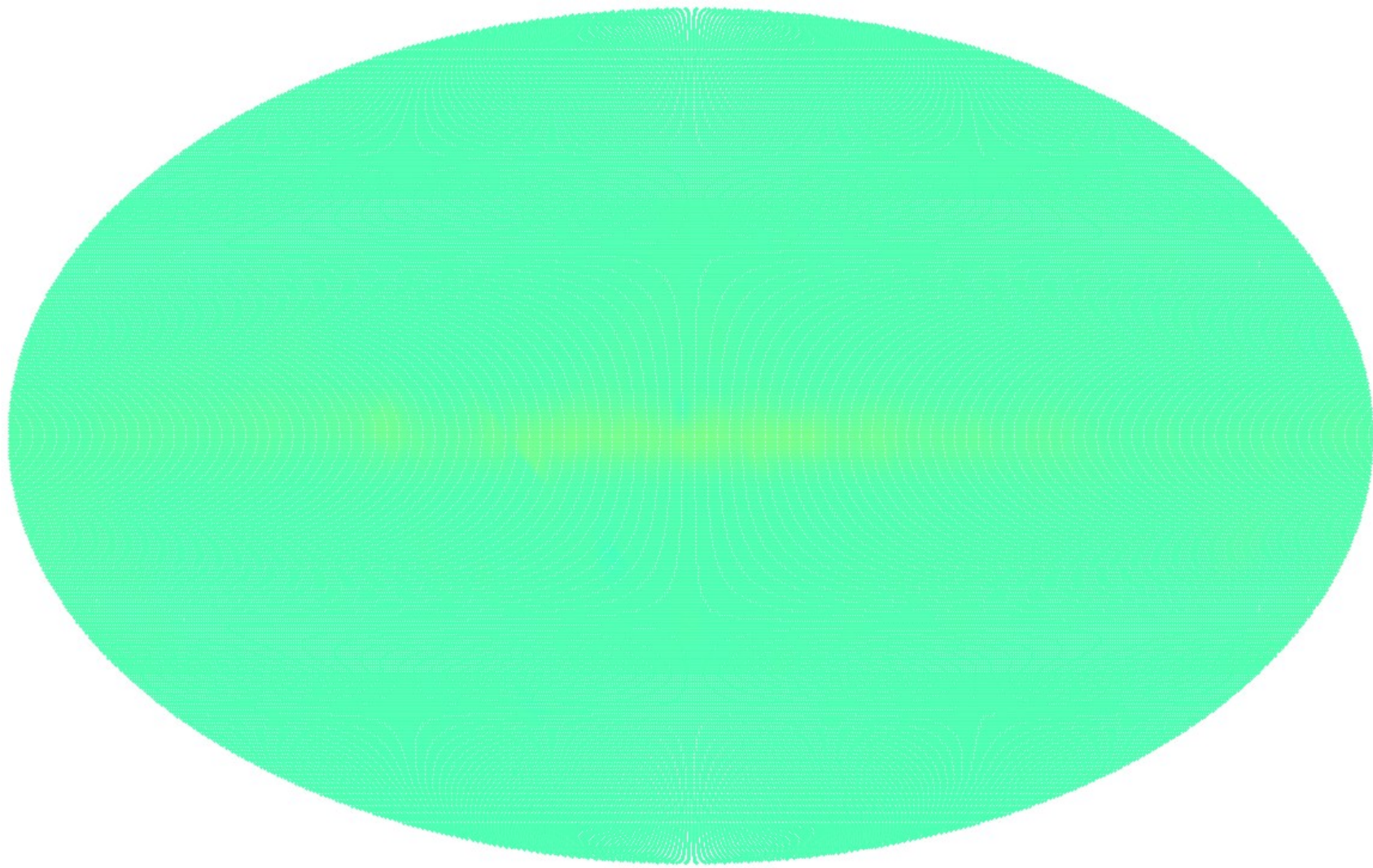


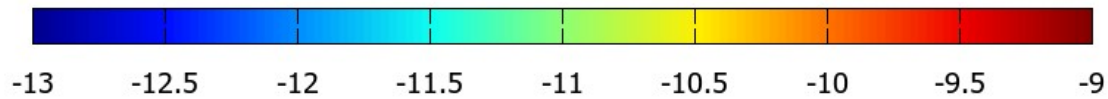
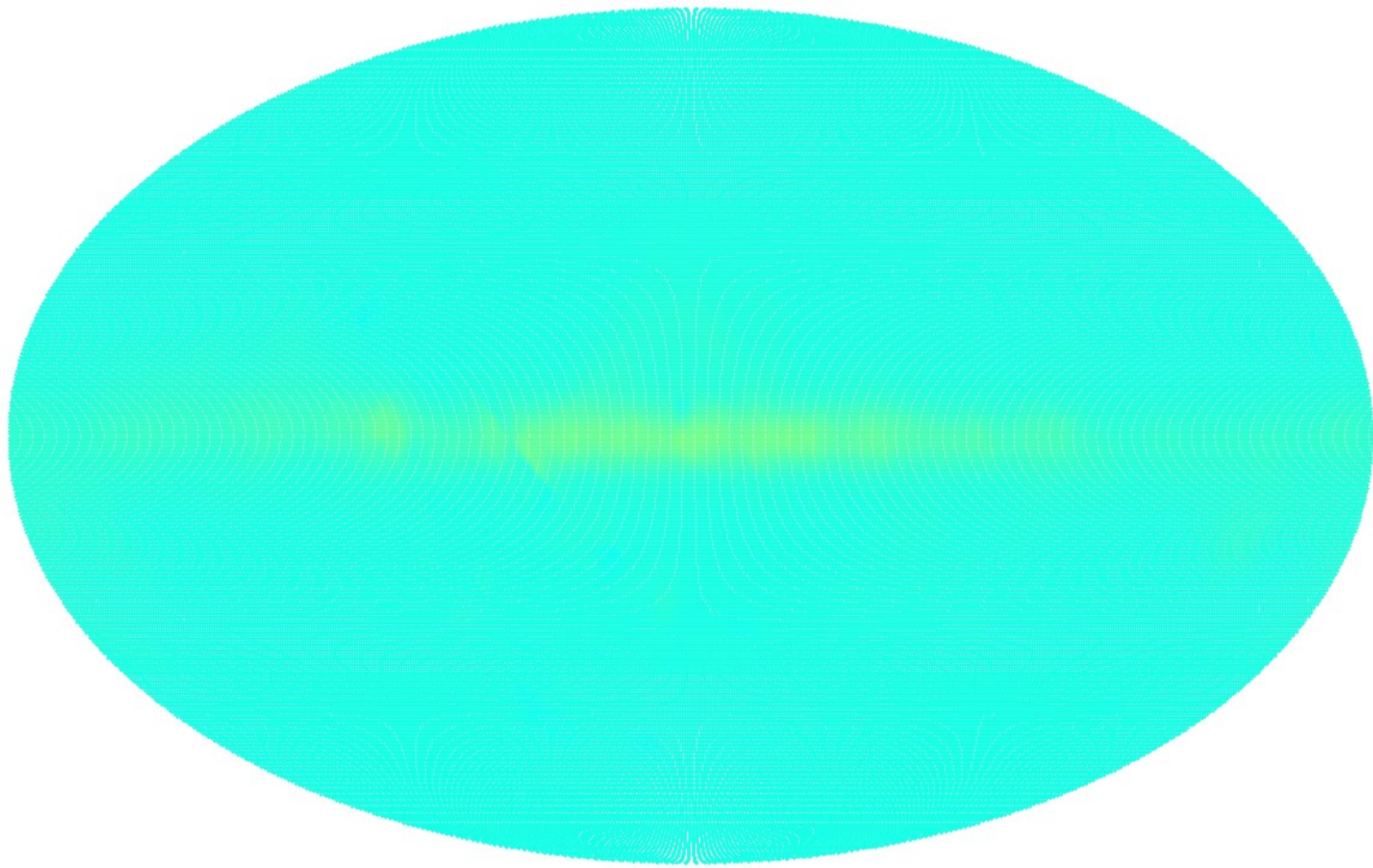


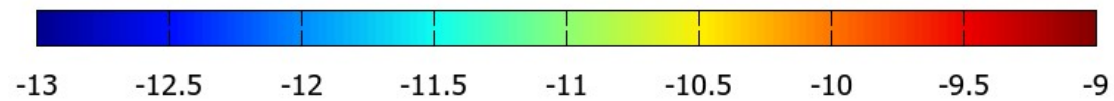
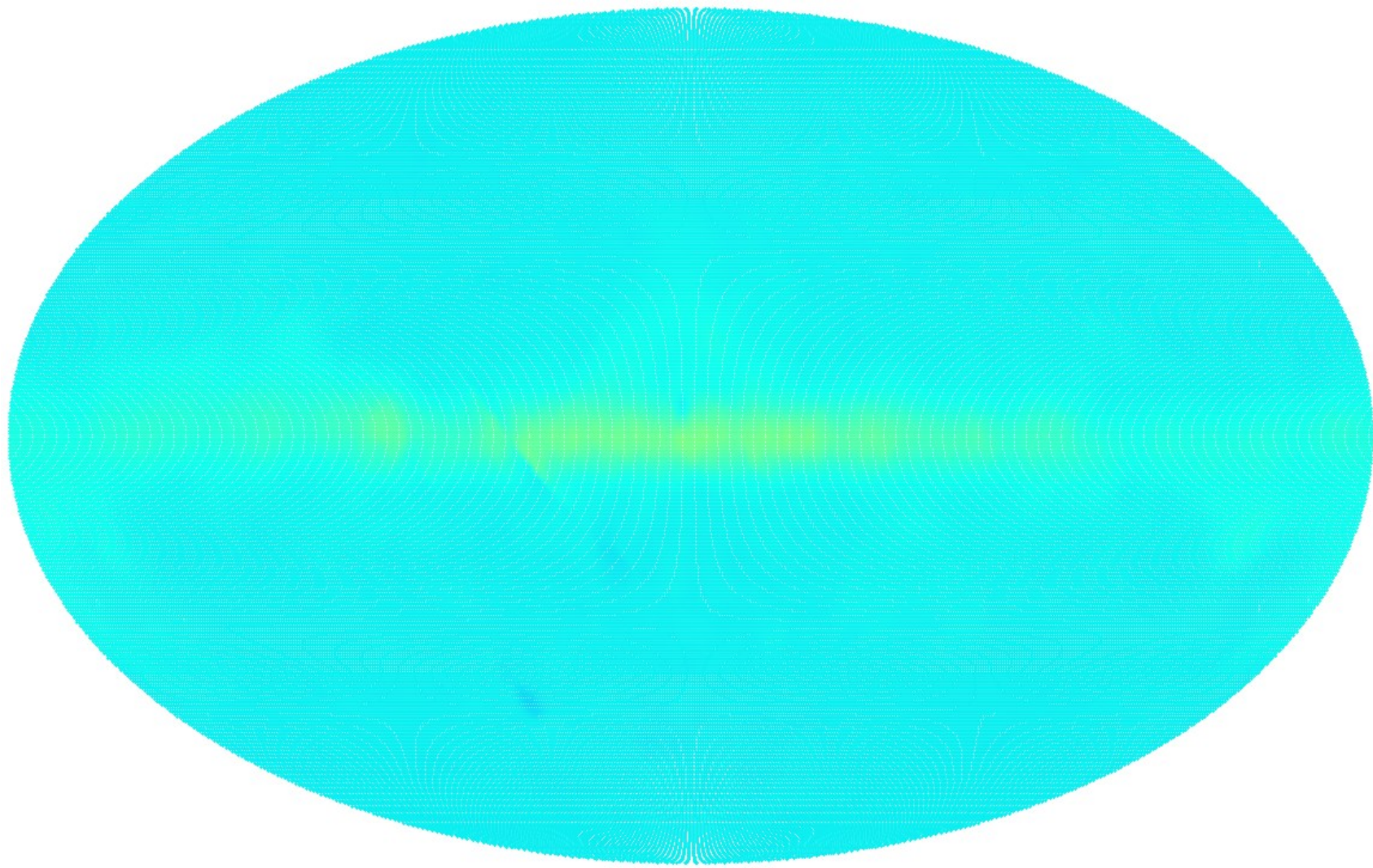


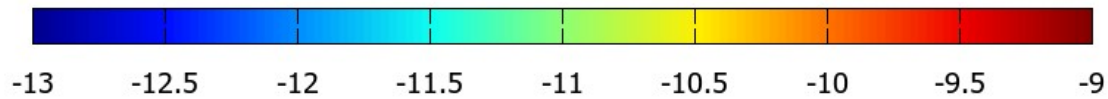
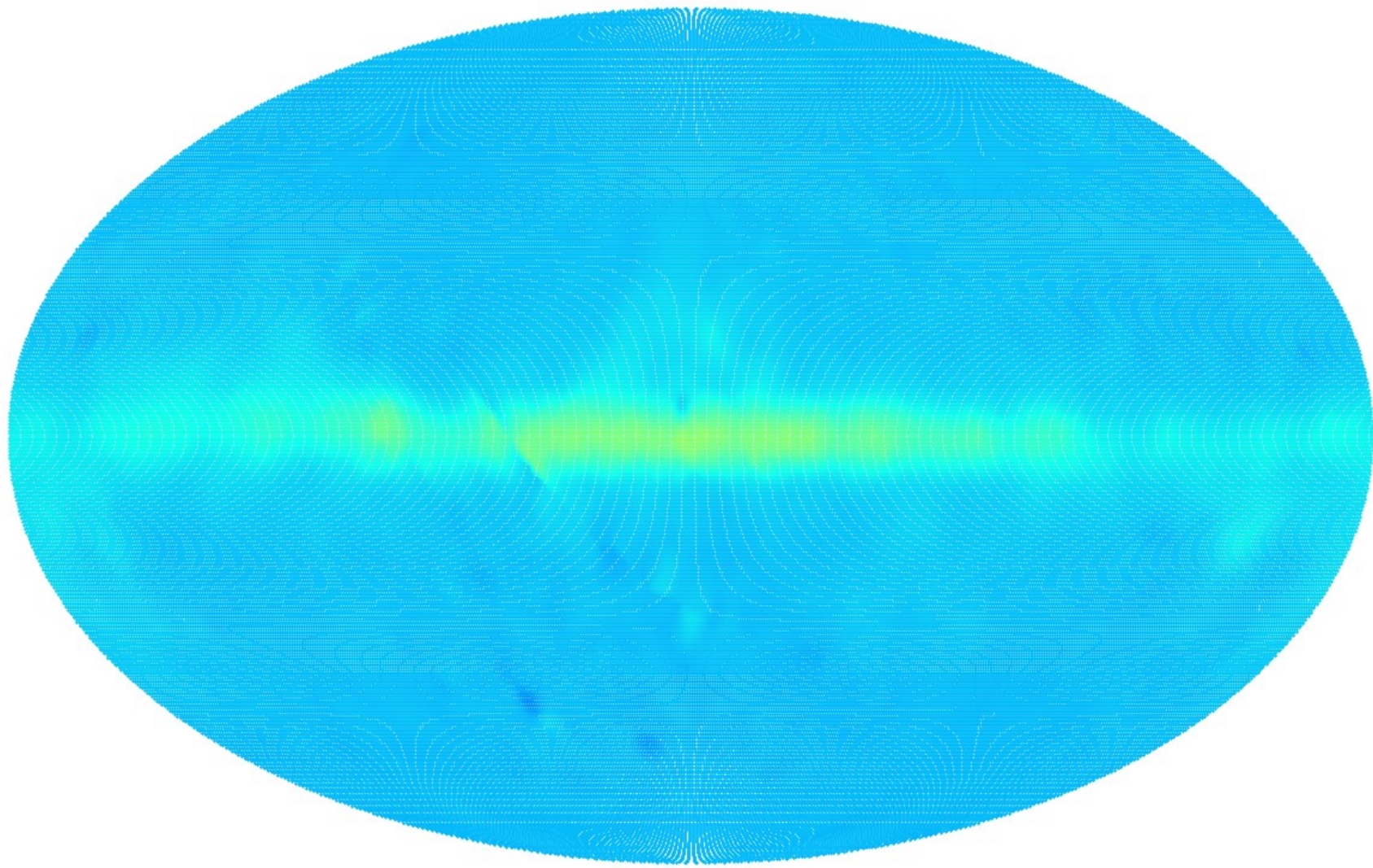


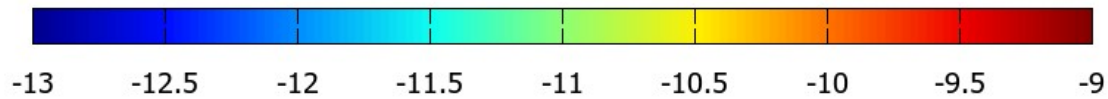
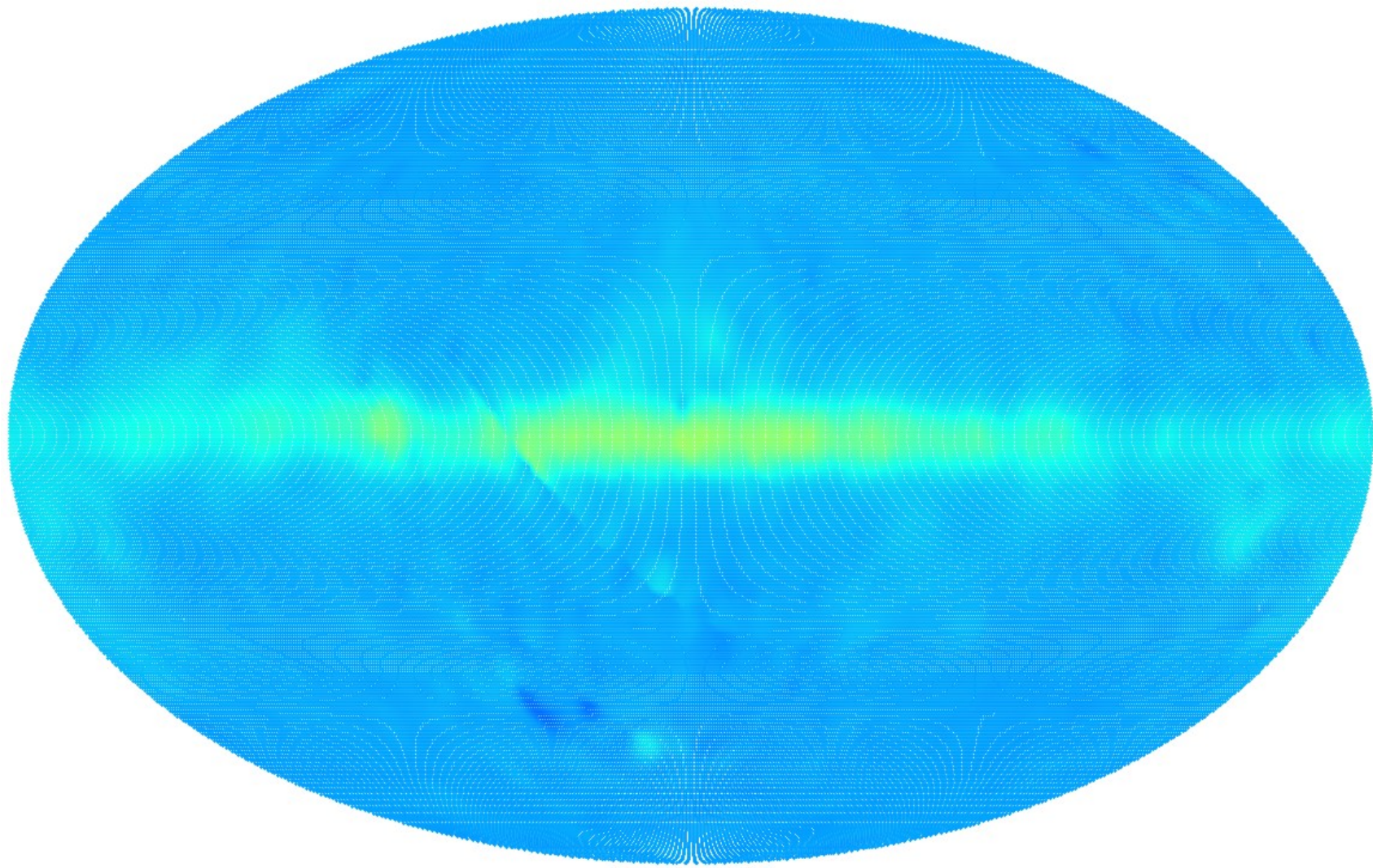


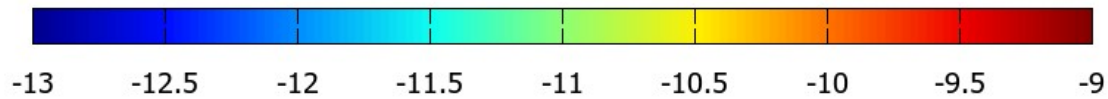
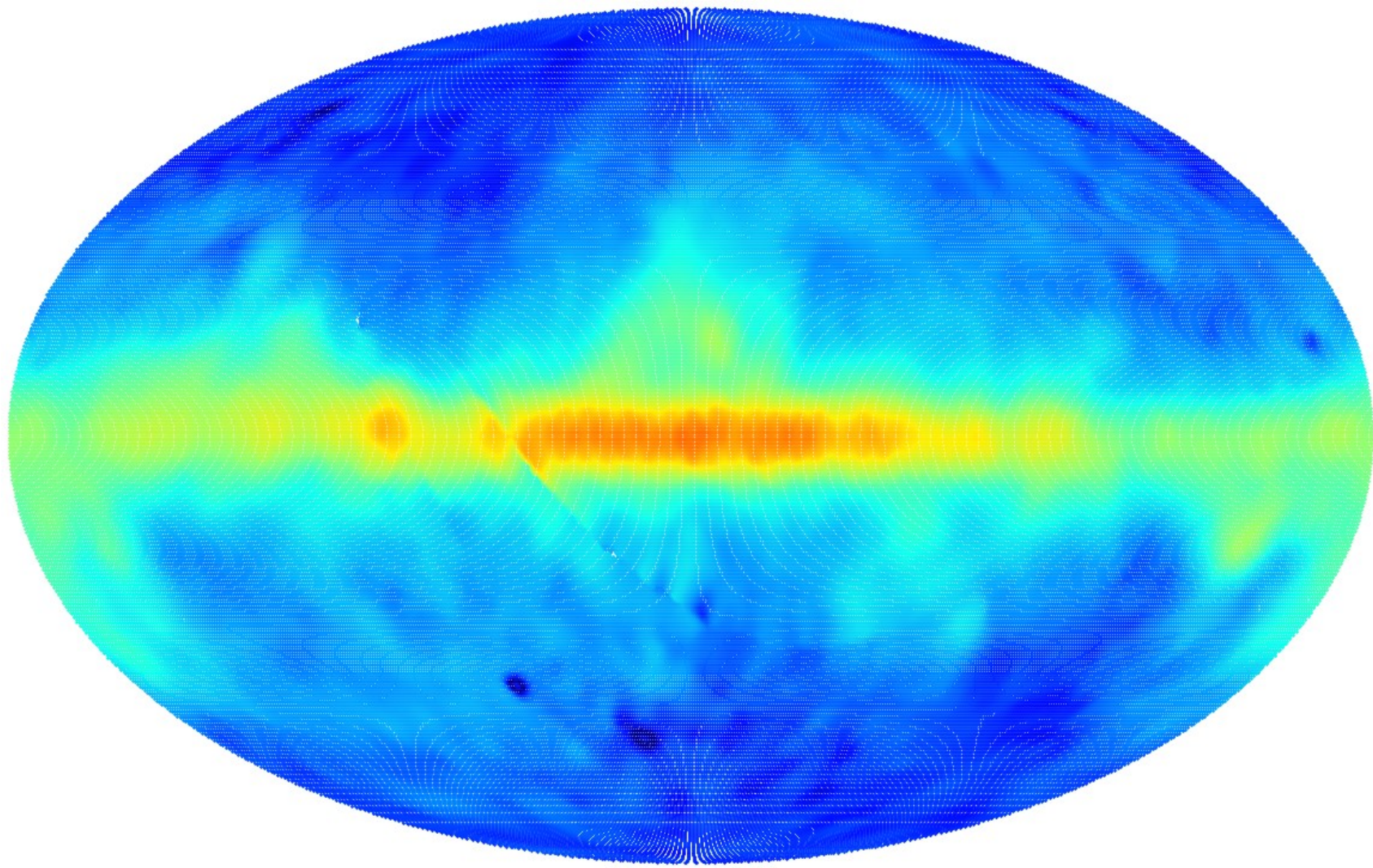


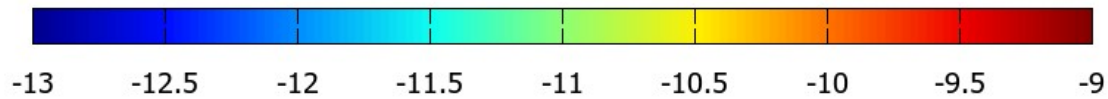
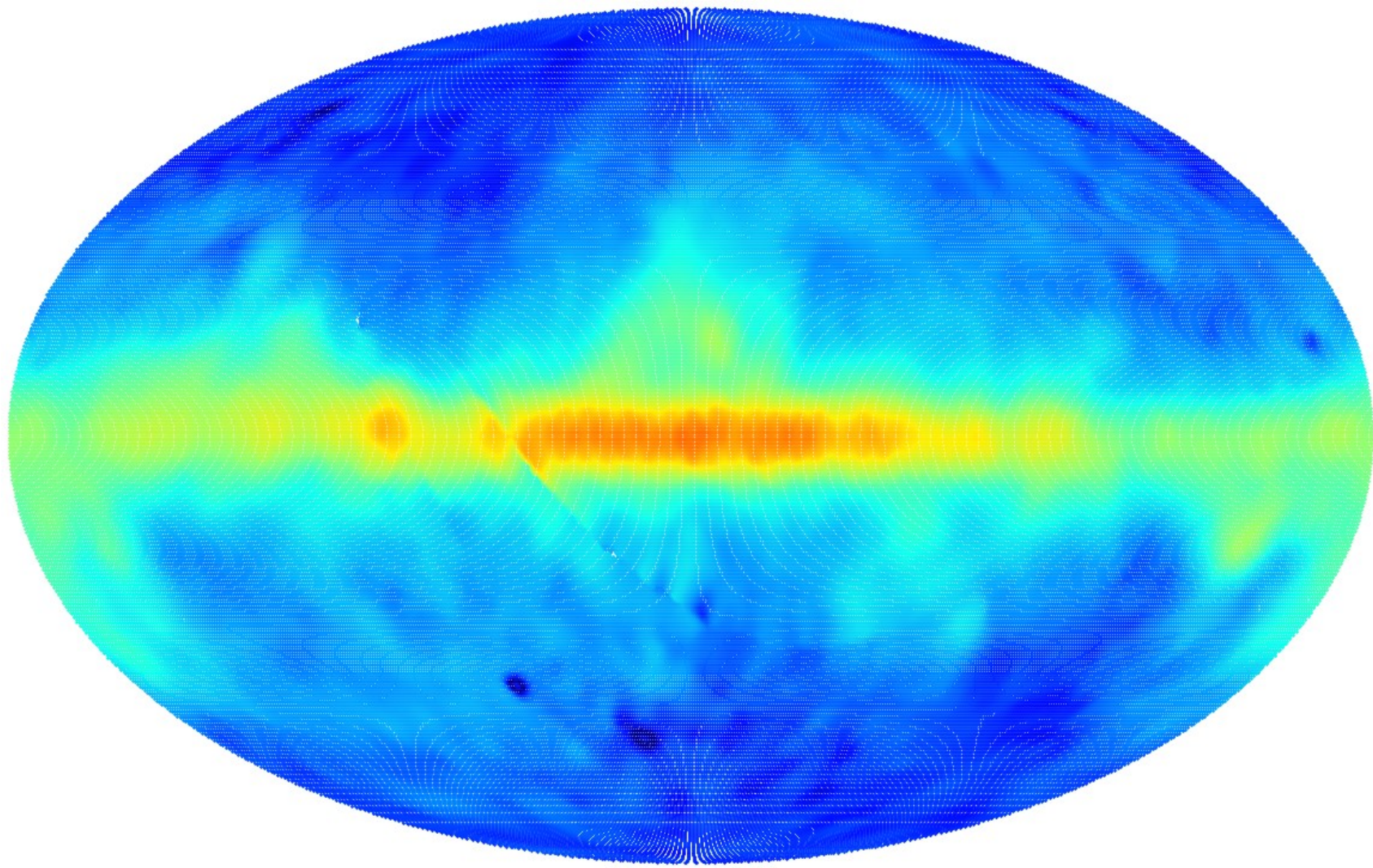


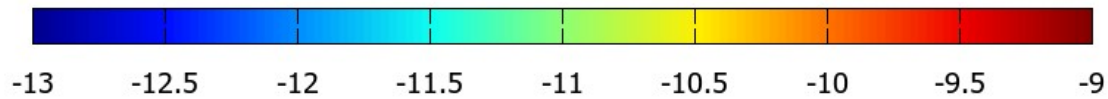
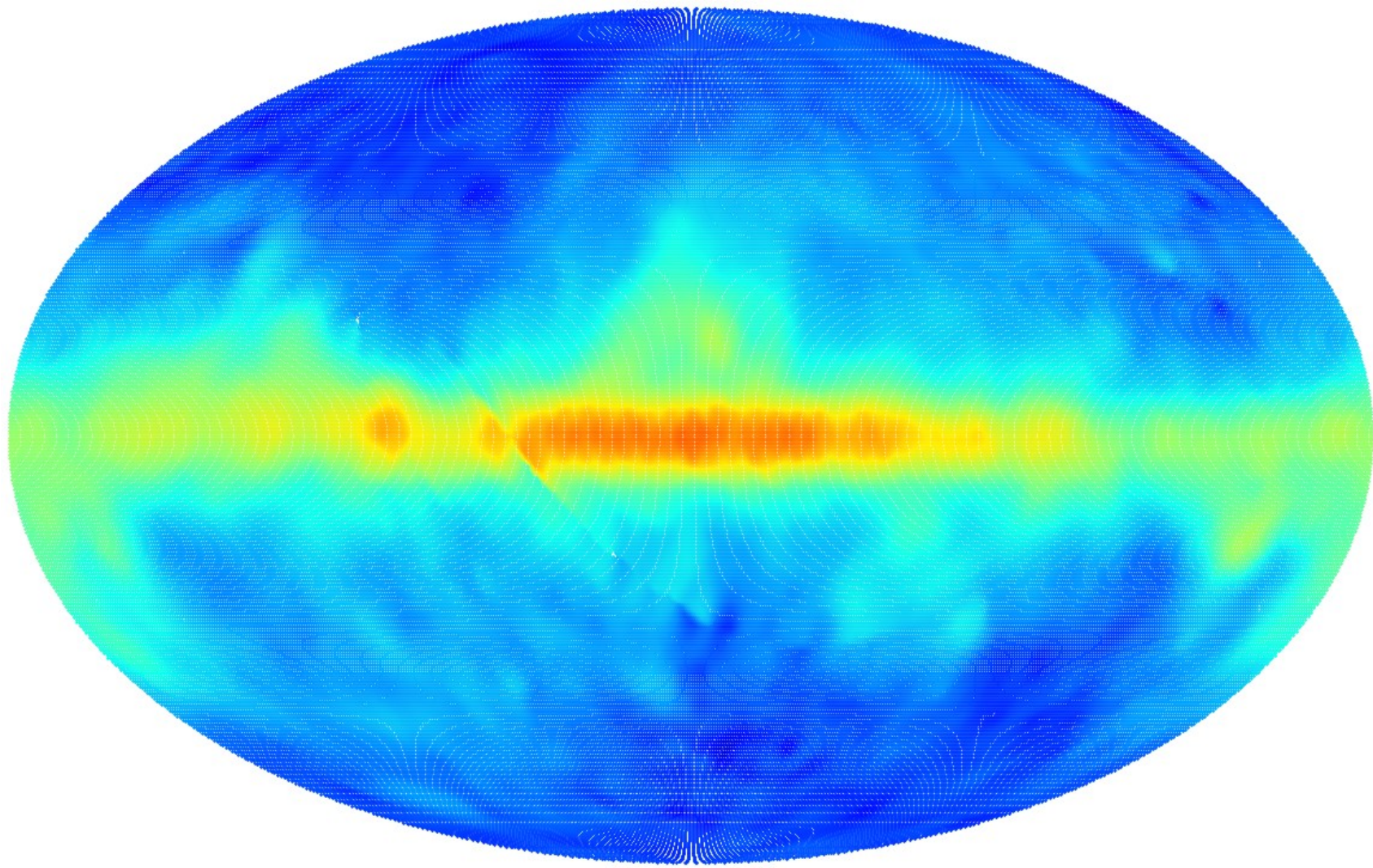


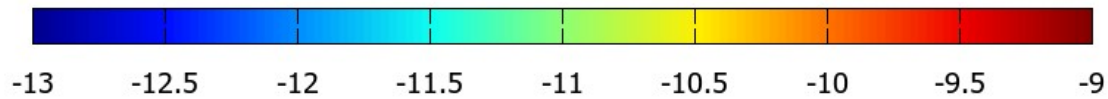
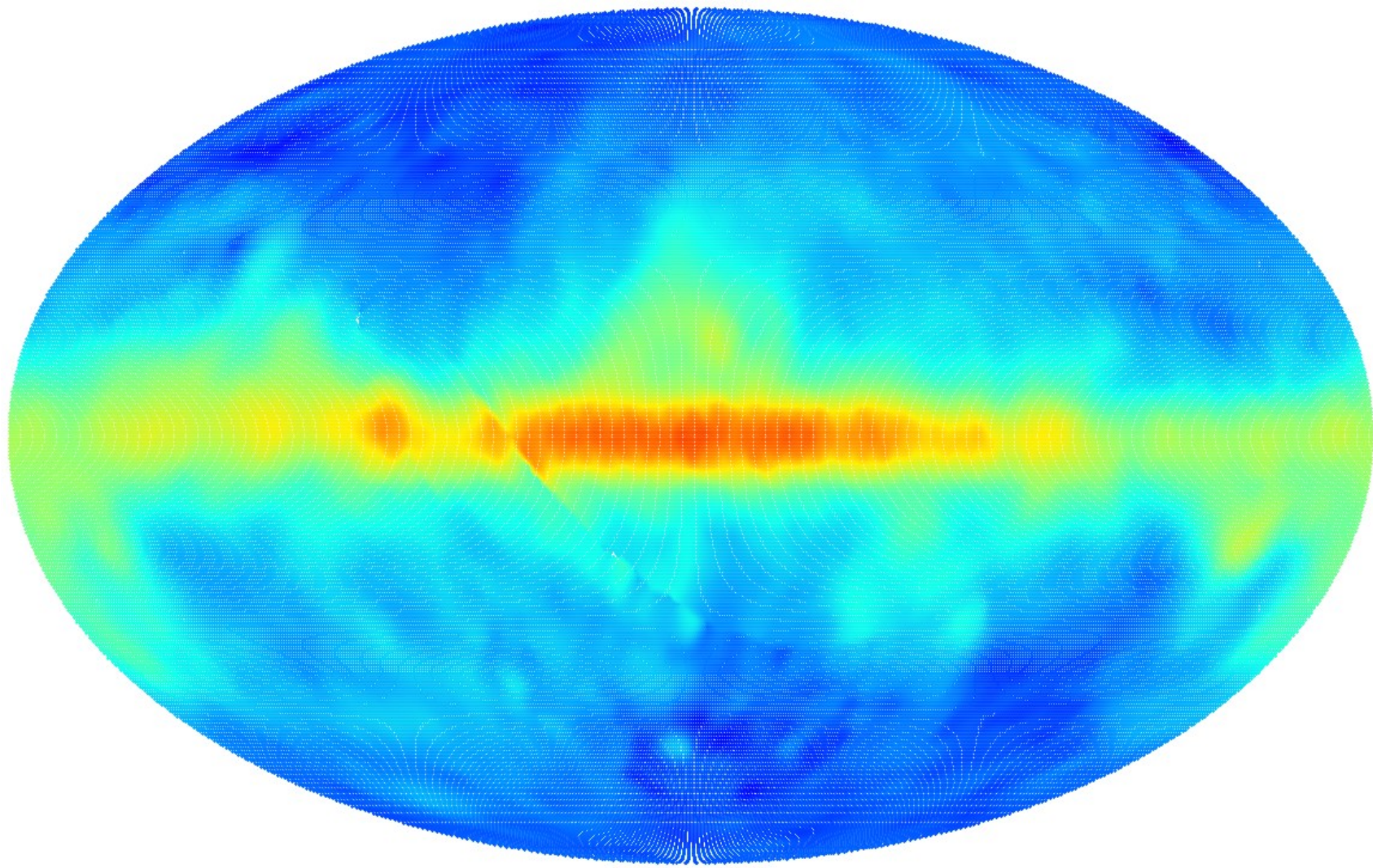


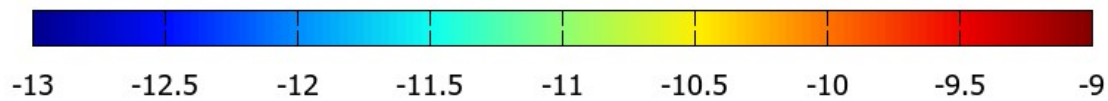
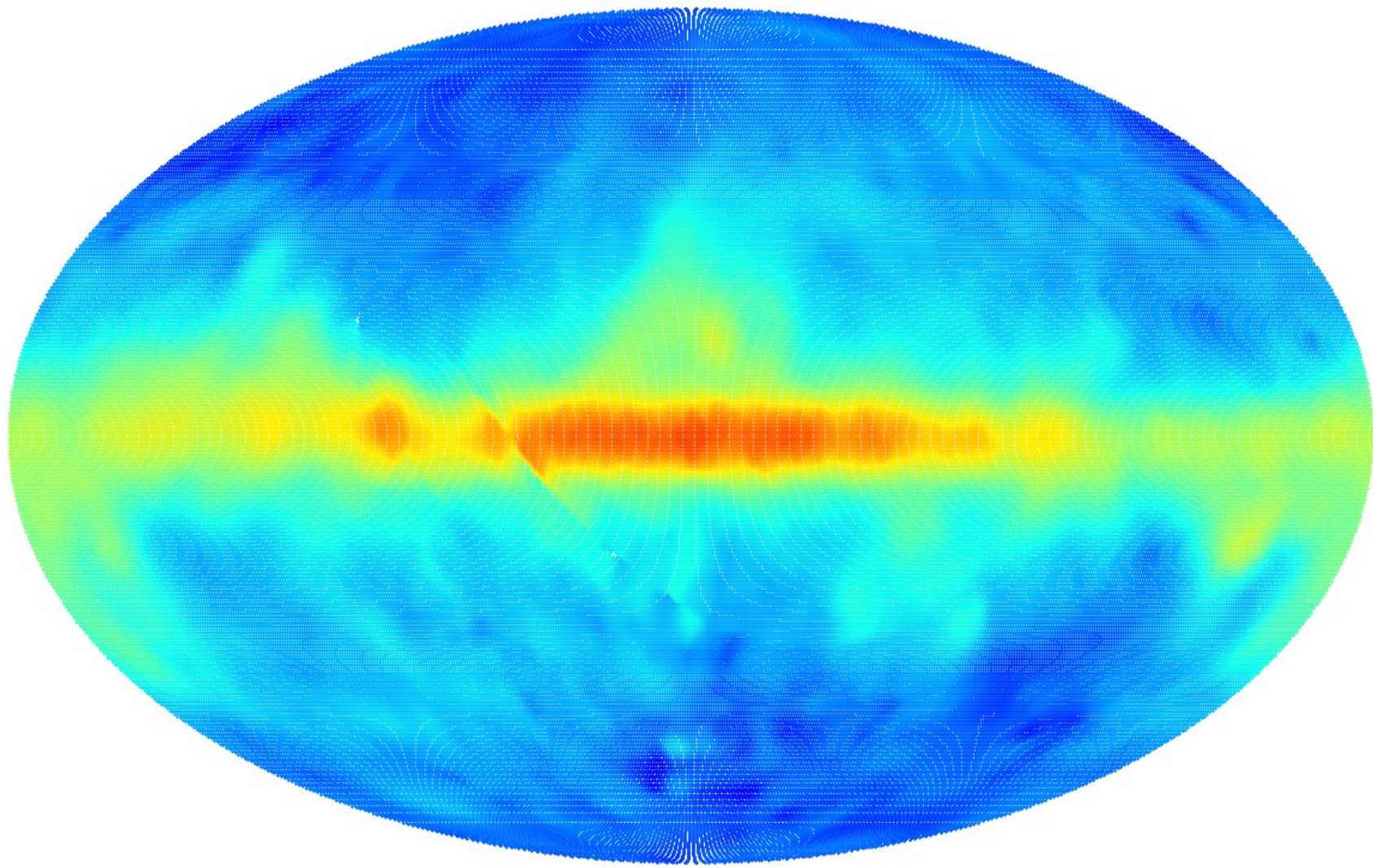


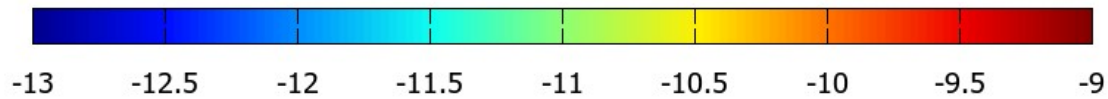
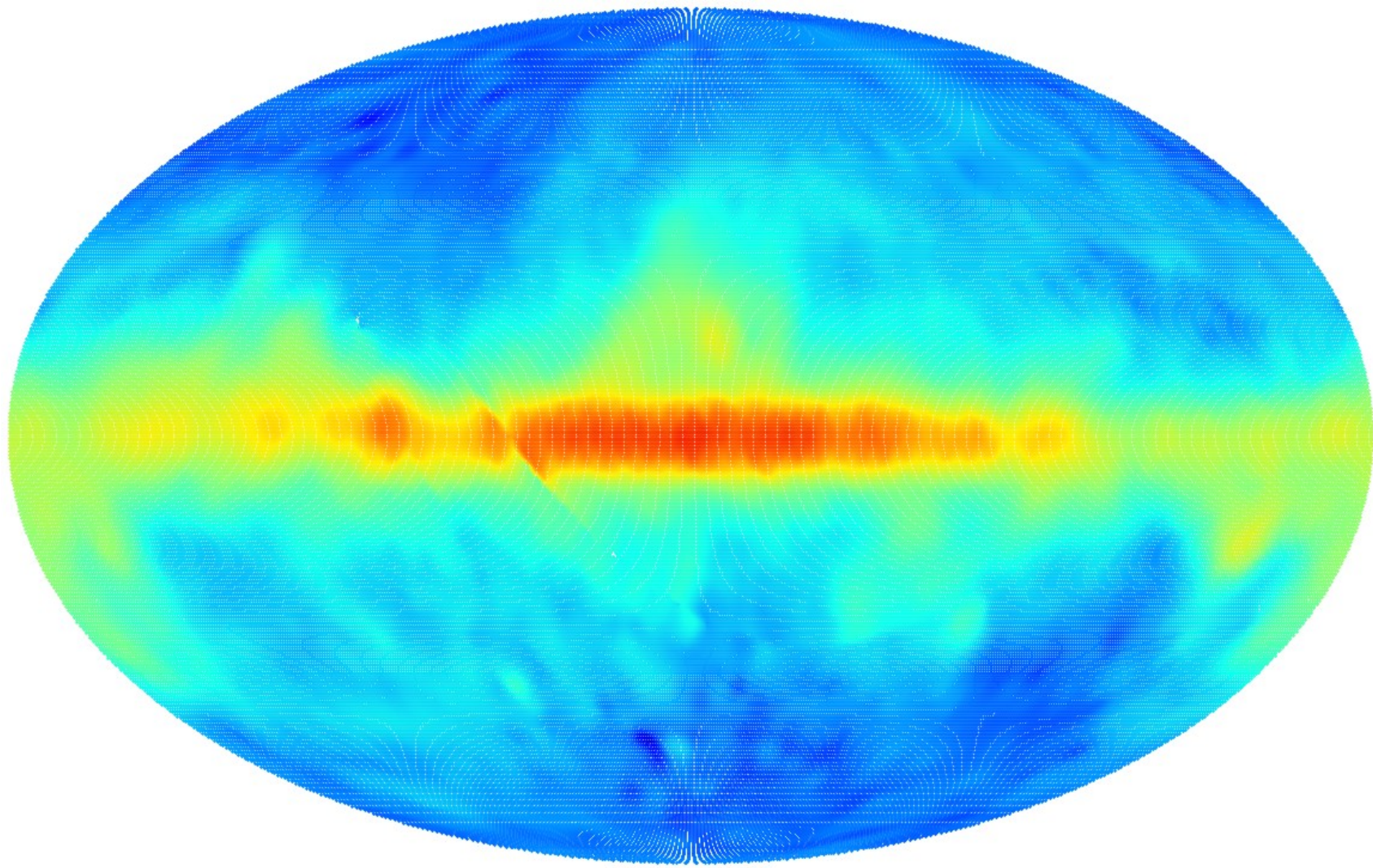


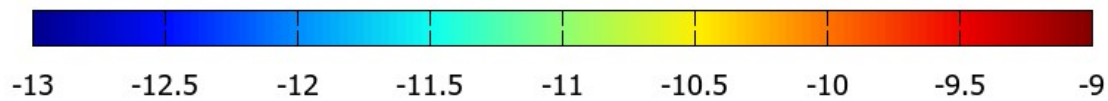
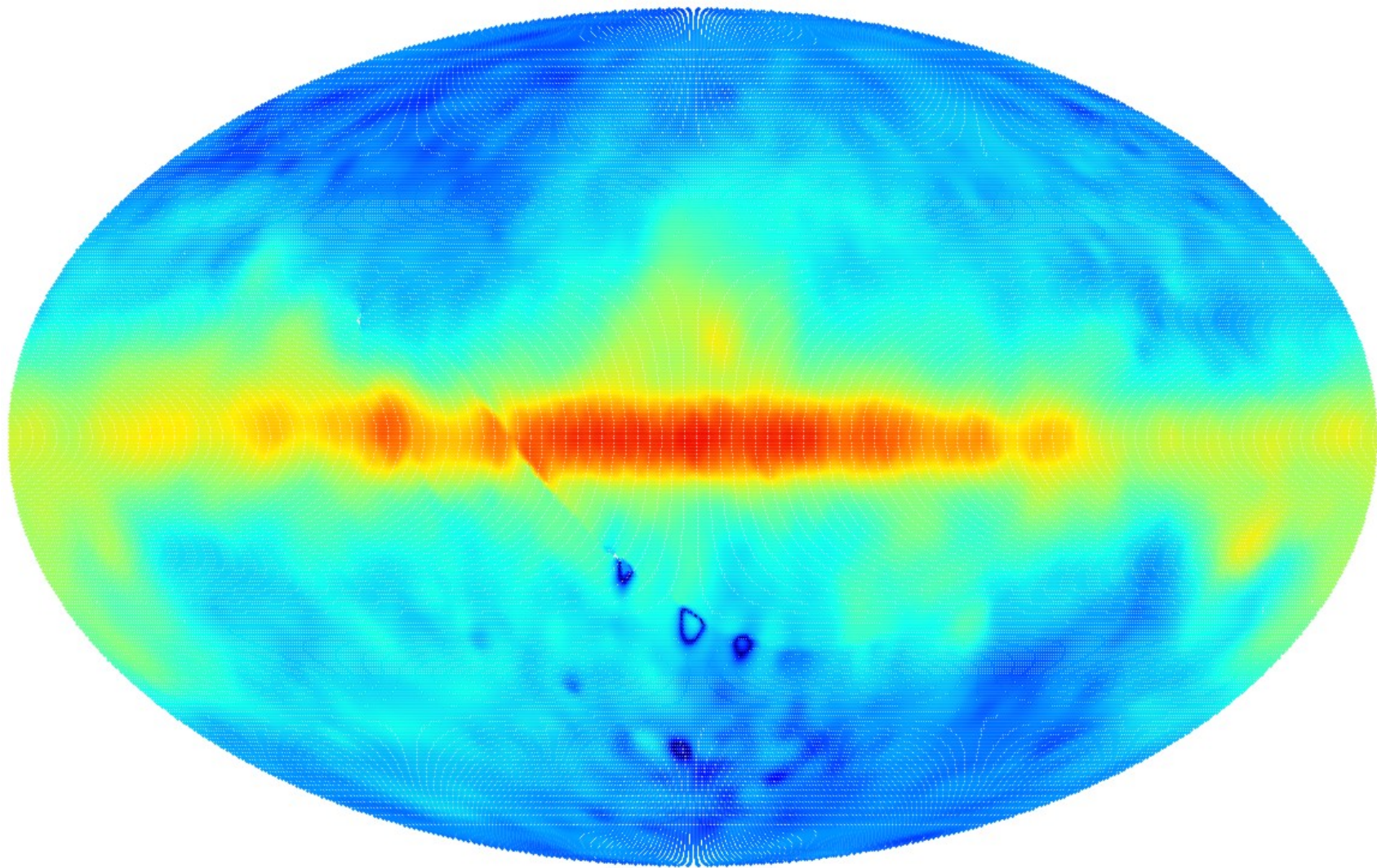


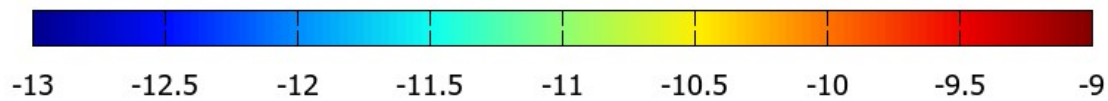
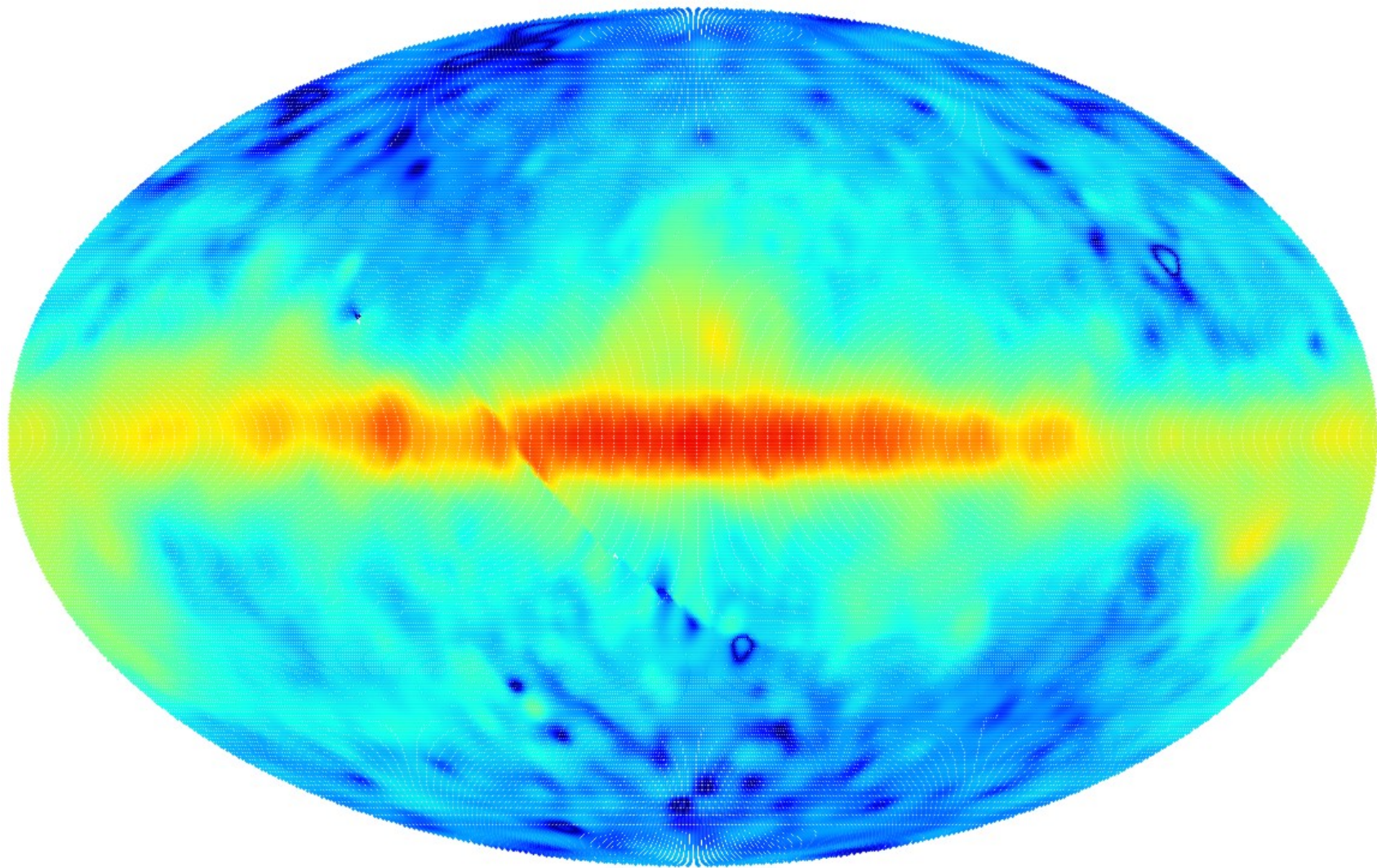


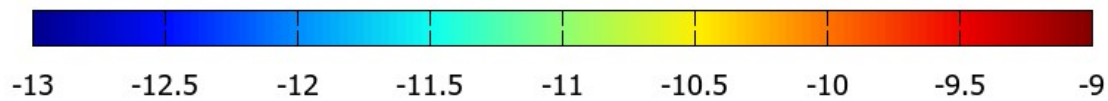
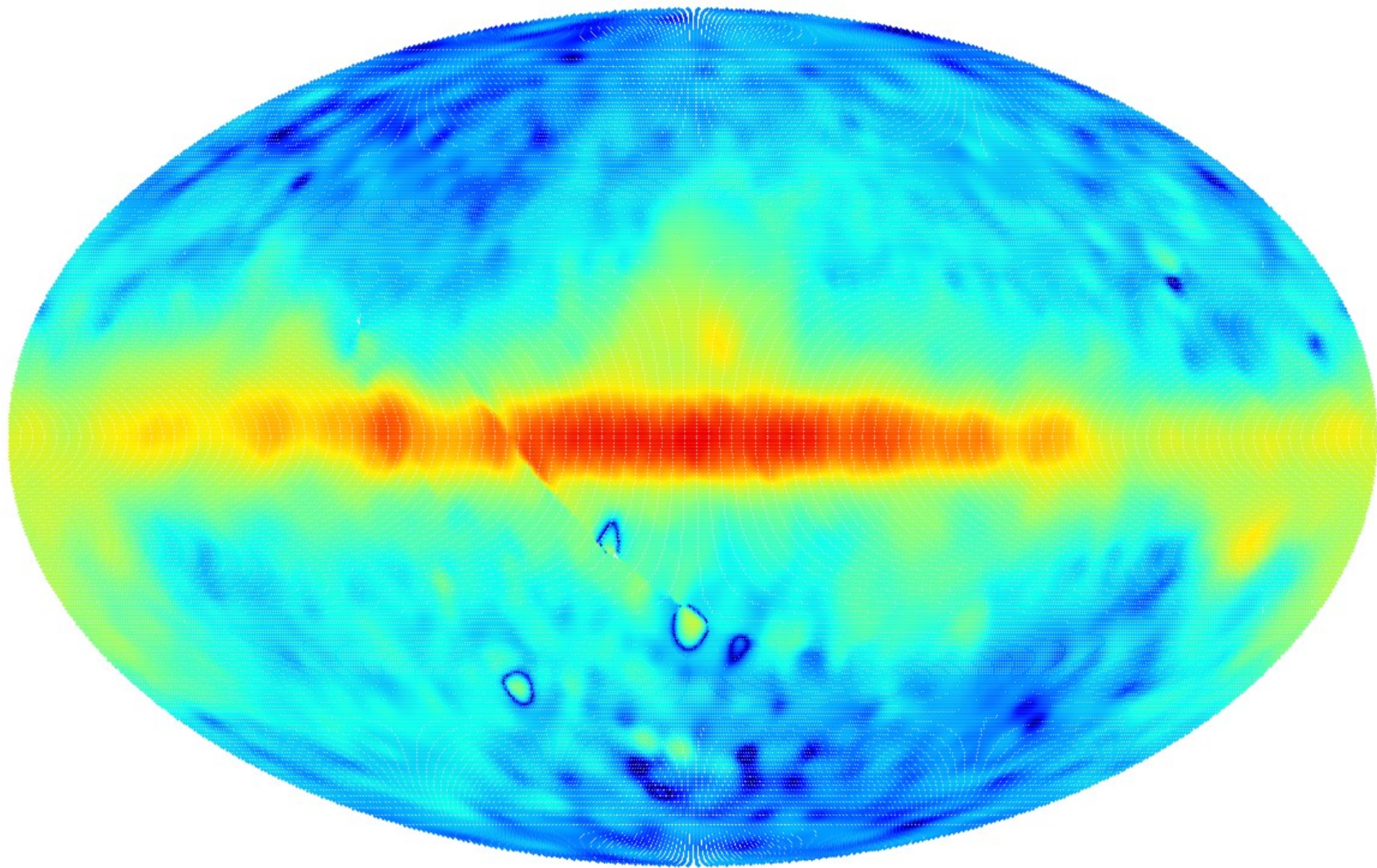


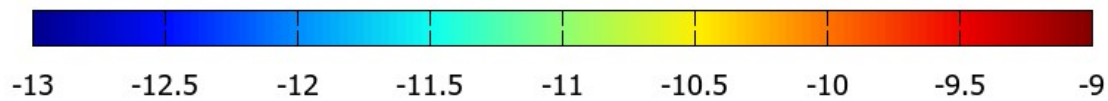
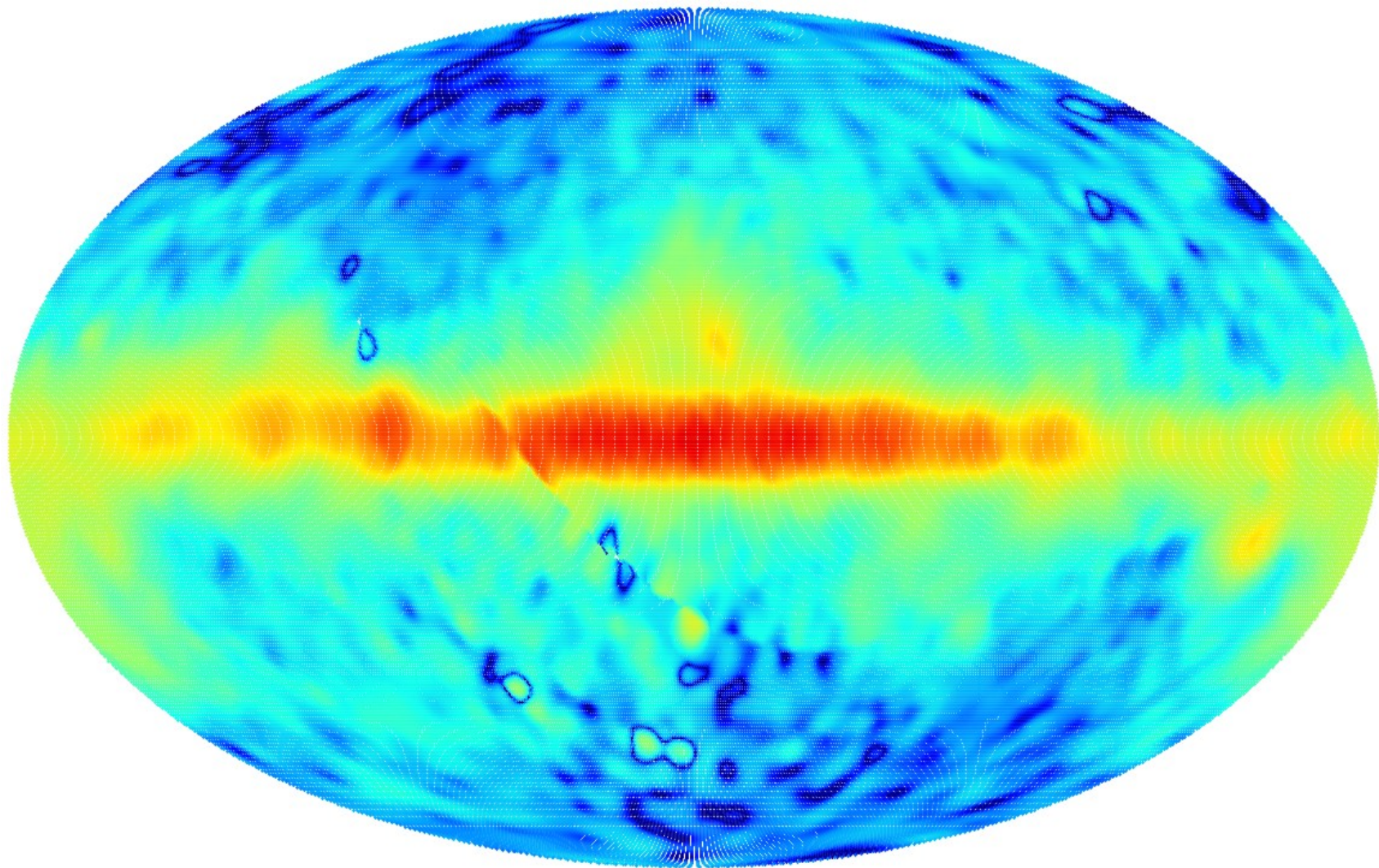


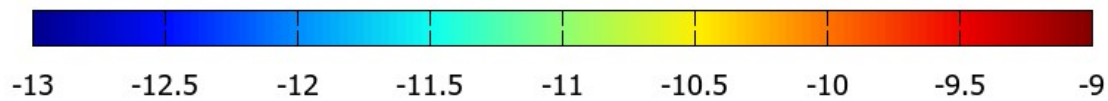
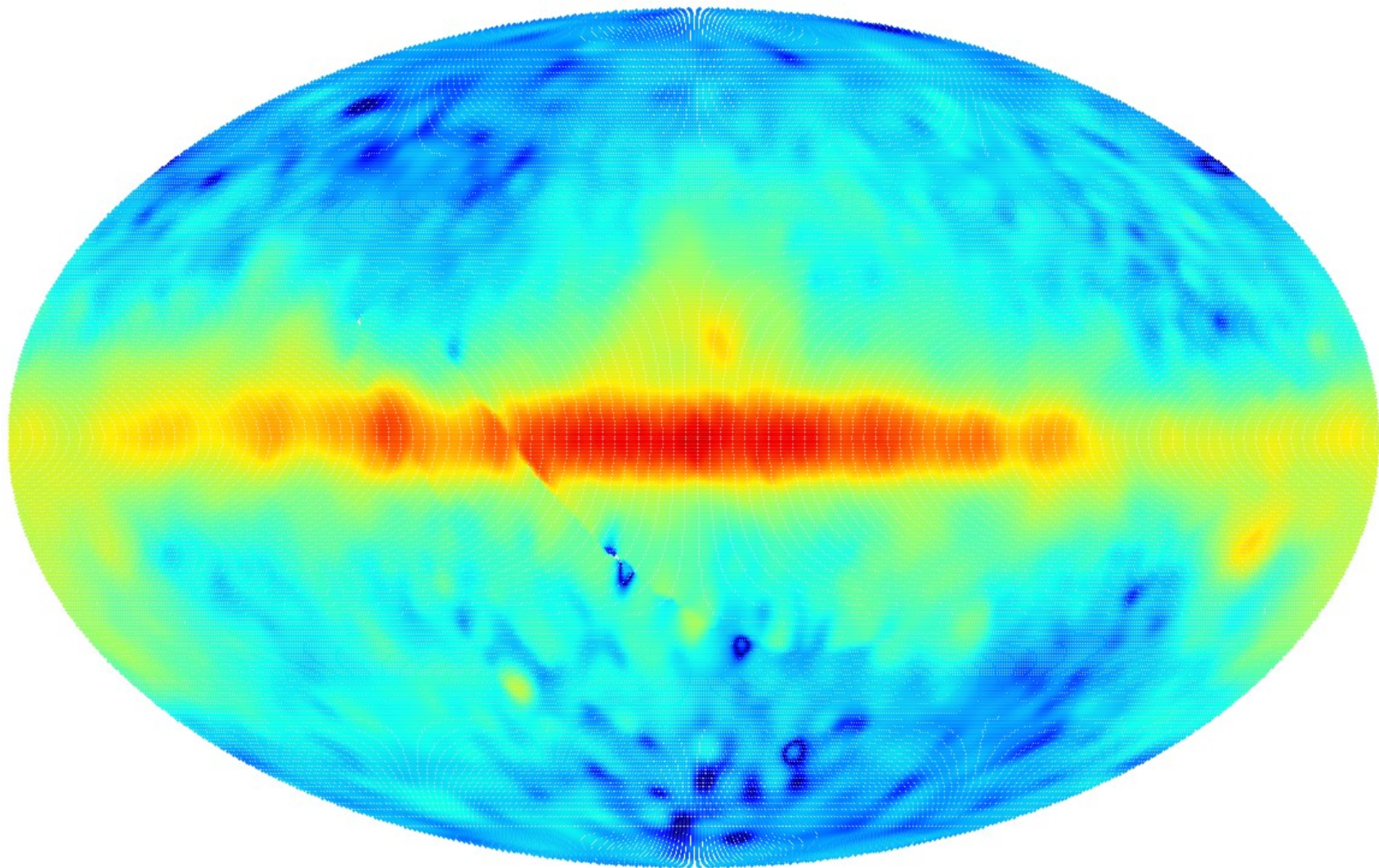


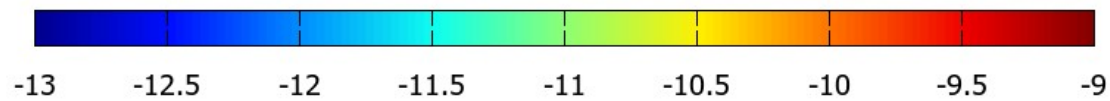
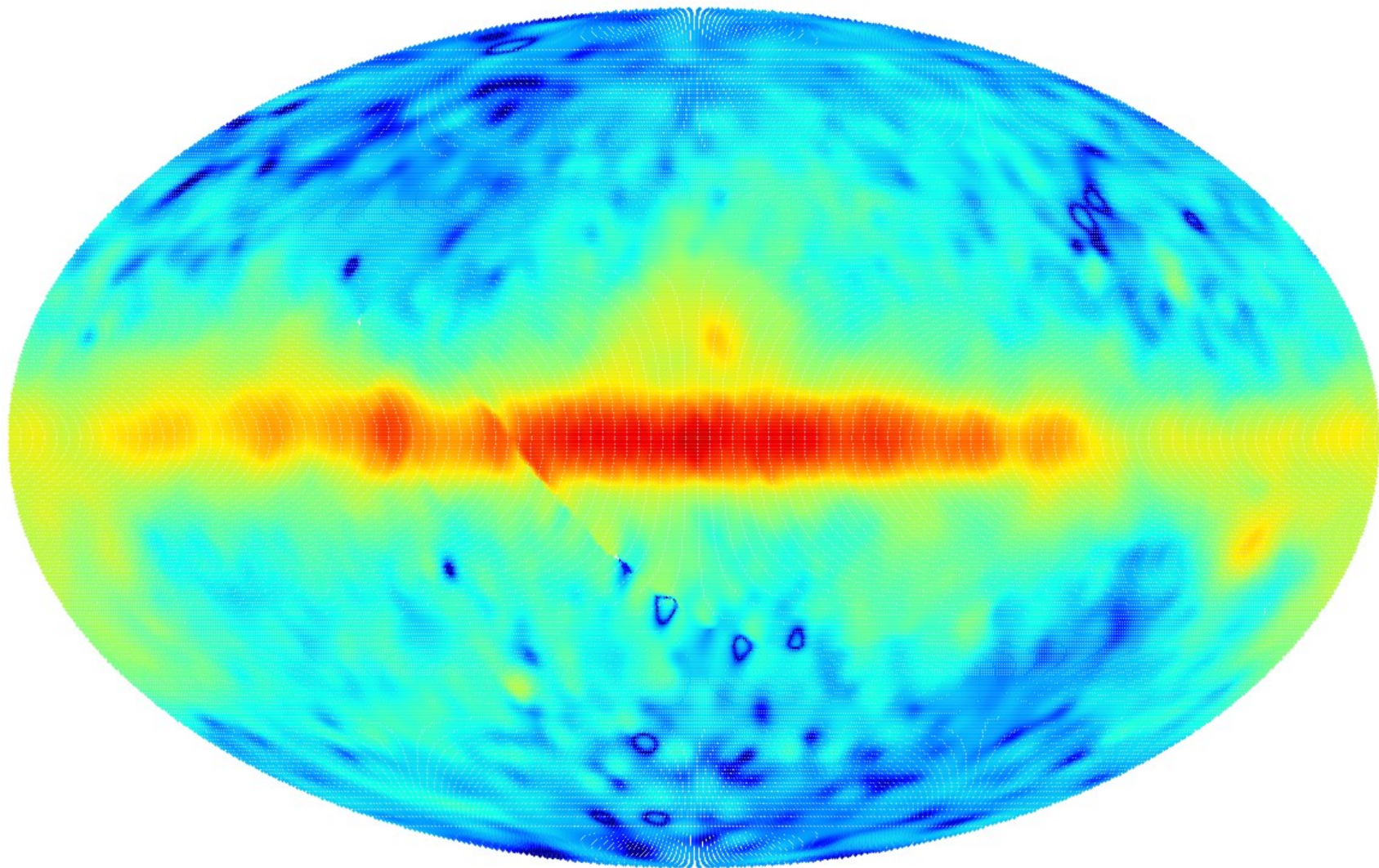


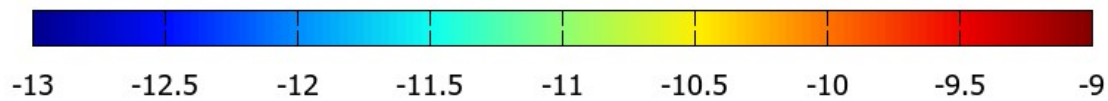
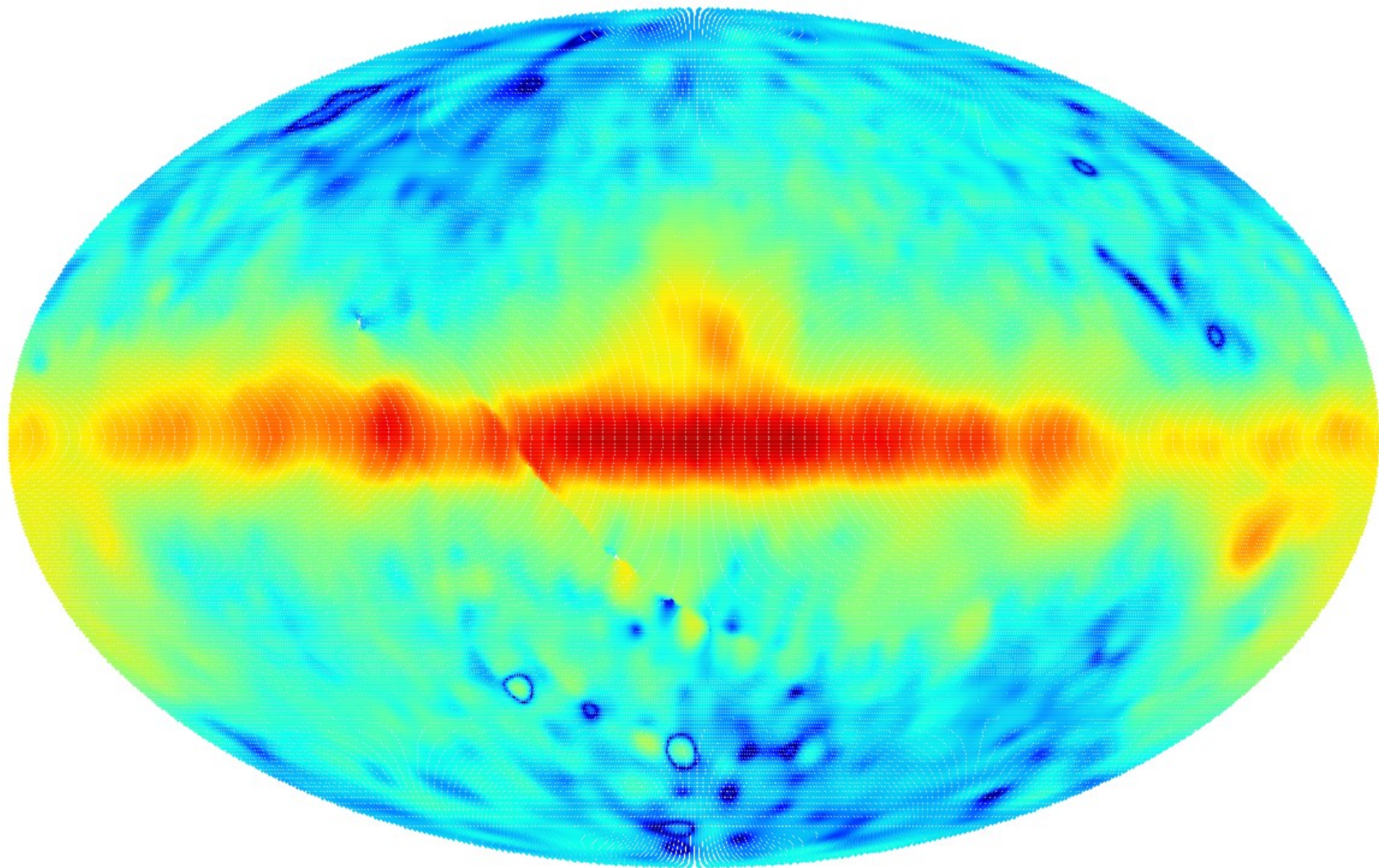


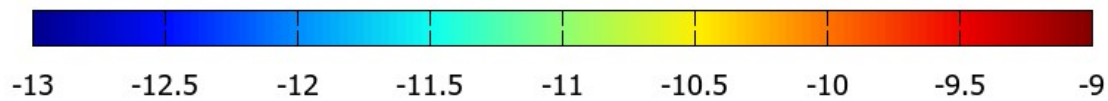
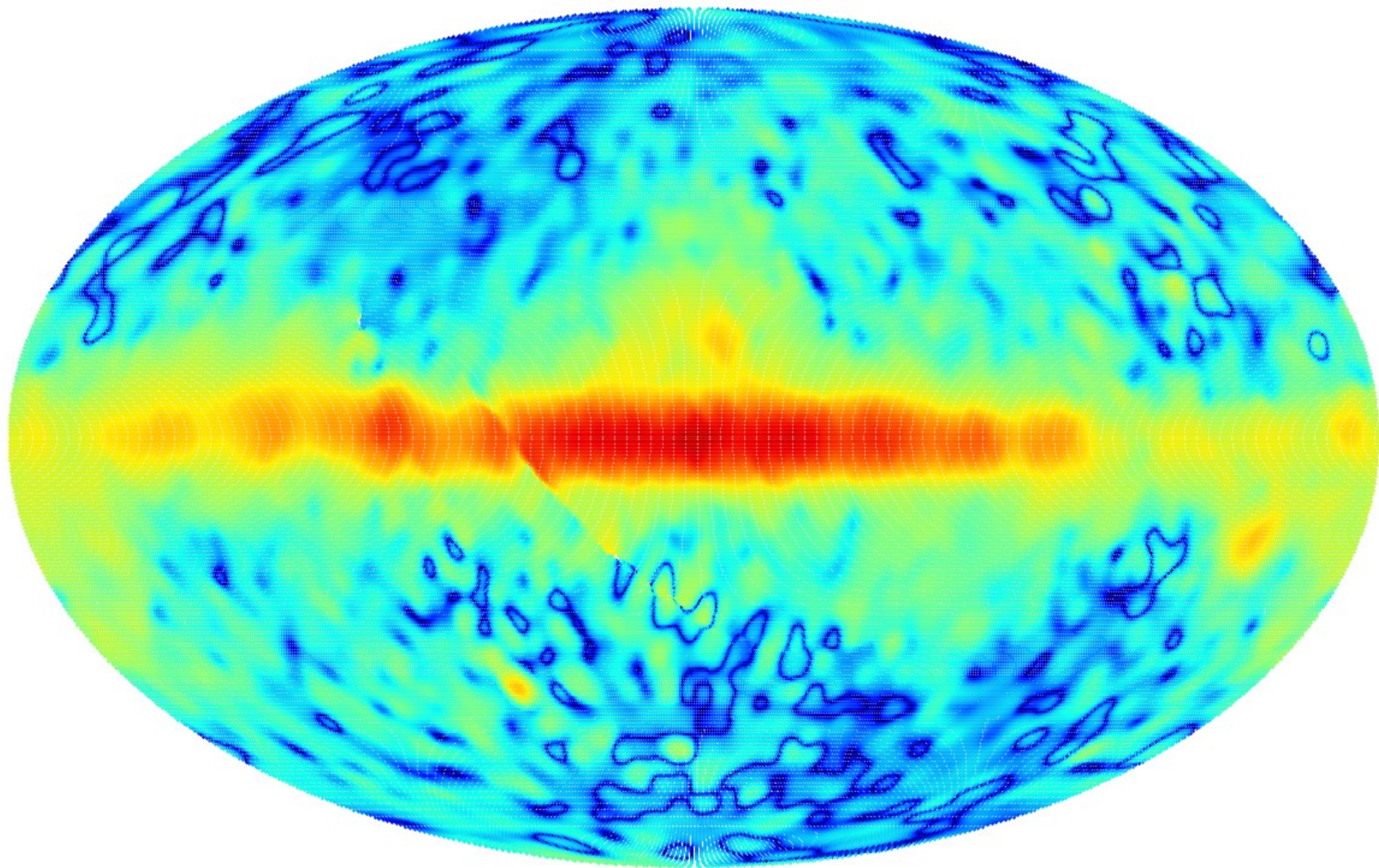


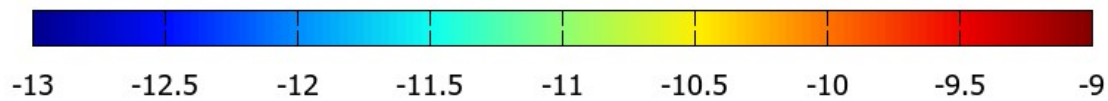
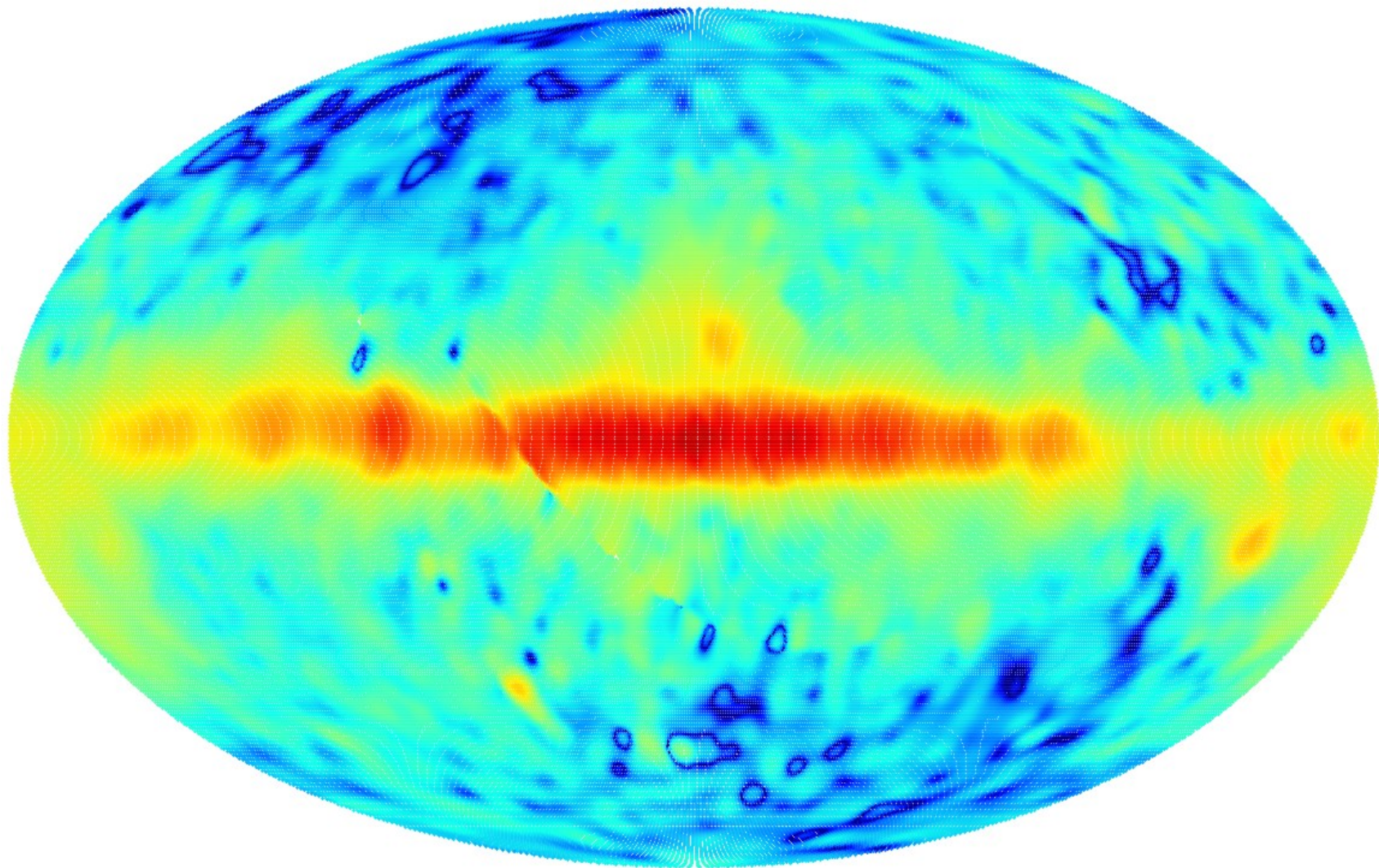


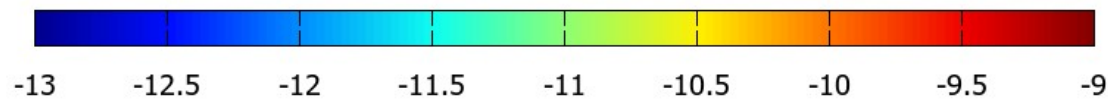
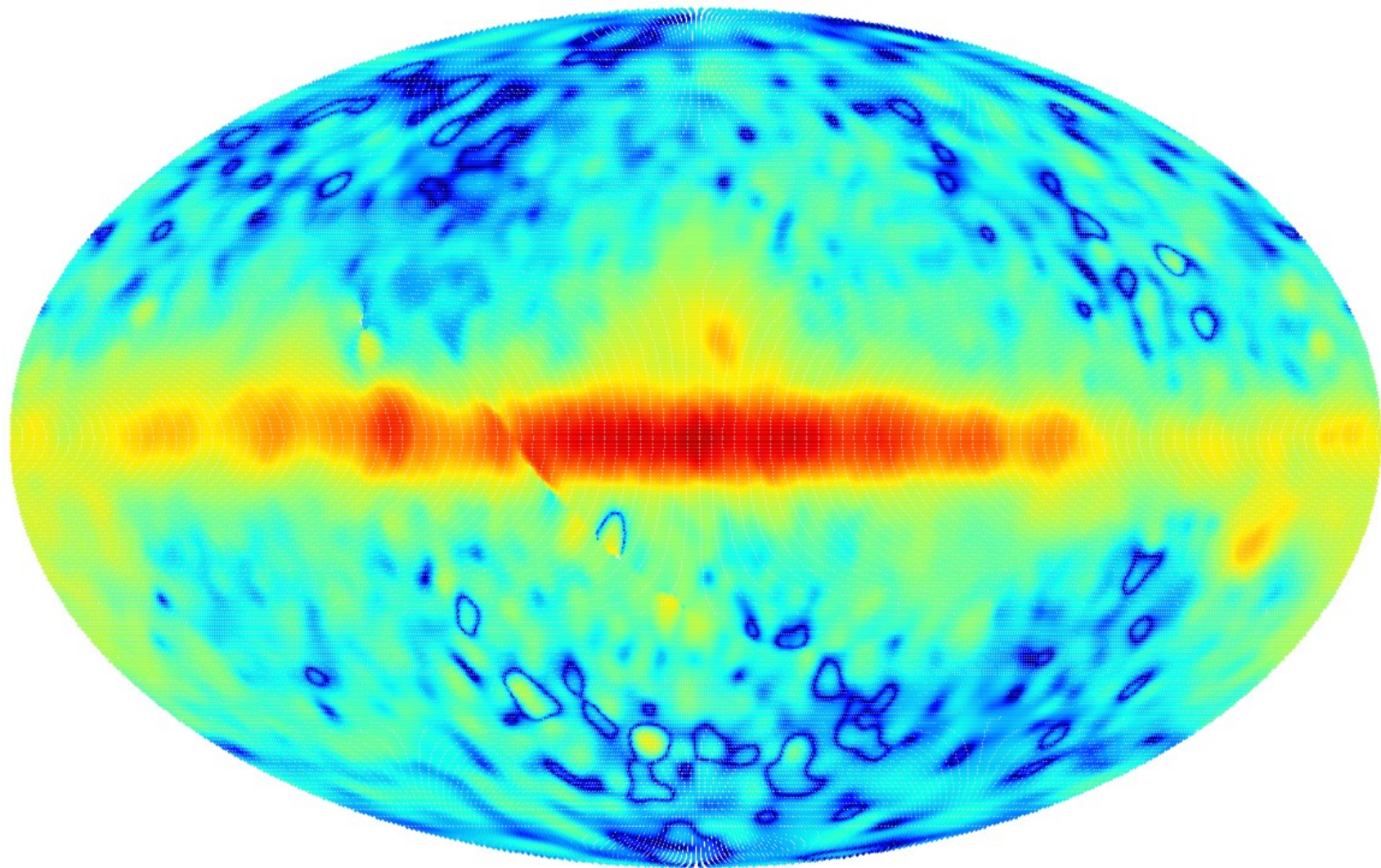


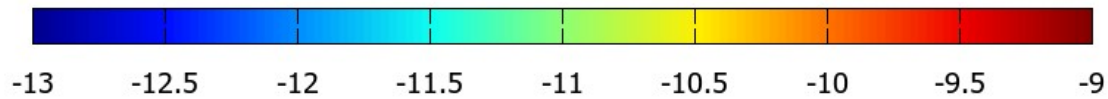
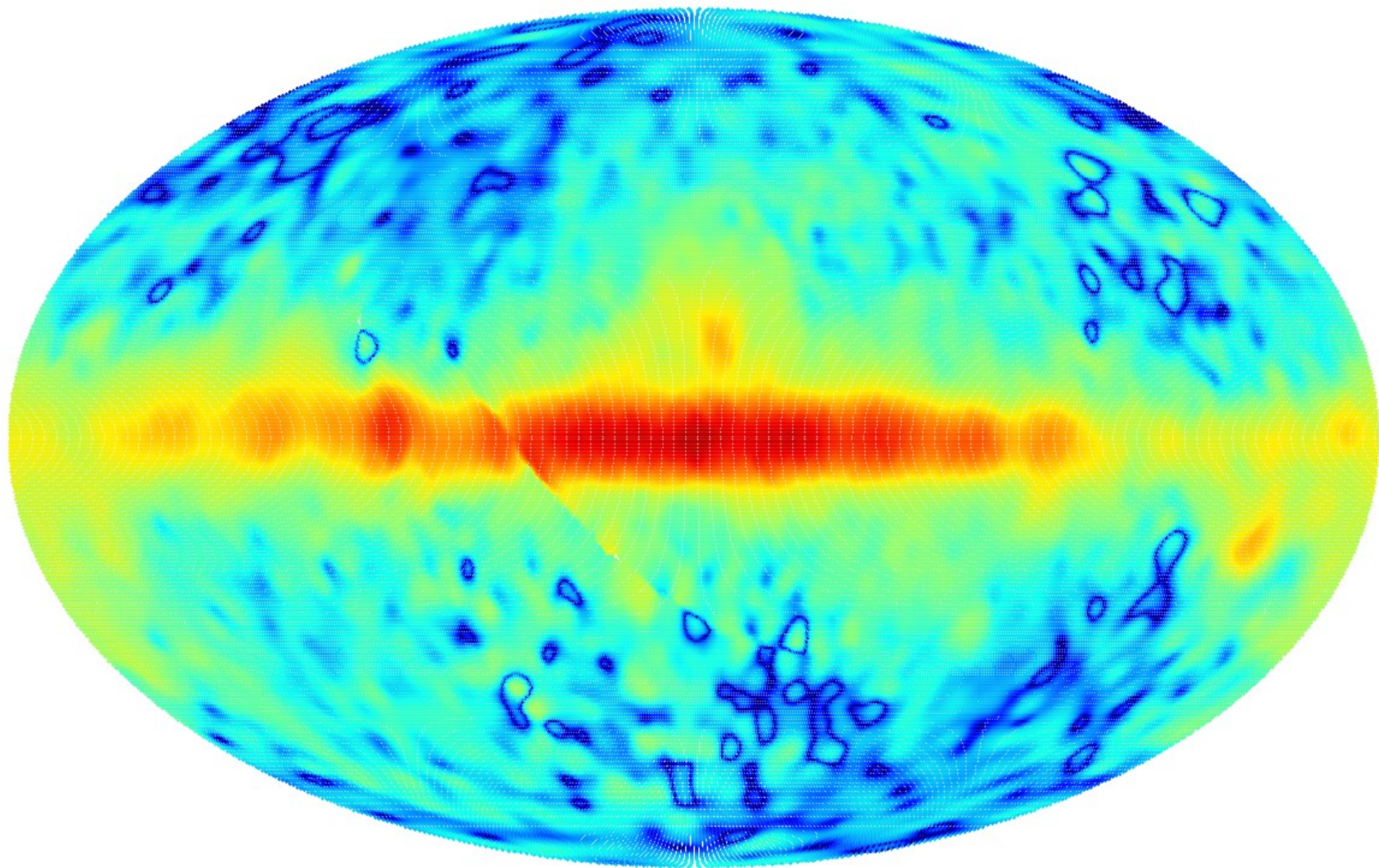


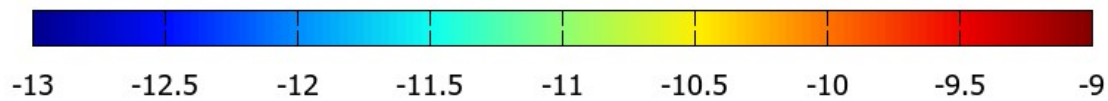
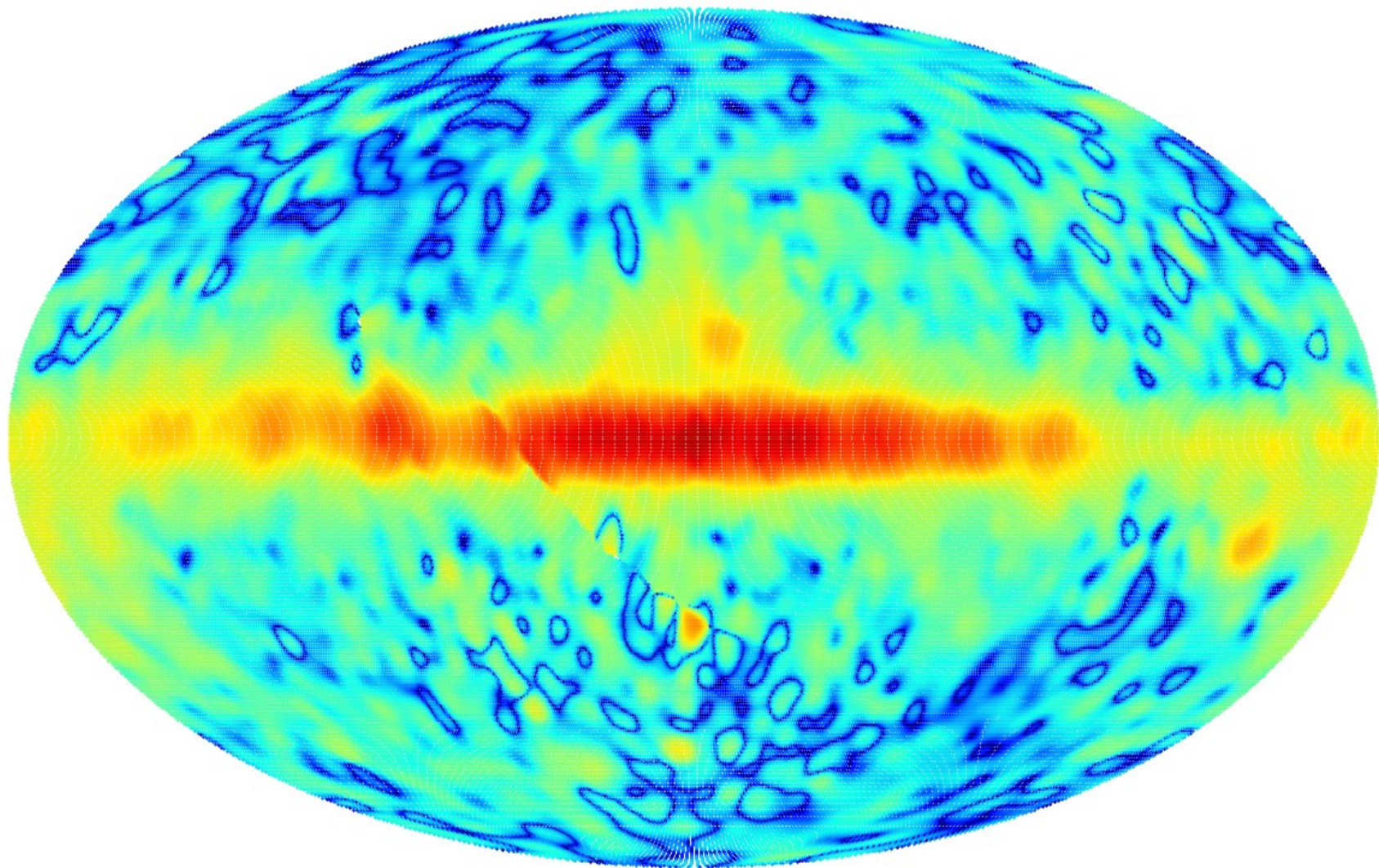


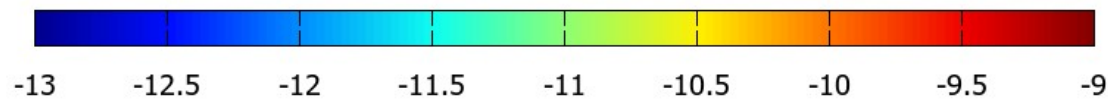
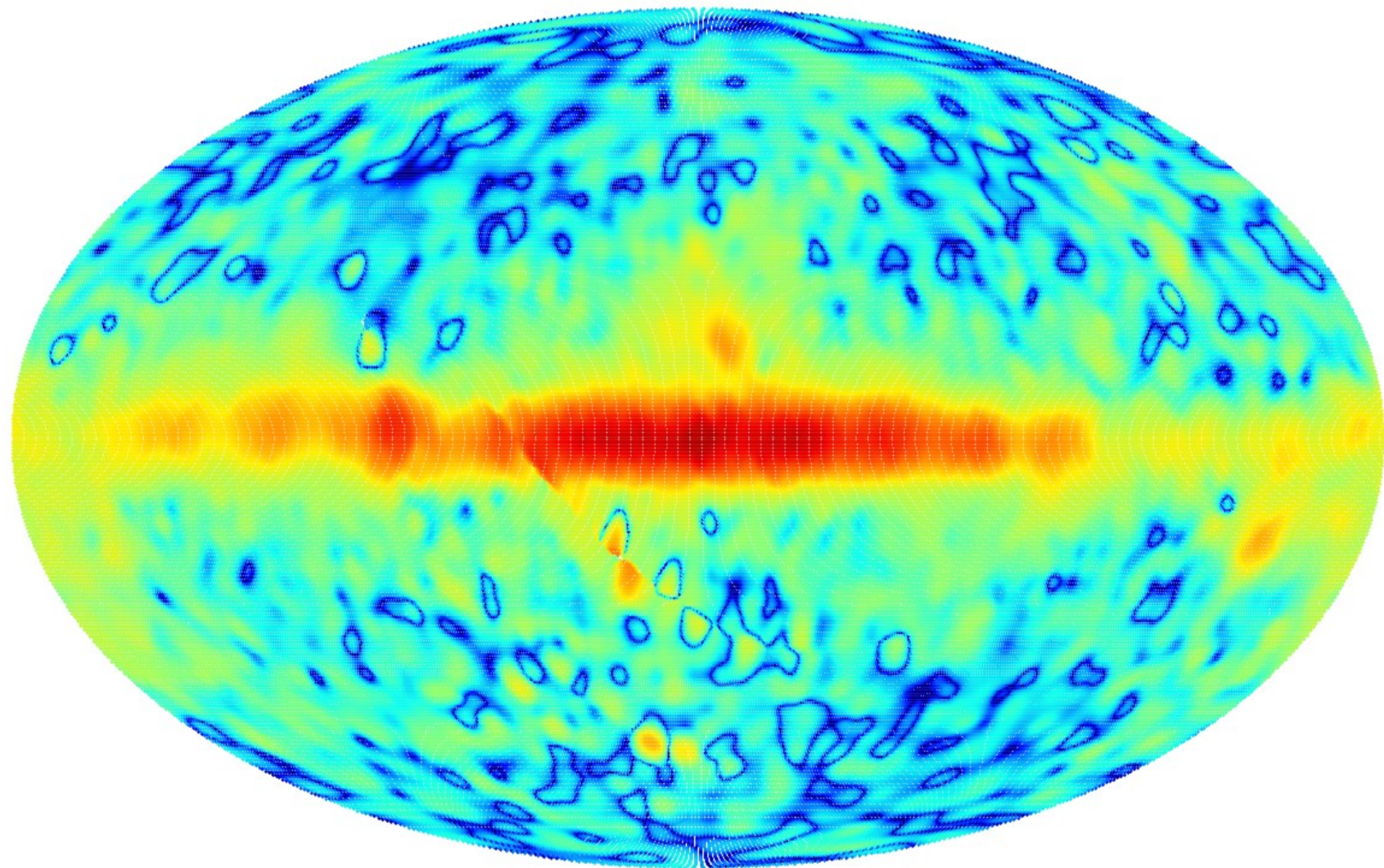


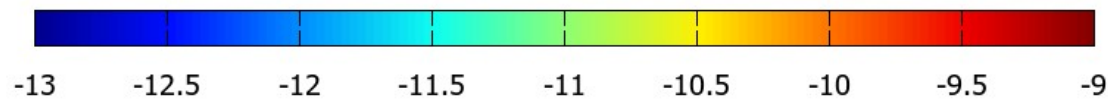
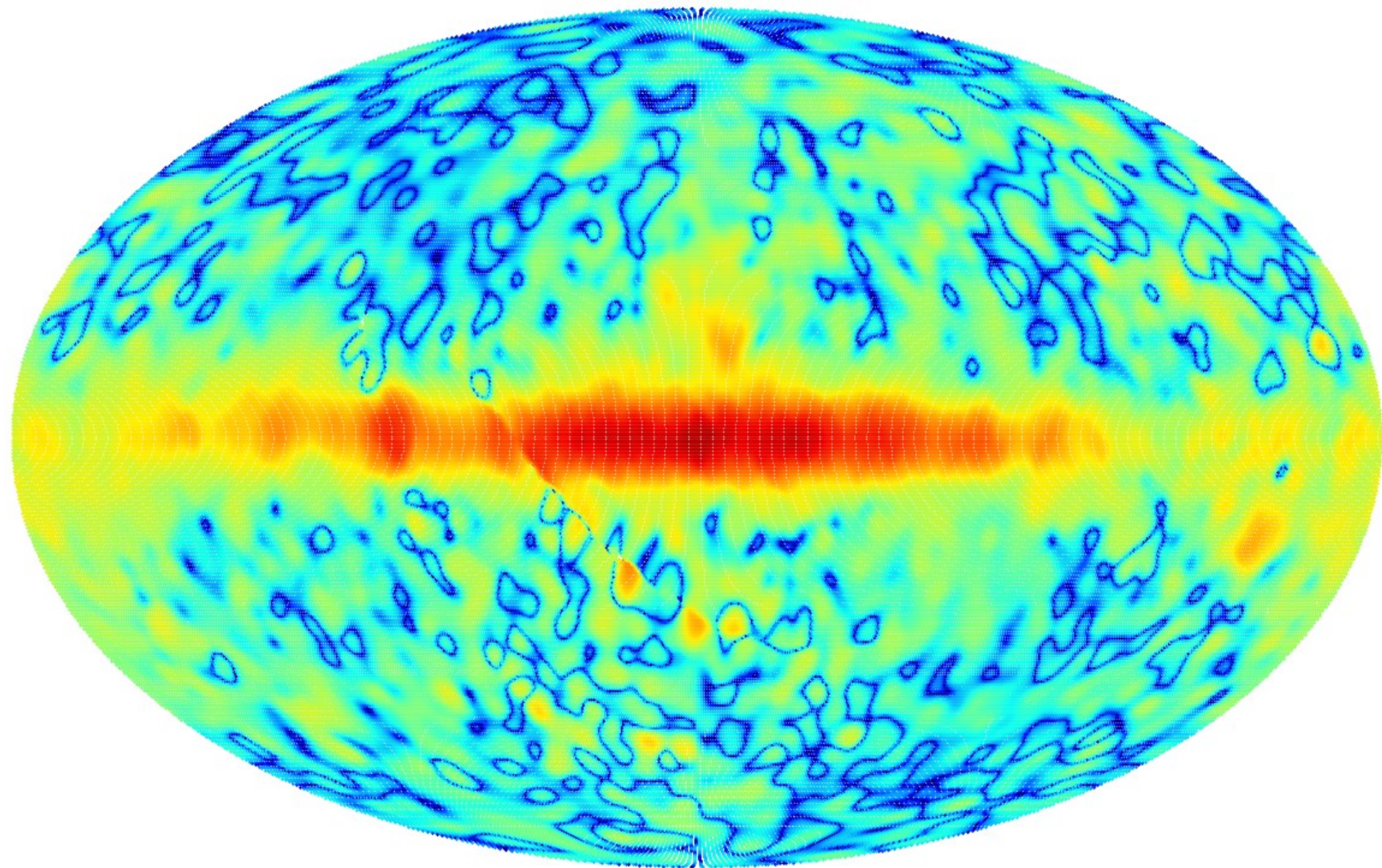


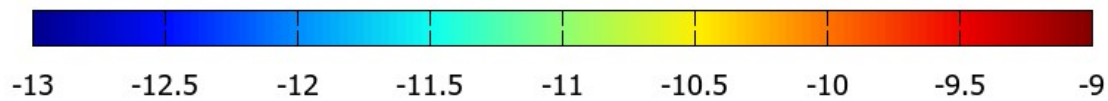
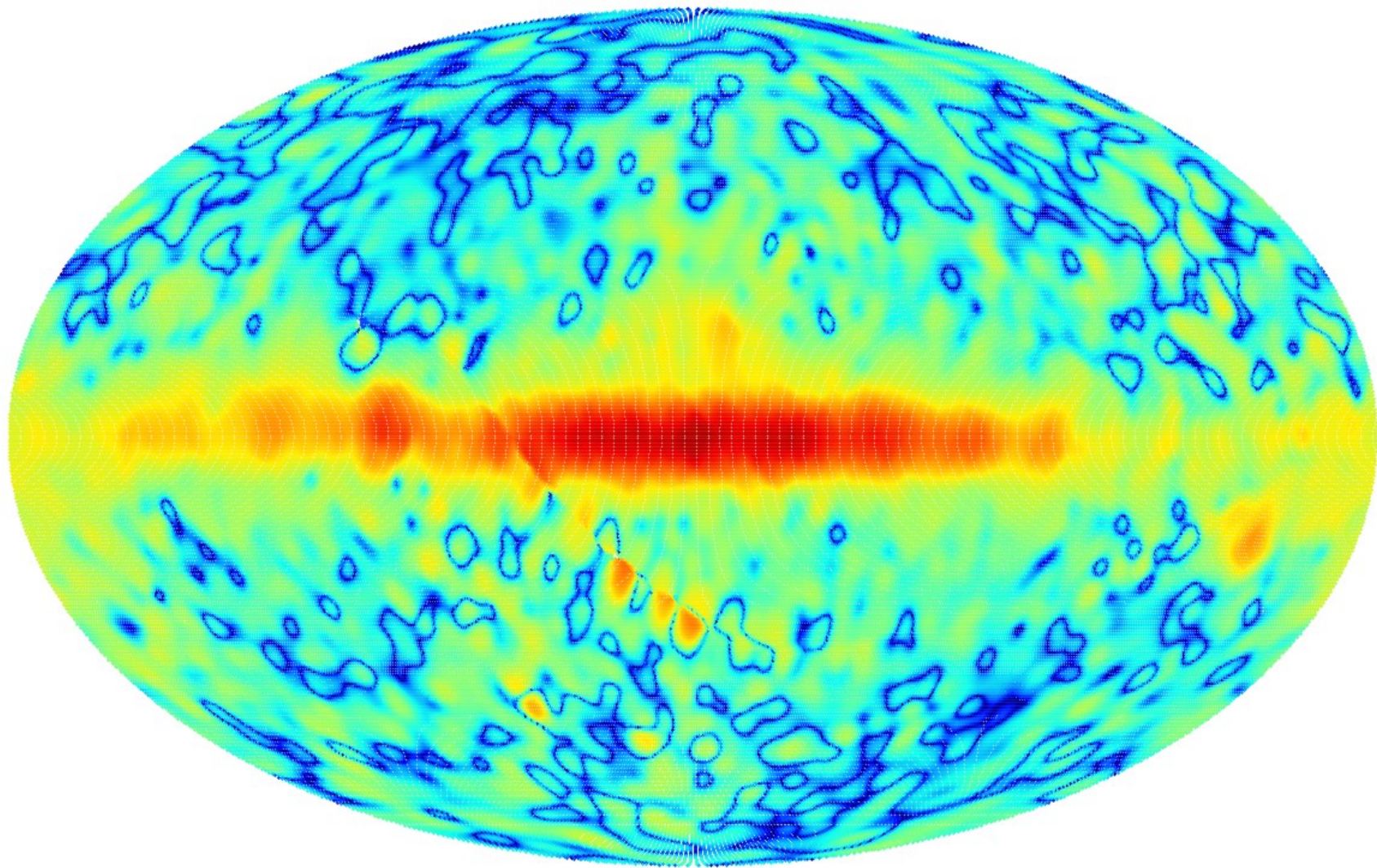


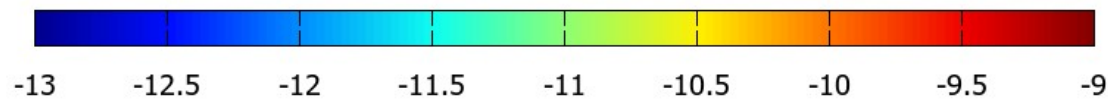
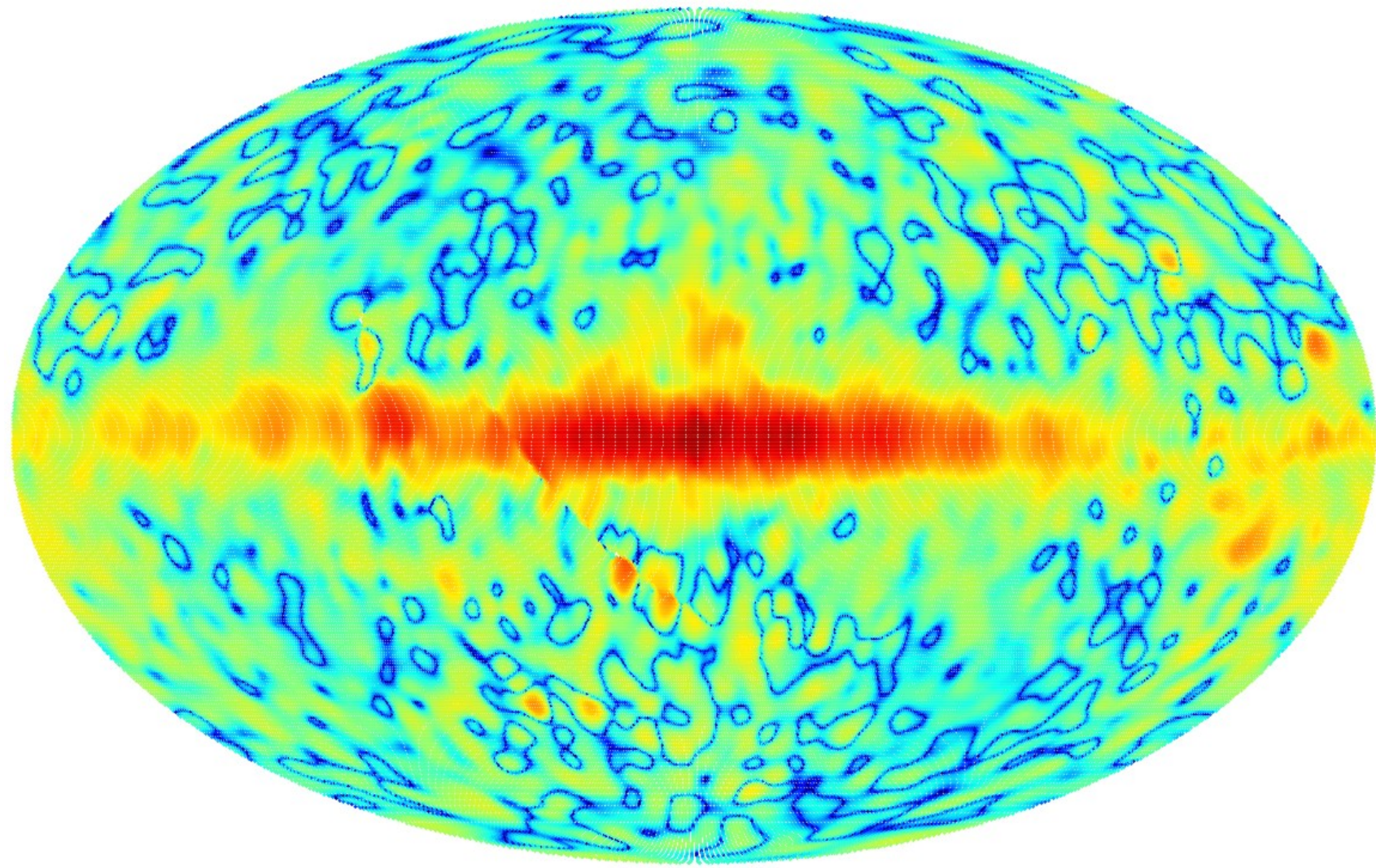


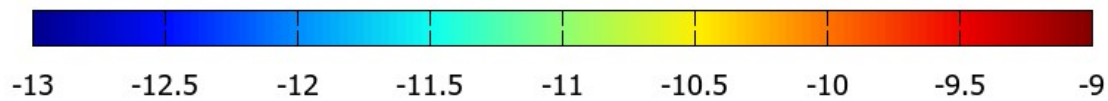
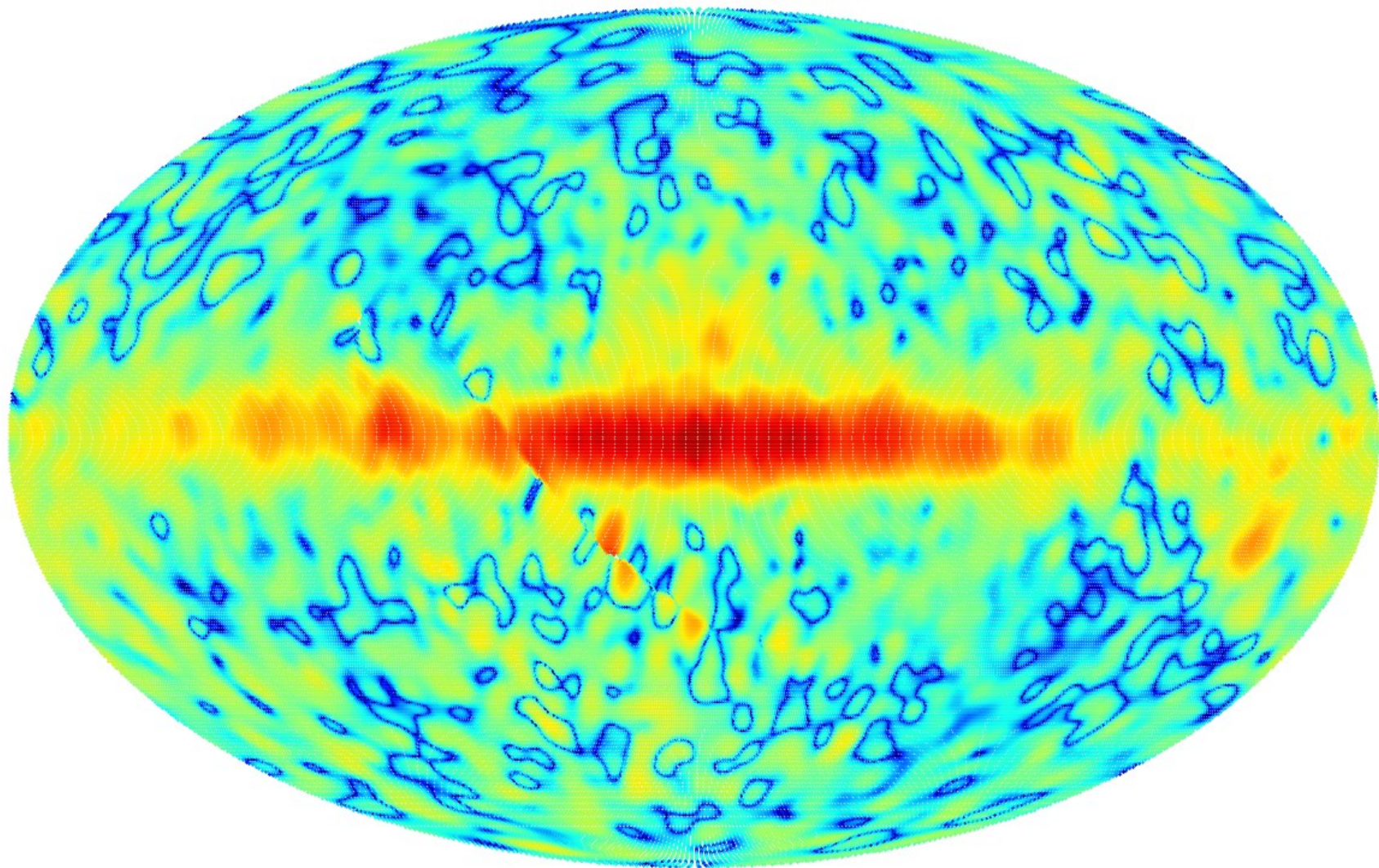


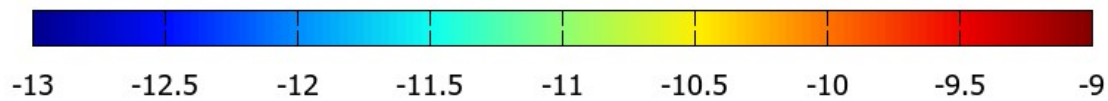
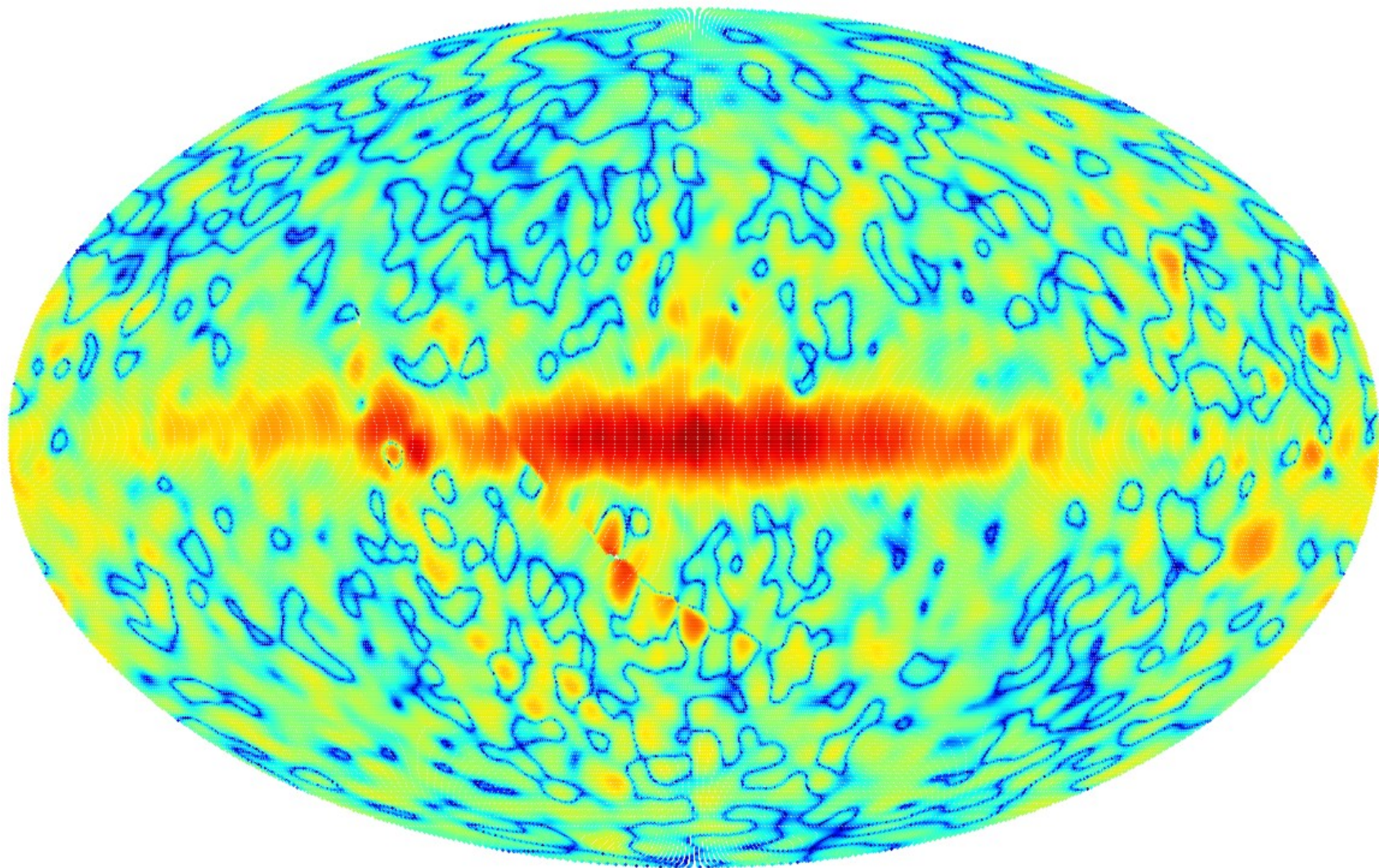


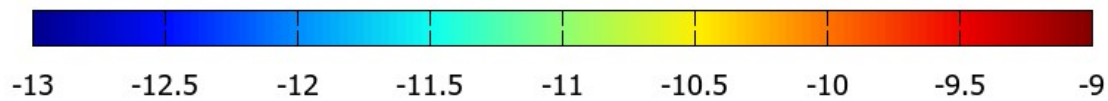
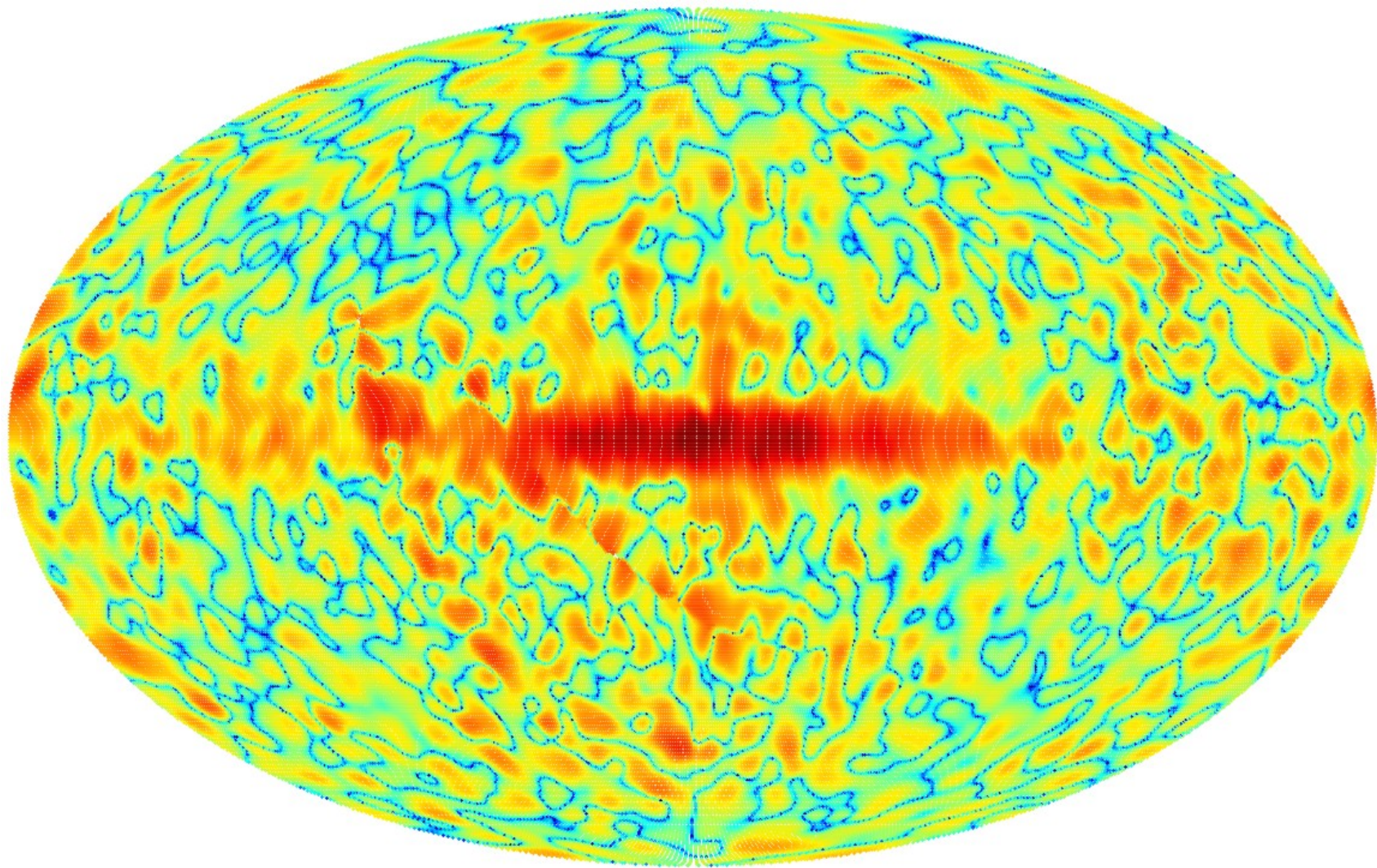






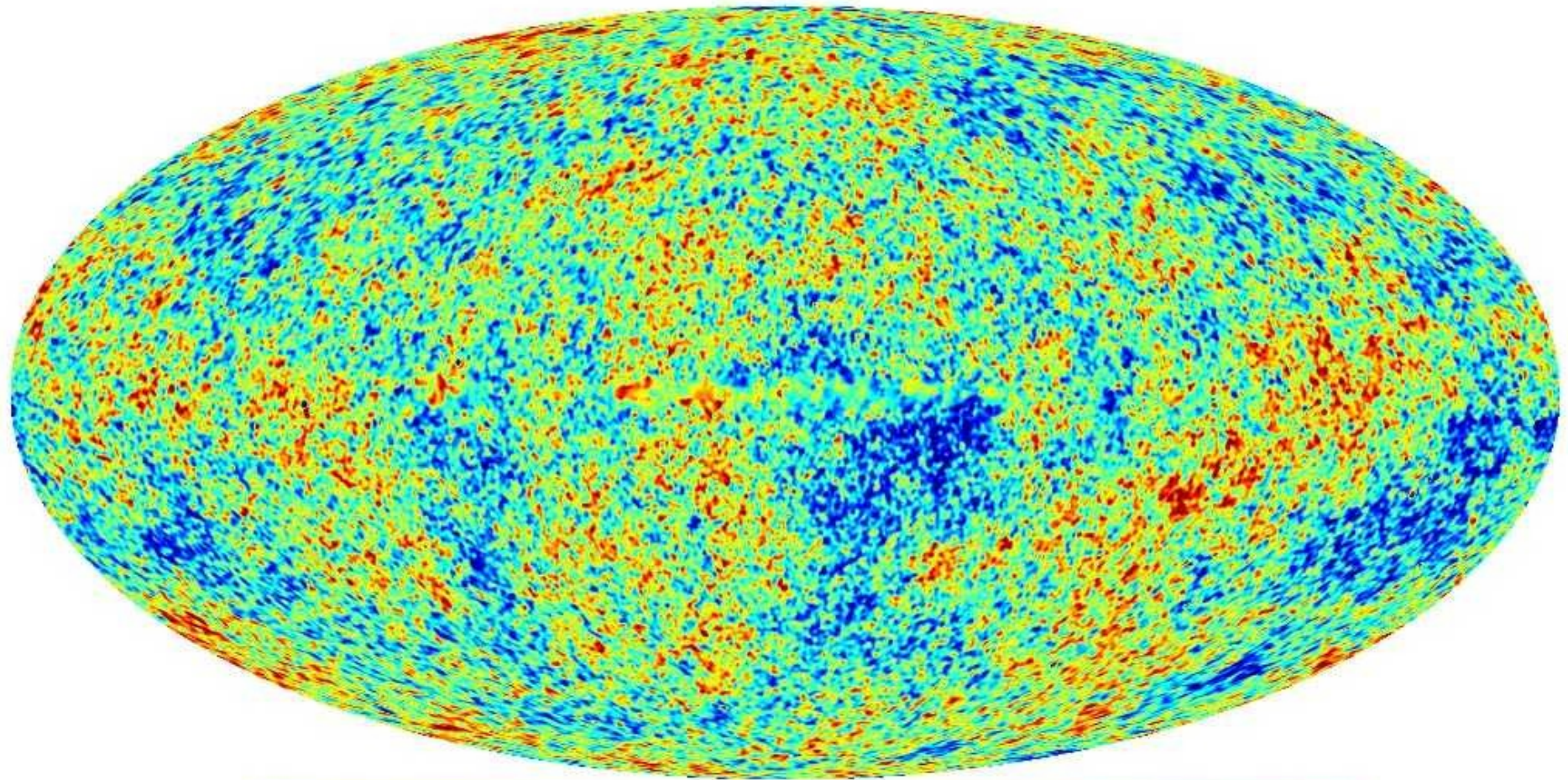






The CMB is very homogeneous but...

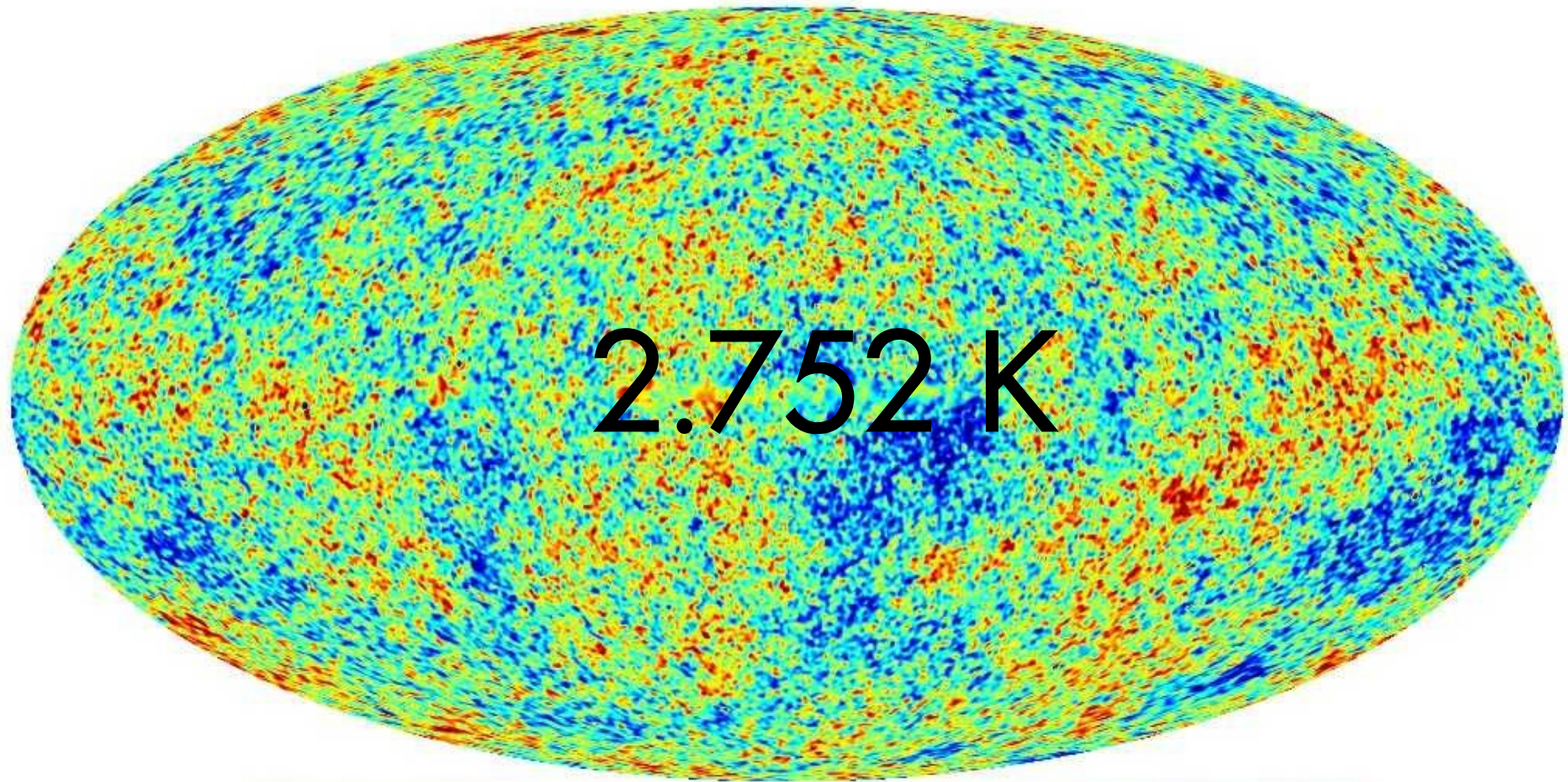
CMB anisotropies



-200 μK

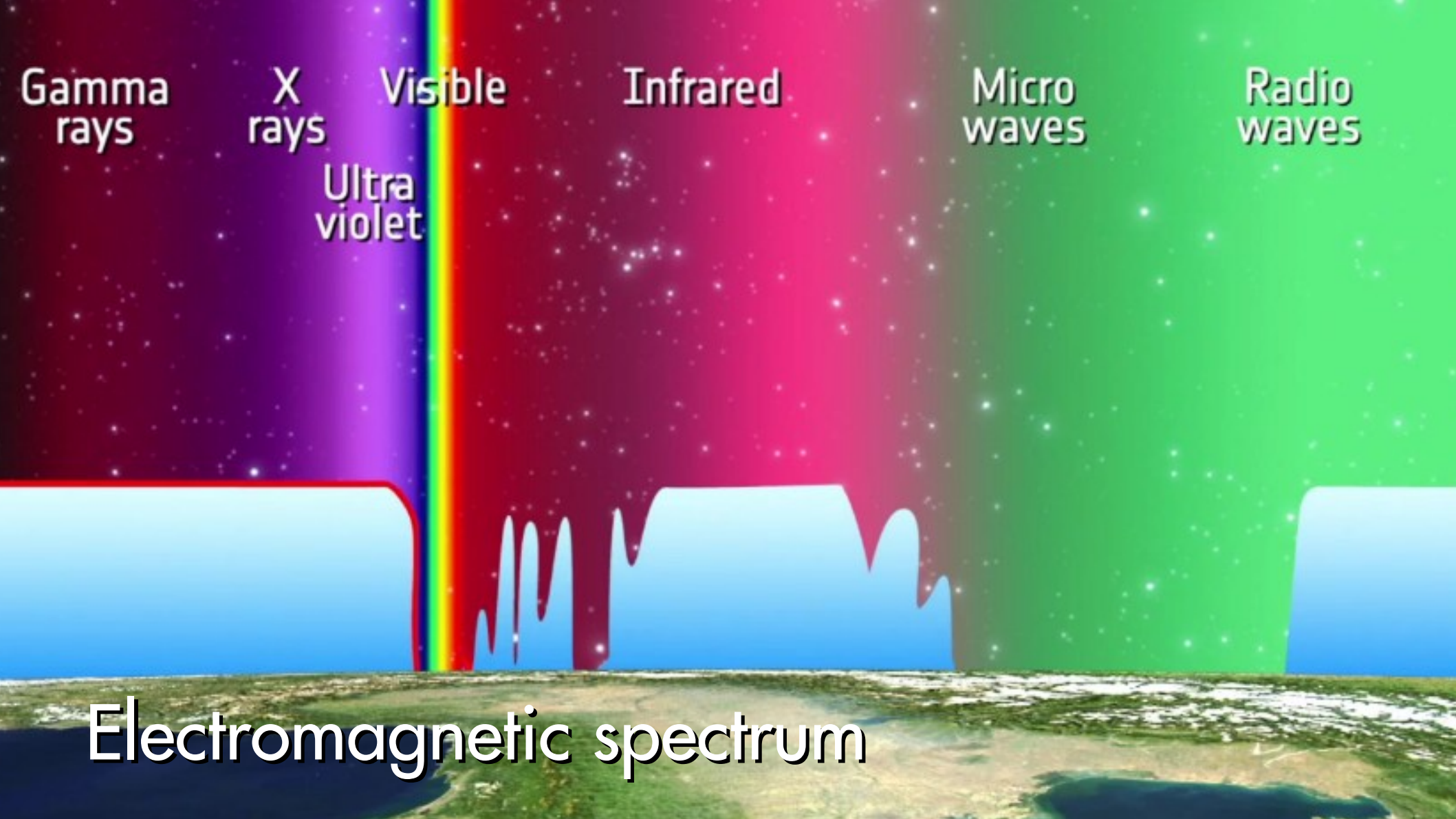
200 μK

CMB anisotropies



-200 μ K

200 μ K



Gamma
rays

X
rays

Visible

Ultra
violet

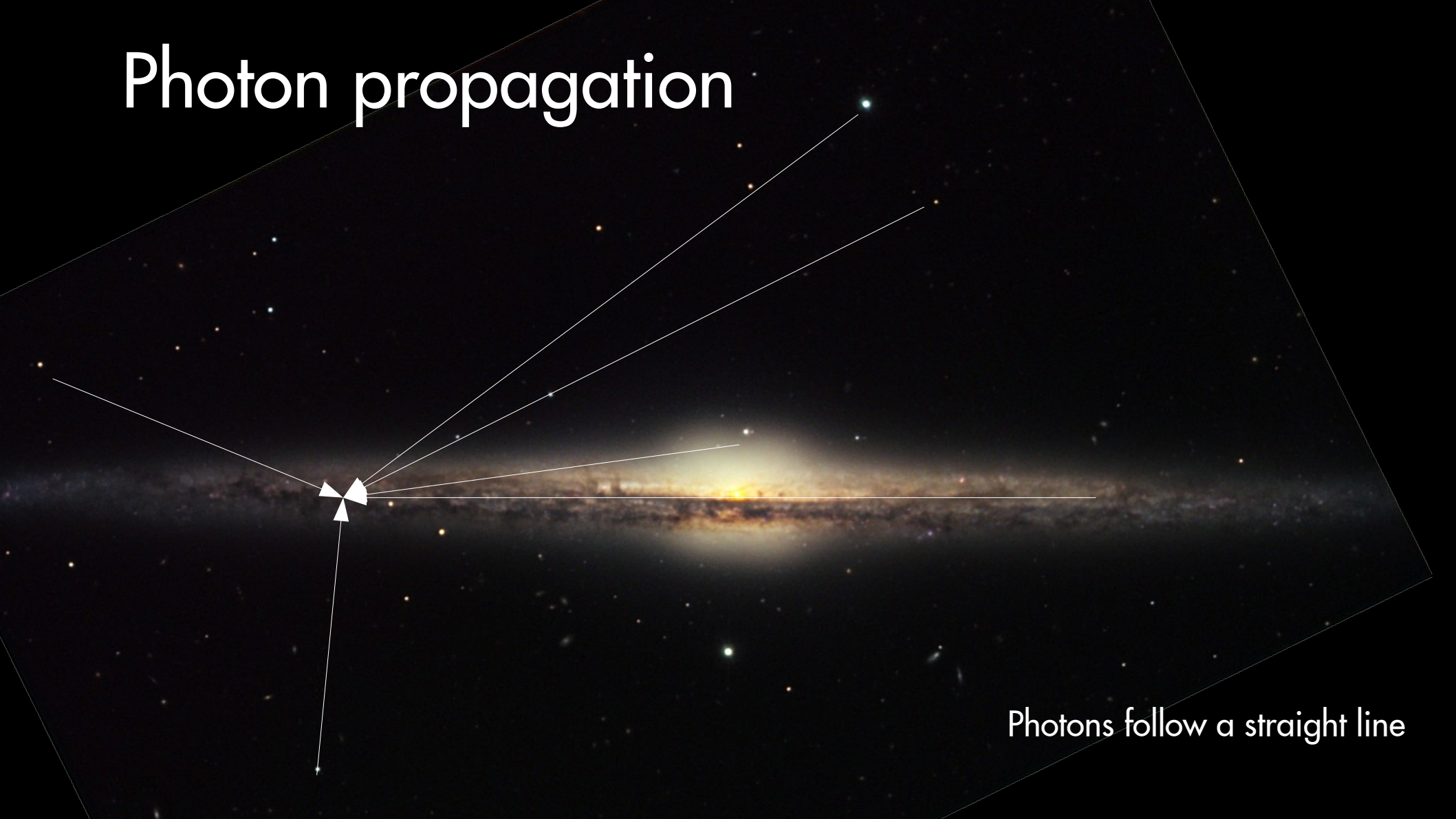
Infrared

Micro
waves

Radio
waves

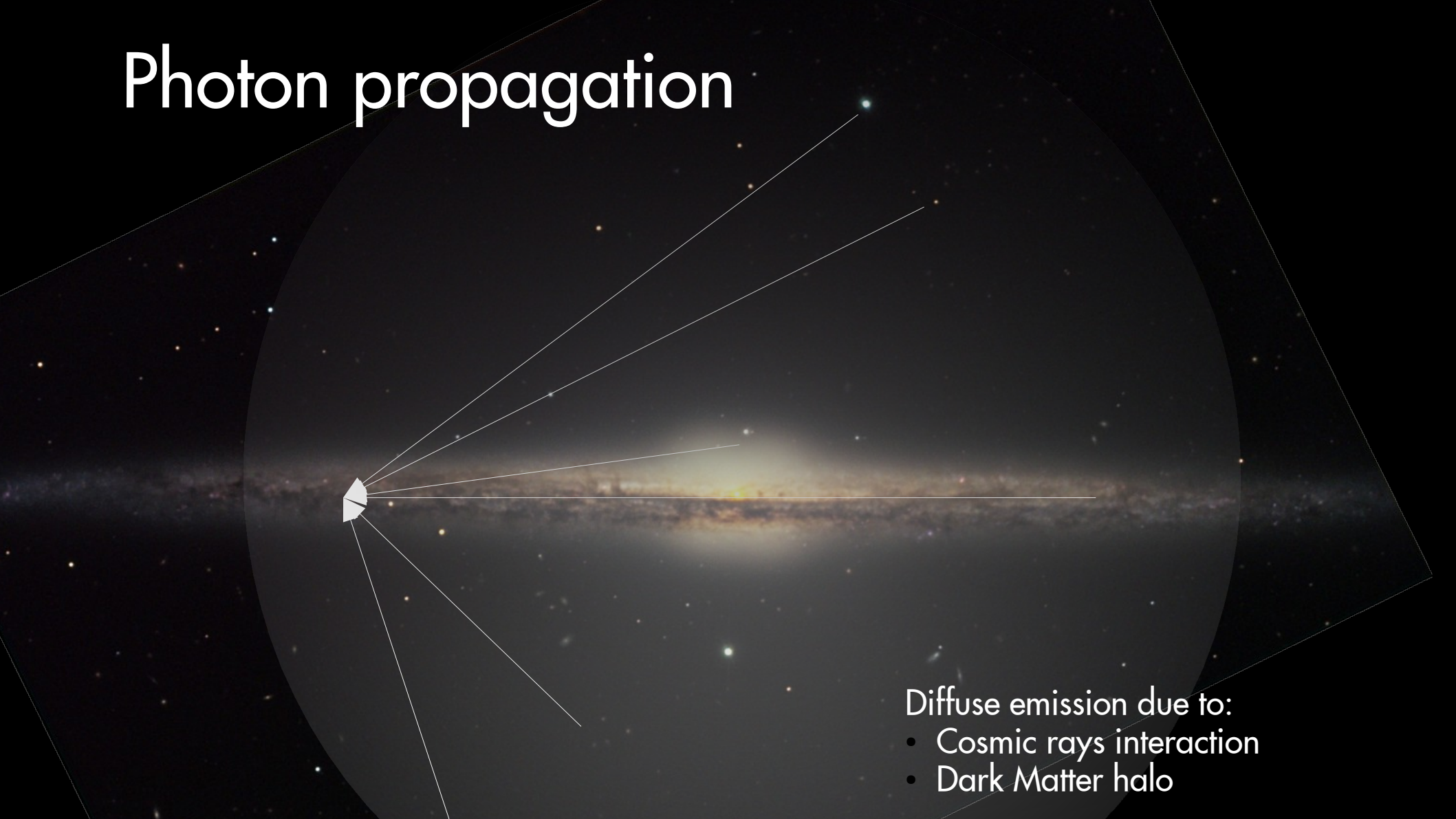
Electromagnetic spectrum

Photon propagation



Photons follow a straight line

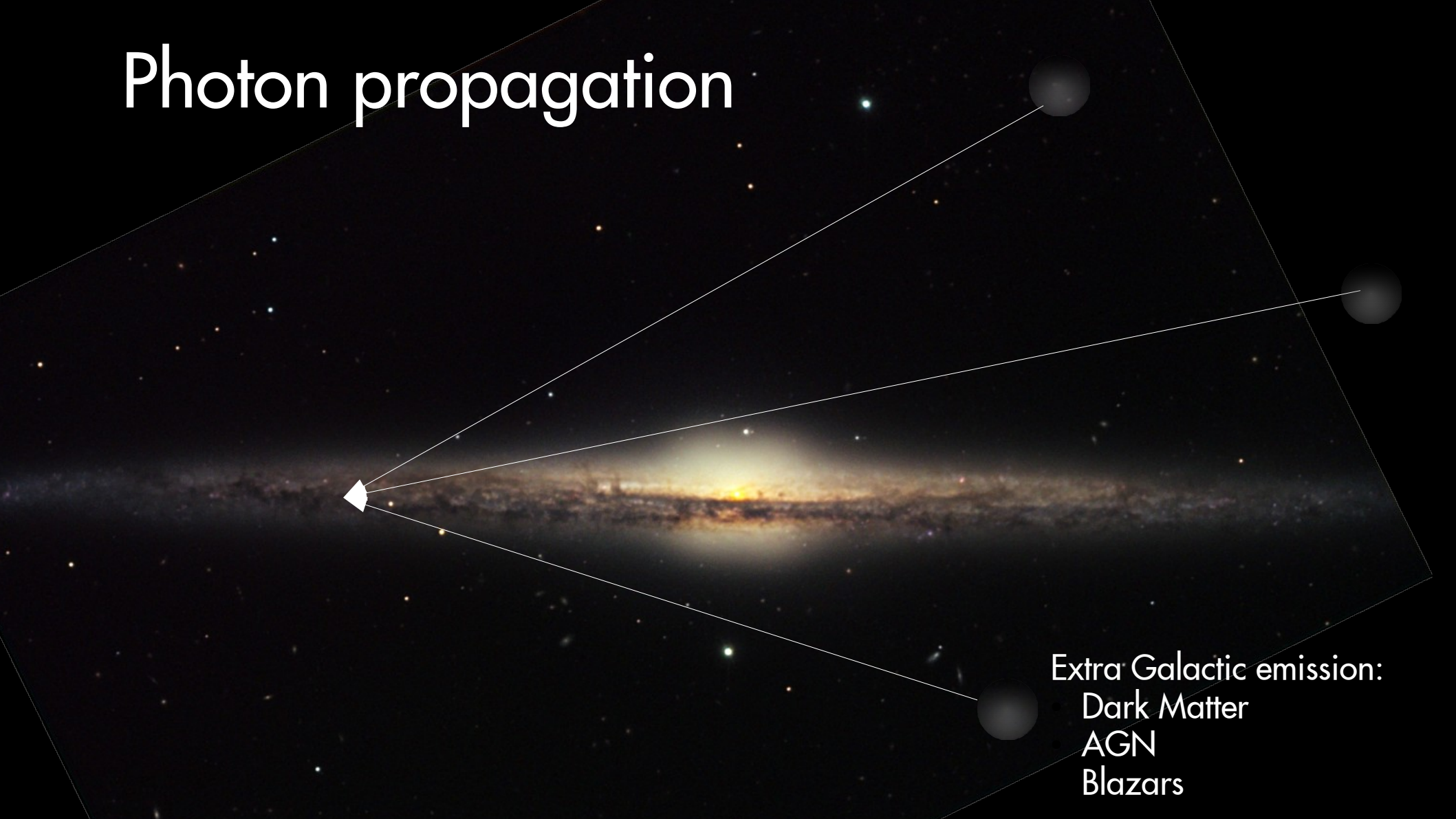
Photon propagation



Diffuse emission due to:

- Cosmic rays interaction
- Dark Matter halo

Photon propagation



Extra Galactic emission:
Dark Matter
AGN
Blazars

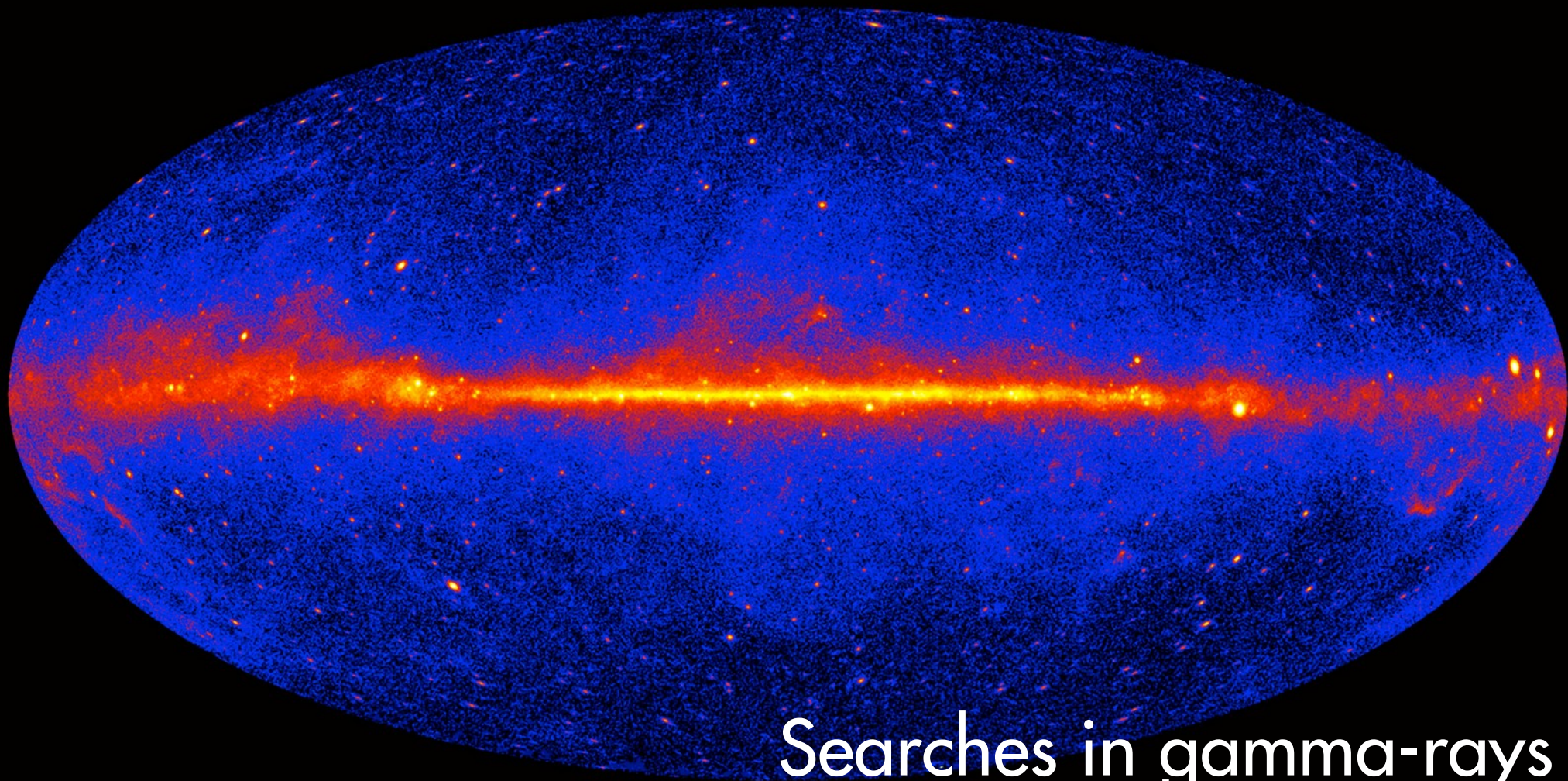
Photon flux

Since photons propagate in straight line, the flux comes from the cumulative contributions from sources

$$\frac{d\Phi}{dE} = \frac{1}{\Delta\Omega} \int d\Omega \int_{\text{l.o.s.}} \frac{s(r(l), E)}{4\pi} dl$$

In the case of Dark Matter Searches:

$$\frac{d\Phi}{dE} = \underbrace{\frac{1}{4\pi m_{\text{DM}}^2} \sum_i \langle \sigma_i v \rangle \frac{dN_\gamma^i}{dE}}_{\text{particle physics}} \times \underbrace{\frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega \int_{\text{l.o.s.}} \rho^2(r(l)) dl}_{\text{J-factor}}$$



Searches in gamma-rays

Gamma-ray observatories



Fermi-LAT (low orbit)
Calorimeter

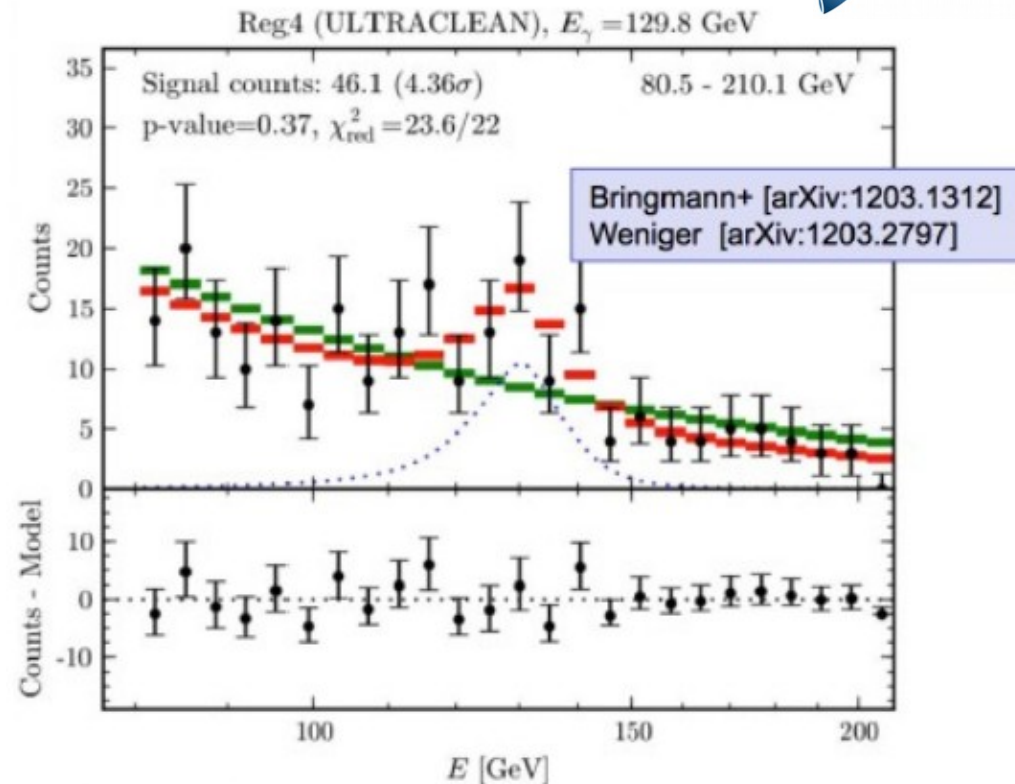
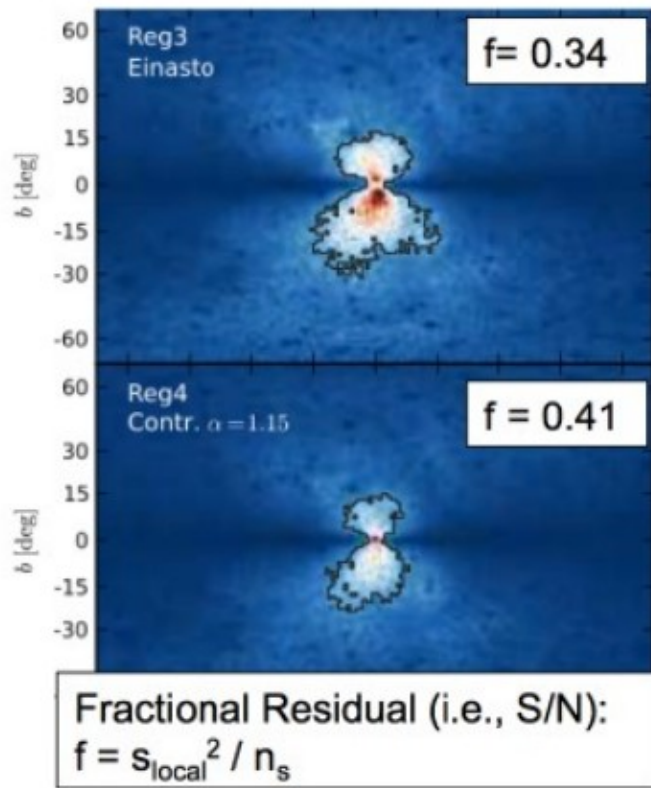


HESS (Namibia), MAGIC (Spain),
CTA (Spain and Chile)
Atmosphere Cherenkov



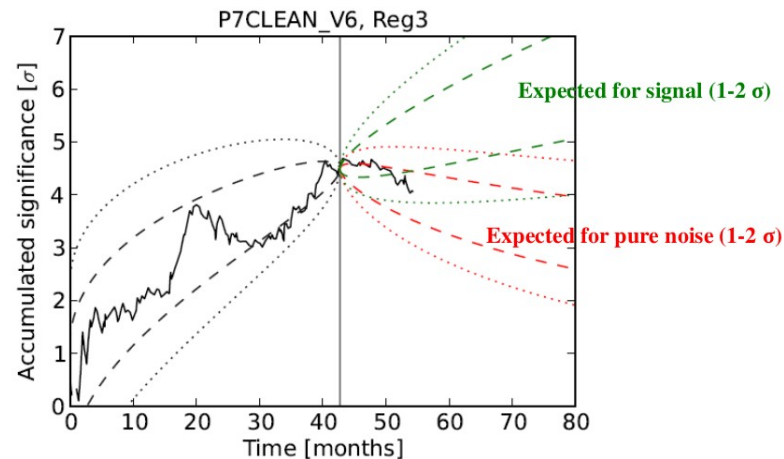
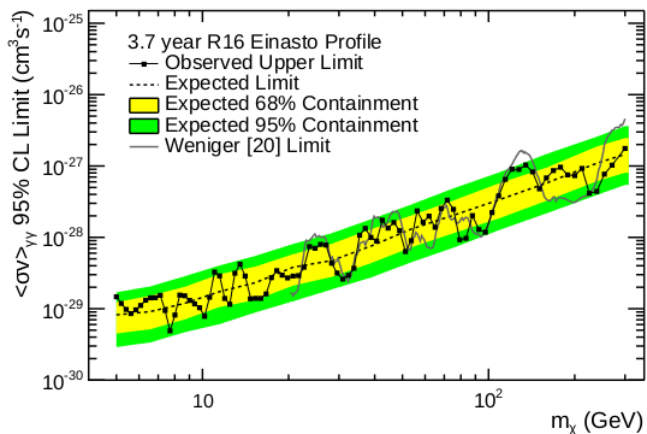
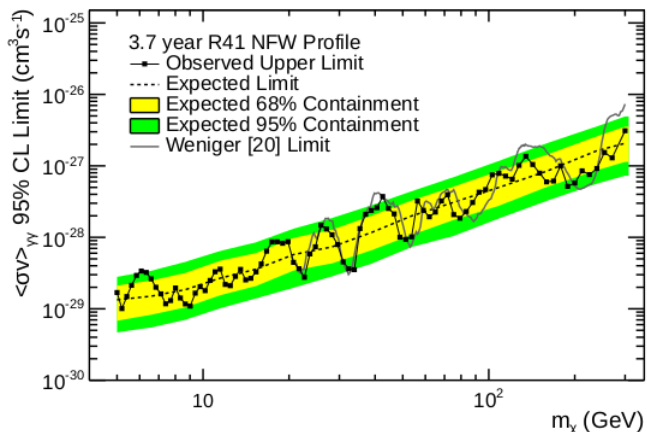
HAWC (Mexico)
Water Cherenkov

Searches in gamma rays (gamma lines)



Tentative gamma line of 130 GeV coming from the Galactic Center

Searches in gamma rays

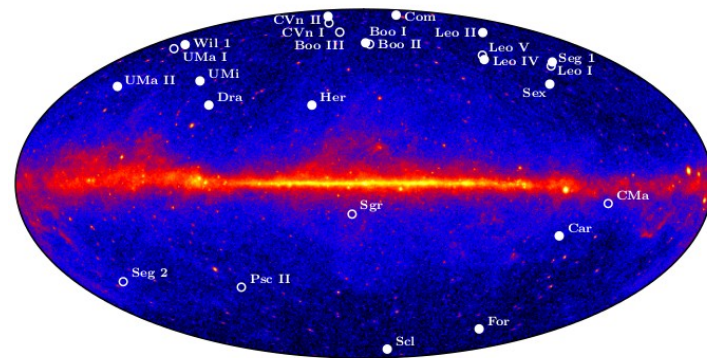
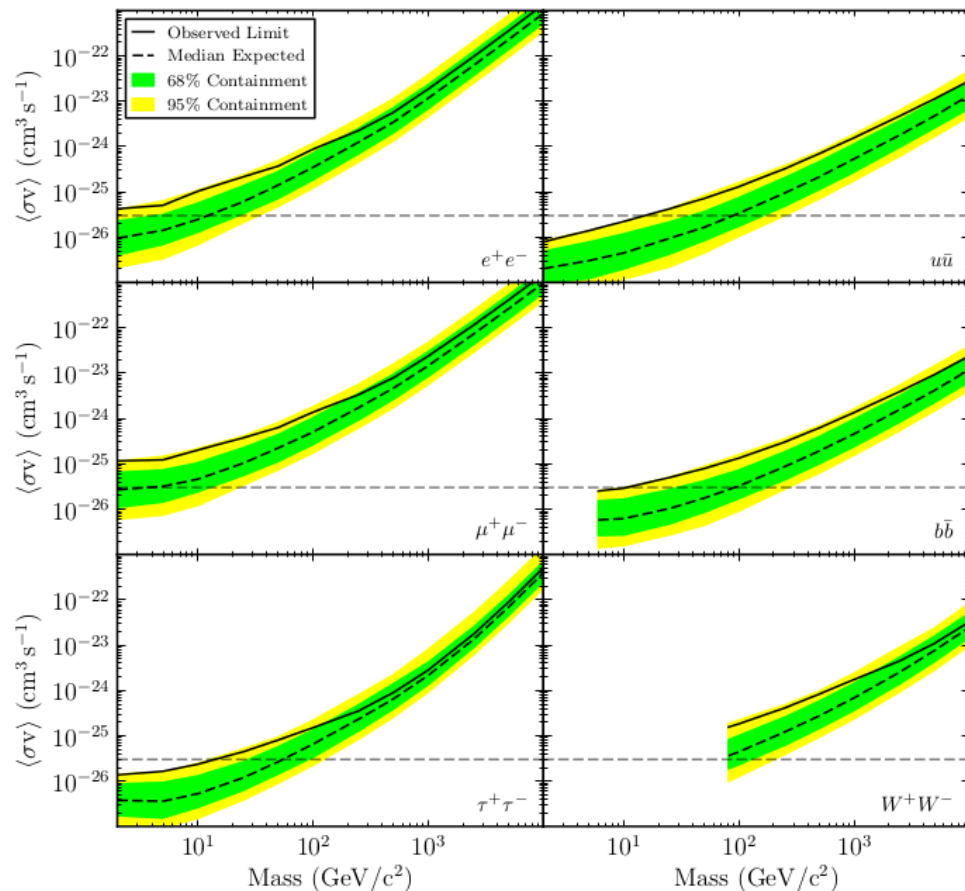


C. Weniger. arXiv:1303.1798

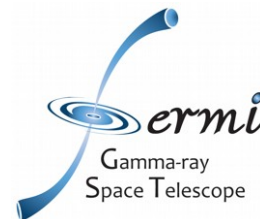


Fermi-LAT Collaboration
PRD 88, 082002 (2013). arXiv:1305.5597

Searches in gamma rays (Dwarf Spheroidal Galaxies)



Combined analysis on 25 Dwarf Spheroidal Galaxies

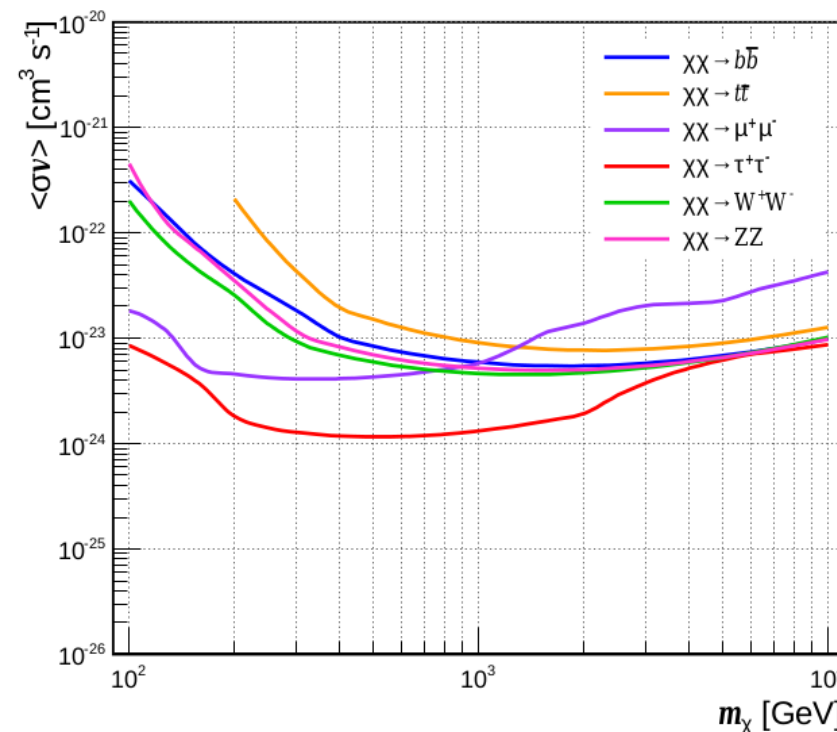
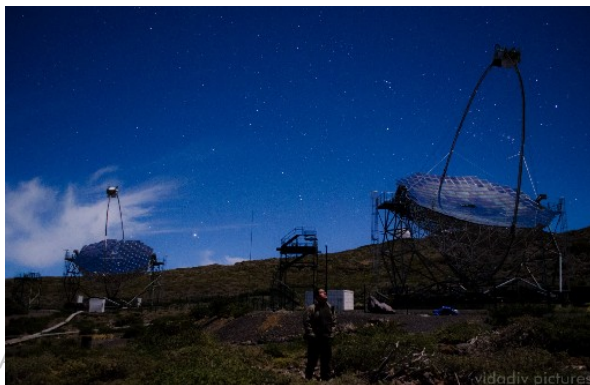
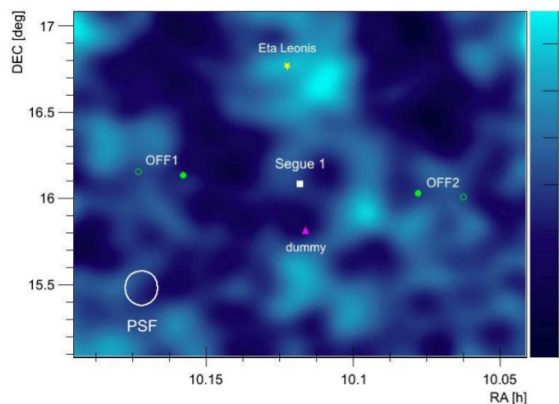


Fermi-LAT Collaboration.
arXiv:1310.0828

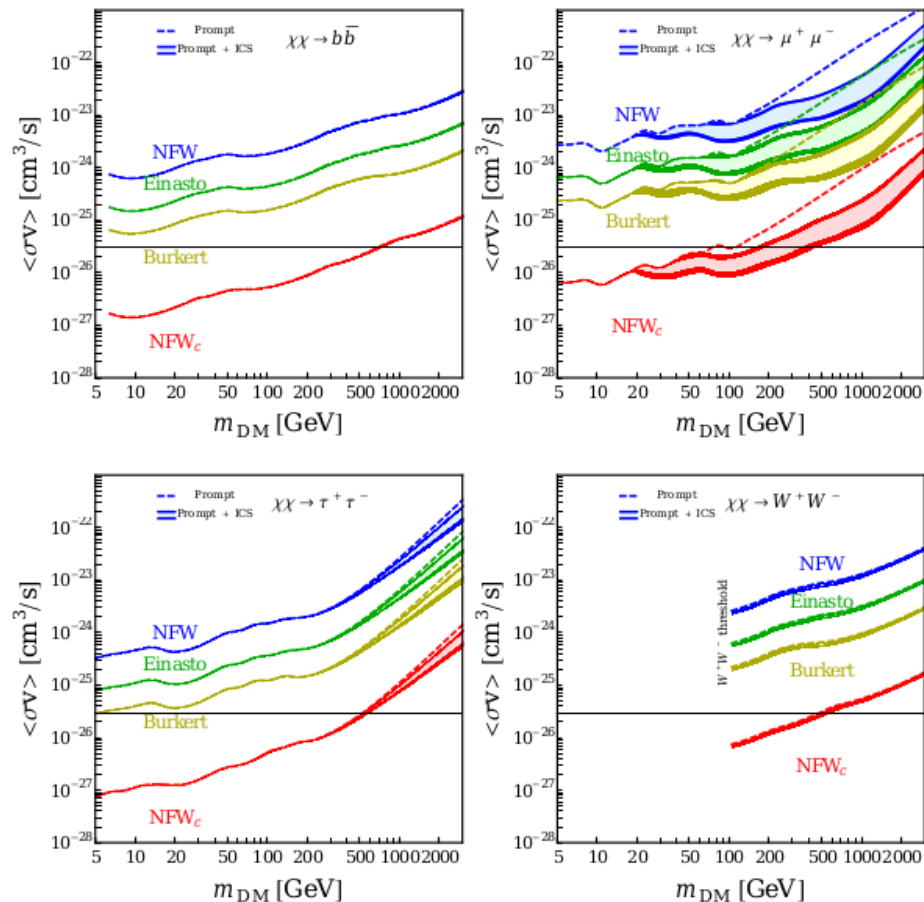
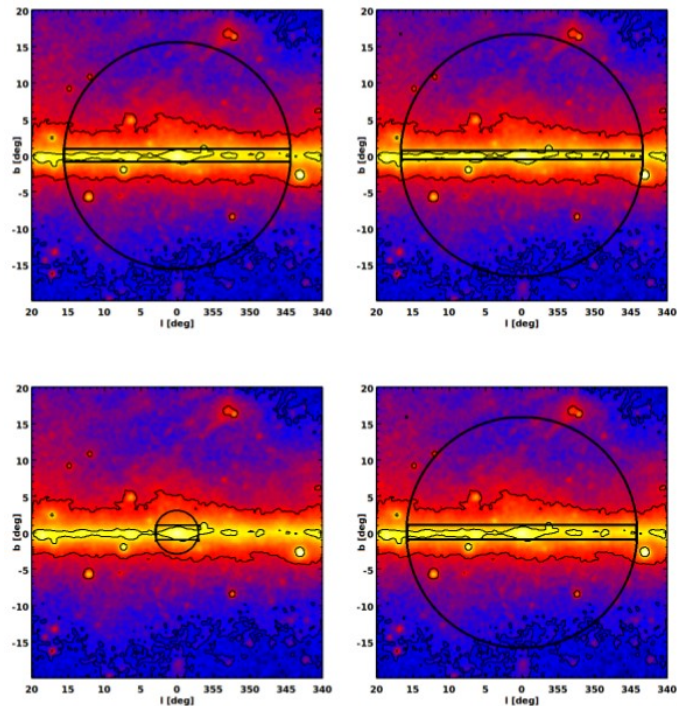
Searches in gamma rays



Optimized dark matter searches in deep observations of Segue 1 with MAGIC, arXiv:1312.1535



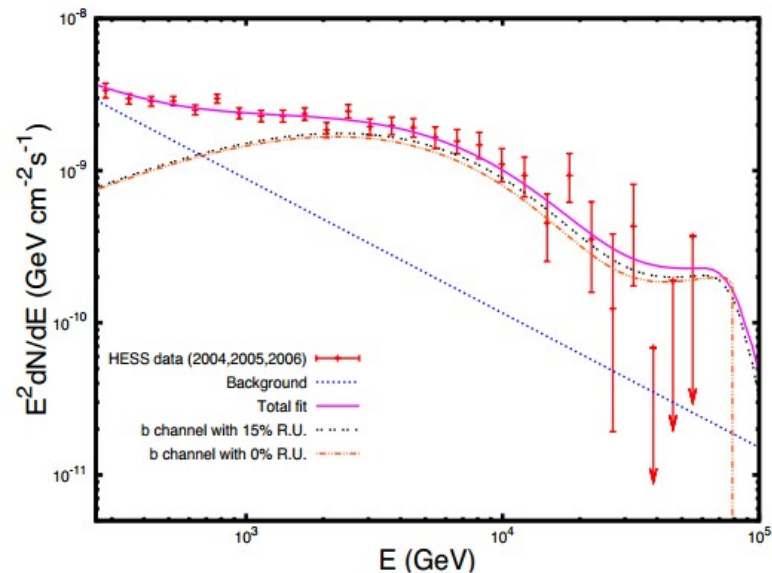
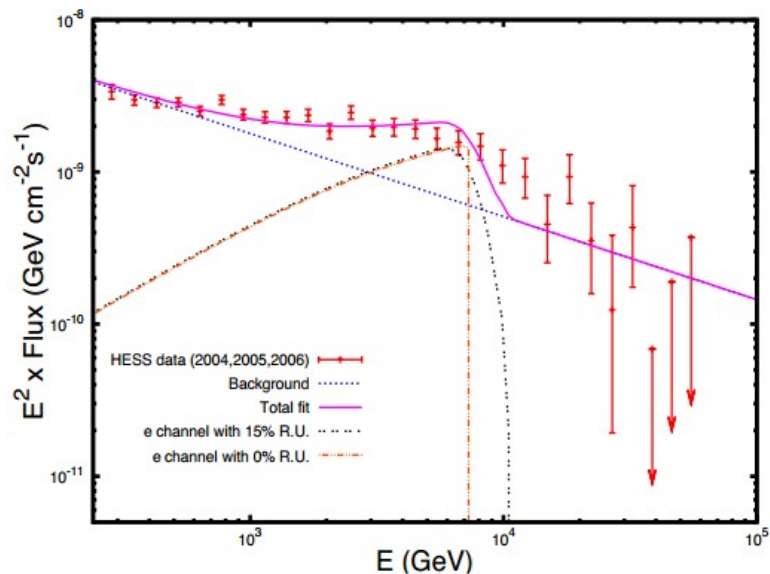
Searches in gamma rays (Galactic Center)



G. Gómez-Vargas et al.
JCAP10(2013)029. arXiv:1308.3515

Searches in gamma rays (Galactic Center)

Cembranos et al.
arXiv:1302.6871

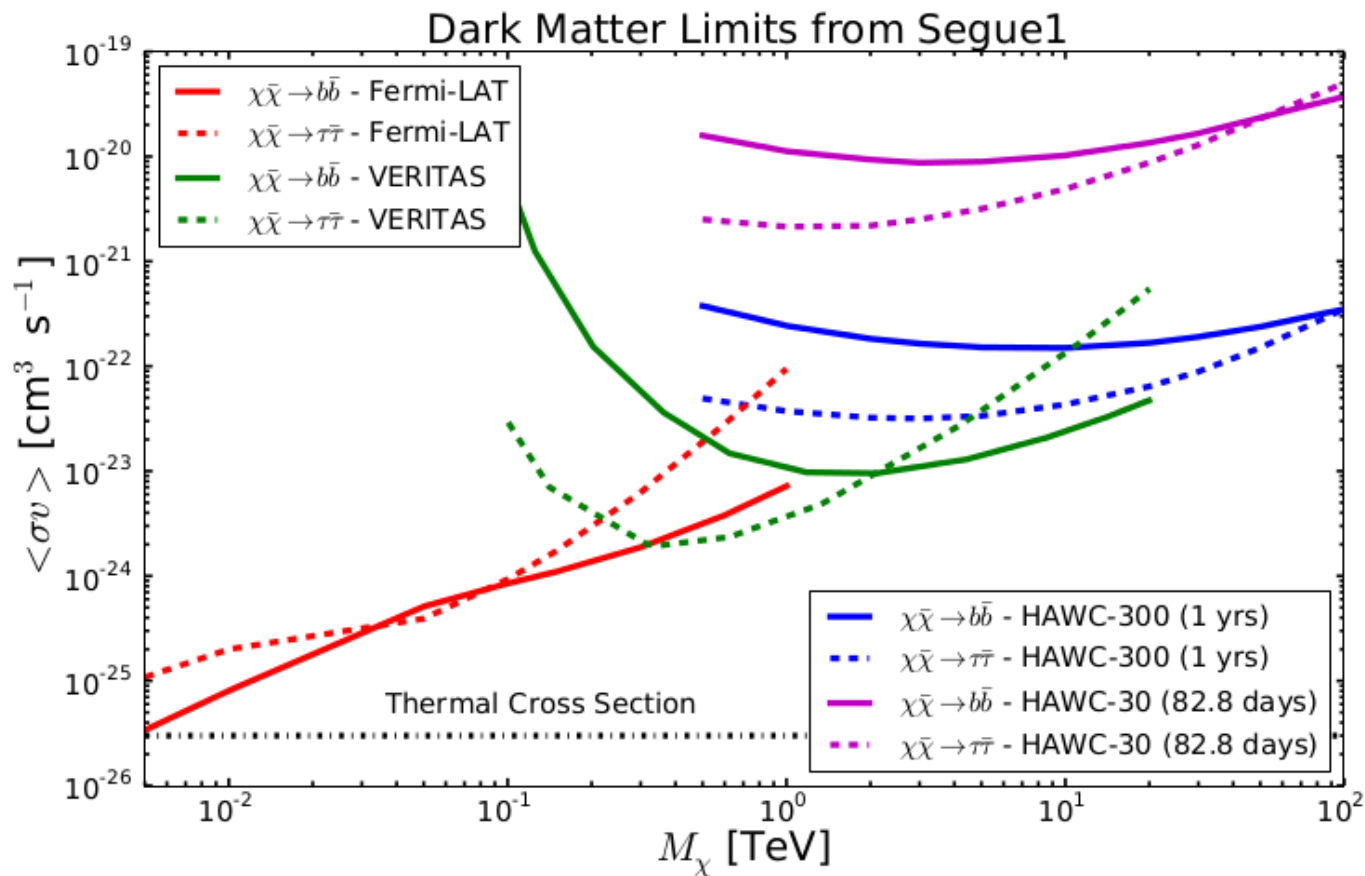


Observation done with HESS indicate a signal compatible with DM at the TeV range

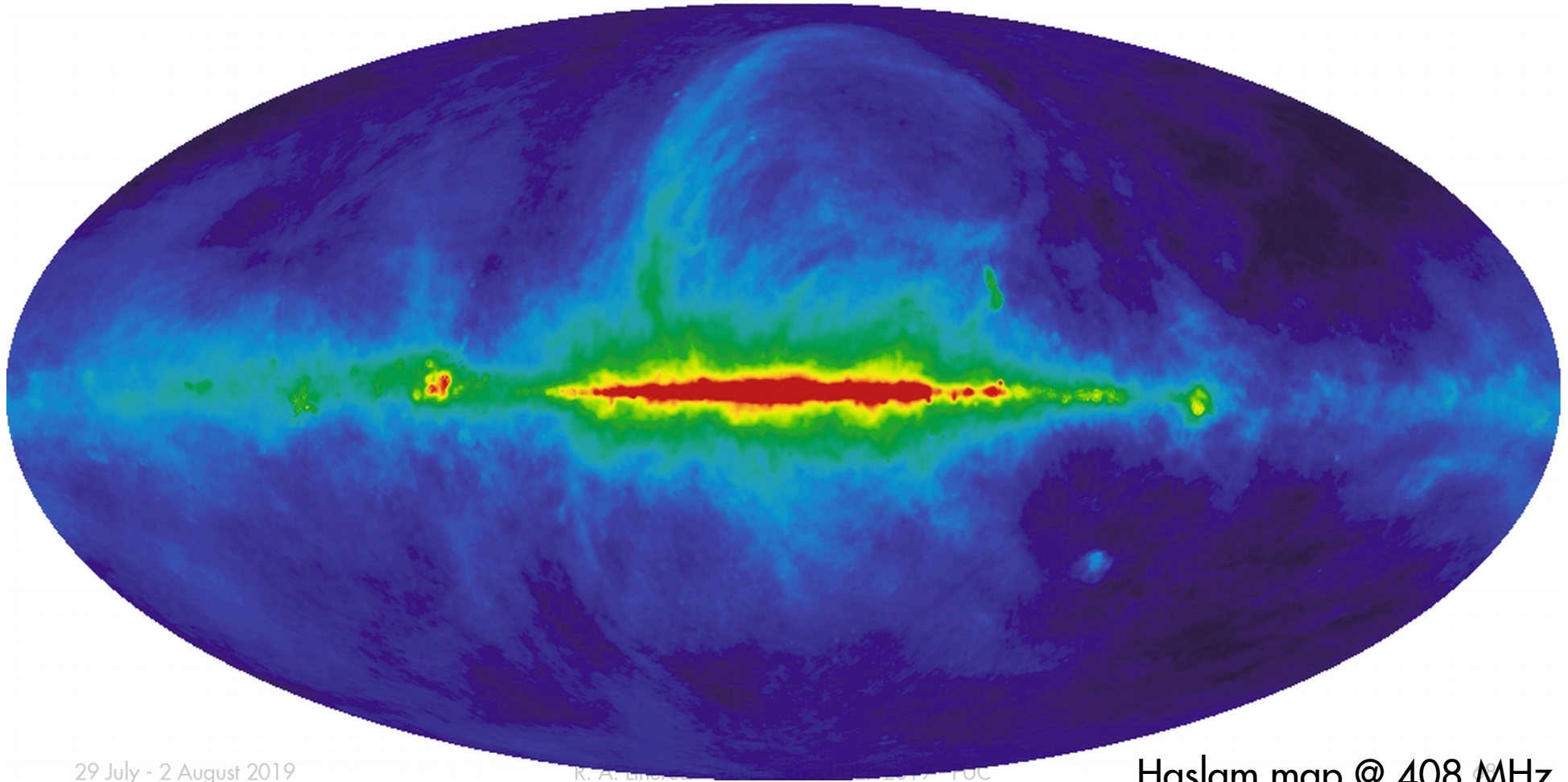
Searches in gamma rays



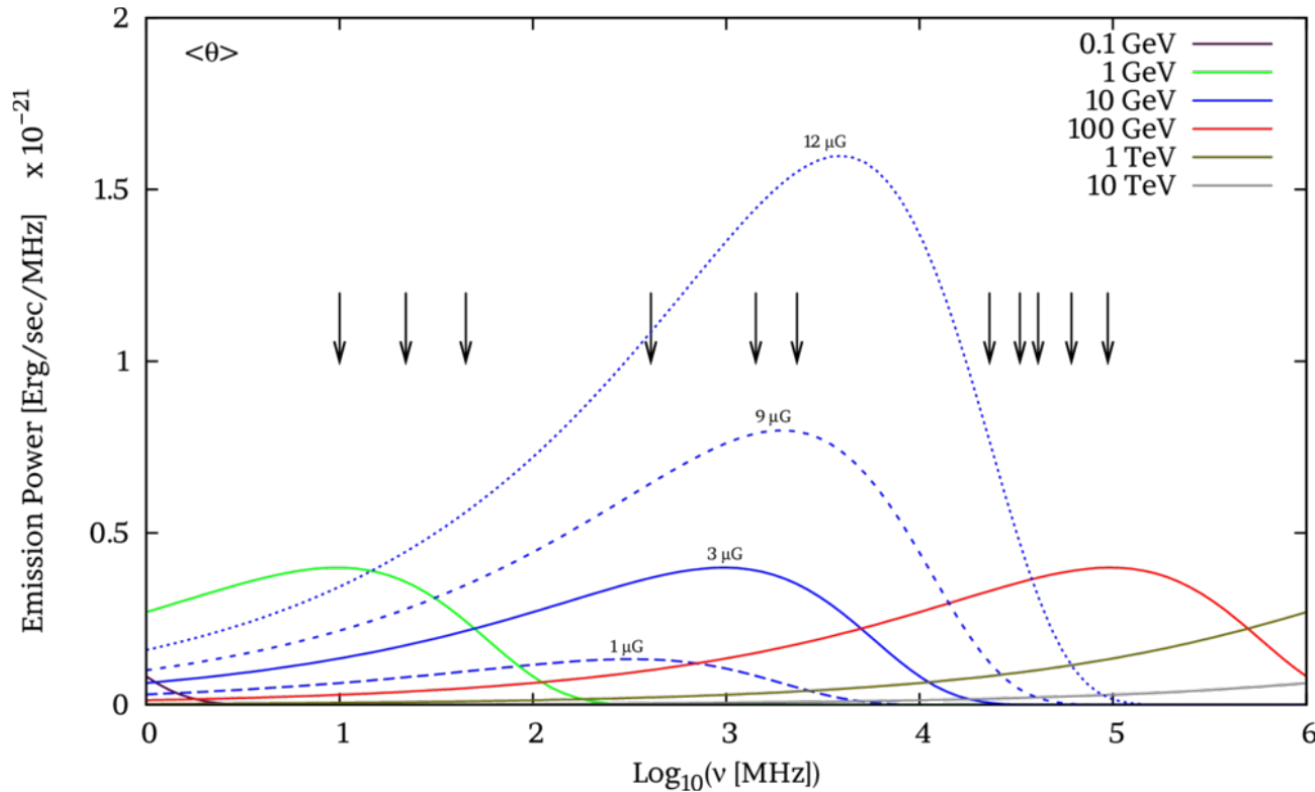
HAWC Collab. ICRC 2013
arXiv:1310.0073



Synchrotron radiation



Synchrotron radiation

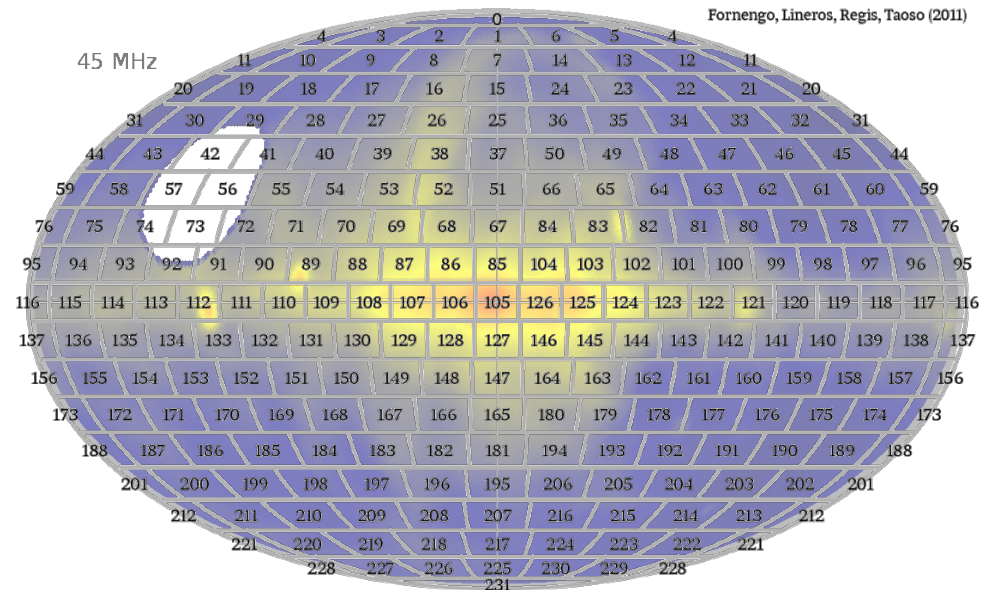
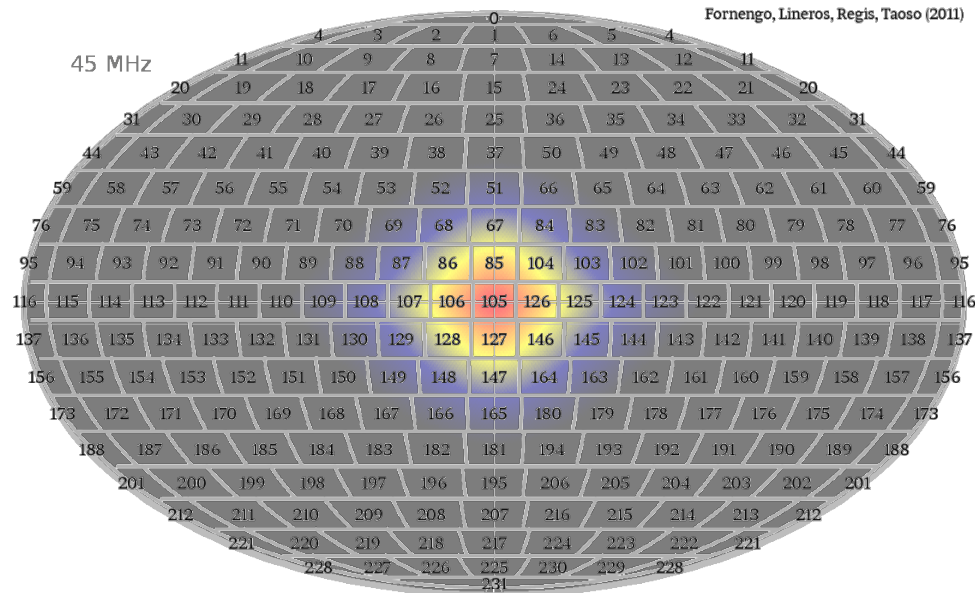


$$\frac{dw}{d\nu}(\nu, B_{\perp}) = \frac{\sqrt{3} e^3 B_{\perp}}{m_e c^2} F\left(\frac{\nu}{\nu_{c,\perp}}\right)$$

$$\nu_{c,\perp} = \frac{3eB_{\perp}E^2}{4\pi m_e^3 c^5}$$

$$F(x) = x \int_x^{\infty} d\zeta K_{5/3}(\zeta)$$

Galactic DM radio emission



$$T_{\text{DM}} \leq T_{\text{obs}} + 3\sigma$$

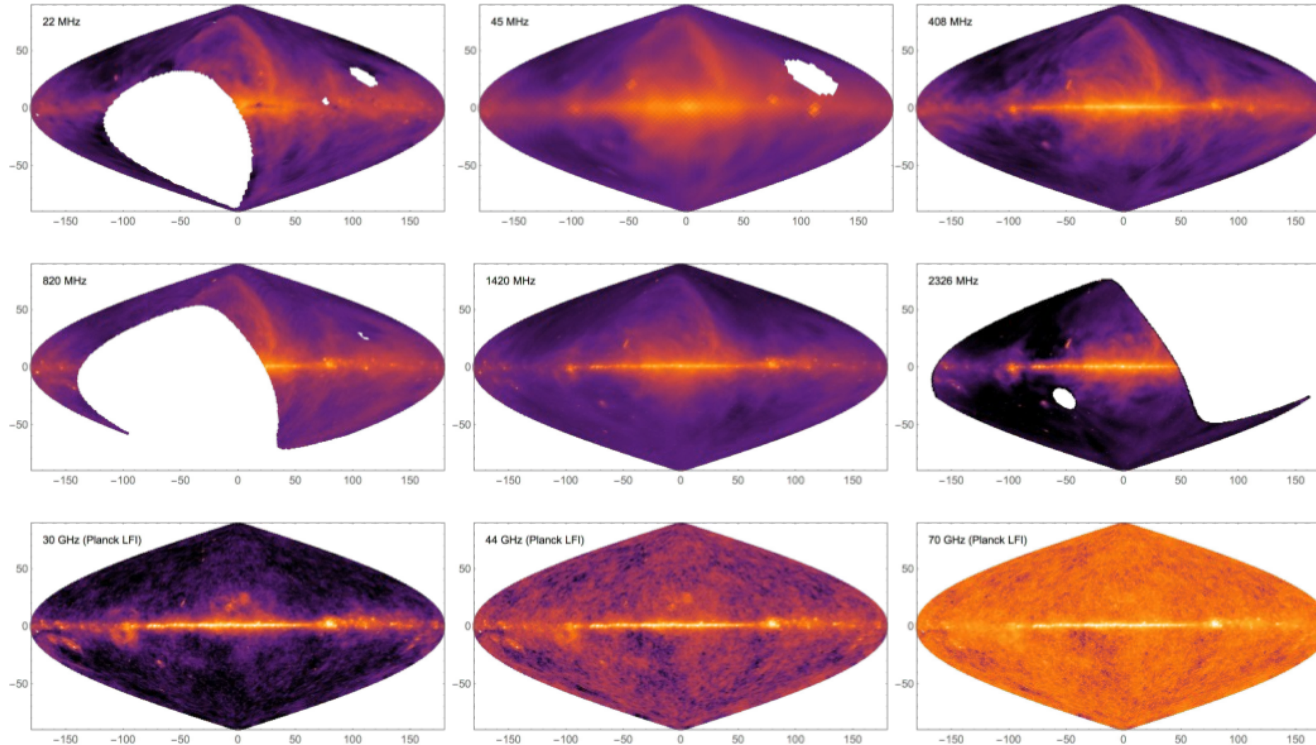
Conservative: direct comparison Obs and DM
 Progressive: (astro) galactic emission included

Galactic DM radio emission

Cirelli et al.
arxiv: 1604.06267

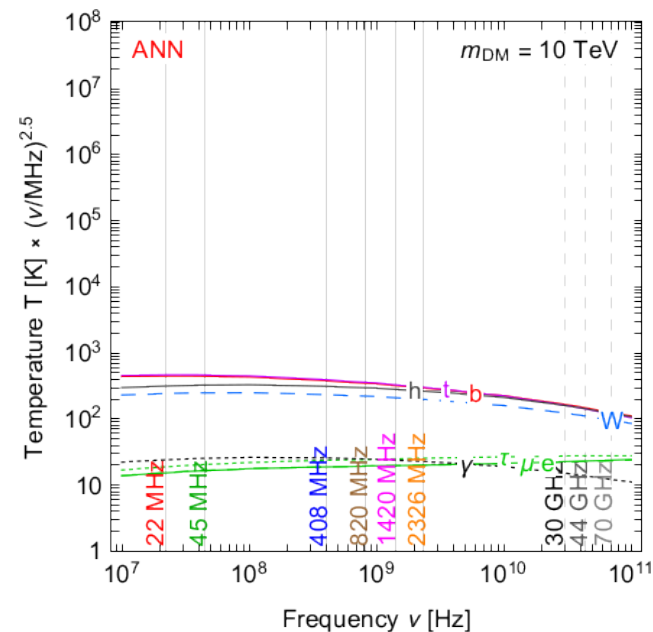
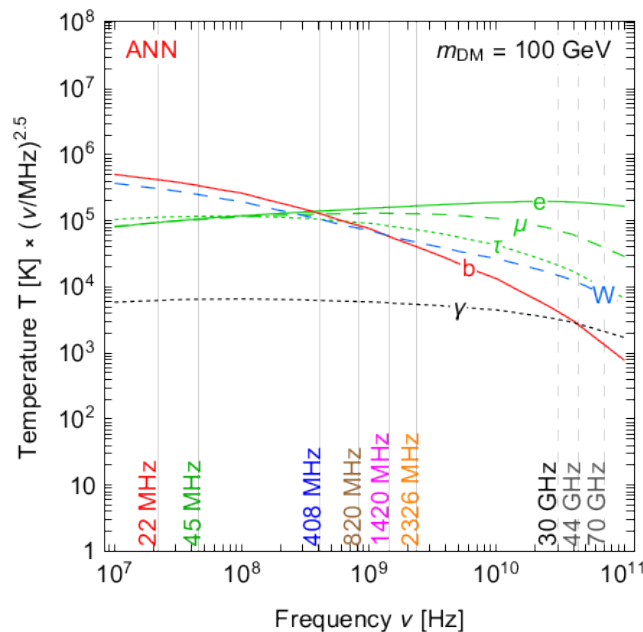
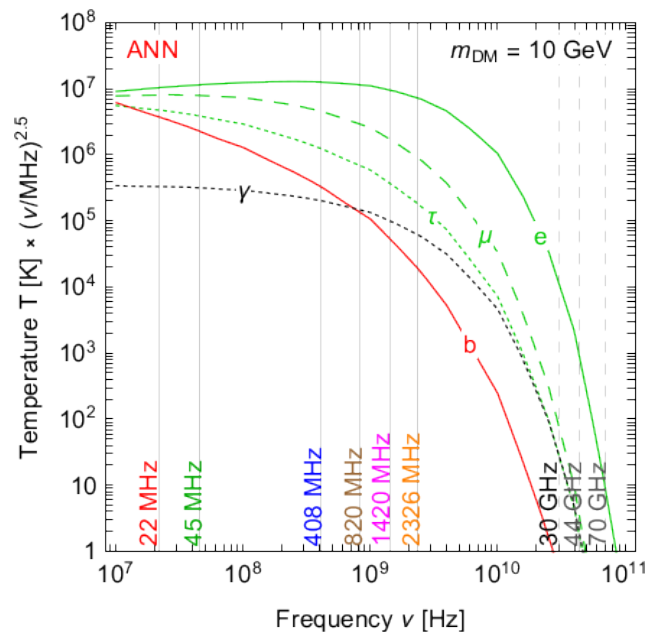
9 data sets

From 22 MHz to 70 GHz



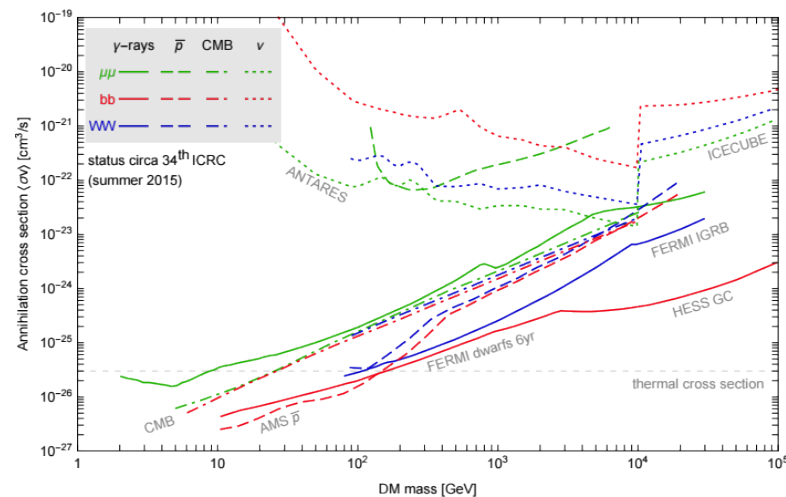
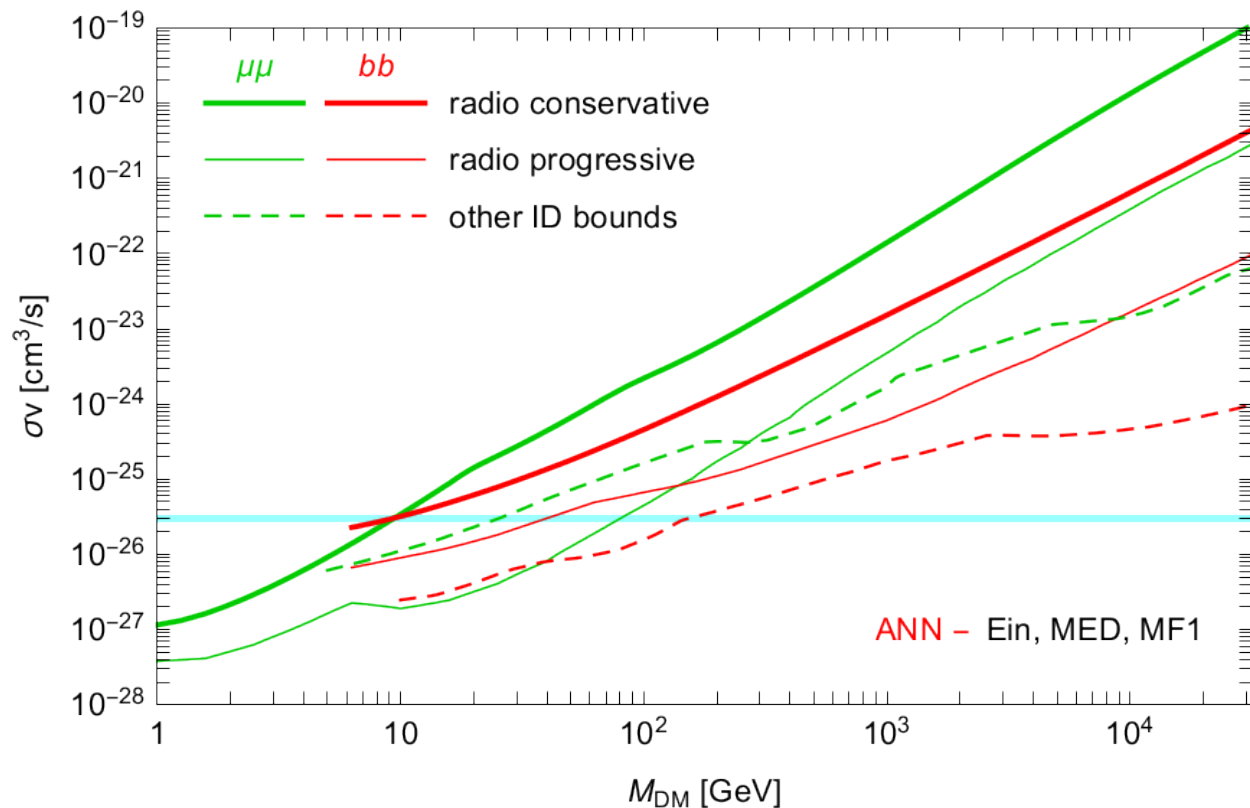
<i>Frequency</i>	<i>Source and Reference</i>	<i>Sky coverage</i>
22 MHz	Roger et al. [38]	73%
45 MHz	Guzman et al. [39]	96%
408 MHz	Haslam et al. [40]	100%
820 MHz	Berkhuijsen [41]	51%
1420 MHz	Reich et al. [42–44]	100%
2326 MHz	Jonas et al. [45]	97%
30 GHz	PLANCK-LFI [46]	100%
44 GHz	PLANCK-LFI [46]	100%
70 GHz	PLANCK-LFI [46]	100%

Galactic DM radio emission



DM mass and annihilation spectra reveals the **multi-frequency** constraining capability

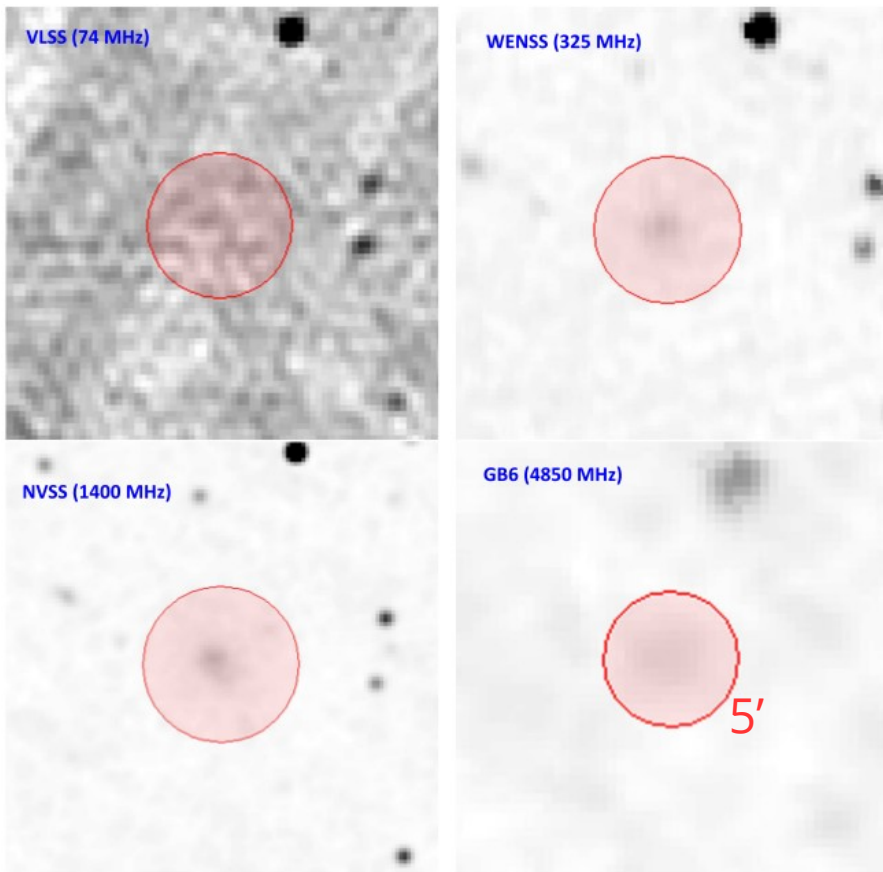
Galactic DM radio emission



The constraints improve in the progressive scheme

DM radio emission in M31

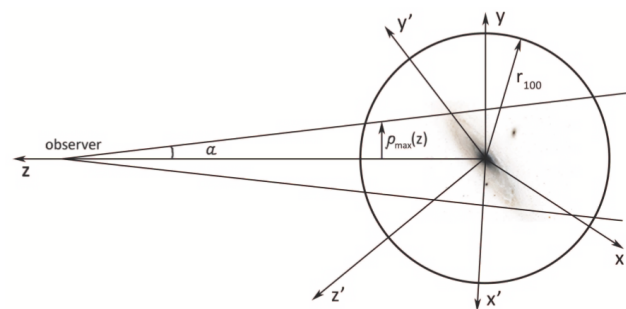
Egorov et al.
arxiv:1304.0517



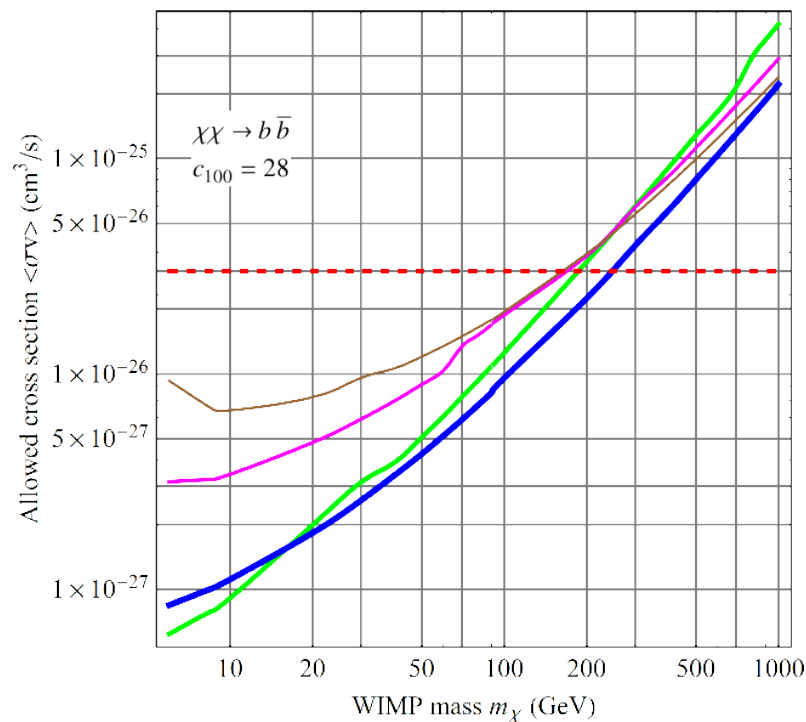
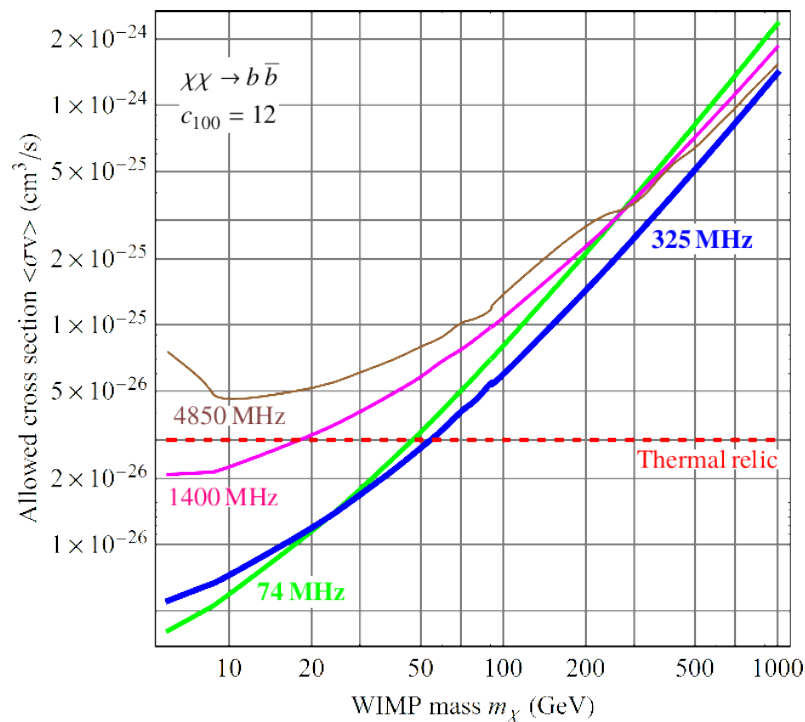
M31 is expected to be very similar to the Milky Way

Analysis based on the central region of M31 at frequencies:

74, 325, 1400, and 4850 MHz

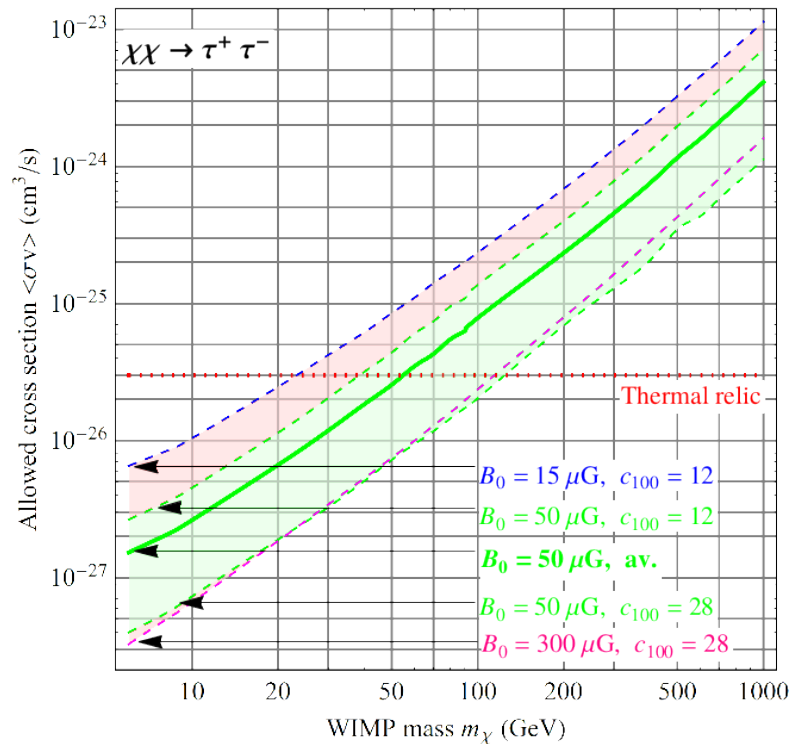
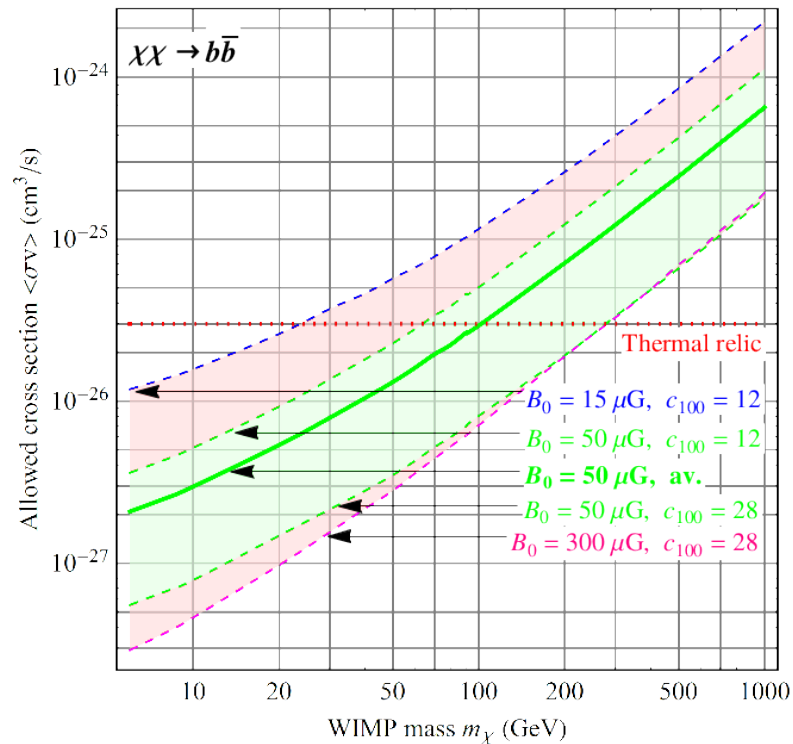


DM radio emission in M31



The concentration value c_{100} has a big impact in the overall signal

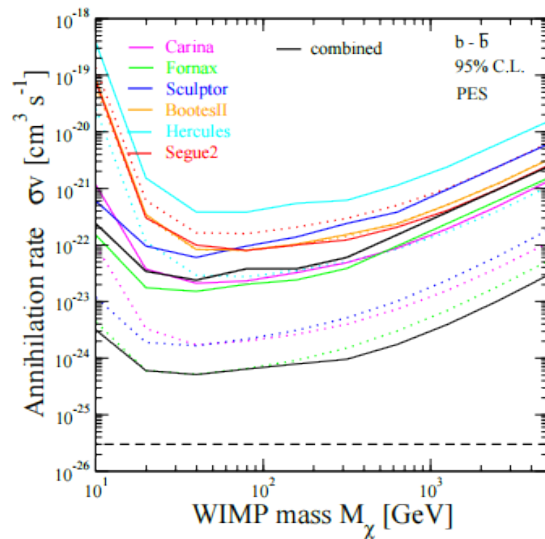
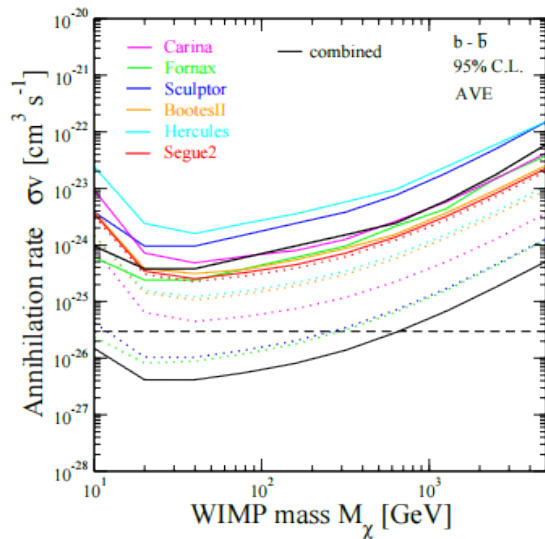
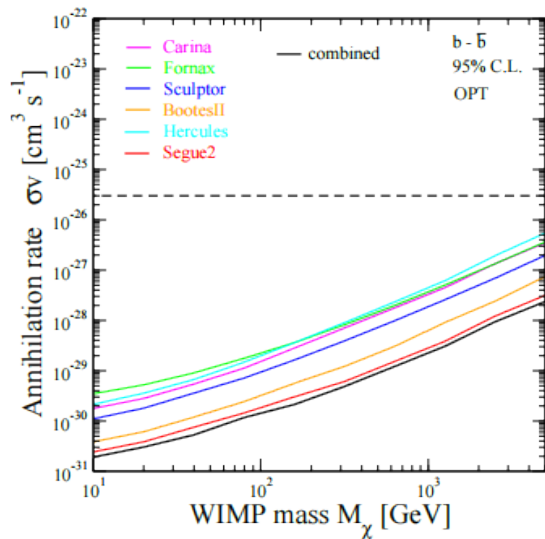
DM radio emission in M31



After including uncertainties from **DM distribution** and **magnetic field**

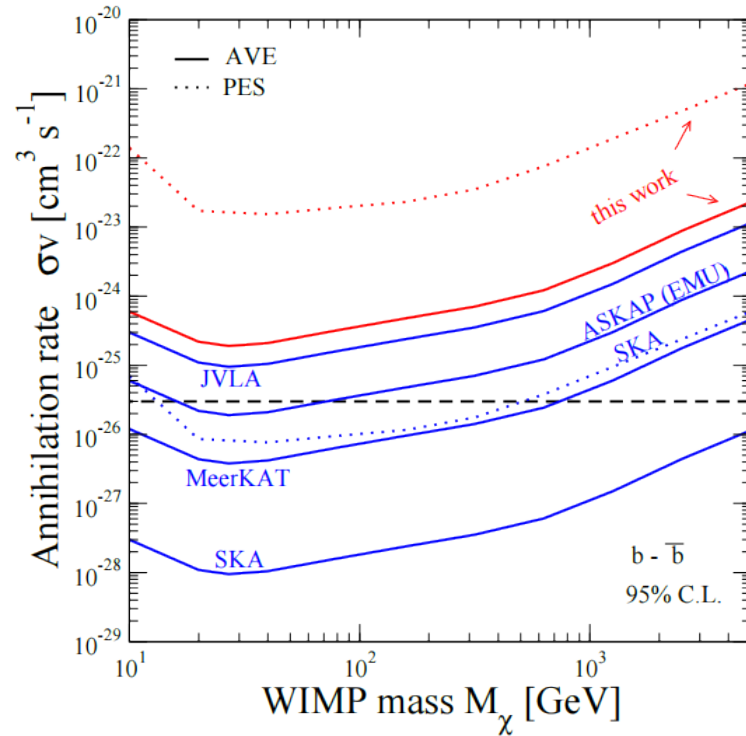
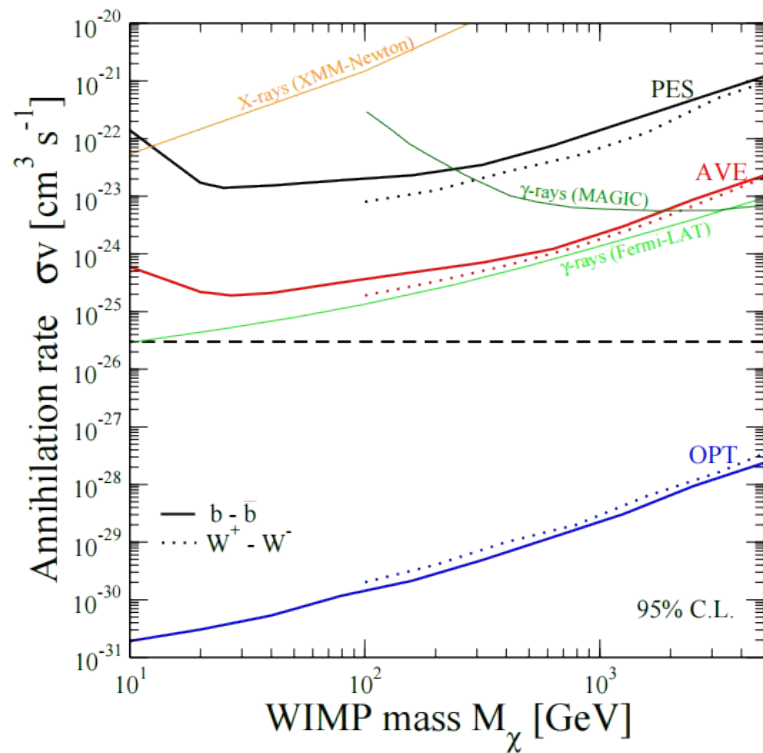
Radio from dSph using ATCA

Name	magnetic field	diffusion scheme	DM profile
OPT	B_{eq}^{obs}	loss-at-injection	Einasto
AVE	$\max(B_{SFR}, 1 \mu\text{G})$	$D = 3 \cdot 10^{28} (E/\text{GeV})^{0.3} \exp(r/r_*) \text{ cm}^2/\text{s}$	NFW
PES	B_{SFR0}	$D = 10^{30} (E/\text{GeV})^{0.3} \exp(r/r_*) \text{ cm}^2/\text{s}$	Burkert



Observation at 16cm over 6 dSph. 3 assumptions. :-), :-|, and :-(|

Radio from dSph using ATCA



Constraints from dSph could be very strong with future observation like SKA

The Smith's Cloud

image: NRAO, Wikipedia

A. Drlica-Wagner et al. 1405.1030

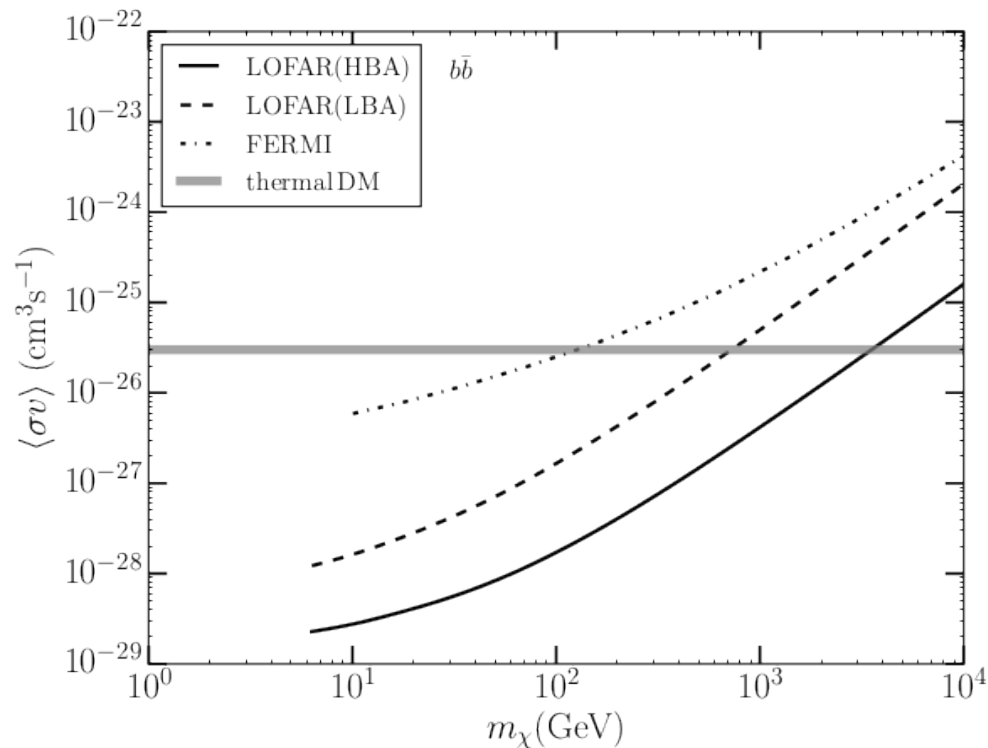
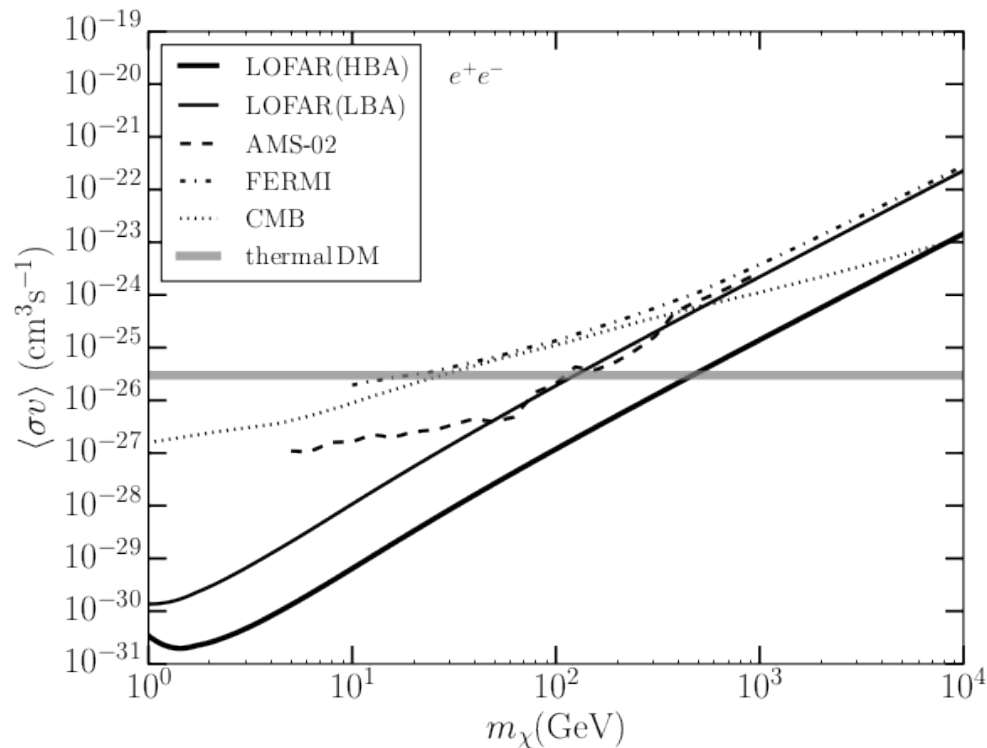
SUMMARY OF SMITH CLOUD DARK MATTER HALO PARAMETERS.

Profile	r_s (kpc)	ρ_0 ($M_\odot \text{ kpc}^{-3}$)	M_{tidal} ($M_\odot$)	J-factor ($\text{GeV}^2 \text{ cm}^{-5} \text{ sr}$)
NFW	1.04	3.7×10^7	1.1×10^8	9.6×10^{19}
Burkert	1.04	3.7×10^7	1.3×10^8	4.2×10^{18}
Einasto	1.04	9.2×10^6	2.0×10^8	1.8×10^{20}

High Velocity Cloud (hydrogen) at ~ 12.4 kpc from Sun ~ 2.9 kpc below the Galactic Plane

The Smith's Cloud

N. Leite et al.
arxiv:1606.03515



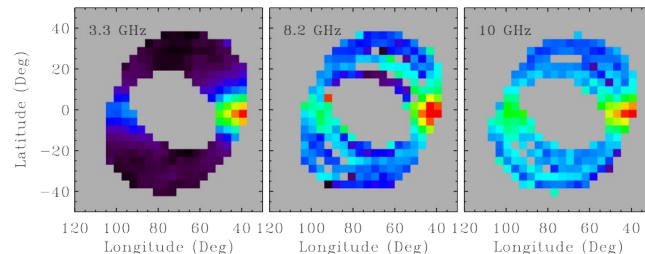
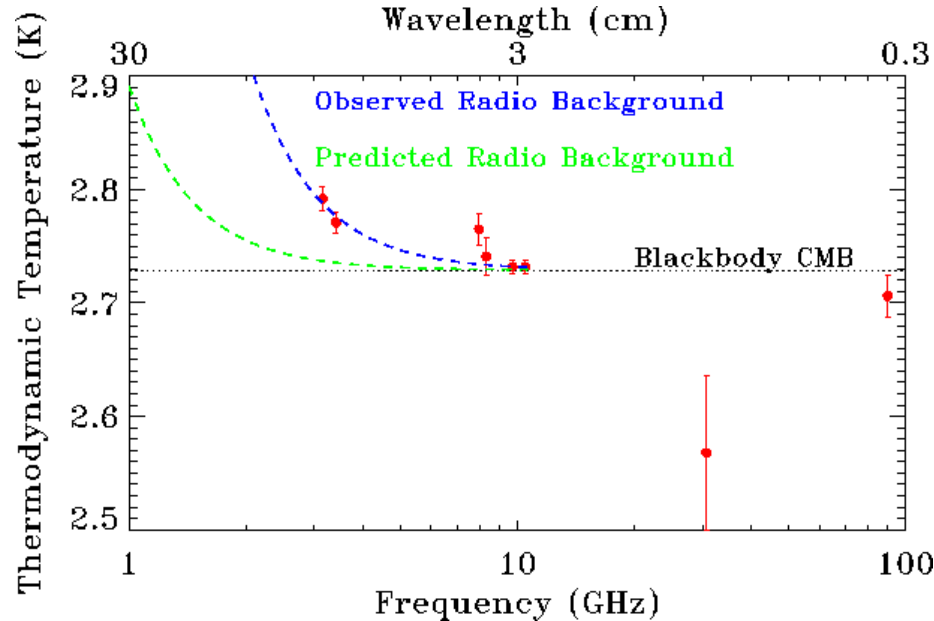
Projected LOFAR limits for 8hrs observation time. LBA = 60 MHz, HBA = 150 MHz

Isotropic radio background



They have reported an excess in the radio background which is bigger than the expected with known sources

$$T_{sky}(\nu, \alpha, \delta) = T_{cmb}(\nu) + T_{gal}(\nu, \alpha, \delta) + \underline{T_{UERS}(\nu)}$$

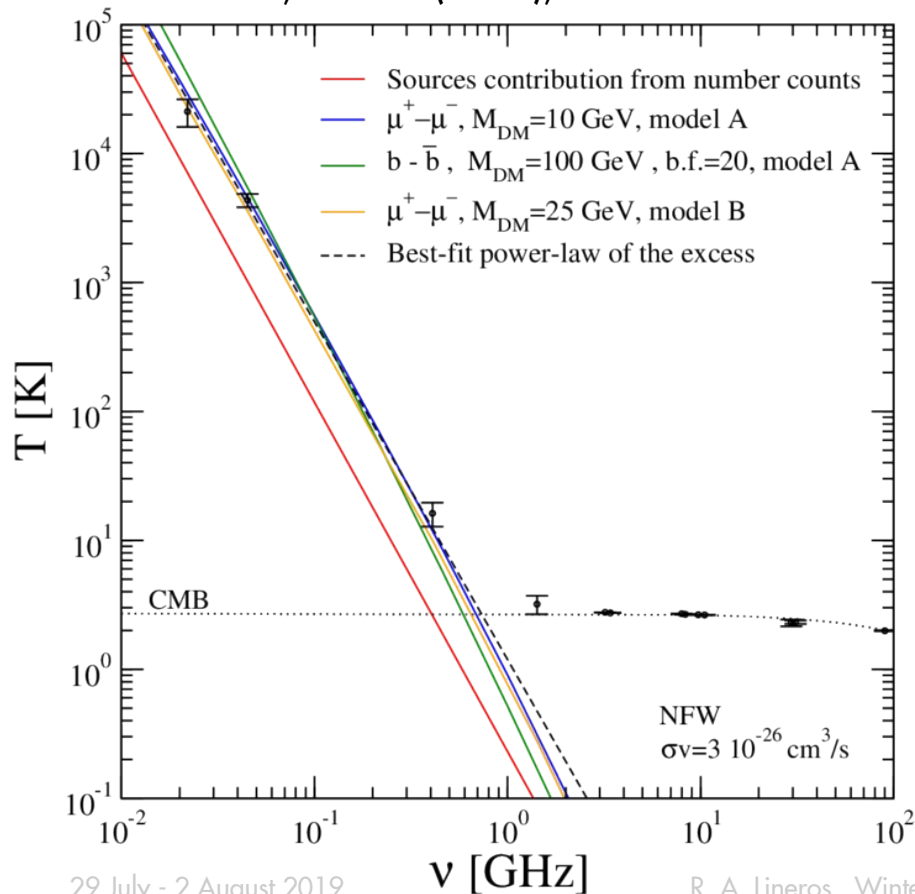


Firxen et al. 0901.0555
Seiffert et al. 0901.0559

arcade.gsfc.nasa.gov

Isotropic radio background

PRL 107,271302 (2011), arxiv:1108.0569



DM can provide the missing signal

Alternative explanations

- Faint quasars
- Radio-quiet AGNs
- Star forming galaxies
- Unresolved galactic sources(?)

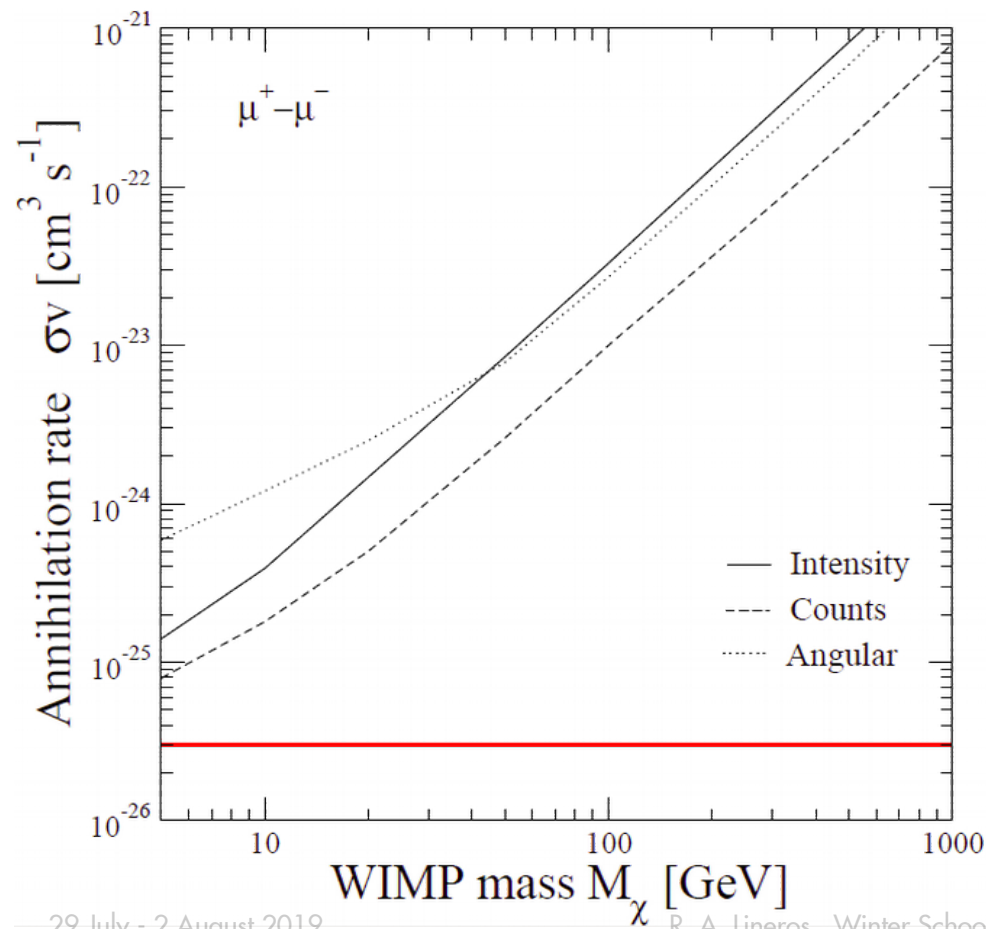
More details:

Gervasi et al. arxiv:0803.4138

Singal et al. arxiv:0909.1997

Isotropic radio background

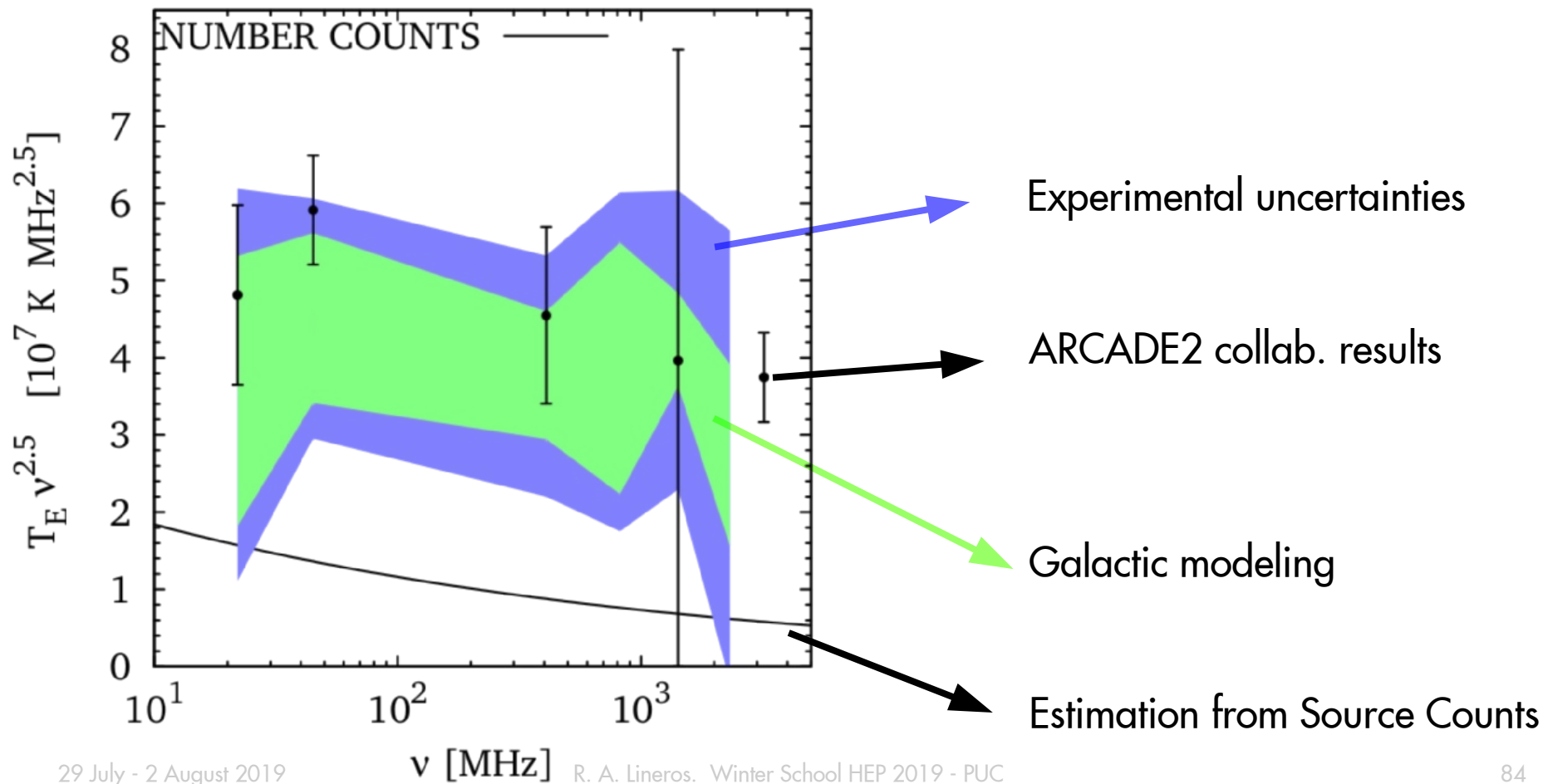
Fornengo et al.
arxiv:1112.4517



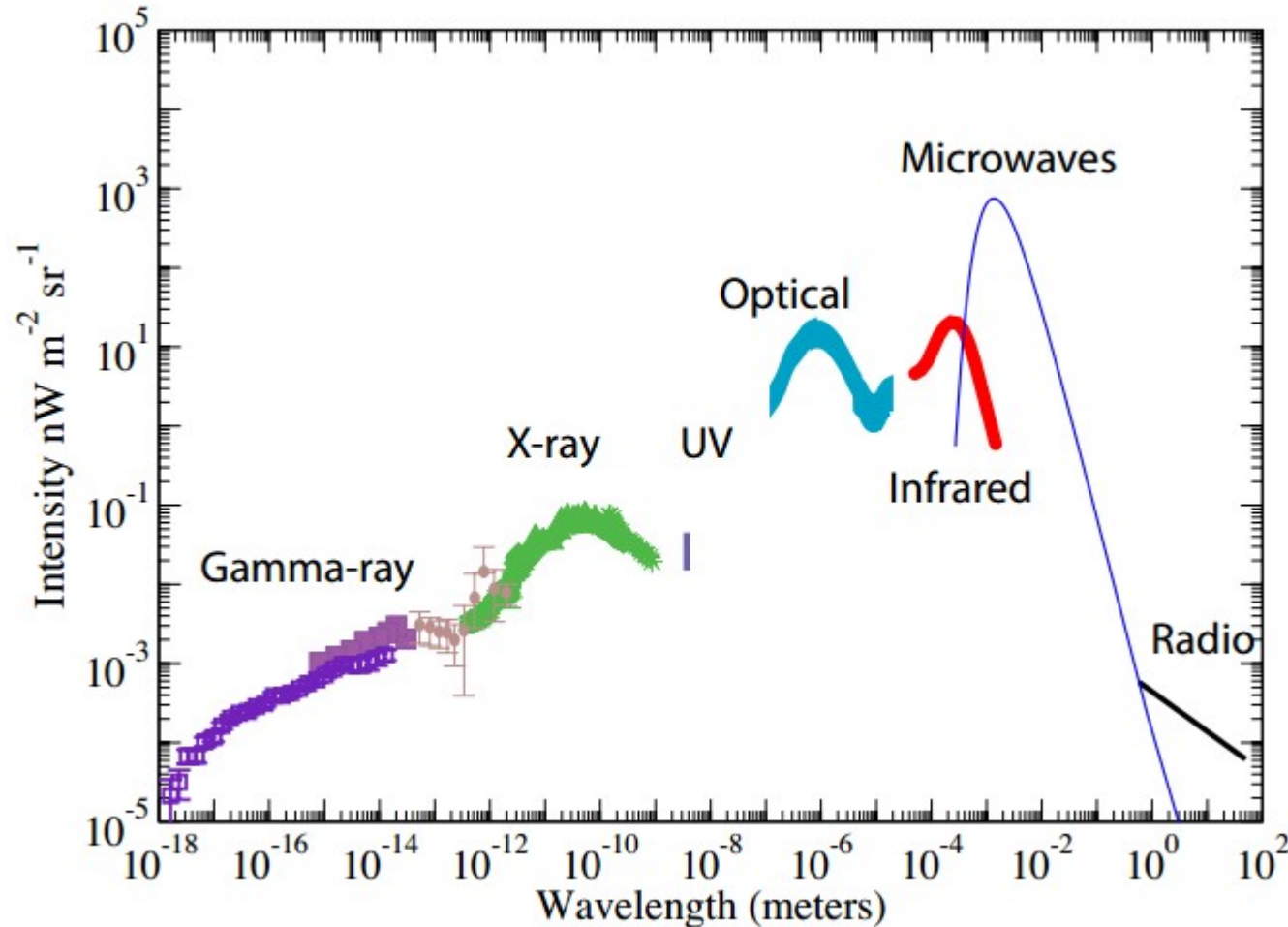
Constraints on the DM contribution can be obtained via

- Intensity
- Source count
- Angular power spectrum

Isotropic radio background



Extragalactic Background Light (EBL)

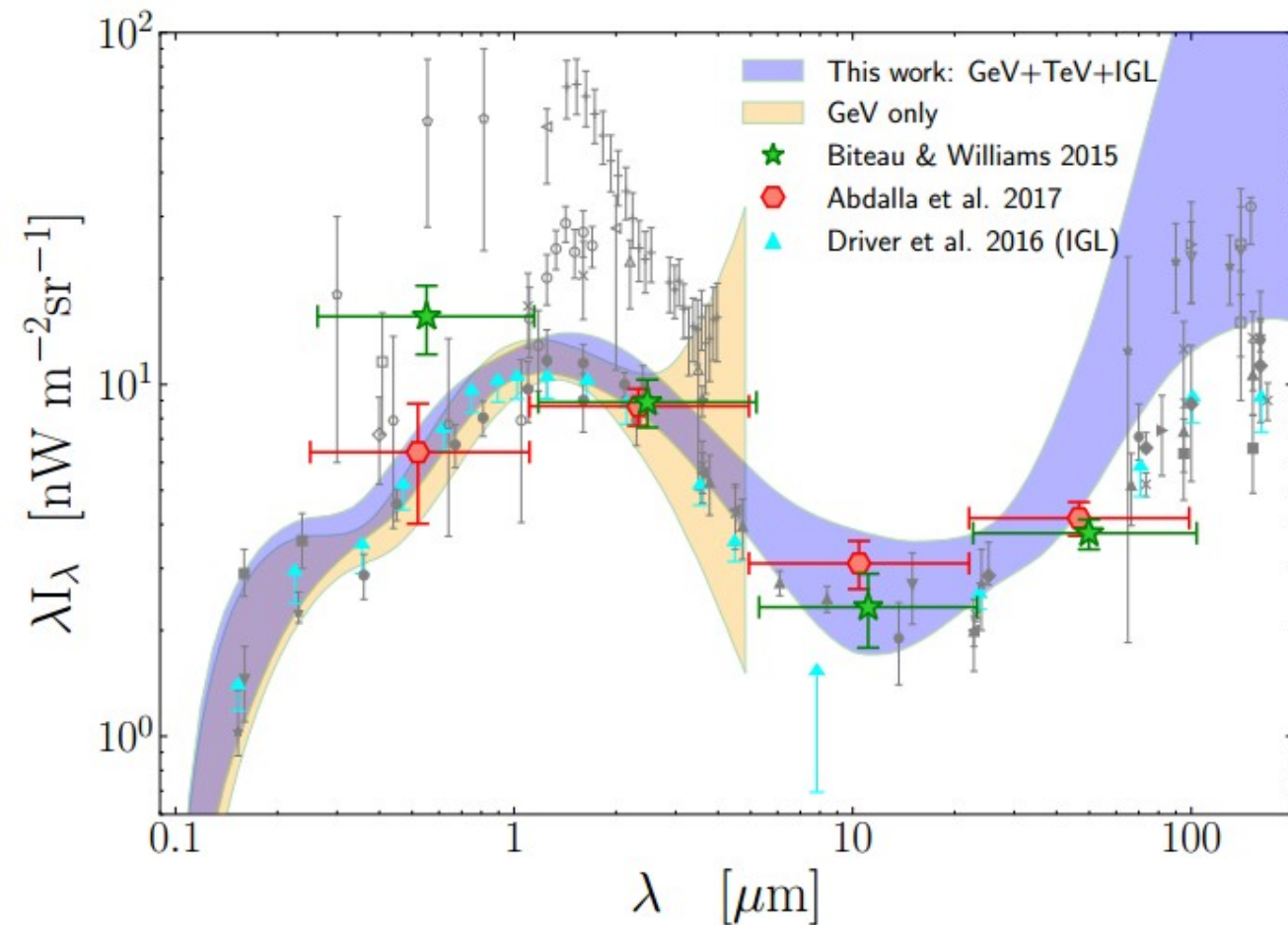


Cooray arXiv:1602.03512

- The whole EM spectrum carries information about the non thermal history of the Universe
- Important input to understand UHECR propagation

Extragalactic Background Light (EBL)

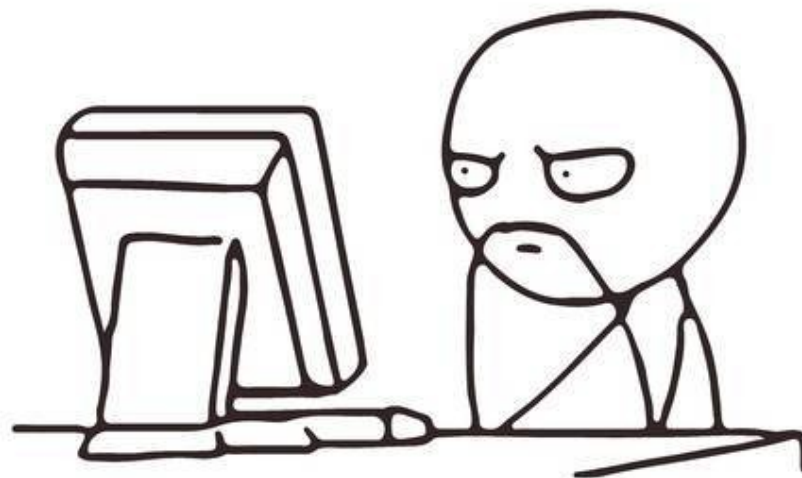
Desai et al. arXiv:1903.03126



- The intensity indicate the radiated power
- Optical depth of the Universe

Other phenomena

- Sunyaev–Zeldovich effect
- X-ray from keV Dark Matter
- Axion-Photon conversion
- Black holes
- Pulsar physics
- Gamma-ray bursts
- and many more



That's all

Gamma-rays

X-rays

Radiowaves

Microwaves

