



Universidad
Católica del Norte



lawphysics
Latin American Webinars on Physics

Los multimensajeros del Universo

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El Plan

0. El Universo

1. Astropartículas

2. Fotones

3. Neutrinos

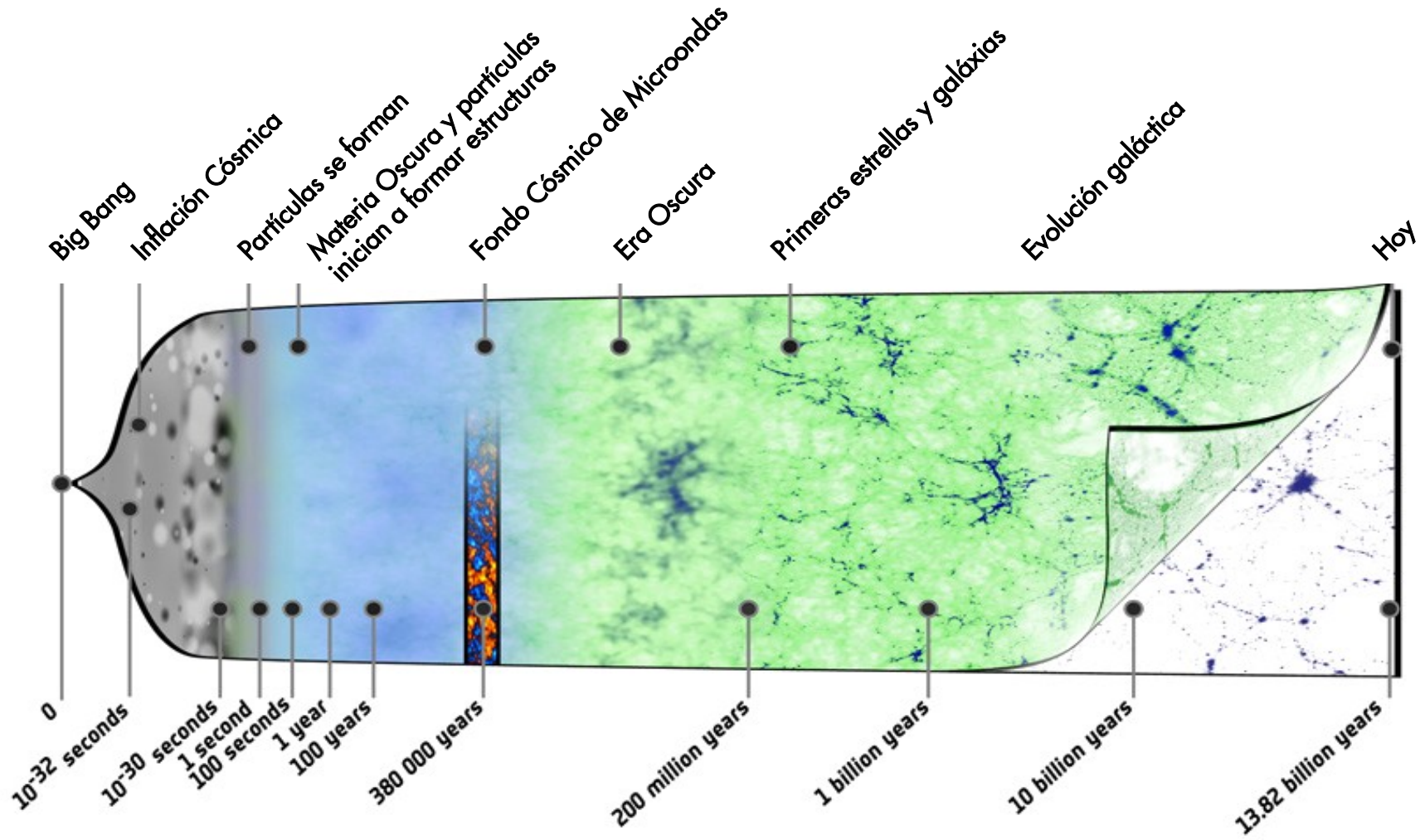
4. Rayos Cósmicos

5. Ondas Gravitacionales

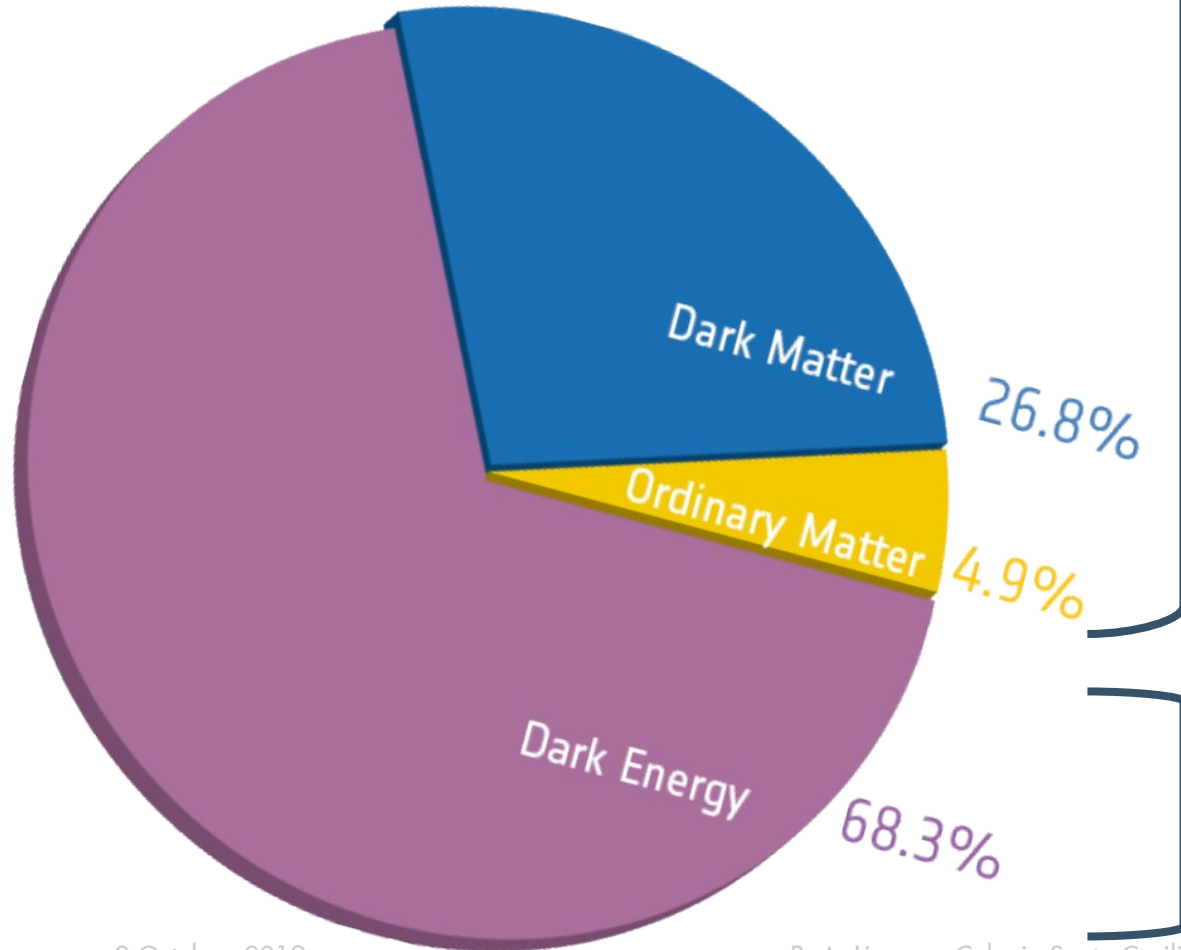
¿De que está hecho el Universo?



La breve historia del Universo



Tarta Cósmica



La materia en el Universo es

- 15.4% Materia Ordinaria
- 84.5% Materia Oscura

Energía Oscura

energía del espacio expansión acelerada del Universo

Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



 Hierro



 O. Gravitacionales



El planeta está constantemente bombardeado por partículas y ondas que son producto de la actividad del Universo

Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



 Hierro



O. Gravitacionales

} Neutrales

Partículas neutrales se propagan en línea recta.



Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



 Hierro



O. Gravitacionales

Cargados
Rayos C3smicos

Se desvían debido a los campos magn3ticos



Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



 Hierro



O. Gravitacionales } Vibraciones del espacio

Pequeñas perturbaciones del espacio que afectan a todo.

Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



 Hierro



 O. Gravitacionales

Todos estos mensajeros nos ayudan a entender:
fuentes astrofísicas, medio intergaláctico, física fundamental

Mensajeros del espacio exterior



γ Fotones



ν Neutrinos



e^- Electrones



 Protones



 Helio



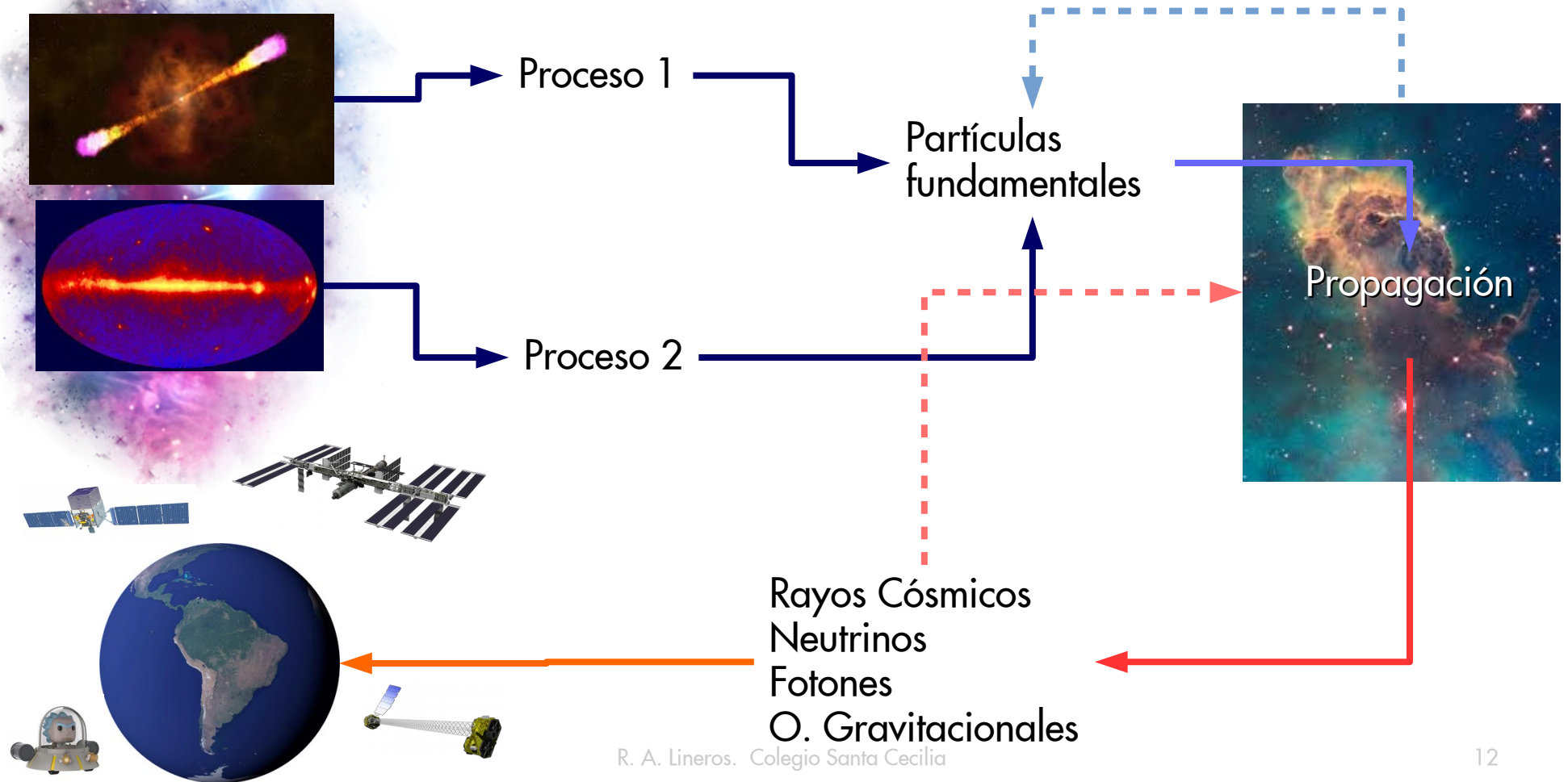
 Hierro



O. Gravitacionales

Física de astropartículas = multimensajeros y multi-longitud de onda

Multimensajeros



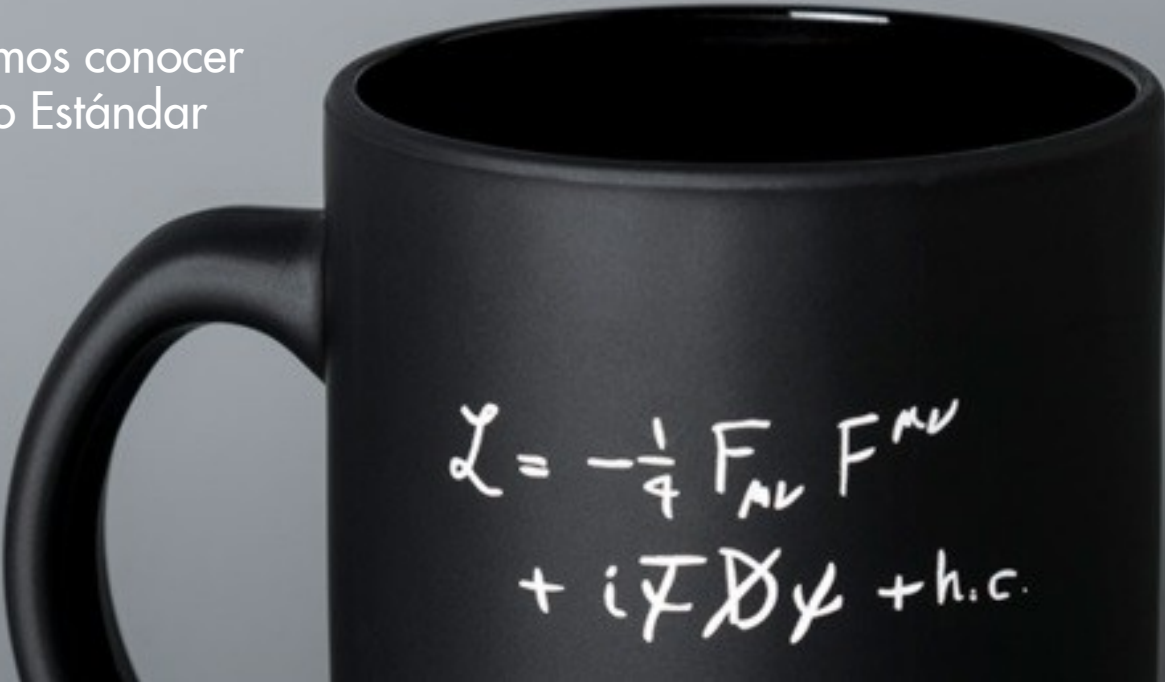
La física detrás del Universo



Los ladrillos fundamentales

Para entender a las astropartículas necesitamos entender porque las partículas se comportan así.

Necesitamos conocer
el Modelo Estándar


$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + \text{h.c.}$$

partículas y sus
interacciones

El Modelo Estándar

SM matter families



Simetrías

- CPT
- $SU(3)_c$: Color
- $SU(2)_L$: Isospin
- $U(1)_Y$: Hipercarga

Materia

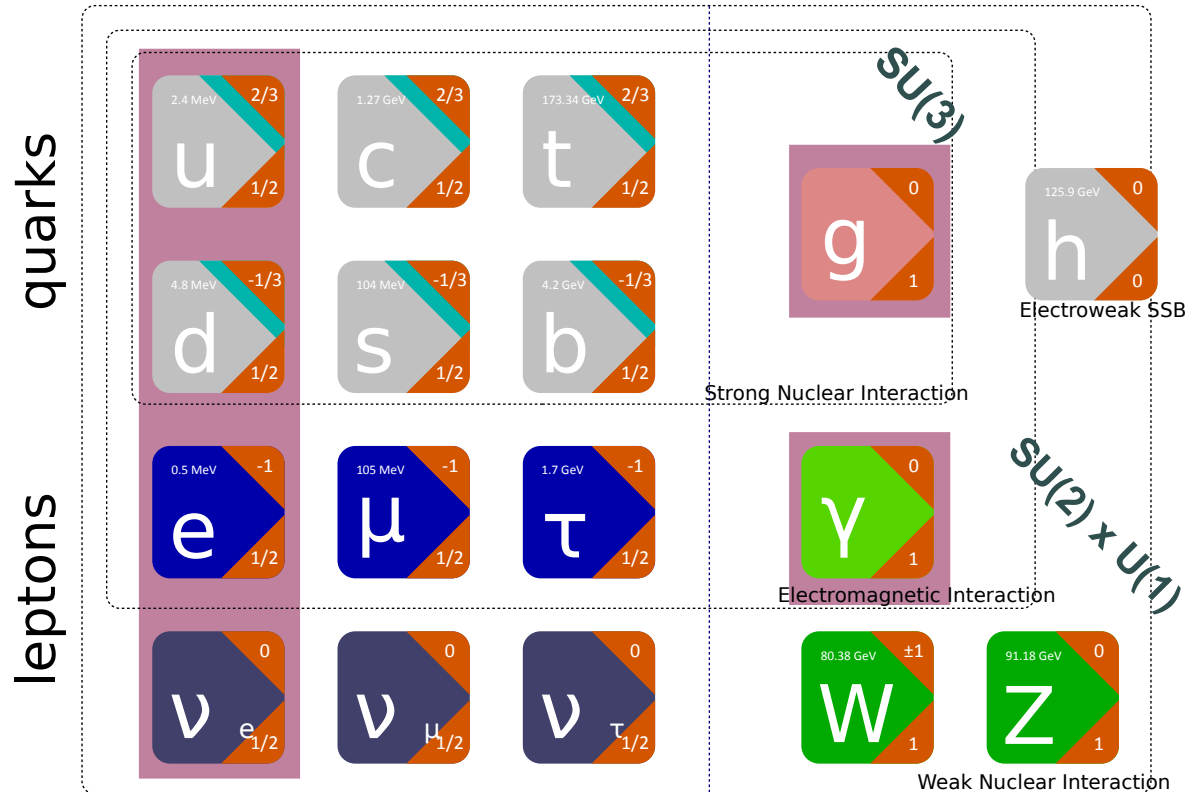
- 3 familias de quarks
- 3 familias de leptones

El campo de Higgs

- $SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}$
- Masa a las partículas fundamentales

El Modelo Estándar

SM matter families



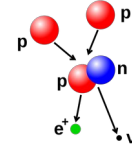
- Neutrinos sin masa
- Número Bariónico
- Número Leptónico

Objetos estables

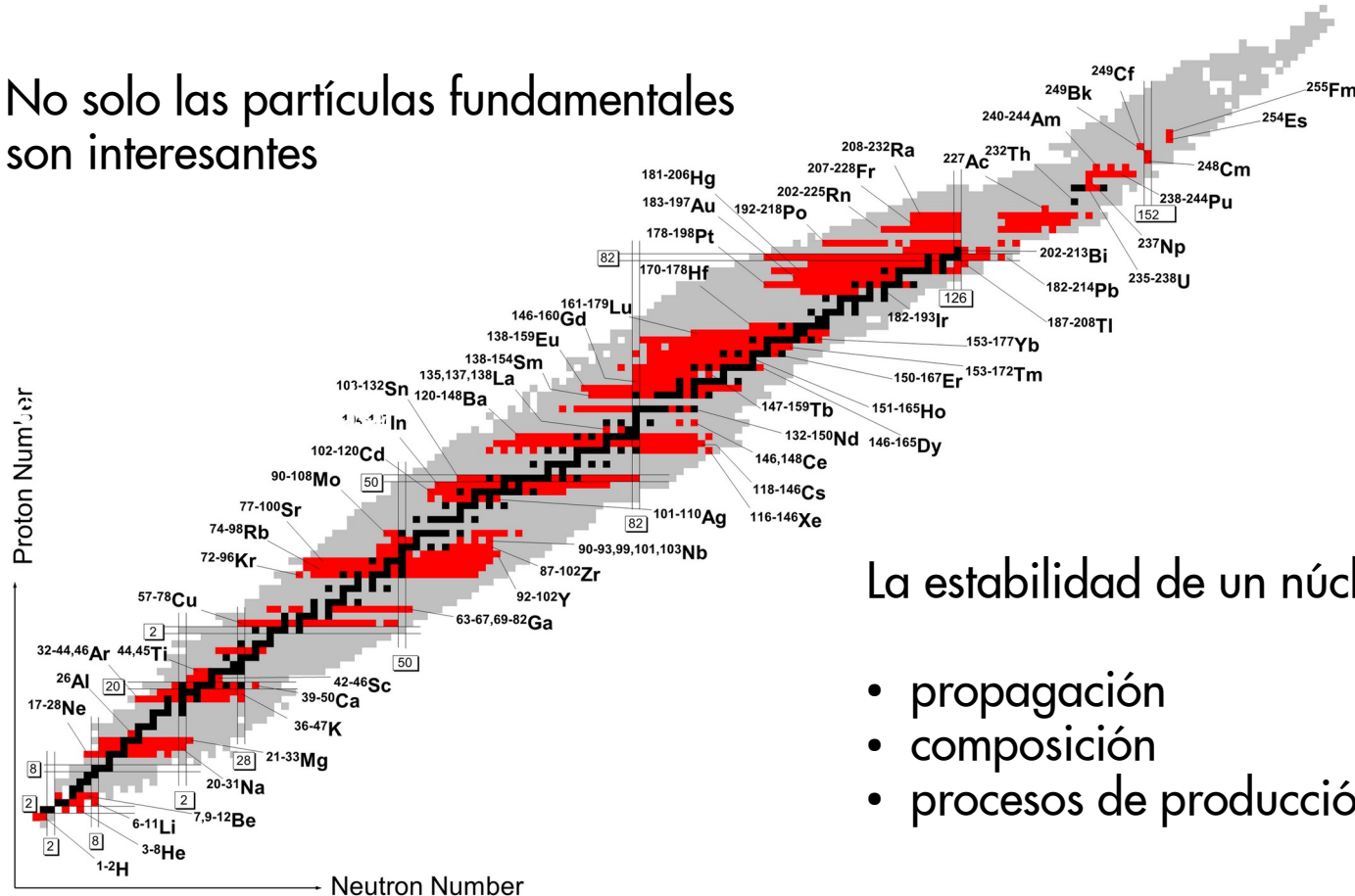
- Fotones
- Electrones y neutrinos
- Protones (quarks bound states)
- Materia nuclear
- Átomos
- Etc.

Física Nuclear

No solo las partículas fundamentales son interesantes



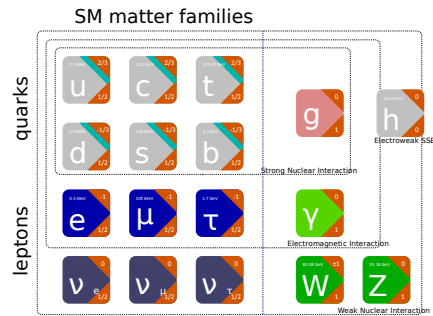
Nucleosíntesis



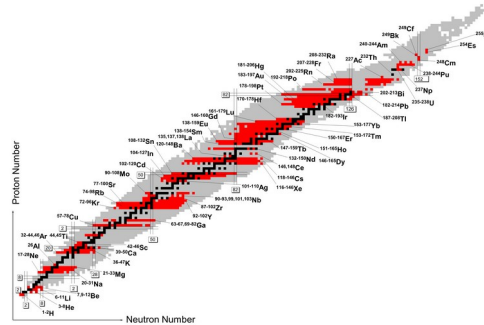
La estabilidad de un núcleo nos da información

- propagación
- composición
- procesos de producción

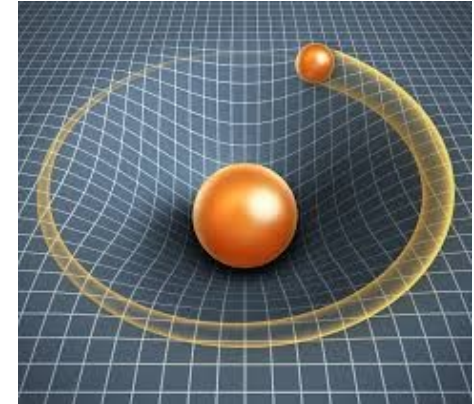
Éxito total!



Física de partículas



Física nuclear

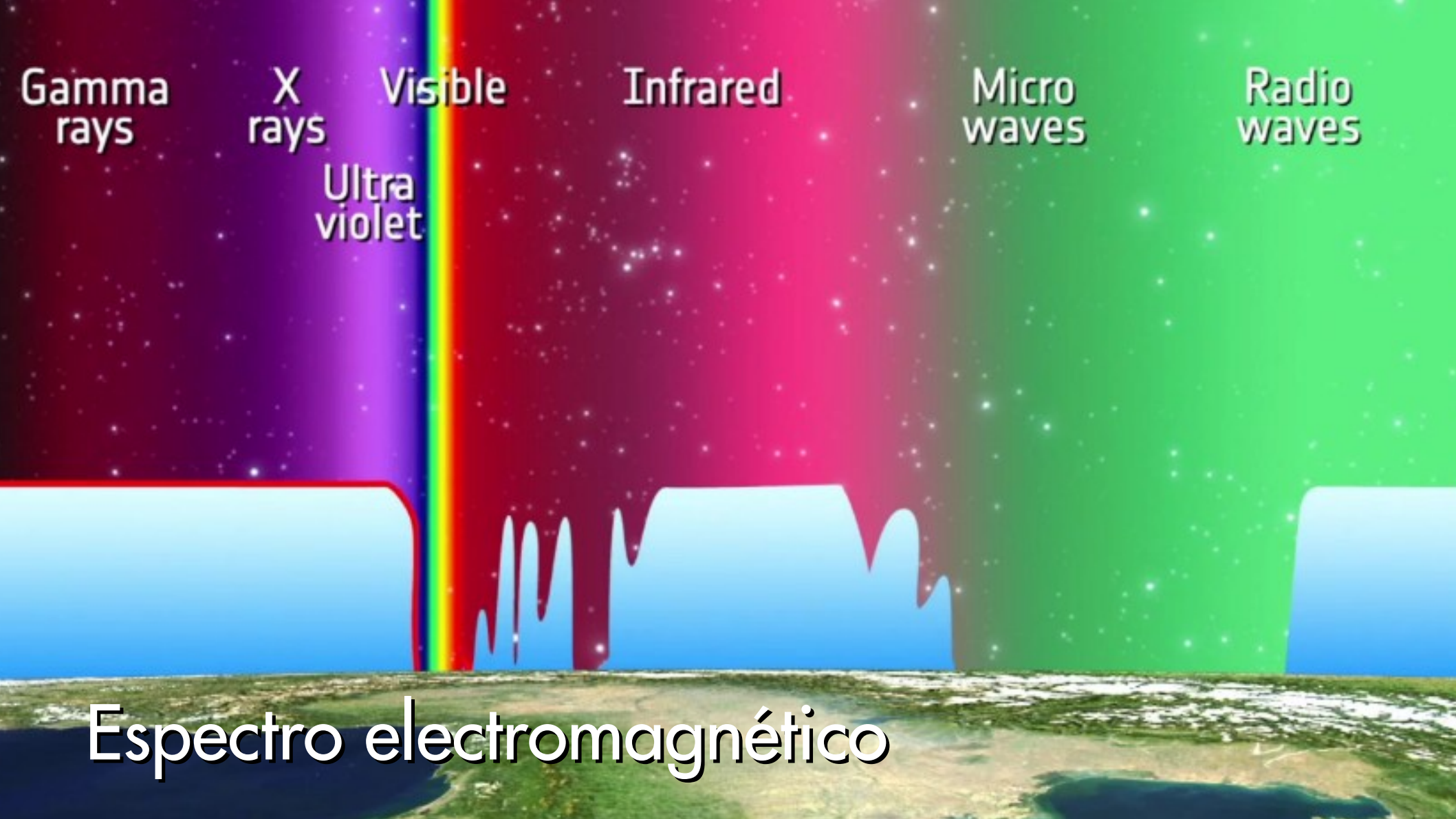


Gravedad

La mejor descripción de los objetos y sus interacciones que nos permiten describir el comportamiento del Universo

A man with light brown hair and a serious expression is standing in a dark, dense forest at night. He is wearing a brown jacket over a dark shirt. He holds a large, bright, glowing white sphere in his right hand, which illuminates his face and the surrounding foliage. The background is dark and filled with the silhouettes of trees and branches.

Fotones y radiación electromagnética



Gamma
rays

X
rays

Visible
Ultra
violet

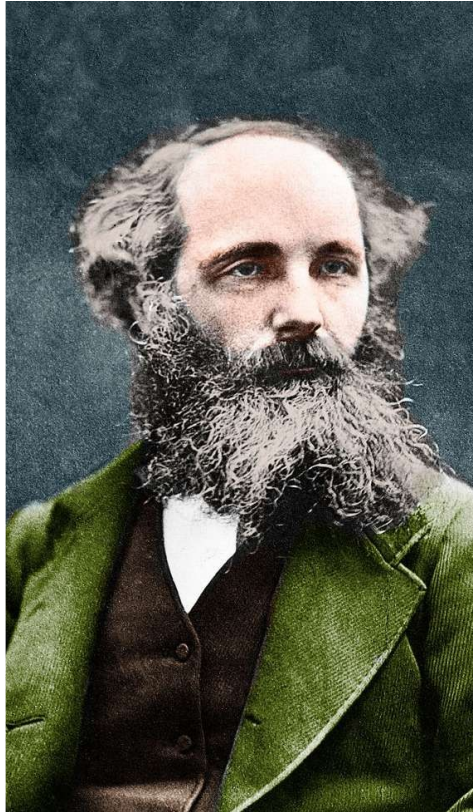
Infrared

Micro
waves

Radio
waves

Espectro electromagnético

Ecuaciones de Maxwell



Descripción unificada de la electricidad y el magnetismo

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

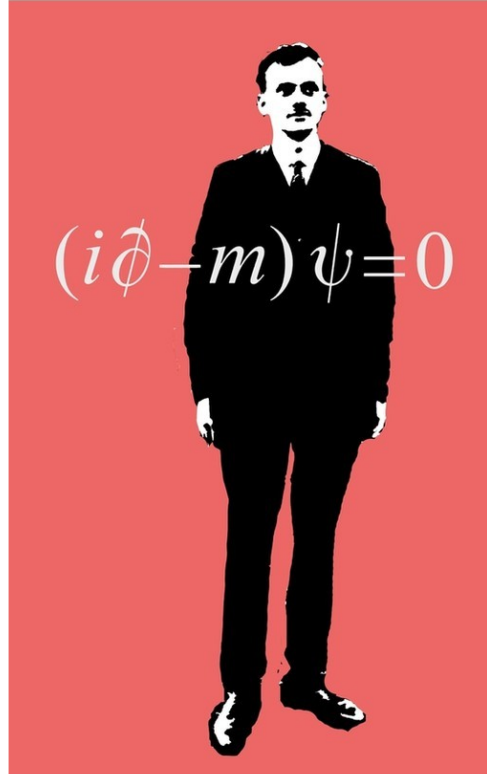
$$\nabla \cdot \mathbf{B} = 0$$

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

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

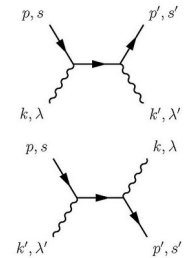
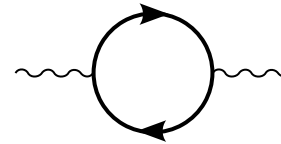
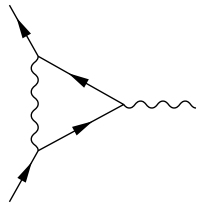
Describen el comportamiento de las ondas electromagnéticas

Electrodinámica Cuántica



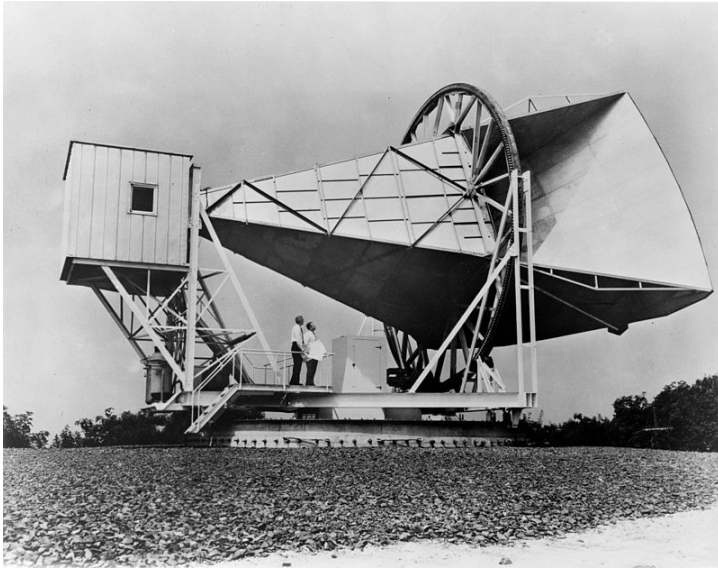
La descripción cuántica del comportamiento entre partículas cargadas y el electromagnetismo

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

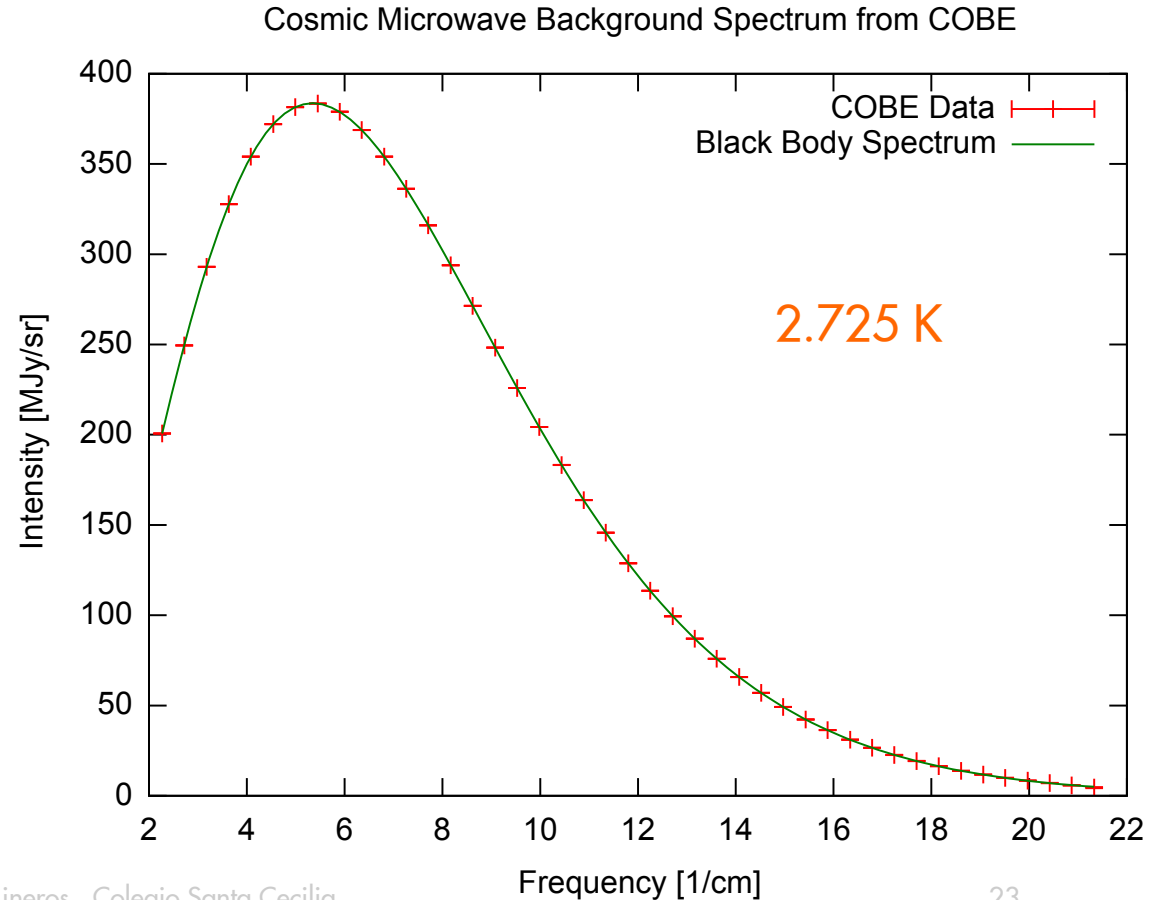


Pilar fundacional del Modelo Estándar

Fondo Cósmico de Microondas

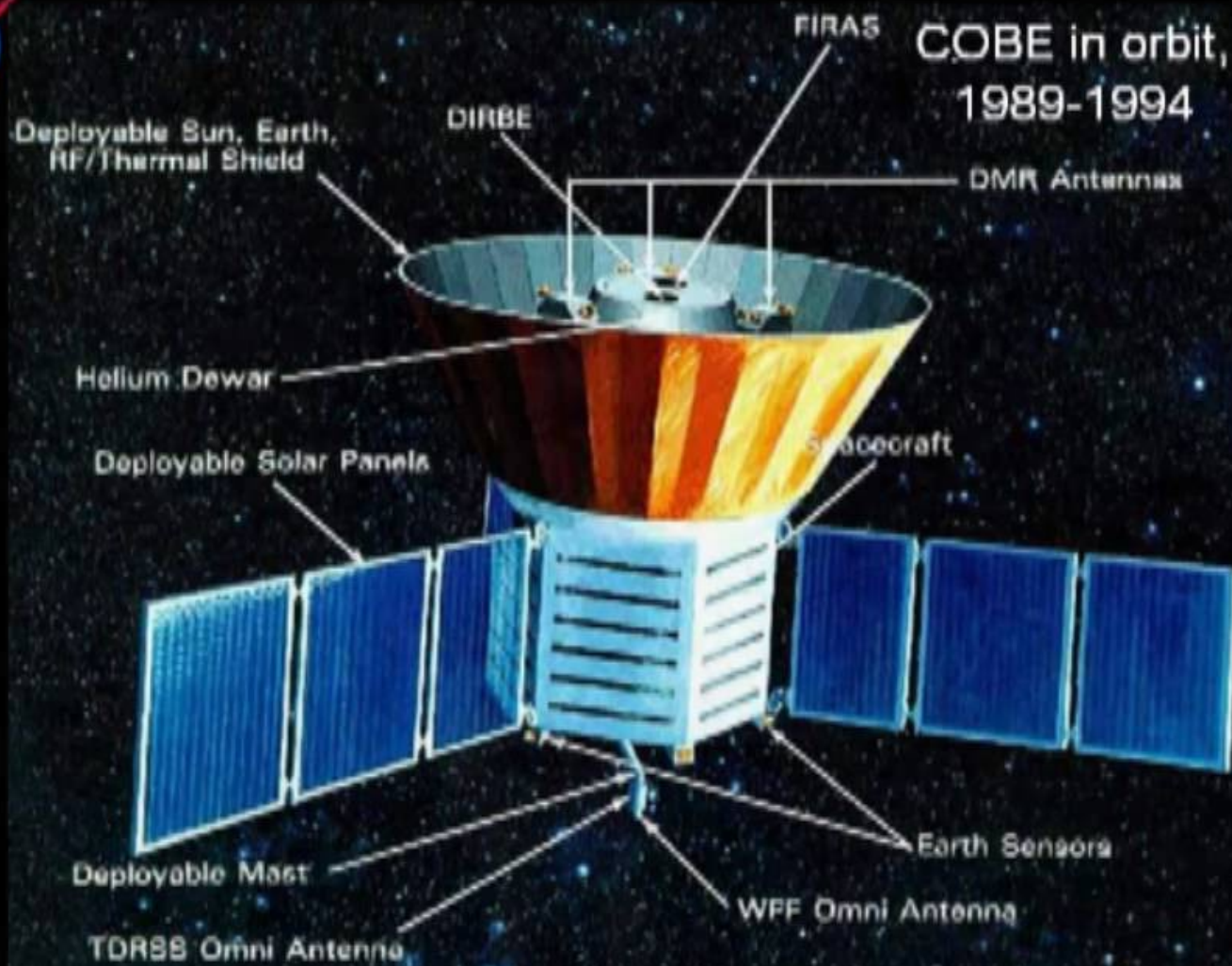


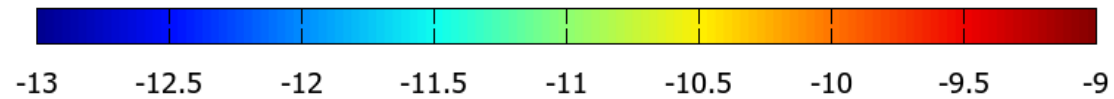
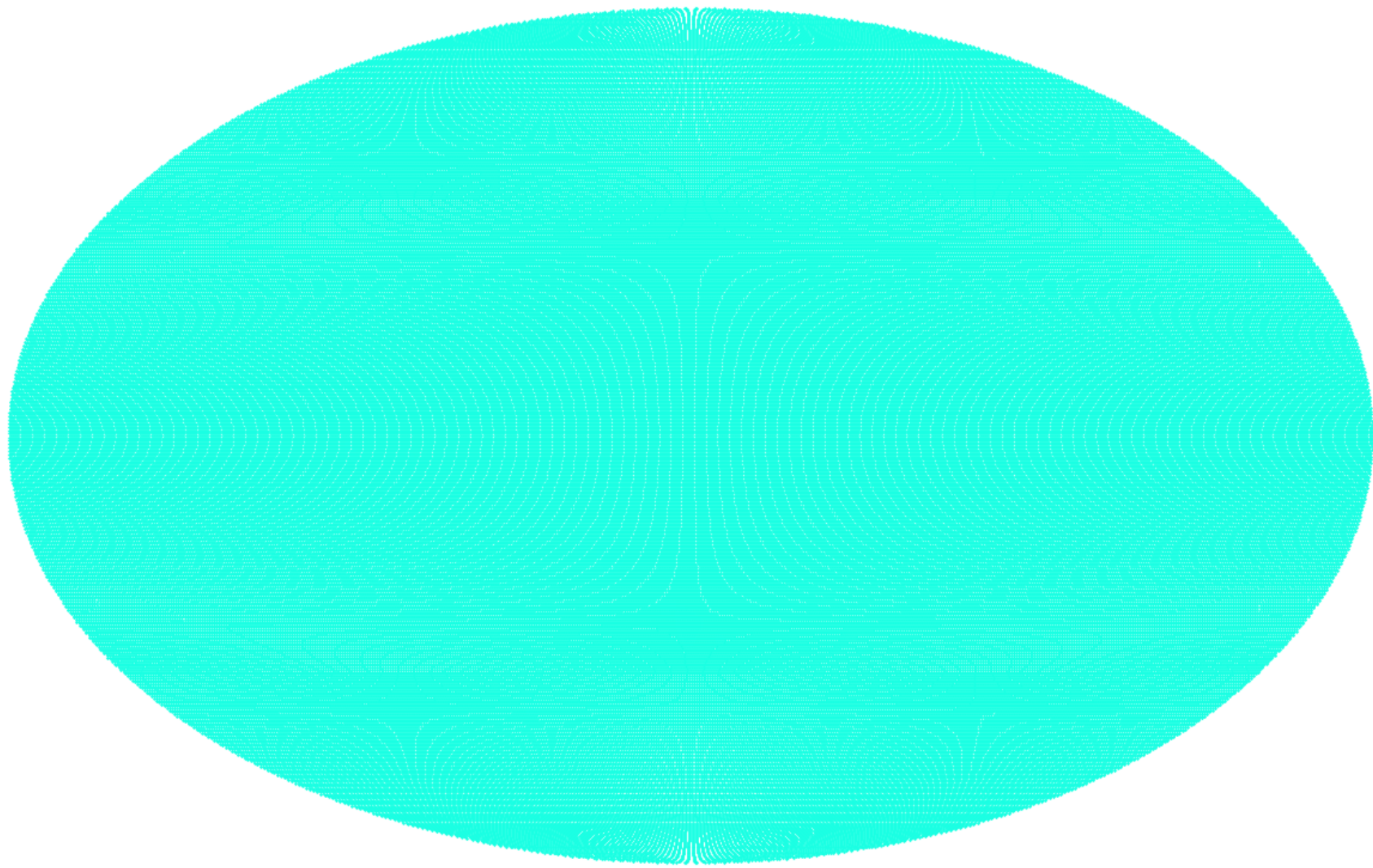
Penzias y Wilson descubren este fondo usando una antena

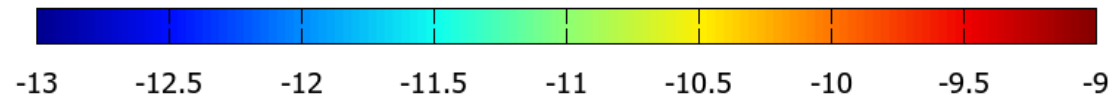
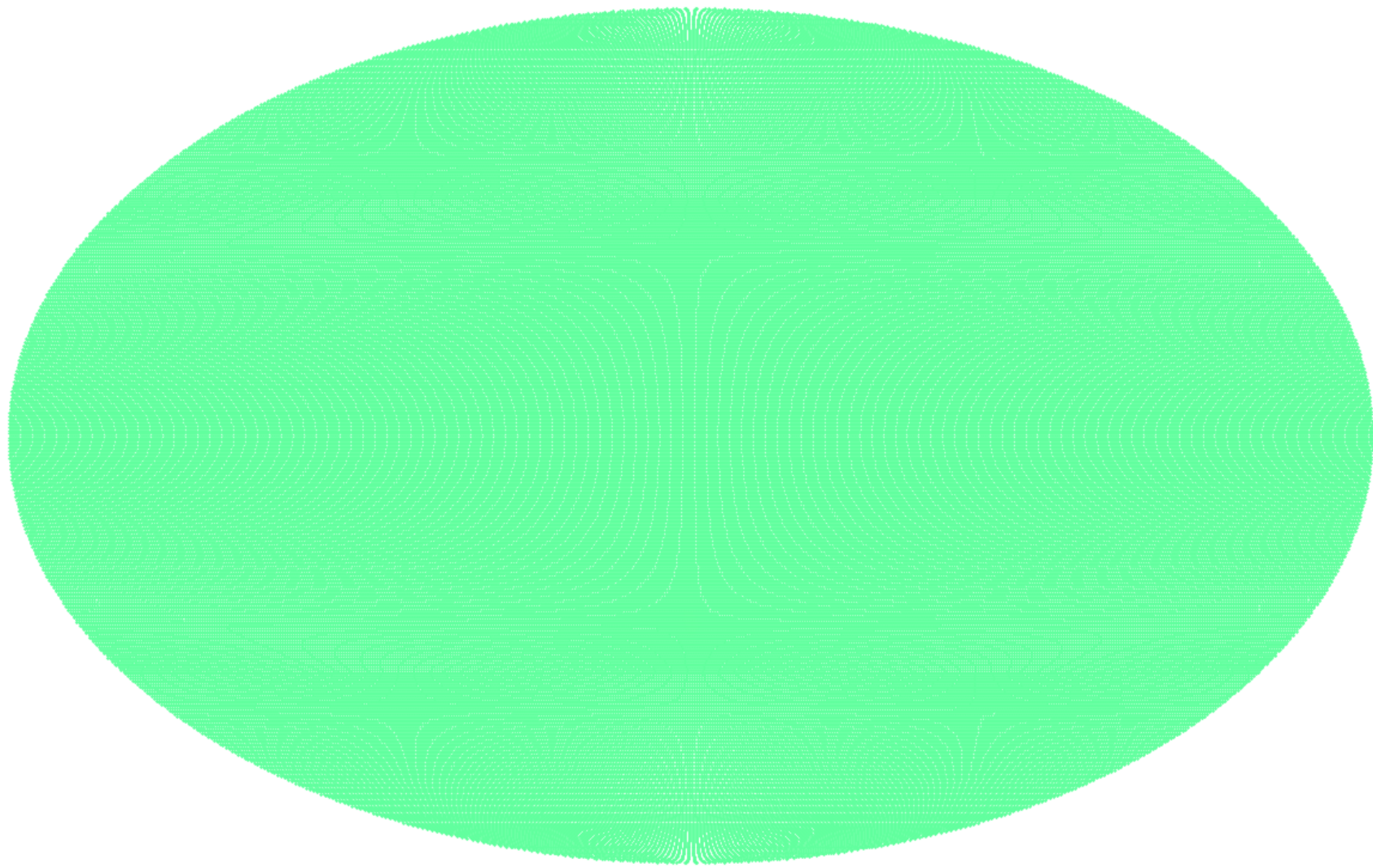


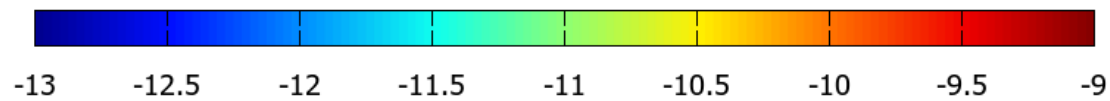
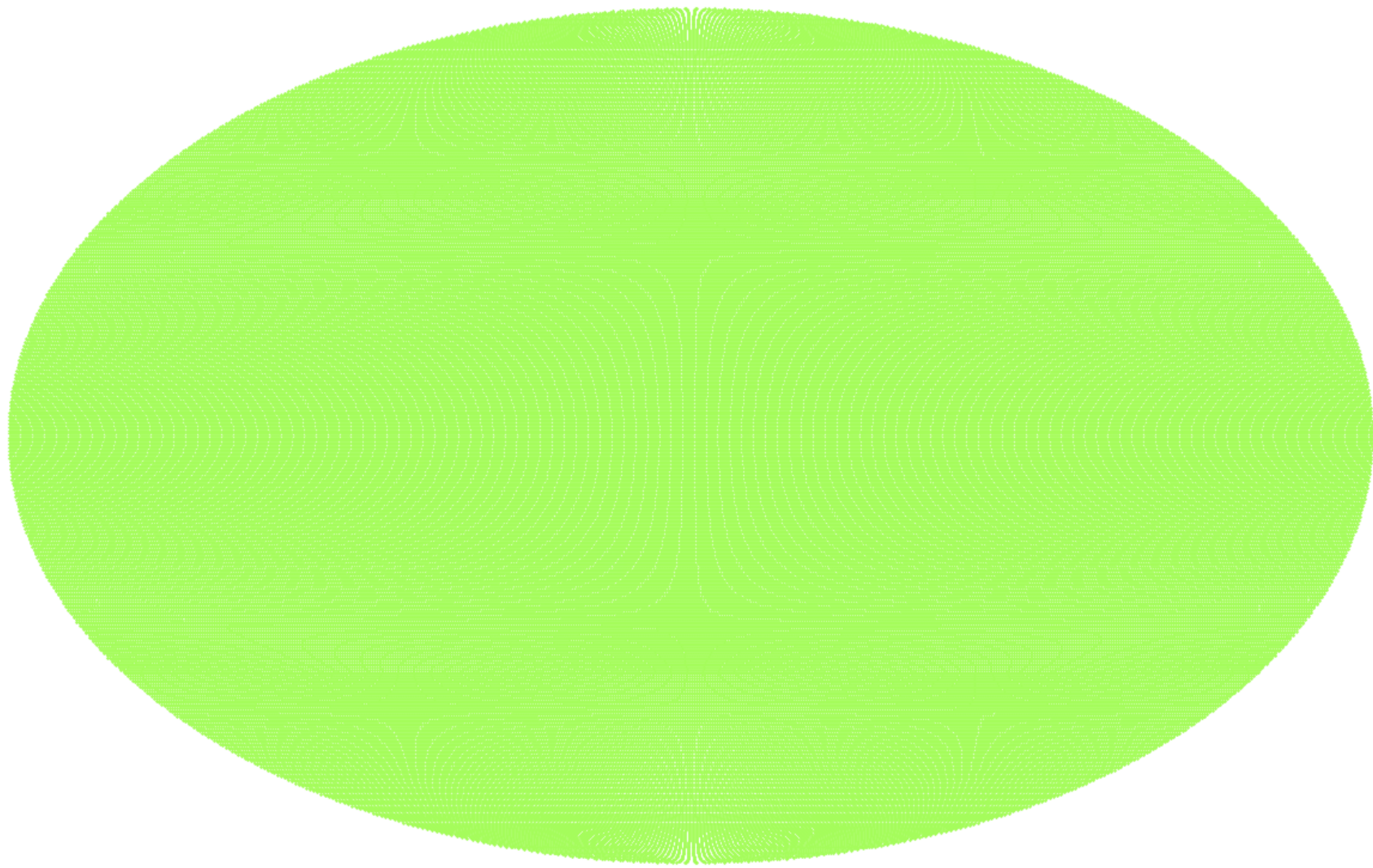


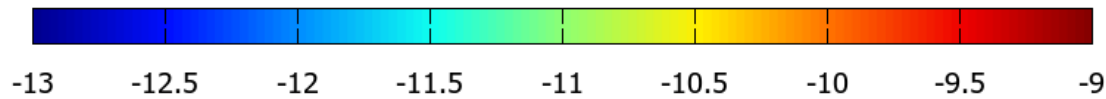
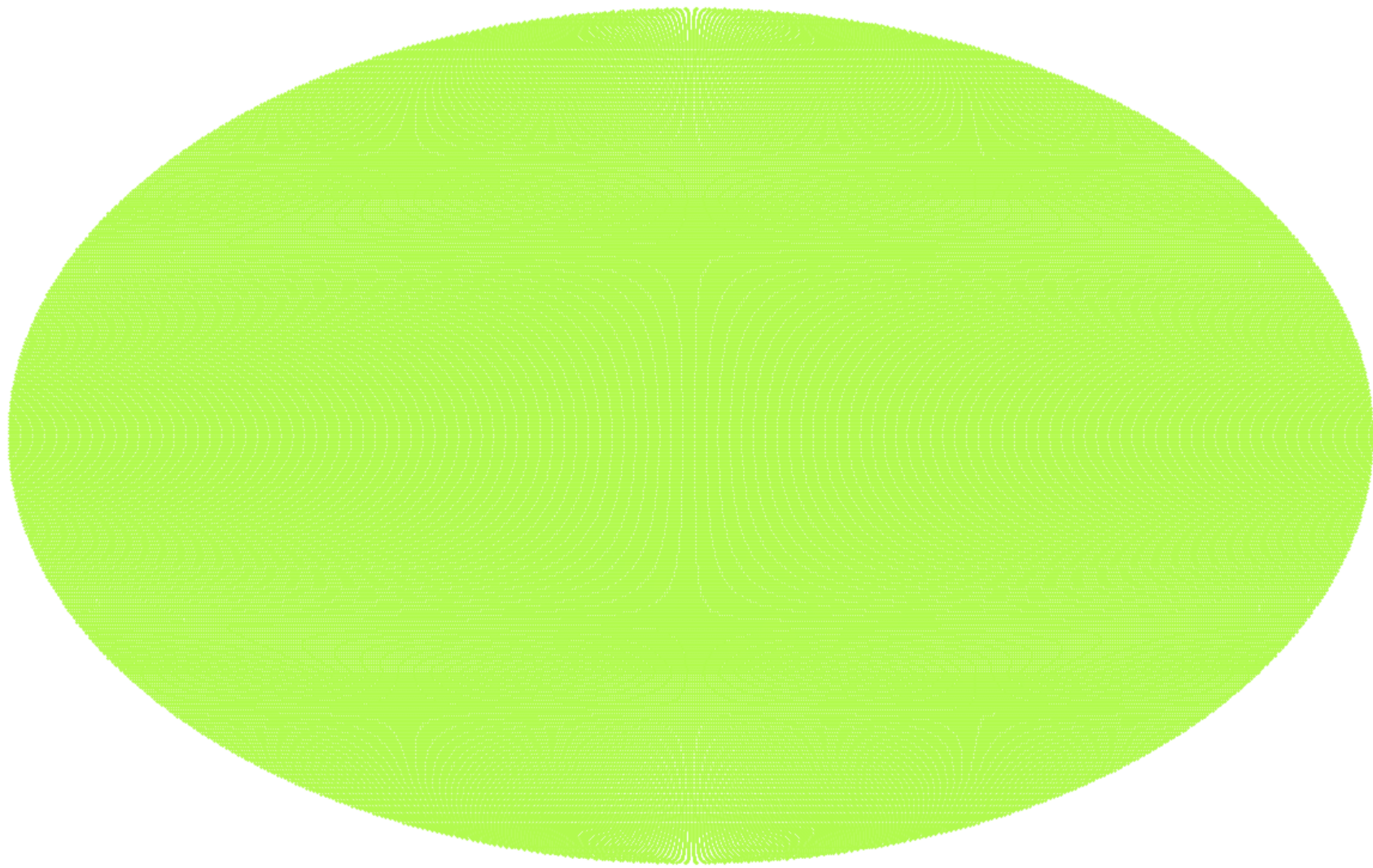
COBE in orbit,
1989-1994

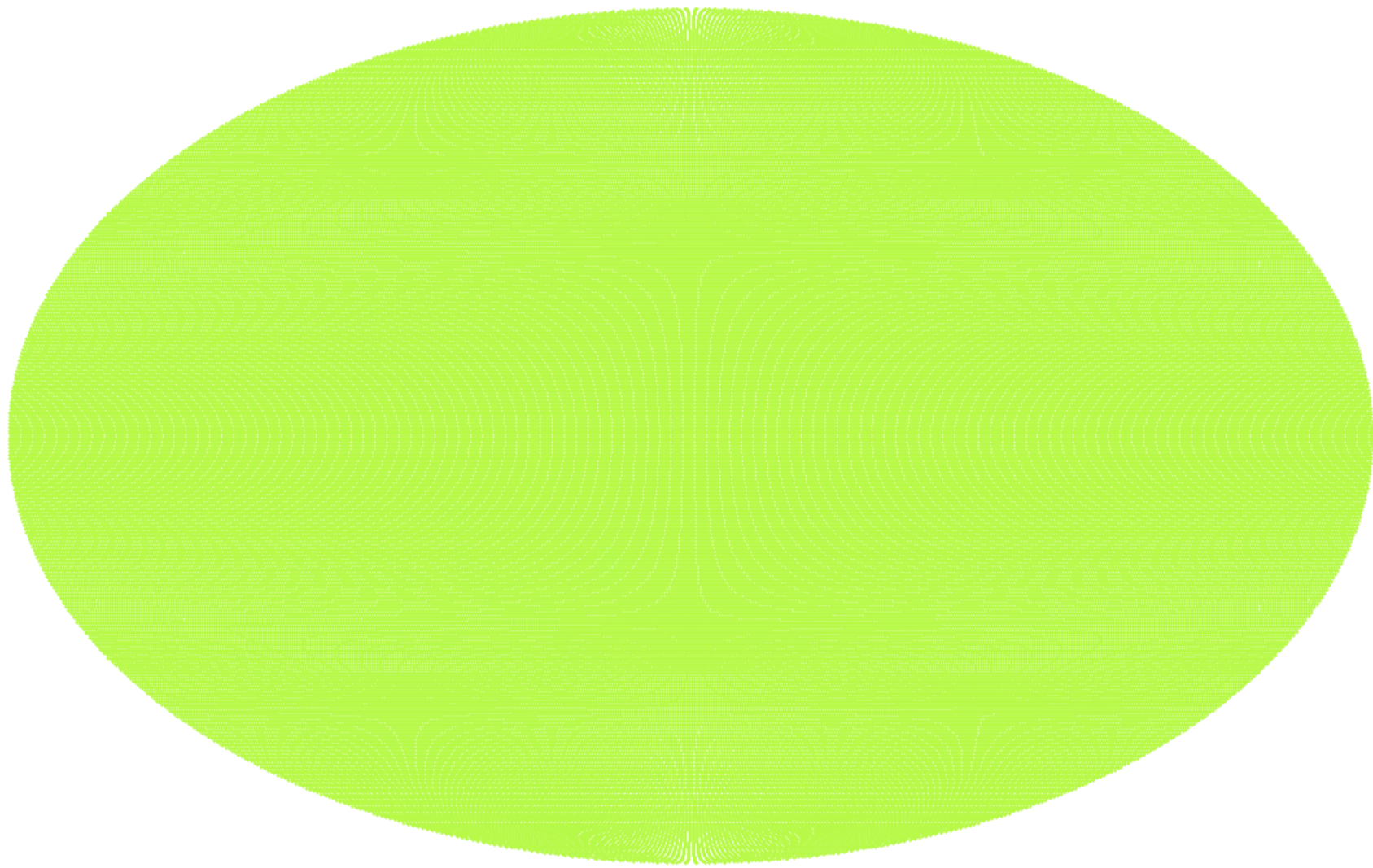


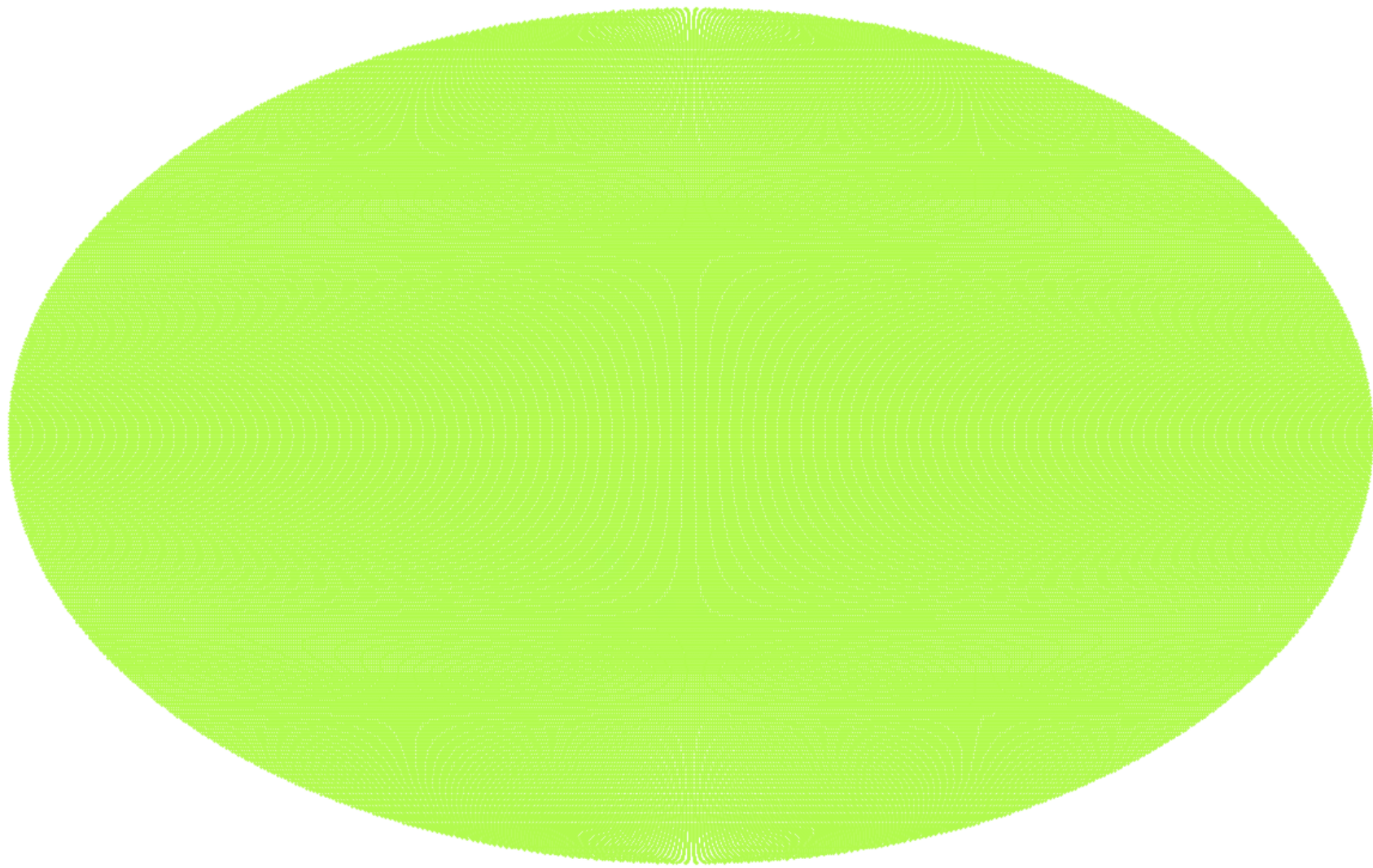


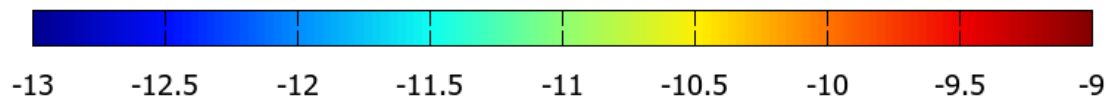
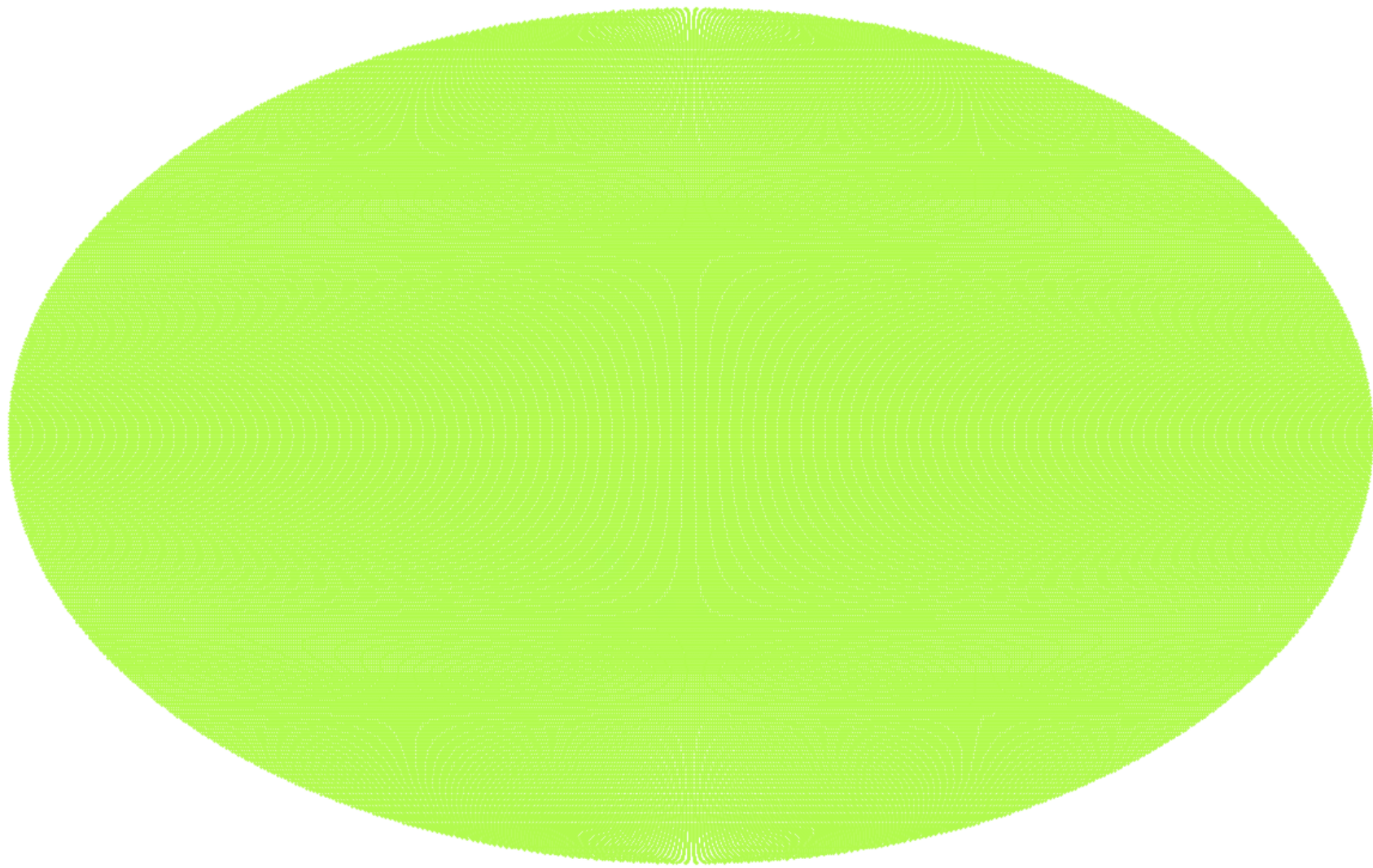


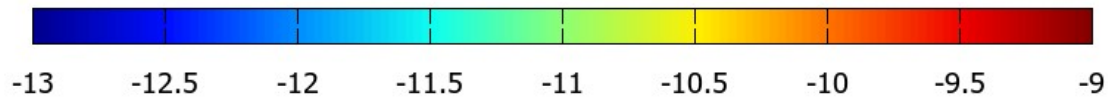
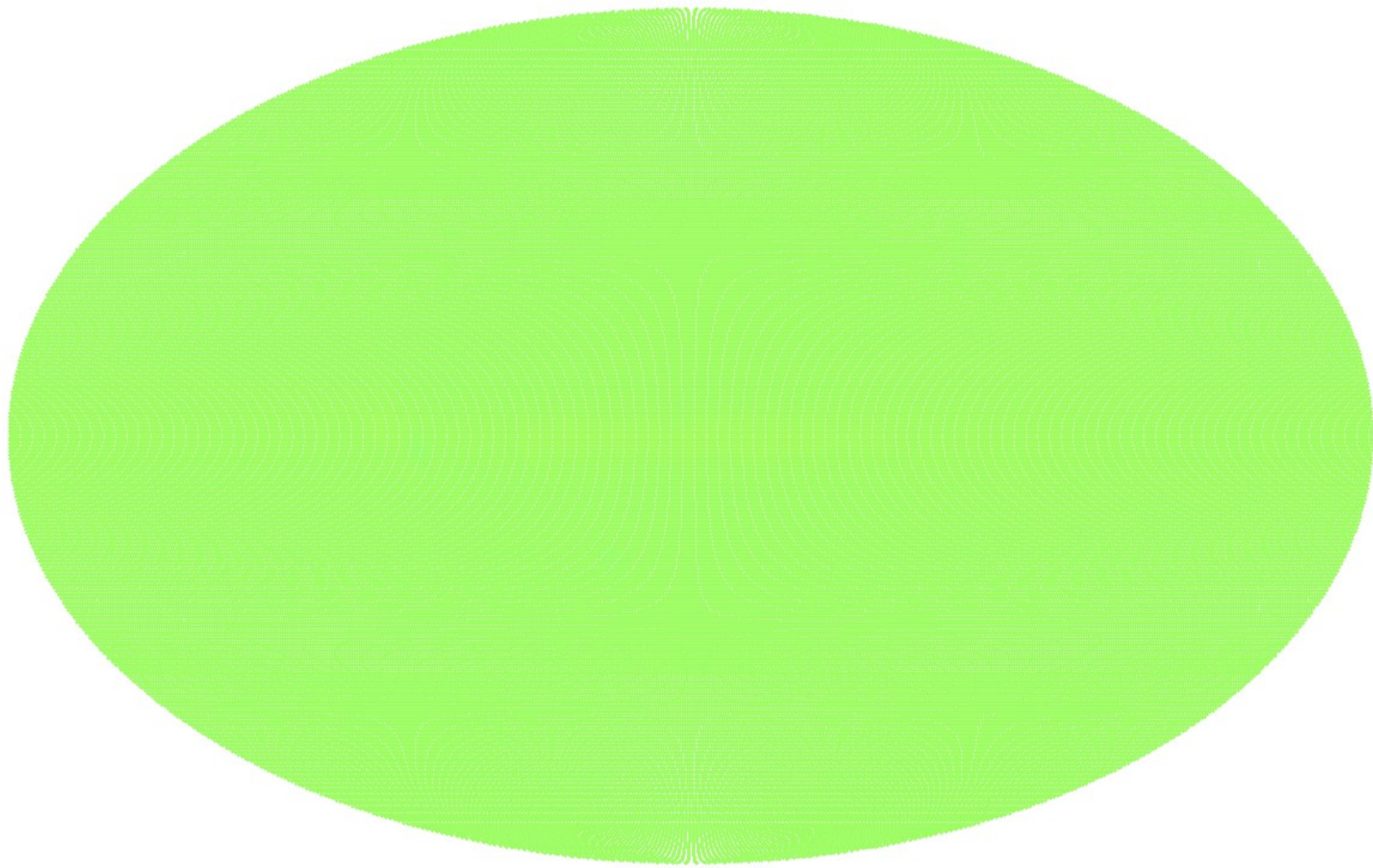


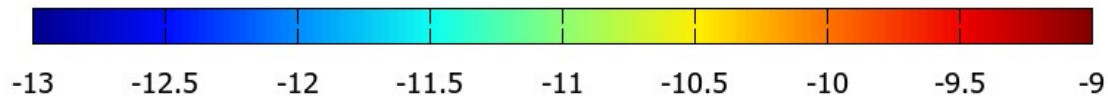
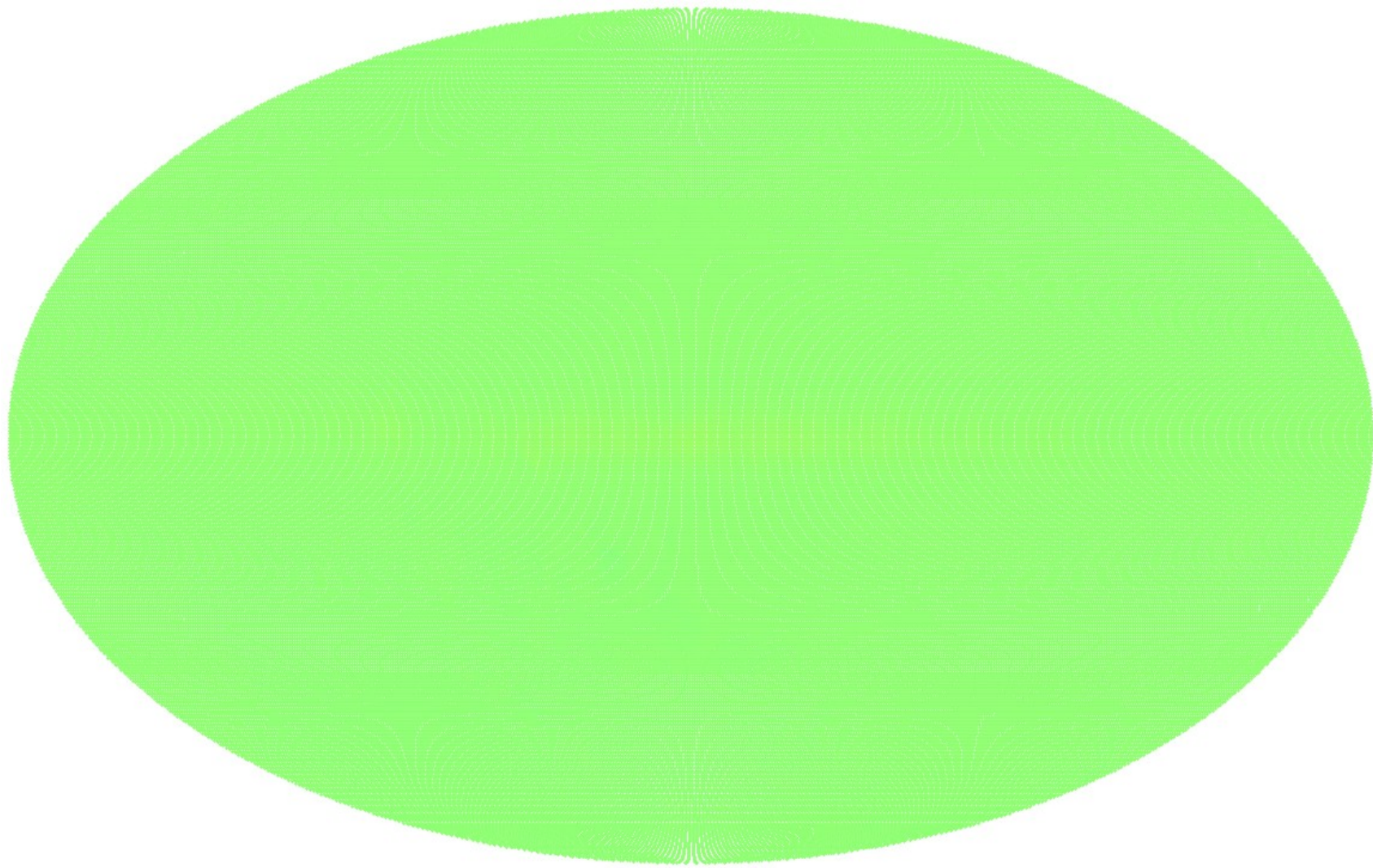


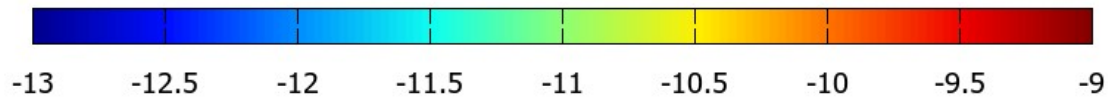
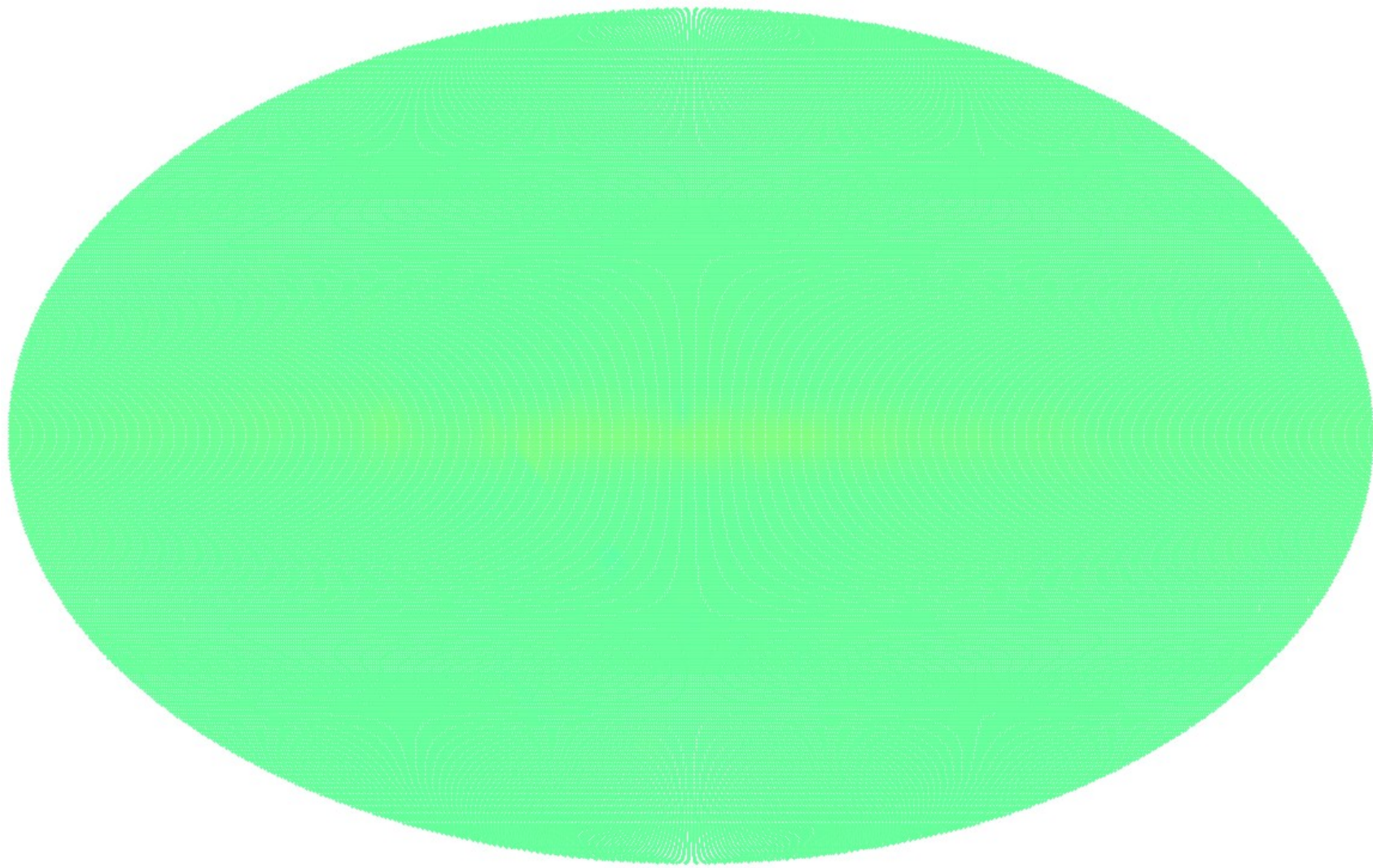


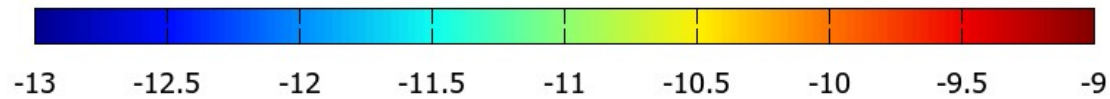
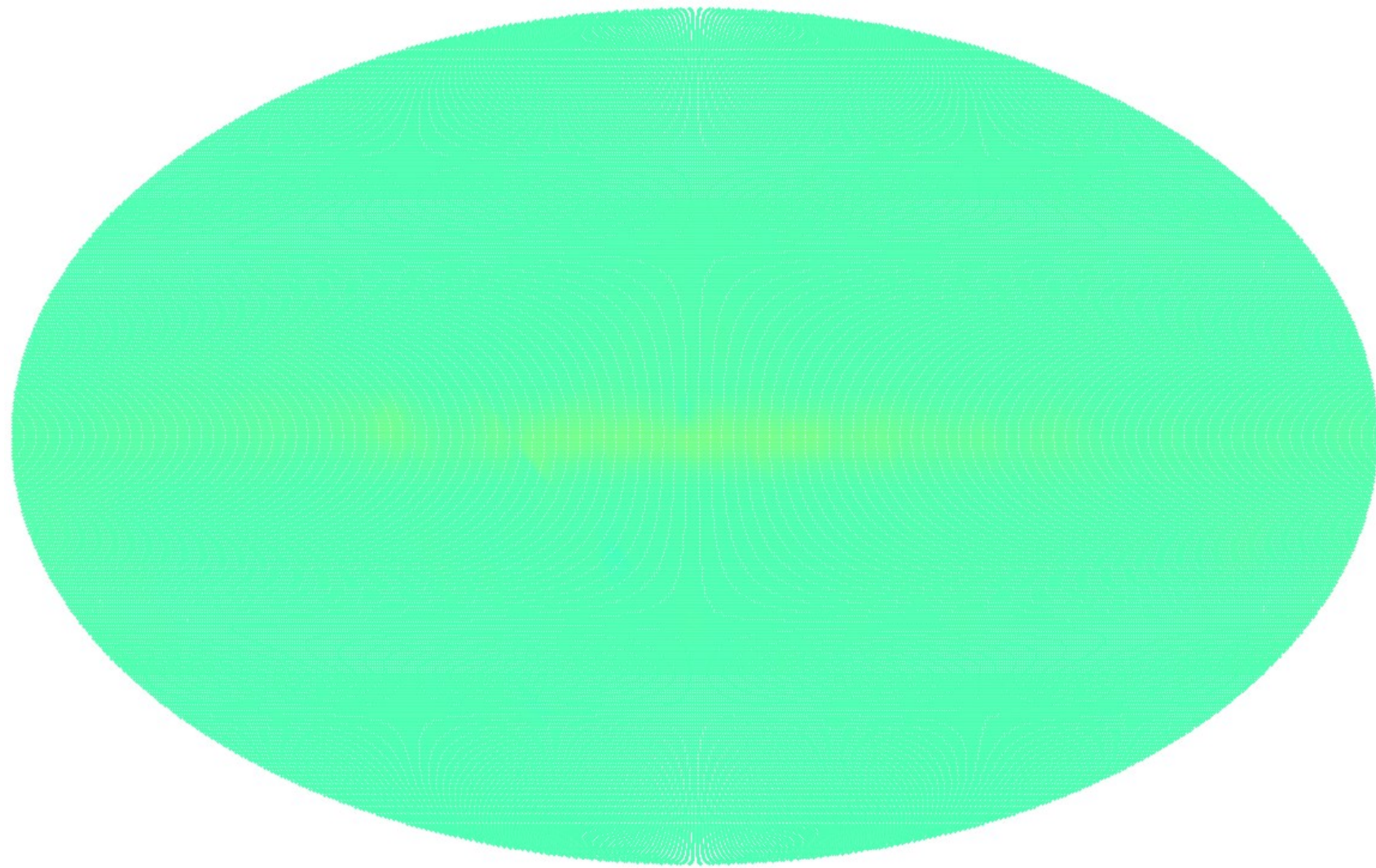


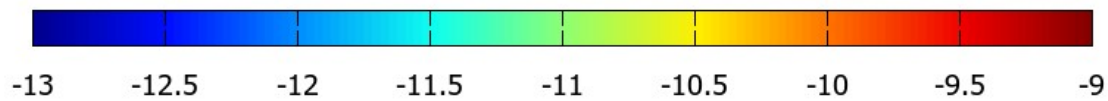
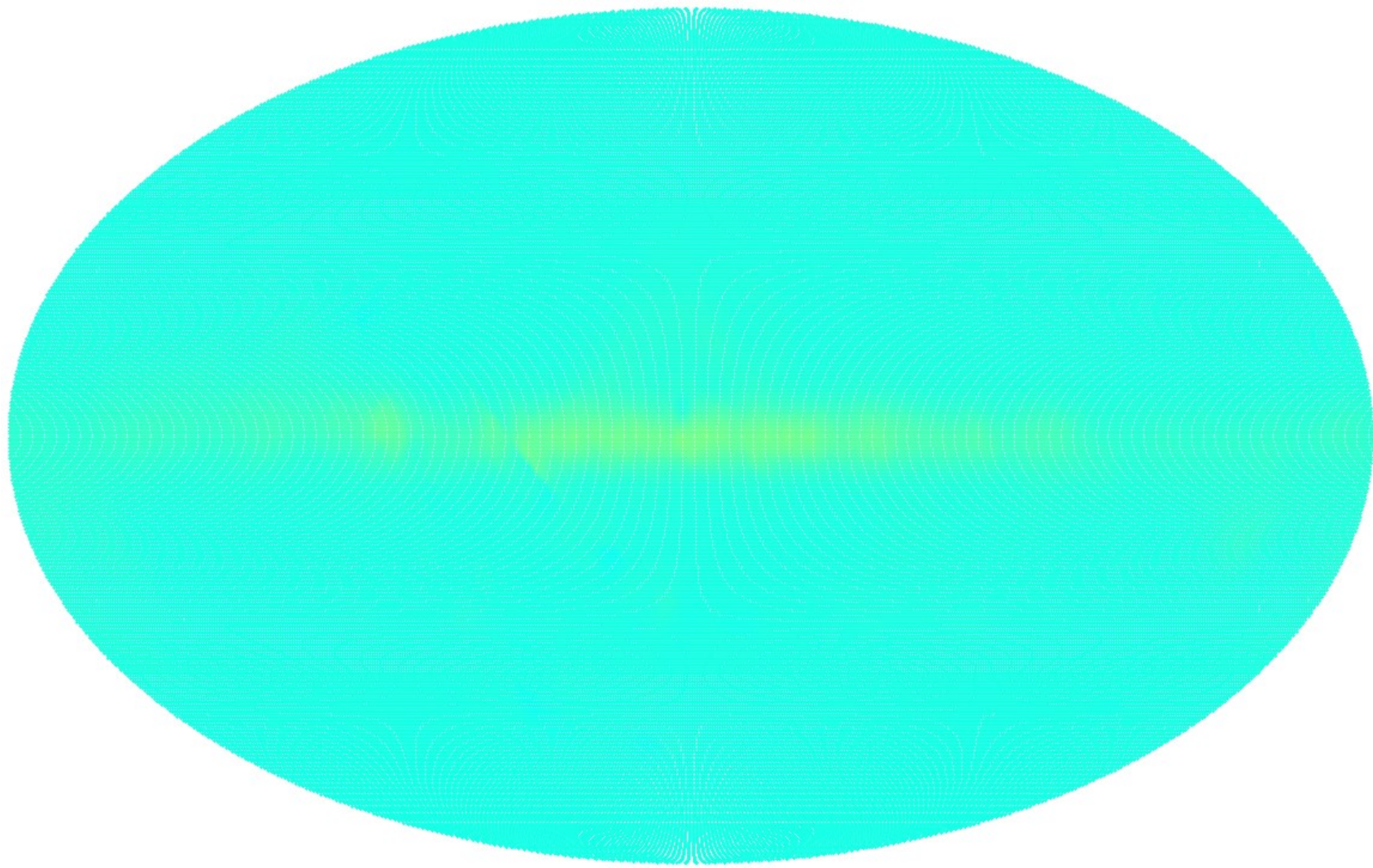


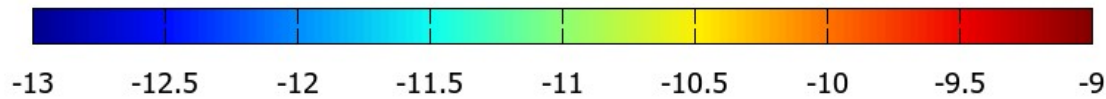
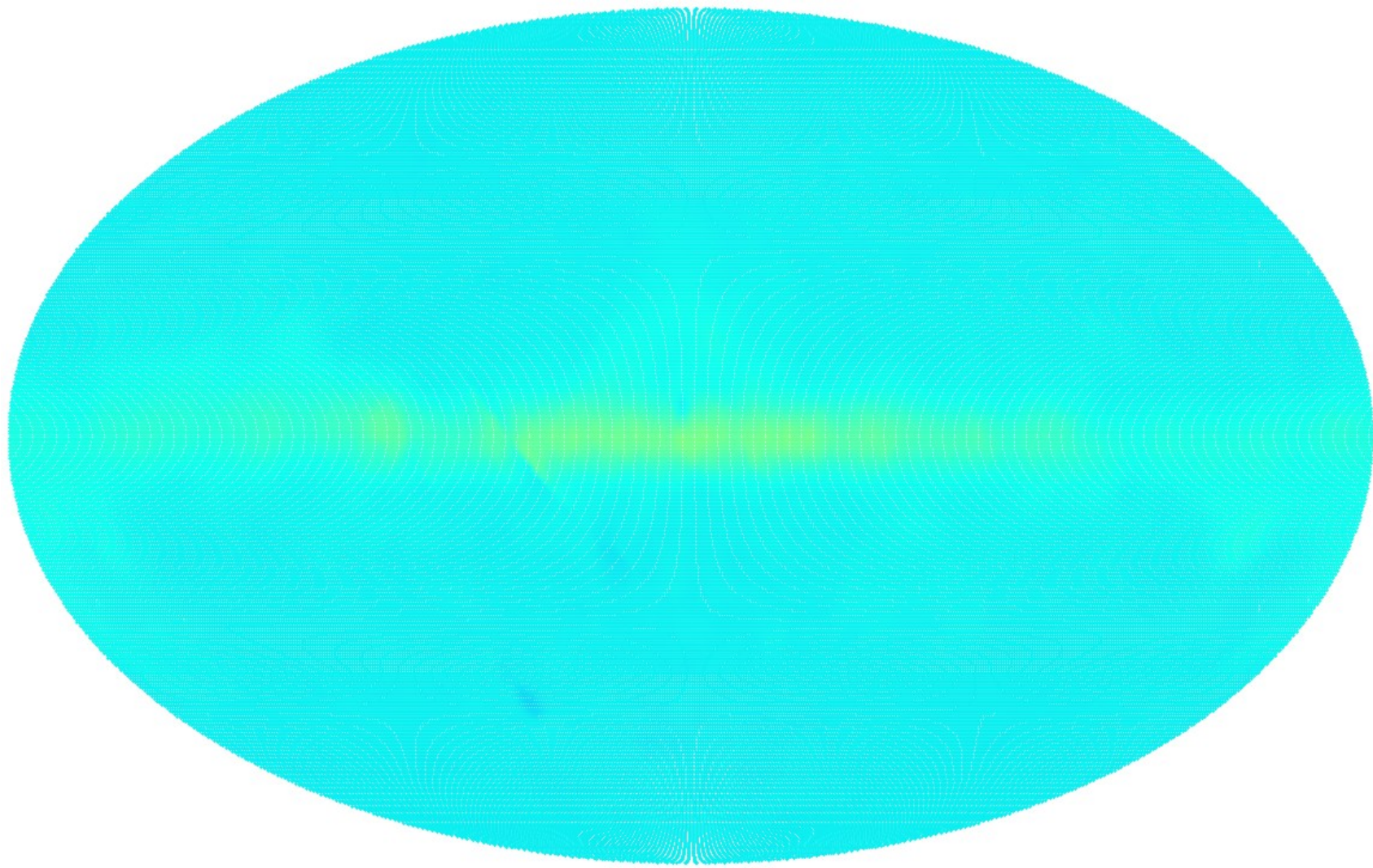


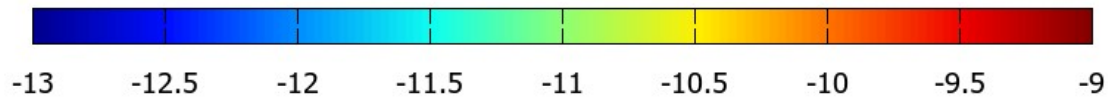
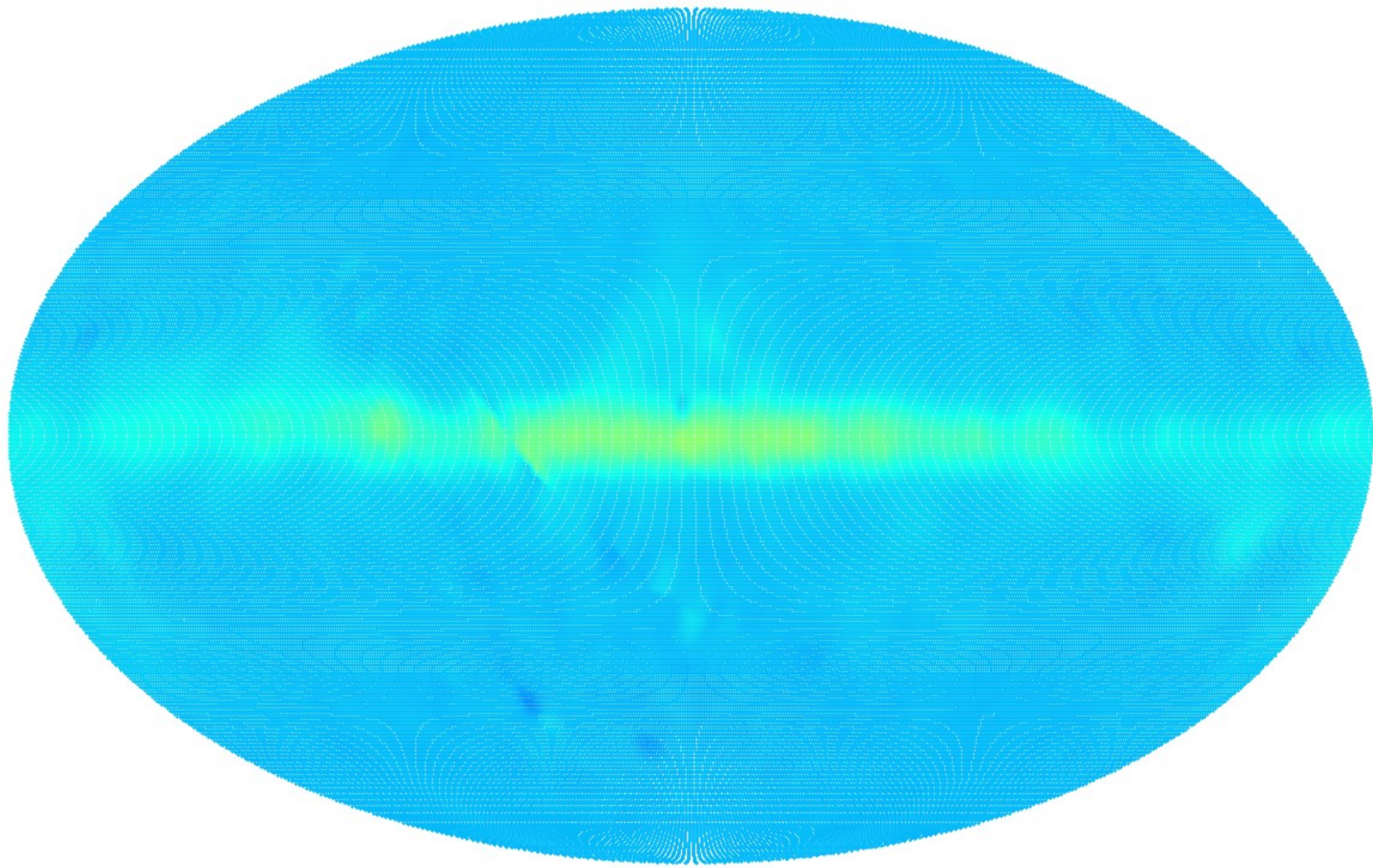


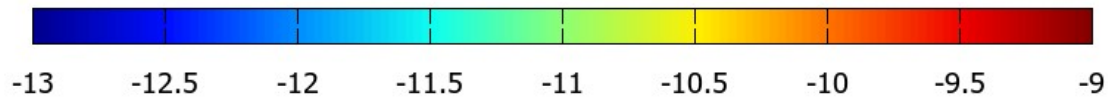
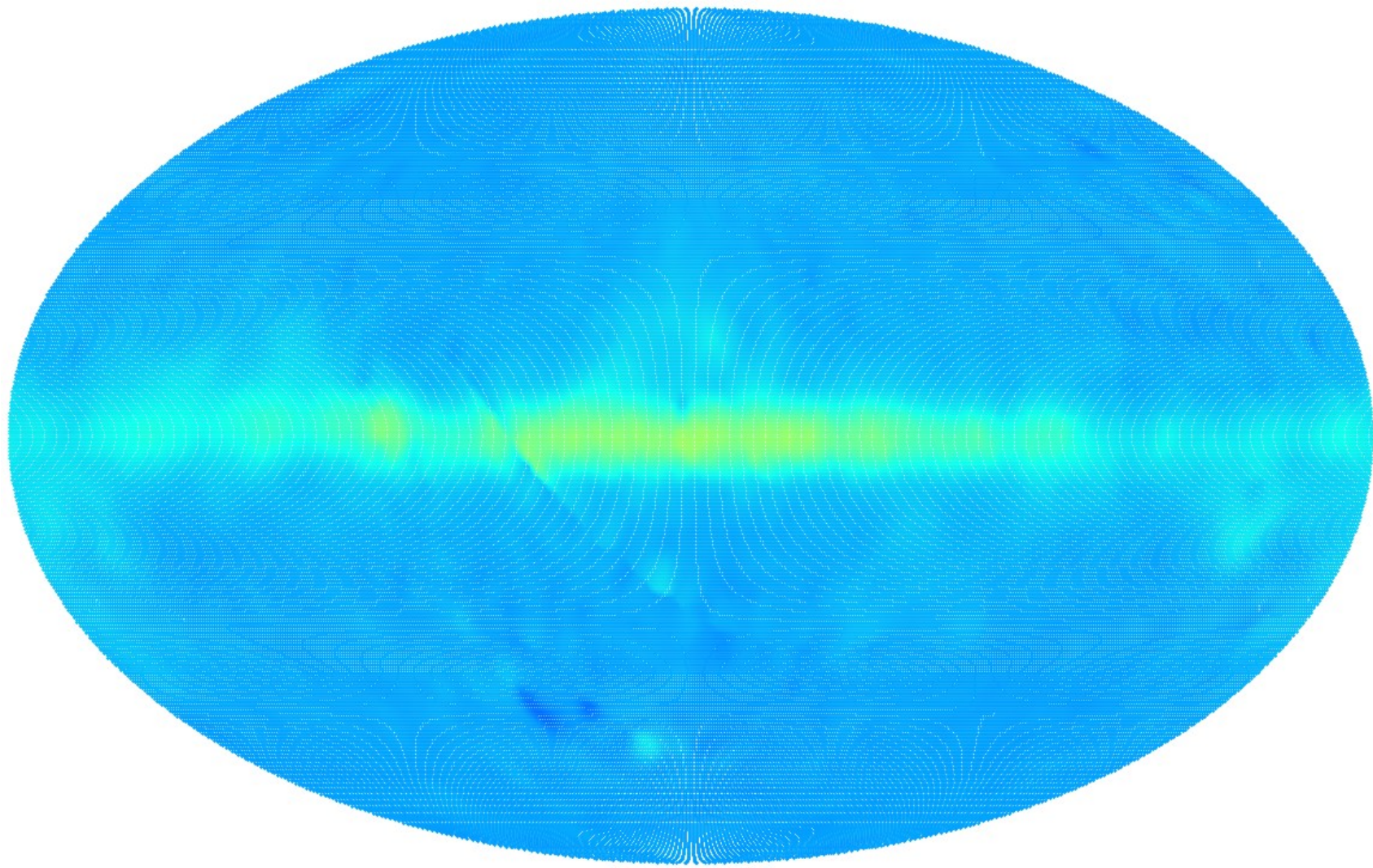


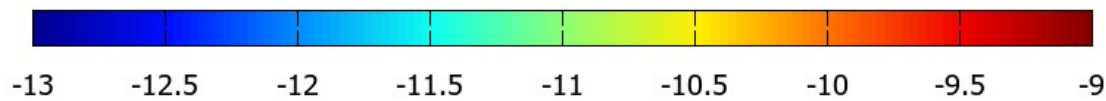
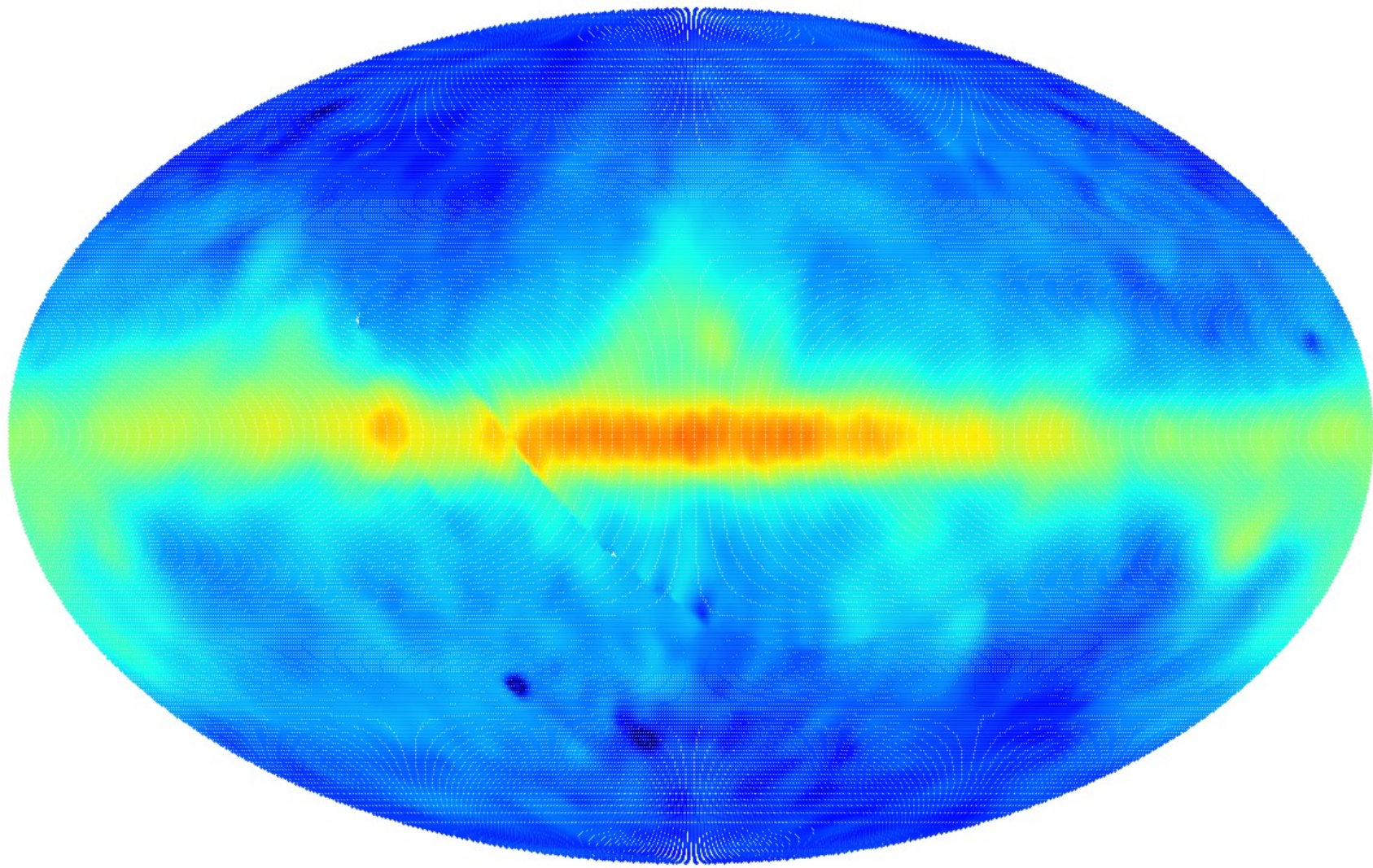


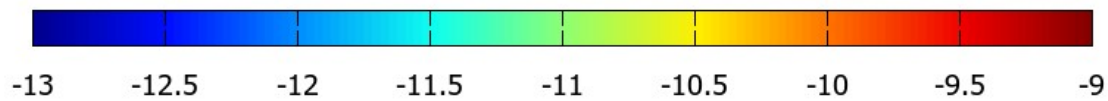
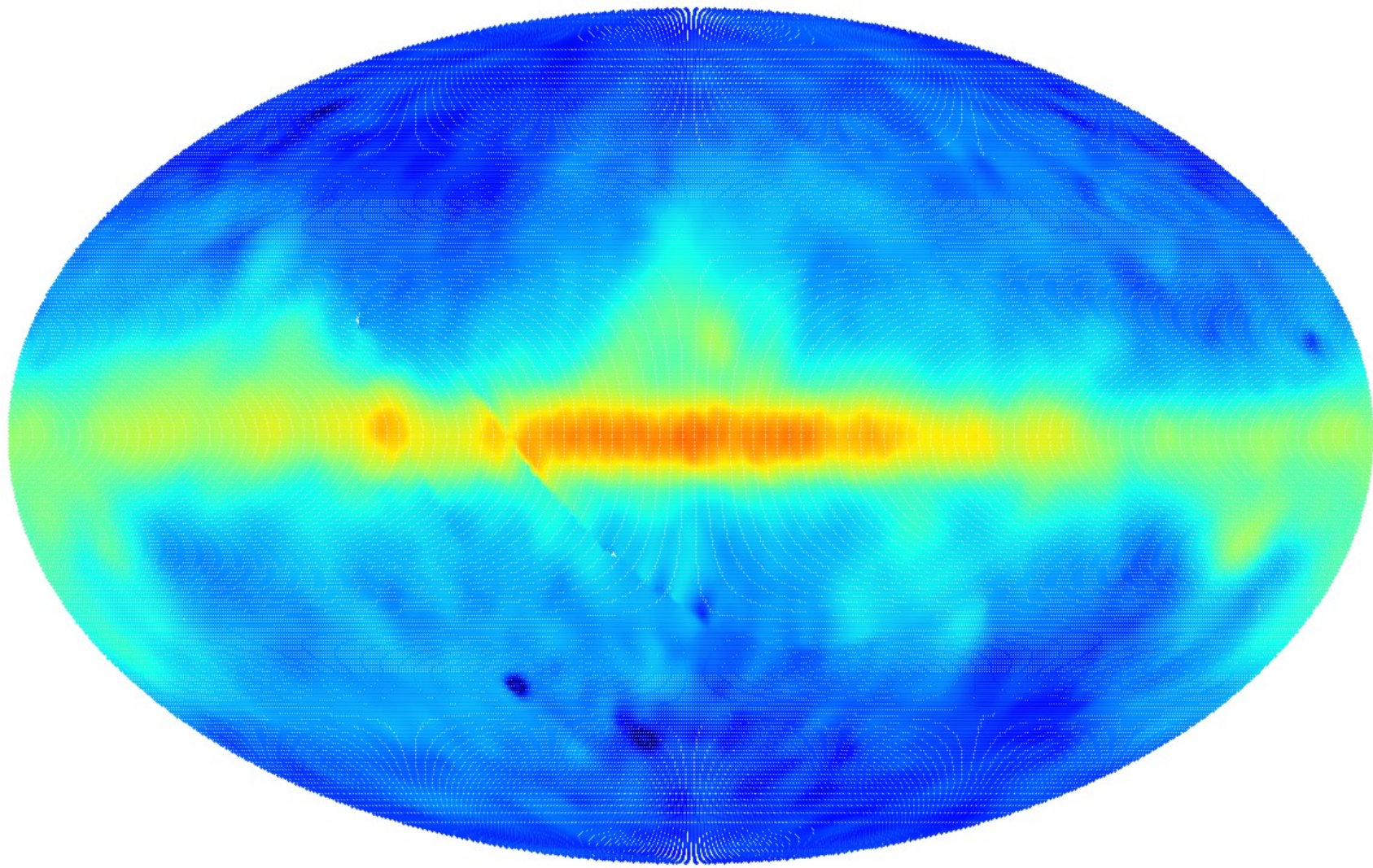


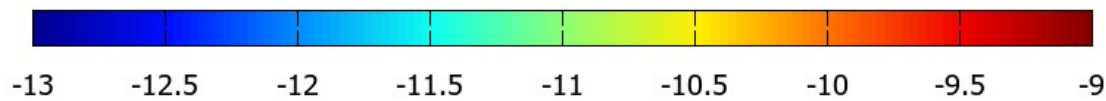
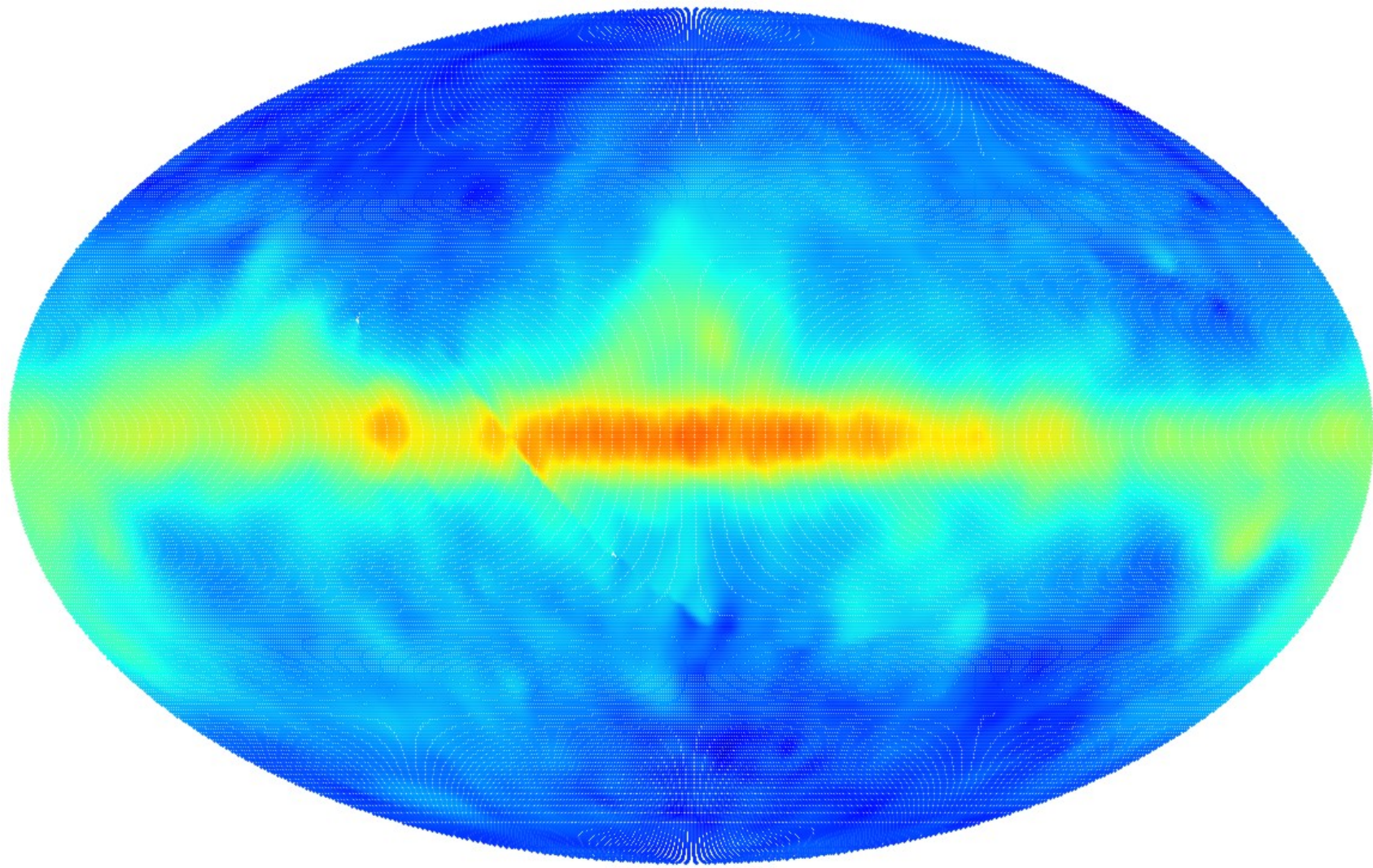


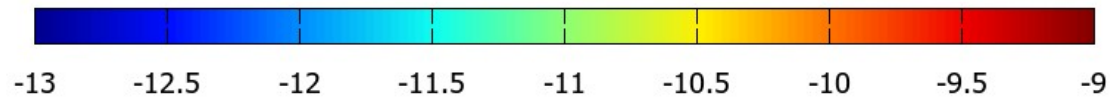
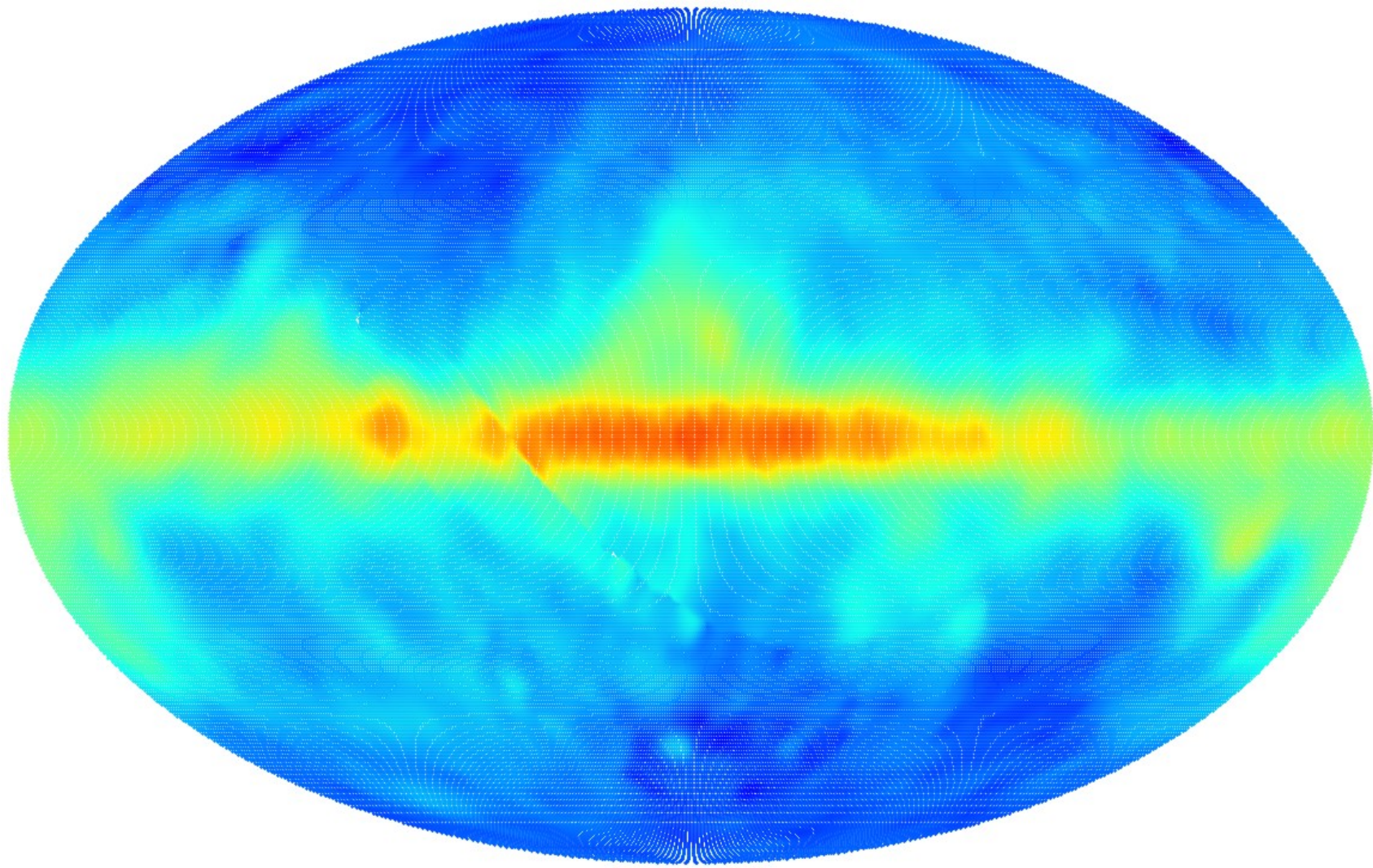


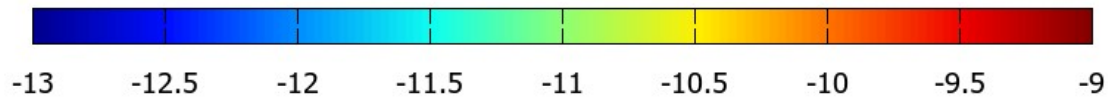
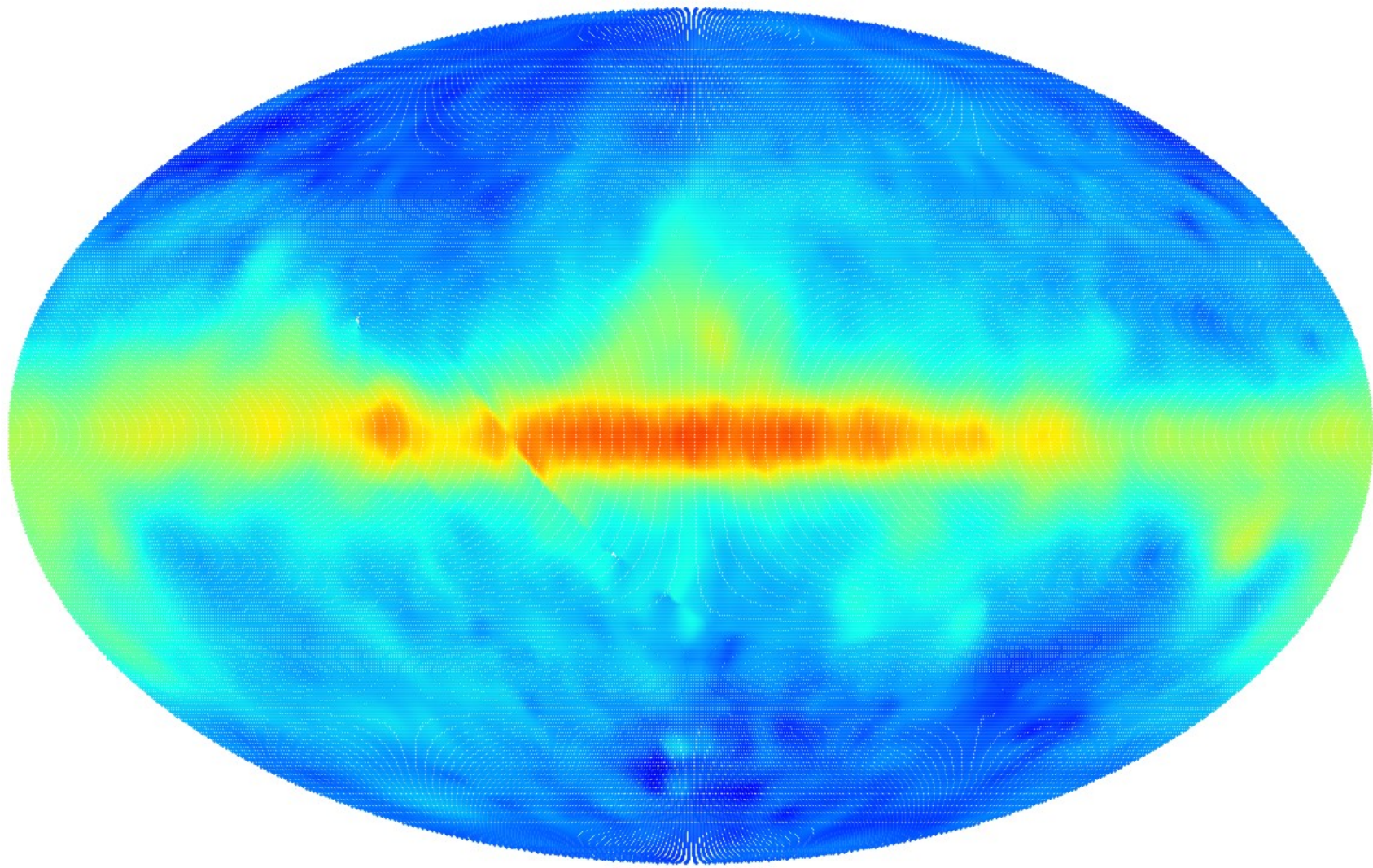


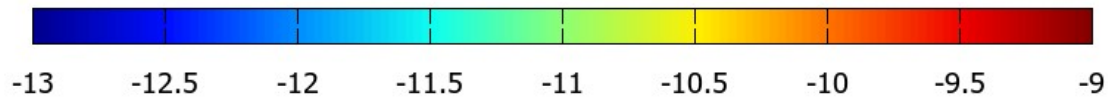
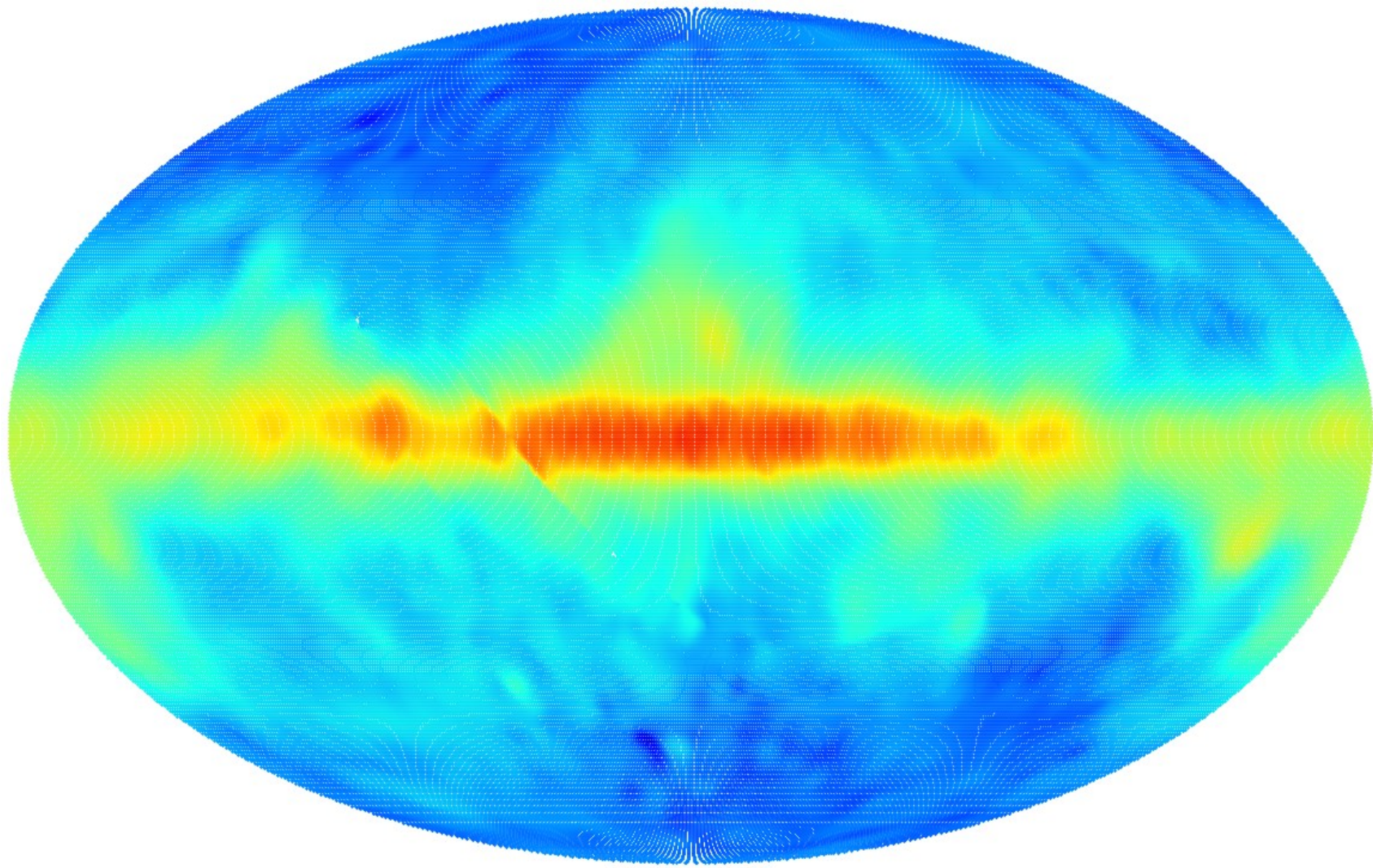


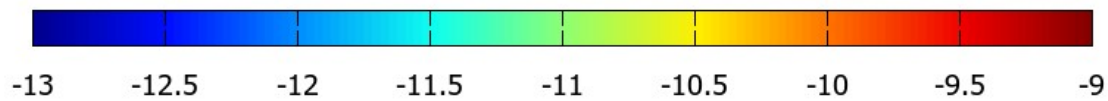
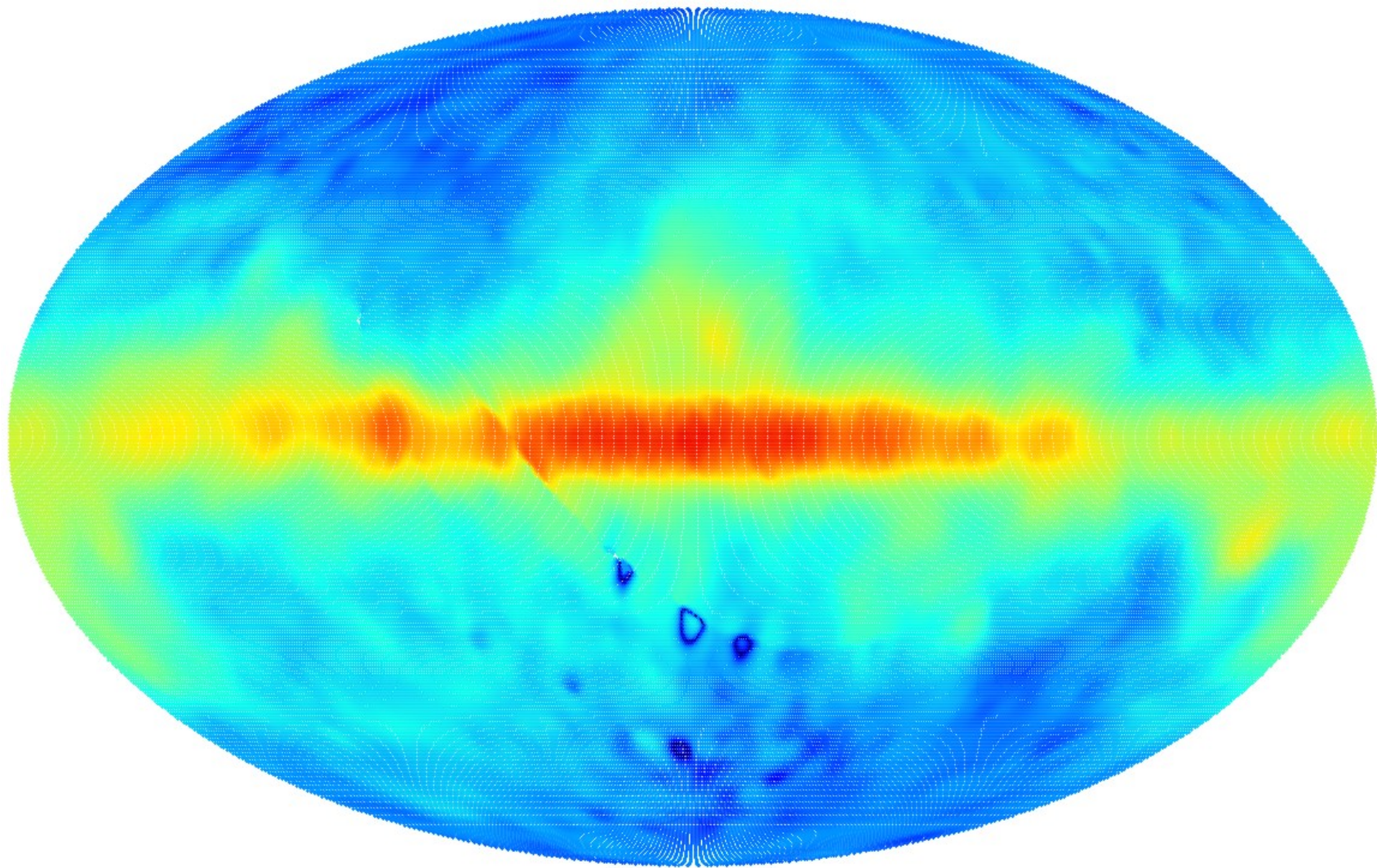


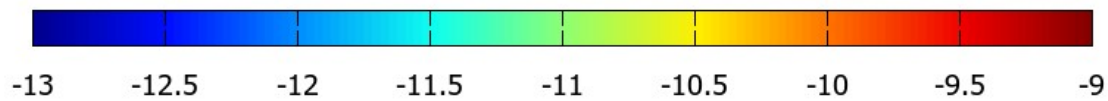
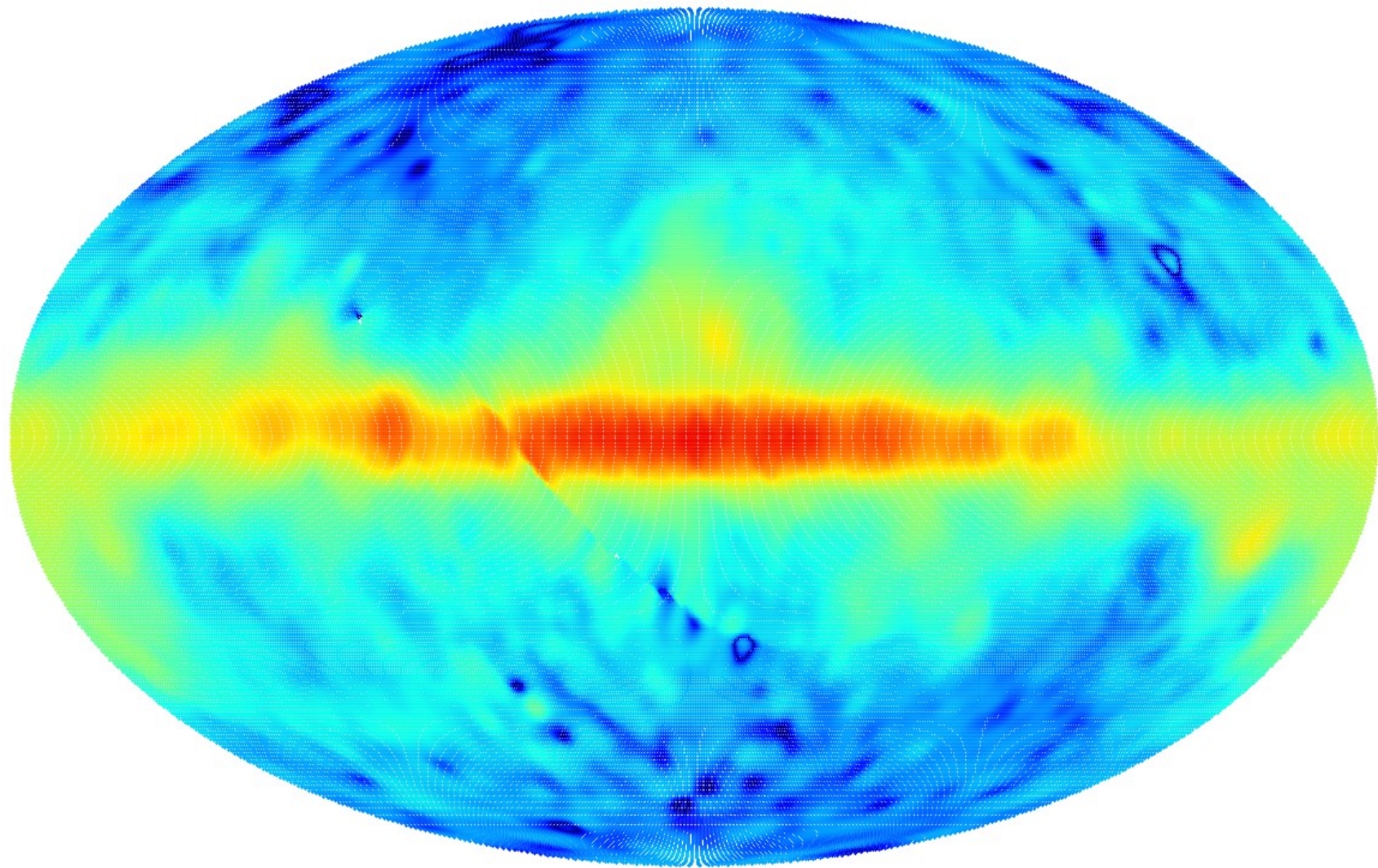


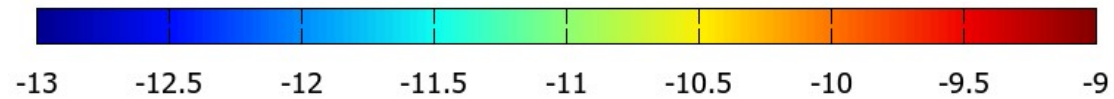
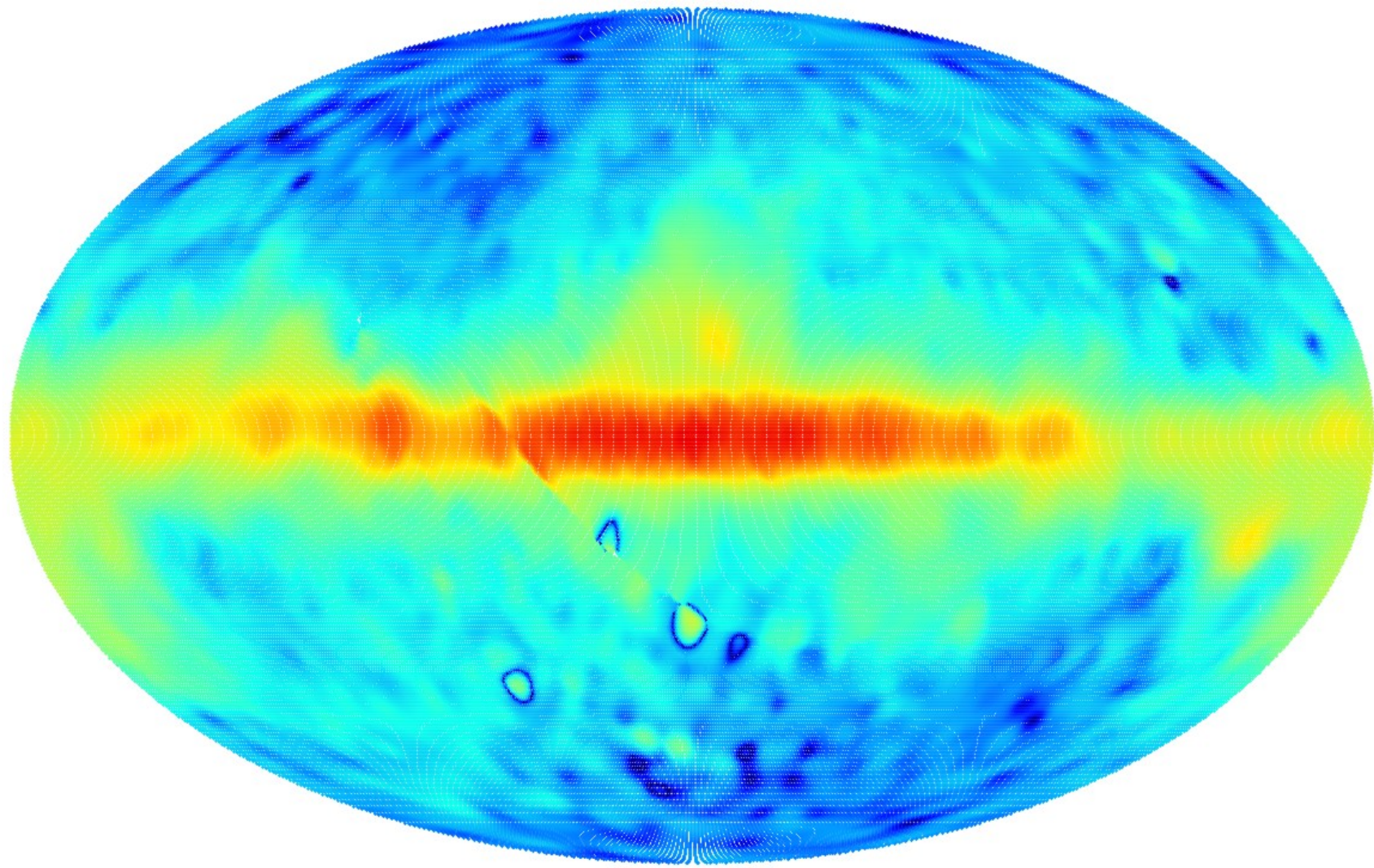


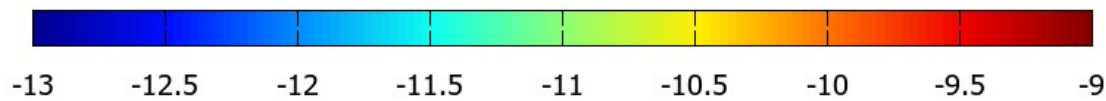
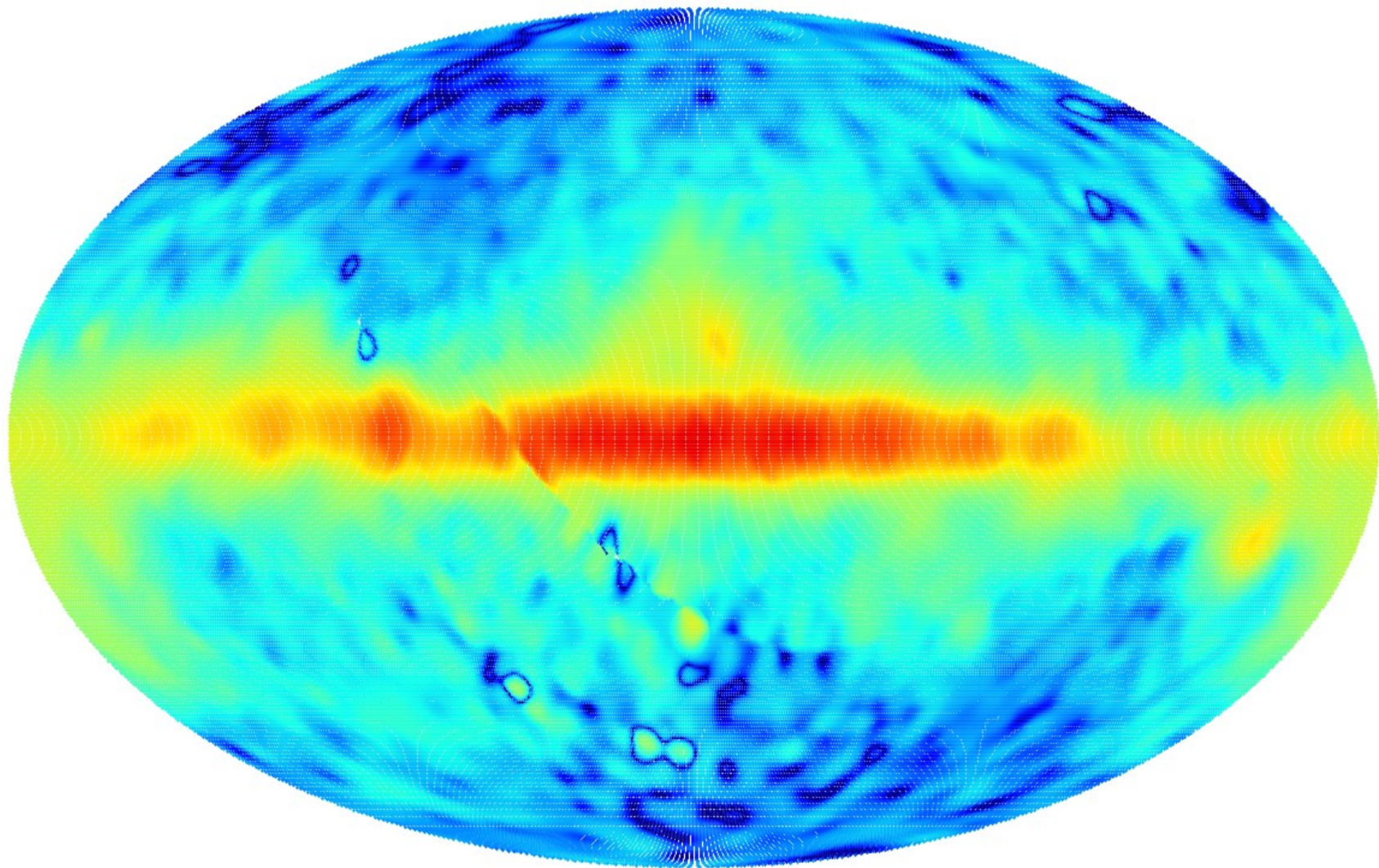


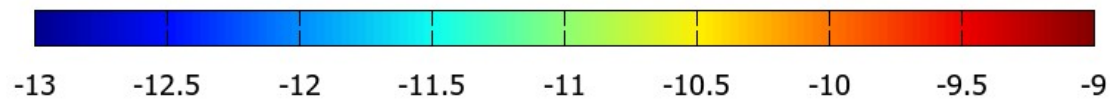
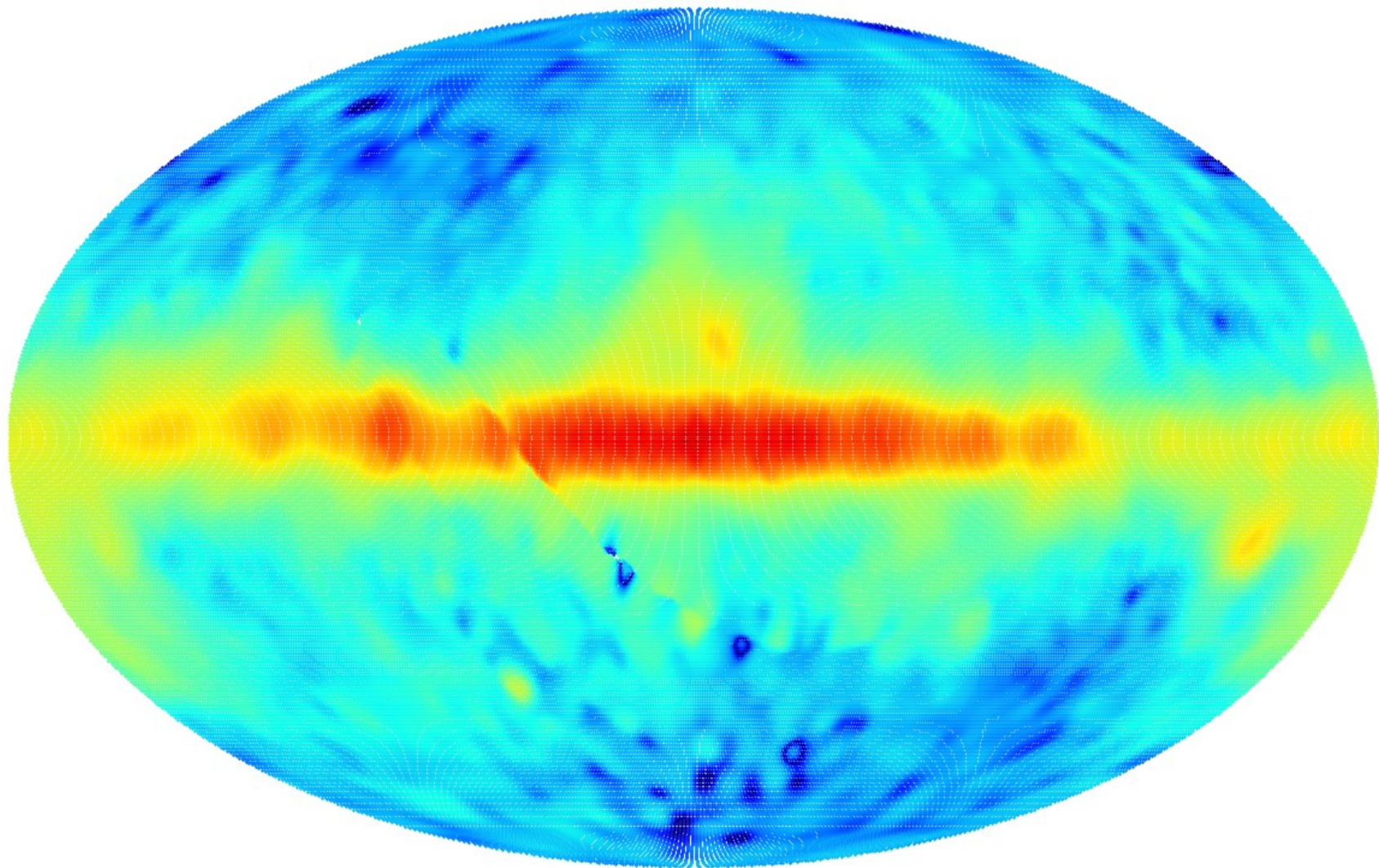


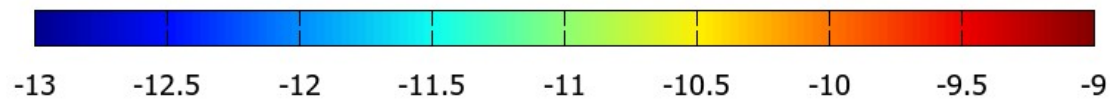
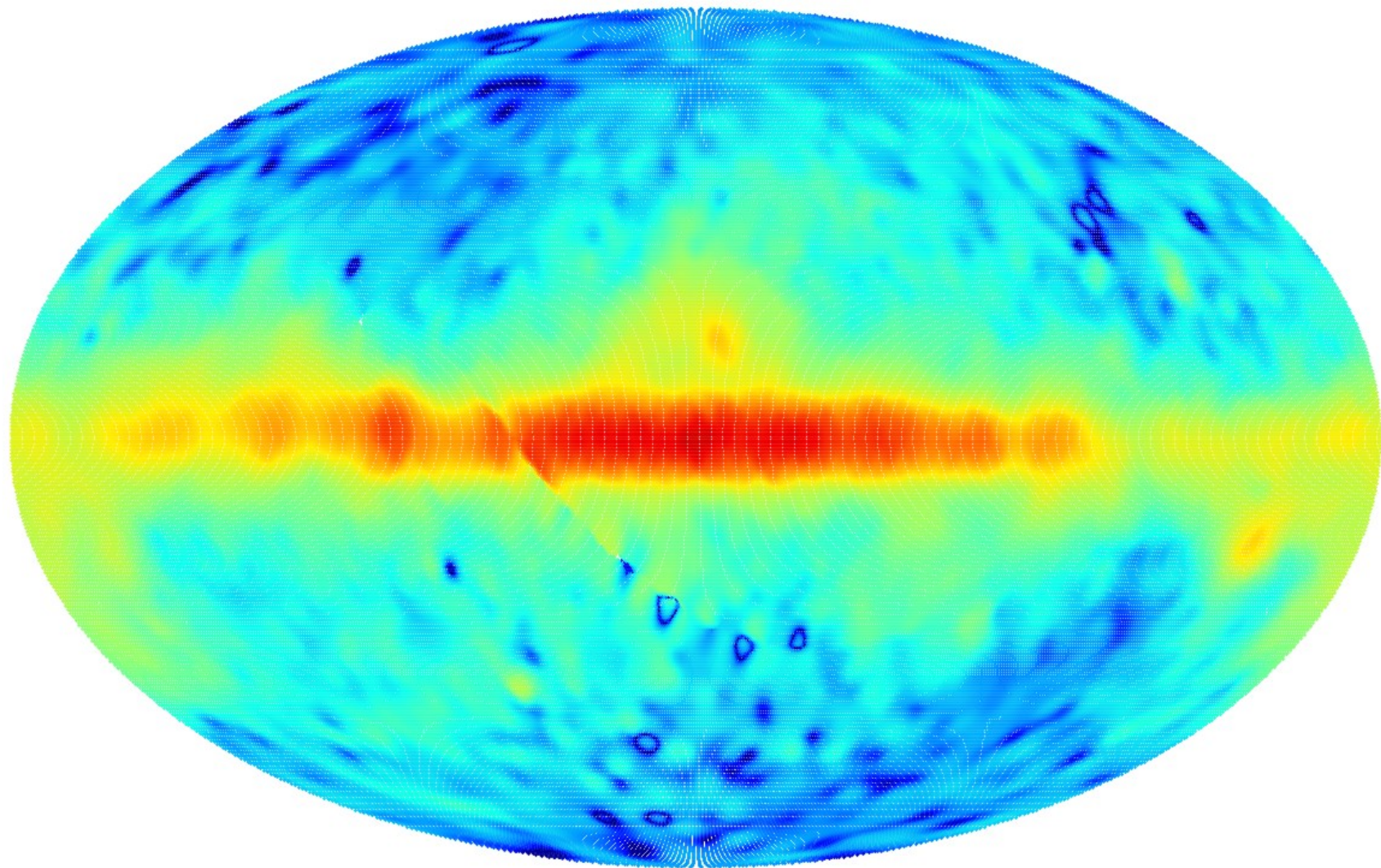


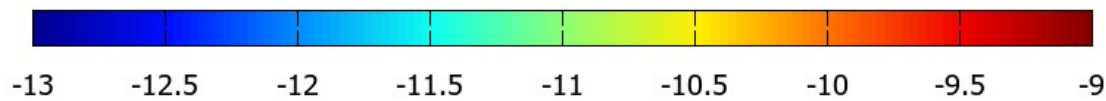
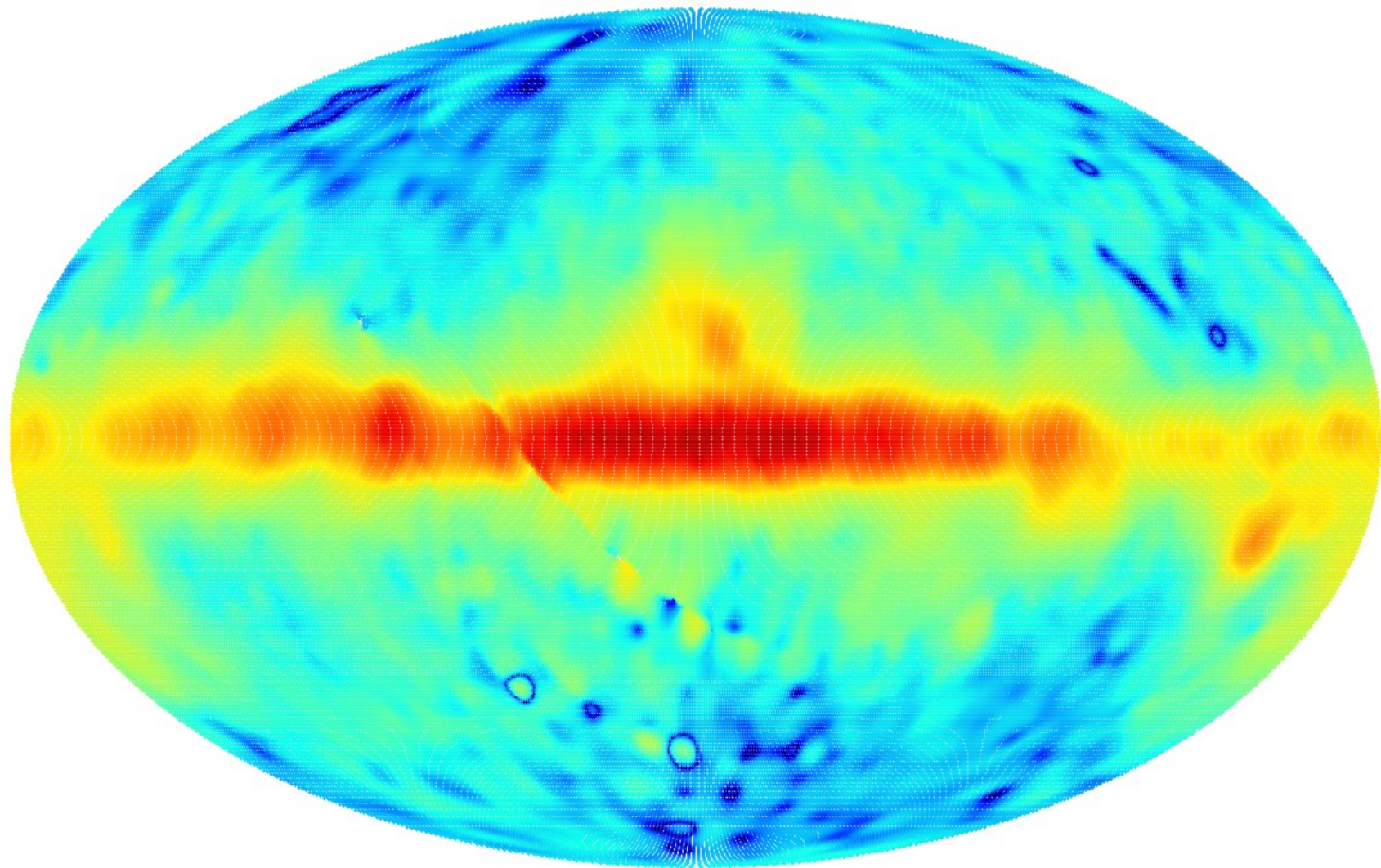


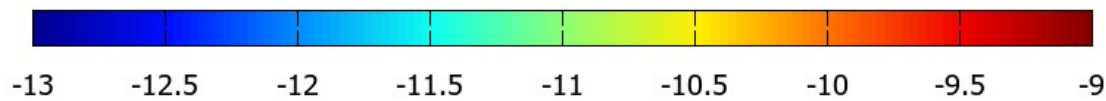
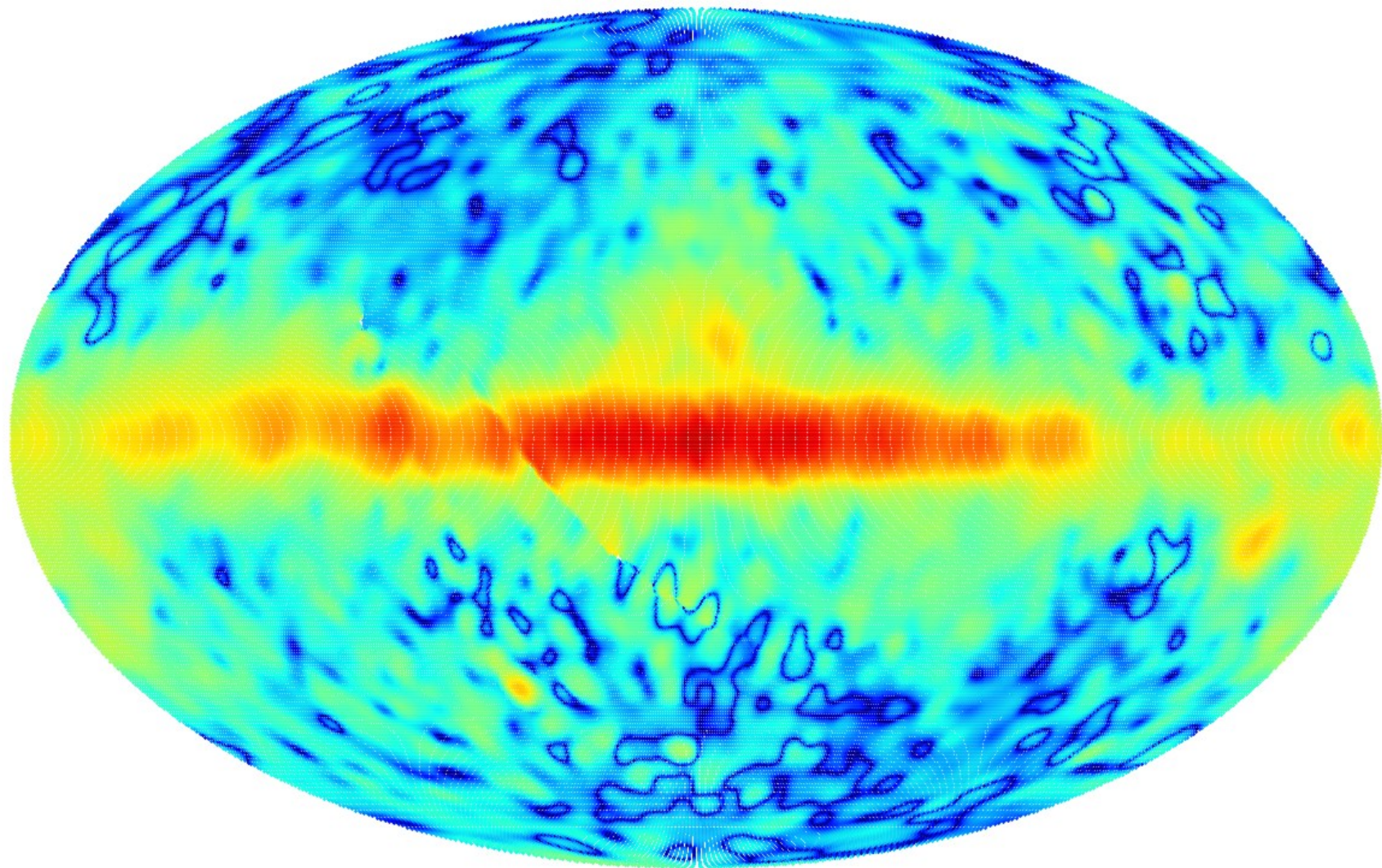


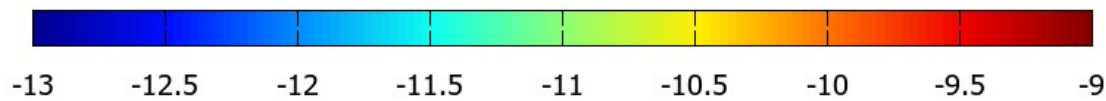
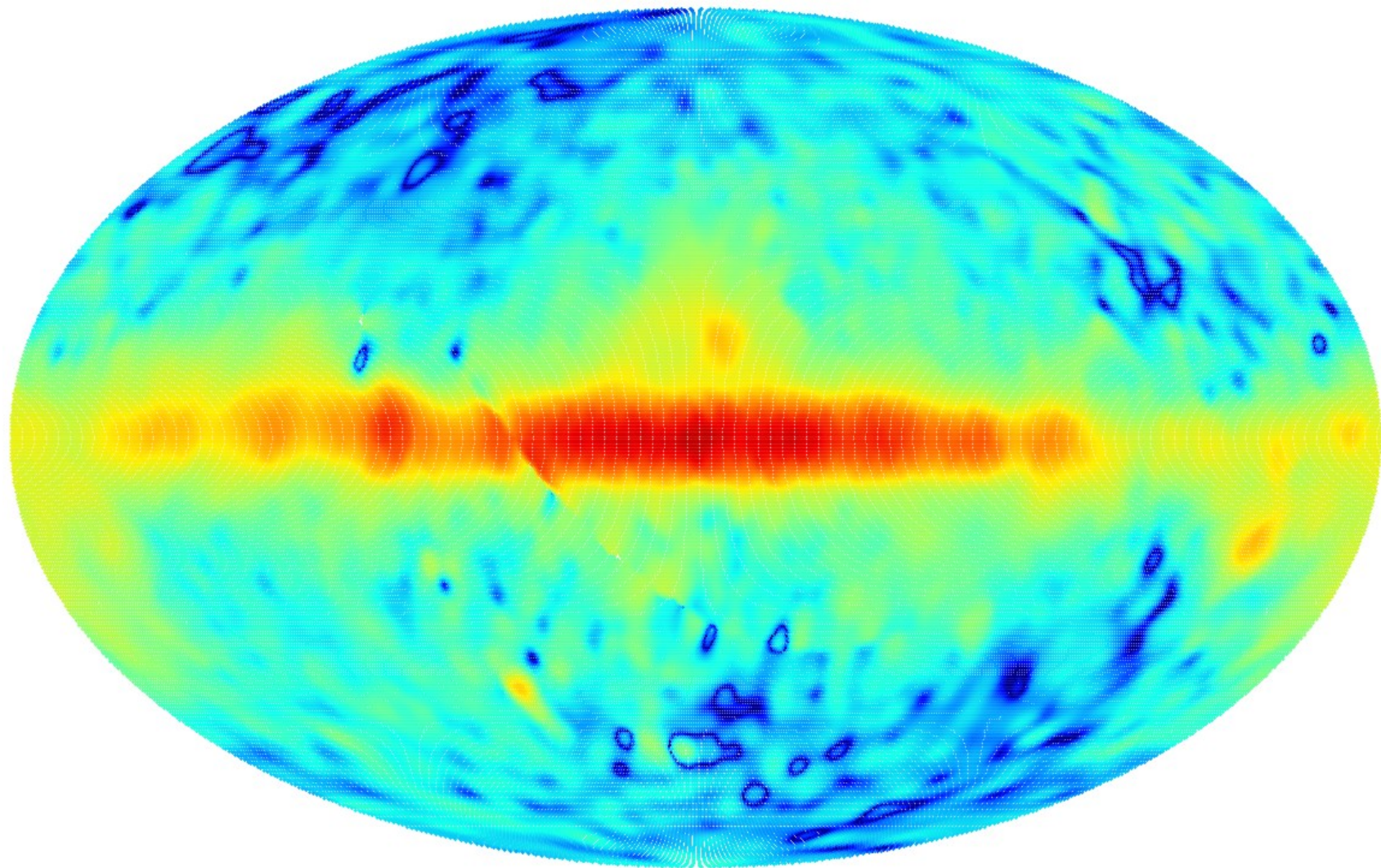


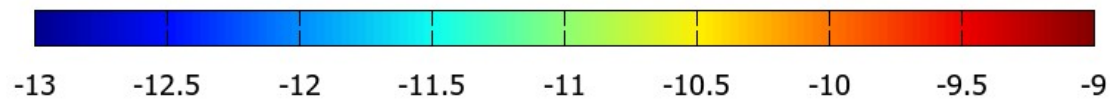
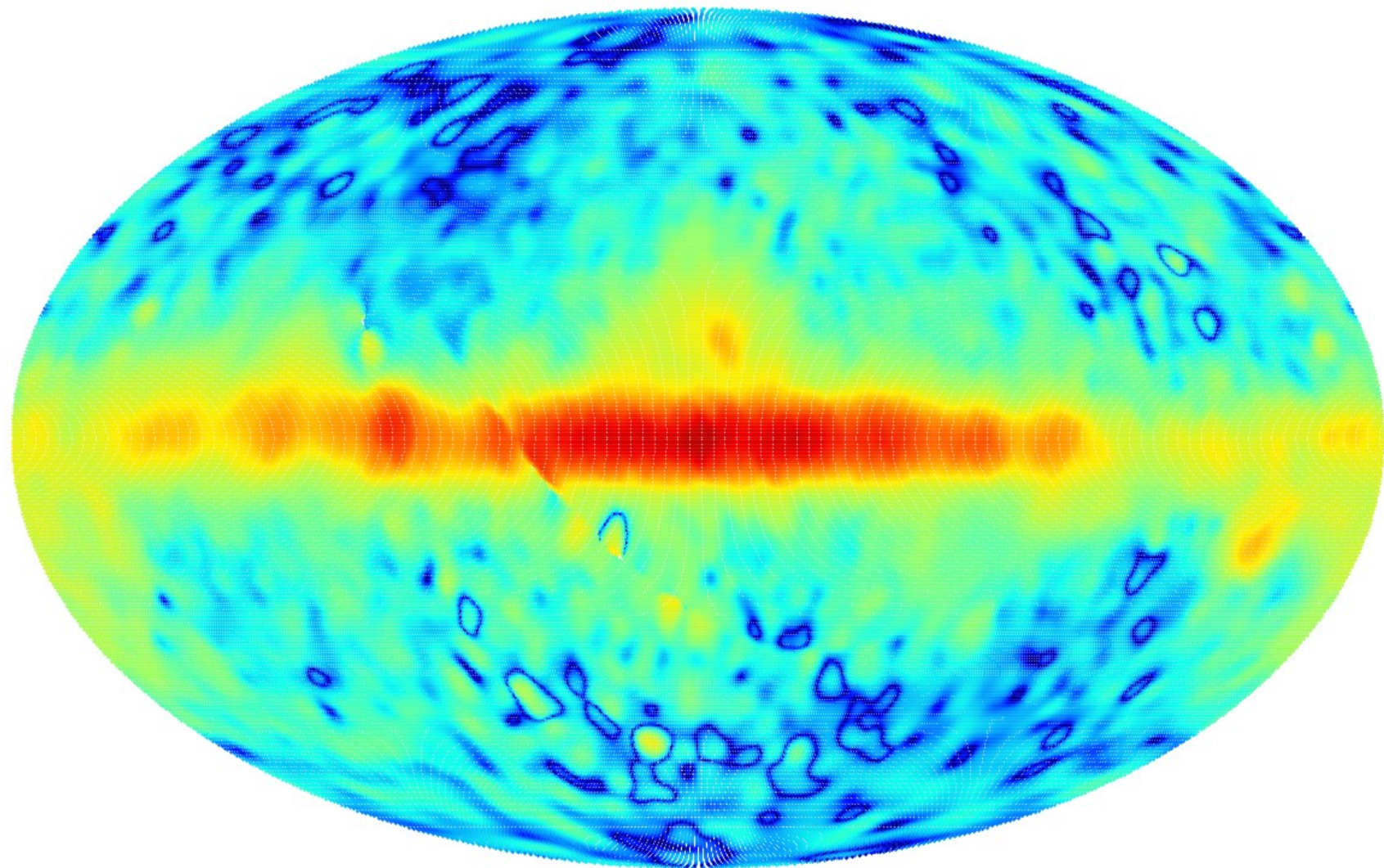


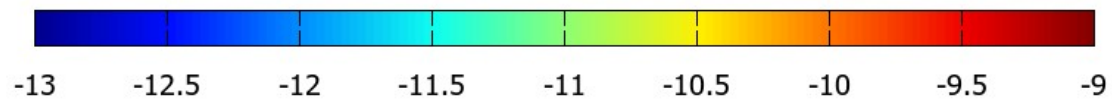
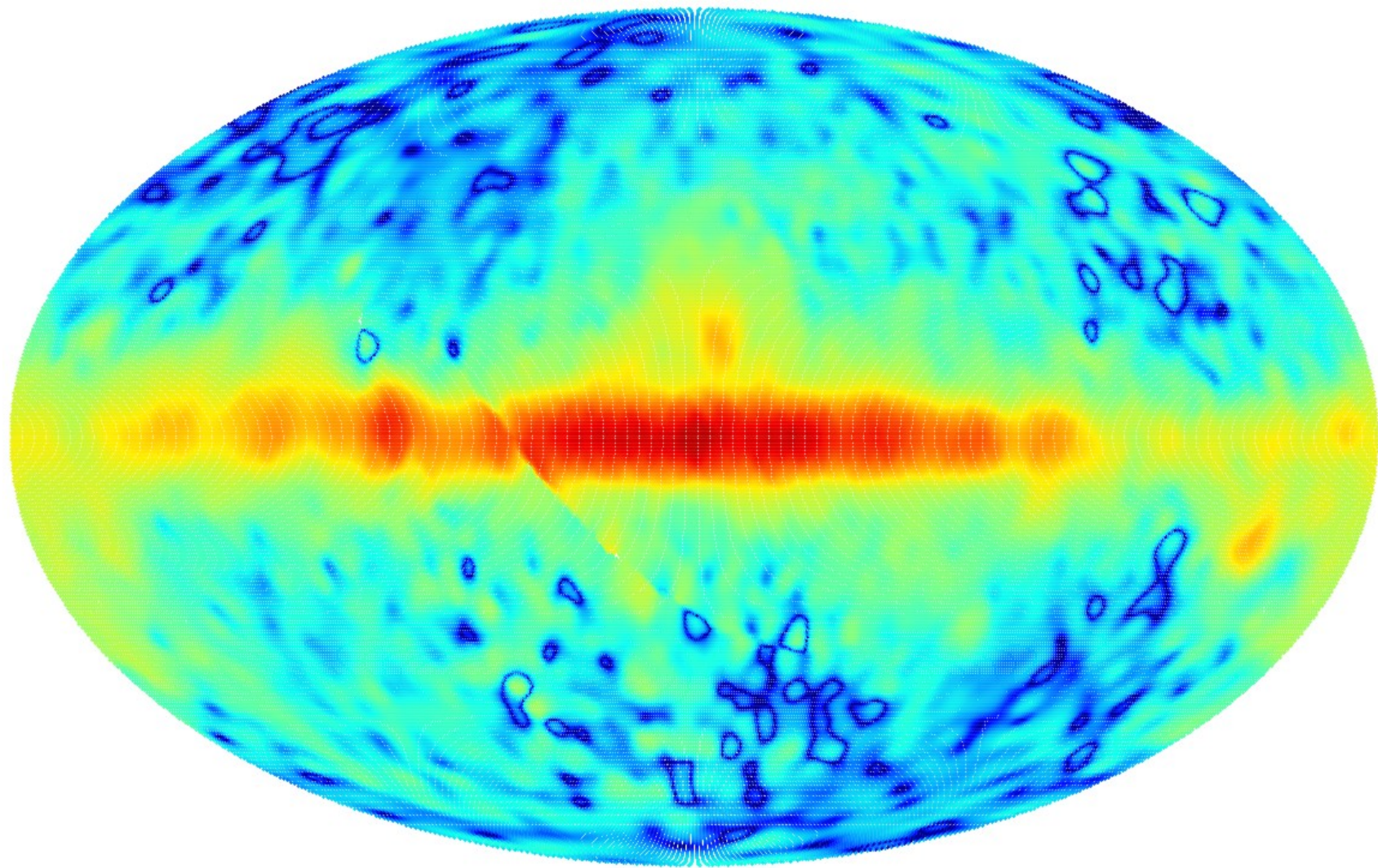


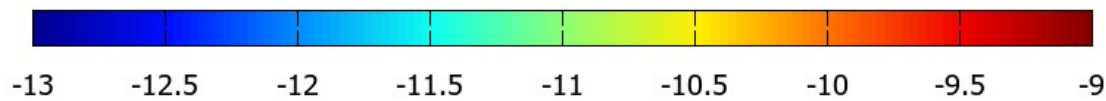
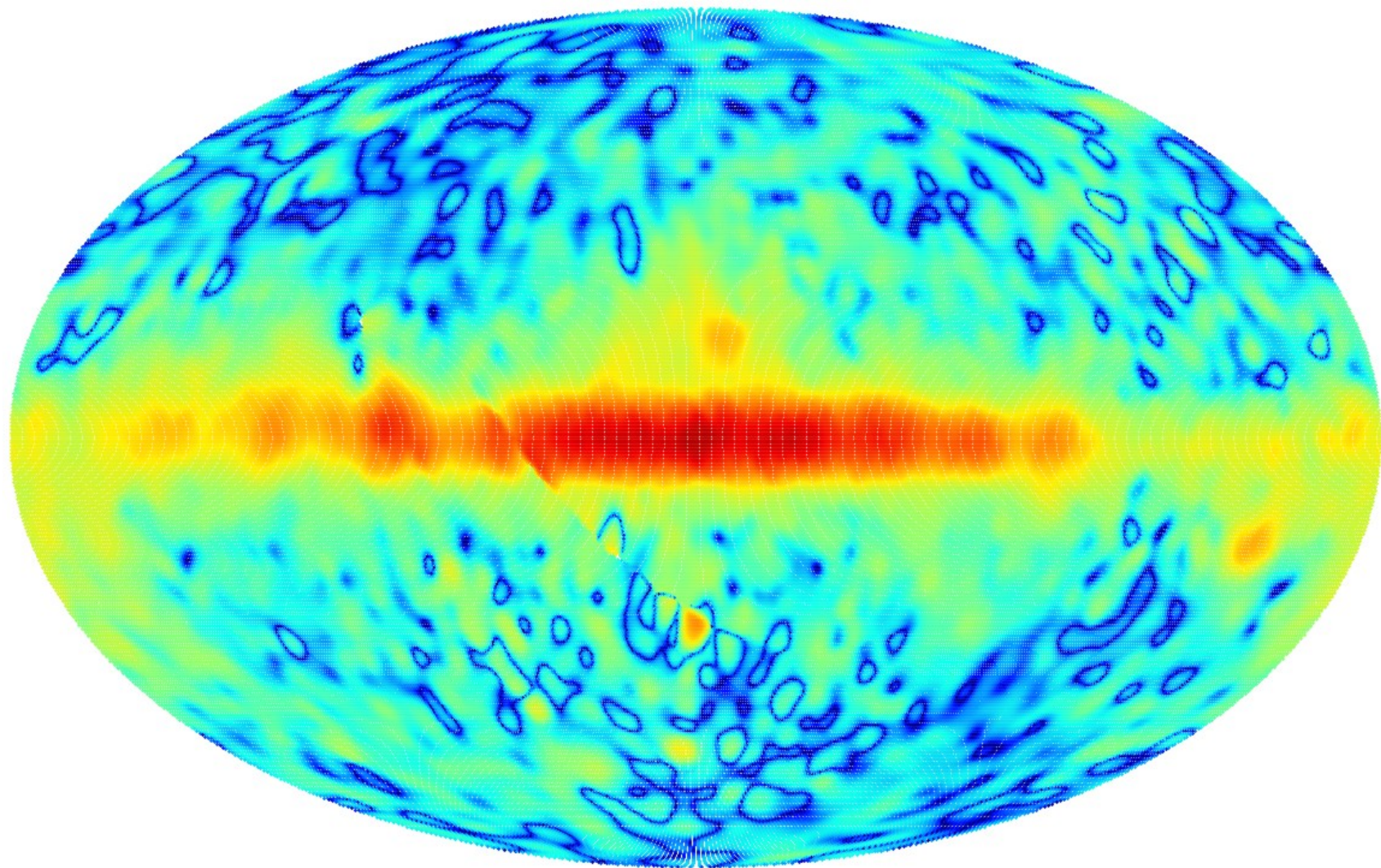


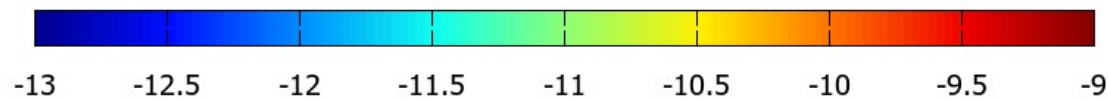
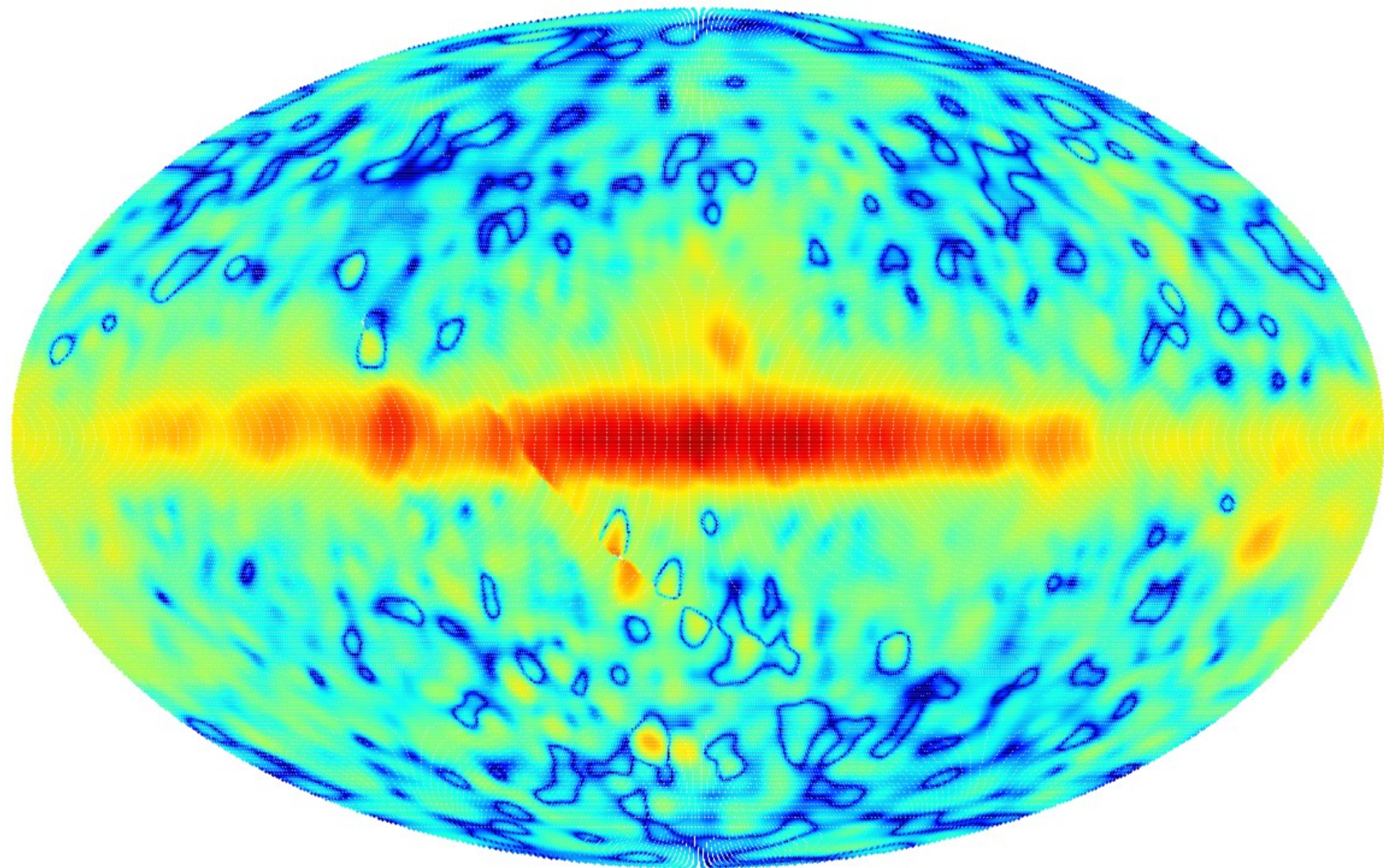


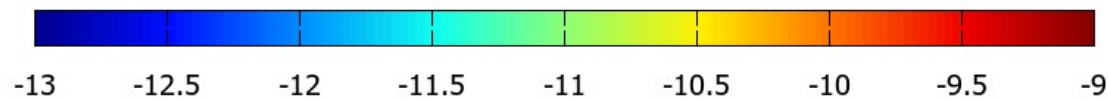
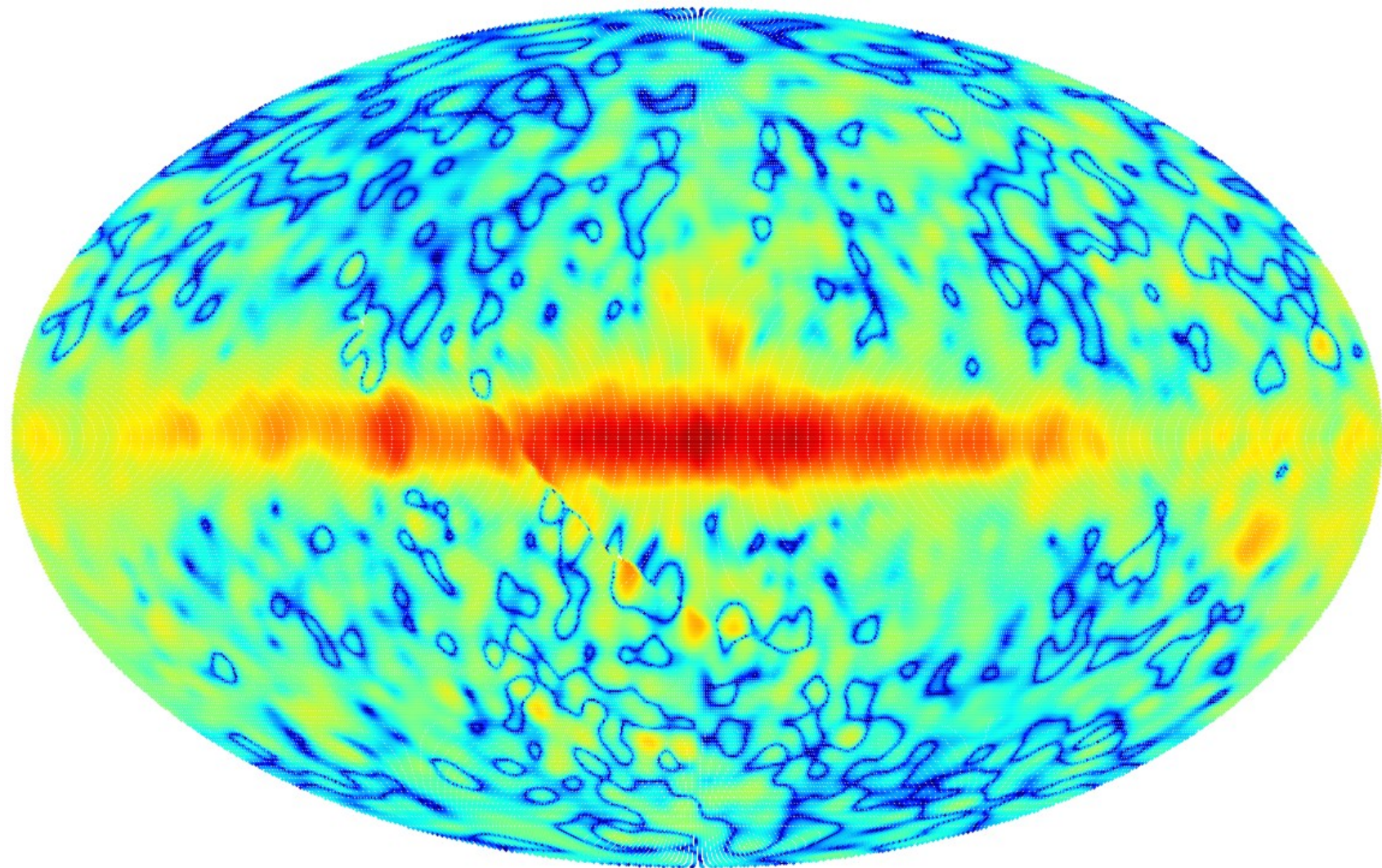


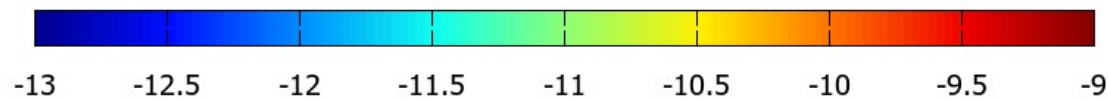
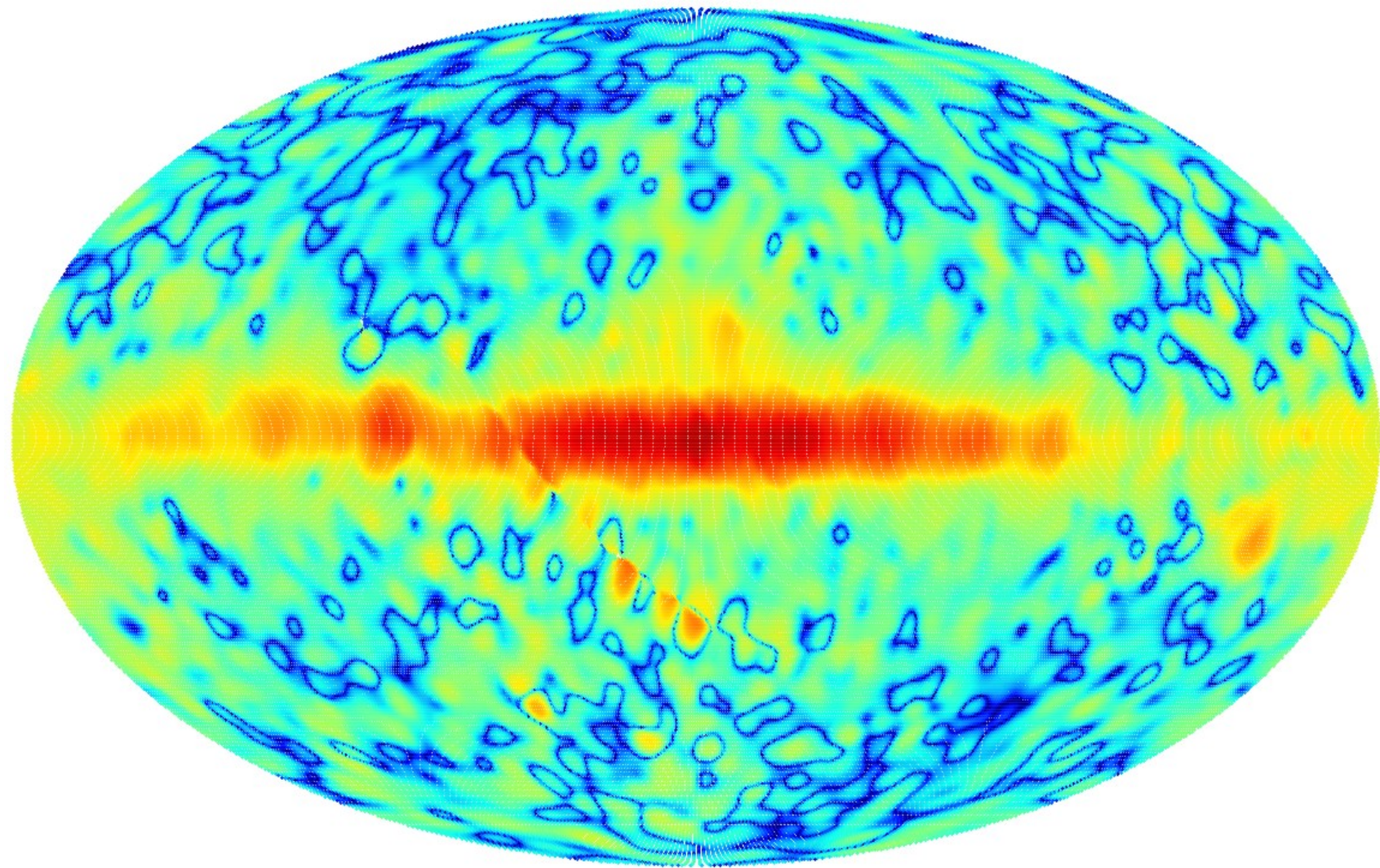


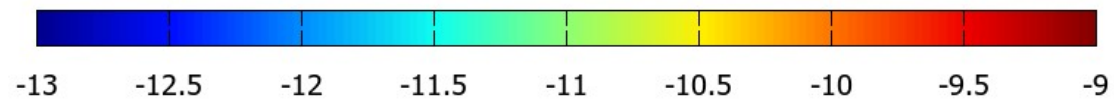
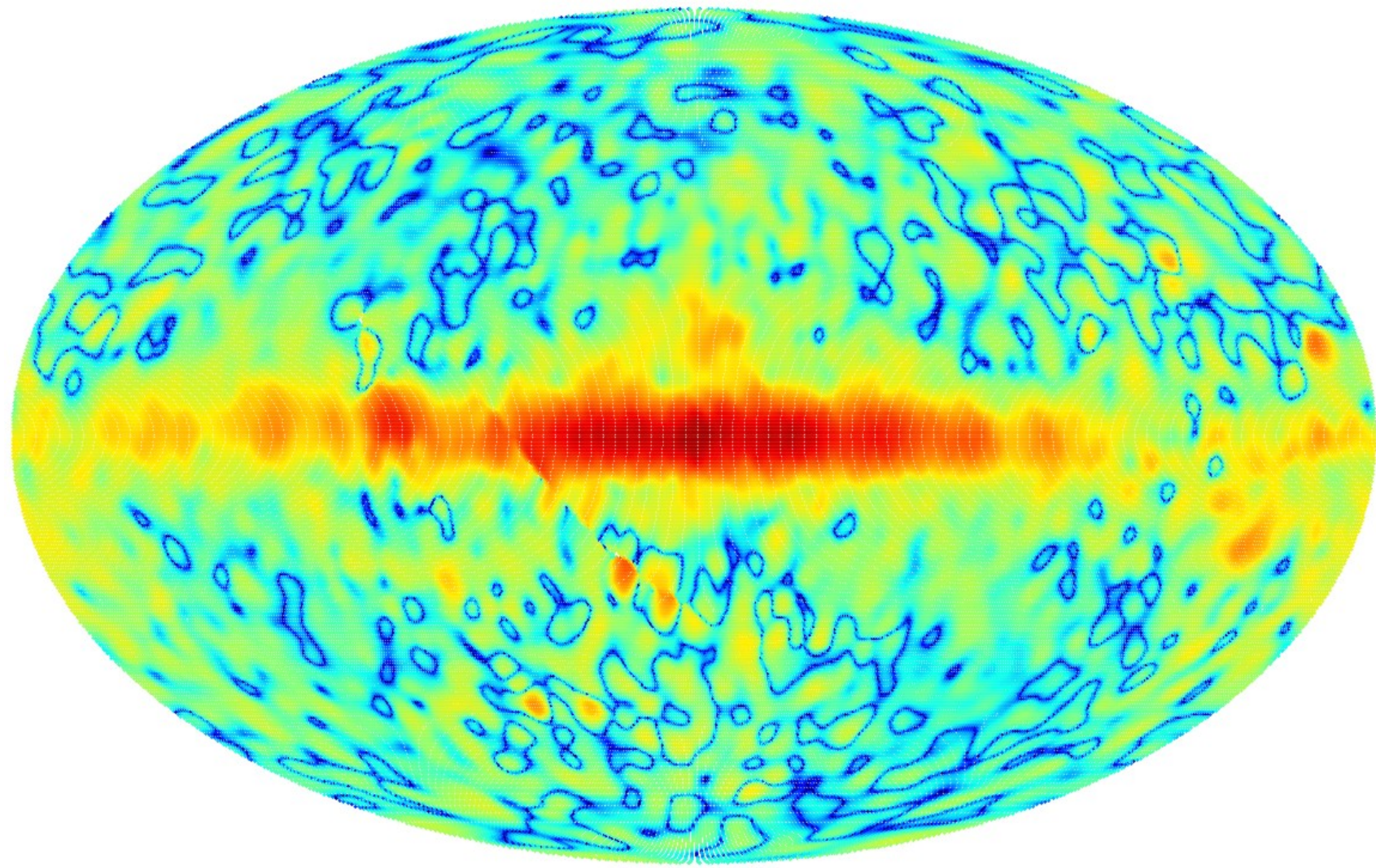


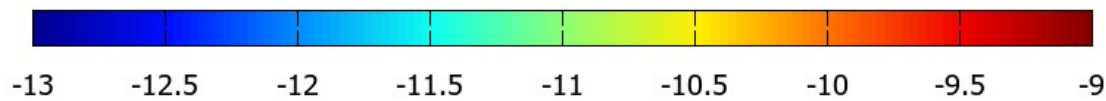
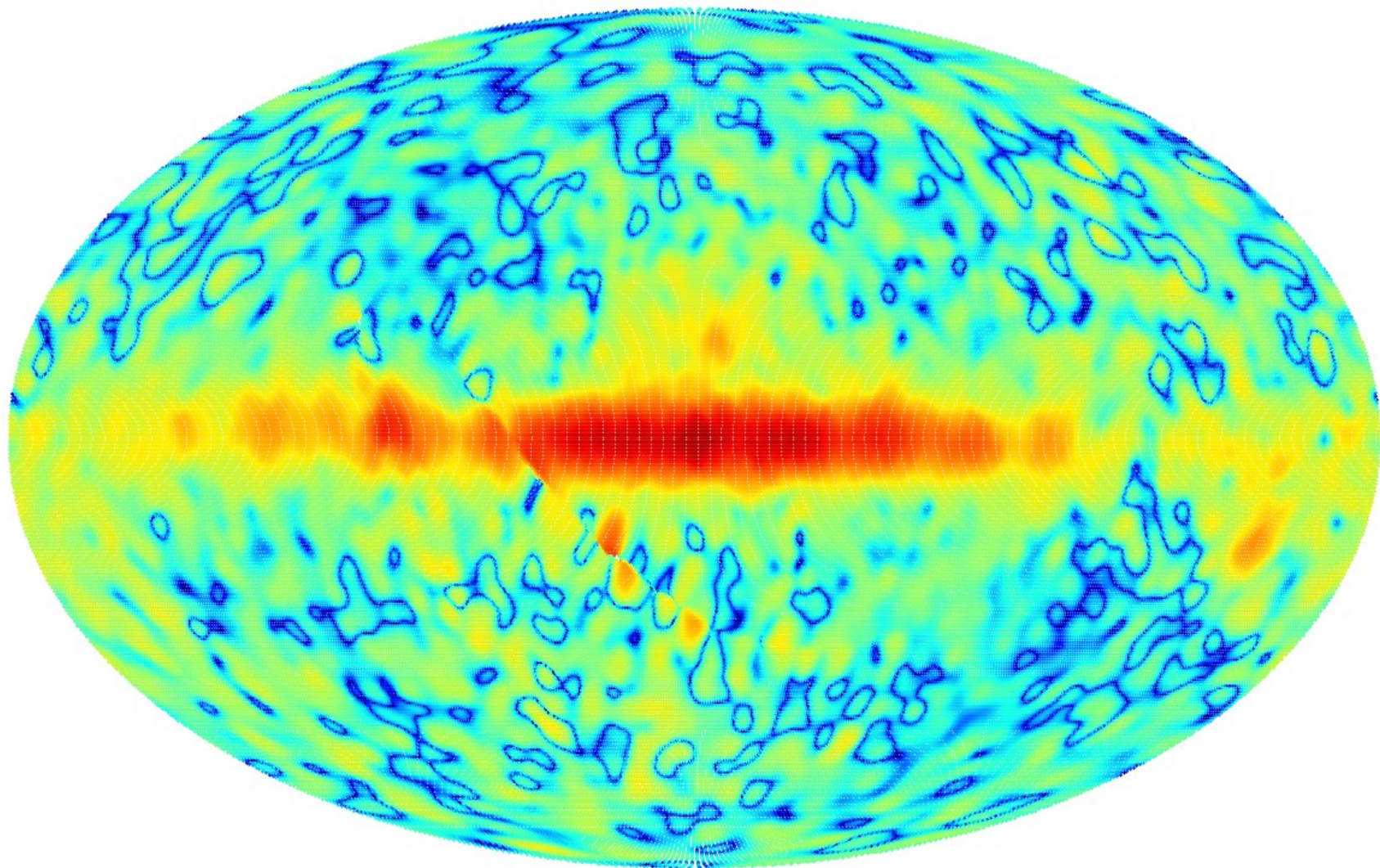


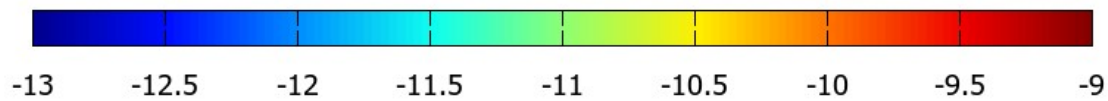
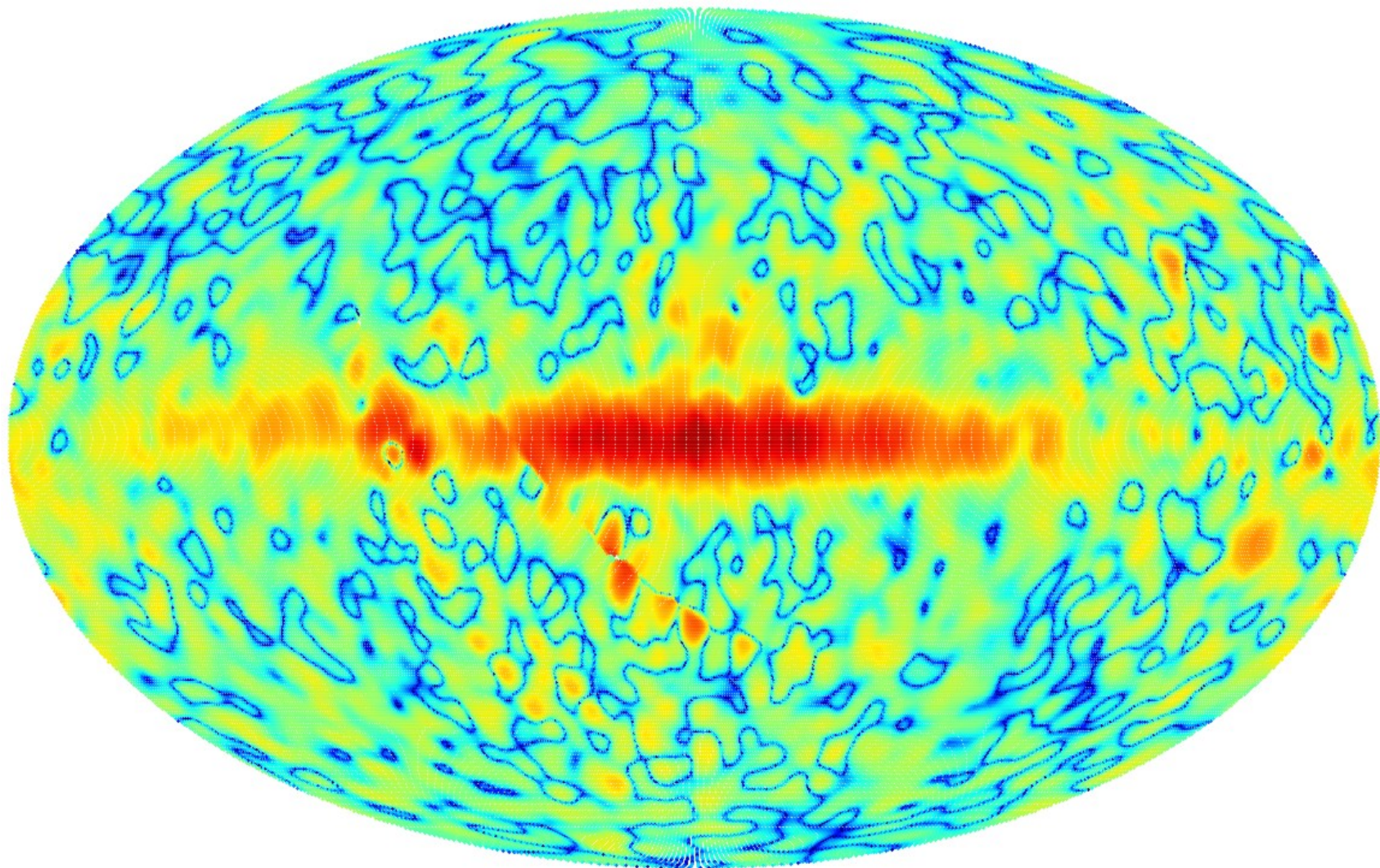




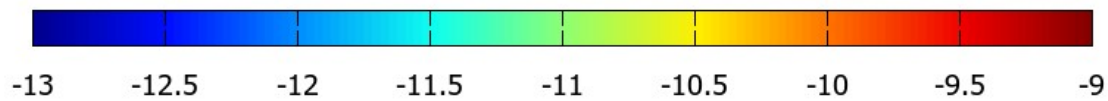
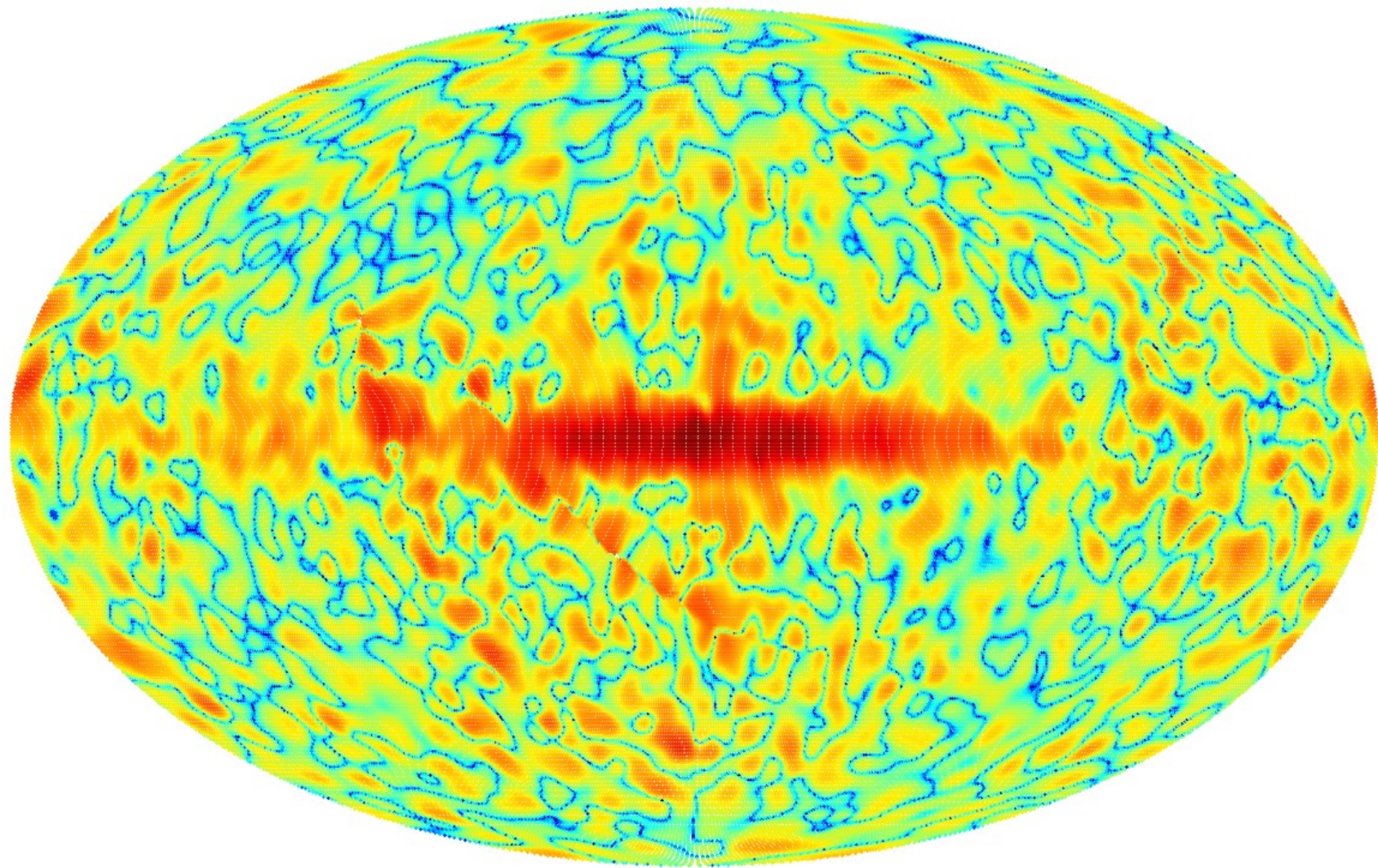






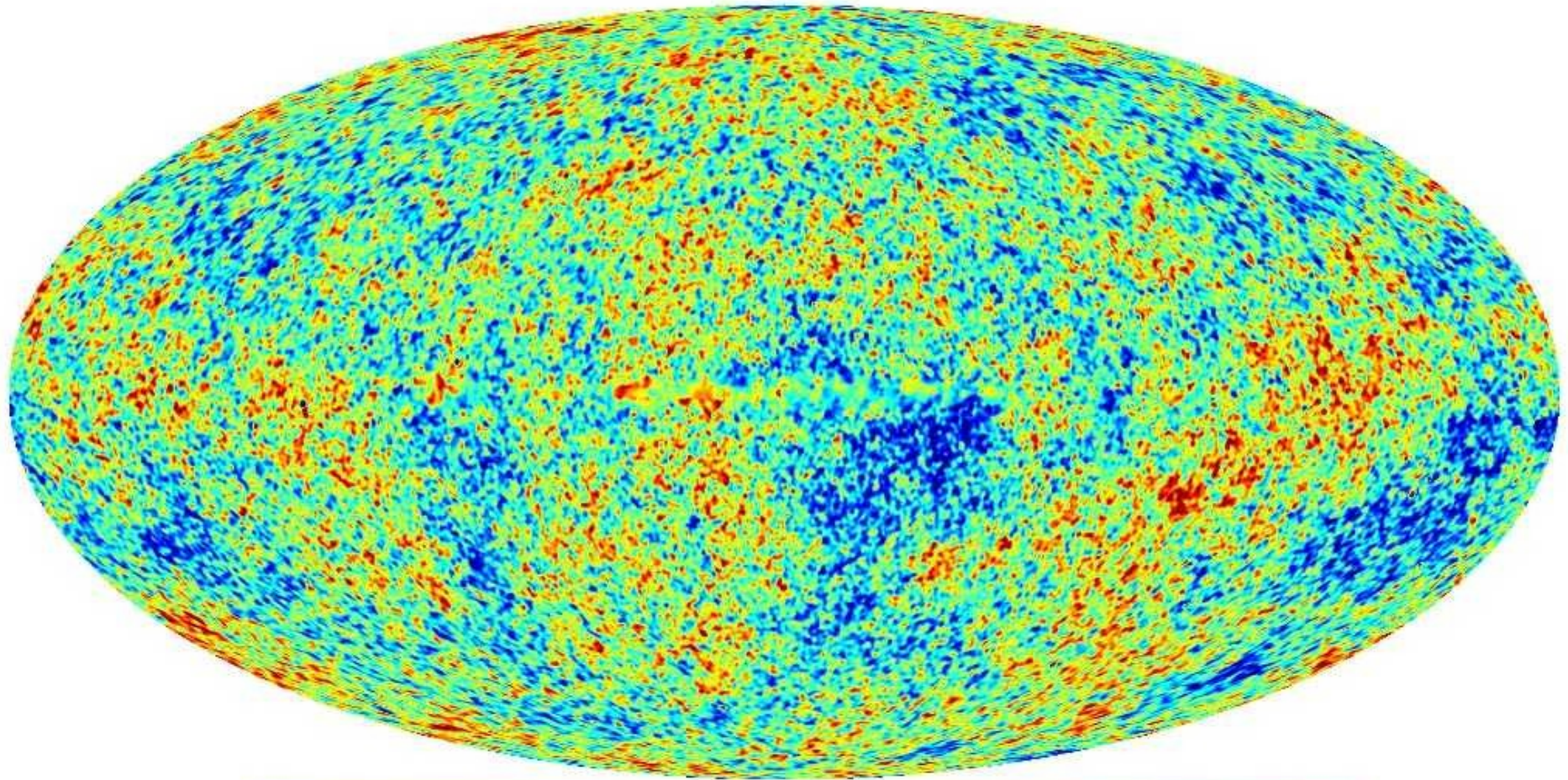


-13 -12.5 -12 -11.5 -11 -10.5 -10 -9.5 -9



El FCM es muy homogéneo pero...

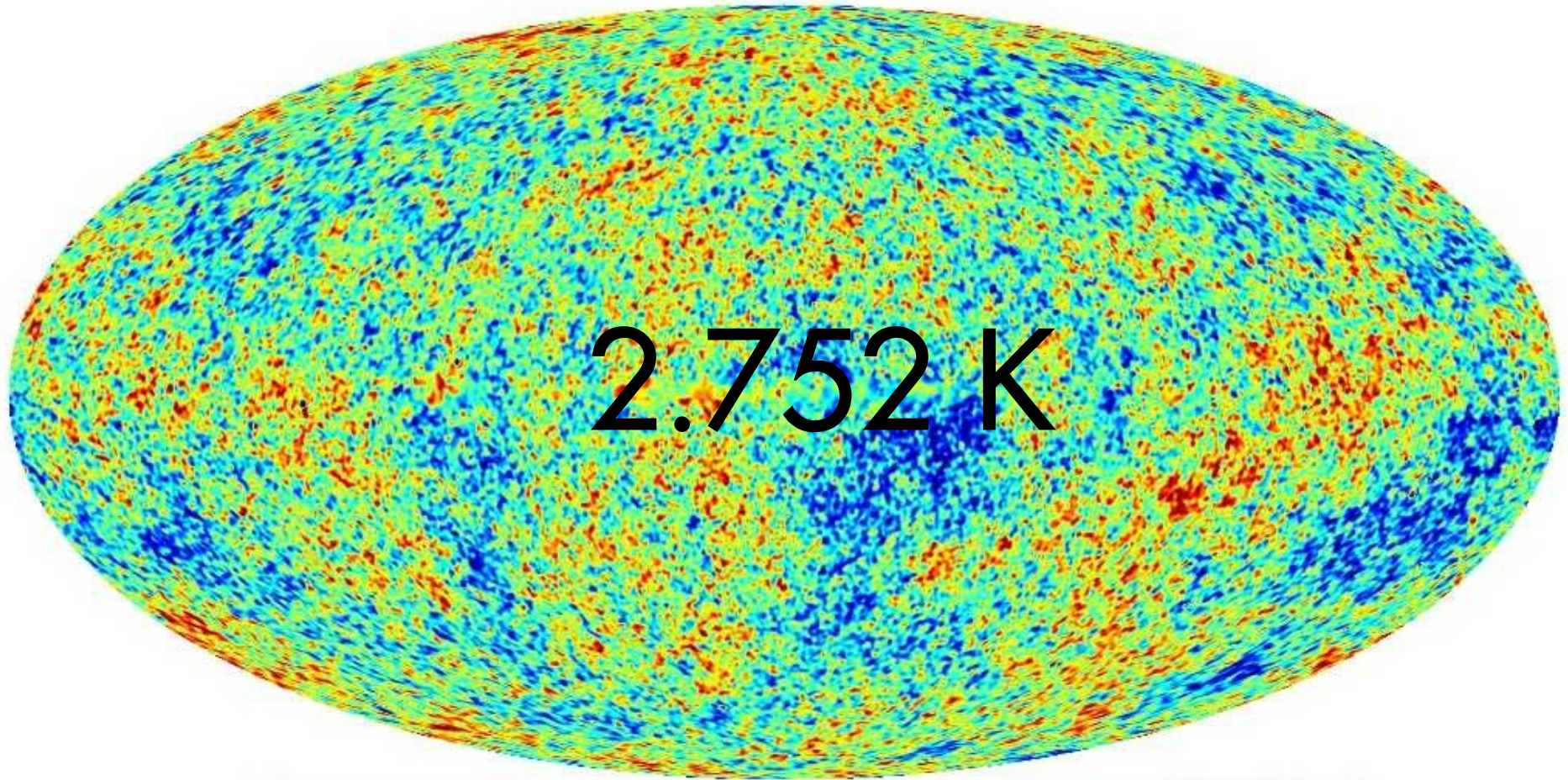
está lleno de anisotropías



-200μK

200μK

la huella digital del Big Bang



Observatorios de Rayos Gamma



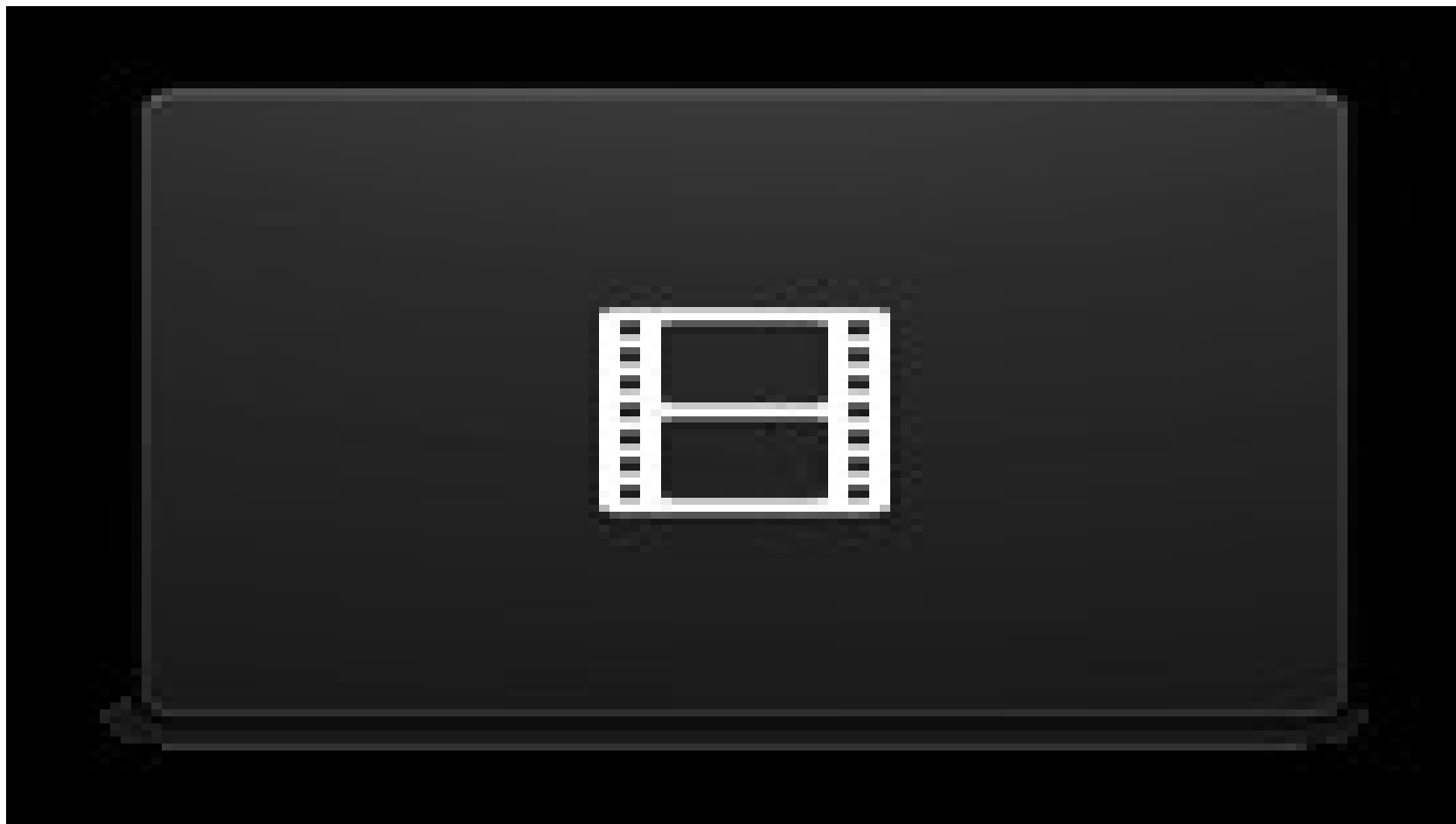
Fermi-LAT (Satélite)

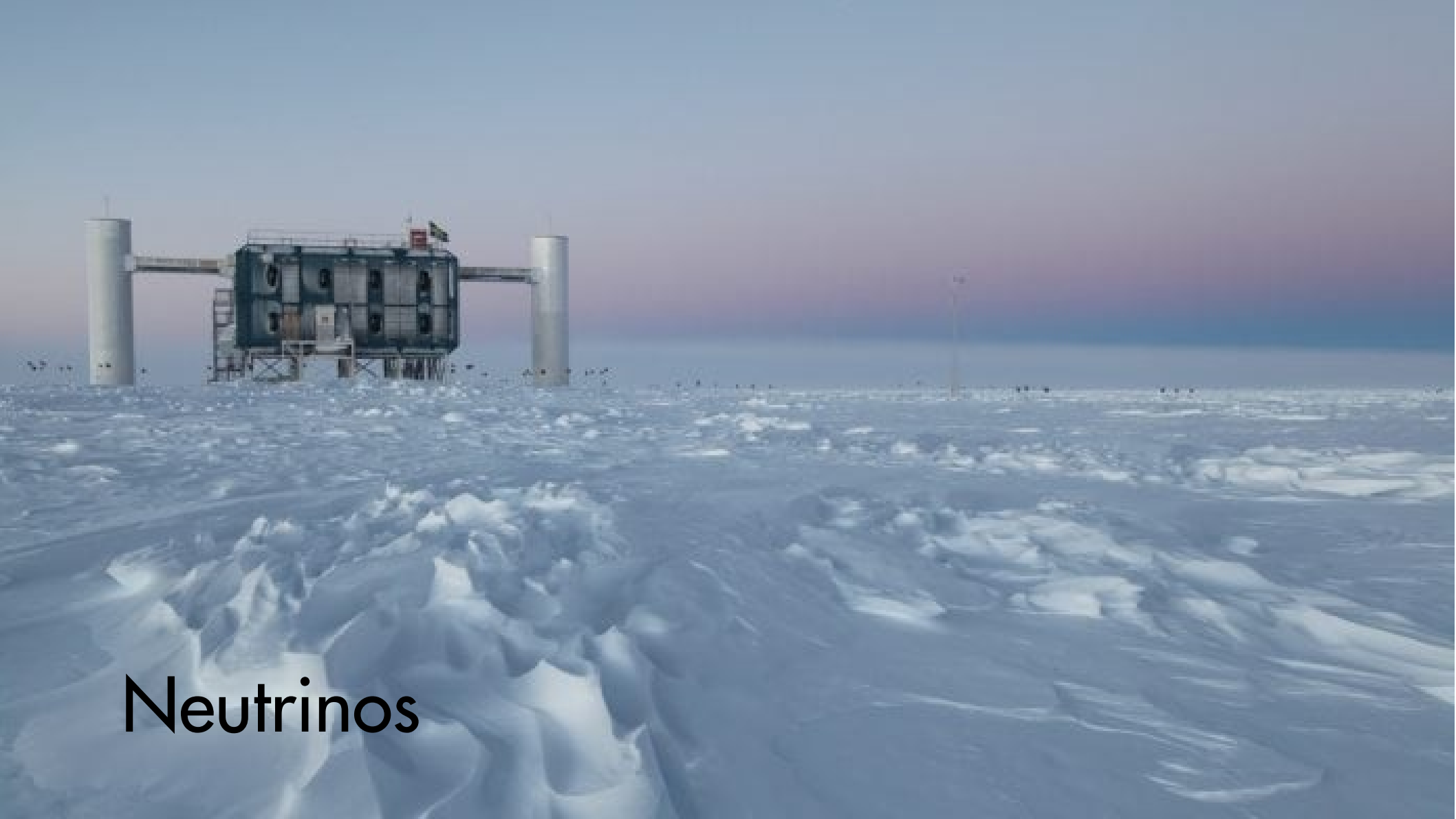


HESS (Namibia), MAGIC (España),
CTA (España y Chile)



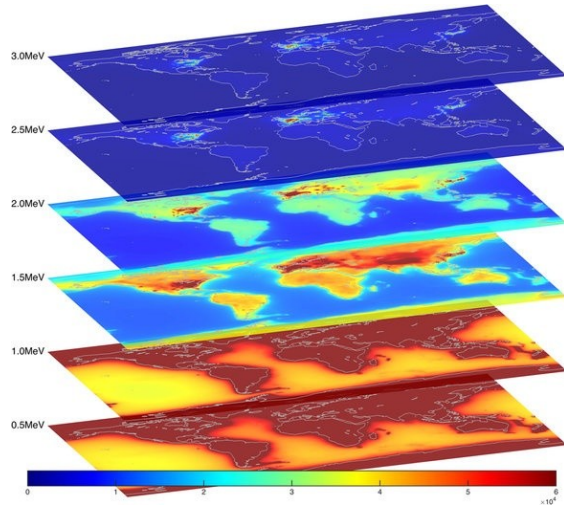
HAWC (México)



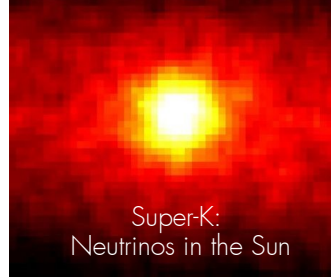
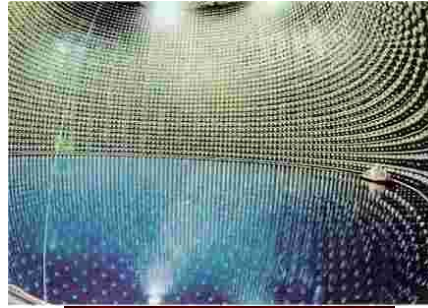
A photograph of the IceCube Neutrino Observatory in Antarctica. The central structure is a dark, rectangular building with a grid of windows, flanked by two tall, white cylindrical towers. It sits on a metal platform in the middle of a vast, flat, white icy landscape. The sky is a pale, hazy blue. In the foreground, there are large, jagged ice floes.

Neutrinos

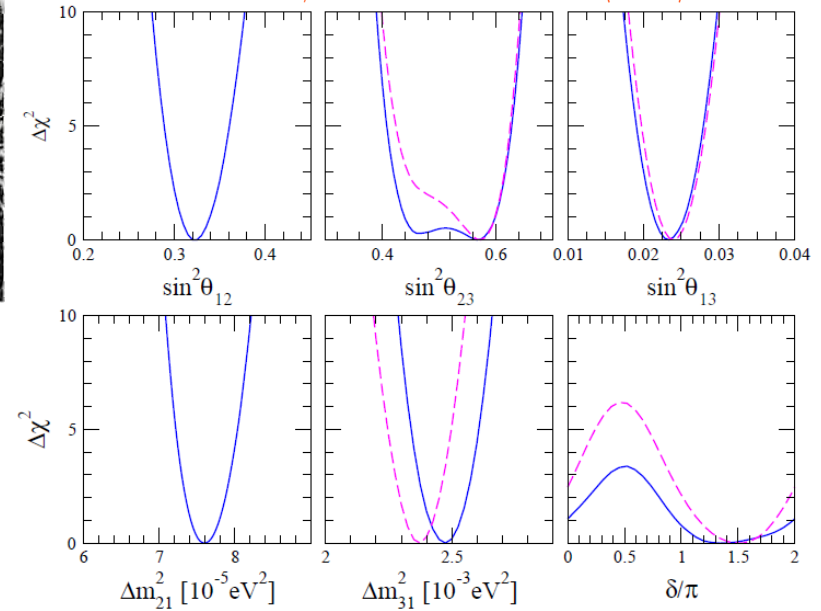
Neutrinos



AGM2015: Antineutrino Global Map 2015

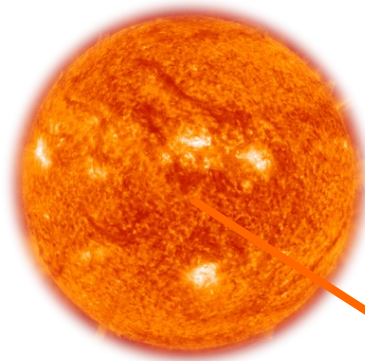


Forero, Tortola and Valle PRD 90 (2014) 093006



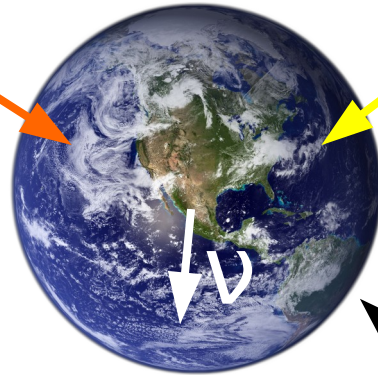
Son las partículas muy ligeras y misteriosas. Participan en los decaimientos radioactivos. Interactúan muy poco

Fuentes de neutrinos



Sol

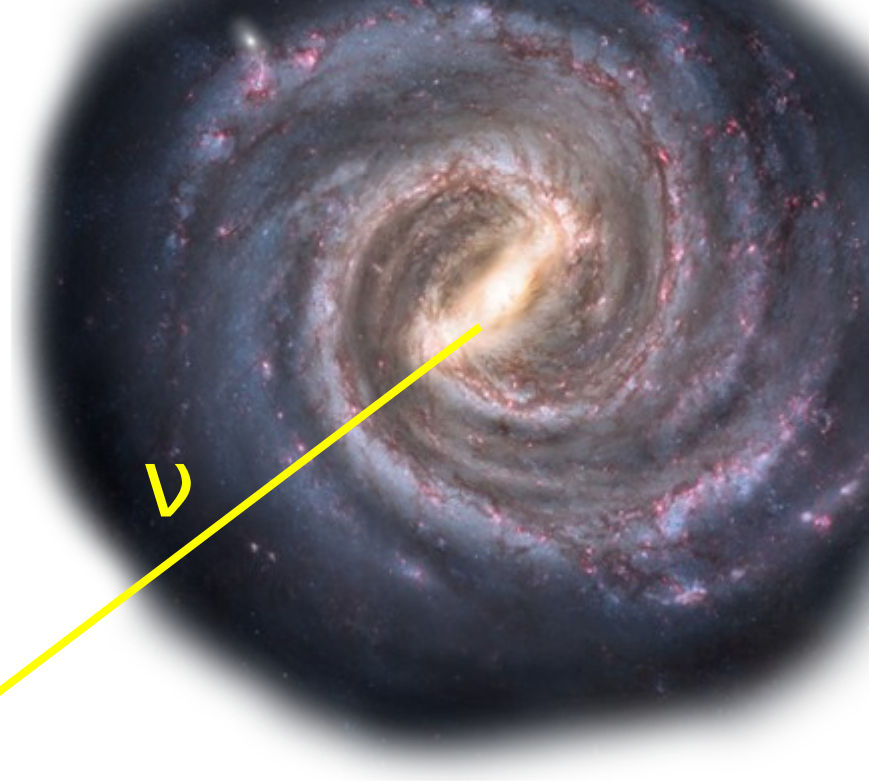
ν



Reactores Nucleares
La Tierra
La atmósfera

ν

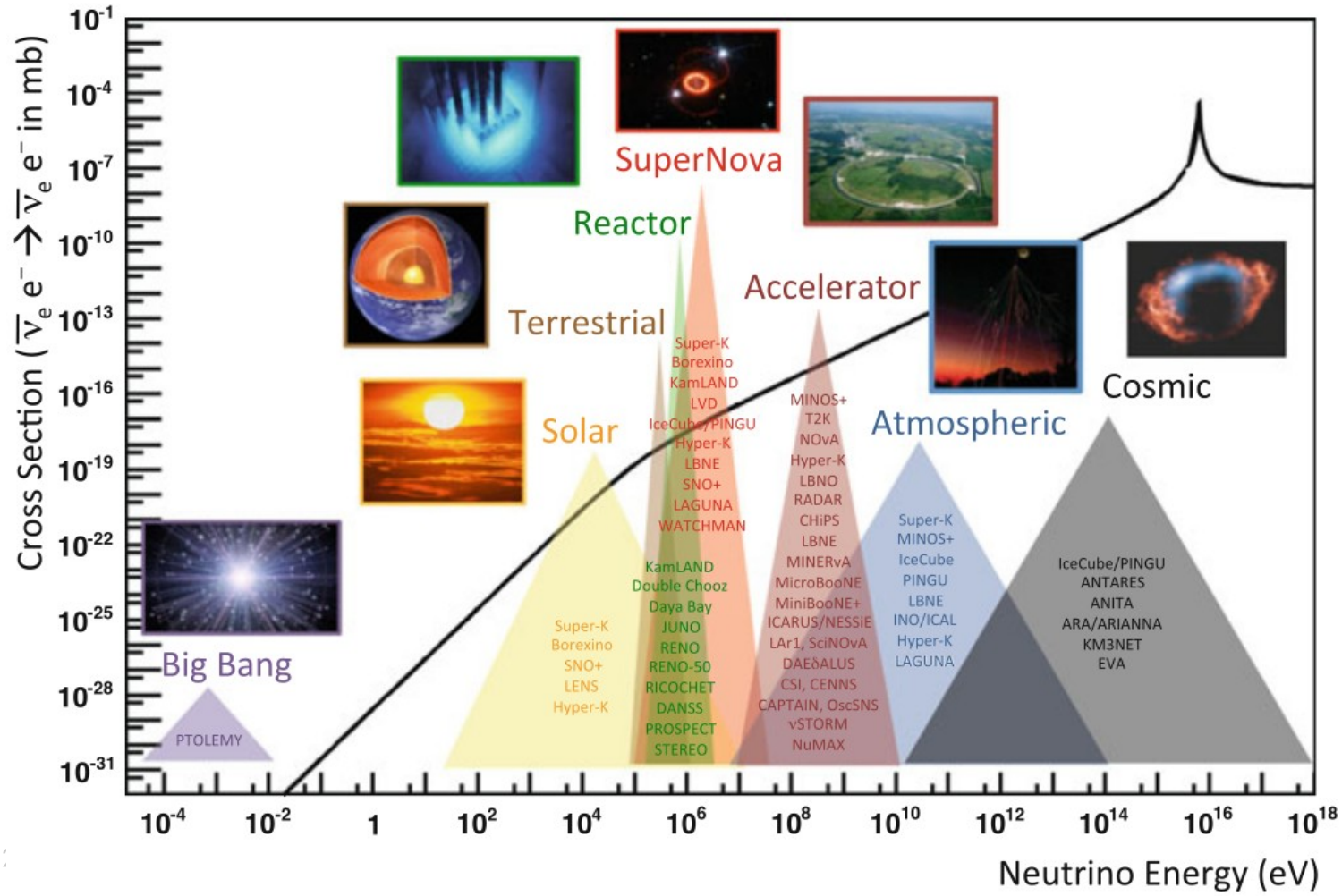
ν



ν

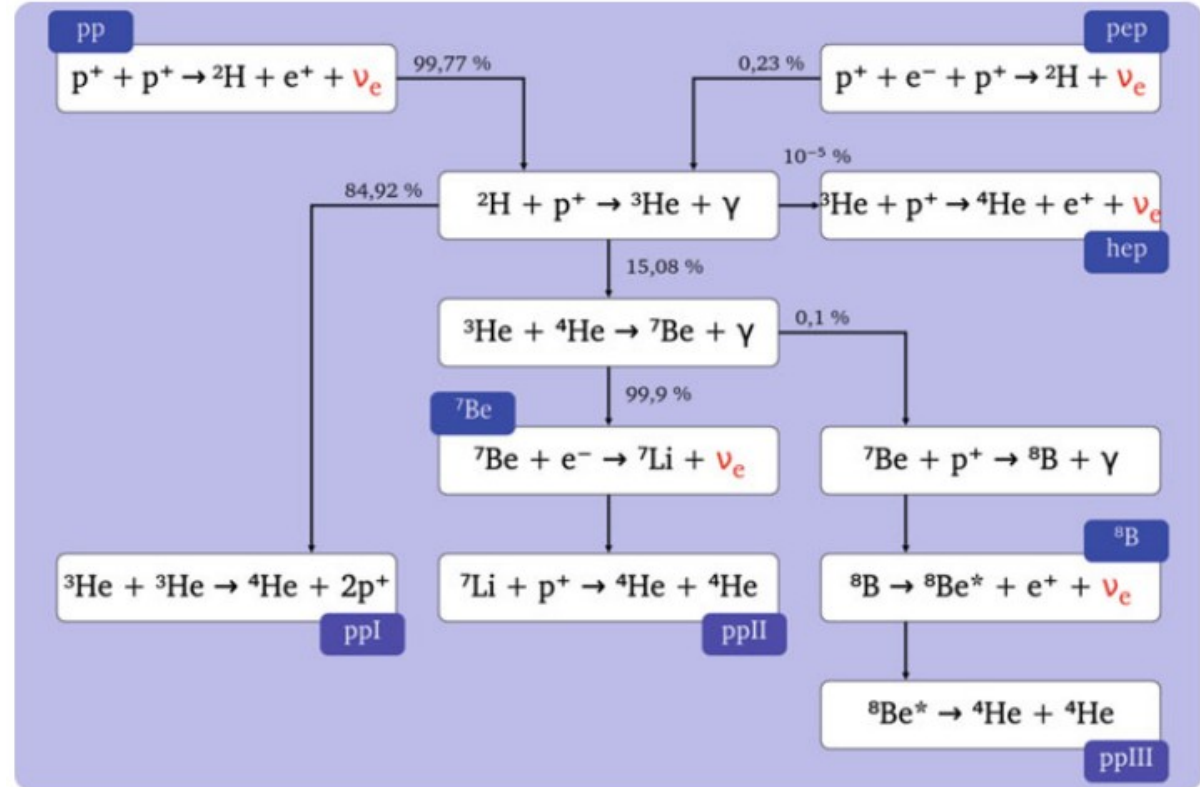
La vía Láctea
Centro galáctico
Big Bang

Fuentes de neutrinos



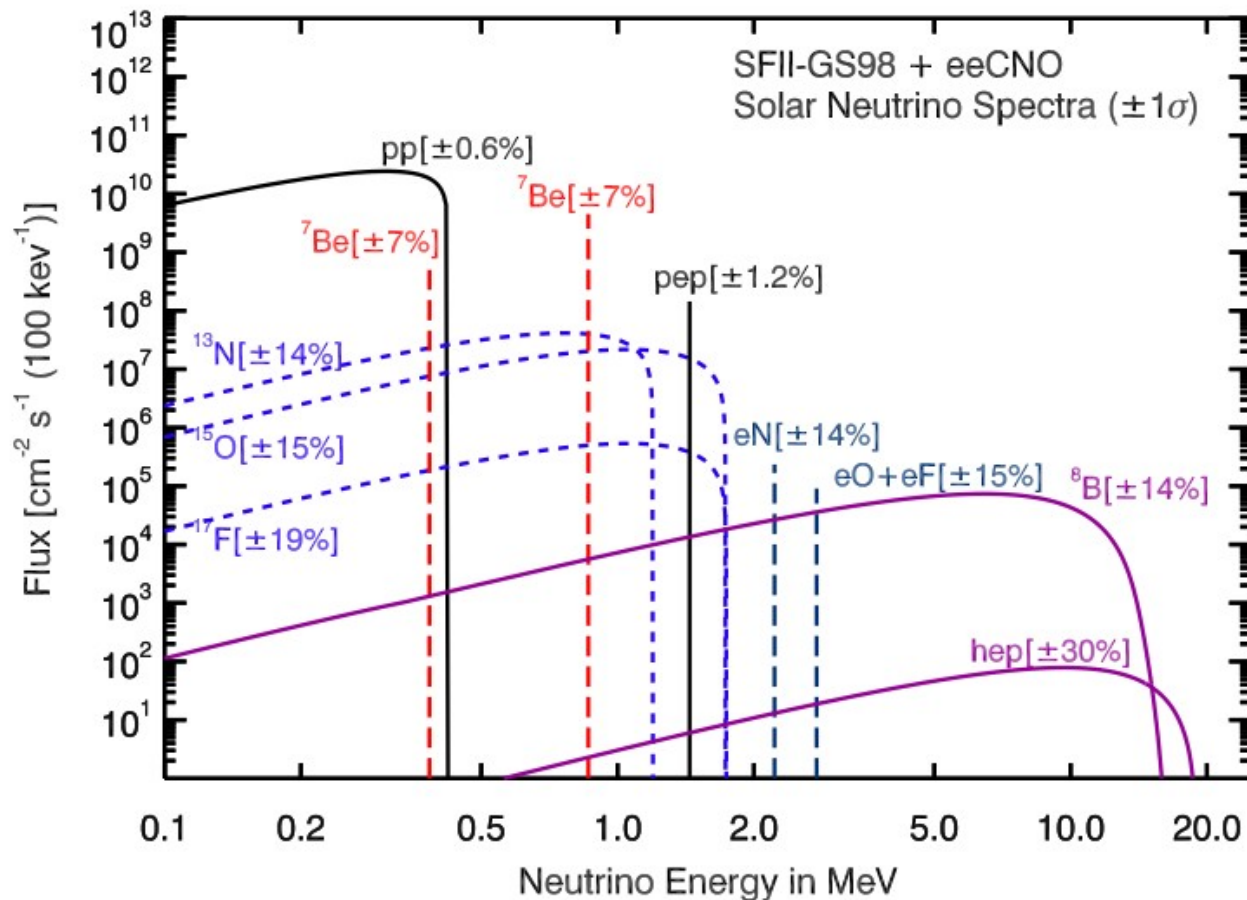
Neutrinos Solares

El Sol es muy brillante en neutrinos

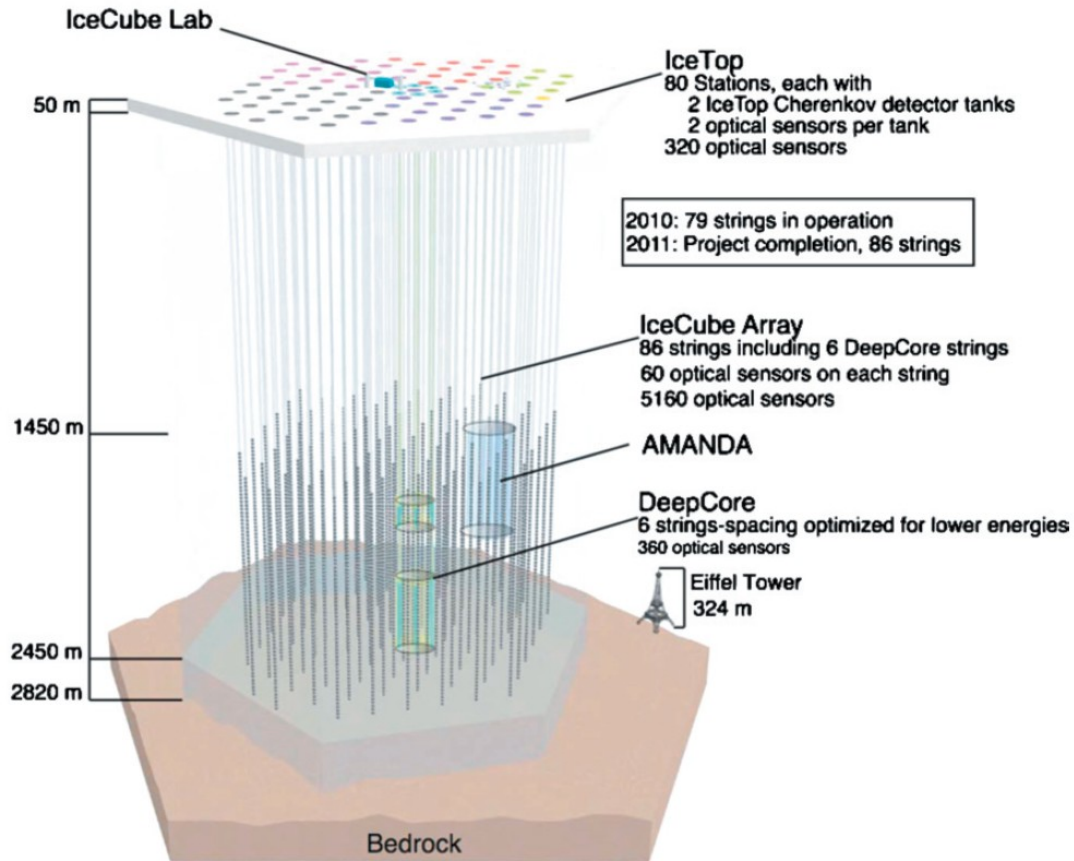


Neutrinos Solares

Nos permite ver el interior



Observatorios



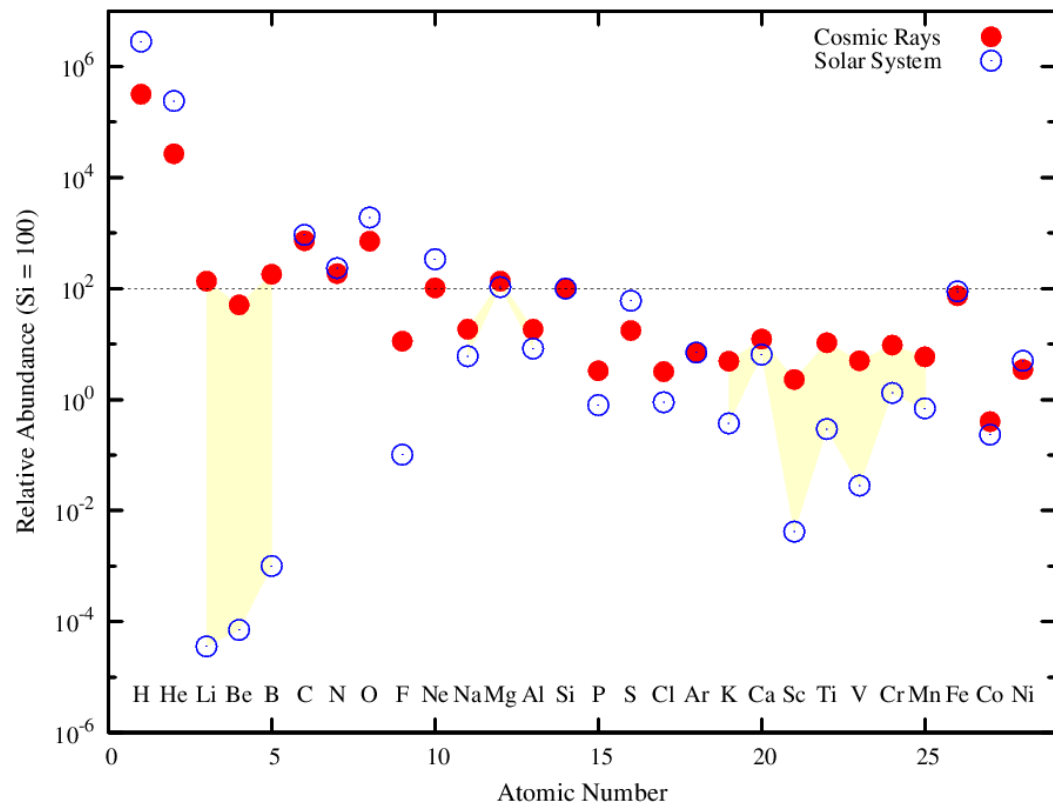
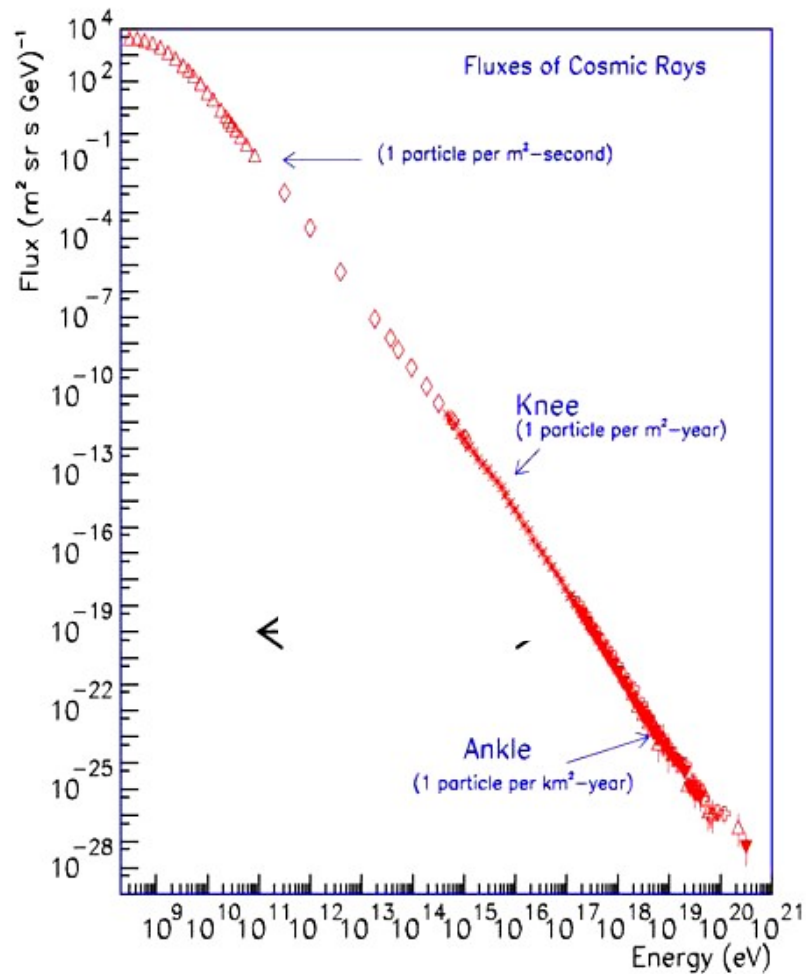
IceCube



Rayos Cósmicos

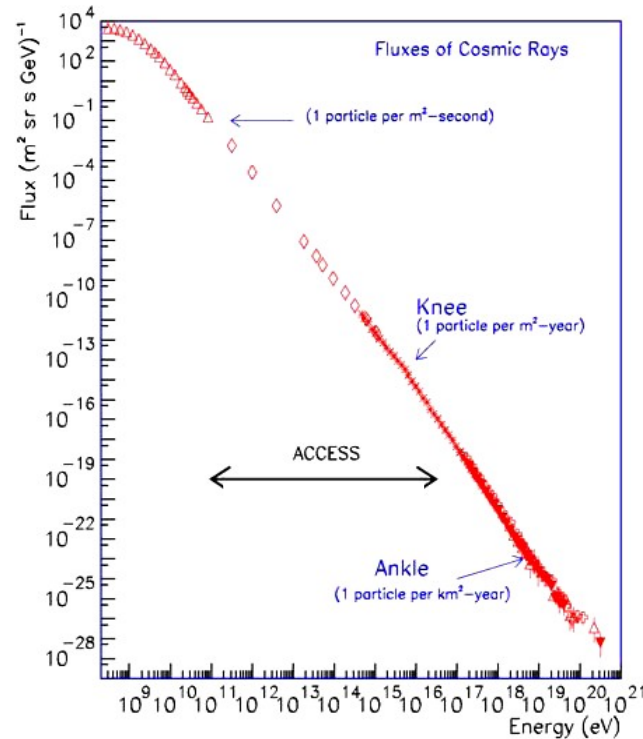


Energía y composición



¿Cómo observar Rayos Cósmicos?

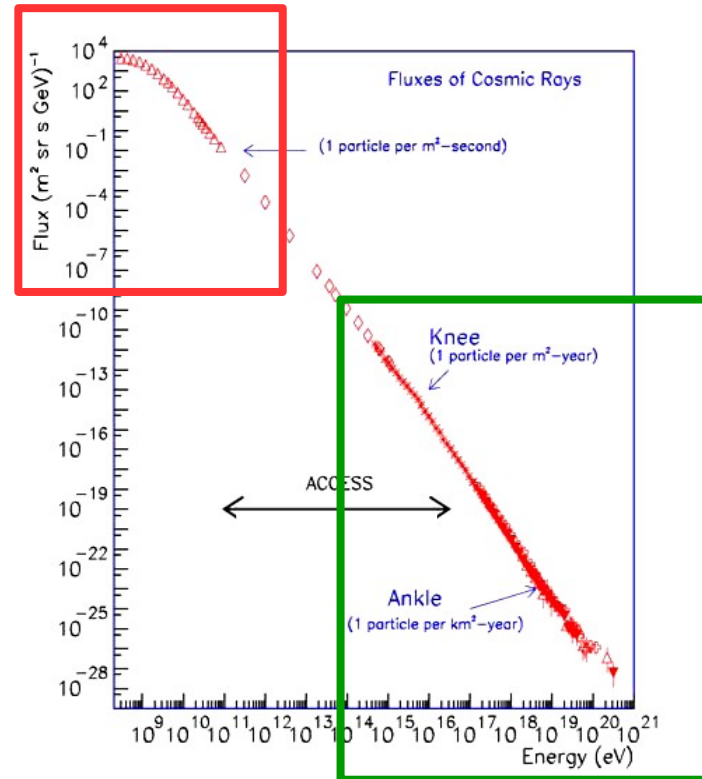
si la atmósfera absorbe gran cantidad de éstos.



¿Cómo observar Rayos Cósmicos?

si la atmósfera absorbe gran cantidad de éstos.

Detectores en
el espacio



detectores de
superficie

Observatorios de altitud



ATIC (antartida)



PAMELA (satélite)



AMS02 (ISS)

Observatorios de altitud

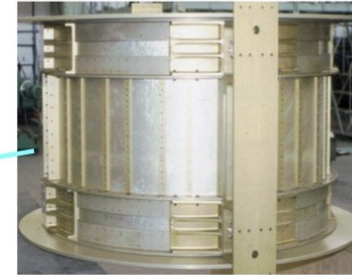
TRD



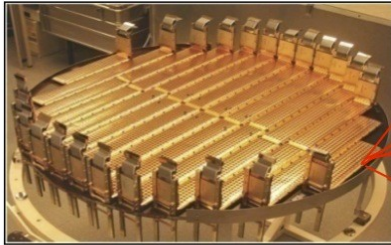
TOF



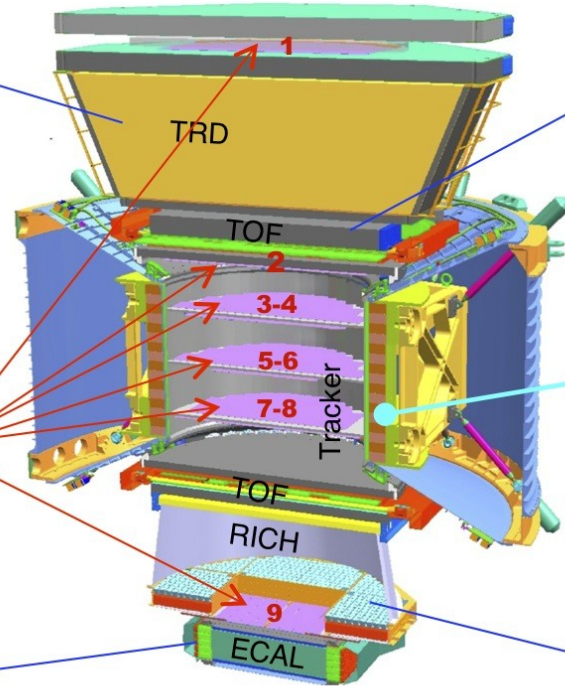
Magnet



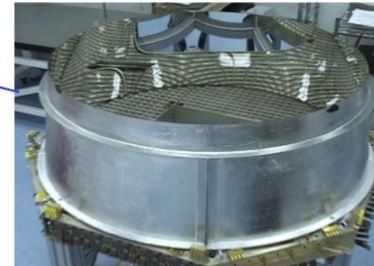
Silizium Spurdetektor



ECAL



RICH



Observatorios de altitud

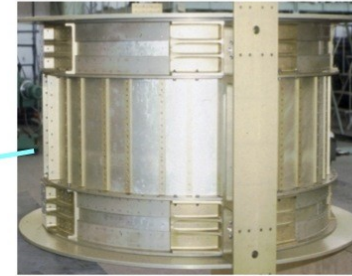
TRD



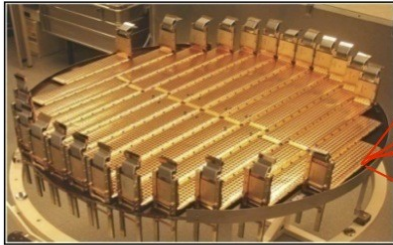
TOF



Magnet



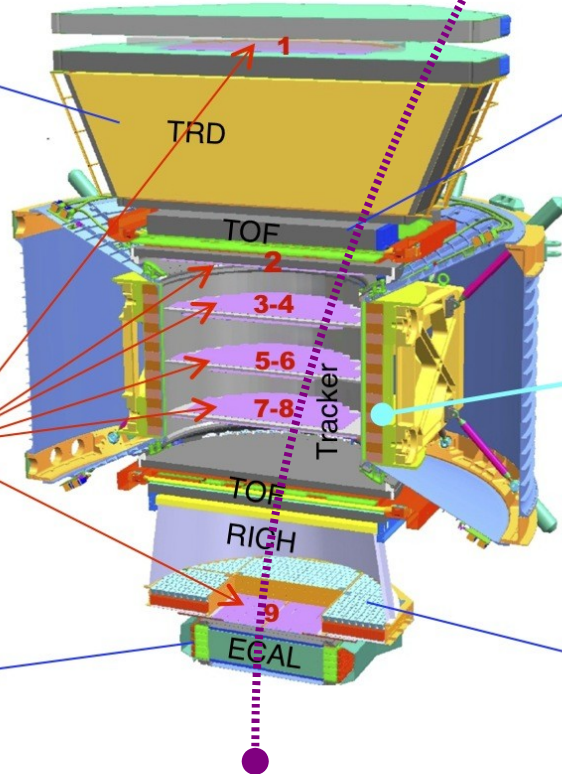
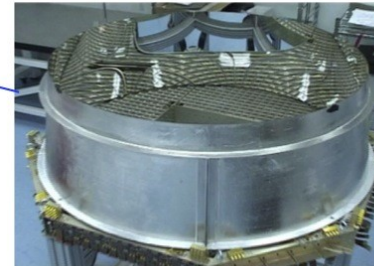
Silizium Spurdetektor



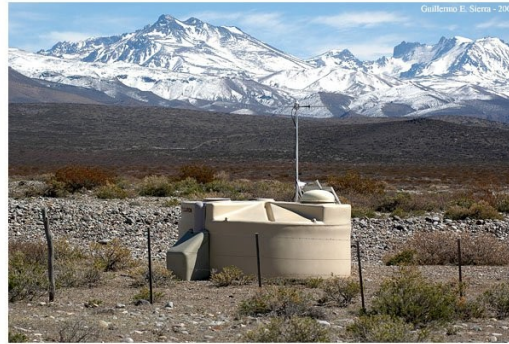
ECAL



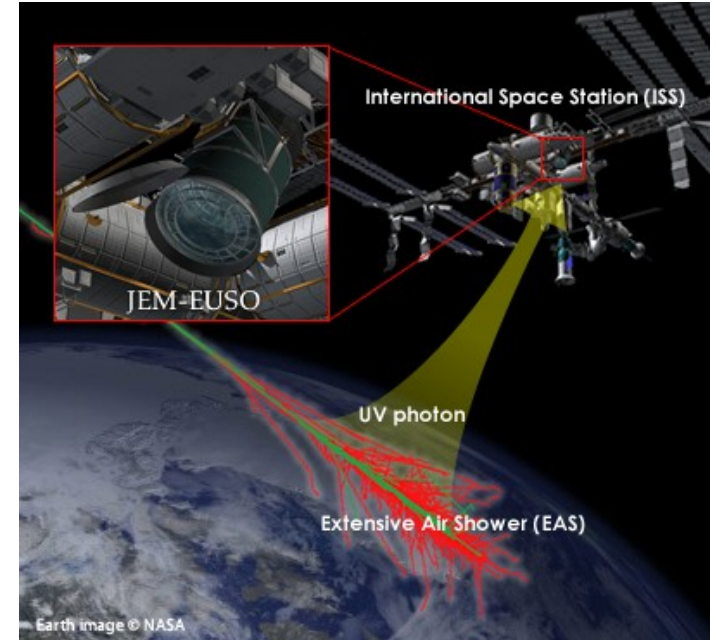
RICH



Observatorios de alta energía



Pierre Auger (Argentina)



JEM-EUSO (ISS)

Observatorio Pierre Auger



Telescopio de fluorescencia

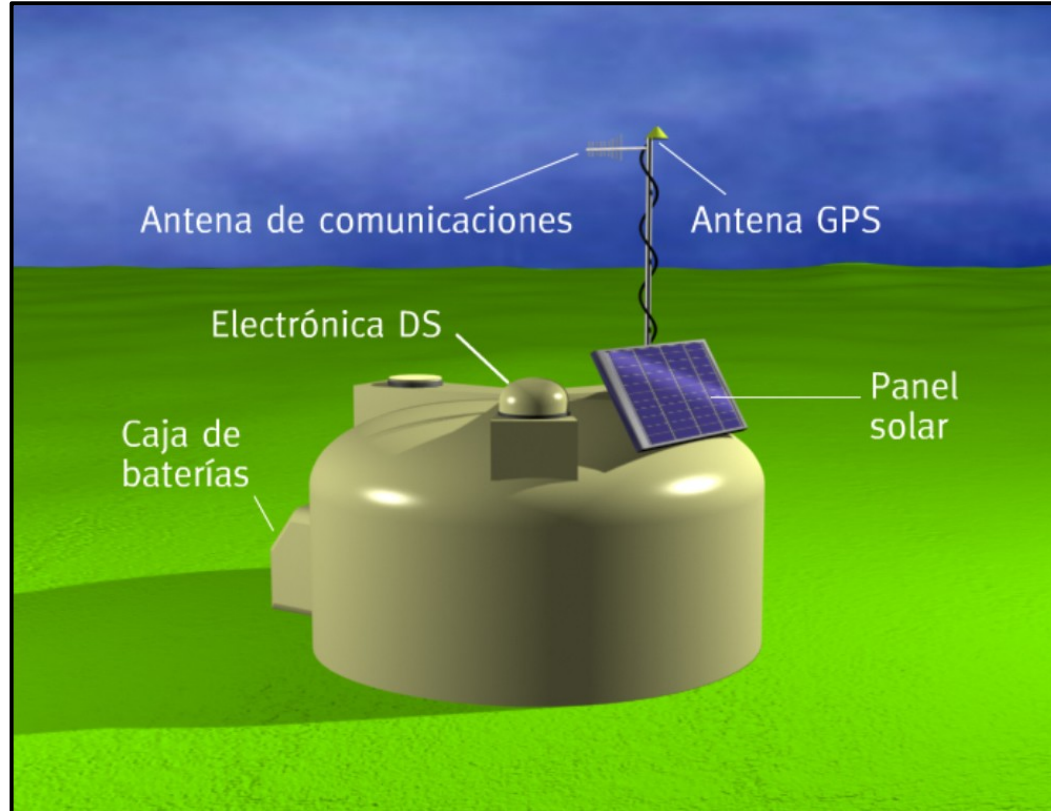


Vacas

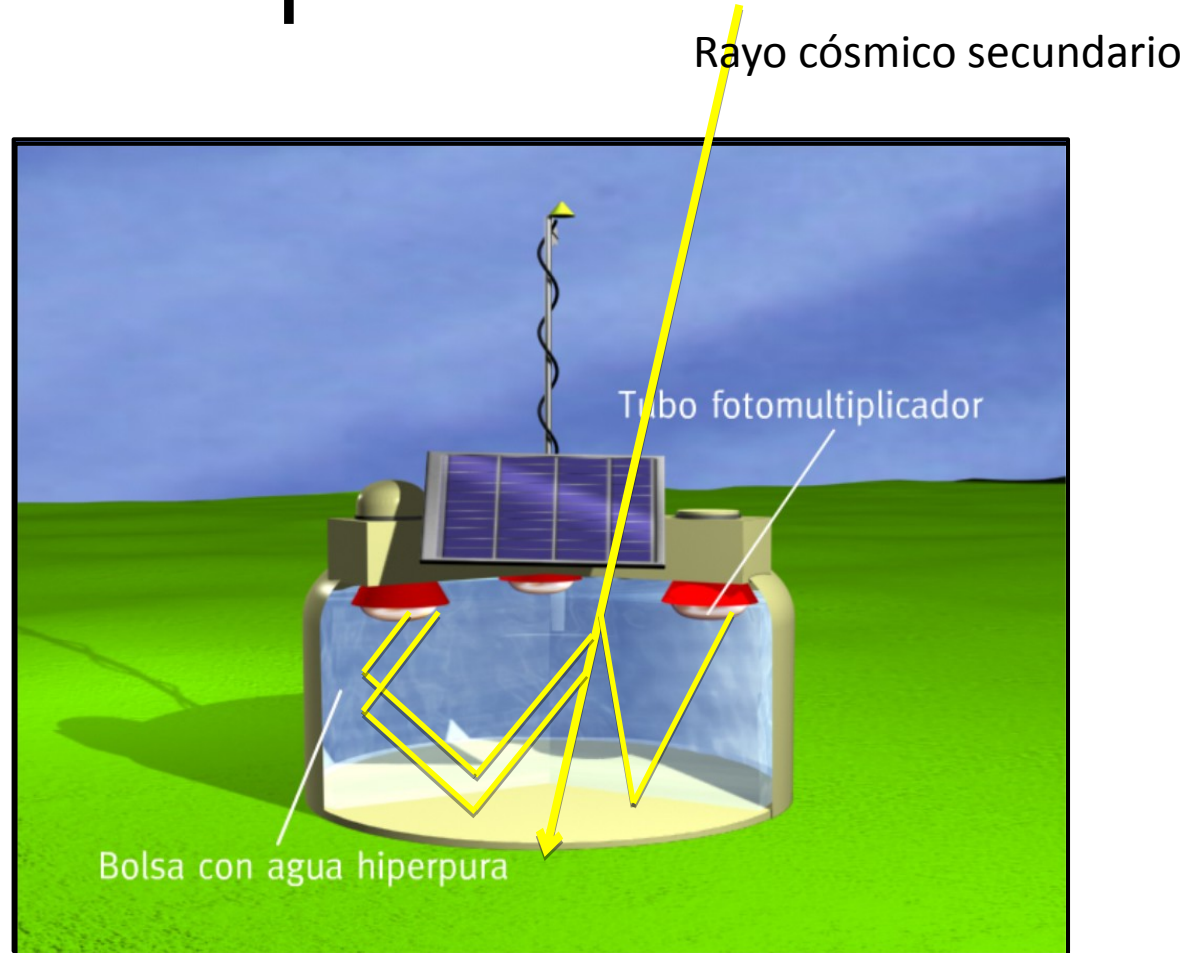
Detector de superficie



Detector de superficie



Detector de superficie

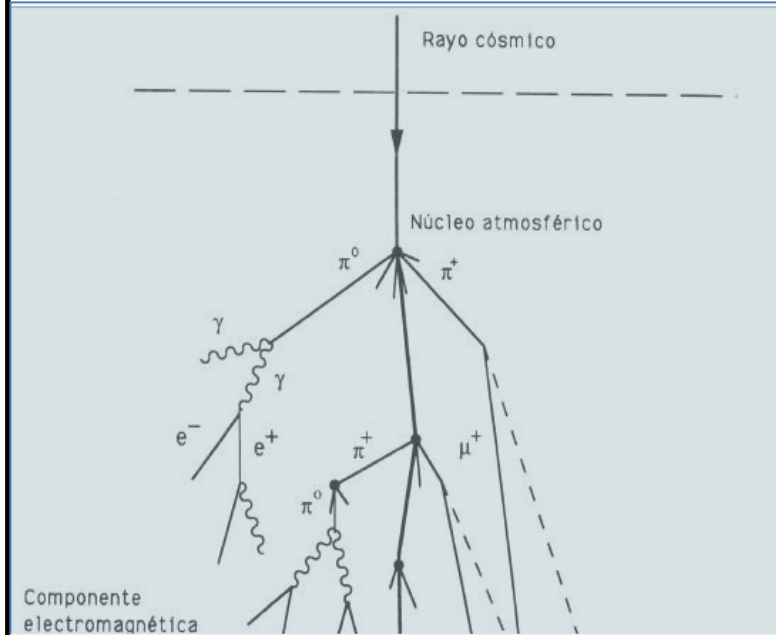


Llueven Rayos Cósmicos

- La atmósfera detiene al rayo cósmico primario
- Se produce una reacción en cadena

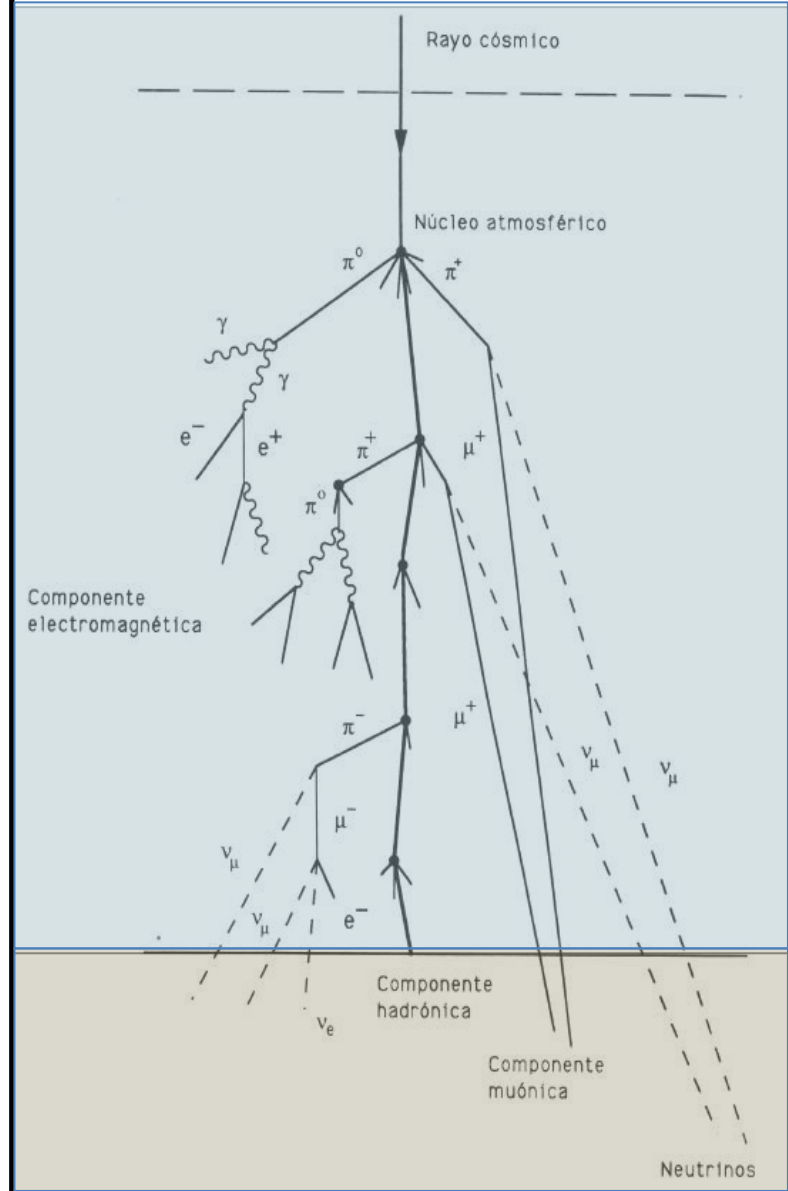
Llueven Rayos Cósmicos

- La atmósfera detiene al rayo cósmico primario
- Se produce una reacción en cadena



Llueven Rayos Cósmicos

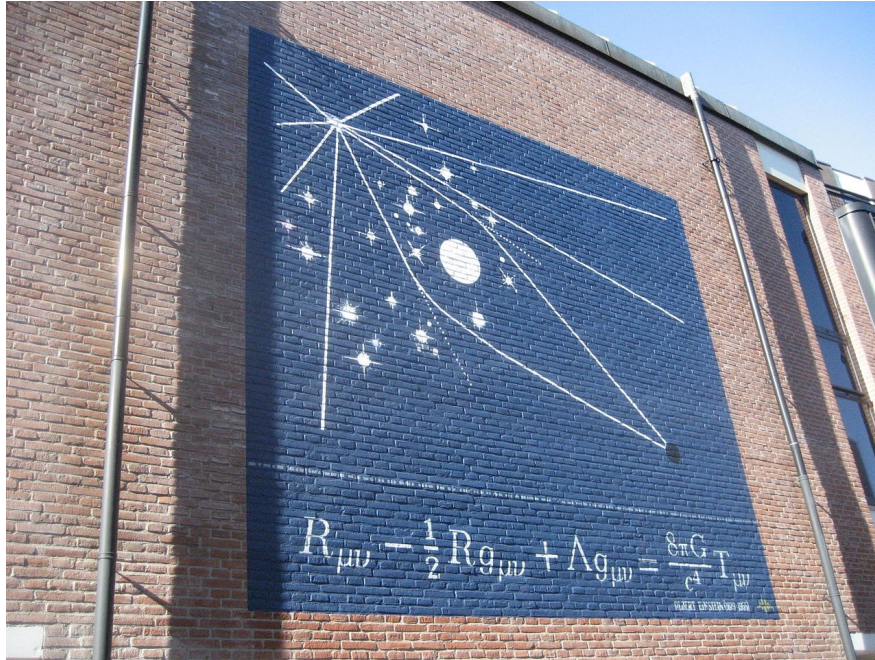
- La atmósfera detiene al rayo cósmico primario
- Se produce una reacción en cadena



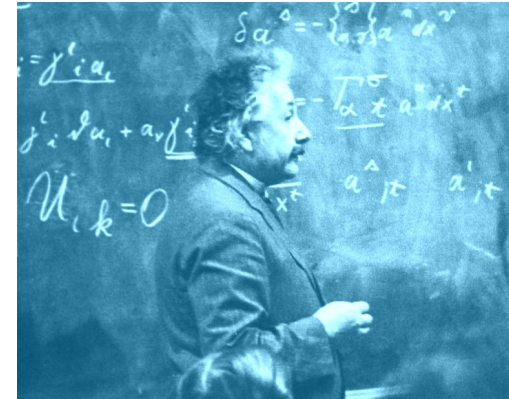
Ondas Gravitacionales

An aerial photograph of the LIGO (Laser Interferometer Gravitational-Wave Observatory) facility in a vast, arid desert landscape. A long, straight, light-colored road or path stretches across the foreground and middle ground, leading towards a small cluster of white and blue buildings in the lower right. In the background, a range of low, hazy mountains is visible under a clear blue sky. The text "Ondas Gravitacionales" is overlaid in the center of the image.

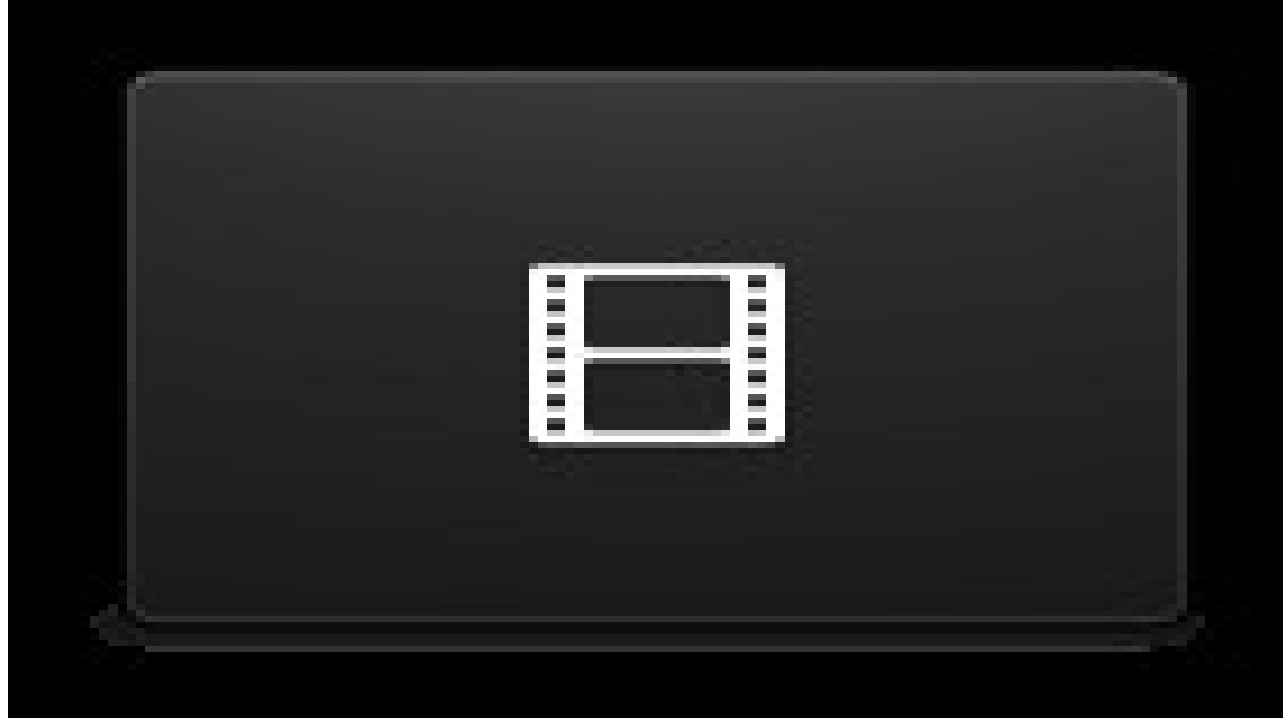
Ondas Gravitacionales



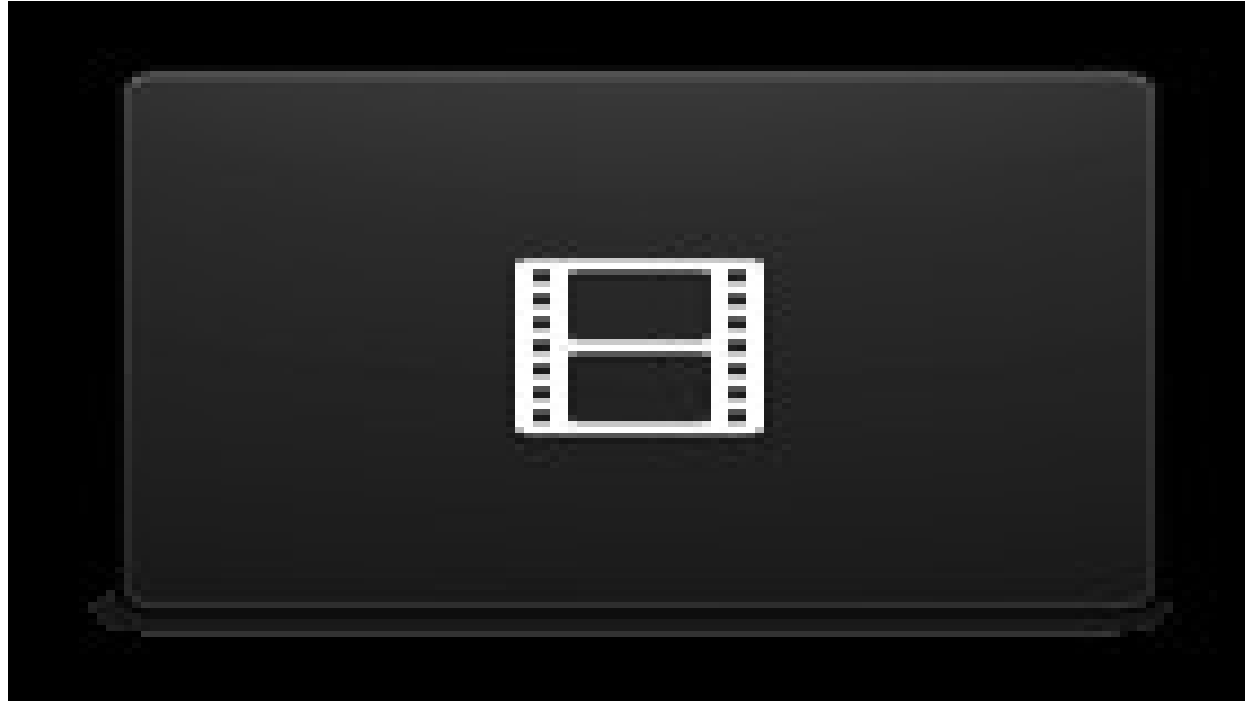
Son una de las muchas predicciones de la relatividad general que describe la gravedad como una deformación del espacio-tiempo



Ondas Gravitacionales



Ondas Gravitacionales



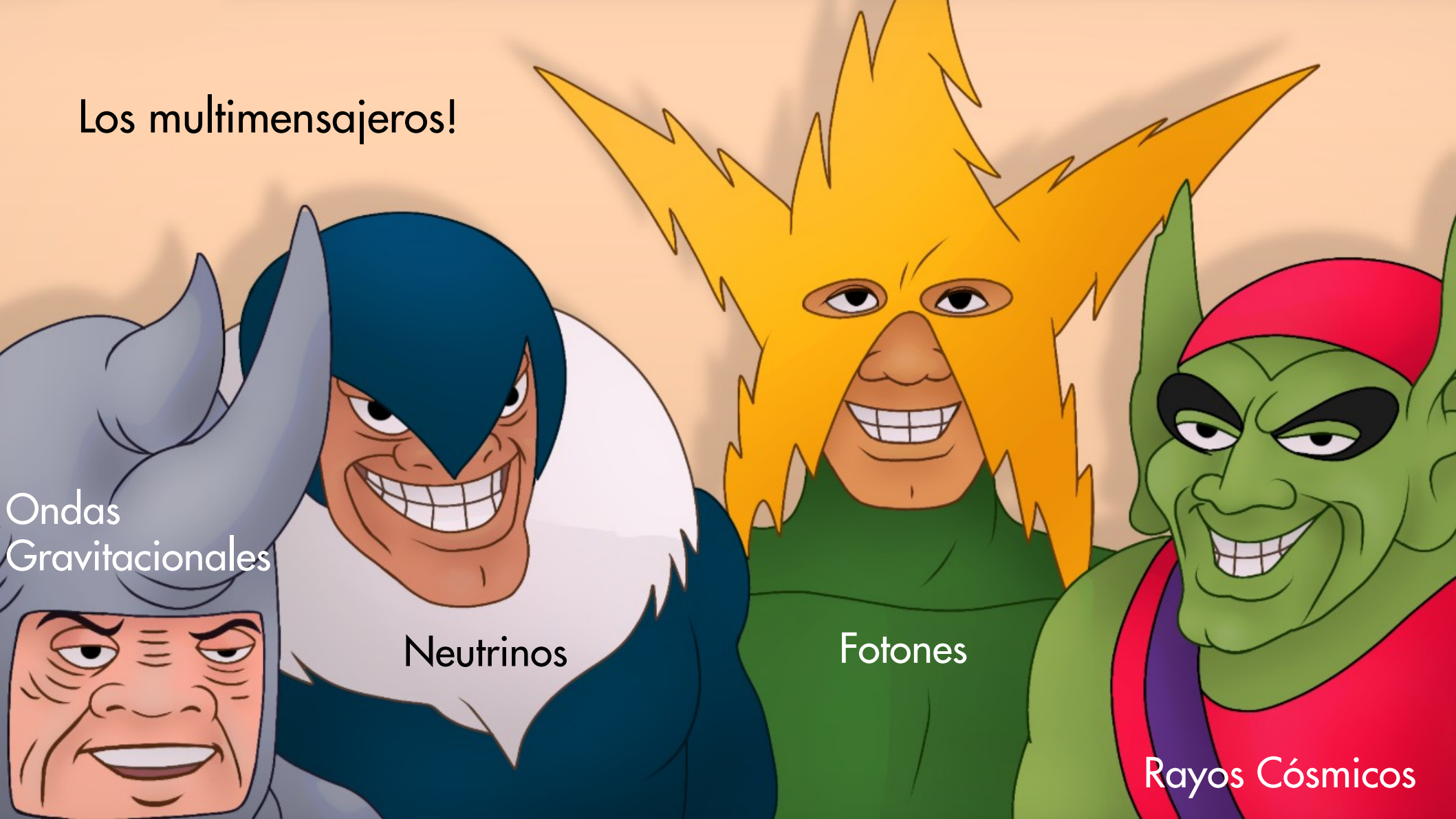
Los multimensajeros!

Ondas
Gravitacionales

Neutrinos

Fotones

Rayos Cósmicos



Gracias

