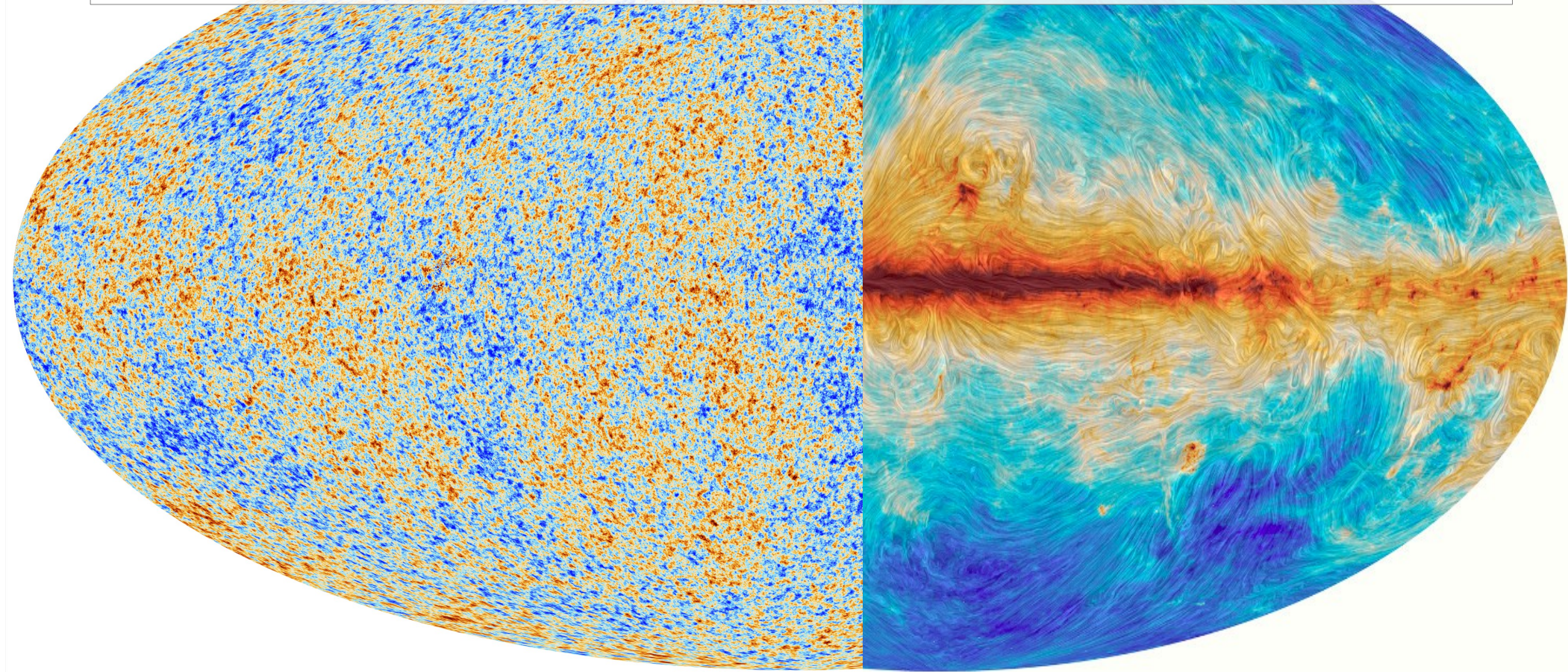


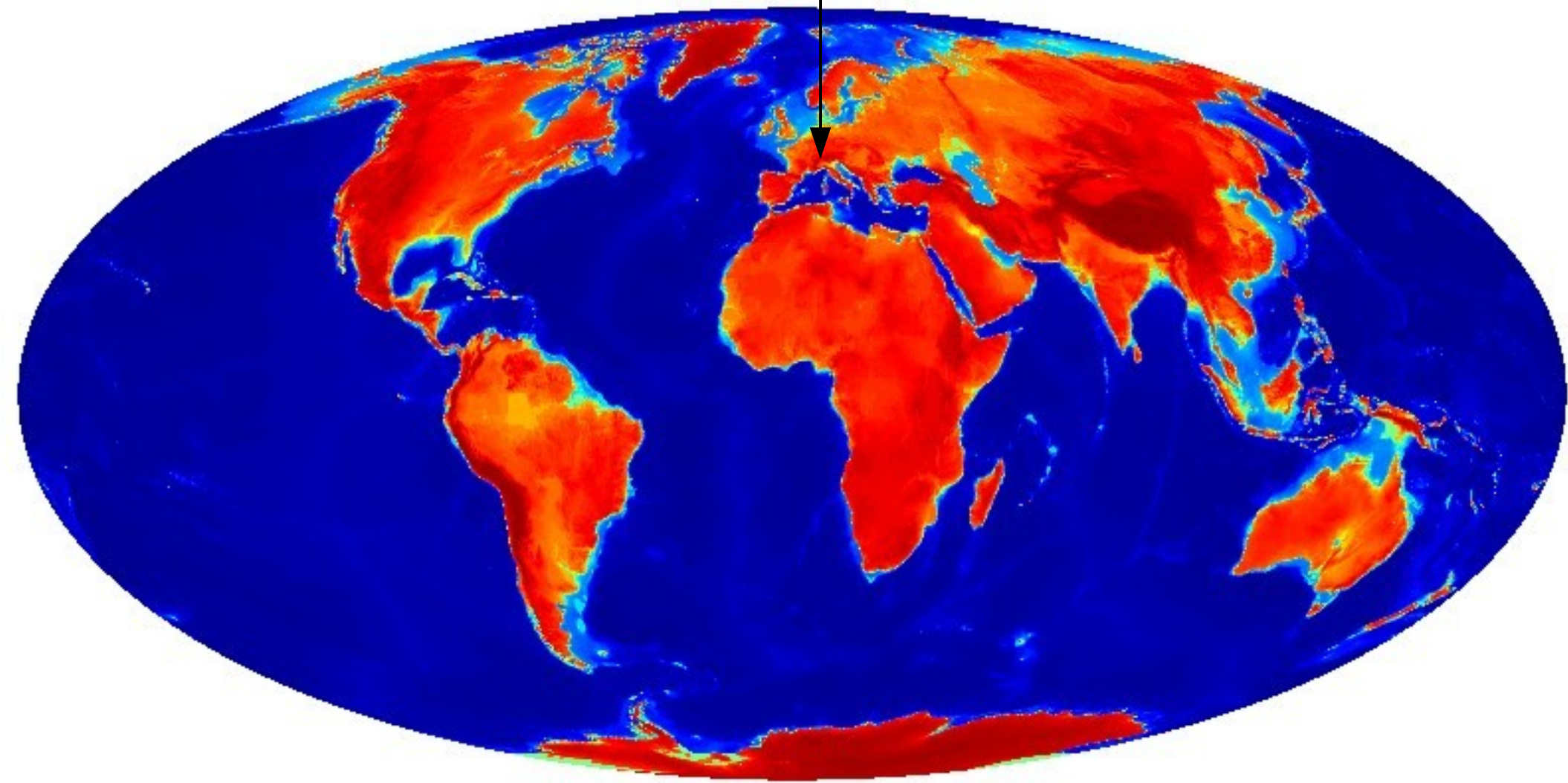
Vom Anfang der Zeit unser Kosmos im Mikrowellenlicht

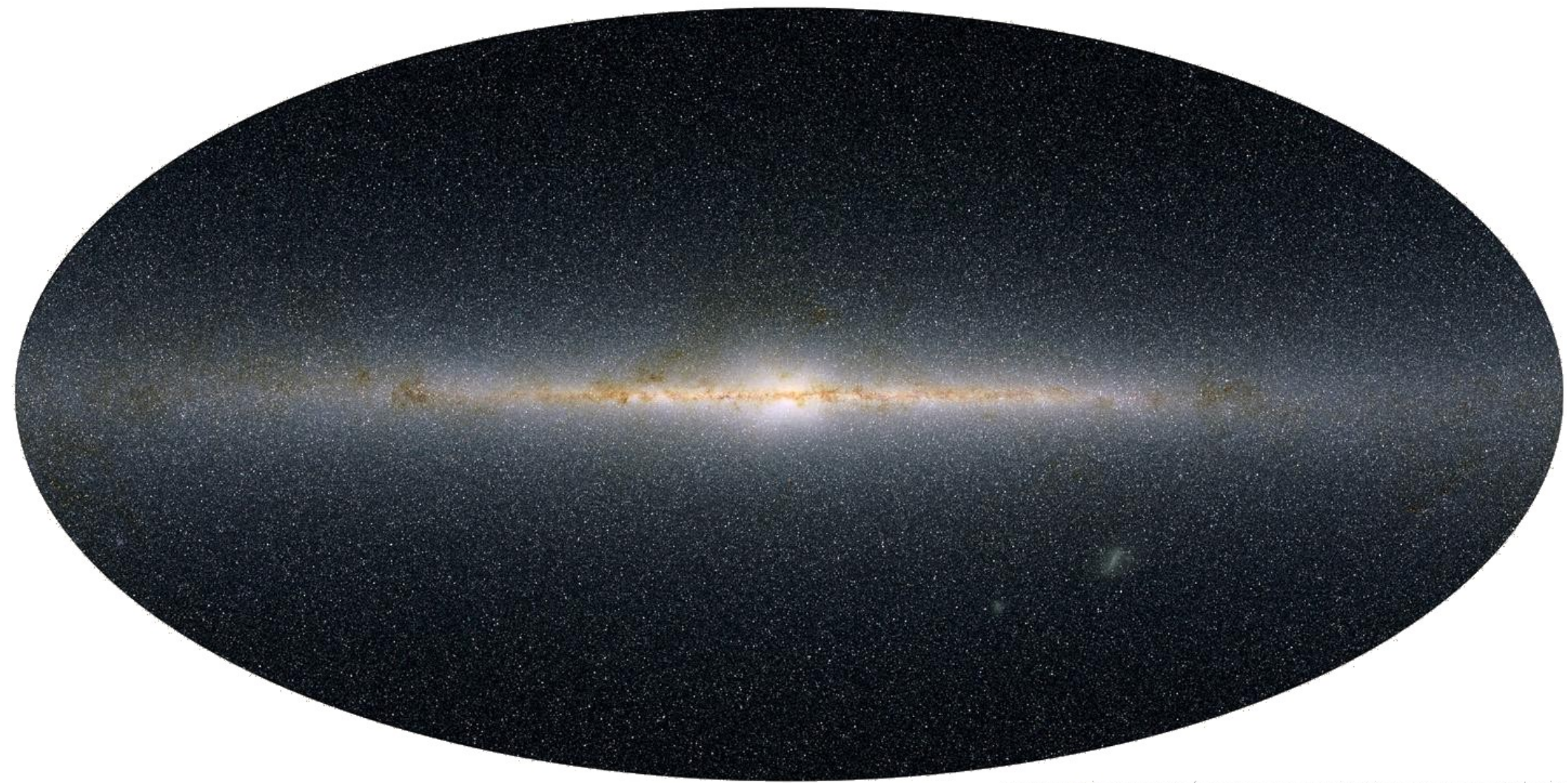
Torsten Enßlin (MPI für Astrophysik) für die Planck-Kollaboration

100 Jahre Allgemeine Relativitätstheorie, 13. November 2015, Zürich



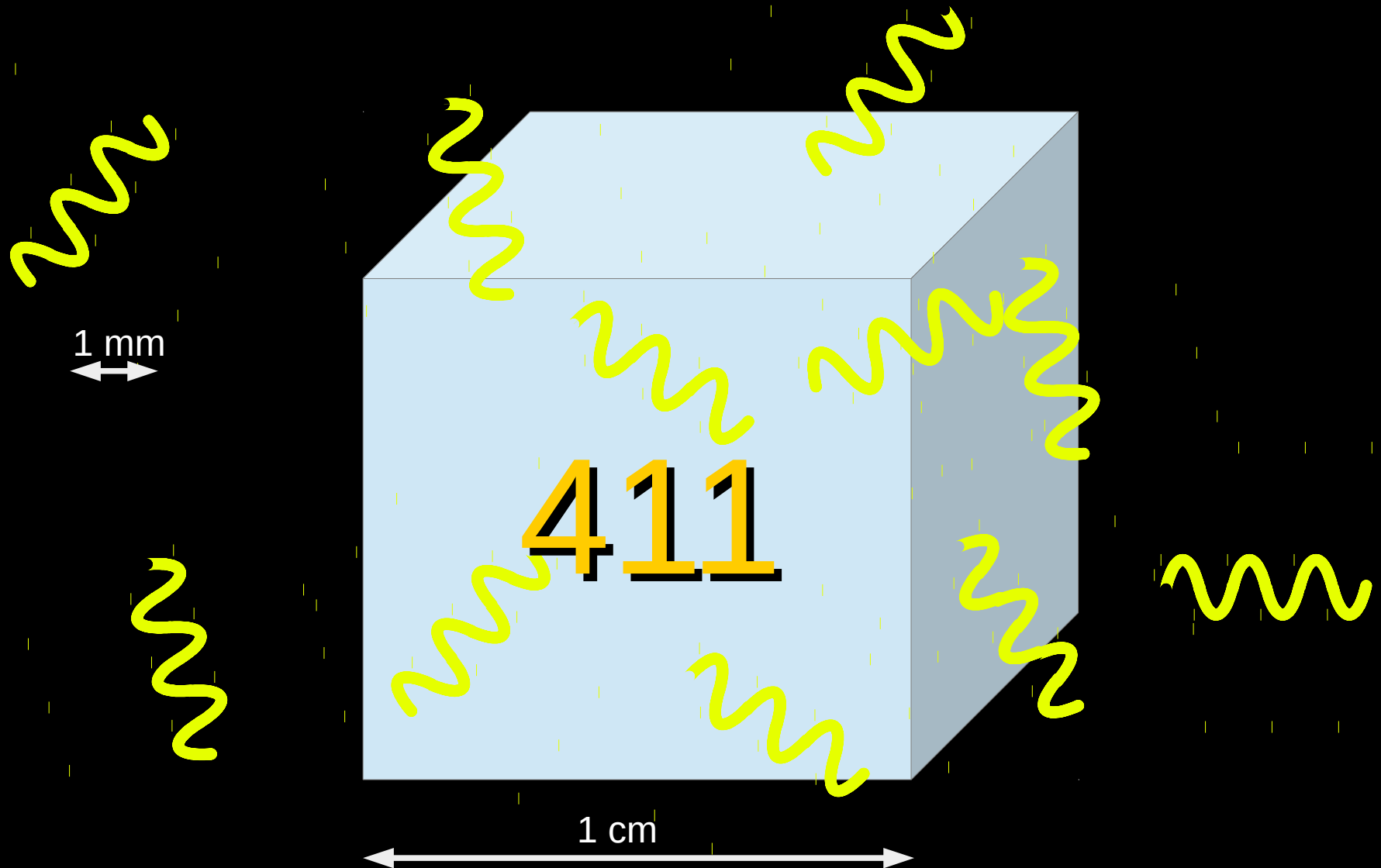
Zürich





Two Micron All Sky Survey Image Mosaic; Infrared Processing and Analysis Center/Caltech & University of Massachusetts

Mikrowellenhintergrundstrahlung

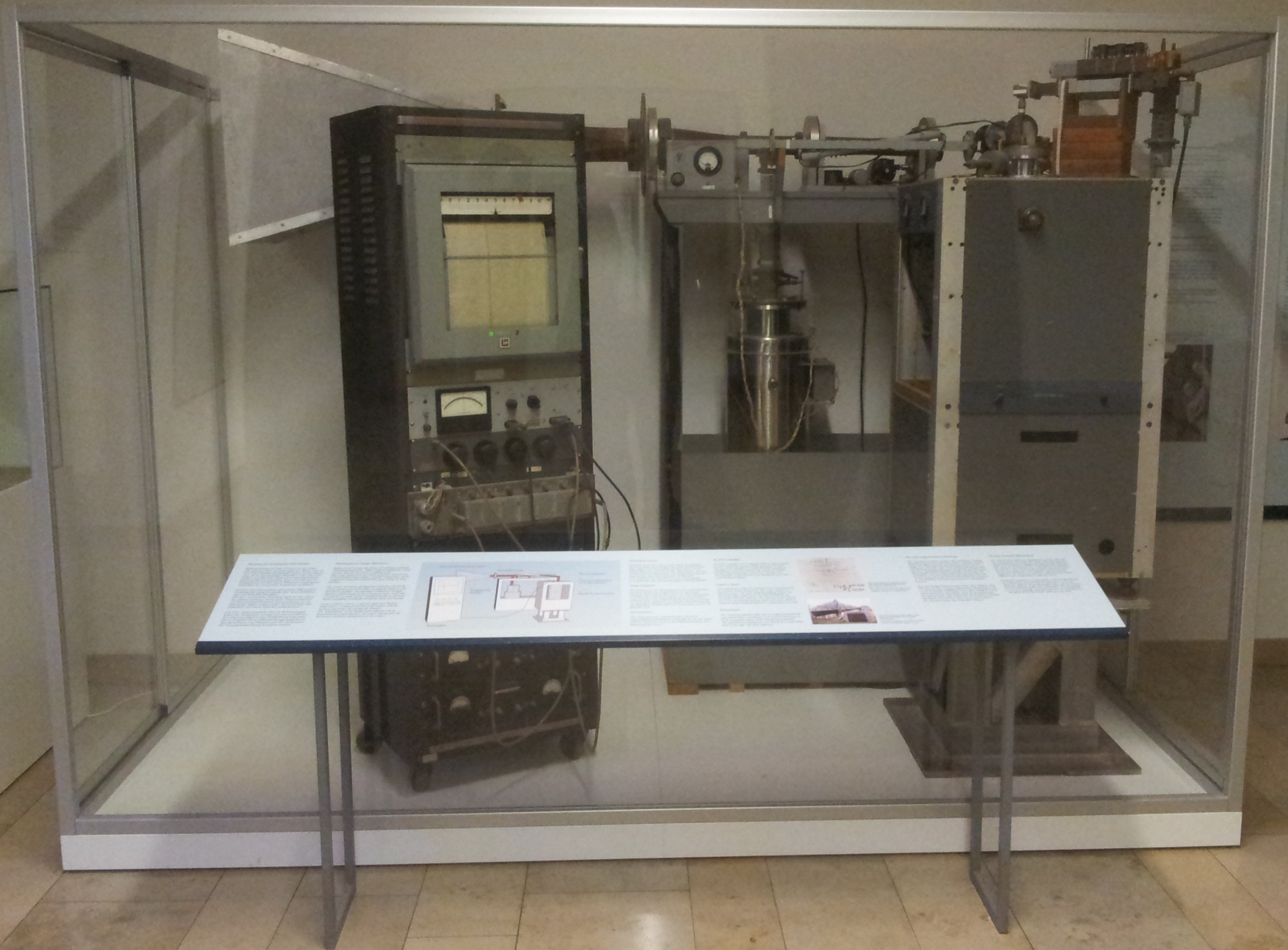


Entdeckung der Hintergrundstrahlung durch Penzias & Wilson 1965

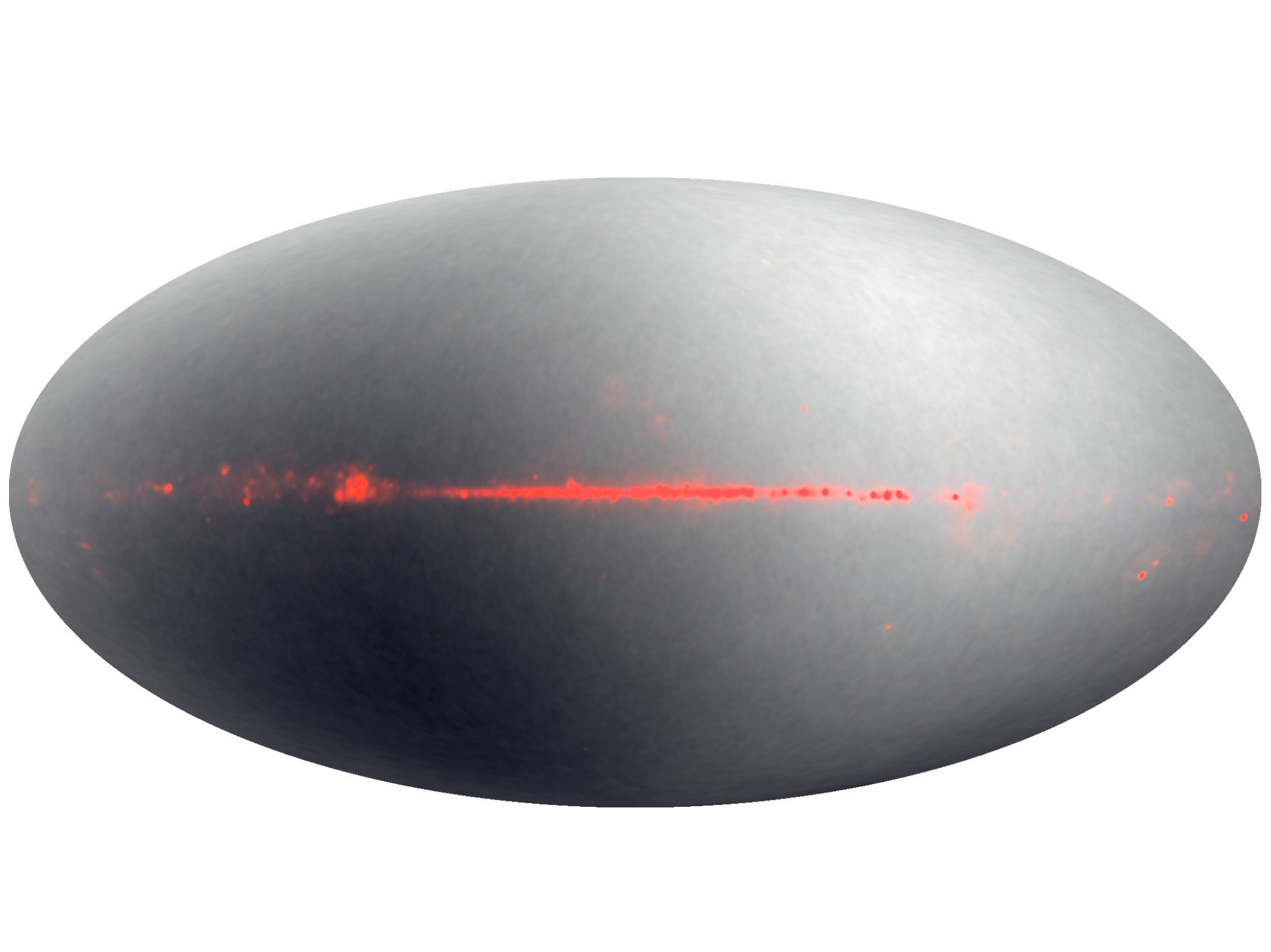


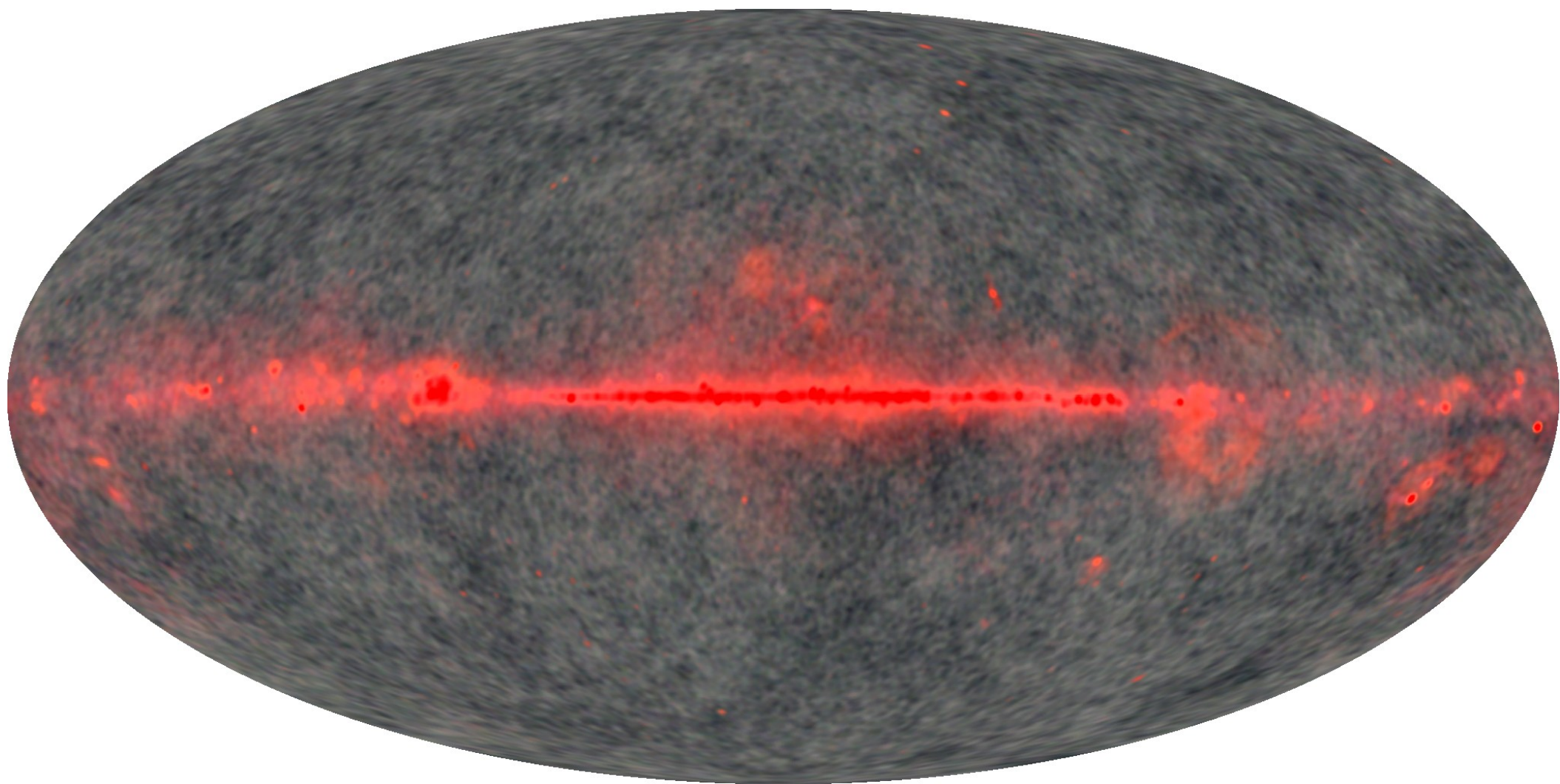
Gamov 1946



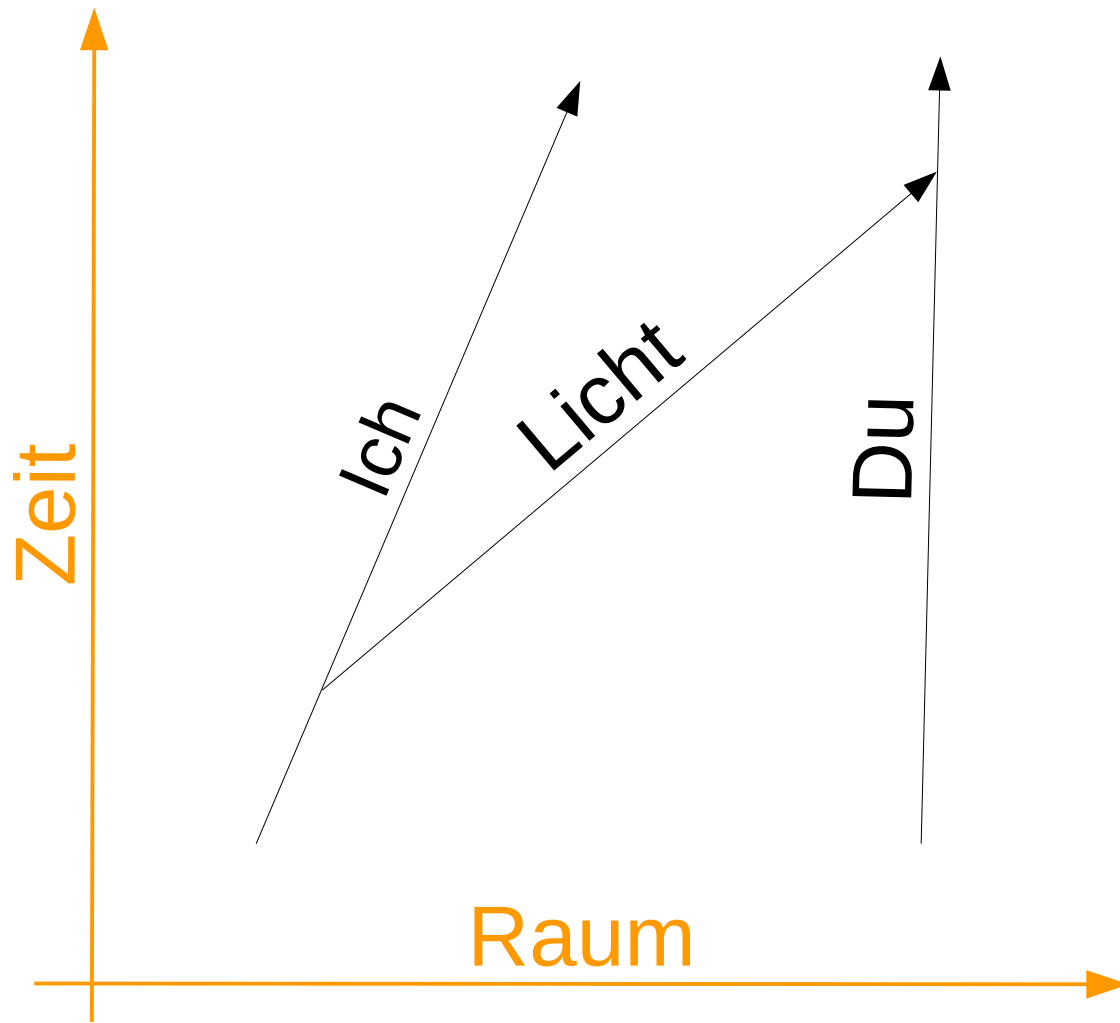


Das Universum scheint
sehr gleichförmig zu sein.

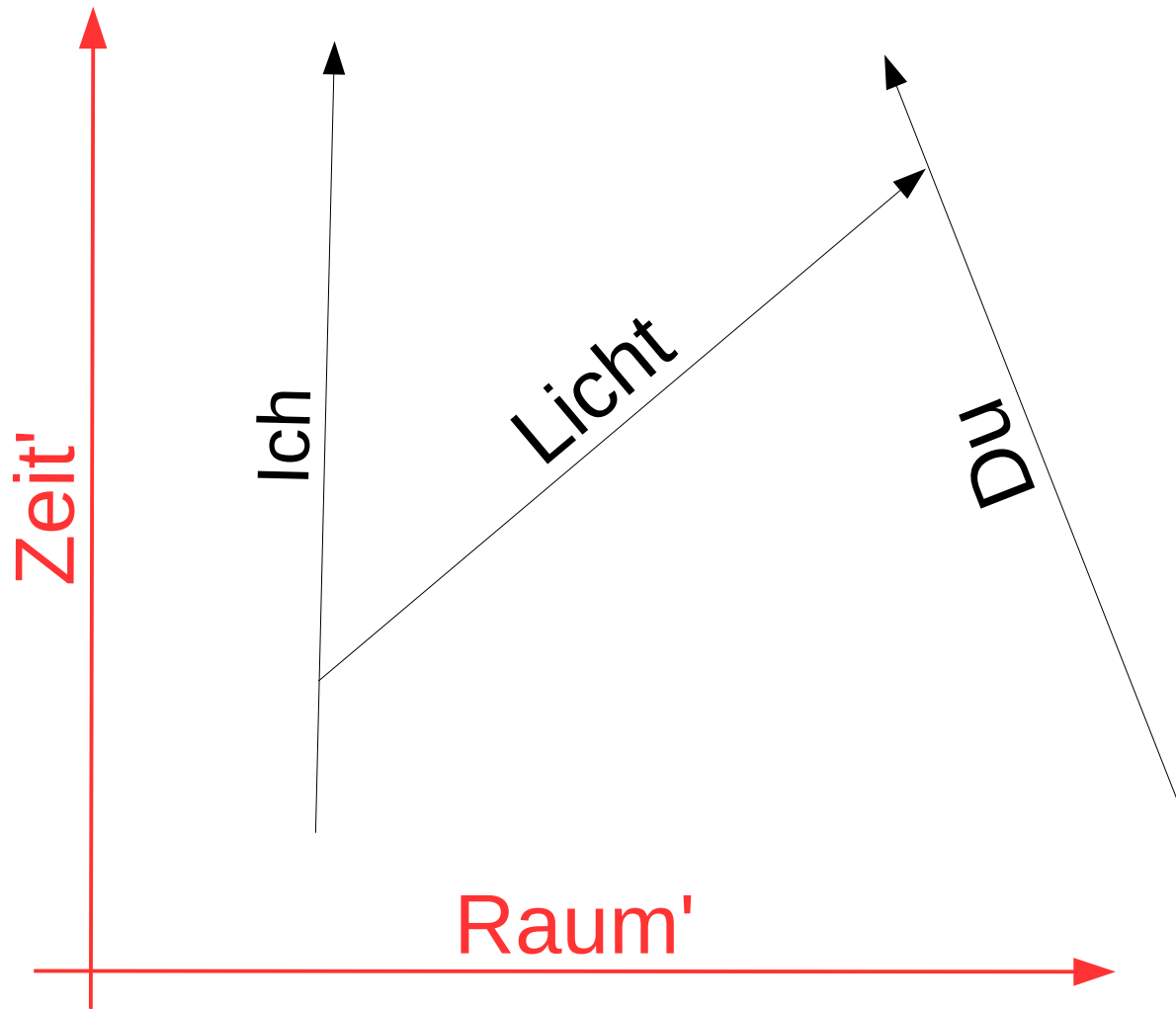




Spezielle Relativitätstheorie



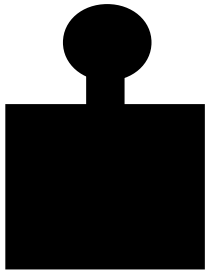
Spezielle Relativitätstheorie



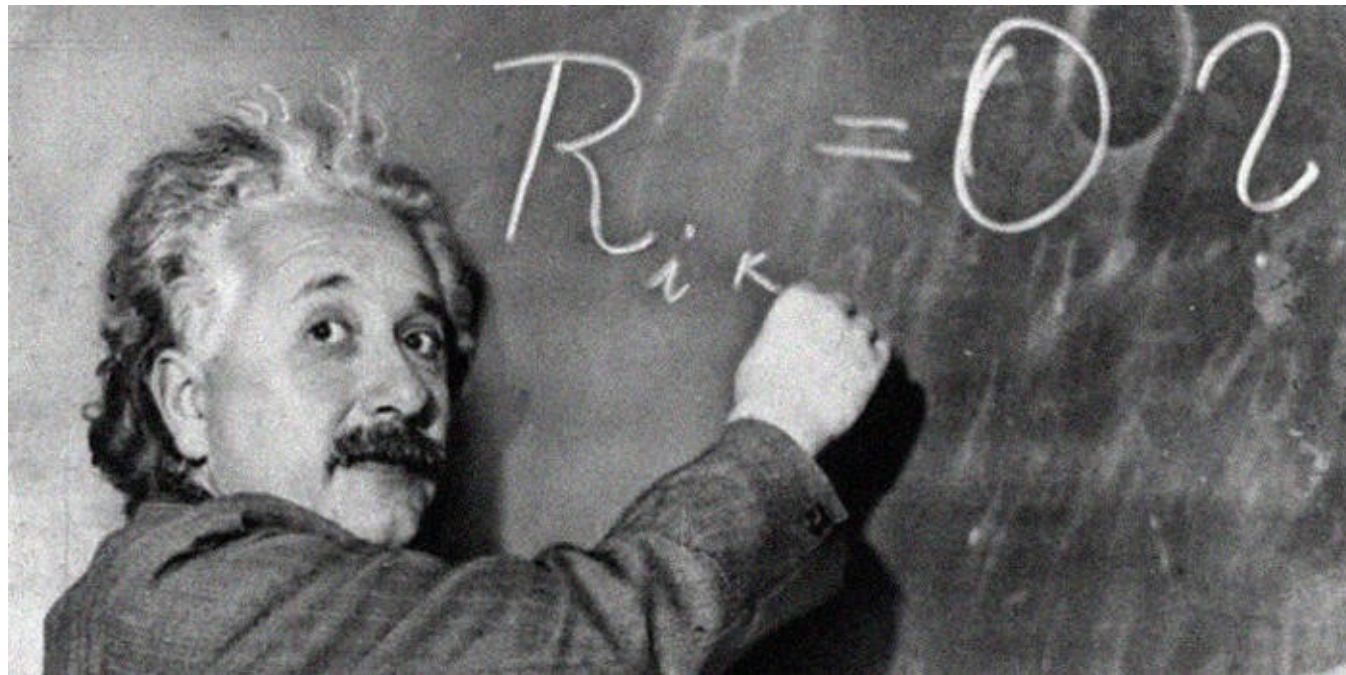
$$E = m c^2$$



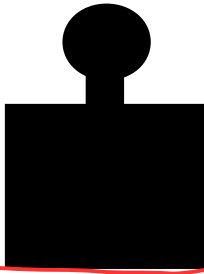
Allgemeine Relativitätstheorie



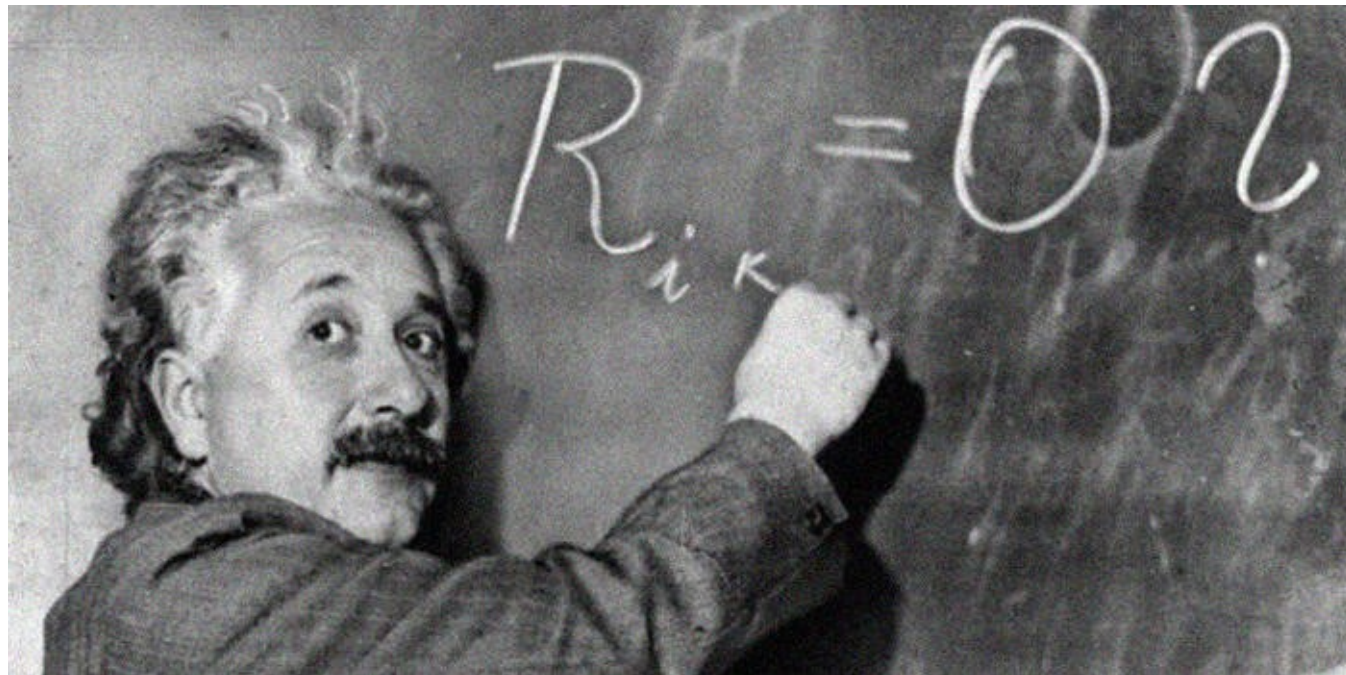
Raum



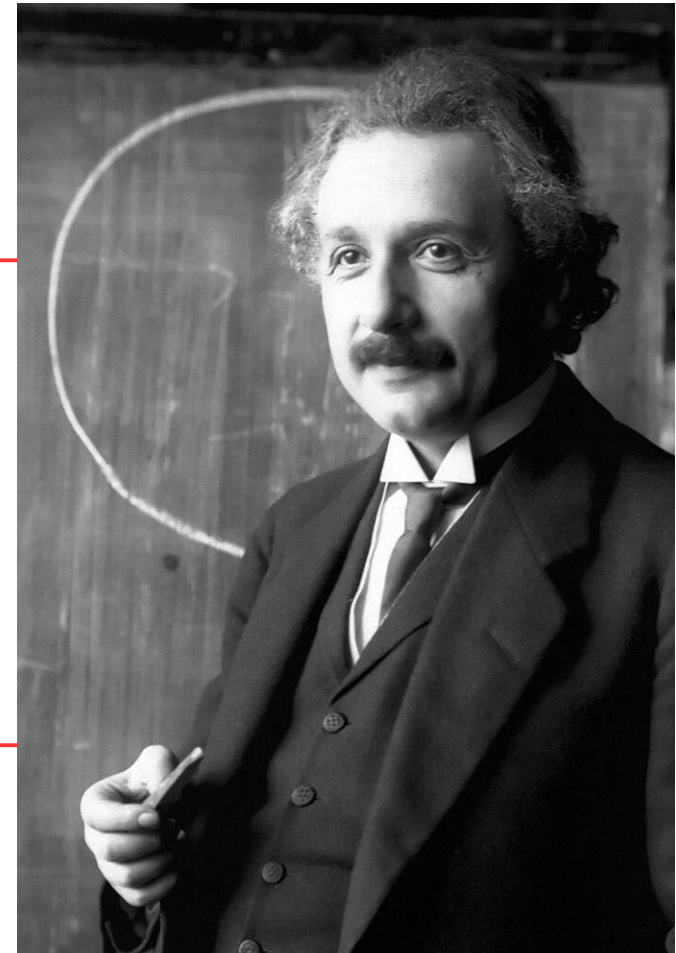
Allgemeine Relativitätstheorie



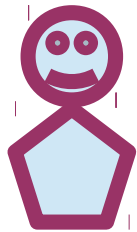
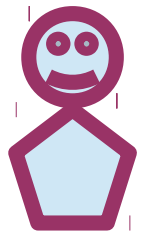
Raum



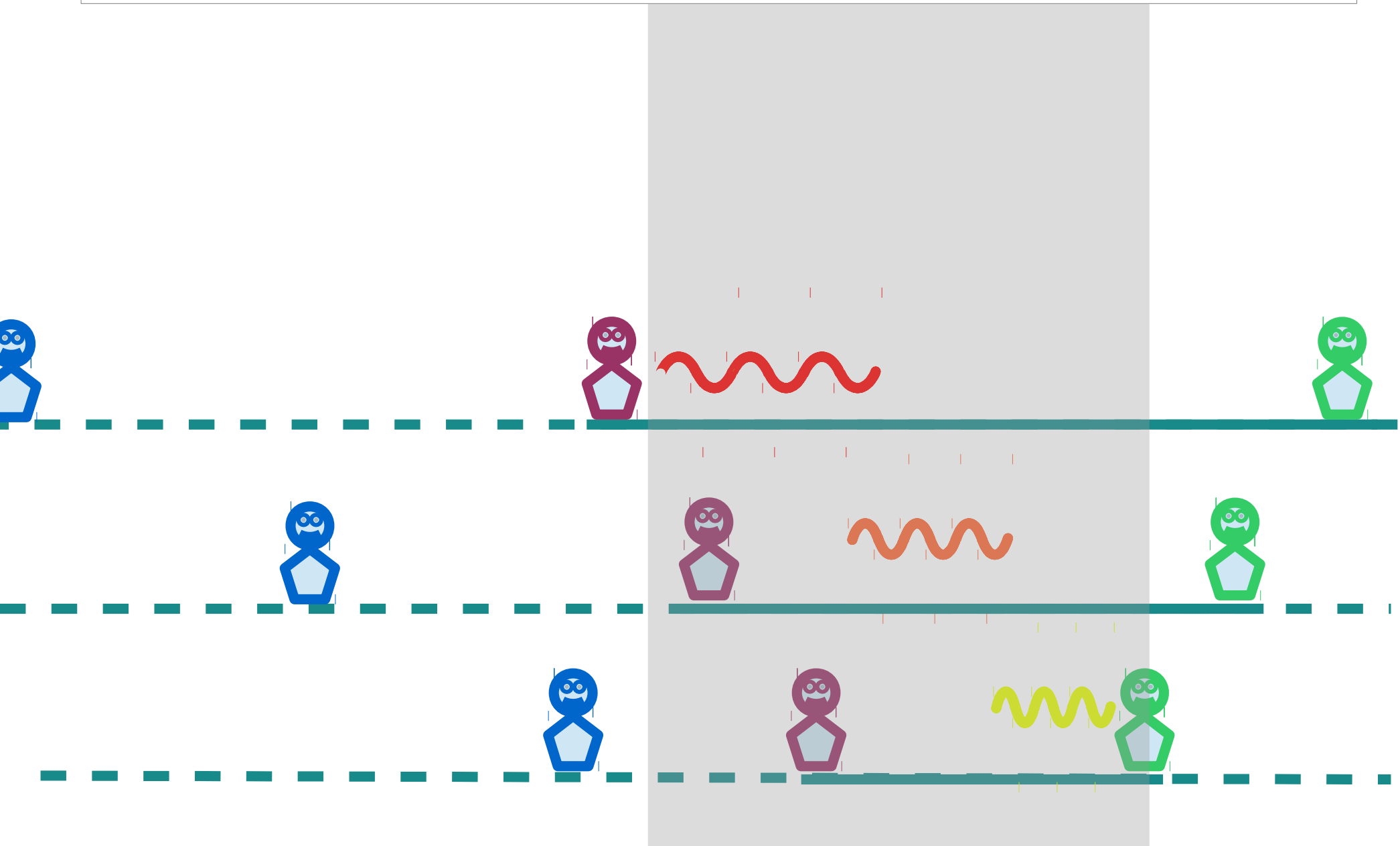
Kosmologie



Der expandierende Kosmos



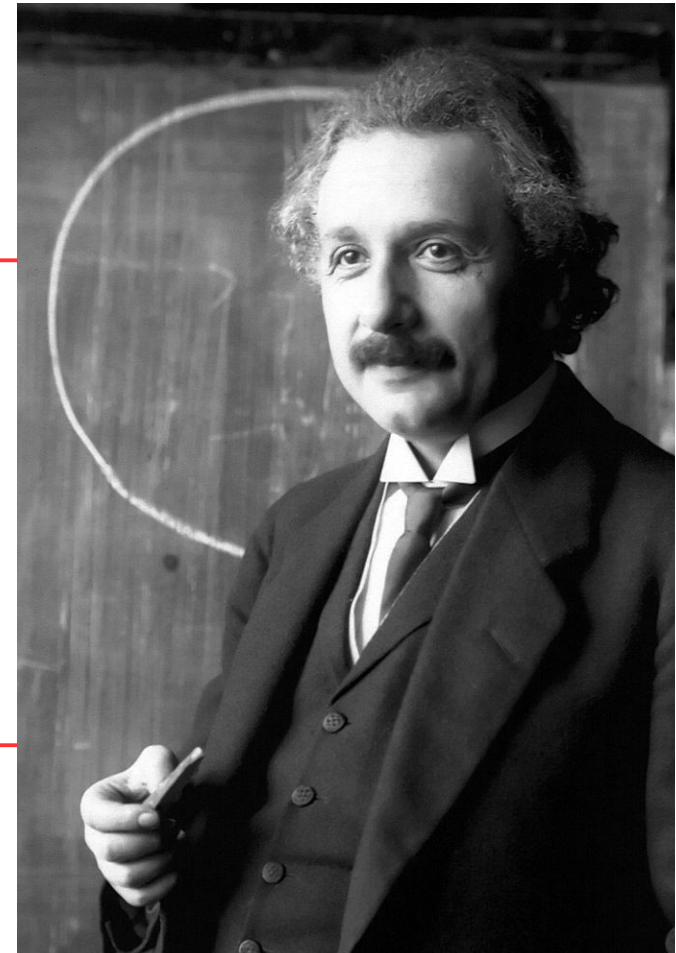
Horizont



Kosmologie



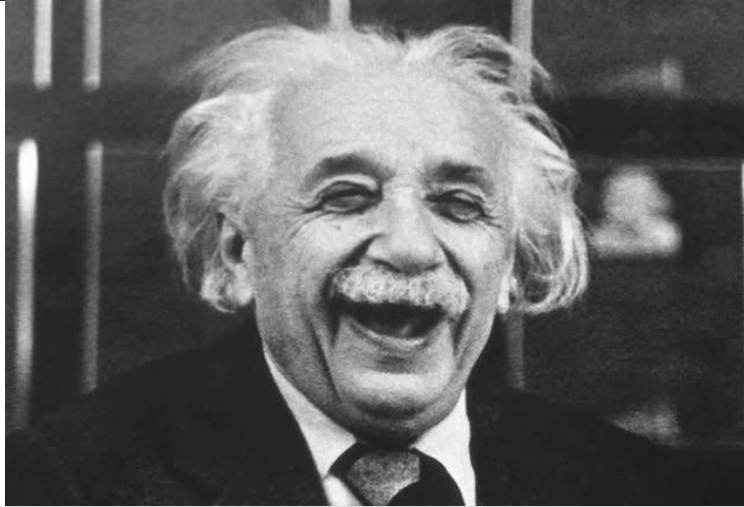
$$E = mc^2$$

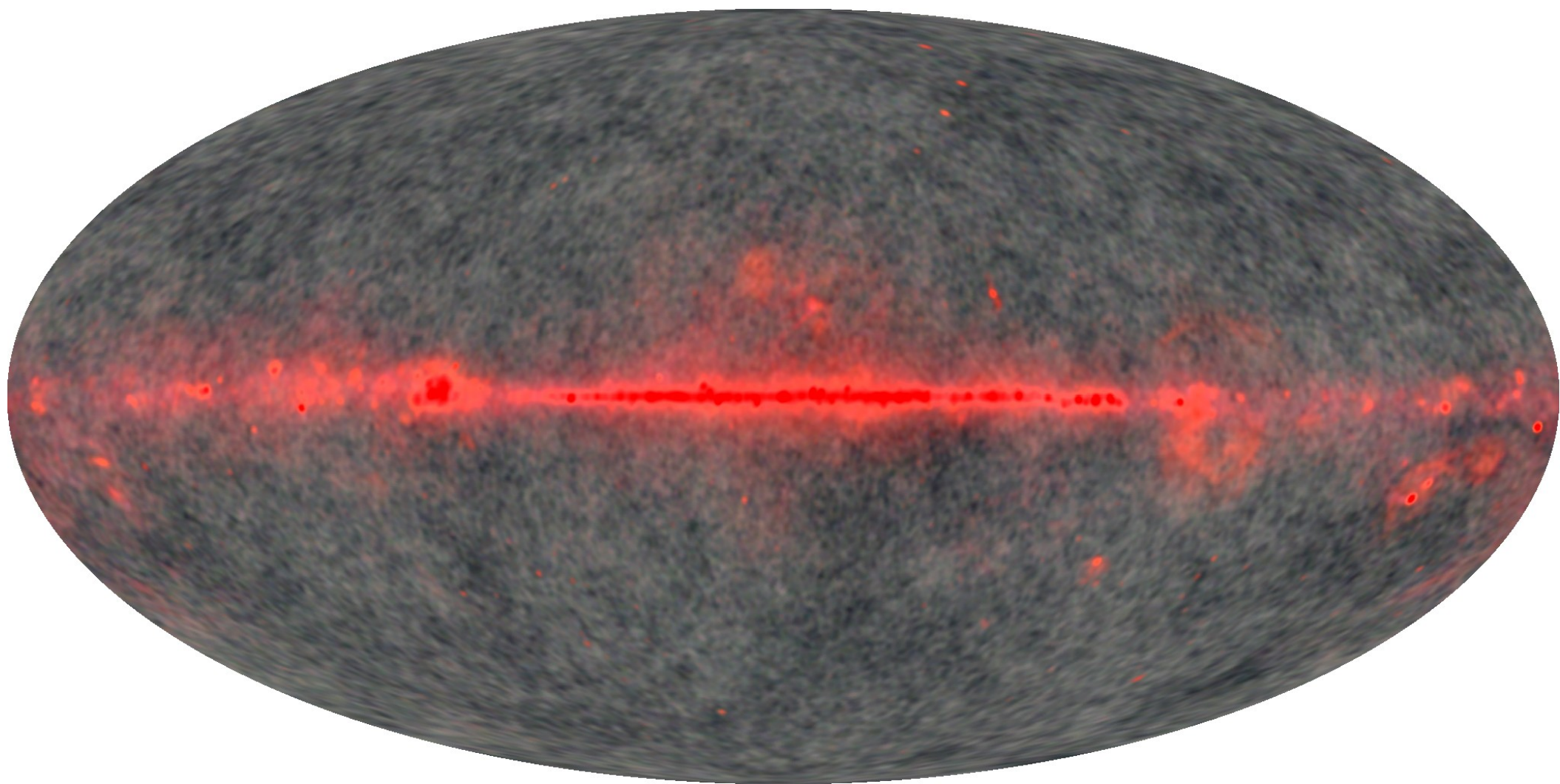


Quantenphysik



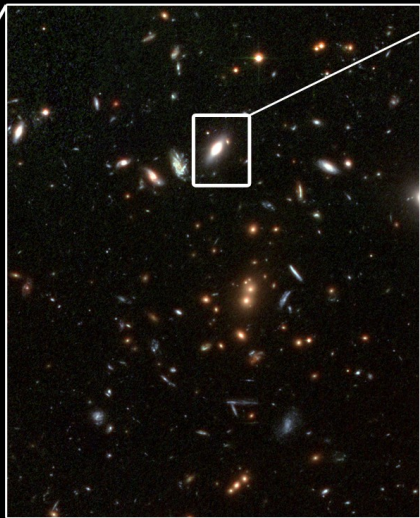
All together now: Inflationstheorie







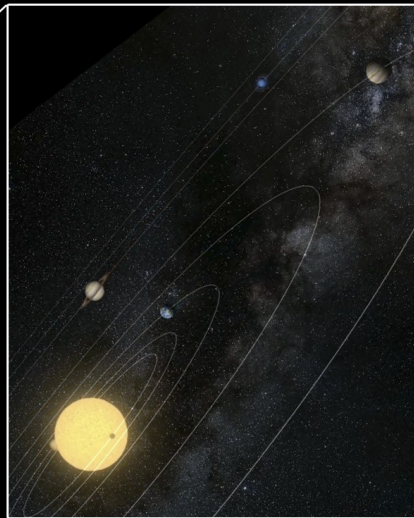
Clusters of galaxies

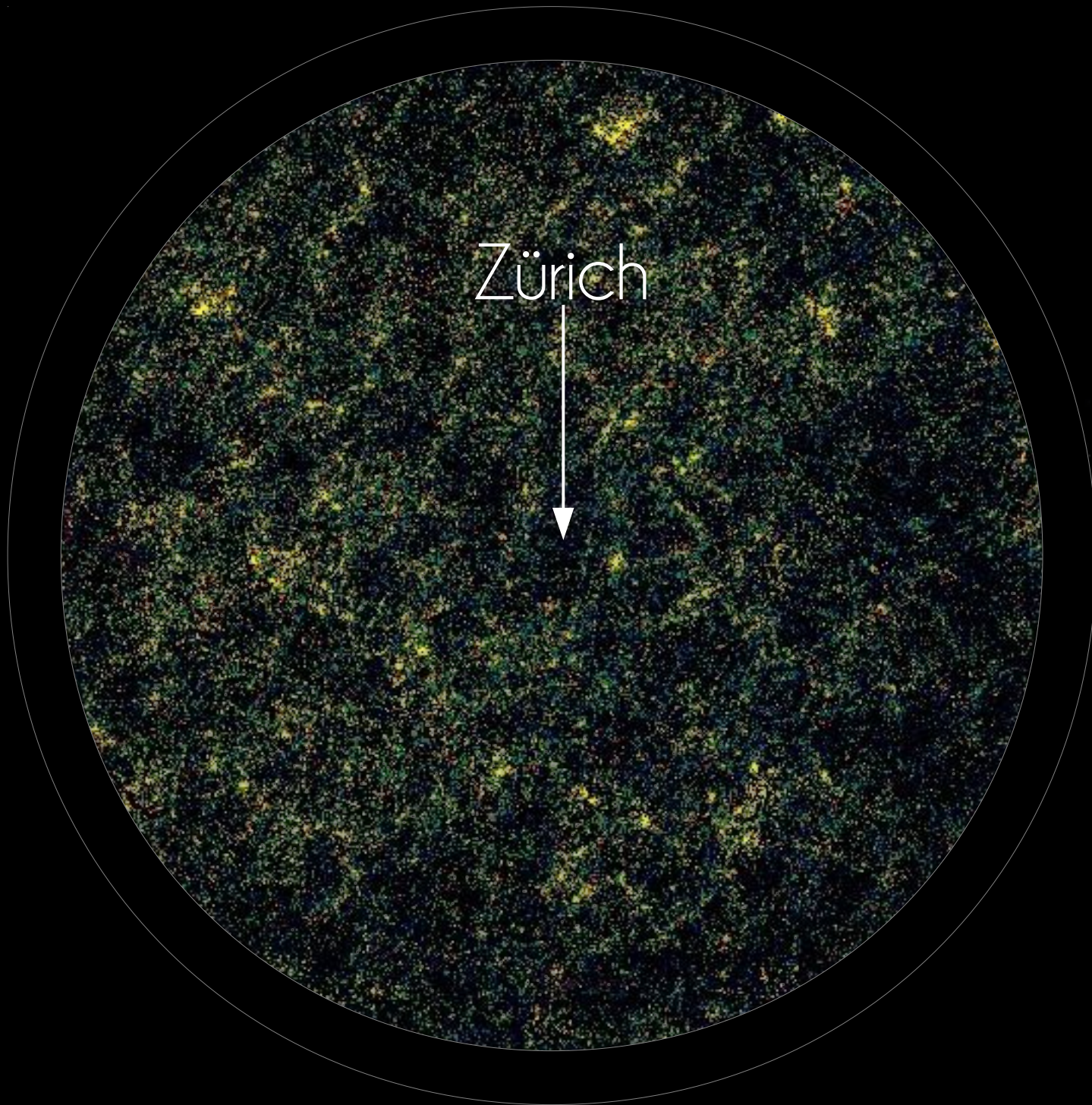


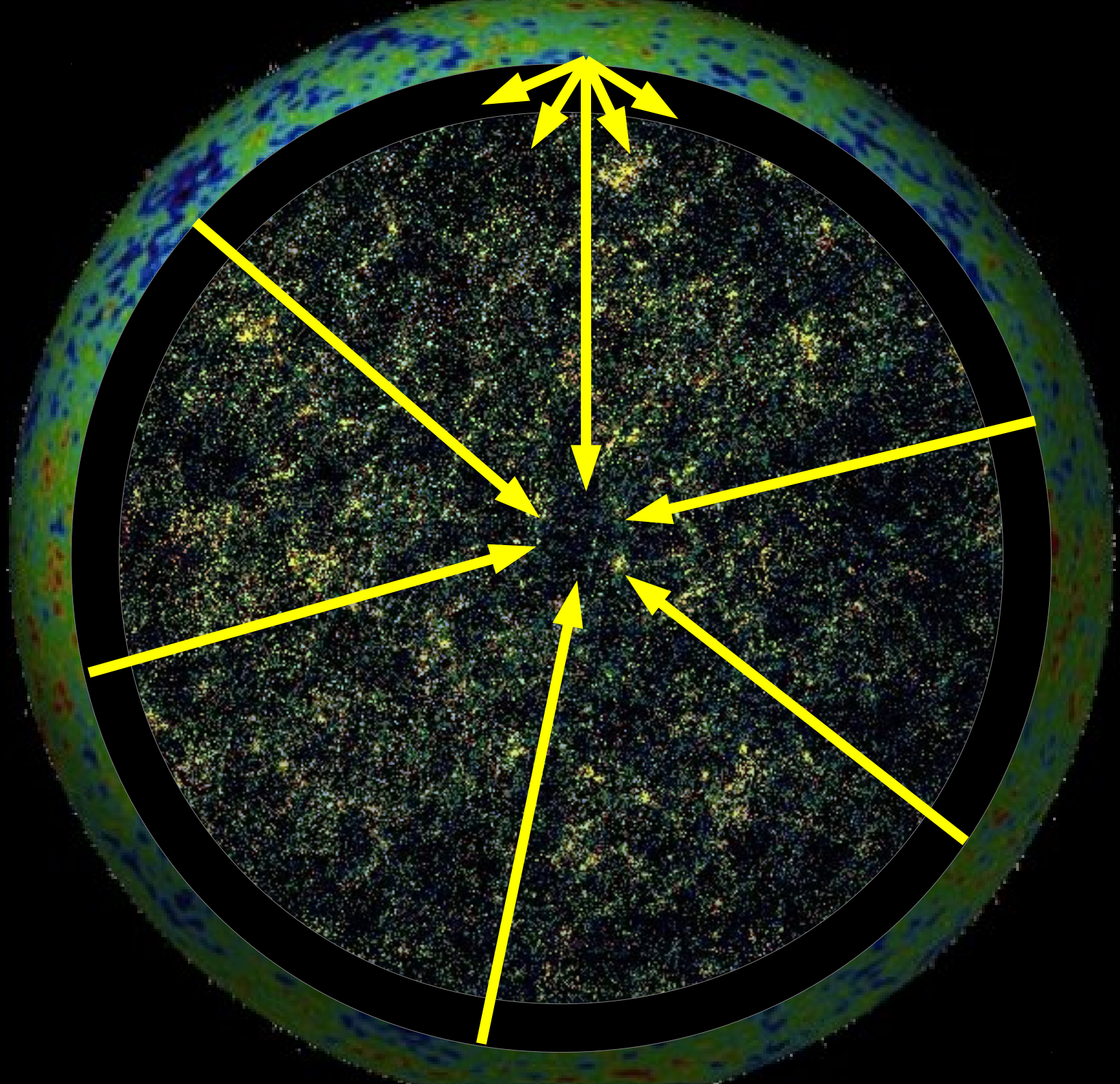
Galaxy



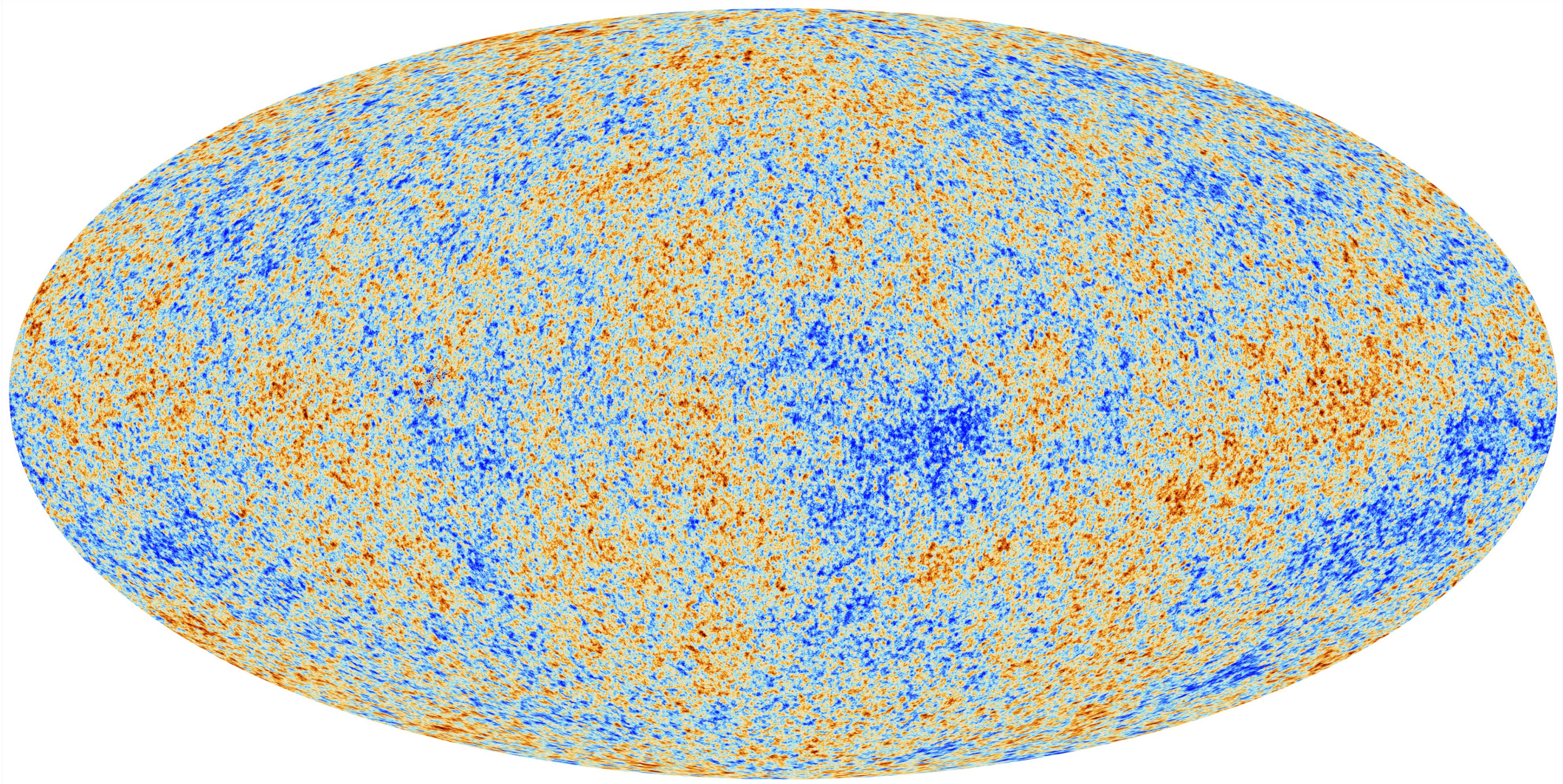
Solar System



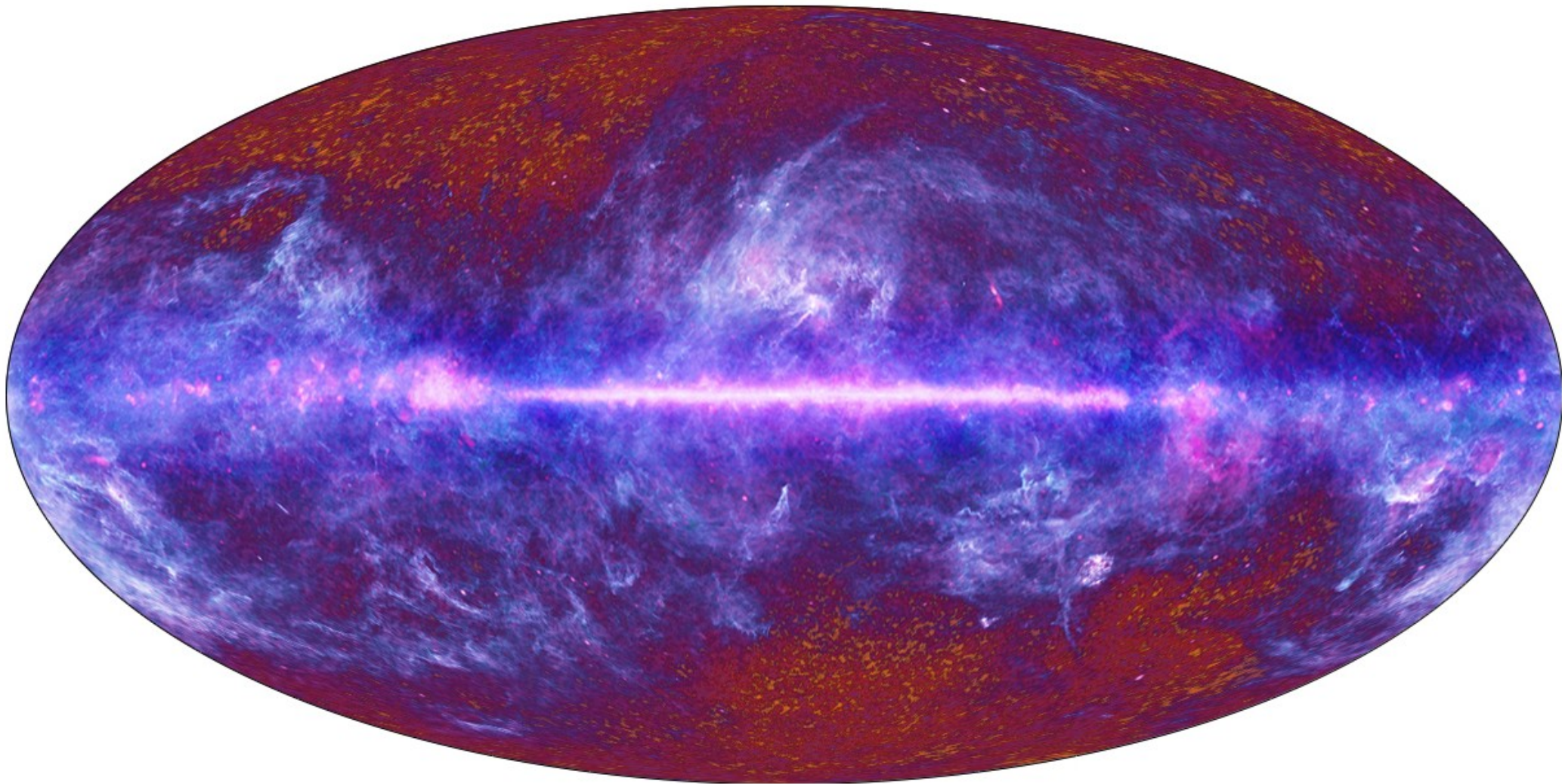




Der kosmische Mikrowellenhintergrund



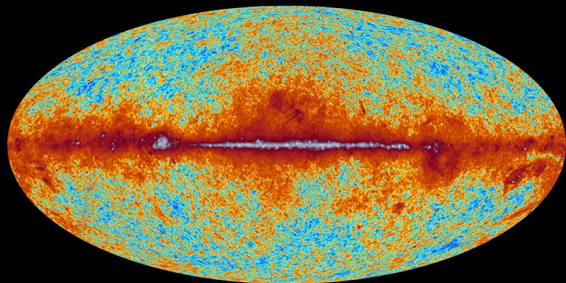
Der Mikrowellenhimmel



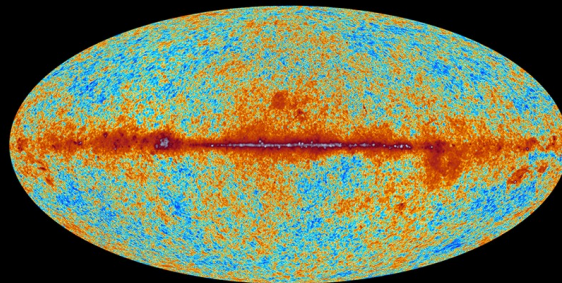


planck

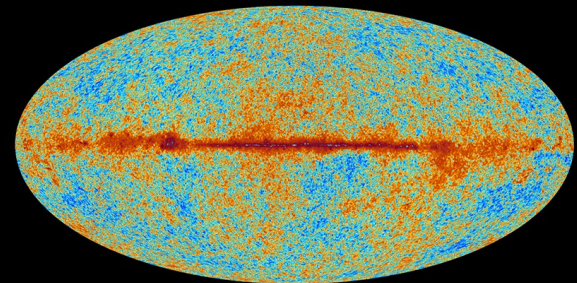
The sky as seen by Planck



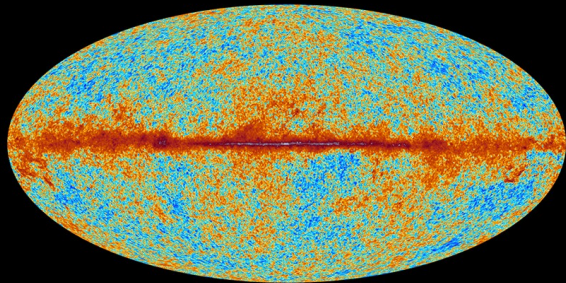
30 GHz



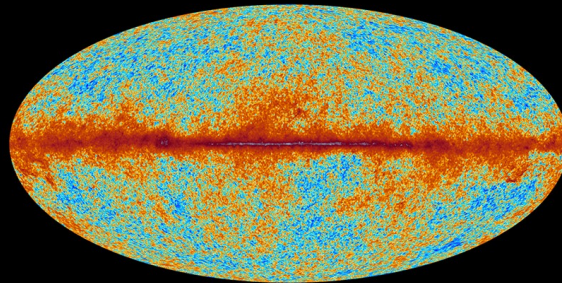
44 GHz



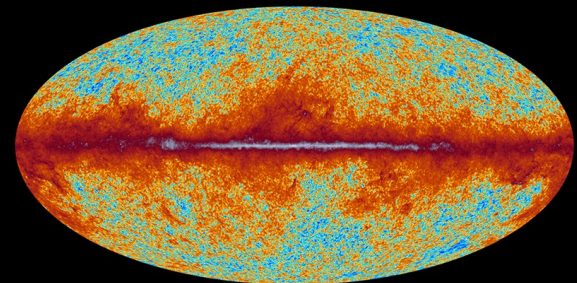
70 GHz



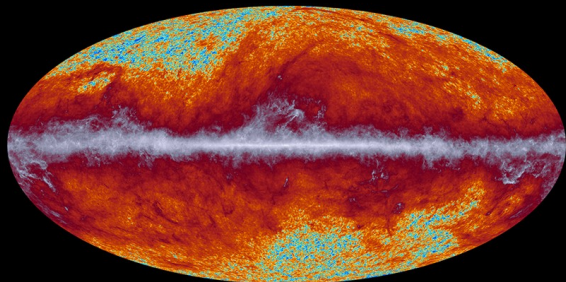
100 GHz



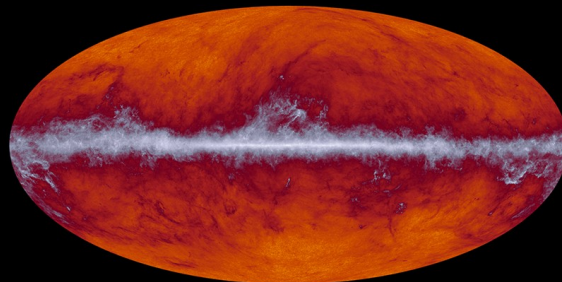
143 GHz



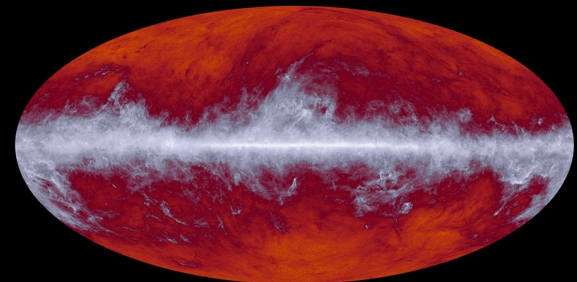
217 GHz



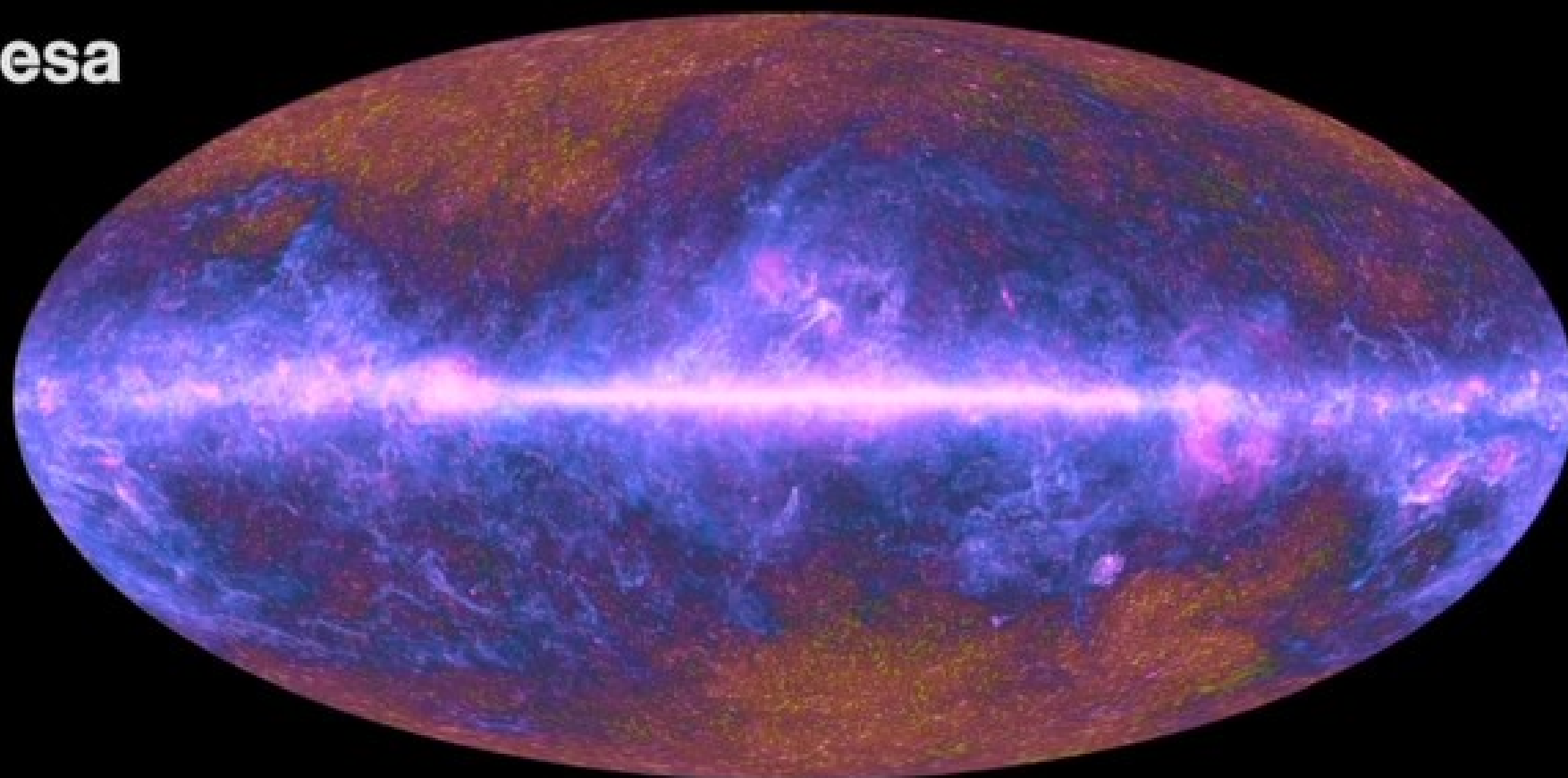
353 GHz



545 GHz



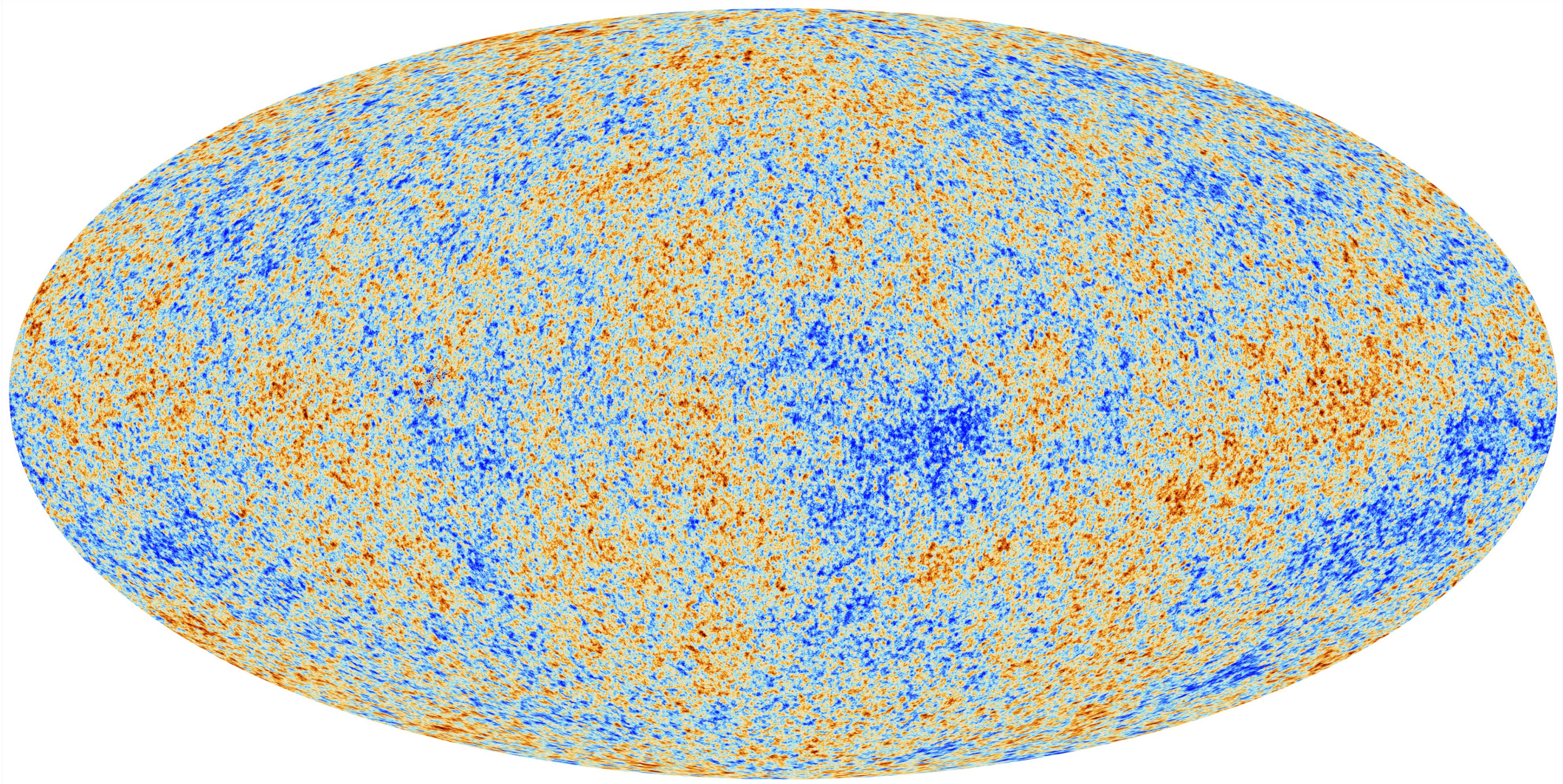
857 GHz



Individual sources + Radio emission from the Milky Way + Dust emission from the Milky Way + Cosmic Microwave Background

All emissions at microwave & submillimetre wavelengths

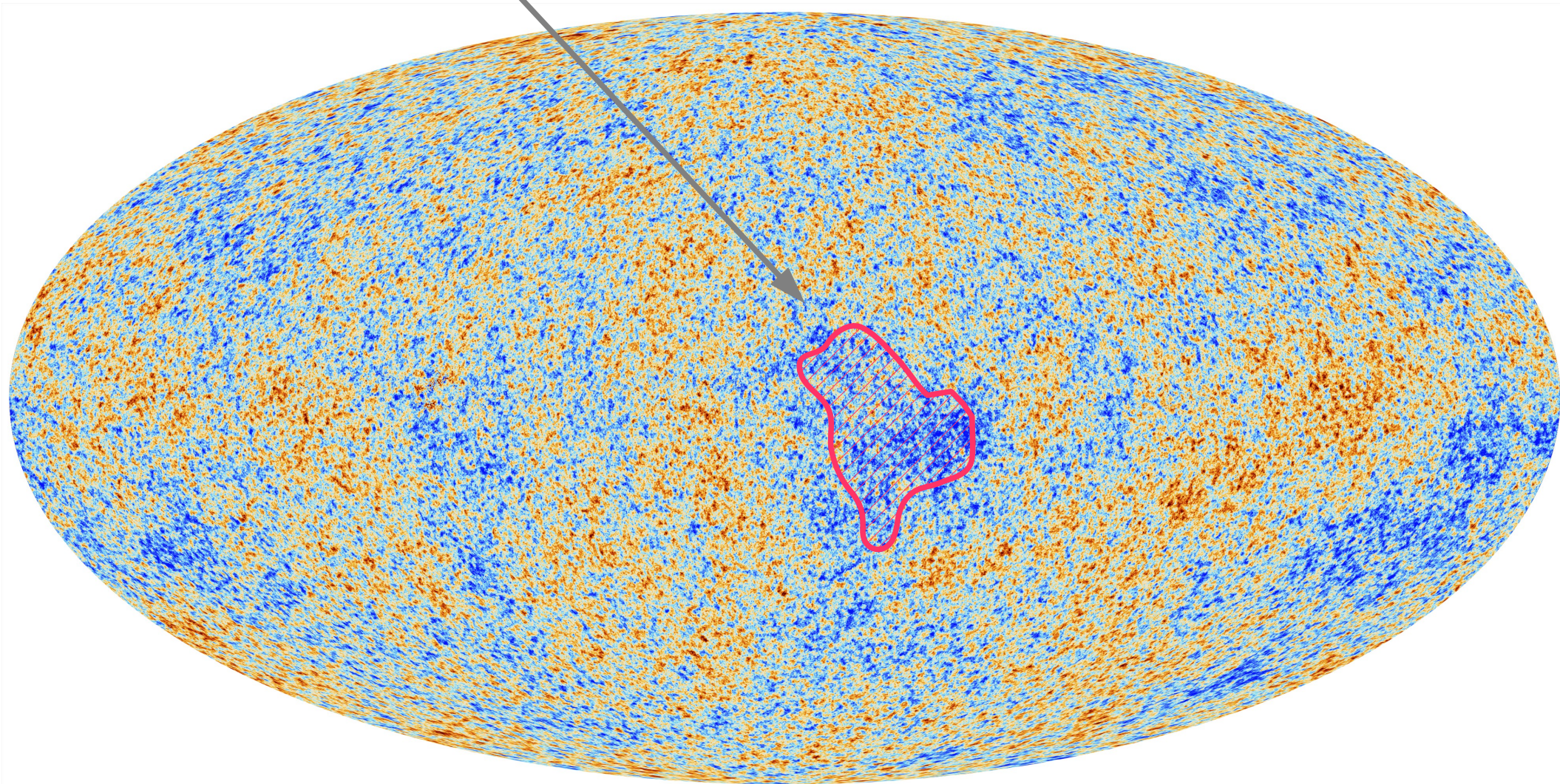
Der kosmische Mikrowellenhintergrund

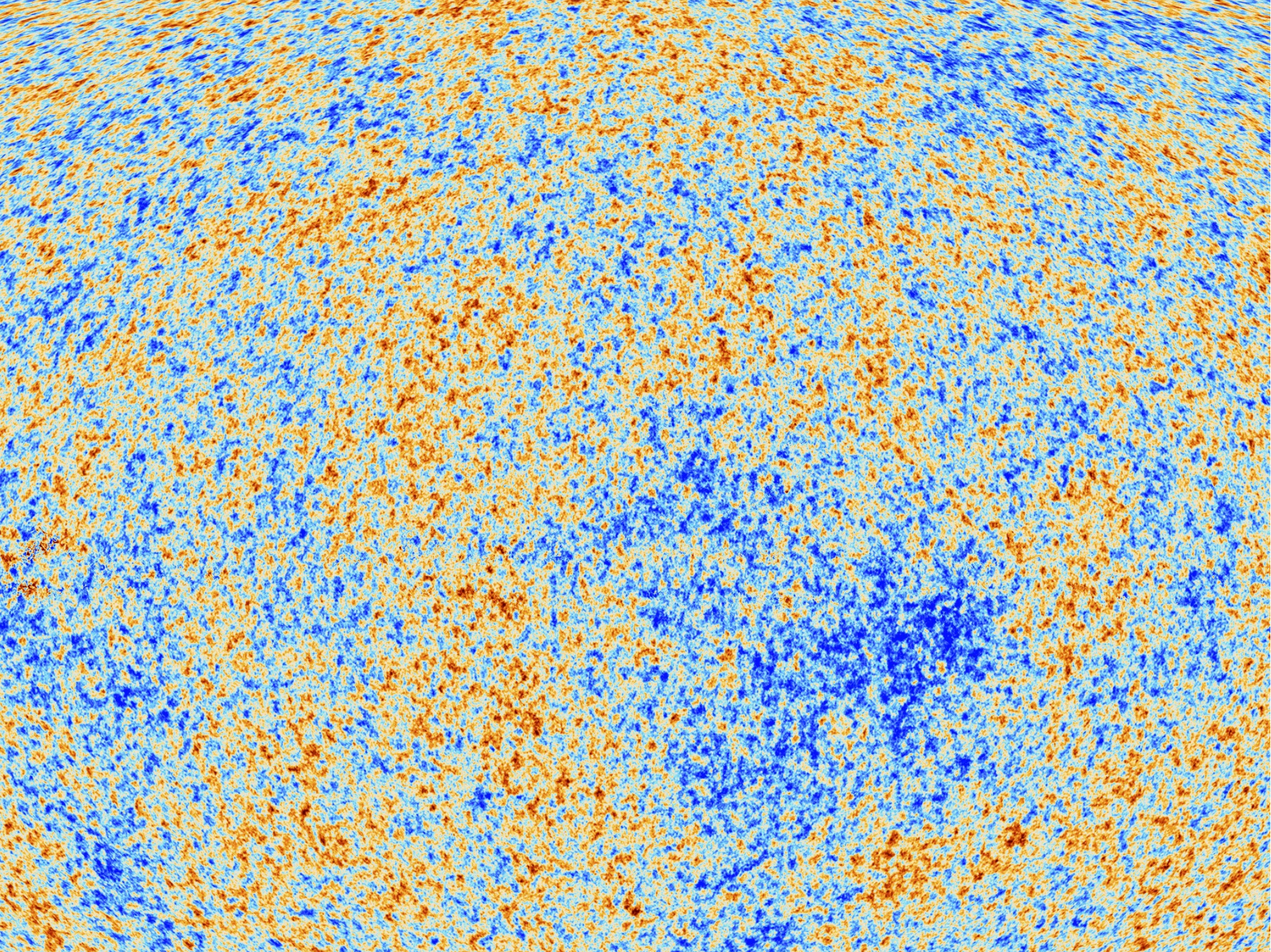


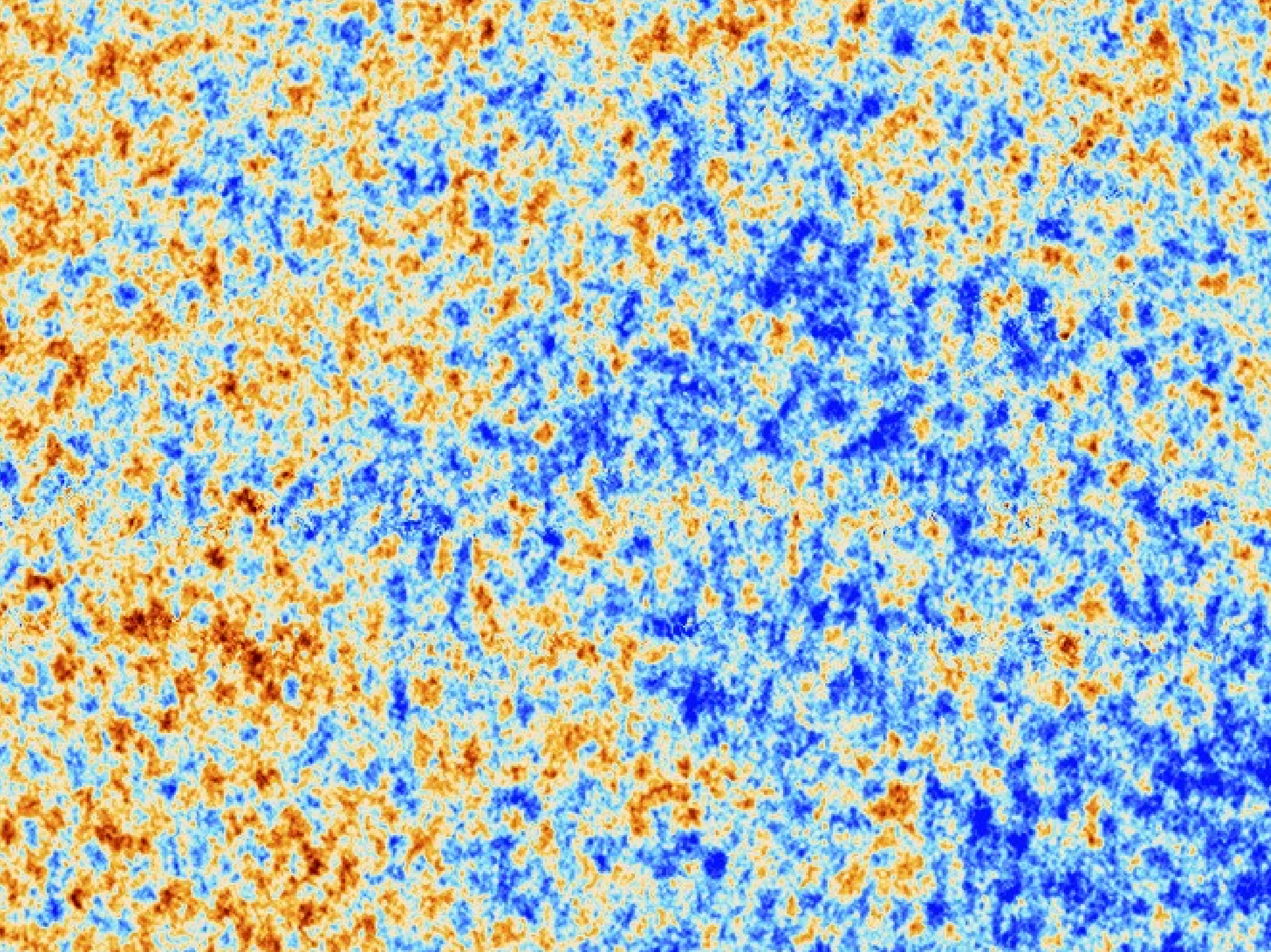
Effekt der Gravitation
auf Photonen

ϕ_{grav}

$$\frac{\delta T}{T} = \frac{1}{3} \phi_{grav}$$

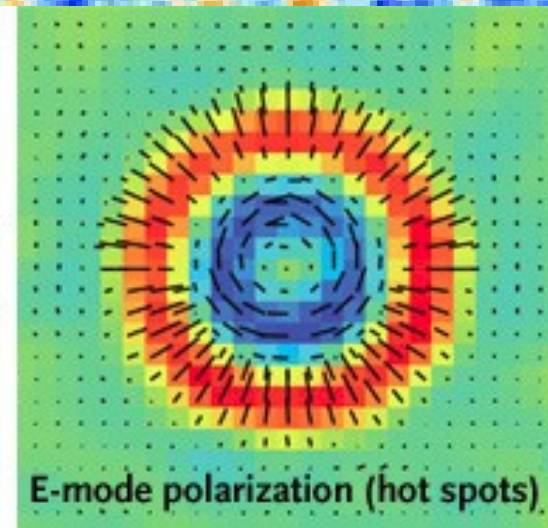
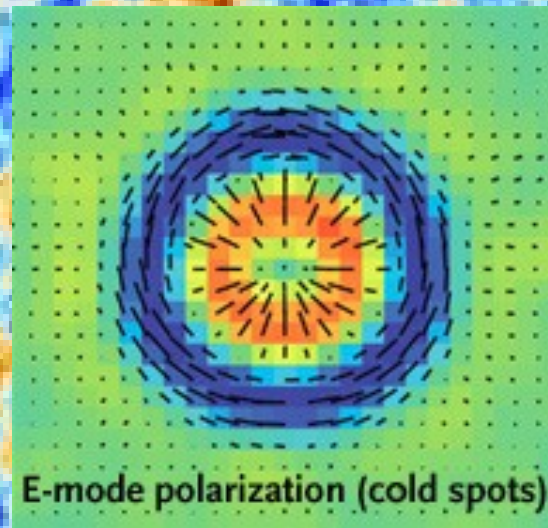
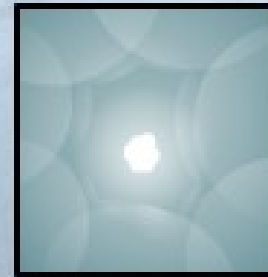
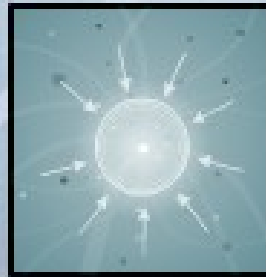
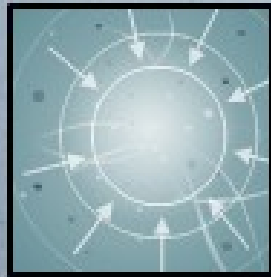
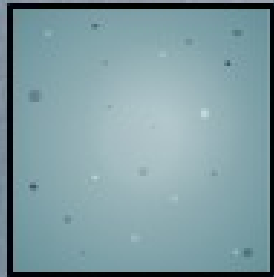






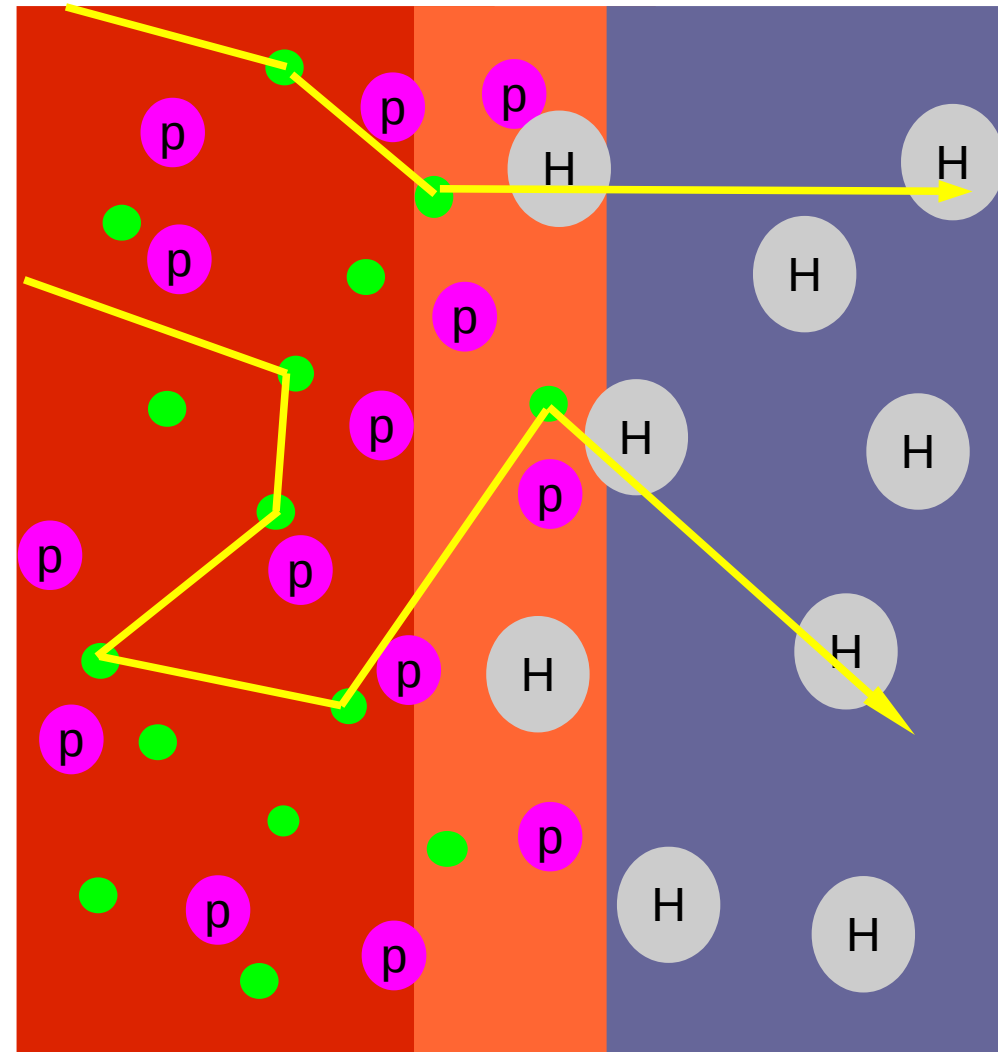


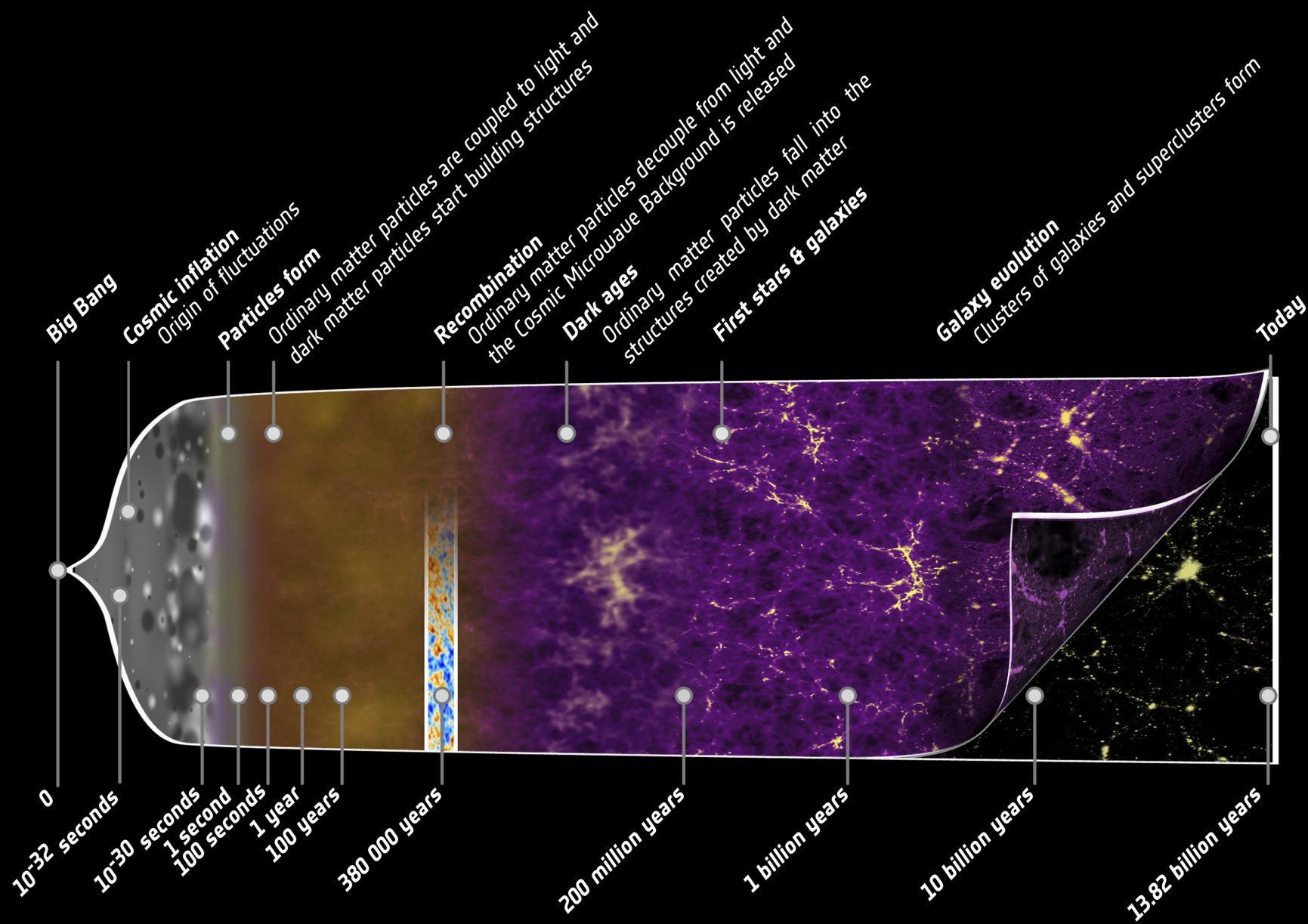
ca. 1 Winkelgrad



Atombildung & Photonendiffusion

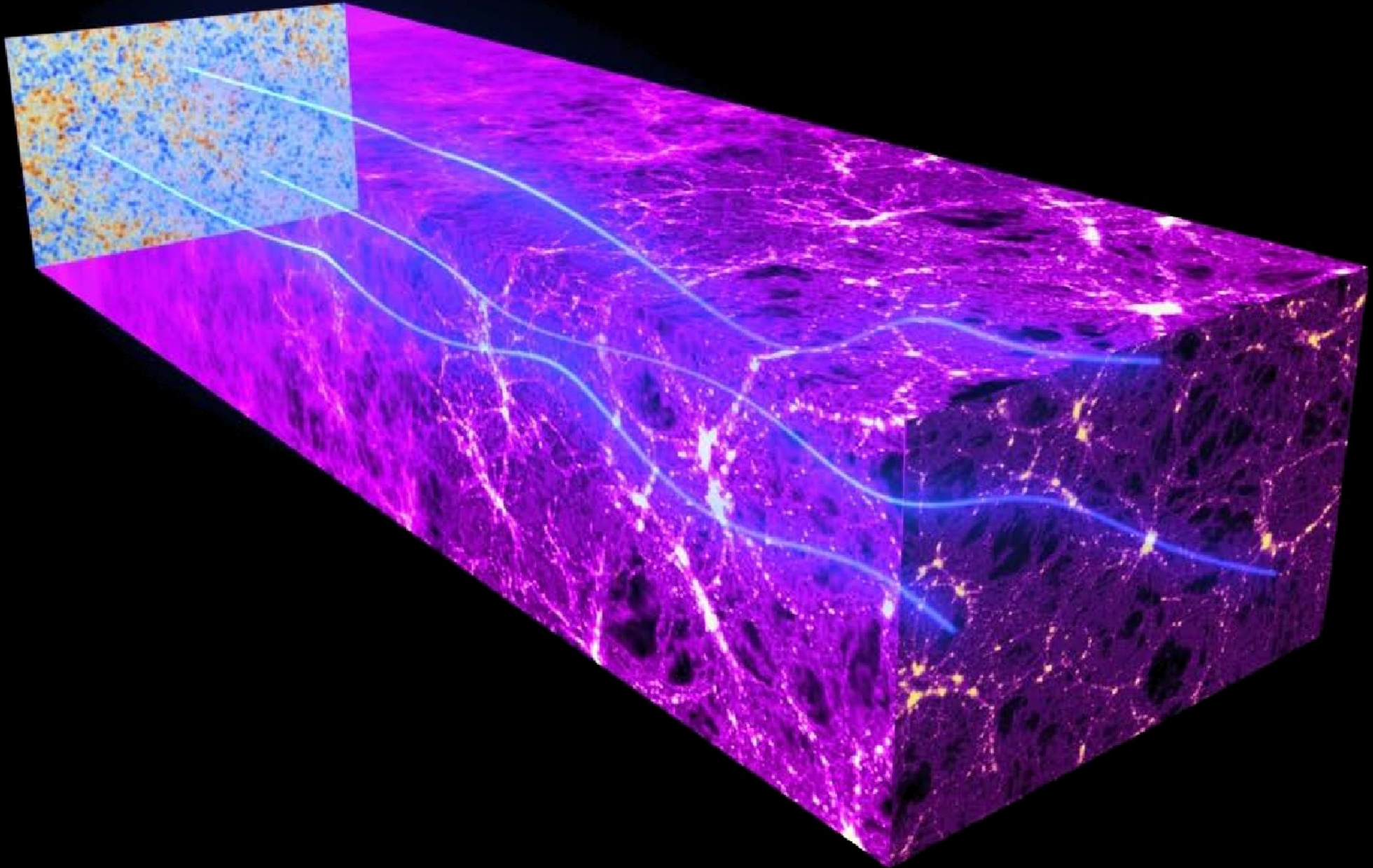
- Vor der Atombildung: Photonen streuen an freien Elektronen
- Danach: Photons strömen frei durchs Universum
- Heute sichtbare CMB Licht von der Fläche der letzten Photonenstreuung
- Endliche Dauer der Bildung erlaubt Photonen zu wandern
- Strukturen unterhalb von 5 Bogenminuten sind ausgelöscht (1/6 Monddurchmesser)



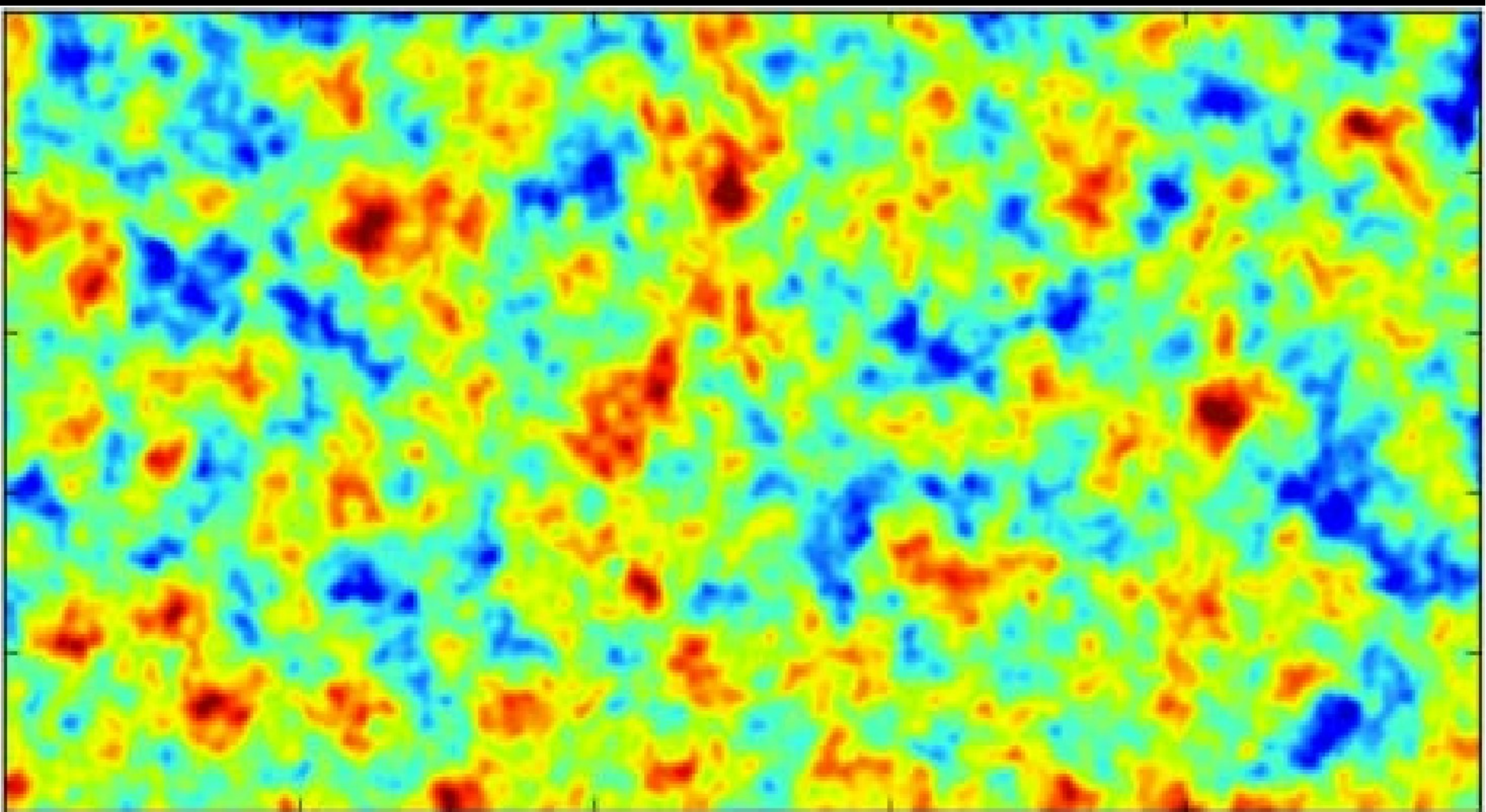


Photonenreise

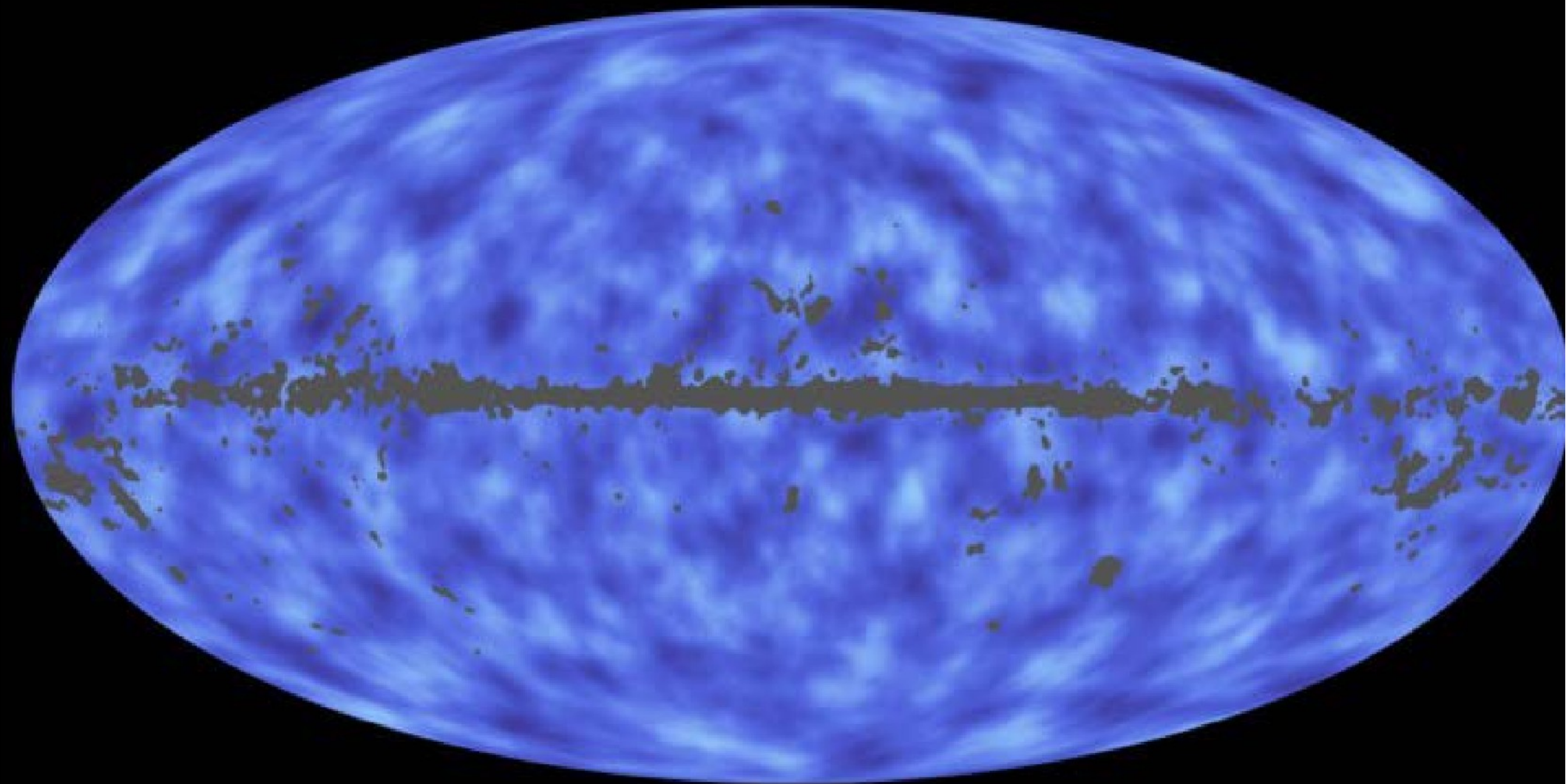
Gravitationslinseneffekt



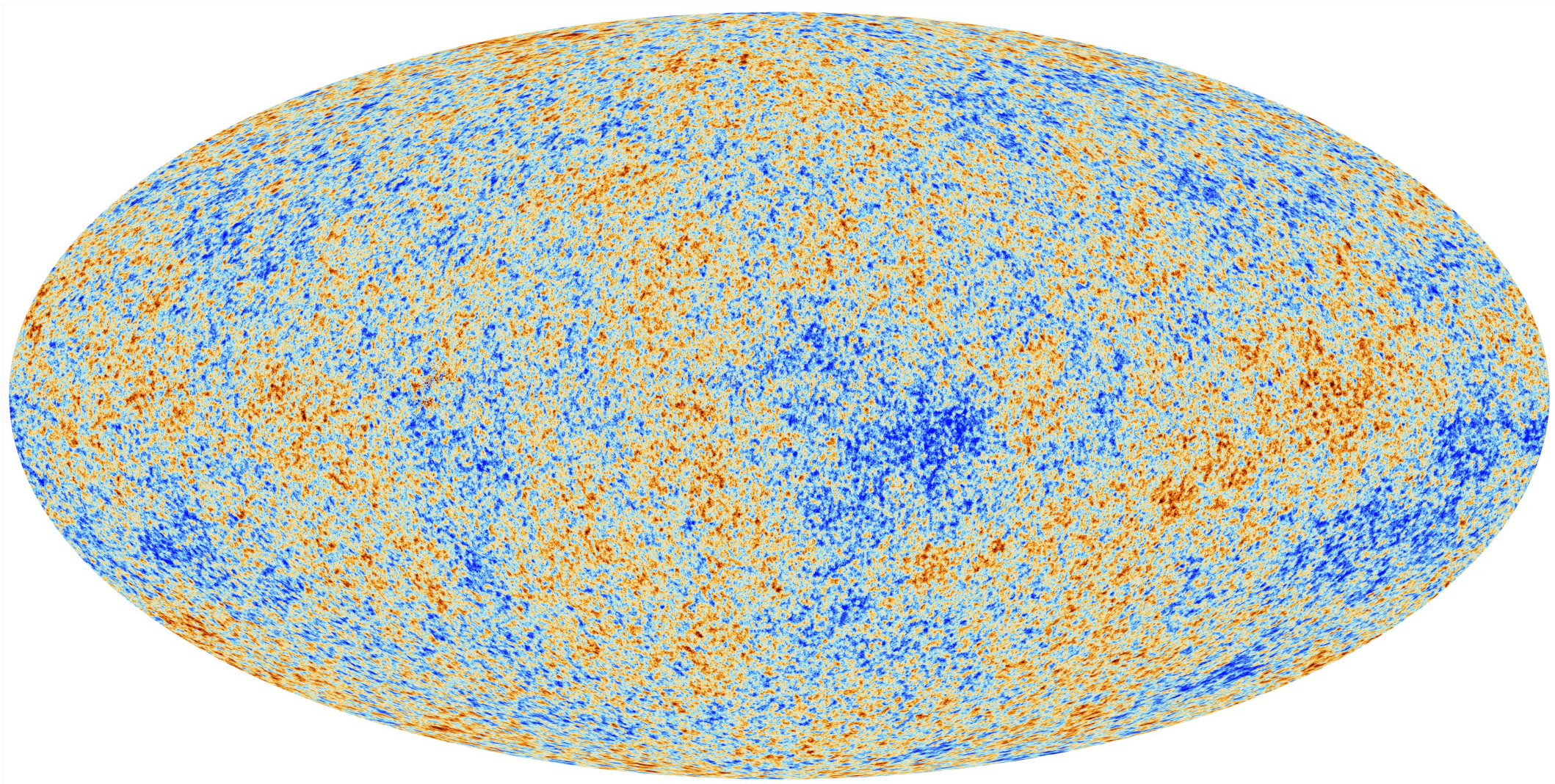
Gravitationslinseneffekt



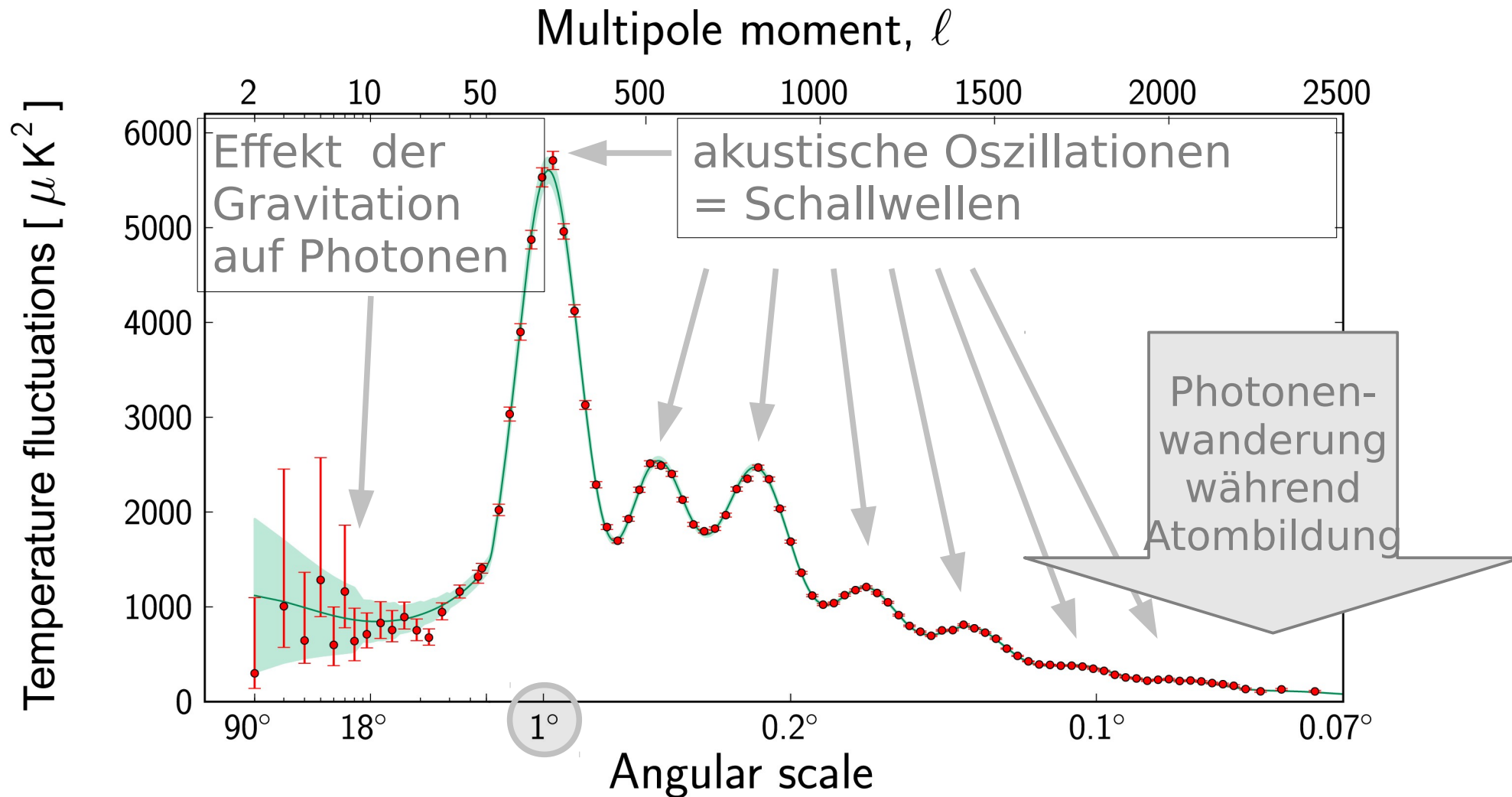
Projizierte Massenverteilung



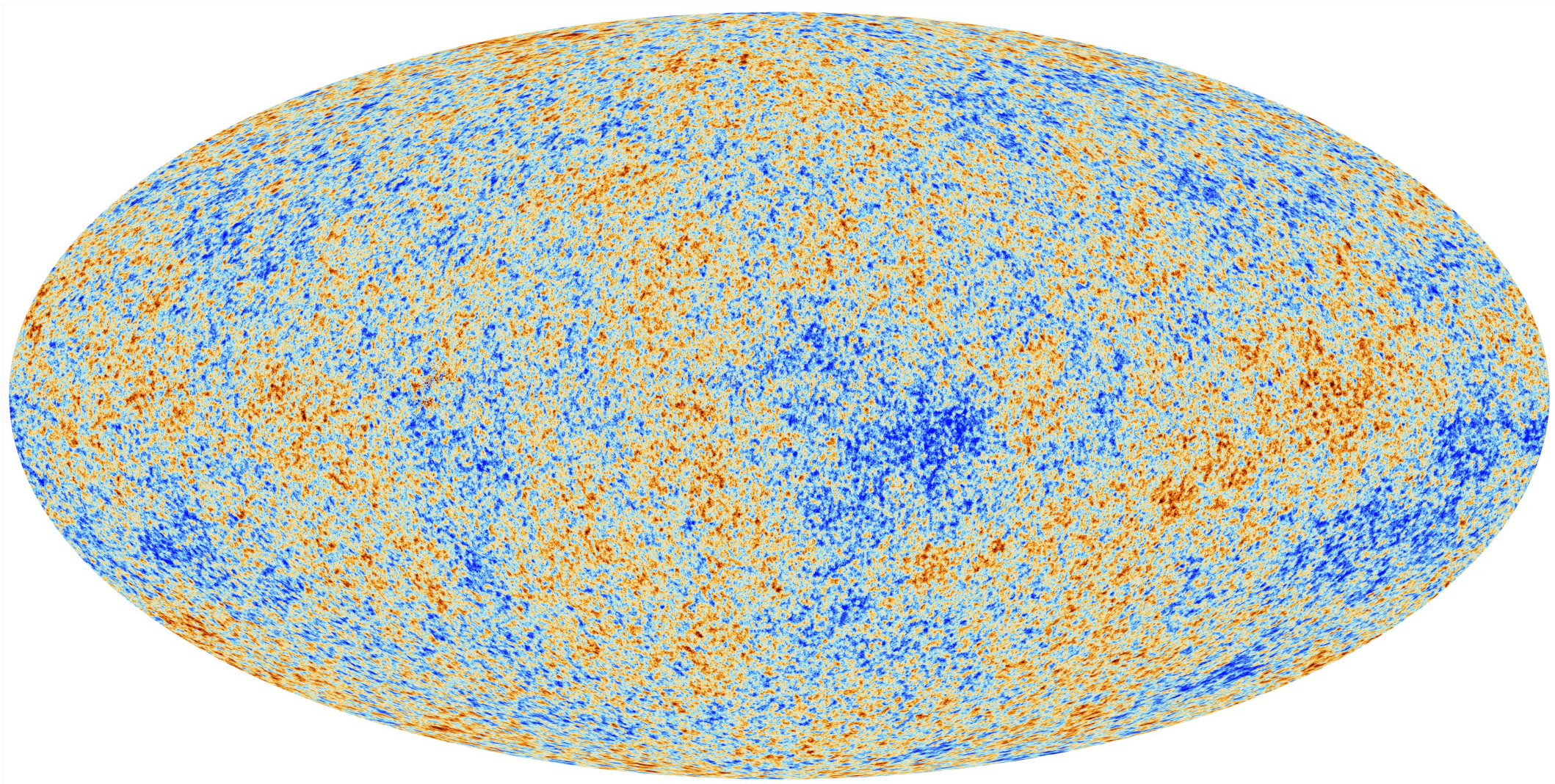
Der kosmische Mikrowellenhintergrund



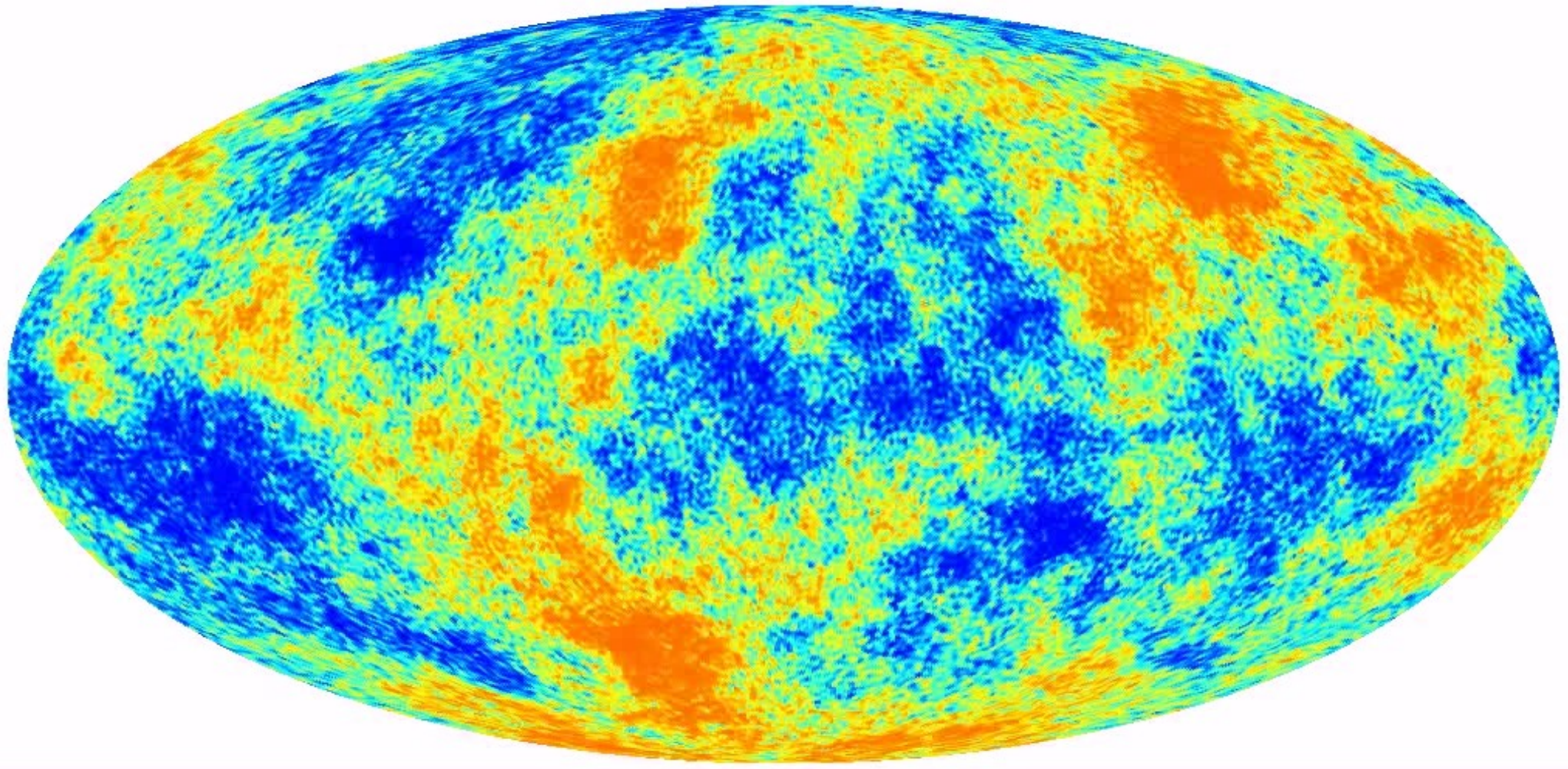
Räumliches Leistungsspektrum



Der kosmische Mikrowellenhintergrund



Simulation

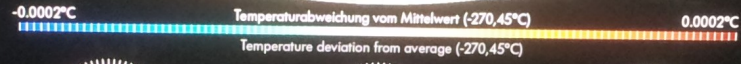


Mikrowellen besteht un-
hatten, um das Weltall z
Epoche das Dunkle Zeite

'Der kosmische Fingerabdruck The Cosmic Fingerprint

Simuliertes Universum
Simulated Universe

Unser Universum
Our Universe



Der kosmische Fingerabdruck

Die Temperaturschwankungen der kosmischen Mikrowellenstrahlung hängen eng mit dem Aufbau und der Entwicklung des Universums zusammen. Während die die das Universum gezeichnete Muster, Dunkle Materie und Dunkle Energie und beschreiben die, was sich das gesamte Muster der Hintergrundstrahlung auszeichnet. Die 'Fingerabdruck' des Universums ist ein Bild, das die Entwicklung des Universums zeigt. Es ist ein Bild, das die Entwicklung des Universums zeigt. Es ist ein Bild, das die Entwicklung des Universums zeigt.

The Cosmic Fingerprint

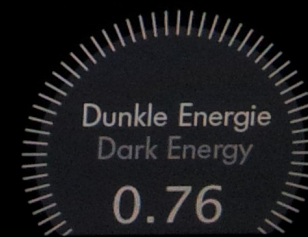
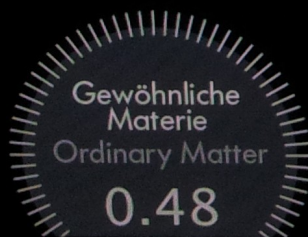
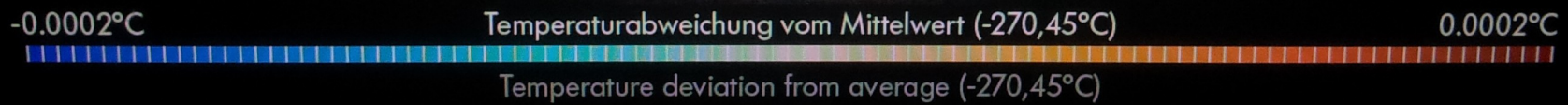
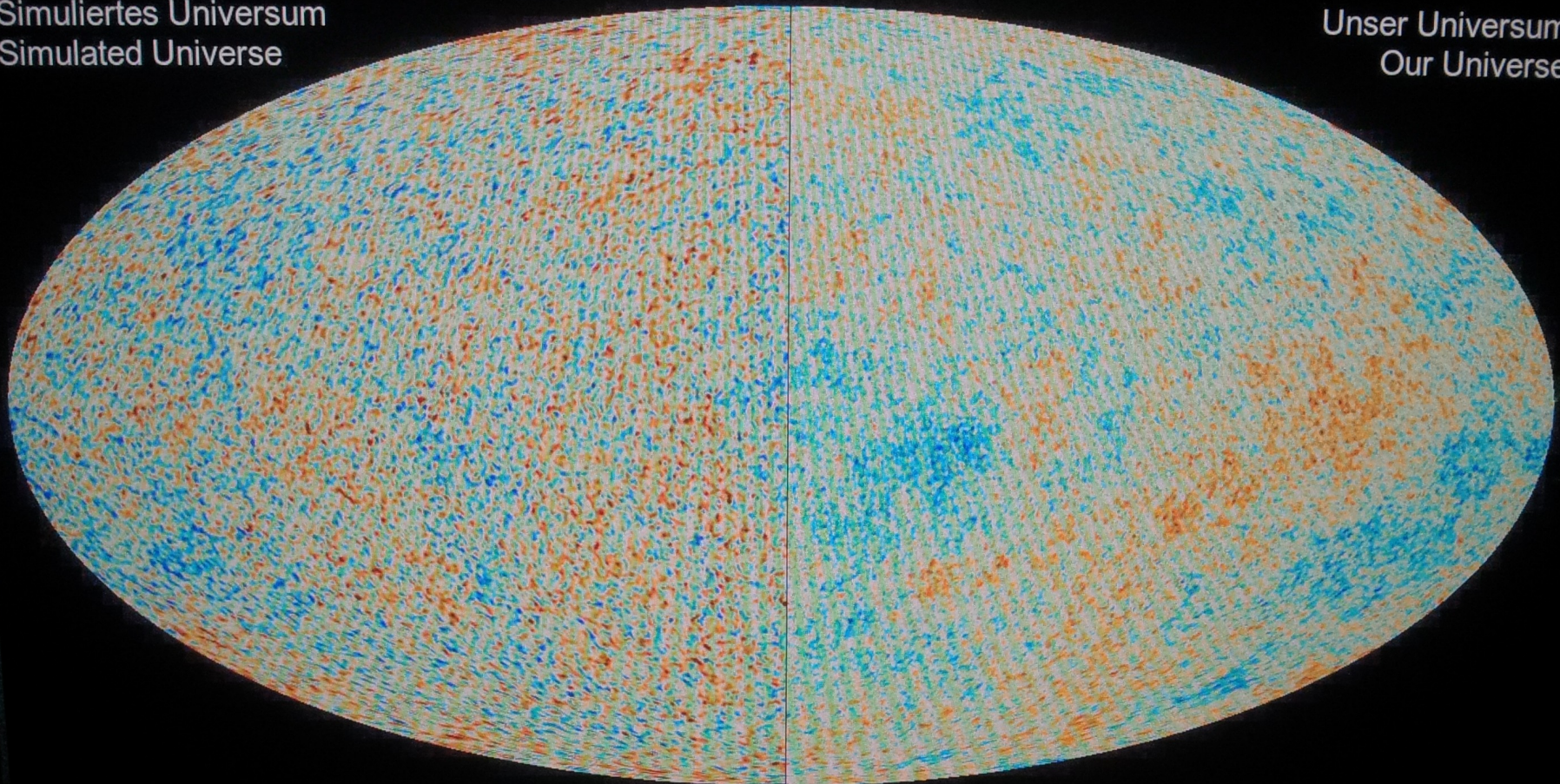
The temperature fluctuations of the cosmic microwave radiation are closely related to the structure and development of the universe. While the pattern drawn by the universe, dark matter and dark energy and describe the, what the entire pattern of the background radiation is characterized. The 'fingerprint' of the universe is a picture that shows the development of the universe. It is a picture that shows the development of the universe. It is a picture that shows the development of the universe.



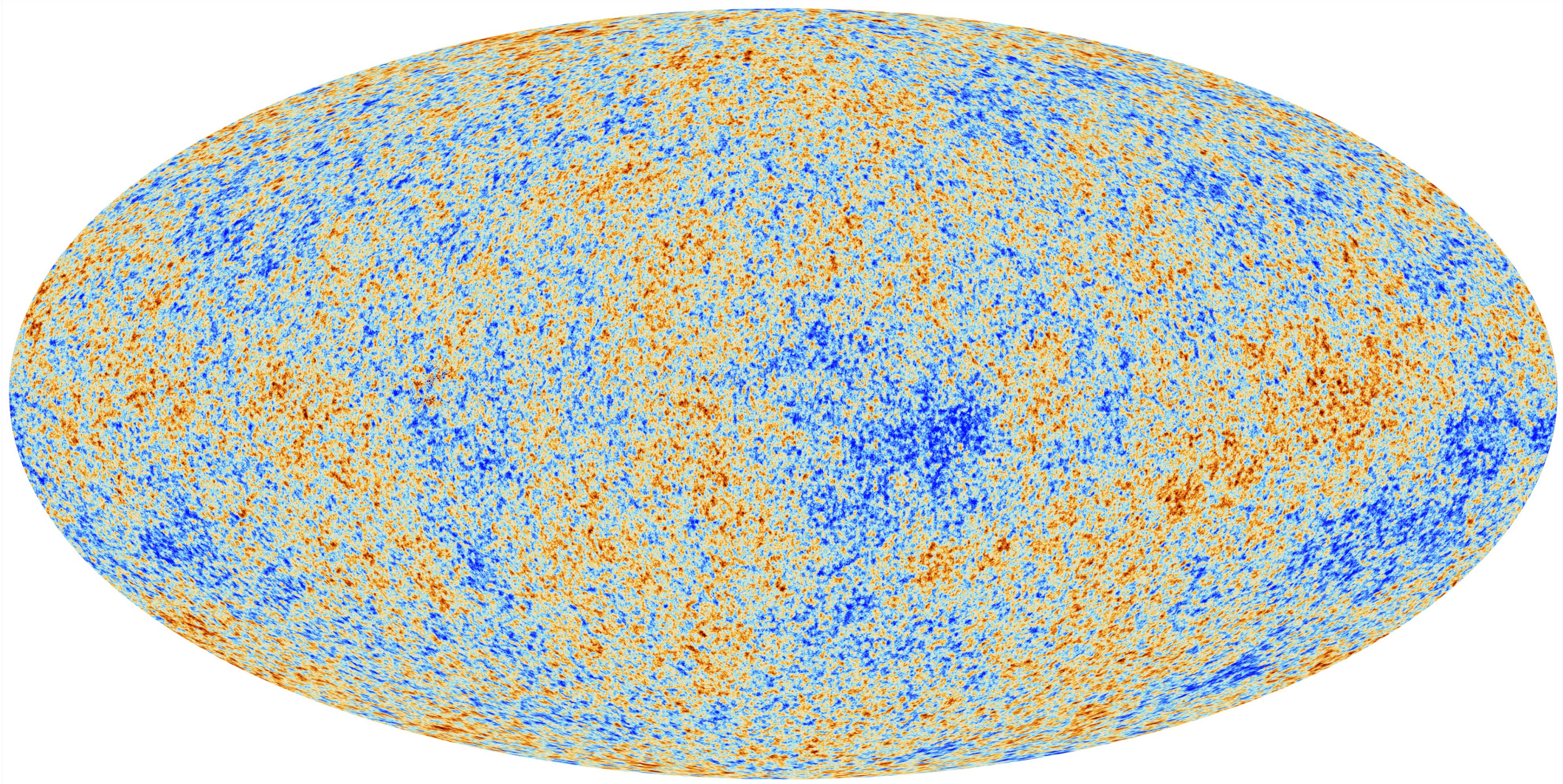
Der kosmische Fingerabdruck The Cosmic Fingerprint

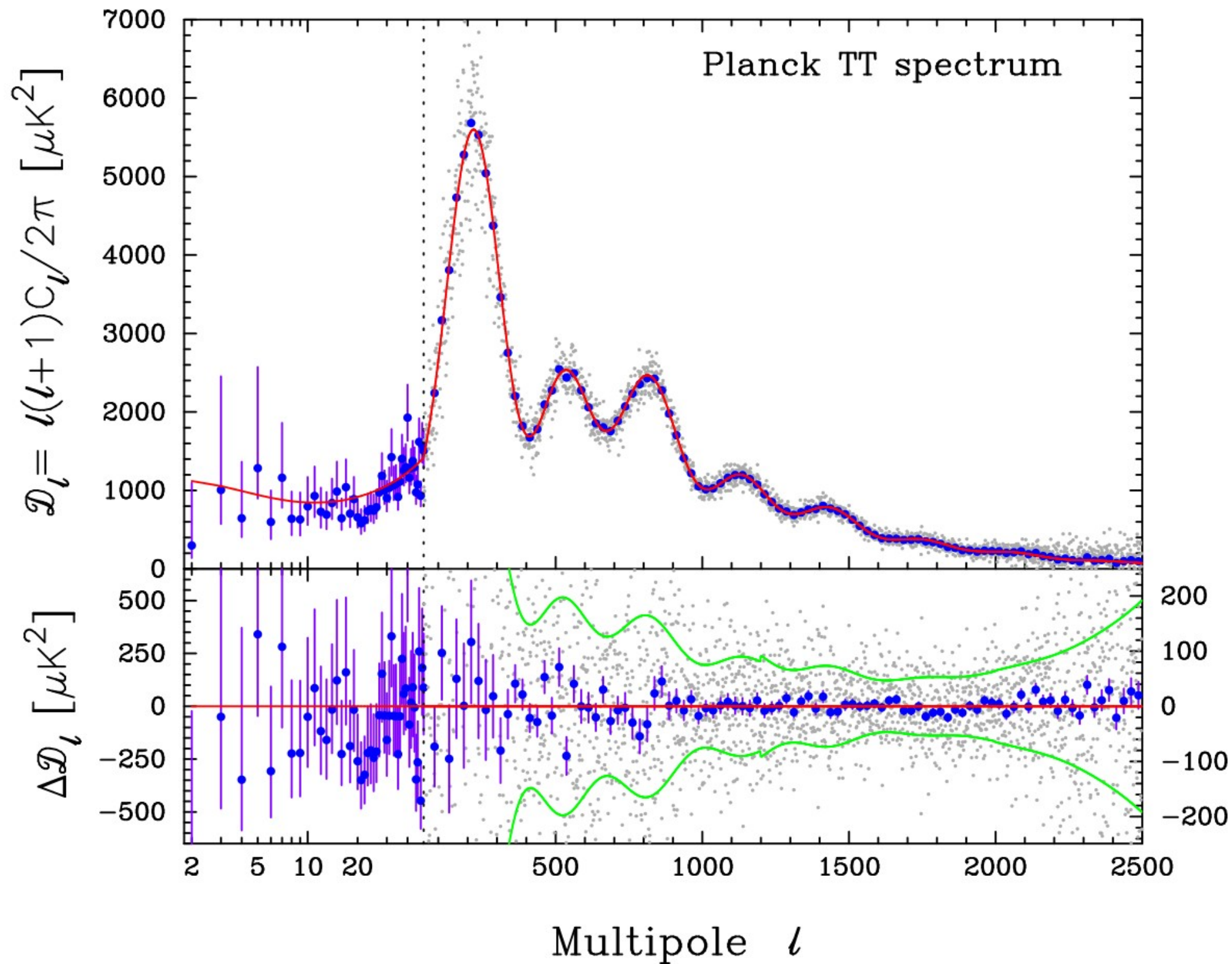
Simuliertes Universum
Simulated Universe

Unser Universum
Our Universe



Der kosmische Mikrowellenhintergrund



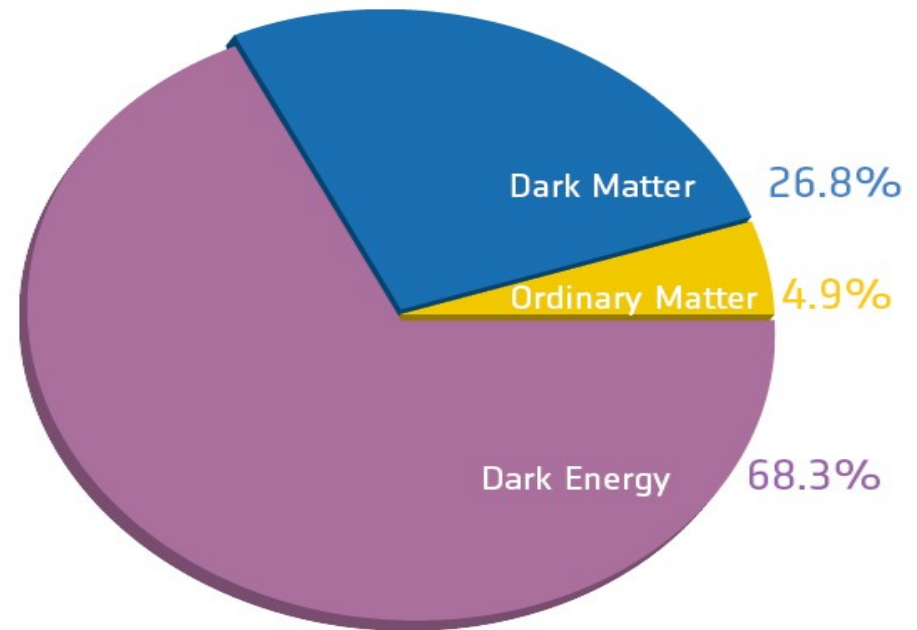


Präzisionsmessung kosmologischer Parameter

Etwa mehr gewöhnliche und dunkle
Materie (4.9% und 26.8%)
(zuvor 4.5% und 22.7%)

Kleinere Ausdehnungsrate des
Universums von 67.15 km/s/Mpc
(zuvor 69.32 km/s/Mpc)

Größeres Alter des Universums:
13.82 Milliarden Jahre
(zuvor 13.77 Milliarden Jahre)

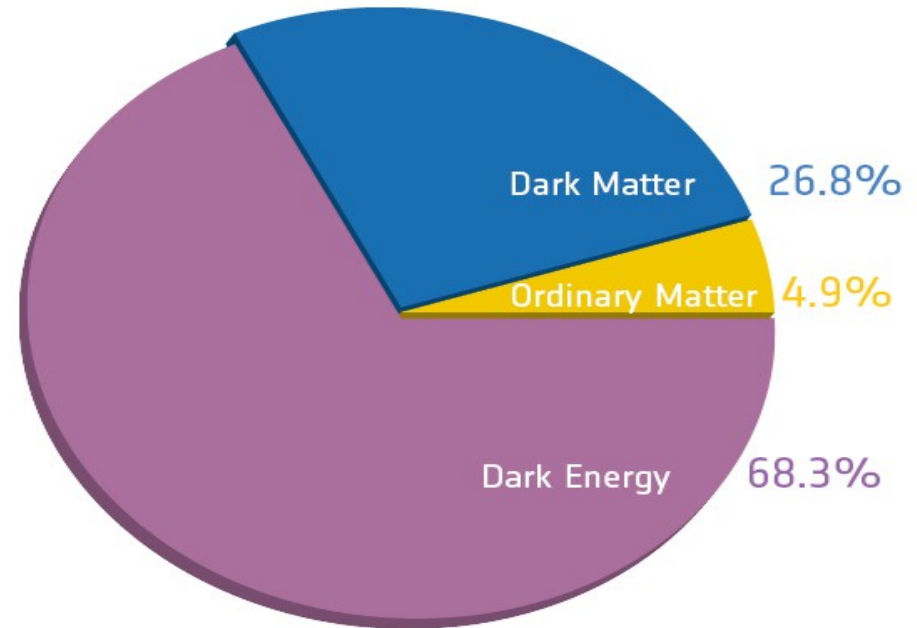


After Planck

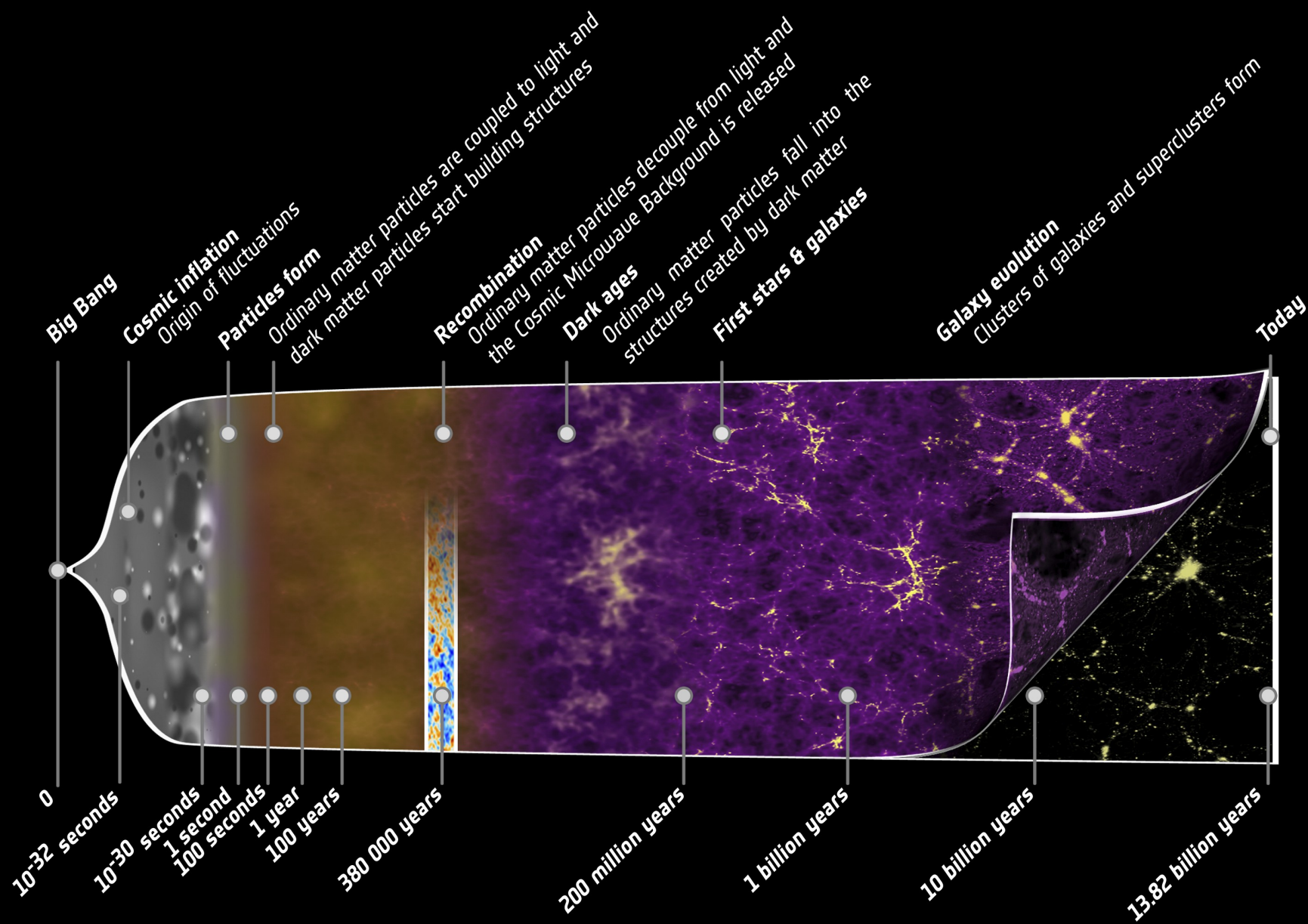
Präzisionsmessung kosmologischer Parameter

Unser Universum wurde
(dank Planck)

schwerer,
langsamer &
älter !

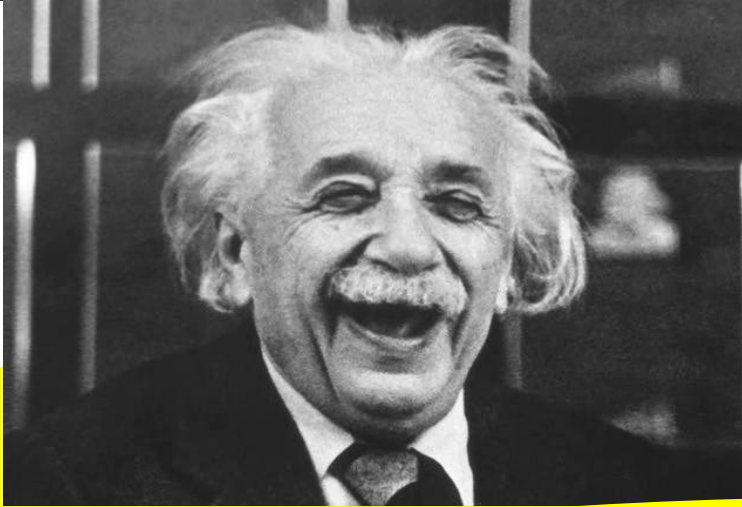


After Planck

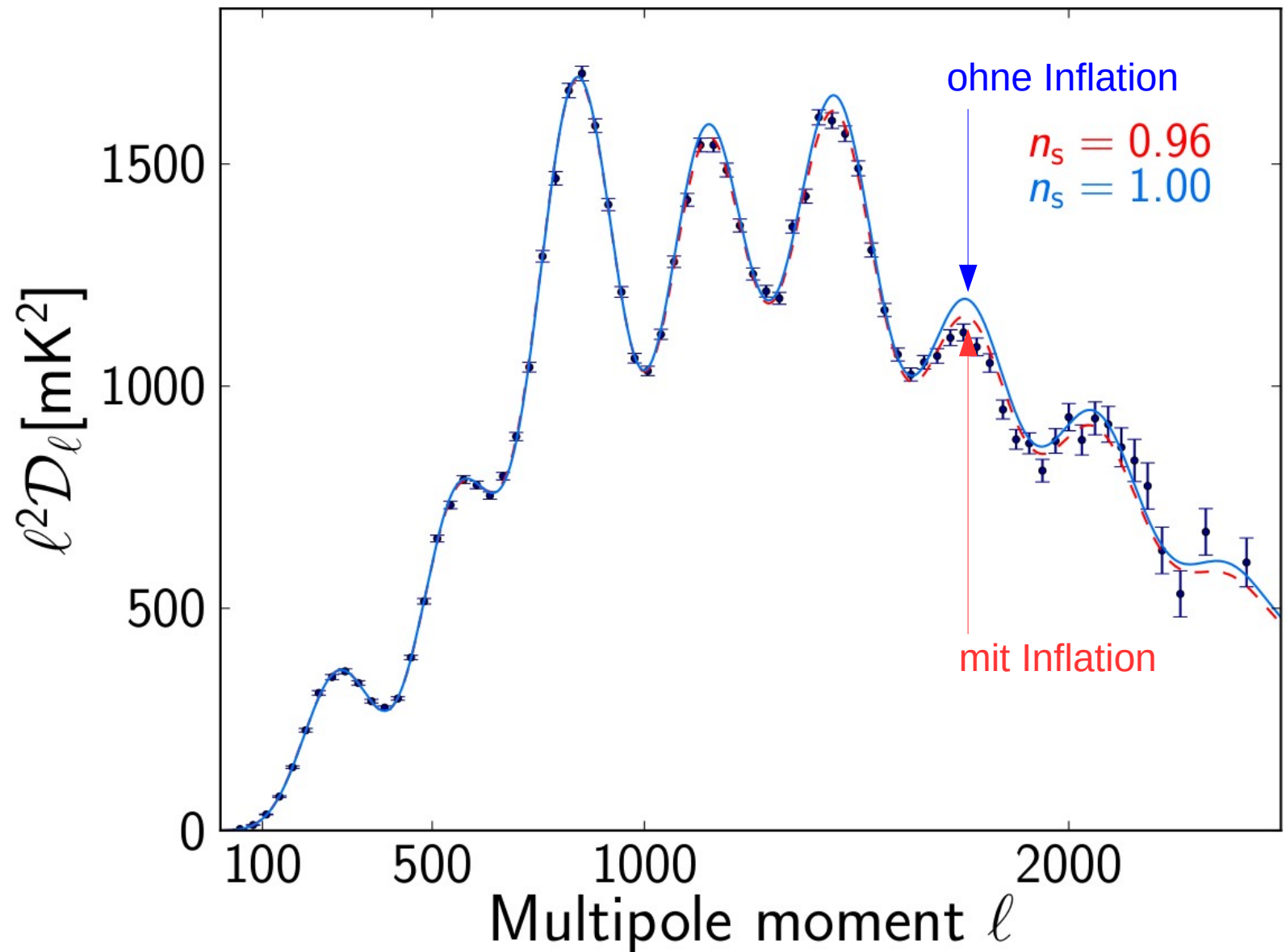




All together now: Inflationstheorie



Erste Bestätigung der Inflationstheorie



Big Bang

Big Bang plus
 10^{-43} seconds

quantum-gravity era

inflation

Big Bang plus
 10^{-35} seconds?

cosmic microwave background

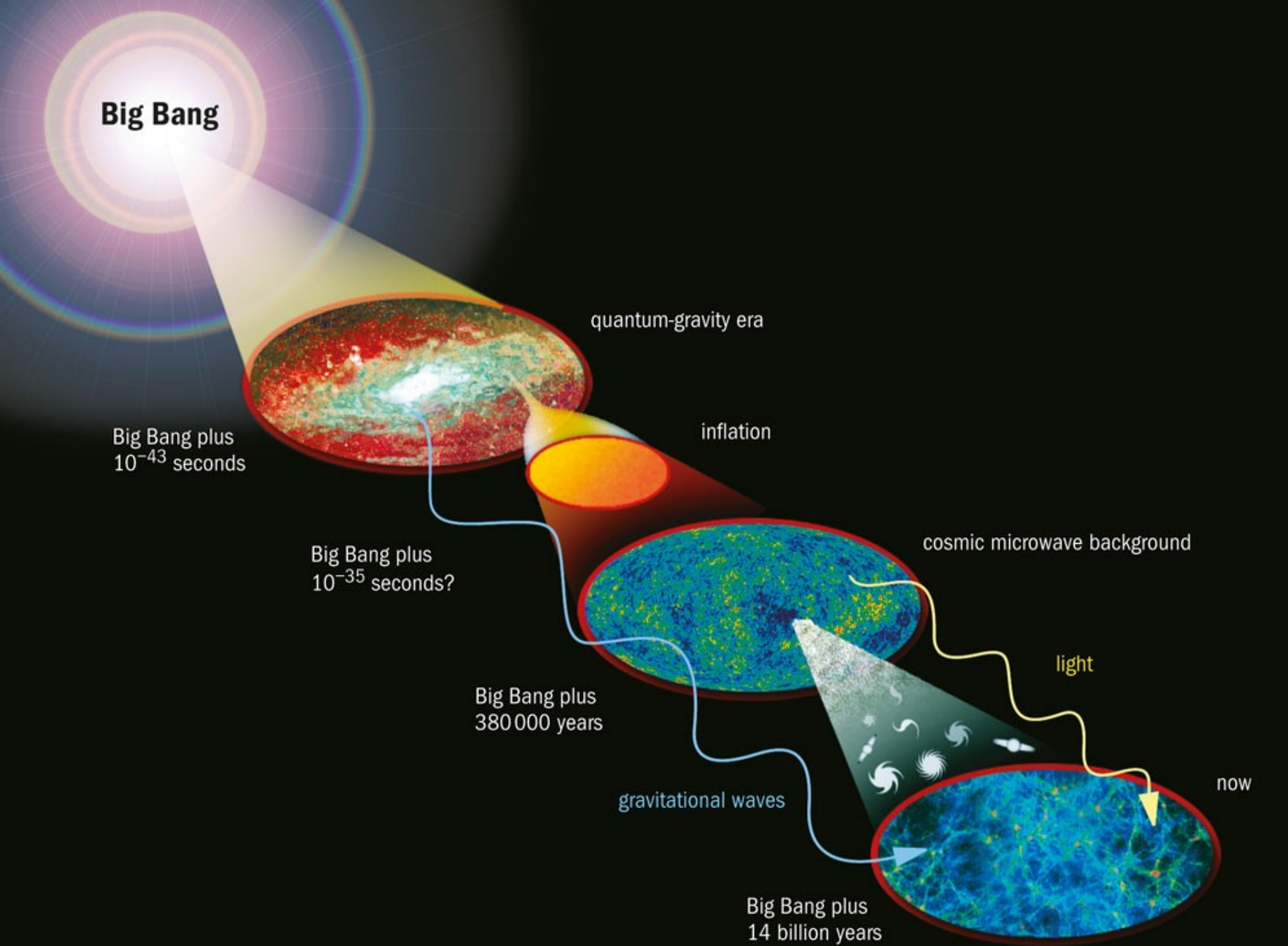
Big Bang plus
380 000 years

light

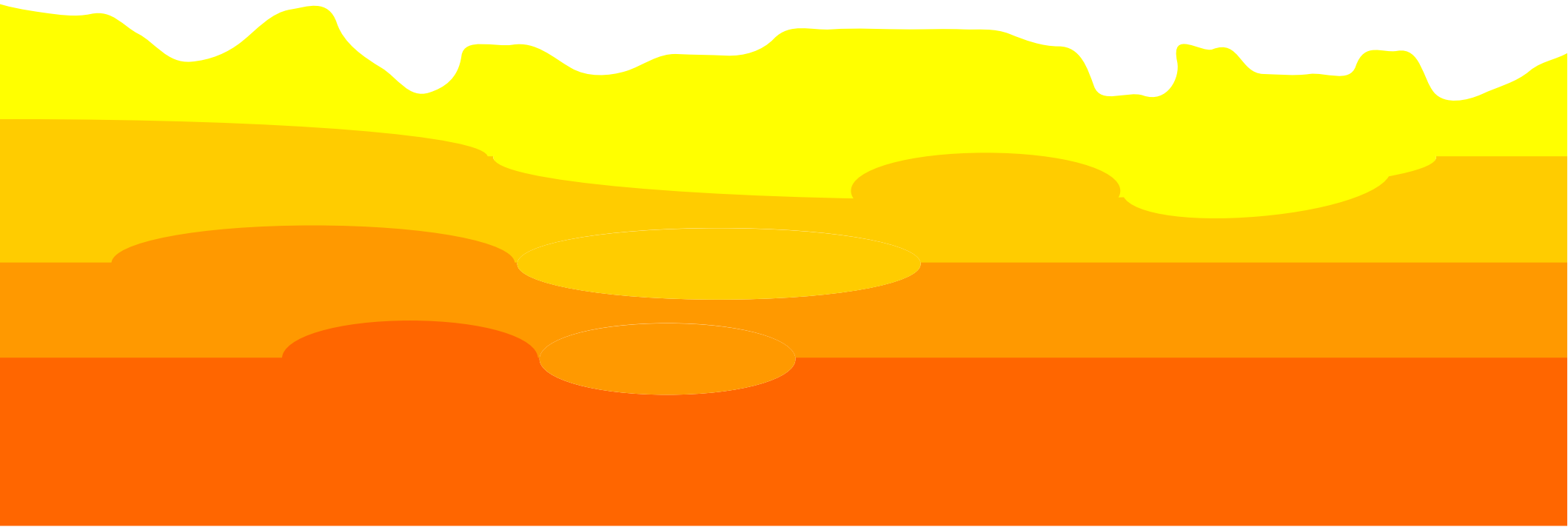
gravitational waves

now

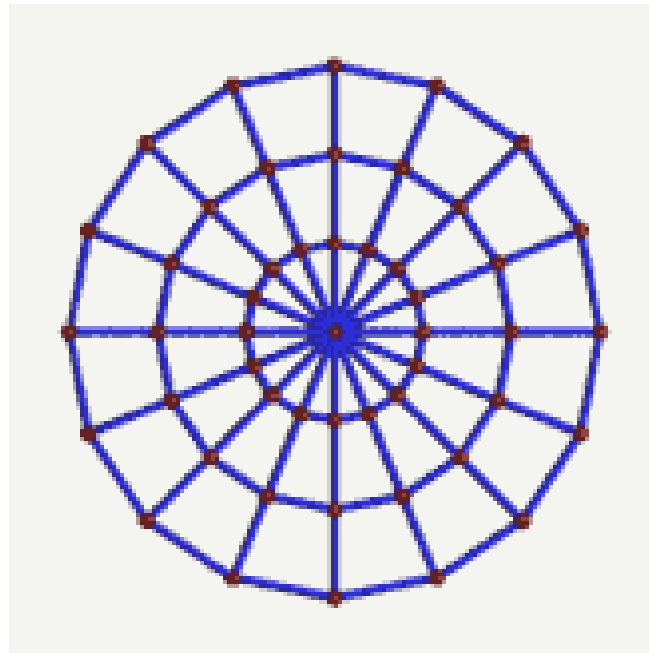
Big Bang plus
14 billion years



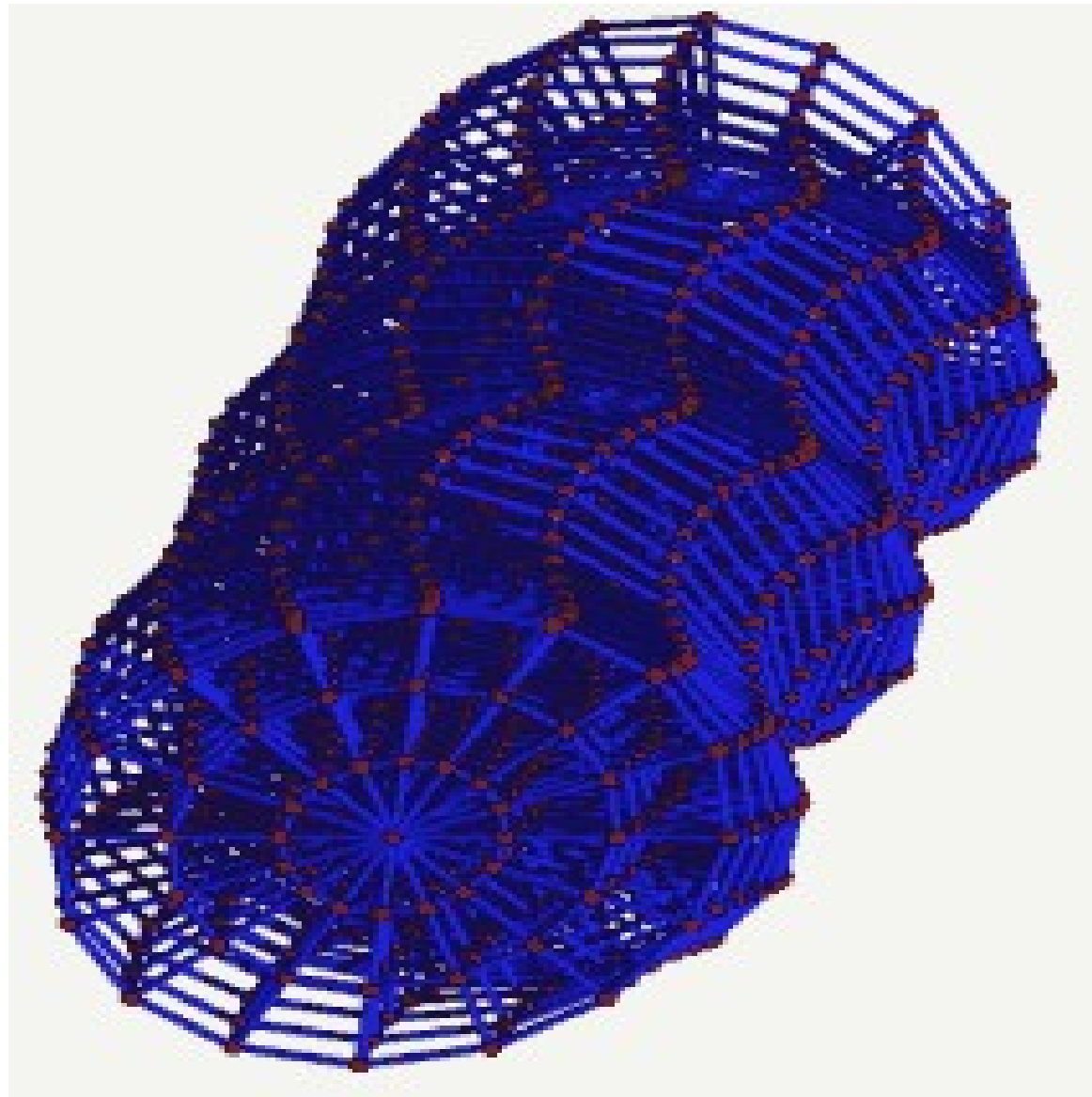
All together now: Inflationstheorie



Gravitationswellen



Gravitationswellen

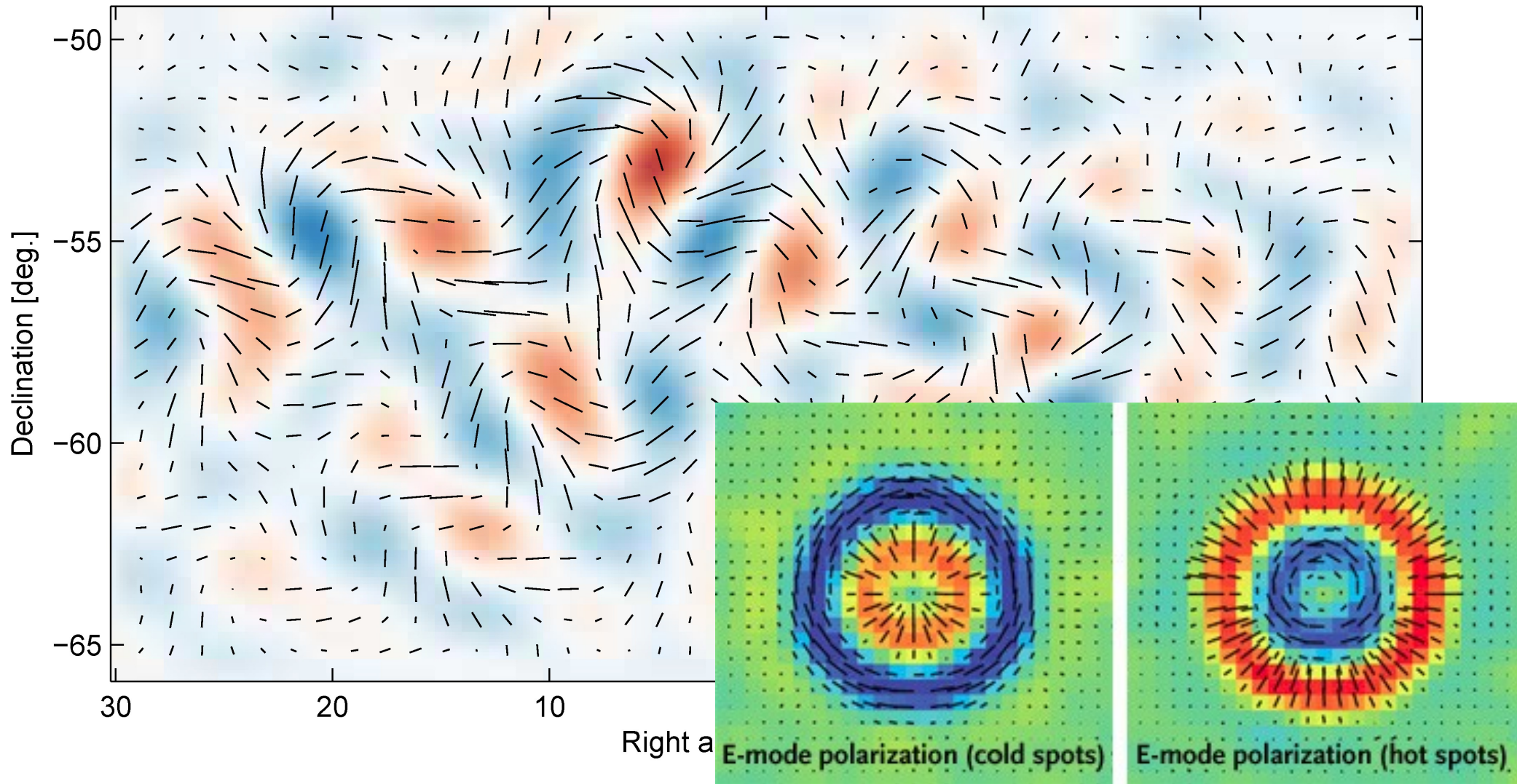


BICEP2



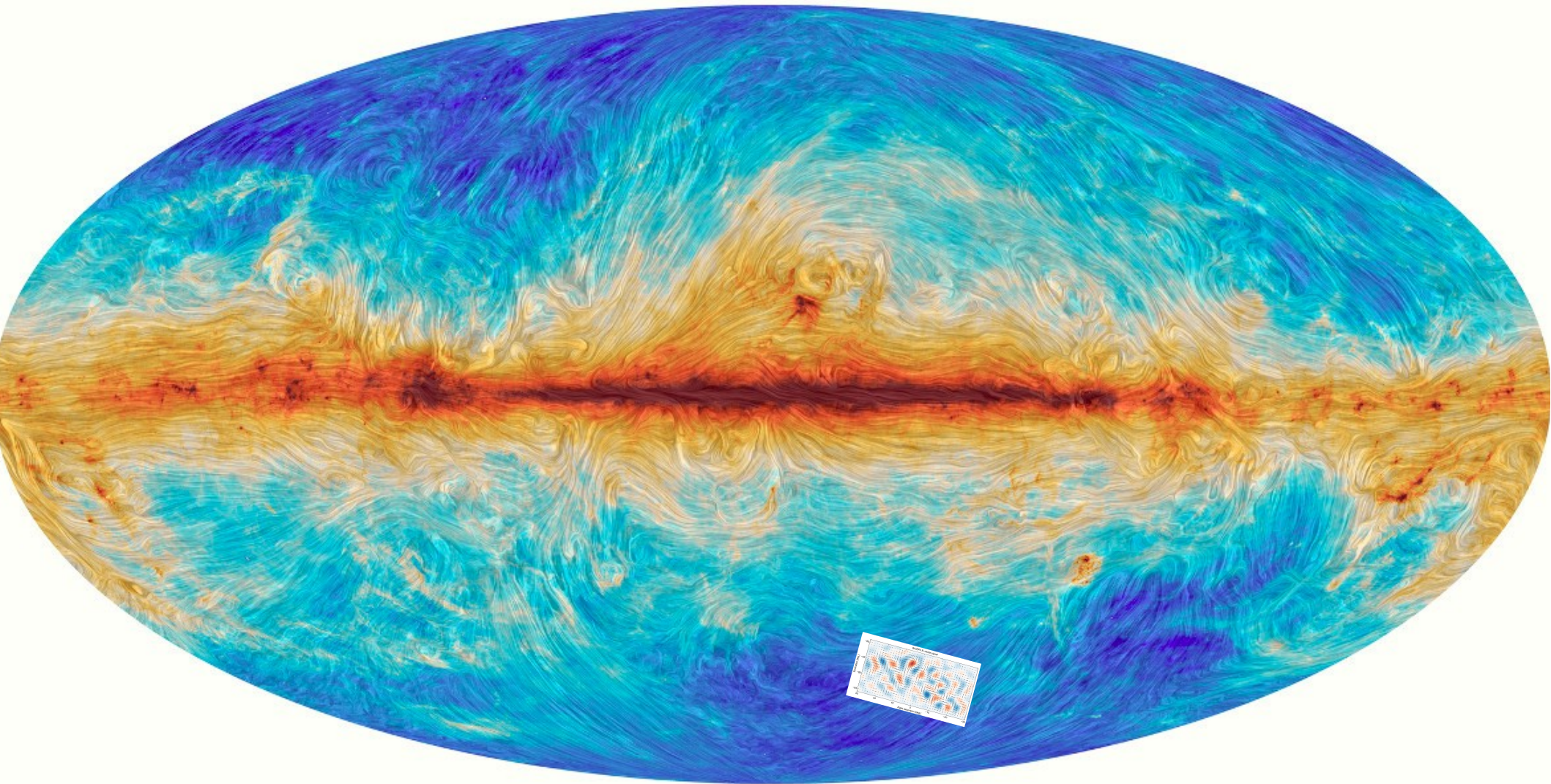
Spiralmuster in der Mikrowellenpolarisation

BICEP2 B-mode signal



Polarisation galaktischen Staubs

mit Planck



Zusammenfassung

Das Licht des Urknalls existiert noch heute als Mikrowellenstrahlung mit einer Temperatur von 2.725 Kelvin

Strukturen in dieser Temperatur zeugen von Schallwellen, Materieverdichtungen, und anderen Vorgängen im frühen und heutigen Universum

Die präzise Vermessung dieser Strukturen gibt Einblicke in die Entstehung, Geschichte und Zusammensetzung des Kosmos

Wir beginnen in die Inflationäre Phase direkt nach dem Urknall zu spähen, während der Quanteneffekte die Saat für alle im Kosmos sichtbaren Strukturen gelegt haben sollten.

Zusammenfassung

Albert Einsteins Spezielle und Allgemeine Relativitätstheorie, sowie die von ihm mitbegründete Quantenphysik, liefern gemeinsam eine erstaunliche Theorie des Ursprung des Kosmos, die Inflationstheorie, welche nun, einhundert Jahre nach der Komplettierung der Allgemeinen Relativitätstheorie, durch präzise Messungen unterstützt wurde.

The scientific results that we present today are the product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada



planck



National Research Council of Italy



Deutsches Zentrum für Luft- und Raumfahrt e.V.

