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# Cosmic Structures – Why is the Universe not empty?

Science Circle Lecture  
February 22nd, 2021

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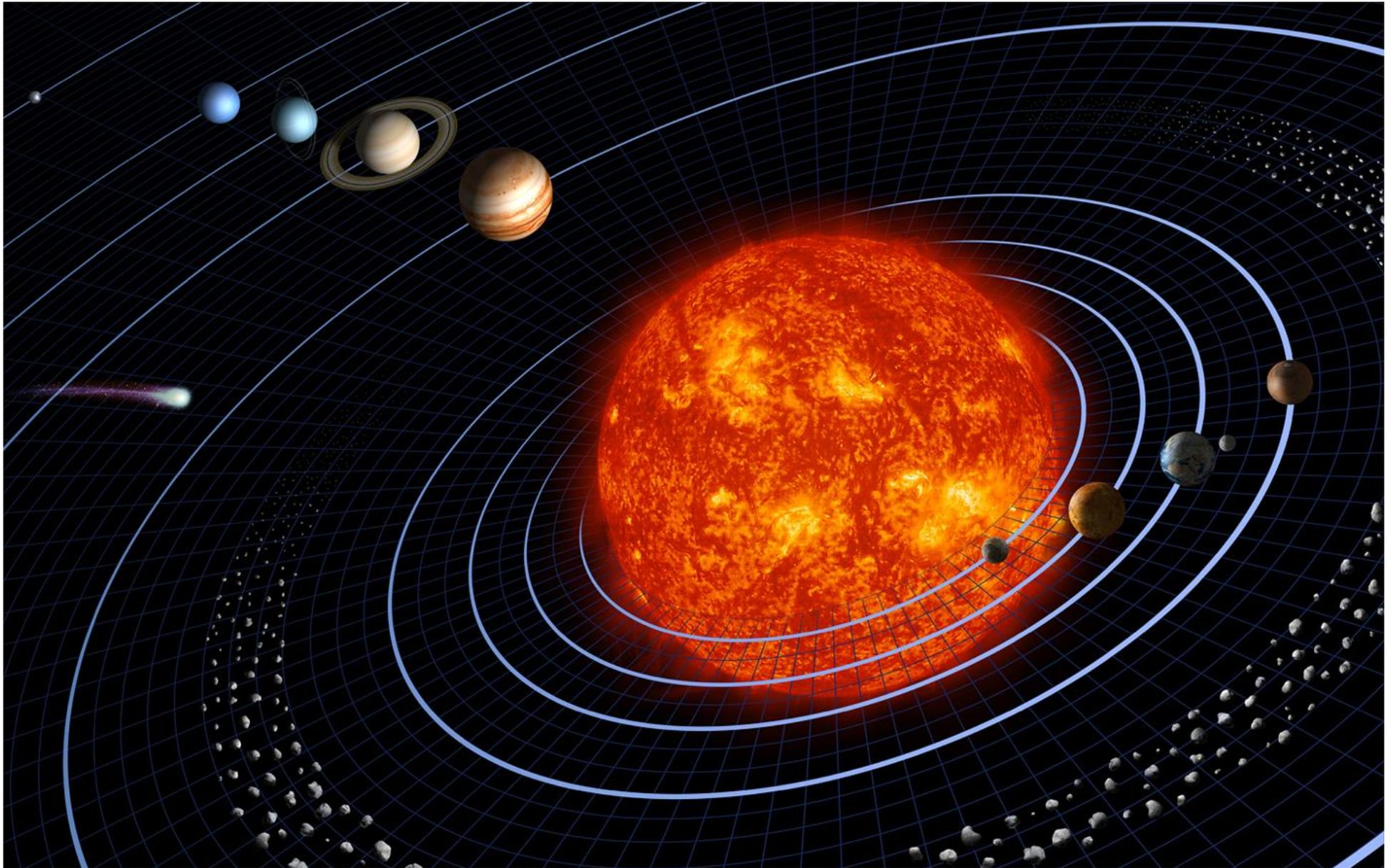
Embassy  
of the Federal Republic of Germany  
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# Our Environment: the Solar System



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# Our galaxy: the Milky Way



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# Other galaxies



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# Galaxy clusters



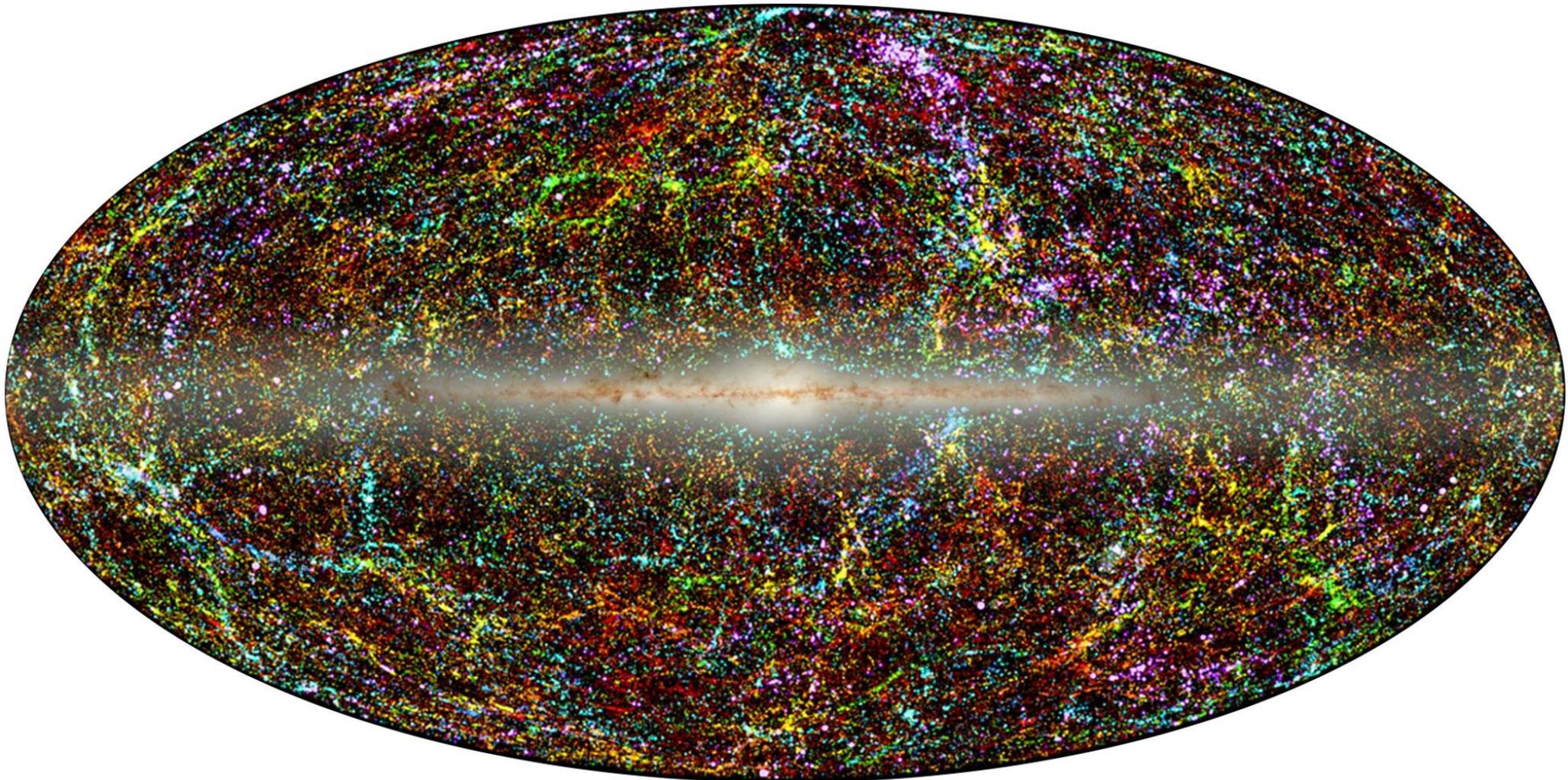
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# Large-scale structures



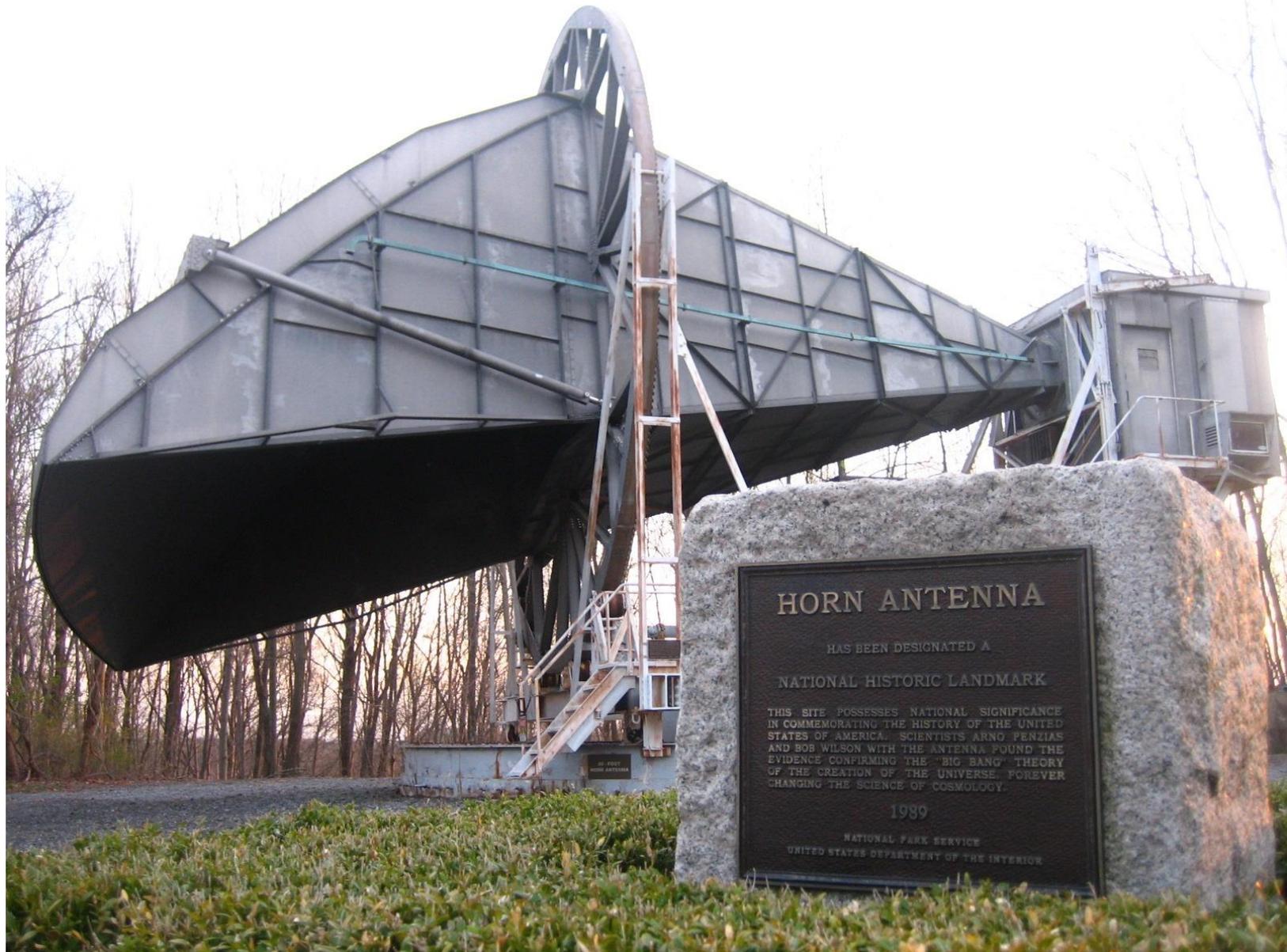
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# An ear listening to the early universe



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## HORN ANTENNA

HAS BEEN DESIGNATED A  
NATIONAL HISTORIC LANDMARK

THIS SITE POSSESSES NATIONAL SIGNIFICANCE  
IN COMMEMORATING THE HISTORY OF THE UNITED  
STATES OF AMERICA. SCIENTISTS ARNO PENZIAS  
AND BOB WILSON WITH THE ANTENNA FOUND THE  
EVIDENCE CONFIRMING THE "BIG BANG" THEORY  
OF THE CREATION OF THE UNIVERSE, FOREVER  
CHANGING THE SCIENCE OF COSMOLOGY.

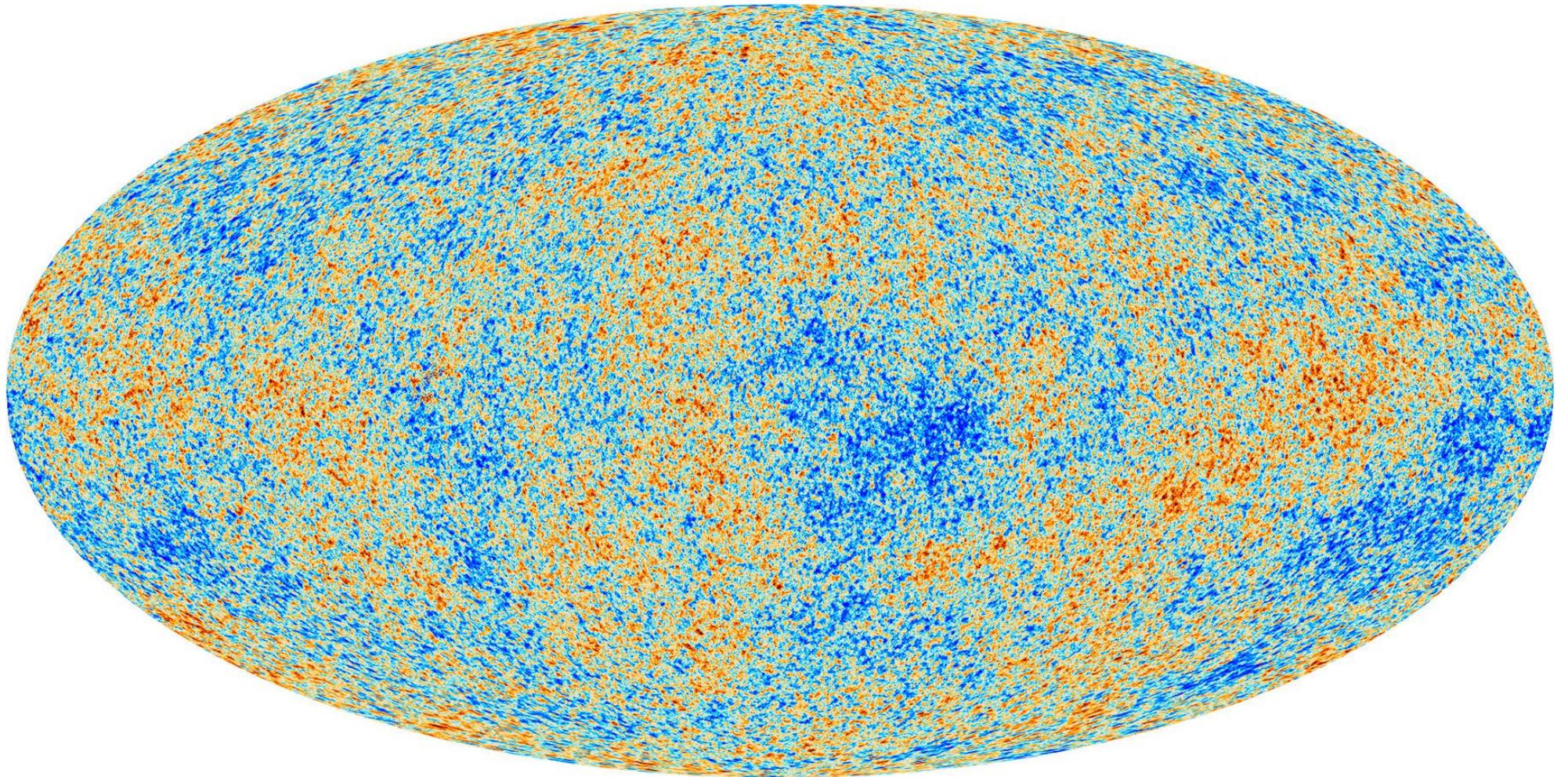
1989

NATIONAL PARK SERVICE  
UNITED STATES DEPARTMENT OF THE INTERIOR

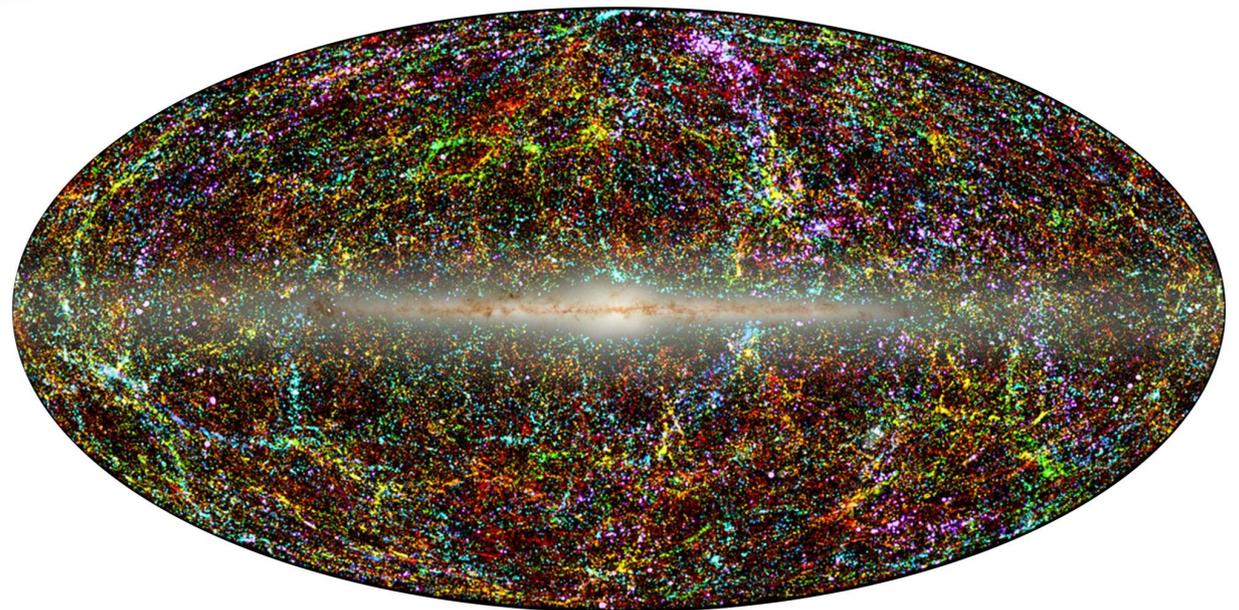
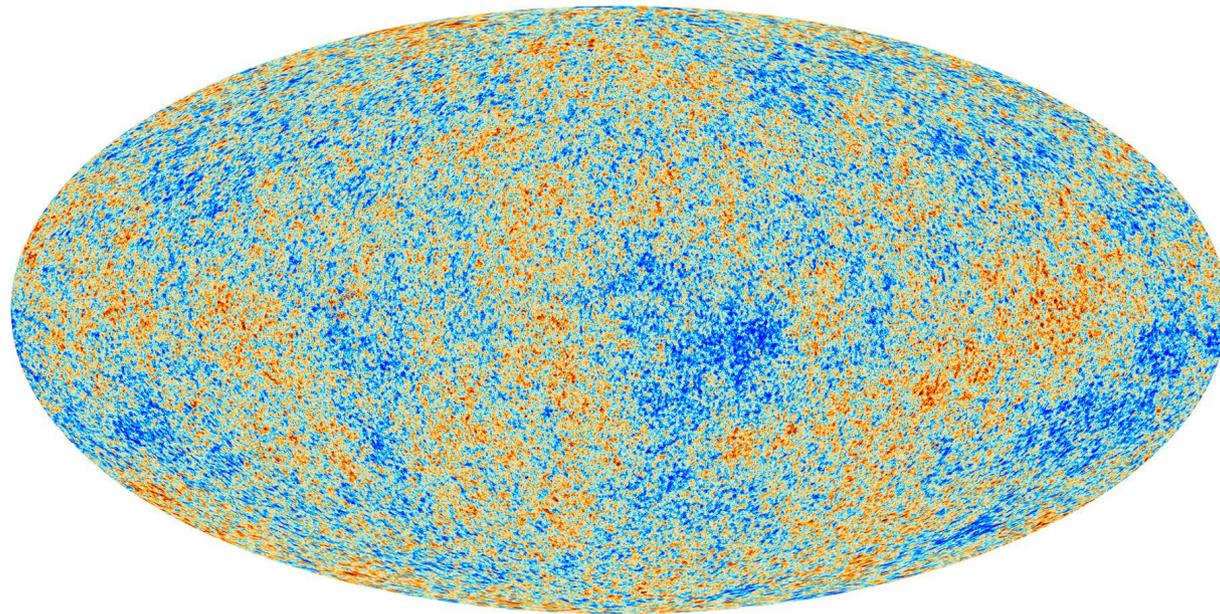
# Leftover cosmic heat



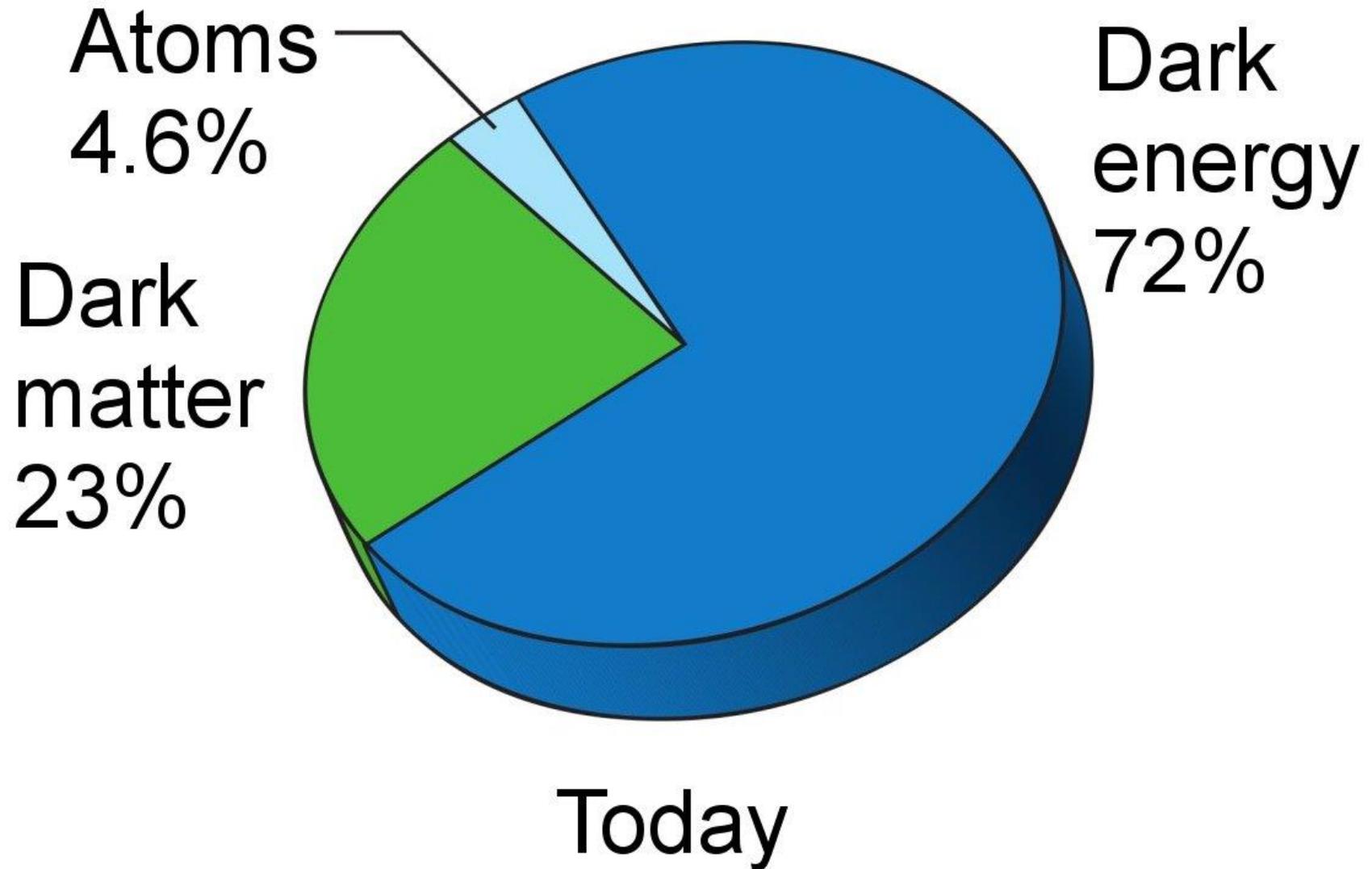
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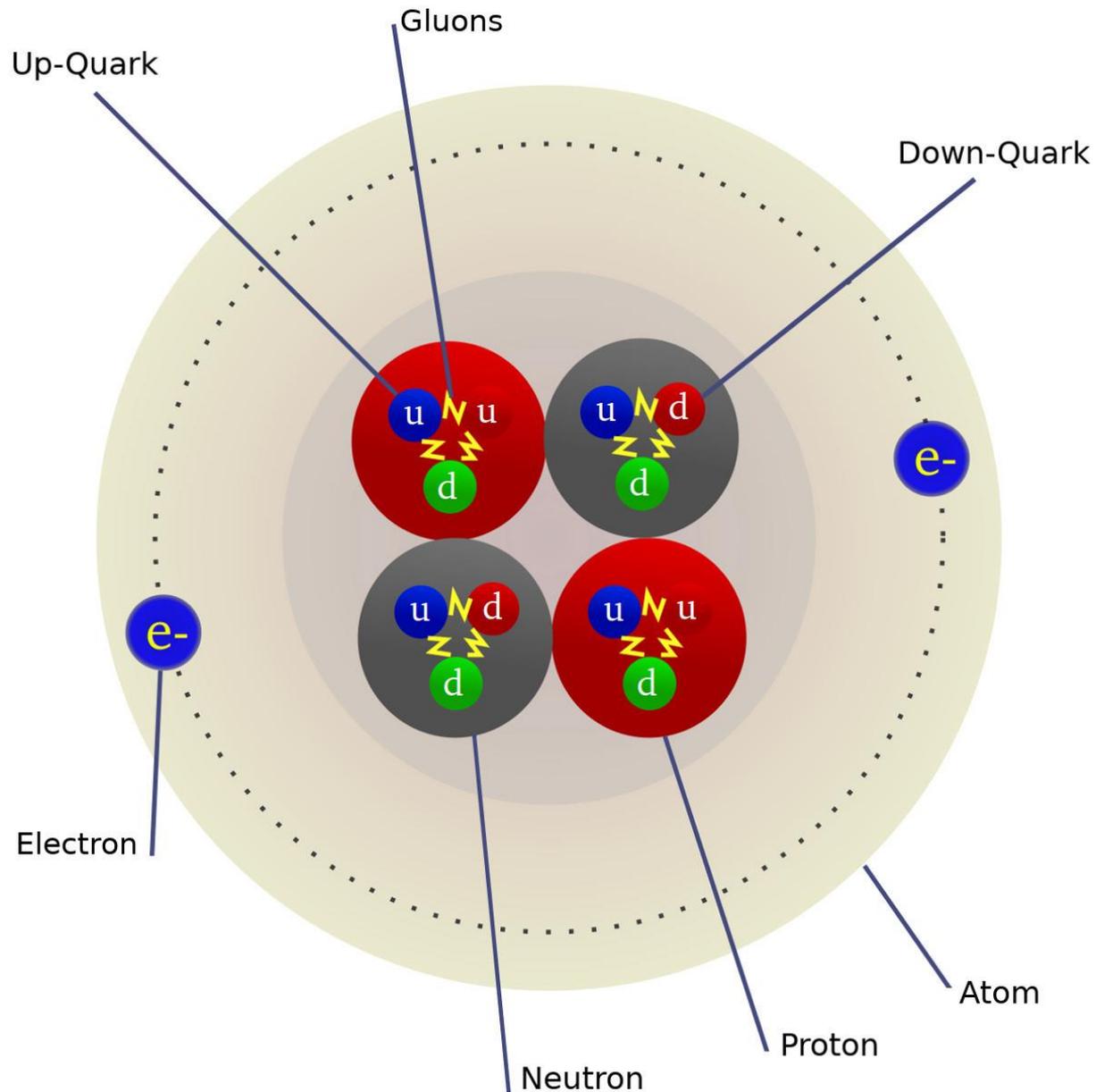
# Structures then and now



# Ingredients to cosmic structures



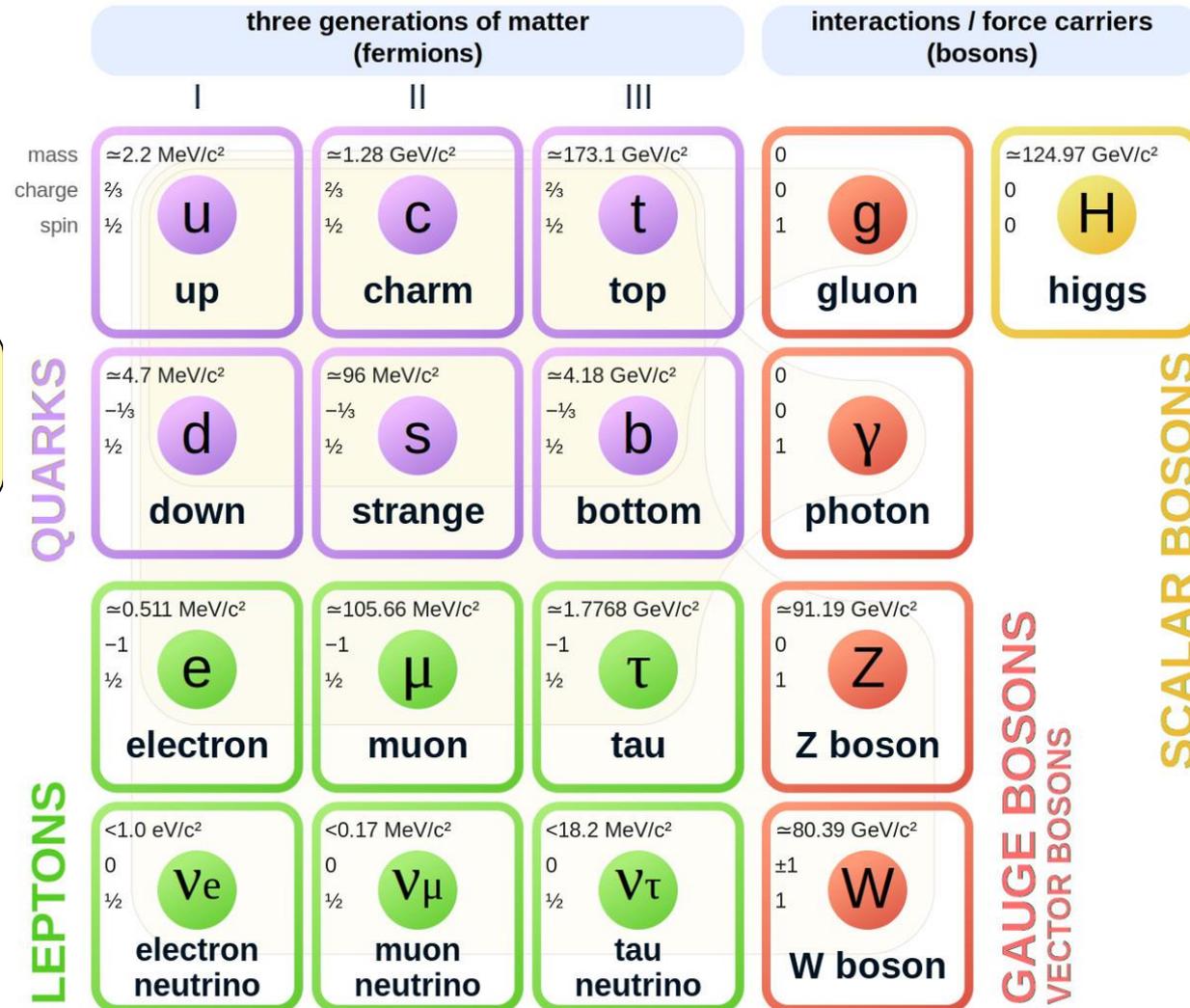
# Matter as we know it



# The zoo of known elementary particles



## Standard Model of Elementary Particles



Baryons: three Quarks  
Proton: uud  
Neutron: udd

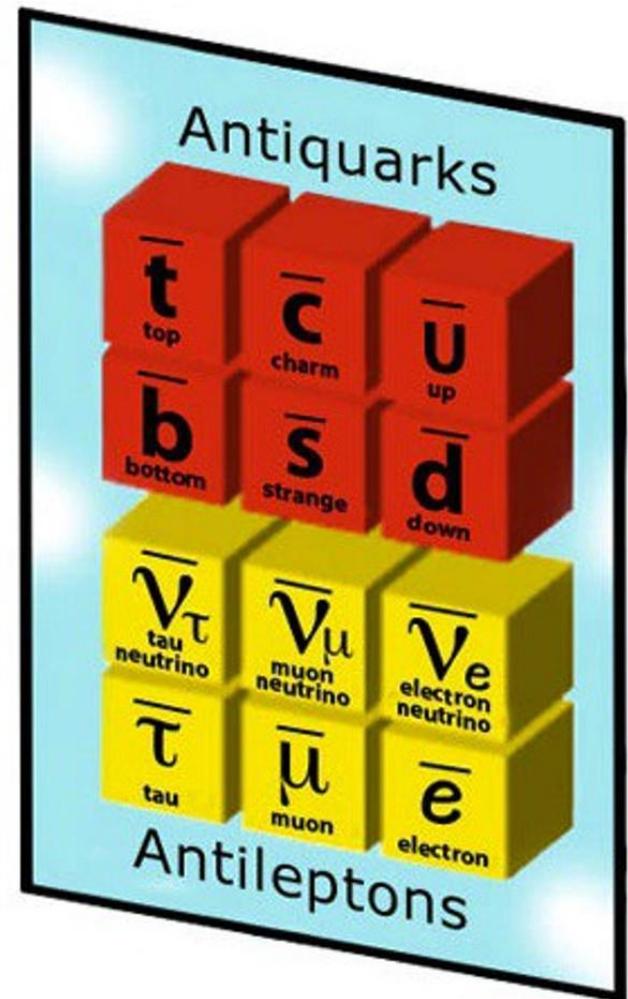
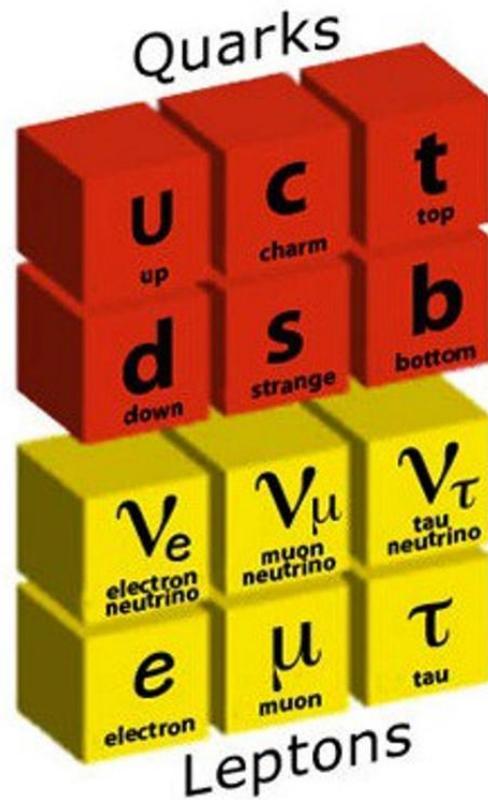
QUARKS

LEPTONS

GAUGE BOSONS  
VECTOR BOSONS

SCALAR BOSONS

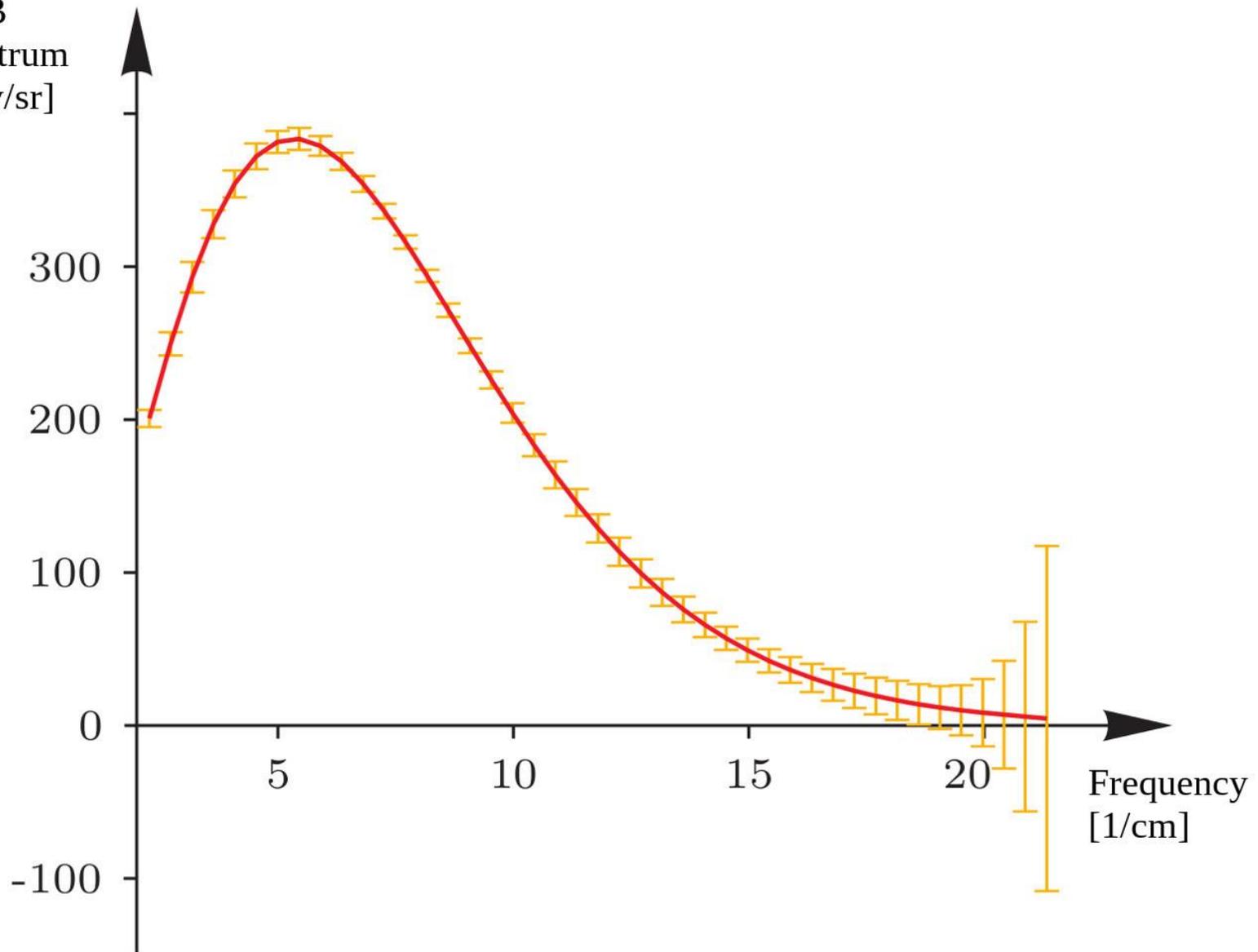
# Matter and Antimatter



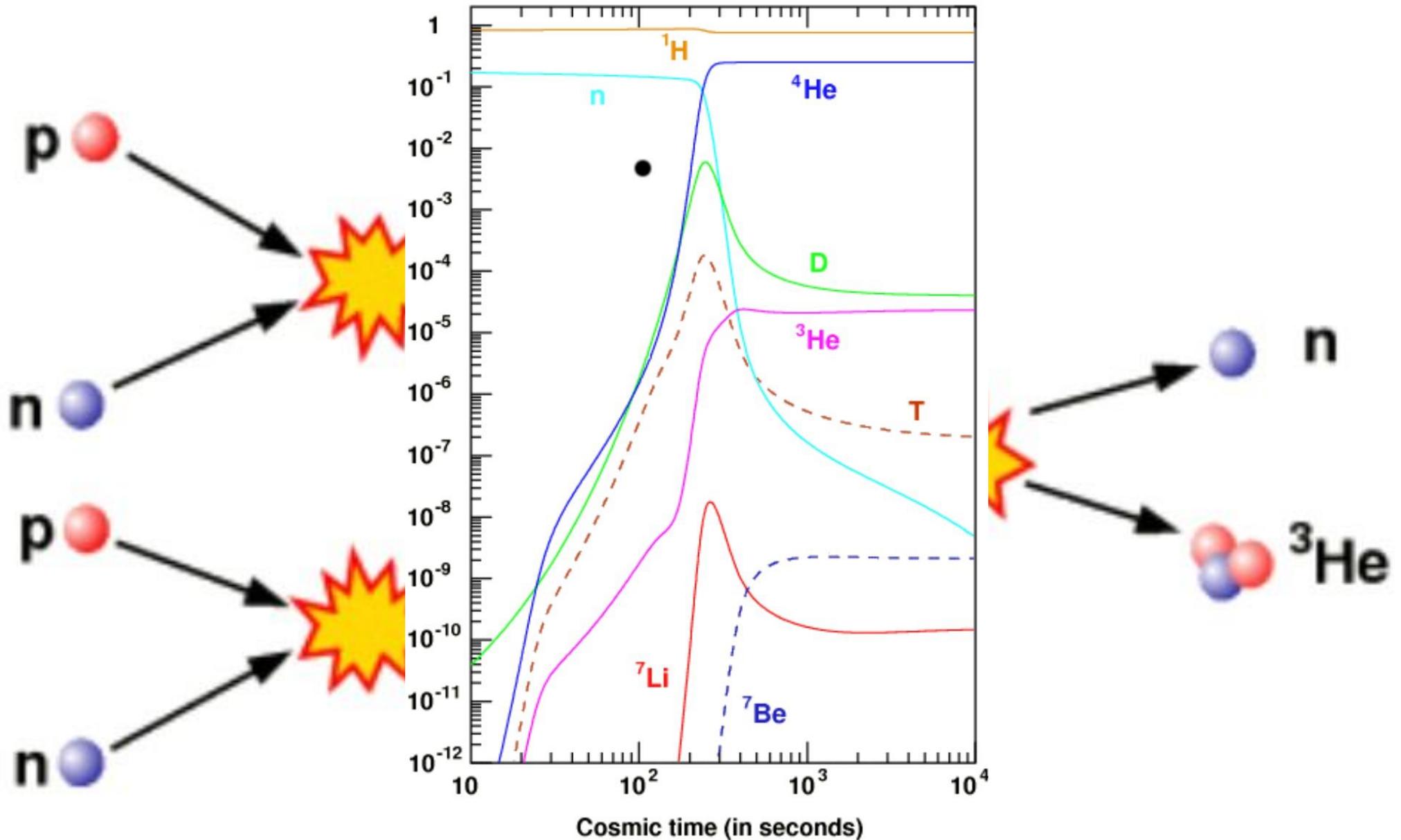
# Photons in the leftover heat



CMB  
Spectrum  
[MJy/sr]



# “Normal” matter in the Universe



# Sacharow conditions



- (1) Baryonen must be able to convert into something else.
- (2) Physical laws must be slightly different for matter and antimatter.
- (3) The very early Universe cannot have been in thermal equilibrium.

*Within the Standard Model  
of particle physics,  
these conditions cannot  
be satisfied.*