Explorando o Universo – dos Quarks aos Quasares

Aula: Cosmologia

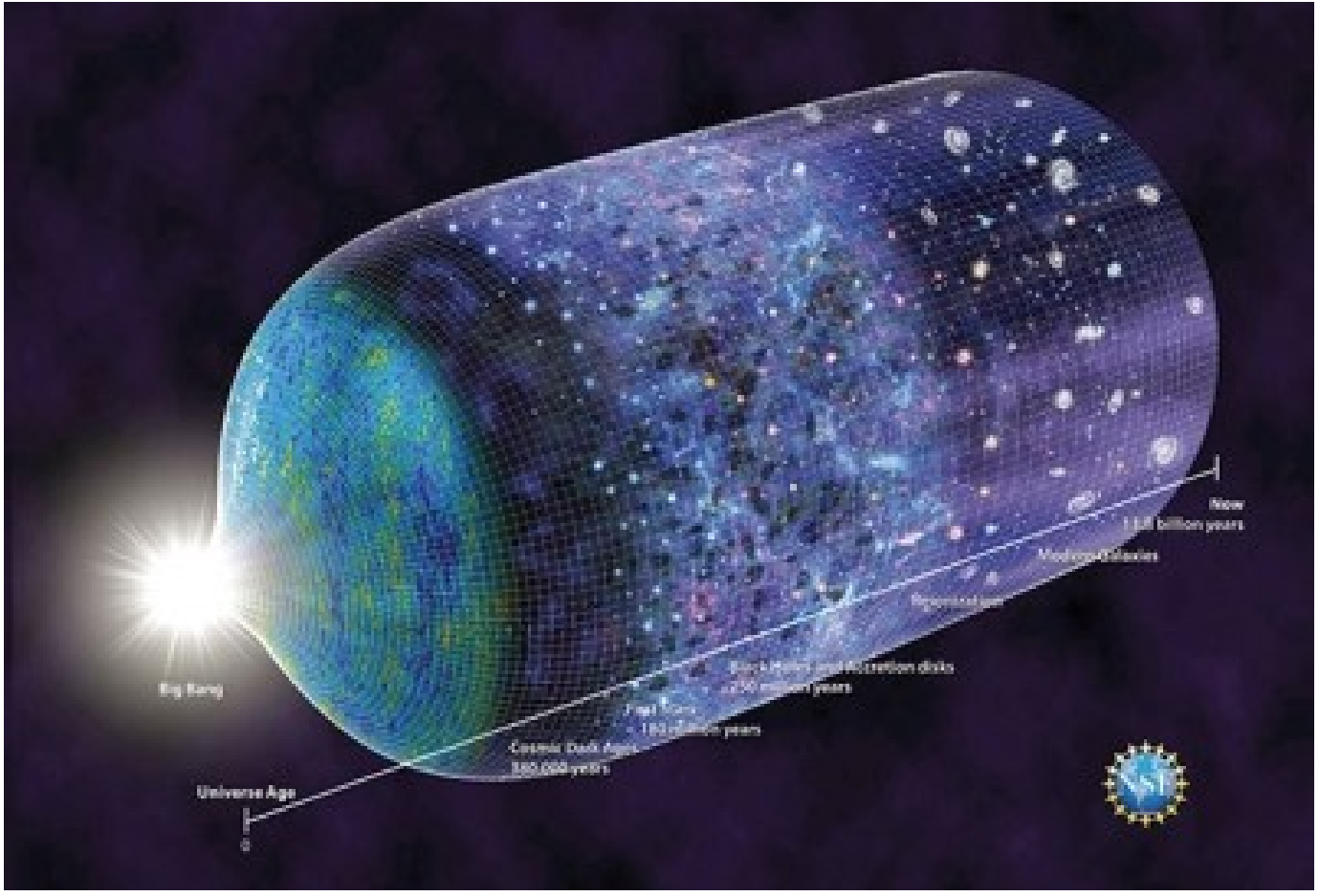
Um rápido passeio pela história do Universo

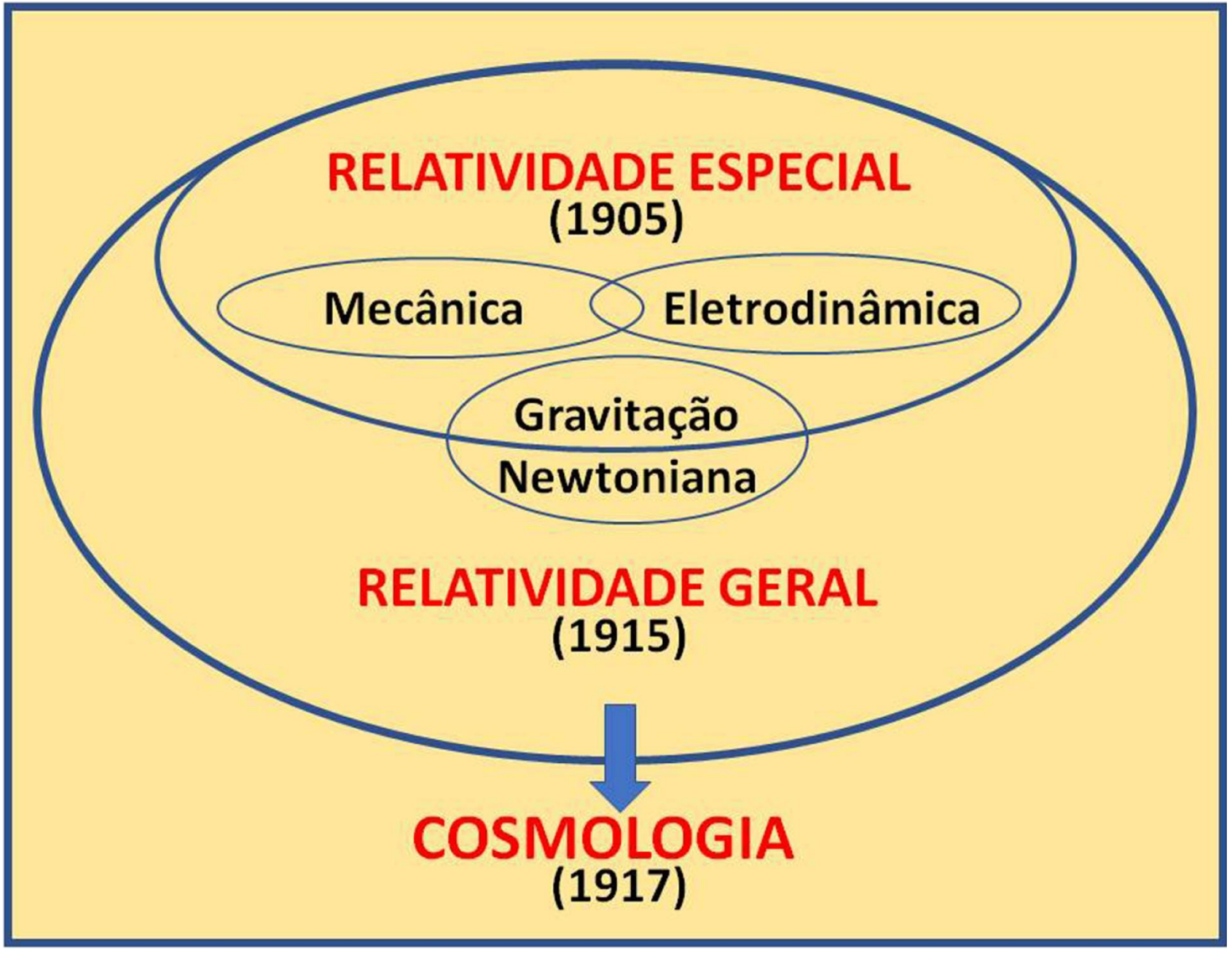
Prof. Rafael Nunes

Objetivos

- Compreender qualitativamente a dinâmica e evolução do Universo
- Nucleossíntese, Recombinação e Radiação Cósmica de Fundo
- Constituintes do Universo e as suas proporções
- Energia Escura
- Universo em Grande Escala
- Extra*: Astronomia de Ondas Gravitacionais
- Extra*: Discussão complementar sobre matéria escura

O que é Cosmologia ?




RELATIVIDADE ESPECIAL
(1905)
Mecânica
Eletrodinâmica
Gravitação
Newtoniana
RELATIVIDADE GERAL
(1915)
COSMOLOGIA
(1917)

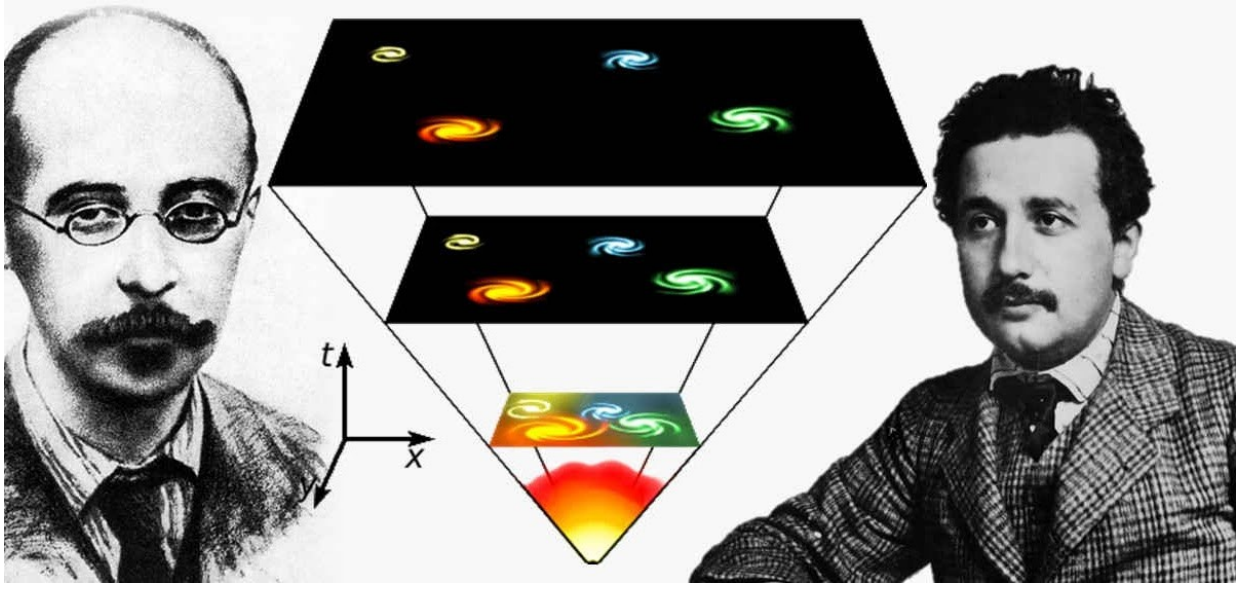
Panorama histórico até 1930

1915 - Surgimento da teoria da relatividade geral. Expansão métrica do espaço apresentadas por A. Friedman em 1922 a partir das equações de campo de Einstein.

1923 - E. Hubble descobre uma estrela variável Cefeida na "Nebulosa de Andrômeda". 1929 descobriu que o universo está se expandindo. Dois anos depois, G. Lemaître sugere que a expansão pode ser atribuída a um "Big Bang" inicial.

Comentários gerais

e outros fatos históricos.

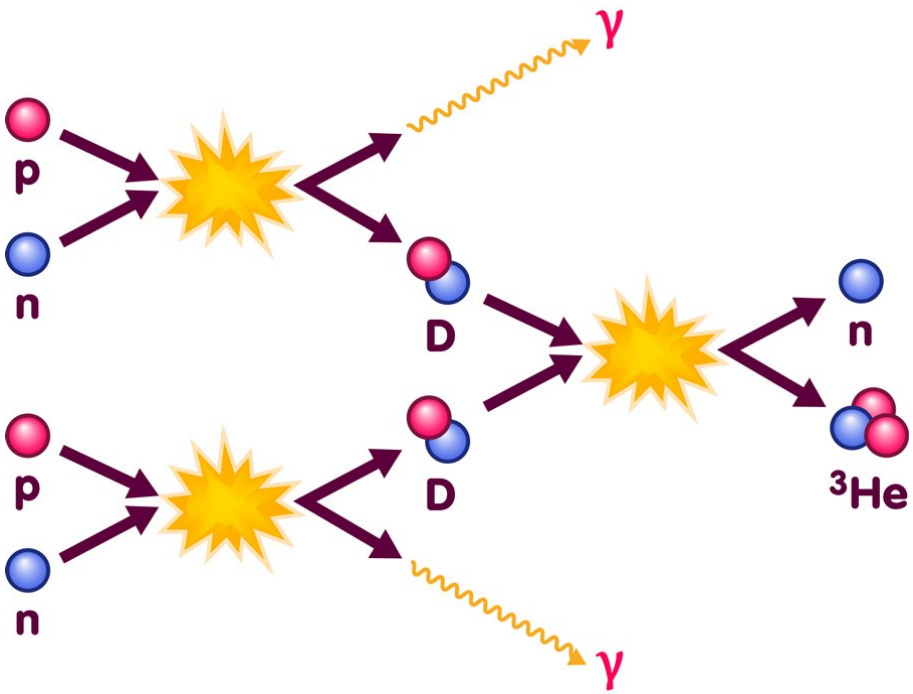


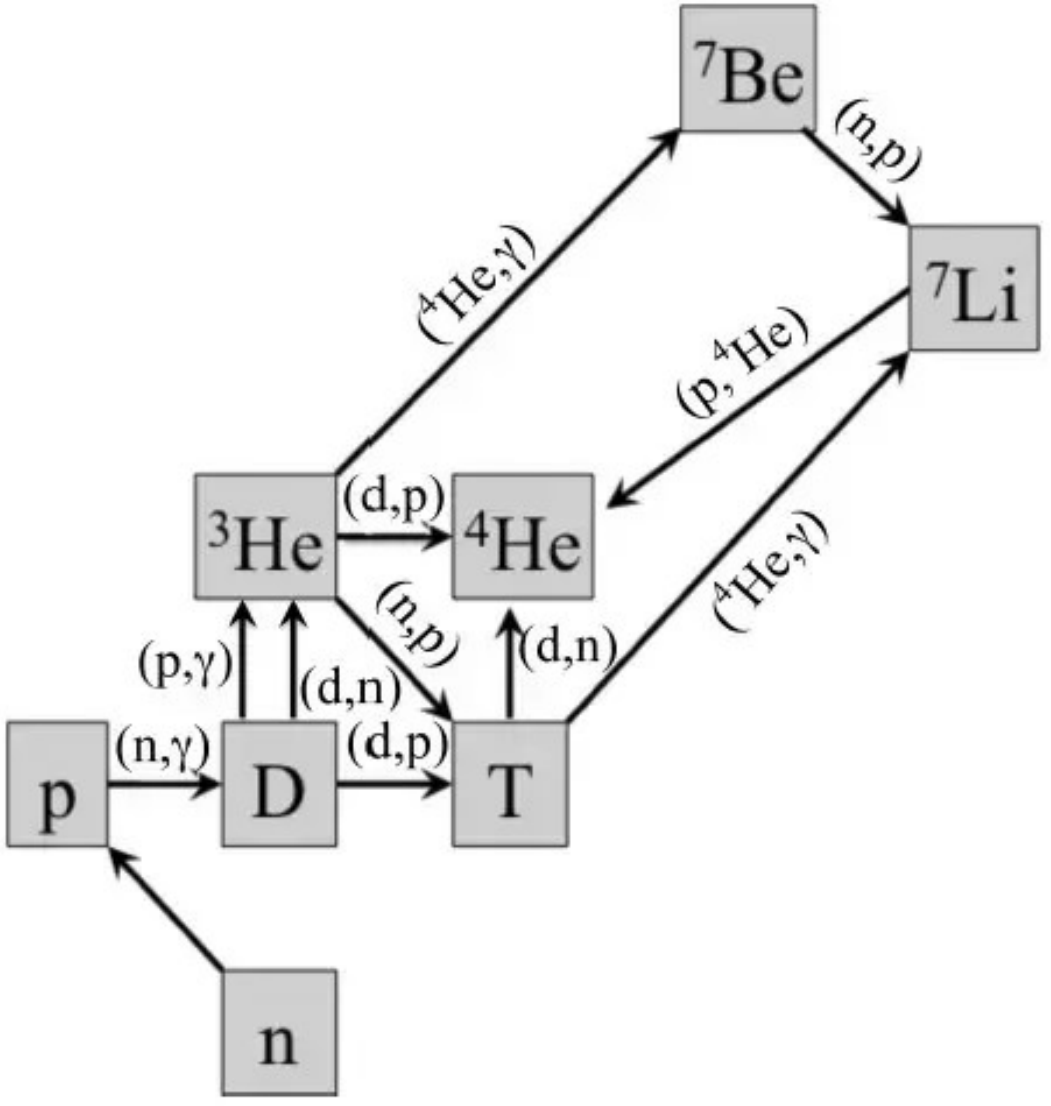
Surgimento dos primeiros núcleos atômicos: Os primeiros minutos de Universo

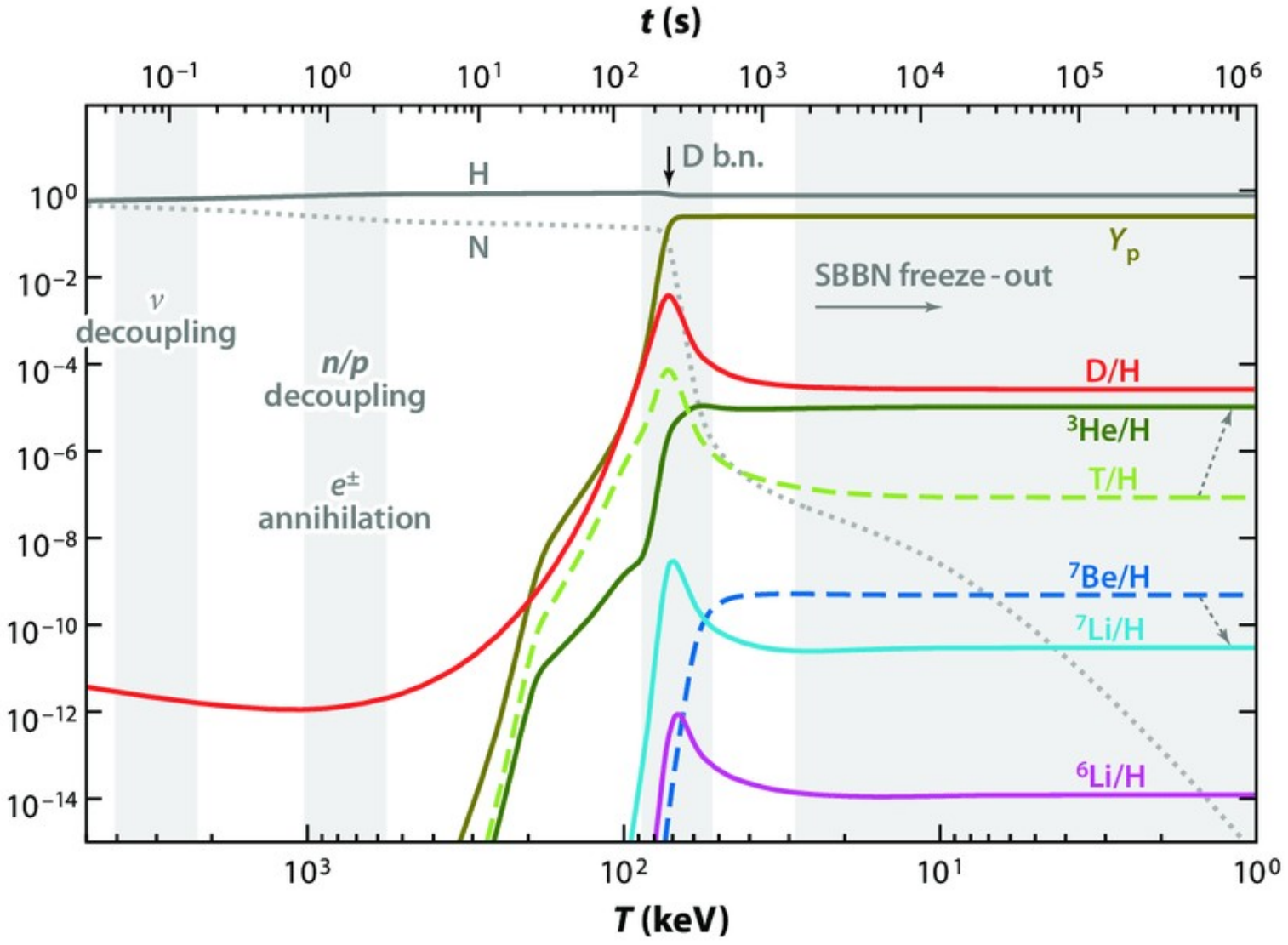
Em 1948, o físico russo George Gamow mostrou que a teoria de Universo em expansão poderia explicar as elevadas abundâncias dos elementos químicos hidrogênio e hélio no universo.

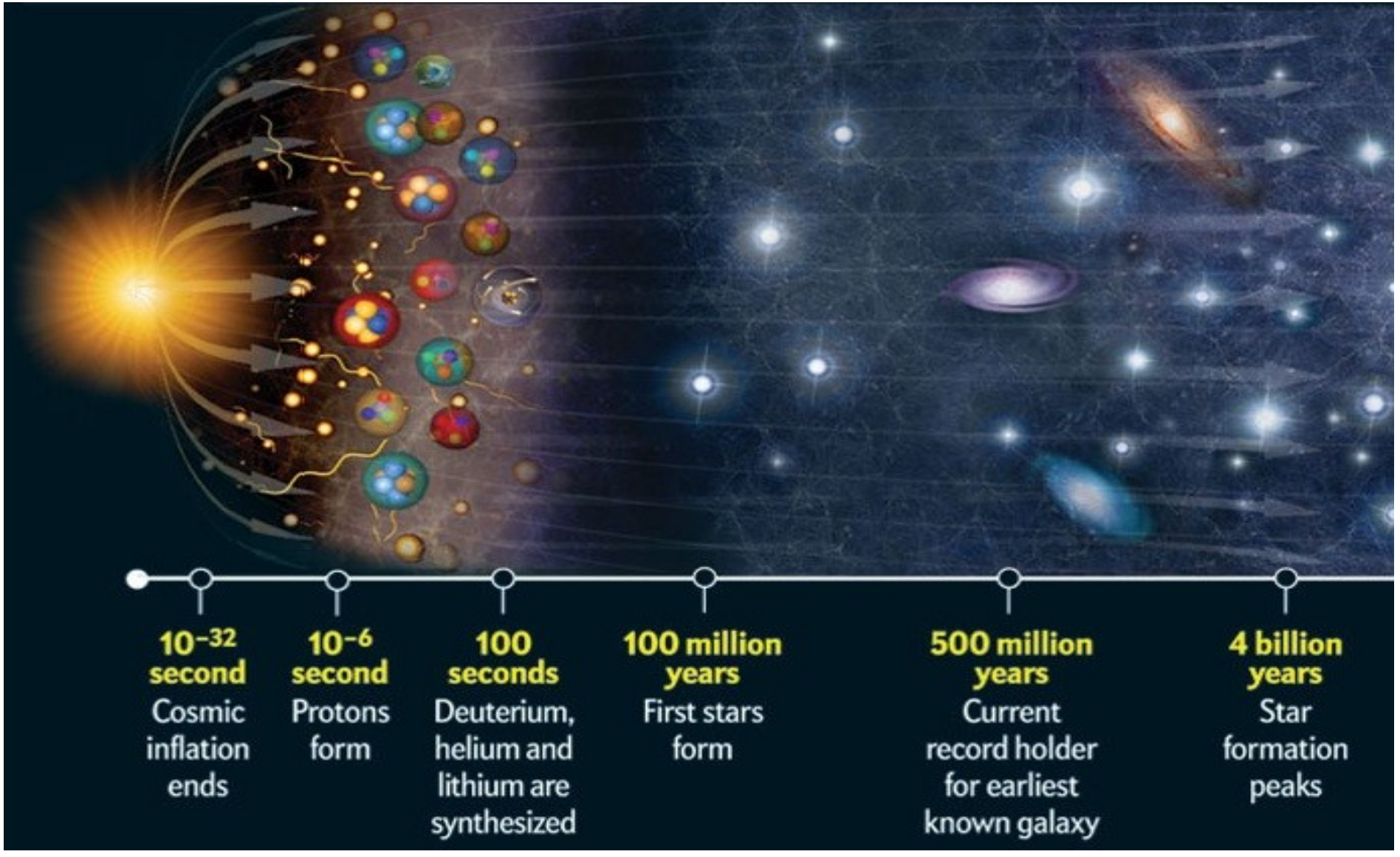
+ Rápida revisão de física nuclear e partículas.

+Comentários gerais e fatos históricos.



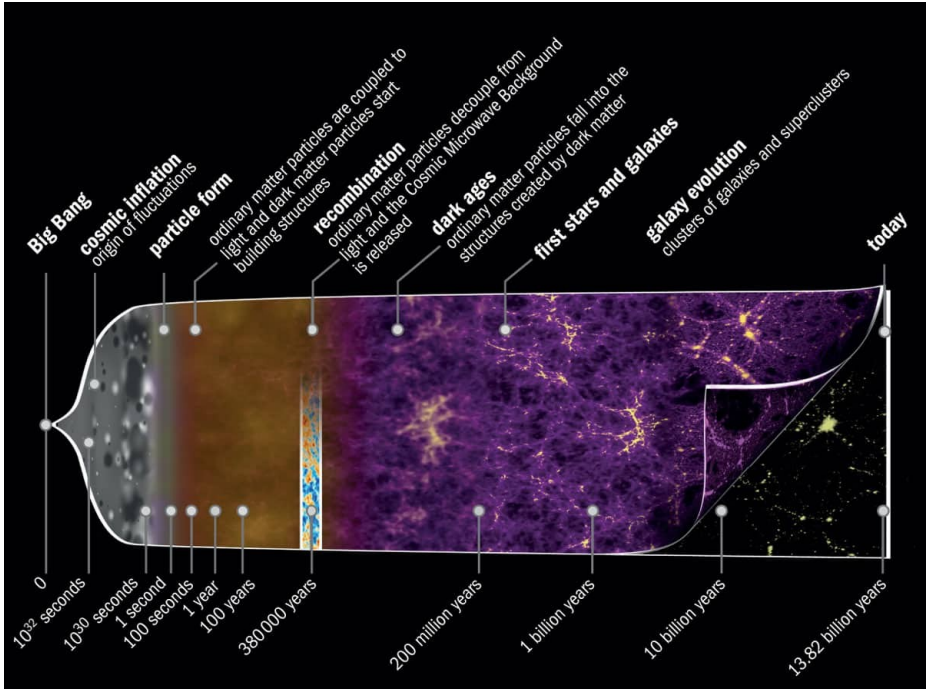

^{7}Be
(n,p)
^{7}Li
(^{4}He,γ)
(p, ^{4}He)
^{3}He
(d,p)
^{4}He
(n,p)
(p,γ)
(d,n)
(d,n)
(^{4}He,γ)
p
(n,γ)
D
(d,p)
T
n

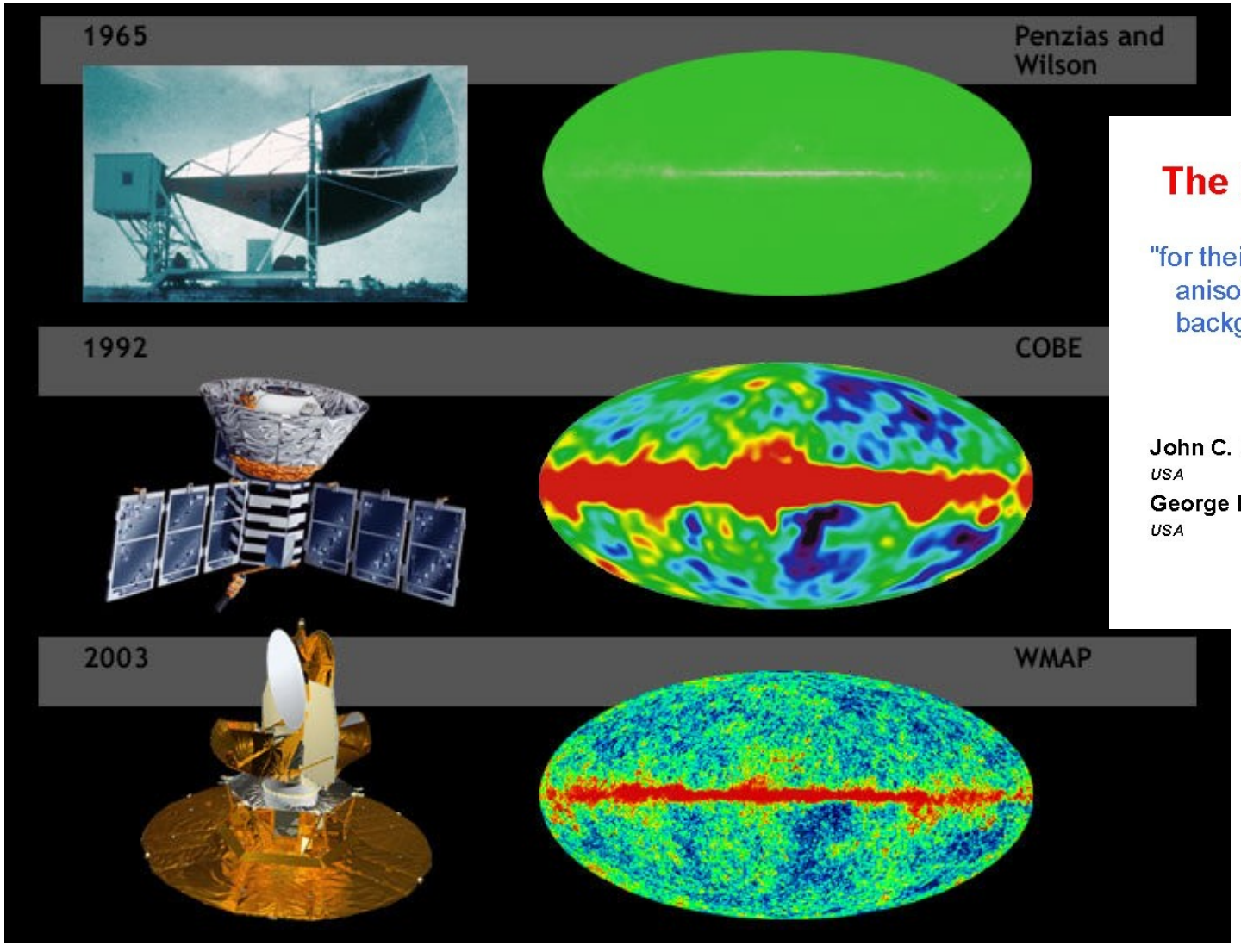

t (s)
10^−1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
D b.n.
H
N
Y_p
SBBN freeze-out
ν decoupling
n/p decoupling
e± annihilation
D/H
3He/H
T/H
7Be/H
7Li/H
6Li/H
10^0
10^−2
10^−4
10^−6
10^−8
10^−10
10^−12
10^−14
10^3
10^2
10^1
10^0
T (keV)


10^{-32} second
Cosmic inflation ends
10^{-6} second
Protons form
100 seconds
Deuterium, helium and lithium are synthesized
100 million years
First stars form
500 million years
Current record holder for earliest known galaxy
4 billion years
Star formation peaks

Foi também previsto, baseado nesse modelo, a existência de uma radiação isotrópica e de espectro bem definido que teria se originado há bilhões de anos atrás, numa época próxima ao início do Universo. **Radiação cósmica de fundo.**

Descoberta experimentalmente em 1965 por Arno Penzias e Robert Woodrow Wilson. Nobel de Física em 1978.

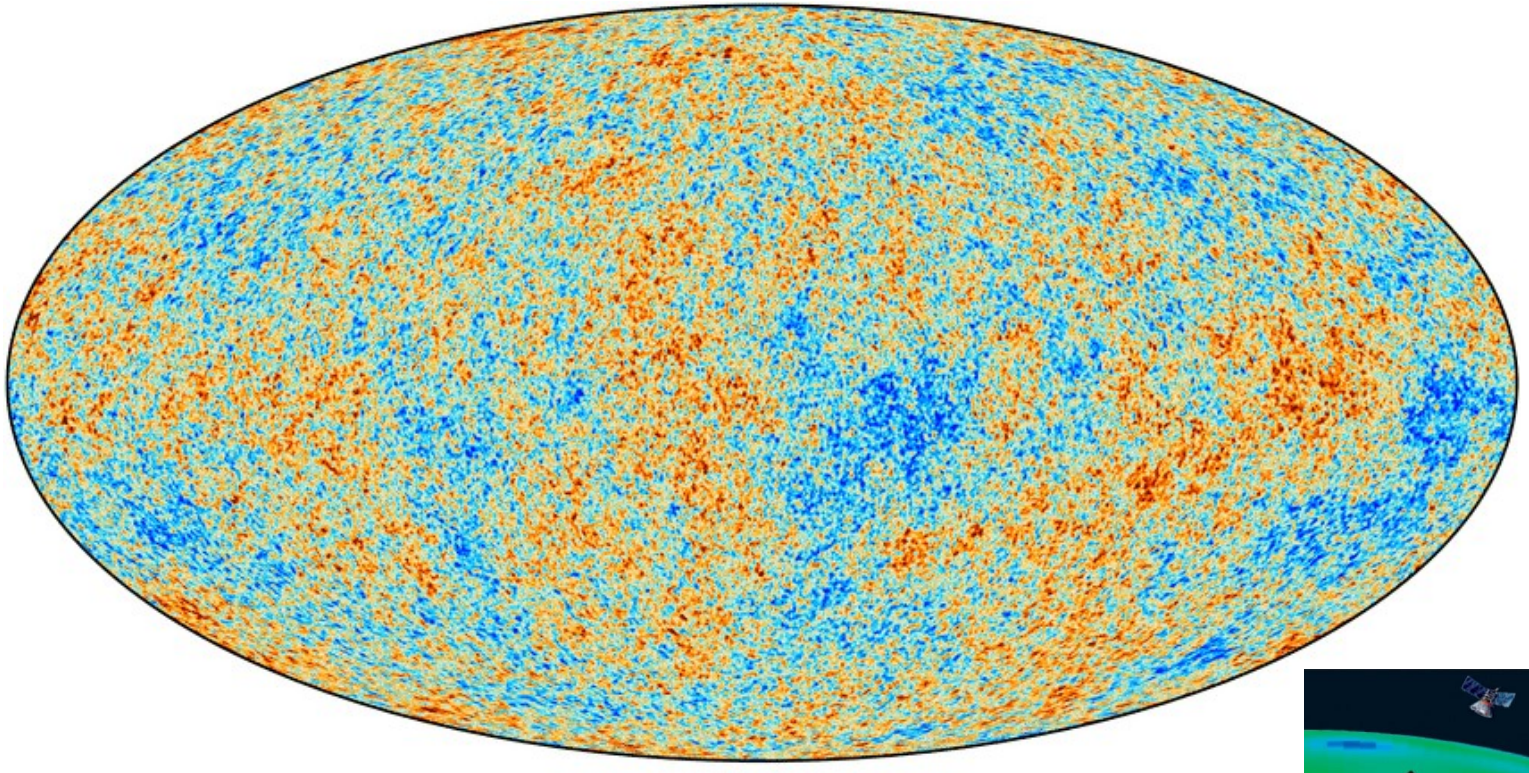


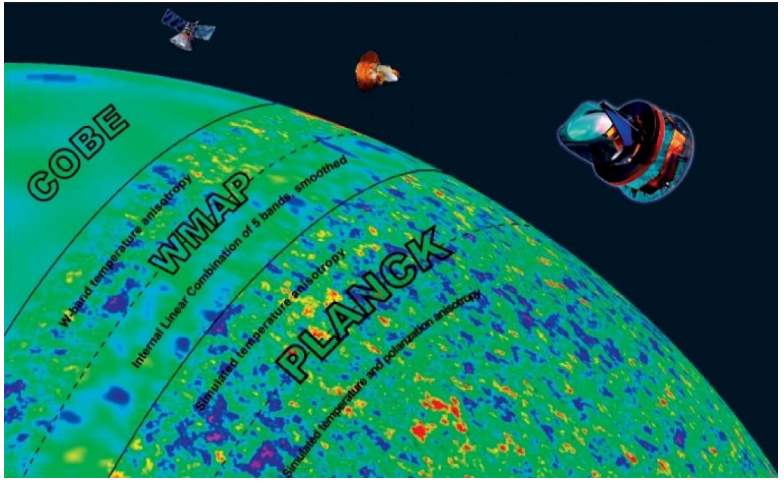


The Nobel Prize in Physics 2006

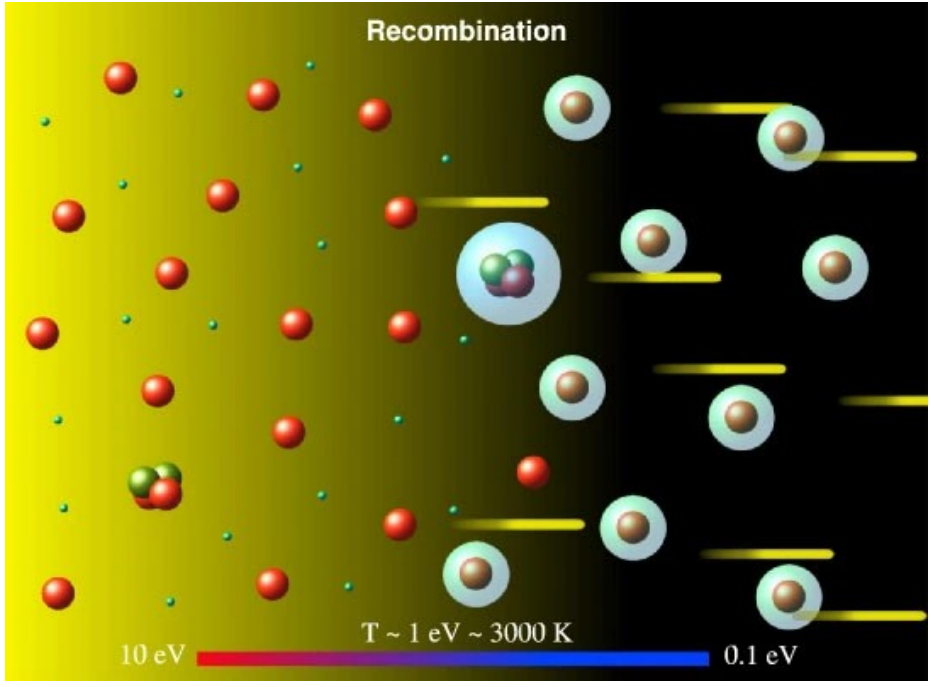
"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"

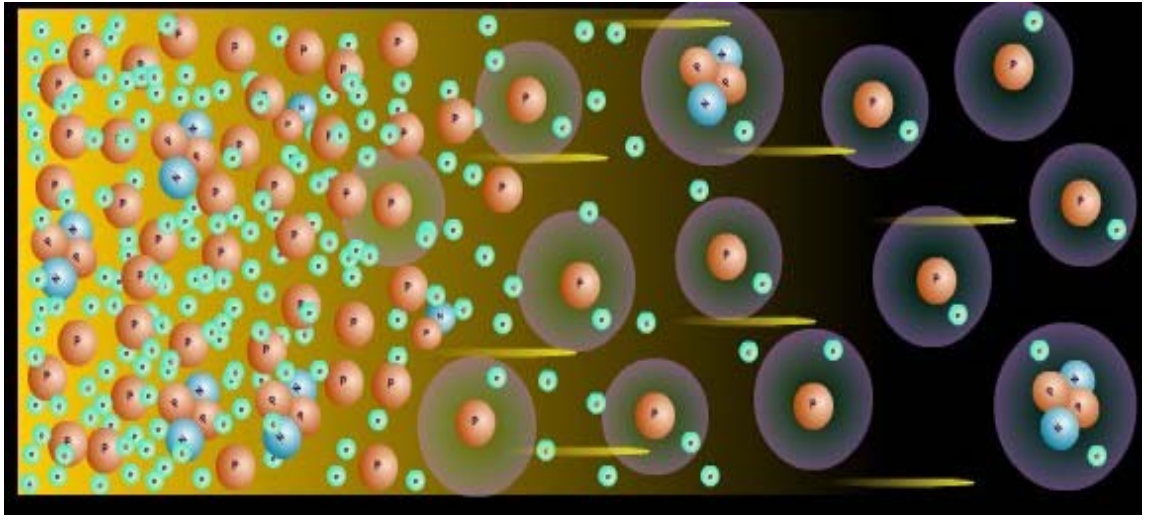
John C. Mather
USA
George F. Smoot
USA


−300
μK
300

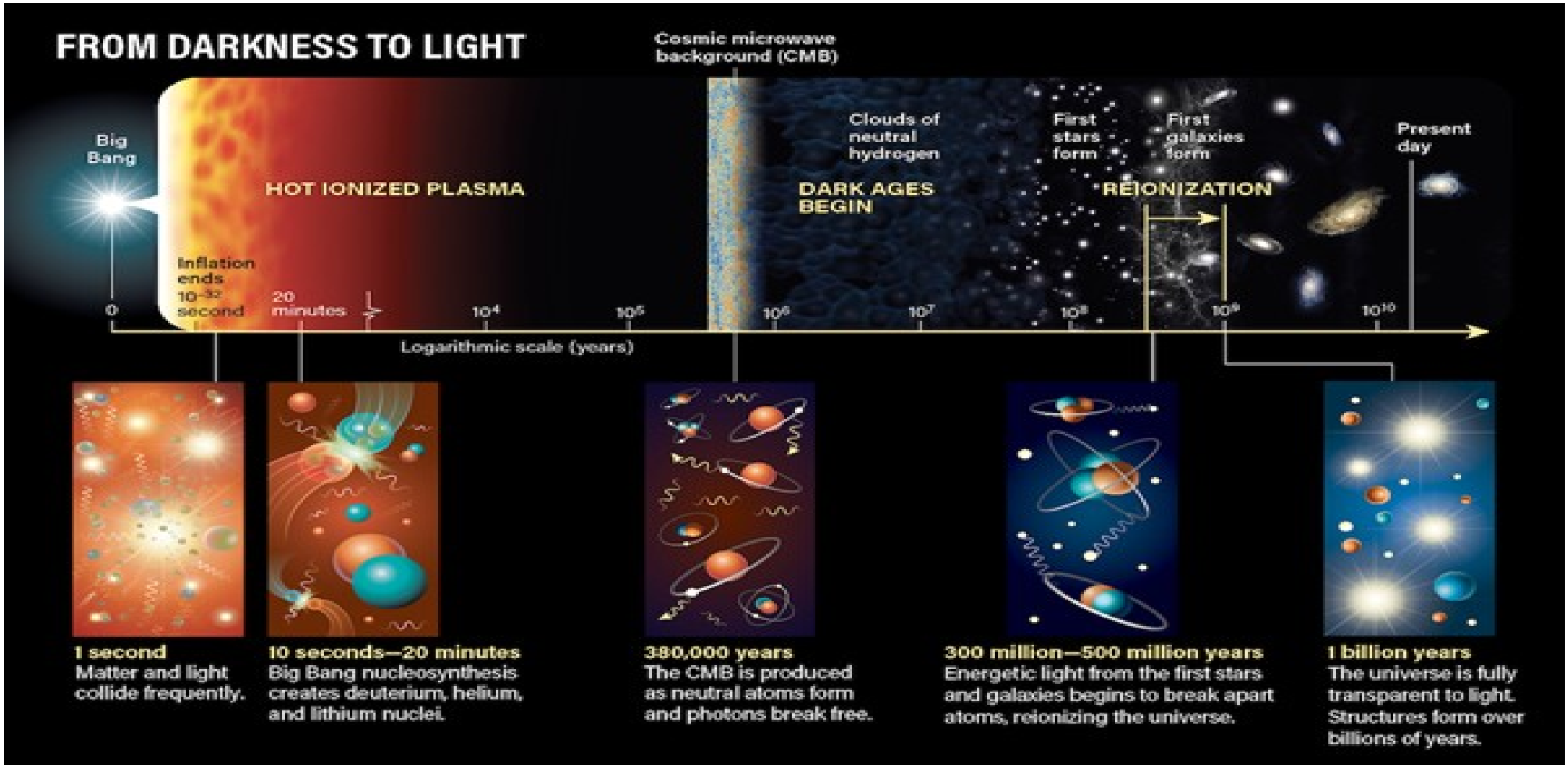

COBE
WMAP
PLANCK
WMAP 7-yr temperature anisotropy
Internal Linear Combination of 5 bands, smoothed
Simulated temperature anisotropy
Simulated temperature and polarization anisotropy

Quando se formaram os primeiros átomos ?



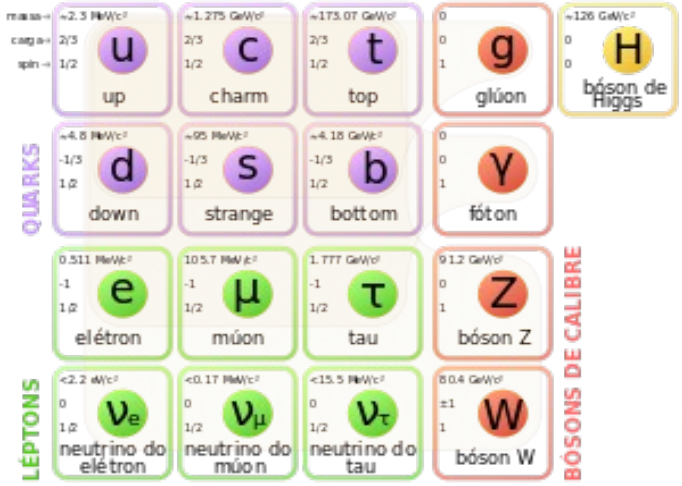


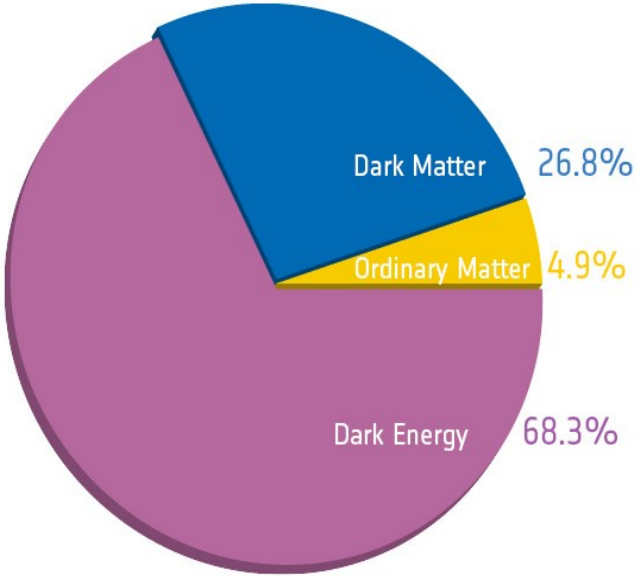
Visão Geral

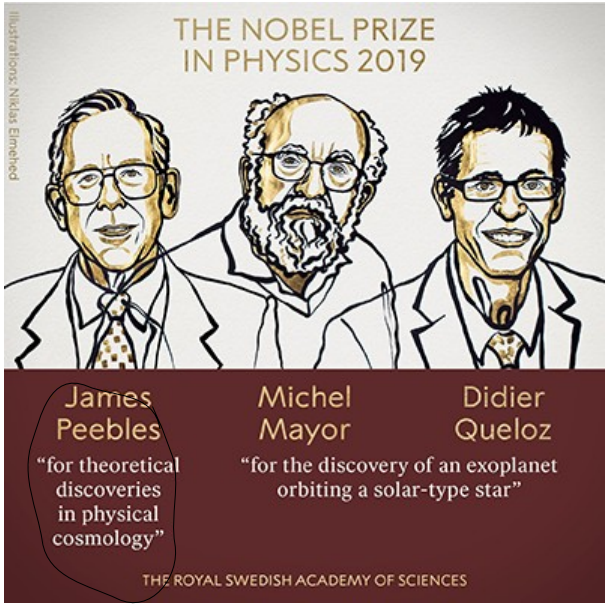

FROM DARKNESS TO LIGHT
Cosmic microwave background (CMB)
Big Bang
HOT IONIZED PLASMA
Inflation ends 10^{-32} second
20 minutes
Clouds of neutral hydrogen
DARK AGES BEGIN
First stars form
First galaxies form
REIONIZATION
Present day
0
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
Logarithmic scale (years)
1 second
Matter and light collide frequently.
10 seconds—20 minutes
Big Bang nucleosynthesis creates deuterium, helium, and lithium nuclei.
380,000 years
The CMB is produced as neutral atoms form and photons break free.
300 million—500 million years
Energetic light from the first stars and galaxies begins to break apart atoms, reionizing the universe.
1 billion years
The universe is fully transparent to light. Structures form over billions of years.

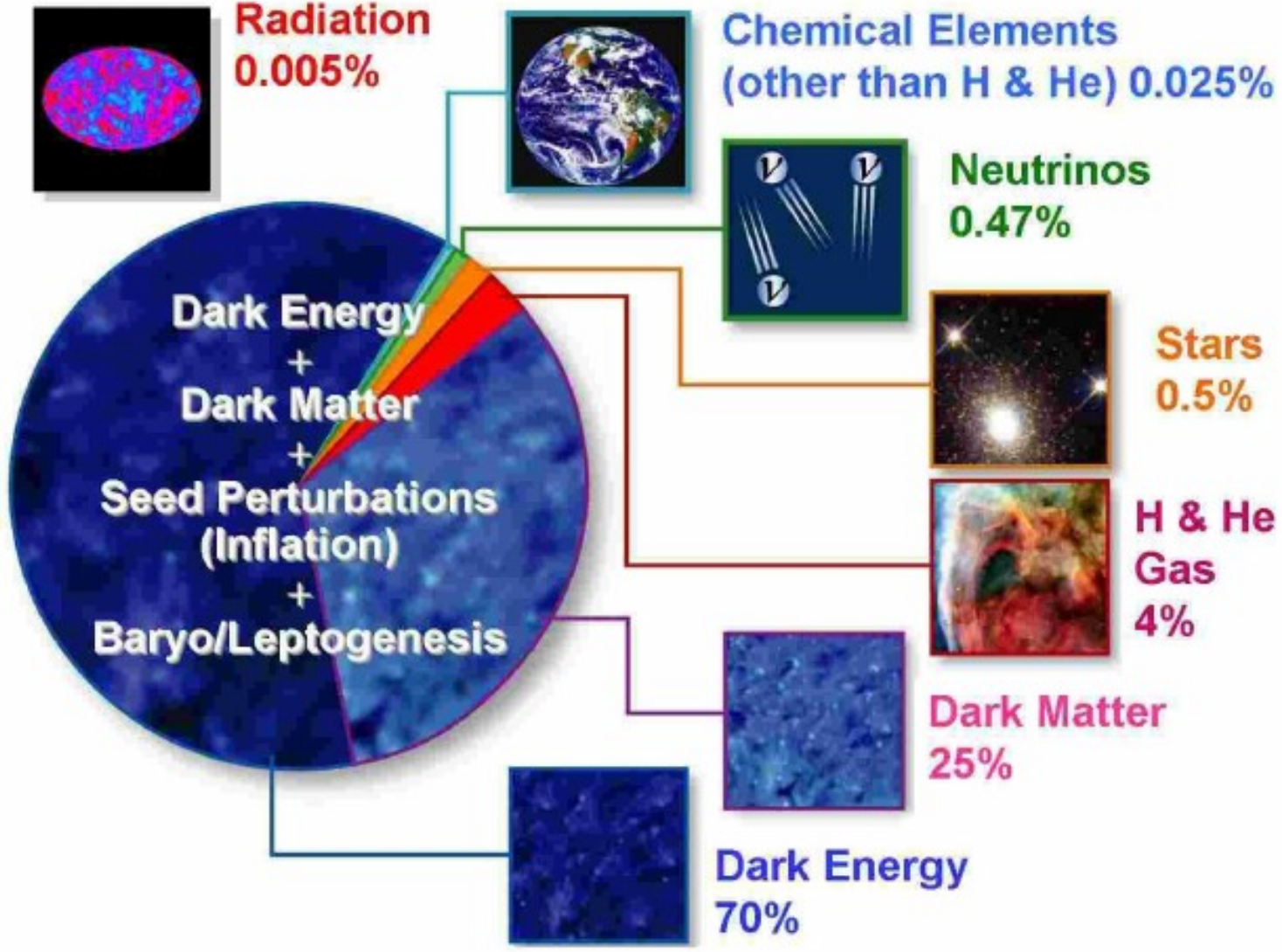
Precisamos de um modelo para nosso Universo ...

Modelo padrão da Cosmologia:

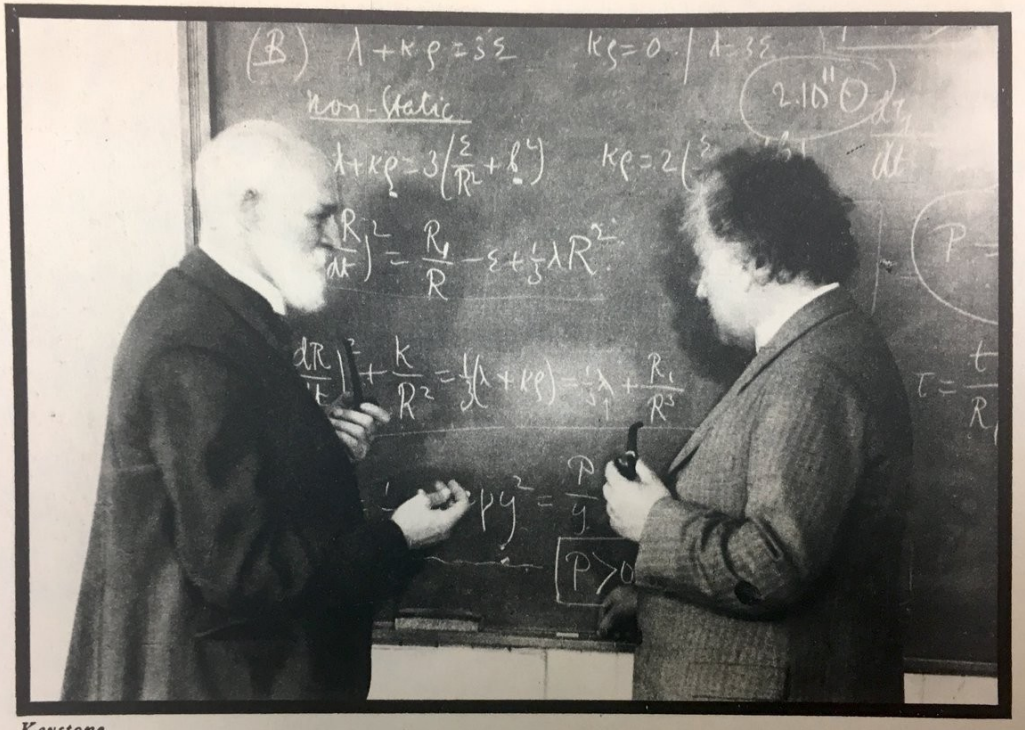







Radiation
0.005%
Chemical Elements
(other than H & He) 0.025%
Neutrinos
0.47%
Stars
0.5%
H & He
Gas
4%
Dark Matter
25%
Dark Energy
70%
Dark Energy
+
Dark Matter
+
Seed Perturbations
(Inflation)
+
Baryo/Leptogenesis

Visão geral entre 1932 - 1998

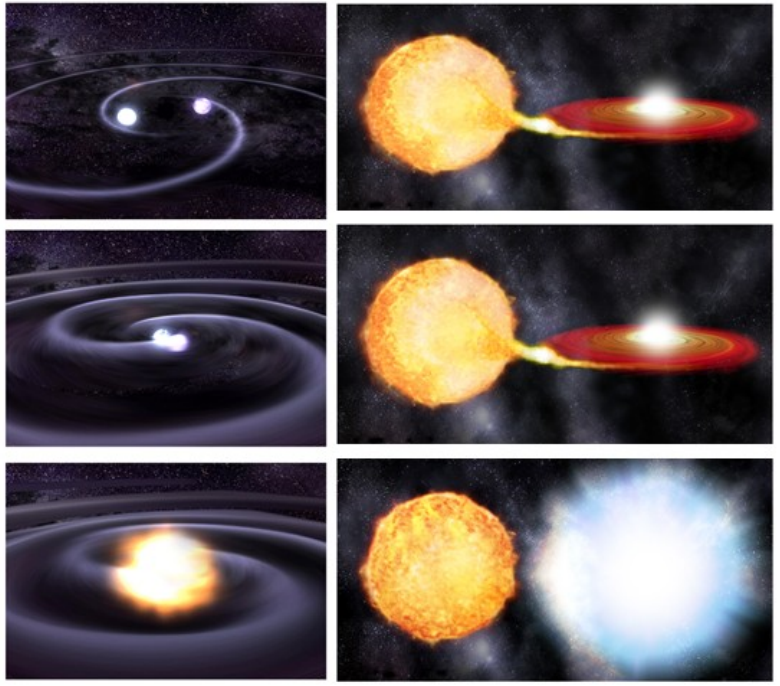


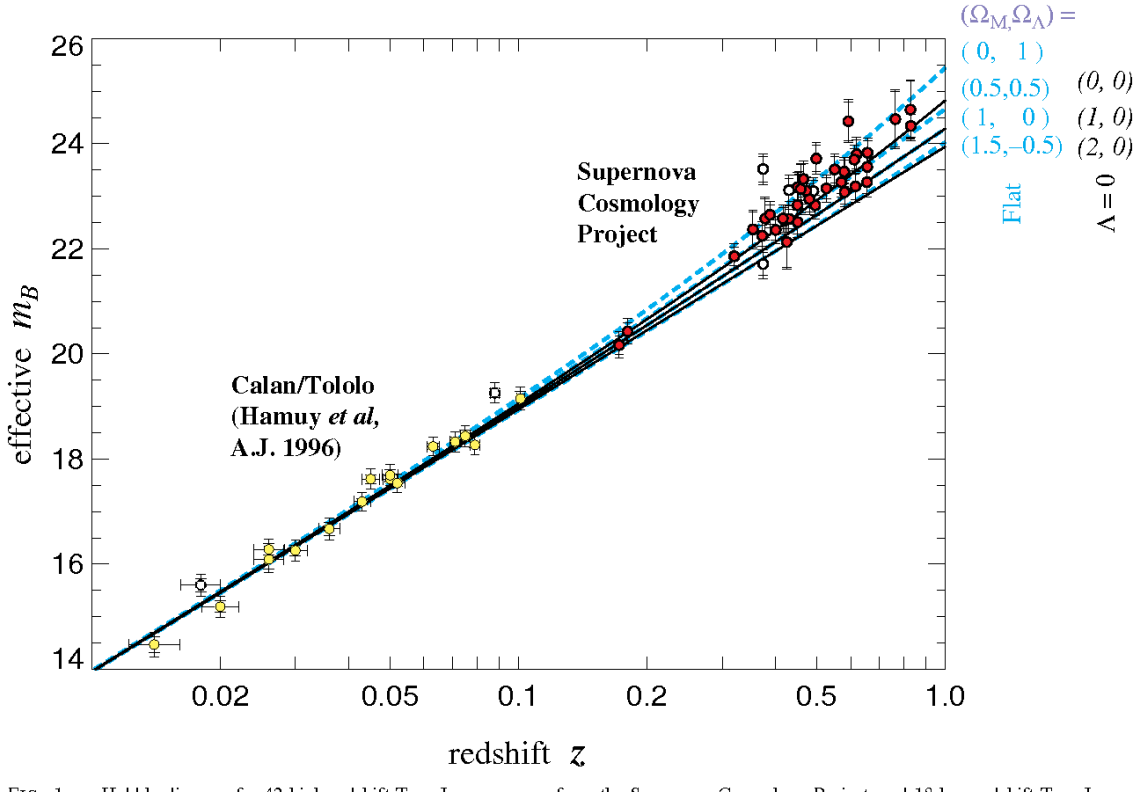
Keystone

WILLEM DE SITTER AND ALBERT EINSTEIN

. . . revising their theories on a Cal Tech blackboard, to accord with Dr. Hubble's discoveries in the sky.

Uma mudança de paradigma

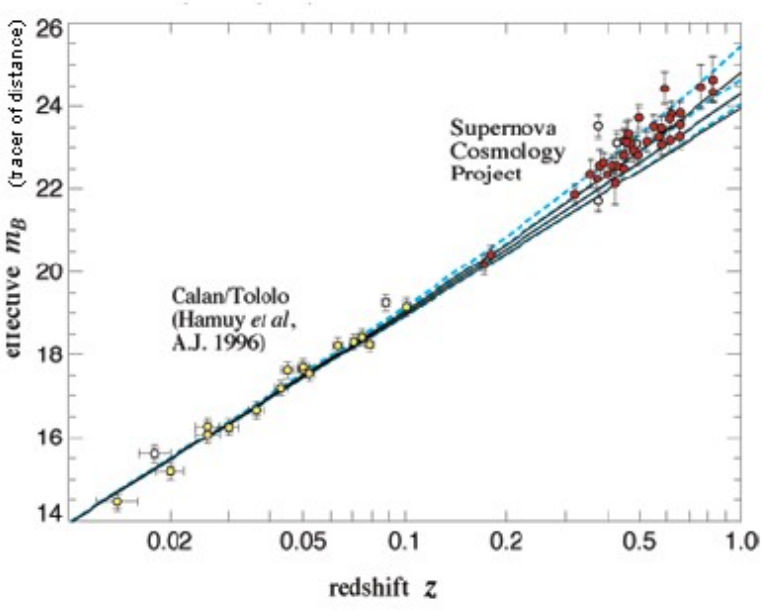


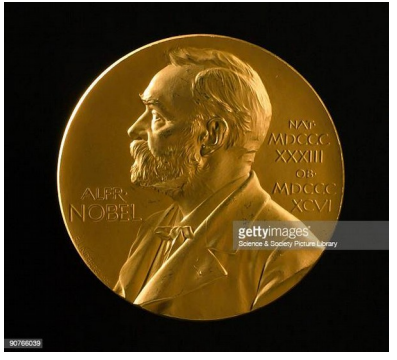


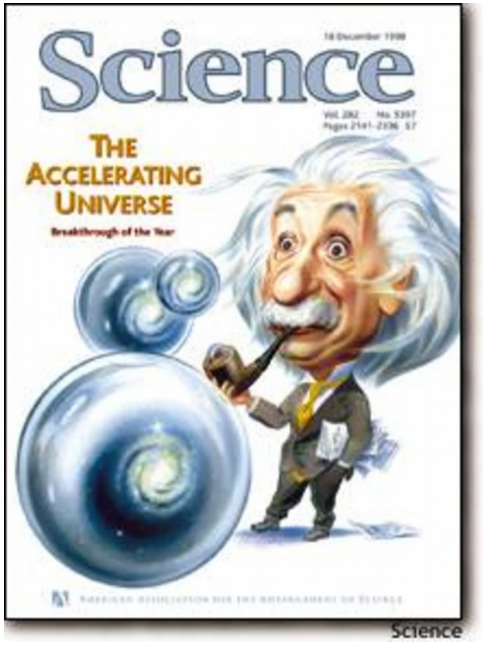
Accelerated expansion at late time

Distances in an accelerating expanding Universe are greater than in a decelerated expansion.

SNIa looks less bright than it would be in a Universe expanding in a decelerated way.



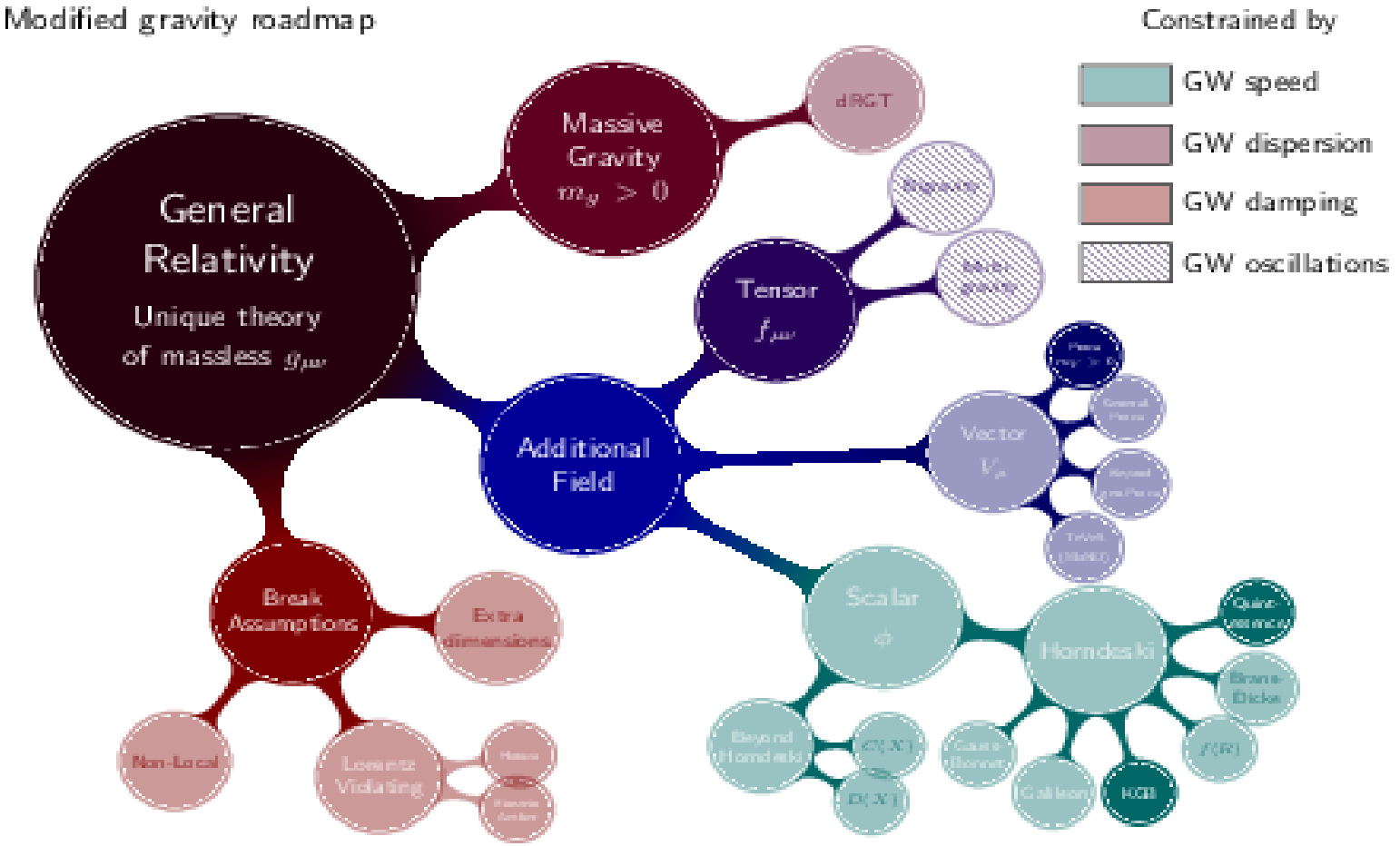




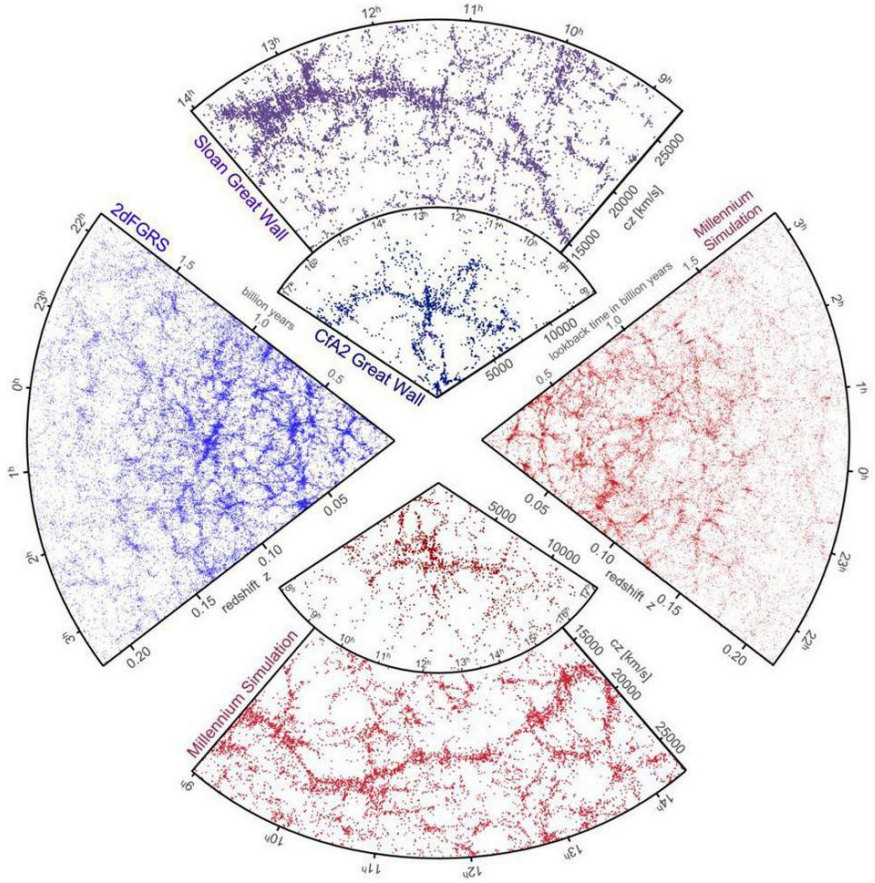

WHAT IS
DARK ENERGY?

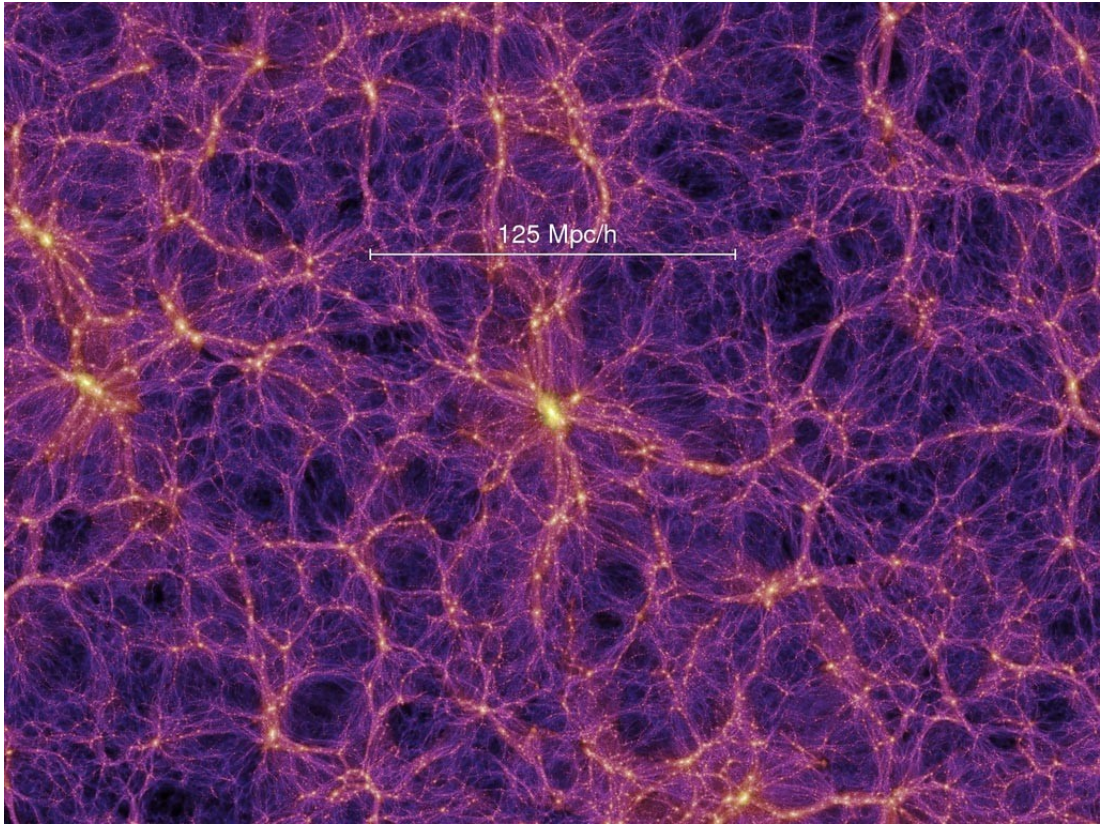
Constante cosmologia, energia escura. Comentários gerais e fatos históricos.

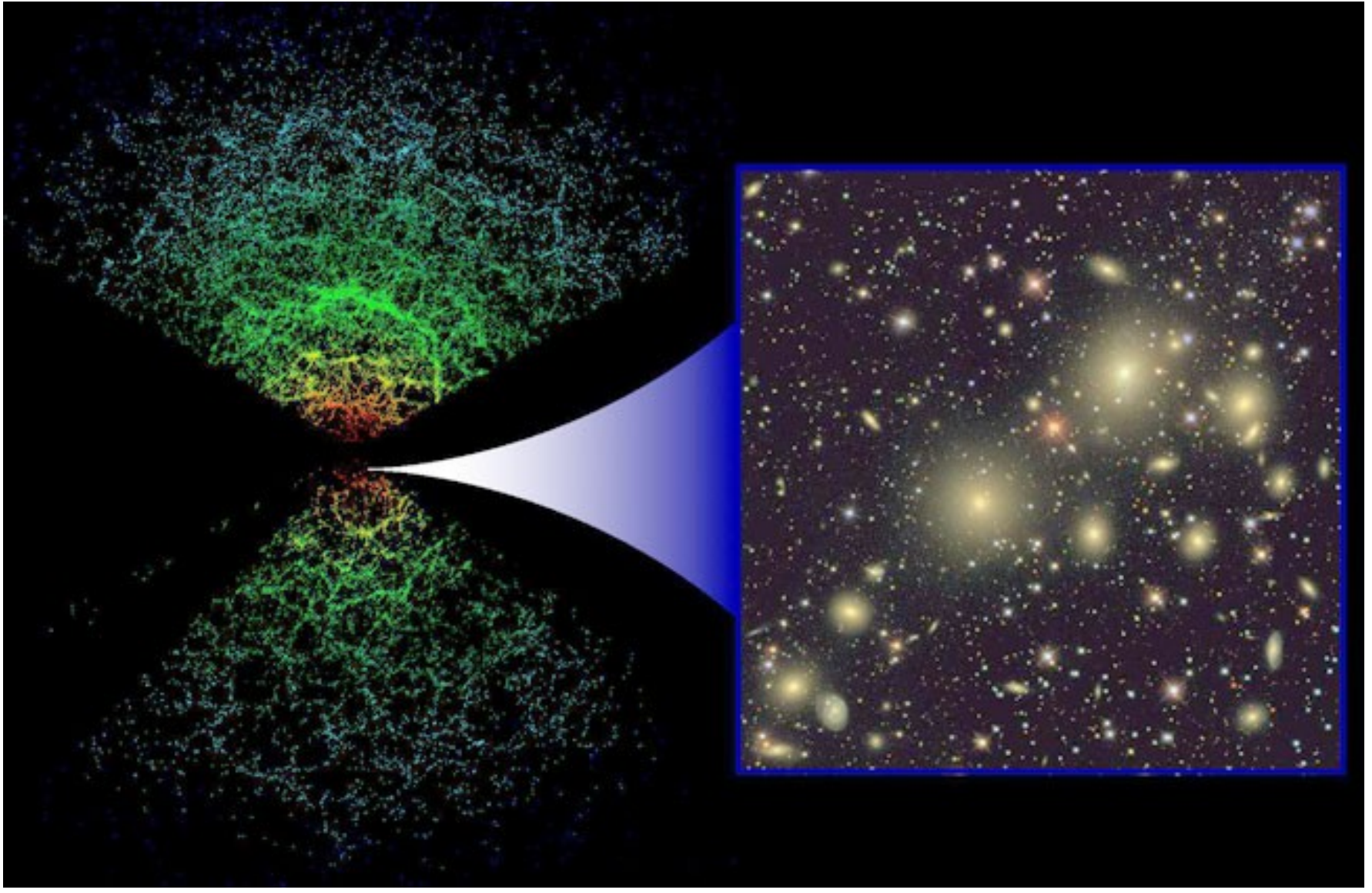
Principais Candidatos

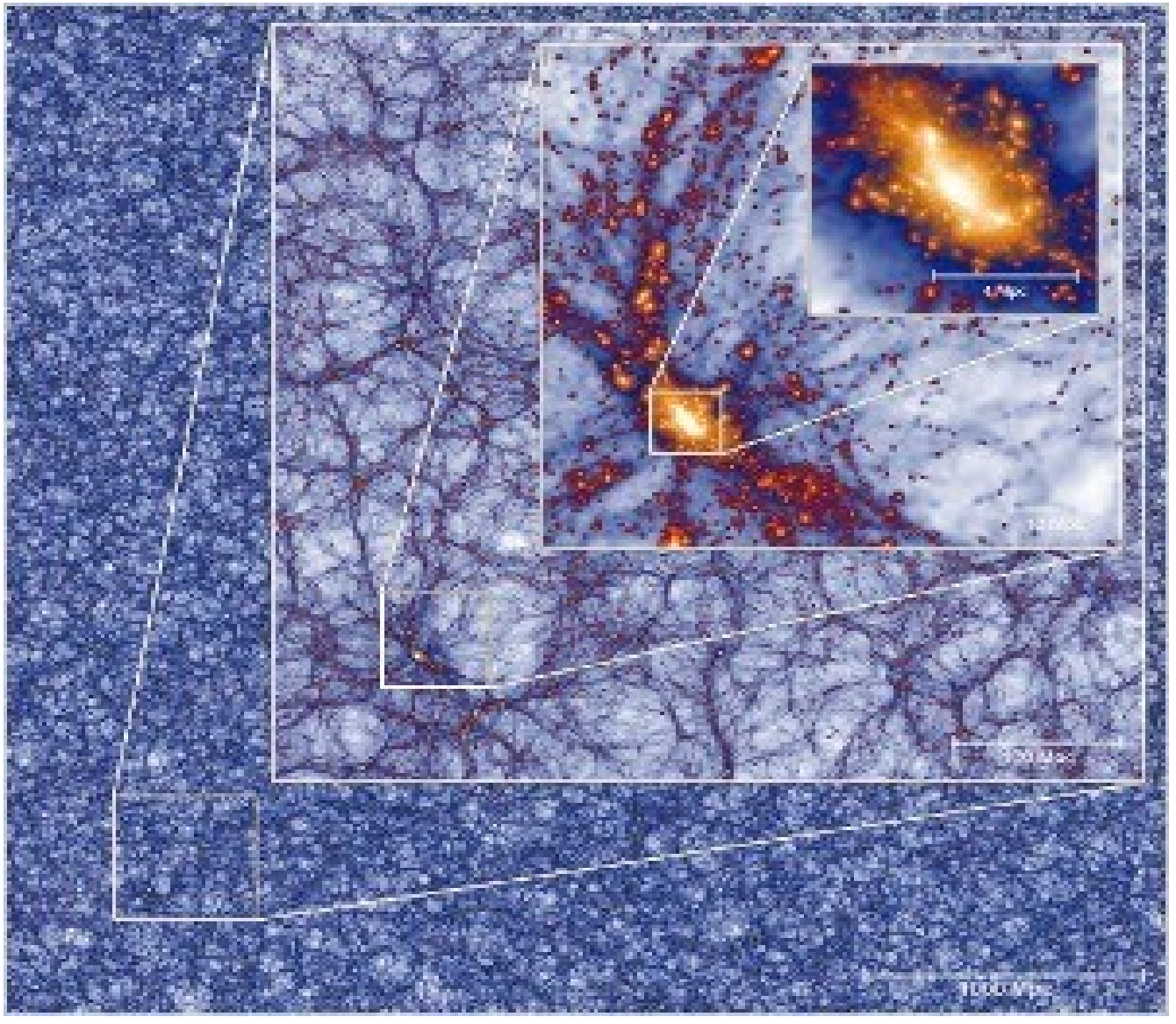


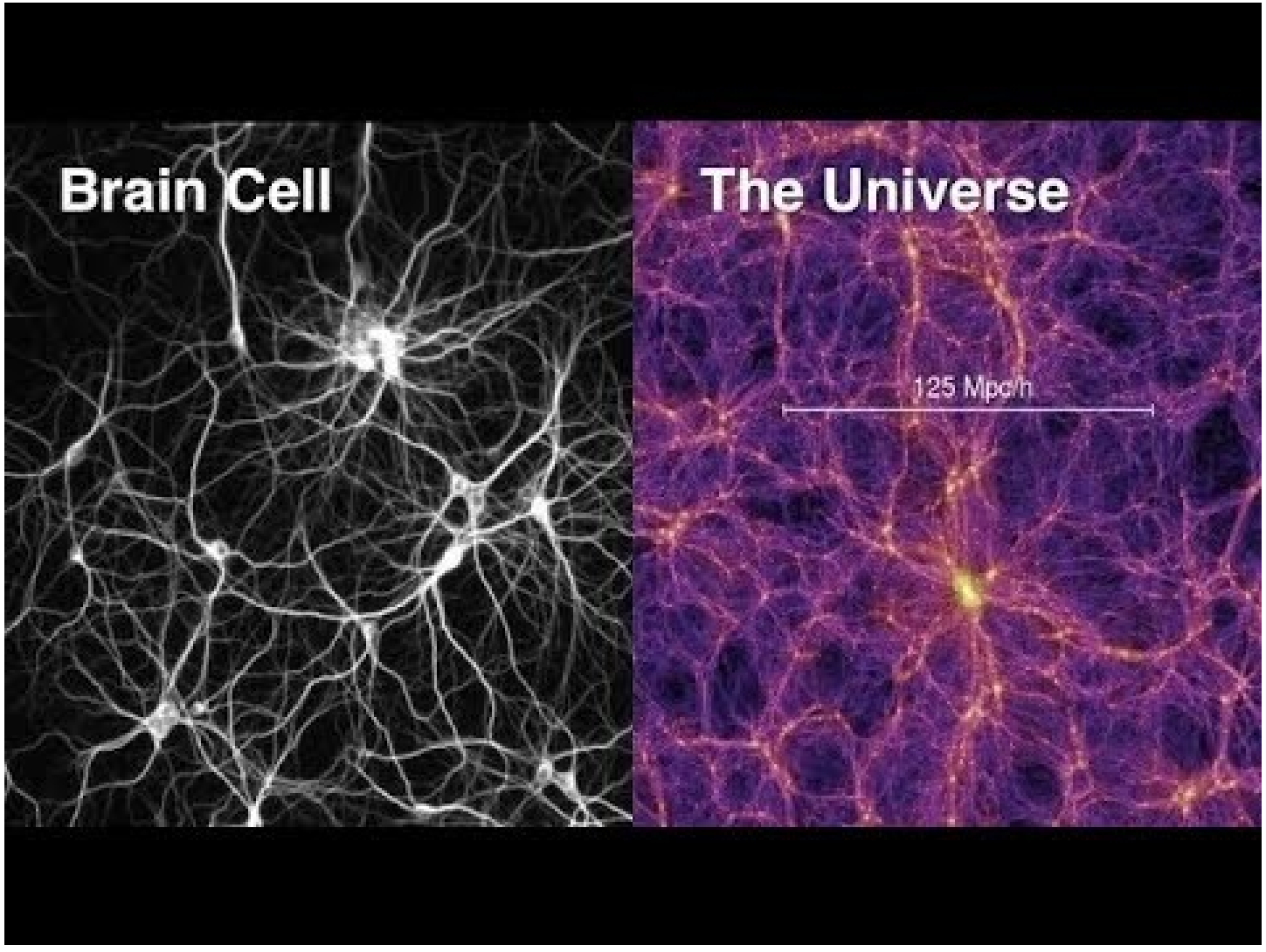
Estrutura do Universo em Grande Escala





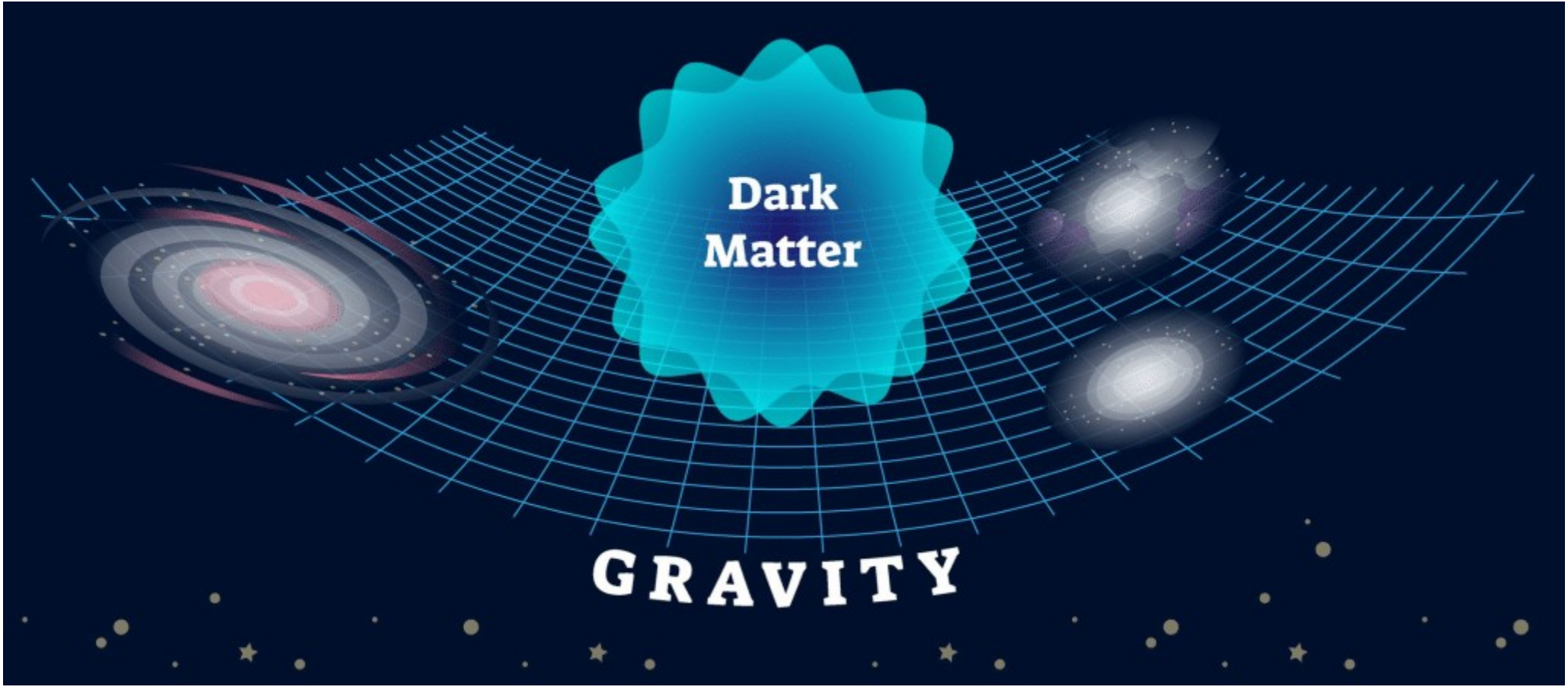





Brain Cell
The Universe
125 Mpc/h

https://wwwmpa.mpa-garching.mpg.de/galform/millennium/

Extra



Principais evidência indiretas para existência de materia escura

1 - Radiação cósmica de fundo

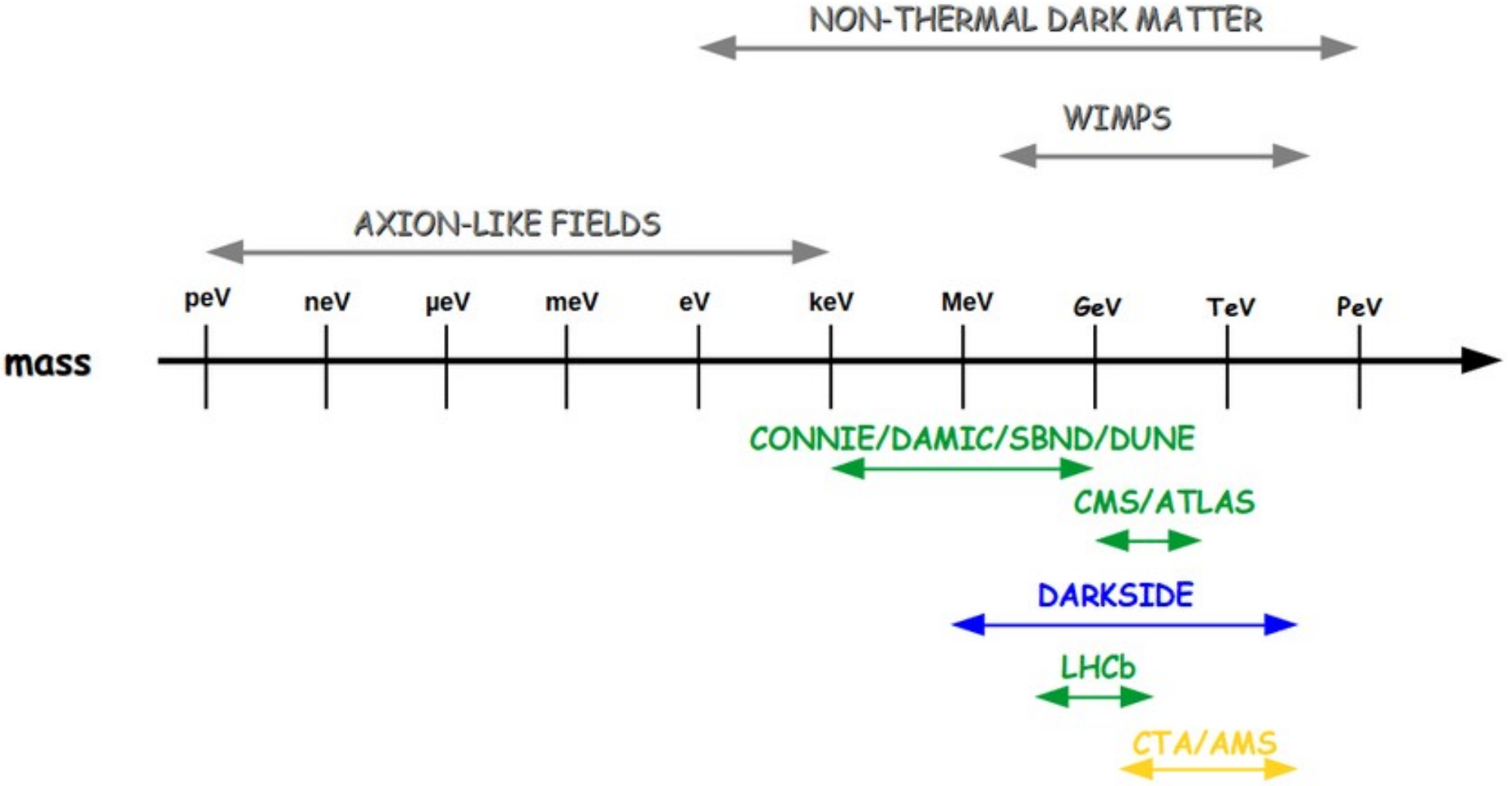
2 - Estrutura do Universo em Grande Escalas

3 - Lentes Gravitacionais

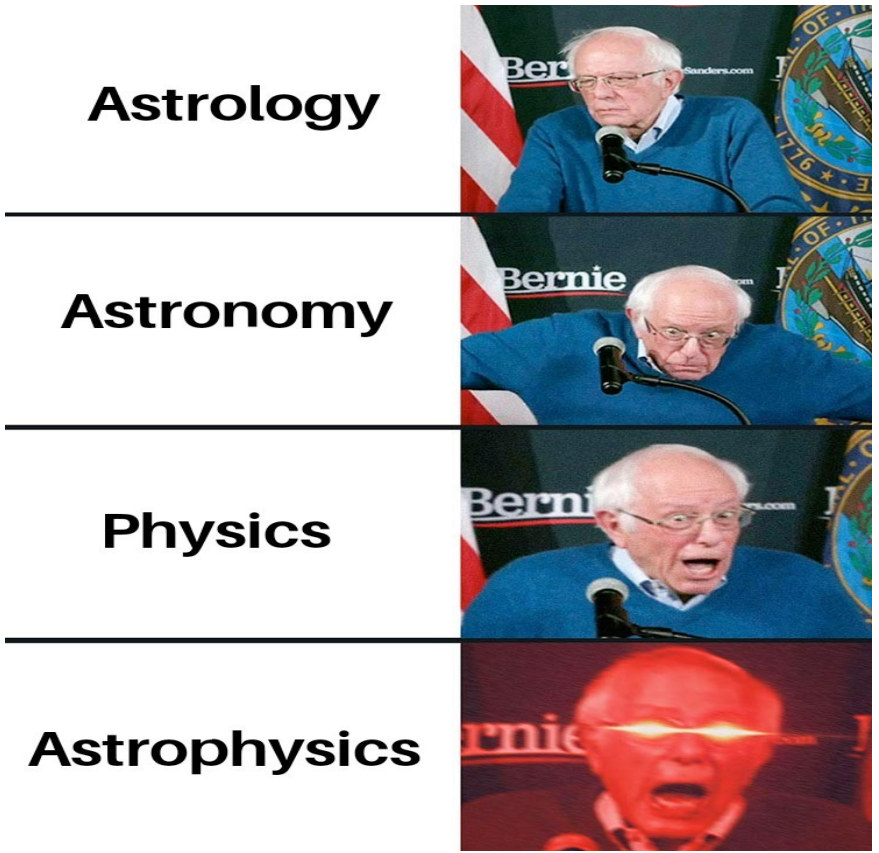
4 - Grupos e aglomerados de Galáxias

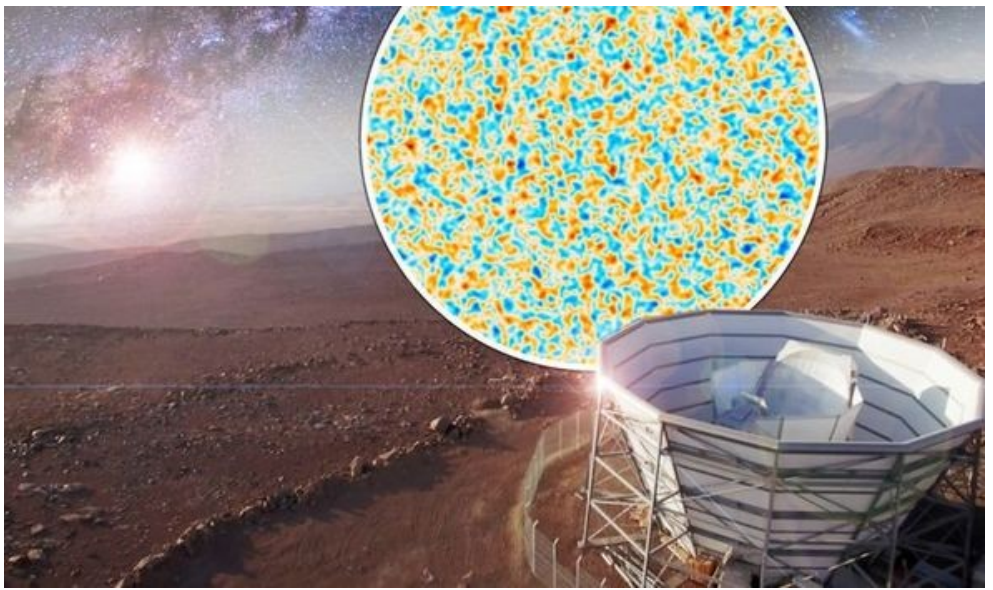
5 - Dinâmica e cinemática de Galáxias


Dark Matter
Light bosons
Axion-like Particles
Fuzzy Dark Matter
QCD Axions
Neutrinos
Standard Model ν
Sterile neutrinos
Weak Scale
Super-symmetry
Extra-dimensions
Little Higgs
Effective Field Theory
Simplified Models
Other Particle
WIMPzilla
Self-interacting
Superfluid
Macroscopic
Macros
MaCHOs
Primordial BHs
Modified Gravity
MOG
TeVeS
MoND
Emergent Gravity

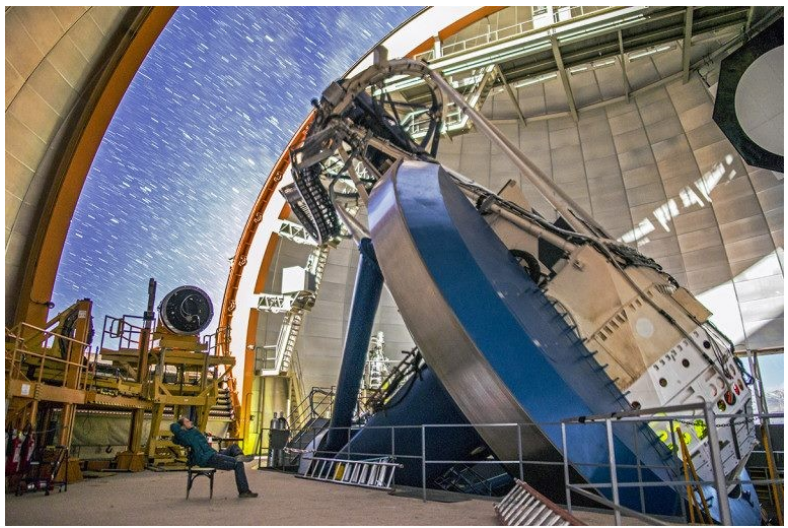

NON-THERMAL DARK MATTER
WIMPS
AXION-LIKE FIELDS
peV
neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
mass
CONNIE/DAMIC/SBND/DUNE
CMS/ATLAS
DARKSIDE
LHCb
CTA/AMS

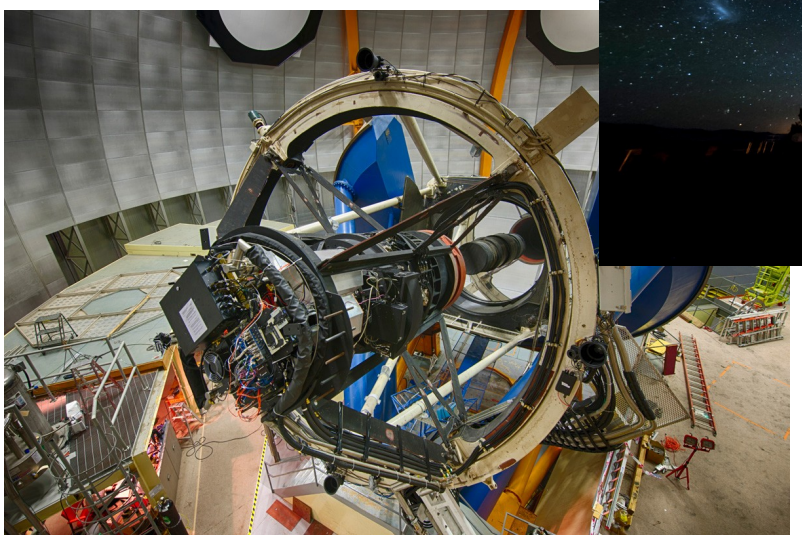
Alguns experimentos atuais





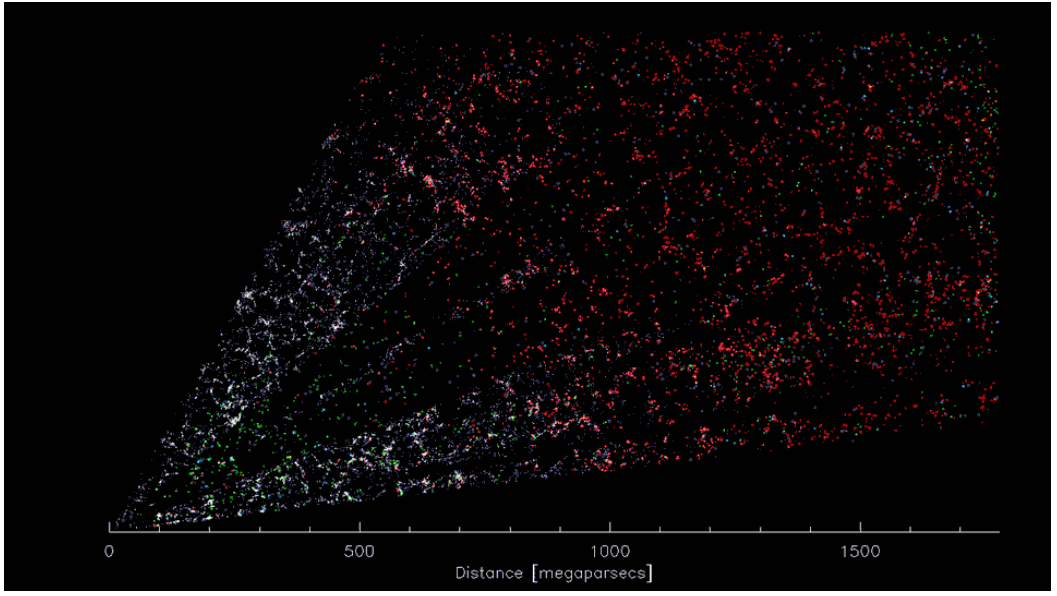
The Dark Energy Survey:
https://www.darkenergysurvey.org/

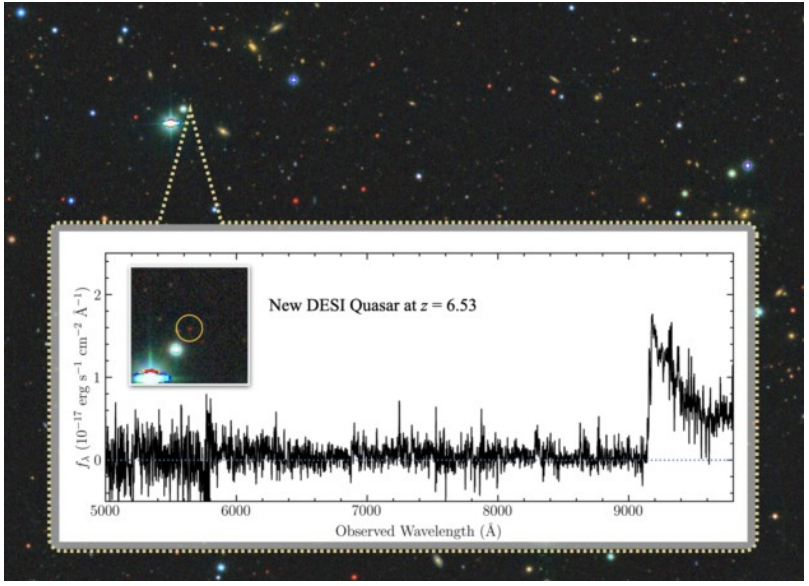




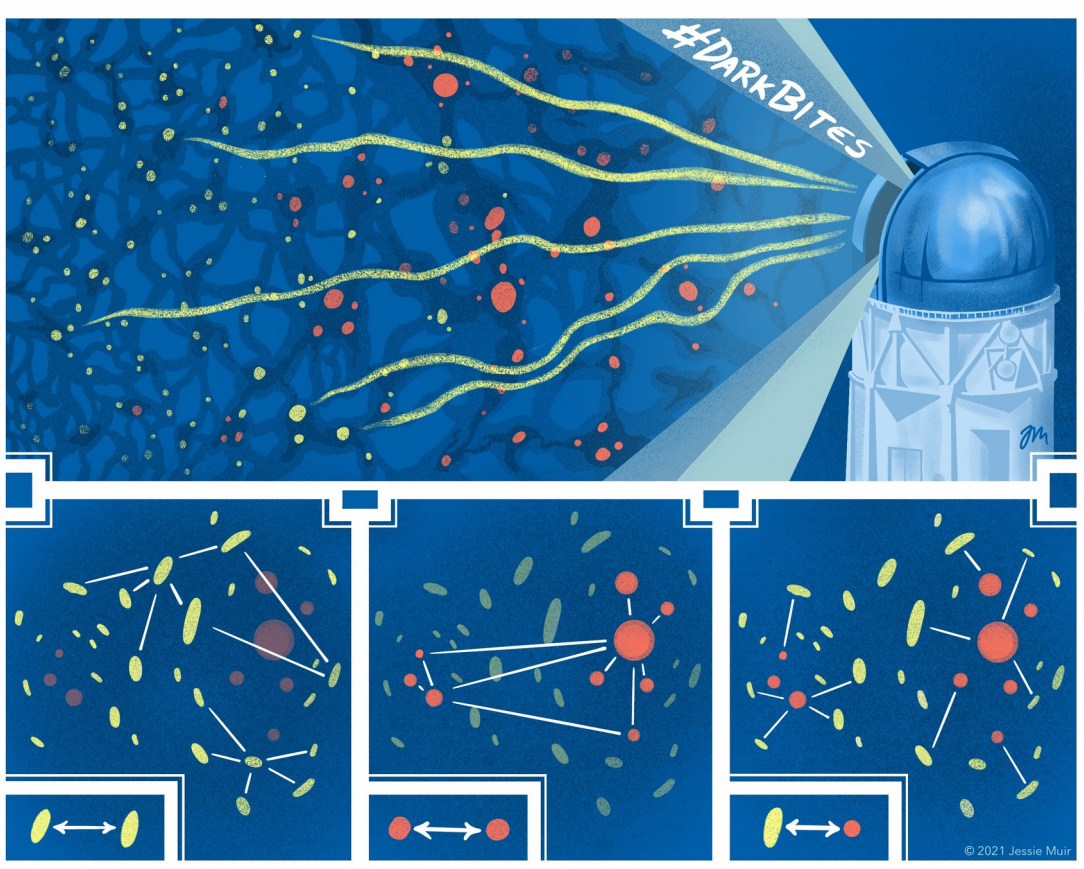
Dark Energy Spectroscopic Instrument (DESI)

- 3D Map of the Cosmos

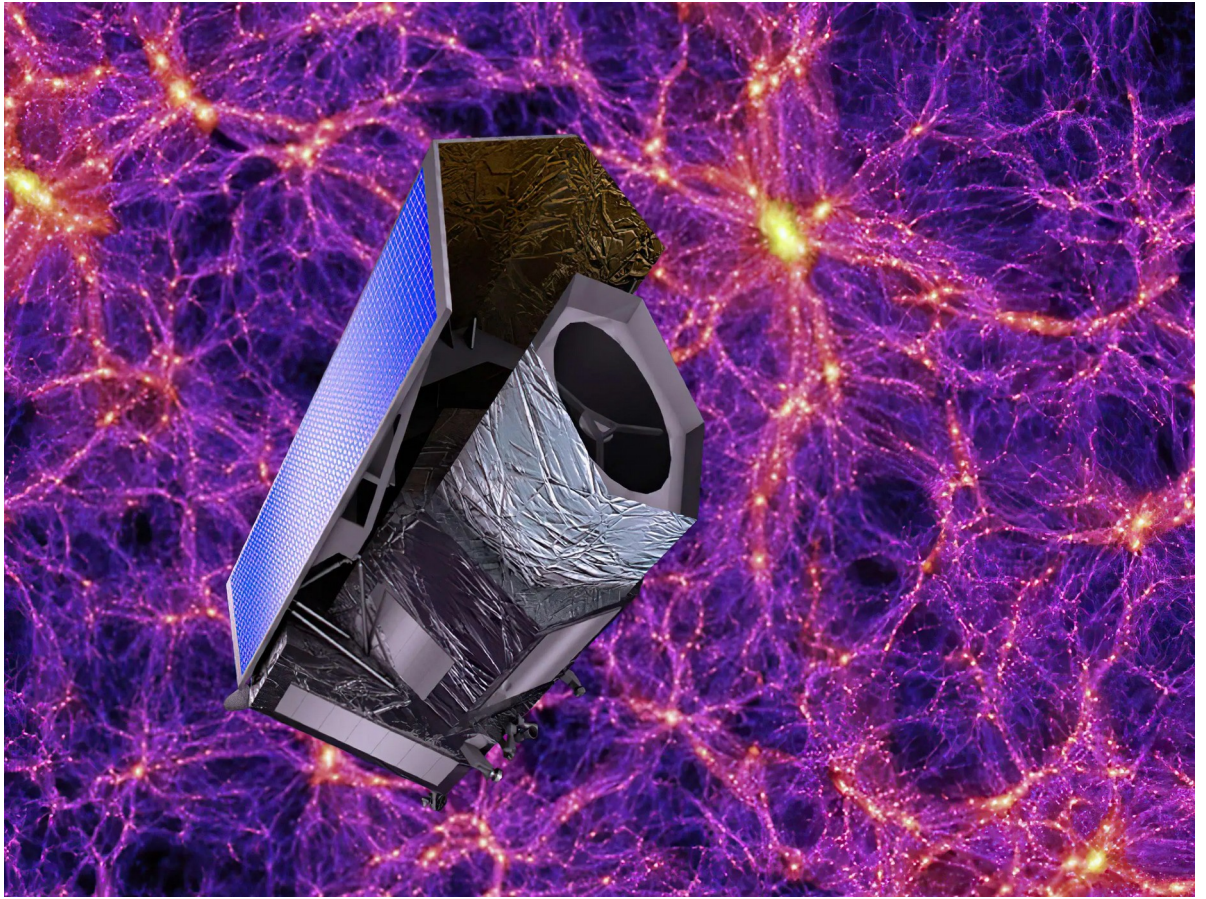




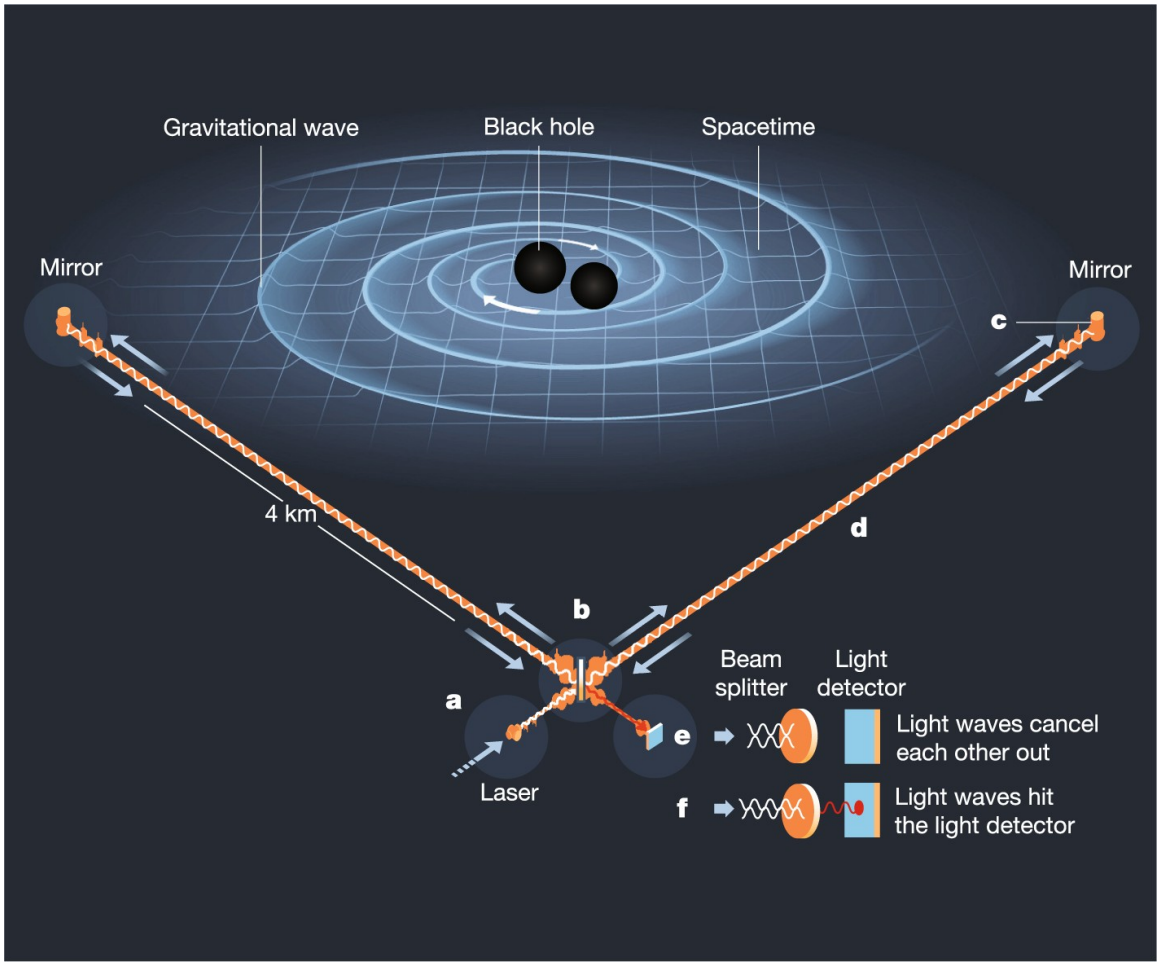
KiDS, the Kilo-Degree Survey : a large optical imaging survey in the Southern sky.

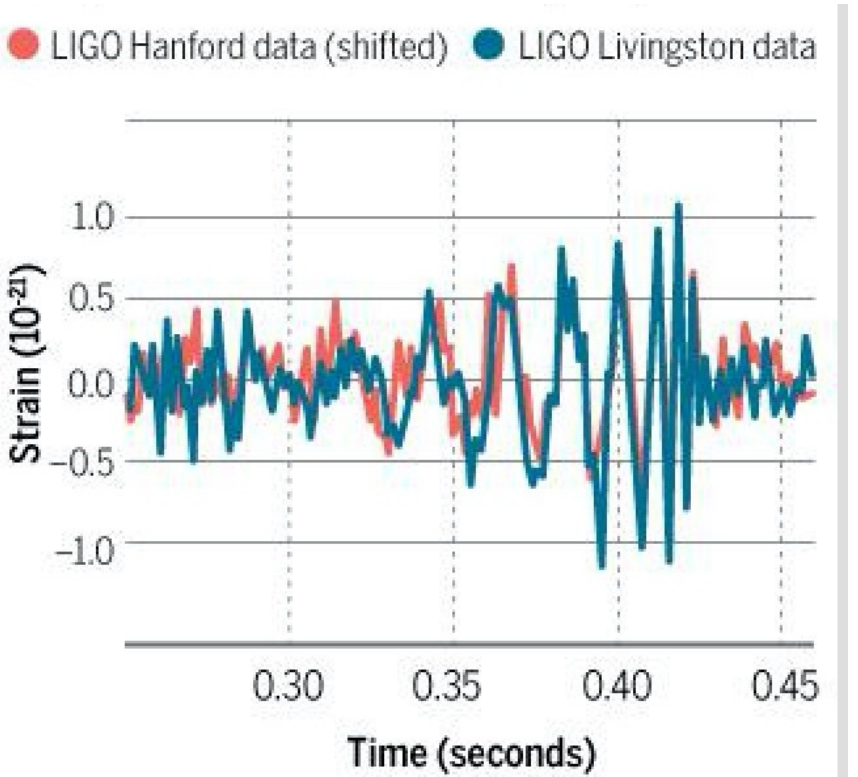


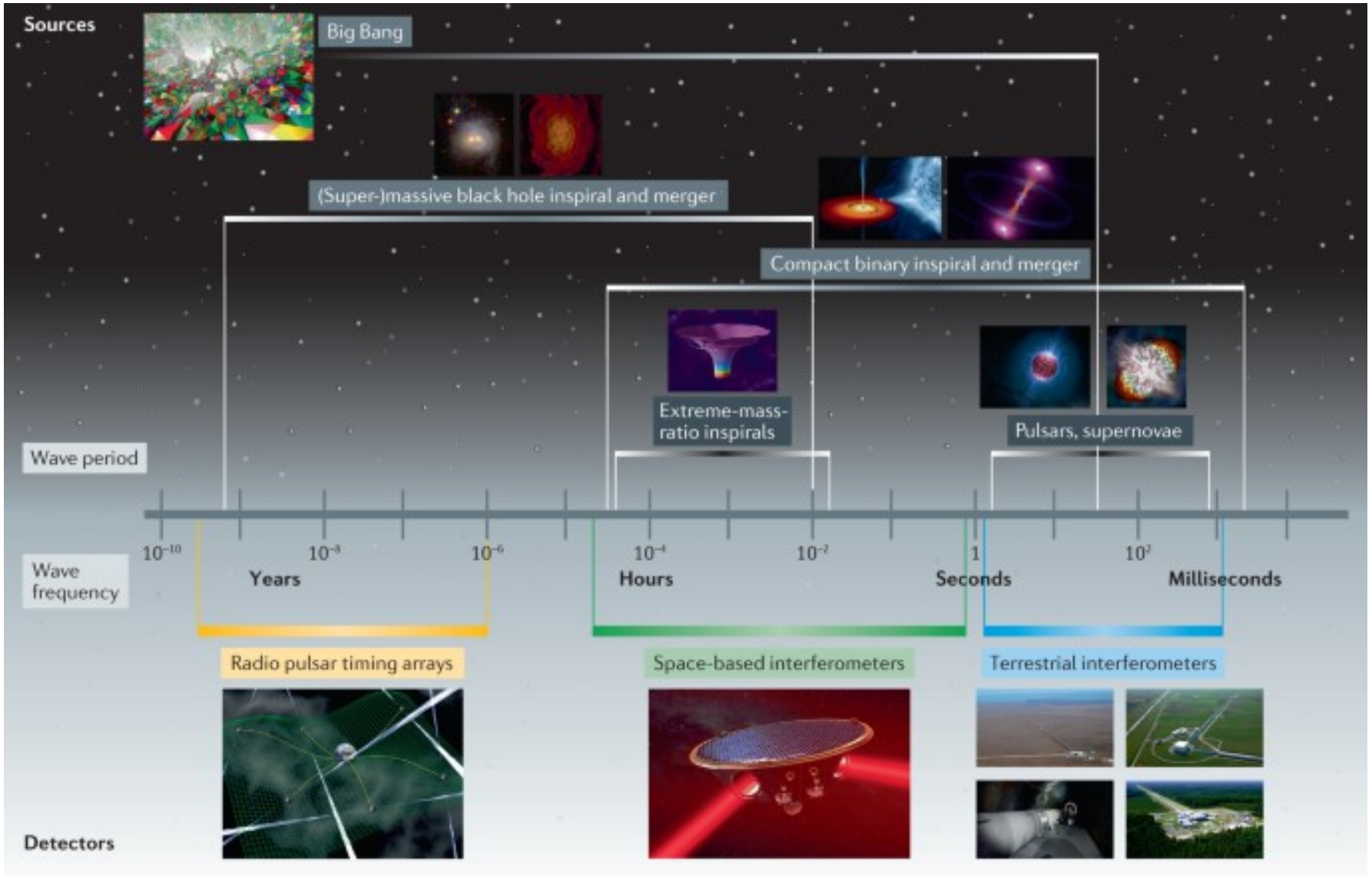
Euclid “Dark Universe” Space Telescope



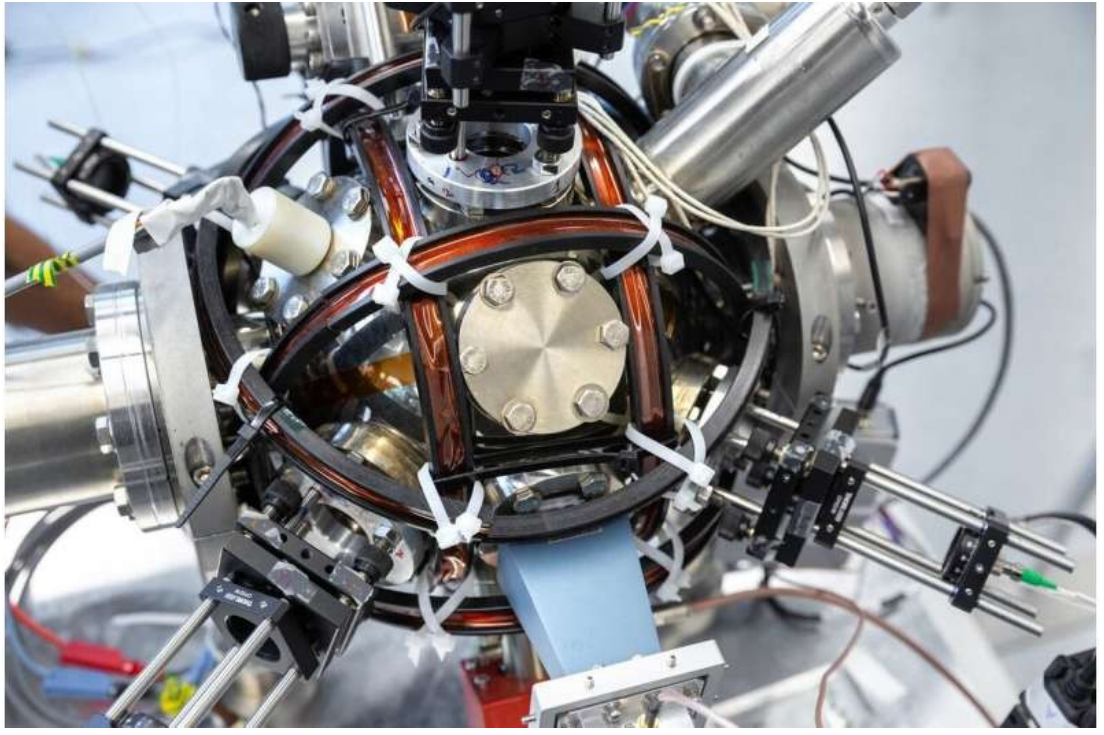
Dark Energy and Gravitational-Wave Astronomy

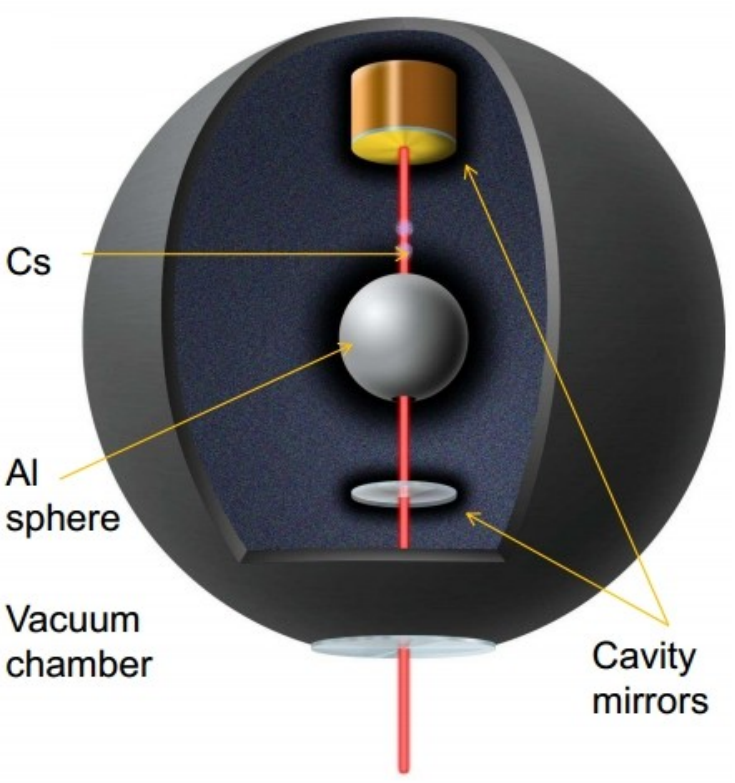


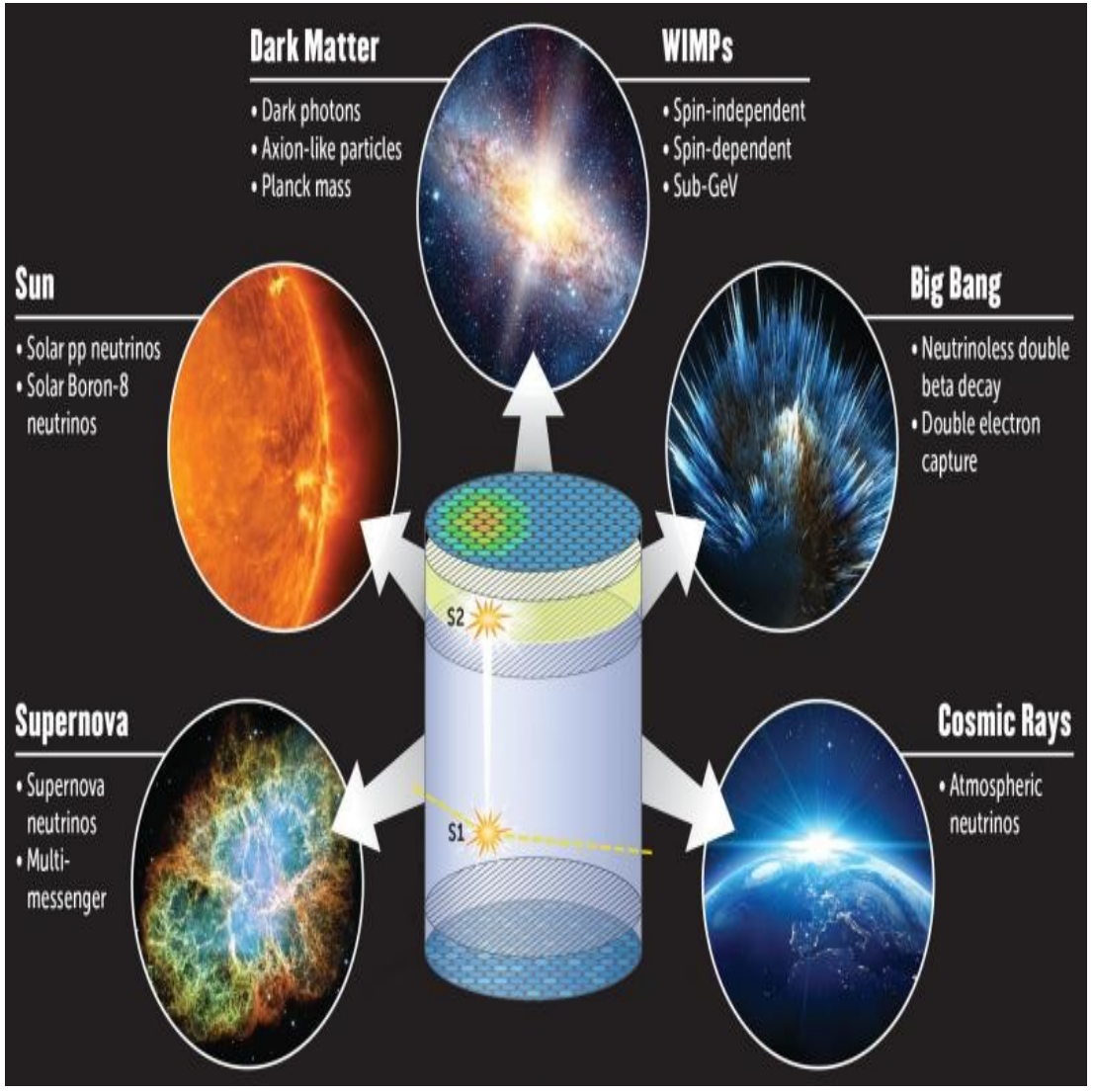


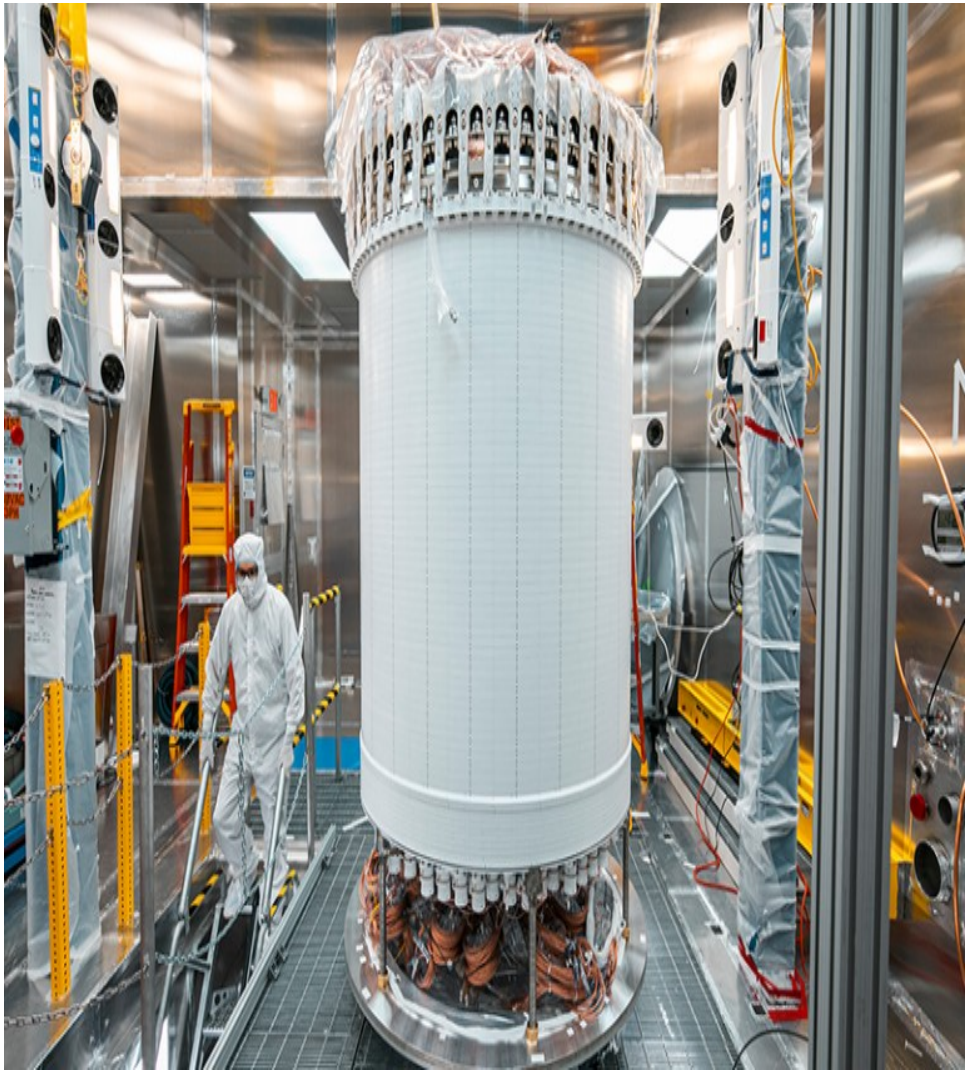

Sources
Big Bang
(Super-)massive black hole inspiral and merger
Compact binary inspiral and merger
Extreme-mass-ratio inspirals
Pulsars, supernovae
Wave period
Wave frequency
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
1
10^{2}
Years
Hours
Seconds
Milliseconds
Radio pulsar timing arrays
Space-based interferometers
Terrestrial interferometers
Detectors

Lab-based dark energy experiment






Dark Matter
• Dark photons
• Axion-like particles
• Planck mass
WIMPs
• Spin-independent
• Spin-dependent
• Sub-GeV
Sun
• Solar pp neutrinos
• Solar Boron-8 neutrinos
Big Bang
• Neutrinoless double beta decay
• Double electron capture
S2
S1
Supernova
• Supernova neutrinos
• Multi-messenger
Cosmic Rays
• Atmospheric neutrinos



Questões de fixação

1- Quais as previsões básicas do modelo padrão já comprovadas ?

2 - O que é a nucleossíntese primordial ? Quando se formaram os núcleos atômicos leves ? Como se formaram os primeiros átomos ?

3 - Quais são os constituintes do Universo e as suas proporções ?

4 - O que é energia escura ?

FIM!