Croatian Teacher Programme

Uvod u kozmologiju

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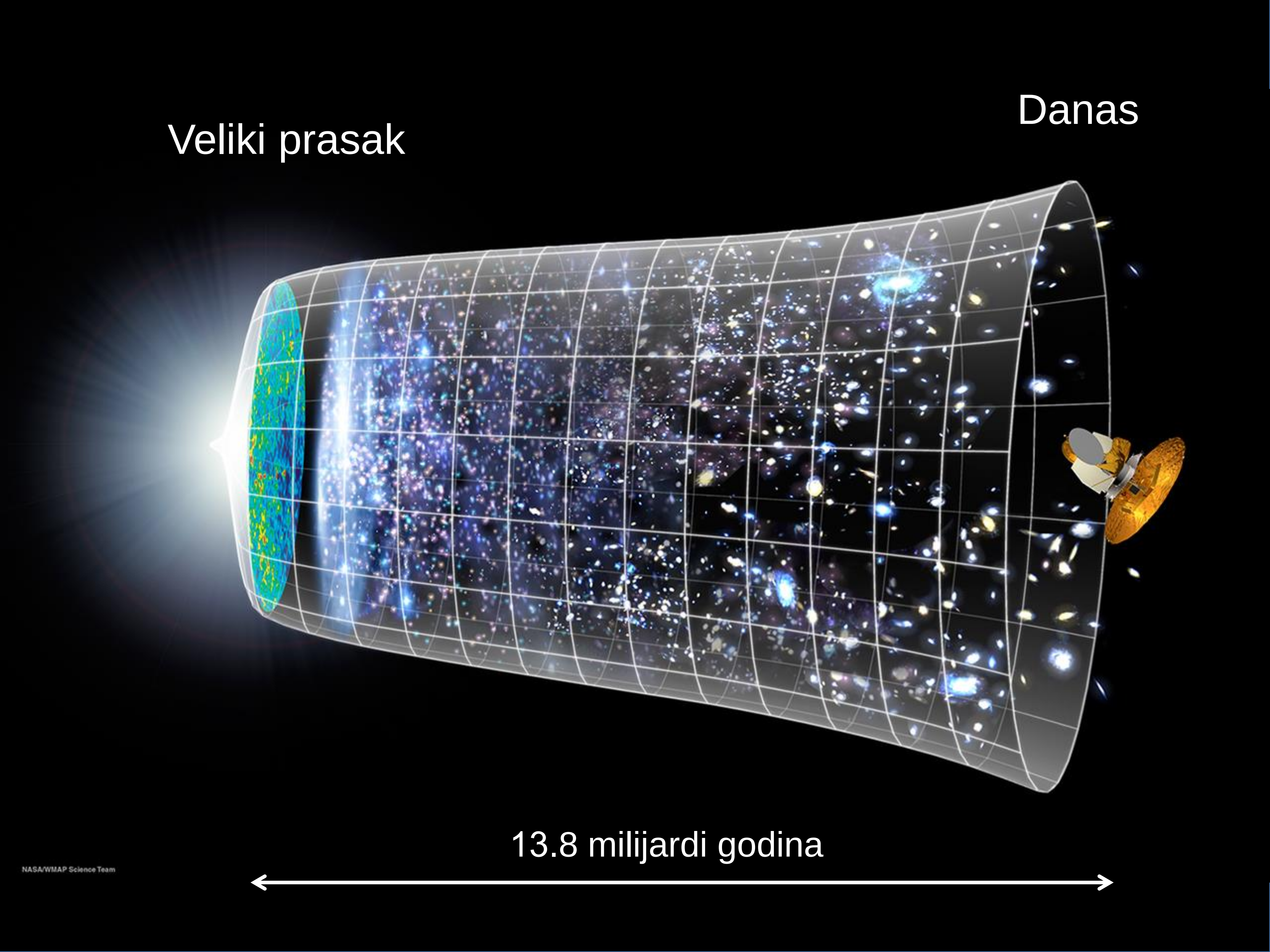
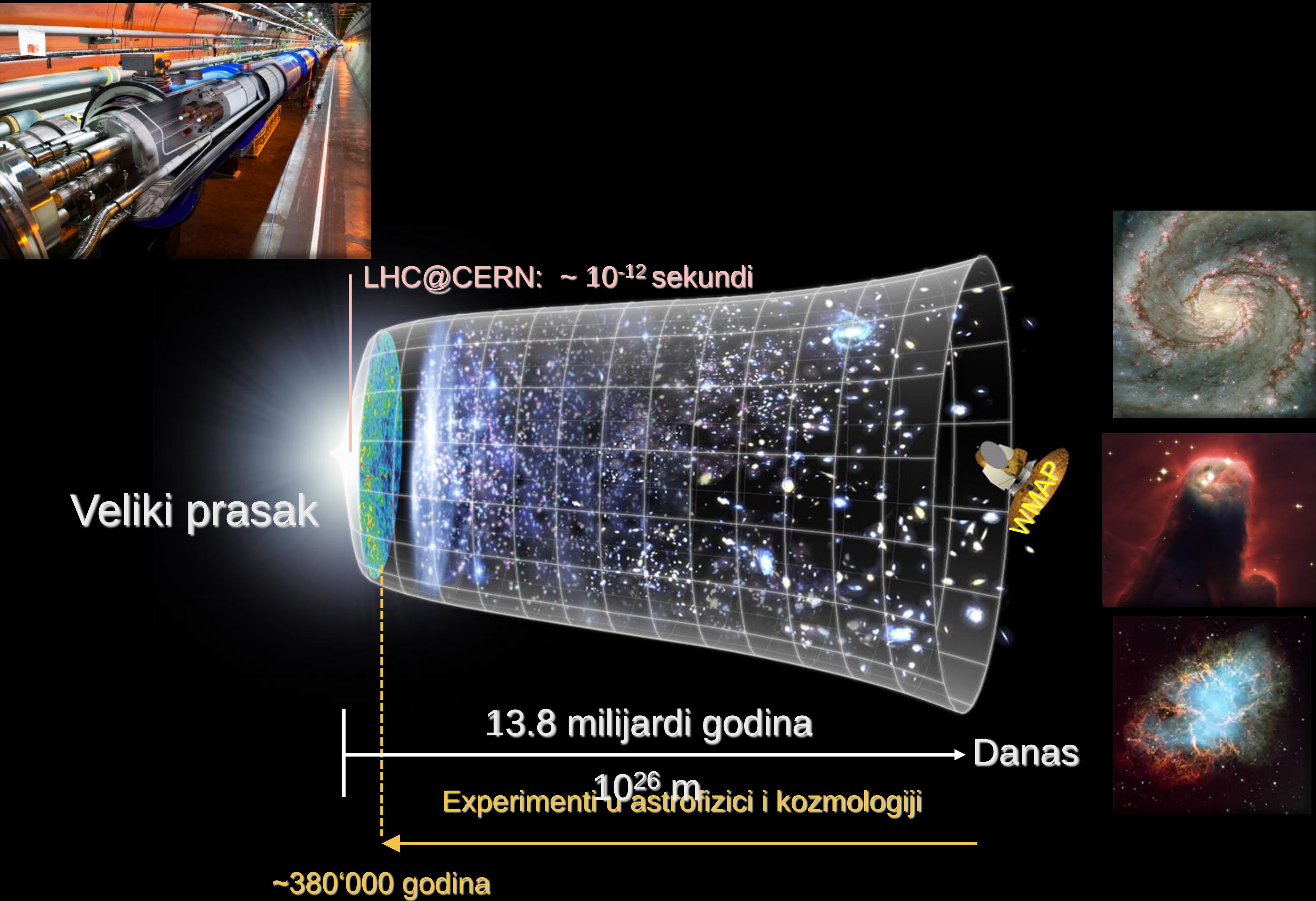
Spremljeno prema: wmap.gsfc.nasa.gov

CERN, 12. travnja 2017.


Veliki prasak
Danas
13.8 milijardi godina
NASA/WMAP Science Team


LHC@CERN: ~ 10^{-12} sekundi
Veliki prasak
WMAP
13.8 milijardi godina
Danas
10^{26} m
Experimenti u astrofizici i kozmologiji
~380‘000 godina

Što je kozmologija?

- Kozmologija je dio znanosti koji proučava svojstva svemira kao cjeline
    - i to na velikoj prostornoj skali
- Kozmologija koristi znanstvenu metodu za razumijevanje
    - Postanka
    - Evolucije
    - Konačne sudbine

  cijelog svemira.
- Teorija o nastanku i evoluciji svemira koja danas predvladava zove se

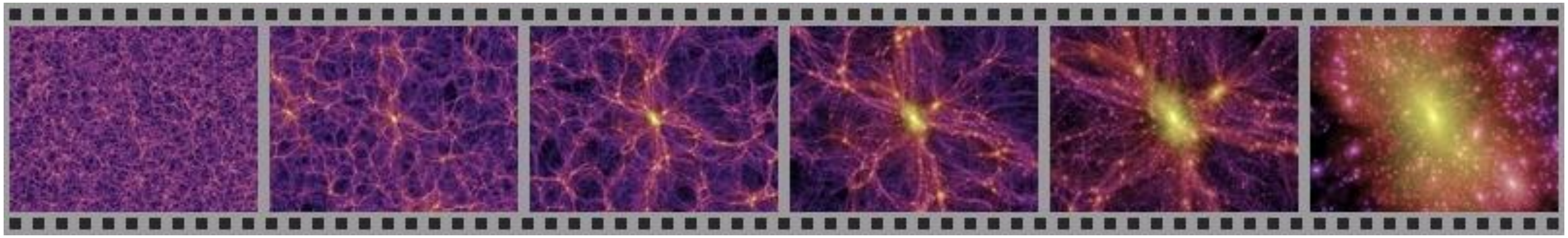
Teorija Velikog praska

The Big Bang theory

The Big Bang Theory

Kozmologija Velikog praska

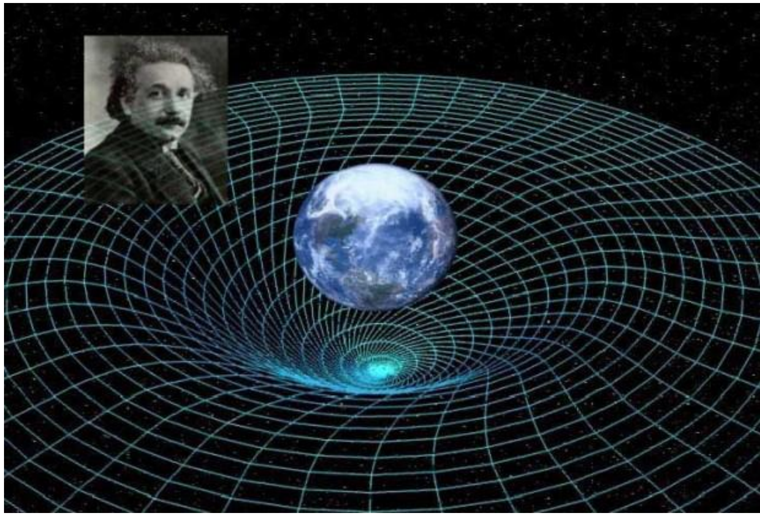
- Globalni pogled:
  - Svemir je nastao prije oko 12 – 14 milijardi godina
  - Dio svemira koji sada vidimo bio je tada samo par milimetara širok
  - Od tog malog i vrućeg dijela svemira se proširio na velika i hladna prostranstva svemira koja mi danas nastanjujemo

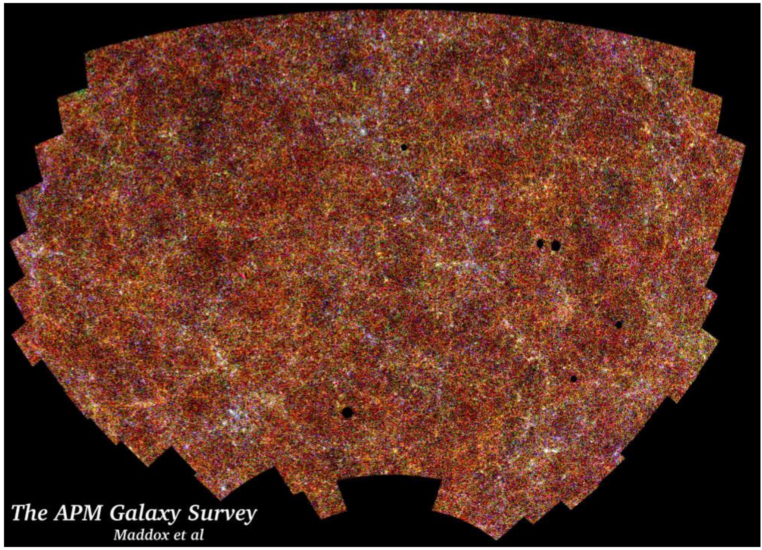


  - Ostatke ove vruće materije možemo danas vidjeti u obliku hladne mikrovalne kozmičke pozadine **(Cosmic Microwave Background radiation, CMB)**
    - Koja danas prožima cijeli svemir
    - Vidljiva je mikrovalnim detektorima kao uniforman sjaj preko cijelog neba

Teorijske osnove modela velikog praska

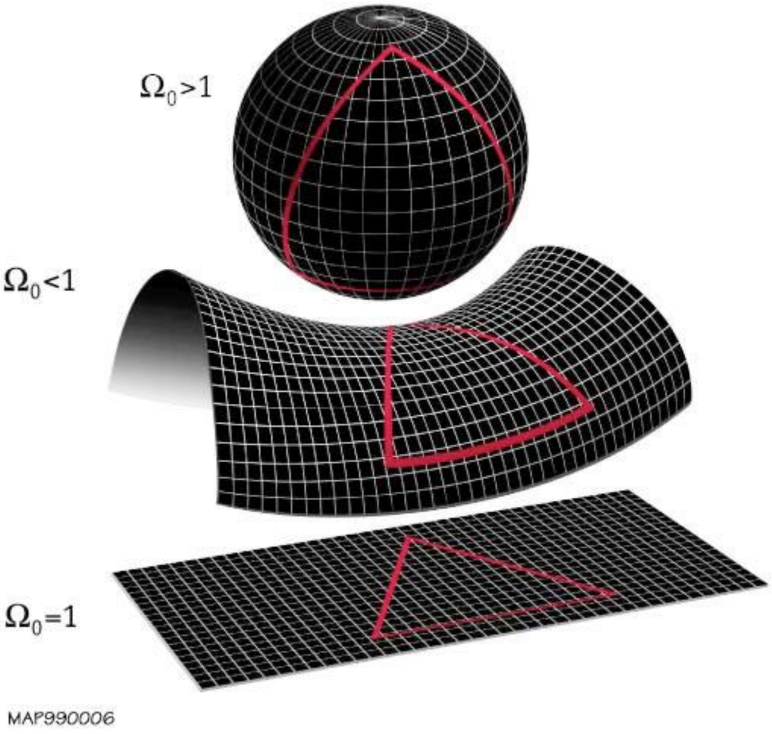
- Model velikog praska utemeljen je na dva teorijska stupa
  - **Opća teorija relativnosti**
    - Einstein 1916.
    - Ključni koncept: gravitacija se više ne opisuje preko gravitacijskog polja, nego se radi o distorziji prostor-vremena
    - John Wheeler: "*Matter tells space how to curve, and space tells matter how to move*"
  - **Kozmološki princip**
    - Materija u svemiru je raspodjeljena ***homogeno i izotropno***, kad se usrednji preko velikih skala
    - Ova pretpostavka je danas provjerena u mnoštvu eksperimenata





Dinamika prostor-vremena

- Slijedeći "Kozmološki princip" distorzije prostor-vremena, zbog gravitacijskog efekta na materiju, mogu imati samo jedan od tri oblika
  - Pozitivno zakrivljen
  - Negativno zakrivljen
  - Ravan
- Pažnja!
  - Mi samo vidimo svemir koji je od nas udaljen 13.77 milijardi godina
    - To je naš **horizont**
  - Svemir može imati i kompleksniju ukupnu geometriju, a da nama lokalno i dalje izgleda ovako



Gustoća materije → geometrija svemira

- Srednja gustoća materije u svemiru jednoznačno određuje geometriju svemira
- Srednja gustoća za ravni svem

$$\rho_{crit} = \frac{3H_0^2}{8\pi G}.$$

  - H_0 = Hubblova konstanta
  - G = Gravitacijska konstanta
  - ρ_{crit} = 6 atoma vodika na m^3
- Kozmološki parametar gustoće

$$\Omega_0 \equiv \frac{\rho_0}{\rho_{crit}} = \frac{8\pi G\rho_0}{3H_0^2}.$$

  - Za izmjerenu vrijednost vidjeti kasnije WMAP rezultat

table 28-1 The Geometry and Average Density of the Universe

Geometry of space	Curvature of space	Type of universe	Combined average mass density (ρ_0)	Density parameter (Ω_0)
Spherical	positive	closed	$\rho_0 > \rho_c$	$\Omega_0 > 1$
Flat	zero	flat	$\rho_0 = \rho_c$	$\Omega_0 = 1$
Hyperbolic	negative	open	$\rho_0 < \rho_c$	$\Omega_0 < 1$

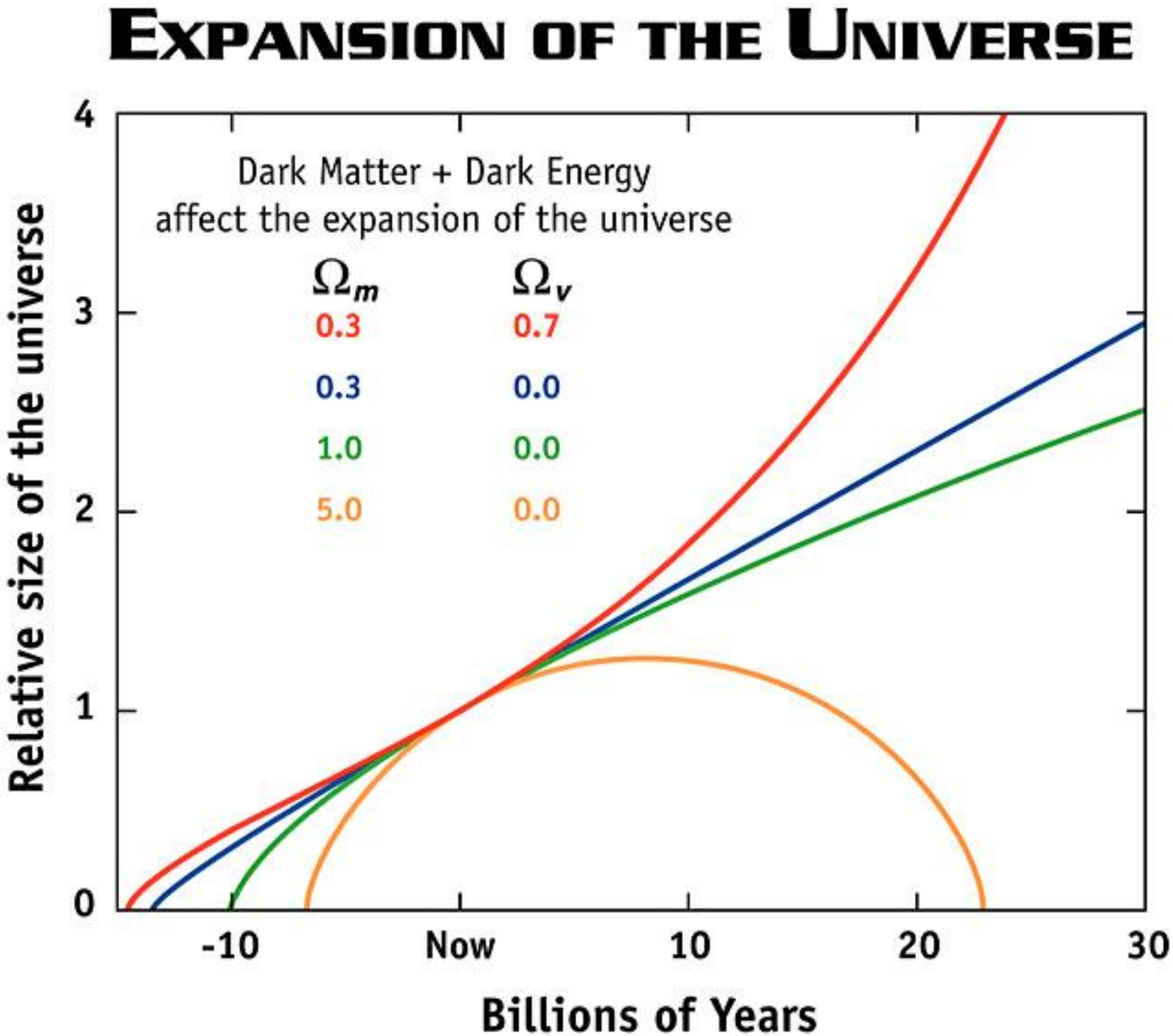
Neki važni parametri svemira

table 28-2 **Some Key Properties of the Universe**

Quantity	Significance	Value*
Hubble constant, H_0	Present-day expansion rate of the universe	71^{+4}_{-3} km/s/Mpc
Density parameter, Ω_0	Combined mass density of all forms of matter *and* energy in the universe, divided by the critical density	1.02 ± 0.02
Matter density parameter, Ω_m	Combined mass density of all forms of matter in the universe, divided by the critical density	0.27 ± 0.04
Density parameter for ordinary matter, Ω_b	Mass density of ordinary atomic matter in the universe, divided by the critical density	0.044 ± 0.004
Dark energy density parameter, Ω_Λ	Mass density of dark energy in the universe, divided by the critical density	0.73 ± 0.04
Age of the universe, T_0	Elapsed time from the Big Bang to the present day	$(1.37 \pm 0.02) \times 10^{10}$ years
Age of the universe at the time of recombination	Elapsed time from the Big Bang to when the universe became transparent, releasing the cosmic background radiation	$(3.79^{+0.08}_{-0.07}) \times 10^5$ years
Redshift z at the time of recombination	Since the cosmic background radiation was released, the universe has expanded by a factor $1 + z$	1089 ± 1

**Values are from the first year of WMAP data. (NASA/WMAP Science Team)*

Širenje svemira



Neke od krivih koncepcija o svemiru

- Neki od važnih pojmova za izbjegavanje krivih koncepcija o svemiru
  - Veliki prasak se nije pojavio u jednoj jedinoj točki u prostoru, kao neka vrsta "eksplozije"
    - O njemu je bolje razmišljati kao istovremeno pojavljivanje prostora svugdje u svemiru
    - Dio prostora koje je sada naš horizont nije bio veći od točke na samom početku
    - Ako je prostor unutar i van našeg horizonta
      - sada beskonačan, bio je i rođen beskonačan
      - sada zatvoren i konačan, bio je rođen u nultom volumenu i narastao iz toga
    - U oba slučaja nema "centra ekplozije" – točke iz koje se cijeli svemir raširio
  - Po definiciji, svemir sadržava sav prostor koji mi znamo, tako da je pitanje u što se svemir širi izvan dometa modela Velikog praska
  - Izvan dometa modela Velikog praska je i pitanje što je prouzročilo Veliki prasak
    - Danas imamo mnoštvo teorija koje spekuliraju o ovom pitanju, ali niti jedna nema pouzdane predikcije koje bi se mogle eksperimentalno provjeriti

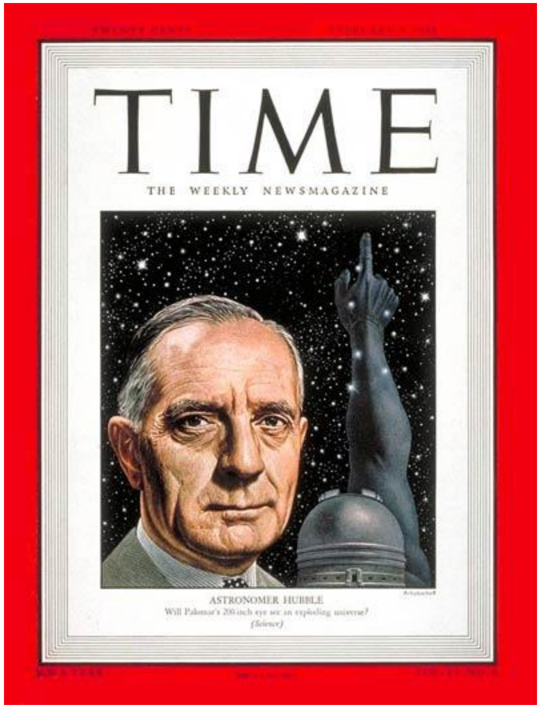
Veliki prasak

- Veliki prasak u biti ne označava početak našeg svemira
- Veliki prasak je kraj našeg terijskog razumijevanja svemira

- O Velikom prasku ne trebamo razmišljati kao o ”singularitetu na početku vremena”
- Veliki prasak je oznaka za trenutak u vremenu koji u biti ne razumijemo

Sean Caroll

Provjere teorije Velikog praska



- Model velikog praska potvrđen je mnogim opažanjima
- Najvažniji među njima su
  - Širenje svemira
  - Količina lakih elemenata (H, He, Li) u svemiru
  - Kozmičko pozadinsko zračenje
- Ova tri opažanja snažno podupiru hipotezu da je svemir evoluirao iz jako vrućeg i gustog plina
  - Plin nije imao izraženu strukturu

Provjere velikog praska: širenje svemira

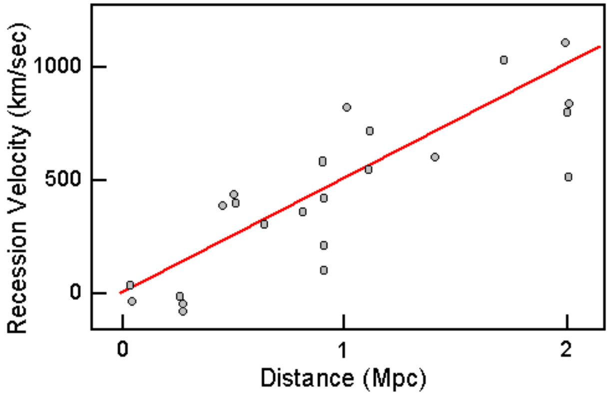
- Hubblov zakon:
  1. Objekti u dubokom svemiru se udaljavaju od Zemlje
  2. Brzina galaksija koje se udaljavaju od Zemlje proporcionalna je njihovoj udaljenost

  Što su dalje udaljavaju se većim brzinama
- Ovaj zakon je prvi izveo Georges Lemaitre 1927.
  - Izvod slijedi iz Opće teorije relativnosti
  - Lemaitre je čak predložio i vrijednost konstante
    - Koju danas zovemo Hubbleova konstanta
- 1929. godine Hubble je eksperimentalno potvrdio ovaj zakon
  - I preciznije izmjerio konstantu
- Zakon u matematičkom obliku:

$$v = H_0 D$$

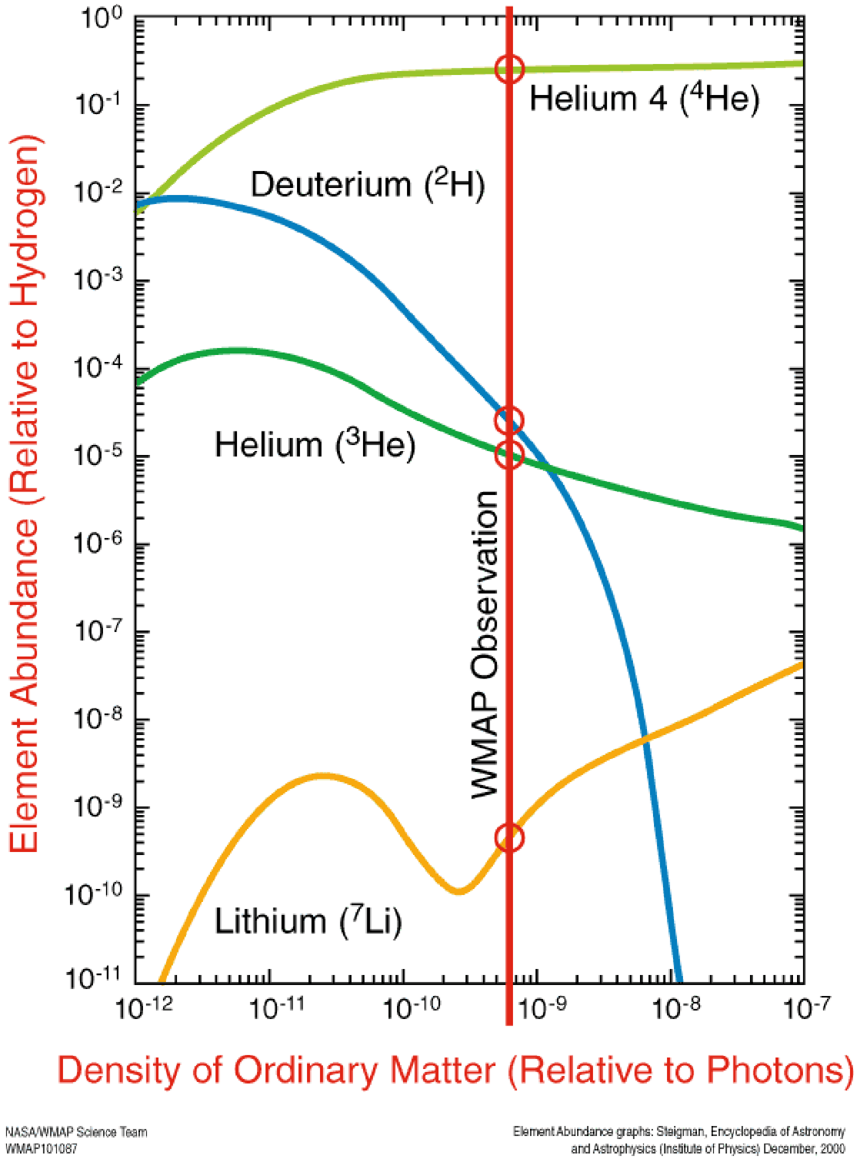
  - v = brzina galaksije
  - Hubblova konstanta H_0 = 71 km/s/Mpc
  - D = udaljenost do galaksije

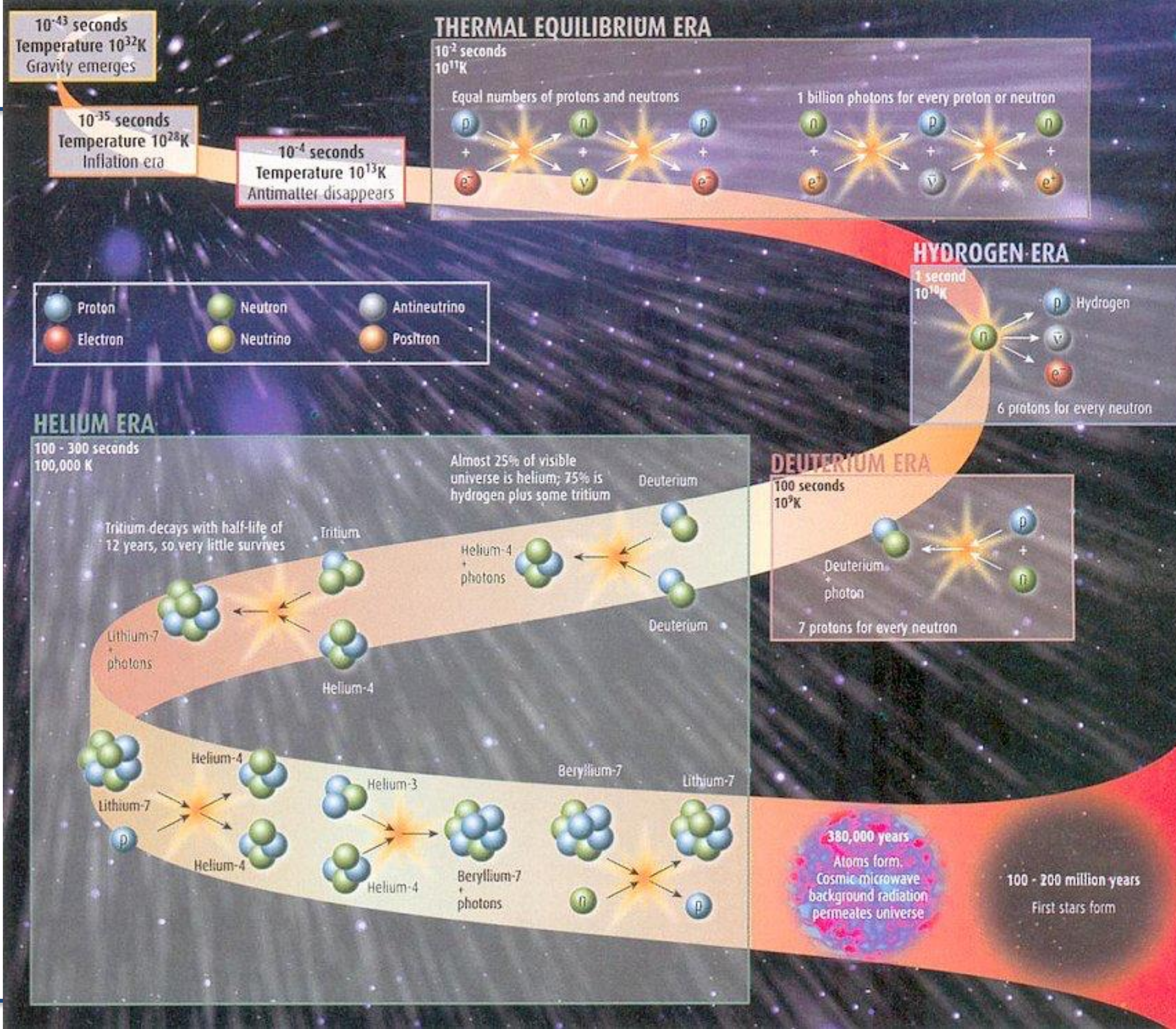
Hubble's Data (1929)



Provjere Velikog praska: laki elementi

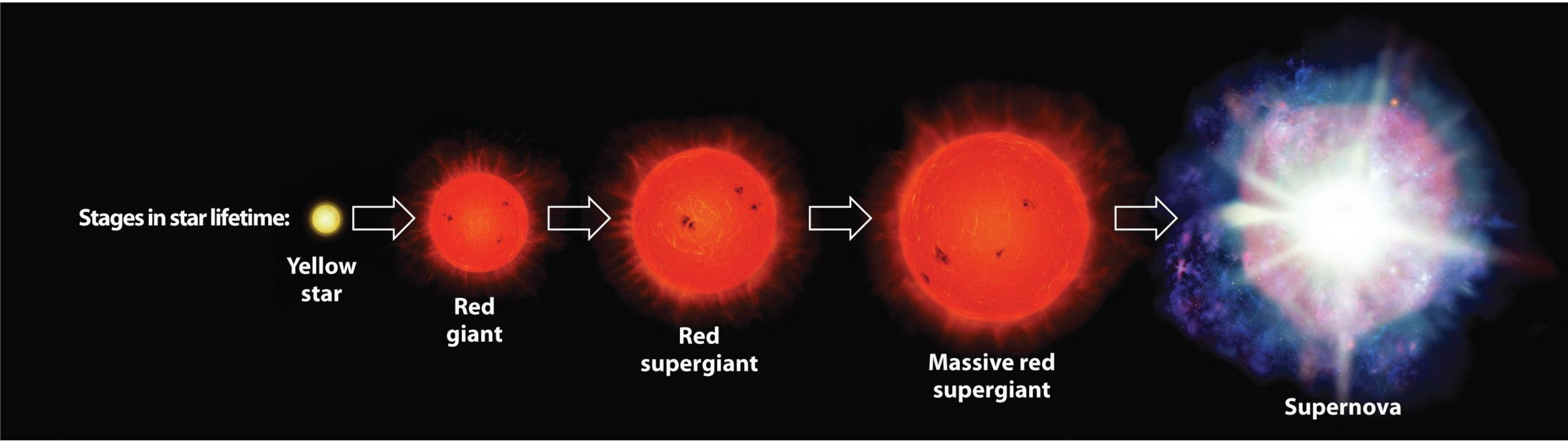
- Rani svemir je bio veoma vruće mjesto
  - 1 sekundu nakon početka $T = 10^9$ K
    - I svemir je bio pun neutrona, protona, elektrona, pozitrona, fotona i neutrina
- Kako se svemir hladio
  - Neutroni su se
    - ili raspali u protone i elektrone
    - Ili su se kombinirali s protonima u deuterij
  - U prve 3 minute većina deuterija se kombinirala i napravila helij
    - Tada su se pojavile i male količine litija
- Ovaj proces stvaranja lakih elemenata se naziva "Nukleosinteza u Velikom prasku"
  - Bing Bang nucleosynthesis (BBN)



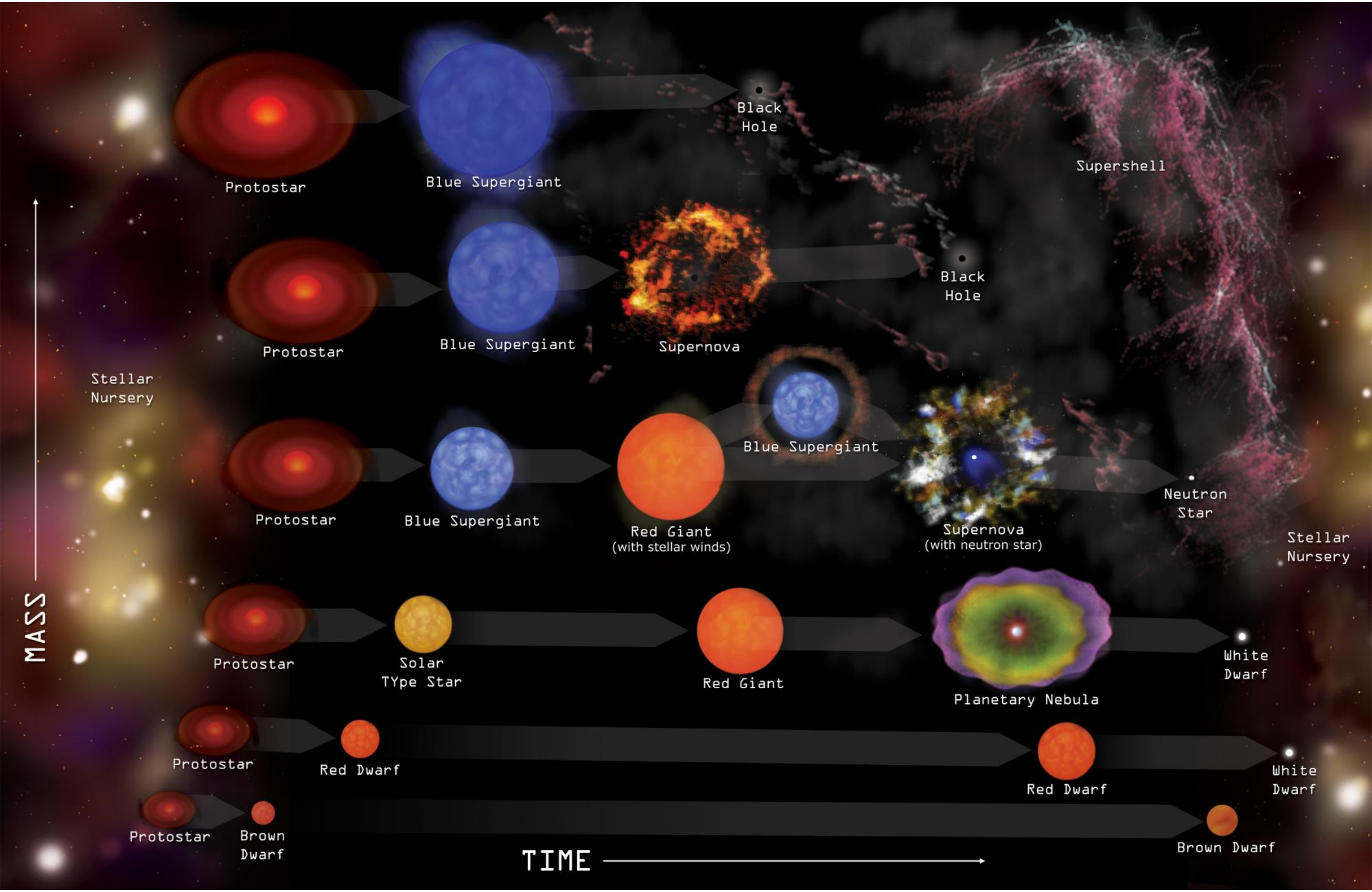


10^{-43} seconds
Temperature 10^{32}K
Gravity emerges
10^{-35} seconds
Temperature 10^{28}K
Inflation era
10^{-4} seconds
Temperature 10^{13}K
Antimatter disappears
THERMAL EQUILIBRIUM ERA
10^{-2} seconds
10^{11}K
Equal numbers of protons and neutrons
1 billion photons for every proton or neutron
HYDROGEN ERA
1 second
10^{10}K
Hydrogen
6 protons for every neutron
Proton
Neutron
Antineutrino
Electron
Neutrino
Positron
DEUTERIUM ERA
100 seconds
10^{9}K
Deuterium + photon
7 protons for every neutron
HELIUM ERA
100 - 300 seconds
100,000 K
Almost 25% of visible universe is helium; 75% is hydrogen plus some tritium
Deuterium
Helium-4 + photons
Deuterium
Tritium decays with half-life of 12 years, so very little survives
Tritium
Lithium-7 + photons
Helium-4
Helium-4
Helium-3
Beryllium-7
Lithium-7
Lithium-7
Helium-4
Helium-4
Beryllium-7 + photons
380,000 years
Atoms form.
Cosmic microwave background radiation permeates universe
100 - 200 million years
First stars form

Sinteza elemenata u zvijezdama

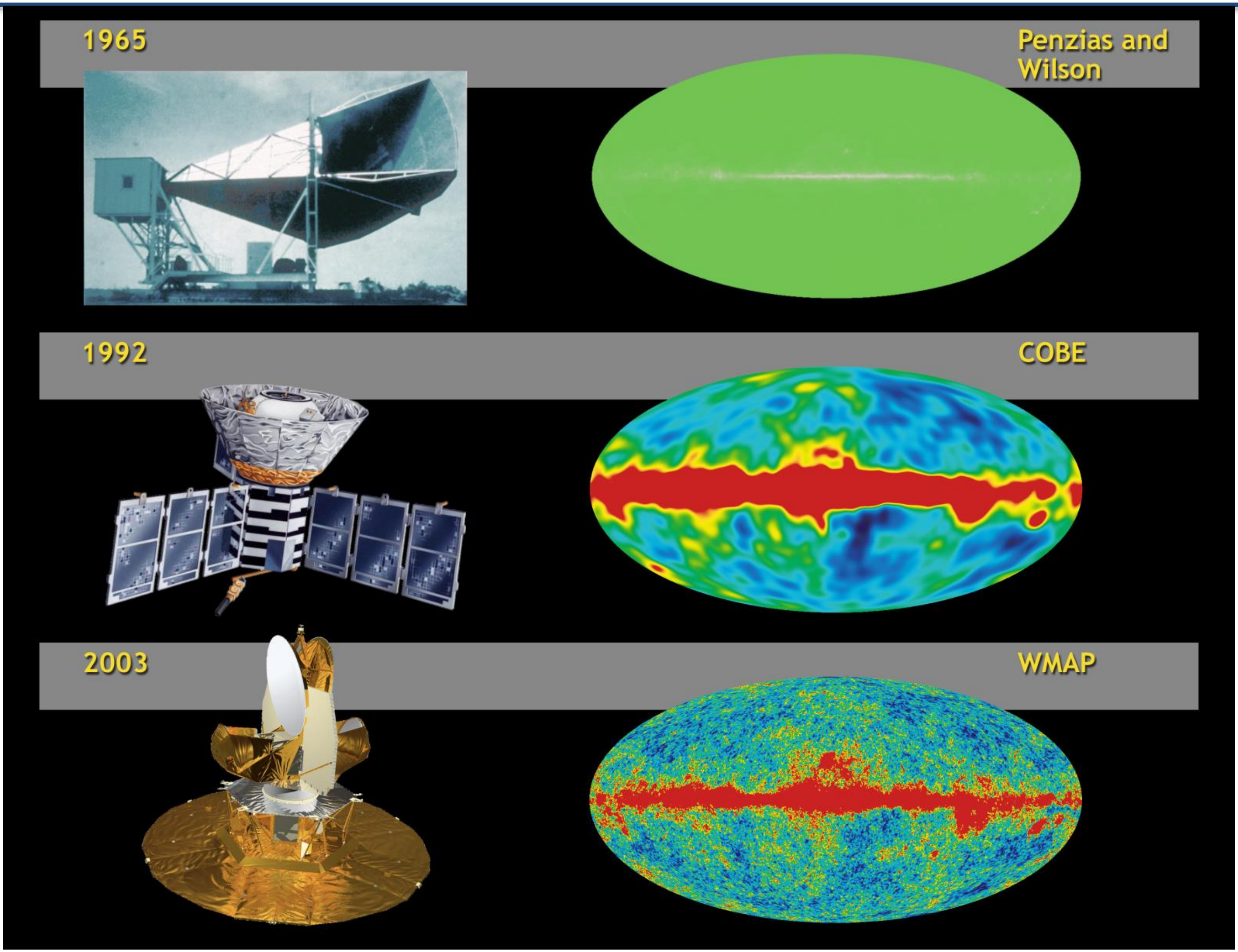


	Yellow star	Red giant	Red supergiant	Massive red supergiant	Supernova
Core Temperature:	1.5×10^7 K	2×10^8 K	7×10^8 K	3×10^9 K	1×10^{11} K
Primary Nuclear Reaction:	^1H fusion	^4He fusion	$^4He + ^{12}C$ $^{12}C + ^{12}C$ $^{12}C + ^{16}O$	Proton–neutron exchange reactions	Multiple neutron captures
Elements Formed:	He	C, O, Ne, Mg	Na, Si, S, Ar, Ca	Fe, Ni	Elements with $Z > 28$



Protostar
Blue Supergiant
Black Hole
Supershell
Protostar
Blue Supergiant
Supernova
Black Hole
Stellar Nursery
Protostar
Blue Supergiant
Red Giant (with stellar winds)
Blue Supergiant
Supernova (with neutron star)
Neutron Star
Stellar Nursery
MASS
Protostar
Solar TYpe Star
Red Giant
Planetary Nebula
White Dwarf
Protostar
Red Dwarf
Red Dwarf
White Dwarf
Protostar
Brown Dwarf
Brown Dwarf
TIME

Provjere Velikog praska: CMB



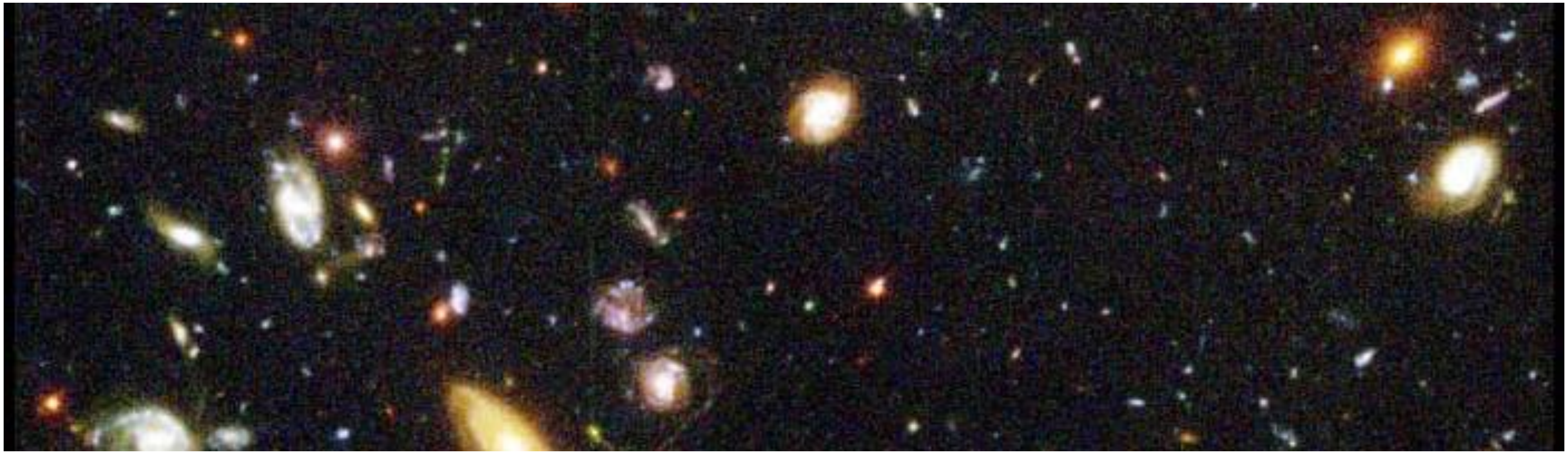
- Za detalje vidi malo kasnije ...

Ali to nije sve ...

- ► Model Velikog praska nije kompletan
- ► Ne objašnjava
  - ▪ Zašto je svemir tako uniforman na velikim skalama?
  - ▪ Zašto je tako neuniforman na malim skalama?
    - • Ili kako su nastale zvijezde i galaksije
- ► Većina kozmologa danas smatra da je odgovor za oba ova pitanja

Teorija inflacije

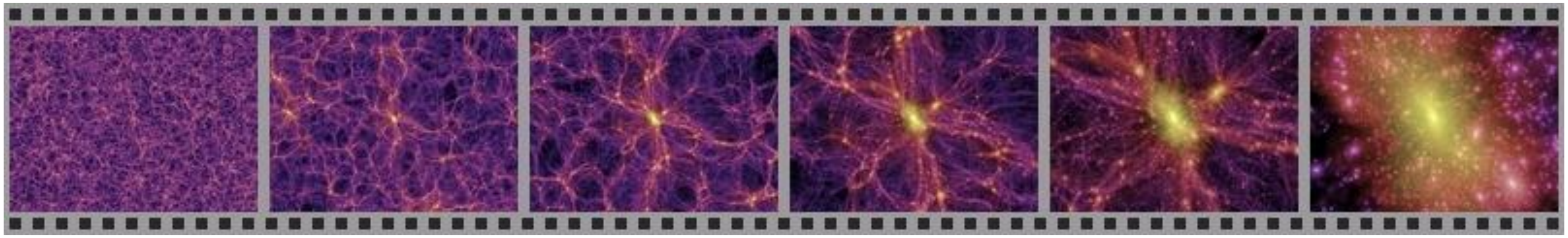
Kako su se pojavile strukture u svemiru?



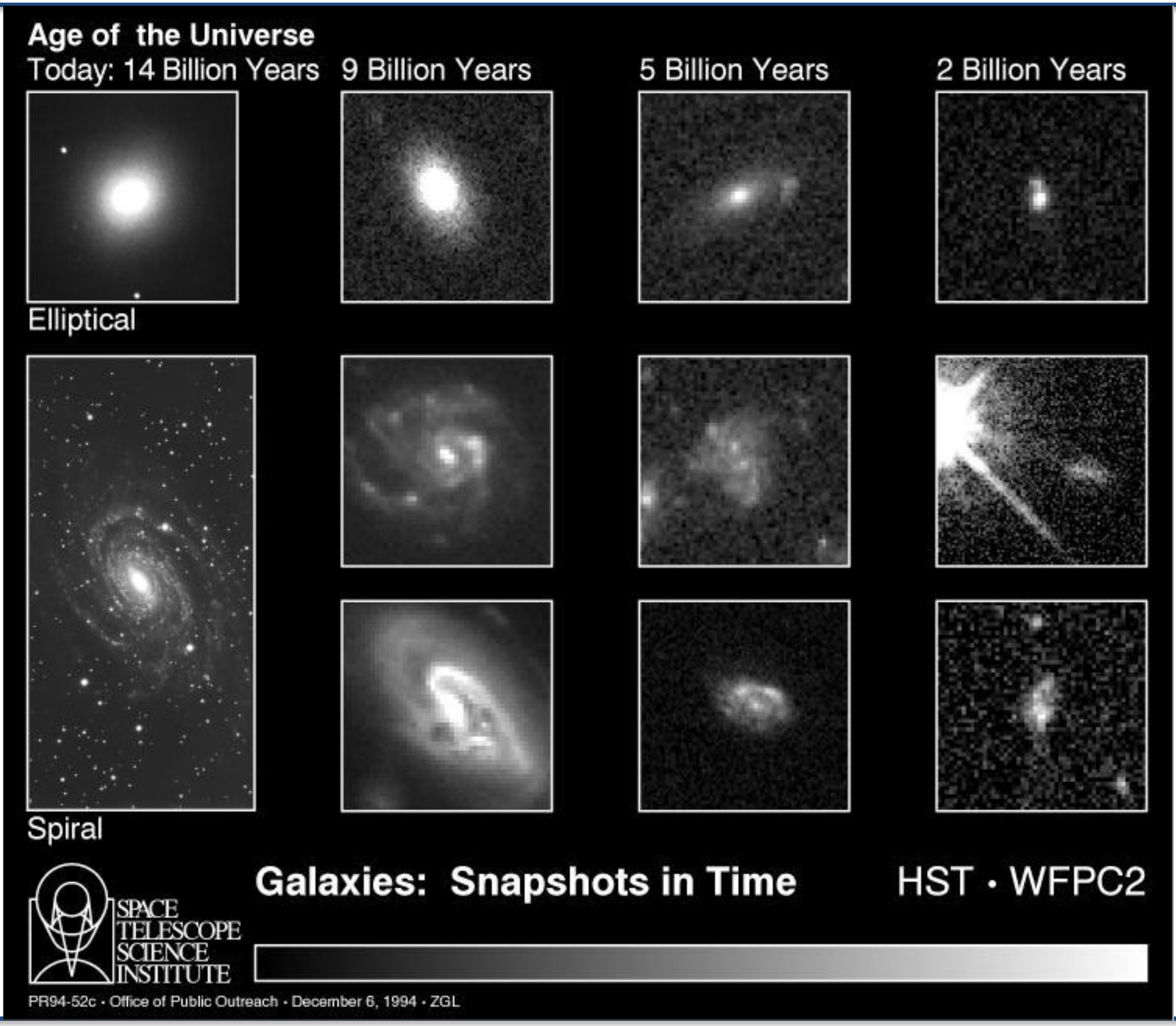
- Većina kozmologa danas smatra da su se strukture u svemiru izrasle iz malih fluktuacija u skoro uniformnom ranom svemiru
- Ove fluktuacije se mogu vidjeti kroz male temperaturne razlike u mikrovalnom pozadinskom zračenju
  - Malo više o ovome nešto kasnije ...
- Što bi moglo proizvesti ovakve fluktuacije?
  - Inflacija
  - Topološki defekti

Gravitacijsko stvaranje struktura

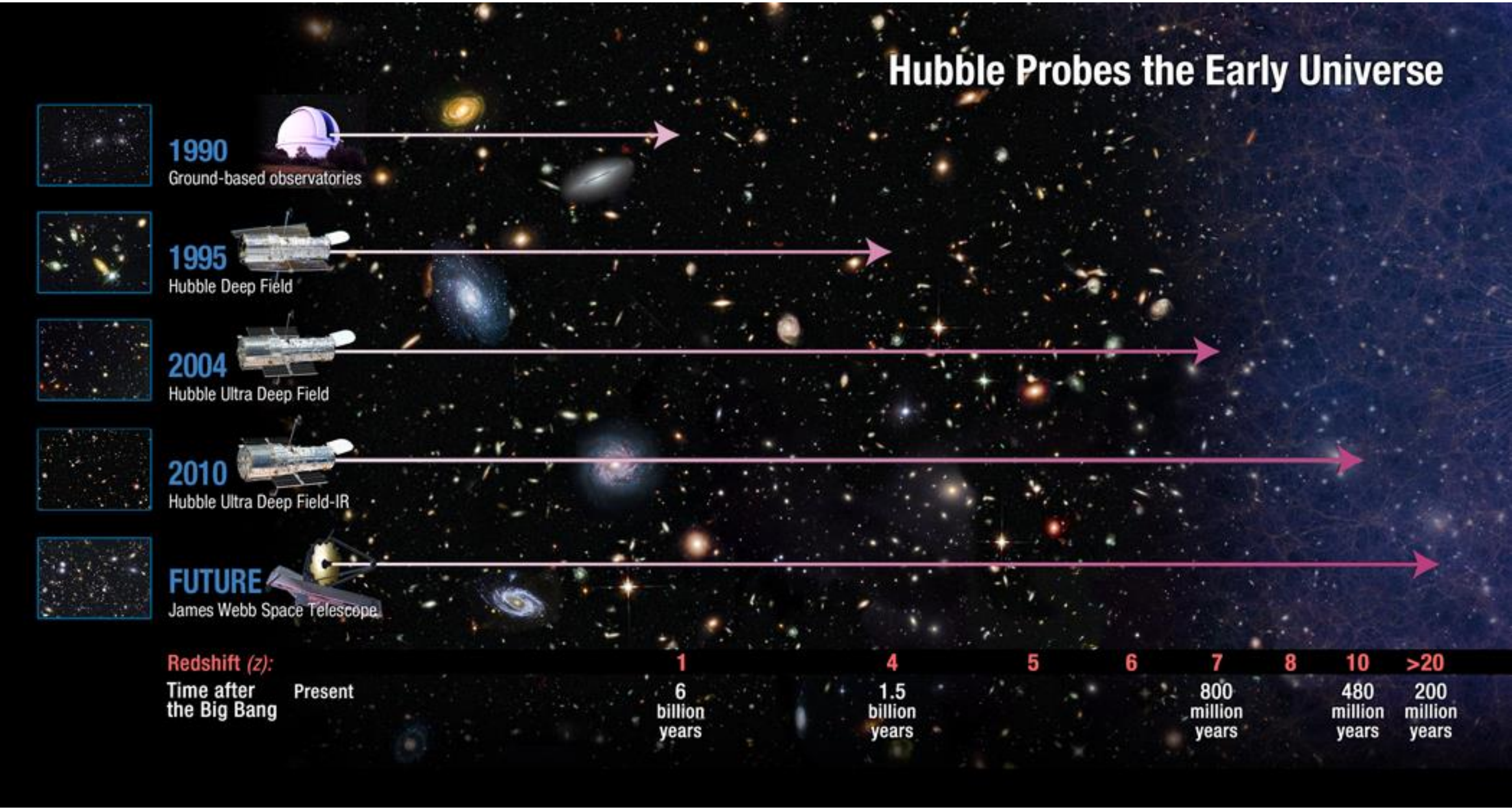
- Kad je svemir bio 1/1000 sadašnje veličine
  - Oko 500 000 godina nakon Velikog praska
  - Gustoća prostora koji sada obuhvaća Mliječnu stazu, bila je možda 0.5% veća od gustoće susjednih područja
  - Zbog toga se ovaj dio prostora širio sporije od susjednih područja
- Kao rezultat ovog sporijeg širenja, razlika u gustoći je još više rasla
- Kad je svemir bio 1/100 sadašnje veličine
  - Oko 15 milijuna godina nakon Velikog praska
  - Napše područje svemira je vjerojatno bilo oko 5% gušće od susjednih područja
- Ovo postupno povećanje razlike u gustoće i dalje se nastavlja kako se svemir širi
- Kad je svemir bio 1/5 sadašnje veličine
  - Oko 1,2 milijarde godine nakon Velikog praska
  - Naše područje svemira je bilo 2 puta gušće od susjednih područja
  - Kozmolozi smatraju da se središnji dio naše galaksije stvorio upravo tada
  - Zvijezde u vanjskim krajevima galaksije su se vjerojatno stvorile kasnije
  - Neki kozmolozi spekuliraju da su neke od galaksije koje smo nedavno vidjeli Hubble Space Telescopeom u biti galaksije u nastajanju



Galaksije kroz vrijeme

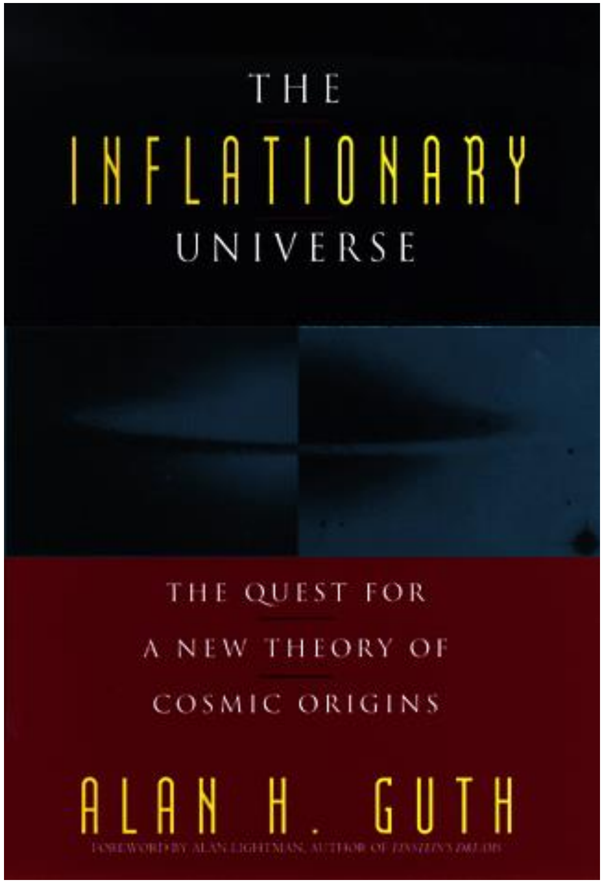


Hubble Space Telescope i rani svemir

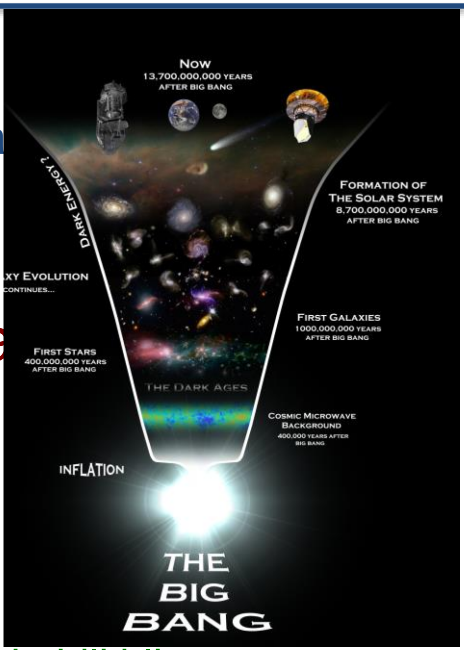


Teorija inflacije

- Osim na pitanje stvaranja struktura u svemiru, daje rješenje i na tri velika problema teorije Velikog praska
  - Problem ravne geometrije svemira
    - Zašto je svemir skoro savršeno ravan, a zbog širenja bi ili trebao biti jako zakrivljen ili su početni uvjeti bili ekstremno dobro podešeni
      - Što je blago-rečeno čudno
  - Problem horizonta
    - Kako su se jako udaljeni dijelovi svemira mogli “dogovoriti” da imaju skoro istu temperaturu, ako ne mogu komunicirati
      - Ili kako je uspostavljena termodinamička ravnoteža u svemiru bez kontakt jednog dijela svemira s drugim
  - Problem magnetskog monopola
    - Kozmologija Velikog praska sugerira velik broj magnetskih monopola
    - Činjenica da još nismo detektirali niti jedan predstavlja ozbiljan problem za model Velikog praska



Kako teorija inflacija rješava ove probleme?



- Inflacija:
  - Praktički odmah nalon početka svemir se u djeliću vremena raširio na ogromne udaljenosti
    - Povećao se za faktor 10^{26}
- Kako to rješava probleme teorije Velikog praska
  - Problem ravne geometrije svemira
    - Zbog brzog širenja bilo koja inicijalna zakrivljenost prostora postaje lokalno skoro ravna
  - Problem horizonta
    - Kako je svemir bio malen, razni sadašnji dijelovi svemira su tada bili blizu
    - Kako se svemir raširio jako brzo i jako puno, ovi dijelovi svemira nisu imali vremena “odgovorit se” i ostali su na veoma bliskoj temperaturi
  - Problem magnetskog monopola
    - Tijekom inflacije gustoća magnetskih monopola opada eksponencijalno, tako da je njihova količina danas zanemariva
- Bonus
  - Objašnjenje strukture svemira preko fluktuacija
  - Povezuje fiziku čestica (kroz fazu lomljenja simetrije) s kozmologijom

Odgovori na neka osnovna pitanja

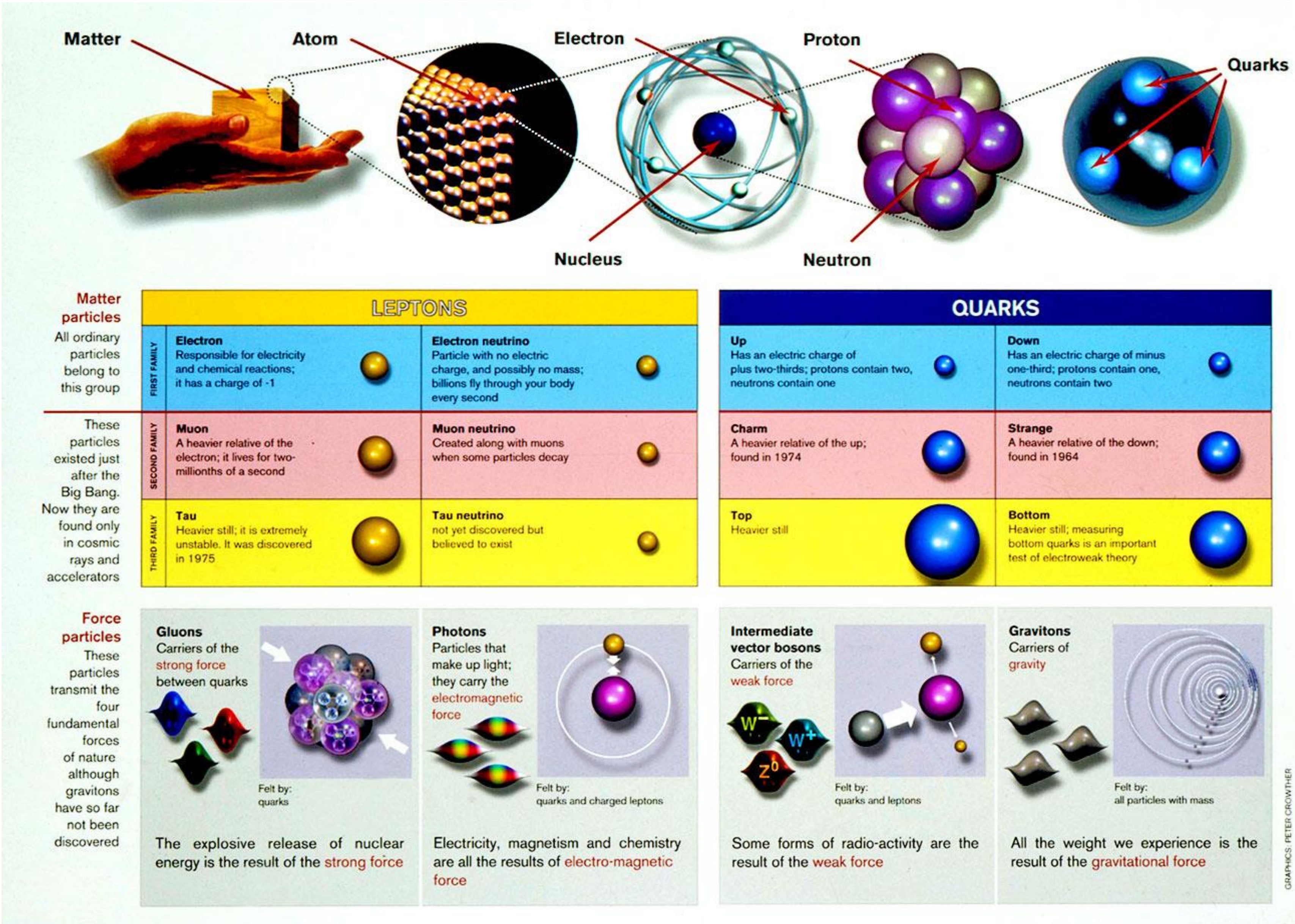
- Do sada smo model Velikog praska opisivali općenito:
  - Na najvećoj mogućoj prostornoj skali svemir izgleda uniformno
  - Trenutno se i dalje širi
  - Postoje jake naznake da je u prošlosti bio vrući i gušći
- Sada ćemo odgovoriti na neka specifična pitanja:
  - **Od čega se sastoji svemir?**
  - **Kako se brzo svemir širi danas?**
  - **Koliko je svemir star?**
  - **Kakav je oblik svemira? Otvoren, ravan, zatvoren ili nešto drugo?**
  - **Kako se brzina širenja svemira mijenja s vremenom?**
  - **Kakva je budućnost svemira?**
- Danas živimo u doba preciznih kozmoloških mjerenja
  - Kroz observacije supernova, galaksija, skupina galaksija, CMB i lakih elemenata

Najvažnija neodgovorena pitanja

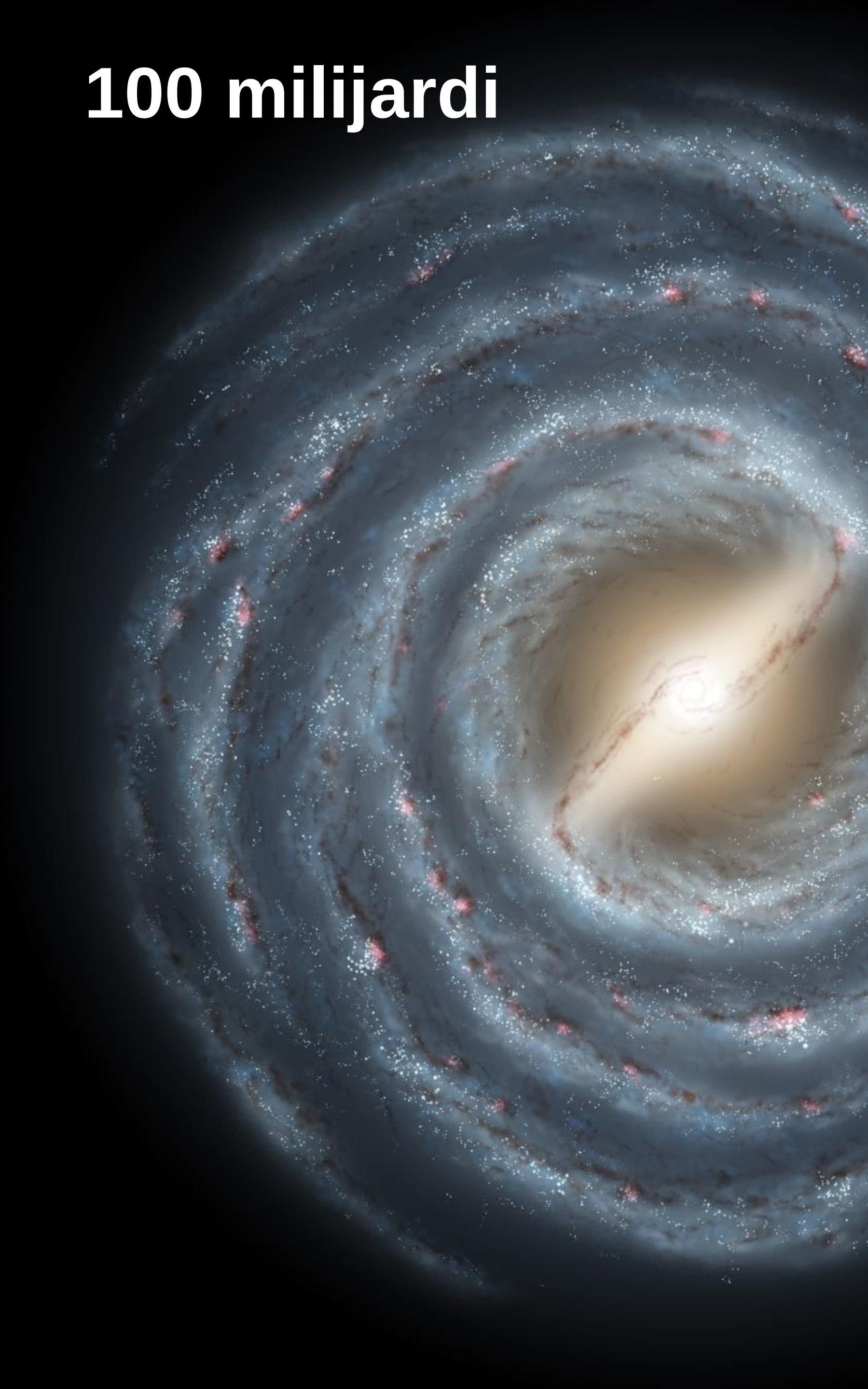
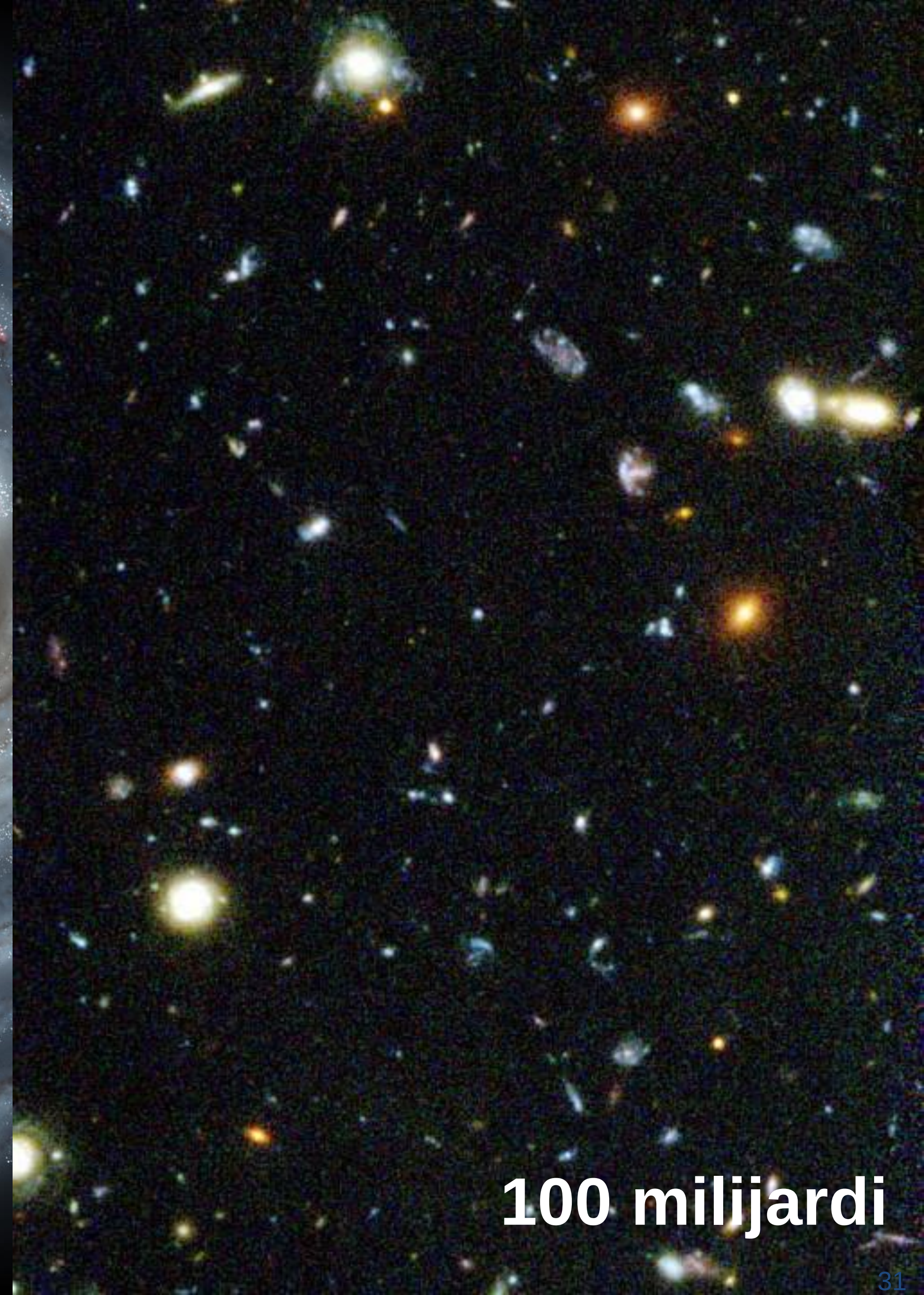
- Pitanje broj 1

Od čega se sastoji svemir?

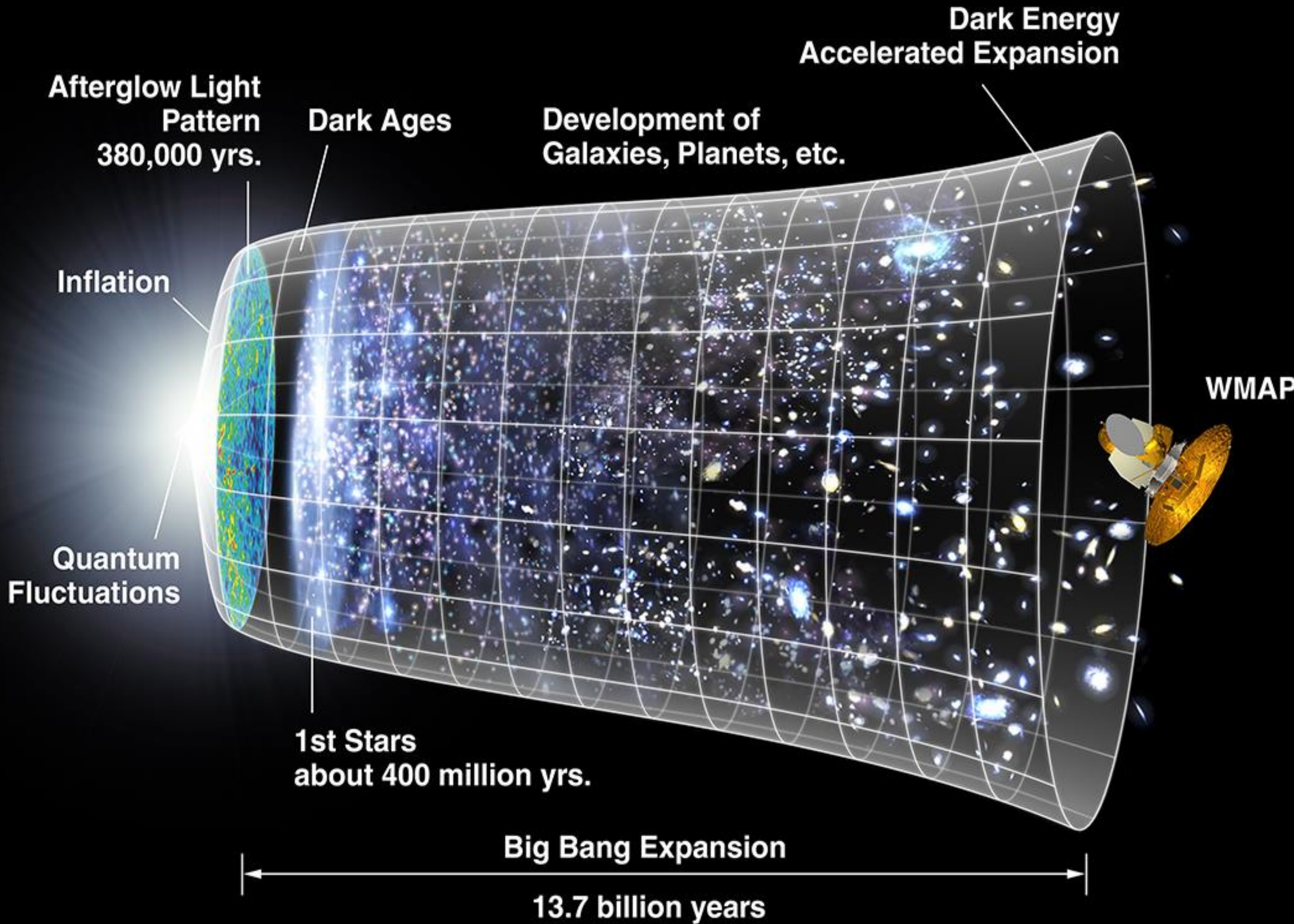
Što znamo?

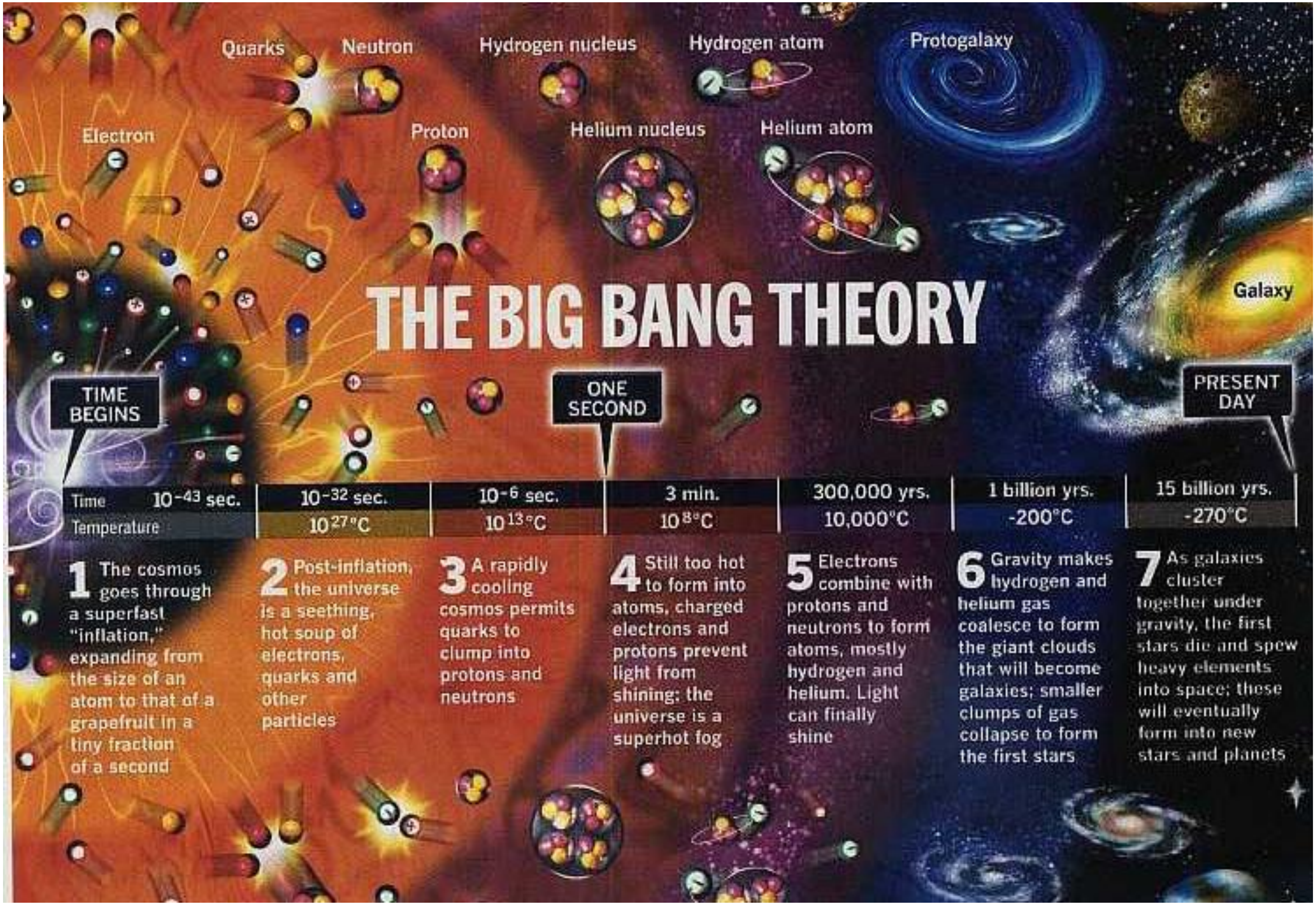


Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron
Matter particles
All ordinary particles belong to this group
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators
LEPTONS
QUARKS
FIRST FAMILY
SECOND FAMILY
THIRD FAMILY
Electron
Responsible for electricity and chemical reactions; it has a charge of -1
Electron neutrino
Particle with no electric charge, and possibly no mass; billions fly through your body every second
Up
Has an electric charge of plus two-thirds; protons contain two, neutrons contain one
Down
Has an electric charge of minus one-third; protons contain one, neutrons contain two
Muon
A heavier relative of the electron; it lives for two-millionths of a second
Muon neutrino
Created along with muons when some particles decay
Charm
A heavier relative of the up; found in 1974
Strange
A heavier relative of the down; found in 1964
Tau
Heavier still; it is extremely unstable. It was discovered in 1975
Tau neutrino
not yet discovered but believed to exist
Top
Heavier still
Bottom
Heavier still; measuring bottom quarks is an important test of electroweak theory
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered
Gluons
Carriers of the strong force between quarks
Felt by: quarks
The explosive release of nuclear energy is the result of the strong force
Photons
Particles that make up light; they carry the electromagnetic force
Felt by: quarks and charged leptons
Electricity, magnetism and chemistry are all the results of electro-magnetic force
Intermediate vector bosons
Carriers of the weak force
W−
W+
Z0
Felt by: quarks and leptons
Some forms of radio-activity are the result of the weak force
Gravitons
Carriers of gravity
Felt by: all particles with mass
All the weight we experience is the result of the gravitational force
GRAPHICS: PETER CROWTHER


100 milijardi

100 milijardi

Od Velikog praska do današnjeg dana




Quarks
Neutron
Hydrogen nucleus
Hydrogen atom
Protogalaxy
Electron
Proton
Helium nucleus
Helium atom
Galaxy
THE BIG BANG THEORY
TIME BEGINS
ONE SECOND
PRESENT DAY
Time
Temperature
10-43 sec.
10-32 sec.
10 27 °C
10-6 sec.
10 13 °C
3 min.
10 8 °C
300,000 yrs.
10,000°C
1 billion yrs.
-200°C
15 billion yrs.
-270°C
1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second
2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons
4 Still too hot to form into atoms, charged electrons and protons prevent light from shining: the universe is a superhot fog
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine
6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars
7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

10^{-43}s Era kvantne gravitacije

Gravitacije se odvaja kao posebna sila, ostale sile ostaju ujedinjene u jednu (Veliko ujedinjenje)

Pretpostavljamo

t < 10^{-43} s : The Big Bang

The universe is considered to have expanded from a singl point with an infinitely high energy density (infinite temperature). Is there a meaning to the question what existed before the big bang?

t - 10^{-43} s, 10^{32} K (10^{19} GeV, 10^{-34} m) : Gravity "freezes" out

All particle types (quarks, leptons, gauge bosons, and undiscovered particles e.g.Higgs, sparticles, gravitons) and their anti-particles are in a thermal equilibrium (being created and annihilated at equal rate). These coexist with photons (radiation).

Through a phase transition gravity "froze" out and becam distinct in its action from the weak, electromagnetic and strong forces. The other three forces could not be distinguished from one another in their action on quarks and leptons. This is the first instance of the breaking of symmetry amongst the forces.

10^{-35} s Era velikog ujedinjenja

Inflacija prestaje, širenje se nastavlja. Prestaje era velikog ujedinjenja. Jaka i elektroslaba sila počinju se razlikovati.

t 10^{-35} s, 10^{27} K (10^{16} GeV, 10^{32} m) : Inflation

The rate of expansion increases exponentially for a short period. The universe doubled in size every 10^{-34} s. Inflation stopped at around 10^{-32} s. The universe increased in size by a factor of 10^{50} This is equivalent to an object the size of a proton swelling to 10^{19} light years across.

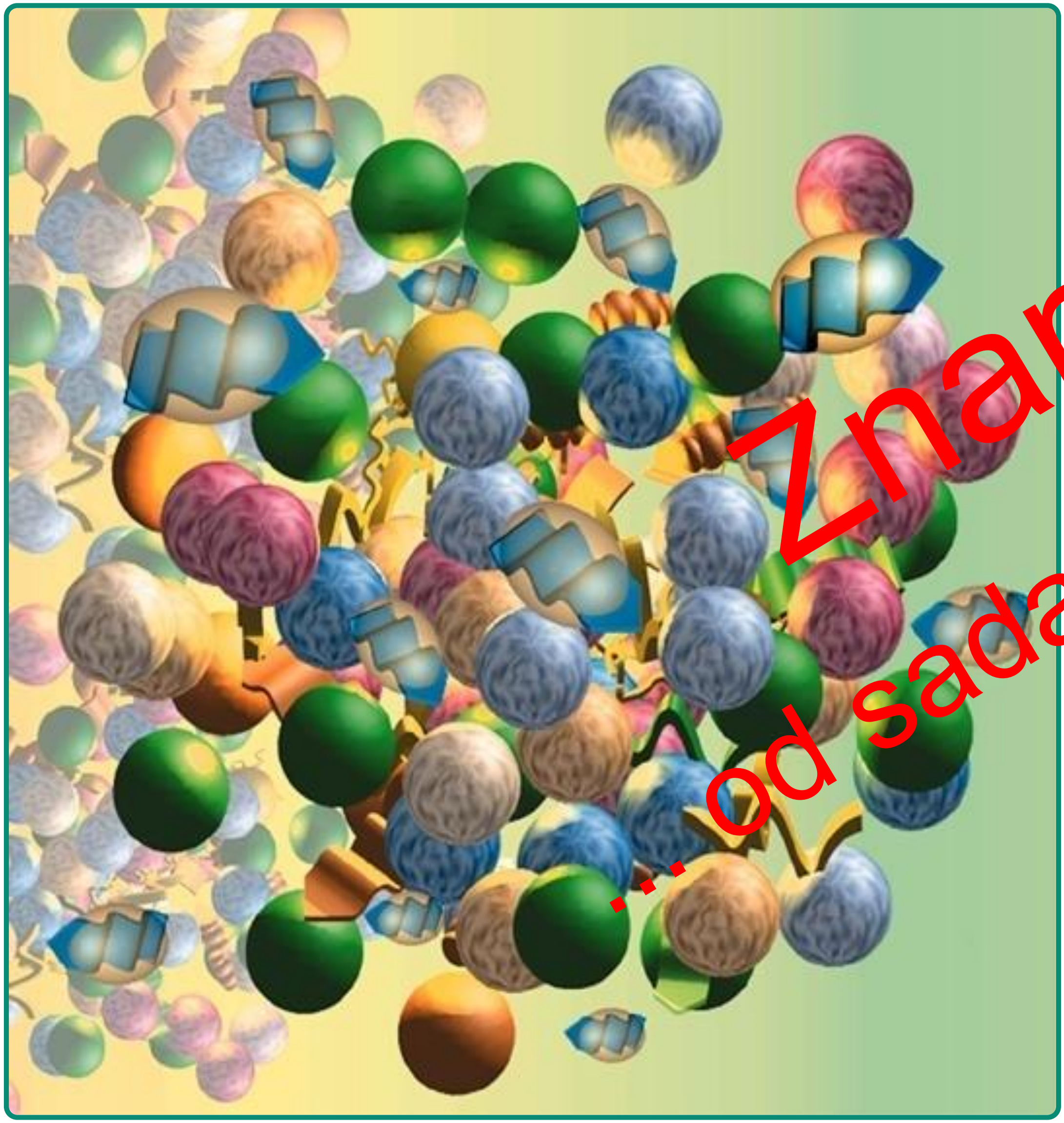
However the presently visible universe was only 3 m in size after inflation. This solves the problems of 'horizon' (how is it possible for two opposing parts of the present universe to be at the same temperature when they cannot have interacted with each other before recombination) and 'flatness' (density of matter is close to the critical density).

t 10 $^{-32}$ s : Strong forces freezes out

Through another phase transition the strong force "freezes" out and a slight excess of matter over anti-matter develops. This excess, at a level of 1 part in a billion, is sufficient to give the presently observed predominance of matter over anti-matter. The temperature is too high for quarks to remain clumped to form neutrons or protons and so exist in the form of a quark gluon plasma. The LHC can study this by colliding together high energy nuclei.

Pretpostavljamo

10^{-10} s Elektroslaba era



Razdvaja se elektroslaba sila

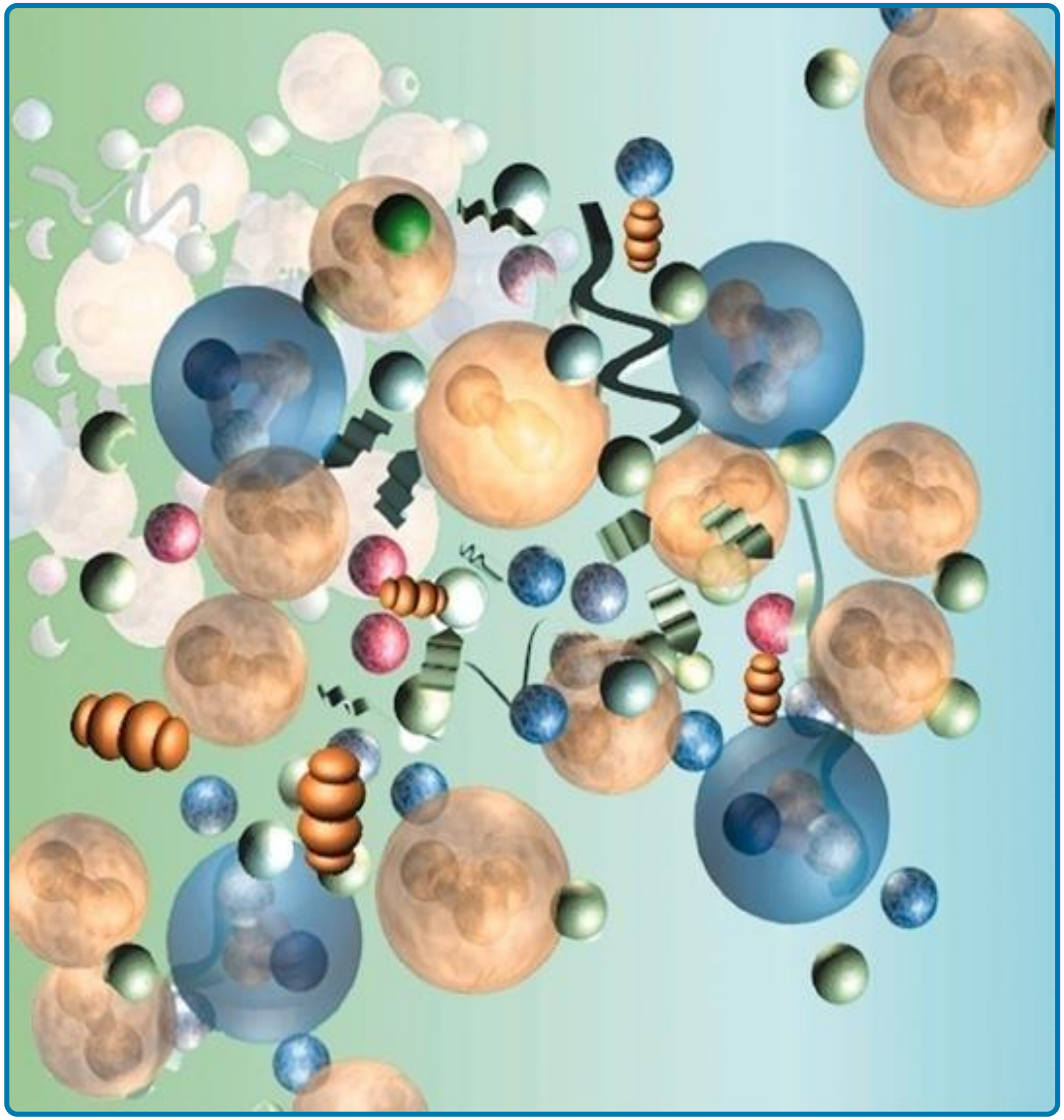
Znamo

... od sada nadalje ...

t - 10^{-10} s, 10^{15} K (100 GeV, 10^{18} m) : Electromagnetic and Weak Forces separate

The energy density corresponds to that at LEP. As the temperature fell the weak force "freezes" out and all four forces become distinct in their actions. The antiquarks annihilate with the quarks leaving a residual excess of matter. W and Z bosons decay. In general unstable massive particles disappear when the temperture falls to a value at which photons from the black-body radiation do not have sufficient energy to create a particle-antiparticle pair.

10^{-4} s Stvaranje protona i neutrona



Kvarkovi se kombiniraju i ujedinjavaju u protone i neutrone

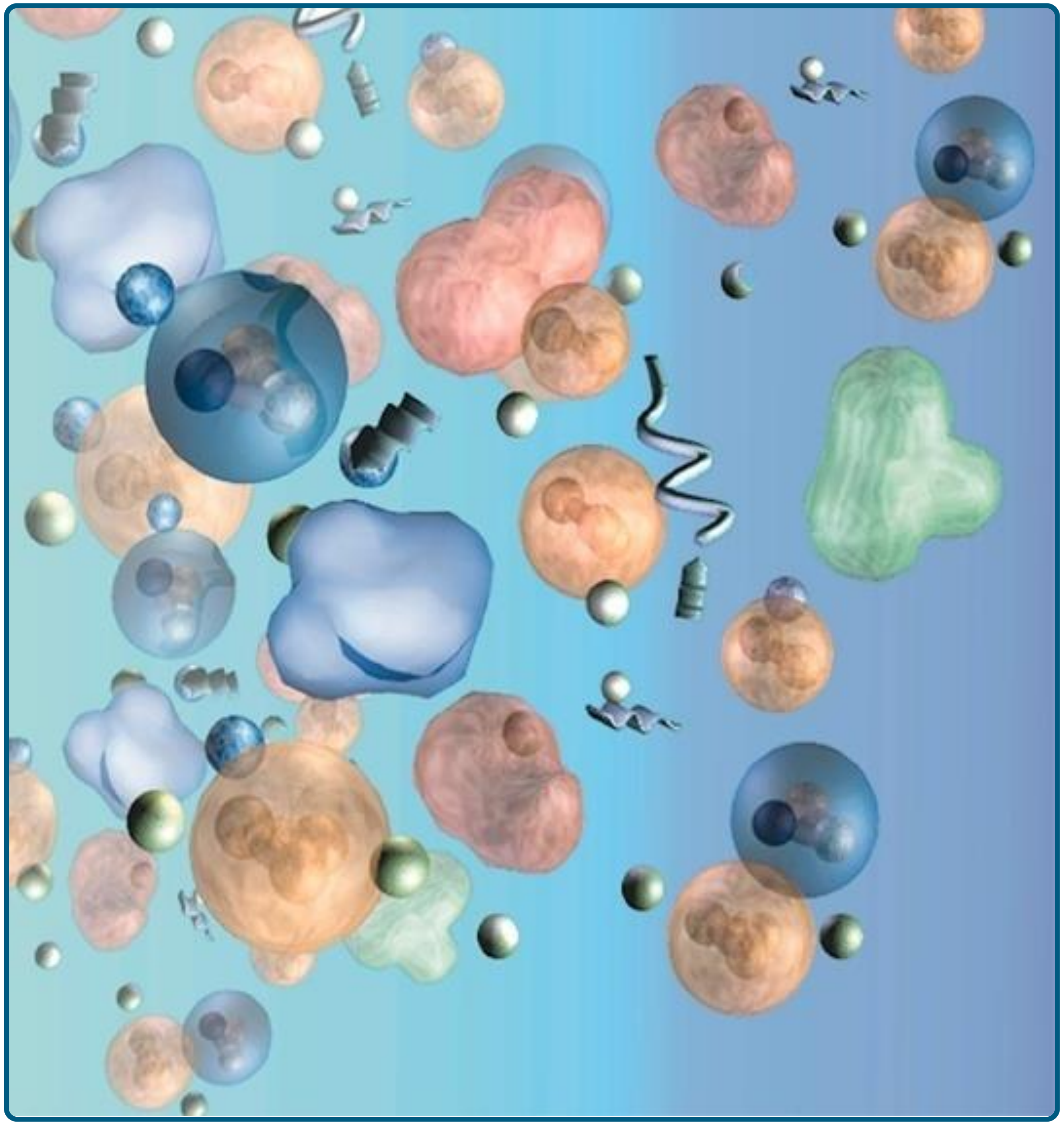
t - 10^{-4} s, 10^{13} K (1 GeV, 10^{-16} m) : Protons and Neutrons form

The universe has grown to the size of our solar system. As the temperature drops quark-antiquark annihilation stops and the remaining quarks combine to make protons and neutrons.

t = 1 s, 10^{10} K (1 MeV, 10^{-15} m) : Neutrinos decouple

The neutrinos become inactive (essentially do not participate further in interactions). The electrons and positrons annihilate and are not recreated. An excess of electrons is left. The neutron-proton ratio shifts from 50:50 to 25:75.

100 s

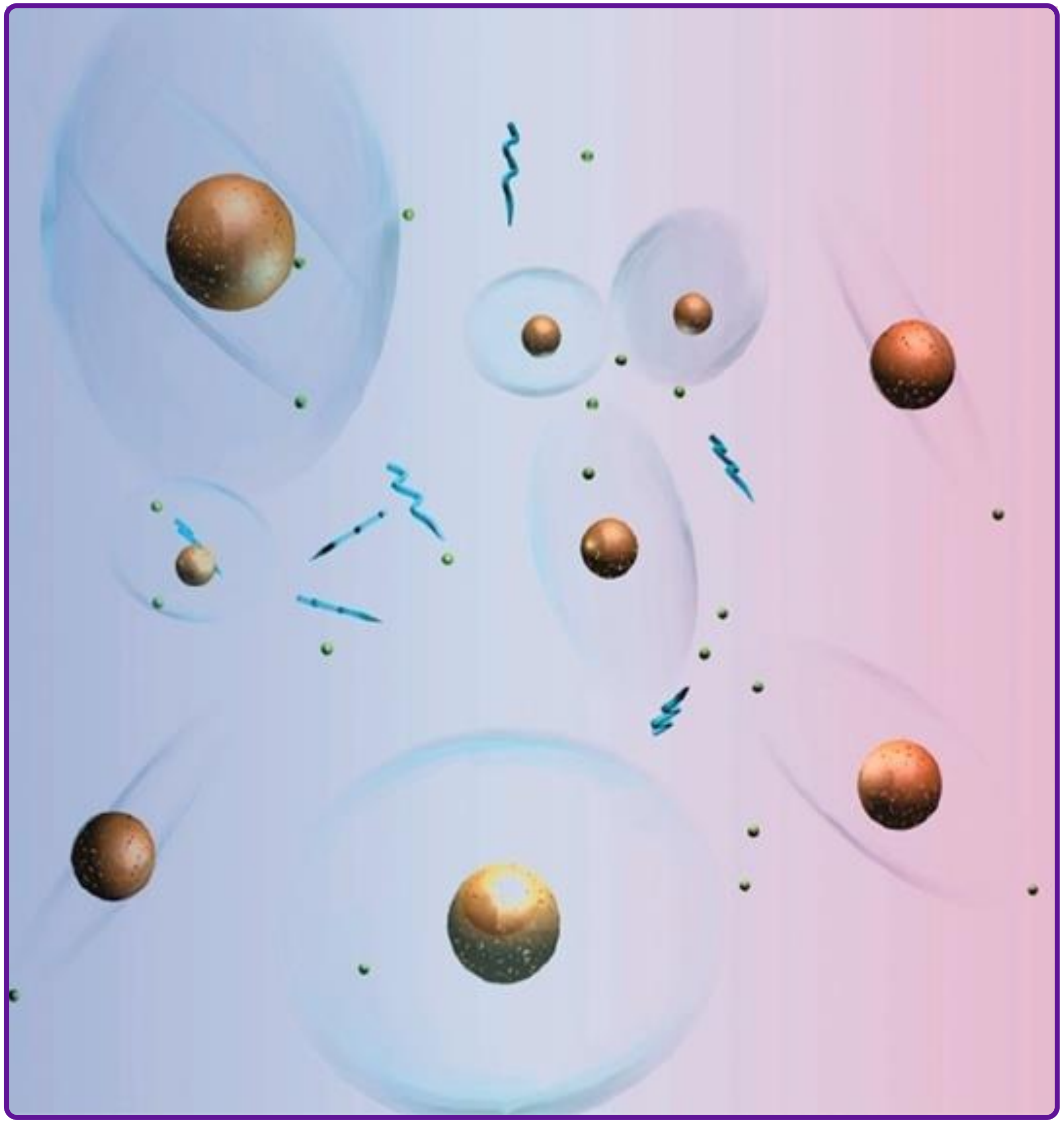


Protoni i neutroni se kombiniraju u jezgru helija

t = 3 minutes, 10^9 K (0.1 MeV, 10^{12} m) : Nuclei are formed

The temperature is low enough to allow nuclei to be formed. Conditions are similar to those that exist in stars today or in thermonuclear bombs. Heavier nuclei such as deuterium, helium and lithium soak up the neutrons that are present. Any remaining neutrons decay with a time constant of ~ 1000 seconds. The neutron-proton ratio is now 13:87. The bulk constitution of the universe is now in place consisting essentially of protons (75%) and helium nuclei. The temperature is still too high to form any atom and electrons form a gas of free particles.

380 000 godina Atomi i era svjetla



Svemir postaje proziran i ispunjen svjetlom

t =380 000 years, 6000 K (0.5 eV, 10^{-10} m) :
Atoms are created

Electrons begin to stick to nuclei. Atoms of hydrogen, helium and lithium are created. Radiation is no longer energetic enou to break atoms. The universe becomes transparent. Matter density dominates. Astronomy can study the evolution of the Universe back to this time.

Milijardu godina

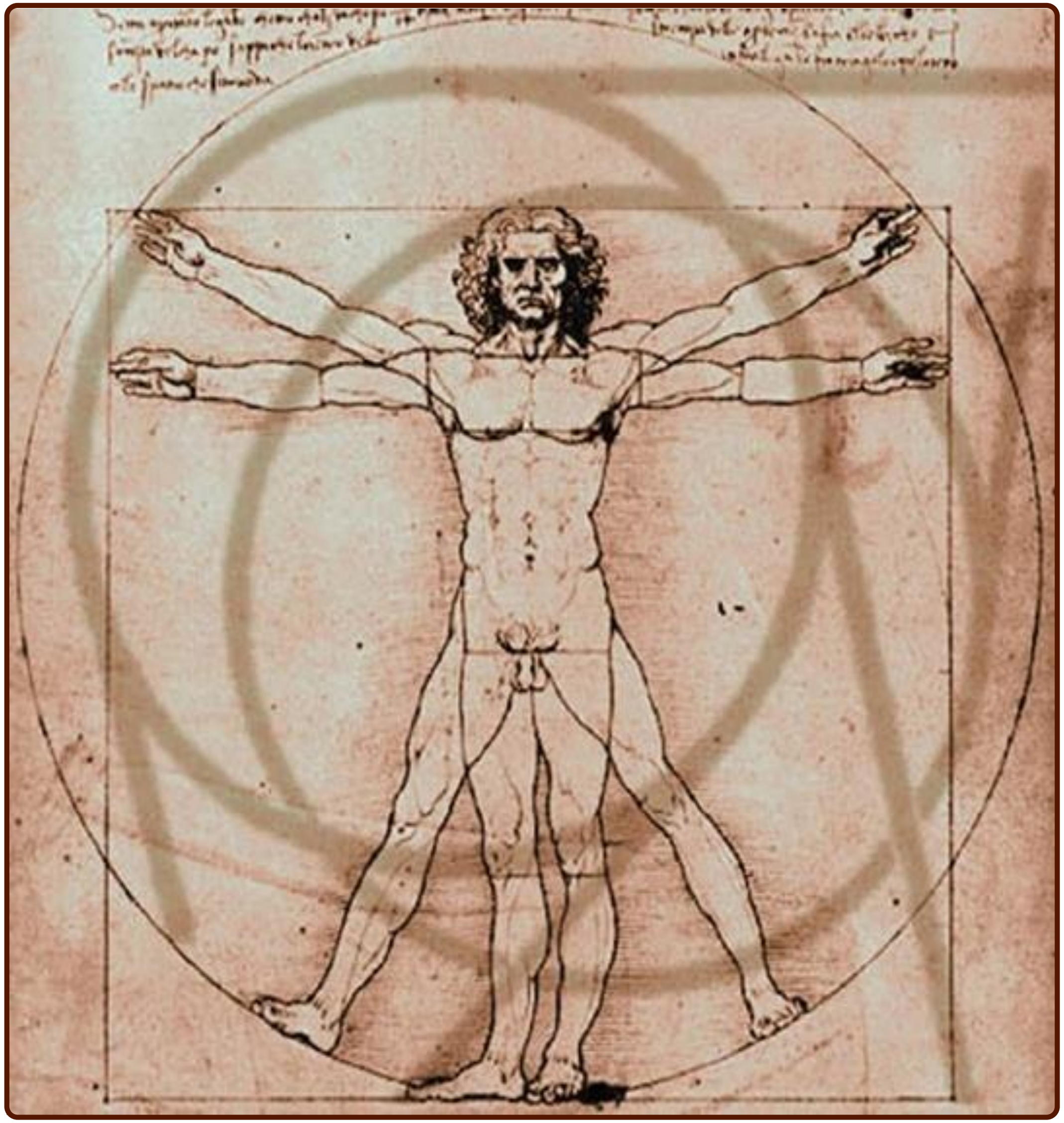
Stvaranje galaksija

Galaksije se počinju stvarati

t = 10^9 years, 18 K : Galaxy Formation

Local mass density fluctuations act as seeds for stellar and galaxy formation. The exact mechanism is still not understood. Nucleosynthesis, synthesis of heavier nuclei such as carbon up to iron, starts occurring in the thermonuclear reactors that are stars. Even heavier elements are synthesized and dispersed in the brief moment during which stellar collapse and supernovae explosions occur.

13,8 milijardi godina Danas

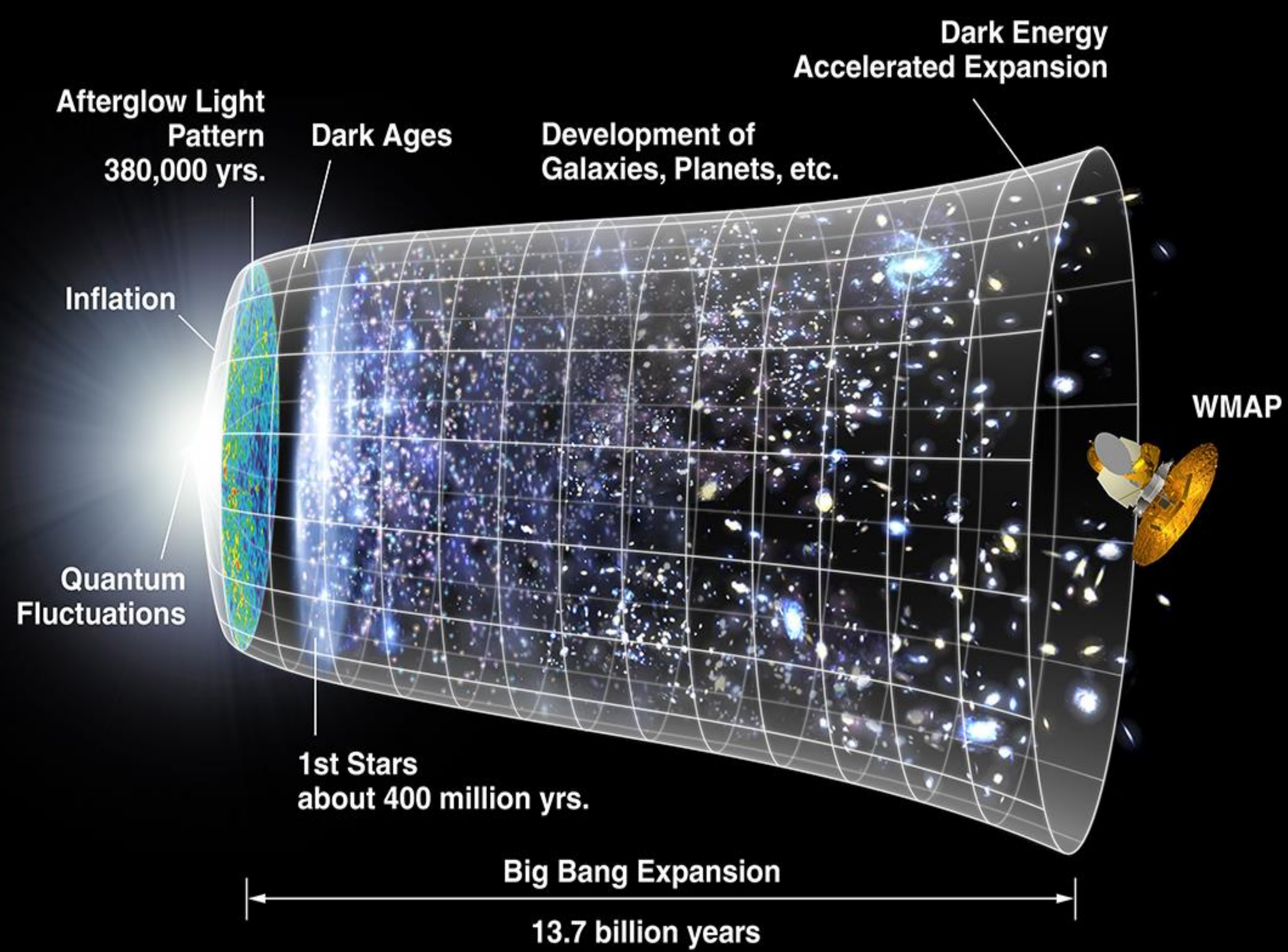


Čovjek se počeo pitati odakle sve ovo!

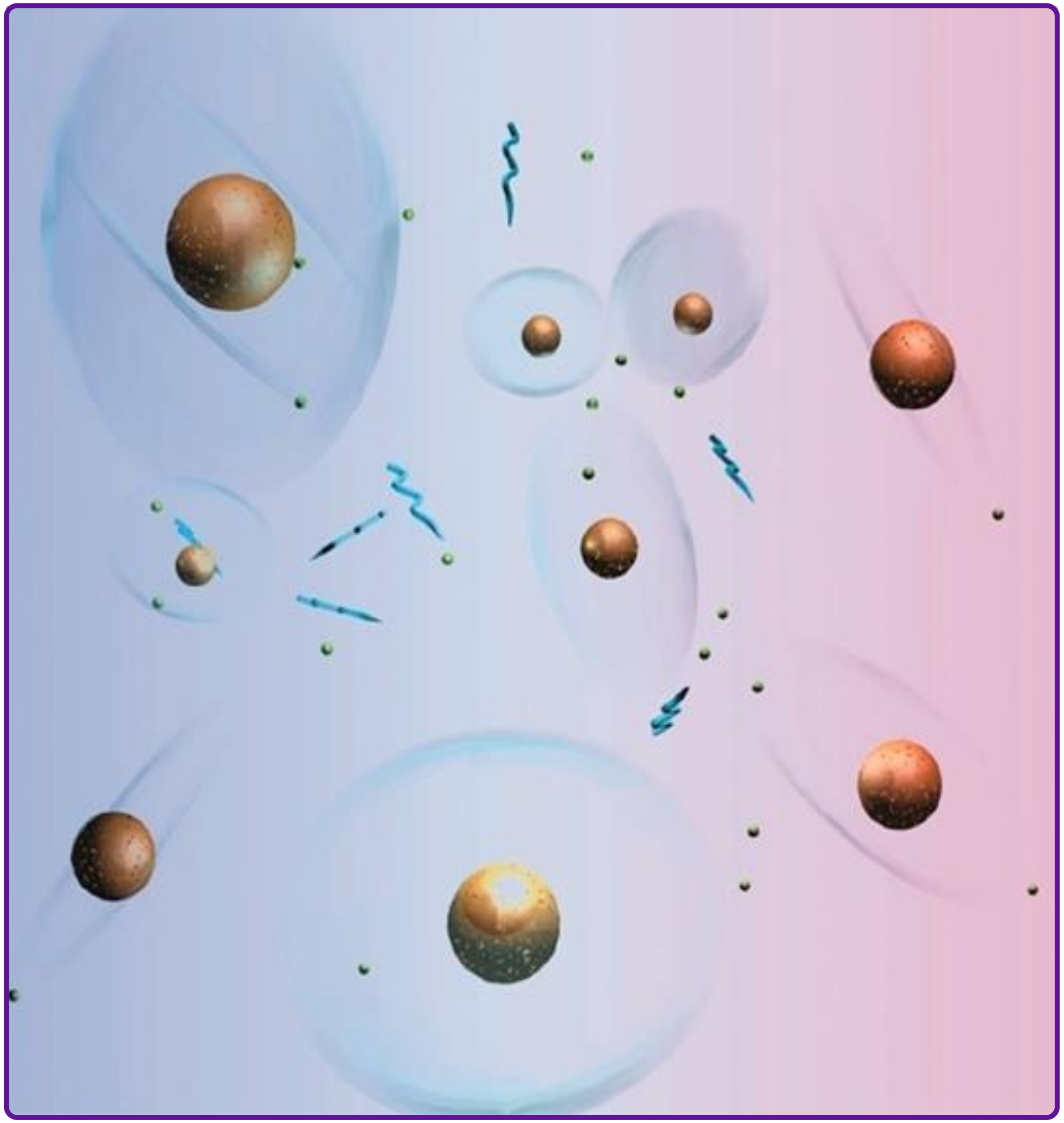
$t = 15 \times 10^9$ years, 3 K : Humans

The present day. Chemical processes have linked atoms to form molecules. From the dust of stars and through coded messages (DNA) humans emerge to observe the universe around them.

Od Velikog praska do današnjeg dana



380 000 godina Atomi i era svjetla



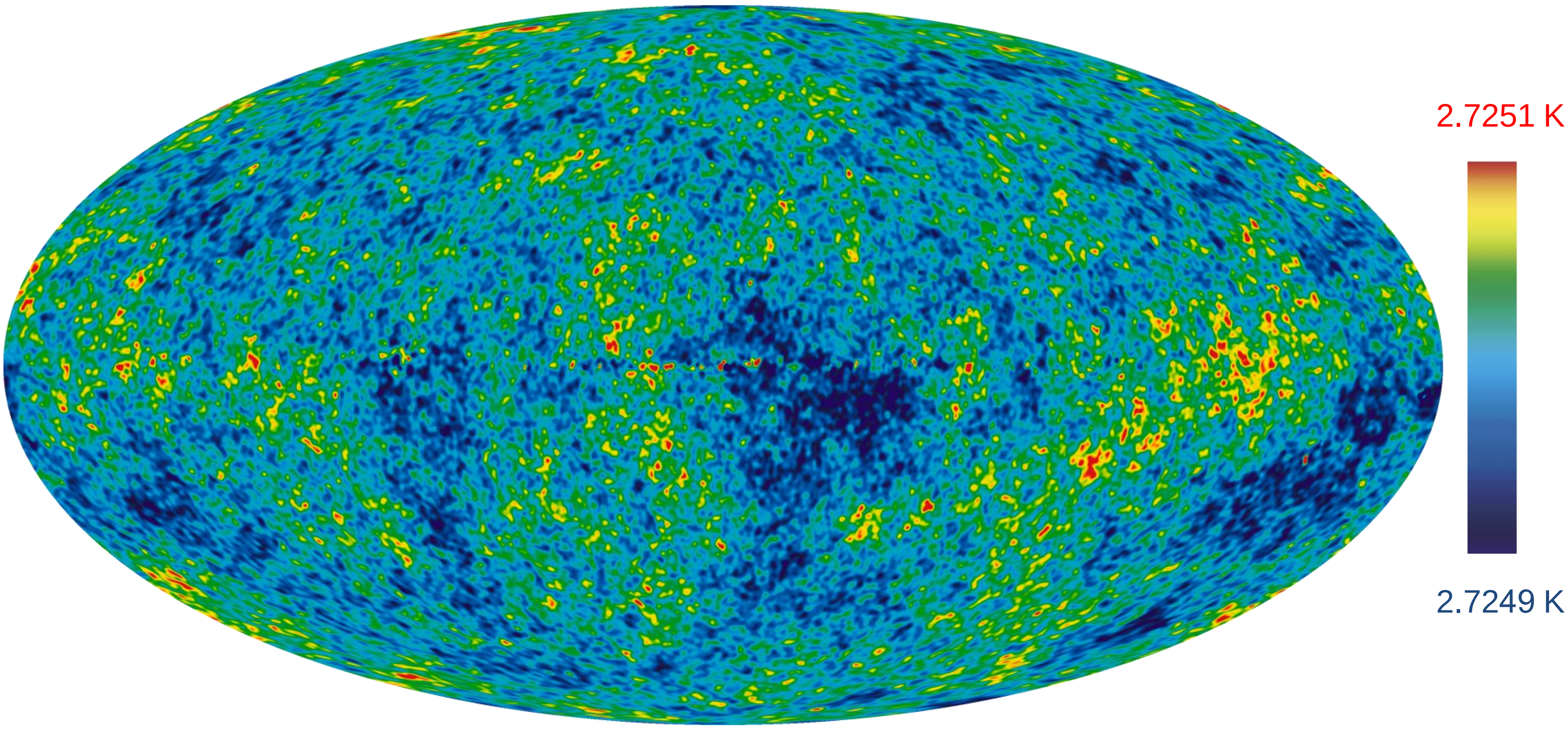
Svemir postaje proziran i ispunjen svjetlom

t =380 000 years, 6000 K (0.5 eV, 10^{-10} m) : Atoms are created

Electrons begin to stick to nuclei. Atoms of hydrogen, helium and lithium are created. Radiation is no longer energetic enoug to break atoms. The universe becomes transparent. Matter density dominates. Astronomy can study the evolution of the Universe back to this time.

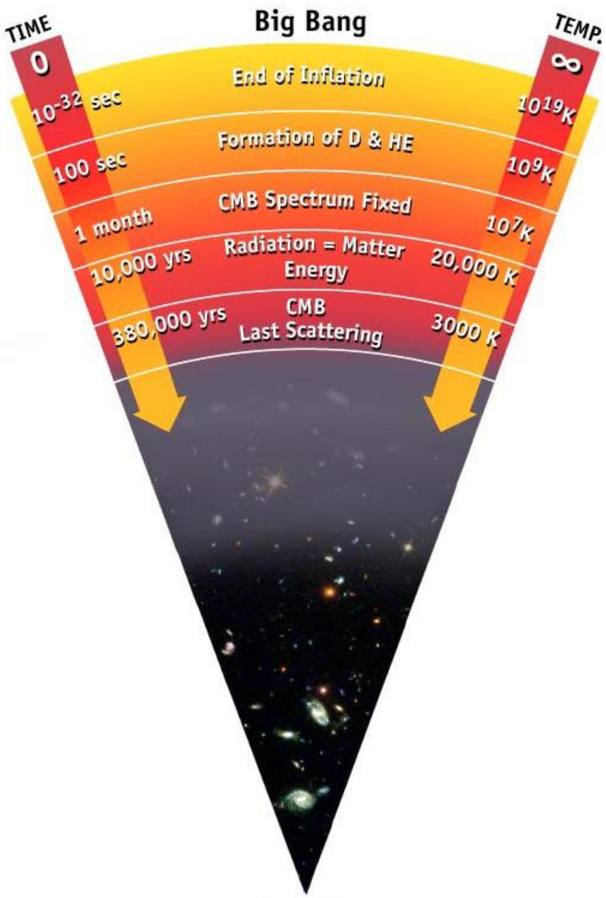
Wilkinson Microwave Anisotropy Probe

WMAP



Ove minijaturne promjene u temperaturi su ozrokovane minijaturnim promjenama gustoće materije na mjestima gdje se svjetlost zadnji put raspršila, kad je svemir bio star 380 000 godina.

Što mi u biti vidimo u WMAP slici?

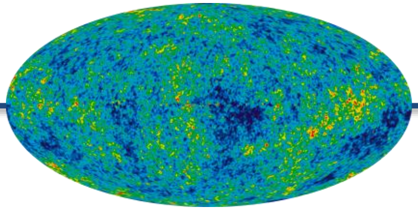


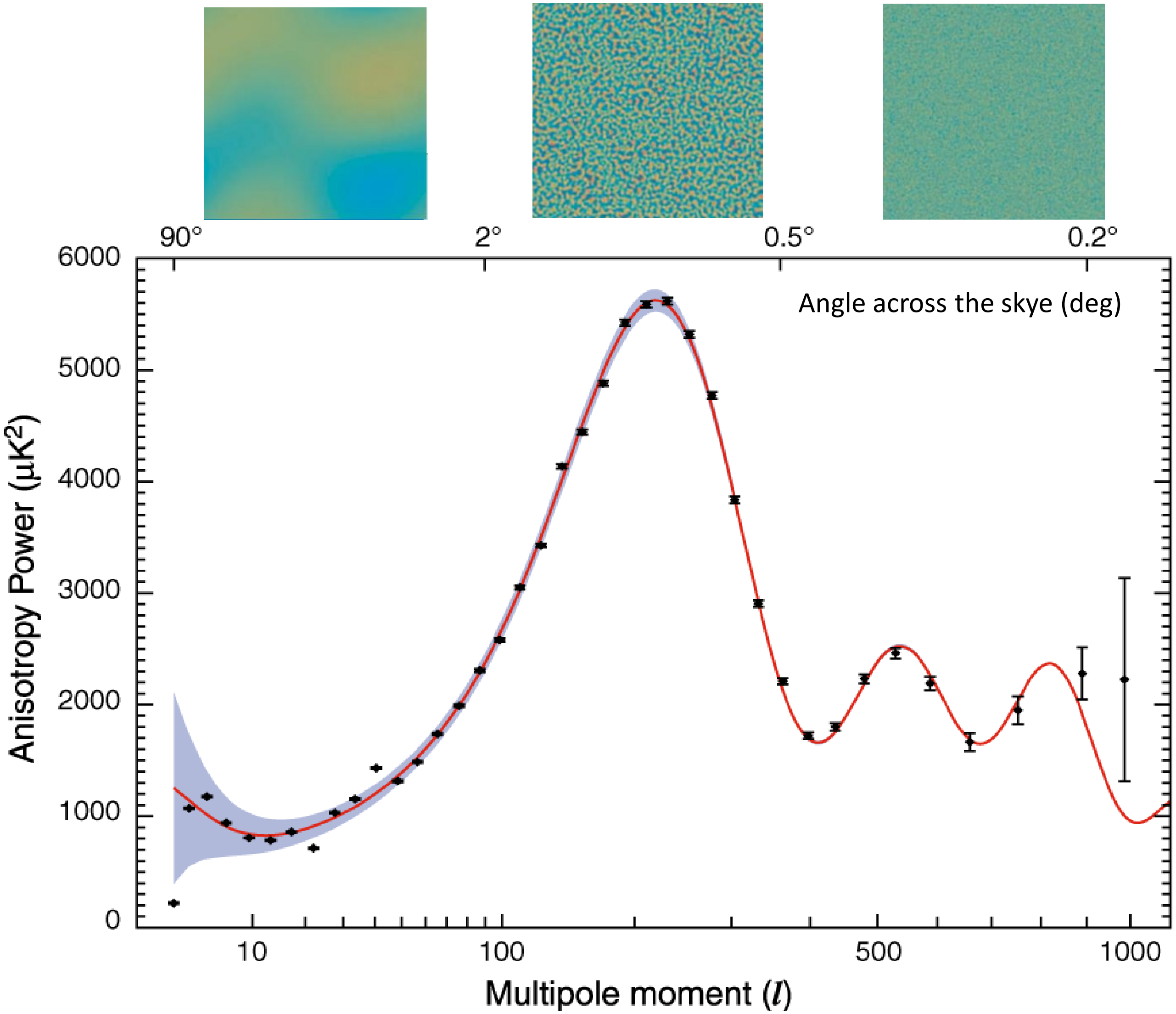
DANAS
13.7 milijardi godina
nakon Velikog praska

Mi možemo vidjeti samo površinu oblaka, tj. mjesto gdje se svjetlo zadnji put raspršilo

"Površina zadnjeg raspršenja" mikrovalnog pozadinskog zračenja je sličan efekt kao površina oblaka. Svjetlo koje dolazi sa Sunca rasprši se od oblaka, i kroz prozirnu atmosferu dolazi do našeg oka.

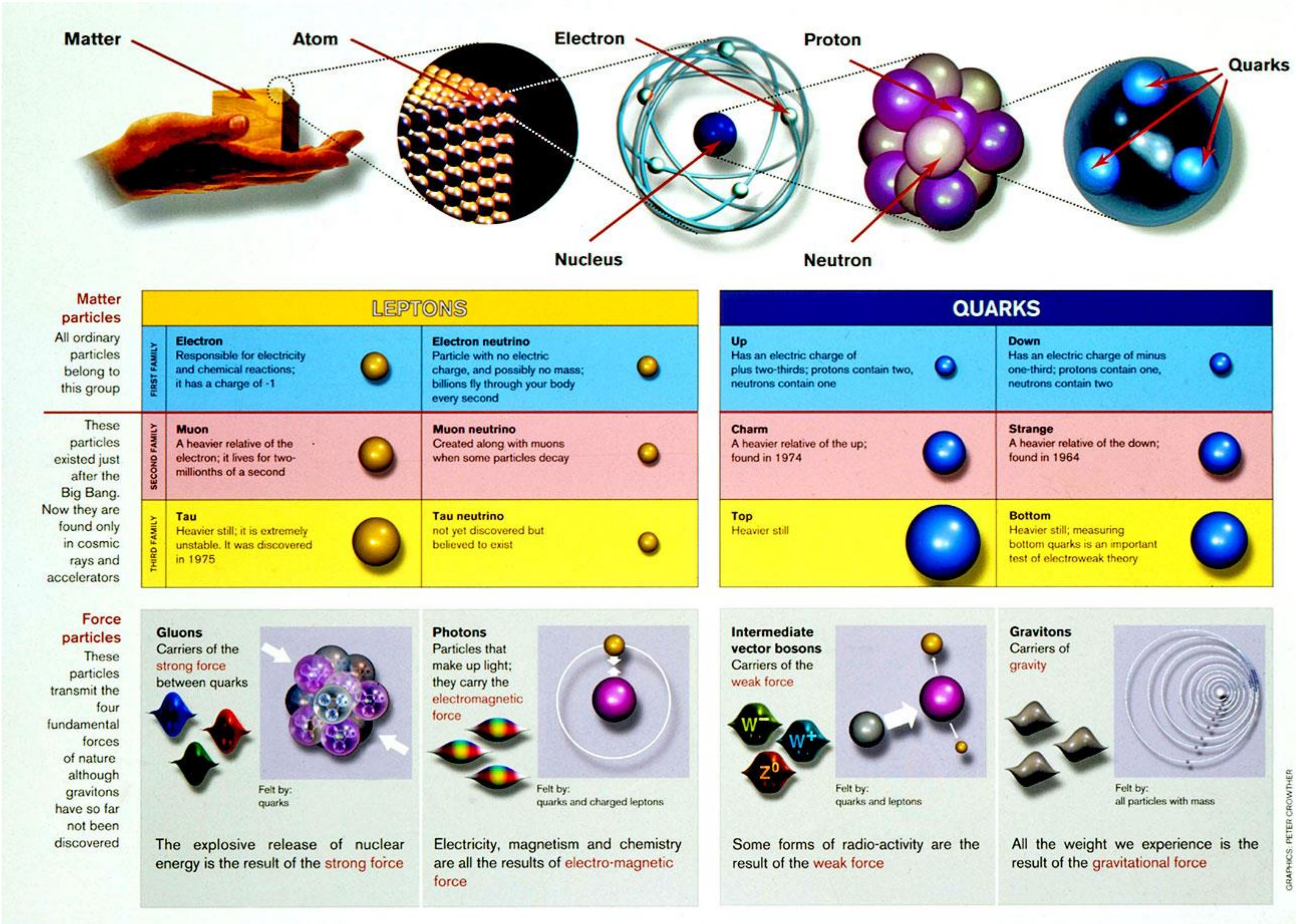
Rezultati mjerenja



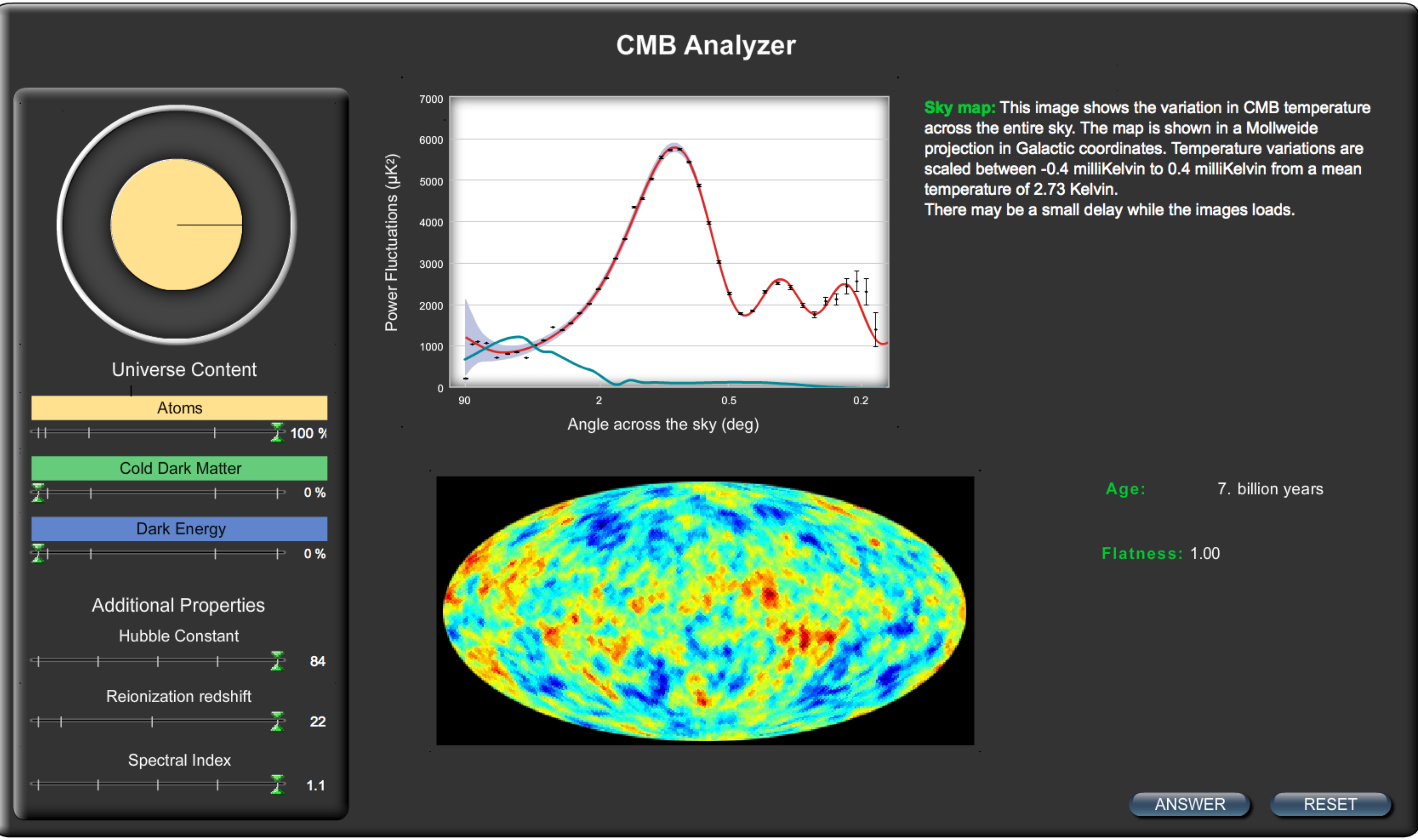


Kako objasniti ove rezultate?

Što znamo?

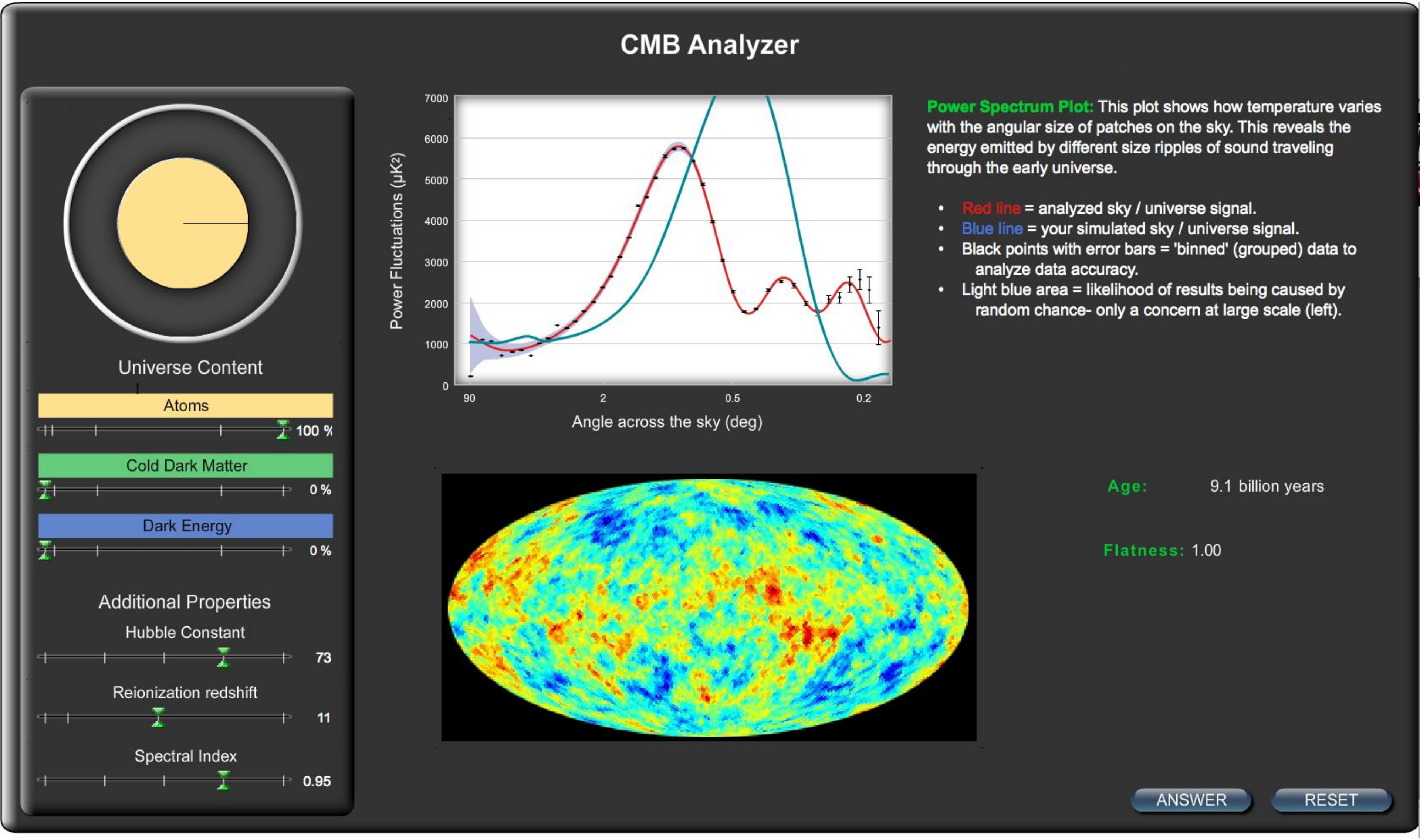

Matter
Atom
Electron
Proton
Quarks
Nucleus
Neutron
Matter particles
All ordinary particles belong to this group
These particles existed just after the Big Bang. Now they are found only in cosmic rays and accelerators
LEPTONS
QUARKS
FIRST FAMILY
SECOND FAMILY
THIRD FAMILY
Electron
Responsible for electricity and chemical reactions; it has a charge of -1
Electron neutrino
Particle with no electric charge, and possibly no mass; billions fly through your body every second
Up
Has an electric charge of plus two-thirds; protons contain two, neutrons contain one
Down
Has an electric charge of minus one-third; protons contain one, neutrons contain two
Muon
A heavier relative of the electron; it lives for two-millionths of a second
Muon neutrino
Created along with muons when some particles decay
Charm
A heavier relative of the up; found in 1974
Strange
A heavier relative of the down; found in 1964
Tau
Heavier still; it is extremely unstable. It was discovered in 1975
Tau neutrino
not yet discovered but believed to exist
Top
Heavier still
Bottom
Heavier still; measuring bottom quarks is an important test of electroweak theory
Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered
Gluons
Carriers of the strong force between quarks
Felt by: quarks
The explosive release of nuclear energy is the result of the strong force
Photons
Particles that make up light; they carry the electromagnetic force
Felt by: quarks and charged leptons
Electricity, magnetism and chemistry are all the results of electro-magnetic force
Intermediate vector bosons
Carriers of the weak force
W−
W+
Z0
Felt by: quarks and leptons
Some forms of radio-activity are the result of the weak force
Gravitons
Carriers of gravity
Felt by: all particles with mass
All the weight we experience is the result of the gravitational force
GRAPHICS: PETER CROWTHER

Izgradite svemir!

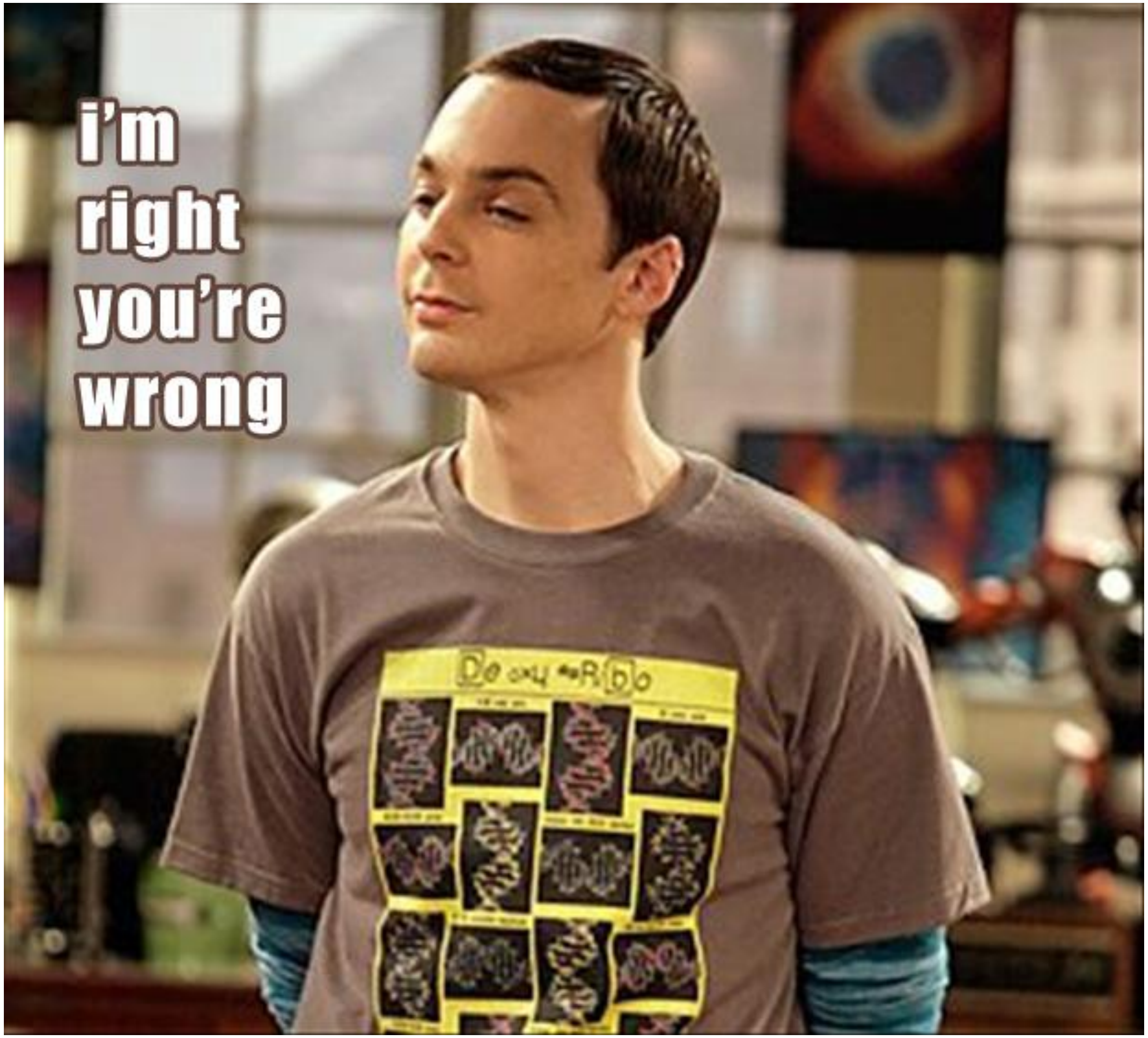


http://map.gsfc.nasa.gov/resources/camb_tool/cmb_plot.swf

Svemir 100% od atoma?

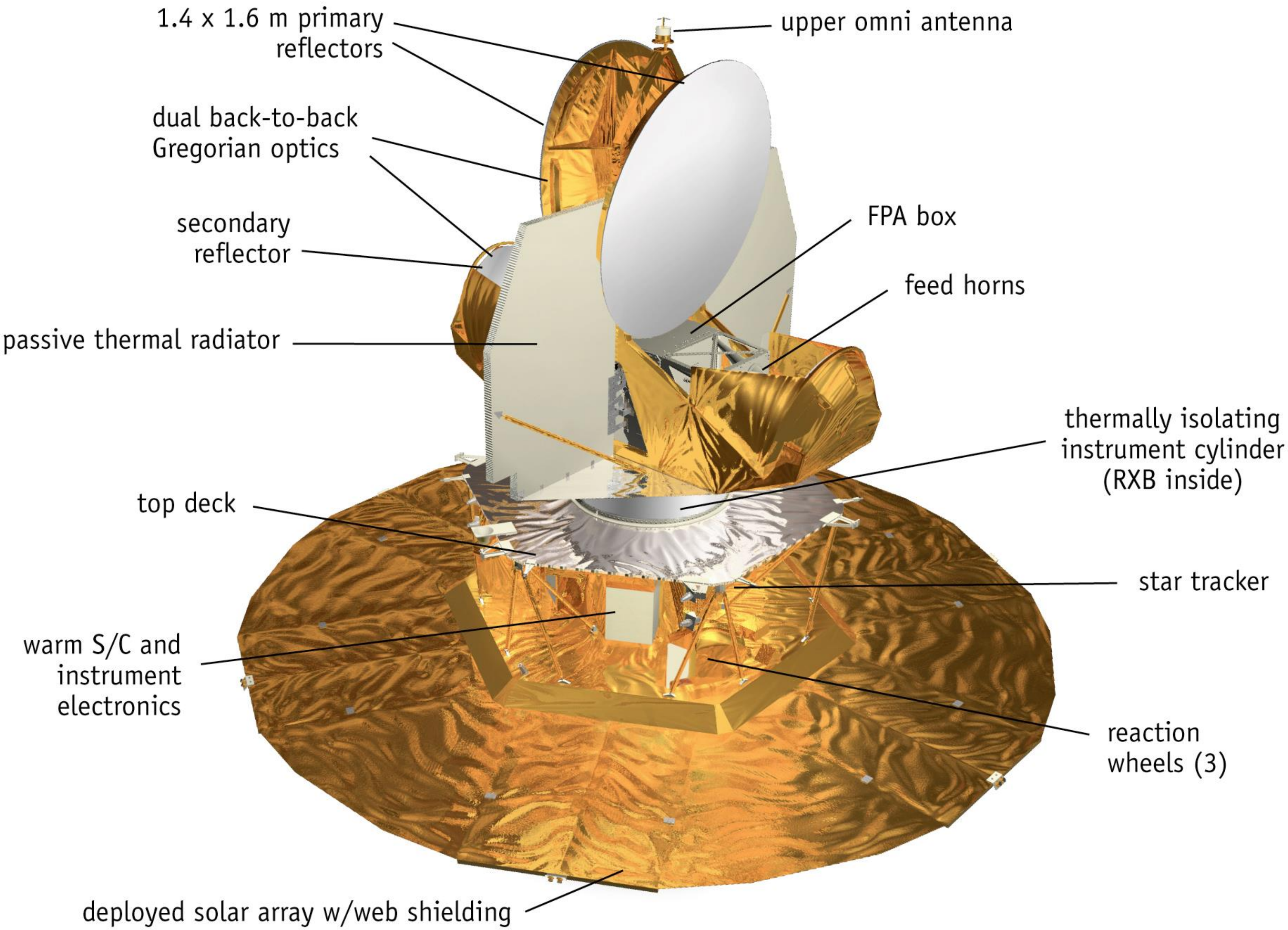


Teorija se ne slaže s eksperimentom!



Je li stvarno ovako?

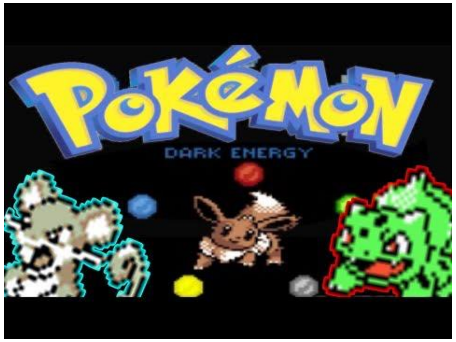
Prva pomisao: vjerojatno je problem s eksperimentom!



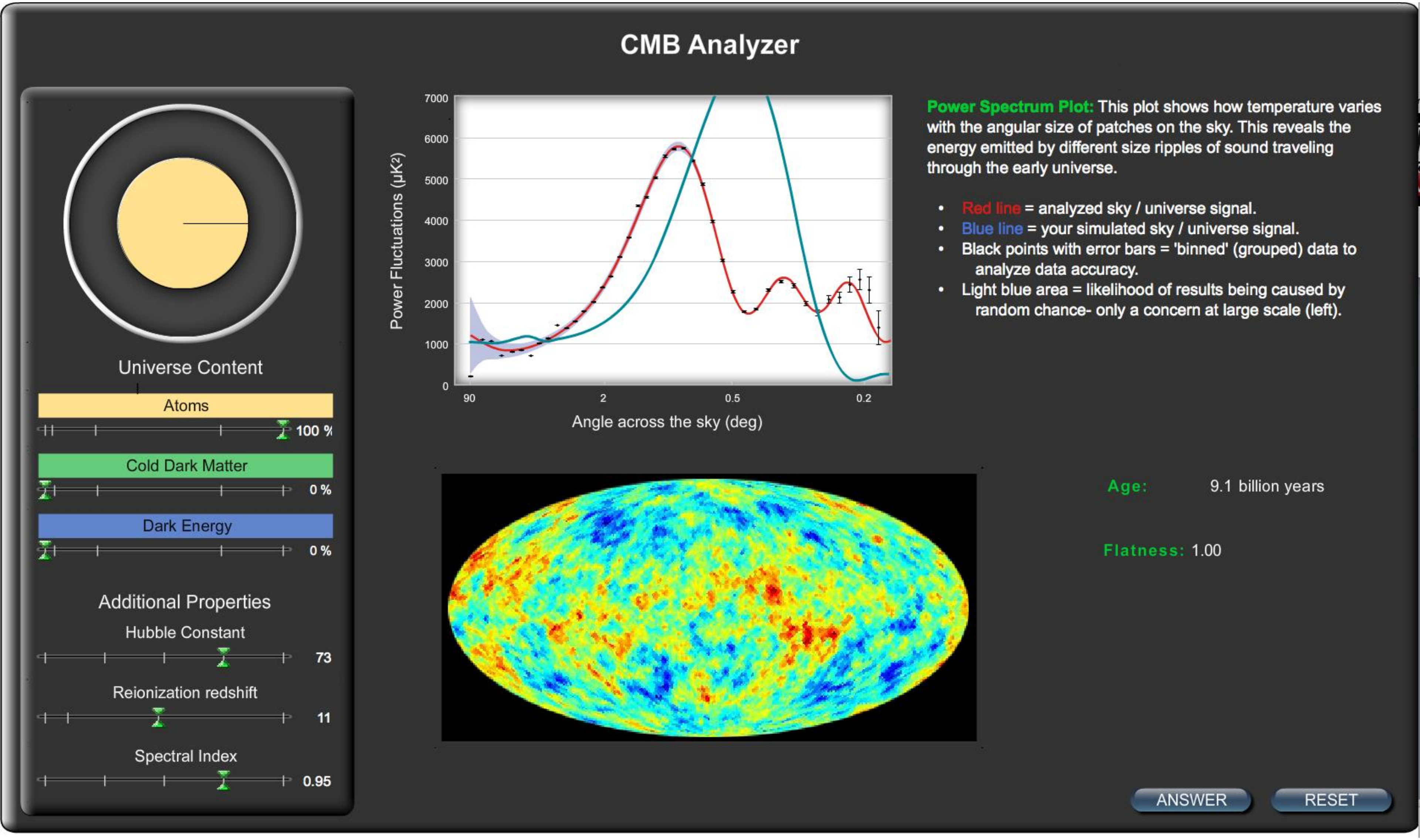
Wilkinson Microwave Anisotropy Probe

Što je još u svemiru osim atoma?

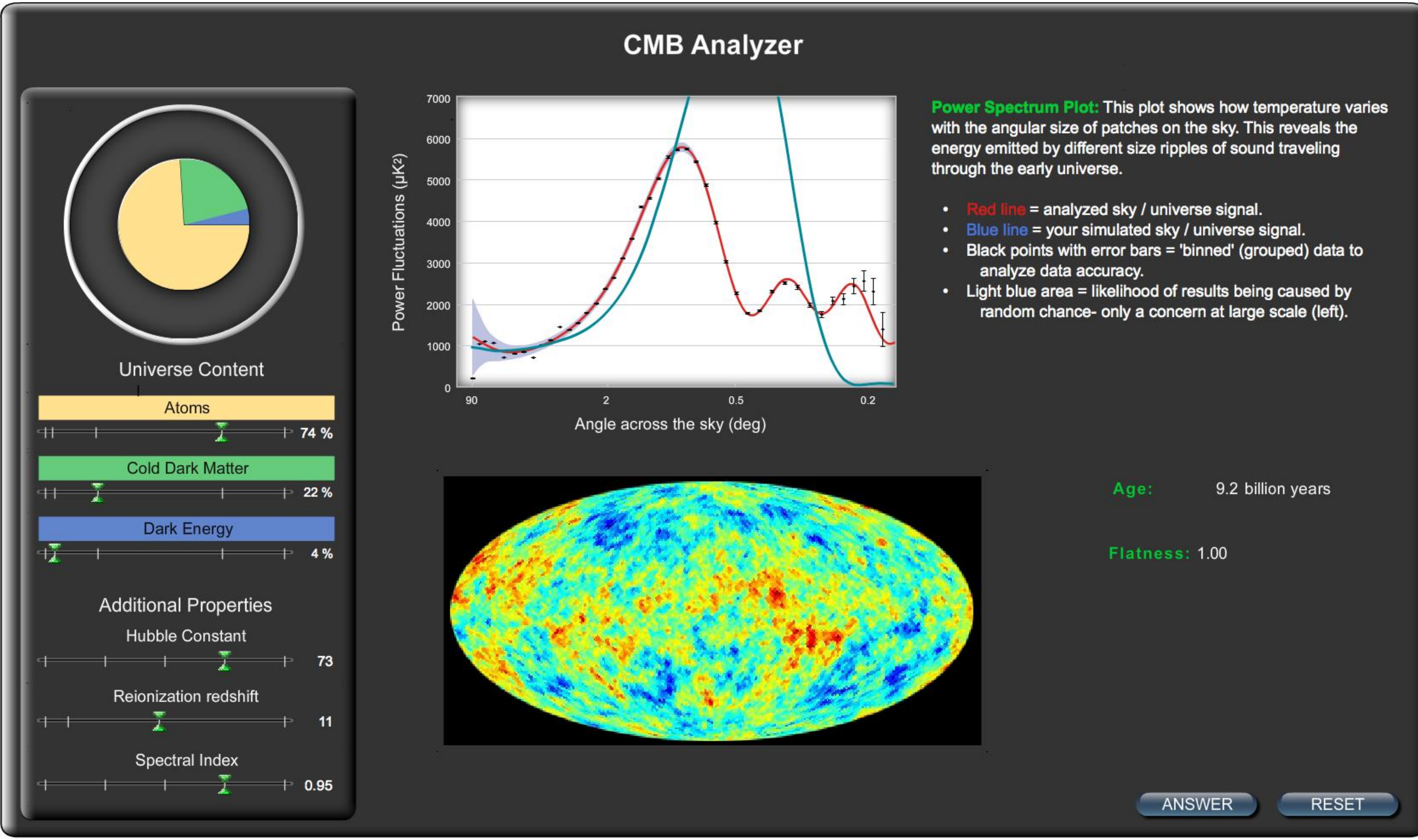
- Nešto što ima svojstva materije, ali ga "ne vidimo"
  - Ili znanstvenije rečeno: nešto što niti emitira niti apsorbira elektromagnetsko zračenje, ali međudjeluje s običnom materijom (tj. atomima) kroz gravitaciju
  - Kraće ime: **TAMNA MATERIJA**
  - Moguće verzije tamne materije
    - **Hladna tamna materija (Cold Dark Matter, CDM)**
      - Massive Compact Halo Objects (MACHO) → malo vjerojatno
      - Neke teške čestice koje još nisu viđene (npr. superimetrične čestice)
    - Topla tamna materija
      - Sterilni neutrini
    - Vruća tamna materija
      - Neutrini
    - Miješana tamna materija
- Nešto što ima svojstva energije, ali ne znamo točno o kojem obliku energije se radi, osim što znamo da uzrokuje širenje svemira
  - Kraće ime: **TAMNA ENERGIJA**



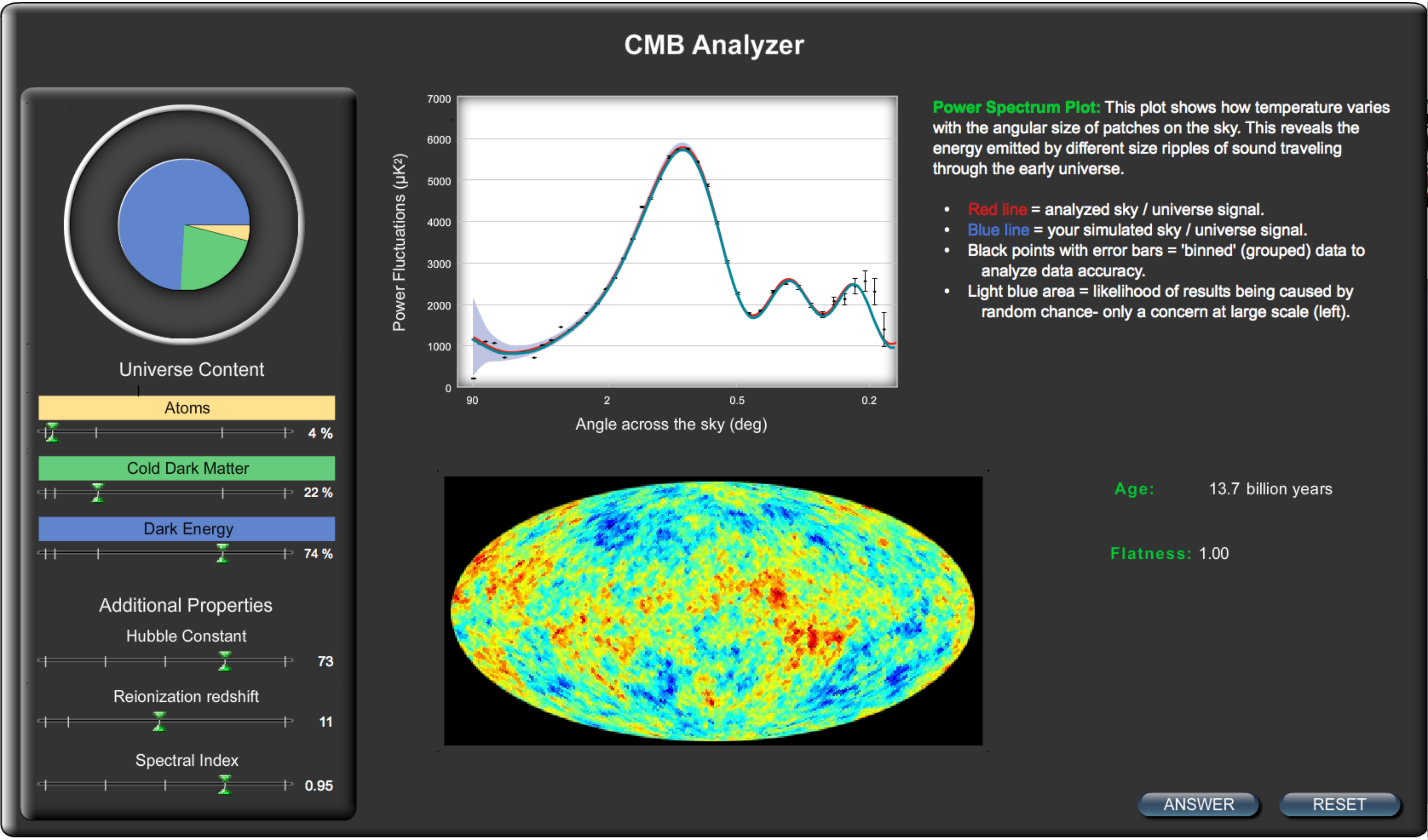
Svemir 100% od atoma?

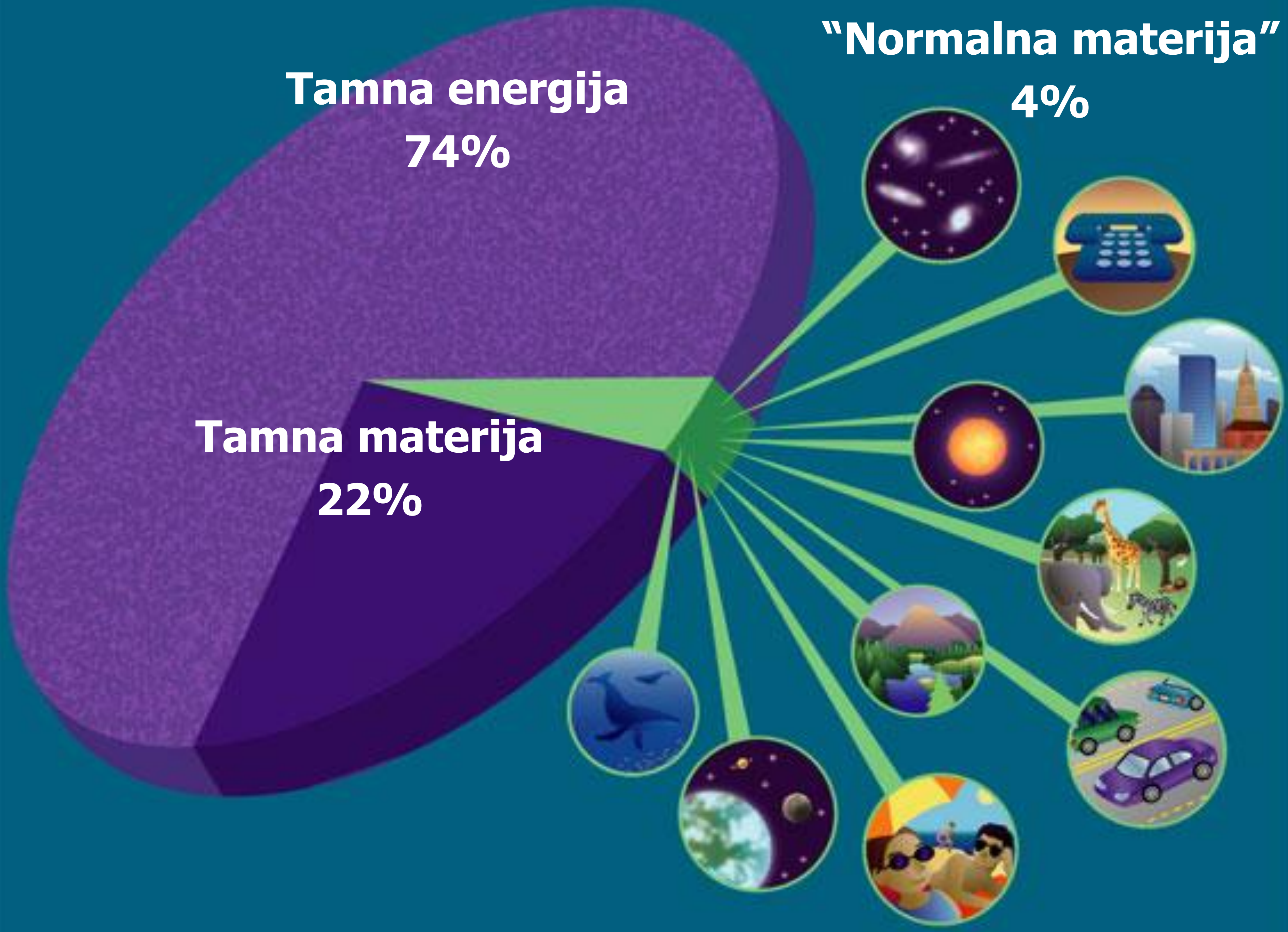


Svemir: 74% atoma, 22% CDM, 4% DE!



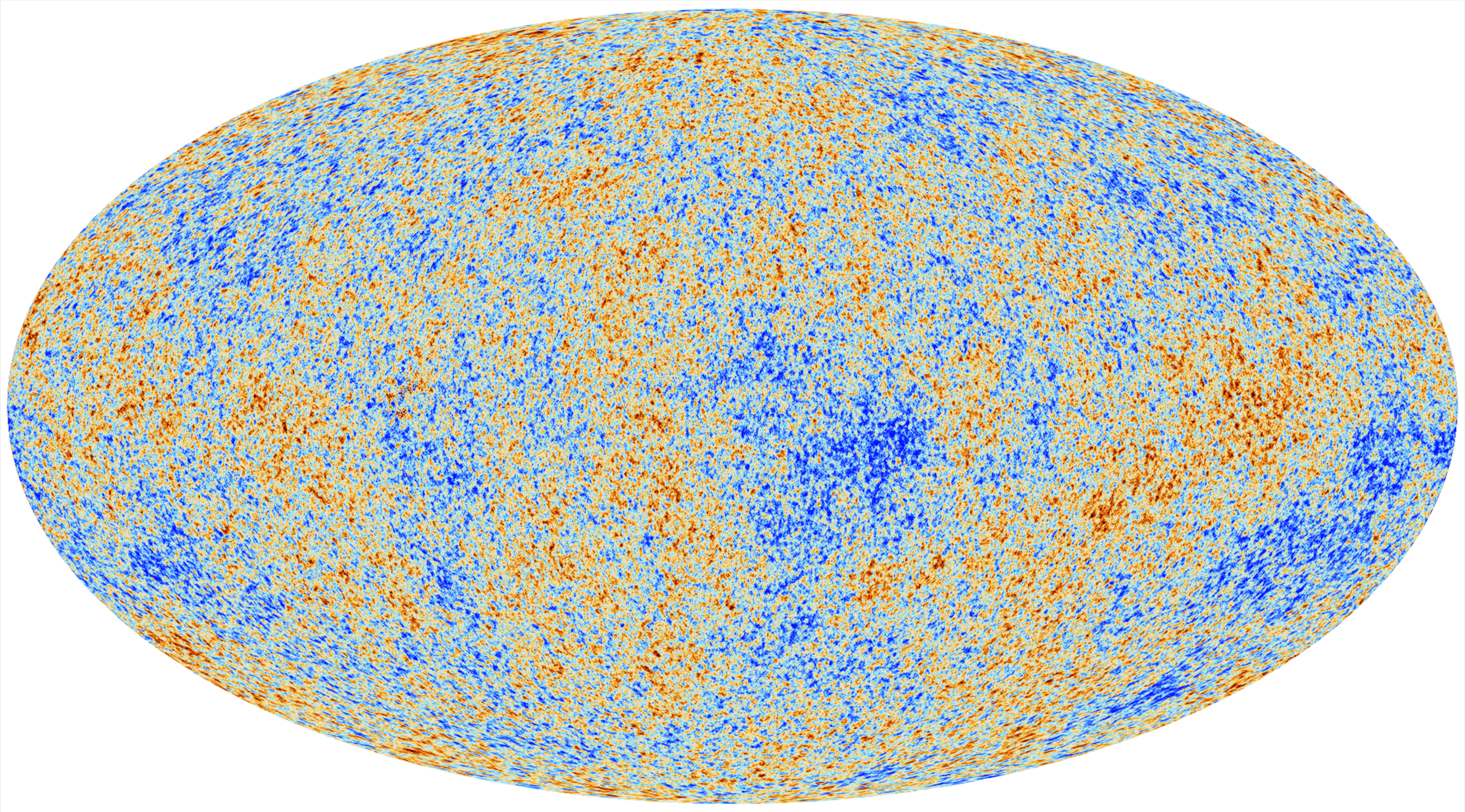
Podaci i teorija se slažu!



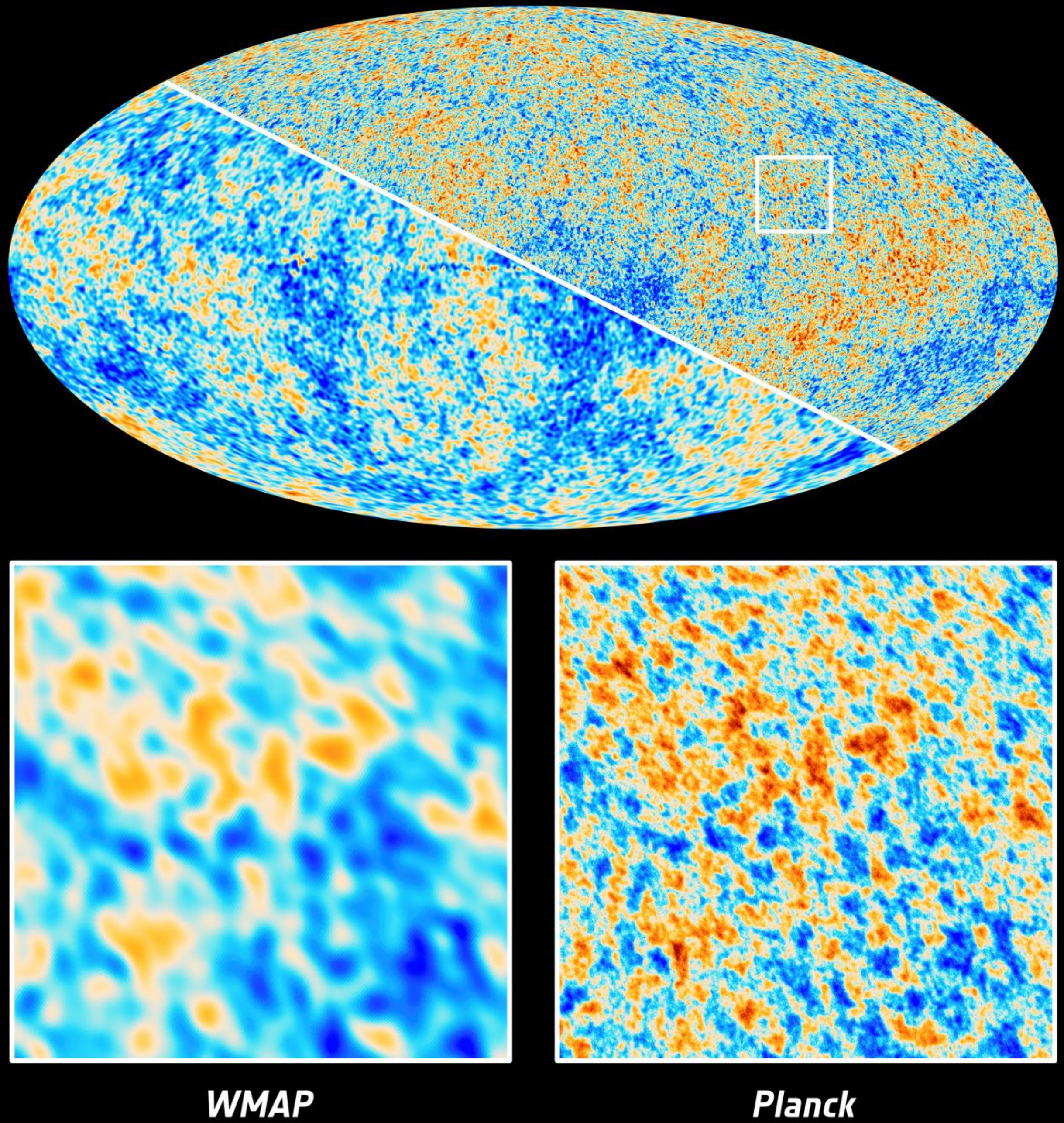

"Normalna materija"
4%
Tamna energija
74%
Tamna materija
22%

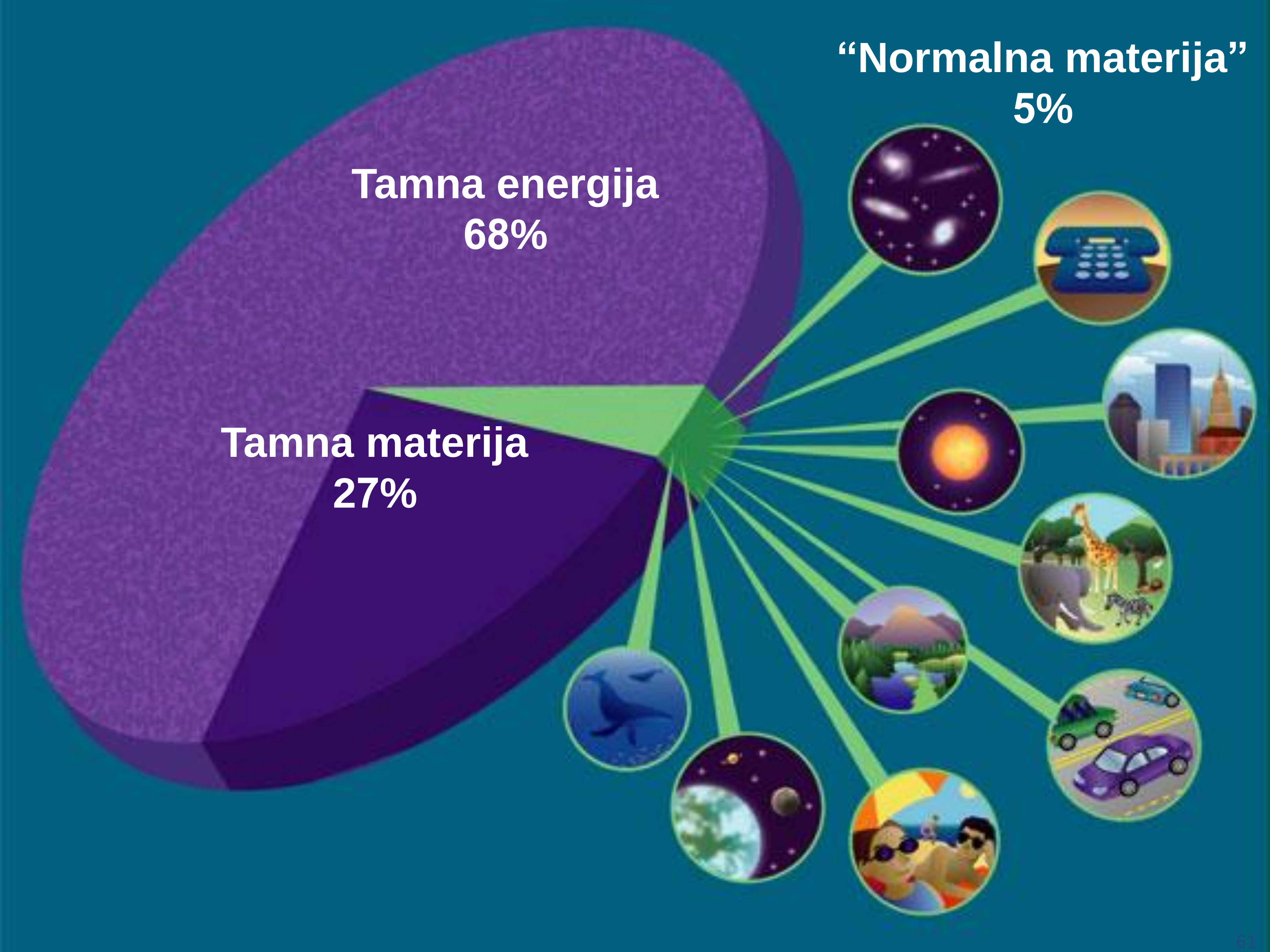

Lako se prevariti gledajuć u svijetlo nebo!
Tamna energija upravlja njegovom sudbinom
Tamna tvar ga veže

Najnoviji rezultati: Planck satelit



The Cosmic Microwave Background as seen by Planck and WMAP




"Normalna materija"
5%
Tamna energija
68%
Tamna materija
27%

Je li razlika između WMAP i PLANCK rezultata problem?

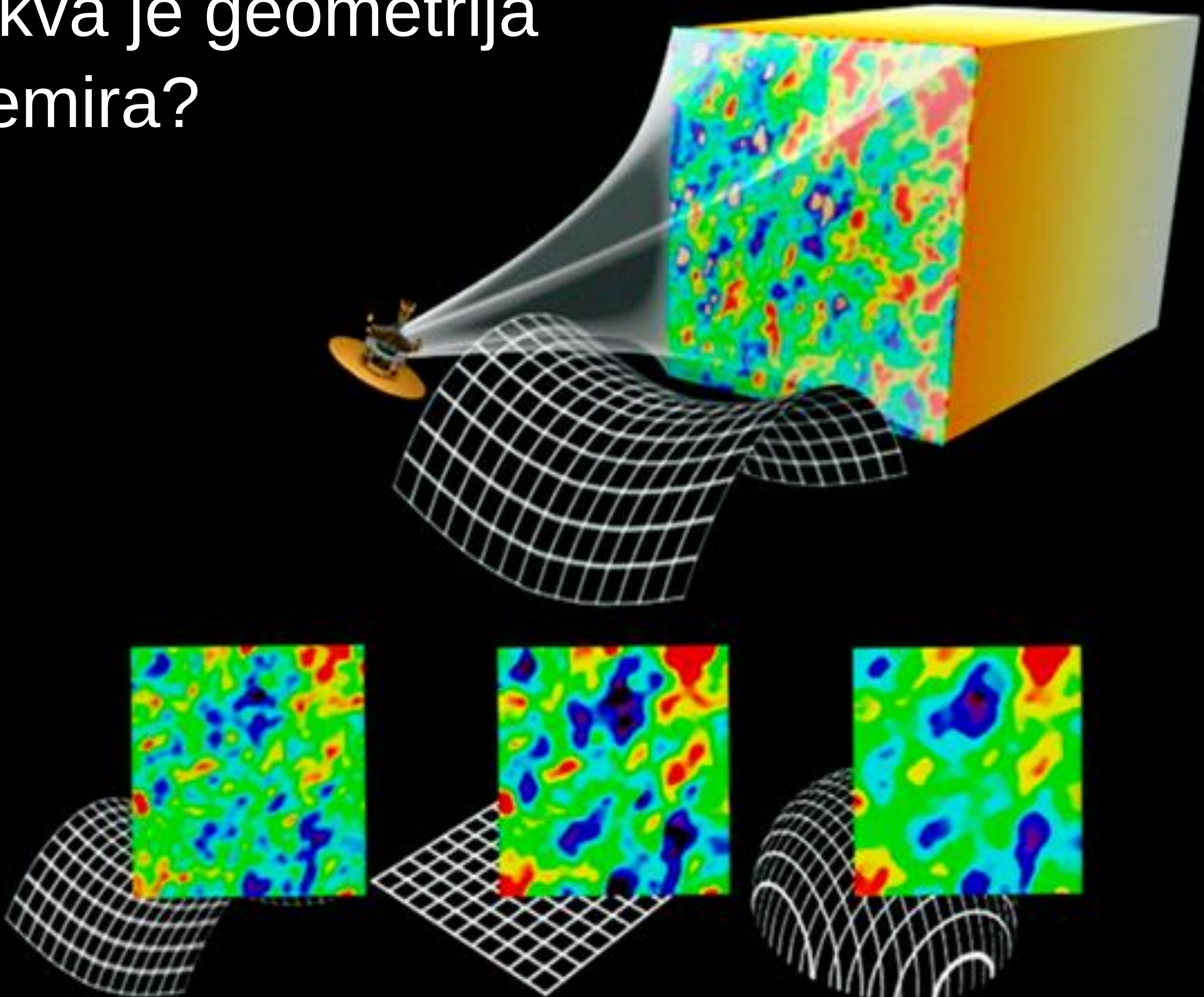
Comparison of *Planck*-only and *WMAP*-only Six-Parameter ΛCDM Fits[a]

Parameter	*Planck* ("CMB+Lens")	*WMAP* (9-year)	Difference value	Difference *WMAP* σ
$\Omega_b h^2$	0.02217 ± 0.00033	0.02264 ± 0.00050	-0.00047	0.9
$\Omega_c h^2$	0.1186 ± 0.0031	0.1138 ± 0.0045	0.0048	1.1
Ω_Λ	0.693 ± 0.019	0.721 ± 0.025	-0.028	1.1
τ	0.089 ± 0.032	0.089 ± 0.014	0	0
t_0 (Gyr)	13.796 ± 0.058	13.74 ± 0.11	56 Myr	0.5
H_0 (km s^{-1}Mpc^{-1})	67.9 ± 1.5	70.0 ± 2.2	-2.1	1.0
σ_8	0.823 ± 0.018	0.821 ± 0.023	0.002	0.1
Ω_b	0.0481[b]	0.0463 ± 0.0024	0.0018	0.7
Ω_c	0.257[b]	0.233 ± 0.023	0.024	1.0

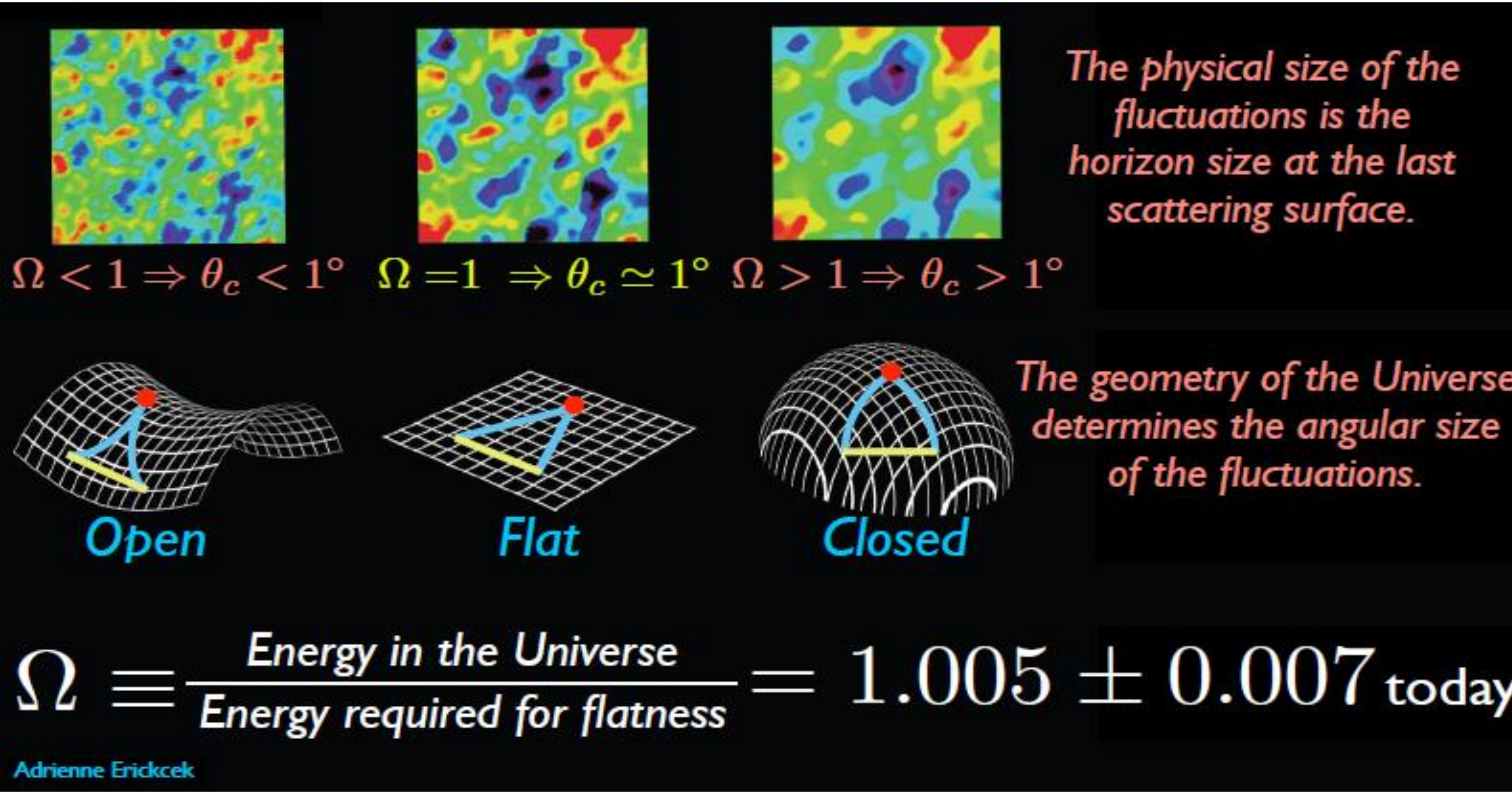
[a] The new *Planck* results strongly favor the standard six-parameter ΛCDM model with parameter values that are consistent with *WMAP* parameters, as shown in this table which compares results derived entirely from *Planck* data with those derived entirely from *WMAP* data.

[b] Parameters derived from quoted values. No error estimate is given for this data/model combination.

Kakva je geometrija svemira?



Bonus iz WMP-a

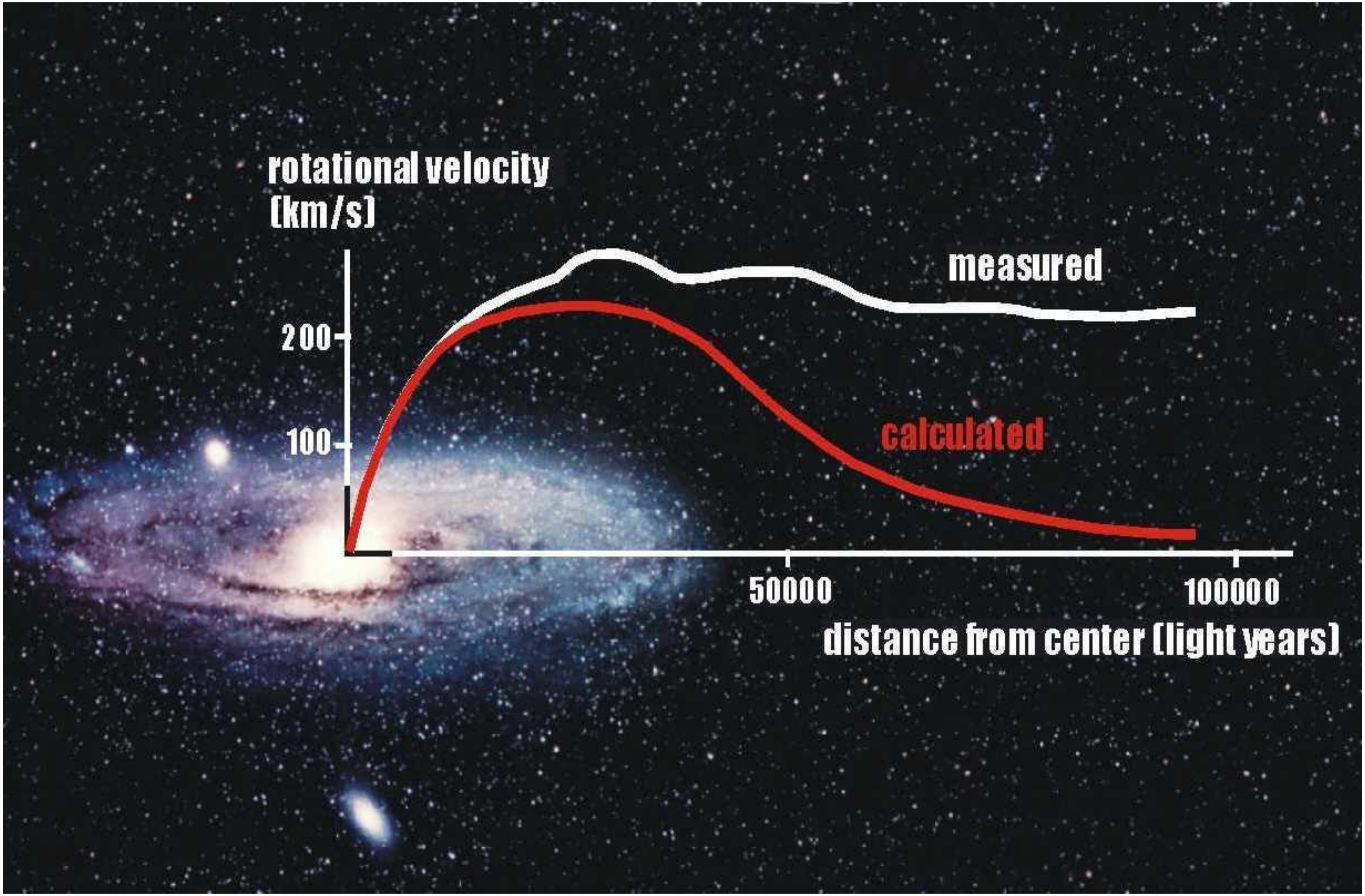



100 milijardi
SVE OVO JE SAMO 5% SVEMIRA!
100 milijardi

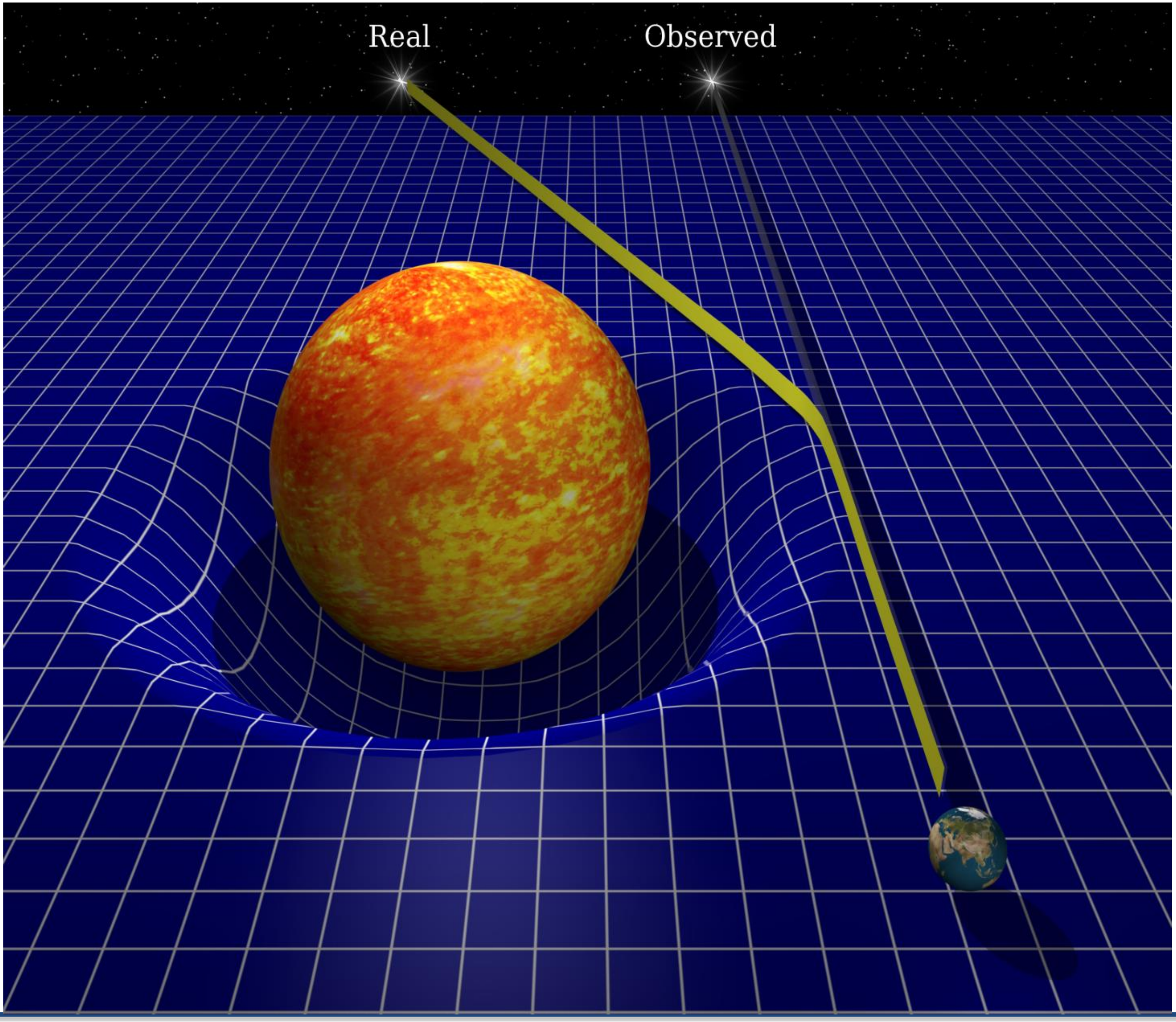

I am
the
center
of the
universe

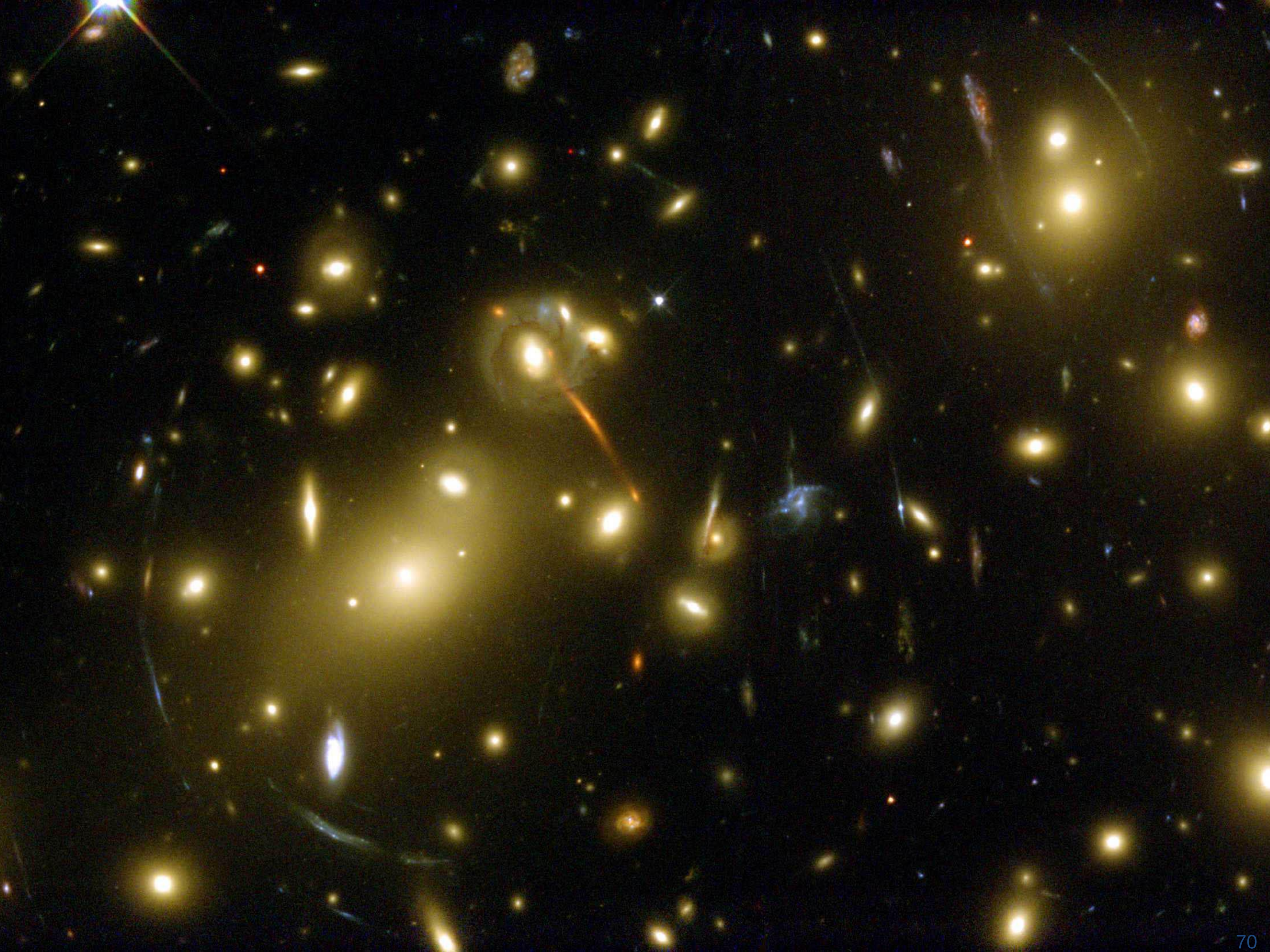
Ima li i drugih dokaza za postojanje tamne materije i tamne energije?

Tamna materija: rotacijske brzine zvijezda u galaksijama

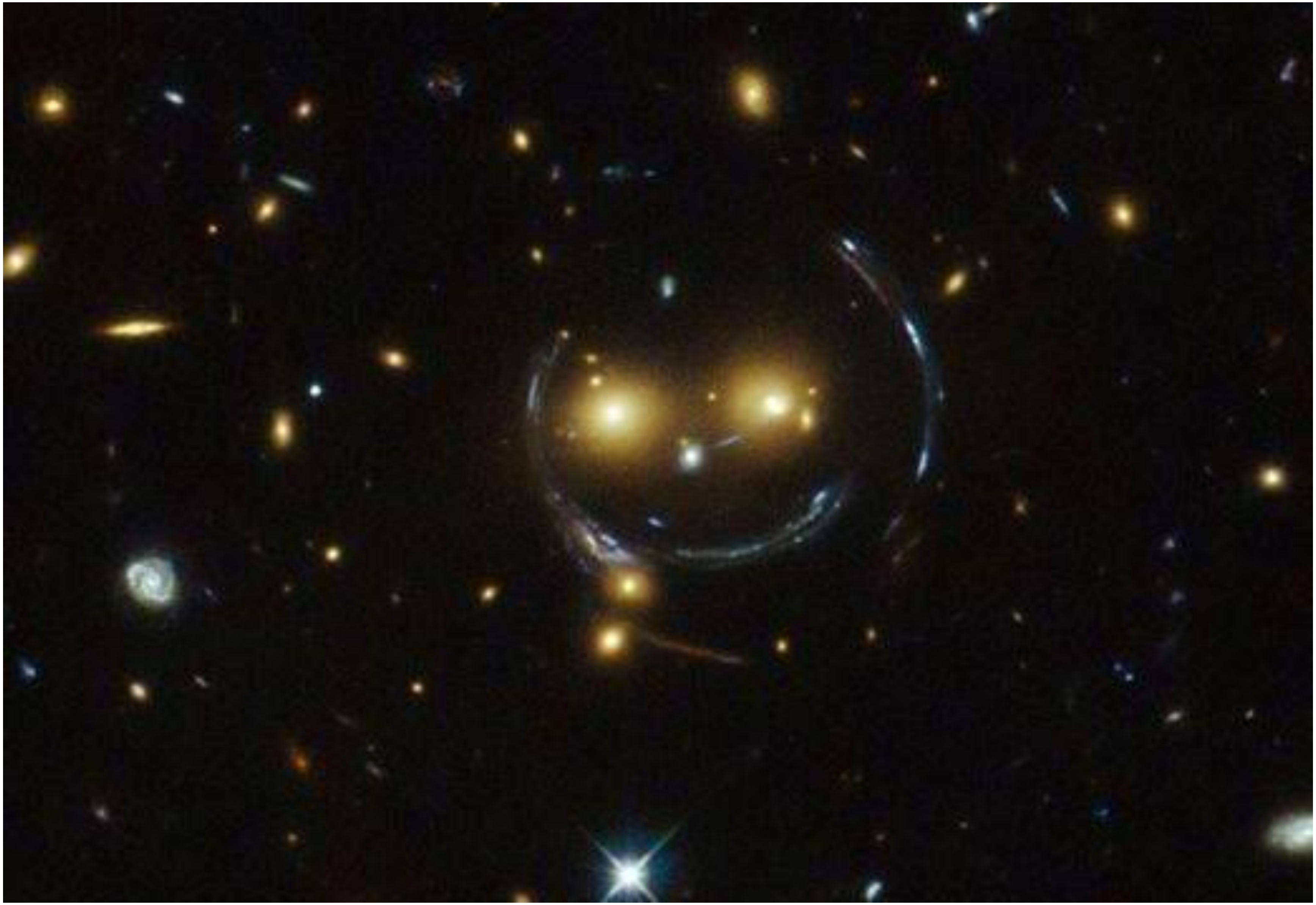


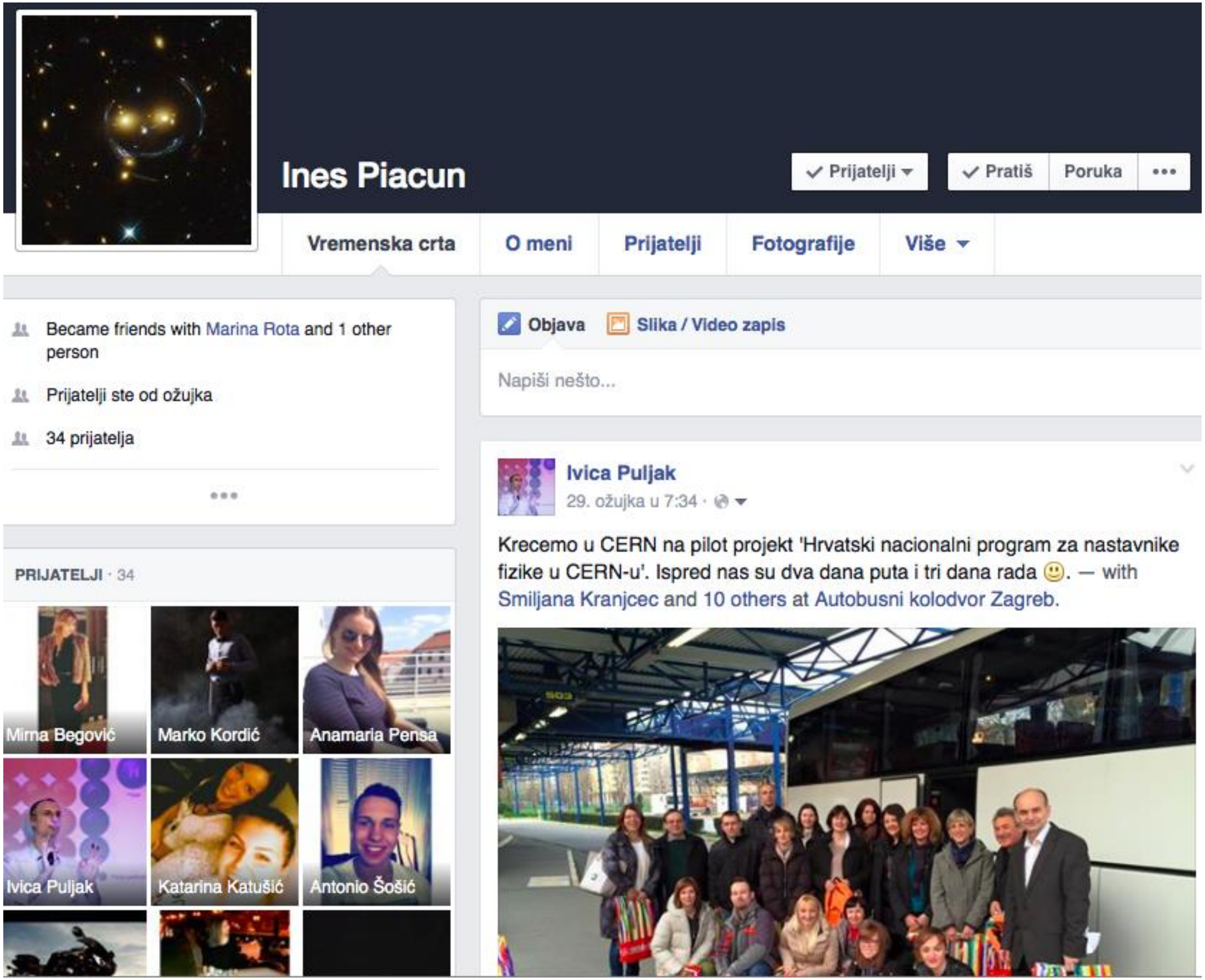
Tamna materija: gravitacijske leće

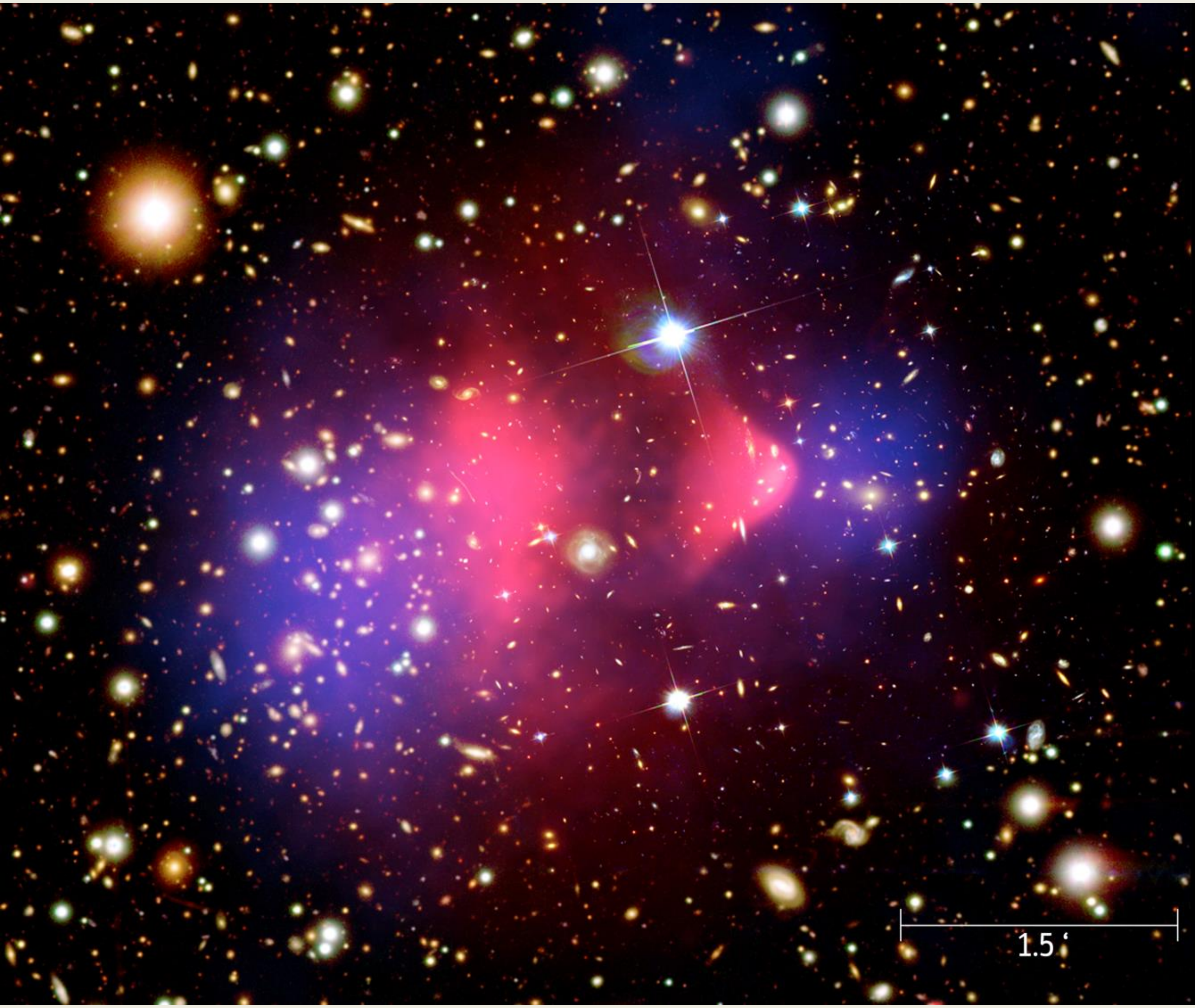




Tko je ovo?




Ines Piacun
Prijatelji
Pratiš
Poruka
Vremenska crta
O meni
Prijatelji
Fotografije
Više
Became friends with Marina Rota and 1 other person
Prijatelji ste od ožujka
34 prijatelja
PRIJATELJI · 34
Mirna Begović
Marko Kordić
Anamaria Pensa
Ivica Puljak
Katarina Katušić
Antonio Šošić
Objava
Slika / Video zapis
Napiši nešto...
Ivica Puljak
29. ožujka u 7:34
Krecemo u CERN na pilot projekt 'Hrvatski nacionalni program za nastavnike fizike u CERN-u'. Ispred nas su dva dana puta i tri dana rada. — with Smiljana Kranjcec and 10 others at Autobusni kolodvor Zagreb.



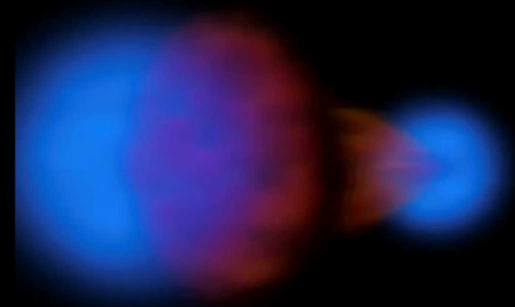
Direct Proof of Dark Matter

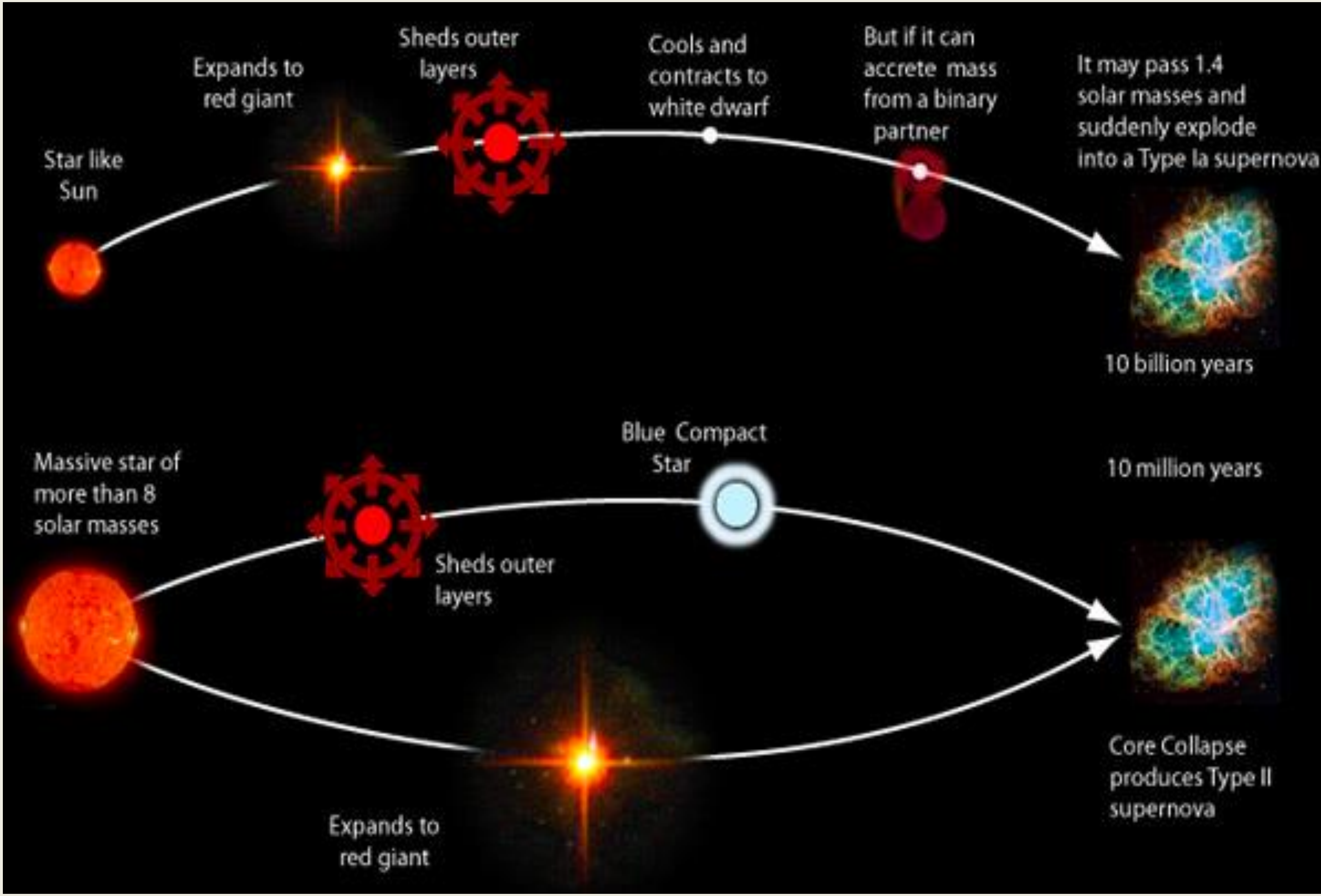
This composite image shows the galaxy cluster 1E 0657-56, also known as the "bullet cluster." This cluster was formed after the collision of two large clusters of galaxies, the most energetic event known in the universe since the Big Bang.

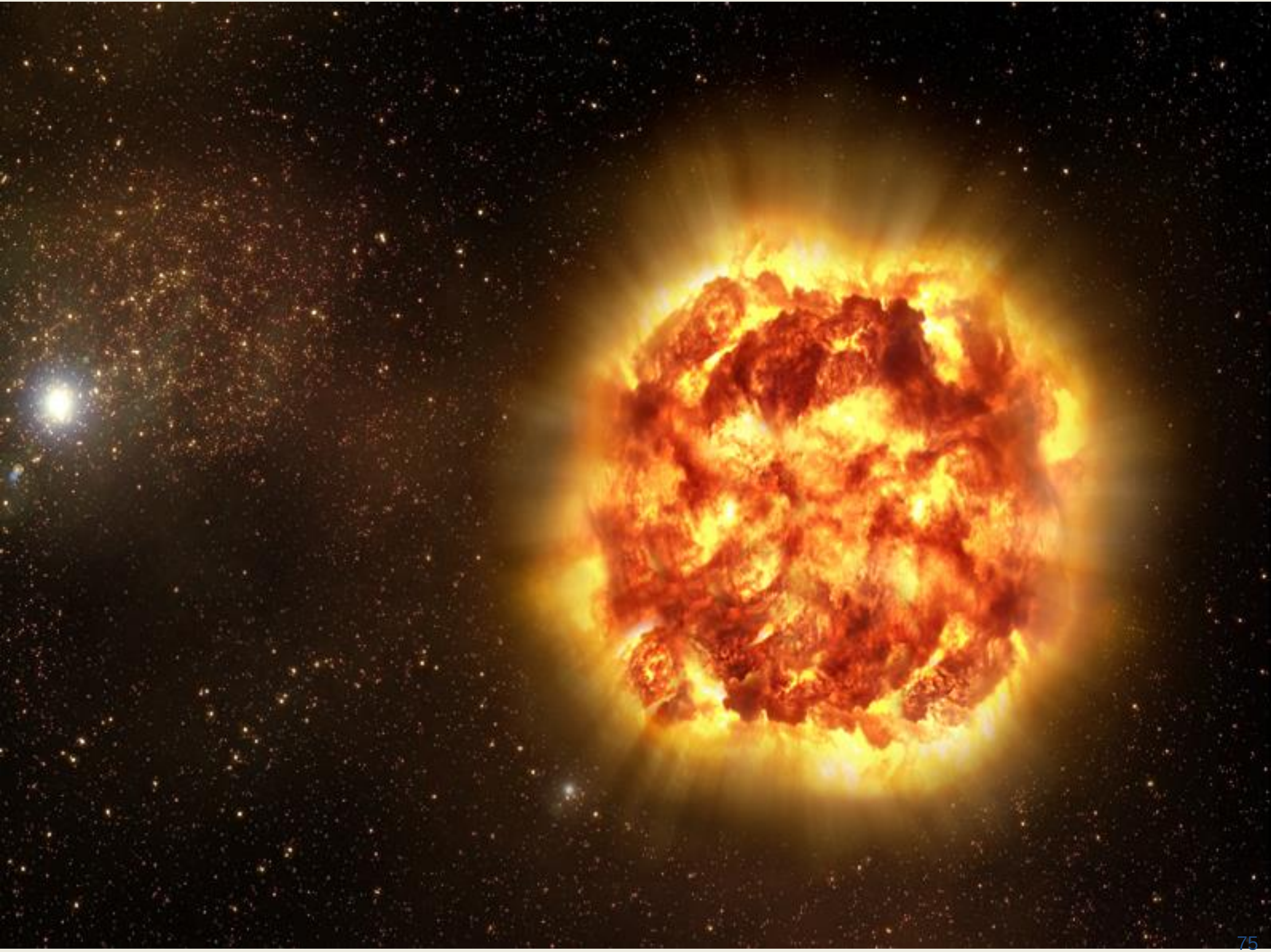
Hot gas detected by Chandra in X-rays is seen as two pink clumps in the image and contains most of the "normal," or baryonic, matter in the two clusters. The bullet-shaped clump on the right is the hot gas from one cluster, which passed through the hot gas from the other larger cluster during the collision. An optical image from Magellan and the Hubble Space Telescope shows the galaxies in orange and white. The blue areas in this image show where astronomers find most of the mass in the clusters. The concentration of mass is determined using the effect of so-called gravitational lensing, where light from the distant objects is distorted by intervening matter. Most of the matter in the clusters (blue) is clearly separate from the normal matter (pink), giving direct evidence that nearly all of the matter in the clusters is dark.

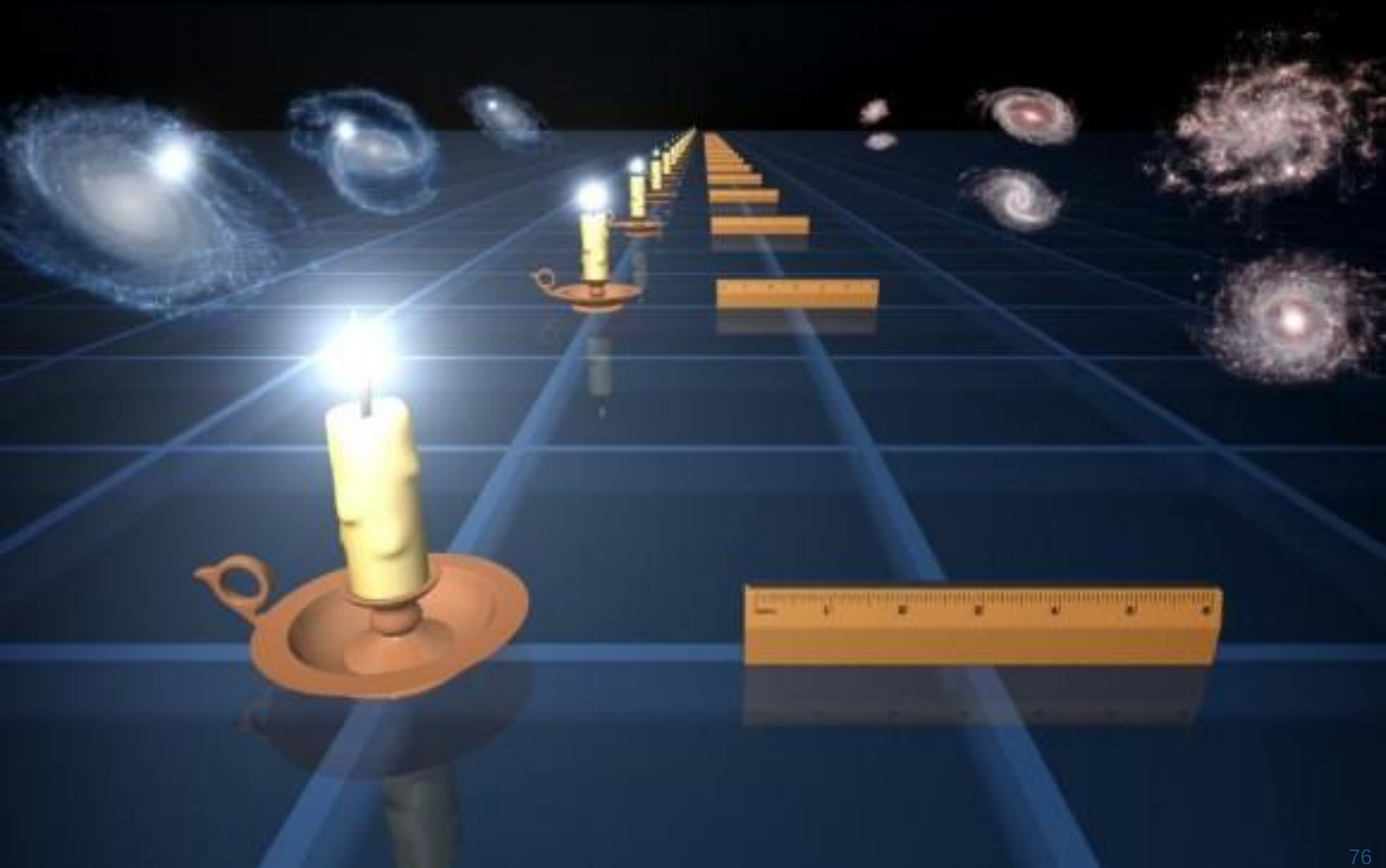
The animation below shows an artist's representation of the huge collision in the bullet cluster. Hot gas, containing most of the normal matter in the cluster, is shown in red and dark matter is in blue. During the collision the hot gas in each cluster is slowed and distorted by a drag force, similar to air resistance. In contrast, the dark matter is not slowed by the impact, because it does not interact directly with itself or the gas except through gravity, and separates from the normal matter.

Left: X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al., Below: NASA/CXC/M.Weiss

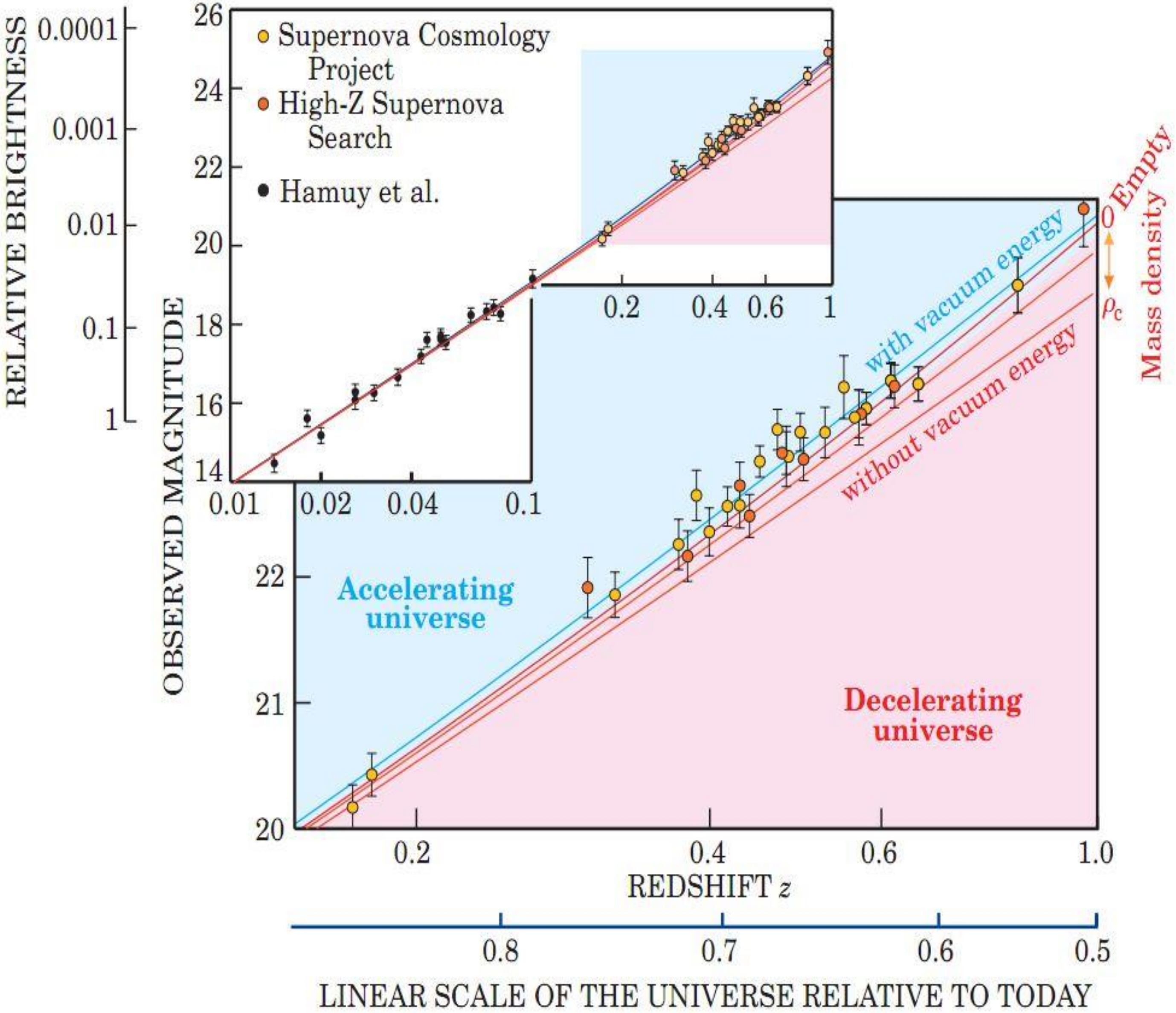



Star like Sun
Expands to red giant
Sheds outer layers
Cools and contracts to white dwarf
But if it can accrete mass from a binary partner
It may pass 1.4 solar masses and suddenly explode into a Type Ia supernova
10 billion years
Massive star of more than 8 solar masses
Sheds outer layers
Blue Compact Star
10 million years
Expands to red giant
Core Collapse produces Type II supernova





Tamna energija: mjerenje supernova



Dark energy could be the offspring of the Higgs boson

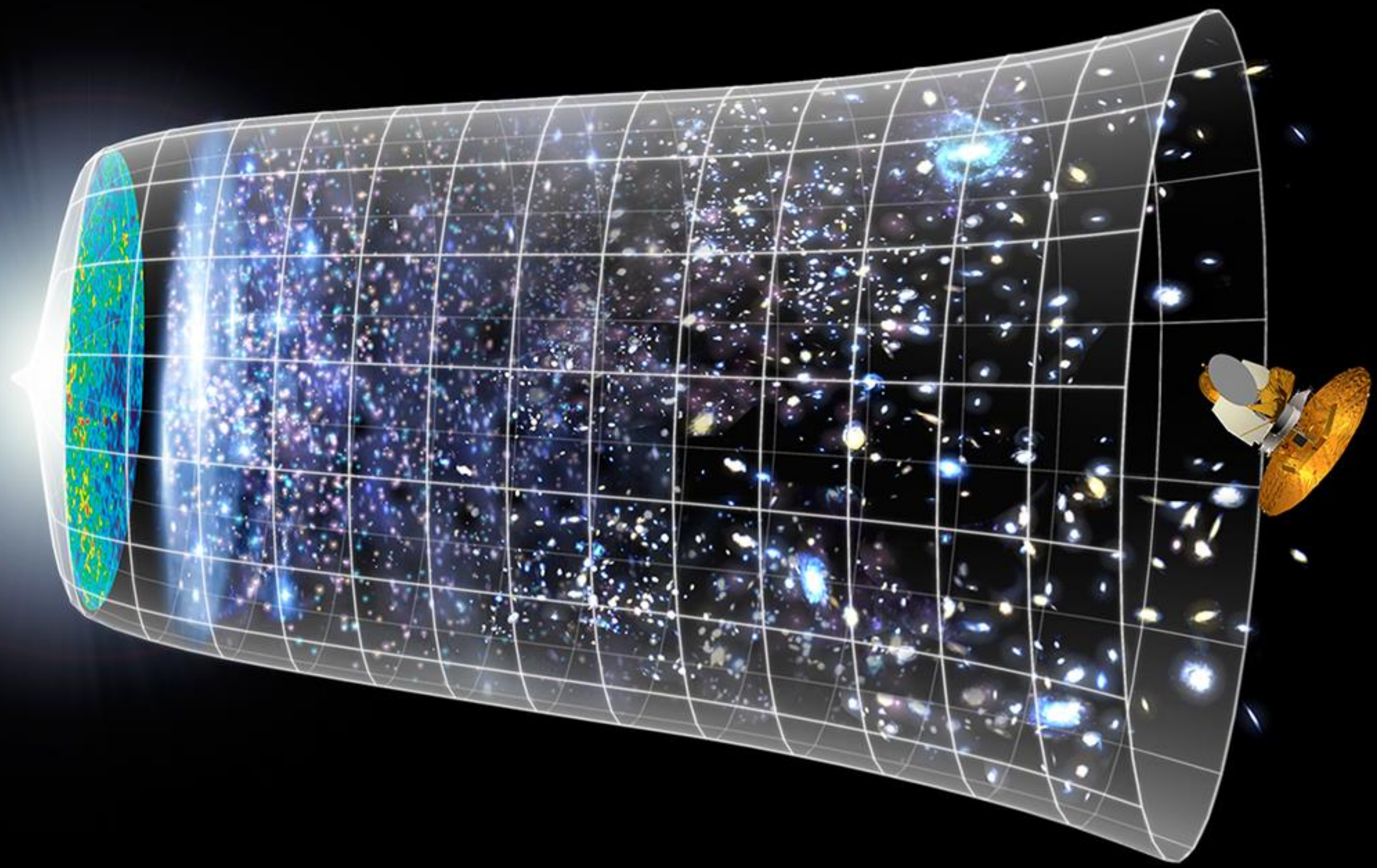
- 16:23 14 August 2013 by Lisa Grossman
- For similar stories, visit the The Higgs boson and Cosmology Topic Guides

The particle credited with giving others mass, the Higgs boson, may also be to blame for the universe flying apart ever faster. That's because the Higgs boson could, in principle, be giving rise to dark energy.

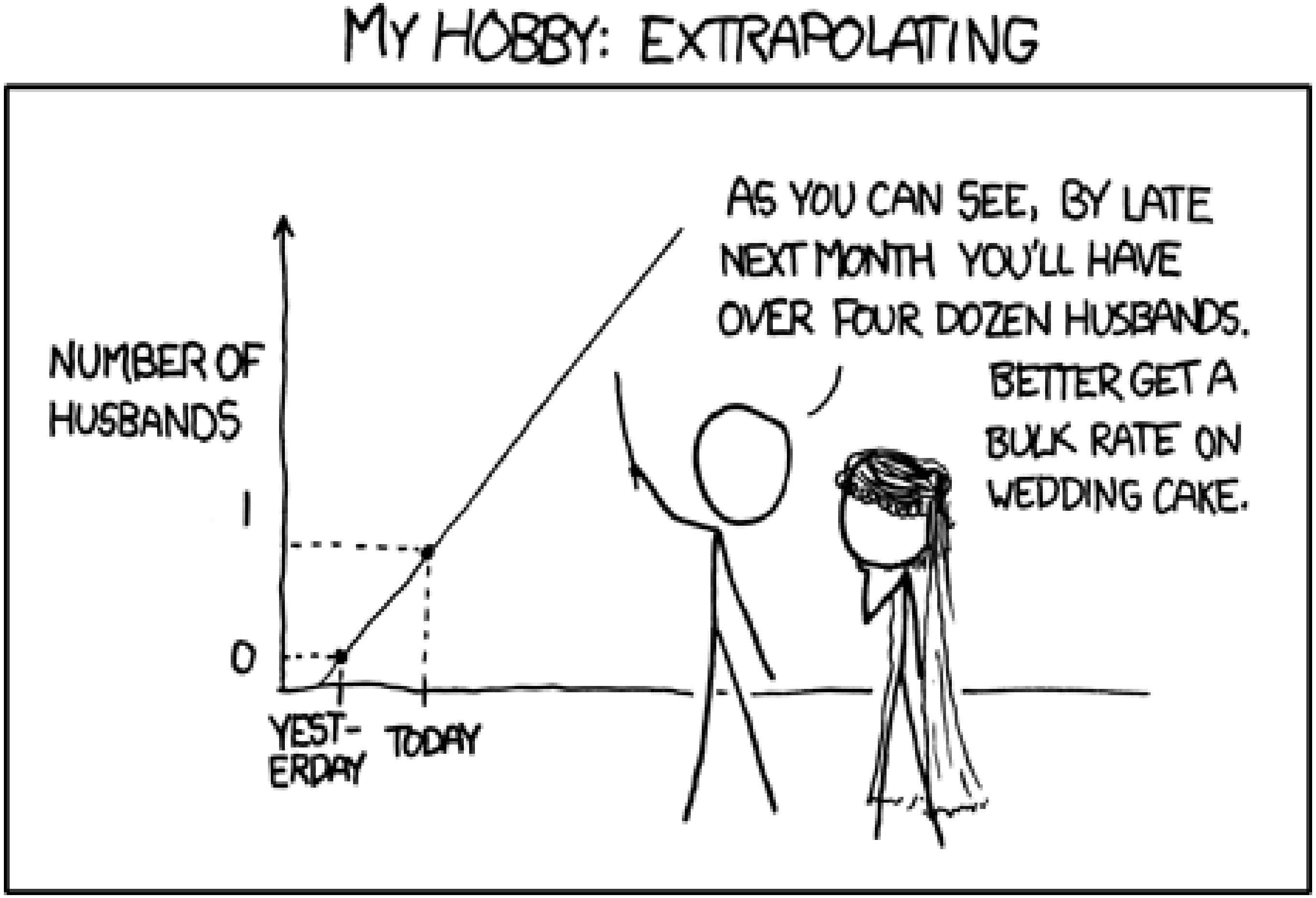
The standard model of particle physics encompasses the fundamental particles that make up matter, as well as associated fields. The photon, for instance, is tied to the electromagnetic field. Discovered last year, the Higgs boson also comes with an associated field but, unlike others of its class, the Higgs field is scalar – it does not act in a specific direction.

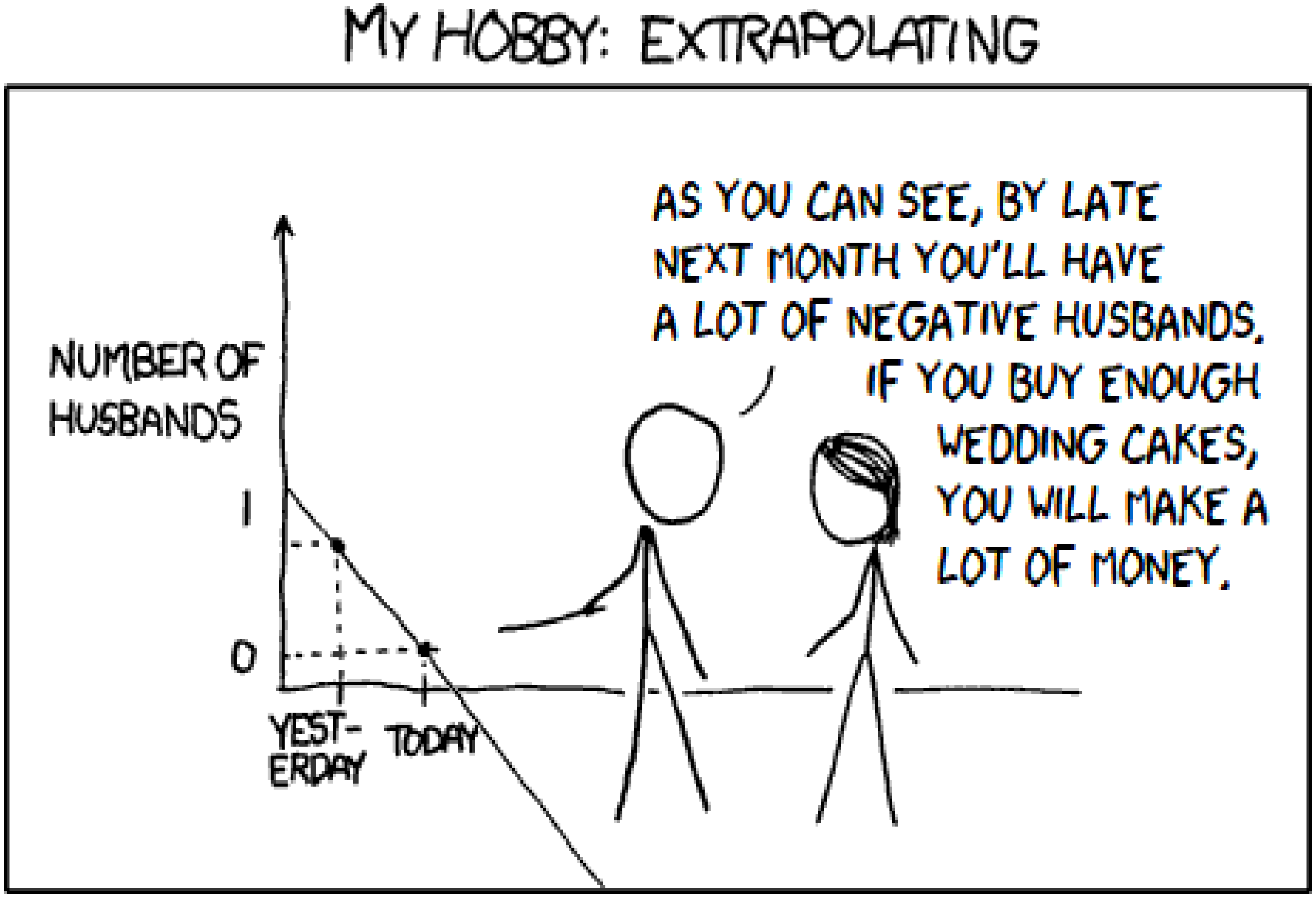
Taken together, the known particle fields create a certain density of energy permeating the universe. Before the discovery of dark energy, particle physicists were worried that the simplest versions of the standard model predicted an enormous, possibly infinite energy density that would force the universe to expand at an ever-increasing rate.

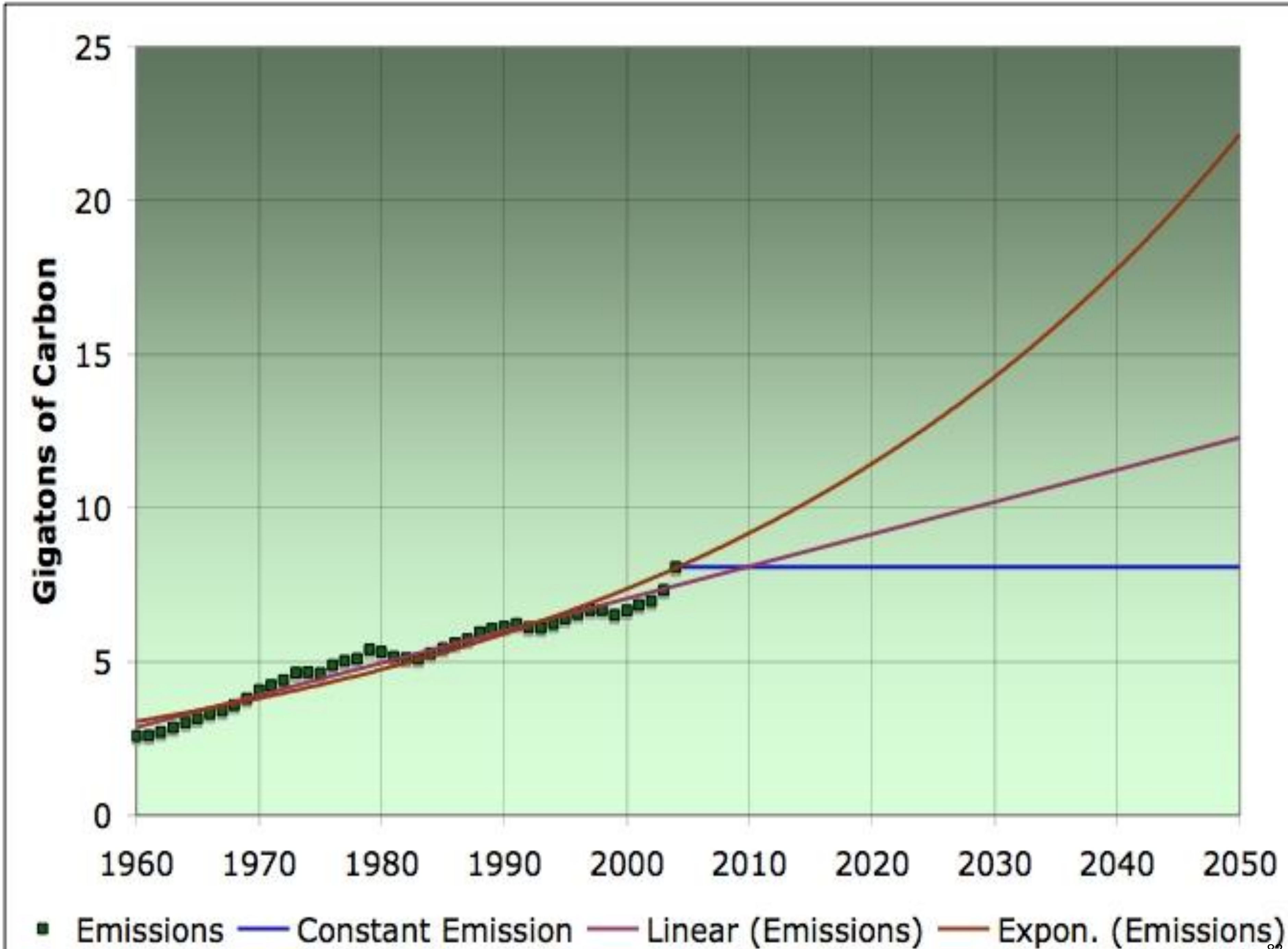
Kako je sve [možda] započelo?

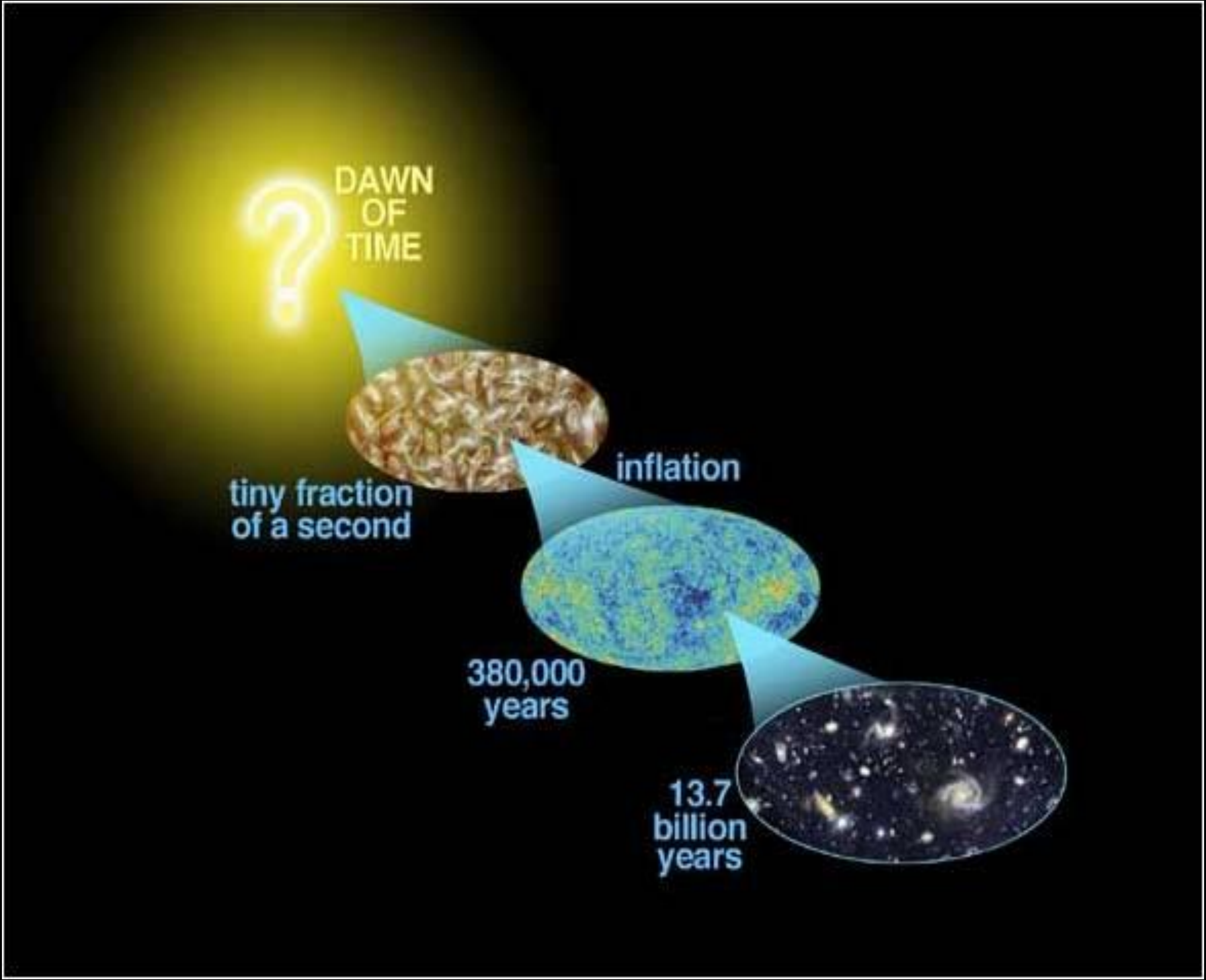


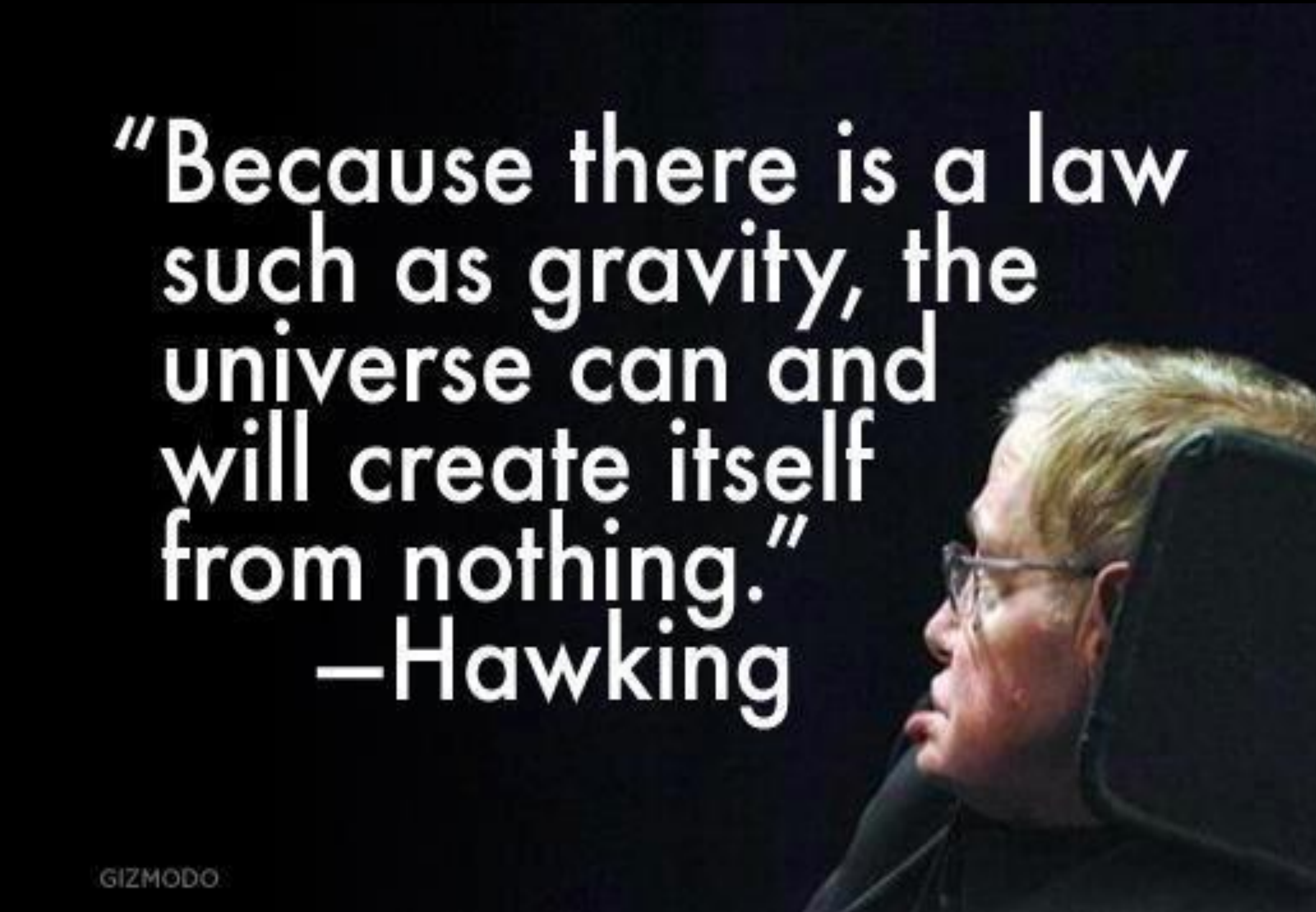
NASA/WMAP Science Team


MY HOBBY: EXTRAPOLATING
NUMBER OF HUSBANDS
1
0
YEST- ERDAY
TODAY
AS YOU CAN SEE, BY LATE NEXT MONTH YOU'LL HAVE OVER FOUR DOZEN HUSBANDS.
BETTER GET A BULK RATE ON WEDDING CAKE.

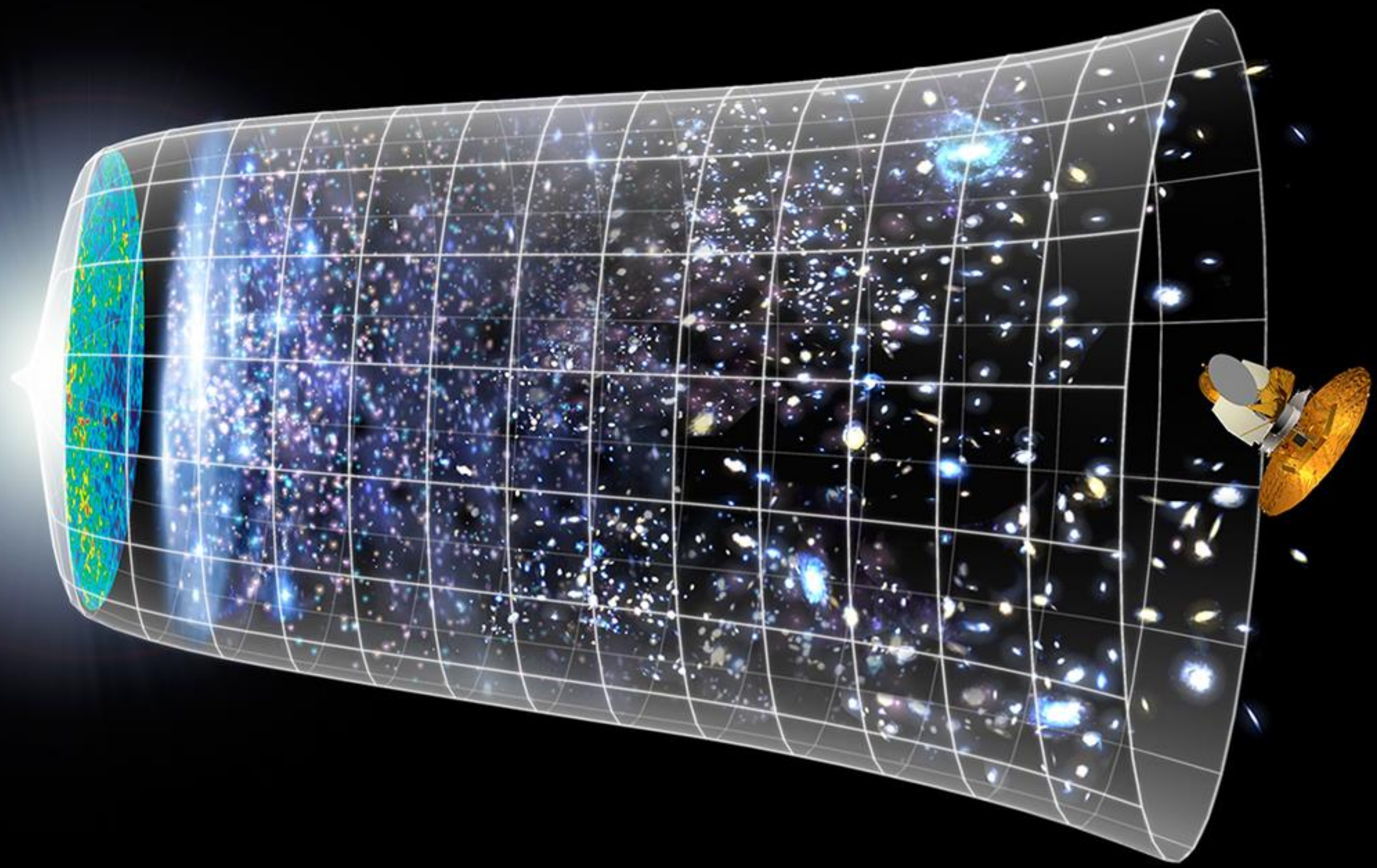

MY HOBBY: EXTRAPOLATING
NUMBER OF HUSBANDS
1
0
YEST-ERDAY
TODAY
AS YOU CAN SEE, BY LATE NEXT MONTH YOU'LL HAVE A LOT OF NEGATIVE HUSBANDS.
IF YOU BUY ENOUGH WEDDING CAKES, YOU WILL MAKE A LOT OF MONEY.


Gigatons of Carbon
25
20
15
10
5
0
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Emissions
Constant Emission
Linear (Emissions)
Expon. (Emissions)


DAWN OF TIME
inflation
tiny fraction of a second
380,000 years
13.7 billion years


"Because there is a law such as gravity, the universe can and will create itself from nothing."
—Hawking
GIZMODO

ŠTO JE TO **NIŠTA**?



NASA/WMAP Science Team

Najljepša jednadžba znanosti

- Einsteinova originalna jednadžba

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Svemir koji se širi — Materija i energija u svemiru

- Opća teorija relativnost s kozmološkom konstantom

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

Svemir koji se širi — Kozmološka konstanta — Materija i energija u svemiru

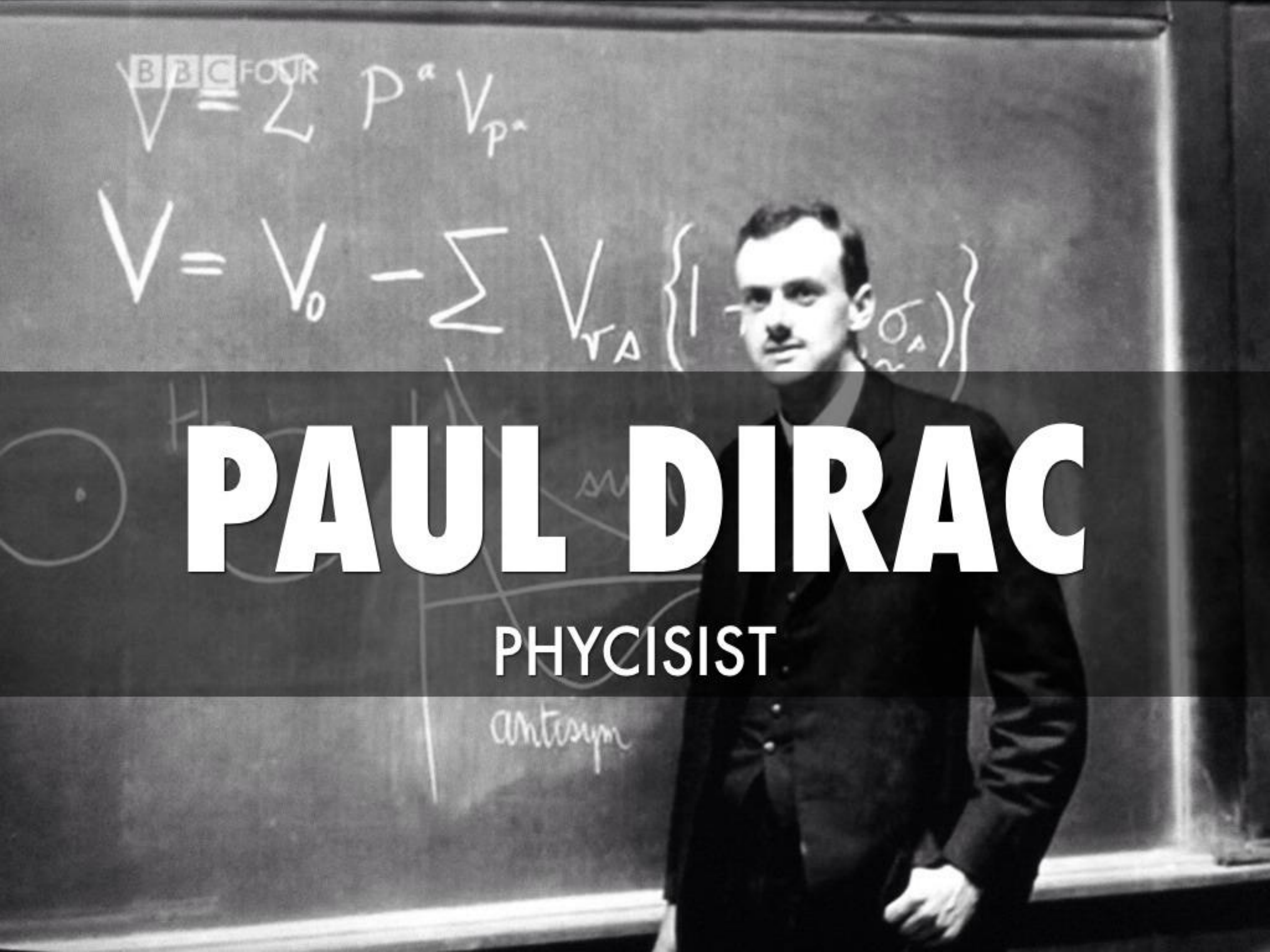
- Kozmološka konstanta i ”tamna energija”

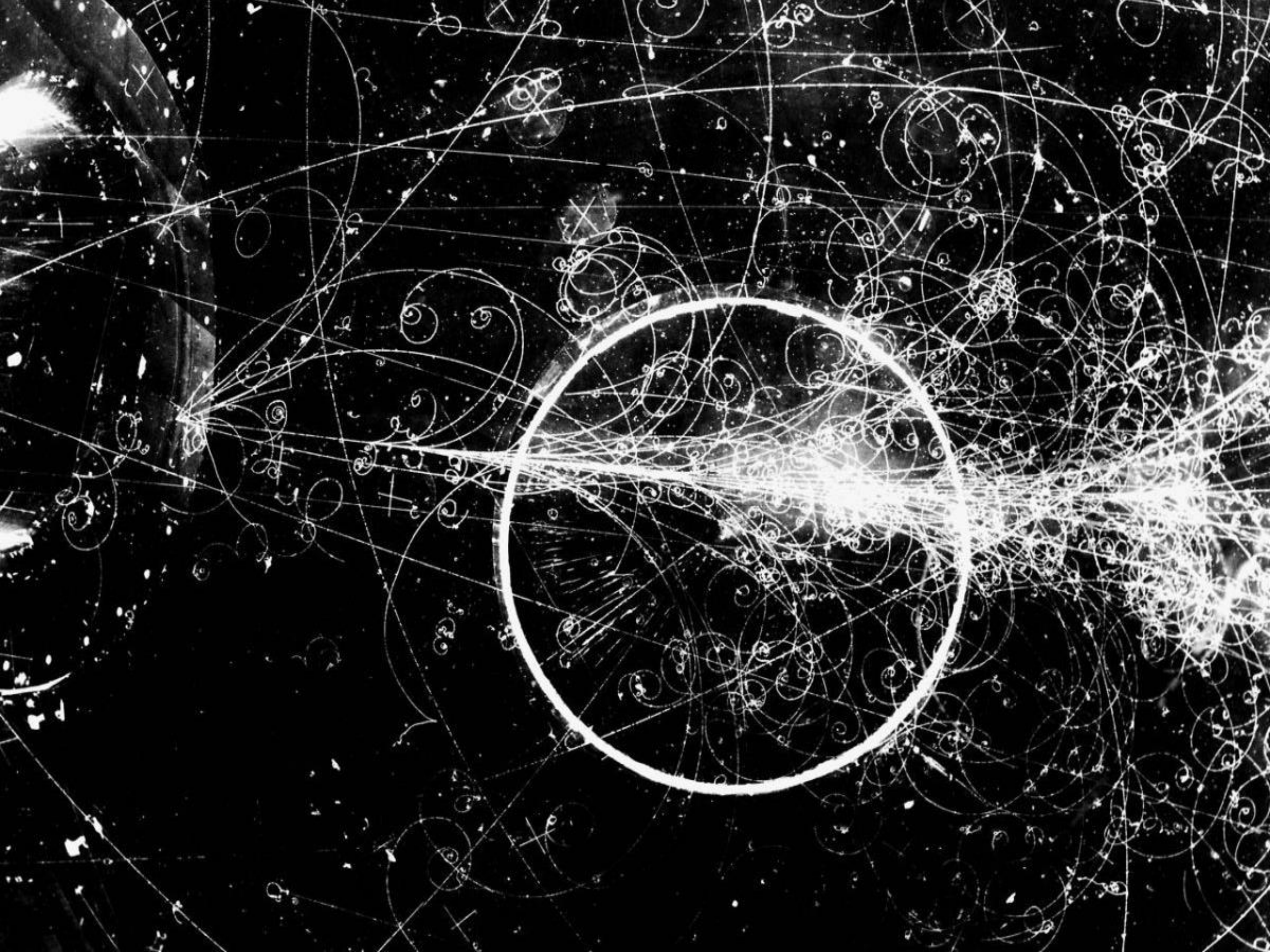
$$G_{\mu\nu} = 8\pi G T_{\mu\nu} - \rho_{\Lambda} g_{\mu\nu}$$

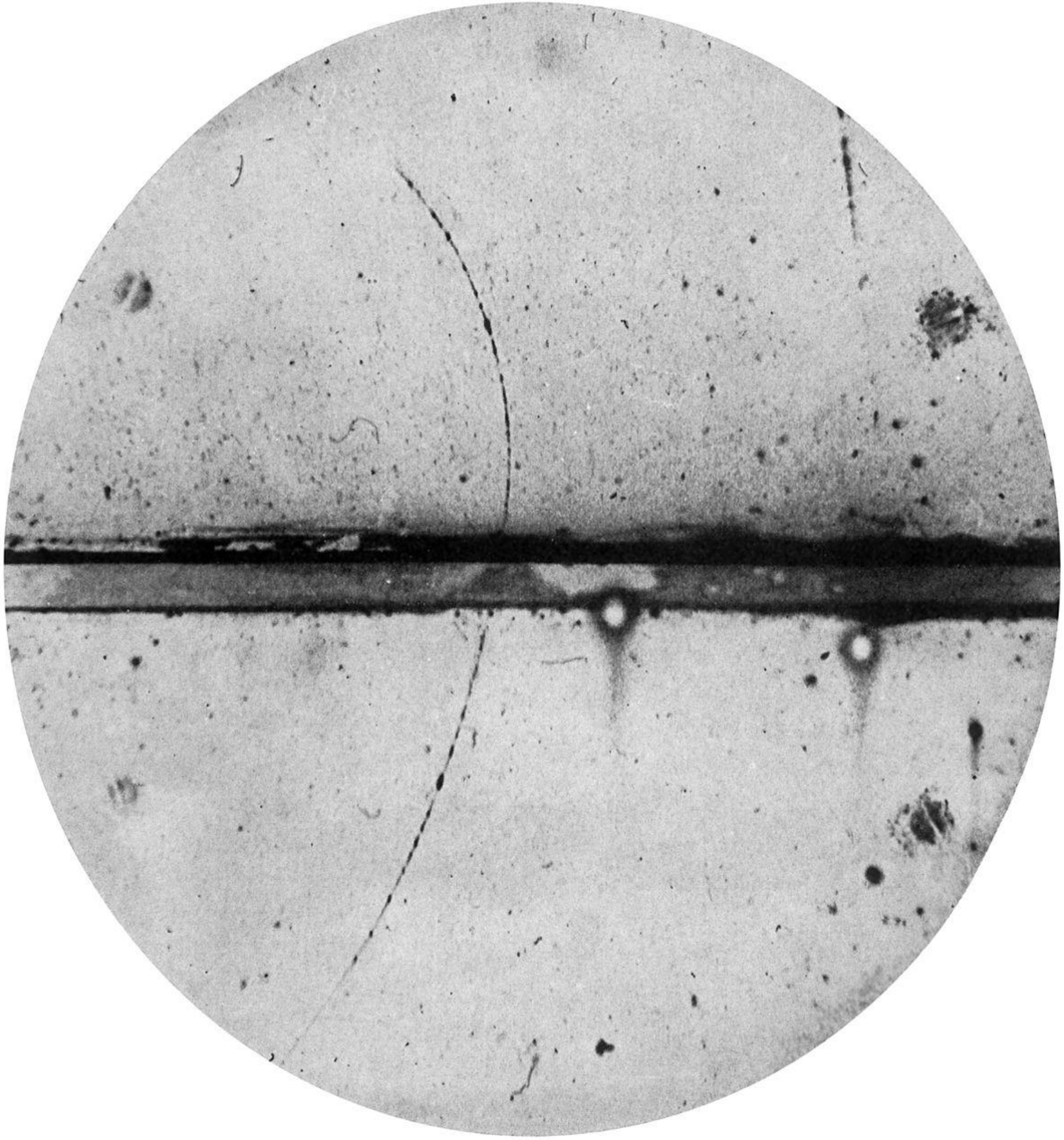
Svemir koji se širi — Materija i energija u svemiru

KVANTNA FIZIKA

SPECIJALNA TEORIJA RELATIVNOSTI

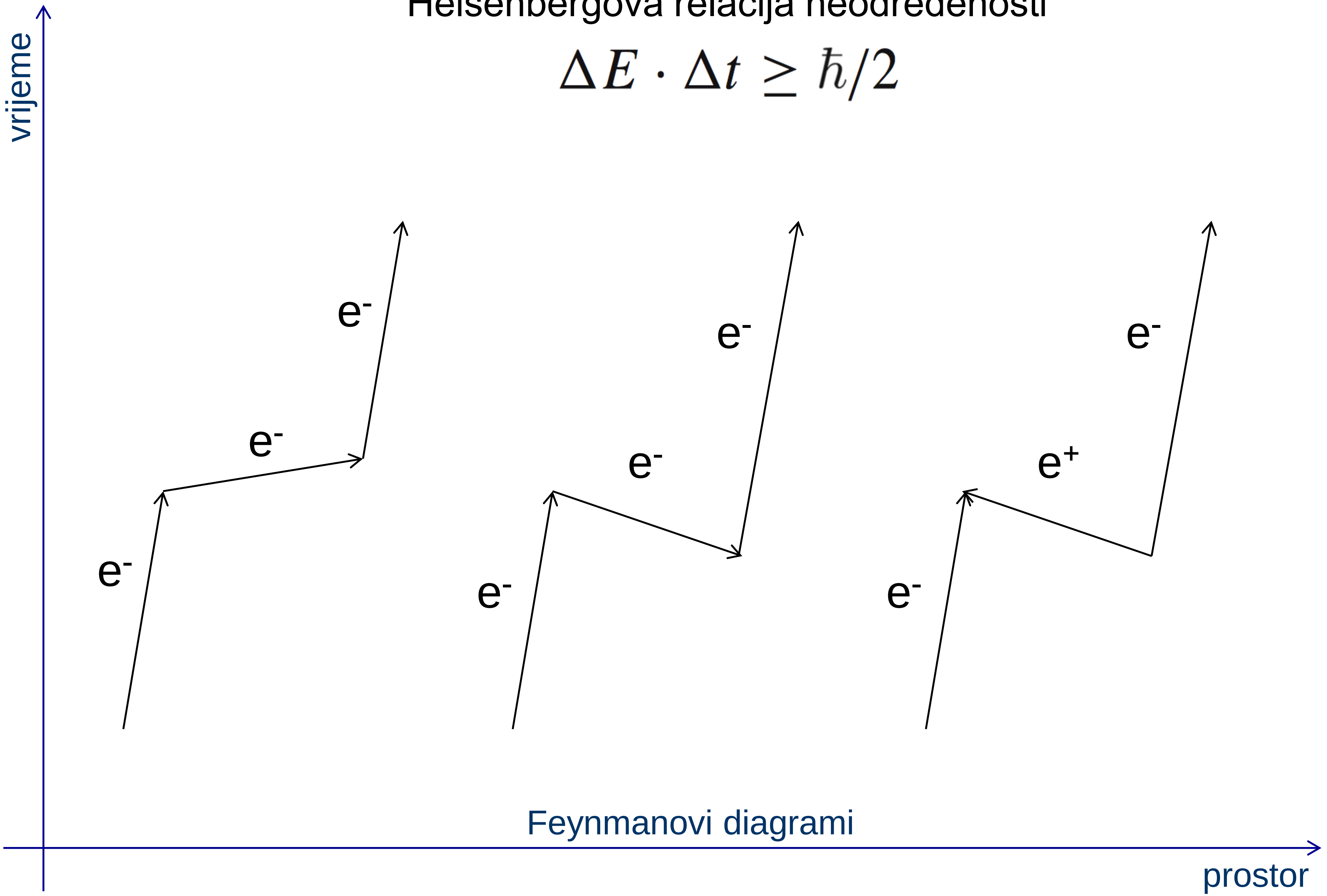

PAUL DIRAC
PHYCISIST





Heisenbergova relacija neodređenosti

$$\Delta E \cdot \Delta t \geq \hbar/2$$

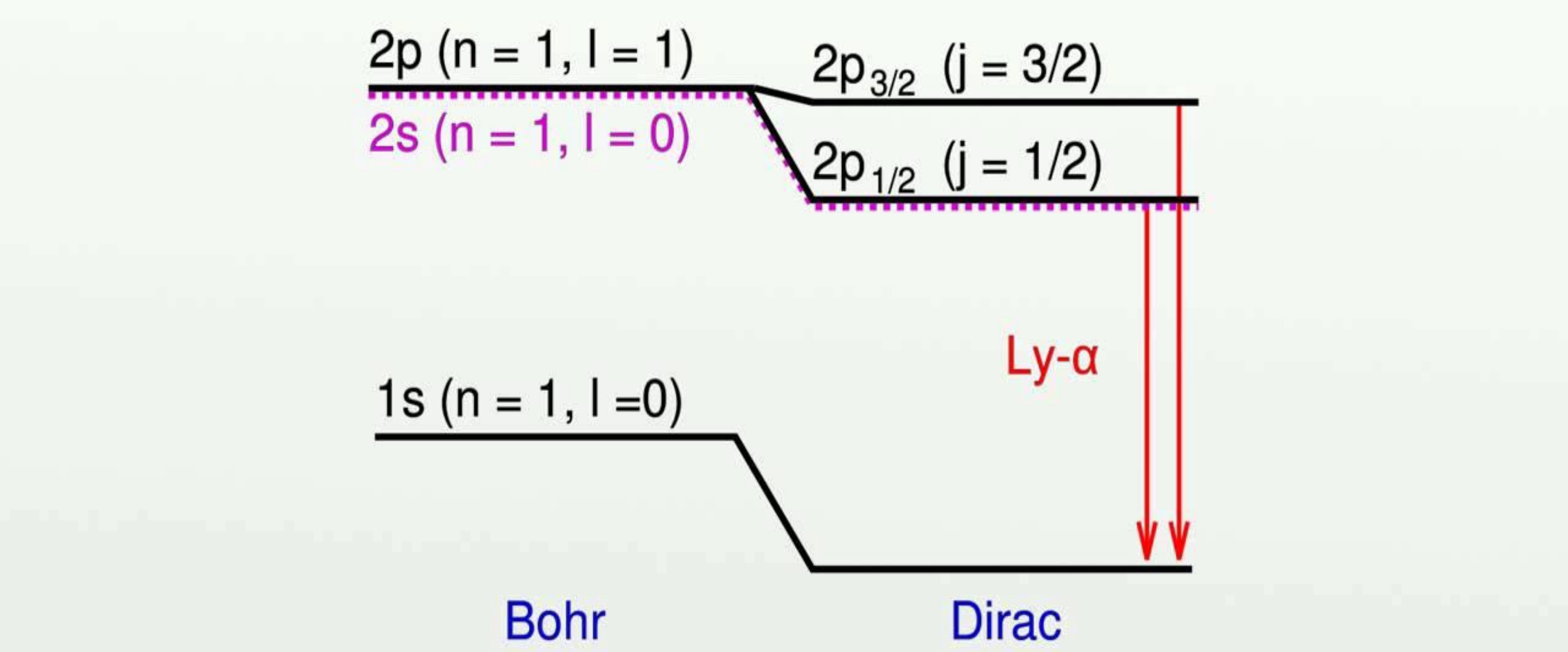


Virtualne čestice u stvarnosti

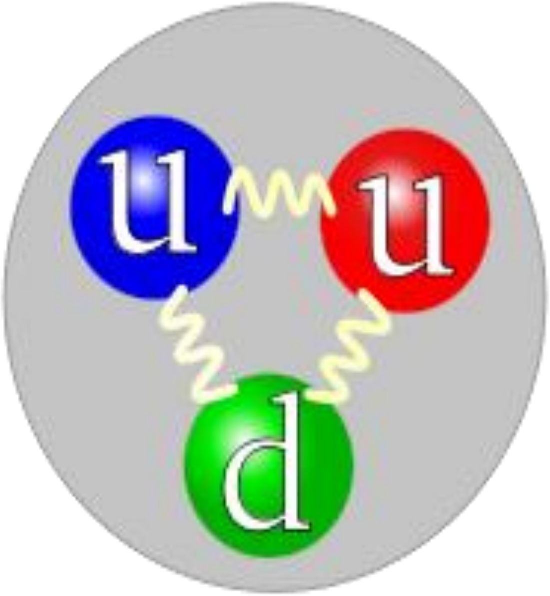
- Uvesti novu ideju koja se ne može mjeriti bi bilo slično diskusiji o tome koliko anđela može stati na glavu igle
- Direktno ne možemo mjeriti virtualne čestice
  - Ali njihovi indirektni efekti proizvode većinu svemira kojeg znamo
  - I ne samo to: njihov utjecaj na fizikalne procese je najpreciznije izračunati proračun u znanost uopće
- Primjeri
  - Vodikov atom i Lambov pomak
    - Preciznost od 1 u milijardu, kao udaljenost do sunca do na preciznost od jednog centimetra
  - Masa protona

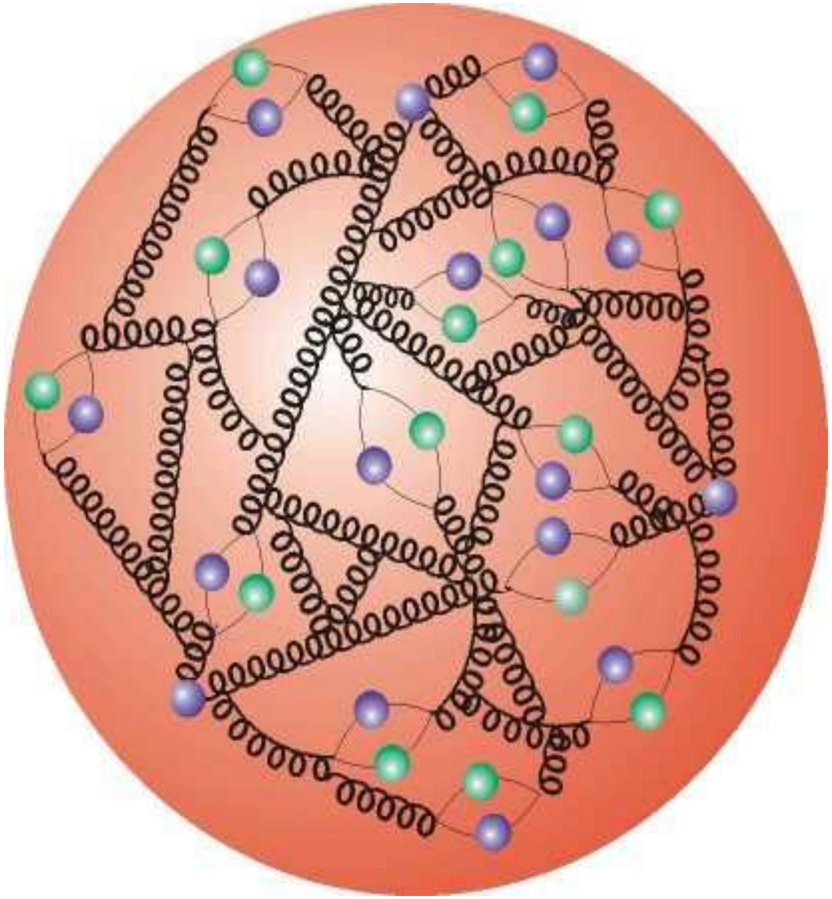
Virtualne čestice u svakodnevnom životu

Lambov pomak



Masa protona i neutrona



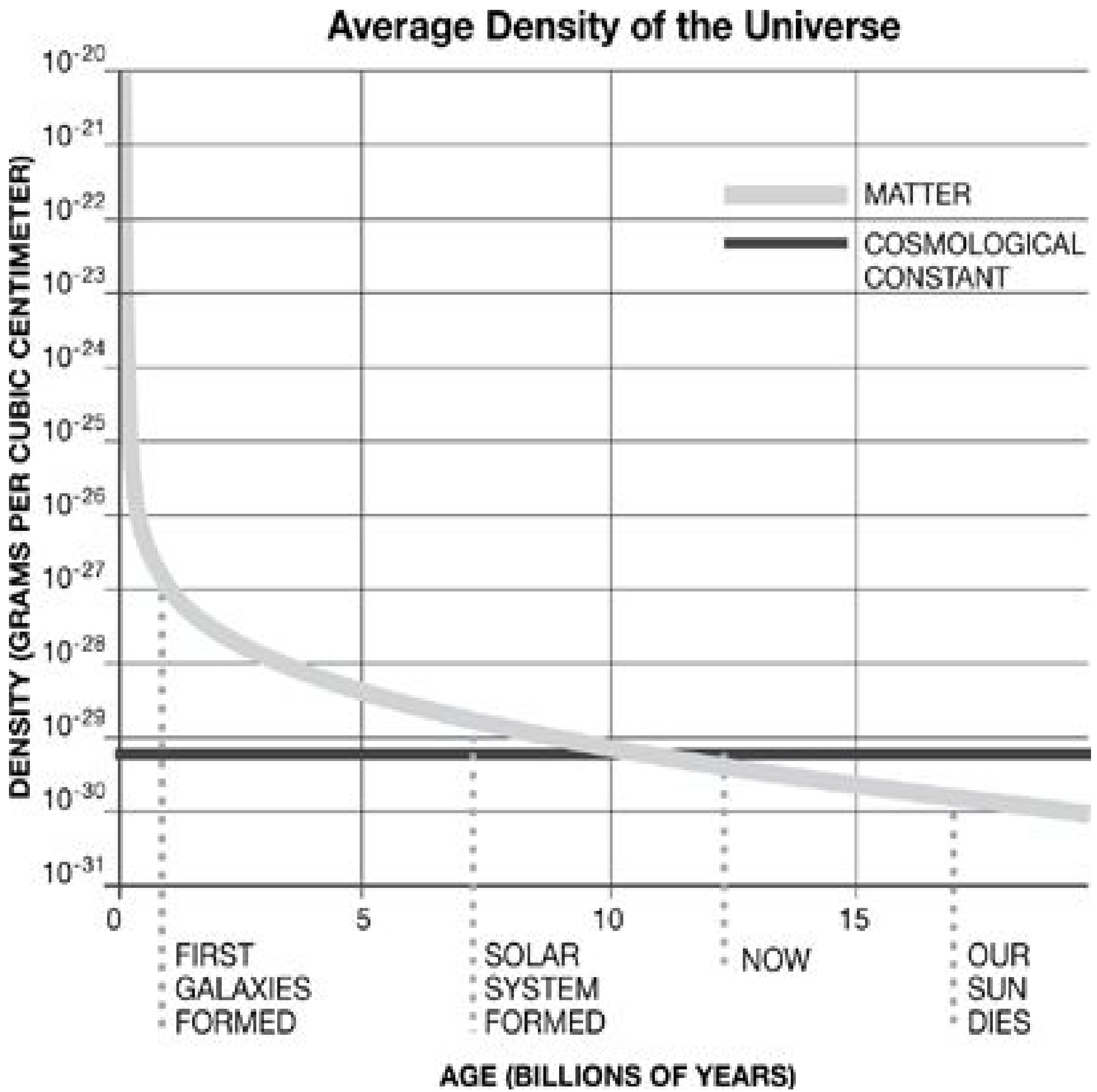


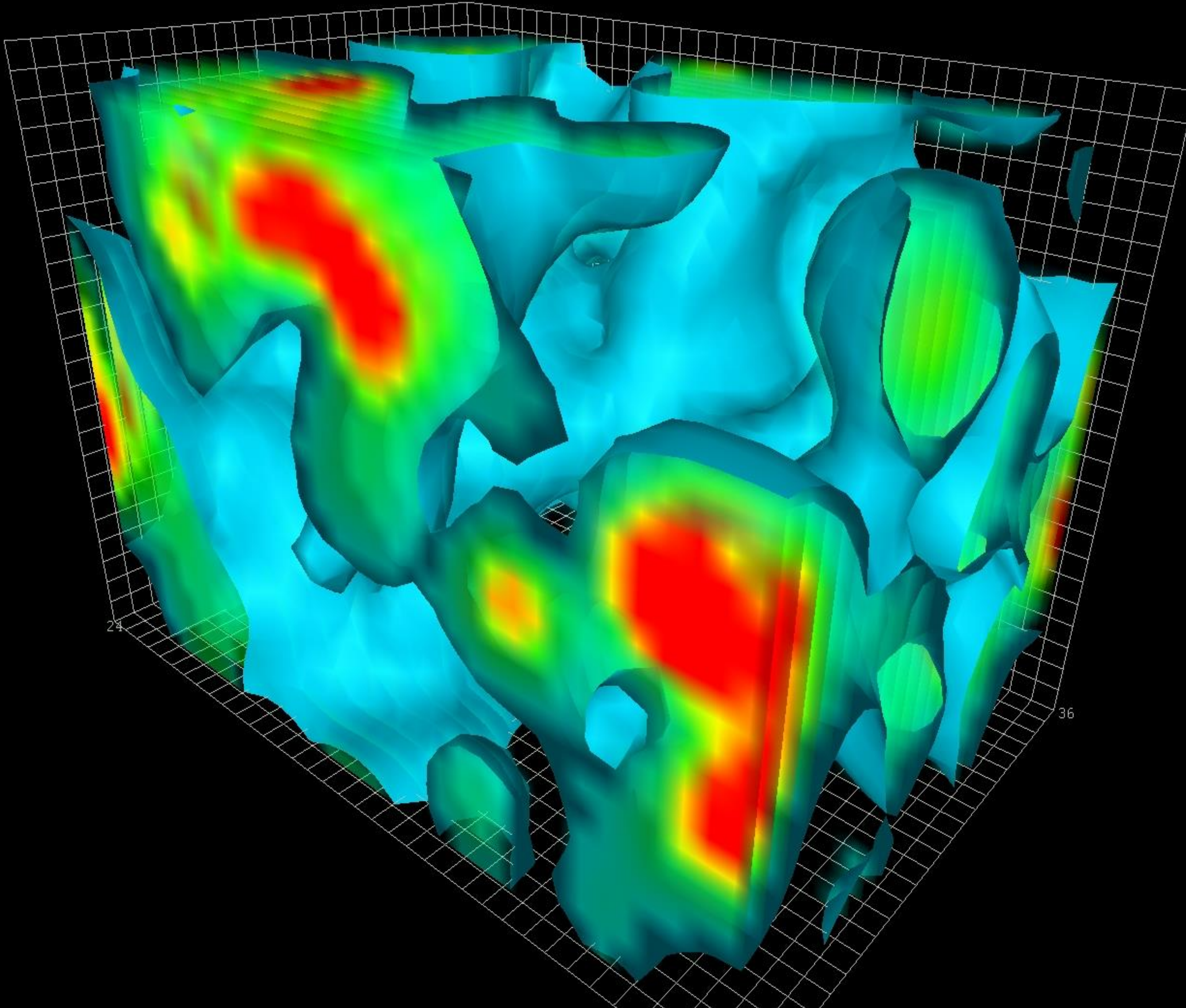
1 000 000 000 000 000 000 000 000
000 000 000 000 000 000 000 000
000 000 000 000 000 000 000 000
000 000 000 000 000 000 000 000
000 000 000 000 000 000 000 000
000

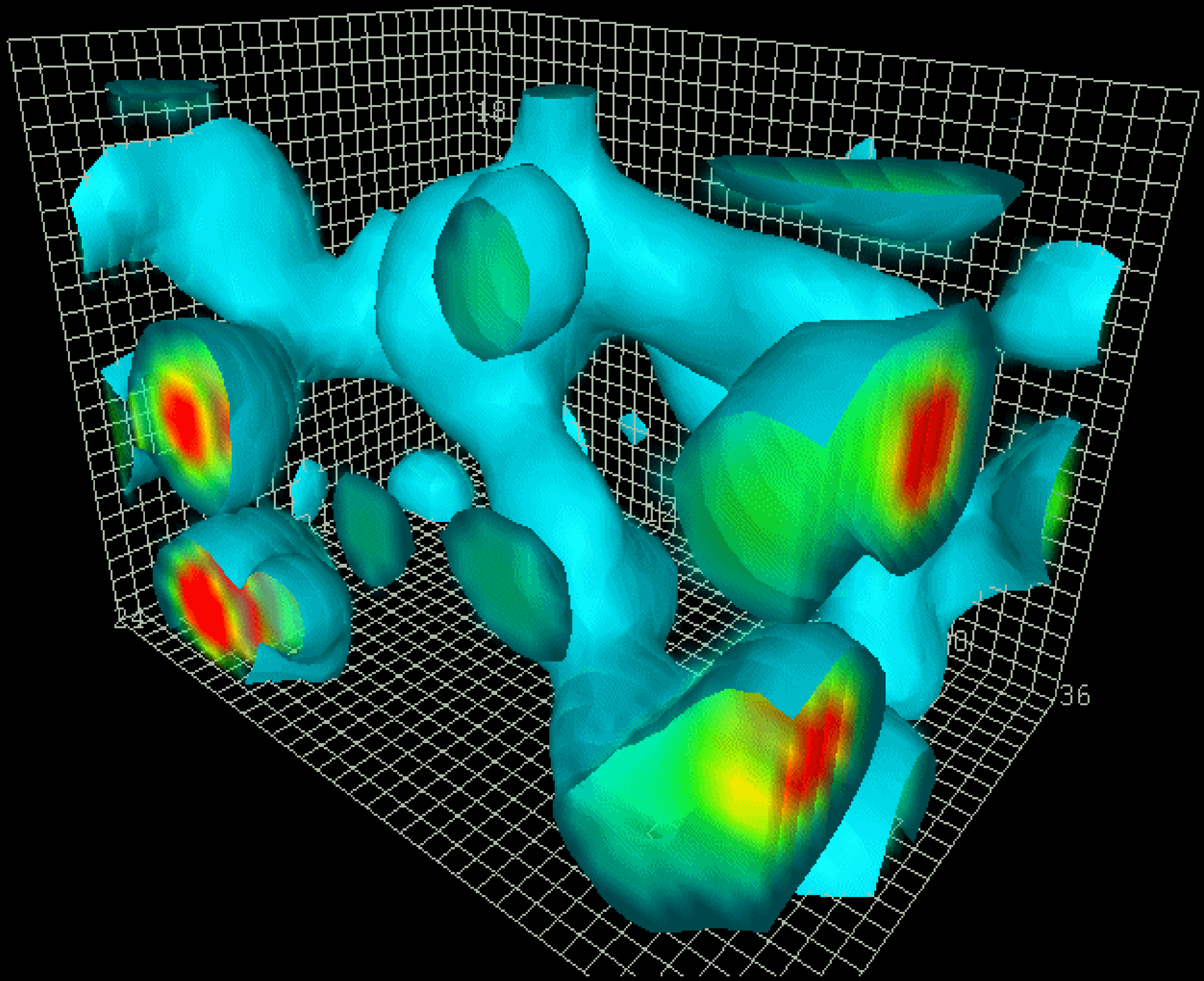
$$10^{120}$$

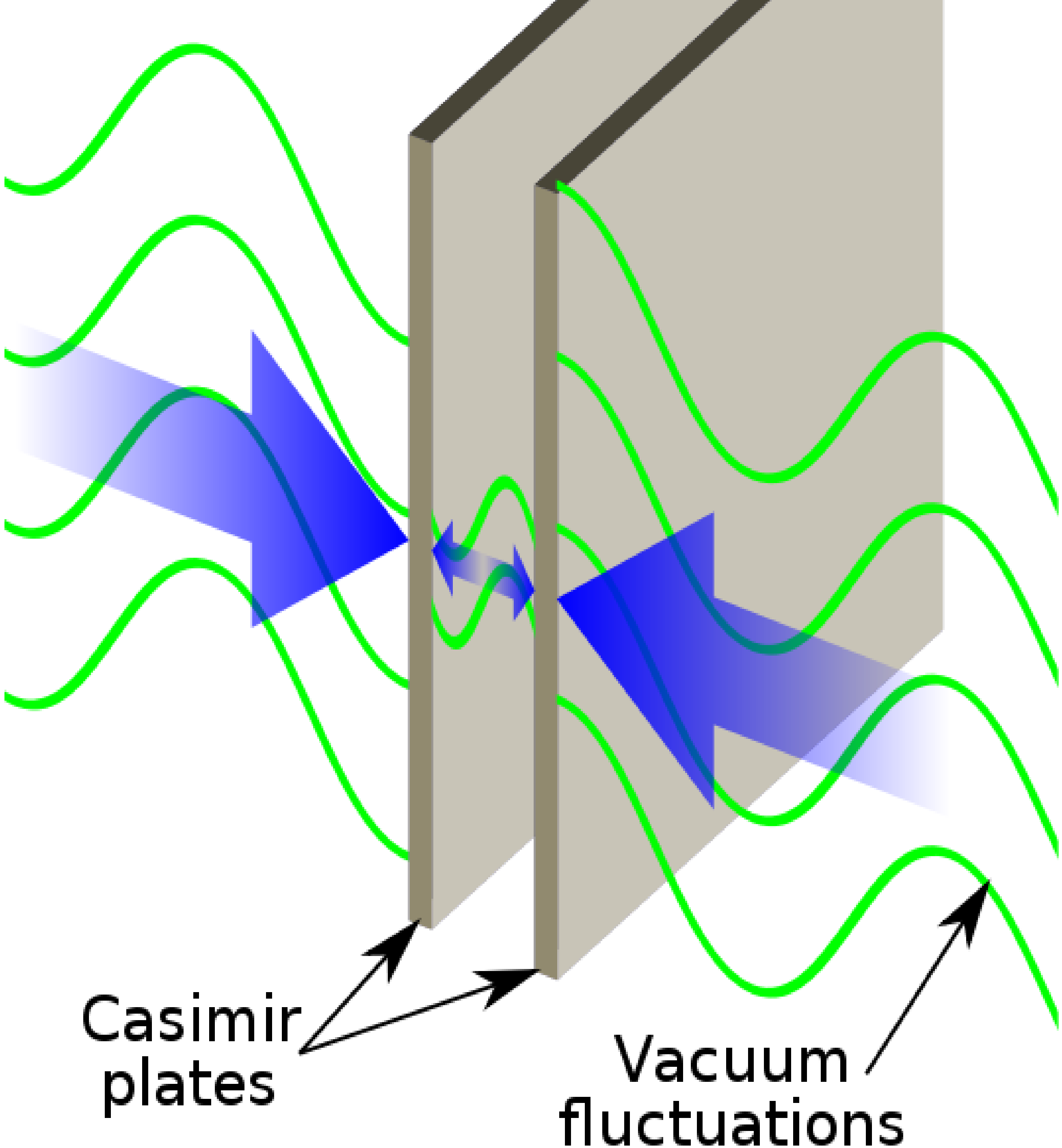
Mi živimo u **specijalnom vremenu**

I to jedinom u kojem možemo zaključiti da živimo u specijalnom vremenu

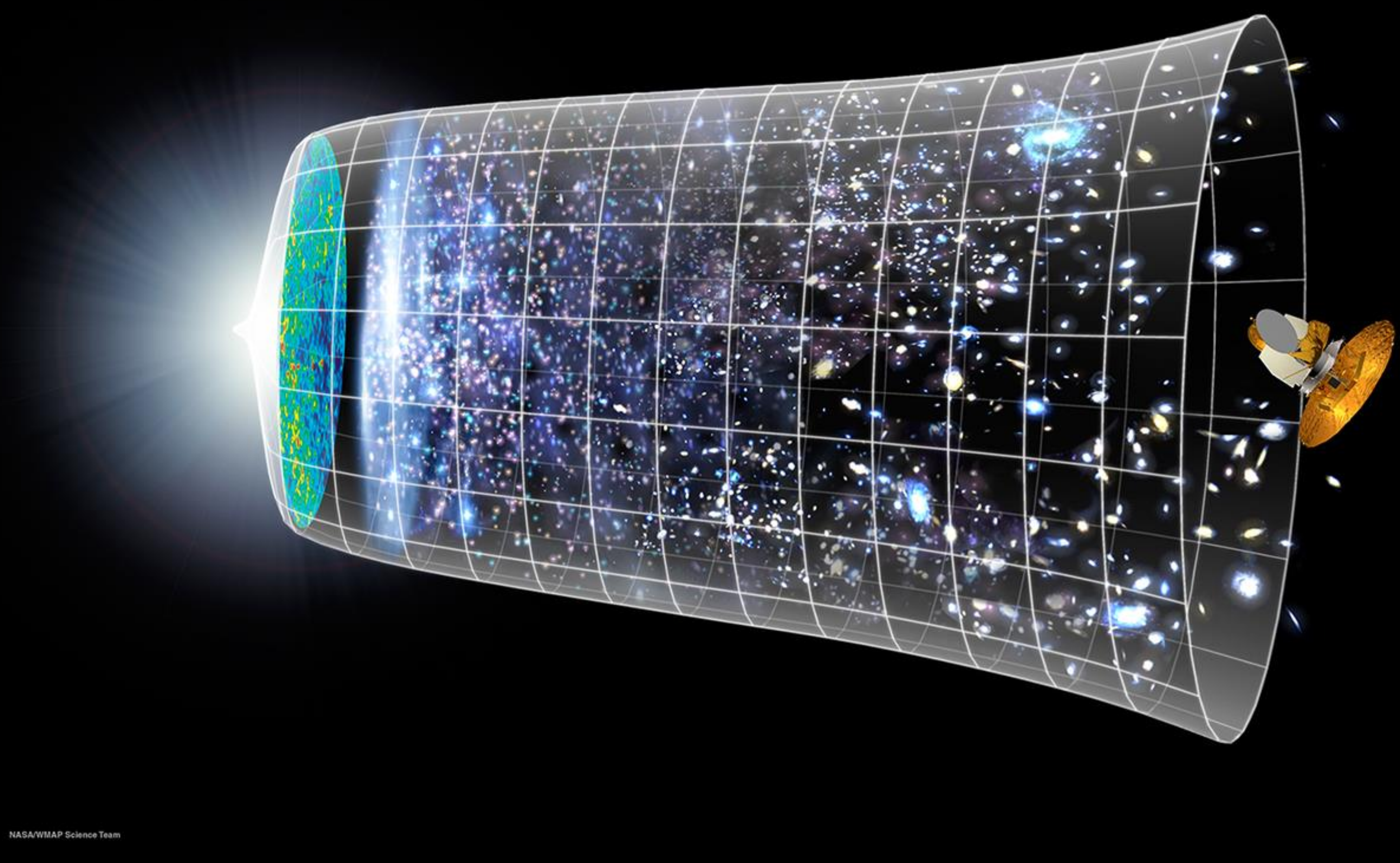

Average Density of the Universe
DENSITY (GRAMS PER CUBIC CENTIMETER)
10-20
10-21
10-22
10-23
10-24
10-25
10-26
10-27
10-28
10-29
10-30
10-31
MATTER
COSMOLOGICAL CONSTANT
0
5
10
15
FIRST GALAXIES FORMED
SOLAR SYSTEM FORMED
NOW
OUR SUN DIES
AGE (BILLIONS OF YEARS)

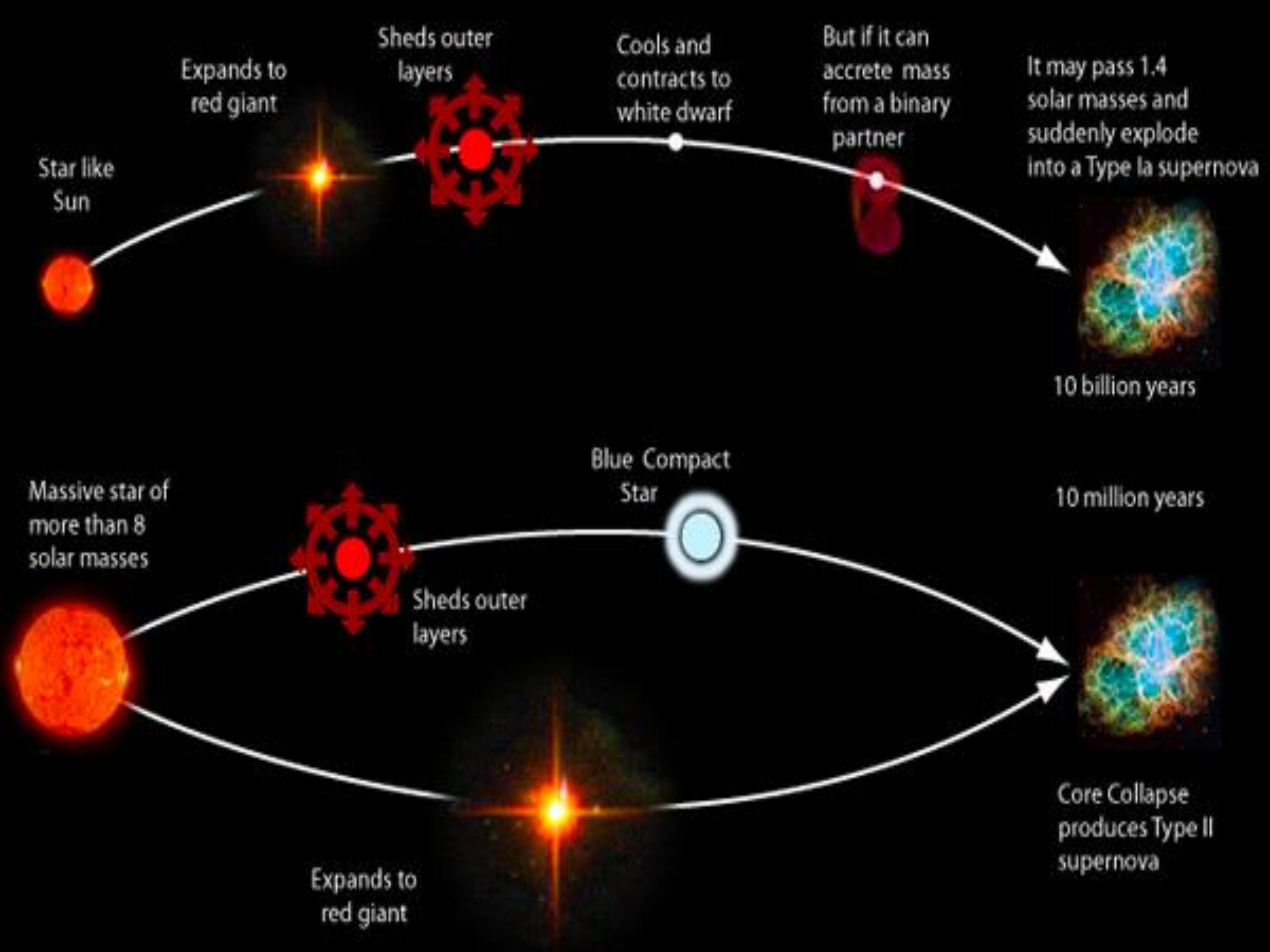

24
36


36

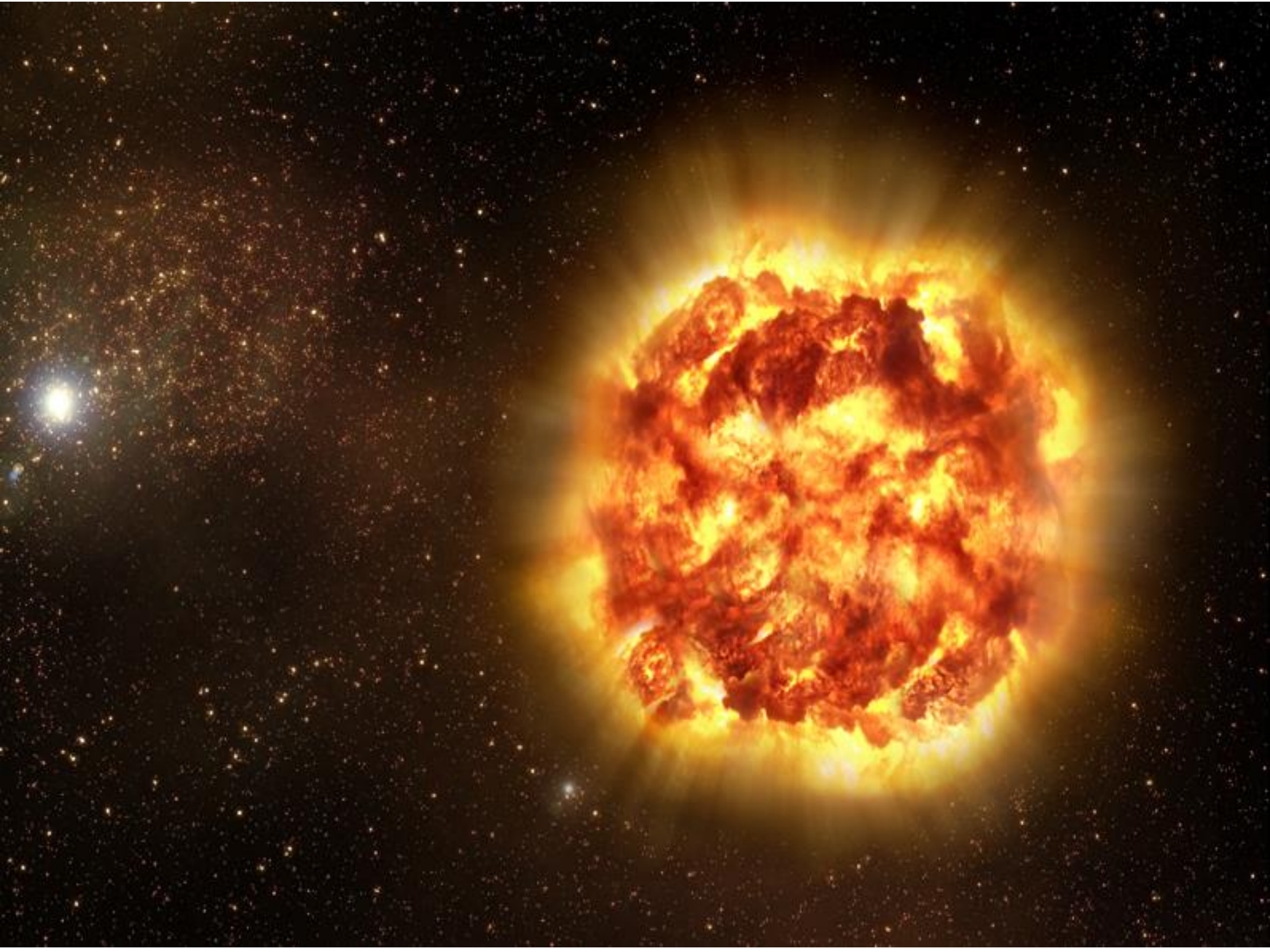

Casimir plates
Vacuum fluctuations

Kako će sve [možda] završiti?

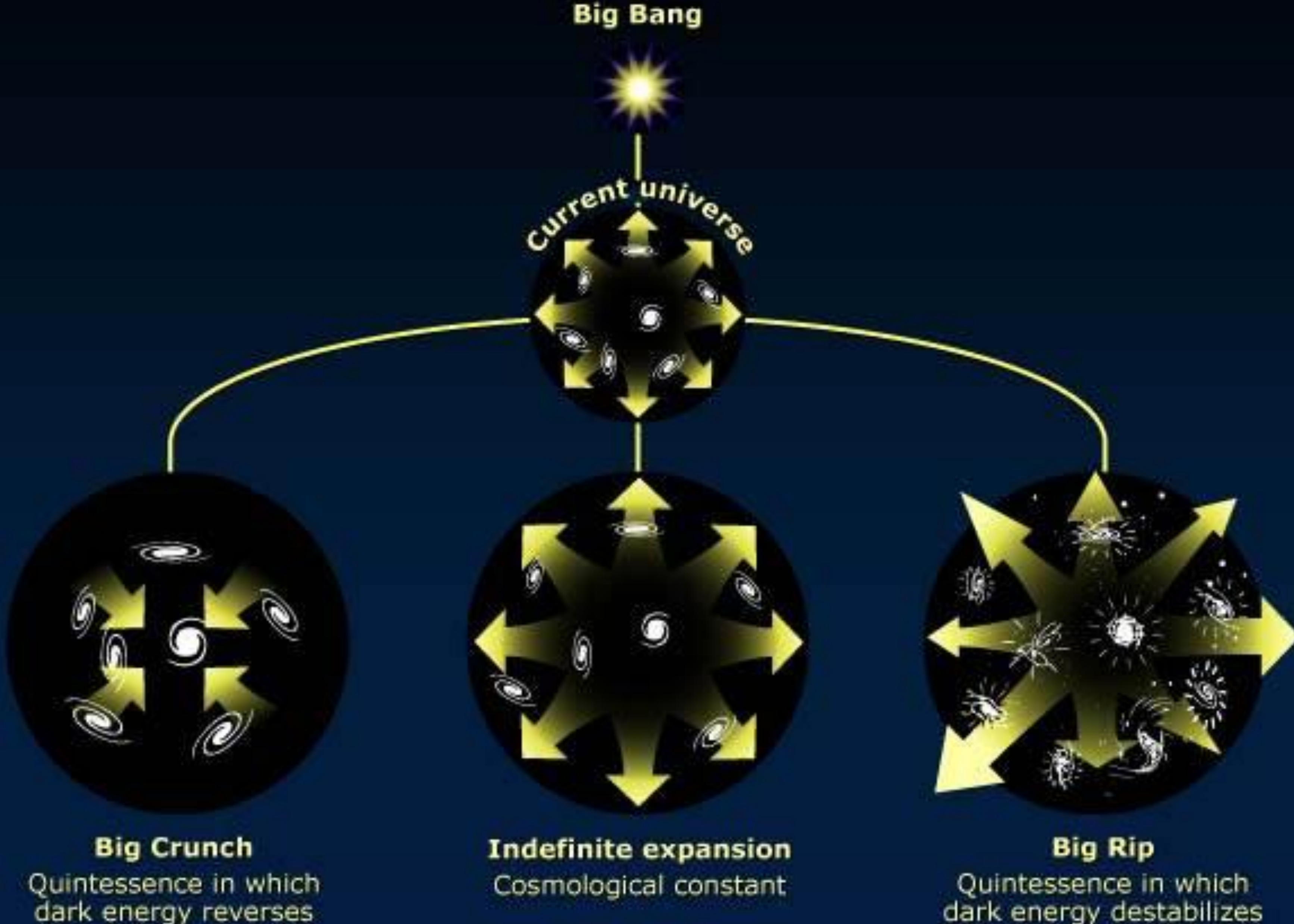


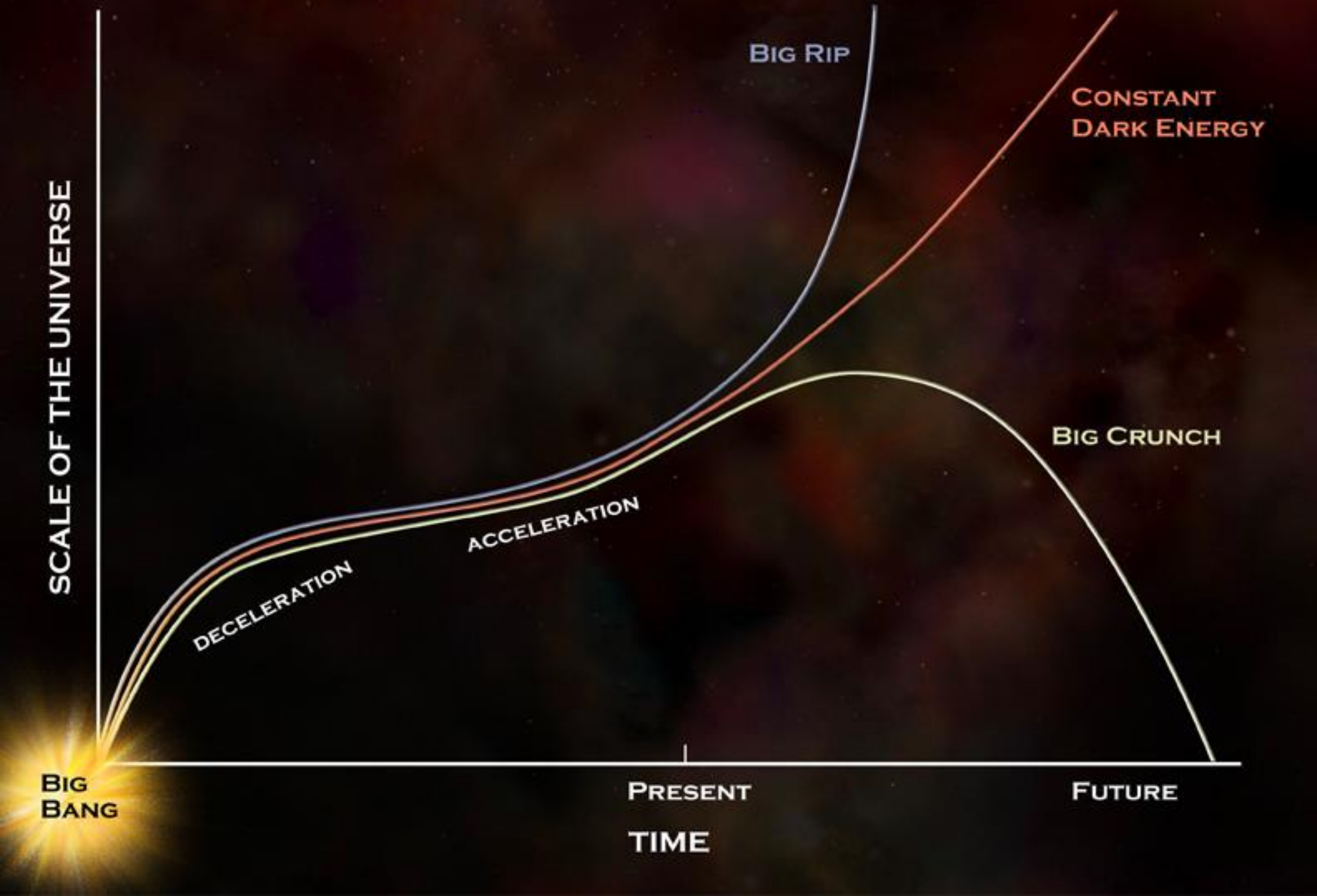


Star like Sun
Expands to red giant
Sheds outer layers
Cools and contracts to white dwarf
But if it can accrete mass from a binary partner
It may pass 1.4 solar masses and suddenly explode into a Type Ia supernova
10 billion years
Massive star of more than 8 solar masses
Sheds outer layers
Blue Compact Star
10 million years
Expands to red giant
Core Collapse produces Type II supernova



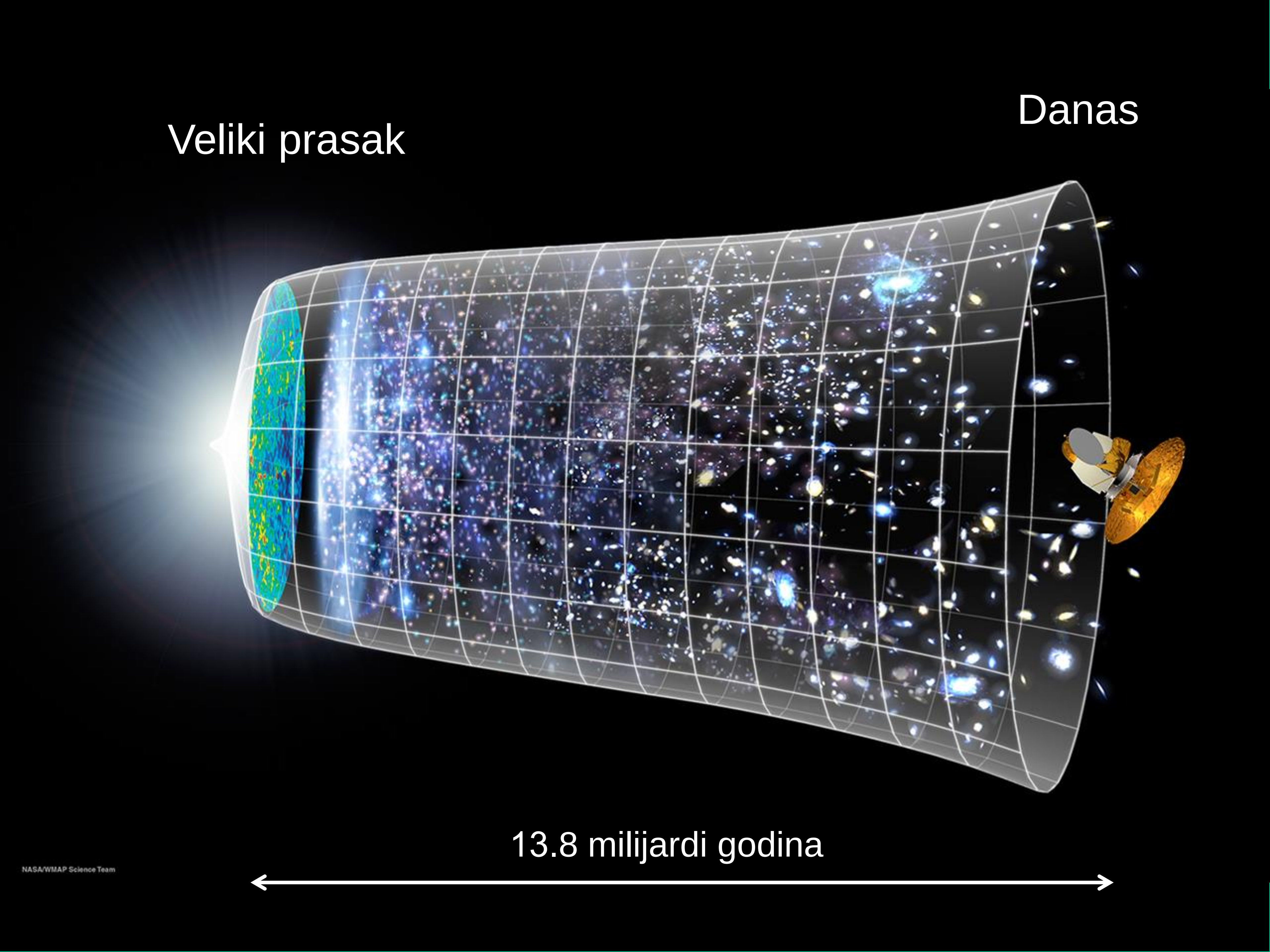
Future fates of the dark-energy universe





Big Rip
Constant
Dark Energy
Big Crunch
Scale of the Universe
acceleration
deceleration
Big
Bang
Present
Future
Time


MULTIVERSE


Veliki prasak
Danas
13.8 milijardi godina
NASA/WMAP Science Team