

Chemistry element data

1 H Hydrogen	2 He Helium																	10 Ne Neon	11 Na Sodium	12 Mg Magnesium	13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon	19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon	55 Cs Cesium	56 Ba Barium	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon	87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Uub Ununbium	113 Uut Ununtrium	114 Uuq Ununquadium	115 Uup Ununpentium	116 Uuh Ununhexium	117 Uus Ununseptium	118 Uuo Ununoctium
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Odakle sve ovo?



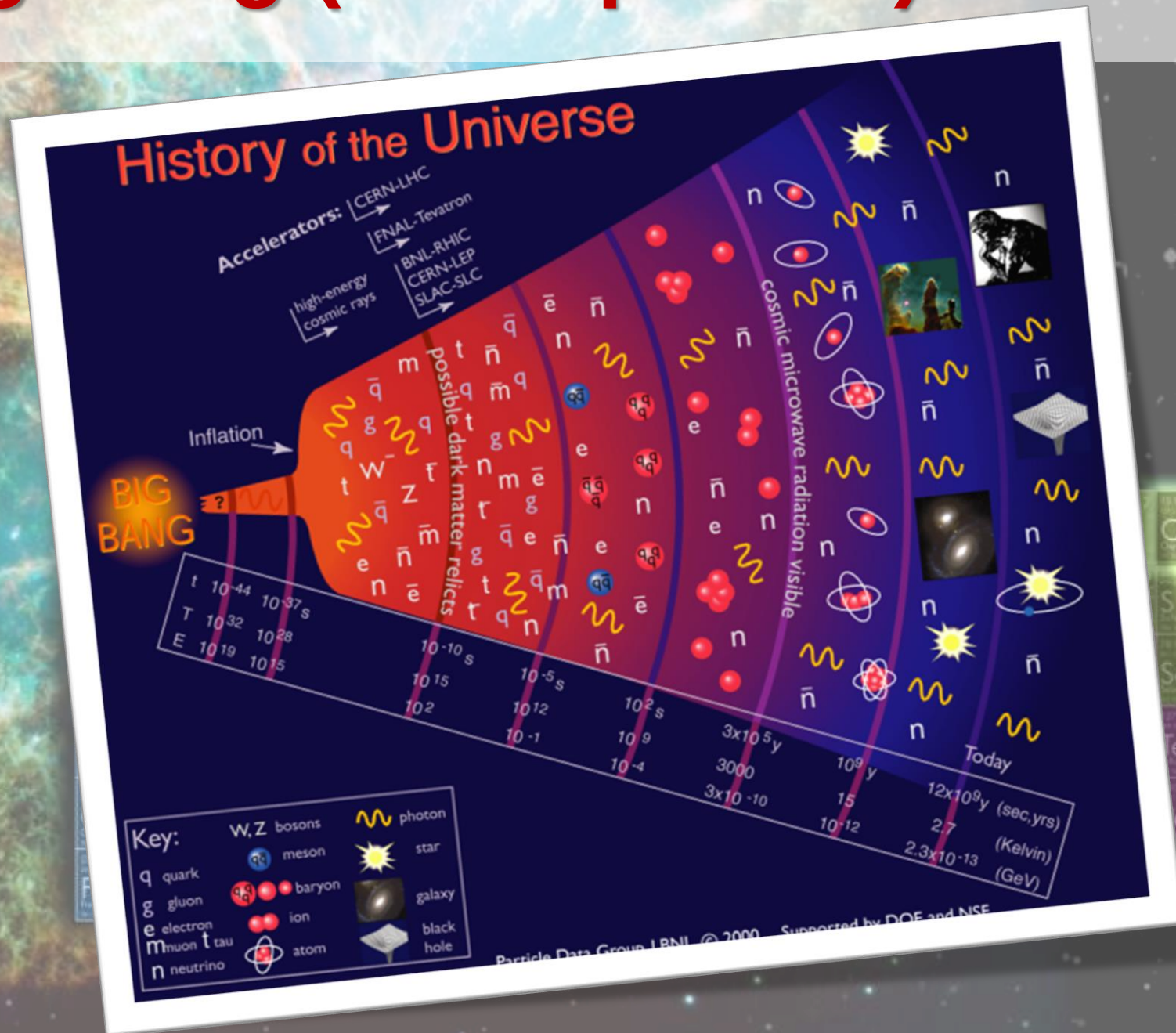
1.00794 1 H Hydrogen	
6.941 3 Li Lithium	9.012182 4 Be Beryllium
22.989769 11 Na Sodium	40.078 12 Mg Magnesium
39.0983 19 K Potassium	40.078 20 Ca Calcium
85.4678 37 Rb Rubidium	87.62 38 Sr Strontium
132.90545 55 Cs Cesium	137.327 56 Ba Barium
223 87 Fr Francium	226 88 Ra Radium

			4.002602 2 He Helium
12.0107 6 C Carbon	14.0064 7 N Nitrogen	15.999 8 O Oxygen	18.998403 9 F Fluorine
28.0855 14 Si Silicon	30.973762 15 P Phosphorus	32.06 16 S Sulfur	35.453 17 Cl Chlorine
72.64 32 Ge Germanium	74.921595 33 As Arsenic	78.96 34 Se Selenium	79.904 35 Br Bromine
118.710 50 Sn Tin	121.757 51 Sb Antimony	127.60 52 Te Tellurium	126.90447 53 I Iodine
208.9796 82 Pb Lead	208.9796 83 Bi Bismuth	209 84 Po Polonium	208.9796 85 At Astatine
289 114 Fl Flerovium	289 115 Uup Ununpentium	289 116 Uuh Ununhexium	289 117 Uus Ununseptium
			289 118 Uuo Ununoctium

Big Bang (veliki prasak)...



Big Bang (veliki prasak)...



															
1 H Hydrogen		2 He Helium													
3 Li Lithium		4 Be Beryllium		5 B Boron		6 C Carbon		7 N Nitrogen		8 O Oxygen		9 F Fluorine		10 Ne Neon	
11 Na Sodium		12 Mg Magnesium		13 Al Aluminum		14 Si Silicon		15 P Phosphorus		16 S Sulfur		17 Cl Chlorine		18 Ar Argon	
19 K Potassium		20 Ca Calcium		21 Sc Scandium		22 Ti Titanium		23 V Vanadium		24 Cr Chromium		25 Mn Manganese		26 Fe Iron	
27 Co Cobalt		28 Ni Nickel		29 Cu Copper		30 Zn Zinc		31 Ga Gallium		32 Ge Germanium		33 As Arsenic		34 Se Selenium	
35 Br Bromine		36 Kr Krypton		37 Rb Rubidium		38 Sr Strontium		39 Y Yttrium		40 Zr Zirconium		41 Nb Niobium		42 Mo Molybdenum	
43 Tc Technetium		44 Ru Ruthenium		45 Rh Rhodium		46 Pd Palladium		47 Ag Silver		48 Cd Cadmium		49 In Indium		50 Sn Tin	
51 Sb Antimony		52 Te Tellurium		53 I Iodine		54 Xe Xenon		55 Ba Barium		56 La Lanthanum		57 Ce Cerium		58 Pr Praseodymium	
59 Nd Neodymium		60 Pm Promethium		61 Sm Samarium		62 Eu Europium		63 Gd Gadolinium		64 Tb Terbium		65 Dy Dysprosium		66 Ho Holmium	
67 Er Erbium		68 Tm Thulium		69 Yb Ytterbium		70 Lu Lutetium		71 Hf Hafnium		72 Ta Tantalum		73 W Tungsten		74 Re Rhenium	
75 Os Osmium		76 Ir Iridium		77 Pt Platinum		78 Au Gold		79 Hg Mercury		80 Tl Thallium		81 Pb Lead		82 Bi Bismuth	
83 Po Polonium		84 At Astatine		85 Rn Radon		86 Fr Francium		87 Ra Radium		88 Ac Actinium		89 Th Thorium		90 Pa Protactinium	
91 U Uranium		92 Np Neptunium		93 Pu Plutonium		94 Am Americium		95 Cm Curium		96 Bk Berkelium		97 Cf Californium		98 Es Einsteinium	
99 Fm Fermium		100 Md Mendelevium		101 Nh Nihonium		102 Ds Darmstadtium		103 Rg Roentgenium		104 Uu Ununquadium		105 Uuh Ununhexium		106 Uub Ununseptium	

Svaki atom na Zemlji...

... nekada je bio deo jedne zaboravljene zvezde!

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Big Bang

Supernovae

Large Stars

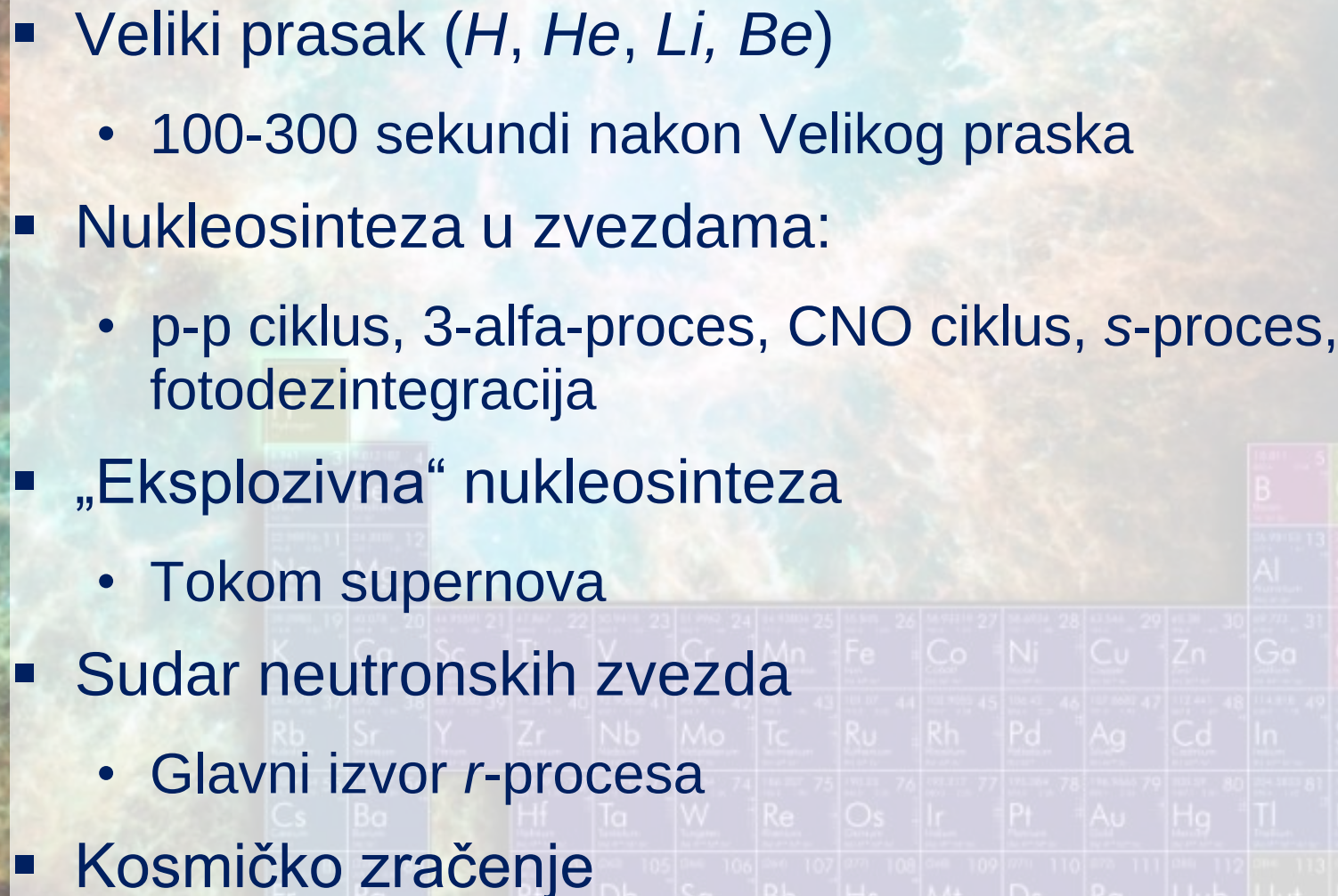
Small Stars

Cosmic Rays

Nukleosinteza

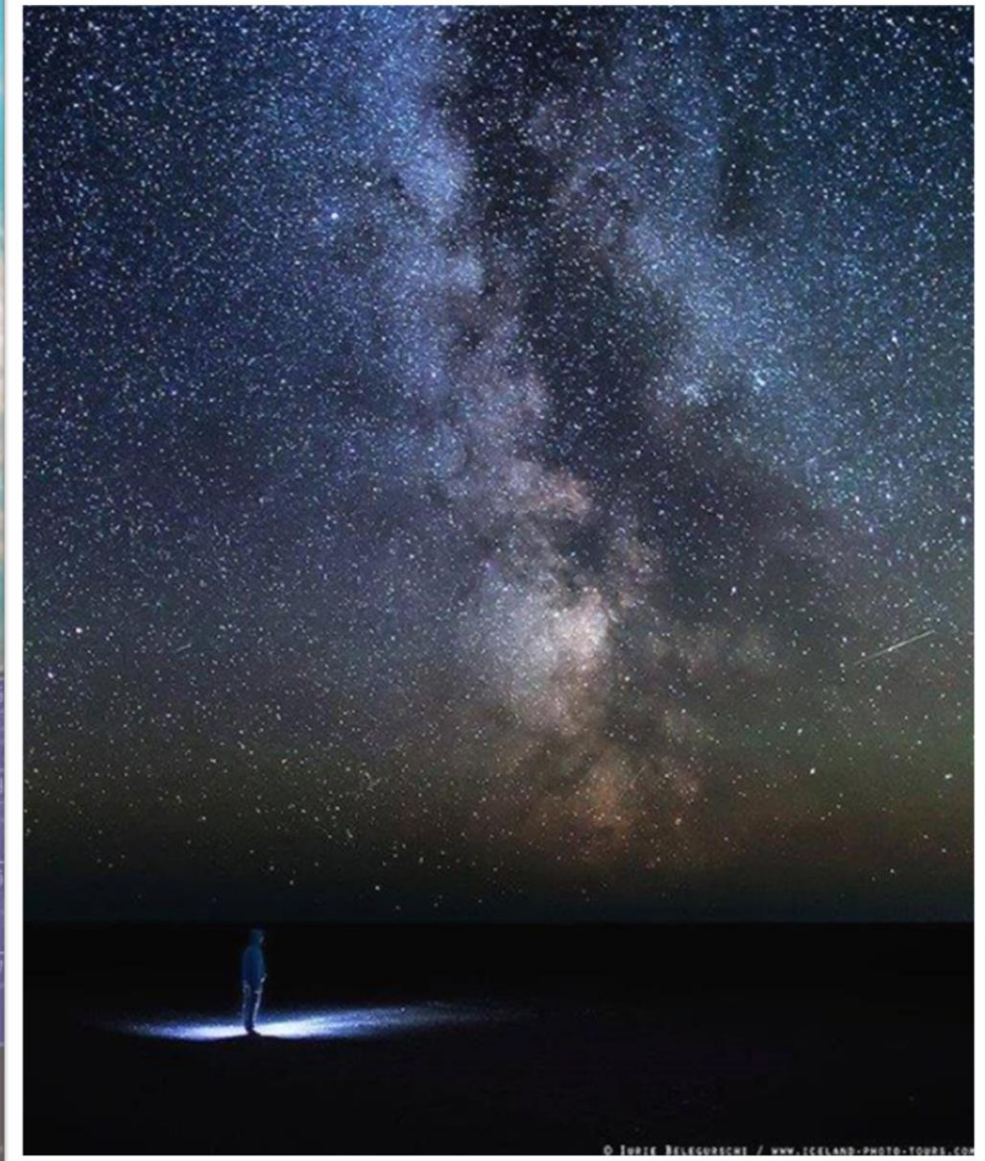
- Prva ideja – elementi nastali kad i svemir
- H i He – najrasprostranjeniji (ostali samo 2% mase Sunčevog sistema); ledeći O i C .
- Artur Edington (1920) – prva ideja o fuziji vodonika u zvezdama; mogu i ostali – slabo prihvaćena ideja.
- Hans Bete (1938) – nuklearne reakcije --> kako sija Sunce
- Fred Hojl – nastanak težih elemenata
- E. Margaret Burbidge, G. R. Burbidge, William A. Fowler, and F. Hoyle, *Synthesis of the Elements in Stars*, Rev. Mod. Phys. 29, 547 (1957) <https://doi.org/10.1103/RevModPhys.29.547>

Nukleosinteza

- 
- Veliki prasak (*H, He, Li, Be*)
 - 100-300 sekundi nakon Velikog praska
 - Nukleosinteza u zvezdama:
 - p-p ciklus, 3-alfa-proces, CNO ciklus, s-proces, fotodezintegracija
 - „Eksplozivna“ nukleosinteza
 - Tokom supernova
 - Sudar neutronske zvezde
 - Glavni izvor *r*-procesa
 - Kosmičko zračenje

Zvezde su uvek iste?

- “Tačkice” na nebu
- Ogromne lopte vrelog gasa
- Toplota nastaje u njihovom centru
- Različite boje





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Fr	Ra	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
Francium	Radium	Rutherfordium	Dubnium	Seaborgium	Berkelium	Hassium	Moscovium	Darmstadtium	Roentgenium	Ununbium	Ununtrium	Ununquadium	Ununpentium	Ununhexium	Ununseptium	Ununoctium

118

Naša zvezda - Sunce



	4.002602 2 He Helium
18.998403 9 F Fluorine	20.1797 10 Ne Neon
35.453 17 Cl Chlorine	39.948 18 Ar Argon
79.904 35 Br Bromine	83.798 36 Kr Krypton
126.9044 53 I Iodine	131.293 54 Xe Xenon
170.907 85 At Astatine	222 86 Rn Radon
117 117 Uus Ununseptium	118 118 Uuo Ununoctium

Ali...



He	2
Ne	10
Ar	18
Kr	36
Xe	54
Rn	86
Uuh	116
Uus	117
Uuo	118

Slike nam pričaju priču...



	N Nitrogen	O Oxygen	F Fluorine	Ne Neon
14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Slike nam pričaju priču...



Slike nam pričaju priču...



Kako stvoriti zvezdu?

■ Sastojci:

- Vodonik
- Gravitacija
- Vreme... mnogo vremena



- zduh - 30×10^{18} at./cm³)
- eratura: 100K
(C)

-

HST • WFPC2

1. Hester and P. Scowen (AZ State Univ.), NASA
PRC92-444 - ST SCI OPO - November 5, 1992

Tamna maglina



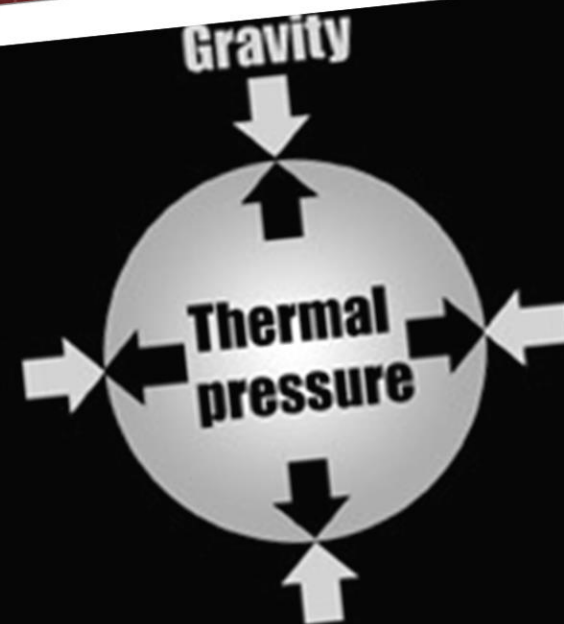
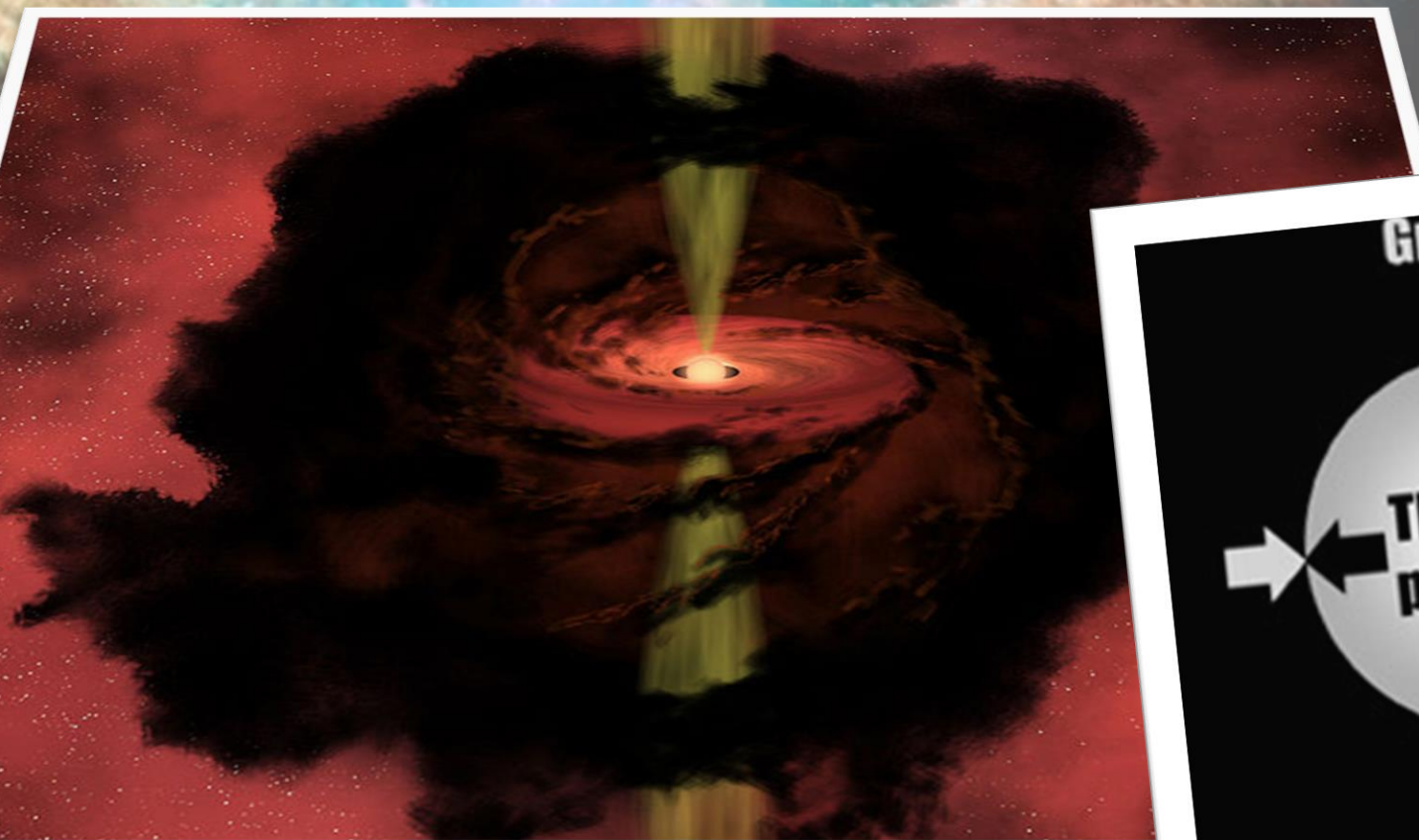
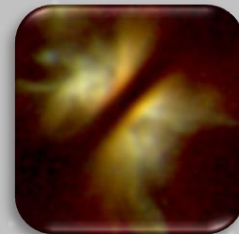
Ag	Cd	In	Sn	Sb	Te	I	Xe
107.8662 47	112.414 48	114.818 49	118.710 50	121.757 51	127.6 52	126.905 53	131.29 54
Au	Hg	Tl	Pb	Bi	Po	At	Rn
196.966569 79	200.59 80	204.3833 81	207.2 82	208.9804 83	209 84	210 85	222 86
Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
272 111	287 112	288 113	289 114	290 115	291 116	292 117	293 118

Globula

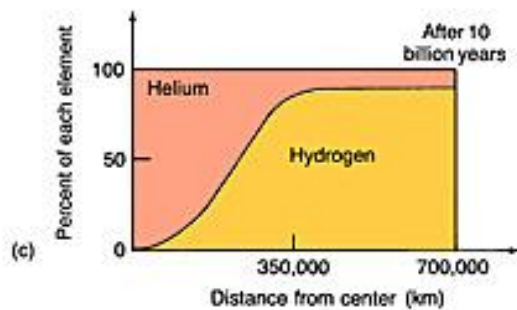
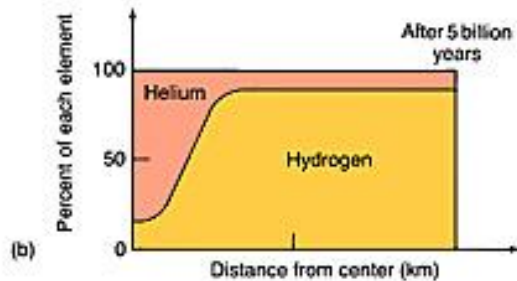
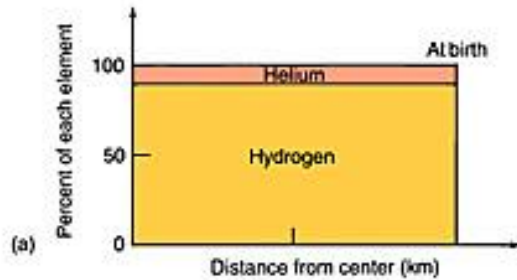
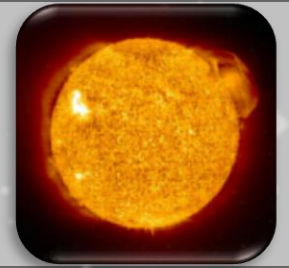


		4.002602 2.003 He Helium	2
9	18.998403 1.007 F Fluorine	20.1797 10.007 Ne Neon	10
	35.453 35.453 Cl Chlorine	39.948 39.948 Ar Argon	18
4	79.904 79.904 Br Bromine	83.798 83.798 Kr Krypton	36
2	126.9044 126.9044 I Iodine	131.293 131.293 Xe Xenon	54
4	174.927 174.927 At Astatine	222 222 Rn Radon	86
6	117 117 Uus Ununseptium	294 294 Uuo Ununoctium	118

Protozvezda



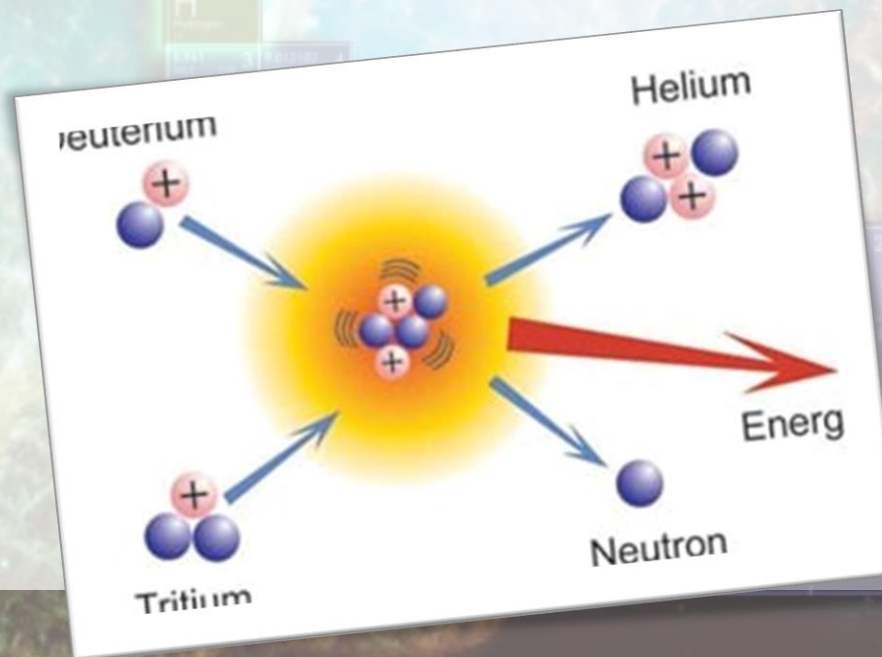
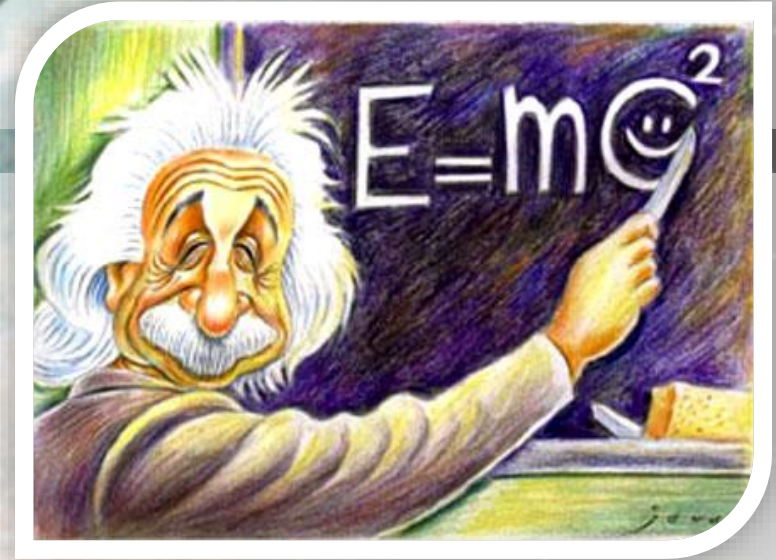
Zvezda je rođena



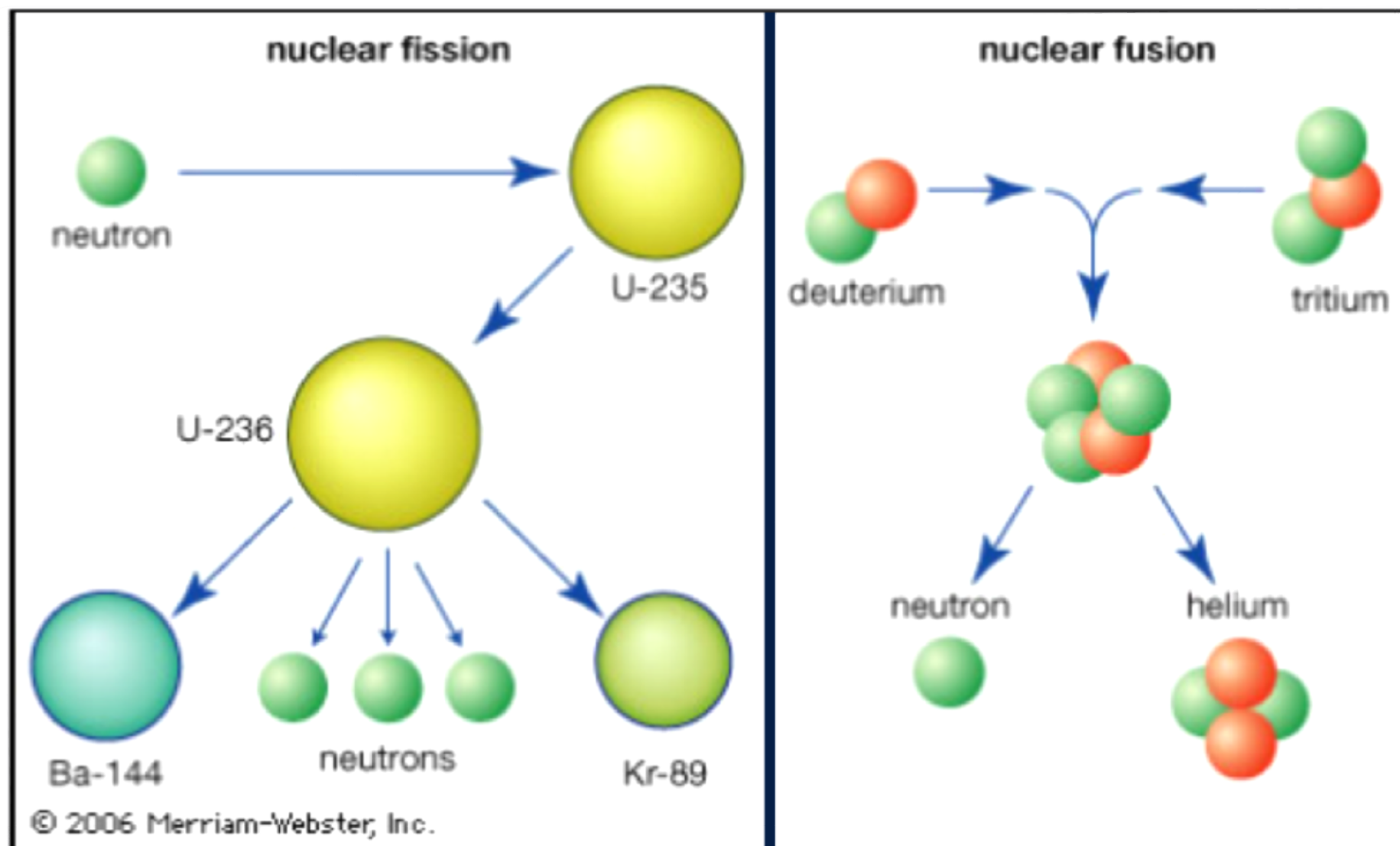
- Temperatura: 10 miliona stepeni

Kako sijaju zvezde?

- Vatra? Ne ☹️
 - Energija Sunca: $2 \cdot 10^{-4} \frac{J}{kg \cdot s}$
- Hemijska reakcija? Ne ☹️
- Fuzija! DA! 😊



Nuklearna fuzija vs fisija



Nuklearna fuzija

- Spajanje lakih jezgara i dobijanje jezgra veće mase
- Jezgro 1 + jezgro 2 $\rightarrow$ jezgro 3 + energija
- Tokom fuzione reakcija ukupna masa se smanjuje – masa jezgra 3 manja je od zbira masa jezgra 1 i jezgra 2
- Ekvivalencija mase i energije: $E = mc^2$
 - 1 kg $\rightarrow$ 9×10^{16} J
- Zakon održanja mase i energije

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

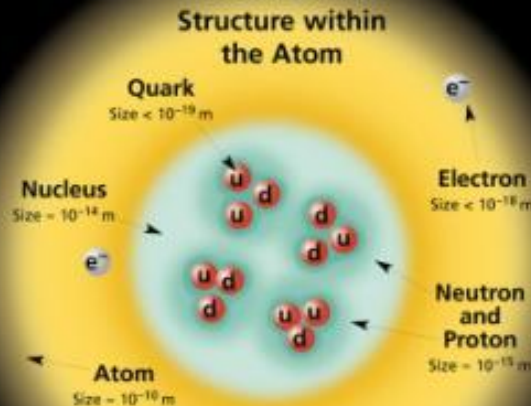
The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-11}$	0
e^- electron	0.000511	-1
ν_μ muon neutrino	<0.0002	0
μ^- muon	0.106	-1
ν_τ tau neutrino	<0.02	0
τ^- tau	1.7771	-1

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c ²	Electric charge
u up	0.003	2/3
d down	0.006	-1/3
c charm	1.3	2/3
s strange	0.1	-1/3
t top	175	2/3
b bottom	4.3	-1/3



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 3.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1		
Name	Mass GeV/c ²	Electric charge
γ photon	0	0
W^-	80.4	-1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq .

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2

Property \ Interaction	Gravitational	Weak	Electromagnetic	Strong	
		(Electroweak)		Fundamental	Residual
Acts on:	Mass - Energy	Flavor		Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons		Electrically charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0		γ	Gluons
Strength relative to electromag. for two u quarks at:	10^{-41}	0.8		1	25
for two protons in nucleus	10^{-41}	10^{-4}		1	60
	10^{-36}	10^{-7}		1	Not applicable to hadrons
					20

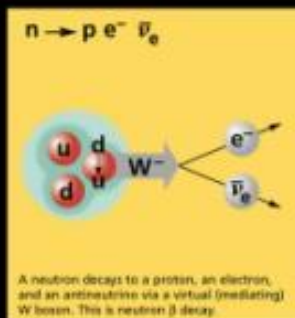
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 148 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	-1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter

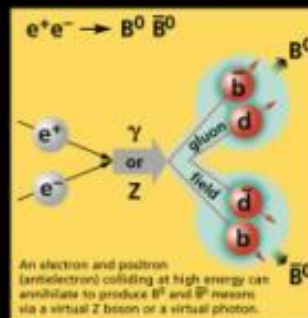
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or - charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ , and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

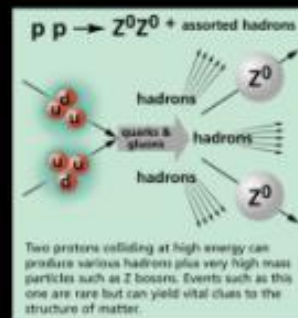
These diagrams are an artist's conception of physical processes. They are not exact and have no meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W^- boson. This is neutron β decay.



An electron and positron (antilepton) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at <http://ParticleAdventure.org>

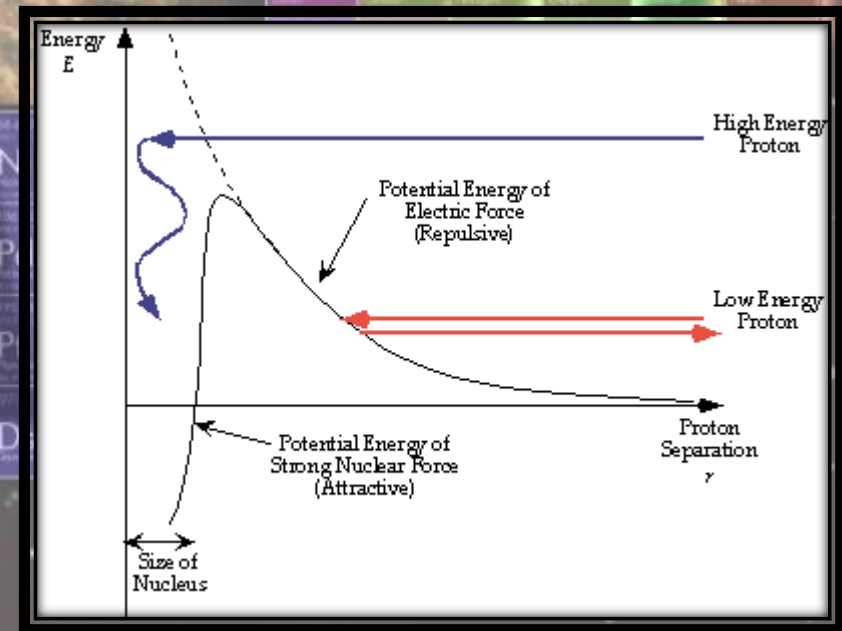
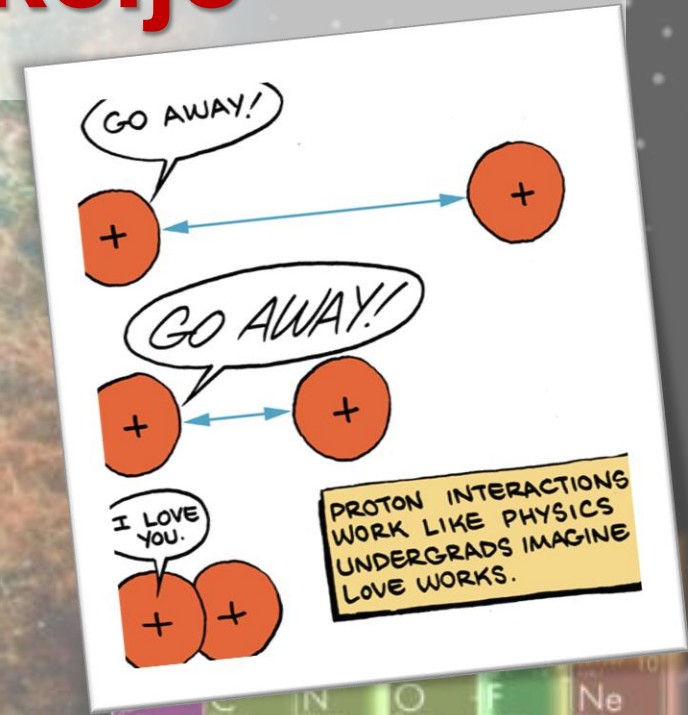
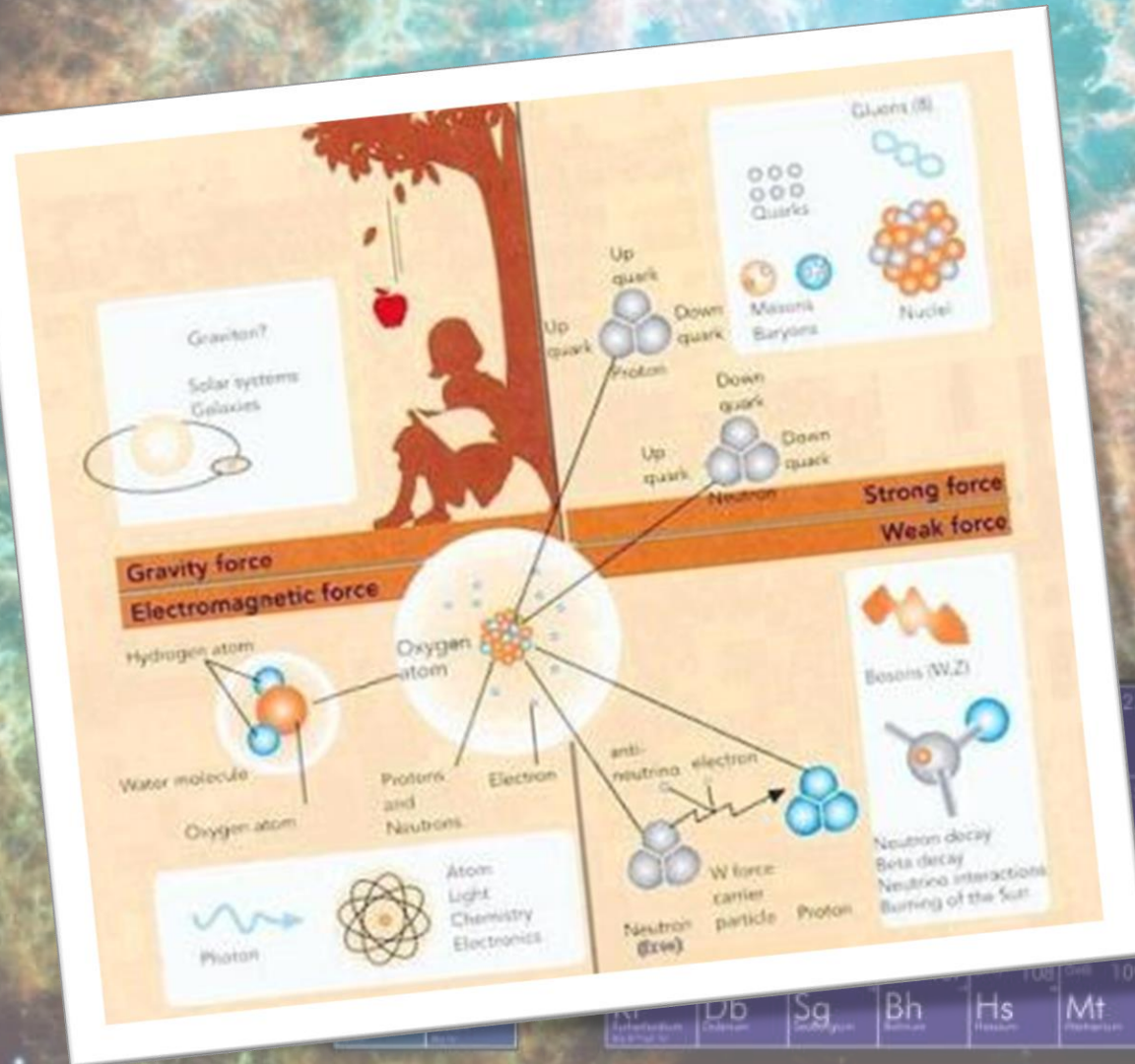
This chart has been made possible by the generous support of:

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American Physical Society, Division of Particles and Fields
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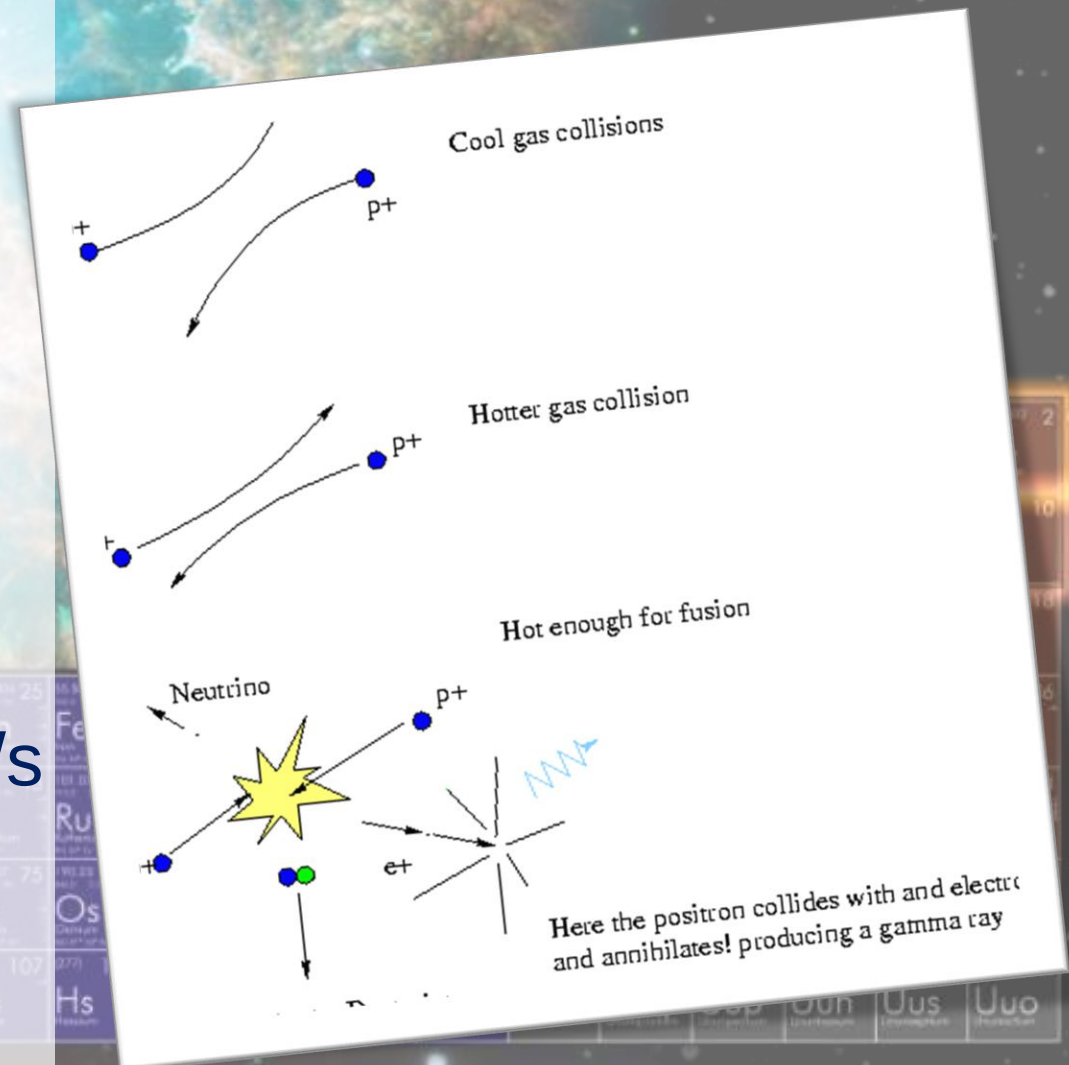
<http://CPEPweb.org>

Fundamentalne interakcije

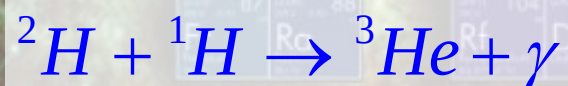
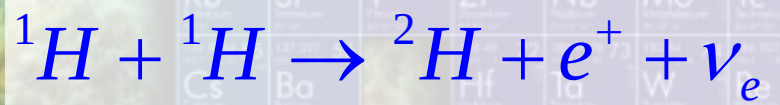
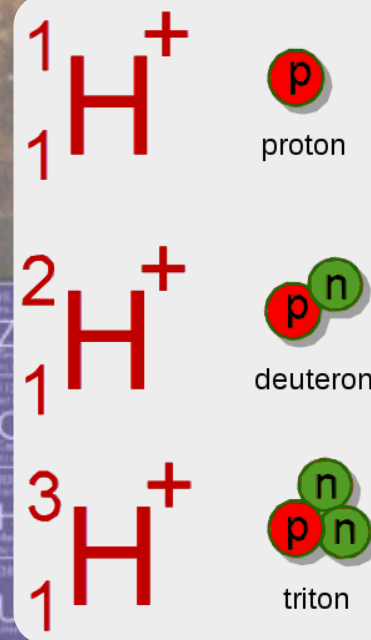
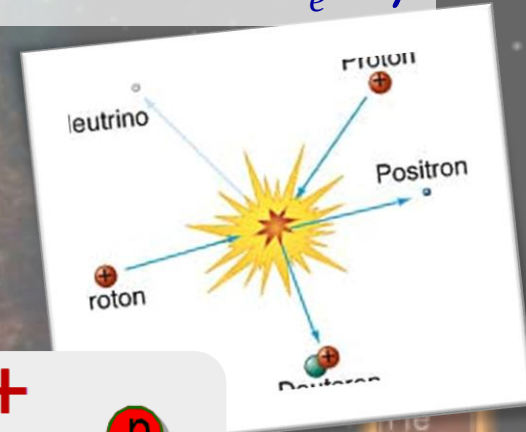
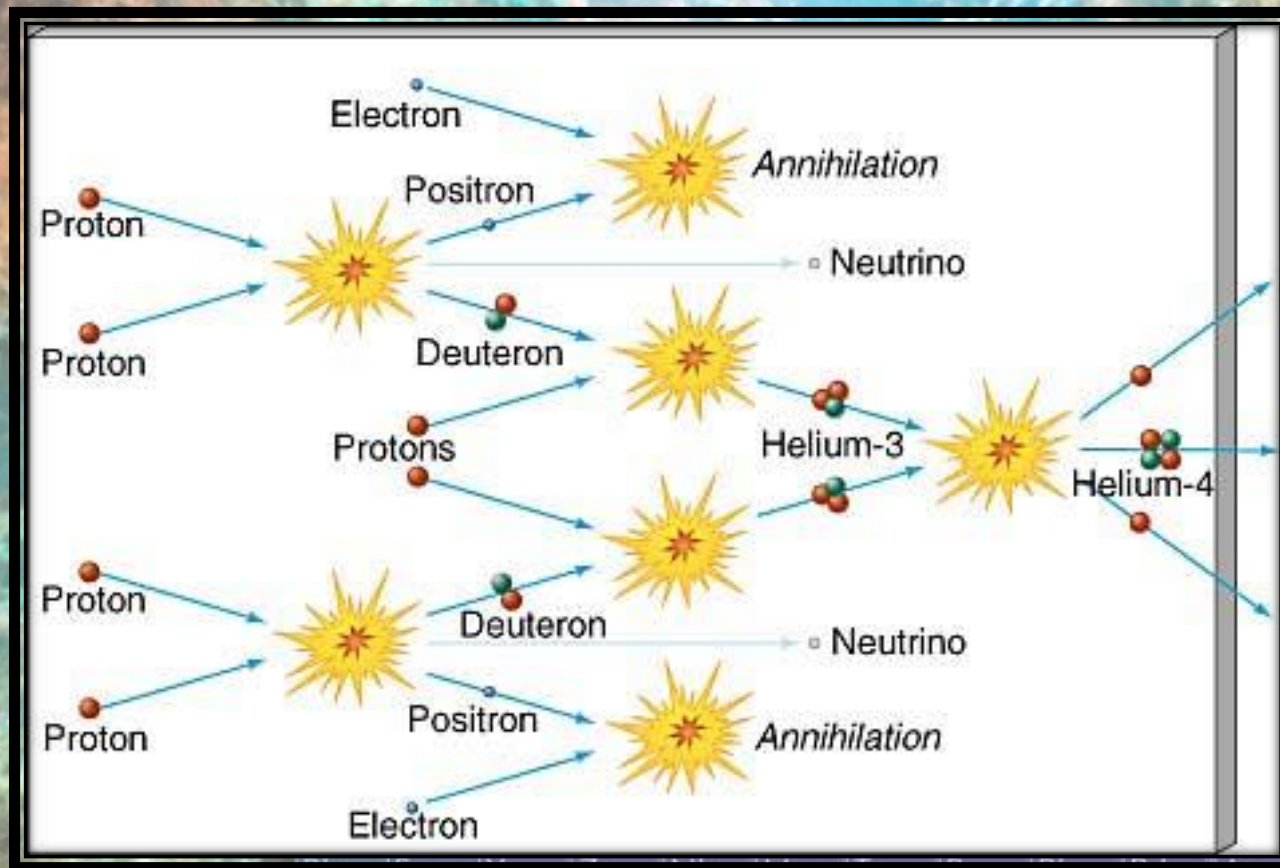


Nuklearna fuzija

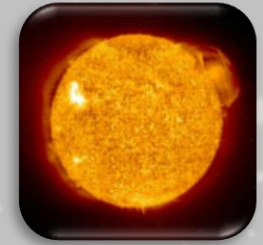
- Velika brzina
- Jaka nuklearna sila
- Rastojanje: 10^{-15} m
- Brzina: nekoliko 100 km/s
- Temperatura: 10^7 K



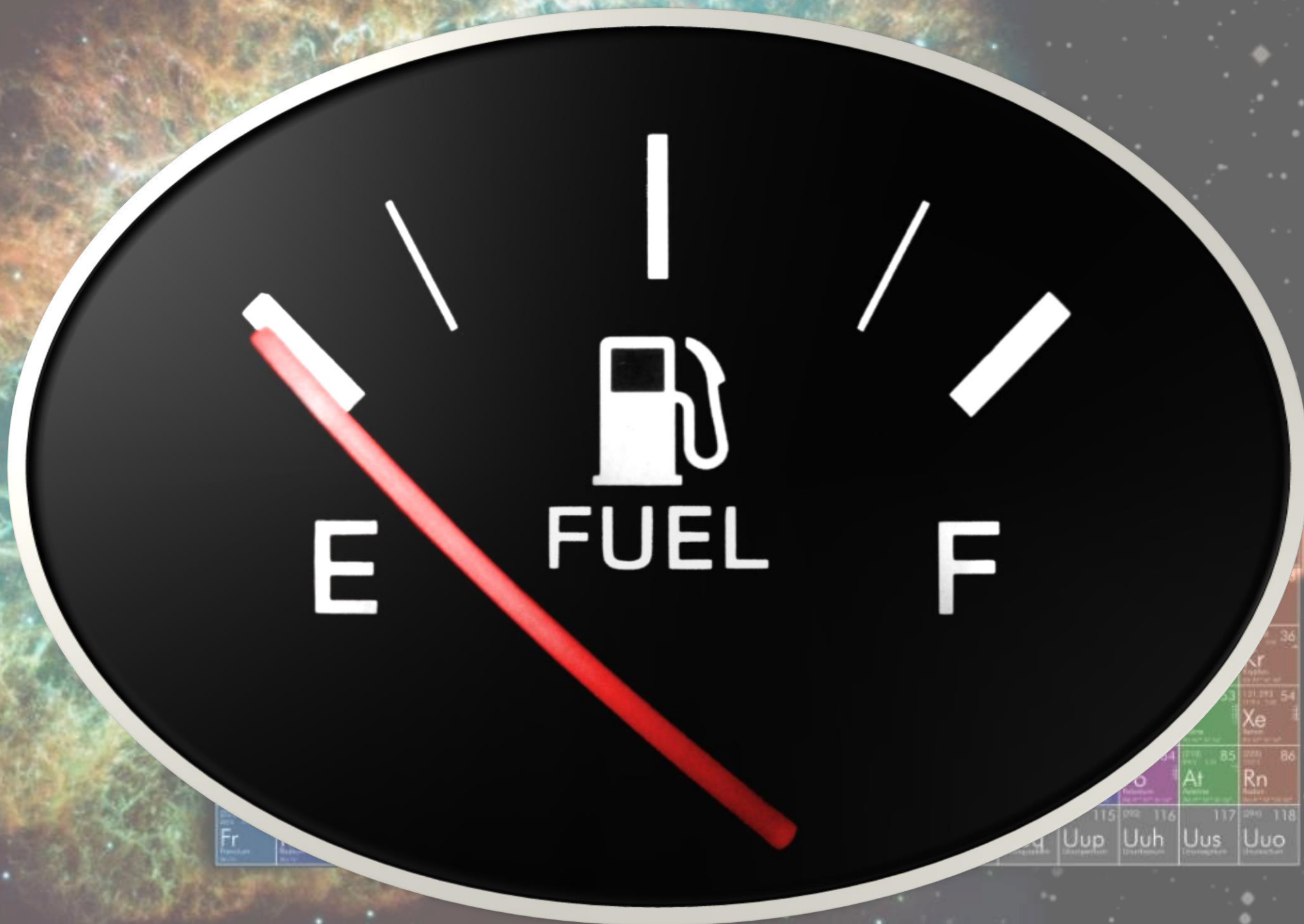
Proton-protonski ciklus



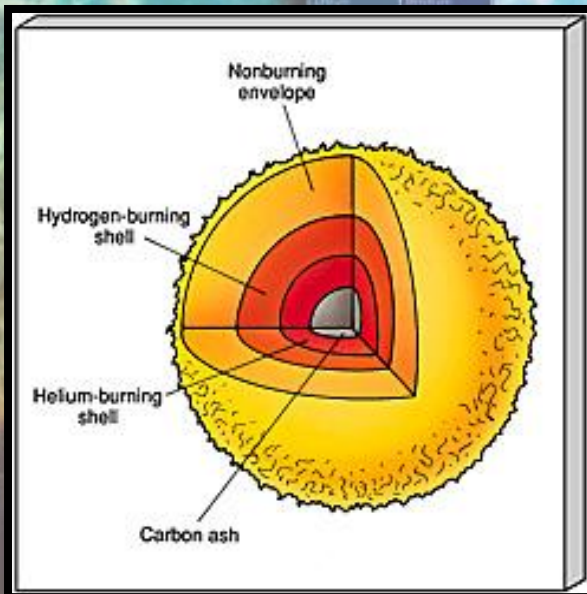
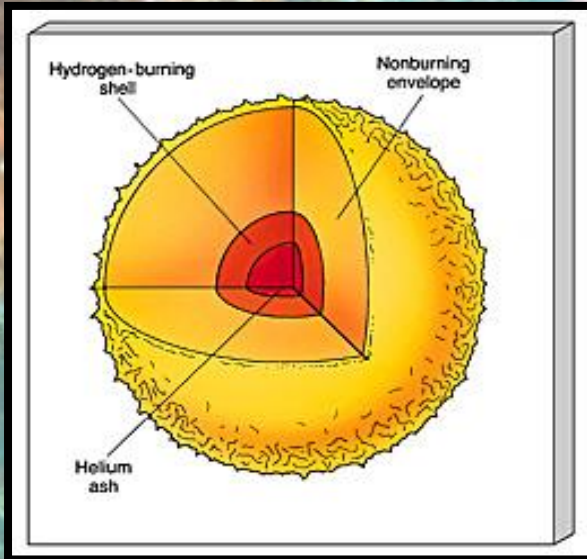
Koliko energije?



- Precizni eksperimenti na Zemlji - određene mase svih čestica u p-p ciklusu
- 4 protona - $6,6943 \cdot 10^{-27} \text{kg}$
- jezgro helijuma - $6,6466 \cdot 10^{-27} \text{kg}$
- defekt mase - $0,048 \cdot 10^{-27} \text{kg} \Rightarrow 4,3 \cdot 10^{-12} \text{J}$ (26,7 MeV)
- 1 kg vodonika $\Rightarrow 6,4 \cdot 10^{13} \text{J}$ (više nego dovoljno)
- svake sekunde **700 miliona tona** vodonika fuzijom prelazi u **695 miliona tona** helijuma, a od **5 miliona tona** nastaje energija
- ***1 sekunda = 500000 godina potrošnje na Zemlji!***

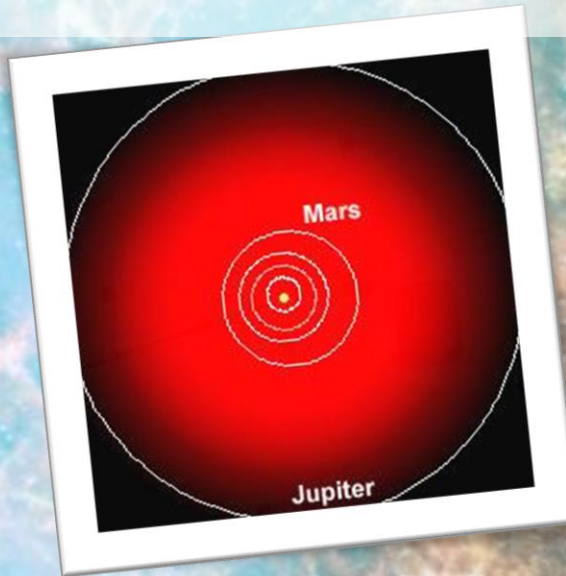
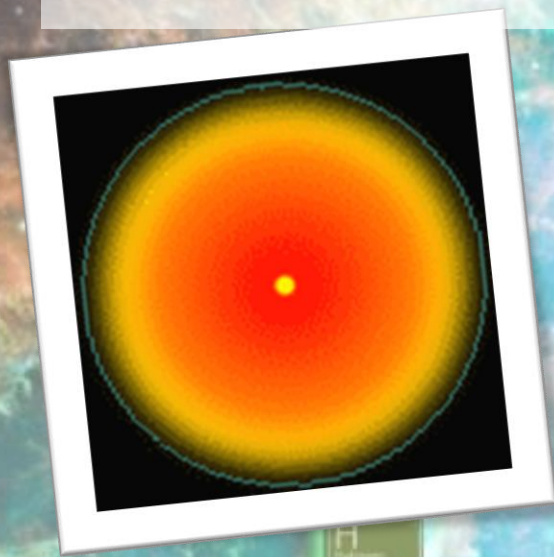


Početak kraja



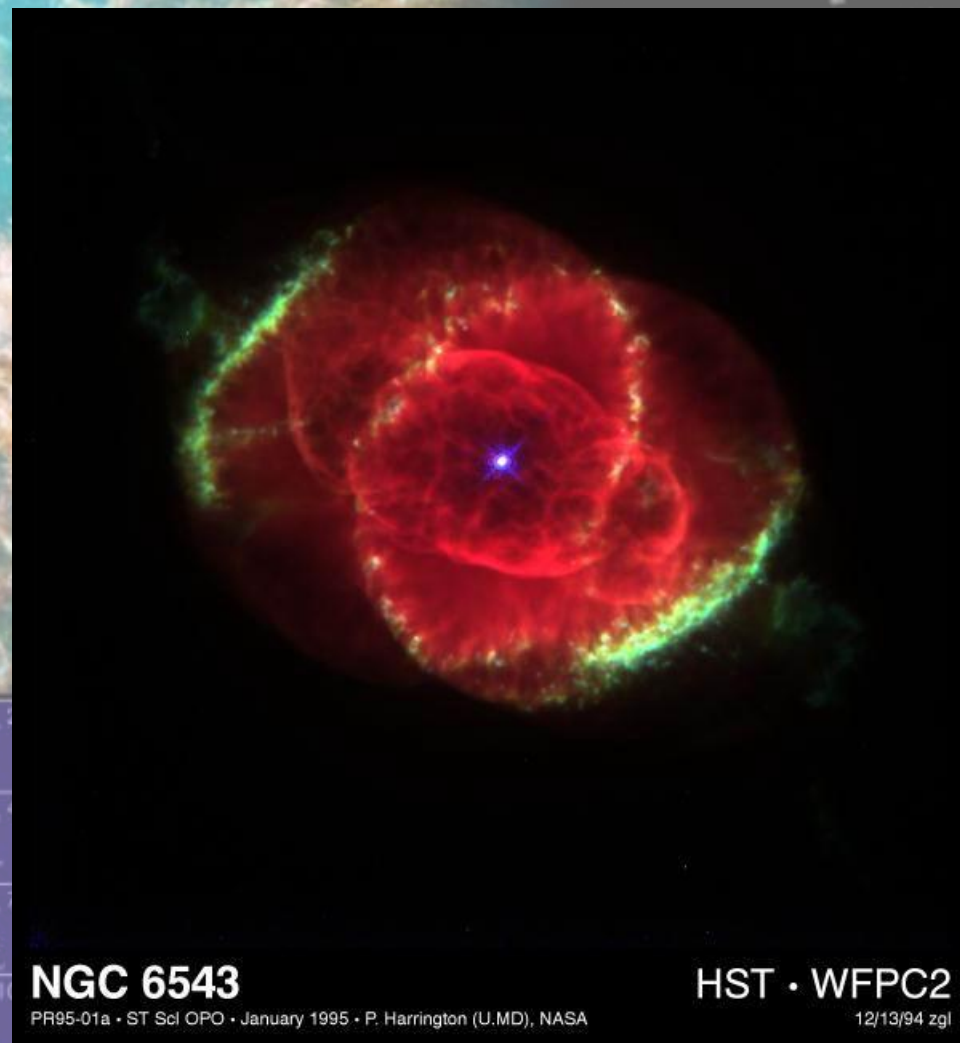
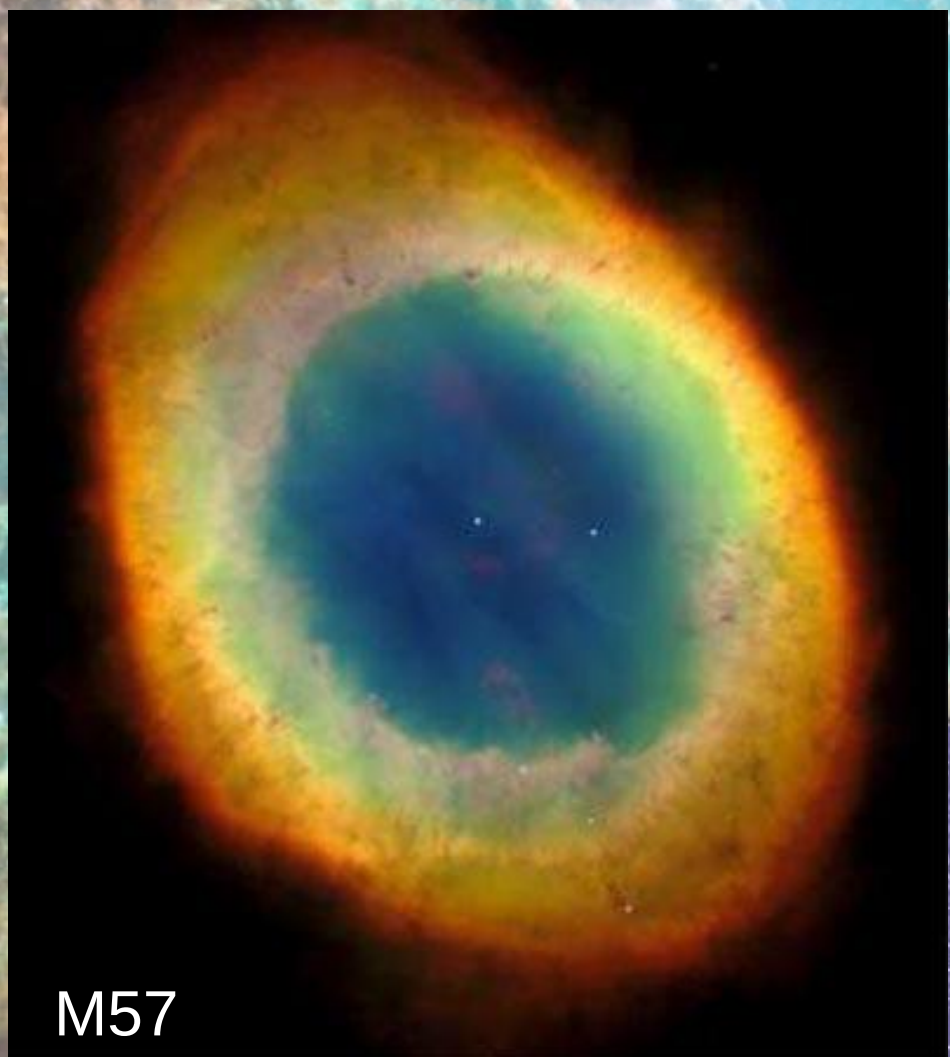
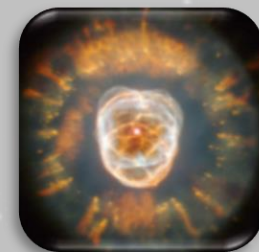
- “Sagorevanje” vodonika u ljusci oko jezgra
- Jezgro
 - Temperatura **100 miliona** stepeni
 - “sagorevanje” helijuma
 - “pepeo”: ugljenik i kiseonik
- Zvezda raste, površina hladi
- Zapremina oko **milijardu puta** veća
- **Crveni džin**

Crveni džin



- Aldebaran (Bik)
 - 15 najsjajnijih zvezda, 15x veći od Sunca; orbita Merkura
- Antares (Škorpija)
 - 13. po sjaju, 12000x sjajniji od Sunca, $\frac{3}{4}$ rastojanja do Jupitera
- Betelgez (Orion)
 - 11. po sjaju, 15000x sjajniji od Sunca, 20x veća masa

Planetarna maglina

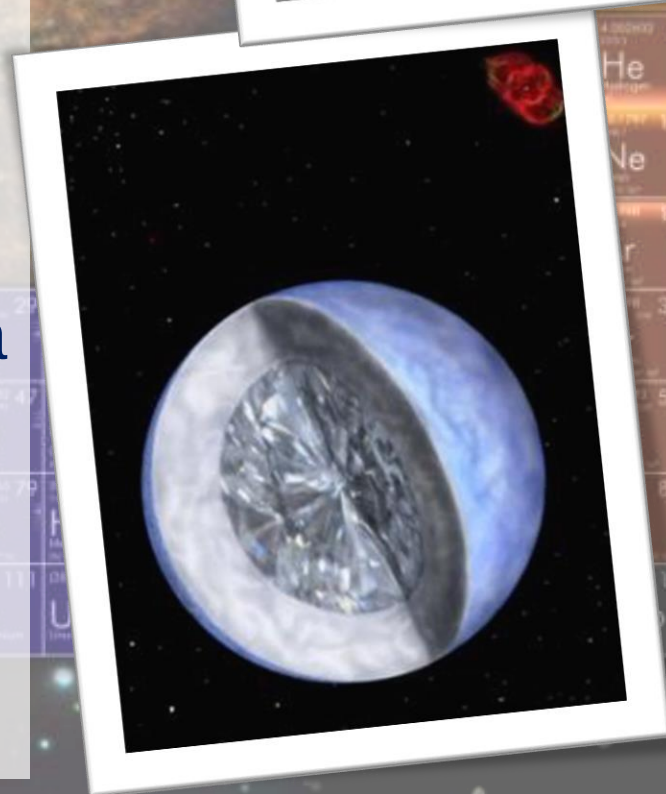


“Mačije oko”

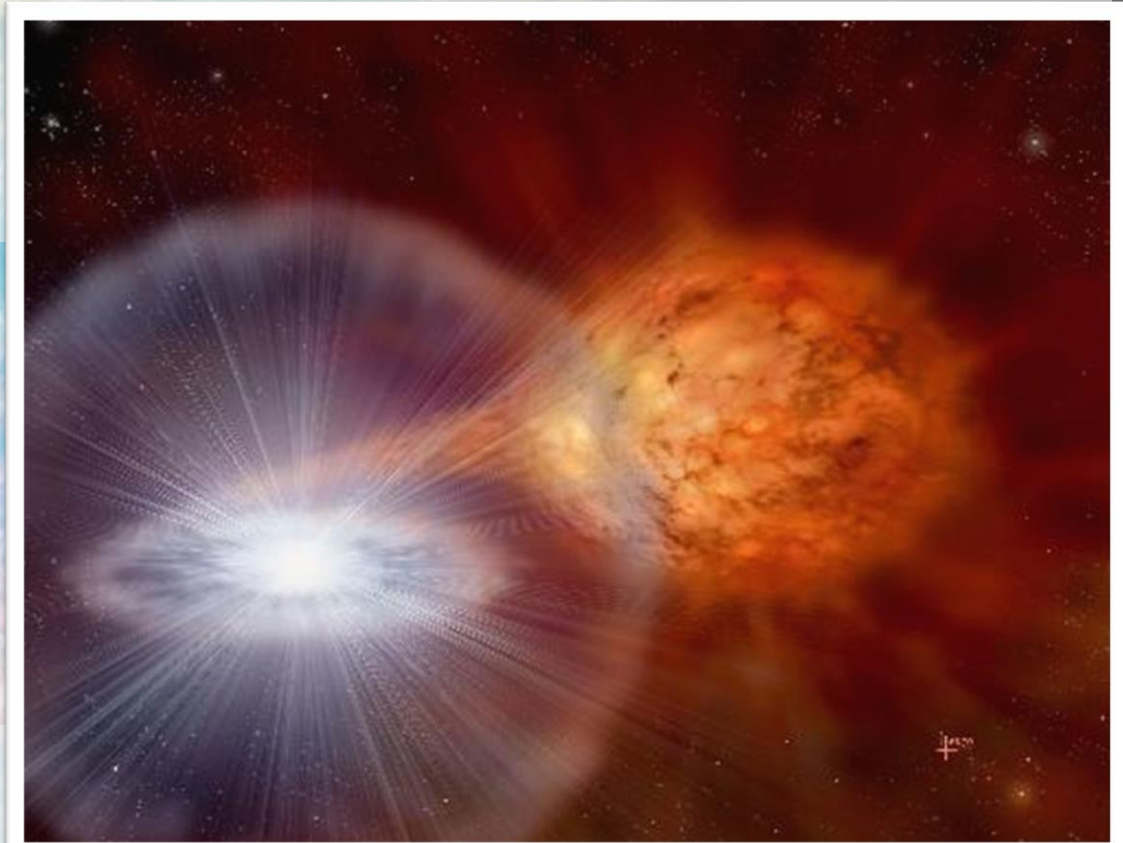
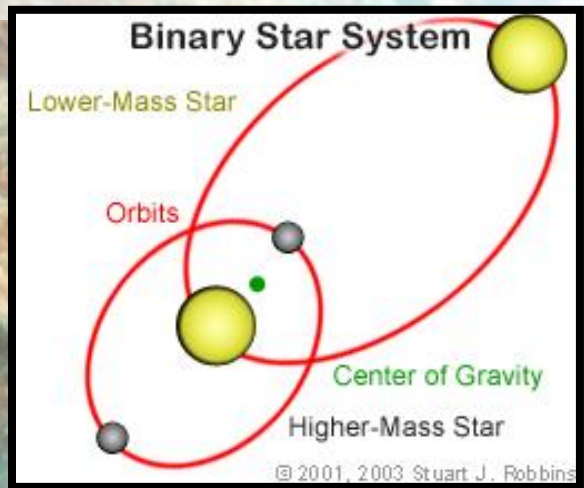
Beli patuljak



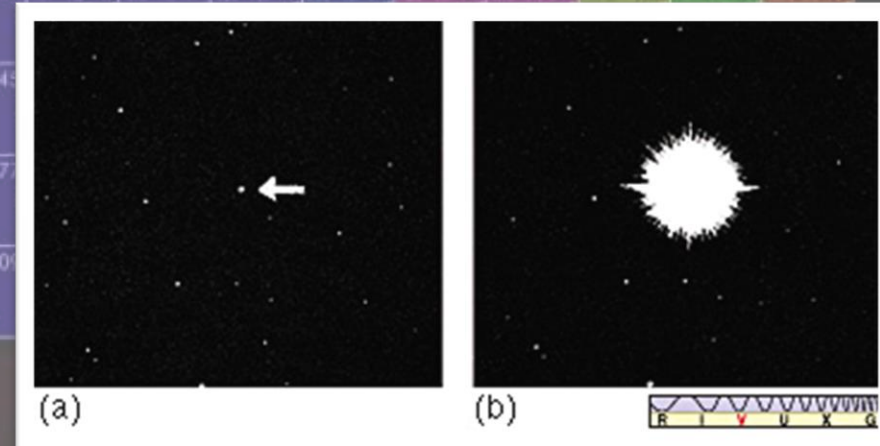
- Mnogo praznog prostora...
- “Pritisak” elektrona
- 1,4 solarne mase, 10.000 km;
- $1 \text{ cm}^3 \rightarrow 60 \text{ tona!}$
- Beli patuljci se hlade $\rightarrow$ temperatura međuzvezdanog prostora, mrki patuljci
- Neki beli patuljci – zanimljiva sudbina



Nova



- Sjaj - 10 hiljada puta!
- Masa – 1/10 solarne
- beli patuljci – objašnjeni ~1930
- Čandrasekar
- Granica 1,4 solarne mase
- Svake godine 6-10

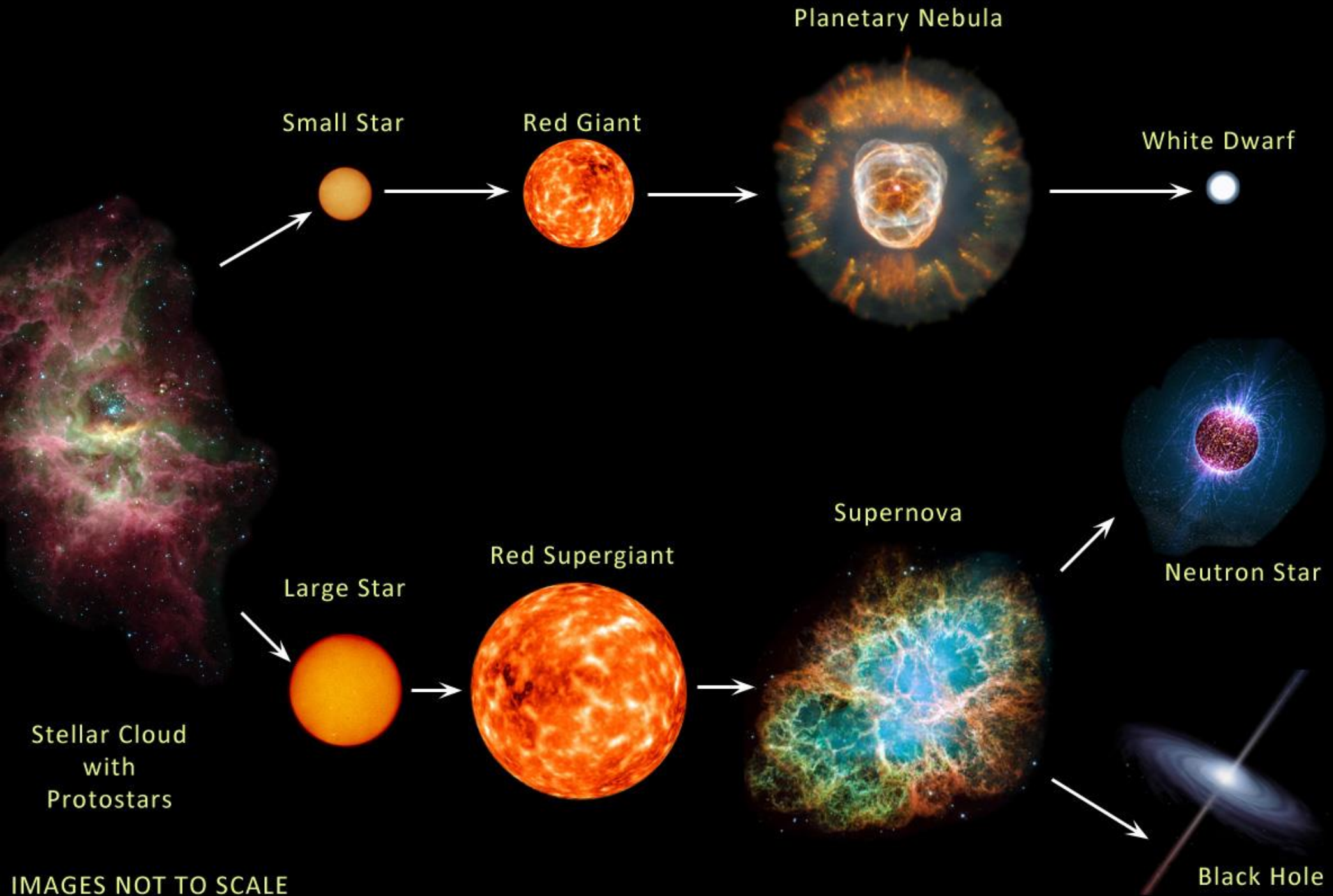


Male i velike zvezde

- Većina zvezda – slične Suncu
- Postoje i druge zvezde – plavičaste, blještavo sjajne
- Spika (Devica), Aherar (Eridan), skoro sve sjajne u Orionu
- Masa zvezda:
 - mala – žive dugo, evoluiraju polako
 - velika – žive kratko, evoluiraju brzo
- Crveni džin – teško se razlikuju
- Mala masa – jezgro (ugljenik, kiseonik) – inertno
- Velika masa – termonuklearne reakcije se nastavlja

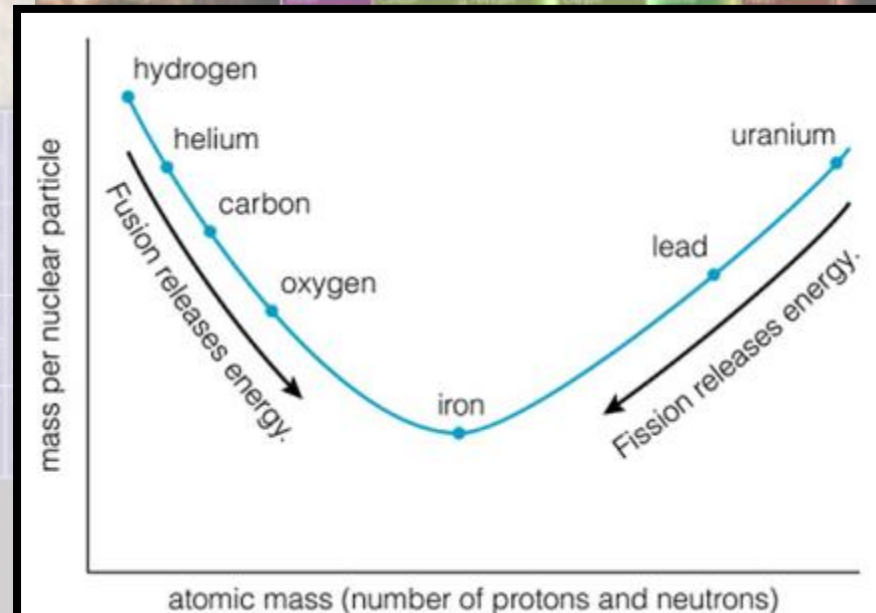
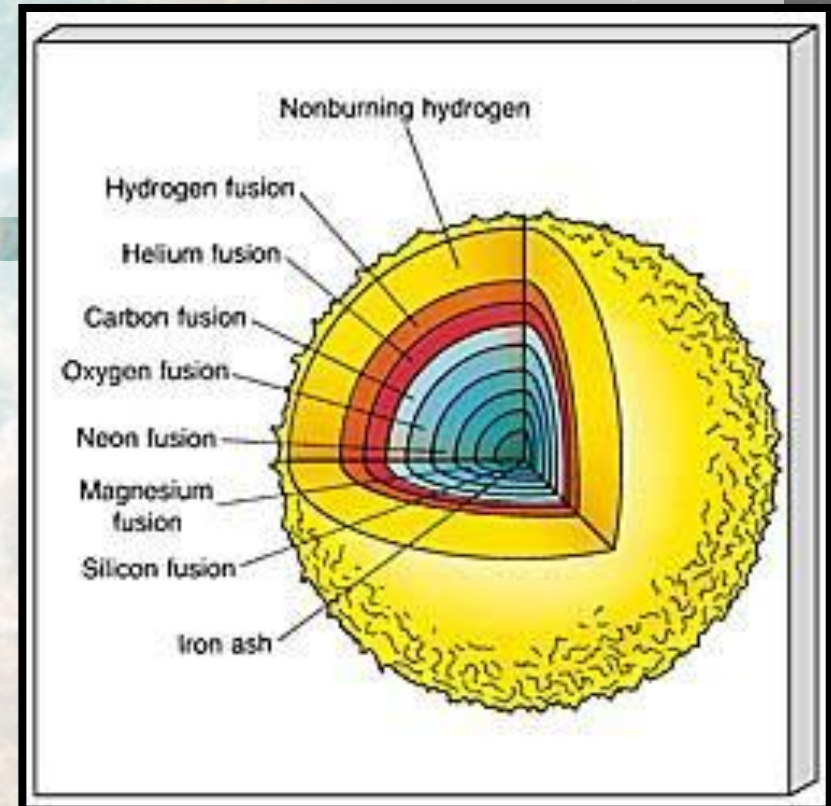


EVOLUTION OF STARS

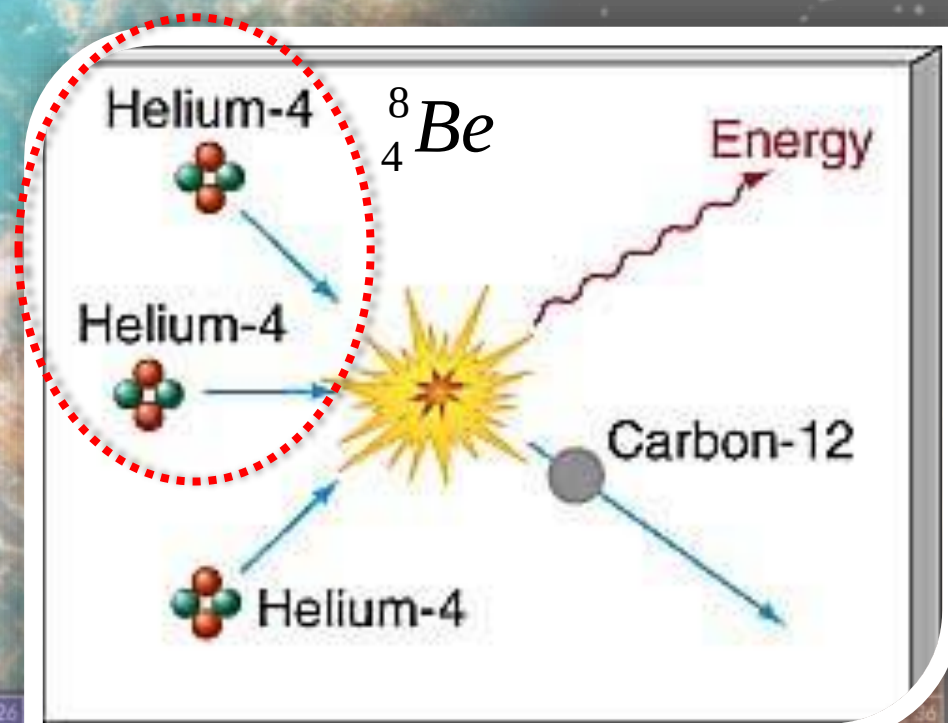
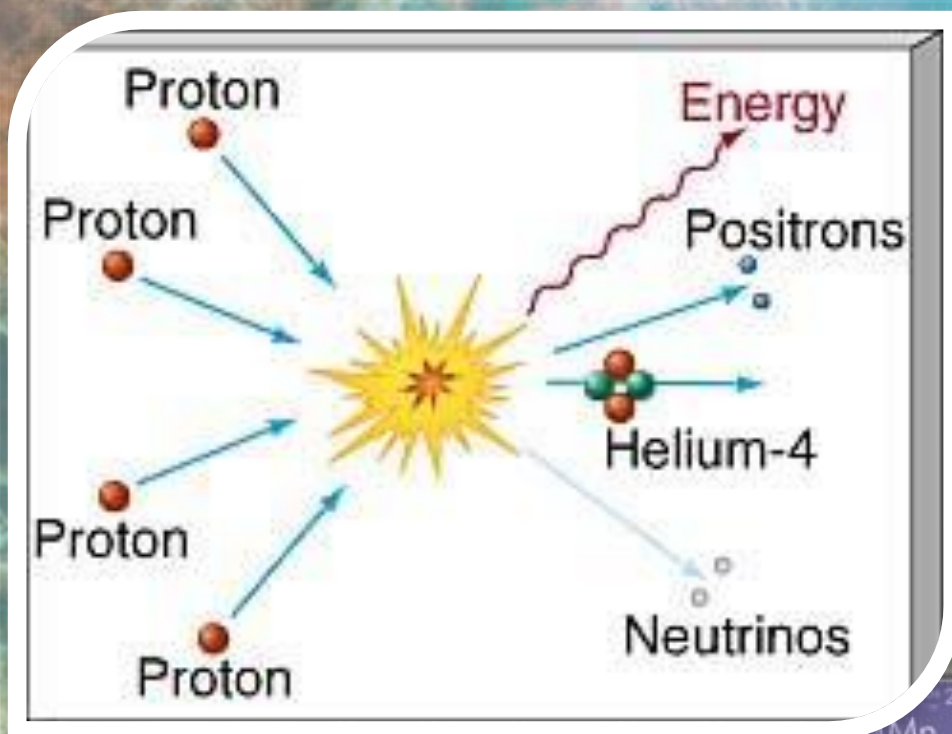


Velike brzo žive...

- Brzina:
 - 20 solarnih masa
 - vodonik - 10 miliona god.
 - helijum – milion godina
 - Ugljenik – 1000 godina
 - Kiseonik – 1 godina
 - Silicijum → gvozdeno jezgro za 1 dan
- Temperatura raste
 - 700 miliona – ugljenik
 - milijardu – kiseonik
 - 3 milijarde – silicijum
- Inertno gvožđe!

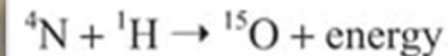
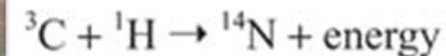
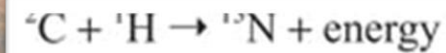
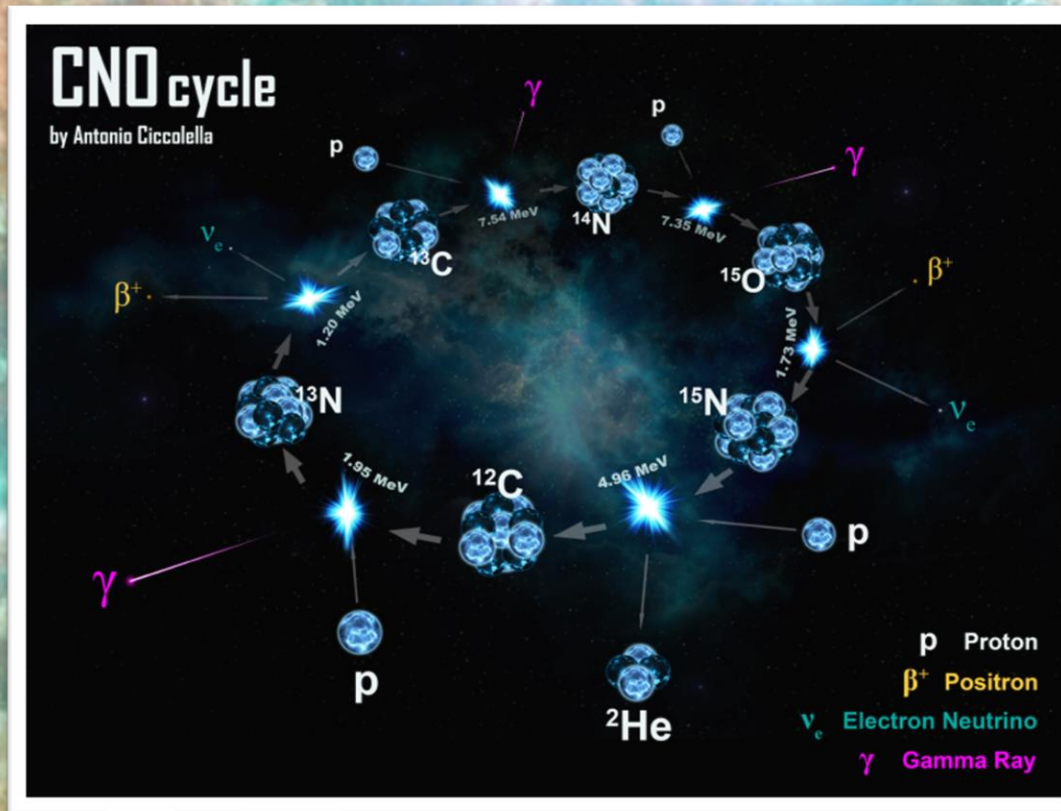


Fuzija vodonika i helijuma



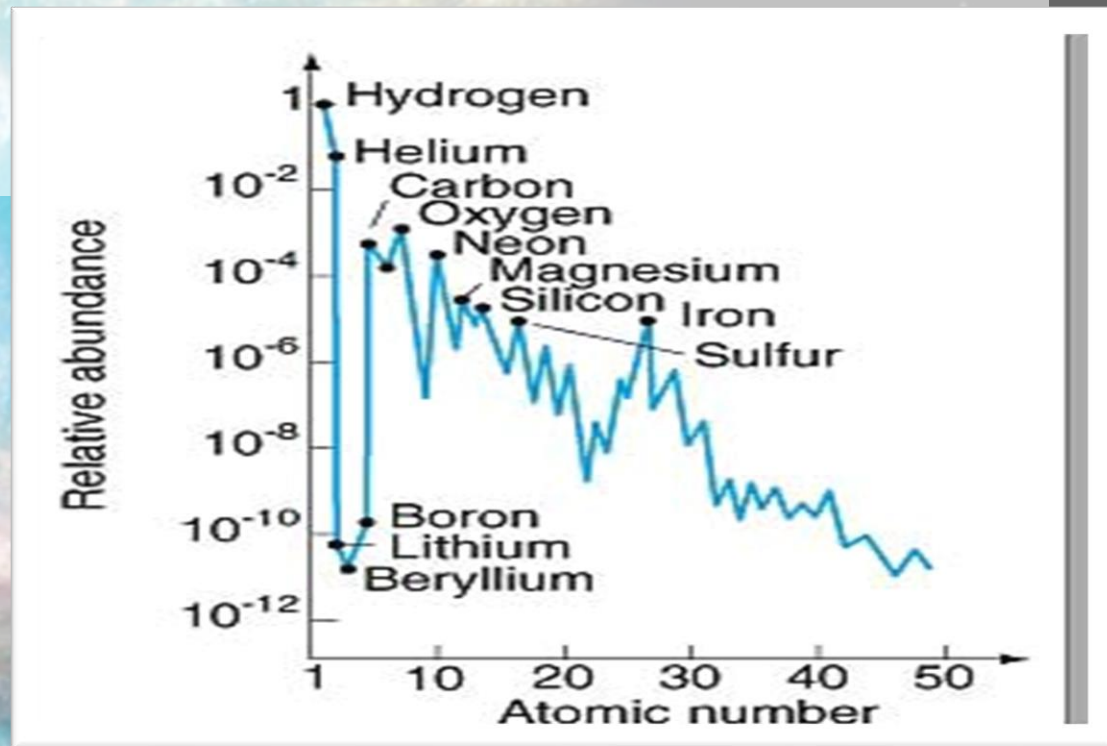
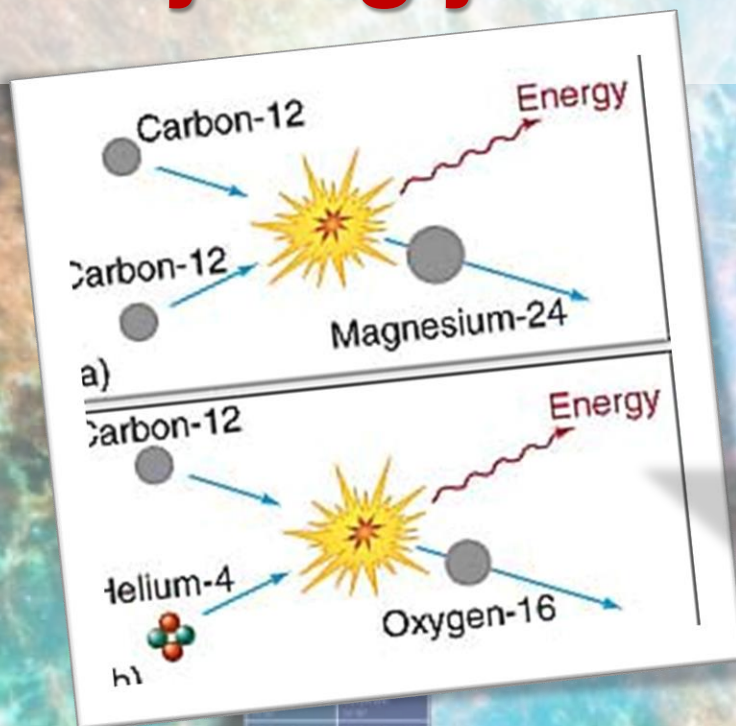
- Proton-protonski ciklus, temperatura 10^7K
- Tri-alfa proces, temperatura 10^8K

CNO ciklus



- Dominantan u zvezdama 1,3 puta veće mase od Sunca

Fuzija ugljenika

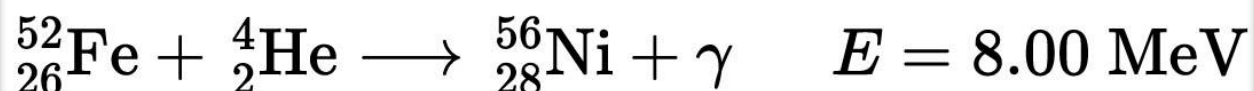
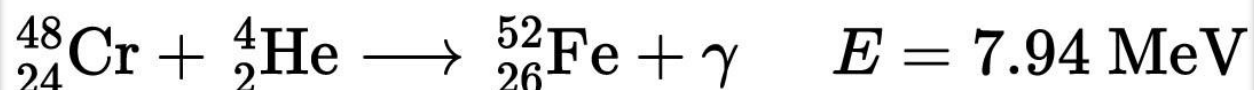
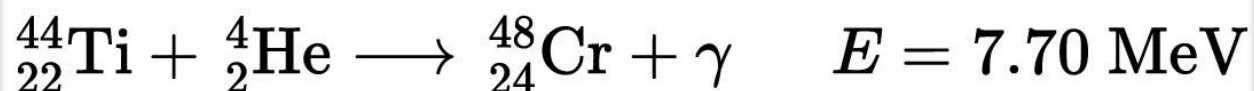
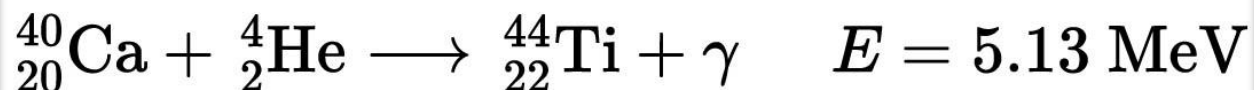
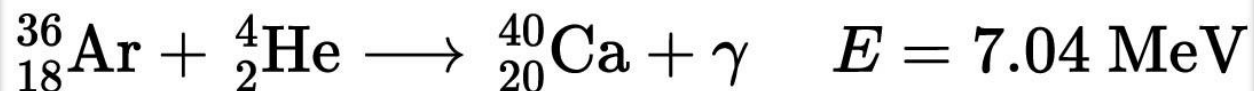
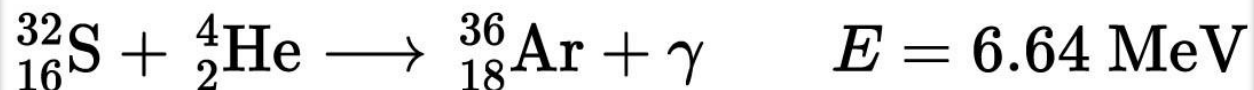
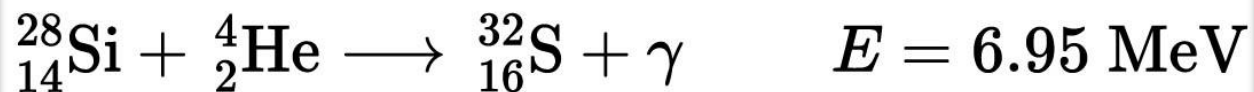
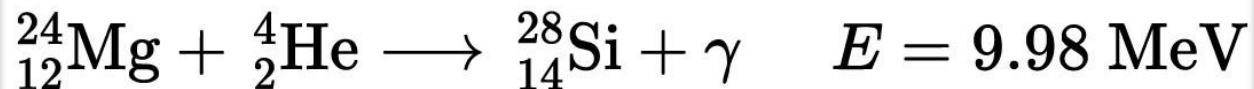
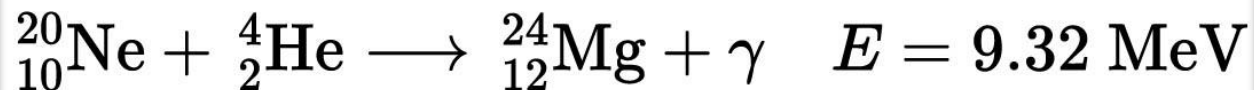
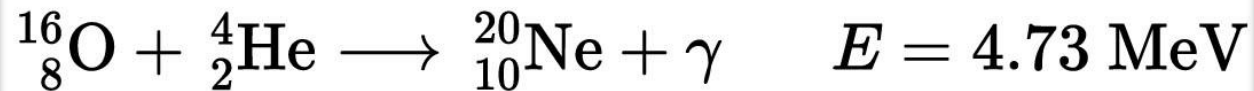
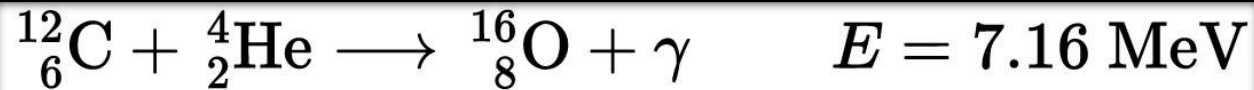


- Temperatura 10^9K
- Teža jezgra $\rightarrow$ veći broj protona $\rightarrow$ ogromne temperature
- Fuzija ugljenik-helijum, temperatura $6 \cdot 10^8\text{K}$

$$^{16}\text{O} + ^{16}\text{O} \rightarrow ^{32}\text{S} + \text{energija}$$

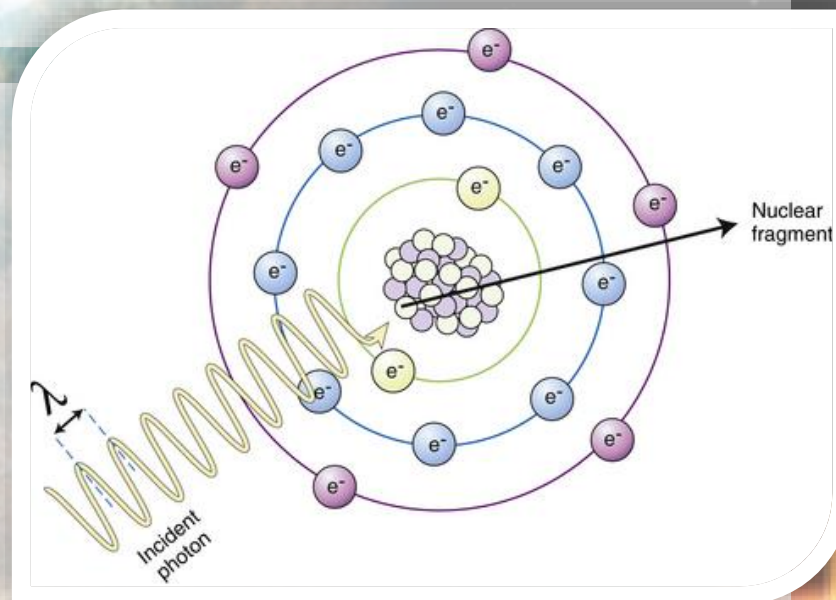
$$^{16}\text{O} + ^4\text{He} \rightarrow ^{20}\text{Ne} + \text{energija}$$
- proces zahvata helijuma

Alfa proces

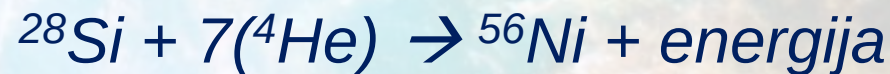


Nije sve tako jednostavno

- Helijum nije jedini element koji učestvuje u fuzionim reakcijama sa drugim elementima
- Emisija i apsorpcija protona i neutrona
- Kad se pojavi **silicijum** – temperatura $3 \cdot 10^9 \text{K}$
- Razaranje jezgara, gama zracima, na jezgra helijuma (**fotodisintegracija**)
- Ne samo da uništava silicijum, omogućava nastanak težih jezgara



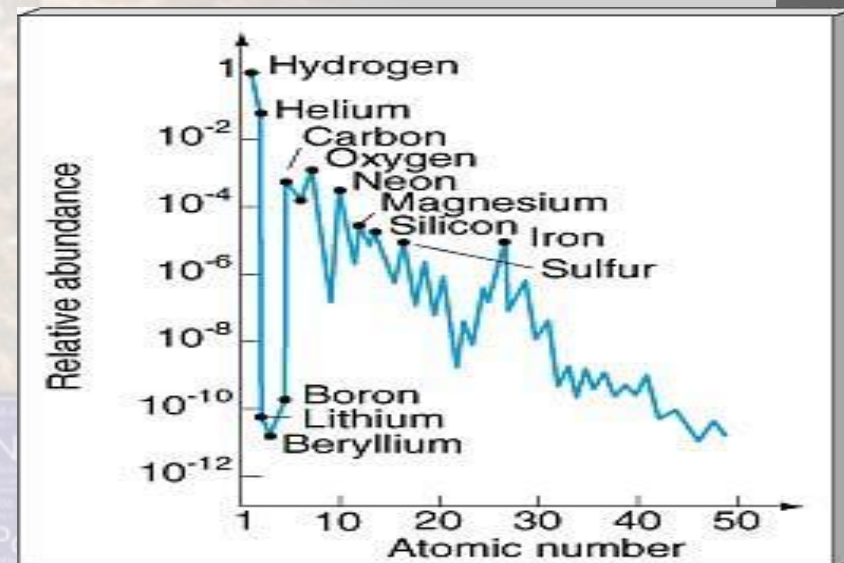
- Silicijum zahvata neku od nastalih alfa-čestica
- Proces u nekoliko etapa, konačno



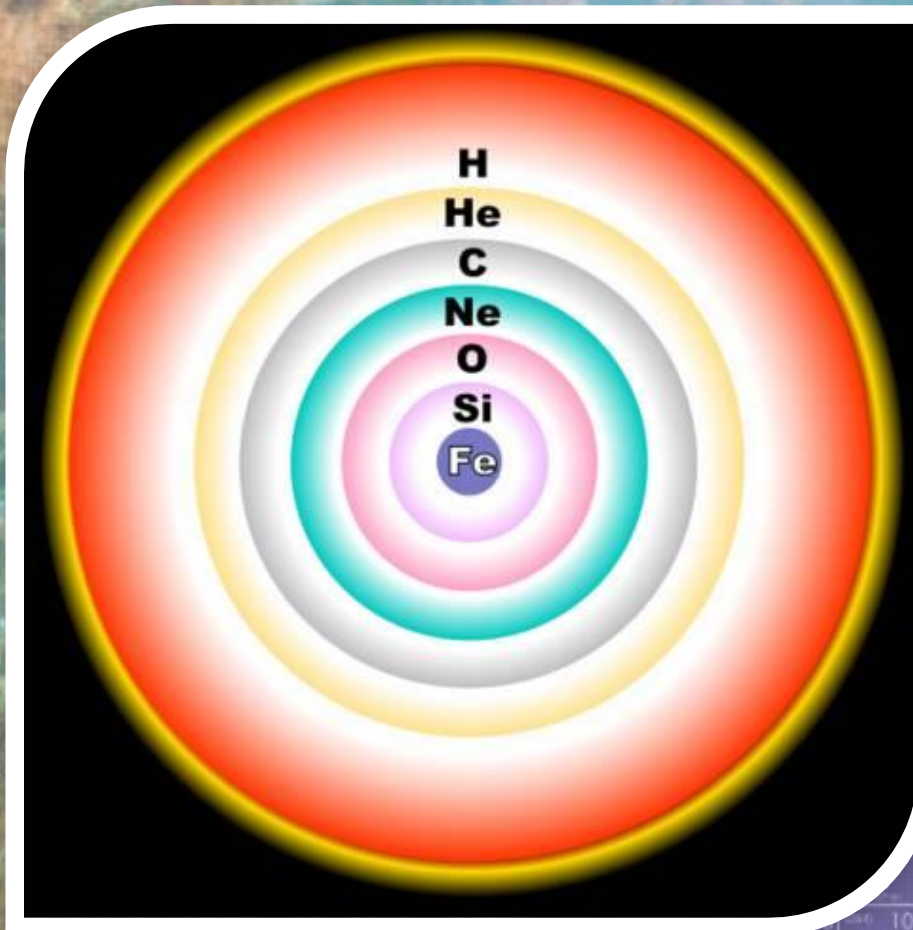
- Alfa-proces
- *nikl-56* → *kobalt-56* → *gvožđe-56*

- **gvožđe-56 „najjače“ vezano atomsko jezgro**

- 26 protona, 30 neutrona
- Najveća energija veze jezgra
- Nagomilava u jezgru zvezde
- Elementi grupe gvožđa – veća rasprostranjenost



Pre eksplozije



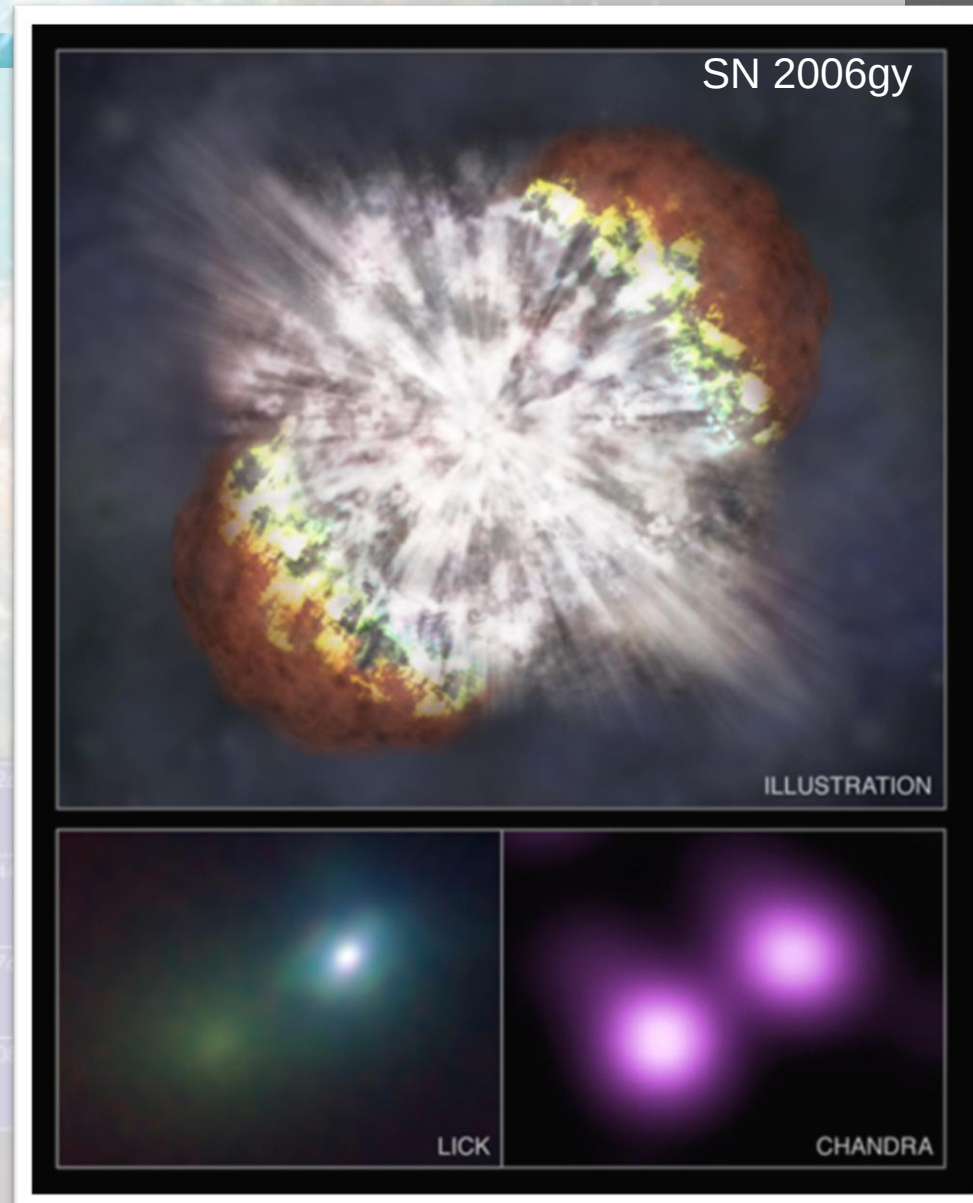
Fr	Ra	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
Francium	Radium	Rutherfordium	Dubnium	Seaborgium	Berkelium	Hassium	Moscovium	Darmstadtium	Roentgenium	Ununbium	Ununtrium	Ununquadium	Ununpentium	Ununhexium	Ununseptium	Ununoctium
87	88	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118



***100 miliona
milijardi triliona
atomskih bombi***

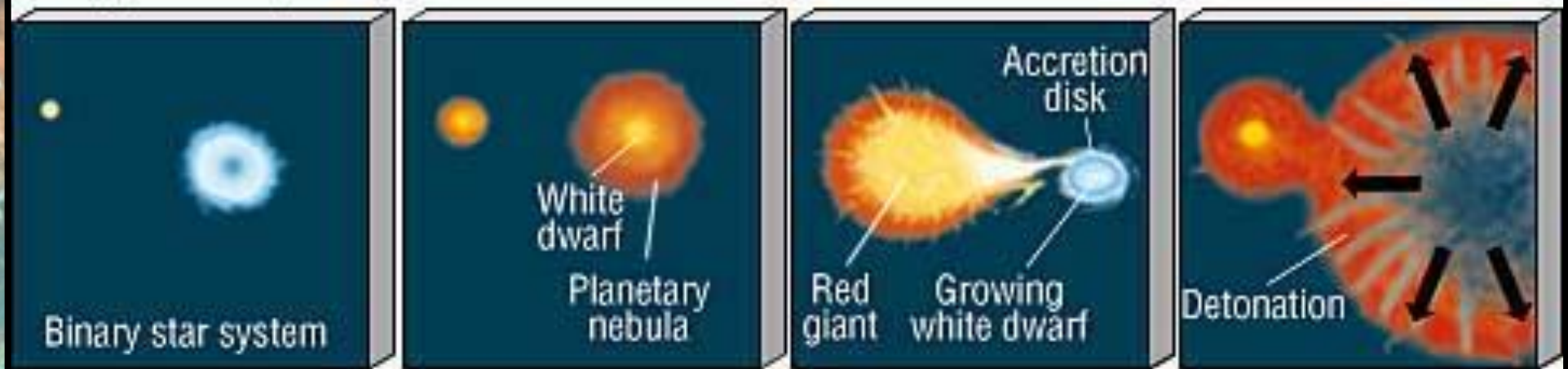
Supernova

- Udarni talas – brzina nekoliko desetina hiljada km/s
- Eksplozija – odbacivanje spoljašnjih slojeva
- Ogromna oslobođena energija
- Sjajnija od čitave galaksije!
- Bljesak svetlosti jednak sjaju milijardi Sunaca i taj sjaj dostiže za nekoliko sati.
- Ista zvezda može postati nova nekoliko puta, ali zvezda može biti supernova samo jednom!

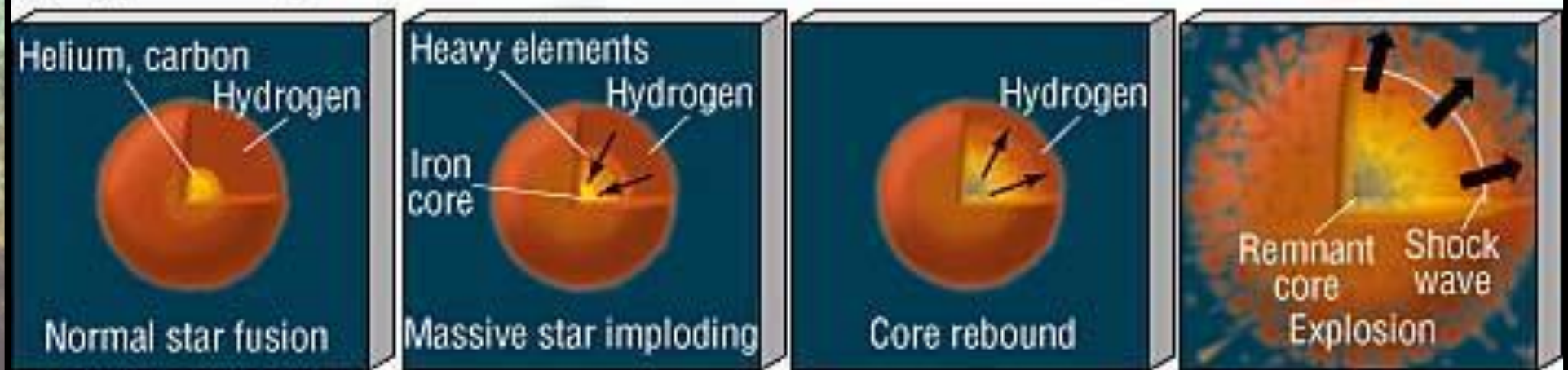


Dva tipa supernovih

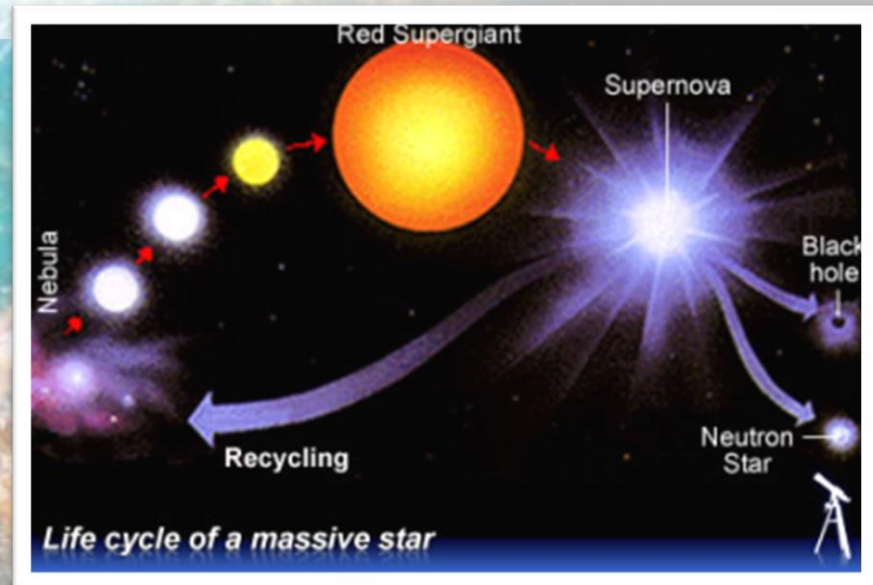
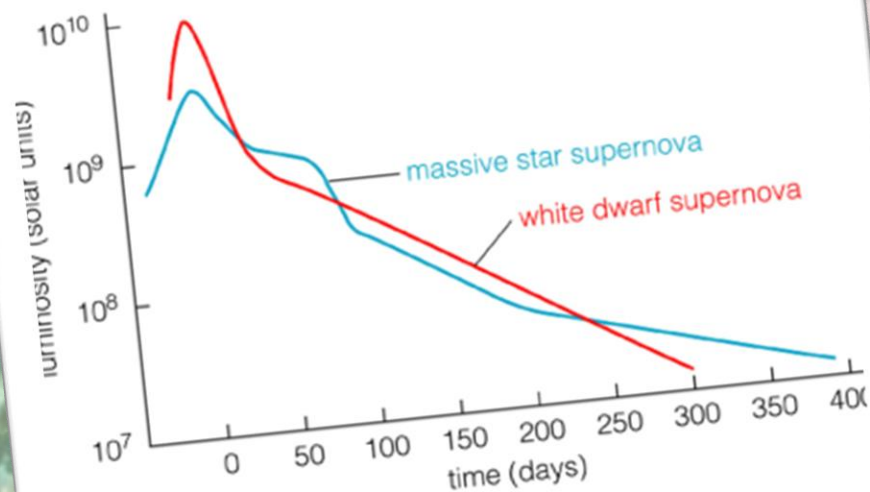
(a) Type- I Supernova



(b) Type- II Supernova



Dva tipa supernovih



Cs Cesium 55	Ba Barium 56
Fr Francium 87	Ra Radium 88

Hf Hafnium 72	Ta Tantalum 73
Rf Rutherfordium 104	Db Dubnium 105

W Tungsten 74	Re Rhenium 75
Sg Seaborgium 106	Bh Bohrium 107

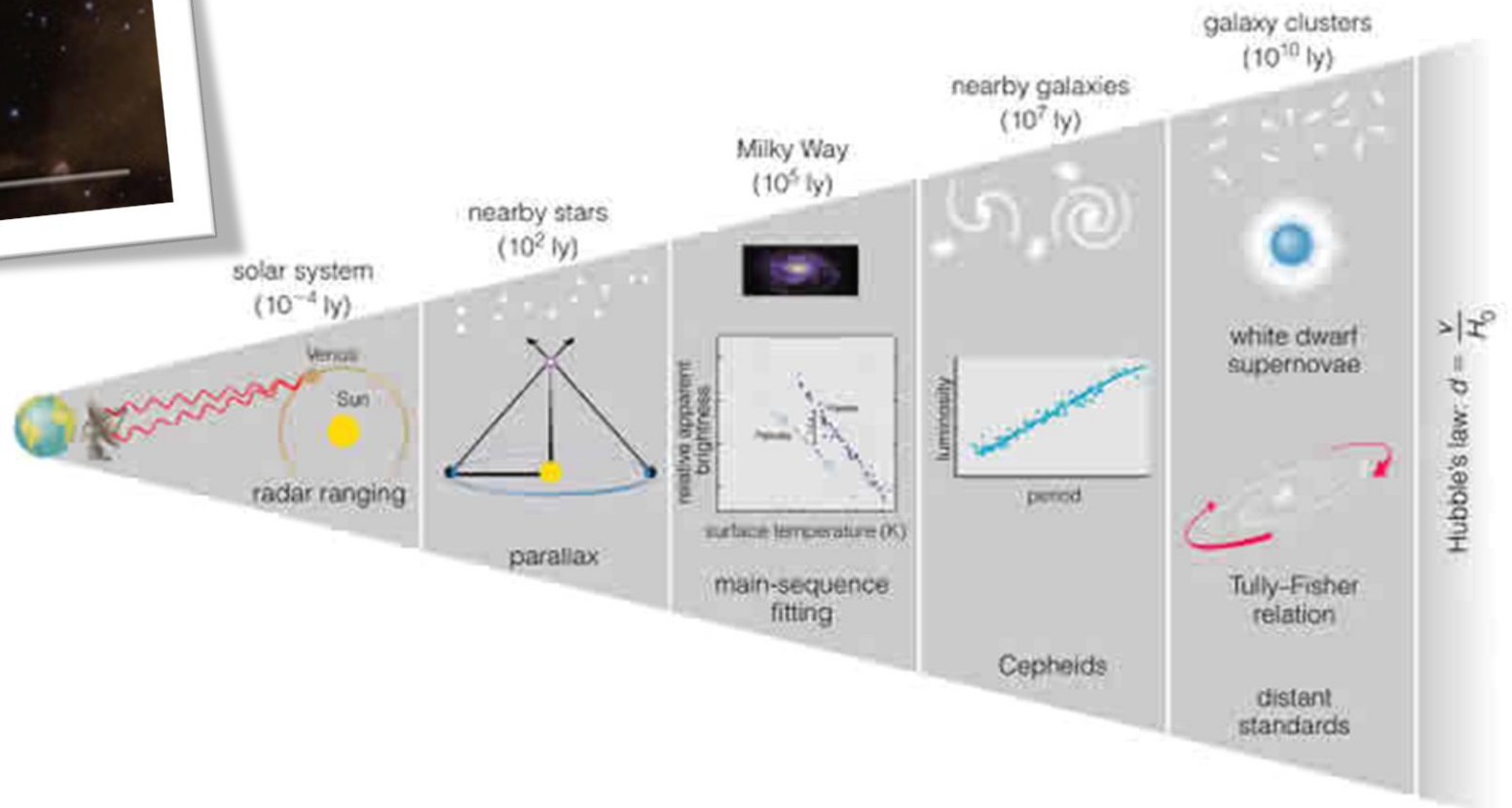
Os Osmium 76	Ir Iridium 77
Hs Hassium 108	Mt Meitnerium 109

At Astatine 85	Rn Radon 86
Uus Ununseptium 117	Uuo Ununoctium 118

Standardne “sveće” – tip Ia

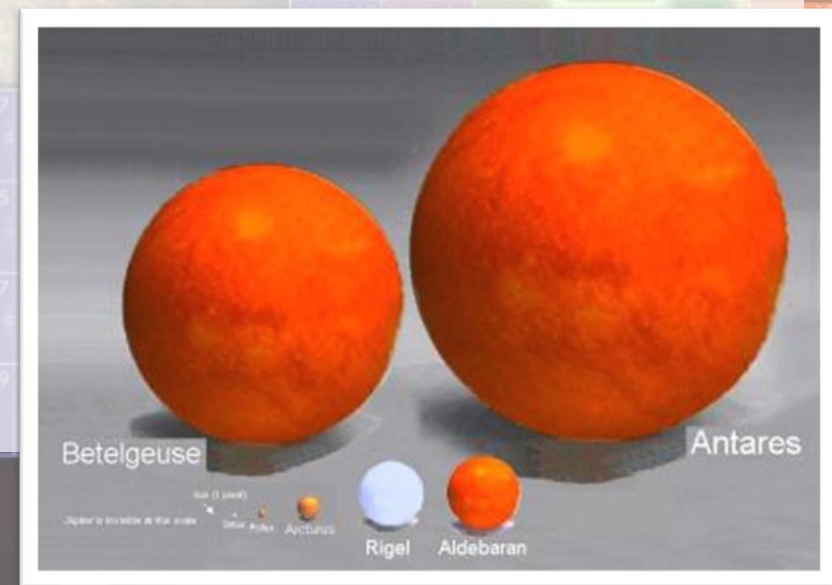
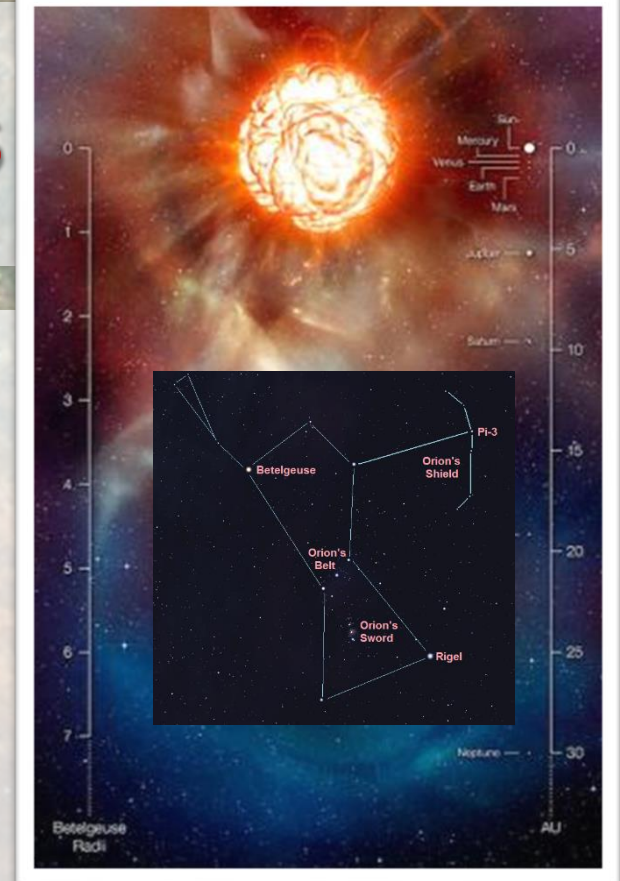


11	Na	Sodium
19	K	Potassium
37	Rb	Rubidium
55	Cs	Cesium
87	Fr	Francium



Betelgez – Alfa Orionis

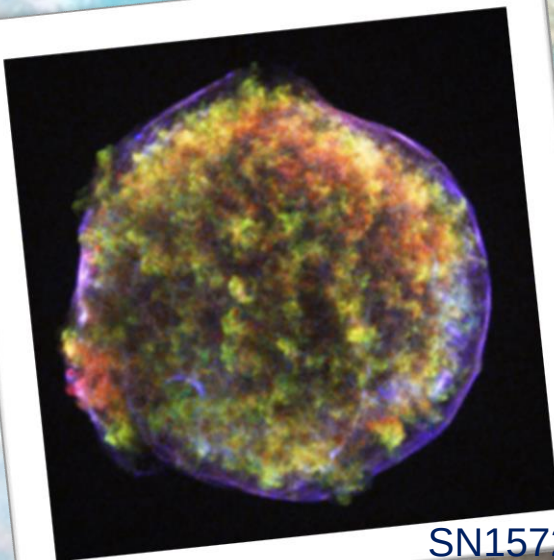
- Masa: 18-19 masa Sunca
- Prečnik: ~1000 puta veći Sunca
- Sjaj: ~150.000 puta veći
- Temperatura: 3500K
- Daljina: 650 sv. godina



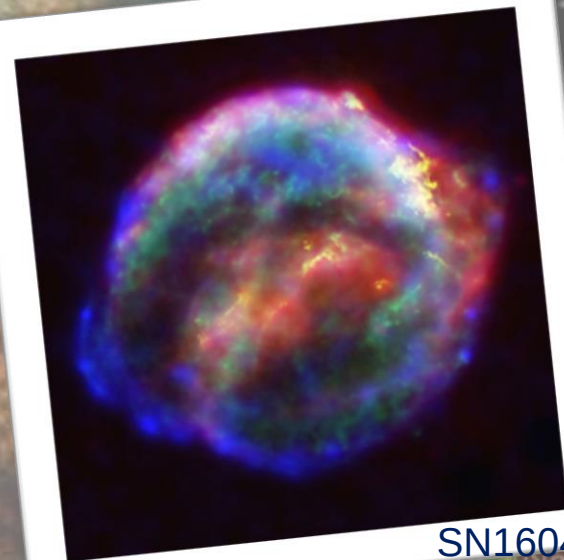
Kako znamo?



SN1054



SN1572



SN1604

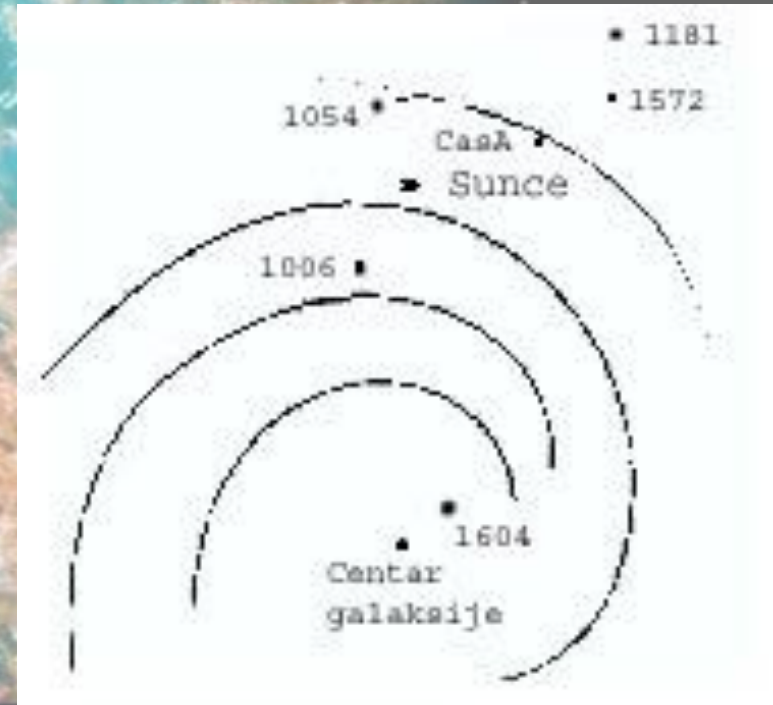
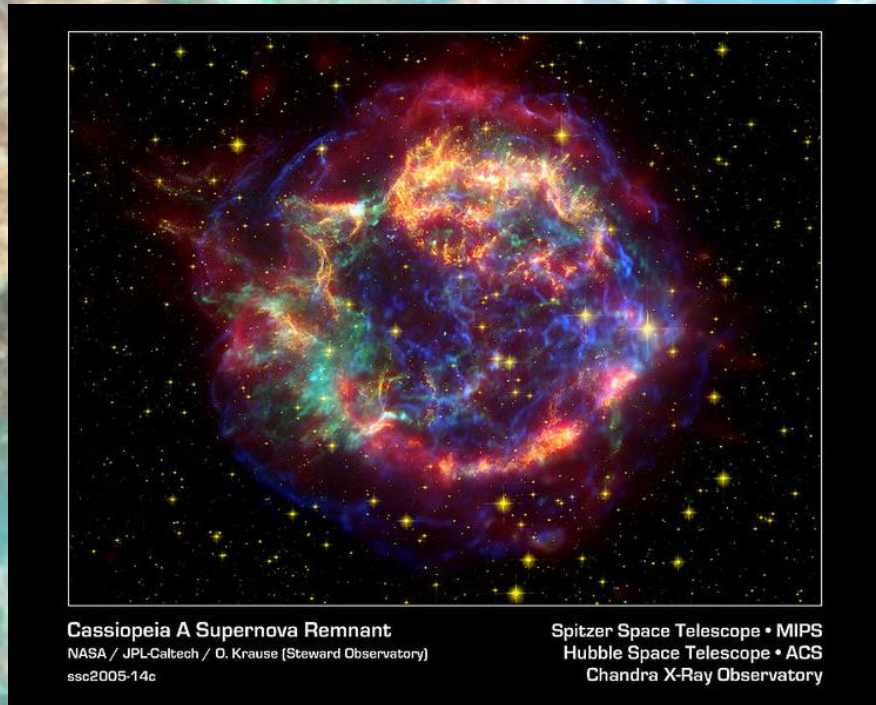


SN1006



SN1987

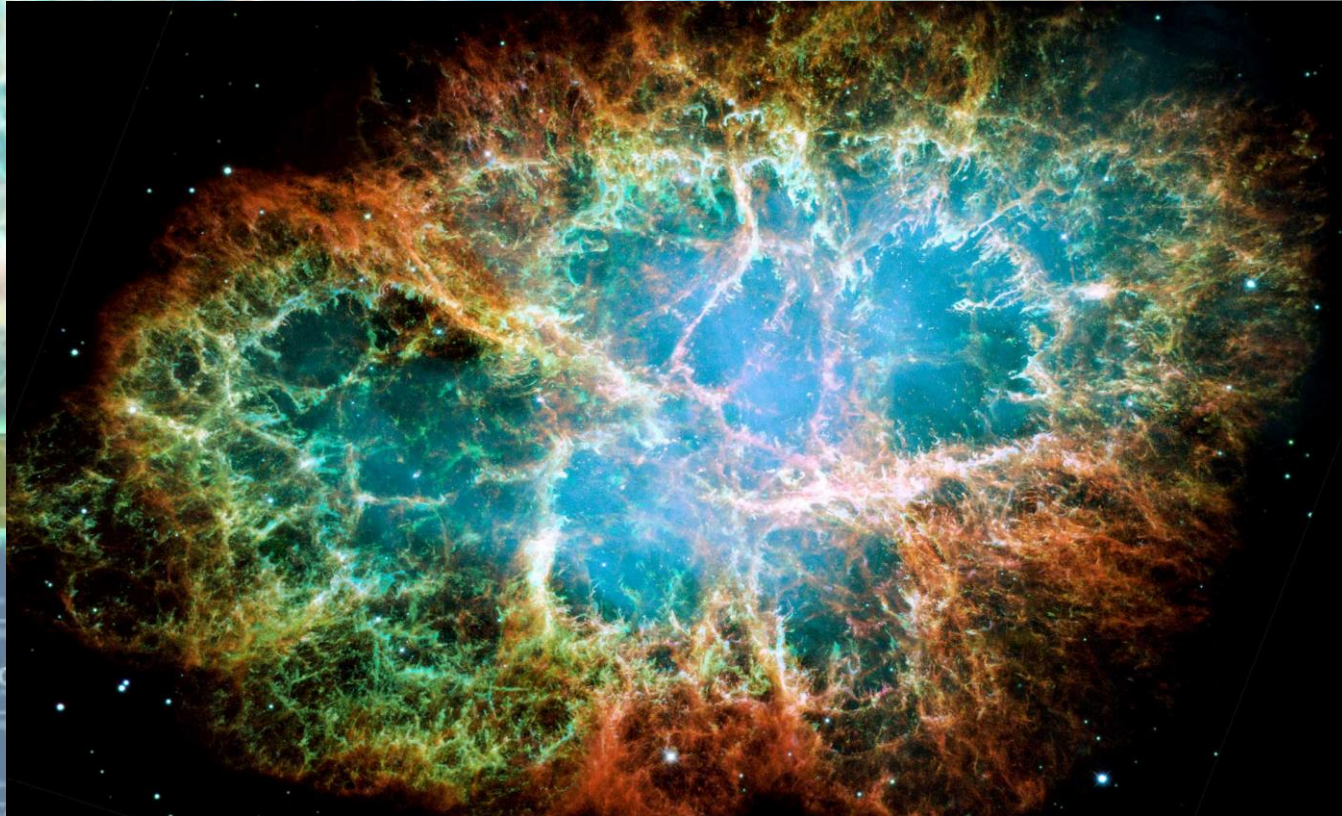
Supernove u našem komšiluku



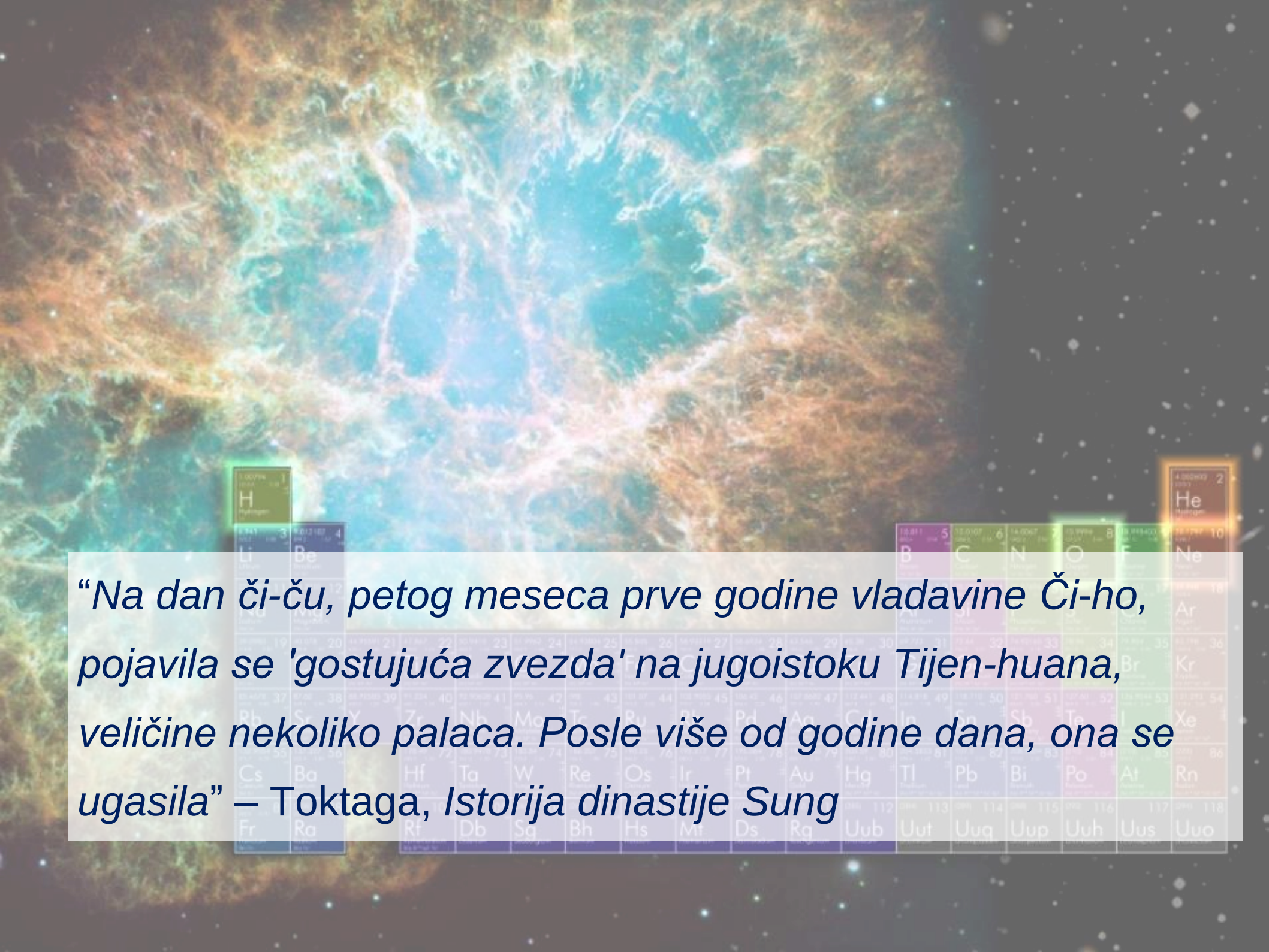
- 10 supernova u našoj galaksiji u poslednjih 1000 godina
- CasA – nema je u istoriji, radio posmatranja - videla se u VII veku
 - Najjači radio izvor, 10.000 sg, stara 300 god (možda 16. avgust 1680 – nova zvezda u katalogu)
- Svaka – bar 100 pc ispod ili iznad galaktičke ravni
- Krug 100 pc – 1 supernova svakih 500.000 god.
- Najmlađa SNR G1.9+0.3 (1868. god; otkrivena 1985, starost određena 2008)

M1 – Maglina Rak (SN1054)

(NGC 1952; Taurus; +8,4 mag; 6300 s.g.)



- 4. jula 1054. g. kineski astronomi na istočnom delu neba
- Dostigla -6^m (1/4 Meseca)
- naredna 23 dana – videla po danu
- opažena i na drugom kraju sveta – iznad današnjeg Novog Meksika i Arizone, zabeležili je indijanski slikari

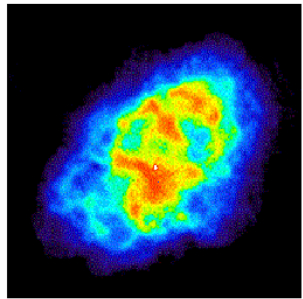


“Na dan či-ču, petog meseca prve godine vladavine Či-ho, pojavila se 'gostujuća zvezda' na jugoistoku Tijen-huana, veličine nekoliko palaca. Posle više od godine dana, ona se ugasila” – Toktaga, Istorija dinastije Sung

M1 – Maglina Rak (SN1054)

(NGC 1952; Taurus; +8,4 mag; 6300 s.g.)

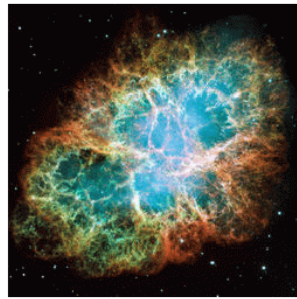
Crab Nebula: Remnant of an Exploded Star (Supernova)



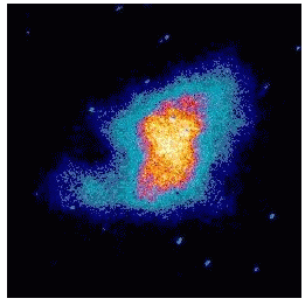
Radio wave (VLA)



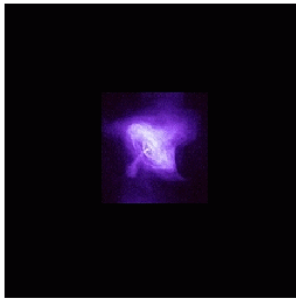
Infrared radiation (Spitzer)



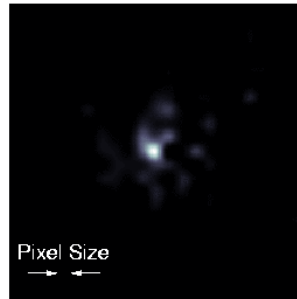
Visible light (Hubble)



Ultraviolet radiation (Astro-1)



Low-energy X-ray (Chandra)



High-energy X-ray (HEFT)
*** 15 min exposure ***

- Daljina 6.300 s.v. god.
- 28. avgust 1758. – Š. Mesije
- maglina 10 s.g. u prečniku, brzina 1800 km/s
- Sjaj -3.2^m (1000 x Sunce)
- 1948. – jak radio izvor
- 1964. – izvor X-zraka

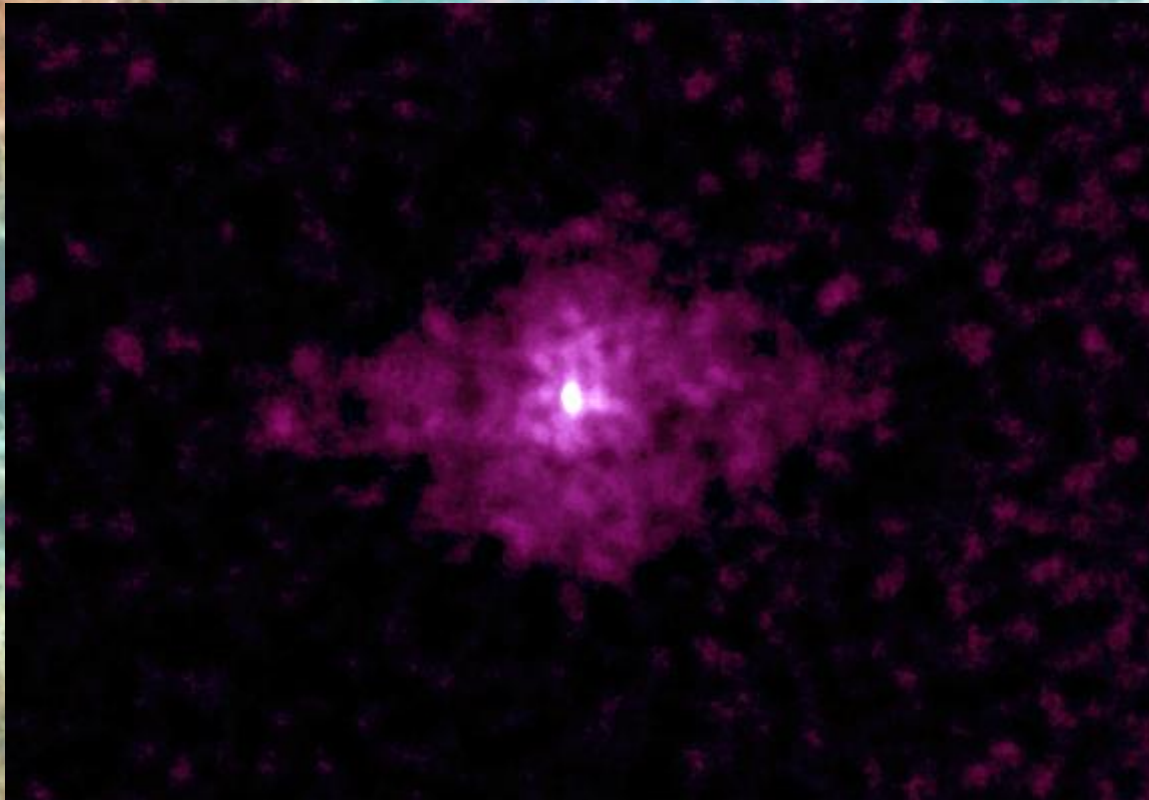
M1 – Maglina Rak (SN1054)

(NGC 1952; Taurus; +8,4 mag; 6300 s.g.)

- X-zračenje oko 100 puta intenzivnije nego VIS
- 1968 - pulsar (NP0532)
- 30 obr/sec – najmlađi pulsar
- mala zvezda, apsolutni sjaj približno kao Sunce

1.00794 1 H Hydrogen	4.002602 2 He Helium																
6.941 3 Li Lithium	9.012182 4 Be Beryllium	10.811 5 B Boron	12.0107 6 C Carbon	14.0067 7 N Nitrogen	15.9994 8 O Oxygen	18.998403 9 F Fluorine	20.1797 10 Ne Neon										
22.989769 11 Na Sodium	24.30409 12 Mg Magnesium	26.9815385 13 Al Aluminium	28.08558 14 Si Silicon	30.97376 15 P Phosphorus	32.06 16 S Sulfur	35.453 17 Cl Chlorine	39.948 18 Ar Argon										
39.0983 19 K Potassium	40.078 20 Ca Calcium	44.955912 21 Sc Scandium	47.867 22 Ti Titanium	50.9415 23 V Vanadium	51.99616 24 Cr Chromium	54.938044 25 Mn Manganese	55.845 26 Fe Iron	58.933194 27 Co Cobalt	58.933194 28 Ni Nickel	63.546 29 Cu Copper	65.38 30 Zn Zinc	69.723 31 Ga Gallium	72.64 32 Ge Germanium	74.9216 33 As Arsenic	78.96 34 Se Selenium	80.9124 35 Br Bromine	83.798 36 Kr Krypton
85.4678 37 Rb Rubidium	87.62 38 Sr Strontium	88.90584 39 Y Yttrium	91.224 40 Zr Zirconium	92.90638 41 Nb Niobium	95.94 42 Mo Molybdenum	98.9062 43 Tc Technetium	101.07 44 Ru Ruthenium	101.07 45 Rh Rhodium	106.42 46 Pd Palladium	107.8682 47 Ag Silver	112.411 48 Cd Cadmium	114.818 49 In Indium	118.710 50 Sn Tin	121.760 51 Sb Antimony	127.60 52 Te Tellurium	126.90447 53 I Iodine	131.293 54 Xe Xenon
132.90545 55 Cs Cesium	137.327 56 Ba Barium	175.077 57 La Lanthanum	178.49 72 Hf Hafnium	180.94788 73 Ta Tantalum	183.84 74 W Tungsten	186.207 75 Re Rhenium	186.207 76 Os Osmium	192.222 77 Ir Iridium	195.084 78 Pt Platinum	196.96655 79 Au Gold	200.59 80 Hg Mercury	204.3803 81 Tl Thallium	207.2 82 Pb Lead	208.9804 83 Bi Bismuth	209 84 Po Polonium	210 85 At Astatine	222 86 Rn Radon
223 87 Fr Francium	226 88 Ra Radium	227 89 Ac Actinium	261 104 Rf Rutherfordium	262 105 Db Dubnium	263 106 Sg Seaborgium	264 107 Bh Bohrium	265 108 Hs Hassium	266 109 Mt Meitnerium	268 110 Ds Darmstadtium	271 111 Rg Roentgenium	272 112 Uub Ununbium	284 113 Uut Ununtrium	289 114 Uuq Ununquadium	289 115 Uup Ununpentium	291 116 Uuh Ununhexium	293 117 Uus Ununseptium	294 118 Uuo Ununoctium

SN 1181



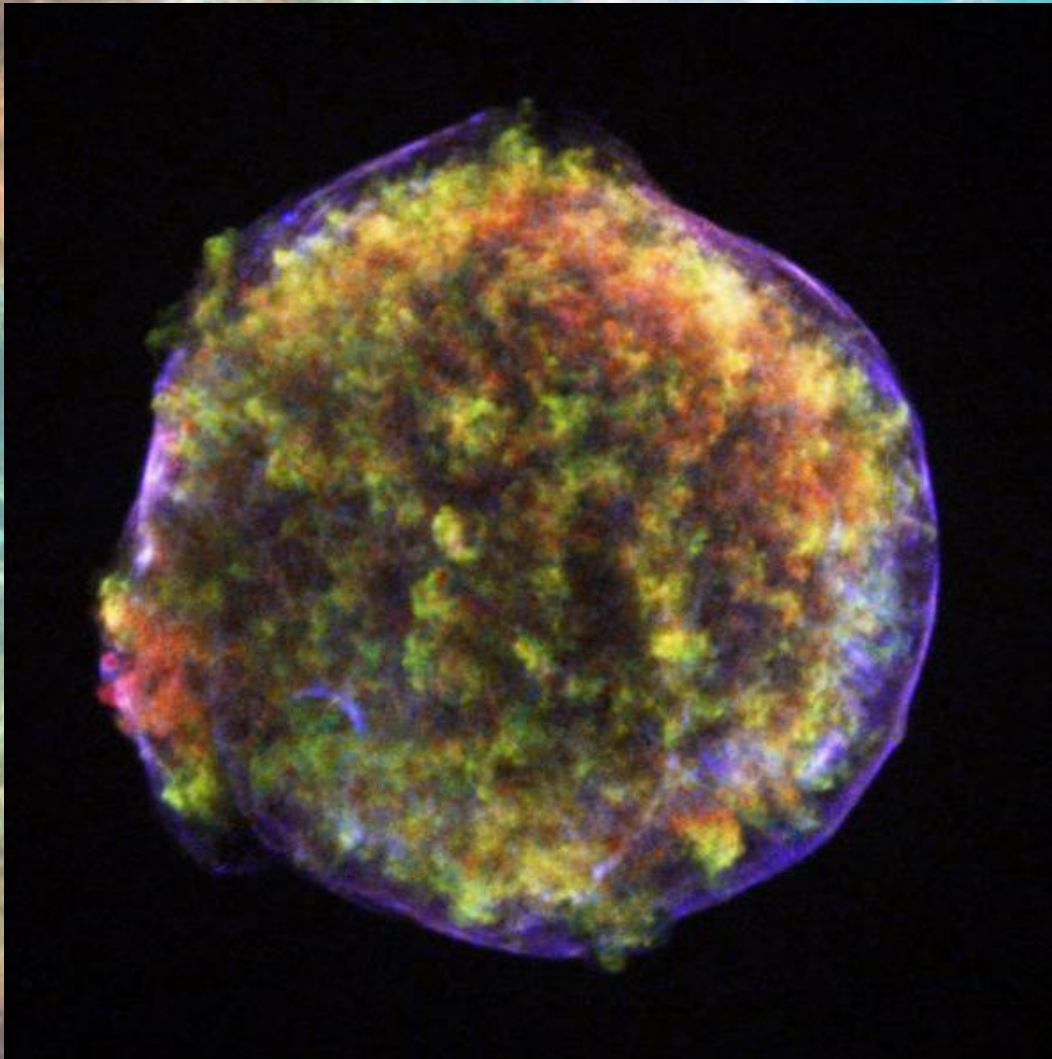
- 4 – 6 avgusta
- Kineski i Japanski astronomi
- Sazvežđe: Cassiopeia
- Vidljiva 185 dana
- Radio izvor 3C58
 - Rotira 15 puta u sec
 - Prva “kvark-zvezda”
- Sjaj supernove: -1^m

Cs Cesium 55 132.905	Ba Barium 56 137.327
Fr Francium 87	Ra Radium 88

Hf Hafnium 72 178.49	Ta Tantalum 73 180.948	W Tungsten 74 183.84	Re Rhenium 75 186.207	Os Osmium 76 190.23	Ir Iridium 77 192.222	Pt Platinum 78 195.084
Rf Rutherfordium 104	Db Dubnium 105	Sg Seaborgium 106	Bh Bohrium 107	Hs Hassium 108	Mt Meitnerium 109	Ds Darmstadtium 110

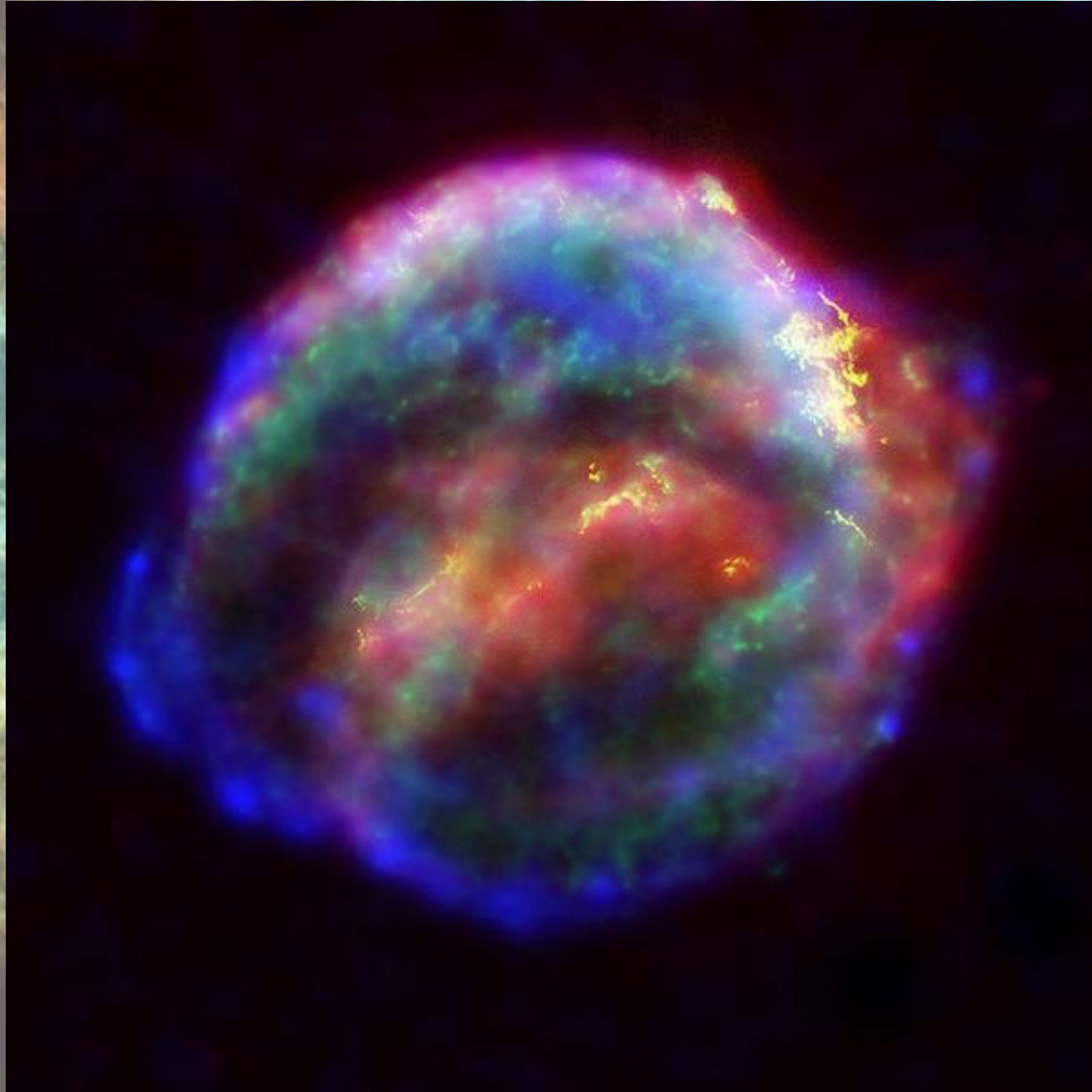
Ni Nickel 28 58.693	Cu Copper 29 63.546	Zn Zinc 30 65.38	Ga Gallium 31 69.723	Ge Germanium 32 72.63	As Arsenic 33 74.922	Se Selenium 34 78.96	Br Bromine 35 79.904	Kr Krypton 36 83.80
Pd Palladium 46 106.90	Ag Silver 47 107.868	Cd Cadmium 48 112.411	In Indium 49 114.818	Sn Tin 50 118.710	Sb Antimony 51 121.757	Te Tellurium 52 127.6	I Iodine 53 126.905	Xe Xenon 54 131.29
Au Gold 79 196.967	Hg Mercury 80 200.59	Tl Thallium 81 204.38	Pb Lead 82 207.2	Bi Bismuth 83 208.98	Po Polonium 84	At Astatine 85	Rn Radon 86	
Uub Ununbium 112	Uut Ununtrium 113	Uuq Ununquadium 114	Uup Unupentium 115	Uuh Ununhexium 116	Uus Ununseptium 117	Uuo Ununoctium 118		

SN 1572



- 11. novembar
- Tiho Brahe
- Sjajnija od Venere (-4^m)
- Mart 1574 – nevidljiva golim okom
- Mlečni put, Cassiopeia
- Supernova Ia
- Gas – 9000 km/h
- Zvezda – G2
 - “pomogla” nastanku SN
 - 10.000 svetlosnih godina

SN 1604

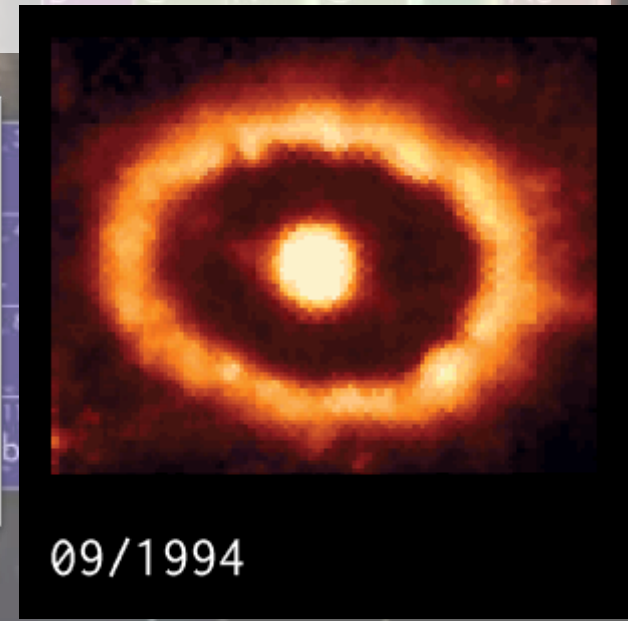
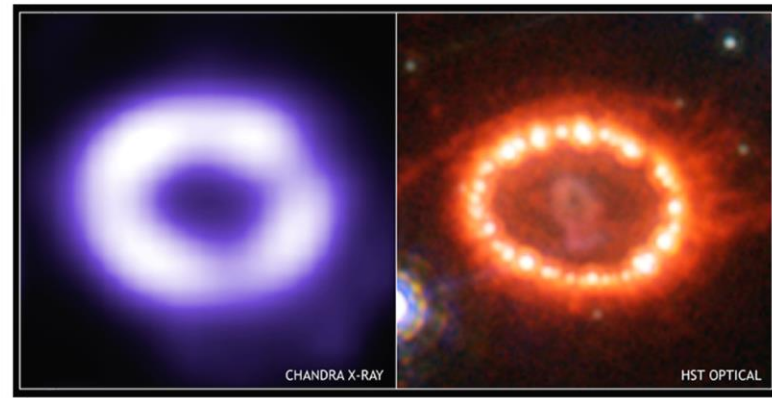
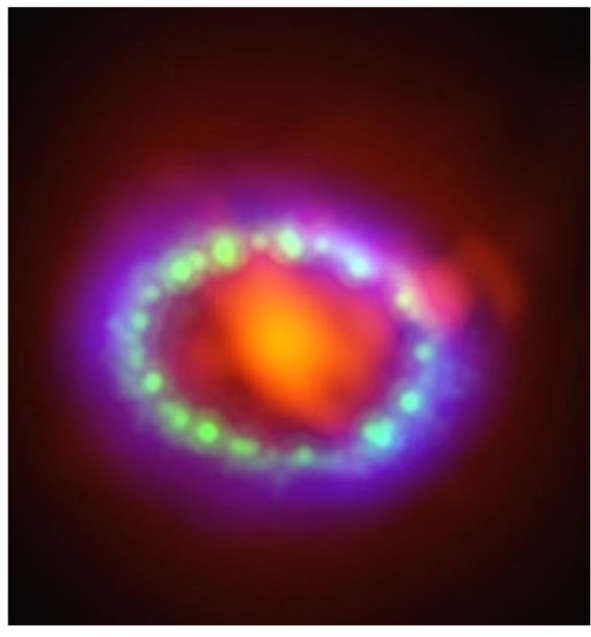
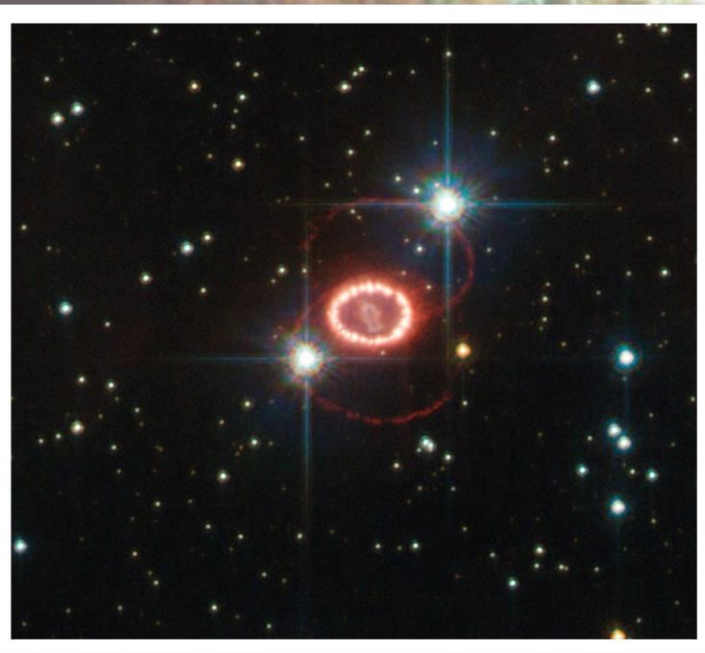


- 9. oktobra 1604
- Keplerova SN (zvezda), 17. oktobar 1604
- 20.000 svetlosnih godina
- Sjajnija od svih planeta osim Venere (-2.5^m)

Supernova SN1987A

- Noć 23.-24. februar 1987. godine
- Jan Šelton, opservatorija Las Campanas (čileanski Andi)
- Veliki Magelanov oblak
- Rudnik cinka – Kamioka (Japan)
 - 11 događaja u istoj sekundi
 - Rudnik u Ohaju – istovremeno 6 događaja
 - Verovatnoća nezamislivo mala!
 - Sudar sa neutrinima
- Nekoliko sati kasnije – australijski astronomi prepoznali zvezdu:
 - super-džin B3, 40 puta veći prečnik od Sunca
 - Sanduleak-69202

- Daljina 168.000 svetlosnih godina
- Sjaj +3^m
- Prva fotografija snimljena HST-om, kraj 1990. god
- Tri prstena
- 2001 – izbačeni materijal „udario“ prvi prsten; jaka emisija X zračenja (3 puta veći fluks, 2001-2009)
- HST i VLT (fotografije 1994-2014) – sjaj bledi, udarni talas uništio prsten. Izbledeće 2020-2030.



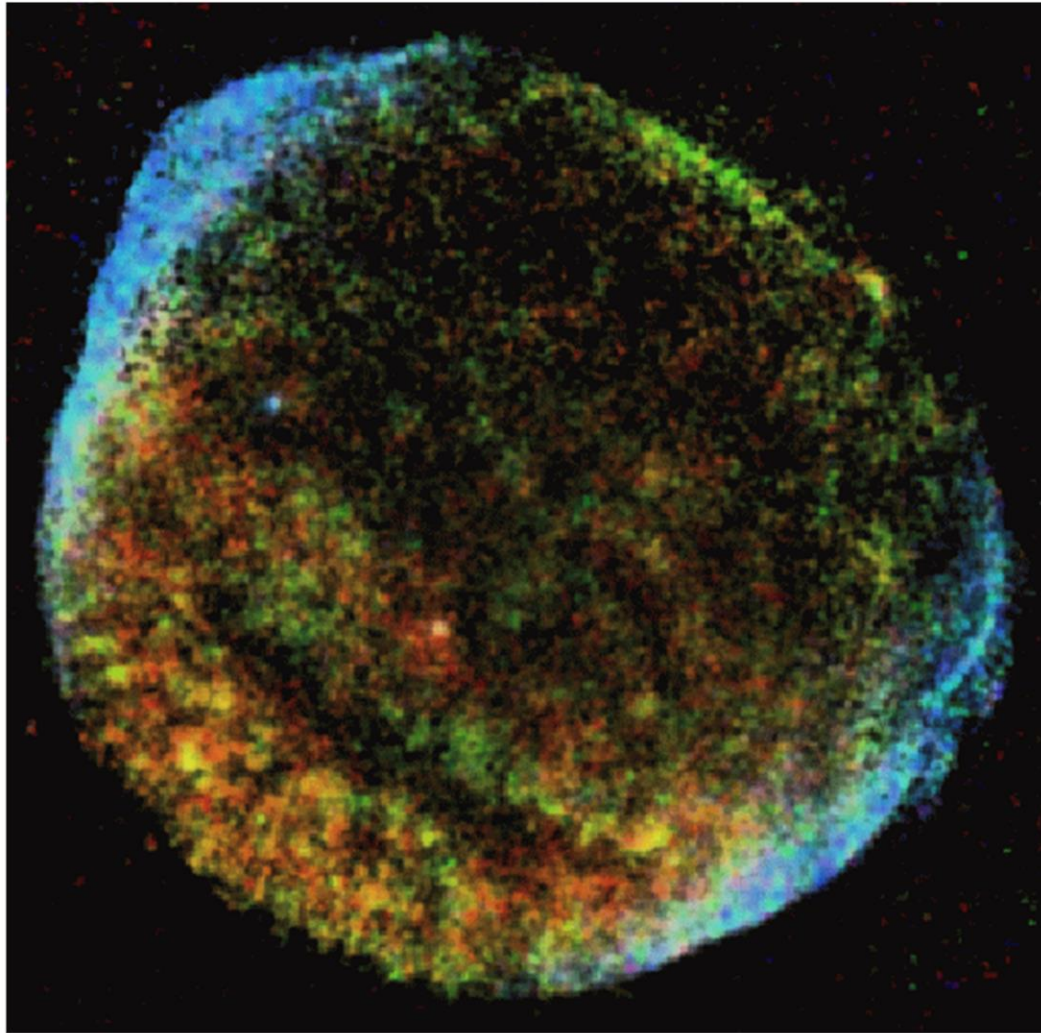
SN1006

- Najsjajnji događaj u istoriji
- 1. maj 1006. godine
- Švajcarska, Egipat, Irak, Kina, Japan, S. Amerika
- Egipatski astrolog Ali bin Ridwan
 - 2.5-3 puta veći disk od Venere
 - $\frac{1}{4}$ sjaja Meseca
- Supernova tipa Ia
- Neki izvori - senka

Cs Cesium 55	Ba Barium 56
Fr Francium 87	Ra Radium 88

Rf Rutherfordium 104	Db Dubnium 105	Sg Seaborgium 106	Bh Bohrium 107	Hs Hassium 108	Mt Meitnerium 109	Ds Darmstadtium 110	Rg Roentgenium 111	Uub Ununbium 112	Uut Ununtrium 113	Uuq Ununquadium 114	Uup Ununpentium 115	Uuh Ununhexium 116	Uus Ununseptium 117	Uuo Ununoctium 118
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SN 1006



- Sjaj -7.5^m
- U centru – pulsar ili crna rupa – nepoznato
- Oblak – 2.800 km/h



Elementi teži od gvožđa

- Zahvat neutrona
- Neutroni – sporedni produkti nuklearnih reakcija
- Nemaju naelektrisanje – nema odbojnih sila
- „Spajanje“ sa gvoždem → izotop veće mase
- S-proces (*slow neutron capture*)

- Jezgro postaje nestabilno, raspada se



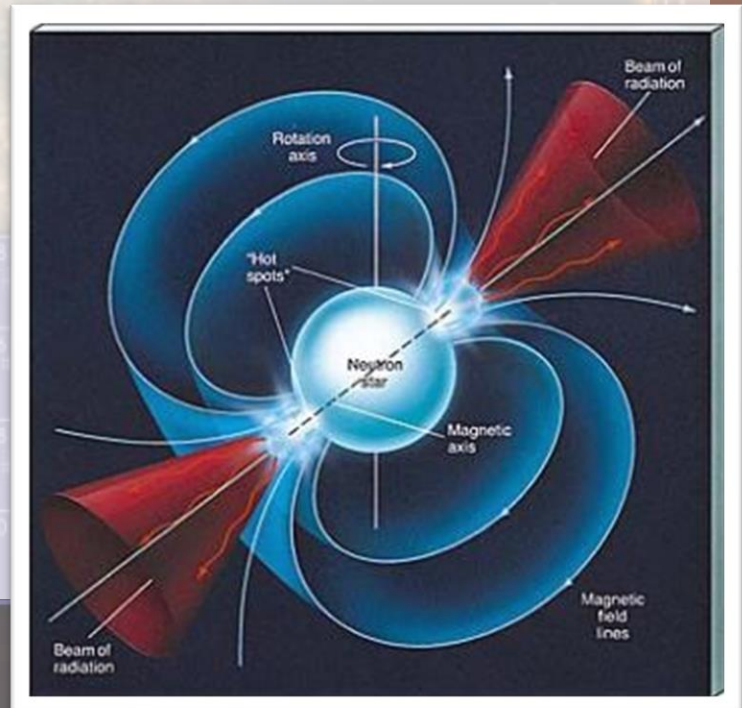
- ^{59}Fe – radioaktivno, raspada se na kobalt-59, stabilan
- Svaki uspešan zahvat – oko godinu dana, nestabilna jezgra imaju dovoljno vremena da pređu u stabilna
- Nastali: olovo, bakar, srebro, zlato

Najteži elementi

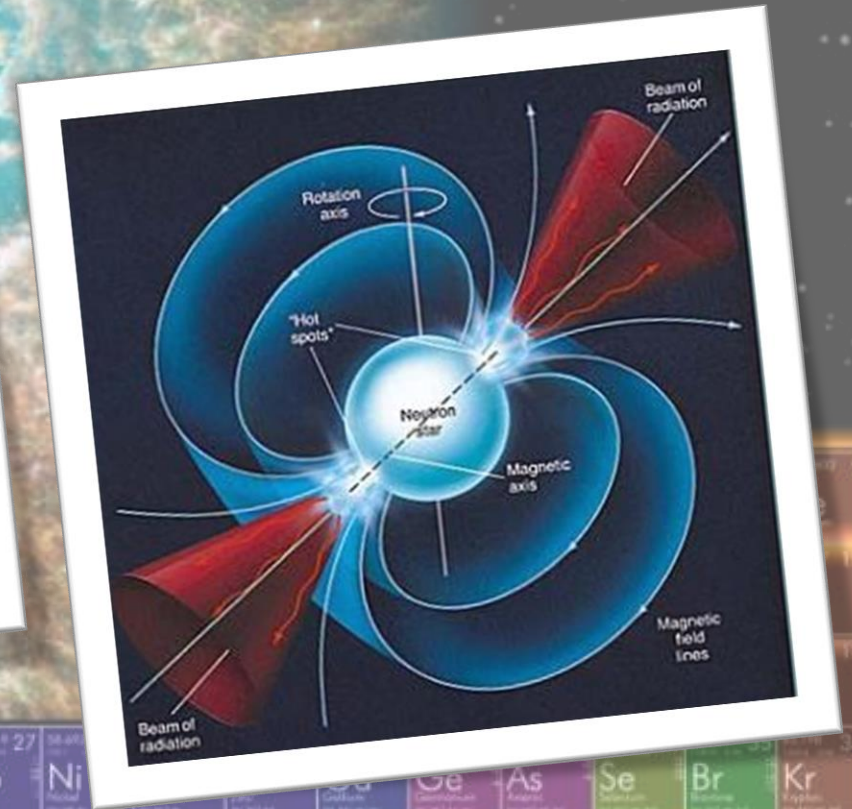
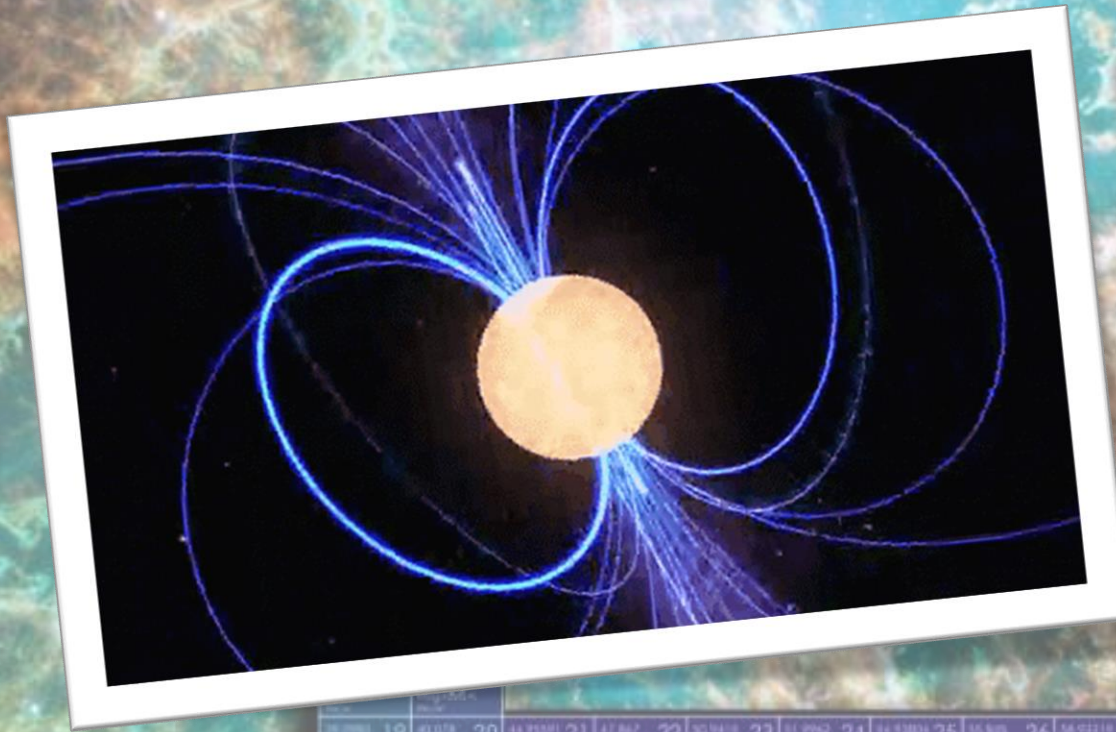
- S-proces – do bizmuta-209 (najteži neradioaktivan element)
- Ne može torijum, uran, plutonijum
- S-proces nemoguć – novo jezgro raspada za kraće vreme nego što je potrebno za nastanak
- *r*-proces (*rapid*)
 - prvih 15 minuta eksplozije, broj slobodnih neutrona raste
- Stopa zahvata neutrona – velika
- Najteži elementi nastaju nakon smrti matične zvezde
- Rasprostranjenost oko milijardu puta manja nego vodonika i helijuma

Neutronska zvezda

- “Pritisak” neutrona
- Uvećana verzija belog patuljka
- Beli patuljak 10.000 km, neutronska zvezda 30 km.
- Kašičica materijala – 40 milijardi tona



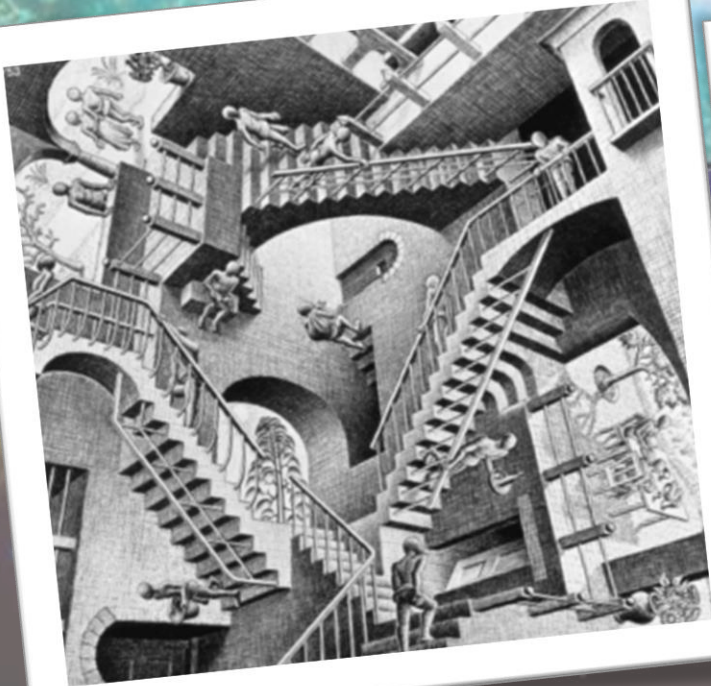
Pulsari



- 1967. godina → LGM1 → pulsari
- LGM – *Little Green Man*

Crne rupe

- Neutronske zvezde – do 2,5 solarne mase
- Jedno od najznačajnijih teorijskih otkrića XX veka
- 40-50 puta veća masa



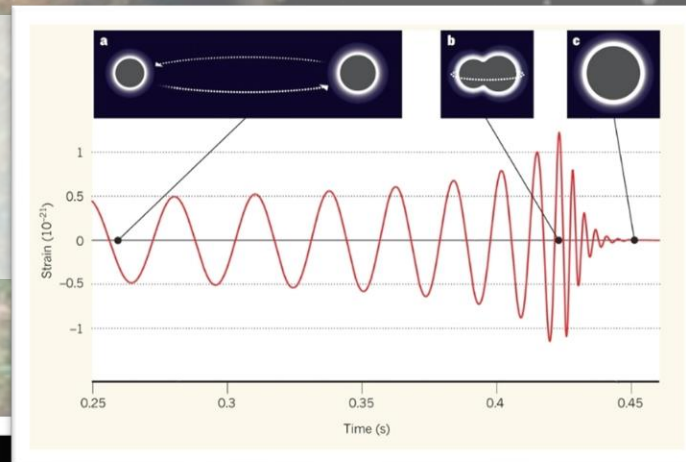
- Maurits Cornelis Escher (1898-1972)
- Relativity, 1953.
- Waterfall, 1961.

Sudar dve crne rupe...



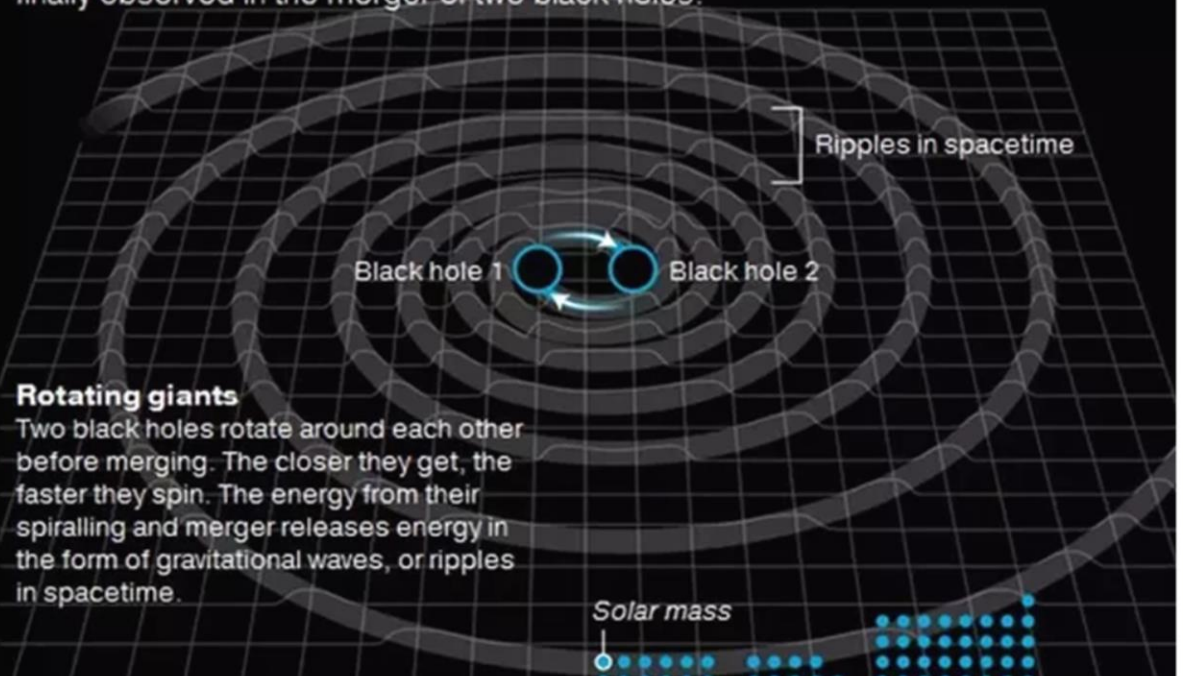
... gravitacioni
talasi!

GW150914



Ripples in spacetime

Theorized by Einstein, gravitational waves are finally observed in the merger of two black holes.

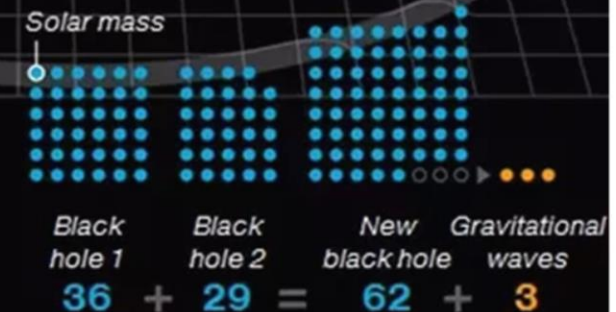


Rotating giants

Two black holes rotate around each other before merging. The closer they get, the faster they spin. The energy from their spiralling and merger releases energy in the form of gravitational waves, or ripples in spacetime.

Enormous energy

The result of the merger is a bigger black hole, though it's less massive than the two combined black holes. The equivalent of three solar masses is converted into energy, in the form of gravitational waves.



Sudar dve neutronske zvezde

■ Gravitacioni talasi

- GW170817
- GW170814
- GW170104
- GW151226
- GW150914

■ Nobelova nagrada iz fizike za 2017. godinu

GW170817

Binary neutron star merger

A LIGO / Virgo gravitational wave detection with associated electromagnetic events observed by over 70 observatories.



 Distance
130 million light years

 Discovered
17 August 2017

 Type
Neutron star merger



12:41:04 UTC

A gravitational wave from a binary neutron star merger is detected.

gravitational wave signal

Two neutron stars, each the size of a city but with the mass of the sun, collided into each other.

gamma ray burst

A short gamma ray burst is an intense beam of gamma ray radiation which is produced just after the merger.

+ 2 seconds

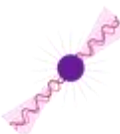
A gamma ray burst is detected.



GW170817 allows us to measure the expansion rate and the age of the universe directly using gravitational waves for the first time.



Detecting gravitational waves from a BNS event allows us to find out more about the structure of neutron stars.



This multimessenger event provides confirmation that neutron star mergers can produce short gamma ray bursts.



The observation of a kilonova allowed us to show that BNS mergers could be responsible for the production of all heavy elements, like gold, in the universe.



Observing both electromagnetic and gravitational waves from the event provides confirmation that gravitational waves travel at the same speed as light.

kilonova

Decaying heavy ions produce an optically bright kilonova, producing heavy metals like gold.



+10 hours 52 minutes

A new bright source of optical light is detected in a galaxy called NGC 4993, in the constellation of Hydra.

+11 hours 36 minutes
Infrared emission observed.

+15 hours
Bright ultraviolet emission detected.

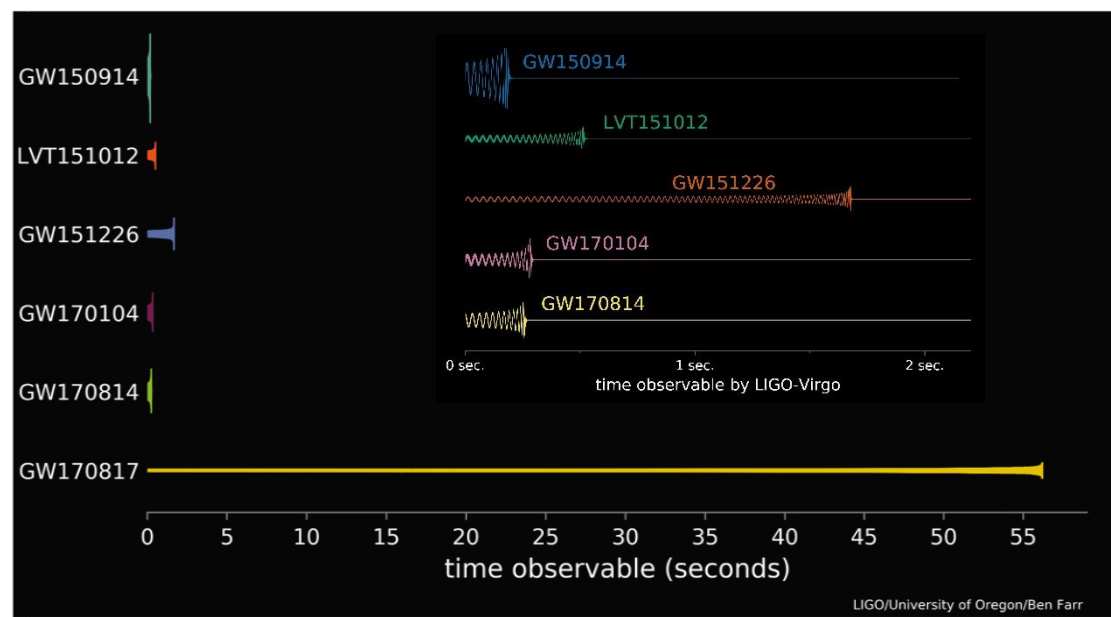
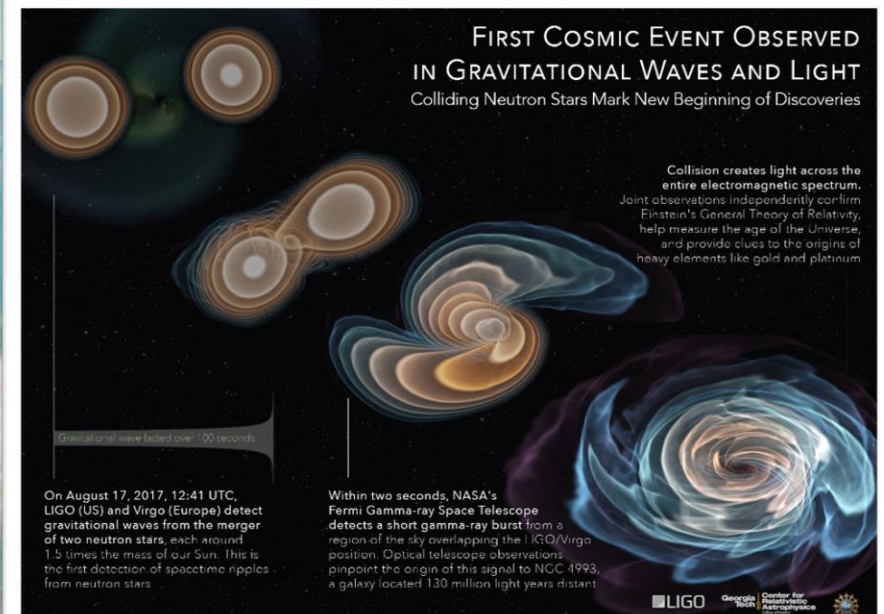
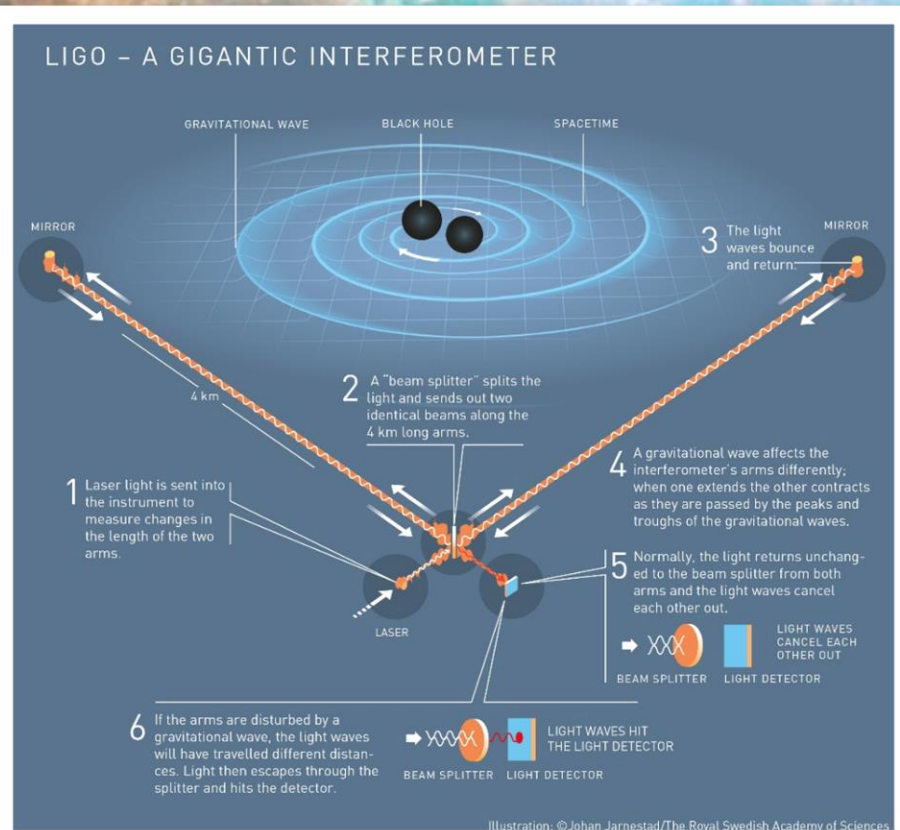
+9 days
X-ray emission detected.



+16 days

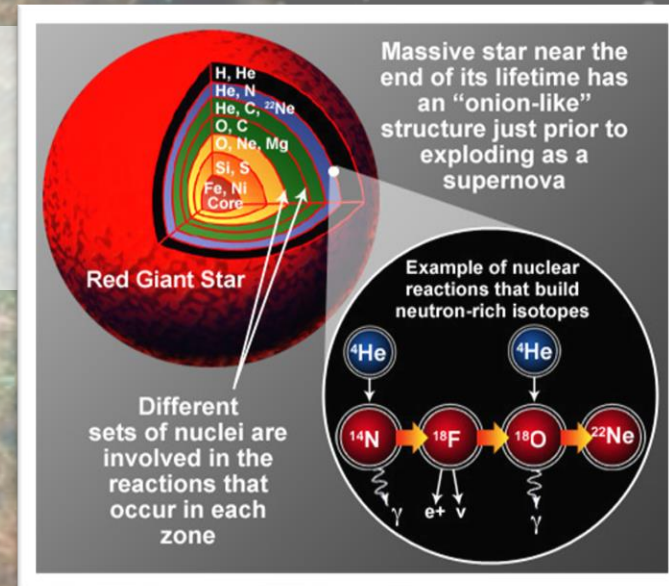
Radio emission detected.

Gravitacioni talasi



Svaki atom na Zemlji...

... nekada je bio deo jedne zaboravljene zvezde!



H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

Big Bang

Supernovae

Large Stars

Small Stars

Cosmic Rays