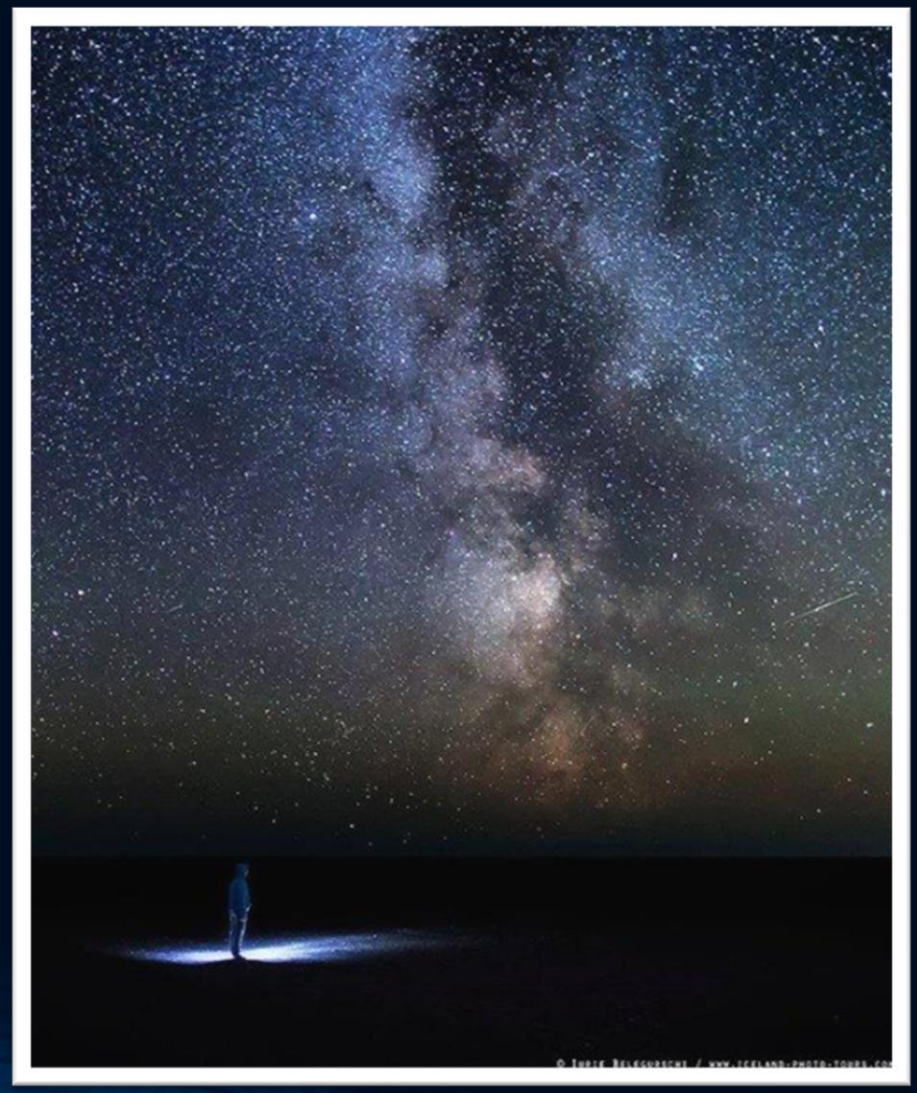
Nastanak zvezda

Zvezde su uvek iste?

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



http://vimeo.com/57130400

Naša zvezda - Sunce

Ali...

Slike nam pričaju priču...

Slike nam pričaju priču...

Slike nam pričaju priču...

Kako stvoriti zvezdu?

- Sastojci:
  - Vodonik
  - Gravitacija
  - Vreme… mnogo vremena

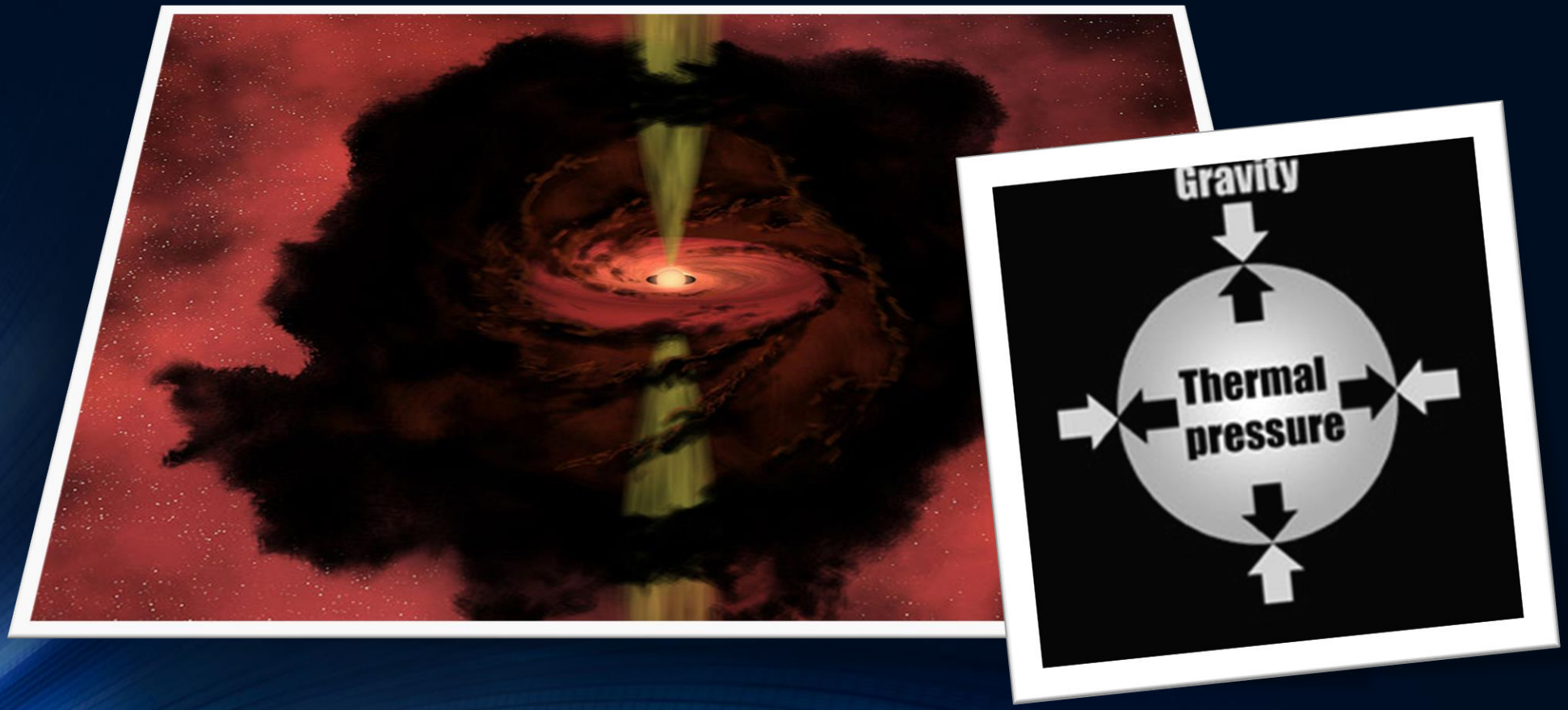
Zvezdano porodilište

- Gustina:
  - 10 atoma vodonika/cm3
  - 16 vodonika – 1 helijum
  - (vazduh - 30x1018 at./cm3)
- Temperatura: 100K (-173OC)

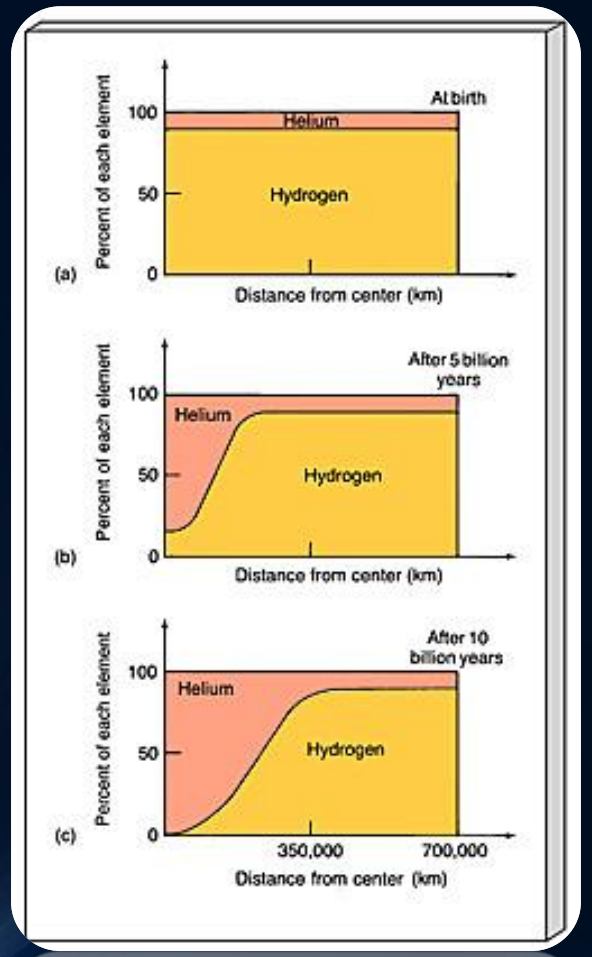
Tamna maglina

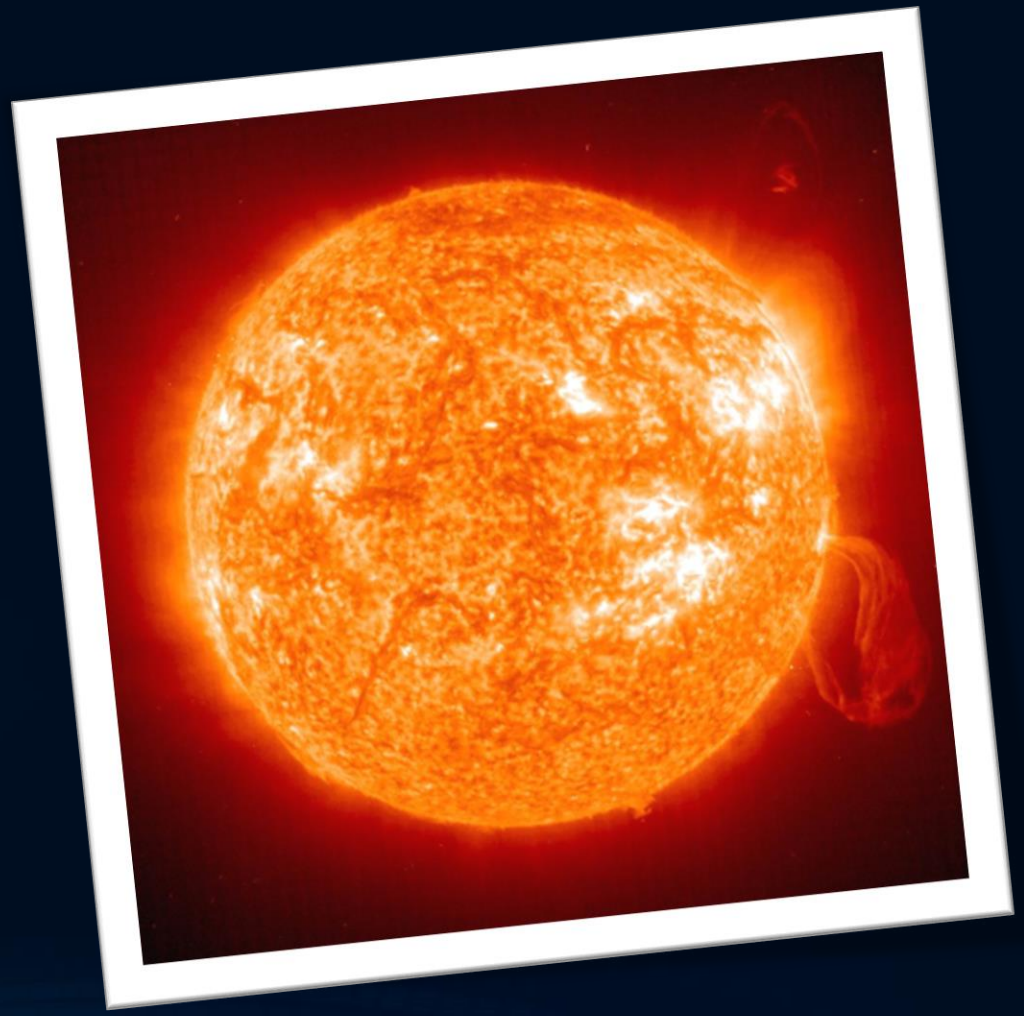
Globula

Protozvezda



Zvezda je rođena

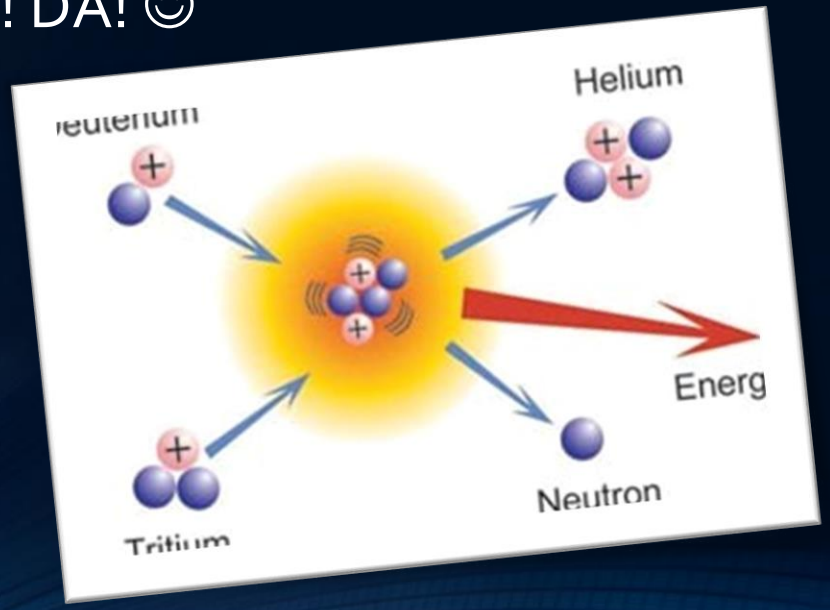


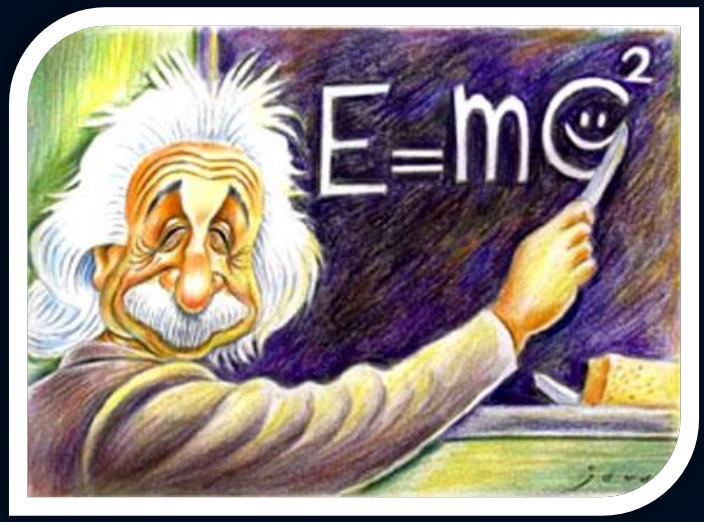


- Temperatura: 10 miliona stepeni

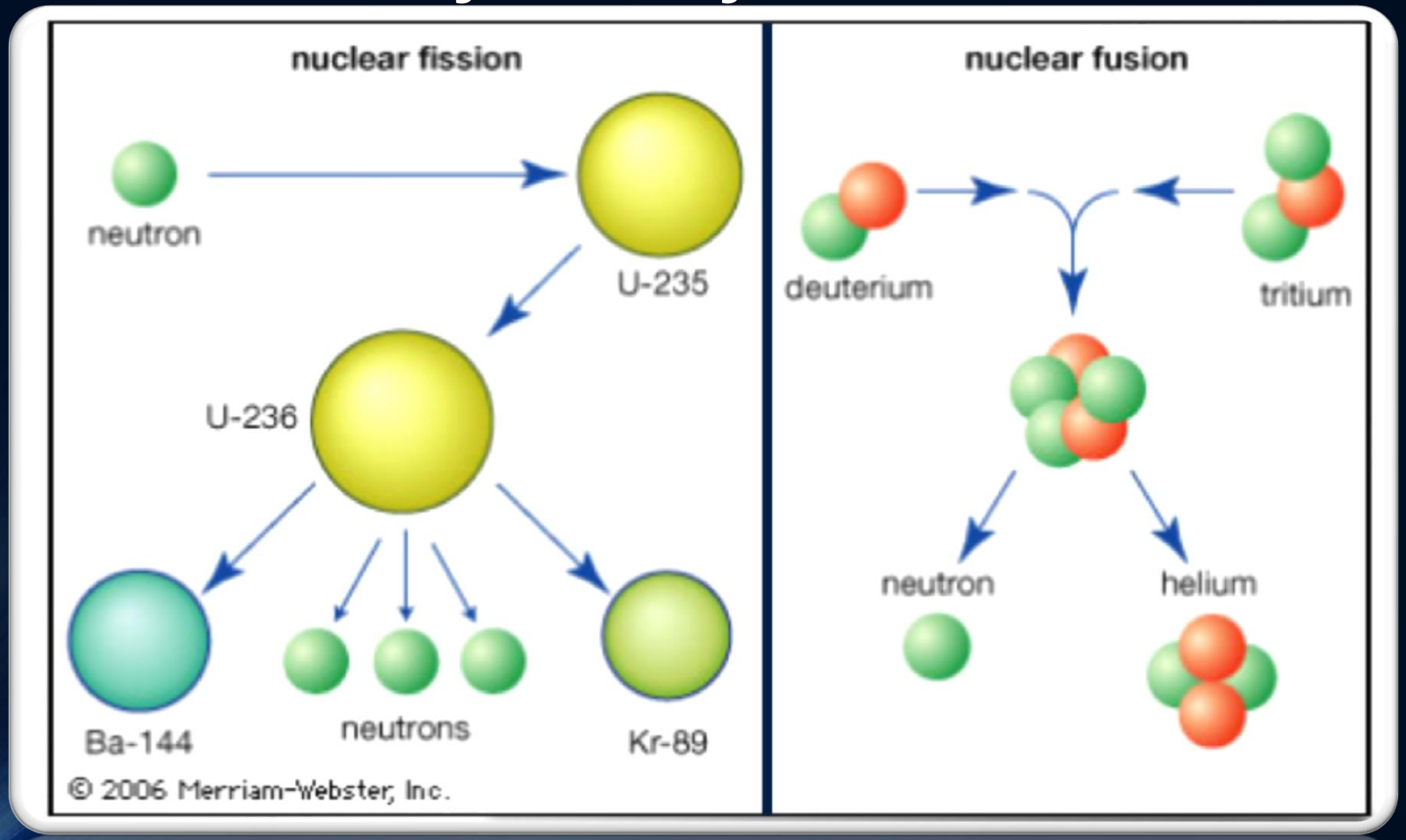
Kako sijaju zvezde?

- 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 -> 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 = mc2
  - 1 kg --> 9 x 1016 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	$<1\times10^{-8}$	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

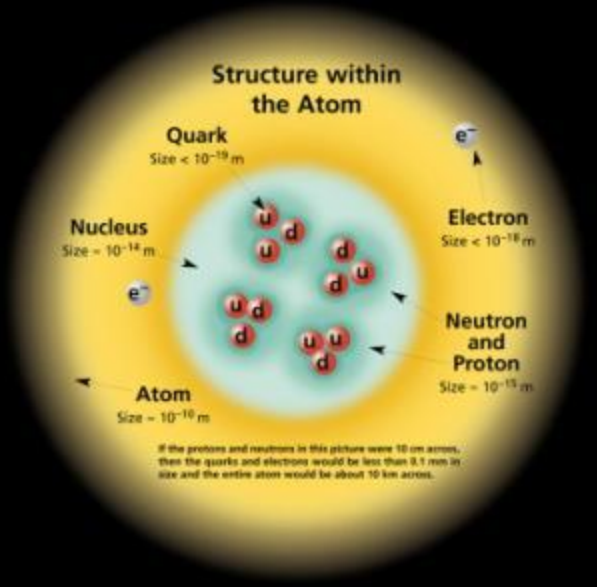
Quarks spin = 1/2

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

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



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

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag. for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag. for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

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

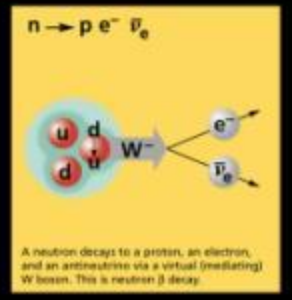
Mesons $q\bar{q}$

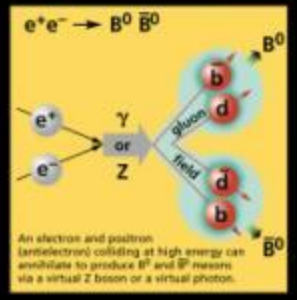
Mesons are bosonic hadrons. There are about 140 types of mesons.

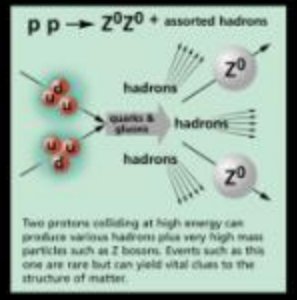
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

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.



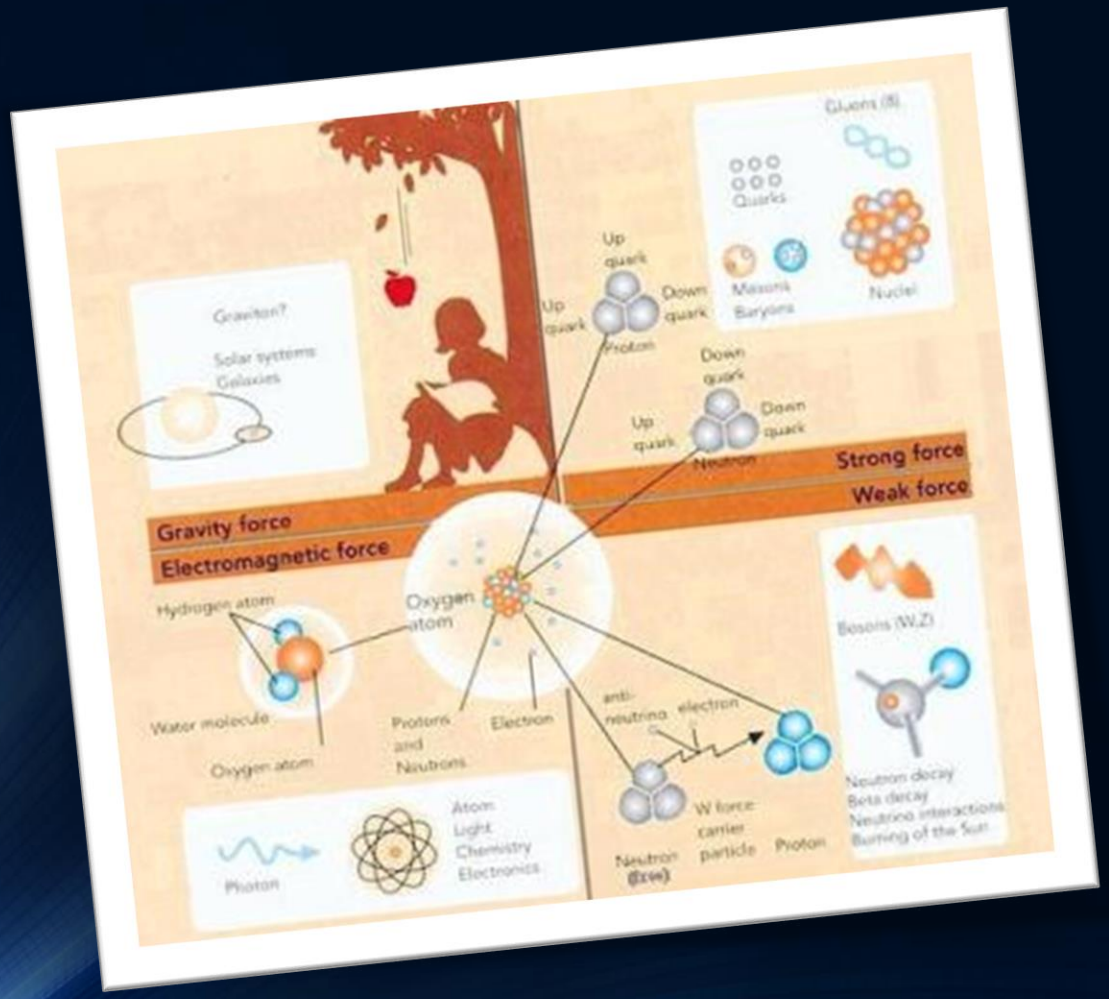


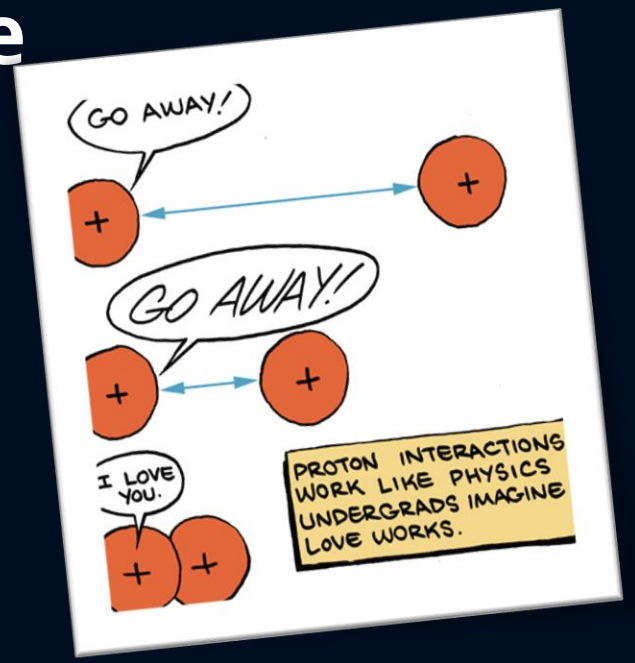


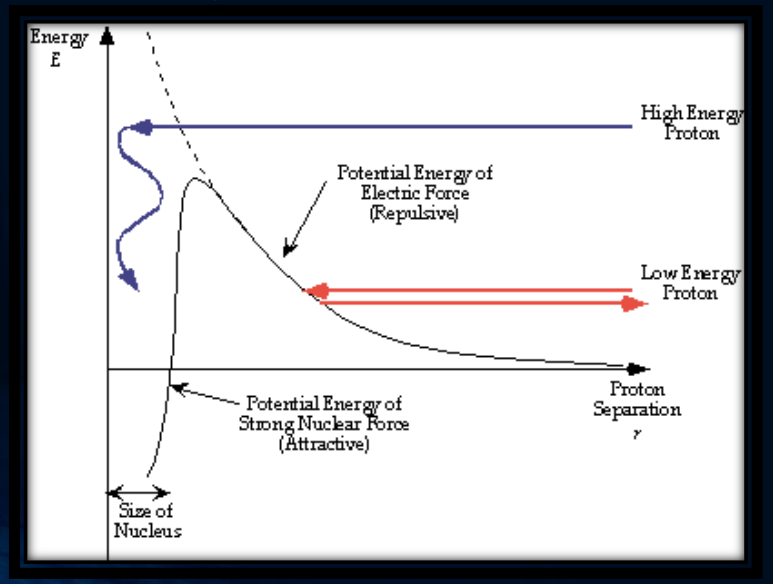
The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
Lawrence Berkeley National Laboratory
Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

Fundamentalne interakcije

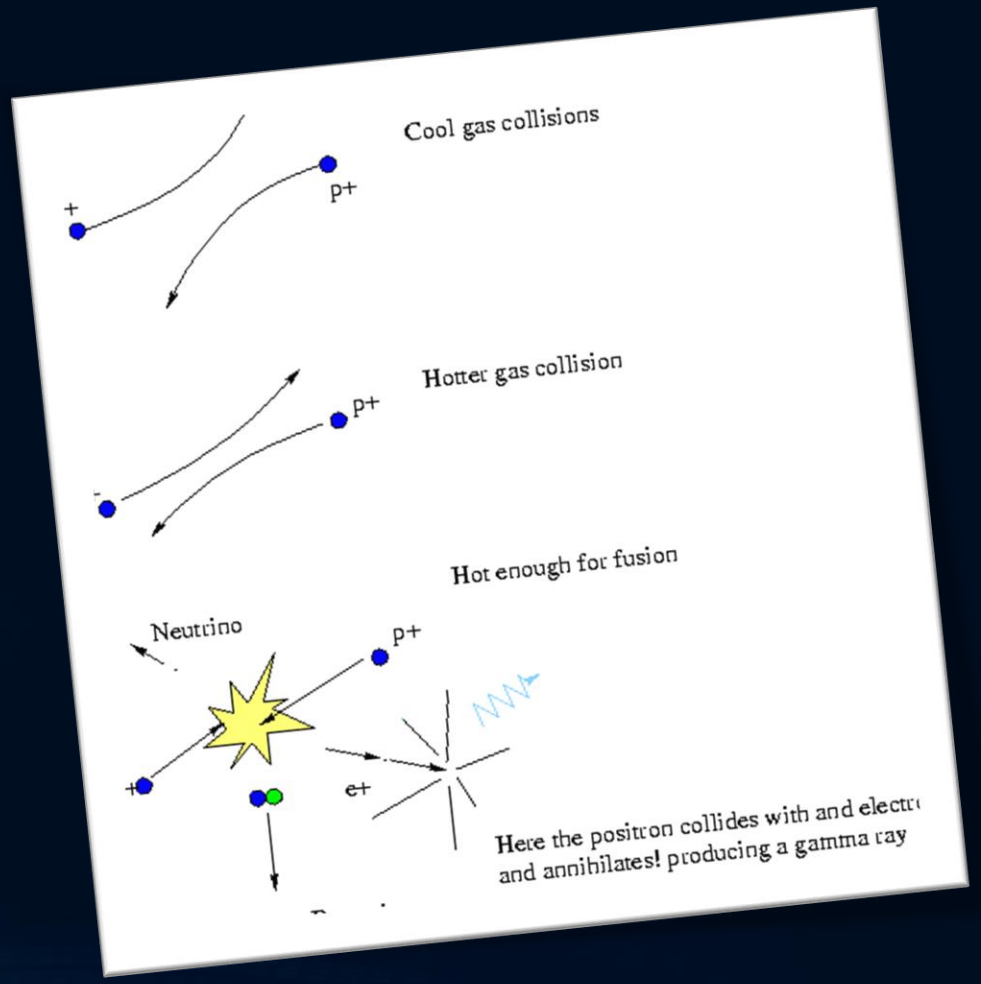




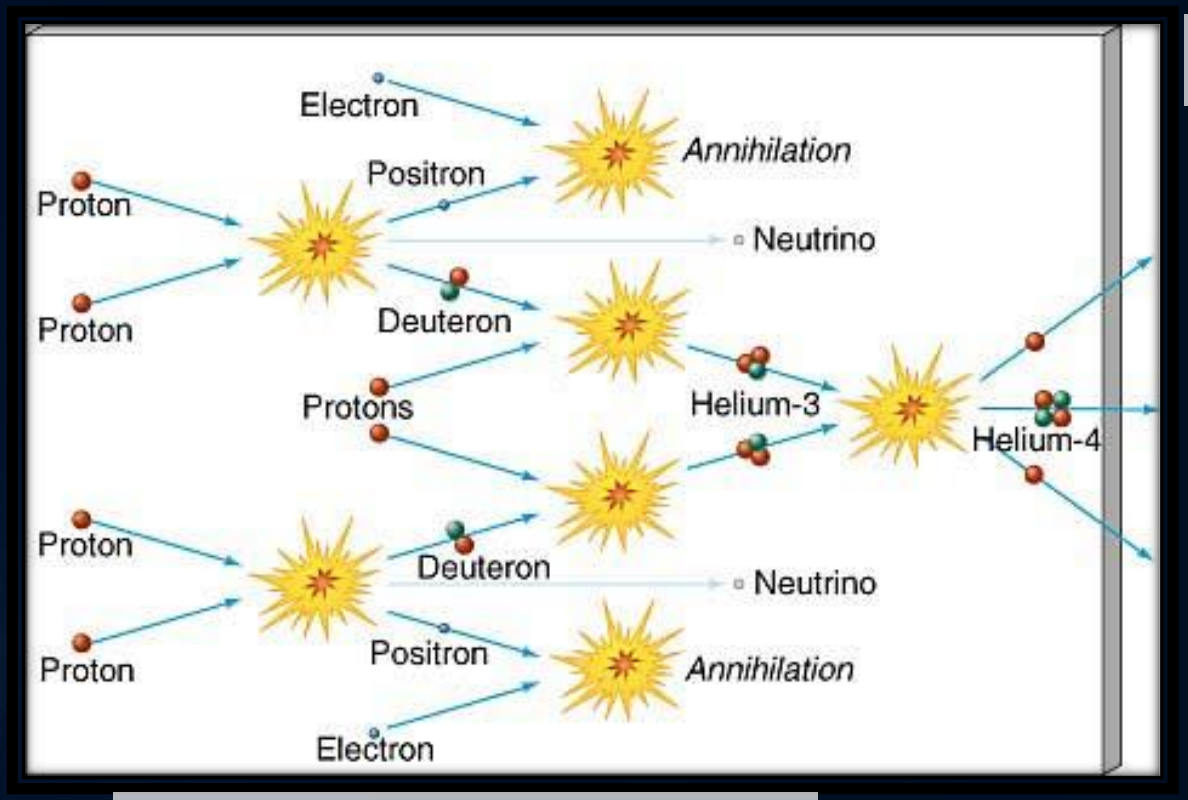


Nuklearna fuzija

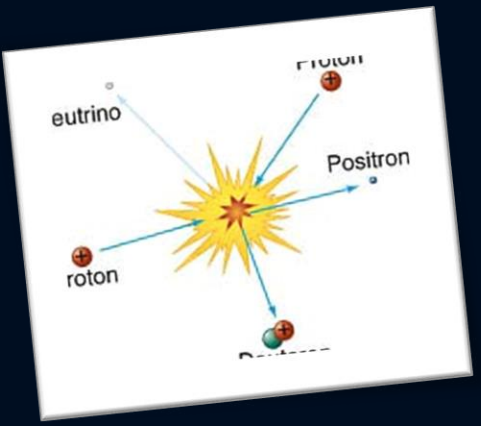
- Velika brzina
- Jaka nuklearna sila
- Rastojanje: 10-15 m
- Brzina: nekoliko 100 km/s
- Temperatura: 107 K



Proton-protonski ciklus



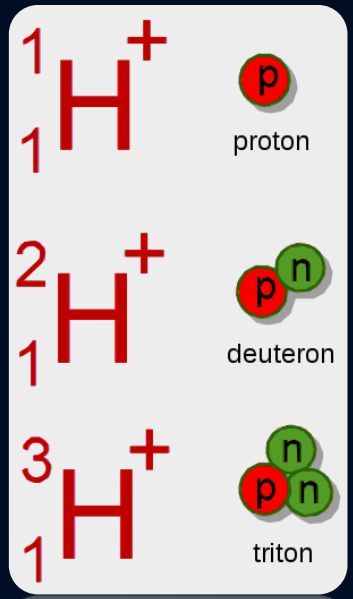
$$4(^1H) \rightarrow {}^4He + 2\nu_e + \gamma$$

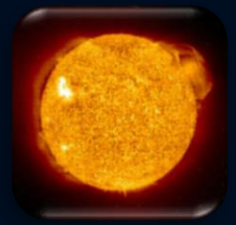


$$^1H + {}^1H \rightarrow {}^2H + e^+ + \nu_e$$

$$^2H + {}^1H \rightarrow {}^3He + \gamma$$

$$^3He + {}^3He \rightarrow {}^4He + {}^1H + {}^1H + \gamma$$





Koliko energije?

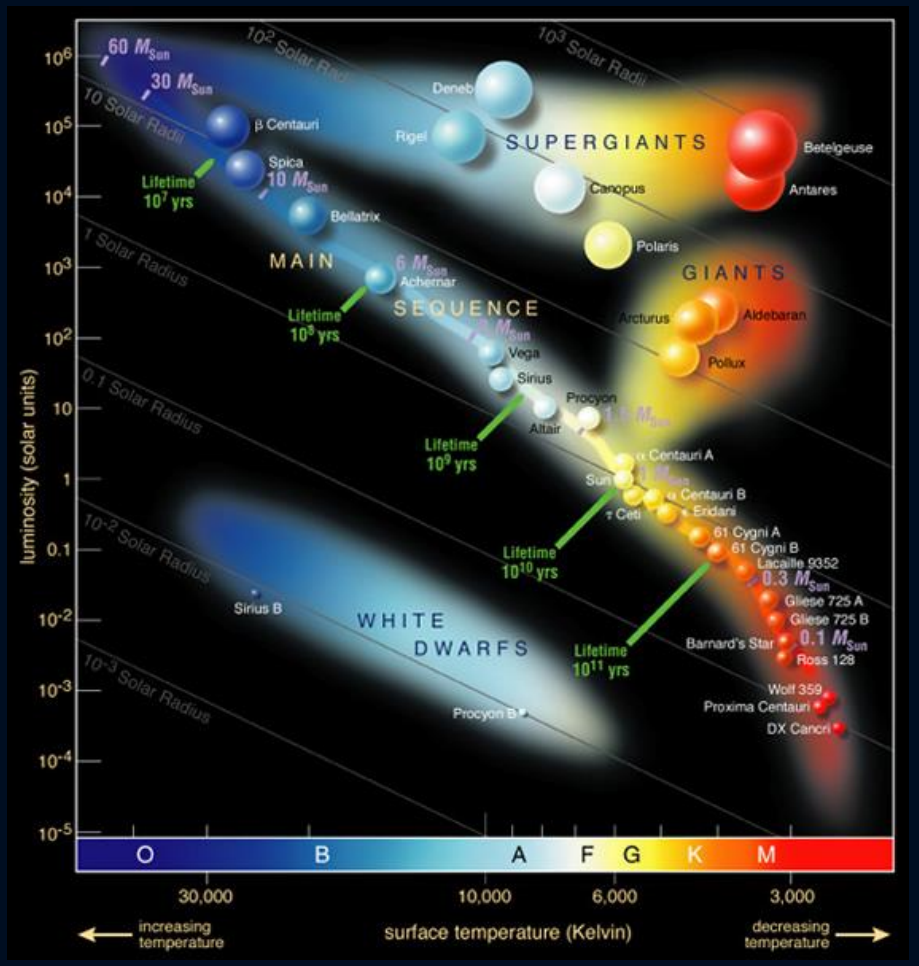
- Precizni eksperimenti na Zemlji - određene mase svih čestica u p-p ciklusu
- 4 protona - 6,6943◦10-27kg
- jezgro helijuma - 6,6466◦10-27kg
- defekt mase - 0,048◦10-27kg => 4,3◦10-12J (26,7 MeV)
- 1 kg vodonika => 6,4◦1013 J (više nego dovoljno)
- svake sekunde 700 miliona tona vodonika fuzijom prelazi u 695 miliona tona helijuma, a od 5 miliona tona nastaje energija
- **1 sekunda = 500000 godina potrošnje na Zemlji!**

Hercšprung-Raselov dijagram

FIZIČKE KARAKTERISTIKE I TIPOVI ZVEZDA

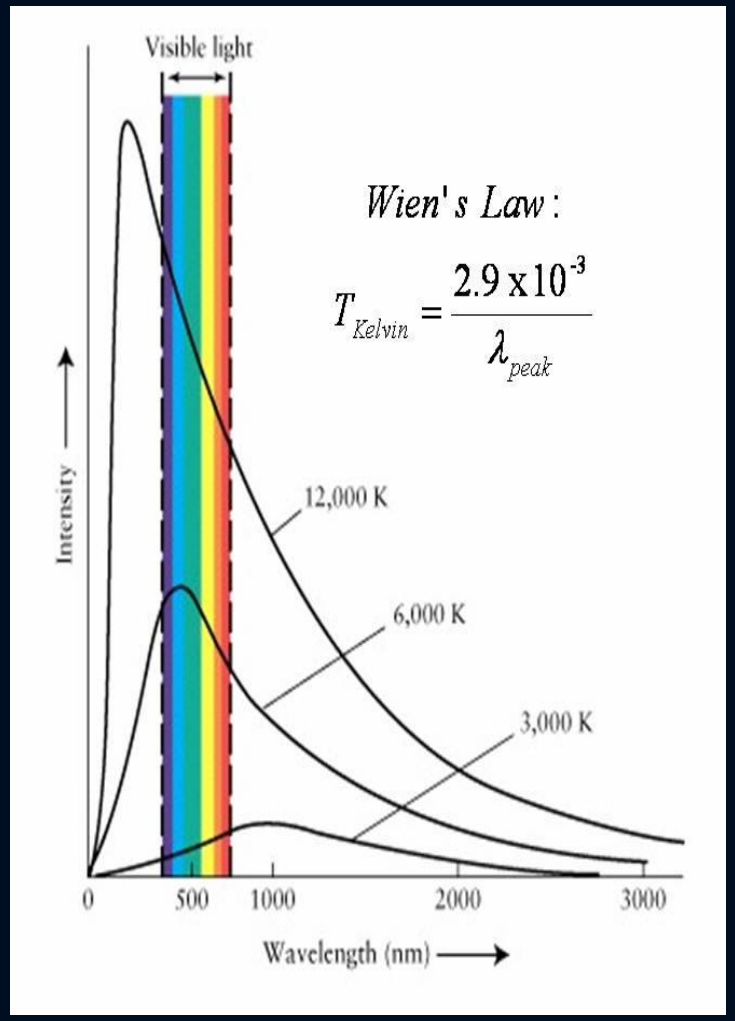
Malo istorije

- **Ejnar Hercšprung** *(Ejnar Hertzsprung)*
  - Veza između spektralnih boja zvezda i njihovog sjaja
    - Većina zvezda - što su plavije njihov sjaj je veći
    - Mali broj zvezda – odstupanje
  - Rezultati objavljeni 1905. i 1907. godine (slabije poznati časopisi)
- **Henri Noris Rasel** *(Henry Norris Russell)*
  - Apsolutna zvezdana veličina u korelaciji sa spektralnom klasom, koja je funkcija boje površine (temperature) zvezde

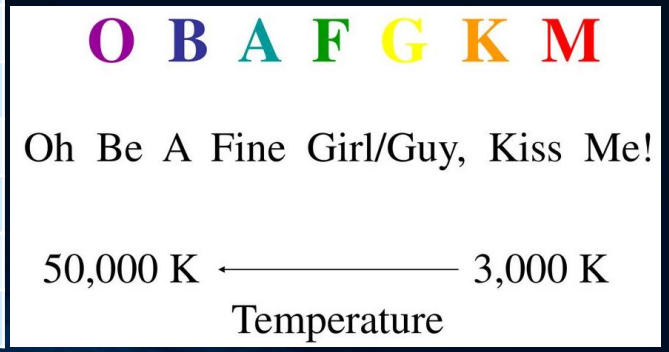


Klasifikacija zvezda

- **Vinov zakon (pomeranja) -** zračenje apsolutno crnog tela, sa porastom temperature, maksimum krive intenziteta zračenja postaje viši i pomera se ka kraćim talasnim dužinama.
  - Izvodi se iz Plankovog zakona zračenja.
- Posledica – spektralna klasifikacija zvezda



Classification	Temperature	Max Wavelength	Color
O0	40,000 K	72.5 nm	Blue
B0	20,000 K	145 nm	Light Blue
A0	10,000 K	290 nm	White
F0	7,500 K	387 nm	Yellow-White
G0	5,500 K	527 nm	Yellow
K0	4,000 K	725 nm	Orange
M0	3,000 K	966 nm	Red



Harvardska spektralna klasifikacija zvezda

- Zvezde se mogu klasifikovati na različite načine.
- Po izgledu spektra dele se na spektralne klase: *O-B-A-F-G-K-M*
- Svaka klasa podeljena je na **deset potklasa** (od 0 do 9), a uvedene su i **potklase** *R, N, S i W*.
- Ovde su osnovni kriterijumi klasifikacije temperatura fotosfere (površina zvezde) i linijski spektar.

Harvardska spektralna klasifikacija zvezda

- Klasa O:
  - plavobele zvezde visoke temperature (25 000-35 000 K).
  - Velike su mase i sjaja.
  - Spektri: apsorpcione linije jonizovanog kalcijuma, azota i kiseonika i emisione neutralnog vodonika i helijuma.
  - Tipični predstavnik λ Orionis.
- Klasa B:
  - plave zvezde temperature 15 000-25 000 K.
  - Izrazite apsorpcione linije helijuma i vodonika (pojačavaju se idući ka klasi A) i diskretne apsorpcione linije jonizovanog kalcijuma.
  - Tipične zvezde Rigel, Spika i Regulus.

Harvardska spektralna klasifikacija zvezda

- Klasa A:
  - bele zvezde temperature oko 9 000 K.
  - Izražene apsorpcione linije vodonika (bez helijuma).
  - Zbog nižih temperatura pojačavaju se linije jonizovanog kalcijuma.
  - Tipične zvezde Sirijus i Vega.
- Klasa F:
  - žuto-bele zvezde nešto sjajnije od Sunca. Temparatura im je oko 7 000 K.
  - Najintenzivnije su im linije jonizovanog kalcijuma, a slabe linije vodonika.
  - Pojavljuju se apsorpcione linije metala.
  - Tipične zvezde su Procion i Kastor.

Harvardska spektralna klasifikacija zvezda

- Klasa G:
  - žute zvezde slične Suncu, temeperature oko 6 000 K.
  - Apsorpcione linije vodonika još su slabije, a jačaju linije metala i jonizovanog kalcijuma.
  - Tipični predstavnici su Sunce (G2) i Kapela.
- Klasa K:
  - narandžasto-žute zvezde, površinske temperature 4 000 – 4500 K.
  - Intenzitet kalcijumovih linije je najveći, vodonikove linije su vrlo slabe.
  - Uočljivo je mnoštvo apsorpcionih linija metala i pojavljuju se linije molekula vodonika.
  - Tipične zvezde su: Poluks, Aldebaran i Arkturus.

Harvardska spektralna klasifikacija zvezda

- Klasa M:
  - crvenkaste zvezde, temperature 2 500 – 3 500 K.
  - Linije metala dostižu maksimalan intenzitet. Pojačava se intenzitet traka titan-oksida.
  - U ovoj klasi se pojavljuju i neke promenljive zvezde, sa emisionim linijama vodonika.
  - Tipične zvezde Antares, Betelgejz i Mira Ceti.

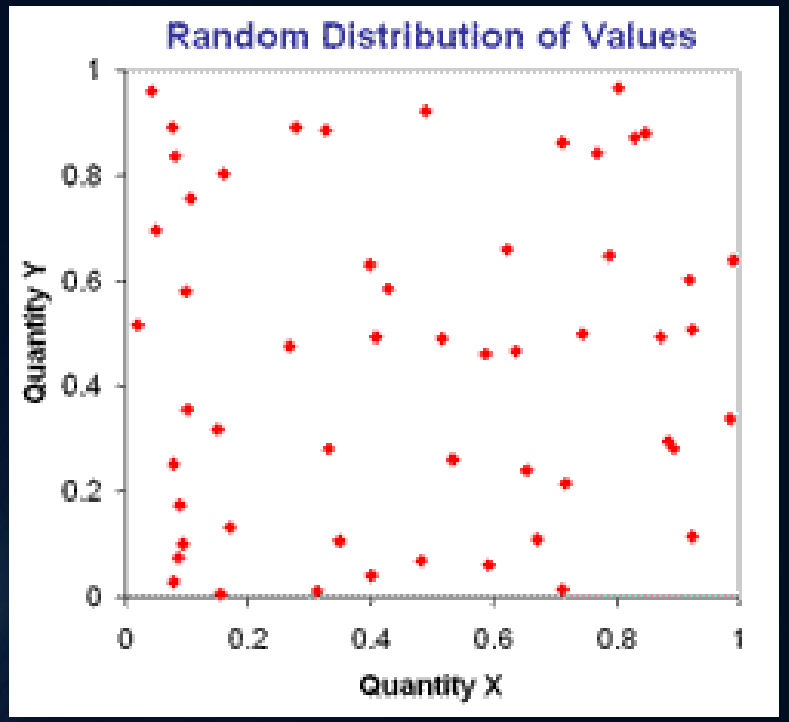
Harvardska spektralna klasifikacija zvezda

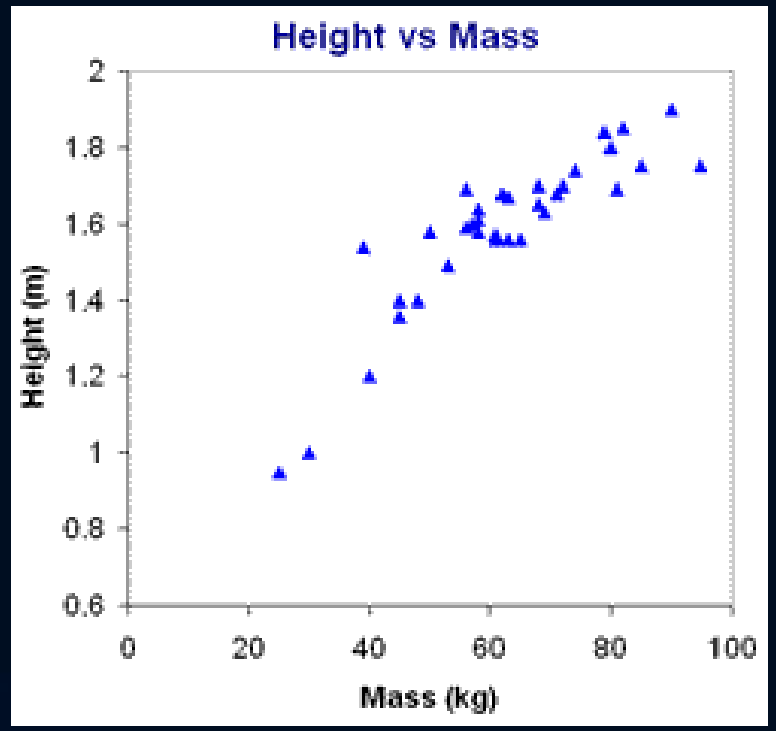
- Potklasa R:
  - narandžasto-crvene, temperature oko 3 500 K.
  - Dominiraju apsorpcione trake CO_2, cijana i CO.
  - Tipične su: RU Virginis i S Cameleopardalis.
- Potklasa N:
  - tamnocrvene zvezde, temperature oko 2 500 K.
  - Spektri su im slični klasi R, ali su linije slabijeg intenziteta.
  - Tipičan predstavnik S Cephei.

Harvardska spektralna klasifikacija zvezda

- Potklasa S:
  - zvezde slične klasi M, ali sa slabijim linijama titan-oksida.
  - Javljaju se i linije cirkonijum-oksida i emisione linije vodonika.
  - Često su promenljive zvezde.
  - Tipična zvezda: R Cygni.
- Potklasa W:
  - to su Volf-Rajeve zvezde.
  - Temperature su im jako visoke (50 000-100 000 K).
  - Belo su plave boje i vrlo sjajne.
  - U spektru se javljaju široke emisione linije i trake azota ili ugljenika, uz kiseonika i helijum.

OK, šta sad? *Nije „modelovanje" ali je (astro)fizika...*

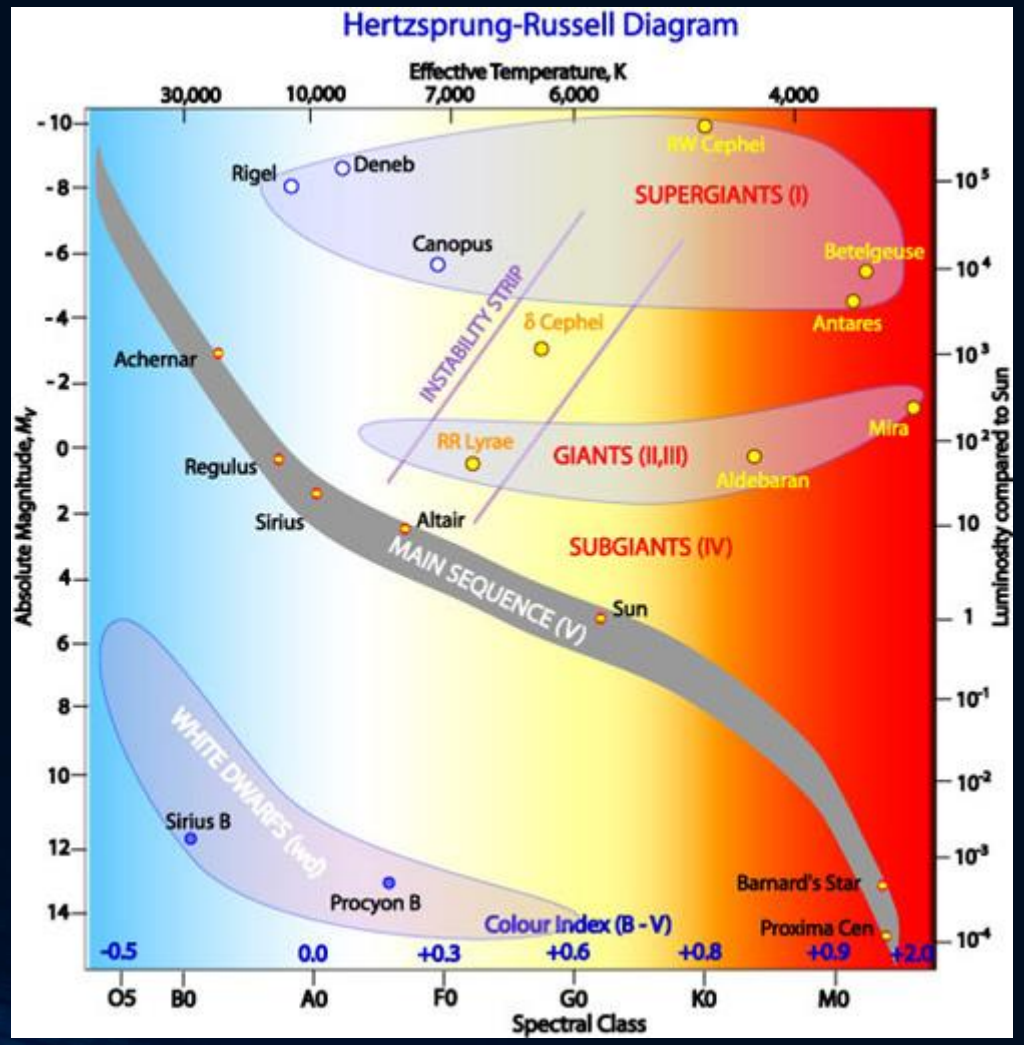




- Slučajna, homogena, raspodela
- **Korelacija** – mala grupa ljudi, visina vs masa

Hercšprung-Raselov (HR) dijagram

- Jedan od najznačajnijih grafikona u astrofizici, 1911 – 1913. godina
- Veza između temperature i sjaja zvezda – grupisanje
- Ogromna većina zvezda, kao i Sunce – glavni niz (*Main Sequence*)
- Džinovi i superdžinovi
- Beli patuljci



Primer: M klasa

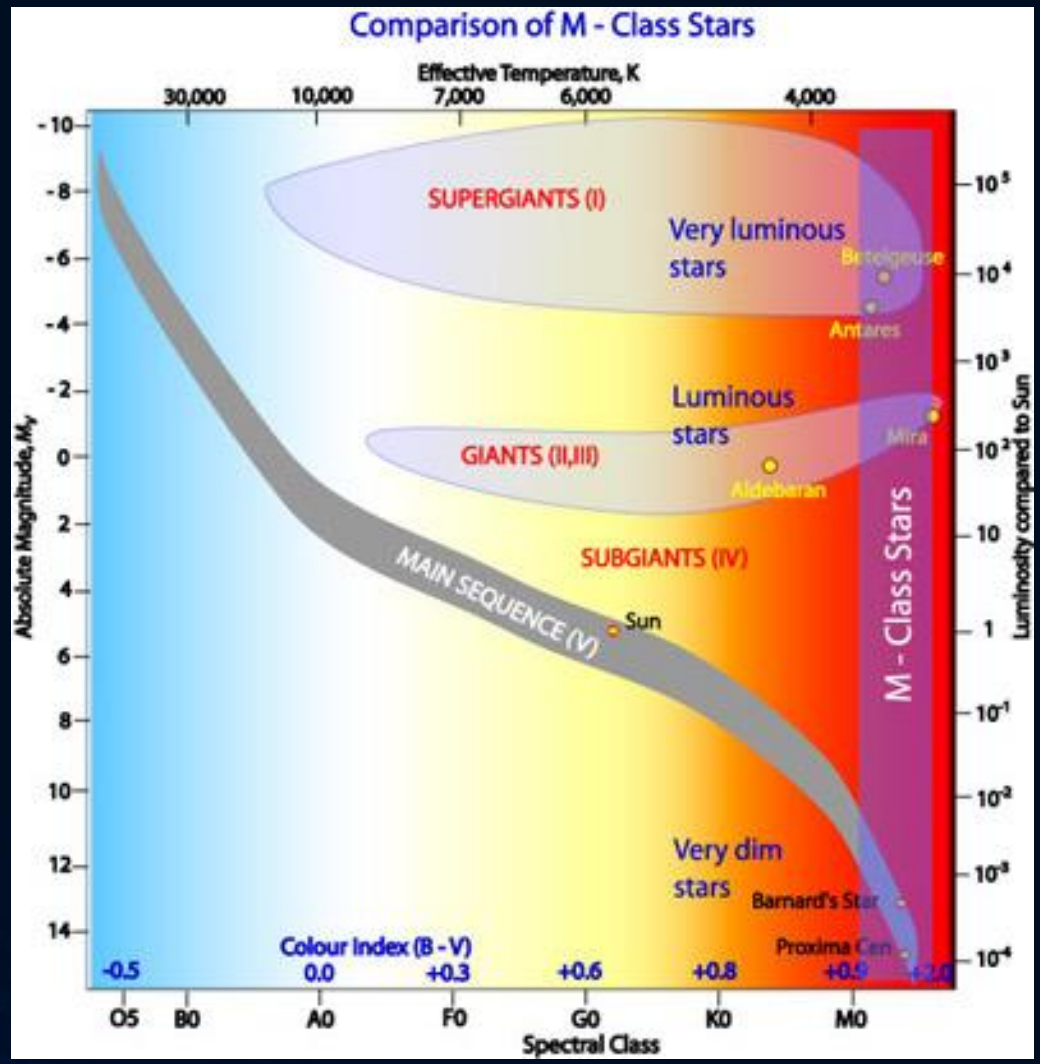
- Tri grupe zvezda
- Dole desno: *Proxima Centauri* i *Barnardova zvezda*
  - Oko 2.500 K, magnituda 13 (1/10.000 sjaja Sunca)
- Sredina: *Mira*
  - Hladna, ali većeg sjaja
- Gore desno: *Antares* i *Betelgeuse*
  - Hladne, ali još većeg sjaja (10.000 veći sjaj od Sunca)
- Stefan-Bolcmanov *(Stefan-Boltzmann)* zakon

$$I \approx \sigma T^4$$

- Dve zvezde, ista temperatura ali različite dimenzije

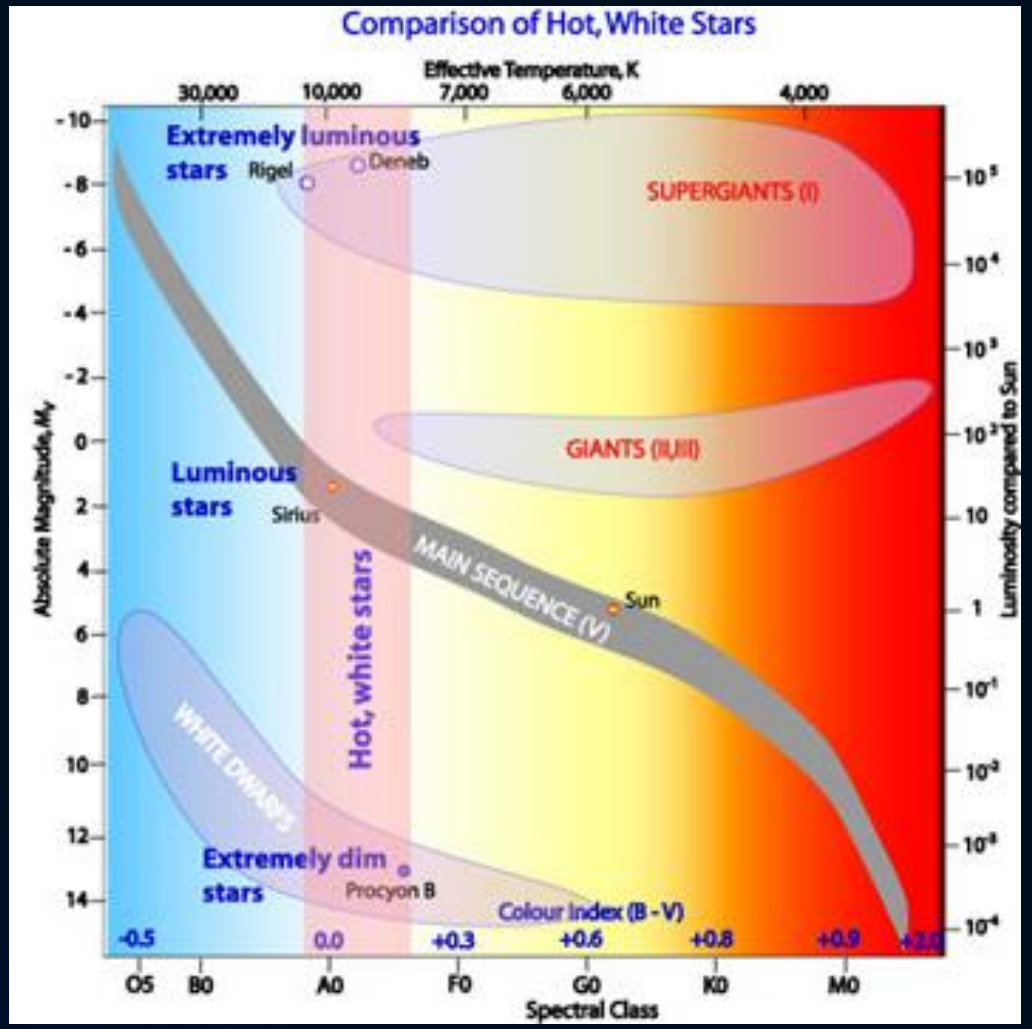
$$L \approx 4\pi R^2 \sigma T^4$$

- Klase sjaja: superdžinovi (I, II), džinovi (III), glavni niz (V) – iz istorijskih razloga „patuljci" u ovoj grupi



Primer: A klasa

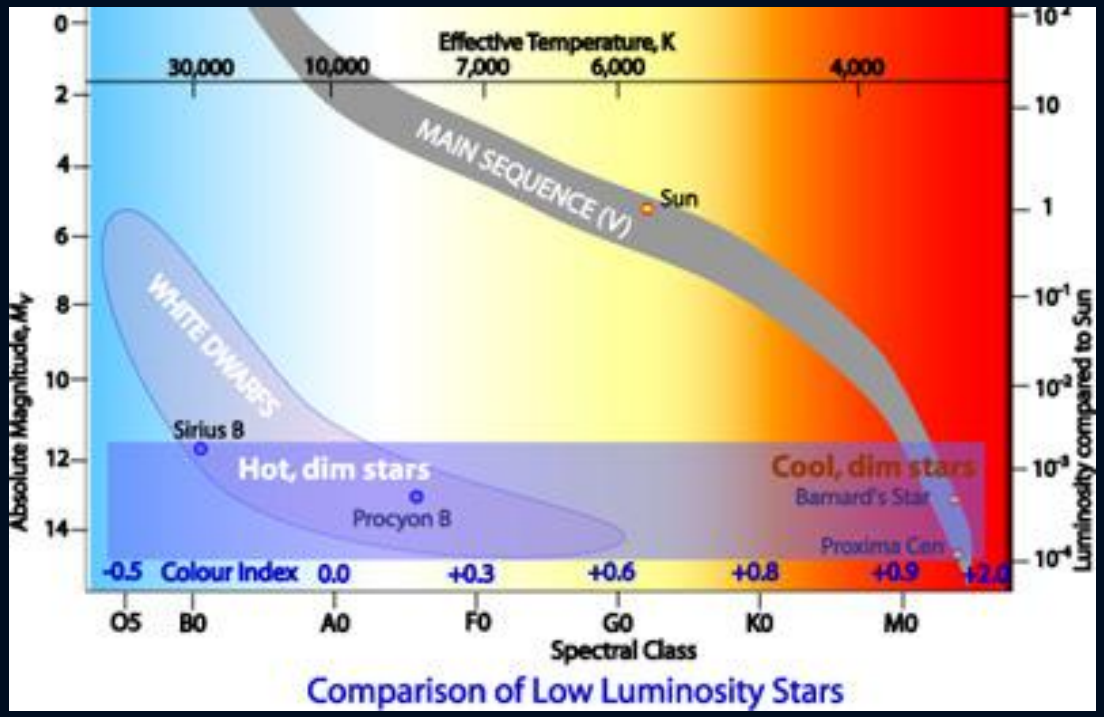
- Isto tri grupe zvezda
- Superdžinovi: Rigel i Deneb
- Ista temperatura ali veći sjaj nego Sirijus
  - Glavni niz, topliji od Bernardove zvezde
- Na dnu – Procyon B
  - Beli patuljak
  - Visoka temperatura (10.000+ K), malih dimenzija
  - Ne treba mešati sa starim terminom „patuljak" – male zvezde glavnog niza
  - Dimenzije – slične Zemlji, manje od 1/100 Sunca
  - Spektralna klasa wd (prefix) ili VII



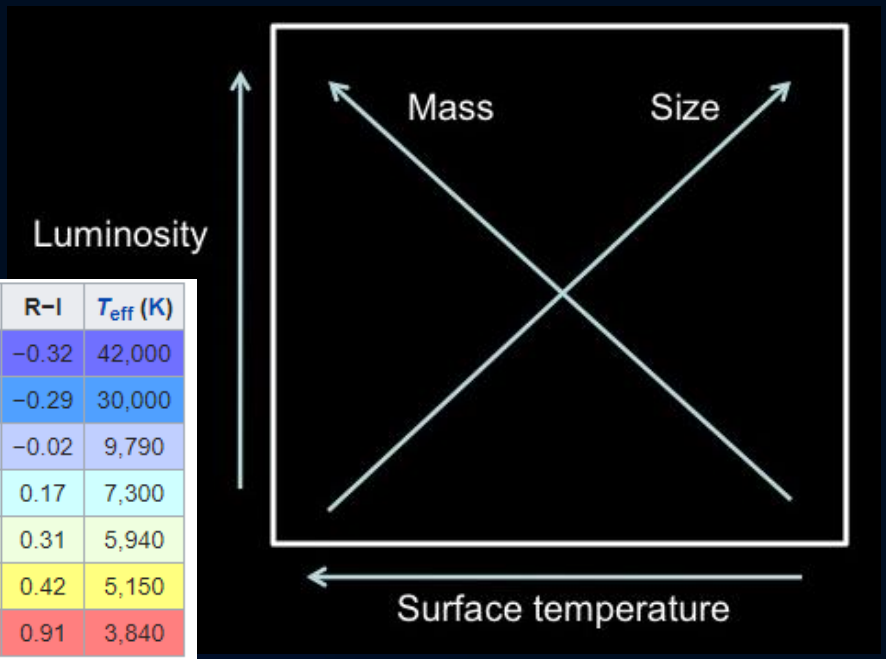
„Horizontalne razlike“

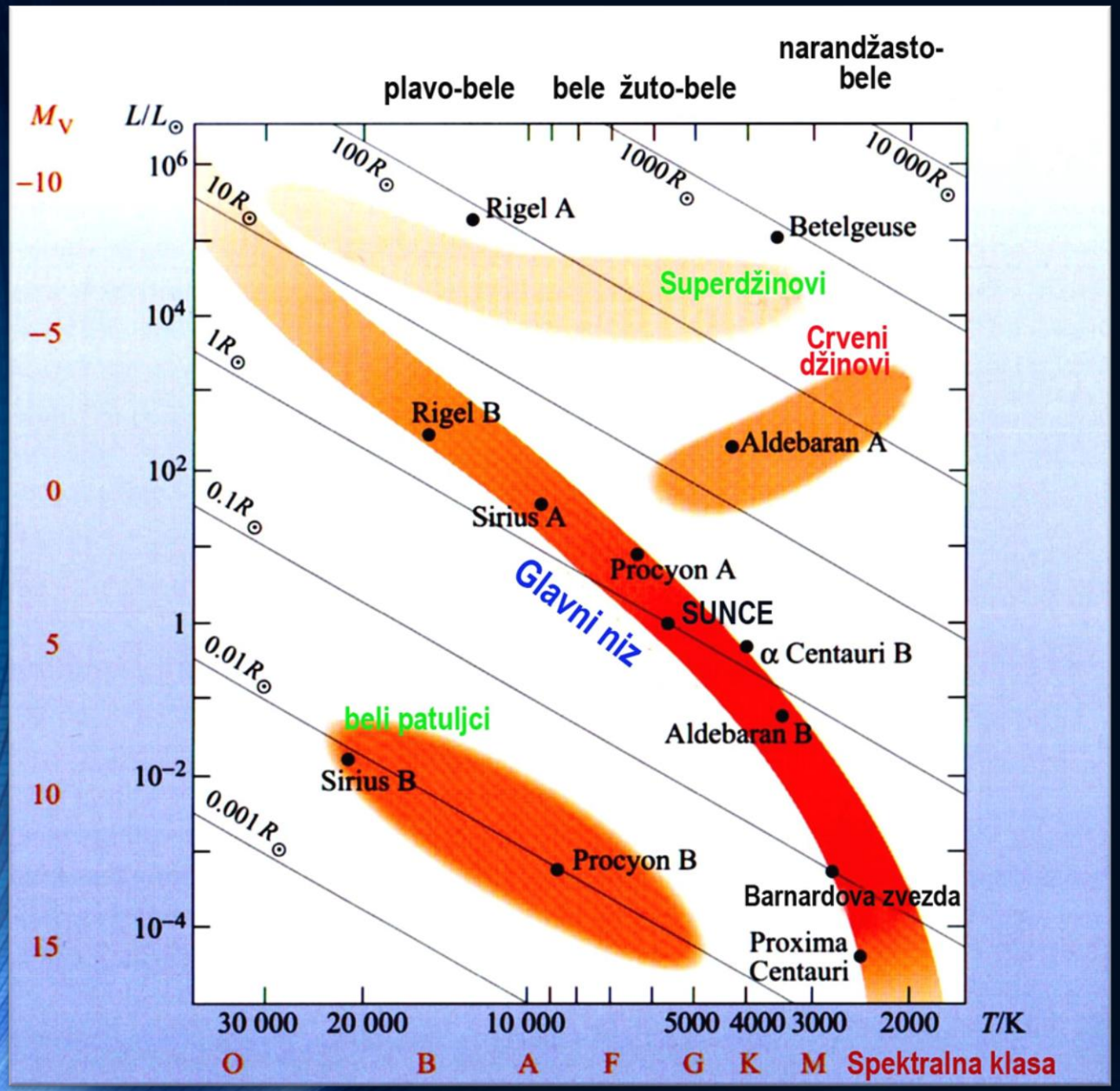
- Procyon B i Bernardova zvezda
  - Ista (mala) luminoznost, +13 mag
  - Procyon B – emituje mnogo više energije po jedinici mase u sekundi
- Indeks boje (*color index*)
  - Broj, na logaritamskoj skali, određuje boju objekta
  - Manji broj – hladniji objekat (više „plav“)
  - Vega – nula!

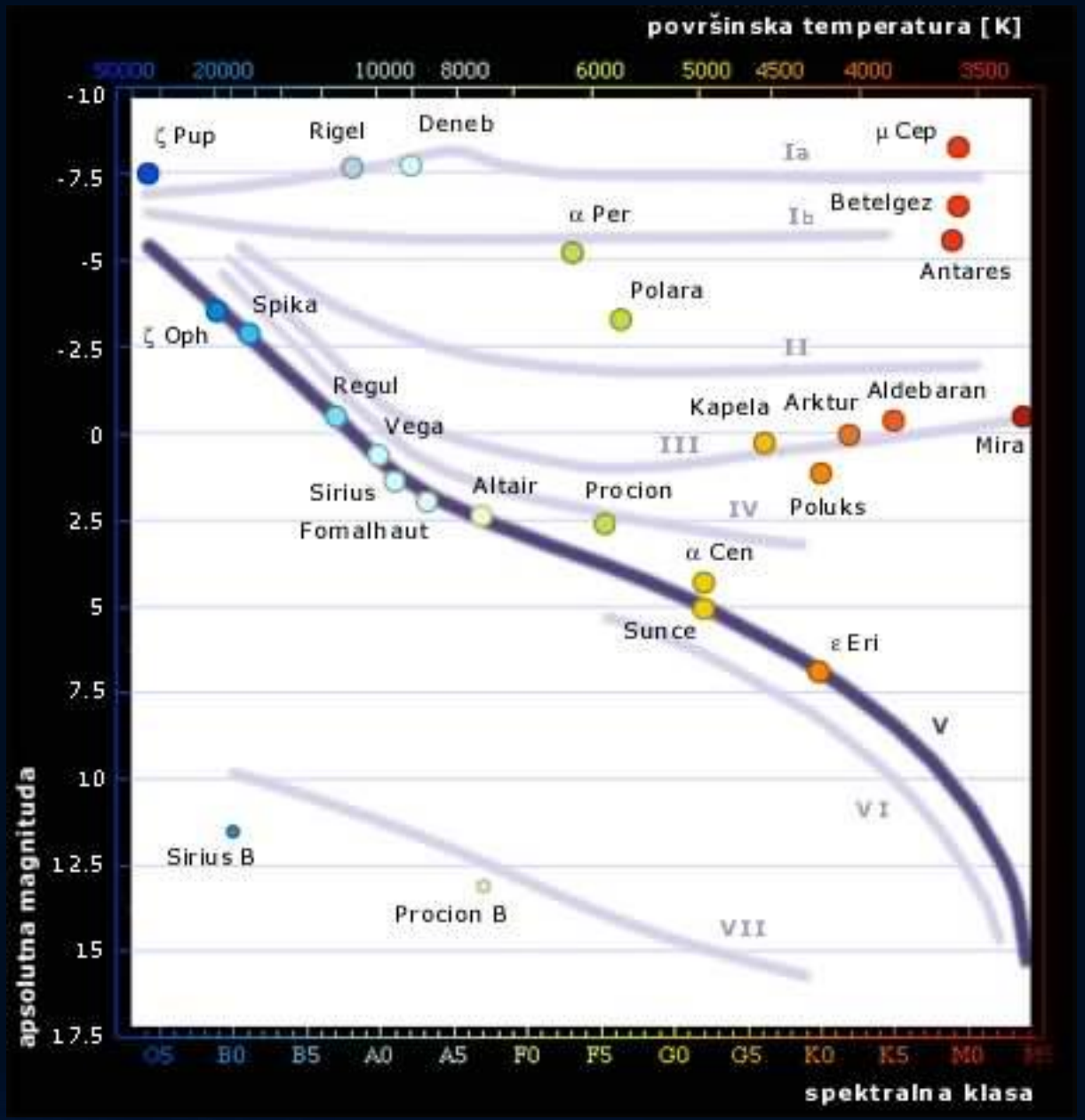
$$T = 4600\ K\left(\frac{1}{0{,}92(B-V)+1{,}7}+\frac{1}{0{,}92(B-V)+0{,}62}\right)$$



Class	B−V	U−B	V−R	R−I	T_{eff} (K)
O5V	−0.33	−1.19	−0.15	−0.32	42,000
B0V	−0.30	−1.08	−0.13	−0.29	30,000
A0V	−0.02	−0.02	0.02	−0.02	9,790
F0V	0.30	0.03	0.30	0.17	7,300
G0V	0.58	0.06	0.50	0.31	5,940
K0V	0.81	0.45	0.64	0.42	5,150
M0V	1.40	1.22	1.28	0.91	3,840







D. Gajić, beleške sa predavanja

Ž. Mitkovski / AM

Osnovne karakteristike klasa

Class	Effective temperature[1][2][3]	Vega-relative chromaticity[4][5][nb 1]	Chromaticity (D65)[6][7][4][nb 2]	Main-sequence mass[1][8] (solar masses)	Main-sequence radius[1][8] (solar radii)	Main-sequence luminosity[1][8] (bolometric)	Hydrogen lines	Fraction of all main-sequence stars[9]
O	≥ 30,000 K	blue	blue	≥ 16 $M_\odot$	≥ 6.6 $R_\odot$	≥ 30,000 $L_\odot$	Weak	~0.00003%
B	10,000–30,000 K	blue white	deep blue white	2.1–16 $M_\odot$	1.8–6.6 $R_\odot$	25–30,000 $L_\odot$	Medium	0.13%
A	7,500–10,000 K	white	blue white	1.4–2.1 $M_\odot$	1.4–1.8 $R_\odot$	5–25 $L_\odot$	Strong	0.6%
F	6,000–7,500 K	yellow white	white	1.04–1.4 $M_\odot$	1.15–1.4 $R_\odot$	1.5–5 $L_\odot$	Medium	3%
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04 $M_\odot$	0.96–1.15 $R_\odot$	0.6–1.5 $L_\odot$	Weak	7.6%
K	3,700–5,200 K	light orange	pale yellow orange	0.45–0.8 $M_\odot$	0.7–0.96 $R_\odot$	0.08–0.6 $L_\odot$	Very weak	12.1%
M	2,400–3,700 K	orange red	light orange red	0.08–0.45 $M_\odot$	≤ 0.7 $R_\odot$	≤ 0.08 $L_\odot$	Very weak	76.45%

Yerkes luminosity classes

Luminosity class	Description	Examples
0 *or* Ia+	hypergiants or extremely luminous supergiants	Cygnus OB2#12 – B3-4Ia+ [19]
Ia	luminous supergiants	Eta Canis Majoris – B5Ia [20]
Iab	intermediate-size luminous supergiants	Gamma Cygni – F8Iab [21]
Ib	less luminous supergiants	Zeta Persei – B1Ib [22]
II	bright giants	Beta Leporis – G0II [23]
III	normal giants	Arcturus – K0III [24]
IV	subgiants	Gamma Cassiopeiae – B0.5IVpe [25]
V	main-sequence stars (dwarfs)	Achernar – B6Vep [22]
sd (*prefix*) *or* VI	subdwarfs	HD 149382 – sdB5 *or* B5VI [26]
D (*prefix*) *or* VII	white dwarfs [nb 3]	van Maanen 2 – DZ8 [27]

Harvardska spektralna klasifikacija

Main sequence stars (V)

Spectral Type	Temperature (K)	Absolute Magnitude	Luminosity (in solar luminosities)
O5	54,000	-4.5	200,000
O6	45,000	-4.0	140,000
O7	43,300	-3.9	120,000
O8	40,600	-3.8	80,000
O9	37,800	-3.6	55,000
B0	29,200	-3.3	24,000
B1	23,000	-2.3	5550
B2	21,000	-1.9	3190
B3	17,600	-1.1	1060
B5	15,200	-0.4	380
B6	14,300	0	240
B7	13,500	0.3	140
B8	12,300	0.7	73
B9	11,400	1.1	42
A0	9600	1.5	24
A1	9330	1.7	20
A2	9040	1.8	17
A3	8750	2.0	14
A4	8480	2.1	12
A5	8310	2.2	11
A7	7920	2.4	8.8
F0	7350	3.0	5.1
F2	7050	3.3	3.8
F3	6850	3.5	3.2
F5	6700	3.7	2.7
F6	6550	4.0	2.0
F7	6400	4.3	1.5
F8	6300	4.4	1.4
G0	6050	4.7	1.2
G1	5930	4.9	1.1
G2	5800	5.0	1
G5	5660	5.2	0.73
G8	5440	2.6	0.51
K0	5240	6.0	0.38
K1	5110	6.2	0.32
K2	4960	6.4	0.29
K3	4800	6.7	0.24
K4	4600	7.1	0.18
K5	4400	7.4	0.15
K7	4000	8.1	0.11
M0	3750	8.7	0.080
M1	3700	9.4	0.055
M2	3600	10.1	0.035
M3	3500	10.7	0.027
M4	3400	11.2	0.022
M5	3200	12.3	0.011
M6	3100	13.4	0.0051
M7	2900	13.9	0.0032
M8	2700	14.4	0.0020
L0	2600	*	0.00029
L3	2200	*	0.00013
L8	1500	*	0.000032
T2	1400	*	0.000025
T6	1000	*	0.0000056
T8	800	*	0.0000036

*- not visible to the human eye (for the most part)

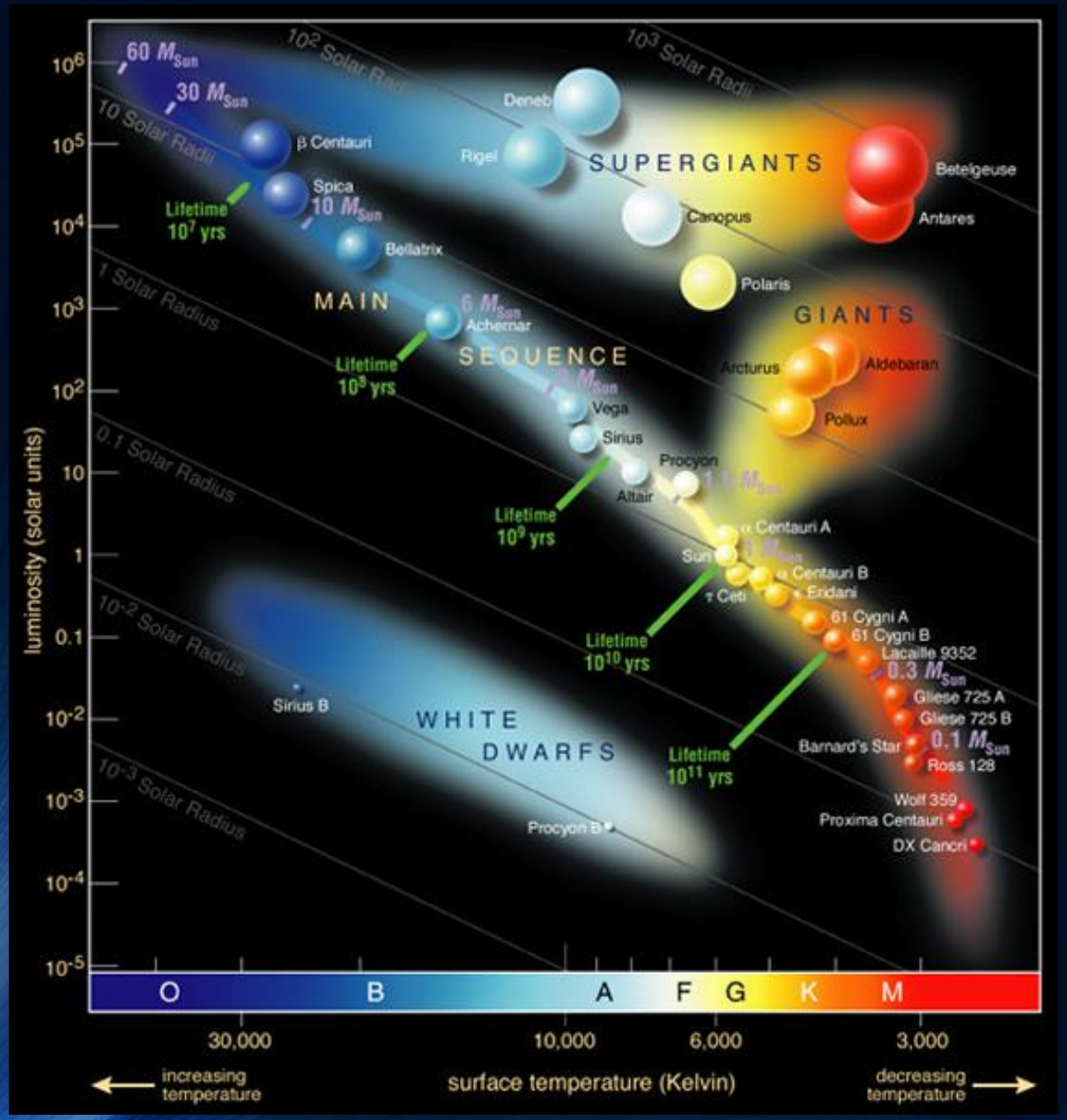
Giants (III)

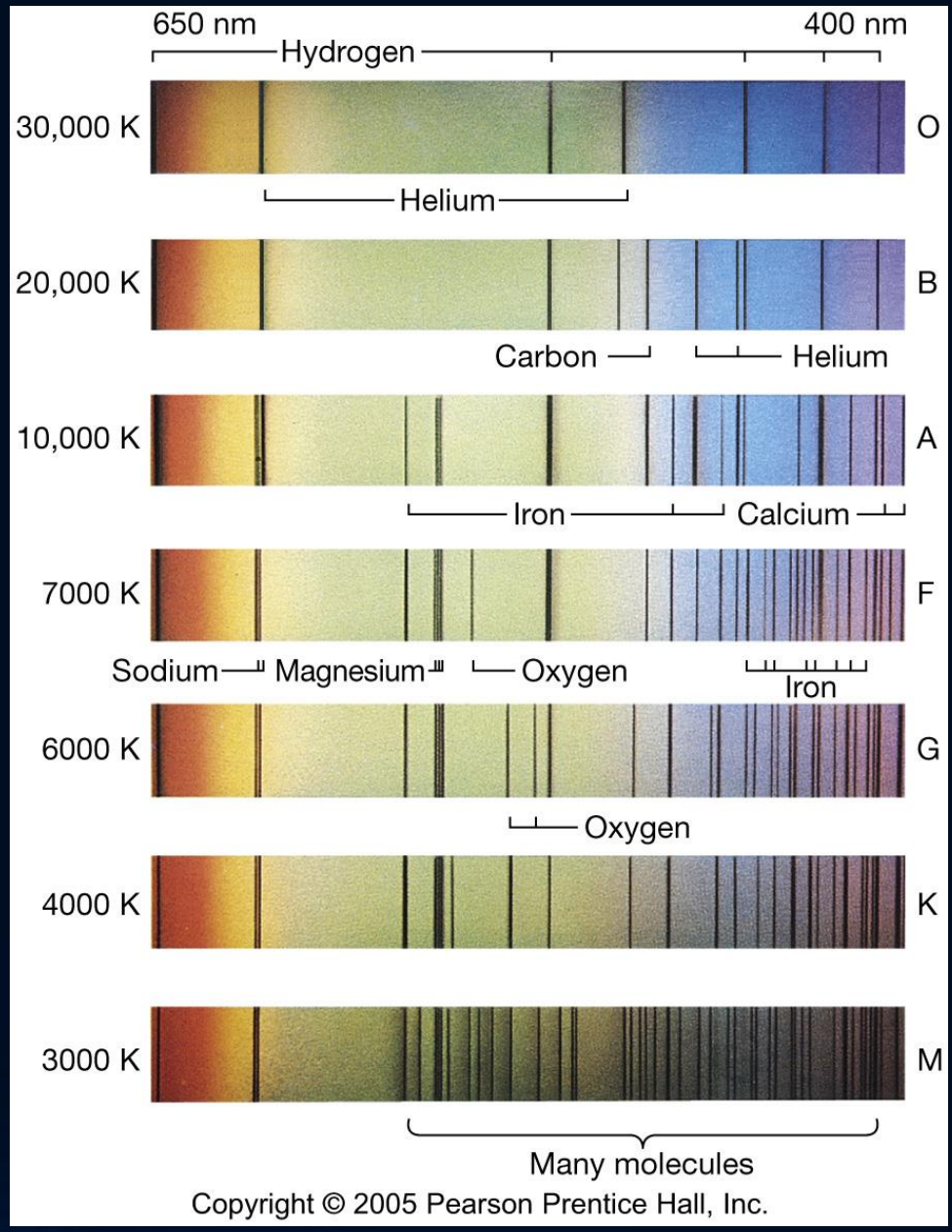
Spectral Type	Temperature (K)	Absolute Magnitude	Luminosity (in solar luminosities)
G5	5010	0.7	127
G8	4870	0.6	113
K0	4720	0.5	96
K1	4580	0.4	82
K2	4460	0.2	70
K3	4210	0.1	58
K4	4010	0.0	45
K5	3780	-0.2	32
M0	3660	-0.4	15
M1	3600	-0.5	13
M2	3500	-0.6	11
M3	3300	-0.7	9.5
M4	3100	-0.75	7.4
M5	2950	-0.8	5.1
M6	2800	-0.9	3.3

Superglants (I)

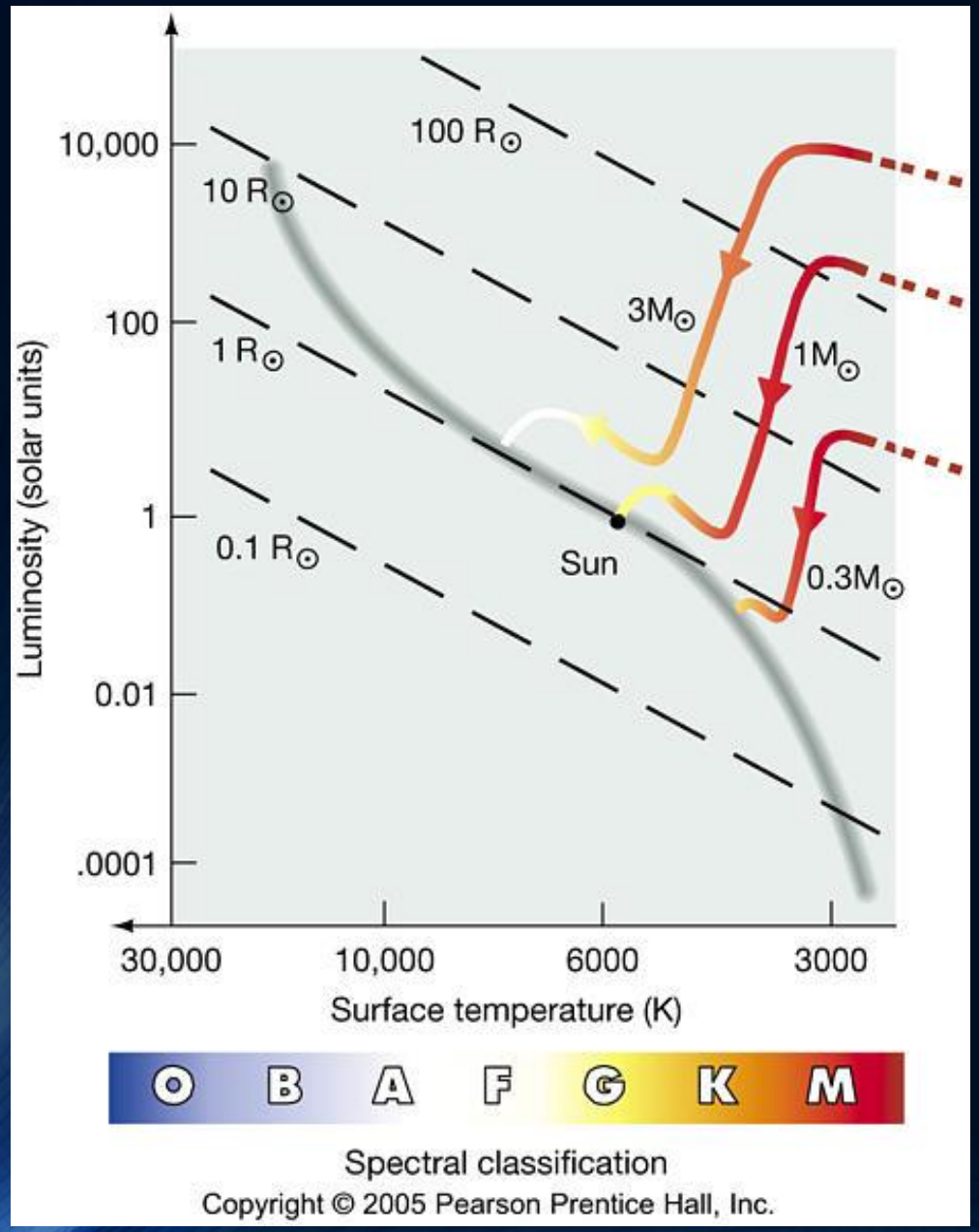
Spectral Type	Temperature (K)	Absolute Magnitude	Luminosity (in solar luminosities)
B0	21,000	-6.4	320,000
B1	16,000	-6.4	280,000
B2	14,000	-6.4	220,000
B3	12,800	-6.3	180,000
B5	11,500	-6.3	140,000
B6	11,000	-6.3	98,000
B7	10,500	-6.3	82,000
B8	10,000	-6.2	73,000
B9	9700	-6.2	61,000
A0	9400	-6.2	50,600
A1	9100	-6.2	44,000
A2	8900	-6.2	40,000
A5	8300	-6.1	36,000
F0	7500	-6	20,000
F2	7200	-6	18,000
F5	6800	-5.9	16,000
F8	6150	-5.9	12,000
G0	5800	-5.9	9600
G2	5500	-5.8	9500
G5	5100	-5.8	9800
G8	5050	-5.7	11,000
K0	4900	-5.7	12,000
K1	4700	-5.6	13,500
K2	4500	-5.6	15,200
K3	4300	-5.6	17,000
K4	4100	-5.5	18,300
K5	3750	-5.5	20,000
M0	3660	-5.3	50,600
M1	3600	-5.3	52,000
M2	3500	-5.3	53,000
M3	3300	-5.3	54,000
M4	3100	-5.2	56,000
M5	2950	-5.2	58,000

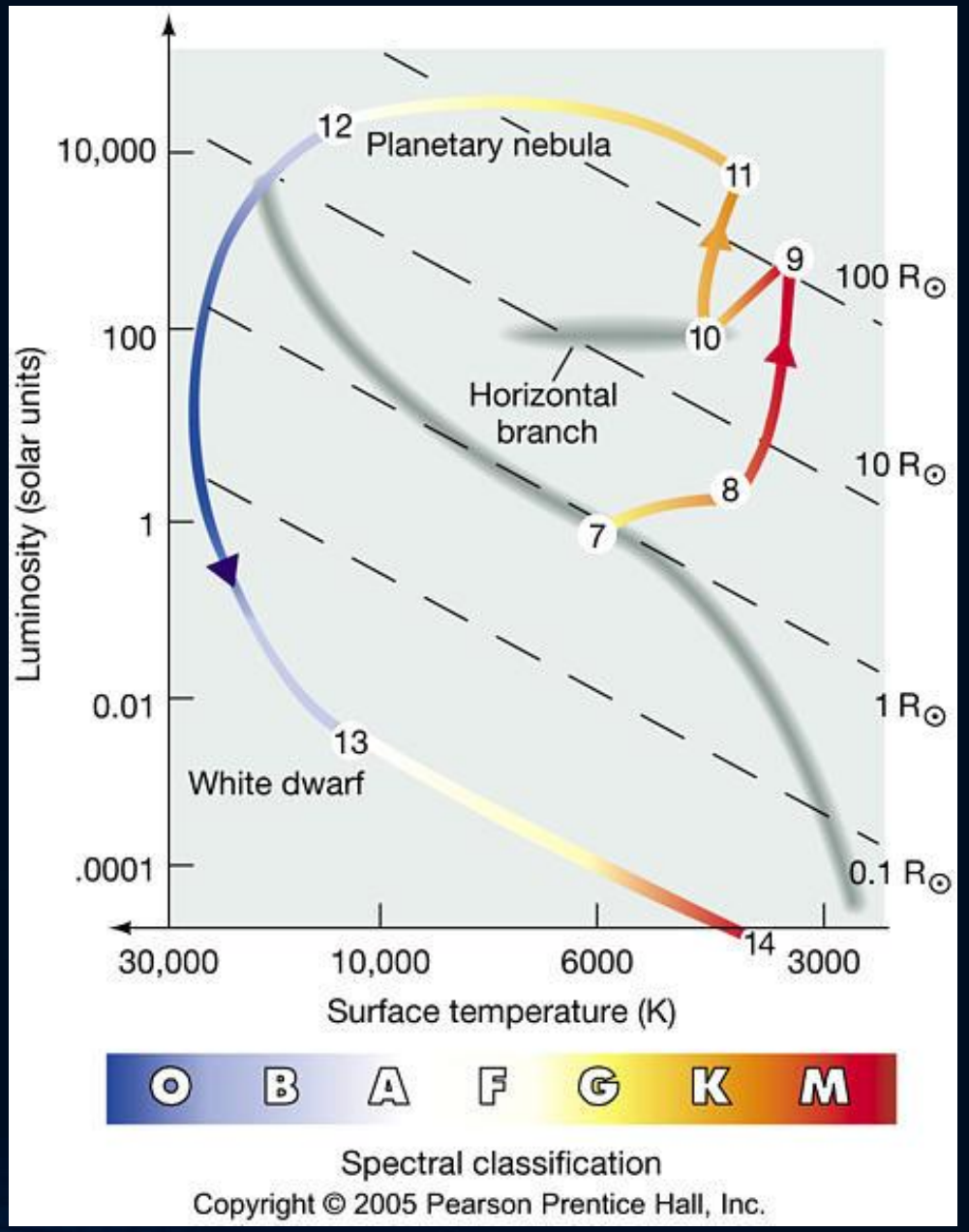
Život zvezda?





Život zvezda?





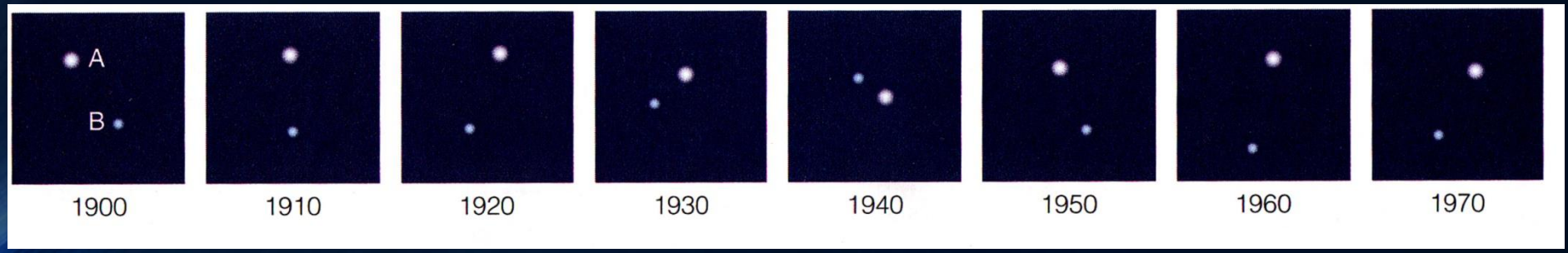
Kretanje zvezda

Kretanje zvezda?

Kretanje zvezda

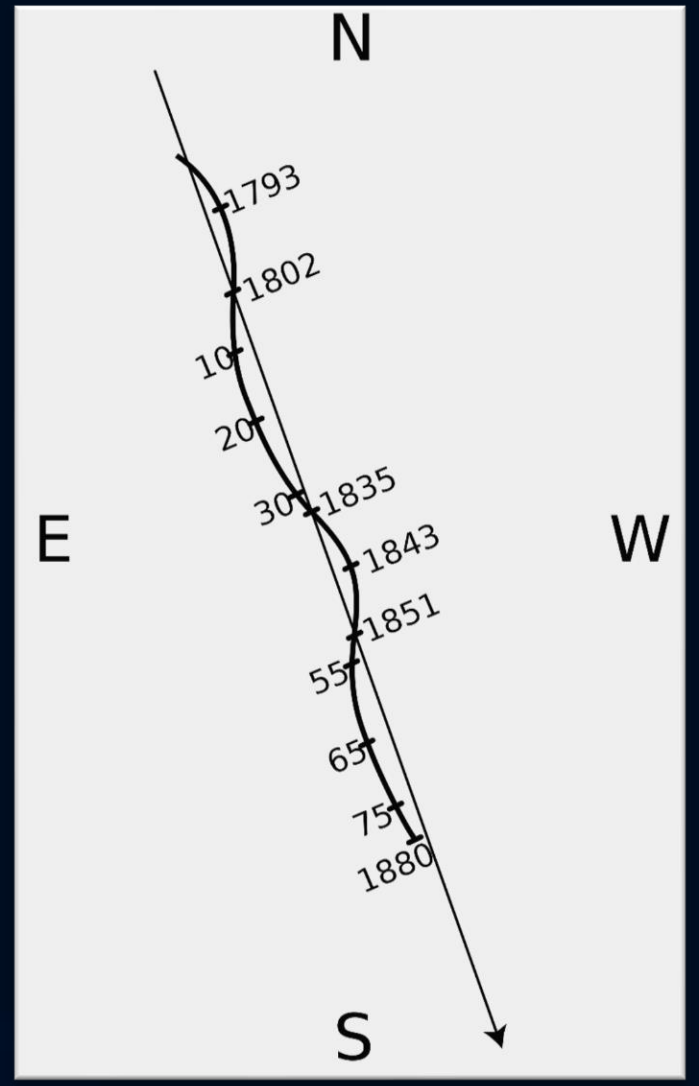
- Prividno (dnevno i godišnje) – rotacija i kretanje Zemlje
- Stvarno međusobno kretanje zvezda
- Halej (pre tri veka) zabeležio kretanje Sirijusa
- Sistematsko, višedecenijsko snimanje i posmatranje
- Najlakše registruje kod bliskih zvezda

Bernardova zvezda

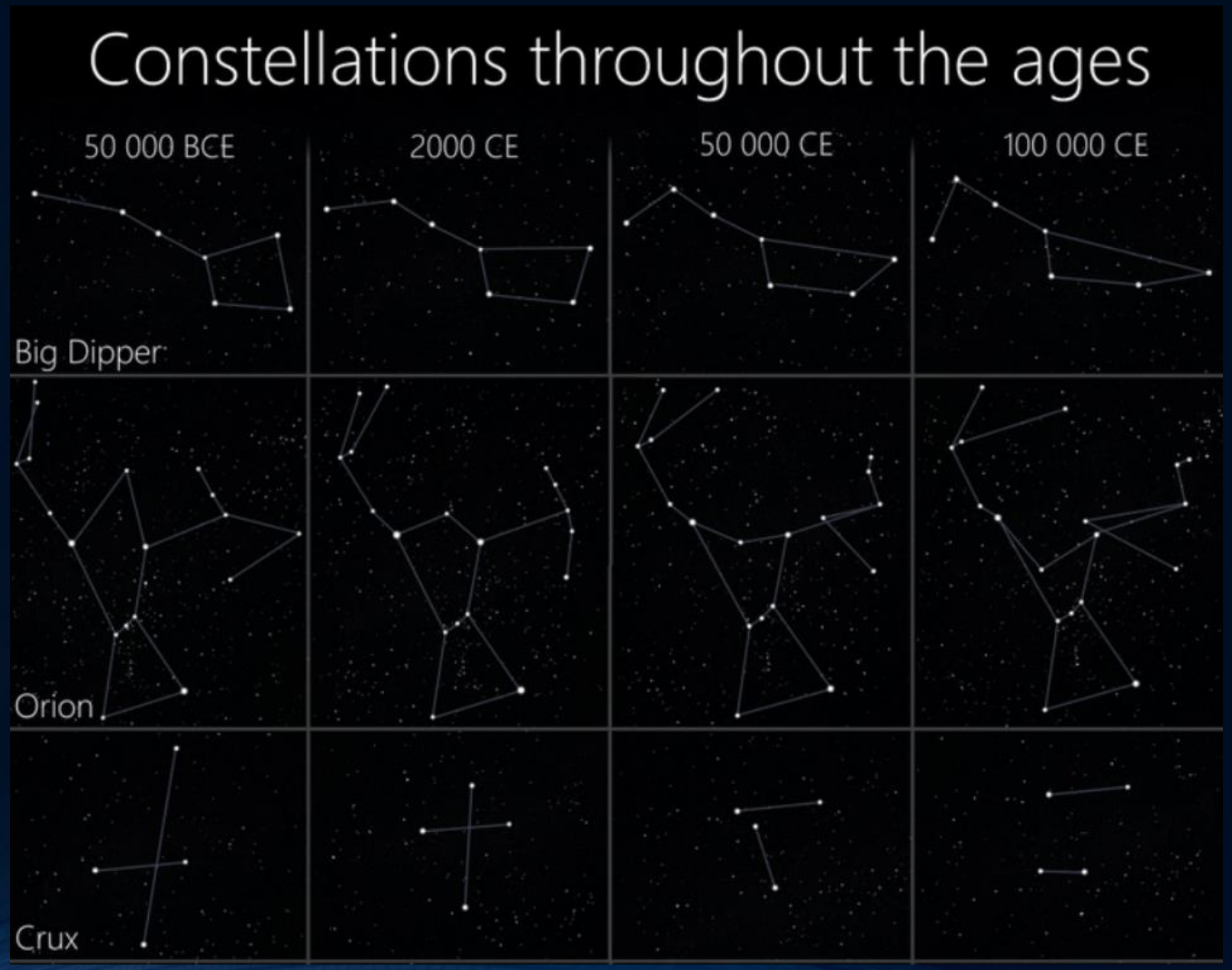


Kretanje zvezda

- Na osnovu varijacija u kretanju – postojanje pratilaca
- Kretanje – velike brzine, teško uočava zbog rastojanja
- U dužim vremenskim intervalima – promena sazvežđa
- Sopstveno kretanje – promena pravca pod kojim vidimo zvezdu ili promena njenog položaja na nebeskoj sferi
  - Ugaona veličina – manja ako je zvezda dalja



Sazvežđa

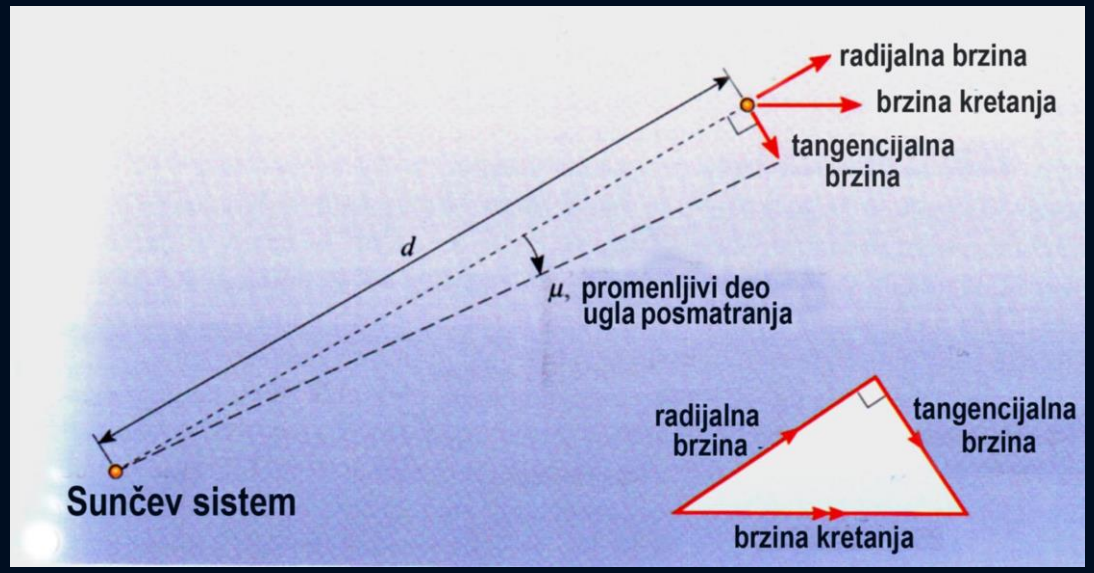

Constellations throughout the ages
50 000 BCE
2000 CE
50 000 CE
100 000 CE
Big Dipper
Orion
Crux

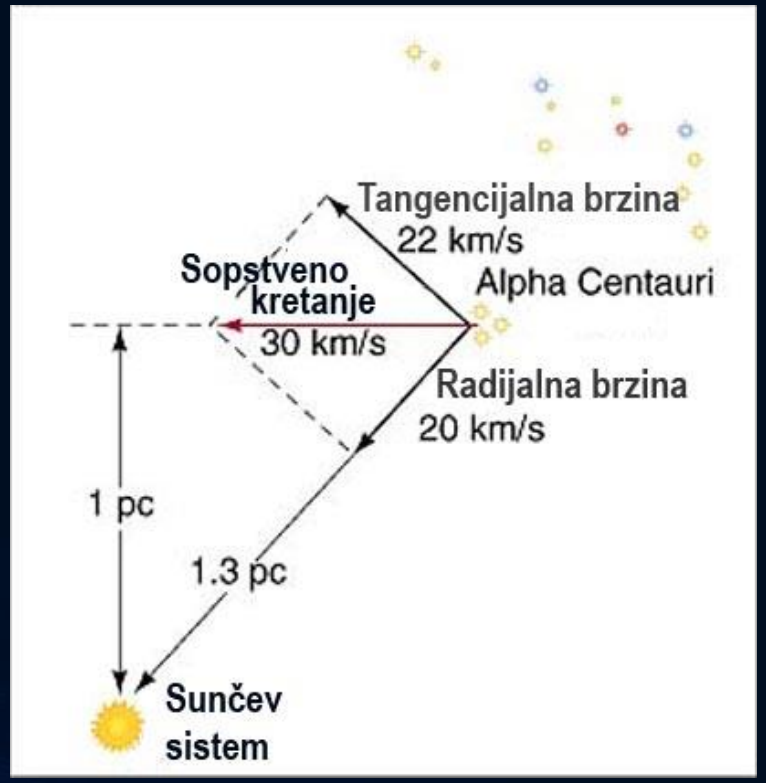
Sopstveno kretanje

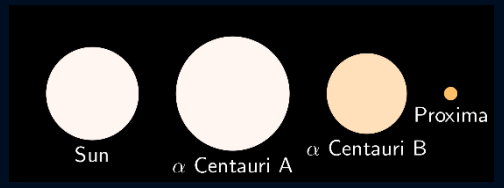
- Dve komponente
  - Radijalna
  - Tangencijalna

$$v^2 = v_t^2 + v_r^2$$

- Brzine zvezda 20-30 km/s, može 250+ km/s
- Tangencijalne brzine – pomeraj na fotografijama (interval više godina)
- Radijalne brzine – Doplerov efekat (Hajgens, 1808. godine – prvi put)

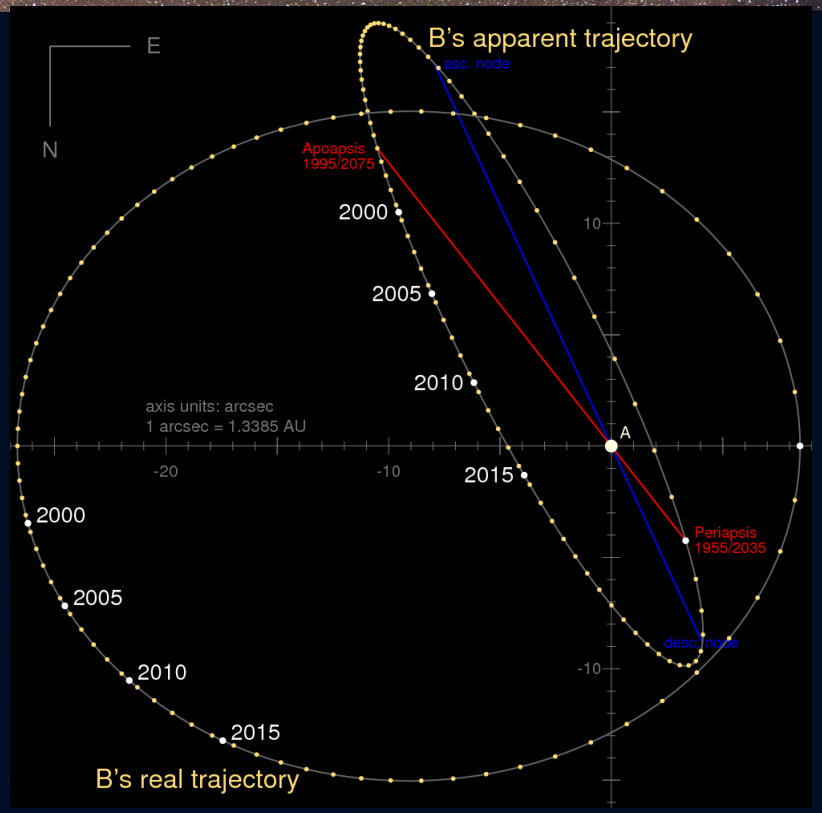






Alpha Cenauri

- Najbliža zvezda i planetarni sistem; 4,37 ly.
- Trostruka zvezda:
  - A – Rigel Kentaurus, B – Toliman, C – Proxima Centauri
  - Golim okom AB – jedna zvezda, -0,27 mag
  - Treća najsjajnija zvezda (posle Sirijusa i Kanopusa)
- Jedna planeta – Proxima Centaury b
  - Malo veća od Zemlje, u habitacionoj zoni
  - Otkriće: 2016, ESO
    - Metod radijalne brzine – periodični Doplerovi pomaciji u spektru matične zvezde ukazuju na postojanje planete

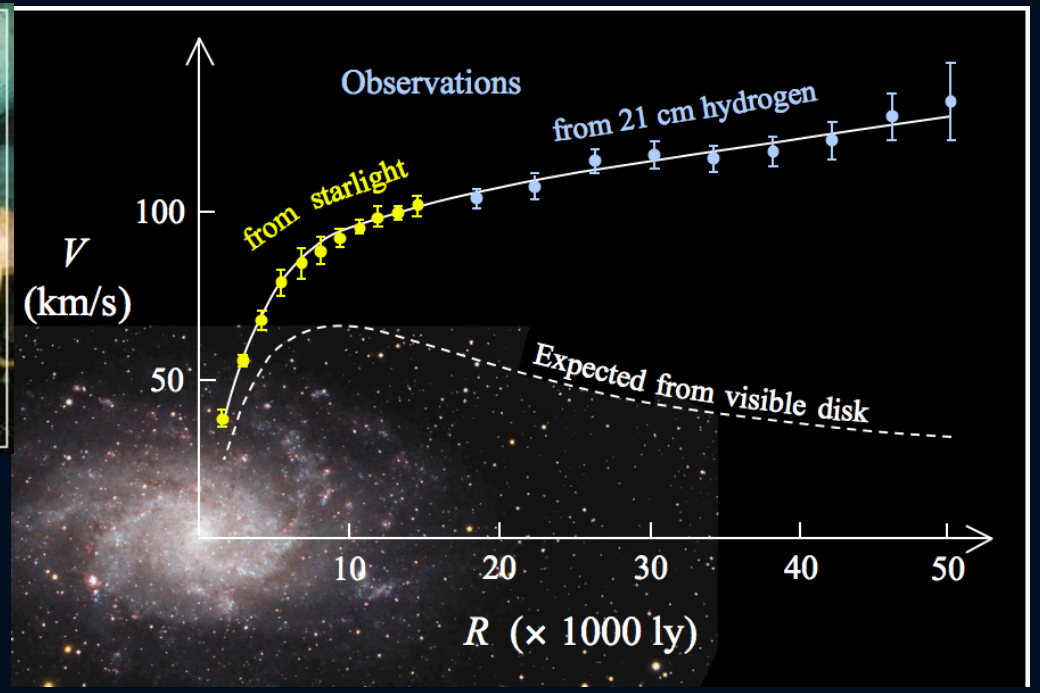


Bernardova zvezda

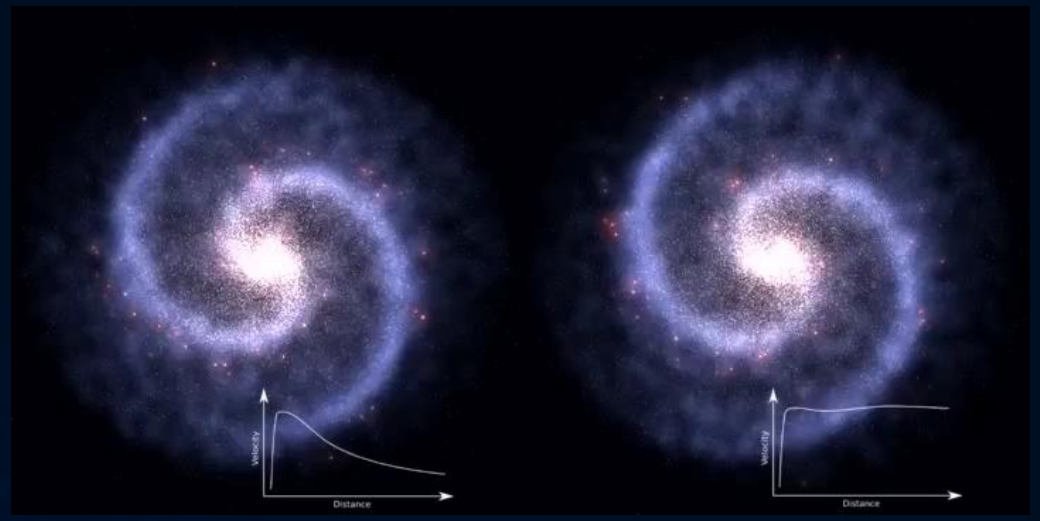
- Mali crveni patuljak, 12 milijardi godina, +9,5 mag
- Najbliža na severnoj hemisferi (6 ly), ukupno 4. od Sunca
- Ime: Edward Barnard
  - Zabeležena na fotopločama 1888-1890, Harvard
  - Sopstveno kretanje, 1916: brzina 10,3 lučnih sekundi/god
    - U odnosu na Sunce 108 km/s
- Planeta – superzemlja, 3,2 mase Zemlje, orbita 0,4 AU
- Za nekoliko hiljada godina – bliža od Proxima Centauri

Tamna strana svemira?

Tamna materija

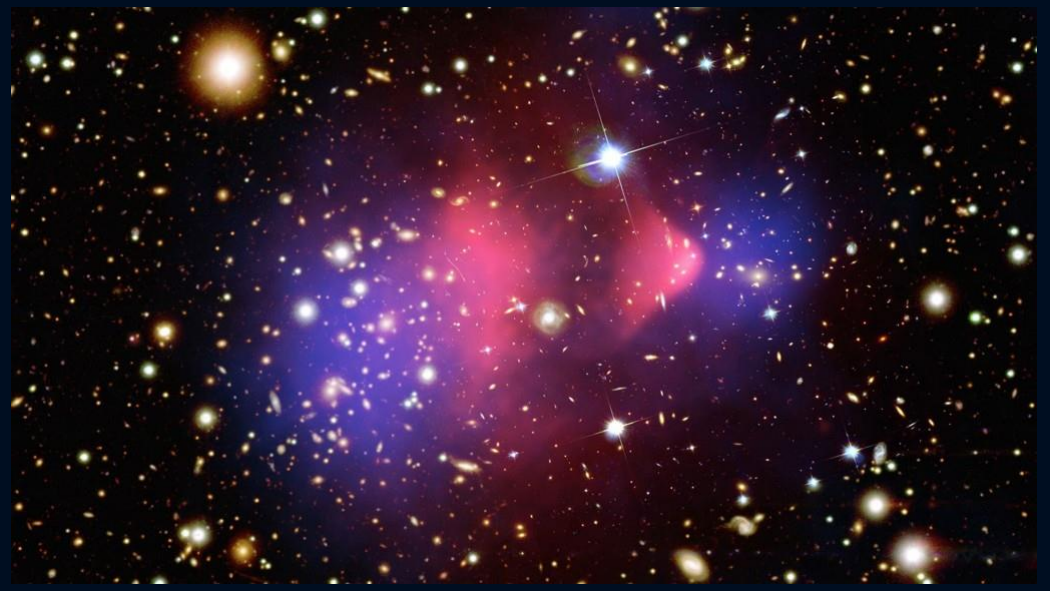


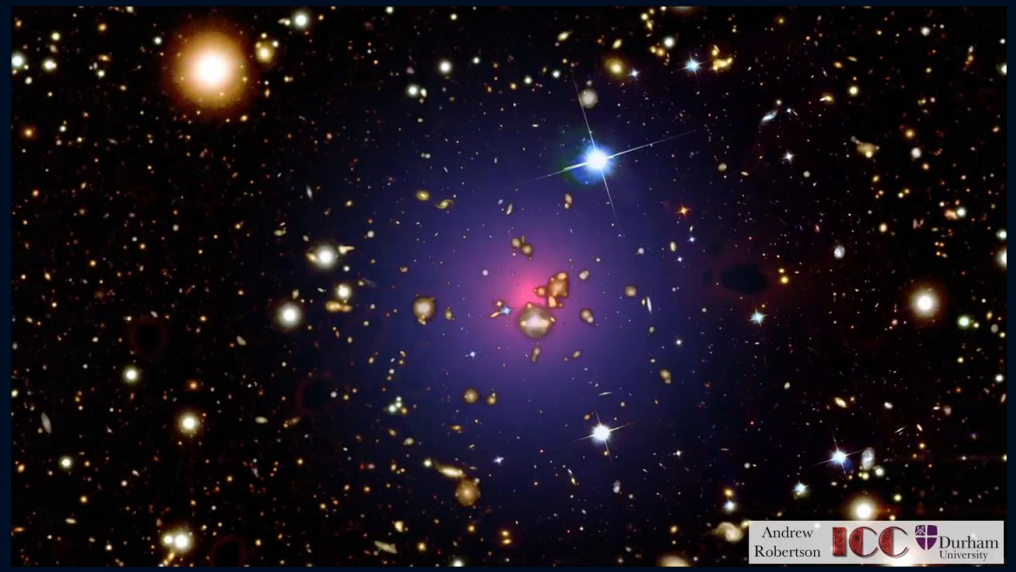
- Interaguje samo gravitaciono
- Vera Rubin (1928-2016)
- Rotacija galaksija ???
  - Centar galaksije - gust
  - Orbitalna brzina vidljivih zvezda i gasa
- Raspodela brzina nije kao u planetarnom sistemu
- Galaksije – ista ili veća brzina!
  - Veća masa od vidljive
- Uronjene u „halo" tamne materije
  - V. Rubin: 5 – 10 puta više tamne materije
  - 95% galaksije – halo (tamna materija)



Galaktička jata

- Prva ideja o tamnoj materiji
  - Fritz Zwicky (1930)
  - Galaksije u jatima kreću suviše brzo – jata bi se raspala
    - Tamna materija ih drži na okupu
- Bullet Cluster (1E 0657-558)
  - Sudar dva galaktička jata; gravitaciono sočivo
  - Najbolji dokaz postojanja tamne materije (slično MACS J0025.4-1222)
  - Rastojanje 3,7 milijardi ly;
  - Statistički značaj rezultata 8σ (nikako ne ide u prolog MOND)





Pitanja?