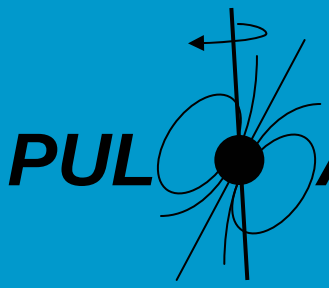
SUPERNOVE,



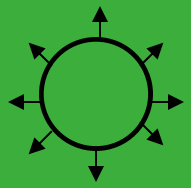
PULSARI

I ROTACIJA

ZVEZDA-RODITELJA

SADRŽAJ

- *SUPERNOVE*
  - *Evolucija zvezda – konačne faze*
  - *Klasifikacija supernovih*
- *PULSARI*
  - *“Radio-tihe” neutronske zvezde*
- *ZVEZDE-RODITELJI*



SUPERNOVE

- eksplozije zvezda

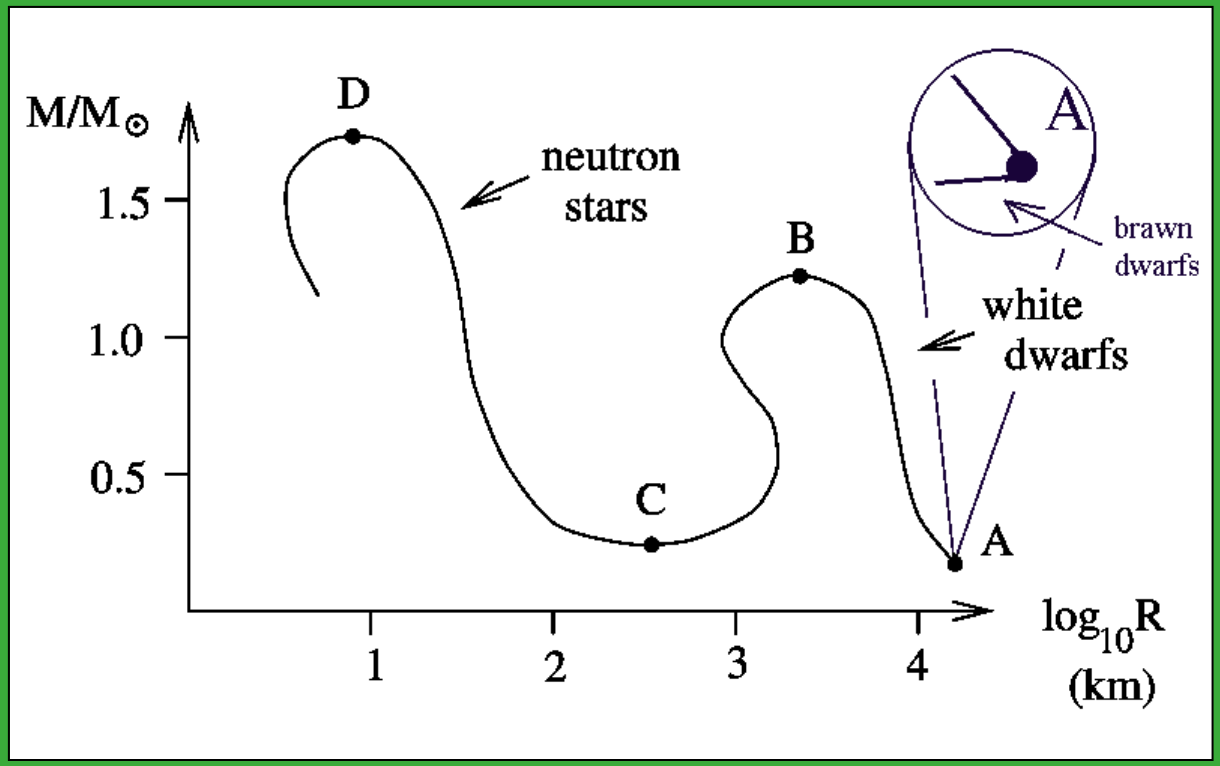
- istorijske supernove:

Datum	Zapis	Sazvežđe	Ostatak
AD 185?	kineske hronike	Kentaur	G315.4-2.3?
AD 1006	kaluđeri u Švajcarskoj i Italiji	Vuk	G327.6+14.6
AD 1054	kineske hronike, arapski astronomi	Bik	Crab
AD 1181	kineske hronike	Kasiopeja	3C58
AD 1572	Tycho	Kasiopeja	G120.1+2.1
AD 1604	Kepler	Zmijonoša	G4.5+6.8
AD 1680?	Flamsteed?	Kasiopeja	Cas A
AD 1885	Hartwig	Andromeda	(S And)

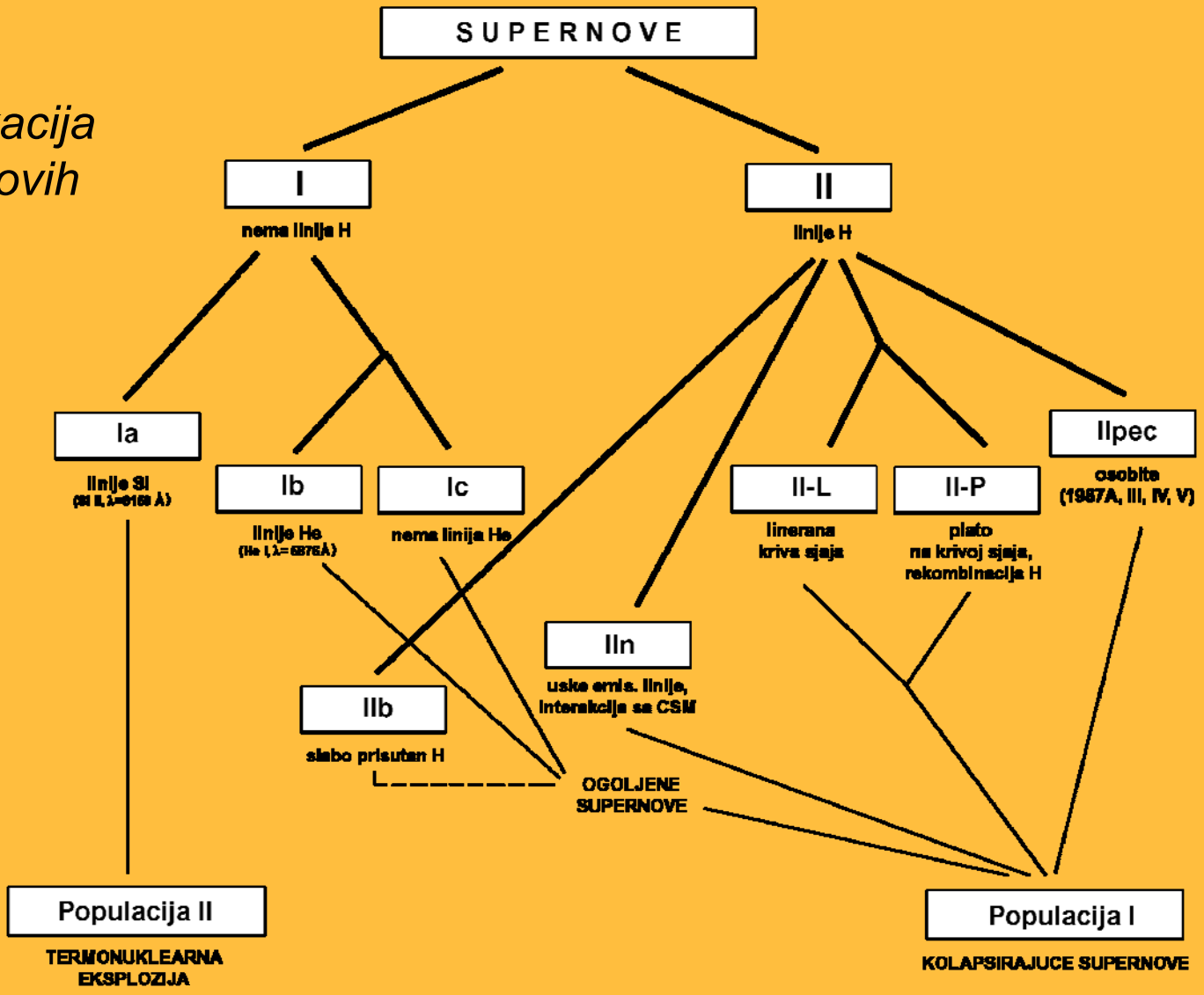
- ostaci supernovih (SNR)

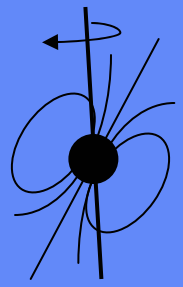
Evolucija zvezda – konačne faze

- beli patuljci, pulsari - neutronske zvezde, crne rupe



Klasifikacija supernovih





Pulsari

- jaka magnetna polja i velike uglovne brzine

- očuvanje magnetnog fluksa i momenta impulsa:

$$B = B_0(R_0/R)^2,$$

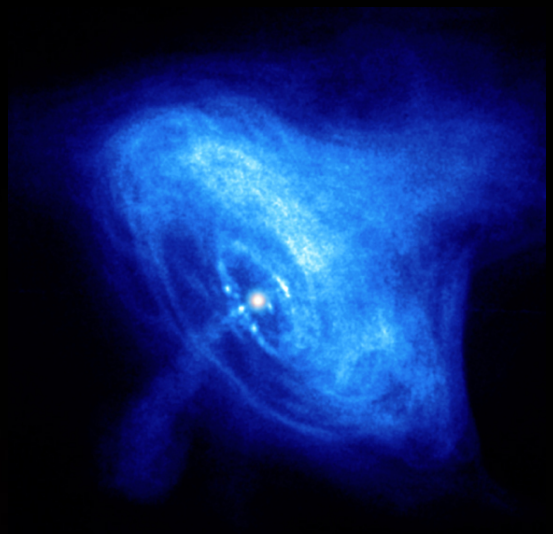
$$\omega = \omega_0(R_0/R)^2,$$

- "problem pulsara": velike rezidualne brzine

- asociranost pulsara i ostataka supernovih, pulsarske magline (PWN)

Crab

Optical

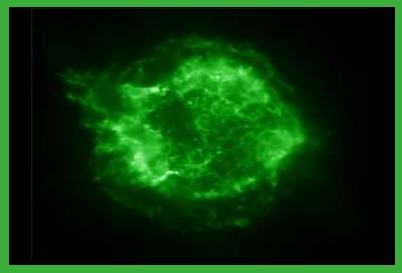


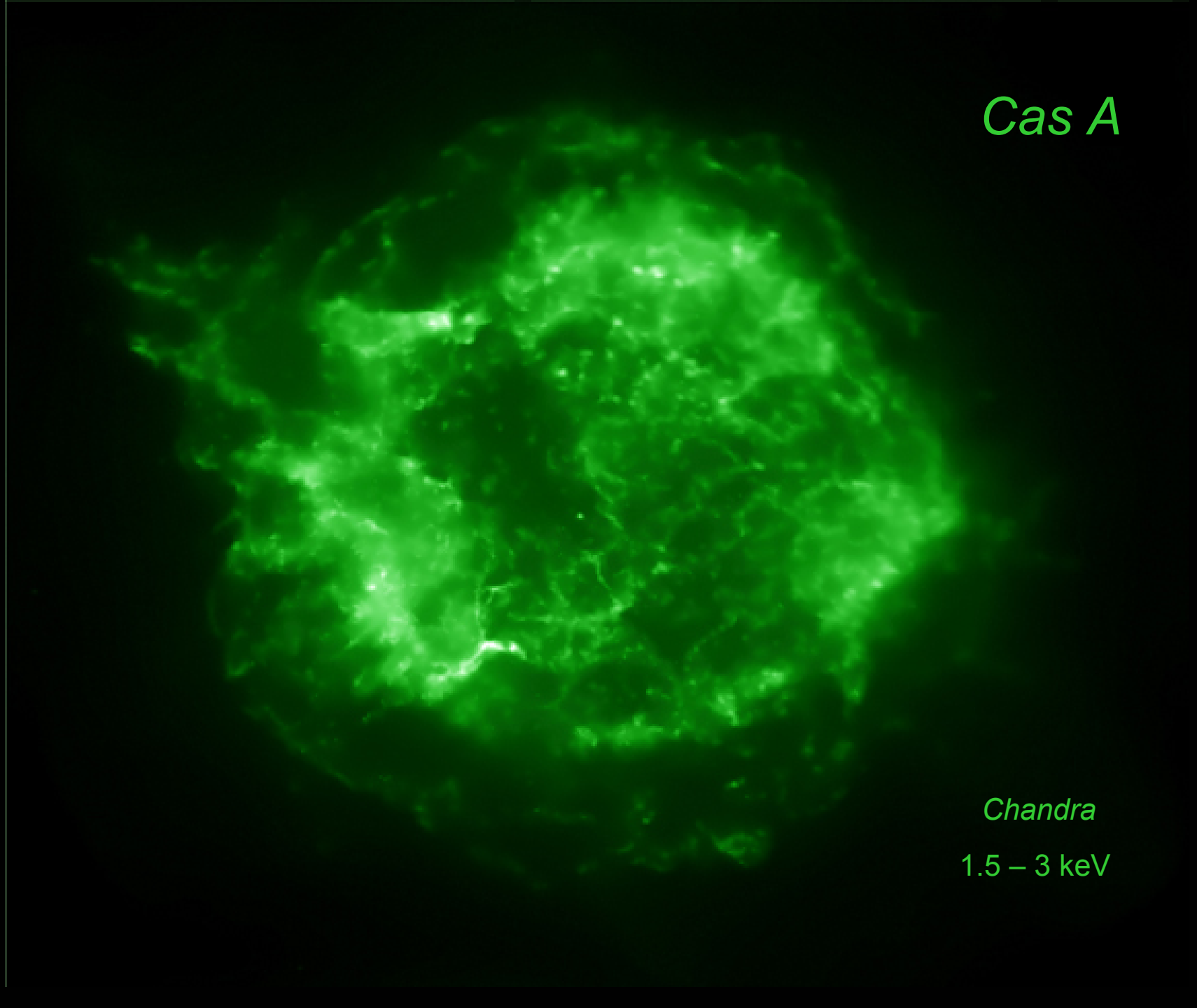
X (Chandra)

"Radio-tihe" neutronske zvezde

- Klasifikacija ostataka prema optičkim osobinama (Mathewson et al. 1983):
  - B (*Balmer-dominated*), sa dominantnim Balmerovim linijama,
  - O (*oxygen-rich*), bogati kiseonikom,
  - P/C (*plerionic, composite*), plerioni, odnosno kompozitni, i
  - evoluirani ostaci
- van den Bergh (1988) predlaže:
  - SN Ia → B SNR
  - SN Ib → O SNR
  - SN II → P/C SNR
  - evoluirani ostaci (SN Ia, Ib, II)

- SN Ib/c – usamljene O (W-R) ili zvezde u TDS (Nomoto et al. 1994, Woosley et al. 1995)?
- potencijalno važna činjenica: šest od osam O ostataka nema asocirane PWN, kod dva ostataka, Cas A i Pup A, otkrivene radio-tihe neutronske zvezde.




Cas A
Chandra
1.5 – 3 keV

• O ostaci i asocirani pulsari (NZ):

SNR	Udaljenost	Radio-tiha NZ	Pulsar (PWN)	Period	Karakt.vreme ($\tau = P/2\dot{P}$)	Magn.polje ($B^2 = 10^{39} P\dot{P}$)
	d [kpc]			P [s]	τ [god]	B [gauss]
Cas A	3.4	+	−			
Pup A	2.2	+	−			
G 292.0+1.8	6.2	−	+	0.135	2890	10×10^{12}
N132 D	50	−	−			
0540-69.3	50	−	+	0.050	1660	22×10^{12}
0102-72.3	60	−	−			
0103-72.6	60	−	−			
NGC 4449	4200	−	−			

• Anomalijski X pulsari:

Pulsar	Period	Karakt.vreme ($\tau = P/2\dot{P}$)	Magn.polje ($B^2 = 10^{39} P\dot{P}$)	SNR	Udaljenost
	P [s]	τ [god]	B [gauss]		d [kpc]
1E 1048.1–5937	6.45	3400	4.4×10^{14}		
1E 2259+586	6.98	2.2×10^5	5.9×10^{13}	G 109.1-1.0	3.5
4U 0142+61	8.69	6.9×10^4	1.3×10^{14}		
RXSJ170849–4009	11.00	8700	4.7×10^{14}		
1E 1841–045	11.77	4700	6.9×10^{14}	Kes 73	6.8
AX J1845.0–0300	6.97			G 29.6+0.1	

OBJAŠNJENJE:

Gubitak mase – jakim zvezdanim vetrom
ili prepunjavanjem Roche-ovog ovala

$$\dot{M} \sim 10^{-6} M_{\odot}/\text{god},$$

$$\dot{M} \approx k(M/M_{\odot})^{a},$$

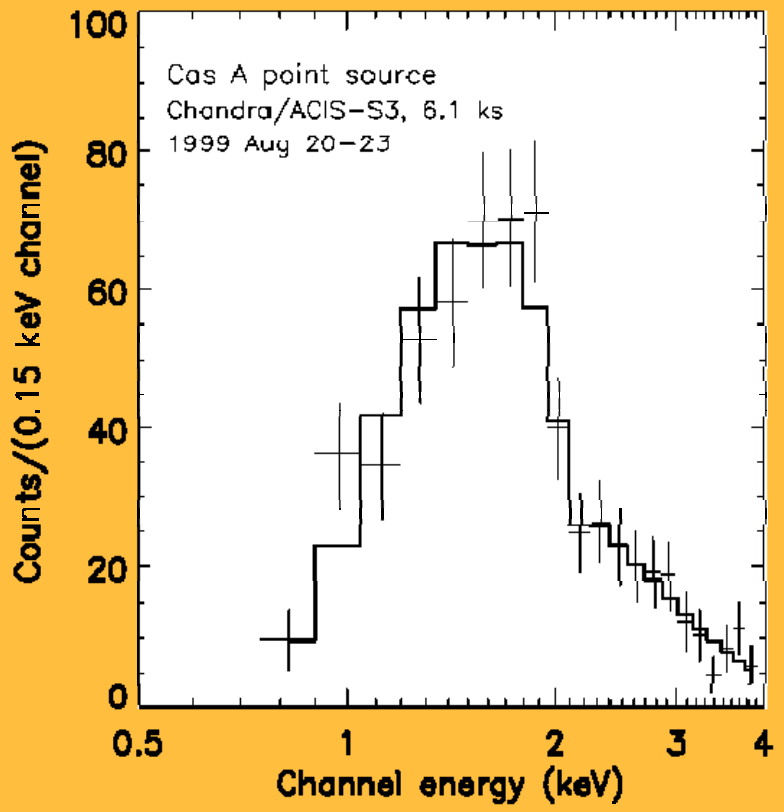
- SN Ib/c (IIb) – gubatak mase / ugaonog momenta – sporija rotacija (posebno u TDS), veza sa anomalijskim X pulsarima (AXP)?
- Uporediti sa Crab i Vela pulsarima (P = o.o33, o.o89 s)
- Ponovo prikupljanje mase – ubrzanje (Chevalier 2005), slično kao “ponovno rađanje”
- SN Ic pec ili Id (hipernove) – “sačuvana” rotacija – model kolapsara (Woosley 1993)

Model, podaci?

Termalno + netermalno zracenje

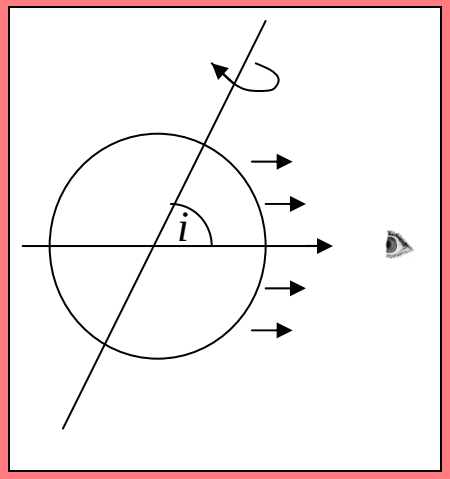
- crno telo, atmosfera neutronske zvezde, zračenje e^- e^+ parova u magnetosferi NZ

- Cas A (Chakrabarty et al. 2001, Mereghetti et al 2002)



Rotacija!

- širenje spektralnih linija
- crno telo?



Boltzmann-ova $\mathcal{H}$-teorema:

$$\frac{d\mathcal{H}}{d\lambda} = 0, \quad \mathcal{H} = \frac{\mathcal{N}}{\mathcal{V}}, \quad \Rightarrow I_\nu/\nu^3 = \text{const.}$$

Doplerov pomak:

$$\nu' = \nu \frac{\sqrt{1 - v^2/c^2}}{1 - \frac{v}{c}\cos\alpha'}$$

Zračenje crnog tela:

$$I_\nu = \frac{2h\nu^3/c^2}{e^{h\nu/kT} - 1}$$

$$v_{eq} = R\Omega, \quad v_{eq}/c \ll 1$$

$$I'_\nu \approx \frac{2h\nu'^3/c^2}{e^{\frac{h\nu'}{kT}(1 - R\Omega \sin\theta\cos\varphi\sin i/c)} - 1}$$

$$I'_\nu \approx \frac{2h\nu'^3/c^2}{e^{\frac{h\nu'}{kT}} (1 - \frac{h\nu'}{kT} R\Omega \sin\theta\cos\varphi\sin i/c) - 1}$$

$$F_\nu = \int I_\nu \sin\theta d\theta d\varphi = ?$$

NZ – opšta teorija relativnosti!

- Schwarzchild-ova geometrija

$$ds^2 = -(1 - \frac{2GM}{rc^2})dt^2 + (1 - \frac{2GM}{rc^2})^{-1}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2)$$

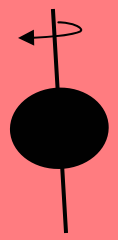
– gravitacioni pomak:

$$z = \left(1 - \frac{2GM}{Rc^2}\right)^{-1/2} - 1$$

$$T_\infty = \frac{T}{1+z}$$

$$L = \frac{dE}{d\tau} = \frac{1}{\sqrt{1 - \frac{2GM}{Rc^2}}\sqrt{1 - \frac{2GM}{Rc^2}}}\frac{dE_\infty}{dt} = \frac{1}{1 - \frac{2GM}{Rc^2}}L_\infty$$

$$L_\infty = 4\pi d^2 F_\infty = \frac{4\pi R^2}{1 - \frac{2GM}{Rc^2}}\sigma T_\infty^4$$

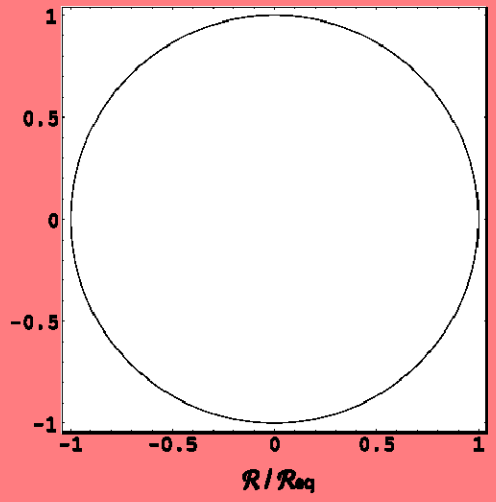


Zvezde-roditelji

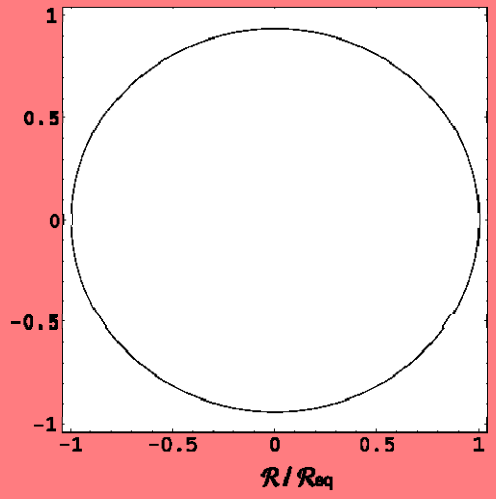
- velike mase, radijusi, brza rotacija

O–B zvezde
– Roche-ov model

$$\Phi_{\mathrm{eff}} = -\frac{GM}{r} - \frac{1}{2}\Omega^2 r^2 \sin^2\theta$$



Slunce



$8 M_\odot$ $5 R_\odot$ $v_{eq} \sim 200$ km/s

Umesto zaključka

- *Supernove ⇐ pre-supernove ⇐ zvezde-roditelji?*

  dve identifikacije:
  SN 1987A u Velikom Magelanovom Oblaku - plavi superdžin,
  SN 1993J u M81 – crveni superdžin

- *Radio-pulsari ∨ “radio-tihe” neutronske zvezde?*