Isolated neutron stars: masses, velocities, evolution

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Plan of the talk

Introduction. News.

Evolution of NSs.

– Population synthesis.

– Stochastic period evolution.

Close-by young NSs and BHs.

– Connections with CR physics.

– Stars in the solar proximity. The Gould Belt.

– Mass spectrum of close-by NSs.

– Log N – Log S of cooling NSs.

– Age-distance diagram.

– Isolated BHs.

Low-mass NSs. Mechanism of formation. Motivation.

Bimodality of the kick velocity distribution. Hadron vs. Quark.

Correlations between different parameters (mass, velocity etc.).

Neutron stars – compact (~10 km) objects with stellar (~1.5 $M_\odot$) masses

"Diamonds forever"

BUT

Stars are not diamonds!

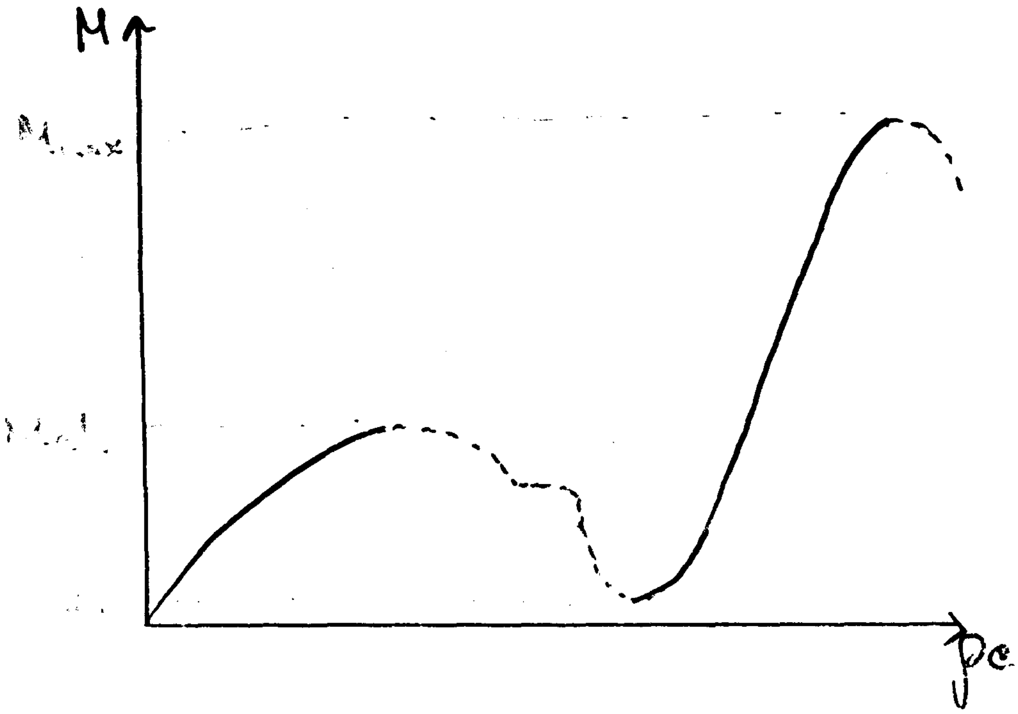
$$\lg t \approx 9.9 - 3.8 \lg(M_\odot) + \lg^2(M_\odot)$$

$t_{min} \gtrsim 10^6$ yrs

~1.4 $M_\odot$ ~2.5 $M_\odot$

White Dwarfs			Neutron Stars	Black Holes
He	C-O	Mg-Ne-O		

~3 $M_\odot$ ~8 $M_\odot$ ~10 $M_\odot$ ~40 $M_\odot$



[illegible]
[illegible]
[illegible]

N S Structure.

(10÷18) km

~ 4 km

~ 10^{15} g cm^{-3}

($\rho_c > \rho_{nuc}$)

in ~ 10^{-3} s

~ 0.1÷0.3

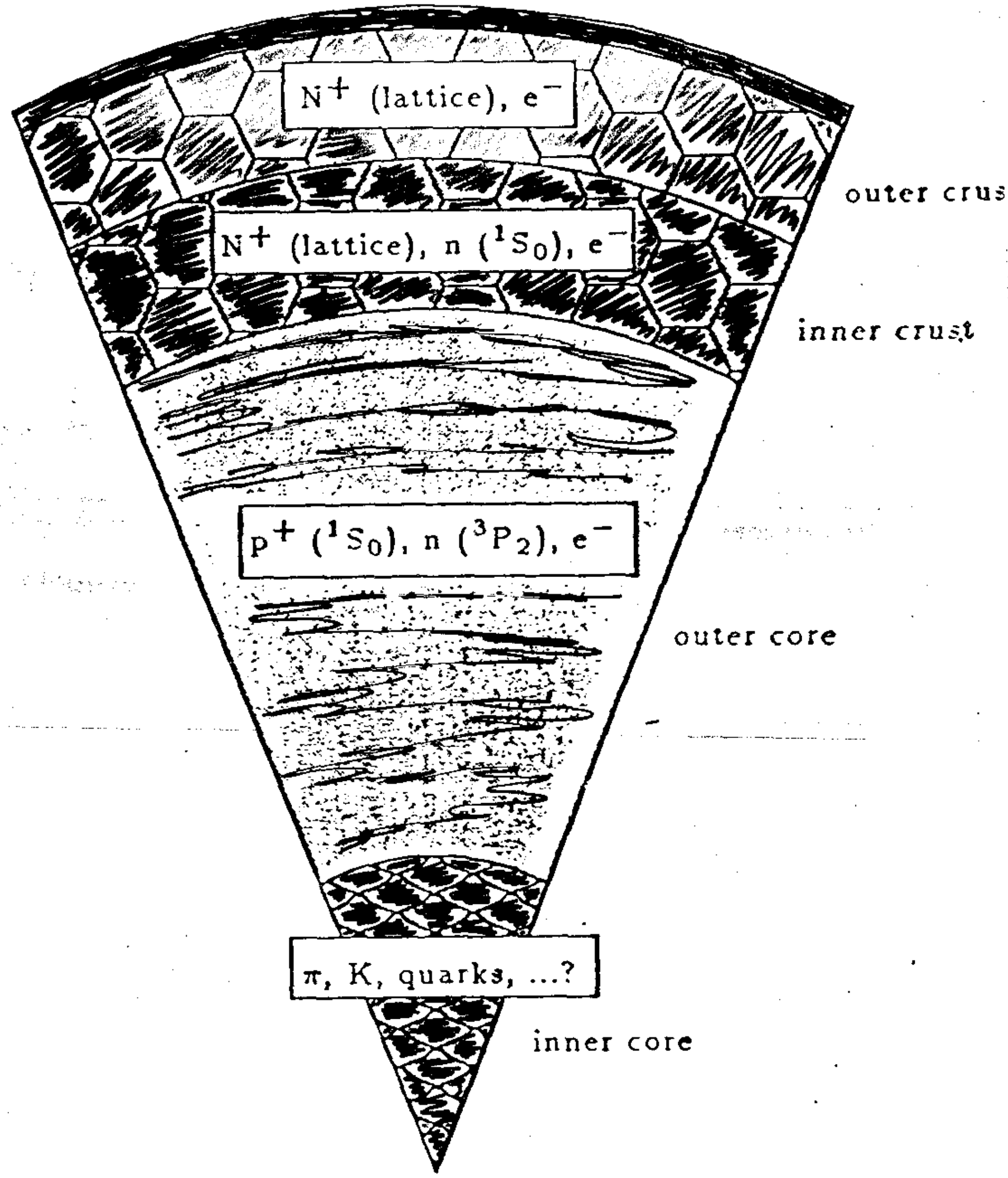


Fig. 1. Schematic view of the internal structure of a neutron star

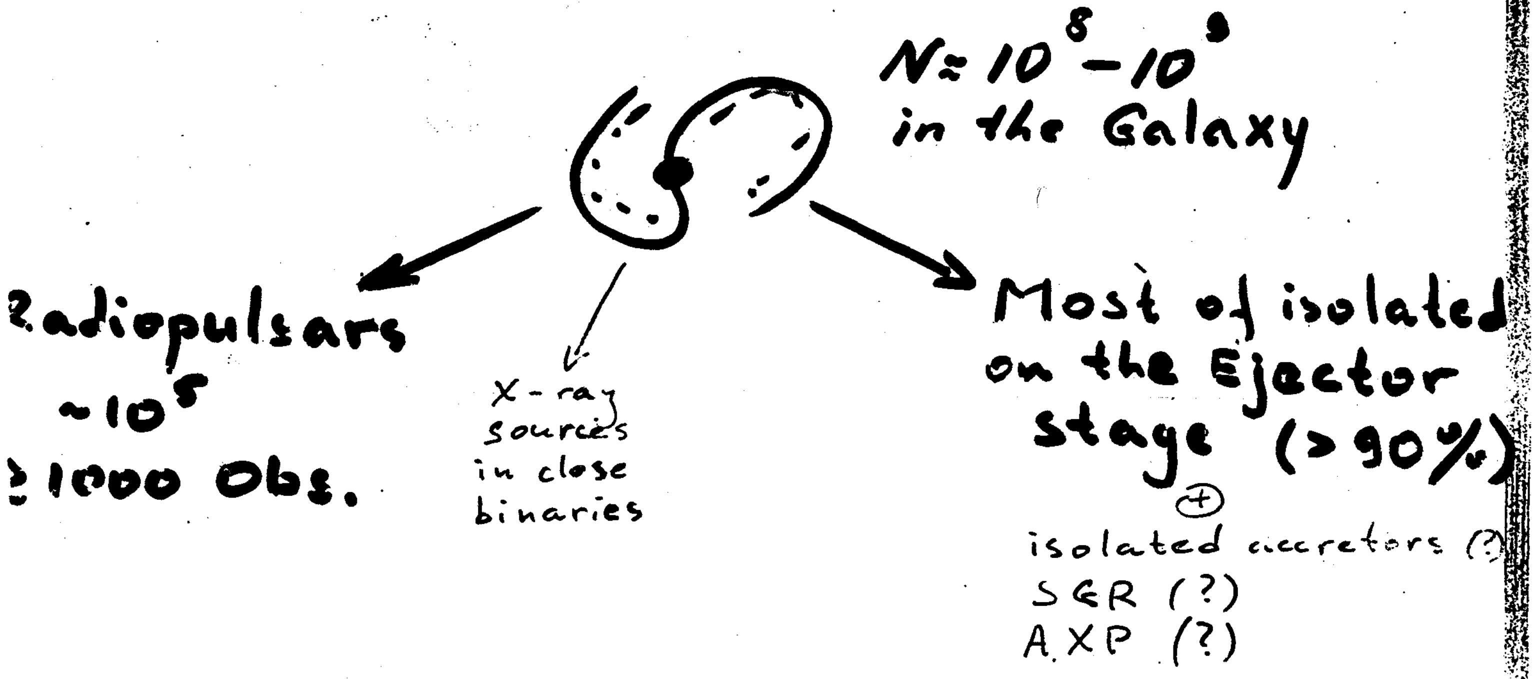
(from D. Langlois astro-ph/0008161)

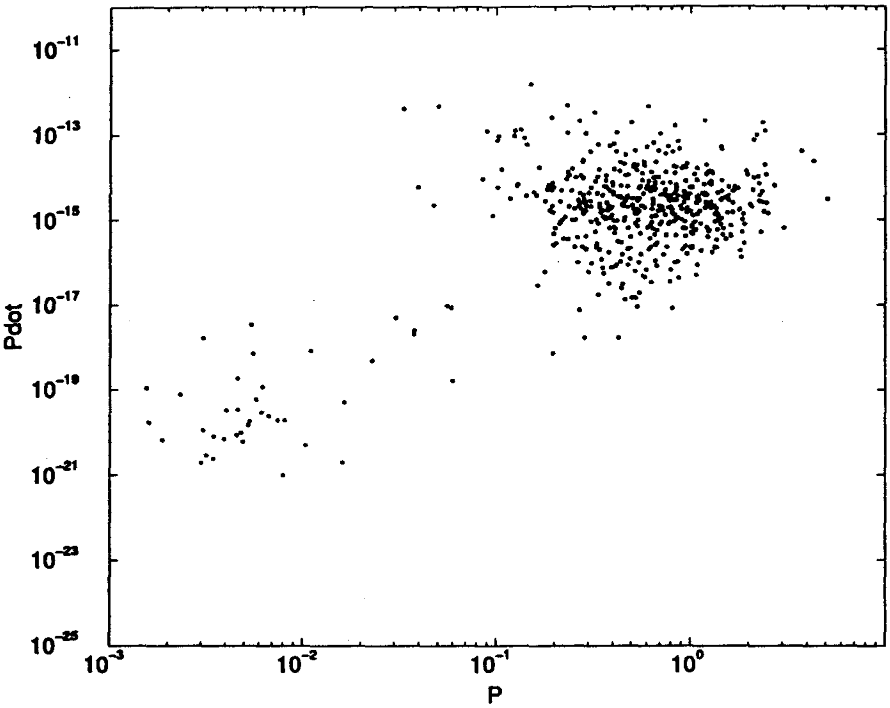
NSs can appear as sources of different nature:

as isolated objects (radio pulsars, old isolated accreting NSs, soft $\gamma-$ repeaters etc.) and as binary companions, usually as X-ray sources in close binary systems, powered by wind or disk accretion from a secondary companion.

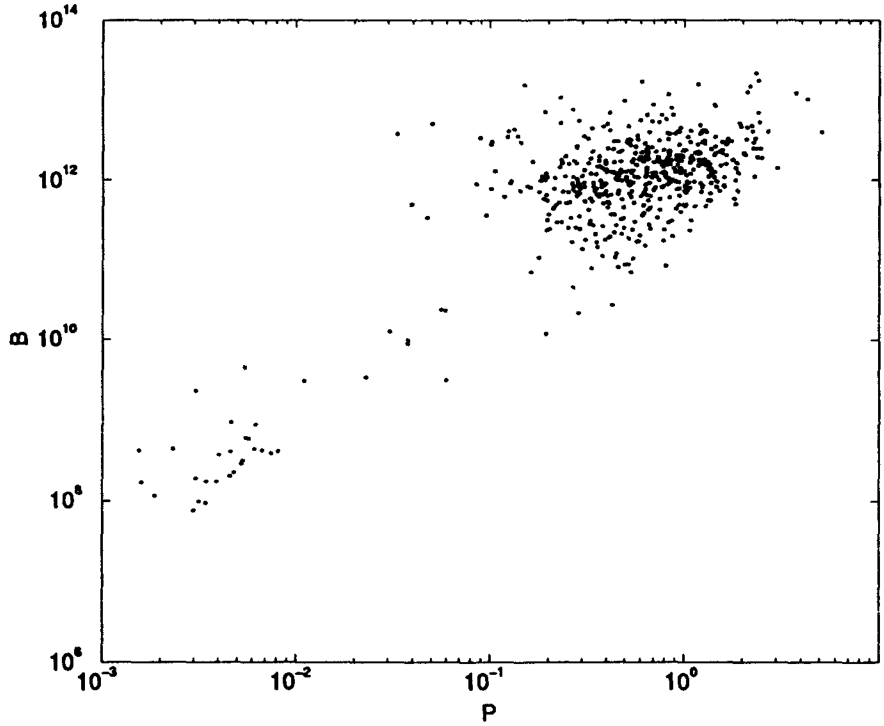
X-ray pulsars are probably one of the most prominent among these sources, because there important parameters of NSs (spin period, magnetic field etc.) can be determined.

Now we know more than 40 X-ray pulsars.





Pdot
P



B
P

Astrophysical appearances of NSs

Astronomy — is the only purely observational natural science!
We have just emission ...

Number of NSs in the Galaxy:

$$10^8 < N_{NS} < 10^9$$

Main parameters, which determine astrophysical appearence:

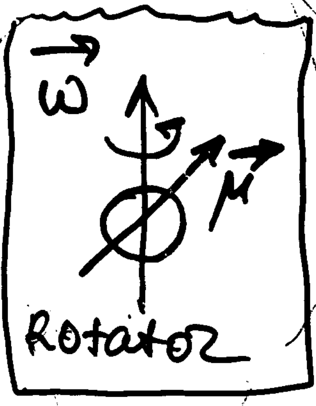
- Spin period, p
- Magnetic field, B
- Mass, M
- Spatial velocity, v
- Angle between spin and magnetic axis, α

...plus parameters of the ISM ...

1. Radio pulsars
2. AXPs
3. SGRs
4. CCO in SNRs
5. Geminga+
6. The "Magnificent seven"

+lensing
+unidentified EGRET sources
+unidentified ROSAT sources

Classification of magnetic compact stars.



The classification of compact stars involving various regime of interaction between compact star and environment plasma.

A regime of interaction of rotator with accreting plasma is determined by relation between five characteristic radii:

1. R_{st} - Stop Radius determined from $P_m = P_A$
2. R_l - light cylinder radius $R_l = c/\omega$
3. R_c - corotation radius $R_c = (GM/\omega^2)^{1/3}$
4. R_G - accretion radius (Bondi radius) $R_G = 2GM/v^2$
5. a - separation

$$R_{st} = \begin{cases} R_A \text{ (Alfven radius) if } R_{st} \le R_l \\ R_{sh} \text{ (Shwartzman radius) if } R_{st} > R_l \end{cases}$$

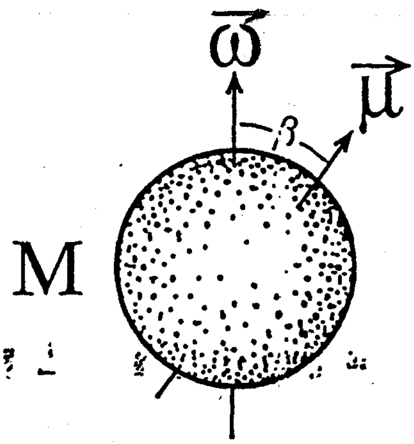


Figure 3: Schematic representation of a gravimagnetic rotator.

Table 1: Classification of neutron stars

	Type	Characteristic radii relation	Accretion rate	Observational appearances
E	ejector	$R_{st} > R_G$ $R_{st} > R_l$	$\dot{M}_c \leq \dot{M}_{cr}$	radiopulsars soft γ-ray repeater Cyg X-3? LSI+61 303?
P	propeller	$R_c < R_{st}$ $R_{st} \leq R_G$ $R_{st} \leq R_l$	$\dot{M}_c \leq \dot{M}_{cr}$	X-ray transients? rapid burster? γ-bursters??? magnetic Ap-stars
A	accretor	$R_{st} \leq R_G$ $R_{st} \leq R_l$	$\dot{M}_c \leq \dot{M}_{cr}$	X-ray pulsars, bursters, CVs intermediate polars
G	georotator	$R_G < R_{st}$ $R_{st} \leq R_c$	$\dot{M}_c \leq \dot{M}_{cr}$	Earth, Jupiter
M	magnetor	$R_{st} > a$ $R_c > a$???	$\dot{M}_c \leq \dot{M}_{cr}$	AM Her, polars
SE	superejector	$R_{st} > R_l$	$\dot{M}_c > \dot{M}_{cr}$	?
SP	superpropeller	$R_c < R_{st}$ $R_{st} \leq R_l$ $R_{st} \leq R_l$	$\dot{M}_c > \dot{M}_{cr}$	?
SA	superaccretor	$R_{st} \leq R_c$ $R_{st} \leq R_G$	$\dot{M}_c > \dot{M}_{cr}$	SS433? T Tau stars? ultrasoft superluminous sources?

Main equation for magneto-rotational evolution:

$$I \frac{d\omega}{dt} = K_{su} - K_{sd}$$

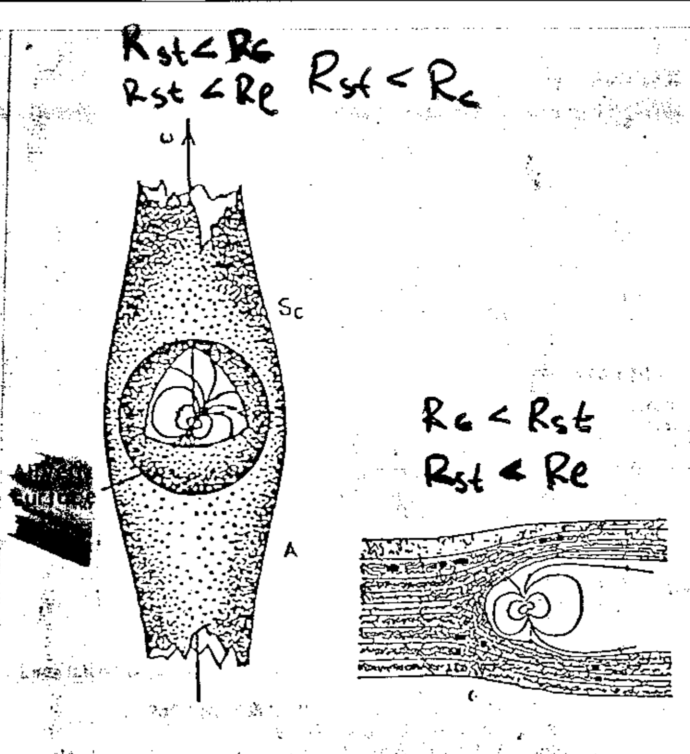


Figure 6: Accretor (to the left) and Georotator (to the right).

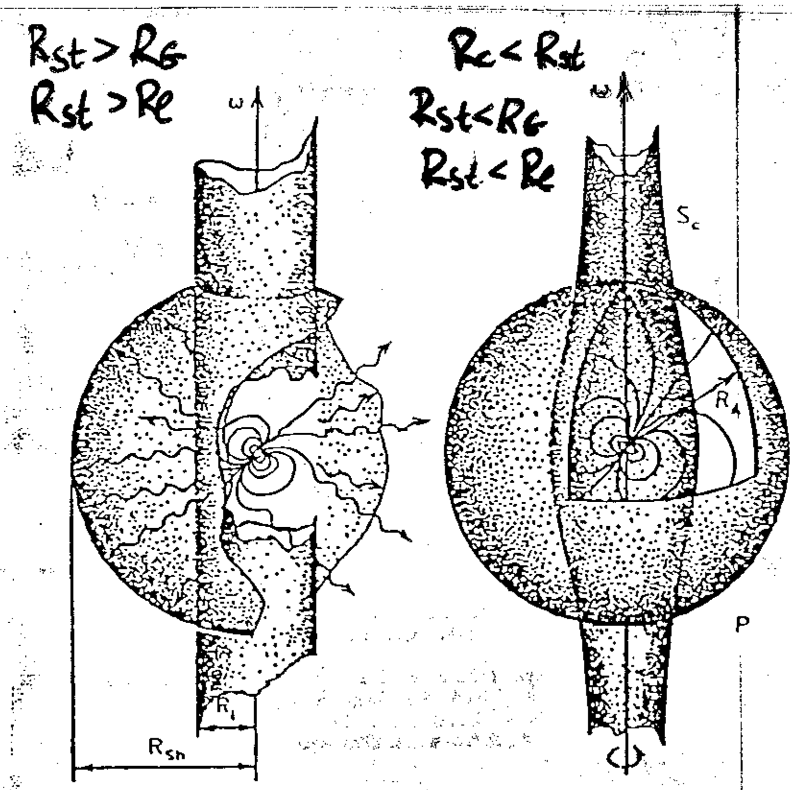


Figure 5: Ejector (to the left) and Propeller (to the right).

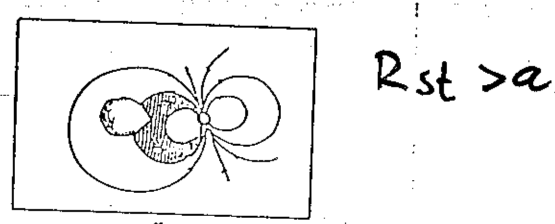


Figure 7: Magnetor.

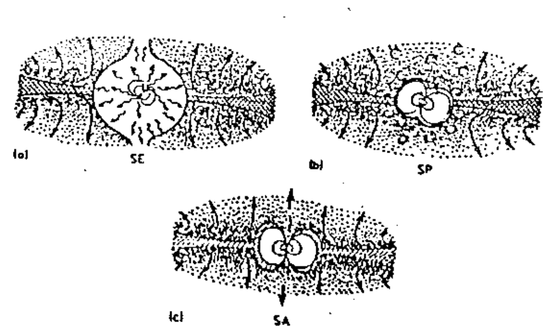
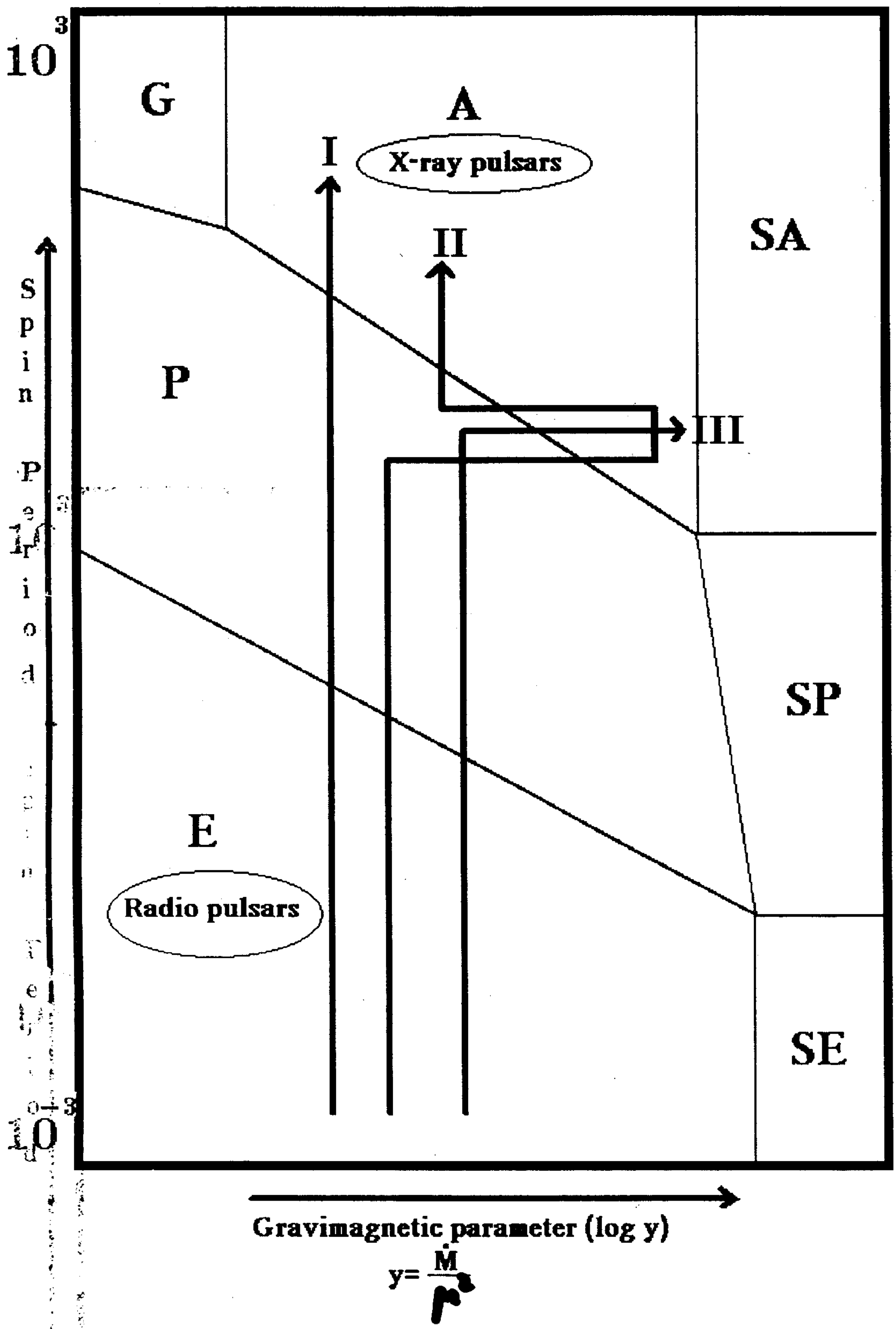


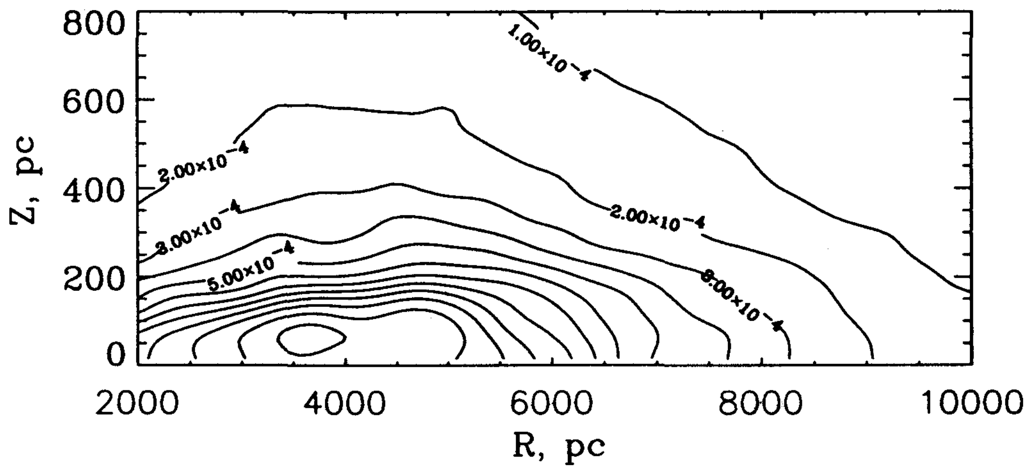
Figure 8: Supercritical stages.



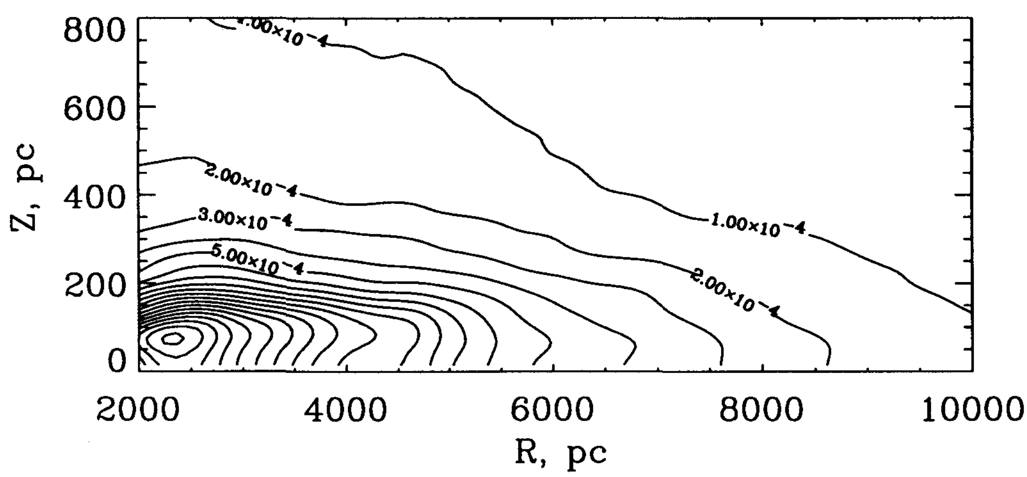
10^3
G
A
I
X-ray pulsars
II
SA
Spin Period
P
III
SP
E
Radio pulsars
SE
10^{-3}
Gravimagnetic parameter (log y)
$y = \frac{\dot{M}}{\mu^2}$

DISTRIBUTION OF NS IN THE GALAXY

Distribution of all isolated NSs in the Galaxy in the $R - z$ plane. The data is calculated by a Monte Carlo of > 10000 individual tracks on a fine grid (10 pc in z direction and 100 pc in R direction). Curves were smoothed, all irregularities are of statistical nature. Kick velocity is assumed following Arzoumanian et al. (2002). NSs are born in the thin disc with semithickness 75 pc. No NS born inside $R = 2$ kpc and outside $R = 16$ kpc are taken into account. Results are normalized to have in total $5\ 10^8$ NSs born in the described region. Density contours are shown with a step 0.0001 pc^{-3}.



NS formation rate is assumed to be proportional to the square of the ISM density at the birthplace.



All parameters are as in the previous figure except the distribution of NS formation rate, it is asusmed to be proportional to $[\exp(-z/75\,\mathrm{pc})\exp(-R/4\,\mathrm{kpc})]$.

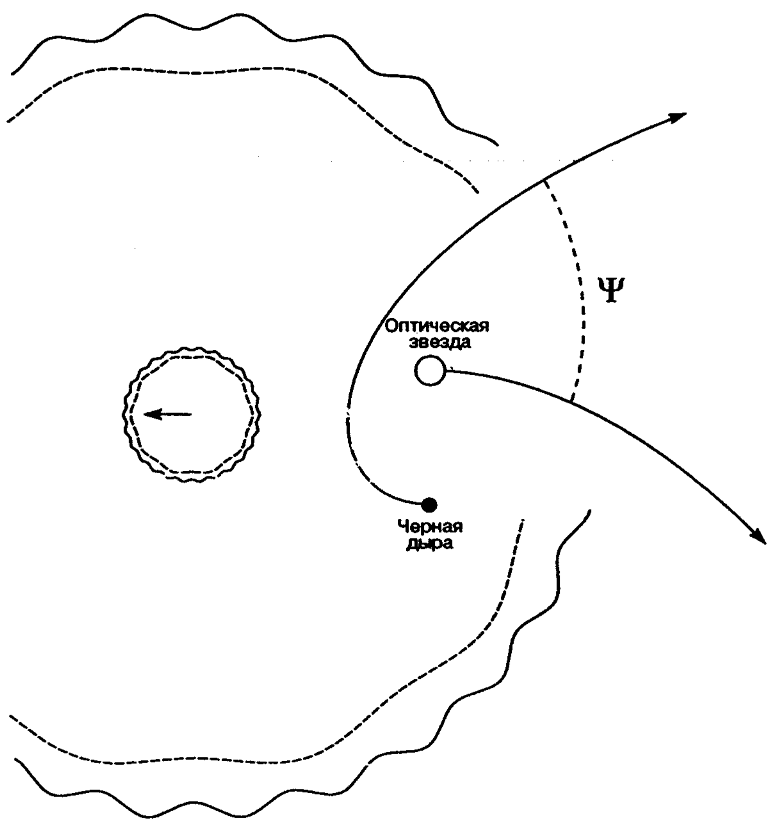
Is it clearly seen that in that case NSs are stronger concentrated towards the galactic center, then in the case of NS formation rate proportional to the square of the ISM density.

Close young isolated black holes

(Astronomy Letters Vol. 28, p.609)

- There are 56 runaways stars in 700 pc around the Sun (Hoogerwerf et al. 2001)
- 4 of them have $M > 33\,M_{\odot}$
- If the seconatry has $M_2 > 33\,M_{\odot}$ then M_1 was significantly higher → BH !

We calculate binary disruption (for zero kick) and then model stars' and BHs' orbits. Finally we can estimate the present day position of a BH.



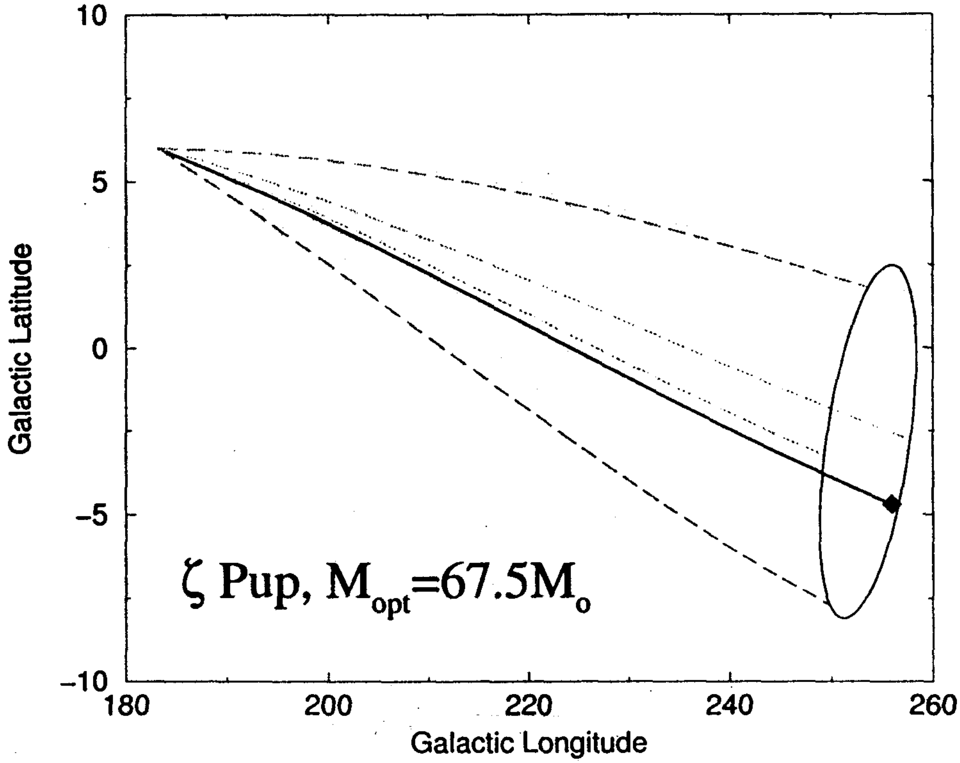
Runaway stars in solar vicinity.

Некоторые близкие убегающие звезды.

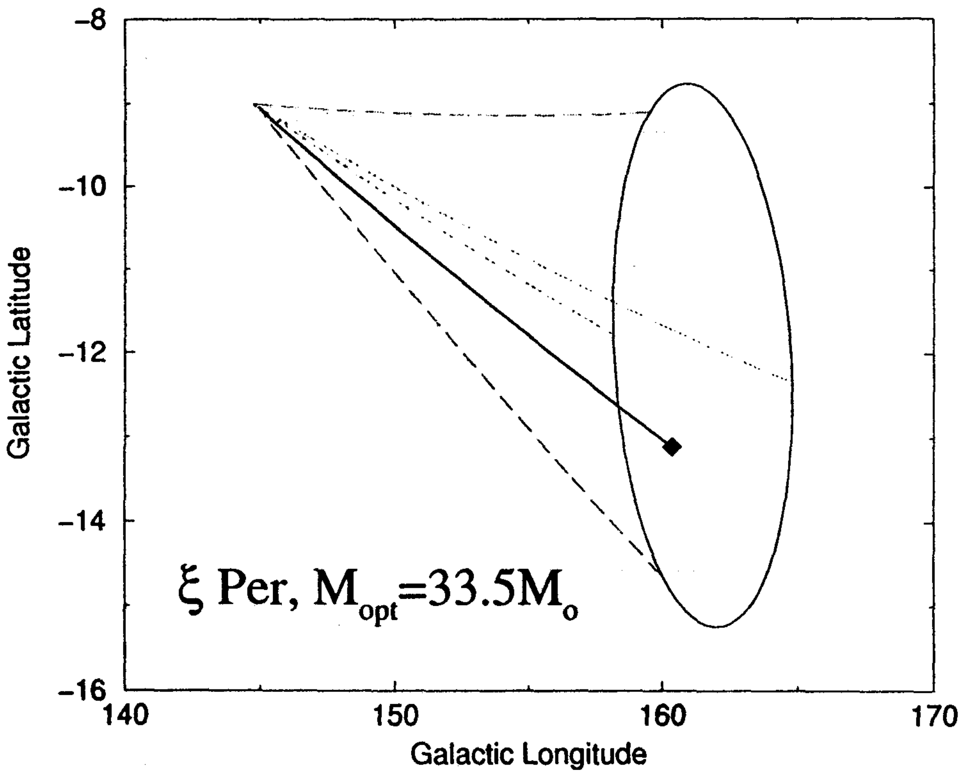
(Таблица из статьи Hoogerwerf et al A&A, 365, 49 (2001); astro-ph/0010057)

HIP	HD	Name	α ($^{h\ m\ s}$) [J1991.25]	δ ($^{\circ\ \prime\ \prime\prime}$) [J1991.25]	π [mas]	$\mu_{\alpha*}$ [mas yr^{-1}]	μ_δ [mas yr^{-1}]	v_{rad} [km s^{-1}]	v_{space} [km s^{-1}]	$v_{rot} \sin i$ [km s^{-1}]	SpT	M_{SK} [$M_\odot$]	M_{BB} [$M_\odot$]	ϵ [#]
3881	4727	ν And	0 49 48.83	+41 04 44.2	4.80 ± 0.75	22.68 ± 0.53	-18.05 ± 0.48	-23.9 ± 1.2	32.1	80[a]	B5V+F8V	6.9[b]		
14514*	19374	53 Ari	3 07 25.69	+17 52 47.9	4.32 ± 0.98	-23.54 ± 0.93	9.30 ± 0.95	21.2 ± 1.2[c]	39.4	10[d]	B1.5V	10.4	8.5	
→ 18614*	24912	ξ Per	3 58 57.90	+35 47 27.7	1.84 ± 0.70	1.92 ± 0.74	2.30 ± 0.62	58.8 ± 5.0[e]	64.9	204	O7.5III	33.8	33.5	0.1
22061	30112		4 44 42.16	+0 34 05.4	2.94 ± 0.86	-44.89 ± 0.77	-29.28 ± 0.67	6.0 ± 5.0	86.5		B2.5V	8.6	7.5	
24575*	34078	AE Aur	5 16 18.15	+34 18 44.0	2.24 ± 0.74	-4.05 ± 0.66	43.22 ± 0.44	57.5 ± 1.2	113.3	25	O9.5V	15.9	21.1	0.0
26241	37043	ι Ori	5 35 25.98	−05 54 35.6	2.46 ± 0.77	2.27 ± 0.65	-0.62 ± 0.47	28.7 ± 1.1[f]	8.0	71[g]	O9III+B1III[h]	37.8[i]	38.6	
27204*	38666	μ Col	5 45 59.89	−32 18 23.0	2.52 ± 0.55	3.01 ± 0.52	-22.62 ± 0.50	109.0 ± 2.5	107.8	111	O9.5V	15.9	21.1	
29678	43112		6 15 08.46	+13 51 03.9	2.38 ± 0.72	24.21 ± 0.76	10.65 ± 0.49	36.0 ± 5.0	63.0	<25[j]	B1V	11.5	12.0	
38455	64503		7 52 38.65	−38 51 46.2	5.09 ± 0.52	-9.49 ± 0.43	4.02 ± 0.42	-31.0 ± 5.0	41.4	212[k]	B2V	9.4	8.0	
→ 38518	64760		7 53 18.16	−48 06 10.6	1.68 ± 0.50	-4.90 ± 0.53	5.89 ± 0.38	41.0 ± 5.0	31.1	220[d]	B0.5Iab	25.0	35.1	
→ 39429	66811	ζ Pup	8 03 35.07	−40 00 11.5	2.33 ± 0.51	-30.82 ± 0.44	16.77 ± 0.41	-23.9 ± 1.2	62.4	203	O4I		67.5	0.1
42038	73105		8 34 09.60	−53 04 17.5	2.87 ± 0.47	-12.14 ± 0.54	10.13 ± 0.48	37.0 ± 10.0	31.3		B3V	7.9	7.0	
46950	83058		9 34 08.80	−51 15 19.0	3.50 ± 0.53	-8.50 ± 0.49	6.39 ± 0.48	35.0 ± 10.0	32.1		B1.5IV	10.4[m]	9.0	
48943	86612		9 59 06.32	−23 57 02.8	5.19 ± 0.77	-23.22 ± 0.70	5.30 ± 0.70	39.0 ± 5.0	35.2	230[d]	B5V	5.8		
49934	88661		10 11 46.47	−58 03 38.0	2.52 ± 0.50	-10.71 ± 0.49	6.63 ± 0.45	31.0 ± 10.0	31.2	280[d]	B2IVnpe	9.4[m]	8.0	
57669	102776		11 49 41.09	−63 47 18.6	7.10 ± 0.69	-17.93 ± 0.95	4.44 ± 0.63	29.0 ± 2.5	31.1	251[n]	B3V	7.9	7.0	
69491	124195		14 13 39.84	−54 37 32.2	2.96 ± 0.63	-18.03 ± 0.41	-11.15 ± 0.41	66.0 ± 10.0	77.2		B5V	5.8		
76013	137387	κ^1 Aps	15 31 30.82	−73 23 22.4	3.20 ± 0.59	0.38 ± 0.48	-18.28 ± 0.55	62.0 ± 5.0	69.0		B1npe			
81377*	149757	ζ Oph	16 37 09.53	−10 34 01.7	7.12 ± 0.71	13.07 ± 0.85	25.44 ± 0.72	-9.0 ± 5.5	23.5	348	O9.5Vnn	15.9	21.1	0.1
82868	152478		16 56 08.85	−50 40 29.2	4.34 ± 0.82	-10.21 ± 0.84	-9.55 ± 0.62	19.0 ± 5.0	30.3		B3Vnpe	7.9	7.0	
91599	172488		18 40 48.06	−08 43 07.5	3.61 ± 1.16	-9.64 ± 1.13	-22.64 ± 0.79	34.1 ± 1.2[o]	44.7		B0.5V	12.7	13.5	
102274	197911		20 43 21.62	+63 12 32.9	1.42 ± 0.62	-13.72 ± 0.53	-3.66 ± 0.53	-3.8 ± 5.0	46.1		B5			
→ 109556*	210839	λ Cep	22 11 30.58	+59 24 52.3	1.98 ± 0.46	-7.22 ± 0.44	-11.06 ± 0.39	-75.1 ± 1.2	74.0	214	O6I	40.0	64.6	0.1
	J0826+2637		8 26 51.31	+26 37 25.6	2.6	61 ± 3	-90 ± 2			P =0.53	$\tau = 4.92$	1.4[p]		
	J0835−4510		8 35 20.68	−45 10 35.8	2.0	-48 ± 2	35 ± 1			0.09	0.01	1.4[p]		
	J1115+5030		11 15 38.35	+50 30 13.6	1.9	22 ± 3	-51 ± 3			1.65	10.53	1.4[p]		
	J1932+1059		19 32 13.87	+10 59 31.8	5.9	99 ± 6	39 ± 4			0.22	3.10	1.4[p]		
	Geminga[q]		6 33 54.15	+17 46 12.9	6.4 ± 1.7	138 ± 4	97 ± 4					1.4[p]		

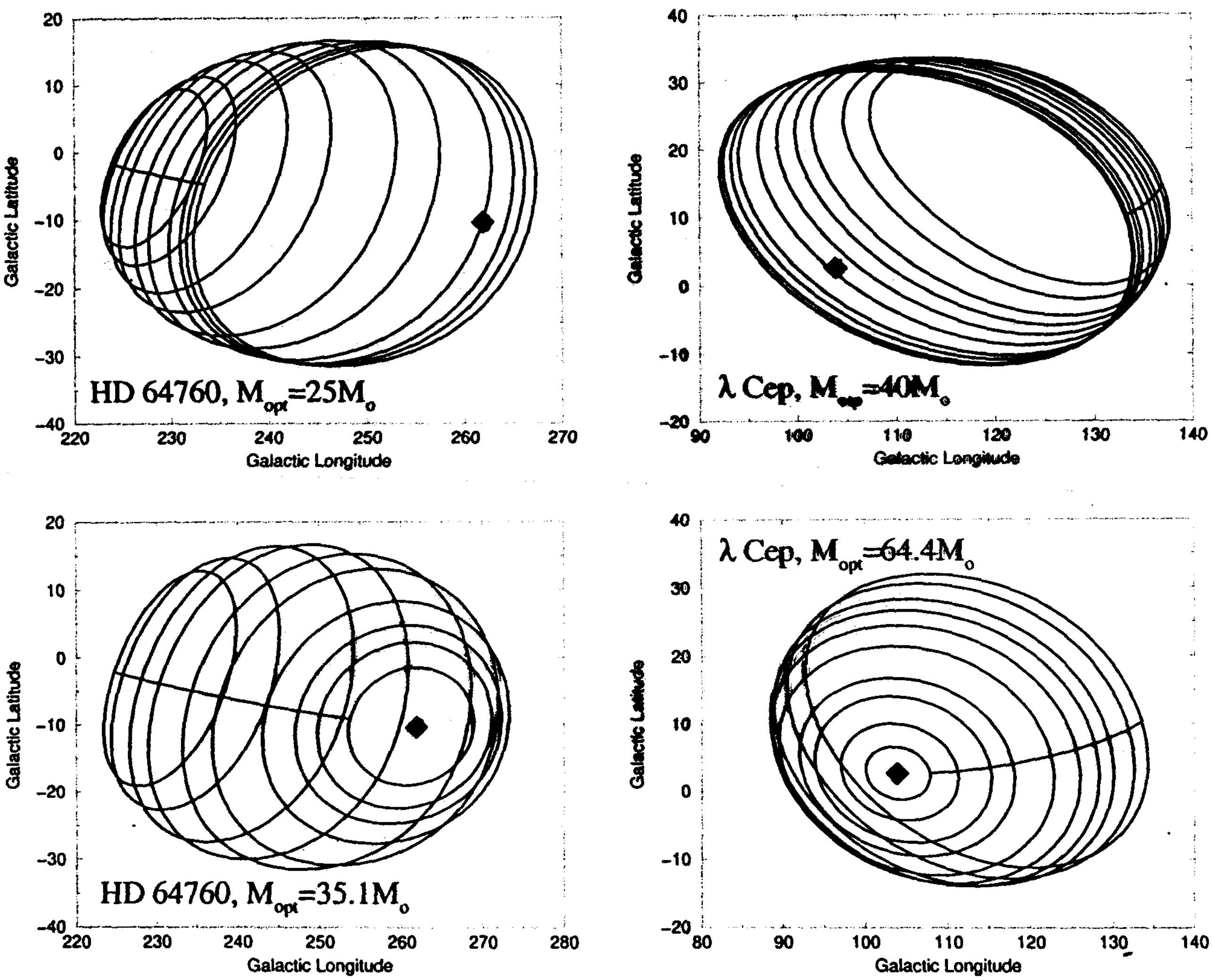
56 in ~700pc

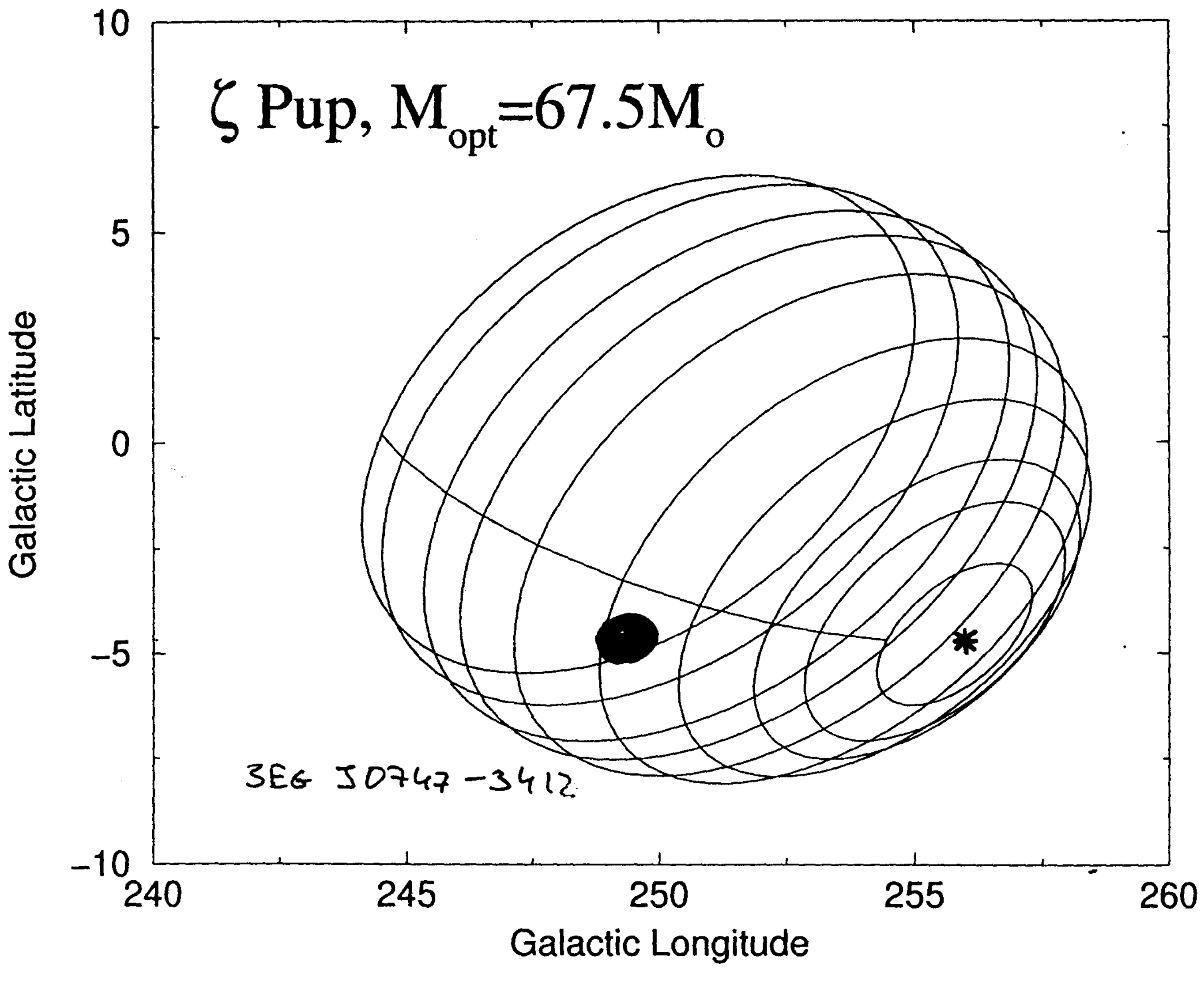


10
5
0
-5
-10
180
200
220
240
260
Galactic Latitude
Galactic Longitude
ζ Pup, M_opt=67.5M_o

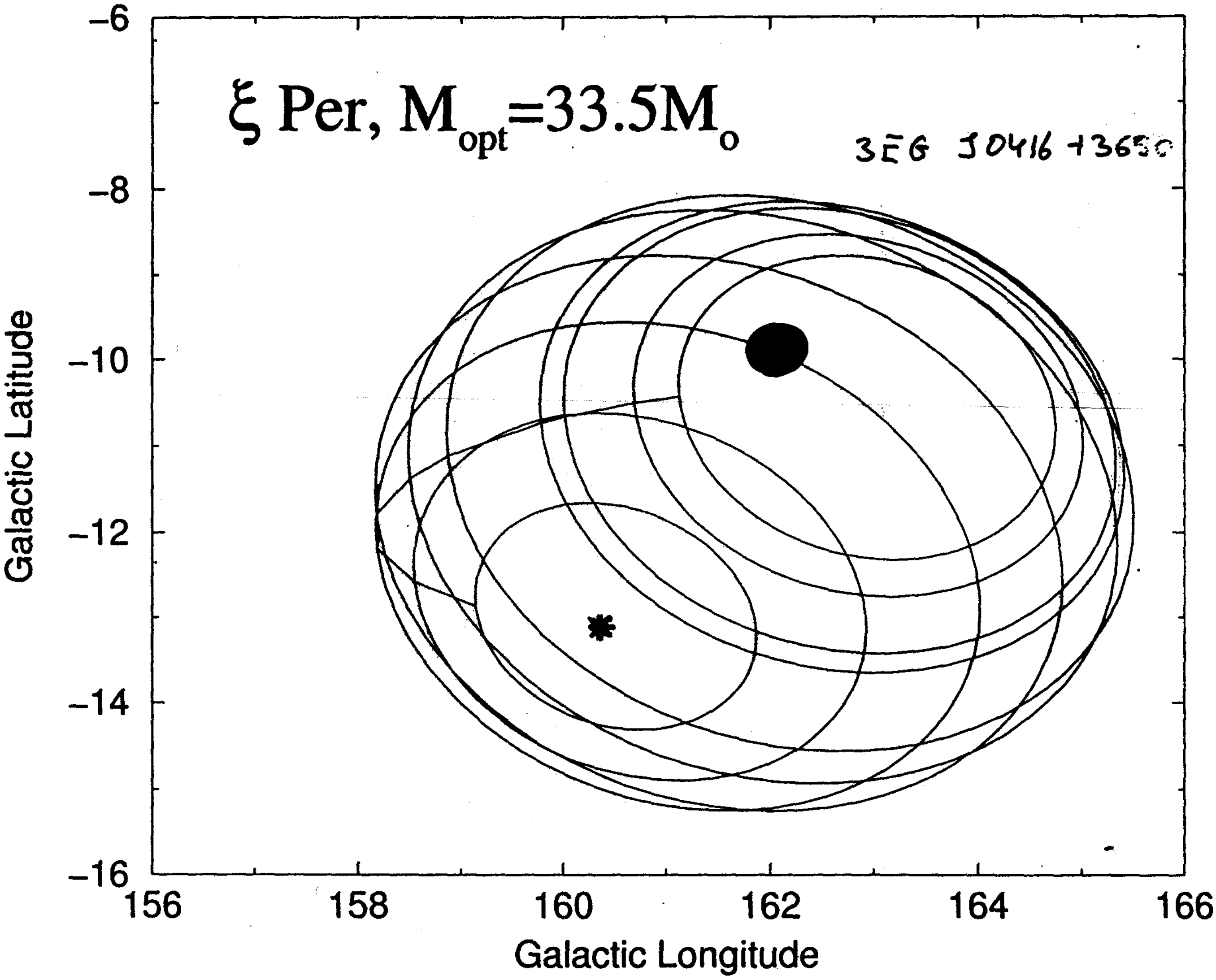


-8
-10
-12
-14
-16
140
150
160
170
Galactic Latitude
Galactic Longitude
ξ Per, M_opt=33.5M_o


HD 64760, M_{opt}=25M_o
λ Cep, M_{opt}=40M_o
HD 64760, M_{opt}=35.1M_o
λ Cep, M_{opt}=64.4M_o
Galactic Latitude
Galactic Longitude



ζ Pup, M_opt=67.5M_o
3EG J0747-3412
Galactic Latitude
Galactic Longitude
10
5
0
−5
−10
240
245
250
255
260



ξ Per, M_{opt}=33.5M_o
3EG J0416+3650
Galactic Latitude
−6
−8
−10
−12
−14
−16
156
158
160
162
164
166
Galactic Longitude