The effects of a neutron star translational and rotational motion in observable timing and evolution of radiopulsars

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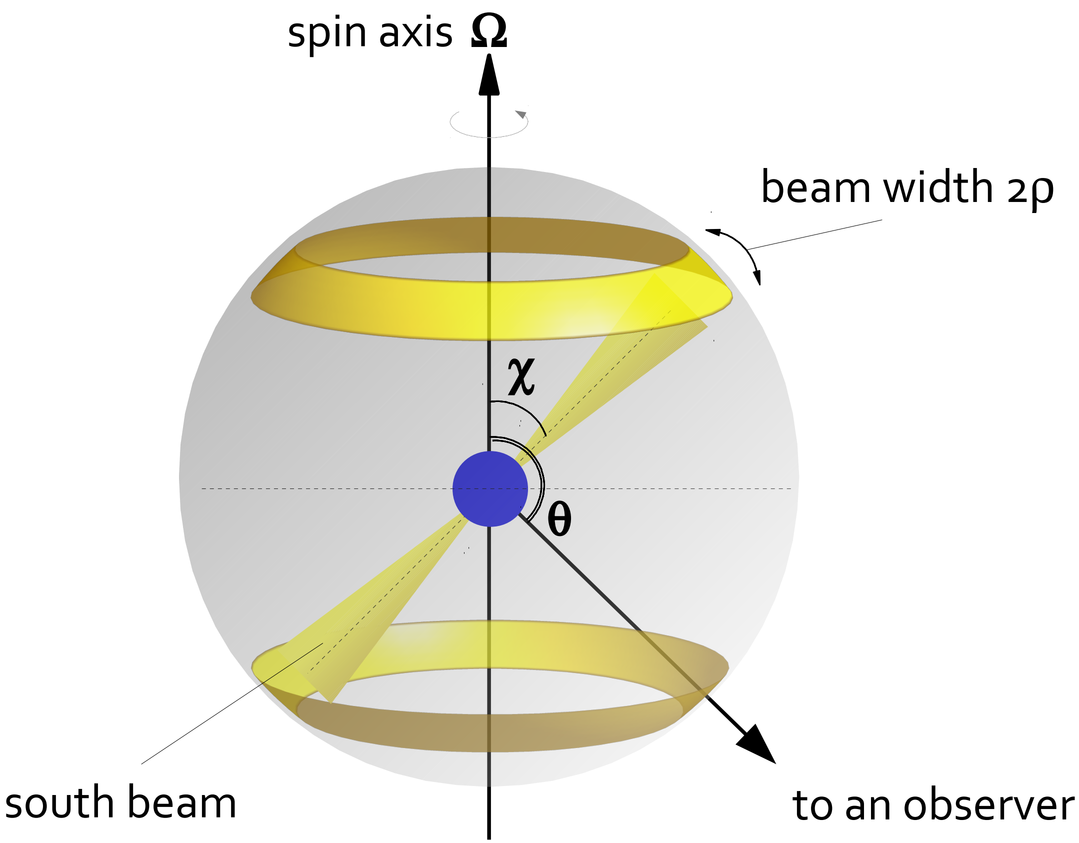
Outline

We've studied the influence of neutron stars complex rotation (possible free & force precession) and **space motion** on the observed properties pulsars ensemble: timing behaviour, distribution density on the P-Pdot diagram etc.

Contents of this talk:

- Pulsars beaming fraction and observed fraction
- Anisotropy in spin – observer angles distribution
- Modeling a galaxy of pulsars
- Results
- Conclusions



observed fraction

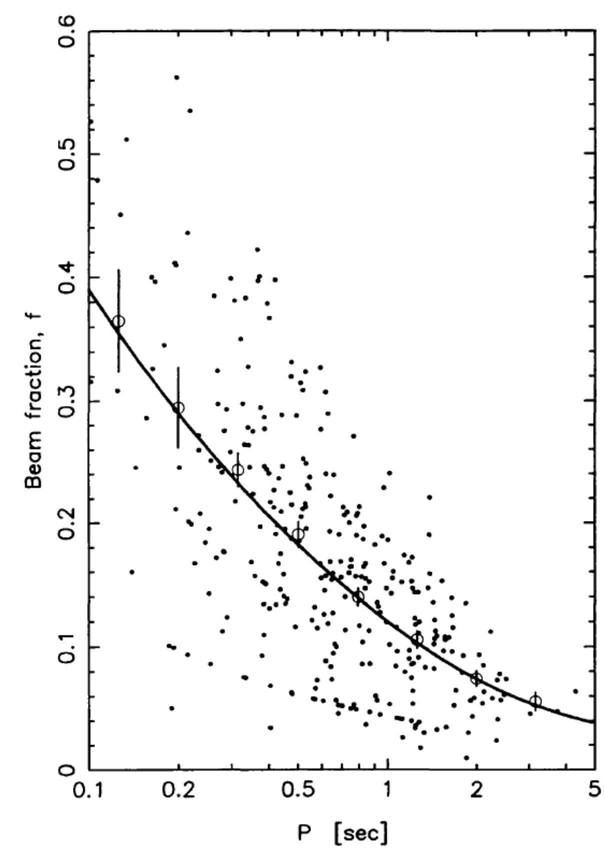
$$OF \equiv \frac{\text{number of pulsars directed to an observer}}{\text{total number of active pulsars}}$$

***BF* of a pulsars group is an equivalent to their *OF* only in case of isotropically distributed θ**

beaming fraction

$$BF \equiv \frac{\text{illuminated solid angle}}{4\pi} = f(\chi, \rho)$$

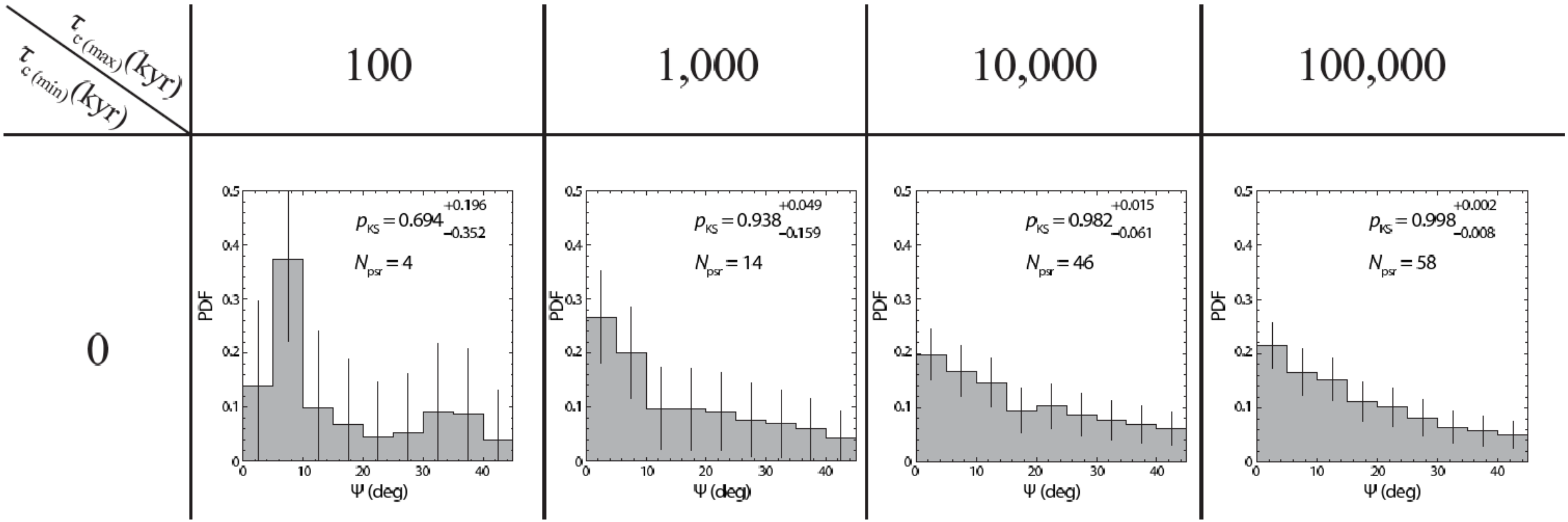
$$\langle BF \rangle = 0.09 \cdot \log^2\left(\frac{P}{10\,sec}\right) + 0.03$$



(Tauris & Manchester 1998)

Pulsars spin-velocity alignment

Several authors (Johnston et al. 2005, Rankin 2007, Noutsos et al. 2013) argued in favour of observational evidence of the **alignment** of the rotational and velocity vectors for isolated pulsars.



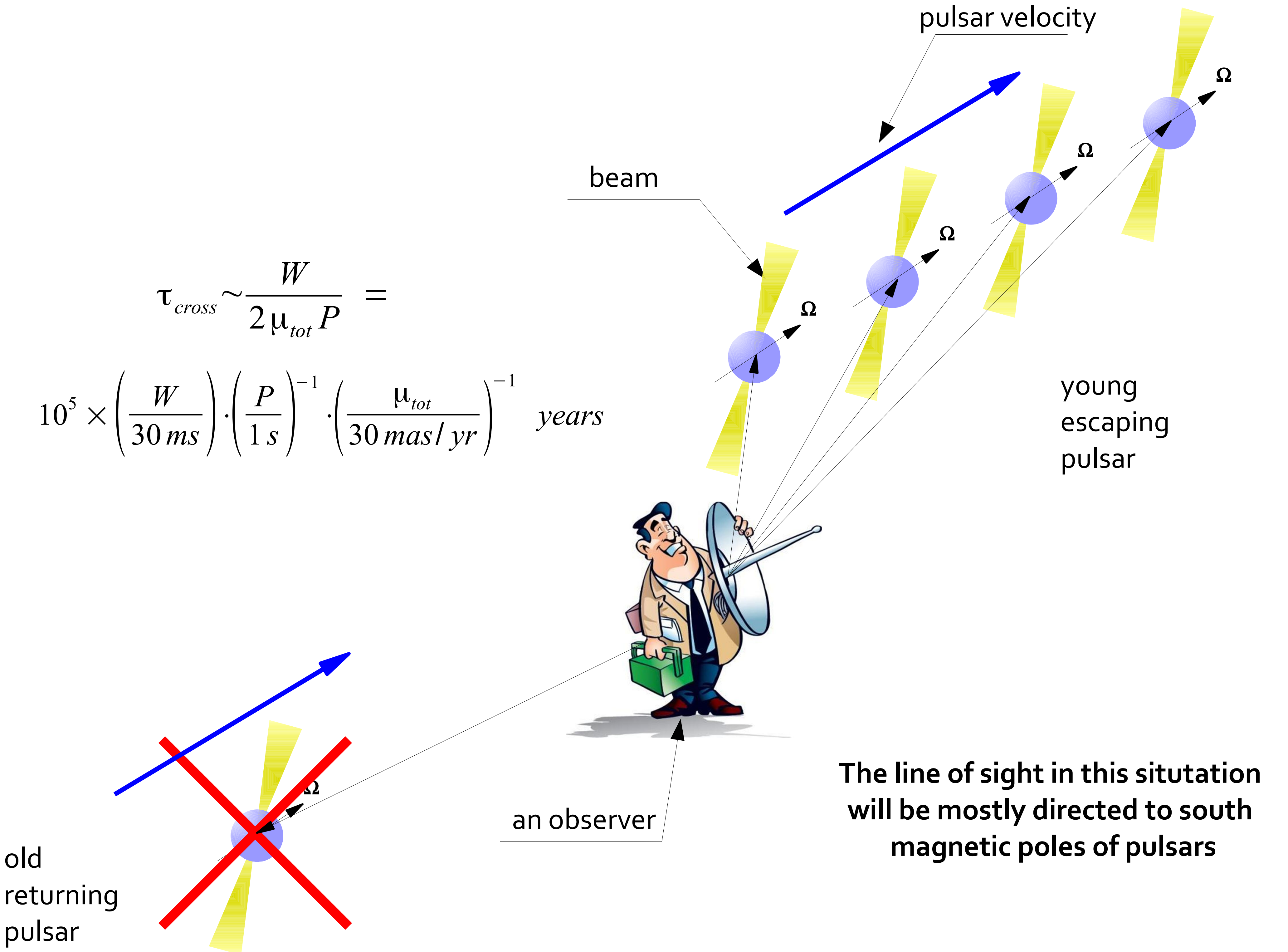
(Noutsos et al. 2013: distributions of spin-velocity angle Ψ for different age intervals)

In this case angle θ between spin axis and direction to an observer is distributed anisotropically.

So, OF is not equivalent to BF any more!

$$\tau_{cross} \sim \frac{W}{2\mu_{tot} P} =$$

$$10^5 \times \left(\frac{W}{30\,ms}\right) \cdot \left(\frac{P}{1\,s}\right)^{-1} \cdot \left(\frac{\mu_{tot}}{30\,mas/yr}\right)^{-1} \quad years$$



The line of sight in this situtation will be mostly directed to south magnetic poles of pulsars

What have we actually done?

beaming excess

$$BE = \frac{OF - BF}{BF}$$

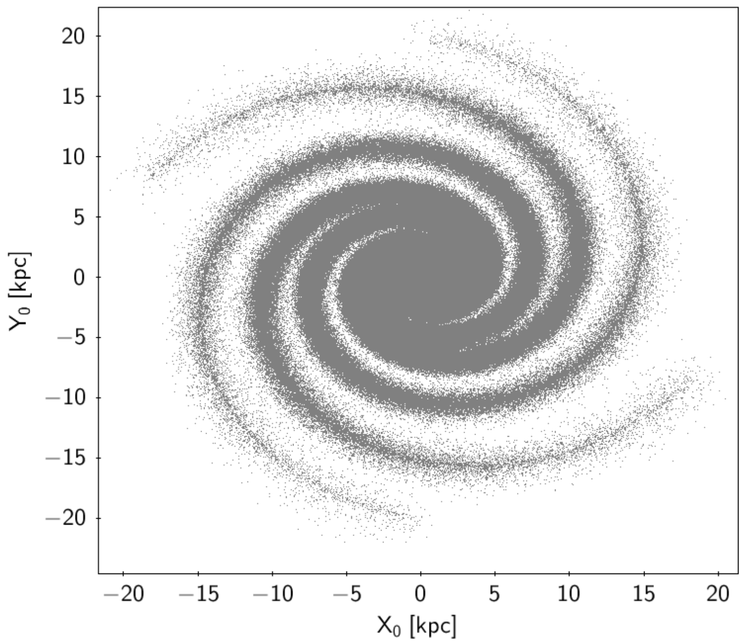
How large can it be?
How is it distributed over P-Pdot diagram?
How does it depend on the constituents of pulsars evolution model?

- We have investigated the properties of *BE* for a set of models of pulsars evolution using population synthesis approach.
- We have focused on the evolution of spin-velocity and spin-observer angles. Also we have modeled the evolution of magnetic inclination angle χ and pulsar beam width ρ.
- Moreover, we have made sure that pulsar spin axis conserves its direction in space during pulsar life in spite of braking torque affecting a neutron star.

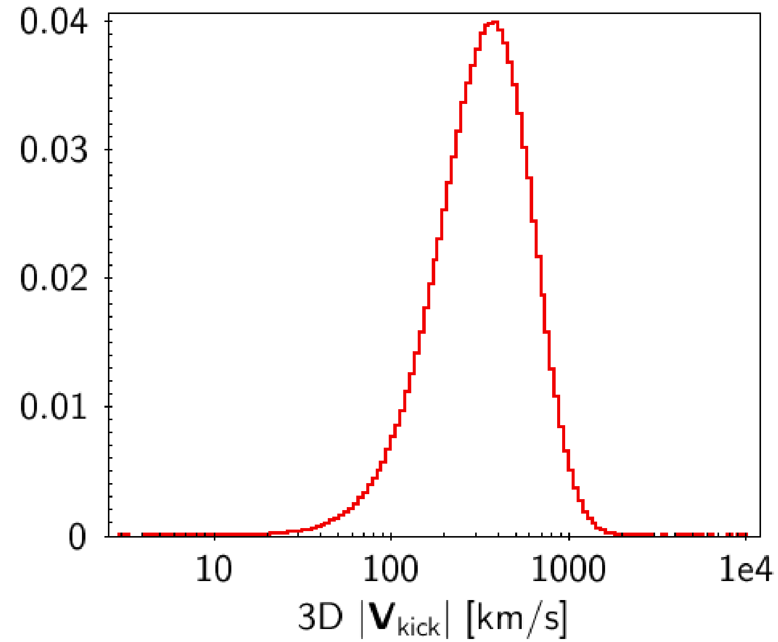
Model of pulsars ensemble evolution

Our population code (GALP) basically reproduces the best model of Faucher-Giguere & Kaspi (2006):

Galactic structure & gravitational potential



Double-sided exponent with $\langle V_{3D} \rangle \sim 380$ km/s



- Vector of kick velocity is distributed isotropically over the sky
- Initial periods P_0 *[sec] ~ normal(0.3, 0.15)*
- Initial magnetic filelds *log B [Gs] ~ normal(12.55, 0.55)*
- Ages *t [Gyr] ~ uniform(0, 1)*
- Approximation of the «death line» in the form $Pdot/P^3 = const$

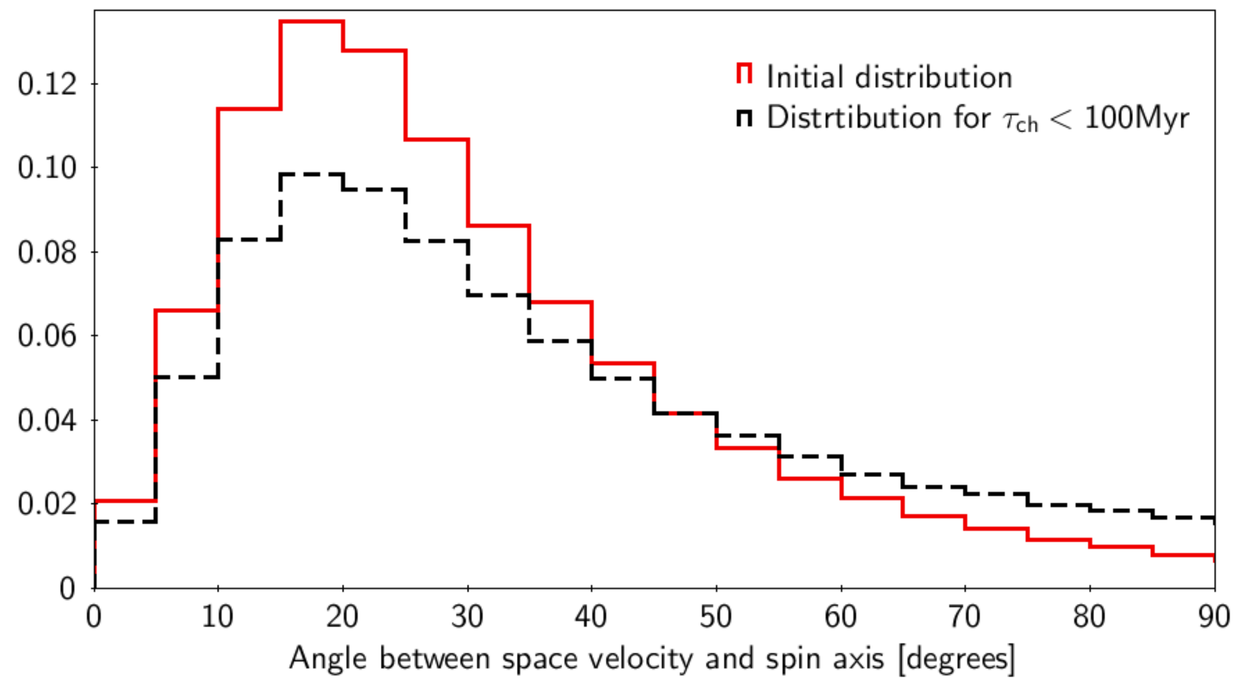
Our extension of the model

- Spin axis $\boldsymbol{\Omega}$ is directed precisely along $\mathbf{V_{kick}}$
- Initial magnetic angles χ_0 are distributed isotropicaly, i.e. *PDF*(χ_0) = *sin* χ_0/*2*
- Pulsar beam has cone-like geometry with opening angle 2ρ = *0.2/sqrt(P [sec])* radians
- Velocity of the Sun's LSR is 220 km/s
- Spindown law in generalized form: $\dot{\Omega} = -\alpha B_0^2 \beta_0^2 \cdot \exp\left(-\frac{2t}{T_\Omega}\right) \cdot \Omega^3$
- Magnetic angle evolution in generalized form: $F(\chi) = F(\chi_0) \cdot \exp\left(-\frac{t}{T_\chi}\right)$

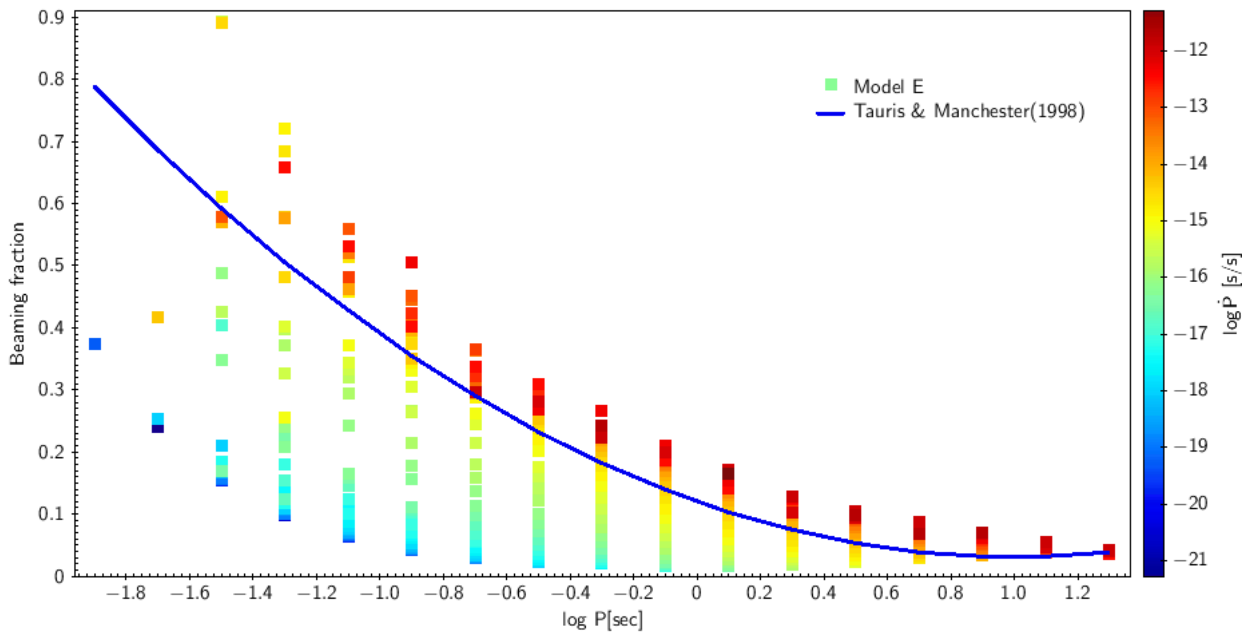
Mod	Description	β_0	T_Ω	T_χ	F(χ)
A	FG&K 2006 spindown: χ = const, $\dot{\Omega} = -\alpha B_0^2 \cdot \Omega^3$	1	*inf*	*inf*	χ
B	Magnetic alignment: $\sin\chi = \sin\chi_0 \cdot e^{-t/T_\chi}$, $\dot{\Omega} = -\alpha B_0^2 \cdot \Omega^3$	1	*inf*	10^7 yr	sin χ
C	Magnetic disalignment: $\cos\chi = \cos\chi_0 \cdot e^{-t/T_\chi}$, $\dot{\Omega} = -\alpha B_0^2 \cdot \Omega^3$	1	*inf*	10^7 yr	cos χ
D	χ = const, $B(t) = B_0 \cdot e^{-t/T_\Omega}$, $\dot{\Omega} = -\alpha B^2 \cdot \Omega^3$	1	10^7 yr	*inf*	χ
E	Classical MD spindown-like law with magnetic alingment	sin χ_0	10^7 yr	10^7 yr	sin χ
F	Electric current spindown-like law with magnetic disalingment (Beskin et al. 1993)	cos χ_0	10^7 yr	10^7 yr	cos χ

Results: spin-velocity alignment & average beaming fraction

Orientation of space velocity vector is always partially uncorrelated with that of spin axis due to LSR velocity

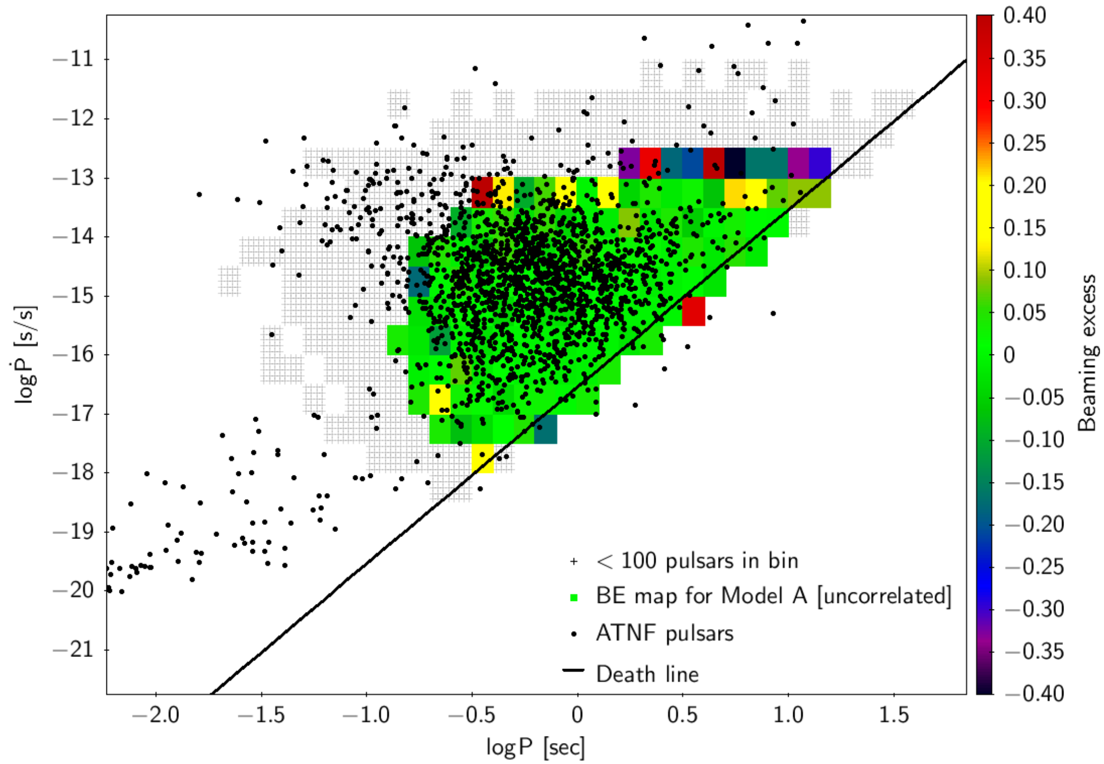


We have reproduced the empirical dependence of Tauris & Manchester (1998) for beaming fraction.

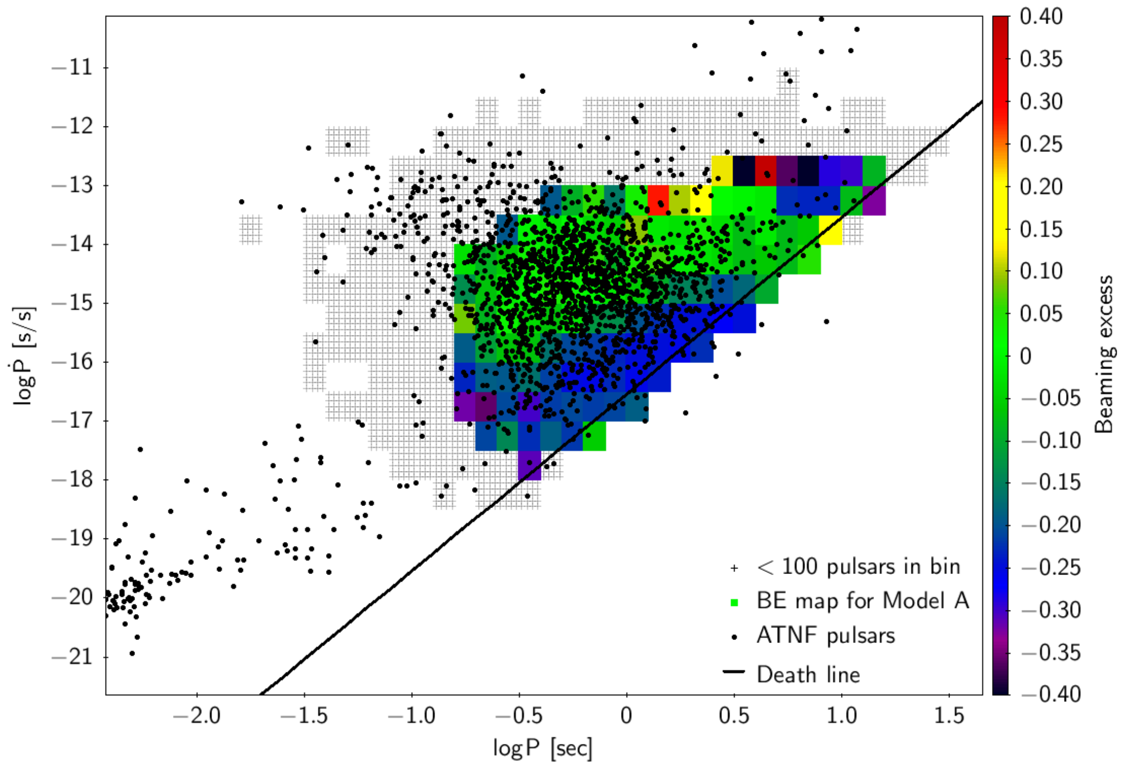


Results: FG&K model

BE distribution in case when **Ω** is distributed isotropically and independent of the kick direction.



Spin-velocity alignment included into the model leads to negative beaming excess.



Integral (over P-Pdot distribution) value:

-0.173 ± 0.003

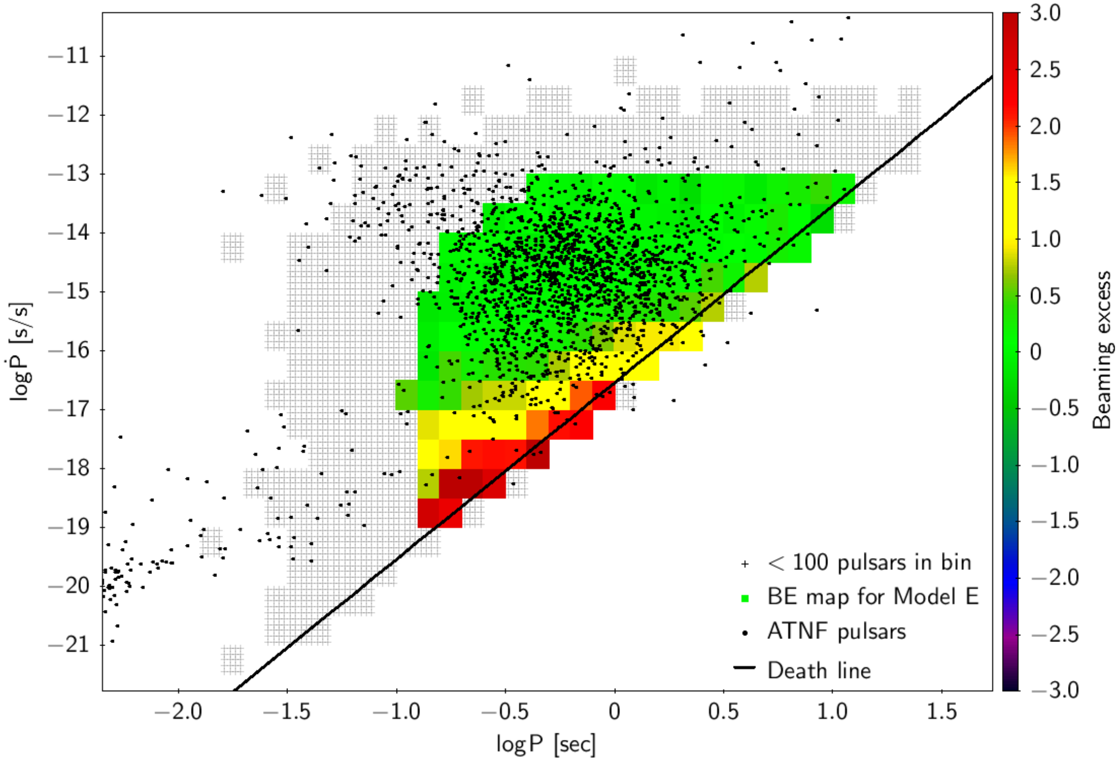
I.e. the fraction of pulsars directed to an observer is 17.3% less than their average beaming factor.

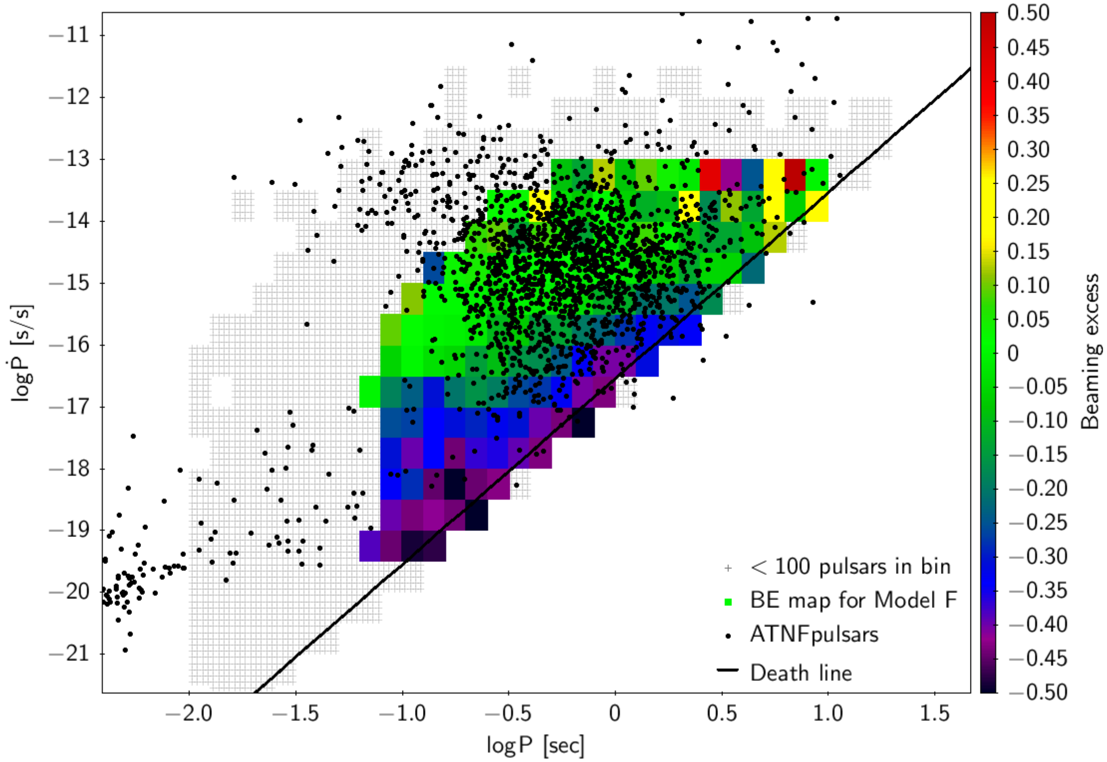
Results:
alignment vs. disalignment

Integral BE for Model E (alignment):
+0.31 ± 0.01

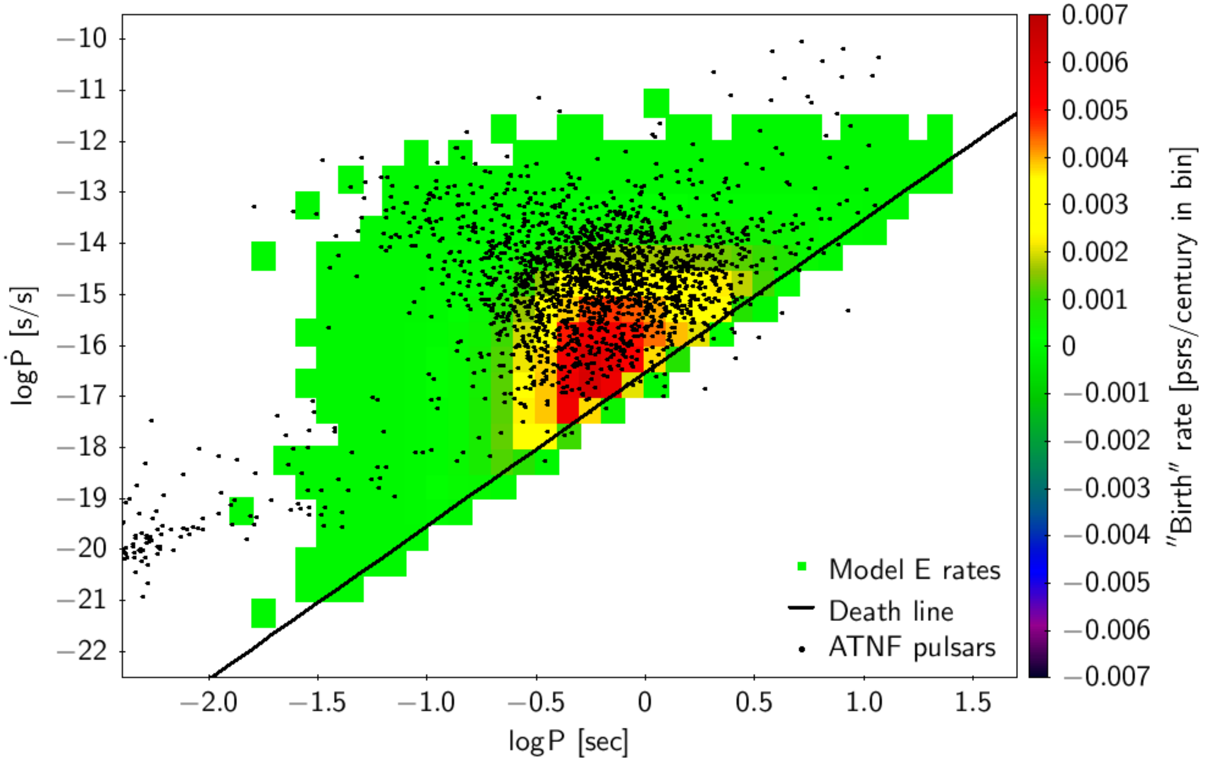
Magnetic alignment leads to strong positive BE, while disalignment leads to the strong negative one.

For Model F (disalignment):
-0.199 ± 0.004





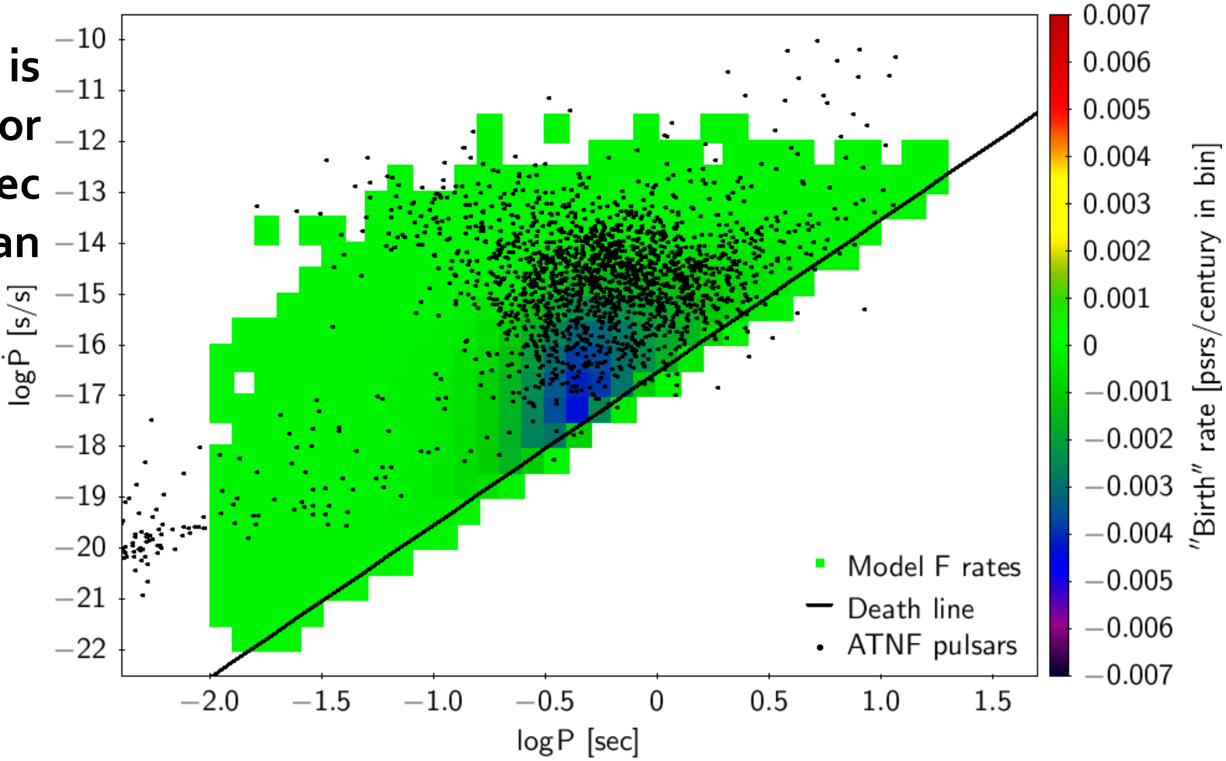
Observed birthrates of radiopulsars



Integral effect for Model E (alignment):

$$(+0.230 \pm 0.001) \times \left(\frac{N_{active}}{10^6\, pulsars} \right) \left[\frac{psrs}{century} \right]$$

The effect of beaming excess is accompanied by seeming «birth» or «death» of pulsars near P ~ 0.5 sec (discussed by Vivekanand & Narayan 1981; Vranesevic et al. 2004)



For Model F (disalignment):

$$(-0.407 \pm 0.003) \times \left(\frac{N_{active}}{10^6\, pulsars} \right) \left[\frac{psrs}{century} \right]$$

Results: summary

Mod	Description	Total Beaming Excess	Additional «birth» rate [psrs/century] for $N_{total} = 10^6$
A	FG-K 2006 spindown: χ = const, $\dot{\Omega}=-\alpha B_0^2 \cdot \Omega^3$	-0.173 ± 0.003	-0.042 ± 0.001
B	Magnetic alignment: $\sin\chi=\sin\chi_0 \cdot e^{-t/T_\chi}$, $\dot{\Omega}=-\alpha B_0^2 \cdot \Omega^3$	+0.79 ± 0.01	+0.050 ± 0.001
C	Magnetic disalignment: $\cos\chi=\cos\chi_0 \cdot e^{-t/T_\chi}$, $\dot{\Omega}=-\alpha B_0^2 \cdot \Omega^3$	-0.370 ± 0.003	-0.09 ± 0.01
D	χ = const, $B(t)=B_0 \cdot e^{-t/T_\Omega}$, $\dot{\Omega}=-\alpha B^2 \cdot \Omega^3$	-0.065 ± 0.005	-0.108 ± 0.002
E	Classical MD spindown-like law with magnetic alingment	+0.31 ± 0.01	+0.230 ± 0.001
F	Electric current spindown-like law with magnetic disalingment	-0.199 ± 0.004	-0.407 ± 0.004

Conclusions

- Spin-velocty alignment introduces strong anisotropy into the distribution of spin-observer angles of active pulsars.
- This asymmetry leads to the beaming excess – the difference between the observed fraction and average beaming fraction of a pulsars group. Integral value of BE may reach tens of percents. Thus this effect has to be taken into account within a population synthesis.
- The effect of beaming excess is acompanied by the bias in the observed pulsars bithrate and causes a seeming source of newborn pulsars on the P-Pdot diagram.
- BE strongly depends on the model of pulsar evolution. It probalby may help to distinguish observationally magnetic alignment and disalignment of radiopulsars.