The effects of non-linear mutual friction on glitches

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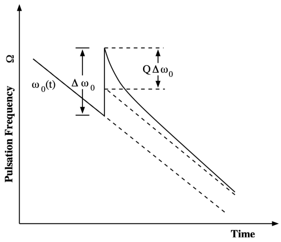
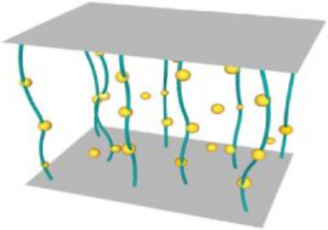
Glitches and Superfluidity

Pulsar glitches are due to transfer of angular momentum from the superfluid internal component to the observed one. The initial ΔL can be built up because the superfluid vortices are pinned (to proton flux-tubes/nuclei) and the superfluid component cannot slow down. The glitch is started once this vortices are torn away from their pinning sites.



Cartoon of a pulsar glitch



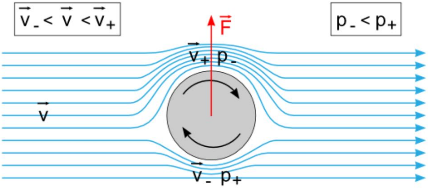
Cartoon of pinned vortices, taken from https://departments.icmab.es

Vortex Mediated Mutual Friction

To have an angular momentum transfer we need an interaction between the superfluid and the observable component: the vortex mediated mutual friction.

Vortex Dynamics:

- straight vortices
- Magnus lift:
  $\mathbf{f}_M = \rho_n \boldsymbol{\kappa} \times \mathbf{v}_{Ln}$
- linear drag force:
  $\mathbf{f}_D = -\mathcal{R}\mathbf{v}_{Lp}$



In the linear case we can solve for $v_{Lp}(v_{np})$:

$$\mathbf{F}_{MF} = \rho_n \Big(\mathcal{B}_c \, \boldsymbol{\omega}_n \times \mathbf{v}_{np} + \mathcal{B}_d \, \hat{\boldsymbol{\omega}}_n \times \big(\boldsymbol{\omega}_n \times \mathbf{v}_{np} \big) \Big) \, .$$

Microscopic Drag Force

The drag force felt by the vortices can be computed through the energy dissipated in the system. There are several mechanisms, and each of them is expected to be dominant for different $|\mathbf{v}_{Lp}|$ regimes:

- Vortex Kelvin excitations due to interaction with nuclei (crust)[1]: $\mathcal{R} \propto |v_{Lp}|^{-3/2}$
- Phonon excitations in the nuclei lattice (crust)[2]: $\mathcal{R} = const$
- Vortex Kelvin excitations due to interaction with proton flux tubes (core)[3]: $\mathcal{R} \propto |v_{Lp}|^{-3/2}$
- Isotropic quantum turbulence[4]: $|f_D| \propto |v_{Lp}|^3$

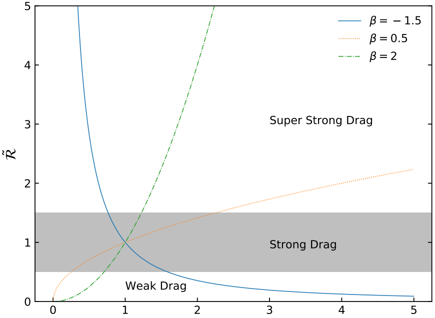
[1]Epstein, R.I. and Baym, G., Ap.J. , 387-276
[2]P.B.Jones, MNRAS,243-257
[3]Link, B., Phys.Rev.Lett. 91, 101101
[4]Andersson et al., MNRAS 381-747

Non-Linear Mutual Friction

For a glitch rigid model we only need the angular momentum transfer rate $\mathcal{B}_{MF}$. This cannot be solved in general but must be computed at each step of integration.

$$v^x_{Lp} = \frac{\tilde{\mathcal{R}}}{1+\tilde{\mathcal{R}}^2} v^\varphi_{np} = \mathcal{B}_{MF}\, v^\varphi_{np}$$

Simple Power Law drag:



- hydro interpretation $\beta > 0$
- transition between two regimes

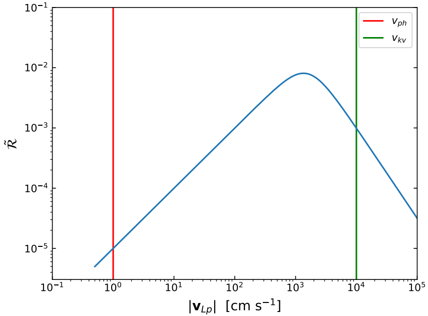
$$\tilde{\mathcal{R}} = \left(\frac{|\mathbf{v}_{Lp}|}{v_0}\right)^\beta \mathcal{R}$$

$$\beta_{12} = \frac{\log(\mathcal{R}_2/\mathcal{R}_1)}{\log(v_2/v_1)}$$

Realistic Model for the crust

With the simple case above one cannot consider typical powers relevant for the kelvonic drag case: we introduced a simple interpolation for the drag profile.

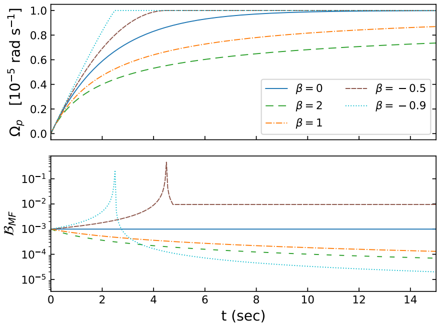
Realistic Model for the crust:



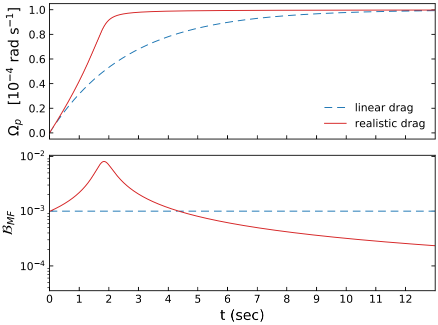
$$\tilde{\mathcal{R}} = \left(\mathcal{R}_1^{-1} \left(\frac{v_{Lp}}{v_{ph}} \right)^{-1} + \mathcal{R}_2^{-1} \left(\frac{v_{Lp}}{v_{kv}} \right)^{\frac{3}{2}} \right)^{-1}$$

- high lags $v_{Lp} \geq 10^3$ cm/s : kelvonic drag
- small lags $v_{Lp} \approx 10$ cm/s : phonon drag

Glitch Rise Times



Simple power law Drag

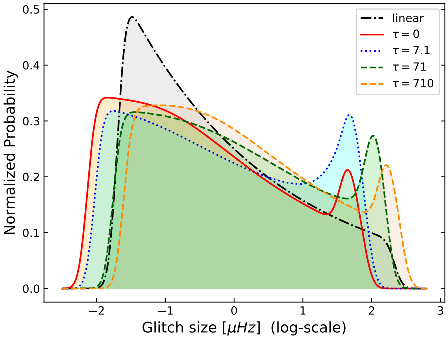


Realistic Model

$$\dot{\Omega}_n = -2\mathcal{B}_{MF}\Omega_n\left(\Omega_n - \Omega_p\right)$$

$$x_p\,\dot{\Omega}_p + x_n\,\dot{\Omega}_n = -\alpha$$

Glitch Size Distributions



Because the initial lag is uncertain, and the frequency evolution of the model is fully determined by that, we have studied the glitch size distribution for the realistic model. With an initial lag power-law distribution, we are able to reproduce the observed bi-modal one.

Thank You