Glitch recovery and rotational equilibrium in pulsars

Aspen

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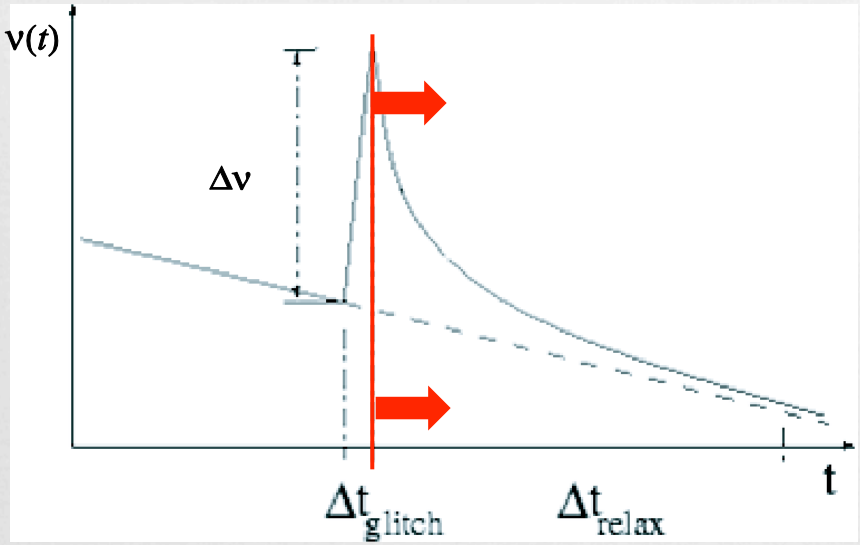
NORDITA

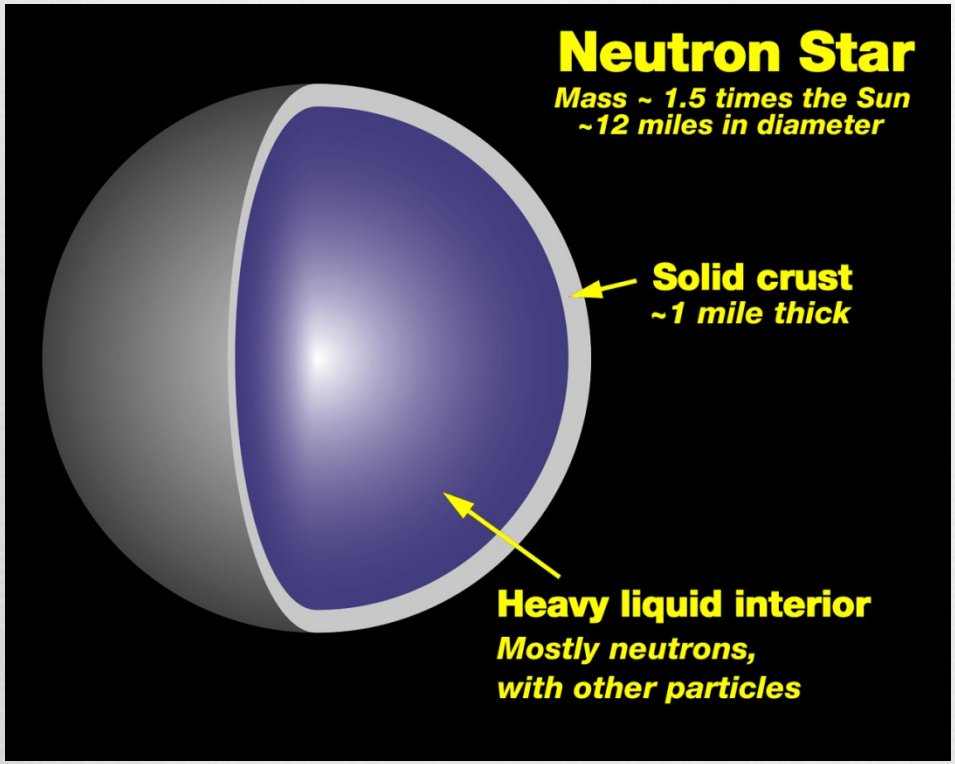
Glitch recovery



- Two stages:
  - Spin up (< minute)
  - Recovery (~days to weeks to ??)

- Interested in long term behavior (recovery)
- What can we learn about the interior?

Hydrodynamic recovery models



Crust

Viscosity, $\nu^{-1}E^{-1/2}$

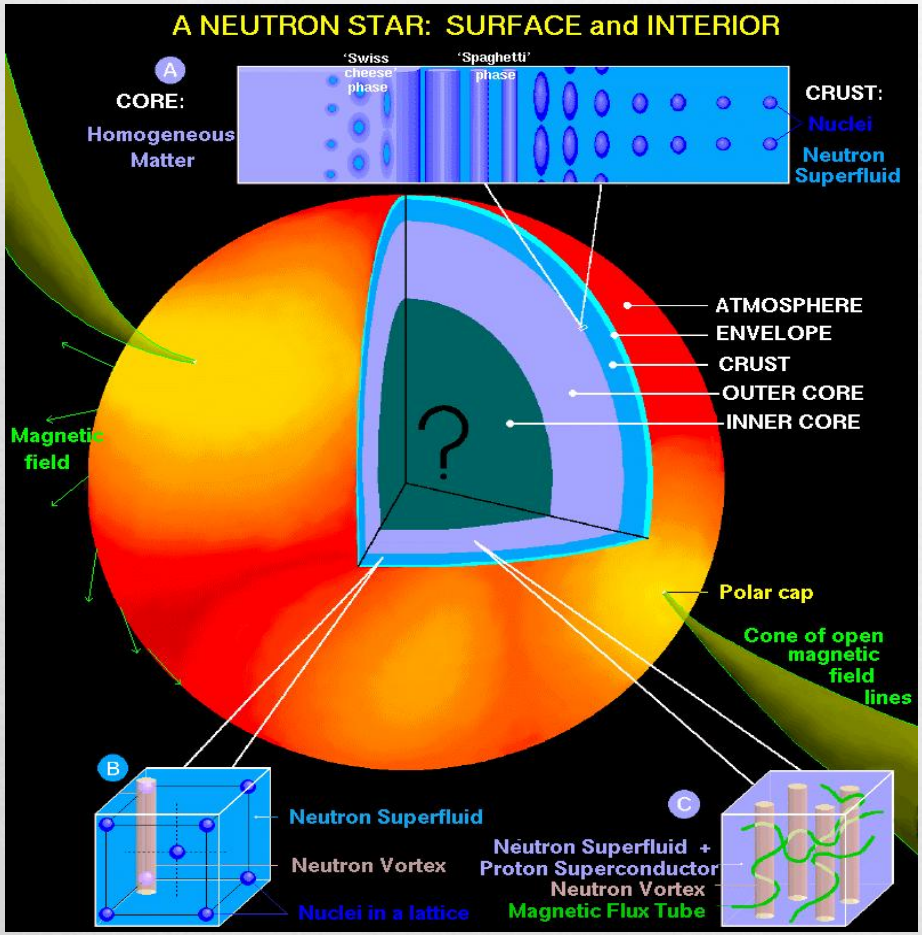
Magnetic field

Viscous fluid
(e.g. Proton-electron plasma)

Mutual friction, $\nu^{-1}B^{-1}$

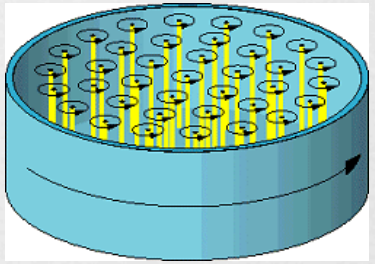
Inviscid fluid
(e.g. Neutron condensate)

Vortex physics



- Vortices

  -> mutual friction



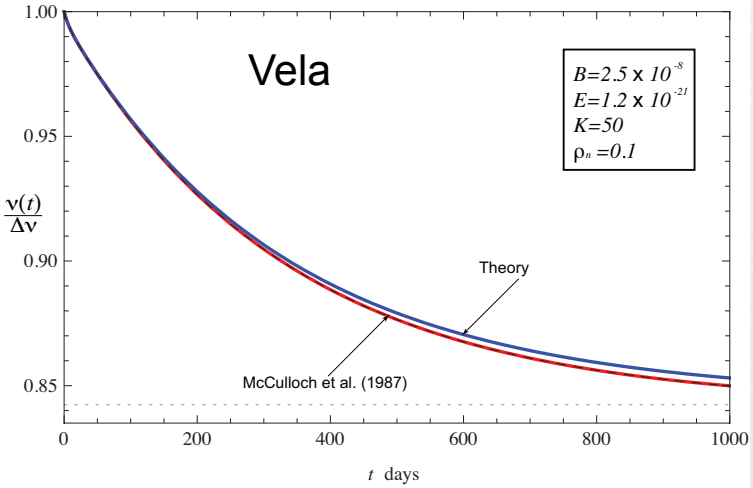
- Pinning

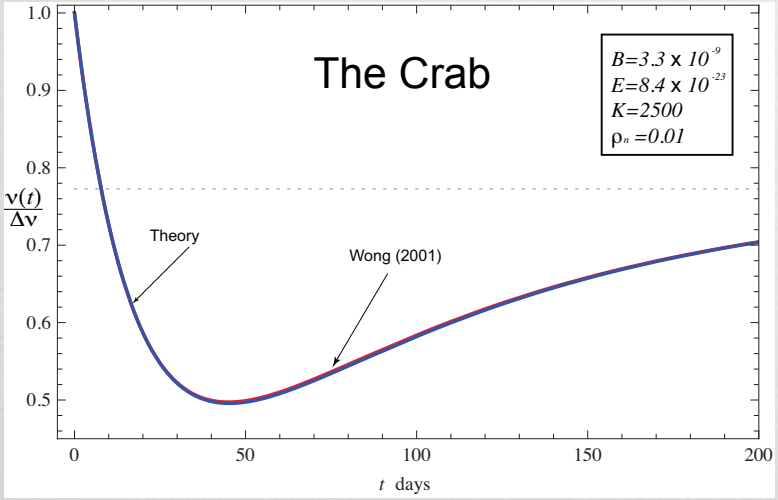
  -> thermal creep (Link 2012)

$$B \propto e^{-A(1-\Delta\omega/\Delta\omega_c)/T}$$

Fitting to timing data

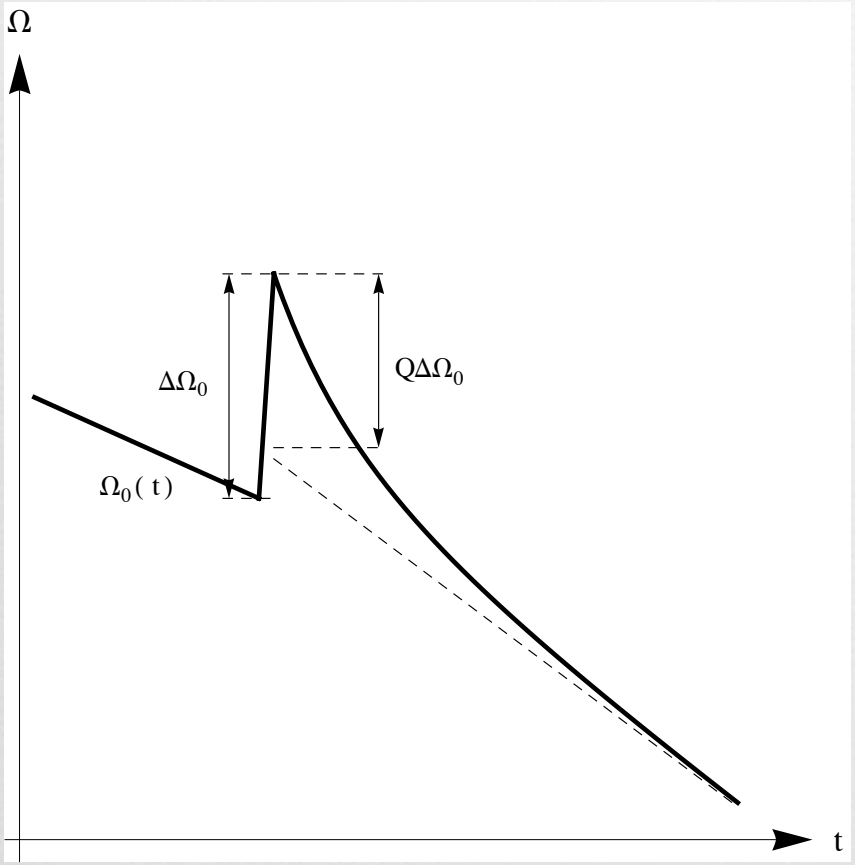
(van Eysden & Melatos 2010)





- Can extract nuclear parameters
  - Viscosity (E)
  - Mutual friction (B)
  - Crust Fraction (K)
  - Charged component density fraction (ρ_n)
- Model also sheds light on recovery physics
  - Quasi exponential
  - Overshoot

Challenges for hydrodynamic models

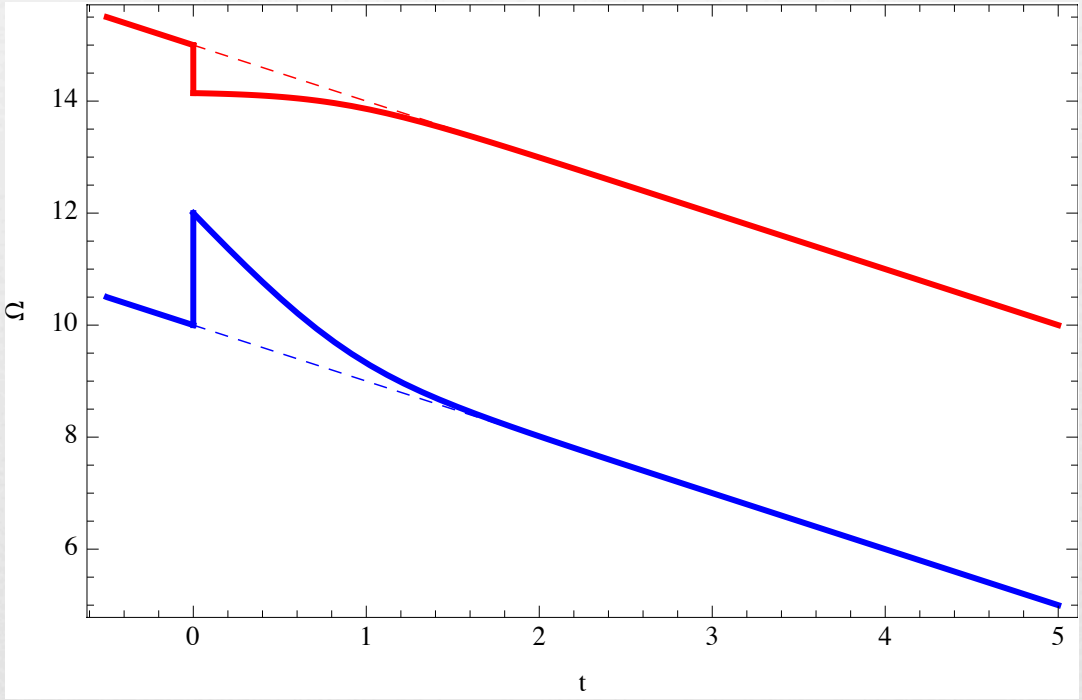


- Recovery typically fitted to

$$\nu(t) = \sum_n \Delta\nu_n e^{-t/t_n} + \Delta\nu_p + \Delta\dot{\nu}_p\, t$$

- Permanent increase in frequency and frequency derivative

Theory (Link 2012)



- Hydrodynamic models always recover completely!
- Q always unity!

Superfluid reservoir?

- Part of the star decoupled during spin-down
- Injects angular momentum during glitch (permanent increase in frequency)
- Increases moment of inertia (permanent increase in frequency derivative)
- But what is this component?

No rotational equilibrium?

- Glitches never recover completely?

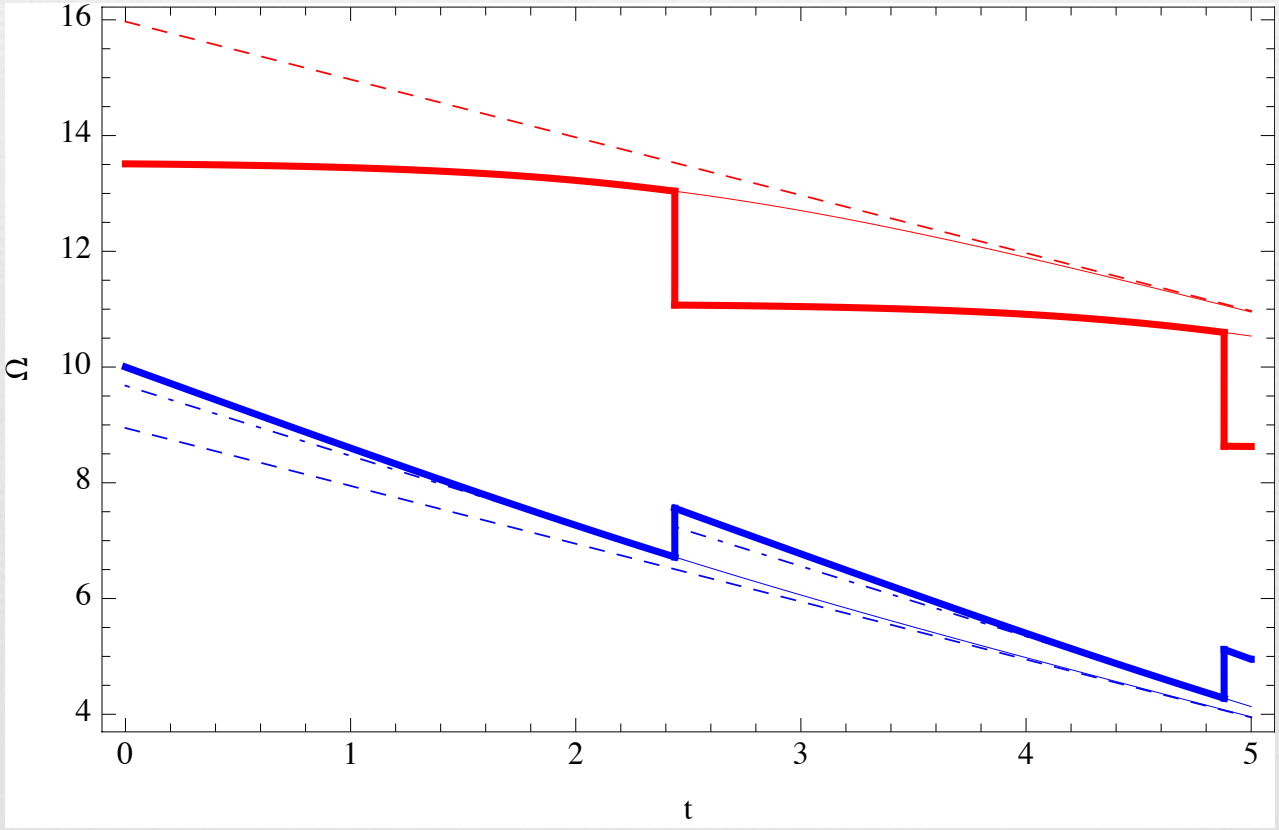
Glitch	Date	MJD	CM	t_4	t_3	t_2	t_1	$\Delta\nu_4$	$\Delta\nu_3$	$\Delta\nu_2$	$\Delta\nu_1$	$\Delta\nu_p$	$\Delta\nu$	Ref.
					d						μHz			
1	28-Feb-1969	40280				10	120			0.052	0.467	25.6	26.2	1
2	29-Aug-1971	41192				4	94			0.036	0.30	22.6	22.9	1
3	09-Sep-1975	42664				4	35			0.01	0.079	22.2	22.2	1
4	13-Jul-1978	43693				6	75			0.083	0.389	33.8	34.3	1
5	10-Oct-1981	44888				6	14			0.01	0.024	12.7	12.7	1
	10-Oct-1981	44889				1.6	233			0.092	2.26	10.5	12.8	2
6	10-Aug-1982	45192				3	21.5			0.057	0.126	22.8	23.0	1
	10-Aug-1982	45192				3.2	60			0.23	0.79			2
7	12-Jul-1985	46258				6.5	332			0.066	2.76			2
	12-Jul-1985					6.8				0.165				3
8	24-Dec-1988	47519	*		0.4	4	96		0.108	0.086	0.376	19.7	20.2	4
	24-Dec-1988	47520	*		0.73	6.97	707		0.092	0.083	6.74	13.3	20.2	5
9	20-Jul-1991	48458	*		0.56	5.94	254		0.255	0.169	2.84			5
	20-Jul-1991		*		0.59	4.9	49		0.317	0.152	0.231			3
10	26-Jul-1994	49560	*									9.6	9.6	5
	26-Jul-1994		*											3
11	27-Aug-1994	49592	*			1.59	15			0.024	0.027	2.1	2.2	5
	27-Aug-1994		*			6					0.032			3
12	13-Oct-1996	50370					916				14.8	9.1	23.9	6
13	16-Jan-2000	51559	*	0.0008	0.53	3.29	19	0.02	0.31	0.193	0.236	34.5	35	7
14	07-Jul-2004	53193	*	0.0007	0.23	2.1	26.14	54	0.21	0.13	0.16	22.8	77.3	8

[1] (Cordes et al. 1988), [2] (McCulloch et al. 1987), [3] (Flanagan 1996), [4] (Flanagan 1990), [5] (McCulloch 1996)
[6] (Wang et al. 2000), [7] (Dodson et al. 2002), [8] (Dodson et al. 2007)

Q=0.024

Q=0.34

Non-equilibrium model



- Gives apparent non-zero Q

Questions

- Is the ‘permanent change’ in frequency and derivatives an artifact of fitting the data?
- Is there a need for a reservoir?
- How do you get such long recovery times?

Conclusions

- Need to take a careful look at recoveries – are pulsars in rotational equilibrium between glitches?
- Vela shows quasi-periodic behavior – ‘reservoir recycling’? Special case?
- Input welcome!