Pulsars spin-up:
a semi-analytical approach

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PoD workshop

Neutron stars

Figure 1: NASA/CXC/SAO; Optical: NASA/STScI; Infrared: NASA-JPL-Caltech

A **Neutron star** is a dense core left behind after a massive star goes supernova and explodes.

- Radius $\sim$ 10km
- Mass $\sim (1.3 - 3)M_{\odot}$
- High densities $\sim 10^{15}\mathrm{g/cm^3}$

Neutron stars

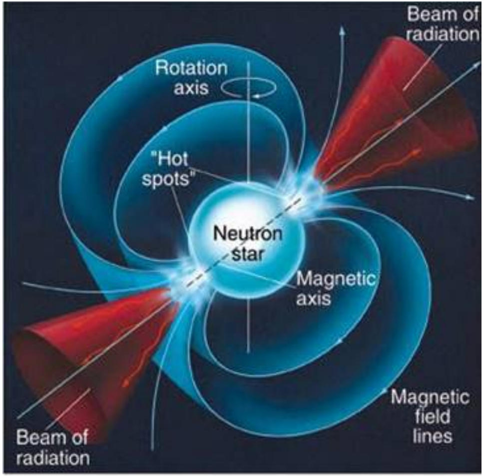


Figure 2: Illustration of a neutron star

As the neutron star rotates, it **spins down** due to emission of electromagnetic radiation.

Dipole model emission:

$$\dot{\Omega} \propto B^2 \Omega^3$$

$$B \propto e^{-\Delta t/\tau}$$

Spin-down

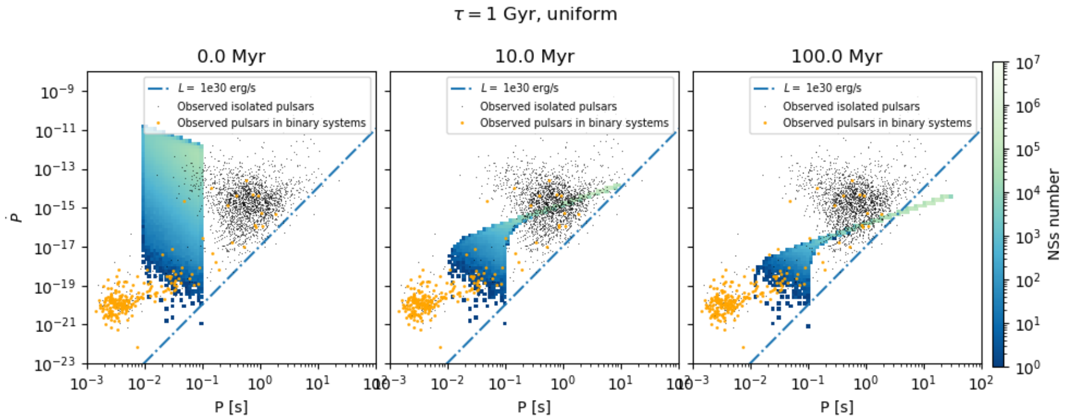
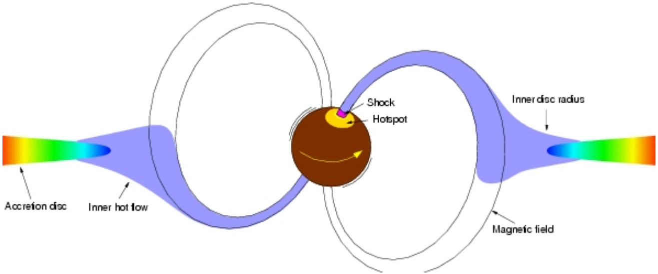


Figure 3: Pulsars spin-down
Observed pulsars from the ATNF catalog [Manchester et al., 2005]

Spin-up



During Roche lobe overflow (RLO) the infalling matter carries angular momentum that can **spin-up** the pulsar.

$$\dot{J} = V_{diff} R_A^2 \dot{M}_{NS}$$

$$V_{diff} = \Omega_K - \Omega_{NS}$$

$$B \propto e^{-\Delta M_{NS}/\Delta M_d}$$

Stellar EVolution N-body

Population synthesis code written in C++

Stellar evolution

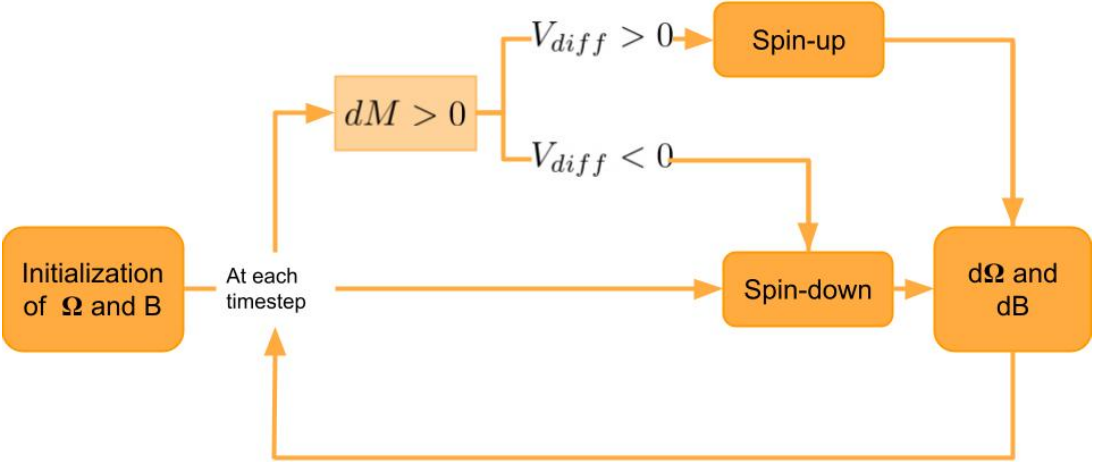
interpolation of precomputed stellar tracks

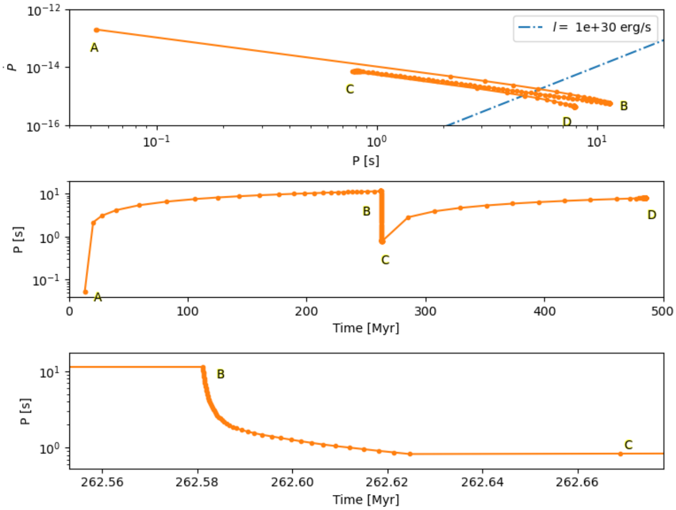
Binary processes

analytical and semi-analytical models

[Mapelli et al., 2020, Spera and Mapelli, 2017, Spera et al., 2019]

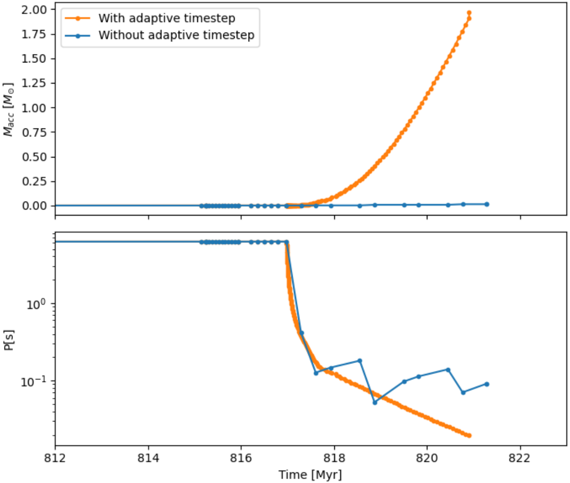
Spin evolution implementation in SEVN





- **A.** Formation of the first Neutron Star
- **B.** Roche Lobe Overflow event
- **C.** End of Roche Lobe Overflow
- **D.** Formation of the second compact object

Adaptive timestep

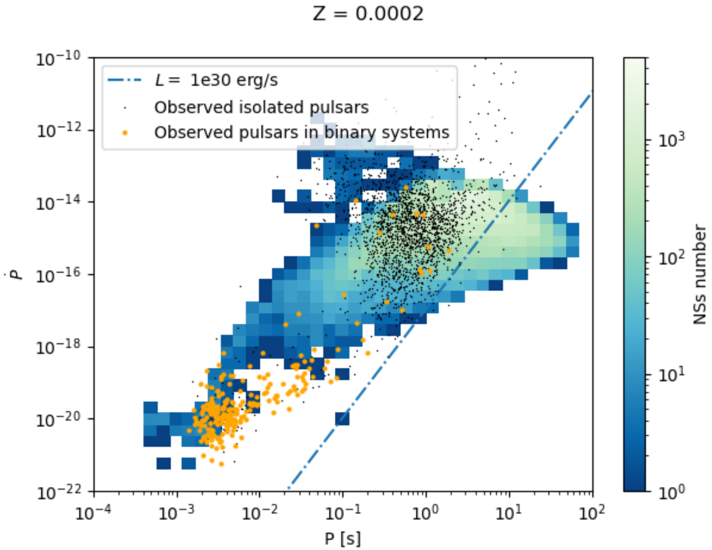


Adaptive timestep

$\longrightarrow$ timestep is set such that Ω_{NS} varies $< 5\%$

Without adaptive timestep:

- Unstable solution
- Propeller effect halt accretion



- Spin-up allows to populate the region of the millisecond pulsars
- Adaptive timestep to guarantuee convergence

Figure 4: Observed pulsars from the ATNF catalog [Manchester et al., 2005]

Backup

Spin-down

$$\dot{\Omega} = \frac{8\pi B^2 R^6 \sin^2(\alpha)\Omega^3}{3\mu_0 c^3 I} \tag{1}$$

$$B = (B_0 - B_{min})e^{-\Delta t/\tau} + B_{min} \tag{2}$$

Spin-up

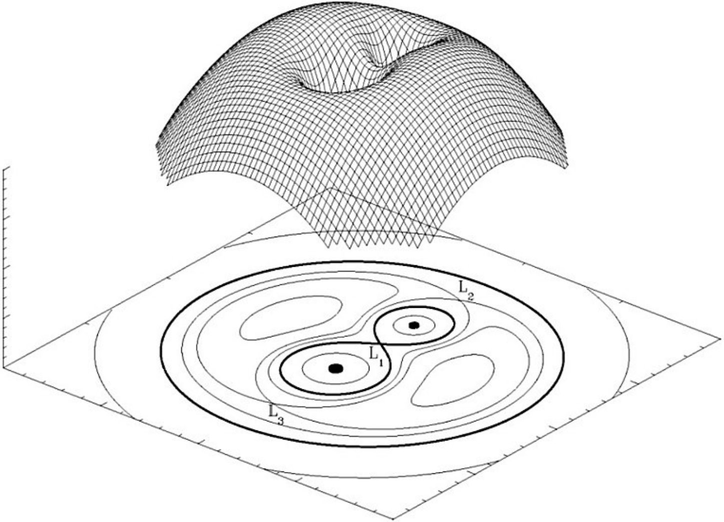
$$\dot{J} = V_{diff} R_A^2 \dot{M}_{NS} \tag{3}$$

$$V_{diff} = \Omega_K - \Omega_{NS} \tag{4}$$

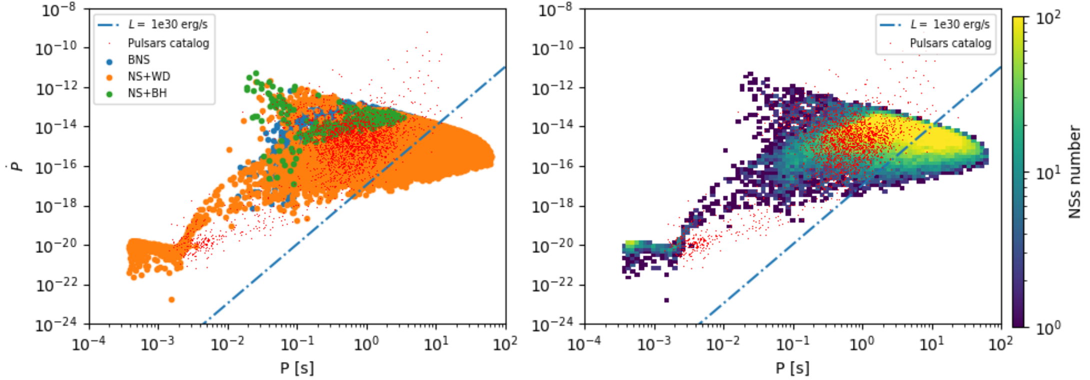
$$B = (B_0 - B_{min})e^{-\Delta M_{NS}/\Delta M_d} + B_{min} \tag{5}$$

$$R_{Alfven} = \left(\frac{2\pi^2}{G\mu_0^2}\right)^{1/7} \left(\frac{R^6}{\dot{M}_{NS} M_{NS}^{1/2}}\right)^{1/7} B^{4/7} \tag{6}$$

Roche-Lobe potential



Z = 0.02



References

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