Effect of supernova asymmetry on the coalescence rate of binary neutron stars

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Outline

- Alignment of spin axis and space velocity of young pulsars
- Effect of the spin-kick velocity alignment on the binary NS coalescence rate
- Distribution of angles between NS spin axes and orbital angular momentum (important for GW templates (Apostolatos et al. 1996, Apostolatos 1996))
Pulsar velocity – spin axis alignment

- $<50^\circ$ spin-kick alignment follows from radio pulsar polarization measurements (Johnston et al. 2005, 25 pulsars; also Wang et al. 06)

- $\sim 10^\circ$ alignment is apparent from X-ray morphology of pulsar wind nebulae around young Vela-like radio pulsars (Helfand et al. 01, Kargaltsev et al 07, $\sim 10$ PWNe)
Vela pulsar in X-rays

Pulsar velocity
Morphology of pulsar wind nebulae

- Young (10-30 kyr) Vela-like pulsars with PWNe
- X-rays from toroidal termination shocks
- Chandra ASI observations (Kargaltsev et al. 2007, astro-ph/0611599)
**NS kick velocity**

1. **Neutrino asymmetry in strong magnetic field** (Fryer & Kusenko 06)

2. **Hydrodynamics of neutrino convection and/or fallback** (Burrows & Hayes 96, Scheck et al. 04, 06 (2D))

3. **Magnetorotational SN explosion** (Ardeljan, Bisnovaty-Kogan, Moiseenko 04-06)

4. **Rotational collapse with stellar core fission to double NS and explosion of the lightest NS** (Imshennik et al. 1992-2007; SN 1987A two neutrino signals?)

5. **Random multiple kicks** (Spruit & Phinney 98, Wang et al 06)

   5 yields no preferential spin – velocity angle; 1,2,3 favors spin-kick alignment; 4 suggests
Kick velocity model

- Central kick (no torque) (Spruit & Phinney 98, Ng & Romani 07)
- Randomly distributed inside the cone with polar angle $\theta$
- Maxwellian $f(v) \sim v^2 \exp\left(-\frac{v^2}{v_0^2}\right)$
Double NS formation scenario

- Standard scenario of double NS formation (e.g. Tutukov, Yungelson, van den Heuvel, etc. 1973-2007)
- Standard common envelope treatment
- No hypercritical accretion onto NS
- Evolution of magnetized NS is taken into account (Lipunv, Postnov, Prokhorov 87, 96)
Galactic DNS merging rate for isotropic kick

- NS from $30 > M > 8 \, M_\odot$
- Random Maxwellian kick
- Stationary galactic SFR $= 3 \, M_\odot \, \text{/yr}$
- Salpeter IMF $dN/dM \sim M^{-1.35}$
Relative DNS merging rates for anisotropic kicks
NS spin-orbit misalignment

Accretion induced alignment
$V = 100 \text{ km/s}$
$V=200 \text{ km/s}$
V=400 km/s
Misalignment constraints from geodetic precession in binary pulsars

- **PSR 1913+16** old NS, ms PSR $\Psi \sim 20^0$ (Weisberg & Taylor 02)

- **PSR B1534+12** old NS, ms PSR $\Psi \sim 25^0$ (Stairs et al. 04)

- **PSR J0737-3039A** old NS, ms PSR $0^0 < \Psi < 60^0$ (Manchester et al. 05)

- **PSR J0737-3039B** young PSR $\Psi \sim 0^0$ ? (Burgay et al. 05)

- **Note:** Spin-orbit misalignment may be reduced by PSR wind interaction (as in case of PSR J0737-3039 double pulsar system, e.g. Arons et al. 05, Demorest et al. 04)
Conclusions

- Observational evidence for spin-space velocity alignment in young single radio pulsars suggests natal NS spin - kick velocity alignment.

- Strong kick alignment reduces expected binary NS merging rate by up to 10 times and produces specific distribution of spin-orbit misalignment angles.

- Spin-orbit misalignment complicates binary NS coalescing GW templates and should be taken into account.