

Suppression of superkicks in BBH inspiral

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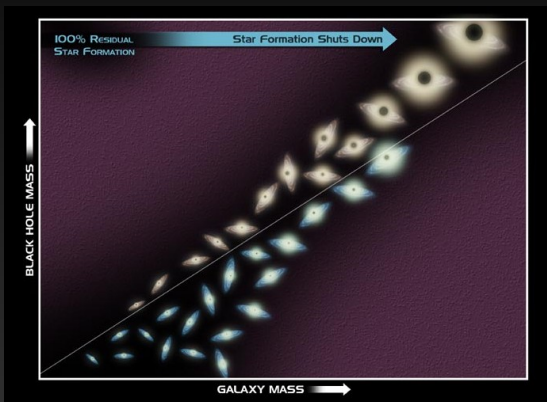
IV Black Holes Workshop, 20th December 2011

E. Berti, M. Kesden



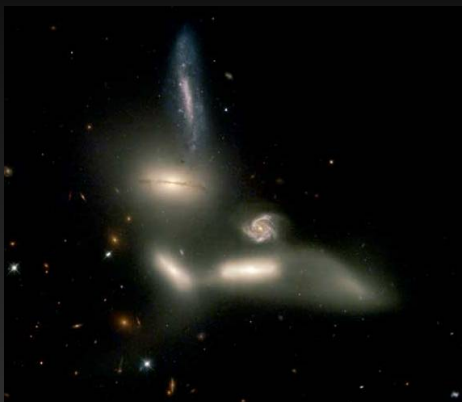
Introduction

- Galaxies ubiquitously harbor BHs
- BH properties correlated with bulge properties
e. g. J.Magorrian *et al.*, AJ 115, 2285 (1998)



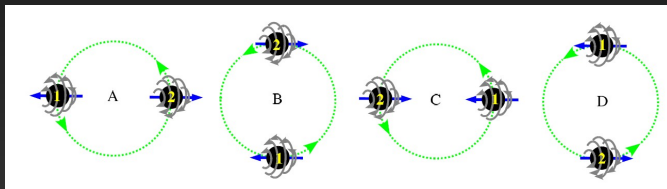
Introduction

- Most widely accepted scenario for galaxy formation: hierarchical growth; “bottom-up”
- Galaxies undergo frequent mergers, especially elliptic ones

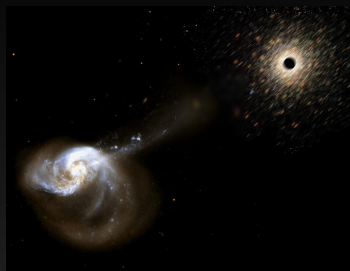


Superkicks

- Numerical relativity breakthroughs in 2005
Pretorius, PRL 95, 121101 (2005)
Campanelli, Lousto, Marronetti & Zlochower, PRL 96, 111101 (2006)
Baker, Centrella, Choi, Koppitz & van Meter, PRL 96, 111102 (2006)
- NR now able to accurately calculate kicks
- **Superkicks**: up to several 1000 km/s
González, Hannam, Sperhake, Brüggmann & Husa, PRL 98, 231101 (2007)
Campanelli, Lousto, Zlochower & Merritt, ApJ 659, L5 (2007)
- $>$ escape velocities from giant galaxies!



Ejection/displacement of SMBHs possible



- Doppler shifts of BLR vs. NLR: 2,650 km/s
Komossa *et al.*, ApJ 678, L81 (2008)
- Isophotal analysis of M87: central BH displaced
Betcheldor *et al.*, ApJ 717, L6 (2010)
- **Still:** Virtually every E galaxy observed has a BH!

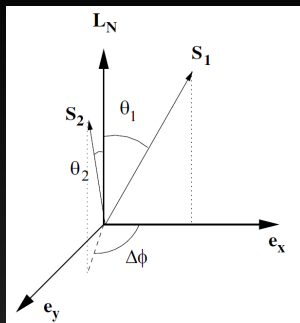
Possible explanations

- Superkicks are a relatively special configuration
 $q = \frac{1}{10} \dots 1$ EOB study $\Rightarrow \sim 10\%$ of kicks $\gtrsim 500 \dots 1000$ km/s
Schnittman & Buonanno, ApJ 662, L63 (2007)
- Torques from accreting gas can align \vec{S} with \vec{L} : $10\dots 30^\circ$
Bogdanović, Reynolds & Miller, ApJ 661, L147
Dotti *et al.*, MNRAS 402, 682 (2010)
- Efficiency depends on accretion flow and sufficient gas
- **New mechanism** to suppress superkicks:
GW driven inspiral aligns \vec{S}_1 and \vec{S}_2 provided more massive BH is partially aligned.
Kesden, Sperhake & Berti, PRD 81, 084054 (2010)
Kesden, Sperhake & Berti, ApJ 715, 1006 (2010)

Framework

- PN equations of motion for precessing, qc BBHs
Kidder, PRD 52, 821 (1995)
- Quadrupole-monopole interaction
Poisson, PRD 57, 5287 (1997)
- Spin-spin interaction
Mikoczi, Vasuth & Gergely, PRD 71, 124043 (2005)
- Adaptive stepsize integrator STEPPERDOPR5
- PN evolution from $R = 1000 M$ on; sub-parsec scale
- Guided by resonances which act on timescales $\gg t_p$
Schnittman, PRD 70, 124020 (2004)

Spin-orbit resonances; Schnittman (2004)



- Configurations for which L_N , S_1 , S_2 precess at same frequency
- One parameter family of solutions; R
- θ_1 , θ_2 , $\Delta\phi$ remain fixed on precession time scale t_p
- These solutions have either $\Delta\phi = 0^\circ$ or $\Delta\phi = 180^\circ$

Evolution in θ_1, θ_2 plane for $q = 9/11$

$$\theta_1 := \angle(\vec{S}_1, \vec{L}_N)$$

$$\theta_2 := \angle(\vec{S}_2, \vec{L}_N)$$

$$\theta_1 = \theta_2$$

$$\vec{S} \cdot \vec{L}_N = \text{const}$$

$$\vec{S}_0 \cdot \vec{L}_N = \text{const}$$

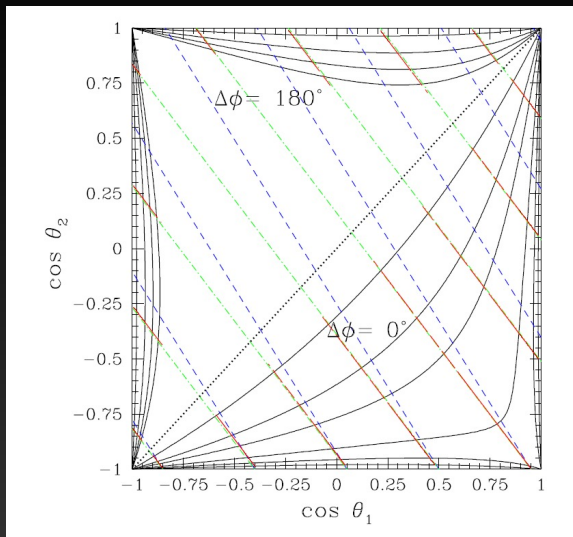
evolution

\Rightarrow BHs approach

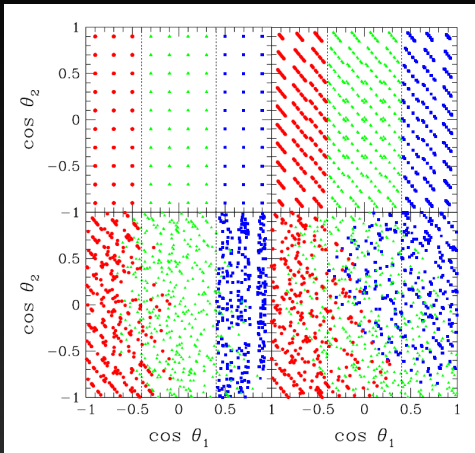
$$\theta_1 = \theta_2$$

$\Rightarrow \vec{S}_1, \vec{S}_2$ align

if θ_1 small

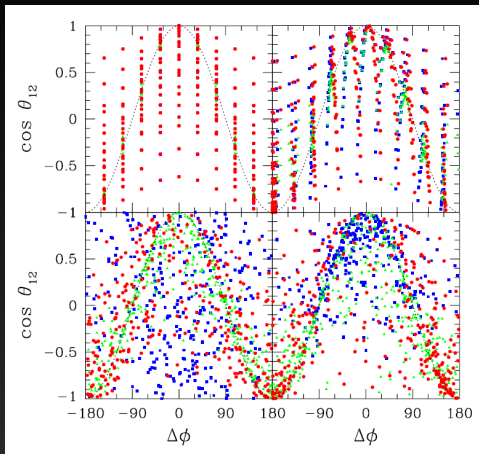


Distributions in θ_1, θ_2 plane at different R



- Isotropic $10 \times 10 \times 10$ grid of configurations
- At $R = 1000 M + \epsilon, 1000 M, 100 M, 10 M$

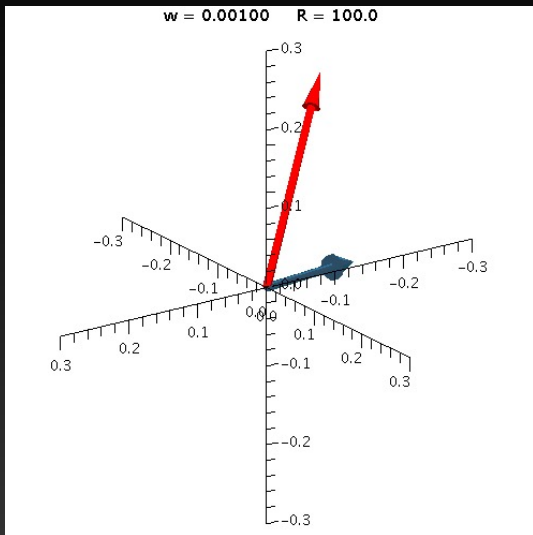
Distributions in θ_{12} , $\Delta\phi$ plane at different R



- Isotropic $10 \times 10 \times 10$ grid of configurations
- At $R = 1000 M + \epsilon$, $1000 M$, $100 M$, $10 M$

Time evolution of \vec{S}_1, \vec{S}_2

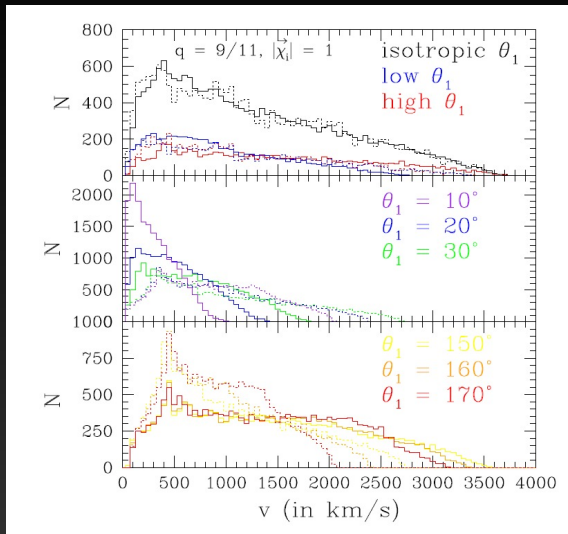
$$q = \frac{9}{11}, \theta_1 = 10^\circ, \theta_2 = 154^\circ, \Delta\phi = 264^\circ$$



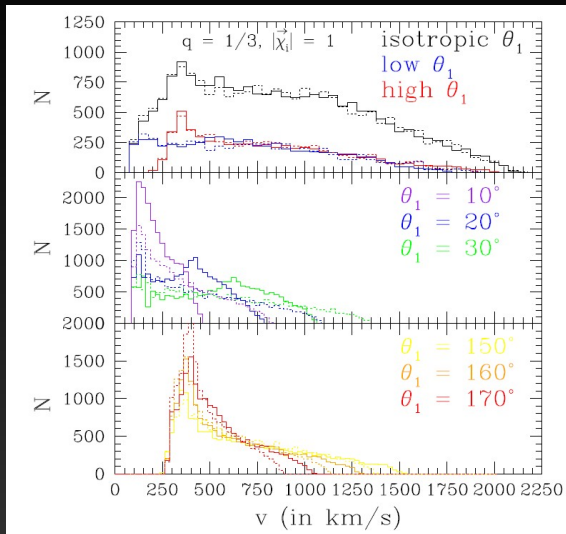
Calculation of kick

- **Ensemble 1:** $10 \times 10 \times 10$ in $\theta_1, \theta_2, \Delta\phi$
- **Ensemble 2:** $\theta_1 = 10^\circ, 20^\circ, 30^\circ$ with 30×30 in $\theta_2, \Delta\phi$
- **Ensemble 3:** $\theta_1 = 150^\circ, 160^\circ, 170^\circ$ with 30×30 in $\theta_2, \Delta\phi$
- Spin evolution gives us $\vec{S}_1, \vec{S}_2, \vec{L}$ at any time
- Use **kick formula** by RIT or Goddard group
Campanelli, Lousto, Zlochower & Merritt, ApJ 659, L5 (2007)
Baker *et al.*, ApJ 682, L29 (2008)
 $\Rightarrow v_{\text{kick}}(r)$
- Compare **kick distribution** with and without PN inspiral

Kick distributions with and without PN inspiral $q = \frac{9}{11}$



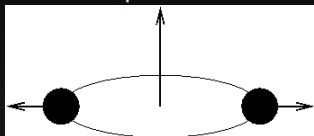
Kick distributions with and without PN inspiral $q = \frac{1}{3}$



Even larger kicks: superkick and hang-up

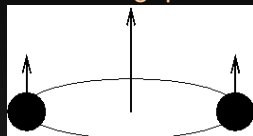
Lousto & Zlochower, arXiv:1108.2009 [gr-qc]

Superkicks

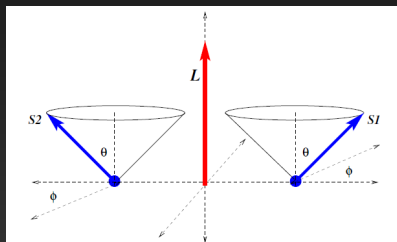


- Moderate GW generation
- Large kicks

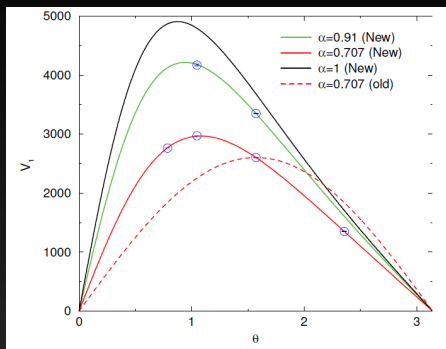
Hangup



- Strong GW generation
- No kicks

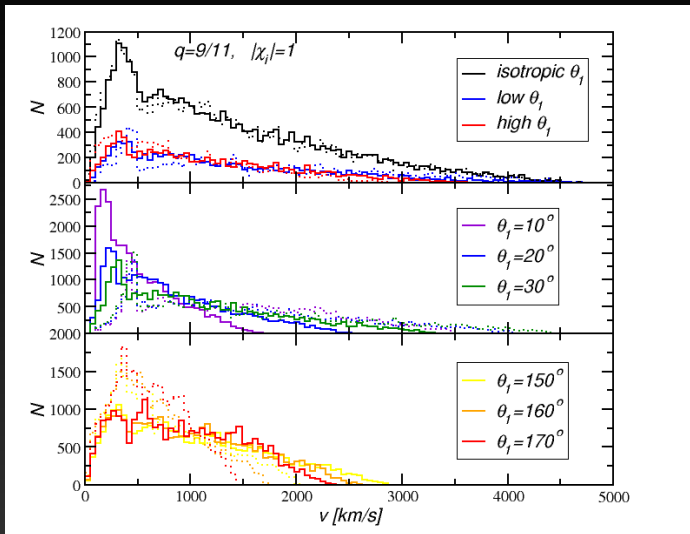


Superkicks and orbital hang-up



- Maximum kick about 25 % larger: $v_{\max} \approx 5000$ km/s
- Distribution asymmetric in θ
- Largest recoil for **partial alignment**

Kick distributions with and without PN inspiral $q = \frac{9}{11}$



Conclusions

- GW driven inspiral on subparsec scale aligns (anti aligns) \vec{S}_1, \vec{S}_2 if more massive BH initially partially aligned (anti aligned) with \vec{L}_N
- This is true for resonance **and** non-resonance binaries!
- Resonances attract aligned (anti aligned) configurations towards $\Delta\phi = 0^\circ$ (180°)
- Accretion torque will partially align \vec{S}_1 with \vec{L}_N
- \Rightarrow spin alignment likely to dominate
- The GW driven alignment substantially suppresses superkicks
- Reconciles superkicks with observation of SMBHs in galaxies
- Superkick suppression still efficient for **hang-up kicks**