

WE DO NOT KNOW
what drives black hole spins
in binary black hole mergers detected via gravitational waves?

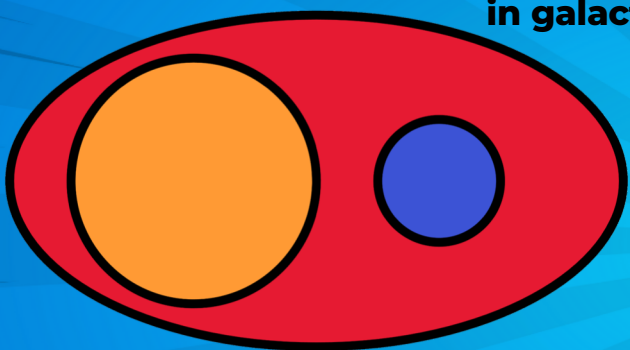
Vishal Baibhav
Columbia University

LIGO-Virgo-Kagra have detected

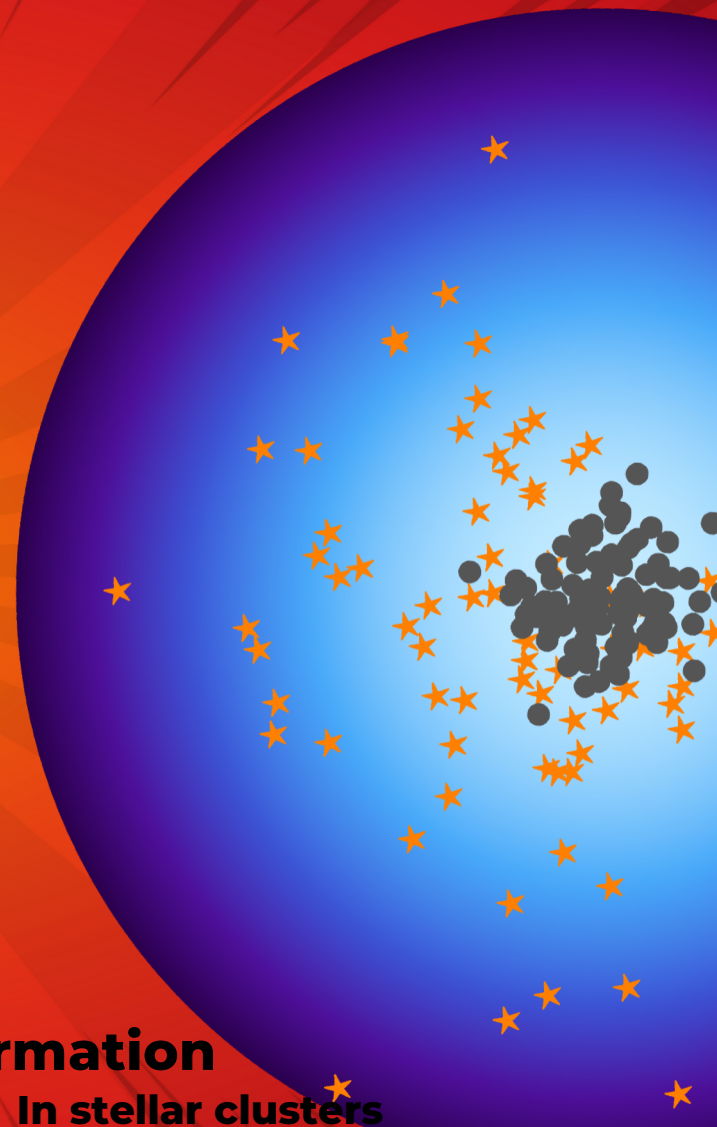
90 mergers

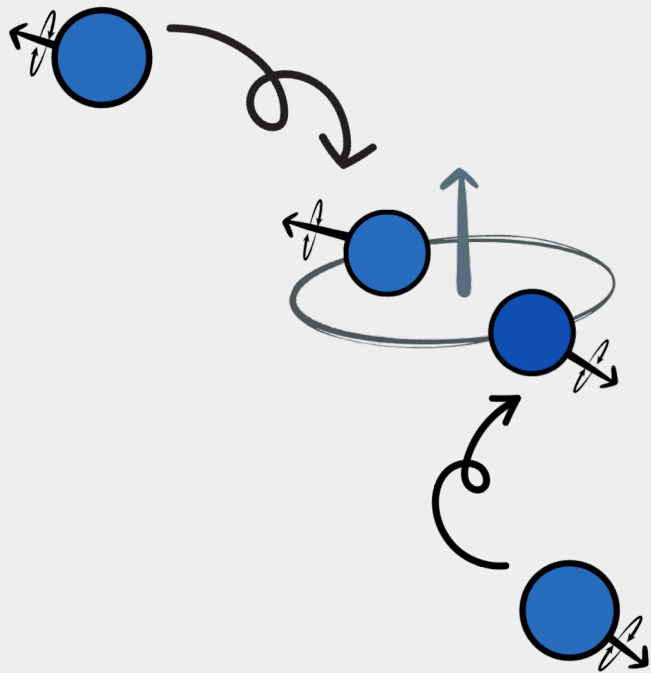
involving black holes and neutron stars

Isolated binary evolution
in galactic fields

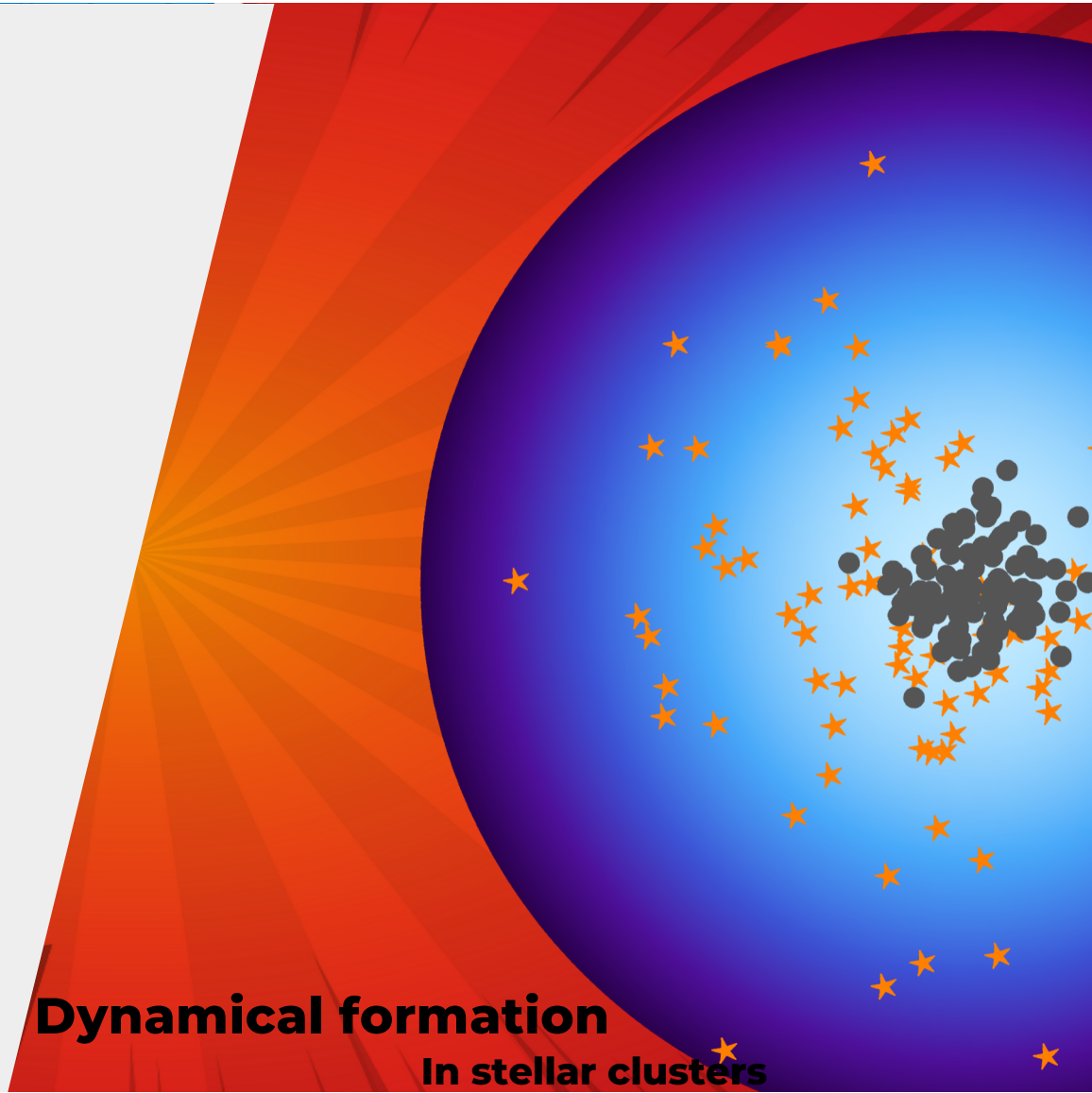


Dynamical formation
In stellar clusters

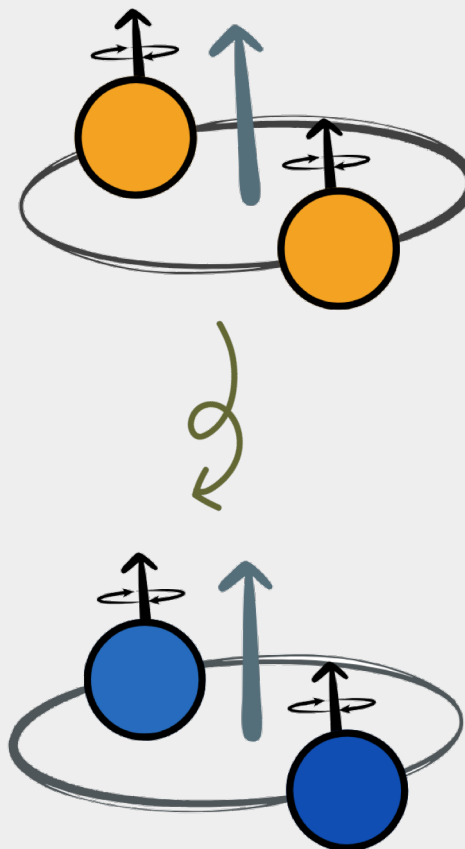
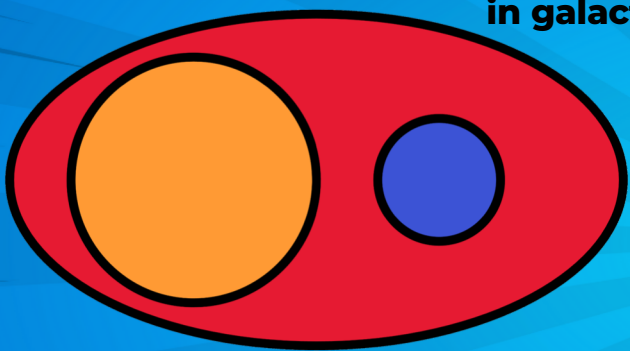




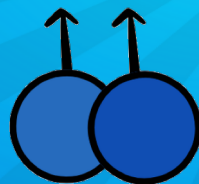
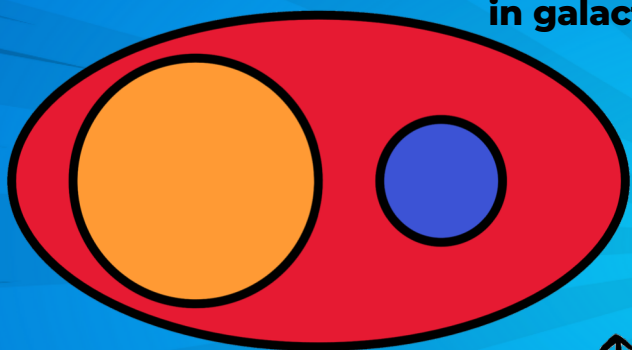
Dynamical formation
In stellar clusters



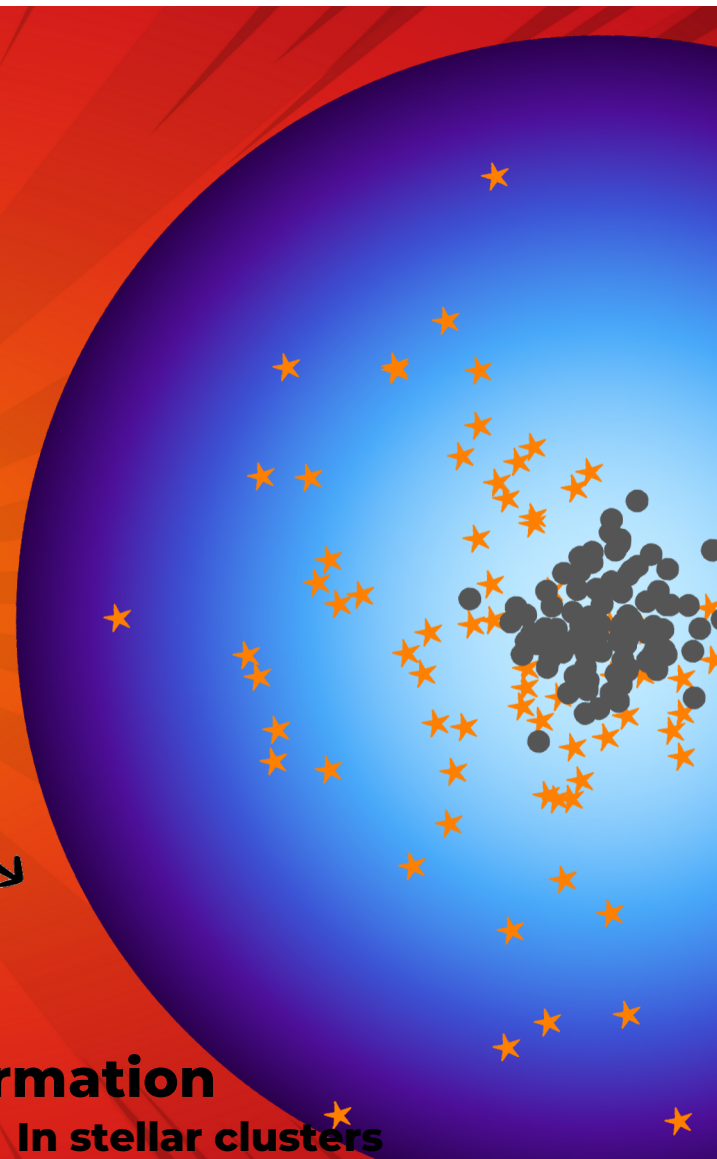
Isolated binary evolution in galactic fields



Isolated binary evolution
in galactic fields



Dynamical formation
In stellar clusters



Conclusion



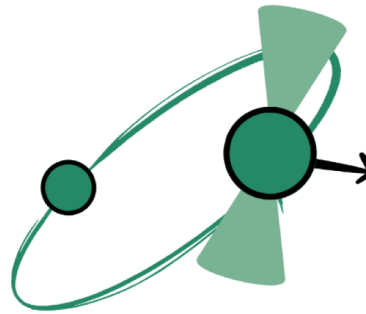
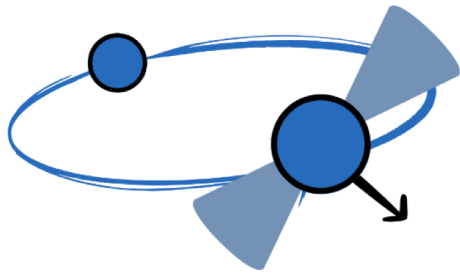
Only dynamical environments can produce highly misaligned binaries



NO

Problem 1.

EM observations do not support the popular theory



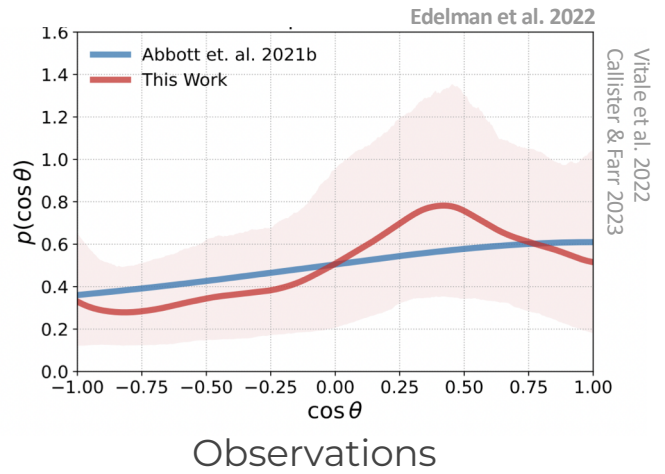
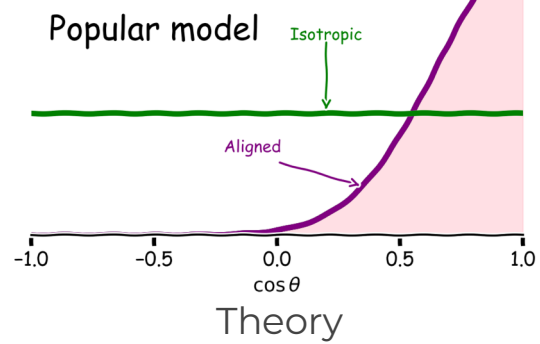
PSR J0737-3039: $130 \pm 1^\circ$
PSR J1906+0746: $104 \pm 10^\circ$
PSR J1141-6545: $38^\circ \pm 13$, $150 \pm 20^\circ$
MAXI J1820+070: 42° , 63° , 117° , 138°

Breton et al. 2008
Desvignes et al. 2019
Krishnan et al. (2019)
Poutanen et al. (2022)

Compact objects in isolated binaries
do not have spins aligned with orbital angular momentum

Problem 2.

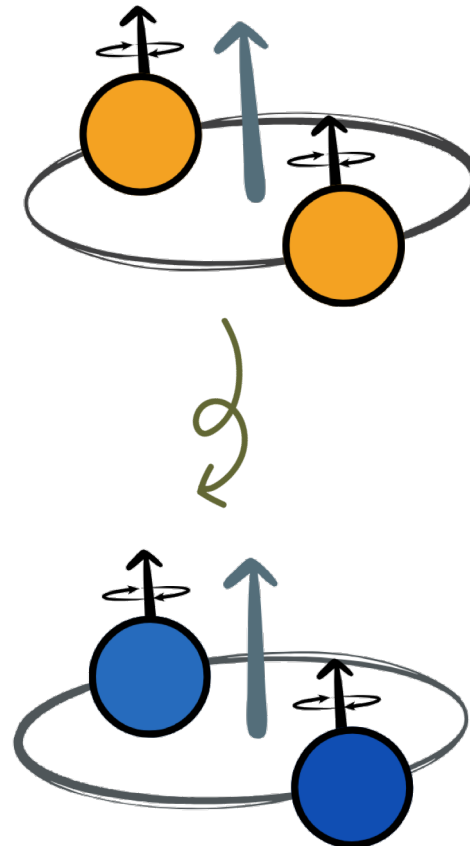
GW observations do not support the popular theory

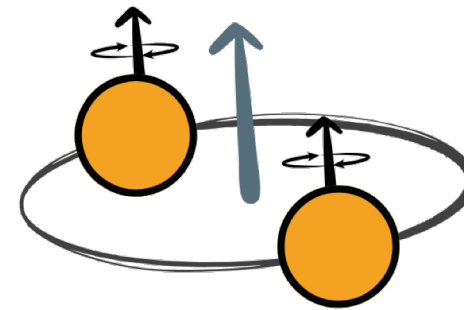
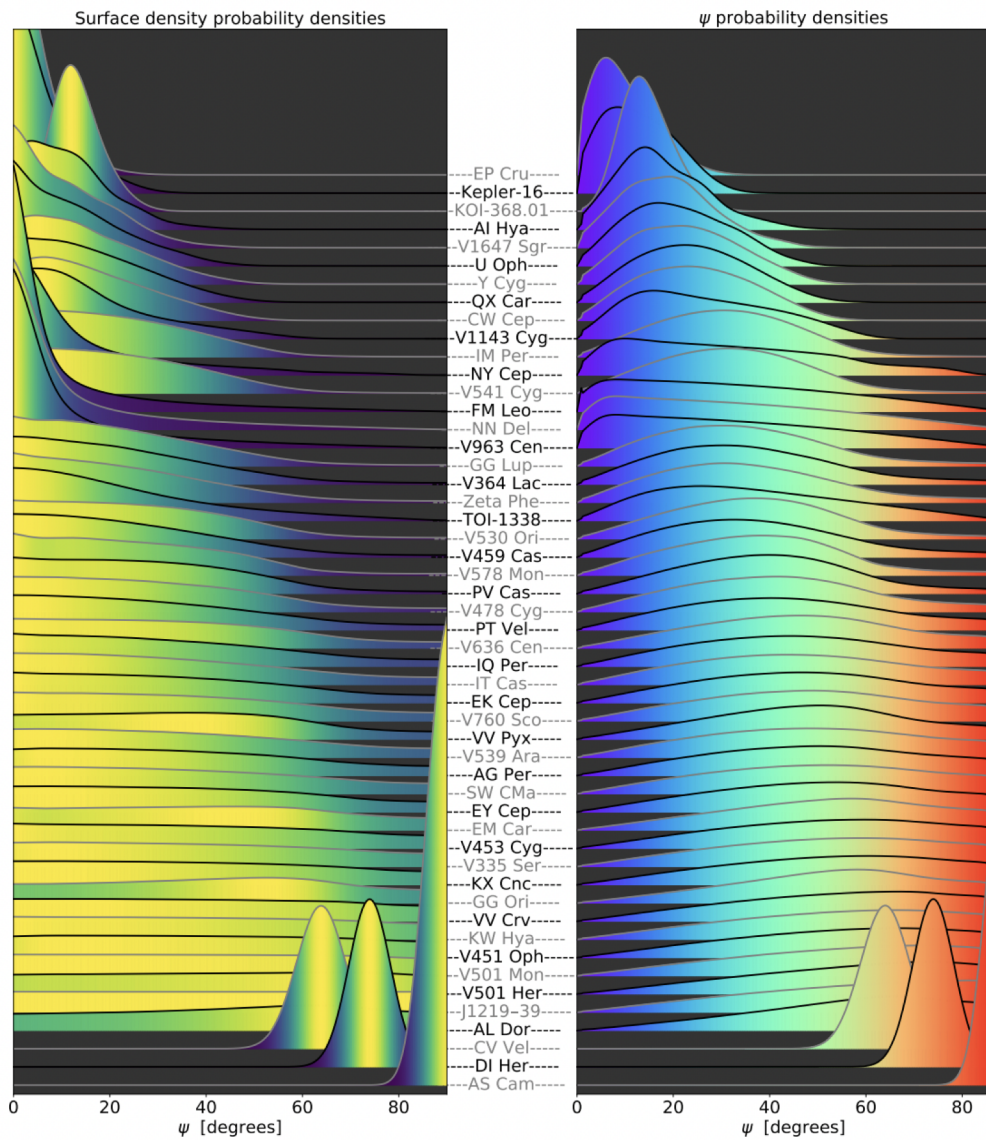


The popular model predicts a peak at zero tilt, yet observations hint non-zero tilt peak.

WE DO NOT KNOW
what drives black hole spins?

1. Natal spins





BANANA Project

Binaries Are Not Always Neatly Aligned

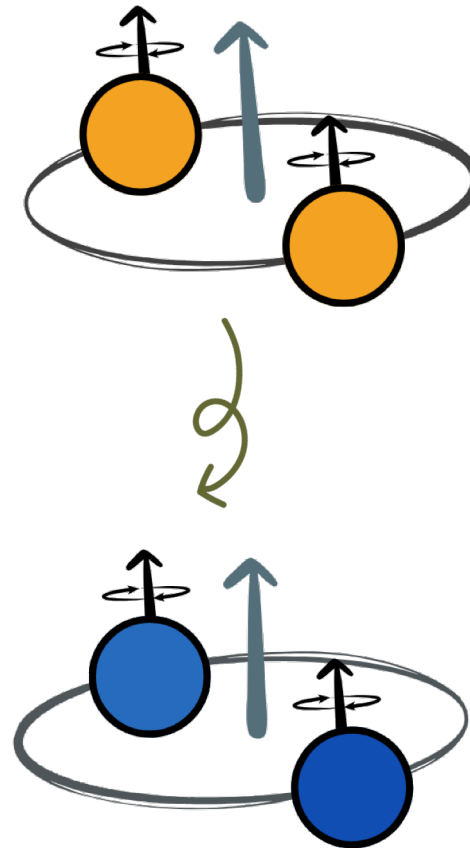
Albrecht+ 2010

Albrecht+ 2012

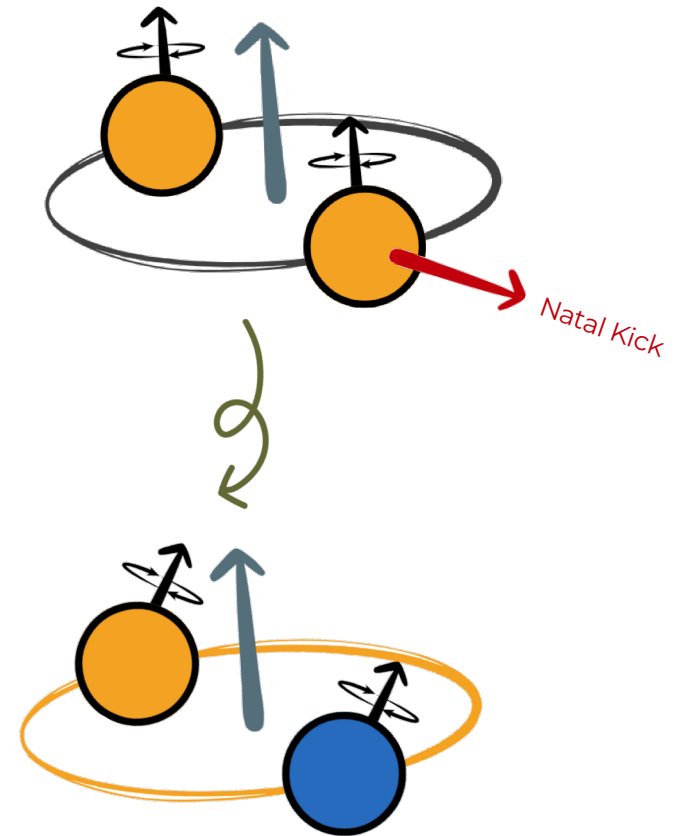
Albrecht+ 2014

Marcussen, Albrecht. 2021

1. Natal spins

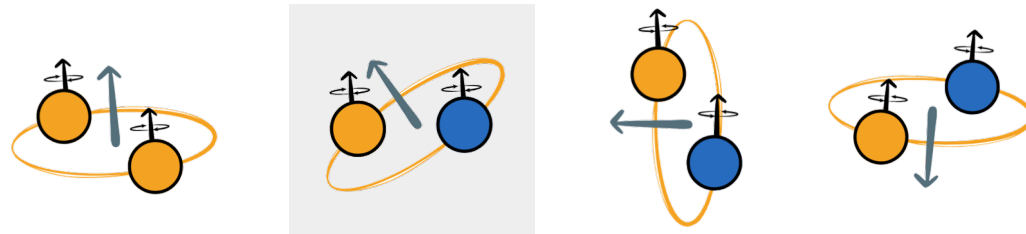
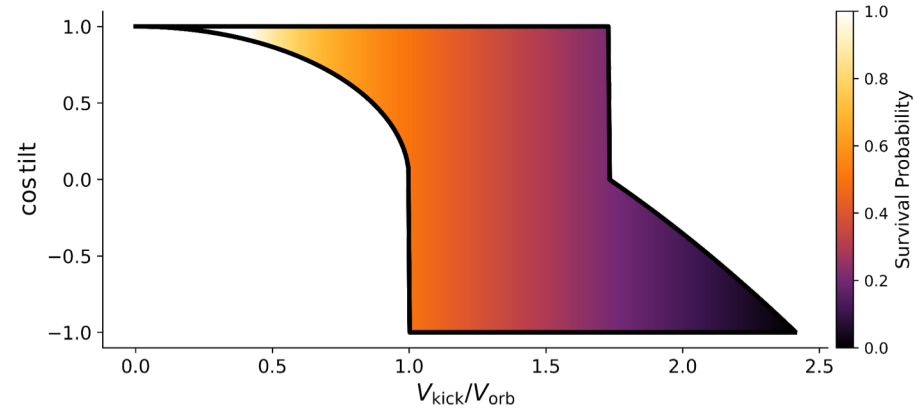


1. Natal spins

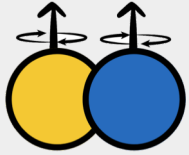


1. Natal spins

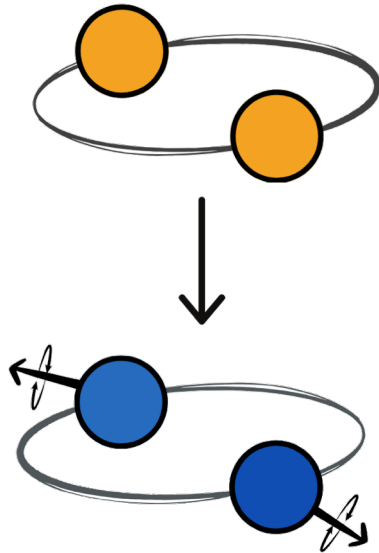
Higher Natal Kicks, Greater Spin Tilts, More Disruption



1. Natal spins



2. Isotropic spins



When black holes don't inherit spins from the star:

internal gravity waves, accreting convective layers, SASI

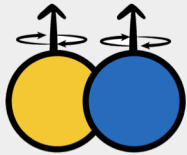
Fuller et al 2014

McNeill Muller 2020

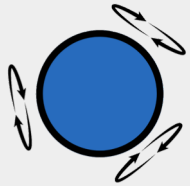
Antoni, Quataert 2021, 2023

See Tauris 2022

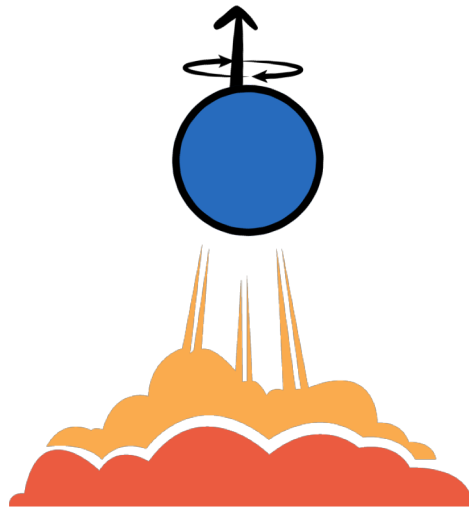
1. Natal spins



2. Isotropic spins



3. Spins parallel to Natal Kick



Pulsar observations

Johnston et al. 2005

Ng & Romani 2007

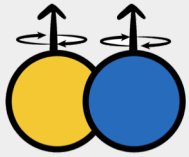
Noutsos et al. 2012, 2013

Core-Collapse Simulations & Hydrodynamical mechanisms

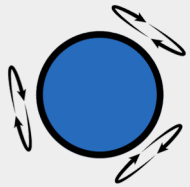
Janka et al 2021

Burrows et al 2023

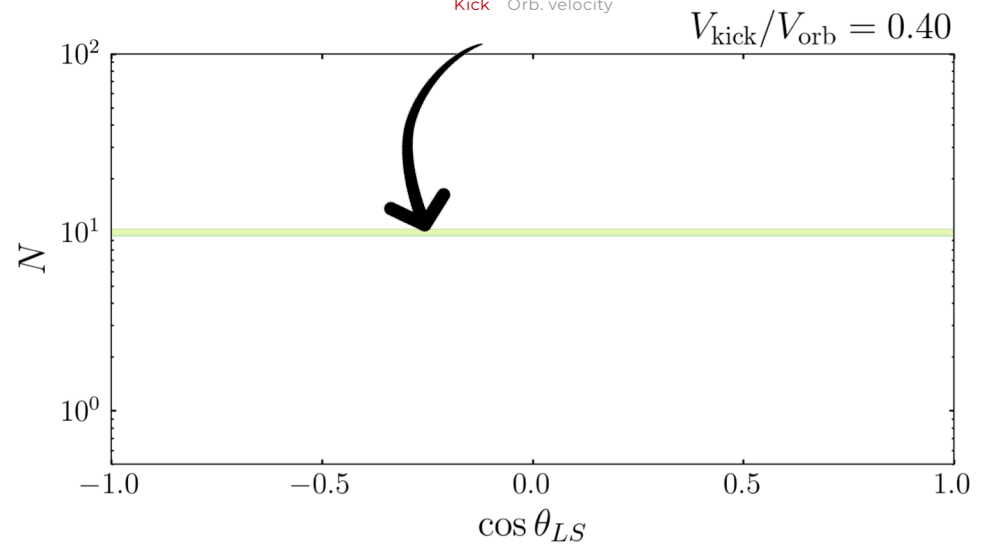
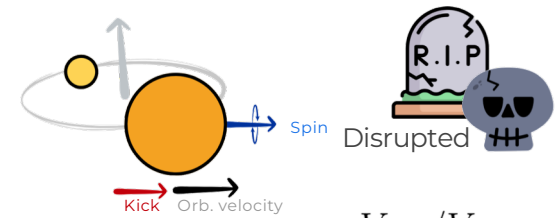
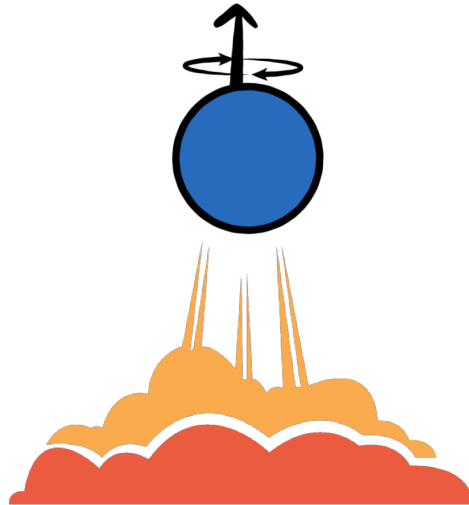
1. Natal spins



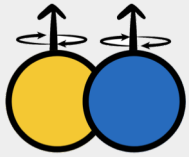
2. Isotropic spins



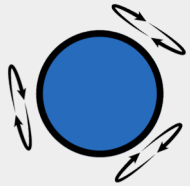
3. Spins parallel to Natal Kick



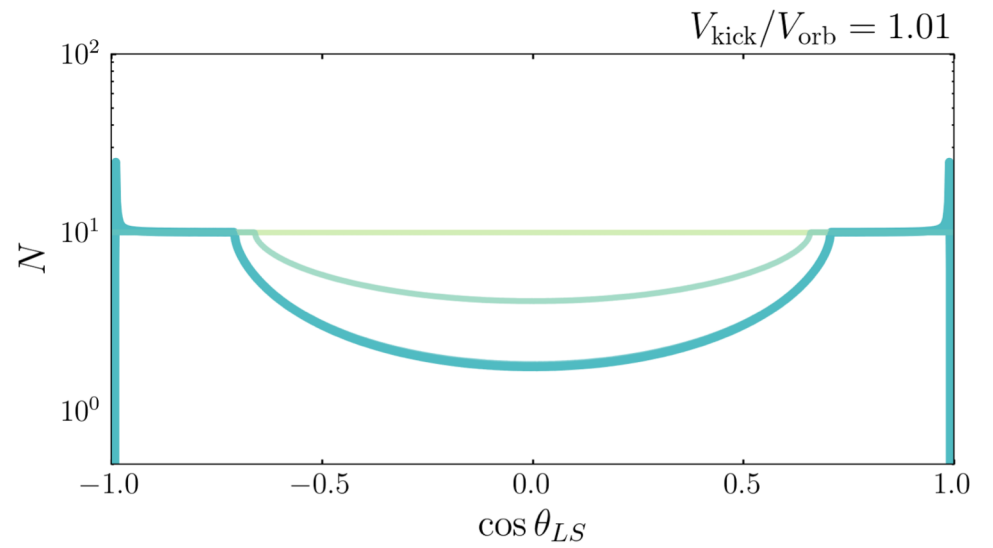
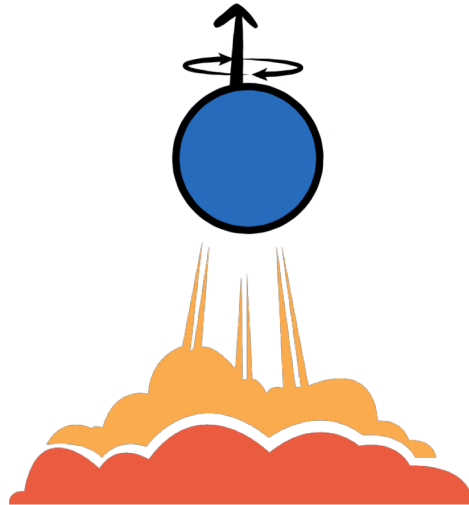
1. Natal spins



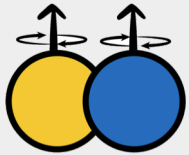
2. Isotropic spins



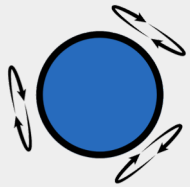
3. Spins parallel to Natal Kick



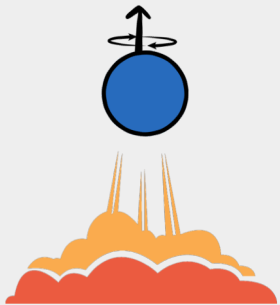
1. Natal spins



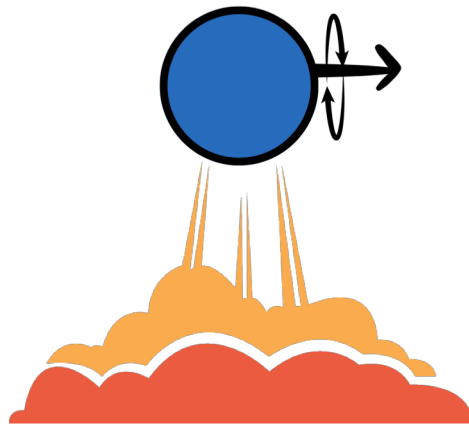
2. Isotropic spins



3. Spin || Kick



4. Spins perpendicular to Natal Kick



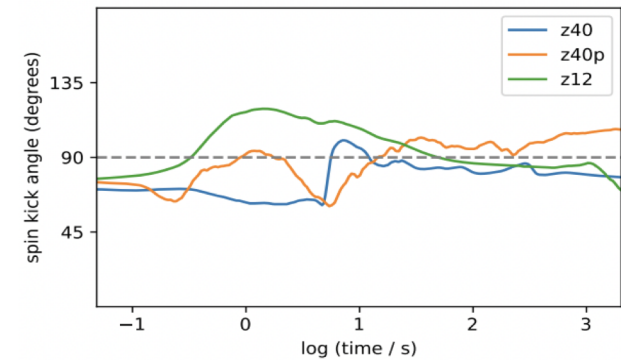
Off-center explosions, Asymmetric fallback of ejecta

Phinney Spruit 1998

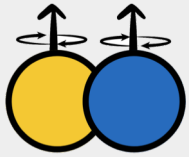
Farr et al 2011

Muller et al 2018

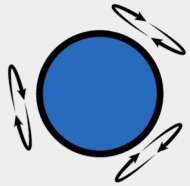
Chan Muller Heger 2020



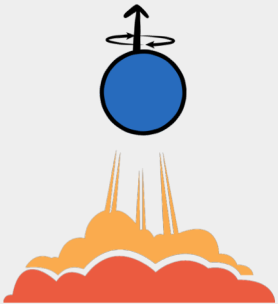
1. Natal spins



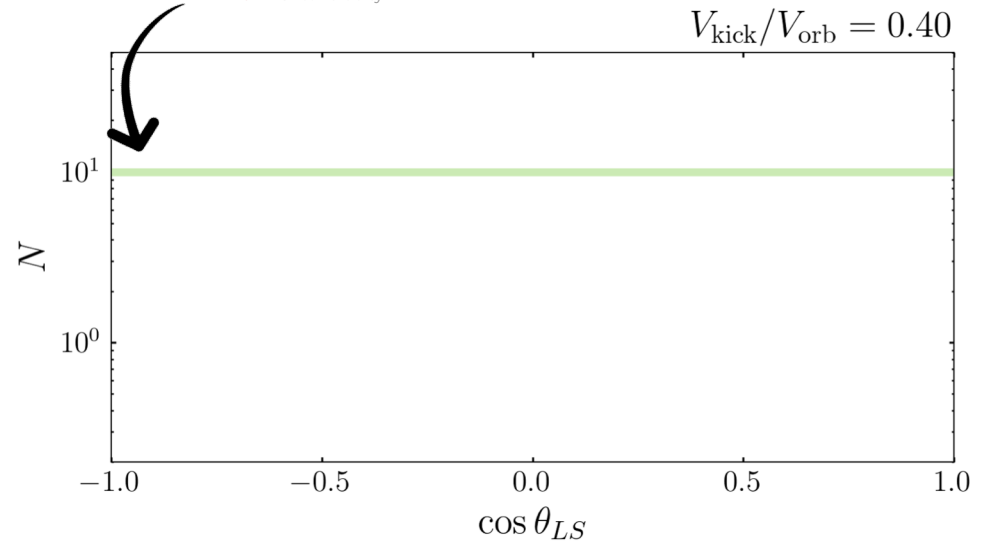
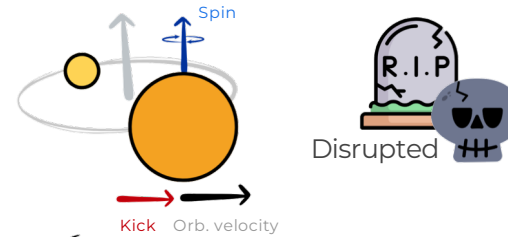
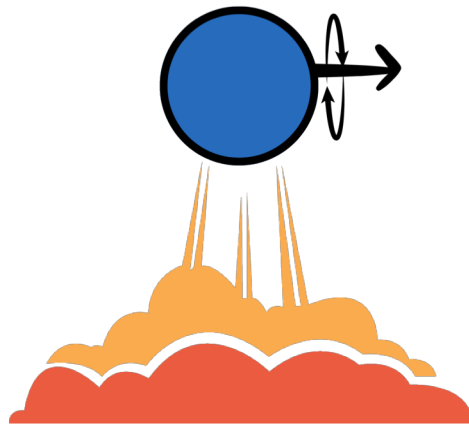
2. Isotropic spins



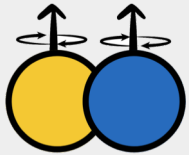
3. Spin || Kick



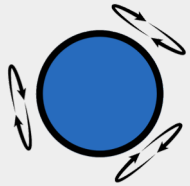
4. Spins perpendicular to Natal Kick



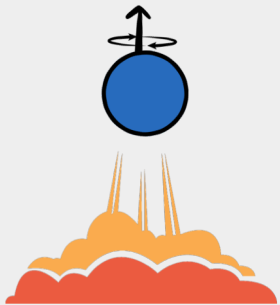
1. Natal spins



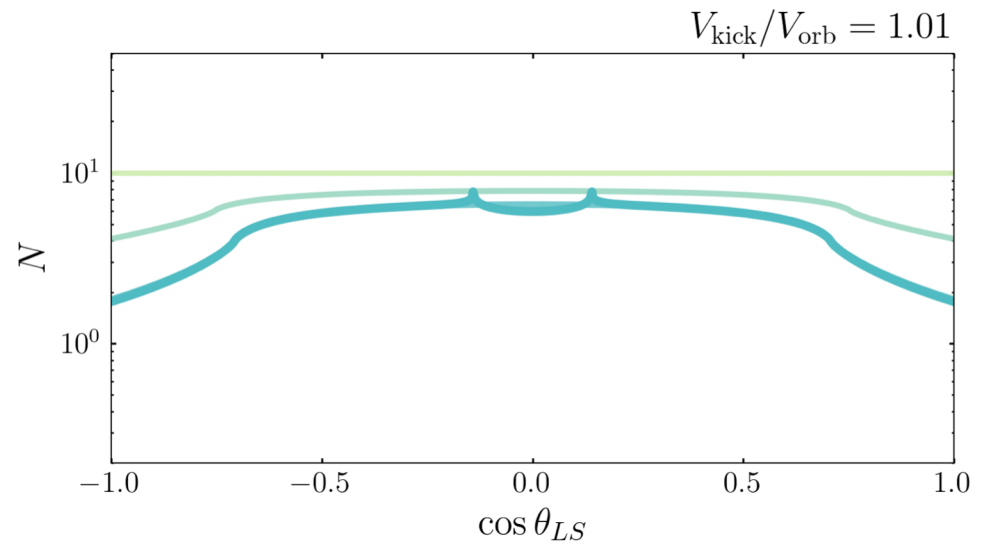
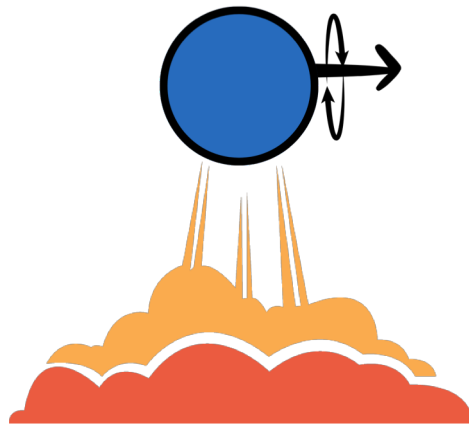
2. Isotropic spins



3. Spin || Kick

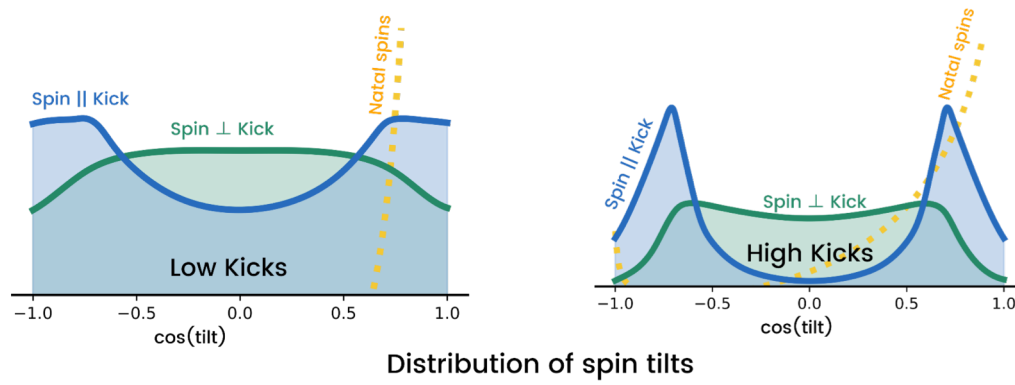


4. Spins perpendicular to Natal Kick



WE DO NOT KNOW

what drives black hole spins?

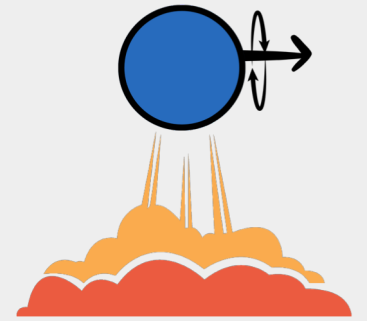
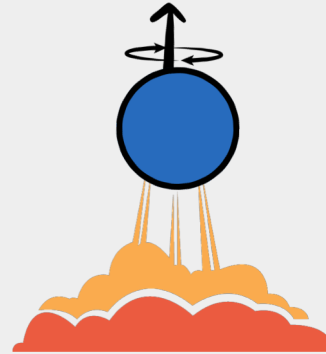
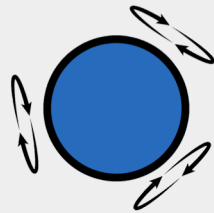
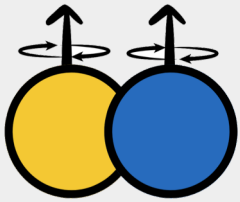


Natal spins

Isotropic spins

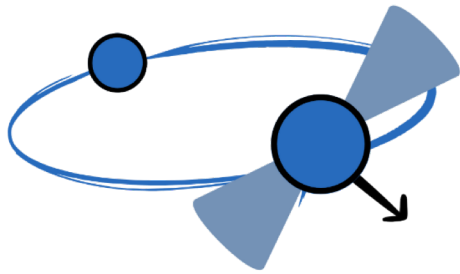
Spin || Kick

Spin \perp Kick

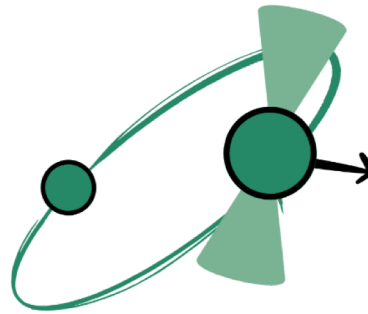


Problem 1.

EM observations do not support the popular theory



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PSR J1906+0746: $104 \pm 10^\circ$
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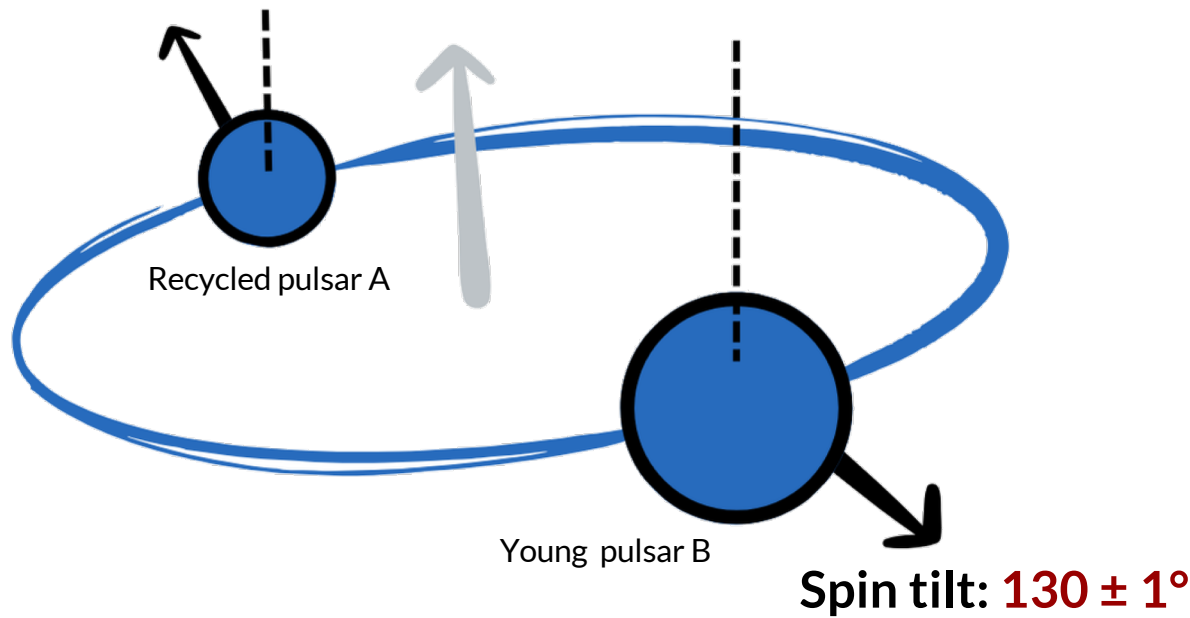


Need small natal kicks

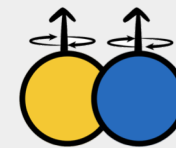
$$V_{\text{kick}} < 0.5 V_{\text{orb}}$$

(95% upper limit)

Spin tilt: $< 3^\circ$



PSR J0737-3039 A/B



Natal spins

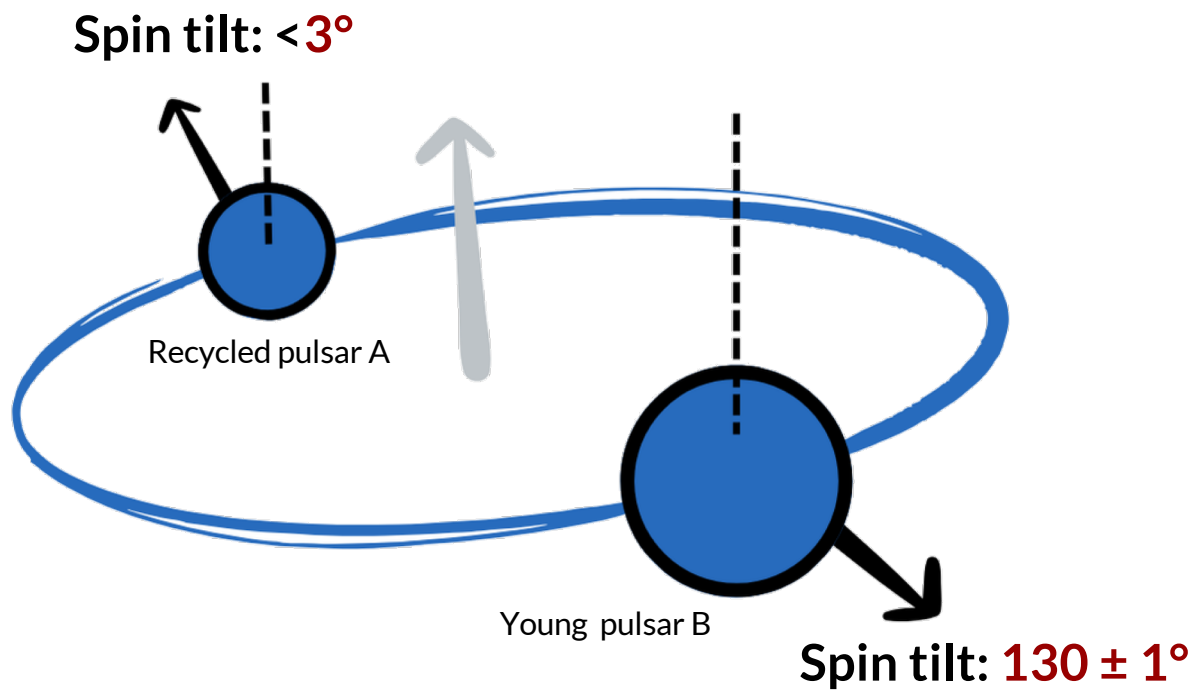
Need large natal kicks

$$V_{\text{kick}} = 1.5-2 V_{\text{orb}}$$

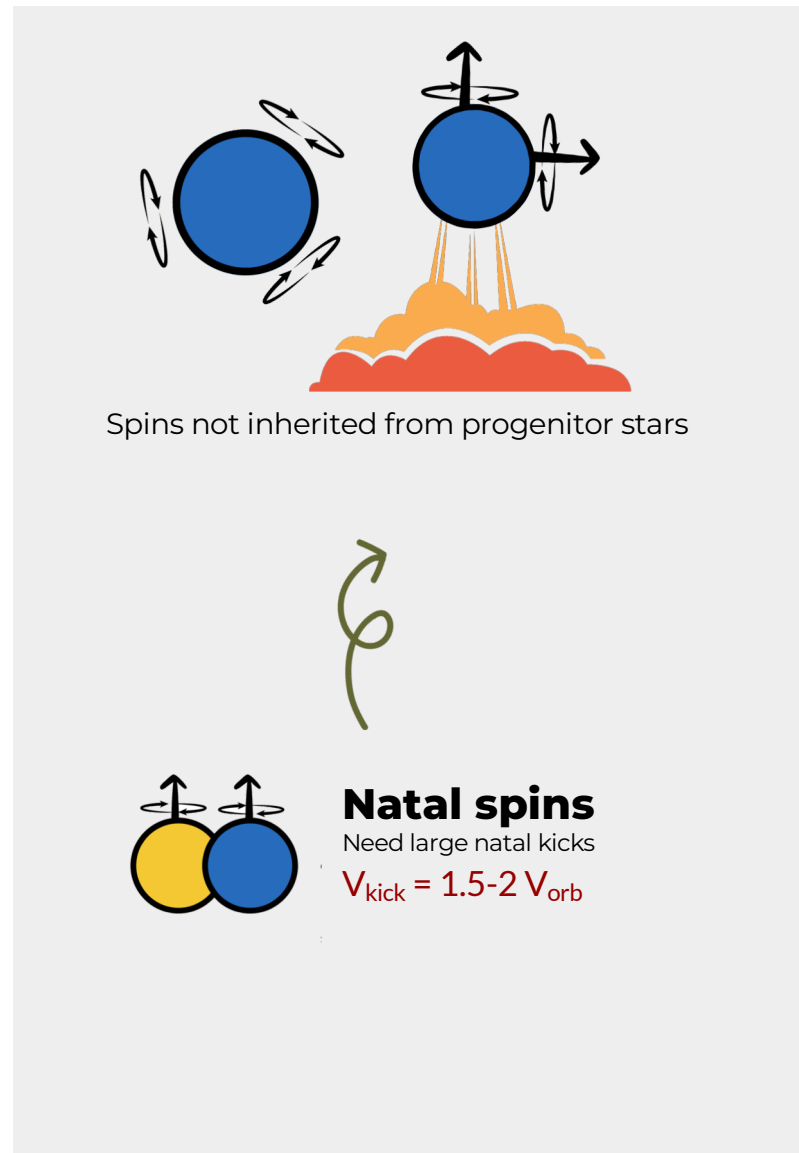
Inconsistent with Pulsar A

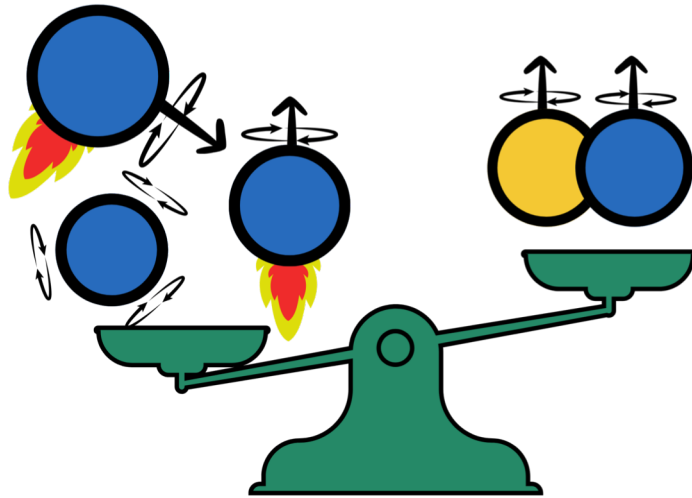
70-90% of the systems

would be **disrupted**



PSR J0737-3039 A/B



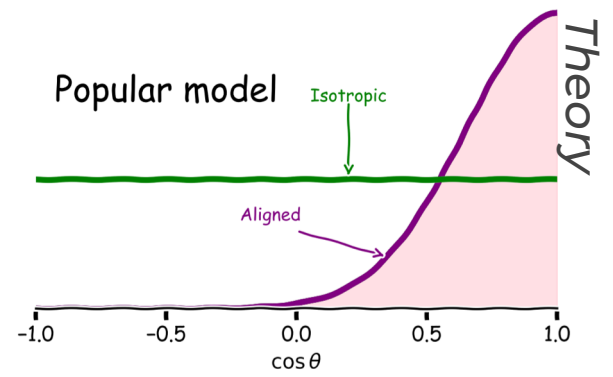
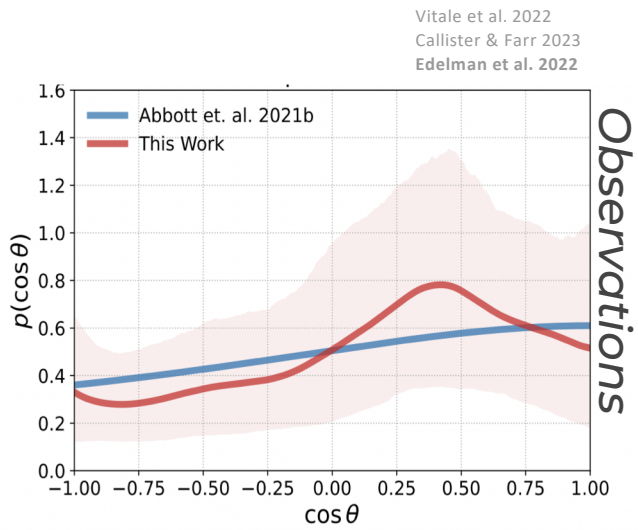


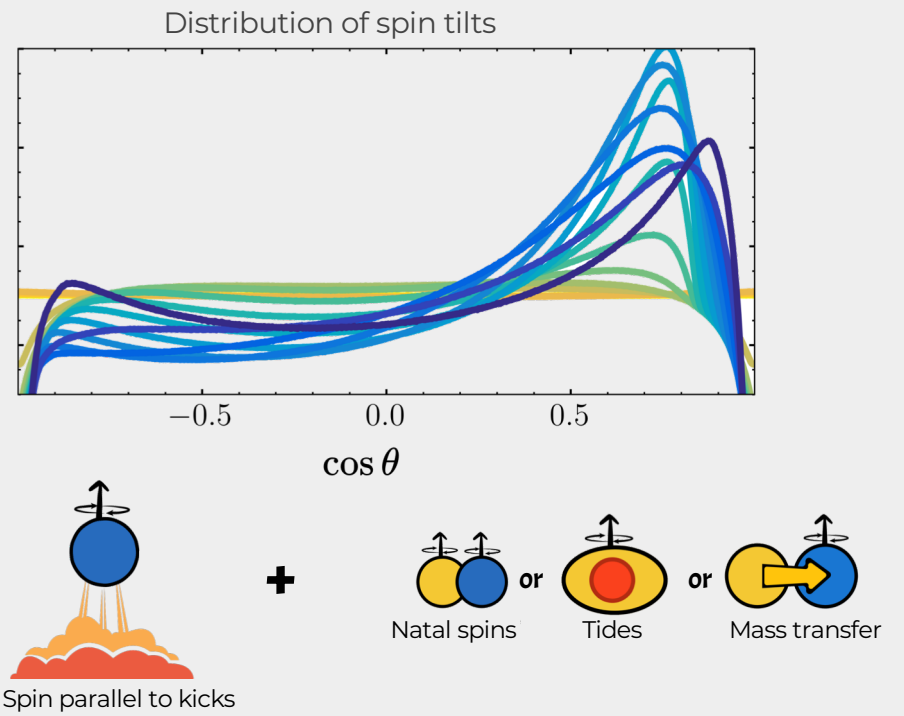
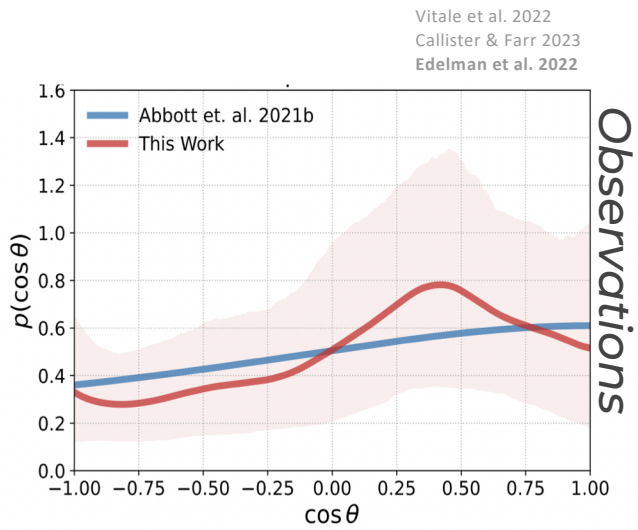
Natal spin model is disfavored with a

Bayes factor >10

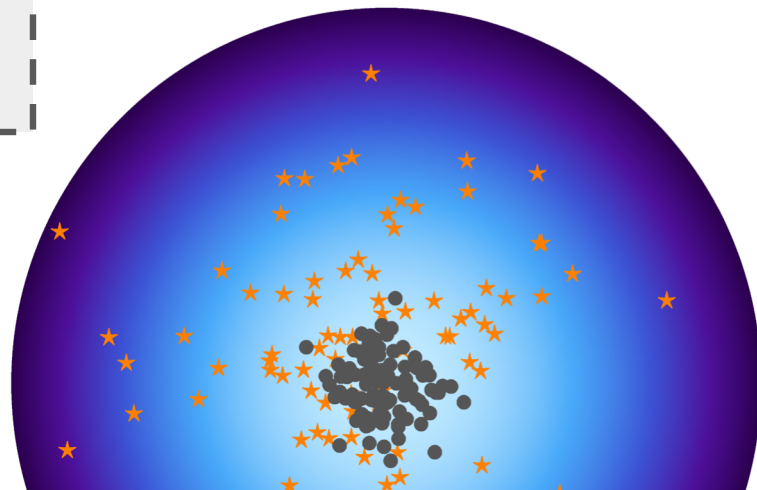
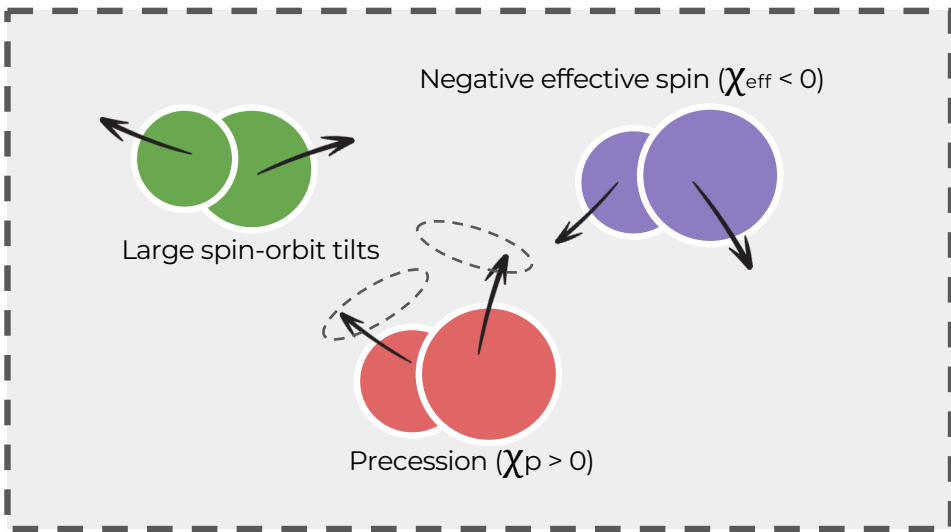
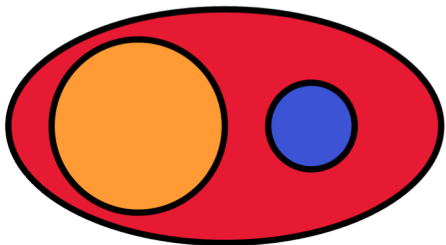
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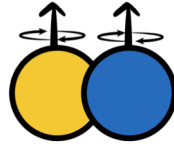
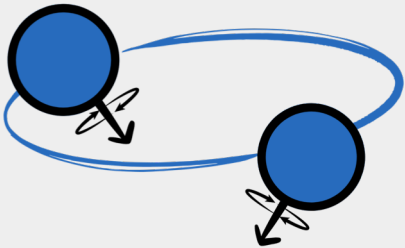


Can BH Spins Reveal the formation pathways of GW sources?



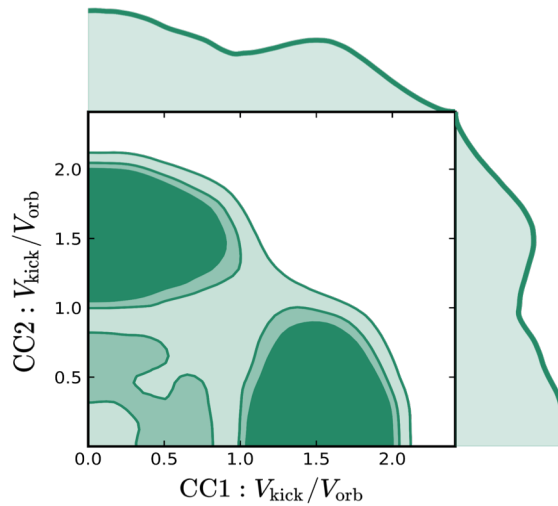
GW191109

Negative χ_{eff}



Natal spins

Need large natal kicks to explain large misalignments



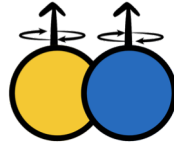
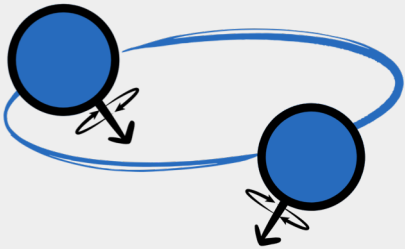
~90% of the systems
would be **disrupted**

Was GW191109 assembled
dynamically in stellar clusters?

- Zhang et al 2023

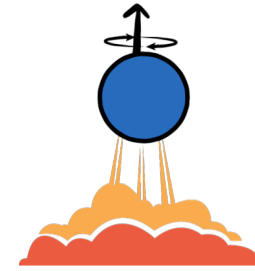
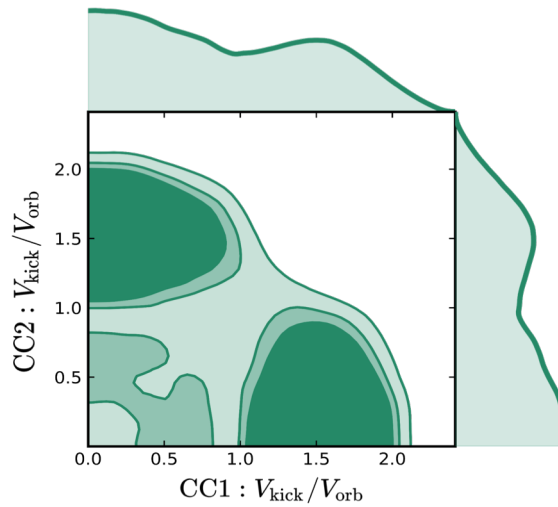
GW191109

Negative χ_{eff}



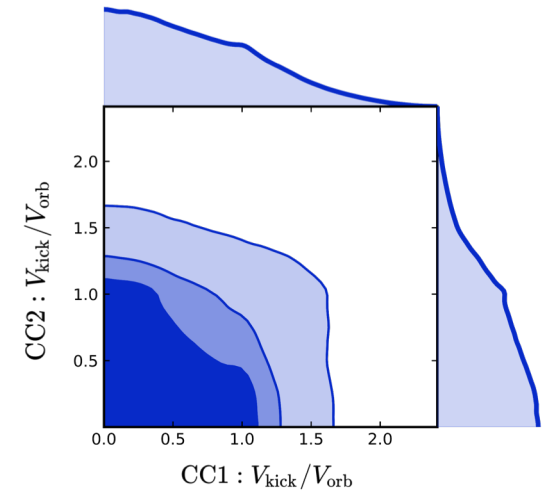
Natal spins

Need large natal kicks to explain large misalignments



Spin parallel to kicks

large natal kicks are not required



Conclusion



Only dynamical environments can produce highly misaligned binaries



NO