Spins remember

spin signatures of astrophysical black hole formation mechanisms

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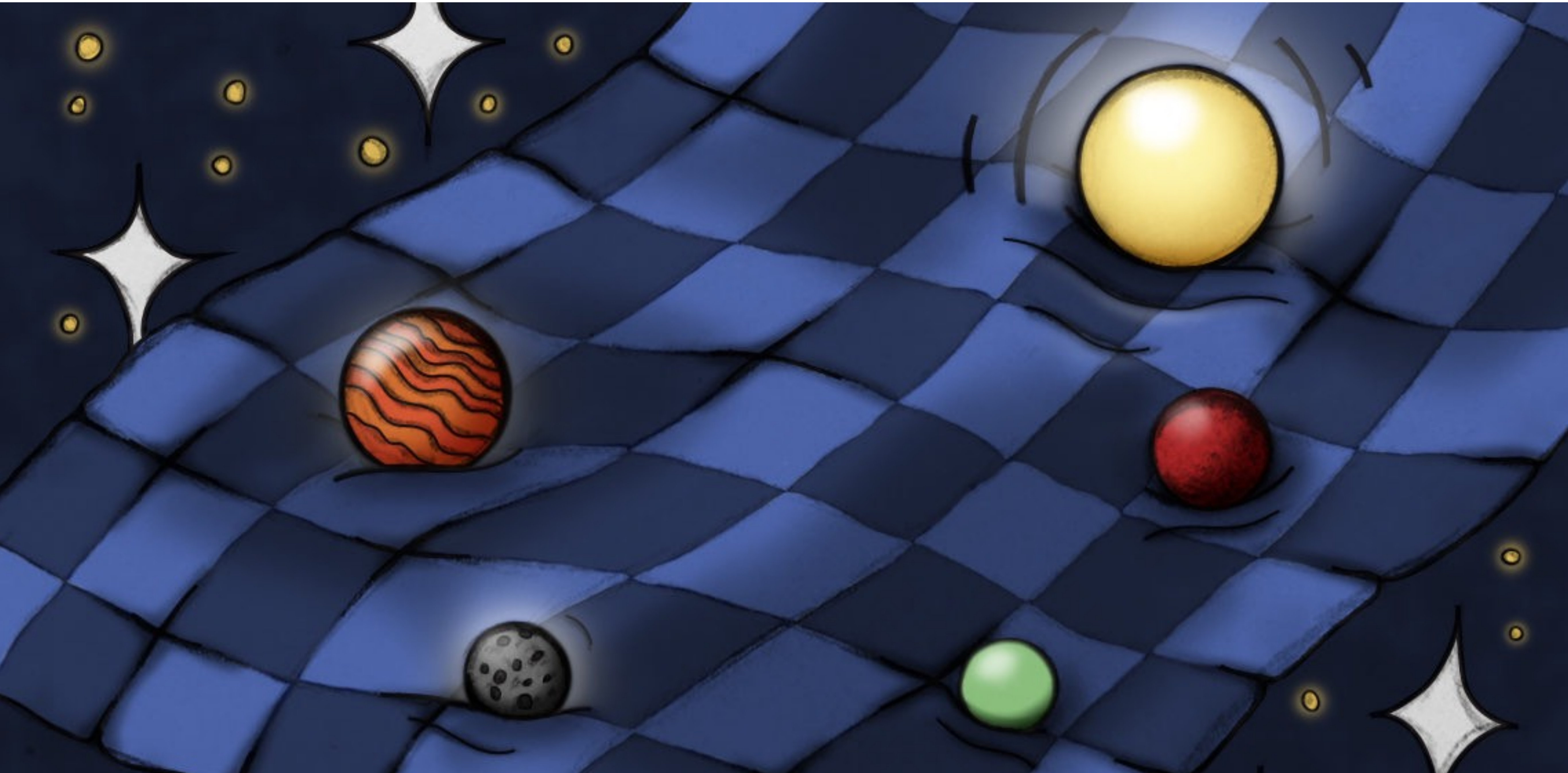
Outline

1. PN: spins and symmetries
2. Spins remember precise formation steps!
3. Spins remember mergers!

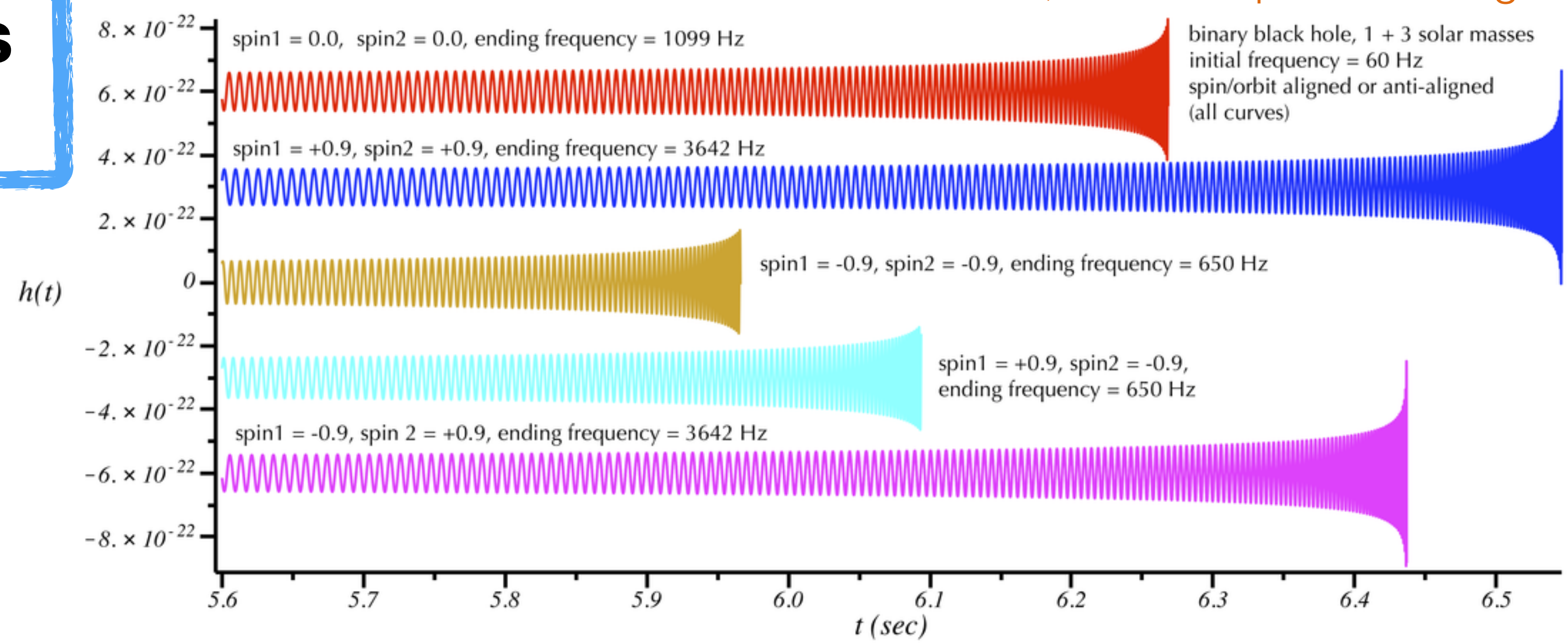


Spin in the waveform

Aligned components of the spins

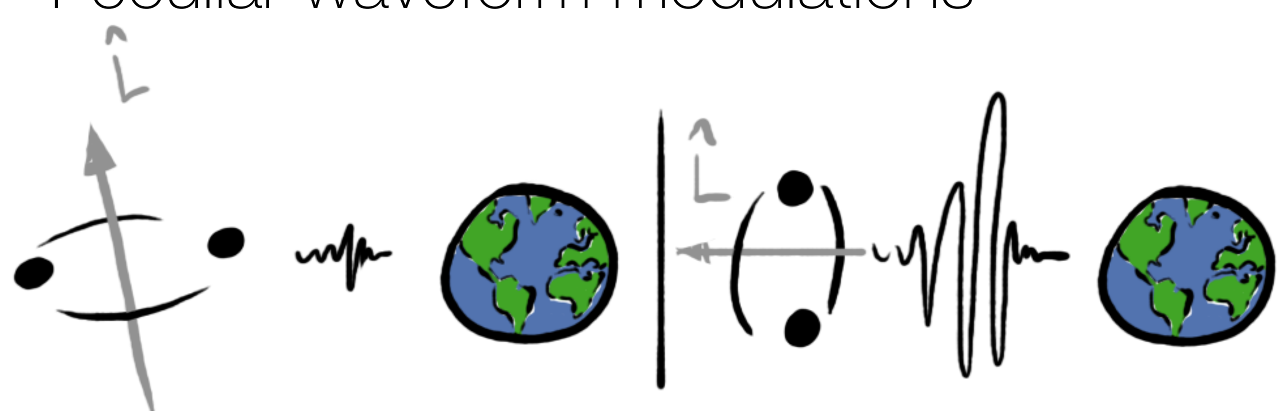
- Different merger frequency (analog of the ISCO)
- Aligned spins take longer to merge

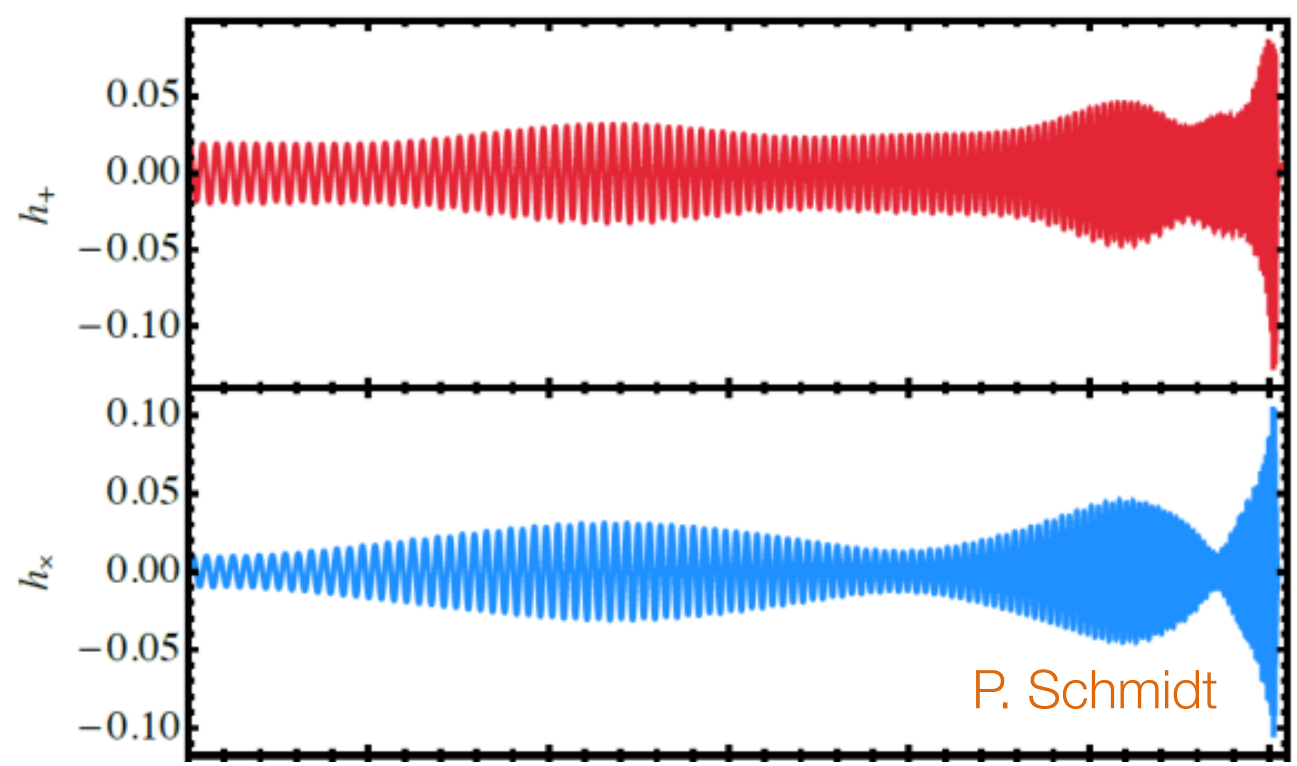
M. Favata, soundofspacetime.org



Orbital-plane components of the spins

- spin precession; orbital plane precession
- Peculiar waveform modulations





PN spin geometry

Evolutionary equations

- Spin precession $\dot{\mathbf{S}}_i = \mathbf{\Omega}_i \times \mathbf{S}_i$
- Momentum conservation $\dot{\hat{\mathbf{L}}} = -(\dot{\hat{\mathbf{S_1}}} + \dot{\hat{\mathbf{S_2}}})/\mathbf{L}$
- Radiation reaction $\dot{r} = \mathrm{PN\,approximant}$

Constraints

- Mass ratio $q = m_2/m_1 \leq 1$
- Spin magnitudes χ_1, χ_2
- Total mass $M = m_1 + m_2 = 1$
- Take a smart frame

…3 evolving variables $\theta_1, \; \theta_2, \; \Delta\Phi$

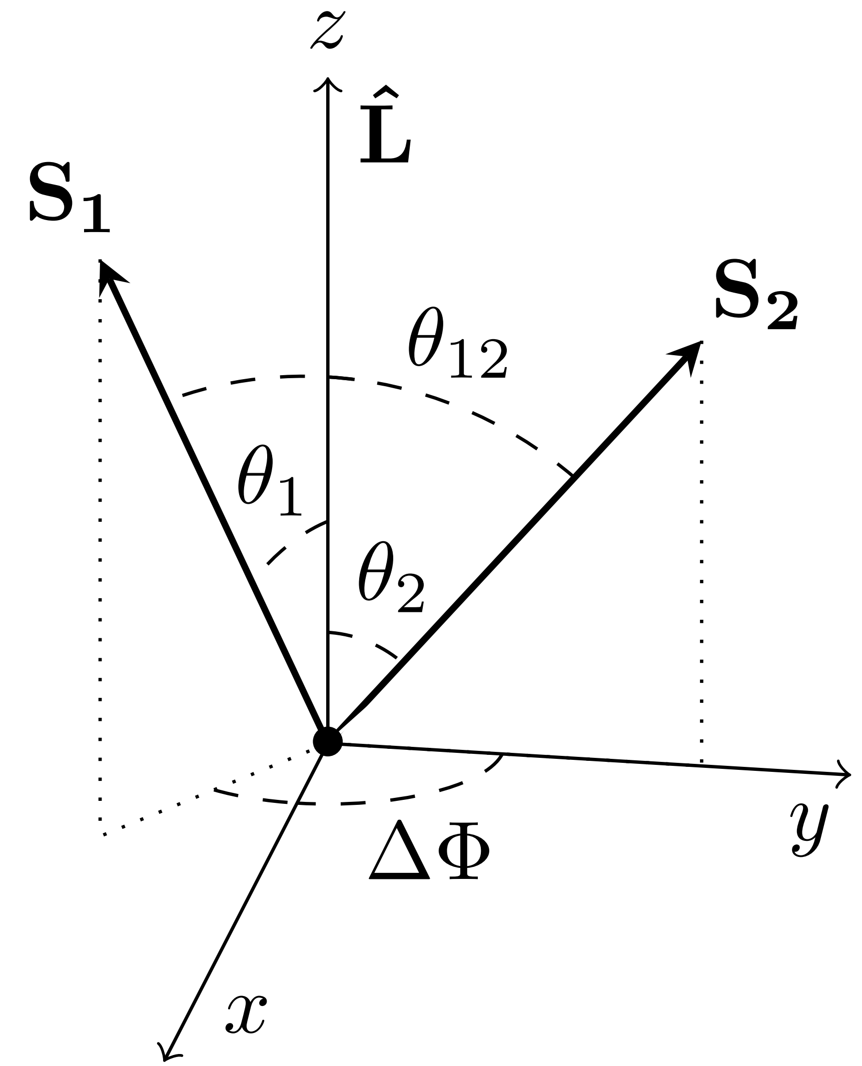
(more immediate)

…or equivalently $\xi \; (\chi_{\rm eff}), \; J, \; S$

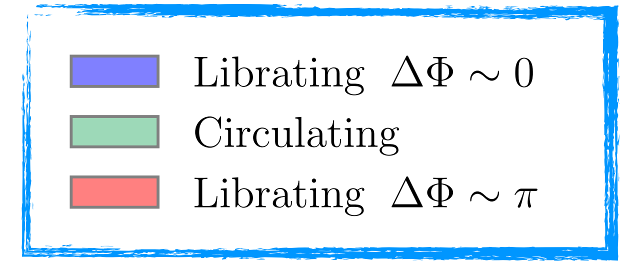
(more physical! Timescale separation)

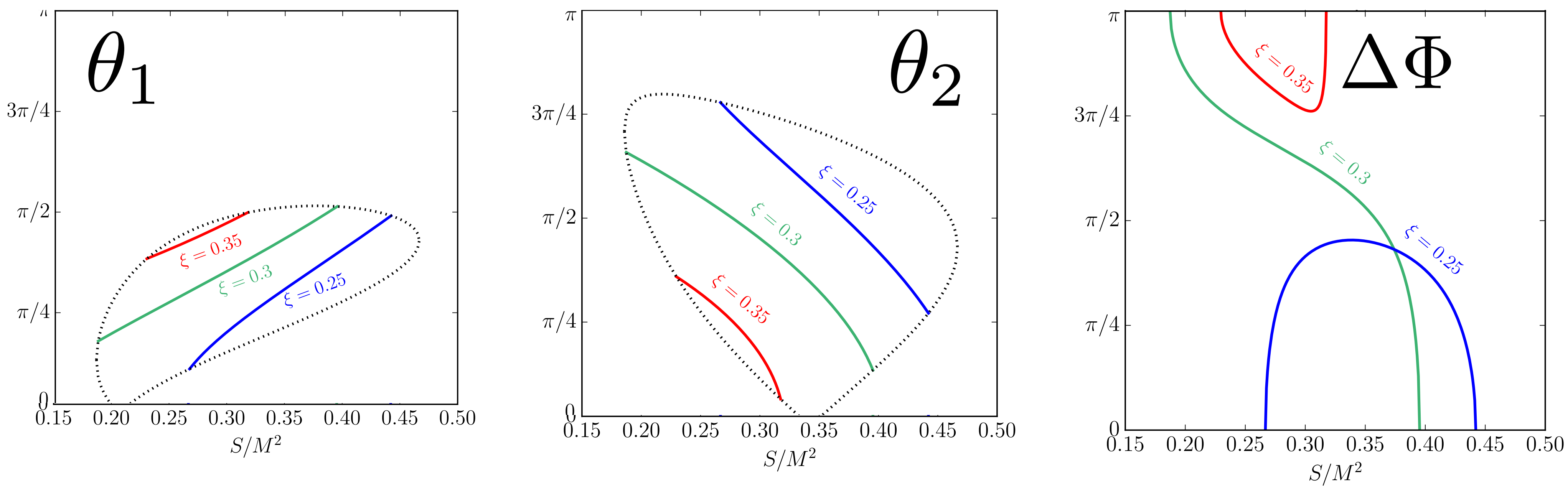
…often condensed in to 2 variables for waveform modeling $\chi_{\rm eff}, \; \chi_{\rm p}$

(not immediate, and half-way physical only…)



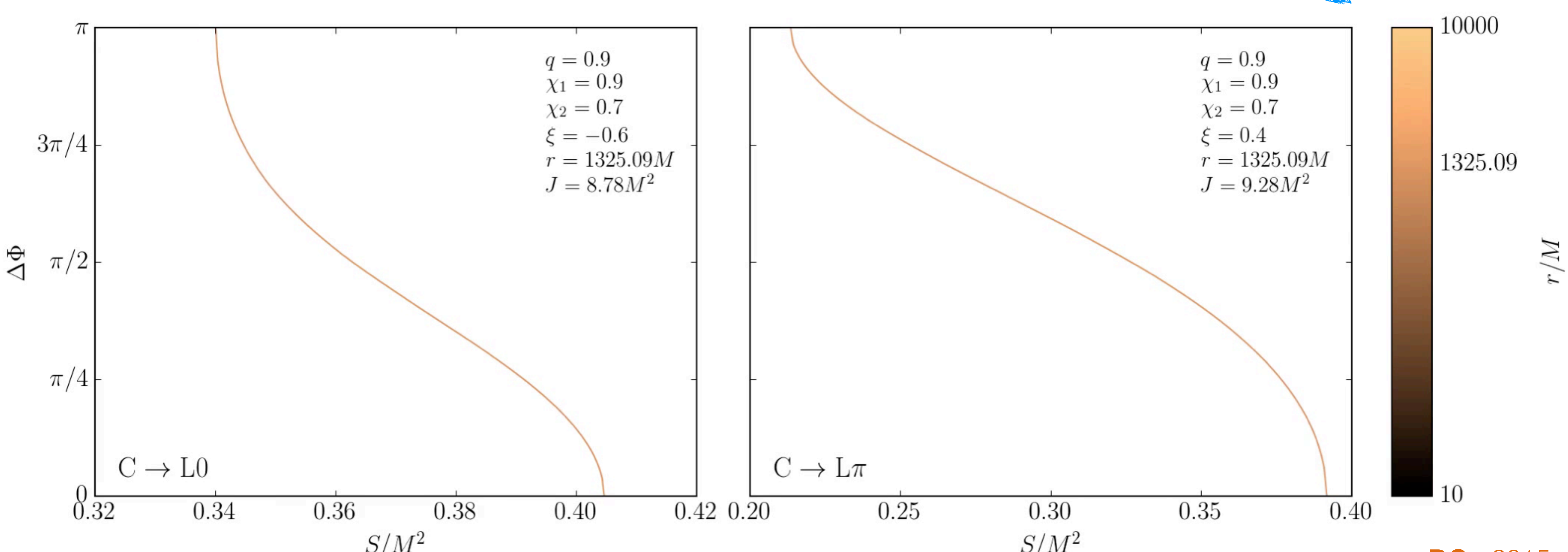
The secret is Δϕ





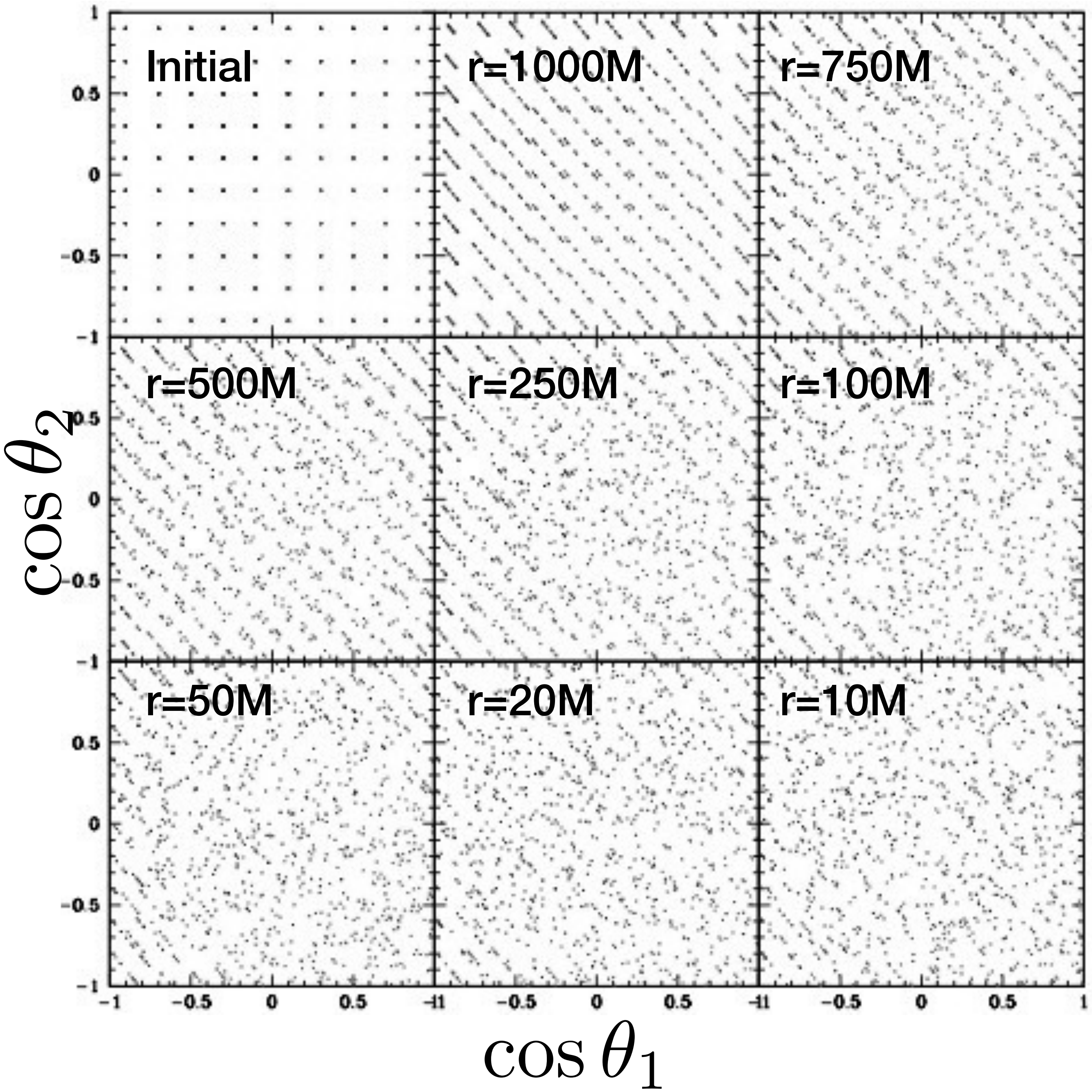
Morphologies

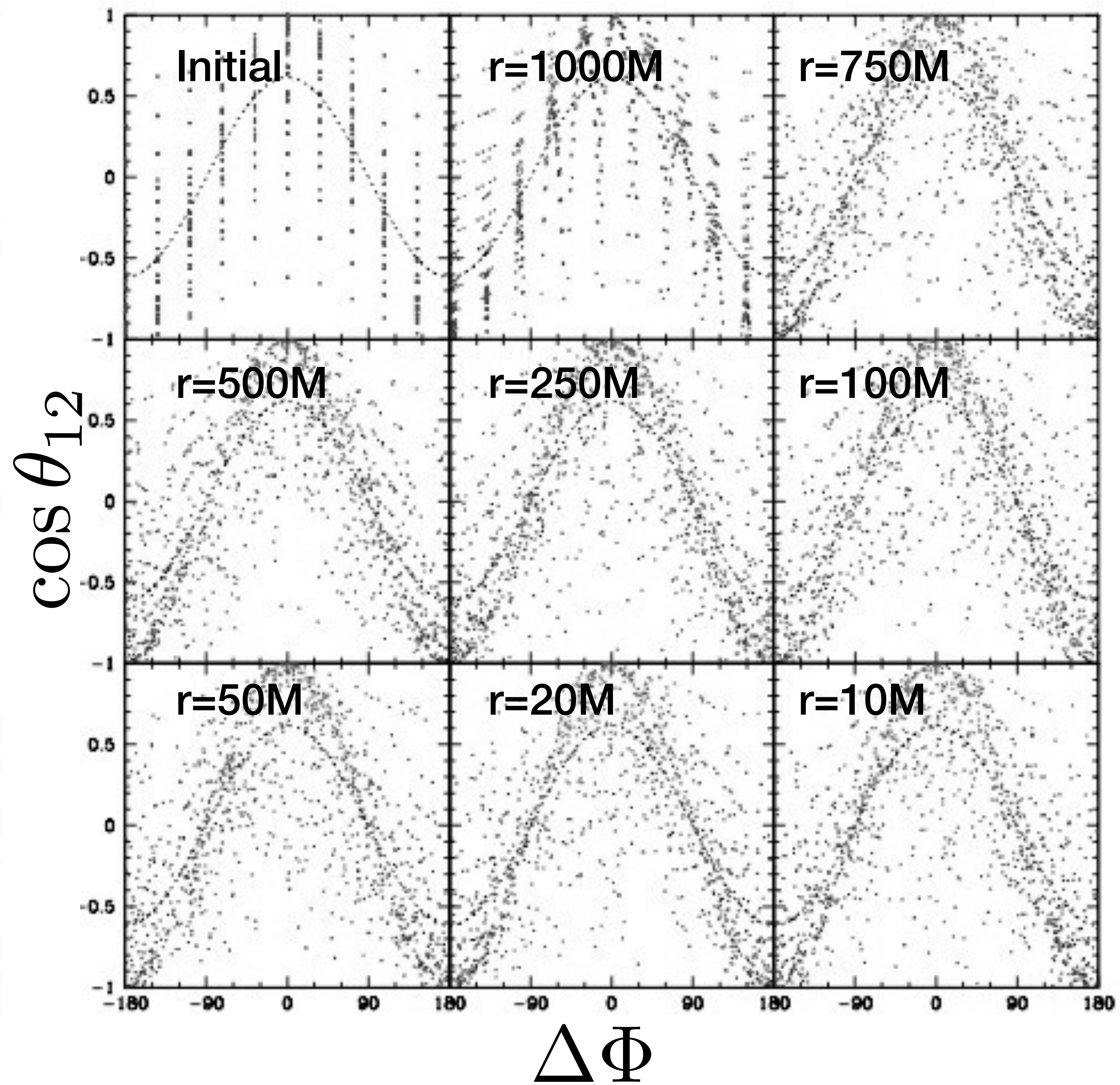
Transitions



DG+ 2015

(A)symmetric spin orientations





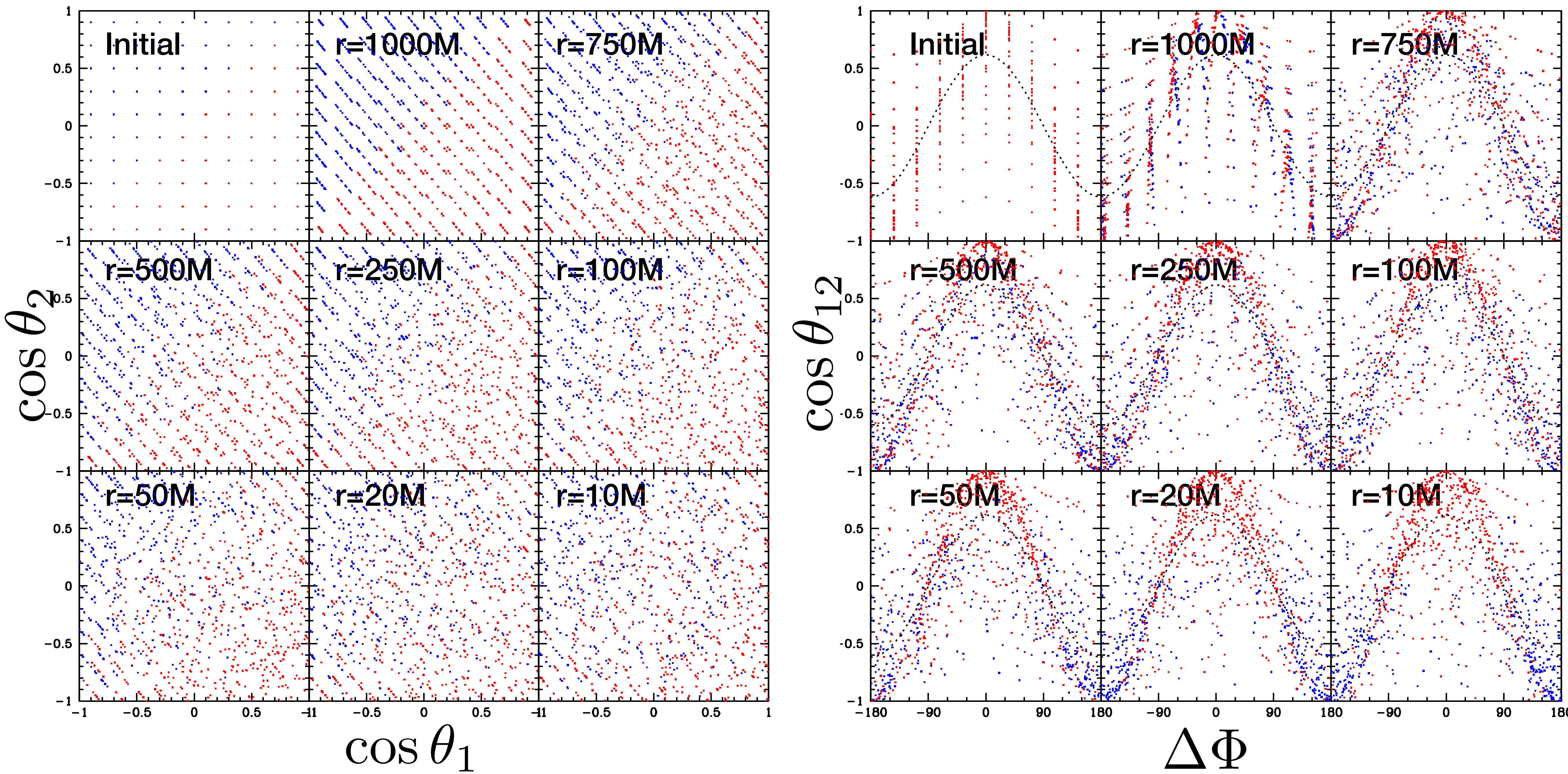
Isotropic distributions stay isotropic

Bogdanovic+ 2007, **DG**+ 2015

$q = 9/11$

$\chi_1 = \chi_2 = 1$

(A)symmetric spin orientations



Attractors! Critical dependence on the initial conditions

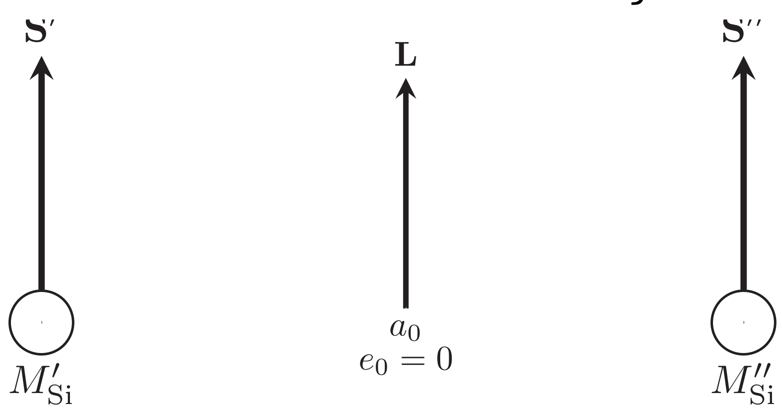
Schnittman 2004, Kesden+2010a,b,2015; Berti+2012, **DG**+2013,2014,2015a,b

$q = 9/11$

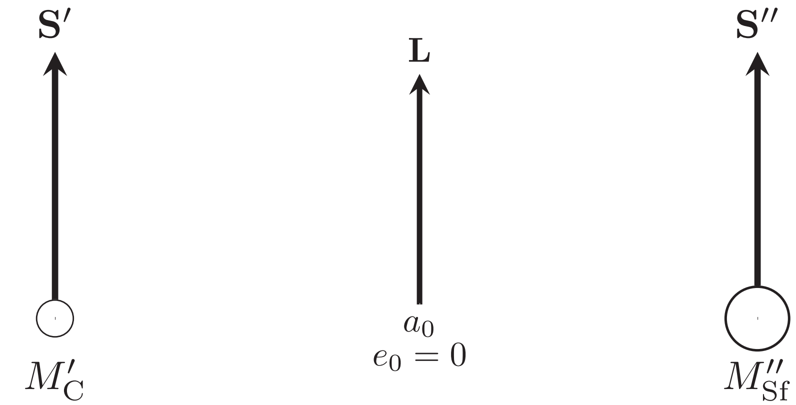
$\chi_1 = \chi_2 = 1$

Field binaries, spin tracking

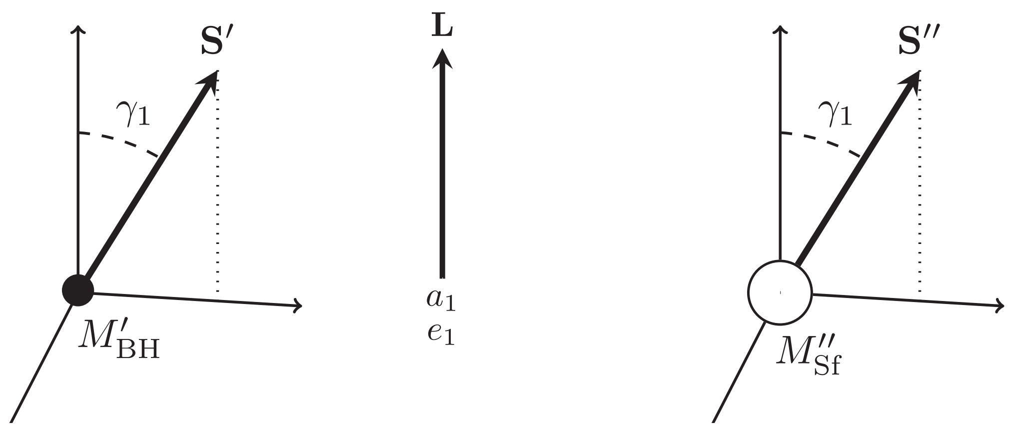
1. Massive binary stars



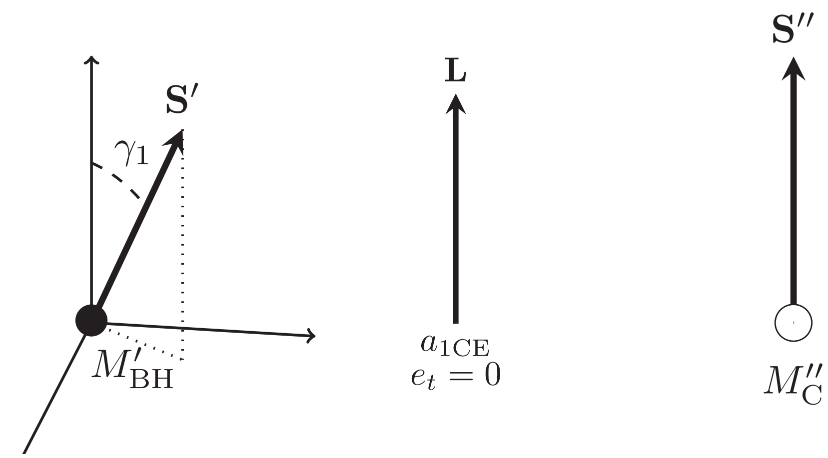
2. Mass transfer



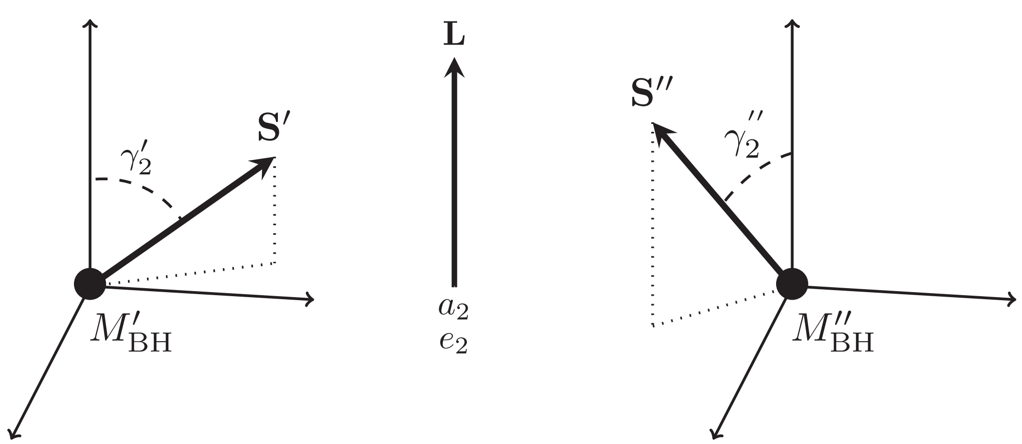
3. 1st Supernova explosion



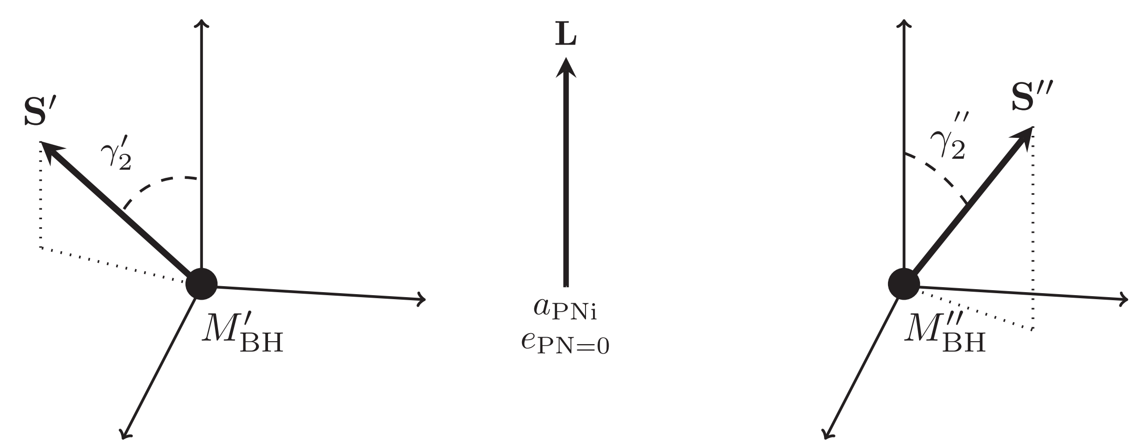
4. Tides, common envelope



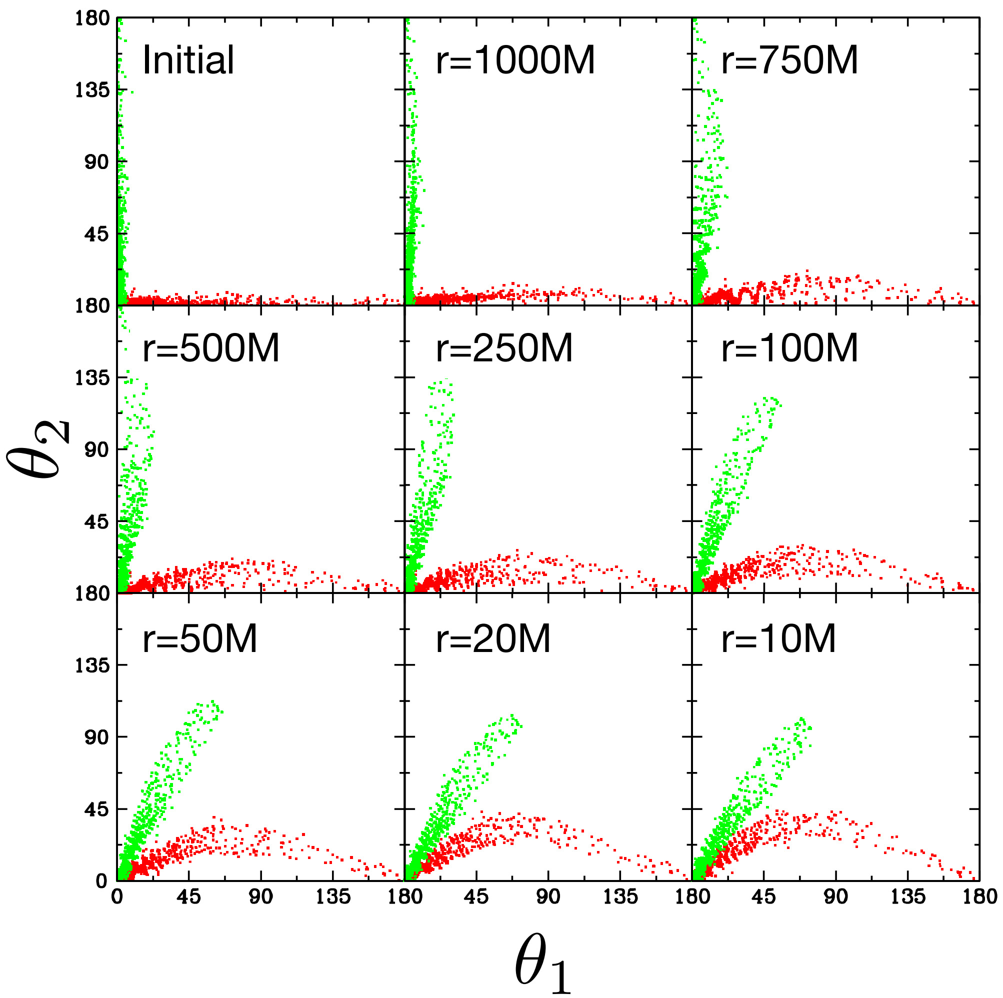
5. 2nd Supernova explosion

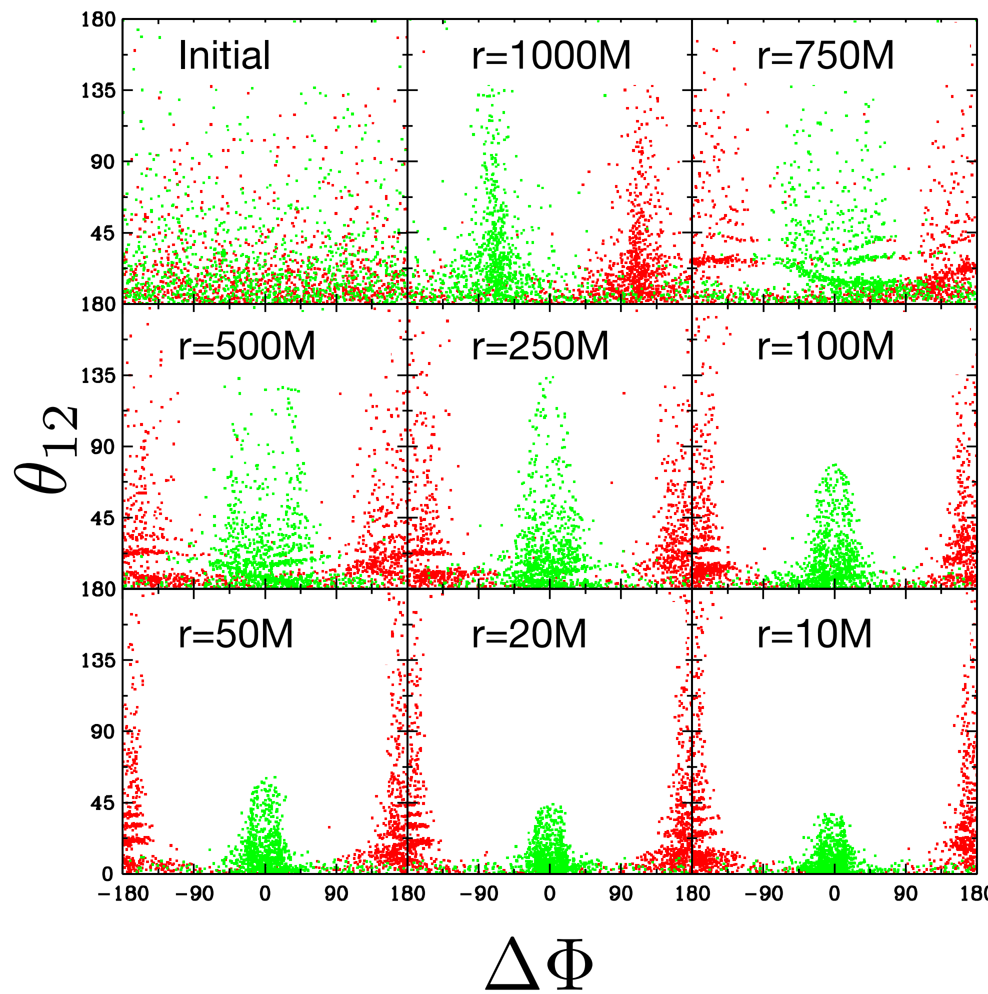


5. Inspiral, merger, LIGO



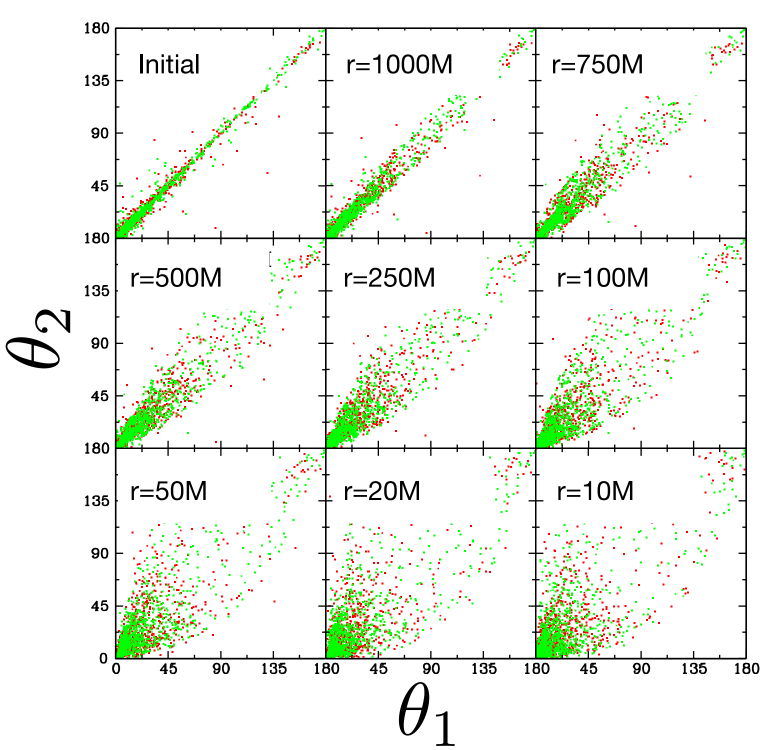
A diagnostic of BH binary formation

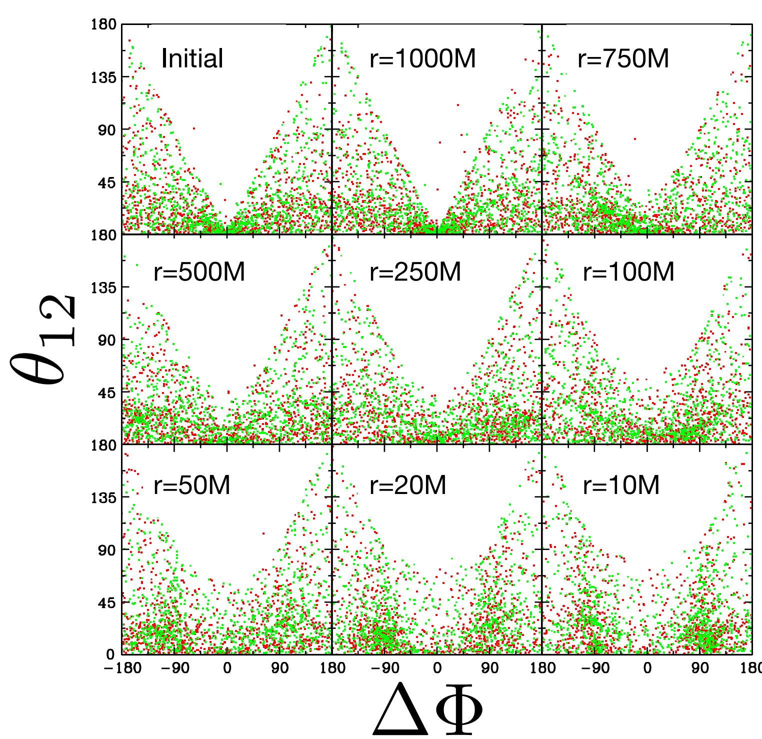




Tides

Mass transfer:
efficient?
or not?





No Tides

- Tides introduce the necessary asymmetry to trigger spin orbit resonances: **not tides, no fun**
- Mass transfer decides **who is the big guy**

DG+ 2013

A diagnostic of BH binary formation

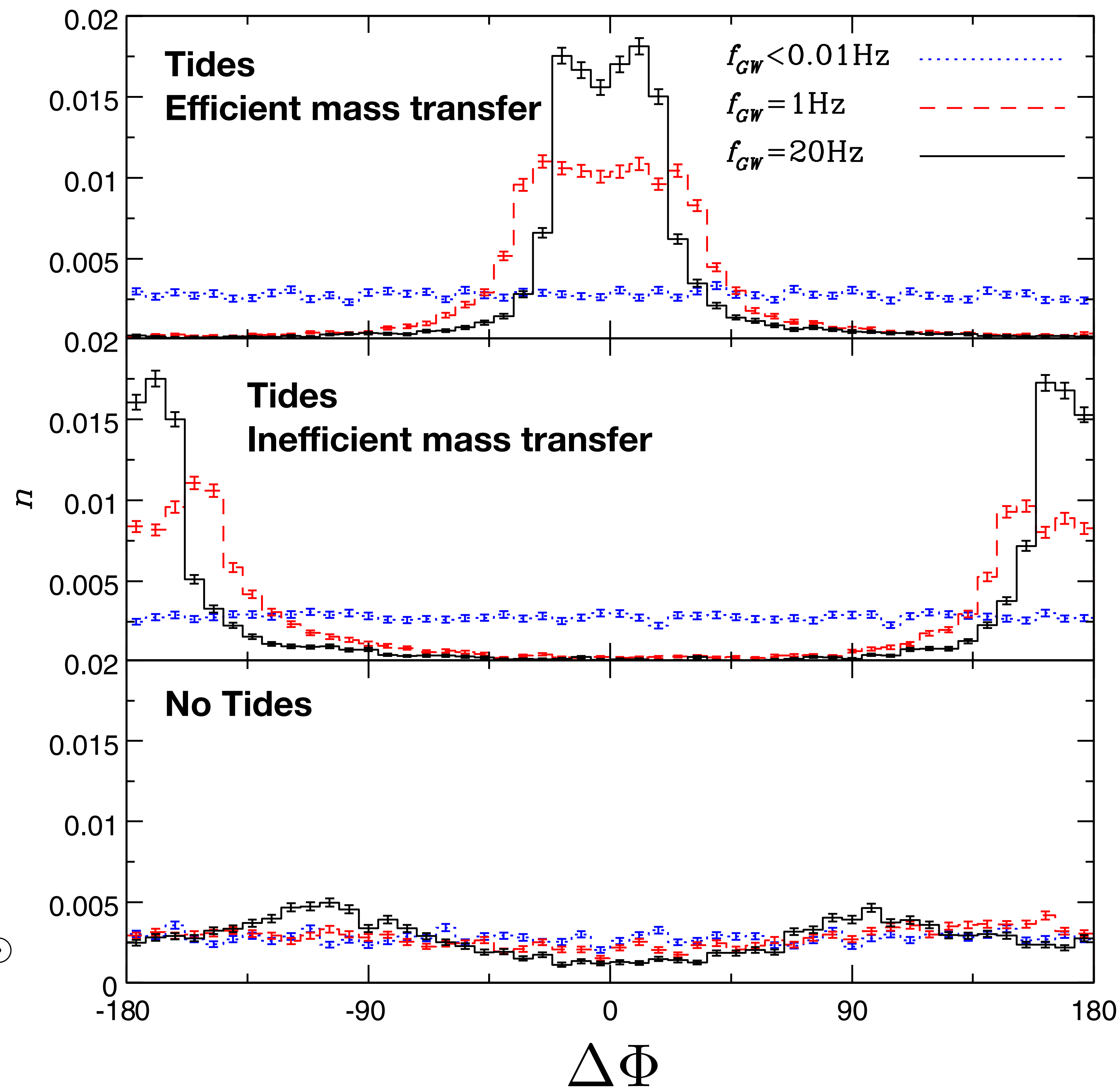
Two main knobs:

- **Tides**: when the system is formed of a BH and a star, can tidal interactions align the star's spin?
- **Mass transfer**: is mass transfer efficient enough to reverse the mass ratio?

Spin dynamics remembers *precise* formation steps!

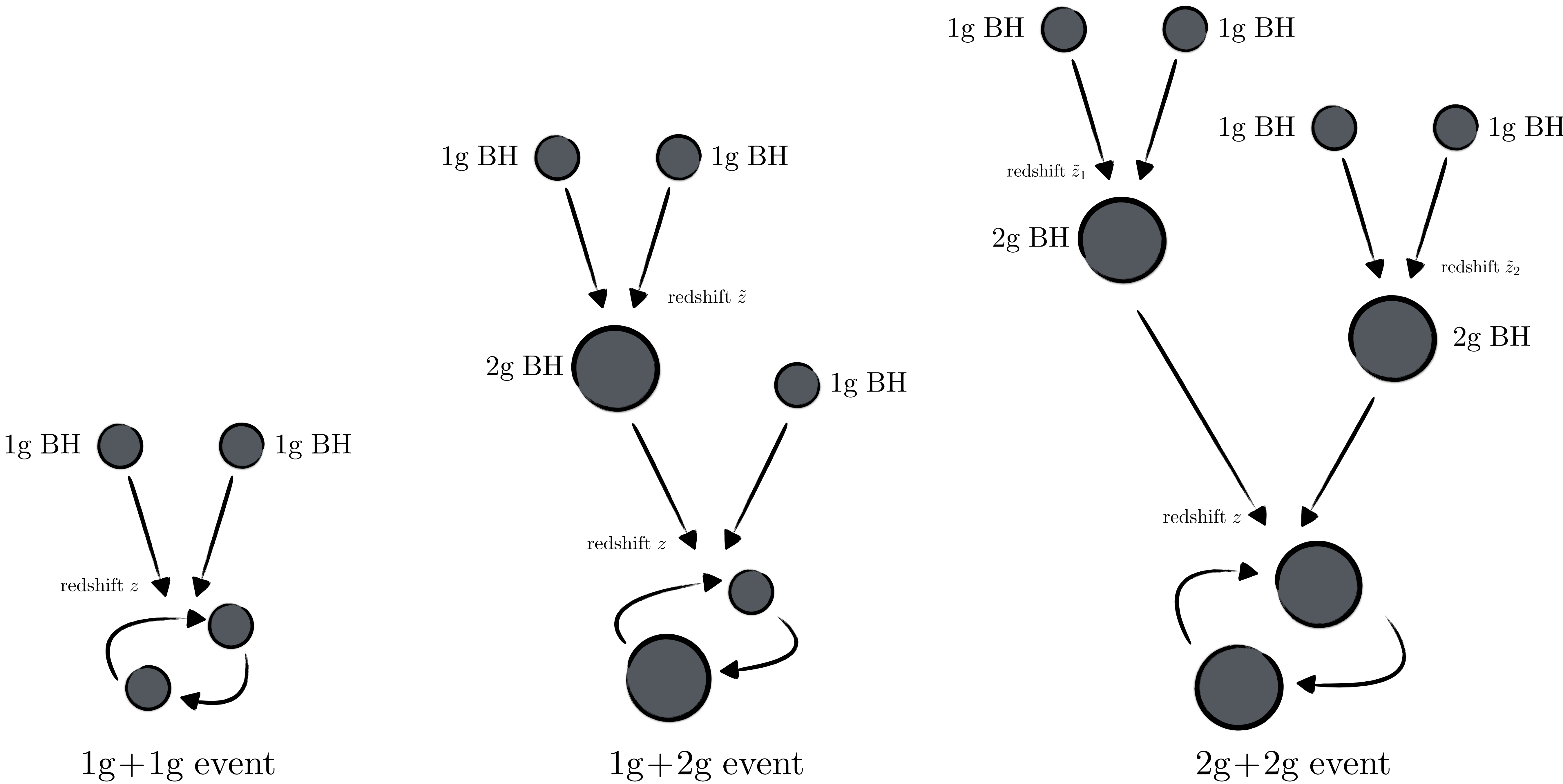
Caveat: a fiducial binary

- Progenitor stars ~30 $M_\odot$
- BH binaries total mass **13.5** $M_\odot$
- Mass ratio **q=0.8**
- Maximally spinning BHs



Can we infer previous mergers happened?

Preliminary

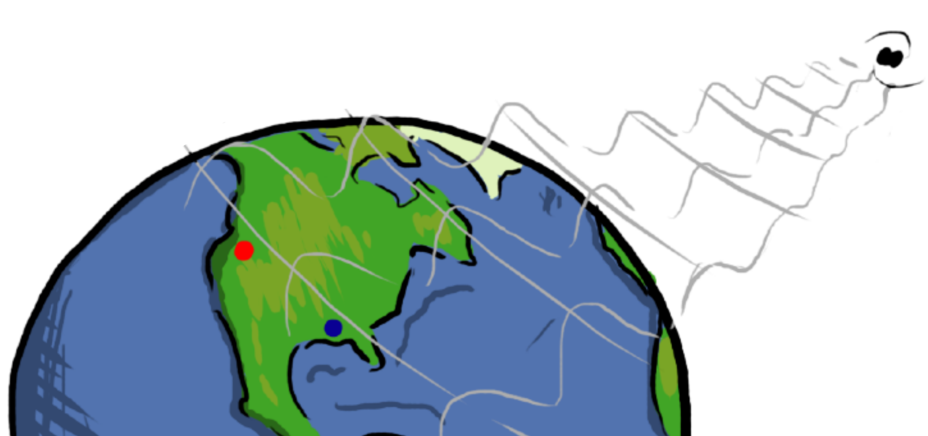


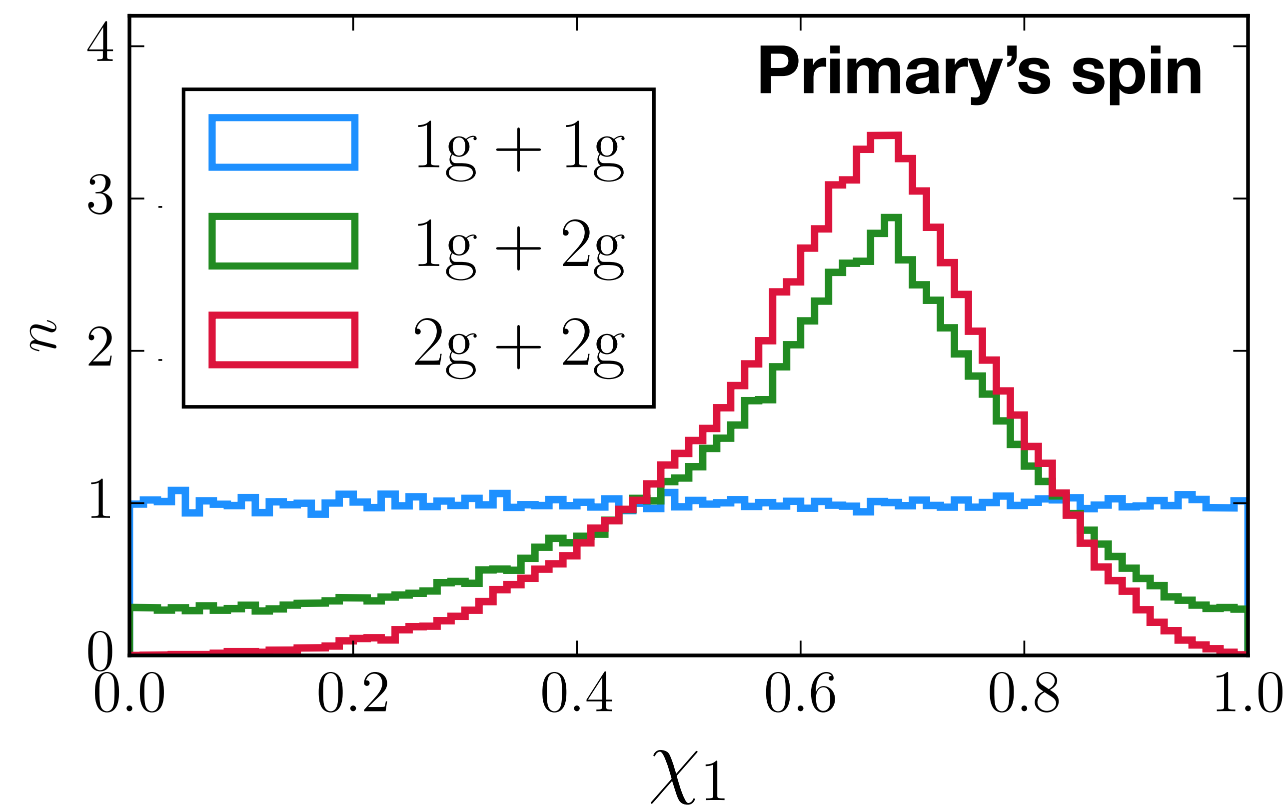
Bayesian model comparison is under way… **DG** Berti in prep

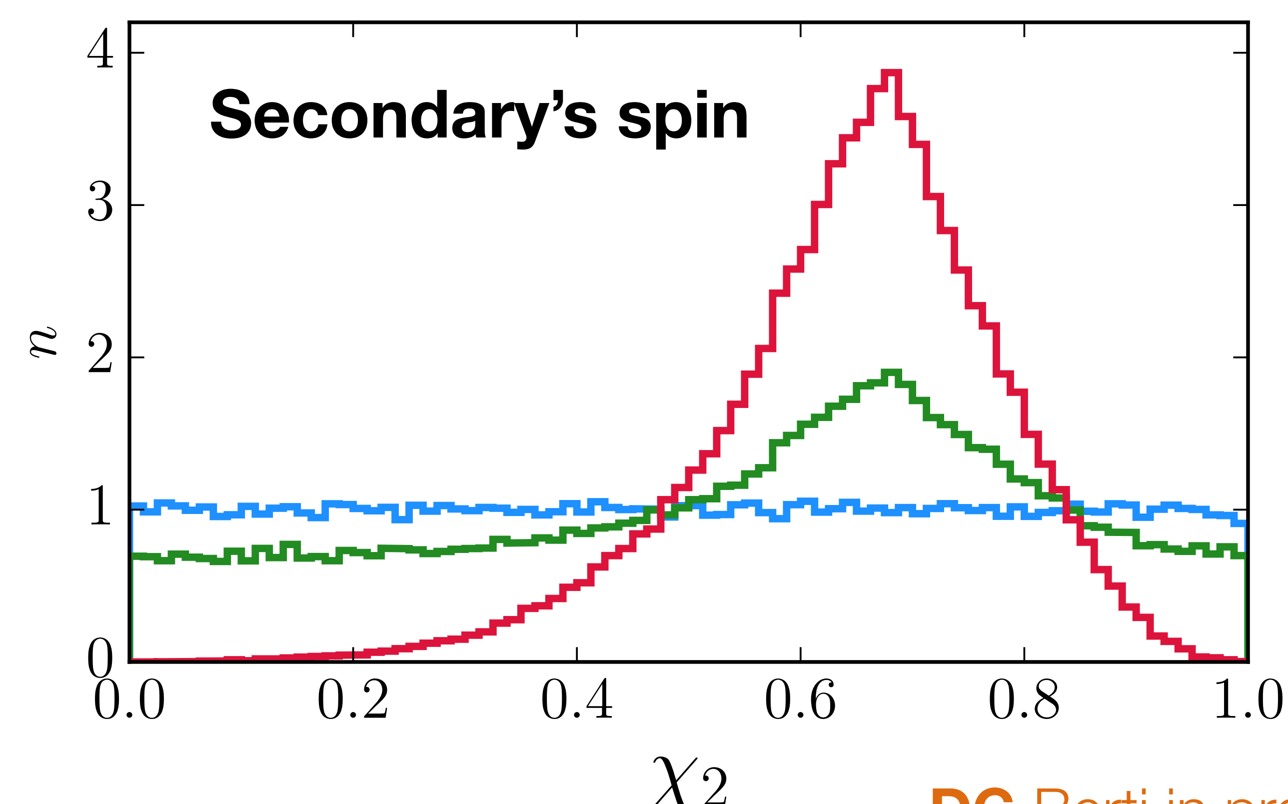
Spins, 1st and 2ng generations

- At merger, the binary's orbital angular momentum has to be converted into spin
- More or less whatever you do wher you merge to BHs, you get ~0.7!

Spins remember previous mergers!

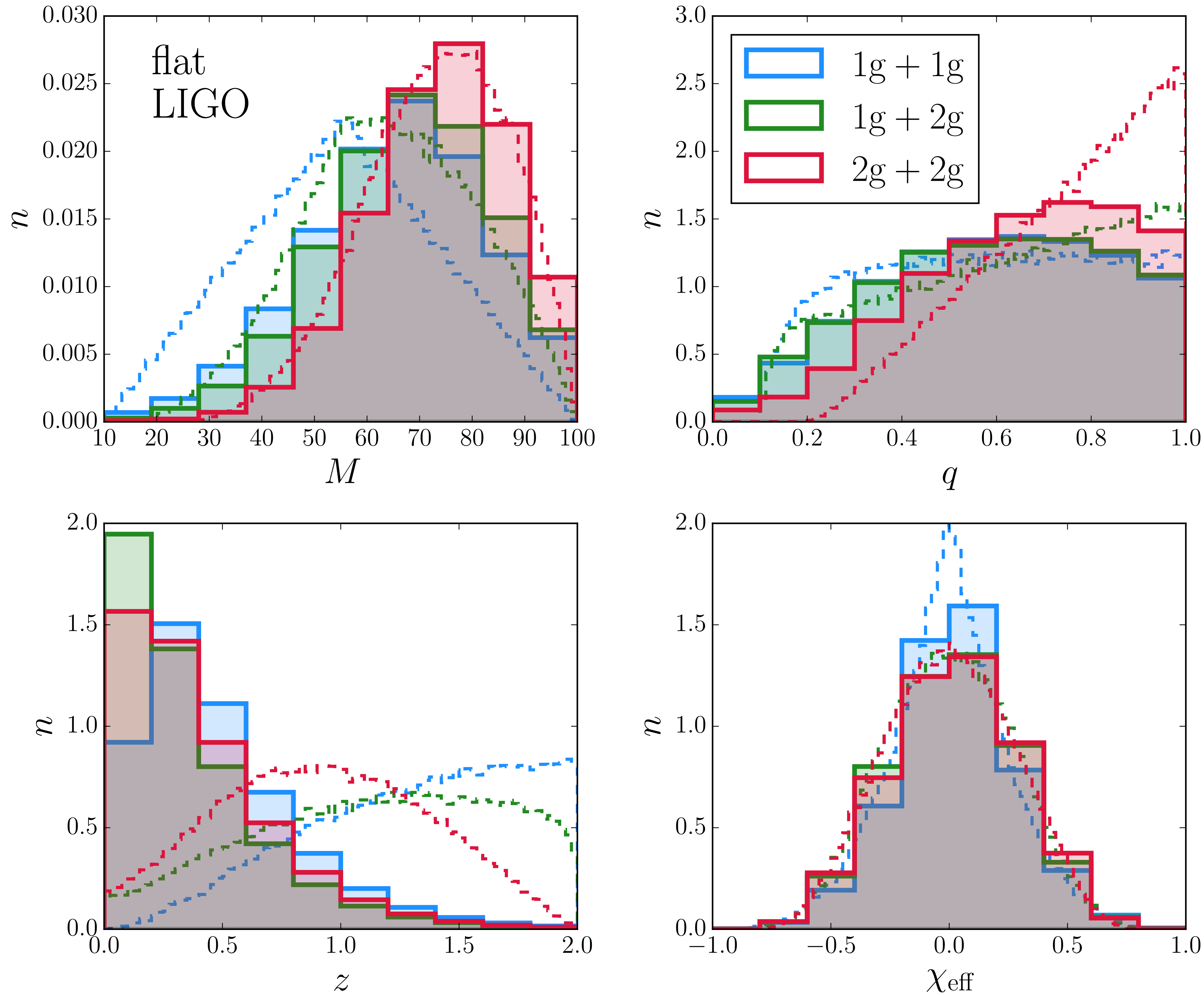






DG Berti in prep

More mergers means…



Mergers means:

- more massive
- equal mass
- closer
- higher spins

Analysis:

- filter SNR
- measurement errors, spread over multiple bins
- Bayesian model comparison

DG Berti in prep

Try this at home

precession: new open-source python module

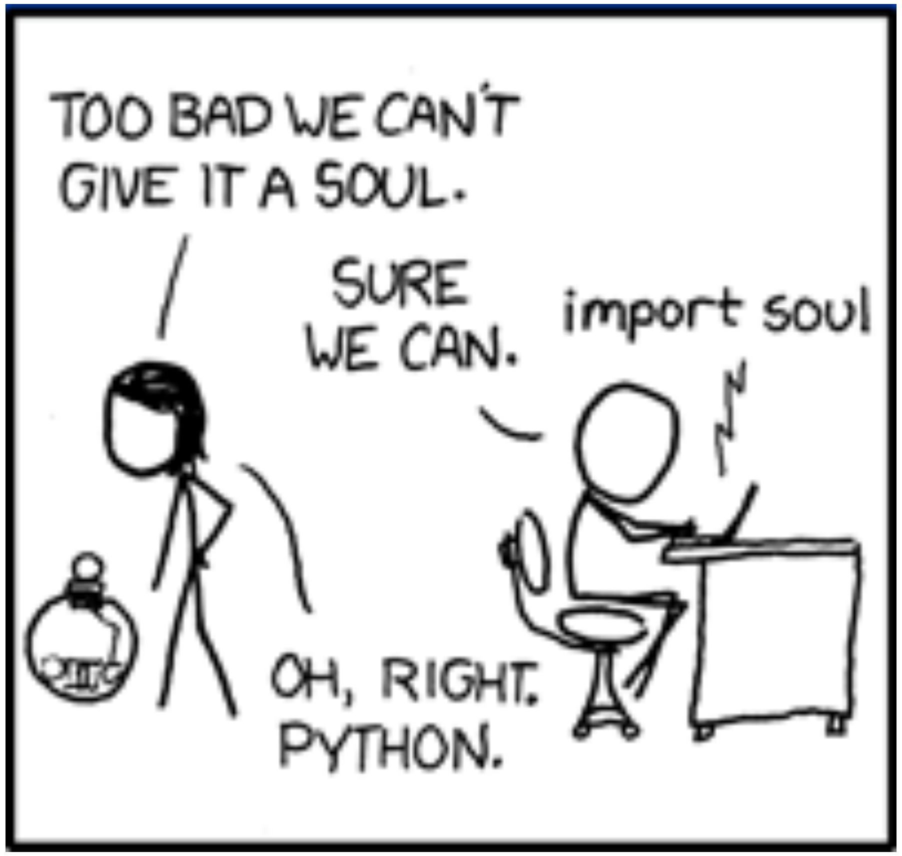
Distributed on **GitHub,** uploaded on the Python package index (**pip**)

I'm easy…

```
pip install precession
>>> import precession
```

Features

1. Precessional dynamics
2. Orbit-averaged inspirals
3. Precession-averaged inspirals
4. Superkick predictions
5. API documentation
6. Tests and tutorial



… check me out!

davidegerosa.com/precession

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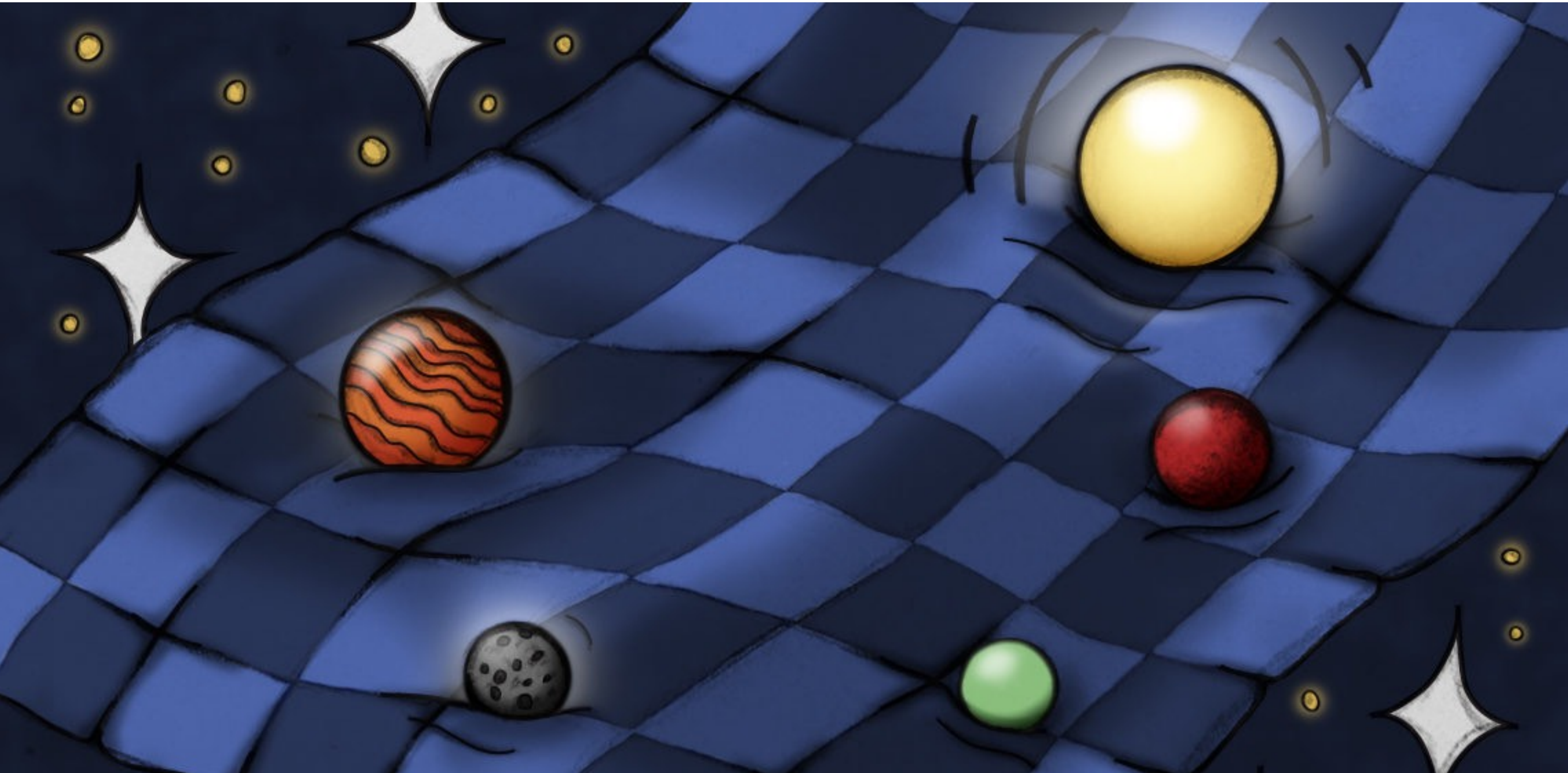

Interested? Here to know more

- Astrophysical spin modeling

Gerosa+ 2013, arXiv:1302.4442

- PN dynamics: spin morphologies, transitions, etc

Gerosa+ 2015, arXiv:1506.03492

- First and second generation black holes

Gerosa & Berti 2017, in preparation

- PRECESSION code

Gerosa & Kesden 2015, arXiv:1605.01067