The underlying simplicity of precessing black-hole binaries

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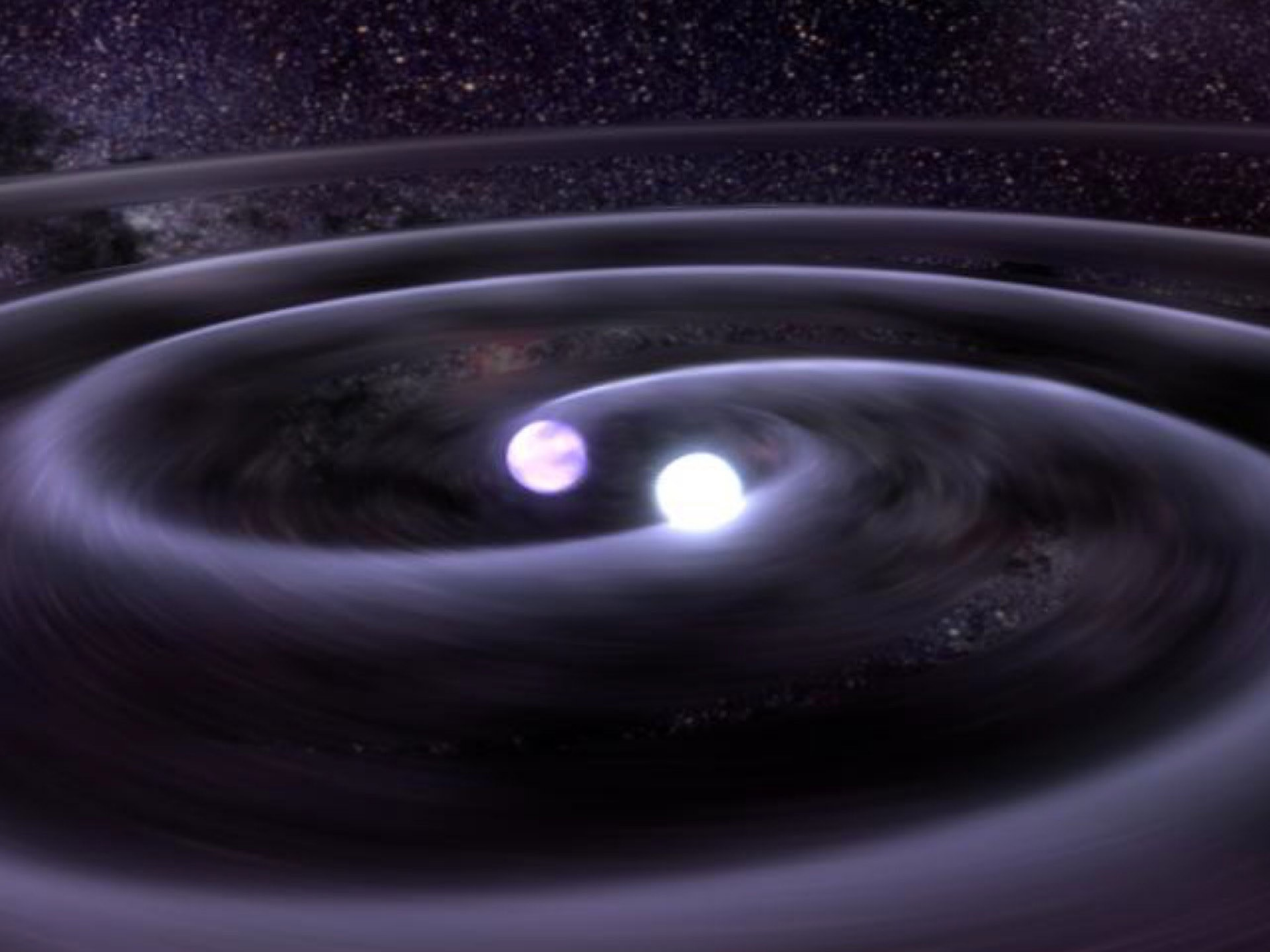
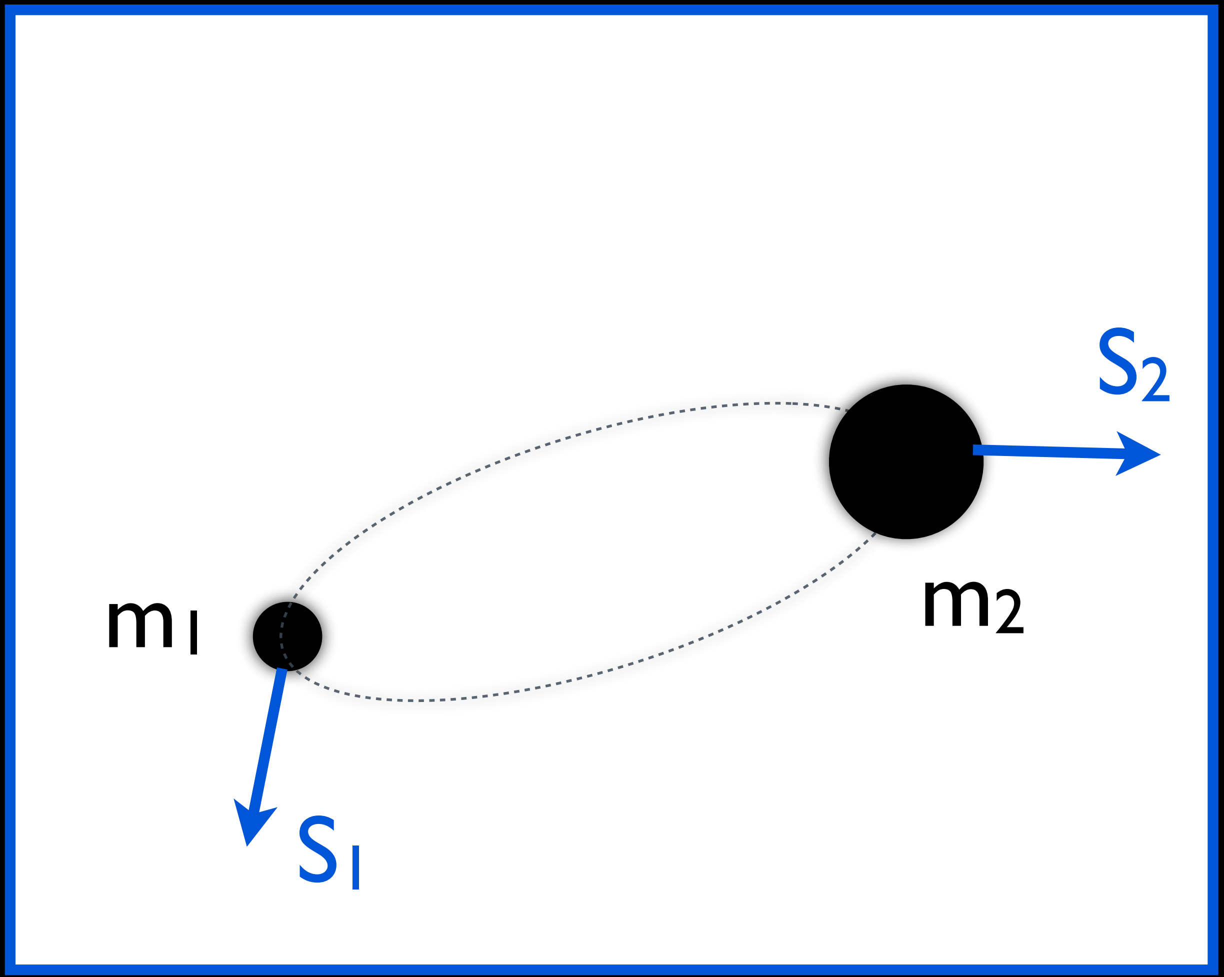
Geneva



Masses: m_1, m_2
Spins: $\mathbf{S}_1, \mathbf{S}_2$

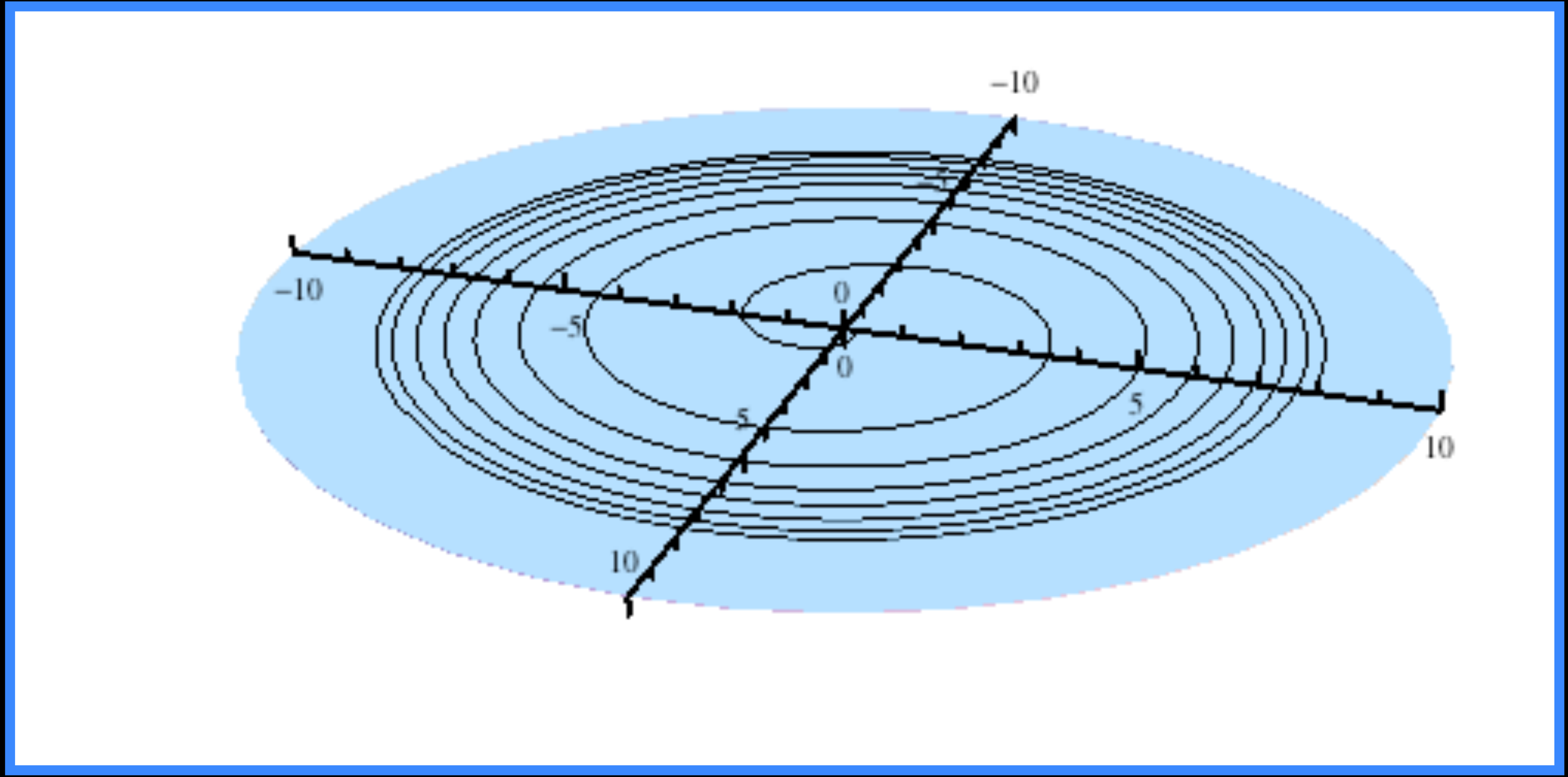
(8 parameters)



useful combinations:

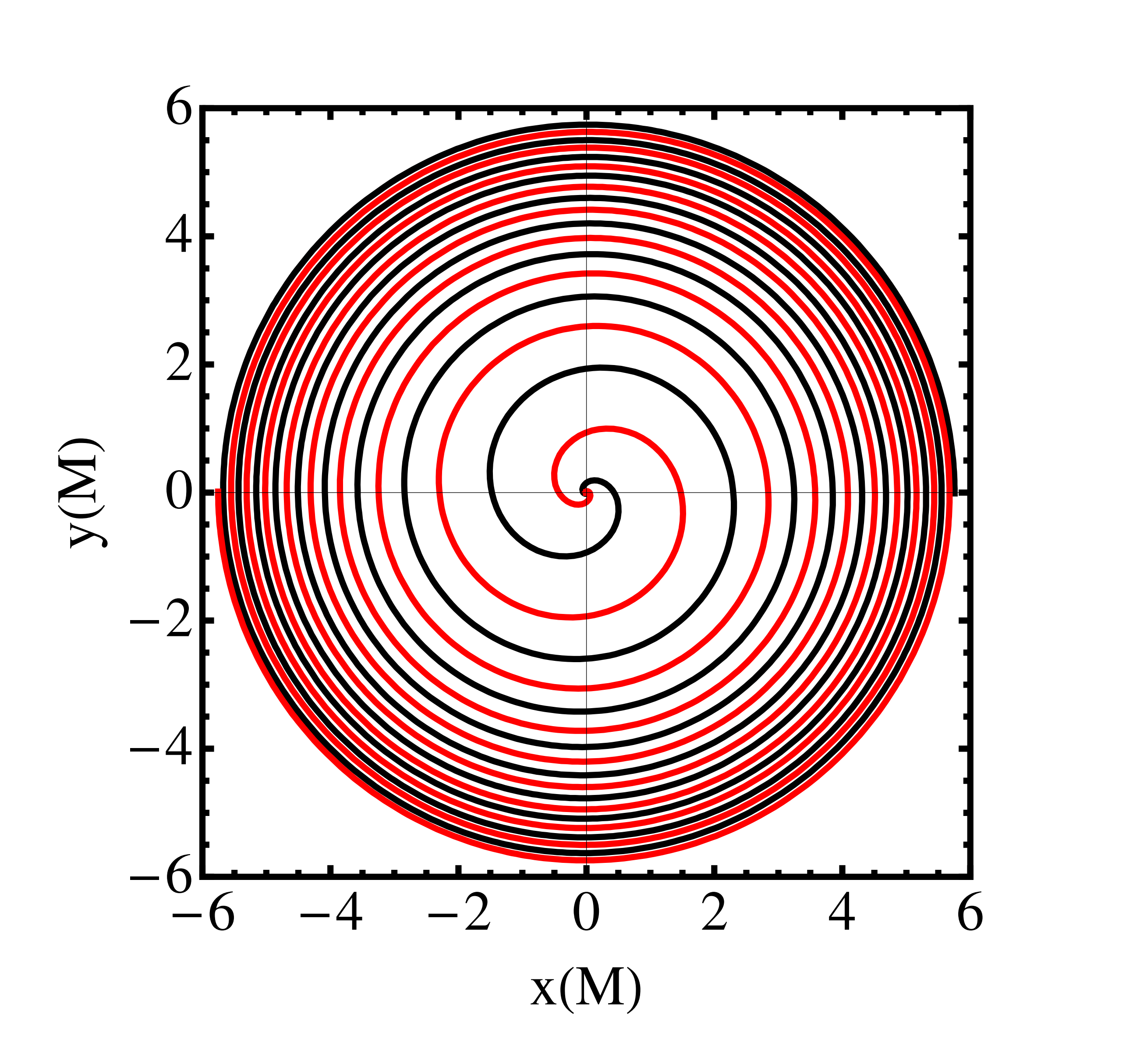
$$M = m_1 + m_2$$
$$q = m_2 \,/\, m_1$$
$$\eta = m_1\, m_2 \,/\, M^2$$
$$\chi = S/m^2$$

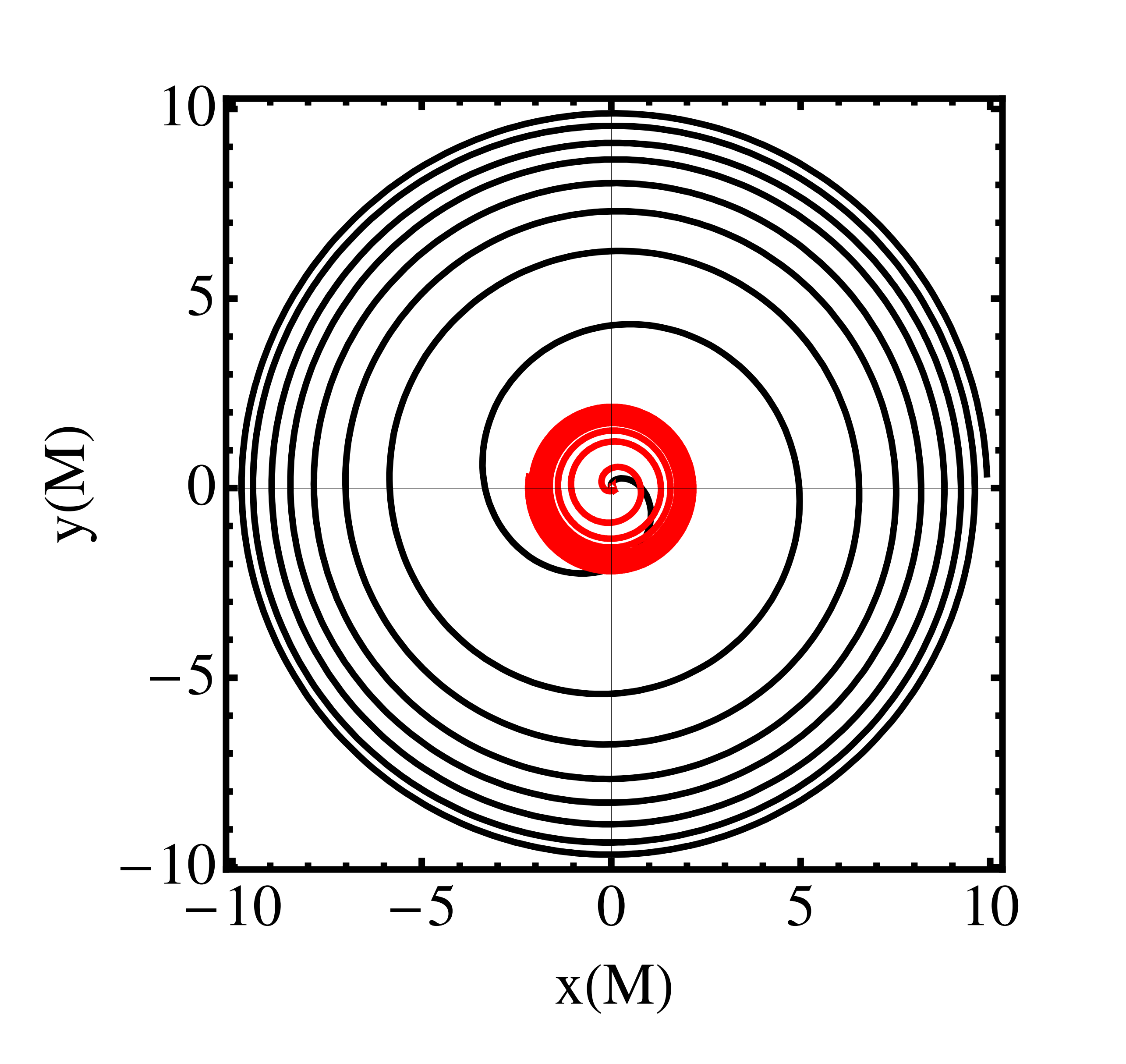
Nonspinning black holes



(Mass ratio 1:4, $\eta = 0.16$)

Nonspinning black holes





Amplitude:

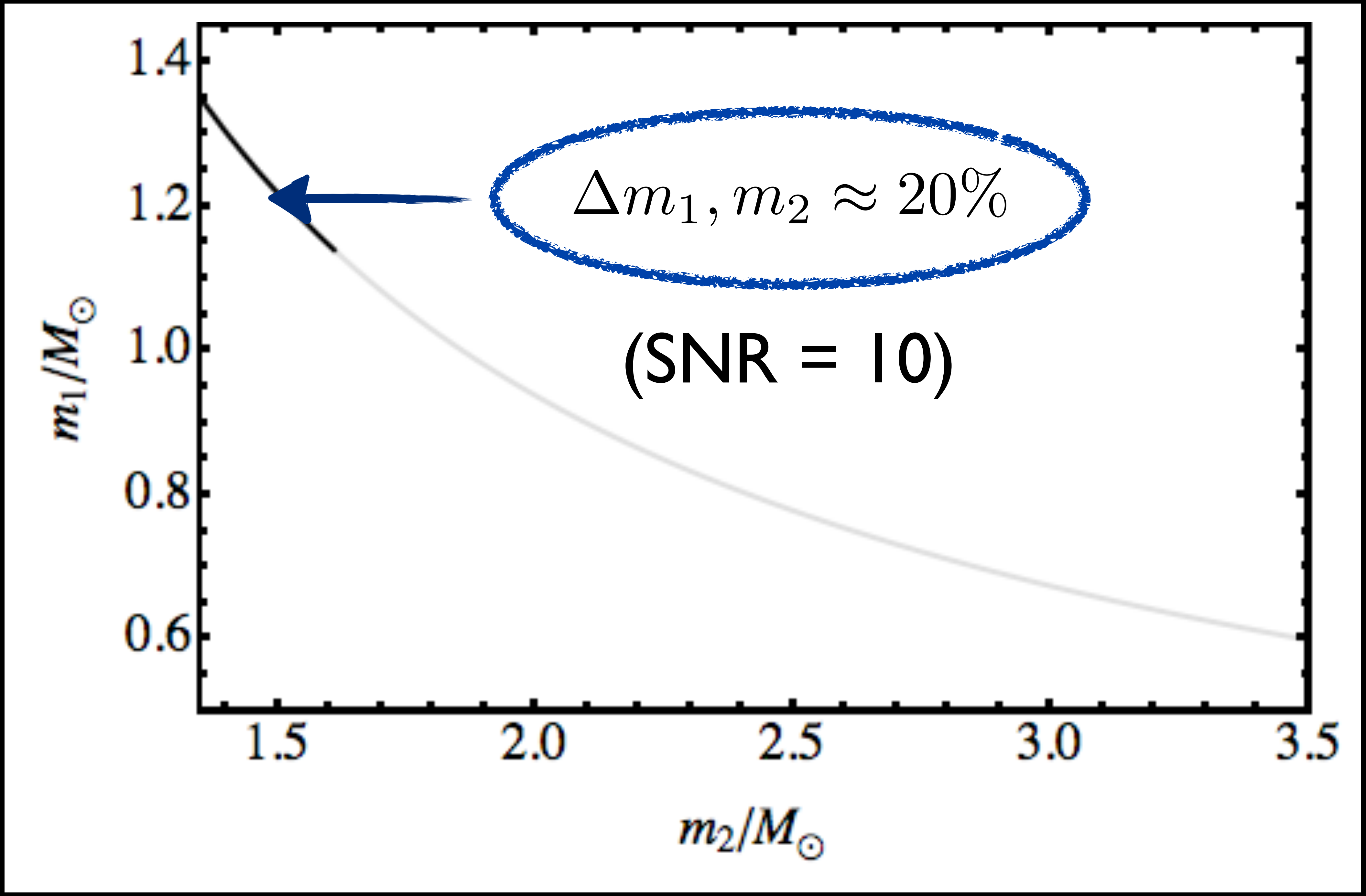
Optimally oriented (face on)

Edge on

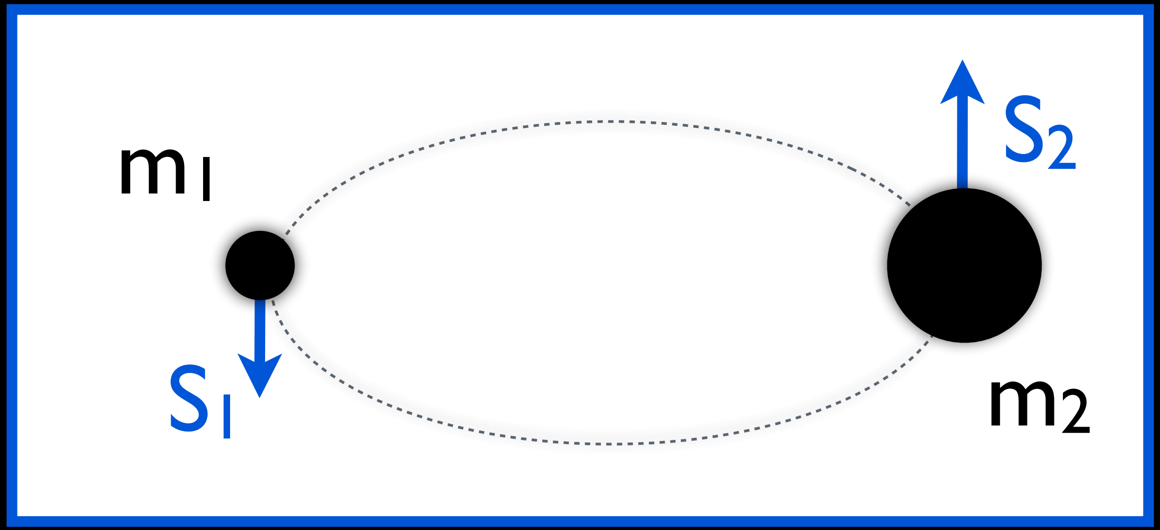
Signal shape is independent of orientation

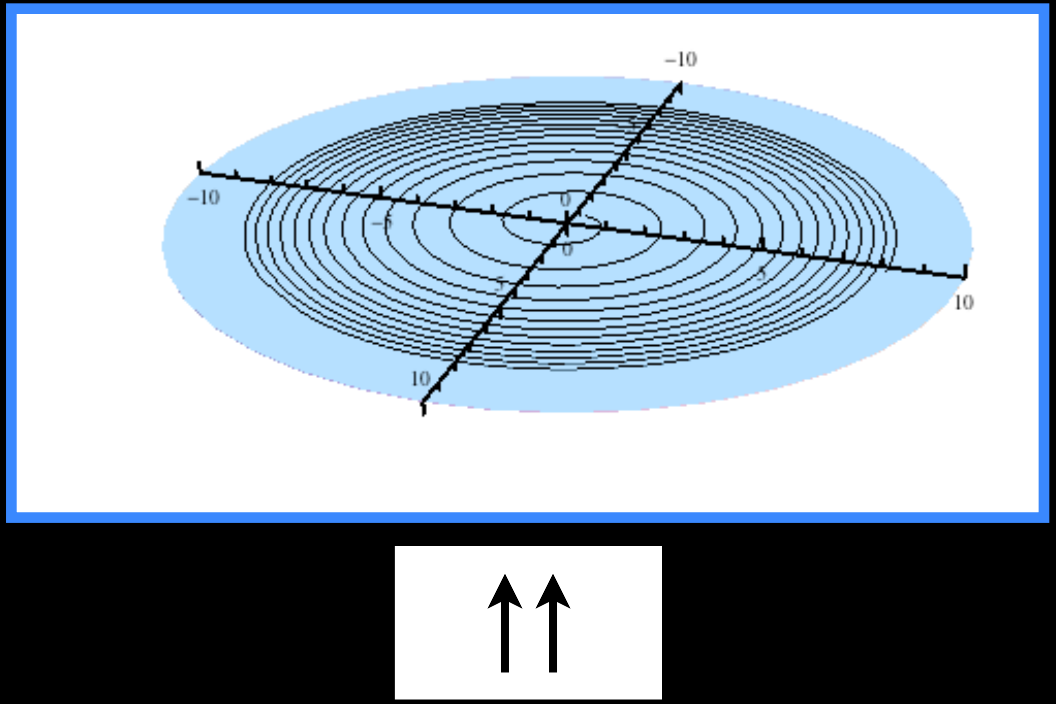
Key information is in the phasing

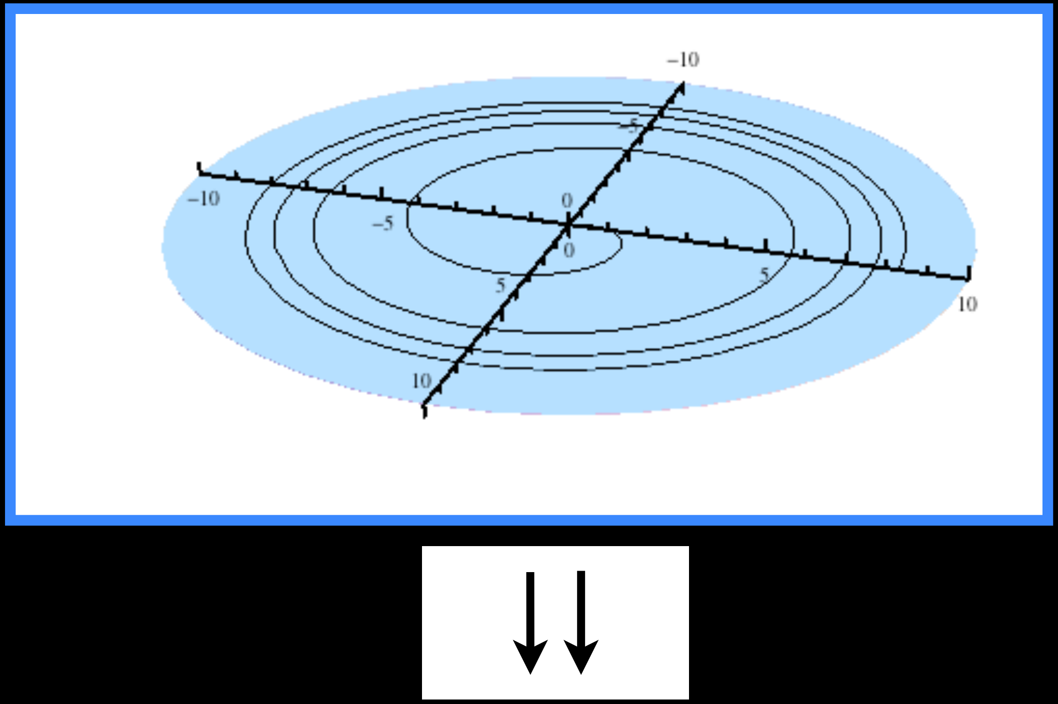
Mass measurements



Aligned spins







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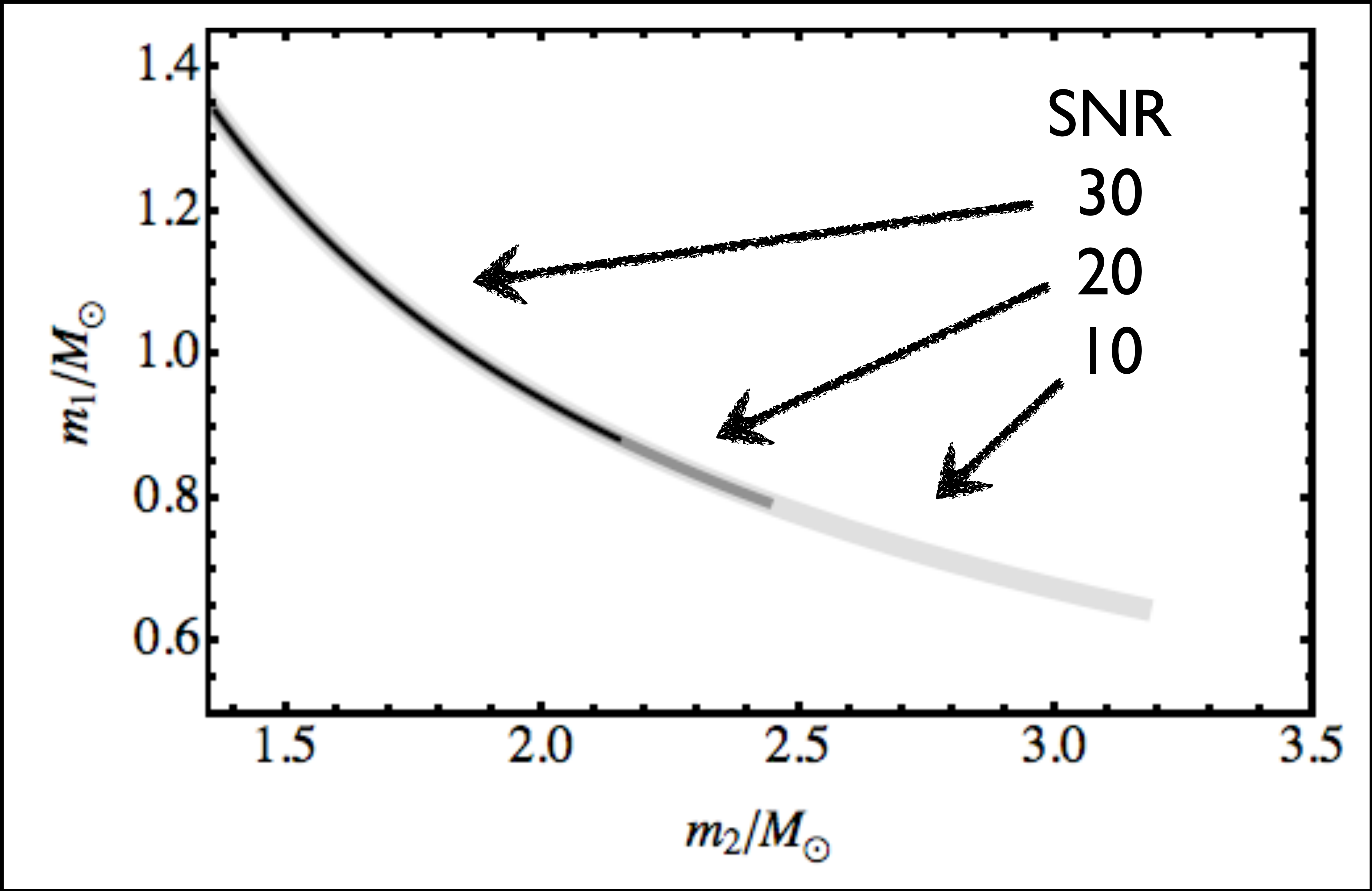
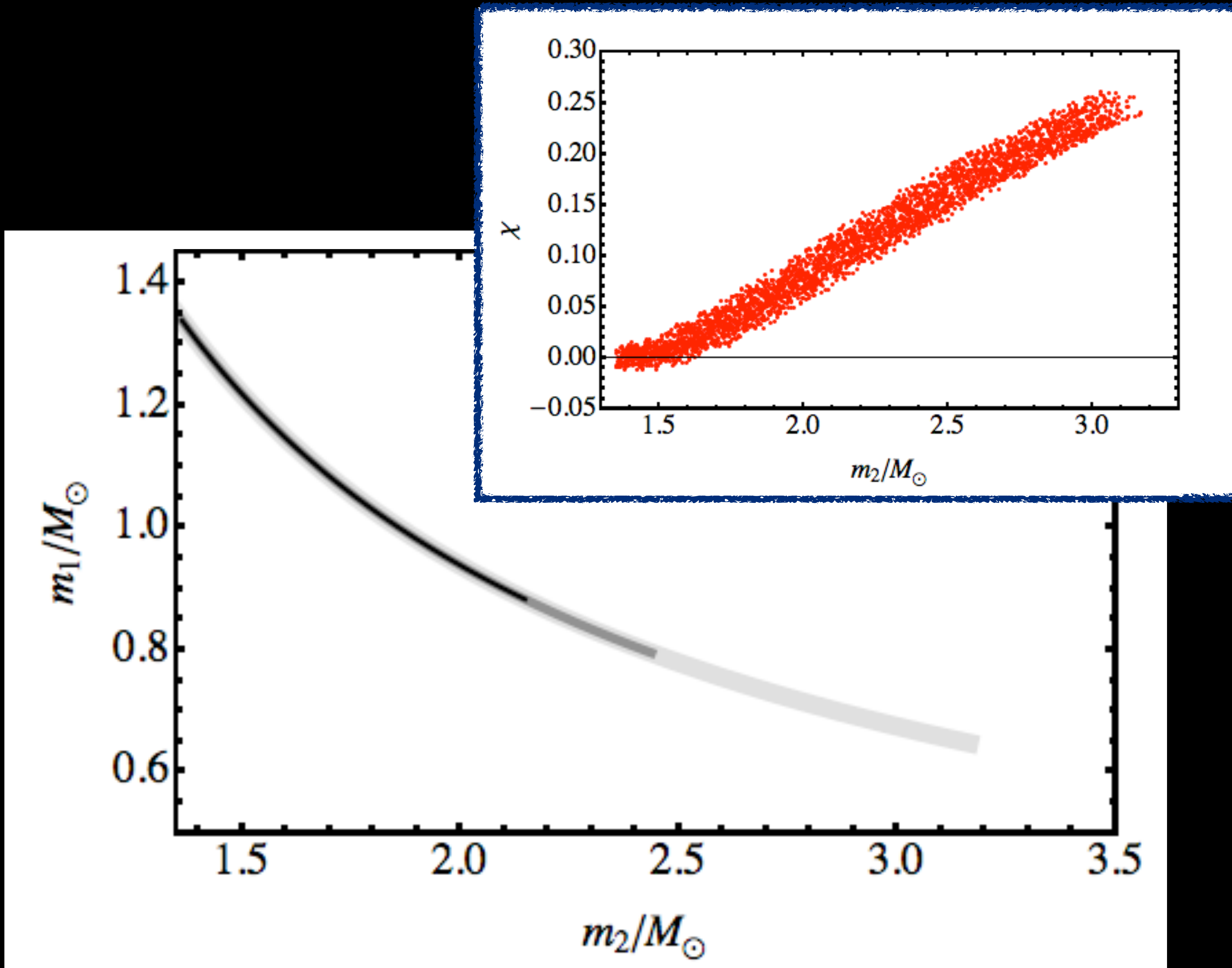




0.30
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
χ
1.5
2.0
2.5
3.0
$m_2/M_\odot$
1.4
1.2
1.0
0.8
0.6
$m_1/M_\odot$
1.5
2.0
2.5
3.0
3.5
$m_2/M_\odot$

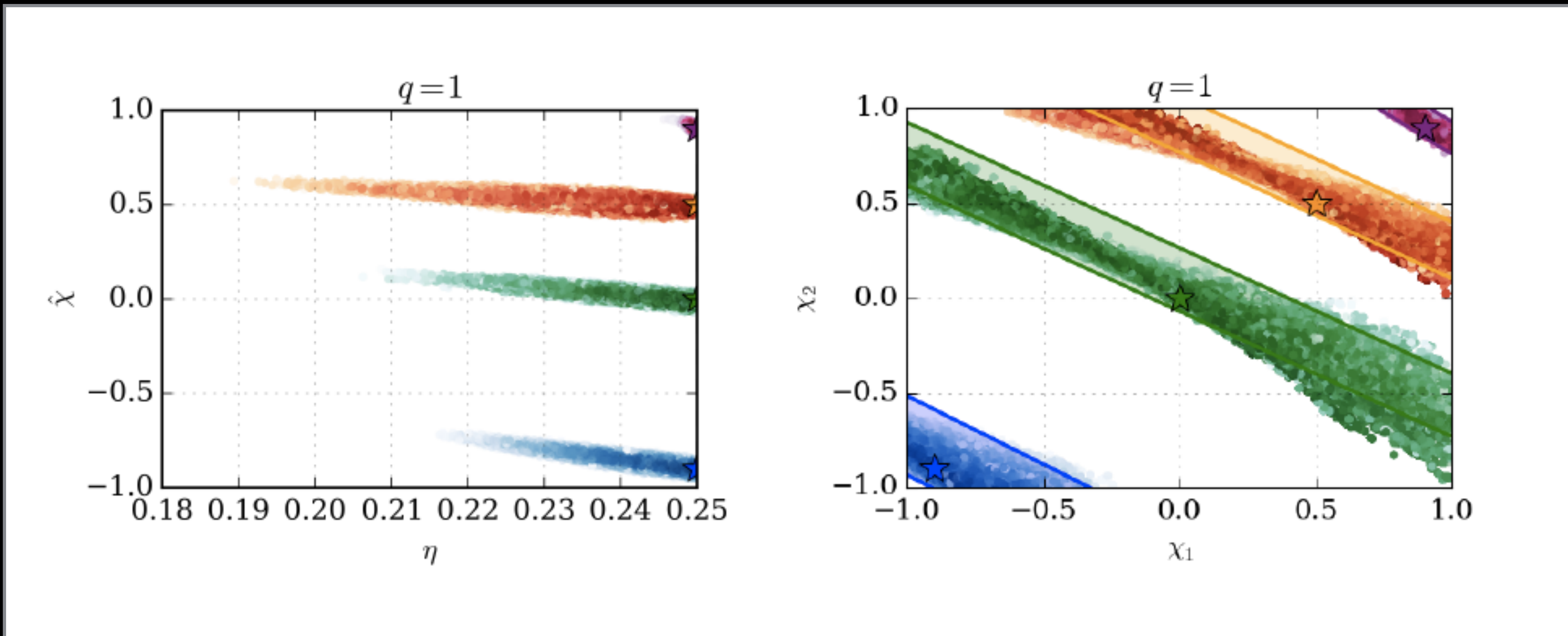
What is “χ”?

χ is a weighted <u>sum</u> of the two spins

χ is the dominant spin effect on the phasing

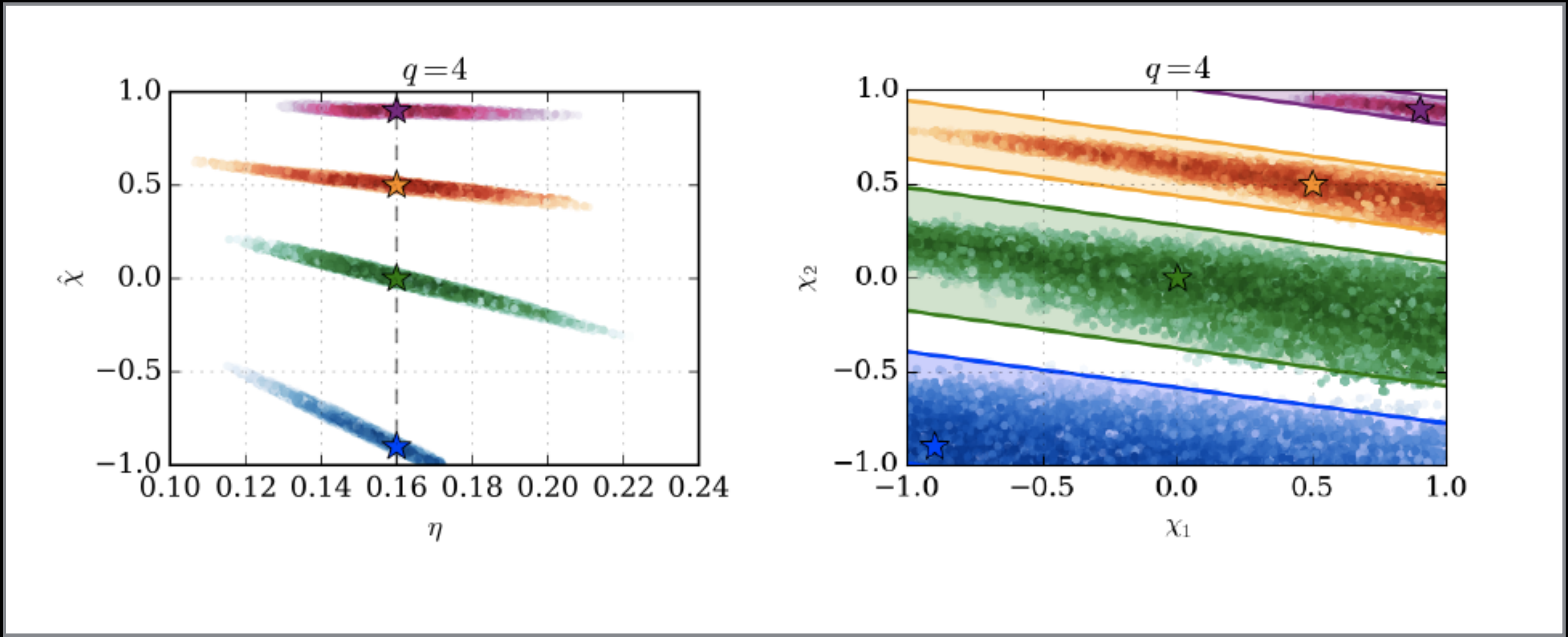
The individual spins have only a weak effect

(50-solar-mass, equal spins)



[Puerrer, Hannam, Ohme (2015, to appear)]

(50-solar-mass, equal spins)



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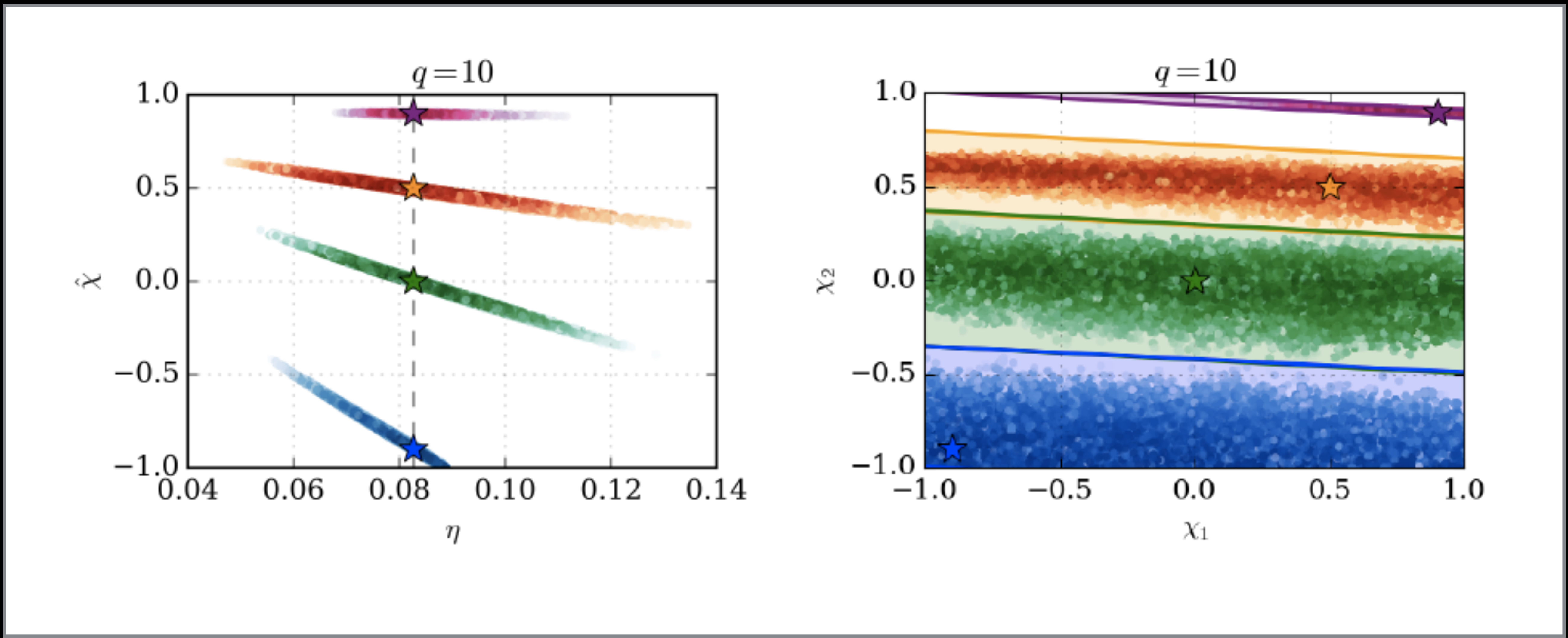
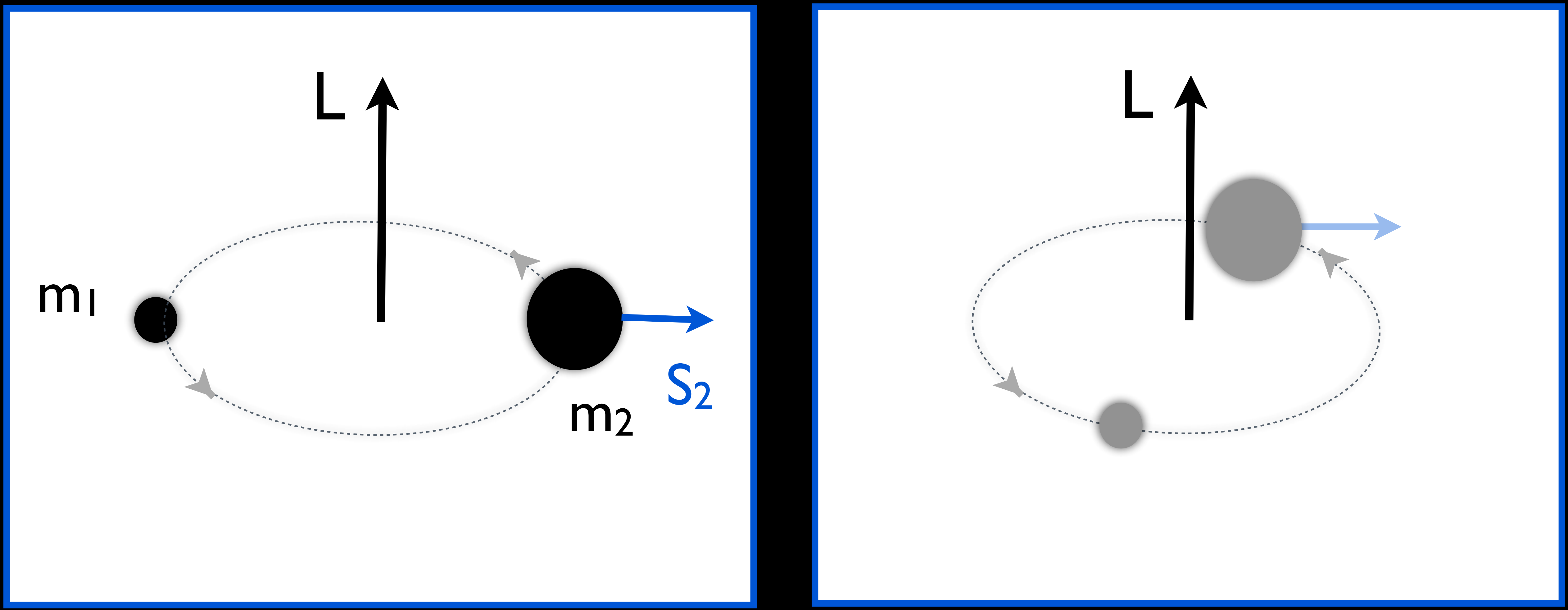


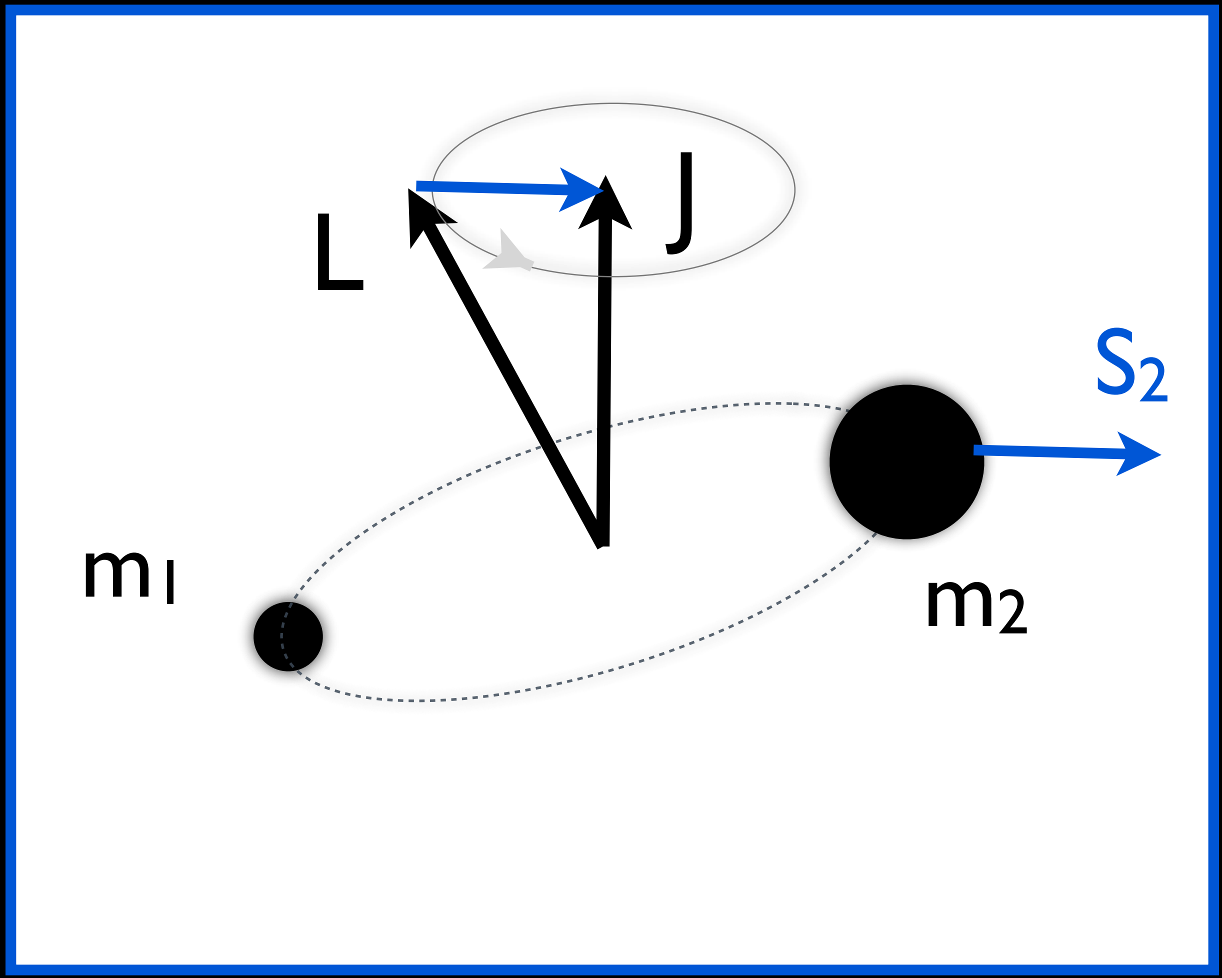
[Puerrer, Hannam, Ohme, 2015 (to appear)]

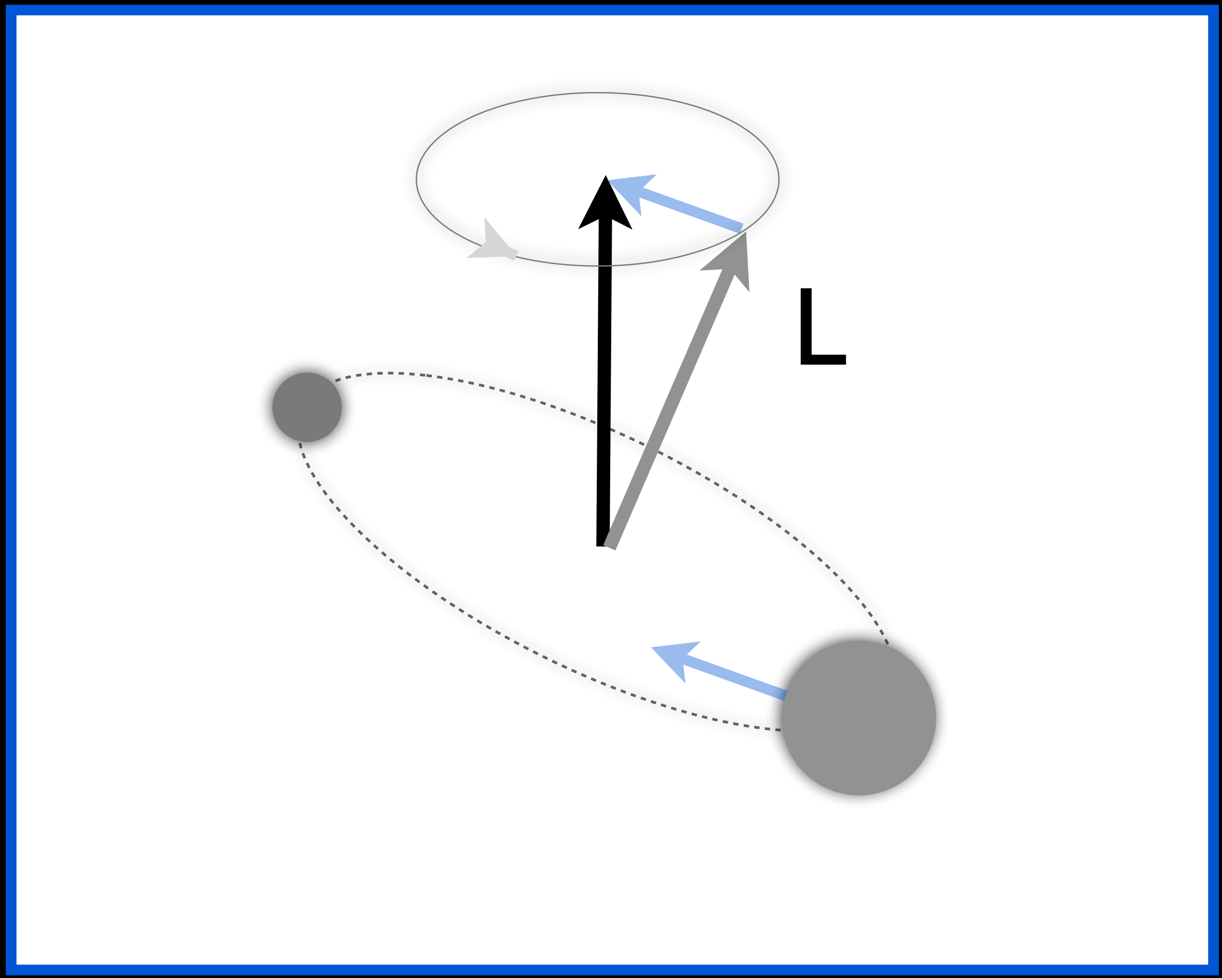
Orbital precession



Newtonian gravity:
L, S_1, S_2 remain fixed

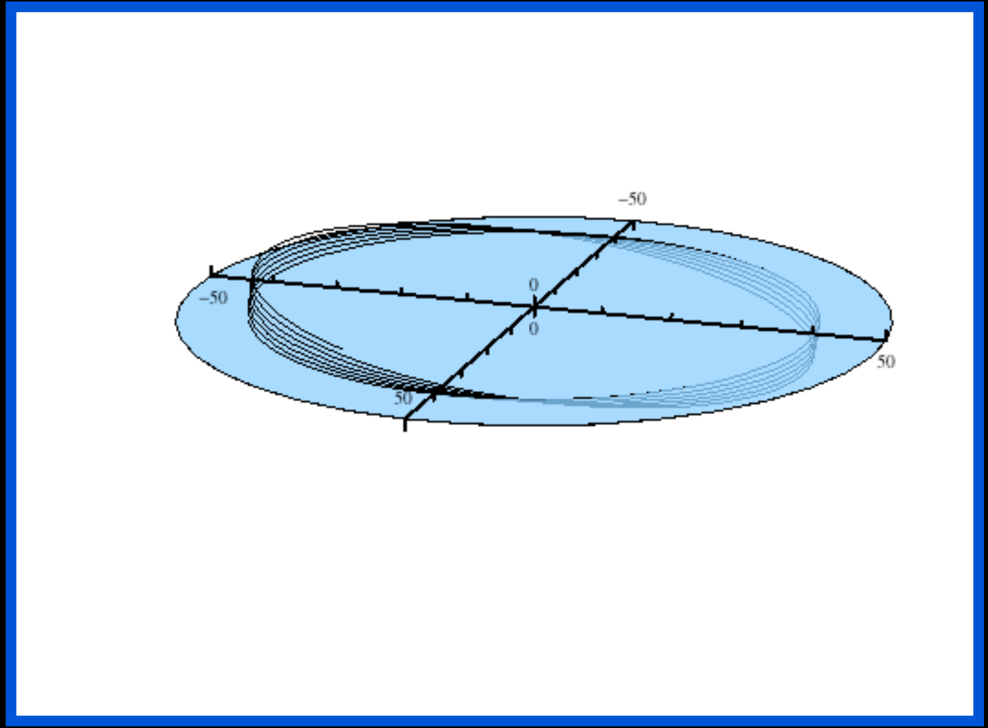
Orbital precession



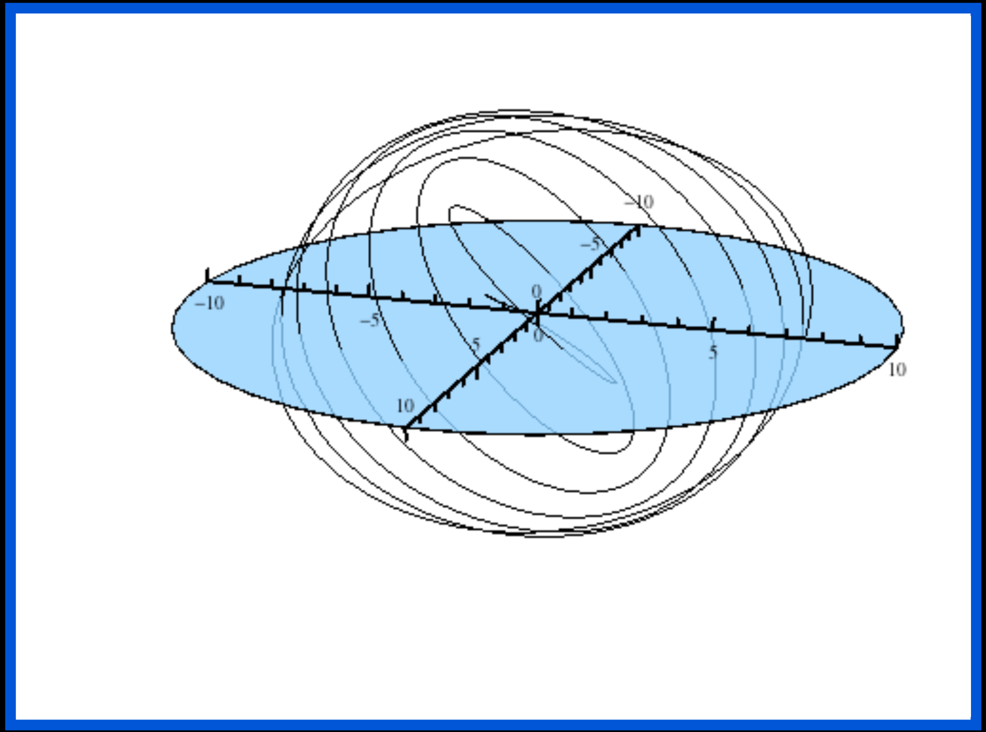


General relativity
(L, S_1, S_2) precess around J

Precessional dynamics

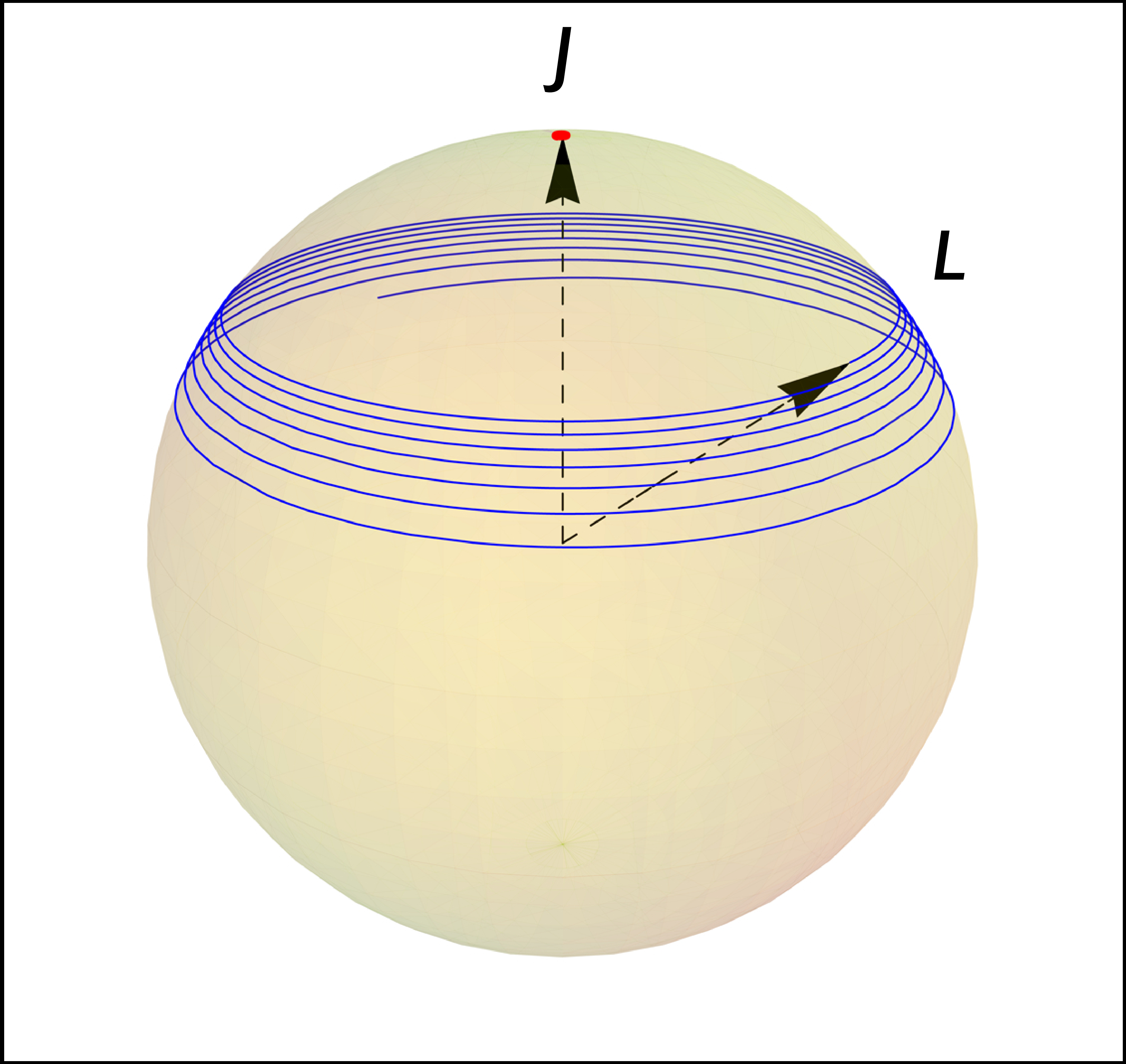


Large separation



Merger

Example:
q=3, $|S_2|$ = 0.75
(in plane)



Orientation dependence

q=3, $|\mathbf{S}_2|$ = 0.75 (in plane)

Observer aligned with J

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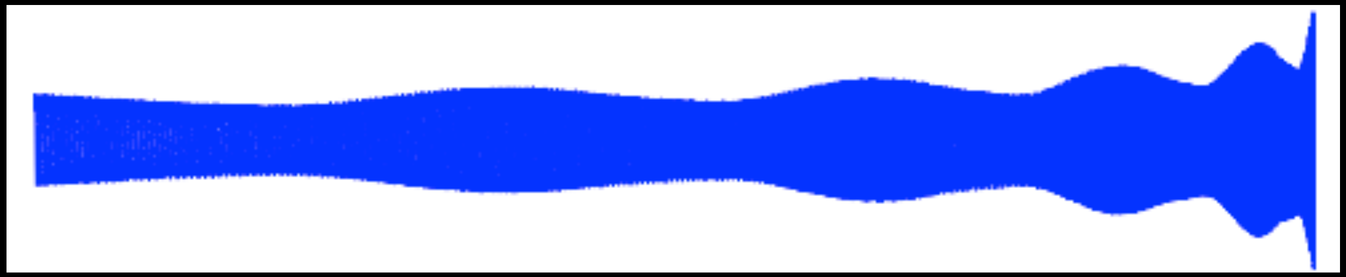
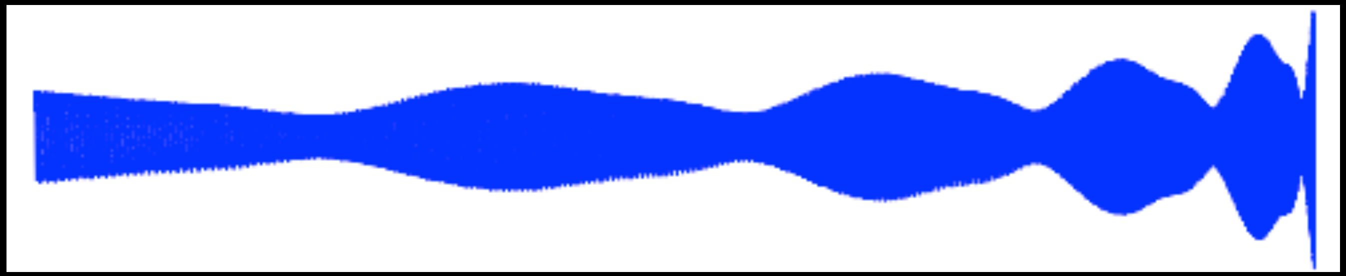


Observer inclined $\pi/6$ to J



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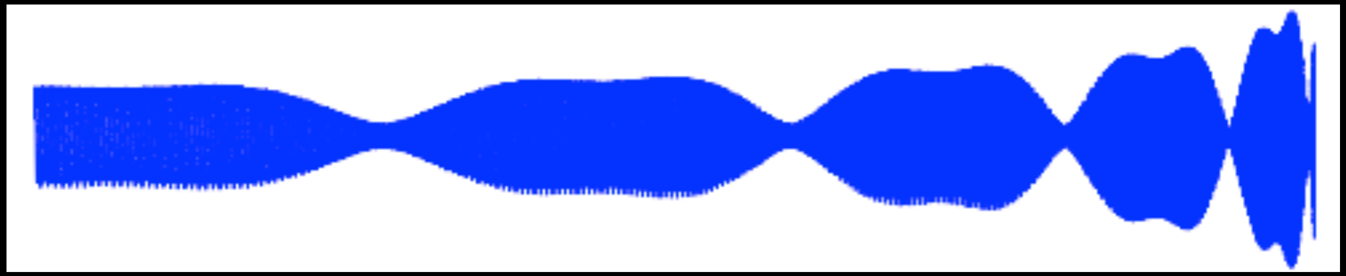


Observer inclined $\pi/2$ to J

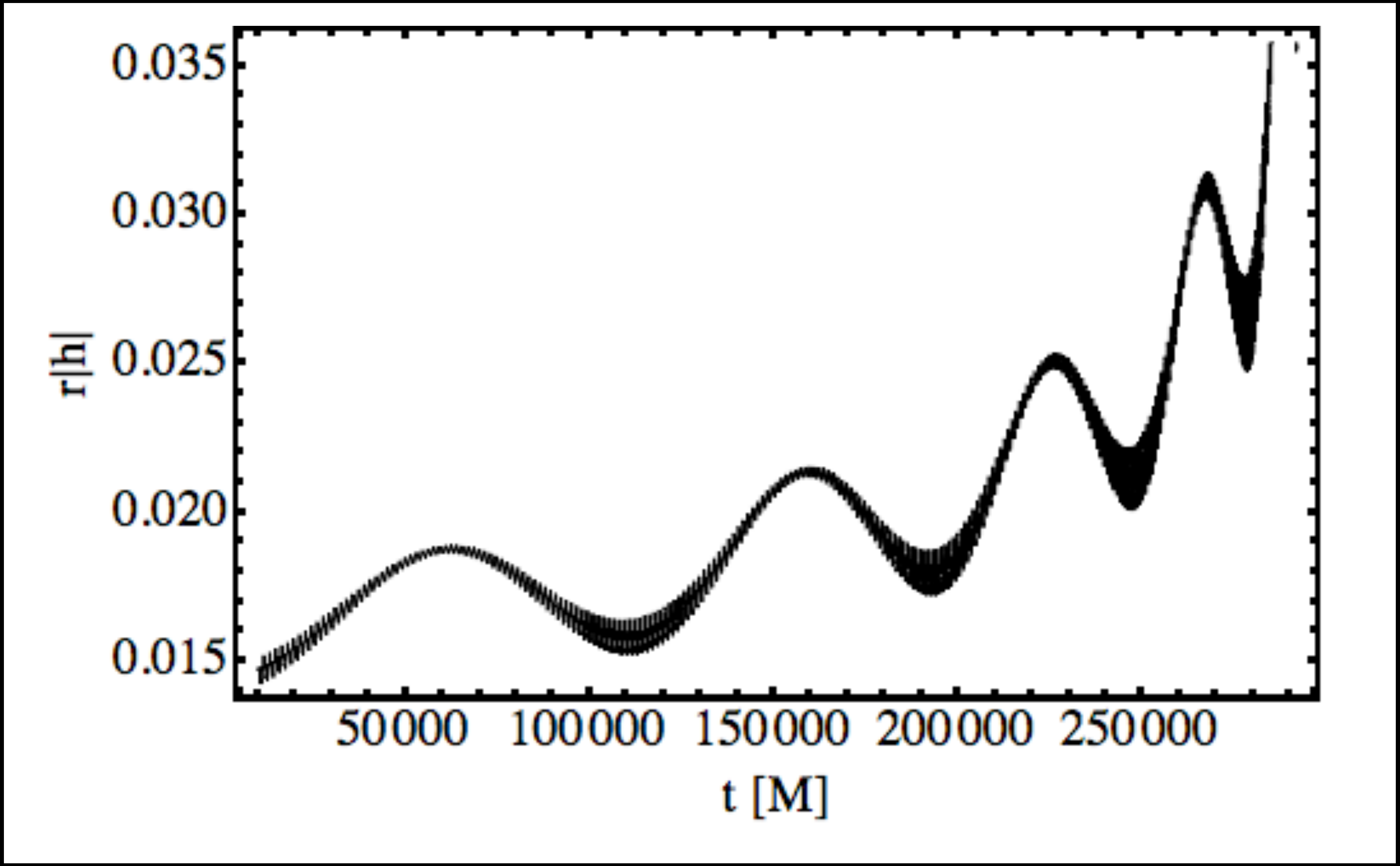
Aside: modelling precession

Precessing waveform =

(non-precessing waveform)

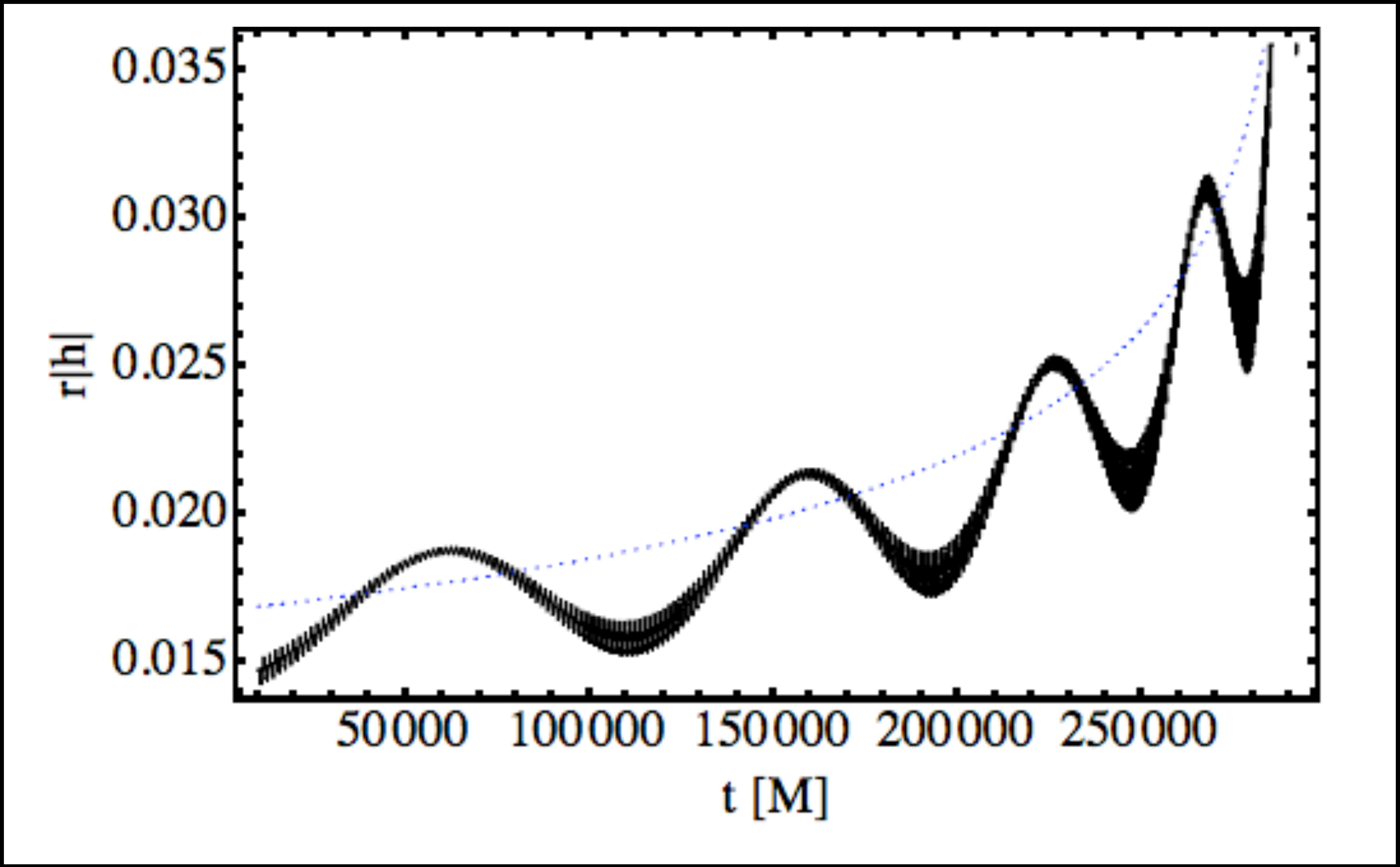
x (time dependent rotation)

(Inclination 2.8 rad)



[Schmidt, Hannam, Husa (2012)]

(Inclination 2.8 rad)



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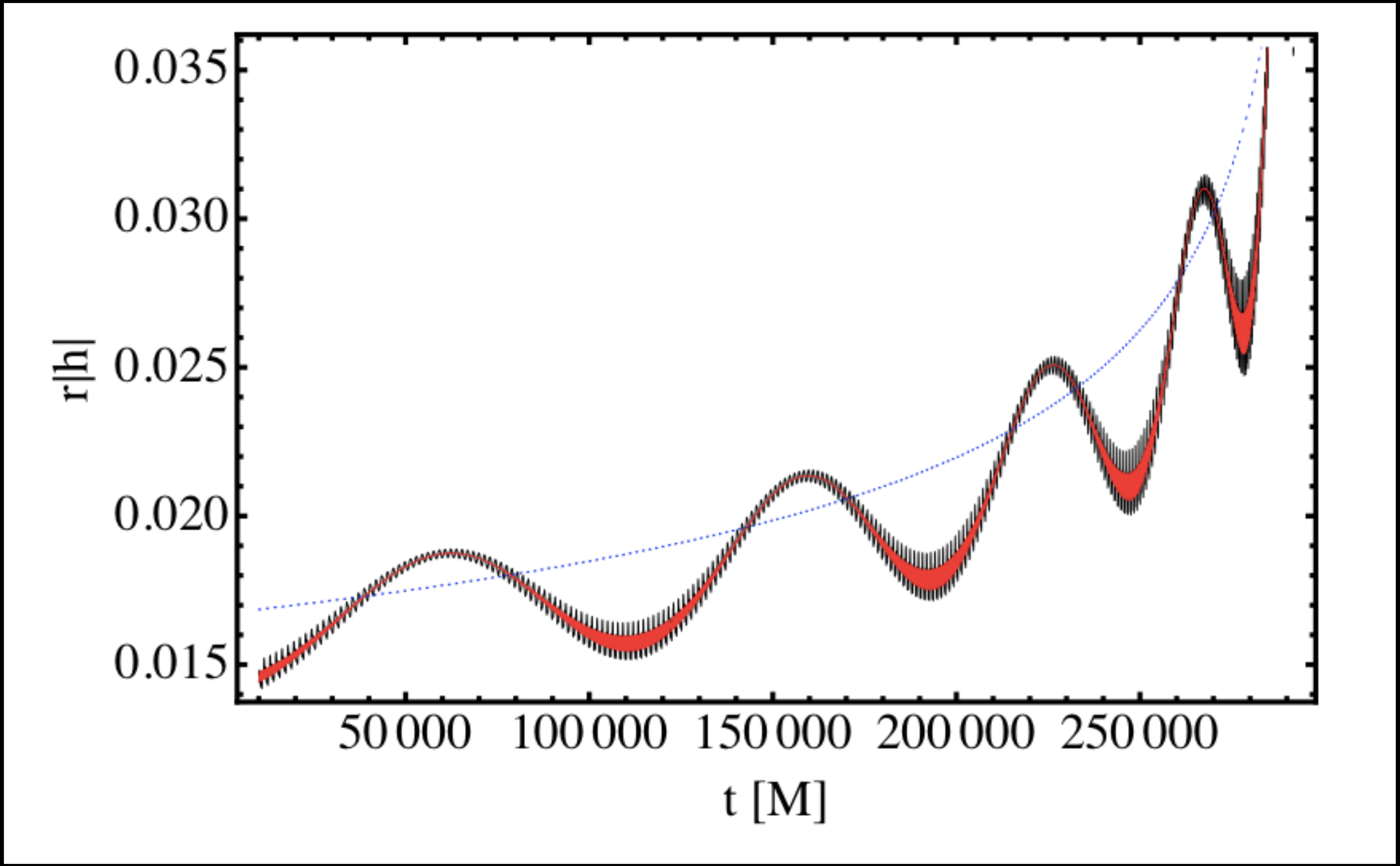


[Schmidt, Hannam, Husa (2012)]

Aside: modelling precession

Precessing waveform =

(non-precessing waveform)

x (time dependent rotation)

Accurate non-precessing models are crucial

(See next talk by Sascha Husa)

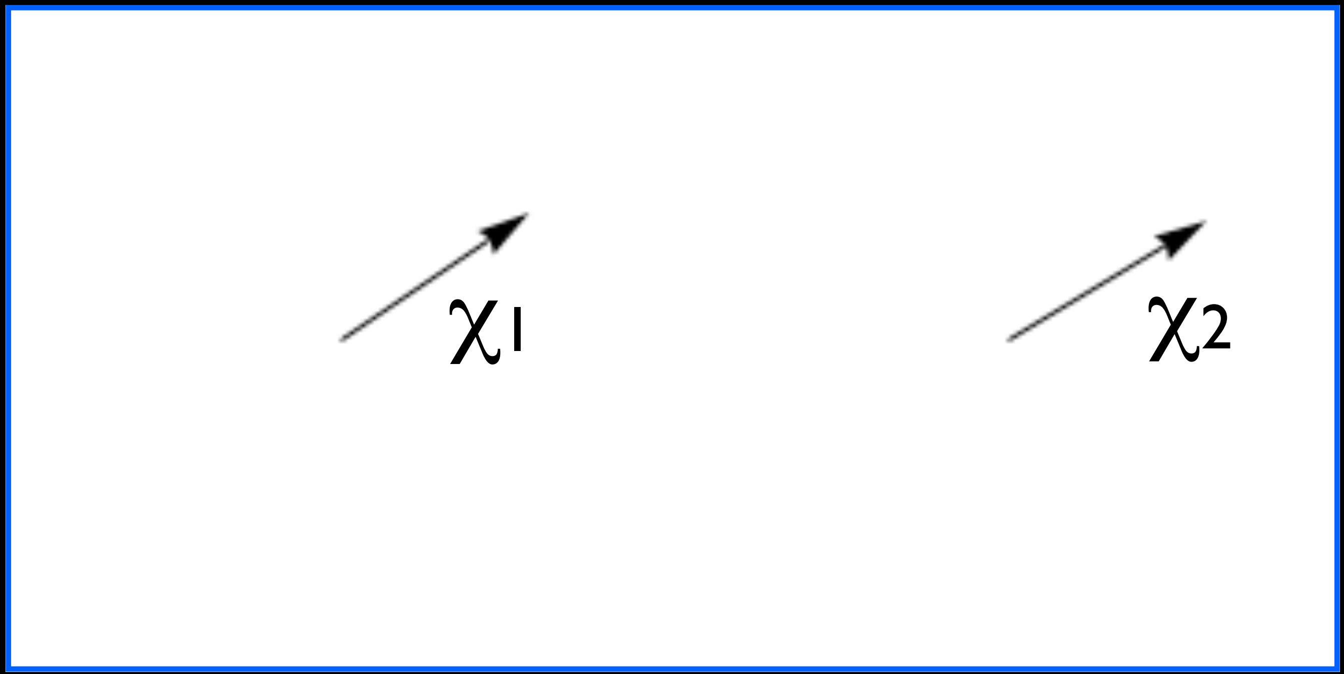
For non-precessing binaries we
used only *one* spin parameter

Can we use the same trick for precession?
i.e., replace
the four in-plane spin components
with *one* "precession spin"?

A precession parameter

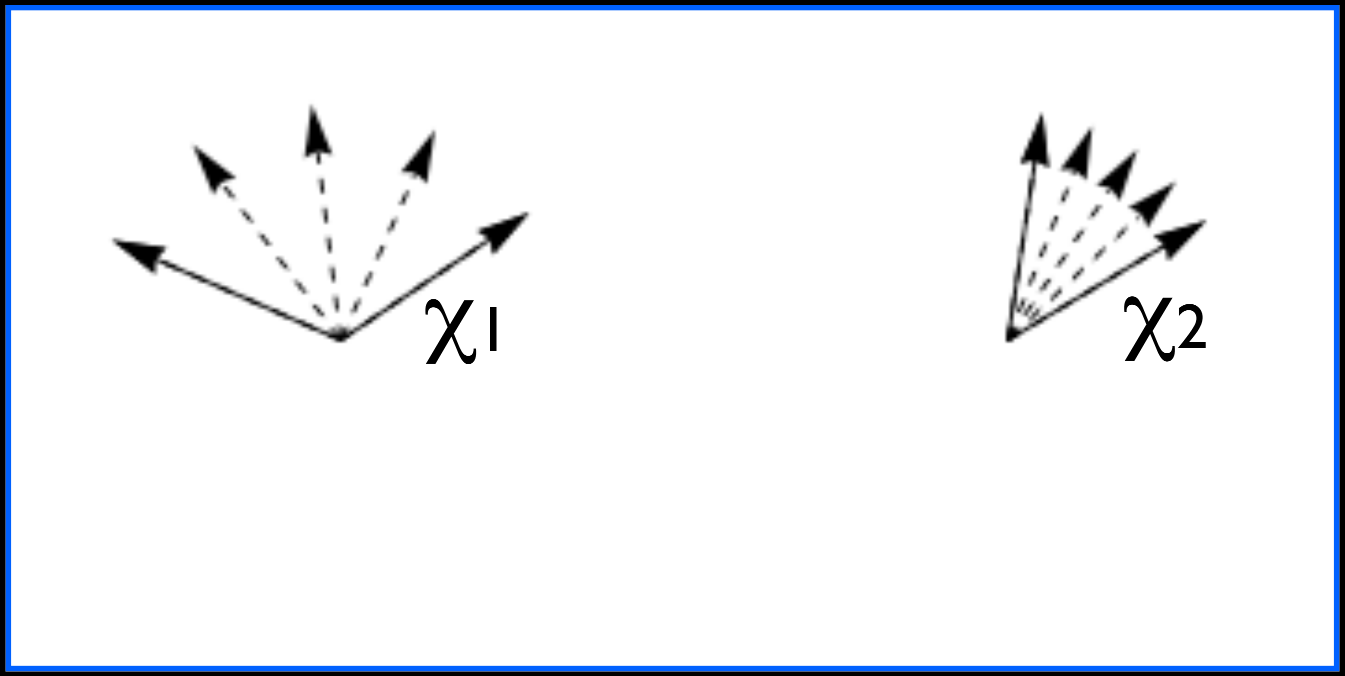
- Consider one spinning BH
- spin rotates in the plane during evolution
- Precession effects dominated by in-plane spin *magnitude*!

Double spins?



Double spins?

- Spins rotate at different rates
- Consider only the average spin in the plane, "χ_p"!



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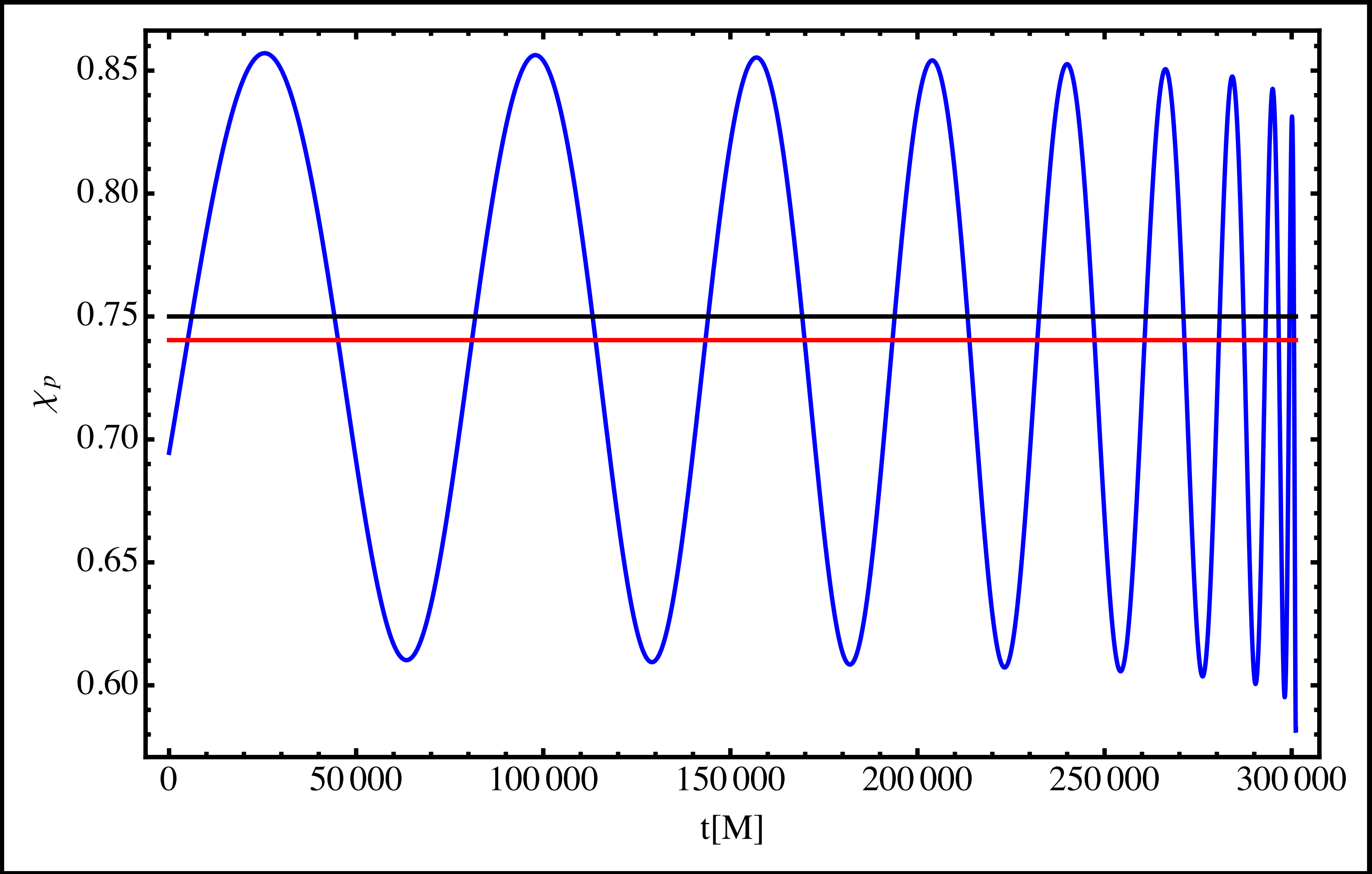
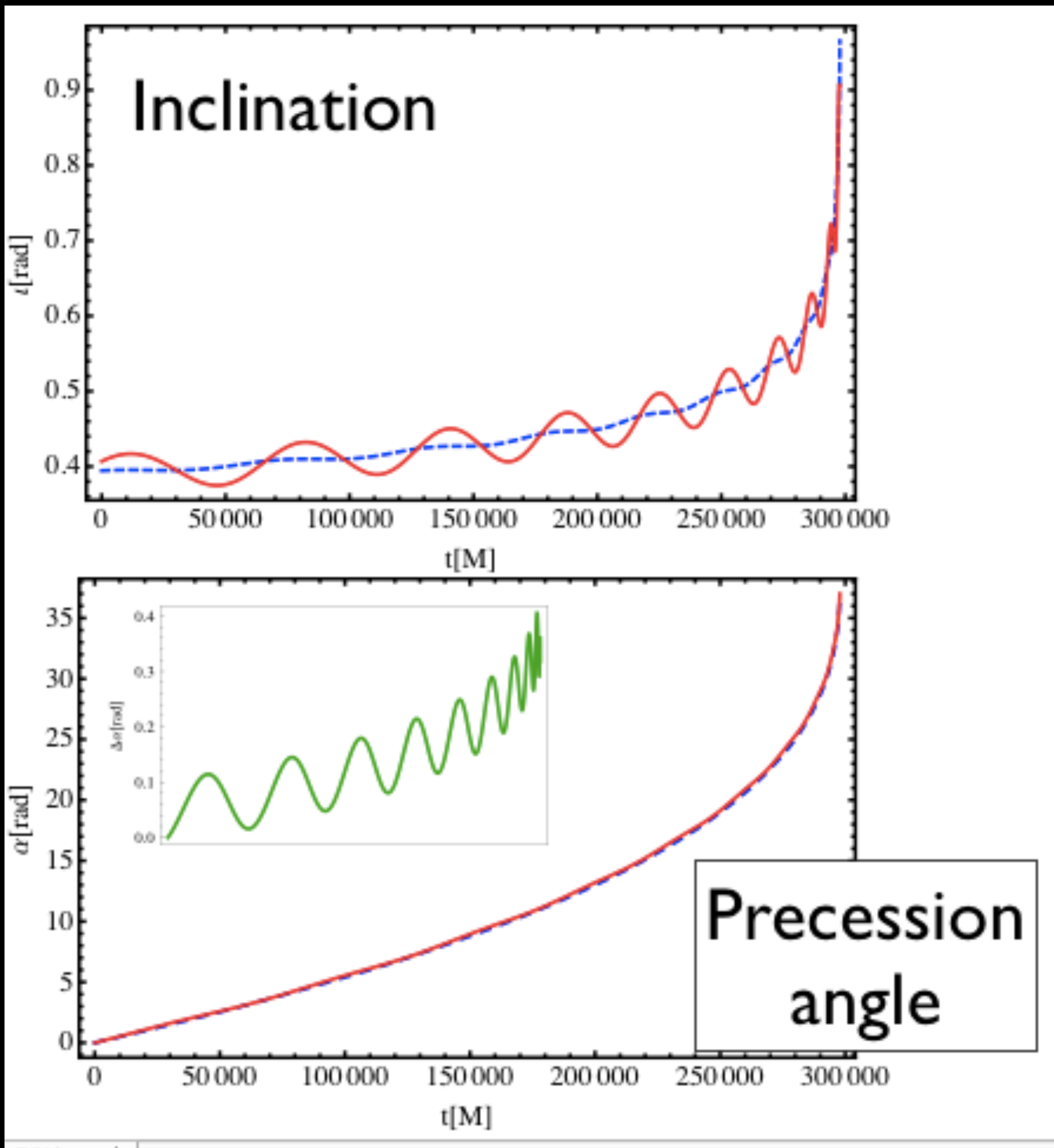
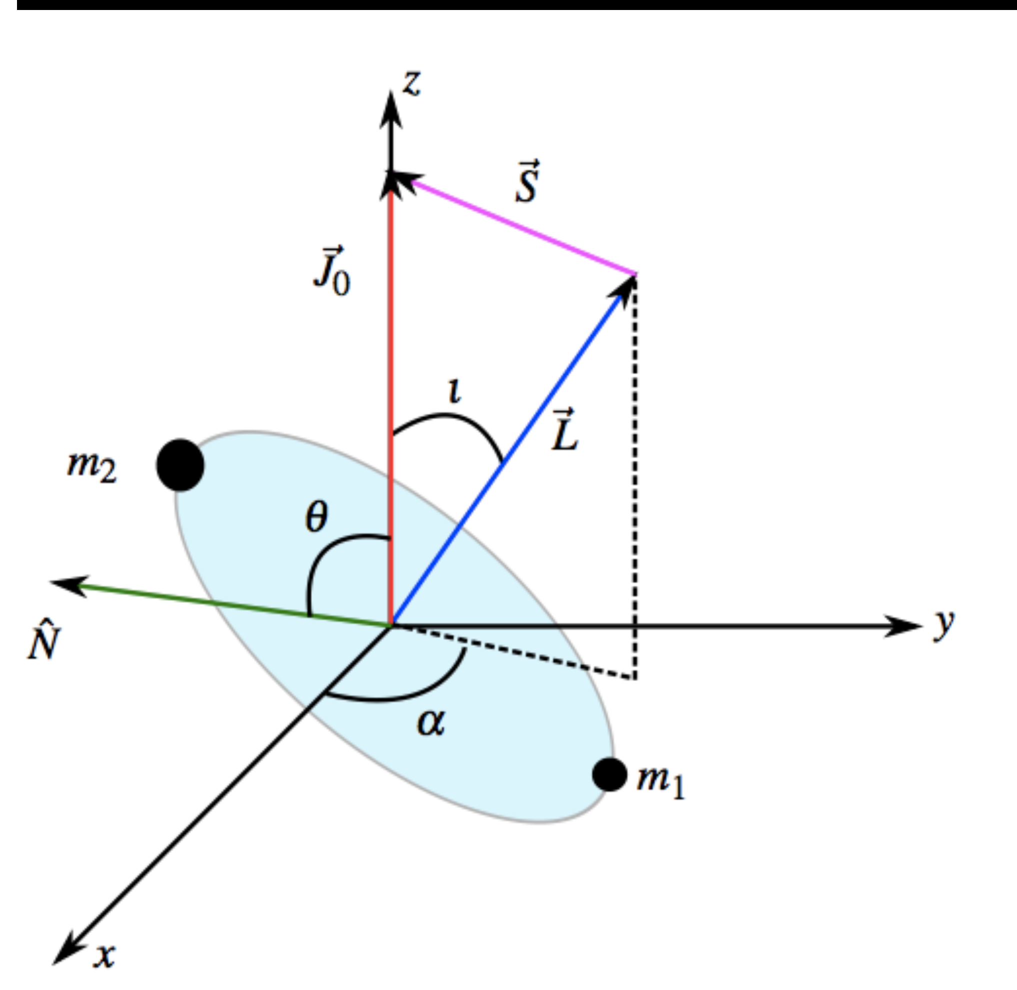


$q=3$,
$\chi_1=(-0.2,-0.4,0.3)$
$\chi_2=(0.747, 0.045, 0.1)$

$\chi_p = 0.75$

Compare precession angles





[Schmidt, Ohme, Hannam (2015)]

Summary

- Non-precessing-binary inspiral dominated by mass ratio and "effective spin", χ.
- Precession (approximately) decouples from non-precessing effects.
- Precession effects parametrized also by "effective precession spin", χ_p.

- Current inspiral-merger-ringdown waveforms exploit these degeneracies and simplifications.
- How well do these work through merger? Stay tuned…