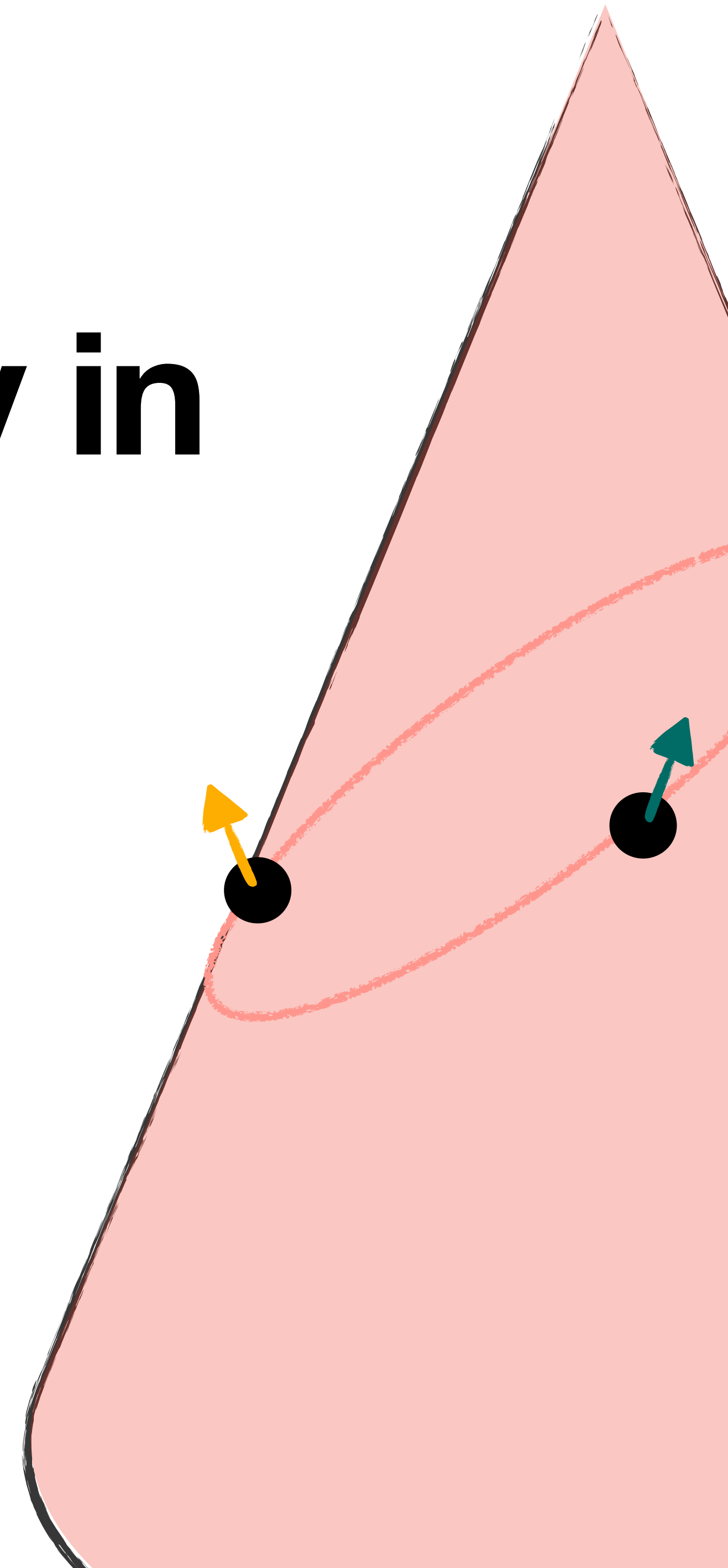
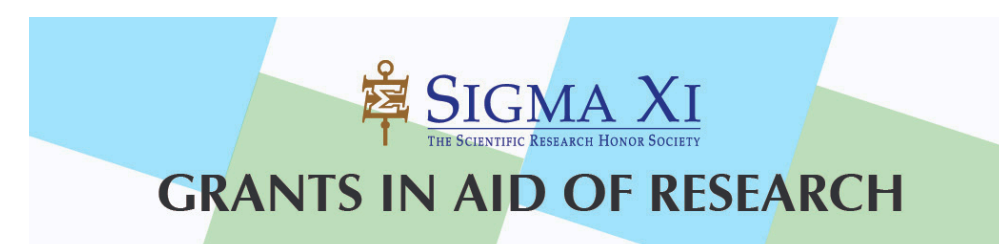


Spin-eccentricity interplay in merging black holes

XXV SIGRAV Conference on General Relativity and Gravitation

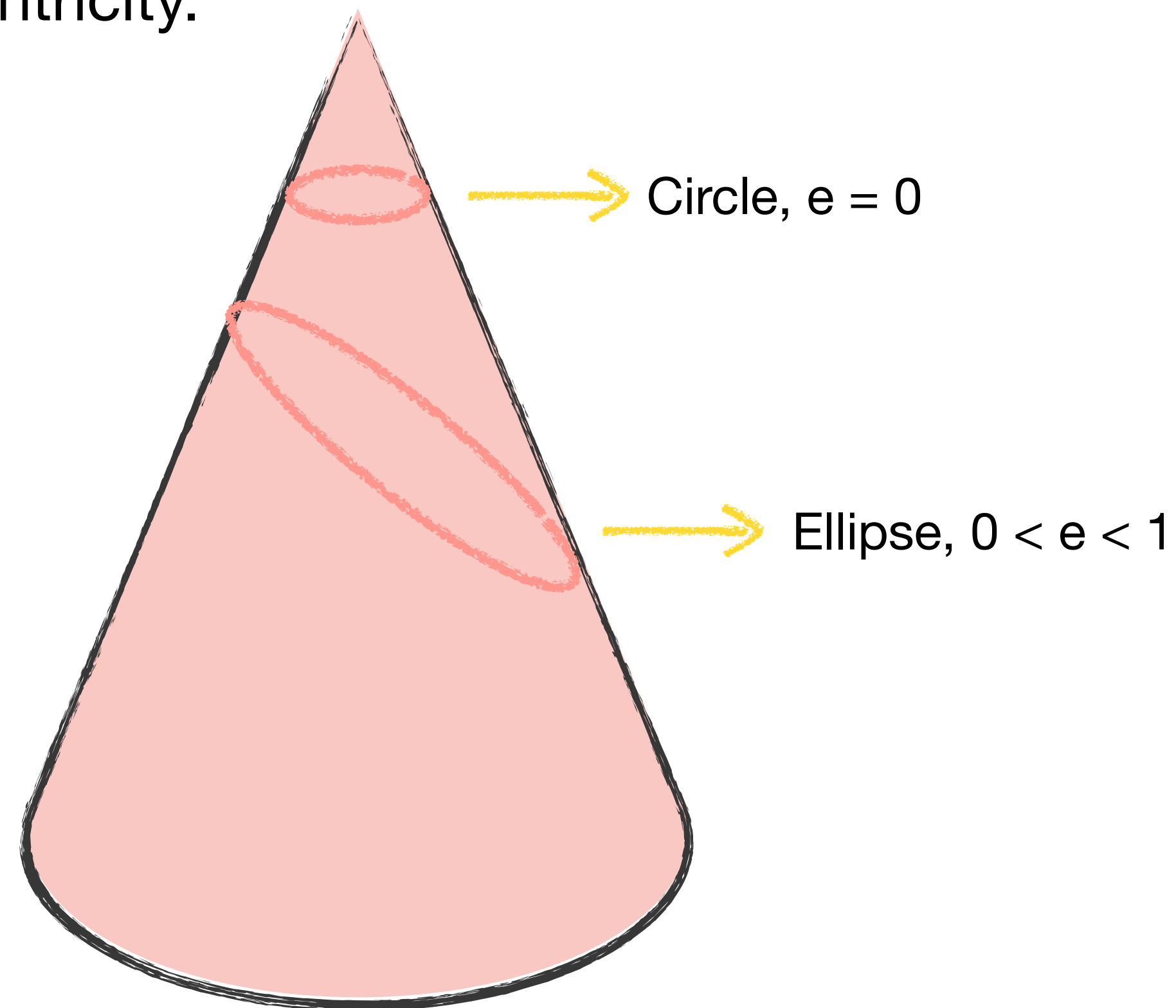
Giulia Fumagalli, Davide Gerosa, Nicholas Loutrel



Black hole binaries

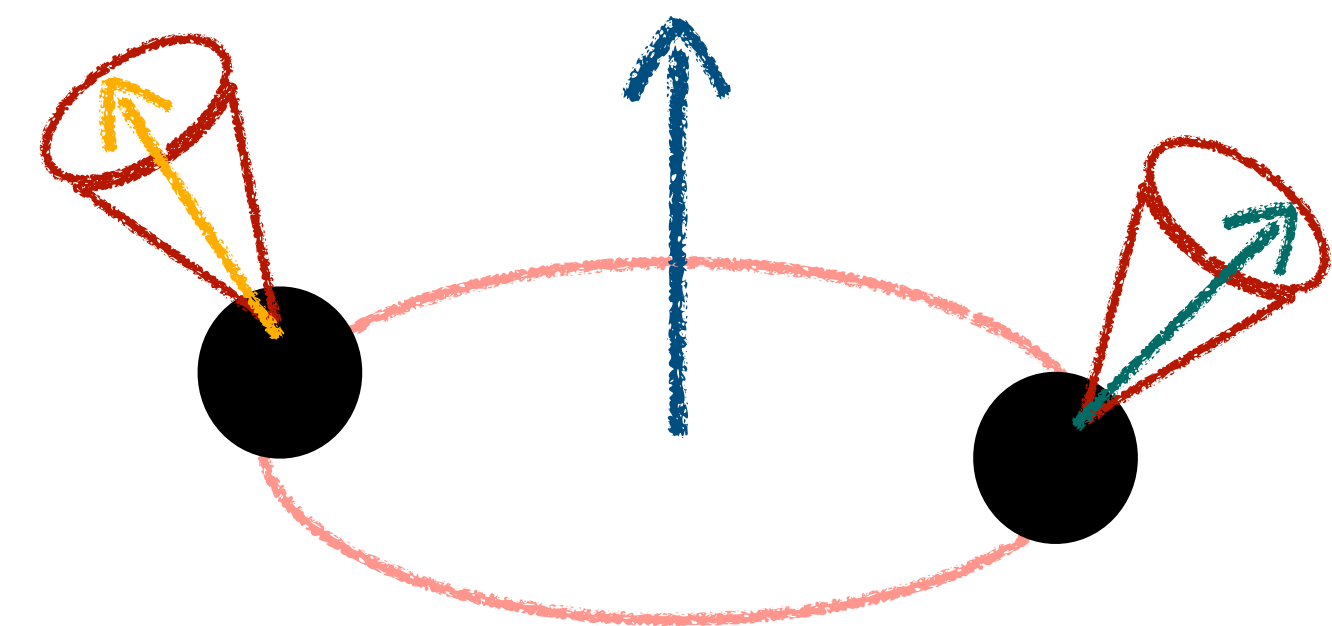
Orbital eccentricity*

Kepler's First Law: the trajectories within a two-body system are described by conic sections whose shapes are determined by the eccentricity.



Orientation of the spin

If the spins are misaligned, the spin-orbit and spin-spin couplings induce precession of angular momenta = orientations in space vary. [1]



Eccentricity and precession both leave an imprint on the gravitational signal [2]

Formation Channel

Dynamical

Strong gravitationally driven encounter between already formed BH [3].

- High eccentricity
- Misaligned spin = Precession

Isolated

Two stars evolve side-by-side until they become BHs and remain bound [4].

- Quasi-circular
- Non Precessing

Precession is not always a good indicator [5].

We need **simultaneous** measurements of **eccentricity** and **precession** to get a hint on the formation channel.

What's the problem?

1. From Peters's equations [2], we expect binaries to arrive at mergers almost circular



2. Ground-based detectors are and will not be sensitive to eccentricities lower than [6]

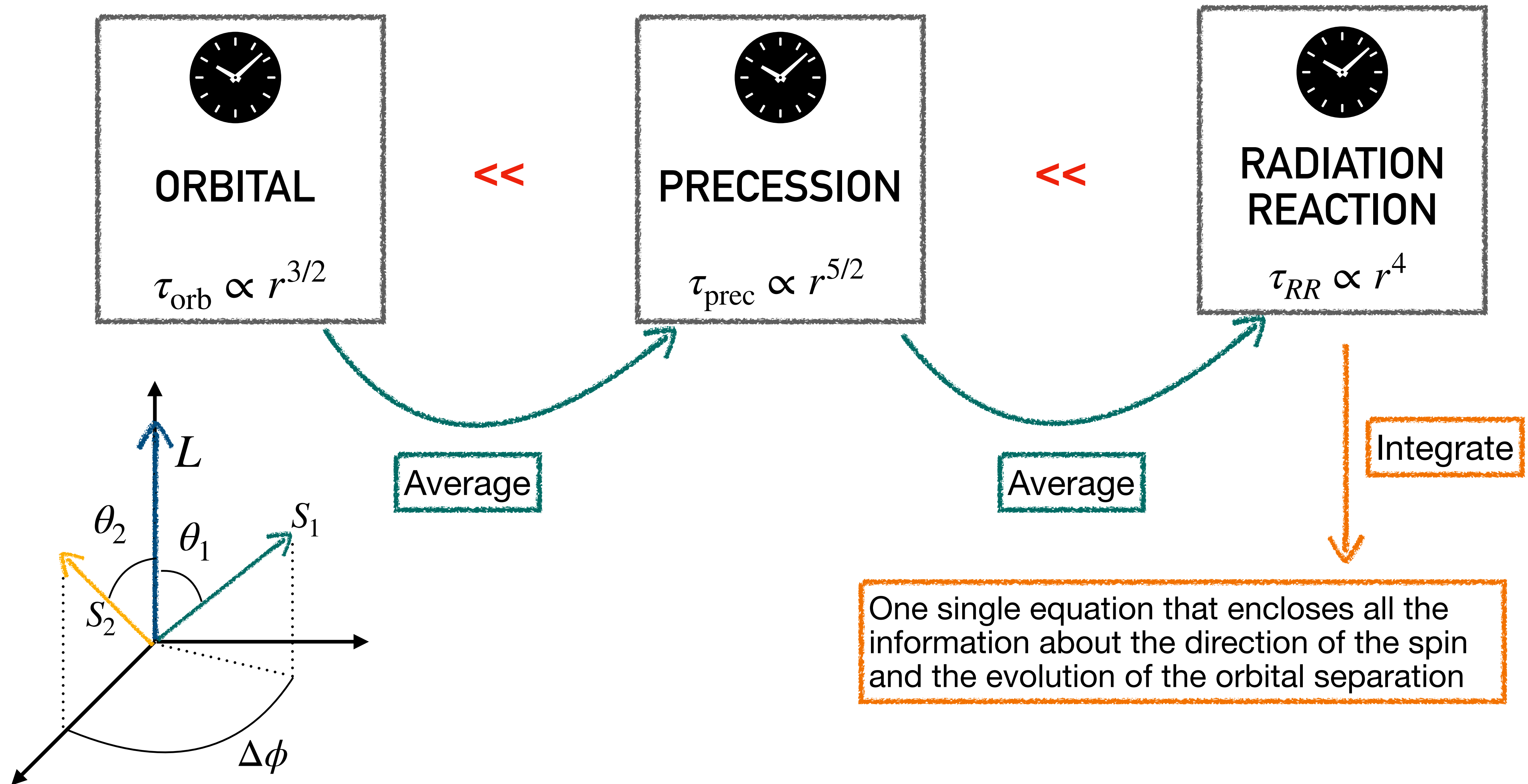
LIGO, Virgo	$e \sim 0.05$	ET, CE	$e \sim 10^{-4}$
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3. We expect to observe eccentric mergers [7], but:
 - We still miss precessing and eccentric templates.
 - Precession and eccentricity can be confused [8].

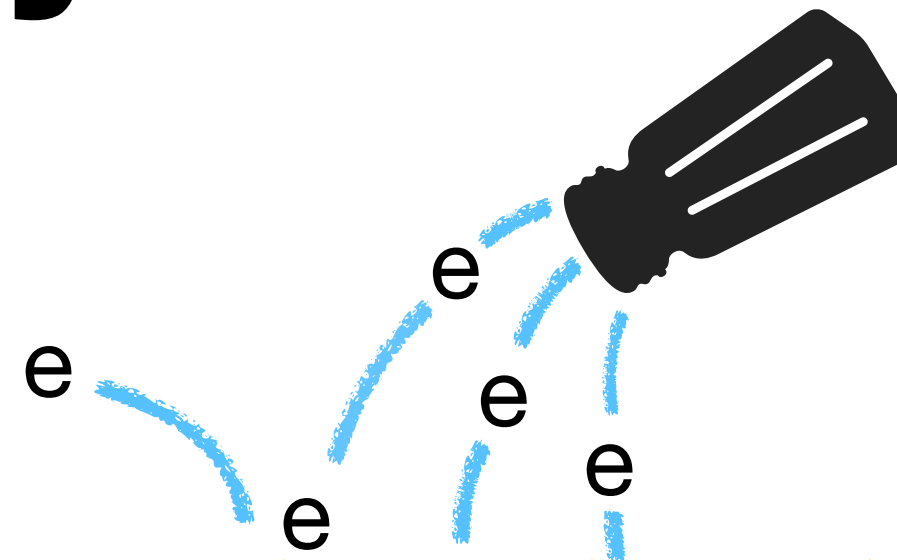
Do spins dream about eccentricity?

- The evolution of the spins may be influenced by eccentricity
- By studying the spins, we can say something about eccentricity.
- We consider the formalism introduced by Gerosa, **GF**, et al. (2023).
- It possible to follow the evolution of **circular** and **precessing** BHs binaries forward in time (from formation to merger) and also backward! All this in a fraction of a second.

The precession average formalism



Adding eccentricity



Gerosa, **GF**, et al. 2023

$$\left\langle \frac{da}{de} \right\rangle = \frac{12 a [1 + (73/24)e^2 + (37/96)e^4]}{19 e (1 - e^2) [1 + (121/304)e^2]}$$

But valid in the circular limit!

1. Apply a coordinate transformation to precession equations:

$$\begin{cases} r \longrightarrow \frac{r}{\gamma^2} \\ t \longrightarrow \frac{t}{\gamma^3} \end{cases} \quad \gamma = \frac{1}{\sqrt{1 - e^2}}.$$

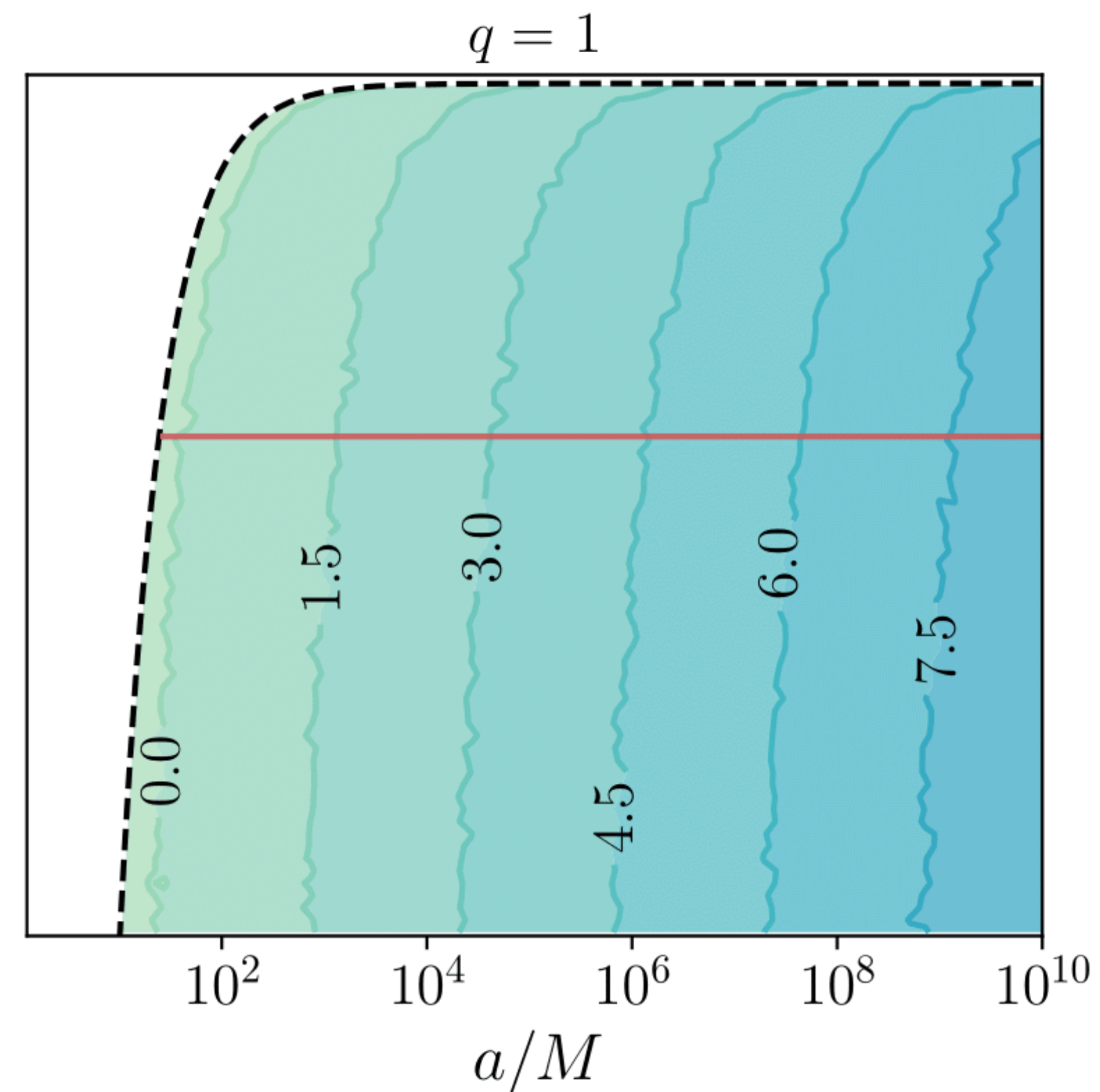
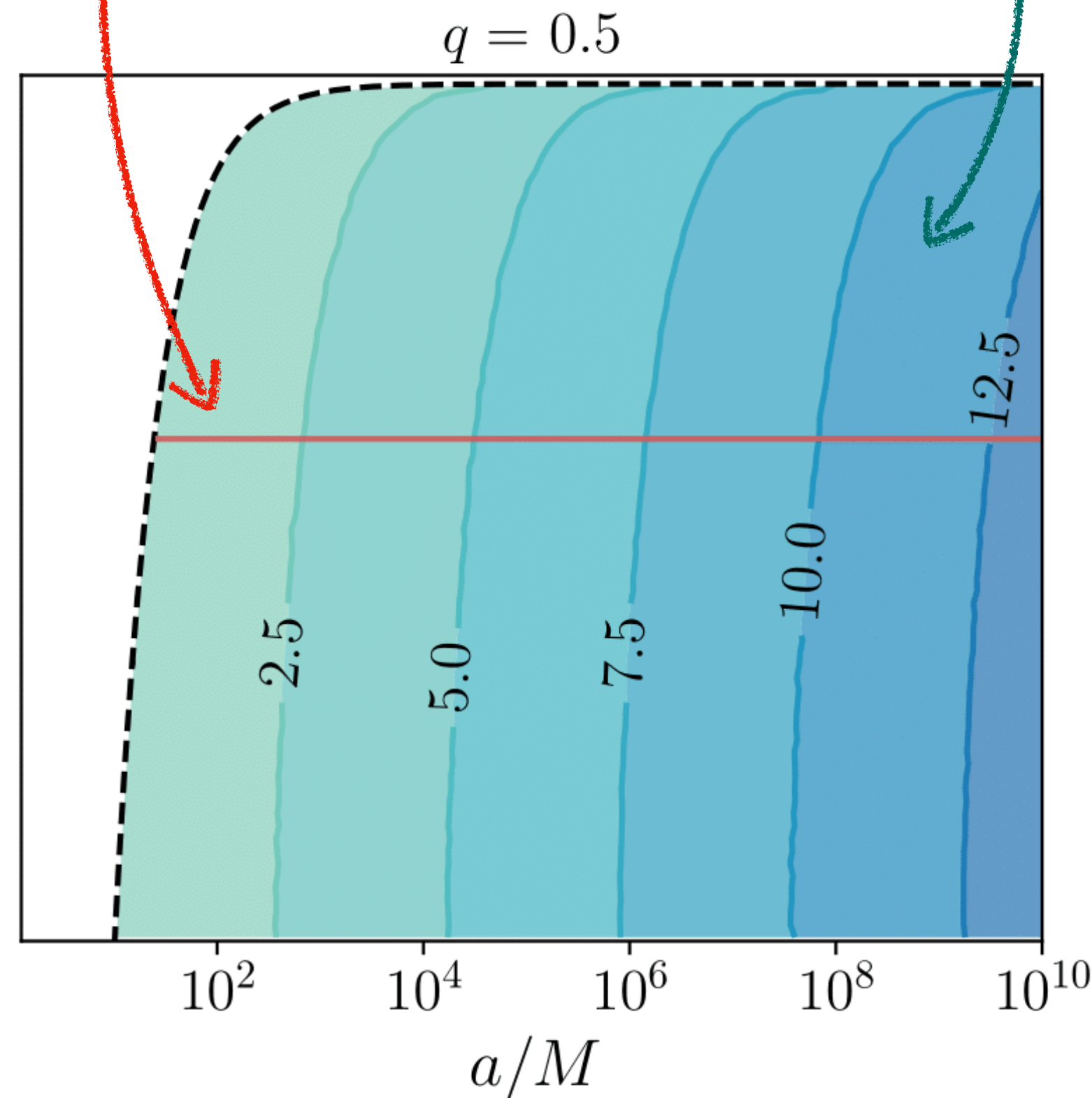
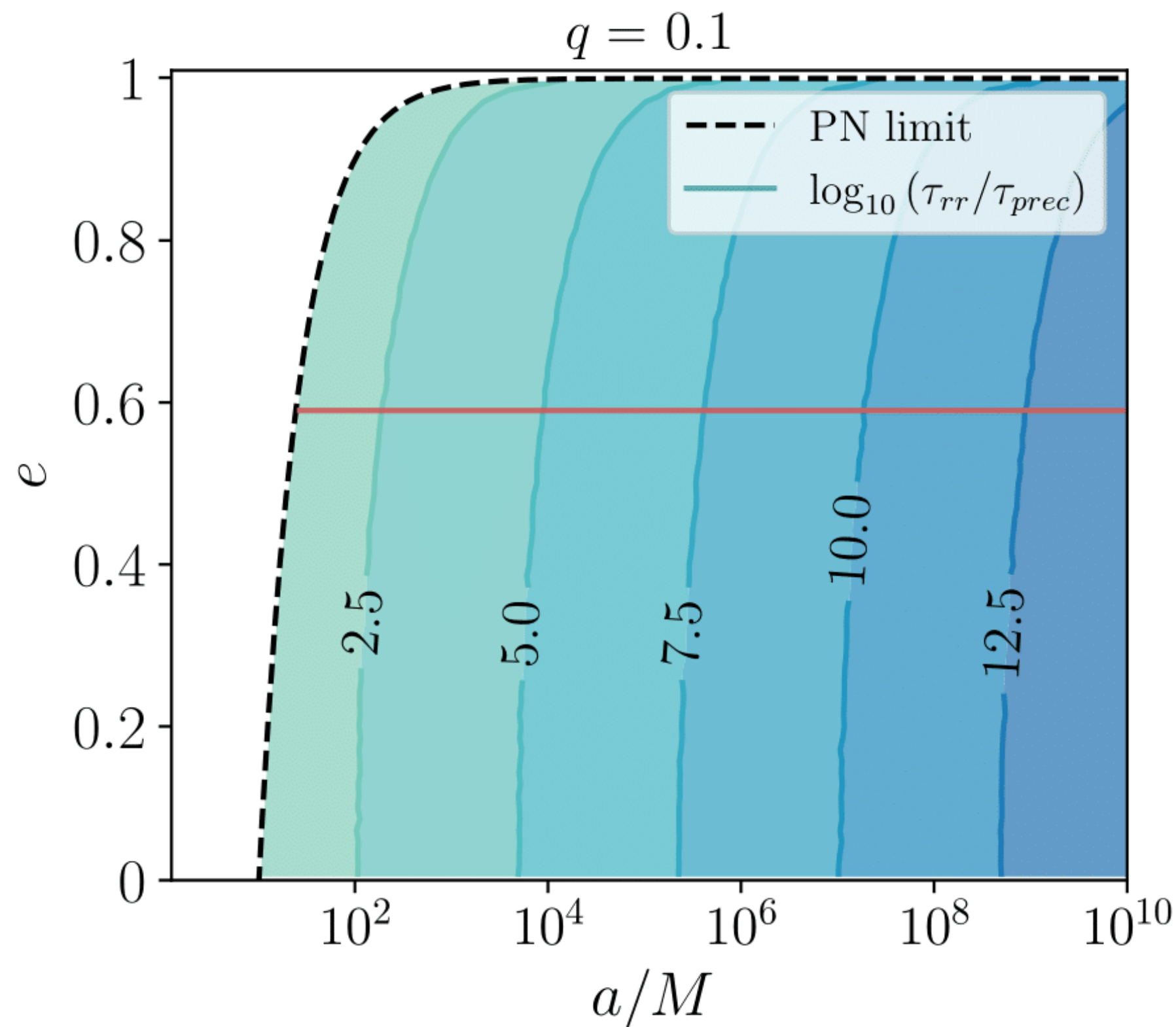
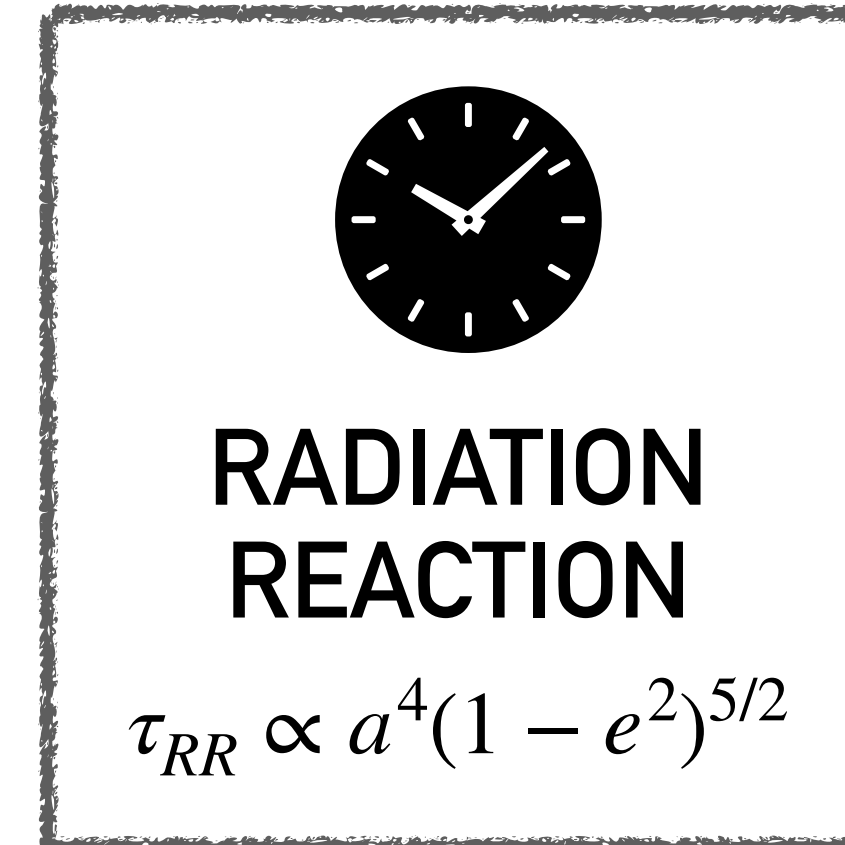
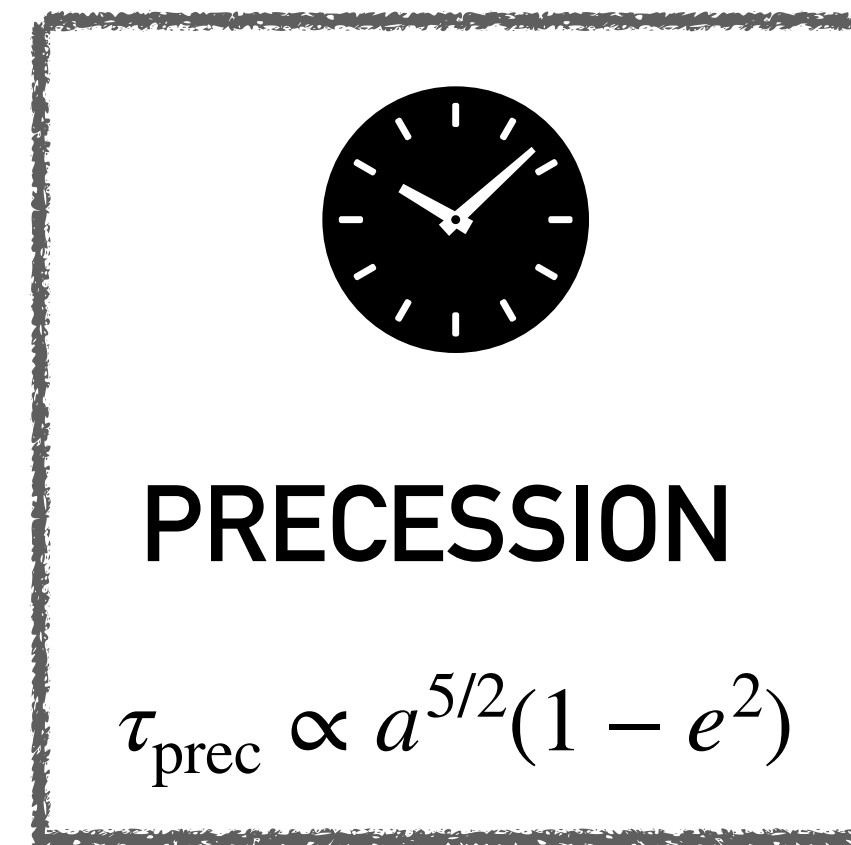
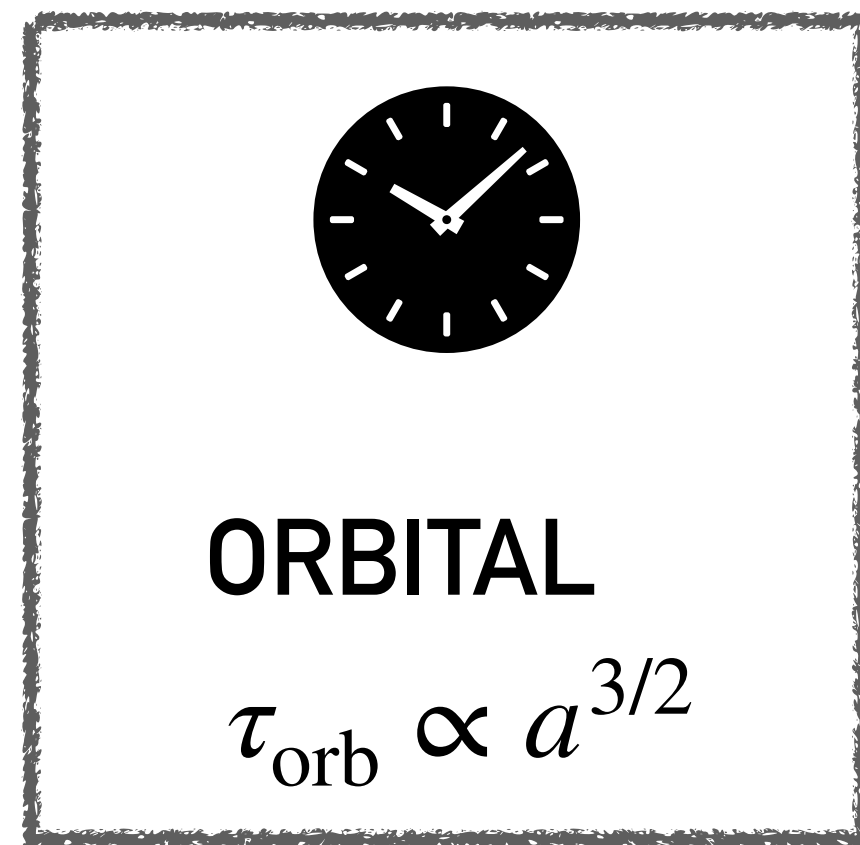
2. Add a new equation to consider the evolution of eccentricity:

$$\frac{du}{du_c} = - \frac{12u_c u (7u_c^2 - 15u^2)}{37u_c^4 - 366u_c^2 u^2 + 425u^4}$$

$$u_c \equiv u(a, e = 0) = \frac{(1 + q)^2}{2qM^2} \sqrt{\frac{M}{a}},$$

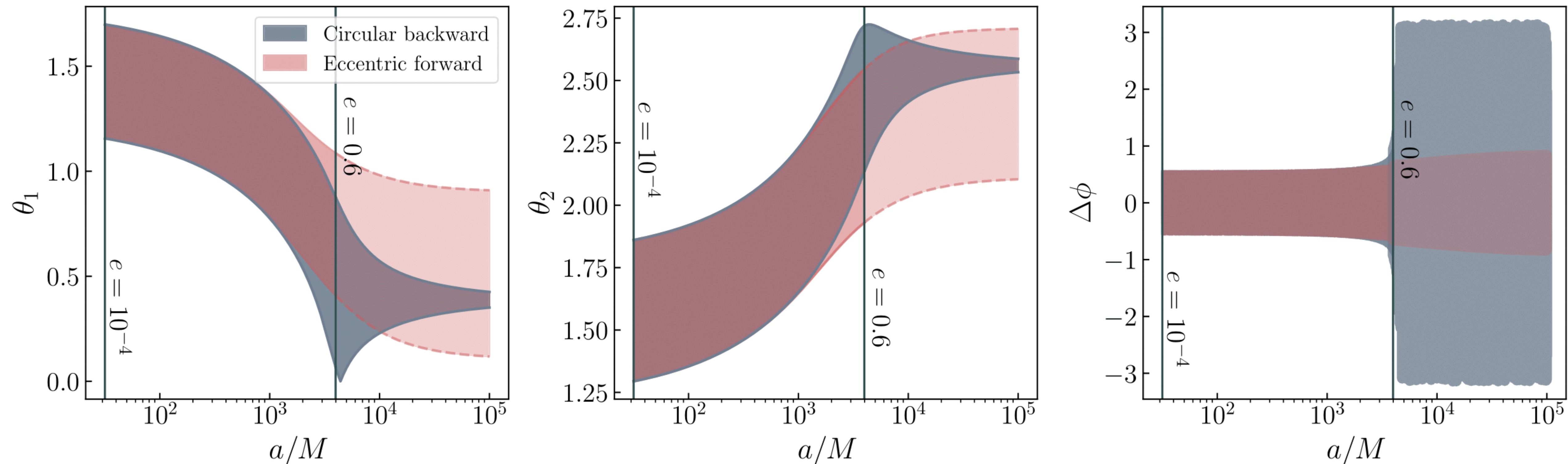


New equations, new timescales

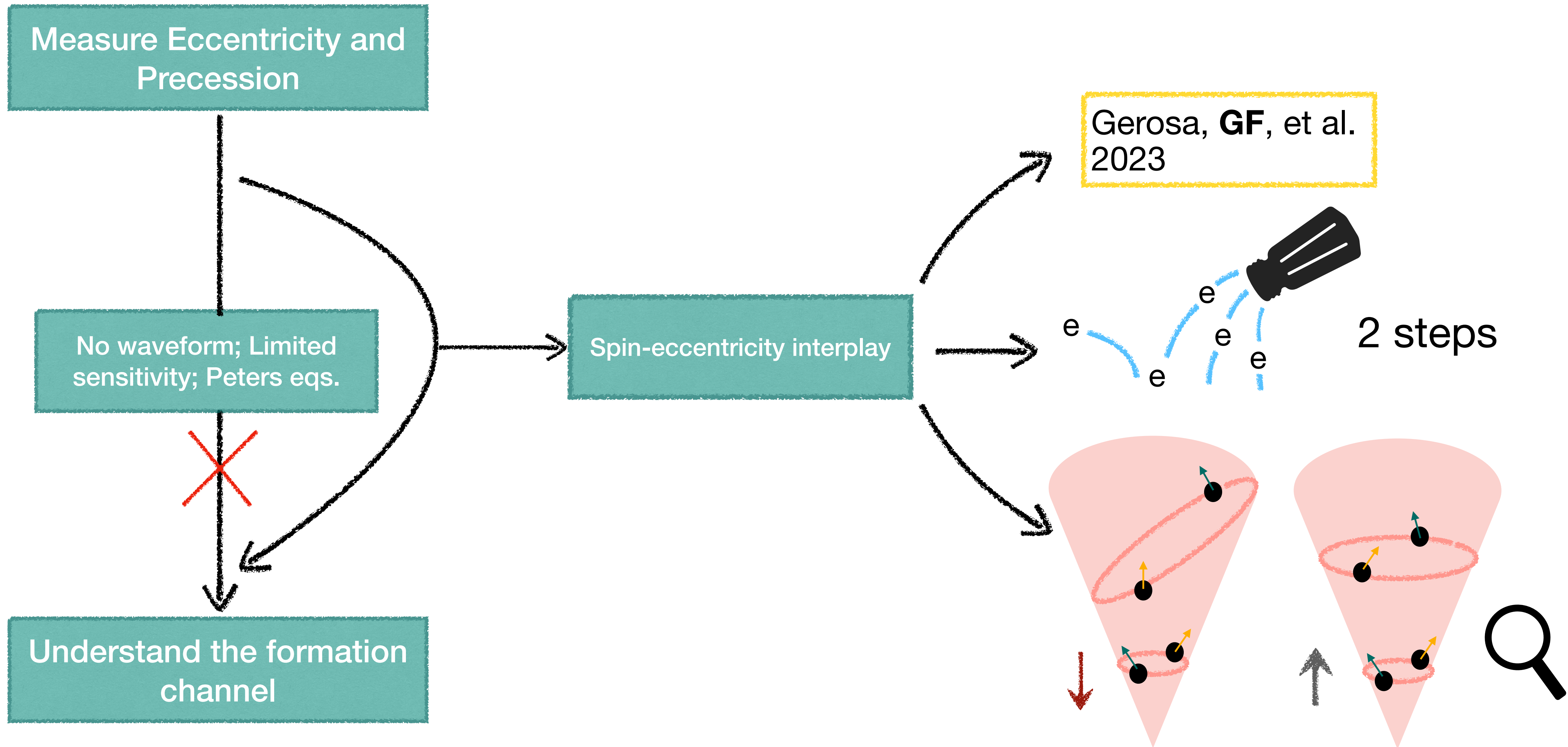


Looking for an interplay

- We said that if $e < 10^{-4}$ at merger, detectors are not able to distinguish between a circular binary and a binary that is eccentric at formation.
- We put ourselves in the shoes of the detectors. We consider an eccentric binary at formation. We evolved the spins until the merger. Then we trace back their evolution, as this binary was circular.



Summary



Conclusions

- It has been possible to easily expand the circular precessing formalism to eccentric binaries. We use all the equations and the implementation of Gerosa, **GF**, et al. 2023.
- We clearly observe an interplay between spin evolution and eccentricity.
- Further study on the interplay is ongoing (morphologies).

Thank you for the attention

