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Scattering of two BHs in higher dimensions

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Phys. Rev. D **83** 121501, HO,K.Nakao,M.Shibata

Introduction

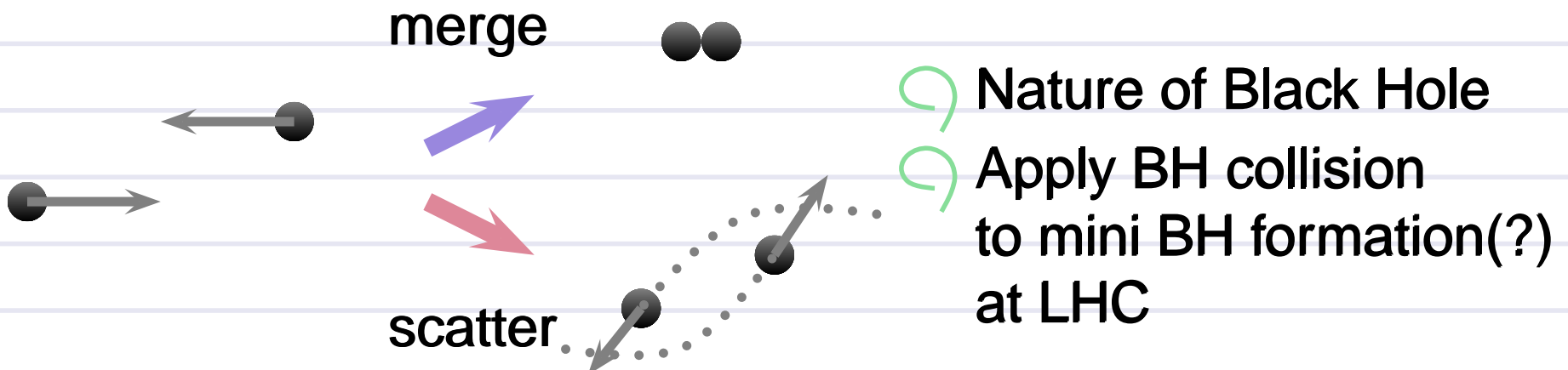
Binary Black Hole



Gravitational wave source

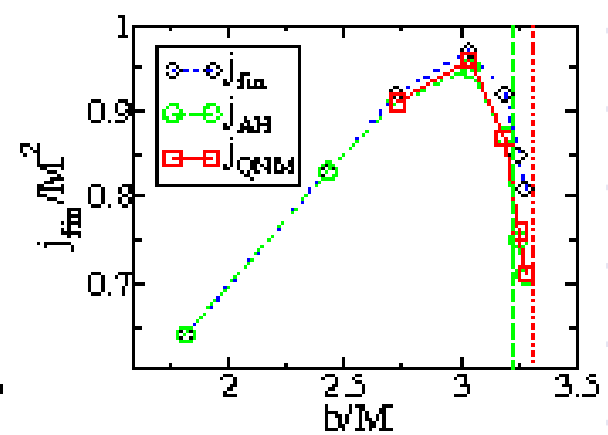
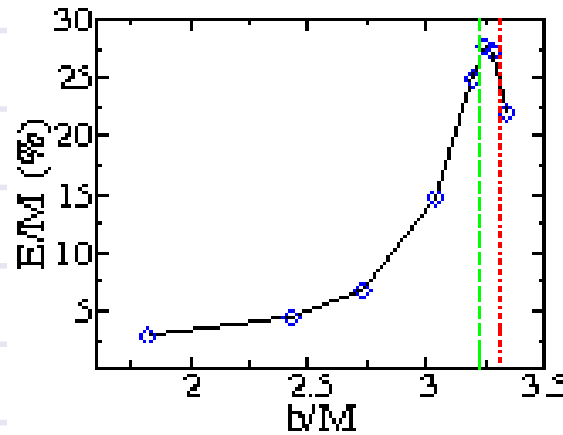
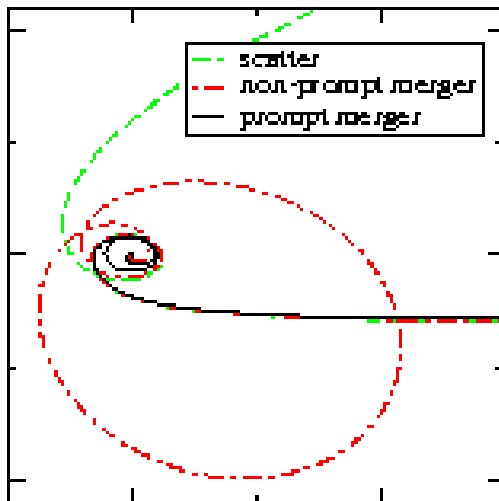
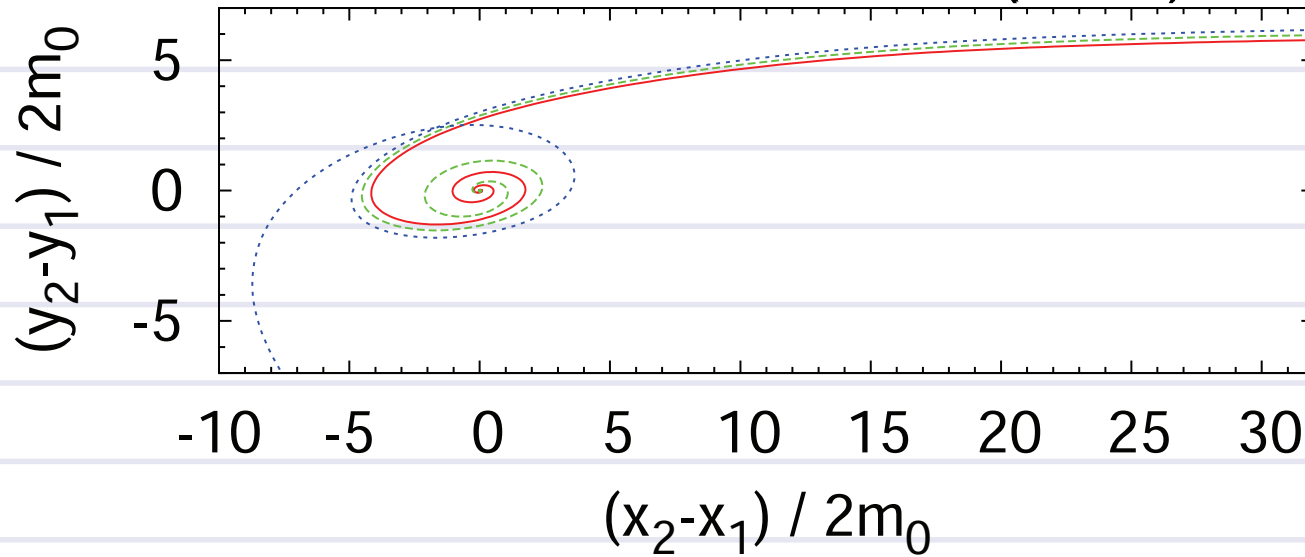
Galaxy evolution

High-velocity Black Hole collision



Collision of BHs(4D)

Shibata,HO,Yamamoto(2008)



Sperhake,Cardoso,Pretorius,Berti,Hinderer,Yunes(2009)

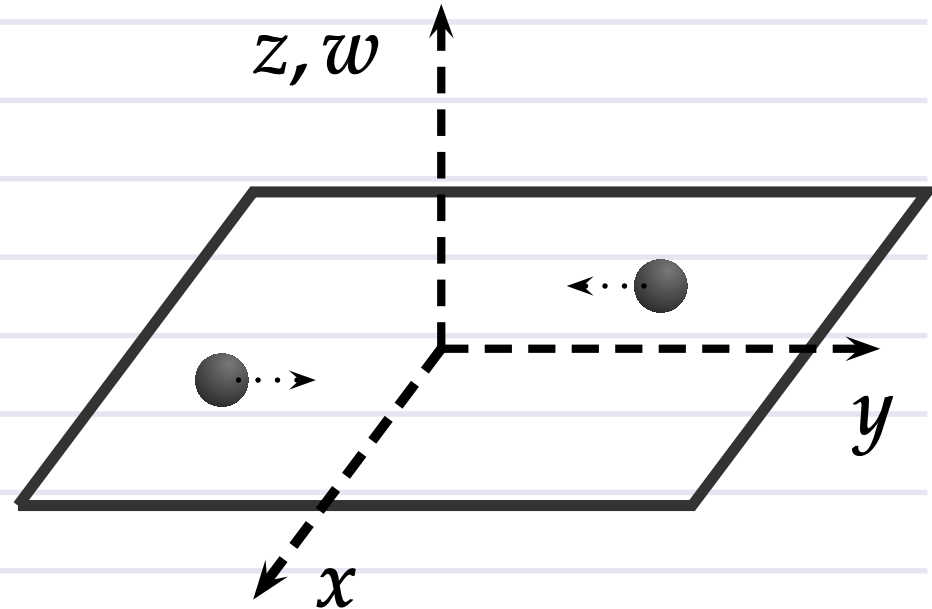
Setup

🌀 CODE : SACRA ND

🌀 AMR method

🌀 Running on PC

➔ **Prof. Shibata's talk**



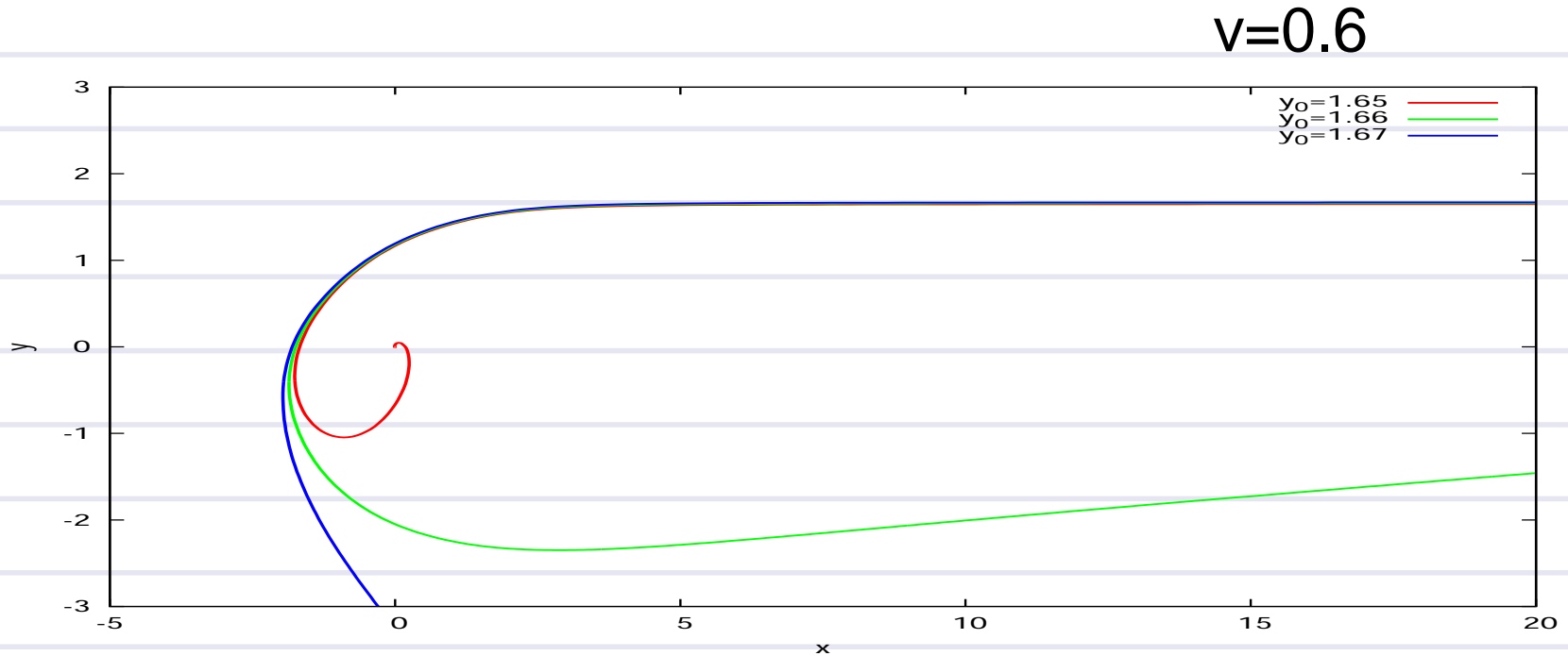
🌀 D-dimensional Numerical Relativity

🌀 BSSN formalism

🌀 CARTOON method(Z-W symmetry)

🌀 Initial condition : superimposing Boost BHs

Orbit of higher-dimensional collision(5D)

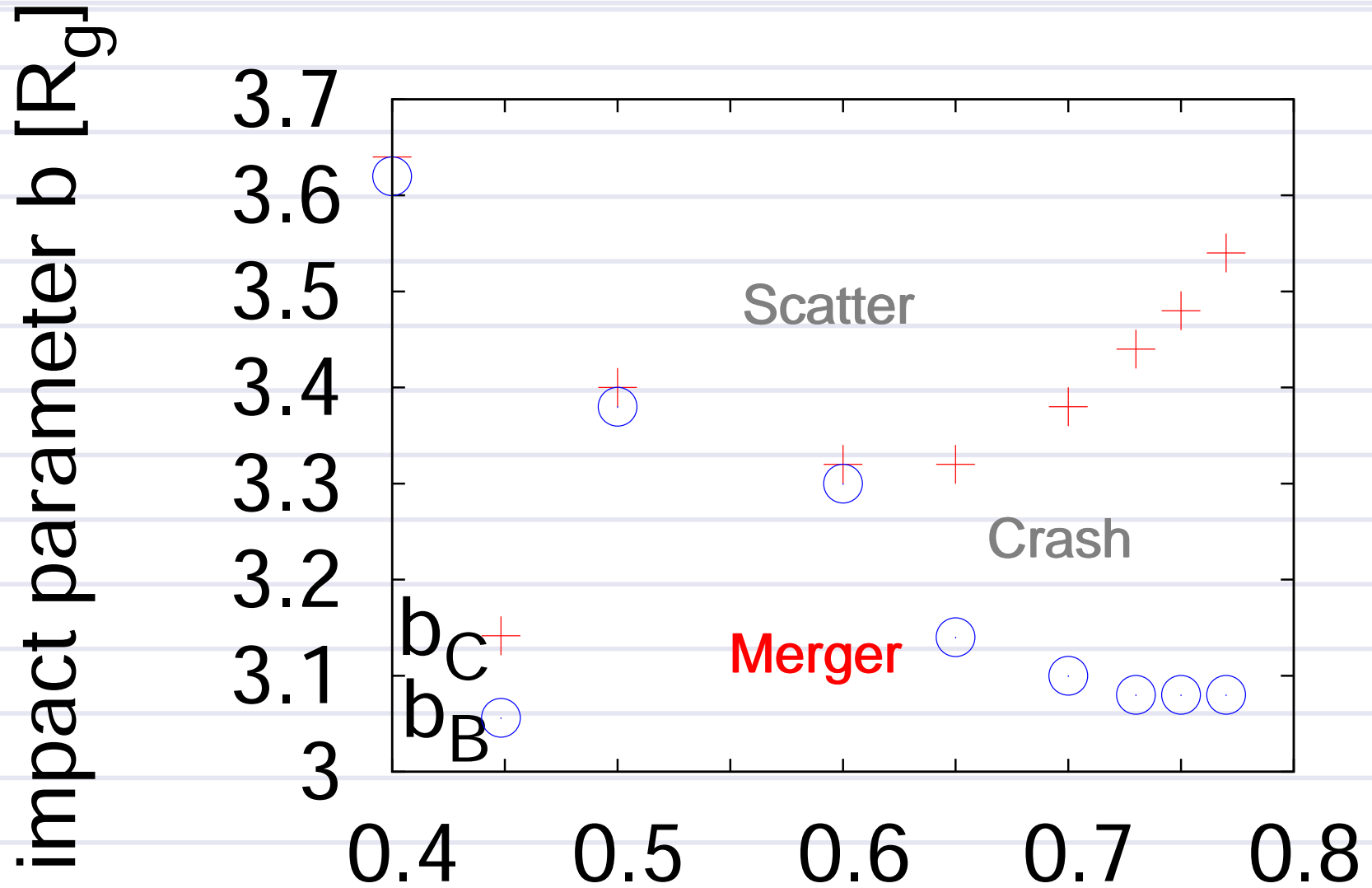


Colors show the difference of **impact parameter**.

We can not see “Non-prompt merger”.

Gravity in 5D is stronger than in 4D in small scale.

Scatter-Merger relation(5D)



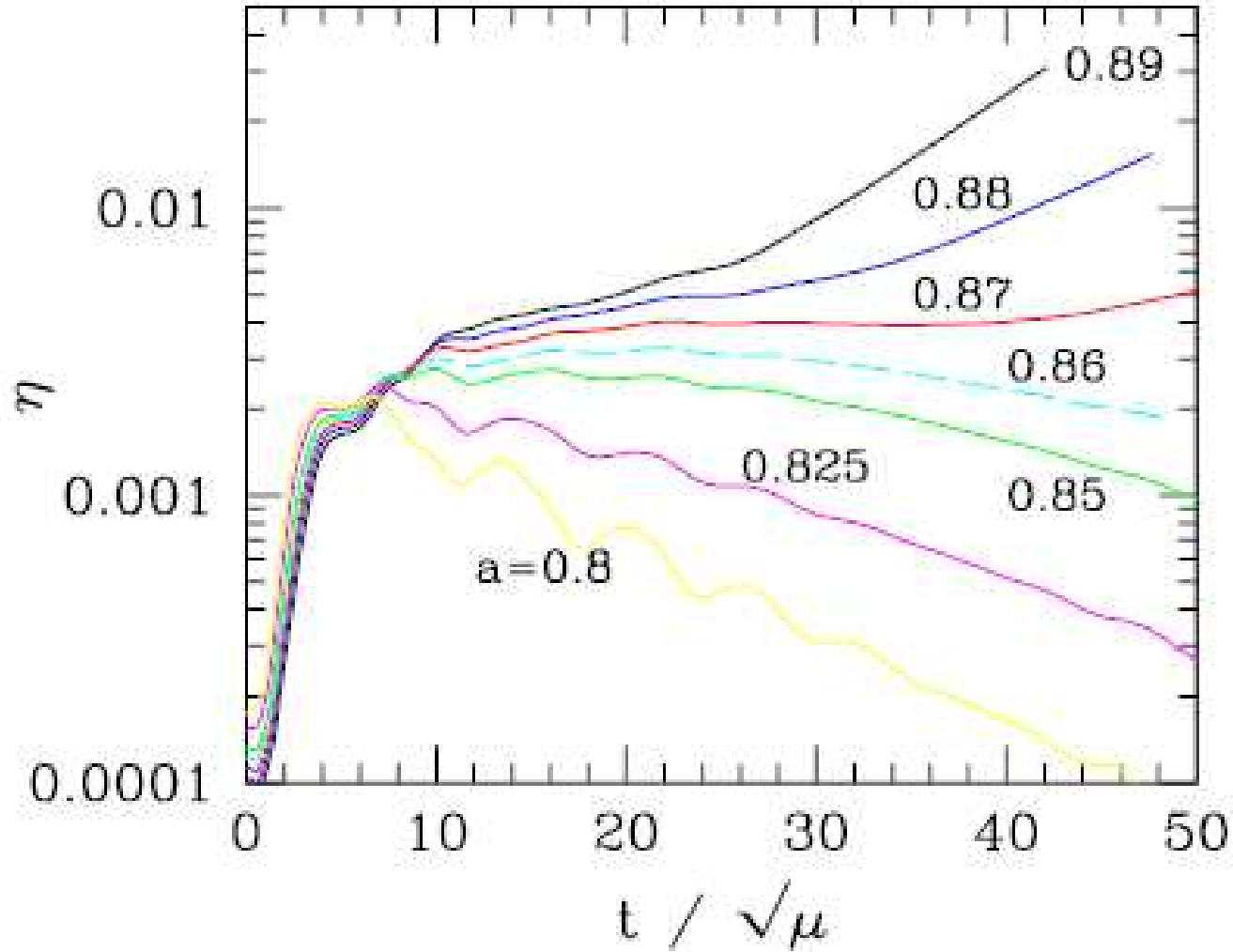
b_C : Scatter with certainty

b_B : Merger with certainty

V

Bar-mode instability of higher dimensional BH

Shibata, Yoshino(2010)



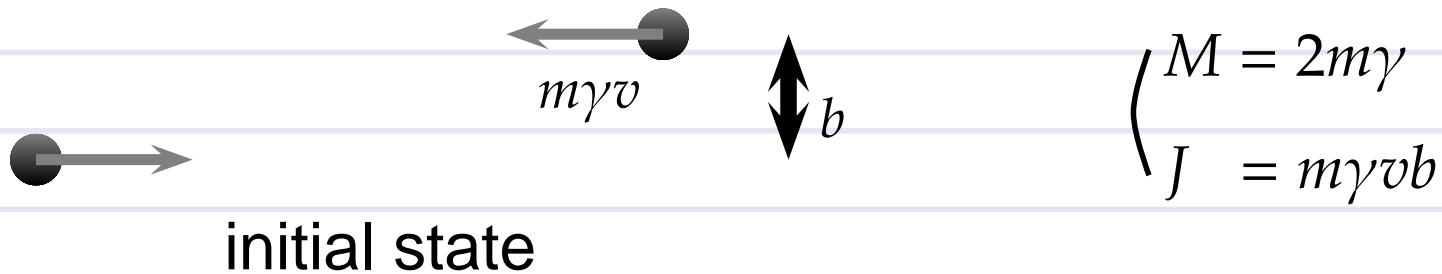
May crash region be caused by this instability?

Expectation of Kerr parameter

🌀 Mass and Angular momentum for 5D Myers-Perry BH
Empanan, Reall(08)

$$M = \frac{3}{8}\pi\mu \quad J = \frac{2}{3}Ma$$

🌀 Newtonian gravity (without GW)

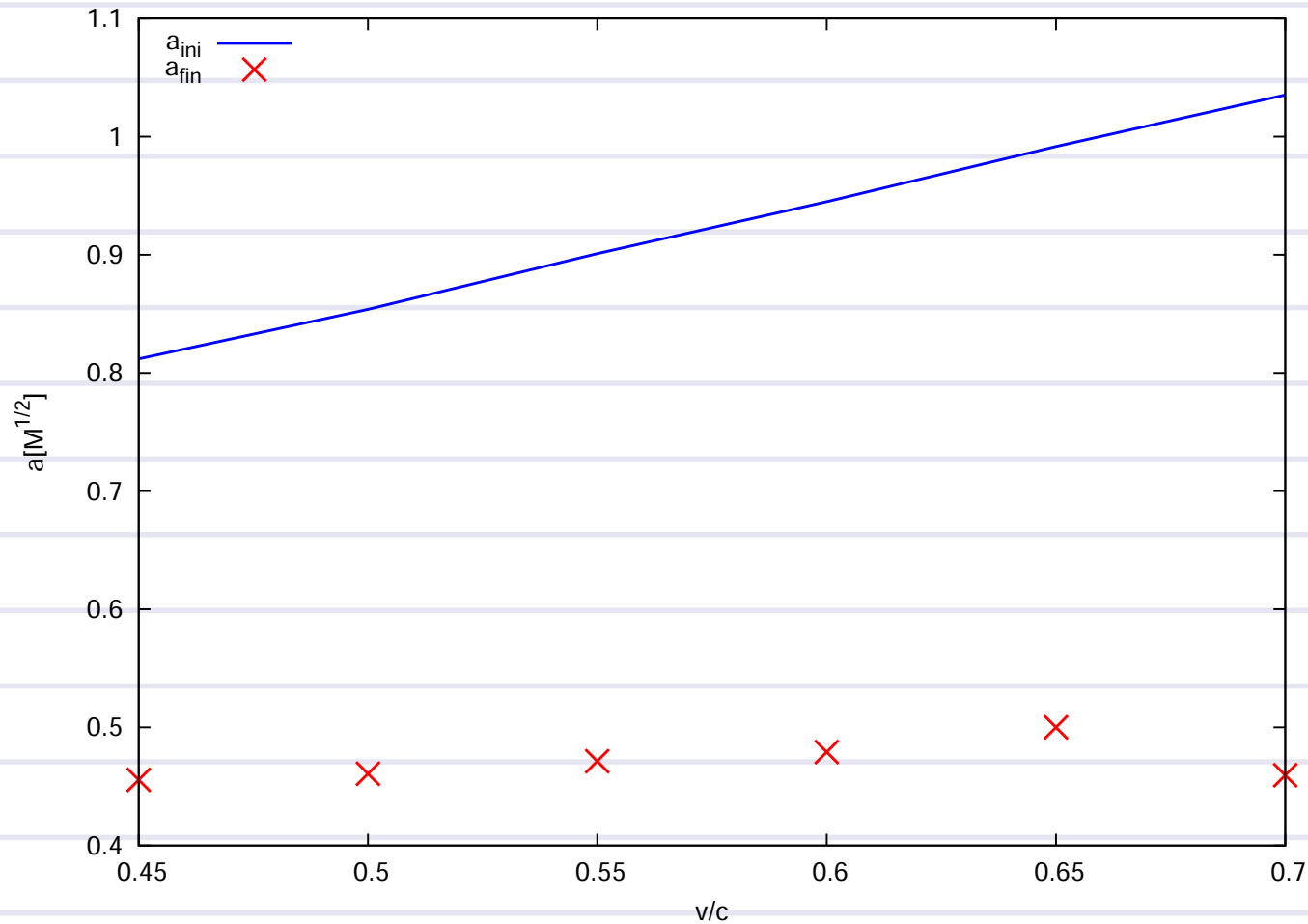


final state

$$a = \frac{3}{2} \frac{J}{M} = \frac{3bv}{4}$$
$$\frac{a}{\sqrt{2m\gamma}} = \frac{3bv}{4\sqrt{2m\gamma}}$$

non-dimensional Kerr parameter

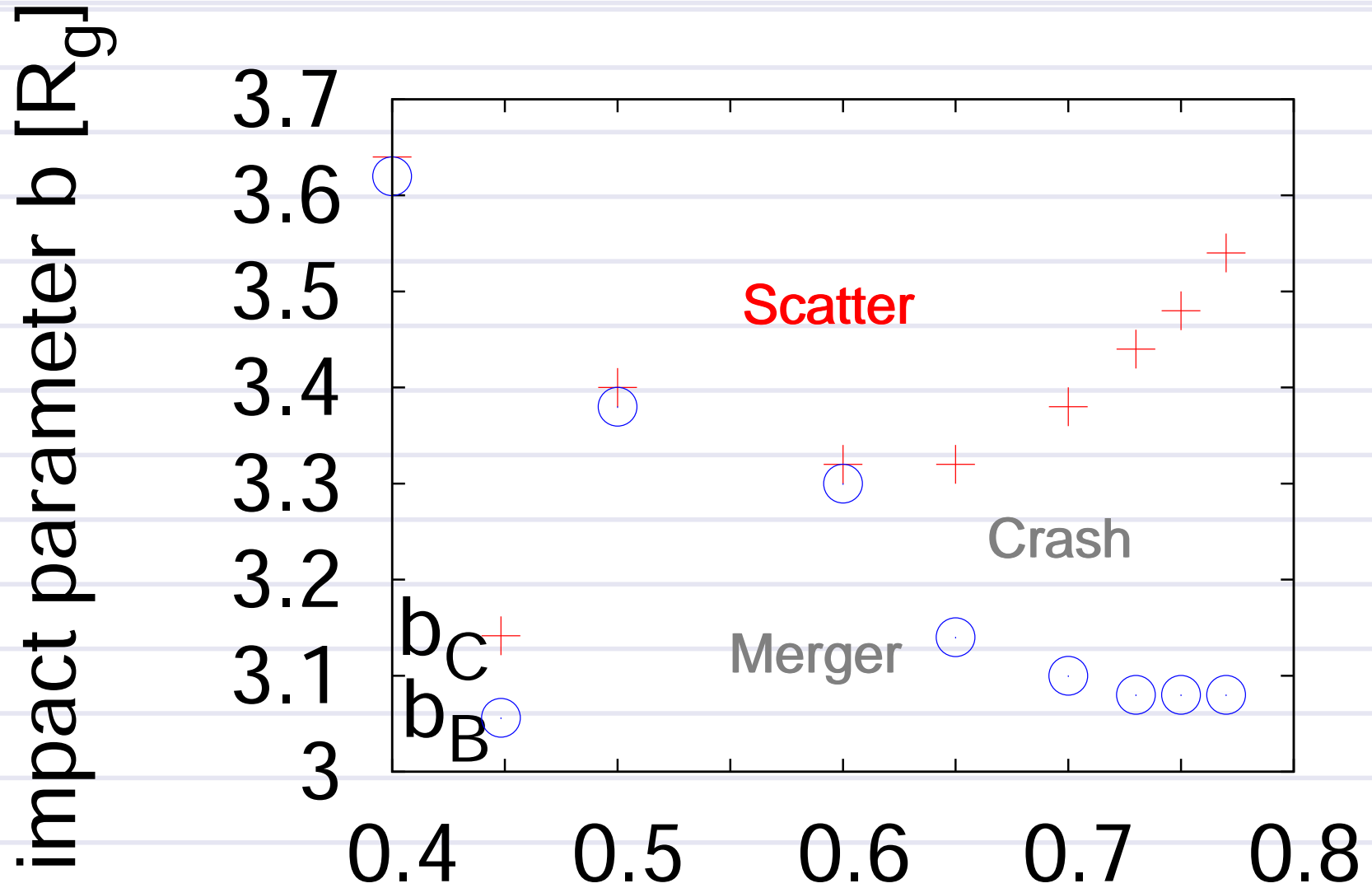
Calculation of Kerr parameter



Generated BH in merger region with certainty has small spin.

Other instability? (Gregory-Laflamme etc.)

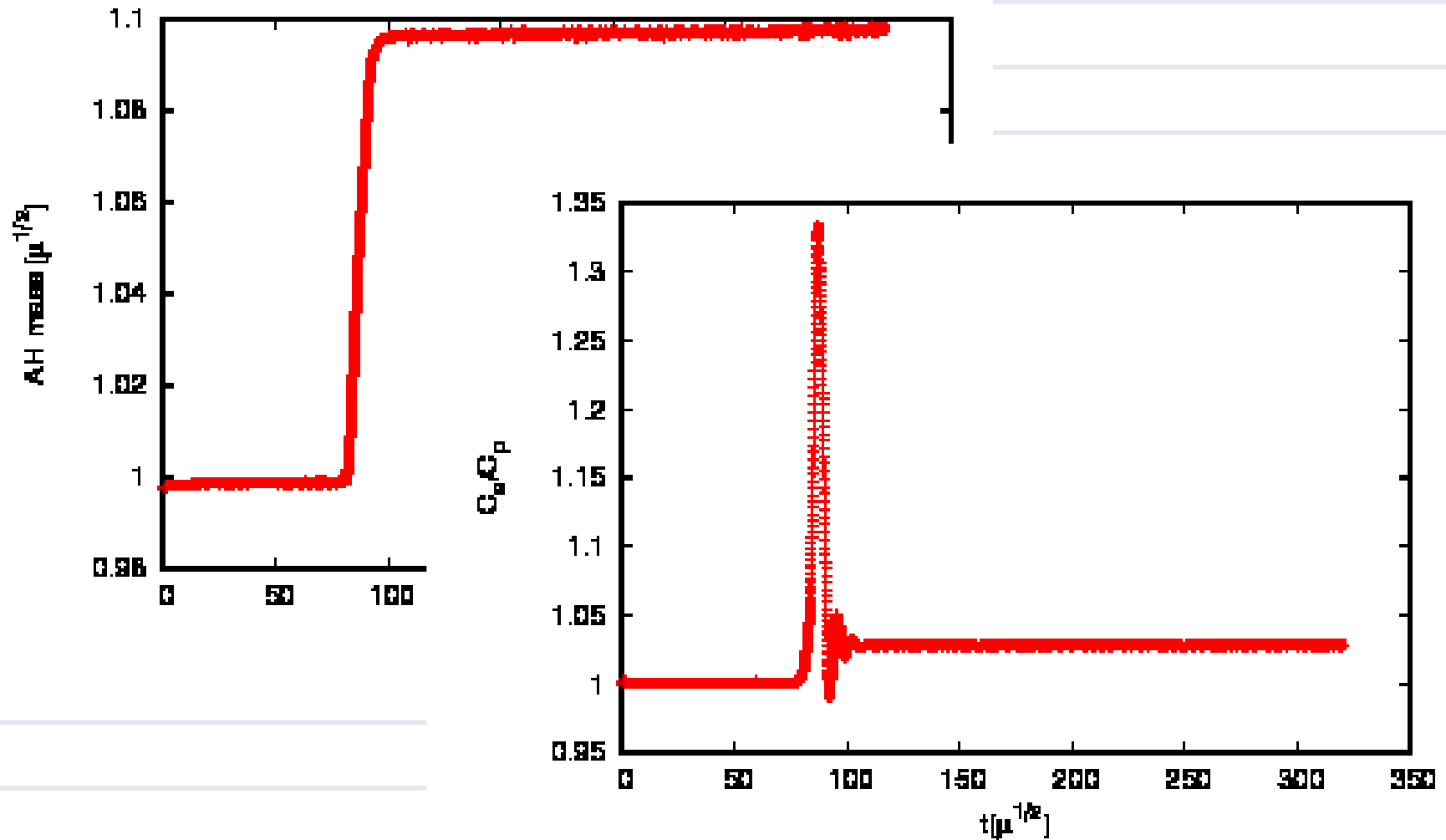
Scatter-Merger relation(5D)



b_C : Scatter with certainty

b_B : Merger with certainty

BH mass after scattering

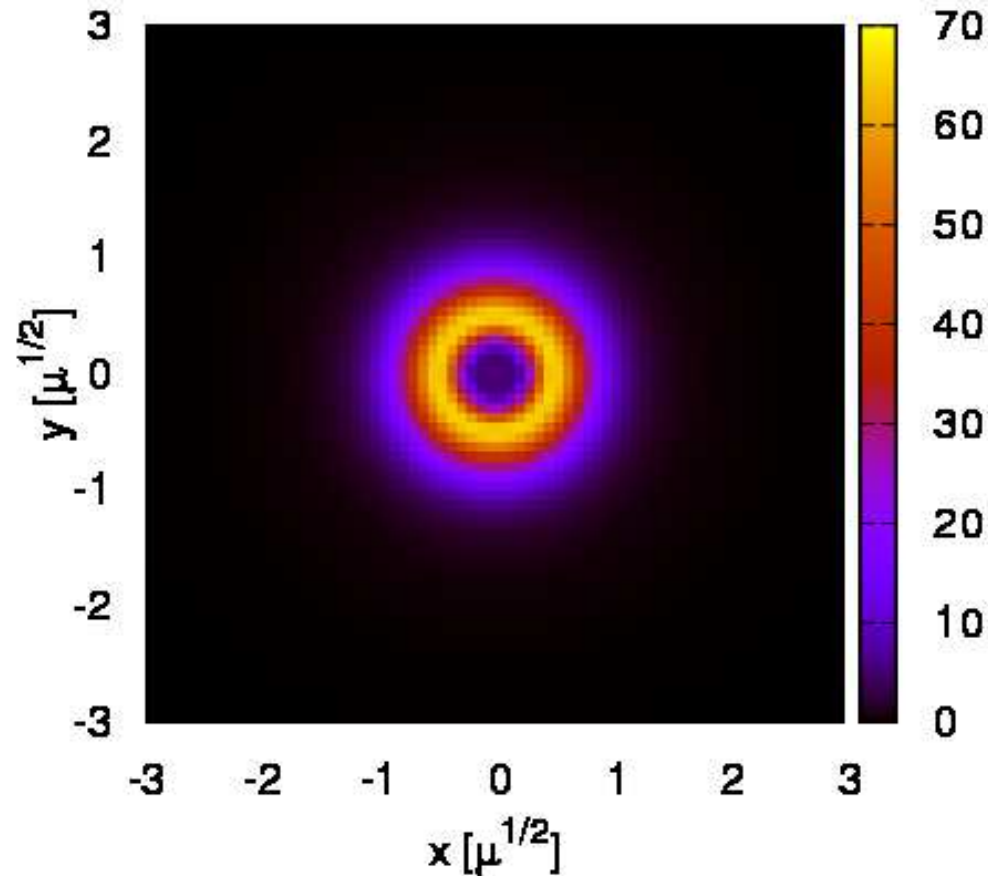


Scattering increase BH mass and anugular momentum.

This is “tidal effect.”(Price(1943),Poisson(2004))

Kretschmann scalar

gauge invariant scalar : $R_{abcd}R^{abcd}$



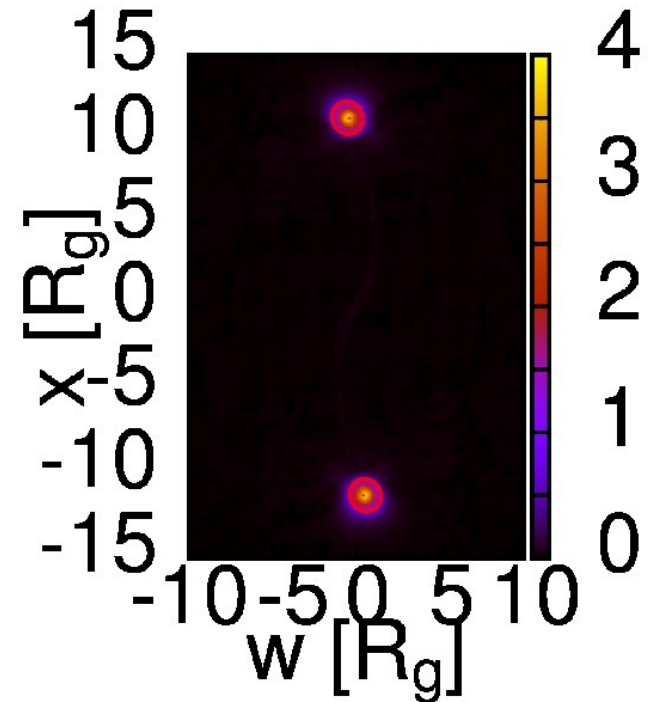
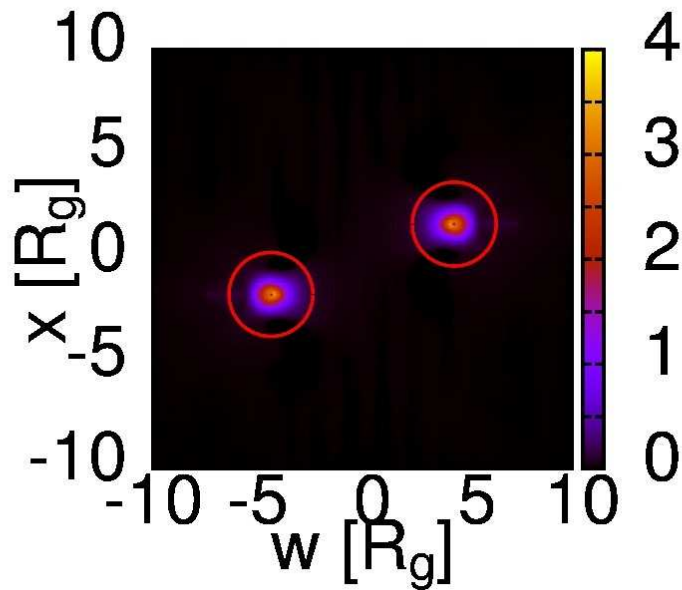
isotropic Schwarzschild BH as reference

Kretschmann scalar of BH scattering

Animation

Caution :: This movie is so quick!

Before and After collision



Red curve :: Horizon of BHs

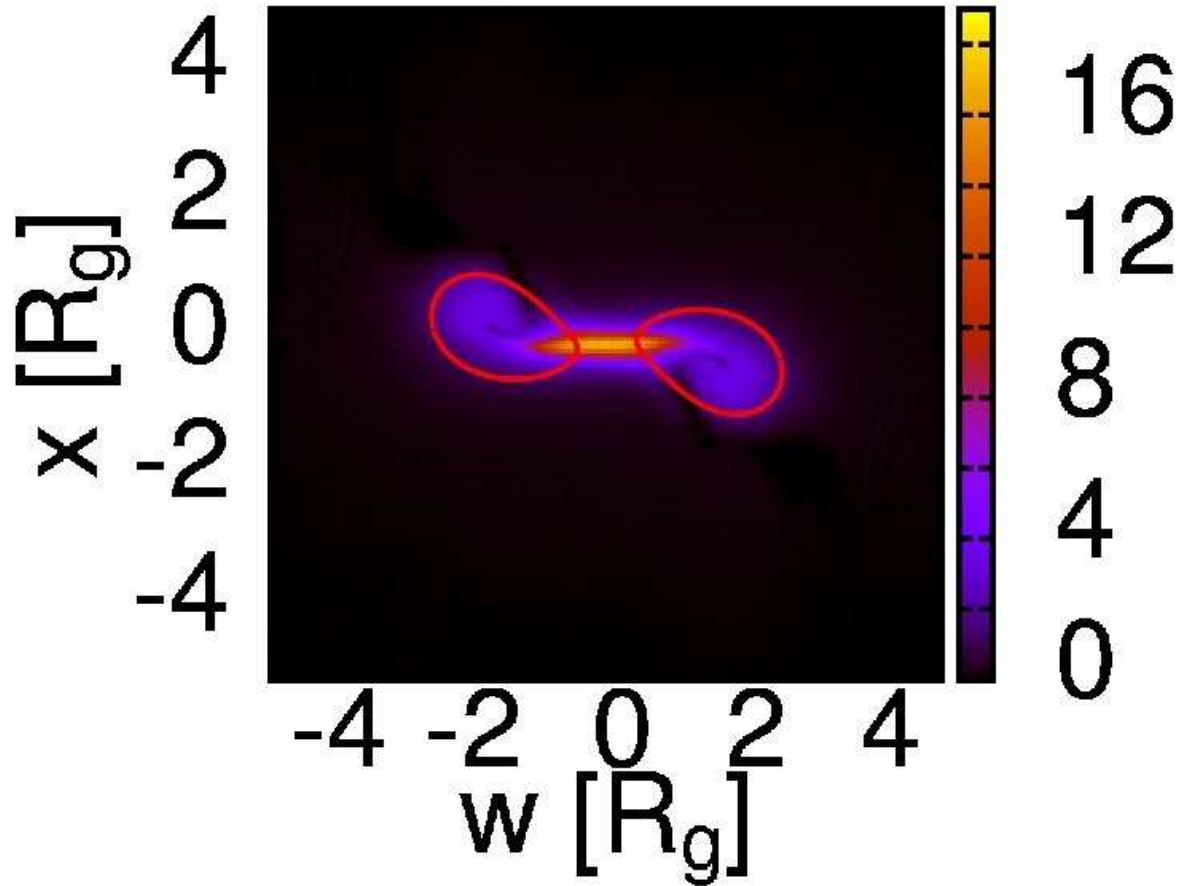
before collision

after collision

Kretschmann scalar normalized
by the value of Schwarzschild BH horizon

During collision

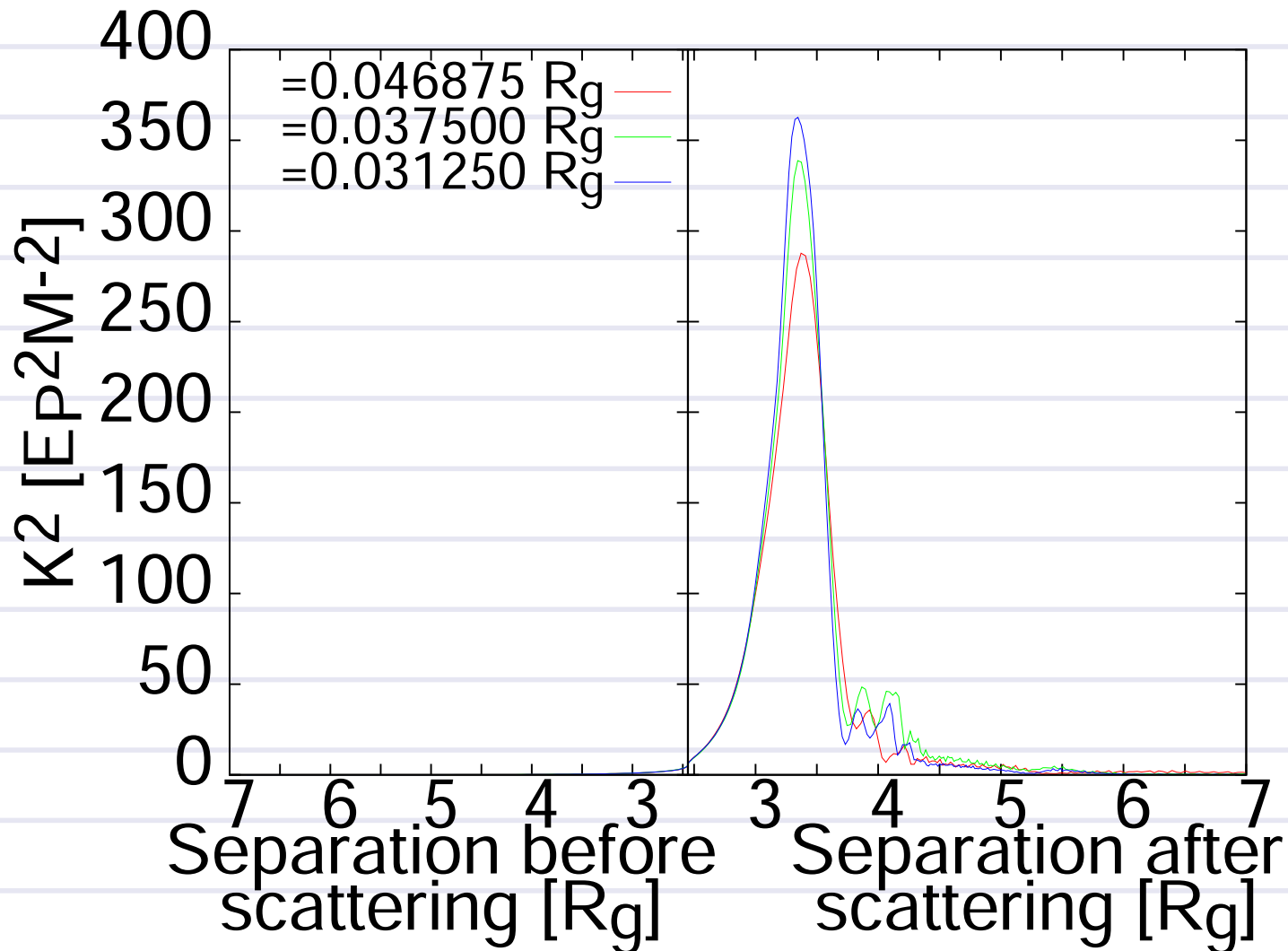
HO, Nakao, Shibata(2011)



disturbed horizon

Kretschmann scalar outside BH horizon

Kretschmann scalar and BH separation

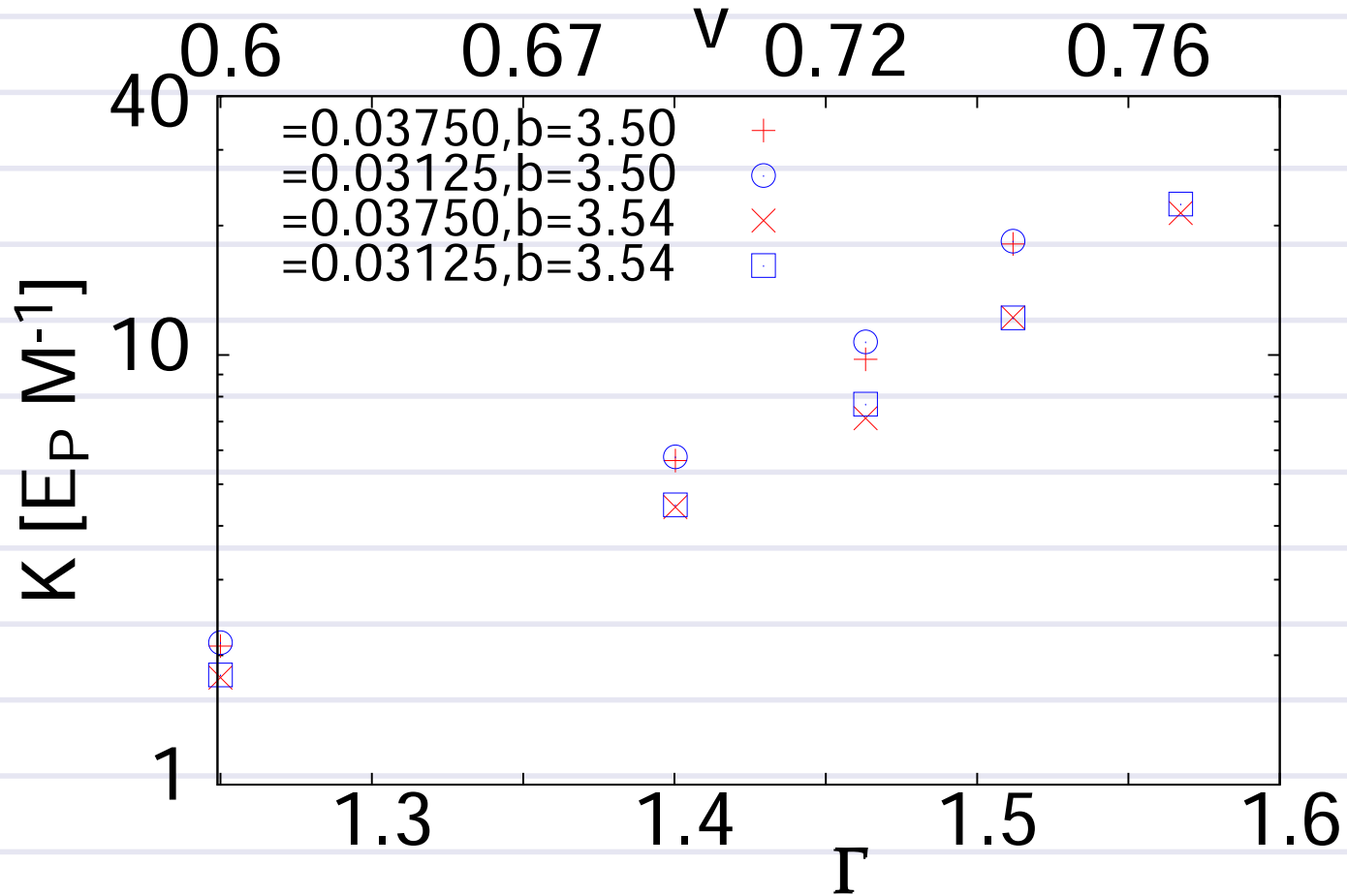


Horizontal axis : separation (Time goes from left to right.)

Vertical axis : square of Kreschmann scalar

Color : difference of resolution

Initial velocity of BH



Horizontal axis : BH velocity(v, Γ)

Vertical axis : Maximum of Kretschmann scalar

Impact parameter is fixed

Summary

- 🌀 We performed the collision of two BHs in 5 dimensions with Numerical Relativity.
- 🌀 We study the region of scattering with certainty.
- 🌀 BHs after less violent scattering increase their mass and angular momentum because of tidal effect.
- 🌀 Kretschmann scalar outside the horizon of BHs is so large with some impact parameter and initial velocity of BHs.

Future Work

- 🌀 I want to study the region of difficult calculation in detail.