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Gravitational waves from a spinning compact object in EMRI

PRD, 94: 104010 (2016)
arXiv:1609.00356

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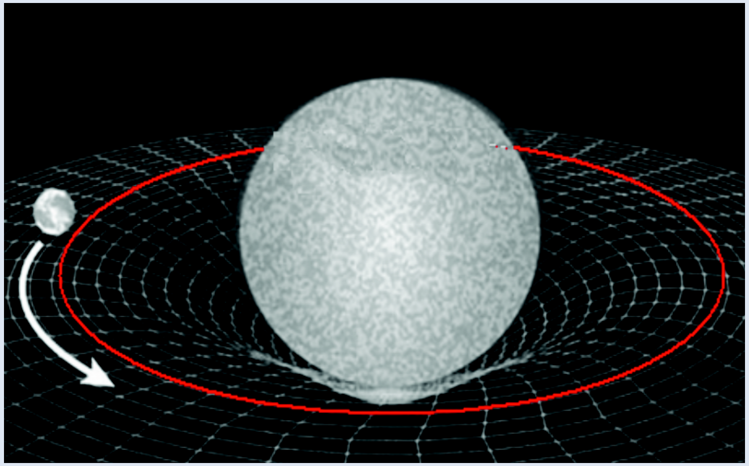
Astrophysical Setup

The centres of galaxies are occupied
by SuperMassive Black Holes with masses $M=10^5$-10^9 $M_{\odot}$.

An Extreme Mass Ratio Inspiral is the inspiral of a stellar compact object into a SMBH, and this inspiral follows approximately (adiabatically) the geodesic motion. An improved approximation includes the spin of the inspiraling object.

Laser Interferometer Space Antenna-like gravitational wave detectors designed to detect signals from EMRI.



Babak, Gair, Petiteau & Sesana, CQG (2010)
Amaro-Seoane et al. ArXiv: 1202.0839

Spinning particle equations

Mathisson, APP (1937), Papapetrou, PRSL (1951)

A pole-dipole (mass-spin) approximation for an extended body.

$$\frac{D\ p^\mu}{d\tau} = -\frac{1}{2}\ R^\mu_{\ \nu\kappa\lambda} v^\nu S^{\kappa\lambda}$$

$$\frac{D\ S^{\mu\nu}}{d\tau} = p^\mu\ v^\nu - v^\mu\ p^\nu$$

$$v^\mu \ = \ dx^\mu / d\tau$$

In general the velocity is not parallel to the momenta

Cannot evolve the system of ODEs, the system is not closed!

SSC

Spin Supplementary Conditions (SSC)

$$v_\mu S^{\mu\nu} = 0$$

Pirani, APP (1956)

$$p_\mu S^{\mu\nu} = 0$$

Tulczyjew, APP (1959)

$$V_\mu S^{\mu\nu} = 0$$

Ohashi, PRD (2003), Kyrian and Semerak, MNRAS (2007)
Semerak and Sramek, PRD (2015)

$$p^\mu = \mathrm{m} v^\mu - v_\nu \frac{D\ S^{\mu\nu}}{d\lambda}$$

Mass definitions

$$\mu := \sqrt{-p^\mu p_\mu}$$

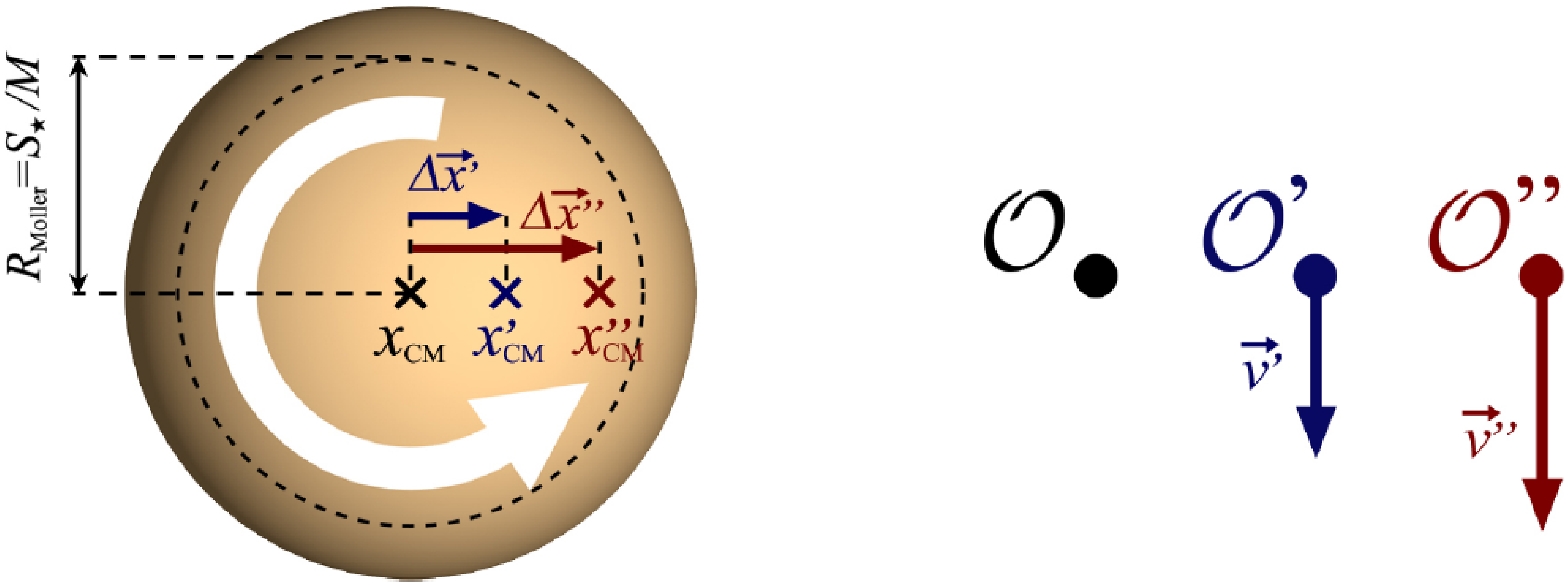
$$\mathrm{m} := -v^\mu p_\mu$$

Spin measure

$$S^2 = \frac{1}{2}\ S_{\mu\nu}\ S^{\mu\nu}$$

Different observers

Costa, Natario, Fundamental Theories of Physics 179 (2015)

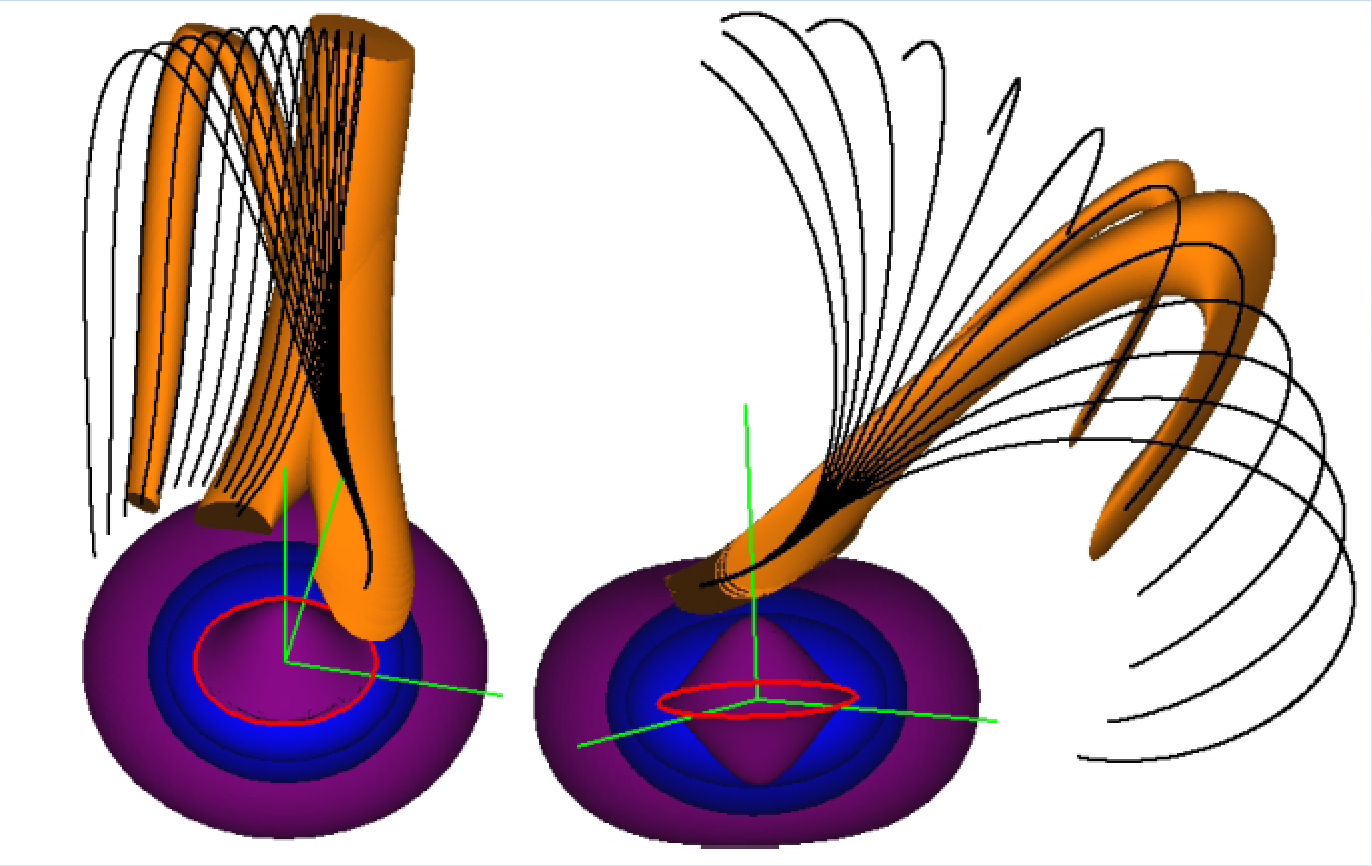


Upper bound of separation for different SSCs.

Möller, CDIAS (1949)

Minimal radius of a body not rotating with superluminous speed.

Out of worldtube



Kyrian and Semerak, MNRAS (2007)

EOB Hamiltonian

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Damour, Jaranowski, Shafer, PRD (2008)

Hamiltonian from Tulczyjew SSC by imposing by hand $D S^{\mu\nu}/d\tau=0$

Damour, Nagar, PRD (2014)

EOB Hamiltonian for circular equatorial orbits

$$\hat{H} = \hat{P}_\phi \left(G_S \hat{a}_1 + G_{S_*} \frac{m_2}{m_1} \hat{a}_2 \right) + \sqrt{A \left(1 + \hat{P}_\phi^2 U_c^2 \right)}$$

Motivation

- No prescription is more correct than the other.

- A SSC choice should be just a gauge.

- How the different prescription relate to each other?

- Do they produce similar GW signals when put to the same physical situation, i.e. radius and spin?

Investigation setup

- Circular equatorial orbits on Schwarzschild .

- Spin $\sigma = S(\mu M)$ aligned with the angular momentum.

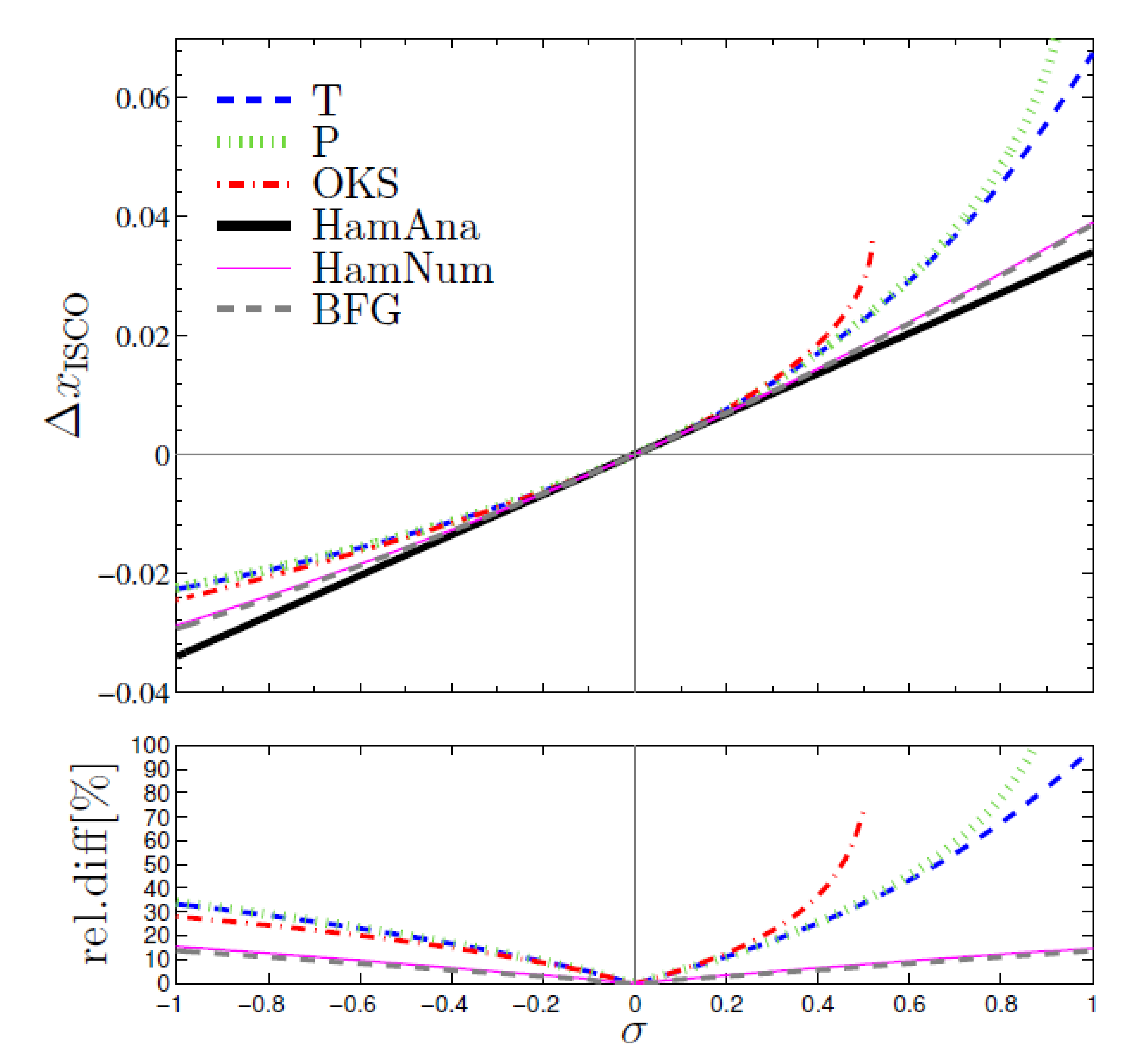
- Not shifting of centroids for different SSC, not comparing exactly the same body.

- Comparing similar physical situations, i.e. comparisons for the same σ and x.

- GW energy fluxes computed through a time domain Teukolsky equation solver, called Teukode.

Harms, GL, Nagar, Bernuzzi, PRD (2016)

ISCO

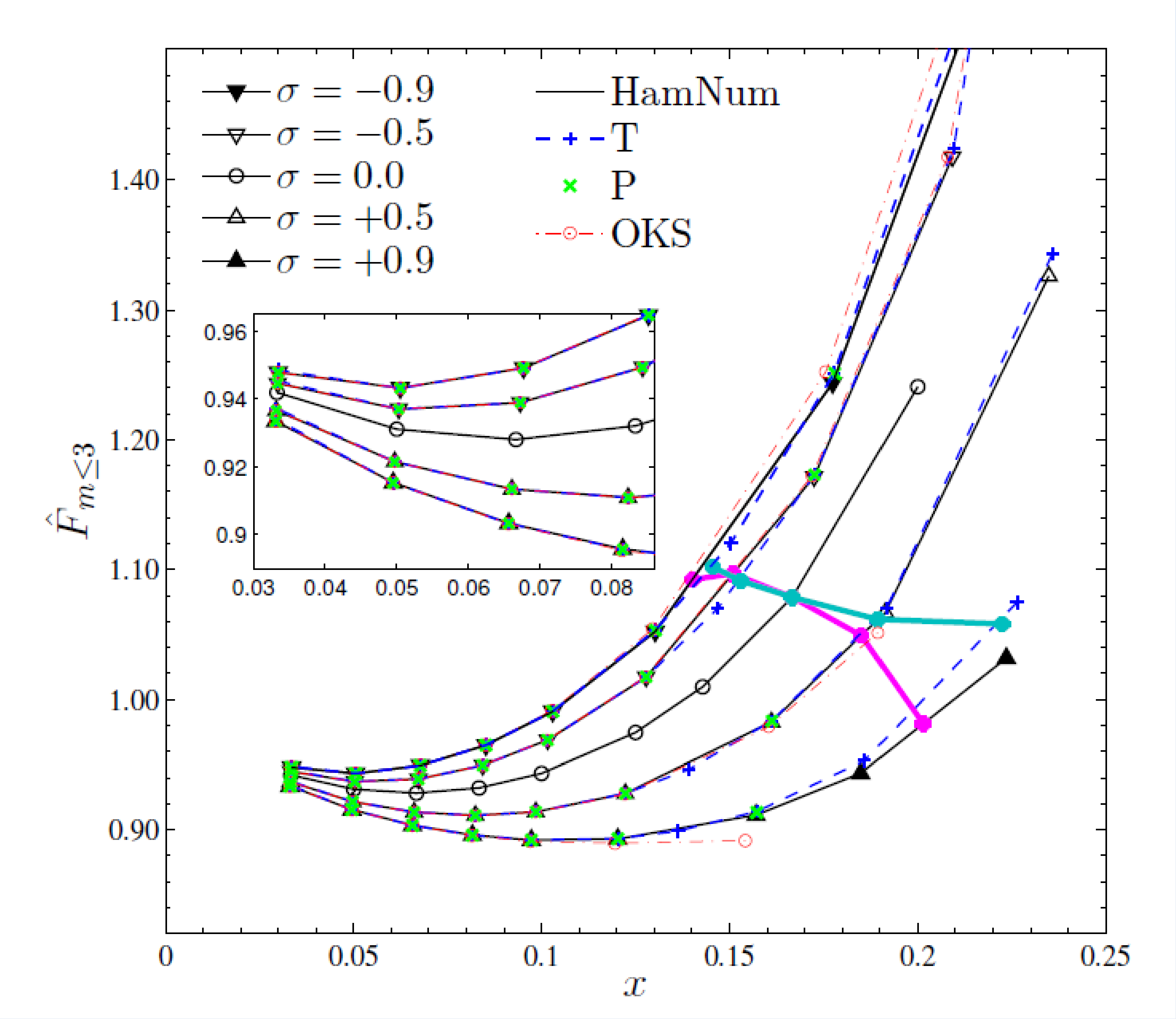


$$x \equiv (M\Omega)^{2/3}$$

$$x^{\rm ISCO} = \frac{1}{6} + \frac{\sigma}{12\sqrt{6}}$$

$$\Delta x_{\rm ISCO}(\sigma) = x_{\rm ISCO}(\sigma) - x_{\rm ISCO}(0) = x_{\rm ISCO}(\sigma) - \frac{1}{6}$$

GW energy Fluxes



$$F = \sum_{m=1}^{\infty} F_m$$

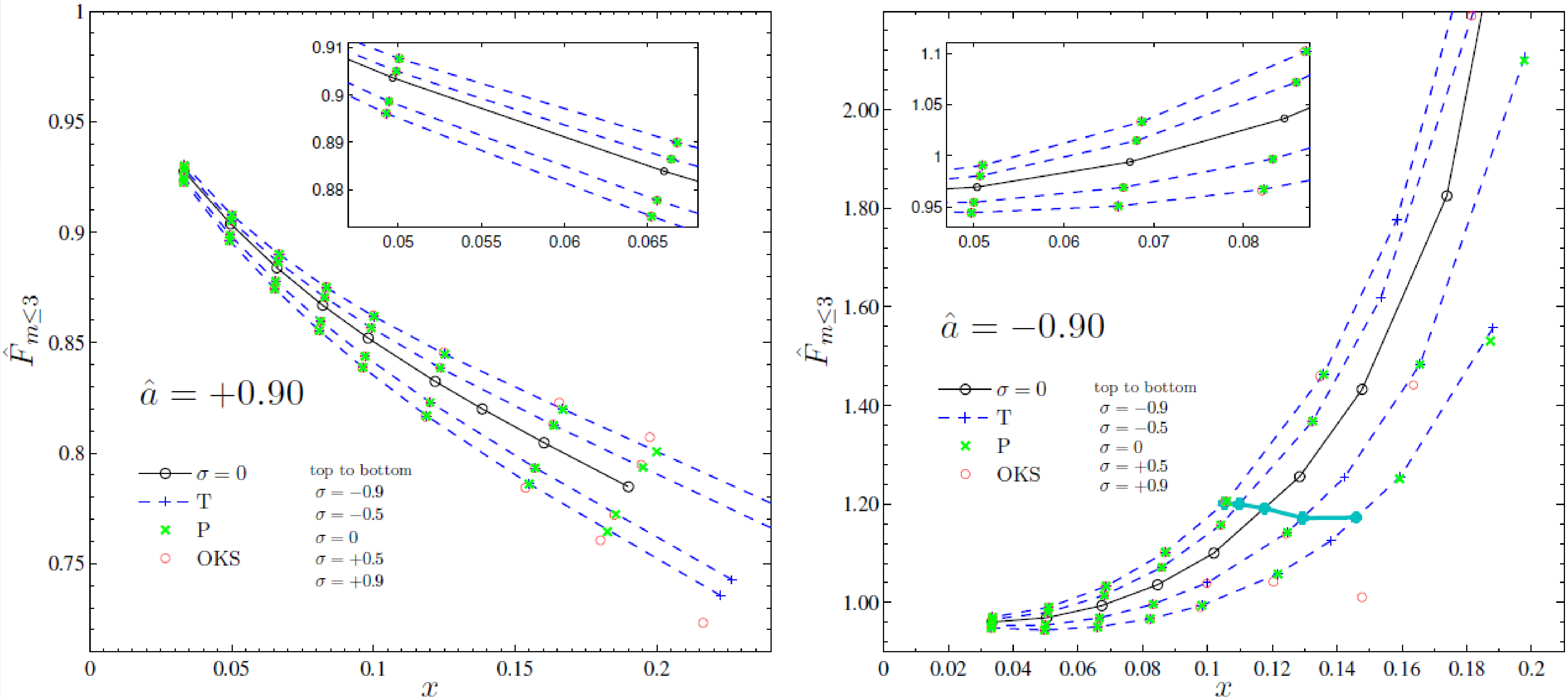
Conclusions

The SSC choice seems not to be “just” a gauge for the pole-dipole approximation. Further investigation needed.

Different prescriptions agree for low spins and low frequencies, while disagree for high spins and high frequencies.

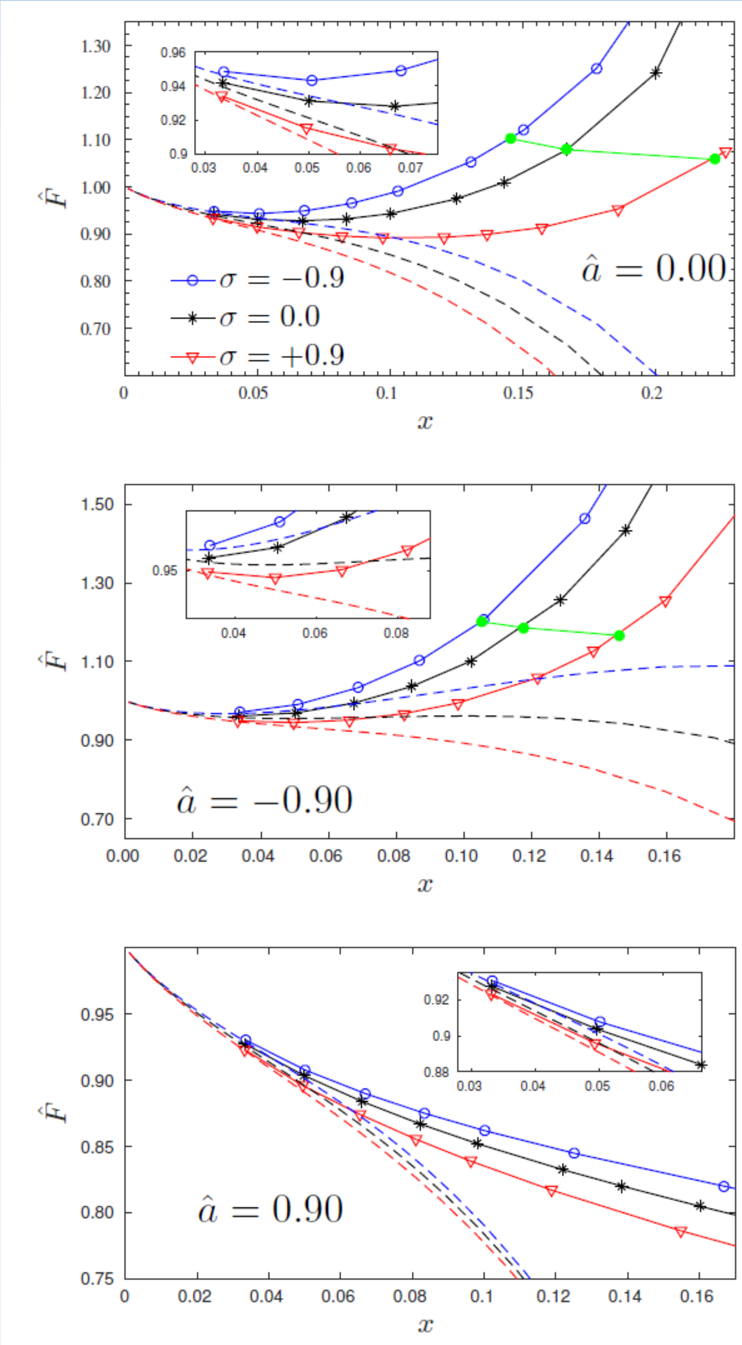
For astrophysical relevant spin values there will no practical discrepancies.

Fluxes from Kerr



Harms, GL, Nagar, Bernuzzi, in preparation

Fluxes from Kerr:Tul vs PN2.5



Harms, GL, Nagar, Bernuzzi, PRD (2016)
Tanaka, Mino, Sasaki, Shibata, PRD (1996)