Analytic models for compact binaries
spin and **dynamic tides**

Jan Steinhoff

in collaboration with Tanja Hinderer, Alessandra Buonanno, and Andrea Taracchini

Steinhoff etal, arXiv:1608.01907   Hinderer etal, PRL **116** (2016) 181101

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GR21, Party Space, Columbia University, New York, July 13th, 2016

Results for post-Newtonian approximation with spin

conservative part of the motion of the binary; see talk by Michele Levi on Monday

post-Newtonian (PN) approximation: expansion around $\frac{1}{c} \to 0$ (Newton)

order	c^0 N	c^{-1}	c^{-2} 1PN	c^{-3}	c^{-4} 2PN	c^{-5}	c^{-6} 3PN	c^{-7}	c^{-8} 4PN
non spin	✔		✔		✔		✔		✔
spin-orbit				✔		✔		✔	
S_1^2					✔		✔		✔ (derived last year)
$S_1 S_2$					✔		✔		✔
Spin^3								✔ (derived last year) (✔) (partial)	
Spin^4									✔ (derived last year) (✔) (partial)
⋮									⋱

✔ known (✔) partial ✔ derived last year

Work by many people ("just" for the spin sector): Barker, Blanchet, Bohé, Buonanno, O'Connell, Damour, D'Eath, Faye, Hartle, Hartung, Hergt, Jaranowski, Marsat, Levi, Ohashi, Owen, Perrodin, Poisson, Porter, Porto, Rothstein, Schäfer, Steinhoff, Tagoshi, Thorne, Tulczyjew, Vaidya

Zones, separation of scales, and effective theory

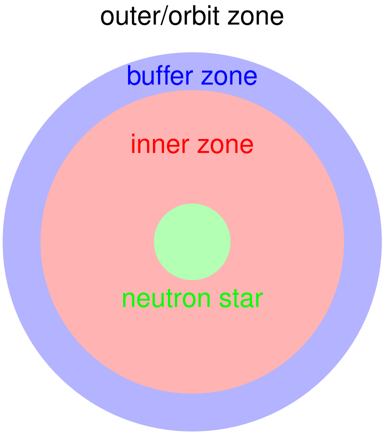
EFT program in classical gravity: Goldberger, Rothstein, PRD **73** (2006) 104029; . . .

various zones → separation of scales

scales continue down the star:
→ fluid, nucleons, quarks, ?

The physics at "smaller" scales admits
an Effective Field Theory (EFT) description!

Here: Effective theory for dynamical tides
→ dynamical, time-dependent response
(of the inner zone to perturbations from the outer zone)
→ harmonic oscillator effective theory for multipoles



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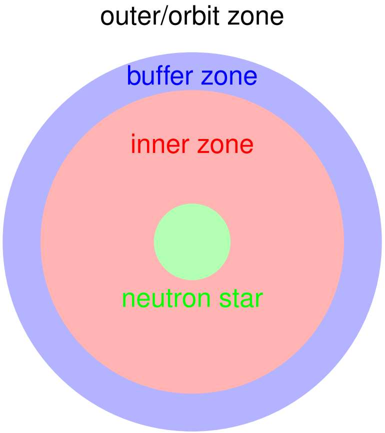

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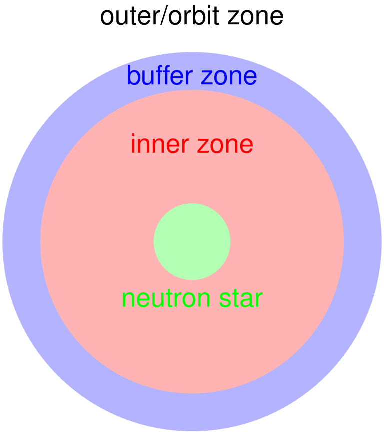

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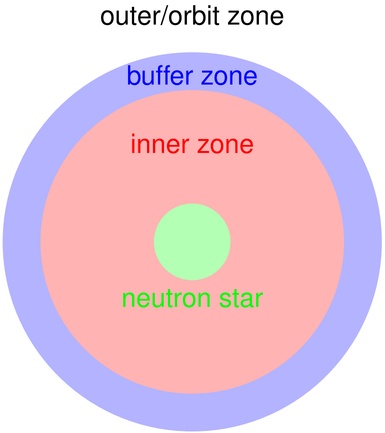

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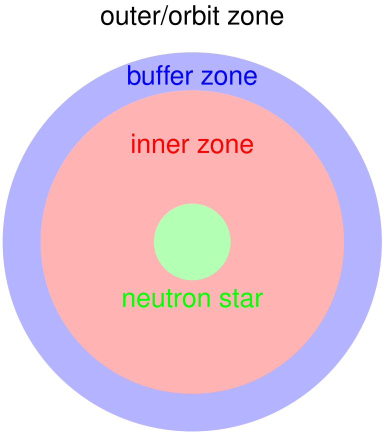

Dynamical tides in general relativity

Their description through an effective action [JS, Hinderer, Taracchini, Buonanno, in preparation]

Relativistic effective Lagrangian for dynamical tides: $Q_{\mu\nu} u^{\nu} = 0$

$$L_Q = \frac{z}{4\lambda\omega_f^2}\left[\frac{1}{z^2}\frac{DQ_{\mu\nu}}{d\sigma}\frac{DQ^{\mu\nu}}{d\sigma} - \omega_f^2 Q_{\mu\nu}Q^{\mu\nu}\right] - \frac{z}{2}E_{\mu\nu}Q^{\mu\nu} + \frac{z}{4}K\,E_{\mu\nu}E^{\mu\nu} + \ldots$$

$$u^{\mu} = \frac{Dx^{\mu}}{d\sigma}, \qquad z = \sqrt{-u^{\mu}u_{\mu}} \quad \text{(is the redshift for } \sigma = t\text{)}$$

- Newtonian case: [Flanagan, Hinderer, PRD **77** (2008) 021502]
- λ is the tidal deformability (Love number)
- identify ω_f with real part of quasi-normal-mode frequency
- K linked to (almost) completeness of modes: $K \approx 0$

ω_f and K are not fixed by a matching, but by physical intuition!

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Relativistic effects on dynamic tides

What are the genuine relativistic effects?

- redshift effect
- gravitomagnetism
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Both effectively shift
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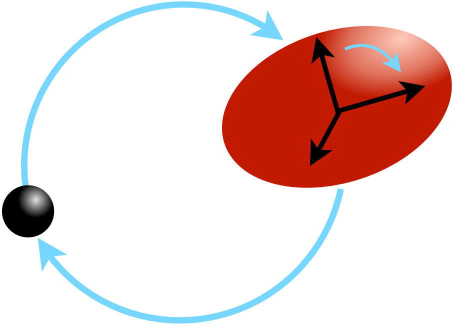

frame of the neutron star is dragged
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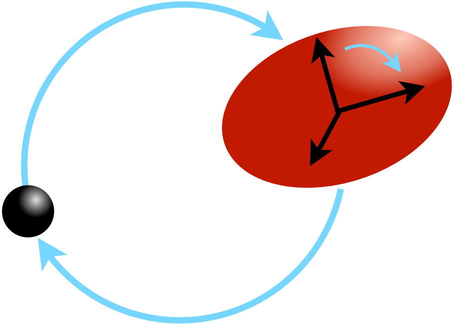

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Computing the post-Newtonian (PN) corrections

Frame dragging interaction

tidal spin: $S_Q^{ij} = 4 Q^{k[i} P^{j]k}$
generates infinitesimal rotations
$\rightarrow$ frame dragging

substitute $S^{ij} \rightarrow S_Q^{ij}$ in known potentials! $\rightarrow$ lazy

The tidal driving force

$$\text{tidal:} \quad -\frac{1}{2} E_{\mu\nu} Q^{\mu\nu} \qquad \text{vs.} \qquad \text{spin induced:} \quad \frac{C_{\mathrm{ES}^2}}{2m} E_{\mu\nu} S^{\mu} S^{\nu}$$

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super lazy!!! agrees with Vines, Flanagan, PD **88** (2013) 024046

Harder: implementation into effective-one-body, analyze various models, ...

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Conclusions

All you need is λ! ?

pics/allLove

Almost, need more coefficients
linked to dynamical tides!

λ, ω_f, K, ...

Dynamical tides become important
close to resonance with ω_f

Increase tidal effect by $\sim$ 30%!

Dynamical tides are important for accurate waveform models

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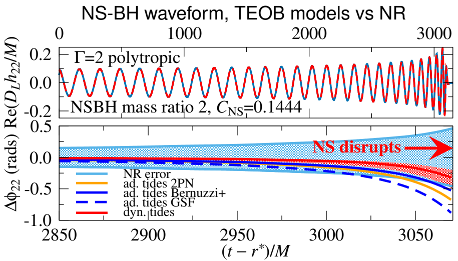

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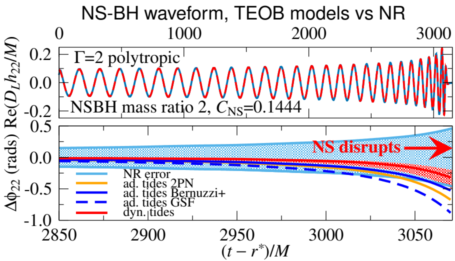

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