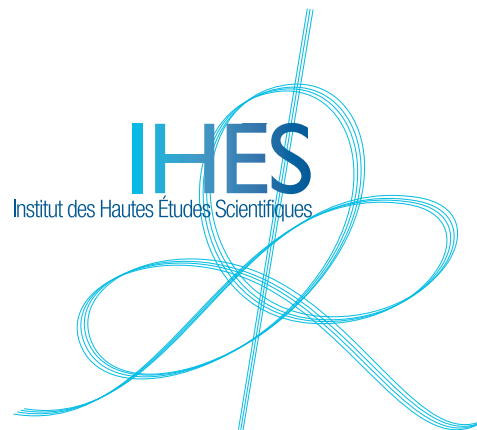


Théorie du mouvement et du rayonnement gravitationnel de deux trous noirs

Thibault Damour

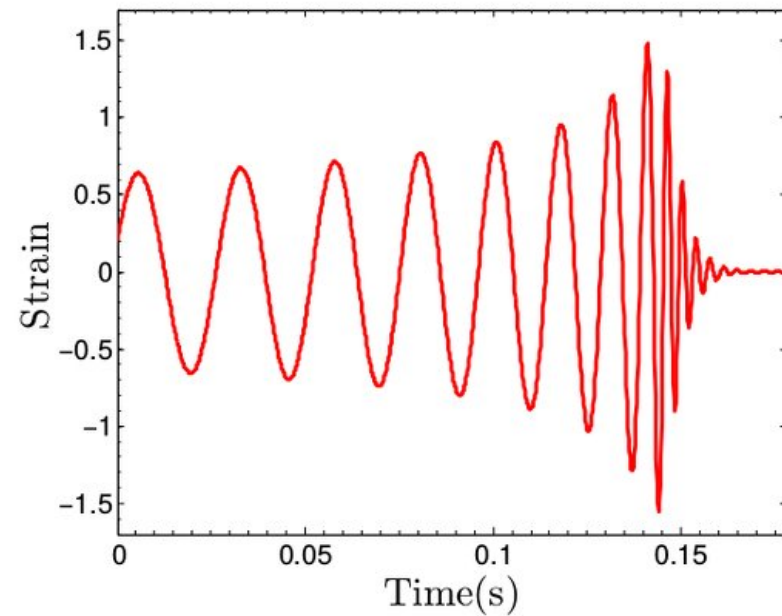
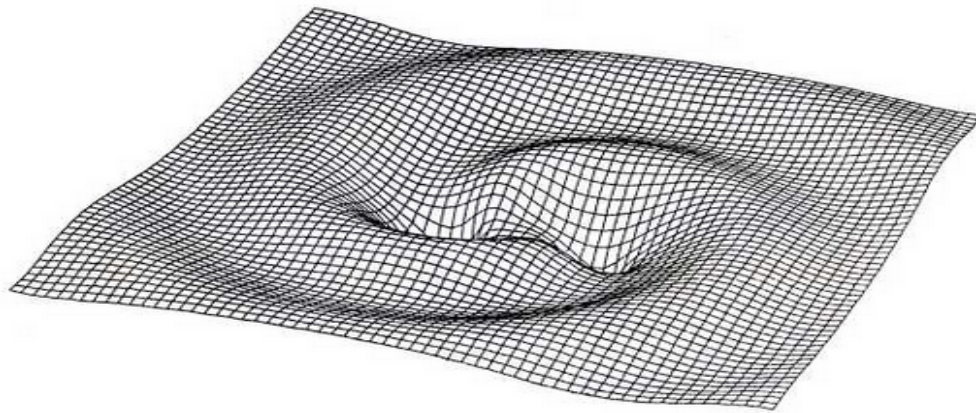
Institut des Hautes Etudes Scientifiques



Mouvement et Rayonnement en Relativité Générale

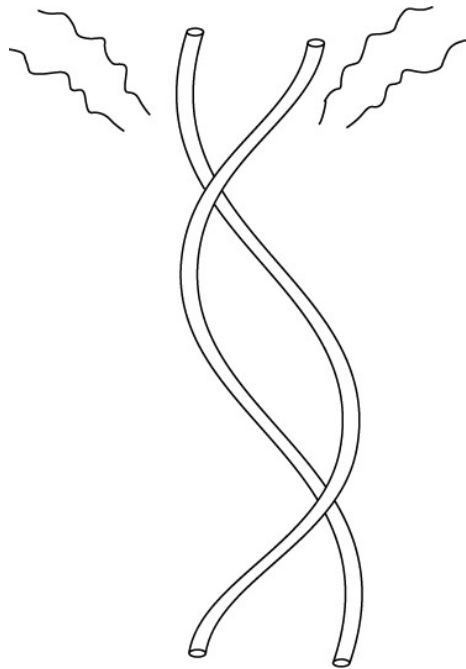


$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$



Mouvement (circulaire) et rayonnement à l'ordre le plus bas

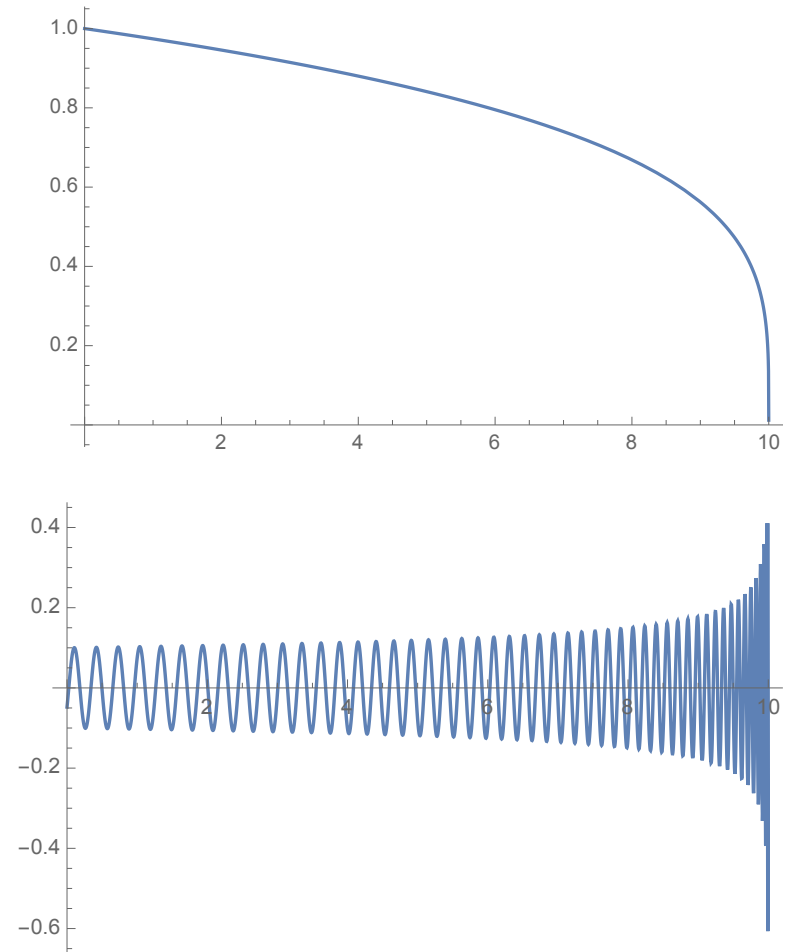
Dyson 1963, utilisant Einstein 1918, Landau-Lifchitz 1951
Binaire de deux étoiles à neutrons

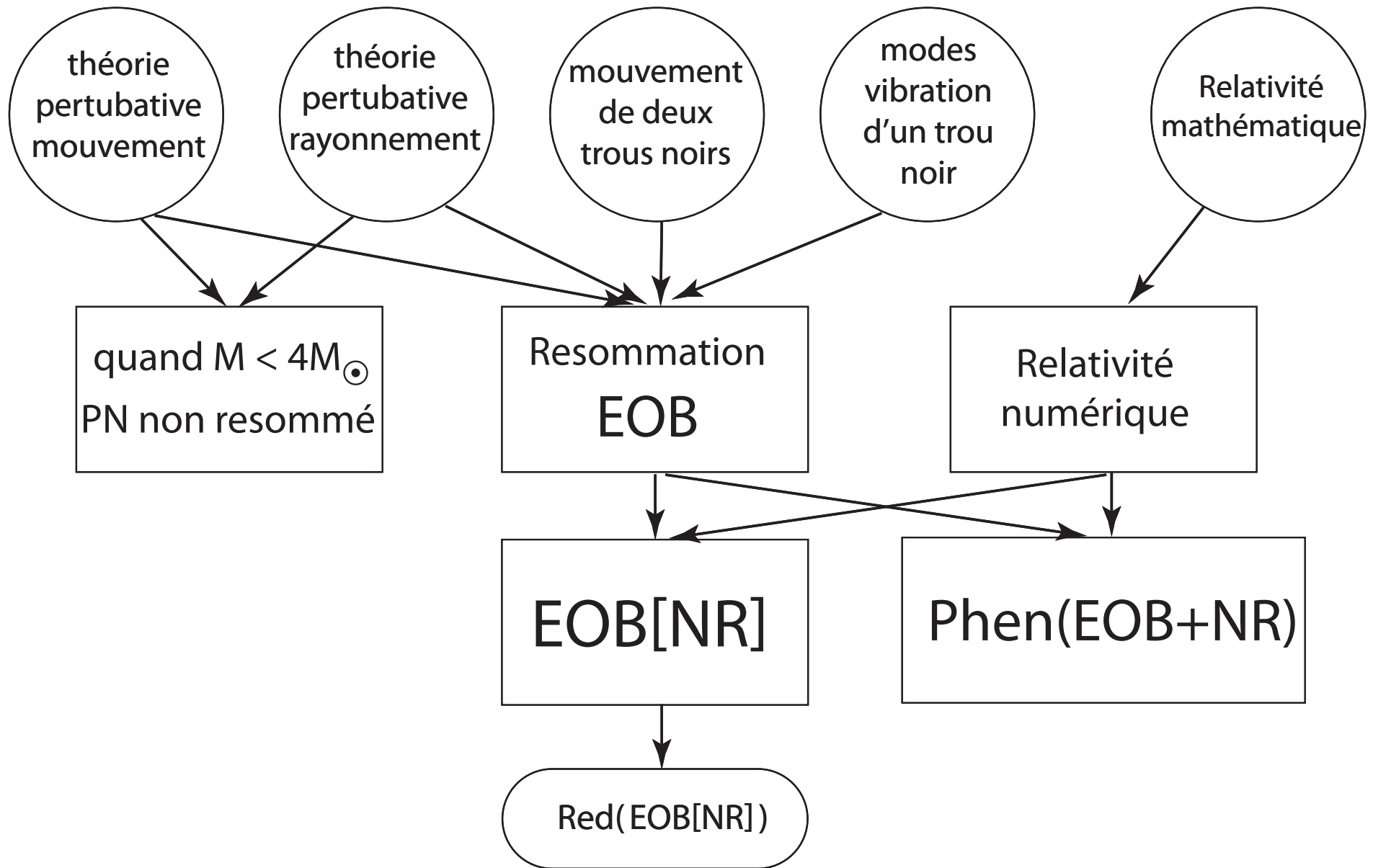


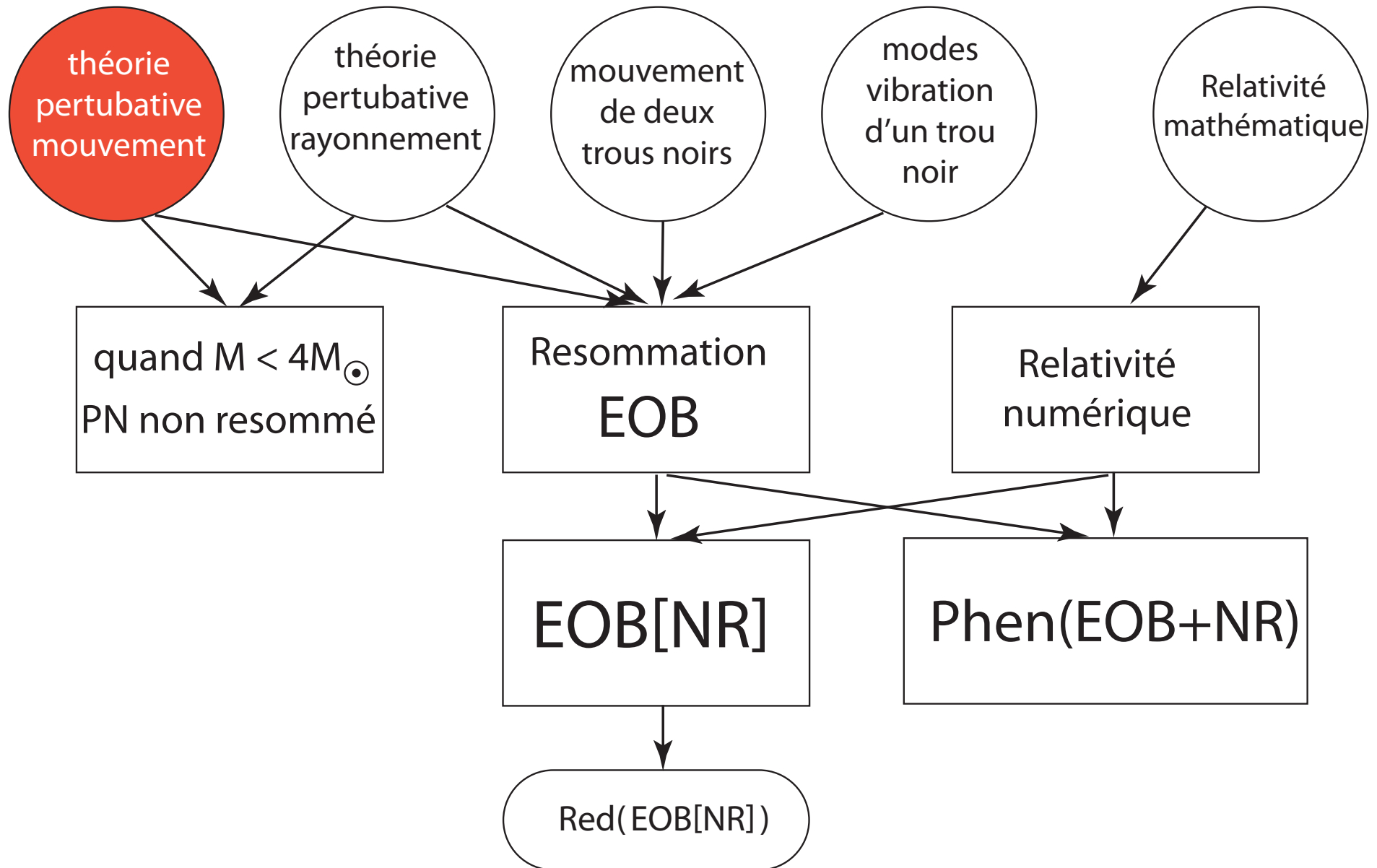
$$E = -\frac{G m_1 m_2}{2r}$$

$$\frac{d}{dt} E = -F$$

$$F = \frac{32 G^4}{5 c^5} \frac{m_1^2 m_2^2 (m_1 + m_2)}{r^5}$$





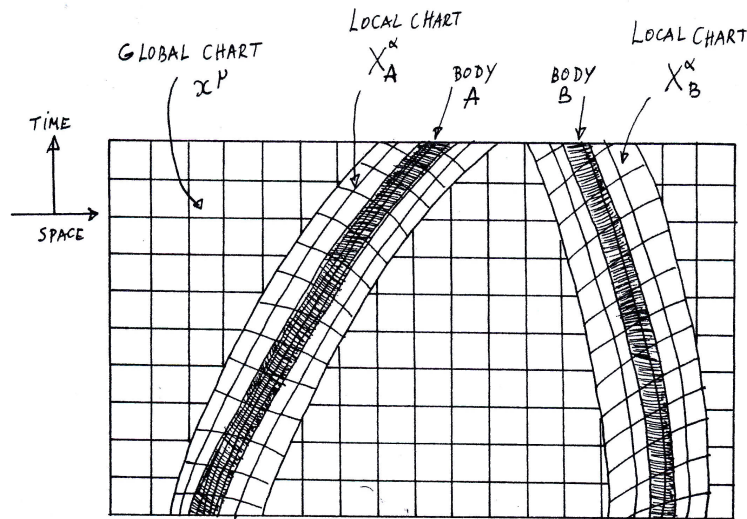


Longue histoire du problème à deux corps

- Einstein 1912 : principe géodésique $-\int m \sqrt{-g_{\mu\nu} dx^\mu dx^\nu}$
- Einstein 1913-1916: post-Minkowskien $g_{\mu\nu}(x) = \eta_{\mu\nu} + h_{\mu\nu}(x)$, $h_{\mu\nu} \ll 1$
- Einstein, Droste : post-Newtonien $h_{00} \sim h_{ij} \sim \frac{v^2}{c^2}$, $h_{0i} \sim \frac{v^3}{c^3}$, $\partial_0 h \sim \frac{v}{c} \partial_i h$
- 1916-1938 Eq. mouvt N corps à Newton $(1 + v^2/c^2) = 1\text{PN}$

Einstein-Infeld-Hoffmann 1938

Nouvelles techniques en théorie perturbative du mouvt



- approche multi-cartes et raccordements de développements asymptotiques [Demianski-Grishchuk 74](#), [D'Eath 75](#), [Kates 80](#), [Damour 82](#)

- nécessaire pour la théorie du mouvement des pulsars binaires ([Damour-Deruelle 81-82](#)) qui a montré que la propagation par **ondes** de la gravitation rendait compte des observations ([Taylor et al, 79-93](#))



- squelettonisation : $T_{\mu\nu} \rightarrow$ masses ponctuelles ([Infeld 54....](#))
- importation de la **régularisation analytique** ([Riesz 49](#)) et **dimensionnelle** ([t'Hooft-Veltman 72](#)) en Relativité Générale ([Damour 80](#), [Damour-Jaranowski-Schäfer 01](#))

Equations post-newtoniennes du mouvt [2-corps, spin =0)]

- 1PN (incluant v^2/c^2) Lorentz-Droste '17, EIH '38, Eddington-Clark '38
- 2PN (inc. v^4/c^4) Ohta-Okamura-Kimura-Hiida '74, Damour-Deruelle '81
Damour '82, Schäfer '85, Kopeikin '85
- 2.5 PN (inc. v^5/c^5) Damour-Deruelle '81, Damour '82, Schäfer '85,
Kopeikin '85
- 3 PN (inc. v^6/c^6) Jaranowski-Schäfer '98, Blanchet-Faye '00,
Damour-Jaranowski-Schäfer '01, Itoh-Futamase '03,
Blanchet-Damour-Esposito-Farèse' 04, Foffa-Sturani '11
- 3.5 PN (inc. v^7/c^7) Iyer-Will '93, Jaranowski-Schäfer '97, Pati-Will '02,
Königsdörffer-Faye-Schäfer '03, Nissanke-Blanchet '05, Itoh '09
- 4PN (inc. v^8/c^8) Jaranowski-Schäfer '13, Foffa-Sturani '13,
Bini-Damour '13, Damour-Jaranowski-Schäfer '14

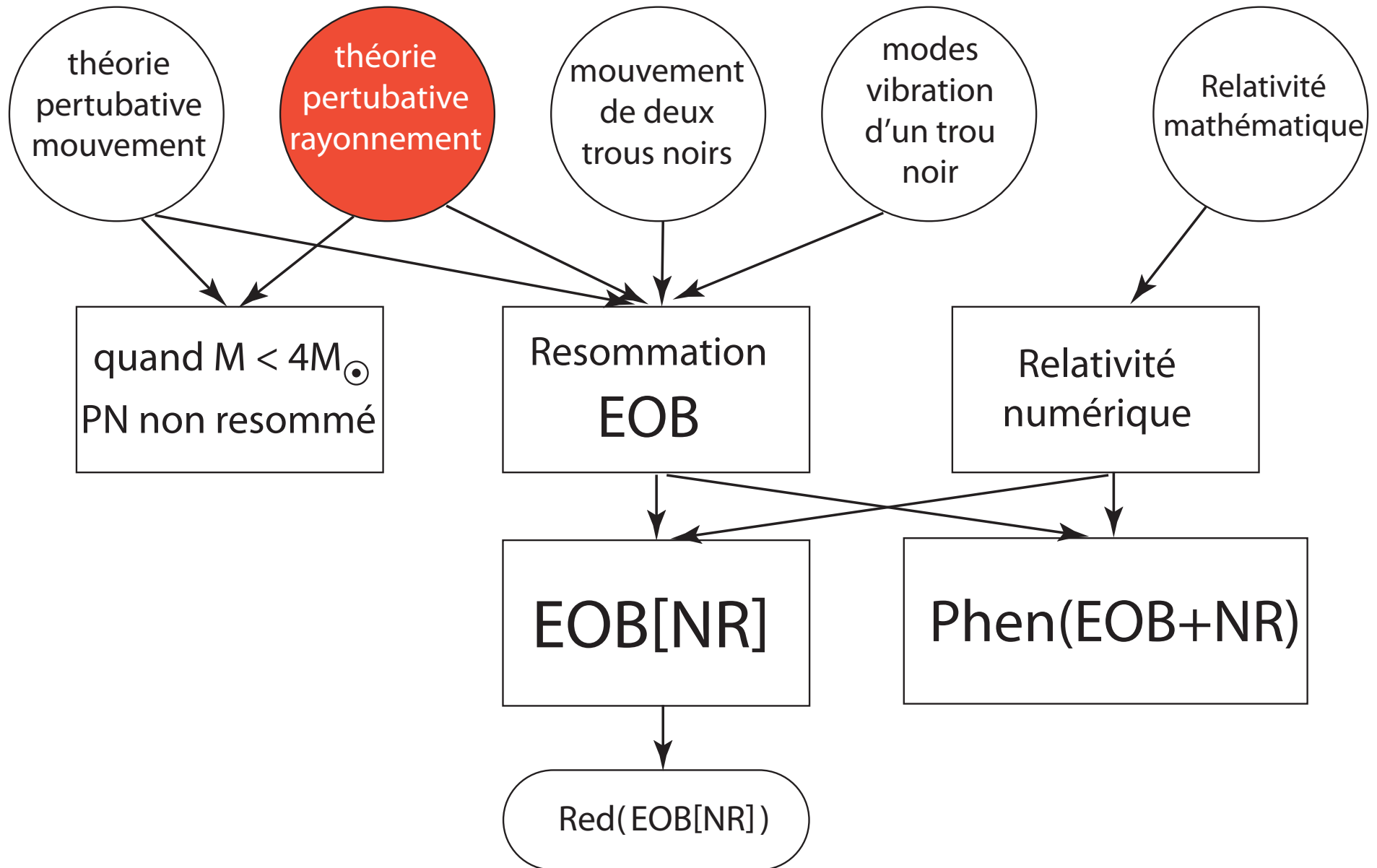
Nouvelle propriété : **non-localité temporelle**

2-body CoM Newton + 1PN + 2PN + 3PN Hamiltonian

$$\begin{aligned}
 \hat{H}_N(\mathbf{r}, \mathbf{p}) &= \frac{\mathbf{p}^2}{2} - \frac{1}{r}, \\
 \hat{H}_{1\text{PN}}(\mathbf{r}, \mathbf{p}) &= \frac{1}{8}(3\nu - 1)(\mathbf{p}^2)^2 - \frac{1}{2} \left\{ (3 + \nu)\mathbf{p}^2 + \nu(\mathbf{n} \cdot \mathbf{p})^2 \right\} \frac{1}{r} + \frac{1}{2r^2}, \\
 \hat{H}_{2\text{PN}}(\mathbf{r}, \mathbf{p}) &= \frac{1}{16} (1 - 5\nu + 5\nu^2) (\mathbf{p}^2)^3 + \frac{1}{8} \left\{ (5 - 20\nu - 3\nu^2) (\mathbf{p}^2)^2 - 2\nu^2(\mathbf{n} \cdot \mathbf{p})^2 \mathbf{p}^2 - 3\nu^2(\mathbf{n} \cdot \mathbf{p})^4 \right\} \frac{1}{r} \\
 &\quad + \frac{1}{2} \left\{ (5 + 8\nu)\mathbf{p}^2 + 3\nu(\mathbf{n} \cdot \mathbf{p})^2 \right\} \frac{1}{r^2} - \frac{1}{4}(1 + 3\nu) \frac{1}{r^3}, \\
 \hat{H}_{3\text{PN}}(\mathbf{r}, \mathbf{p}) &= \frac{1}{128} (-5 + 35\nu - 70\nu^2 + 35\nu^3) (\mathbf{p}^2)^4 \\
 &\quad + \frac{1}{16} \left\{ (-7 + 42\nu - 53\nu^2 - 5\nu^3) (\mathbf{p}^2)^3 + (2 - 3\nu)\nu^2(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^2 + 3(1 - \nu)\nu^2(\mathbf{n} \cdot \mathbf{p})^4 \mathbf{p}^2 - 5\nu^3(\mathbf{n} \cdot \mathbf{p})^6 \right\} \frac{1}{r} \\
 &\quad + \left\{ \frac{1}{16} (-27 + 136\nu + 109\nu^2) (\mathbf{p}^2)^2 + \frac{1}{16} (17 + 30\nu)\nu(\mathbf{n} \cdot \mathbf{p})^2 \mathbf{p}^2 + \frac{1}{12} (5 + 43\nu)\nu(\mathbf{n} \cdot \mathbf{p})^4 \right\} \frac{1}{r^2} \\
 &\quad + \left\{ \left(-\frac{25}{8} + \left(\frac{\pi^2}{64} - \frac{335}{48} \right) \nu - \frac{23\nu^2}{8} \right) \mathbf{p}^2 + \left(-\frac{85}{16} - \frac{3\pi^2}{64} - \frac{7\nu}{4} \right) \nu(\mathbf{n} \cdot \mathbf{p})^2 \right\} \frac{1}{r^3} \\
 &\quad + \left\{ \frac{1}{8} + \left(\frac{109}{12} - \frac{21}{32} \pi^2 \right) \nu \right\} \frac{1}{r^4}.
 \end{aligned}$$

2-body CoM 4PN Hamiltonian [DJS 2014]

$$\begin{aligned}
 \hat{H}_{4\text{PN}}(\mathbf{r}, \mathbf{p}) = & \left(\frac{7}{256} - \frac{63}{256}\nu + \frac{189}{256}\nu^2 - \frac{105}{128}\nu^3 + \frac{63}{256}\nu^4 \right) (\mathbf{p}^2)^5 \\
 & + \left\{ \frac{45}{128}(\mathbf{p}^2)^4 - \frac{45}{16}(\mathbf{p}^2)^4\nu + \left(\frac{423}{64}(\mathbf{p}^2)^4 - \frac{3}{32}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^3 - \frac{9}{64}(\mathbf{n} \cdot \mathbf{p})^4(\mathbf{p}^2)^2 \right) \nu^2 \right. \\
 & + \left(-\frac{1013}{256}(\mathbf{p}^2)^4 + \frac{23}{64}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^3 + \frac{69}{128}(\mathbf{n} \cdot \mathbf{p})^4(\mathbf{p}^2)^2 - \frac{5}{64}(\mathbf{n} \cdot \mathbf{p})^6\mathbf{p}^2 + \frac{35}{256}(\mathbf{n} \cdot \mathbf{p})^8 \right) \nu^3 \\
 & + \left. \left(-\frac{35}{128}(\mathbf{p}^2)^4 - \frac{5}{32}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^3 - \frac{9}{64}(\mathbf{n} \cdot \mathbf{p})^4(\mathbf{p}^2)^2 - \frac{5}{32}(\mathbf{n} \cdot \mathbf{p})^6\mathbf{p}^2 - \frac{35}{128}(\mathbf{n} \cdot \mathbf{p})^8 \right) \nu^4 \right\} \frac{1}{r} \\
 & + \left\{ \frac{13}{8}(\mathbf{p}^2)^3 + \left(-\frac{791}{64}(\mathbf{p}^2)^3 + \frac{49}{16}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^2 - \frac{889}{192}(\mathbf{n} \cdot \mathbf{p})^4\mathbf{p}^2 + \frac{369}{160}(\mathbf{n} \cdot \mathbf{p})^6 \right) \nu \right. \\
 & + \left(\frac{4857}{256}(\mathbf{p}^2)^3 - \frac{545}{64}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^2 + \frac{9475}{768}(\mathbf{n} \cdot \mathbf{p})^4\mathbf{p}^2 - \frac{1151}{128}(\mathbf{n} \cdot \mathbf{p})^6 \right) \nu^2 \\
 & + \left. \left(\frac{2335}{256}(\mathbf{p}^2)^3 + \frac{1135}{256}(\mathbf{n} \cdot \mathbf{p})^2(\mathbf{p}^2)^2 - \frac{1649}{768}(\mathbf{n} \cdot \mathbf{p})^4\mathbf{p}^2 + \frac{10353}{1280}(\mathbf{n} \cdot \mathbf{p})^6 \right) \nu^3 \right\} \frac{1}{r^2} \\
 & + \left\{ \frac{105}{32}(\mathbf{p}^2)^2 + \left(\left(\frac{2749\pi^2}{8192} - \frac{589189}{19200} \right) (\mathbf{p}^2)^2 + \left(\frac{63347}{1600} - \frac{1059\pi^2}{1024} \right) (\mathbf{n} \cdot \mathbf{p})^2\mathbf{p}^2 + \left(\frac{375\pi^2}{8192} - \frac{23533}{1280} \right) (\mathbf{n} \cdot \mathbf{p})^4 \right) \nu \right. \\
 & + \left(\left(\frac{18491\pi^2}{16384} - \frac{1189789}{28800} \right) (\mathbf{p}^2)^2 + \left(-\frac{127}{3} - \frac{4035\pi^2}{2048} \right) (\mathbf{n} \cdot \mathbf{p})^2\mathbf{p}^2 + \left(\frac{57563}{1920} - \frac{38655\pi^2}{16384} \right) (\mathbf{n} \cdot \mathbf{p})^4 \right) \nu^2 \\
 & + \left. \left(-\frac{553}{128}(\mathbf{p}^2)^2 - \frac{225}{64}(\mathbf{n} \cdot \mathbf{p})^2\mathbf{p}^2 - \frac{381}{128}(\mathbf{n} \cdot \mathbf{p})^4 \right) \nu^3 \right\} \frac{1}{r^3} \\
 & + \left\{ \frac{105}{32}\mathbf{p}^2 + \left(\left(\frac{185761}{19200} - \frac{21837\pi^2}{8192} \right) \mathbf{p}^2 + \left(\frac{3401779}{57600} - \frac{28691\pi^2}{24576} \right) (\mathbf{n} \cdot \mathbf{p})^2 \right) \nu \right. \\
 & + \left. \left(\left(\frac{672811}{19200} - \frac{158177\pi^2}{49152} \right) \mathbf{p}^2 + \left(\frac{110099\pi^2}{49152} - \frac{21827}{3840} \right) (\mathbf{n} \cdot \mathbf{p})^2 \right) \nu^2 \right\} \frac{1}{r^4} \\
 & + \left\{ -\frac{1}{16} + \left(\frac{6237\pi^2}{1024} - \frac{169199}{2400} \right) \nu + \left(\frac{7403\pi^2}{3072} - \frac{1256}{45} \right) \nu^2 \right\} \frac{1}{r^5} \\
 & - \frac{1}{5} \frac{G^2 M}{c^8} I_{ij}^{(3)}(t) \times \text{Pf}_{2r_{12}/c} \int_{-\infty}^{+\infty} \frac{dv}{|v|} I_{ij}^{(3)}(t+v)
 \end{aligned}$$



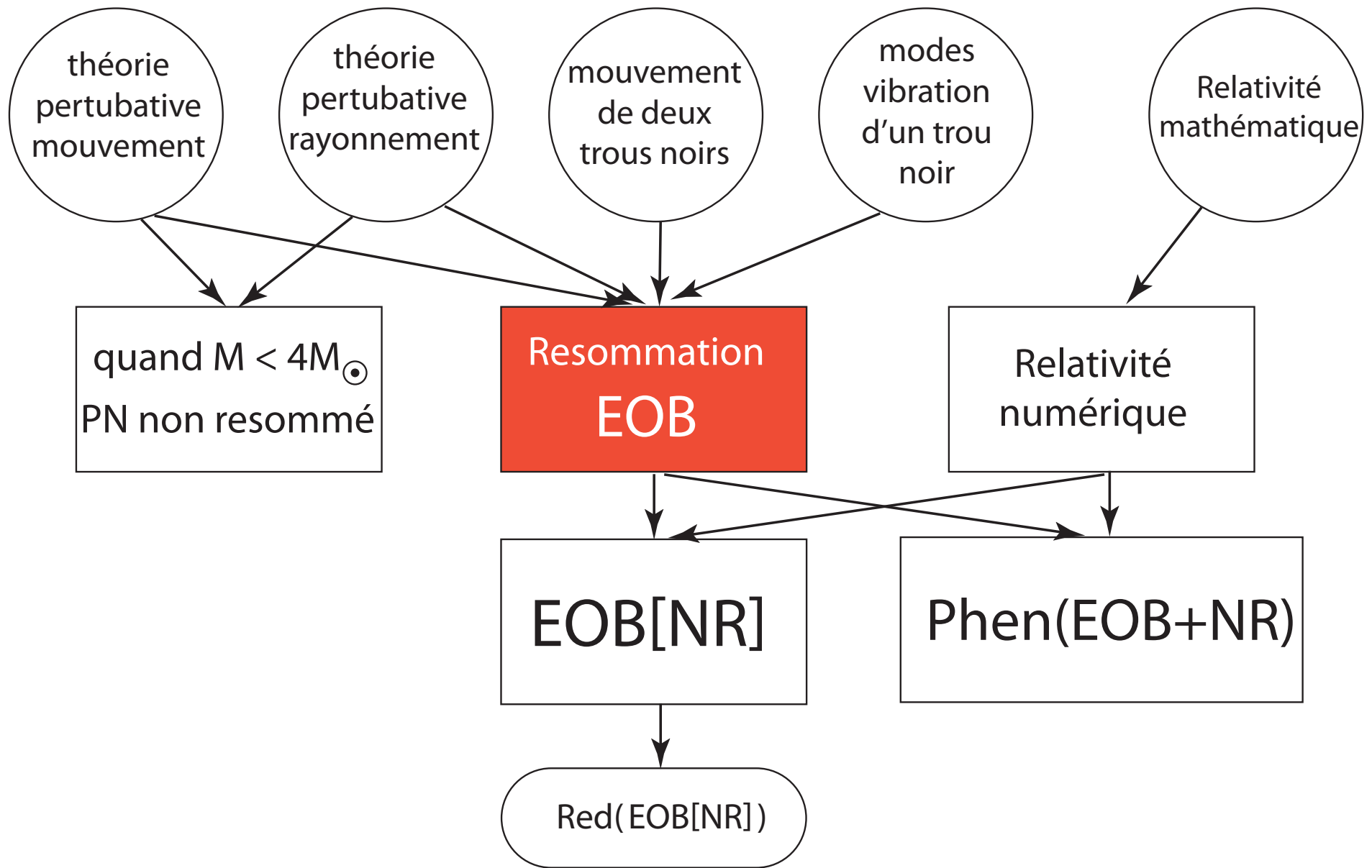
Théorie perturbative de la génération d'OG

- Einstein 1916, 1918, Landau-Lifshitz 1949, Fock 1959 : première approximation : quadrupolaire
- Structure à l'infini : ~ 1960 : Bondi, Sachs, Penrose ,...
- Développement multipolaire : Mathews 62, Pirani 64, Campbell-Morgan 71
- Effets non linéaires : Bonnor-Rotenberg 66, ... Thorne 80
- **Formalisme MPM** : Blanchet-Damour 86-, Damour-Iyer 91, ... combine **multipolaire** + itération **post-Minkowskien** + **prolongement analytique** pour intégrales divergentes

Calculs perturbatifs du flux gravitationnel émis par 2 corps

- ordre de le plus bas : Einstein 1918 Peters-Mathews 63
- $1 + (v^2/c^2)$: Wagoner-Will 76
- $\dots + (v^3/c^3)$: Blanchet-Damour 92, Wiseman 93
- $\dots + (v^4/c^4)$: Blanchet-Damour-Iyer Will-Wiseman 95
- $\dots + (v^5/c^5)$: Blanchet 96
- $\dots + (v^6/c^6)$: Blanchet-Damour-Esposito-Farèse-Iyer 2004
- $\dots + (v^7/c^7)$: Blanchet

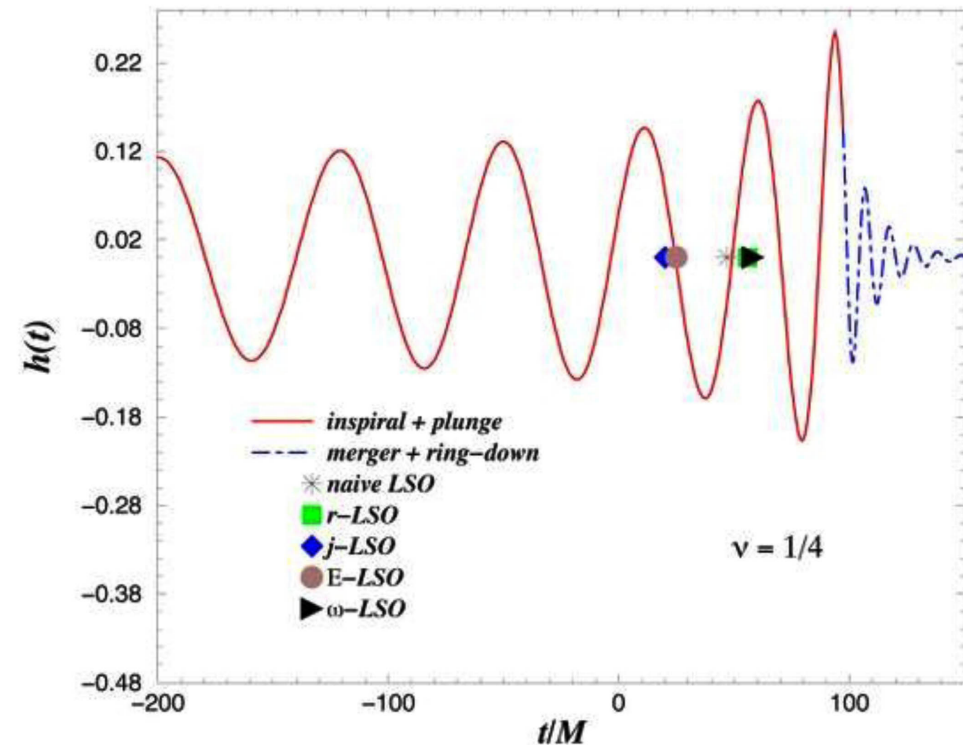
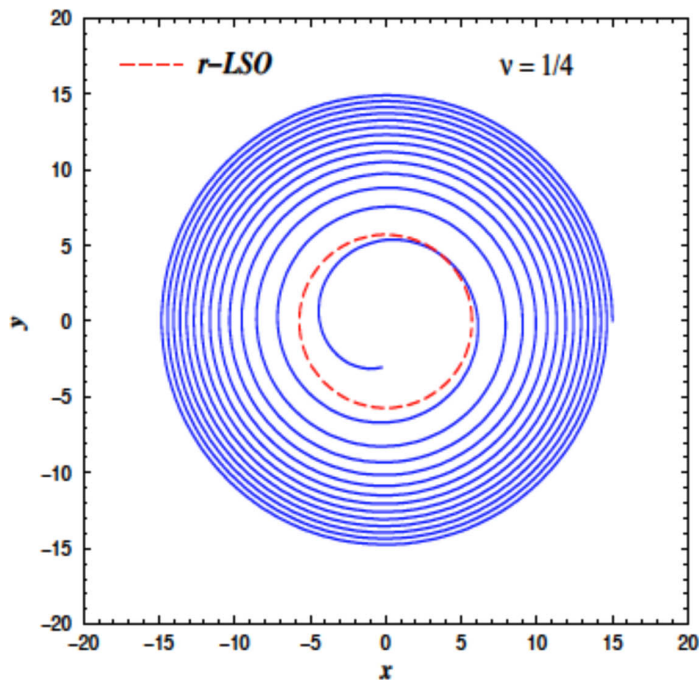
$$\begin{aligned} \mathcal{F} = \frac{32c^5}{5G} \nu^2 x^5 & \left\{ 1 + \left(-\frac{1247}{336} - \frac{35}{12} \nu \right) x + 4\pi x^{3/2} \right. \\ & + \left(-\frac{44711}{9072} + \frac{9271}{504} \nu + \frac{65}{18} \nu^2 \right) x^2 + \left(-\frac{8191}{672} - \frac{583}{24} \nu \right) \pi x^{5/2} \\ & + \left[\frac{6643739519}{69854400} + \frac{16}{3} \pi^2 - \frac{1712}{105} \gamma_E - \frac{856}{105} \ln(16x) \right. \\ & \quad \left. + \left(-\frac{134543}{7776} + \frac{41}{48} \pi^2 \right) \nu - \frac{94403}{3024} \nu^2 - \frac{775}{324} \nu^3 \right] x^3 \\ & \left. + \left(-\frac{16285}{504} + \frac{214745}{1728} \nu + \frac{193385}{3024} \nu^2 \right) \pi x^{7/2} + \mathcal{O} \left(\frac{1}{c^8} \right) \right\}. \end{aligned}$$



Méthode Effective One Body (EOB)

Buonanno-Damour 1999, 2000 ; Damour-Jaranowski-Schäfer 2000, Damour 2001

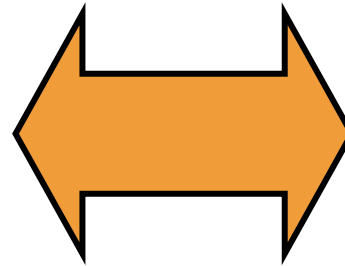
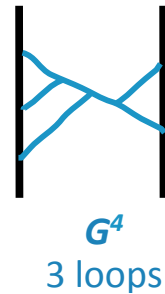
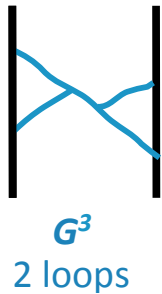
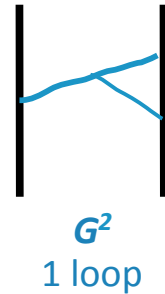
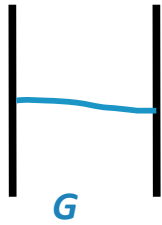
Resommation des résultats perturbatifs \longrightarrow description de la coalescence et du ringdown (Vishveshwara 70, Davis-Ruffini-Tiomno 1972)



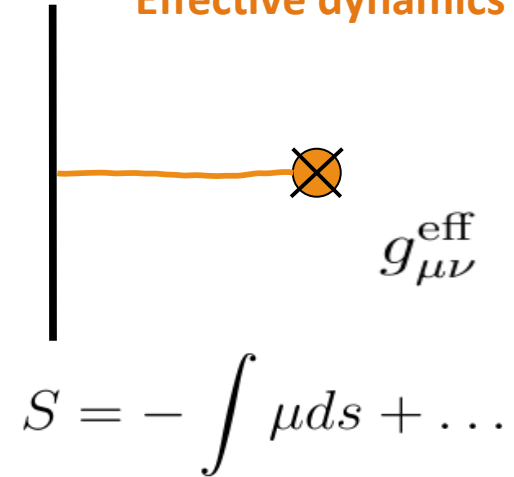
Prédictions : transition continue, non adiabaticité, forme d'onde complète, spin final (OK à 10%)

Dynamique resommée EOB

Real dynamics



Effective dynamics



$$H = H_0 + \left(G H_1 + \frac{G^2}{c^2} H_2 + \frac{G^3}{c^4} H_3 + \frac{G^4}{c^6} H_4 \right) \left(1 + \frac{1}{c^2} + \dots \right)$$

Effective metric

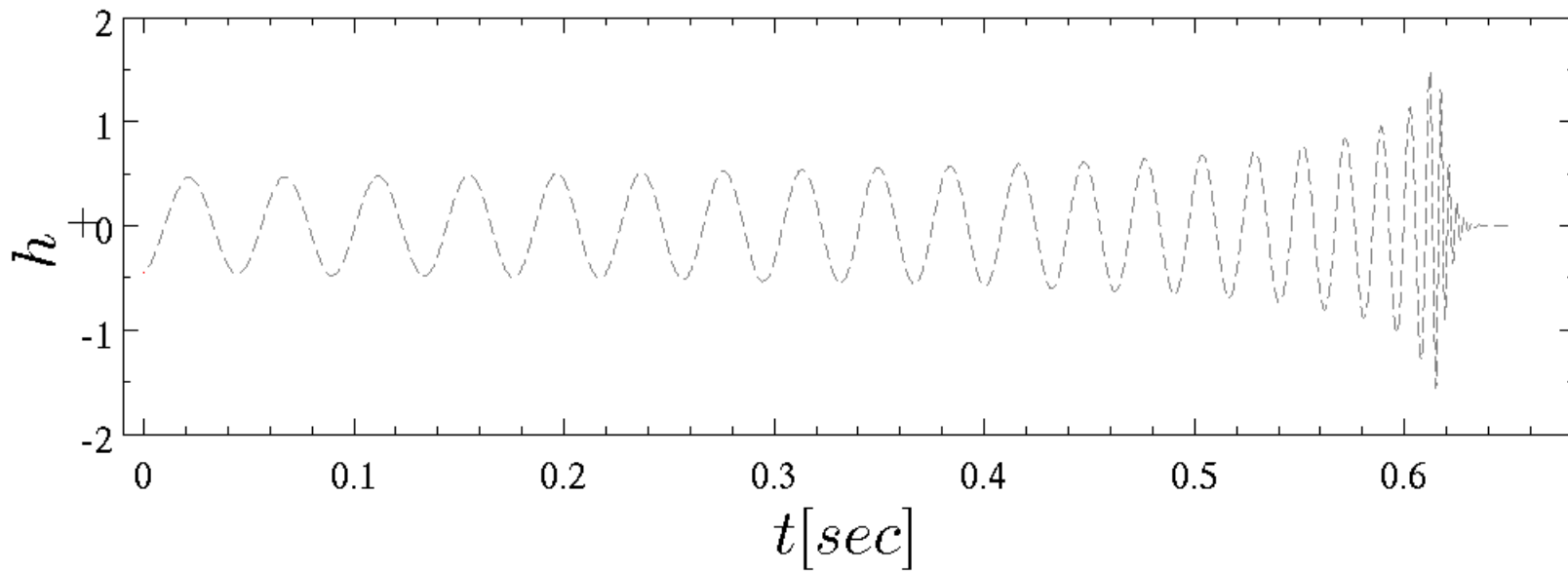
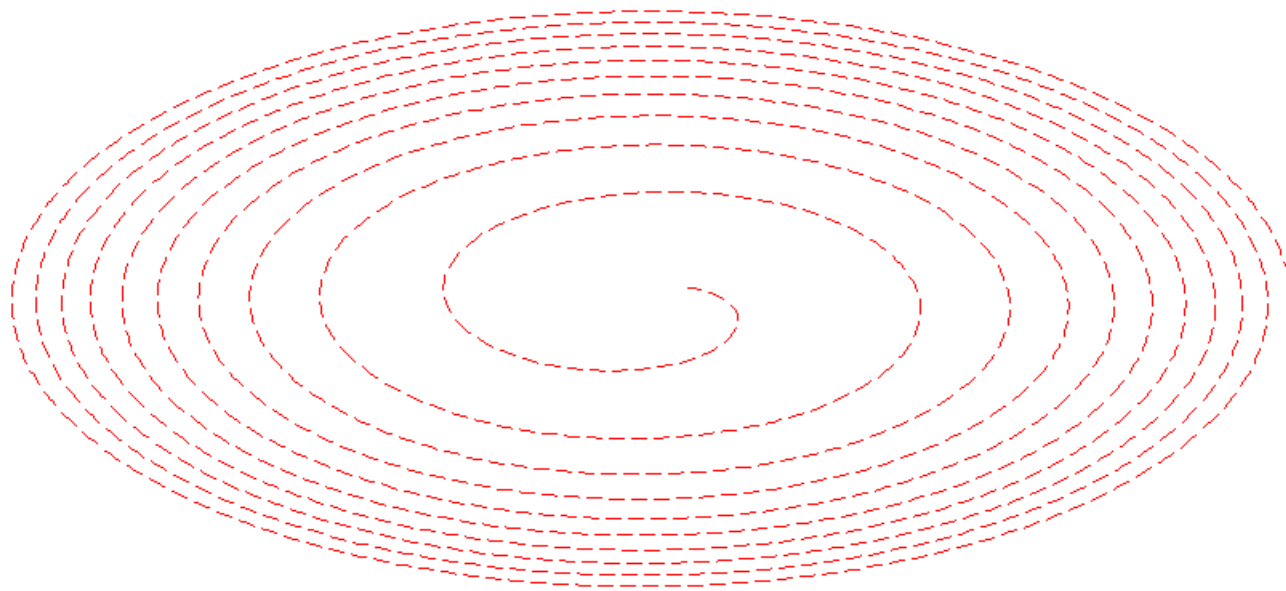
$$ds_{\text{eff}}^2 = -A(r)dt^2 + B(r)dr^2 + r^2 (d\theta^2 + \sin^2 \theta d\varphi^2)$$

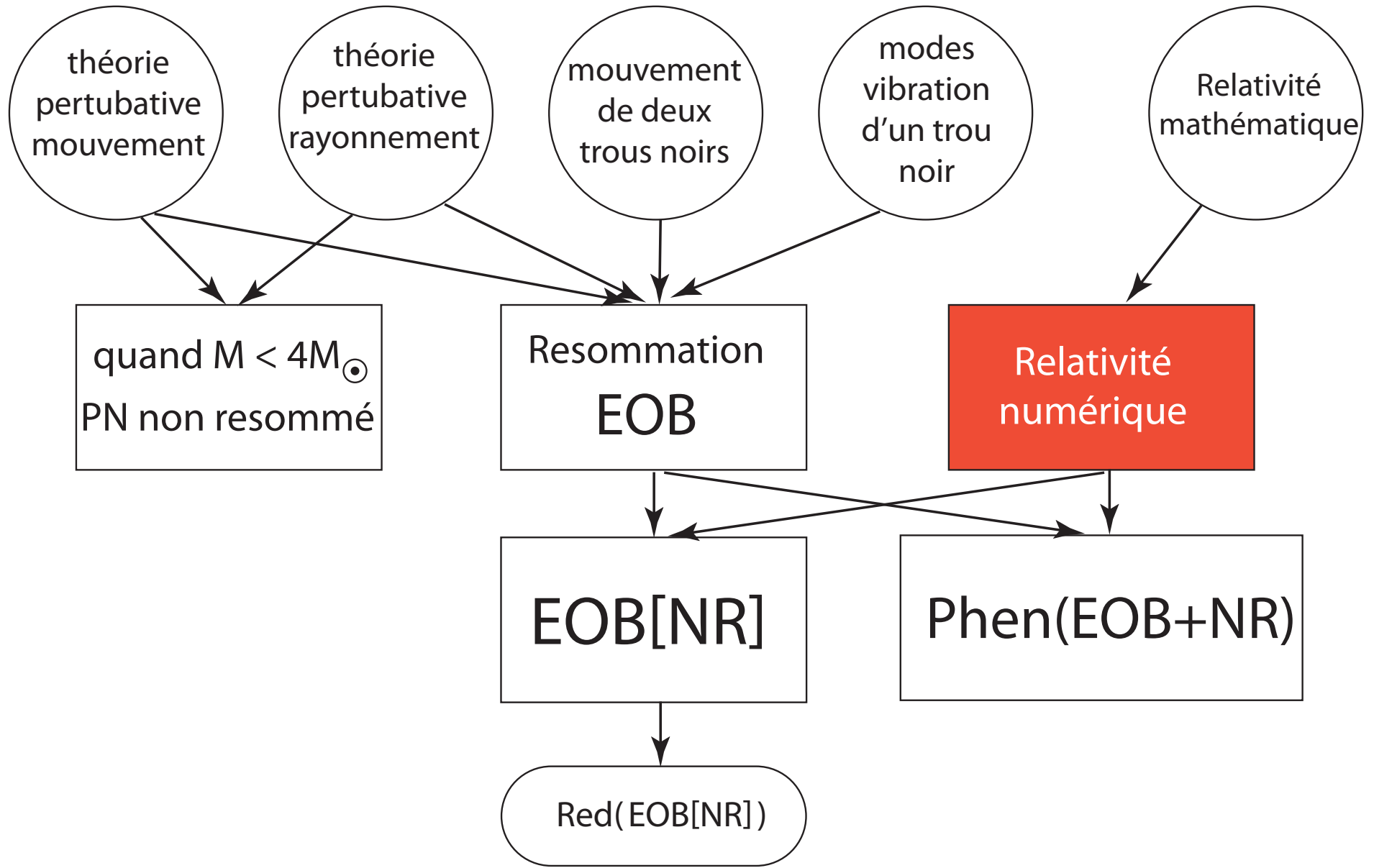
Hamiltonien resommé EOB

$$ds_{\text{eff}}^2 = -A(r)dt^2 + B(r)dr^2 + r^2 (d\theta^2 + \sin^2 \theta d\varphi^2)$$

$$H_{\text{EOB}} = M \sqrt{1 + 2\nu \left(\frac{1}{\mu} \sqrt{A(r) \left(\mu^2 + \frac{p_r^2}{B(r)} + \frac{p_\phi^2}{r^2} + 2\nu(4 - 3\nu) \left(\frac{GM}{r} \right)^2 \frac{p_r^4}{\mu^2} \right) - 1} \right)}$$

$$M = m_1 + m_2, \quad \mu = \frac{m_1 m_2}{m_1 + m_2}, \quad \nu = \frac{m_1 m_2}{(m_1 + m_2)^2} = \frac{\mu}{M}$$





Relativité Numérique (NR)

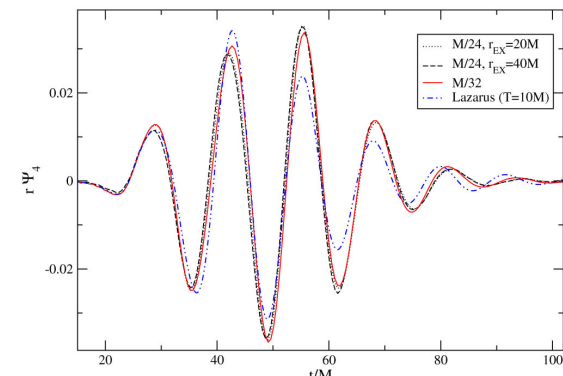
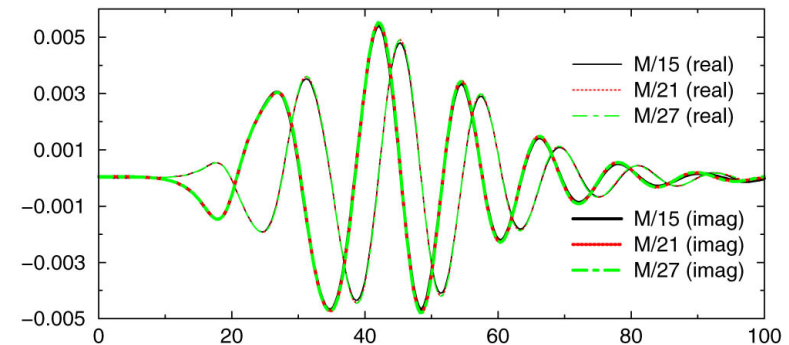
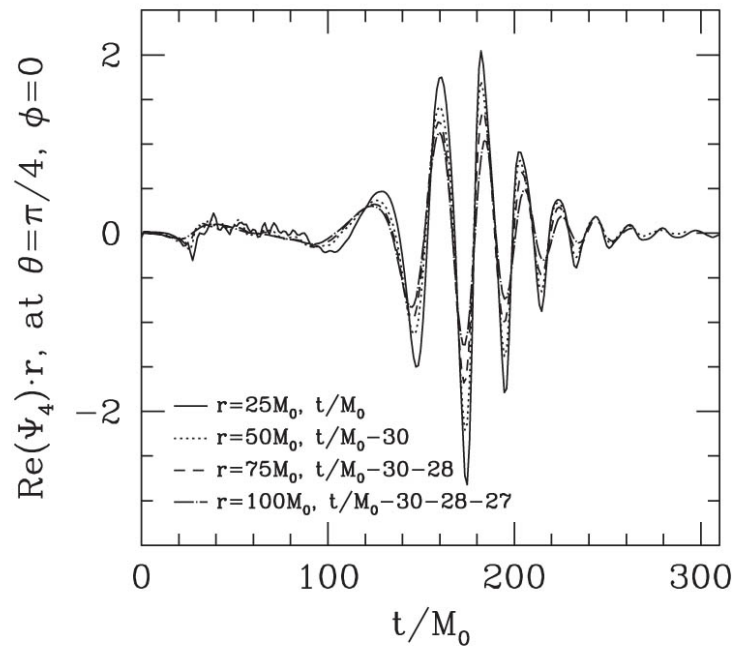
Fondements mathématiques : Darmois 27, Lichnerowicz 43, Choquet-Bruhat 52-

Percées : Pretorius 2005 **coordonnées harmoniques généralisées**, excision

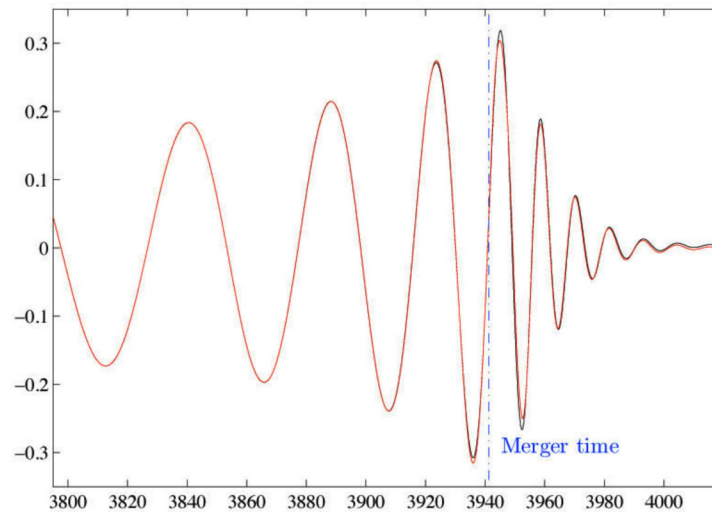
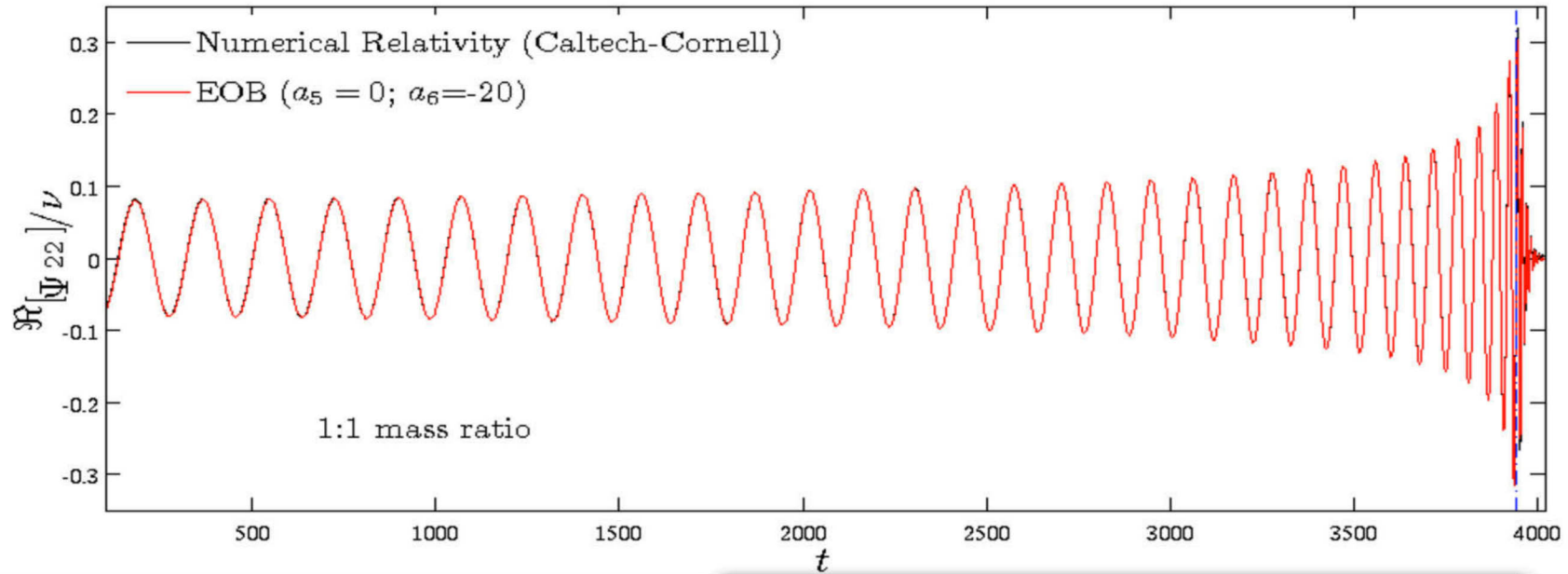
Campanelli-Lousto-Maronetti-Zlochover 2006

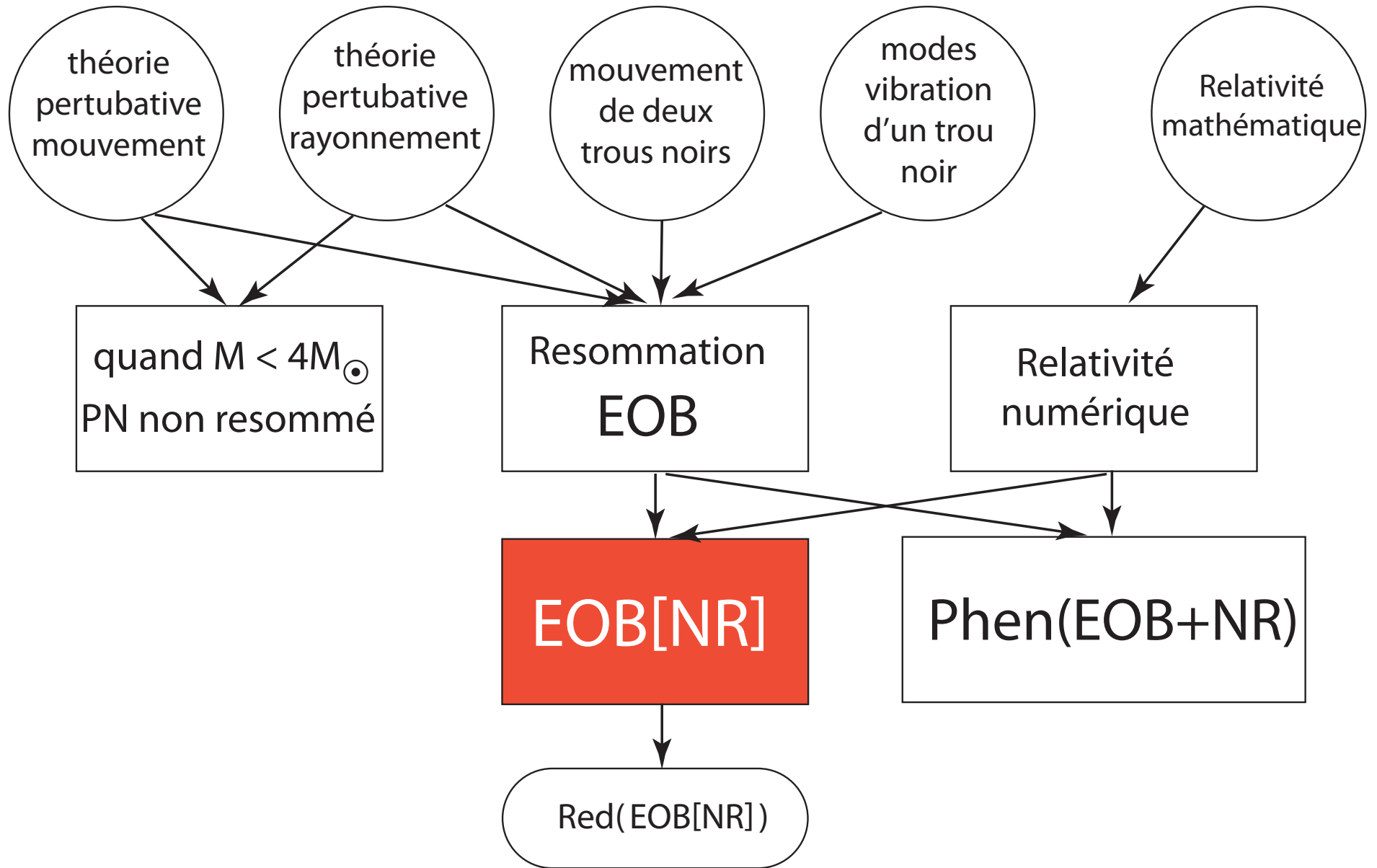
Baker-Centrella-Choi-Koppitz-van Meter 2006

Moving punctures



Forme d'onde en Relativité Numérique (Caltech-Cornell, SXS)





Complétion /extension de EOB ; Calibration de EOB[NR]

Buonanno,Damour 99	(2 PN Hamiltonian)
Buonanno,Damour 00	(Rad.Reac. full waveform)
Damour, Jaranowski,Schäfer 00	(3 PN Hamiltonian)
Damour 01, Buonanno, Chen, Damour 05,	
Damour-Jaranowski,Schäfer 08, Barausse, Buonanno, 10,	(spin)
Nagar 11, Balmelli-Jetzer 12, Taracchini et al 12,14,	
Damour,Nagar 14	
Damour, Nagar 07, Damour, Iyer, Nagar 08	(factorized waveform)
Buonanno, Cook, Pretorius 07, Buonanno, Pan, Taracchini,...	(comparison, calibration to NR)
Damour, Nagar 10	(tidal effects)
Bini, Damour 13, Damour, Jaranowski, Schäfer 15	(4 PN Hamiltonian)

Forme d'onde **resommée** EOB

(Damour-Iyer-Sathyaprakash 1998) Damour-Nagar 2007, Damour-Iyer -Nagar 2008

$$h_{\ell m} \equiv h_{\ell m}^{(N, \epsilon)} \hat{h}_{\ell m}^{(\epsilon)} \hat{h}_{\ell m}^{\text{NQC}}$$

$$\hat{h}_{\ell m}^{(\epsilon)} = \hat{S}_{\text{eff}}^{(\epsilon)} T_{\ell m} e^{i\delta_{\ell m}} \rho_{\ell m}^{\ell}$$

$$T_{\ell m} = \frac{\Gamma(\ell + 1 - 2i\hat{k})}{\Gamma(\ell + 1)} e^{\pi\hat{k}} e^{2i\hat{k} \ln(2kr_0)}$$

$$\begin{aligned} \rho_{22}(x; \nu) = & 1 + \left(\frac{55\nu}{84} - \frac{43}{42} \right) x + \left(\frac{19583\nu^2}{42336} - \frac{33025\nu}{21168} - \frac{20555}{10584} \right) x^2 \\ & + \left(\frac{10620745\nu^3}{39118464} - \frac{6292061\nu^2}{3259872} + \frac{41\pi^2\nu}{192} - \frac{48993925\nu}{9779616} - \frac{428}{105} \text{eulerlog}_2(x) + \frac{1556919113}{122245200} \right) x^3 \\ & + \left(\frac{9202}{2205} \text{eulerlog}_2(x) - \frac{387216563023}{160190110080} \right) x^4 + \left(\frac{439877}{55566} \text{eulerlog}_2(x) - \frac{16094530514677}{533967033600} \right) x^5 + \mathcal{O}(x^6), \end{aligned}$$

$$\mathcal{F}_{\varphi} \equiv -\frac{1}{8\pi\Omega} \sum_{\ell=2}^{\ell_{\max}} \sum_{m=1}^{\ell} (m\Omega)^2 |Rh_{\ell m}^{(\epsilon)}|^2$$

NR-completed resummed 5PN EOB radial A potential

4PN analytically complete + 5 PN logarithmic term in the $A(u, \nu)$ function,

With $u = GM/R$ and $\nu = m_1 m_2 / (m_1 + m_2)^2$

[Damour 09, Blanchet et al 10, Barack-Damour-Sago 10, Le Tiec et al 11,

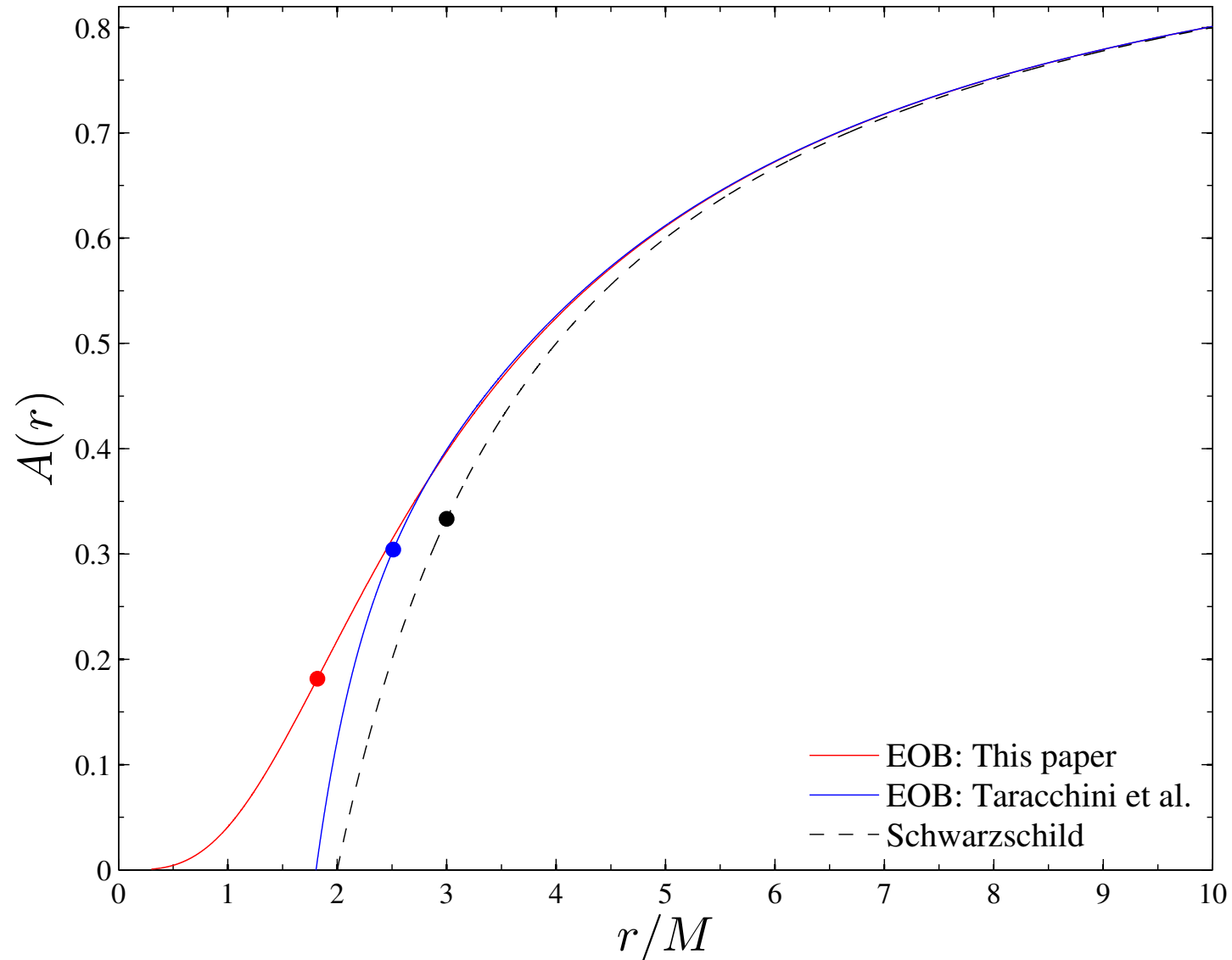
Barausse et al 11, Akcay et al 12, Bini-Damour 13,

Damour-Jaranowski-Schäfer 14, Nagar-Damour-Reisswig-Pollney 15]

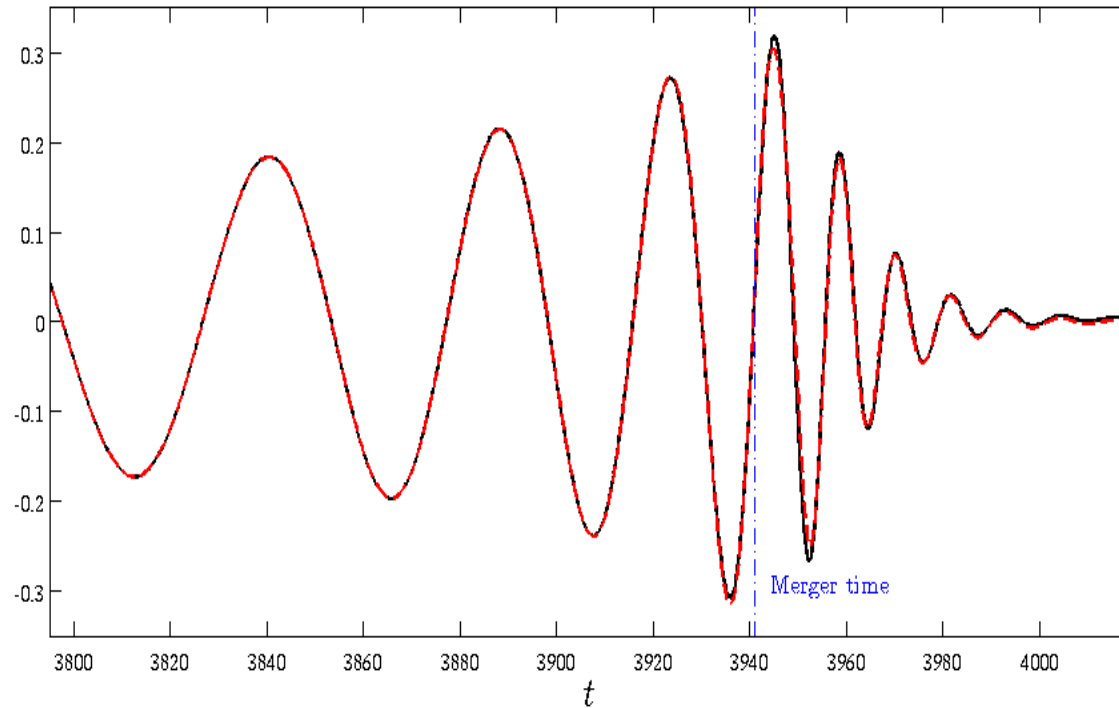
$$\begin{aligned} A(u; \nu, a_6^c) &= P_5^1 \left[1 - 2u + 2\nu u^3 + \nu \left(\frac{94}{3} - \frac{41}{32} \pi^2 \right) u^4 \right. \\ &+ \nu \left[-\frac{4237}{60} + \frac{2275}{512} \pi^2 + \left(-\frac{221}{6} + \frac{41}{32} \pi^2 \right) \nu + \frac{64}{5} \ln(16e^{2\gamma} u) \right] u^5 \\ &+ \left. \nu \left[a_6^c(\nu) - \left(\frac{7004}{105} + \frac{144}{5} \nu \right) \ln u \right] u^6 \right] \end{aligned}$$

$$a_6^{c \text{ NR-tuned}}(\nu) = 81.38 - 1330.6 \nu + 3097.3 \nu^2$$

Comparing the EOB A potentials of Nagar et al 15 and Taracchini et al 14 to $A^{\text{Schw}} = 1 - 2M/r$

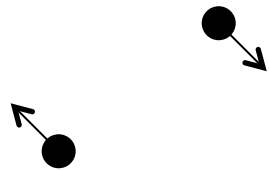


Comparaison EOB / Relativité Numérique



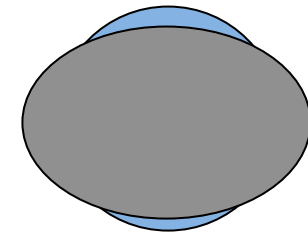
Inspiral + « plunge »

Ringdown

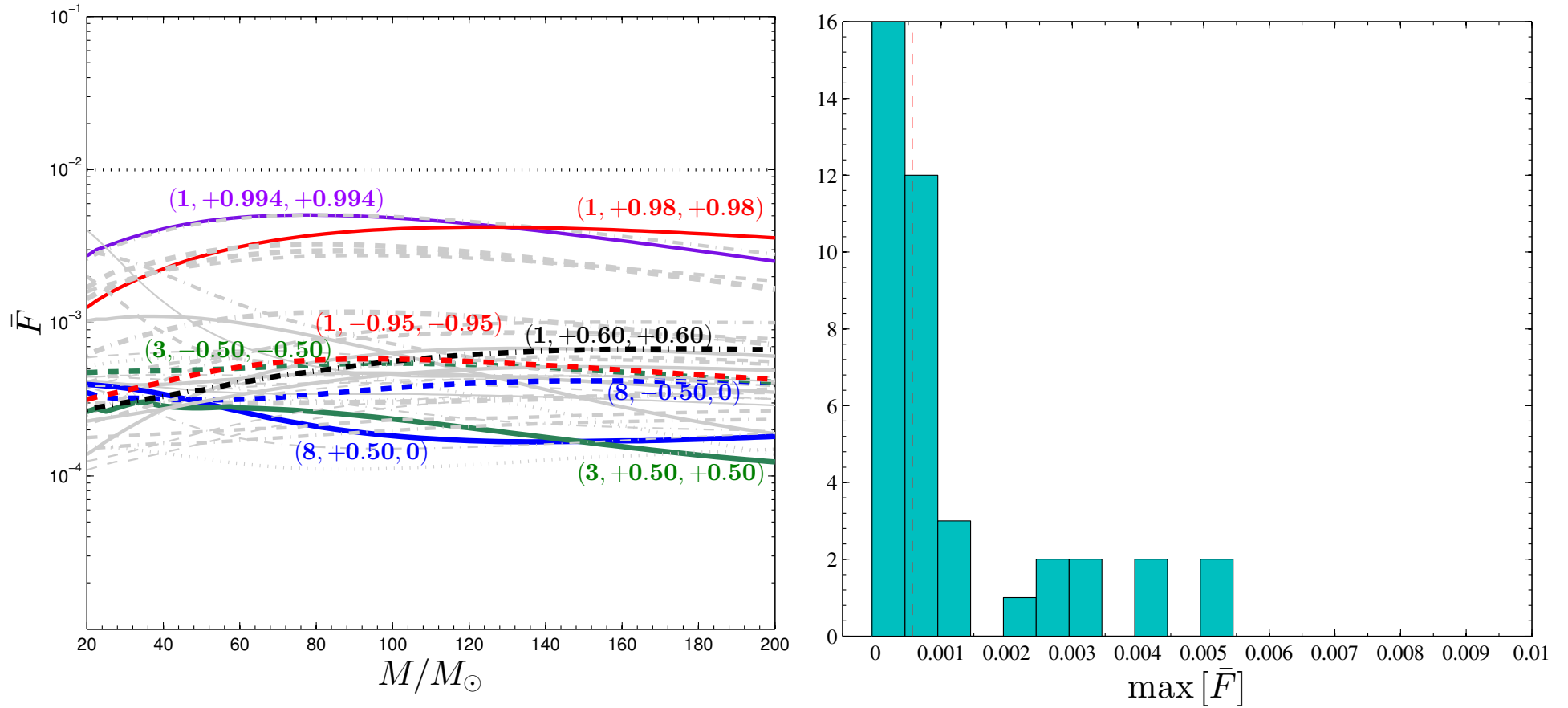


Two orbiting point-masses:
Resummed dynamics

Ring BH

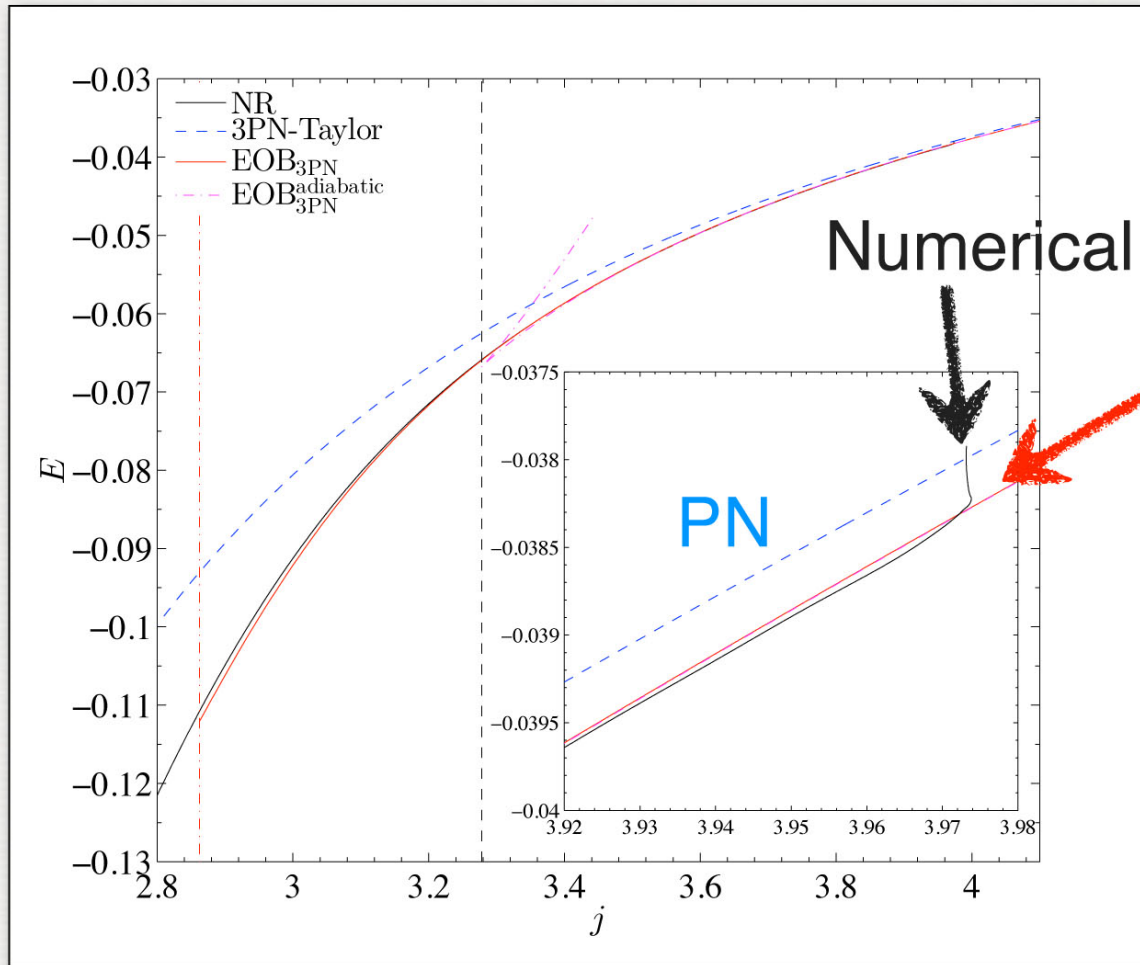


EOB/NR unfaithfulness = $1 - F$ for spinning BBH



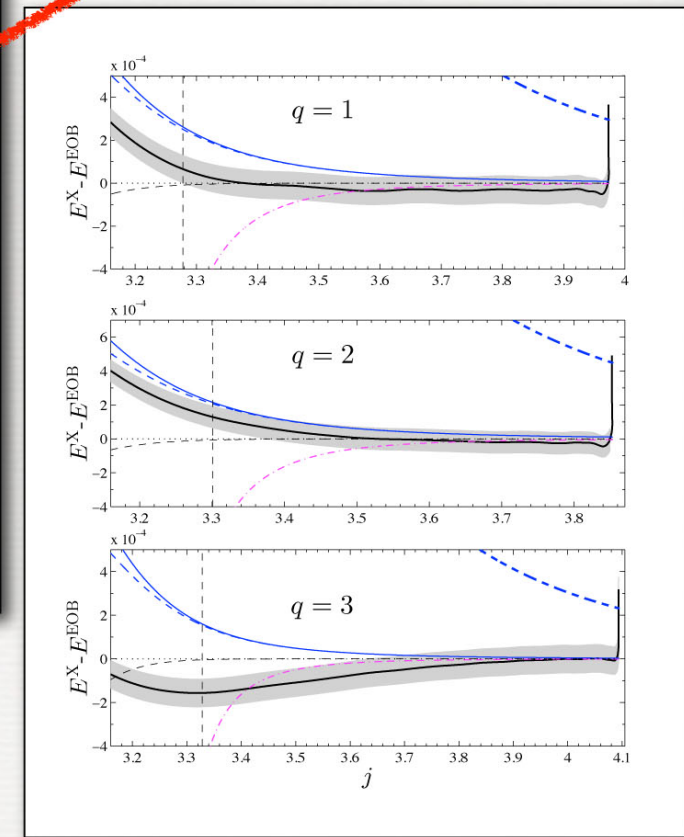
Nagar, Damour, Reisswig, Pollney 2016

ENERGY AND ANGULAR MOMENTUM IN NONSPINNING BLACK-HOLE BINARIES: E(J)



Damour, Nagar, Pollney, Reisswig 2012

EOB-analytical

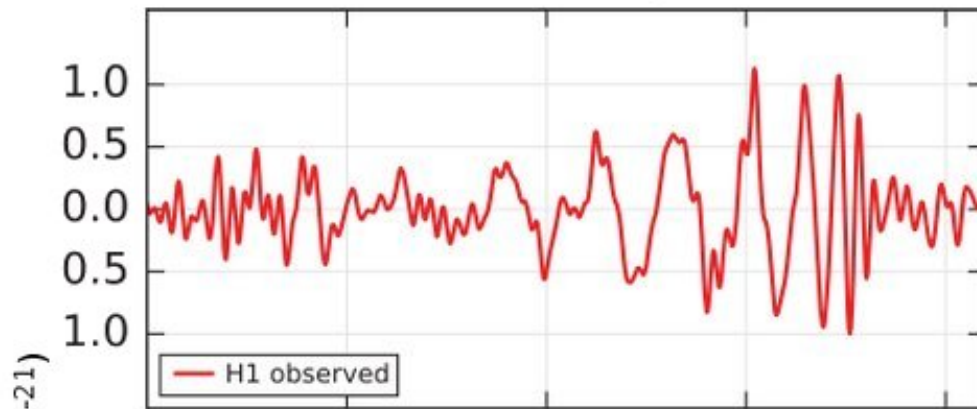


$$j = |\vec{j}_0^{\text{ADM}} - \Delta \vec{j}_{\text{GWs}}|$$

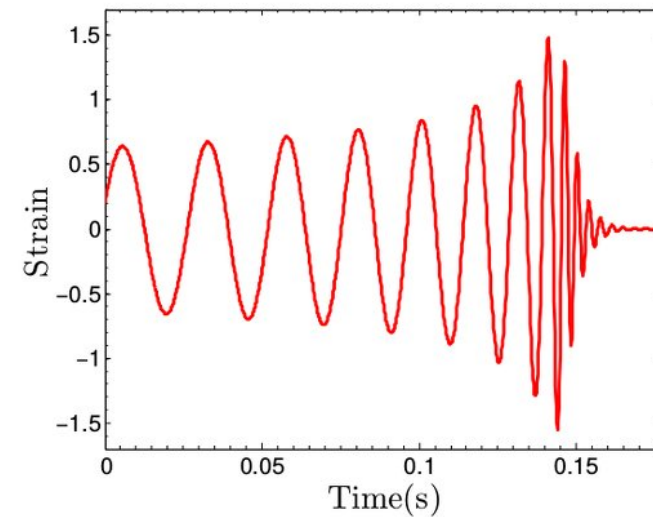
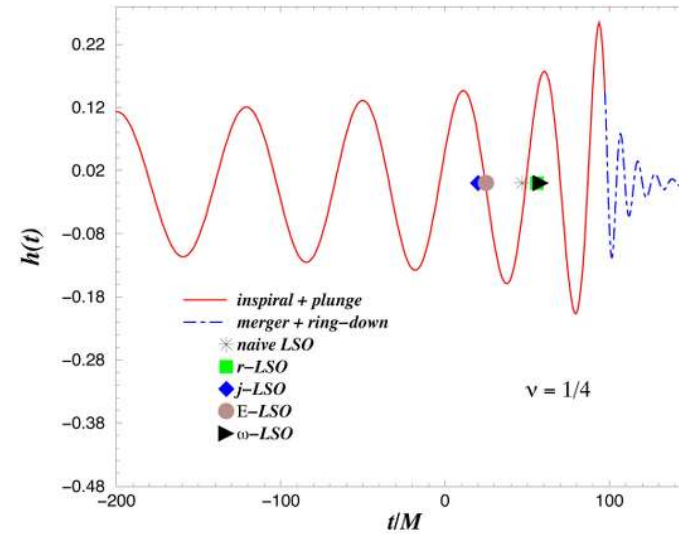
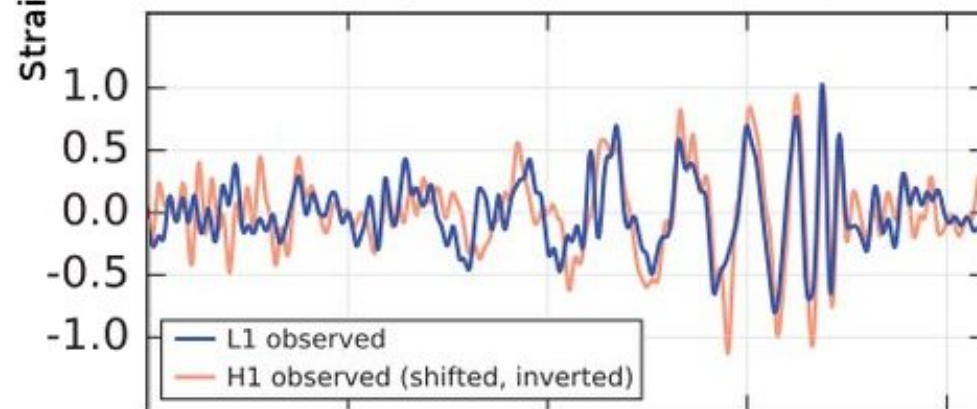
$$E = E_0^{\text{ADM}} - \Delta E_{\text{GWs}}$$

GW150914 vs EOBNR-IHES

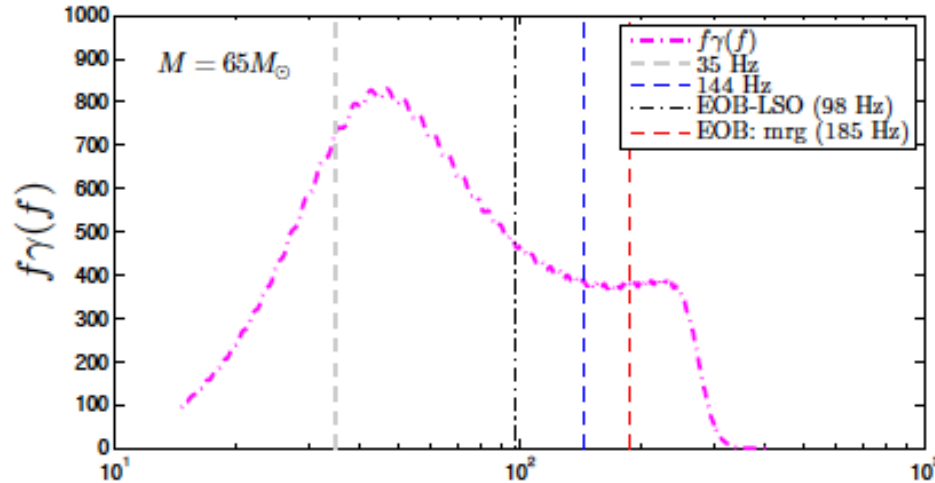
Hanford, Washington (H1)



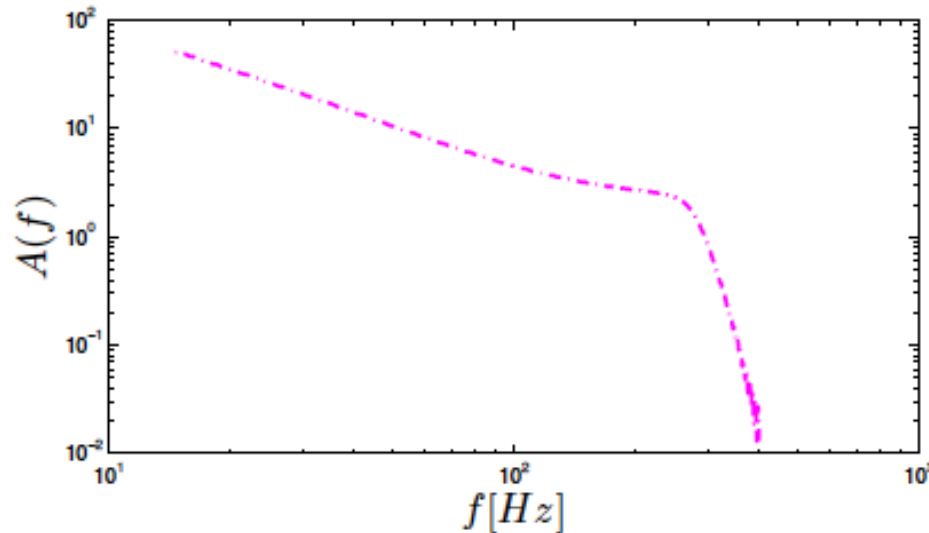
Livingston, Louisiana (L1)

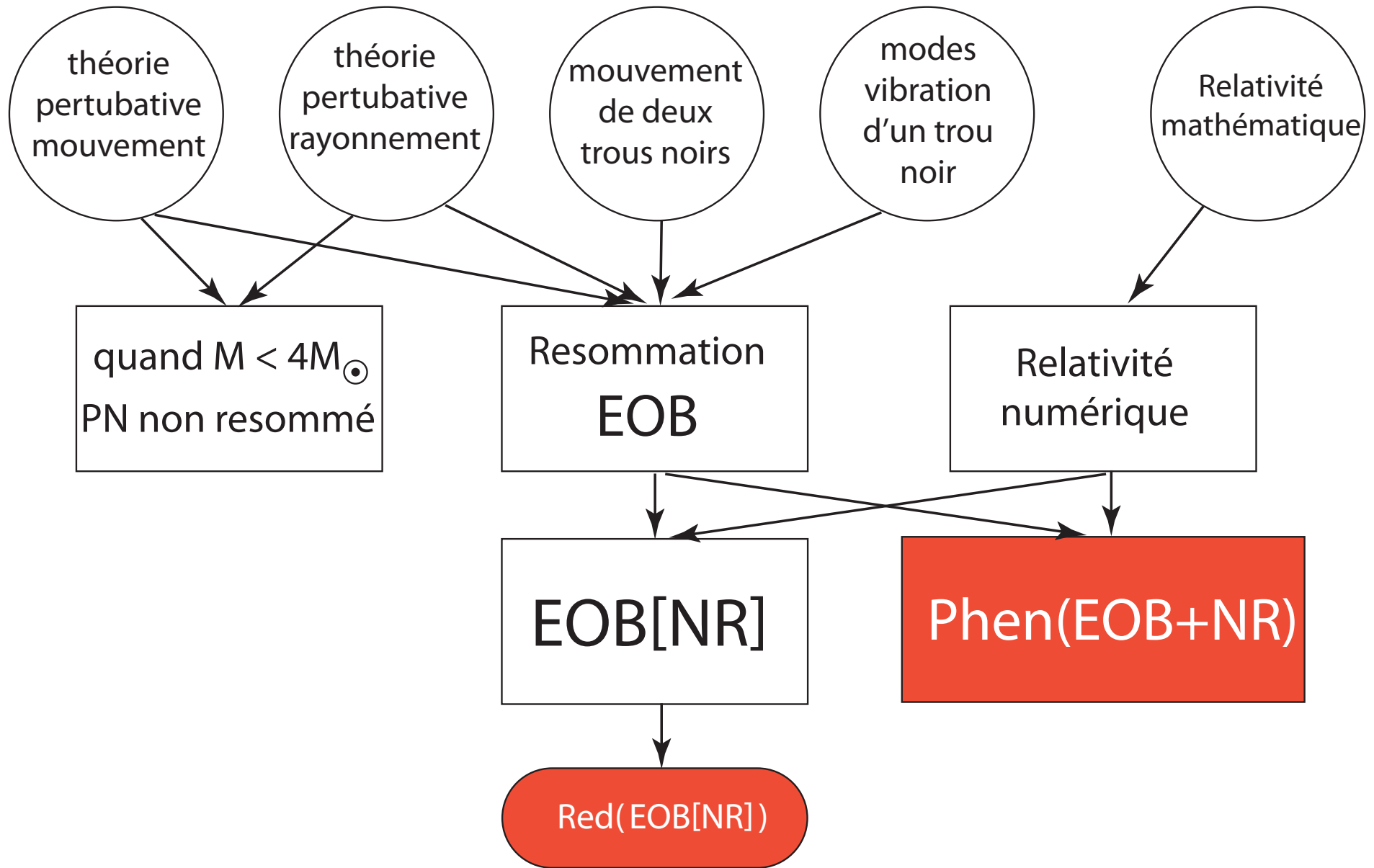


SNR2 of GW150914



$$f_{\gamma}(f) = \frac{f |\tilde{h}(f)|^2}{S_n(f)}$$





Modèles rapides à calculer

Reduced Order Model version (Pürrer 2014, 2016) of EOB[NR] (Taracchini et al 2014)

Phenomenological model (Ajith et al 2007, Hannam et al 2014, Husa et al 2016, Kahn et al 2016)

of FFT of hybrids EOB + NR

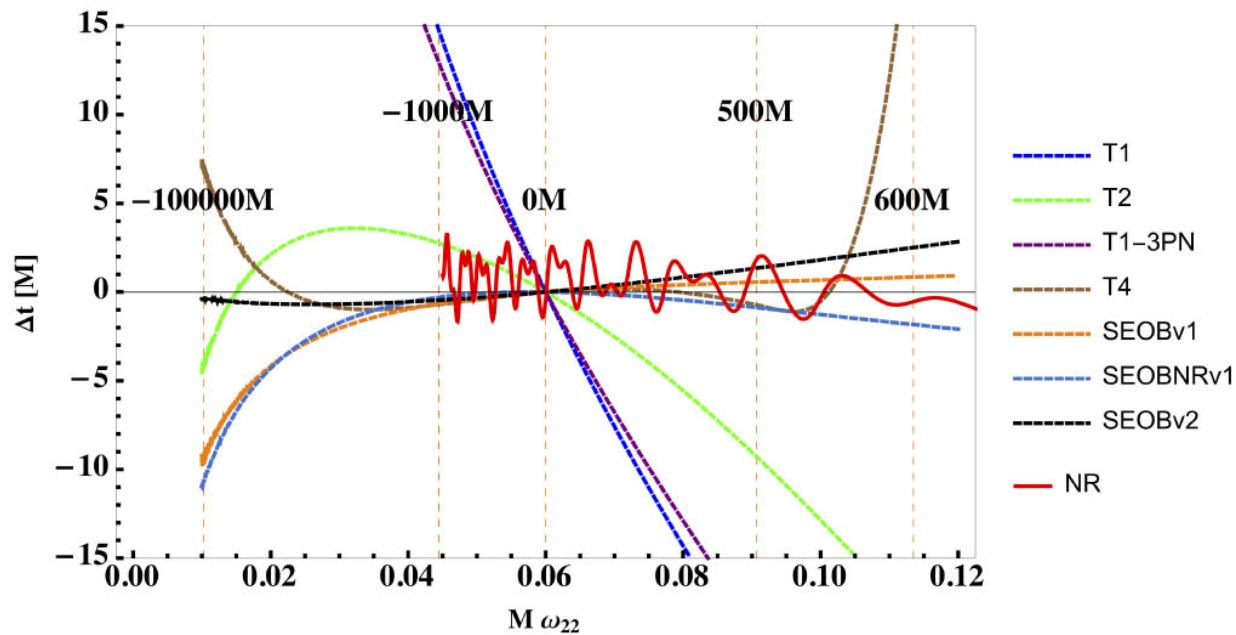


FIG. 4: Time shift Δt according to Eq. (2.16) as a function of wave frequency $M\omega$ for the case of non-spinning $q = 1$, using SEOBNRv2 as the reference waveform and SXS:BBH:0001 from the SXS catalogue as the NR waveform. As is well known, the SEOBNRv2 model and TaylorT4 are very close to the NR result in this case. Uncalibrated SEOBv2 (uncalibrated SEOBNRv2) is also very close, while TaylorT1, TaylorT1 cut off at 3PN order, and TaylorT2 show significant dephasing. The SEOBNRv1 and SEOBv1 (uncalibrated SEOBNRv1) show rather similar performance, with good agreement with NR, and disagreement with SEOBNRv2 at lower frequencies.

Husa et al 2016

Conclusions

- Après un long chemin théorique, qui s'est surtout développé à partir des années 1980, la théorie avait prédit (analytiquement ≥ 2000 et numériquement ≥ 2005) le signal d'OG émis par la fusion de deux trous noirs.
- Cette prédiction théorique du signal ($f(m_1, m_2, S_1, S_2)$) est cruciale pour extraire le signal par filtrage adapté et mesurer les paramètres de la source.
- L'école française (avec ses ramifications internationales) a joué un rôle central dans tous les aspects analytiques de ce travail (théorie perturbative du mouvement, théorie perturbative des OG, formalisme EOB)
- La Relativité Numérique s'est en revanche développée ailleurs qu'en France (ou qu'en Italie) : USA, Canada, Allemagne ...
- L'extension et l'amélioration de la modélisation théorique reste une aire active de recherche : BNS, Spins, effets de marées, excentricité, ... , surtout pour prédire les signaux EM associés dans le cas où il existe NS