

Systemes binaires : l'approche de la theorie effective

Adrien Kuntz

Avec Federico Piazza, Filippo Vernizzi

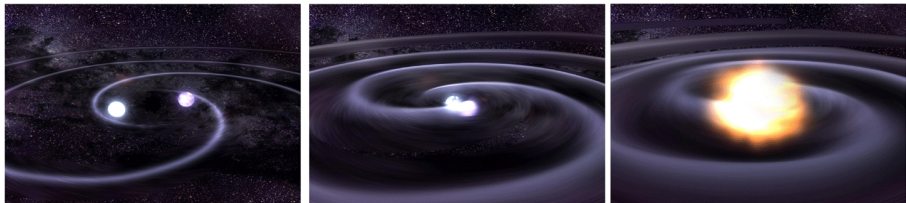
Centre de Physique Theorique, Marseille

24 octobre 2018

Outline

- 1 Binary system overview
- 2 NRGR in a scalar-tensor theory
 - Building up the action
 - Conservative dynamics
 - Dissipative dynamics
- 3 Outlook and conclusions

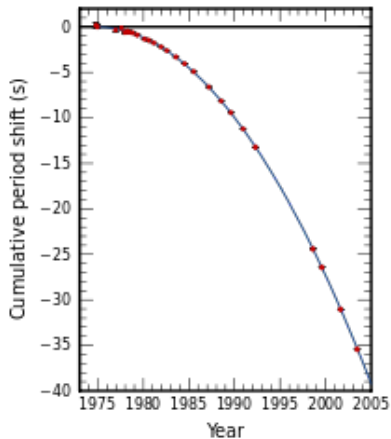
The object under study



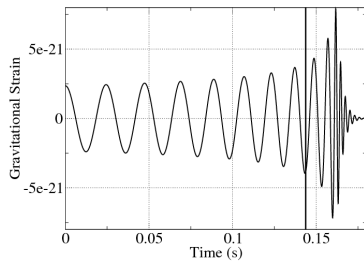
NASA/CXC/GSFC/T.Strohmayer

Which observables ?

Prehistoric times

 \dot{E}

Today

 $\phi(t)$

Some orders of magnitude

- VIRGO/LIGO band : 10Hz - 1kHz

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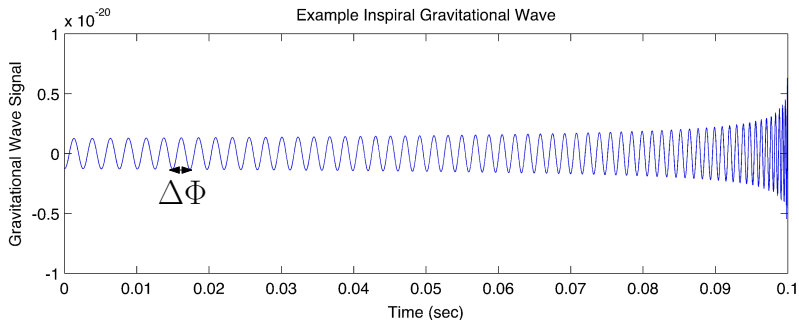
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- $t \sim 5 \text{ min.}$
- $\Phi = 2 \int_{t_i}^{t_f} \omega(t) dt \sim 4 \times 10^4 \text{ rad}$

The impressive precision of GW detectors

Corrections 3 PN $\Delta\Phi \sim v^4\Phi \sim 1$!



A. Stuver/LIGO

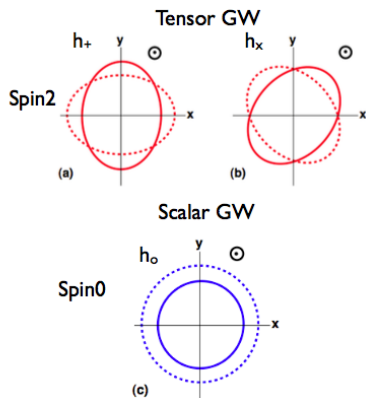
Modified gravity effects : Scalar-tensor theory

- Additional power loss

C.M. Will, 2014

Modified gravity effects : Scalar-tensor theory

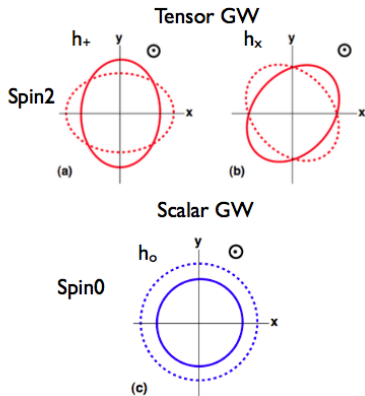
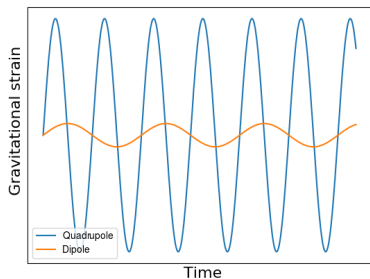
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- Supplementary polarisation



C.M. Will, 2014

Modified gravity effects : Scalar-tensor theory

- Additional power loss
- Supplementary polarisation
- Dipolar radiation !

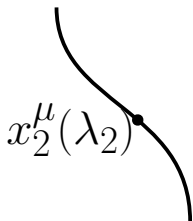
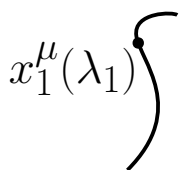


C.M. Will, 2014

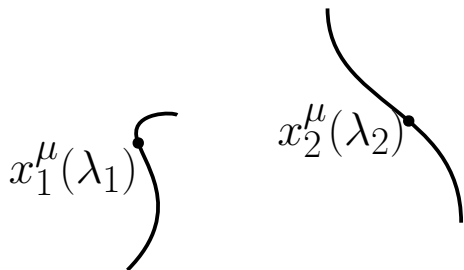
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Invariances of the system

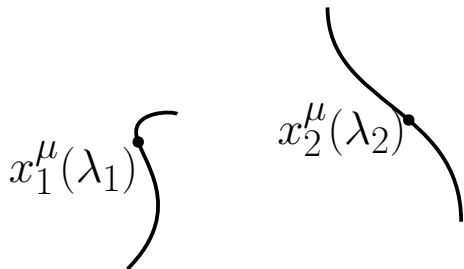


Invariances of the system



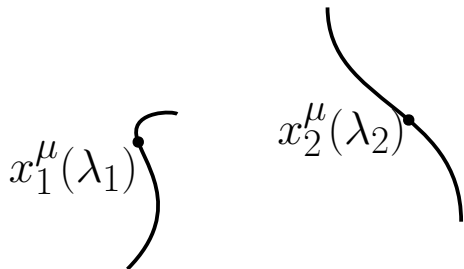
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Invariances of the system



Fluctuating field

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

- $x^\mu \rightarrow x'^\mu(x) \Rightarrow$ Use R and $g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi$
- $\lambda_a \rightarrow \lambda'_a(\lambda_a) \Rightarrow$ Use $d\tau = \sqrt{g_{\mu\nu} dx^\mu dx^\nu} = dt \sqrt{1 - v^2 - h_{\mu\nu} v^\mu v^\nu}$

Point particles action

$$S = S_{grav} + S_{pp,1} + S_{pp,2}$$

$$S_{grav} = \frac{m_P^2}{2} \int d^4x \sqrt{-g} R$$

$$S_{pp,a} = - m_a \int d\tau_a$$

Point particles action

$$S = S_{grav} + S_{pp,1} + S_{pp,2}$$

$$S_{grav} = \frac{m_P^2}{2} \int d^4x \sqrt{-g} R - \frac{1}{2} \int d^4x \sqrt{-g} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi$$

$$S_{pp,a} = -m_a \int d\tau_a + a \frac{m_a}{m_P} \int d\tau_a \phi + b \frac{m_a}{m_P^2} \int d\tau_a \phi^2 + \dots$$

'Quantum' gravity

Integrate out fluctuating fields :

$$e^{iS_{\text{ef}}[\mathbf{x}_1(t), \mathbf{x}_2(t)]} = \int \mathcal{D}[h_{\mu\nu}] \mathcal{D}[\phi] e^{iS[\mathbf{x}_1(t), \mathbf{x}_2(t), h_{\mu\nu}, \phi]}$$

S_{ef} contains the dynamics of the point-particles only

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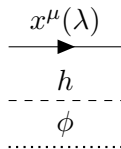
$$\Re(S_{\text{ef}}) = \int dt L[\mathbf{x}_a, \mathbf{v}_a] \quad \text{Conservative dynamics}$$

and

$$\Im(S_{\text{ef}}) = \frac{T}{2} \int dE d\Omega \frac{d^2\Gamma}{dE d\Omega} \quad \text{Dissipative dynamics}$$

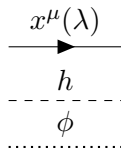
In practice

- Feynman expansion

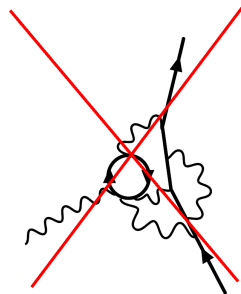


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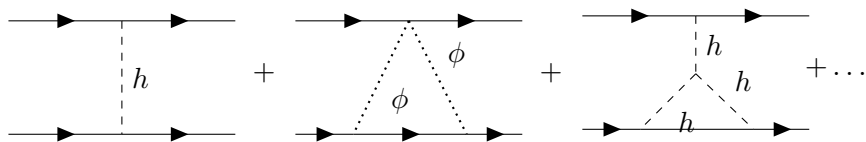


- No loops ! $\frac{\hbar}{L} \sim 10^{-76}$ where $L = mrv$



In practice

$$iS_{\text{ef}} =$$



Power-counting rules

Small expansion parameter

$$\frac{Gm}{r} \sim v^2$$

Vertex

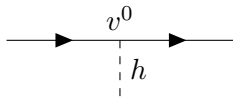
Expression

Weight

Power-counting rules

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Vertex

Expression

$$\frac{m}{2} \int dt h_{00}$$

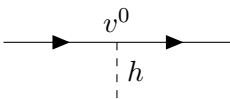
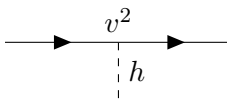
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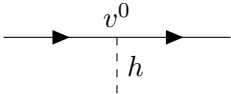
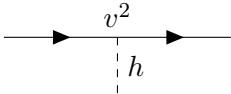
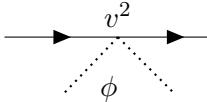
$$\frac{Gm}{r} \sim v^2$$

Vertex		
Expression	$\frac{m}{2} \int dt h_{00}$	$\frac{m}{2} \int dt h_{ij} v^i v^j$
Weight	v^0	v^2

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Small expansion parameter

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Vertex			
Expression	$\frac{m}{2} \int dt h_{00}$	$\frac{m}{2} \int dt h_{ij} v^i v^j$	$bm \int dt \phi^2$
Weight	v^0	v^2	v^2

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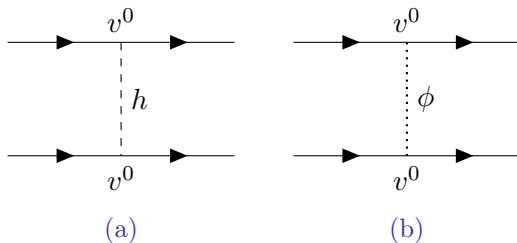
v^0 (or Newtonian) Lagrangian


Figure: Feynman diagrams contributing to the Newtonian potential

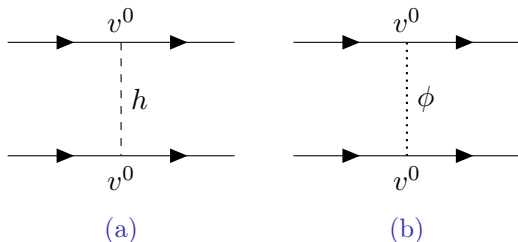
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Figure: Feynman diagrams contributing to the Newtonian potential

$$L_{v^0} = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \frac{G_N m_1 m_2}{|\mathbf{x}_1(t) - \mathbf{x}_2(t)|} (1 + 2a^2)$$

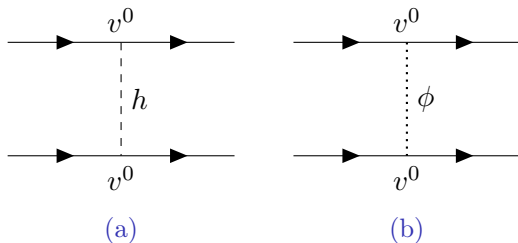
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$$\tilde{G} = G_N(1 + 2a^2)$$

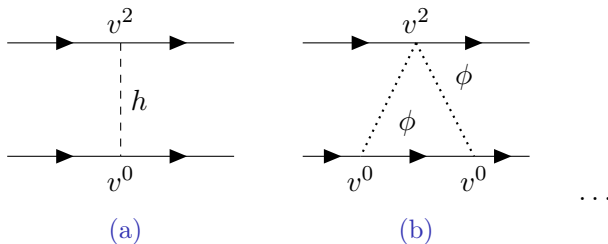
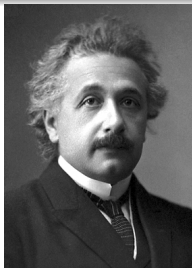
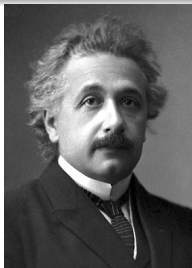
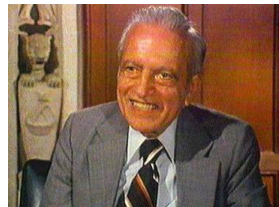
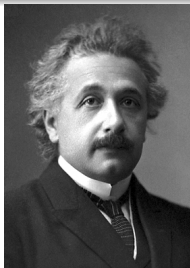
v^2 (or EIH) Lagrangian


Figure: Some Feynman diagrams contributing to the v^2 Lagrangian

v^2 (or EIH) Lagrangian

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v^2 (or EIH) Lagrangian



$$\begin{aligned}
 L_{EIH} = & \frac{1}{8} \sum_a m_a v_a^4 \\
 & + \frac{\tilde{G} m_1 m_2}{2|\mathbf{x}_{12}|} \left[(v_1^2 + v_2^2) - 3\mathbf{v}_1 \cdot \mathbf{v}_2 - \frac{(\mathbf{v}_1 \cdot \mathbf{x}_{12})(\mathbf{v}_2 \cdot \mathbf{x}_{12})}{|\mathbf{x}_{12}|^2} + 2\gamma(\mathbf{v}_1 - \mathbf{v}_2)^2 \right] \\
 & - \frac{\tilde{G}^2 m_1 m_2 (m_1 + m_2)}{2|\mathbf{x}_{12}|^2} (2\beta - 1)
 \end{aligned}$$

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Multipole expansion

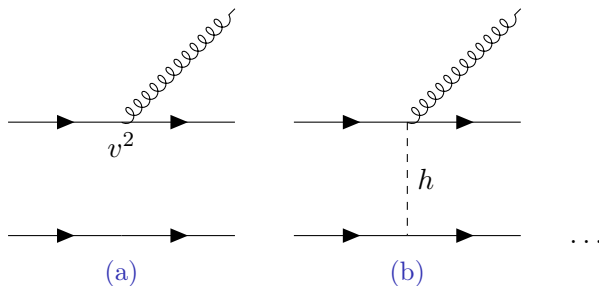


Figure: Some Feynman diagrams for the emission of one radiation scalar.

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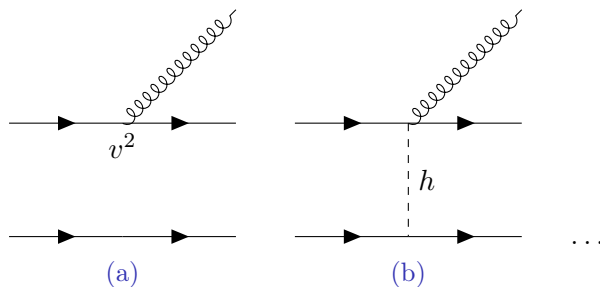


Figure: Some Feynman diagrams for the emission of one radiation scalar.

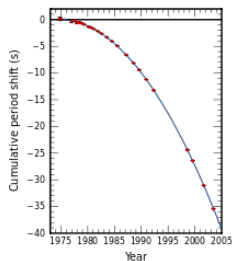
Net result :

$$S_{\text{int}} = \frac{1}{2} \int dt I_h^{ij} R_{0i0j} + \frac{1}{m_P} \int dt \left(I_\phi \bar{\phi} + I_\phi^i \partial_i \bar{\phi} + \frac{1}{2} I_\phi^{ij} \partial_i \partial_j \bar{\phi} \right) + \dots$$

Radiated power

Quadrupole formula :

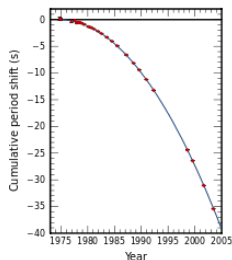
$$P_h = \frac{G_N}{5} \left\langle \ddot{I}_h^{ij,2} \right\rangle + \dots$$



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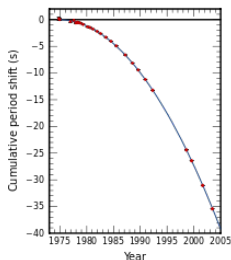
Monopole, dipole and quadrupole scalar radiation :

$$P_\phi = 2G_N \left(\left\langle \dot{I}_\phi^2 \right\rangle + \frac{1}{3} \left\langle \ddot{I}_\phi^2 \right\rangle + \frac{1}{30} \left\langle \ddot{I}_\phi^{ij}{}^2 \right\rangle + \dots \right)$$

Radiated power

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$$P_h = \frac{G_N}{5} \left\langle \ddot{I}_h^{ij} \right\rangle^2 + \dots$$



Monopole, dipole and quadrupole scalar radiation :

$$P_\phi = 2G_N \left(\left\langle \dot{I}_\phi^2 \right\rangle + \frac{1}{3} \left\langle \ddot{I}_\phi^i \right\rangle^2 + \frac{1}{30} \left\langle \ddot{I}_\phi^{ij} \right\rangle^2 + \dots \right)$$

$$I_\phi = \text{Const} + v^2 \text{correction}, \quad I_\phi^i \propto a_1 - a_2$$

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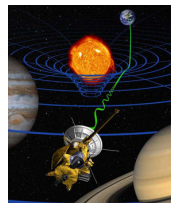
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Conformal transformation

$a \frac{m_a}{m_P} \int d\tau_a \phi$ and $b \frac{m_a}{m_P^2} \int d\tau_a \phi^2$ can be seen as

Conformal coupling

$$\tilde{g}_{\mu\nu} = A(\phi)g_{\mu\nu}$$



Conformal transformation

$a \frac{m_a}{m_P} \int d\tau_a \phi$ and $b \frac{m_a}{m_P^2} \int d\tau_a \phi^2$ can be seen as

$$\begin{aligned} \Rightarrow -m \int d\tilde{\tau} &= -m \int d\tau \sqrt{A} \\ &= -m \int d\tau \left(1 - a \frac{\phi}{m_P} - b \frac{\phi^2}{m_P^2} \right) \end{aligned}$$

Conformal coupling

$$\tilde{g}_{\mu\nu} = A(\phi) g_{\mu\nu}$$



Disformal operator...

Other operator allowed :

$$m \int d\tau \partial_\mu \phi \frac{dx^\mu}{d\tau}$$

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$$m \int d\tau \partial_\mu \phi \frac{dx^\mu}{d\tau} = m \int d\tau \frac{d\phi}{d\tau}$$

is a total derivative !

Disformal operator...

Other operator allowed :

$$m \int d\tau \partial_\mu \phi \frac{dx^\mu}{d\tau} = m \int d\tau \frac{d\phi}{d\tau}$$

is a total derivative !

but

$$m \int d\tau \left(\frac{d\phi}{d\tau} \right)^2$$

is allowed...

...from disformal transformation

Disformal coupling

$$\tilde{g}_{\mu\nu} = A(\phi)g_{\mu\nu} + B(\phi)\partial_\mu\phi\partial_\nu\phi$$

...from disformal transformation

Disformal coupling

$$\tilde{g}_{\mu\nu} = A(\phi)g_{\mu\nu} + B(\phi)\partial_\mu\phi\partial_\nu\phi$$

$$\Rightarrow d\tilde{\tau}^2 = d\tau^2 \left(A + B \left(\partial_\mu\phi \frac{dx^\mu}{d\tau} \right)^2 \right)$$

We plan to study the effects of such an operator, as we done for the conformal coupling

Conclusion

- We generalized NRGR to a scalar-tensor theory
- Effective theory point of view : operators allowed by symmetries
- We plan to examine the effects of disformal couplings