Fundamental Physics, Cosmology and Astrophysics

"Inflation, Light Bosonic Dark Matter and Modified Theories of Gravity"

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ICTP
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CERN

CERN Theory Group Retreat 2016

St Genis - Adagio Hotel

Motivations

Inflation:

- How many degrees of freedom are responsible for Primordial Perturbations (PPs)?
- Do the PPs have quantum origin? Thermal? Other?
- If quantum, why, when, and under which conditions can they be treated as classical?
- How much we will be able to learn about these questions from future experiments?
- How robust are the prediction obtained in the semiclassical approximation?
- Are quantum corrections and back-reaction important? Under perturbative control?

Standard cosmological model: ΛCDM $\rightarrow$ Dark contributions

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Light bosonic dark matter:

- DM could consist of some ``cold'' (small velocity dispersion) undiscovered particles
- An alternative model: DM consist of very light bosons or axion-like particles which can be basically described as a classical scalar field that experience oscillations

$$\Phi(\vec{x},t) = \Phi_0 \cos(m_\Phi t + \Upsilon(\vec{x}))$$

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Modified theories of gravity:

- The acceleration of the Universe can be described by properly adjusting Λ
- Other models provide alternative explanations of this acceleration (e.g. modified theories of gravity)

The predictions of each candidate model must be confronted with data, but *Not just cosmological data* but data on all scales where the models make *calculable predictions* that can be tested observationally or experimentally

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General objectives:

- To identify and characterize observable signatures
- To assess the robustness of the theoretical predictions

Main focus this year (and achievements)

Inflation:

- Non-perturbative **QFT** in curved spaces: Infrared effects in de Sitter **(dS)** space-time for interacting quantum fields (with F. D. Mazzitelli and L. Trombetta)
- Relevant for inflationary models (metric ~ dS)

Our latest contributions:

- *O(N) model in Euclidean dS space: beyond the leading infrared approximation*, JHEP09(2016)117
- *Massless Interacting Scalar Fields in dS space,* EPJ Web of Conferences 125, 05019 (2016)

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In brief:

$$S = \int d^d x \left[\frac{1}{2} \phi_a \left(-\Box + m^2 \right) \phi_a + \frac{\lambda}{8N} (\phi_a \phi_a)^2 \right]$$

- *Perturbation theory in* λ *breaks down for* $m^2 \lesssim \sqrt{\lambda} H^2$
- *To go beyond LO in* $1/N$ *and in* λ *is very technically involved*

O(N) model in Euclidean dS space:

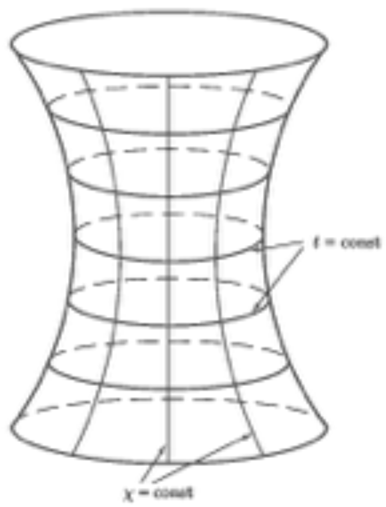
DLN, L. Trombetta, D. Mazzitelli, JHEP09(2016)117

- *We exploited an analytical continuation of the 2-pt functions from dS to the Euclidean sphere*

- *We developed a method to compute the 2-pt functions, based on:*
  - *An exact treatment of the Euclidean zero modes*
  - *A partial resummation of leading secular terms (which involves nonzero modes)*
  - *A systematic calculation of higher order corrections in both* $\sqrt{\lambda}$ *and in* $1/N$

- *We are working on generalizing the method to the case of negative square mass* $m^2 \to -\mu^2$

$$dS = \{X \in C^{d+1} : -X_0^2 + ... + X_d^2 = H^{-2}\}$$



$(X^0 \to iX^0)$

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- *Binary Pulsars as Resonant Detectors of Light Dark Matter* (with D. Blas and S. Sibiryakov): to appear soon!

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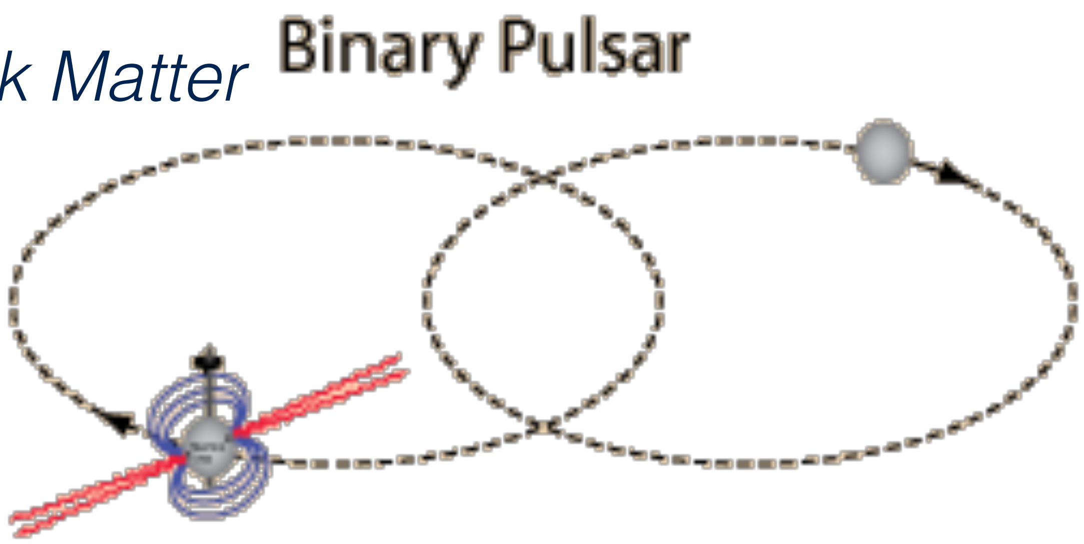

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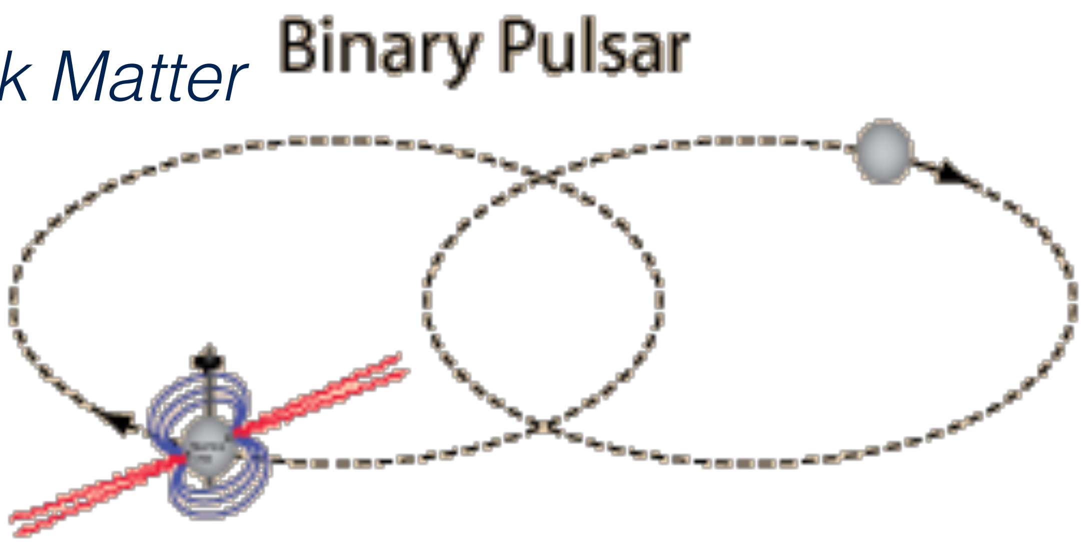

$$\Phi(\vec{x},t) = \Phi_0 \cos(m_\Phi t + \Upsilon(\vec{x}))$$

In brief:

$$\rho_{DM} = \frac{m_\Phi \Phi_0^2}{2}$$

Only gravity!

$$p_{DM} = -\rho_{DM} \cos(2m_\Phi t + 2\Upsilon) \quad \Rightarrow \quad h_{ij} \sim -\frac{2\pi G \rho_{DM}}{m_\Phi^2} \delta_{ij} \cos(2m_\Phi t + 2\Upsilon)$$

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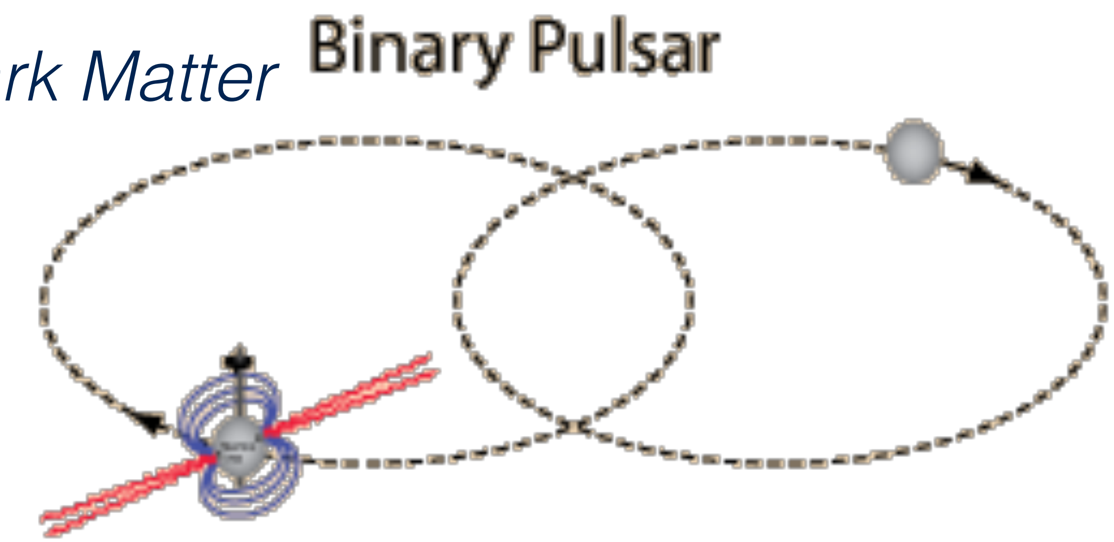

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Resonances:

$$m_\Phi = \frac{N\pi}{P_b} \quad (N \in \mathbb{N}) \quad \Longrightarrow \quad \langle \dot{P}_b \rangle \sim -5 \times 10^{-18} \left(\frac{P_b}{100\,\mathrm{d}}\right)^2 \left(\frac{\rho_{DM}}{0.3\,\frac{\mathrm{GeV}}{\mathrm{cm}^3}}\right) \frac{\pi \sin(2\Upsilon) J_N(Ne)}{N}$$

E. g. Double Pulsar (PSR J0737-3039) $\langle \Delta \dot{P}_b \rangle \sim \mathcal{O}(10^{-16})$

Direct coupling

$$\Phi(\vec{x},t)=\Phi_0\cos(m_\Phi t+\Upsilon(\vec{x}))$$

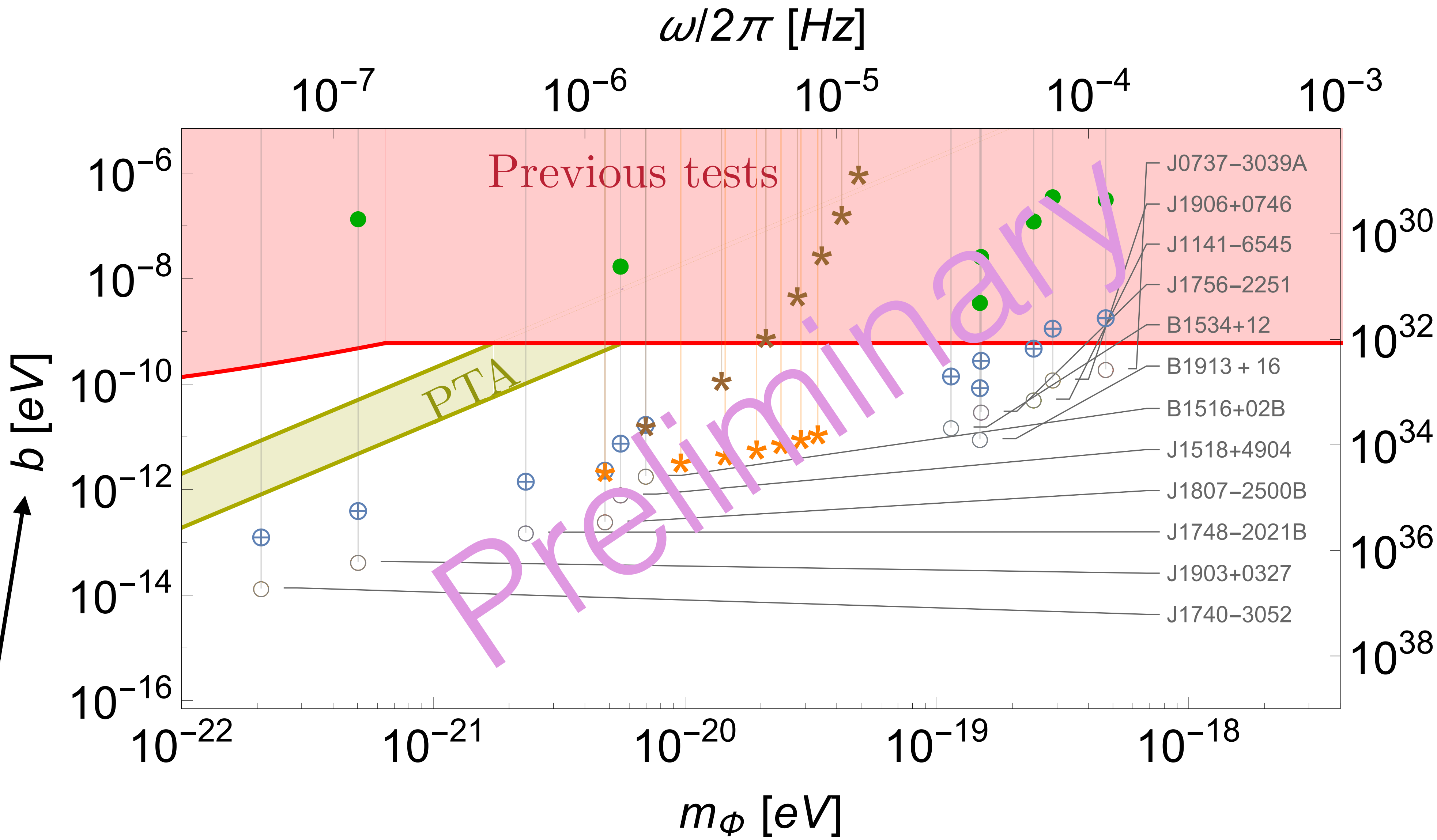
$$S_A=-\int d\tau_A\, m_A(\Phi)\sim-\int d\tau_A\, m_A^0(1+\alpha_A\Phi)$$

Resonances

$$m_\Phi=\frac{2N\pi}{P_b}\quad(N\in\mathbb{N})$$

$N=1$

Using the effect on $\langle\dot{P}_b\rangle$:



$\Lambda_1^{-1}\sim\mathcal{O}(\alpha_1,\alpha_2)$

Higgs portal: $\mathcal{L}\supset b\Phi|H|^2$ $\qquad b\equiv\frac{9}{2}\frac{m_h^2}{\Lambda_1}$

Modified theories of gravity:

- Careful analysis of EQDMG (with S. Anselmi, S. Kumar, and G. Starkman):
  - Extended Quasi-Dilaton Massive Gravity I: Fixed Point Analysis -> to appear soon!
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In brief:

- *We consider a specific model: EQDMG*
- *Background FRW solutions assuming only dust and radiation:*
  - *Is it possible to have future de Sitter attractor fixed points?*
  - *What is (if any) the region of the parameter space that is compatible with the observed background evolution of the universe?*

$$S = \frac{M_{\rm Pl}^2}{2}\int d^4x\sqrt{-g}\left[R - \frac{\omega}{M_{\rm Pl}^2}\partial_\mu\sigma\partial^\mu\sigma + 2m_g^2(\mathcal{L}_2 + \alpha_3\mathcal{L}_3 + \alpha_4\mathcal{L}_4)\right]$$

$$\mathcal{L}_2 \equiv \frac{1}{2}\left([\mathcal{K}]^2 - [\mathcal{K}^2]\right)$$

$$\mathcal{L}_3 \equiv \frac{1}{6}\left([\mathcal{K}]^3 - 3[\mathcal{K}][\mathcal{K}^2] + 2[\mathcal{K}^3]\right)$$

$$\mathcal{L}_4 \equiv \frac{1}{24}\left([\mathcal{K}]^4 - 6[\mathcal{K}]^2[\mathcal{K}^2] + 3[\mathcal{K}^2]^2 + 8[\mathcal{K}][\mathcal{K}^3] - 6[\mathcal{K}^4]\right)$$

$$\mathcal{K}^\mu{}_\nu = \delta^\mu{}_\nu - e^{\sigma/M_{\rm Pl}}\left(\sqrt{g^{-1}f}\right)^\mu{}_\nu$$

$$f_{\mu\nu} \equiv \eta_{ab}\partial_\mu\phi^a\partial_\nu\phi^b - \frac{\alpha_\sigma}{M_{\rm Pl}^2 m_g^2}e^{-2\sigma/M_{\rm Pl}}\partial_\mu\sigma\partial_\nu\sigma$$

THANKS!