GRAVITATIONAL ATOMS

NIKLAS G. NIELSEN, ANDREA PALESSANDRO, MARTIN S. SLOTH

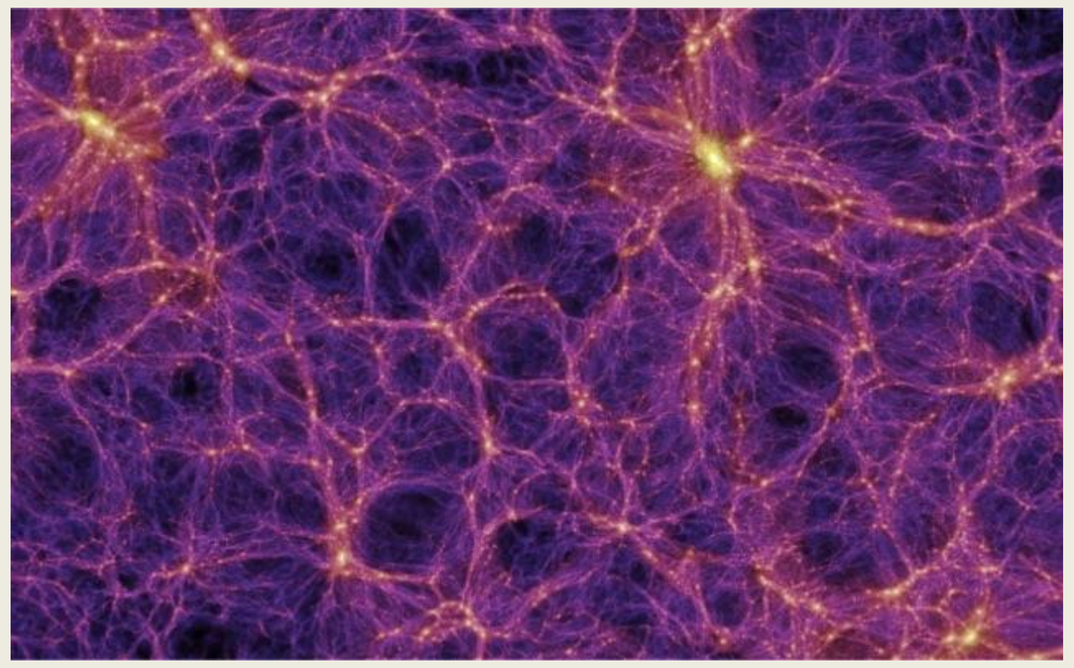
ABSTRACT

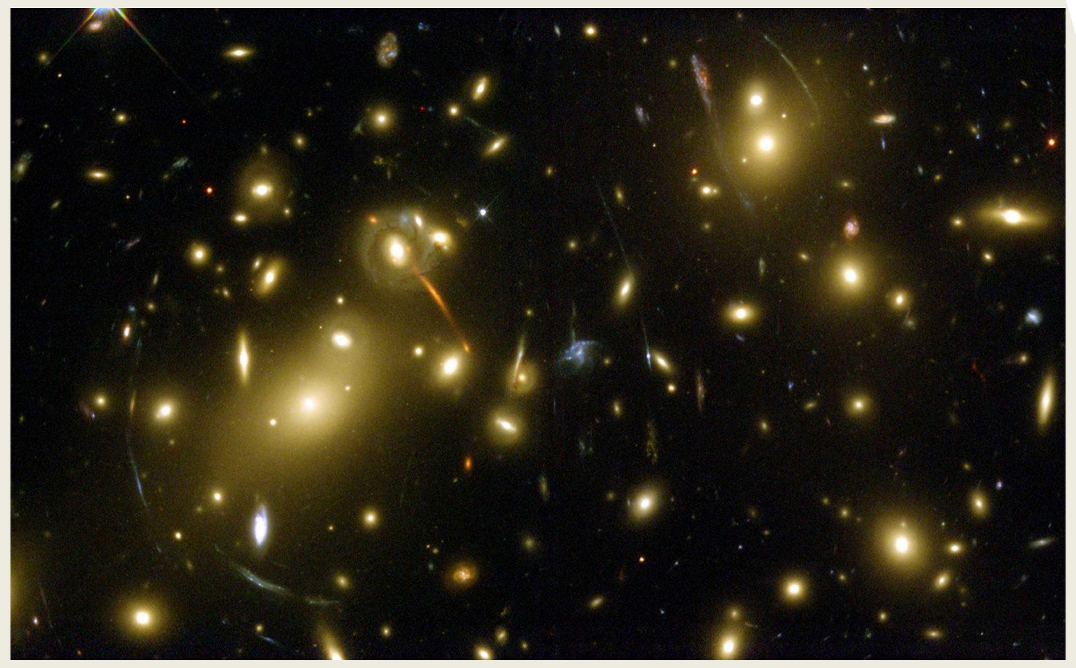
Gravity is weak for ordinary particles, $m/q \ll m_p$, and is therefore completely irrelevant in atomic physics, where gauge forces dominate. However, there could be heavy particles X in a yet unexplored dark sector for which gravity is the strongest force $m_X/q_X \gg m_p$. These particles could form purely gravitational atoms, which are unstable and predominantly decay to gravitons. The frequency of the resulting gravitational wave signal is always higher than 10^{13} Hz, if Einstein gravity holds up to the Planck scale, and ΛCDM is unmodified.

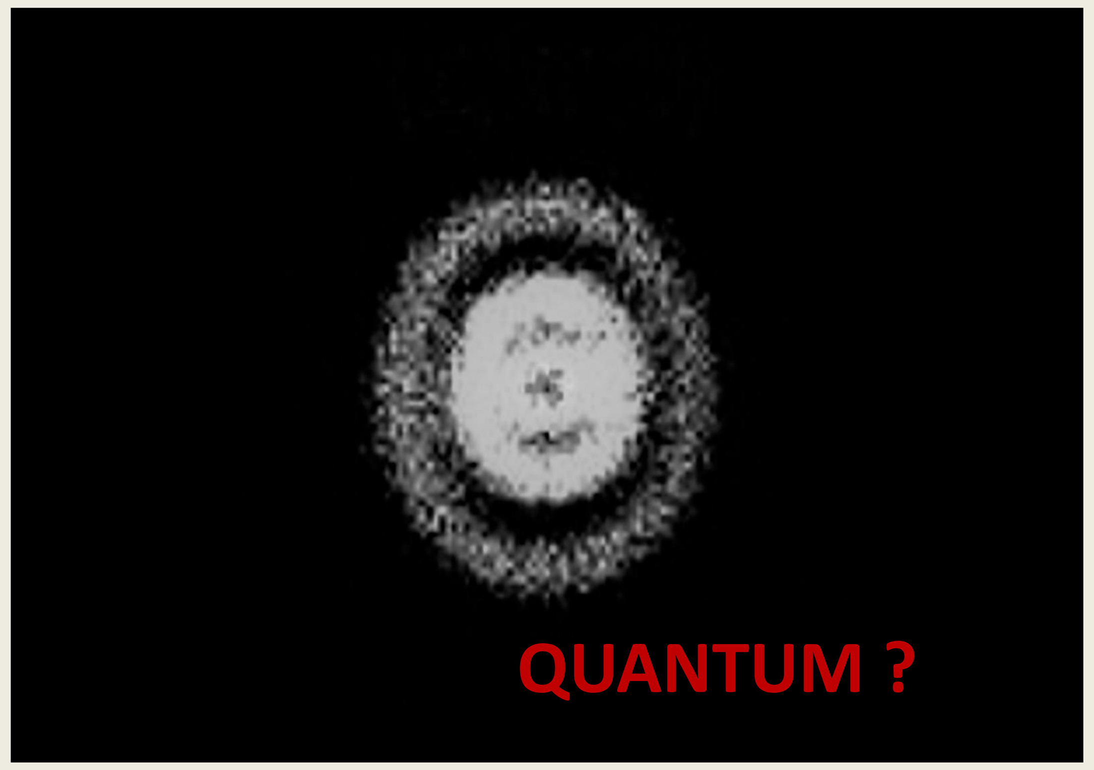
THE MINIMAL MODEL

- Scalar particle X in a dark sector that has only standard gravitational interactions. The dark sector is maximally decoupled from the visible sector.
- Gravitational atoms are created in the very early universe, close to reheating and they evolve in the usual ΛCDM scenario.
- The formation mechanism is such that only 2-particle atoms are efficiently created, and predominantly in their ground state.
- Decay rate $\Gamma \sim \alpha_G^5 m_X$. ($\alpha_G = m_X^2/m_p^2$)
- Lower bound on the mass from disruption by tidal forces in galaxies: $m_X \geq 10^{-8}\, m_p$.
- Disruption by Hubble expansion: $m_X > (H\, m_p^2)^{\frac{1}{3}}$.
- Near Planckian atoms decay immediately after being produced, sourcing a highly energetic, isotropic, and nearly monochromatic gravitational wave signal. The minimum frequency is $m_X T_0/T_{rh} \sim 10^{13}$Hz.

GRAVITATIONAL BOUND STATES IN THE UNIVERSE







THE PIDM MODEL

Planckian Interacting Dark Matter (PIDM) is a minimal scenario of dark matter assuming only gravitational interactions with the standard model.

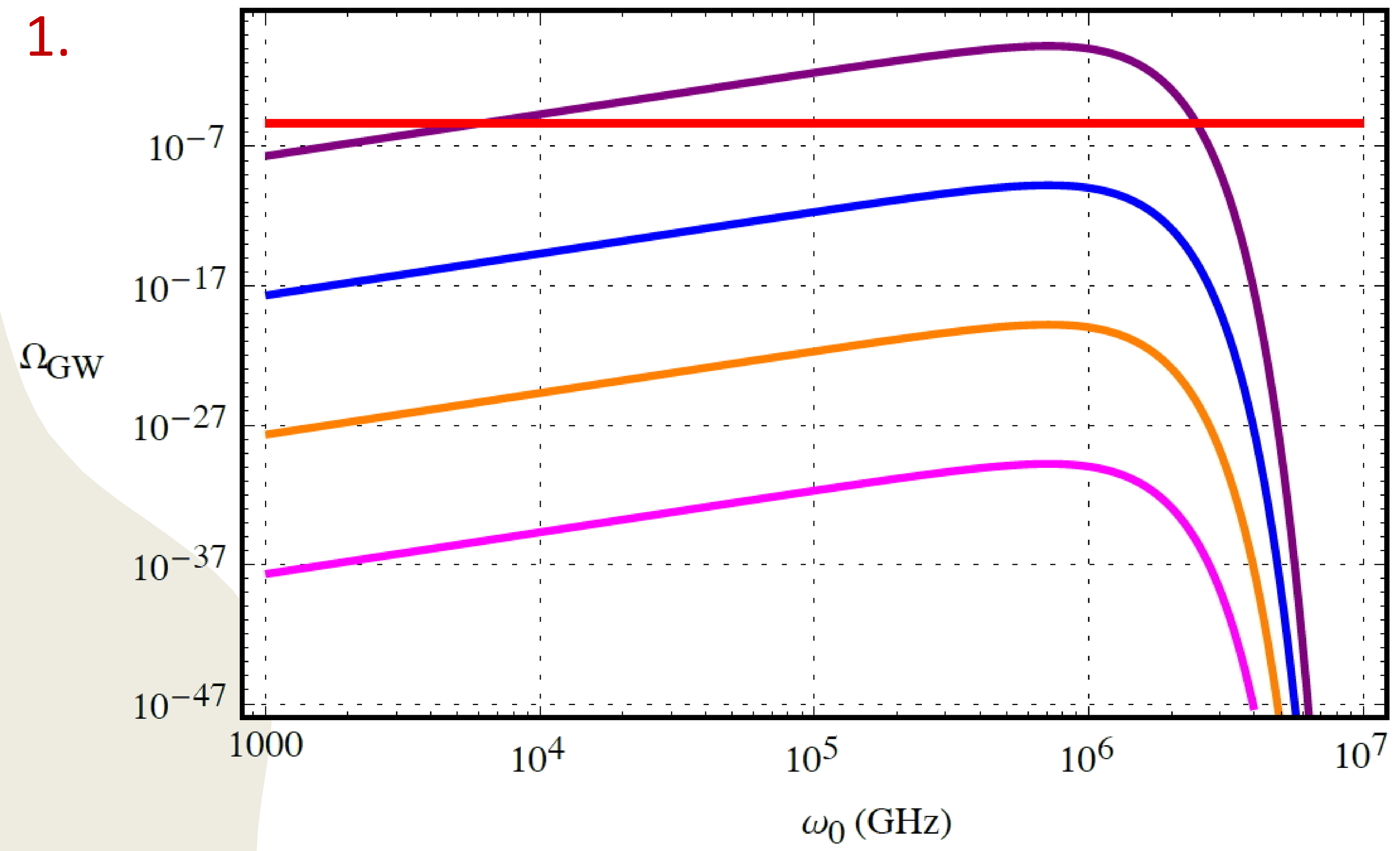
PIDM are produced by gravitational scattering in the thermal plasma of the Standard Model sector. Gravitational atoms are produced by the same mechanism with a number density suppressed by $\sim \alpha_G^3$.

The abundance of gravitational atoms in this scenario is

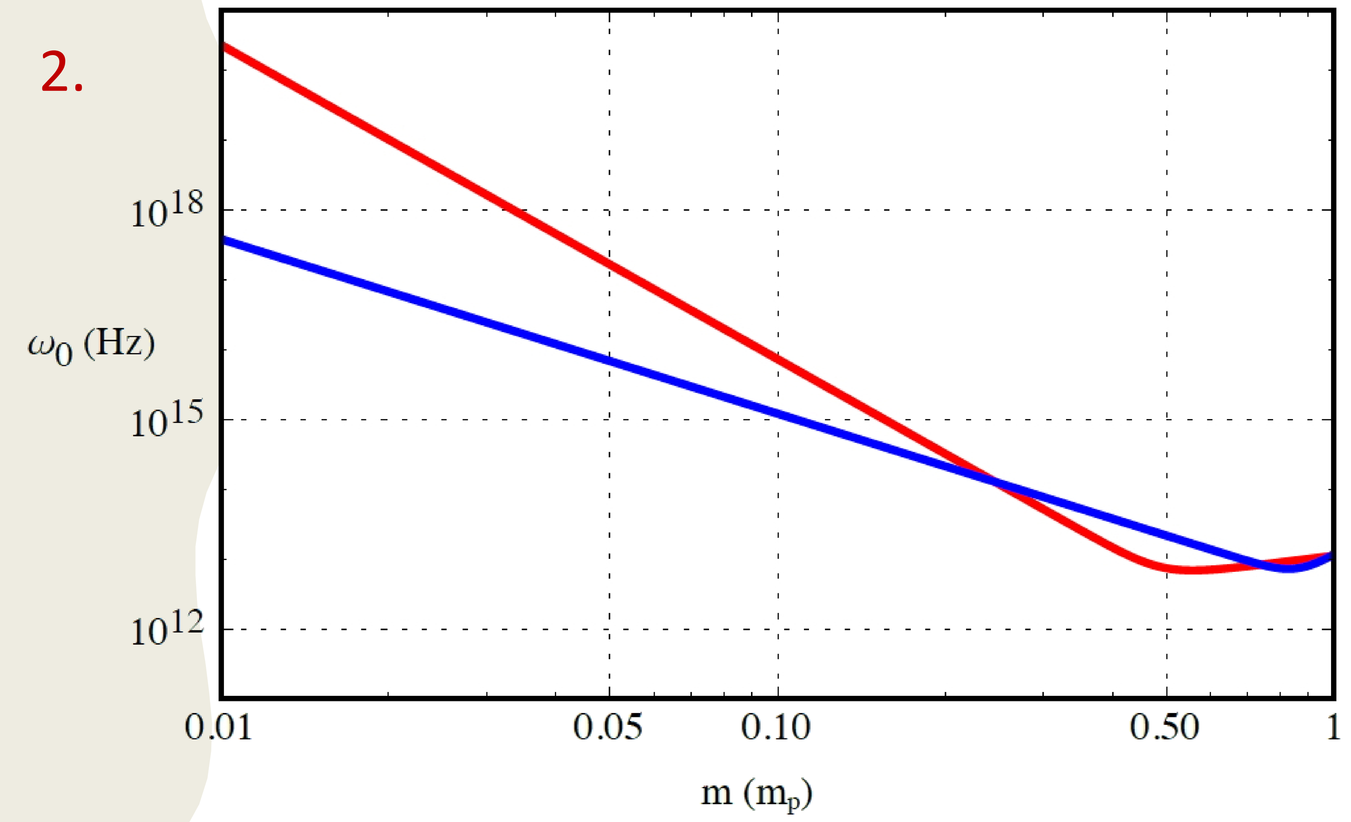
$$n_B = \alpha_G^3 \sqrt{\frac{\pi m_X^3}{T_{rh}^3}}\, n_X$$

n_X = dark matter abundance

1.



2.



1. Gravitational wave density parameter for $T_{rh} = 10^{-3} m_p$, $m_X = 0.1\, m_p$, and $n_B = \alpha T_{rh}^3$ with $\alpha = 1, 10^{-10}, 10^{-20}, 10^{-30}$, from top to bottom.

2. Peak frequency of the monochromatic gravitational wave signal produced by gravitational atoms for $T_{rh} = 10^{-3} m_p$.

Acknowledgements

Joseph Conlon, Mathias Garny, Nemanja Kaloper, Florian Niedermann and McCullen Sandora for helpful comments.

Oxford particle theory group for hospitality.