Superradiance and binaries

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Solutions to many BSM puzzles involve **ultralight bosons**.

- **Strong CP.** Why is θ_{QCD} so small?

  [Peccei and Quinn '77; Wilczek '78; Weinberg '78; Kim '79; Zhitnitsky '80; Shifman, Vainshtein, Zakharov '80; Dine, Fischler, Srednicki '81]

- **Dark Matter.** What comprises 85% of matter in our universe?

  [Preskill, Wise, Wilczek '83; Abbott and Sikivie '83; Dine and Fischler '83; Hu, Barkana, Gruzinov, '00]

- **String Axiverse.** Bosons from string compactifications?

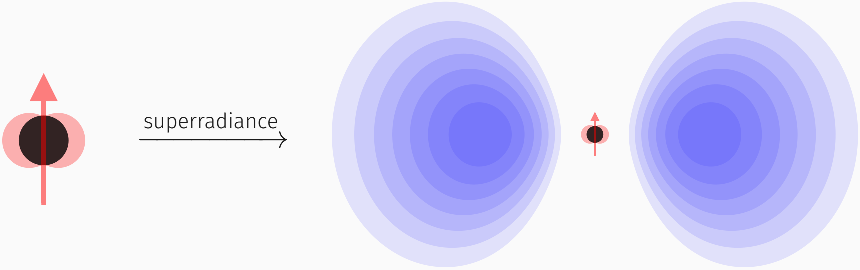
  [Arvanitaki, Dimopoulos, Dubovsky, Kaloper, March-Russell '09; Demirtas, Long, McAllister, Stillman '18]

- **Hierarchy Problem.** Why is the weak force so strong?

  [Graham, Kaplan, Rajendran '15, '19; Hook '18; Arkani-Hamed, Cohen, et. al. '17; D'Agnolo and Teresi '21]

Weakly coupled fields, often with **no abundance** in the universe.

The Gravitational Atom

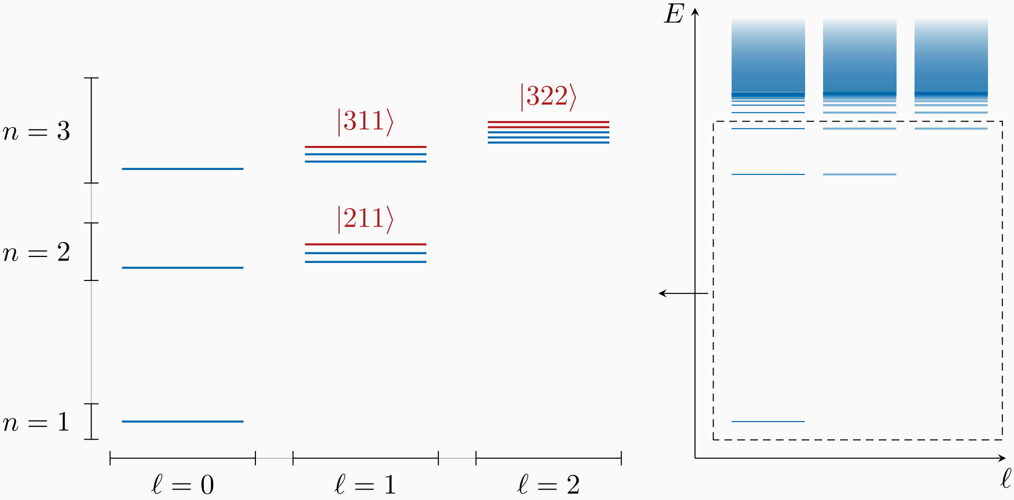


$$(\Box - \mu^2)\Phi = 0 \quad \longrightarrow \quad i\frac{\mathrm{d}\psi}{\mathrm{d}t} \approx \left(-\frac{1}{2\mu}\nabla^2 - \frac{\alpha}{r} + \dots\right)\psi$$

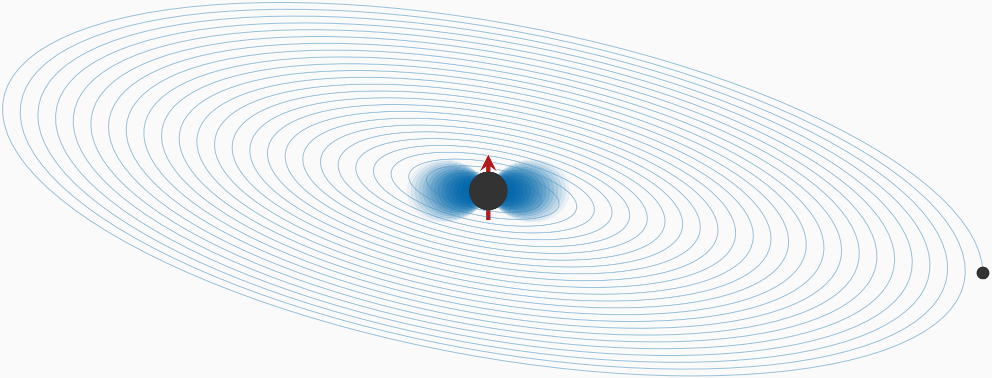
Gravitational fine structure constant: $\alpha = \mu M \sim \mathcal{O}(0.1)$.

[Zeldovich '72; Starobinsky '73; Dolan '07; Arvanitaki et al. '09]

The spectrum

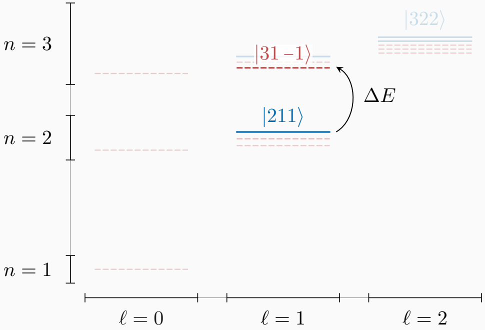


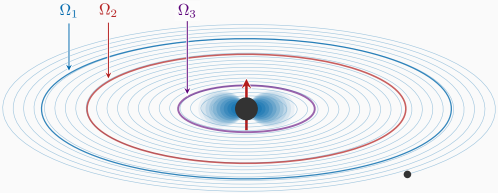
How does a cloud affect a **binary inspiral**?



The binary can induce transitions between bound states ("resonances") and excite unbound states ("ionization")...

Resonances

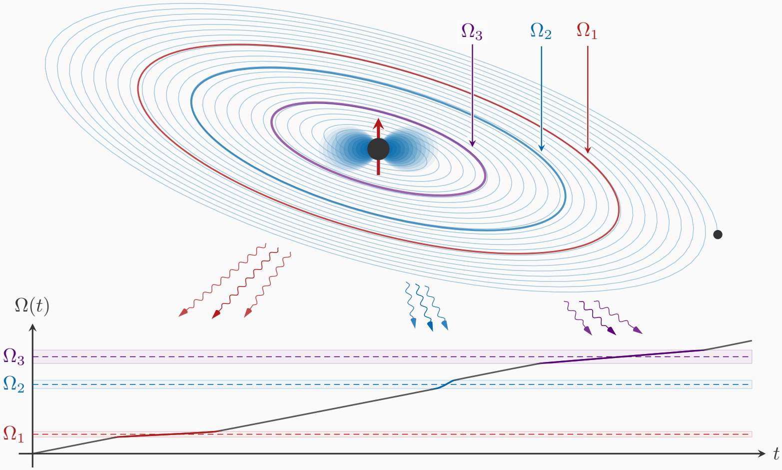




Resonance frequency: $\Omega_r = \left|\frac{\Delta E}{\Delta m}\right| \sim 10\,\text{mHz}\left(\frac{10^4 M_\odot}{M}\right)\left(\frac{\alpha}{0.2}\right)^3$

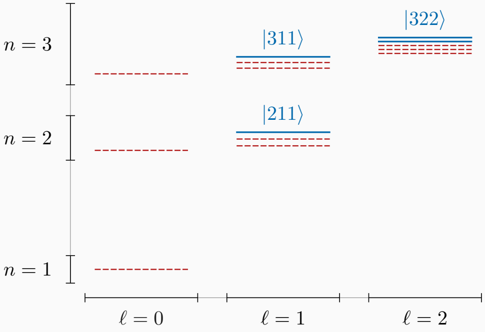
[Baumann, Chia, Porto, Stout '18]

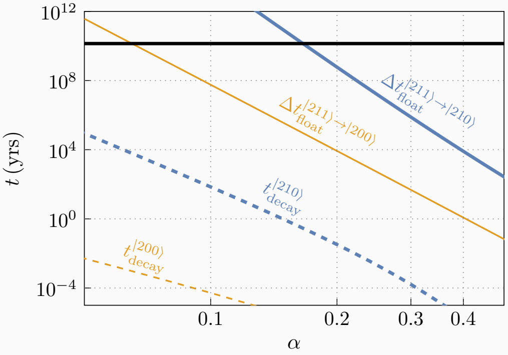
Floating and sinking resonances



[Baumann, Chia, Porto, Stout '19]

All **fine** and **hyperfine** resonances are **floating** and **decaying**.

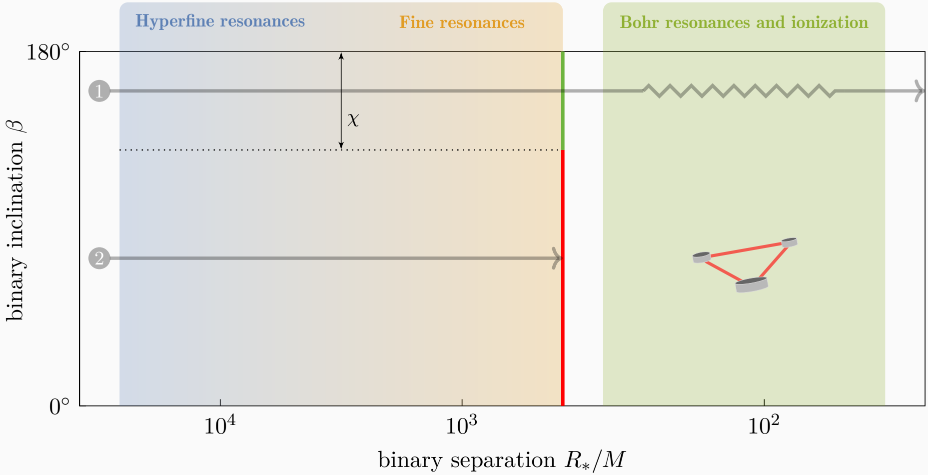




$\Delta t_{\rm float} \gg t_{\rm decay} \quad \Longrightarrow$ No state change, only **destruction** or **survival**.

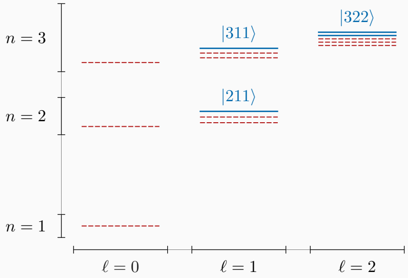
[GMT, Spieksma, Bertone '24]

The resonant history



[GMT, Spieksma, Bertone ’24]

Bohr floating resonances?



- Most Bohr resonances are **sinking**
- Notable exception: $|322\rangle \to |211\rangle$

Bohr floating res. also not triggered for counter-rotating $\Longrightarrow$ **Need binary formation at small separation.**

Clous is efficiently ionized for $q \sim 1$ $\Longrightarrow$ **Need small mass ratio**

[GMT, Spieksma, Bertone '24]

Frequencies and timescales

Hyperfine: [assuming $\Delta m/g = 1$]

$$\text{from } |211\rangle: \qquad f_{\mathrm{GW}} = 17\,\mathrm{mHz}\left(\frac{10M_\odot}{M}\right)\left(\frac{\tilde{a}}{0.5}\right)\left(\frac{\alpha}{0.2}\right)^6$$

$$\text{from } |322\rangle: \qquad f_{\mathrm{GW}} = 1\,\mathrm{mHz}\left(\frac{10M_\odot}{M}\right)\left(\frac{\tilde{a}}{0.5}\right)\left(\frac{\alpha}{0.2}\right)^6$$

$$\Delta t_{\mathrm{float}} = \text{very very long}$$

Bohr:

$$|322\rangle \to |211\rangle: \qquad f_{\mathrm{GW}} = 3.6\,\mathrm{mHz}\left(\frac{10^4 M_\odot}{M}\right)\left(\frac{\alpha}{0.2}\right)^3$$

$$\Delta t_{\mathrm{float}} = 5.8\,\mathrm{yrs}\left(\frac{M}{10^4 M_\odot}\right)\left(\frac{q}{10^{-3}}\right)^{-2}\left(\frac{\alpha}{0.2}\right)^{-3}$$