Gravitational Collider Physics via Pulsar-Black Hole Binaries

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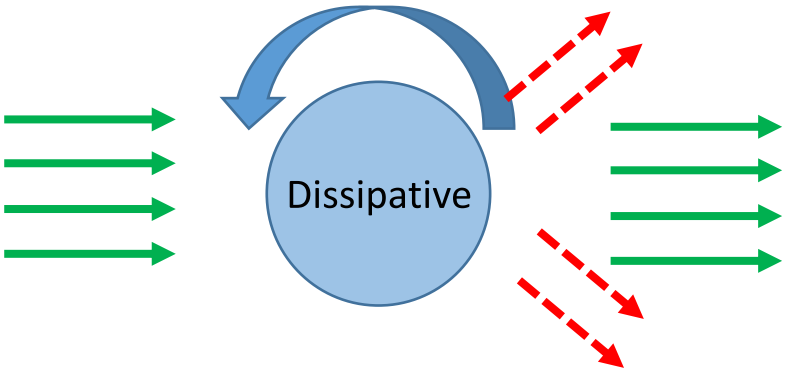
Q: What is Gravitational Collider Physics (GCP)?

A: A way to probe ultralight bosons via BHs.

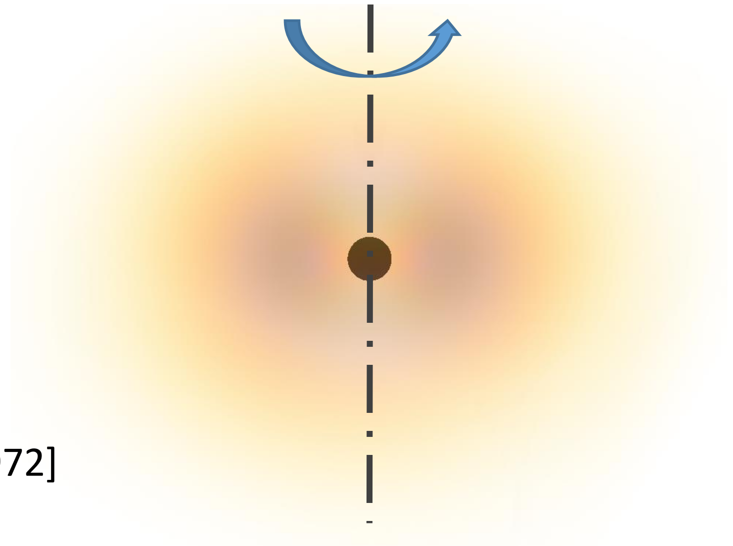
[Baumann et al, 2019, 2020]

GCP: Superradiance and the G-atom

- Rotational Superradiance, Zel'Dovich, 1971



- Superradiant instability ⇨ Kerr BH grows a ultralight boson cloud



$$\alpha \equiv G M_B \mu \ll 1$$

[Press & Teukolsky, 1972]
[Damour et al. 1976]

GCP: Superradiance and the G-atom

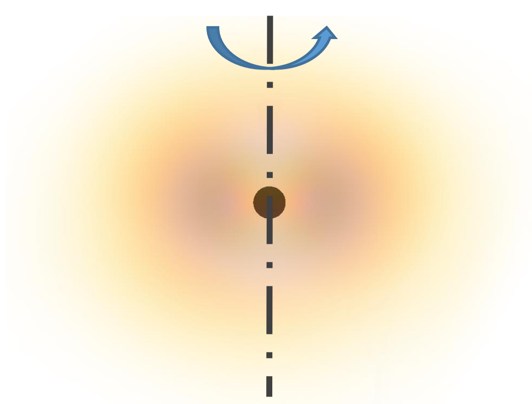
Atomic spectrum:

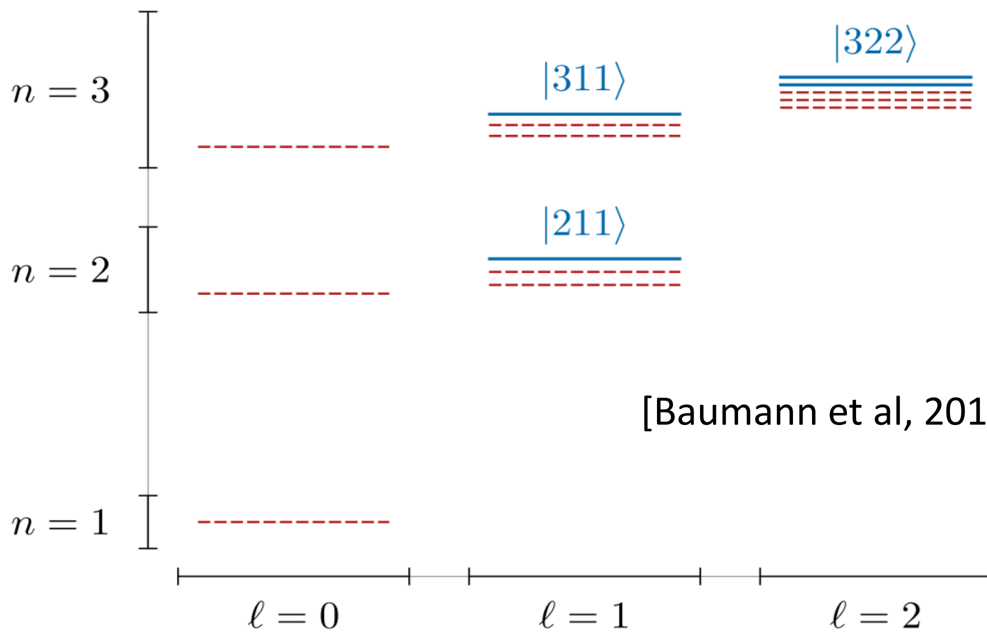
ψ_{nlm} , with $\omega_{nlm} = E_{nlm} + i\Gamma_{nlm}$ $\begin{cases} < 0 & \text{Absorption} \\ > 0, & \text{Superradiance} \end{cases}$

[Press & Teukolsky, 1972]
[Damour et al., 1976]
[Detweiler, 1980]

$$E_{nlm} = \mu\left(1 - \frac{\alpha^2}{2n^2} + \alpha^4 A(n,l) + \alpha^5 \tilde{a} m\, B(n,l) + \cdots\right)$$

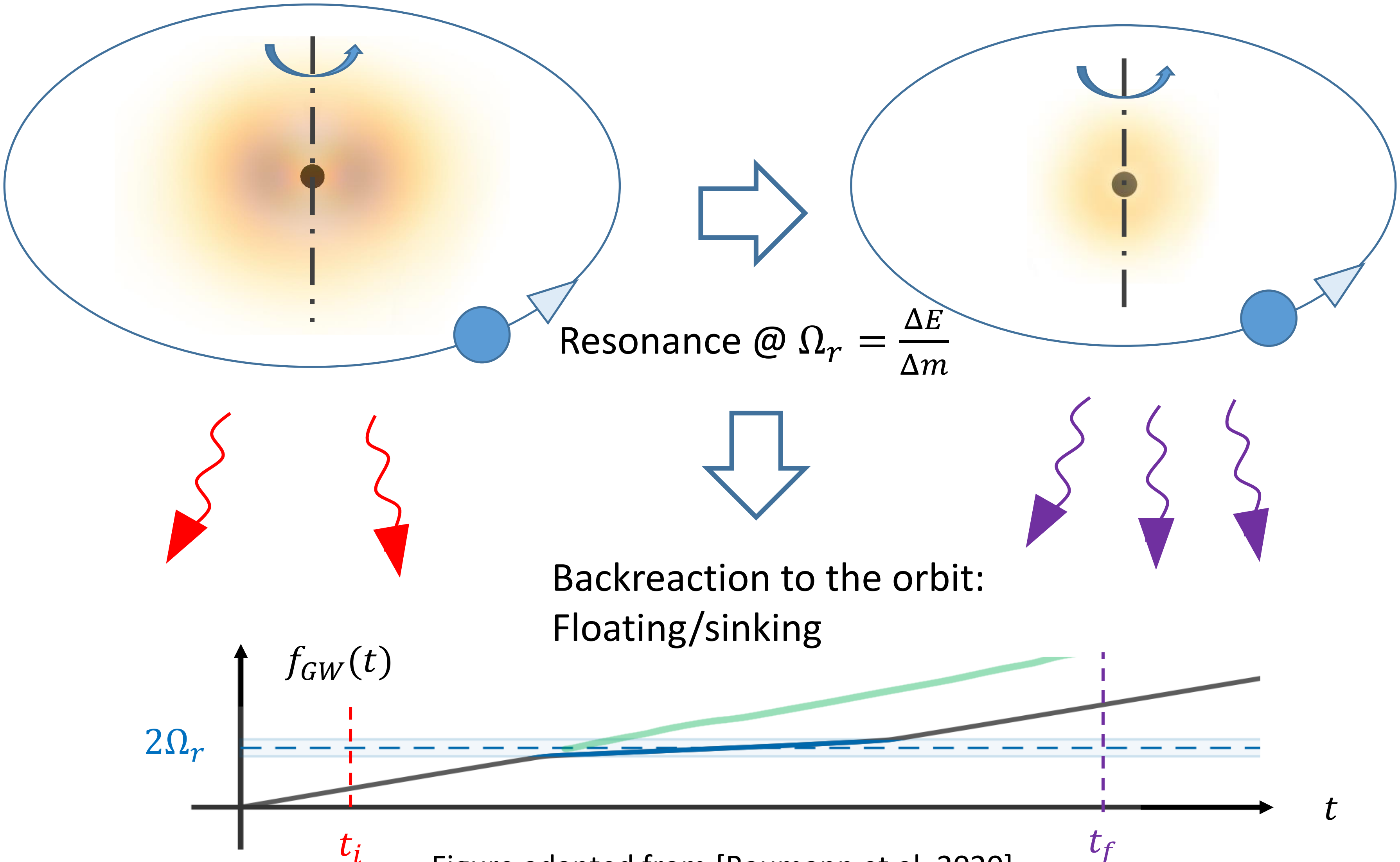
Rest mass | Bohr | Fine | Hyperfine





[Baumann et al, 2019, 2020]

GCP: G-atom in a binary



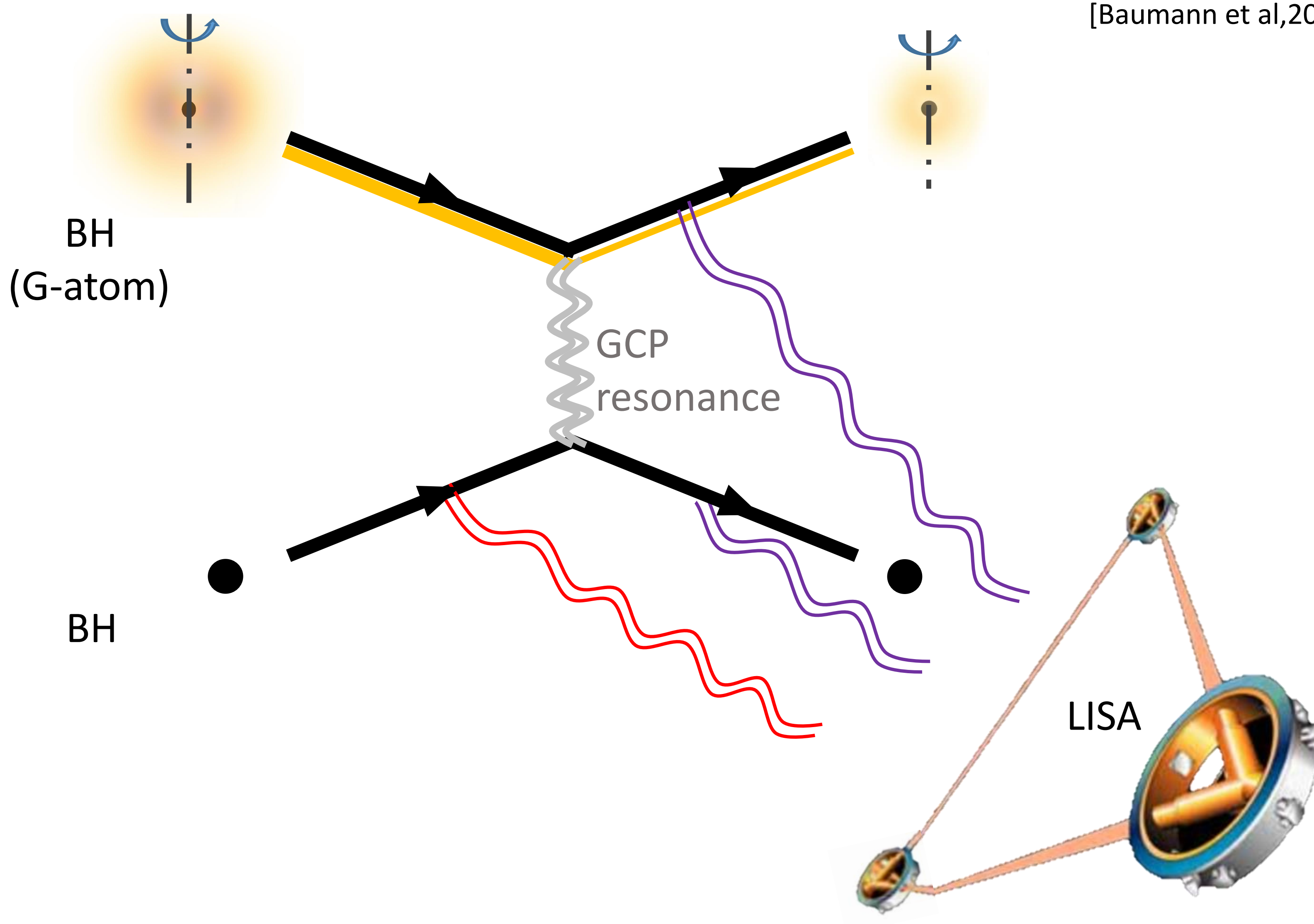
Resonance @ $\Omega_r = \frac{\Delta E}{\Delta m}$

Backreaction to the orbit:
Floating/sinking

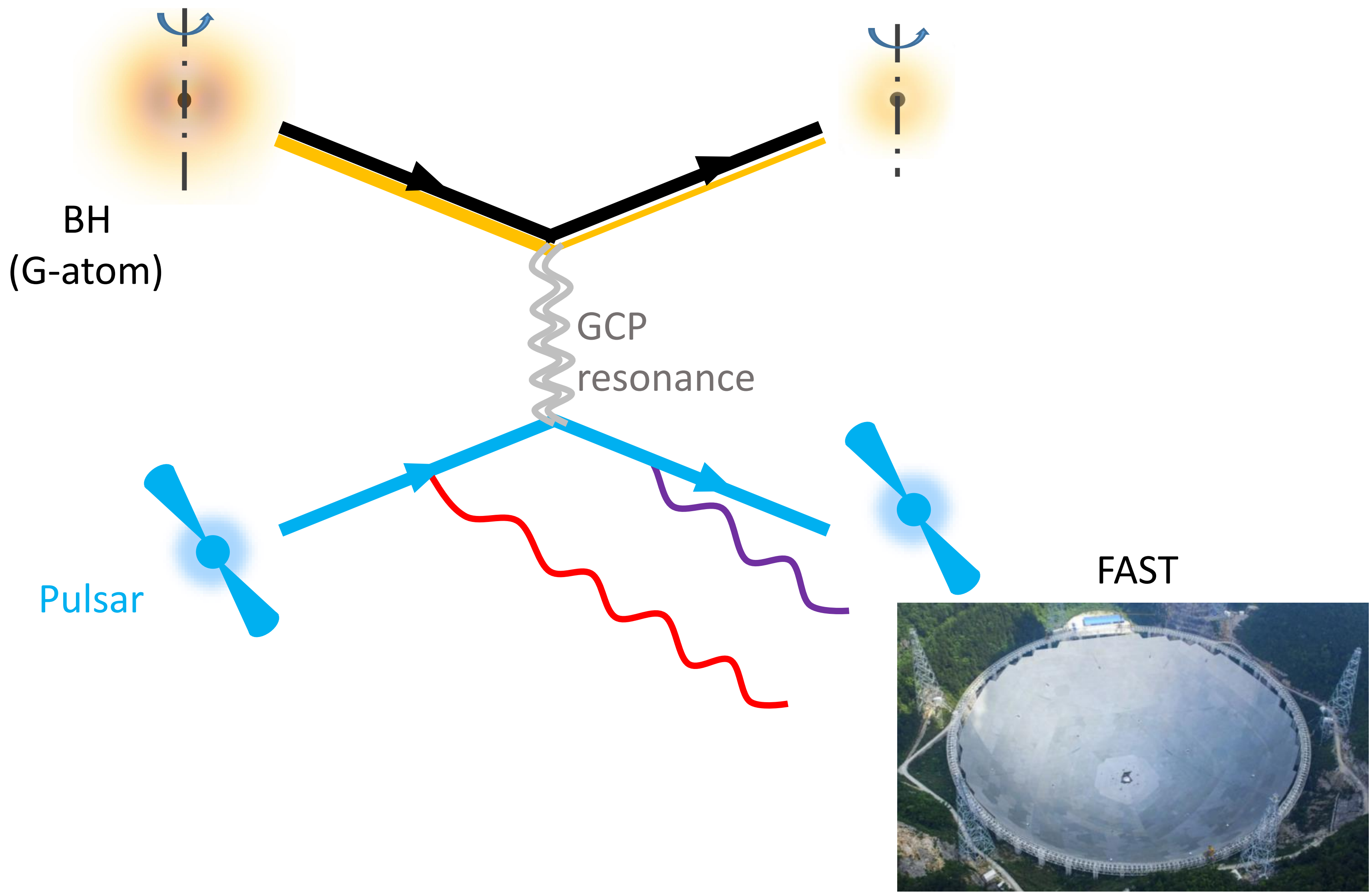
Figure adapted from [Baumann et al, 2020]

GCP: The BH-BH-GW channel

[Baumann et al,2019,2020]



GCP: The PSR-BH-Radio channel



GCP via PSR-BHs: What to see?

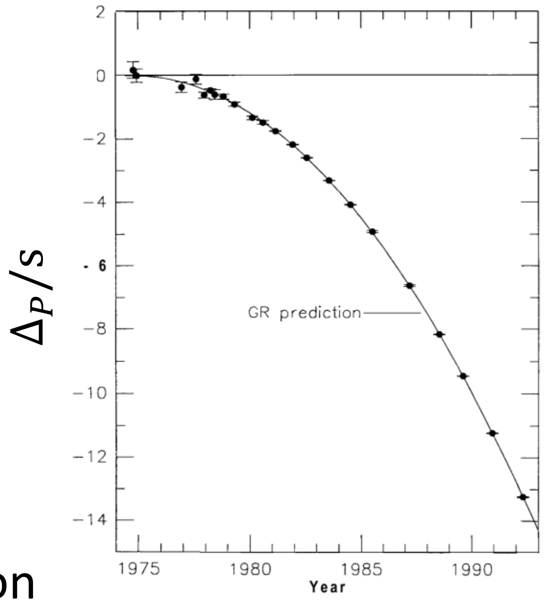
- Observable: Periastron time shift

$$\Delta_P(t) = t - P(0)\int_0^t \frac{1}{P(t')}dt'$$

Rømer delay + pulse counting

GR: $\dot{P}\Big|_{GR} = -\frac{96}{5}(2\pi)^{8/3}(GM_B)^{5/3}\frac{q}{(1+q)^{1/3}}P^{-5/3}$

[Hulse & Taylor 1975]

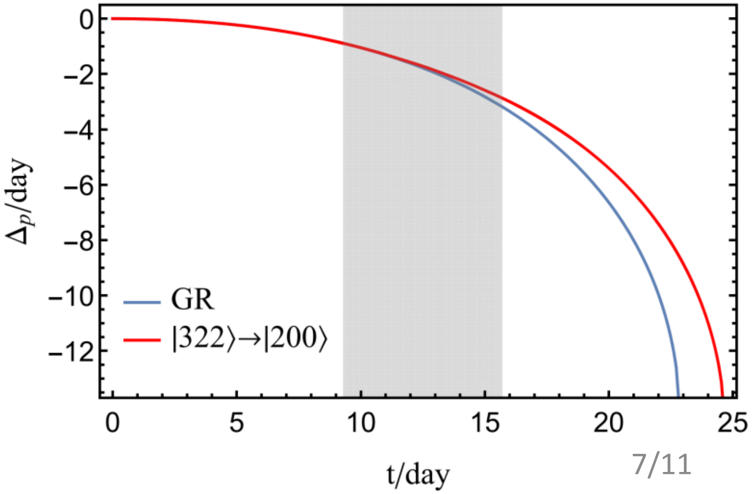


- In GCP, we expect a backreaction-induced deviation

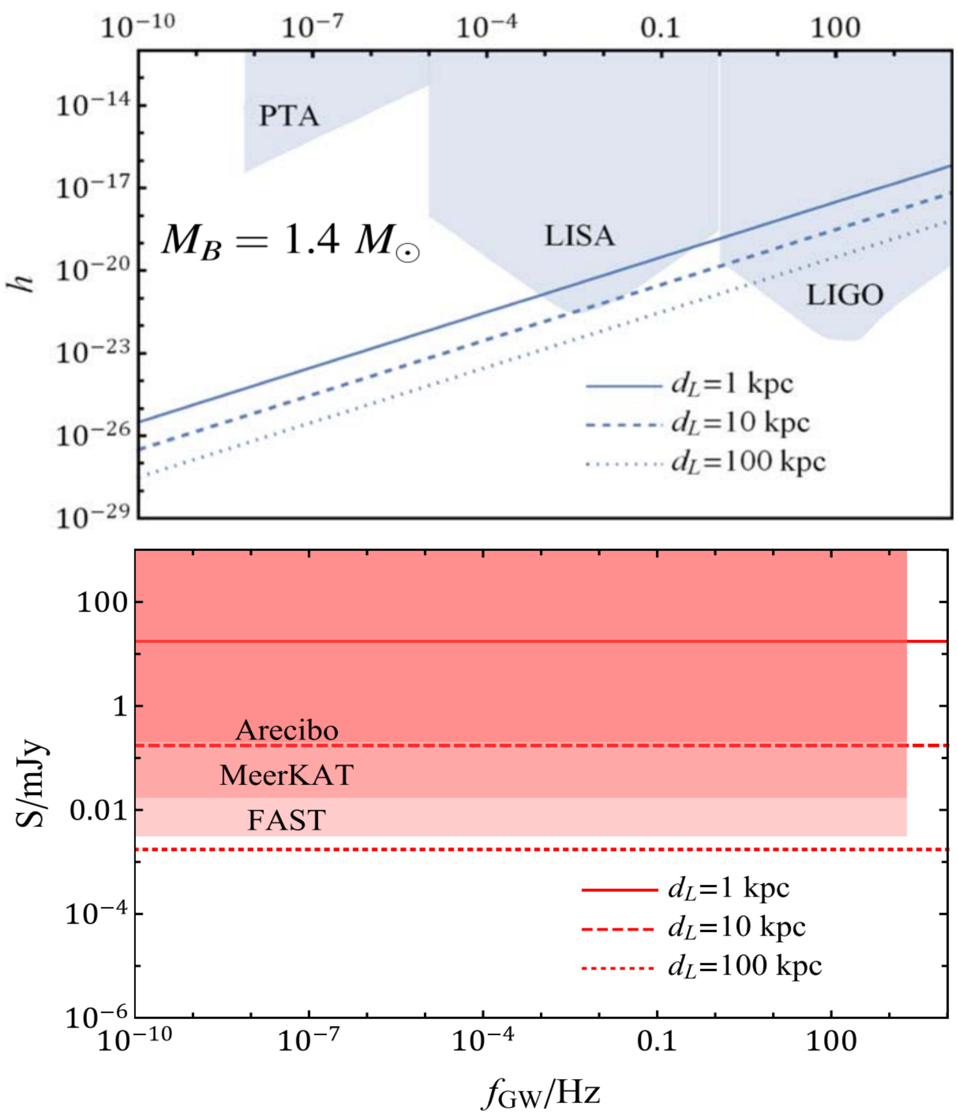
$$\dot{P}\Big|_{GCP} = \dot{P}\Big|_{GR} \times \frac{1}{1 \pm \delta \times \Pi\left(\frac{P-P_r}{\Delta P_r}\right)}$$

Size of backreaction

Resonance window



GCP via PSR-BHs: Can we see it?



- Pulsar luminosity $S = \frac{L_\nu}{d_L^2}$

Pulsar cannot be too far:

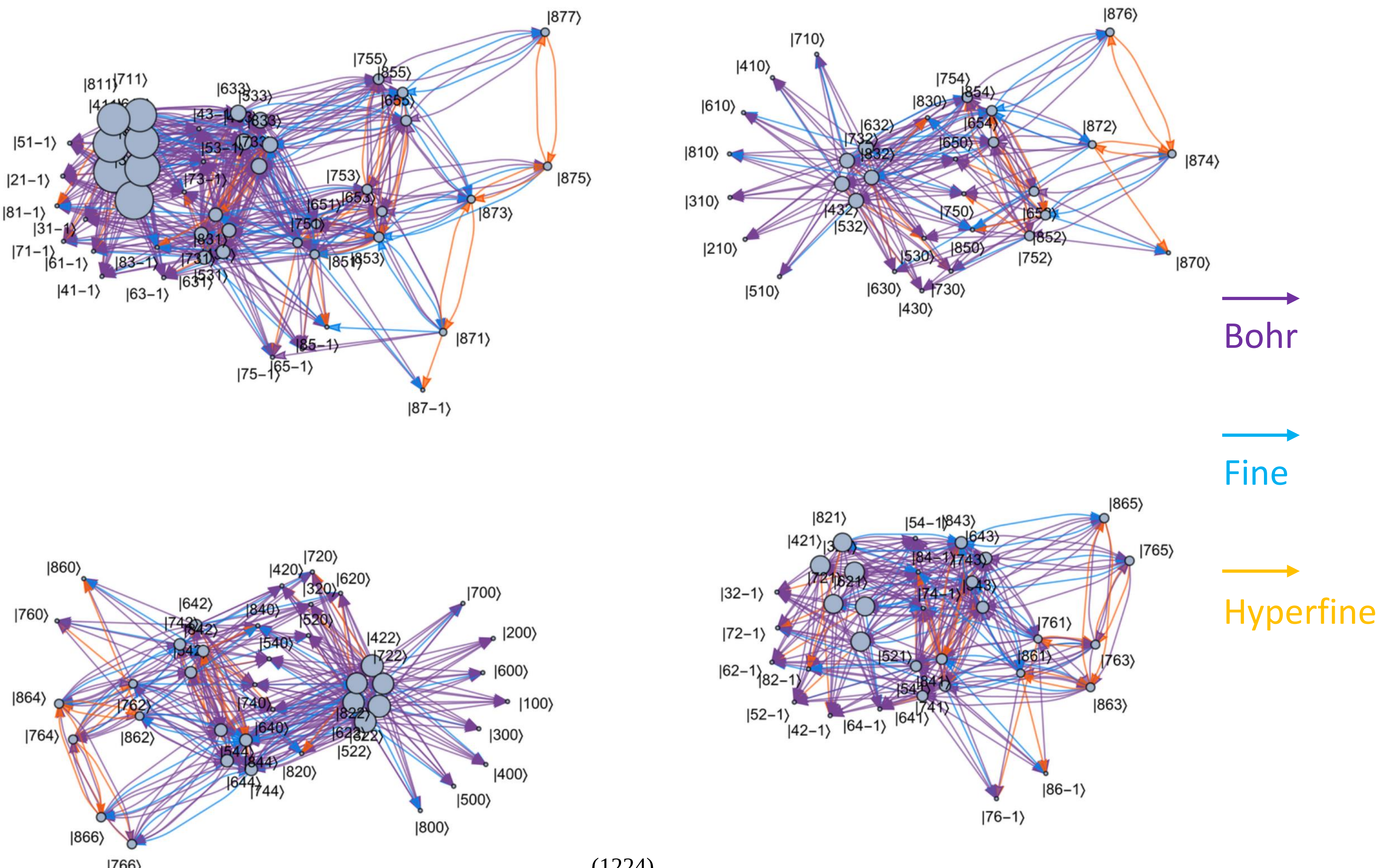
$$d_L \lesssim 10^2\ \mathrm{kpc}$$

Estimated number of PSR-BH binaries in the Milky Way:

$$N \sim 10^2\text{-}10^3$$

[Chattopadhyay et al. 2020]

GCP via PSR-BHs: Which transitions?

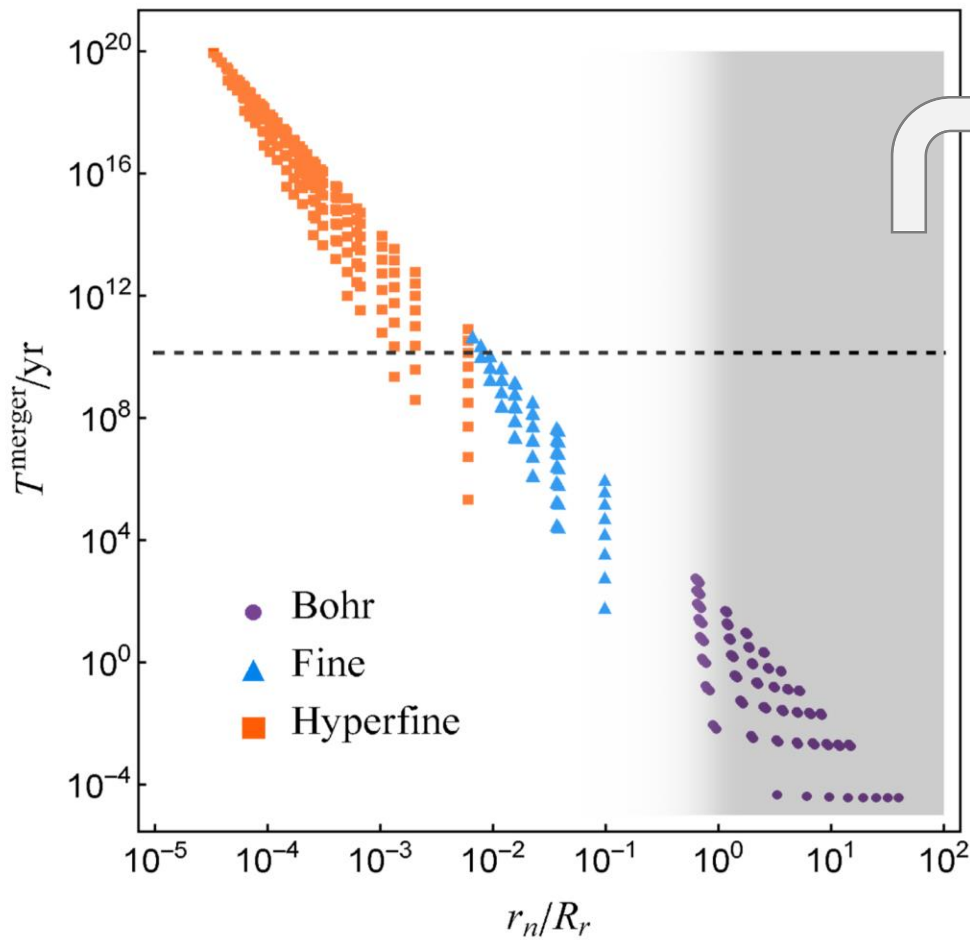


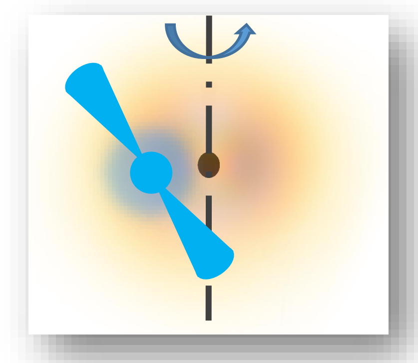
(1224)

(b) Allowed GCP transitions up to $n_{\max} = 8$

GCP via PSR-BHs: Bohr vs F/HF

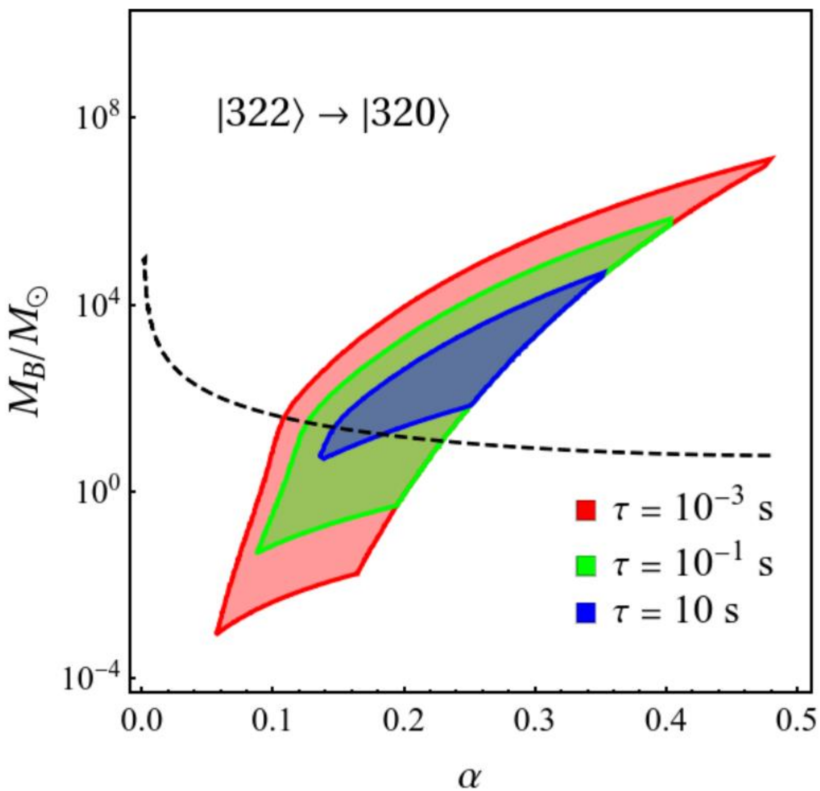
Larger
event
rate





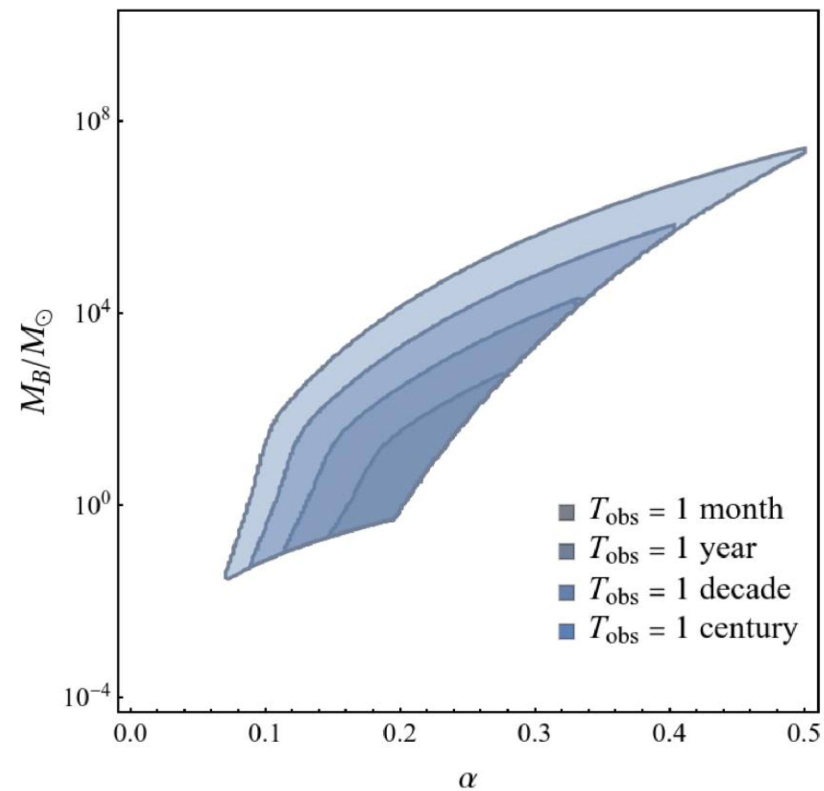
Better analytic control

GCP via PSR-BHs: Parameter space



Feasible region:

$10^{-18}\text{eV} < \mu < 10^{-8}\text{eV}$



A **long-term** observation

e.g., LISA lifetime = 4-6 yrs (?)
Arecibo lifetime = 57 yrs (✓)

Conclusion

- GCP is a interesting tool to probe ultralight boson DM with BHs
- A new *PSR-BH-Radio* channel as a complement:

	BH-BH-GW channel	***PSR-BH-Radio* channel**
Instrument	Space-based GW detectors (LISA, Taiji, Tianqin, …)	Earth-based radio telescopes (FAST, MeerKAT, …)
Distance reach	Long	Short
Timing accuracy	Low	High
Lifetime	Short	Long
Feasible transition type	Bohr	Fine/hyperfine

☐ More systematic analysis? Event rate? WD-BH-Doppler channel?

Thank you for listening!