Superradiant Instability of Magnetic Black Holes

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With: Marina de Amicis, Richard Brito, Conor Dyson and Rodrigo Panosso Macedo.

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Introduction

- Gravitational wave detectors (LVK, LISA …) probe strong gravity.
- Black holes become discovery engines: higher-derivatie completions of GR, ultralight boson dark matter candidates, early universe…
- Crucial to understand BH physics: superradiance, GW spectrum …
- *Today's talk*: magnetic BHs are multi-messenger sources via a new superradiant instability.

Magnetic Black Holes

- Magnetic monopoles are GUT predictions, and are ubiquitous in ST.

['t Hooft '74, Polyakov '74]

- Not observed nowadays: very hard to produce, inflation.

- May be found inside BHs, leading to *magnetic BHs*.

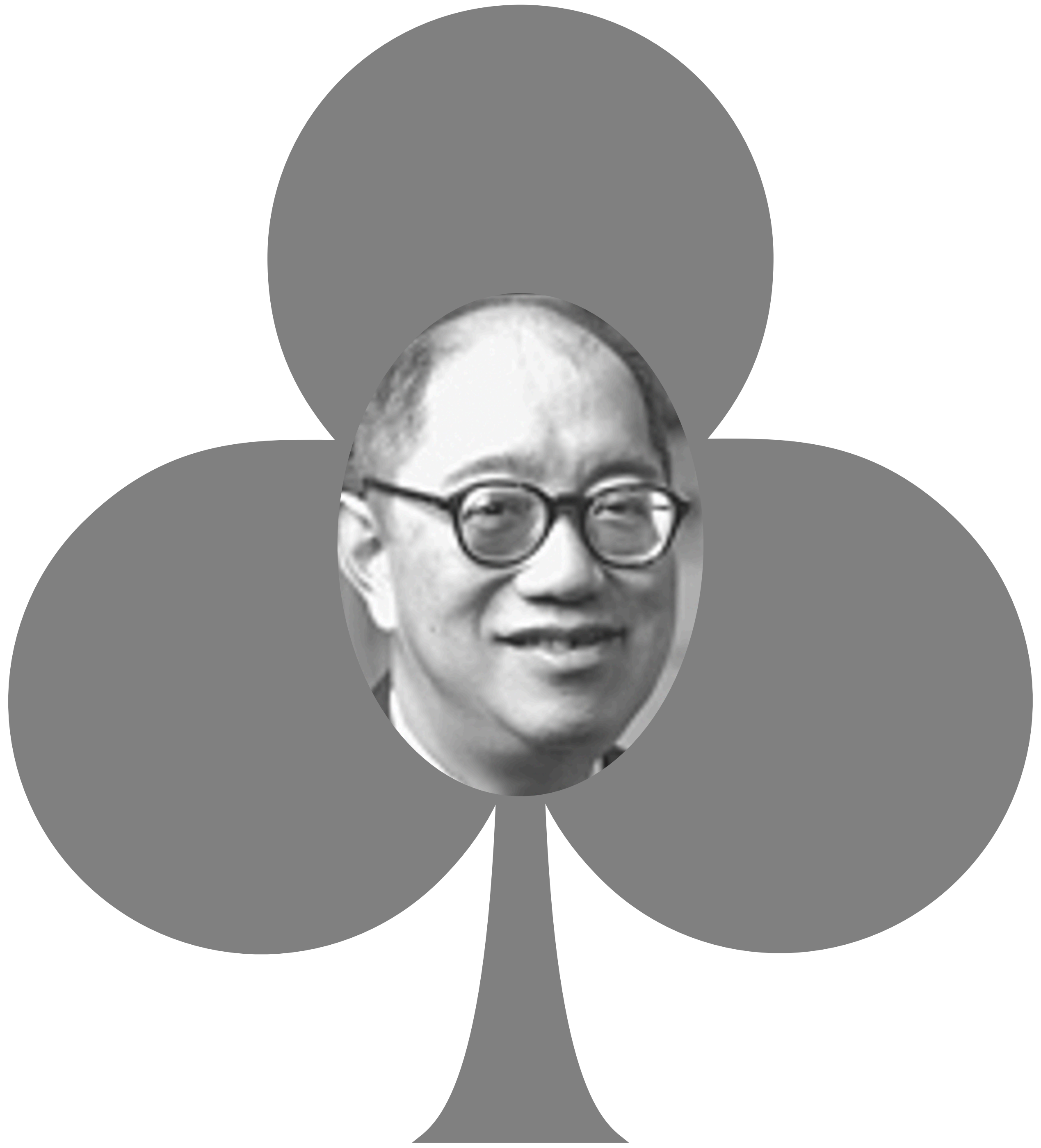
[Gibbons '77, Ortiz '92, Lee+ '92, Stojkovic+ '05, Maldacena '21…]

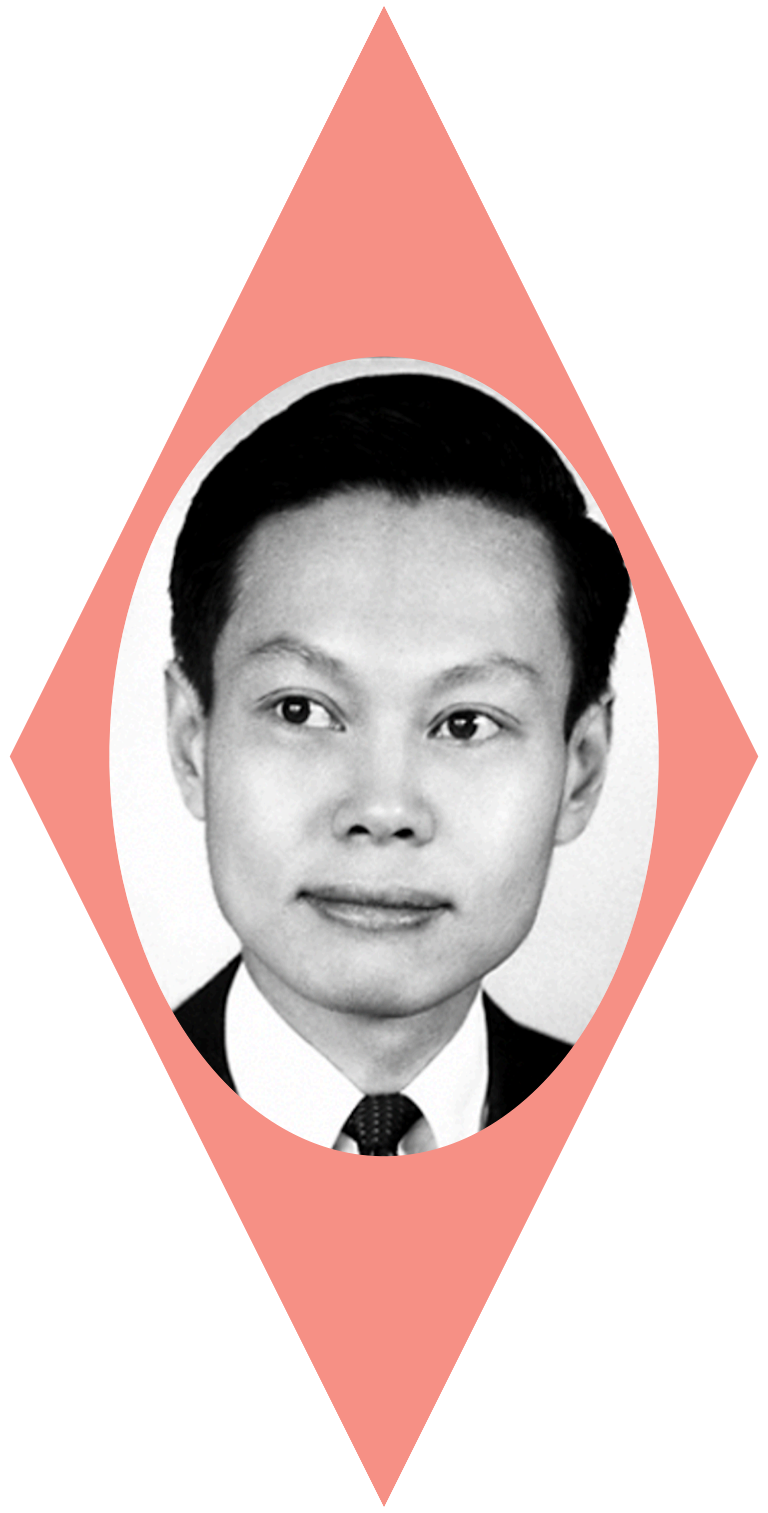
- What are their signatures?

[Liu+ '20, Carullo+ '22, DP+ '23, de Felice+ '23, Kobayashi+ '23, Zhang+ '23, Wang+ '23…]

Magnetic charges are much more than a smooth deformation…

Lessons from Thomson, Dirac, Wu and Yang





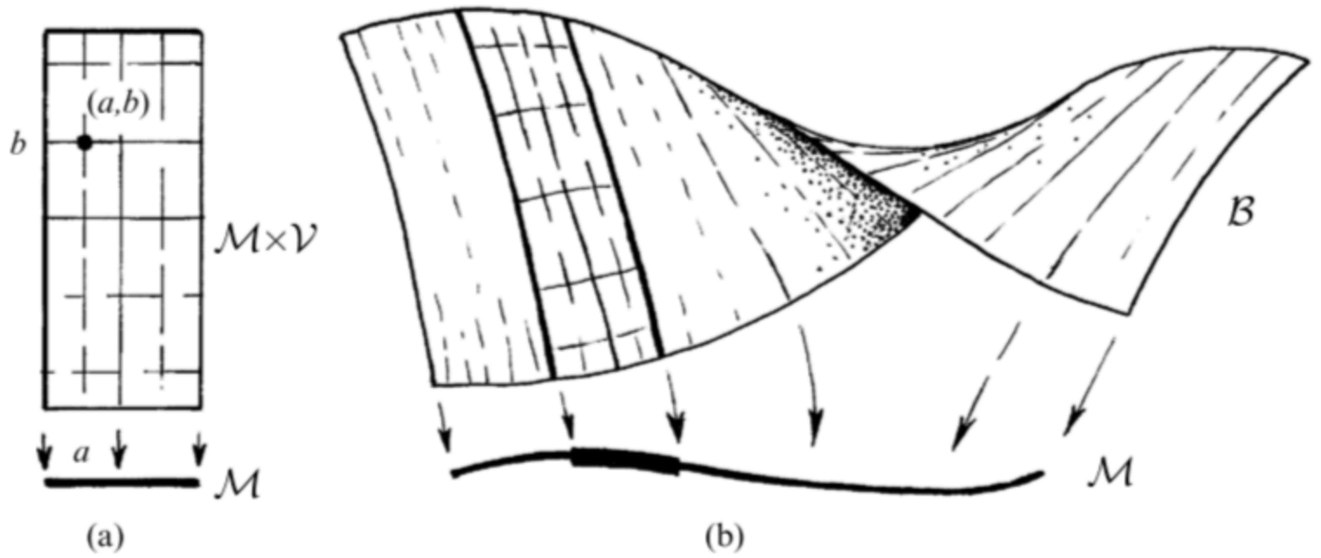
[Thomson 1904]

$$\vec{J} = -eP\,\hat{z}$$

[Dirac '31]

$$2Pe = \pm N, \quad N = 0,1,2,3...$$

[Wu and Yang '76]

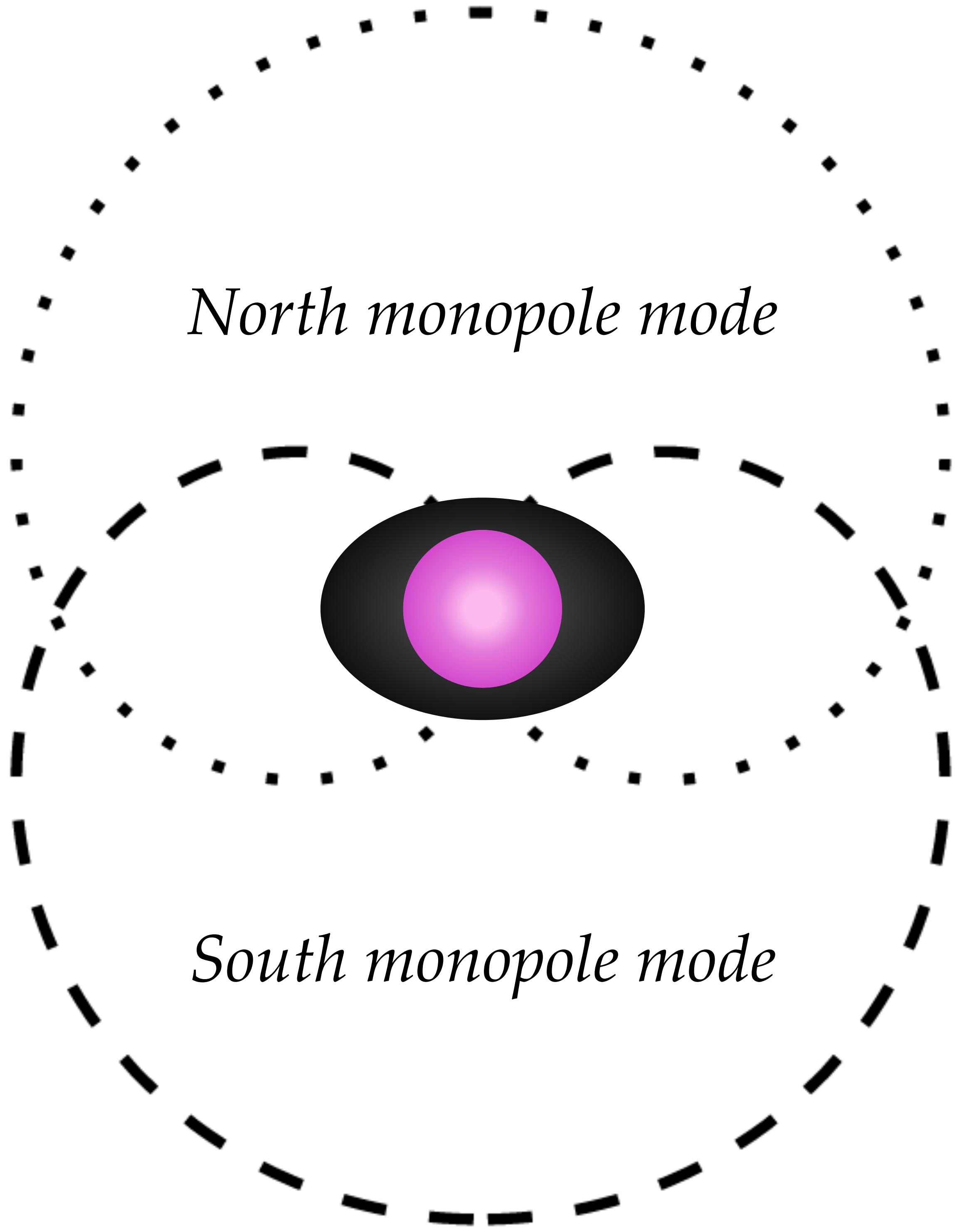


Monopole Spherical Harmonics

$$\mathbf{D} = \nabla + ieA \qquad L_l = -i\epsilon_{ljk}x^j\mathbf{D}^k + eP\frac{x^l}{r}$$

$$L^2Y_{q,\ell,m} = \ell(\ell+1)Y_{q,\ell,m} \quad L_zY_{q,\ell,m} = mY_{q,\ell,m} \quad (q \equiv -eP)$$

$$2|q| = 0,1,2,\ldots \quad \ell = |q|, |q|+1,\ldots \quad m = -\ell, -\ell+1,\ldots,\ell$$

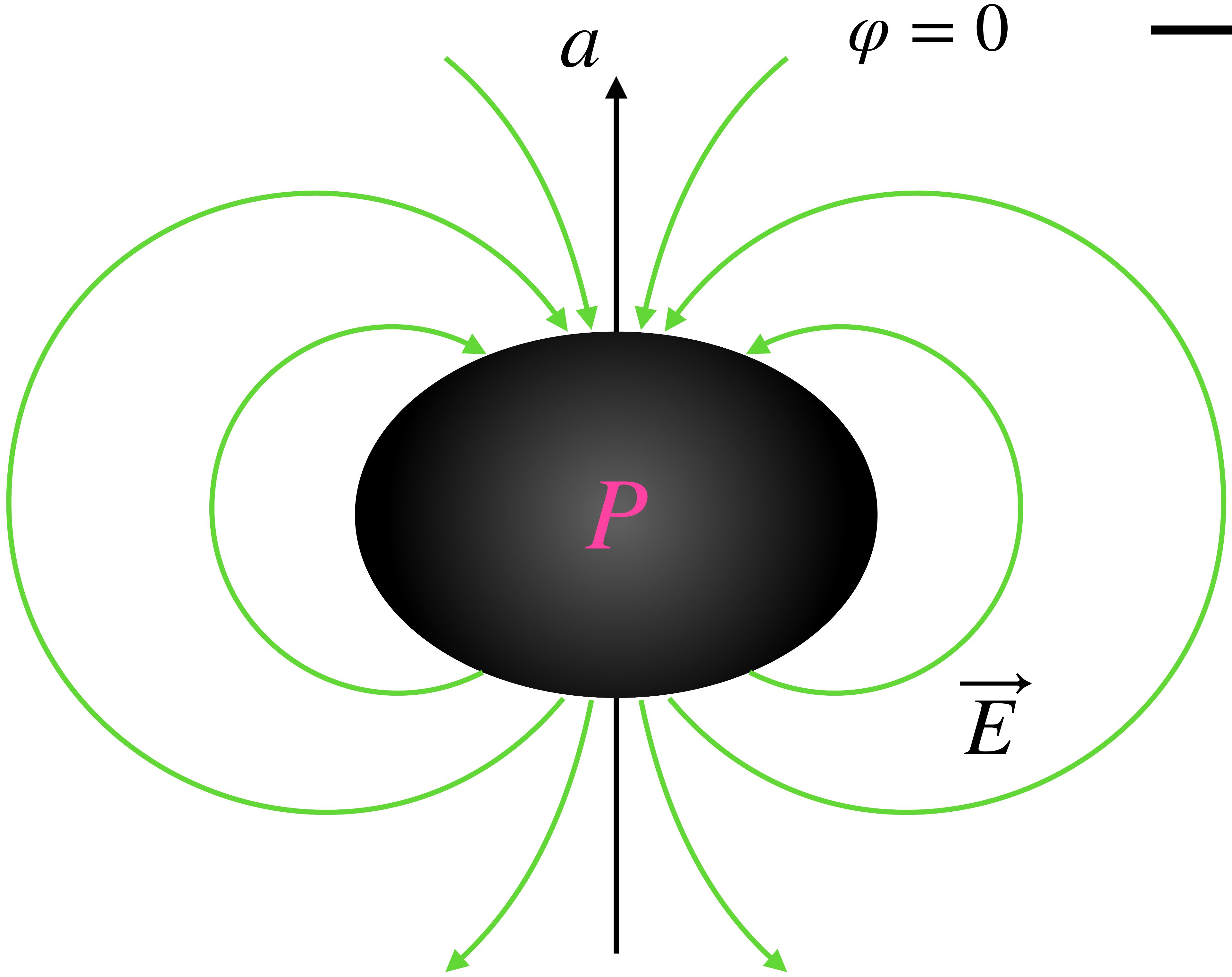


$$|q| = \ell = \pm m$$

$$Y^{\pm}_{q,|q|,\mp q} \sim (1 \pm \cos\theta)^{|q|}$$

Theory and Set Up

$$S[g,A,\varphi] = \frac{1}{16\pi}\int d^4x\sqrt{-g}\left(R - F^2\right) - \frac{1}{2}\int d^4x\sqrt{-g}\left(D_a\bar{\varphi}D^a\varphi + \mu^2\bar{\varphi}\varphi\right) \qquad (D = \nabla + ieA)$$



$$\varphi = 0 \longrightarrow \varphi = e^{-i\omega t}e^{im\phi}\Psi(r,\theta)$$

$$(i)\quad \omega = \omega_R + i\omega_I$$

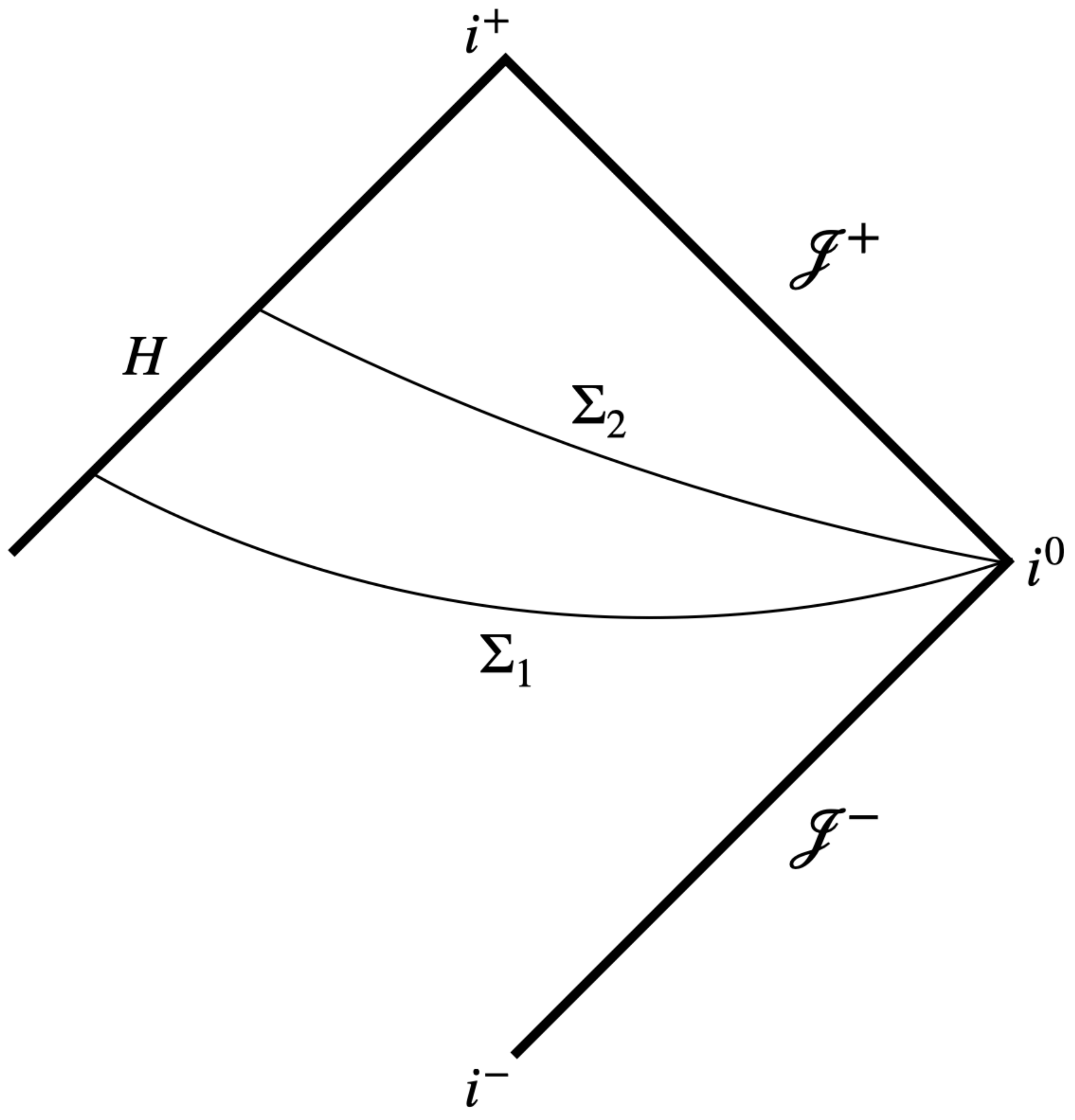
$$(ii)\quad \varphi \sim e^{-\sqrt{\mu^2-\omega^2}r} \qquad (r\to\infty)$$

$$\Delta E = \left(\omega_I^2 + \omega_R\omega_*\right)\int_H e^{2\omega_I v}|\psi|^2\tilde{\epsilon}$$

$$\Delta J = m\omega_*\int_H e^{2\omega_I v}|\psi|^2\tilde{\epsilon}$$

$$\Delta Q = -e\omega_*\int_H e^{2\omega_I v}|\psi|^2\tilde{\epsilon}$$

$$\omega_* = \omega_R - m\Omega$$



[Ortín and DP '22, Dyson and DP '23]

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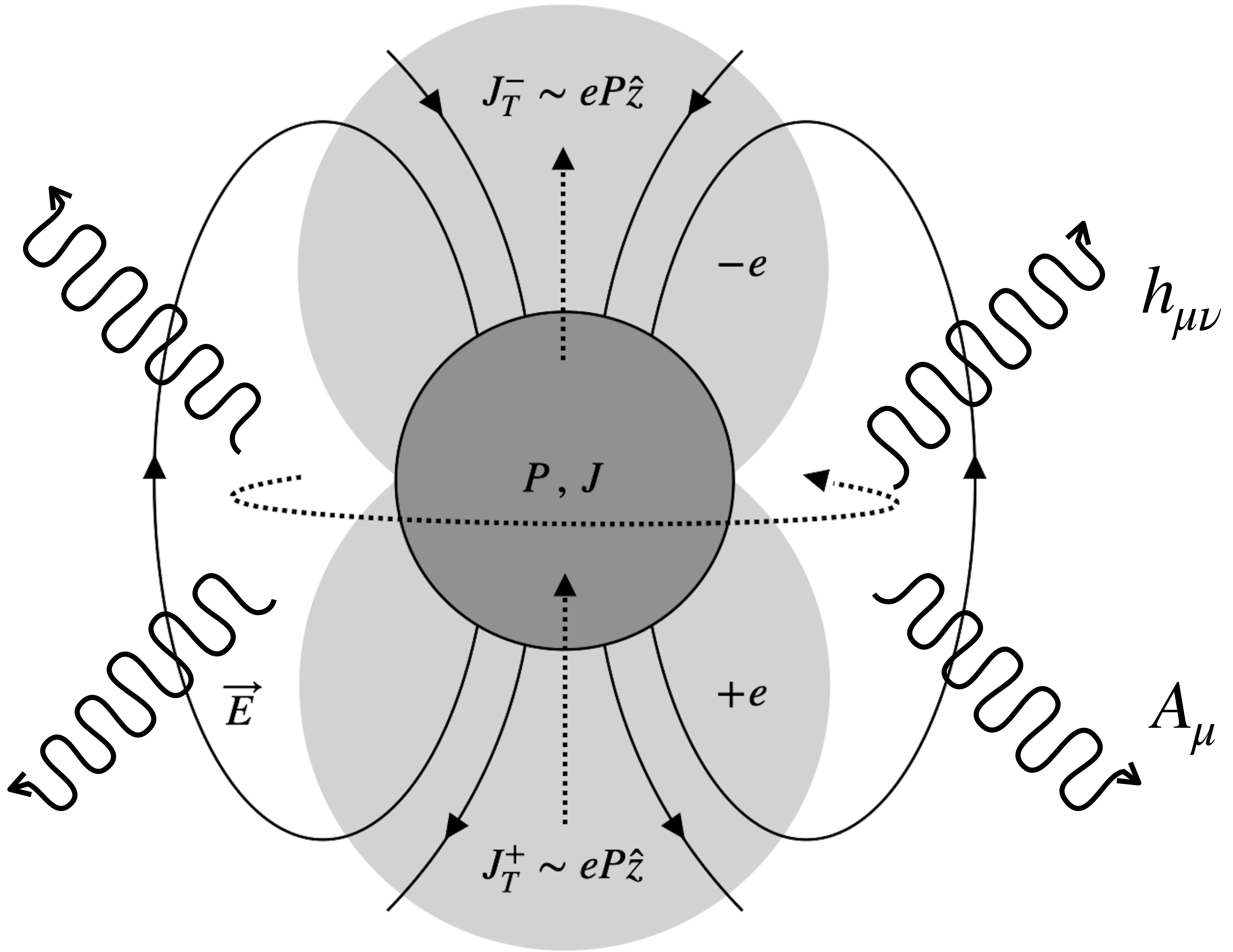
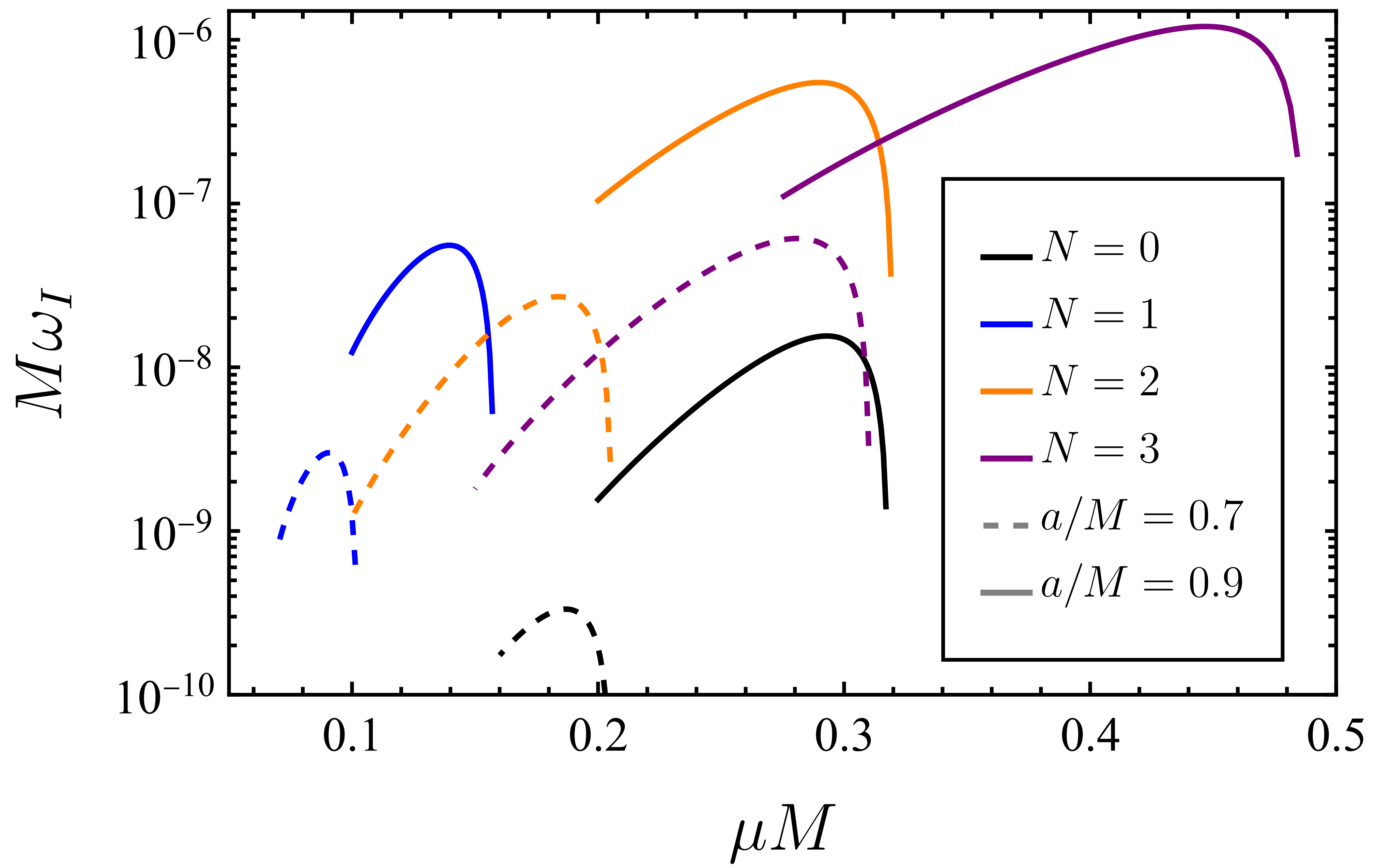


$e/\mu = e/\mu(\pi^{\pm}) \quad N = 0,1,2,3 \;\rightarrow (P/M \sim 10^{-19})$



$\left(a = 0.9,\, N = 0,\, \mu = \mu(\pi^0)\right) \;\longrightarrow\; M \sim 5 \times 10^{11} kg,\;\; \tau_{SI} \sim 10^{-16} s \;\longrightarrow\; \tau_{SI}/\tau(\pi^0) > 1$ ✗

$\left(a = 0.9,\, N = 3,\, \mu = \mu(\pi^{\pm})\right) \;\longrightarrow\; M \sim 10^{12} kg,\;\; \tau_{SI} \sim 10^{-18} s \;\longrightarrow\; \tau_{SI}/\tau(\pi^{\pm}) = 10^{-10}$ ✓

[DP, de Amicis, Brito, Macedo, '24]

Conclusions

- Rotating magnetic black holes are superradiantly unstable.
- Novel mechanism for superradiant instability.
- With a *single* monopole the instability is relevant for SM fields.
- Rotating magnetic black holes are sources of (high-frequency) GWs and EM radiation.