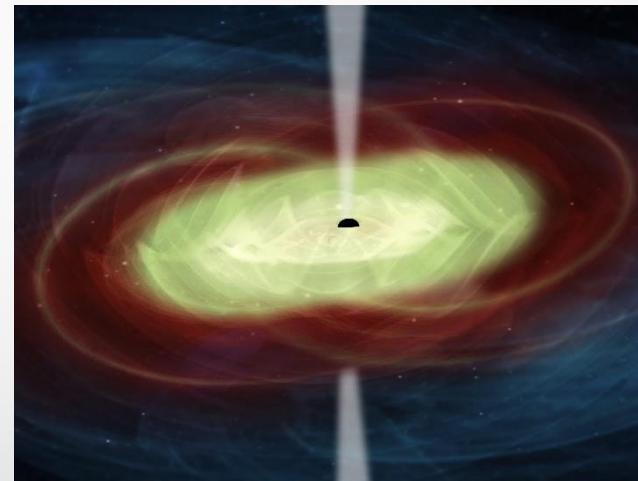


Black Holes Lessons from Multipole Ratios: A New Window into Black Holes

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Iosif Bena and Daniel R. Mayerson:

- « A New Window into Black Holes, » [arXiv:2006.10750 [hep-th]] *(short paper)*
- « Black Holes Lessons from Multipole Ratios, » [arXiv:2007.09152 [hep-th]] *(long paper)*

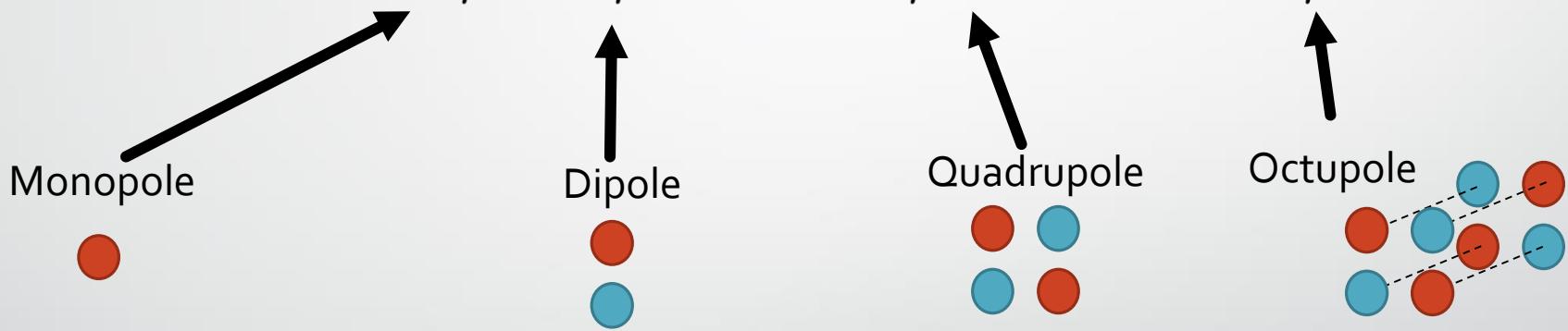
Outline

- Gravitational multipoles
- New Kerr Multipole Ratios
- New SUSY BH Multipole Ratios
- Multipole (Ratios) – A New Window into Black Holes

Gravitational multipoles (1)

- Multipoles in electrodynamics

$$V = \sum_{l \geq 0} \frac{1}{r^{l+1}} M_l P_l(\cos \theta) = \frac{M_0}{r} + \frac{M_1}{r^2} \cos \theta + \frac{M_2}{r^3} P_2(\cos \theta) + \frac{M_3}{r^4} P_3(\cos \theta) + \dots$$



- Problem in GR: coordinate transformations \leftrightarrow multipoles not well-defined?
- Solution: Geroch-Hansen, Thorne formalism

Gravitational multipoles (2)

- Mass multipoles M_l ,

$$g_{tt} \sim \sum_l \frac{M_l}{r^{l+1}}$$

- Mass $M = M_0$

- current multipoles S_l

$$g_{t\phi} \sim r \sum_l \frac{S_l}{r^{l+1}} \quad (\text{axisymmetry})$$

- angular momentum $J = S_1$

- Basic example: Kerr (M, a)

- Multipoles: $M_{2n} = M(-a^2)^n, \quad S_{2n+1} = Ma(-a^2)^n$

$$M_{2n+1} = S_{2n} = 0$$

New Kerr Multipole Ratios (1)

- Kerr: $M_{2n} = M(-a^2)^n$, $S_{2n+1} = Ma(-a^2)^n$ $M_{2n+1} = S_{2n} = 0$
- Undefined multipole ratios: e.g. $\mathcal{R} \equiv \frac{M_2 S_2}{M_3 S_1}$ 
- Deform Kerr to more general string theory BH
 - Most general STU black hole with 10 parameters [Compere, Chow 2014]
- Now \mathcal{R} is well-defined!
- Take limit back:
 - Note: *limit is well-defined!*

$$\lim_{(\text{def. BH}) \rightarrow (\text{Kerr})} \mathcal{R} := \mathcal{R}_{\text{Kerr}}$$
- Examples: $\mathcal{R} \equiv \frac{M_2 S_2}{M_3 S_1} = 1$ $\frac{M_{l+2} S_l}{M_l S_{l+2}} = 1 - \frac{4}{3 + (-1)^l(2l + 1)}$

Analogy: $\frac{\sin 0}{0} = ?$
vs
 $\lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$

New Kerr Multipole Ratios (2)

- **String theory prediction** for small deviations from Kerr

- Constrains all perturbative deviations away from Kerr! $\delta(\text{Kerr}) \sim \epsilon$

$$S_{2n} = -nM(-a^2)^n \epsilon$$

$$M_{2n+1} = nMa(-a^2)^n \epsilon$$

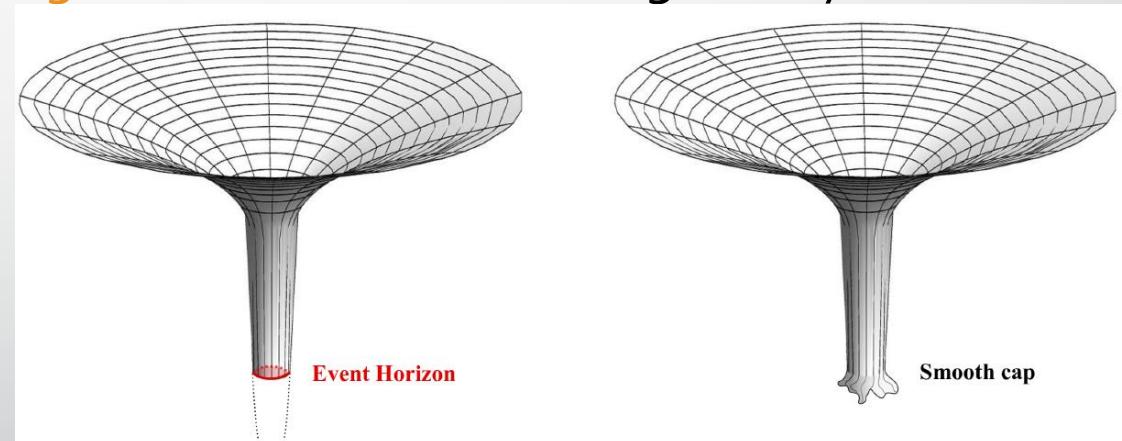
$$\delta M_{2n} = -n^2 M(-a^2)^n \left(\frac{2n-3}{4n} \right) \epsilon^2$$

$$\delta S_{2n+1} = -n^2 (-a^2)^n Ma \left(\frac{2n+1}{4n} \right) \epsilon^2$$

- Constrains models of (small) deviations of Kerr!

New SUSY BH Multipole Ratios (1)

- Same procedure for (non-rotating) 4D supersymmetric BH
 - non-rotating: all multipoles vanish except $M_0 = M$
- Deform and then $\lim_{(\text{def. BH}) \rightarrow (\text{SUSY})} \mathcal{R} := \mathcal{R}_{\text{SUSY}}$ **Indirect**
- OR: use « **fuzzballs** » or **microstate geometries** of BH in string theory
 - Supersymmetric
 - Smooth
 - No horizon
 - Same asymptotic charges as BH
 - Extra (string theory) dims:
« bubbles » in space
- Second way to calculate ratios: $\mathcal{R}_{(\text{microstate})} := \mathcal{R}_{\text{SUSY}}$ **Direct**



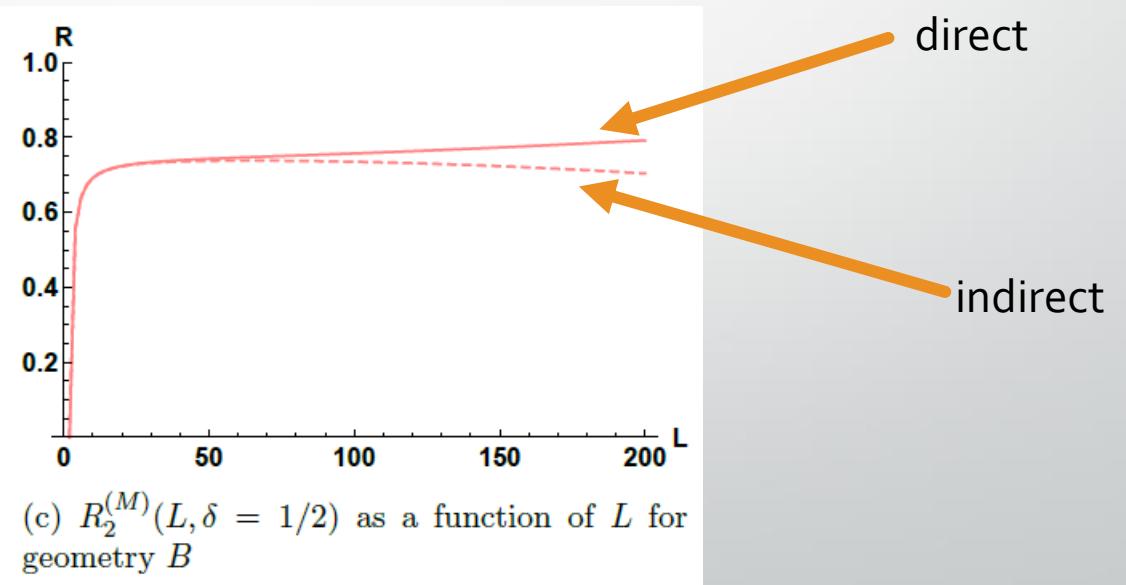
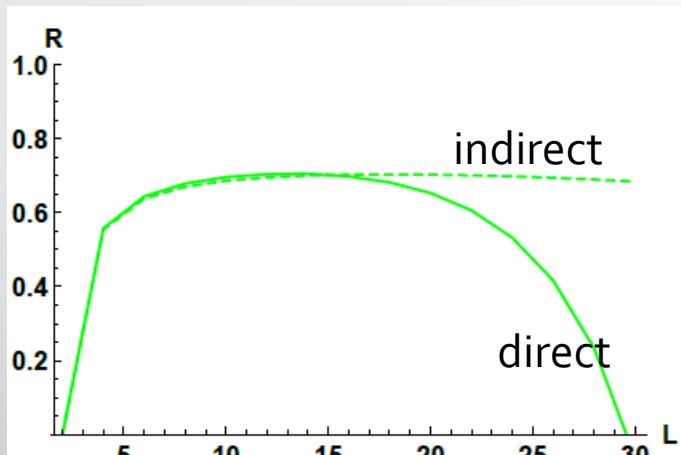
Also: Bianchi, Consoli, Grillo, Morales, Pani 2007.01743 & 2008.01445

New SUSY BH Multipole Ratios (2)

- Remarkable agreement between **indirect** and **direct** for some BHs

$$\lim_{(\text{def. BH}) \rightarrow (\text{SUSY})} \mathcal{R} := \mathcal{R}_{\text{SUSY}}$$

$$\mathcal{R}_{(\text{microstate})} := \mathcal{R}_{\text{SUSY}}$$



Multipole (Ratios): A New Window into Black Holes

- **New multipole ratios for Kerr (and SUSY BH)**
 - Kerr = (special) limit of generic 4D BH in string theory
 - Define new multipole ratios: $\lim_{(\text{def. BH}) \rightarrow (\text{Kerr})} \mathcal{R} := \mathcal{R}_{\text{Kerr}}$
 - **String theory prediction** for small deviations away from Kerr
 - Constrains models of (small) deviations of Kerr!
- **Observational consequences...? (more speculative)**
 - Late-time relaxation after BH formation; how different multipole rad. dies out
 -  Relation to quasinormal modes?
 - Measurements find different multipole (ratios)?
 -  Deformations are in theory \neq string theory
 -  OR: BH horizon scale physics very different than GR!