TIDAL RESPONSE OF REGULAR BLACK HOLES

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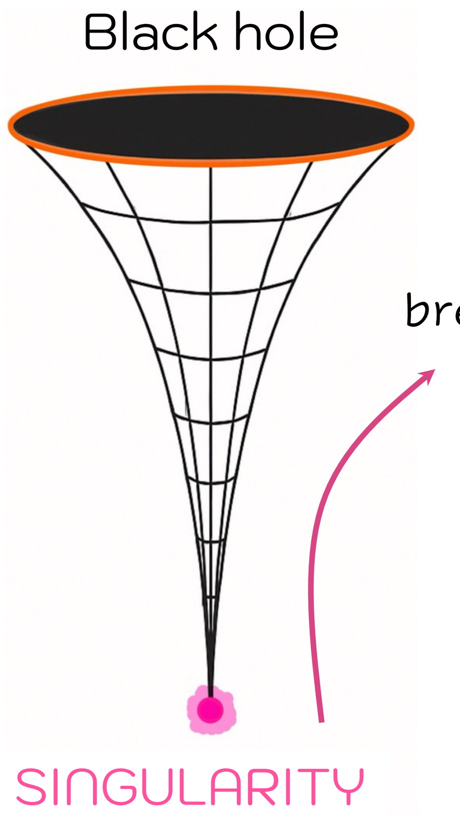
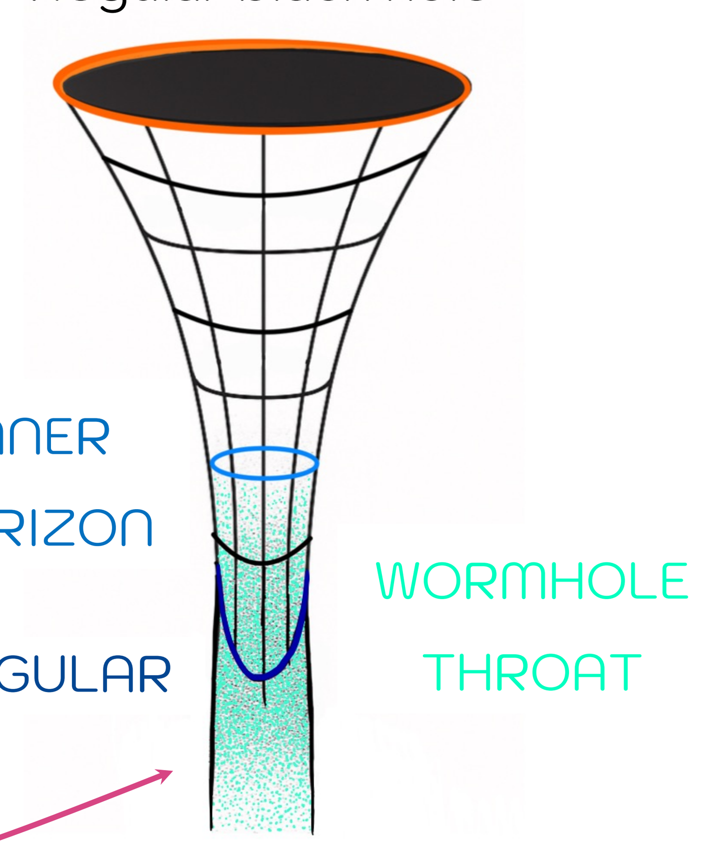
REGULAR BLACK HOLES



breakdown in the structure of spacetime

one approach

quantum gravity modifies the internal structure @ ℓ



Regular black hole → $ds^2 = -e^{-2\phi(r)}\left(1-\frac{2m(r)}{r}\right)dt^2 + \left(1-\frac{2m(r)}{r}\right)^{-1}dr^2 + r^2(d\theta^2+\sin^2\theta d\varphi^2)$

Fan-Wang	$\phi(r)=0$	$m(r)=\frac{Mr^3}{(r+\ell)^3}$
Hayward	$\phi(r)=0$	$m(r)=\frac{Mr^3}{r^3+2M\ell^2}$
Bardeen	$\phi(r)=0$	$m(r)=\frac{Mr^3}{(r^2+\ell^2)^{3/2}}$
Simpson-Visser	$\phi(r)=\frac{1}{2}\log\left(1-\frac{\ell^2}{r^2}\right)$	$m(r)=M\left(1-\frac{\ell^2}{r^2}\right)+\frac{\ell^2}{2r}$

TIDAL DEFORMATION

Extracted from the metric's asymptotic behavior

$$g_{00} = -1 + \frac{2m(r)}{r} + \frac{2}{r^{l+1}}\left[\sqrt{\frac{4\pi}{2l+1}}\mathcal{Q}_{lm}Y^{lm} + \dots\right] - \frac{2}{l(l-1)}r^l[\mathcal{E}_{lm}Y^{lm} + \dots]$$

$$g_{03} = \frac{2}{r^l}\left[\sqrt{\frac{4\pi}{2l+1}}\frac{\mathcal{S}_{lm}}{l}\sin\theta\frac{\partial Y^{lm}}{\partial\theta} + \dots\right] + \frac{2r^{l+1}}{3l(l-1)}\left[\mathcal{B}_{lm}\sin\theta\frac{\partial Y^{lm}}{\partial\theta} + \dots\right]$$

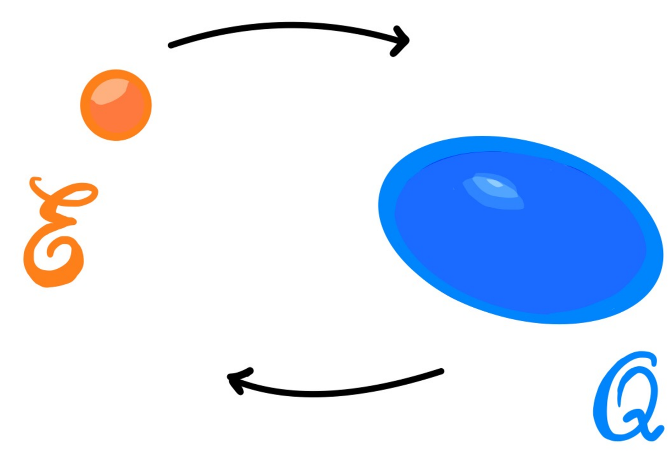
ambiguities

LOVE NUMBER

polar $\quad \boxed{\alpha_{lm} = -\frac{l(l-1)}{M^{2l+1}}\sqrt{\frac{4\pi}{2l+1}}\frac{\mathcal{Q}_{lm}}{\mathcal{E}_{lm}}}$

axial $\quad \boxed{\beta_{lm} = 3\frac{(l-1)}{M^{2l+1}}\sqrt{\frac{4\pi}{2l+1}}\frac{\mathcal{S}_{lm}}{\mathcal{B}_{lm}}}$

characterize tidal effects

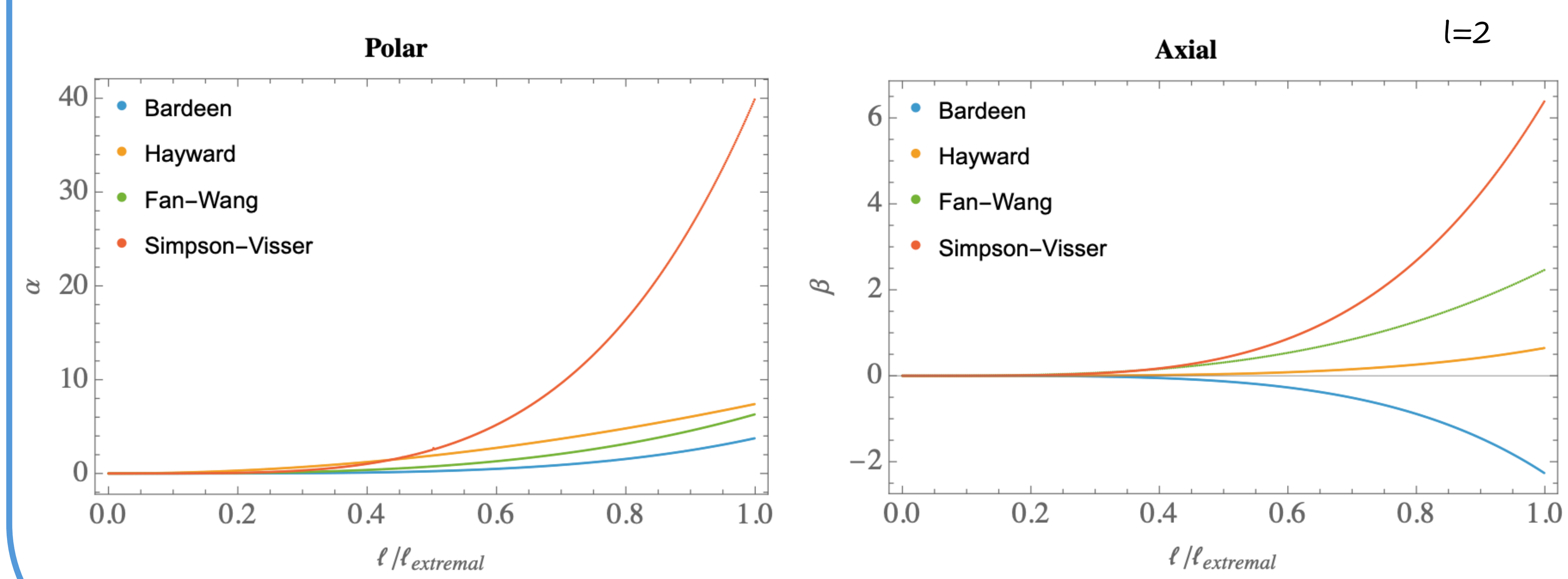


The Love number describes how much an object is deformed $\mathcal{Q}$ due to an external field $\mathcal{E}$

FULL GRAVITATIONAL PERTURBATIONS

Models interpreted within general relativity with exotic matter

l=2

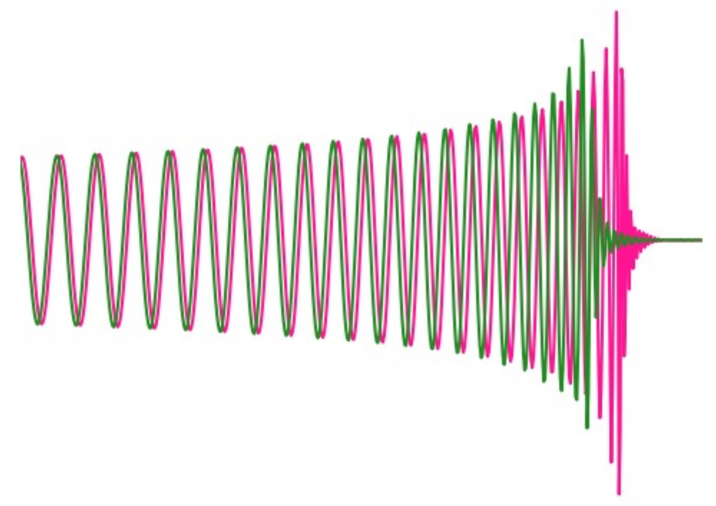


Numerical results (not possible to solve analytically)

DETECTION

Phase shift in binary black hole mergers could reach few radians

ambiguities between our Love number & gravitational waves observables



TEST-FIELD PERTURBATIONS

$$\frac{d^2\psi_s}{dr_*^2} - V_s\psi_s = 0 \quad \text{for spin s perturbation}$$

LEADING ORDER j IN ℓ

Expanding $m(r) = M + \sum_{i=1}^{\infty}\ell^i\sum_{k=1}^{Ni}M_{ik}\frac{M^{k-i+1}}{r^k}$, $\phi(r) = \sum_{i=1}^{\infty}\ell^i\sum_{k=1}^{Ri}\phi_{ik}\frac{M^{k-i}}{r^k}$

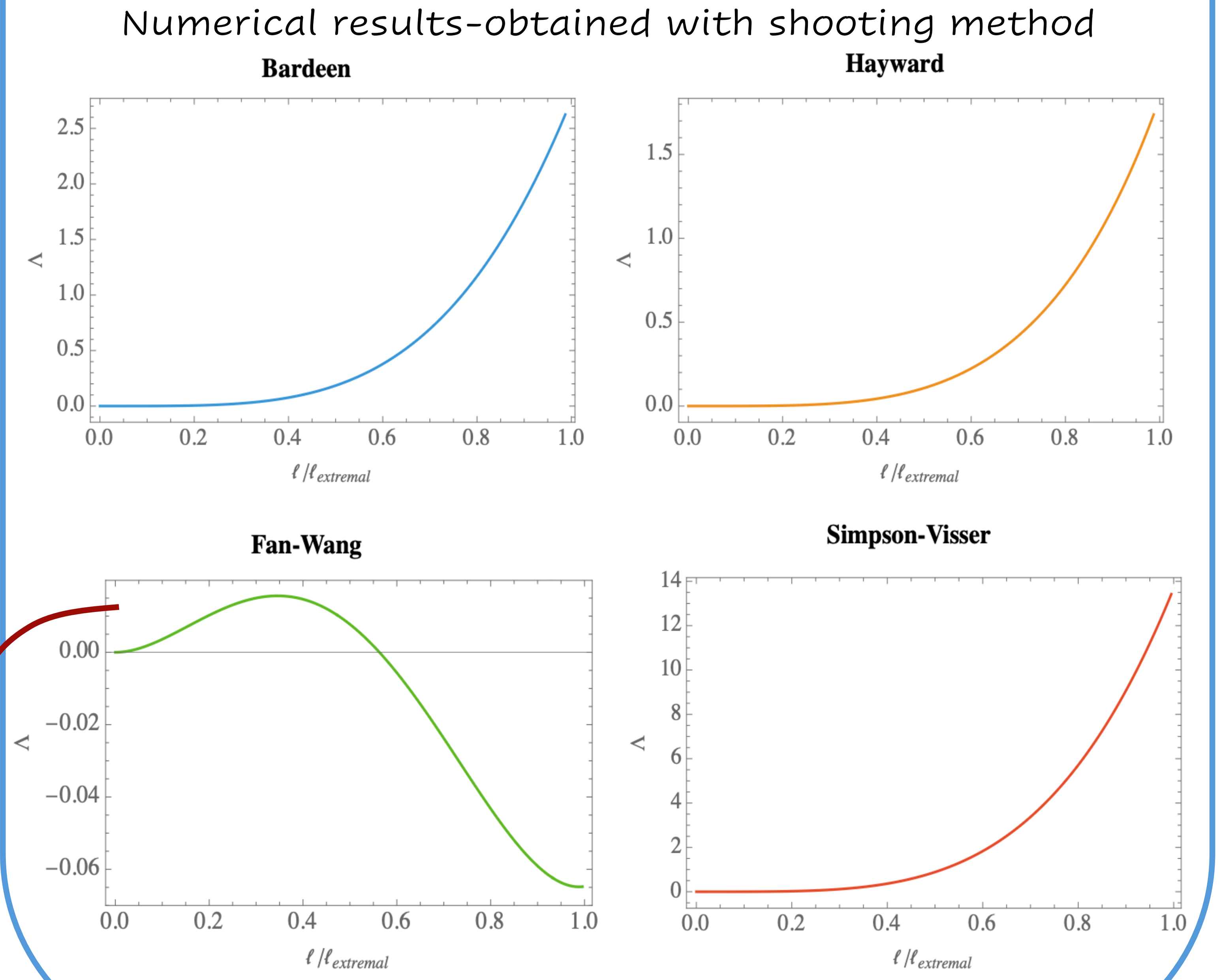
a coefficient M_{jn} or ϕ_{jp} leads to

- zero Love number if n<2s and p<2s (n<2 and p<2 if s=0)
- non-zero running Love number $\left(\propto\frac{1}{r^l}\text{ and }\frac{\log r}{r^l}\right)$ if 2s≤n≤2l or 2s≤p≤2l+1 (2≤n≤2l or 2≤p≤2l+1 if s=0)
- non-zero Love number if n>2l or p>2l+1

BEYOND LEADING ORDER

s=l=2

Numerical results-obtained with shooting method



Perfect agreement with analytical results

SUMMARY

Dominant coefficients in the perturbative expansion of the l=2 Love numbers @ small ℓ

	Test-field	Axial	Polar
Bardeen	$42/5M\ell^4$	$\sim -5.8M\ell^4$	$\sim 0.03M^3\ell^2 + 10M\ell^4$
Hayward	$24/5M\ell^4$	$\sim 1.8M\ell^4$	$\sim 13M^3\ell^2$
Fan-Wang	$128/25M^3\ell^2$	$\sim 95M^2\ell^3$	$\sim 220M^2\ell^3$
Simpson-Visser	$68/75M\ell^4$	$\sim 0.4M\ell^4$	$\sim 0.05M^3\ell^2 + 40M\ell^4$

→ Regular black holes possess distinct, though subtle, tidal signatures → May serve as observational probes of black hole's interior

hint

similar conclusions could hold in quantum gravity

PAPER

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