Recent Researches related to GWs

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Interested Topics

- New type of GW Source in massive gravity
  (Recent progress is made mainly in this topic)

- Quantum noise reduction in GW detectors

QNMs of Generalized RN black holes (M<0) in massive gravity

1. Generalized RN black holes (M<0)

The spherically symmetric solution in massive gravity

$$ds^2 = f(r)dt^2 - f(r)^{-1}dr^2 - r^2 d\Omega^2$$

$$f(r) = 1 - \frac{2GM}{r} - \frac{\mu(G|M|)^{\lambda}|}{r^{\lambda}} \qquad (1)$$

In $\lambda=2$, $M<0$ and $\mu \geq 0$ case, the event horizon lies at $r_h = GM(-1 + \sqrt{1+\mu})$

Now, we consider concretely the behaviors of the space-time under scalar perturbation. The Regge-Wheeler equation is

$$\frac{d^2\psi(r^*)}{dr^{*2}} + [\omega^2 - V(r)]\psi(r^*) = 0 \qquad (2)$$

where the tortoise coordinate r^* is defined as

$$r^* = \int \frac{1}{f(r)} dr$$

and the effective potential is

$$V(r) = \left(1 + \frac{2}{r} - \frac{\mu}{r^2}\right) [\frac{l(l+1)}{r^2} - \frac{2}{r^3} + \frac{2\mu}{r^4}]$$

For $l = 0$, the effective potential $V(r) \to -0$ as $r_* \to +\infty$. So, we do not consider $V(r)$ for $l = 0$ here. When $\mu \geq \mu c$, the effective potential is positive and vanishes at $r_* \to \pm\infty$ for $l \geq 1$, shown in figure. And it arrives at a maximum value at $rmax$, the root of $V'(r) = 0$. Under these conditions, black hole perturbations is equivalent to one-dimensional quantum-mechanical scattering near the peak of a potential barrier.

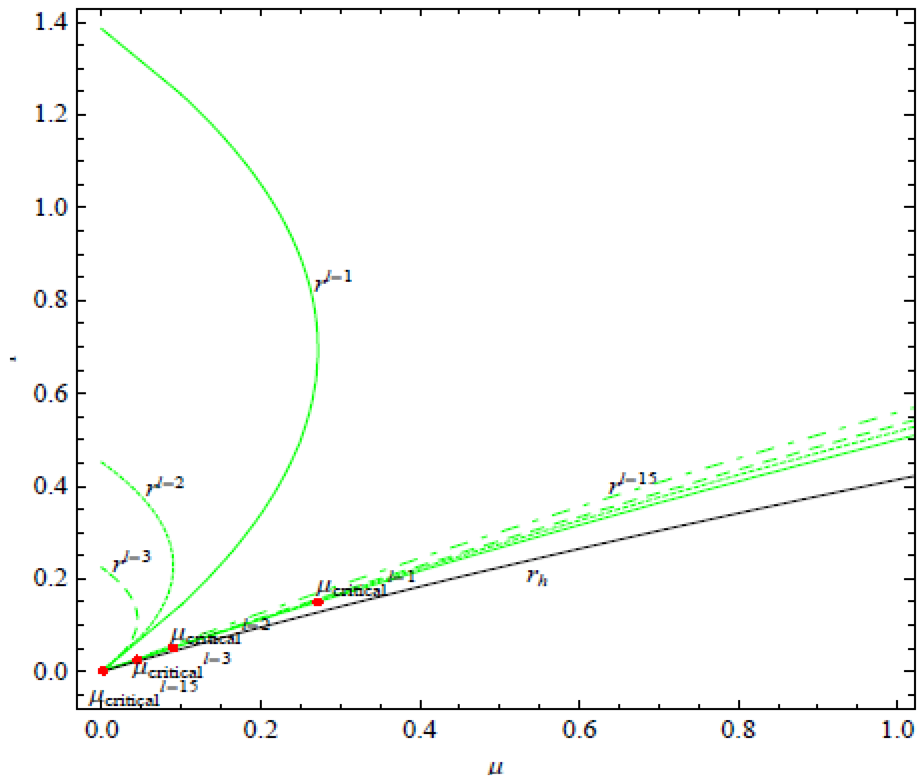

FIG. 3. For $\lambda = 2$, $M < 0$ and $\mu > 0$ black holes, the roots of the basic equation describing the black-hole perturbations at $r > r_h$ are shown for different l. As $\mu \geq \mu^l_{critical}$, black hole perturbations are analogues of one-dimensional quantum-mechanical scattering near the peak of a potential barrier.

2. The numerical results

TABLE II. The numerical solutions to the Regge-Wheeler equation for the scalar perturbation of a generalized RN black hole with $M < 0$ and $\mu = 0.3$.

l	$n=0$	$n=1$	$n=2$	$n=3$
0	-	-	-	-
1	13.888408-29.852351i	12.610674-85.707748i	8.843091-142.274443i	3.117079-199.095643i
2	19.464288-25.824884i	14.501163-81.926237i	6.631980-137.741514i	4.955571+193.891657i
3	28.820470-22.404443i	19.238281-76.894533i	7.135630-131.667047i	10.098395+187.086146i
4	39.536527-20.982343i	27.604850-71.909089i	13.028908-125.068688i	6.943613+179.209209i

Then, we use WKB method to numerically calculate the solutions to the basic equation for resonant perturbations of the black hole with $\lambda = 2$, $M < 0$ and $\mu = 0.3$. The results are shown in Table II. The relations between the complex frequencies and l are discussed. We find that the imaginary parts of the complex frequencies are not always negative at the third overtone ($n = 3$). As $l \geq 2$, the imaginary parts are positive at $n = 3$. It means that once this black hole suffers external perturbations, its resonant perturbations at n=3 will grow which leads to this black hole disappearing.