

# Science with 3G Detectors: The Nature of Compact Objects

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for “Extreme Gravity & Fundamental Physics/Waveform Models”  
Working Groups

# The making of 3G report of XG & Fund. Physics/WM Groups

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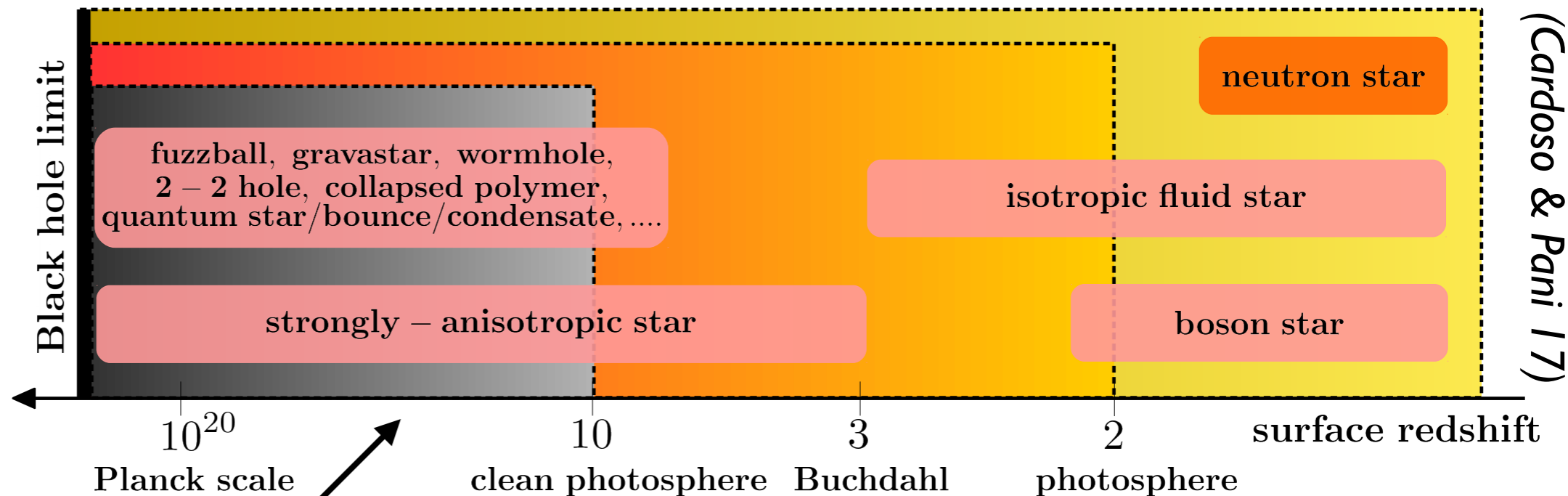
- **Four subgroups** were **formed** with contact persons:
  - Fundamental questions in gravity and particle physics (*Chatziioannou & Sotiriou*)
  - Extreme matter (*Vitale & Yunes*)
  - Exotic objects and phenomena (*Archisman & Pani*)
  - Waveform modeling and data-analysis challenges (*Ajith & Pürrer*)
- **Preliminary draft** produced in late June.
- Co-chairs *Buonanno, Lehner & van den Broeck* worked on preliminary draft and produced **first revised version of 3G report** on Sep 28 [<https://github.com/gwic-3g/3g-science-case/blob/master/work-space/xg/XG-WM-report-v1.pdf>]
- So far, several **people have contributed to 3G** report, including *Arun, Barausse, Baryakhtar, Brito, Dietrich, East, Gerosa, Harry, Hinderer, Maselli, Pratten, Shao, Tamanini, van de Meent, Varma, Vines, Zumalacarregui, Yang, ...*

# Schematic classification of dark compact objects

- **Compactness:**

$$\frac{GM_{\text{BH}}}{R_{\text{BH}}c^2} = 0.5$$

$$\frac{GM_{\text{NS}}}{R_{\text{NS}}c^2} \approx 0.3$$

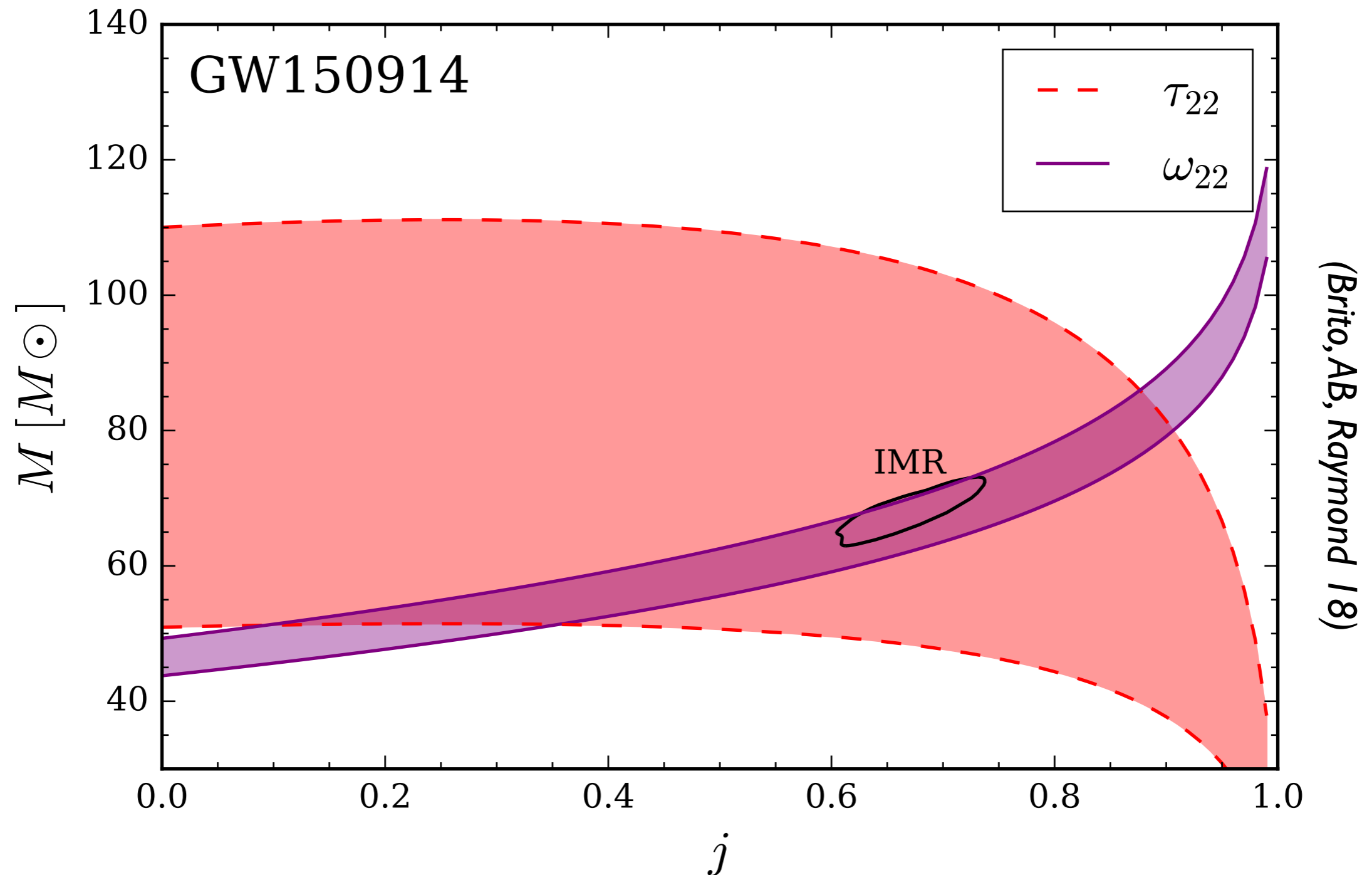


Body's **compactness** expressed as **gravitational redshift at surface**

- Is the **end option of collapse** a Kerr BH?
- **Absence of horizon.**
- Neutron-star **composition.**
- **Quasi-normal modes** inconsistency.
- **Signatures of exotic matter** in GW signal.

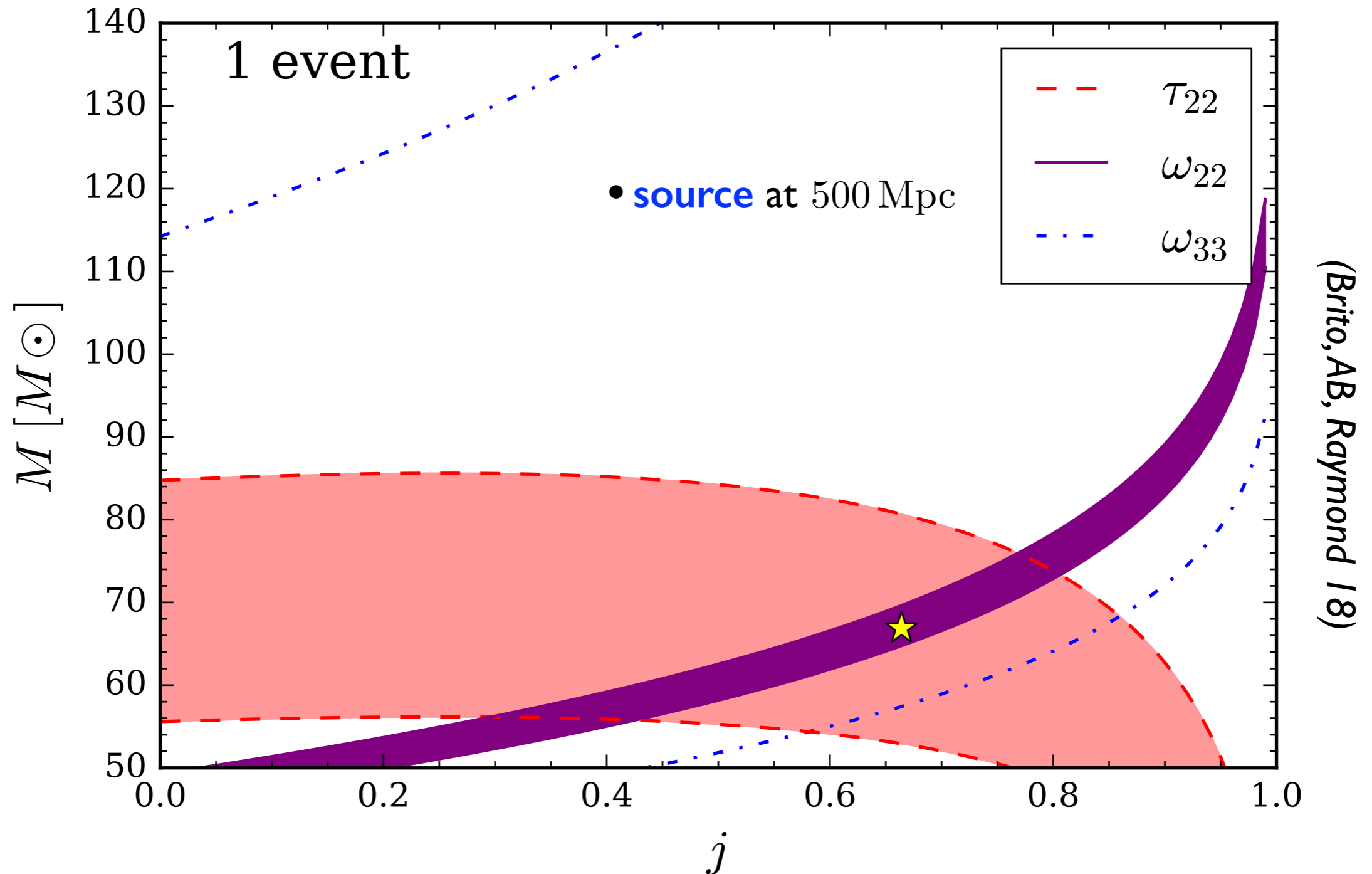
# Probing if black hole observed is black hole in GR: O1 run

- BH **quasi-normal modes** depend only on BH **mass and spin**. Can we disprove it?



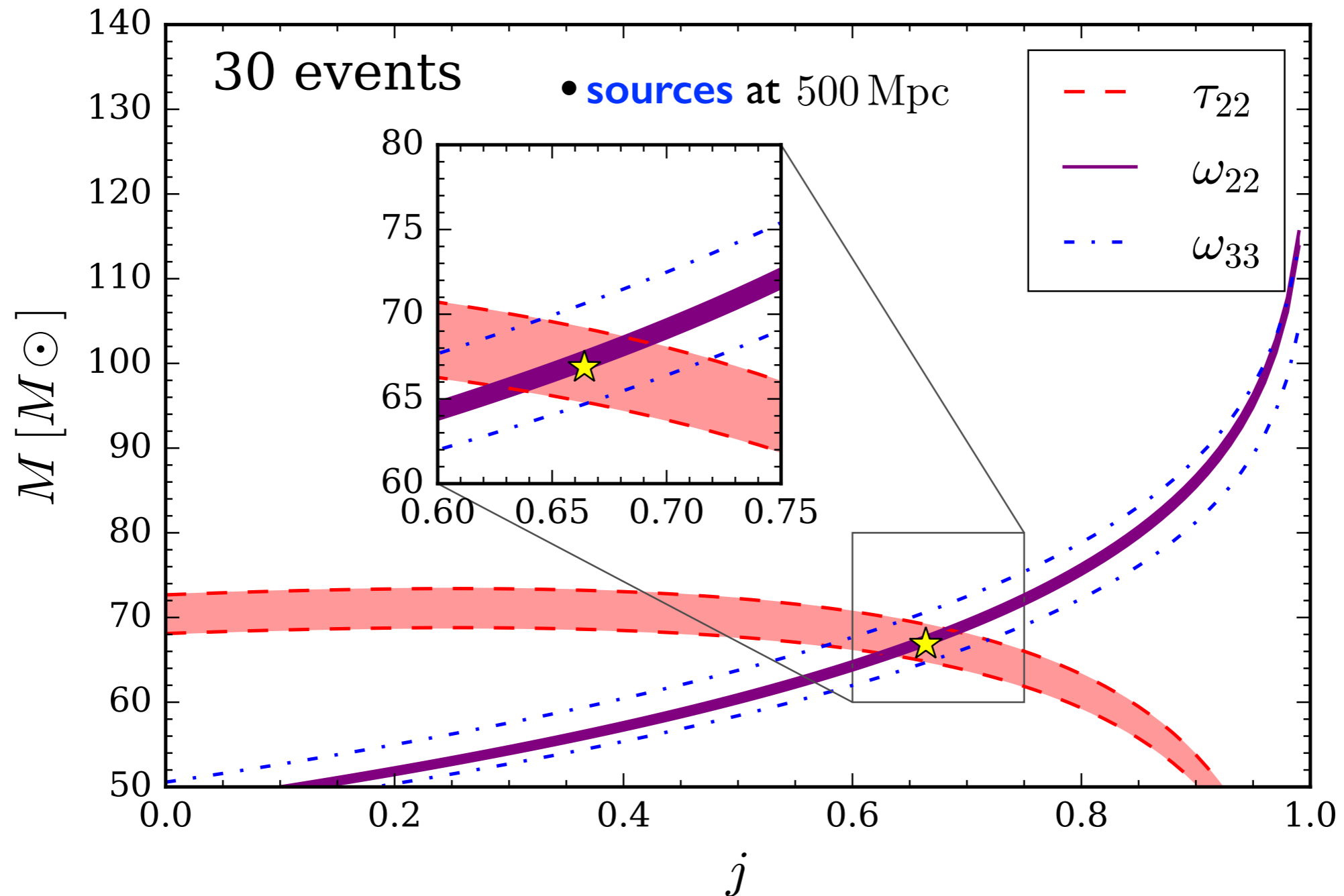
# Probing if black hole observed is black hole in GR: 2G detectors

- **GW150914-like event with LIGO & Virgo @ design sensitivity**



# Probing if black hole observed is black hole in GR: 2G detectors

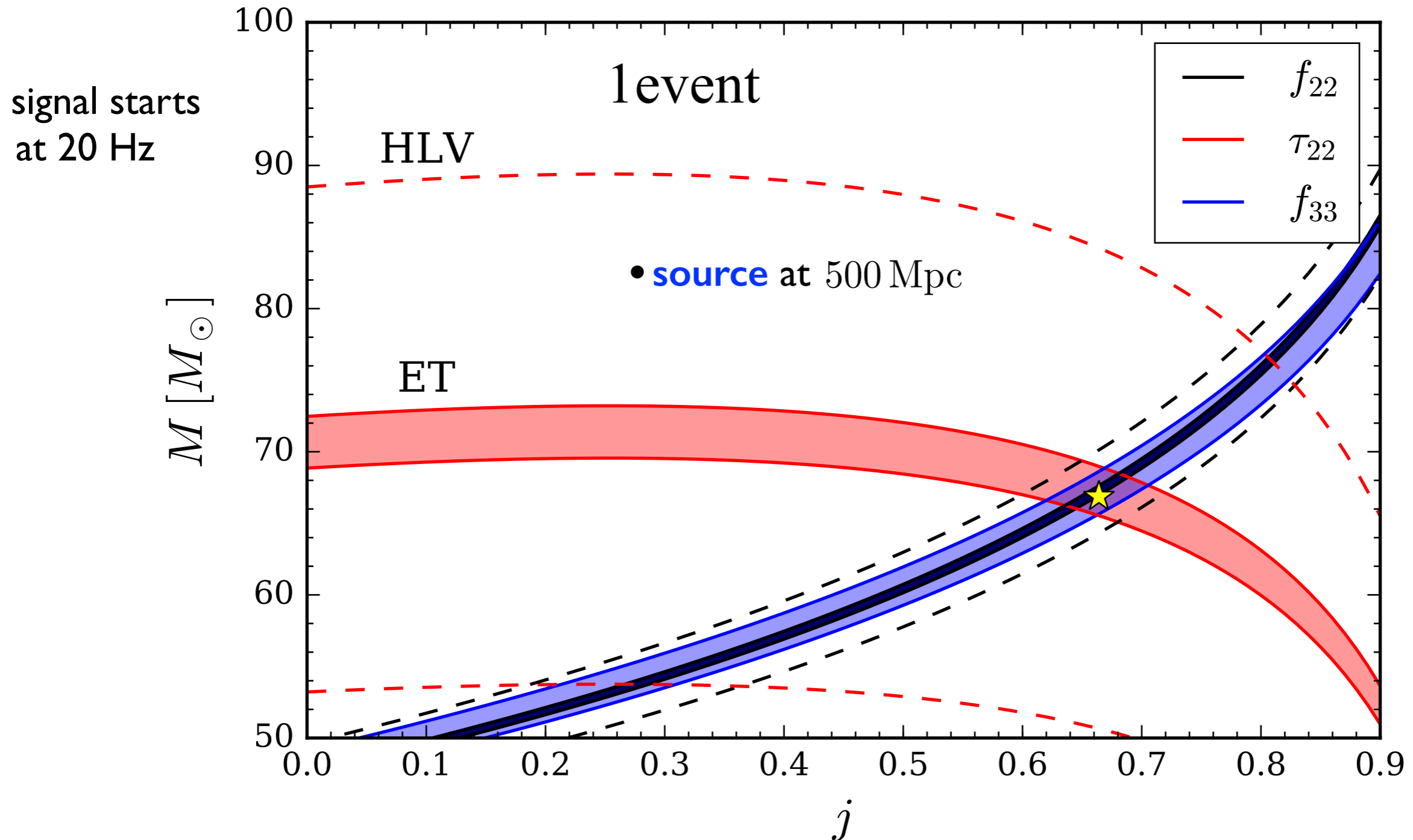
- **GW150914-like event with LIGO & Virgo @ design sensitivity**



(Brito, AB, Raymond 18)

# Probing if black hole observed is black hole in GR: 3G detectors

## • GW150914-like event with 3G detectors

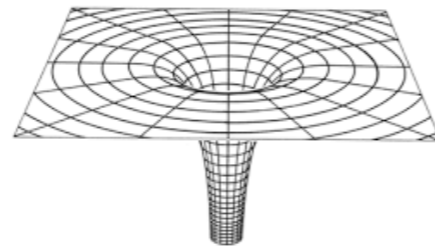
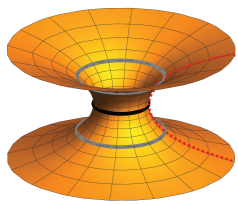


- **3G detectors** will observe  **$10^2$ - $10^4$  events** per year suitable for **BH spectroscopy**.

# Echoes as signatures of exotic compact objects

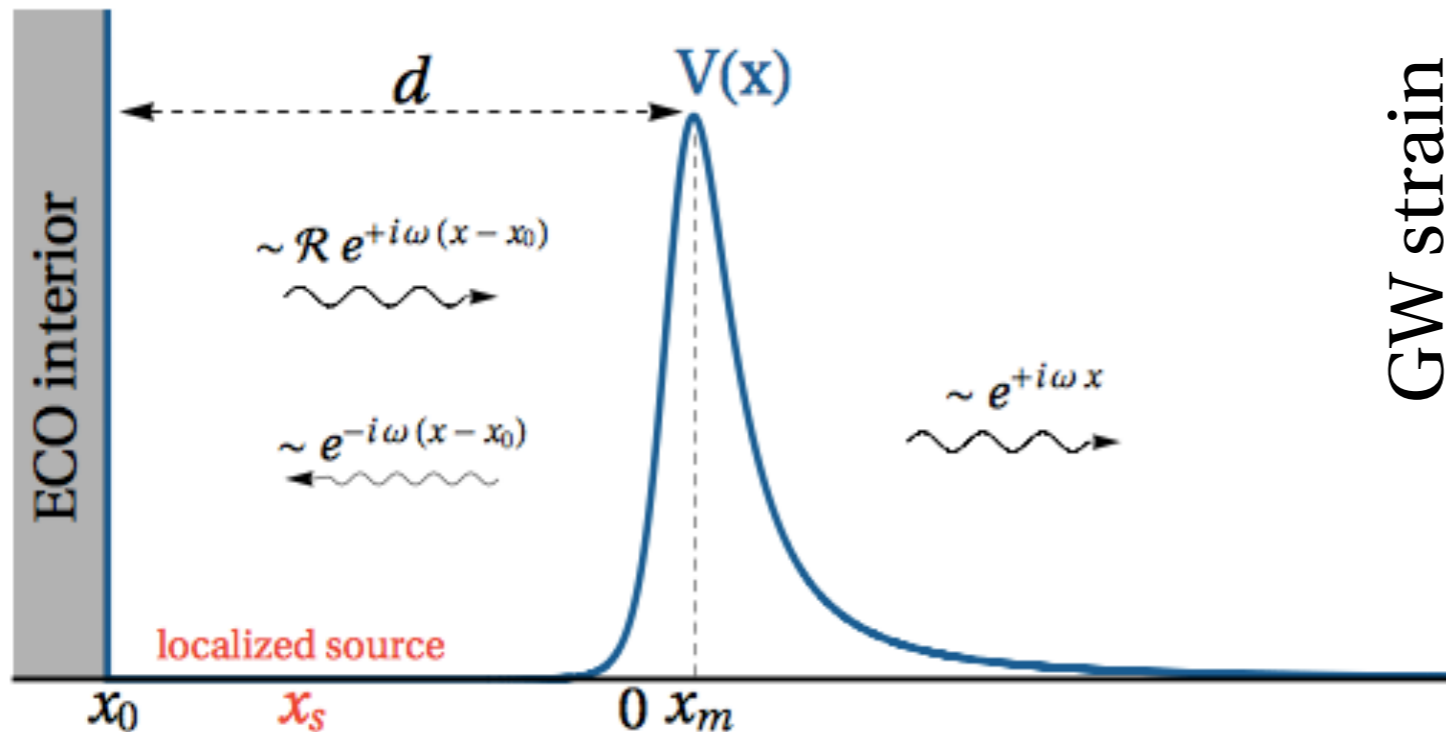
horizonless objects

wormhole

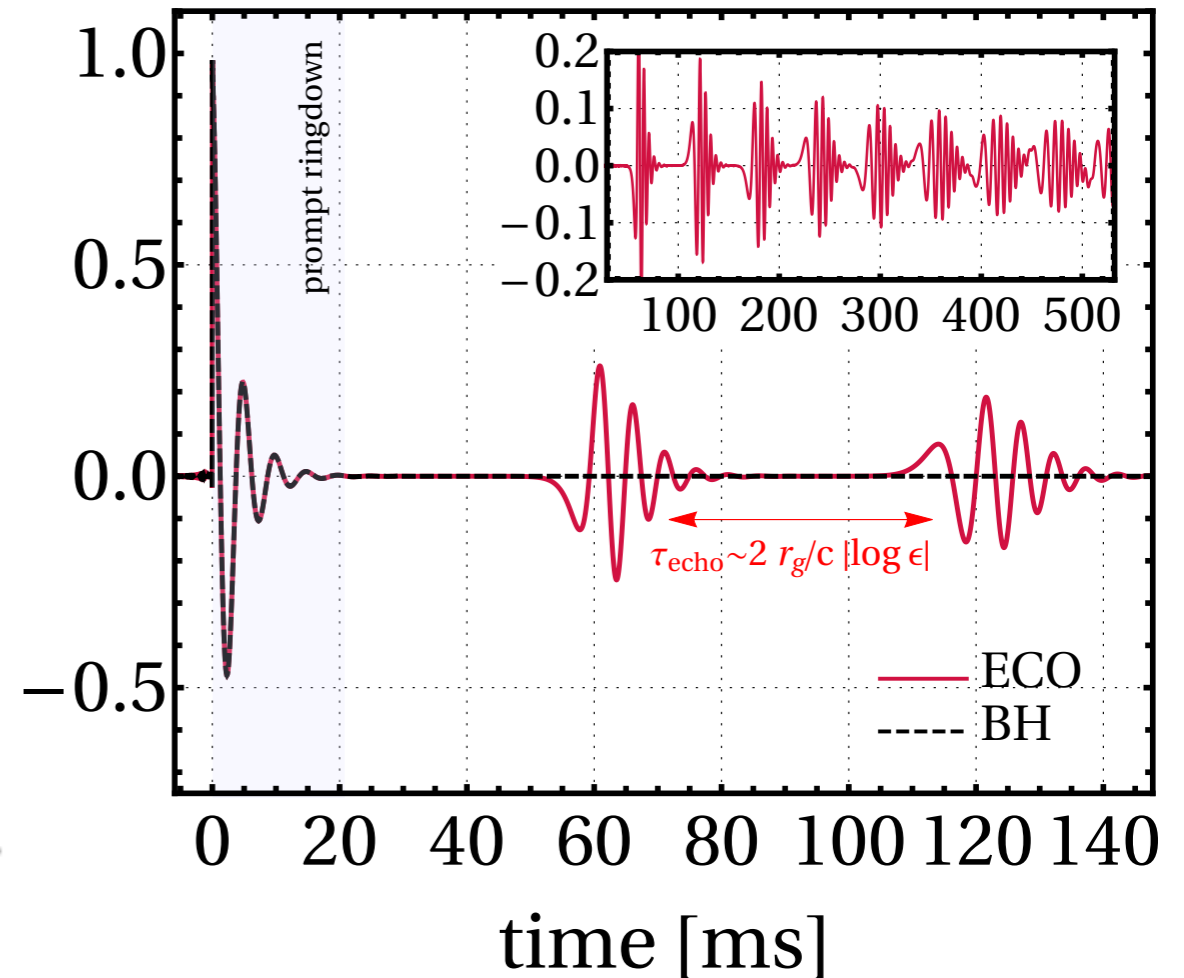


black hole

- If **horizon** is replaced by “**surface**”, ringdown signal is modified, “**echoes**” are emitted after merger.



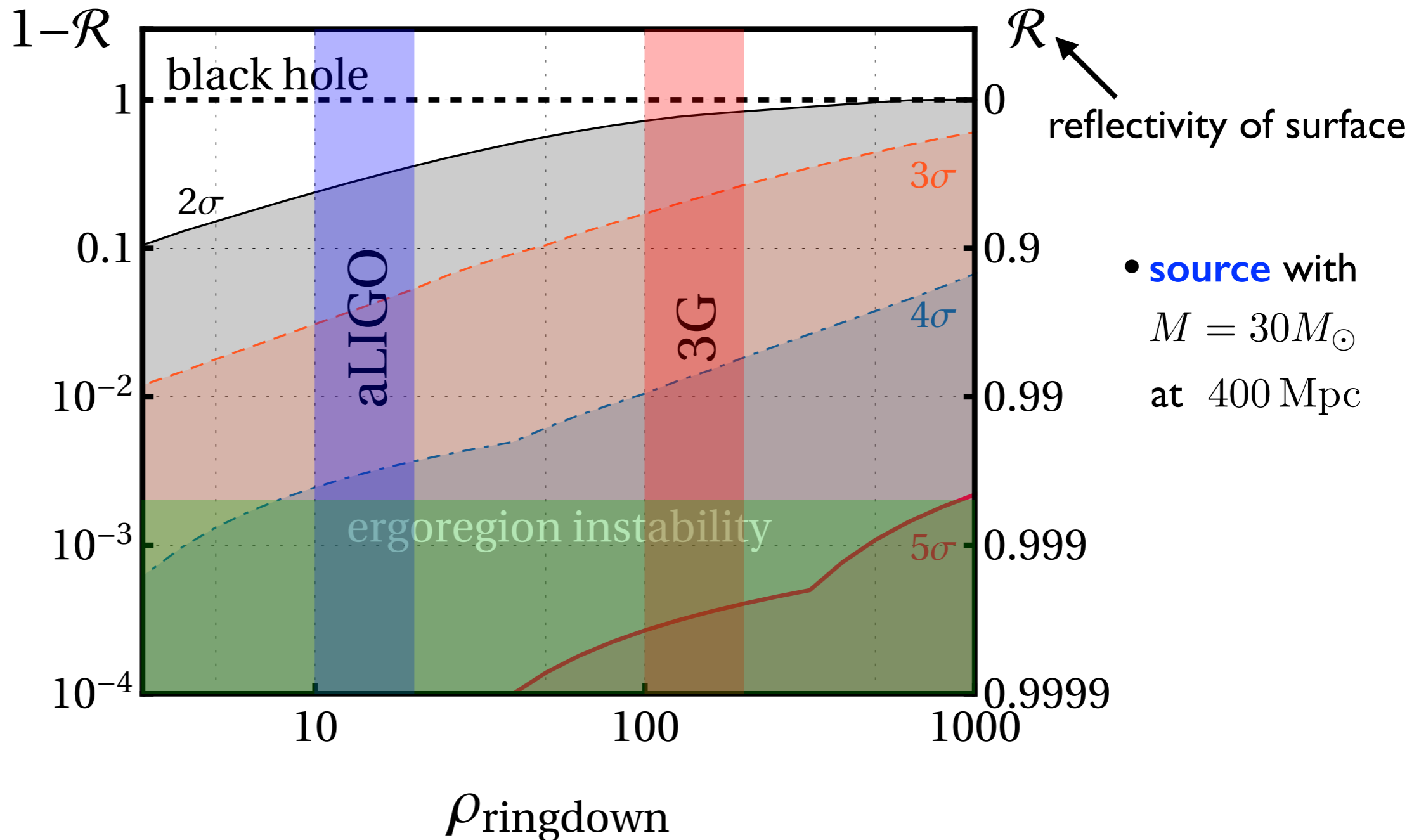
GW strain



(Testa & Pani 18)

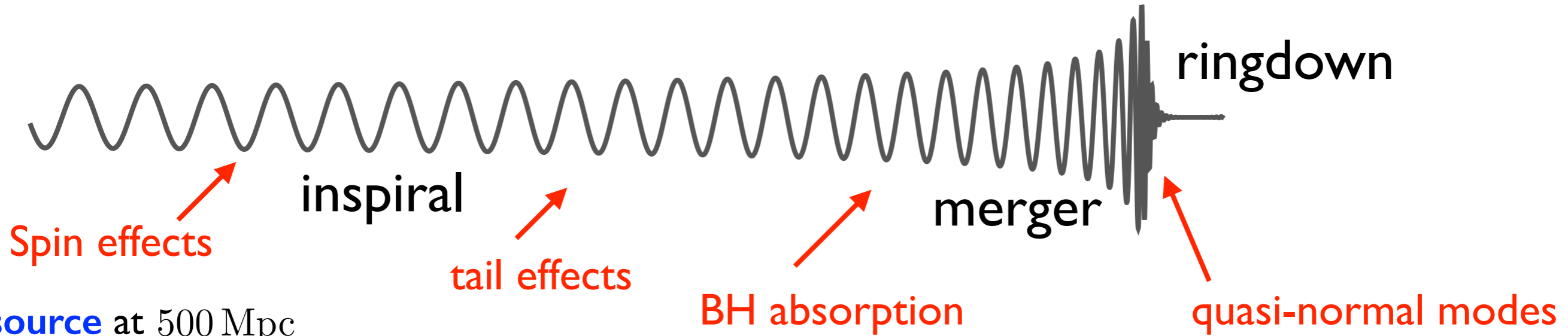


# Echoes as signatures of exotic compact objects: 3G detectors

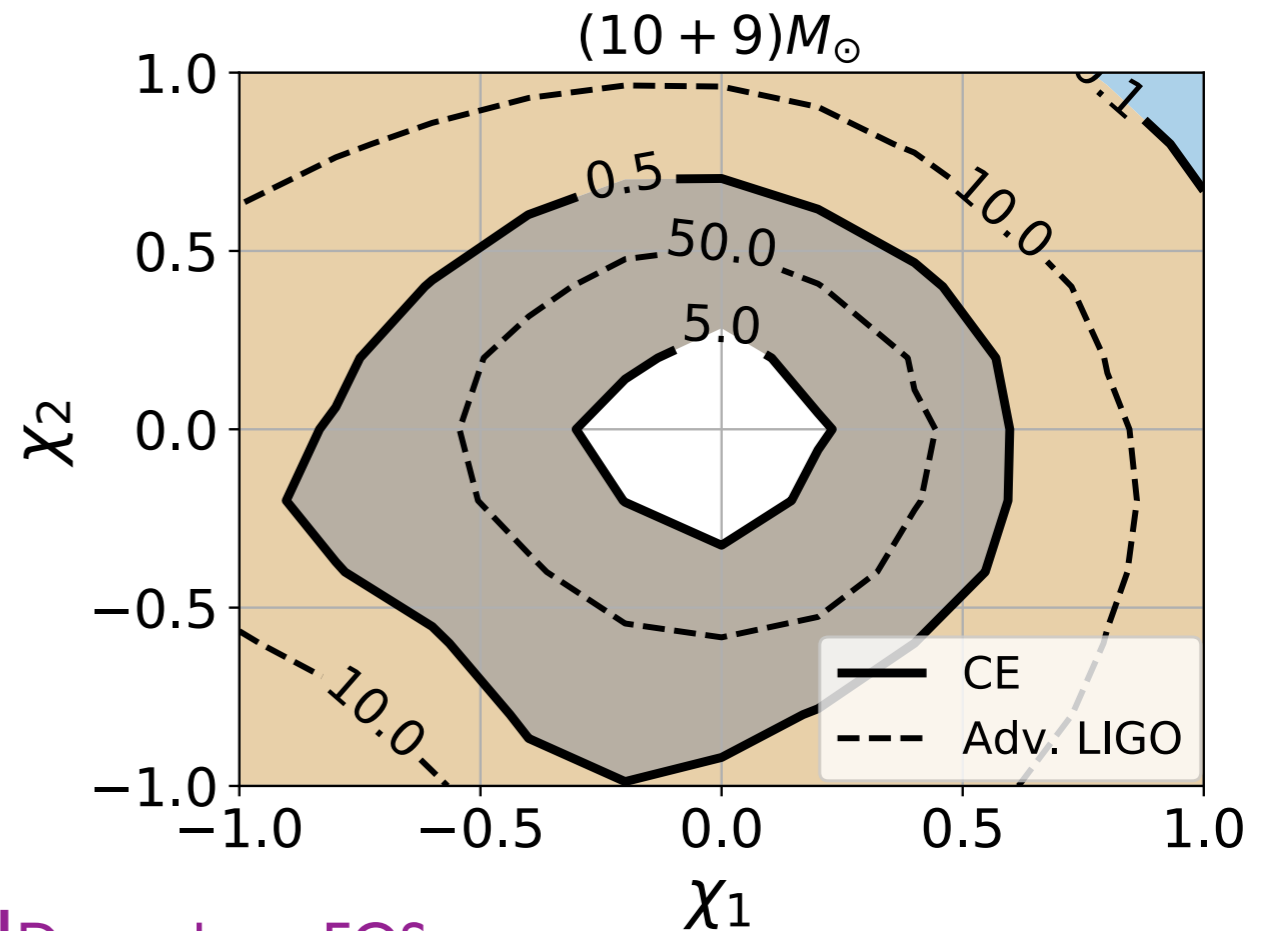
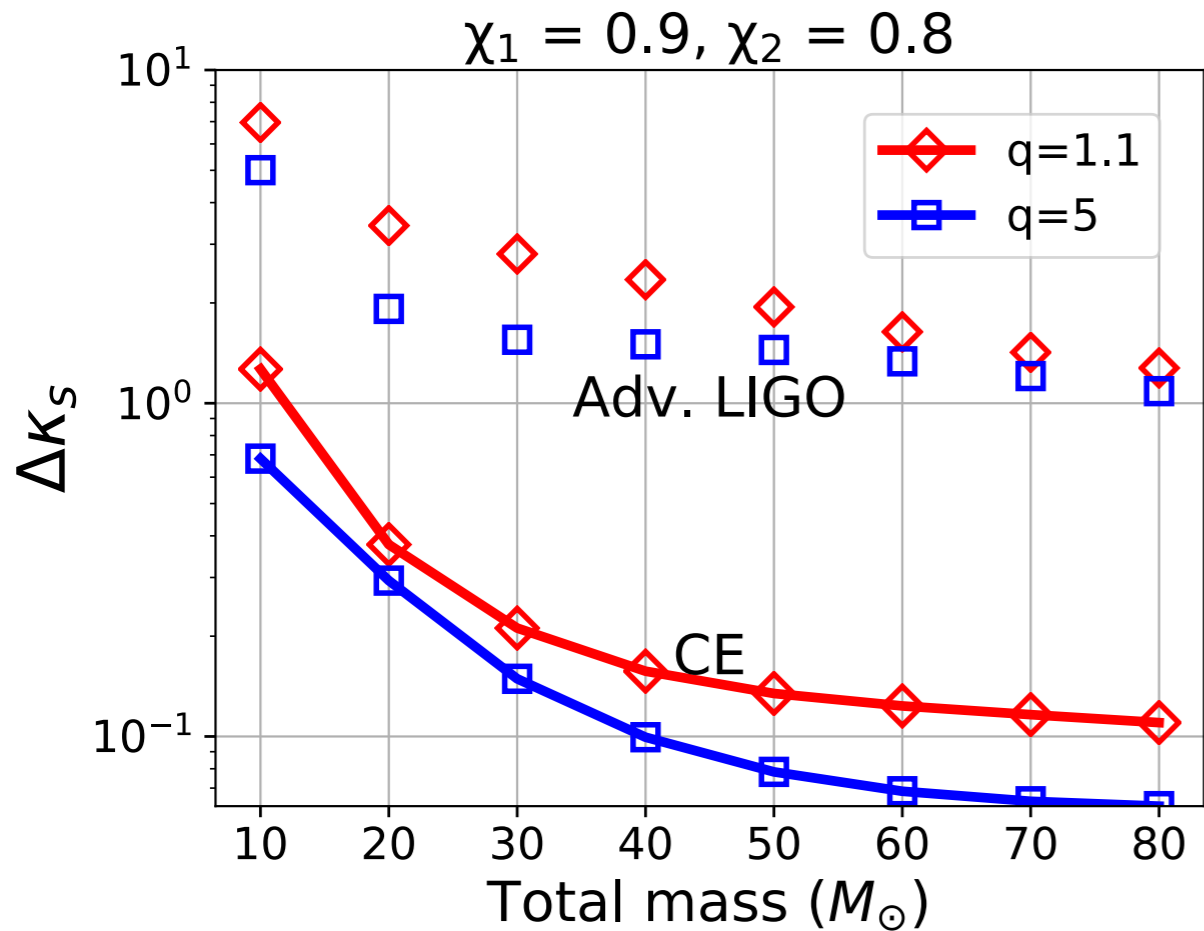


- **3G detectors** will allow to **exclude/detect GW echoes** for models not ruled out by ergoregion instability, including near-horizon Planckian corrections.

# Unveiling nature of compact-object through spin-induced quadrupole

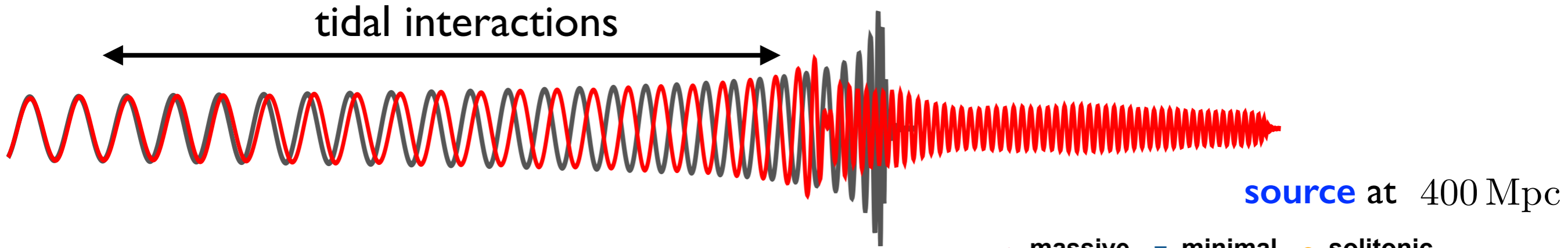


- **source** at 500 Mpc



- **Spin-induced** quadrupole:  $Q_i = -\kappa_i \chi_i^2 m_i^3$   $\kappa_{\text{BH}} = 1$
- Depends on EOS

# Unveiling nature of compact-object through tidal deformability



- Neutron stars:**

$$\Lambda = \frac{\lambda}{m_{\text{NS}}^5} = \frac{2}{3} k_2 \left( \frac{R_{\text{NS}} c^2}{G m_{\text{NS}}} \right)^5$$

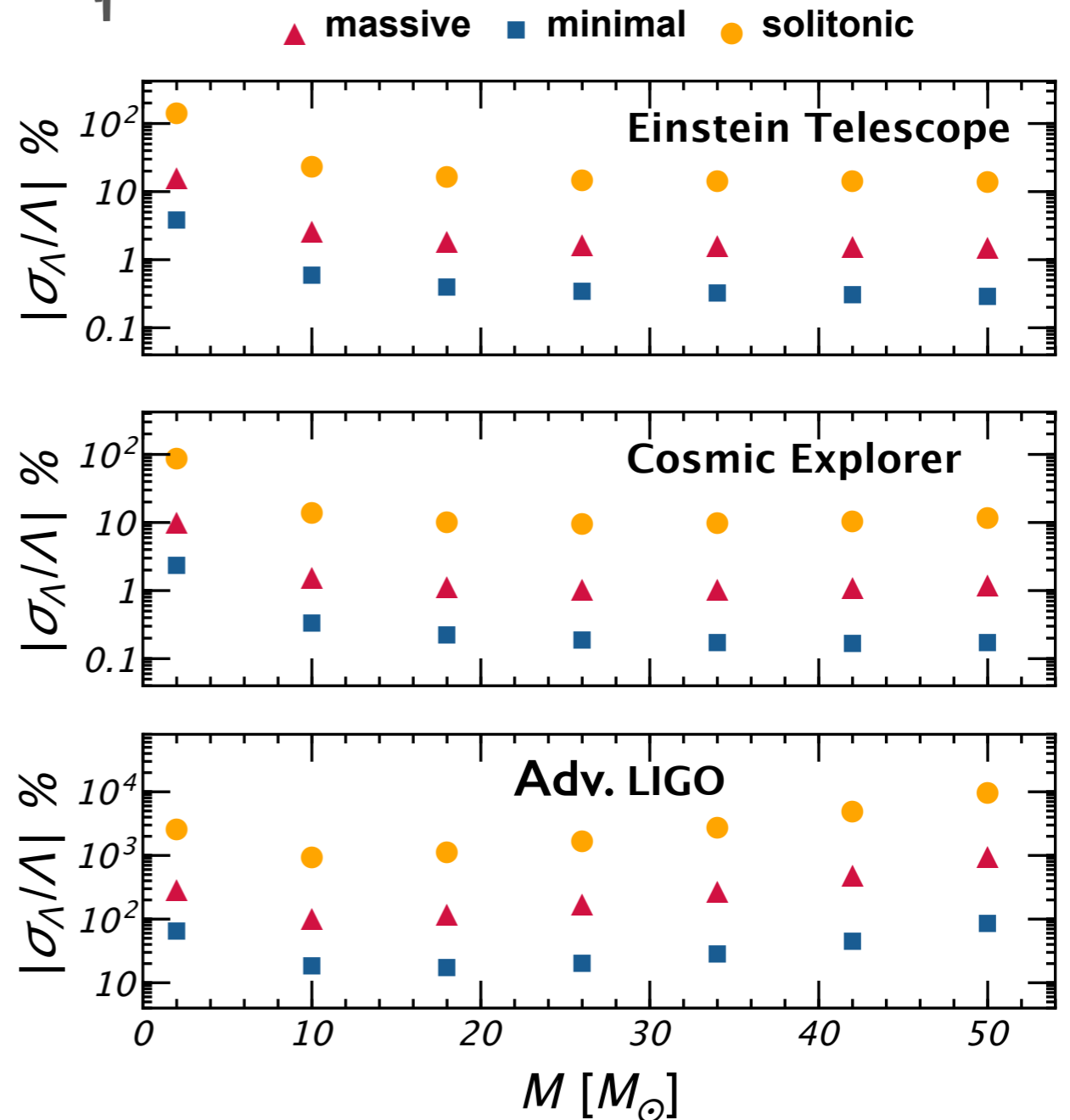
↑  
Depends on EOS & compactness

$$\Lambda = \lambda / M^5$$

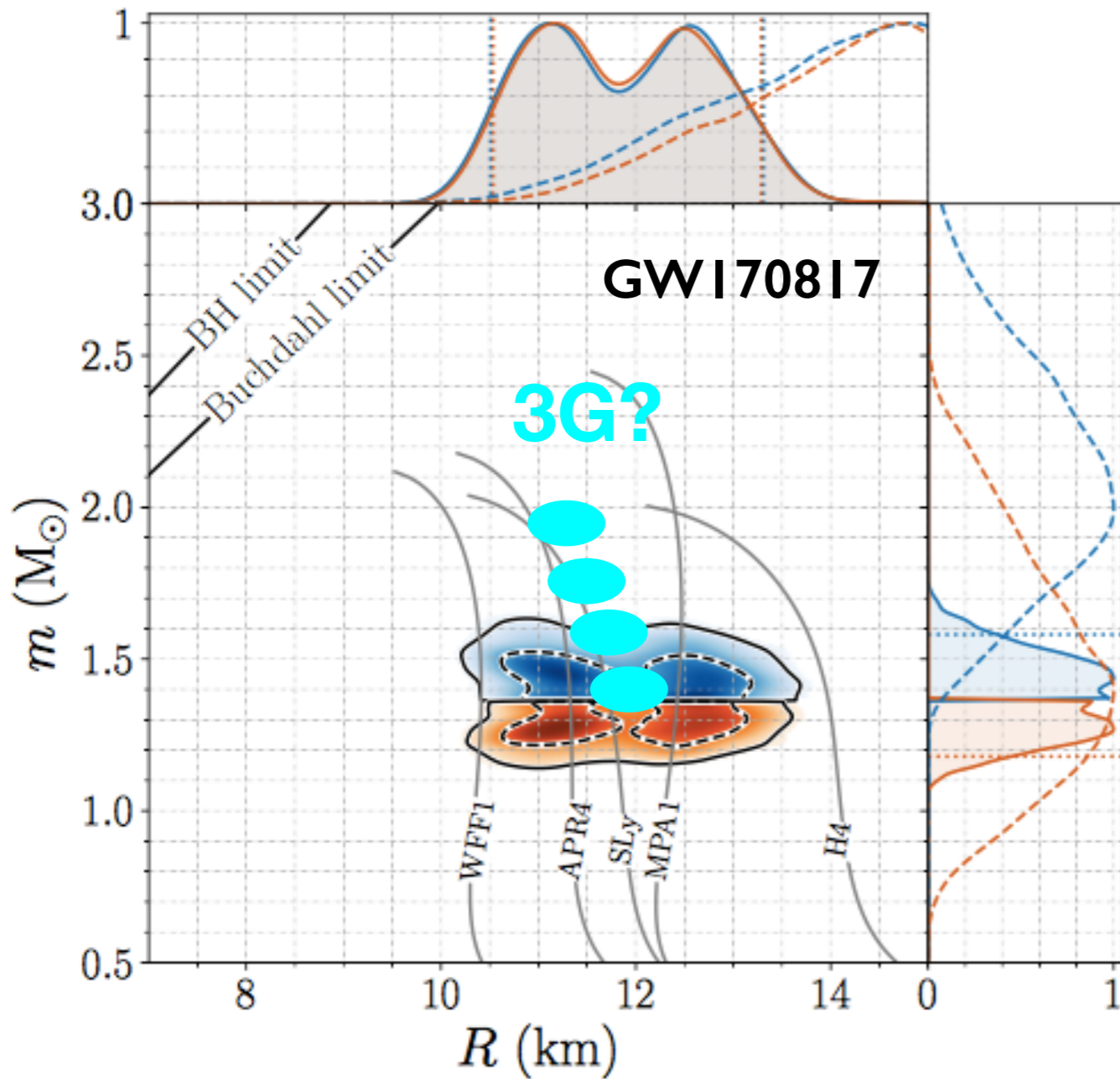
- Black holes:**  $\Lambda = 0$

- Neutron stars:**  $\Lambda_{\text{min}} \sim 10$

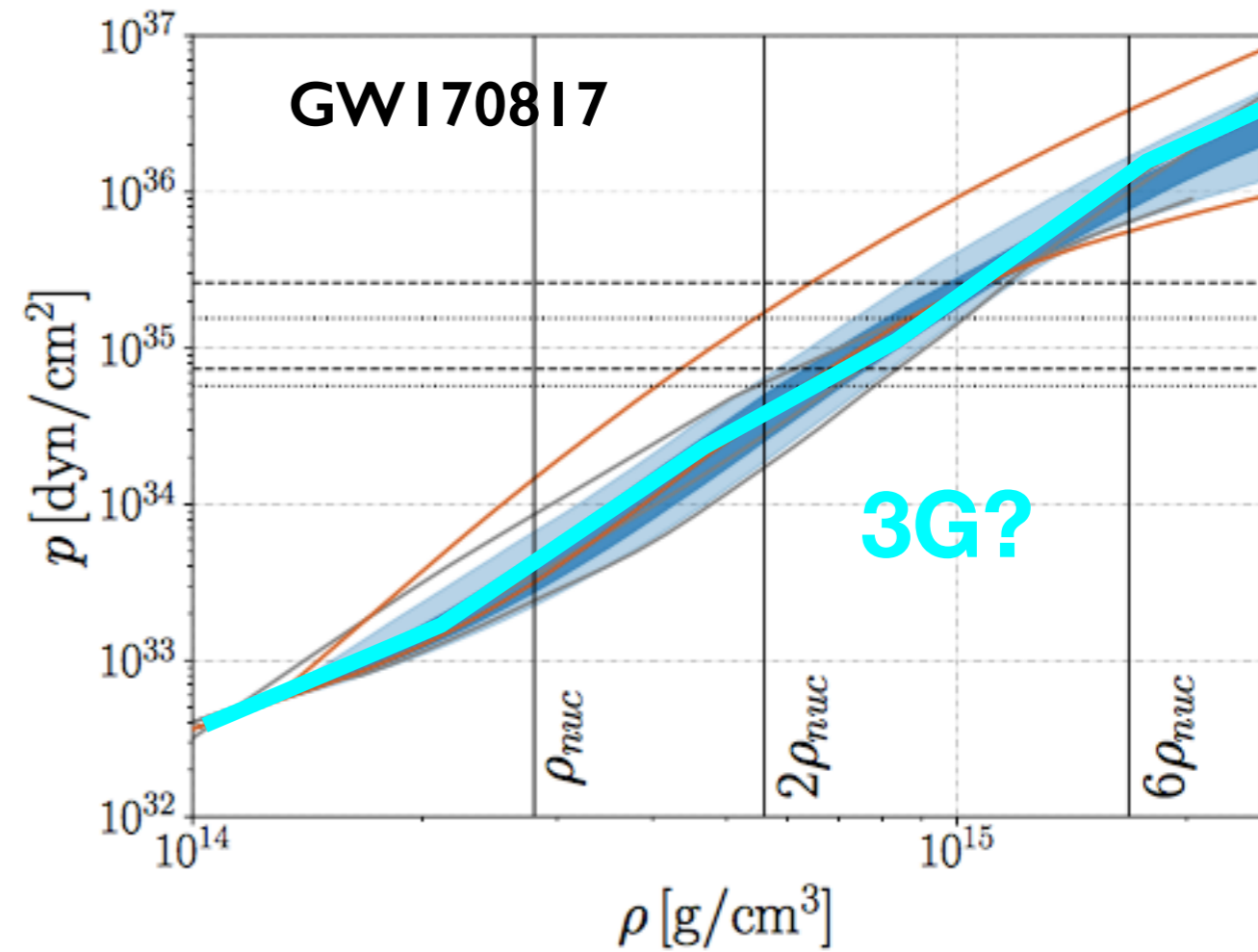
- Boson stars:**  $\Lambda_{\text{min}} \sim 1$



# Constraining NS radius/pressure/density with 3G detectors



(Abbott et al. arXiv:1805.1181)



- **Planned analysis** using **3G detectors** for final 3G report.

# Questions

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- Is there **anything else** we should be **high-lighting and/or quantifying** in the report about the **nature of compact objects** with **3G detectors**?
- What are **The genuine & unique science priorities** of **3G detectors** on **extreme-gravity & fundamental physics** ?