Did GW150914 produce a rotating gravastar?

Cecilia Chirenti
CMCC - UFABC

Work done in collaboration with
Luciano Rezzolla (Frankfurt University) [arxiv:1602.08759v1]

UFABC

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Black hole mimickers

- Possible models include:
  - gravastars
  - boson stars
  - wormholes
  - superspinars

Gravastars [Mazur and Mottola, 2004]

- Alternative to the end state of stellar evolution
- “gravitational vacuum condensate star”
- almost as compact as a black hole
- no event horizon or central singularity

Formation of a gravastar

- Gravitational collapse of a massive star
- Phase transition as stellar radius approaches its Schwarzschild radius…
- … leading to the formation of a de Sitter core!
- Baryonic mass of the stars becomes a shell of stiff matter surrounding the core

(Speculation!)

Original gravastar model

$$\delta = r_2 - r_1$$

$$\mu = M/r_2$$

- Interior $0 \le r \le r_1, \ \rho = -p$

- Shell $r_1 \le r \le r_2, \ \rho = +p$
- Exterior $r_2 \le r, \ \rho = p = 0$

5-layer model!

Other gravastars

- 3-layer model (infinitesimally thin shell of matter) [Wisser and Wiltshire, 2004]
- Fluid gravastar model (no shells) [Cattoen, Faber and Visser, 2005]
- Electrically charged gravastars [Horvat, Ilijic and Marunovic, 2009]
- Magnetized gravastars [Turimov,Ahmedov and Abdujabbarov, 2009]
- Rotating gravastars [Uchikata and Yoshida, 2016]
- etc…

Stability of a gravastar

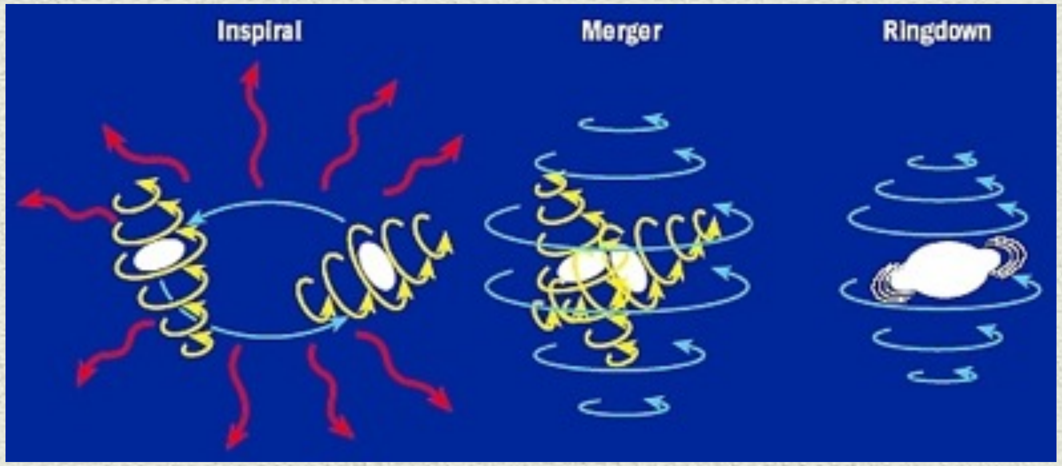
- Non-rotating gravastars:
  - Radial oscillations [Visser and Wiltshire, 2004; Horvat, Ilijic and Marunovic, 2011]
  - Gravitational (polar and axial) perturbations [DeBenedictis et al., 2006; Chirenti and Rezzolla, 2008; Pani et al., 2009]
- Rotating gravastars:
  - Scalar perturbations (ergoregion instability) [Cardoso et al., 2007; Chirenti and Rezzolla, 2008]
- It's always possible to find stable configurations…

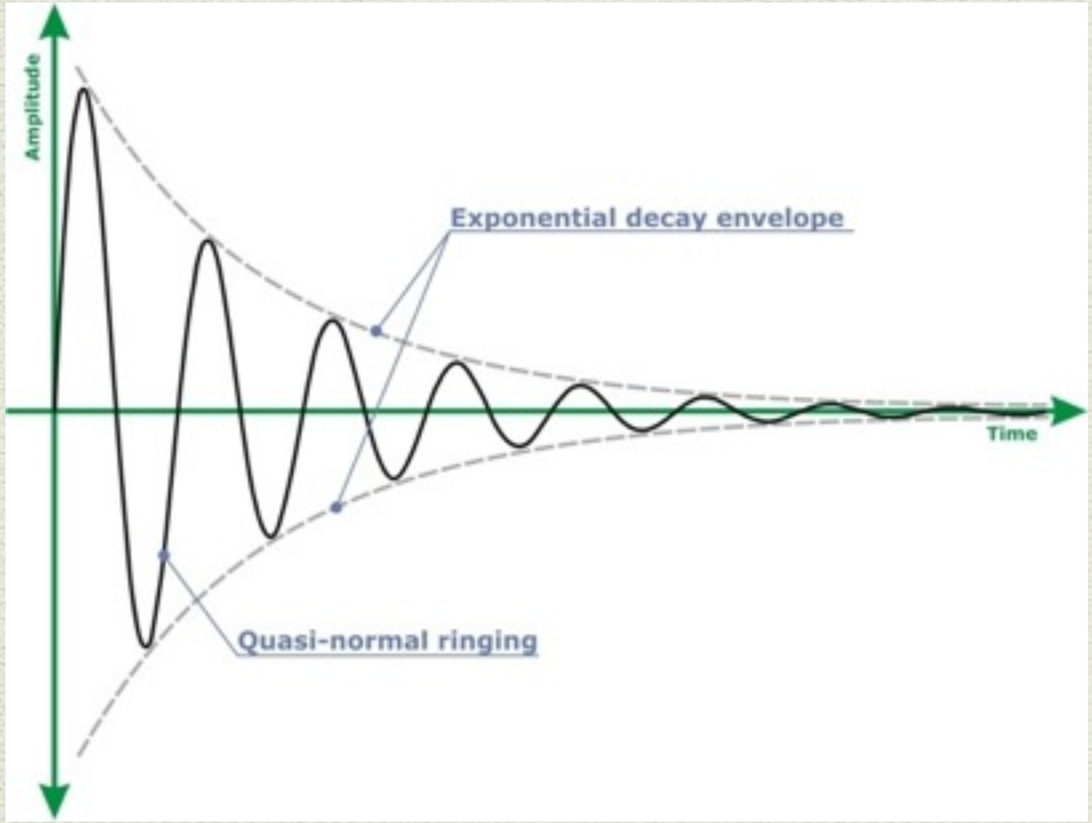
How to tell a gravastar from a black hole: observational signatures

- Limits from accreting black holes' luminosity [Broderick and Narayan, 2007]
- Gravastar shadows [Sakai, Saida and Tamaki, 2014]
- I-Love-Q relations for gravastars [Pani, 2015]
- Gravitational radiation: quasinormal modes from gravastars [Chirenti and Rezzolla, 2008]

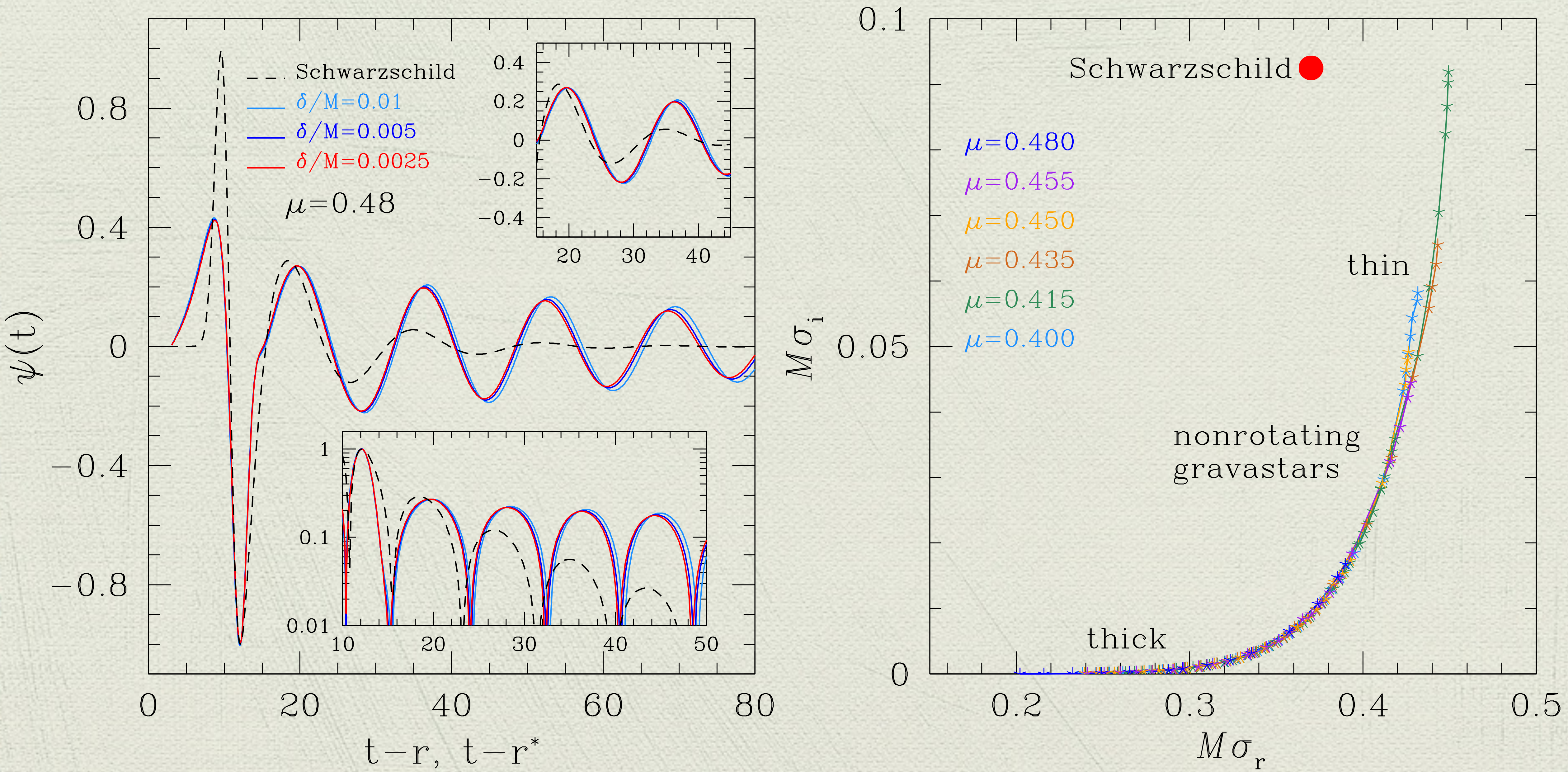
Quasinormal modes

- Characteristic modes of oscillation: “fingerprint” from the source
- Independent from the initial perturbation: frequencies depend only on the source

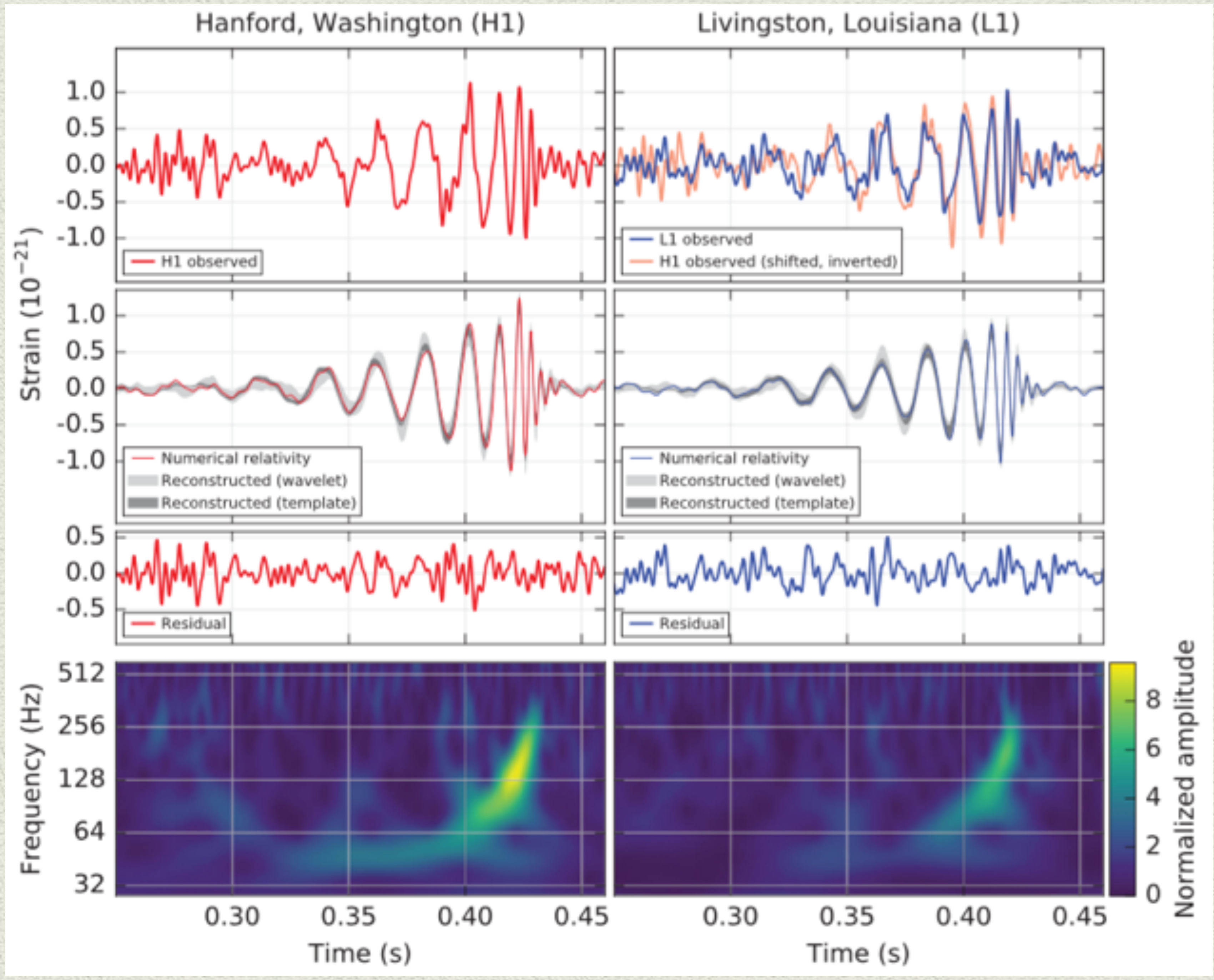




Gravitational radiation from a non-rotating gravastar



Gravitational wave detection with LIGO: GW150914



Interpretation of GW150914

- merger of two black holes with masses 36 and 29 solar masses
- resulting black hole with mass 62 solar masses and dimensionless spin 0.67
- 3 solar masses radiated in gravitational waves

Could it have been gravastars instead of black holes?

- Inspiral phase:
    - 2 compact objects - not necessarily black holes: it could have been a binary gravastar system!
- The merger:
    - Numerical relativity simulations needed
- Final object:
    - Quasinormal mode signature can be used to identify the source

Quasinormal modes for rotating gravastars?

- A fluid gravastar is a compact star with a very funny equation of state
- Neutron star oscillations are already very well understood
- Frequencies for rotating stars can be obtained from results for non-rotating stars: rotational corrections
- We adapt this method for rotating gravastars

Rotational corrections

- Frequencies for rotating neutron stars can be calculated as [Ferrari, Guartieri and Marassi, 2007]:

$$\sigma_r \approx \sigma_{r,0}(1 + m\epsilon\sigma_r') + O(\epsilon^2)$$

$$\sigma_i \approx \sigma_{i,0}(1 + m\epsilon\sigma_i') + O(\epsilon^2)$$

- First correction:

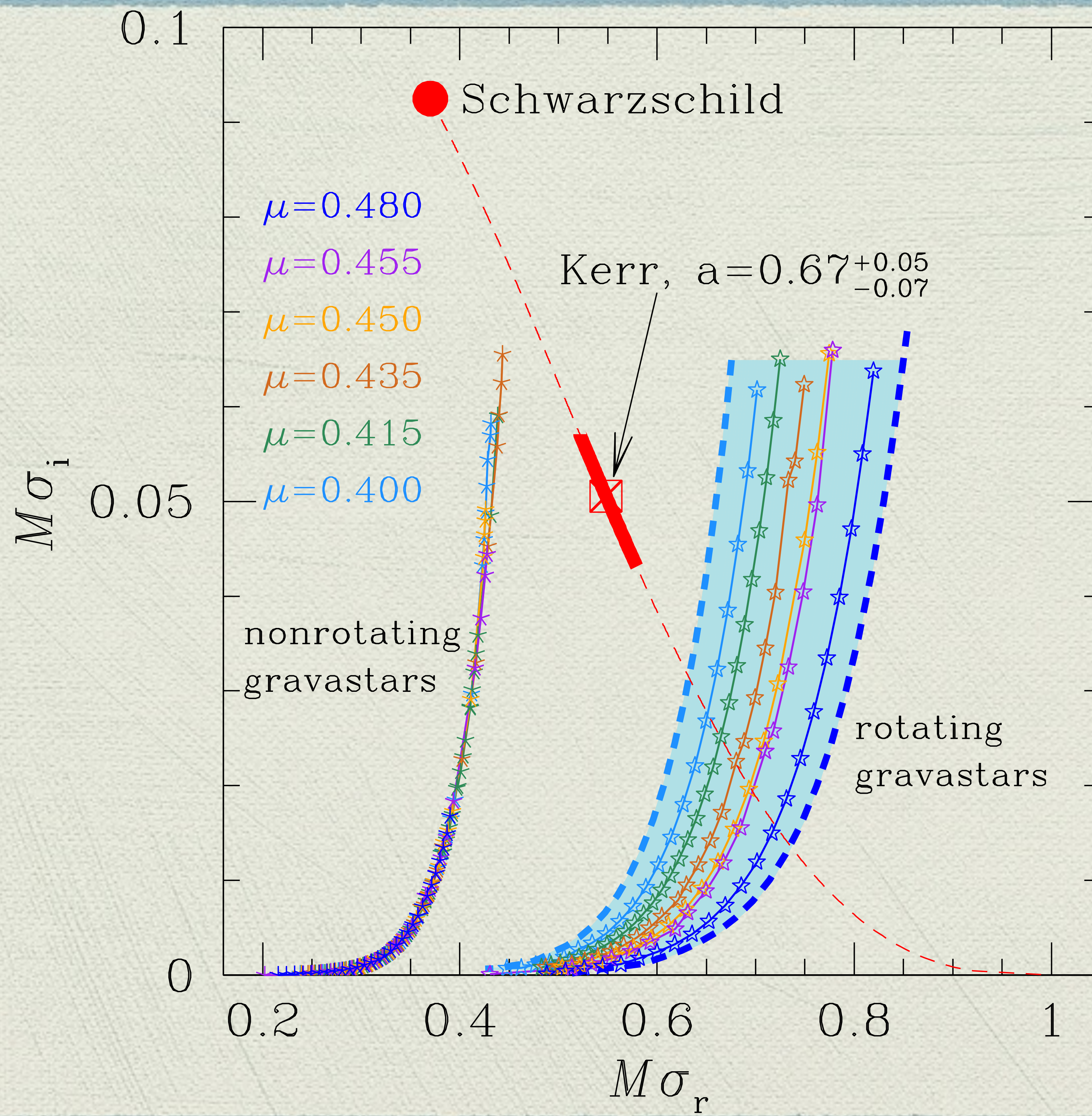
$$\epsilon \equiv \frac{\Omega}{\Omega_K} \approx \frac{J/(MR^2)}{\Omega_K} \approx \chi\sqrt{\mu}$$

- Second correction:

$$\sigma_{r,i}' = \sigma_{r,i}'(\mu)$$

- Extrapolating the results to rotating gravastars: validity…?

Estimating the quasinormal modes for rotating gravastars



Conclusions

- Constraining different interpretations of GW150914 is still hard
- Estimation of the perturbative response of rotating gravastars (with rotational correction)
- Rotating gravastar signal is distinct from observed signal
- Resulting compact object is unlikely to be a gravastar
- Binary objects are unlikely to be gravastars