Merger of weakly-interacting compact objects

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GR21 meeting, July 12 2016
(New York, USA)

Merger of exotic compact objects

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Charged black holes

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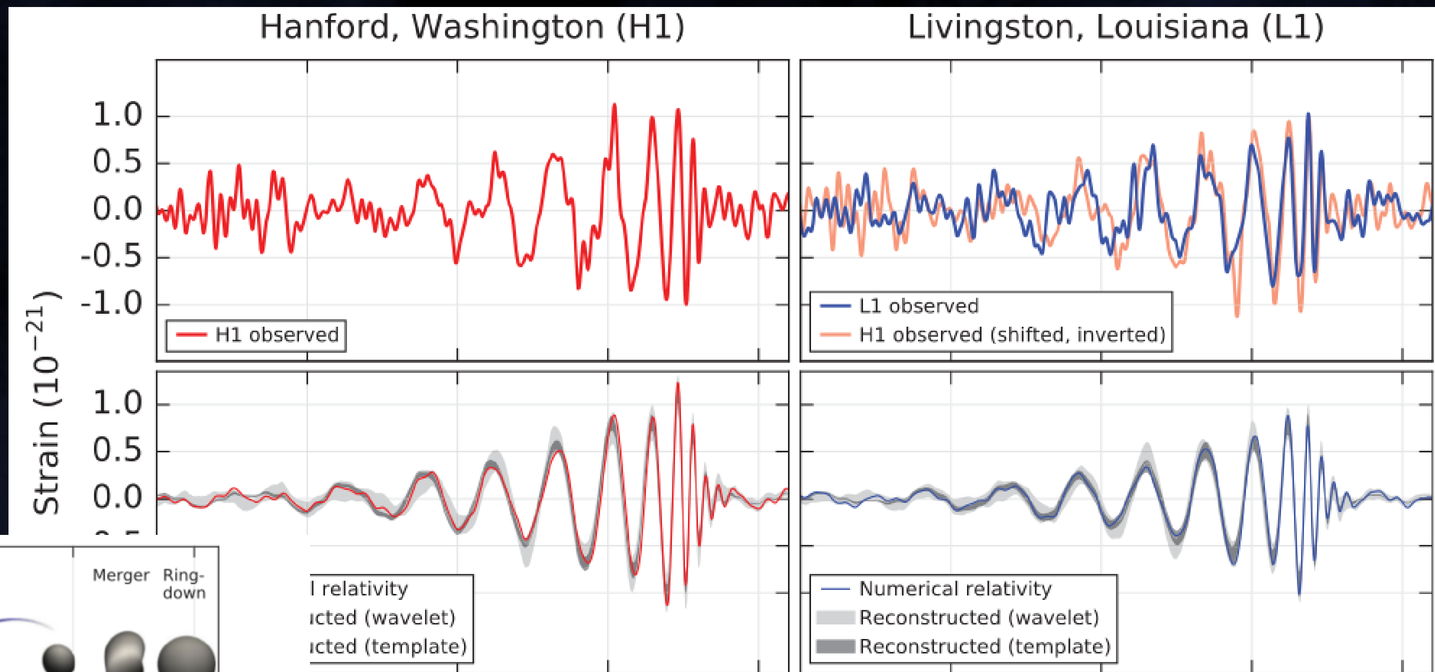
What could we learn from GW observations?

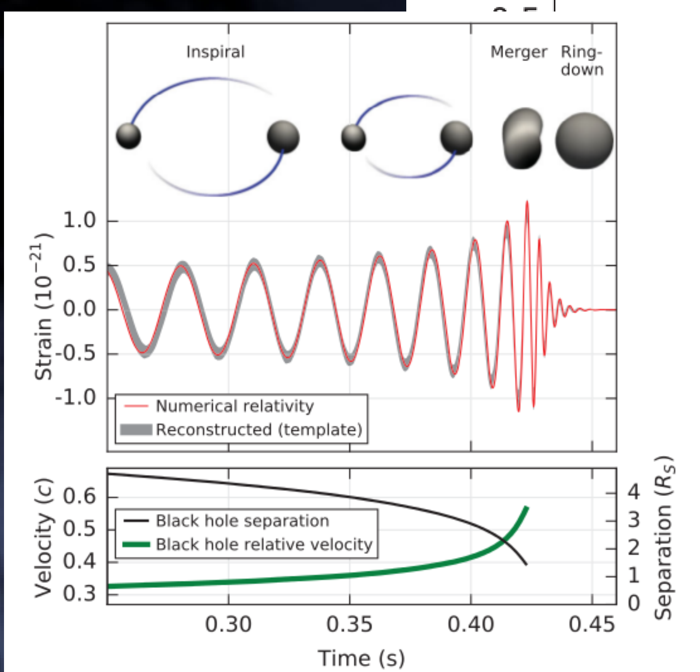
- Gravity : the dynamical strong-field regime might put constraints on the gravity theory (GR or an alternative theory)

- Matter : merger of compact objects (population of black holes and neutron stars) , exotic compact objects? [Pani’s talk]

- Electromagnetic counterparts: correlate observations from different channels (EM radiation and GW) to extract more information from the system

What can we learn from GW150914?





Merger of two black holes

$M = 65\ M_\odot$ ($M_1 = 36\ M_\odot$, $M_2 = 29\ M_\odot$)

Theoretical implications

[Yune's & Yagi's talk]

BHs vs Exotic Compact Objects (ECOs)

- GW150914 is well-explained by the merger of a binary black hole system… but is this the only possibility?

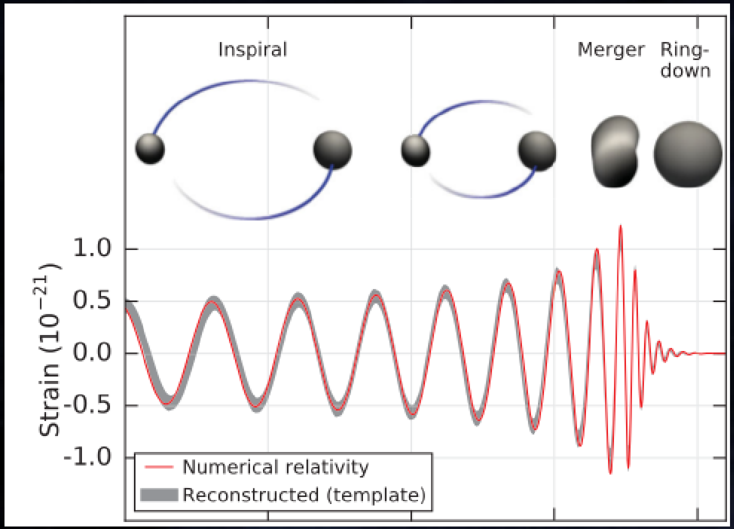
- Merger of Exotic Compact Objects?
  ECOs can be characterized by their interaction forces, the presence of a well defined surface and their compactness C=M/R

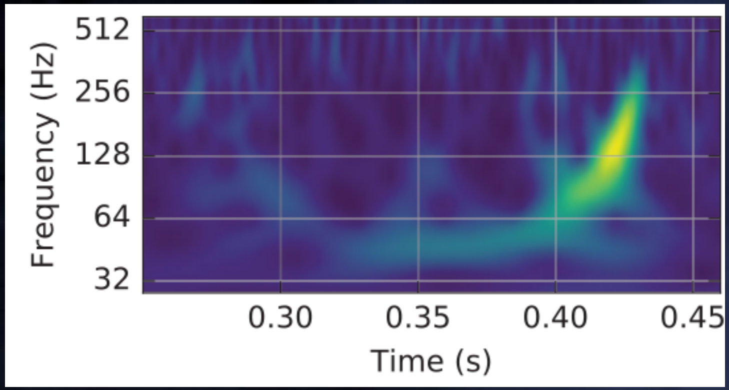
ECOS	Only gravity forces	Matter interaction
"Hard" surface	Dark stars C<0.33	Fermion stars C<0.25 Solitonic BS C<0.3 Gravastars C<0.5
"Soft" surface	Boson stars C<0.15 BHs C=0.5	Boson stars C<0.15

- Study numerically the merger of these ECOs and analyze GWs!!

GW150914

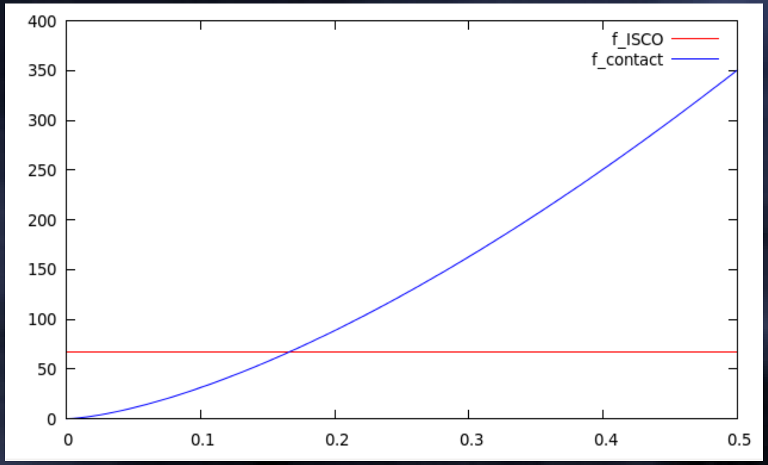
- Explain the frequency increase at f ≈ 64 Hz and the ring-down





- Innermost Stable Circular Orbit (ISCO) of BH

$$f_{ISCO} = 1/(6^{3/2}\,\pi\, M) \sim 67\ \text{Hz}$$



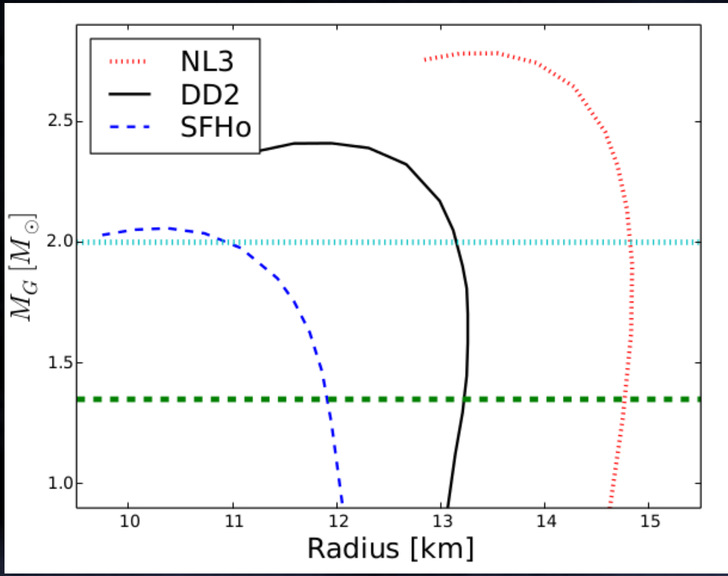
- Contact frequency of stars (i.e, a=2R)

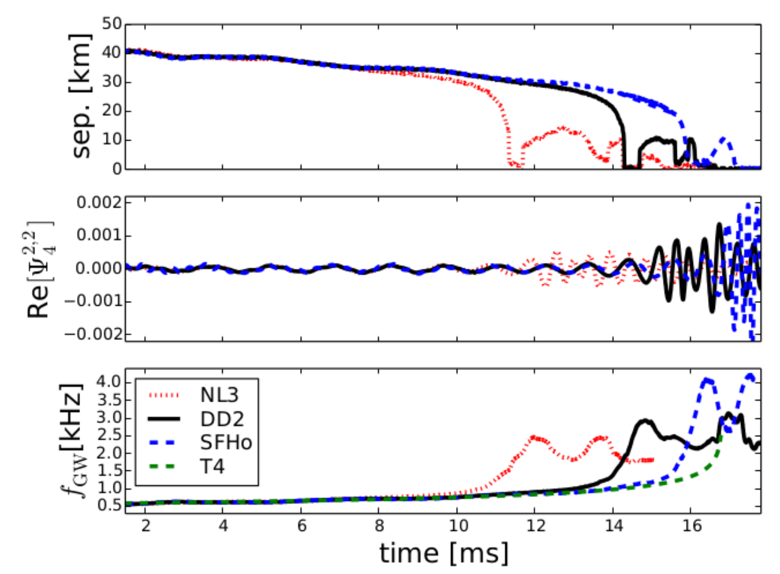
$$f_c \approx C^{3/2}/(\pi M)$$

$C=M/R$

Fermion stars (NS) as ECOs?

- Consider soft/medium/stiff EoS (i.e, small/medium/large radius) and compare with GW from BHs [CP++, PRD 92 (044045)]



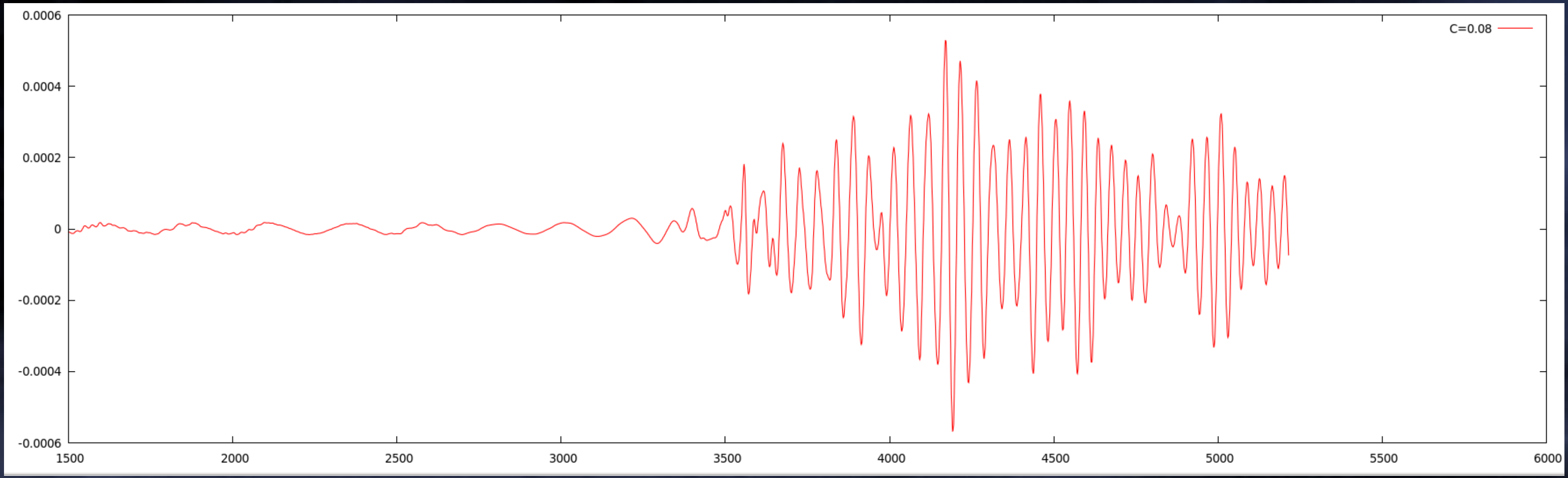


- Compactness between C=0.137-0.166 (but for M=2 → C=0.268)
- The GW frequency during the inspiral approach the BBH one, but the waveform is completely different after merger (rotating and vibrating star) and the masses are too small

Dark stars (DS) as ECOs?

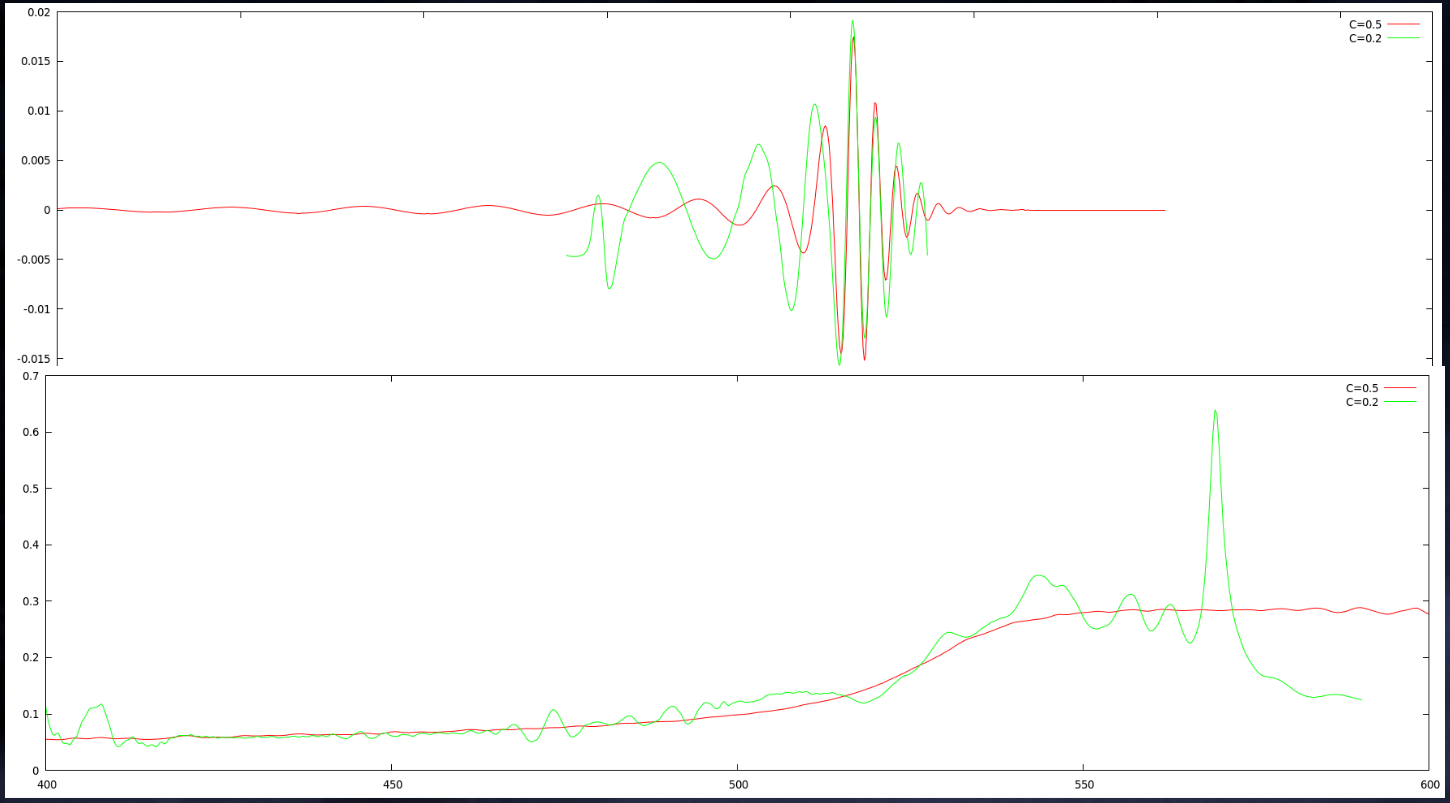
- DSs modeled with perfect fluids [CP,Cardoso,Pani++, in prep]

  - polytropic EoS $P = K\rho^{\Gamma}$ with Γ=2.0-2.5
  - two different fluids which only interact through gravity
  - generalization of black hole binary!



- DS with low compactness (C=0.08) has no ring-down

Dark stars (DS) as ECOs?



Ψ_4

freq

- DS with high compactness (C=0.2) matches the frequency but collapse to a BH after merger

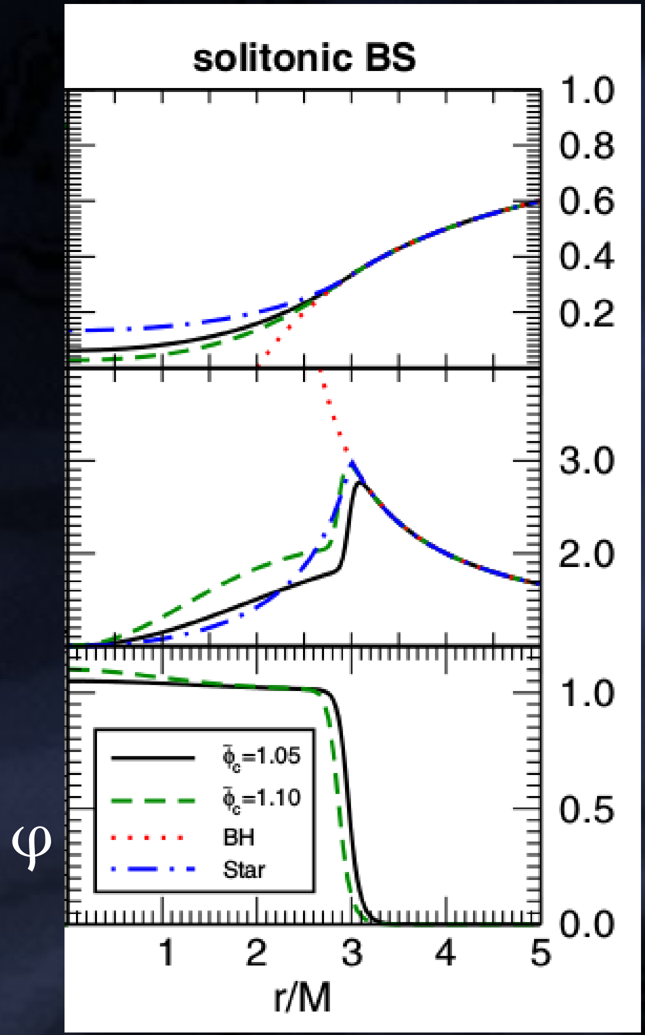
Boson stars (BS) as ECOs?

- BSs modeled using complex scalar field [CP,Cardoso,Pani++, in prep]

  - Smooth evolution through the Klein-Gordon equations

  - self-interacting potential
    $V = \mu^2\varphi^2(1 - 2\varphi^2/\sigma^2)^2$

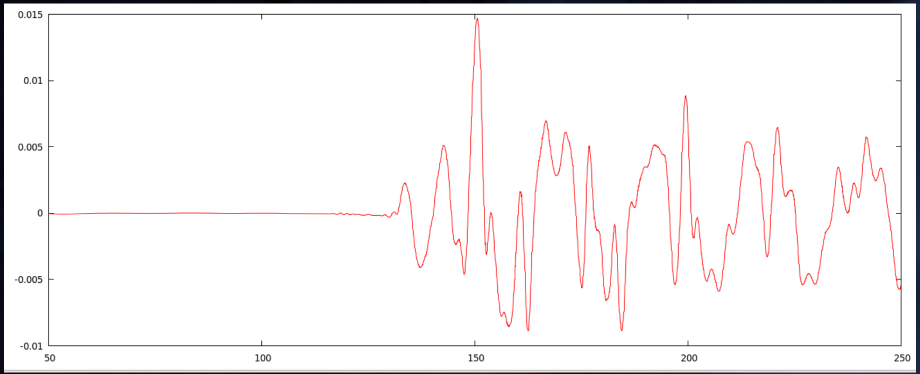
  - only head-on collisions

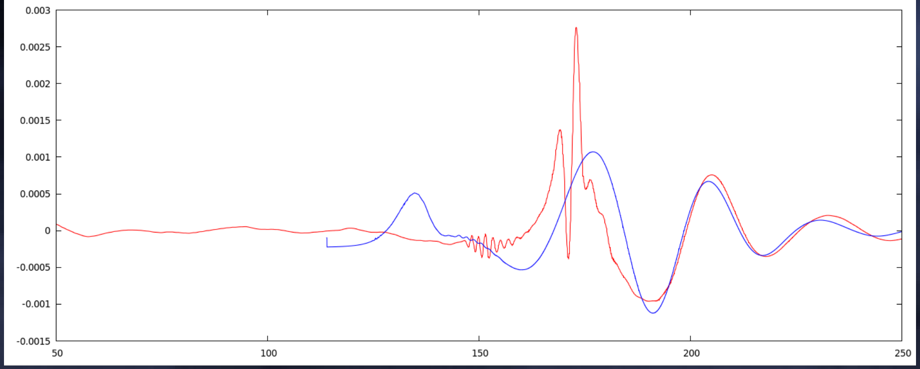


[Macedo++, PRD 88 (064046)]

Boson stars (BS) as ECOs?

• the low compactness (C=0.12) merge and yield to a strongly perturbed BS emitting strong GWs





• the medium compactness (C=0.18) have some dynamics before collapsing to a BH, while the high compactness (C=0.30) collapses to two BHs even before the merger

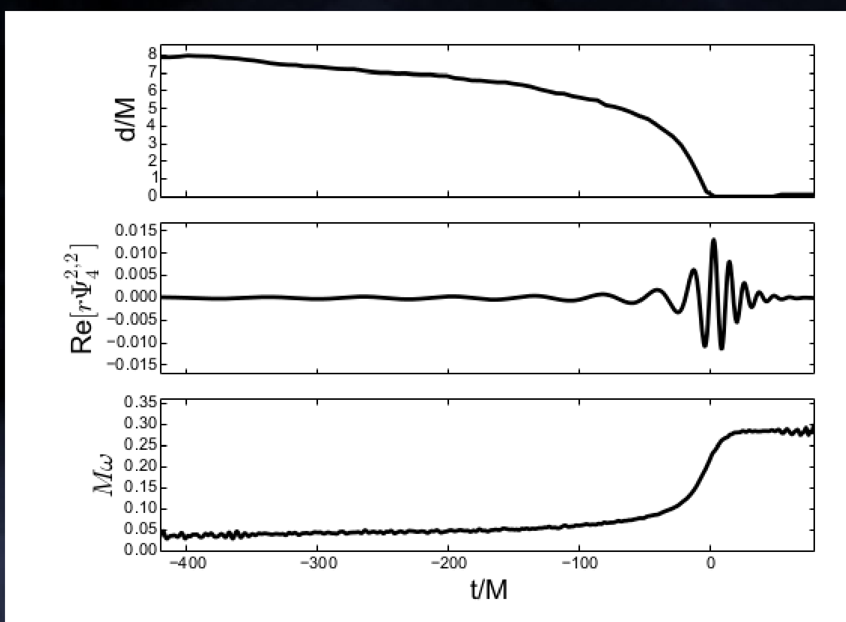
Fermi GBM Observations of LIGO Gravitational Wave event GW150914

- "Fermi Gamma-ray Burst Monitor (GBM) observations at the time of the Laser Interferometer Gravitational-wave Observatory (LIGO) event GW150914 reveal the presence of a weak transient source above 50 keV, 0.4 s after the GW event was detected, with a false alarm probability of 0.0022. Its localization is ill-constrained but consistent with the direction of GW150914. The duration and spectrum of the transient event suggest it is a weak short Gamma-Ray Burst" [arXiv:1602.03920]

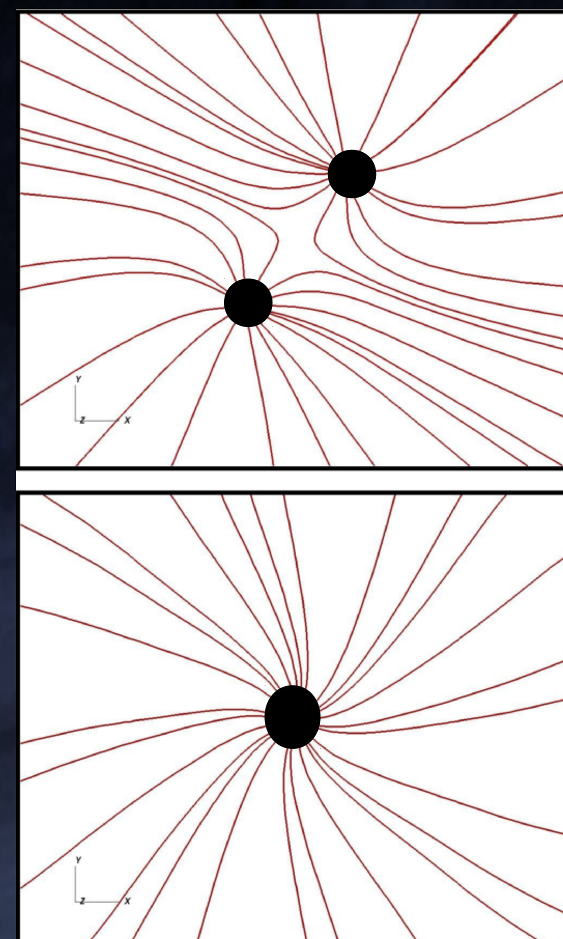
- How can a binary black hole system emit EM radiation?
  - collapse of a star into two lamps and then into two BHs
  - dead disk around one of the BHs
  - charged black holes [arXiv:1602.04542]
  - magnetic reconnection [arXiv:1603.01950]
  - and more...

Charged Black Holes

- Consider (electrically or magnetically) charged black holes in a "charged starved" (electrovacuum) or force-free environment [Liebling & CP, arXiv:1607.02140]



GWs



E fields

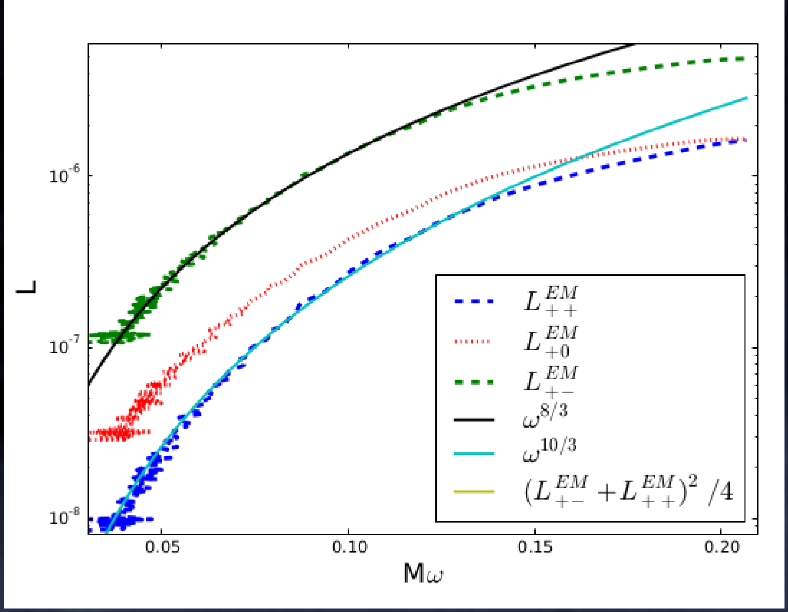
Charged Black Holes

- The EM luminosity depends on the charge configuration
- It is mainly dipolar (l=m=1), or quadrupolar (l=m=2) when the dipolar radiation is suppressed

$$L_{++} = 1.3 \times 10^{-8} \left[\frac{q}{0.01}\right]^2 \left[\frac{M\omega}{0.04}\right]^{10/3}$$

$$L_{+0} = 3.8 \times 10^{-8} \left[\frac{q}{0.01}\right]^2 \left[\frac{M\omega}{0.04}\right]^{8/3}$$

$$L_{+-} = 1.3 \times 10^{-7} \left[\frac{q}{0.01}\right]^2 \left[\frac{M\omega}{0.04}\right]^{8/3}$$



$$L^{\rm peak}_{\rm EM} \approx 10^{53}{\rm ergs/s} \left[\frac{q}{0.01}\right]^2$$

$$E_{\rm EM} \approx 10^{50}{\rm ergs} \left[\frac{q}{0.01}\right]^2 \left[\frac{M}{M_\odot}\right].$$

- Consistent with GBM observation if q=Q/M ~ 10^{-5} - 10^{-4}

In conclusion...

- All the ECOs considered here shows some problem to match the observed GW150914, especially in the ring-down
- Either consider (even more) exotic objects, or conclude that the observed GWs are either produced by binary BH mergers or by ECOs + prompt collapse to a BH
- Charged black holes could produce an EM counterparts consistent with GBM even with a “small” charge