南京大学
NANJING UNIVERSITY

Gravitational Waves from Primordial Black Hole Inspiraling inside Compact Star:

Novel Probe for Dense Matter Equation of State

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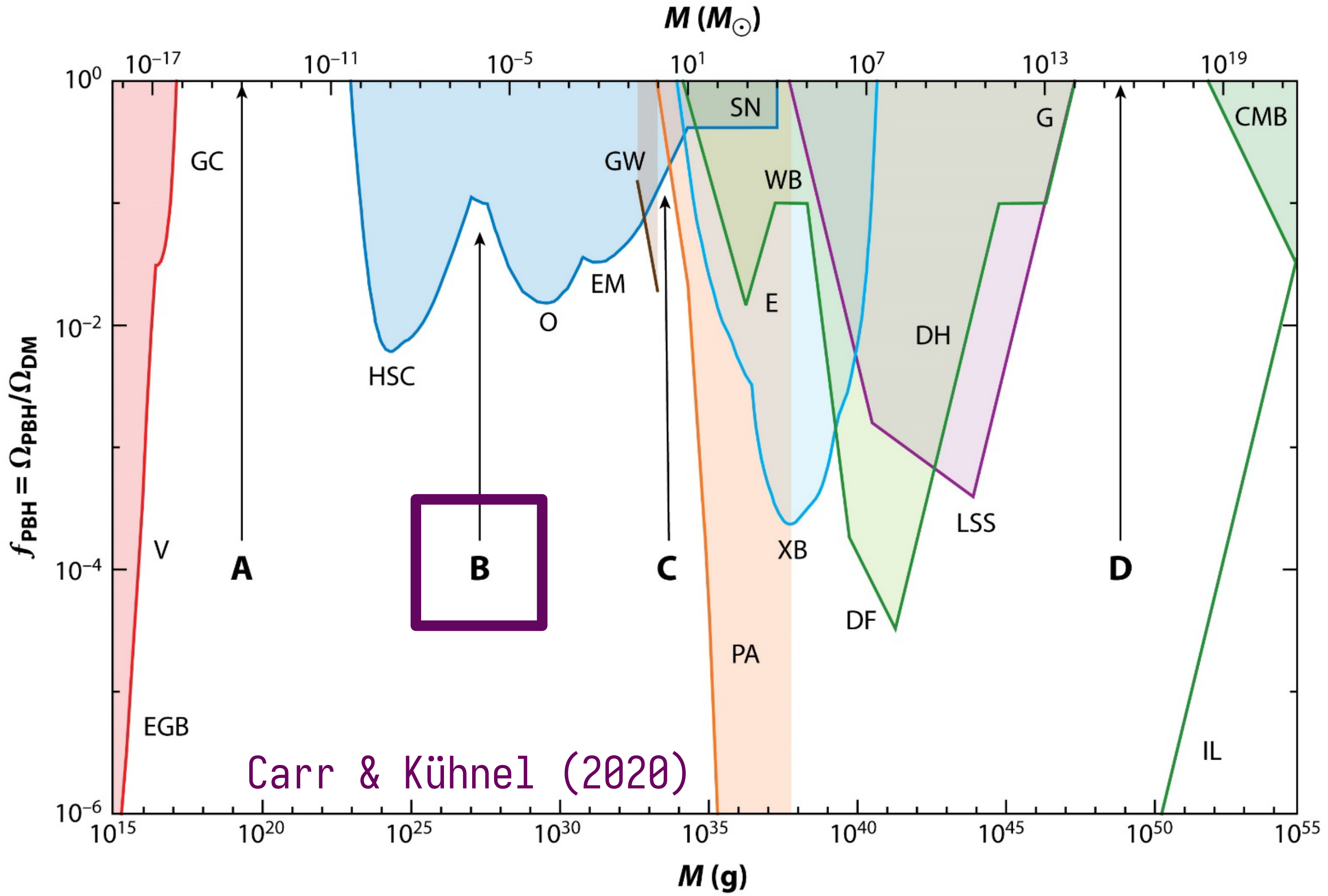
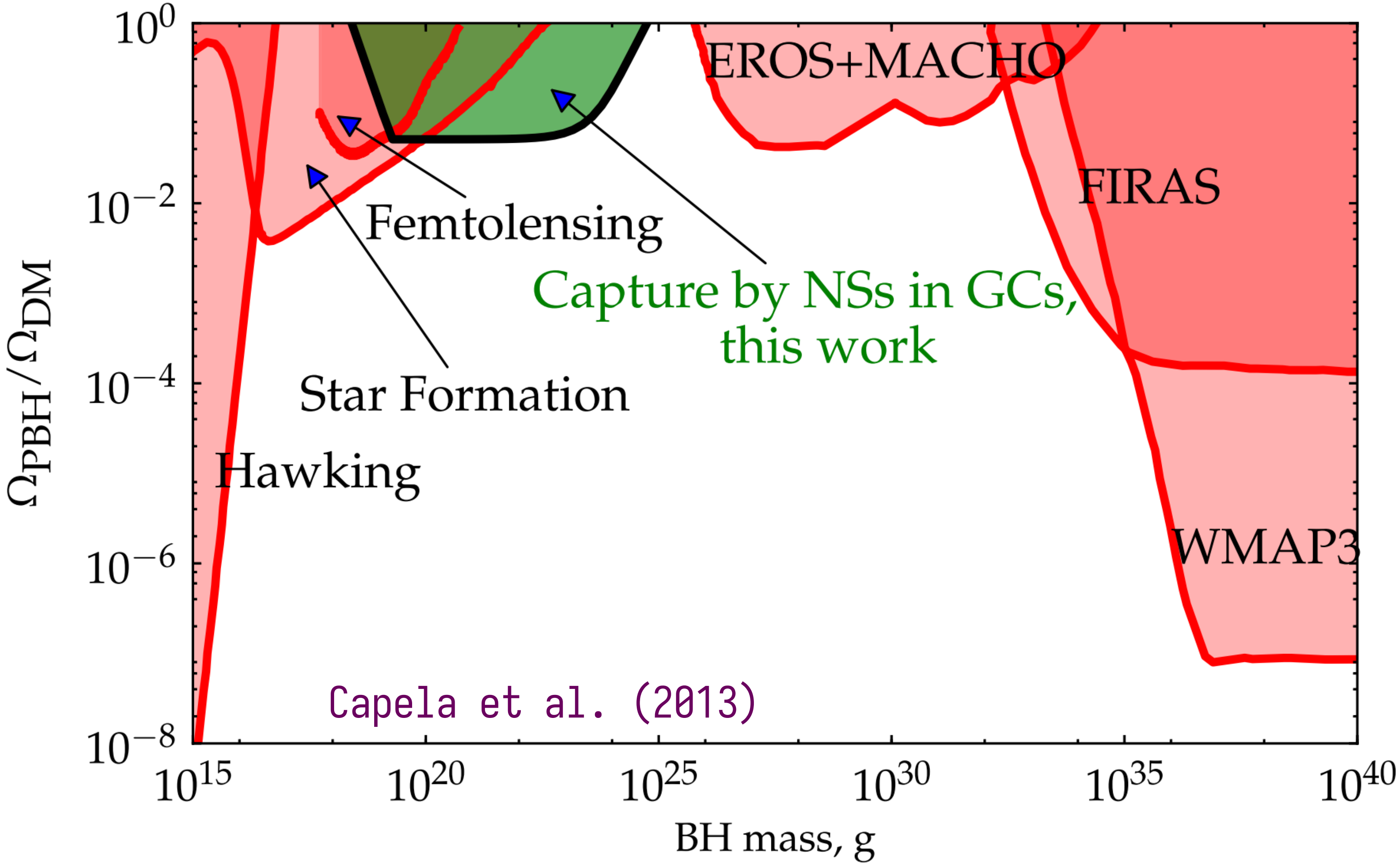
PBHs as Dark Matter

- Hawking evaporation
- **Lensing**
- Gravitational Waves
- Accretion
- CMB distortion
- Large-scale structure
- Dynamical effects



Compact Star as Probe

- NS rich in GCs
- DM rich in GCs
- NS capture PBH
- PBH destroy NS
- Can NS survive?



Compact Star as Probe

> “... survival of stars does not constrain PBHs, but ... could be constrained if we can work out the observational signature of this process.” (Montero-Camacho et al. 2019)

Observational Signatures?

- Transmutation
  - Fast radio bursts
    - (Fuller & Ott 2015, Abramowicz et al. 2018, Kainulainen et al. 2021)
  - r-process nucleosynthesis
    - (Fuller et al. 2017)
  - Gamma-ray bursts & e^{+}
    - (Takhistov 2019)
  - Solar-mass black holes
    - (Takhistov et al. 2021)

- **Primordial black hole mass?**

Observational Signatures!

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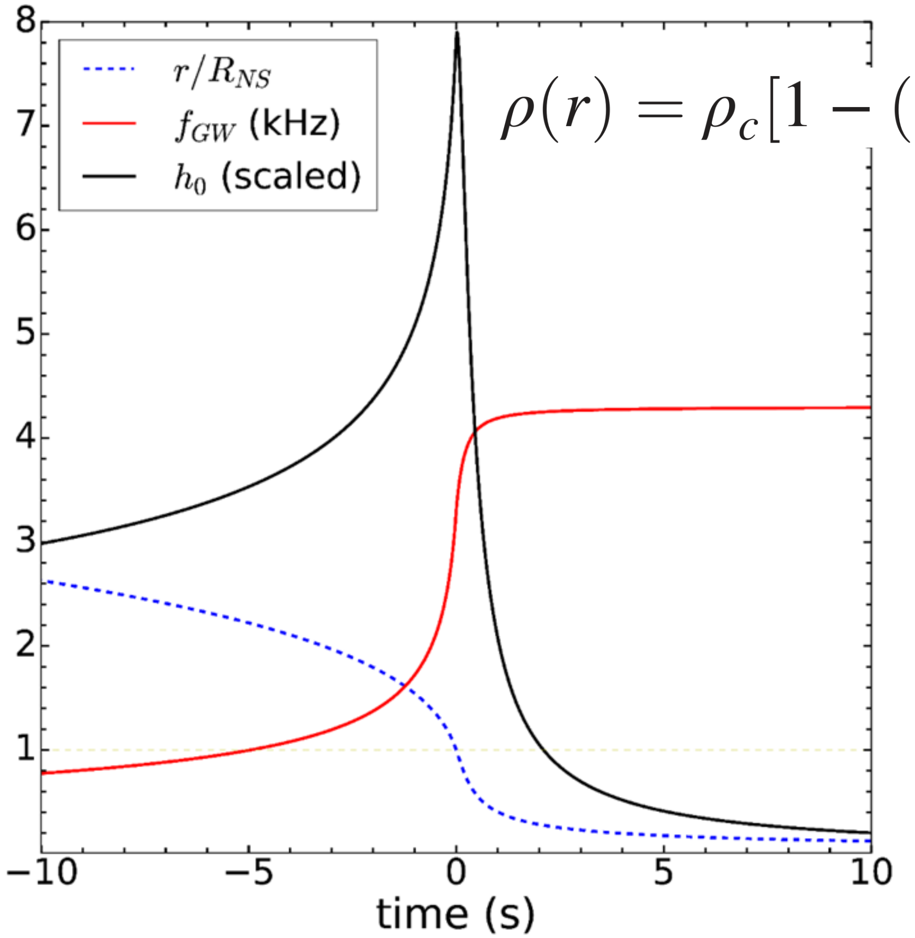
- **Gravitational waves from inspiral!**



Horowitz & Reddy (2019)

$$\rho(r) = \rho_c[1 - (r/R_{\rm NS})^2]^{1/2}$$

> "… is *monochromatic* with frequency $f_\star \sim$ kHz and with a *constant amplitude* estimated as
> $$h_0 = \frac{4\sqrt{2}G}{dc^4} m r^2 \omega_\star^2 \approx 2.5 \times 10^{-25} \left(\frac{m}{10^{25}\,\mathrm{g}}\right)\left(\frac{1\ \mathrm{kpc}}{d}\right)"$$

(italic font set by the original authors)

Génolini et al. (2020)

GWs as Observation Signature

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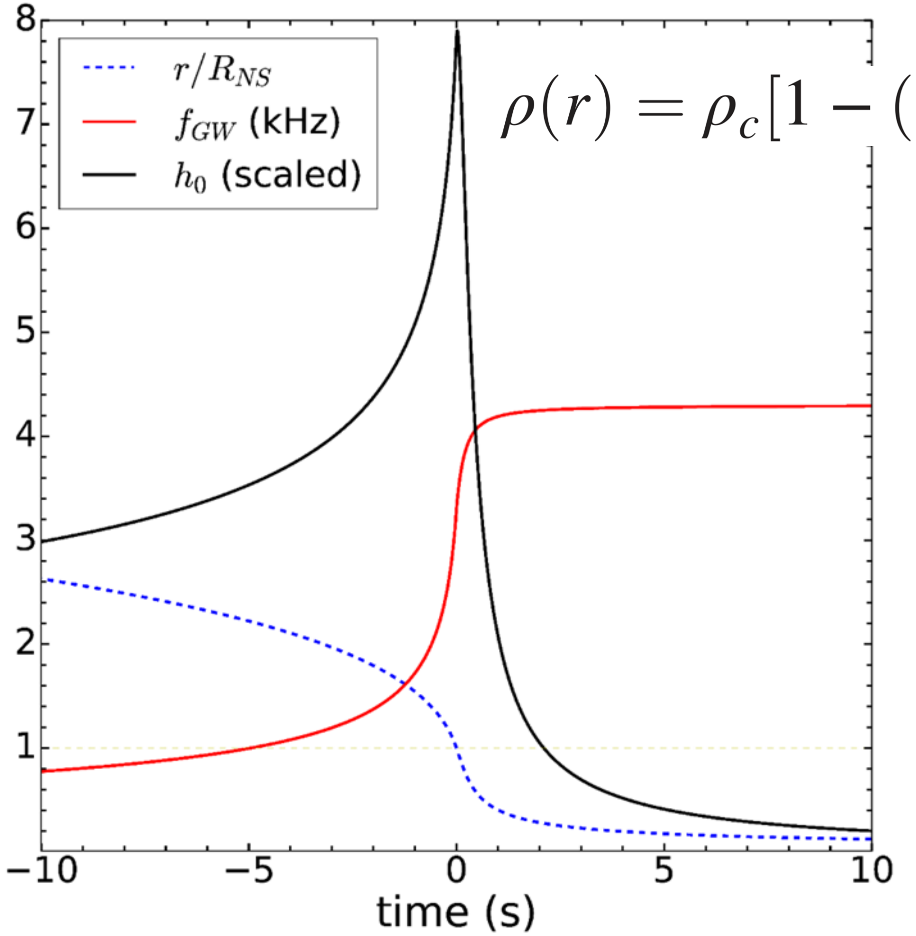

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Génolini et al. (2020)

Dependence on Stellar Structure

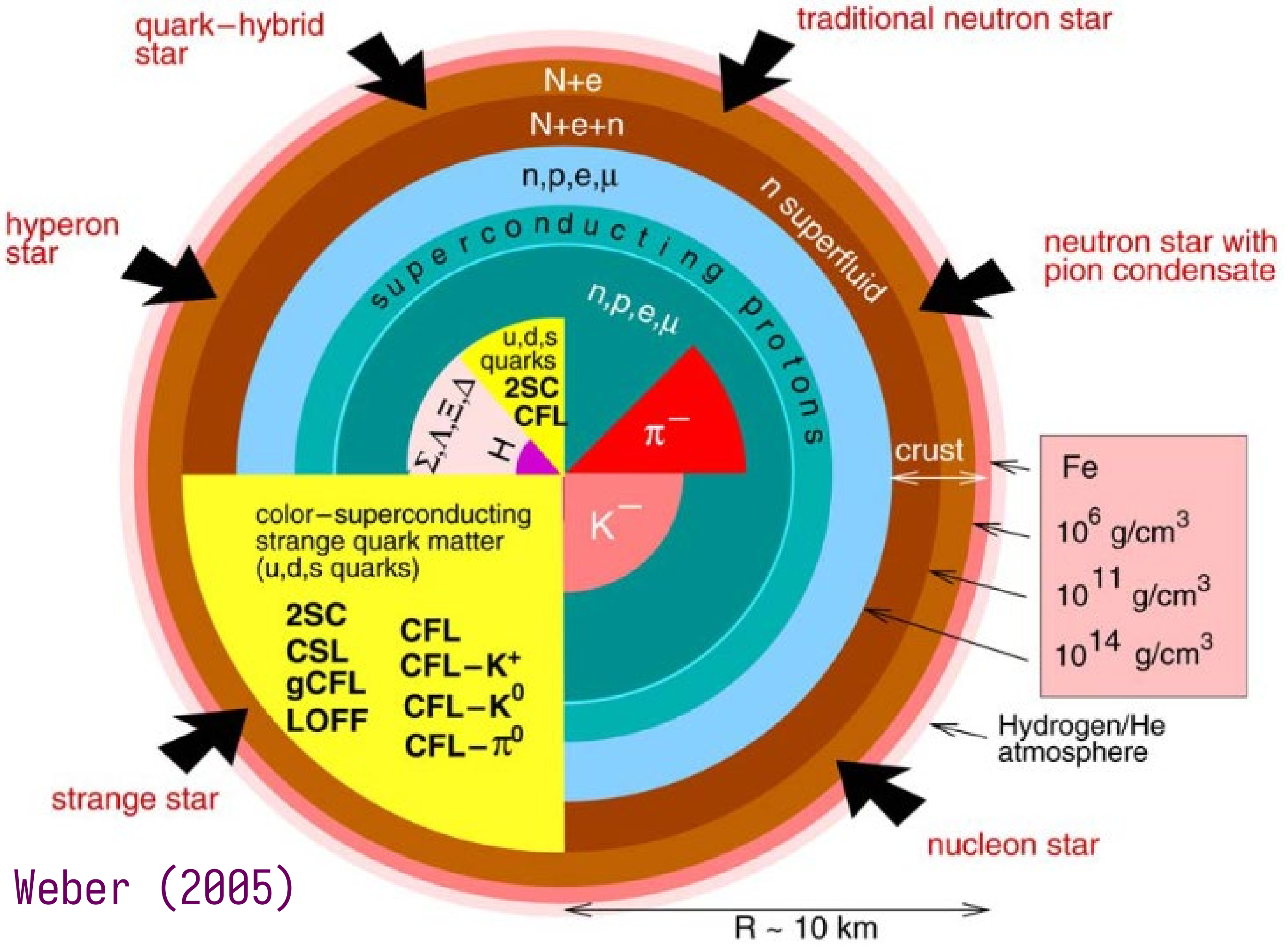
- Energy-losing channels
  - Dynamical friction

$$\boldsymbol{F}_{\rm DF} = -\frac{4\pi\rho m_{\rm PBH}^2}{v^2}(\mathcal{I}_r\hat{\boldsymbol{r}} + \mathcal{I}_\varphi\hat{\boldsymbol{\varphi}})$$

  - Accretion

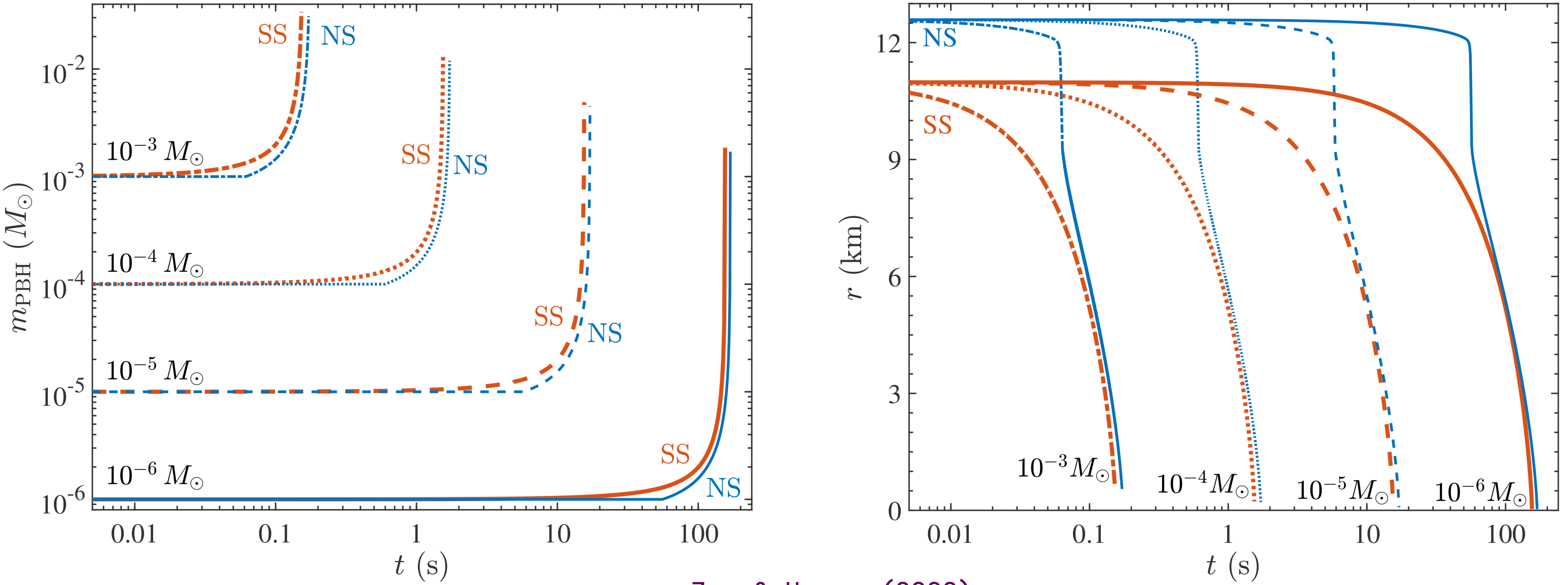
$$\dot{m}_{\rm PBH} = \frac{4\pi\lambda\rho m_{\rm PBH}^2}{(c_s^2 + v^2)^{3/2}}$$

  - Post-Newtonian (GWs)
- Stellar structure
  - Neutron star (BSk 24)
  - Strange star (MIT-Bag)



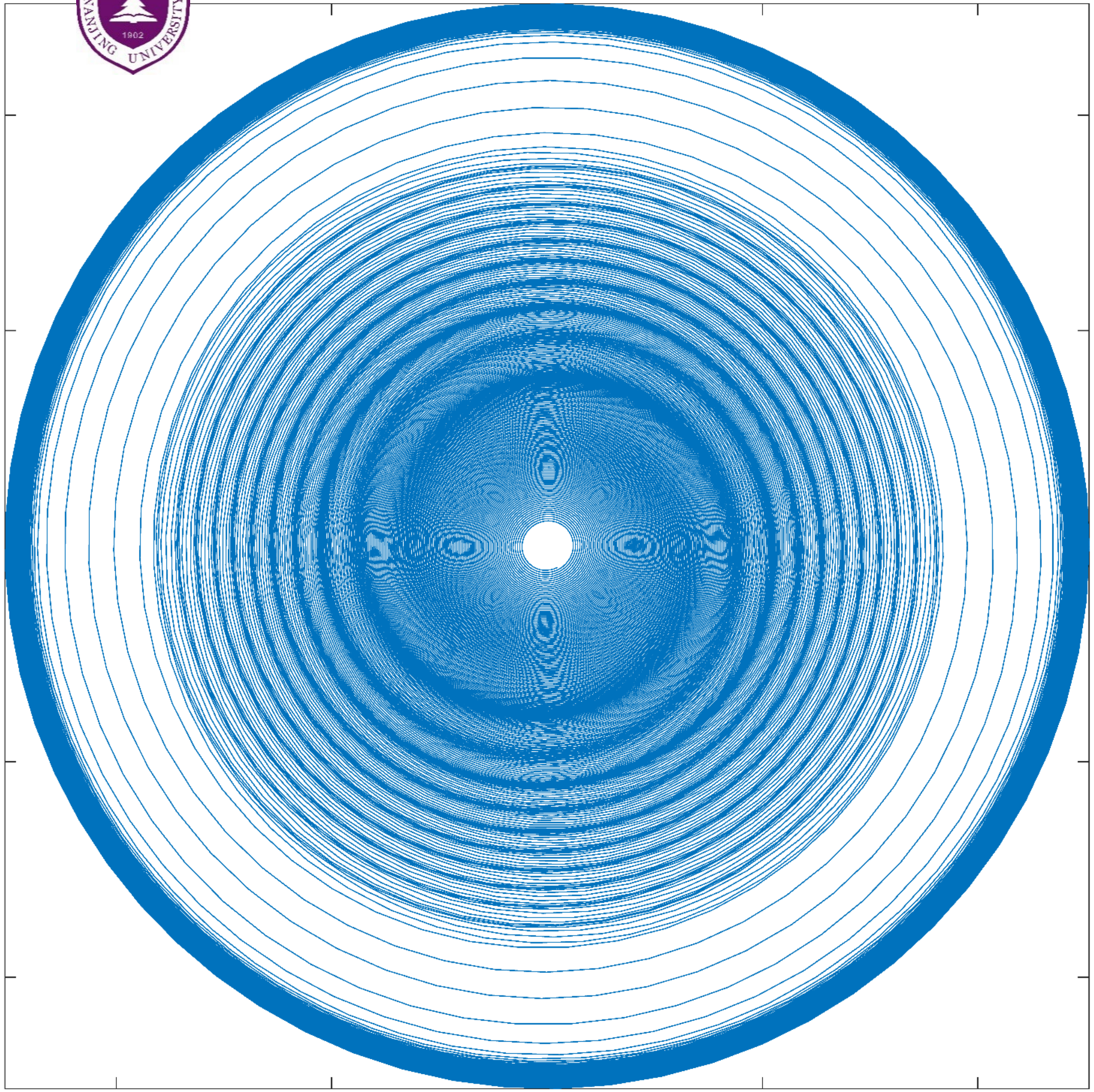
Weber (2005)

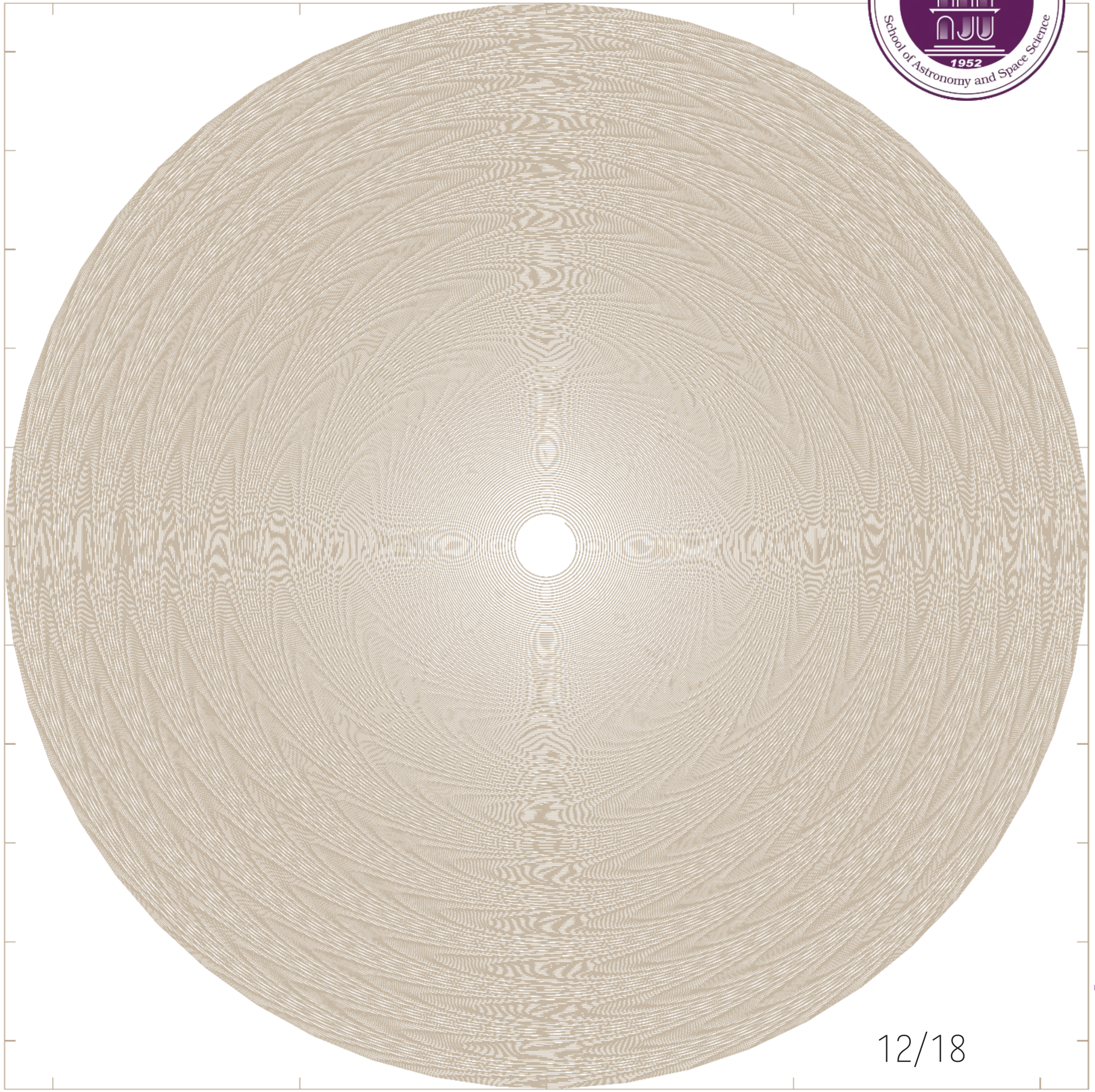
Binary Evolution



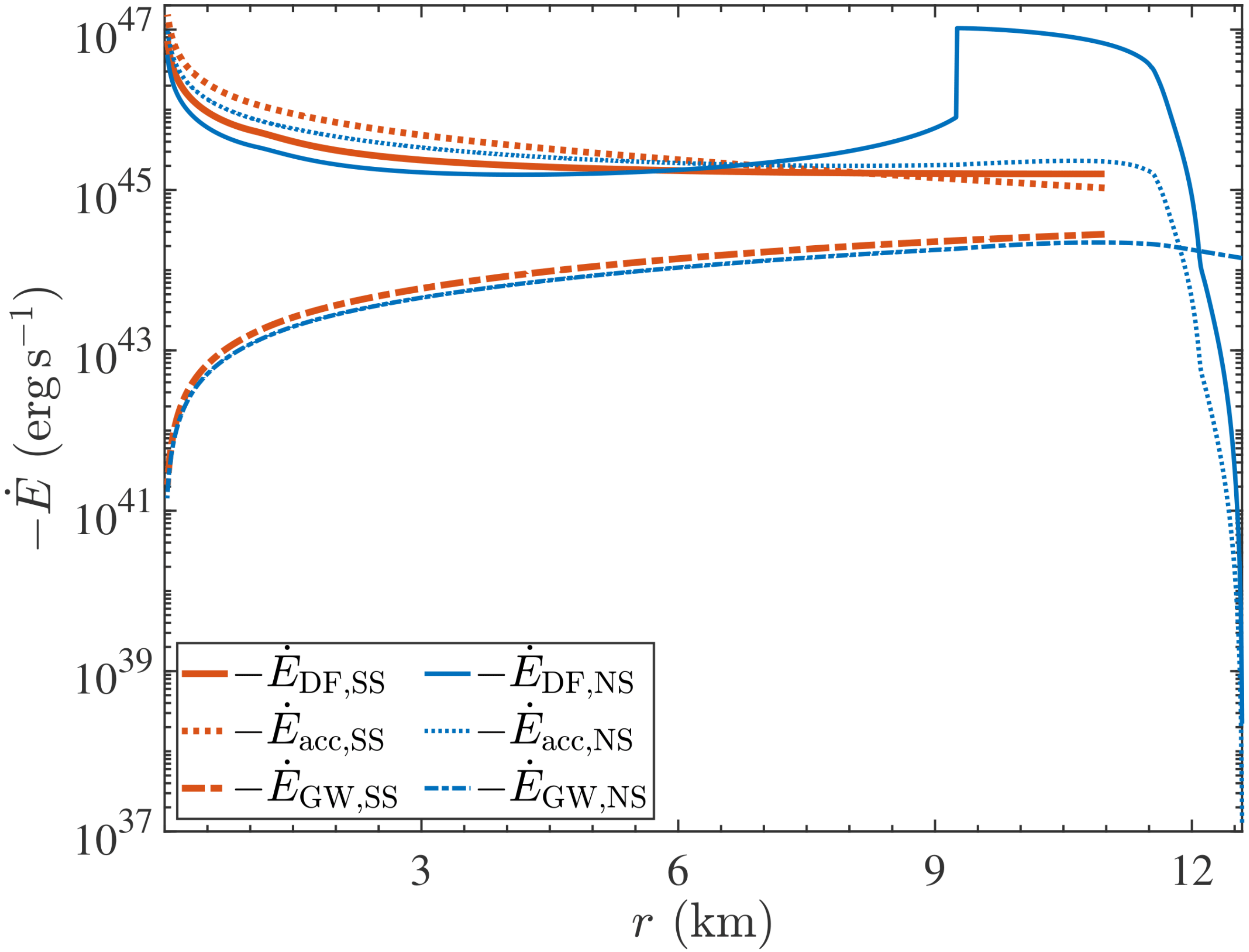
Zou & Huang (2022)

Orbit: Neutron Star vs. Strange Star





Energy-losing Channels



Zou & Huang (2022)

$m_{\rm PBH} r^2$ is **NOT** a Constant

"… is *monochromatic* with frequency $f_\star \sim$ kHz and with a *constant amplitude* estimated as

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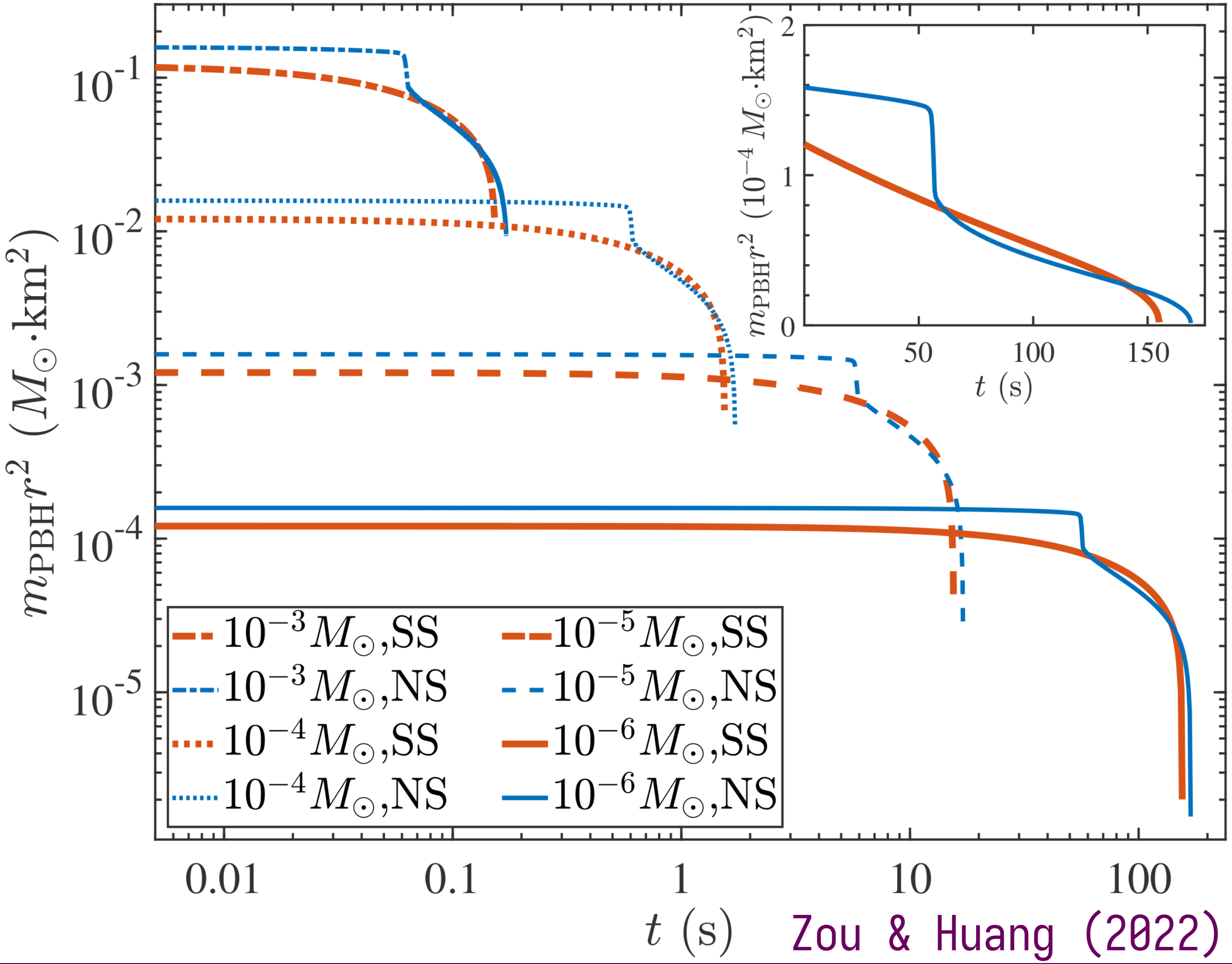
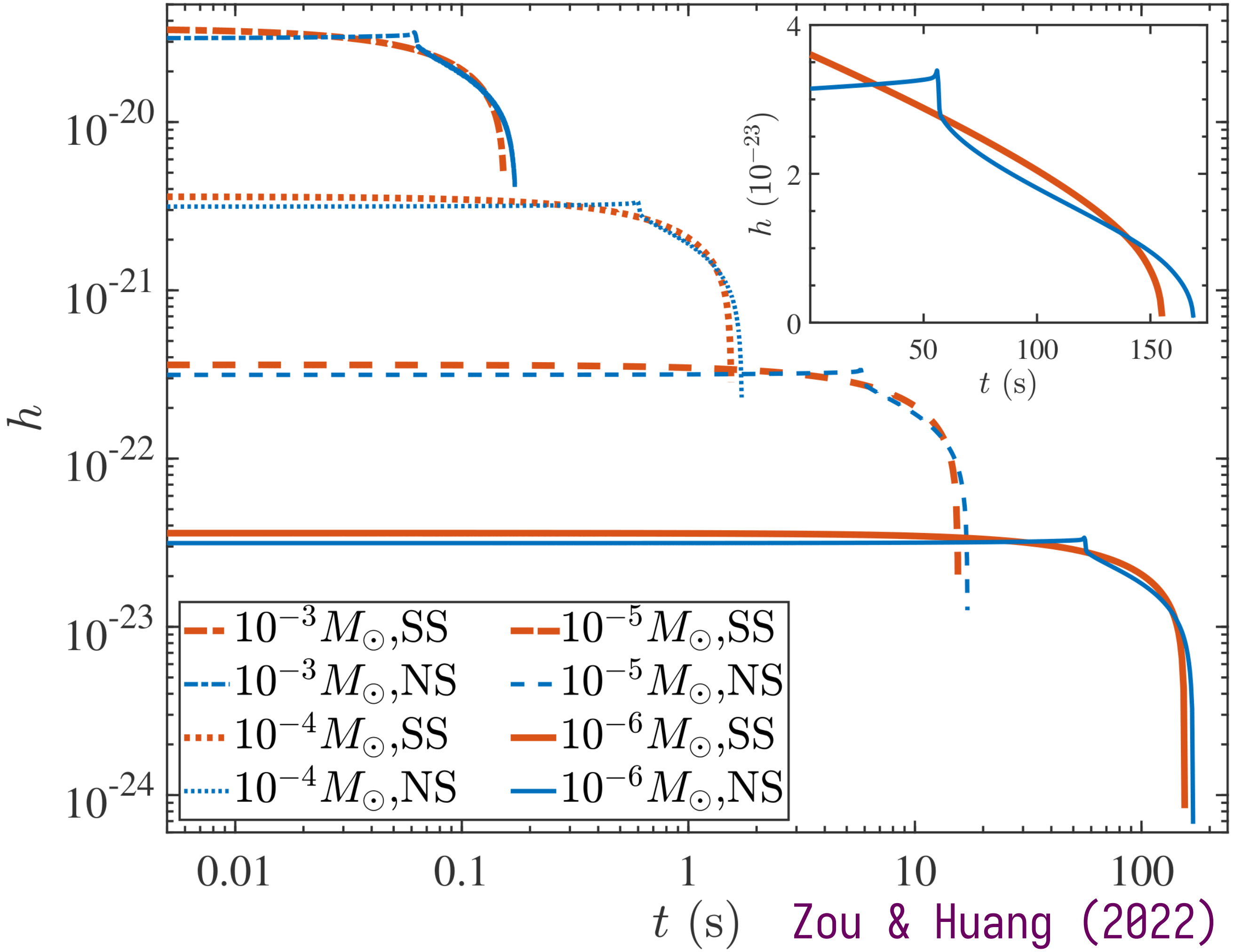


Zou & Huang (2022)

$$h_+ = -\frac{4\mu v^2}{D_\mathrm{L}} \cos 2\varphi,$$

$$h_\times = -\frac{4\mu v^2}{D_\mathrm{L}} \sin 2\varphi,$$



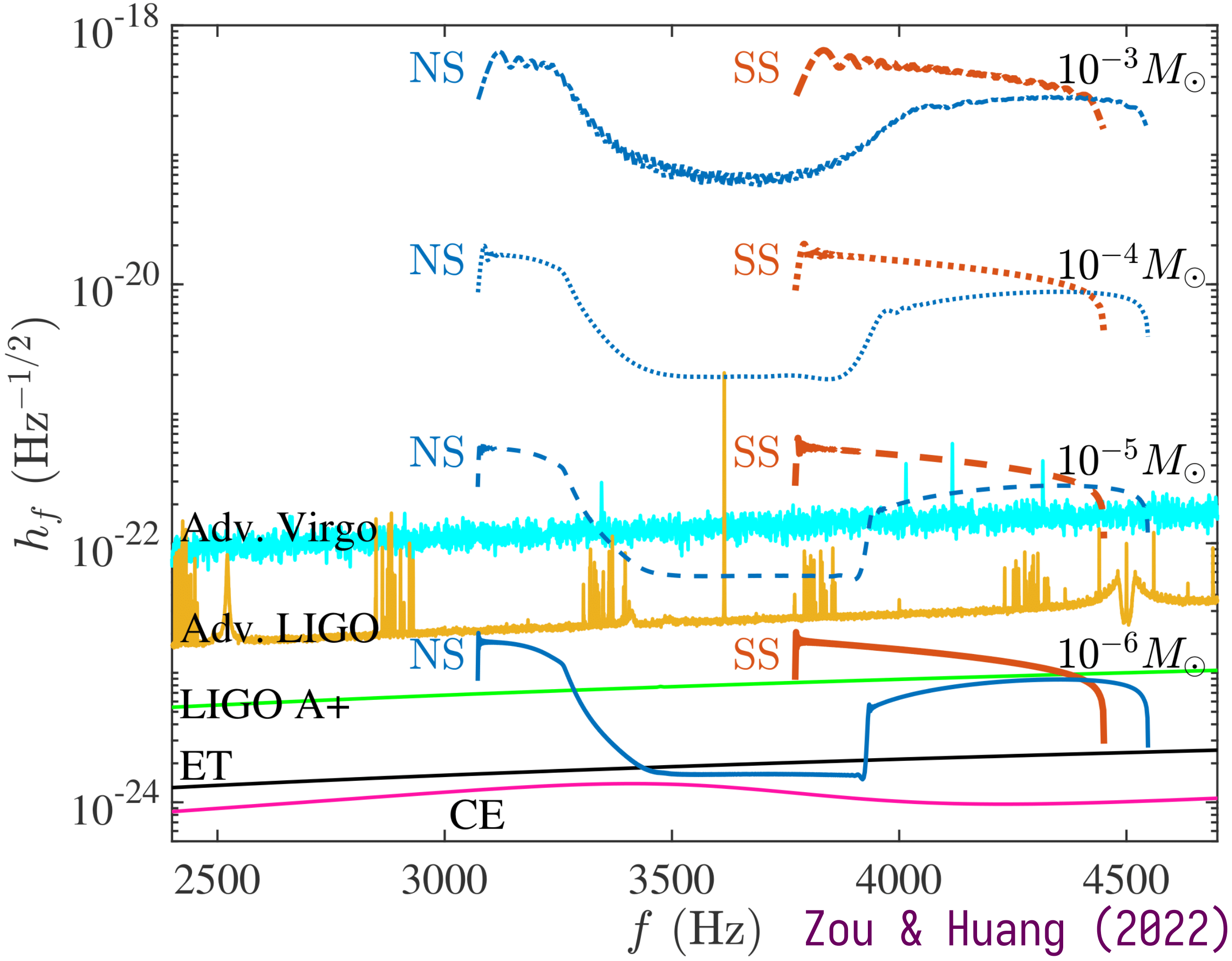
Zou & Huang (2022)

Power Spectral Density

$$h_+ = -\frac{4\mu v^2}{D_{\rm L}}\cos 2\varphi,$$

$$h_\times = -\frac{4\mu v^2}{D_{\rm L}}\sin 2\varphi,$$

$$h_f = 2f^{1/2}|\tilde{h}(f)|$$



Zou & Huang (2022)

GWs from PBH inspiraling inside compact star:

- constrain PBHs' fraction of dark matter
- probe the dense matter equation of state

Summary

GWs from PBH inspiraling inside compact star:

- constrain PBHs' fraction of dark matter
- probe the dense matter equation of state

Thank you!

Zou, Z.-C. & Huang, Y.-F.* 2022, *ApJL*, **928**:L13