NANJING UNIVERSITY

Searching for Strange Quark Matter Objects through Gravitational Waves

Speaker: Ze-Cheng Zou (邹泽城)

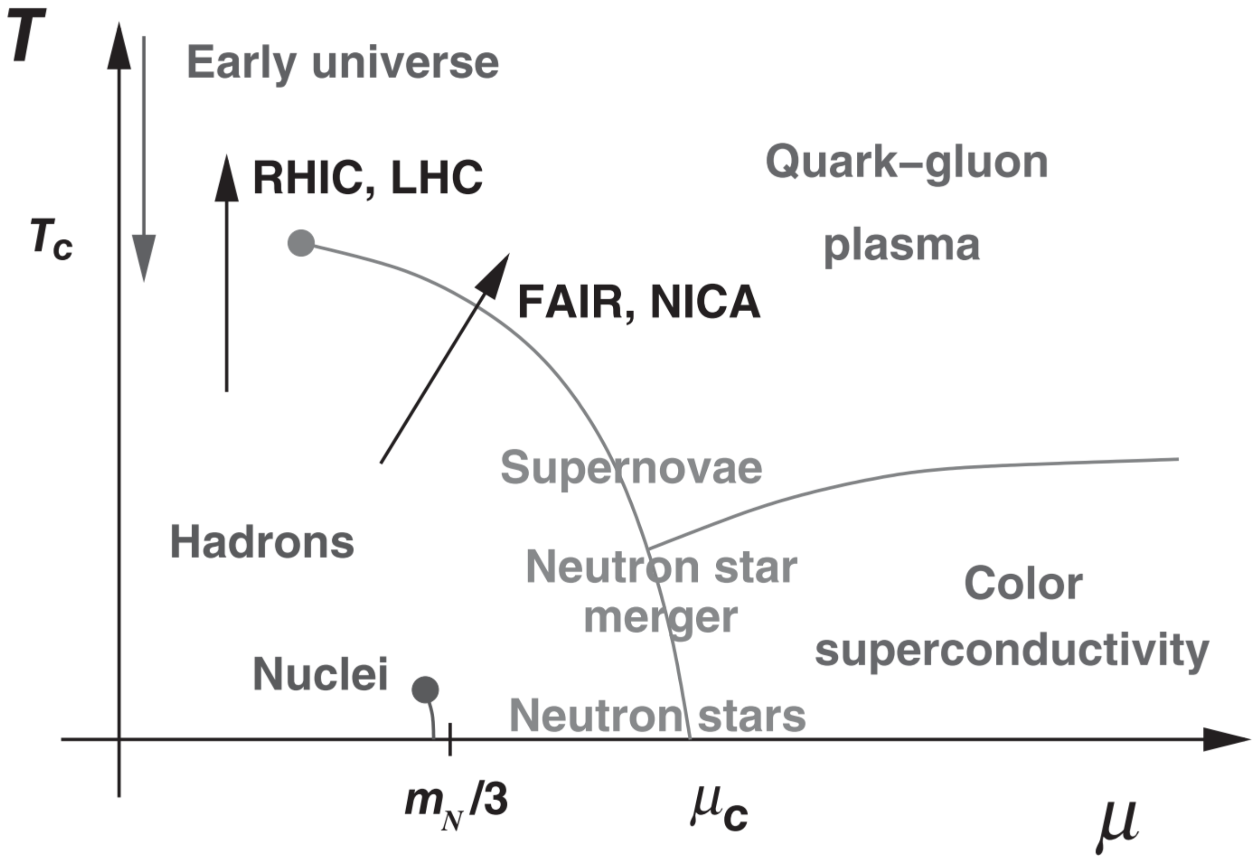
Main Contri.: Y.F.Huang, J.J.Geng, A.Kurban, X.Wang, Y.B.Yu, X.L.Zhang

Outline

- What is inside a compact star?
- Strange quark matter and strange objects
- How to differentiate them from ordinary neutron stars?
- Unique gravitational waves from strange quark matter objects

What is inside a compact star?

- About saturation density n_0
  - Experimental constraints
  - Effective theories work well
- Well above $2n_0$
  - ?



Schaffner-Bielich 2020

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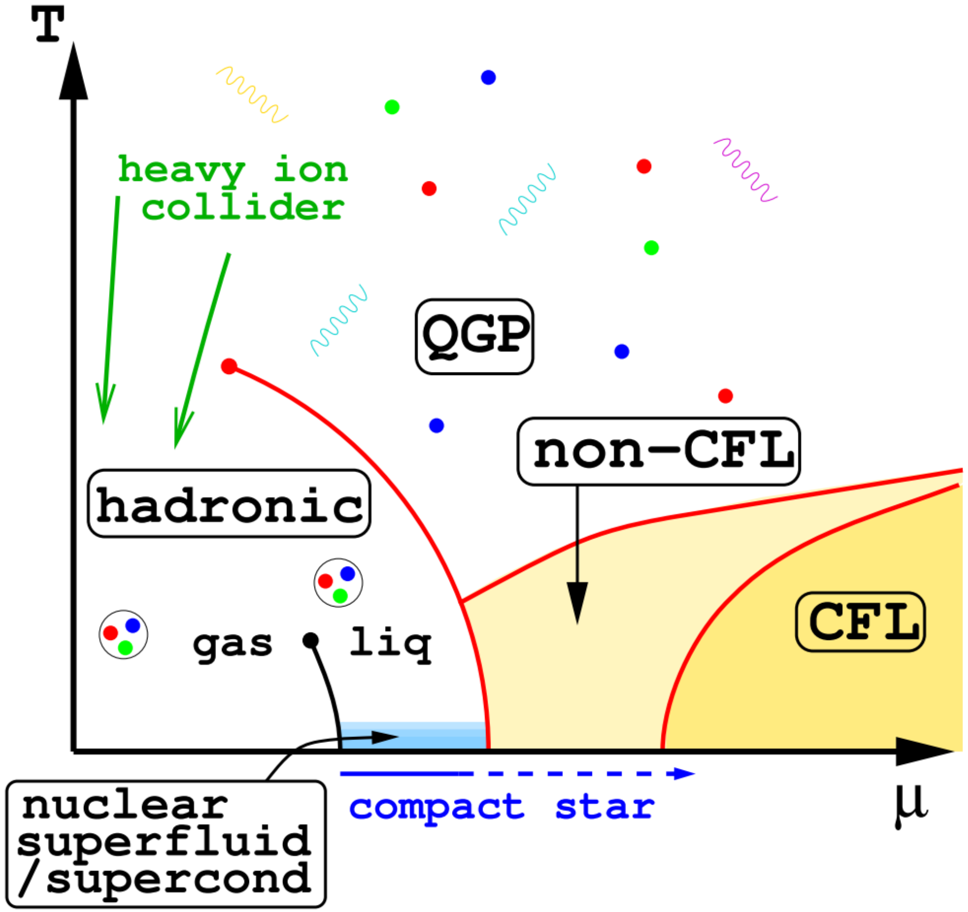

Alford 2019

What is inside a compact star?

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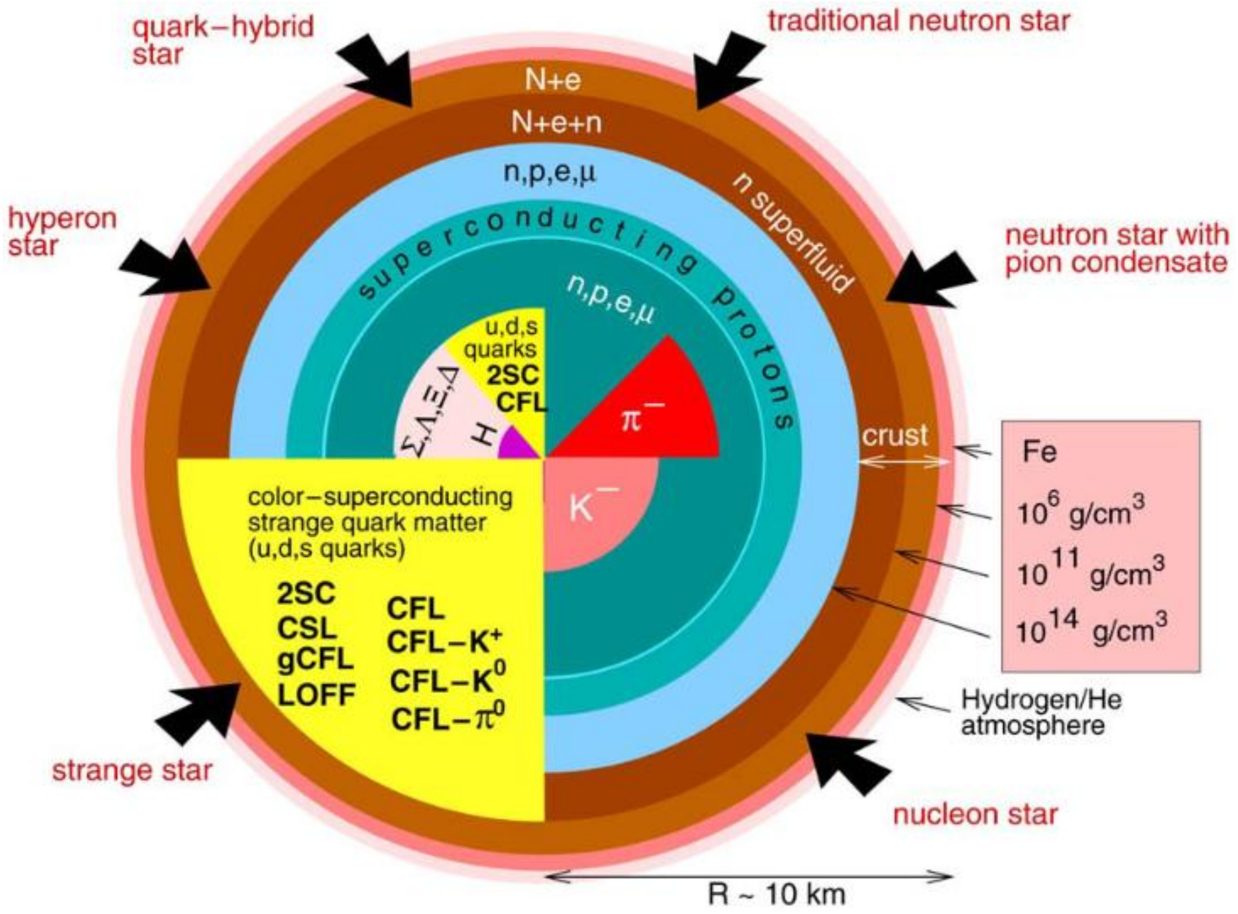
- Well above $2n_0$
  - Pure *npe* matter?
  - Hyperons?
  - Meson condensates?
  - Quarks?
  - ...



Weber 2005

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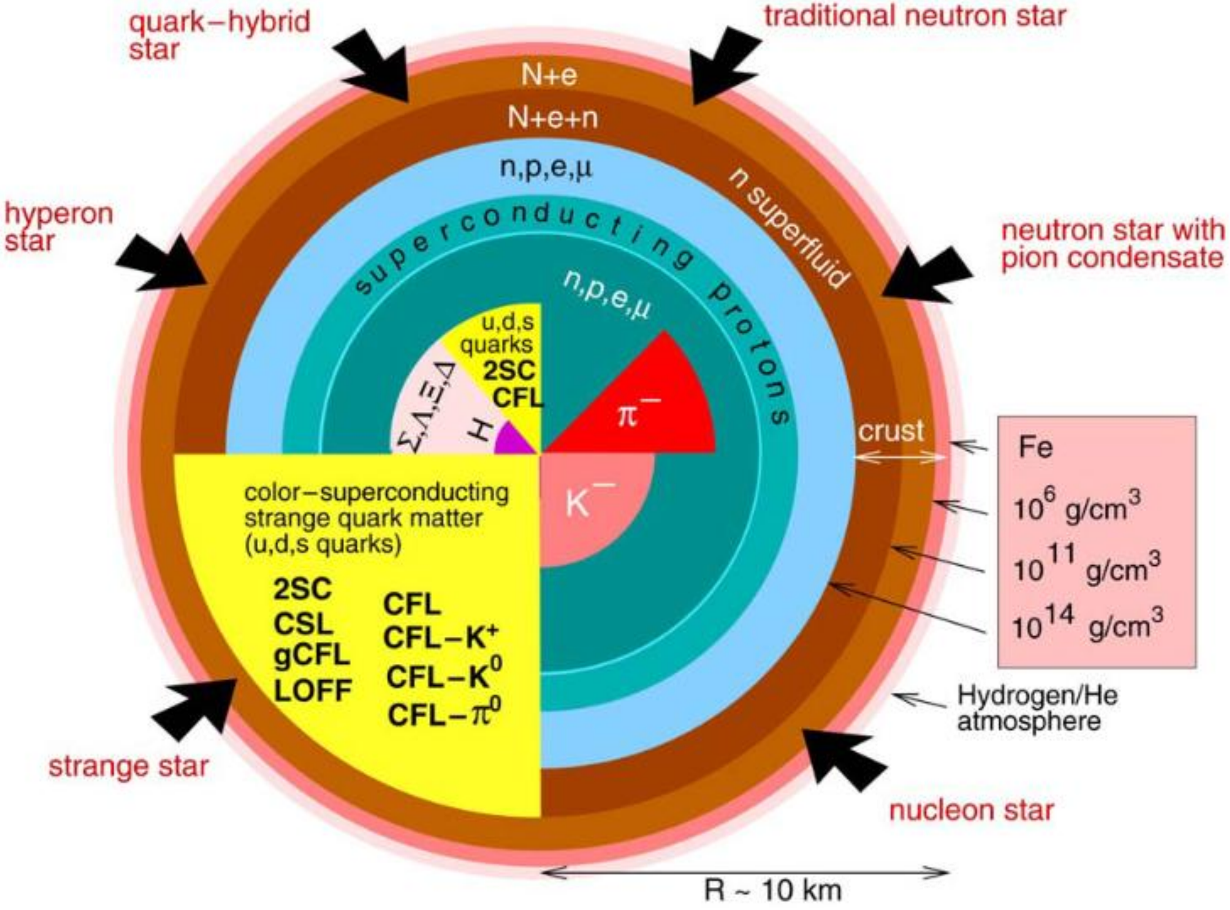
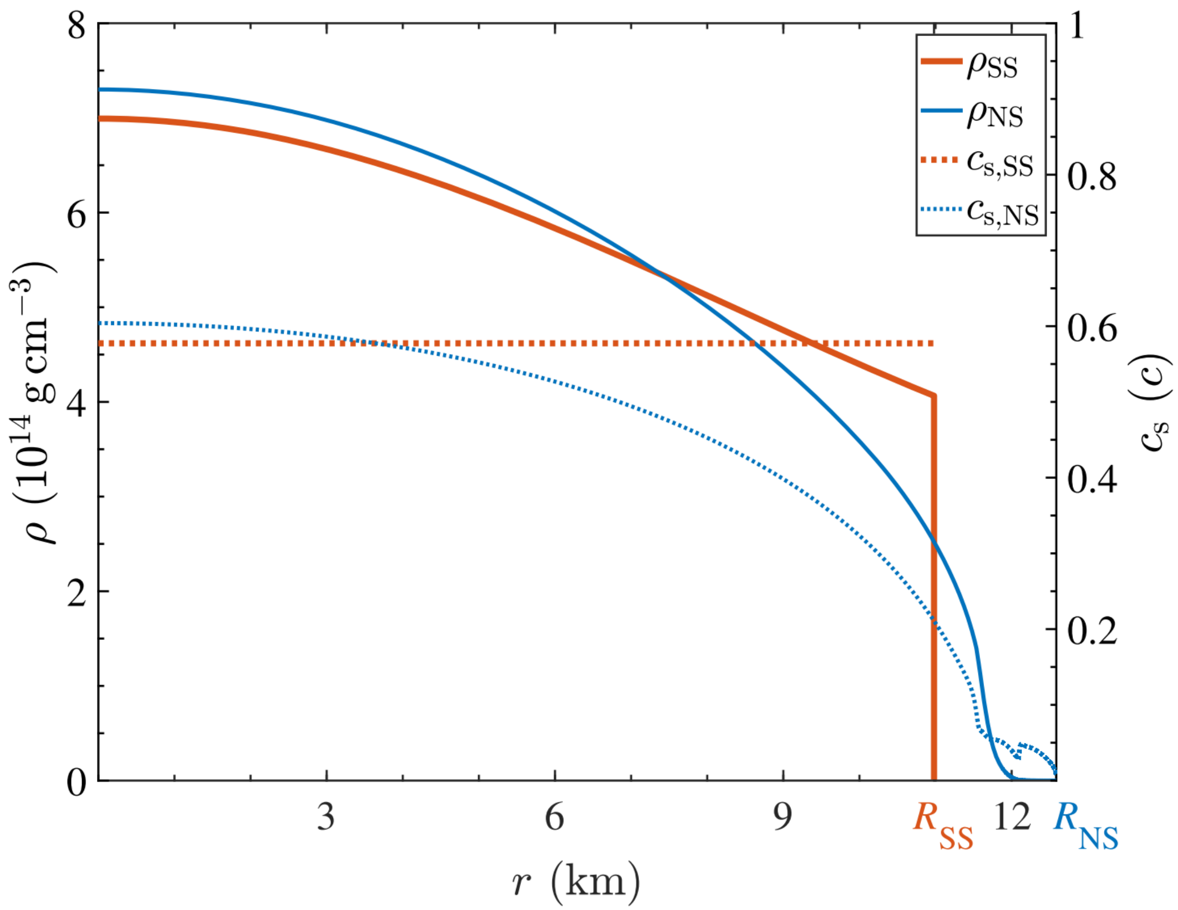
  - ...
- **Self-bound** quark matter?



Weber 2005

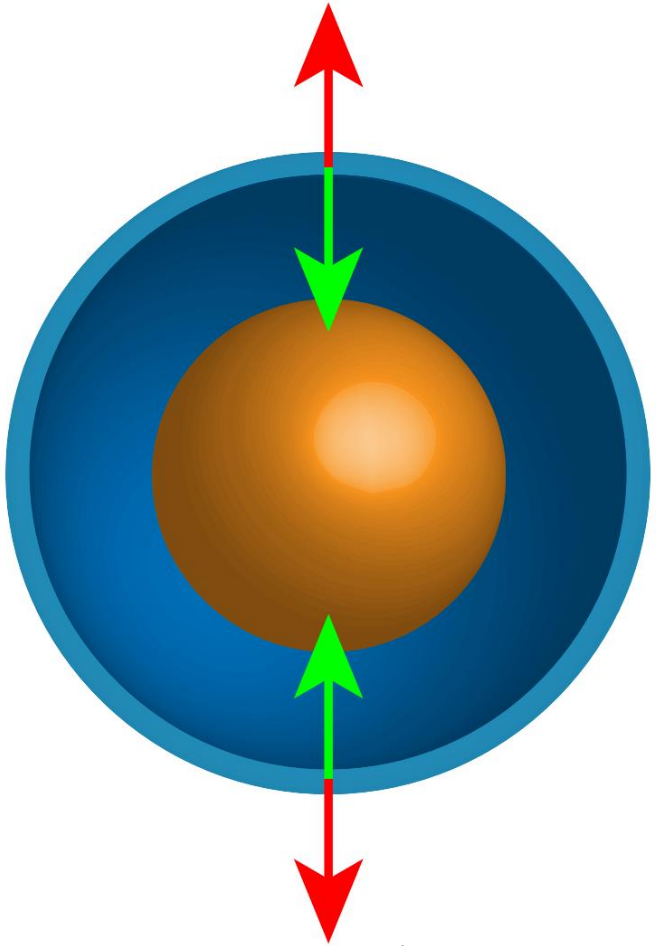
Strange quark matter (SQM)

- Composed of free quarks
  - *uds*
- SQM hypothesis
  - SQM may be absolutely stable
  - Self-bound

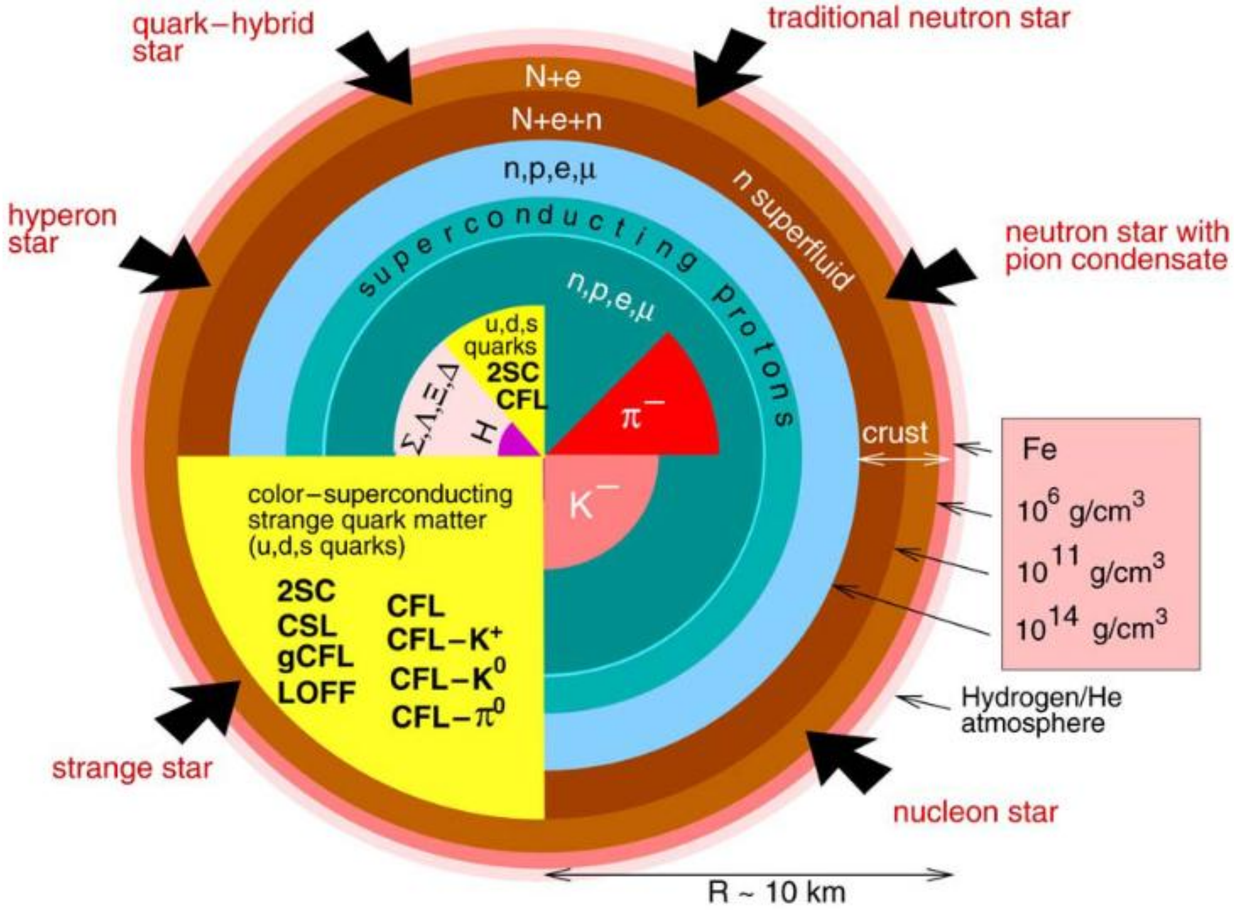


Zou & Huang 2022

What is inside a compact star?

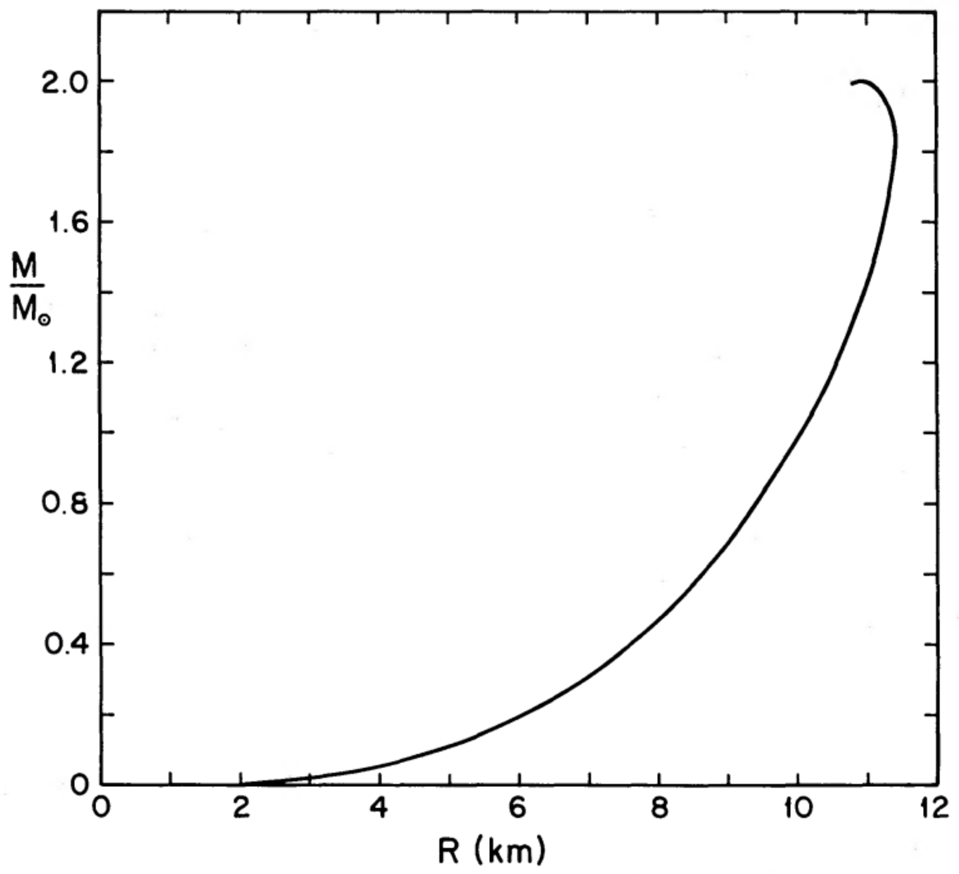


Zou+2022

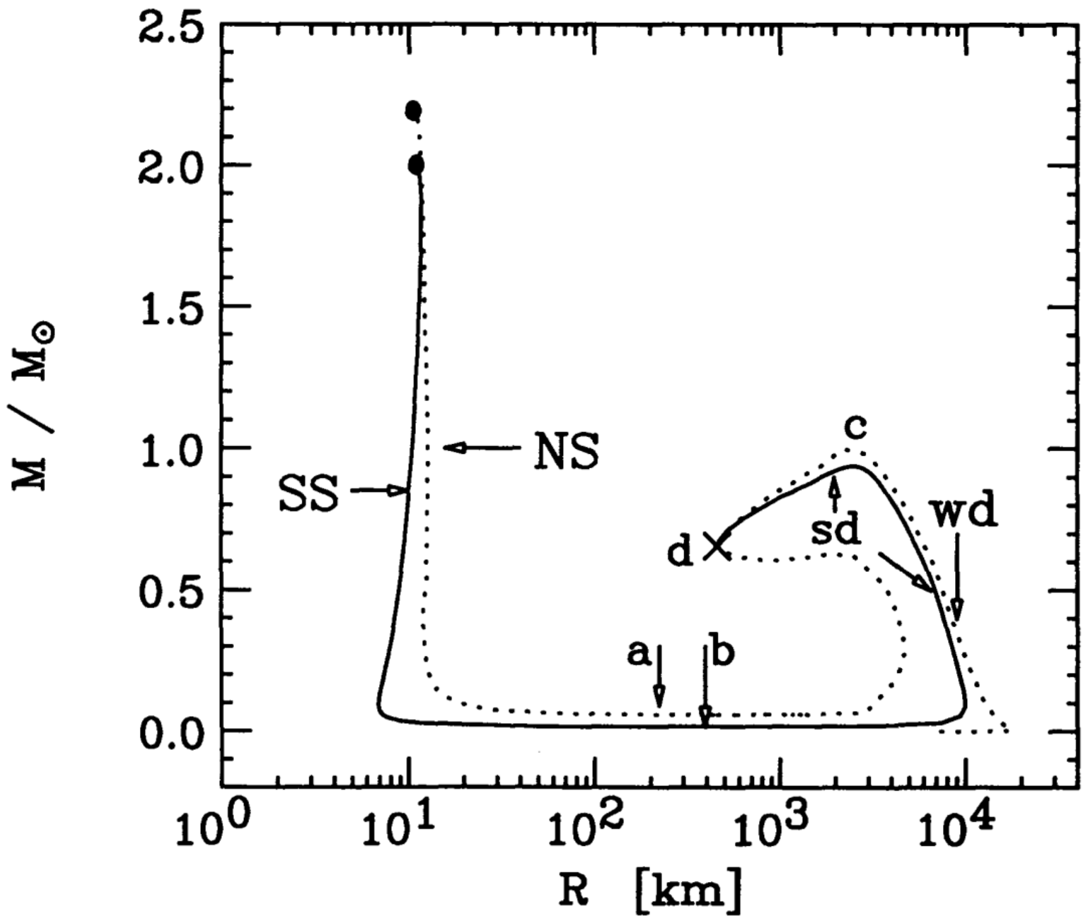


Weber 2005

SQM objects



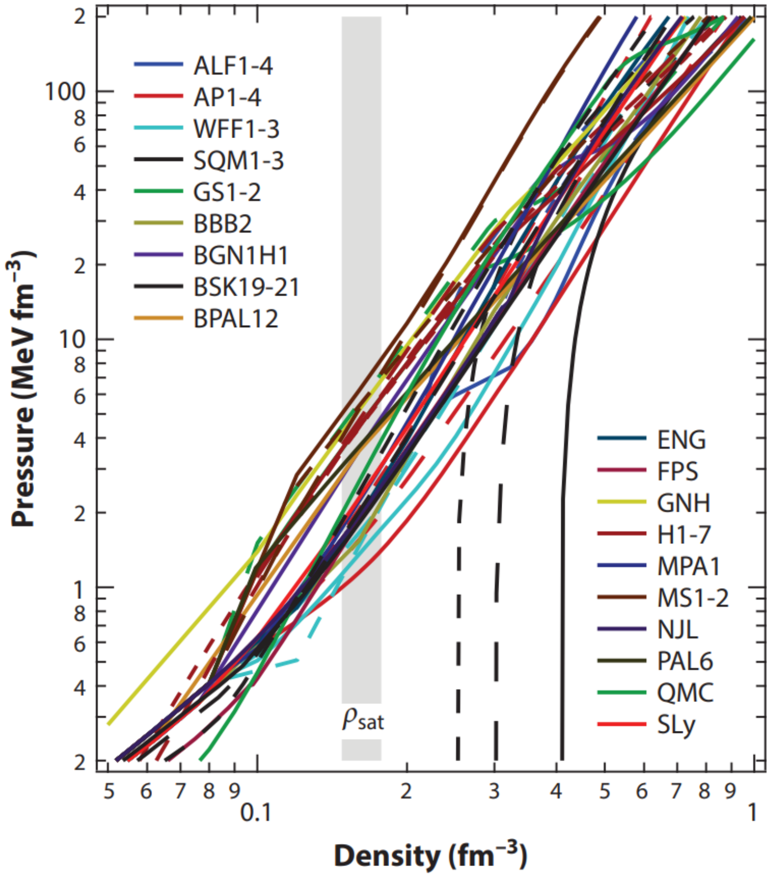
Alcock+1986



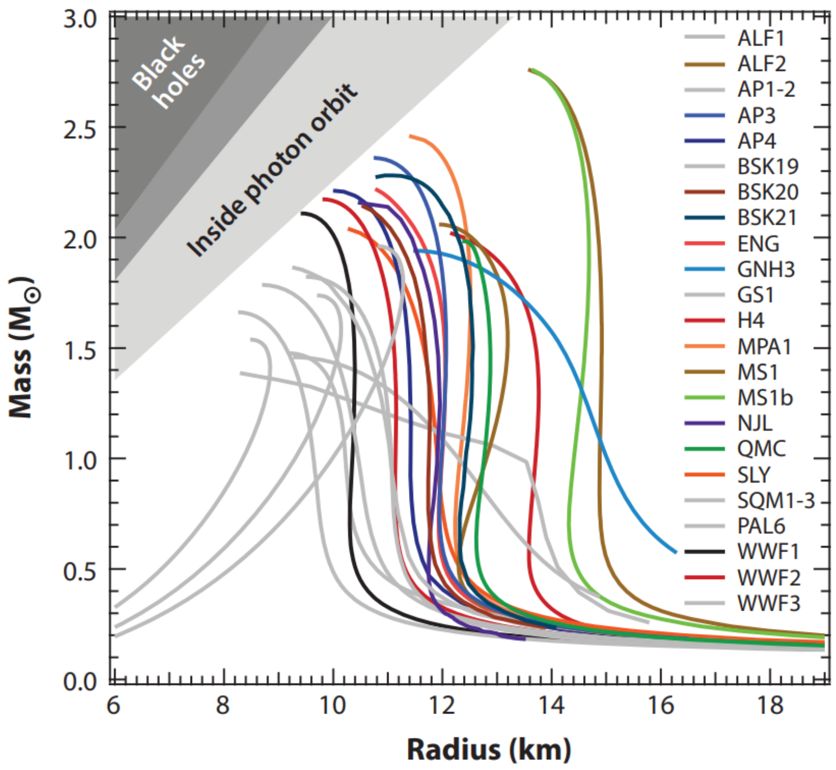
Glendenning 1995

Strange stars vs Neutron stars

- Mass-radius relation

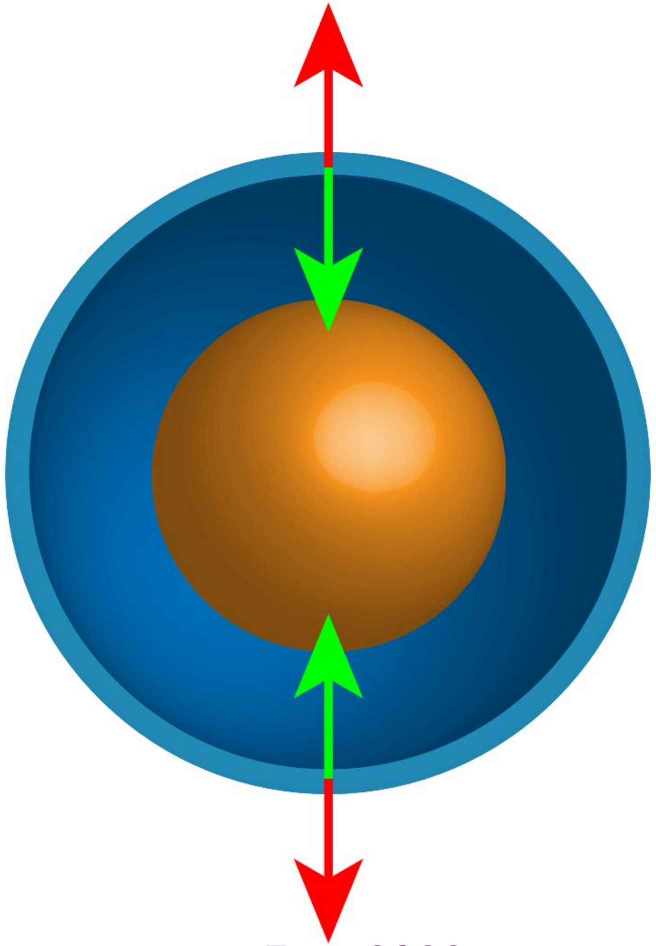


Özel & Freire 2016



Strange stars vs Neutron stars

- Mass-radius relation
- Maximum spin
- Cooling
- Tidal deformation
- Stellar oscillation



Zou+2022

Strange stars vs Neutron stars

- Mass-radius relation
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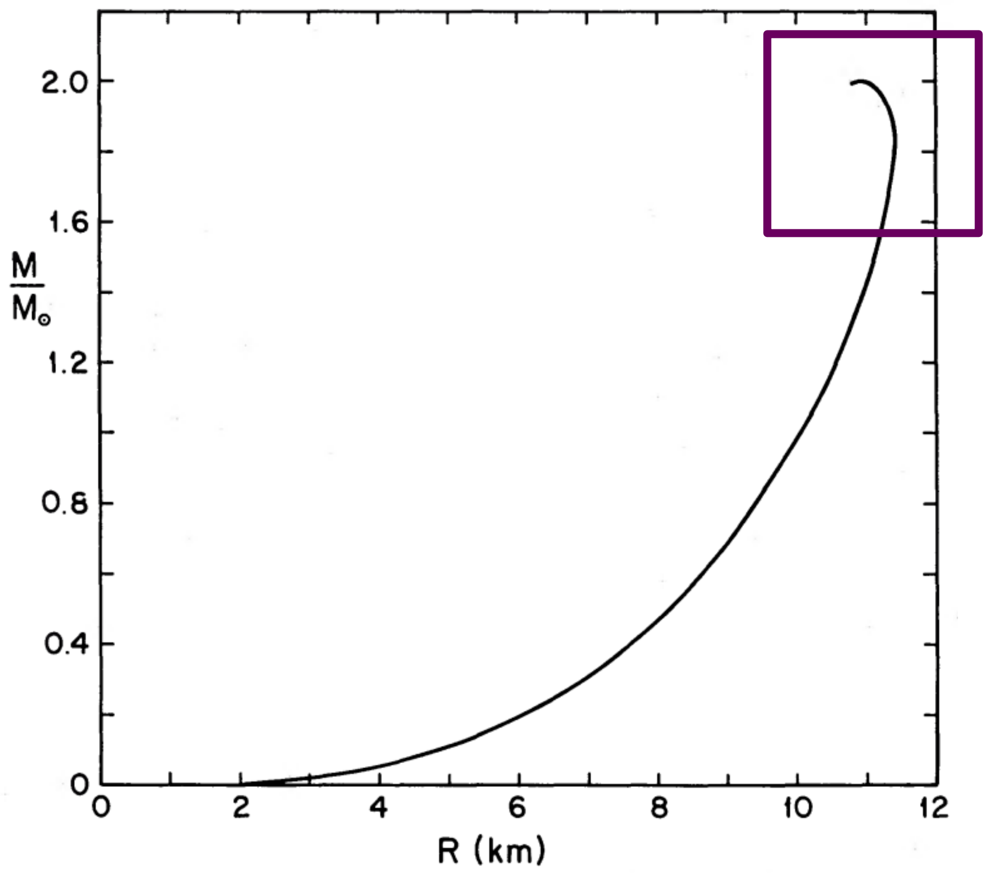
- Stellar oscillation
- **That we have no definite consensus is the only consensus we have.**

SQM objects



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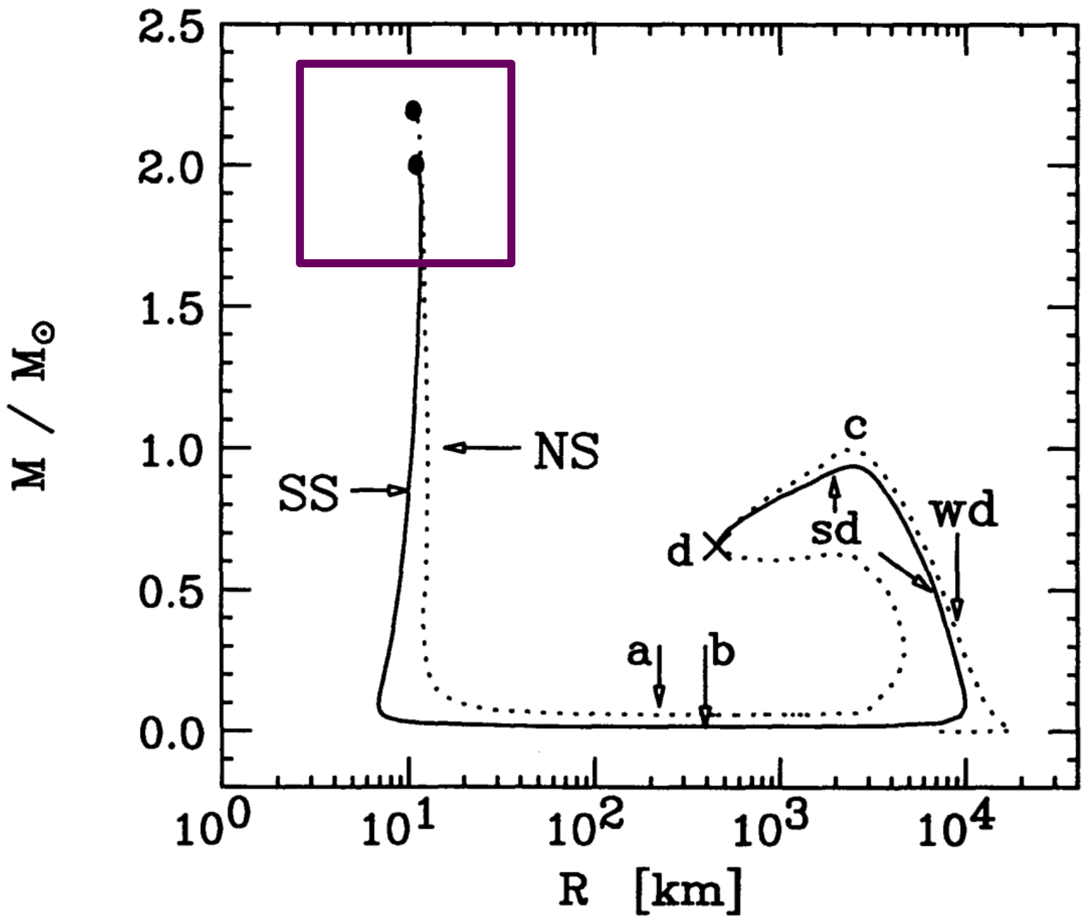
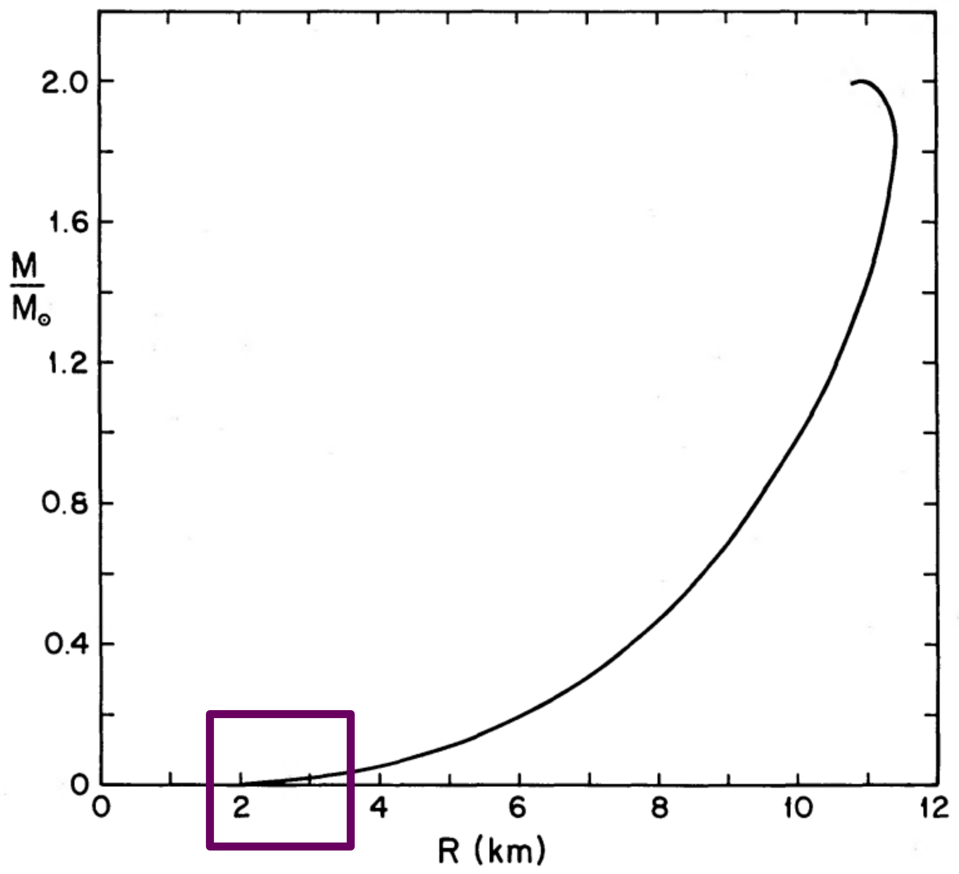


Glendenning 1995

SQM objects



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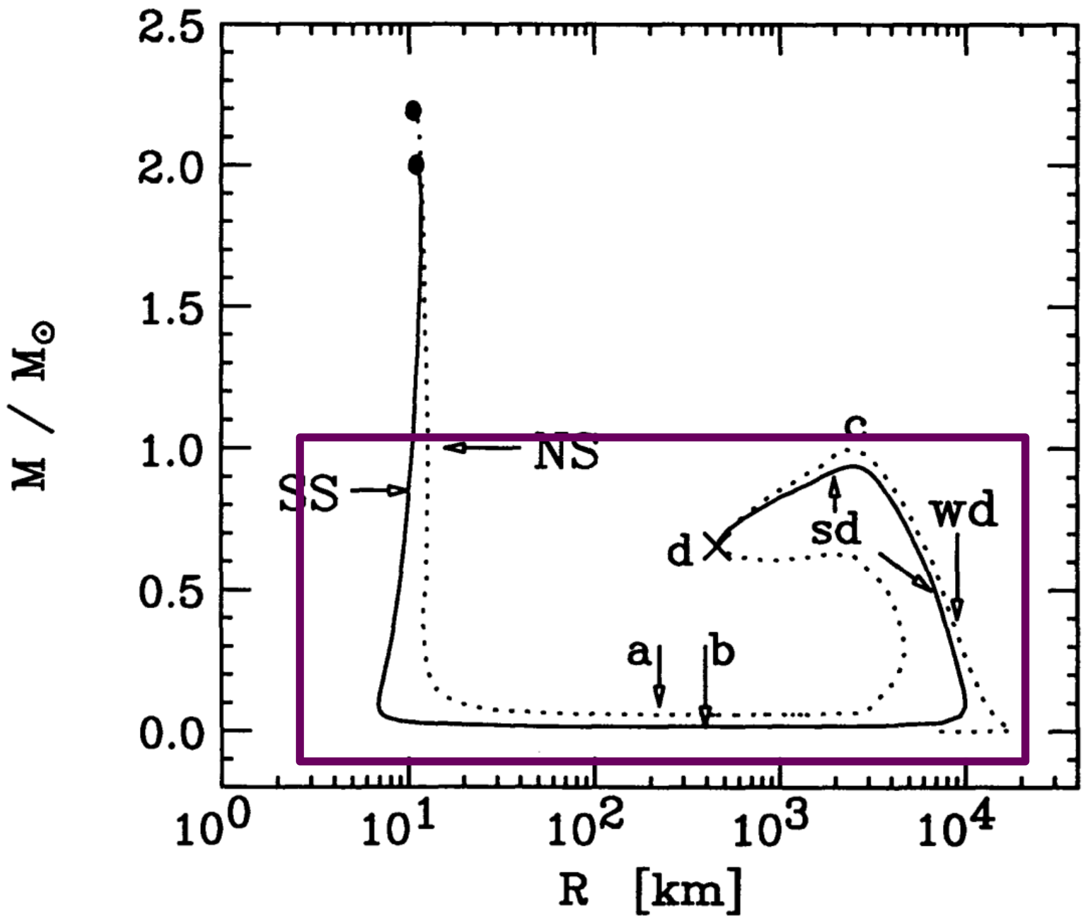

Glendenning 1995

At the low central pressure end...

- (Bare) strange planets vs normal planets
- (Crusted) strange dwarfs vs white dwarfs
- **SQM objects are more compact**
  - $P = (\rho - 4B)/3$, $P \to 0$, $\rho \to 4B \sim 4 \times 10^{14} \mathrm{g\,cm^{-3}}$
  - **Where to find?**
  - **How to distinguish?**

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Close-in “planets” of compact stars

- The normal disrupted, the strange survives.
- $r_{\mathrm{td}} \approx 5.1 \times 10^{10} \left(\frac{\rho}{10\ \mathrm{g\,cm^{-3}}}\right)^{-1/3}\ \mathrm{cm} \approx 1.5 \times 10^{6} \left(\frac{\rho}{4{\times}10^{14}\ \mathrm{g\,cm^{-3}}}\right)^{-1/3}\ \mathrm{cm}$

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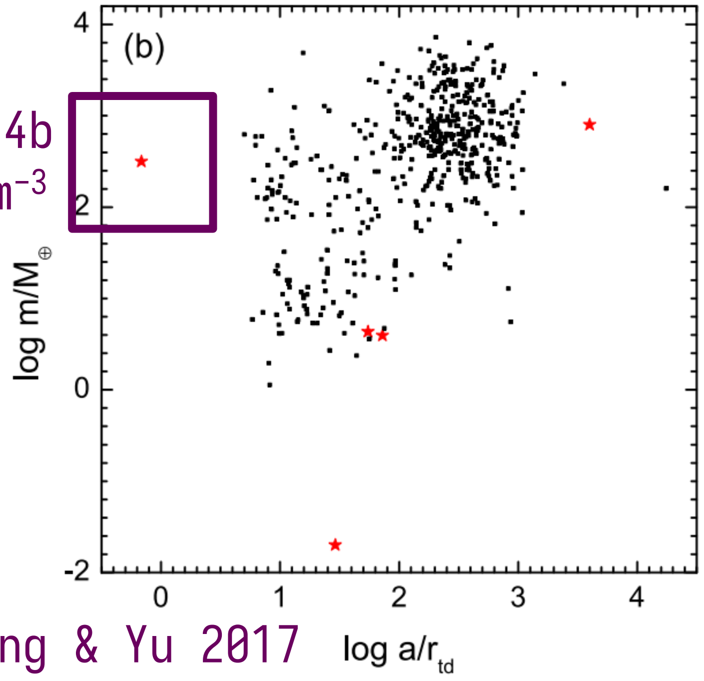
PSR J1719-14b
ρ > 23 g cm^{-3}



Huang & Yu 2017

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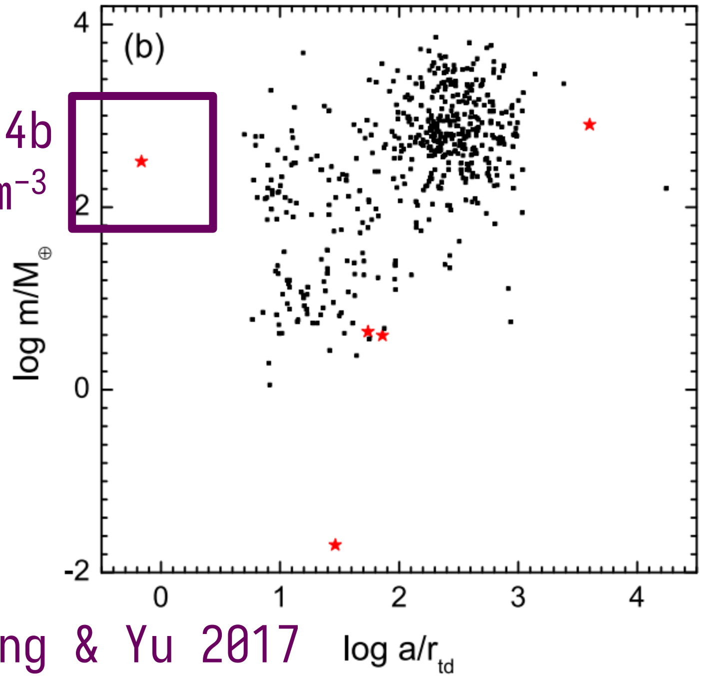
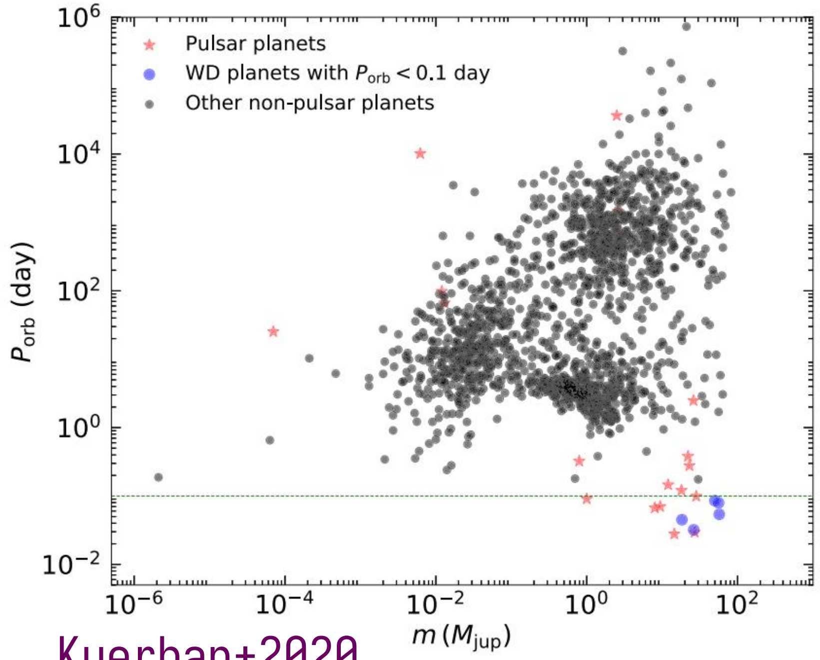


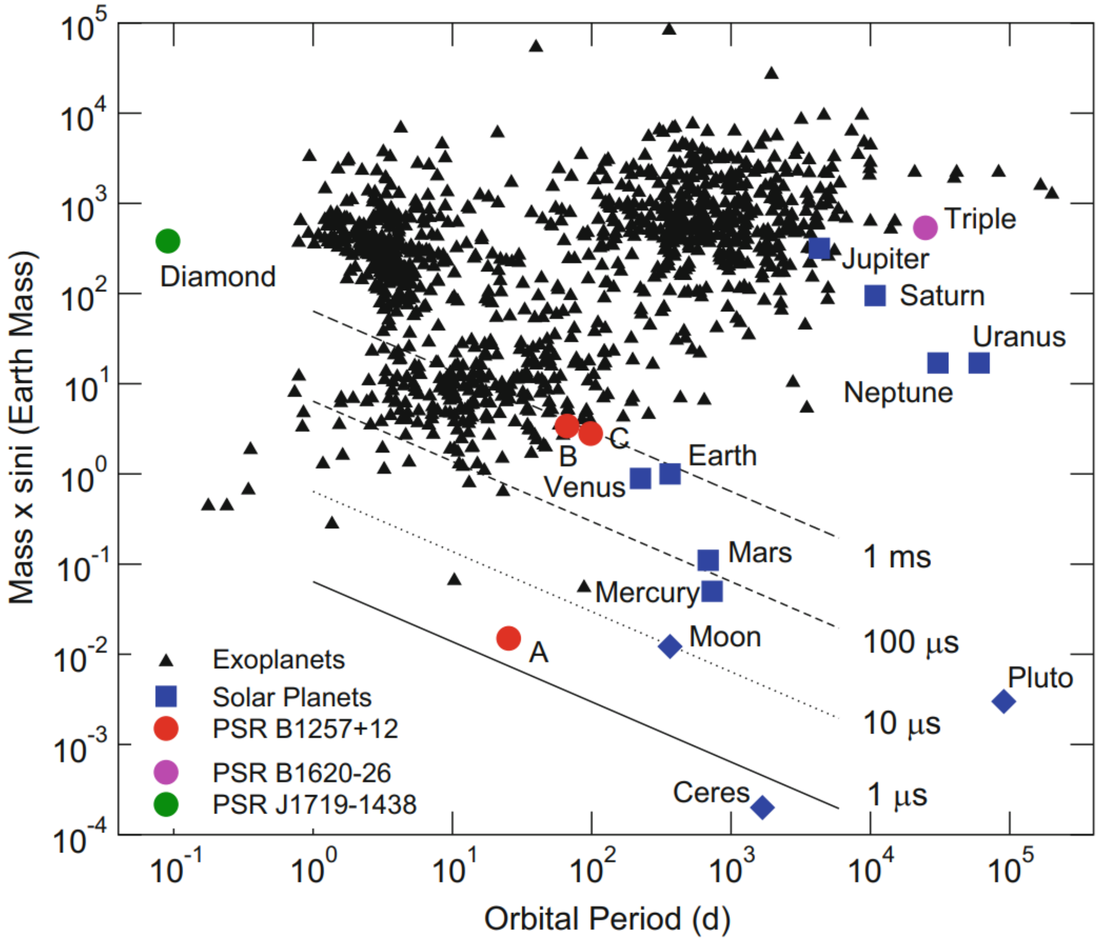
Huang & Yu 2017



Kuerban+2020

How to find and distinguish?

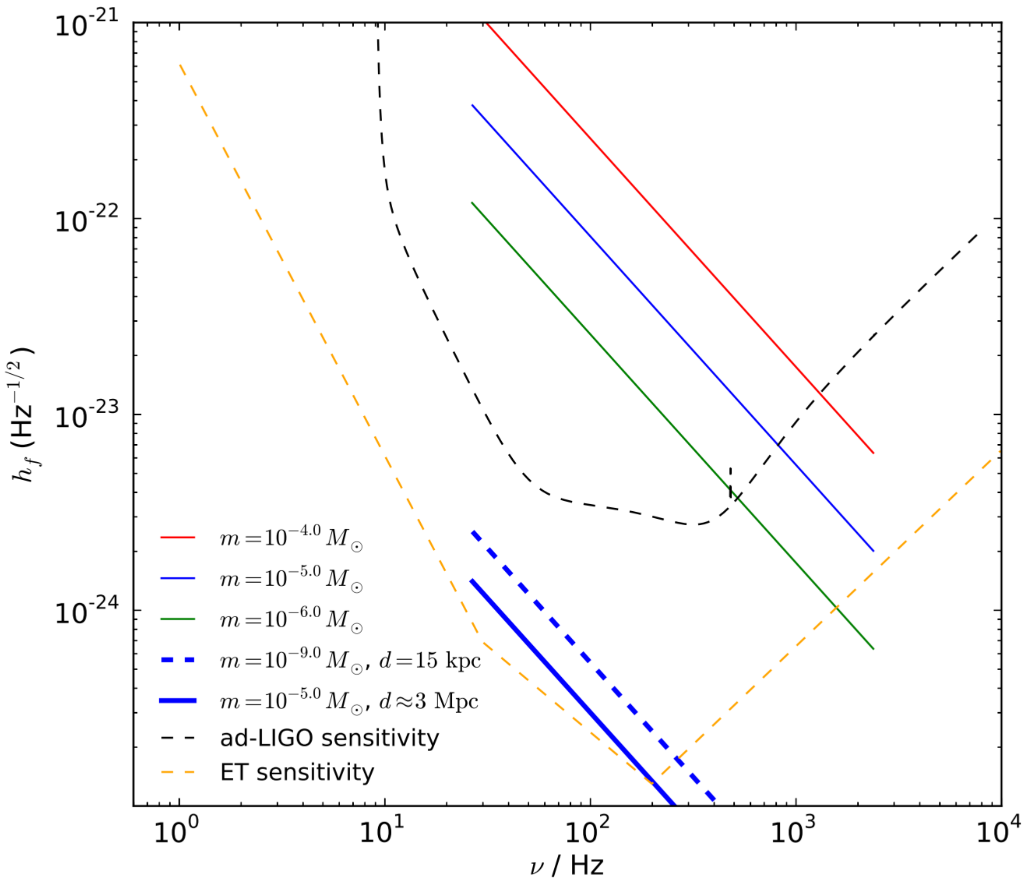
- Radio timing method favorites massive planet in **large** orbit



Kramer 2018

How to find and distinguish?

- Radio timing method favorites massive planet in **large** orbit
- Gravitational waves favorites massive planet in **tight** orbit



Geng+2015

Gravitational Waves from SQM object systems

- Radio timing method favorites massive planet in **large** orbit
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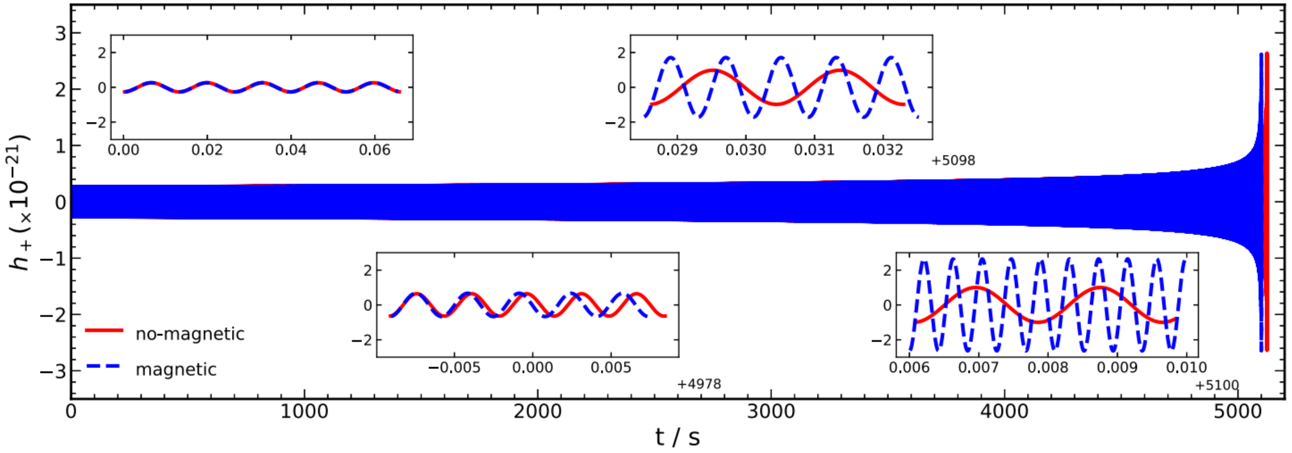
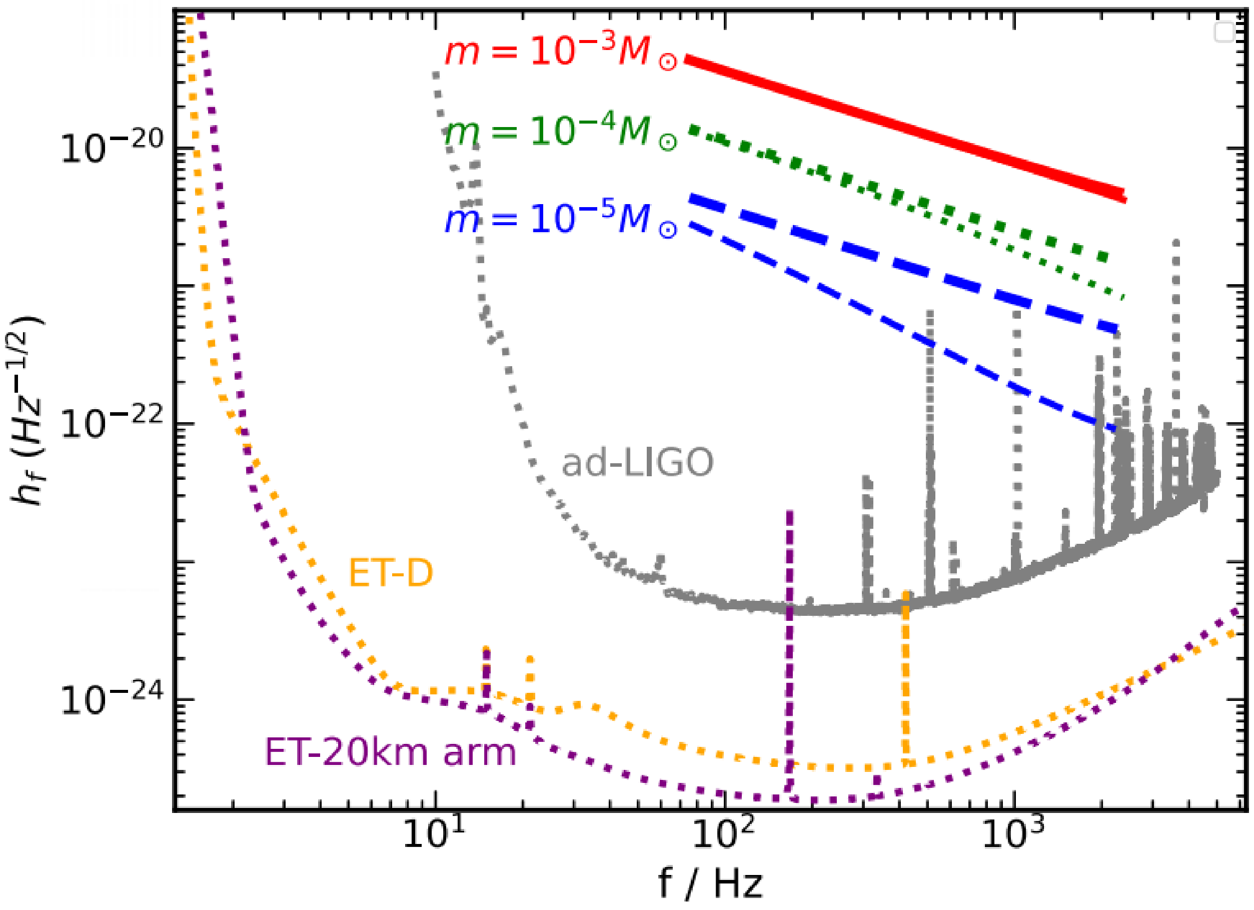
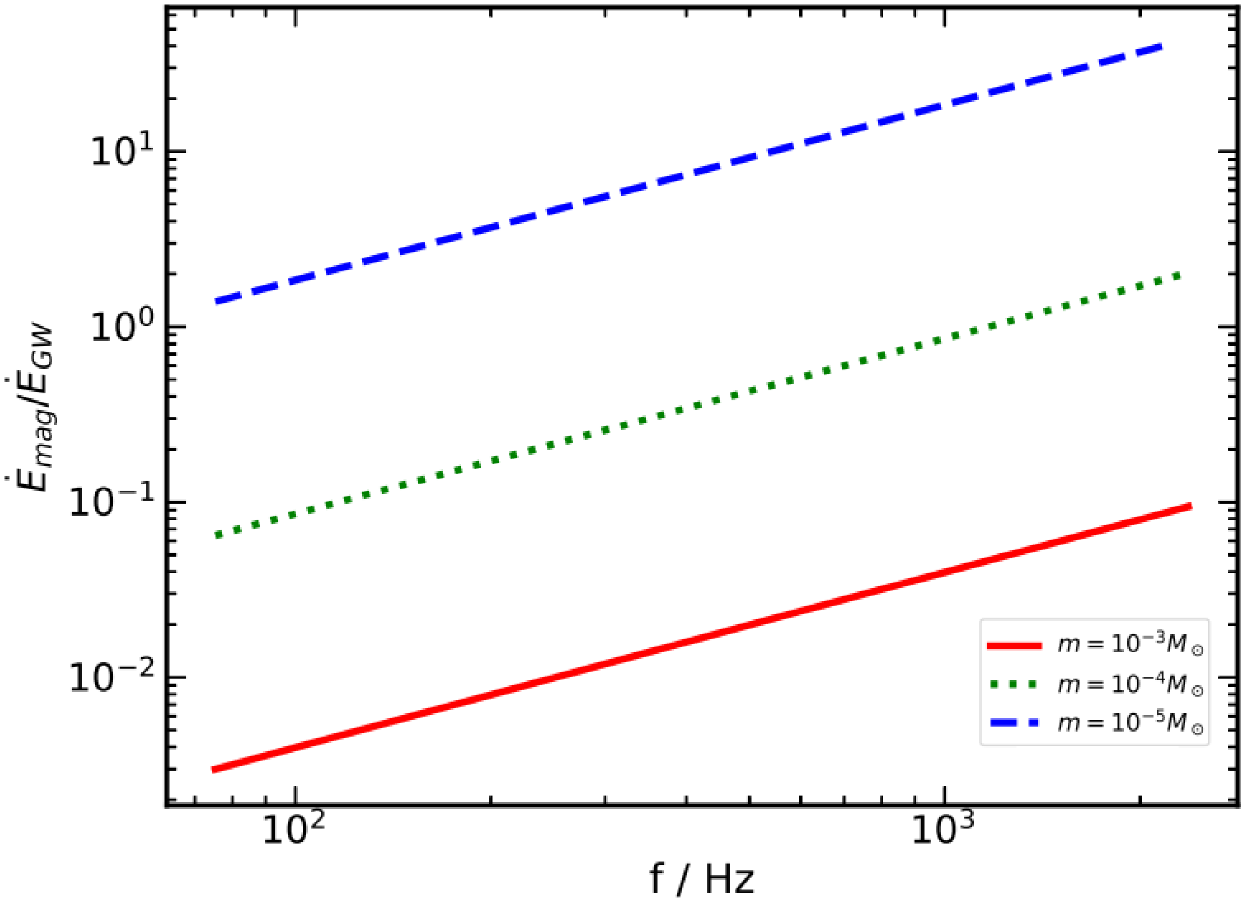
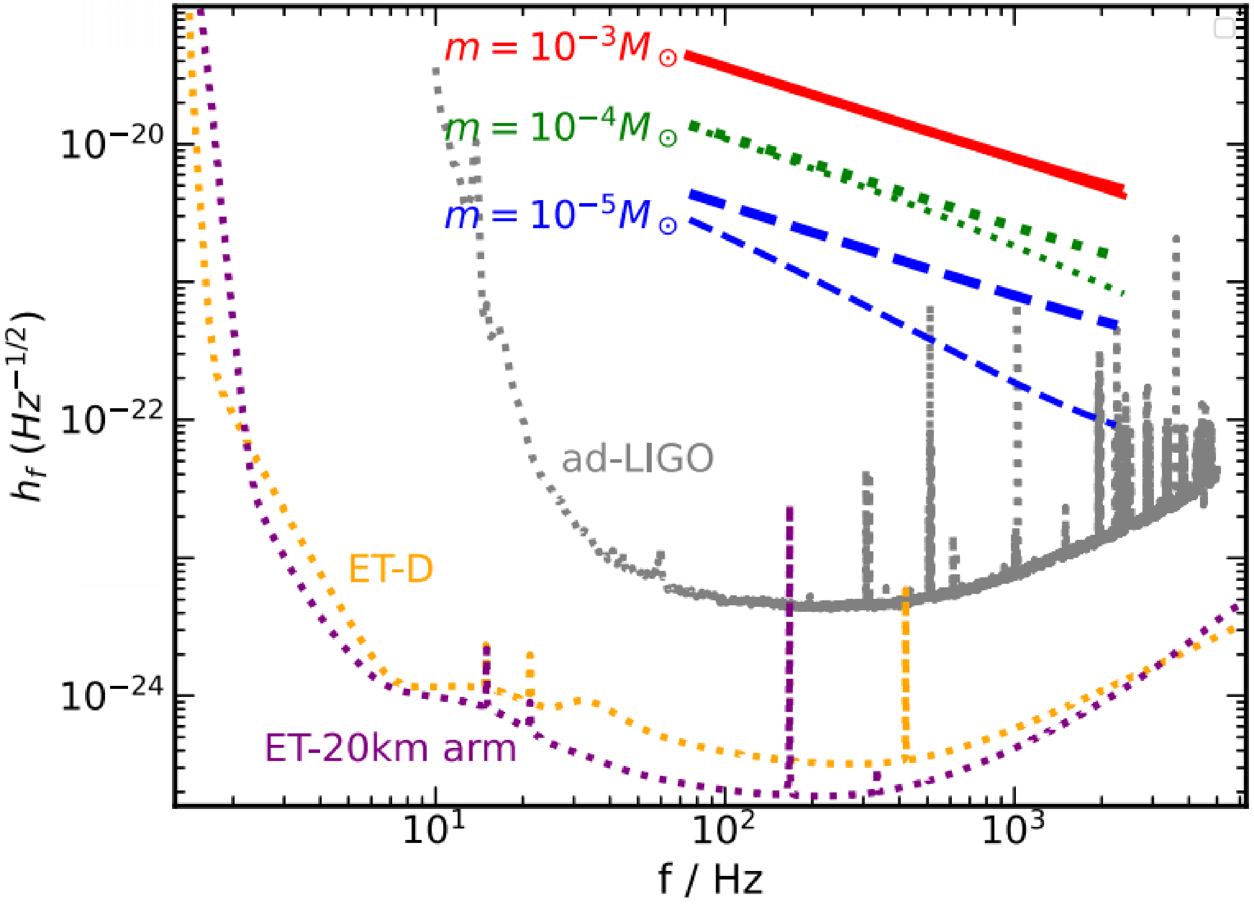




Zhang, Zou, Huang+2024



Zou+2024



Zhang, Zou, Huang+2024

What if...

- the strange planet is a primordial black hole (PBH)?

What if...

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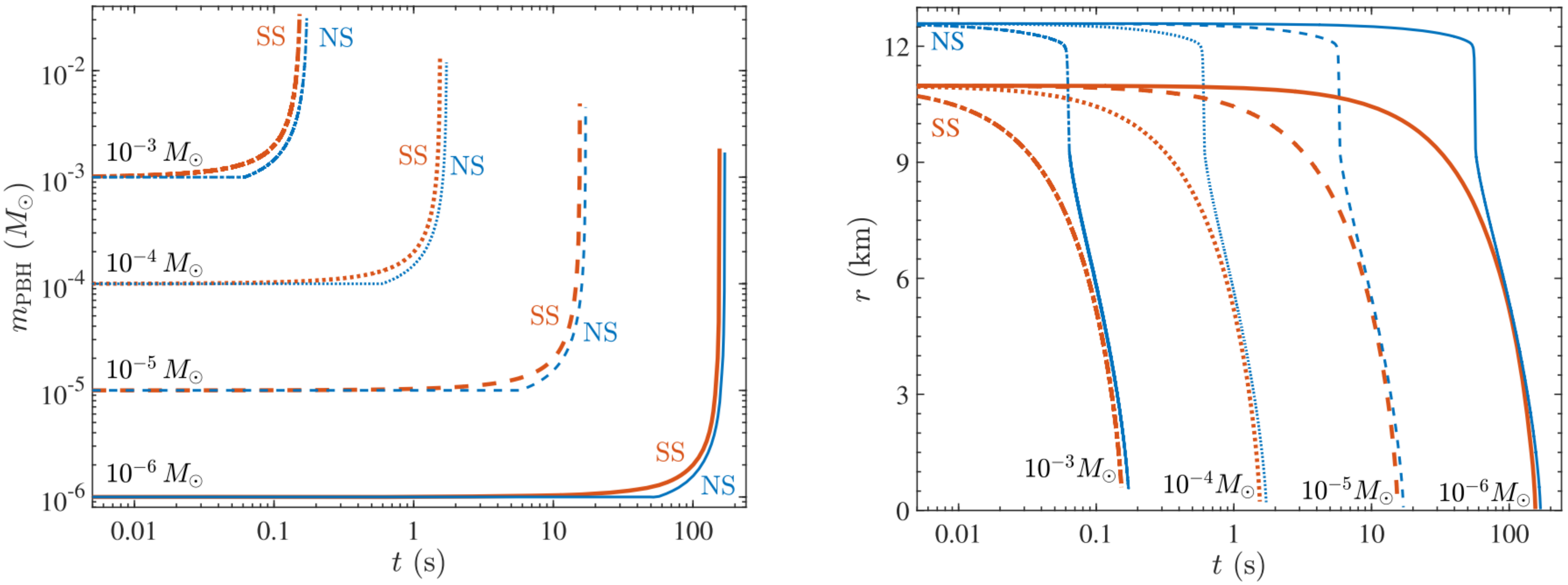
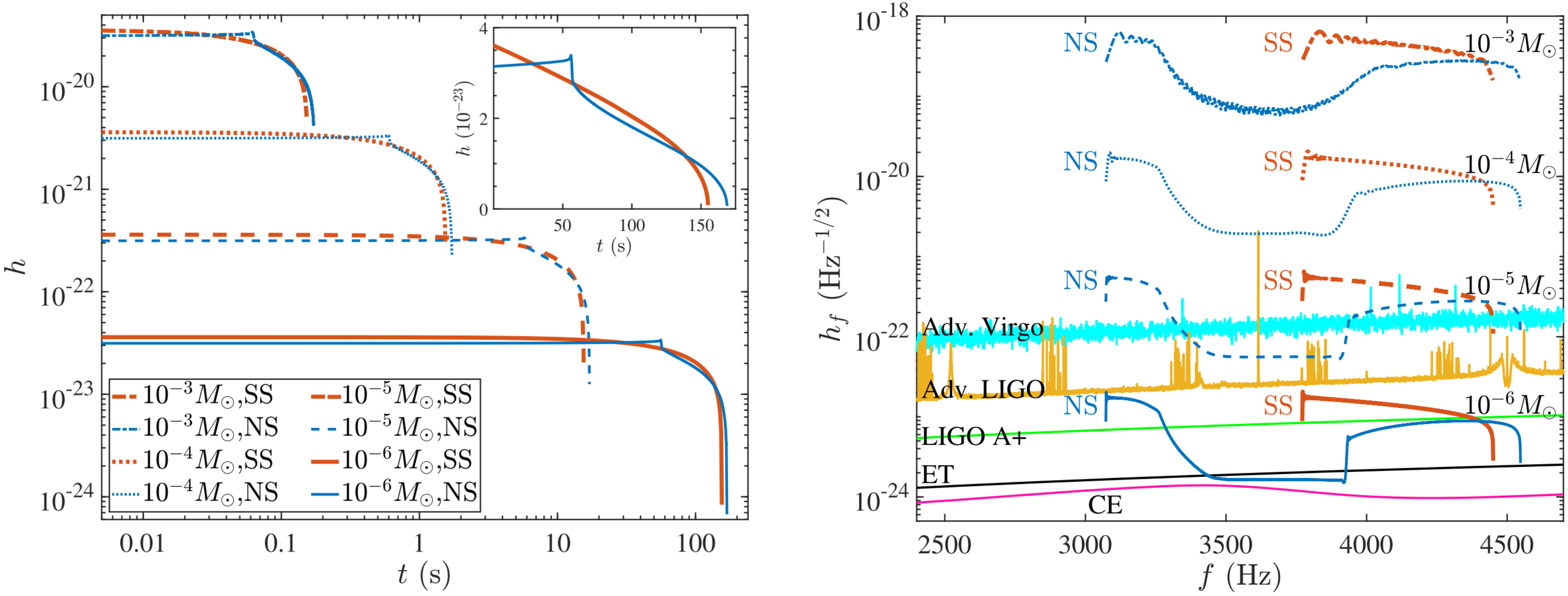
  - Strange planet merges and ringdowns
  - PBH tunnels inside

PBH inside a strange star and a neutron star



Zou & Huang 2022

PBH inside a strange star and a neutron star



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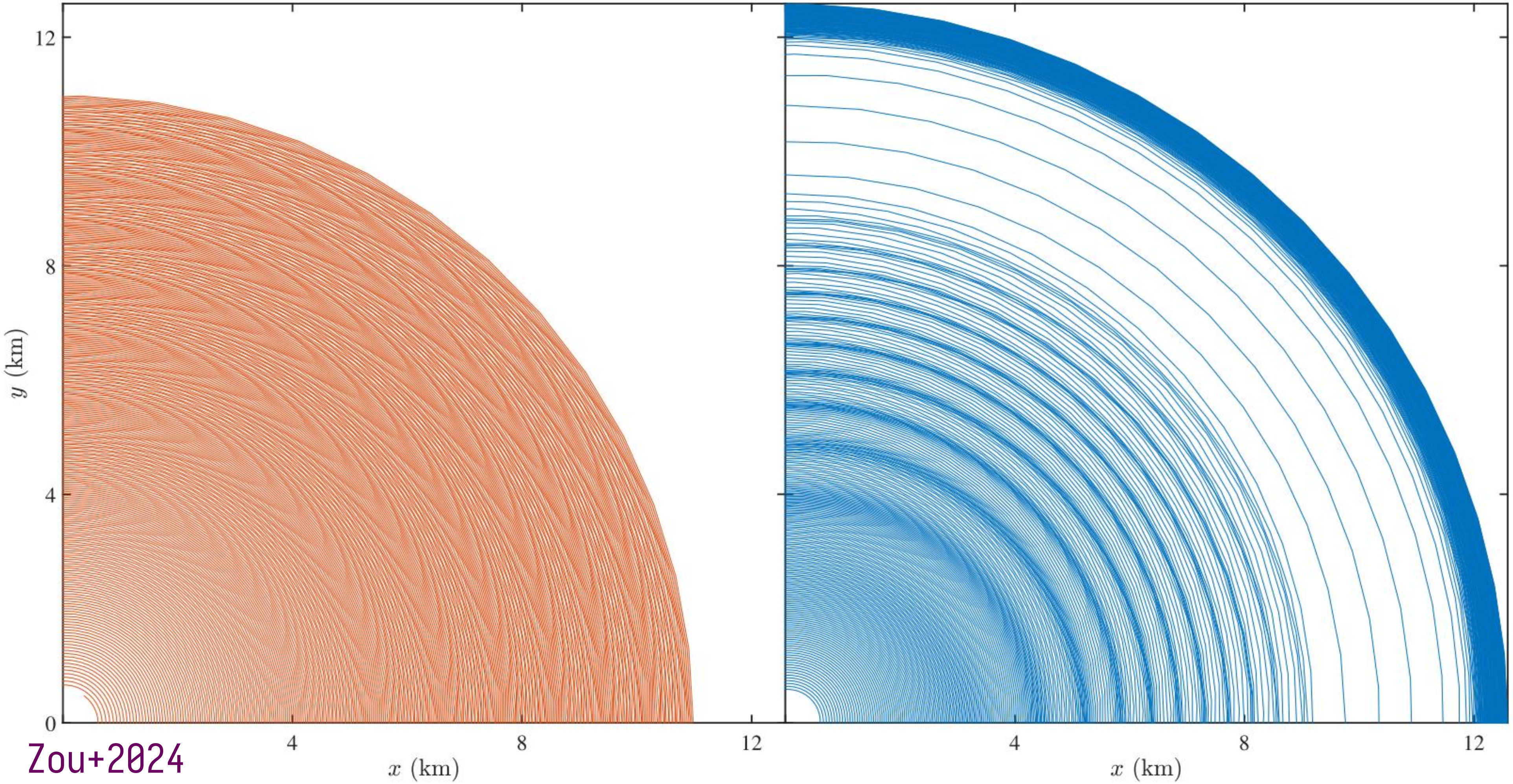

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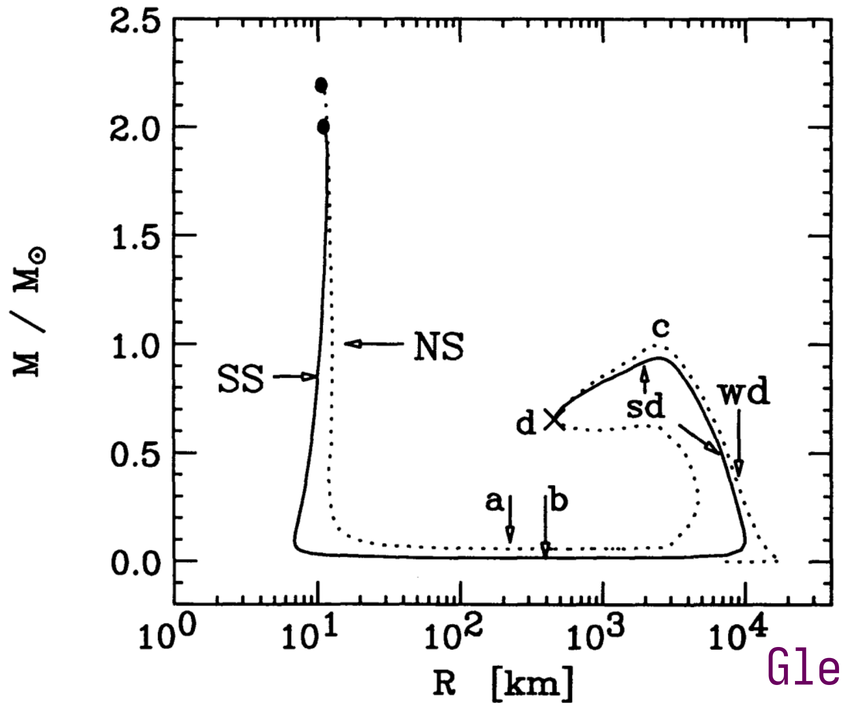
Strange dwarfs

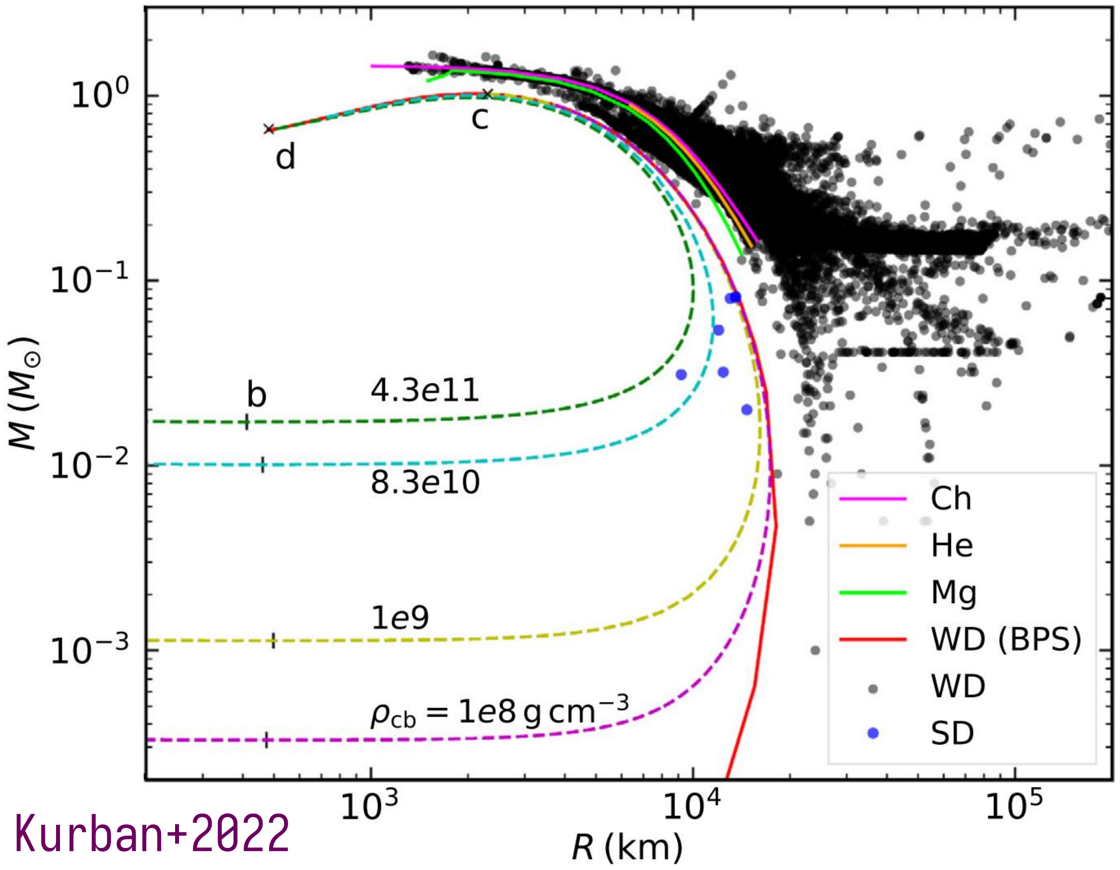
- Stabilized by Coulomb barrier between normal crust and quark core
  - Unique objects under SQM hypothesis
  - Di Clemente+2023, Gonçalves+2023, Zhang Huang Zou 2024



Glendenning 1995

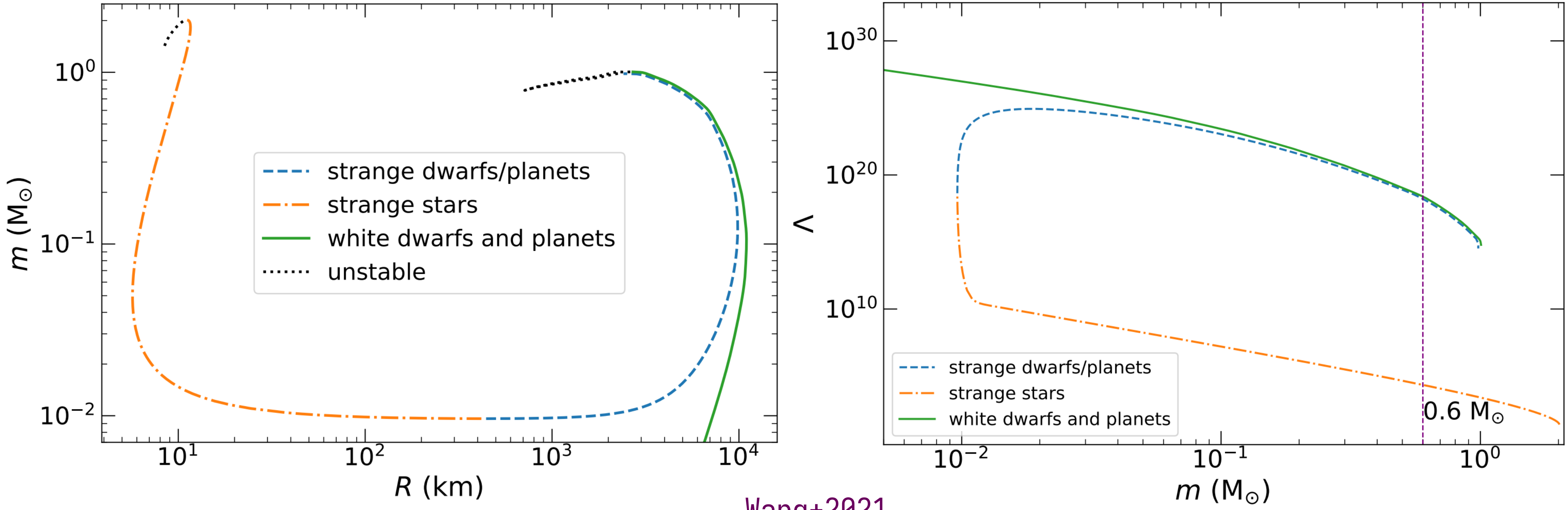
Strange dwarfs

- Stabilized by Coulomb barrier between normal crust and quark core
  - Unique objects under SQM hypothesis
- Compactness criterion still holds



Kurban+2022

- Tidal deformability



Wang+2021

Summary

- SQM may be absolutely stable
  - We do not know exactly what is inside a compact star
- Strange stars are observationally similar to neutron star
  - Strange planets and dwarfs can help to examine SQM hypothesis
- Close-in strange planets emits strong gravitational waves
  - Gravitational waves differentiate strange planets from PBHs as well
  - PBH inside also probes dense matter of compact star
- Strange dwarfs are uniquely stable under SQM hypothesis

Thank you!