New GW sources from collapsars

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FEET 24

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Gravitational waves

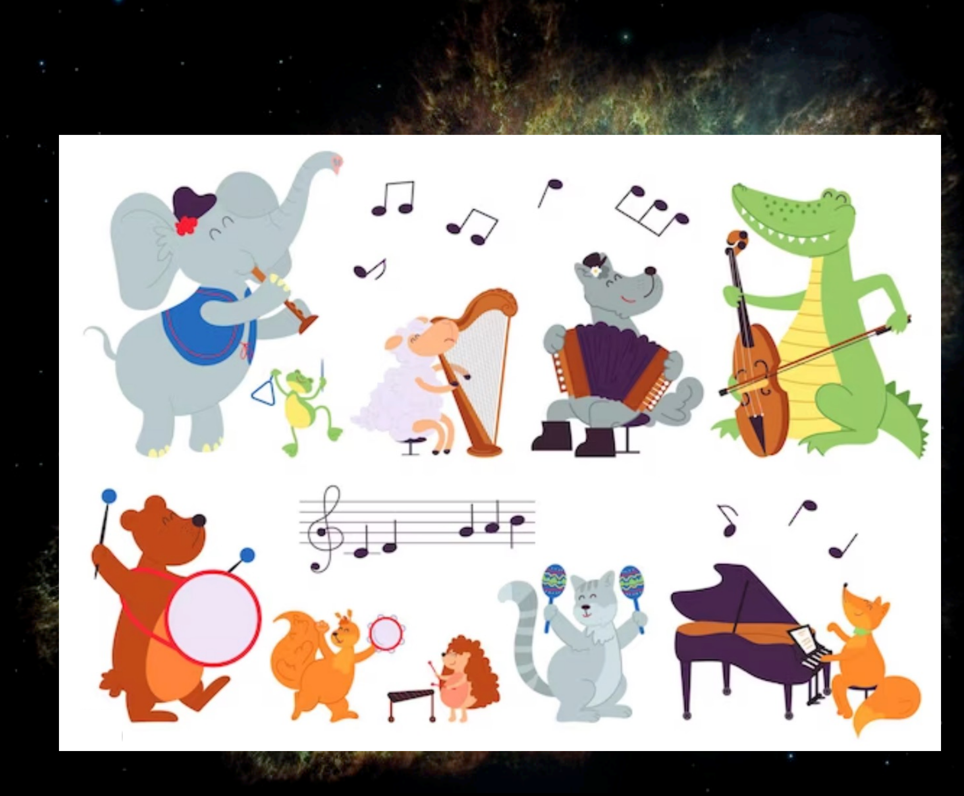
Inspiral GWs

Binary black holes

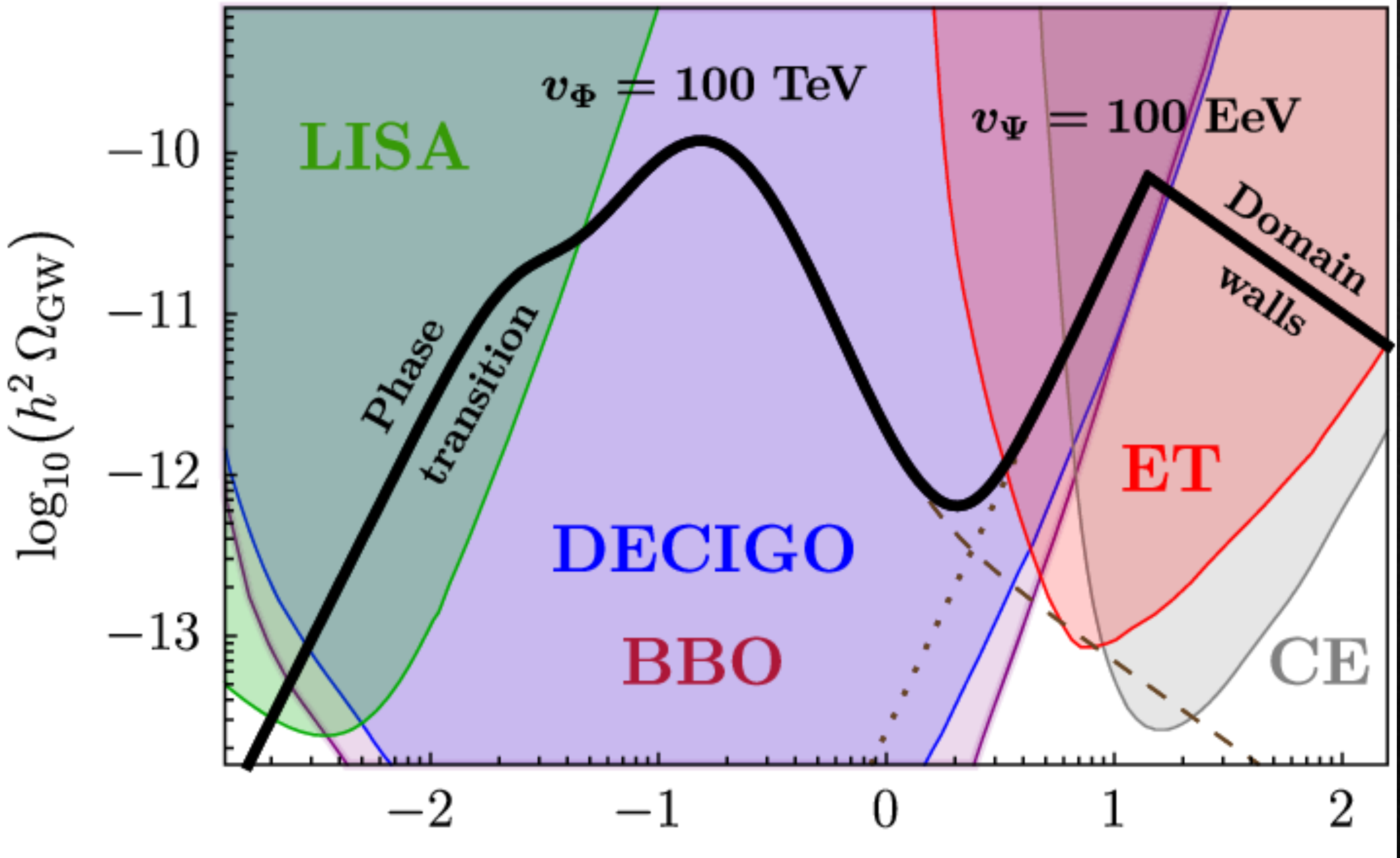
Black hole-neutron star

Burst-type GWs

Supernovae?

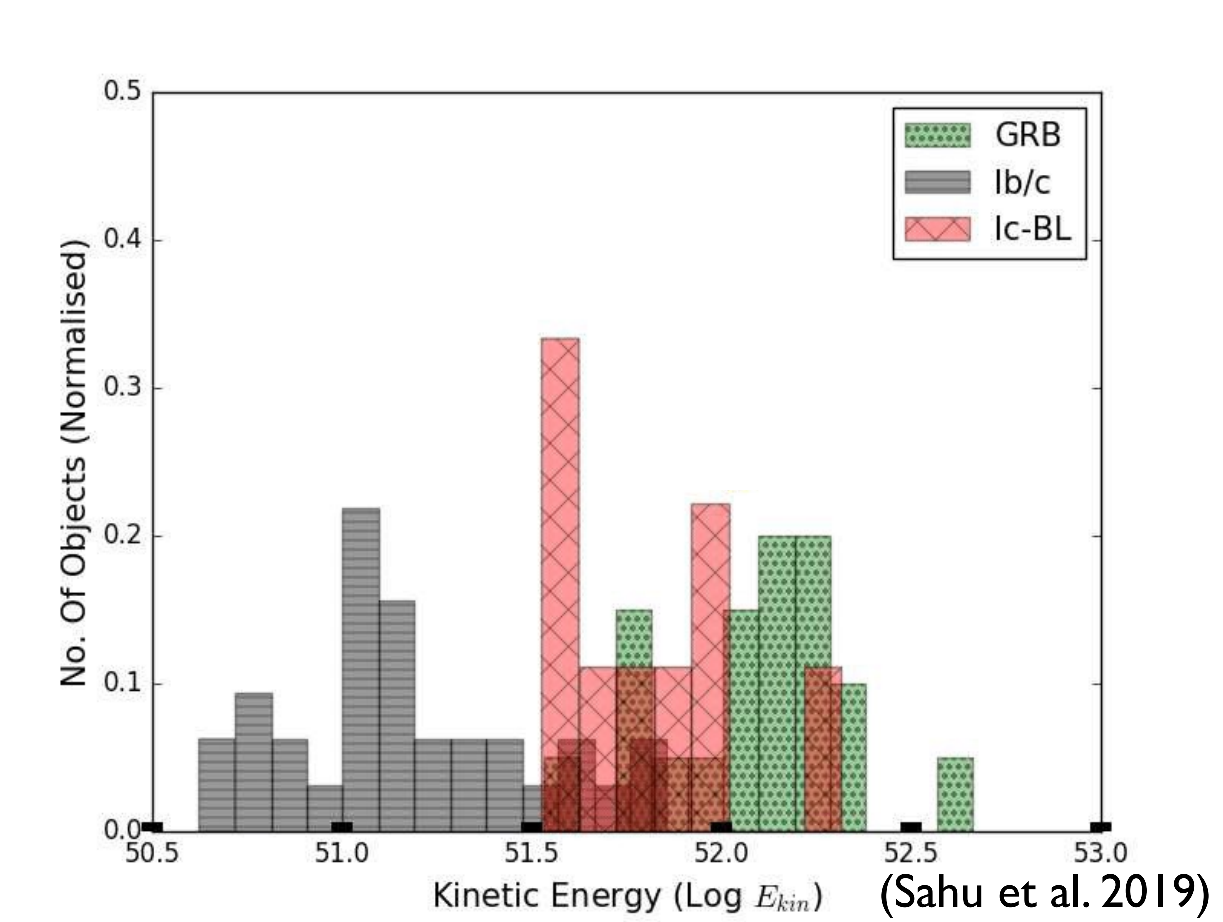


Next-generation GWs



(Fornal et al. 2023)

Gravitational waves from collapsars



(Sahu et al. 2019)

+

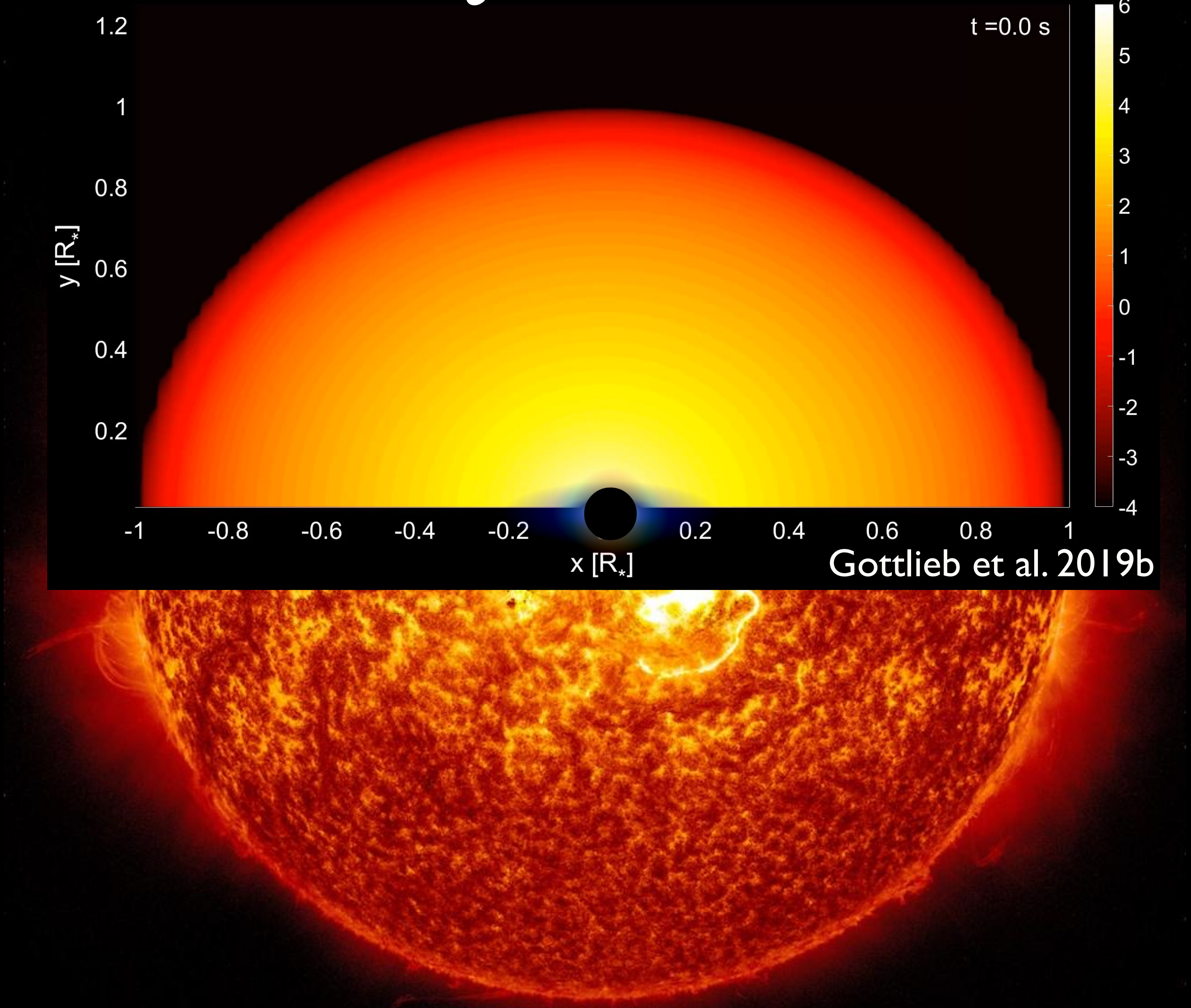
Quadrupole

$$h_{ij} \propto \ddot{Q}_{ij}$$

$$h_+ = h_{yy} - h_{xx}$$

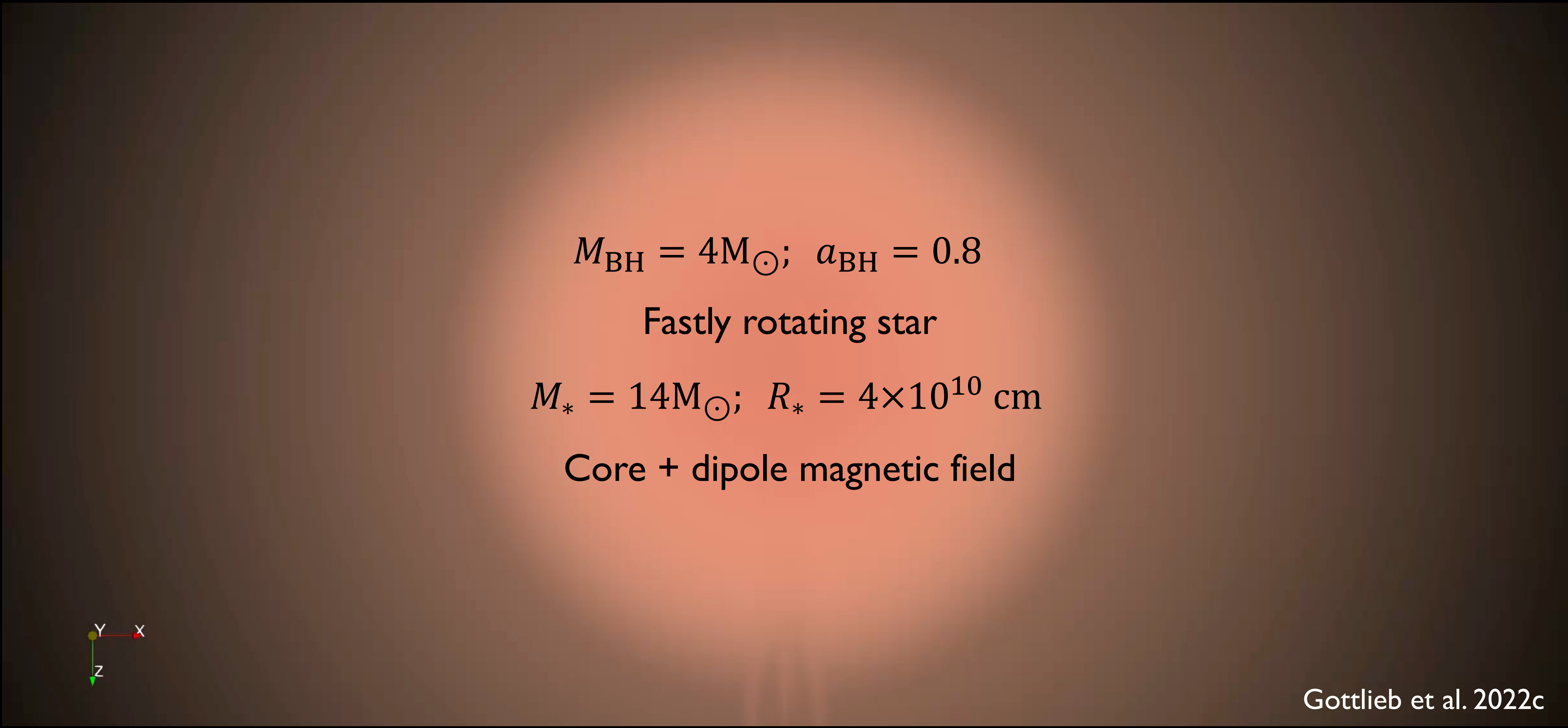
$$h_\times = 2h_{xy}$$

Dynamics



Gottlieb et al. 2019b

Dancing jets



$M_{\rm BH} = 4{\rm M}_\odot$; $a_{\rm BH} = 0.8$

Fastly rotating star

$M_* = 14{\rm M}_\odot$; $R_* = 4\times10^{10}$ cm

Core + dipole magnetic field

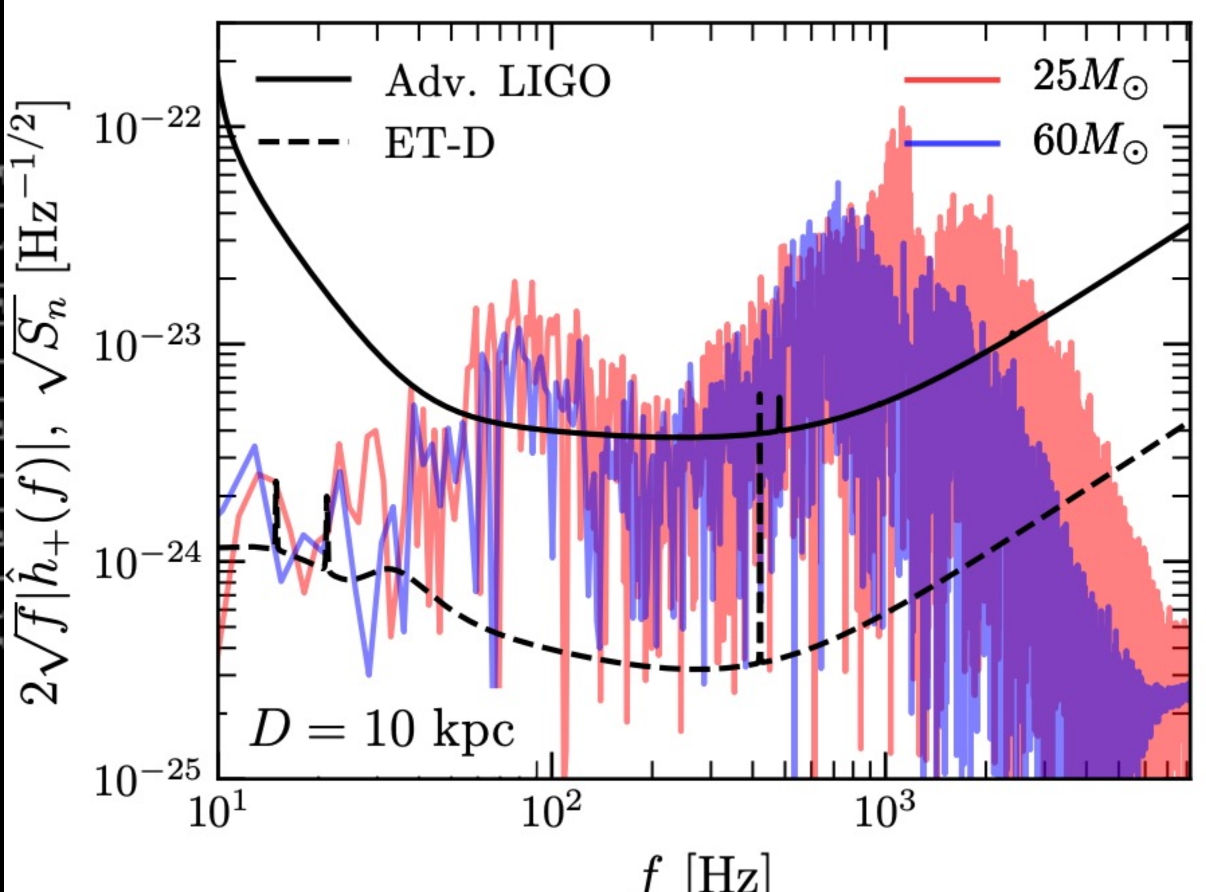
Gottlieb et al. 2022c

Dancing jets

Gottlieb et al. 2022c

Protoneutron star accretion

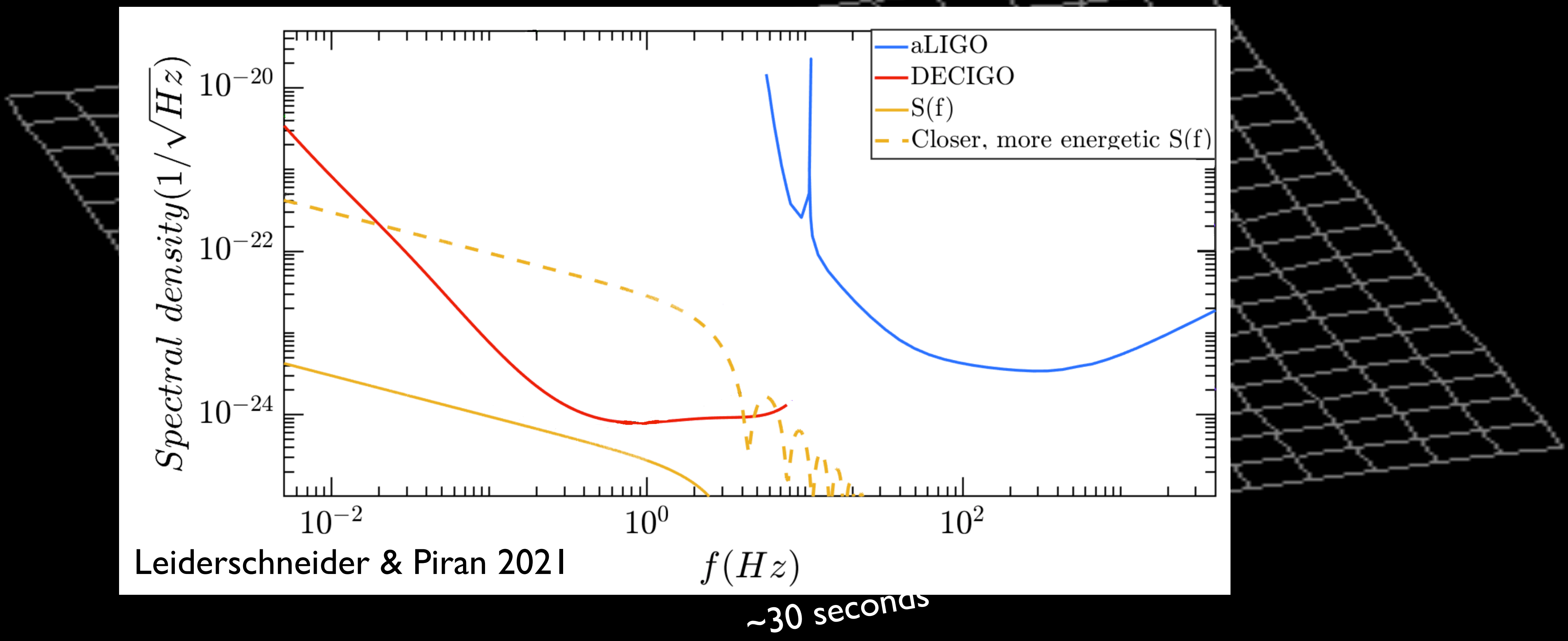
- 10 – 100 kpc detection horizon - too weak (Morozova et al. 2018; Radice et al. 2019; Vartanyan et al. 2023; Mezzacappa & Zanolin 2024)



Radice et al. 2019

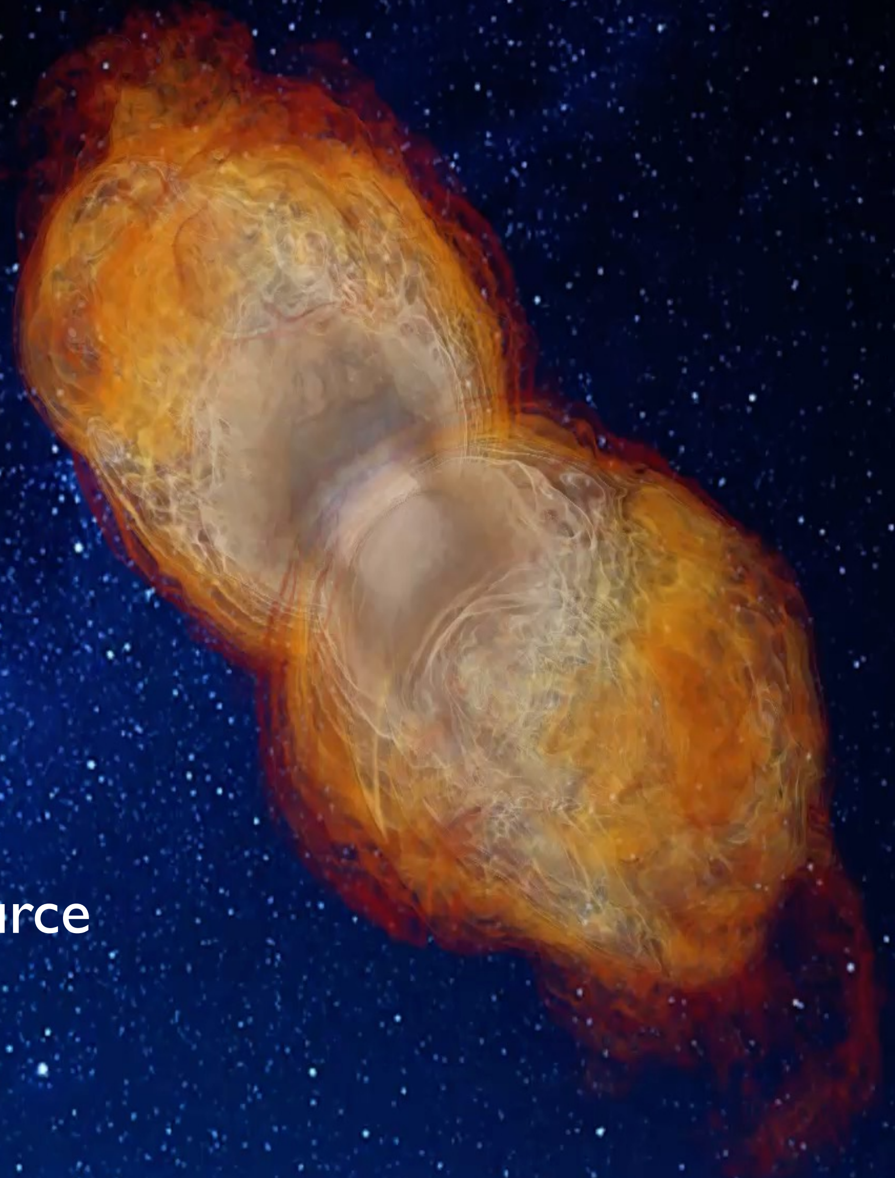
Jets

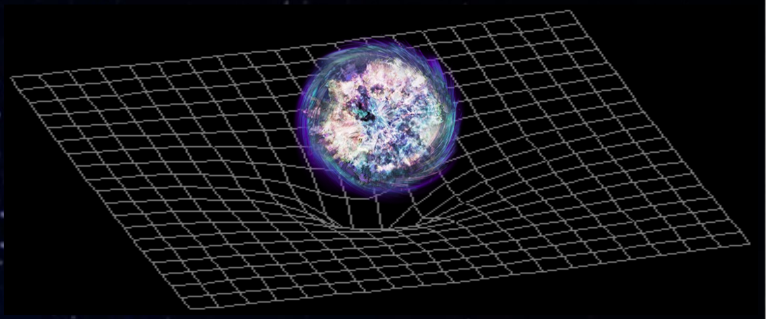
- $f_{GW} \approx 0.03$ Hz (Sago et al. 2004; Birnholtz & Piran 2013; Leiderschneider & Piran 2021)
- Might be relevant to LISA
- Semi-numerical calculation by Urrutia et al. 2023, but fully numerical calculation is needed

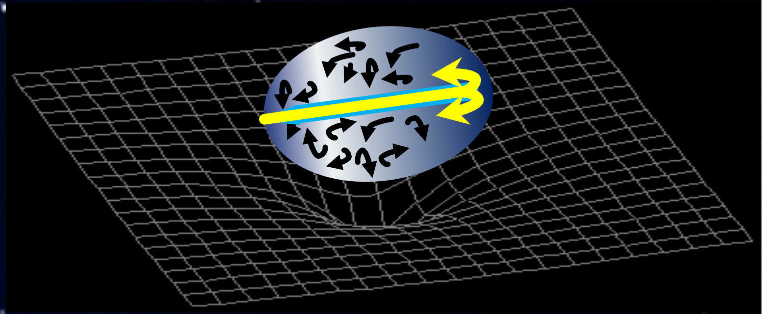


Leiderschneider & Piran 2021

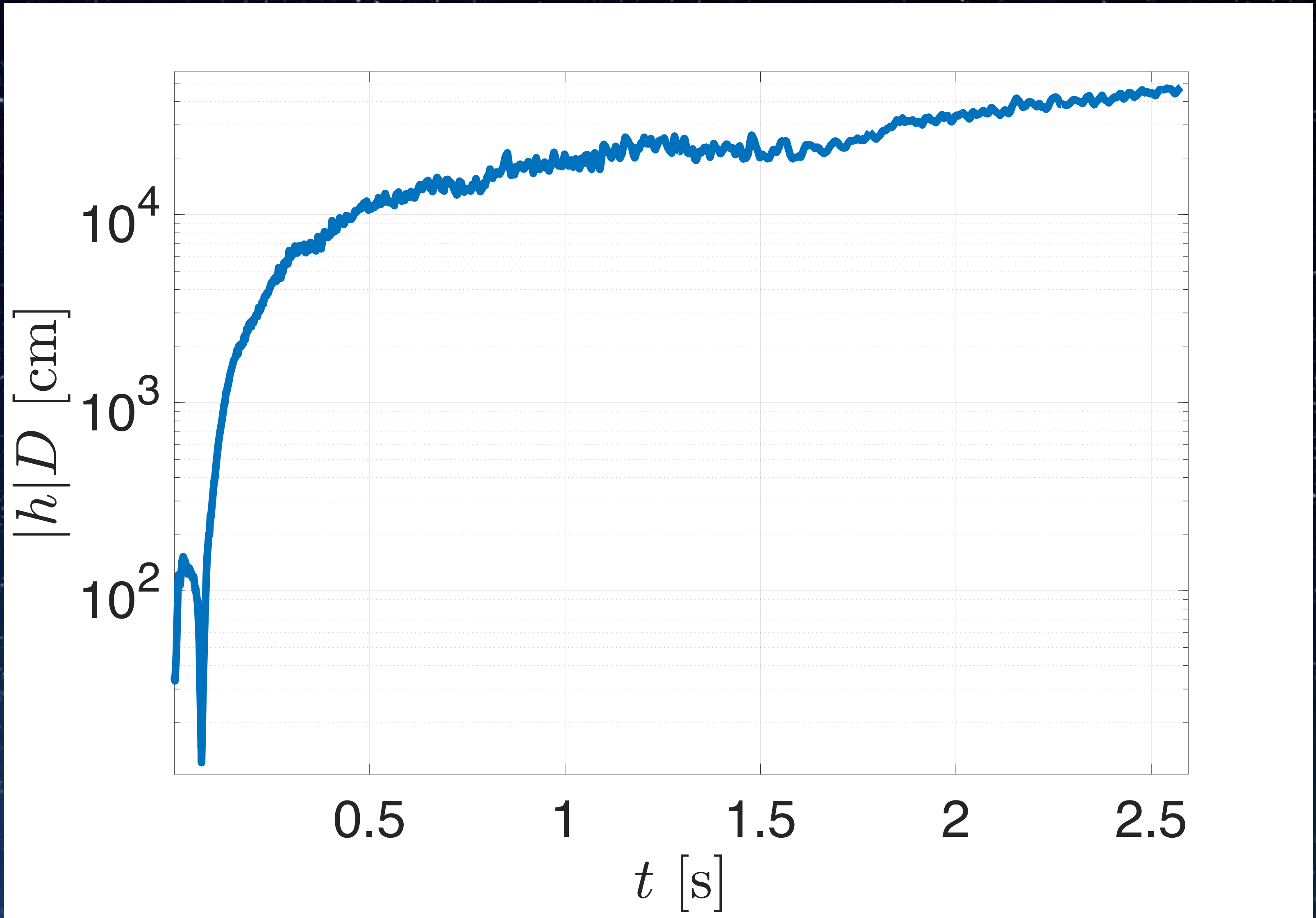
Multi-messenger cocoons





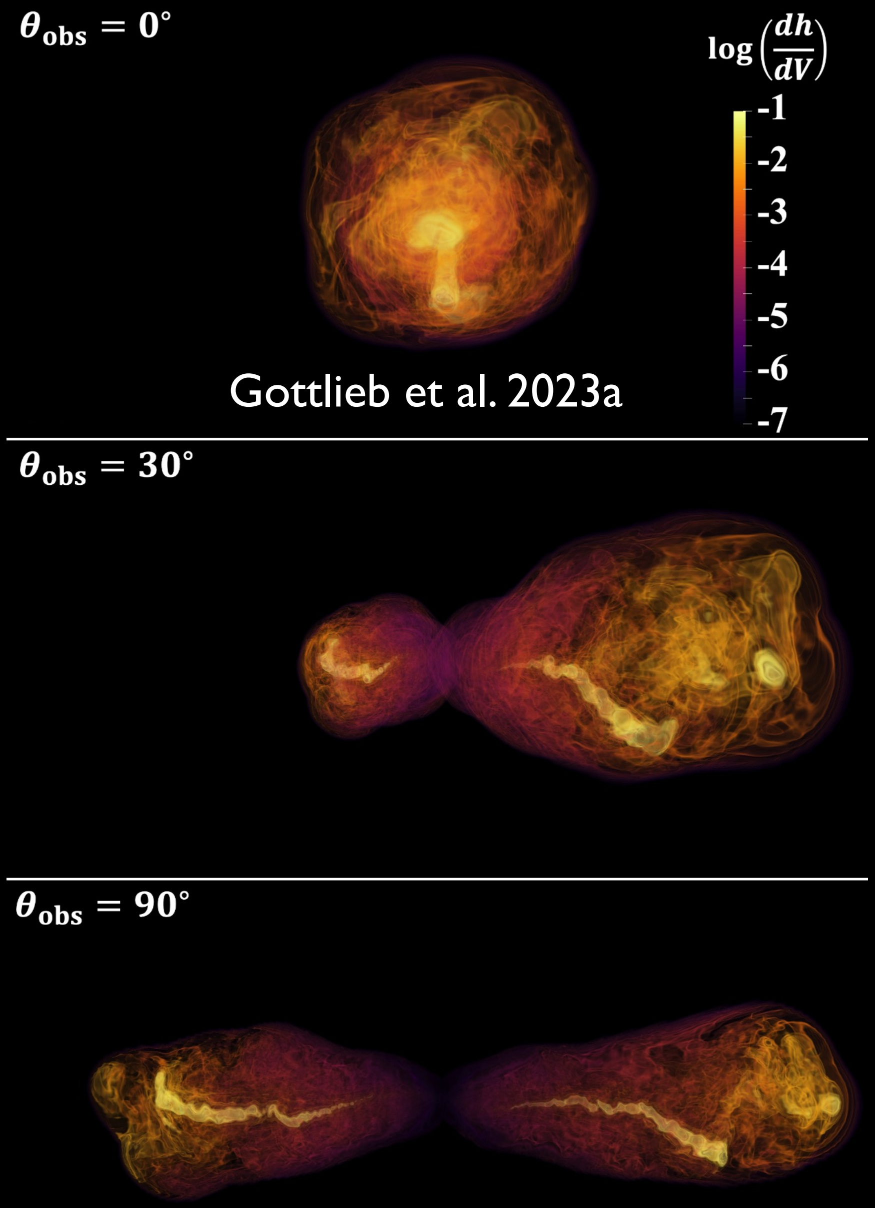


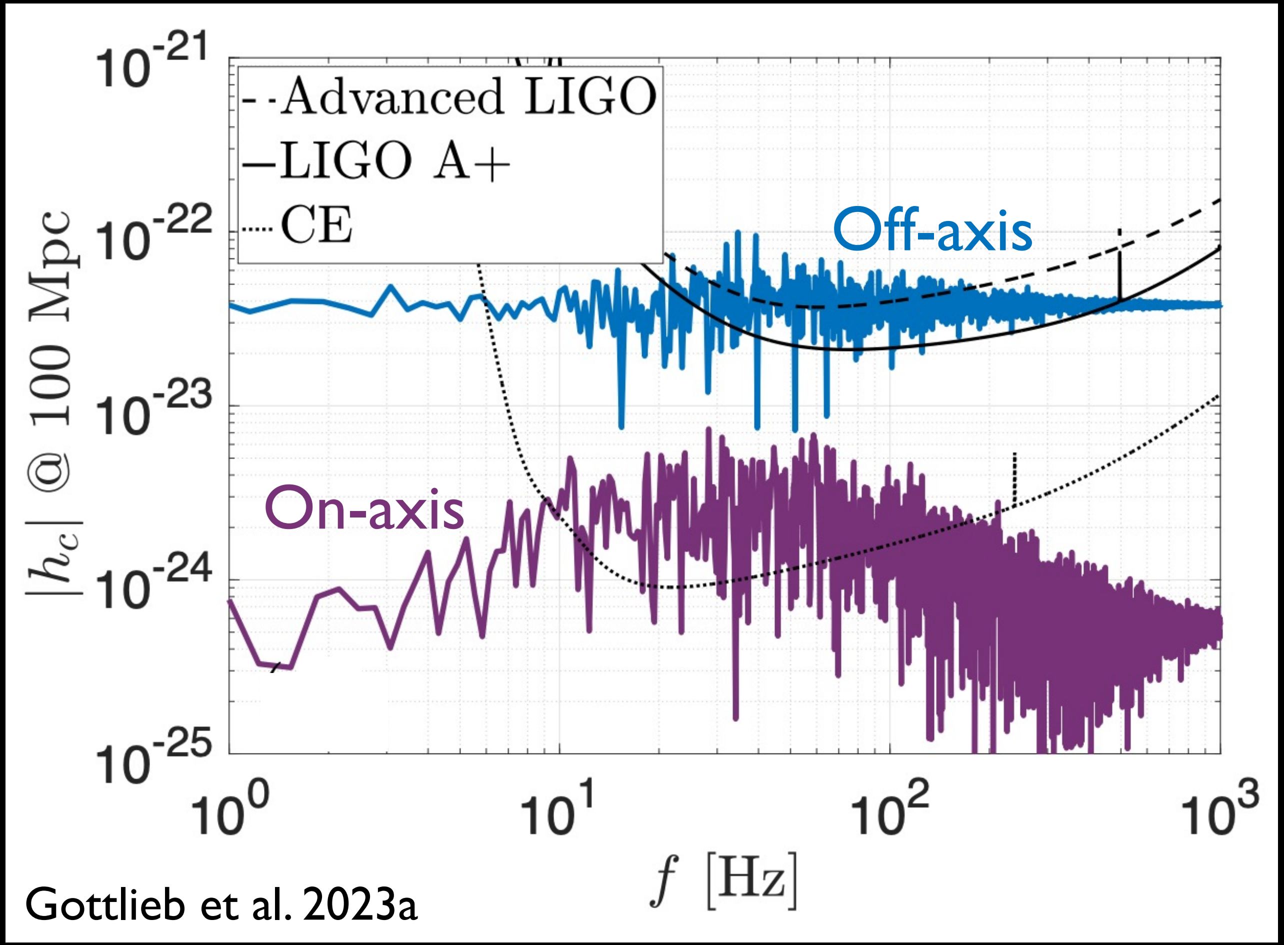
- ✓ Shape: hourglass
- ✓ Frequency: fast evolution
- ✓ Energy: $E_c \geq E_{\mathrm{GRB}}$
- ➢ Promising multi-messenger source



10^4
10^3
10^2
$|h|D$ [cm]
0.5
1
1.5
2
2.5
t [s]

New gravitational wave source





- Strong off-axis emission at ~10-100 Hz frequencies
- Strongest non-inspiral GWs in CE frequency bands
- Targeted search using ZTF, Rubin Observatory, ULTRASAT, UVEX
- ~10 events per year in CE

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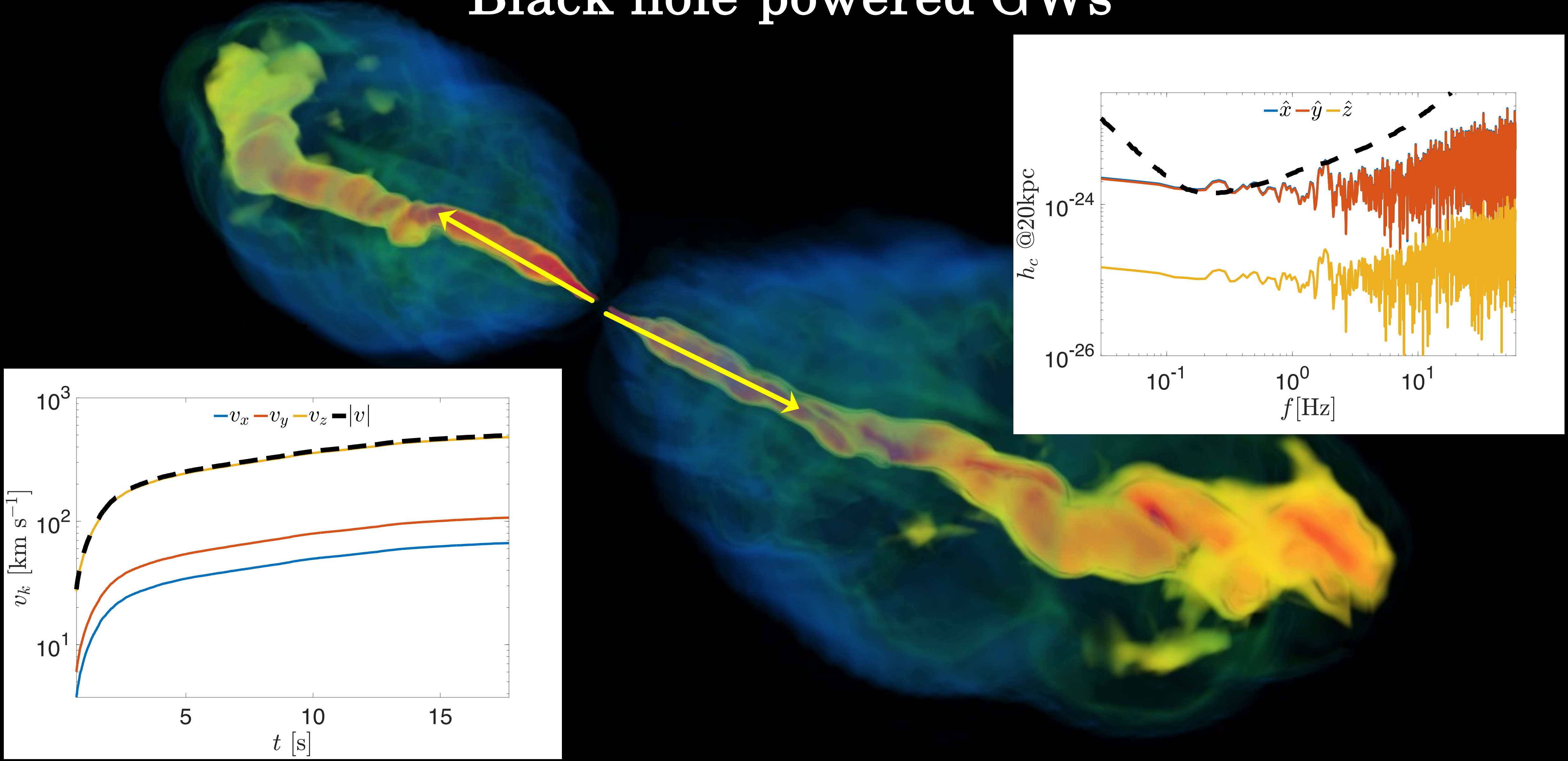
Black hole-powered GWs

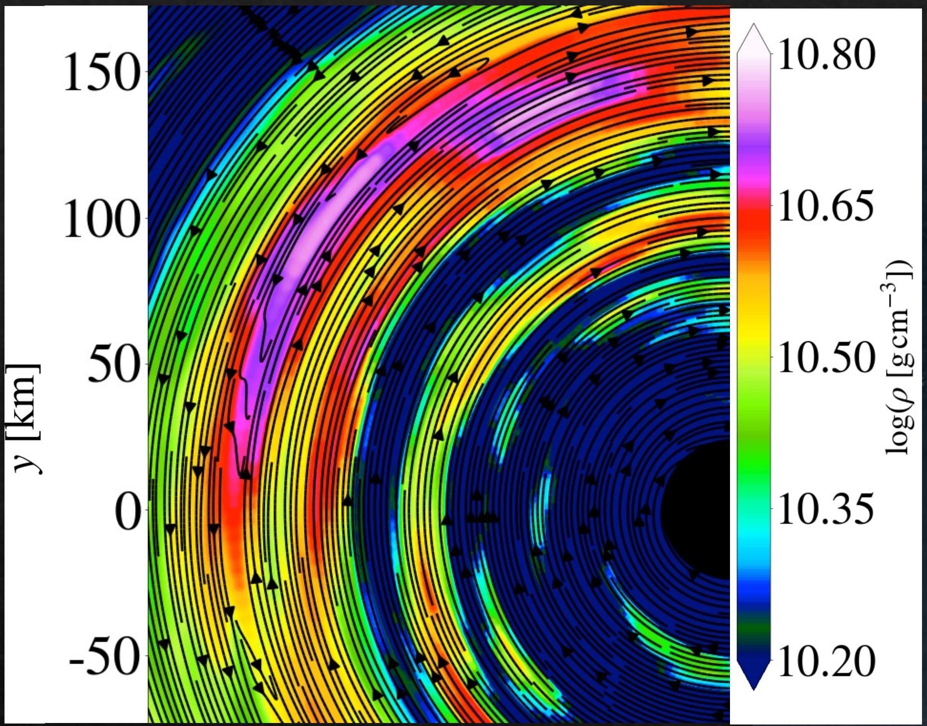


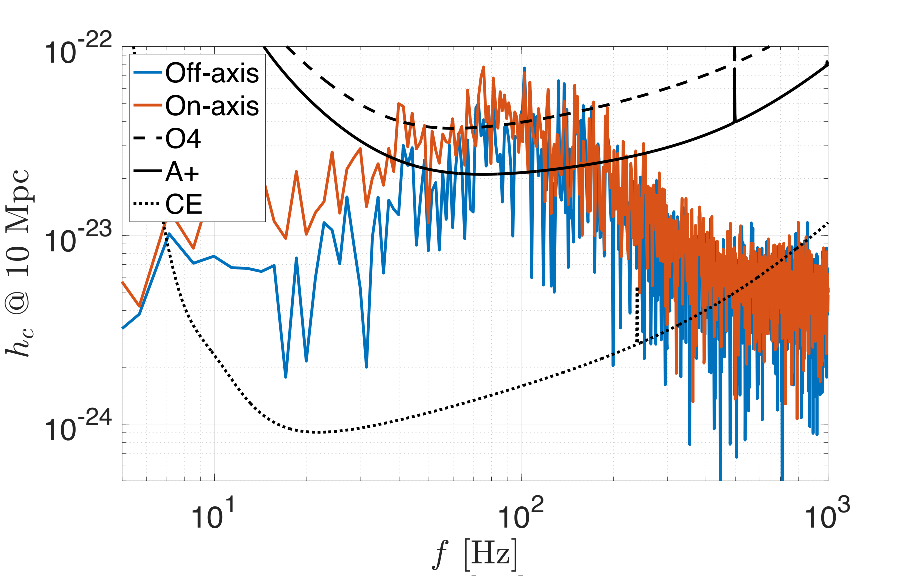
Disk-powered GWs: Thin vs. Thick

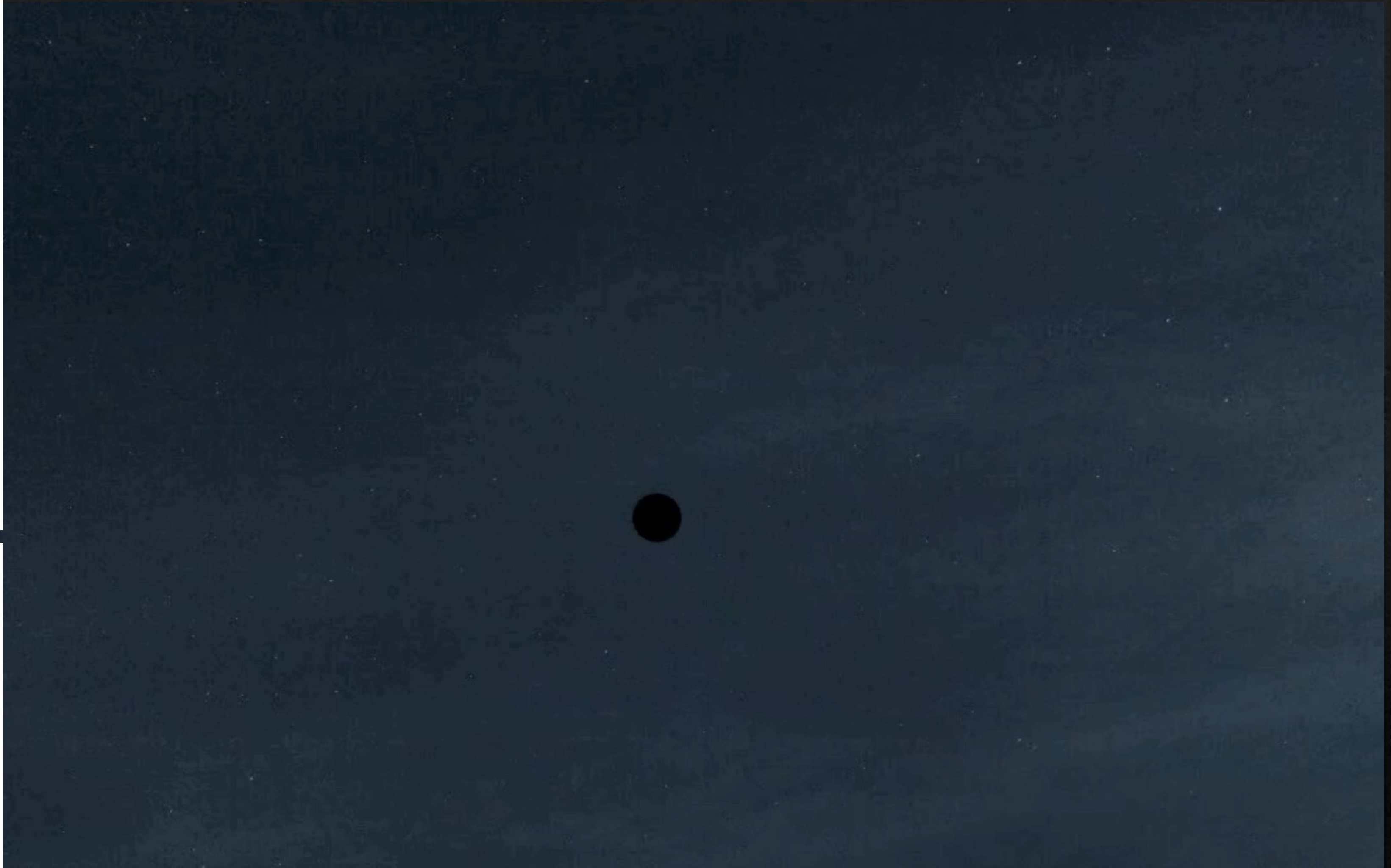
Thin disks:

- Denser → Stronger GWs
- Denser → Instabilities - $Q_T = \frac{\Omega c_s}{\pi G \Sigma_d}$ (Piro & Pfahl 2007)
- Compact → Coherent GWs
- Motivated in collapsars and mergers

GWs from thin disks







$$f_{GW} = \frac{\mu\Omega}{2\pi} = \frac{\mu}{2\pi}\sqrt{\frac{GM_{BH}}{R_d^3}}$$

GWs from thin disks

Comparing disk-powered GWs with other sources

1. Disk-powered GWs are weaker than cocoons but ~1000 stronger than SNe

2. Disk are more abundant

3. Easier to form templates

4. What physics can we learn? BH natal properties? Structure of collapsar progenitors?