

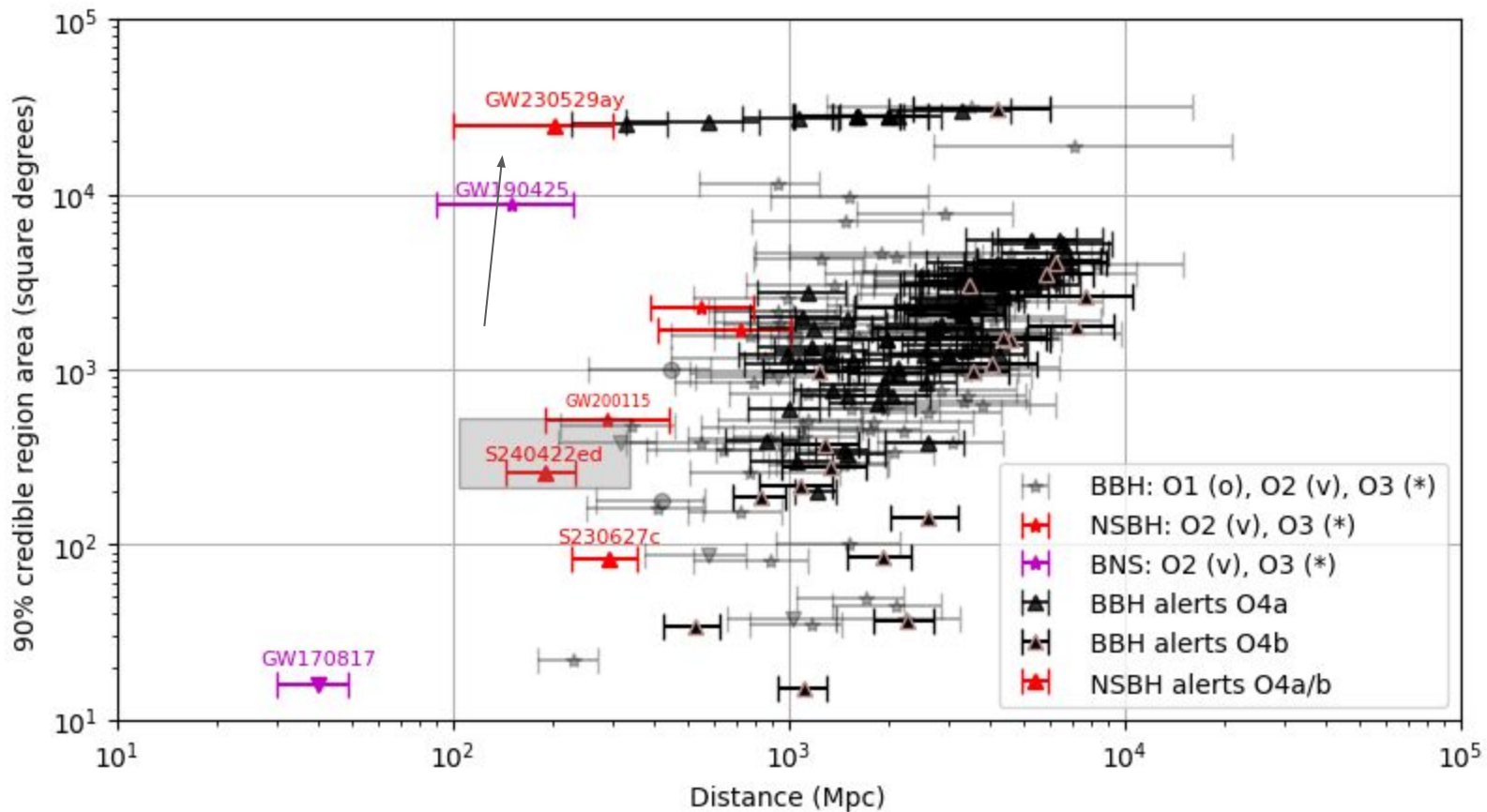


# Quantity of ejectae for NS-BH mergers

S. Antier (OCA)



# Where we are in terms of alerts in O4



# Neutron star composition

## INSIDE A NEUTRON STAR

A NASA mission will use X-ray spectroscopy to gather clues about the interior of neutron stars — the Universe's densest forms of matter.

### Outer crust

Atomic nuclei, free electrons

### Inner crust

Heavier atomic nuclei, free neutrons and electrons

### Outer core

Quantum liquid where neutrons, protons and electrons exist in a soup

### Inner core

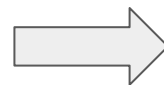
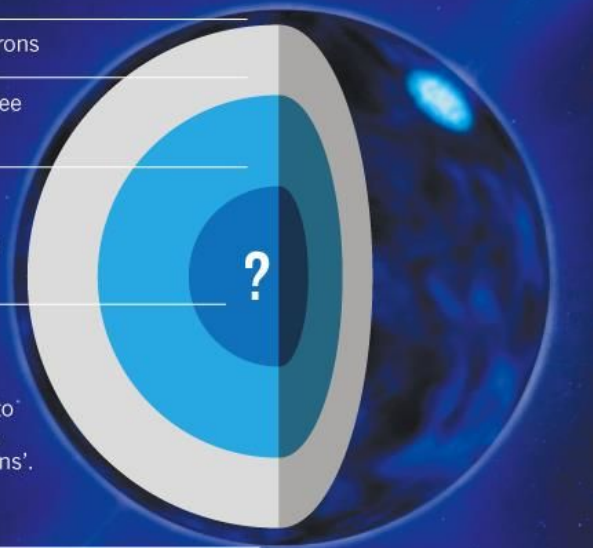
Unknown ultra-dense matter. Neutrons and protons may remain as particles, break down into their constituent quarks, or even become 'hyperons'.

### Atmosphere

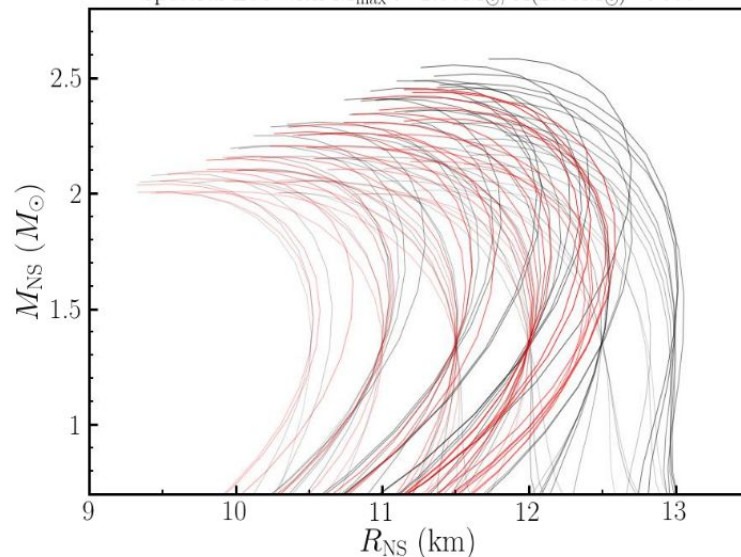
Hydrogen, helium, carbon

Beam of X-rays coming from the neutron star's poles, which sweeps around as the star rotates.

©nature



Spectral EoS with  $M_{\max} > 1.97M_{\odot}$ ,  $\Lambda(1.36M_{\odot}) < 800$



Size and maximum mass of neutron stars are important observables to constrain the properties of dense nuclear matter!

# Neutron star masses

Mass distribution of neutron stars in binary pulsar systems

GW190814, 2.6 ?

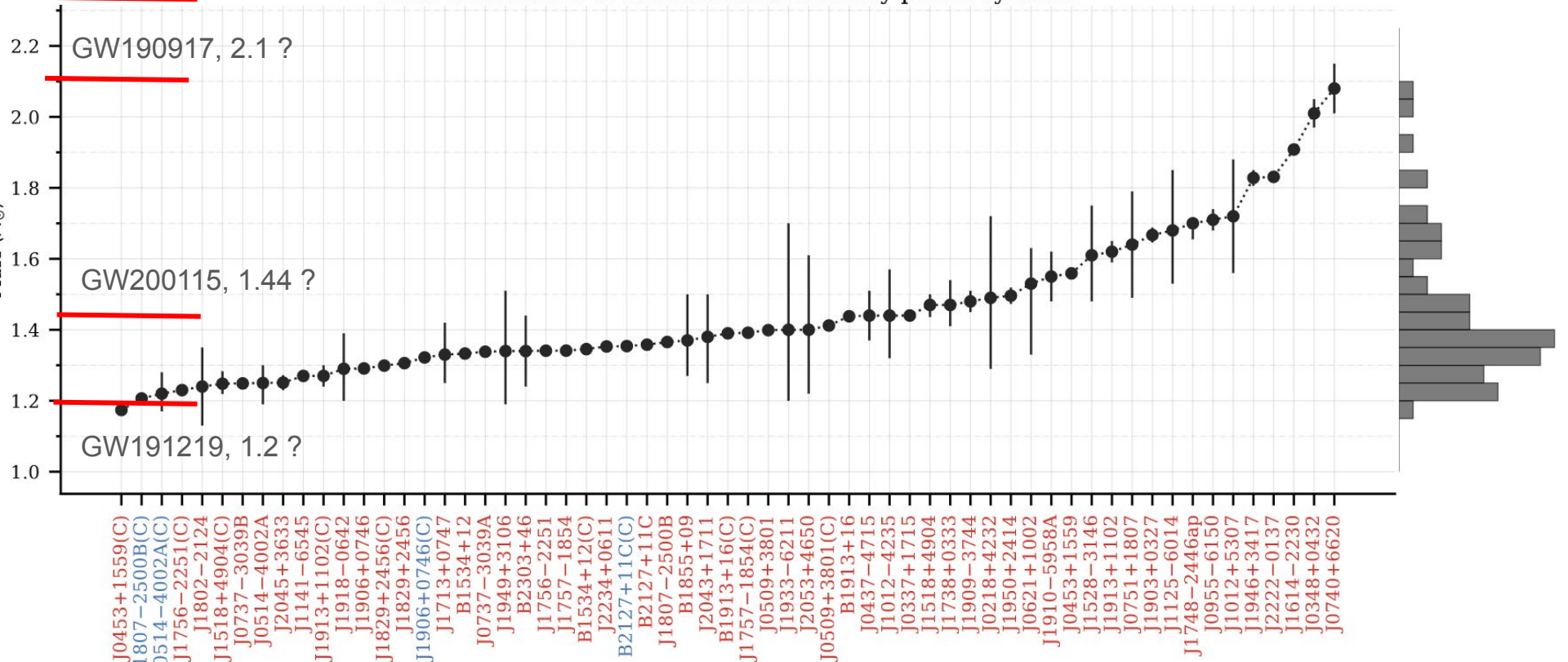
GW190917, 2.1 ?

GW200115, 1.44 ?

GW191219, 1.2 ?

J0453+1559(C)  
J1807-2500(B)(C)  
J0514-4002(A)(C)  
J1756-2251(C)  
J1802-2124  
J1518+4904(C)  
J0737-3039(B)  
J0514-4002(A)  
J2045+3633  
J1141-6545  
J1913+1102(C)  
J1918-0642  
J1906+0746  
J1829+2456(C)  
J1829+2456  
J1906+0746(C)  
J1713+0747  
B1534+12  
J0737-3039(A)  
J1949+3106  
B2303+46  
J1756-2251  
J1757-1854  
B1534+12(C)  
J2234+0611  
B2127+11(C)  
B2127+11(C)  
J1807-2500(B)  
B1855+09  
J2043+1711  
B1913+16(C)  
J1757-1854(C)  
J0509+3801  
J1933-6211  
J2053+4650  
J0509+3801(C)  
B1913+16  
J0437-4715  
J1012-4235  
J0337+1715  
J1518+4904  
J1738+0333  
J1909-3744  
J0218+4232  
J1950+2414  
J0621+1002  
J1910-5958(A)  
J0453+1559  
J1528-3146  
J1913+1102  
J0751+1807  
J1903+0327  
J1125-6014  
J1748-2446gap  
J0955-6150  
J1012+5307  
J1946+3417  
J2222-0137  
J1614-2230  
J0348+0432  
J0740+6620

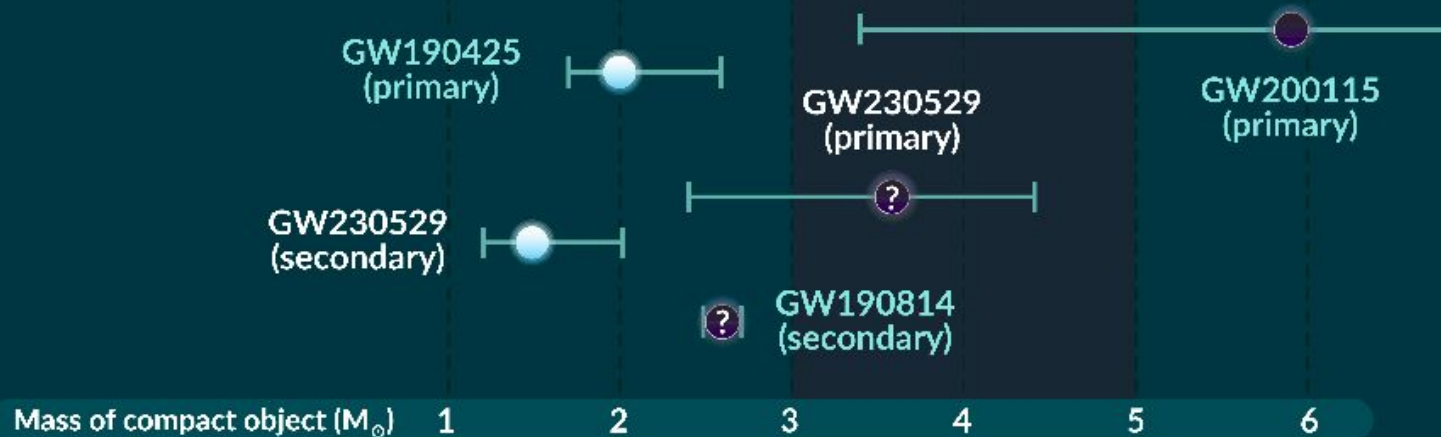
pfreire et al.,



## The less impact BH

# FILLING THE MASS $\longleftrightarrow$ GAP

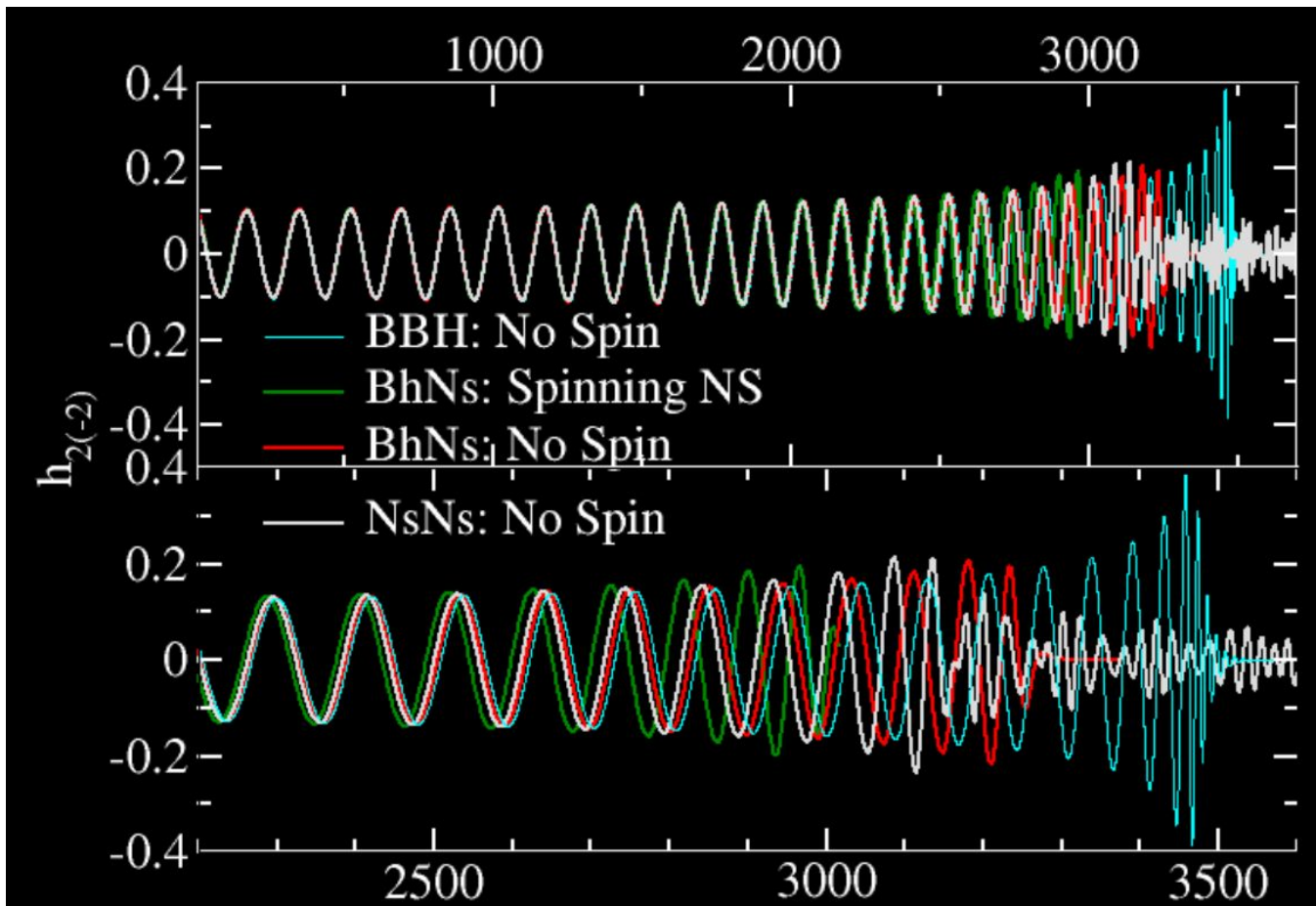
*with observations of compact binaries from gravitational waves*



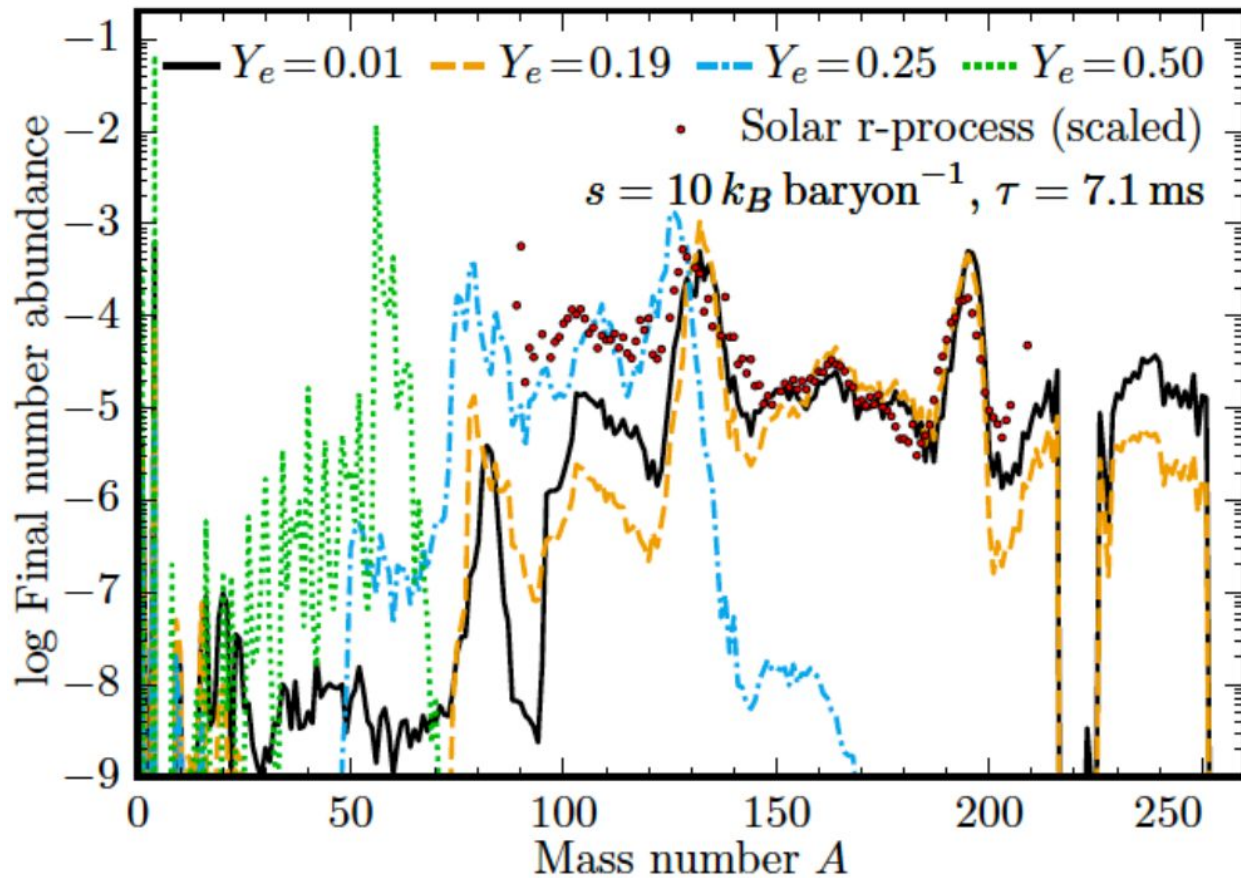
Includes components of compact binary mergers detected with a False Alarm Rate (FAR) of less than 0.25 per year



## Finite size effects in gravitational waves



## r-process: Importance of outflow composition

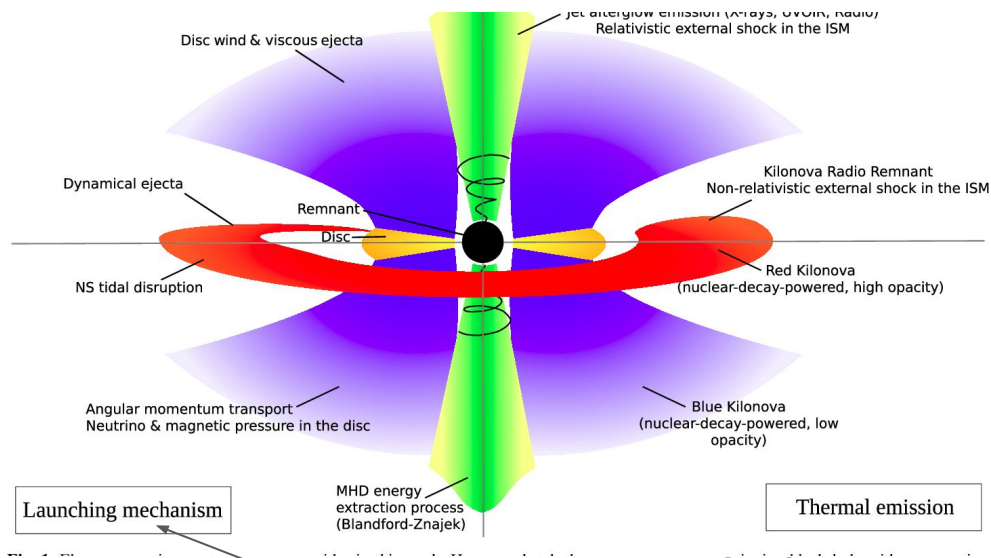


$Y_e$  = Electron Fraction  
= (#protons)/(#nucleons)

# NS disruption by the BH

On certain conditions (NS enough deformable, the ratio between the NS and the BH, the spin of the BH), we may have tidal disruption of the NS

Dynamical ejecta



Salafia et al.,

Disk wind ejecta



# Initial conditions

Aspect	Details
<b>Source Properties of NS-BH Event</b>	
NS Mass	$1.3 - 1.4M_{\odot}$
BH Mass	$3.0 - 5.0M_{\odot}$
Spins	<ul style="list-style-type: none"> <li>• BH Spin: <math>Spin_{zBH} \in [-0.8, 0.8]</math></li> <li>• NS Spin: None</li> </ul>
Equation of State of matter	<i>SLy</i>
Compatness of the binary	$C < 0.14$
<b>Ejecta from the NS disruption (<math>M_{dyn}</math>)</b>	
Mass Range	$0.001 - 0.15M_{\odot}$
<b>Ejecta from the accretion disk (<math>M_{disk,wind}</math>)</b>	
Mass Range	$0.001 - 0.15M_{\odot}$
Outflow	5% – 40% not accreted
<b>Kilonova Light Curves</b>	
Models	<ul style="list-style-type: none"> <li>• 2D model (blue and red)</li> <li>• 1D bolometric</li> </ul>

## Dynamical ejecta



$$M_{ej,rem} = m_{dyn} + m_{wind} = m_{dyn} + \xi \times m_{disk}$$

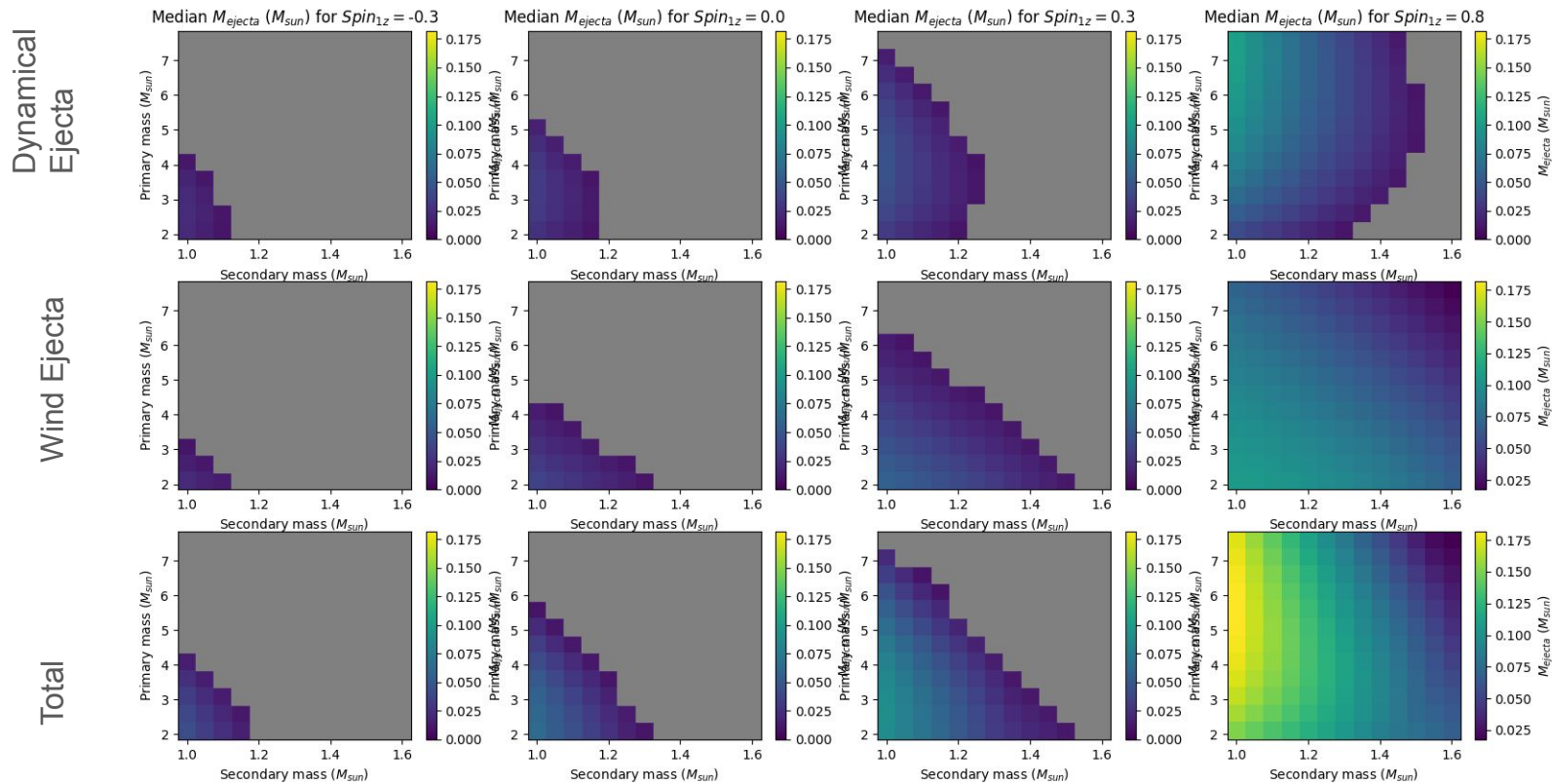
where  $M_{ej,rem}$  is the ejecta from the NS disruption by the BH,  $m_{dyn}$  the dynamical ejecta,  $m_{wind}$  the disk wind ejecta,  $m_{disk}$  the disk mass and  $\xi$  the proportion of unbound material from the disk. In our study, we cal-

## Disk wind ejecta

Use of Foucart, 2018, Krugel 2020 and Raaijmakers 2020

# Ejectae Mass, Equation of state SLy

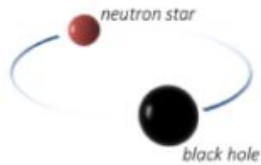
Dynamical Ejecta, Wind Ejecta, and Total,  $\xi = 0.3$



# What is happening next? From ejectae quantities to Kilonova lightcurves!

*Binary properties*

$$\vec{x} = \{M_{\text{BH}}, M_{\text{NS}}, \chi_{\text{BH}}, \Lambda_{\text{NS}}, \dots\}$$



*Outflow properties*

$$\vec{y} = \{M_{\text{dyn}}, M_{\text{wind}}, v_{\text{dyn}}, v_{\text{wind}}, \dots\}$$



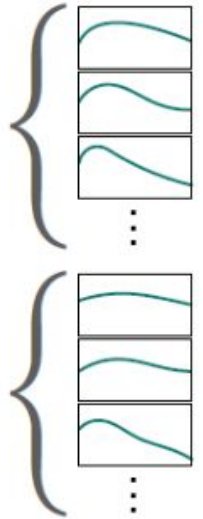
*Light curves*

$$\begin{matrix} \vec{x}_1 \\ \vdots \\ \vdots \end{matrix}$$

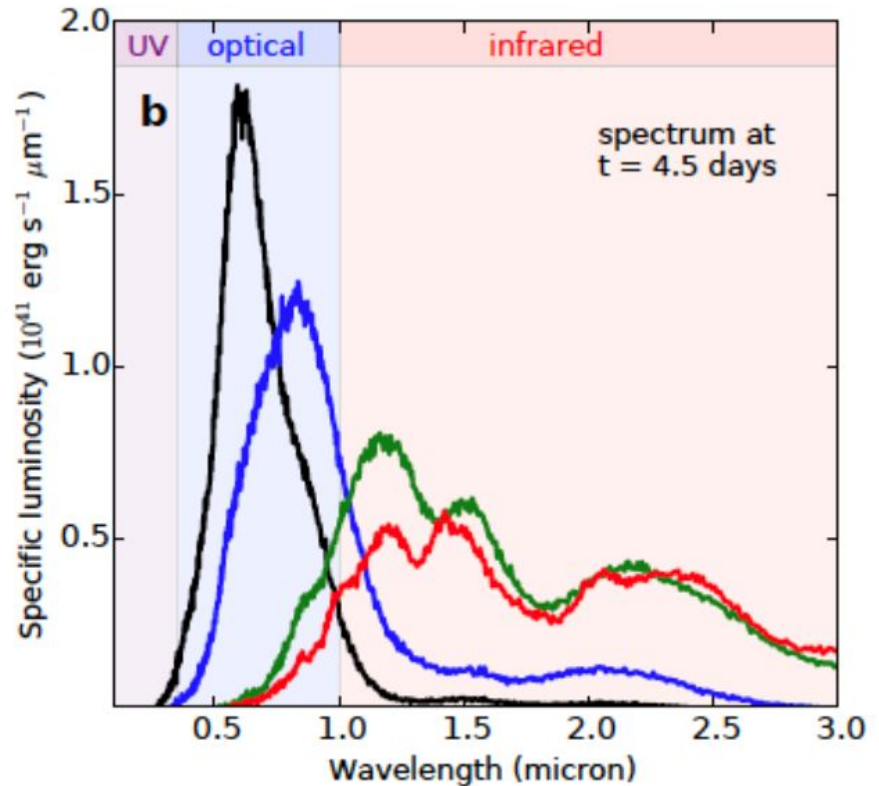
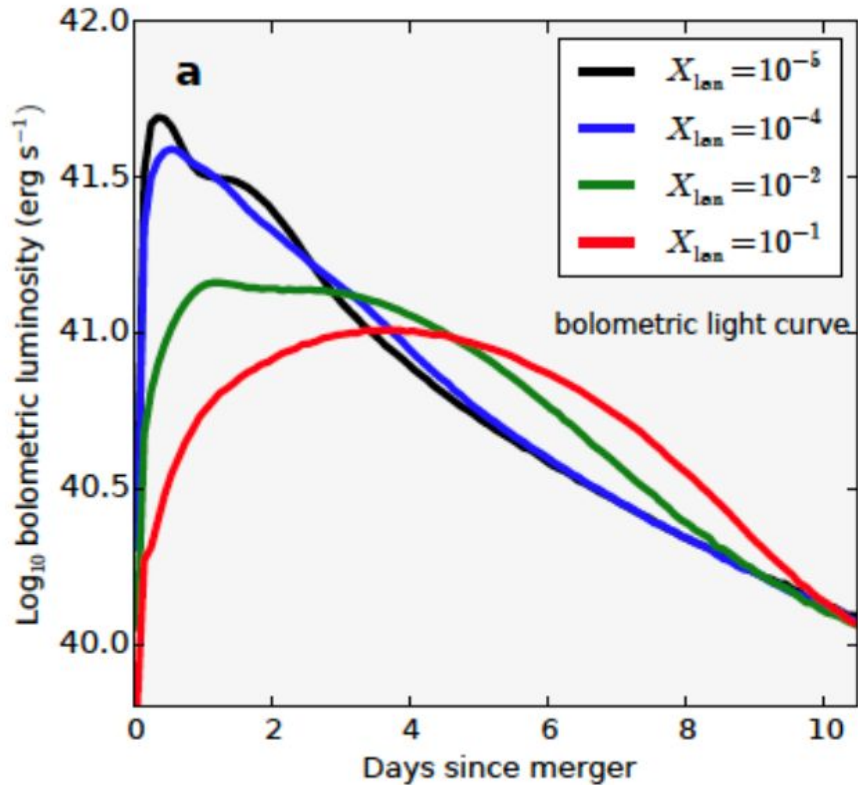
*Fit formulae to numerical simulations*

$$\begin{matrix} \vec{y}_{11} \\ \vec{y}_{12} \\ \vec{y}_{13} \\ \vdots \end{matrix}$$

*Semi-analytical light curve model*



## What is happening next? From ejectae quantities to Kilonova lightcurves!



See Bulla et al., as comparison

## Conclusions

Observations in multi-wavelength



Kilonova constraints



Ejecta masses



Binary system properties



Ultra-dense matter properties

This talk