Electromagnetic counterparts to Compact Binary Mergers

[… and the excitement of joint GW/EM observations….]

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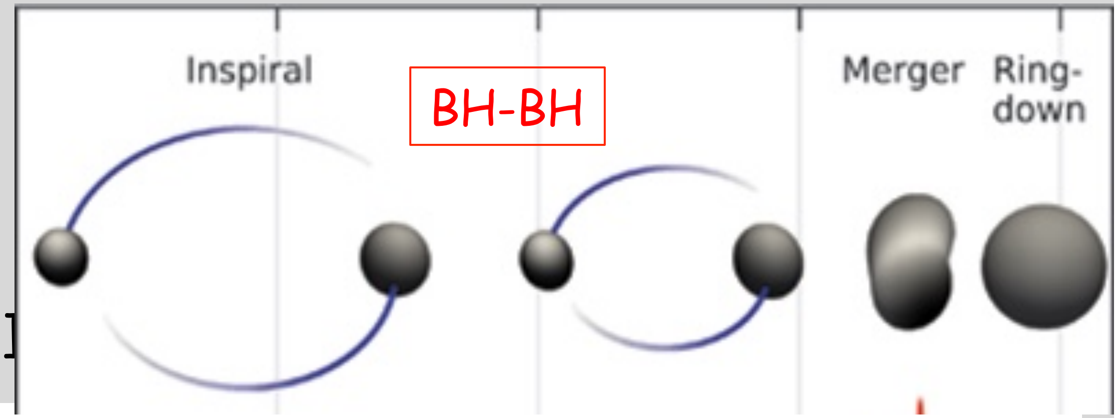
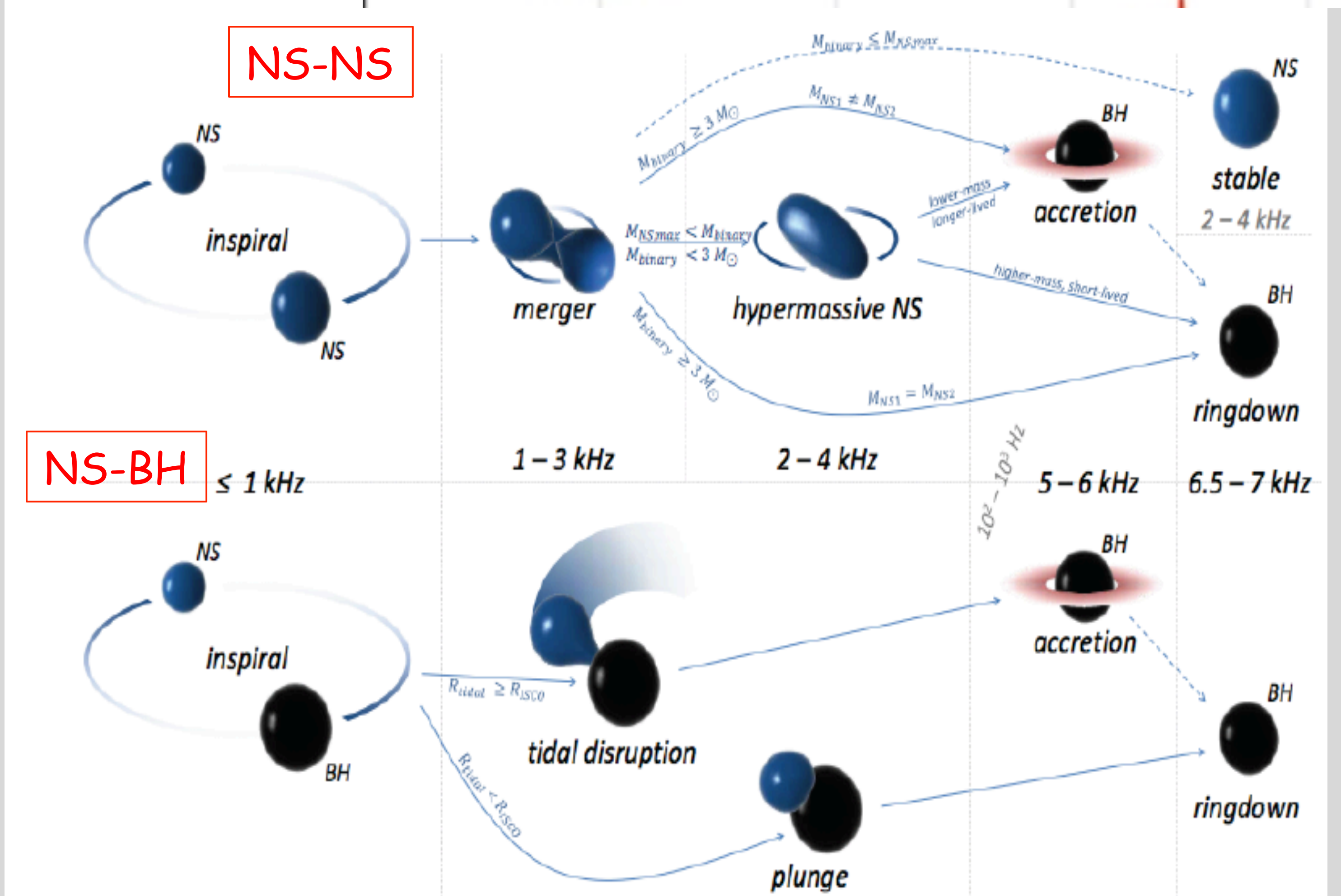
GWs from BH-BH, NS-NS, and NS-BH mergers

[Bartos et al. 2013]



GW emission associated to various phases of the merger

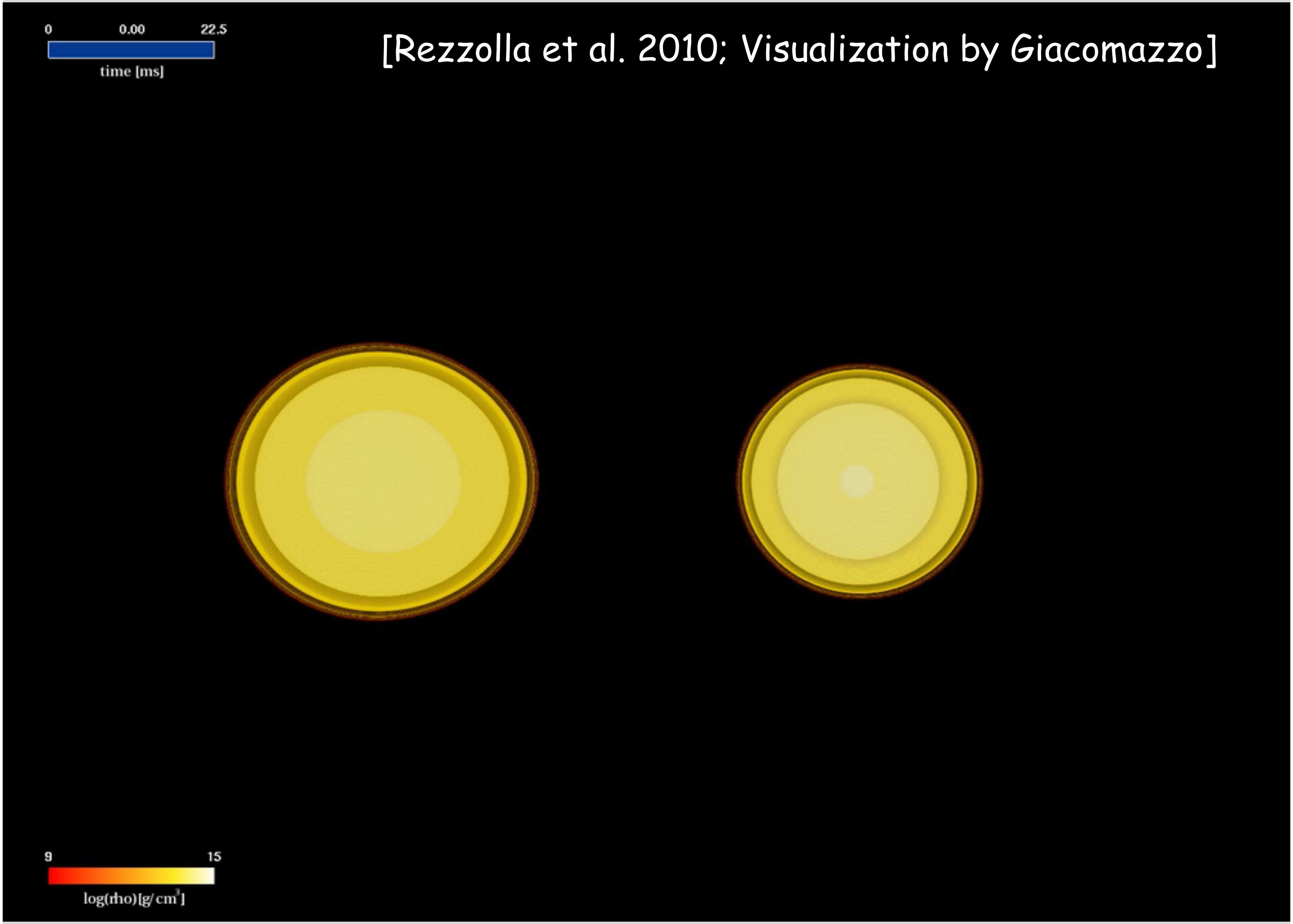


EM counterparts to these mergers:
theoretical expectations

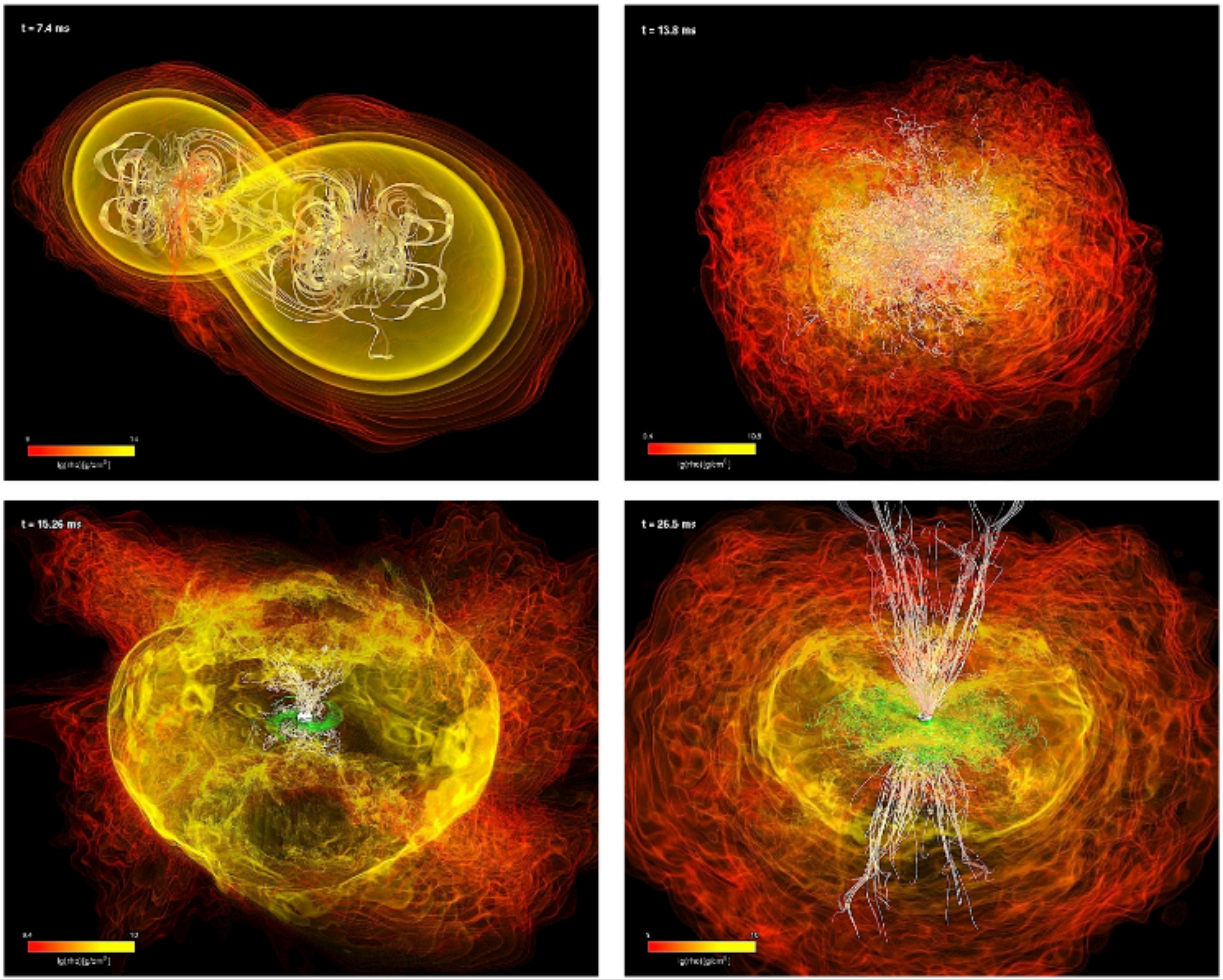
- BH-BH merger → None
  [remnant compact object = BH]
  [though ideas exist..]

- NS-BH merger → Short Gamma-Ray Burst, Afterglow, Kilonova for mass ratios q <~ 3-5
  None for higher q
  [remnant compact object = BH]

- NS-NS merger → Short Gamma-Gay burst, Afterglow, Kilonova
  [remnant compact object = BH or NS]


0
0.00
22.5
time [ms]
[Rezzolla et al. 2010; Visualization by Giacomazzo]
9
15
log(rho)[g/cm^3]

Evidence for possible formation of a jet [Rezzolla et al. 2011]

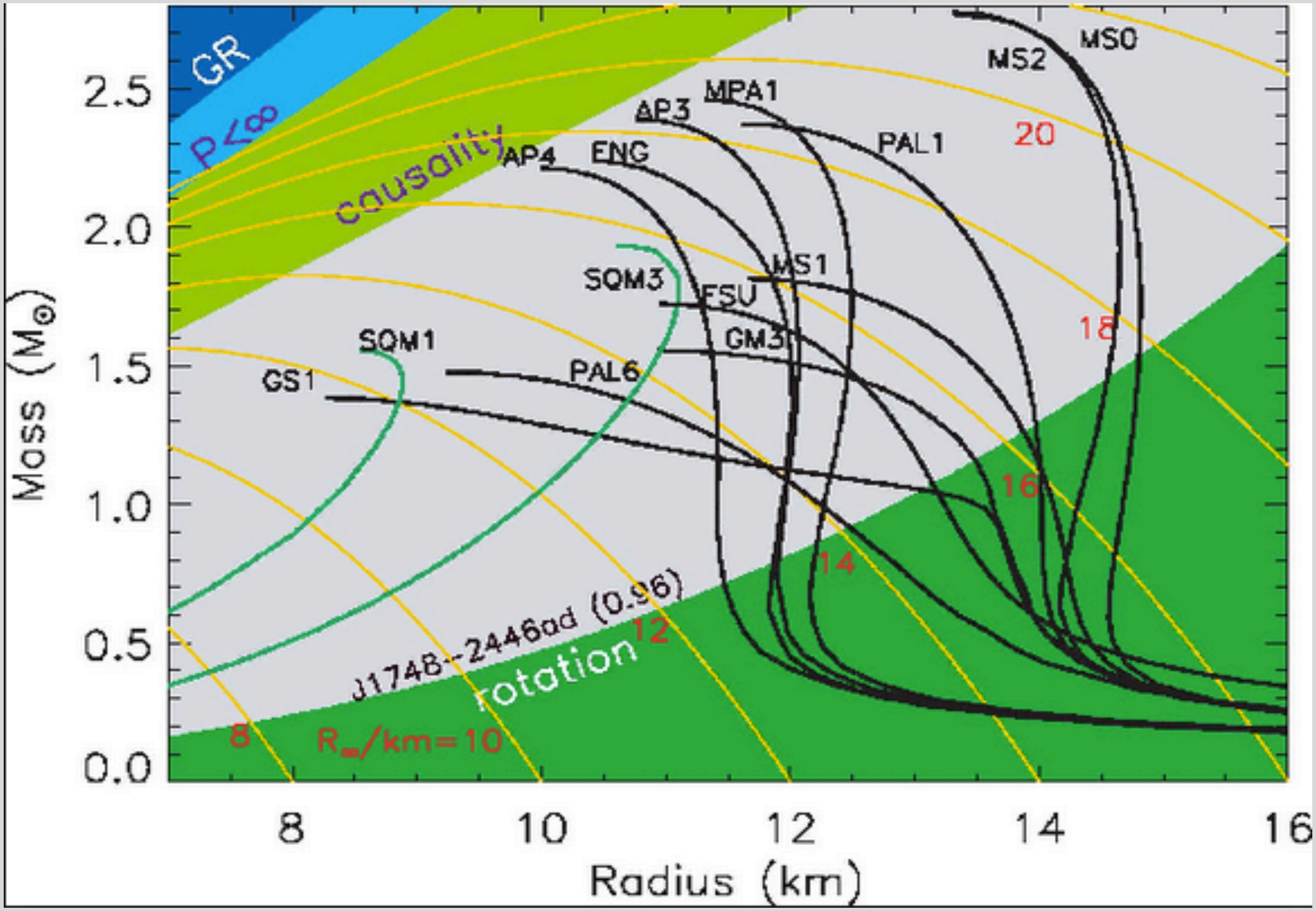


GW + EM signatures

- Constrain binary compact object formation channels via localizations
- Measure independently luminosity distance & redshift → measure Hubble constant
- Constrain difference between speed of light and speed of gravity
- New tests of Lorentz invariance
- Learn about origin of very heavy elements

- Probe jet formation, speed and evolution → physics of the merger - association with SGRBs?
- Constrain the equation of state of dense matter

The Holy Grail of the *Equation of State (EOS) of Neutron Stars*

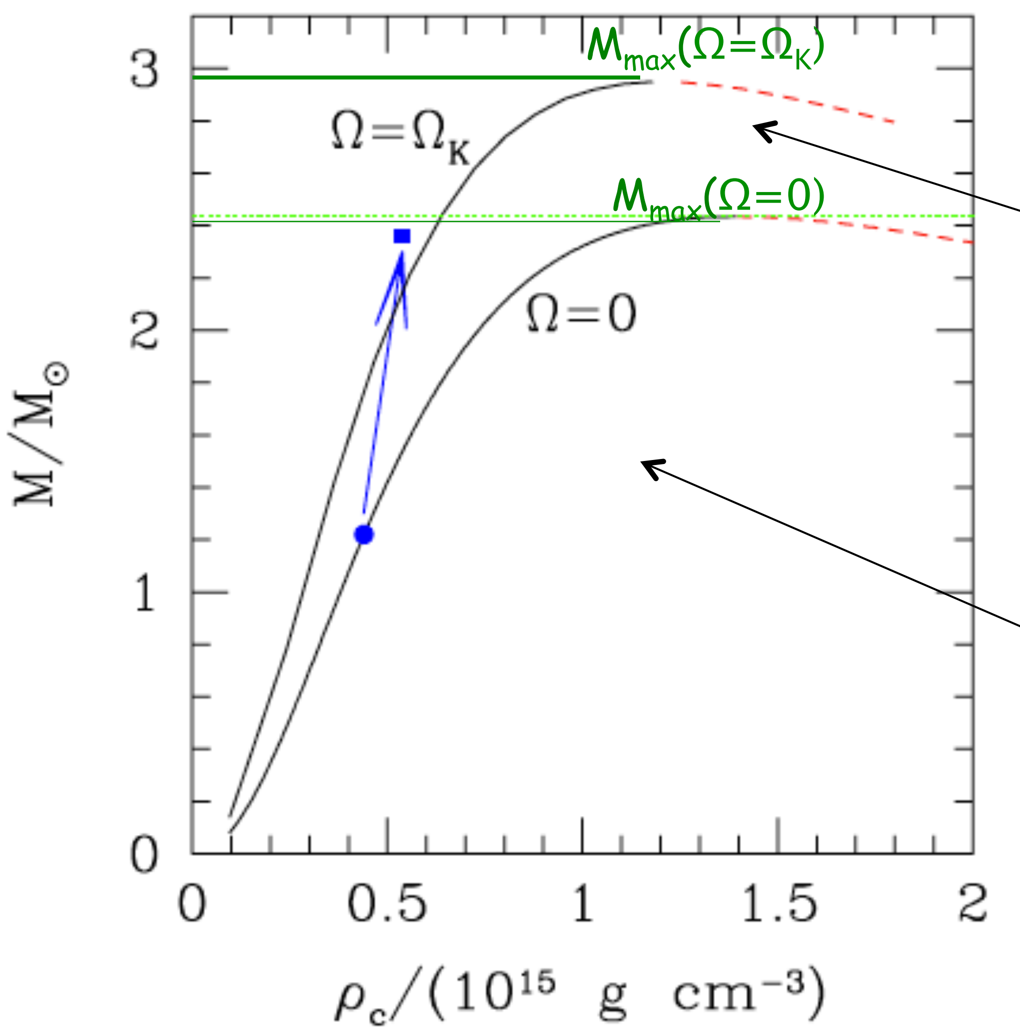


[Lattimer & Prakash 2007, 2015]

'Traditional' methods aim at direct measurements of Mass (Keplerian motion) and Radius (size of emitting region, PFs)

Gravitational waves open a new 'window' to the problem

What happens when two neutron stars merge?



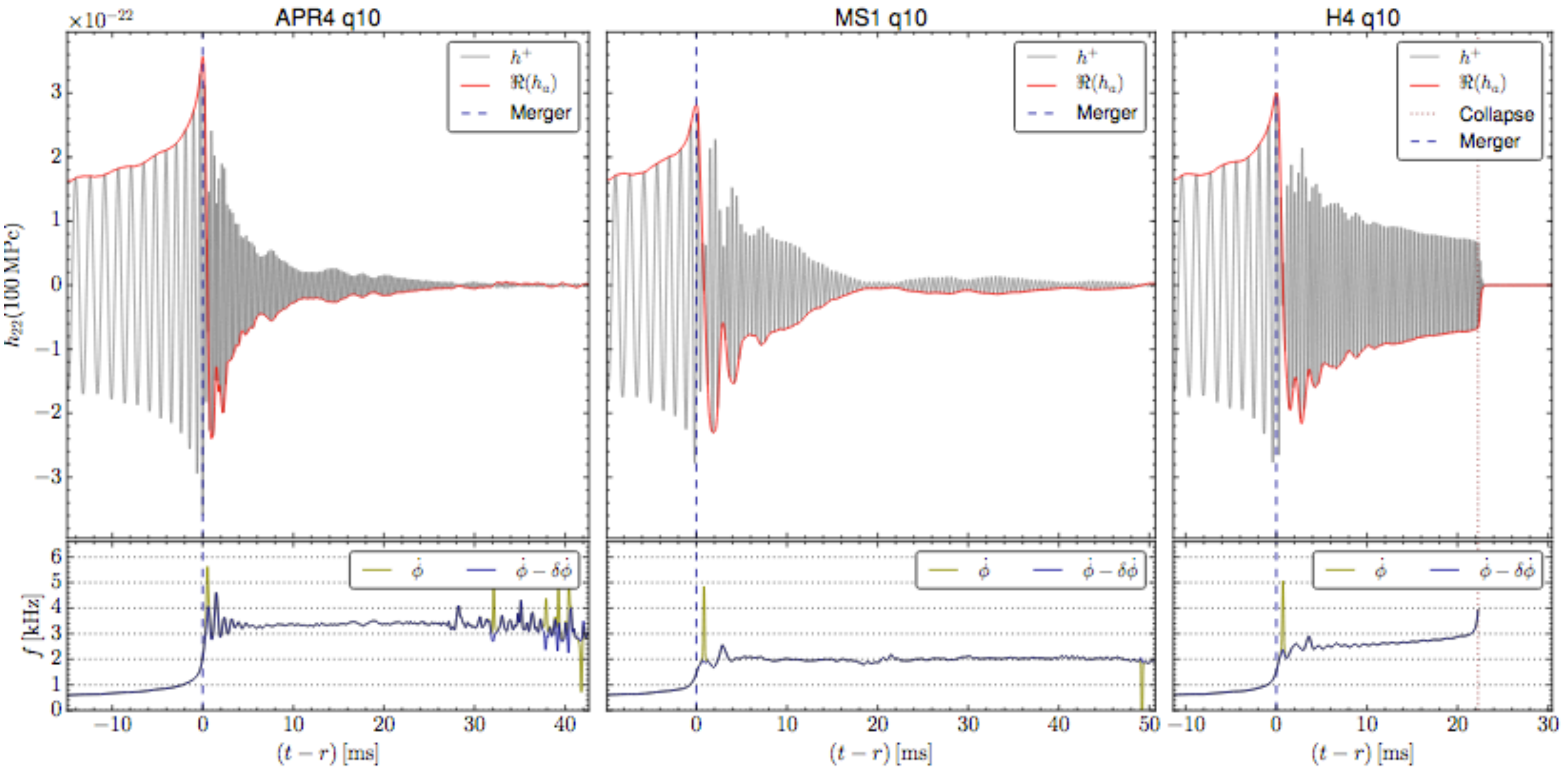
It depends…. but in a way which is sensitive to the NS EOS

Supramassive NS:
collapsing to a Black Hole after slowing down, at the point at which $M_{NS} = M_{max}(\Omega)$

Stable NS

GWs bear imprint of NS EOS – compute with GRMHD simulations

[Giacomazzo & Perna 2013]



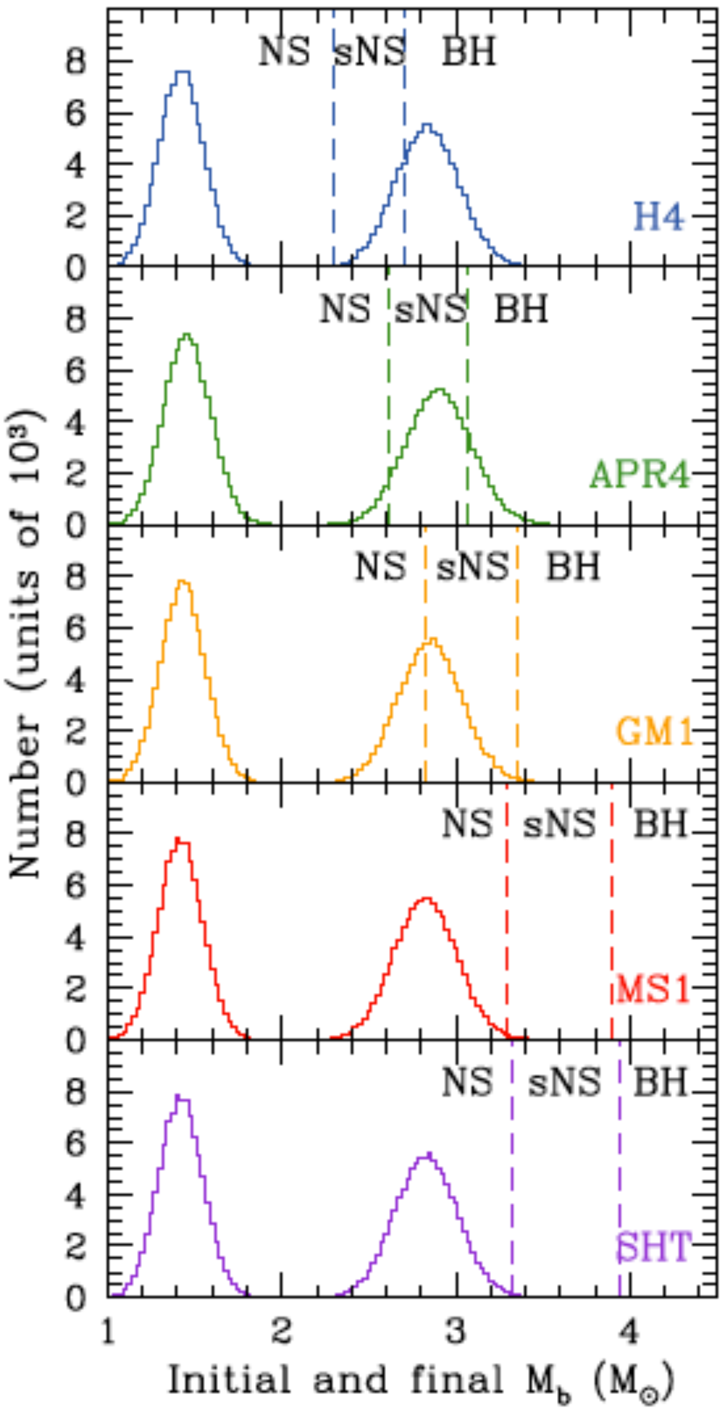
[Ciolfi et al. 2017]

GW signal sensitive to equation of state of neutron stars

→ Merger of NSs probe physics of dense matter

Can we still learn something from EM + GWs on the NS EOS without measuring the detailed GW signal?

Dominant post-merger oscillation frequency can be measured only for merger events within about 20 Mpc
[Clark et al. 2014; Bauswein 2015]



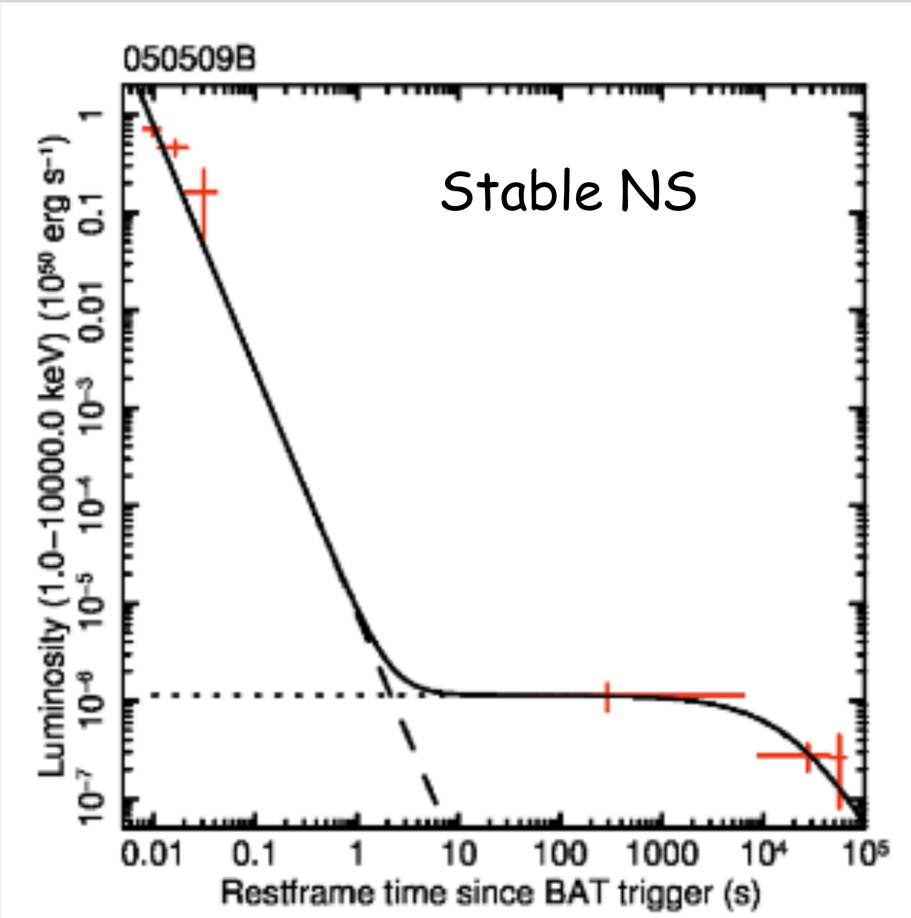
Predictions for distributions of remnants based on the observed distribution of NS in binaries

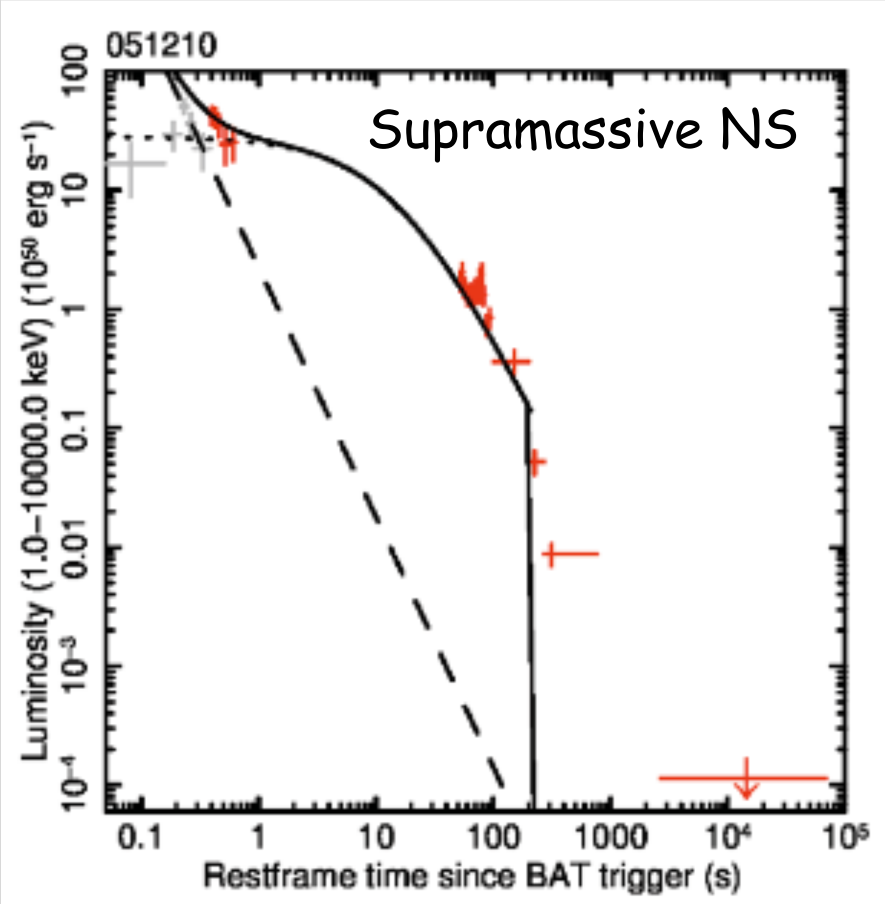
Fraction of outcome products (stable NS, supramassive NS, BH) highly dependent on the EOS of the NS

Simply identifying the remnant product in a fraction of merger events can constrain the NS EOS: both GWs and EM counterparts helpful for that.

[Piro, Giacomazzo & Perna 2017]

EM counterparts may help reveal the nature of the compact object left behind after the merger





[Rowlinson et al. 2013]

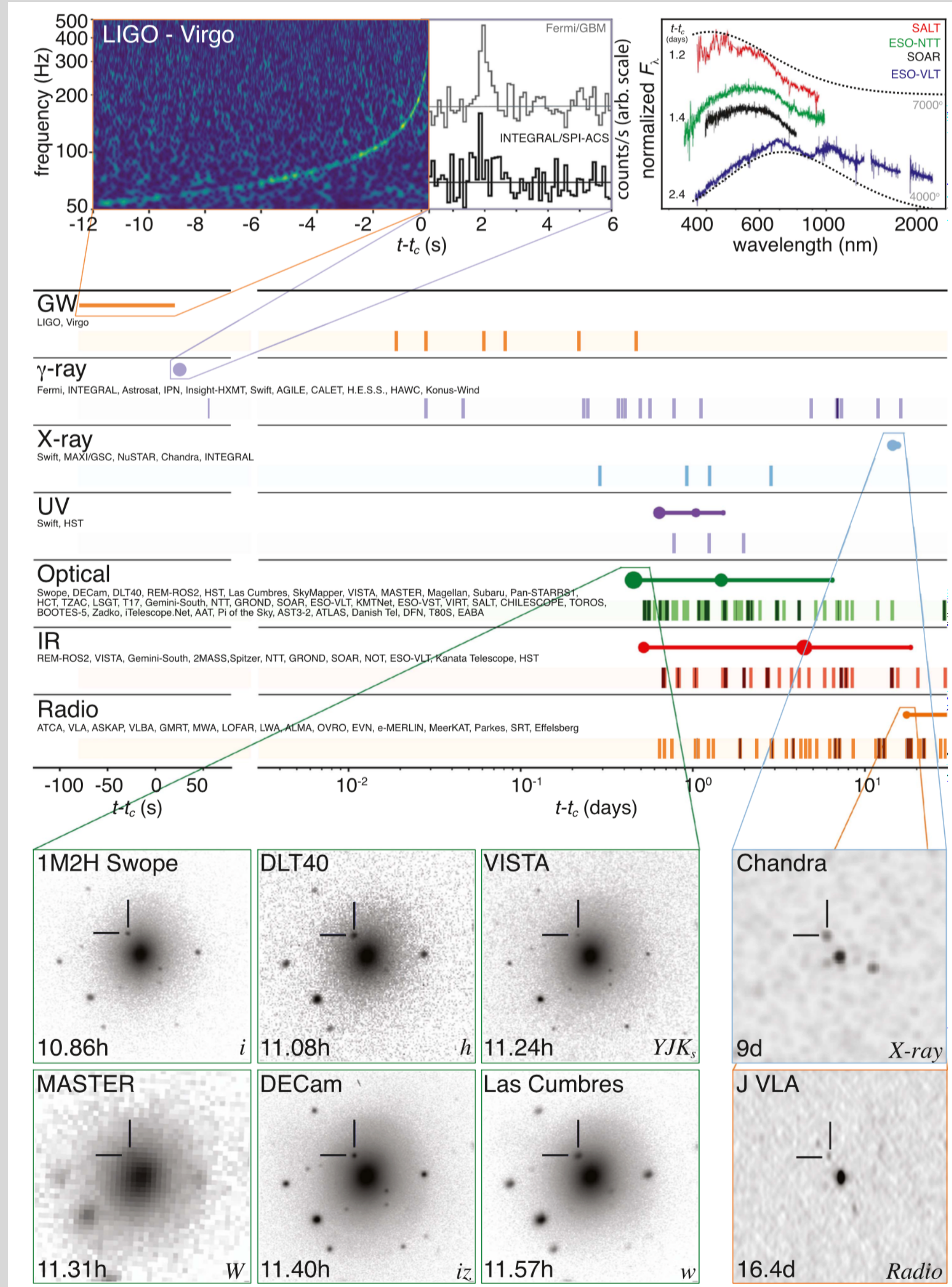
GW170817
EM170817

The beginning of MultiMessenger Astronomy!

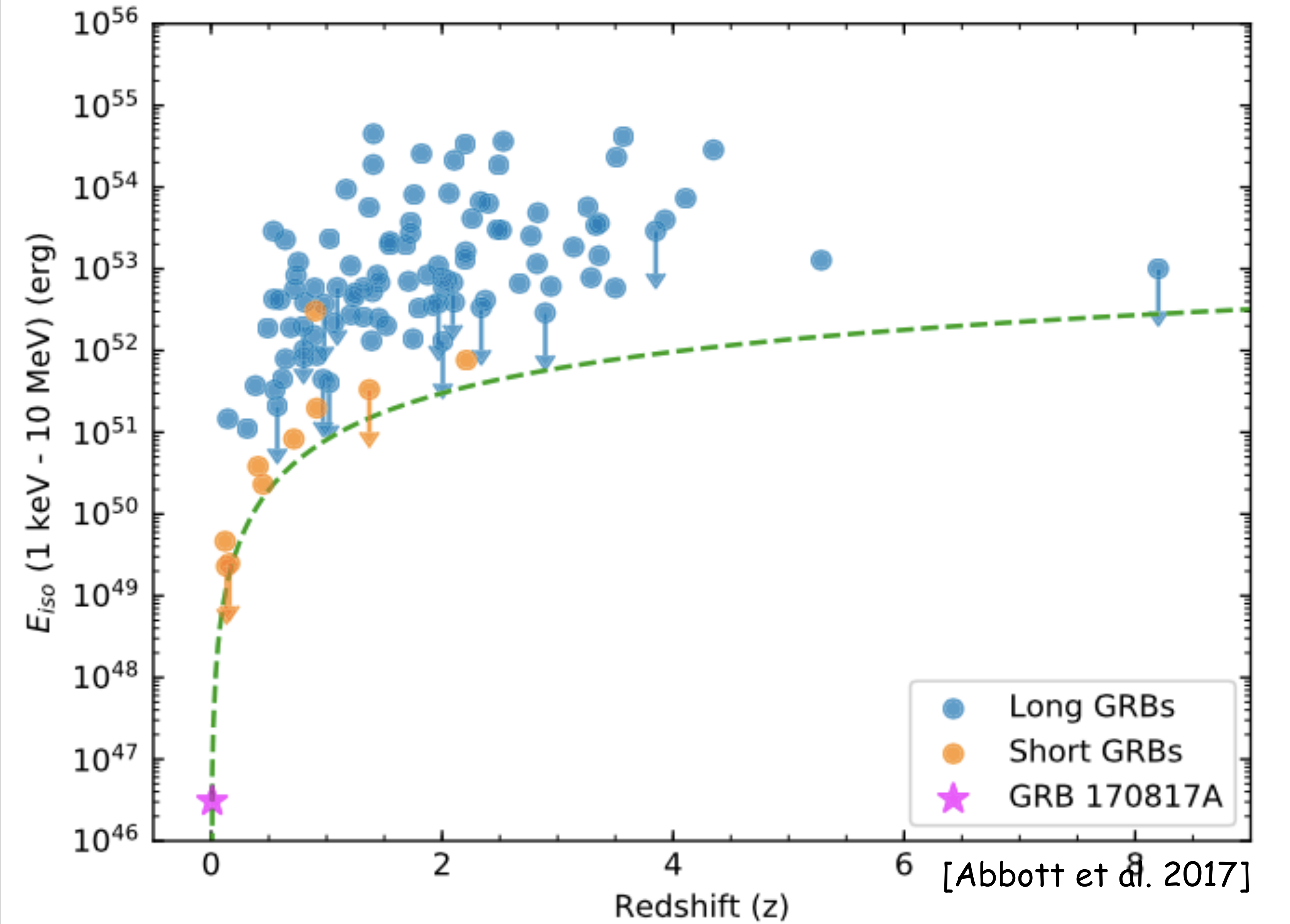
Following the GW event, radiation is detected in the entire EM spectrum, from Gamma-rays to Radio

130 million light years away

[LVC+FERMI joint collaborations, ApJL, 2017]



An important question: *was GRB 170817 a "standard" GRB?*



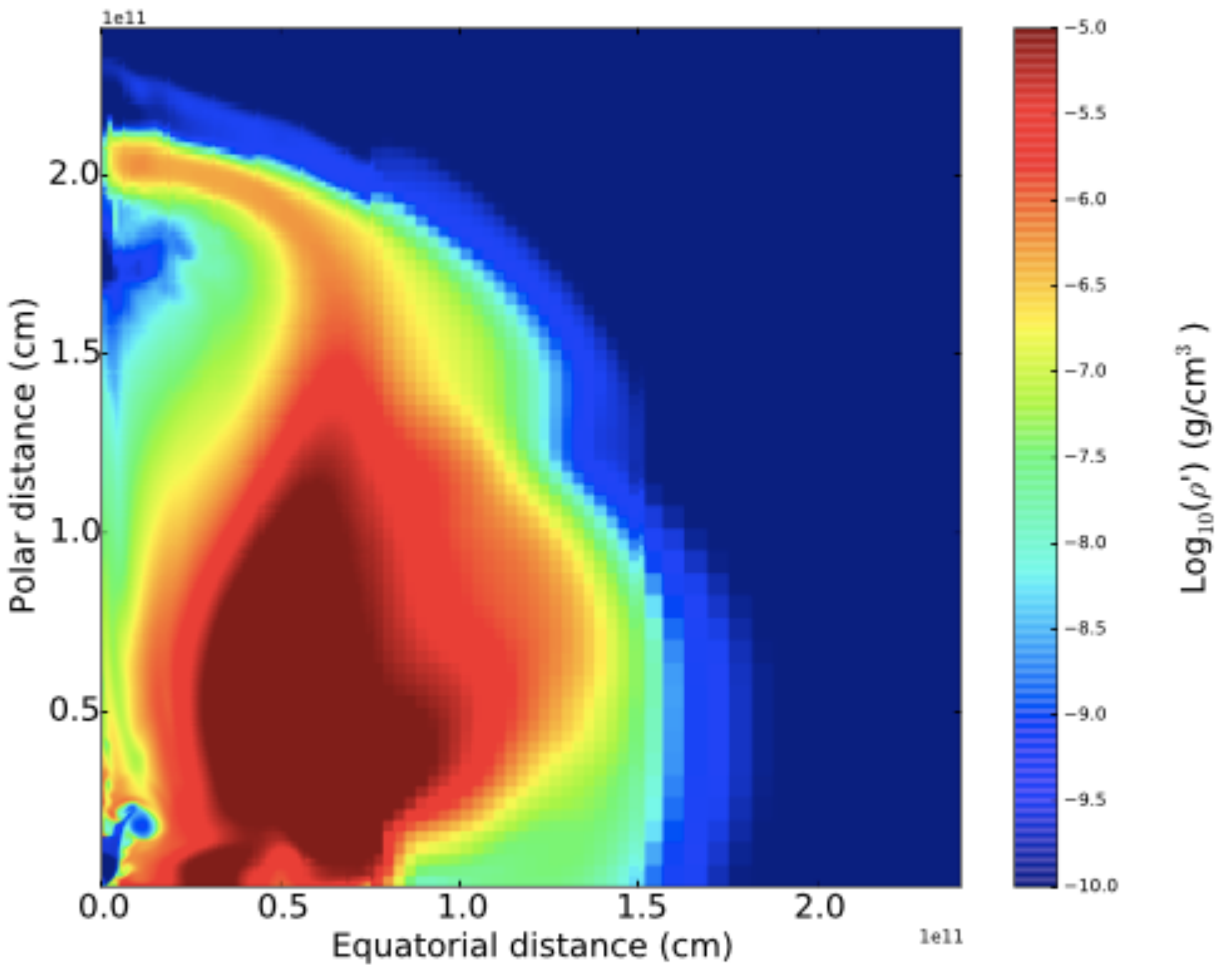
[Abbott et al. 2017]

Energetics ~10^3-10^4 times lower than those of the "standard" Short GRBs

This is not surprising after all...

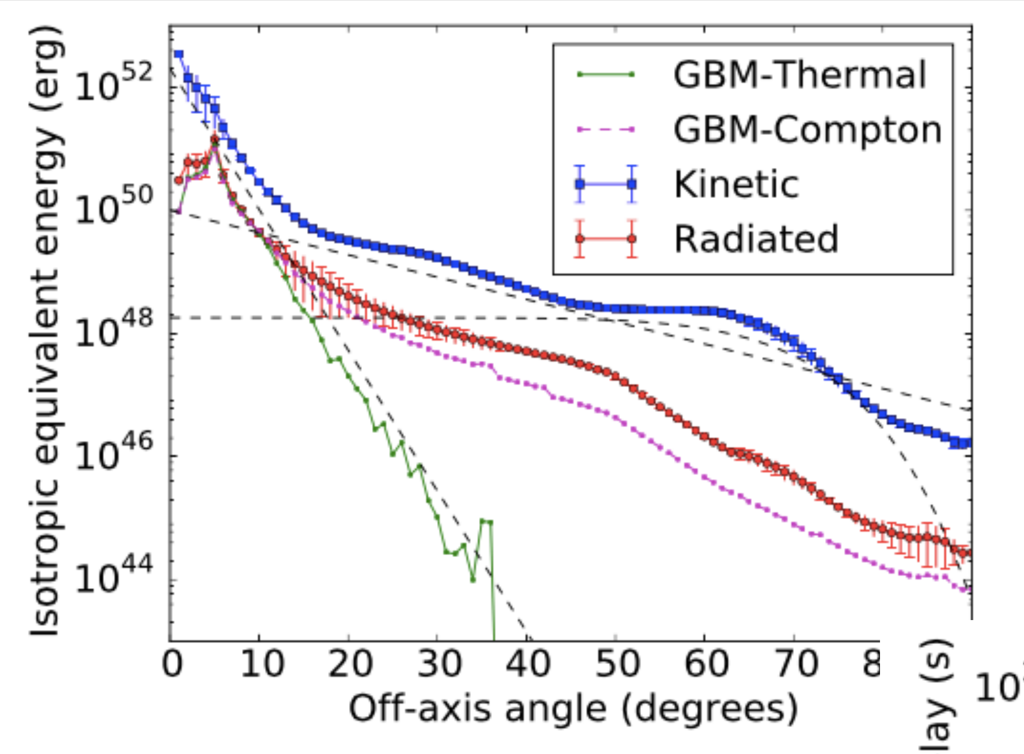
Emission is likely to be jetted – measured average jet angle of short GRBs ~ 16^0 --→ only about 1/20 expected 'on-axis' and hence bright.

What about the other events?

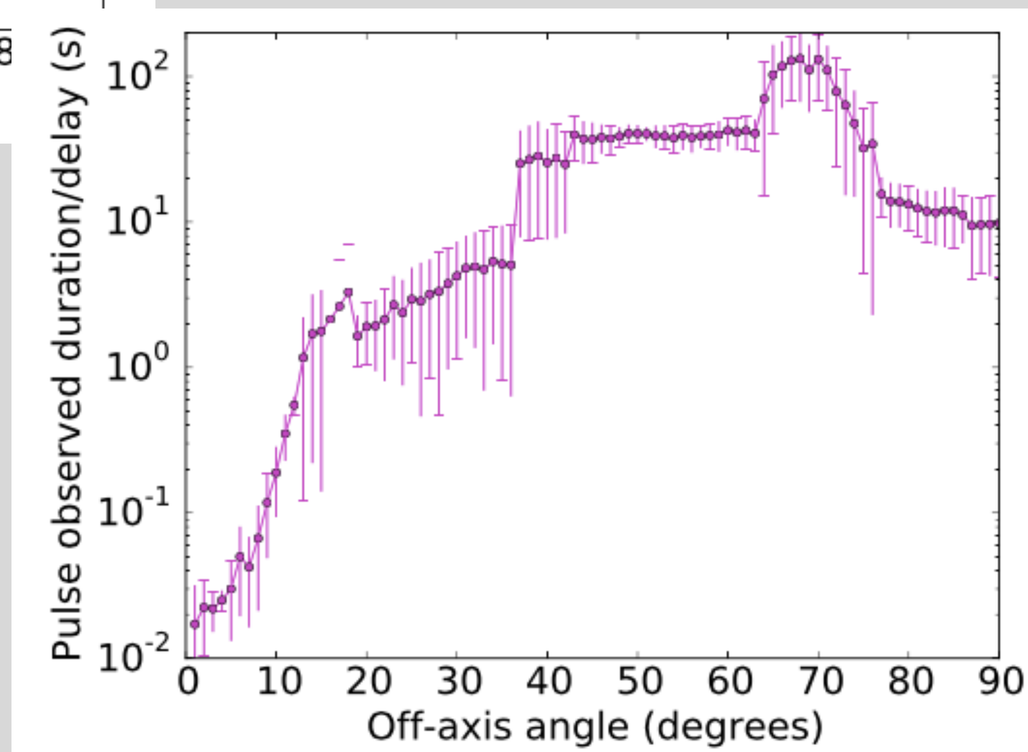


Snapshot of simulation (with the code FLASH) of a 16^0 jet propagating within NS-NS merger ejecta

[Lazzati et al. 2017]

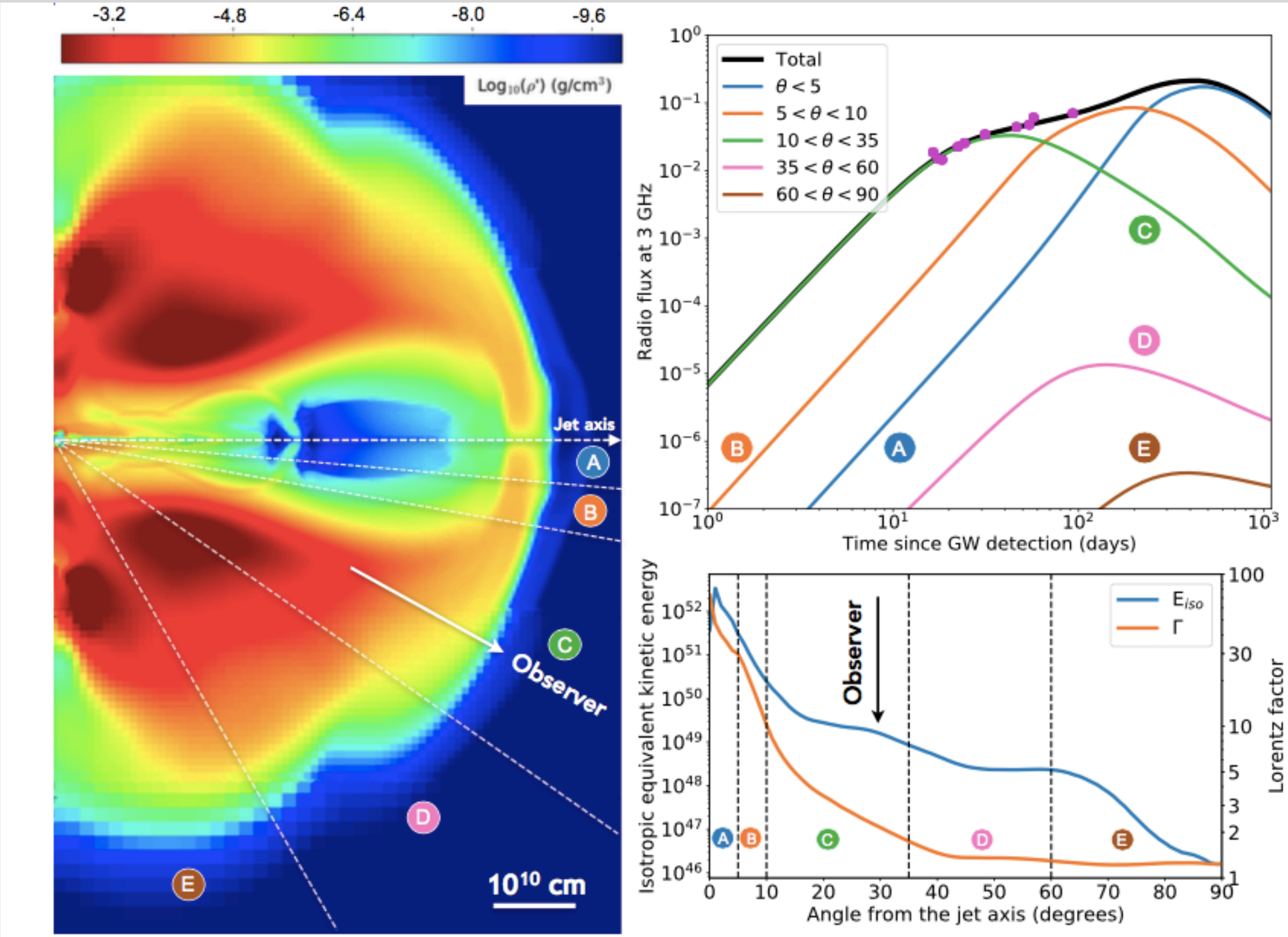


Viewing angles around 30^0 can reproduce both the energetics and the time delay between the GW and EM emission in the source GW 170817 / GRB 170817



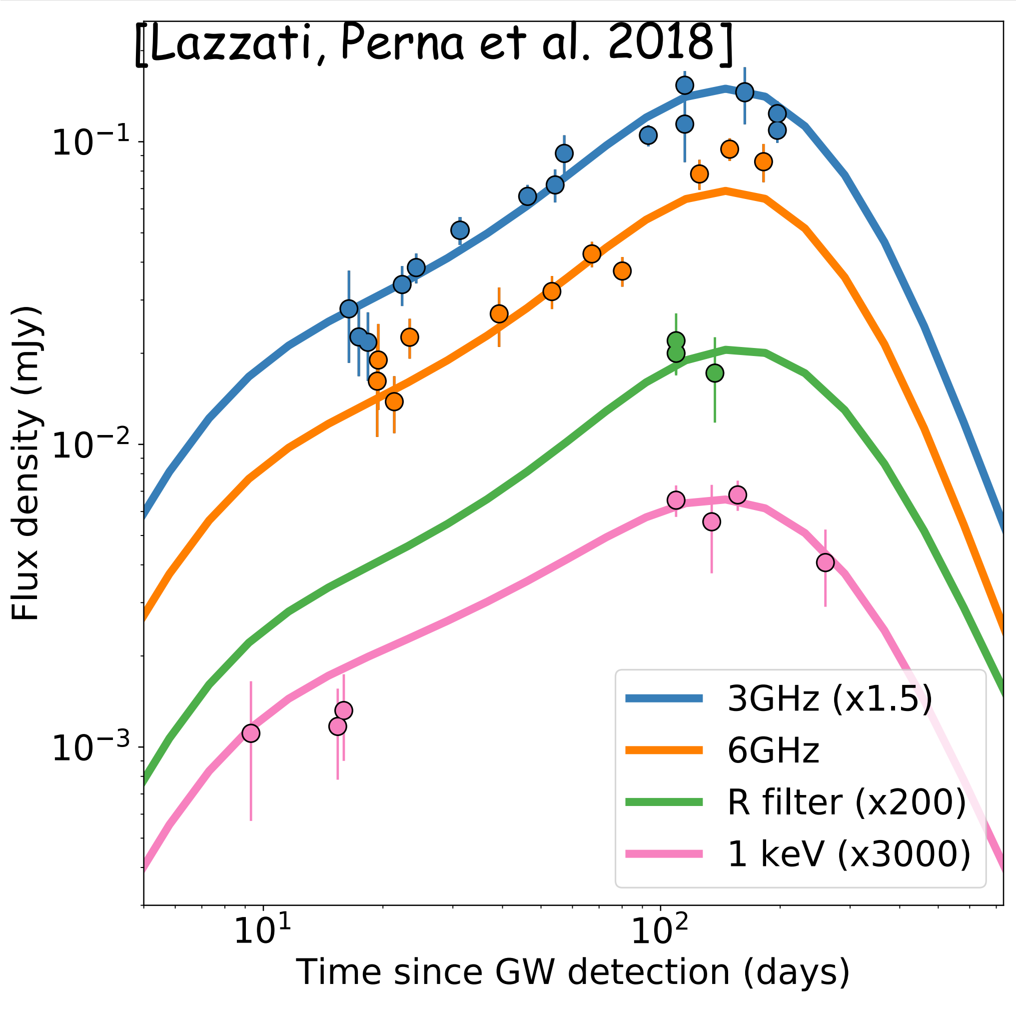
[Lazzati et al. 2017]

Broadband observations over a much longer timescale yield a consistent picture



[Lazzati, Perna et al. 2018]

Best-fit model for the multi-wavelength afterglow of GW170817



Viewing angle ~ 30^0 ;
best fit over first 145
days of data

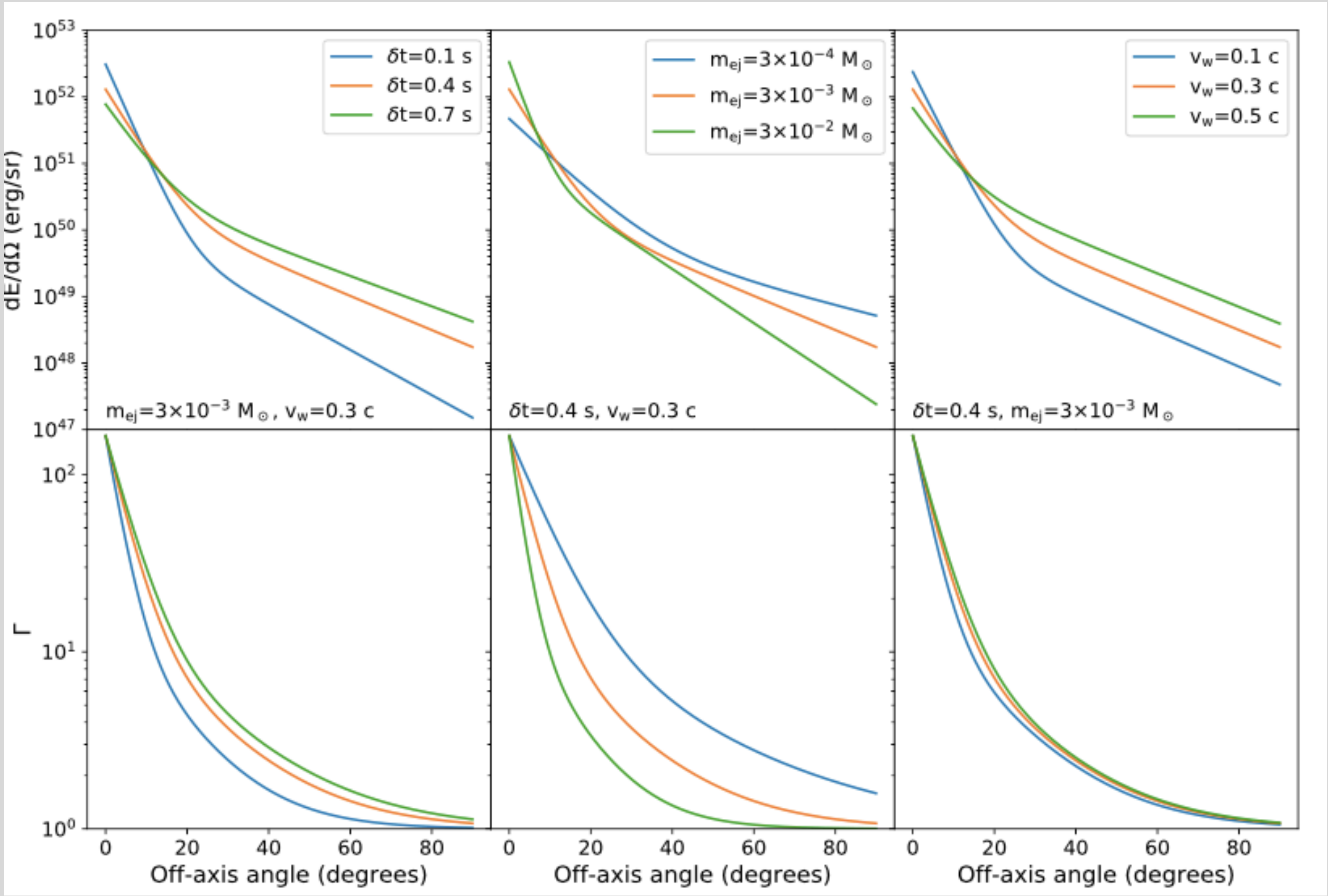
GRB170817 *is* consistent with a standard' Short GRB seen off axis

Interpretation initially debated since data could also be fitted with an isotropic, mildly relativistic shock powered by continuous energy injection [Mooley et al 2017]

VLBI measurements after 207 days settled the issue
→ GW170817 was associated with a relativistic jet and
hence a 'standard' short GRB [Ghirlanda et al 2018;Mooley et al. 2018]

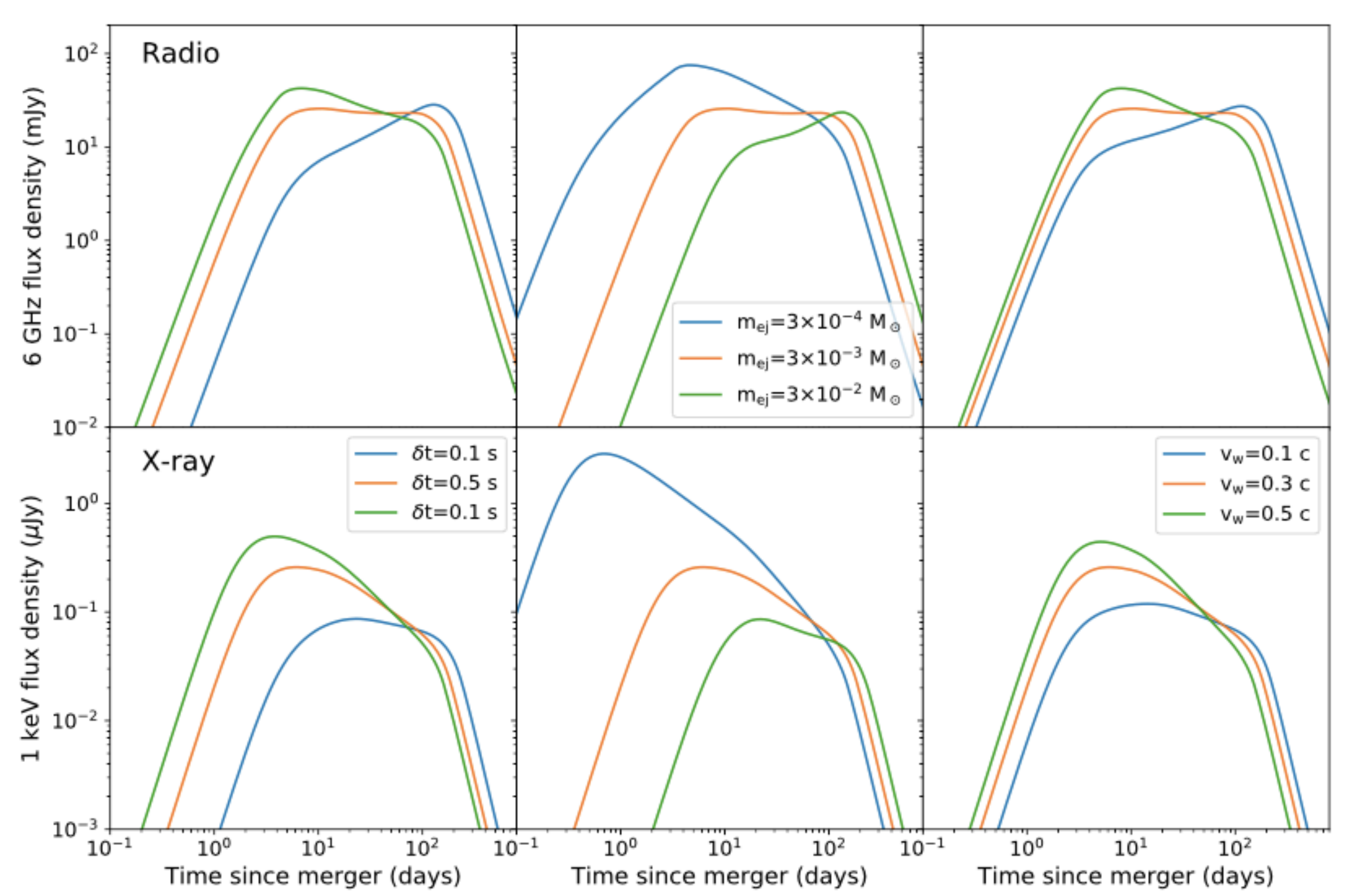
Looking into the future and searching for more diagnostics

Properties of jet molded by environment (i.e. ejected mass) in which it propagates



[Lazzati & Perna 2019]

Signatures imprinted in the light curves → sensitivity to ejecta properties → sensitivity to EOS of dense matter



[Lazzati & Perna 2019]

SUMMARY

The detection of GWs, in connection with EM emission from Binary Compact Objects is bound to have a profound impact on our understanding of high-energy phenomena, theory of gravity, nuclear physics, and cosmology alike.

It is the beginning of a  era!