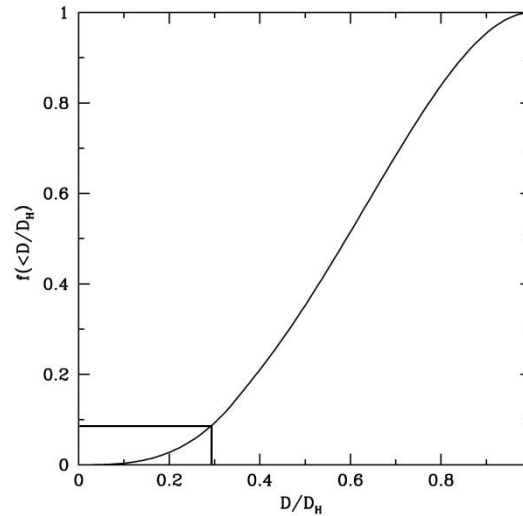
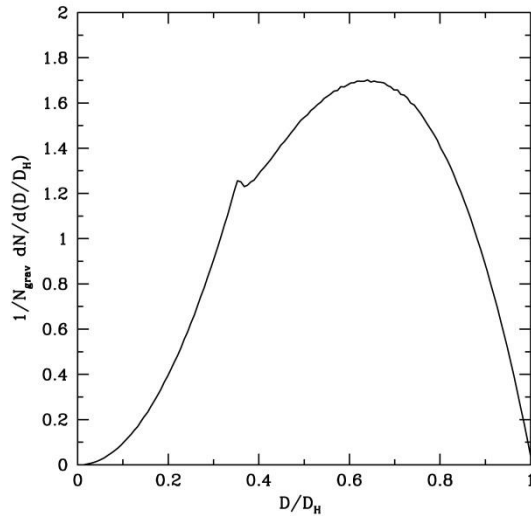


GW170817: bilan des observation multi-messagers: qu'avons nous appris?

$D = 40 \text{ Mpc}$ ($D_H = 136 \text{ Mpc}$) ; $\theta_v = 20 - 25^\circ \rightarrow$ an **EXCEPTIONAL** event: GW + GRB + KN + AG !!!



$$D/D_H = 0.3$$

$$f_d(D/D_H < 0.3) = 8.8\%$$

$$f_a(\theta_v < 25^\circ) = 1 - \cos \theta_v = 0.094$$

$$f_{\text{GW}} = 0.29$$

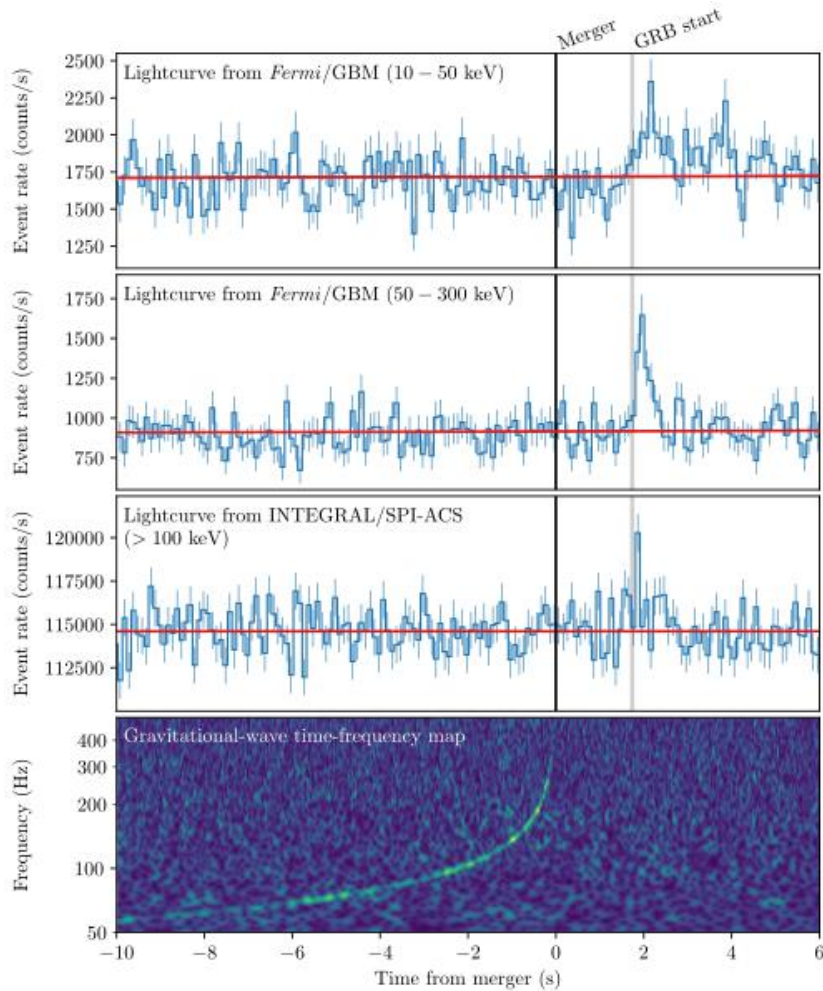
Taux attendu pour des événements comme GW/GRB 170817 :

$$\tau_{170817} = \tau_{\text{NSNS}} \times f_{\text{GW}} \times f_d \times f_a = \tau_{\text{NSNS}} \times 2.4 \cdot 10^{-3}$$

$$\tau_{\text{NSNS}} \sim 10/\text{an} \rightarrow \tau_{170817} \sim 1/40 \text{ ans !!!}$$

\rightarrow les événements à venir seront plus lointains et/ou plus inclinés

- GRB



Starts 1.7 s after GW signal ; duration: $\tau=1.5$ s

$$\Delta t = t_{\text{jet}} + t_{\text{diss}} = t_{\text{jet}} + R_{\text{diss}}/2c\Gamma^2 \sim \tau$$

GRB: photons above 100 keV

from 0 – 0.7 s : non thermal spectrum followed by a (possibly) thermal tail

Very underluminous: $L_p \sim 10^{47}$ erg/s

$$E_{\gamma, \text{iso}} \sim 4 \times 10^{46} \text{ erg}$$

→ outlier of $E_p - L_{\text{iso}}$ correlations

(underluminous) GRB possible 25° off-axis

Cannot come from central jet seen off-axis

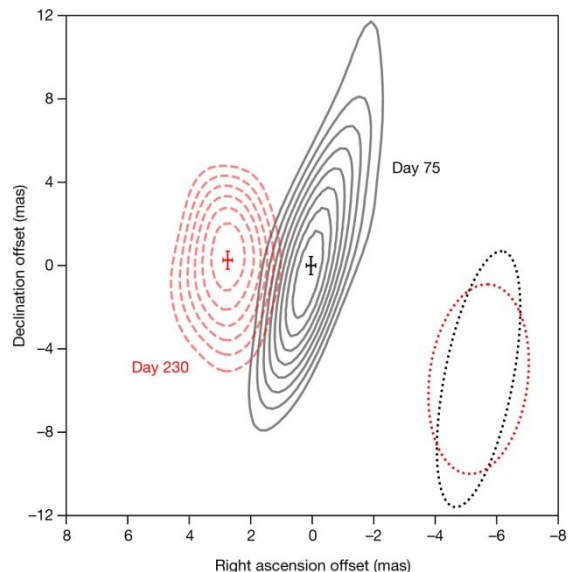
“standard”/new scenario:

→ shock breakout at the cocoon boundary

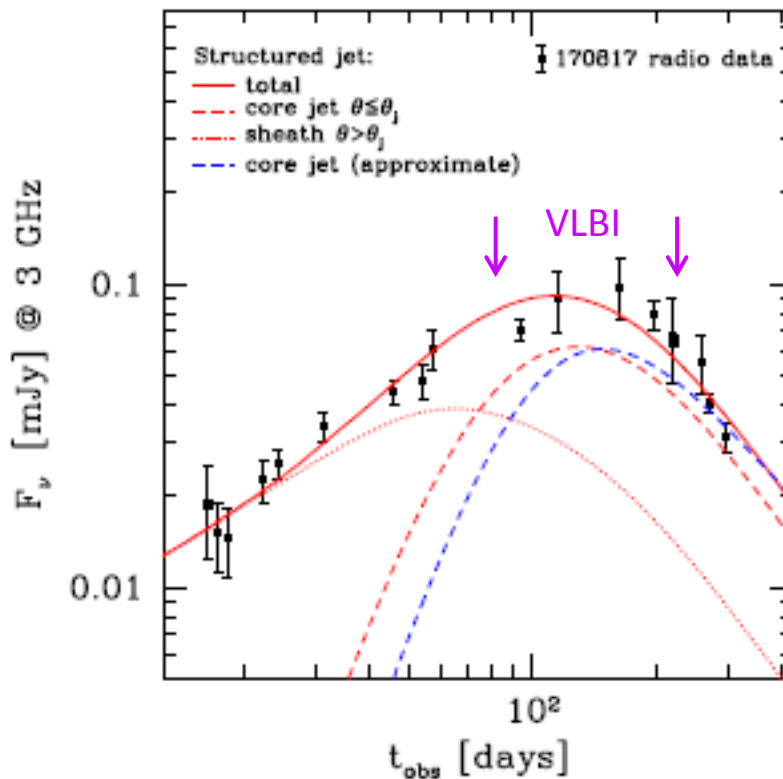
• **Afterglow**

Radial or/and angular structure ? A priori both can fit the data

But VLBI data indicates the presence of a central decelerating jet



(Mooley et al, 2018)



$\theta_j = 4^\circ$
 $\theta_v = 22^\circ$
 $n = 3 \cdot 10^{-3} \text{ cm}^{-3}$
 $E_{c,iso} = 2 \cdot 10^{52} \text{ erg}$

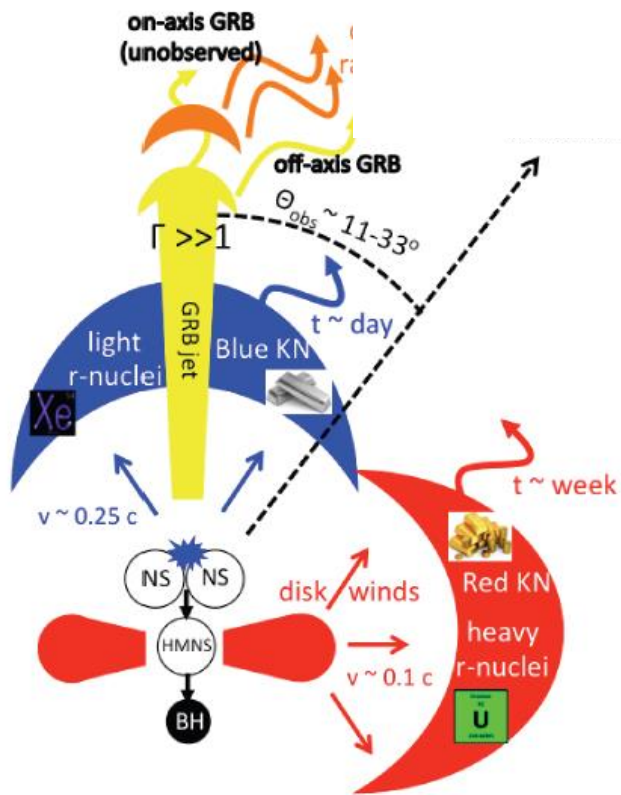
(Duque et al, 2019)

$$\Gamma(\theta_v - \theta_j) \sim 1 \text{ at peak} \rightarrow \Gamma = 2 - 4$$

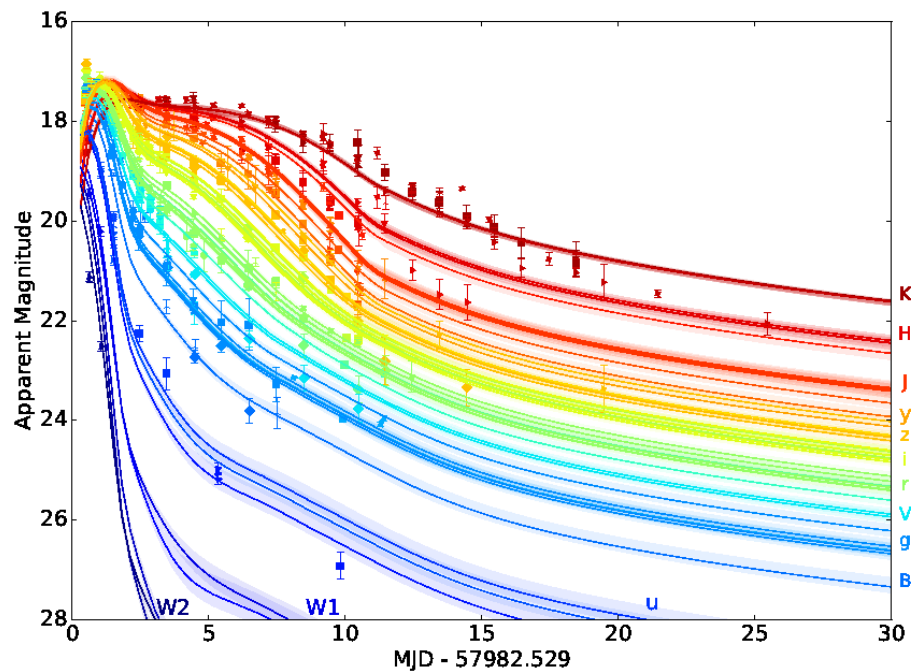
Same spectral regime from radio to X-rays: similar light curves \rightarrow offset X/radio fixes electron spectral index $N(E) \propto E^{-p}$ at $p=2.2$

• Kilonova

Expanding gas heated by radioactivity of neutron rich nuclei



(Metzger, 2017)



Red KN: $M_{ej} = 0.05 M_{\odot}$; $v_{ej} = 0.15 c$; $\kappa = 3.65 \text{ cm}^2/\text{g}$

Blue KN: $M_{ej} = 0.023 M_{\odot}$; $v_{ej} = 0.25 c$; $\kappa = 0.5 \text{ cm}^2/\text{g}$

(Villar et al, 2017)

What have we learned ?

- A structured ejecta $\dot{e}(\theta), \Gamma(\theta)$ was produced with a successful central jet
- A (weak) GRB can be produced 25° off-axis
- The unusual afterglow results (mostly) from the angular structure of the ejecta (with contributions from more energetic, more on-axis material received later → “angular tomography” of the ejecta)
- A blue (polar, high v , low κ) + a red (equatorial, lower v , large κ) KN were produced

What we would like to know:

- What level of diversity can we expect from NS+NS mergers?

Intrinsic:

- is the jet always successful ?
- can the merger produce a long-lived (how long?) massive neutron star?

External medium:

- is there a class of fast mergers ? → high density external medium (R. Duque’s talk)

Viewing angle:

- exploring the angular structure of the ejecta

- How frequent are BH+NS mergers ?

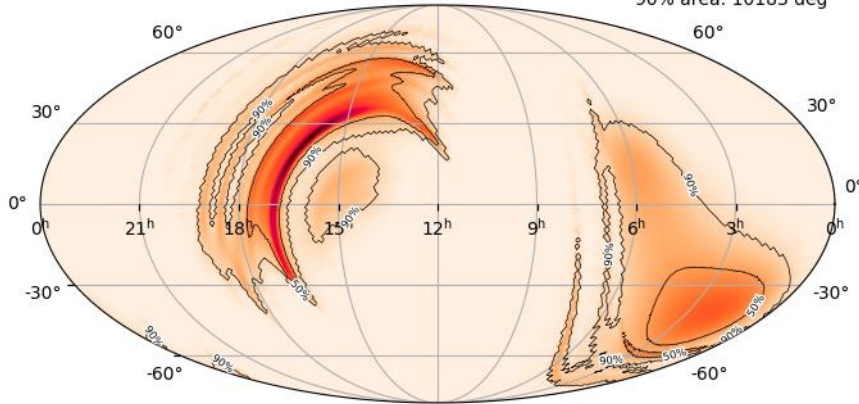
How similar/different are their prompt/afterglow emissions , their kilonovae ?

→ **More events !**

NS + NS events in O3

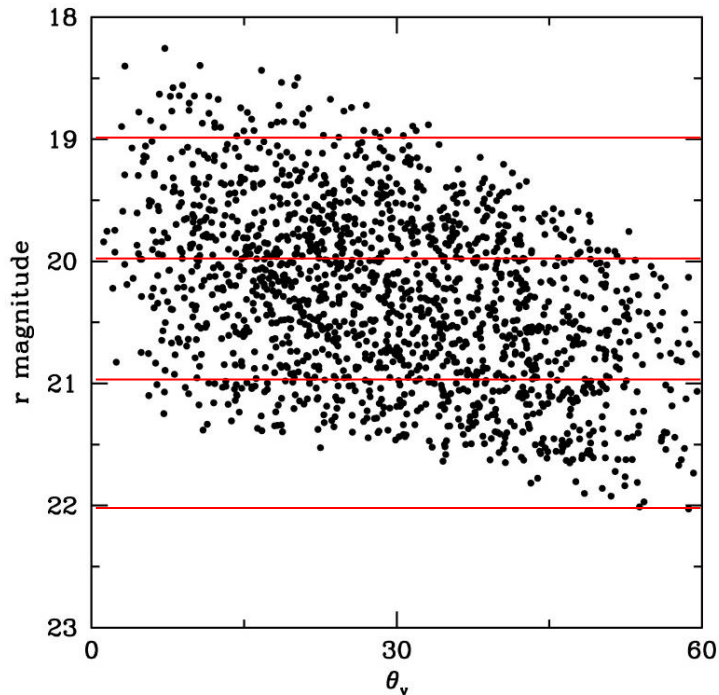
S190425z: $D=156 \pm 41$ Mpc

event ID: G330561
50% area: 2806 deg²
90% area: 10183 deg²



• 170817

Very large error box (Livingstone + Virgo only)
but reasonable coverage by ZTF (40%)
~ 70 reported candidates but no KN found
→ not in the searched area
or fainter than mag 20.5



Viewing angle-magnitude diagram
for a KN at the distance of S190425z:

m_r brighter than:	22	21	20	19
%:	100	67	36	0.3

KN 170817: $m_r = 17.2$

GRB 170817: a truly exceptional event

Before a full analog of GRB 170817 is found:

- GRB 150101B ($z=0.13$; 520 Mpc): no GW, more distant, more on-axis (13°)
delayed afterglow, kilonova
- large optical surveys (LSST) to find (orphan) kilonovae
- improved GW sensitivity and localization capabilities to find weak electromagnetic counterparts (KN, early AG)