



# Short Duration Gamma-Ray Bursts and Their Outflows in Light of GW170817

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The detection of GW170817, its extensive multi-wavelength follow-up campaign, and the large amount of theoretical development and interpretation that followed, have resulted in a significant step forward in the understanding of the binary neutron star merger phenomenon as a whole. One of its aspects is seeing the merger as a progenitor of short gamma-ray bursts (SGRB), which will be the subject of this review. On the one hand, GW170817 observations have confirmed some theoretical expectations, exemplified by the confirmation that binary neutron star mergers are the progenitors of SGRBs. In addition, the multimessenger nature of GW170817 has allowed for gathering of unprecedented data, such as the trigger time of the merger, the delay with which the gamma-ray photons were detected, and the brightening afterglow of an off-axis event. All together, the incomparable richness of the data from GW170817 has allowed us to paint a fairly detailed picture of at least one SGRB. I will detail what we learned, what new questions have arisen, and the perspectives for answering them when a sample of GW170817-comparable events have been studied.

**Keywords:** gamma-ray bursts, relativistic astrophysics, hydrodynamics, gravitational waves, binary mergers, transient sources

## 1 INTRODUCTION

Gamma-ray bursts (GRBs) are some of the most energetic explosions in the present day Universe, characterized by the release of large amounts of energy, within a few milliseconds to tens of seconds, resulting in the acceleration of relativistic outflows and the release of high-energy photons (Fishman and Meegan, 1995; Piran, 1999; Mészáros, 2002; Gehrels et al., 2009; Kumar and Zhang, 2015). They can be divided in at least two classes, based on the duration of their prompt phase, in which their emission is concentrated in the hard X-ray and gamma-ray bands and is characterized by fast variability (Kouveliotou et al., 1993). Long duration GRBs last 2 s or more, while short duration GRBs (SGRBs) last between a few milliseconds and 2 s. Alternative classifications have also been introduced, considering, e.g., short GRBs with extended emission (Norris and Bonnell, 2006; Dainotti et al., 2010; Norris et al., 2010; Barkov and Pozanenko, 2011; Dainotti et al., 2017), or attempting a more physical classification based on inferred progenitor properties (Lü et al., 2010; Bromberg et al., 2013).

In the last two and a half decades, the study of GRBs has concentrated on long duration GRBs, and a general consensus has grown around a model in which these events are associated with the collapse of the core of massive stars (Woosley and Bloom, 2006). While the collapse of most massive stars would ignite a core-collapse supernova, those that are fastly spinning and metal poor could also trigger a long duration GRB, powered by a compact central engine (Woosley, 1993;

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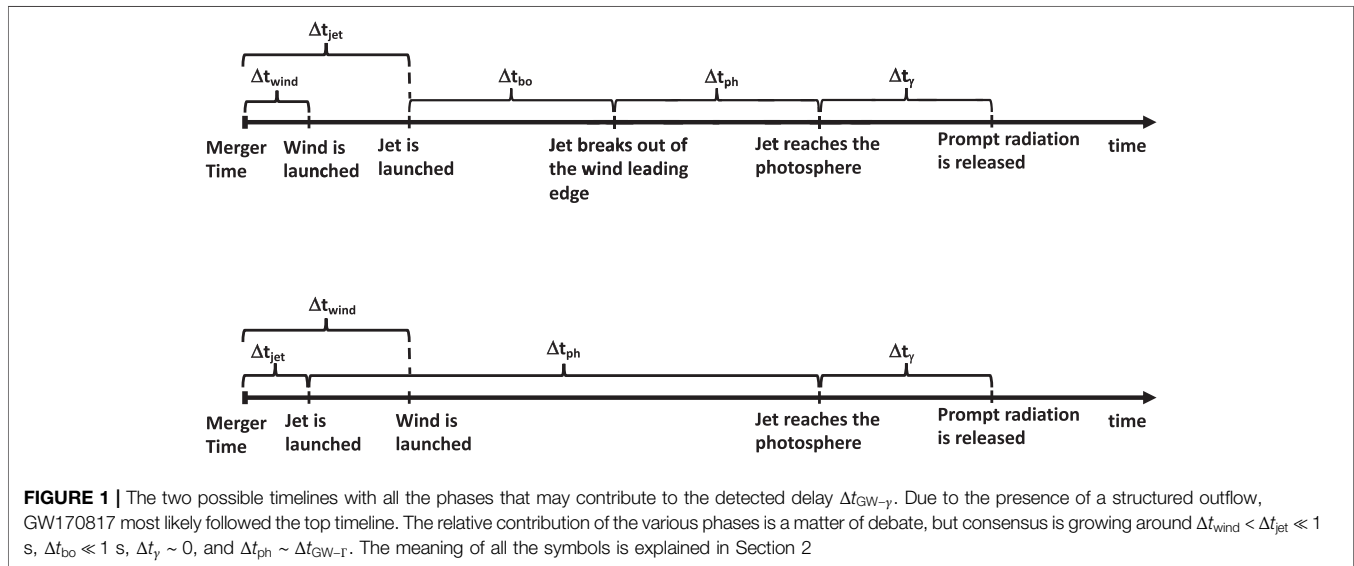
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Woosley and Heger, 2006; Yoon et al., 2006). Whether the central engine is a fastly spinning, highly magnetized neutron star (NS) (Bucciantini et al., 2008; Bucciantini et al., 2009; Metzger et al., 2011) or an accreting black hole (BH) (Woosley, 1993; Lee et al., 2000; Lei et al., 2013) is the matter of open debate.

The interest on SGRBs had increased in the last decade, initially as a consequence of the launch of the Fermi satellite, which had a higher efficiency for detecting and localizing them compared to its predecessors (Meegan et al., 2009). More recently, the theoretical expectation that SGRBs had to be associated with the merger of binary NS systems (or, perhaps, system made by a BH and a NS) (Belczynski et al., 2006; Lee and Ramirez-Ruiz, 2007; Fong and Berger, 2013; Giacomazzo et al., 2013; Ruiz et al., 2016; Ciolfi, 2018) has made them the expected and highly anticipated high-frequency counterparts of gravitational wave sources (Nakar et al., 2006; Kiuchi et al., 2010; Schutz, 2011). Such expectations were supported by energetic and temporal arguments. Powering a GRB requires a large amount of energy, comparable to the rest mass of a stellar object converted to energy. In addition, said energy needs to be released in a matter of a fraction of a second, at least for SGRBs. Naked compact objects (NS and BH) are the only available candidates that can offer the required energy within a region of less than a light second. However, isolated NS and BH are unlikely progenitors, since some catastrophic event needs to take place to cause the sudden release of a large fraction of their total energy. Binary mergers are therefore a natural candidate, when at least one of the two members is a NS, since a binary BH system would merge in a bigger BH that would swallow all the matter and energy, instead of ejecting them as a relativistic outflow.<sup>1</sup>

All these expectations were confirmed by the detection of GW170817 (Abbott et al., 2017a) and its associated GRB

GRB170817A (Abbott et al., 2017b; Goldstein et al., 2017; Savchenko et al., 2017; Zhang et al., 2018), afterglow, and kilonova (KN) (Abbott et al., 2017c; Abdalla et al., 2017; Alexander et al., 2017; Arcavi et al., 2017; Coulter et al., 2017; Cowperthwaite et al., 2017; Evans et al., 2017; Haggard et al., 2017; Hallinan et al., 2017; Kasen et al., 2017; Kim et al., 2017; Margutti et al., 2017; Pian et al., 2017; Siebert et al., 2017; Smartt et al., 2017; Soares-Santos et al., 2017; Tanvir et al., 2017; Troja et al., 2017; Valenti et al., 2017; D'Avanzo et al., 2018; Margutti et al., 2018; Mooley et al., 2018a; Mooley et al., 2018c; Lyman et al., 2018; Resmi et al., 2018; Villar et al., 2018; Ghirlanda et al., 2019; Lamb et al., 2019a). In this contribution I will review the key observations of GW170817 as a SGRB (also known as GRB170817A), the questions that were answered, and the new ones that were spurred, and briefly discuss what more insight is expected from the detection of more systems akin to GW170817 in future GW observing runs.

## 2 BEFORE THE PROMPT EMISSION

In this **Section 1** will review the physics of the SGRB outflow before the prompt emission phase begins, as it happened in GW170817. First of all, there is little doubt that the GW signal of GW170817 came from a binary compact merger, and that the masses of the two compact objects are compatible with being NS (Abbott et al., 2017a; Abbott et al., 2017b; Abbott et al., 2017c). The GW signal by itself does not allow to distinguish between NSs and BHs, but the richness of the electromagnetic signal that followed requires the presence of baryonic matter, and therefore at least one of the two components of the binary had to be a NS. Most likely they were both NSs (Coughlin and Dietrich, 2019).

### 2.1 The Time Delay

Besides the identification of the progenitor, a very important piece of information that GW170817 provided is the merger time,

<sup>1</sup>Some have suggested, however, that even binary BH mergers could produce a weak electromagnetic transient, under certain conditions (Perna et al., 2016; Liu et al. 2016; Zhang, 2016).

which allowed for the measuring of the time delay between the GWs and the gamma-ray signals. This delay, which we indicate as  $\Delta t_{\text{GW-}\gamma}$ , can be due to several reasons, as detailed below and shown in **Figure 1** (Granot et al., 2017; Lin et al., 2018; Zhang, 2019; Lazzati et al., 2020; Lucca and Sagunski 2020).

- **Engine Delay**—While the time of the merger is the earliest time at which the jet from the central engine can be produced, there is the possibility of some delay (Cook et al., 1994; Lasota et al., 1996; Vietri and Stella, 1998; Ciolfi and Siegel, 2015). Such delay is difficult to predict theoretically but can be likely due either to the need of a transition in the engine itself or to the need of amplifying the magnetic field to a value large enough to launch a jet. The former can be quite long, up to years, and usually invokes a metastable, fastly spinning NS that collapses into a BH when its rotation period is increased by either internal or external torques. We indicate this delay time as  $\Delta t_{\text{eng}}$ .
- **Wind Delay**—Owing to the detection of a KN and an off-axis SGRB from a structured outflow, we know that GW170817 ejected a non-relativistic wind. There can be a delay in launching such a wind as well, and we indicate it as  $\Delta t_{\text{wind}}$ . It should be noted, however, that this delay can in principle be negative since the NS surfaces are tidally shredded in the last few orbits before the merger.
- **Breakout delay**—If the wind is ejected before the jet, then the jet has to propagate through the wind. The propagation happens at sub-relativistic speed, causing a delay of the head of the jet with respect to the GW signal that travels at the speed of light (Matzner, 2003; Morsony et al., 2007; Bromberg et al., 2011; Lazzati and Perna, 2019). We indicate the time it takes for the jet head to cross the wind as  $\Delta t_{\text{bo}}$ . The jet-wind interaction also causes the development of a cocoon (Ramirez-Ruiz et al., 2002), confined by the surrounding wind. This leads to the development of a structured outflow that maintains a bright core but develops wide, energetic wings at large polar angles (Lazzati et al., 2017a; Lazzati et al., 2017b).
- **Photospheric delay**—After the outflow has broken out of the leading edge of the wind, it needs to propagate out to the photospheric radius. At this point the jet becomes transparent and the necessary conditions for the release of the prompt gamma-ray radiation are met. We indicate the delay due to the propagation from the break out radius to the photospheric radius as  $\Delta t_{\text{ph}}$ .
- **Dissipation delay**—While at the photospheric radius the prompt emission can be radiated, it does not mean it is. In some models, such as the popular internal shock synchrotron model, the outflow needs to propagate out to the internal shock radius before the bulk energy of the flow is dissipated and turned into radiation. We indicate this additional delay as  $\Delta t_{\text{d}}$ .

For the first time, a measurement of the sum of all these possible delays was available for GW170817 (Abbott et al., 2017b). The prompt gamma-ray radiation was detected with a delay  $\Delta t_{\text{GW-}\gamma} \approx 1.75$  s. Several attempts have been made to constrain the various individual contributions, but a general consensus has not been

achieved (Shoemaker and Murase, 2018; Gill et al., 2019b; Beniamini et al., 2020a; Hamidani et al., 2020). A few robust inferences can however be made (Lazzati et al., 2020). Overall, the measured delay was fairly small, since GW170817 ejected a significant amount of energy toward the observer but its Lorentz factor could be at most moderate ( $\Gamma < 7$ ) (Beniamini et al., 2020b). These combine to a large photospheric radius and a photospheric delay

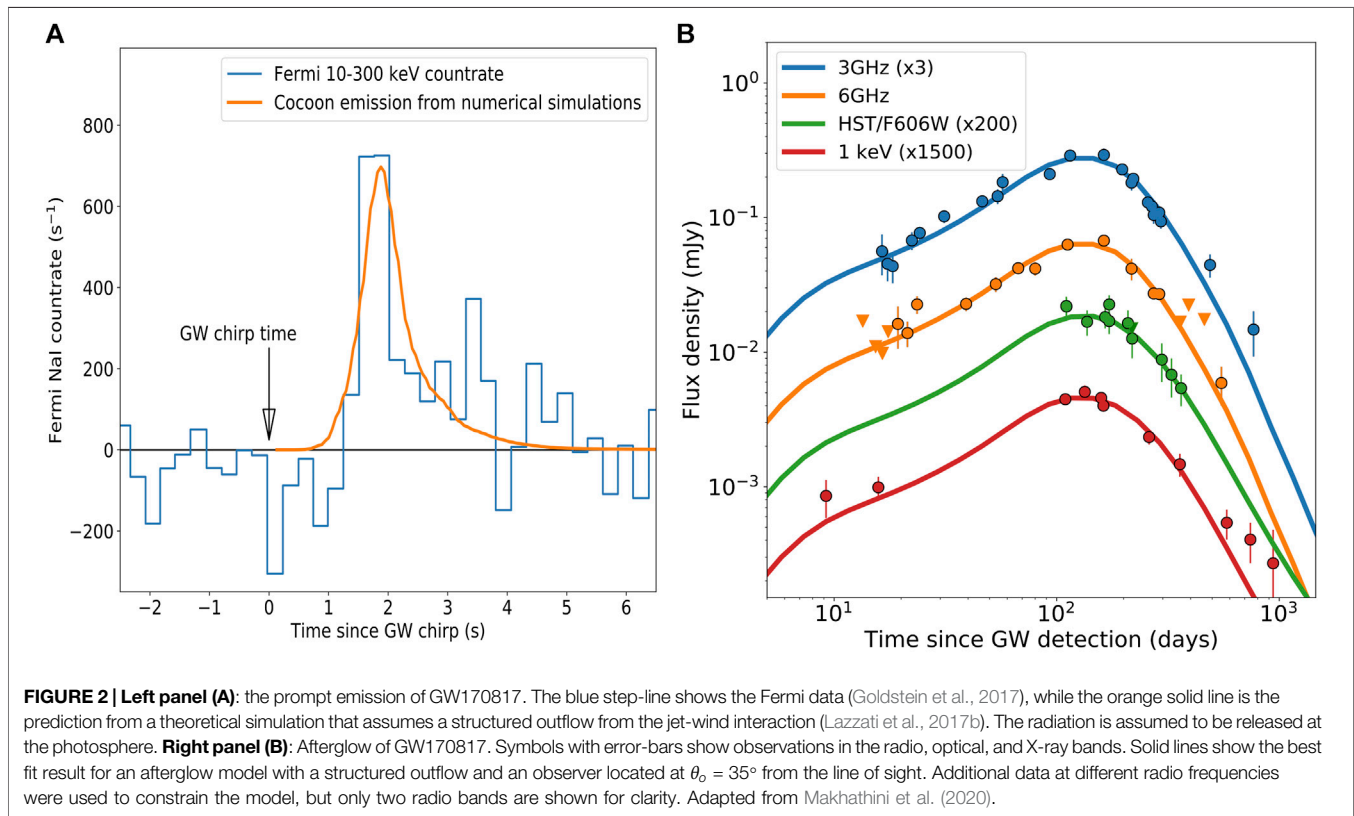
$$\Delta t_{\text{ph}} \sim \frac{R_{\text{ph}}}{c\Gamma^2} = 1.4 \frac{R_{\text{ph}}}{2 \times 10^{12} \text{ cm}} \left(\frac{7}{\Gamma}\right)^2 \text{ s} \quad (1)$$

The photospheric delay therefore had to contribute to a sizable part of the delay, since any other non-photospheric emission mechanism would require a longer delay (this allows to use the above equation to put a Lower limit on  $\Gamma$  (Beniamini 2020a). The wind delay, if there was any, had to be smaller than the jet delay, so that the jet-wind interaction could generate a structured outflow, as requested for modeling the afterglow emission. For the same reason, the jet delay itself could be fairly small but could not be null. Finally, the breakout and dissipation delays had to be small in order to accommodate the large expected photospheric delay. Note, however, that the prompt emission spectrum had a non-thermal shape, a property that is not expected from a simple photospheric emission model (see **Section 3** for a more thorough discussion).

## 2.2 The Shaping of the Outflow

GW170817 was also the first GRB for which evidence of a structured outflow could be unequivocally determined. The structure of the outflow could be intrinsic, as the jet itself could have been launched with a non-uniform polar structure (Aloy et al., 2005; Kathirgamaraju et al., 2019). However, the relatively large energetics of GW170817 in gamma-rays and the shape of its afterglow lightcurve (see **Section 4**) suggest a wide structure, most likely brought about by the jet interaction with the wind from the merger (Lazzati and Perna, 2019; Salafia et al., 2020).

A typical SGRB jet with isotropic equivalent energy  $E_{\text{iso}} = 10^{53}$  erg and asymptotic Lorentz factor  $\eta = 100$  has a baryon rest mass  $M_0 = E_{\text{iso}}/\eta c^2 \sim 10^{-4} M_{\odot}$ . If it encounters a wind mass  $M_{\text{wind}} \geq M_0/\eta \sim 10^{-6} M_{\odot}$  it is shocked and the velocity of propagation of its head is slowed until the working surface of the jet head is in causal contact, allowing for the wind material and the shocked jet material to move to the side instead of accumulating in front of the jet and thereby slowing it down (Matzner, 2003; Morsony et al., 2007; Bromberg et al., 2011; Lazzati and Perna, 2019). As a consequence, a high-pressure cocoon inflates around the jet, composed by partially mixed jet and wind material. As the jet breaks out of the wind leading edge, the cocoon loses the confining effect of the wind material and is released. Since it has large pressure, it accelerates creating a broad structure around the jet with decreasing energy and Lorentz factor for increasing polar angle. This process therefore turns a collimated jet into a structured outflow. It requires a small wind mass that is well below the expected amount of baryons ejected in a binary NS merger. The cocoon structure can be studied analytically, by enforcing pressure balance between the jet, cocoon, and wind material at their respective contact surfaces, or through numerical simulations. Despite its importance for



predicting burst/merger observability and understanding the structure and composition of the merger wind and jet, the polar profile of the outflow is highly debated. Analytic functions ranging from Gaussian, power-law, and exponential have been tested, and even numerical simulations do not provide an unequivocal answer (Murguia-Berthier et al., 2014; Nagakura et al., 2014; Lazzati et al., 2017b; Murguia-Berthier et al., 2017a; Murguia-Berthier et al., 2017b; Duffell et al., 2018; Granot et al., 2018a; Wu and MacFadyen, 2018; Xie et al., 2018; Geng et al., 2019; Gill et al., 2019a; Kathirgamaraju et al., 2019; Hamidani et al., 2020; Hamidani and Ioka, 2020; Murguia-Berthier et al., 2020; Takahashi and Ioka 2020a; Takahashi and Ioka 2020b).

### 3 THE PROMPT EMISSION

Approximately 1.75 s after the GW chirp, a gamma-ray pulse was observed by both the Fermi and INTEGRAL satellites from a position compatible with the direction from which the GWs arrived (Goldstein et al., 2017; Savchenko et al., 2017). The pulse was made by an initial spike of about half a second followed by a broader, less intense tail, for an overall duration of  $\sim 2$  s. Two characteristics make this gamma-ray pulse different from the population of previously observed SGRBs: it is markedly less energetic than an average cosmological SGRB and, given its energetics, it has a very high peak frequency (Fong et al., 2015). As a matter of fact, the detection itself was surprising because the chance of having a SGRB jet pointing along the line of sight for the first GW-selected binary merger was expected to be small (Metzger and

Berger, 2012; Ghirlanda et al., 2016). That is because the amplitude of the GWs depend only mildly on the orientation of the binary, while the intensity of the radiation from a narrow, relativistic jet drops quickly for any line of sight outside the jet itself. Such an expectation was based, however, on the properties of a narrow jet and not on the possibility that the jet-wind interaction would cause a structured outflow to form. Predictions from models with structured outflows had indeed shown that, for moderately large off-axis angles, a detectable signal would be expected from a GW-detected merger (Lazzati et al., 2017a; Lazzati et al., 2017b). A similar effect might be responsible for X-ray flashes, when a long duration GRB is seen off-axis (Yamazaki 2020, Yamazaki 2003).

The structured outflow model was successful at predicting that a SGRB would be detectable even at large off-axis angles (Lazzati et al., 2017a; Lazzati et al., 2017b). It correctly predicted the off-axis burst energetics and its duration. It could also successfully explain the detected delay between the GWs and the  $\gamma$ -rays. A comparison between the Fermi data and the bolometric photospheric emission (Lazzati et al., 2017b) is shown in the left panel of **Figure 2**. The one aspect of GW170817 that cannot be accounted for by the simple photospheric cocoon emission is the  $\gamma$ -ray spectrum of the prompt emission. At least in first approximation, the photosphere of an off-axis structured outflow is expected to produce a thermal pulse with temperature (Lazzati et al., 2017a; Lazzati et al., 2017b)

$$T_{\text{obs}} \approx \left( \frac{L\Gamma^2}{4\pi\sigma R_{\text{ph}}^2} \right)^{\frac{1}{4}} = 10^7 \left( \frac{L}{10^{47} \text{erg}} \right)^{\frac{1}{4}} \left( \frac{\Gamma}{100} \right)^{\frac{1}{2}} \left( \frac{10^{12} \text{cm}}{R_{\text{ph}}} \right)^{\frac{1}{2}} \text{K} \quad (2)$$



which would produce a spectrum peaked at a few KeV, in severe tension with the observed peak frequency at  $\sim 150$  keV (Goldstein et al., 2017). This is due to the fact that the cocoon, which energized the outflow at large off axis, is not expected to be radially structured, and therefore no significant dissipation is expected to occur around the photospheric radius, differently from the photospheres of long GRBs (Lazzati et al., 2009; Parsotan et al., 2018). One possible explanation is that the prompt radiation was due to an external shock (Veres et al., 2018). However, given the low Lorentz factor and low interstellar medium densities expected in the surroundings of GW170817, the timing of the prompt emission, less than 2 s after the launching of the jet, is difficult to explain. Alternatively, the prompt emission could be due to the breakout of the cocoon from the leading edge of the wind (Kasliwal et al., 2017; Bromberg et al., 2018; Gottlieb et al., 2018; Nakar et al., 2018). The shock breakout model can explain the energetics and spectrum of the prompt emission (Nakar and Sari, 2012) but requires a finely tuned setup in which the wind is very fast, so that it can reach a large enough radius at the breakout time. The origin of the prompt emission spectrum is therefore not been explained in a completely satisfactory way, yet (Kisaka et al., 2018; Meng et al., 2018; Pozanenko et al., 2018; Ioka and Nakamura, 2019; Matsumoto et al., 2019). The observation of more SGRBs from GW-detected mergers will offer further observational constraints to shed light on this remaining riddle.

## 4 THE AFTERGLOW

The afterglow of GW170817 had its own share of unique features. To begin with, it was not detected for more than a week, until it was bright enough to be seen first in X-rays (Margutti et al., 2017; Troja et al., 2017) and, at around the two weeks mark, in radio waves (Hallinan et al., 2017; Troja et al., 2017). The detection of the afterglow at optical wavelengths had to wait for the dimming of the associated KN, and was performed only around day 110 with the Hubble Space Telescope (Lyman et al., 2018). Such late appearance of an afterglow is unprecedented, since the typical behavior is that the afterglow peaks very early, minutes to hours after the burst, and only dims with time afterward (van Paradijs et al., 2000; Nousek et al., 2006). A second unique feature of the afterglow of GW170817 was that, even after it was detected, it sustained a slow brightening at all wavelengths (Margutti et al., 2017; Mooley et al., 2018c; Ruan et al., 2018; Troja et al., 2019b), eventually peaking  $\sim 150$  days after the GW detection and dropping in luminosity steeply afterwards (Dobie et al., 2018; Makhathini et al., 2020) (see the right panel of **Figure 2**).

The outflow from GW170817 along the direction toward Earth was under-energetic by a factor 10,000 to 100,000 times with respect to a typical SGRB (Fong et al., 2017). An outstanding question was therefore whether GW170817 had a misaligned, SGRB-like jet pointing in a different direction or not (Lazzati et al., 2018; Mooley et al., 2018a; Salafia et al., 2018). If it did, then the identification of the SGRB progenitors with binary NS mergers would be secured. If did not, then what GW170817 was associated with would be a new class of dim,

possibly isotropic,  $\gamma$ -ray transients. Unfortunately, telling whether a misaligned relativistic jet is present is not easy, since all the radiation is relativistically beamed away from the line of sight. The slow but steady brightening was shown to be consistent with the presence of a jet, its energy contribution along the line of sight growing with the deceleration of the external shock (Xiao et al., 2017; De Colle et al., 2018; Finstad et al., 2018; Granot et al., 2018b; Lamb and Kobayashi, 2018; Lazzati et al., 2018; Nakar et al., 2018; Fraija et al., 2019a; Fraija et al., 2019b; Beniamini et al., 2020b; Oganessian et al., 2020). However, a radially stratified spherical outflow could reproduce the observations as well, albeit at the price of adding a never observed before component to the models (Li et al., 2018; Mooley et al., 2018c; Nakar et al., 2018; Nakar and Piran, 2018; Salafia et al., 2018). Some evidence in favor of a jet was provided by the steep post-peak decay at all wavelengths (Alexander et al., 2018; Jin et al., 2018; Lamb et al., 2018; Mooley et al., 2018b; Nynka et al., 2018; Fong et al., 2019; Hajela et al., 2019). In addition, it was soon realized that either a relatively large linear polarization (Gill and Granot, 2018) or a small but detectable proper motion of the radio transient could potentially give the final clue. Both observations were carried out. Polarization turned out to be small (Corsi et al., 2018), and only an upper limit of 12 per cent was obtained, still consistent with either explanation. Long baseline radio interferometry turned out to be the key. In one experiment, a small but significant proper motion was detected (Mooley et al., 2018a), while in a second experiment the radio source was confirmed to be point-like (Ghirlanda et al., 2019). Both these characteristics are incompatible with a spherical expansion. In the future, the detection of the counter-jet emission might give additional evidence (Yamazaki 2018).

To date, despite the very high quality of the available data, the unique afterglow of GW170817 can be modeled successfully with the good old external shock synchrotron model (Mészáros and Rees, 1997; Sari et al., 1998), with the only required addition of considering off-axis observers (Granot et al., 2002) and allowing for some structure in the polar direction (Lazzati et al., 2017b; Lazzati et al., 2018). The type of polar stratification is not univocally constrained, since Gaussian, power-law, and exponential profile seem all to give an adequate fit to the data (Lazzati et al., 2018; Troja et al., 2018a; Xie et al., 2018; Ghirlanda et al., 2019). Numerical simulations are also ambiguous, different codes yielding different polar structures, including the three mentioned above (Murguia-Berthier et al., 2014; Nagakura et al., 2014; Lazzati et al., 2017b; Murguia-Berthier et al., 2017a; Murguia-Berthier et al., 2017b; Duffell et al., 2018; Granot et al., 2018a; Wu and MacFadyen, 2018; Xie et al., 2018; Geng et al., 2019; Gill et al., 2019b; Kathirgamaraju et al., 2019; Hamidani et al., 2020). Constraints can be obtained from the lack of a large populations of cosmological off-axis bursts (Beniamini 2019). More observations and further theoretical work are needed to pin down this important aspect that has implications not only on the detectability of bursts but also on the nature of the inner engine and the composition of the ejected jet and wind.

## 5 SUMMARY, DISCUSSION, AND A LOOK AT THE FUTURE

GW170817 was a rich event, a cornerstone detection in our understanding of SGRBs. It confirmed that binary NS mergers are the progenitor of at least some short bursts, it showed us that the top-hat jet model is woefully inadequate for describing the relativistic outflows of SGRBs (and possibly long duration GRBs as well) and it gave us, for the first time ever, a measure of the trigger time and of the delay between the launching of the jet and the detection of the prompt emission radiation.

We now know that the burst associated with GW170817 was a fairly canonical SGRB (Salafia et al., 2019), with a powerful relativistic jet that, after interacting with the merger wind, turned into a structured outflow (Lazzati et al., 2017b; Lazzati et al., 2018). Our line of sight lied somewhere between 15° and 35° away from the jet axis, the lower value obtained by high resolution radio imaging (Mooley et al., 2018c; Ghirlanda et al., 2019), while the larger value being favored by multi-band afterglow modeling and ejecta considerations (Lazzati et al., 2018; Mandel, 2018; Zou et al., 2018). The prompt emission was powered by an energetic cocoon inflated by the interaction of the jet with the merger wind. The gamma-ray radiation was likely released at or near the photosphere, either by a shock breakout (Nakar and Sari, 2012; Kasliwal et al., 2017; Gottlieb et al., 2018) or by other non-thermal mechanisms (Savchenko et al., 2017; Veres et al., 2018). The external shock developed later than usual due to the lower than customary Lorentz factor of the outflow along the line of sight and the afterglow was unusual, characterized by an initial increase in luminosity that lasted for a few months before peaking and beginning a steep declining phase. This behavior is understood to be due to the structure of the outflow, characterized by a polar stratification with a steep decline as a function of angle in both the energy per unit solid angle and the Lorentz factor.

Despite the large amount of observational evidence that allowed us to paint a detailed picture of the dynamic of the relativistic ejecta of GW170817 and their electromagnetic signatures, some questions remain open. First, we do not know the nature of the compact object that launched the relativistic jet. It could have been either a meta-stable NS or a BH, and consensus in this respect hasn't been reached (Piro et al., 2019; Metzger et al., 2018; Pooley et al., 2018; Abedi and Afshordi, 2019). A related mystery is the origin of the observed

1.75 s delay between the GW and the prompt emission. As discussed in Section 2.1 the delay is the sum of many components and it is unclear which dominates, or if several of them have comparable magnitude. Since the photospheric delay is strongly dependent on the viewing angle, observation of several SGRBs from a diverse set of angles will help better understand the origin of the delay. Still unclear is also the physics of the dissipation that powered the prompt emission and the prompt emission mechanism itself. Shock breakouts, internal dissipation such as internal shocks, and even external shocks have been proposed (see Section 3).

Finally, we still do not know how typical GW170817 was. The fact that most likely it originated from a binary NS merger does not exclude the possibility that some—if not most—SGRB are made in NS-BH mergers. It might even be that GW170817 itself was a NS-BH merger (Coughlin and Dietrich, 2019; Kyutoku et al., 2020). Re-analysis of several past bursts have yielded some support the presence of kilonovae in their light curves (Troja et al., 2018b; Beniamini et al., 2019; Lamb et al., 2019b; Troja et al., 2019a) or similarities in their prompt emission (Burns 2018, von Kienlin 2019), showing that GW170817 was not unique. However, there might be cases in which the jet is not successful in breaking out of the wind leading edge, and a weaker transient would be produced (Kasliwal et al., 2017; Mooley et al., 2018c; Salafia et al., 2018). Future GW detections with the power of multimessenger observations will allow to better understand the connection between binary NS mergers, binary NS-BH mergers, and SGRBs.

## AUTHOR CONTRIBUTIONS

DL has written this review article on his own to the best of his knowledge, he has produced all figures himself from publicly available data and codes. The references are extensive but they are by no means exhaustive.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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