galaxies

MDPI

Article

Plasmas in Gamma-Ray Bursts: Particle Acceleration, Magnetic Fields, Radiative Processes and Environments

Asaf Pe'er

Physics Department, Bar Ilan University, Ramat-Gan 52900, Israel; asaf.peer@biu.ac.il; Tel.: +972-3-5318438

Received: 22 November 2018; Accepted: 7 February 2019; Published: 15 February 2019

Abstract: Being the most extreme explosions in the universe, gamma-ray bursts (GRBs) provide a unique laboratory to study various plasma physics phenomena. The complex light curve and broad-band, non-thermal spectra indicate a very complicated system on the one hand, but, on the other hand, provide a wealth of information to study it. In this chapter, I focus on recent progress in some of the key unsolved physical problems. These include: (1) particle acceleration and magnetic field generation in shock waves; (2) possible role of strong magnetic fields in accelerating the plasmas, and accelerating particles via the magnetic reconnection process; (3) various radiative processes that shape the observed light curve and spectra, both during the prompt and the afterglow phases, and finally (4) GRB environments and their possible observational signature.

Keywords: jets; radiation mechanism: non-thermal; galaxies: active; gamma-ray bursts; TBD

1. Introduction

Gamma-ray bursts (GRBs) are the most extreme explosions known since the big bang, releasing as much as 10^{55} erg (isotropically equivalent) in a few seconds, in the form of gamma rays [1]. Such a huge amount of energy released in such a short time must be accompanied by a relativistic motion of a relativistically expanding plasma. There are two separate arguments for that. First, the existence of photons at energies $\gtrsim$ MeV as are observed in many GRBs necessitates the production of $e^{\pm}$ pairs by photon–photon interactions, as long as the optical depth for such interactions is greater than unity. Indeed, the huge luminosity combined with small system size, as is inferred from light-crossing time arguments ensures that this is indeed the case. Second, as has long been suspected and is well established today, small baryon contamination, originating from the progenitor—being either a single, collapsing star or the merger of binary, degenerate stars (e.g., neutron stars or white dwarfs) implies that some baryon contamination is unavoidable. These baryons must be accelerated for the least by the radiative pressure into relativistic velocities.

This general picture was confirmed already 20 years ago by the detection of afterglow—a continuing radiation that is observed at late times, up to weeks, months and even years after the main GRB, at gradually lower frequencies—from X-ray to radio [2–4]. Lasting for many orders of magnitude longer than the prompt phase, this afterglow radiation is much easier to study. Indeed, it had been extensively studied in the past two decades, after the initial detection enabled by the Dutch-Italian Beppo-SAX satellite.

Fitting the observed spectra shows a clear deviation from a black-body spectra. Instead, the afterglow of many bursts is well fitted by synchrotron radiation from a power law distribution of radiative electrons [5–7]; see Figure 1. The late time decay is well explained by the gradual velocity decay of the expanding plasma as it propagates into the surrounding medium. This decay is well-fitted (at late times) by the Blandford–Mckee self-similar solution [8] of a relativistic explosion (I ignore here the early afterglow phase which typically lasts a few minutes, as during this phase the decay does not follow a simple self-similar law, and is as of yet not fully understood).

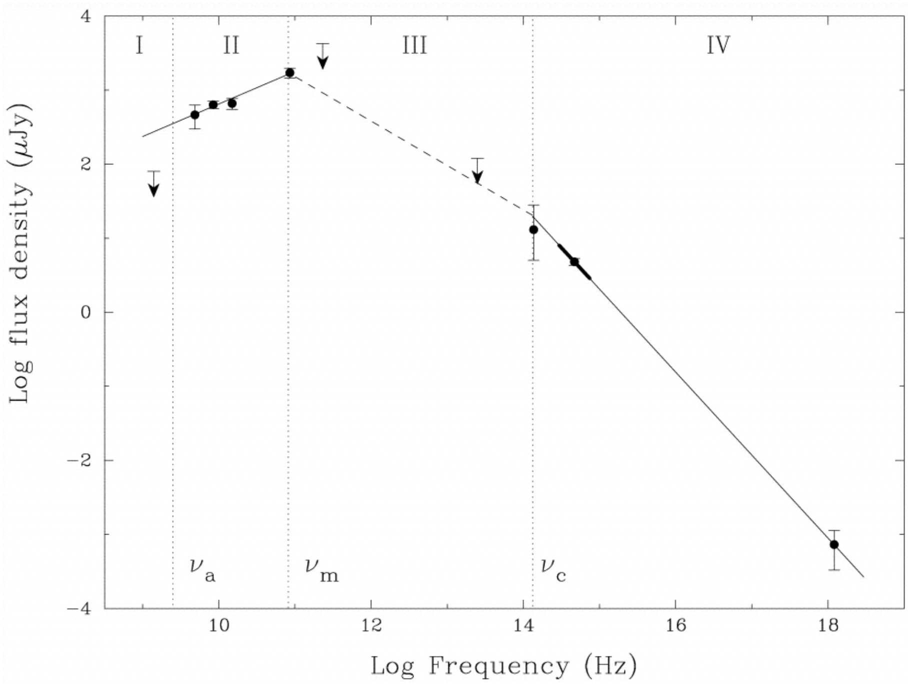

Figure 1. X-ray to radio spectrum of GRB970508 taken 12 days after the event is well fitted by a broken power law, as is expected from a power law distribution of electrons that emit synchrotron radiation. Marked are the transition frequencies: the self absorption frequency ν_a, the peak frequency ν_m and the cooling frequency ν_c. This figure is taken from Galama et al. [9].

At the onset of the afterglow phase, the velocity of the expanding plasma is very close to the speed of light, with initial Lorentz factor of a few hundreds. This is greater than the speed of sound, $c/\sqrt{3}$, and as such necessitates the existence of a highly relativistic shock wave. The combined temporal and spectral analysis thus led to the realization that, at least during the afterglow phase, a relativistic shock wave must exist. This shock wave expands into the circumburst medium, and gradually slows down as it collects and heats material from it.

Interpreting the observed signal during the afterglow phase in the framework of the synchrotron emission model, one finds that the inferred values of the magnetic fields, $\lesssim 1$ G, are about two (and in some cases more) orders of magnitude stronger than the compressed values of the circumburst magnetic field [5,10,11]. This implies that, in order to explain the observed signal, the relativistic shock wave must be able to both (1) accelerate particles to high energies, producing a non-thermal (non-Maxwellian) distribution of particles; and (2) generate a strong magnetic field, which causes the energetic particles to radiate their energy via synchrotron emission.

Studies of the afterglow phase by themselves therefore lead to several very interesting plasma physics phenomena which are not well understood, and are at the forefront of current research. These include (1) the physics of relativistic shock waves, both propagation and stability; (2) particle acceleration to non-thermal distributions; (3) generation of strong magnetic fields; and (4) radiative processes that lead to the observed spectra.

However, the prompt phase of GRB is considered even more challenging. As its name implies, this phenomenon lasts only a short duration of time, typically a few seconds. As opposed to the afterglow phase, this stage is characterized by fluctuative, non-repeating light curve, with no two GRB light curves similar to each other. Furthermore, its spectra does not resemble neither a black body (Planck) spectrum, nor—as has been realized in the past decade—that of a synchrotron emission from a power law distribution of electrons, as in the afterglow phase. Though the large diversity within the bursts prevented, so far, clear conclusions.

Another very challenging aspect is that the origin of the rapid acceleration that results in the relativistic expansion is not yet fully understood. While it was initially thought to occur as a result of the photon's strong radiative pressure (the "fireball" model), in recent years, it has been argued that strong magnetic fields—whose origin may be associated with the progenitor(s), hence external to the outflow, may play a key role in the acceleration process. If this is indeed the case, the plasma must be magnetically dominated, namely $u_B \gg \{u_k, u_{th}\}$, where u_B, u_k and u_{th} are the magnetic, kinetic and thermal energies of the plasma, respectively.

Either way, the plasma in GRBs during its prompt emission phase is characterized by strong interactions accompanied by energy and momentum exchange between the particle and photon fields, and/or the particles and the magnetic fields. Combined with the different conditions during the afterglow phase, one can conclude that GRBs provide a unique laboratory to study various fundamental questions in plasma physics. These are related to the creation of magnetic fields, acceleration of particles, emission of radiation and the interaction between all these three fields. Furthermore, the relativistic expansion can lead to the developments of several instabilities in the expanding plasma, which, in turn, can affect the phenomena previously mentioned.

In this chapter, I highlight the current state of knowledge in these areas. I should stress that I limit the discussion here to plasma physics phenomena only; in recent years, there have been many excellent reviews covering various aspects of GRB phenomenology and physics, and I refer the reader to these reviews for a more comprehensive discussion on the various subjects. A partial list includes Atteia and Boër [12], Gehrels and Mészáros [13], Bucciantini [14], Gehrels and Razzaque [15], Daigne [16], Zhang [17], Berger [18], Meszaros and Rees [19], Pe'er [20], Kumar and Zhang [21], Granot et al. [22], Zhang et al. [23], Toma et al. [24], Pe'er and Ryde [25], Beloborodov and Mészáros [26], Dai et al. [27], van Eerten [28], and Nagataki [29].

Of the many plasma physics effects that exist in GRBs—some of them unique to these objects, I discuss here several fundamental phenomena which emerge directly from GRB studies. Due to the wealth of the subject, I can only discuss each topic briefly. In each section, I refer the reader to (some) relevant literature for further discussion. The topics I cover here include the following: acceleration of particles by relativistic shock waves are discussed in Section 2. Section 3 is devoted to magnetic fields. I discuss generation of magnetic fields by shock waves in Section 3.1, and their possible role during the prompt emission phase in Section 3.2. I briefly discuss the acceleration of particles in magnetically dominated outflow via reconnection of magnetic field lines in Section 3.3. I then discuss the radiation field, which plays a key role in GRBs in Section 4. I first introduce the "classical" radiative processes in Section 4.1 and then introduce the photospheric emission in Section 4.2. Finally, I very briefly consider the different environments into which GRBs may explode and their effects in Section 5 before concluding the paper.

2. Acceleration of Particles in Shock Waves

The idea that shock waves can be the acceleration sites of particles dates back to Enrico Fermi himself [30,31], and had been extensively studied over the years since [32–38]. The key motivation was to explain the observed spectrum and flux of cosmic rays. Fermi's original idea suggests that particles are energized as they bounce back and forth across the shock wave. Its basic details can be found today in many textbooks (e.g., [39]).

In the context of GRBs, it was proposed in the mid 1990s that the relativistic shock waves that exist in GRB plasmas may provide the conditions required for the acceleration of particles to the highest observed energies, $\gtrsim 10^{20}$ eV [40–42]. While this idea is still debatable (e.g., [43]), the observations of >GeV, and up to $\sim$100 GeV photons [44] during the prompt phase of several GRBs implies that very high energy particles must exist in the emitting region. While these particles can be protons, energetically, it is much less demanding if these are electrons that are accelerated to non-thermal distribution at high energies. This is due to the lighter mass of the electrons, which implies much more efficient coupling to the magnetic and photon fields, and hence much better radiative efficiency. These energetic particles, in turn, radiate their energy in the strong magnetic fields that are believed to exist, as well as Compton scatter the photons to produce the very high energy photons observed.

Fitting the observed spectra of many GRBs in the framework of the synchrotron model (namely, under the assumption that the leading radiative mechanism is synchrotron emission by energetic electrons) strongly suggests that the radiating particles do not follow a (relativistic) Maxwellian distribution. Rather, they follow a power law distribution at high energies, $dn_E/dE \propto E^{-p}$, with power law index $p \approx 2.0 - -2.4$ [5,9,45–47]. This power law distribution is exactly what is expected from acceleration of particles in shock waves within the framework of the Fermi mechanism (e.g., [33–35,48]). Intuitively, the power law shape of the distribution can be understood as there is no characteristic momentum scale that exists during the acceleration process, implying that the rate of momentum gain is proportional to the particle's momentum.

The power law index inferred from observations is close to Fermi's original suggestion of 2.0. This is surprising, given that the shock waves in GRBs both during the prompt (if exist) and afterglow phases must be relativistic, while Fermi's work dealt with ideal, non-relativistic shocks.

In fact, the situation is far more complicated. Despite many decades of research, the Fermi process is still not fully understood from first principles. This is attributed mainly to the highly nonlinear coupling between the accelerated particles and the turbulent magnetic field at the shock front. The magnetic field is both generated by the energetic particles (via the generated currents) and at the same time affects their acceleration. This makes analytical models to be extremely limited in their ability to simultaneously track particle acceleration and magnetic field generation.

Due to this complexity, most analytical and Monte Carlo methods use the "test particle" approximation. According to this approximation, during the acceleration process, the accelerated particles interact with a fixed background magnetic field. These models therefore neglect the contribution of the high energy particles to the magnetic field, which occurs due to the currents they generate. This assumption can be justified as long as the accelerated particles carry only a small fraction of the available energy that can be deposited to the magnetic field. However, as explained above, this assumption is not supported by current observations.

Furthermore, relativistic shocks, as are expected in GRBs, introduce several challenges which do not exist when considering non-relativistic shocks. These include (1) the fact that the distribution of the accelerated particles cannot be considered isotropic; (2) mixing of the electric and magnetic fields when moving between the upstream and downstream shock regions; and (3) the fact that it is more difficult to test the theory (or parts of it), and one has to rely on very limited data, which can often be interpreted in more than a single way.

Very broadly speaking, theoretical works can be divided into three categories. The first is a semi-analytic approach (e.g., [49–54]), in which particles are described in terms of distribution functions, enabling analytic or numerical solutions of the transport equations. Clearly, while this is the fastest method, reliable solutions exist only over a very limited parameter space region, and several considerable simplifications (e.g., about the turbulence, anisotropy, etc.) are needed. The second method is the Monte Carlo approach [55–62]. In this method, the trajectories and properties of representative particles are tracked, assuming some average background magnetic fields. The advantage of this method is that it enables exploring a much larger parameter space region than analytical methods while maintaining fast computational speed. The disadvantages are (a) the simplified treatment of the background magnetic field, which effectively implies that the "test particle" approximation is used; and (b) current Monte Carlo codes use a simplified model to describe the details of the interactions between the particles and magnetic fields. For example, many codes use the "Bohm" diffusion model, which is not well-supported theoretically (see [63]).

The third approach is the Particle-In-Cell (PIC) simulations [64–68]. These codes basically solve simultaneously both particle trajectories and electromagnetic fields in a fully self-consistent way.

They therefore provide the "ultimate answer", namely the entire spectra of the accelerated particles alongside the generated magnetic field. They further provide the details of the generated magnetic turbulence as well as visualize the formation process of collisionless shocks. However, these codes are prohibitively computationally expensive, and are therefore limited to a very small range both in time and space. Modern simulations can compute processes on a length scale of no more than a few thousands of skin depth (c/ω_p). This scale is many orders of magnitudes—typically 7–8 orders of magnitude shorter than the physical length scale of the acceleration region, as is inferred from observations. This is an inherent drawback that cannot be overcome in the nearby future.

To conclude this section, GRB observations provide direct evidence—possibly the most detailed observational evidence for the acceleration of particles in relativistic shock waves. This evidence triggered a huge amount of theoretical work aimed at understanding this phenomenon from first physical principles. Due to its huge complexity, and while a huge progress was made in the past two decades or so mainly due to advances in PIC codes, the problem is still far from being solved.

3. Magnetic Fields in GRBs

In addition to the existence of clear evidence that shock waves in GRBs serve as particle acceleration sites, there is a wealth of evidence for the existence of strong magnetic fields in GRBs. When discussing magnetic fields in GRBs, one has to discriminate between two, very different, scenarios.

First, as already discussed above, fitting the data of GRB afterglow strongly suggests that the main radiative mechanism during this phase is synchrotron emission from energetic electrons. This idea therefore implies that strong magnetic fields must exist in the plasma. Fitting the afterglow provides evidence that the magnetic fields are about two orders of magnitude—and in some cases more—than the values expected from compression of the intergalactic field [5,10,11,69,70]. This provides indirect evidence that the relativistic shock wave that inevitably exists during this phase must generate a strong magnetic field, in parallel to accelerating particles.

Second, while no direct evidence currently exists, it had been proposed that, during the prompt emission phase, the GRB plasma may in fact be Poynting-flux dominated [71–78]. If this idea is correct, then the origin of the magnetic field must be external to the plasma—namely originate at the progenitor. In this scenario, the magnetic field serves as an energy reservoir that is used to both accelerate the plasma and at the same time accelerate particles to high energies.

3.1. Magnetic Field Generation in Shock Waves

As is typical to most (in fact, nearly all) astrophysical plasmas, and certainly in GRBs, the shock waves that exist are collisionless, namely they are not mediated by direct collisions between the particles (as opposed, to, e.g., shock waves that occur while a jet plane exceeds the speed of sound in the earth's atmosphere). This can easily be verified for the shock wave in the afterglow phase of GRBs by considering the mean free path for particle interaction, $l = (n\sigma_T)^{-1} \simeq 10^{24}$ cm. Here, $n \simeq 1$ cm^{-3} is the typical interstellar medium (ISM) density, and σ_T is Thompson cross section, which is the typical cross section for particle interaction. This scale is many orders of magnitude longer than the scale of the system, implying that the generated shock waves must be collisionless.

Instead of direct collisions, the shock waves are generated by collective plasma effects, namely the charged particles generate currents. These currents in turn generate magnetic fields that deflect the charged particles trajectories, mixing and randomizing their trajectories, until they isotropize. Thus, the generation of collisionless shock waves must include generation of turbulent magnetic fields. The key questions are therefore related to the details of the process, which are not fully understood. These include: (1) the nature of the instability that generates the turbulent field; (2) the strength—and scale of the generated field; and (3) the interconnection between the particle acceleration process and the magnetic field generation process.

The most widely discussed mechanism by which (weakly magnetized) magnetic fields can be generated is the Weibel instability (e.g., [79–89]). In this model, small fluctuation in the magnetic fields charge separation have opposite charges in the background plasma. These particles then form "filaments" of alternating polarity, which grow with time, as the currents carried by the charged particles positively feed the magnetic fields. This is illustrated in Figure 2, taken from Medvedev and Loeb [80]. Indeed, this instability is routinely observed in many PIC simulations [64–66,90–94], which enable quantifying it. Furthermore, these simulations prove the ultimate connection between the formation of collisionless shock waves and the generation of magnetic fields.

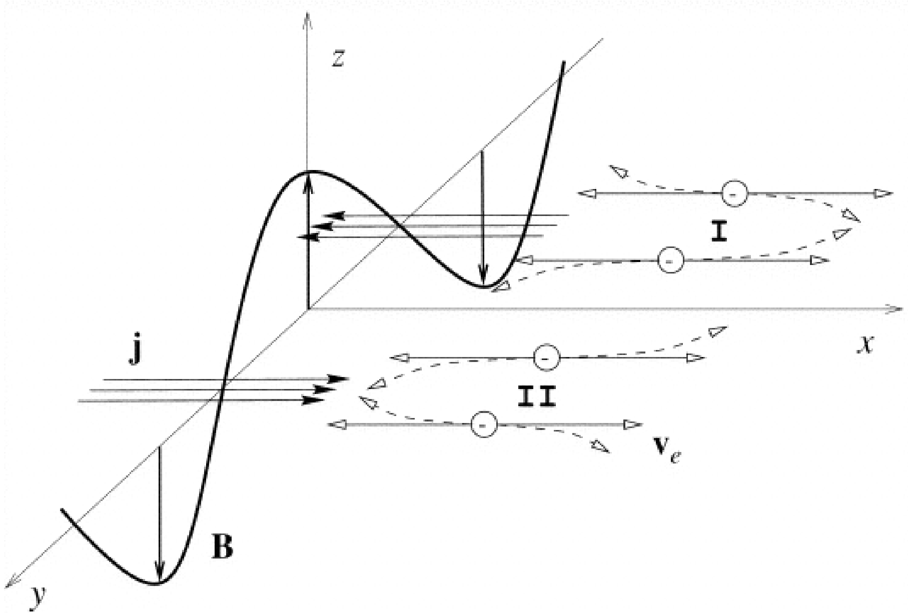

Figure 2. Illustration of the Weibel (also denoted "relativistic two stream") instability, taken from Medvedev and Loeb [80]. A magnetic field perturbation deflects electron motion along the *x*-axis, and results in current sheets (j) of opposite signs in regions I and II, which in turn amplify the perturbation. The amplified field lies in the plane perpendicular to the original electron motion.

However, these same simulations show that the generated magnetic fields decay over a relatively very short length scale, of few tens—few hundreds of plasma skin depth, as was suggested earlier [95–98]; see Figure 3. This is in sharp contrast to the observed synchrotron signal, which requires that the magnetic field, necessary for the synchrotron emission, will remain substantial over a much larger scale, comparable to the scale of the system.

This drawback, clearly observed in modern PIC simulations, triggered a few alternative suggestions. First, it was suggested that the prompt emission can possibly be generated over a much shorter scale than previously thought [99]. Other works investigate the effect of energetic particles (resulting from the acceleration process) on the evolution of the magnetic fields. It was argued [97,100,101] that strong magnetic fields can last over a substantial range due to other types of instabilities. It was further suggested that the gradual increase in the population of high energy particles that results from the Fermi acceleration process gradually increases the characteristic length scale of the magnetic field [102]. Other suggestions include macroscopic turbulence that is generated by larger scale instabilities that take place as the shock waves propagate through a non homogeneous media. Indeed, inevitable density fluctuations in the ambient medium will trigger several instabilities (e.g., Richtmyer–Meshkov or kink) that can in principle grow over a large scale [103–107]. Another possibility, which is very realistic in a GRB environment, is generation of mgnetic fields by various instabilities (such as kinetic Kelvin–Helmholtz, mushroom or kink instability) that are stimulated if the relativistic jet is propagating into an already magnetized plasma [108,109]. Indeed, helical magnetic fields may be important in jet acceleration and collimation (see the following section), and their existence will stimulate turbulence as the jet propagates through the plasma. This scenario differs than that presented in Figure 3, as it includes both reverse and forward shocks, as well as contact discontinuity [110], all provide possible sites for enhancement of magnetic turbulence.

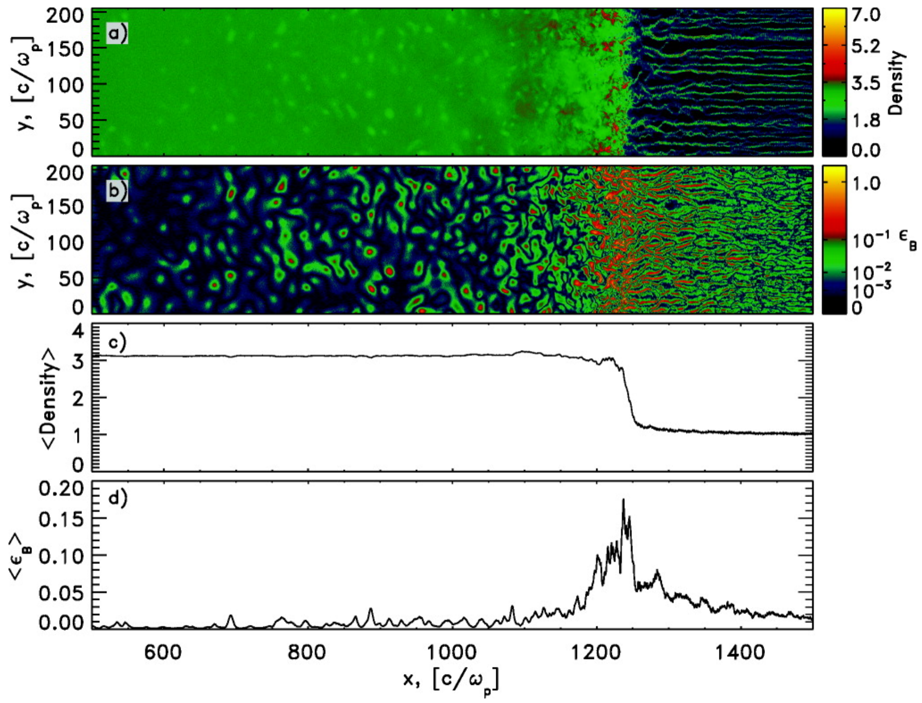

Figure 3. Snapshot of a region from a large 2D relativistic PIC shock simulation, taken from Chang et al. [98]. (**a**) density structure in the simulation plane showing the plasma density enhancements in the foreshock region that steadily grow up to the shock transition region, where the density becomes homogeneous; (**b**) magnetic energy, normalized in terms of upstream energy of the incoming flow. The upstream magnetic filaments, which can be visualized as sheets coming out of the page, that are formed by the Weibel instability reach a peak just before the shock; (**c**) plasma density averaged in the transverse direction as a function of the distance along the flow; (**d**) magnetic energy density averaged in the transverse direction, as a function of distance along the flow. Clearly, strong magnetic fields are generated but quickly decay.

Thus, overall, the origin of the magnetic field as is required to produce the observed (synchrotron) radiation is still an open question. This field remains one of the very active research fields.

3.2. Highly Magnetized Plasma during GRB Prompt Emission?

3.2.1. Motivation

Very early on, it was realized that the extreme luminosity, rapid variability and >MeV photon energies imply that GRB plasma must be moving relativistically during the prompt emission phase; otherwise, the huge optical depth to pair production, $\tau \gtrsim 10^{15}$ would prevent observation of any signal (see, e.g., [20,111,112], for reviews). This idea was confirmed by the late 1990s with the discovery of the afterglow, which proved that the plasma indeed propagates at relativistic speeds.

Thus, two major episodes of energy conversion exist: first, the conversion of the gravitational energy to kinetic energy—namely, the acceleration of plasma that results in the generation of relativistic jet. Second, the huge luminosity suggests that a substantial part of the kinetic energy is dissipated, and used to heat the particles and generate the observed signal.

Originally, it was argued that instabilities within the expanding plasma would generate shock waves, which are internal to the flow (“internal shocks”; see [113–115]). By analogy with the afterglow phase, it was then suggested that a very similar mechanism operates during the prompt phase. Shock waves generated by internal instabilities both generate strong magnetic fields and accelerate particles, which in turn emit the observed prompt radiation [113,116]. In the framework of this model, the internal shocks are therefore the main mechanism of kinetic energy dissipation, and magnetic fields "only" provide the necessary conditions needed for synchrotron radiation.

While this scenario gained popularity by the late 1990s, it was soon realized that it suffers several notable drawbacks. First, the very low efficiency in kinetic energy dissipation, of typically a few % [117–122]. This can be understood, as only the differential kinetic energy between the propagating shells can be dissipated by internal collisions. The only way to overcome this problem is by assuming a very high contrast in the Lorentz factors of the colliding shells [123].

Second, once enough data became available, it became clear that as opposed to the afterglow phase, the simplified version of the synchrotron model does not provide acceptable fits to the vast majority of GRB prompt emission spectra [46,124–127]. Thus, one has to consider alternative emission mechanisms, or, at least, consider ways to modify the synchrotron emission model (see further discussion in Section 4 below).

Third, the details of the initial explosion that triggered the GRB and the mechanism that produce relativistic motion (jet) in the first place remain uncertain. One leading model is the "Collapsar" model [128,129], according to which the core collapse of a massive star triggers the GRB event. In this scenario, the main energy mediators are neutrinos that are copiously produced during the collapse, and transfer the gravitational energy to the outer stellar regions, which are accelerated to relativistic velocities.

An alternative model for the formation of relativistic jets is the mechanism first proposed by Blandford and Znajek [130]. According to this idea, rotational energy and angular momentum are extracted from the created rapidly spinning (Kerr) black hole by strong currents. In this scenario, strong magnetic fields play a key role in the energy extraction process. Thus, the emerging plasma must be Poynting-flux dominated, and the kinetic energy is sub-dominant.

This idea has two great advantages. First, the rotation of a rapidly spinning black hole provides a huge energy reservoir that can in principle be extracted. Second, this mechanism is fairly well understood, and is believed to exist in nature. Furthermore, it does not suffer from the low efficiency problem of the "internal shock" scenario. Indeed, this mechanism gained popularity over the years, and is in wide use for explaining energy extraction in other astronomical objects, such as active galactic nuclei (AGNs; see [131,132]) or X-ray binaries (XRBs; [133]).

I should stress that, as of today, there is no clear evidence that points to which of the two scenarios act in nature to produce the relativistic GRB jets—or possibly a third, as of yet unknown, scenario. However, the possibility that strong magnetic fields may exist motivated studies of the dynamics of highly magnetized plasmas. Under this hypothesis of Poynting-dominated flow, one needs to address two independent questions. The first is the creation of the relativistic jet (namely, the acceleration of the bulk outflow to highly relativistic velocities). The second is the acceleration of (individual) particles to high energies needed to explain the observed radiative signal.

3.2.2. Detailed Models

As opposed to the "internal shock" model, the basic idea in the "Poynting-flux dominated models" is that the strong magnetic fields serve as "energy reservoir". The magnetic energy is converted to kinetic energy and heat (or particle acceleration) by reconnection of the magnetic field lines. In the past few years, many authors considered this possibility. Very crudely speaking, one can divide the models into two categories. The first assumes continuous magnetic energy dissipation (e.g., [72–74,134–141]). These models vary by the different assumptions about the unknown rate of reconnection, outflow parameters, etc. The second type assumes that the magnetic dissipation—hence the acceleration occurs over a finite, short duration [142–149]. The basic idea is that variability in the central engine leads to the ejection of magnetized plasma shells, which expand due to the internal magnetic pressure gradient once they lose causal contact with the source.

A relatively well understood scenario is the "striped wind" model, first proposed in the context of pulsars [150,151]. According to this model, the gravitational collapse that triggers the GRB event leads to a rapidly rotating, highly magnetized neutron star (which can later collapse into a black hole). The rotational axis is misaligned with its dipolar moment, which naturally produces a striped wind above the light-cylinder (see Figure 4). This striped wind consists of cold regions with alternating magnetic fields, separated by hot current sheets. Reconnection of magnetic field lines with opposite polarity is therefore a natural consequence; such reconnection leads to the acceleration of the wind.

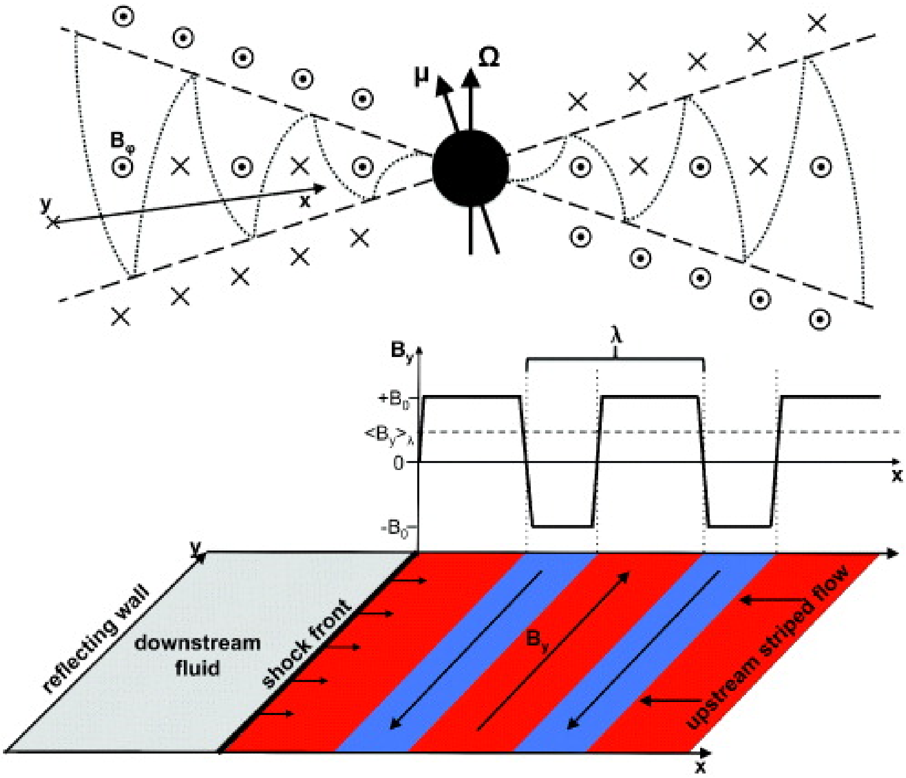

Figure 4. Upper panel: poloidal structure of the striped pulsar wind, according to the solution of Bogovalov [152]. The arrows denote the pulsar rotational axis (along Ω, vertical) and magnetic axis (along μ, inclined). Within the equatorial wedge bounded by the dashed lines, the wind consists of toroidal stripes of alternating polarity, separated by current sheets (dotted lines). Lower panel: 2D PIC simulation setup geometry. The figure is taken from Sironi and Spitkovsky [153].

Evolution of the hydrodynamic quantities in these Poynting-flux dominated outflows within the "striped wind" model was considered by several authors [71–78,154–156]. The scaling laws of the acceleration can be derived under the ideal MHD limit approximation, which is a good approximation due to the high baryon load [71]. Furthermore, in this model, throughout most of the jet evolution the dominated component of the magnetic field is the toroidal component, and so the magnetic field is perpendicular to the outflow direction, $\vec{B} \perp \vec{\beta}$. Under these assumptions, it can be shown that the standard equations of mass, energy and momentum flux conservations combined with the assumption of constant reconnection rate (which is not specified in this model) leads to a well defined scaling law of the Lorentz factor, $\Gamma(r) \propto r^{1/3}$. This is different than the scaling law expected when the acceleration is mediated by photon field, as originally proposed in the classical "fireball" model, $\Gamma(r) \propto r$. Furthermore, these scaling laws lead to testable predictions about the total luminosity that can be achieved in each of the different phases [157]. However, so far, these were not confronted with observations.

The main uncertainty of these models remains the unknown rate in which the reconnection process takes place. This rate is model dependent, and in general depends on the rate of magneto-hydrodynamic (MHD) instabilities that destroy the regular structure of the flow [158–162]. Furthermore, the presence of strong radiative field can affect this rate [156]. It should be noted that several PIC simulations predict a nearly universal reconnection rate, of $\sim 0.1c$ for highly magnetized flows [163–165]. This rate is dictated by the dynamics of the plasmoid instability. However, due to the limitations of existing PIC codes, I think it is fair to claim that this is still an open problem.

3.3. Acceleration of Particles in Highly Magnetized Plasma: Magnetic Reconnection Process

While it is natural to envision a highly magnetized progenitor that results in Poynting-flux dominated outflow in the early stages of GRB evolution, this possibility leads to two basic questions. The first is the details of the reconnection process that dissipates the magnetic energy. The second is the mechanism by which particles are accelerated. Observations of non-thermal emission during the prompt phase necessitates some mechanism that accelerates the particles (for the least, the electrons) to high energies. However, in Poynting-dominated flow, this mechanism needs to be different than the celebrated Fermi process. In this environment of highly magnetized plasmas, both shock formation is limited [166] and particle acceleration by shock waves is suppressed [167].

First, it was shown that the properties of shock waves (if form) and in particular their ability to accelerate particles to high energies are different if these shock waves reside in highly magnetized regions. In this case, the ability of a shock wave to accelerate particles strongly depends on the inclination angle θ between the upstream magnetic field and the shock propagation direction [168–170]. Only if this angle is smaller than a critical angle θ_{crit} can the shock accelerate particle efficiently. At higher angles, charged particles would need to move along the field faster than the speed of light in order to outrun the shock, and therefore cannot be accelerated. I point out, though, that these simulations assumed a simple configuration of the initial magnetic field, and thus the results in GRB jets may differ.

On the other hand, particles can be accelerated to high energies by the reconnection process itself [171–184]; (see [185] for a recent review). The basic idea is that whenever regions of opposite magnetic polarity are present, Maxwell's equations imply that there must be a current sheet in between. In this current layer, magnetic field lines can diffuse across the plasma to reconnect at one or more "x"-lines. When particles cross the current sheet, they are forced back by the reversing magnetic field. This is seen in Figure 5, taken from [186]. The particles can then be accelerated in the direction perpendicular to the plane of reconnection by the generated inductive electric fields [187]. Their energy gain per unit time is therefore $dW/dt = qE \cdot v \sim qEc$ in the relativistic case.

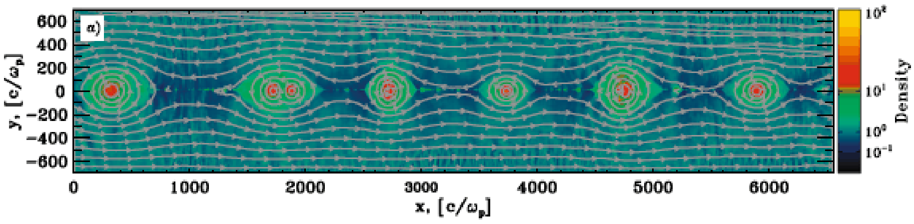

Figure 5. Structure of the particle density in the reconnection layer at $\omega_p t = 3000$, from a 2D simulation of magnetized plasma having magnetization parameter $\sigma = 10$. The figure is taken from [186].

This general idea had been extensively studied over the years by PIC simulations, both 2D [180,181,186–195] and 3D [153,165,169,177,196–199]. These show the generation of hard, non-thermal distribution of energetic particles that are accelerated at (relativistic) reconnection sites. These particles follow a power law distribution, with power law index $p \gtrsim 2$, for strongly magnetized plasma, having magnetization parameter $\sigma \equiv u_B/u_{th} \approx 10$ [186]. Here, u_B, u_{th} are the magnetic field and thermal particle energy densities, respectively. While this index is fairly similar to the one obtained by the Fermi process, it was shown to be sensitive to the exact value of σ [192,194]. Early works suggested that, in a strongly magnetized plasma, the power law index is $p < 2$, implying that most of the energy is carried by the energetic particles. However, recent simulations that were run for longer times and using larger box sizes, showed convergence towards $p \sim 2$ at late times [200].

A heuristic argument for the power law nature of the particle distribution was first suggested by Zenitani and Hoshino [187], and was demonstrated by Sironi and Spitkovsky [186]. More energetic particles have larger Larmor radii, and therefore spend more time near the "x" point of the reconnection layer than particles of lower energies. They suffer less interaction with the reconnected field (in the perpendicular direction), and therefore spend longer time in the accelerated region, where strong electric fields exist. Thus, overall, the gained energy in the acceleration process is proportional to the incoming particle energy, which results in a power law distribution.

Finally, as discussed in the previous section, jet propagation into an already magnetized plasma triggers and enhances several instabilities, such as kinetic Kelvin–Helmholtz or mushroom instabilities. As was recently shown [107,109], these instabilities, which have geometries that are different in nature than the "slab" geometry presented in Figures 4 and 5 above, also serve as acceleration sites of particles [170].

4. Photon Field in GRB Plasmas

Our entire knowledge (or lack thereof) of GRB physics originates from the observed electromagnetic signal. As GRBs are the brightest sources of radiation in the sky, a strong radiation field must exist within the relativistically expanding plasma. This photon field adds to the strong non-thermal particle field and the possible strong magnetic fields that exist.

Similar to the questions outlined above about the sources and role played by magnetic fields (being dominant or sub-dominant), one can divide the basic open questions associated with the photon fields into two categories. The first is understanding the radiative processes that lead to the observed signal. The second is to understand the possible role of the photon field in shaping the dynamics of the GRB outflow.

4.1. Radiative Processes: The Classical Ideas

The most widely discussed model for explaining GRB emission both during the prompt and the afterglow phases is synchrotron emission. This model has several advantages. First, it has been extensively studied since the 1960s [201,202] and its theory is well understood. It is the leading model for interpreting non-thermal emission in many astronomical objects, such as AGNs and XRBs. Second, it is very simple: it requires only two basic ingredients, namely energetic particles and a strong magnetic field. Both are believed to be produced in shock waves or magnetic reconnection process. Third, it is broadband in nature (as opposed, e.g., to the "Planck" spectrum), with a distinctive spectral peak, that could be associated with the observed peak energy. Fourth, it provides a very efficient way of energy transfer, as for the typical parameters, energetic electrons radiate nearly 100% of their energy (during the prompt and parts of the afterglow phases). These properties made synchrotron emission the most widely discussed radiative model in the context of GRB emission (e.g., [5,7,45,203–215], for a very partial list).

Synchrotron emission requires a population of energetic electrons. These electrons, in addition to synchrotron radiation, will inevitably Compton scatter the emitted photons, producing synchrotron-self Compton emission (SSC). This phenomenon is expected to produce high energy photons, that can extend up and beyond the GeV range. Its relative importance depends on the Compton Y parameter, namely the optical depth multiplied by the fractional energy change of each photon. This phenomenon was extensively studied both in the context of the prompt phase [216–219] and the afterglow phase in GRBs [220–225]. Note that the results of the scattering does not only affect the photon field directly, but also indirectly, as the scattering cools the electrons, hence modified the synchrotron emission. Naturally, the importance of this nonlinear effect depends on the Compton Y parameter, and is significantly more pronounced during the prompt phase, where the plasma is much denser and significantly more scattering is expected than during the afterglow phase.

Observations of high energy photons, above the threshold for pair creation, implies that both pair production and pair annihilation can in principle take place. If this happens, then a high energy electromagnetic cascade will occur, namely energetic photons produce $e^{\pm}$ pairs, which lose their energy by synchrotron and SSC, thereby producing another population of energetic photons, etc. These phenomena further modifies the observed spectra in a nonlinear way [216,226,227].

A different suggestion is that the main source of emission is not leptonic, but rather hadronic. This idea lies on the assumptions that the acceleration process, whose details are of yet uncertain, may be more efficient in accelerating protons, rather than electrons to high energies. In this scenario, the main emission mechanism is synchrotron radiation from the accelerated protons [218,221,228–233]. The main drawback of this suggestion is that protons are much less efficient radiators than electrons (as the ratio of proton to electron cross section for synchrotron emission $\sim (m_e/m_p)^2$). Thus, in order to produce the observed luminosity in γ-rays, the energy content of the protons must be very high, with proton luminosity of $\sim 10^{55}$–10^{56} erg s^{-1}. This is at least three orders of magnitude higher than the requirement from leptonic models.

4.2. Photospheric Emission and GRB Dynamics

The idea that photospheric (thermal) emission may play a key role as part of GRB plasma is not new. Already in the very early models of cosmological GRBs, it was realized that the huge energy release, rapid variability that necessitates small emission radii (due to light crossing time argument), and the high $\gtrsim$ MeV photon energy observed, imply the existence of photon-dominated plasma, namely a "fireball" [135,234–236].

Initially, therefore, it was expected that the observed GRB spectra would be thermal. Only with the accumulation of data that showed non-thermal spectra—both during the prompt and afterglow phases—did the synchrotron model gain popularity.

While the synchrotron emission model remains the leading radiative model that can explain the observed signal during the afterglow phase, it was realized by the late 1990s that it fails to explain the low energy part of the prompt emission spectra of many GRBs [46,124–126]. Being well understood, the synchrotron theory provides a robust limit on the maximum low energy spectral slope that can be achieved. As the observed slope in many GRBs was found to be harder than the limiting value, Preece et al. [124] coined the term "synchrotron line of death". Despite two decades of research, this result is still debatable [127,237]. This is due to the different analysis methods chosen. Nonetheless, this observational fact, combined with the fact that the photospheric emission is inherent to GRB fireballs, motivated the study of photospheric emission as a possibly key ingredient in the observed prompt spectra.

Due to the weakness of the observed signal, most of the analysis is done on time integrated signal, as simply not enough photons are observed. However, when analyzing the data of bright GRBs where a time-resolved analysis could be and indeed was done, it was proven that indeed some part (but not all) of the observed prompt spectra can be well fitted with a thermal (Planck) spectrum [238–242]. This was confirmed by several recent observations done with the Fermi satellite [243–249].

From a theoretical perspective, photospheric emission that is combined with other radiative processes was considered as of the early 2000s [250,251]. The key issue is that the thermal photons, similar to the synchrotron photons, can be up-scattered by the energetic electrons. In fact, by definition of the photosphere, they have to be upscattered as the optical depth below the photosphere is >1. This implies both modification of the electron distribution from their initial (accelerated) power law distribution, and modification of the thermal component itself, in a nonlinear way [252,253]. This naturally leads to a broadening of the "Planck" spectrum, which, for a large parameter space region, resembles the observed one [253]. This is demonstrated in Figure 6.

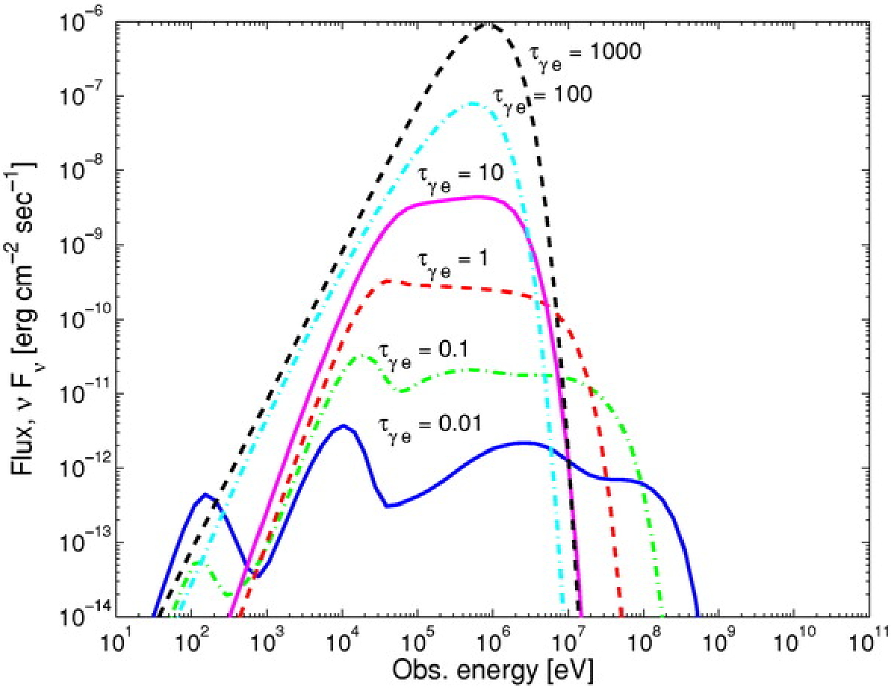

Figure 6. Time averaged broad band spectra expected following kinetic energy dissipation at various optical depths. For low optical depth, the two low energy bumps are due to synchrotron emission and the original thermal component, and the high energy bumps are due to inverse Compton phenomenon. At high optical depth, $\tau \geq 100$, a Wien peak is formed at ~ 10 keV, and is blue-shifted to the MeV range by the bulk Lorentz factor $\simeq 100$ expected in GRBs. In the intermediate regime, $0.1 < \tau < 100$, a flat energy spectrum above the thermal peak is obtained by multiple Compton scattering. The figure is taken from Pe'er et al. [253].

This idea of modified Planck spectra gained popularity in recent years, as it is capable of capturing the key observational GRB properties in the framework of both photon-dominated and magnetic-dominated flows [254–271].

An underlying assumption here is that a population of energetic particles can exist below the photosphere (or close to it). This is not obvious, as recent works showed that the structure of shock waves, if existing below the photosphere ("sub-photospheric shocks"), does not enable the Fermi acceleration process, at least in its classical form [263,272–274]. Nonetheless, particle heating can still take place below the photosphere via other mechanisms—for example, due to turbulence cascade which passes kinetic fluid energy to photons through scattering [275]. Thus, overall, the question of particle heating below the photosphere and sub-photospheric dissipation is still an open one.

A second, independent way of broadening the "Planck" spectra that enables it to resemble the observed prompt emission spectra of many GRBs is the relativistic "limb darkening" effect, which is geometric in nature. By definition, the photosphere is a region in space in which the optical depth to scattering is >1. In a relativistically expanding plasmas, this surface has a non-trivial shape [276]. Furthermore, as photon scattering is probabilistic in nature, the photospheric region is in a very basic sense "vague"—photons have a finite probability of being scattered anywhere in space in which particles exist [258,276–283]; see Figure 7. The exact shape of this "vague" photosphere depends on the jet geometry, and in particular on the jet velocity profile, namely $\Gamma = \Gamma(r, \theta)$. Under plausible assumptions, this relativistic limb darkening effect can lead to an observed spectra that does not resemble at all a "Planck" spectra, and, in addition, can be very highly polarized—up to 40%, if viewed off the jet axis [279,284,285]. This is demonstrated in Figure 8, taken from Lundman et al. [279].

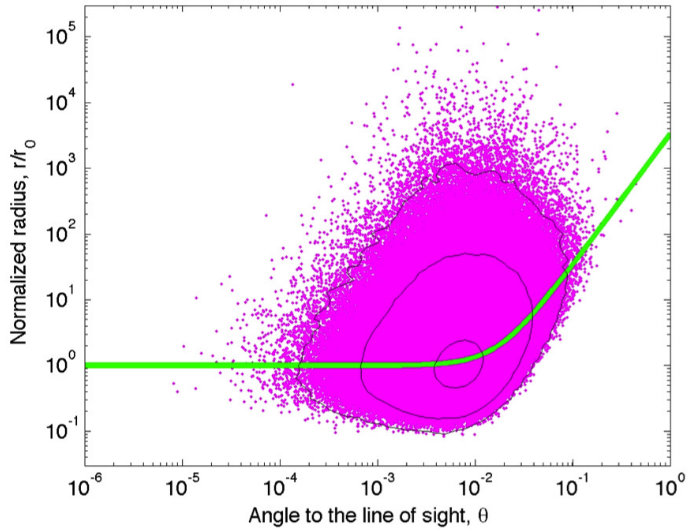

Figure 7. The green line represent the (normalized) photospheric radius r_{ph} as a function of the angle to the line of sight, θ, for spherical explosion. The purple dots represent the last scattering locations of photons emitted in the center of a relativistic expanding "fireball" (using a Monte Carlo simulation). The black lines show contours. Clearly, photons can undergo their last scattering at a range of radii and angles, leading to the concept of "vague photosphere". The observed photospheric signal is therefore smeared both in time and energy. This figure is taken from [276].

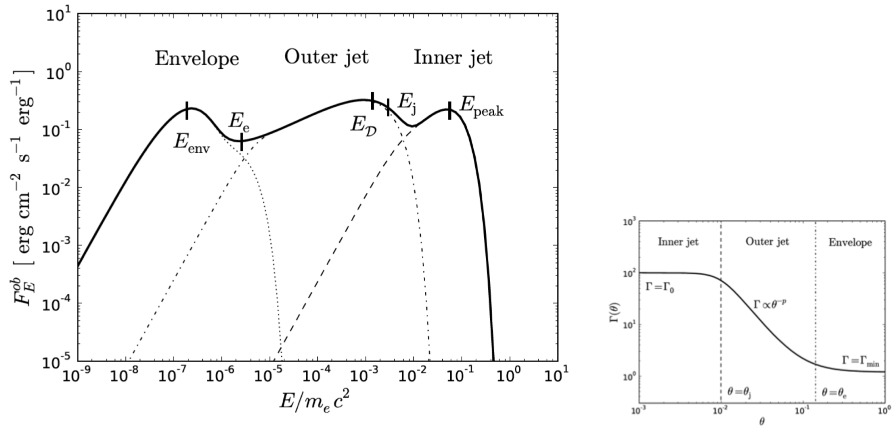

Figure 8. Left: the observed spectrum that emerges from the optically thick regions of an expanding, relativistic jet having a spatial profile, $\Gamma = \Gamma(\theta)$ does not resemble the naively expected "Planck" spectrum. Separate integration of the contributions from the inner jet (where $\Gamma \approx \Gamma_0$), outer jet (where Γ drops with angle) and envelope is shown with dashed, dot dashed and dotted lines, respectively. **Right**: the assumed jet profile. The figure is taken from Lundman et al. [279].

Identification of this thermal emission component has several important implications in understanding the conditions inside the plasma. First, it can be used to directly probe the velocity at the photospheric radius—the innermost region where any electromagnetic signal can reach the observer [286–289]. Second, identification of a photospheric component can be used to constrain the magnetization of the outflow [290–294]. In a highly magnetized outflow, the photospheric component is suppressed, and therefore identifying it can be used to set upper limits on the magnetization. Furthermore, within the context of the "striped wind" model, the existence of strong photon field modifies the rate of reconnection [156]. These identifications led to the suggestion that possibly the GRB outflow is initially strongly magnetized (as is suggested within the Blandford and Znajek [130] mechanism), but that the magnetic field quickly dissipates below the photosphere [293,295].

5. GRB Environments and GRB170817a

One of the key open questions that had been the subject of extensive research over the years is the nature of the GRB progenitors. There are two leading models. The first is the "collapsar" model mentioned above, which involves a core collapse of a massive star, accompanied by accretion into a black hole ([128,129,296–302], and references therein). The second scenario is the merger of two neutron stars (NS–NS), or a black hole and a neutron star (BH–NS). The occurrence rate, as well as the expected energy released, $\sim GM^2/R \sim 10^{53}$ erg (using $M \sim M_\odot$ and $R \gtrsim R_{sch.}$, the Schwarzschild radius of stellar-size black hole), are sufficient for extra-galactic GRBs [303–307].

The association of long GRBs with core collapse supernova, of type Ib/c [6,308–313] serves as a "smoking gun" to confirm that indeed, the long GRB population originates from the "collapsar" scenario. Indeed, in all cases but two (GRB060505 and GRB060614) whenever the GRBs were close enough that evidence for supernovae could be detected, they were indeed observed [314].

While long being suspected, until last year there was only indirect evidence that short GRBs may be associated with the merger scenario. These were mainly based on morphologies of the host galaxies (short GRBs are associated with elliptical galaxies, while long GRBs reside in younger, star-forming galaxies), as well as their position in the sky relative to their host galaxy [315,316]; (For reviews, see, e.g., [18,317,318]). This situation changed with the discovery of the gravitational wave associated with the short GRB170817 [319–321]. This discovery proved that neutron star–neutron star (NS–NS) merger does indeed produce a short GRB, thereby providing the missing "smoking gun". This event, though, was unique in many ways—e.g., the large viewing angle [322], and thus it is not clear whether it is representative of the entire short GRB population. Indeed, a detailed analysis show that the environments of short GRBs do not easily fit this "merger" scenario model [323].

Despite these uncertainties, it is widely believed that these two types of progenitors may end up with very different environments. The merger of binary stars is expected to occur very far from their birthplace, in an environment whose density is roughly constant, and equals the interstellar medium (ISM) density. On the other hand, a massive star (e.g., a Wolf–Rayet type) is likely to emit strong wind prior to its collapse [324], resulting in a "wind" like environment, whose density (for a constant mass ejection rate and constant wind velocity) may vary as $\rho \propto r^{-2}$. I should stress though that this is a very heuristic picture, as the properties of the wind emitted by stars in the last episode before they collapse is highly speculative. Furthermore, even if this is the case, one can predict the existence of a small "bump" in the light curve, resulting from interaction of the GRB blast wave with the wind termination shock [325]. This, though, could be very weak [326], and indeed, no clear evidence for such a jump (whose properties are very uncertain) currently exists.

Nonetheless, as early as a few years after the detection of the first long GRB optical afterglow [3], a split between ISM-like and wind-like environments was observed, with up to 50% of bursts found to be consistent with a homogeneous medium (e.g., [327–329]). In later studies, (e.g., [330,331]), ISM-like environments continued to be found in long GRB afterglows. Further measurements of the spectral and temporal indices for optical [332] and X-ray [70,333–335] afterglows of long GRBs all point to a split in environment types between wind and ISM.

The theoretical analyses that lead to this conclusion are relatively simple, as these are based on measurements of the properties of the late time afterglow. During this stage, the outflow is expected to evolve in a self-similar way. Despite the uncertainty in the detailed of the processes, it is expected that the velocity profile, the particle acceleration and the magnetic field generation all follow well defined scaling laws. These enable the use of the relatively well sampled afterglow data to infer the properties of the environment at late times. From this knowledge, one can hope to constrain the nature of the progenitor, hence the properties of the GRB plasma. The inconsistencies frequently found between the afterglow data of both the long and short GRBs and the simplified environmental models implies that we still have a way to go before understanding the nature of the progenitors, hence the conditions inside the GRB plasmas.

6. Conclusions

GRBs serve as unique laboratories to many plasma physics effects. In fact, GRB observations triggered many basic studies in plasma physics, whose consequences reach far beyond the field of GRBs, and even extend beyond the realm of astrophysics.

GRBs are the only objects known to produce ultra-relativistic shock waves, whose Lorentz factors exceed $\Gamma \gtrsim 100$. As such, they are the only objects that serve as laboratories to study the properties of ultra-relativistic shocks. In Section 2, I highlight a key property that directly follows GRB afterglow observations, that of particle acceleration to high energies in relativistic shock waves. While the existence of cosmic rays implies that such mechanism exists, and although the mechanism by which (non-relativistic) shock waves accelerate particles was discussed in the 1950s by Fermi, the details of the process in two important limits: (1) the relativistic limit, and (2) the "back reaction" of the accelerated particles on the shock structure (i.e., the opposite of the "test particle" limit) are not known. However, from observations in GRB afterglows, it is clear that these two limits are the ones that exist in nature.

Section 3 was devoted to discussing magnetic fields in GRBs. This section was divided into three parts. First, I discussed the current state of knowledge about the generation of strong magnetic fields in shock waves. This again is directly motivated from GRB afterglow observations, which show the existence of strong magnetic fields during this phase. As these fields are several orders of magnitude stronger than the compressed magnetic fields in the ISM, they must be generated by the shock wave itself. It is clear today that the process of magnetic field generation is intimately connected to the process of particle acceleration.

I then discussed energy transfer from magnetic fields by the magnetic reconnection process. This is important in one class of models—the "Poynting flux" dominated models, which assume that early on the main source of energy is magnetic energy. This thus motivates a detailed study of the reconnection process, as a way of transferring this energy to the plasma—both as a way of generating the relativistic jets (accelerating the bulk of the plasma), and as a way of accelerating individual particles to high energies, giving them a non-thermal distribution. This last subject was treated separately in Section 3.3.

In Section 4, I discussed the last ingredient of GRB plasmas, which is the photon field and its interaction with the particle and magnetic fields. The discussion in this section was divided into two parts. I first highlighted the "traditional" radiative processes such as synchrotron emission and Compton scattering that are expected when a population of high energy particles resides in a strongly magnetized region. As far as we know, these are the conditions that exist during the (late time) GRB "afterglow" phase. I then discussed the role of the photosphere in Section 4.2. The photosphere exists in the early stages of GRB evolution, and may be an important ingredient that shapes the prompt emission signal.

However, in addition to shaping the observed prompt emission spectra, the photosphere affects other aspects of the problem as well. As, by definition, the optical depth to scattering below the photosphere is >1, there is a strong coupling between the photon and particle fields. This leads to various effects that modify the structure of sub-photospheric shock waves, affect the dynamics, and can affect the magnetic field–particle interactions, via modification of the magnetic reconnection process. Most importantly, there are several observational consequences that can be tested.

Finally, I briefly discussed in Section 5 our knowledge about the different environments in GRBs. The current picture is very puzzling, and there is no simple way to characterize the environment. The importance of this study lies in the fact that understanding the environment can provide very important clues about the nature of the progenitors, hence on the physical conditions inside the GRB plasmas. Such clues are very difficult to be obtained in any other way.

Thus, overall, GRBs, being the most extreme objects known, provide a unique laboratory to study plasma physics in a unique, relativistic astrophysical environment. While GRB studies triggered and stimulated many plasma physics studies in the laboratory, clearly, unfortunately we cannot mimic the conditions that exist within the GRB environment in the lab. Thus, in the future, by large, we foresee that we will have to continue to rely on GRB observations to provide the necessary input to test the theories.

As I demonstrated here, as of today, there is no consensus on many basic phenomena which are at the forefront of research. However, as the study of GRBs is a very active field—both observationally and theoretically—one can clearly expect a continuous stream of data and ideas that will continue to change this field.

Funding: This research was funded by the European Research Council via the ERC consolidating Grant No. 773062 (acronym O.M.J.).

Acknowledgments: A.P. acknowledges support by the European Research Council via the ERC consolidating Grant No. 773062 (acronym O.M.J.). I wish to thank Antoine Bret for useful discussions.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Abdo, A.A.; Ackermann, M.; Arimoto, M.; Asano, K.; Atwood, W.B.; Axelsson, M.; Baldini, L.; Ballet, J.; Band, D.L.; Barbiellini, G.; et al. Fermi Observations of High-Energy Gamma-Ray Emission from GRB 080916C. *Science* **2009**, *323*, 1688–1693. [CrossRef] [PubMed]
2. Costa, E.; Frontera, F.; Heise, J.; Feroci, M.; in't Zand, J.; Fiore, F.; Cinti, M.N.; Dal Fiume, D.; Nicastro, L.; Orlandini, M.; et al. Discovery of an X-ray afterglow associated with the γ-ray burst of 28 February 1997. *Nature* **1997**, *387*, 783–785. [CrossRef]
3. van Paradijs, J.; Groot, P.J.; Galama, T.; Kouveliotou, C.; Strom, R.G.; Telting, J.; Rutten, R.G.M.; Fishman, G.J.; Meegan, C.A.; Pettini, M.; et al. Transient optical emission from the error box of the γ-ray burst of 28 February 1997. *Nature* **1997**, *386*, 686–689. [CrossRef]
4. Frail, D.A.; Kulkarni, S.R.; Nicastro, L.; Feroci, M.; Taylor, G.B. The radio afterglow from the γ-ray burst of 8 May 1997. *Nature* **1997**, *389*, 261–263. [CrossRef]
5. Wijers, R.A.M.J.; Rees, M.J.; Meszaros, P. Shocked by GRB 970228: The afterglow of a cosmological fireball. *Mon. Notices R. Astron. Soc.* **1997**, *288*, L51–L56. [CrossRef]
6. Galama, T.J.; Vreeswijk, P.M.; van Paradijs, J.; Kouveliotou, C.; Augusteijn, T.; Böhnhardt, H.; Brewer, J.P.; Doublier, V.; Gonzalez, J.F.; Leibundgut, B.; et al. An unusual supernova in the error box of the γ-ray burst of 25 April 1998. *Nature* **1998**, *395*, 670–672. [CrossRef]
7. Wijers, R.A.M.J.; Galama, T.J. Physical Parameters of GRB 970508 and GRB 971214 from Their Afterglow Synchrotron Emission. *Astrophys. J.* **1999**, *523*, 177–186. [CrossRef]
8. Blandford, R.D.; McKee, C.F. Fluid dynamics of relativistic blast waves. *Phys. Fluids* **1976**, *19*, 1130–1138. [CrossRef]
9. Galama, T.J.; Wijers, R.A.M.J.; Bremer, M.; Groot, P.J.; Strom, R.G.; Kouveliotou, C.; van Paradijs, J. The Radio-to-X-ray Spectrum of GRB 970508 on 1997 May 21.0 UT. *Astrophys. J.* **1998**, *500*, L97–L100. [CrossRef]
10. Kumar, P.; Panaitescu, A. Afterglow Emission from Naked Gamma-Ray Bursts. *Astrophys. J.* **2000**, *541*, L51–L54. [CrossRef]
11. Santana, R.; Barniol Duran, R.; Kumar, P. Magnetic Fields in Relativistic Collisionless Shocks. *Astrophys. J.* **2014**, *785*, 29. [CrossRef]
12. Atteia, J.L.; Boër, M. Observing the prompt emission of GRBs. *C. R. Phys.* **2011**, *12*, 255–266. [CrossRef]
13. Gehrels, N.; Mészáros, P. Gamma-Ray Bursts. *Science* **2012**, *337*, 932. [CrossRef] [PubMed]
14. Bucciantini, N. Magnetars and Gamma Ray Bursts. In Proceedings of the IAU Symposium: Death of Massive Stars: Supernovae and Gamma-Ray Bursts, Nikko, Japan, 12–16 March 2012; Volume 279, pp. 289–296. [CrossRef]
15. Gehrels, N.; Razzaque, S. Gamma-ray bursts in the swift-Fermi era. *Front. Phys.* **2013**, *8*, 661–678. [CrossRef]
16. Daigne, F. *GRB Prompt Emission and the Physics of Ultra-Relativistic Outflows*; EAS Publications Series; Castro-Tirado, A.J., Gorosabel, J., Park, I.H., Eds.; Cambridge University Press: Cambridge, UK, 2013; Volume 61, pp. 185–191. [CrossRef]
17. Zhang, B. Gamma-Ray Burst Prompt Emission. *Int. J. Mod. Phys. D* **2014**, *23*, 30002. [CrossRef]
18. Berger, E. Short-Duration Gamma-Ray Bursts. *Annu. Rev. Astron. Astrophys.* **2014**, *52*, 43–105. [CrossRef]
19. Meszaros, P.; Rees, M.J. Gamma-Ray Bursts. *arXiv* **2014**, arXiv:astro-ph.HE/1401.3012.

20. Pe'er, A. Physics of Gamma-Ray Bursts Prompt Emission. *Adv. Astron.* **2015**, *2015*, 907321. [CrossRef]
21. Kumar, P.; Zhang, B. The physics of gamma-ray bursts and relativistic jets. *Phys. Rep.* **2015**, *561*, 1–109. [CrossRef]
22. Granot, J.; Piran, T.; Bromberg, O.; Racusin, J.L.; Daigne, F. Gamma-Ray Bursts as Sources of Strong Magnetic Fields. *Space Sci. Rev.* **2015**, *191*, 471–518. [CrossRef]
23. Zhang, B.; Lü, H.J.; Liang, E.W. GRB Observational Properties. *Space Sci. Rev.* **2016**, *202*, 3–32. [CrossRef]
24. Toma, K.; Yoon, S.C.; Bromm, V. Gamma-Ray Bursts and Population III Stars. *Space Sci. Rev.* **2016**, *202*, 159–180. [CrossRef]
25. Pe'er, A.; Ryde, F. Photospheric emission in gamma-ray bursts. *Int. J. Mod. Phys. D* **2017**, *26*, 1730018–1730296. [CrossRef]
26. Beloborodov, A.M.; Mészáros, P. Photospheric Emission of Gamma-Ray Bursts. *Space Sci. Rev.* **2017**, *207*, 87–110. [CrossRef]
27. Dai, Z.; Daigne, F.; Mészáros, P. The Theory of Gamma-Ray Bursts. *Space Sci. Rev.* **2017**, *212*, 409–427. [CrossRef]
28. van Eerten, H. Gamma-ray burst afterglow blast waves. *Int. J. Mod. Phys. D* **2018**. [CrossRef]
29. Nagataki, S. Theories of central engine for long gamma-ray bursts. *Rep. Prog. Phys.* **2018**, *81*, 026901. [CrossRef]
30. Fermi, E. On the Origin of the Cosmic Radiation. *Phys. Rev.* **1949**, *75*, 1169–1174. [CrossRef]
31. Fermi, E. Galactic Magnetic Fields and the Origin of Cosmic Radiation. *Astrophys. J.* **1954**, *119*, 1. [CrossRef]
32. Axford, W.I.; Leer, E.; Skadron, G. The acceleration of cosmic rays by shock waves. In Proceedings of the International Cosmic Ray Conference, Plovdiv, Bulgaria, 13–26 August 1977; Volume 11, pp. 132–137.
33. Blandford, R.D.; Ostriker, J.P. Particle acceleration by astrophysical shocks. *Astrophys. J.* **1978**, *221*, L29–L32. [CrossRef]
34. Bell, A.R. The acceleration of cosmic rays in shock fronts. I. *Mon. Notices R. Astron. Soc.* **1978**, *182*, 147–156. [CrossRef]
35. Blandford, R.; Eichler, D. Particle acceleration at astrophysical shocks: A theory of cosmic ray origin. *Phys. Rep.* **1987**, *154*, 1–75. [CrossRef]
36. Jones, F.C.; Ellison, D.C. The plasma physics of shock acceleration. *Space Sci. Rev.* **1991**, *58*, 259–346. [CrossRef]
37. Malkov, M.A.; Drury, L.O. Nonlinear theory of diffusive acceleration of particles by shock waves. *Rep. Prog. Phys.* **2001**, *64*, 429–481. [CrossRef]
38. Bell, A.R. Turbulent amplification of magnetic field and diffusive shock acceleration of cosmic rays. *Mon. Notices R. Astron. Soc.* **2004**, *353*, 550–558. [CrossRef]
39. Longair, M.S. *High Energy Astrophysics*; Cambridge University Press: Cambridge, UK, 2011.
40. Milgrom, M.; Usov, V. Possible Association of Ultra–High-Energy Cosmic-Ray Events with Strong Gamma-Ray Bursts. *Astrophys. J.* **1995**, *449*, L37. [CrossRef]
41. Waxman, E. Cosmological Gamma-Ray Bursts and the Highest Energy Cosmic Rays. *Phys. Rev. Lett.* **1995**, *75*, 386–389. [CrossRef]
42. Vietri, M. The Acceleration of Ultra–High-Energy Cosmic Rays in Gamma-Ray Bursts. *Astrophys. J.* **1995**, *453*, 883. [CrossRef]
43. Samuelsson, F.; Bégué, D.; Ryde, F.; Pe'er, A. The Limited Contribution of Low- and High-Luminosity Gamma-Ray Bursts to Ultra-High Energy Cosmic Rays. *arXiv* **2018**, arXiv:astro-ph.HE/1810.06579.
44. Ackermann, M.; Ajello, M.; Asano, K.; Atwood, W.B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M.G.; Bastieri, D.; et al. Fermi-LAT Observations of the Gamma-Ray Burst GRB 130427A. *Science* **2014**, *343*, 42–47. [CrossRef]
45. Tavani, M. A Shock Emission Model for Gamma-Ray Bursts. II. Spectral Properties. *Astrophys. J.* **1996**, *466*, 768. [CrossRef]
46. Crider, A.; Liang, E.P.; Smith, I.A.; Preece, R.D.; Briggs, M.S.; Pendleton, G.N.; Paciesas, W.S.; Band, D.L.; Matteson, J.L. Evolution of the Low-Energy Photon Spectral in Gamma-Ray Bursts. *Astrophys. J.* **1997**, *479*, L39–L42. [CrossRef]
47. Berger, E.; Kulkarni, S.R.; Frail, D.A. A Standard Kinetic Energy Reservoir in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2003**, *590*, 379–385. [CrossRef]

48. Sironi, L.; Keshet, U.; Lemoine, M. Relativistic Shocks: Particle Acceleration and Magnetization. *Space Sci. Rev.* **2015**, *191*, 519–544. [CrossRef]
49. Kirk, J.G.; Heavens, A.F. Particle acceleration at oblique shock fronts. *Mon. Notices R. Astron. Soc.* **1989**, *239*, 995–1011. [CrossRef]
50. Malkov, M.A. Analytic Solution for Nonlinear Shock Acceleration in the Bohm Limit. *Astrophys. J.* **1997**, *485*, 638–654. [CrossRef]
51. Kirk, J.G.; Guthmann, A.W.; Gallant, Y.A.; Achterberg, A. Particle Acceleration at Ultrarelativistic Shocks: An Eigenfunction Method. *Astrophys. J.* **2000**, *542*, 235–242. [CrossRef]
52. Caprioli, D.; Amato, E.; Blasi, P. Non-linear diffusive shock acceleration with free-escape boundary. *Astropart. Phys.* **2010**, *33*, 307–311. [CrossRef]
53. Keshet, U.; Waxman, E. Energy Spectrum of Particles Accelerated in Relativistic Collisionless Shocks. *Phys. Rev. Lett.* **2005**, *94*, 111102. [CrossRef]
54. Keshet, U. Analytic study of 1D diffusive relativistic shock acceleration. *J. Cosmol. Astropart. Phys.* **2017**, *10*, 025. [CrossRef]
55. Kirk, J.G.; Schneider, P. Particle acceleration at shocks—A Monte Carlo method. *Astrophys. J.* **1987**, *322*, 256–265. [CrossRef]
56. Ellison, D.C.; Reynolds, S.P.; Jones, F.C. First-order Fermi particle acceleration by relativistic shocks. *Astrophys. J.* **1990**, *360*, 702–714. [CrossRef]
57. Achterberg, A.; Gallant, Y.A.; Kirk, J.G.; Guthmann, A.W. Particle acceleration by ultrarelativistic shocks: Theory and simulations. *Mon. Notices R. Astron. Soc.* **2001**, *328*, 393–408. [CrossRef]
58. Lemoine, M.; Pelletier, G. Particle Transport in Tangled Magnetic Fields and Fermi Acceleration at Relativistic Shocks. *Astrophys. J.* **2003**, *589*, L73–L76. [CrossRef]
59. Ellison, D.C.; Double, G.P. Diffusive shock acceleration in unmodified relativistic, oblique shocks. *Astropart. Phys.* **2004**, *22*, 323–338. [CrossRef]
60. Summerlin, E.J.; Baring, M.G. Diffusive Acceleration of Particles at Oblique, Relativistic, Magnetohydrodynamic Shocks. *Astrophys. J.* **2012**, *745*, 63. [CrossRef]
61. Ellison, D.C.; Warren, D.C.; Bykov, A.M. Monte Carlo Simulations of Nonlinear Particle Acceleration in Parallel Trans-relativistic Shocks. *Astrophys. J.* **2013**, *776*, 46. [CrossRef]
62. Bykov, A.M.; Ellison, D.C.; Osipov, S.M. Nonlinear Monte Carlo model of superdiffusive shock acceleration with magnetic field amplification. *Phys. Rev. E* **2017**, *95*, 033207. [CrossRef]
63. Riordan, J.D.; Pe'er, A. Pitch-Angle Diffusion and Bohm-type Approximations in Diffusive Shock Acceleration. *arXiv* **2018**, arXiv:astro-ph.HE/1810.11817.
64. Silva, L.O.; Fonseca, R.A.; Tonge, J.W.; Dawson, J.M.; Mori, W.B.; Medvedev, M.V. Interpenetrating Plasma Shells: Near-equipartition Magnetic Field Generation and Nonthermal Particle Acceleration. *Astrophys. J.* **2003**, *596*, L121–L124. [CrossRef]
65. Frederiksen, J.T.; Hededal, C.B.; Haugbølle, T.; Nordlund, Å. Magnetic Field Generation in Collisionless Shocks: Pattern Growth and Transport. *Astrophys. J.* **2004**, *608*, L13–L16. [CrossRef]
66. Spitkovsky, A. Particle Acceleration in Relativistic Collisionless Shocks: Fermi Process at Last? *Astrophys. J.* **2008**, *682*, L5–L8. [CrossRef]
67. Sironi, L.; Spitkovsky, A. Synthetic Spectra from Particle-In-Cell Simulations of Relativistic Collisionless Shocks. *Astrophys. J.* **2009**, *707*, L92–L96. [CrossRef]
68. Nishikawa, K.I.; Frederiksen, J.T.; Nordlund, Å.; Mizuno, Y.; Hardee, P.E.; Niemiec, J.; Gómez, J.L.; Pe'er, A.; Duţan, I.; Meli, A.; et al. Evolution of Global Relativistic Jets: Collimations and Expansion with kKHI and the Weibel Instability. *Astrophys. J.* **2016**, *820*, 94. [CrossRef]
69. Yost, S.A.; Harrison, F.A.; Sari, R.; Frail, D.A. A Study of the Afterglows of Four Gamma-Ray Bursts: Constraining the Explosion and Fireball Model. *Astrophys. J.* **2003**, *597*, 459–473. [CrossRef]
70. Gompertz, B.P.; Fruchter, A.S.; Pe'er, A. The Environments of the Most Energetic Gamma-Ray Bursts. *Astrophys. J.* **2018**, *866*, 162. [CrossRef]
71. Spruit, H.C.; Daigne, F.; Drenkhahn, G. Large scale magnetic fields and their dissipation in GRB fireballs. *Astron. Astrophys.* **2001**, *369*, 694–705. [CrossRef]
72. Drenkhahn, G. Acceleration of GRB outflows by Poynting flux dissipation. *Astron. Astrophys.* **2002**, *387*, 714–724. [CrossRef]

73. Drenkhahn, G.; Spruit, H.C. Efficient acceleration and radiation in Poynting flux powered GRB outflows. *Astron. Astrophys.* **2002**, *391*, 1141–1153. [CrossRef]
74. Vlahakis, N.; Königl, A. Relativistic Magnetohydrodynamics with Application to Gamma-Ray Burst Outflows. I. Theory and Semianalytic Trans-Alfvénic Solutions. *Astrophys. J.* **2003**, *596*, 1080–1103. [CrossRef]
75. Giannios, D. Spectra of black-hole binaries in the low/hard state: From radio to X-rays. *Astron. Astrophys.* **2005**, *437*, 1007–1015. [CrossRef]
76. Giannios, D. Prompt emission spectra from the photosphere of a GRB. *Astron. Astrophys.* **2006**, *457*, 763–770. [CrossRef]
77. Giannios, D.; Spruit, H.C. Spectra of Poynting-flux powered GRB outflows. *Astron. Astrophys.* **2005**, *430*, 1–7. [CrossRef]
78. Mészáros, P.; Rees, M.J. GeV Emission from Collisional Magnetized Gamma-Ray Bursts. *Astrophys. J.* **2011**, *733*, L40. [CrossRef]
79. Weibel, E.S. Spontaneously Growing Transverse Waves in a Plasma Due to an Anisotropic Velocity Distribution. *Phys. Rev. Lett.* **1959**, *2*, 83–84. [CrossRef]
80. Medvedev, M.V.; Loeb, A. Generation of Magnetic Fields in the Relativistic Shock of Gamma-Ray Burst Sources. *Astrophys. J.* **1999**, *526*, 697–706. [CrossRef]
81. Gruzinov, A.; Waxman, E. Gamma-Ray Burst Afterglow: Polarization and Analytic Light Curves. *Astrophys. J.* **1999**, *511*, 852–861. [CrossRef]
82. Wiersma, J.; Achterberg, A. Magnetic field generation in relativistic shocks. An early end of the exponential Weibel instability in electron-proton plasmas. *Astron. Astrophys.* **2004**, *428*, 365–371. [CrossRef]
83. Lyubarsky, Y.; Eichler, D. Are Gamma-Ray Burst Shocks Mediated by the Weibel Instability? *Astrophys. J.* **2006**, *647*, 1250–1254. [CrossRef]
84. Achterberg, A.; Wiersma, J. The Weibel instability in relativistic plasmas. I. Linear theory. *Astron. Astrophys.* **2007**, *475*, 1–18. [CrossRef]
85. Shaisultanov, R.; Lyubarsky, Y.; Eichler, D. Stream Instabilities in Relativistically Hot Plasma. *Astrophys. J.* **2012**, *744*, 182. [CrossRef]
86. Kumar, R.; Eichler, D.; Gedalin, M. Electron Heating in a Relativistic, Weibel-unstable Plasma. *Astrophys. J.* **2015**, *806*, 165. [CrossRef]
87. Bret, A.; Stockem Novo, A.; Narayan, R.; Ruyer, C.; Dieckmann, M.E.; Silva, L.O. Theory of the formation of a collisionless Weibel shock: Pair vs. electron/proton plasmas. *Laser Part. Beams* **2016**, *34*, 362–367. [CrossRef]
88. Pelletier, G.; Bykov, A.; Ellison, D.; Lemoine, M. Towards Understanding the Physics of Collisionless Relativistic Shocks. Relativistic Collisionless Shocks. *Space Sci. Rev.* **2017**, *207*, 319–360. [CrossRef]
89. Bret, A.; Pe'er, A. On the formation and properties of fluid shocks and collisionless shock waves in astrophysical plasmas. *J. Plasma Phys.* **2018**, *84*, 905840311. [CrossRef]
90. Nishikawa, K.I.; Hardee, P.; Richardson, G.; Preece, R.; Sol, H.; Fishman, G.J. Particle Acceleration and Magnetic Field Generation in Electron-Positron Relativistic Shocks. *Astrophys. J.* **2005**, *622*, 927–937. [CrossRef]
91. Kato, T.N. Saturation mechanism of the Weibel instability in weakly magnetized plasmas. *Phys. Plasmas* **2005**, *12*, 080705. [CrossRef]
92. Ramirez-Ruiz, E.; Nishikawa, K.I.; Hededal, C.B. $e^{+/-}$ Pair Loading and the Origin of the Upstream Magnetic Field in GRB Shocks. *Astrophys. J.* **2007**, *671*, 1877–1885. [CrossRef]
93. Spitkovsky, A. On the Structure of Relativistic Collisionless Shocks in Electron-Ion Plasmas. *Astrophys. J.* **2008**, *673*, L39–L42. [CrossRef]
94. Nishikawa, K.I.; Niemiec, J.; Hardee, P.E.; Medvedev, M.; Sol, H.; Mizuno, Y.; Zhang, B.; Pohl, M.; Oka, M.; Hartmann, D.H. Weibel Instability and Associated Strong Fields in a Fully Three-Dimensional Simulation of a Relativistic Shock. *Astrophys. J.* **2009**, *698*, L10–L13. [CrossRef]
95. Gruzinov, A. Gamma-Ray Burst Phenomenology, Shock Dynamo, and the First Magnetic Fields. *Astrophys. J.* **2001**, *563*, L15–L18. [CrossRef]
96. Spitkovsky, A. Simulations of relativistic collisionless shocks: Shock structure and particle acceleration. In *Astrophysical Sources of High Energy Particles and Radiation*; American Institute of Physics Conference Series; Bulik, T., Rudak, B., Madejski, G., Eds.; American Institute of Physics: College Park, MD, USA, 2005; Volume 801, pp. 345–350. [CrossRef]

97. Milosavljević, M.; Nakar, E. Weibel Filament Decay and Thermalization in Collisionless Shocks and Gamma-Ray Burst Afterglows. *Astrophys. J.* **2006**, *641*, 978–983. [CrossRef]
98. Chang, P.; Spitkovsky, A.; Arons, J. Long-Term Evolution of Magnetic Turbulence in Relativistic Collisionless Shocks: Electron-Positron Plasmas. *Astrophys. J.* **2008**, *674*, 378–387. [CrossRef]
99. Pe'er, A.; Zhang, B. Synchrotron Emission in Small-Scale Magnetic Fields as a Possible Explanation for Prompt Emission Spectra of Gamma-Ray Bursts. *Astrophys. J.* **2006**, *653*, 454–461. [CrossRef]
100. Milosavljević, M.; Nakar, E. The Cosmic-Ray Precursor of Relativistic Collisionless Shocks: A Missing Link in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2006**, *651*, 979–984. [CrossRef]
101. Couch, S.M.; Milosavljević, M.; Nakar, E. Shock Vorticity Generation from Accelerated Ion Streaming in the Precursor of Ultrarelativistic Gamma-Ray Burst External Shocks. *Astrophys. J.* **2008**, *688*, 462–469. [CrossRef]
102. Keshet, U.; Katz, B.; Spitkovsky, A.; Waxman, E. Magnetic Field Evolution in Relativistic Unmagnetized Collisionless Shocks. *Astrophys. J.* **2009**, *693*, L127–L130. [CrossRef]
103. Sironi, L.; Goodman, J. Production of Magnetic Energy by Macroscopic Turbulence in GRB Afterglows. *Astrophys. J.* **2007**, *671*, 1858–1867. [CrossRef]
104. Zhang, W.; MacFadyen, A.; Wang, P. Three-Dimensional Relativistic Magnetohydrodynamic Simulations of the Kelvin-Helmholtz Instability: Magnetic Field Amplification by a Turbulent Dynamo. *Astrophys. J.* **2009**, *692*, L40–L44. [CrossRef]
105. Inoue, T.; Asano, K.; Ioka, K. Three-dimensional Simulations of Magnetohydrodynamic Turbulence Behind Relativistic Shock Waves and Their Implications for Gamma-Ray Bursts. *Astrophys. J.* **2011**, *734*, 77. [CrossRef]
106. Mizuno, Y.; Pohl, M.; Niemiec, J.; Zhang, B.; Nishikawa, K.I.; Hardee, P.E. Magnetic-field Amplification by Turbulence in a Relativistic Shock Propagating Through an Inhomogeneous Medium. *Astrophys. J.* **2011**, *726*, 62. [CrossRef]
107. Mizuno, Y.; Hardee, P.E.; Nishikawa, K.I. Spatial Growth of the Current-driven Instability in Relativistic Jets. *Astrophys. J.* **2014**, *784*, 167. [CrossRef]
108. Mizuno, Y.; Pohl, M.; Niemiec, J.; Zhang, B.; Nishikawa, K.I.; Hardee, P.E. Magnetic field amplification and saturation in turbulence behind a relativistic shock. *Mon. Notices R. Astron. Soc.* **2014**, *439*, 3490–3503. [CrossRef]
109. Nishikawa, K.I.; Mizuno, Y.; Gómez, J.; Duţan, I.; Meli, A.; White, C.; Niemiec, J.; Kobzar, O.; Pohl, M.; Pe'er, A.; et al. Microscopic Processes in Global Relativistic Jets Containing Helical Magnetic Fields: Dependence on Jet Radius. *Galaxies* **2017**, *5*, 58. [CrossRef]
110. Ardaneh, K.; Cai, D.; Nishikawa, K.I. Collisionless Electron-ion Shocks in Relativistic Unmagnetized Jet-ambient Interactions: Non-thermal Electron Injection by Double Layer. *Astrophys. J.* **2016**, *827*, 124. [CrossRef]
111. Piran, T. The physics of gamma-ray bursts. *Rev. Mod. Phys.* **2004**, *76*, 1143–1210. [CrossRef]
112. Mészáros, P. Gamma-ray bursts. *Rep. Prog. Phys.* **2006**, *69*, 2259–2321. [CrossRef]
113. Rees, M.J.; Meszaros, P. Unsteady outflow models for cosmological gamma-ray bursts. *Astrophys. J.* **1994**, *430*, L93–L96. [CrossRef]
114. Sari, R.; Piran, T. Variability in Gamma-Ray Bursts: A Clue. *Astrophys. J.* **1997**, *485*, 270–273. [CrossRef]
115. Ramirez-Ruiz, E.; Fenimore, E.E. Pulse Width Evolution in Gamma-Ray Bursts: Evidence for Internal Shocks. *Astrophys. J.* **2000**, *539*, 712–717. [CrossRef]
116. Kobayashi, S.; Piran, T.; Sari, R. Can Internal Shocks Produce the Variability in Gamma-Ray Bursts? *Astrophys. J.* **1997**, *490*, 92. [CrossRef]
117. Mochkovitch, R.; Maitia, V.; Marques, R. Internal Shocks in a Relativistic Wind as a Source for Gamma-Ray Bursts? *Astrophys. Space Sci.* **1995**, *231*, 441–444. [CrossRef]
118. Panaitescu, A.; Spada, M.; Mészáros, P. Power Density Spectra of Gamma-Ray Bursts in the Internal Shock Model. *Astrophys. J.* **1999**, *522*, L105–L108. [CrossRef]
119. Beloborodov, A.M. On the Efficiency of Internal Shocks in Gamma-Ray Bursts. *Astrophys. J.* **2000**, *539*, L25–L28. [CrossRef]
120. Spada, M.; Panaitescu, A.; Mészáros, P. Analysis of Temporal Features of Gamma-Ray Bursts in the Internal Shock Model. *Astrophys. J.* **2000**, *537*, 824–832. [CrossRef]
121. Guetta, D.; Spada, M.; Waxman, E. Efficiency and Spectrum of Internal Gamma-Ray Burst Shocks. *Astrophys. J.* **2001**, *557*, 399–407. [CrossRef]

122. Pe'er, A.; Long, K.; Casella, P. Dynamical Properties of Internal Shocks Revisited. *Astrophys. J.* **2017**, *846*, 54. [CrossRef]
123. Kobayashi, S.; Sari, R. Ultraefficient Internal Shocks. *Astrophys. J.* **2001**, *551*, 934–939. [CrossRef]
124. Preece, R.D.; Briggs, M.S.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; Band, D.L. The Synchrotron Shock Model Confronts a "Line of Death" in the BATSE Gamma-Ray Burst Data. *Astrophys. J.* **1998**, *506*, L23–L26. [CrossRef]
125. Preece, R.D.; Briggs, M.S.; Giblin, T.W.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; Band, D.L. On the Consistency of Gamma-Ray Burst Spectral Indices with the Synchrotron Shock Model. *Astrophys. J.* **2002**, *581*, 1248–1255. [CrossRef]
126. Ghirlanda, G.; Celotti, A.; Ghisellini, G. Extremely hard GRB spectra prune down the forest of emission models. *Astron. Astrophys.* **2003**, *406*, 879–892. [CrossRef]
127. Axelsson, M.; Borgonovo, L. The width of gamma-ray burst spectra. *Mon. Notices R. Astron. Soc.* **2015**, *447*, 3150–3154. [CrossRef]
128. Woosley, S.E. Gamma-ray bursts from stellar mass accretion disks around black holes. *Astrophys. J.* **1993**, *405*, 273–277. [CrossRef]
129. MacFadyen, A.I.; Woosley, S.E. Collapsars: Gamma-Ray Bursts and Explosions in "Failed Supernovae". *Astrophys. J.* **1999**, *524*, 262–289. [CrossRef]
130. Blandford, R.D.; Znajek, R.L. Electromagnetic extraction of energy from Kerr black holes. *Mon. Notices R. Astron. Soc.* **1977**, *179*, 433–456. [CrossRef]
131. Begelman, M.C.; Blandford, R.D.; Rees, M.J. Theory of extragalactic radio sources. *Rev. Mod. Phys.* **1984**, *56*, 255–351. [CrossRef]
132. Wilson, A.S.; Colbert, E.J.M. The difference between radio-loud and radio-quiet active galaxies. *Astrophys. J.* **1995**, *438*, 62–71. [CrossRef]
133. Narayan, R.; McKinney, J.C.; Farmer, A.J. Self-similar force-free wind from an accretion disc. *Mon. Notices R. Astron. Soc.* **2007**, *375*, 548–566. [CrossRef]
134. Usov, V.V. Millisecond pulsars with extremely strong magnetic fields as a cosmological source of gamma-ray bursts. *Nature* **1992**, *357*, 472–474. [CrossRef]
135. Thompson, C. A Model of Gamma-Ray Bursts. *Mon. Notices R. Astron. Soc.* **1994**, *270*, 480. [CrossRef]
136. Vlahakis, N.; Königl, A. Magnetohydrodynamics of Gamma-Ray Burst Outflows. *Astrophys. J.* **2001**, *563*, L129–L132. [CrossRef]
137. Lyutikov, M.; Blandford, R. Gamma Ray Bursts as Electromagnetic Outflows. *arXiv* **2003**, arXiv:astro-ph/031234.
138. Levinson, A. General Relativistic, Neutrino-assisted Magnetohydrodynamic Winds-Theory and Application to Gamma-Ray Bursts. I. Schwarzschild Geometry. *Astrophys. J.* **2006**, *648*, 510–522. [CrossRef]
139. Giannios, D. Prompt GRB emission from gradual energy dissipation. *Astron. Astrophys.* **2008**, *480*, 305–312. [CrossRef]
140. Komissarov, S.S.; Vlahakis, N.; Königl, A.; Barkov, M.V. Magnetic acceleration of ultrarelativistic jets in gamma-ray burst sources. *Mon. Notices R. Astron. Soc.* **2009**, *394*, 1182–1212. [CrossRef]
141. Beniamini, P.; Giannios, D. Prompt gamma-ray burst emission from gradual magnetic dissipation. *Mon. Notices R. Astron. Soc.* **2017**, *468*, 3202–3211. [CrossRef]
142. Contopoulos, J. A Simple Type of Magnetically Driven Jets: An Astrophysical Plasma Gun. *Astrophys. J.* **1995**, *450*, 616. [CrossRef]
143. Tchekhovskoy, A.; McKinney, J.C.; Narayan, R. Simulations of ultrarelativistic magnetodynamic jets from gamma-ray burst engines. *Mon. Notices R. Astron. Soc.* **2008**, *388*, 551–572. [CrossRef]
144. Tchekhovskoy, A.; Narayan, R.; McKinney, J.C. Magnetohydrodynamic simulations of gamma-ray burst jets: Beyond the progenitor star. *New A.* **2010**, *15*, 749–754. [CrossRef]
145. Komissarov, S.S.; Vlahakis, N.; Königl, A. Rarefaction acceleration of ultrarelativistic magnetized jets in gamma-ray burst sources. *Mon. Notices R. Astron. Soc.* **2010**, *407*, 17–28. [CrossRef]
146. Metzger, B.D.; Giannios, D.; Thompson, T.A.; Bucciantini, N.; Quataert, E. The protomagnetar model for gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2011**, *413*, 2031–2056. [CrossRef]
147. Granot, J.; Komissarov, S.S.; Spitkovsky, A. Impulsive acceleration of strongly magnetized relativistic flows. *Mon. Notices R. Astron. Soc.* **2011**, *411*, 1323–1353. [CrossRef]
148. Zhang, B.; Yan, H. The Internal-collision-induced Magnetic Reconnection and Turbulence (ICMART) Model of Gamma-ray Bursts. *Astrophys. J.* **2011**, *726*, 90. [CrossRef]

149. Sironi, L.; Petropoulou, M.; Giannios, D. Relativistic jets shine through shocks or magnetic reconnection? *Mon. Notices R. Astron. Soc.* **2015**, *450*, 183–191. [CrossRef]
150. Kennel, C.F.; Coroniti, F.V. Confinement of the Crab pulsar's wind by its supernova remnant. *Astrophys. J.* **1984**, *283*, 694–709. [CrossRef]
151. Coroniti, F.V. Magnetically striped relativistic magnetohydrodynamic winds—The Crab Nebula revisited. *Astrophys. J.* **1990**, *349*, 538–545. [CrossRef]
152. Bogovalov, S.V. On the physics of cold MHD winds from oblique rotators. *Astron. Astrophys.* **1999**, *349*, 1017–1026.
153. Sironi, L.; Spitkovsky, A. Particle-in-cell simulations of shock-driven reconnection in relativistic striped winds. *Comput. Sci. Discov.* **2012**, *5*, 014014. [CrossRef]
154. Lyubarsky, Y.; Kirk, J.G. Reconnection in a Striped Pulsar Wind. *Astrophys. J.* **2001**, *547*, 437–448. [CrossRef]
155. Spruit, H.C.; Drenkhahn, G.D. Magnetically powered prompt radiation and flow acceleration in GRB. In *Gamma-Ray Bursts in the Afterglow Era*; Astronomical Society of the Pacific Conference Series; Feroci, M., Frontera, F., Masetti, N., Piro, L., Eds.; Societá Italiana de Fisica: Bologna, Spain, 2004; Volume 312, p. 357.
156. Bégué, D.; Pe'er, A.; Lyubarsky, Y. Radiative striped wind model for gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2017**, *467*, 2594–2611. [CrossRef]
157. Pe'er, A. Constraining Magnetization of Gamma-Ray Bursts Outflows Using Prompt Emission Fluence. *Astrophys. J.* **2017**, *850*, 200. [CrossRef]
158. Lyubarskij, Y.E. Energy release in strongly magnetized relativistic winds. *Soviet Astron. Lett.* **1992**, *18*, 356.
159. Begelman, M.C. Instability of Toroidal Magnetic Field in Jets and Plerions. *Astrophys. J.* **1998**, *493*, 291–300. [CrossRef]
160. Giannios, D.; Spruit, H.C. The role of kink instability in Poynting-flux dominated jets. *Astron. Astrophys.* **2006**, *450*, 887–898. [CrossRef]
161. Gill, R.; Granot, J.; Lyubarsky, Y. 2D Relativistic MHD simulations of the Kruskal-Schwarzschild instability in a relativistic striped wind. *Mon. Notices R. Astron. Soc.* **2018**, *474*, 3535–3546. [CrossRef]
162. Sobacchi, E.; Lyubarsky, Y.E. Instability induced by recollimation in highly magnetized outflows. *Mon. Notices R. Astron. Soc.* **2018**, *480*, 4948–4954. [CrossRef]
163. Riquelme, M.A.; Quataert, E.; Sharma, P.; Spitkovsky, A. Local Two-dimensional Particle-in-cell Simulations of the Collisionless Magnetorotational Instability. *Astrophys. J.* **2012**, *755*, 50. [CrossRef]
164. Melzani, M.; Walder, R.; Folini, D.; Winisdoerffer, C.; Favre, J.M. Relativistic magnetic reconnection in collisionless ion-electron plasmas explored with particle-in-cell simulations. *Astron. Astrophys.* **2014**, *570*, A111. [CrossRef]
165. Guo, F.; Liu, Y.H.; Daughton, W.; Li, H. Particle Acceleration and Plasma Dynamics during Magnetic Reconnection in the Magnetically Dominated Regime. *Astrophys. J.* **2015**, *806*, 167. [CrossRef]
166. Bret, A.; Pe'er, A.; Sironi, L.; Sadowski, A.; Narayan, R. Kinetic inhibition of magnetohydrodynamics shocks in the vicinity of a parallel magnetic field. *J. Plasma Phys.* **2017**, *83*, 715830201. [CrossRef]
167. Sironi, L.; Spitkovsky, A.; Arons, J. The Maximum Energy of Accelerated Particles in Relativistic Collisionless Shocks. *arXiv* **2013**, arXiv:astro-ph.HE/1301.5333.
168. Sironi, L.; Spitkovsky, A. Particle Acceleration in Relativistic Magnetized Collisionless Pair Shocks: Dependence of Shock Acceleration on Magnetic Obliquity. *Astrophys. J.* **2009**, *698*, 1523–1549. [CrossRef]
169. Sironi, L.; Spitkovsky, A. Particle Acceleration in Relativistic Magnetized Collisionless Electron-Ion Shocks. *Astrophys. J.* **2011**, *726*, 75. [CrossRef]
170. Matsumoto, Y.; Amano, T.; Kato, T.N.; Hoshino, M. Electron Surfing and Drift Accelerations in a Weibel-Dominated High-Mach-Number Shock. *Phys. Rev. Lett.* **2017**, *119*, 105101. [CrossRef] [PubMed]
171. Romanova, M.M.; Lovelace, R.V.E. Magnetic field, reconnection, and particle acceleration in extragalactic jets. *Astron. Astrophys.* **1992**, *262*, 26–36.
172. Lyutikov, M. Role of reconnection in AGN jets. *New Astron. Rev.* **2003**, *47*, 513–515. [CrossRef]
173. Jaroschek, C.H.; Treumann, R.A.; Lesch, H.; Scholer, M. Fast reconnection in relativistic pair plasmas: Analysis of particle acceleration in self-consistent full particle simulations. *Phys. Plasmas* **2004**, *11*, 1151–1163. [CrossRef]
174. Lyubarsky, Y.E. On the relativistic magnetic reconnection. *Mon. Notices R. Astron. Soc.* **2005**, *358*, 113–119. [CrossRef]

175. Giannios, D. UHECRs from magnetic reconnection in relativistic jets. *Mon. Notices R. Astron. Soc.* **2010**, *408*, L46–L50. [CrossRef]
176. Lazarian, A.; Kowal, G.; Vishniac, E.; de Gouveia Dal Pino, E. Fast magnetic reconnection and energetic particle acceleration. *Planet. Space Sci.* **2011**, *59*, 537–546. [CrossRef]
177. Liu, W.; Li, H.; Yin, L.; Albright, B.J.; Bowers, K.J.; Liang, E.P. Particle energization in 3D magnetic reconnection of relativistic pair plasmas. *Phys. Plasmas* **2011**, *18*, 052105. [CrossRef]
178. Uzdensky, D.A.; McKinney, J.C. Magnetic reconnection with radiative cooling. I. Optically thin regime. *Phys. Plasmas* **2011**, *18*, 042105. [CrossRef]
179. McKinney, J.C.; Uzdensky, D.A. A reconnection switch to trigger gamma-ray burst jet dissipation. *Mon. Notices R. Astron. Soc.* **2012**, *419*, 573–607. [CrossRef]
180. Bessho, N.; Bhattacharjee, A. Fast Magnetic Reconnection and Particle Acceleration in Relativistic Low-density Electron-Positron Plasmas without Guide Field. *Astrophys. J.* **2012**, *750*, 129. [CrossRef]
181. Cerutti, B.; Werner, G.R.; Uzdensky, D.A.; Begelman, M.C. Beaming and Rapid Variability of High-energy Radiation from Relativistic Pair Plasma Reconnection. *Astrophys. J.* **2012**, *754*, L33. [CrossRef]
182. Cerutti, B.; Werner, G.R.; Uzdensky, D.A.; Begelman, M.C. Simulations of Particle Acceleration beyond the Classical Synchrotron Burnoff Limit in Magnetic Reconnection: An Explanation of the Crab Flares. *Astrophys. J.* **2013**, *770*, 147. [CrossRef]
183. Kagan, D.; Milosavljević, M.; Spitkovsky, A. A Flux Rope Network and Particle Acceleration in Three-dimensional Relativistic Magnetic Reconnection. *Astrophys. J.* **2013**, *774*, 41. [CrossRef]
184. Uzdensky, D.A.; Spitkovsky, A. Physical Conditions in the Reconnection Layer in Pulsar Magnetospheres. *Astrophys. J.* **2014**, *780*, 3. [CrossRef]
185. Kagan, D.; Sironi, L.; Cerutti, B.; Giannios, D. Relativistic Magnetic Reconnection in Pair Plasmas and Its Astrophysical Applications. *Space Sci. Rev.* **2015**, *191*, 545–573. [CrossRef]
186. Sironi, L.; Spitkovsky, A. Relativistic Reconnection: An Efficient Source of Non-thermal Particles. *Astrophys. J.* **2014**, *783*, L21. [CrossRef]
187. Zenitani, S.; Hoshino, M. The Generation of Nonthermal Particles in the Relativistic Magnetic Reconnection of Pair Plasmas. *Astrophys. J.* **2001**, *562*, L63–L66. [CrossRef]
188. Bessho, N.; Bhattacharjee, A. Collisionless Reconnection in an Electron-Positron Plasma. *Phys. Rev. Lett.* **2005**, *95*, 245001. [CrossRef] [PubMed]
189. Zenitani, S.; Hoshino, M. Particle Acceleration and Magnetic Dissipation in Relativistic Current Sheet of Pair Plasmas. *Astrophys. J.* **2007**, *670*, 702–726. [CrossRef]
190. Hesse, M.; Zenitani, S. Dissipation in relativistic pair-plasma reconnection. *Phys. Plasmas* **2007**, *14*, 112102. [CrossRef]
191. Lyubarsky, Y.; Liverts, M. Particle Acceleration in the Driven Relativistic Reconnection. *Astrophys. J.* **2008**, *682*, 1436–1442. [CrossRef]
192. Guo, F.; Li, H.; Daughton, W.; Liu, Y.H. Formation of Hard Power Laws in the Energetic Particle Spectra Resulting from Relativistic Magnetic Reconnection. *Phys. Rev. Lett.* **2014**, *113*, 155005. [CrossRef] [PubMed]
193. Nalewajko, K.; Uzdensky, D.A.; Cerutti, B.; Werner, G.R.; Begelman, M.C. On the Distribution of Particle Acceleration Sites in Plasmoid-dominated Relativistic Magnetic Reconnection. *Astrophys. J.* **2015**, *815*, 101. [CrossRef]
194. Werner, G.R.; Uzdensky, D.A.; Cerutti, B.; Nalewajko, K.; Begelman, M.C. The Extent of Power-law Energy Spectra in Collisionless Relativistic Magnetic Reconnection in Pair Plasmas. *Astrophys. J.* **2016**, *816*, L8. [CrossRef]
195. Sironi, L.; Giannios, D.; Petropoulou, M. Plasmoids in relativistic reconnection, from birth to adulthood: First they grow, then they go. *Mon. Notices R. Astron. Soc.* **2016**, *462*, 48–74. [CrossRef]
196. Zenitani, S.; Hoshino, M. The Role of the Guide Field in Relativistic Pair Plasma Reconnection. *Astrophys. J.* **2008**, *677*, 530–544. [CrossRef]
197. Yin, L.; Daughton, W.; Karimabadi, H.; Albright, B.J.; Bowers, K.J.; Margulies, J. Three-Dimensional Dynamics of Collisionless Magnetic Reconnection in Large-Scale Pair Plasmas. *Phys. Rev. Lett.* **2008**, *101*, 125001. [CrossRef]
198. Cerutti, B.; Werner, G.R.; Uzdensky, D.A.; Begelman, M.C. Three-dimensional Relativistic Pair Plasma Reconnection with Radiative Feedback in the Crab Nebula. *Astrophys. J.* **2014**, *782*, 104. [CrossRef]

199. Werner, G.R.; Uzdensky, D.A. Nonthermal Particle Acceleration in 3D Relativistic Magnetic Reconnection in Pair Plasma. *Astrophys. J.* **2017**, *843*, L27. [CrossRef]
200. Petropoulou, M.; Sironi, L. The steady growth of the high-energy spectral cut-off in relativistic magnetic reconnection. *Mon. Notices R. Astron. Soc.* **2018**, *481*, 5687–5701. [CrossRef]
201. Ginzburg, V.L.; Syrovatskii, S.I. Cosmic Magnetobremsstrahlung (synchrotron Radiation). *Annu. Rev. Astron. Astrophys.* **1965**, *3*, 297. [CrossRef]
202. Blumenthal, G.R.; Gould, R.J. Bremsstrahlung, Synchrotron Radiation, and Compton Scattering of High-Energy Electrons Traversing Dilute Gases. *Rev. Mod. Phys.* **1970**, *42*, 237–271. [CrossRef]
203. Rees, M.J.; Meszaros, P. Relativistic fireballs—Energy conversion and time-scales. *Mon. Notices R. Astron. Soc.* **1992**, *258*, 41–43. [CrossRef]
204. Meszaros, P.; Rees, M.J. Relativistic fireballs and their impact on external matter—Models for cosmological gamma-ray bursts. *Astrophys. J.* **1993**, *405*, 278–284. [CrossRef]
205. Meszaros, P.; Laguna, P.; Rees, M.J. Gasdynamics of relativistically expanding gamma-ray burst sources—Kinematics, energetics, magnetic fields, and efficiency. *Astrophys. J.* **1993**, *415*, 181–190. [CrossRef]
206. Mészáros, P.; Rees, M.J.; Papathanassiou, H. Spectral properties of blast-wave models of gamma-ray burst sources. *Astrophys. J.* **1994**, *432*, 181–193. [CrossRef]
207. Paczynski, B.; Xu, G. Neutrino bursts from gamma-ray bursts. *Astrophys. J.* **1994**, *427*, 708–713. [CrossRef]
208. Papathanassiou, H.; Meszaros, P. Spectra of Unsteady Wind Models of Gamma-Ray Bursts. *Astrophys. J.* **1996**, *471*, L91. [CrossRef]
209. Cohen, E.; Katz, J.I.; Piran, T.; Sari, R.; Preece, R.D.; Band, D.L. Possible Evidence for Relativistic Shocks in Gamma-Ray Bursts. *Astrophys. J.* **1997**, *488*, 330. [CrossRef]
210. Sari, R.; Piran, T. Cosmological gamma-ray bursts: Internal versus external shocks. *Mon. Notices R. Astron. Soc.* **1997**, *287*, 110–116. [CrossRef]
211. Sari, R.; Piran, T.; Narayan, R. Spectra and Light Curves of Gamma-Ray Burst Afterglows. *Astrophys. J.* **1998**, *497*, L17. [CrossRef]
212. Pilla, R.P.; Loeb, A. Emission Spectra from Internal Shocks in Gamma-Ray Burst Sources. *Astrophys. J.* **1998**, *494*, L167–L171. [CrossRef]
213. Daigne, F.; Mochkovitch, R. Gamma-ray bursts from internal shocks in a relativistic wind: Temporal and spectral properties. *Mon. Notices R. Astron. Soc.* **1998**, *296*, 275–286. [CrossRef]
214. Granot, J.; Sari, R. The Shape of Spectral Breaks in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2002**, *568*, 820–829. [CrossRef]
215. Gao, H.; Lei, W.H.; Zou, Y.C.; Wu, X.F.; Zhang, B. A complete reference of the analytical synchrotron external shock models of gamma-ray bursts. *New Astron. Rev.* **2013**, *57*, 141–190. [CrossRef]
216. Pe'er, A.; Waxman, E. Prompt Gamma-Ray Burst Spectra: Detailed Calculations and the Effect of Pair Production. *Astrophys. J.* **2004**, *613*, 448–459. [CrossRef]
217. Baring, M.G.; Braby, M.L. A Study of Prompt Emission Mechanisms in Gamma-Ray Bursts. *Astrophys. J.* **2004**, *613*, 460–4767. [CrossRef]
218. Gupta, N.; Zhang, B. Prompt emission of high-energy photons from gamma ray bursts. *Mon. Notices R. Astron. Soc.* **2007**, *380*, 78–92. [CrossRef]
219. Asano, K.; Inoue, S. Prompt GeV-TeV Emission of Gamma-Ray Bursts Due to High-Energy Protons, Muons, and Electron-Positron Pairs. *Astrophys. J.* **2007**, *671*, 645–655. [CrossRef]
220. Sari, R.; Esin, A.A. On the Synchrotron Self-Compton Emission from Relativistic Shocks and Its Implications for Gamma-Ray Burst Afterglows. *Astrophys. J.* **2001**, *548*, 787–799. [CrossRef]
221. Zhang, B.; Mészáros, P. High-Energy Spectral Components in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2001**, *559*, 110–122. [CrossRef]
222. Harrison, F.A.; Yost, S.A.; Sari, R.; Berger, E.; Galama, T.J.; Holtzman, J.; Axelrod, T.; Bloom, J.S.; Chevalier, R.; Costa, E.; et al. Broadband Observations of the Afterglow of GRB 000926: Observing the Effect of Inverse Compton Scattering. *Astrophys. J.* **2001**, *559*, 123–130. [CrossRef]
223. Galli, A.; Piro, L. High energy afterglows and flares from gamma-ray burst by inverse Compton emission. *Astron. Astrophys.* **2007**, *475*, 421–434. [CrossRef]
224. Fan, Y.Z.; Piran, T.; Narayan, R.; Wei, D.M. High-energy afterglow emission from gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2008**, *384*, 1483–1501. [CrossRef]

225. Fraija, N.; González, M.M.; Lee, W.H. Synchrotron Self-Compton Emission as the Origin of the Gamma-Ray Afterglow Observed in GRB 980923. *Astrophys. J.* **2012**, *751*, 33. [CrossRef]
226. Pe'er, A.; Waxman, E. Time-dependent Numerical Model for the Emission of Radiation from Relativistic Plasma. *Astrophys. J.* **2005**, *628*, 857–866. [CrossRef]
227. Gill, R.; Granot, J. The effect of pair cascades on the high-energy spectral cut-off in gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2018**, *475*, L1–L5. [CrossRef]
228. Böttcher, M.; Dermer, C.D. High-energy Gamma Rays from Ultra-high-energy Cosmic-Ray Protons in Gamma-Ray Bursts. *Astrophys. J.* **1998**, *499*, L131–L134. [CrossRef]
229. Totani, T. TEV Burst of Gamma-Ray Bursts and Ultra-High-Energy Cosmic Rays. *Astrophys. J.* **1998**, *509*, L81–L84. [CrossRef]
230. Asano, K.; Inoue, S.; Mészáros, P. Prompt High-Energy Emission from Proton-Dominated Gamma-Ray Bursts. *Astrophys. J.* **2009**, *699*, 953–957. [CrossRef]
231. Razzaque, S.; Dermer, C.D.; Finke, J.D. Synchrotron Radiation from Ultra-High Energy Protons and the Fermi Observations of GRB 080916C. *Open Astron. J.* **2010**, *3*, 150–155. [CrossRef]
232. Asano, K.; Mészáros, P. Delayed Onset of High-energy Emissions in Leptonic and Hadronic Models of Gamma-Ray Bursts. *Astrophys. J.* **2012**, *757*, 115. [CrossRef]
233. Crumley, P.; Kumar, P. Hadronic models for Large Area Telescope prompt emission observed in Fermi gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2013**, *429*, 3238–3251. [CrossRef]
234. Paczynski, B. Gamma-ray bursters at cosmological distances. *Astrophys. J.* **1986**, *308*, L43–L46. [CrossRef]
235. Goodman, J. Are gamma-ray bursts optically thick? *Astrophys. J.* **1986**, *308*, L47–L50. [CrossRef]
236. Shemi, A.; Piran, T. The appearance of cosmic fireballs. *Astrophys. J.* **1990**, *365*, L55–L58. [CrossRef]
237. Burgess, J.M.; Bégué, D.; Bacelj, A.; Giannios, D.; Berlato, F.; Greiner, J. Gamma-ray bursts as cool synchrotron sources. *arXiv* **2018**, arXiv:astro-ph.HE/1810.06965.
238. Ryde, F. The Cooling Behavior of Thermal Pulses in Gamma-Ray Bursts. *Astrophys. J.* **2004**, *614*, 827–846. [CrossRef]
239. Ryde, F. Is Thermal Emission in Gamma-Ray Bursts Ubiquitous? *Astrophys. J.* **2005**, *625*, L95–L98. [CrossRef]
240. Ryde, F.; Pe'er, A. Quasi-blackbody Component and Radiative Efficiency of the Prompt Emission of Gamma-ray Bursts. *Astrophys. J.* **2009**, *702*, 1211–1229. [CrossRef]
241. McGlynn, S.; Foley, S.; McBreen, B.; Hanlon, L.; McBreen, S.; Clark, D.J.; Dean, A.J.; Martin-Carrillo, A.; O'Connor, R. High energy emission and polarisation limits for the INTEGRAL burst GRB 061122. *Astron. Astrophys.* **2009**, *499*, 465–472. [CrossRef]
242. Larsson, J.; Ryde, F.; Lundman, C.; McGlynn, S.; Larsson, S.; Ohno, M.; Yamaoka, K. Spectral components in the bright, long GRB 061007: Properties of the photosphere and the nature of the outflow. *Mon. Notices R. Astron. Soc.* **2011**, *414*, 2642–2649. [CrossRef]
243. Ackermann, M.; Asano, K.; Atwood, W.B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M.; et al. Fermi Observations of GRB 090510: A Short-Hard Gamma-ray Burst with an Additional, Hard Power-law Component from 10 keV TO GeV Energies. *Astrophys. J.* **2010**, *716*, 1178–1190. [CrossRef]
244. Abdo, A.A.; Ackermann, M.; Ajello, M.; Asano, K.; Atwood, W.B.; Axelsson, M.; Baldini, L.; Ballet, J.; Barbiellini, G.; Baring, M.G.; et al. Fermi Observations of GRB 090902B: A Distinct Spectral Component in the Prompt and Delayed Emission. *Astrophys. J.* **2009**, *706*, L138–L144. [CrossRef]
245. Ryde, F.; Axelsson, M.; Zhang, B.B.; McGlynn, S.; Pe'er, A.; Lundman, C.; Larsson, S.; Battelino, M.; Zhang, B.; Bissaldi, E.; et al. Identification and Properties of the Photospheric Emission in GRB090902B. *Astrophys. J.* **2010**, *709*, L172–L177. [CrossRef]
246. Ryde, F.; Pe'er, A.; Nymark, T.; Axelsson, M.; Moretti, E.; Lundman, C.; Battelino, M.; Bissaldi, E.; Chiang, J.; Jackson, M.S.; et al. Observational evidence of dissipative photospheres in gamma-ray bursts. *Mon. Notices R. Astron. Soc.* **2011**, *415*, 3693–3705. [CrossRef]
247. Guiriec, S.; Connaughton, V.; Briggs, M.S.; Burgess, M.; Ryde, F.; Daigne, F.; Mészáros, P.; Goldstein, A.; McEnery, J.; Omodei, N.; et al. Detection of a Thermal Spectral Component in the Prompt Emission of GRB 100724B. *Astrophys. J.* **2011**, *727*, L33. [CrossRef]
248. Iyyani, S.; Ryde, F.; Axelsson, M.; Burgess, J.M.; Guiriec, S.; Larsson, J.; Lundman, C.; Moretti, E.; McGlynn, S.; Nymark, T.; Rosquist, K. Variable jet properties in GRB 110721A: Time resolved observations of the jet photosphere. *Mon. Notices R. Astron. Soc.* **2013**, *433*, 2739–2748. [CrossRef]

249. Guiriec, S.; Daigne, F.; Hascoët, R.; Vianello, G.; Ryde, F.; Mochkovitch, R.; Kouveliotou, C.; Xiong, S.; Bhat, P.N.; Foley, S.; et al. Evidence for a Photospheric Component in the Prompt Emission of the Short GRB 120323A and Its Effects on the GRB Hardness-Luminosity Relation. *Astrophys. J.* **2013**, *770*, 32. [CrossRef]
250. Mészáros, P.; Rees, M.J. Steep Slopes and Preferred Breaks in Gamma-Ray Burst Spectra: The Role of Photospheres and Comptonization. *Astrophys. J.* **2000**, *530*, 292–298. [CrossRef]
251. Mészáros, P.; Ramirez-Ruiz, E.; Rees, M.J.; Zhang, B. X-ray-rich Gamma-Ray Bursts, Photospheres, and Variability. *Astrophys. J.* **2002**, *578*, 812–817. [CrossRef]
252. Pe'er, A.; Mészáros, P.; Rees, M.J. Peak Energy Clustering and Efficiency in Compact Objects. *Astrophys. J.* **2005**, *635*, 476–480. [CrossRef]
253. Pe'er, A.; Mészáros, P.; Rees, M.J. The Observable Effects of a Photospheric Component on GRB and XRF Prompt Emission Spectrum. *Astrophys. J.* **2006**, *642*, 995–1003. [CrossRef]
254. Ioka, K.; Murase, K.; Toma, K.; Nagataki, S.; Nakamura, T. Unstable GRB Photospheres and $e^{+/-}$ Annihilation Lines. *Astrophys. J.* **2007**, *670*, L77–L80. [CrossRef]
255. Thompson, C.; Mészáros, P.; Rees, M.J. Thermalization in Relativistic Outflows and the Correlation between Spectral Hardness and Apparent Luminosity in Gamma-Ray Bursts. *Astrophys. J.* **2007**, *666*, 1012–1023. [CrossRef]
256. Lazzati, D.; Morsony, B.J.; Begelman, M.C. Very High Efficiency Photospheric Emission in Long-Duration γ-Ray Bursts. *Astrophys. J.* **2009**, *700*, L47–L50. [CrossRef]
257. Lazzati, D.; Begelman, M.C. Non-thermal Emission from the Photospheres of Gamma-ray Burst Outflows. I. High-Frequency Tails. *Astrophys. J.* **2010**, *725*, 1137–1145. [CrossRef]
258. Beloborodov, A.M. Collisional mechanism for gamma-ray burst emission. *Mon. Notices R. Astron. Soc.* **2010**, *407*, 1033–1047. [CrossRef]
259. Mizuta, A.; Nagataki, S.; Aoi, J. Thermal Radiation from Gamma-ray Burst Jets. *Astrophys. J.* **2011**, *732*, 26. [CrossRef]
260. Lazzati, D.; Morsony, B.J.; Begelman, M.C. High-efficiency Photospheric Emission of Long-duration Gamma-ray Burst Jets: The Effect of the Viewing Angle. *Astrophys. J.* **2011**, *732*, 34. [CrossRef]
261. Toma, K.; Wu, X.F.; Mészáros, P. Photosphere-internal shock model of gamma-ray bursts: Case studies of Fermi/LAT bursts. *Mon. Notices R. Astron. Soc.* **2011**, *415*, 1663–1680. [CrossRef]
262. Bromberg, O.; Mikolitzky, Z.; Levinson, A. Sub-photospheric Emission from Relativistic Radiation Mediated Shocks in GRBs. *Astrophys. J.* **2011**, *733*, 85. [CrossRef]
263. Levinson, A. Observational Signatures of Sub-photospheric Radiation-mediated Shocks in the Prompt Phase of Gamma-Ray Bursts. *Astrophys. J.* **2012**, *756*, 174. [CrossRef]
264. Veres, P.; Zhang, B.B.; Mészáros, P. The Extremely High Peak Energy of GRB 110721A in the Context of a Dissipative Photosphere Synchrotron Emission Model. *Astrophys. J.* **2012**, *761*, L18. [CrossRef]
265. Vurm, I.; Lyubarsky, Y.; Piran, T. On Thermalization in Gamma-Ray Burst Jets and the Peak Energies of Photospheric Spectra. *Astrophys. J.* **2013**, *764*, 143. [CrossRef]
266. Beloborodov, A.M. Regulation of the Spectral Peak in Gamma-Ray Bursts. *Astrophys. J.* **2013**, *764*, 157. [CrossRef]
267. Hascoët, R.; Daigne, F.; Mochkovitch, R. Prompt thermal emission in gamma-ray bursts. *Astron. Astrophys.* **2013**, *551*, A124. [CrossRef]
268. Lazzati, D.; Morsony, B.J.; Margutti, R.; Begelman, M.C. Photospheric Emission as the Dominant Radiation Mechanism in Long-duration Gamma-Ray Bursts. *Astrophys. J.* **2013**, *765*, 103. [CrossRef]
269. Asano, K.; Mészáros, P. Photon and neutrino spectra of time-dependent photospheric models of gamma-ray bursts. *J. Cosmol. Astropart. Phys.* **2013**, *9*, 8. [CrossRef]
270. Deng, W.; Zhang, B. Low Energy Spectral Index and E_p Evolution of Quasi-thermal Photosphere Emission of Gamma-Ray Bursts. *Astrophys. J.* **2014**, *785*, 112. [CrossRef]
271. Cuesta-Martínez, C.; Aloy, M.A.; Mimica, P.; Thöne, C.; de Ugarte Postigo, A. Numerical models of blackbody-dominated gamma-ray bursts—II. Emission properties. *Mon. Notices R. Astron. Soc.* **2015**, *446*, 1737–1749. [CrossRef]
272. Beloborodov, A.M. Sub-photospheric Shocks in Relativistic Explosions. *Astrophys. J.* **2017**, *838*, 125. [CrossRef]
273. Lundman, C.; Beloborodov, A.M.; Vurm, I. Radiation-mediated Shocks in Gamma-Ray Bursts: Pair Creation. *Astrophys. J.* **2018**, *858*, 7. [CrossRef]

274. Lundman, C.; Beloborodov, A. Radiation mediated shocks in gamma-ray bursts: Subshock photon production. *arXiv* **2018**, arXiv:astro-ph.HE/1804.03053.
275. Zrake, J.; Beloborodov, A.M.; Lundman, C. Sub-photospheric turbulence as a heating mechanism in gamma-ray bursts. *arXiv* **2018**, arXiv:astro-ph.HE/1810.02228.
276. Pe'er, A. Temporal Evolution of Thermal Emission from Relativistically Expanding Plasma. *Astrophys. J.* **2008**, *682*, 463–473. [CrossRef]
277. Beloborodov, A.M. Radiative Transfer in Ultrarelativistic Outflows. *Astrophys. J.* **2011**, *737*, 68. [CrossRef]
278. Pe'er, A.; Ryde, F. A Theory of Multicolor Blackbody Emission from Relativistically Expanding Plasmas. *Astrophys. J.* **2011**, *732*, 49. [CrossRef]
279. Lundman, C.; Pe'er, A.; Ryde, F. A theory of photospheric emission from relativistic, collimated outflows. *Mon. Notices R. Astron. Soc.* **2013**, *428*, 2430–2442. [CrossRef]
280. Ruffini, R.; Siutsou, I.A.; Vereshchagin, G.V. A Theory of Photospheric Emission from Relativistic Outflows. *Astrophys. J.* **2013**, *772*, 11. [CrossRef]
281. Aksenov, A.G.; Ruffini, R.; Vereshchagin, G.V. Comptonization of photons near the photosphere of relativistic outflows. *Mon. Notices R. Astron. Soc.* **2013**, *436*, L54–L58. [CrossRef]
282. Ito, H.; Nagataki, S.; Ono, M.; Lee, S.H.; Mao, J.; Yamada, S.; Pe'er, A.; Mizuta, A.; Harikae, S. Photospheric Emission from Stratified Jets. *Astrophys. J.* **2013**, *777*, 62. [CrossRef]
283. Vereshchagin, G.V. Physics of Nondissipative Ultrarelativistic Photospheres. *Int. J. Mod. Phys. D* **2014**, *23*, 30003. [CrossRef]
284. Lundman, C.; Pe'er, A.; Ryde, F. Polarization properties of photospheric emission from relativistic, collimated outflows. *Mon. Notices R. Astron. Soc.* **2014**, *440*, 3292–3308. [CrossRef]
285. Chang, Z.; Lin, H.N.; Jiang, Y. Gamma-Ray Burst Polarization via Compton Scattering Process. *Astrophys. J.* **2014**, *783*, 30. [CrossRef]
286. Pe'er, A.; Ryde, F.; Wijers, R.A.M.J.; Mészáros, P.; Rees, M.J. A New Method of Determining the Initial Size and Lorentz Factor of Gamma-Ray Burst Fireballs Using a Thermal Emission Component. *Astrophys. J.* **2007**, *664*, L1–L4. [CrossRef]
287. Larsson, J.; Racusin, J.L.; Burgess, J.M. Evidence for Jet Launching Close to the Black Hole in GRB 101219b—A Fermi GRB Dominated by Thermal Emission. *Astrophys. J.* **2015**, *800*, L34. [CrossRef]
288. Pe'er, A.; Barlow, H.; O'Mahony, S.; Margutti, R.; Ryde, F.; Larsson, J.; Lazzati, D.; Livio, M. Hydrodynamic Properties of Gamma-Ray Burst Outflows Deduced from the Thermal Component. *Astrophys. J.* **2015**, *813*, 127. [CrossRef]
289. Wang, Y.Z.; Wang, H.; Zhang, S.; Liang, Y.F.; Jin, Z.P.; He, H.N.; Liao, N.H.; Fan, Y.Z.; Wei, D.M. Evaluating the Bulk Lorentz Factors of Outflow Material: Lessons Learned from the Extremely Energetic Outburst GRB 160625B. *Astrophys. J.* **2017**, *836*, 81. [CrossRef]
290. Zhang, B.; Mészáros, P. An Analysis of Gamma-Ray Burst Spectral Break Models. *Astrophys. J.* **2002**, *581*, 1236–1247. [CrossRef]
291. Daigne, F.; Mochkovitch, R. The expected thermal precursors of gamma-ray bursts in the internal shock model. *Mon. Notices R. Astron. Soc.* **2002**, *336*, 1271–1280. [CrossRef]
292. Zhang, B.; Pe'er, A. Evidence of an Initially Magnetically Dominated Outflow in GRB 080916C. *Astrophys. J.* **2009**, *700*, L65–L68. [CrossRef]
293. Beniamini, P.; Piran, T. The emission mechanism in magnetically dominated gamma-ray burst outflows. *Mon. Notices R. Astron. Soc.* **2014**, *445*, 3892–3907. [CrossRef]
294. Bégué, D.; Pe'er, A. Poynting-flux-dominated Jets Challenged by their Photospheric Emission. *Astrophys. J.* **2015**, *802*, 134. [CrossRef]
295. Meng, Y.Z.; Geng, J.J.; Zhang, B.B.; Wei, J.J.; Xiao, D.; Liu, L.D.; Gao, H.; Wu, X.F.; Liang, E.W.; Huang, Y.F.; Dai, Z.G.; Zhang, B. The Origin of the Prompt Emission for Short GRB 170817A: Photosphere Emission or Synchrotron Emission? *Astrophys. J.* **2018**, *860*, 72. [CrossRef]
296. Paczyński, B. Are Gamma-Ray Bursts in Star-Forming Regions? *Astrophys. J.* **1998**, *494*, L45–L48. [CrossRef]
297. Paczyński, B. Gamma-ray bursts as hypernovae. In *Gamma-Ray Bursts, Proceedings of the 4th Hunstville Symposium*; Meegan, C.A., Preece, R.D., Koshut, T.M., Eds.; American Institute of Physics: College Park, MD, USA, 1998; Volume 428, pp. 783–787. [CrossRef]
298. Fryer, C.L.; Woosley, S.E.; Hartmann, D.H. Formation Rates of Black Hole Accretion Disk Gamma-Ray Bursts. *Astrophys. J.* **1999**, *526*, 152–177. [CrossRef]

299. Popham, R.; Woosley, S.E.; Fryer, C. Hyperaccreting Black Holes and Gamma-Ray Bursts. *Astrophys. J.* **1999**, *518*, 356–374. [CrossRef]
300. MacFadyen, A.I.; Woosley, S.E.; Heger, A. Supernovae, Jets, and Collapsars. *Astrophys. J.* **2001**, *550*, 410–425. [CrossRef]
301. Woosley, S.E.; Bloom, J.S. The Supernova Gamma-Ray Burst Connection. *Annu. Rev. Astron. Astrophys.* **2006**, *44*, 507–556. [CrossRef]
302. Sobacchi, E.; Granot, J.; Bromberg, O.; Sormani, M.C. A common central engine for long gamma-ray bursts and Type Ib/c supernovae. *Mon. Notices R. Astron. Soc.* **2017**, *472*, 616–627. [CrossRef]
303. Eichler, D.; Livio, M.; Piran, T.; Schramm, D.N. Nucleosynthesis, neutrino bursts and gamma-rays from coalescing neutron stars. *Nature* **1989**, *340*, 126–128. [CrossRef]
304. Paczynski, B. Super-Eddington winds from neutron stars. *Astrophys. J.* **1990**, *363*, 218–226. [CrossRef]
305. Narayan, R.; Piran, T.; Shemi, A. Neutron star and black hole binaries in the Galaxy. *Astrophys. J.* **1991**, *379*, L17–L20. [CrossRef]
306. Meszaros, P.; Rees, M.J. Tidal heating and mass loss in neutron star binaries—Implications for gamma-ray burst models. *Astrophys. J.* **1992**, *397*, 570–575. [CrossRef]
307. Narayan, R.; Paczynski, B.; Piran, T. Gamma-ray bursts as the death throes of massive binary stars. *Astrophys. J.* **1992**, *395*, L83–L86. [CrossRef]
308. Hjorth, J.; Sollerman, J.; Møller, P.; Fynbo, J.P.U.; Woosley, S.E.; Kouveliotou, C.; Tanvir, N.R.; Greiner, J.; Andersen, M.I.; Castro-Tirado, A.J.; et al. A very energetic supernova associated with the γ-ray burst of 29 March 2003. *Nature* **2003**, *423*, 847–850. [CrossRef]
309. Stanek, K.Z.; Matheson, T.; Garnavich, P.M.; Martini, P.; Berlind, P.; Caldwell, N.; Challis, P.; Brown, W.R.; Schild, R.; Krisciunas, K.; et al. Spectroscopic Discovery of the Supernova 2003dh Associated with GRB 030329. *Astrophys. J.* **2003**, *591*, L17–L20. [CrossRef]
310. Campana, S.; Mangano, V.; Blustin, A.J.; Brown, P.; Burrows, D.N.; Chincarini, G.; Cummings, J.R.; Cusumano, G.; Della Valle, M.; Malesani, D.; et al. The association of GRB 060218 with a supernova and the evolution of the shock wave. *Nature* **2006**, *442*, 1008–1010. [CrossRef] [PubMed]
311. Pian, E.; Mazzali, P.A.; Masetti, N.; Ferrero, P.; Klose, S.; Palazzi, E.; Ramirez-Ruiz, E.; Woosley, S.E.; Kouveliotou, C.; Deng, J.; et al. An optical supernova associated with the X-ray flash XRF 060218. *Nature* **2006**, *442*, 1011–1013. [CrossRef] [PubMed]
312. Cobb, B.E.; Bloom, J.S.; Perley, D.A.; Morgan, A.N.; Cenko, S.B.; Filippenko, A.V. Discovery of SN 2009nz Associated with GRB 091127. *Astrophys. J.* **2010**, *718*, L150–L155. [CrossRef]
313. Starling, R.L.C.; Wiersema, K.; Levan, A.J.; Sakamoto, T.; Bersier, D.; Goldoni, P.; Oates, S.R.; Rowlinson, A.; Campana, S.; Sollerman, J.; et al. Discovery of the nearby long, soft GRB 100316D with an associated supernova. *Mon. Notices R. Astron. Soc.* **2011**, *411*, 2792–2803. [CrossRef]
314. Cano, Z.; Wang, S.Q.; Dai, Z.G.; Wu, X.F. The Observer's Guide to the Gamma-Ray Burst Supernova Connection. *Adv. Astron.* **2017**, *2017*, 8929054. [CrossRef]
315. Gehrels, N.; Sarazin, C.L.; O'Brien, P.T.; Zhang, B.; Barbier, L.; Barthelmy, S.D.; Blustin, A.; Burrows, D.N.; Cannizzo, J.; Cummings, J.R.; et al. A short γ-ray burst apparently associated with an elliptical galaxy at redshift z = 0.225. *Nature* **2005**, *437*, 851–854. [CrossRef]
316. Fruchter, A.S.; Levan, A.J.; Strolger, L.; Vreeswijk, P.M.; Thorsett, S.E.; Bersier, D.; Burud, I.; Castro Cerón, J.M.; Castro-Tirado, A.J.; Conselice, C.; et al. Long γ-ray bursts and core-collapse supernovae have different environments. *Nature* **2006**, *441*, 463–468. [CrossRef]
317. Nakar, E. Short-hard gamma-ray bursts. *Phys. Rep.* **2007**, *442*, 166–236. [CrossRef]
318. Gehrels, N.; Ramirez-Ruiz, E.; Fox, D.B. Gamma-Ray Bursts in the Swift Era. *Annu. Rev. Astron. Astrophys.* **2009**, *47*, 567–617. [CrossRef]
319. Abbott, B.P.; Abbott, R.; Abbott, T.D.; Acernese, F.; Ackley, K.; Adams, C.; Adams, T.; Addesso, P.; Adhikari, R.X.; Adya, V.B.; et al. GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral. *Phys. Rev. Lett.* **2017**, *119*, 161101. [CrossRef] [PubMed]
320. Abbott, B.P.; Abbott, R.; Abbott, T.D.; Acernese, F.; Ackley, K.; Adams, C.; Adams, T.; Addesso, P.; Adhikari, R.X.; Adya, V.B.; et al. Multi-messenger Observations of a Binary Neutron Star Merger. *Astrophys. J.* **2017**, *848*, L12. [CrossRef]

321. Goldstein, A.; Veres, P.; Burns, E.; Briggs, M.S.; Hamburg, R.; Kocevski, D.; Wilson-Hodge, C.A.; Preece, R.D.; Poolakkil, S.; Roberts, O.J.; et al. An Ordinary Short Gamma-Ray Burst with Extraordinary Implications: Fermi-GBM Detection of GRB 170817A. *Astrophys. J.* **2017**, *848*, L14. [CrossRef]
322. Alexander, K.D.; Berger, E.; Fong, W.; Williams, P.K.G.; Guidorzi, C.; Margutti, R.; Metzger, B.D.; Annis, J.; Blanchard, P.K.; Brout, D.; et al. The Electromagnetic Counterpart of the Binary Neutron Star Merger LIGO/Virgo GW170817. VI. Radio Constraints on a Relativistic Jet and Predictions for Late-time Emission from the Kilonova Ejecta. *Astrophys. J.* **2017**, *848*, L21. [CrossRef]
323. Nysewander, M.; Fruchter, A.S.; Pe'er, A. A Comparison of the Afterglows of Short- and Long-duration Gamma-ray Bursts. *Astrophys. J.* **2009**, *701*, 824–836. [CrossRef]
324. Weaver, R.; McCray, R.; Castor, J.; Shapiro, P.; Moore, R. Interstellar bubbles. II—Structure and evolution. *Astrophys. J.* **1977**, *218*, 377–395. [CrossRef]
325. Pe'er, A.; Wijers, R.A.M.J. The Signature of a Wind Reverse Shock in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2006**, *643*, 1036–1046. [CrossRef]
326. van Eerten, H.J.; Meliani, Z.; Wijers, R.A.M.J.; Keppens, R. No visible optical variability from a relativistic blast wave encountering a wind termination shock. *Mon. Notices R. Astron. Soc.* **2009**, *398*, L63–L67. [CrossRef]
327. Chevalier, R.A.; Li, Z.Y. Gamma-Ray Burst Environments and Progenitors. *Astrophys. J.* **1999**, *520*, L29–L32. [CrossRef]
328. Panaitescu, A.; Kumar, P. Jet Energy and Other Parameters for the Afterglows of GRB 980703, GRB 990123, GRB 990510, and GRB 991216 Determined from Modeling of Multifrequency Data. *Astrophys. J.* **2001**, *554*, 667–677. [CrossRef]
329. Panaitescu, A.; Kumar, P. Properties of Relativistic Jets in Gamma-Ray Burst Afterglows. *Astrophys. J.* **2002**, *571*, 779–789. [CrossRef]
330. Starling, R.L.C.; van der Horst, A.J.; Rol, E.; Wijers, R.A.M.J.; Kouveliotou, C.; Wiersema, K.; Curran, P.A.; Weltevrede, P. Gamma-Ray Burst Afterglows as Probes of Environment and Blast Wave Physics. II. The Distribution of p and Structure of the Circumburst Medium. *Astrophys. J.* **2008**, *672*, 433–442. [CrossRef]
331. Curran, P.A.; Starling, R.L.C.; van der Horst, A.J.; Wijers, R.A.M.J. Testing the blast wave model with Swift GRBs. *Mon. Notices R. Astron. Soc.* **2009**, *395*, 580–592. [CrossRef]
332. Oates, S.R.; Page, M.J.; De Pasquale, M.; Schady, P.; Breeveld, A.A.; Holland, S.T.; Kuin, N.P.M.; Marshall, F.E. A correlation between the intrinsic brightness and average decay rate of Swift/UVOT gamma-ray burst optical/ultraviolet light curves. *Mon. Notices R. Astron. Soc.* **2012**, *426*, L86–L90. [CrossRef]
333. Oates, S.R.; Racusin, J.L.; De Pasquale, M.; Page, M.J.; Castro-Tirado, A.J.; Gorosabel, J.; Smith, P.J.; Breeveld, A.A.; Kuin, N.P.M. Exploring the canonical behaviour of long gamma-ray bursts using an intrinsic multiwavelength afterglow correlation. *Mon. Notices R. Astron. Soc.* **2015**, *453*, 4121–4135. [CrossRef]
334. Li, L.; Wu, X.F.; Huang, Y.F.; Wang, X.G.; Tang, Q.W.; Liang, Y.F.; Zhang, B.B.; Wang, Y.; Geng, J.J.; Liang, E.W.; et al. A Correlated Study of Optical and X-ray Afterglows of GRBs. *Astrophys. J.* **2015**, *805*, 13. [CrossRef]
335. Racusin, J.L.; Oates, S.R.; de Pasquale, M.; Kocevski, D. A Correlation between the Intrinsic Brightness and Average Decay Rate of Gamma-Ray Burst X-ray Afterglow Light Curves. *Astrophys. J.* **2016**, *826*, 45. [CrossRef]