ON RADIATION DRAG AND NEUTRONS IN GRBS

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As it was recently shown by Derishev\cite{Derishev2001}, initial GRB ejecta are likely to contain comparable number of protons and neutrons. During acceleration process, and/or later, due to interaction with external medium, such ejecta are likely to be split into spatially distinct shells of neutron and proton-electron plasmas. This leads to dynamical effects which can affect the afterglow light curves. In this paper we study these effects including, for the first time, radiation drag imposed on the neutron rich ejecta. In the presence of efficient radiation drag and for typical ejecta Lorentz factor (below 400), this is the neutron shell which moves faster and, after conversion to proton-electron plasma, powers the afterglow. After certain amount of deceleration, this shell is hit by the second one. Such collision will lead to reflaring, as observed in some afterglow light curves.

1 Introduction

Recent observational data points toward the hypernova model for long gamma-ray bursts. Within the framework of the hypernova model Lazzati, Ghisellini, Celotti and Rees\cite{Lazzati2001} show that the effects of radiation drag may be very important for the dynamics and radiation of the GRB. The ejecta encountering a dense radiation field can be decelerated and can produce very hard X-ray spectra by upscattering the external radiation field.

Derishev, Kocharovsky, and Kocharovsky\cite{Derishev2001} noticed that the relativistic shock must contain neutrons. Neutrons are coupled to protons when the density is high enough, and if the density becomes low enough already in the acceleration phase then the neutron and proton ejecta will separate.

The latter condition can be satisfied only if $\Gamma > 400$. In this paper we point out that the GRB ejecta can split into the neutron and the proton-electron shells even for $\Gamma < 400$, provided the radiation drag is efficient like suggested by Lazzati et al.\cite{Lazzati2001}.

2 The dynamics of the ejecta

The following timescales, and corresponding distances enter the problem:

- $t_{\text{acc}}$ - the acceleration timescale; acceleration ceases at a distance $r_{\text{acc}} \simeq c t_{\text{acc}}$
- $t_{\text{pn}}$ - the time at which the density drops to the value that the proton neutron coupling becomes inefficient; the decoupling takes place at $r_{\text{pn}} \simeq c t_{\text{pn}}$
- $t_{n}$ - the neutron decay timescale as measured in the lab frame ($t_{n} = 900 \text{s} \times \Gamma$, where $\Gamma$ is the bulk Lorentz factor of the ejecta) the decay takes place at $\approx r_{n} \simeq c t_{n}$
- $t_{a}$ - beginning of the afterglow; the afterglow starts at a distance $r_{a} \simeq c t_{a}$
If \( t_{pn} > t_{acc} \) then the protons and neutrons move together. In the opposite case when \( t_{pn} < t_{acc} \) protons and neutrons will separate.

### 2.1 Without radiation drag

If \( t_{pn} < t_{acc} \) we expect a separation of the proton and neutron stream. The neutrons are accelerated only because they are held in the shock by collisions with protons, and once these collisions become inefficient they lag behind the neutron stream, see Figure 1. This can take place only if \( \Gamma > 400 \).

In the afterglow phase two scenarios may take place depending on \( t_n \) and \( t_a \), as shown in Figures 2 and 3. If \( t_n < t_a \) and \( t_{pn} > t_{acc} \) there will be no separation of protons and neutrons, as shown in the left panel of Figure 2. In all other cases neutrons decay to protons forming a separate flow which sooner or later collides with the original proton flow. If \( t_n > t_a \) (right panel of Figure 2) then at the beginning of the afterglow phase only the protons are decelerated, while the neutrons can stream ahead until they decay to protons at \( r_n \). At this time they begin decelerating and clear the path in front of the original proton shock. The two shocks finally collide at \( r_{coll} \) when the trailing proton shock catches up with the shock formed of the protons formed of the decaying neutrons.

Figure 3 shows the case when the proton and neutron stream is separated in the acceleration phase. The two cases shown are very similar: the afterglow is started by the faster proton stream. The neutrons decay to protons and the two shocks collide when the initial proton wave has been slowed down sufficiently so that the trailing - now faster, shock catches up.

### 2.2 With radiation drag

We present the effect of the radiation drag in Figure 4. We demonstrate there the case when \( t_{pn} > t_{acc} \), i.e. the protons and the neutrons are accelerated together and the neutrons decay after the acceleration phase has ceased. After the acceleration phase the ejecta have to plough through the dense radiation field and the protons are decelerated. At this time however the neutrons are no longer bound to protons, and the two streams separate. The radiation drag ends at \( r_\star \) (the radius of the exploding star) and we now have a leading neutron wave followed by the proton ejecta. If the neutron decay radius \( r_n \) is smaller than the radius \( r_a \) at which the afterglow begins (left panel of Figure 4) then the leading neutrons convert to protons and begin decelerating once they reach \( r_a \). As they decelerate they sweep up the matter in front of the trailing proton ejecta. The two waves collide when the leading shock has slowed down sufficiently so that the trailing one can catch up, which takes place at \( r_{coll} \). The case when the afterglow radius \( r_a \) is smaller than the radius \( r_n \) where neutrons decay to protons is shown in the right panel of Figure 4. The trailing proton shock begins the afterglow, while the leading neutron wave rushes through the external matter without any interaction until it reaches \( r_n \).
Figure 2: The case $t_{pn} > t_{acc}$: in the left panel we present the case, where $t_n < t_a$, and all neutrons decay to protons before the beginning of the afterglow. There is no separation of protons and neutrons. In the right panel we present the opposite case, $t_n > t_a$. Here the afterglow starts at $r_n$ and begins to slow down protons while the neutrons stream ahead. They decay in front of the earlier proton afterglow at $r_n$, and sweep up matter in front of the proton shock. The protons catch up and collide with this shock at $r_{coll}$.

Figure 3: The case when $t_{pn} < t_{acc}$. The protons and the neutrons have been separated already in the acceleration phase. In the left panel we present the case when $t_n < t_a$. Neutrons trail behind the protons, and decay still behind them. Once the afterglow starts and the proton front decelerates the two shocks have chance to collide. Similarly, when $t_n > t_a$ (right panel), the trailing neutrons convert to protons and the two shocks collide.

and converts to protons. At this moment it begins to decelerate and clears the way in front of the trailing proton wave. Once the trailing wave has reached $r_n$ it stops decelerating. The two waves finally collide at $r_{coll}$.

3 Conclusions

The inclusion of both the effects of the radiation drag and of the neutron content in the ejecta inevitably leads to a collision of the two shells in the afterglow phase. Such collision will cause reflaring in the afterglow.

If the external medium is dense enough and the afterglow starts at the distance shorter than the distance of the neutron decay, then in addition to the reflaring discussed above the early afterglow will consist of two components: the first from the proton shell and the second due to the shock formed when neutrons decay to protons. This is illustrated in the right panel of Figure 2 and in the right panel of Figure 4. One component of the afterglow is emitted between $r_a$ and $r_n$ by the proton wave and the second component is formed between $r_n$ and $r_{coll}$ by the deceleration of the protons formed in neutron decays. The two components will very likely overlap in the observers frame.
Figure 4: The effects of radiation drag. Here we demonstrate the case $t_{pn} > t_{acc}$. After the acceleration phase ceases the radiation forces act on protons and slow them down while the neutrons stream ahead. We marked the radius where the radiation drag stops by $r_\ast$. If $r_n < r_a$, (left panel) neutrons first decay to protons, starting the afterglow, and the protons catch up with them at $r_{coll}$ (similarly to top panel in Figure 4). If $r_n > r_a$ we encounter a situation similar to the right panel of Figure 3.

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References

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