Decelerated sub relativistic material with energy Injection

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Abstract

We investigate the evolution of the afterglow produced by the deceleration of non-relativistic material due to its surroundings. The ejecta mass is launched into the circumstellar medium with equivalent kinetic energy expressed as a power-law velocity distribution $E \propto (\Gamma\beta)^{-\alpha}$. The density profile of this medium follows a power law $n(r) \propto r^{-k}$ with k the stratification parameter, which accounts for the usual cases of a constant medium ($k=0$) and a wind-like medium ($k=2$). A long-lasting central engine, which injects energy into the ejected material as ($E \propto t^{1-q}$) was also assumed. With our model, we show the predicted light curves associated with this emission for different sets of initial conditions and notice the effect of the variation of these parameters on the frequencies, timescales and intensities. The results are discussed in the Kilonova scenario.

Introduction

Kilonovae (KNe) are thermal astronomical transients which occur into the coalescence of binary compact objects (NS-NS or BH-NS). Short-duration gamma-ray bursts (sGRBs) are also linked to these events.

As such, KNe may also be studied with the formalism of sGRBs.

In this work, we provide a model for the late-time multi-wavelength afterglow emission due to the deceleration of the outermost non-relativistic in such an event.

Considerations:

- Non-relativistic, adiabatic evolution of the forward shock described by the Sedov-Taylor solution.
- Evolution of the shock front in a stratified medium $(n = A_k R^{-k})$.
- Afterglow consisting of two components:
  - One produced by the non-relativistic ejecta mass. Energy distributed as a power law $E \propto (\Gamma\beta)^{-\alpha}$.
  - The other taking into account energy injection $E \propto t^{1-q}$.

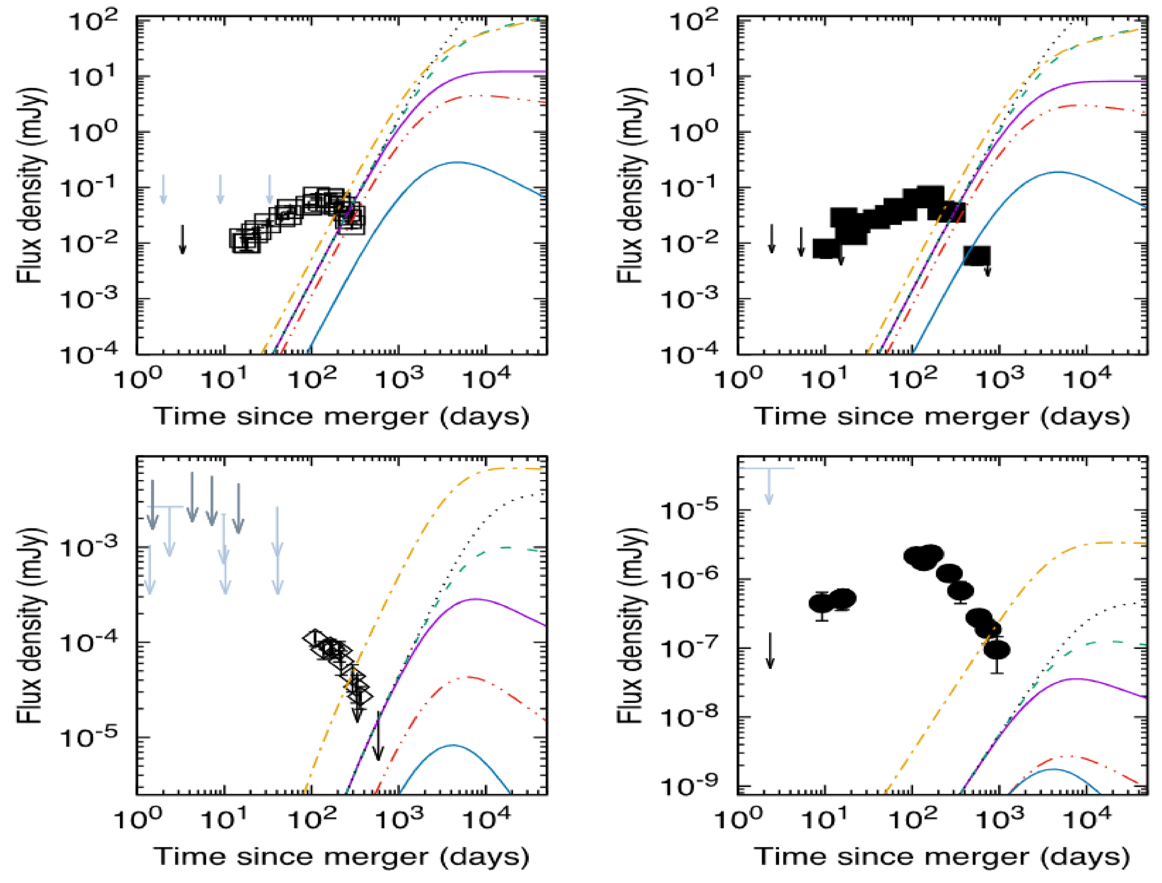
Theoretical Model

Both components may be written with just one expression for the shock velocity and deceleration radius:

$$\beta = \beta^0\,(1+z)^{-\frac{k-3}{\alpha+5-k}}\,A_{\rm k}^{-\frac{1}{\alpha+5-k}}\,\tilde{E}^{\frac{1}{\alpha+5-k}}\,t^{\frac{k-(q+2)}{\alpha+5-k}}\,, \qquad r = r^0\,(1+z)^{-\frac{\alpha+2}{\alpha+5-k}}\,A_{\rm k}^{-\frac{1}{\alpha+5-k}}\,\tilde{E}^{\frac{1}{\alpha+5-k}}\,t^{\frac{\alpha+3-q}{\alpha+5-k}}\,.$$

- For the **energy injection component:** $\alpha = 0$
- For the component **without energy injection:** $q = 1$

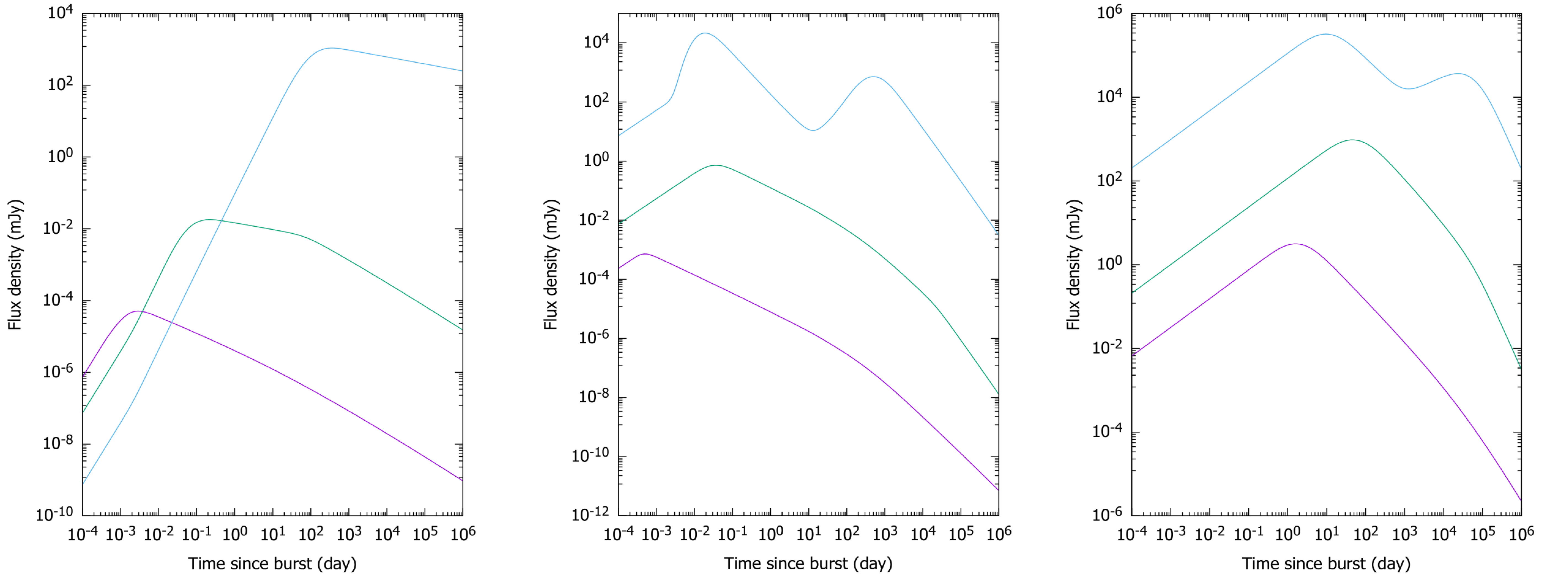
Results and Discussion



Multiwavelength observations and upper limits of GRB 170817A and S190814bv, respectively, with the synchrotron light curves with no energy injection

Results and Discussion

Synchrotron light curves: purple X-ray (1 keV), green optical (1 eV), blue radio (1.6 GHz).



Left and middle panels: no energy injection.
- Left: ISM $(k=0)$.
- Right: Wind-like $(k=2)$.

Right panel:
Energy injection in wind-like medium.

Conclusion

With basis on the Sedov-Taylor solution in the non-relativistic regime, we have derived the dynamics of the shock front. We have calculated synchrotron cooling break frequencies and the spectral peak flux density, with which we have obtained synchrotron light curves in the fast- and slow-cooling regimes.
The model's equations have been left in terms of the stratification parameter k, and the kinetic energy distribution indices α and q. They are ready to be used to describe KNe emission. We have shown the predicted synchrotron light curves in radio at 6 GHz, in the optical at 1 eV and in X-rays at 1 keV for typical values of GRBs afterglows. All the light curves peak on timescales of several months to a few years, similar to those observed in some SNe such as SN 2014C and SN 2016aps. We showed that variations in the density parameter could be observed more easily.

References

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