# Fast Blue Optical Transients as cosmic-ray sources


*R. Brose[1,2], I. Sushch[3,4,5,6], J. Mackey[2]*

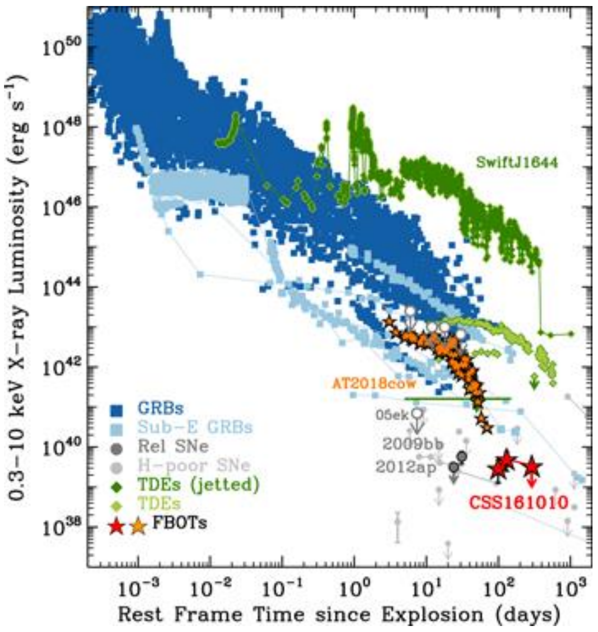
[1] School of Physical Sciences, Dublin City University, Dublin 9, Ireland; [2] Dublin Institute for Advanced Studies, D02 XF86 Dublin 2, Ireland; [3] Astronomical Observatory of Ivan Franko National University of Lviv, UA-79005 Lviv, Ukraine
[4] Gran Sasso Science Institute, 67100 L'Aquila, Italy; [5] Laboratori Nazionali del Gran Sasso, 67100 Assergi L'Aquila, Italy; [6] Centre for Space Research, North-West University, 2520 Potchefstroom, South Africa


## Introduction

Fast Blue Optical Transients (FBOTs) are luminous short-lived events, that strongly emit at blue colors around their peak in the optical waveband. The late-time emission shows similarities to supernovae (SNe) associated with long GRBs and superluminous SNe but the origin of FBOTs is not yet understood.

However, the fast rise-time of the optical emission of a few days indicates fast-moving ejecta interacting with dense material (CSM) close to the "central engine". The high luminosities in the optical, radio and x-ray bands suggest efficient particle acceleration due the high mass passing through the shock and consequently the possibility for high cosmic-ray currents driving magnetic-field growth and consequently acceleration.

**Figure 1:** X-ray luminosity of various transients. AT 2018cow is the only other FBOT with detected X-ray emission [1]




## Foundations

- We performed numerical simulations of particle acceleration and the hydrodynamical evolution of very young SNRs interacting with thin massive shells of $M_{shell} = 2 \cdot M_{\odot}$ after 30+ days after the explosion.
- We placed shells at various distances and evaluated the maximum particle energy and the gamma-ray emission
- Strong gamma-gamma absorption attenuates the initial signal till the SN-photosphere fades

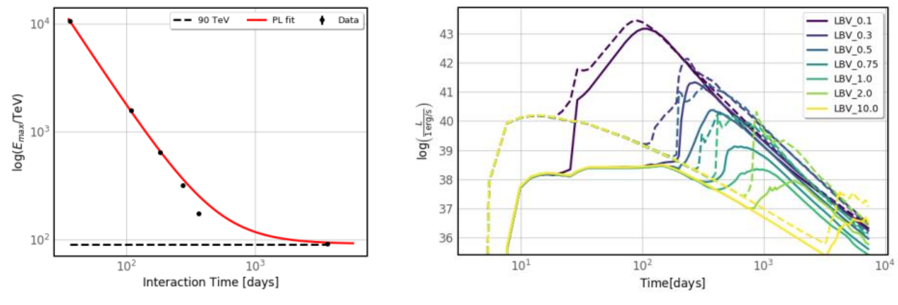



**Figure 2:** (left) Maximum energy of CRs at the end of the 20year long simulations for interacting SNRs depending on the time of shock-shell interaction
(right) Attenuated gamma-ray luminosities at Fermi-LAT (dashed) and H.E.S.S. energies (solid) for different times of shock-shell interactions.

- Generally, earlier interactions produce a higher maximum energy and brighter events

## Assumptions

We use the results of the CC-SNR simulations to build a simple analytical description for the particle population created by an interacting FBOT. The key ingredients are:

- The total energy in CRs is 2% of the explosion energy of $10^{51}$erg
- The maximum particle energy depends on the time of the shock-shell interaction and is given by:

$$E_{max}(t) = 10.8PeV\left(\frac{t}{36days}\right)^{-1.8} + 0.09PeV$$

- The maximum energy is reached only after the complete passage of the shell. Simulations indicate that it takes $\approx 20 \cdot t_{interaction}$ to reach $E_{max}$
- We calculate the target density for the gamma-ray emission assuming the shocked shell is contained within 20% behind the shock and that the shock-radius is given by $R_{sh}(t) = 20{,}000km/s \cdot t$
- The gamma-ray emission is calculated using the *NAIMA*-package [2]

## Results and Discussion

- FBOTs could be producing CRs with energies well beyond the with $E_{max}(3days) \approx 1$EeV
- The modest energy in CRs results in gamma-ray luminosities that are detectable to distances up to roughly 50Mpc with CTA for 50h of observation, which is significantly less than current models suggest
- Later interactions yield not only a lower maximum energy but also a lower gamma-ray luminosity due to the lower ambient density

Of course, our results strongly depend on our initial assumptions. However, this is a first attempt to link FBOTs to a mechanism/progenitor system who's properties are relatively well understood. For instance, our shell-mass of $2 \cdot M_{\odot}$ is basically the maximum expectable from single-progenitor stellar evolution models.

Our predicted emission is in a range that is accessible with current and next-generation gamma-ray instruments.

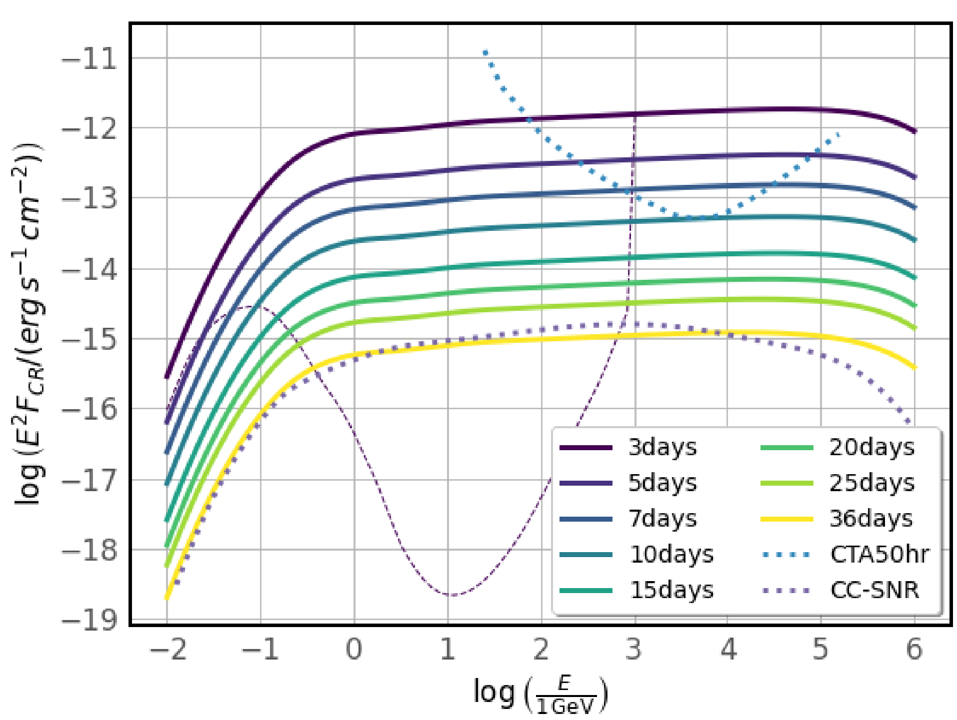



**Figure 3:** Gamma-ray flux of FBOTs at a distance of 50Mpc interacting at various times with a dense shell (solid lines). The dotted purple line represents the results of a numerical simulations of an CC-SNR interacting after 36 days (see foundations). The thin dashed lines illustrates the potential effect of gamma-gamma absorption. Here, properties of a Type-II SN were used.

## Outlook

- Gamma-gamma absorption can significantly influence the detectable gamma-ray signal. We aim to investigate the expected absorption based on the light curves of FBOTs observed so far
- Expand the numerical simulations to earlier interactions and study a broader range of shell-masses
- Calculate the total CR-yield from FBOTs given their relatively low rate of ~0.1% of the CC-SNR rate

## References


[1] Coppejans, D. L., "A Mildly Relativistic Outflow from the Energetic, Fast-rising Blue Optical Transient CSS161010 in a Dwarf Galaxy", The Astrophysical Journal, vol. 895, no. 1, IOP, 2020. doi:10.3847/2041-8213/ab8cc7.

[2] Zabalza, V., "naima: a Python package for inference of relativistic particle energy distributions from observed nonthermal spectra", Proceedings of International Cosmic Ray Conference 2015, 922, 2015, http://adsabs.harvard.edu/abs/2015arXiv150903319Z


## Acknowledgements


This work was supported by funding from the Irish Research Council under the Government of Ireland Postdoctoral Fellowship program.


## Contact:


https://homepages.dias.ie/broserob

robert.brose@dcu.ie