Compton polarization signatures in gamma-ray burst models

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Introduction

- Since the first detection of Gamma-ray Bursts (GRBs) in 1967, GRBs have been an active subject of study with many questions still left unanswered.

- GRBs are some of the most luminous explosions in the universe with typical isotropic luminosities of $\sim 10^{51} - 10^{53} ergs \cdot s^{-1}$.

- A better understanding of the inner workings of GRBs may be useful not only in providing additional information on the properties of the ISM and the possible progenitors of GRBs, but also for Cosmological considerations as GRBs are found at a wide range of redshits ($z = 0.0085 - z = 9.4$).

Phases of GRBs

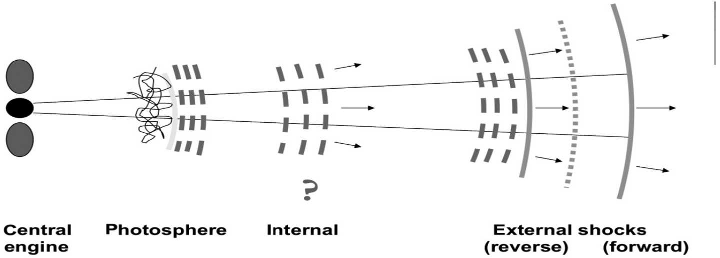
The evolution of GRBs is divided into two phases:

Prompt emission

- Earliest signal detected from GRBs.
- Still not well understood (acceleration, emission mechanisms).

Afterglow

- Relatively simple physics; well understood.
- Collimated GRB jet interacting with ambient medium (ISM, Wind)
- Emission mechanism synchrotron emission.



Polarization considerations

- High energy polarimiters such as POLAR, COSI and IXPe provide additional avenues of probing the various proposed models of GRBs.

- Current polarization measurements for GRBs seem to favour photospheric models.

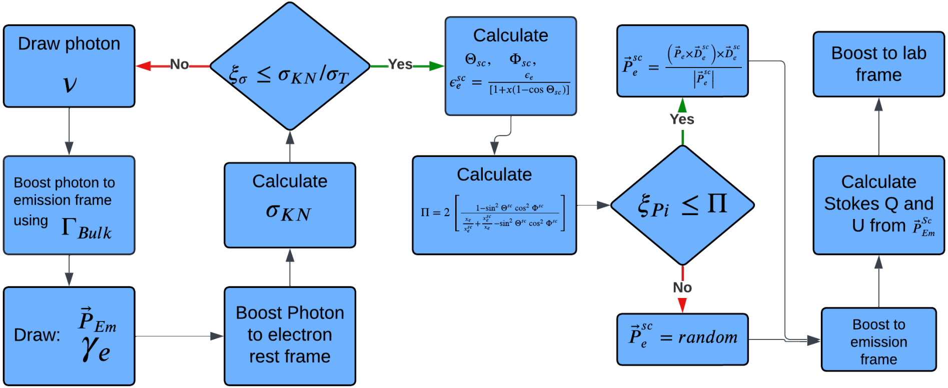
- In spite of this multiple authors (Kole, 2020; Lan et al, 2021; Burgess et al, 2019) have cautioned against the use of time- and energy- integrated polarization data, showing that time- and energy-resolved polarization observations should be considered in order to discriminate between the various prompt emission mechanisms.

A few notes on the code

- Develop a Monte Carlo inverse Compton code to estimate IC polarization for models.
- Algorithm is based off of that developed by Matt et al. (1996) and Dreyer and Böttcher (2020).
- The code is developed in Python primarily using the NUMBA Cuda package to parallelize the calculation of each photon on GPUs.
- Each run of the code considers 5 - 50 million photons.
- Each photon is binned (energy/time resolved) and the final Q and U parameters are calculated by summing over all photons in the bin.

The basic algorithm

1 Introduction



Basic setup of the backscatter-dominated cork model

- Model by Vyas, Pe‘er and Eichler (2021)
- Expanding Cork with constant Bulk Lorentz factor Γ intercepting radiation from center of collapsing star.
- Inner surface of cork at initial radius r_i
- Density of cork in co-moving frame $n` = \dot{M}/\left(\pi m_p \Gamma \beta_\Gamma c r^2 \sin^2(\theta_j)\right)$

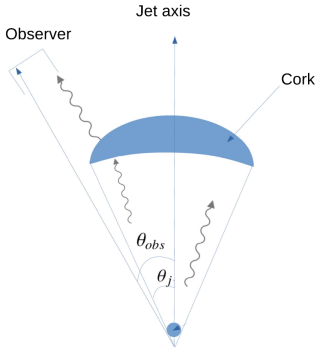
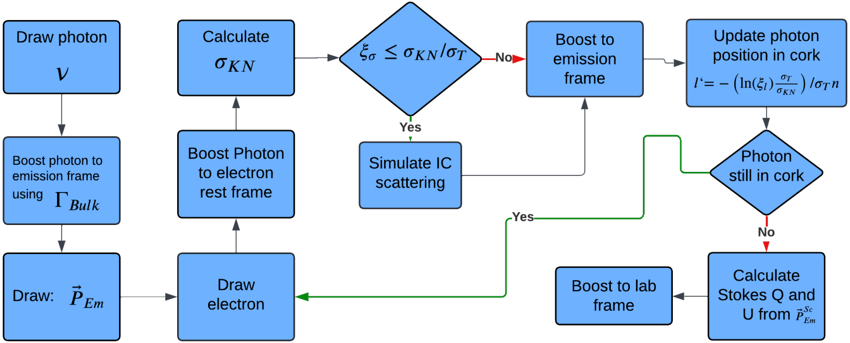


Figure: Taken from Vyas (2021)

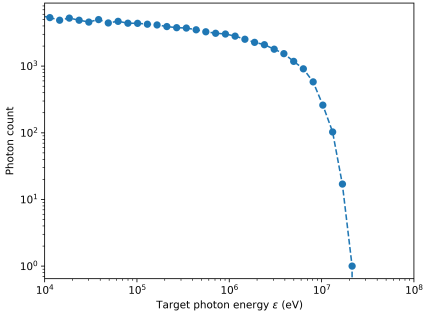
Adapting the code algorithm to the backscatter-dominated cork model

2 Applying the code to a backscatter-dominated model

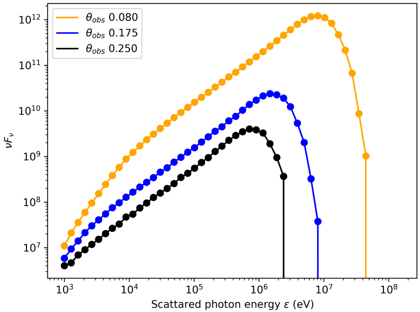


Input parameters for backscatter-dominated run

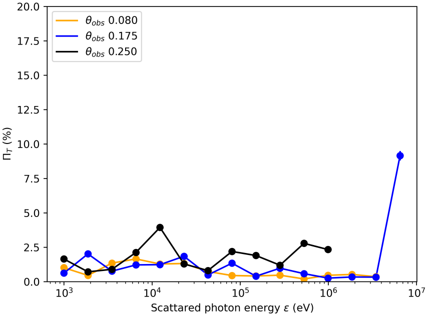
- $\dot{M} = 10^{33} g \cdot s^{-1}$
- Draw electron from Maxwellian dist. with $T_e = 10^8 K$
- Draw photon from modified pair annihilation number spectrum:
  - $F_s = \frac{C_0}{\epsilon} e^{-\frac{C_1 \epsilon^2}{\Theta_r^2}}, \Theta_r = \frac{kT_c}{m_e c^2}$
  - $C_0 = 2 \times 10^{40}, C_1 = 0.045$
- $\Gamma = 100$
- $\theta_j = 0.1$
- $r_i = 10^{12} cm$ (Wolf-Rayet stars)



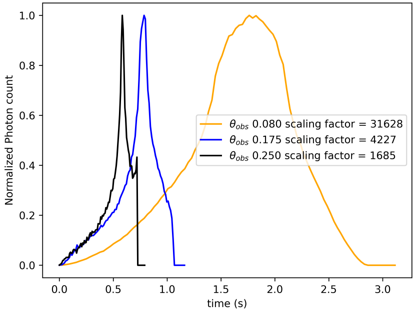
Final spectrum for scattered photons



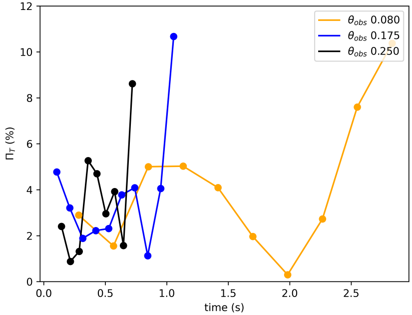
Polarization degree Π as a function of energy



Lightcurve



Polarization degree Π as a function of time



Summary and future outlook

- The Backscatter-dominated cork model considered predict $\Pi < 10\%$ for energy resolved simulations.
- The Backscatter-dominated cork model predicts similarly low PD when time resolved.
- Future outlook is to finalize polarization predictions for a Compton drag model.

Acknowledgments

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- Thank you to the CSR and SA-Gamma for the opportunity to attend.

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Thank you for listening!

Any questions?

Boosting the photon to the electron rest frame

Using the photon wave four-vector $\mathbf{K}_{Em} = \frac{2\pi\epsilon'}{hc}\left[1, \hat{v}\right]$,

- $\mathbf{K}_e = \Lambda \mathbf{K}_{Em}$
- $\mathbf{P}_e = \left(0, P_j^{temp} - \frac{P_t^{temp} K_{e,j}}{K_{e,t}}\right)$, with $j = x, y, z$
- $\mathbf{P}^{temp} = \Lambda \mathbf{P}_{Em}$
- with $\Lambda = \begin{pmatrix} \gamma & -\beta_x\gamma & -\beta_y\gamma & -\beta_z\gamma \\ -\beta_x\gamma & 1 + (\gamma-1)\frac{\beta_x^2}{\beta^2} & (\gamma-1)\frac{\beta_x\beta_y}{\beta^2} & (\gamma-1)\frac{\beta_x\beta_z}{\beta^2} \\ -\beta_y\gamma & (\gamma-1)\frac{\beta_x\beta_y}{\beta^2} & 1 + (\gamma-1)\frac{\beta_y^2}{\beta^2} & (\gamma-1)\frac{\beta_z\beta_y}{\beta^2} \\ -\beta_z\gamma & (\gamma-1)\frac{\beta_x\beta_z}{\beta^2} & (\gamma-1)\frac{\beta_z\beta_y}{\beta^2} & 1 + (\gamma-1)\frac{\beta_z^2}{\beta^2} \end{pmatrix}$