Synchrotron polarization of GRB afterglow shocks with **hydrodynamic-scale** turbulent magnetic field

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Kuwata et al. 2023, ApJ, 943, 118, Kuwata et al. in prep

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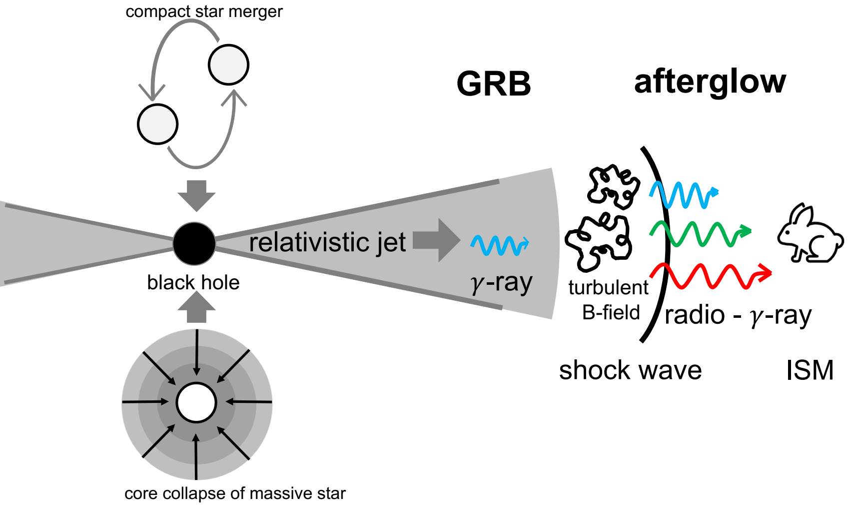
Abstract

We construct a semi-analytic model of afterglow polarization with **hydrodynamic-scale turbulent B-field**. We find that for the isotropic turbulence and the zero-viewing angle, $\Pi_{radio} \sim \Pi_{opt} \sim 2f_B\%$ on average but Π_{radio} can be higher than Π_{opt} at some time intervals. PDs & PAs vary randomly and continuously at both of two bands. On the other hand, for the anisotropic turbulence and the finite viewing angle, the optical polarization shows similar behavior to the plasma-scale field model around the jet break time. These results suggest that **hydrodynamic-scale model is consistent with all polarimetric observational data of afterglows**.

1. What is the origin of the strong magnetic field?

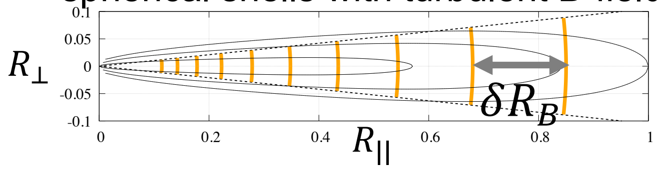


	plasma-scale B-field (e.g., Sironi & Spitkovsky 2011, Lemoine+2019, Huang+2022)	**hydrodynamic-scale B-field** (e.g., Sironi & Goodman 2007, Mizuno+2014)
Coherence length scale of B-field	~the proton plasma skin depth $\sim 10^7$ cm	~the thickness of the shocked region × 0.1 $\sim 10^{15}$ cm
Properties of polarization	• $\Pi_{\rm radio} \leq \Pi_{\rm optical}$ • optical PA - radio PA $= 0^\circ$ or 90°	$\Pi \sim \frac{\Pi_0}{\sqrt{N_{patch}}}$ (frequency dependence is unknown)

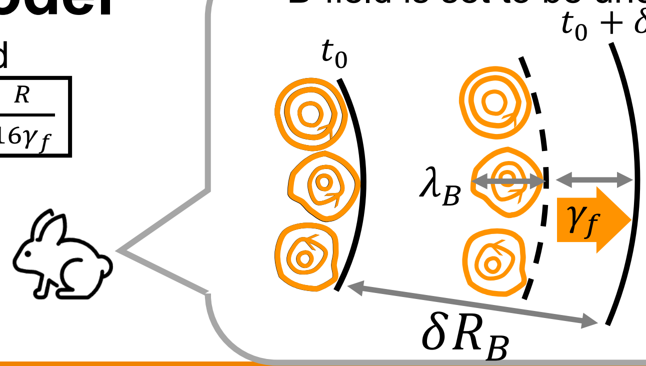
→ afterglow polarization may distinguish B-field model

2. Turbulent B-field model

- ✓ zero-viewing angle & isotropic B-field
- ✓ coherence length of B-field: $\boxed{\lambda'_B = f_B \frac{R}{16\gamma_f}}$
- ✓ spherical shells with turbulent B-field



✓ B-field is set to be unchanged for δR_B



$$\delta t_B^{sh} = \frac{\text{coherence length}}{\text{fluid velocity}} \simeq \frac{\lambda_B^{sh}}{c/3}$$

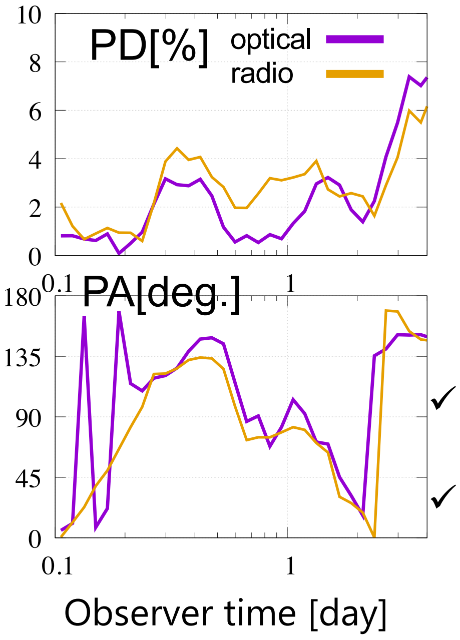
$$\delta R_B \simeq c\delta t_B \simeq 4\lambda'_B \gamma_f = \frac{1}{4} f_B R$$

Q^{sh}: rest frame of the shock
Q': rest frame of the fluid in the down stream
Q : lab frame

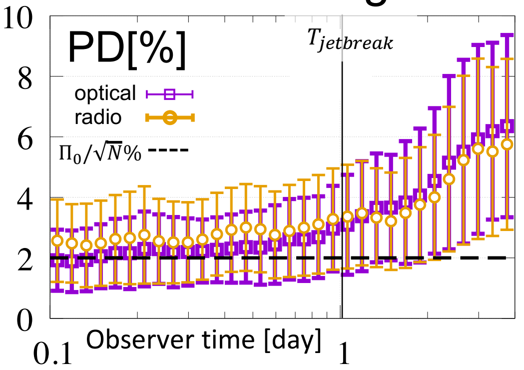
3. Result (isotropic turbulence)

$\theta_v = 2deg., \theta_j = 4deg., 2\langle\delta B_\parallel'^2\rangle / \langle\delta B_\perp'^2\rangle = 1, f_B = 1$

PD & PA curve



realization-averaged PD

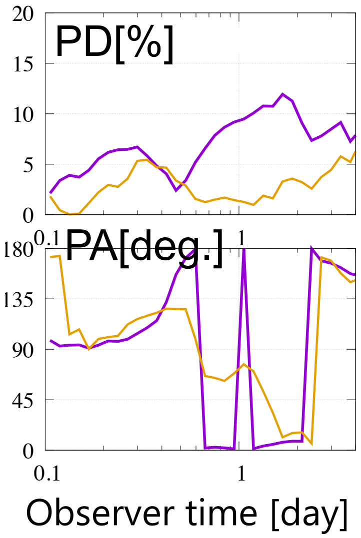


- ✓ PDs & PAs vary **randomly** and **continuously**
- ✓ $\mathbf{\Pi_{radio} \sim \Pi_{opt}}$ on average (consistent with $\Pi \sim \Pi_0/\sqrt{N_{patch}}$) but **can be $\Pi_{radio} > \Pi_{opt}$**

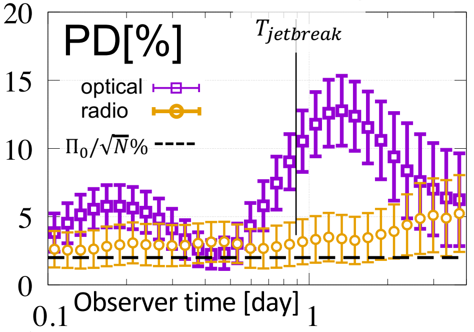
4. Result (anisotropic turbulence)

$\theta_v = 2deg., \theta_j = 4deg., 2\langle\delta B_\parallel'^2\rangle / \langle\delta B_\perp'^2\rangle = 0, f_B = 1$

PD & PA curve



realization-averaged PD



✓ For the highly anisotropic turbulence $\left(\frac{2\langle\delta B_\parallel'^2\rangle}{\langle\delta B_\perp'^2\rangle} < 0.4, \frac{2\langle\delta B_\parallel'^2\rangle}{\langle\delta B_\perp'^2\rangle} > 2\right)$, $\mathbf{\Pi_{opt} > \Pi_{radio}}$ at $T \sim T_{jetbreak}$ and **PAs show 90 deg. flip**

Summary

hydrodynamic-scale model is consistent with obs.

HEPRO VIII @ Institut d'Astrophysique de Paris, 2023/10/23-26