X-ray and MeV Polarization as Powerful Diagnostics for Blazars

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Scientific Goals and Methods

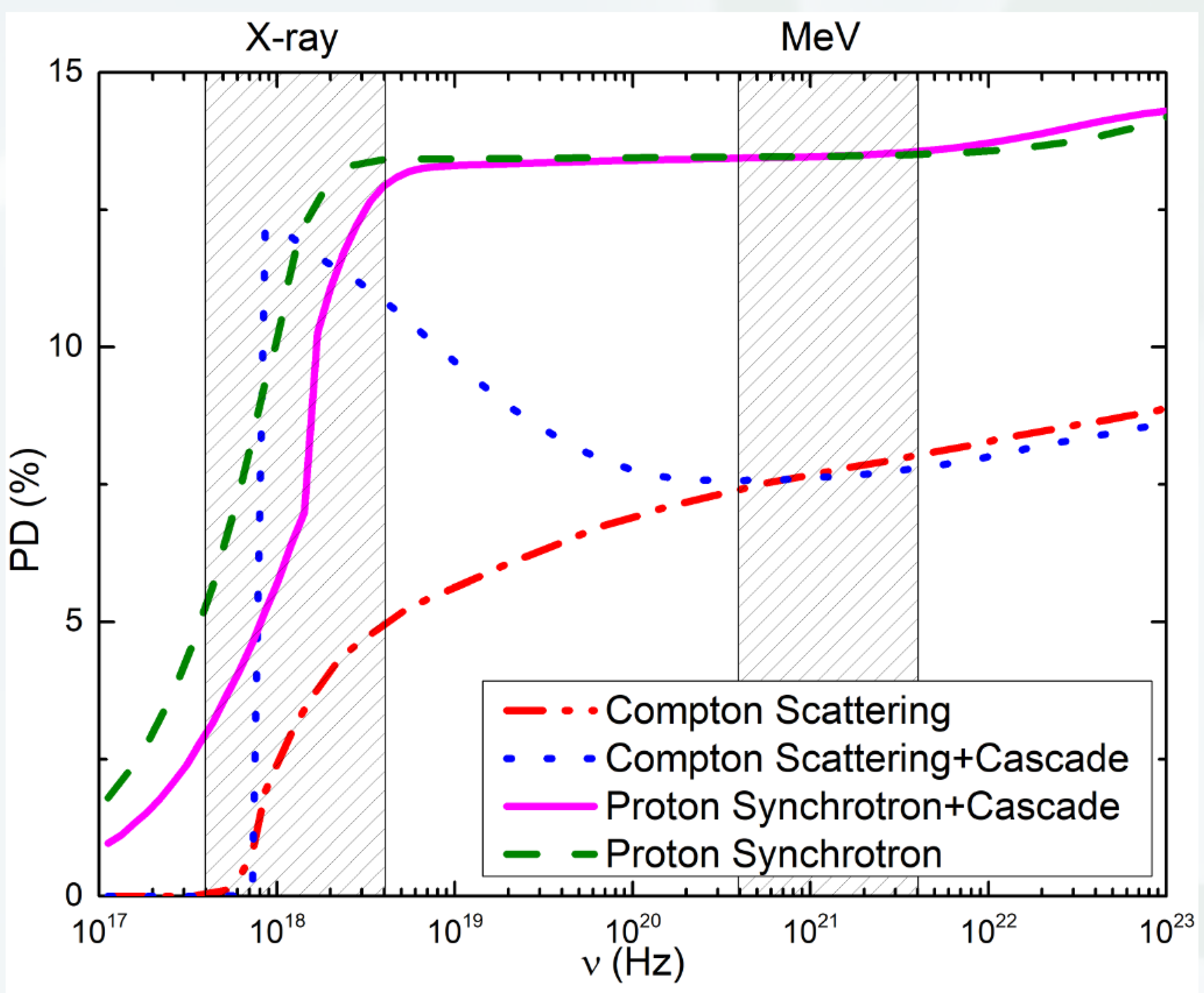
- ❑ Blazars are among the most powerful cosmic particle accelerators, which can be origins of extragalactic cosmic rays and neutrinos.
- ❑ Leptonic and hadronic radiation mechanisms give rise to distinct X-ray and MeV γ-ray polarization in blazars.
- ❑ Time-dependent X-ray polarization can probe the most energetic particle acceleration in high-frequency-peaked BL Lacs.
- ❑ We use semi-analytical approach to study blazar spectra and predict high-energy polarization and neutrino flux.
- ❑ We use particle-in-cell and polarized radiation transfer to compare time-dependent X-ray polarization from magnetic reconnection and turbulence.

Take Away Messages

- ❑ Comparable optical and X-ray polarization degrees in low-synchrotron-peaked blazars imply neutrino production in blazars. IXPE may detect one if the flux is above $10^{-11} erg\ cm^{-2} s^{-1}$ for a one day flare.
- ❑ Comparable optical and MeV γ-ray polarization degrees imply proton synchrotron in blazars. AMEGO-X may detect one if the flux is above $3 \times 10^{-9} erg\ cm^{-2} s^{-1}$ for a one week flare.
- ❑ Flashes of high X-ray polarization degree and highly variable flux are strong evidence for reconnection in high-frequency-peaked BL Lacs. IXPE may distinguish magnetic reconnection and turbulence for Mrk 421 and 501 with optical counterparts.

Leptonic and Hadronic Models

- ❑ Compton scattering by electrons predicts consistently lower polarization degree than synchrotron by protons or hadronic cascading pairs.
- ❑ Non-detection or up to half of the synchrotron polarization degree implies that the high-energy emission is purely leptonic.
- ❑ Similar optical and X-ray polarization degrees suggest pair synchrotron from hadronic cascades. IXPE may detect it during bright X-ray flares in low-synchrotron-peaked blazars.
- ❑ Similar optical and MeV γ-ray polarization degrees are a unique signature for proton synchrotron, implying that the entire high-energy spectral component is dominated by proton synchrotron. AMEGO-X can detect it during bright MeV γ-ray flares in all types of blazars.

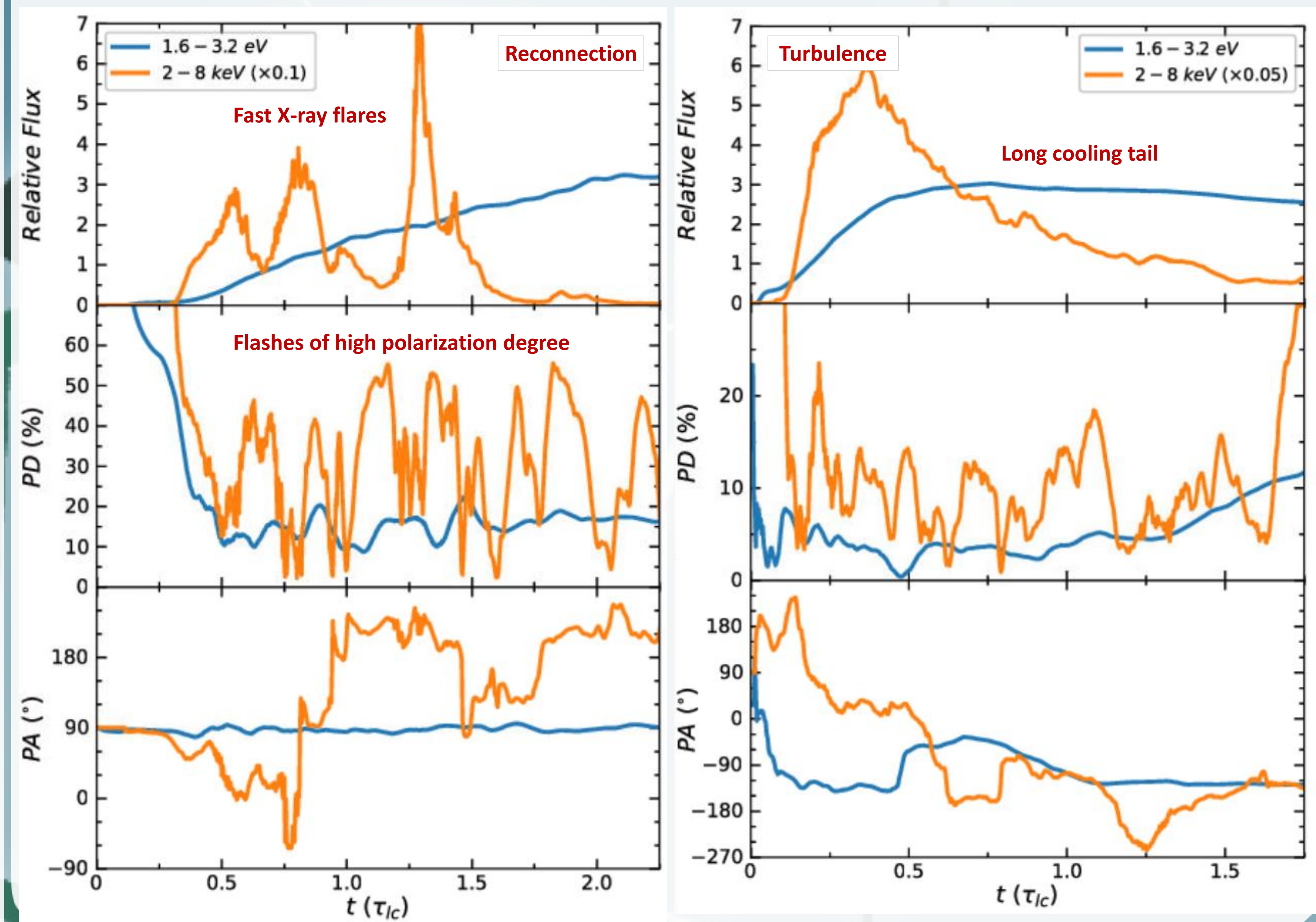


2FHL Name (1)	Optical Pol. (%) (2)	lep. Pol. (1 keV, %) (4)	had. Pol. (1 keV, %) (5)	lep. Pol. (1 MeV, %) (6)	had. Pol. (1 MeV, %) (7)
J0456.9−2323	9.9*	4.2	9.5	1.0	10.1
J0957.6+5523	5.7†	1.6	6.6	1.0	7.2
J1224.7+2124	5.4*	1.8	50.8	0.0	55.3
J1256.2−0548	15.0*	8.7	14.4	1.6	16.4
J1427.3−4204	…	…	…	…	…
J1512.7−0906	3.8*	2.5	9.7	0.0	9.7
J2000.9−1749	13.0†	6.0	13.4	0.5	15.7
J2254.0+1613	5.8*	1.9	6.2	0.0	6.9
J0456.9−2323	35.3*	15.3	34.7	3.6	38.3
J0957.6+5523	…	…	…	…	…
J1224.7+2124	29.1*	1.8	50.8	0.0	55.3
J1256.2−0548	34.5*	20.1	33.1	3.7	37.9
J1427.3−4204	…	…	…	…	…
J1512.7−0906	25.8*	17.1	66.4	0.1	66.6
J2000.9−1749	…	…	…	…	…
J2254.0+1613	25.0*	8.7	28.0	0.2	28.4

keV	MeV	ν	Conclusion
Y	Y	Y	Proton synchrotron, ν, UHECR (?)
N	Y	Y	Proton synchrotron, ν, UHECR (?)
Y	N	Y	Leptonic+hadronic cascades, ν, CR
Y/N	Y/N	N	Unknown mechanism (unlikely) or we need a better IceCube
N	N	Y	ν is not from the blazar zone
N	N	N	Pure leptonic

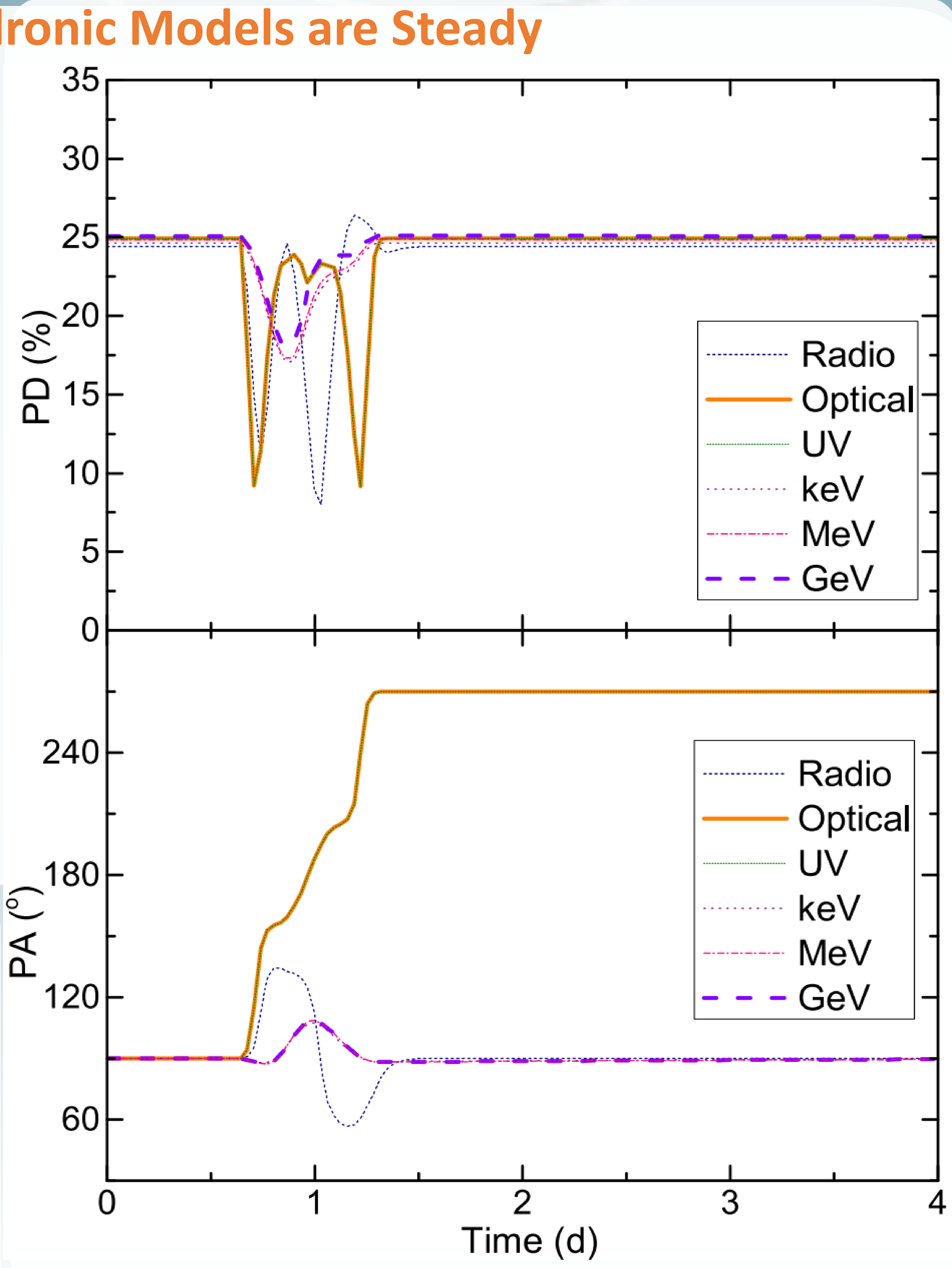
Reconnection and Turbulence Predict Distinct X-ray Polarization

- ❑ Reconnection features highly variable X-ray light curve with multiple peaks, while turbulence has overall smooth X-ray light curve with a clear cooling tail.
- ❑ Reconnection predicts flashes of high X-ray polarization degree and highly variable polarization angle. While turbulence also predicts highly variable X-ray polarization degree and angle, the polarization degree is much lower.



X-ray and MeV γ-ray Polarization from Hadronic Models are Steady

- ❑ Protons cool slower than electrons in the hadronic model, their cooling time scale is usually comparable to the light crossing time of the emission region.
- ❑ While electron synchrotron can trace the local magnetic field evolution, synchrotron by protons and hadronic cascading pairs only react to global magnetic field evolution in the emission region, which happens on much longer time scales.
- ❑ Whether it is shock, reconnection, or turbulence, hadronic X-ray and MeV γ-ray polarization do not vary significantly in time, even if the electron synchrotron counterparts exhibit strong polarization variability.
- ❑ Steady X-ray and MeV γ-ray polarization are ideal for current and future high-energy polarimeters.



References

- ❑ Zhang et al. 2016, ApJ 829, 69
- ❑ Paliya et al., 2018, ApJ 863, 98
- ❑ Zhang et al., 2019, ApJ 876, 109
- ❑ Zhang et al., 2021, ApJ 912, 129

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