How polarization measurements will disentangle gamma-ray bursts models

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TPC-HARPO workshop
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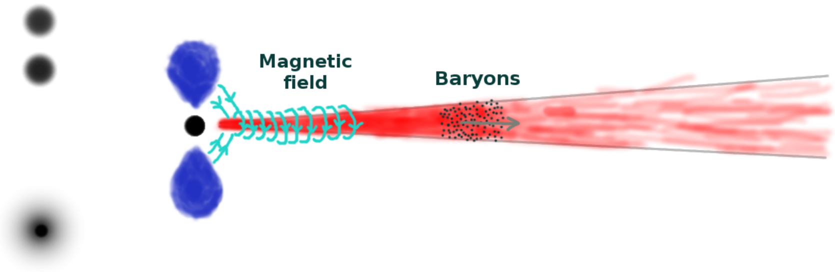
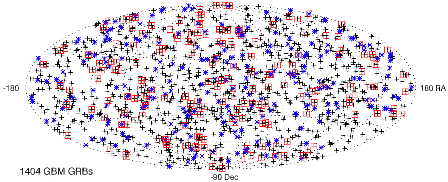
Outline

- GRB models - [radiation mechanisms for GRBs]
- Polarization - [history of prompt polarization]
- LEAP [proposed polarimeter for ISS]
- Consequences for TPC-HARPO [$\gtrsim$MeV range, Compton models]



Gamma-ray Bursts - Overview

- Random directions on the sky ($\sim$ few per week)
- Short/long divide in duration
- Broad non-thermal spectrum emerging complex picture
- Afterglow visible for $\sim$ week(s)
- Prompt: keV to $\lesssim$ MeV, AG: radio to $\lesssim$TeV
- Deduce: compact object, $\Gamma > 100$, $\theta_{\rm jet} \approx$few $^\circ$, $E_{\rm iso} = 10^{51} - 10^{55}$ erg



3$^{\rm rd}$ GBM GRB catalog Bhat+16

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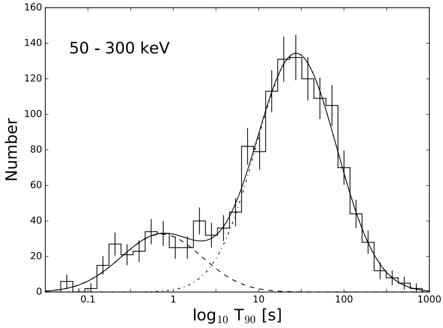

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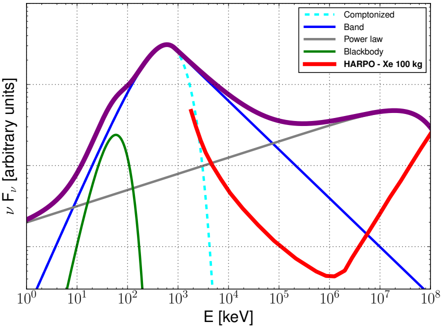

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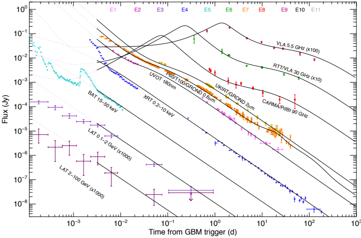

Perley+14

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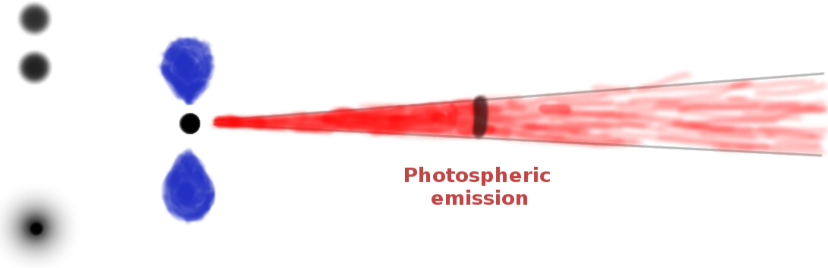
credit: NASA/Swift/deWilde

Scenarios for GRB prompt emission

- Photospheric models (dissipative/non-dissipative)
  - Blackbody / shocks + synchrotron / geometry / $\tau \gg 1$ dissipation
- Internal shocks
  - Shocks + Synchrotron / Self-Compton / magnetic fields
- External shock (?)
  - Synchrotron / Self-Compton



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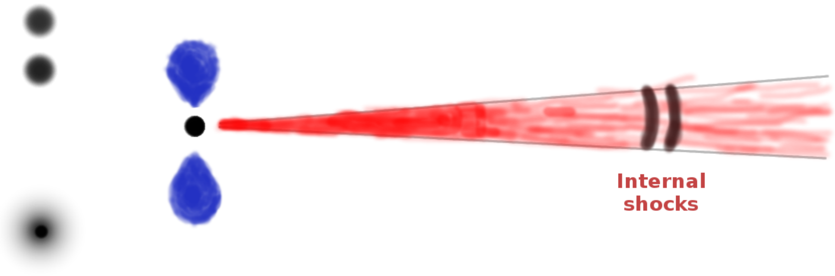

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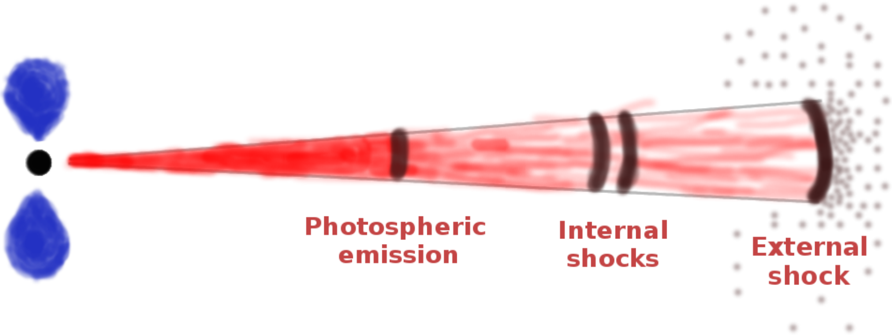
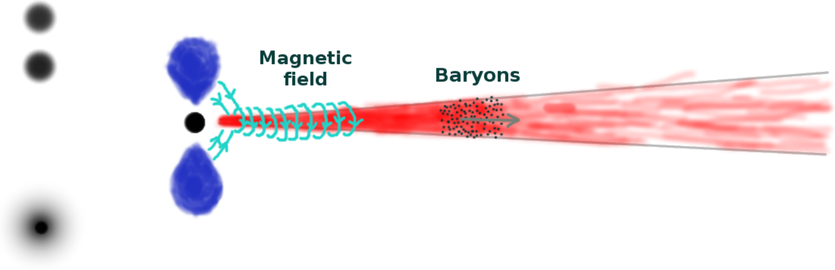


Motivation for polarimetric observations

- What carries the energy in GRB jets?
  $\rightarrow$Baryons
  $\rightarrow$Magnetic fields
- Polarized emission $\rightarrow$ magnetic fields
- Advected from central engine, $B_{\perp} \propto R^{-1}$, $B_{\parallel} \propto R^{-2}$.
- BUT: geometry (mostly viewing angle) can also increase pol. degree
  $\rightarrow$ Jet is viewed at the edge to within $\sim 1/\Gamma$



Prompt polarization history

Table: GRB Polarization Measurements (from McConnell 2016)

Pub Date	GRB	Instrument	Energy (keV)	Π	Refs
2004	GRB 021206	RHESSI	150 – 2000	**80% ± 20%**	Coburn & Boggs 2003
2004	GRB 021206	RHESSI	150 – 2000	$<$ 4.1%	Rutlege & Fox 2003
2004	GRB 021206	RHESSI	150 – 2000	41^{+57}_{-44}%	Wigger+04
2005	GRB 930131	CGRO/BATSE	20 – 1000	(35–100%)	Willis+05
2005	GRB 960924	CGRO/BATSE	20 – 1000	(50–100%)	Willis+05
2007	GRB 041219a	INTEGRAL/SPI	100 – 350	98% ± 33%	Kalemci+07
2007	GRB 041219a	INTEGRAL/SPI	100 – 350	96% ± 40%	McGlynn+07
2009	GRB 041219a	INTEGRAL/IBIS	200 – 800	43% ± 25%	Götz+09
2009	GRB 061122	INTEGRAL/SPI	100 – 1000	$<$ 60%	McGlynn+09
2011	GRB 100826a	IKAROS/GAP	70 – 300	**27% ± 11%**	Yonetoku+11
2012	GRB 110301a	IKAROS/GAP	70 – 300	70% ± 22%	Yonetoku+11
2012	GRB 110721a	IKAROS/GAP	70 – 300	80% ± 22%	Yonetoku+11
2013	GRB 061122	INTEGRAL/IBIS	250 – 800	$>$ 60%	Götz+13
2014	GRB 140206a	INTEGRAL/IBIS	200 – 800	$>$ 48%	Götz+13
2016	GRB 151006a	Astrosat/CZTI	100 – 300	–	Rao+16

GRB prompt emission likely polarized

- Outstanding issues:
  → PA change
  → Explain high Π
- Need: high confidence (low MDP) measurements

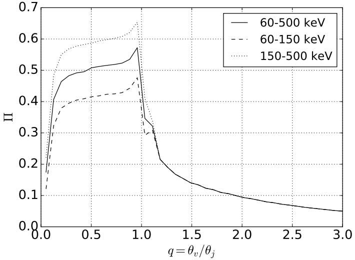
How to calculate polarization from a relativistic source?

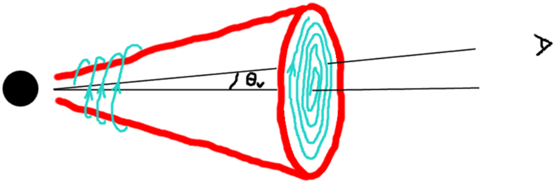
- Synchrotron $\Pi_0 = \frac{p+1}{p+7/3} = \frac{\alpha+1}{\alpha+5/3} \lesssim 0.8$
  $N(\gamma_e) \propto \gamma_e^{-p}$ or $F_\nu \propto \nu^{-\alpha}$
- Compton scattering $\Pi_0 = \frac{1-\cos^2\theta'}{1+\cos^2\theta'} \lesssim 1$
  θ' - scattering angle
- For optically thin sources e.g. Toma+09:
- $I_\nu = \frac{1+z}{D_L^2} \int d\phi \int d\mu \delta_D^2 j'(\nu')$
- $\begin{Bmatrix} Q_\nu \\ U_\nu \end{Bmatrix} = \frac{1+z}{D_L^2} \int d\phi \int d\mu \delta_D^2 j'(\nu') \Pi_0 \begin{Bmatrix} \cos(2\chi) \\ \sin(2\chi) \end{Bmatrix}$
  $\rightarrow j'(\nu')$ - spectral emissivity - carries the spectral shape
  $\rightarrow \Pi_0$ - local pol. degree, χ - local pol. angle
- Integrate for jet surface

- Jitter radiation (Mao+13)
- Dissipative photospheres
  $\rightarrow$ detailed radiative transfer (e.g. Lundman+16)

Models

- Polarization affected by
  → Geometric
  → Intrinsic effects
- Ordered B field (SO) (Granot+03)
- Random B field (SR) (Sari99)
- Compton upscatter (CD) (Lazzati+04)





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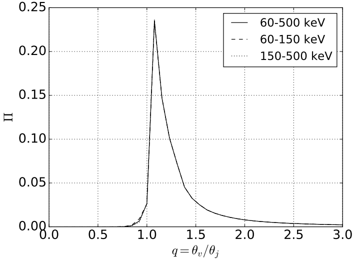

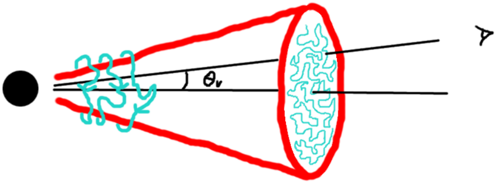

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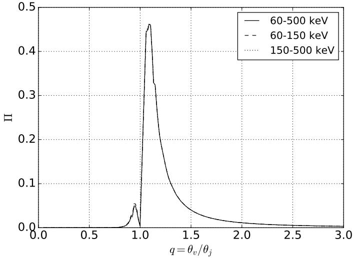
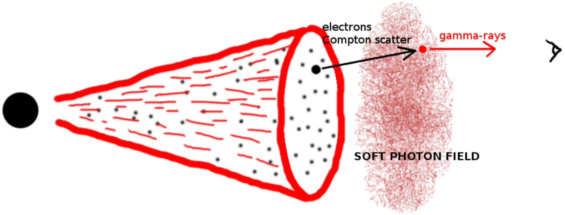
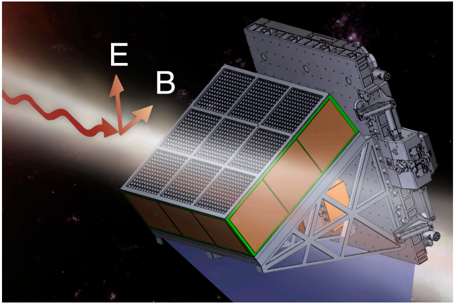




Future - LEAP

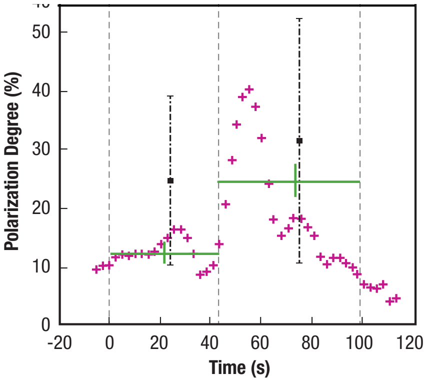
- LargE Area gamma-ray burst Polarimeter (**LEAP**)
- Proposed mission to ISS
- Polarimetry: 30-500 keV
- 30-40 GRB per year, MDP $\lesssim$ 30%



credit: LEAP team

LEAP capabilities

- Consider a bright GRB
- Time-resolved polarization (ICMART, Deng+16)
- Band → synchrotron origin
- Synchrotron or Synchrotron + blackbody
- LEAP - can distinguish between the two cases



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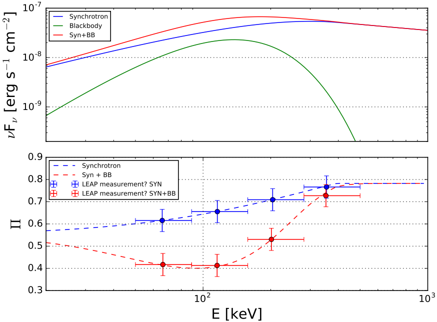
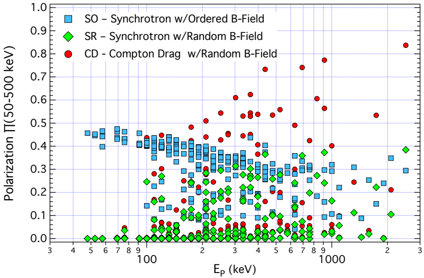


LEAP capabilities 2.

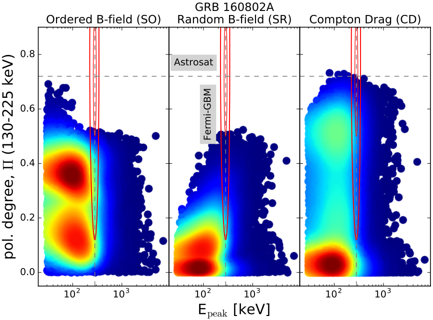
- Consider a set of GRBs with measured Π
- Measure peak energy
- Monte Carlo - so it matches observations (e.g. BATSE, HETE2, GBM fluence)
- LEAP - can distinguish between the three models



Toma+09, McConnell16

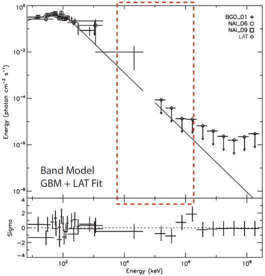
Find GRB model - probabilistic approach

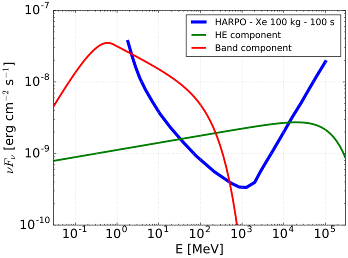
- Which model is best?
- Observe $\Pi \pm \Delta\Pi$, E_{peak}
- Astrosat GRB 160802A
  $\Pi = 0.72 \pm 0.22$ (Rao+17, prelim.)
  $E_{peak} = 282$ keV (GBM)
- Viewing angle, opening angle, Lorentz factor - unknown/uncertain
- Simulate distr. for 3 models
- Integrate over uncertainties (red ellipses)
- **SO : SR : CD = 0.31 : 0.14 : 0.55**



GRBs above 10 MeV - TPC -HARPO

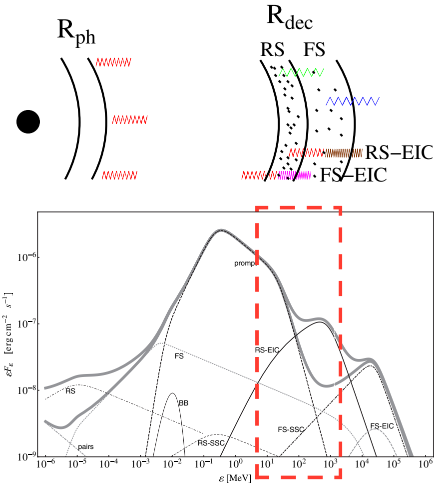
- Uncharted territory - emergence of the afterglow?
- Extension of Band PL - does not continue $\gtrsim$ GeV. Spectral cutoff:
  $\rightarrow$ Pair production
  $\rightarrow \Gamma m_e c^2/(1+z) \sim 100$ MeV
- TPC-HARPO is well suited to observe this spectral regime





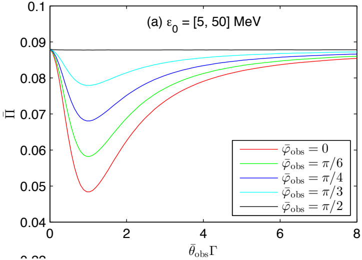
GRBs above 10 MeV - TPC -HARPO 2.

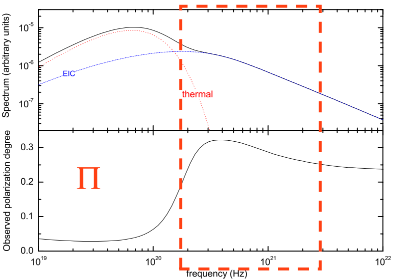
- Emerging new component
  $\rightarrow$ Synchrotron self-Compton (SSC)
  $\rightarrow$ External inverse Compton (EIC)
  $\rightarrow$ something else?
- Transition between Band or synchrotron and power law or Compton (Veres+12)



GRBs above 10 MeV - TPC -HARPO 3.

- Polarization signature
  $\rightarrow$ SSC - low Π - highly geometry dependent (Chang+14)
  $\rightarrow$ EIC - moderate Π (Fan09)
- More detailed modeling needed
  $\rightarrow$ but see talk by Böttcher for blazars
- TPC - HARPO will be able to constrain pol. for bright GRBs





Wrap up

- Interesting times for GRB polarization
- Upcoming MeV-GeV range prompt data exciting
- MeV-GeV polarimetry even more exciting

Thank you!