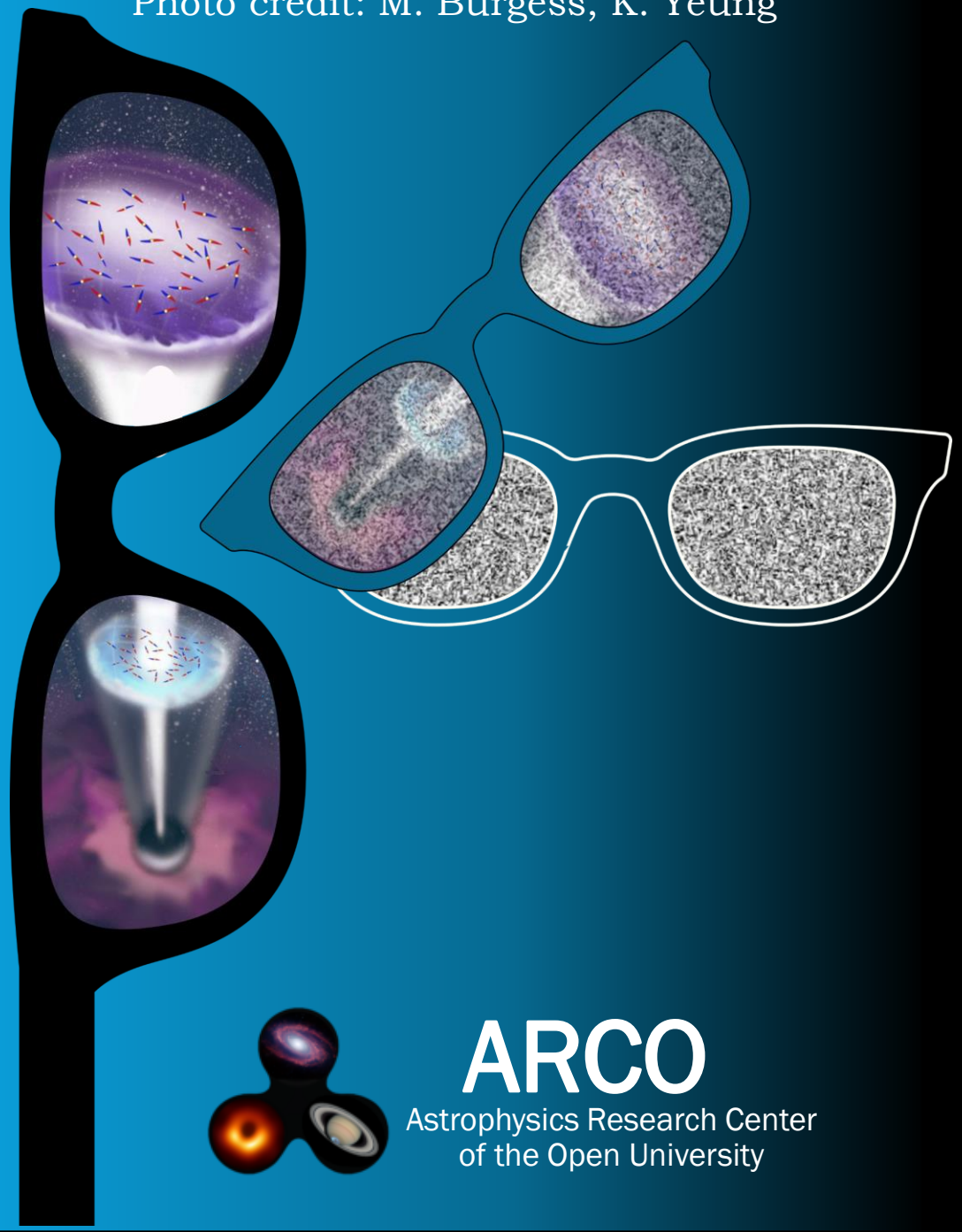


Photo credit: M. Burgess, K. Yeung

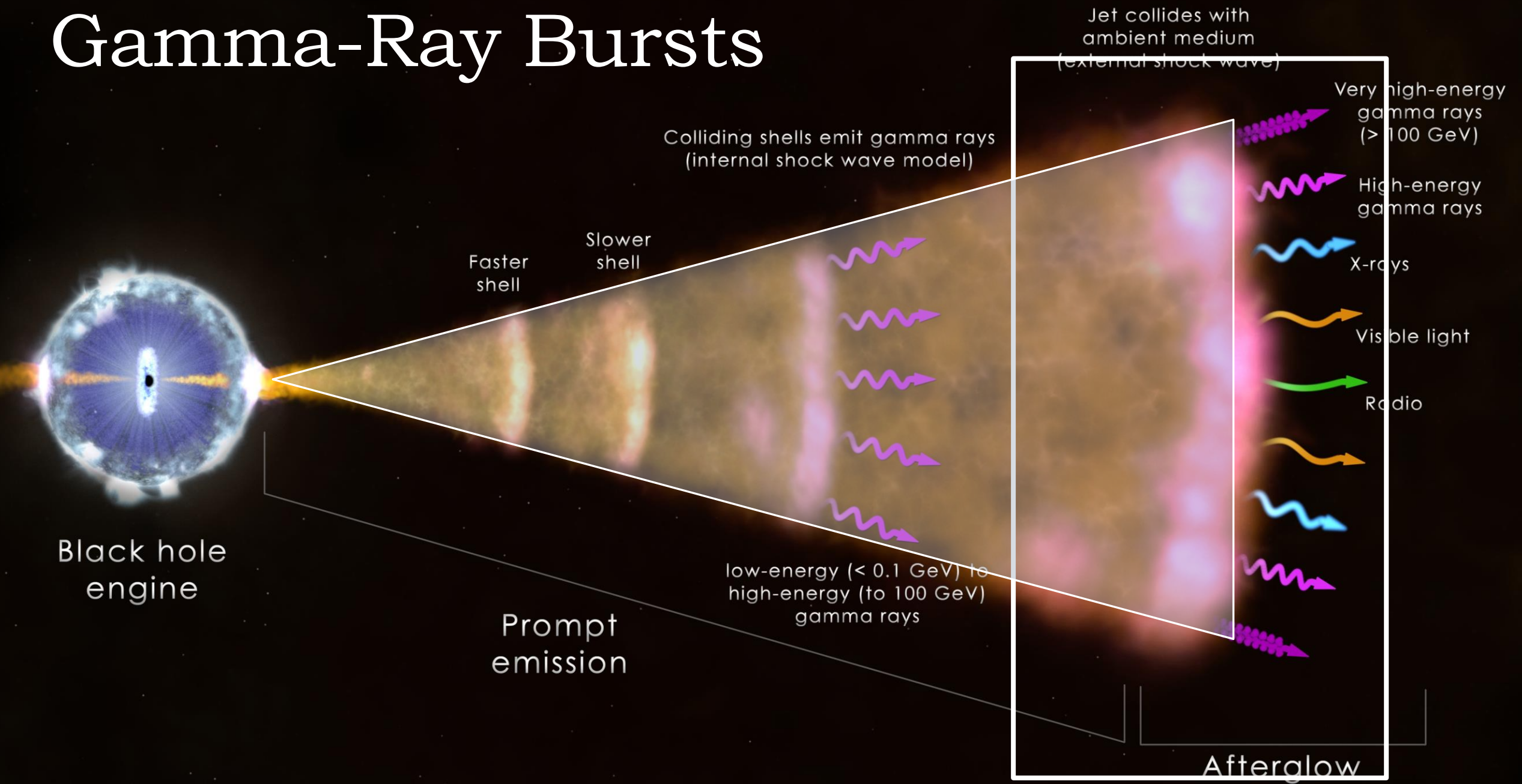
Afterglow Linear Polarization Signatures from Shallow GRB Jets: Implications for GRB 221009A

GAL BIRENBAUM

+ RAMANDEEP GILL, OMER BROMBERG, PAZ BENIAMINI AND JONATHAN GRANOT

ARCO
Astrophysics Research Center of the Open University

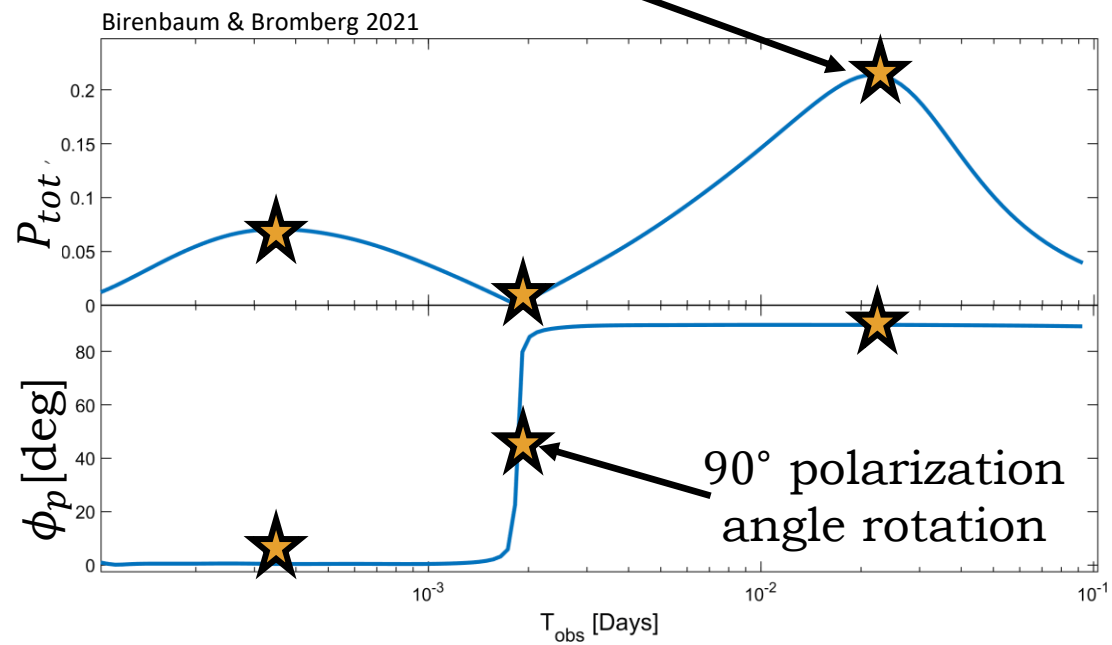
Gamma-Ray Bursts

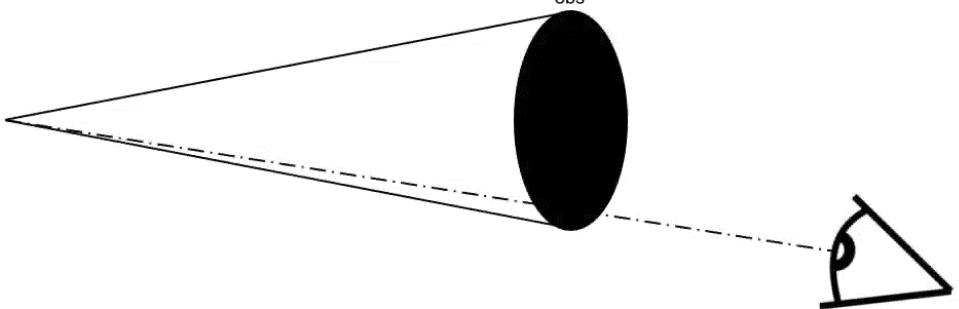


Top Hat Jet - Theory vs. Observations

Polarization signatures

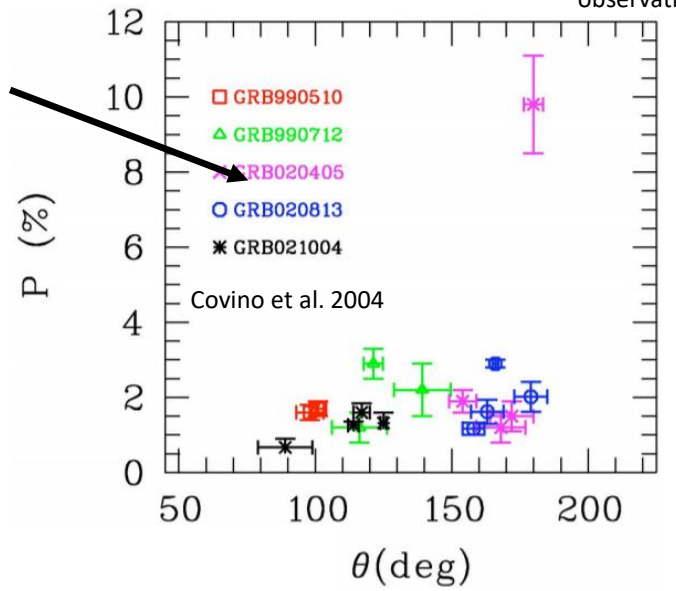
Over 20% during polarization peak



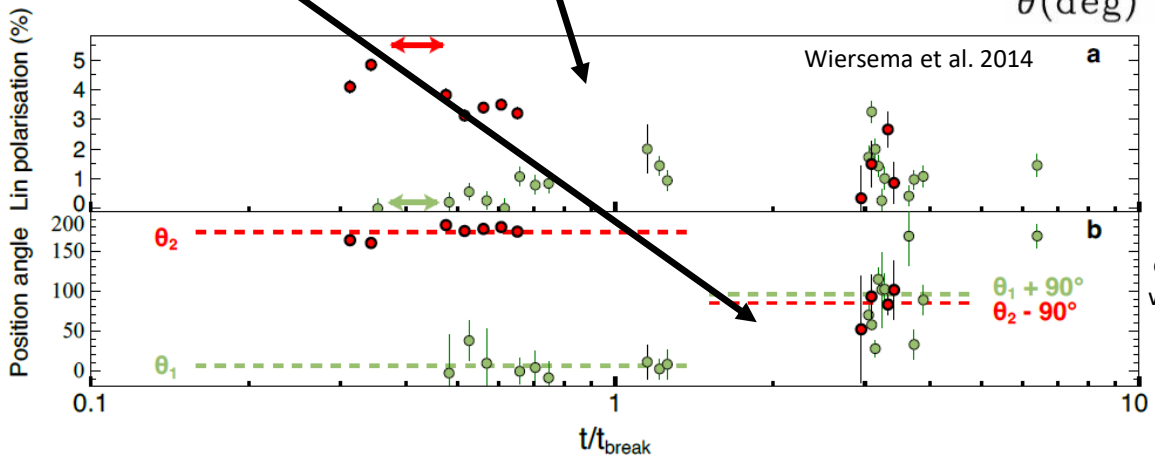


In most GRB AGs: Optical polarization degree is 10% or less

Optical & near infra-red afterglow observations

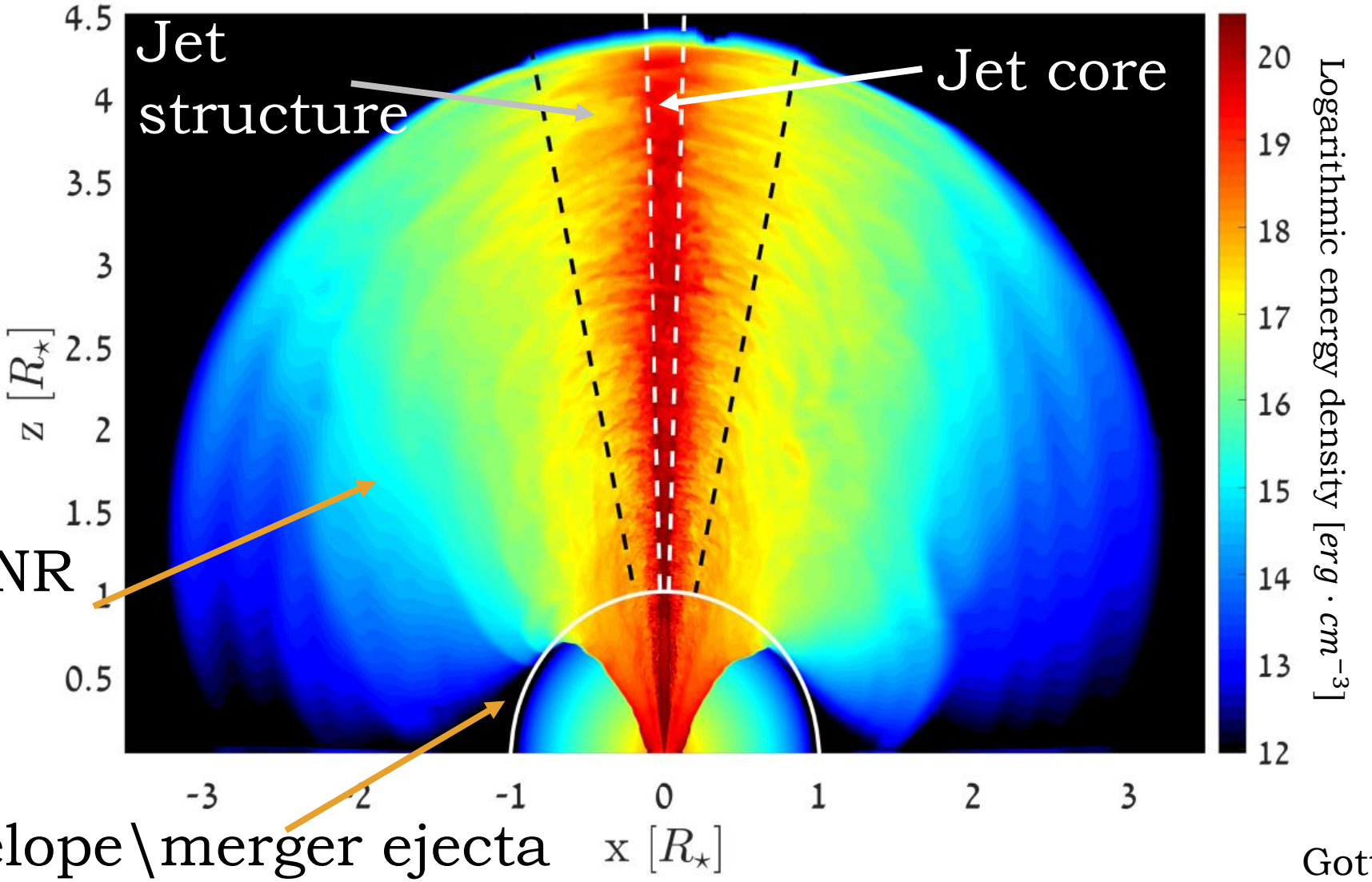


In a few GRB AGs: Polarization angle rotates by 90°



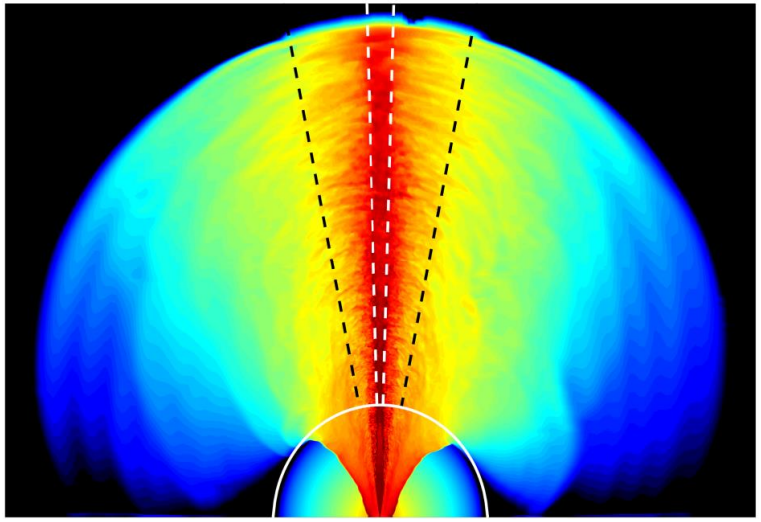
Optical polarimetry observations obtained with the FOcal Reducer and low dispersion Spectrograph (FORS2) on the Very Large Telescope (VLT)

Formation of Structured Jets

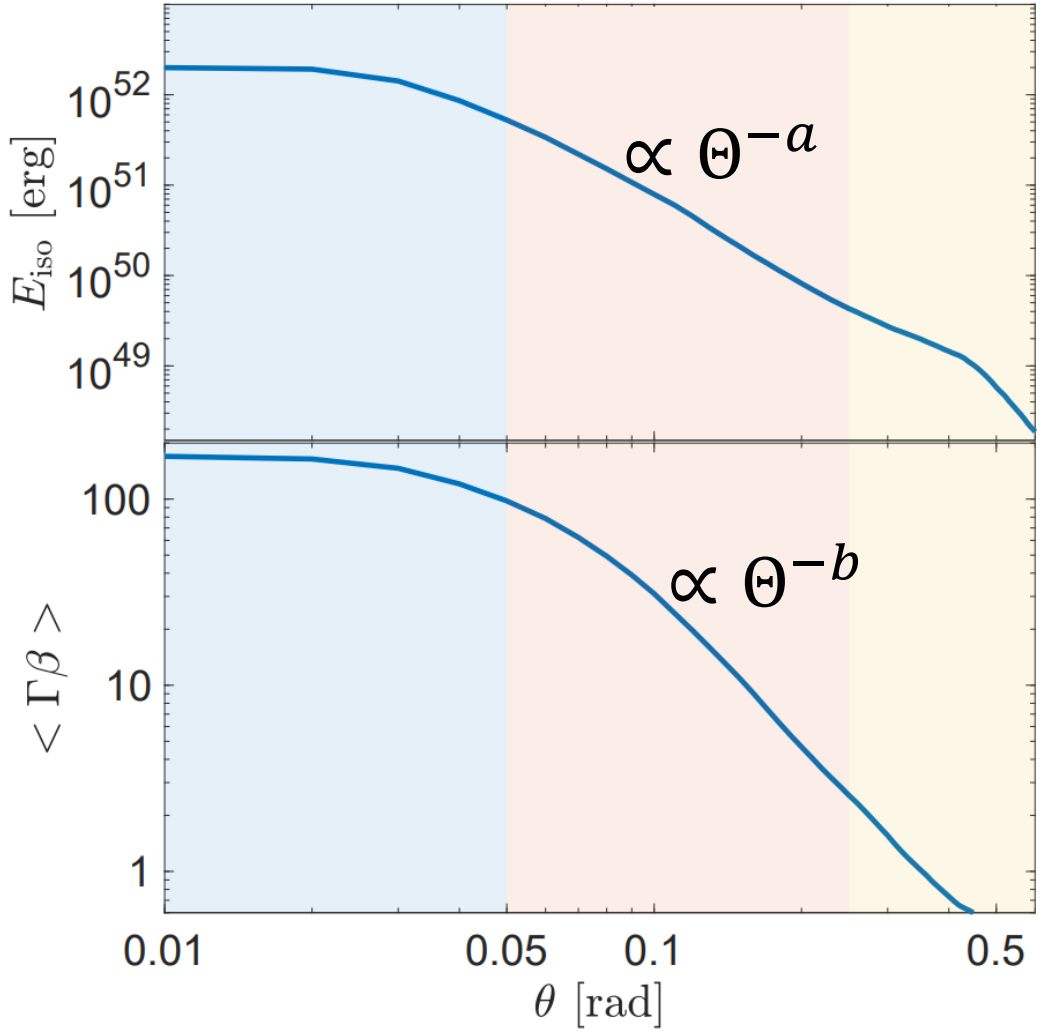


Gottlieb et al. 2021

Power-law Jets



Gottlieb et al. 2021



Nakar (2020)
Gottlieb et al. 2021
Beniamini et al. 2022

GRB 221009A - Observations

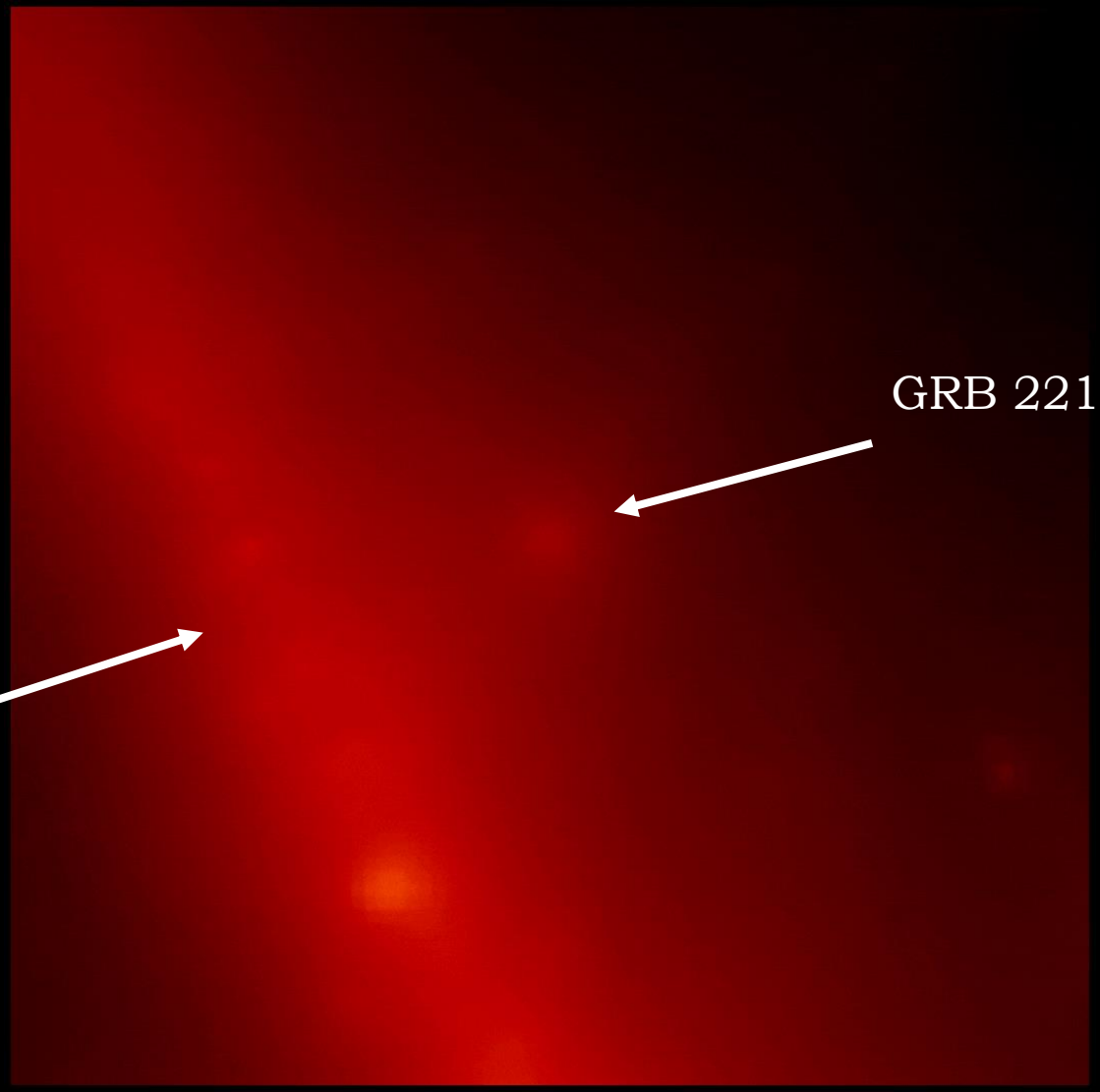
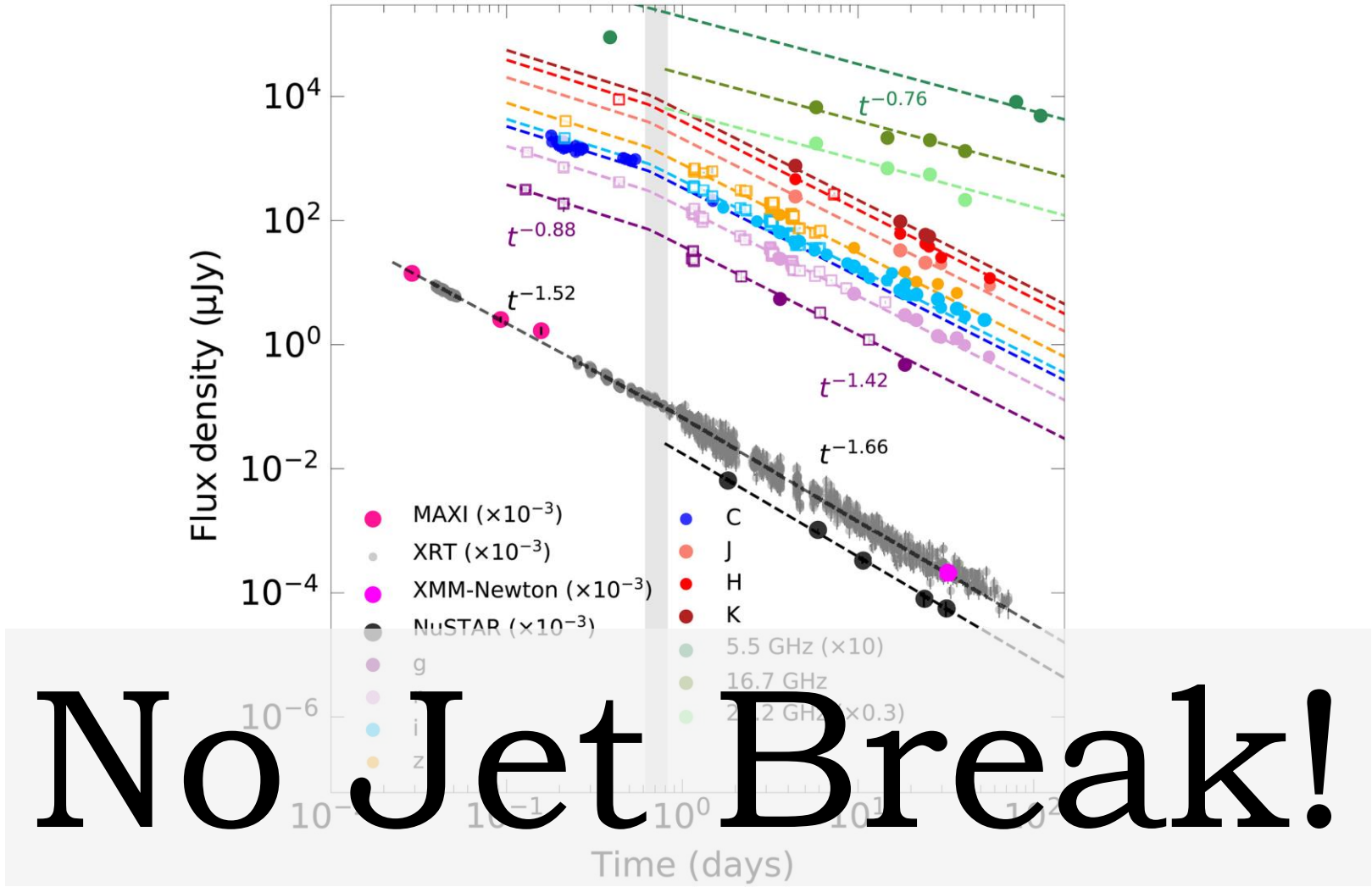


Image Credit:
NASA, DOE,
Fermi LAT Collaboration

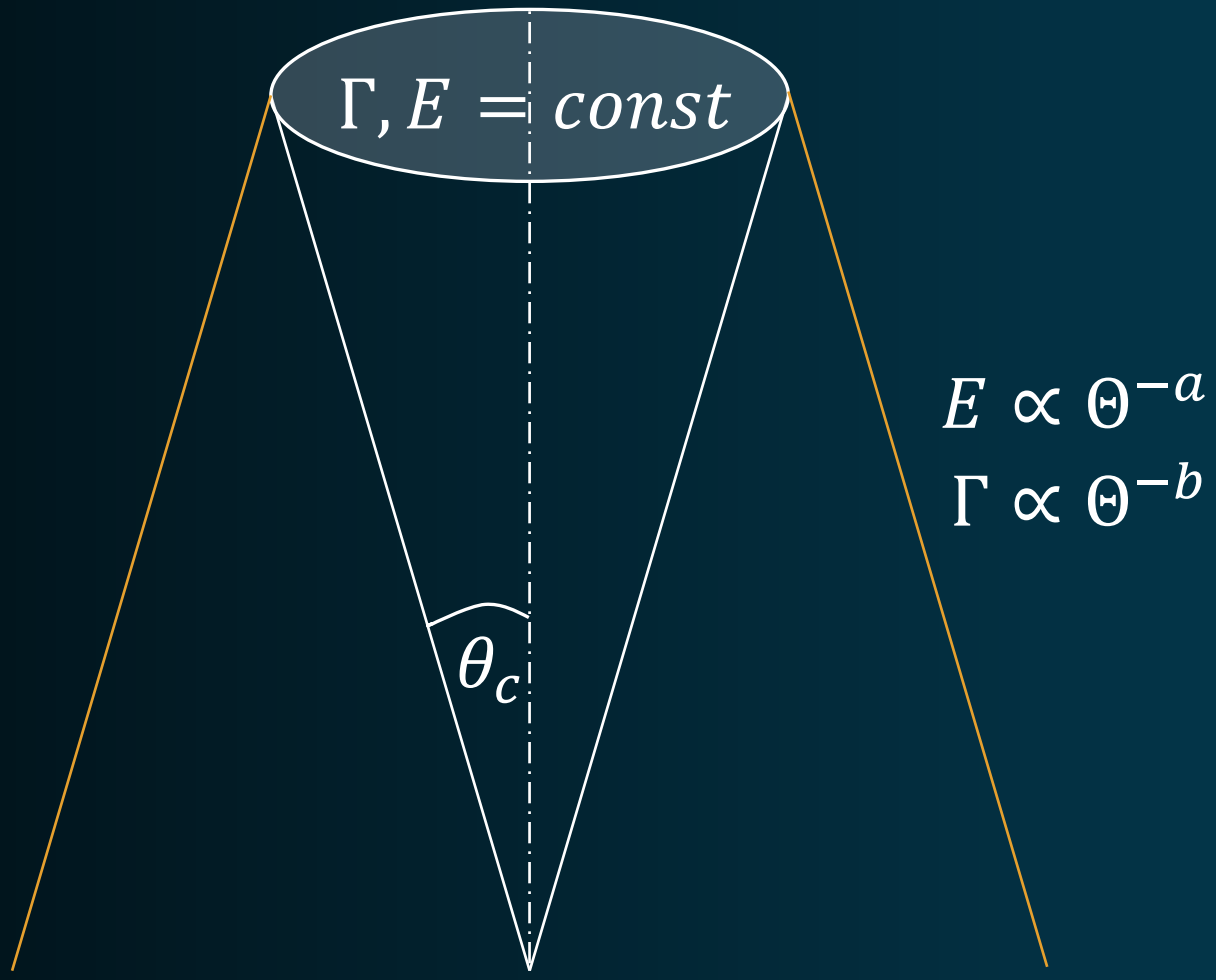
GRB 221009A - Observations



No Jet Break!

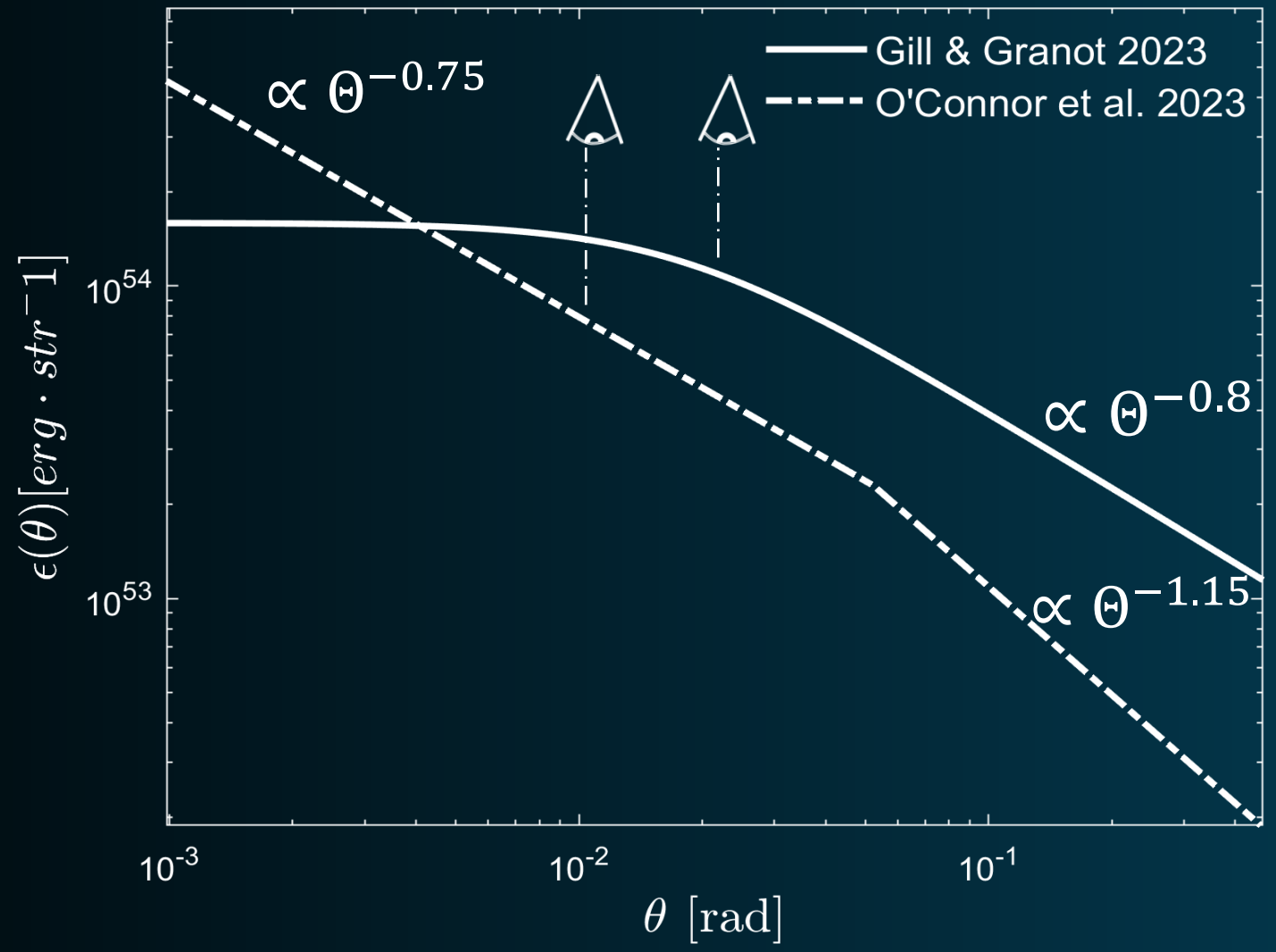
O'Connor et al. 2023

Shallow Jets



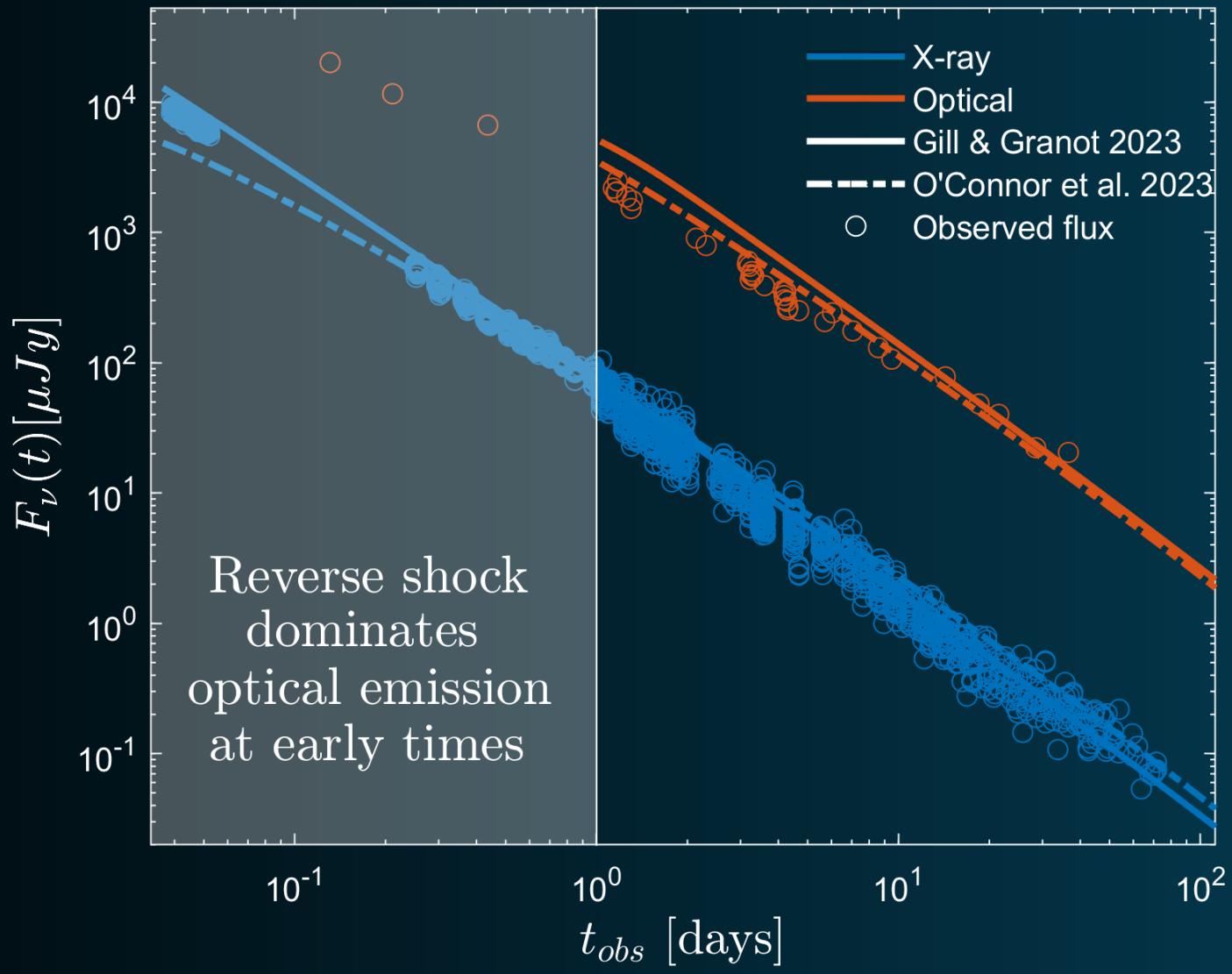
$$E \propto \Theta^{-a}$$
$$\Gamma \propto \Theta^{-b}$$

GRB 221009A


Gill & Granot 2023
O'Connor et al. 2023
$\propto \Theta^{-0.75}$
$\propto \Theta^{-0.8}$
$\propto \Theta^{-1.15}$
$\epsilon(\theta)[erg \cdot str^{-1}]$
10^{54}
10^{53}
10^{-3}
10^{-2}
10^{-1}
θ [rad]

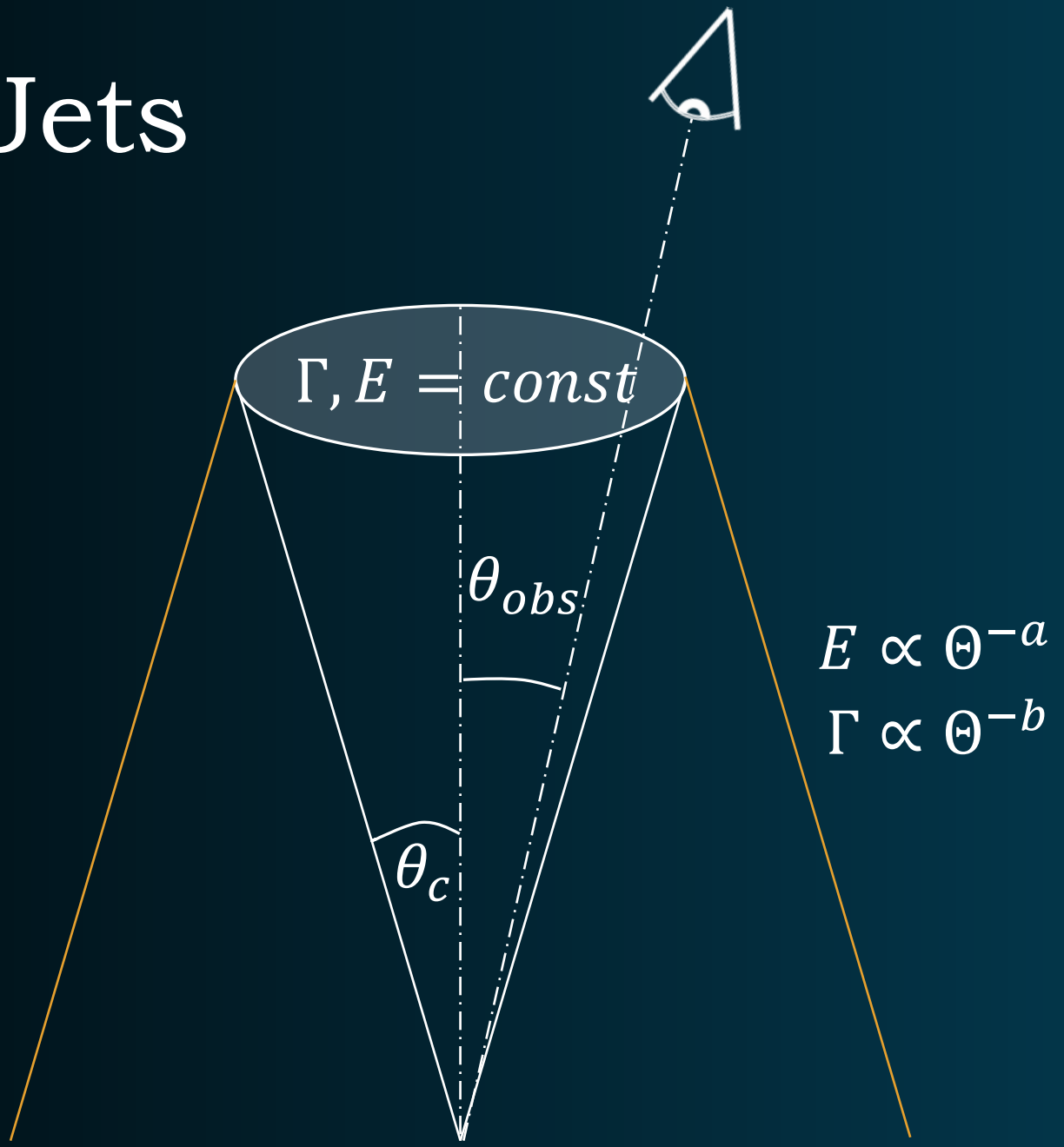
Different Structures Fit the Light Curve!

GRB 221009A


X-ray
Optical
Gill & Granot 2023
O'Connor et al. 2023
Observed flux
Reverse shock dominates optical emission at early times
$F_\nu(t)[\mu Jy]$
t_{obs} [days]
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}

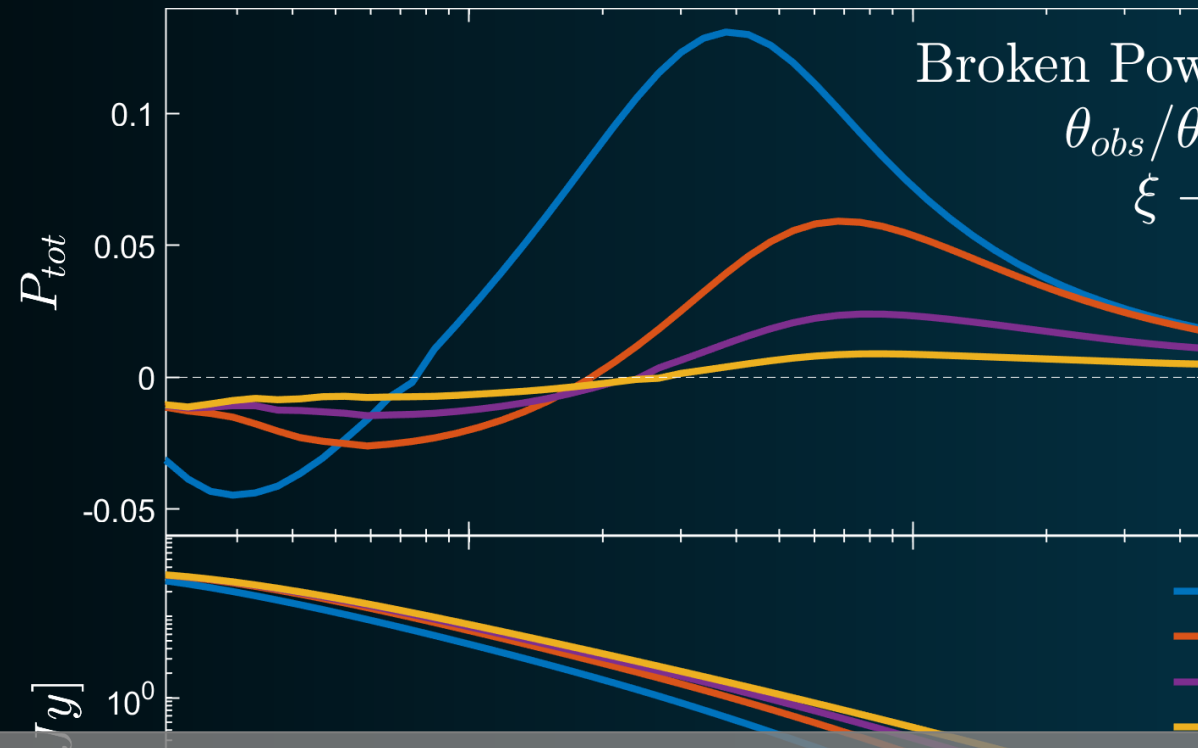
Linear Polarization Can Differentiate Between Structures!

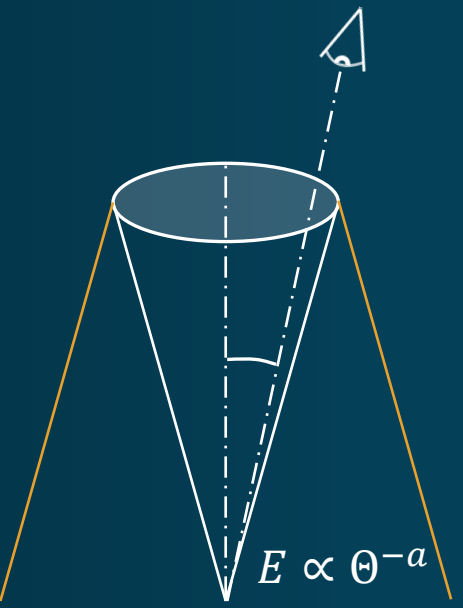
On-axis Jets



$$E \propto \Theta^{-a}$$
$$\Gamma \propto \Theta^{-b}$$

On-axis Jets

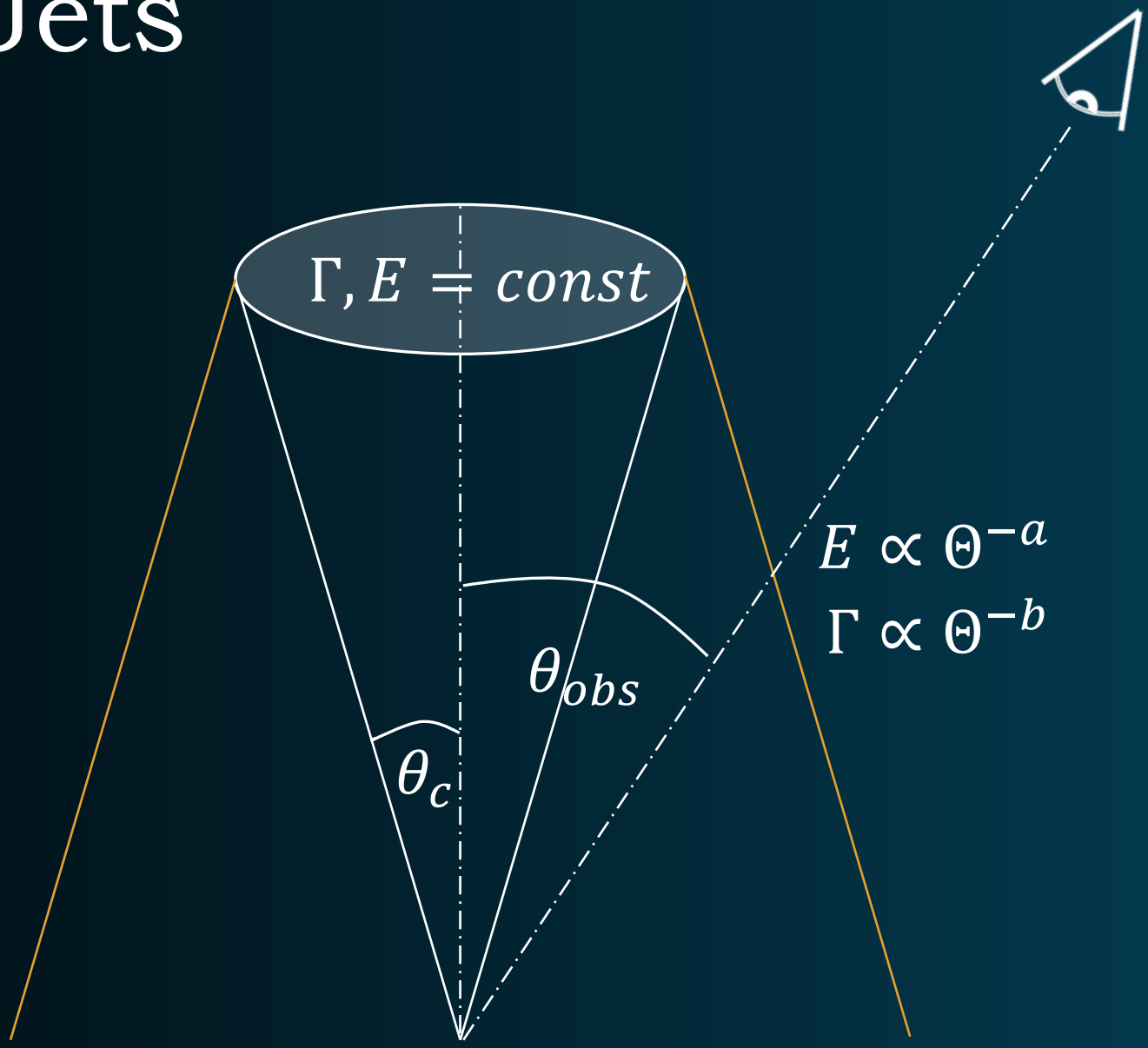




Polarization is lower in shallow jets

Birenbaum et al. 2024

Off-axis Jets



Magnetic Field Structure

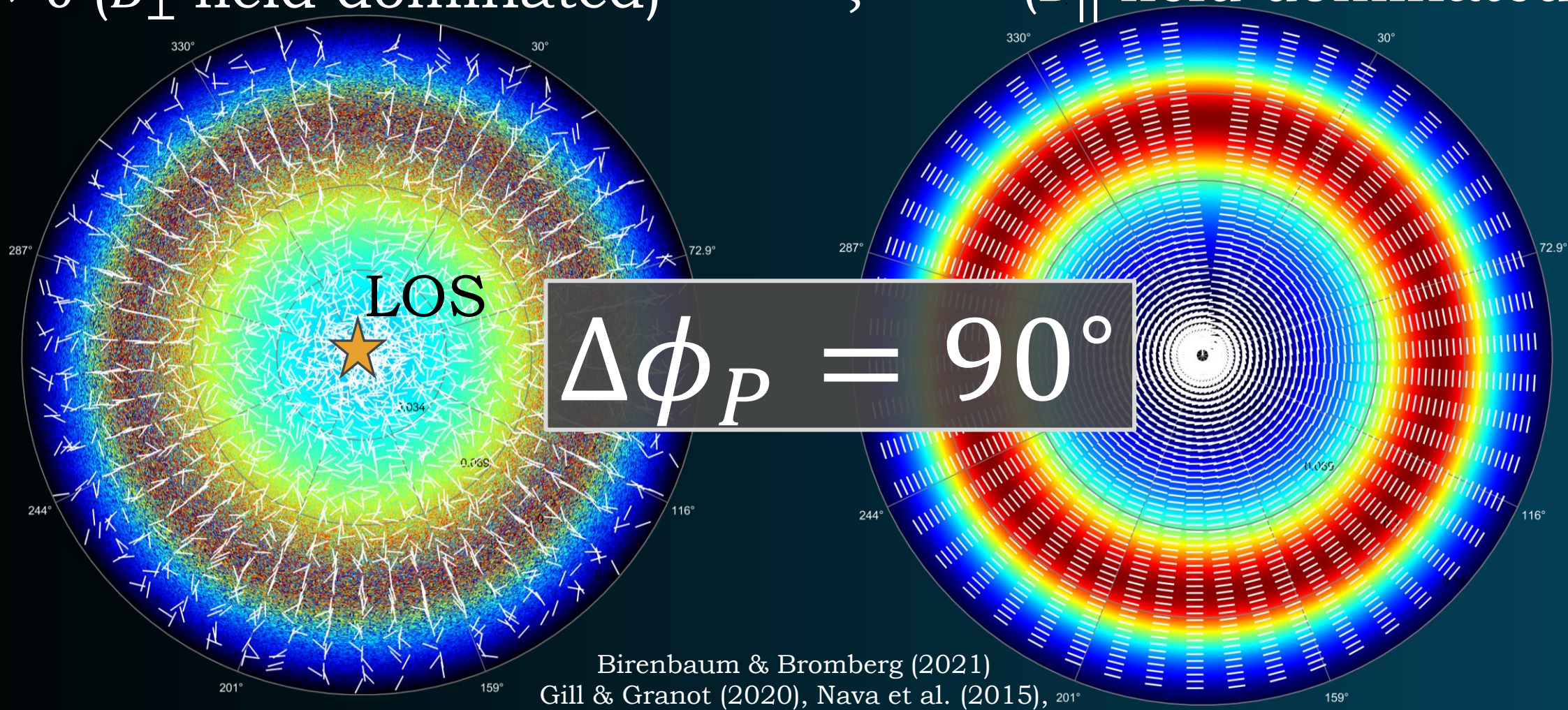
1. Magnetic field structure?
2. Same for all GRBs?

Can be probed using polarization

Polarization Signature

$\xi \to 0$ ($B_\perp$ field dominated)

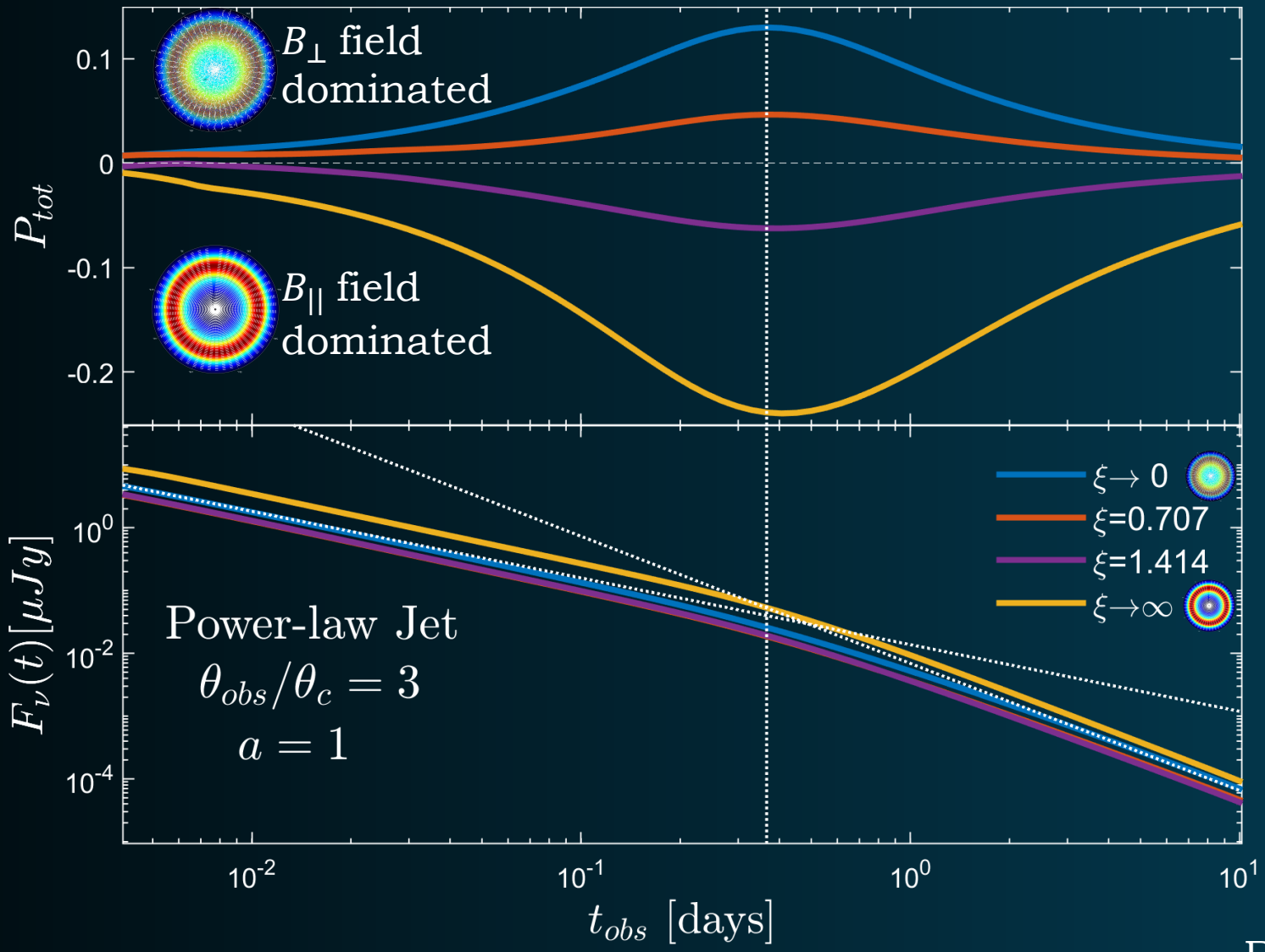
$\xi \to \infty$ ($B_{||}$ field dominated)

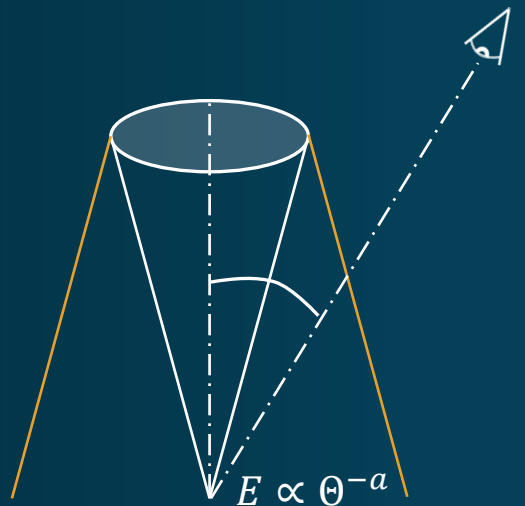


$$\Delta\phi_P = 90°$$

Birenbaum & Bromberg (2021)
Gill & Granot (2020), Nava et al. (2015),
Granot & Konigl (2003), Sari (1999)

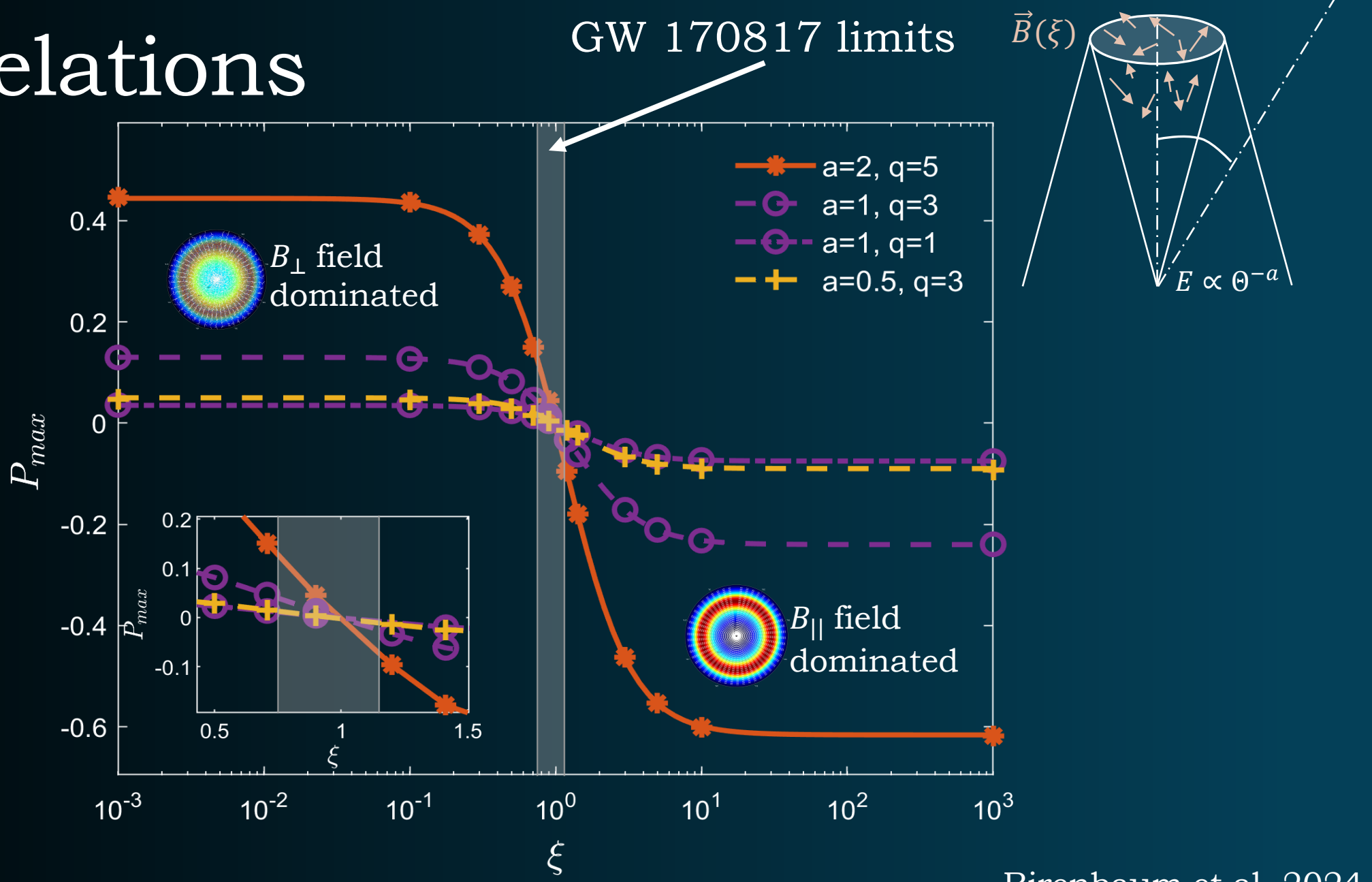
Off-axis Jets





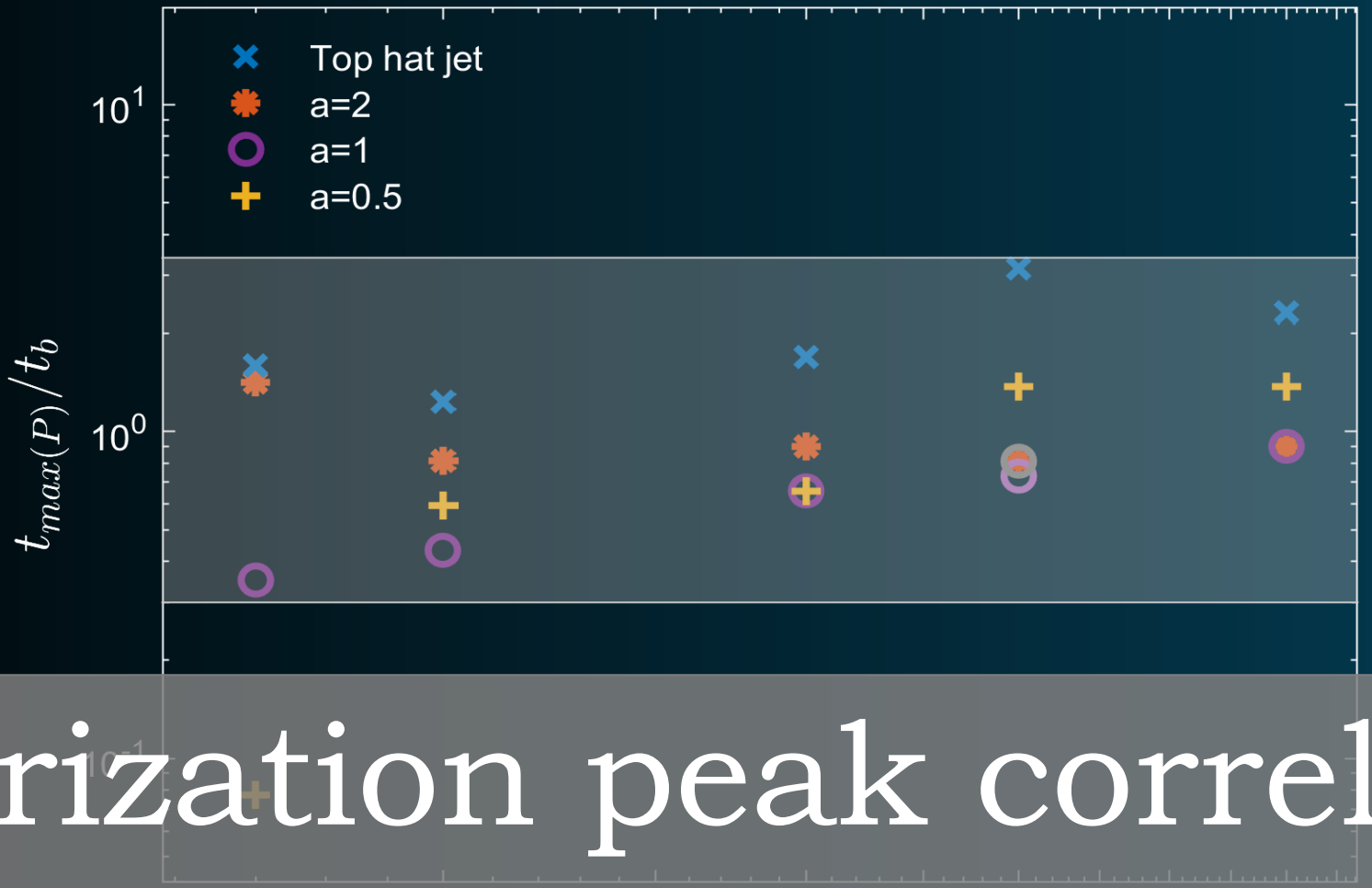
Birenbaum et al. 2024

Correlations



Birenbaum et al. 2024

Correlations



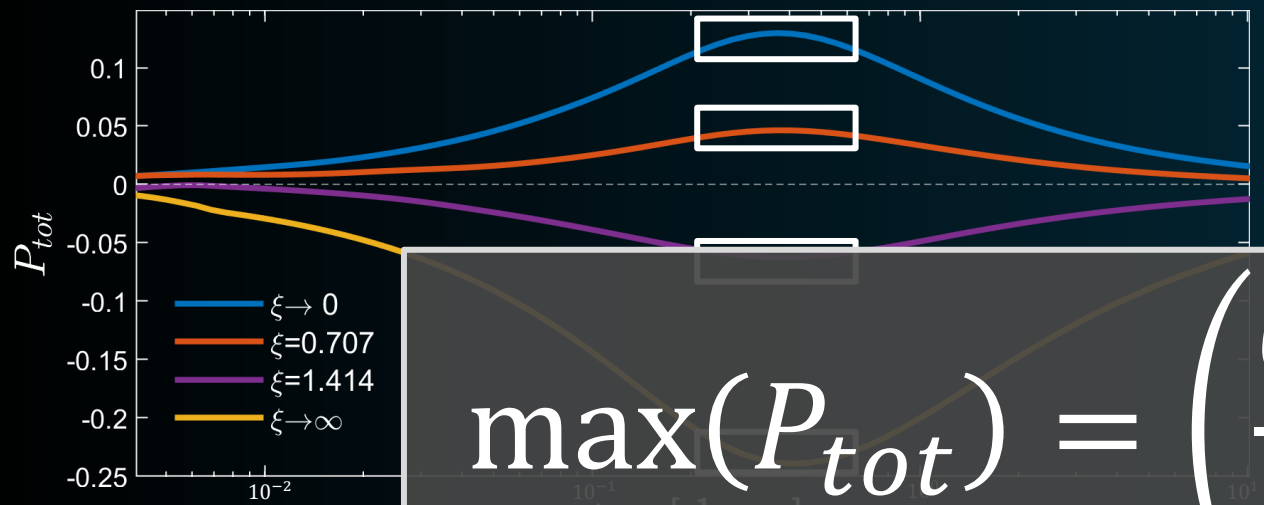
Polarization peak correlates with light curve break!

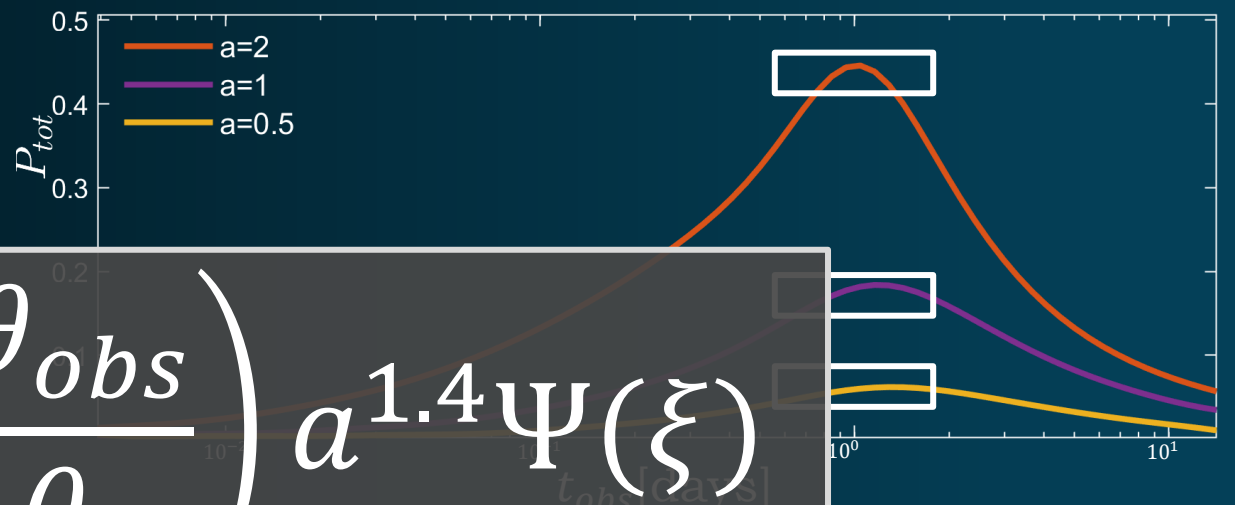
Birenbaum et al. 2024

Birenbaum et al. 2024

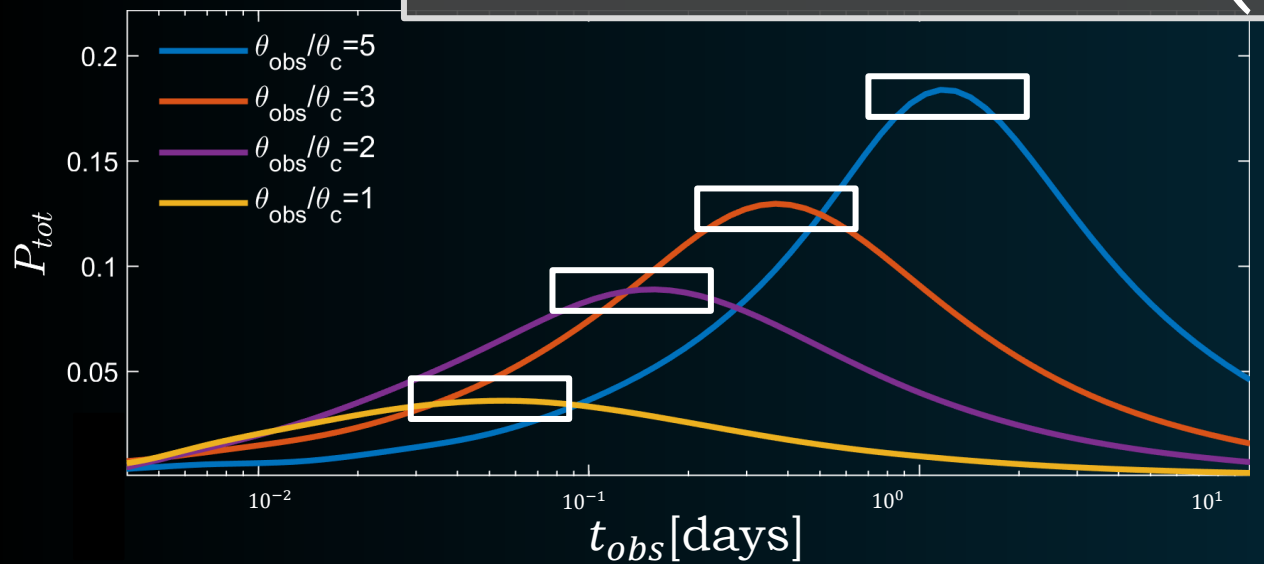
$$\Psi(\xi) = [0.055 \tanh(-2.3 \log_{10} \xi + 0.34) - 0.02]$$

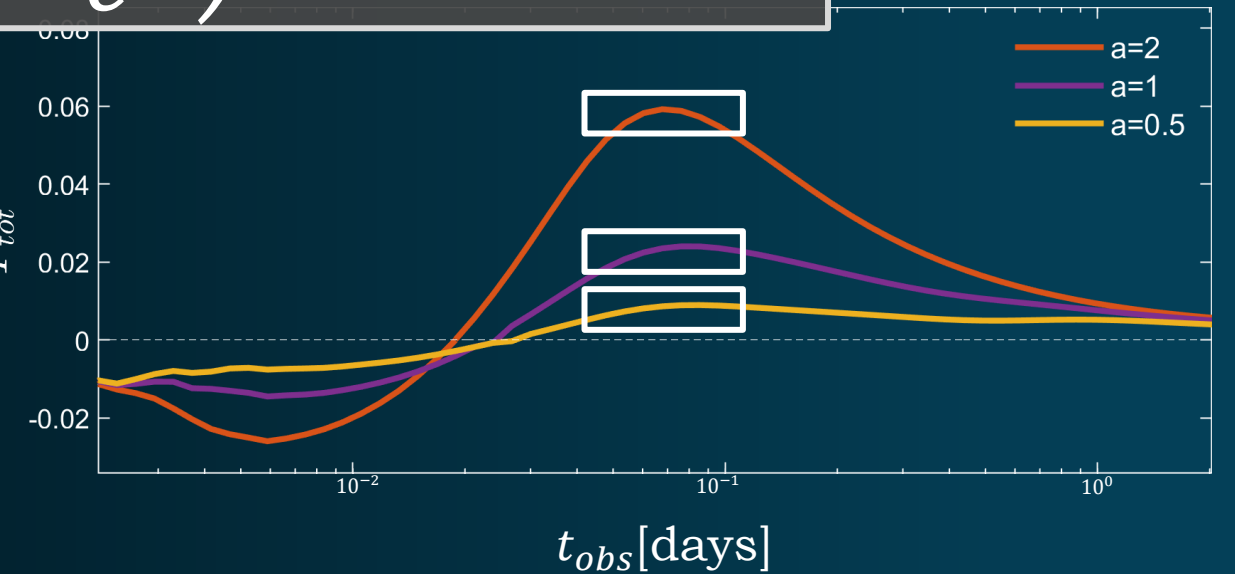
Correlations





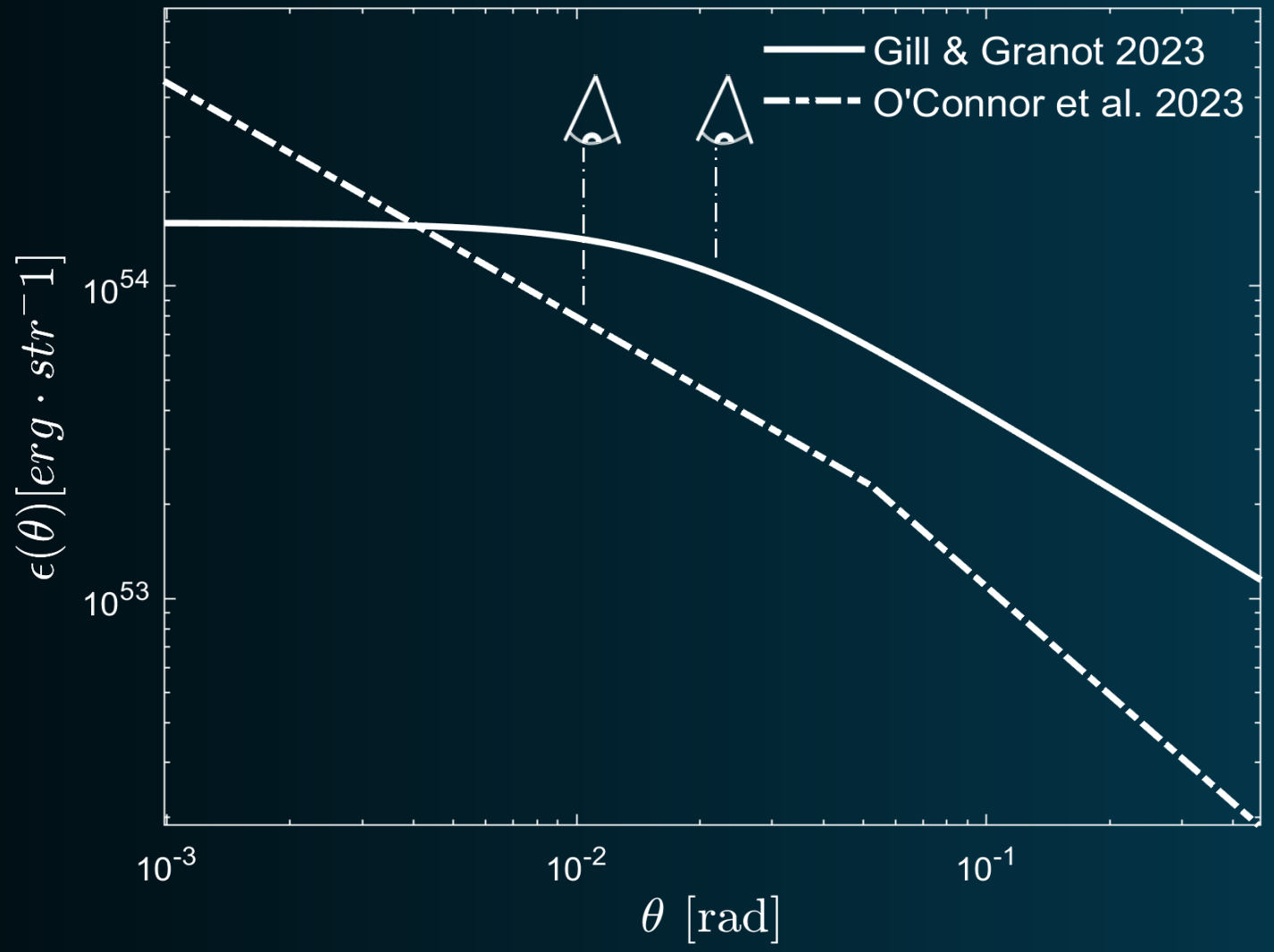
$$\max(P_{tot}) = \left(\frac{\theta_{obs}}{\theta_c}\right) a^{1.4} \Psi(\xi)$$





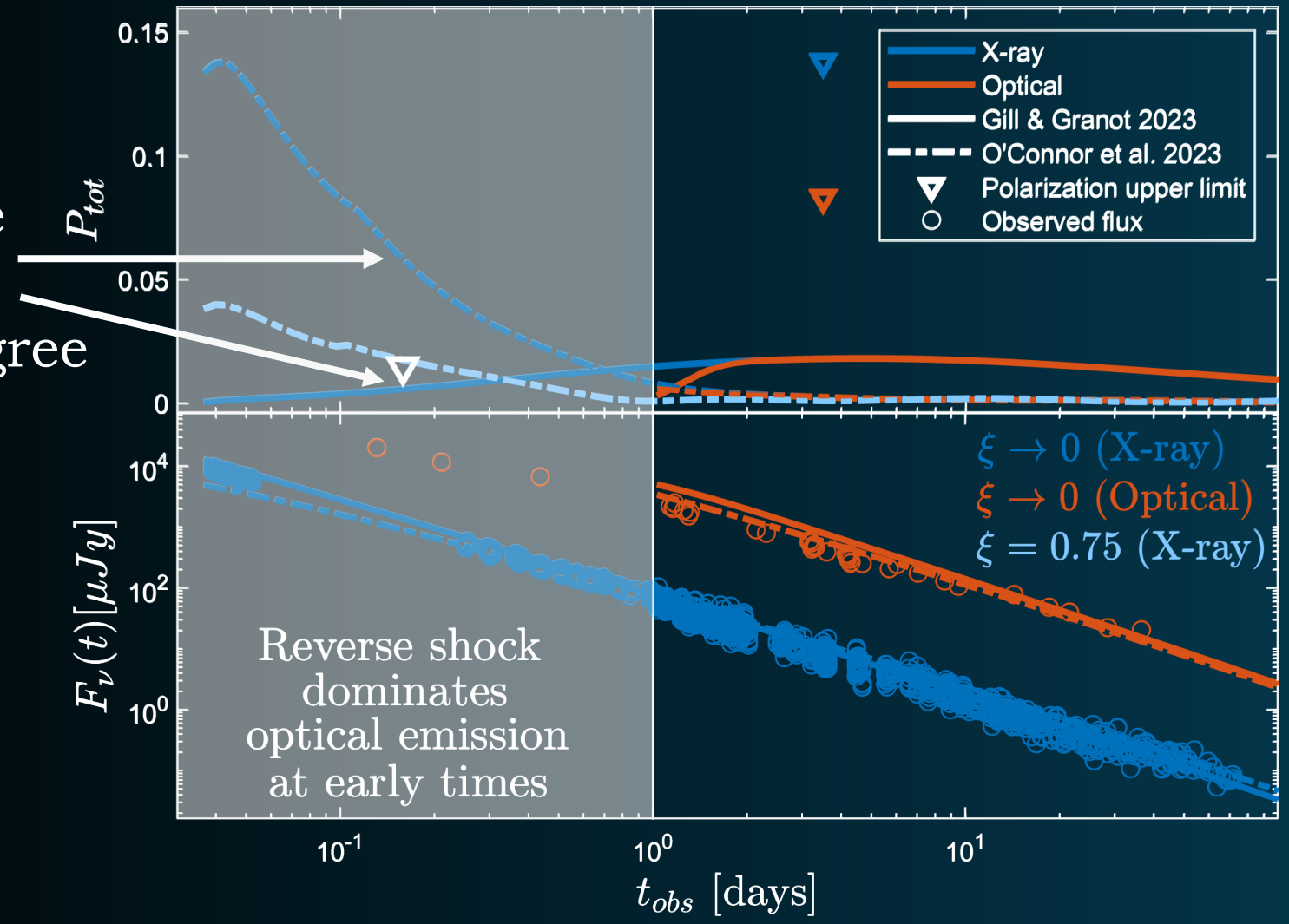
Let’s Go Back To GRB 221009A

GRB 221009A


Gill & Granot 2023
O'Connor et al. 2023
$\epsilon(\theta)[erg \cdot str^{-1}]$
10^{54}
10^{53}
10^{-3}
10^{-2}
10^{-1}
θ [rad]

GRB 221009A

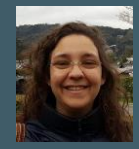
5% difference in polarization degree



Birenbaum et al. 2024

Takeaway Points

On the job market next year!!



birenbaumgal@gmail.com

- The structure of the jet encodes what processes it underwent before breaking out.
- Linear polarization can help breaking the degeneracy in jet structures for varying afterglow models.
- A shallow jet structure decreases polarization which may explain observations better.
- The polarization maximum is associated with a light curve break in both on-axis and off-axis jets and a simple analytical formula relates it to the system parameters.
- Early time observations of GRB 221009A would have allowed to constrain the jet structure and the magnetic field structure behind it.