What is the role of the magnetic fields in Gamma-ray bursts (GRBs) outflows?

The case of GRB 190114C

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What are GRBs?

They are the brightest flashes of gamma-rays in the Universe.

When a massive star collapses into a black hole in a distant galaxy, the material is accelerated to ultra-high speeds along the narrow beam of a jet.

The emission we detect is from:

- The gamma-ray prompt (internal/magnetic dissipation mechanisms).
- The afterglow: reverse and forward shock (deceleration of the material by the ambient medium).

Theoretically challenging

They are a test of physics in extreme environments: strong gravity/magnetic fields with material ejected at velocities close to the speed of light.

We use early-time polarization observations of GRBs to determine the structure of the magnetic field (the degree of order) and distinguish between jet models: **magnetized vs baryonic**.

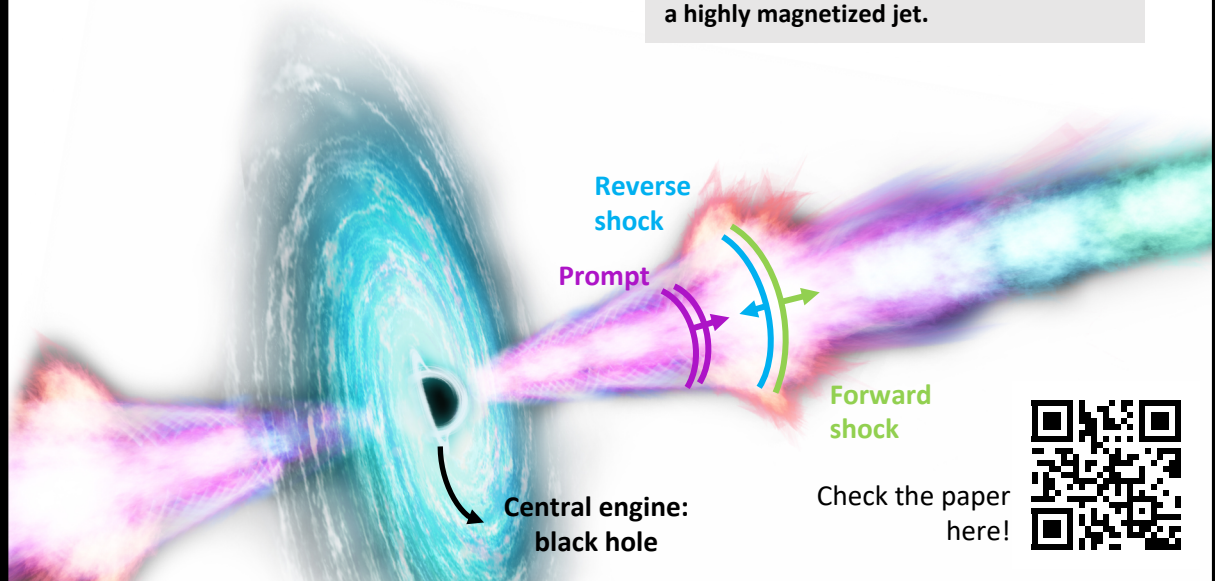
GRBs are highly polarized at early times (for prompt/reverse shock emission), which supports a **mildly magnetized jet model** with large-scale magnetic fields advected from the black hole.

Key-findings

GRB 190114C is the most energetic GRB ever detected (in the TeV domain).

The polarization was surprisingly low seconds after the burst for reverse shock emission.

We need a mechanism for the distortion of the magnetic field during the gamma-ray prompt: magnetic dissipation. **Evidence of a highly magnetized jet.**



Check the paper here!

How are they detected?

If the jet of the GRB points towards the Earth, we can detect them by their characteristic gamma-ray flash.

We are detecting about 200 GRBs per year with spaceborne gamma-ray telescopes, which trigger real-time alerts to ground-based telescopes.

Observationally challenging

The emission fades quickly: we need a rapid response from telescopes.

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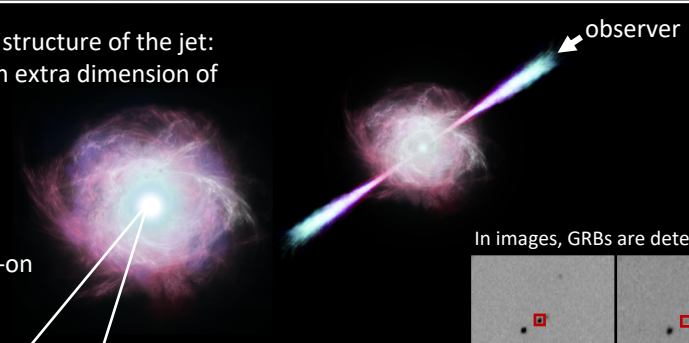
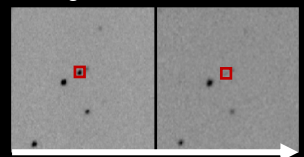
Early-time GRB polarization studies

A direct probe of the structure of magnetic fields within the emission region

We cannot resolve the structure of the jet: polarization (P) gives an extra dimension of information.



In images, GRBs are detected like:



The magnetic field configuration:

P=70% → **P=0%**

Large-scale ordered

Distorted or overlapping emission components

Tangled

The combination of different emission components can reduce the overall polarization.

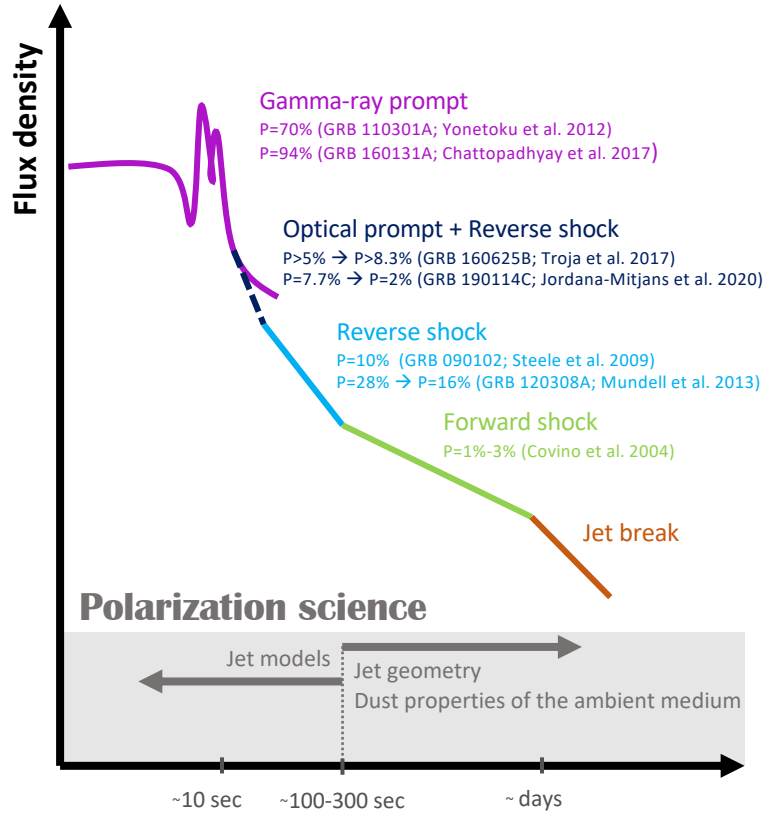
Polarization measurements from prompt and reverse shock emission can discriminate among competing **jet models**:

Baryonic jet: Tangled magnetic fields are locally produced in shocks. **Unpolarized** emission.

Magnetized jet: Large-scale ordered magnetic fields are advected from the central engine. **Highly polarized** emission.

How the jet is launched?	Baryonic	Mildly magnetized	Highly magnetized
Prompt emission dissipation mechanism	Internal	Internal	Magnetic (distortion of the magnetic fields)
Polarized prompt?	x	yes	yes
Polarized reverse shock?	x	yes	x
Polarized forward shock?	x	x	x
Examples		GRB 090102 GRB 120308A	GRB 190114C

The GRB emission



Small/intermediate robotic telescopes

No human intervention (e.g., MASTER global robotic net, Liverpool Telescope)

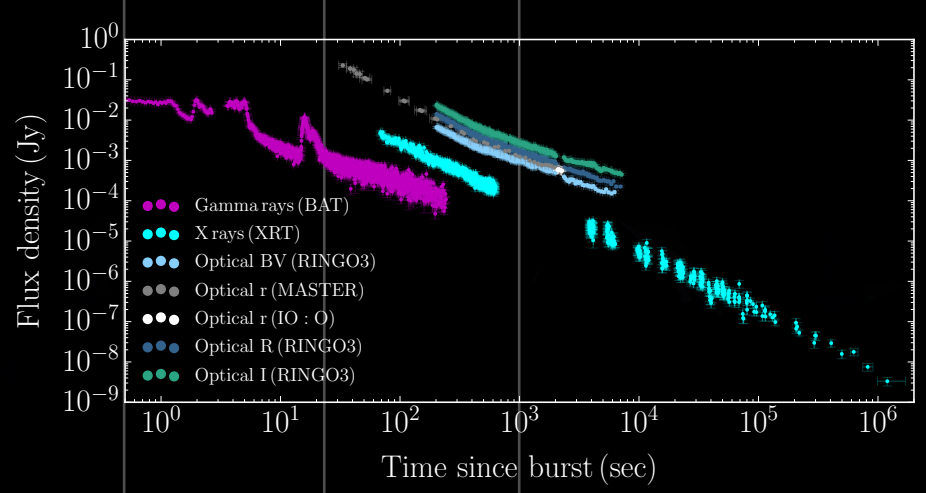
Large telescopes

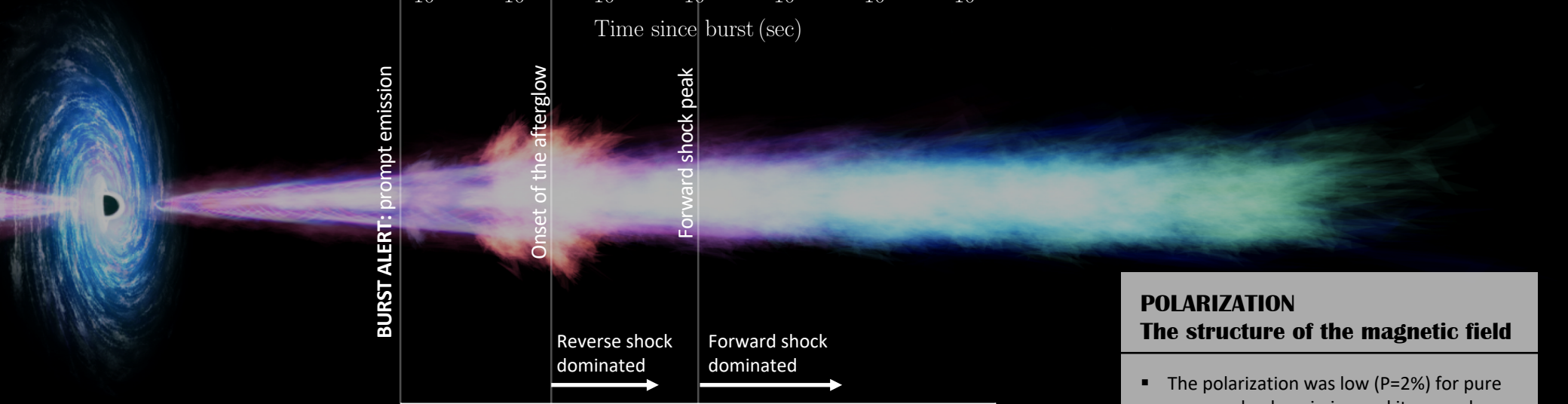
Manual trigger of observations

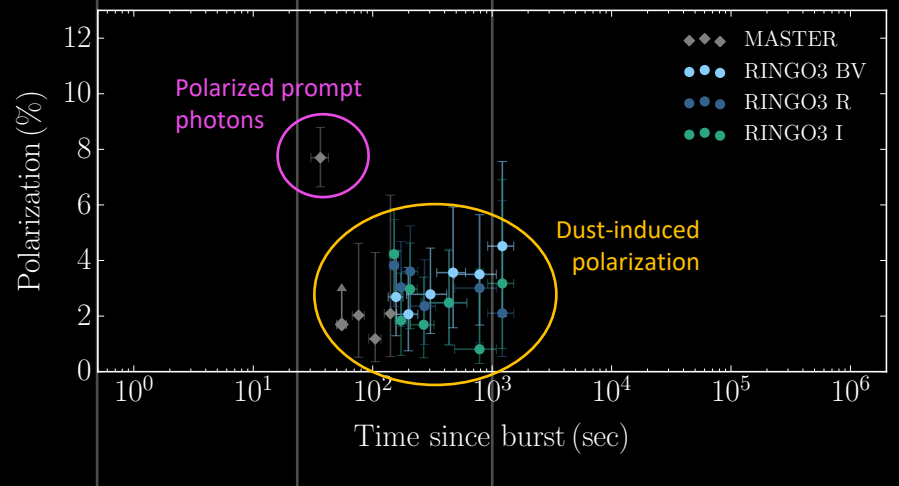
GRB 190114C

A highly magnetized jet

Using observations from:
- Swift BAT / XRT
- MASTER global robotic net
- Liverpool Telescope RINGO3 / IO:O







MODELLING THE EMISSION
The strength of the magnetic field

- The reverse shock was 70 times more magnetized than the forward shock. It hints the existence of primordial magnetic fields advected from the central engine (black hole).

POLARIZATION
The structure of the magnetic field

- The polarization was low (P=2%) for pure reverse shock emission and it was only significantly higher (P=7.7%) at prompt emission timescales: **evidence of a large-scale ordered magnetic field.**
- The constant polarization P=2% for reverse and forward shock emission is dust-induced by the GRB ambient medium.
- The large-scale magnetic field was distorted by the prompt emission; it supports magnetic dissipation mechanisms for prompt emission (e.g., reconnection). **The jet was launched highly magnetized.**