What Turns off Gamma-Ray Bursts ?

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Gamma-ray bursts (GRBs)

Come in 2 flavors:

Short, $\lesssim 2$ s

↓

Coalescence of a compact object binary

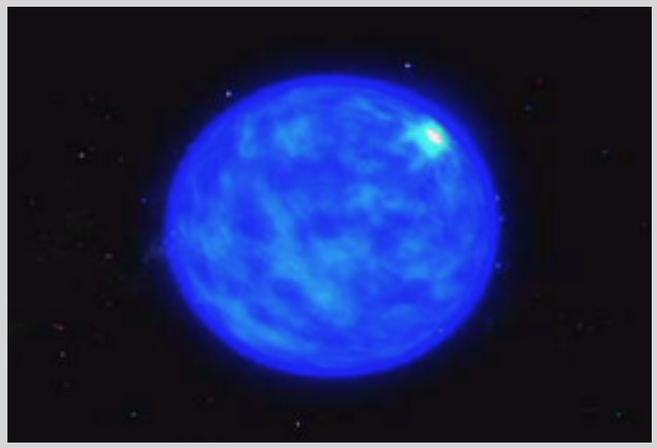
(Lattimer & Schramm 1976; Paczynski 1986, Eichler et al. 1989; Narayan et al. 1999)

Long, $\gtrsim 2$ s

↓

Death of a massive star by core collapse

(Duncan & Thompson 1992, Woosley 1993, MacFadyen & Woosley 1999)



(Credit: NASA / SkyWorks Digital)

Puzzling GRB Lightcurves

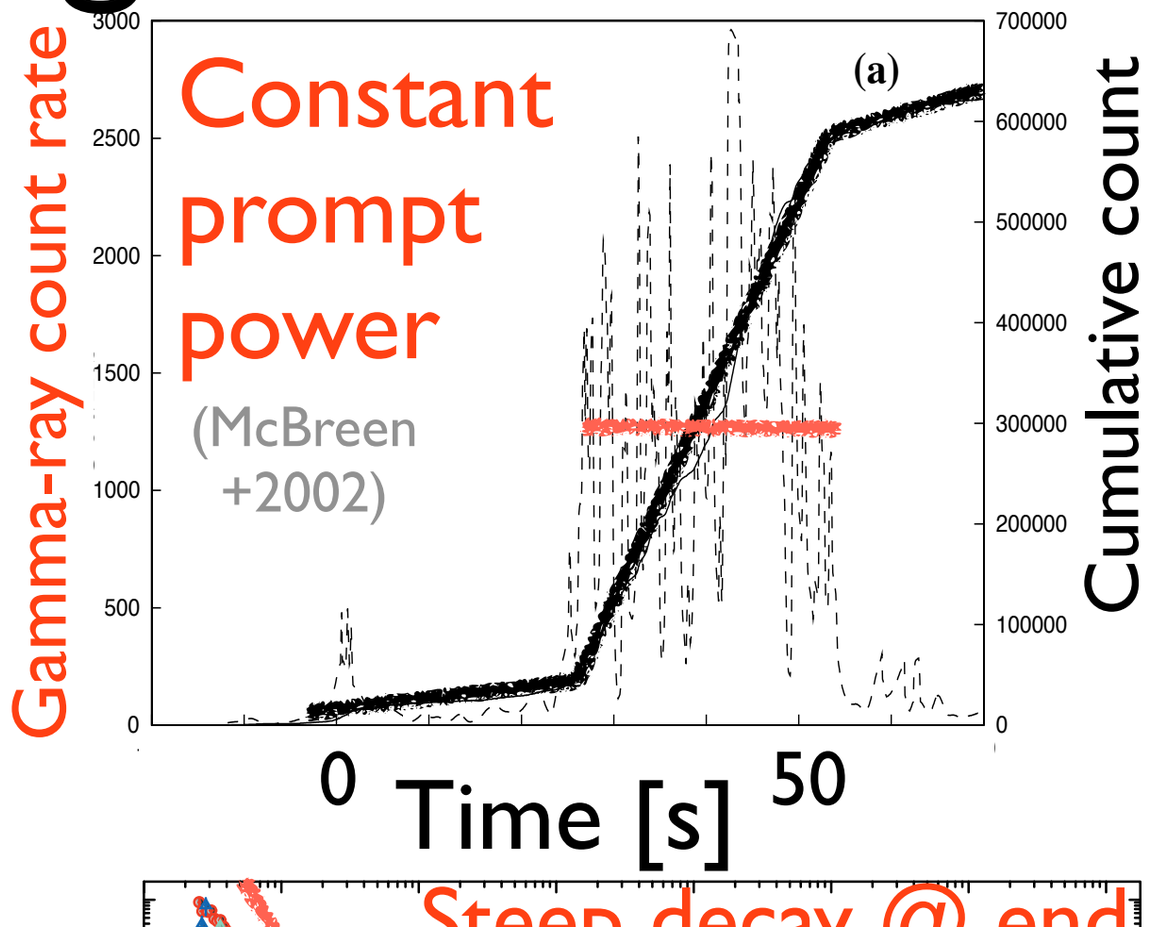
- GRB prompt emission is variable on short time scales
- But on average:

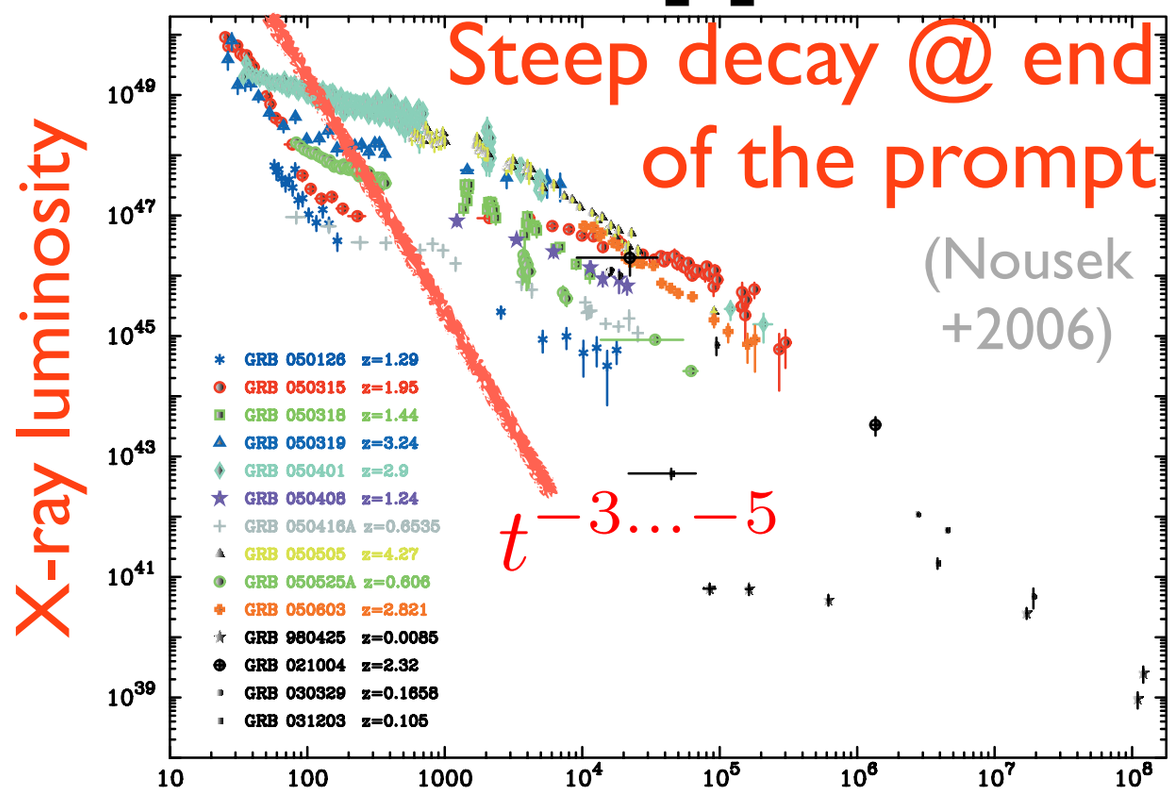
$$L \sim \mathrm{const}$$

- However, at the end, GRBs steeply turns off:

$$L \propto t^{-3...-5}$$

- What causes such an abrupt change of behavior?



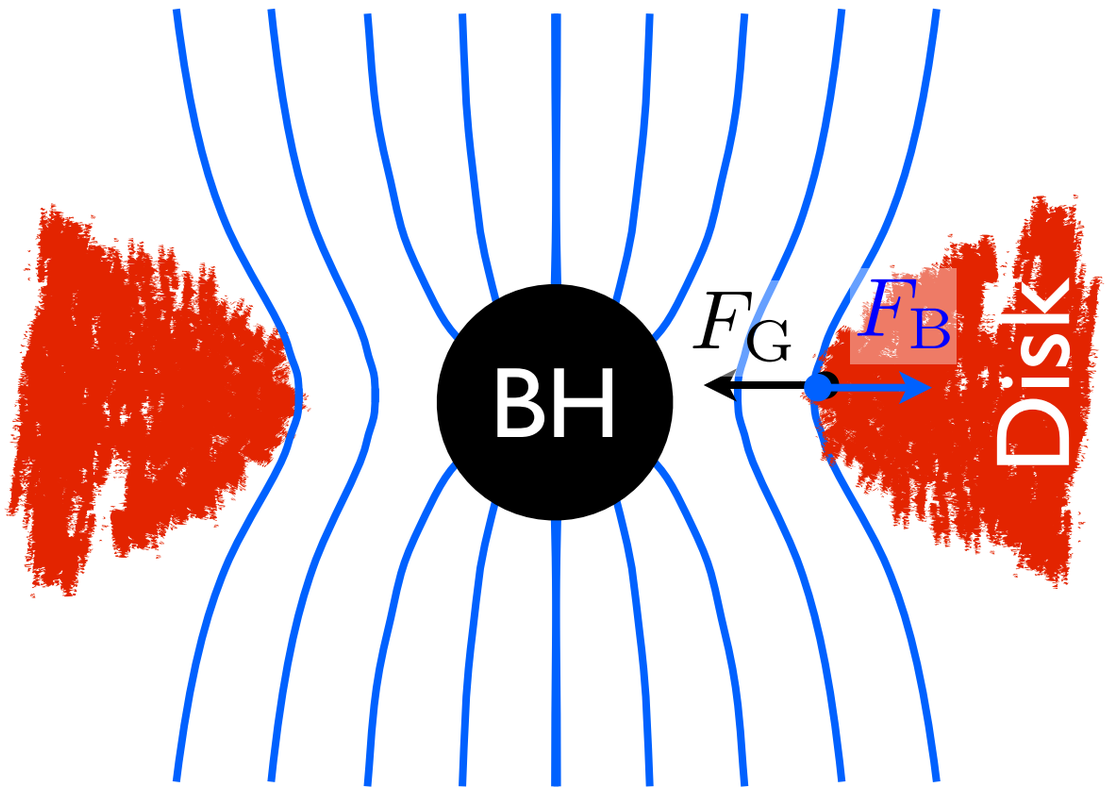


What sets jet power?

$$L_j \sim a^2 B^2 r_g^2 c \propto \Phi^2 \underbrace{(a/M)^2}_{k}$$

What limits L_j and Φ ?

Gravity!



magnetic flux:
$\Phi \sim B r_g^2$

grav. radius:
$r_g = GM/c^2$

B sub-dominant

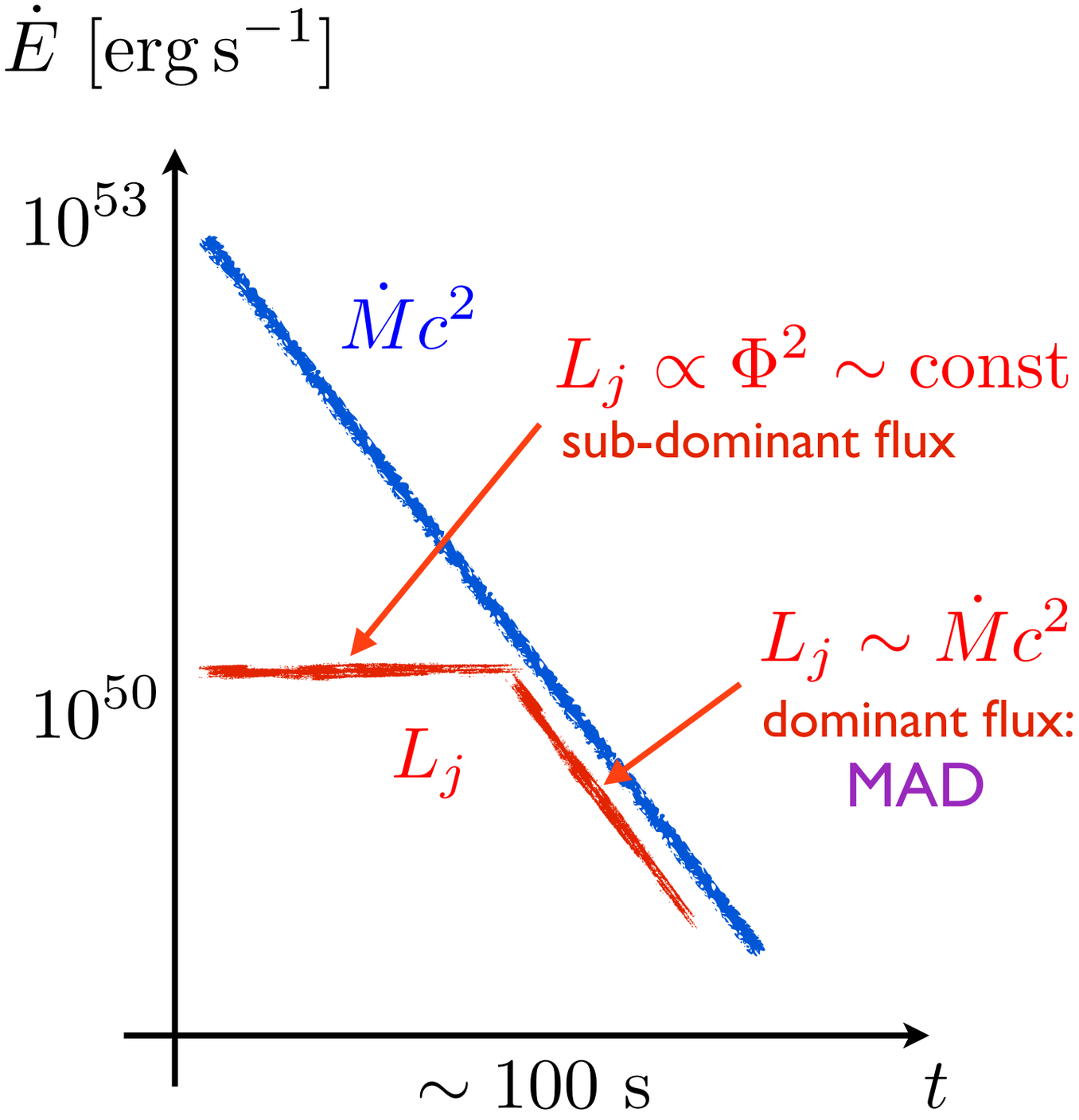
$$0 \leq L_j = k\Phi^2 \leq \dot{M}c^2$$

$$\Phi = 0 \qquad \Phi = \Phi_{\rm MAX}$$

B dominant:
*M*agnetically-
*A*rrested *D*isk
(MAD)

(Narayan+ 2003,
Tchekhovskoy+ 2011)

MADs in GRBs



- After core collapse, accretion power >> jet power → B subdominant:

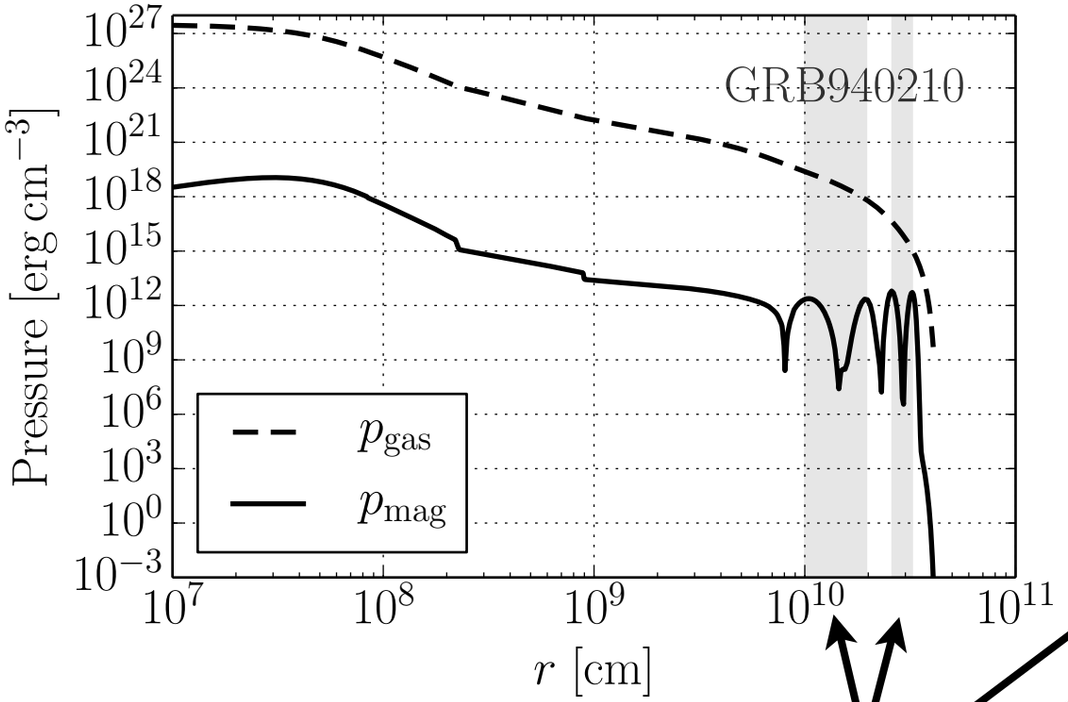
  ➡ jet power ~ constant

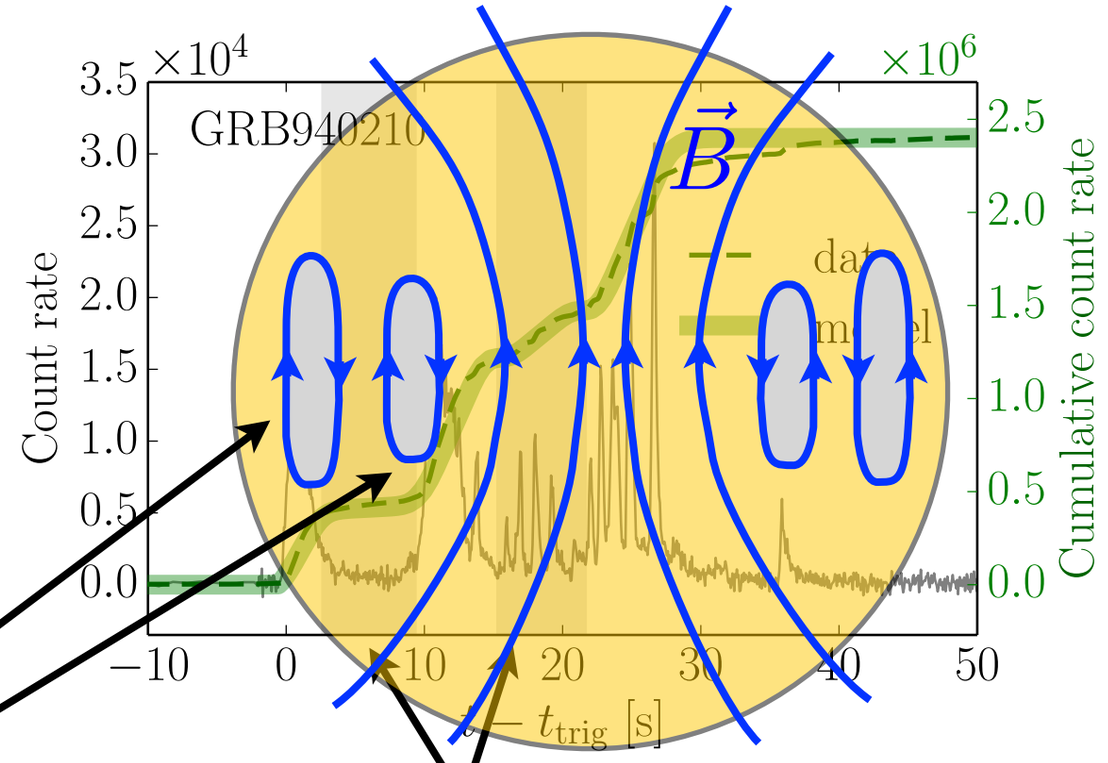
- As Mdot falls, B becomes dynamically important:

  ➡ jet emission shuts off abruptly

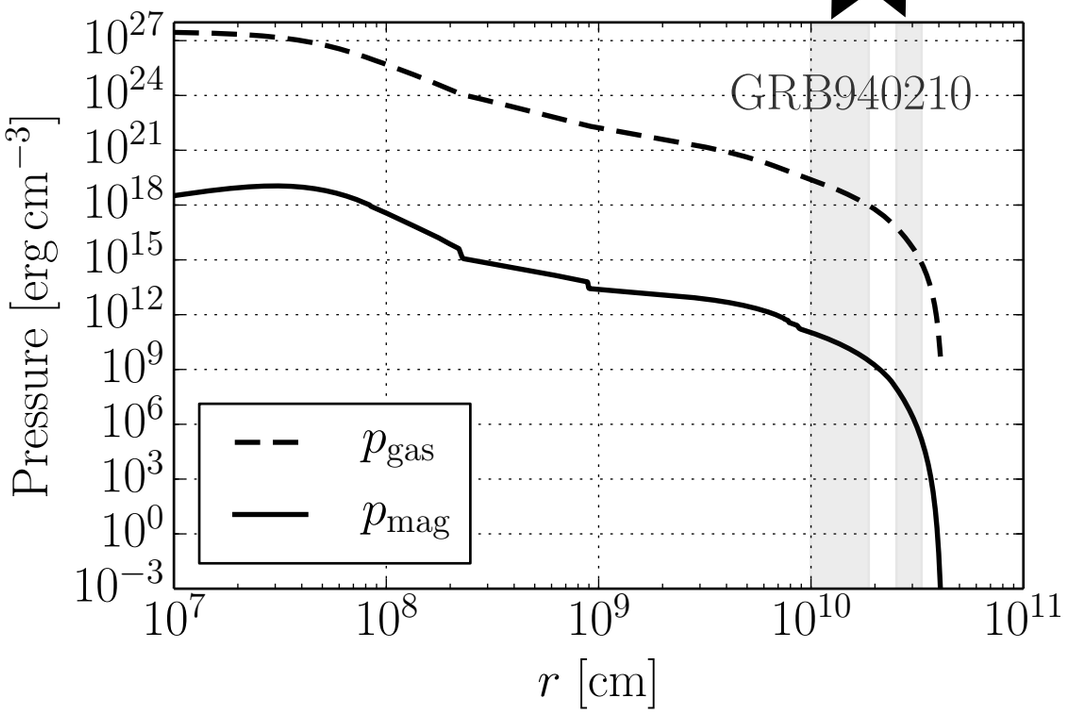
- Naturally accounts for the observed constancy of prompt emission and steep turn off

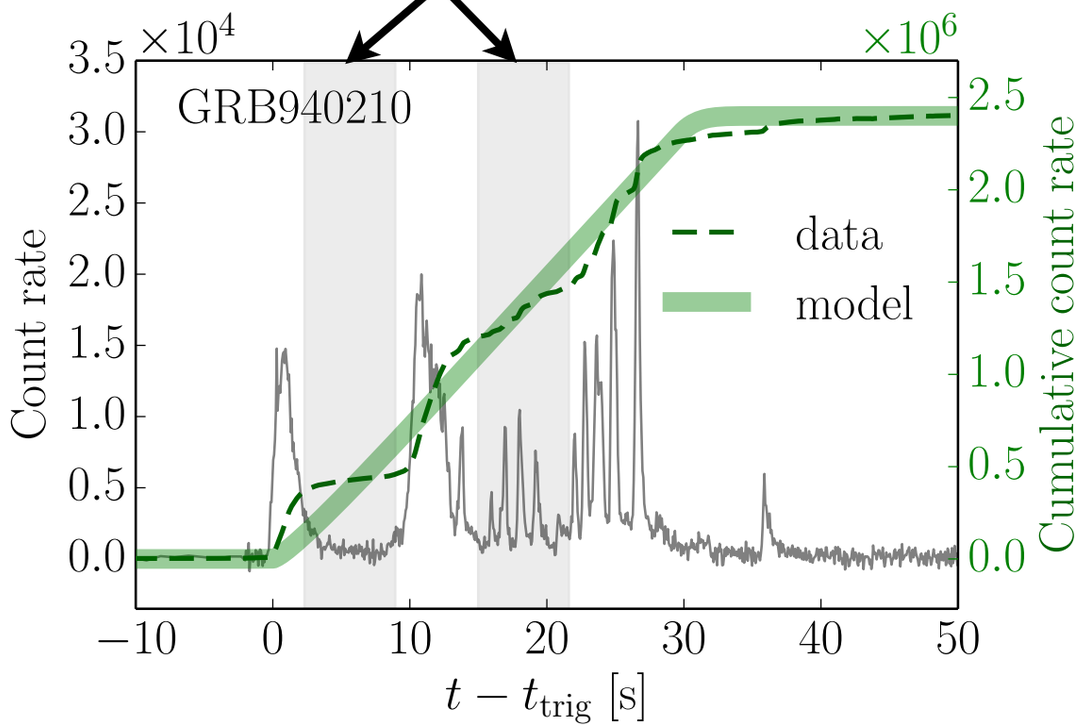
Magnetic "tomography" of stars





GRB luminosity ? "magnetic knots" ⟷ quiescent intervals





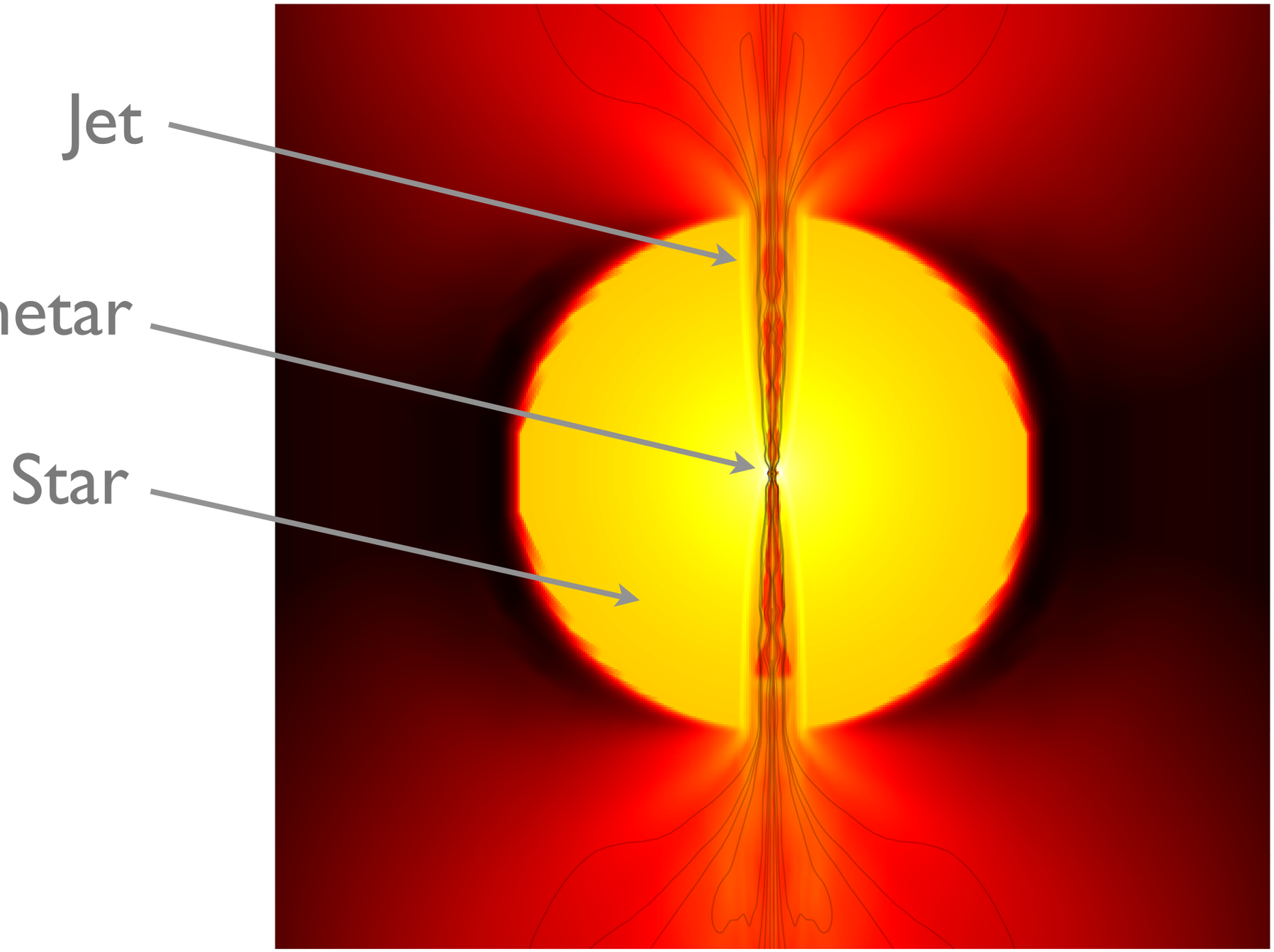
Alexander (Sasha) Tchekhovskoy

(Tchekhovskoy & Giannios, MNRAS, in press)

MAD conclusions

- Stellar magnetic flux is a constant -> constancy of prompt emission
- Magnetic flux becomes dominant (MAD!) -> sharp GRB turn off
- Knots of magnetic flux -> quiescent periods, magnetic "tomography"!

How do GRB jets form?



Spherically symmetric progenitor: $\rho \propto r^{-2.5}$

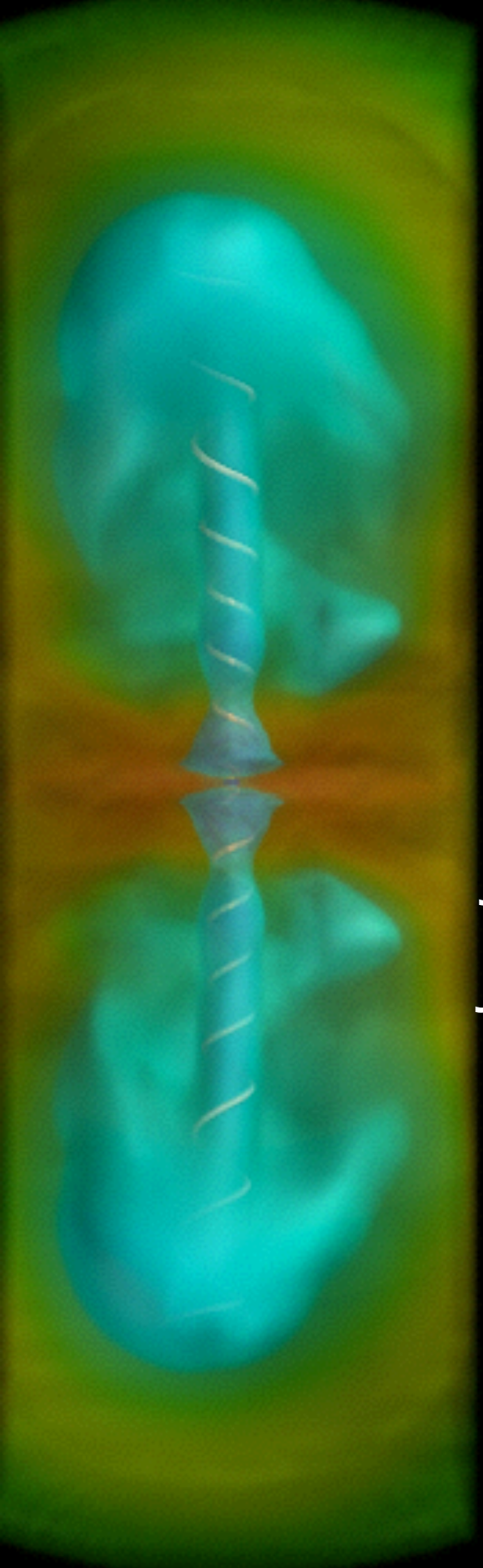
10^{15} G $\leftarrow B_0 \rightarrow 10^{14}$ G

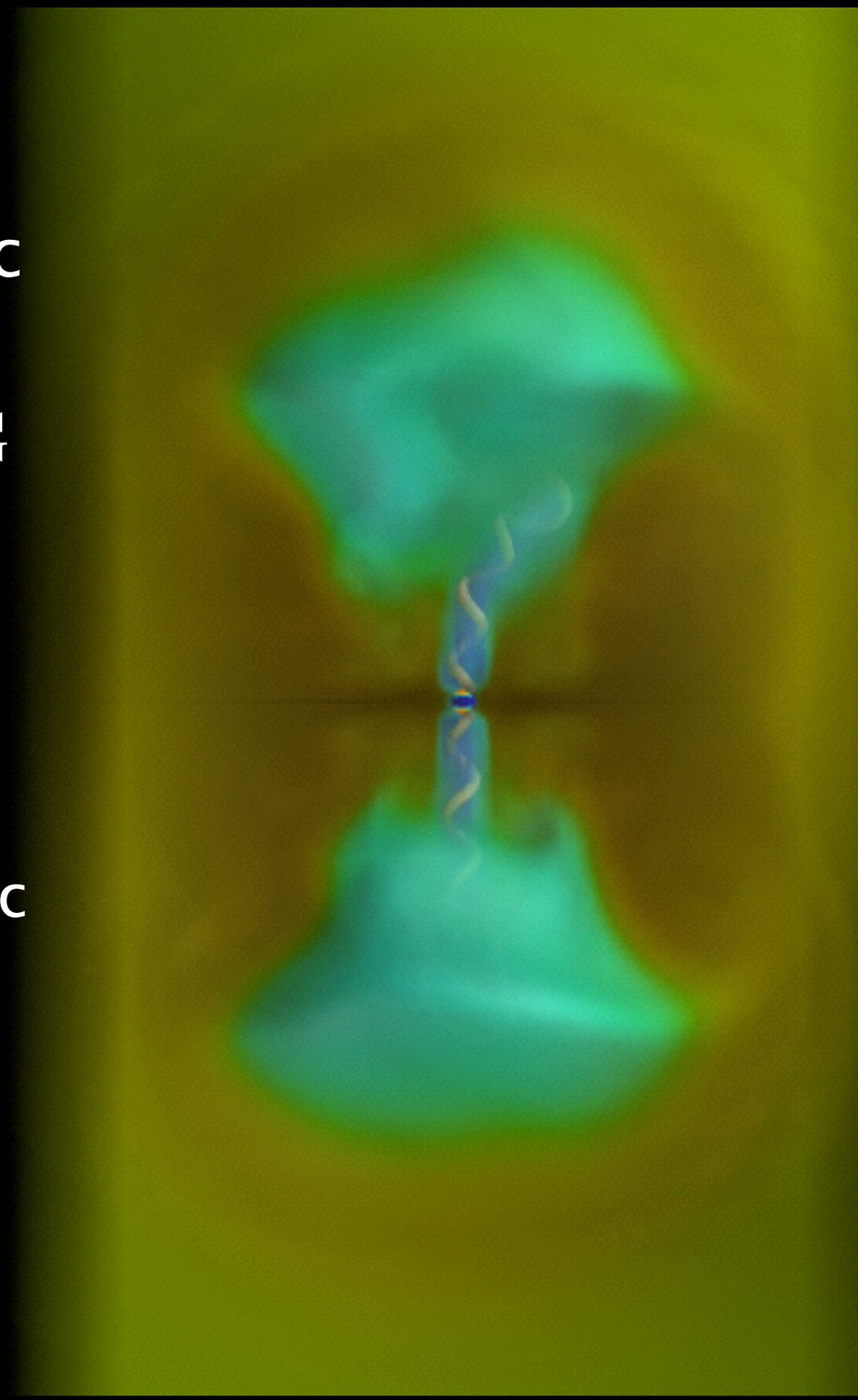
$r_{\rm min} = 4 \times 10^6$ [cm]

$r_{\rm max} = 4 \times 10^8$ [cm]

Jet head speed $v \sim 0.1c$

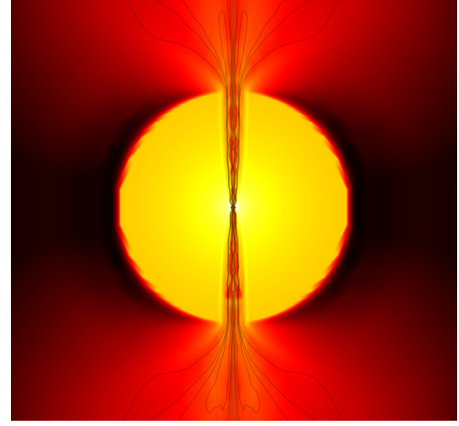
Jet body mildly relativistic

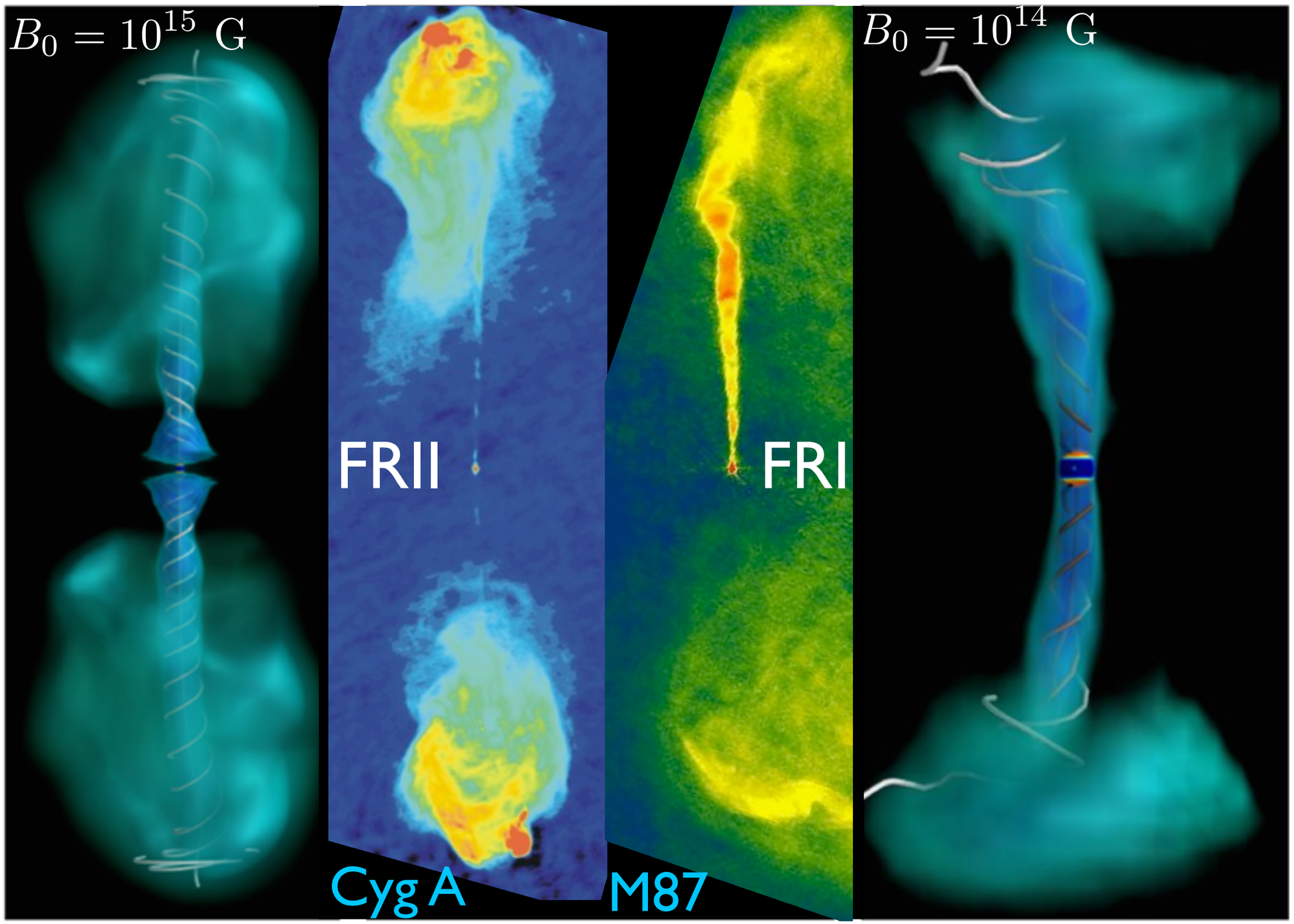




Bromberg & Tchekhovskoy, in prep

So, jets are stable... or not?





Bromberg & Tchekhovskoy, in prep

Conclusions

- GRBs go MAD and shut off
- GRB light curves -> magnetic tomography of stars
- Jets wobble their heads!
  - magnetic jets pretending to be hydro jets
- Ambient medium affects globally jet stability

➡ can unstable jets blow up stars?

- Jet morphology (FRI/FRII) caused by power variations (low/high) alone