

The Diversity of EP GRB and Associated Transients

Hamid Hamidani

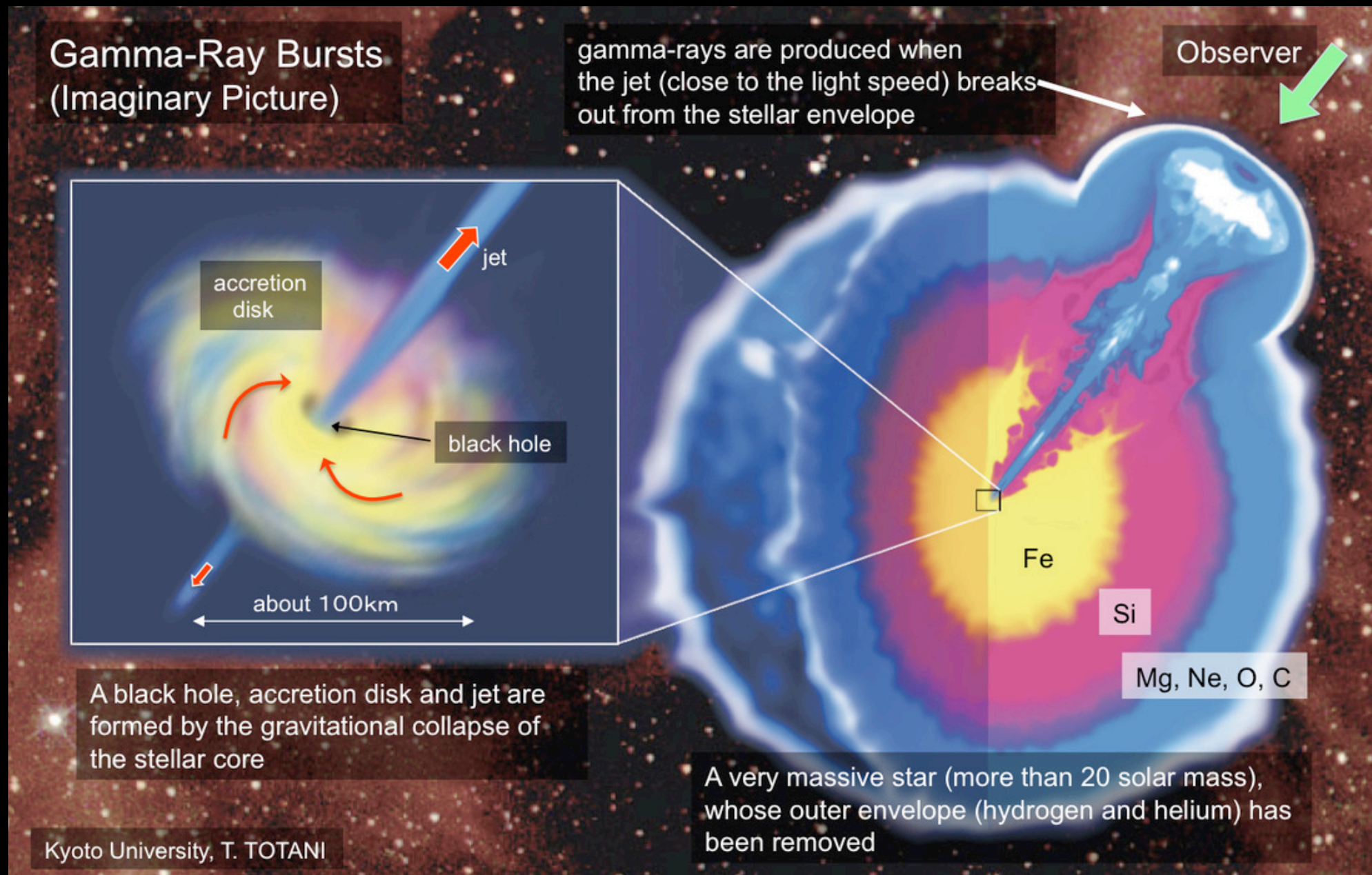
(Future University Hakodate)

With:

**Kunihito Ioka, Masaomi Tanaka, Mingxi Chen, Kazumi
Kashiyama, Christopher Irwin, & Shigeo S. Kimura**

TeVPA, August 31 - September 4, 2026

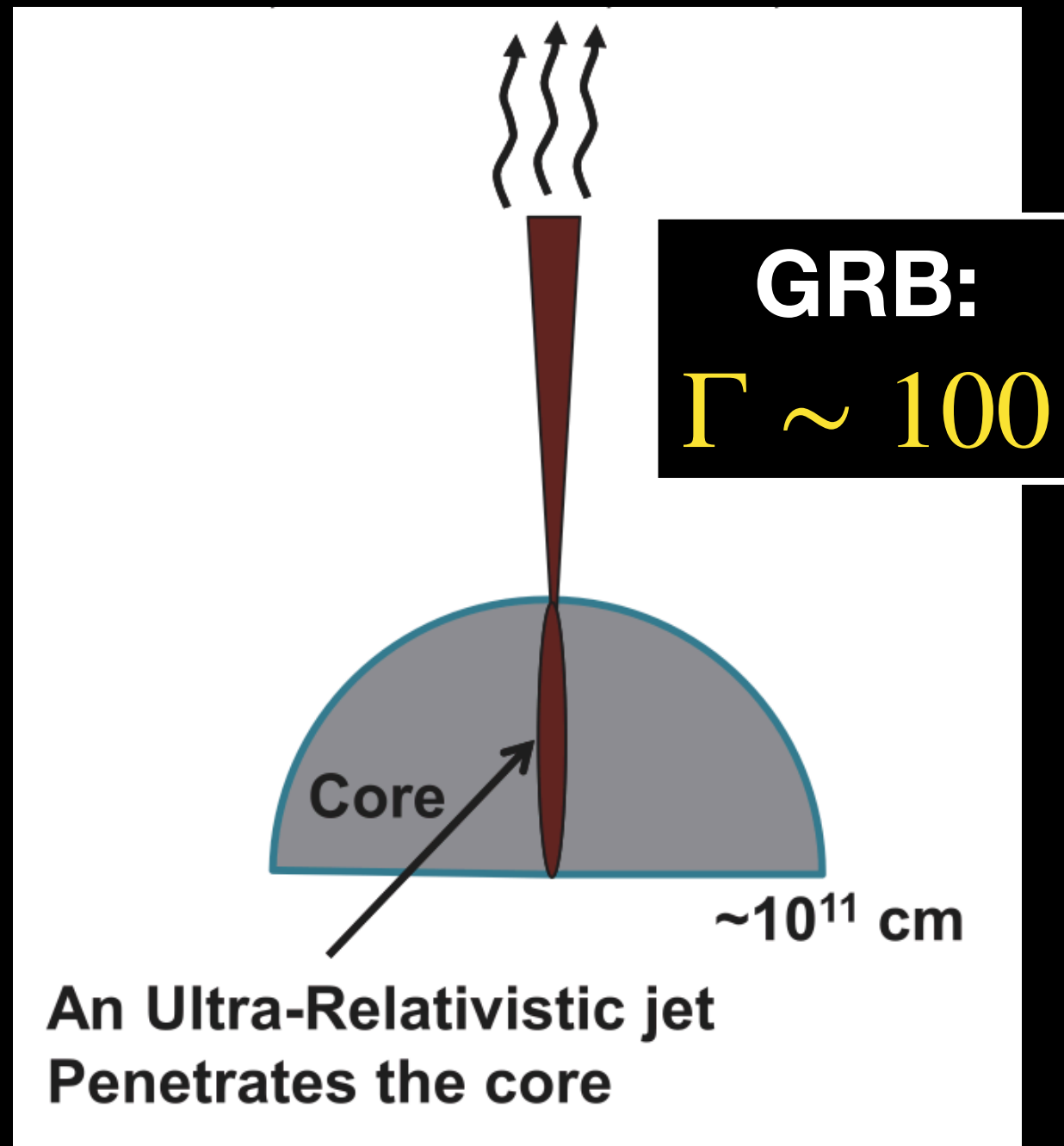
GRBs: Jet-driven explosions



Progenitor: **Wolf-Rayet Star (fast rotating)**

Collapsar Scenario

$$\Gamma = \frac{1}{\sqrt{1 - \beta^2}}$$
$$\beta = v/c$$



Credit: Nakar 15

Key point: We need a stripped/compact Wolf-Rayet Star!

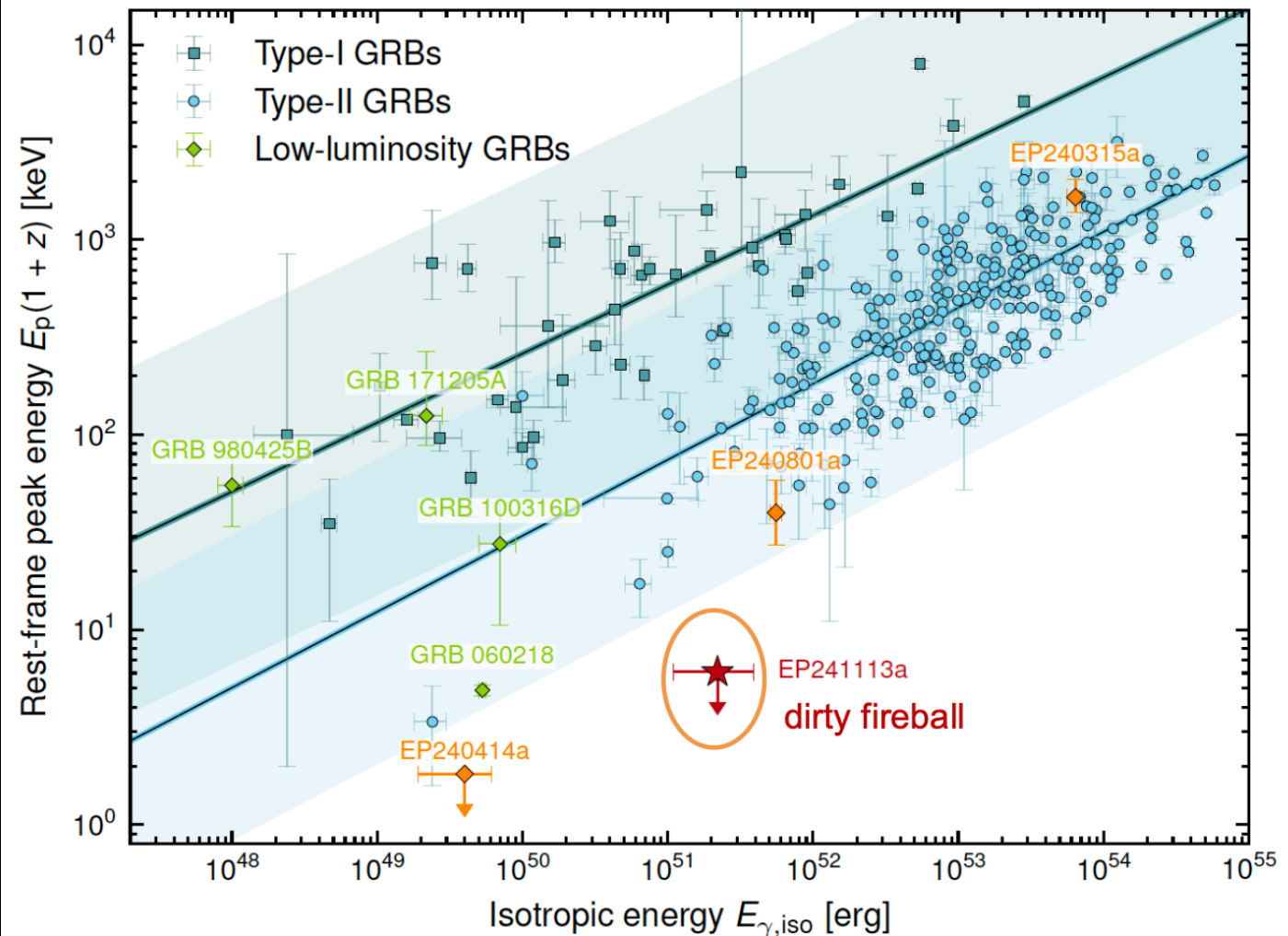
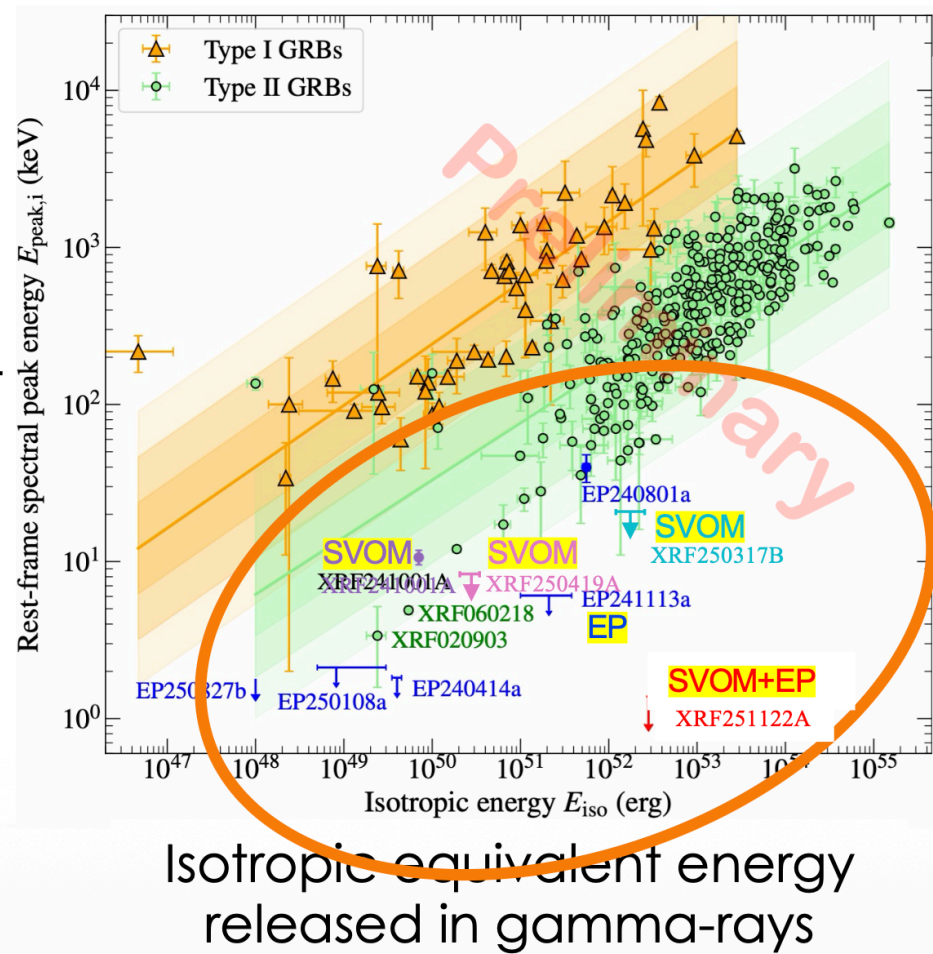
Einstein Probe (& SVOM)



Credit: EP & SVOM

More & more diversity!

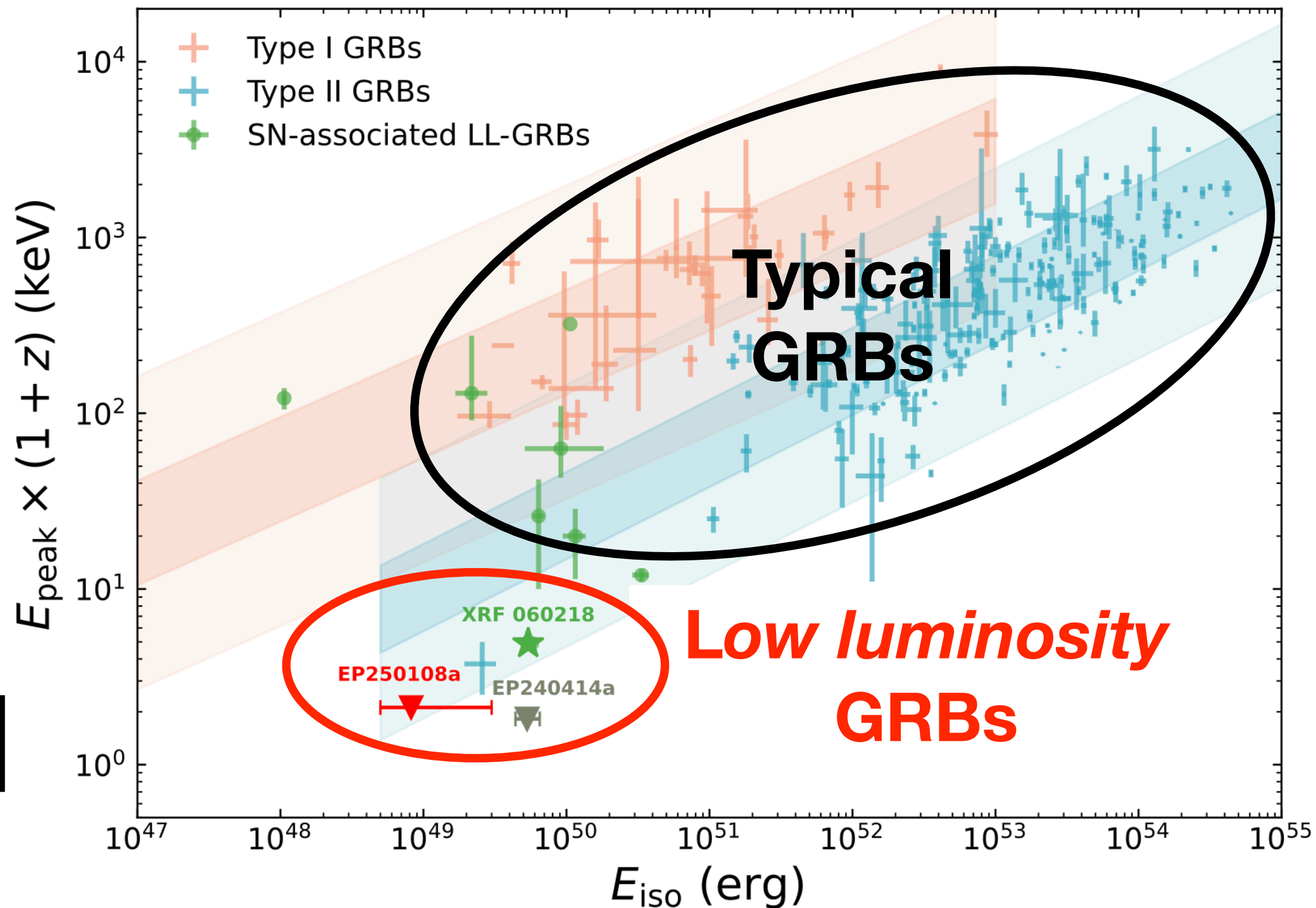
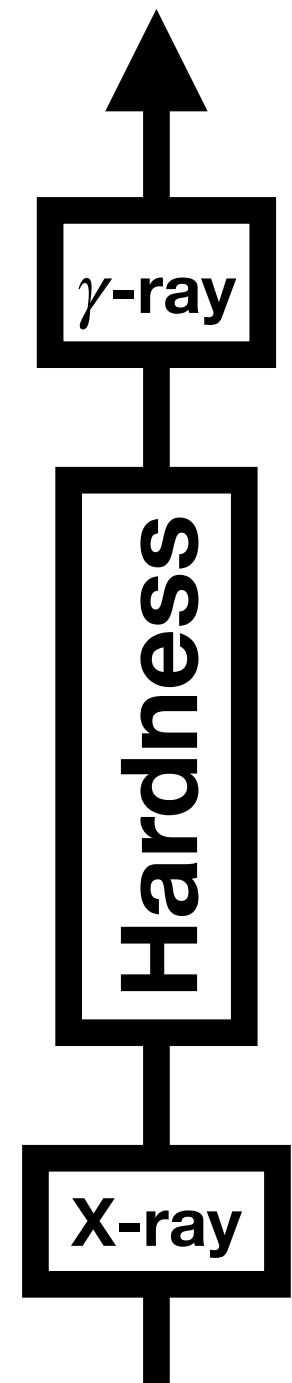
Peak Energy in Source Frame
= Spectral Properties
of the Prompt Emission



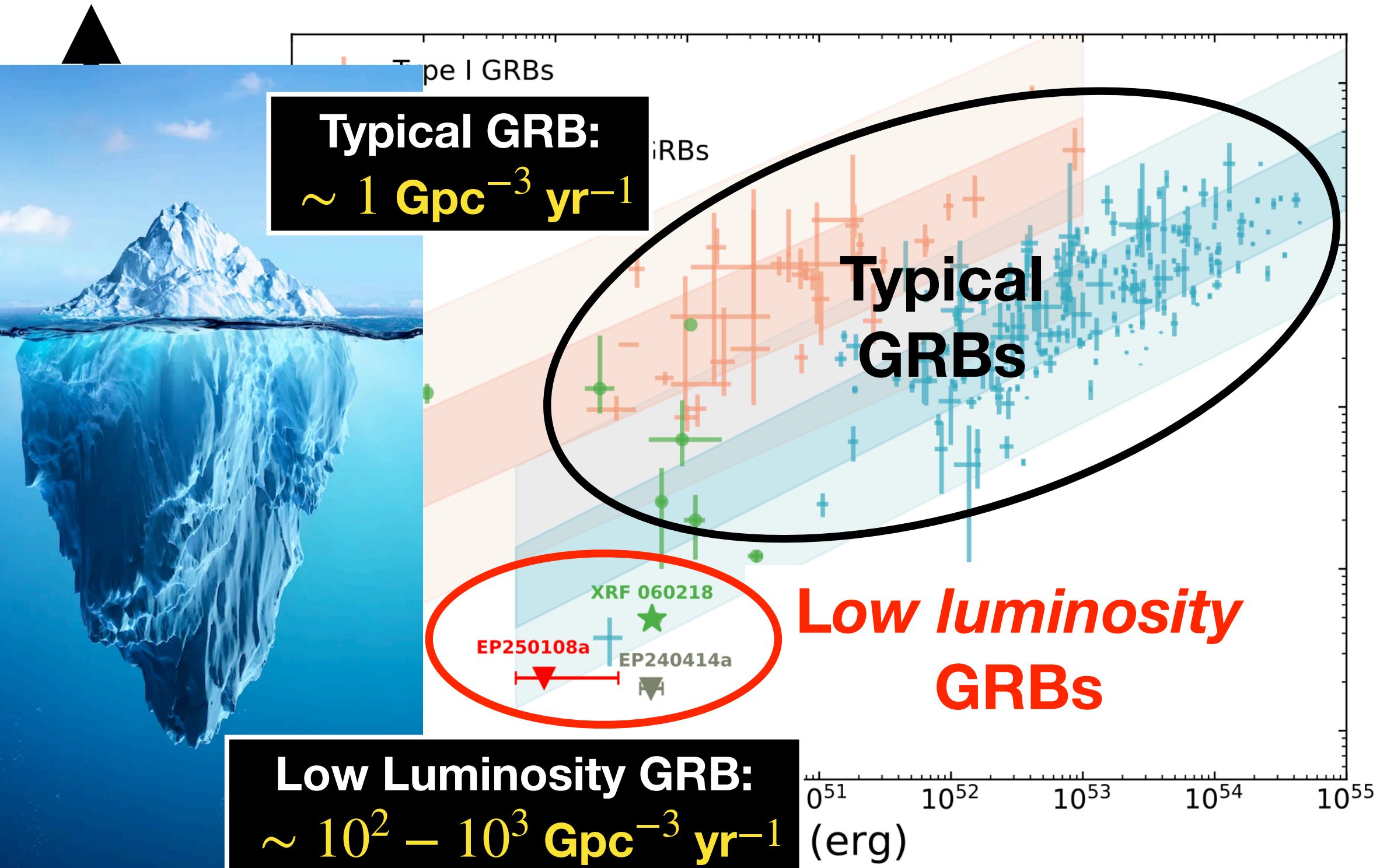
Diego's
Talk
(SVOM)

Liu's Talk
(EP)

LLGRBs [with EP]



LLGRBs [with EP]



Model: Star + “CSM”

Credit: Nakar 15

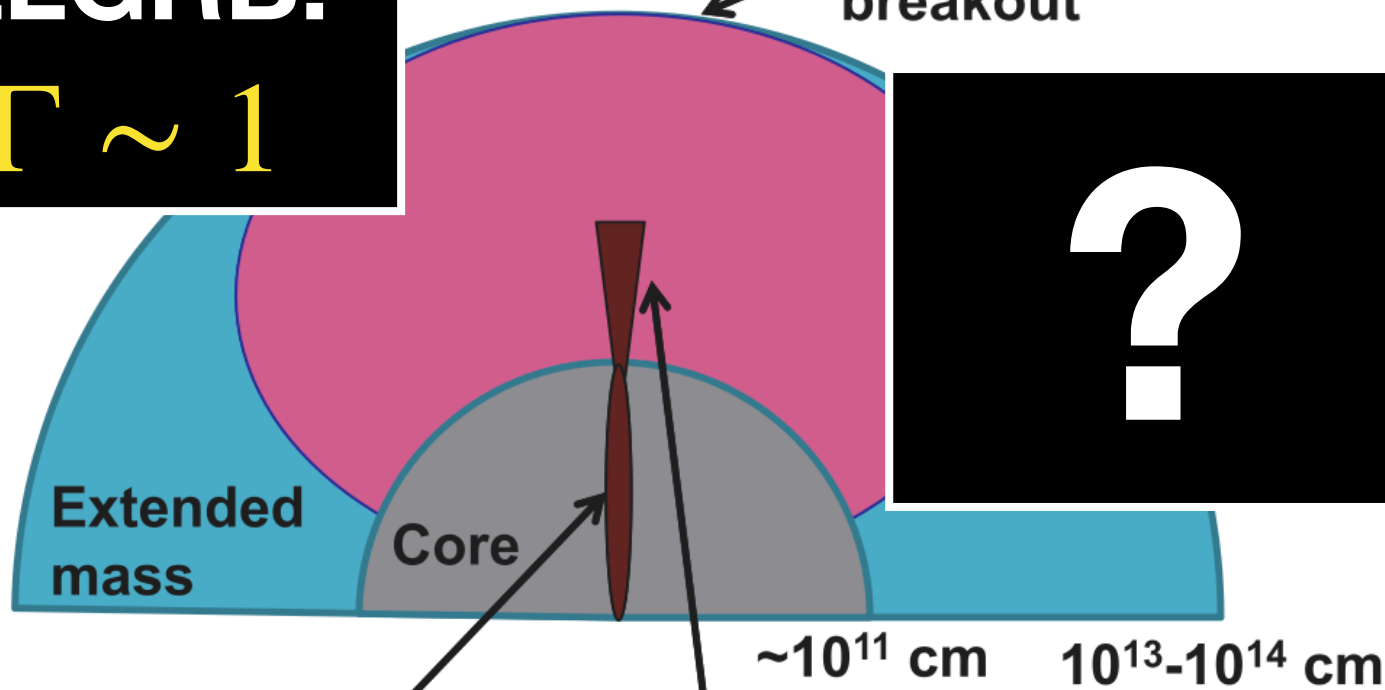
Low-Luminosity GRB

Gamma-rays/Hard X-rays
(low-luminosity, un-collimated, soft, non-variable)

LLGRB:

$$\Gamma \sim 1$$

Shock breakout



An Ultra-Relativistic jet
Penetrates the core – choked in the extended material

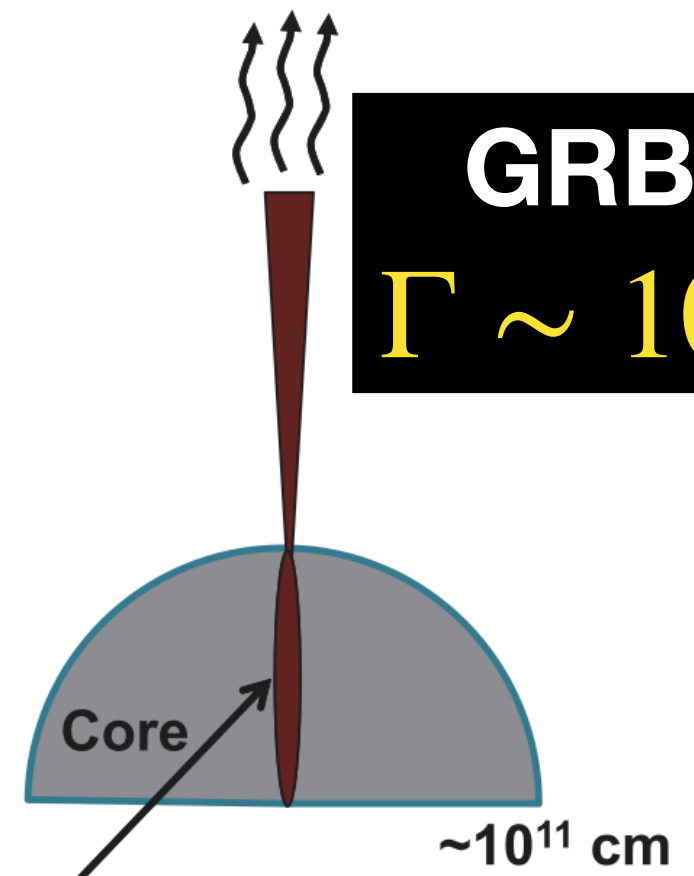
Wolf-Rayet + “CSM”

Long GRB

Gamma-rays
(luminous, collimated, hard, variable)

GRB:

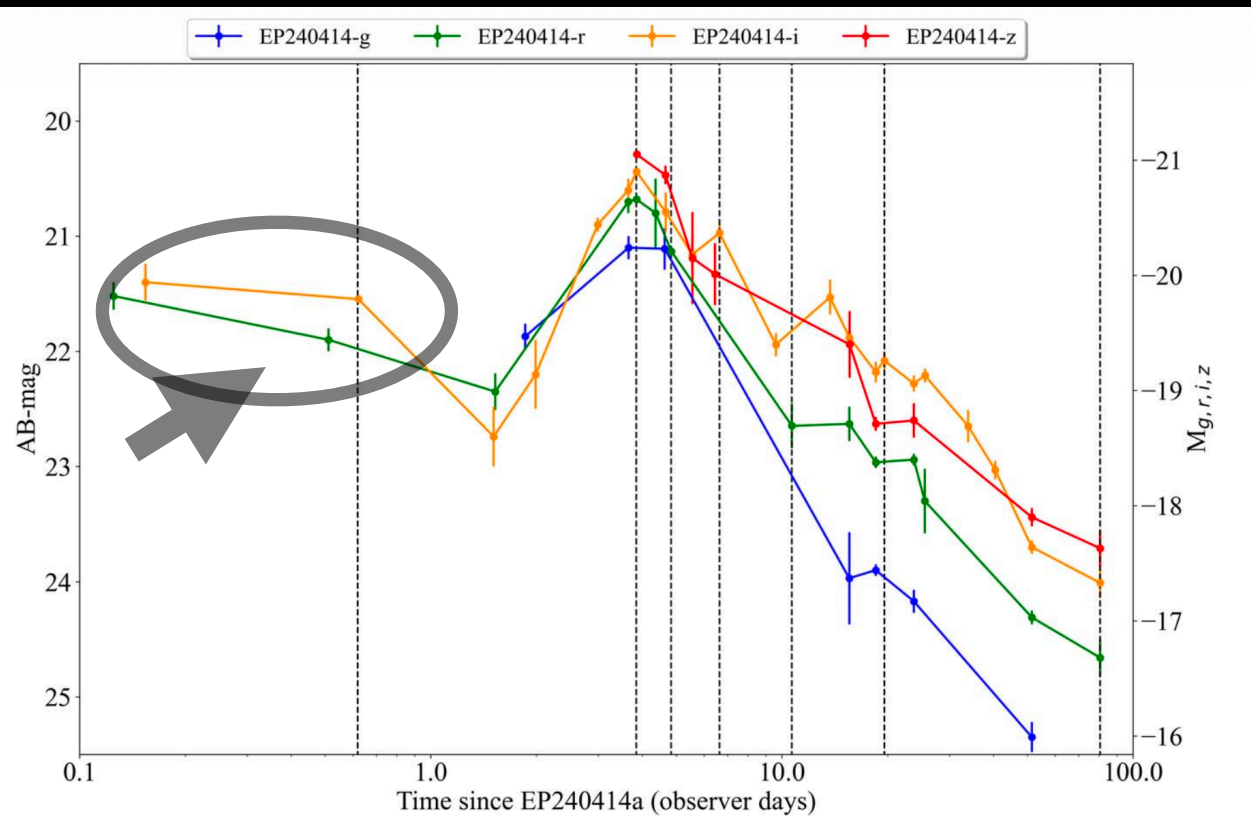
$$\Gamma \sim 100$$



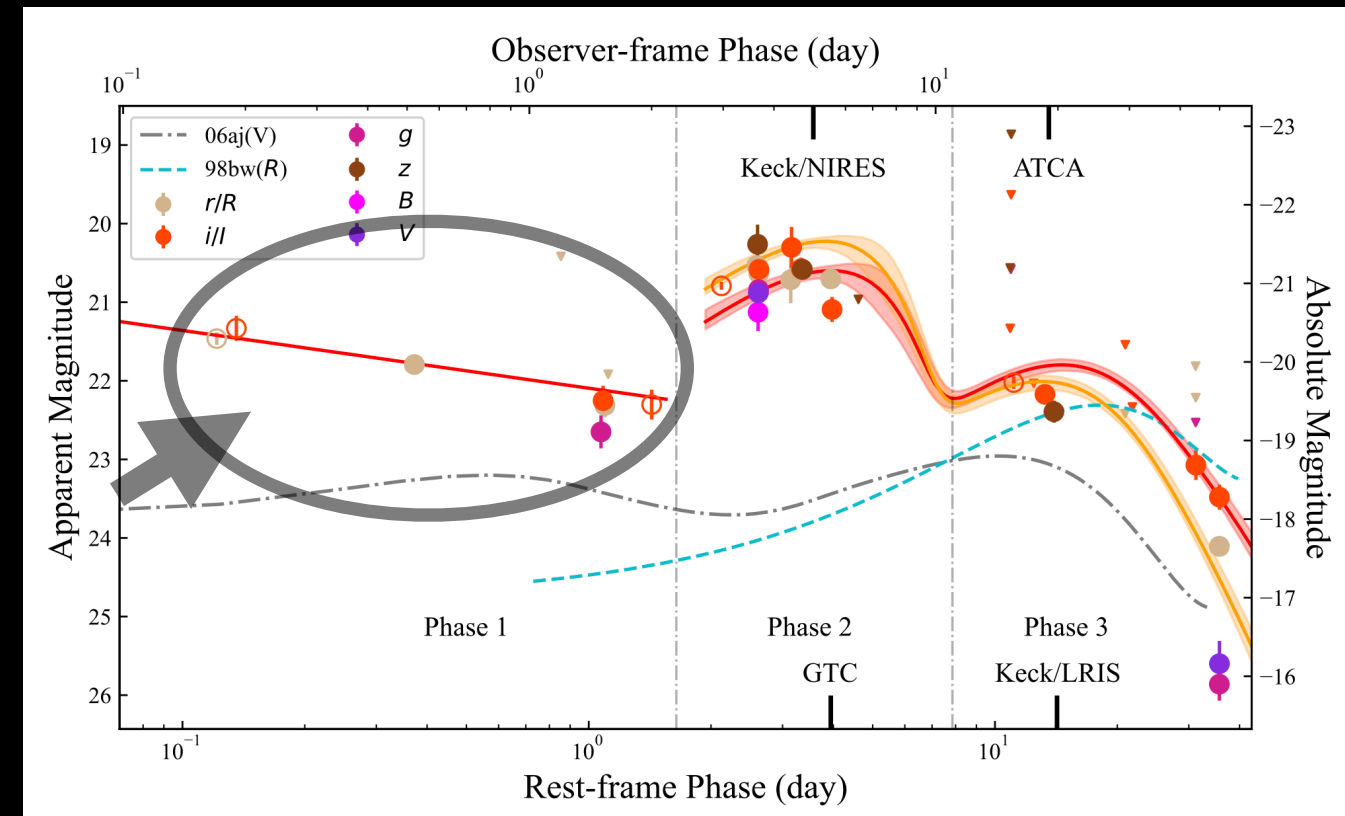
An Ultra-Relativistic jet
Penetrates the core

Wolf-Rayet

Recent Observations: Early CSM Interaction Phase EP240414a

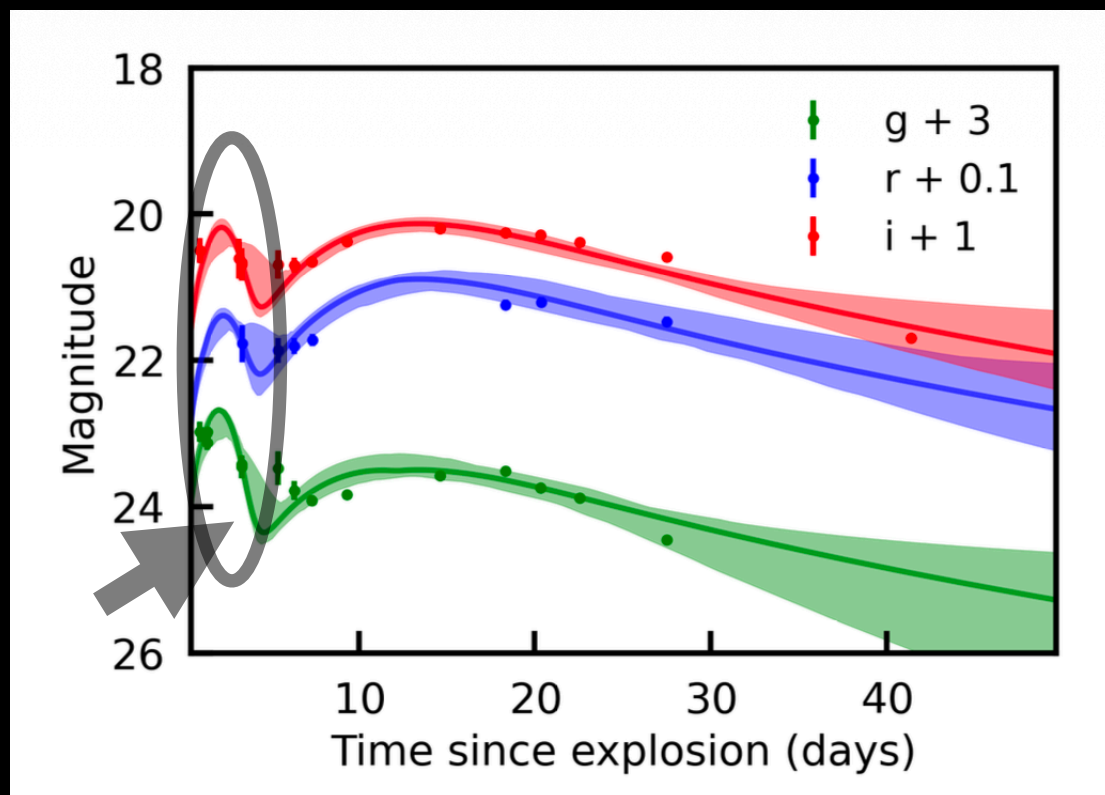


Credit: Dalen+25

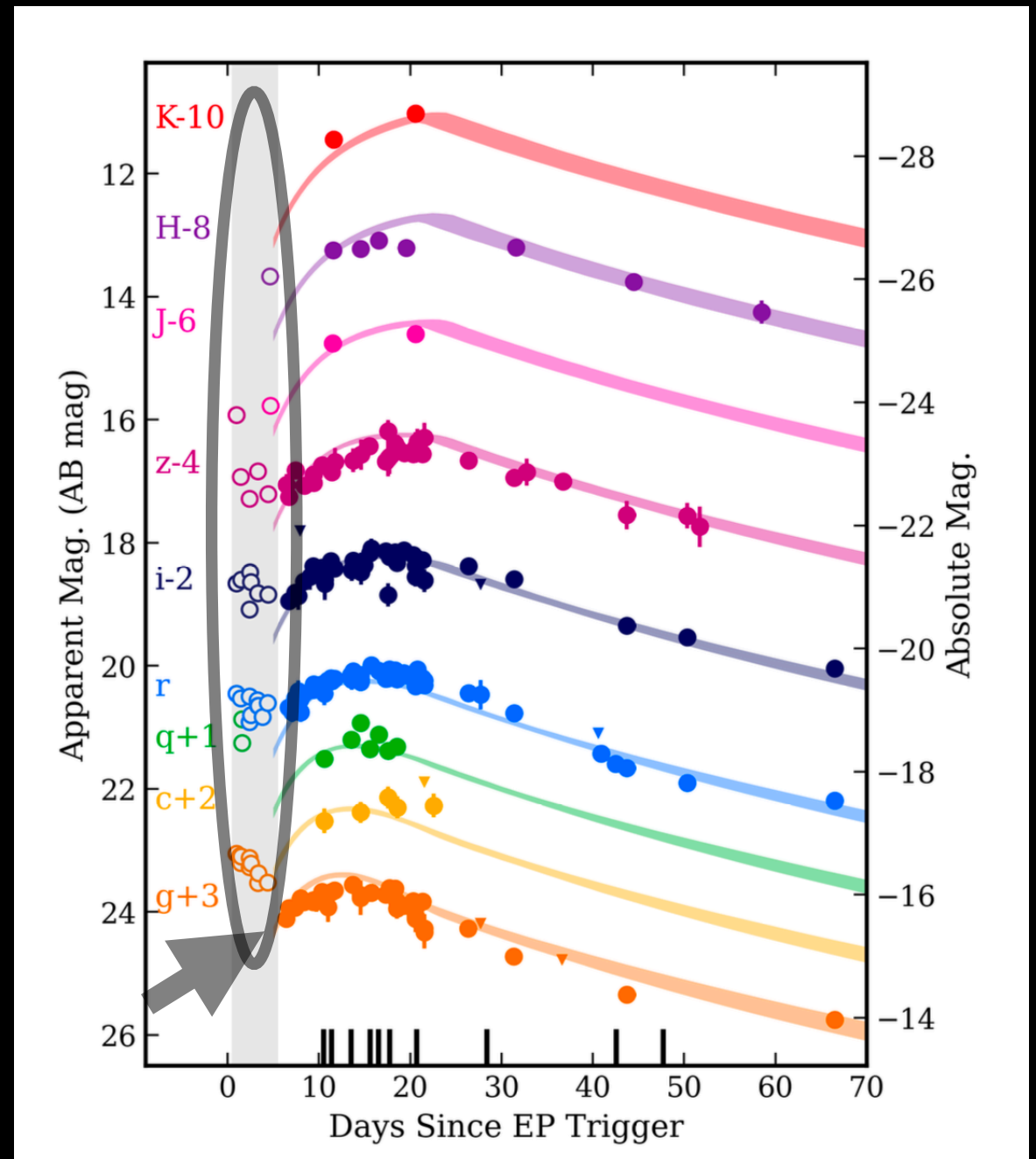


Credit: Sun+25

Recent Observations: Early CSM Interaction Phase EP250108a

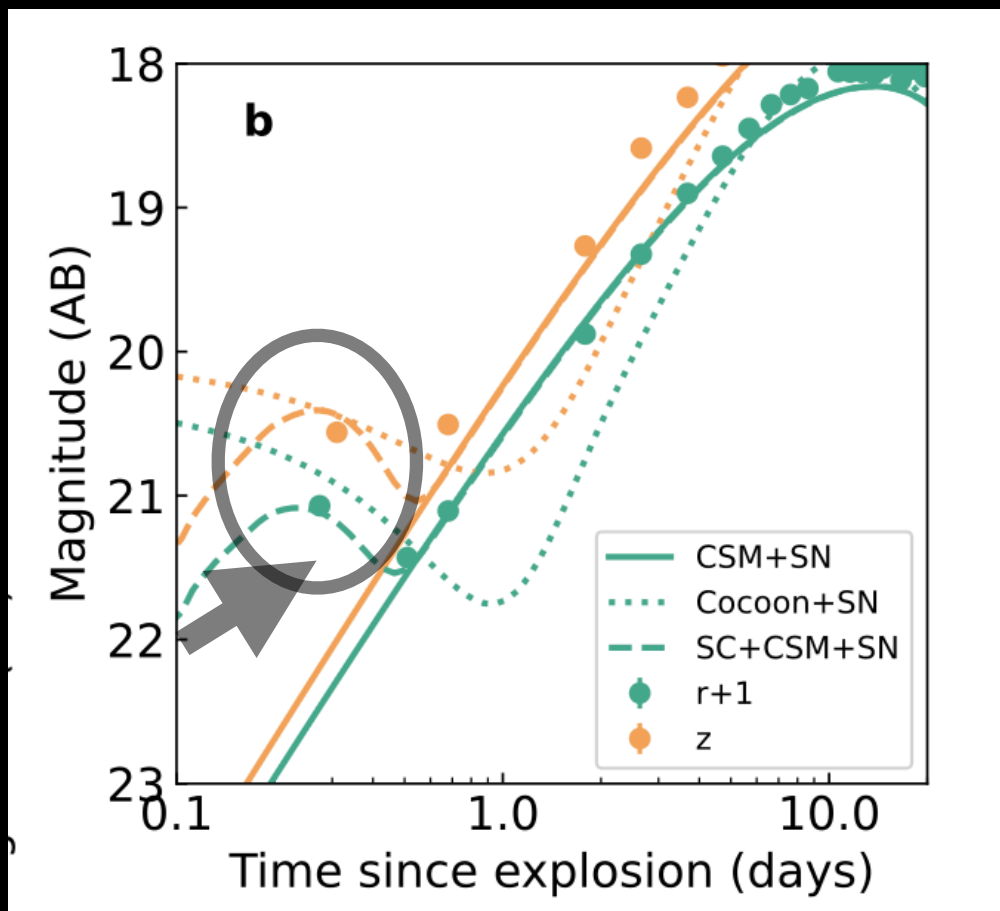


Credit: Srinivasaragavan+26

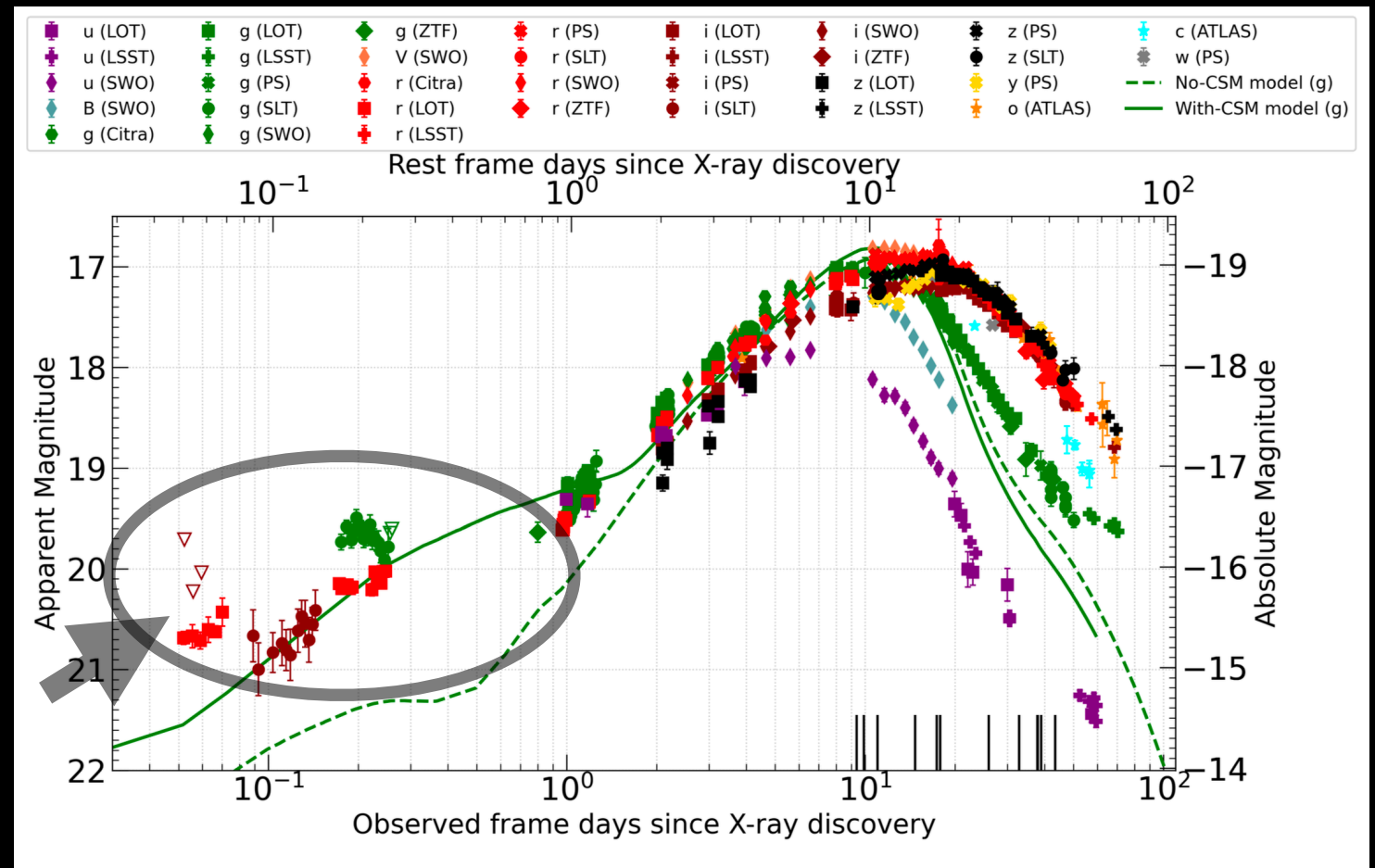


Credit: Rastinejad+26

Recent Observations:
Early CSM Interaction Phase
EP260321a



Credit: Martin-Carrillo+26



Credit: Chen+26

Model: Star + “CSM”

Credit: Nakar 15

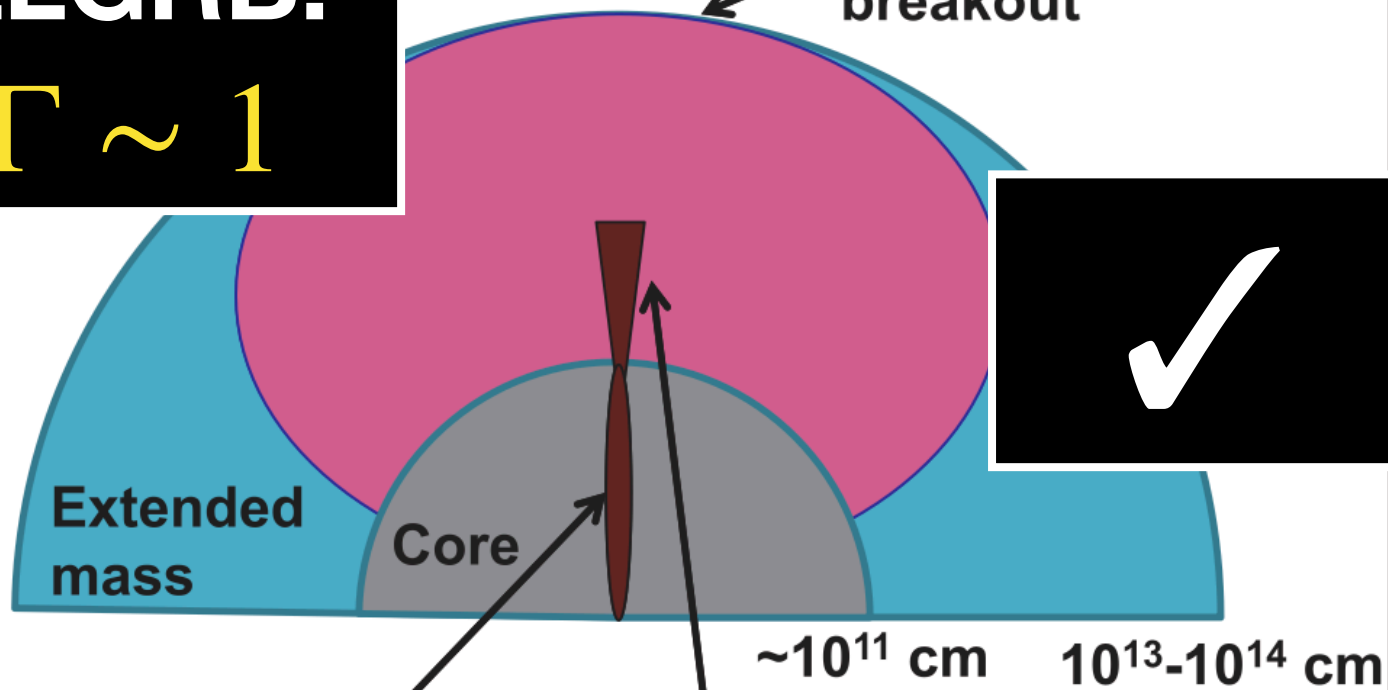
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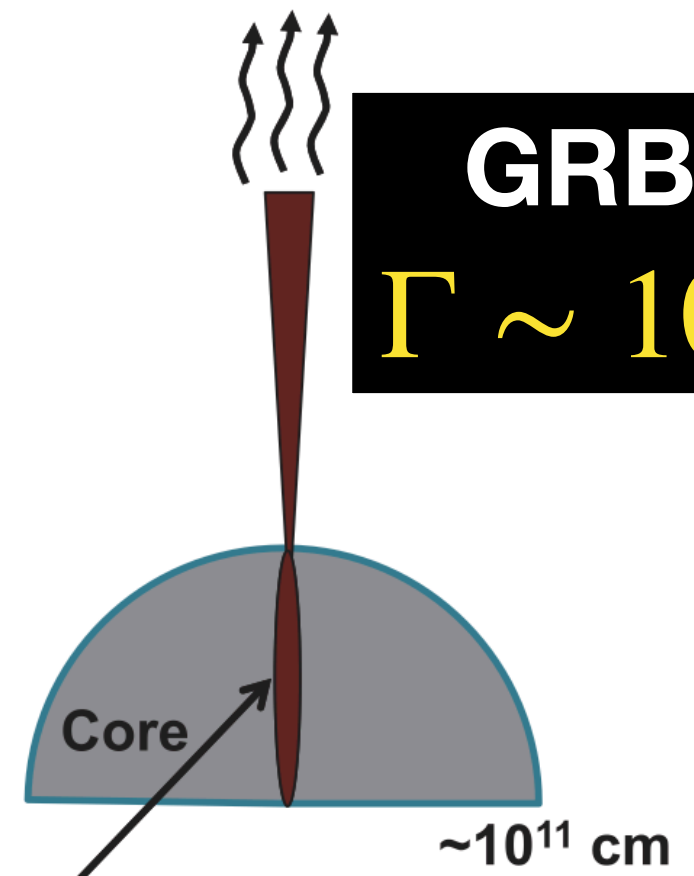
Wolf-Rayet + “CSM”

Long GRB

Gamma-rays
(luminous, collimated, hard, variable)

GRB:

$$\Gamma \sim 100$$



An Ultra-Relativistic jet
Penetrates the core

Wolf-Rayet

Obs. Driven Motivation:

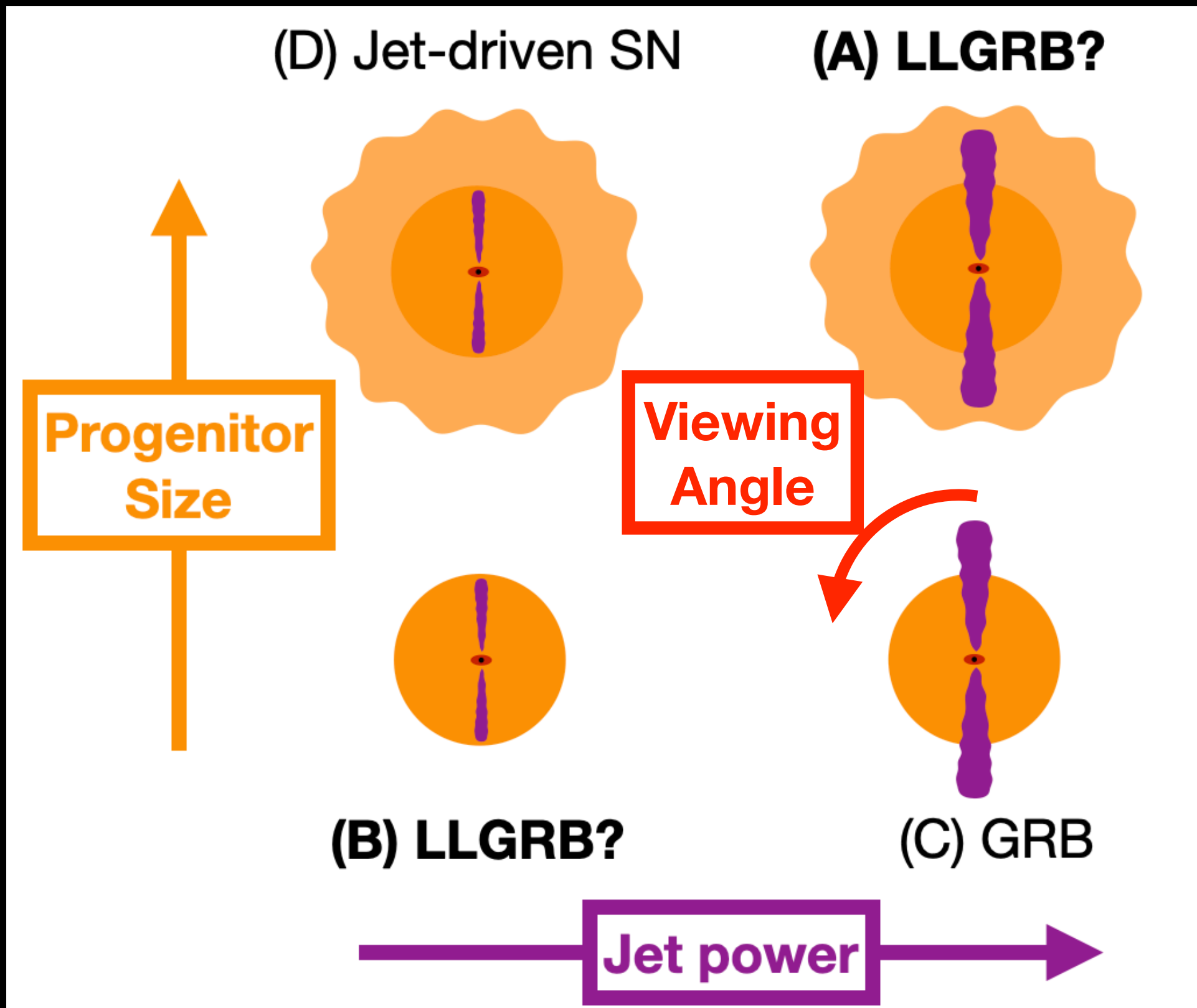
Hints to **GRB Diversity & Jets in CSM**

Goal: Origin of diversity?

→ **We need to understand Jet-CSM**

Ultimate Goal:

Understand what makes GRB/LLGRBs diversity...

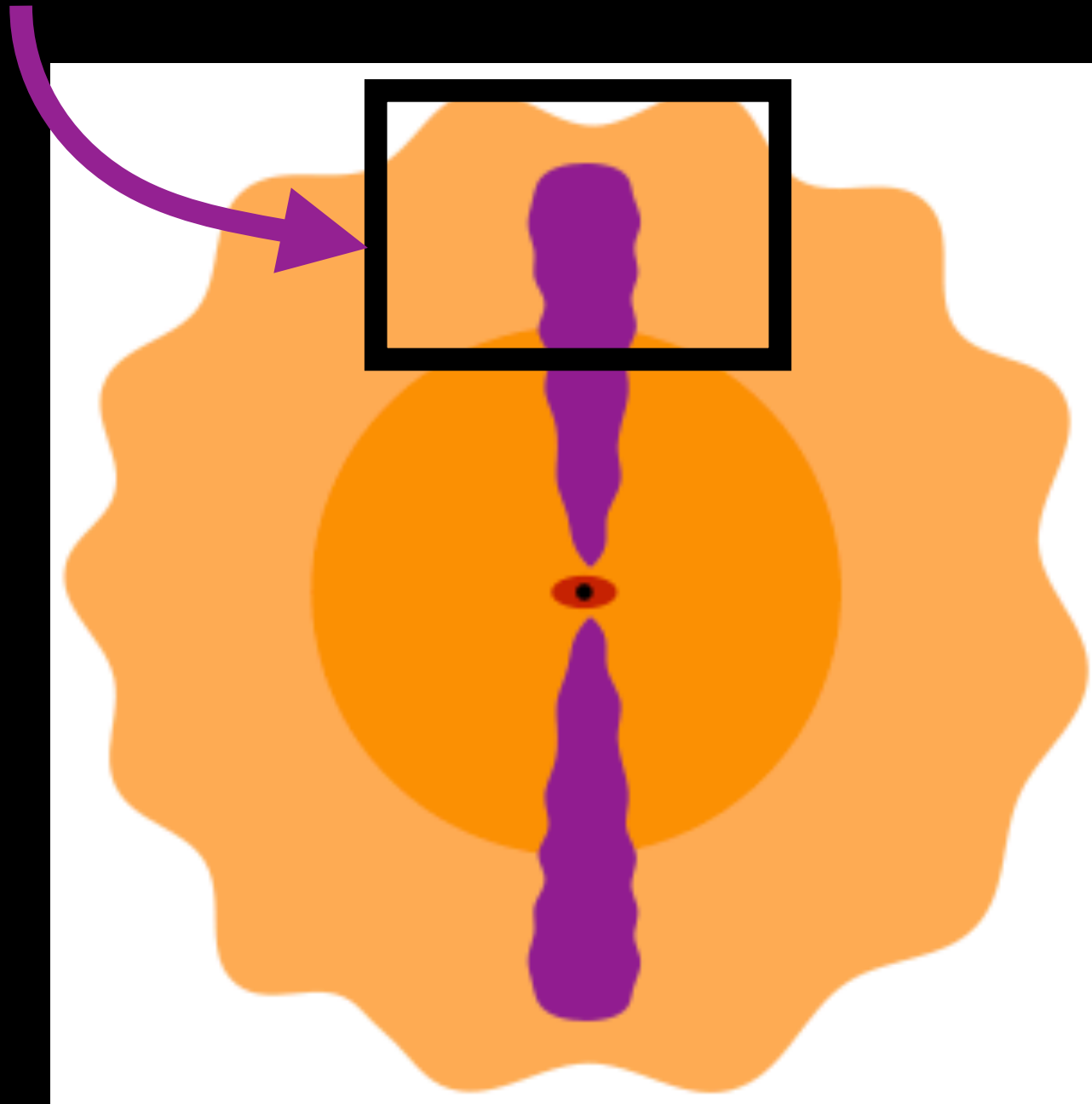


Method:

→ Analytic Modeling of
Jet-CSM Dynamics

Important Point:

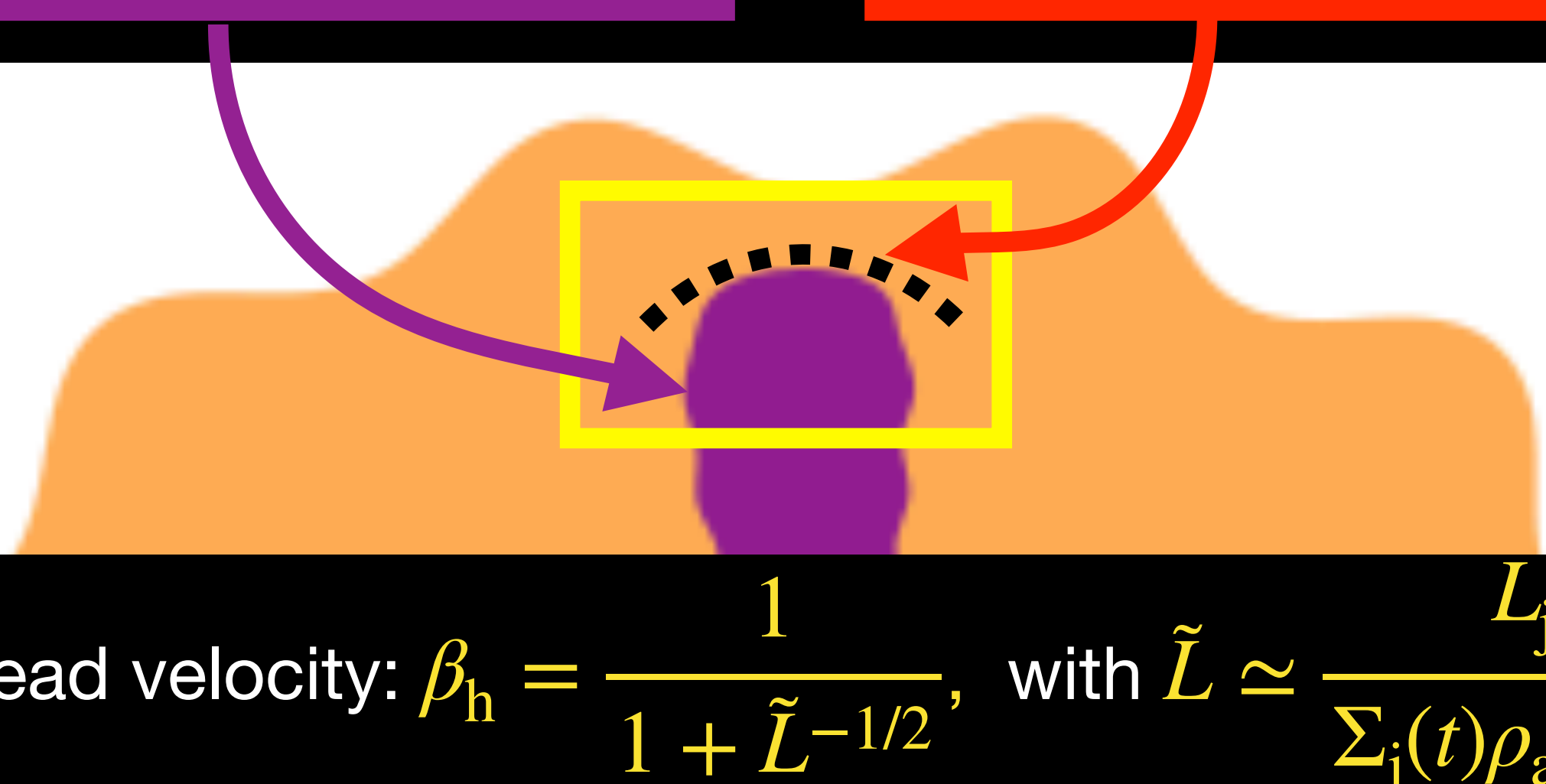
Understand (quantify) how the CSM affects the jet



i.e. Quantify the effect of
e.g., CSM mass, radius, on the jet dynamics/emission

Jet Dynamics

Jump conditions: (Begelman & Cioffi 1989)

$$\underline{h_j \rho_j c^2 (\Gamma \beta)_{jh}^2 + P_j} = \underline{h_a \rho_a c^2 (\Gamma \beta)_{ha}^2 + P_a}$$


The diagram shows a jet head (purple) moving through a medium (orange). A yellow box highlights the shock front (dashed line). A purple arrow points from the left side of the equation to the jet head, and a red arrow points from the right side of the equation to the shock front.

Jet head velocity: $\beta_h = \frac{1}{1 + \tilde{L}^{-1/2}}$, with $\tilde{L} \simeq \frac{L_j}{\Sigma_j(t) \rho_a c^3 \Gamma_a^2}$

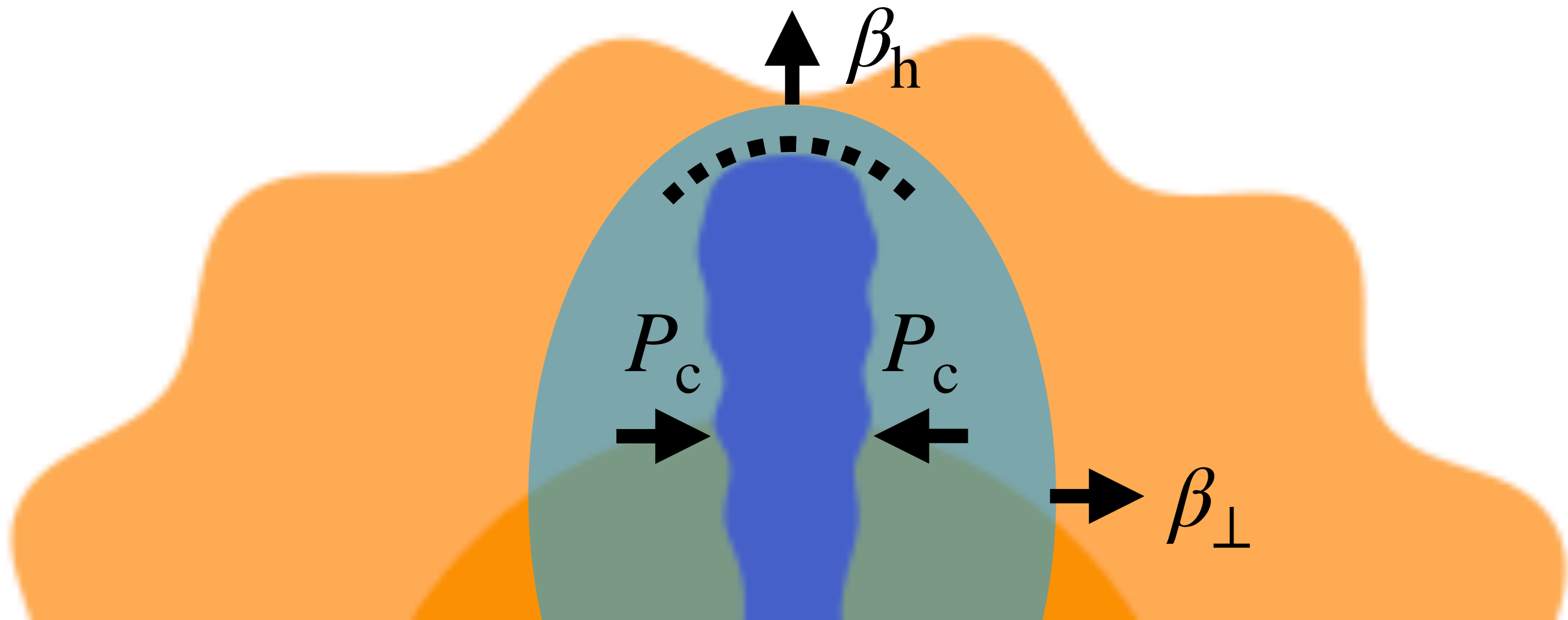
Cocoon & Collimation

$$r_c(t) = c\beta_{\perp}(t - t_0),$$

$$\beta_{\perp} = \sqrt{\frac{P_c}{\rho_a(r_h/2)c^2}},$$

$$P_c = \eta \frac{E_c}{3V_c},$$

$$\Sigma_j(t) = \frac{L_j \theta_0^2}{4cP_c},$$



Inner-Outer Cocoon

$$E_c = E_{c,\text{outer}} + E_{c,\text{inner}}$$

$$E_{c,\text{outer}} \sim f_{\text{mix}} E_c$$

$$E_{c,\text{inner}} \sim (1 - f_{\text{mix}}) E_c$$

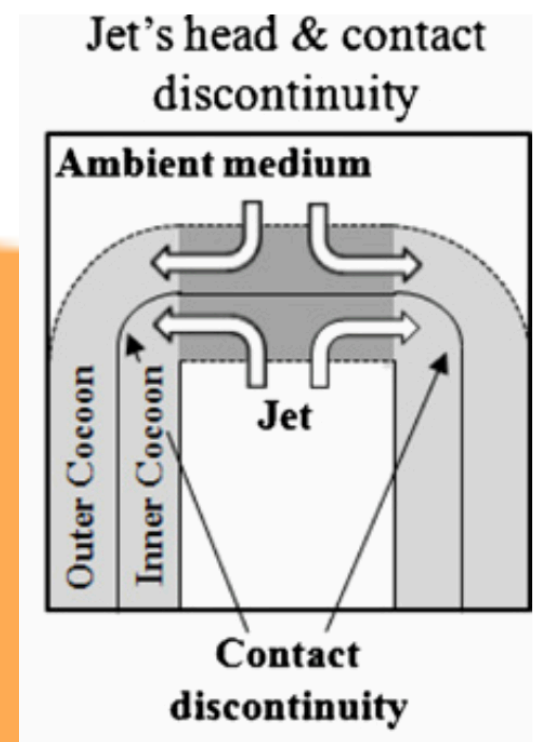
$$f_{\text{mix}} \sim 0.5 - 1$$

**Outer:
(Shocked CSM)**

$$\Gamma\beta \sim 0.1$$

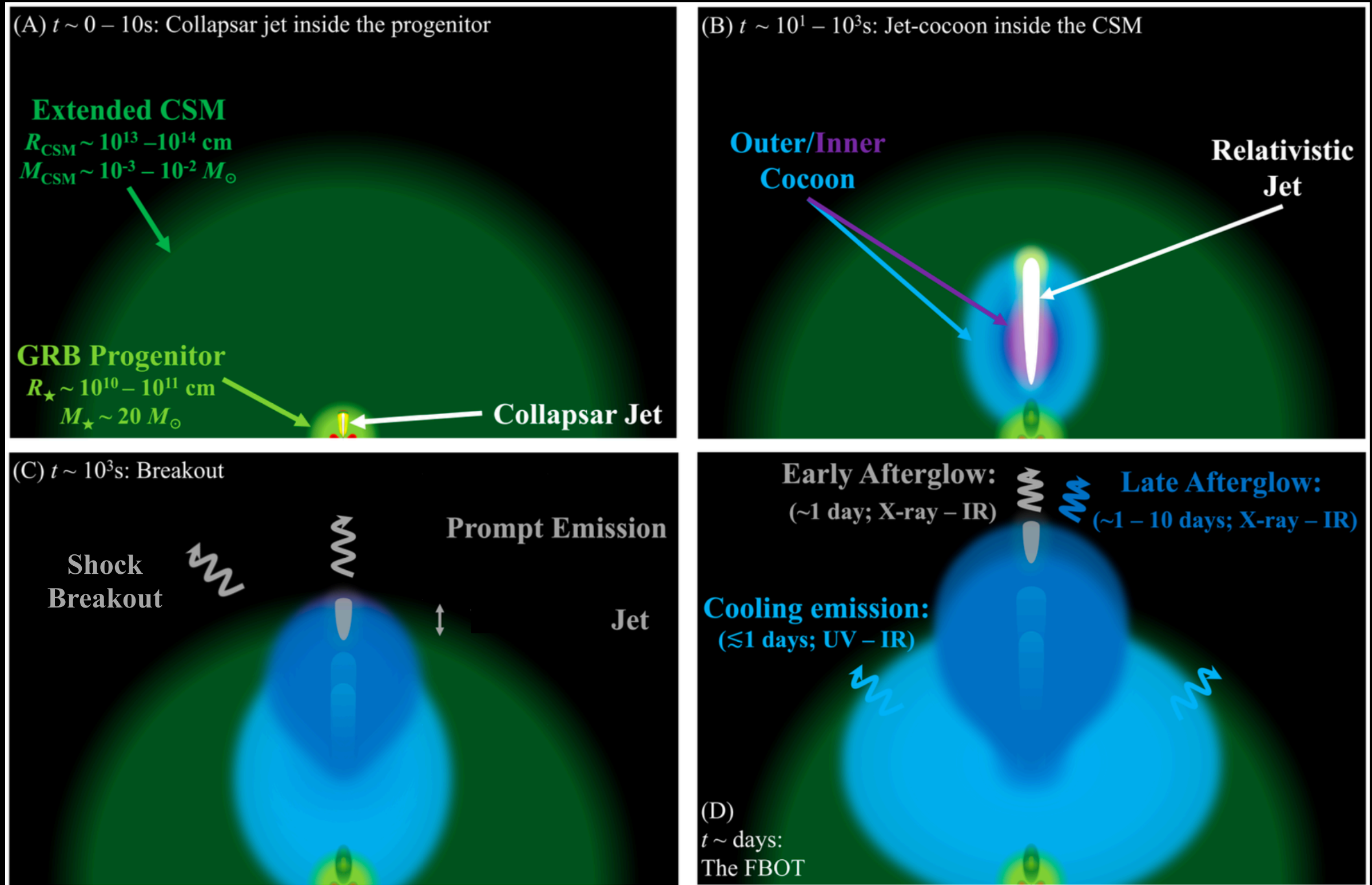
**Inner:
(Shocked Jet)**

$$\Gamma\beta \sim \text{a few}$$

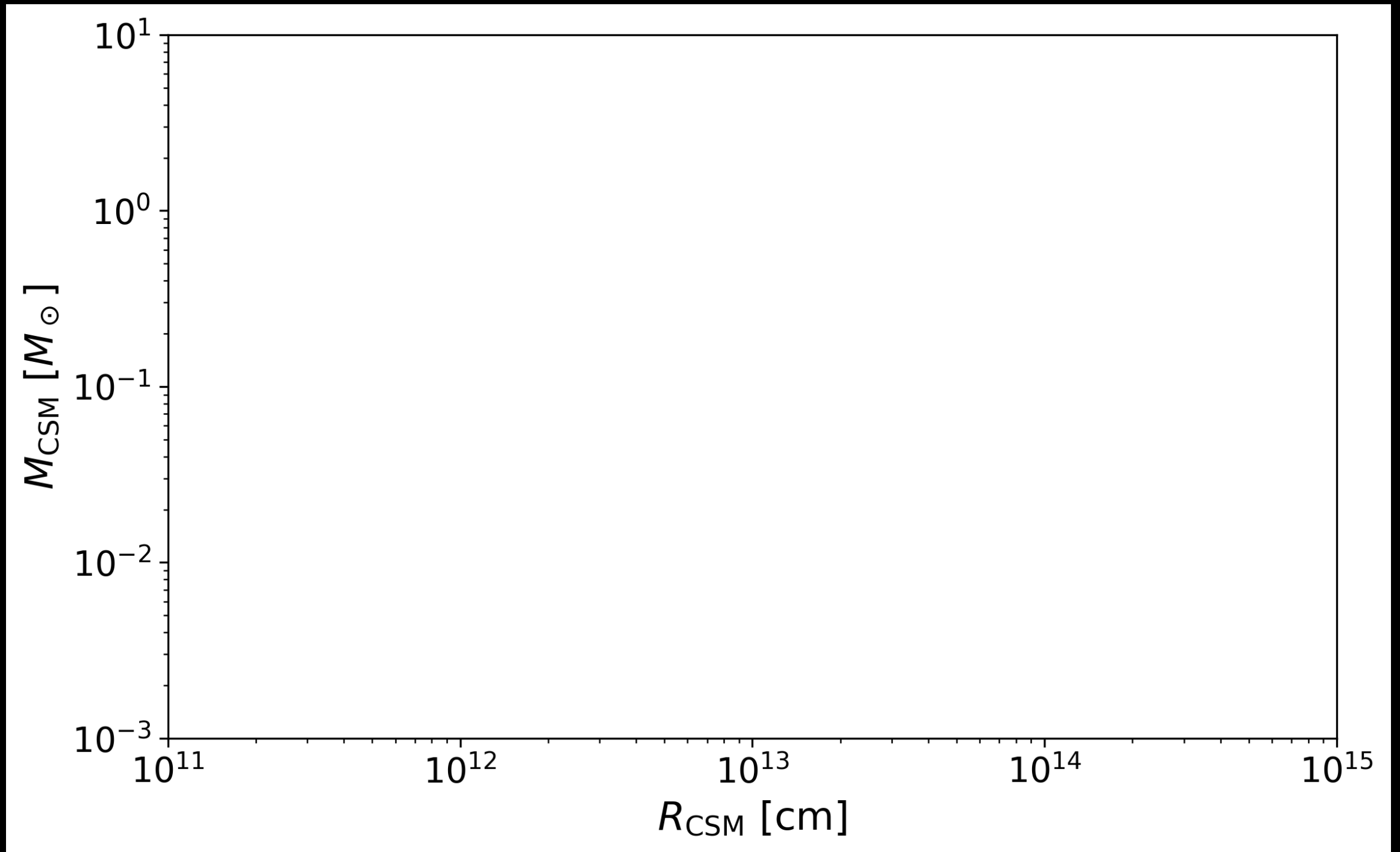


Bromberg et al. 2011

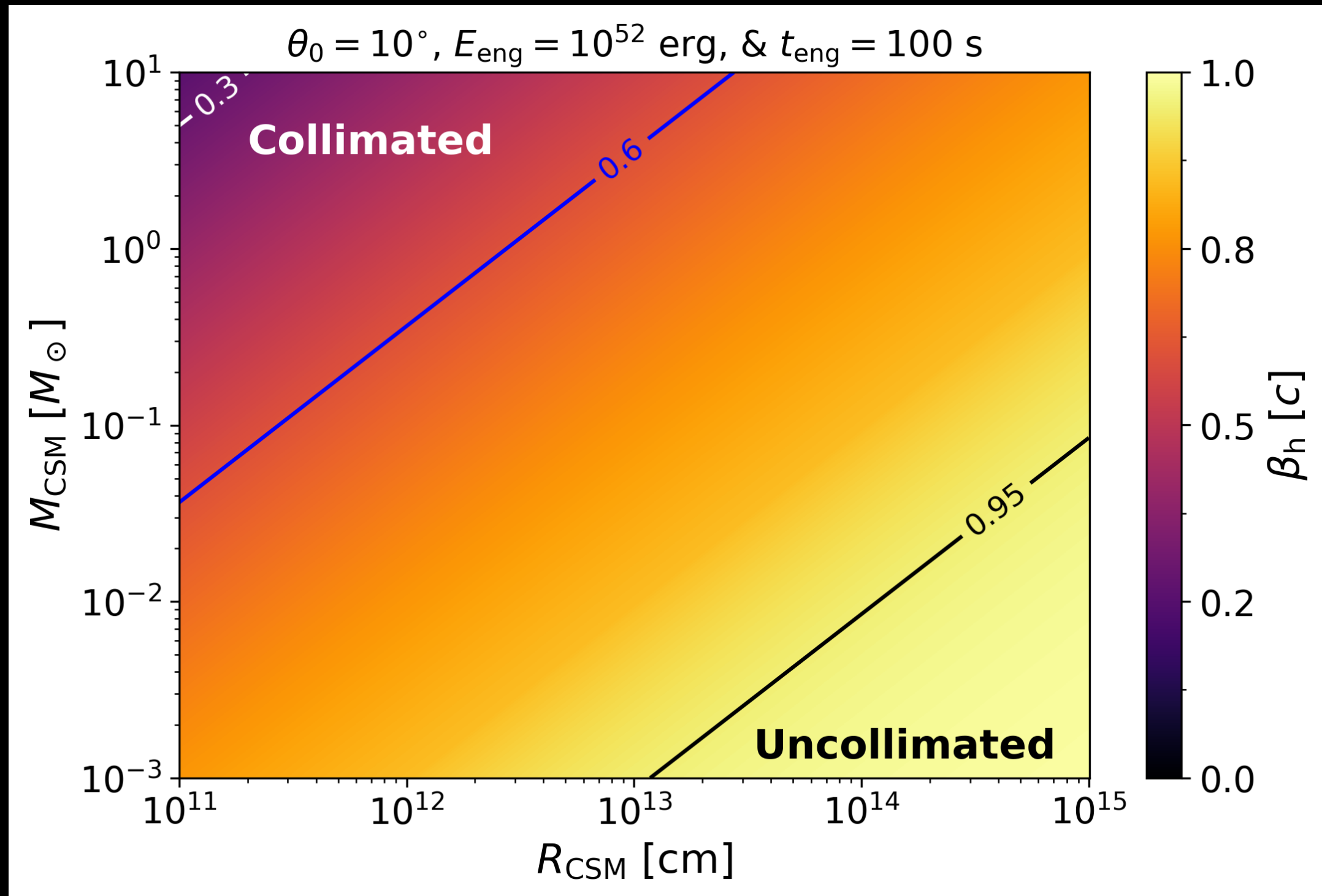
Jet-CSM: The Components



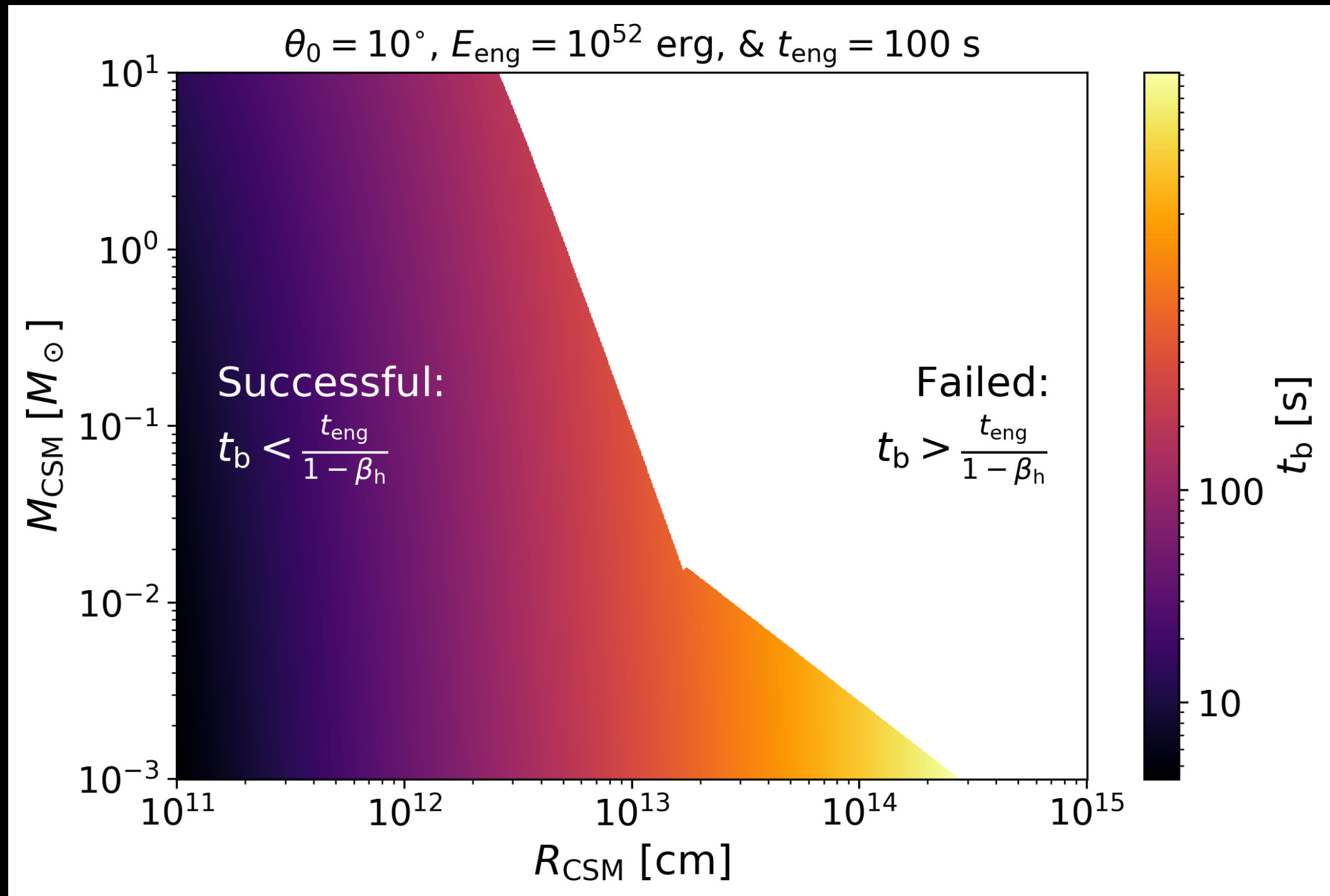
Exploring CSM parameter space



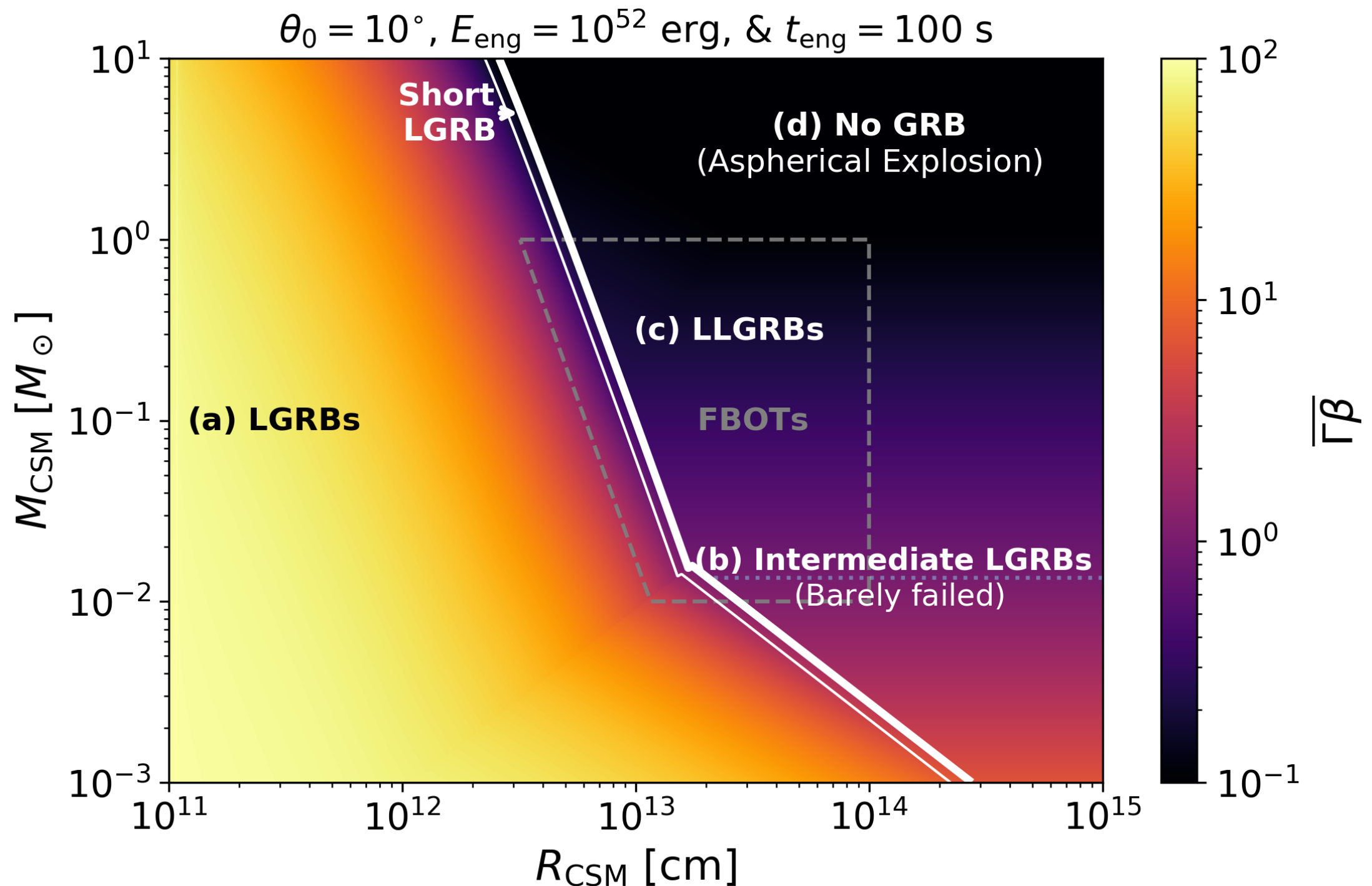
Jet head velocity quantified



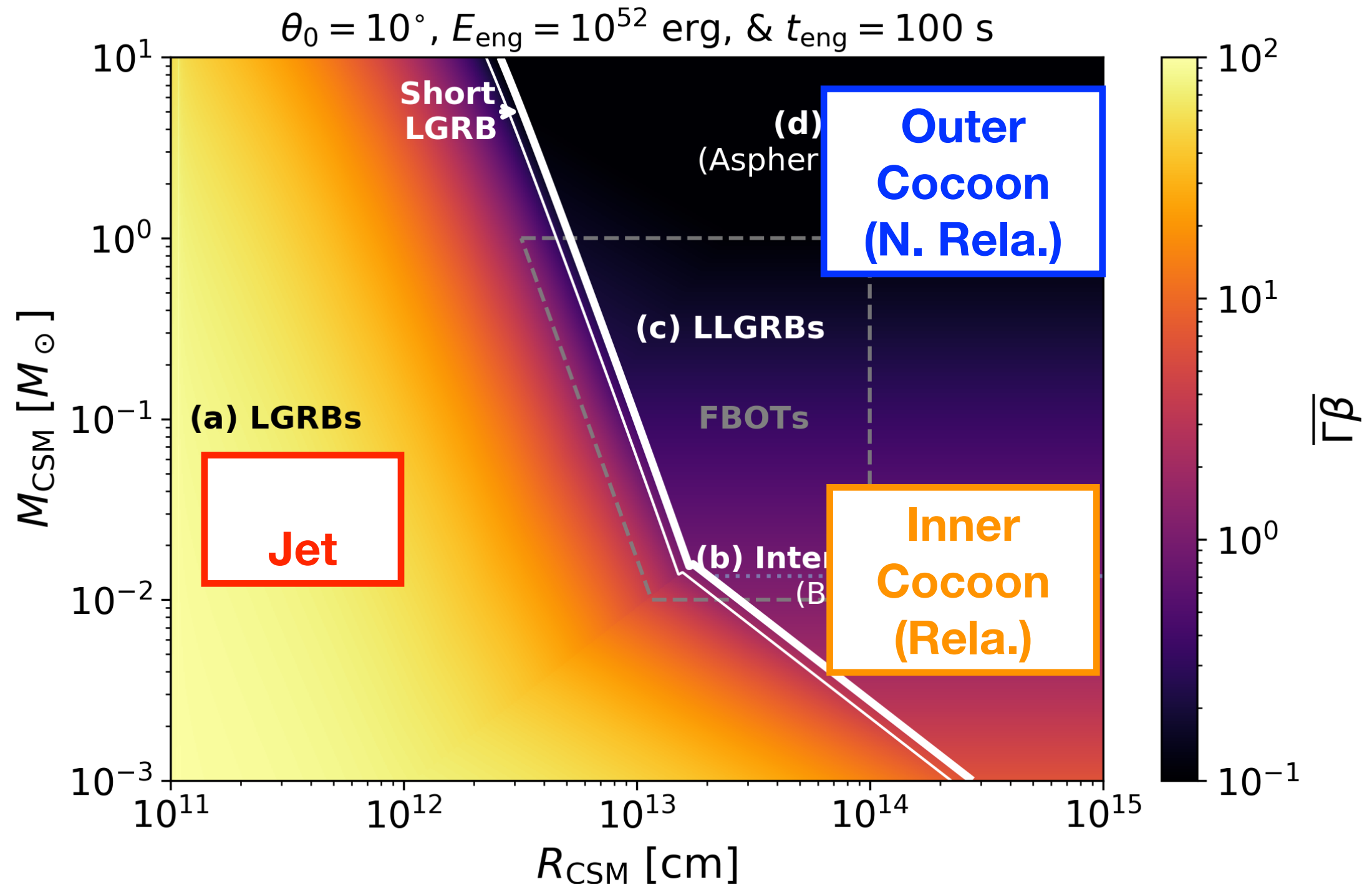
Jet Breakout/Success



Diversity of Transients



Diversity of Transients

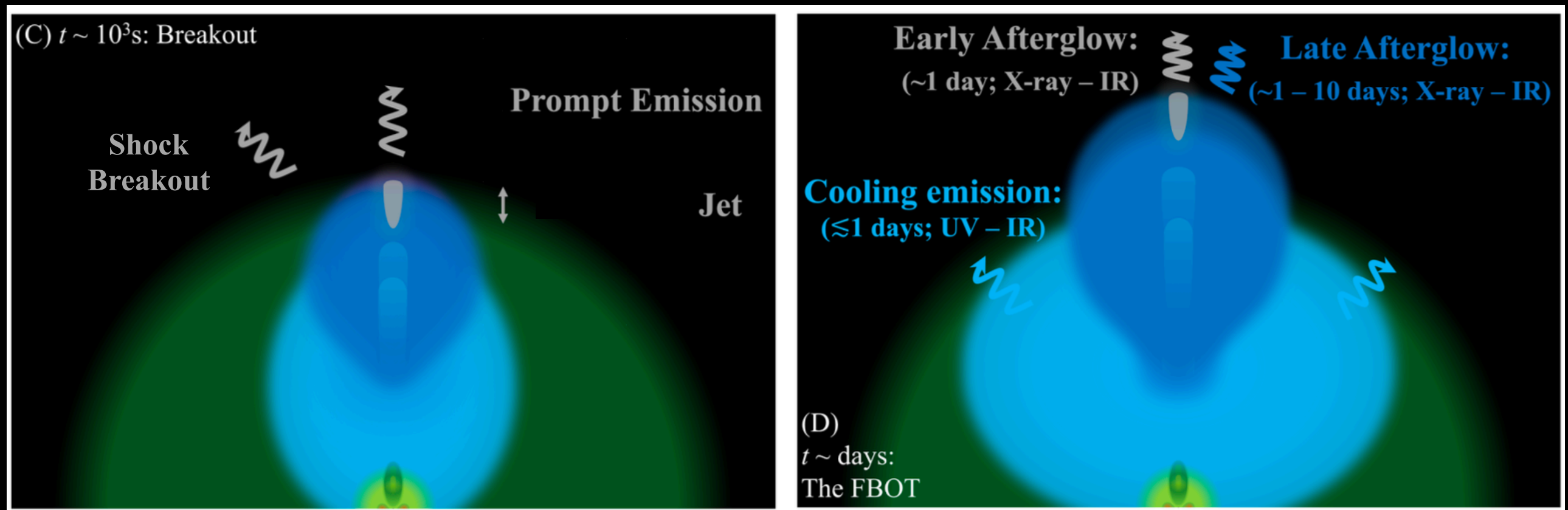


Method:

→ Analytic Modeling of
The **Emission**

Emission Modules

Prompt (η_X), **shock breakout** (Irwin+25), **afterglow** (VegasAfterglow; Wang+25), **cocoon cooling** (HH+25), & the **SN** (1998bw)



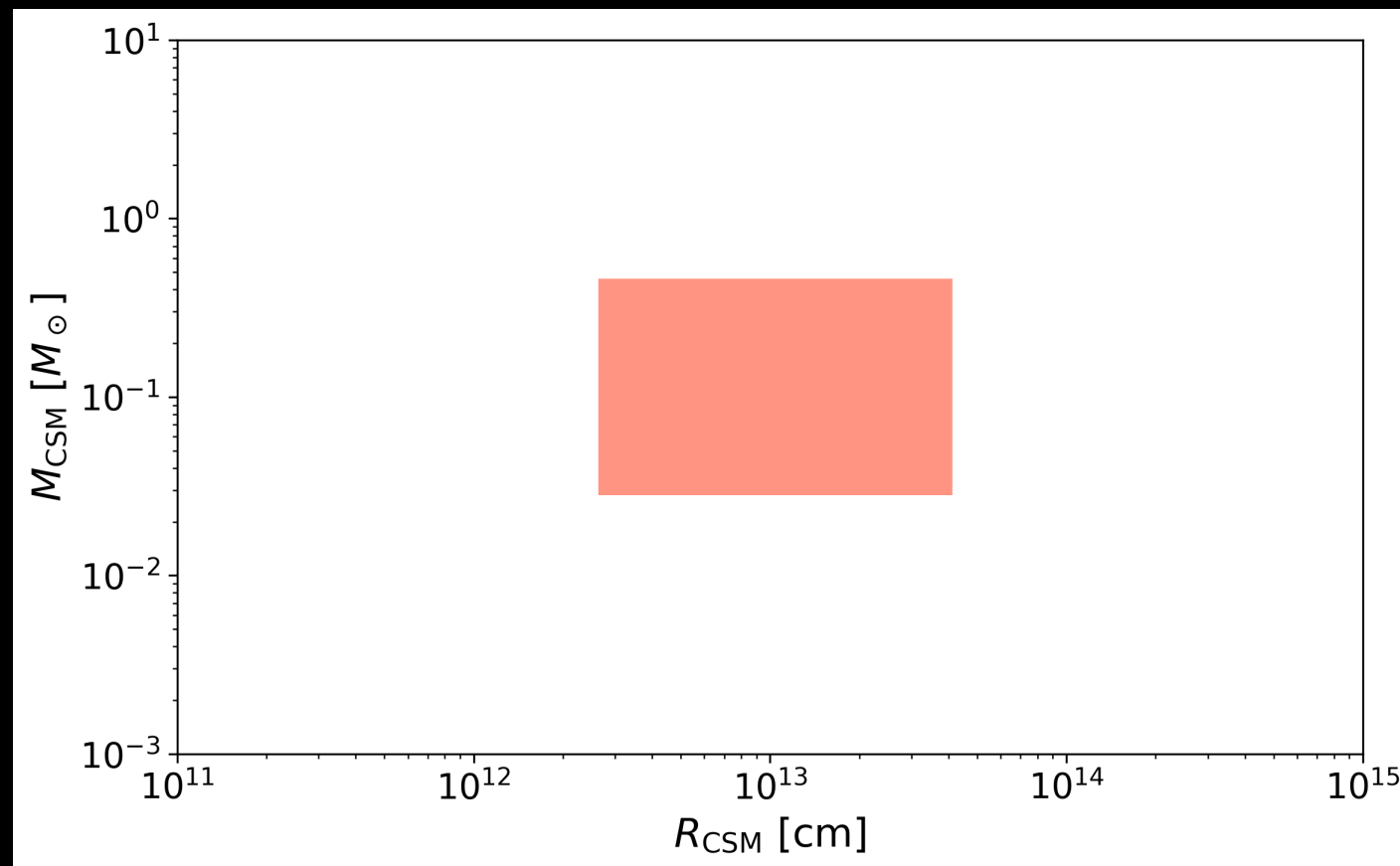
**Let us simulate/explore
different Jet-CSMs transients**

The parameter space

Jet energy ($10^{51} - 10^{52}$ erg), CSM mass ($0.03 - 0.3 M_{\odot}$) and radius ($10^{12.5} - 10^{13.5}$ cm), LOS ($0 - 90^{\circ}$)

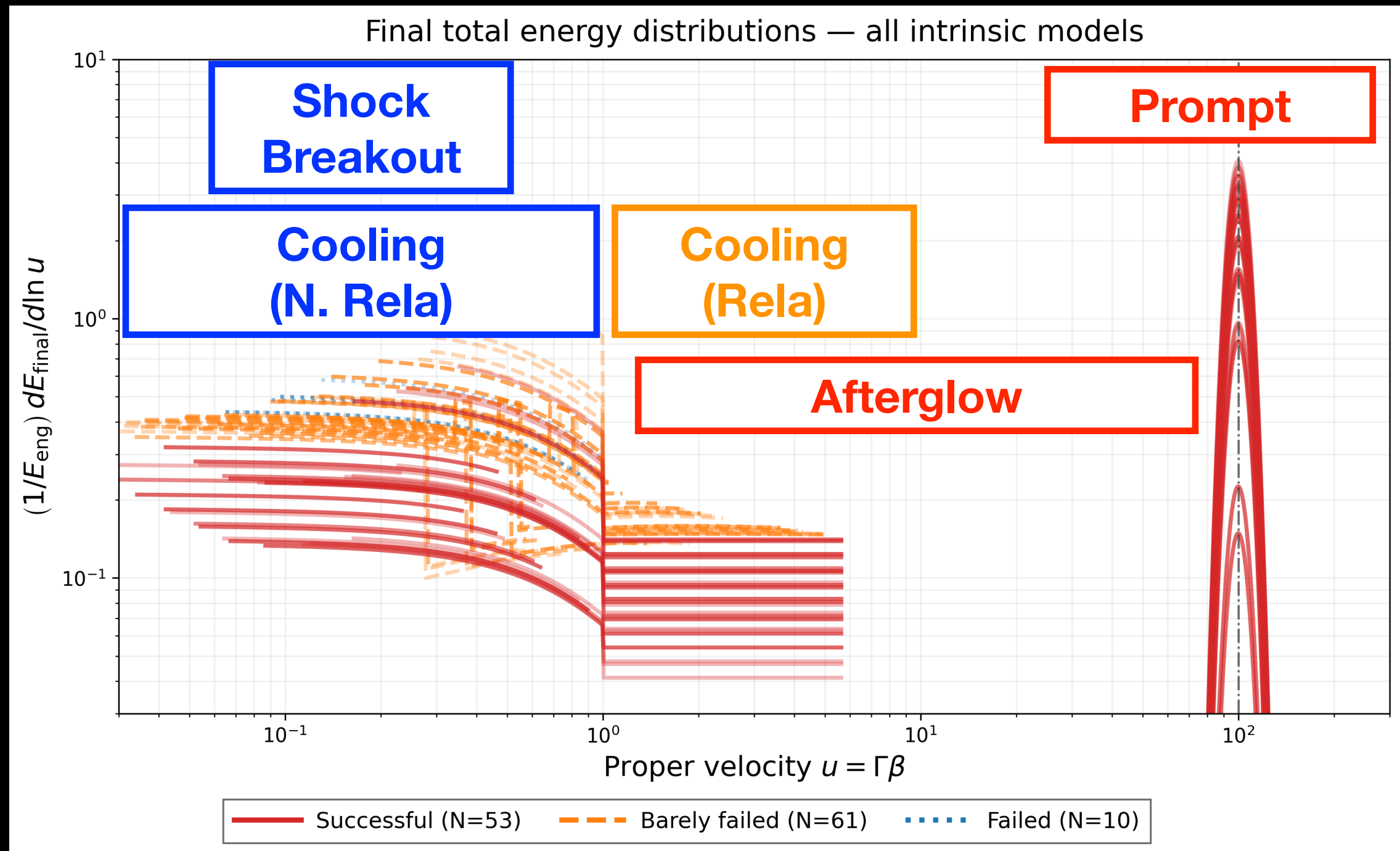
CSM space motivated by recent nearby events: EP240414a, EP250108a, and EP260321a

125 explosion $\times 10^2$ LOS $\sim 10^4$ light curves



Results

Results: Dynamics

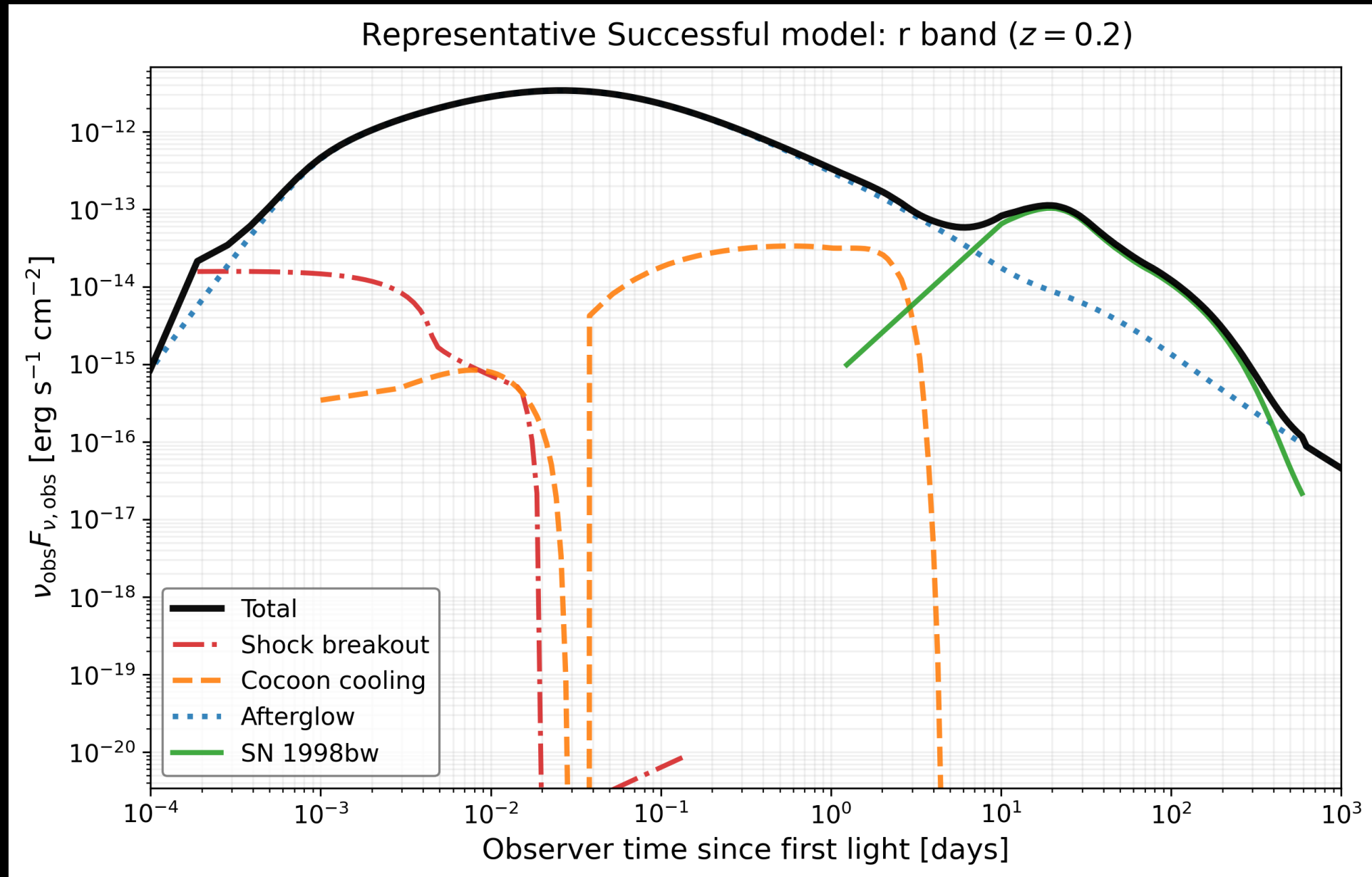


Outer
Cocoon

Inner
Cocoon

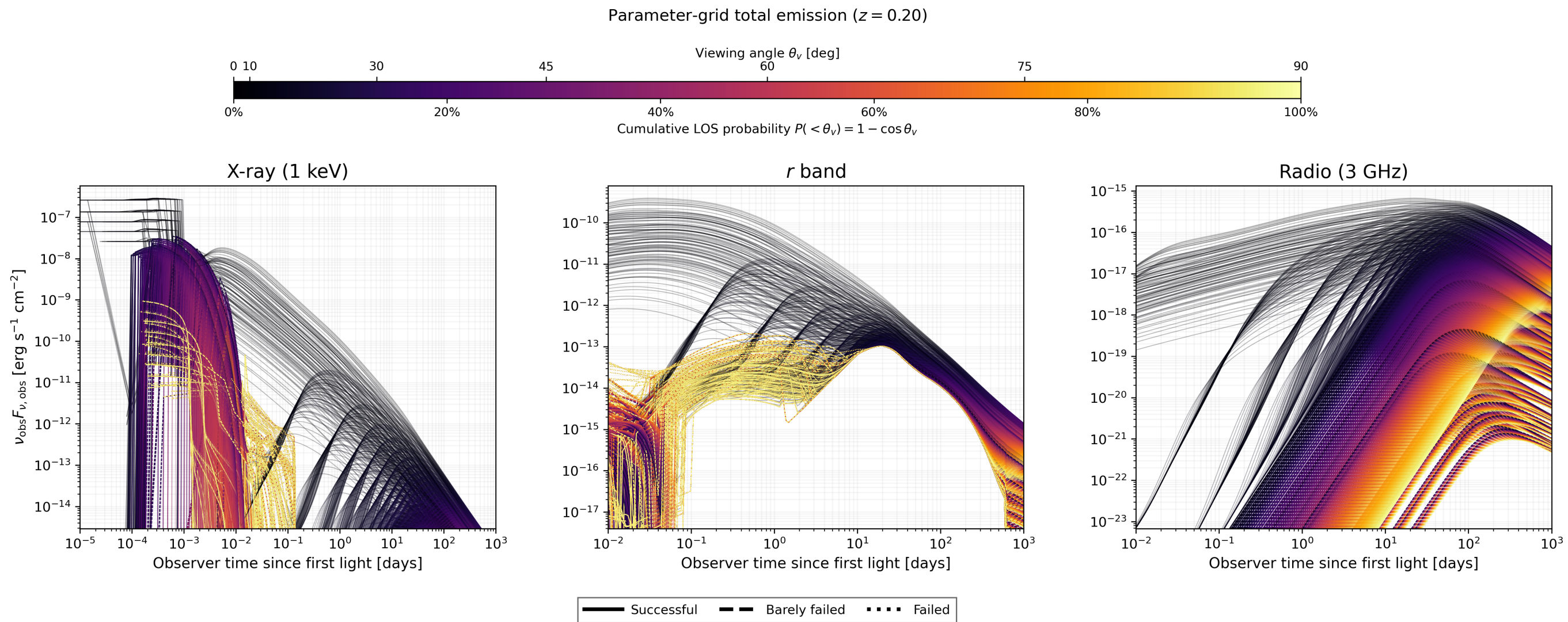
Jet

E.g., One light curve

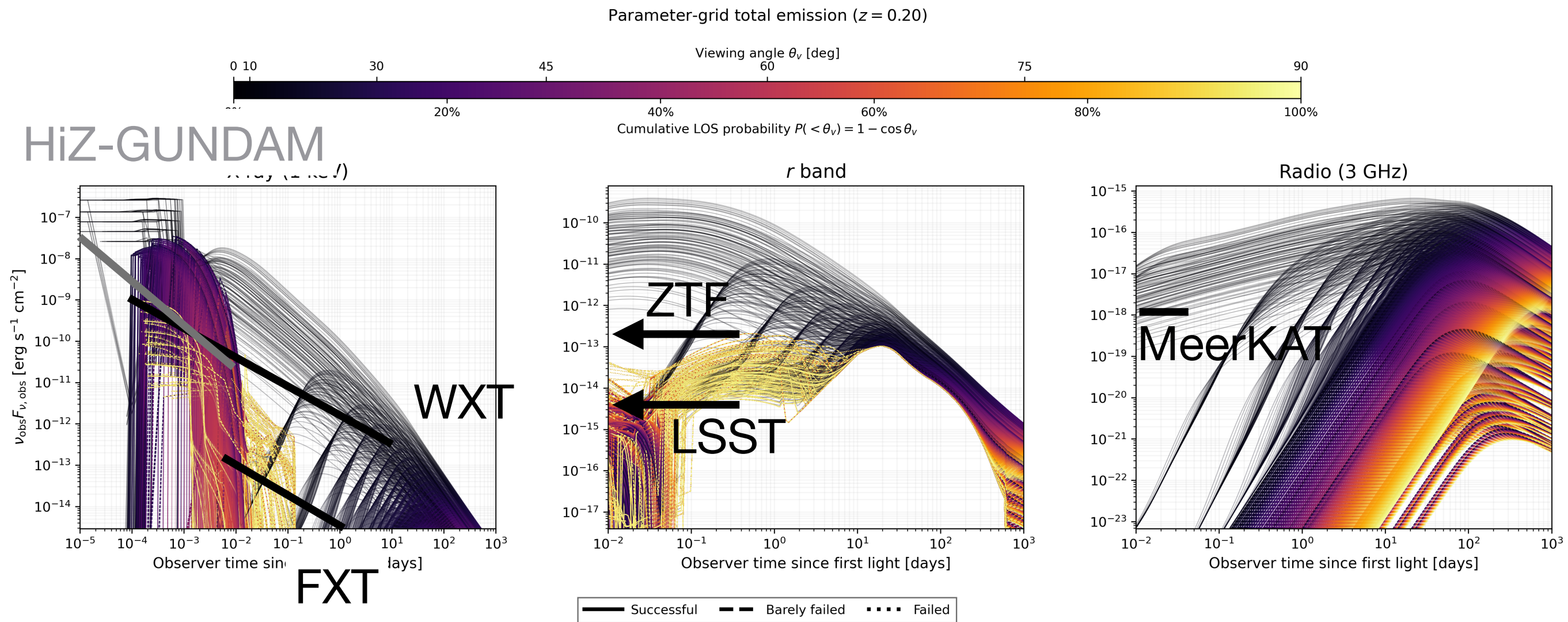


Jet energy ($10^{51.5}$ erg), CSM mass ($0.03 M_{\odot}$) and radius (10^{13} cm), LOS (10°)

Emission: $z = 0.2$ (Preliminary)



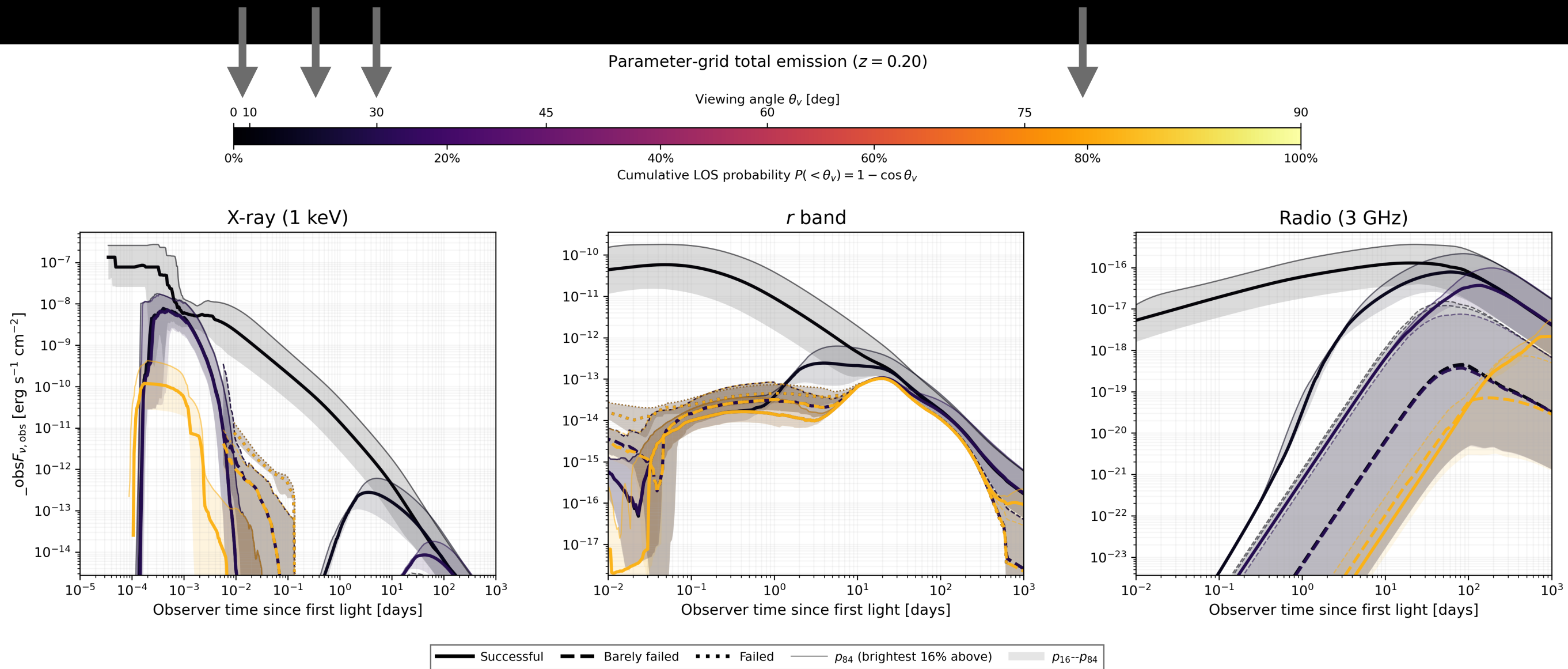
Emission: $z = 0.2$ (Preliminary)



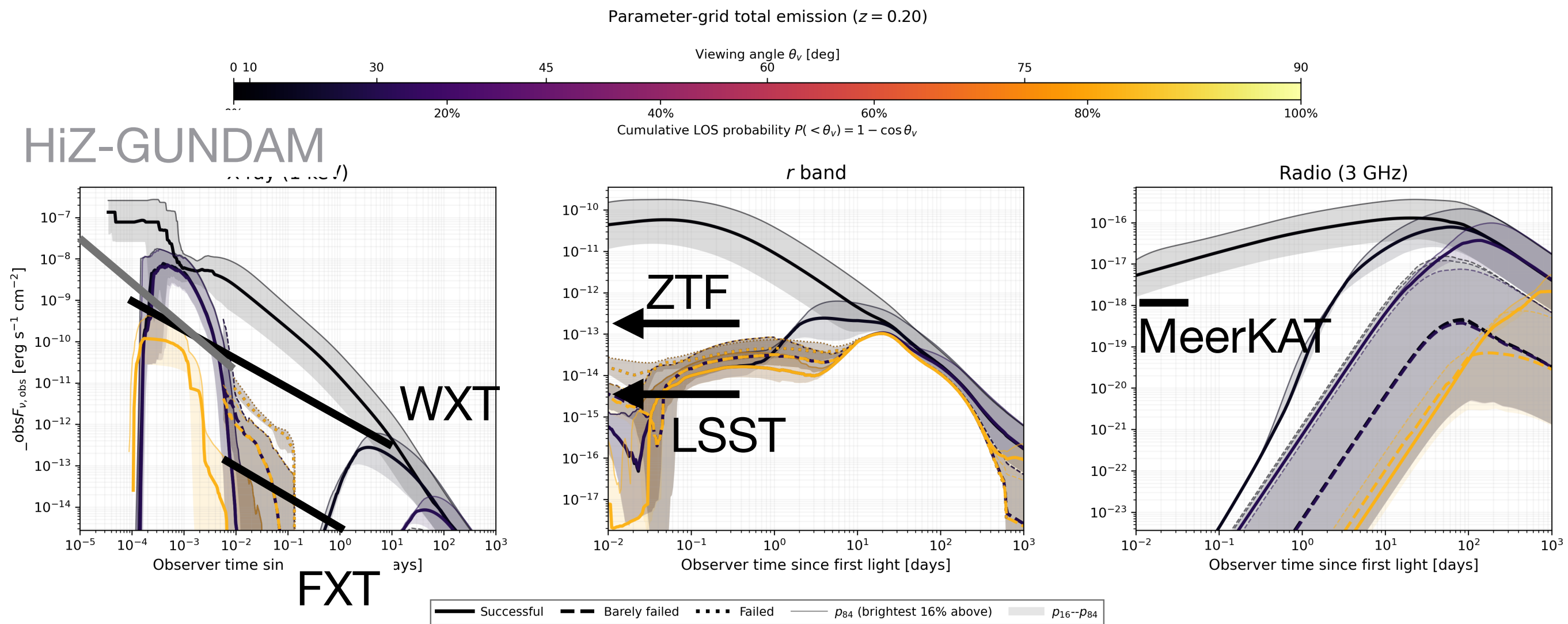
Even with EP + ZTF most $z \gtrsim 0.2$ failed jets are missed

Strong bias to successful GRB + afterglow

Emission: $z = 0.2$ (Preliminary)



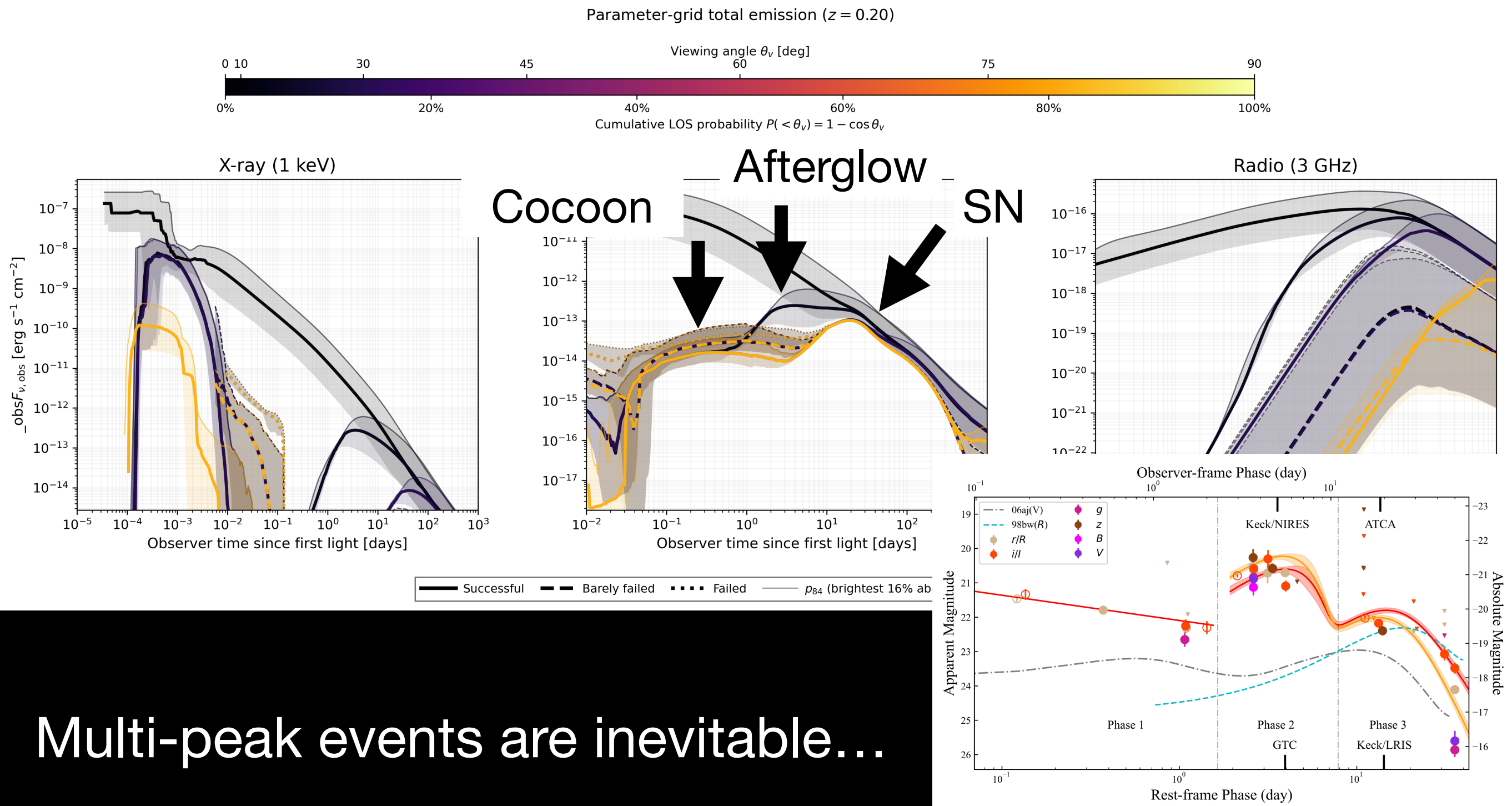
Emission: $z = 0.2$ (Preliminary)



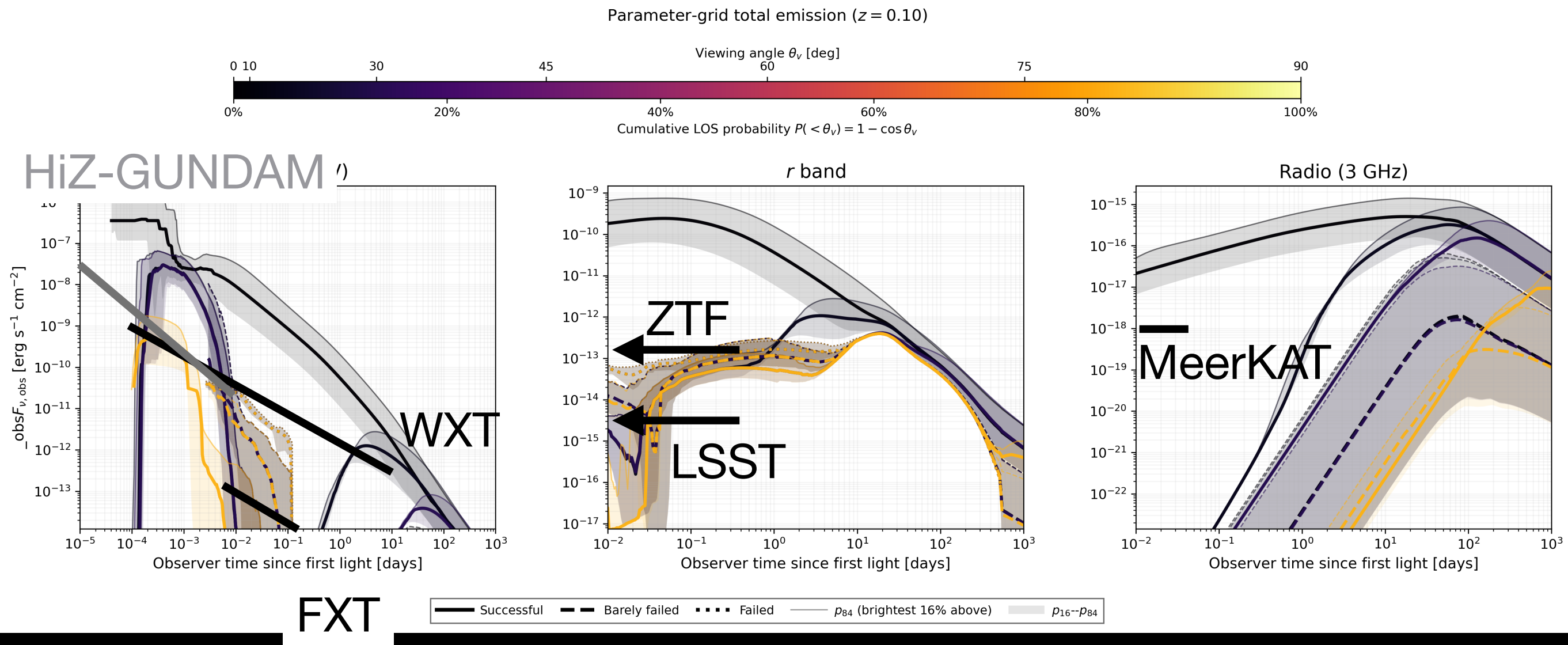
Only the high-L end of our LLGRBs can be detected...

LSST might see most “cocoon + BL Type SNe” events ($z \sim 0.2$)

Emission: $z = 0.2$ (Preliminary)



Emission: $z = 0.1$ (Preliminary)



More of our LLGRB population is detectable if at $z \sim 0.1$,
but still a significant fraction remain hidden

Event Rate

Assuming an intrinsic rate of LLGRBs $\sim 100 \text{ Gpc}^{-3} \text{ yr}^{-1}$

For $z \lesssim 0.1$ (0.42 Gpc): $\sim 30 \text{ events / yr}$

WXT coverage ~ 0.1 (optimistic): $\sim 3 \text{ events / yr}$

Assuming an intrinsic rate of LLGRBs $\sim 100 \text{ Gpc}^{-3} \text{ yr}^{-1}$

For $z \lesssim 0.2$ (0.82 Gpc): $\sim 200 \text{ events / yr}$

WXT coverage ~ 0.1 (optimistic): $\sim 20 \text{ events / yr}$

Summary

Growing evidence for CSM around GRBs

Modeling of jet-CSM dynamics and emission

$\sim 10^4$ of simulated event spanning: jet, CSM,
and viewing angle

Self-consistently produces diverse X-ray/Opt
transients (e.g., multi-peak events)

Multi-wavelength follow-up (& modeling) is
essential to distinguish the different jet
outcomes

Conclusion

EP + ZTF remain biased toward successful and energetic jets (although much less than Swift RIP & Fermi)

Beyond $z \sim 0.2$, the **census** of jet-driven transients becomes increasingly incomplete

Most of jet-driven transients may therefore remain hidden; typically with:

$$\nu L_\nu(1 \text{ keV}) \sim 10^{45} \text{ erg s}^{-1}, t \sim 10^3 - 10^4 \text{ s}$$

Future work: Modeling of EP events, Luminosity function of GRBs, high-energy emission (TeV, ν , etc.)

Detected:
Energetic
failed jets



Undetected: Typical
failed jets

$(z \gtrsim 0.2)$