

# The SN – GRB Connection: Making the continuum of engine-driven explosions

Brian Morsony

University of Maryland

Collaborators:

Davide Lazzati, Raffaella Margutti, Mitch Begelman,  
Chris Blackwell, Diego López-Cámara, Dominic Ryan

# Collapsars

- Woosley 1993
- GRB caused by jet from collapsing star
- Central engine drives jet
- Cocoon propagates through star
  - Blows apart the star
- GRBs should have SN
- Should be H-poor

# Hypernovae

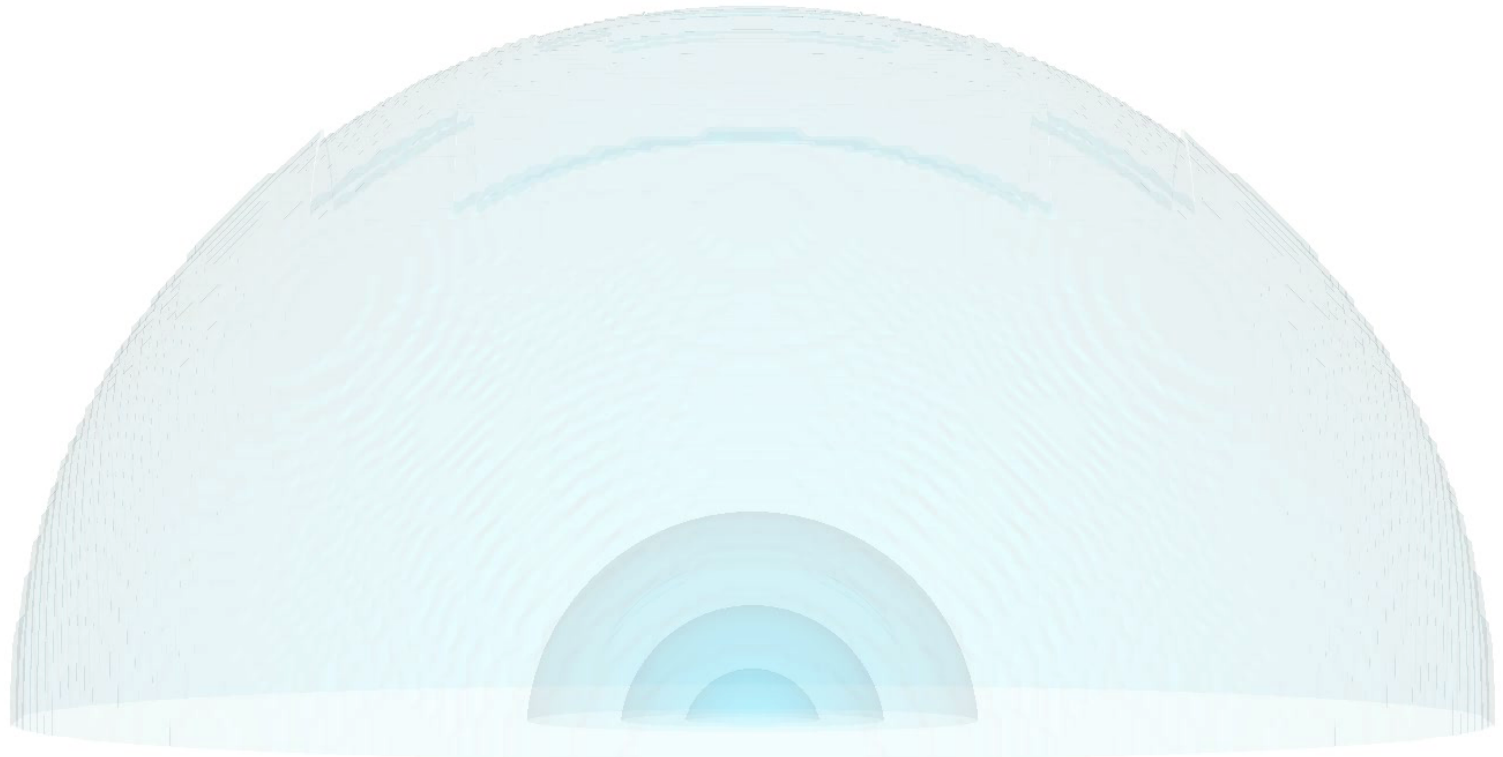
- Broad-line Ic
- $10^{52}$  erg
- 30,000 km/s expansion
- $\sim$  few  $0.1 \times M_{\odot}$  nickel

How do you make a GRB?

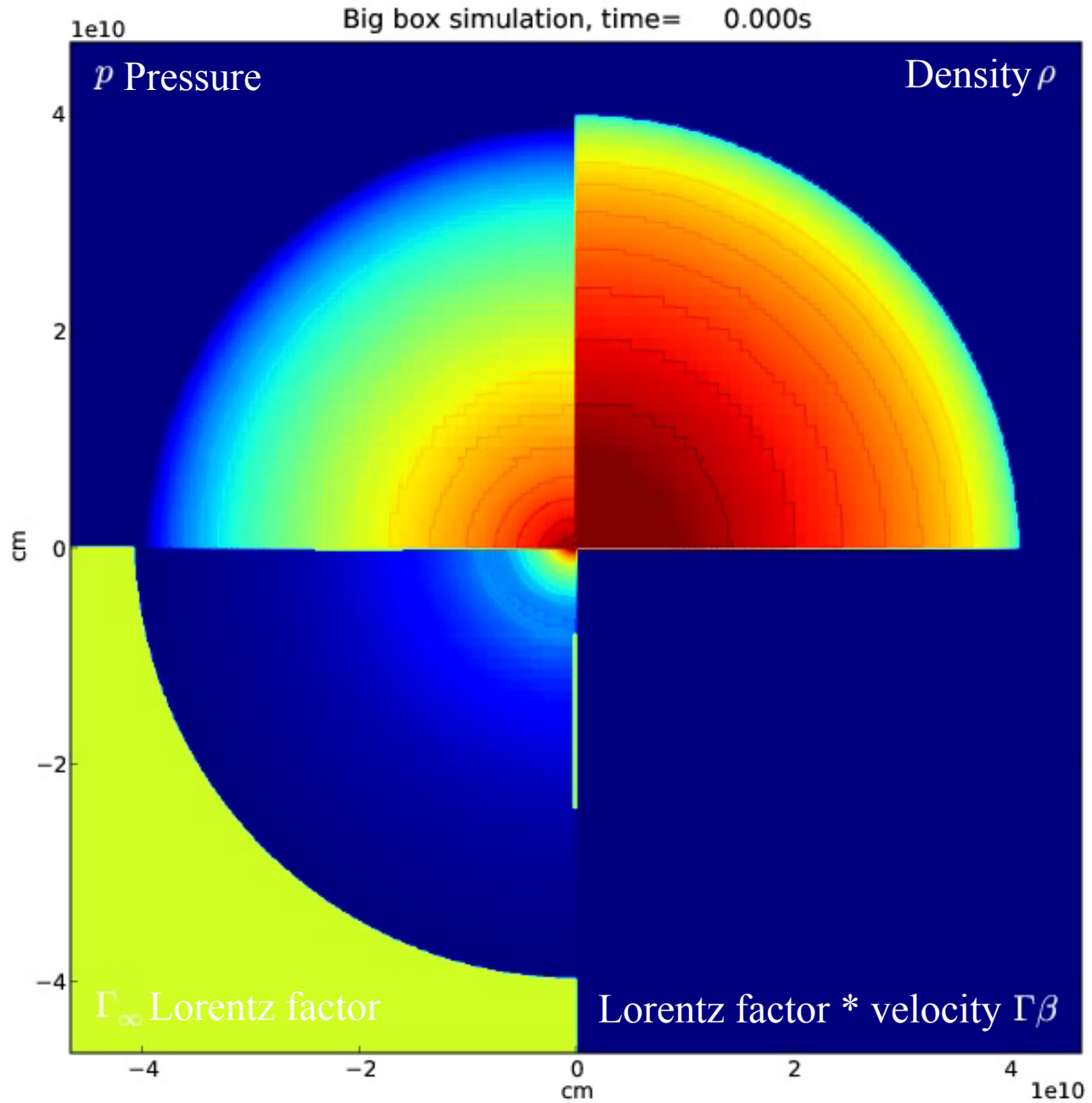
# How do you make a GRB?

- Compact massive star
  - Model 16TI from Woosley & Heger (2006)
- Collimated Jet
- Long lived (10s of seconds)
- Lots of energy ( $\sim 10^{52}$  erg)
  
- Aloy+ 2000, Zhang+ 2003, 2004, Mizuta+ 2007, 2009, Morsony+ 2007, 2010, Lazzati+ 2009, 2011, 2012, etc.

3D



2D

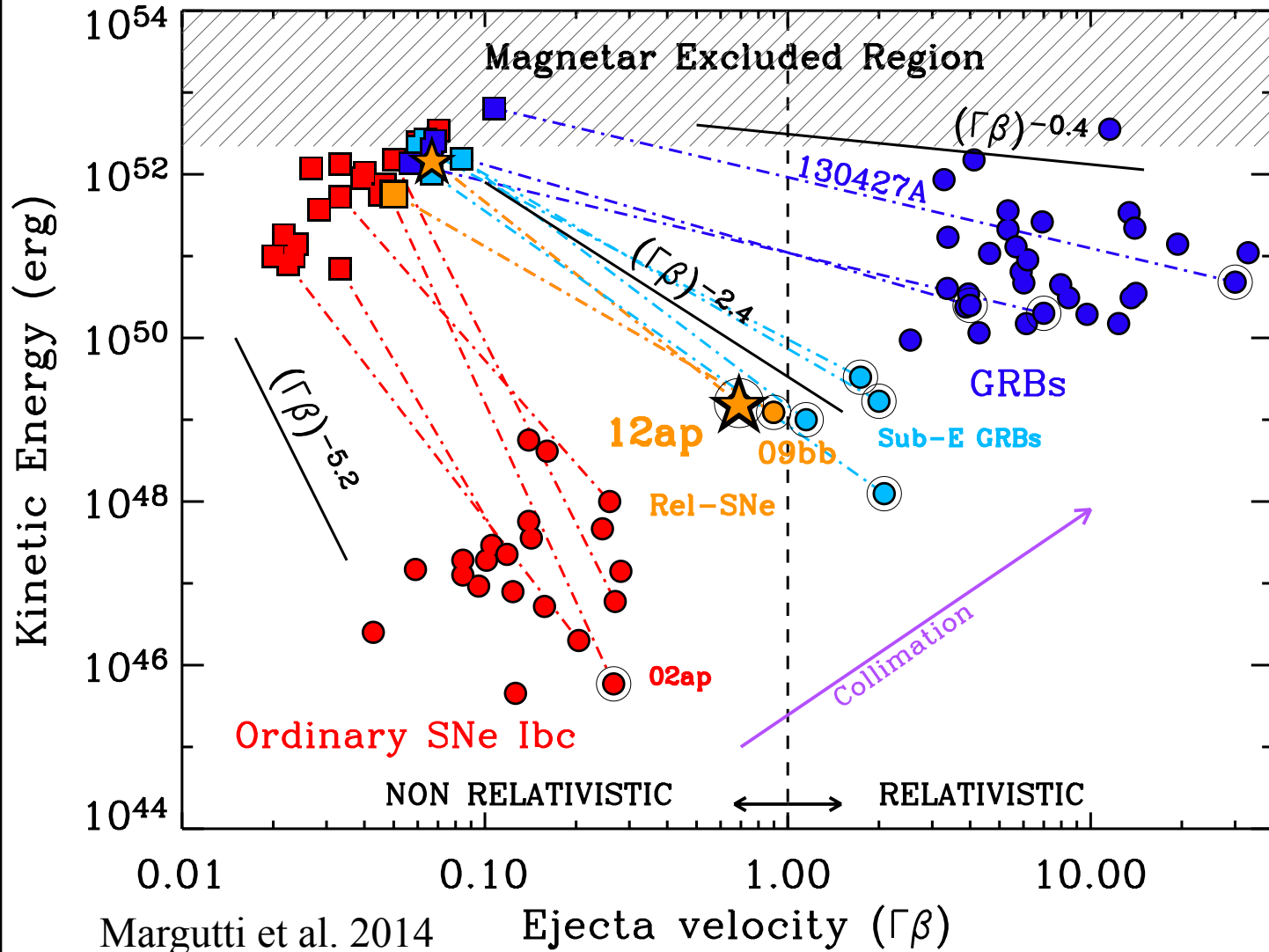


# Continuum of engine-driven events

- Cosmological GRBs
- Low-z GRBs (1998bw)
- Relativistic SN (2009bb, 2012ap)
- All associated with BL-Ic



# Supernova and Radio Energy



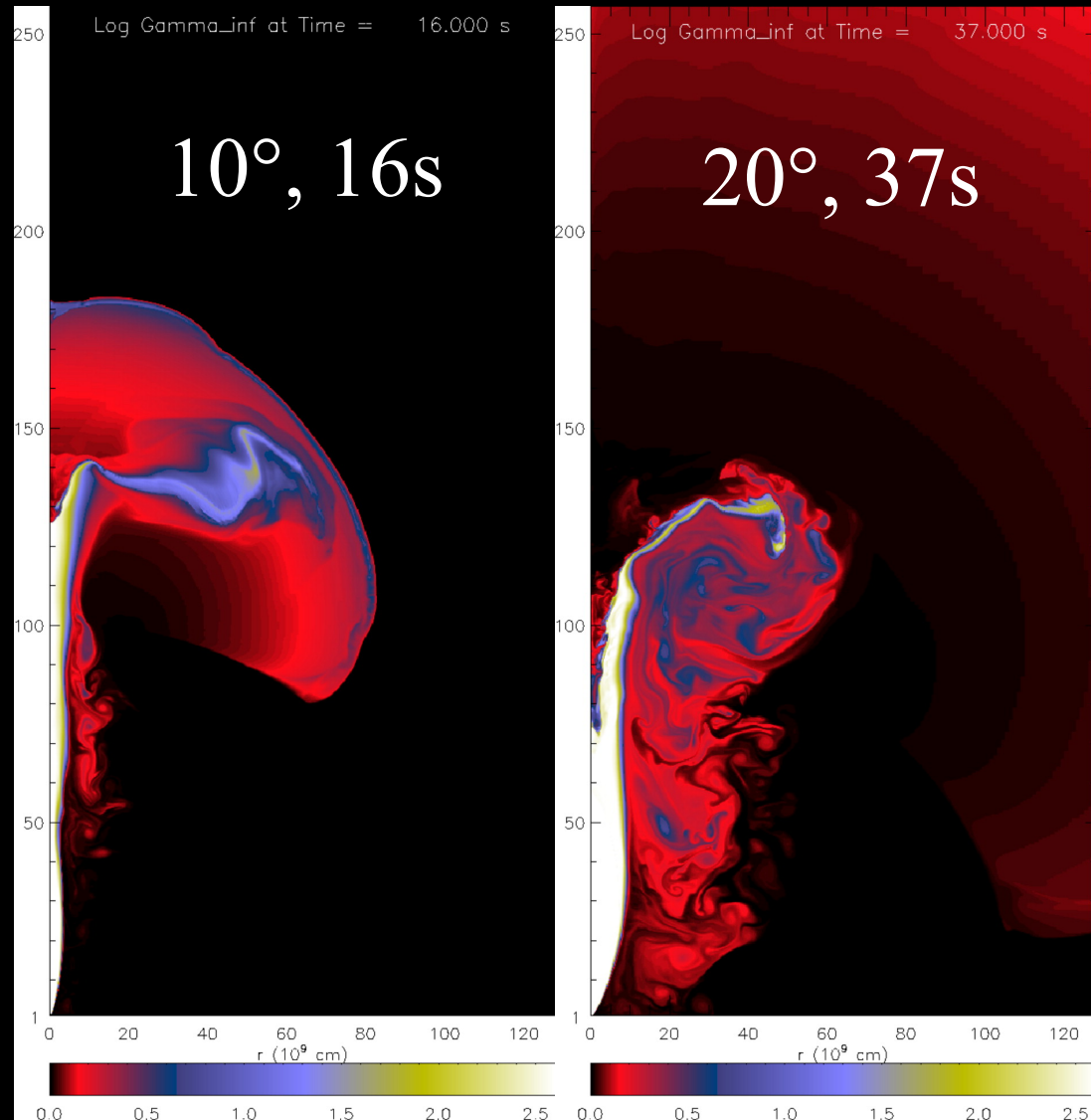
How do you NOT make a GRB?

# How do you NOT make a GRB?

- Easy!
- Wide jet opening angle
- Low jet power
- Wobbly jet
- Larger radius star (extended envelope)

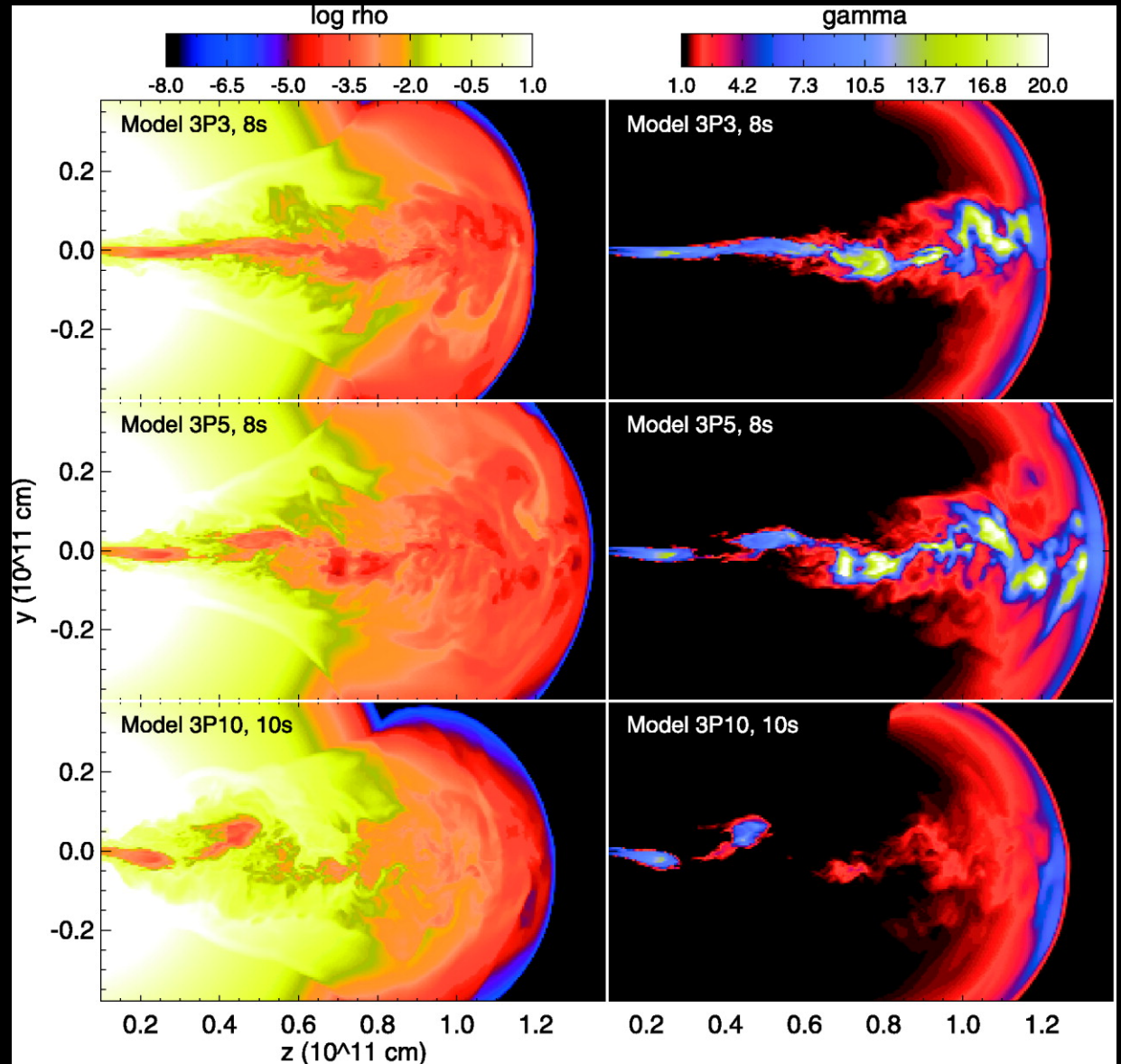
# Wide opening angle

- Morsony et al.  
2007



# Wobbly Jet

- $3^\circ$ ,  $5^\circ$ ,  $10^\circ$  precession
- Zhang, Woosley & Heger 2004

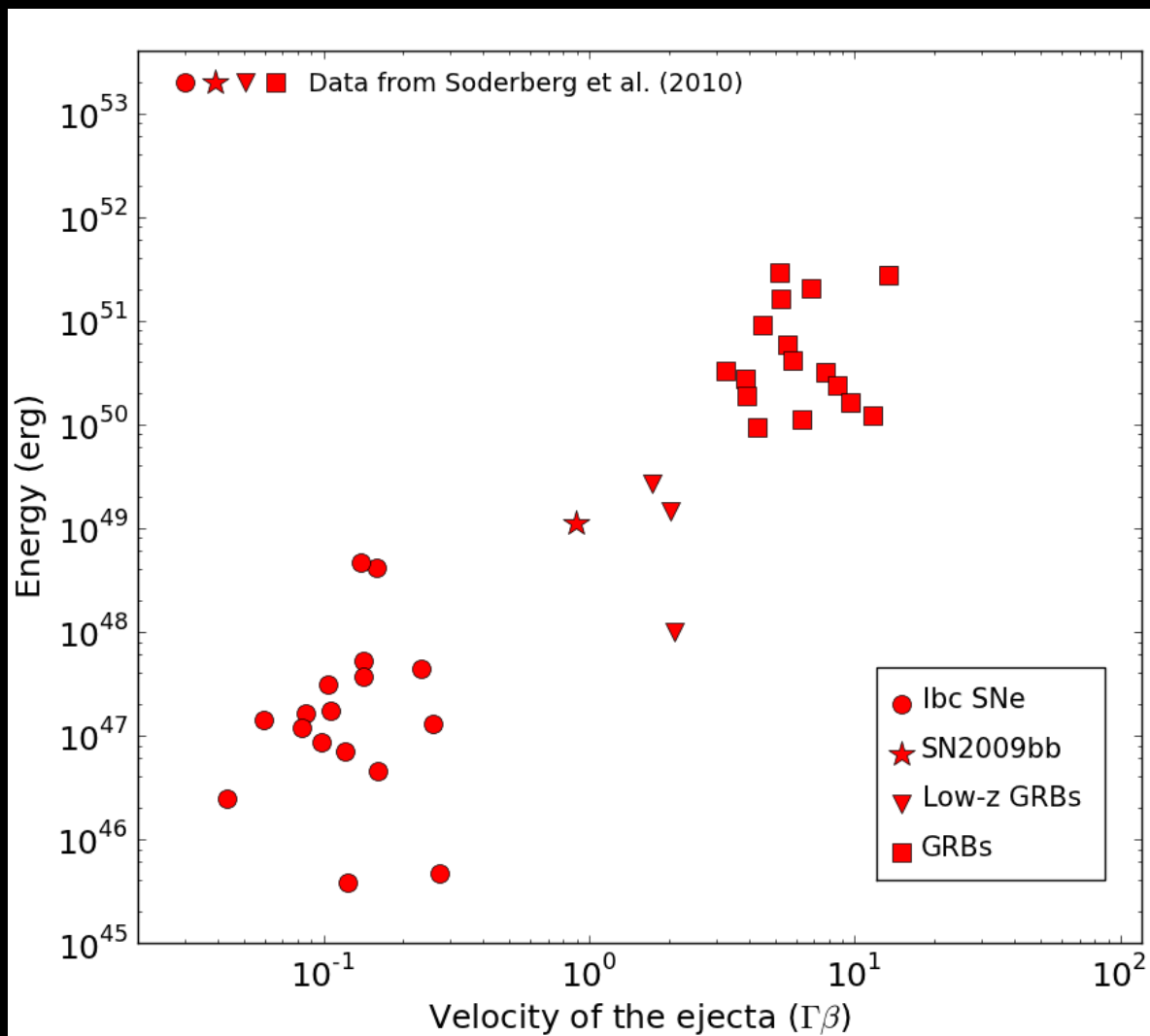


What is needed to make a GRB  
vs. Relativistic SN?

# What is needed to make a GRB vs. Relativistic SN?

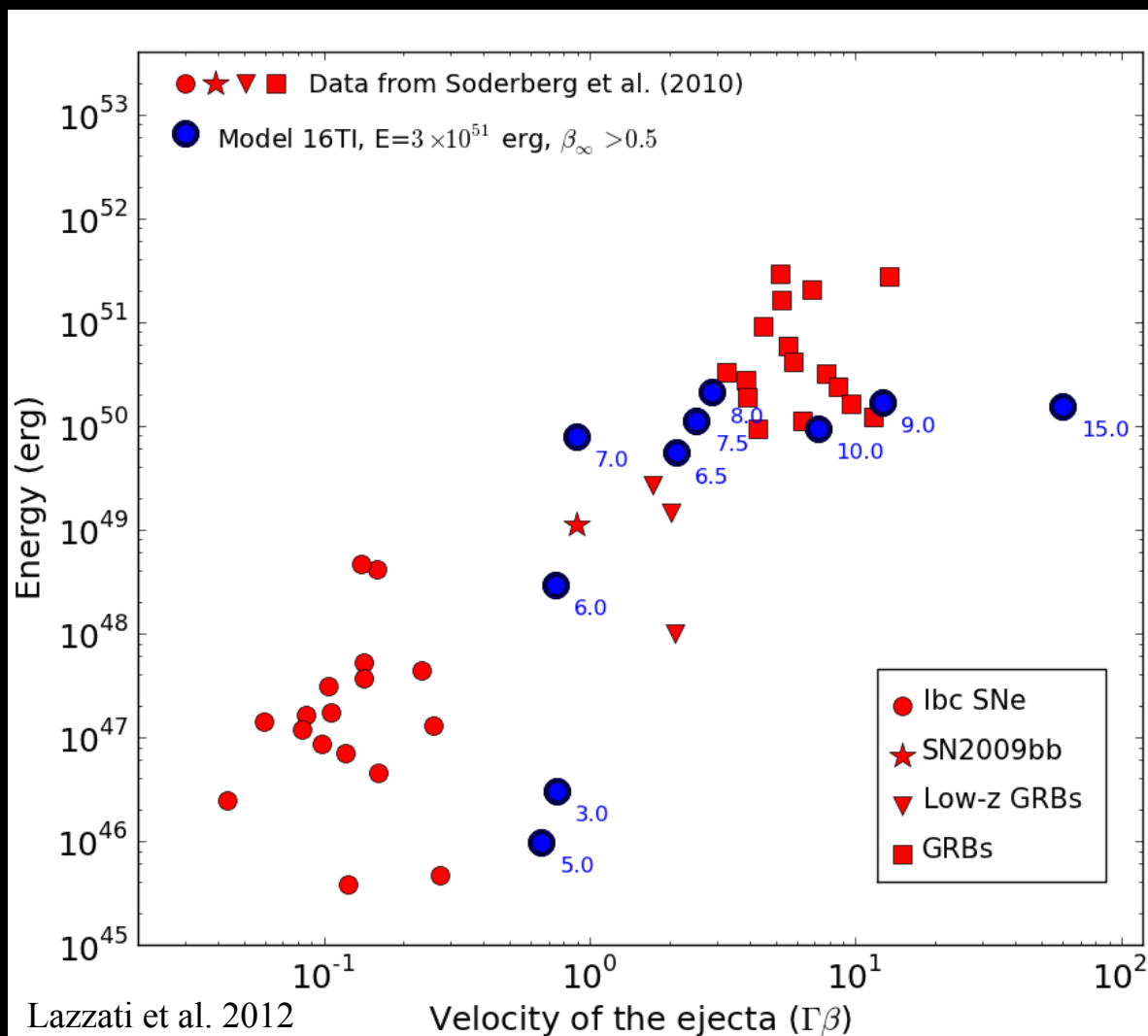
- Set up a GRB simulation with a fixed amount of total energy
- Change how long we take to inject energy
- See how much relativistic material escapes and how fast it's moving

# Radio Energy vs. Velocity

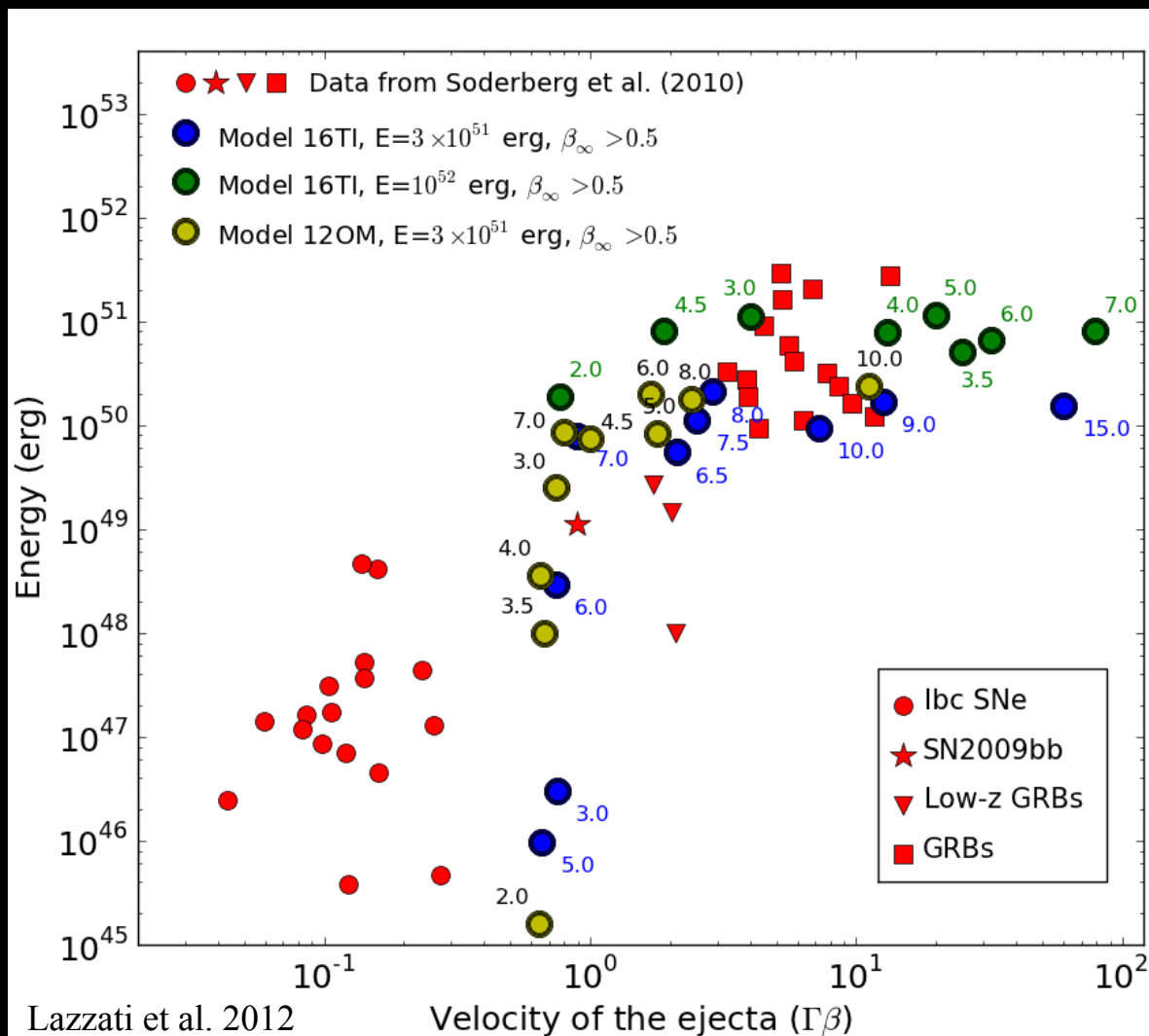




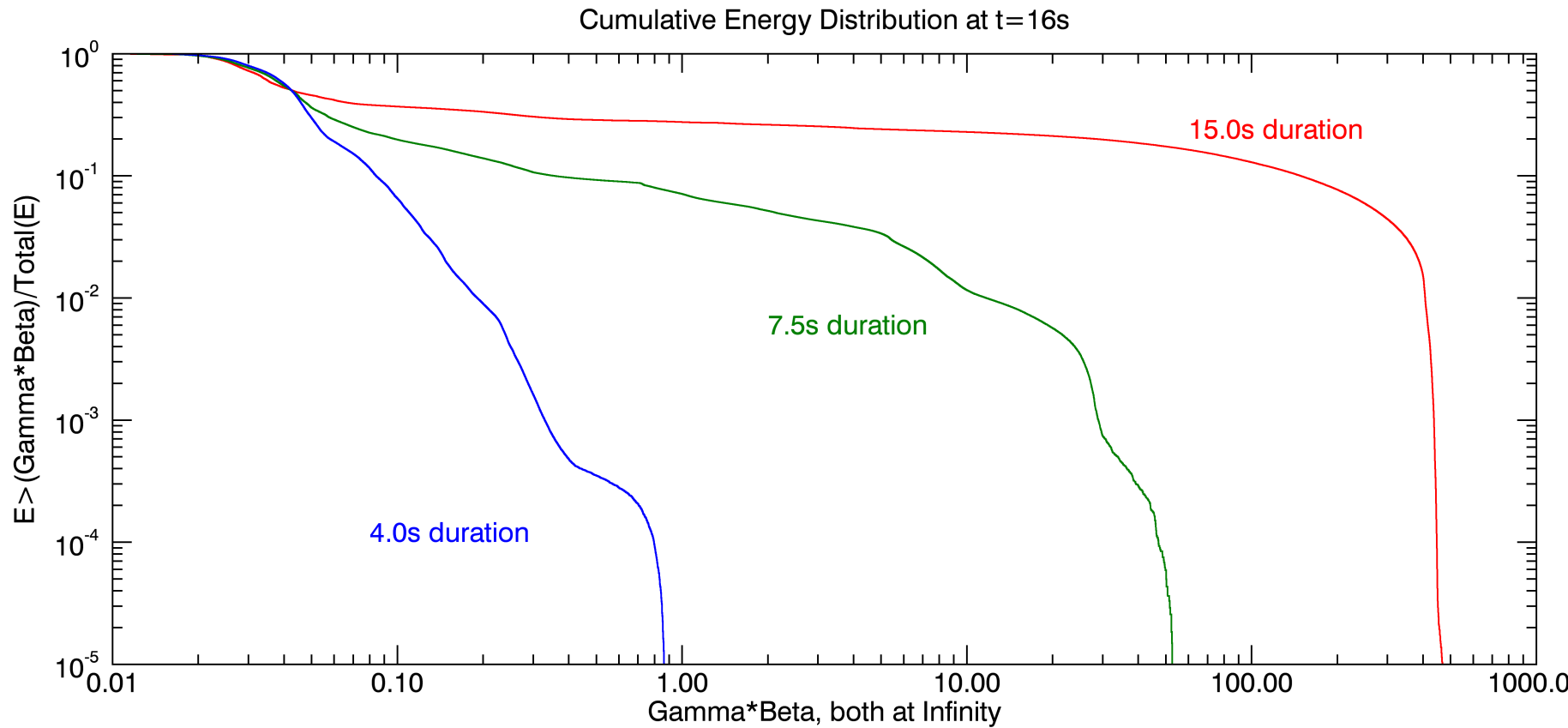
# Radio Energy vs. Velocity



# Radio Energy vs. Velocity

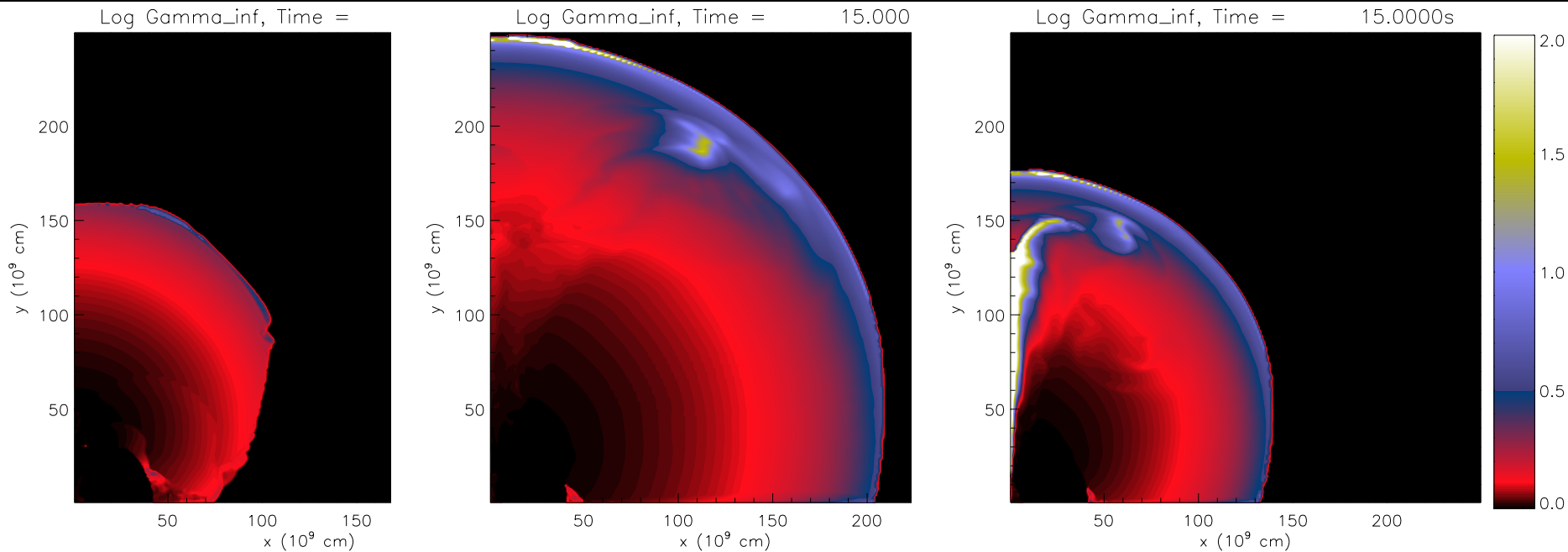


# Energy Distribution



# Morphology

- @ 15s after jet turn-on

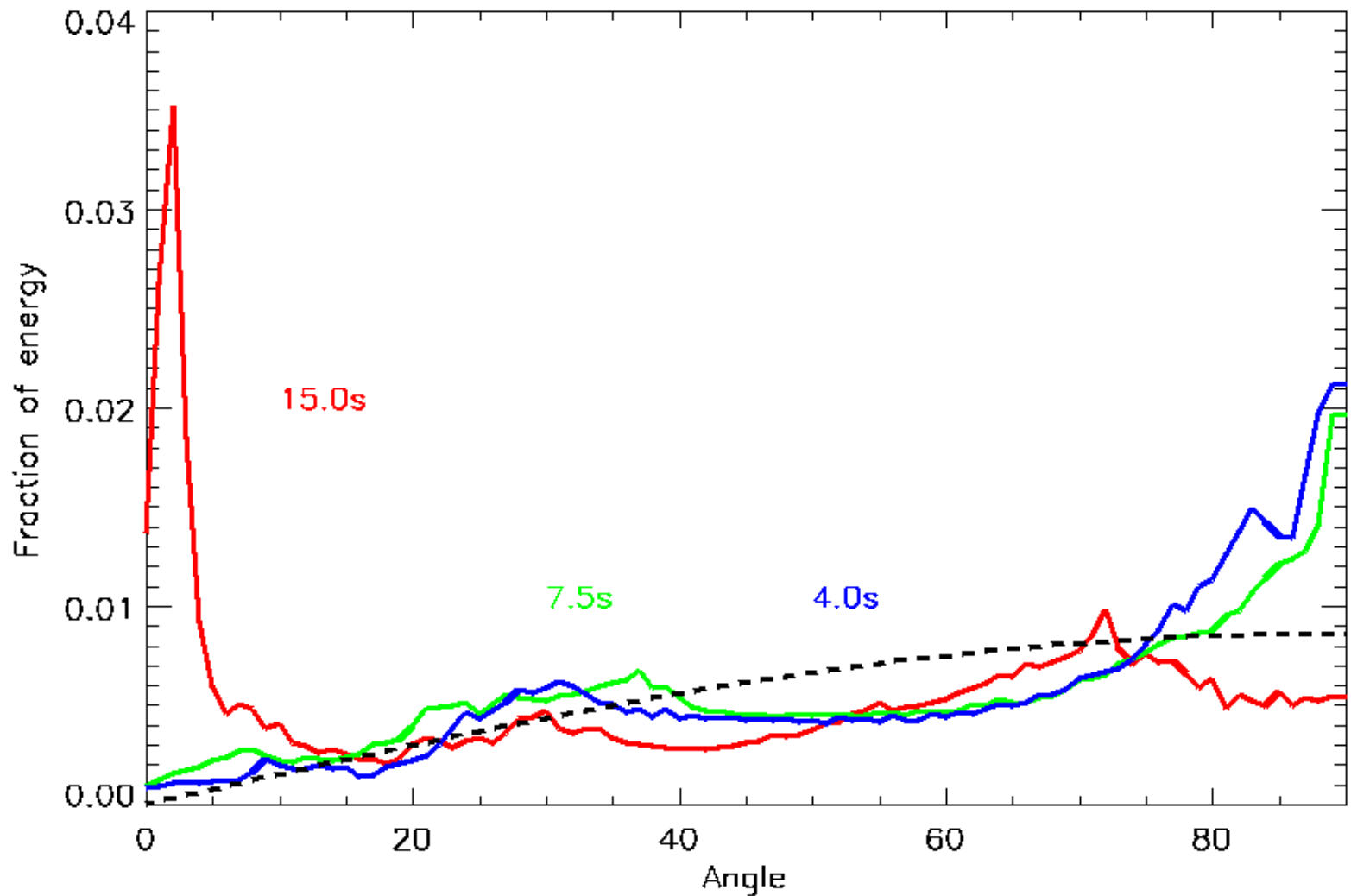


4s Engine

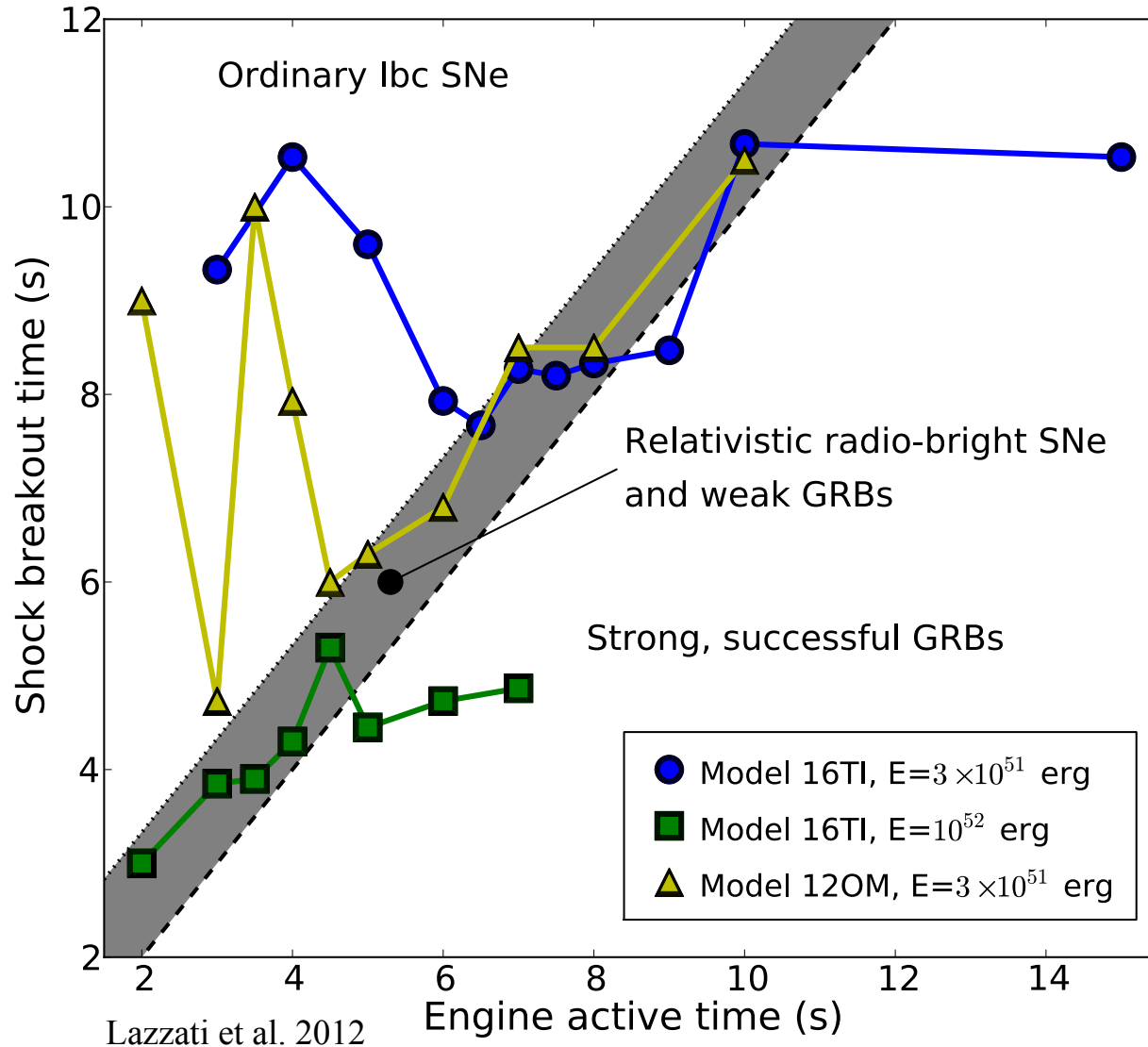
7.5s Engine

15s Engine

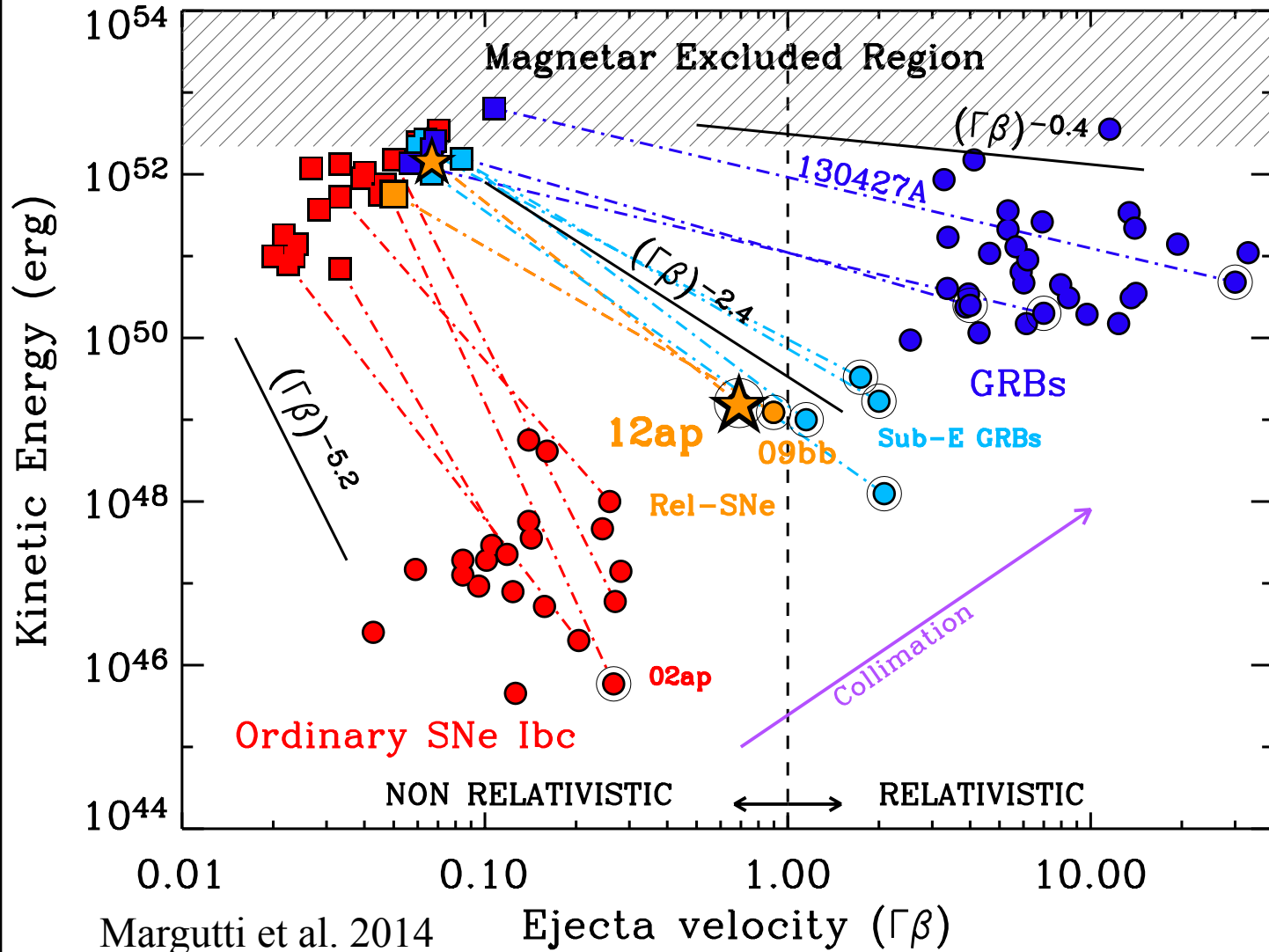
# Total Energy vs. Angle



# Breakout Time vs. Duration



# Supernova and Radio Energy



# How far down does the continuum of events extend?

- Simulations produce explosions with no evidence of jet
- For a low-energy jet ( $2 \times 10^{51}$  erg), jets never break out
- Possible many Ib/c SNe are engine driven

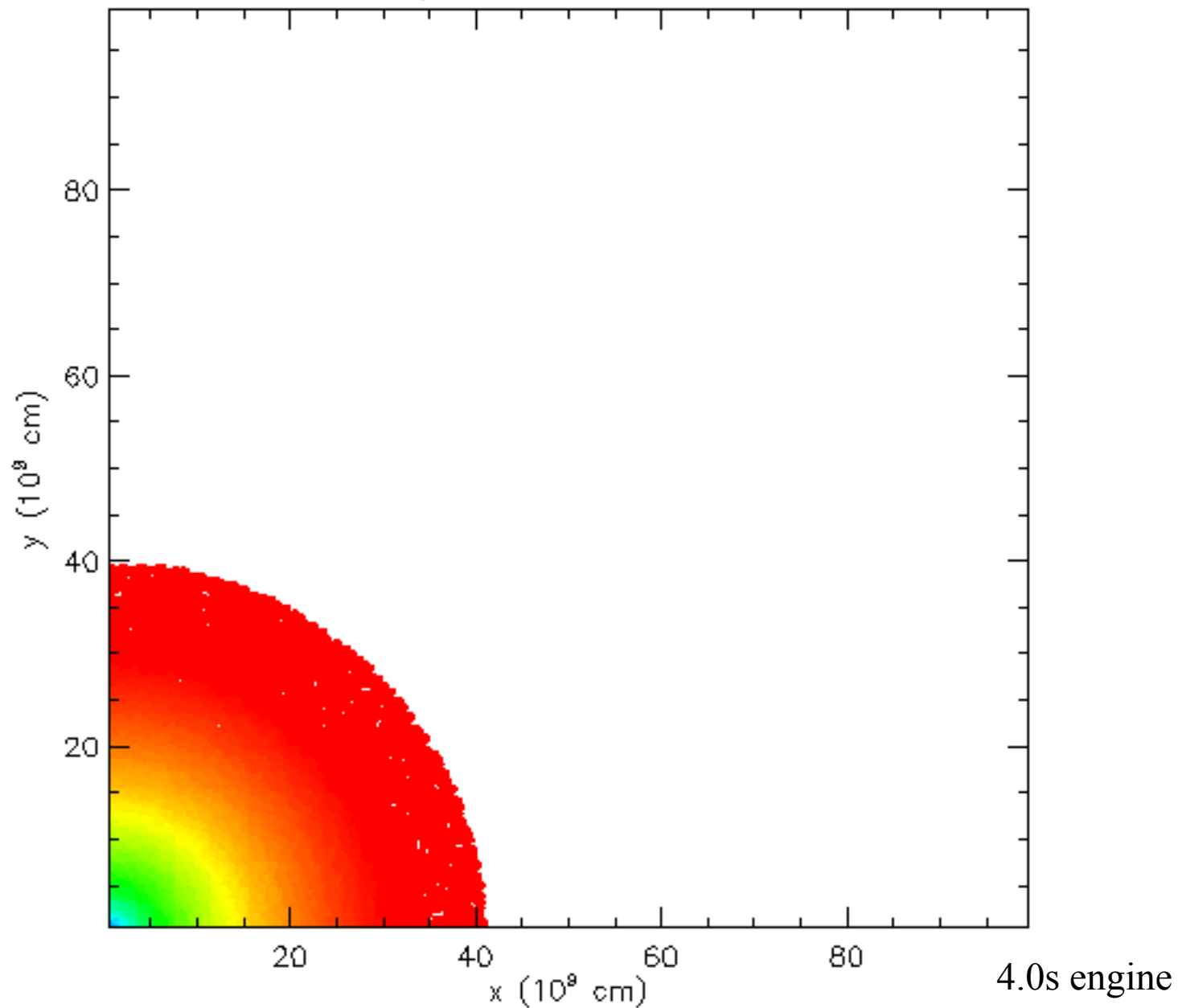


W49B

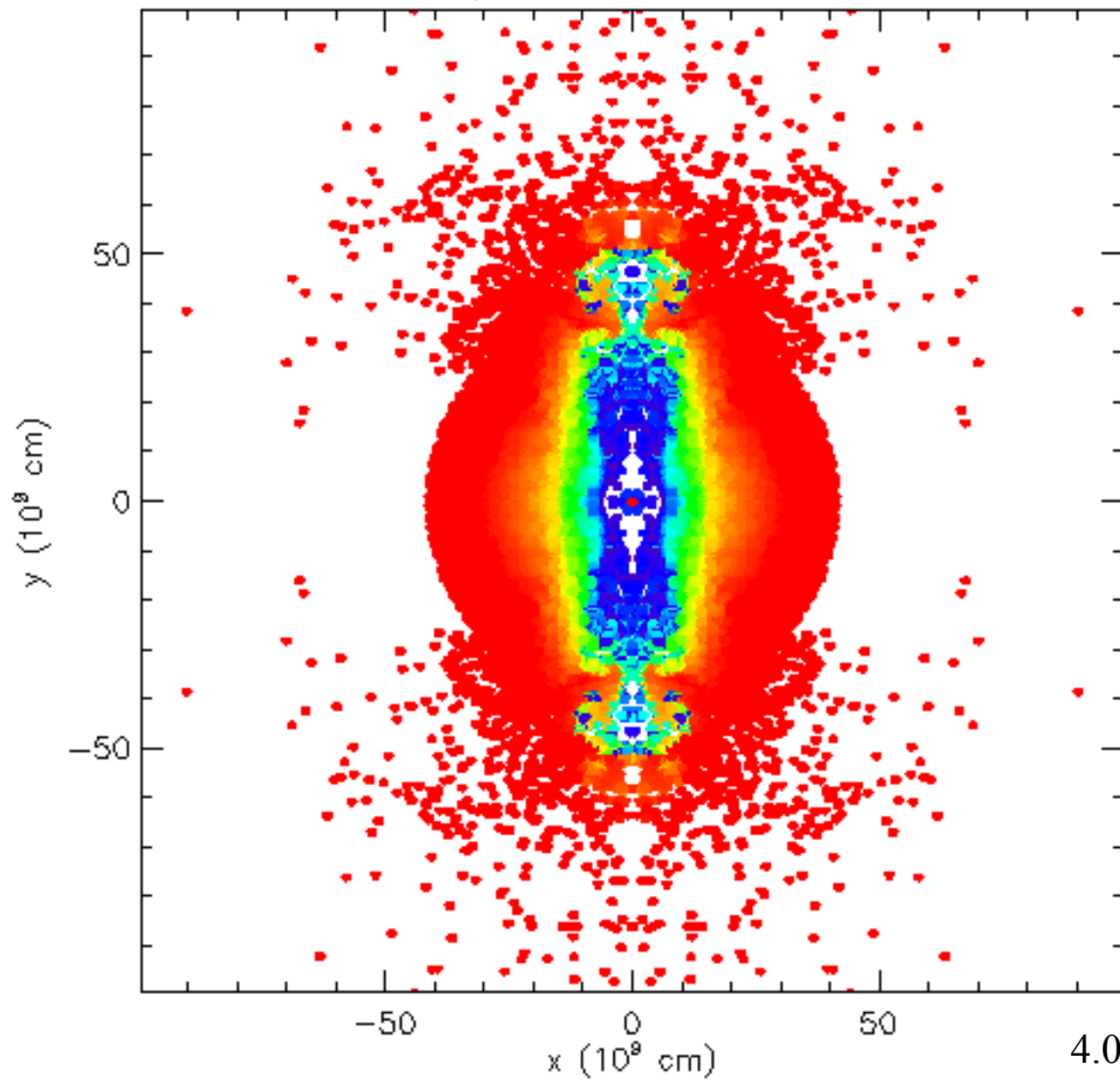


Lopez et al. 2013

Particles, Time = 0.00000s



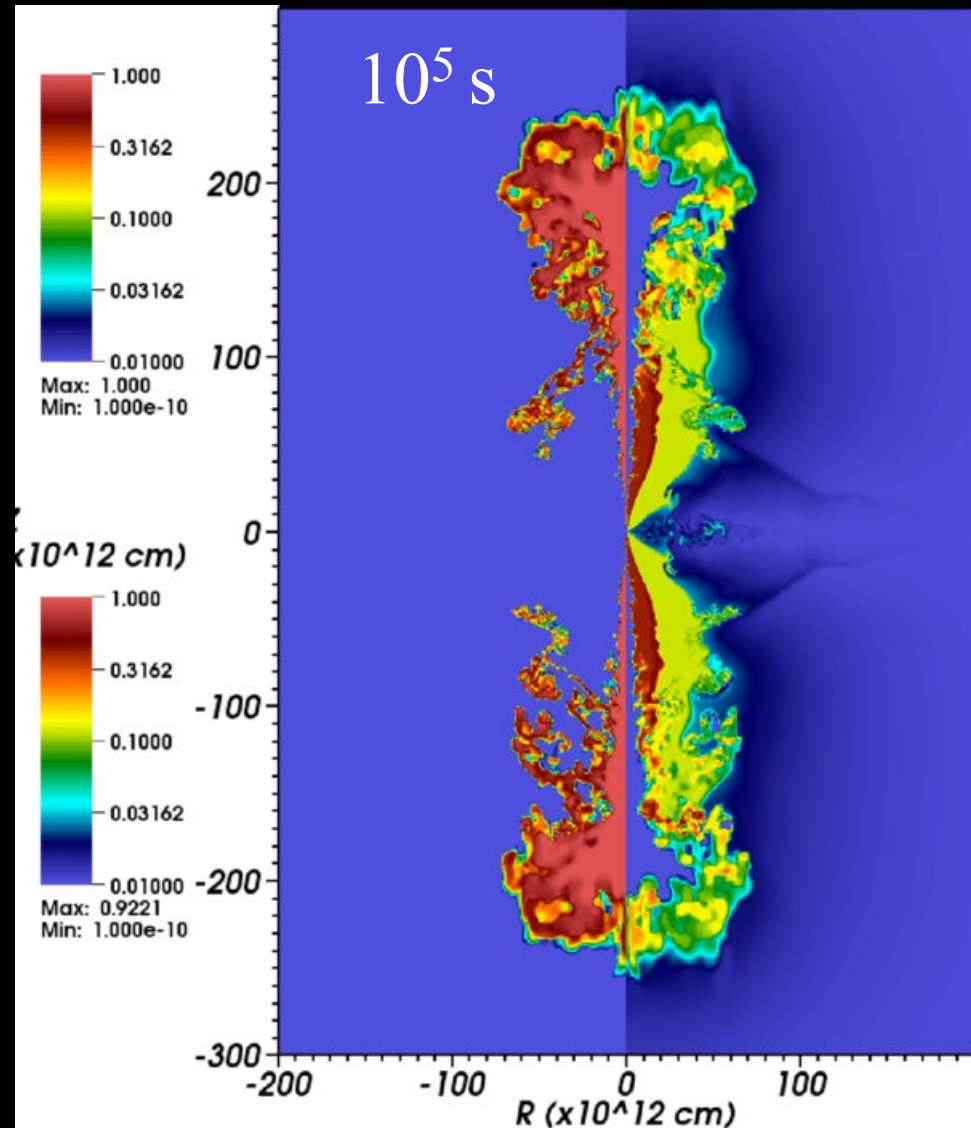
Particles, Time = 15.0000s



4.0s engine

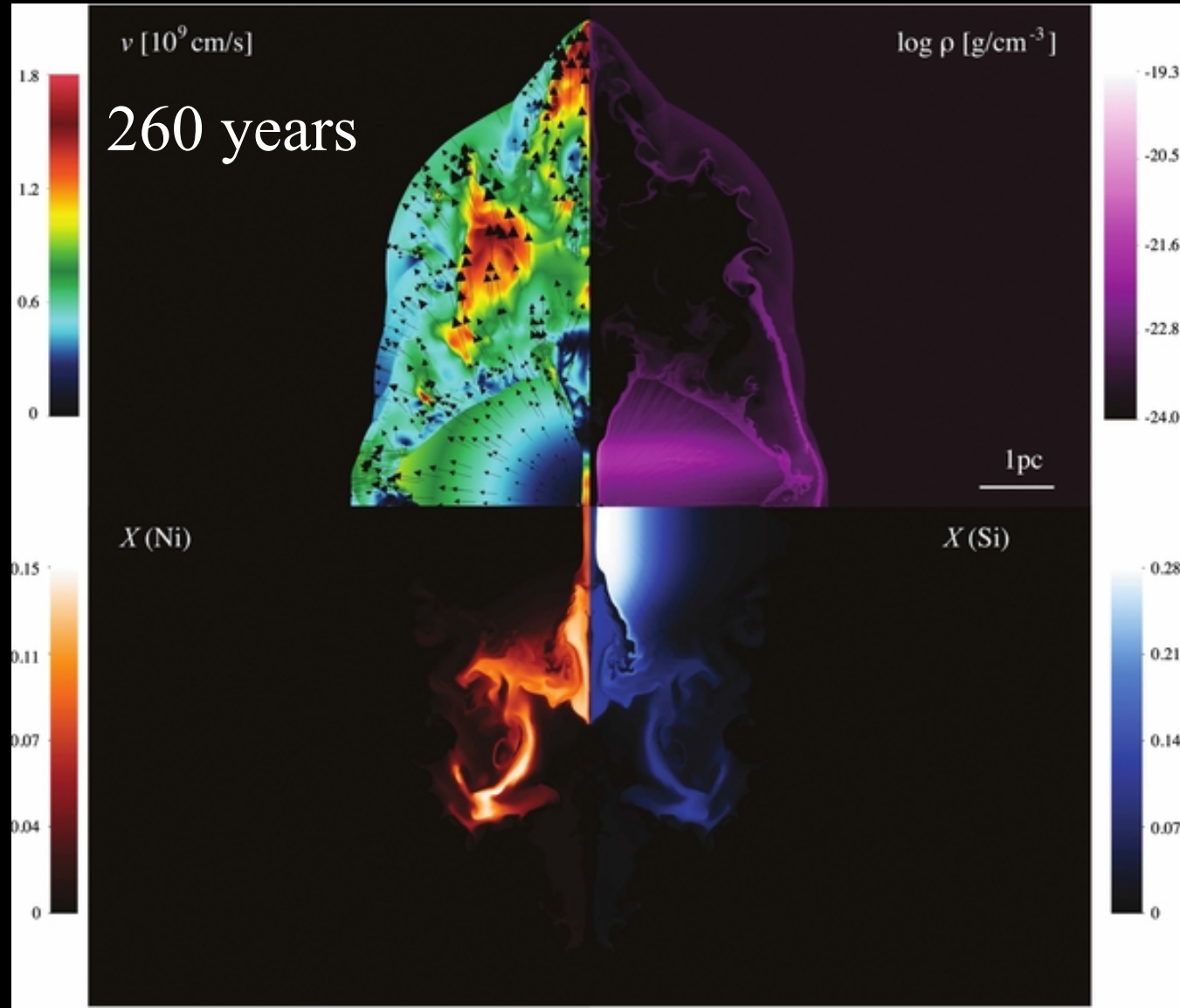
# Inside out supernova

- Couch+ 2011



# W49B Simulation

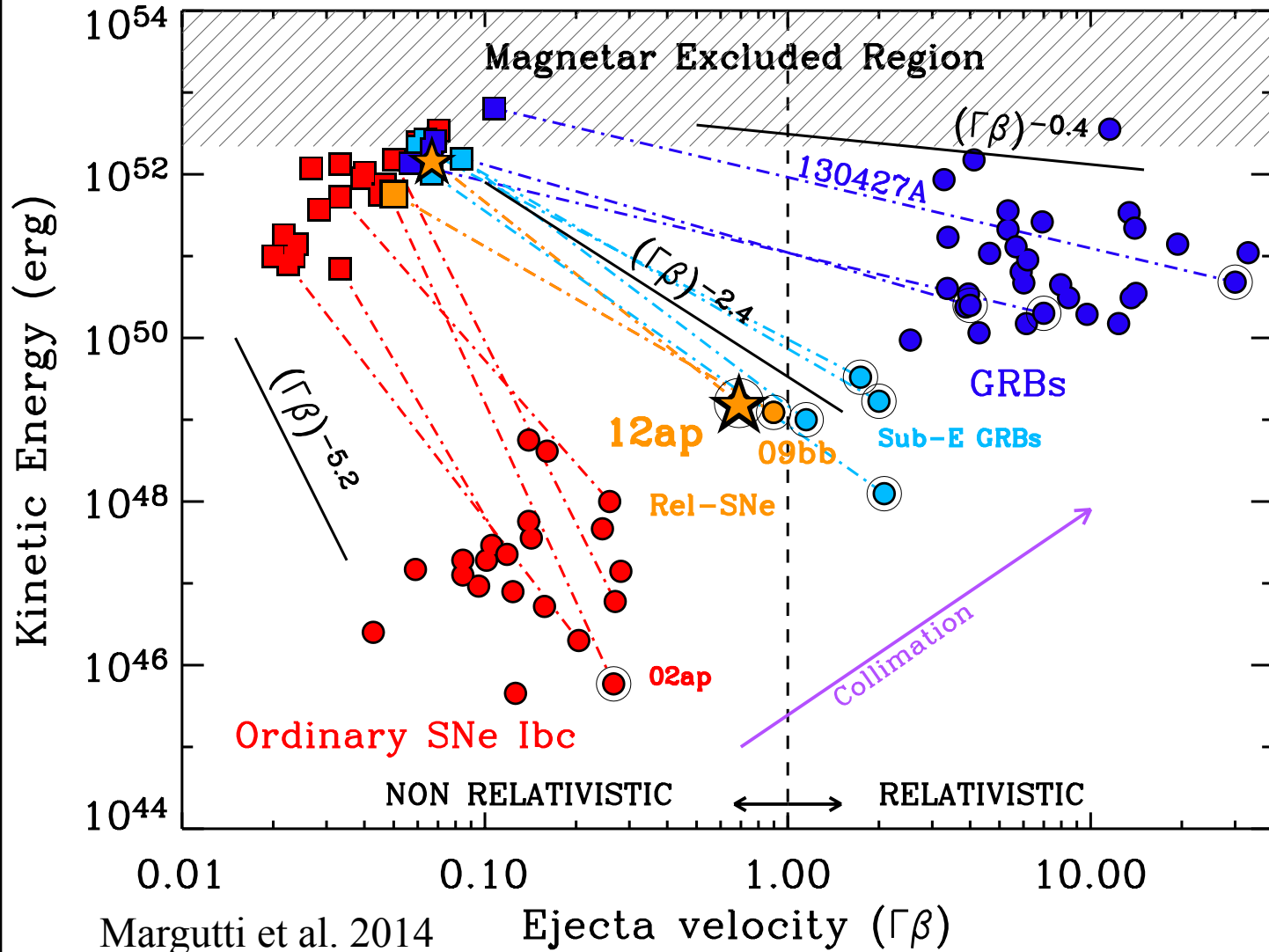
- Gonzalez-Casanova+ 2014



# What is the central engine?

- Black hole, powered by accretion
- Proto-magnetar, powered by spin down
- Either case requires large angular momentum
- Magnetar requires high magnetic field
- Magnetar energy limit  $\approx 2 \times 10^{52}$  erg
  - See, e.g. Mazzali+ 2014

# Supernova and Radio Energy



How is Nickel made?



# How is Nickel made?

- Made in regular SN process, with jet added behind it
  - Probably requires magnetar central engine

# How is Nickel made?

- Made in regular SN process, with jet added behind it
  - Probably requires magnetar central engine
- Made by jet shocking star
  - Difficult to make enough Ni
  - Maeda & Nomoto 2003, Nagataki+ 2006, Fujimoto 2008, Ono+ 2012, Papish+ 2012, 2015

# How is Nickel made?

- Made in regular SN process, with jet added behind it
  - Probably requires magnetar central engine
- Made by jet shocking star
  - Difficult to make enough Ni
- Made in accretion disk
  - Difficult to make enough Ni
  - May not have right electron fraction
  - Requires BH central engine (?)
  - Banerjee+ 2013, Janiuk 2014, Milosavljevic+ 2015

# Engine-driven events

- Cosmological GRBs – yes
- Low-z GRBs – yes
- Relativistic SN – yes
- BL-Ic – probably
- Normal Ib/c – maybe (some? many?)
- Type II – probably not (a few?)

# Unanswered Questions

- How may SN have a central engine?
- What sets the diversity of events?
- What is the central engine?
- What makes Nickel in engine-driven events?