Magnetars and Gamma-Ray Bursts

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Outline

- The idea of magnetar as engines for GRBs
- Millisecond magnetar energetics and GRB dynamics
- How magnetars can drive LGRBs
- Numerical results
- Late time activity
- Diversity
- SN energization
- Constraints and validation of the magnetar model
- Short GRBs with extended emission

The Proto-magnetar idea: energy,

PNS with Magnetars fields ~ 10^{14-15} G
They might be born as fast rotators
Efficient dynamo implies $P \sim t_{conv} \sim$ ms

Millisecond magnetar have the correct energy

$$E_{Rot} \approx 2\times 10^{52}\left(\frac{P}{1\ \mathrm{ms}}\right)^{-2} \mathrm{ergs}$$

Pro

NS are naturally associated to core collapse SN
Less angular momentum required than BH-AD
NS population can explain transition from asymmetric SNe to XRFs to GRBs
Magnetar can show energetic bursts

Typical spin-down times are ~ 100-1000 sec

$$\dot{E} \approx 10^{49}\left(\frac{P}{1\ \mathrm{ms}}\right)^{-4}\left(\frac{B_{Dip}}{10^{15}\ \mathrm{G}}\right)^{2} \mathrm{ergs\ s^{-1}}$$

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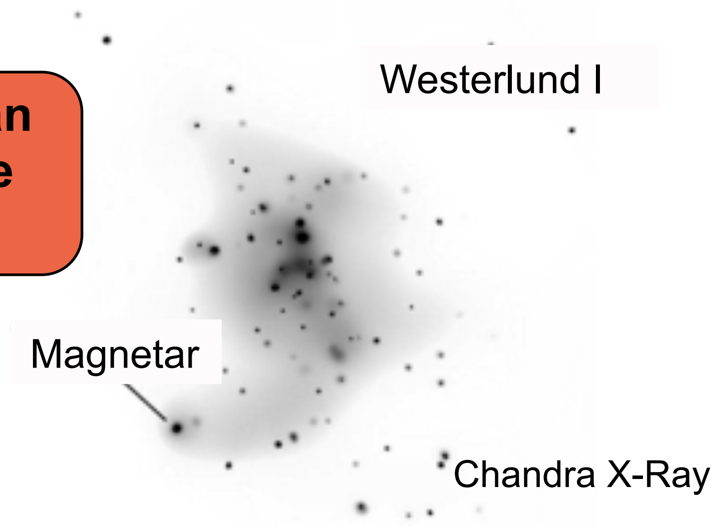
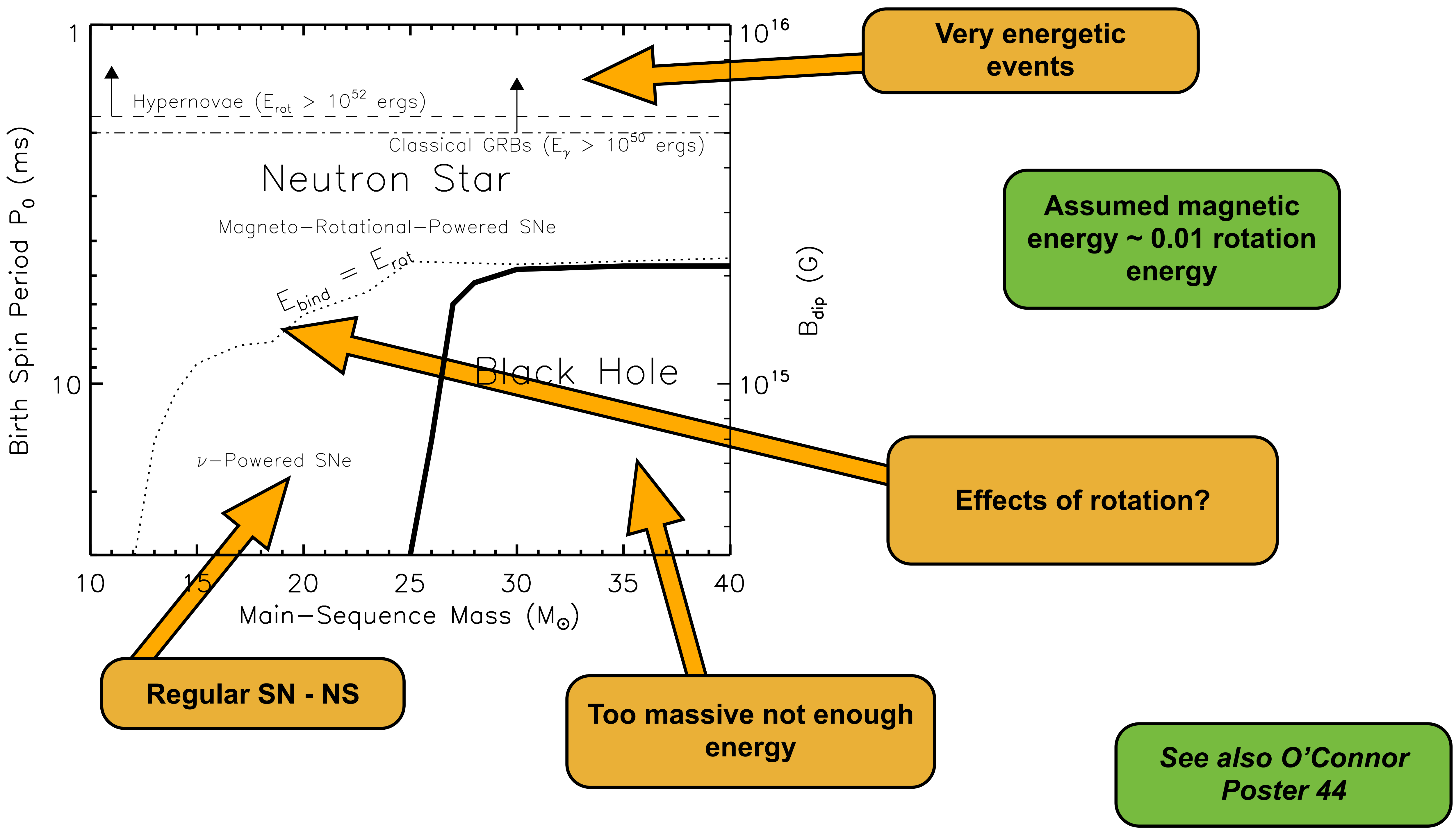
Pulsars have relativistic winds

Magnetars can have massive progenitors



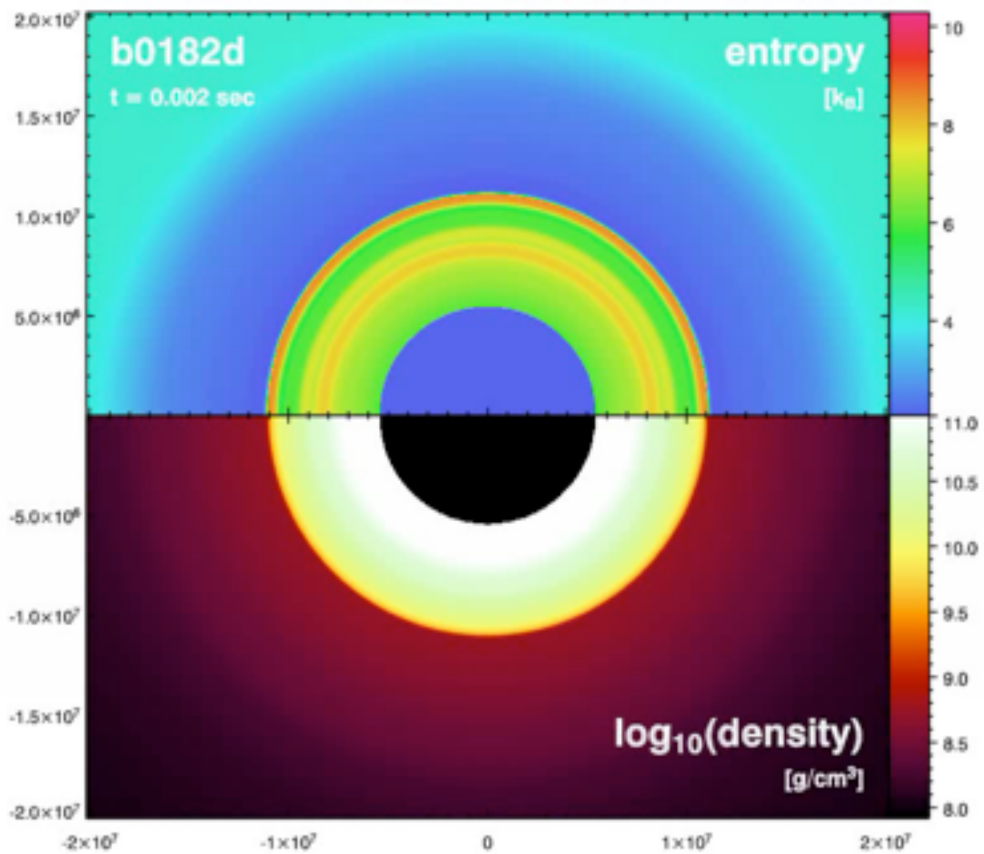
Faintest Cluster Members are O7 (Muno 2006)

and the death of the progenitor.



Extracting the energy via winds

- **Core-Collapse SNe Produce Hot Proto-Neutron Stars that Cool Via ν-Emission ~10^{53} ergs in τ_{KH} ~ 10-100 s**
- **Neutrinos Heat Matter above the PNS Surface, Driving a Thermal Wind into the Evacuated Region Behind the SN Shock (Duncan et al. 1986).**



Scheck et al

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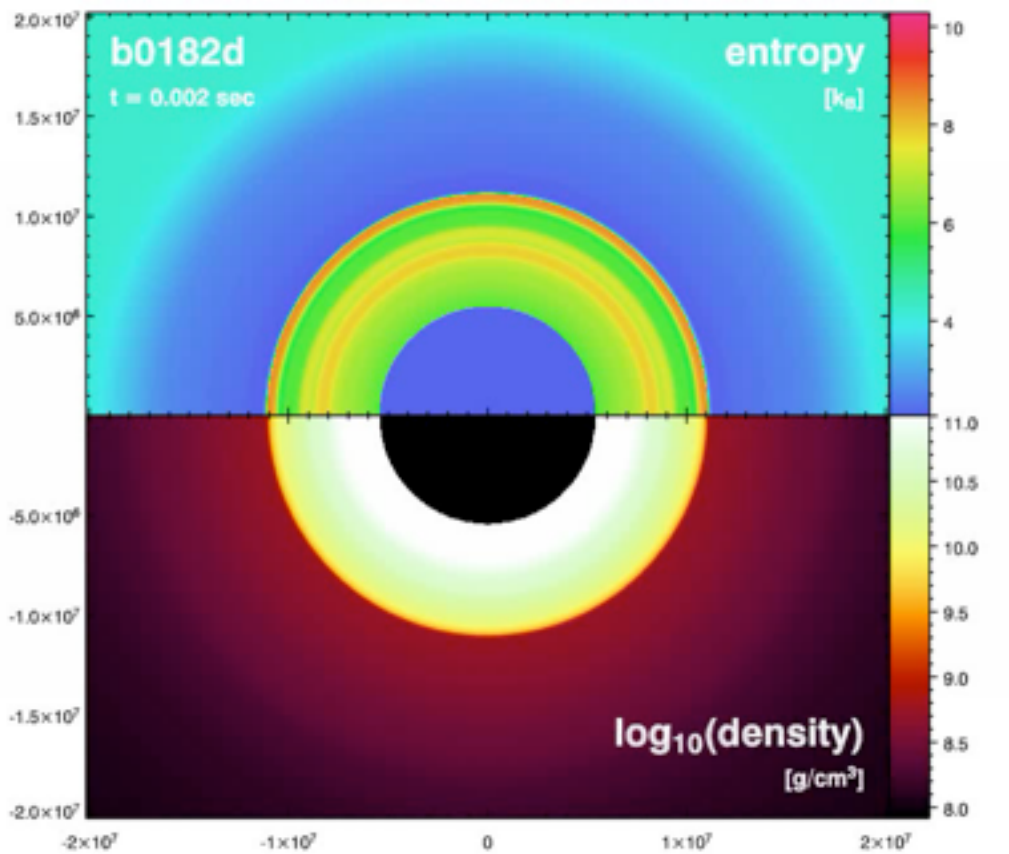

Scheck et al

Regular PNS winds are not dynamically relevant for SN

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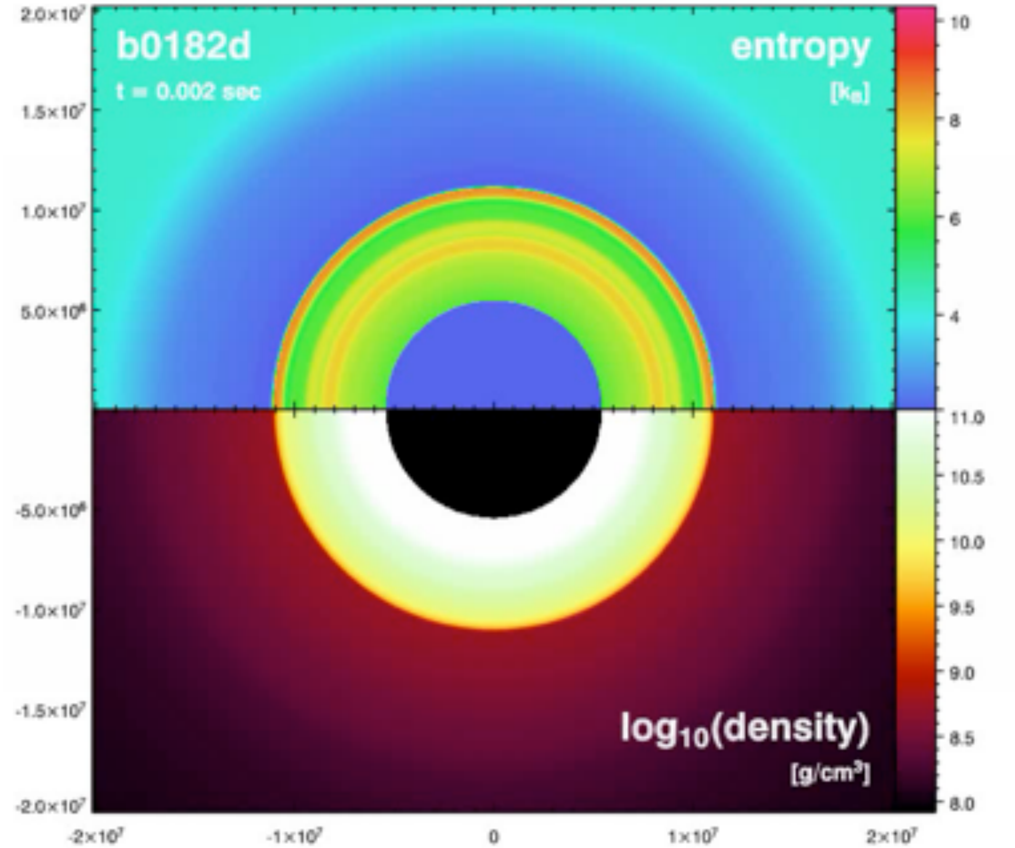

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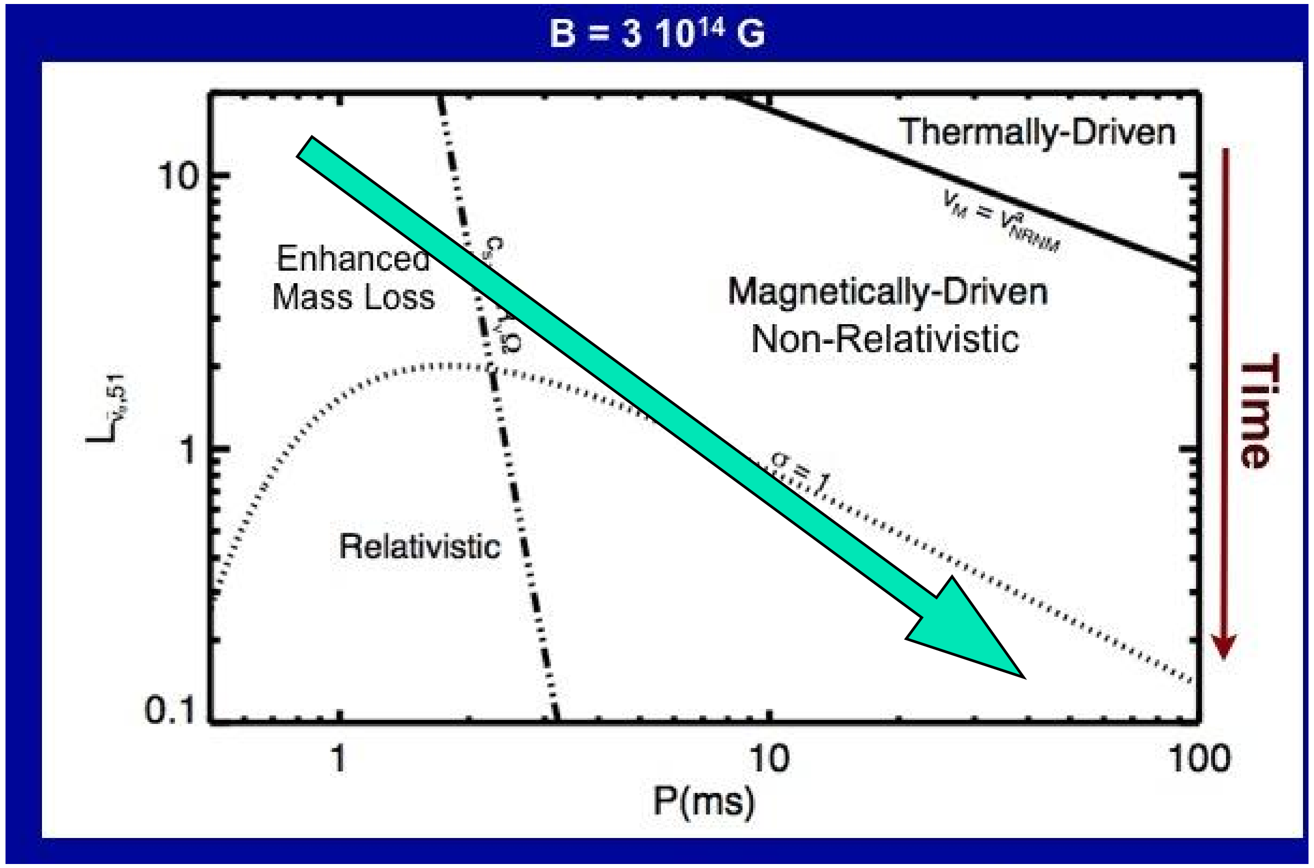

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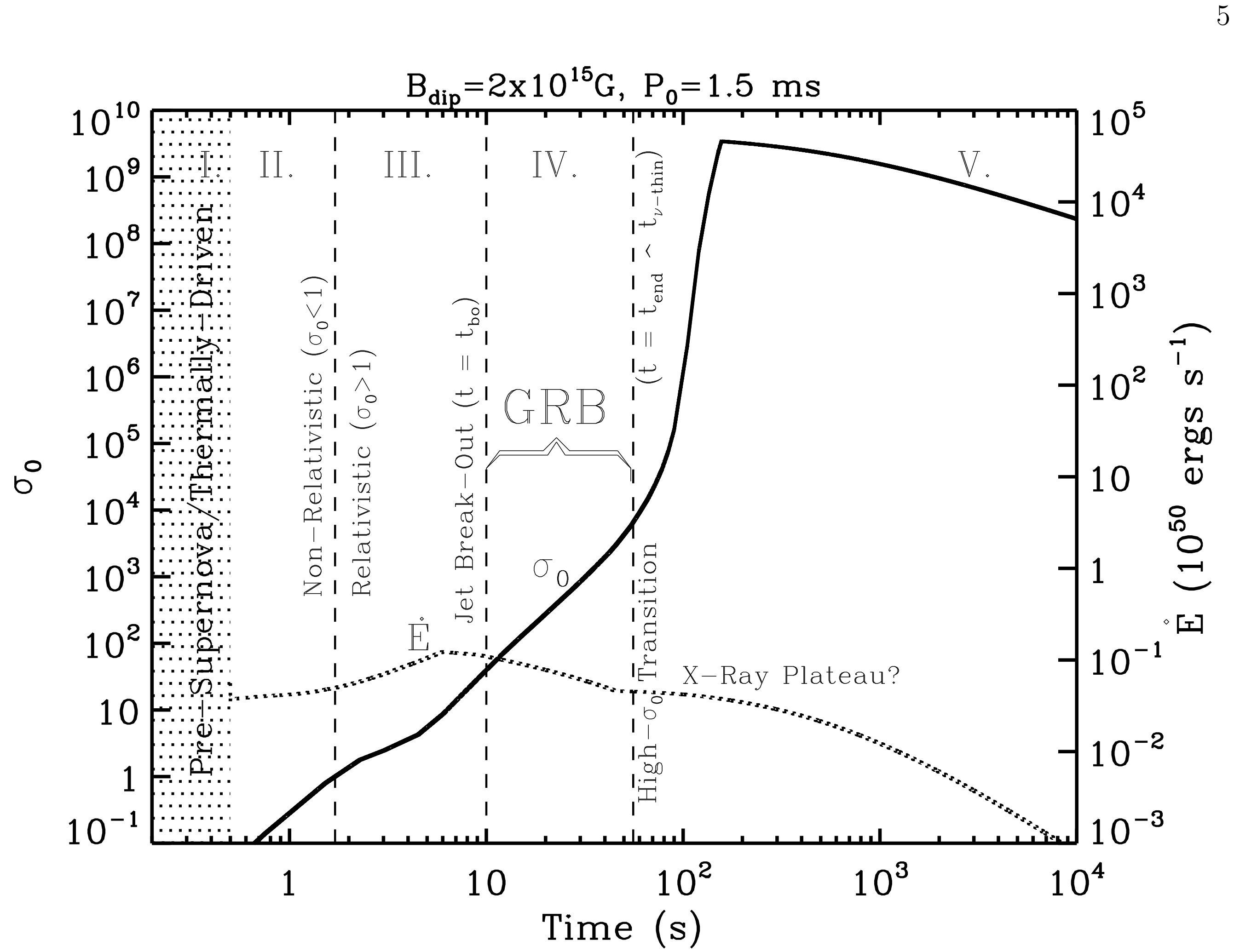
But with Magnetic Field

Magnetar spin-down evolution



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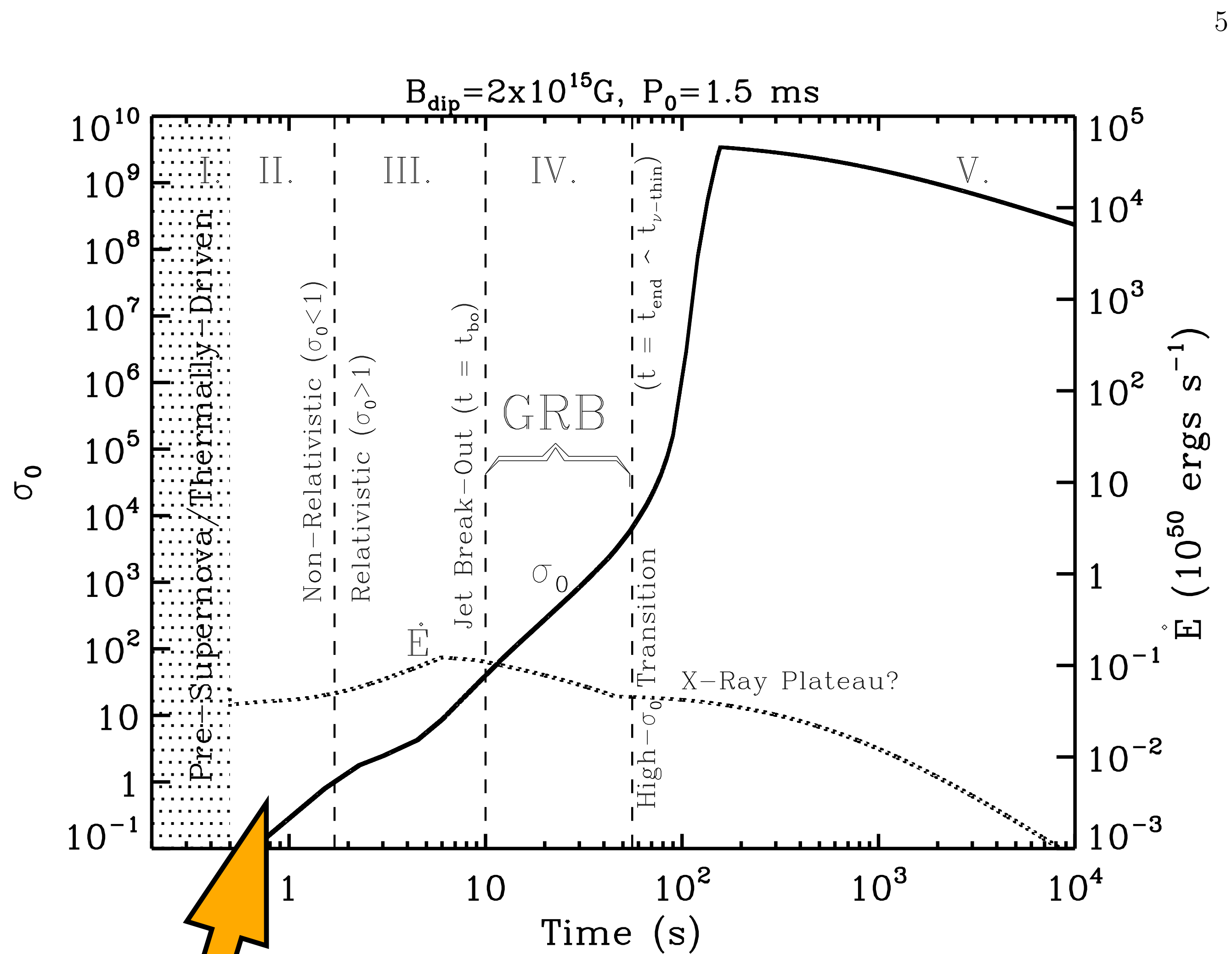

Early non-rel magnetic dominated phase - contraction

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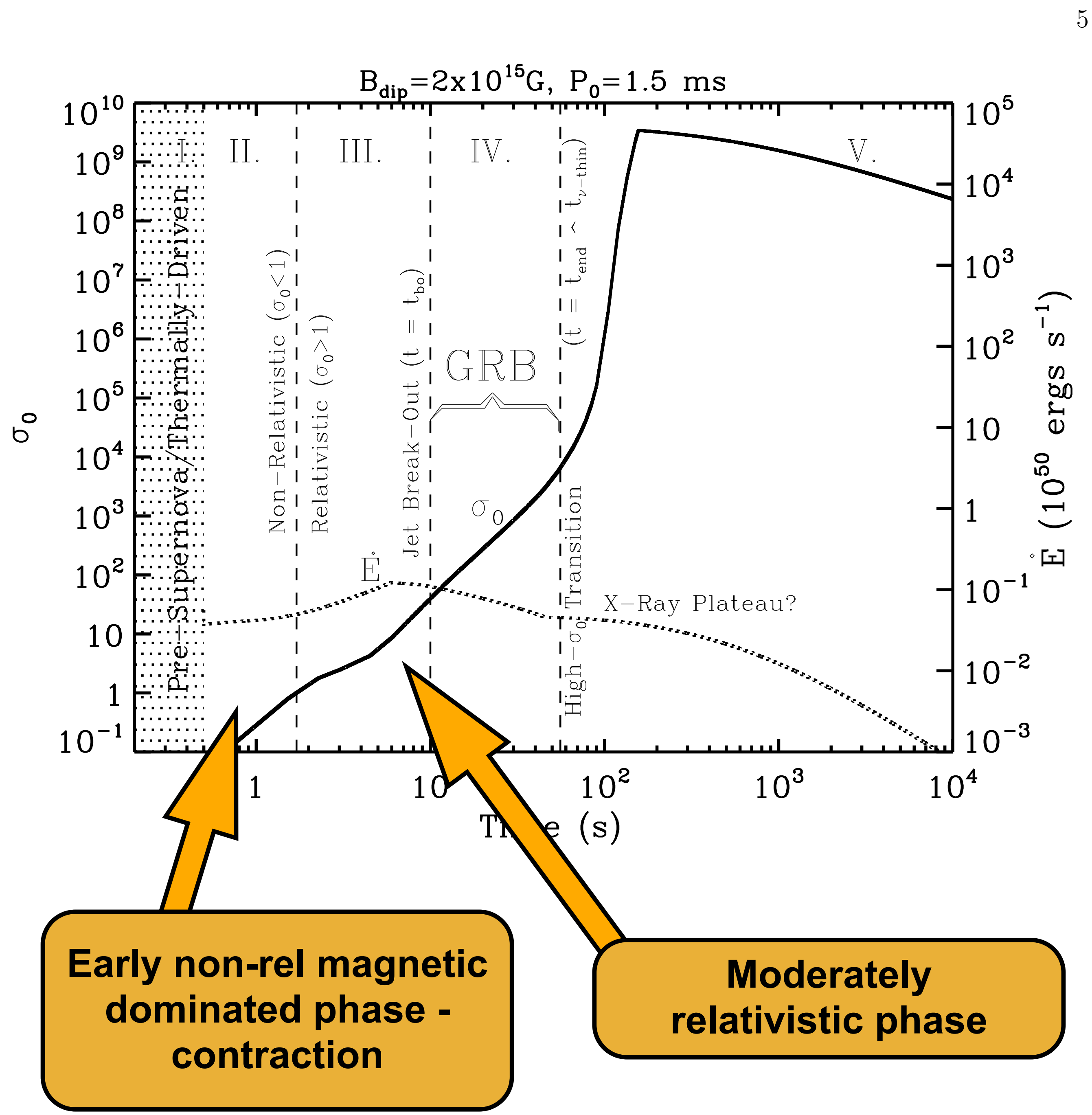
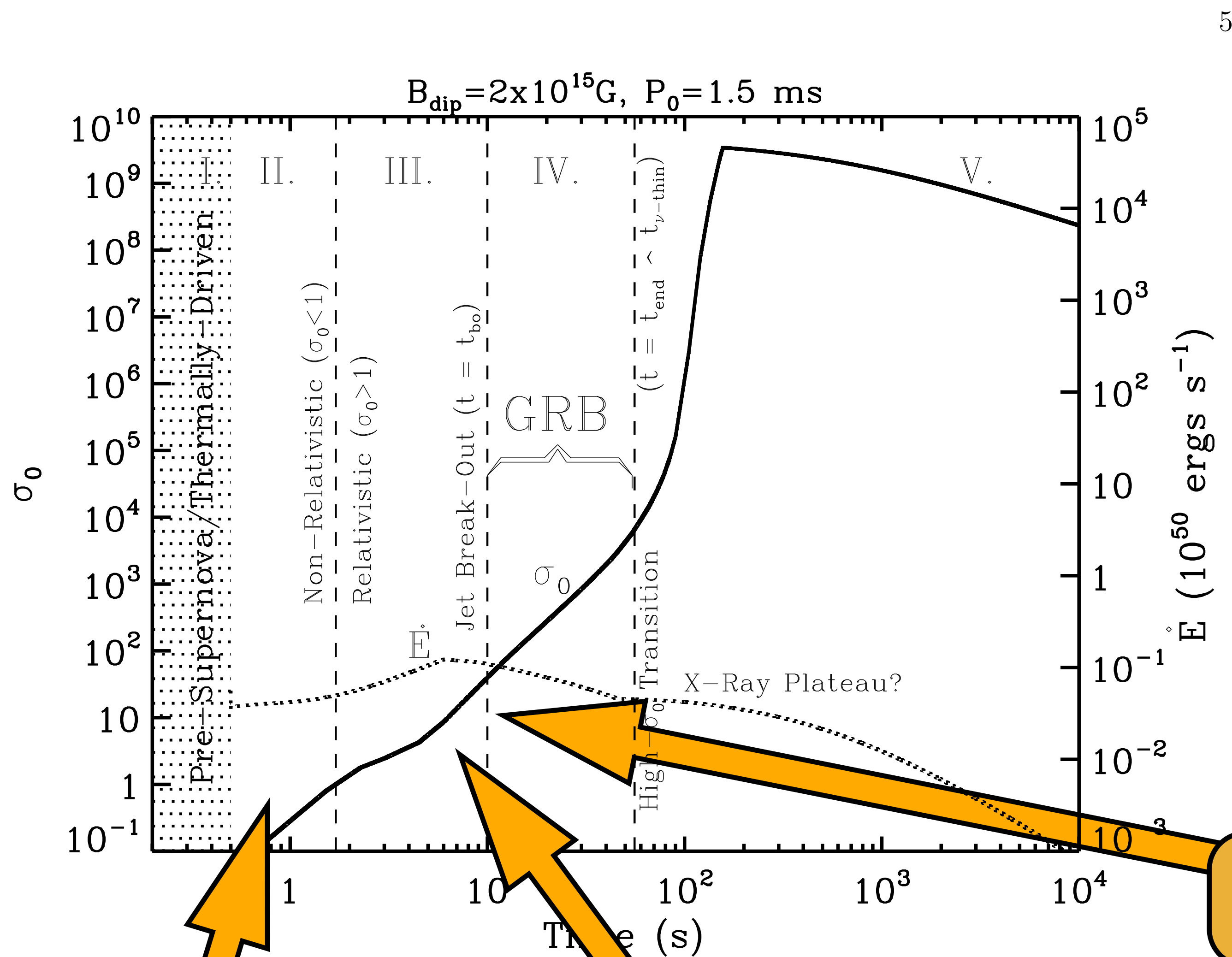


Friday, March 16, 12

Magnetar spin-down evolution



Early non-rel magnetic dominated phase - contraction

Moderately relativistic phase

Break out time

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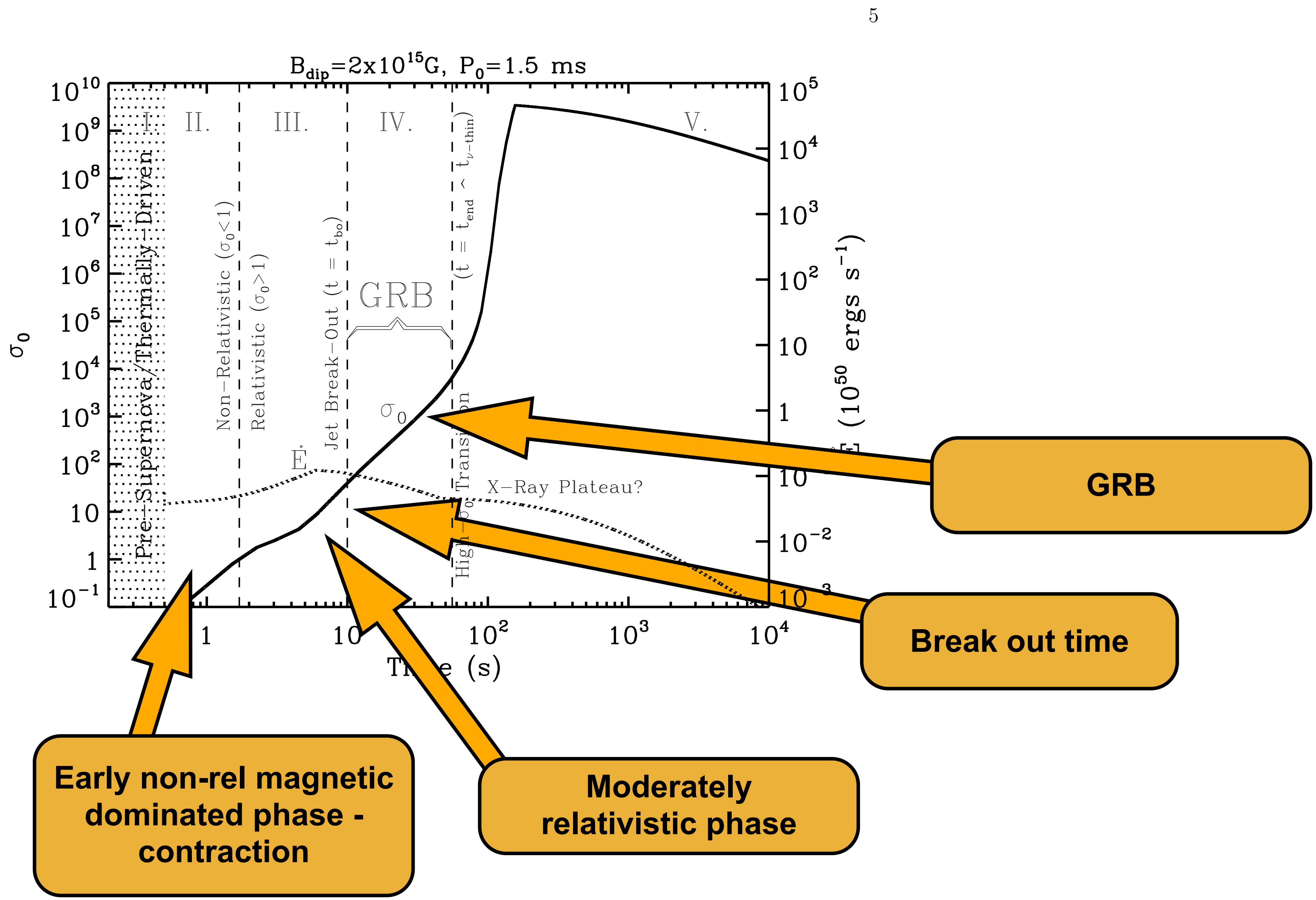

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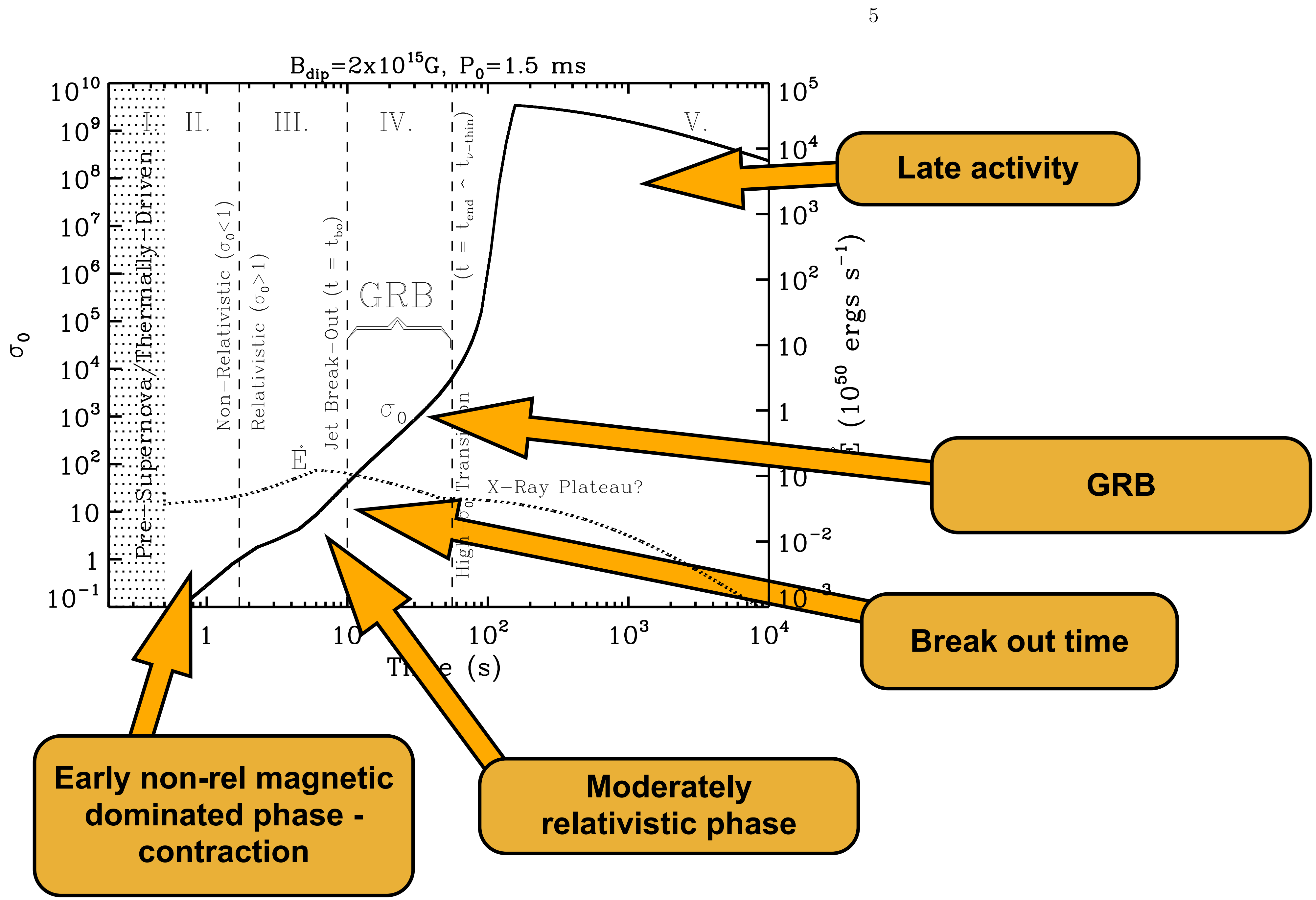

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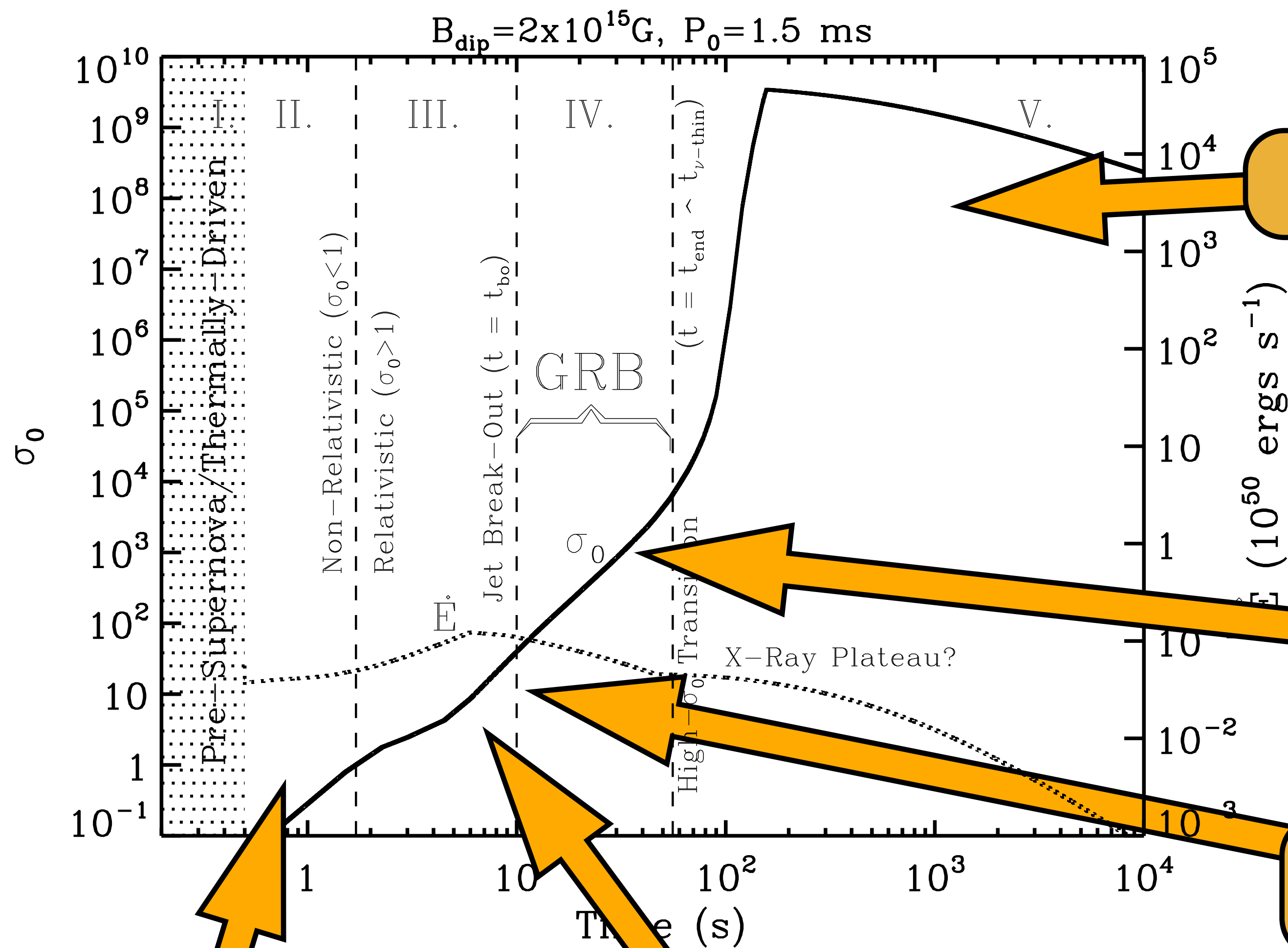
Magnetar spin-down evolution

5



Late activity

GRB

Break out time

Early non-rel magnetic dominated phase - contraction

Moderately relativistic phase

In the Magnetar model the barion loading problem becomes a neutrino cooling problem

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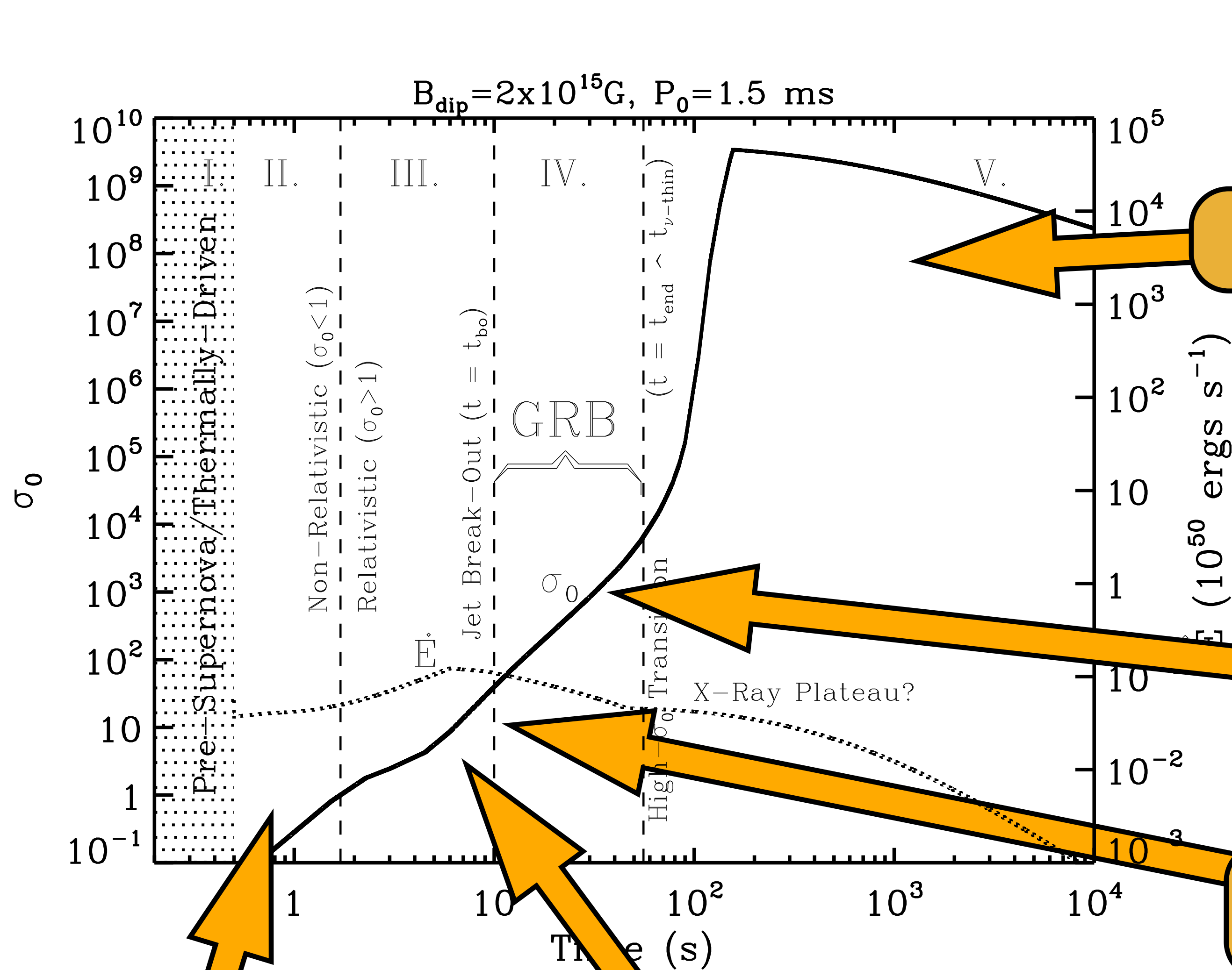

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Early non-rel magnetic dominated phase - contraction

Moderately relativistic phase

No Magnetic Dipole Radiation losses!!

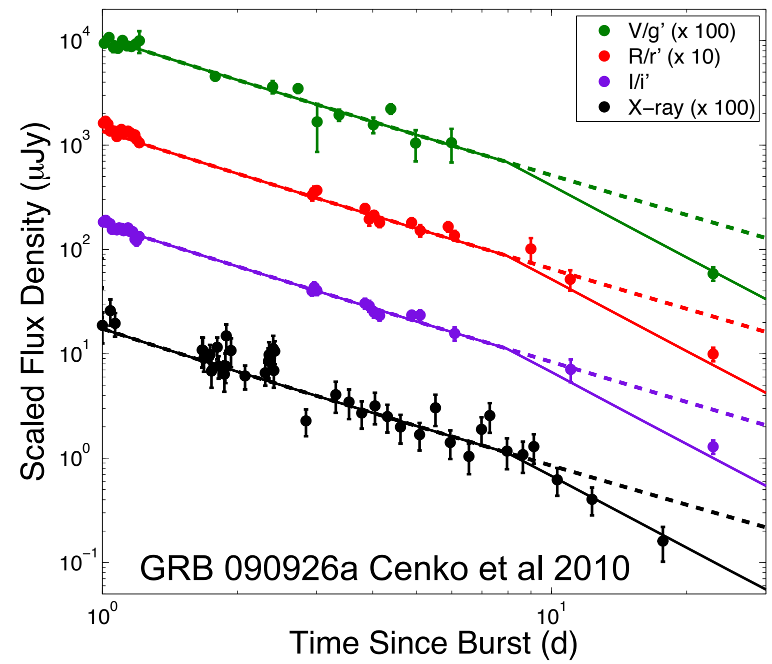
Stellar Wind

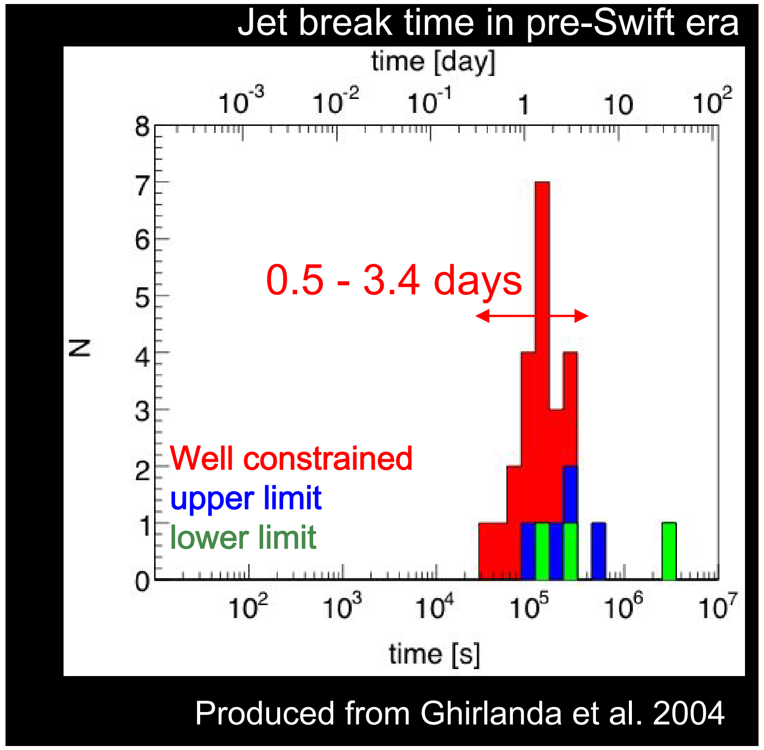
In the Magnetar model the barion loading problem becomes a neutrino cooling problem

Geometry of the Outflow

Evidence for collimation from so called "jet-breaks"

The outflow must be a jet





Komissarov 2005

Bucciantini et al 2005

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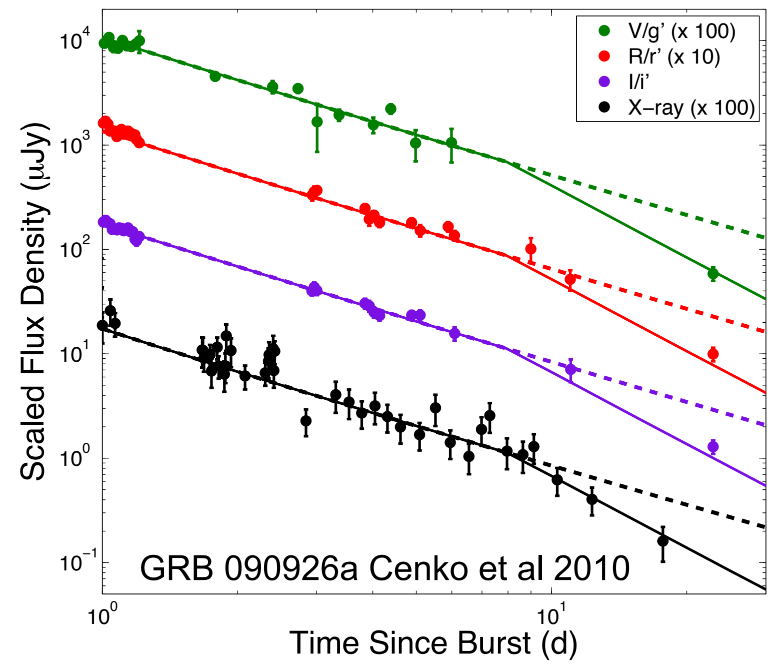

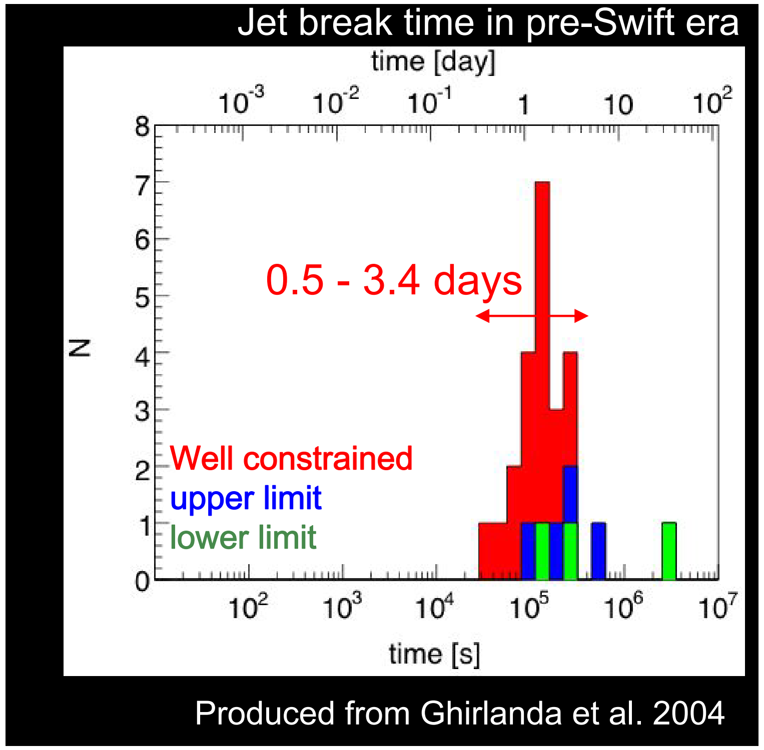

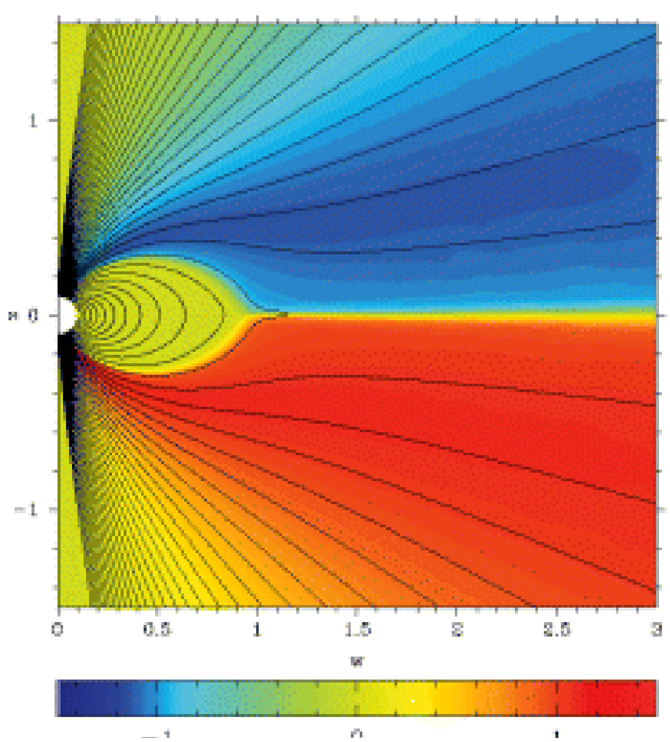

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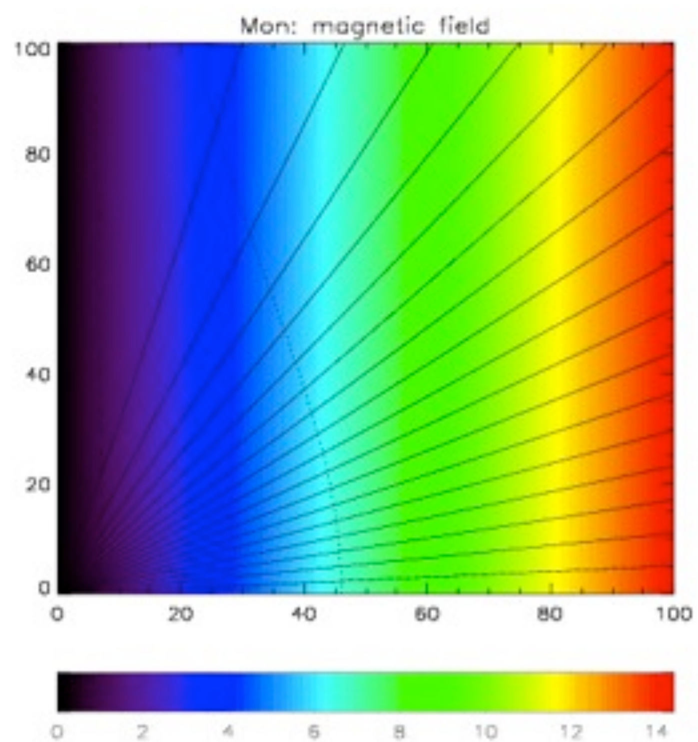


Bucciantini et al 2005

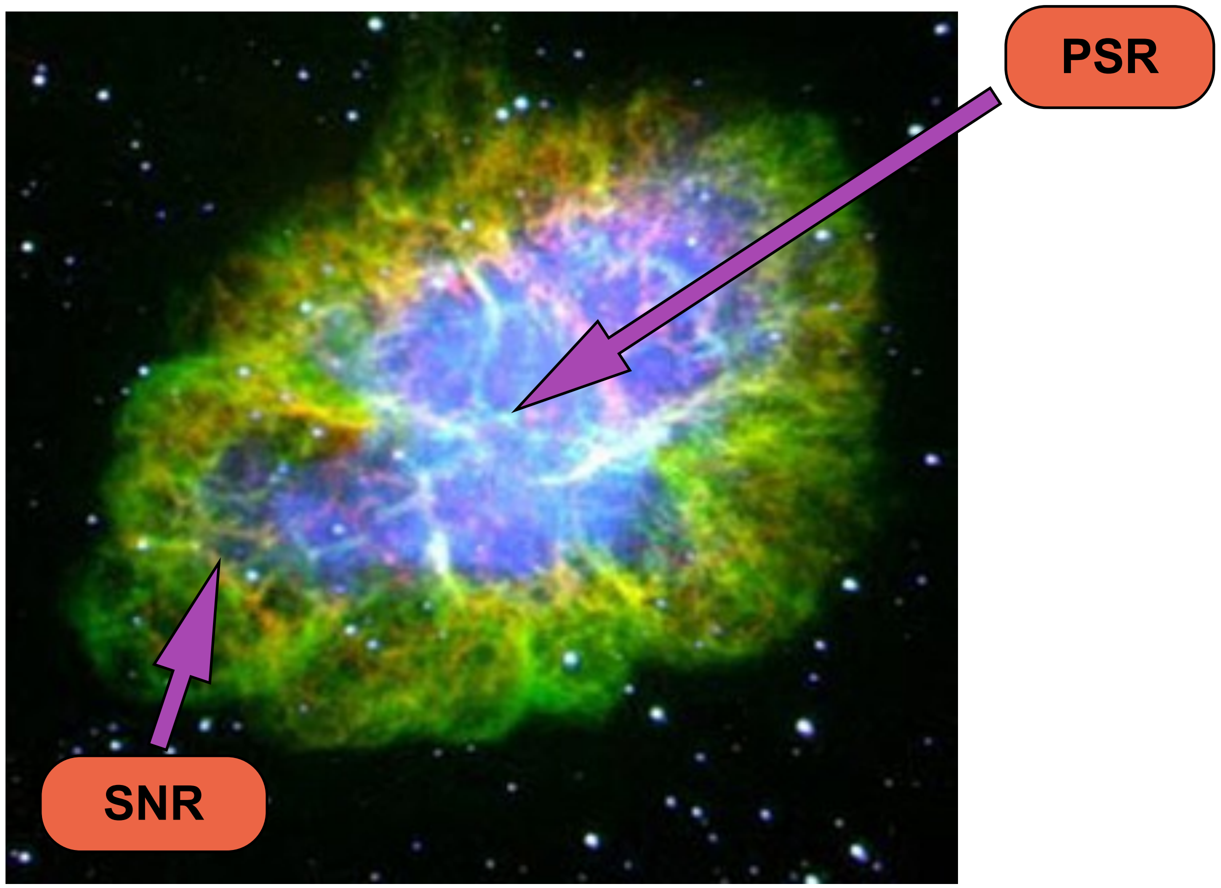
But outflow from compact object cannot self-collimate

Far from the LC the flow is a plit monopole with energy flux concentrated in the equator

What about the interaction with the progenitor?

How do relativistic winds interact with the environment?

Pulsar Wind Nebulae



PWNe are hot bubbles of relativistic particles and magnetic field originated by the interaction of the ultra-relativistic magnetized pulsar wind with the expanding SNR (or with the ISM)

Bigger, less confined and less energetic versions of GRBs?

Cartoon

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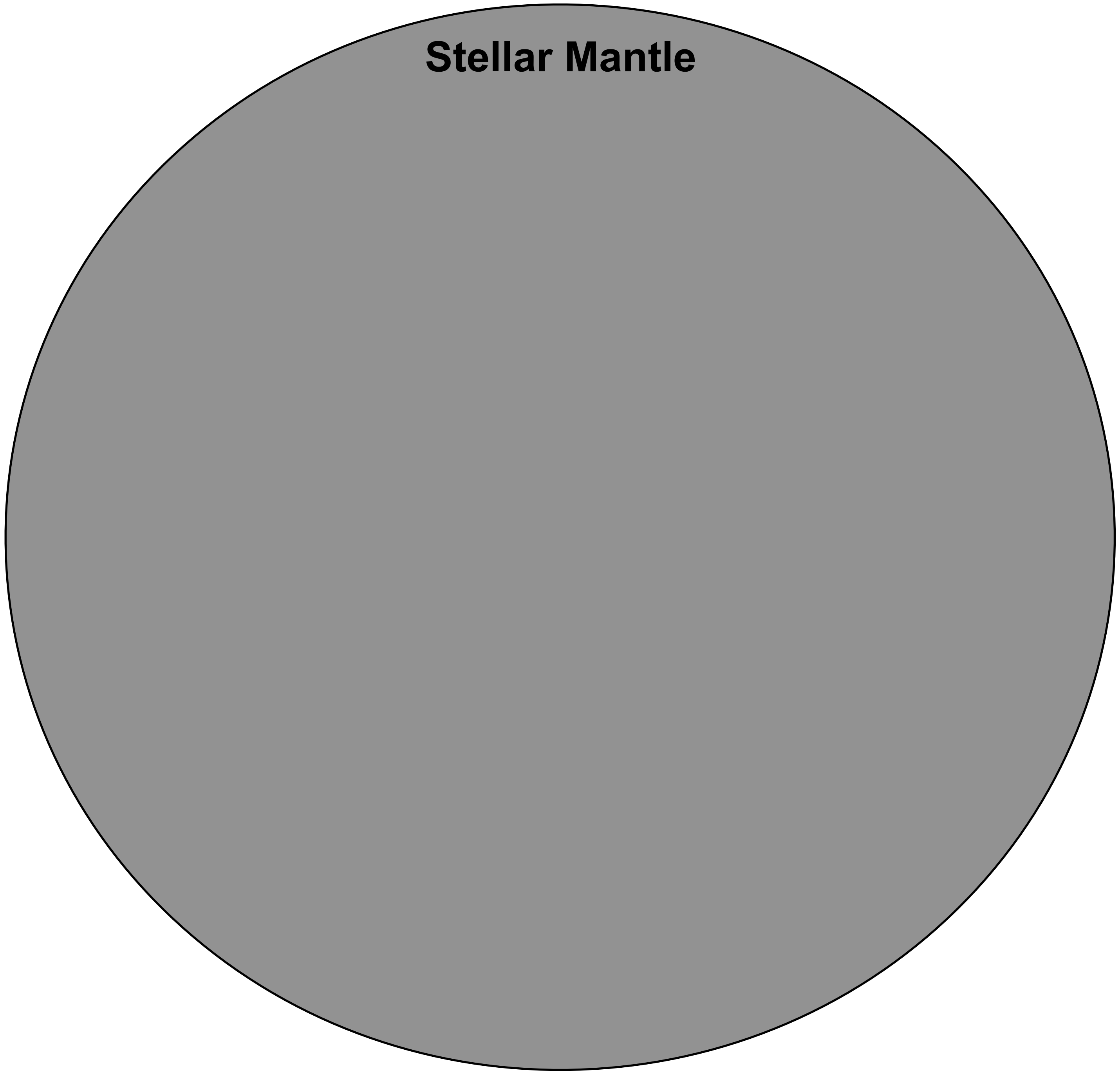
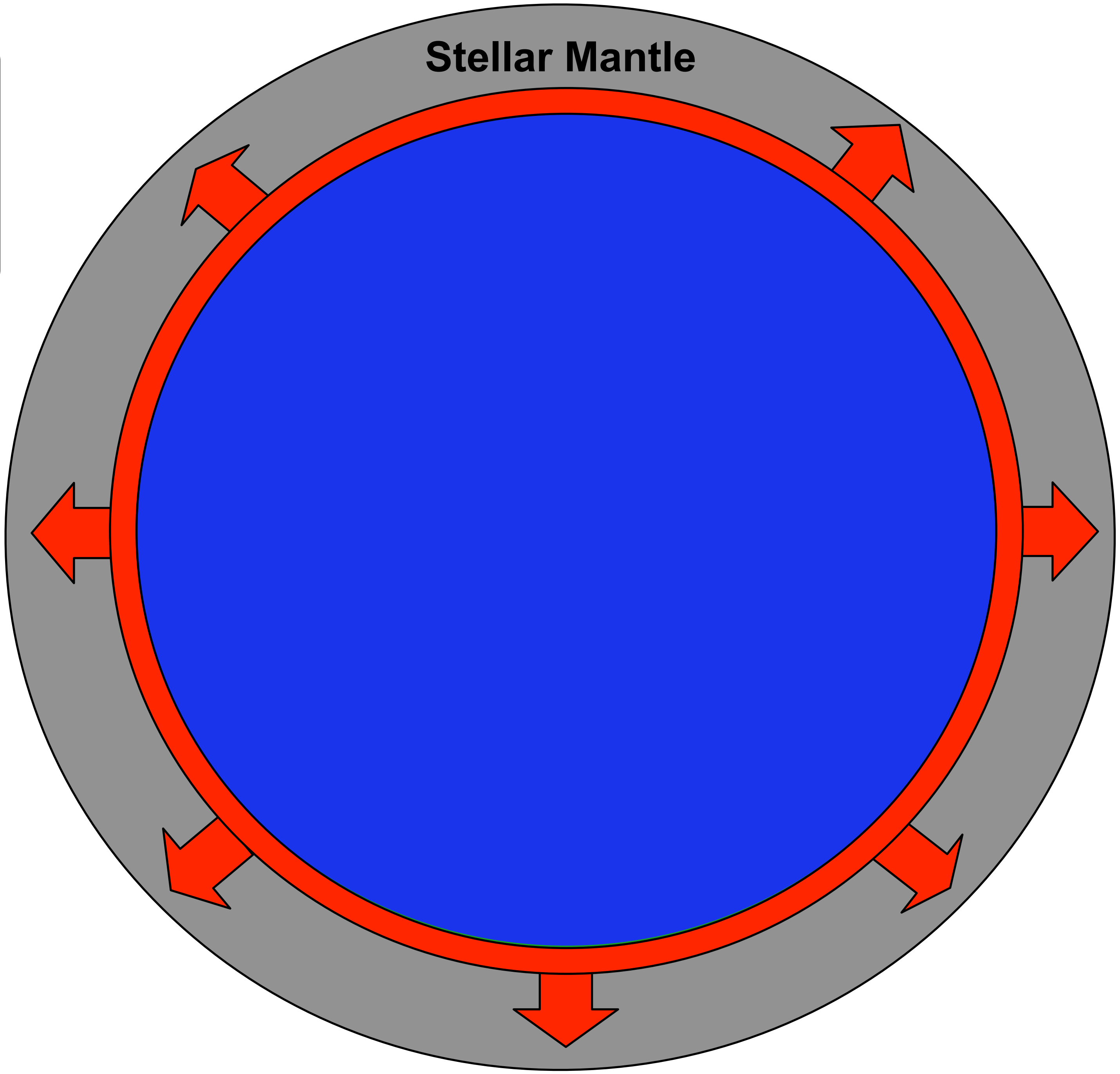


Cartoon

Outgoing SN shock
V_{sn} ~ 0.03-0.05c
SN Shell creates a cavity



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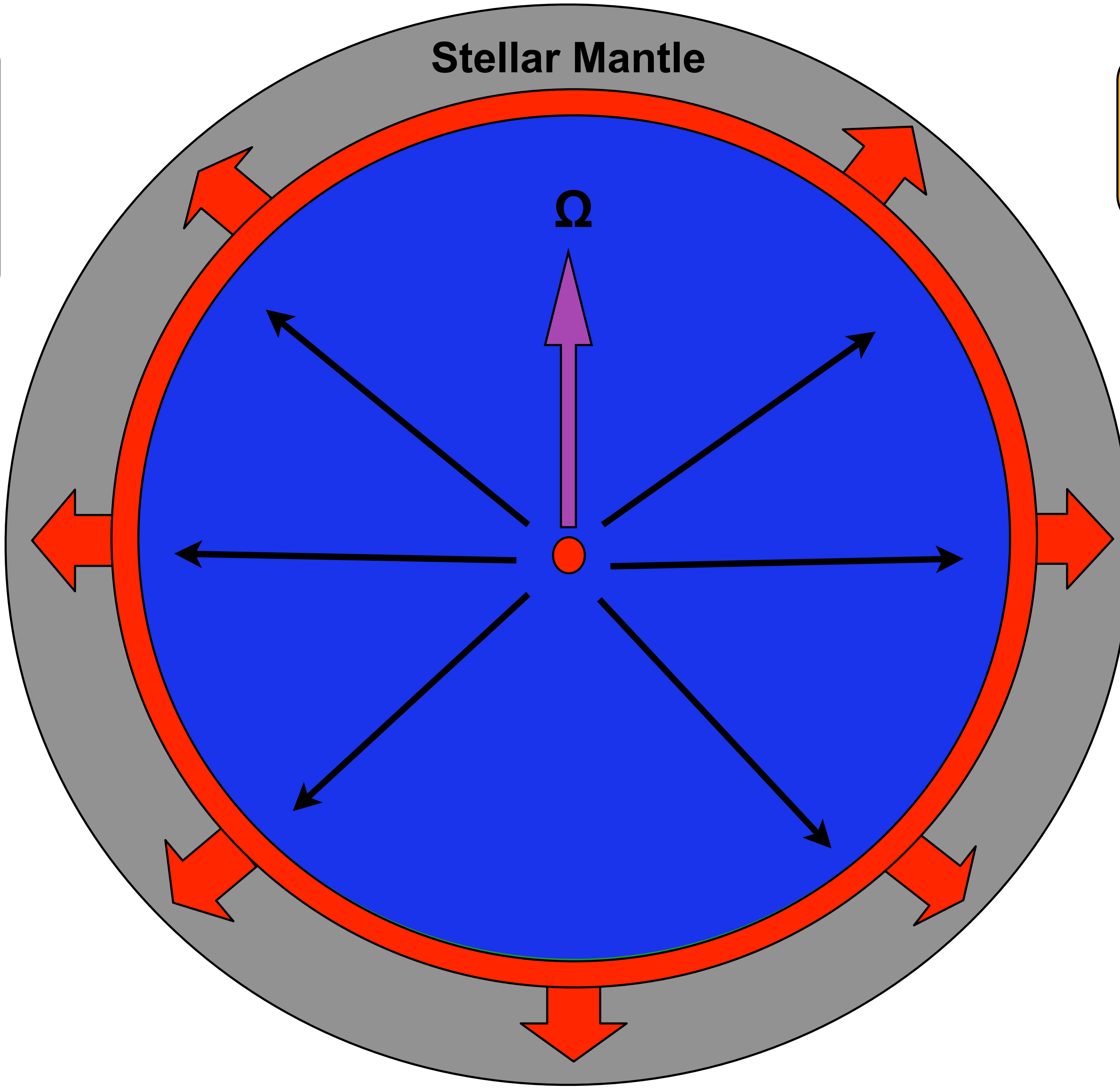

The cavity is swept by the PNS wind

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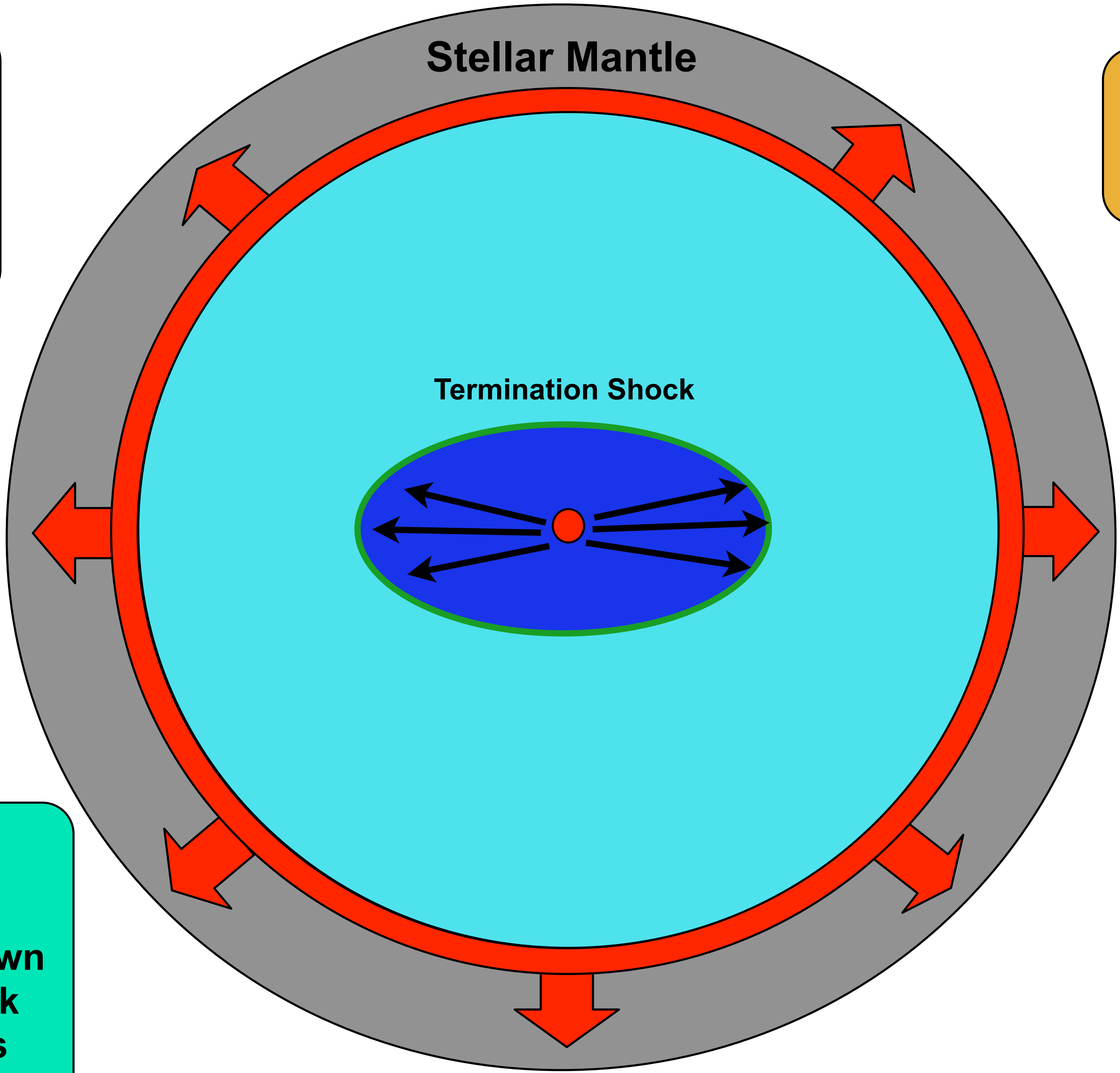

The cavity is swept by the PNS wind

$V_{sn} << V_{wind}$

The wind is slowed down in a termination shock
A Magnetar nebula is formed

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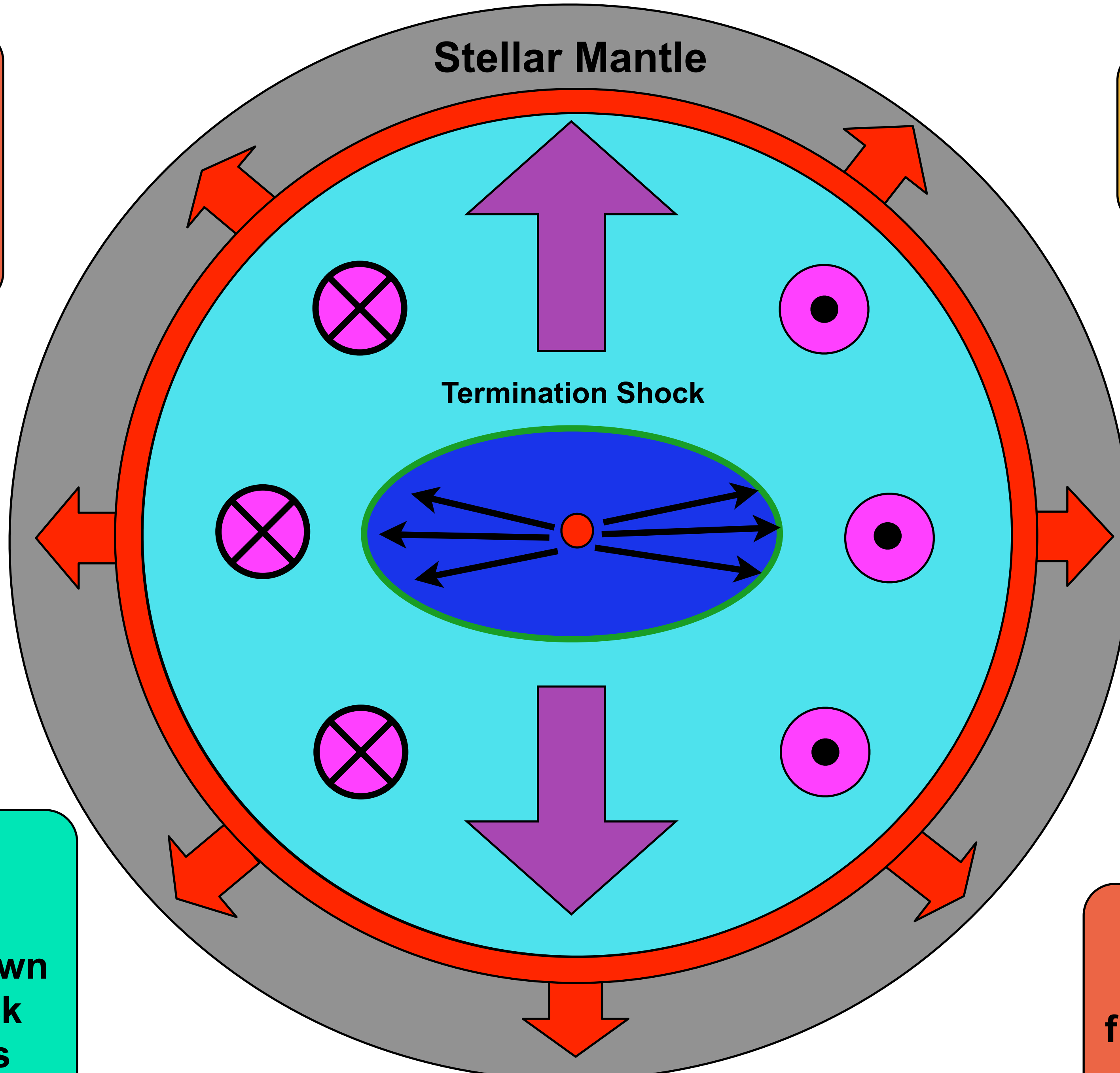

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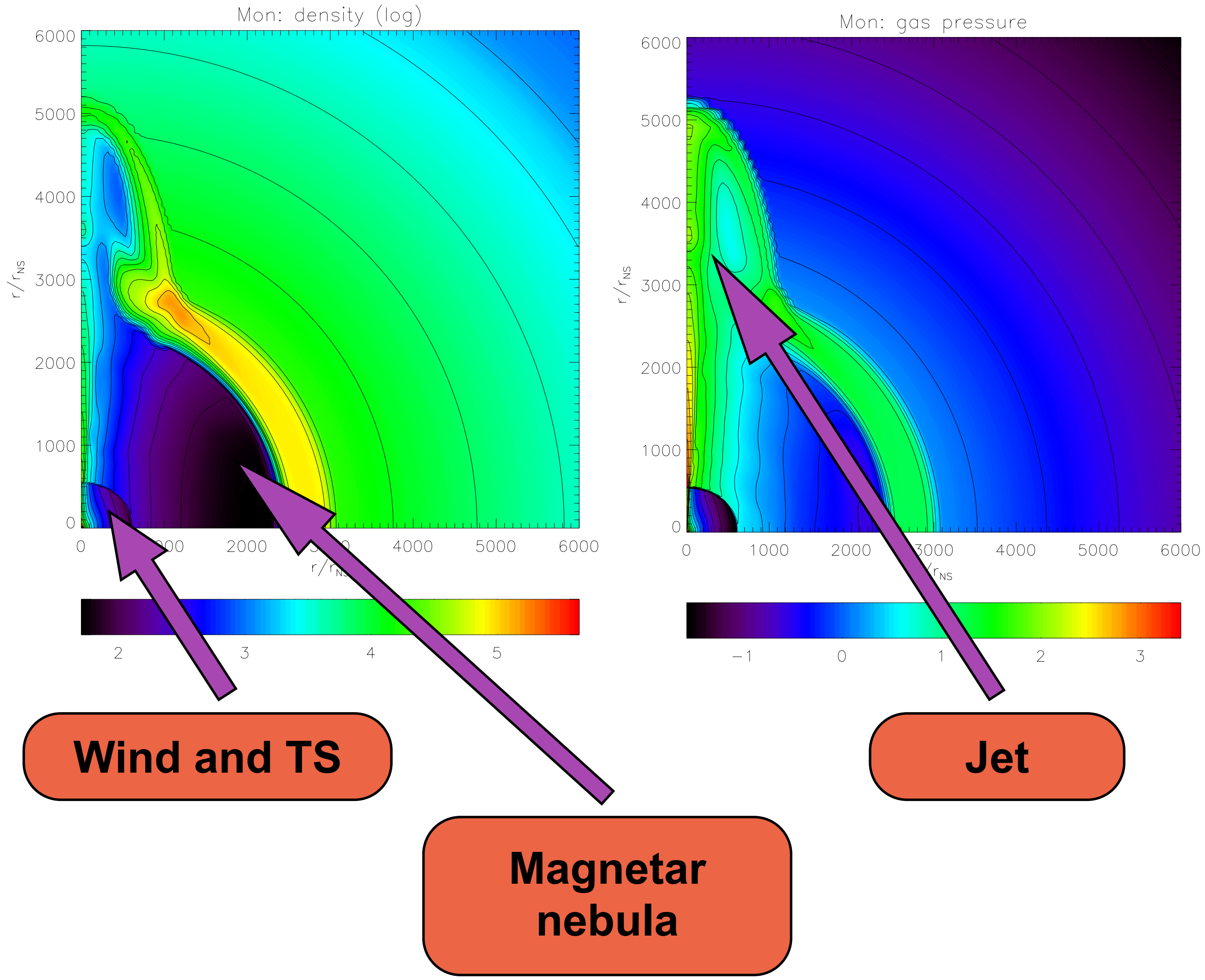
Compressed magnetic field increases pressure on the axis

Interaction with the progenitor



Recent numerical study investigates the transition from the matter dominated phase to the magnetic dominated phase

Jet are ubiquitous feature originating from the confinement of a toroidally dominated magnetic field.

Dissipative processes affect the acceleration of the jet but not the collimation

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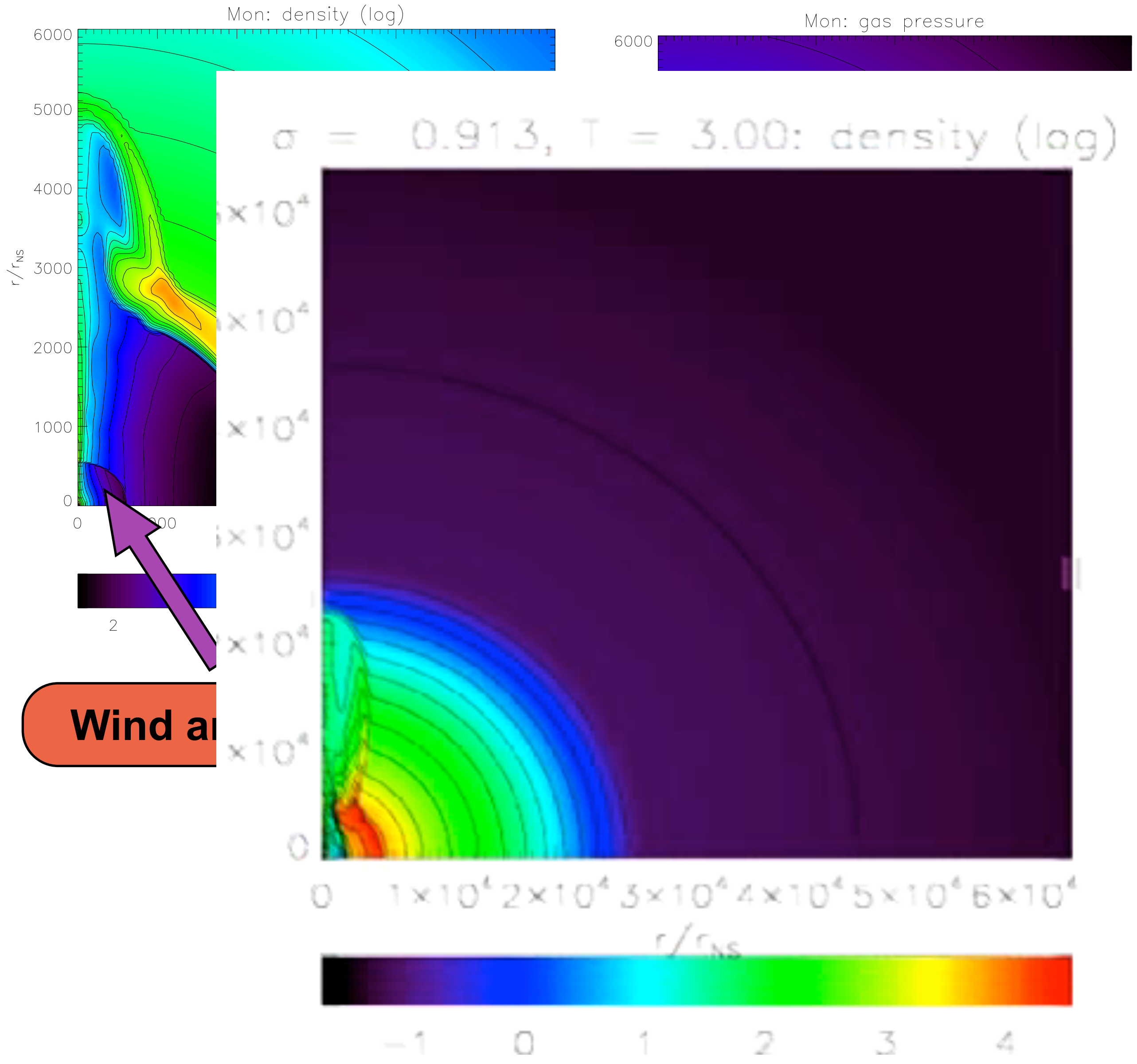

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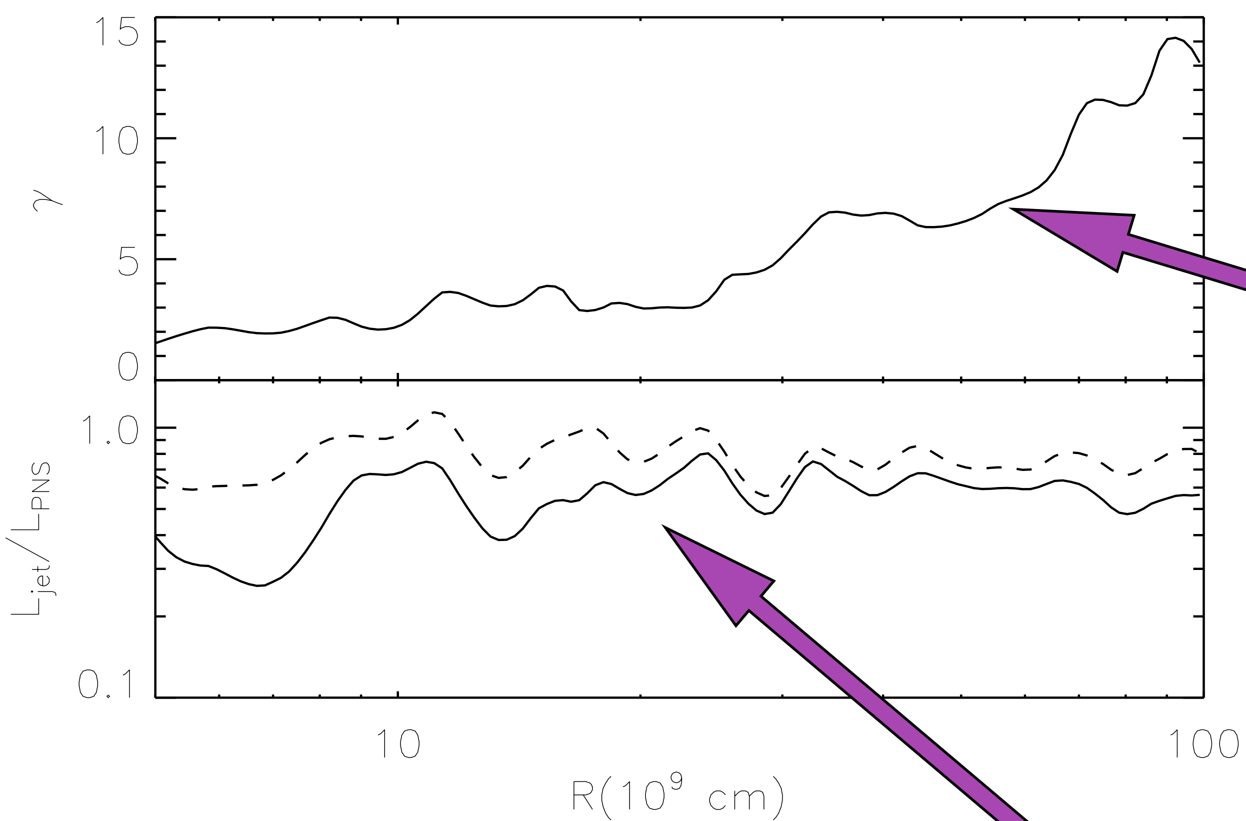
Jet at large distances



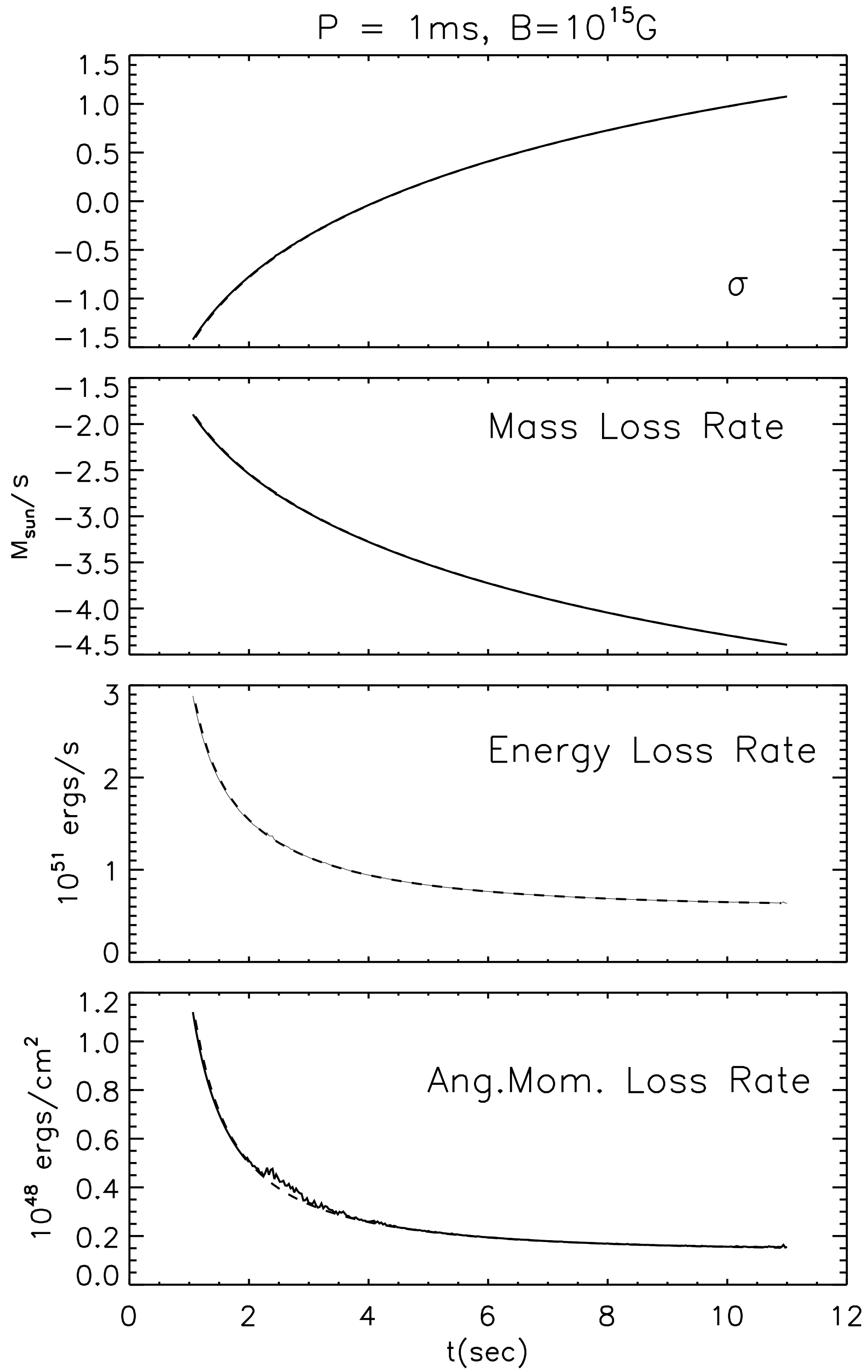
Bucciantini et al. 2007

Lorentz factor increases linearly in radius

Efficient acceleration
Efficient energy flux
Little NS-SN coupling

Most of the energy is carried by the relativistic core of the jet

PNS SN coupling

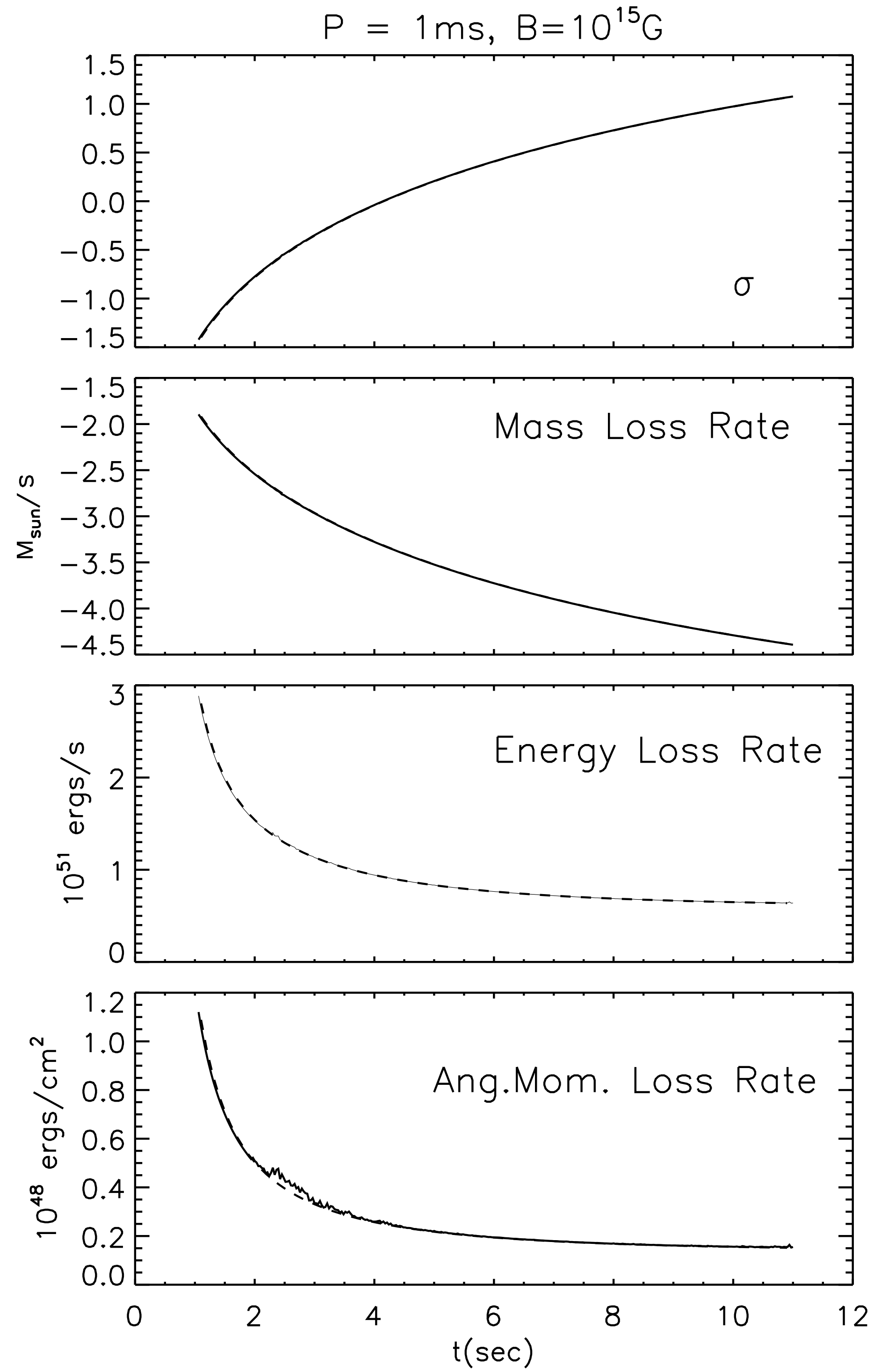


Comparison of the losses for a free-wind case and the case of a PNS confined inside a SN progenitor.

Losses are not changes by confinement, same torque, free wind model for PNS evolution are reliable

The PNS wind does not efficiently powers the SN

PNS SN coupling



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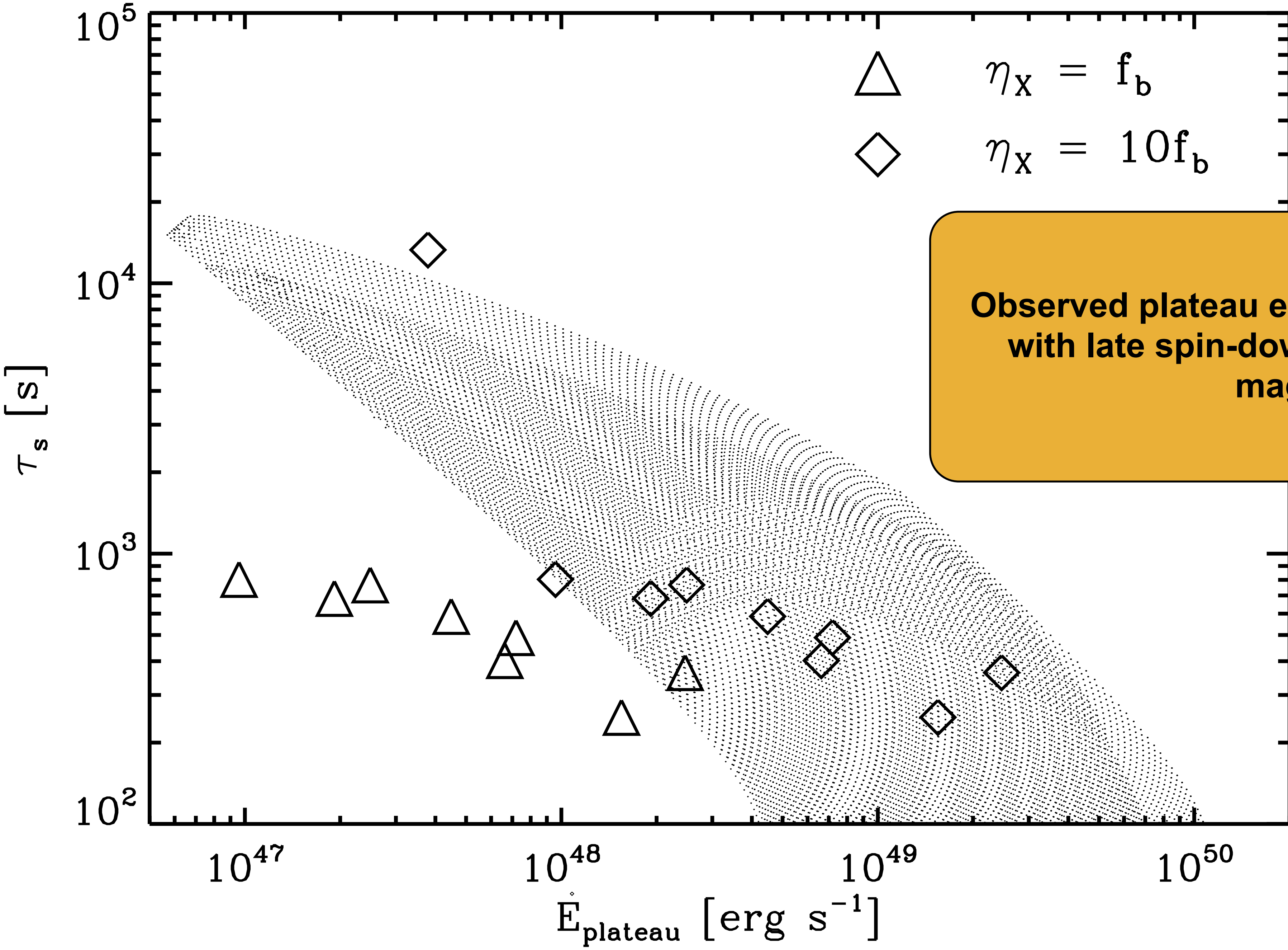
MHD jets at 1s AB produce ~no Ni

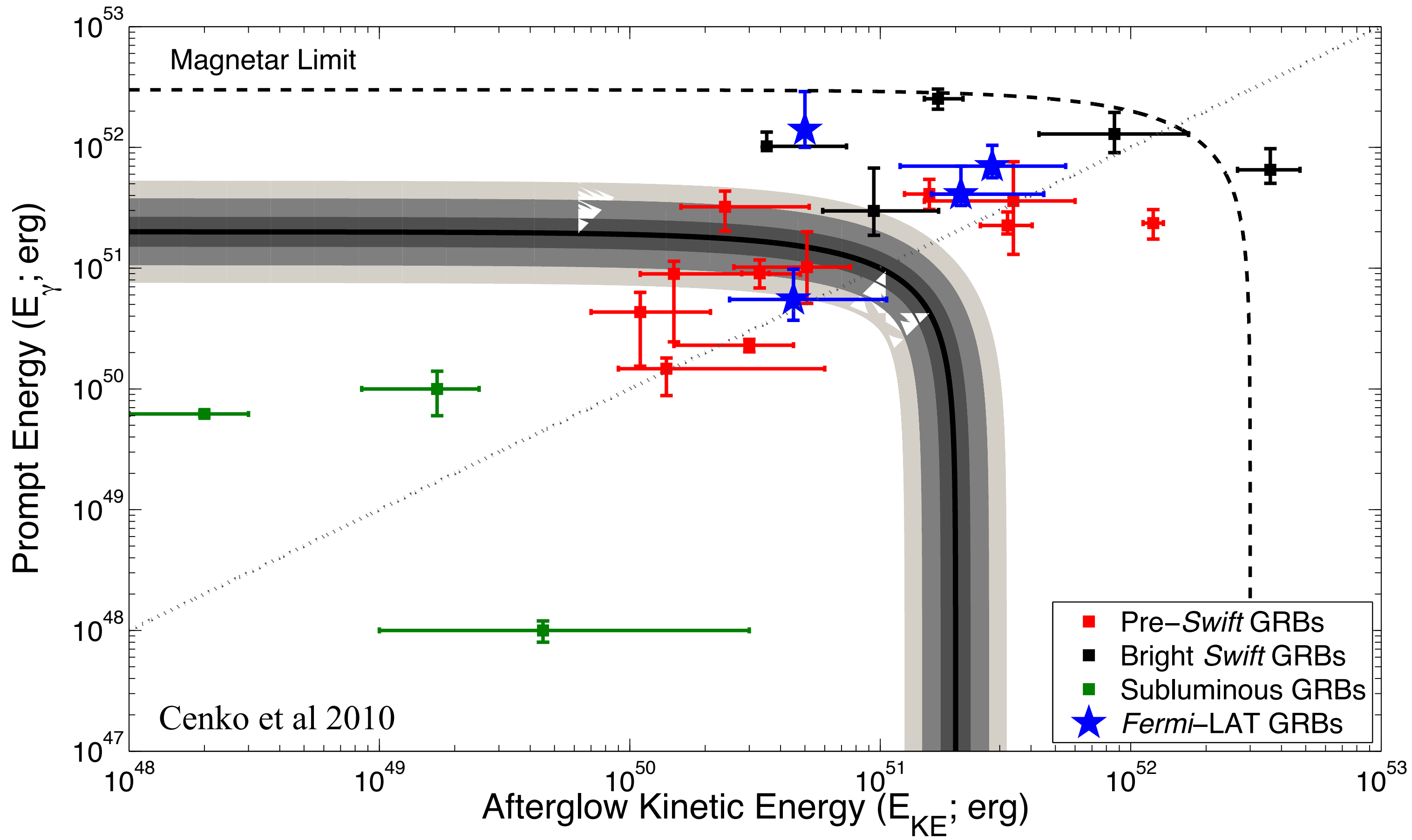
Late activity



Observed plateau energies are compatible with late spin-down injection from the magnetar.

Validating the model

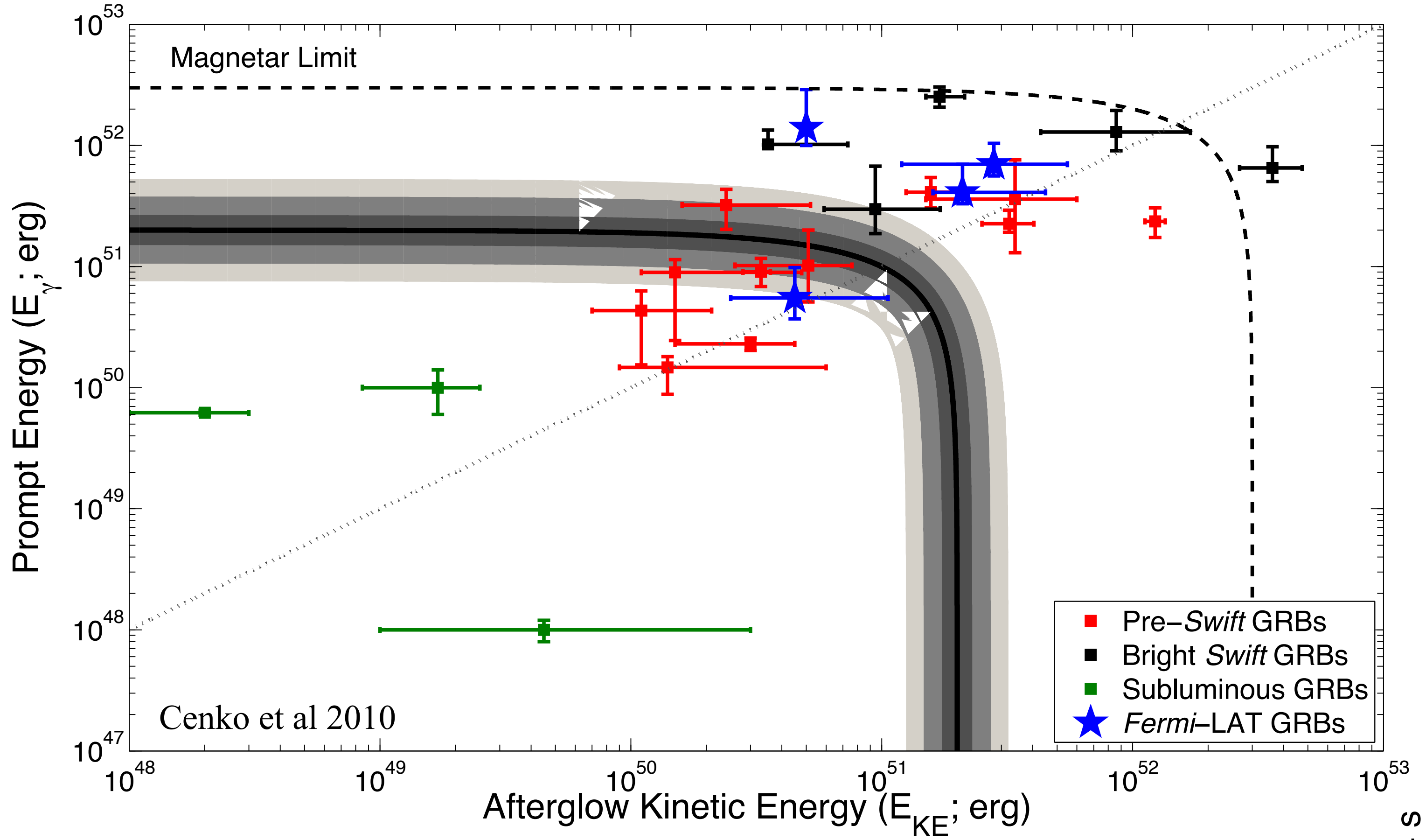
Validating the model



Magnetar model predict a maximum energy

Are there two classes of GRBs? What are the biases?

Validating the model



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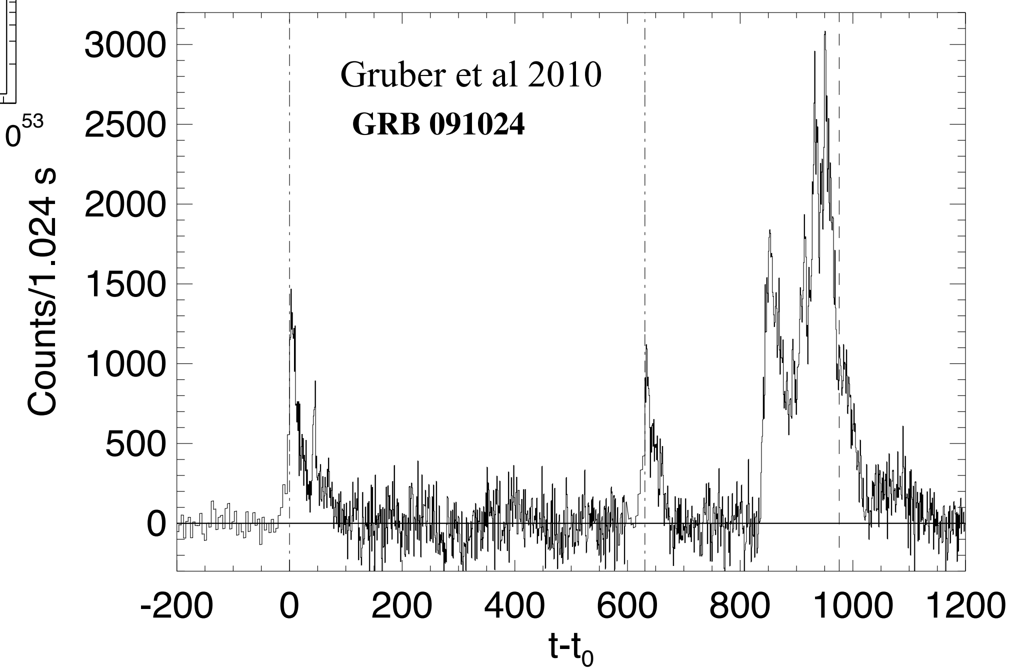
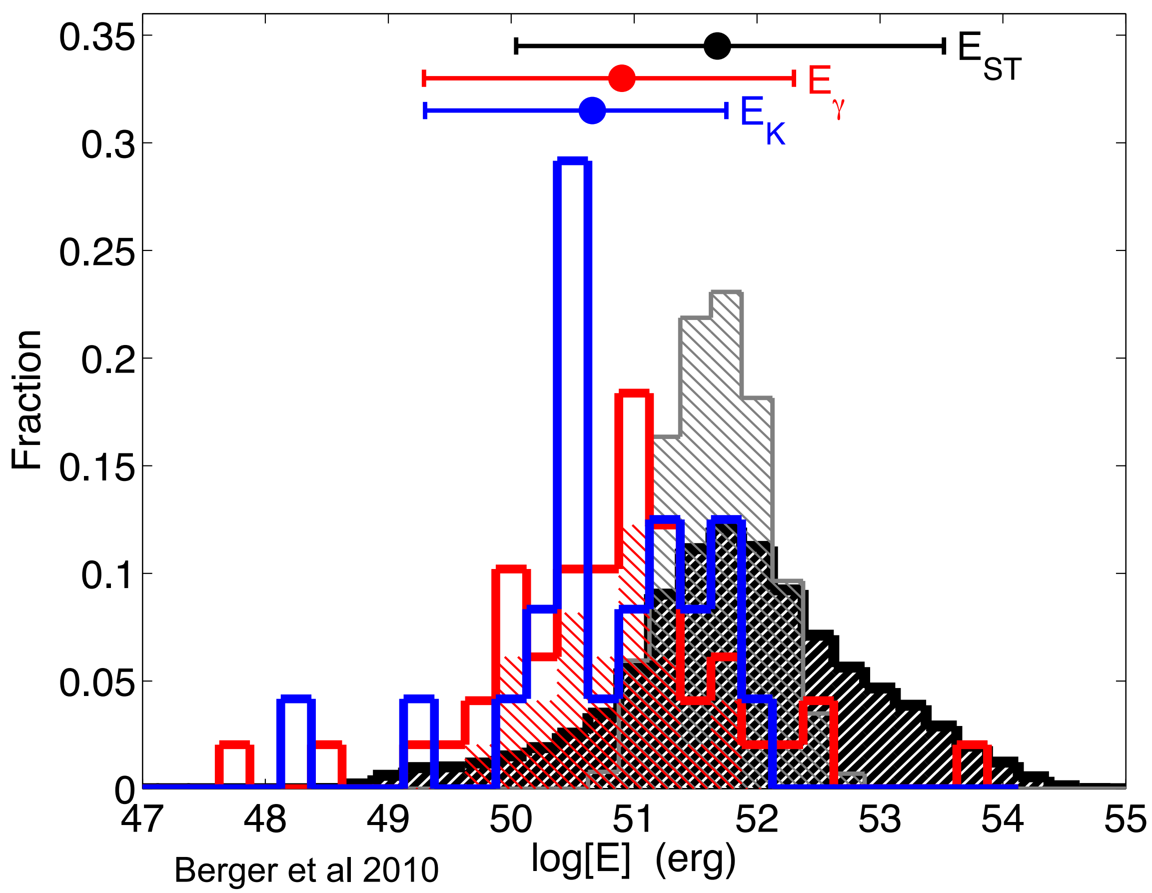


What about duration? Can we have very long prompt phases?

GRB true energetics

$E_{iso} = 10^{54}$ ergs = 1 M_{sun} rest energy
$E\gamma < E_{kin} < E_{tot}$ (GW and Neutrinos)
E_{kin} measured from radio afterglow ~ $10^{51\text{-}52}$ ergs

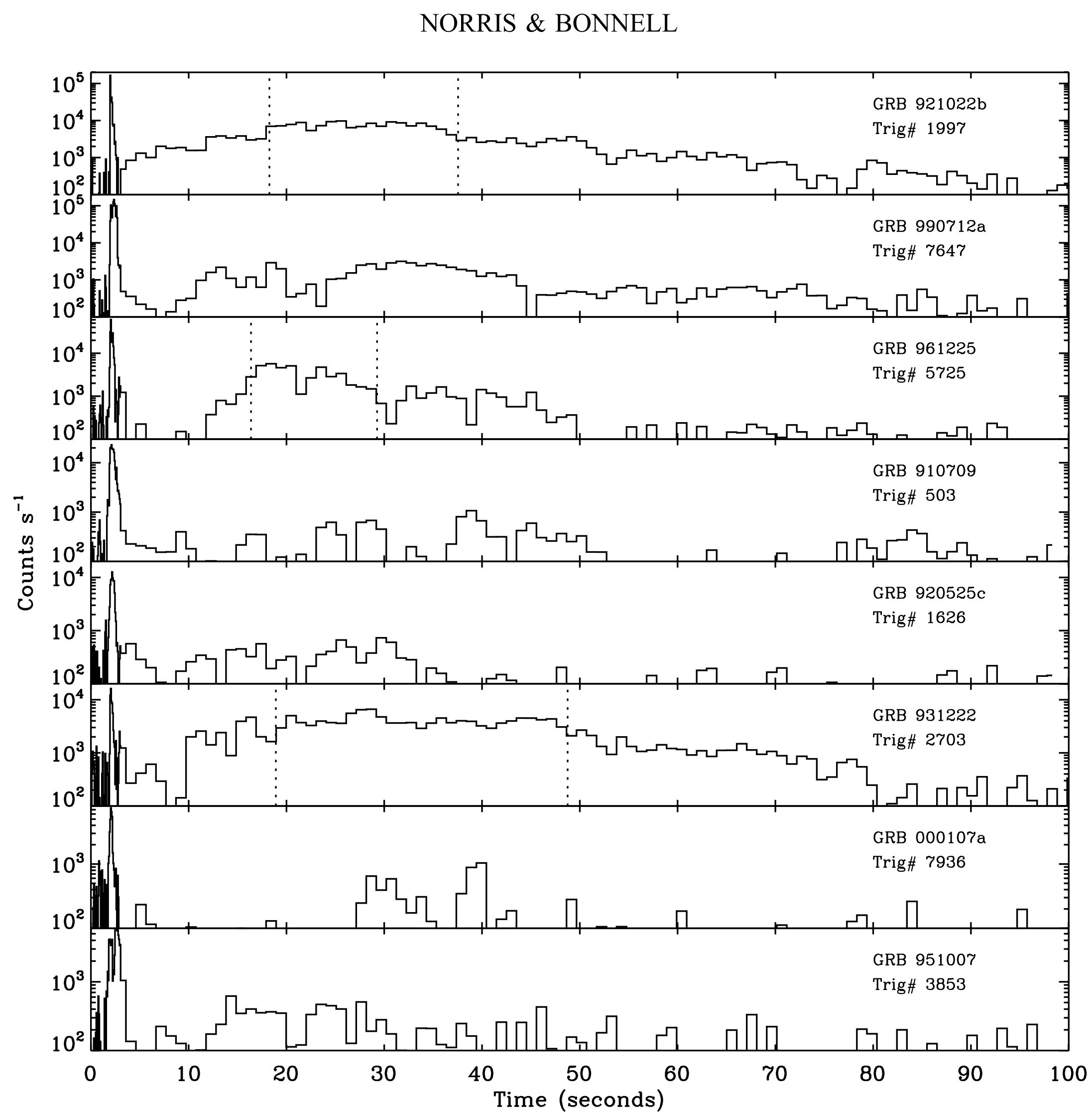
Emission is beamed - Jet
Opening angle ~ 10^{o}

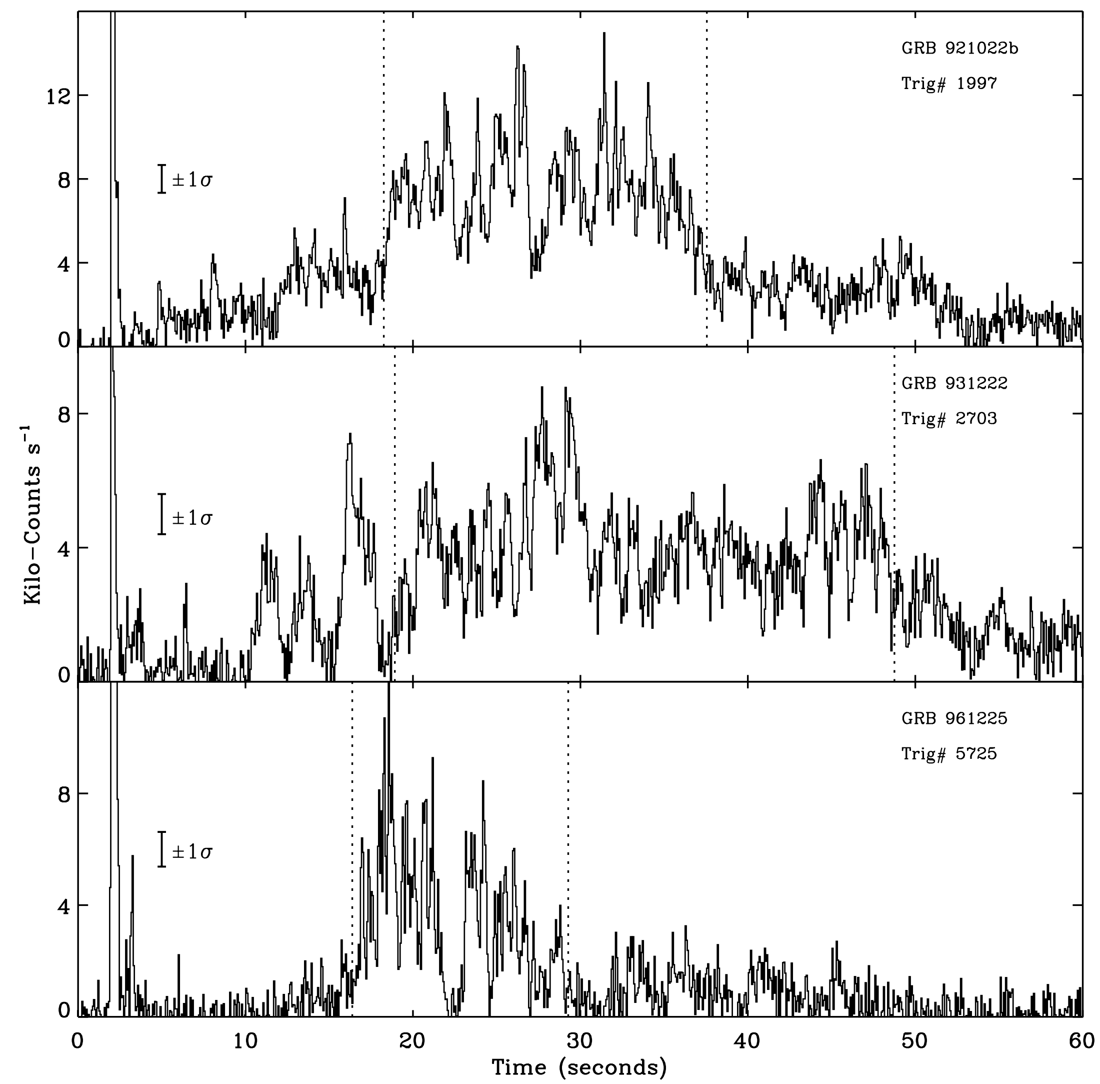


Estimates are model dependent:

Sedov-taylor
On-axis
Synchrotron
Bipolar
Uniform front

Short GRBs with EE





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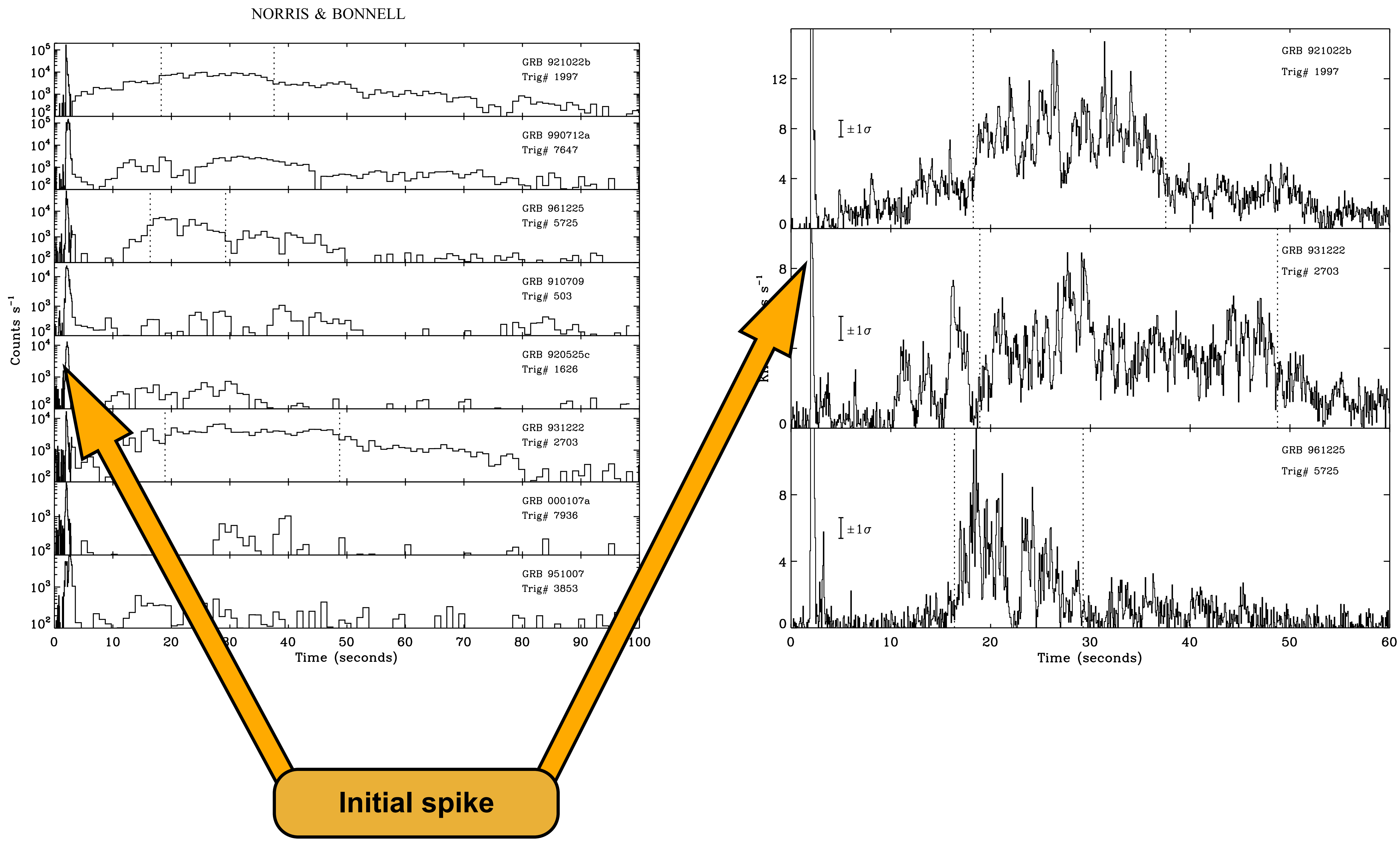

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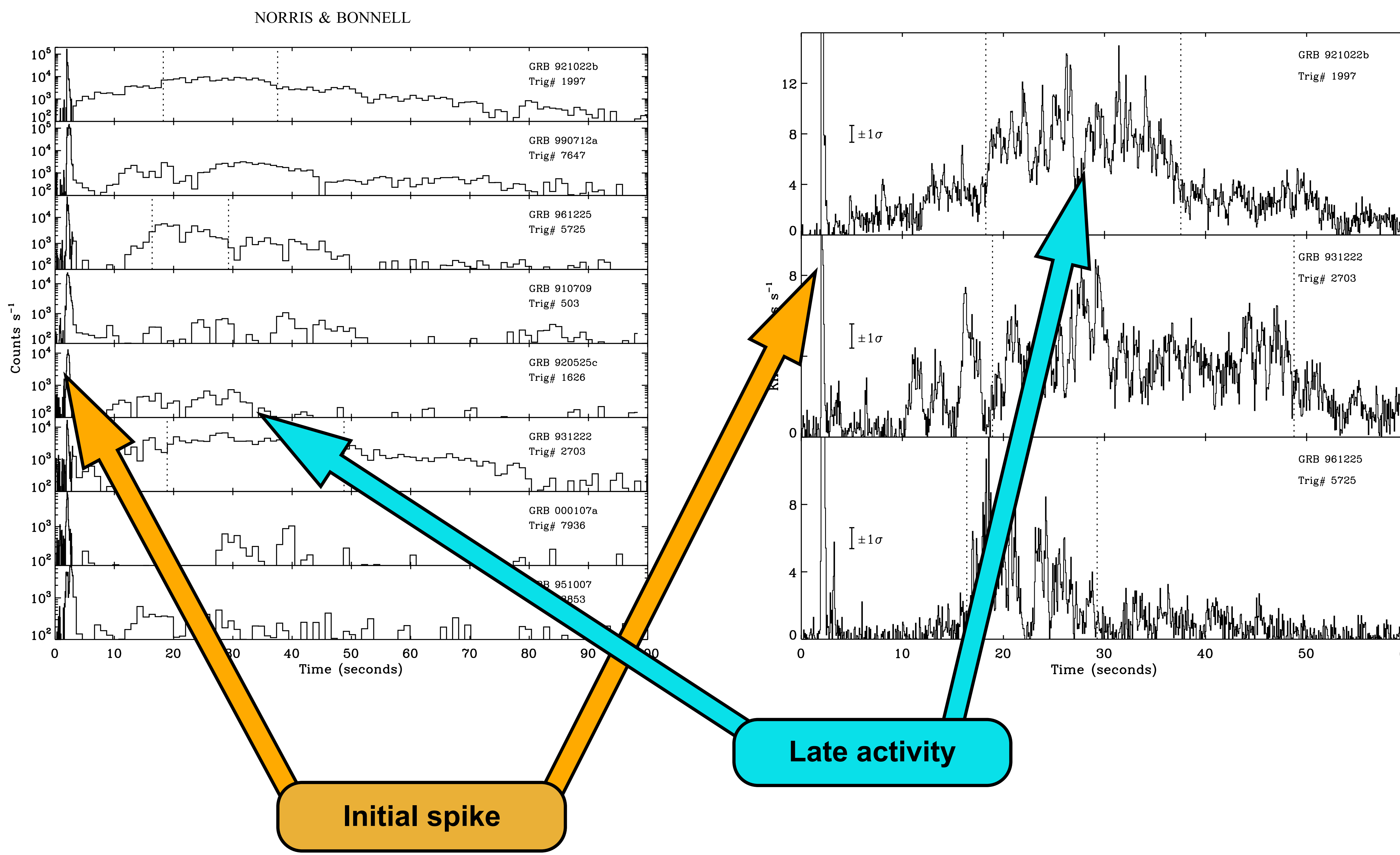

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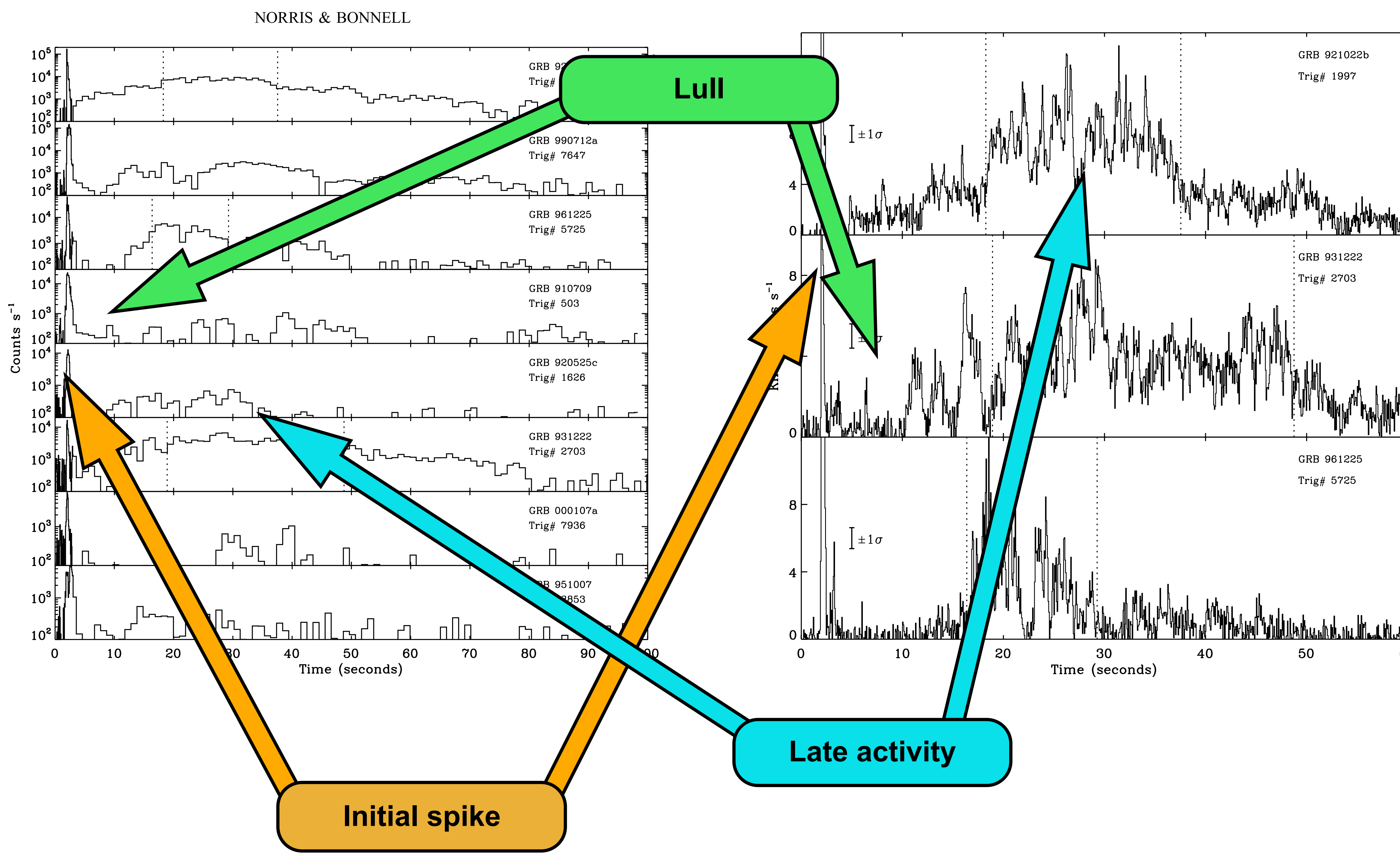

EE and LGRBs

Table 1
Prompt Emission Properties of Swift SGRBs and Candidate SGRBs

GRB	Class Ambiguous?	z	S_{EE}/S_{spike}
050509B	N	0.2249	< 14.3
050724	N	0.258	2.64 ± 0.49
050813	N	0.722?	< 3.64
050906	Y[a]	...	< 14.87
050911	Y[bc]	0.1646?	1.31 ± 0.43
050925	Y[d]	...	< 1.83
051105A	N	...	< 8.06
051210	Y[b]	0.114?	2.72 ± 1.33
051221A	Y[b]	0.5465	< 0.16
051227	Y[b]	...	2.87 ± 0.677
060313	N	...	< 0.29
060502B	N	0.287?	< 3.45
060801	N	1.131?	< 1.84
060614	Y[be]	0.125	6.11 ± 0.25
061006	Y[b]	0.4377	1.75 ± 0.26
061201	N	0.111?	< 0.71
061210	N	0.41?	2.81 ± 0.63
061217	N	0.827	< 3.81
070209	N	...	< 8.08
070429B	N	0.904	< 2.44
070714B	N	0.92	0.477 ± 0.163
070724A	N	0.457	< 4.24
070729	N	...	< 2.16
070731	Y[b]	...	< 1.37
070809	Y[b]	0.219?	< 1.37
070810B	N	...	< 9.40
070923	N	...	< 5.96
071112B	N	...	< 4.14
071227	Y[b]	0.383	1.56 ± 0.49[f]
080503	Y[e]	...	32.41 ± 5.7

The fluence of the EE is comparable or bigger that the initial spike

EE dominates the energetics of the event

Perley et al 2009

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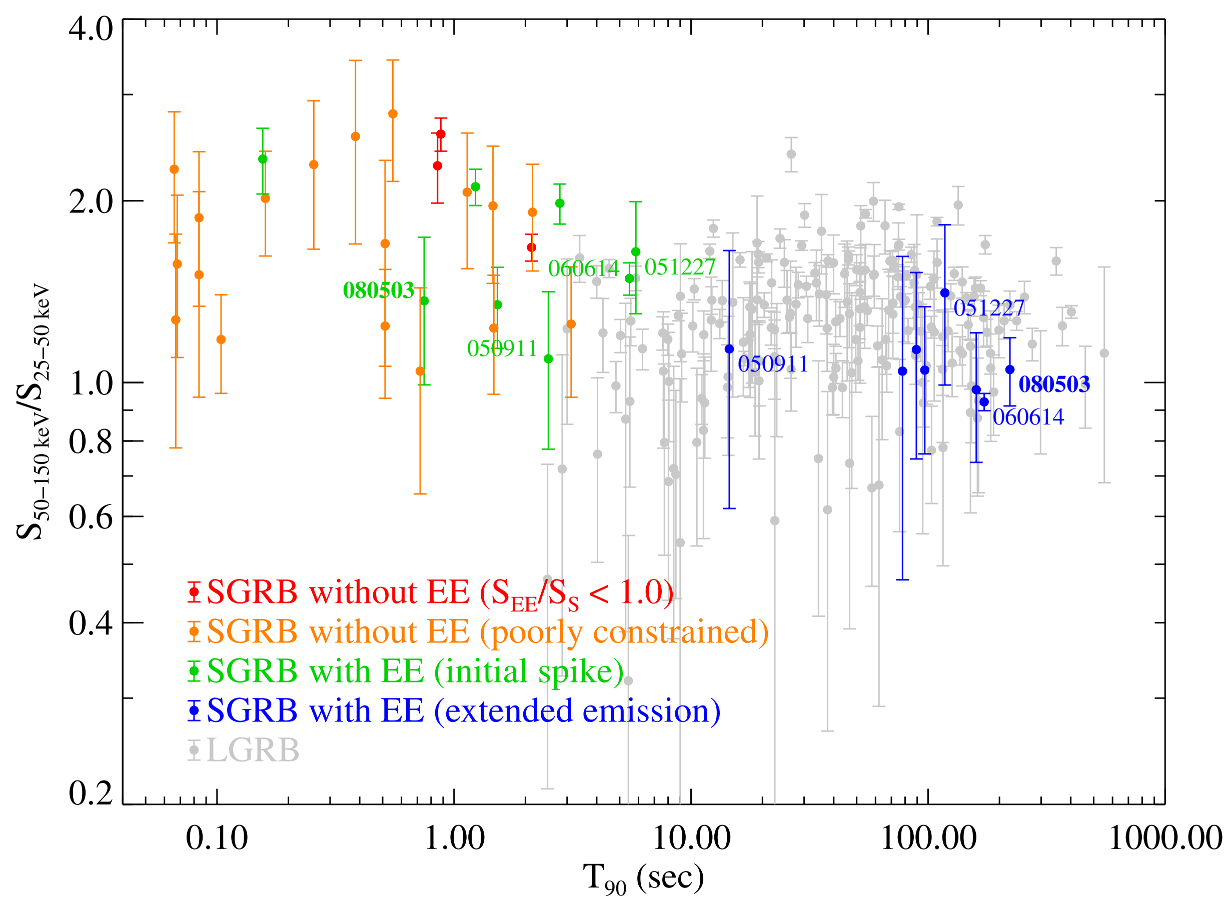
EE has same properties in HR - duration that LGRBs. EE along would be classified as LGRBs

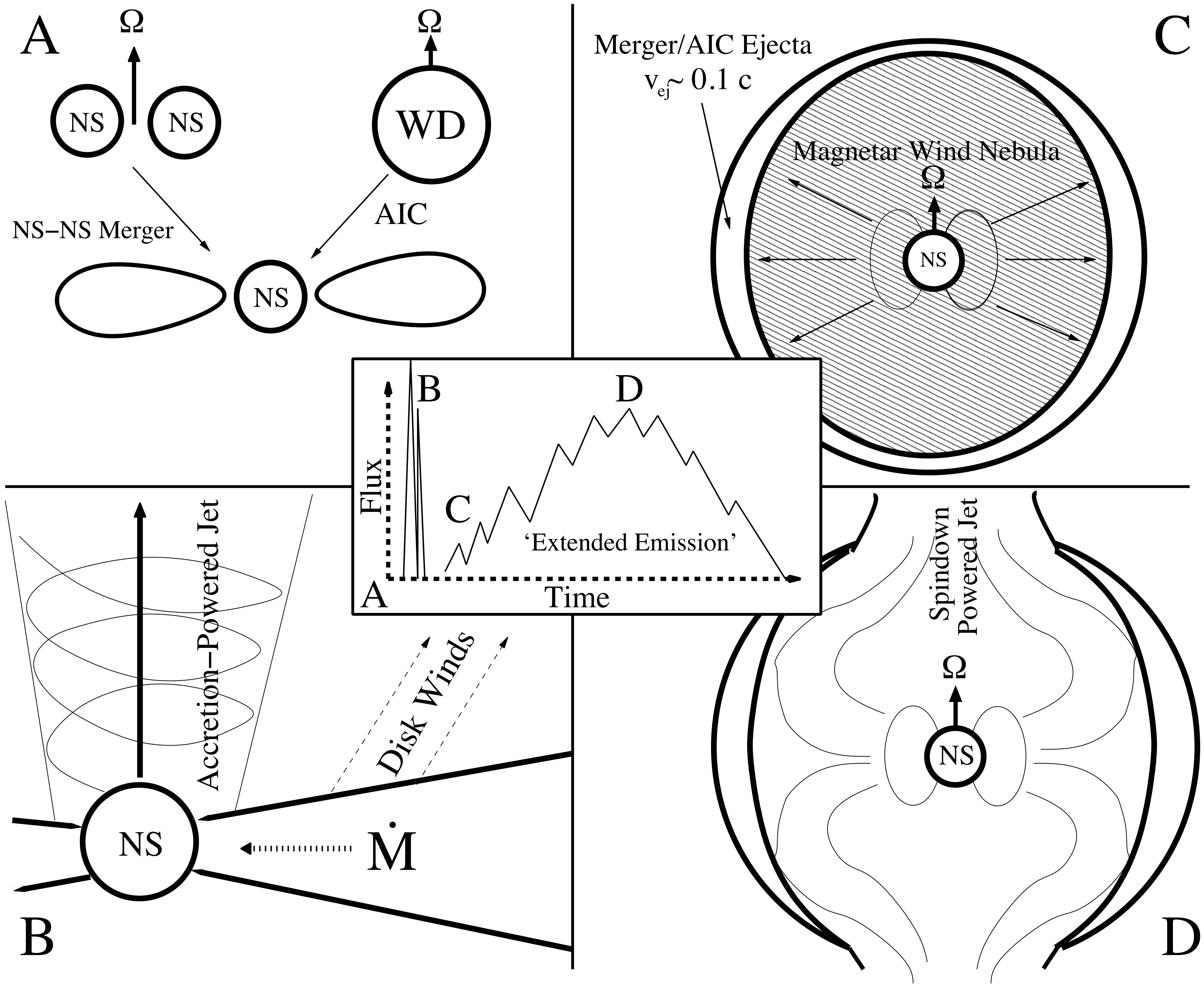


Perley et al 2009

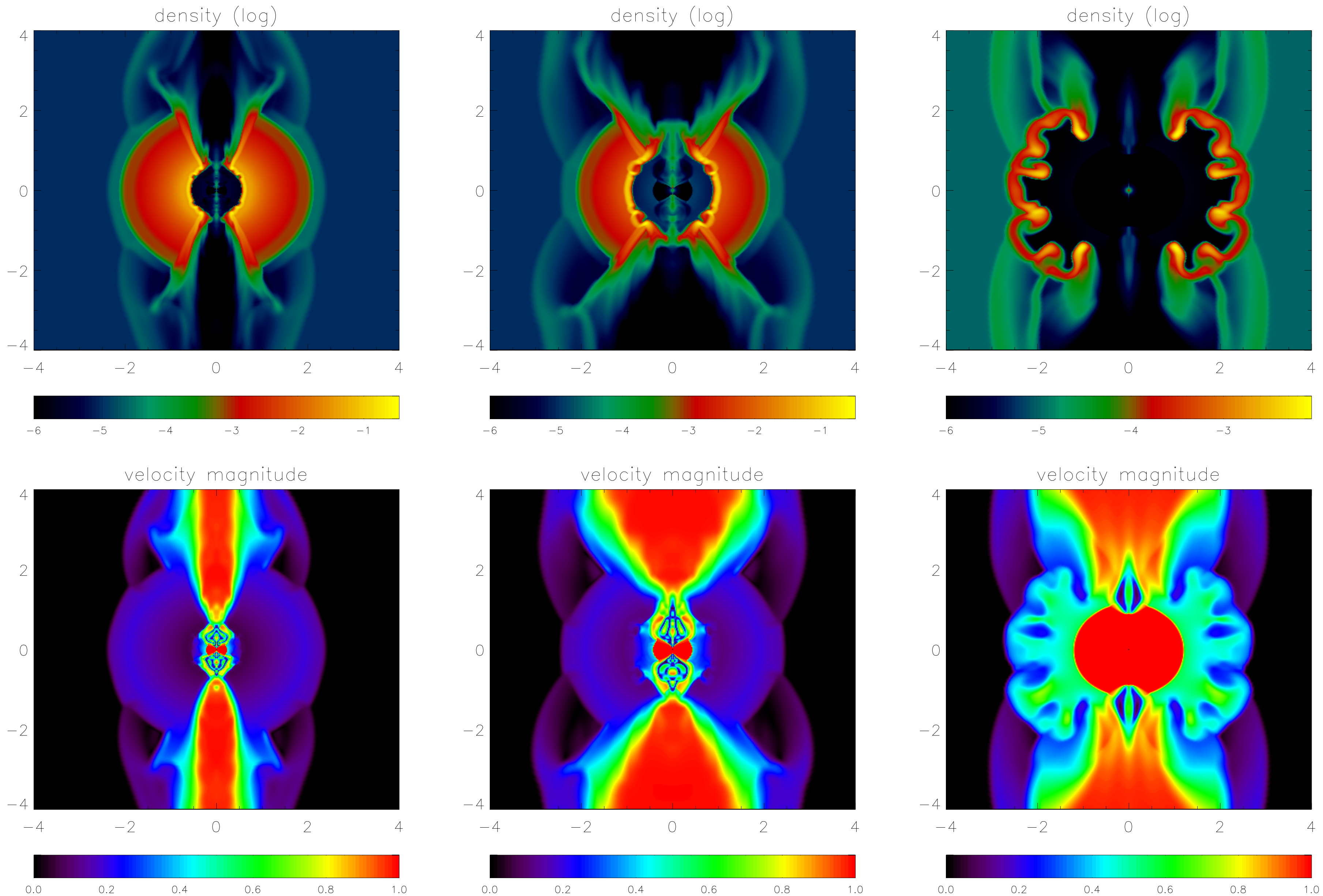
The fluence of the EE is comparable or bigger that the initial spike

EE dominates the energetics of the event

SGRBEEs & Magnetar



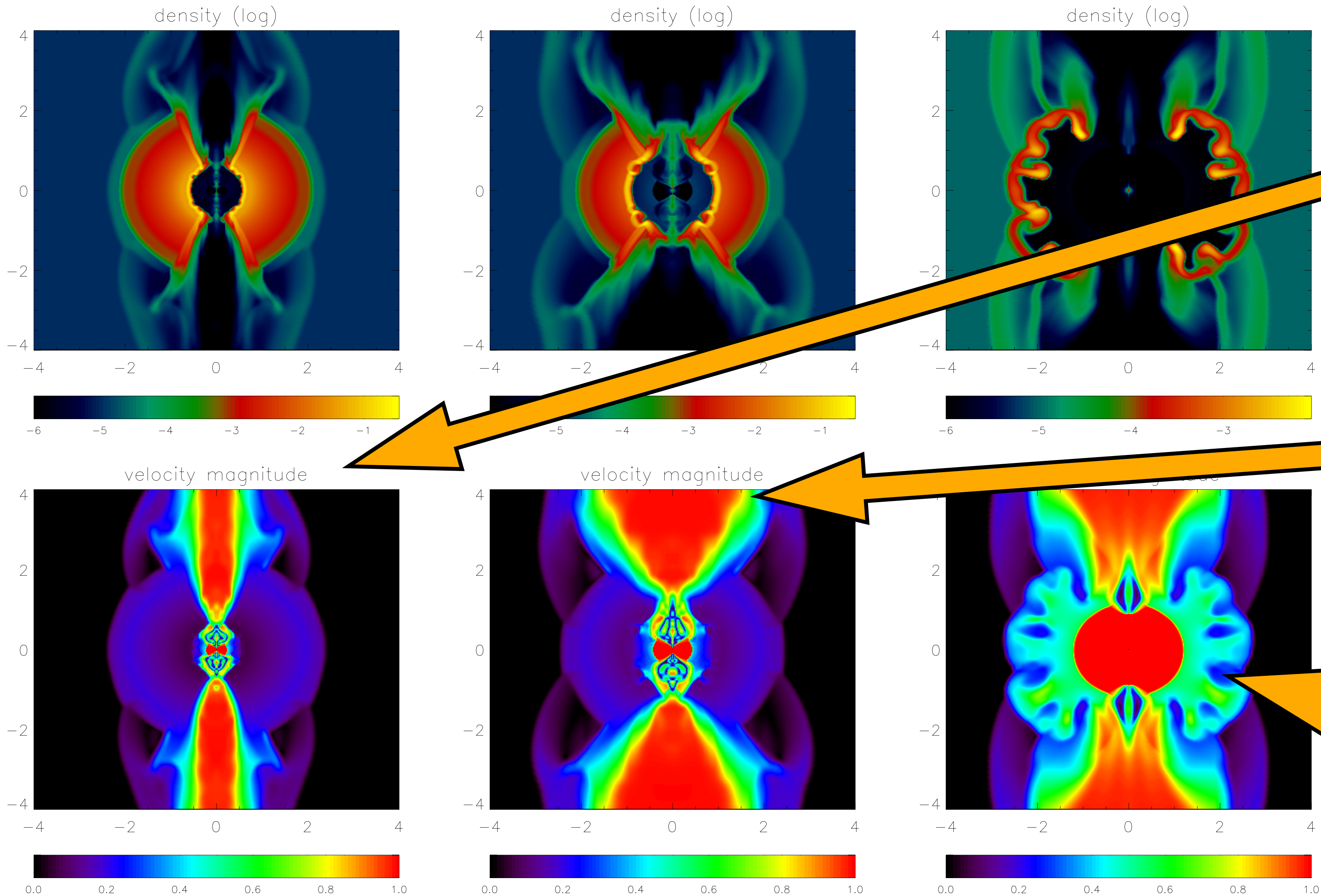
Dynamics of the outflow



The confining ejecta shell is assumes self-similar

The outcome is just a function of the ration of the mass in the ejecta and the PNS luminosity

Dynamics of the outflow



L / M ~ 10^{50} erg / Msun

L / M ~ 10^{51} erg / Msun

L / M ~ 10^{52} erg / Msun

The confining ejecta shell is assumes self-similar

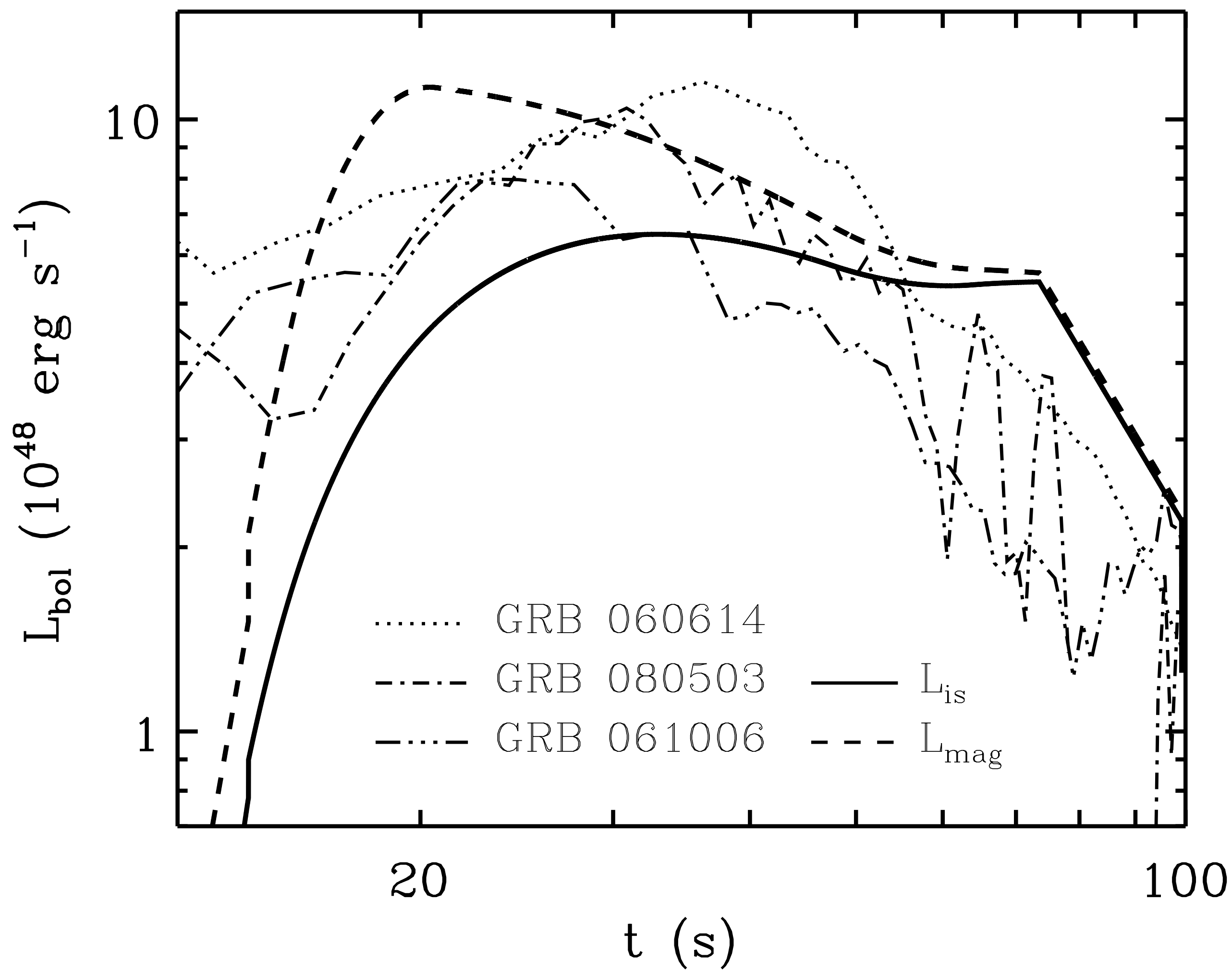
The outcome is just a function of the ration of the mass in the ejecta and the PNS luminosity

A model light-curve

PNS cannot be too energetic if collimation is needed

PNS cannot be too weak if the flow has to become optically thin fast enough to avoid thermalization

The lull can be due either to a buried jet or to the still optically thick outflow



The EE is terminated once the PNS wind becomes leptonic dominated

Conclusions

- The SN connection of LGRBs suggest that neutron star (millisecond magnetars) might be plausible engine
- The magnetar model can be constrained and lead to precise predictions
- The presence of a long lasting engine suggest other form of energy injection than accretion
- Difference in PNS properties can reproduce the observed diversity of LGRBs
- EE and late plateau are clear indication of engine activity at times >> than the typical timescale for accreting o a BH formed during AIC or NS-NS merger
- The properties of the EE closely resemble the behavior of LGRBs
- Millisecond magnetars can be the engine of SGRBEE

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Thank you