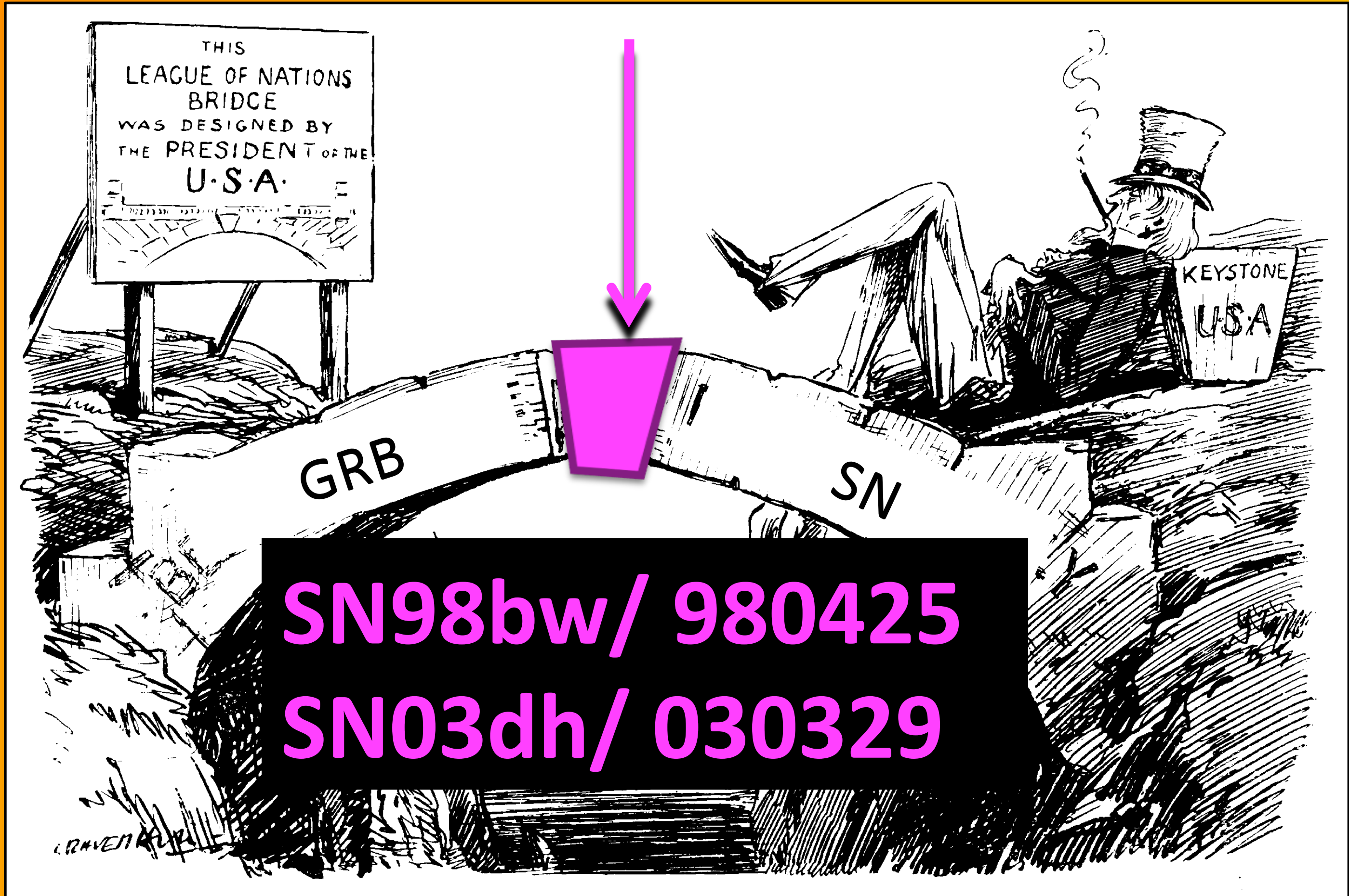
Overview of the GRB-SN connection



THE GAP IN THE BRIDGE.

Raffaella Margutti
Harvard University

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

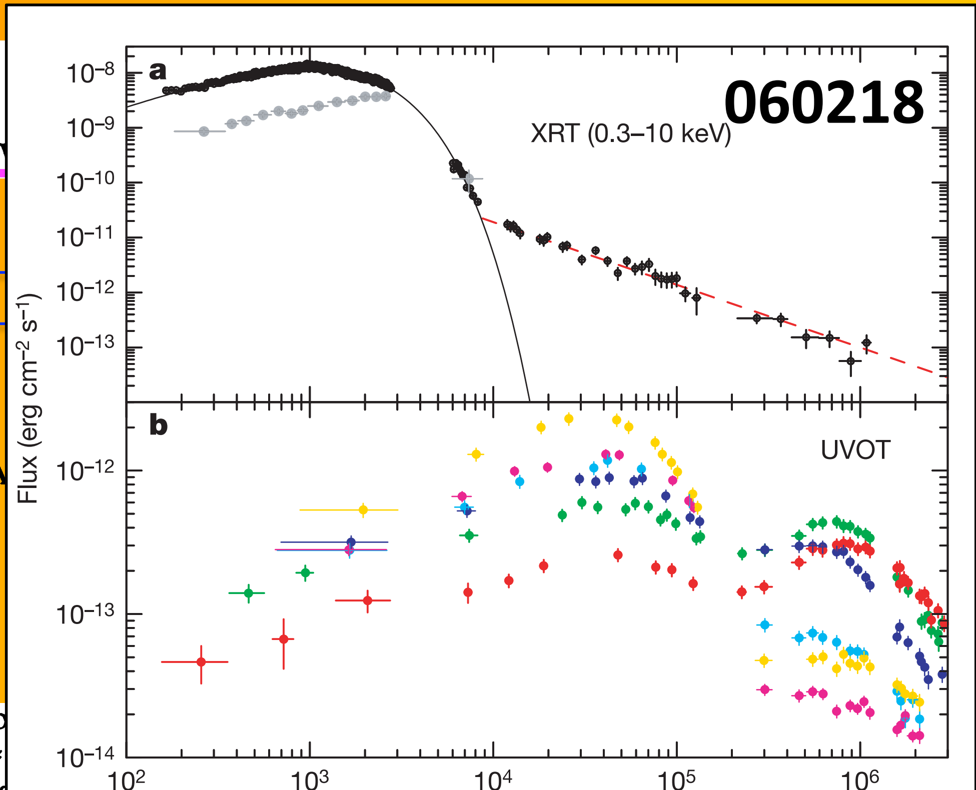
On several occasions in the past we have searched the records of data from early *Vela* spacecraft for indications of gamma-ray fluxes near the times of appearance of supernovae. These searches proved uniformly fruitless. Specific predictions of gamma-ray emission during the initial stages of the development of supernovae have since been made by Colgate (1968).

Shock break–out

1973

. . .

($<10^{-3}$) of the … all fraction
is not inconsistent … gy observed



Campana 2006

GA…

1986

We propose that so… …e quasars, with a
redshift $z \approx 1$ or $z \approx$ … …t 10^{51} ergs within
less than 1 s, making g…

The “collapsar” model

GAMMA-RAY BURSTS FROM STELLAR MASS ACCRETION DISKS AROUND BLACK HOLES[1]

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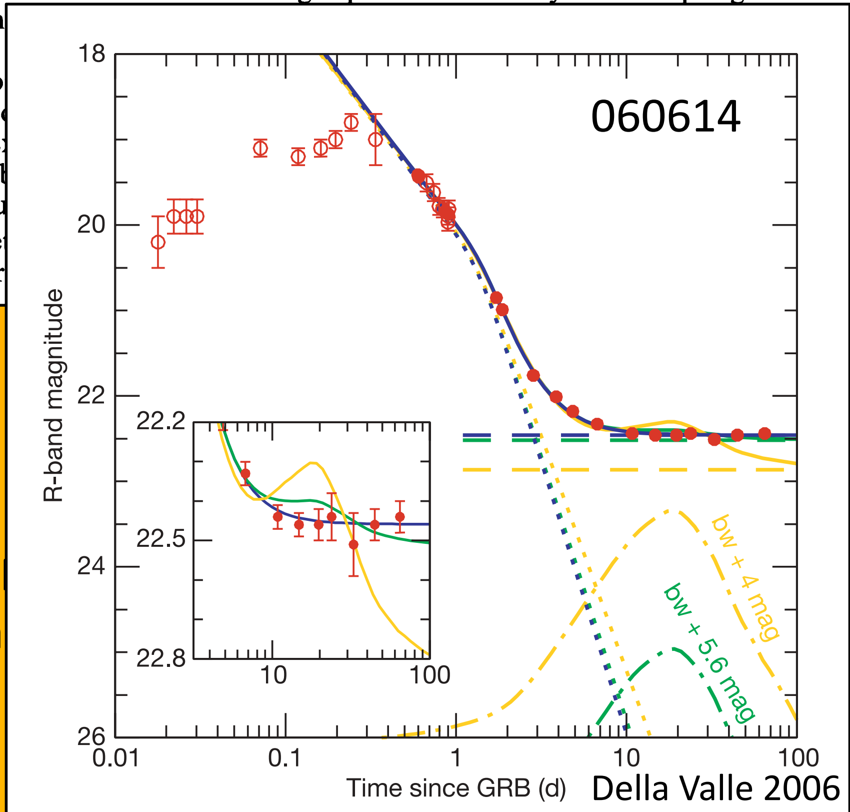
University of California Observatories/Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz, Santa Cruz, CA 95064; and General Studies Group, Physics Department, Lawrence Livermore National Laboratory
Received 1992 June 22; accepted 1992 September 3

ABSTRACT

A cosmological model for gamma-ray bursts is explored in which the radiation is produced as a broadly beamed pair fireball along the rotation axis of an accreting black hole. The black hole may be a consequence of neutron star merger or neutron star–black hole merger, but for long complex bursts, it is more likely to come from the collapse of a single Wolf-Rayet star endowed with rotation (“failed” Type Ib supernova). The disk is geometrically thick and typically has a mass inside 100 km of several tenths of a solar mass. In the failed supernova case, the disk is fed for a longer period of time by the collapsing star. At its inner edge the
disk is thick to its own ... conds. In a region
roughly 30 km across, ... reball is generated
by neutrino annihilatio... ergs s^{-1}. Electron
scattering is more imp... the time scale for
expansion increased. E... pose problems for
production of a hard ... nature and should
have an observable cou...

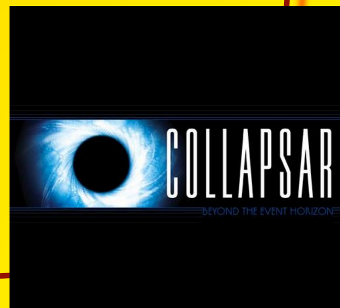
Subject headings: accre... stars: evolution —
super...

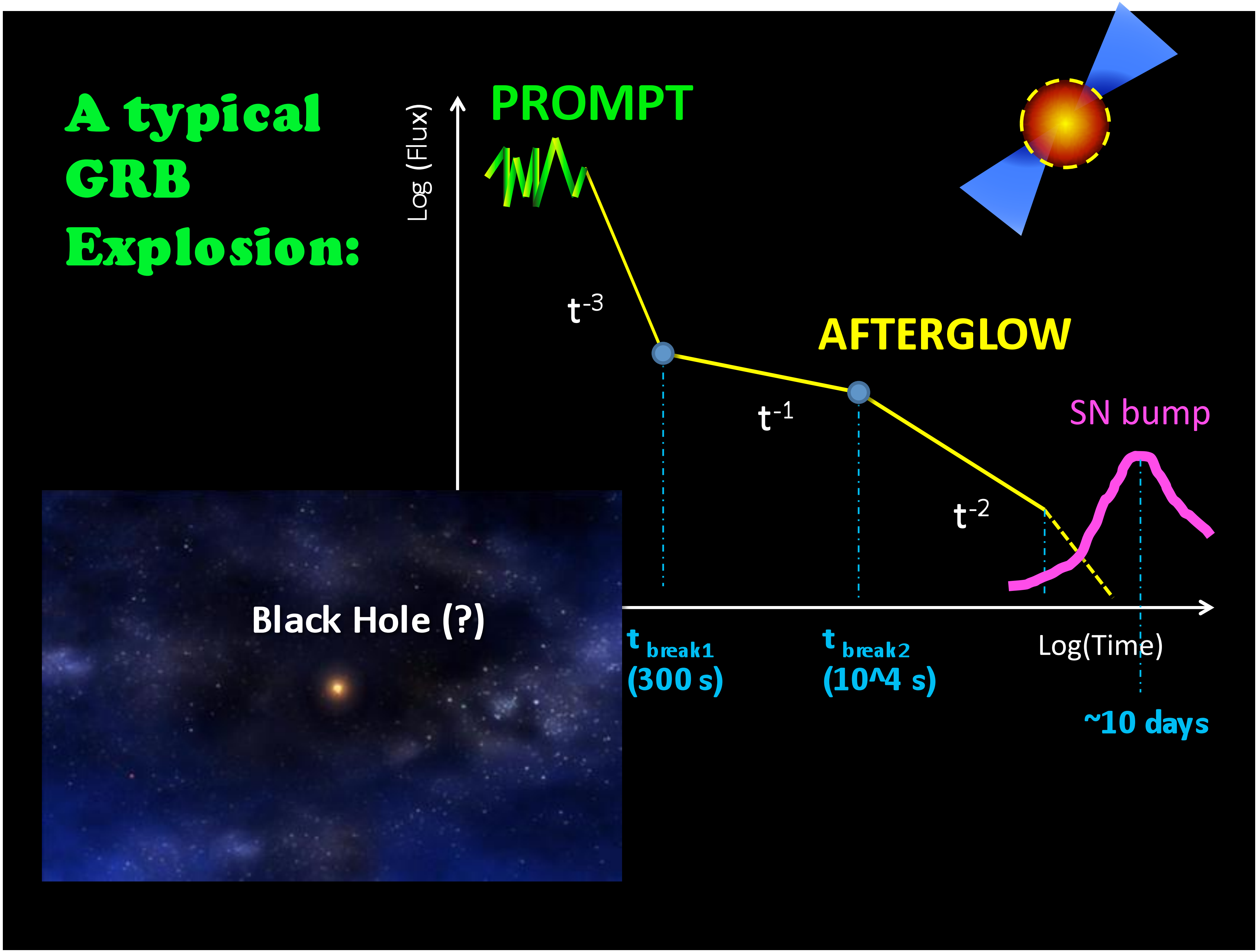


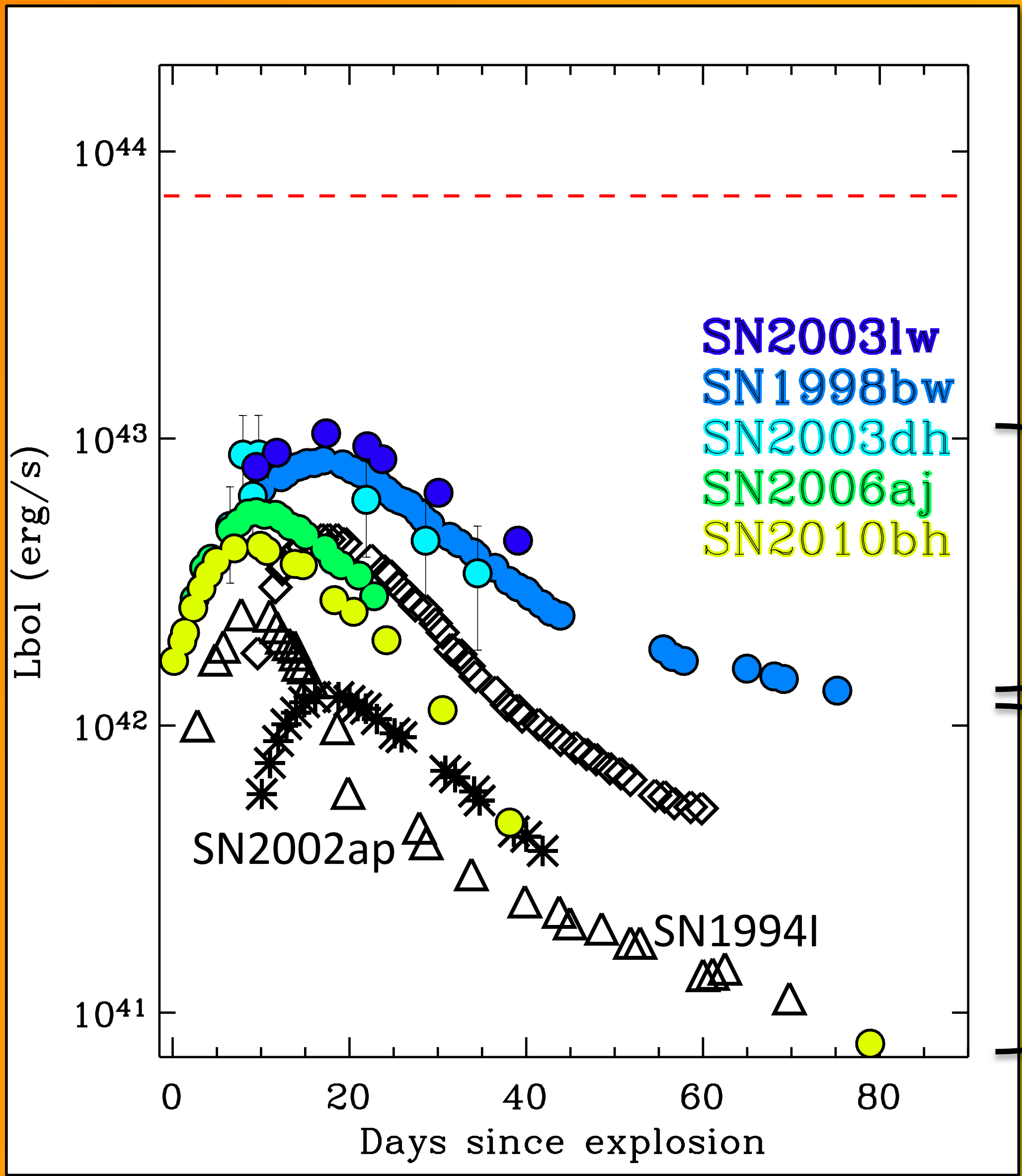
FAILED SN:

--- Little or no ^{56}...

--- No traditiona...

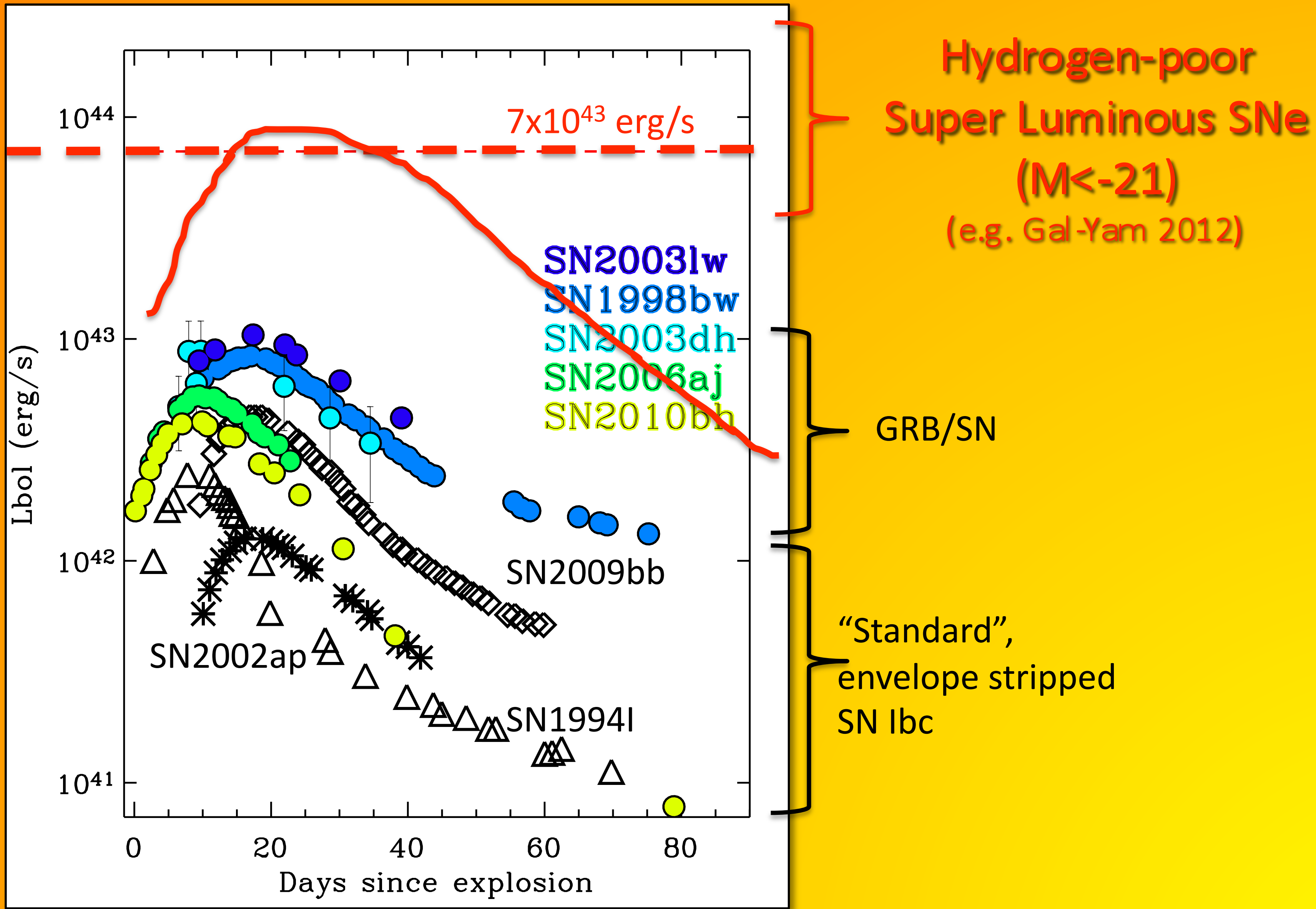



A typical GRB Explosion:
PROMPT
Log (Flux)
t-3
AFTERGLOW
t-1
SN bump
t-2
Black Hole (?)
t break1
(300 s)
t break2
(10^4 s)
Log(Time)
~10 days



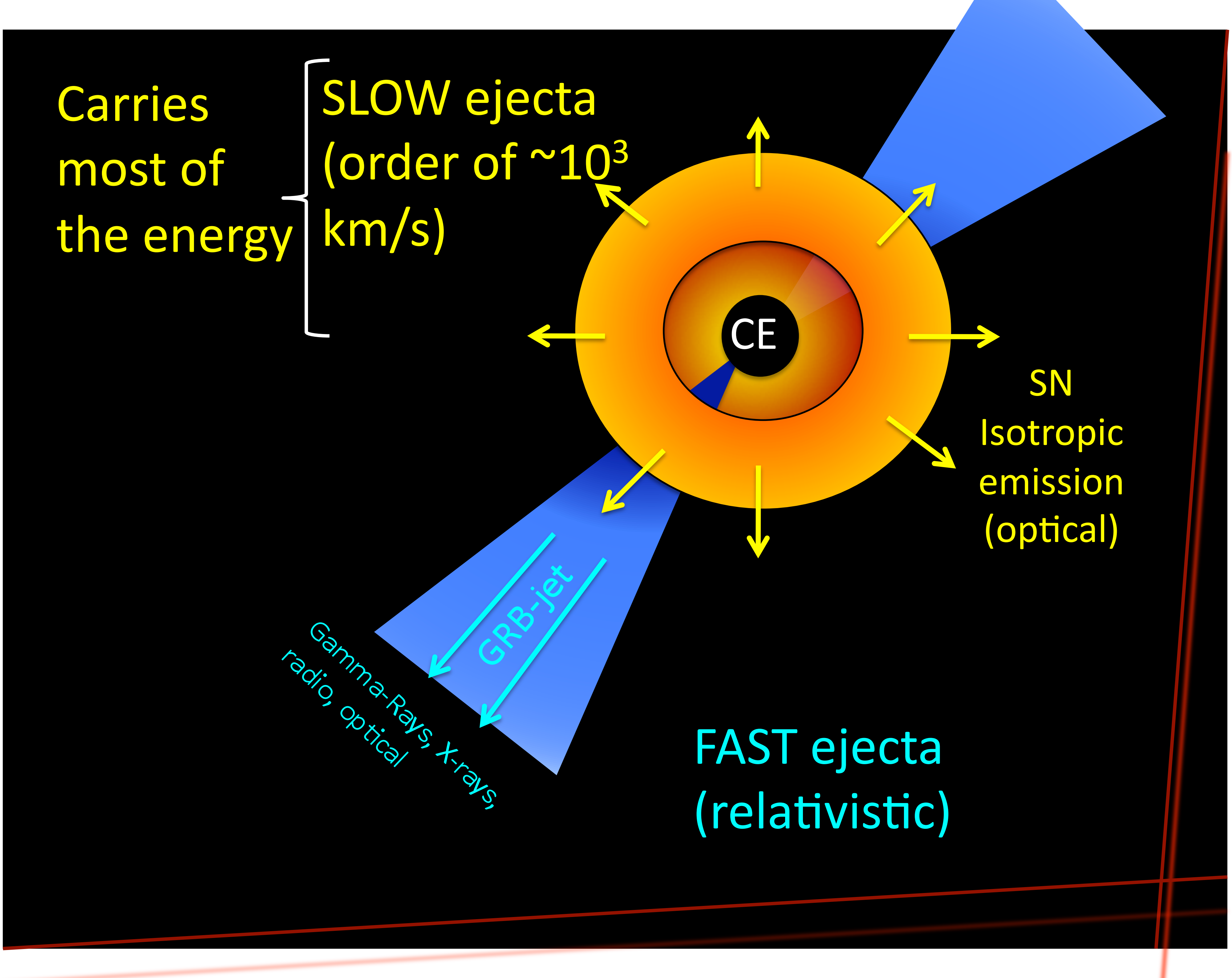
GRB/SNe

"Standard", envelope stripped SN Ibc


7x10^43 erg/s
Lbol (erg/s)
10^44
10^43
10^42
10^41
0
20
40
60
80
Days since explosion
SN2003lw
SN1998bw
SN2003dh
SN2006aj
SN2010bh
SN2009bb
SN2002ap
SN1994I
Hydrogen-poor
Super Luminous SNe
(M<-21)
(e.g. Gal-Yam 2012)
GRB/SN
"Standard",
envelope stripped
SN Ibc

X Which are the **properties** that uniquely characterize the SN/GRB class ?

X How and what can we learn about the SN/GRB central **engine** ?



Carries most of the energy
SLOW ejecta (order of ~10³ km/s)
CE
SN Isotropic emission (optical)
GRB-jet
Gamma-Rays, X-rays, radio, optical
FAST ejecta (relativistic)

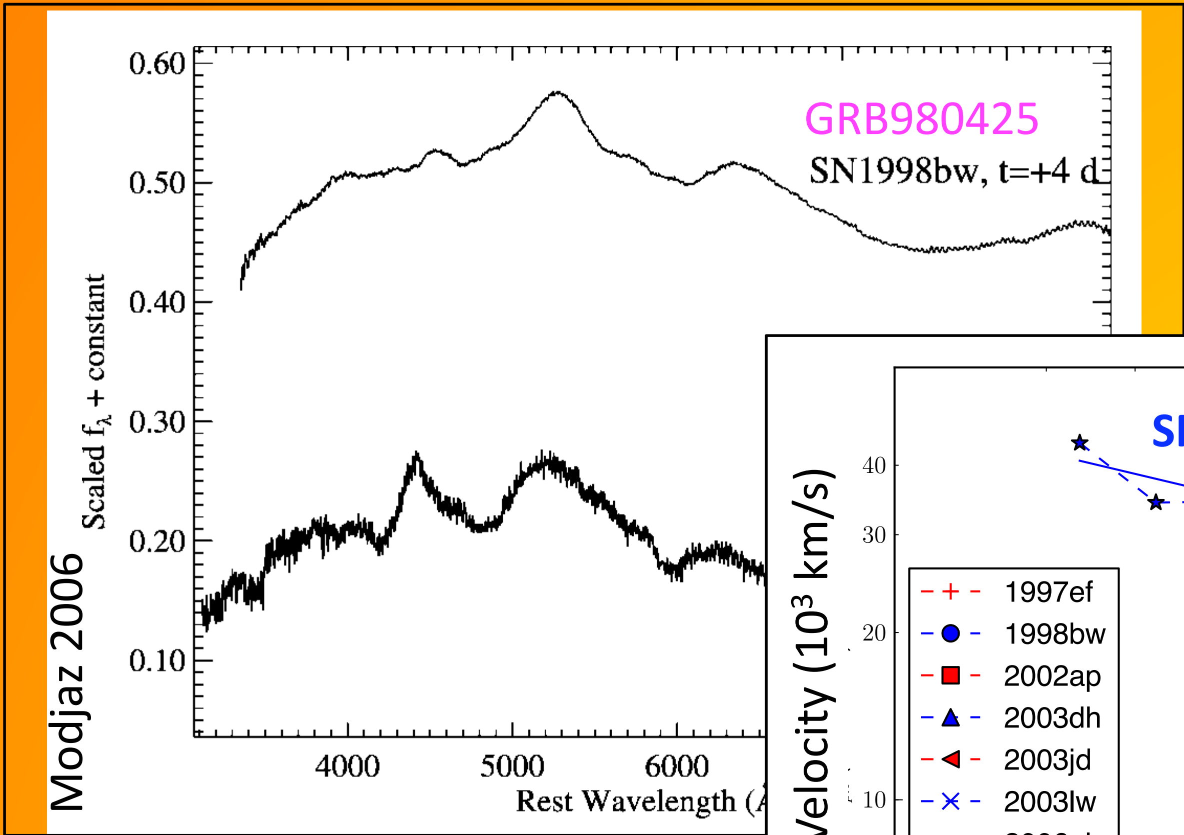
Broad-lined Ic (i.e. envelope stripped progenitor)

Large **kinetic energy** ($E_k>10^{51}$erg) and Ni mass (a few 0.1 Msun)

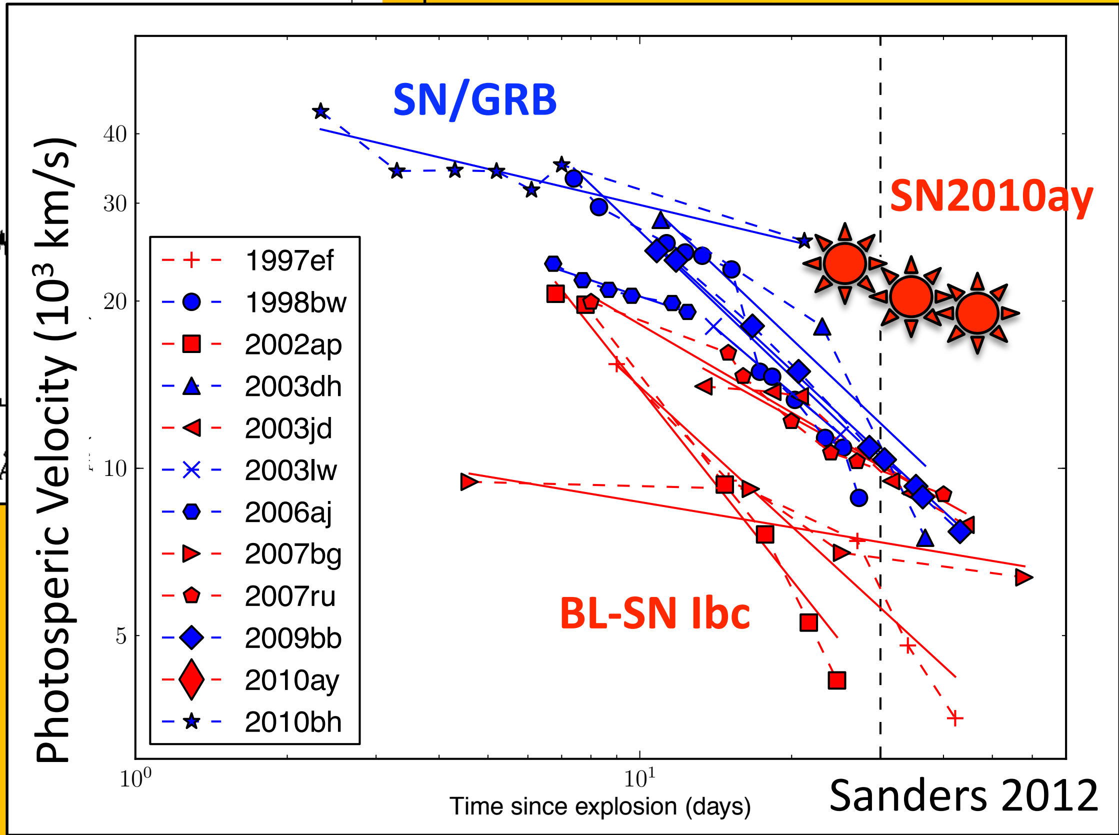
SN/GRB

Suppose we missed the prompt gamma-ray emission: is there ANY other property that would directly tell me that I'm looking at a SN/GRB?

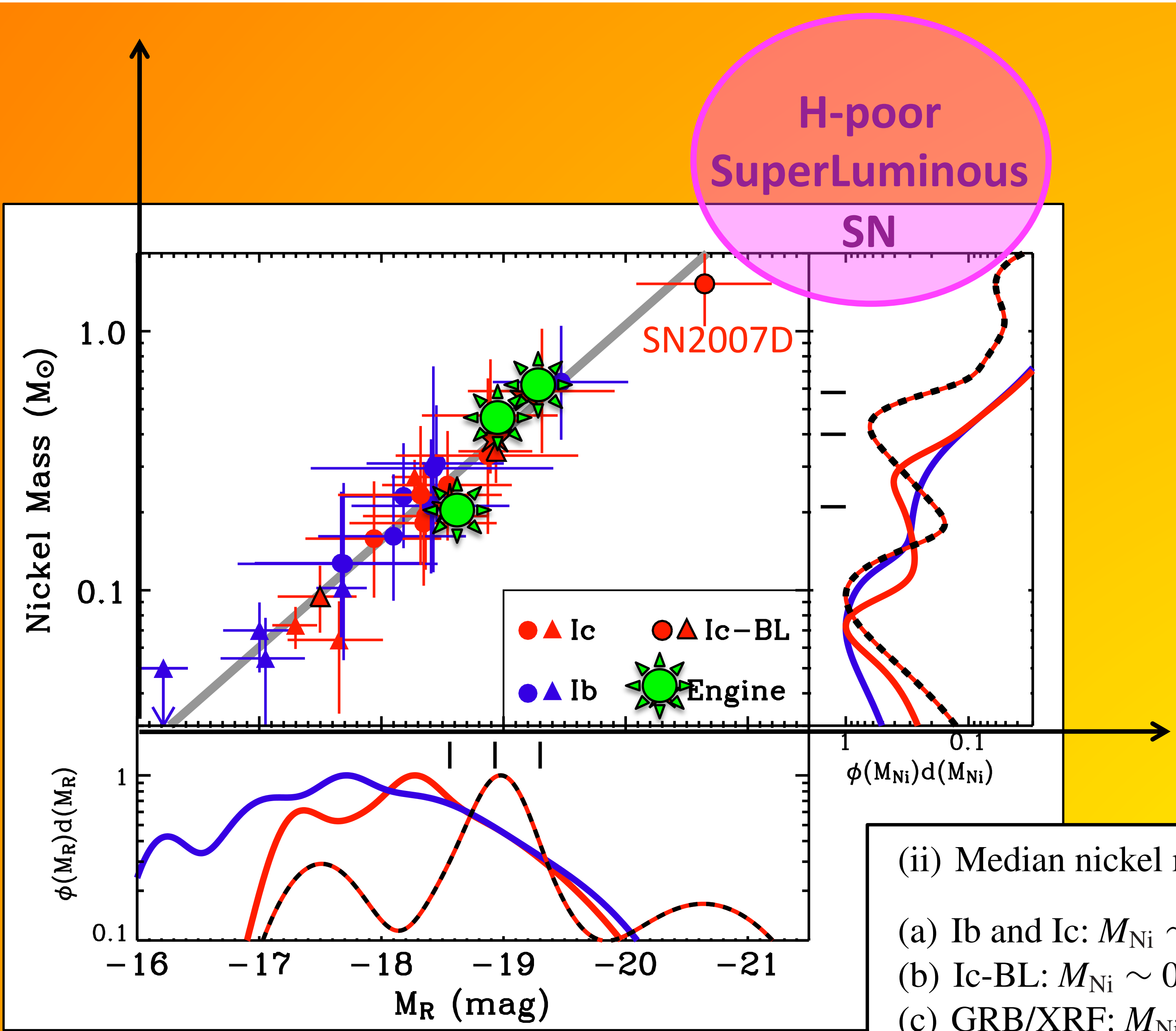
Broad-lined + large Ek + large Ni mass = Very powerful/ energetic explosions



HIGH velocity!
30000-40000 km/s
vs.
10000 km/s



SN/GRB ⟵ (prohibited) ⟶ BL-Ic



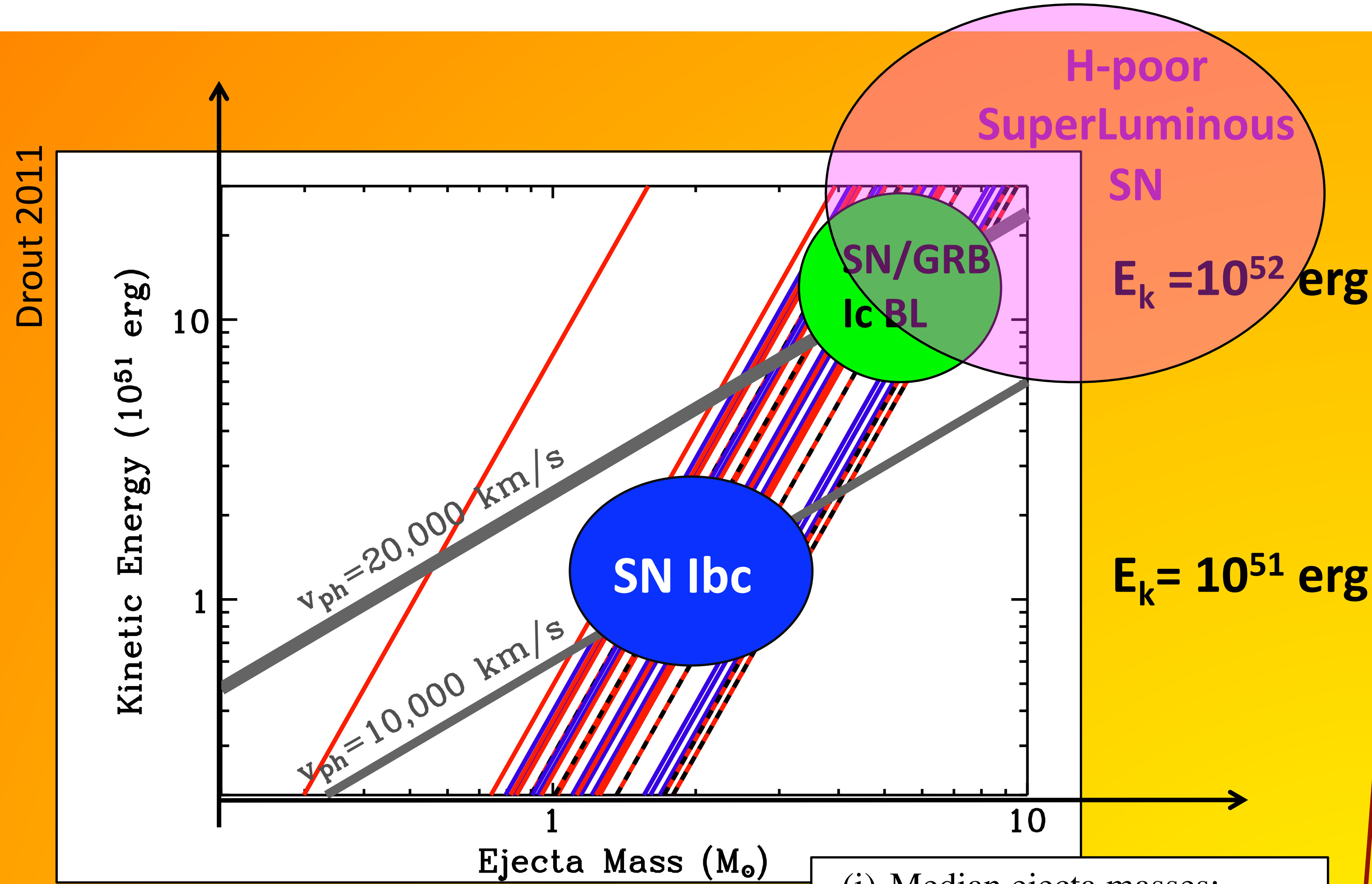
Drout 2011

(ii) Median nickel masses:

(a) Ib and Ic: $M_{\rm Ni} \sim 0.15$–$0.18\,\rm M_\odot$
(b) Ic-BL: $M_{\rm Ni} \sim 0.25\,\rm M_\odot$
(c) GRB/XRF: $M_{\rm Ni} \sim 0.3$–$0.35\,\rm M_\odot$.

Cano 2013

SN/GRB ⟵ ⟶ Large Ni mass



Cano 2013

(iii) Median kinetic energies

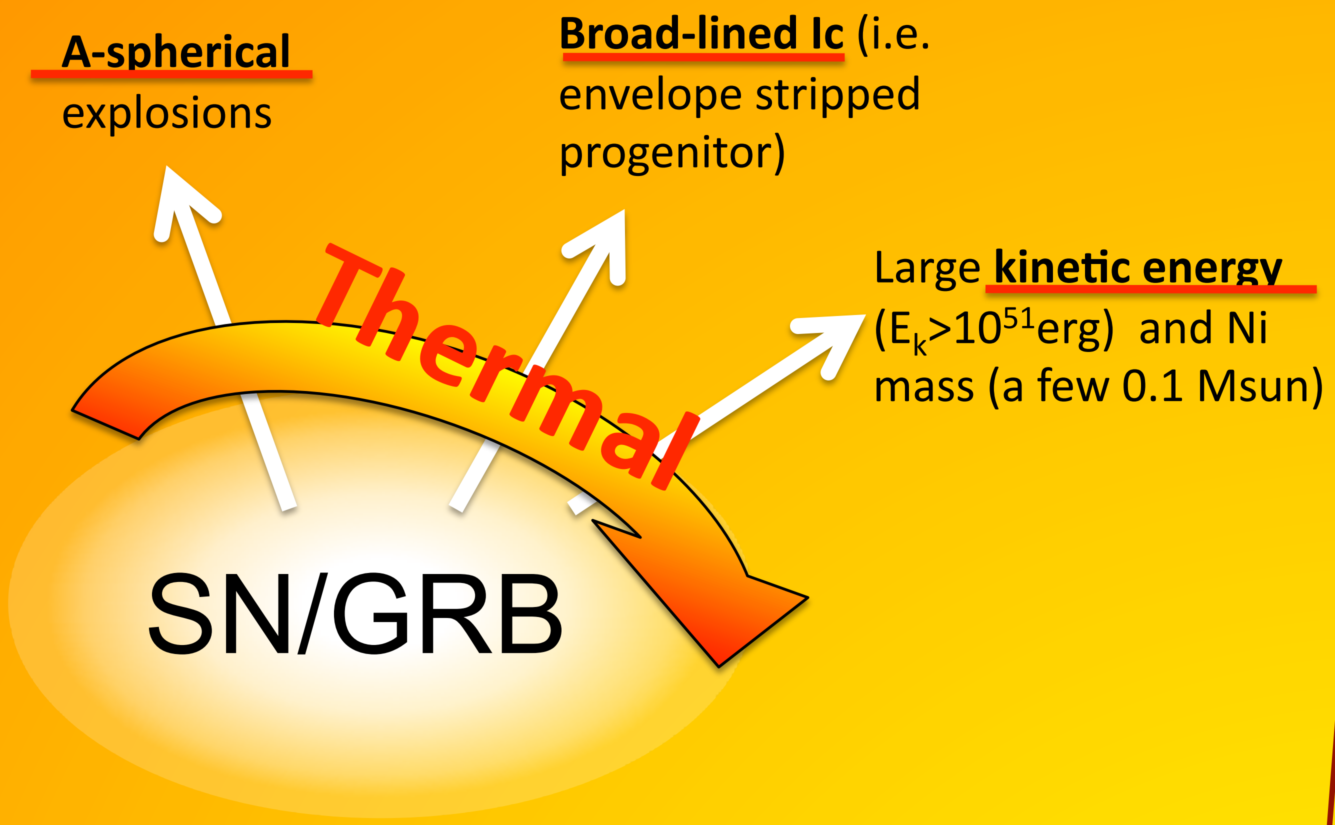
(a) Ib and Ic: $E_k \sim 0.2 \times 10^{52}$ erg
(b) Ic-BL: $E_k \sim 1.0 \times 10^{52}$ erg
(c) GRB/XRF: $E_k \sim 2.0 \times 10^{52}$ erg.

Cano 2013

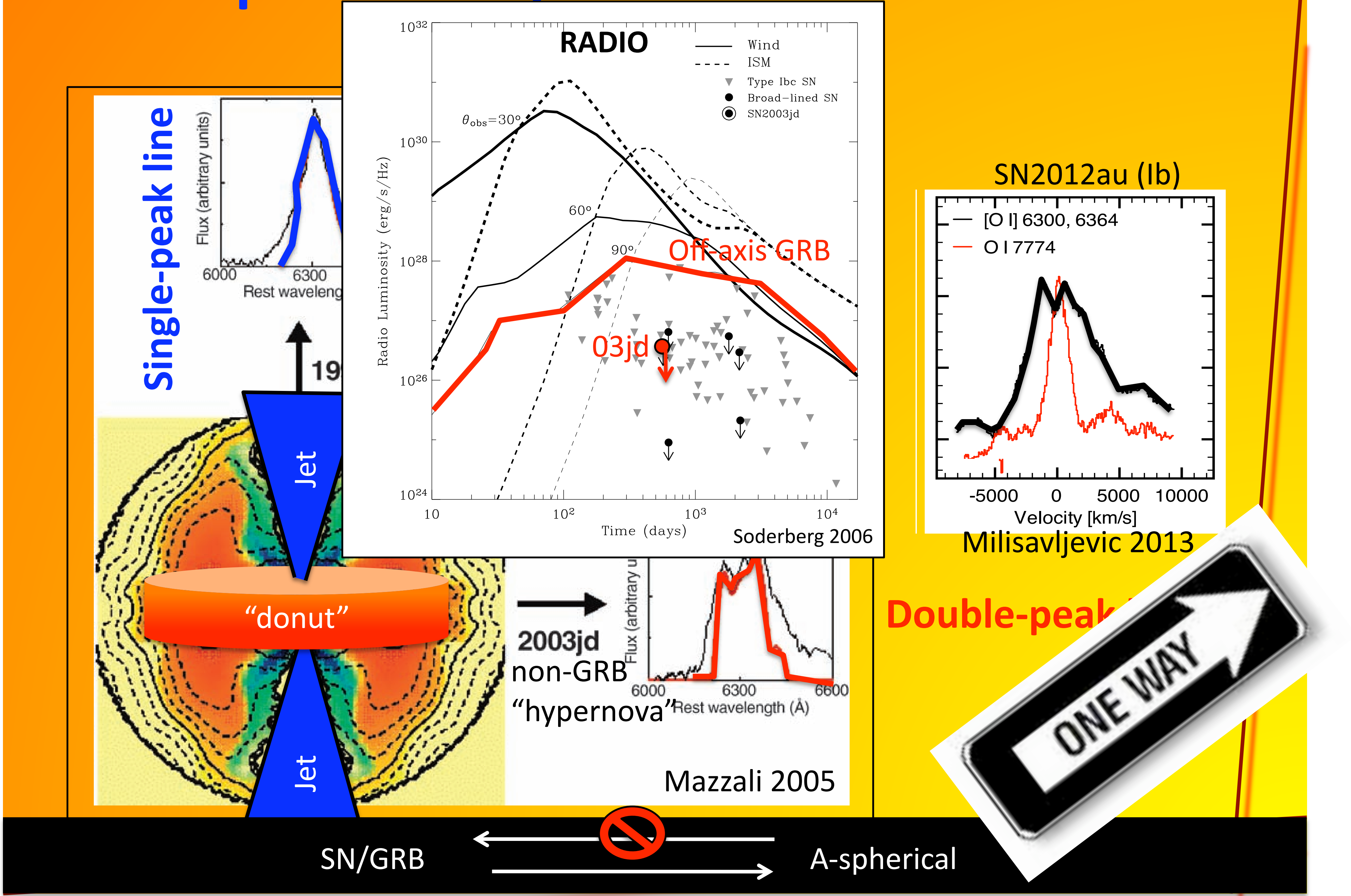
(i) Median ejecta masses:

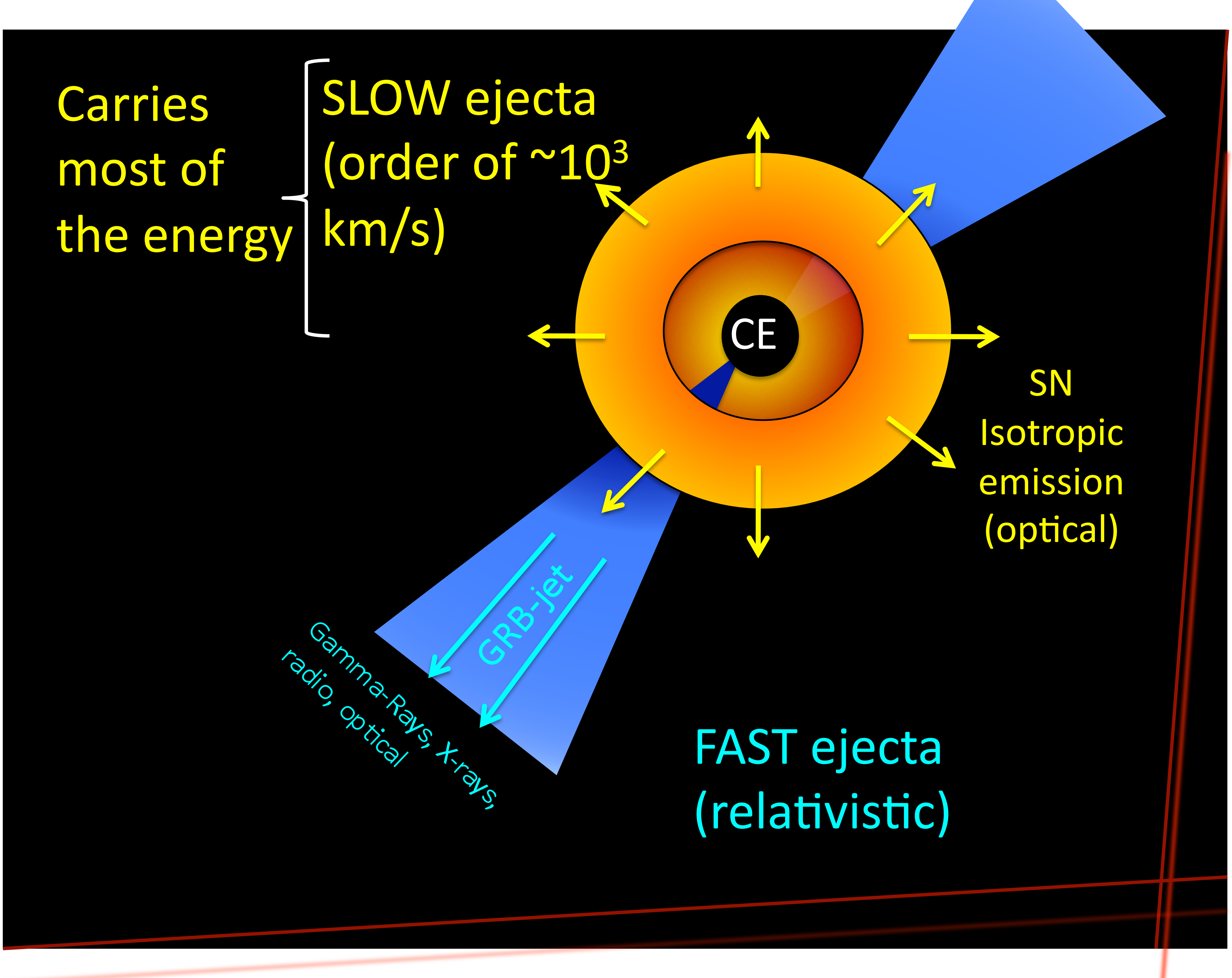
(a) Ib: $M_{ej} \sim 3.9\,M_\odot$
(b) Ic: $M_{ej} \sim 3.4\,M_\odot$
(c) Ic-BL: $M_{ej} \sim 3.9\,M_\odot$
(d) GRB/XRF: $M_{ej} \sim 6.0\,M_\odot$.

SN/GRB **ONE WAY** Ek >= 10^{52} erg

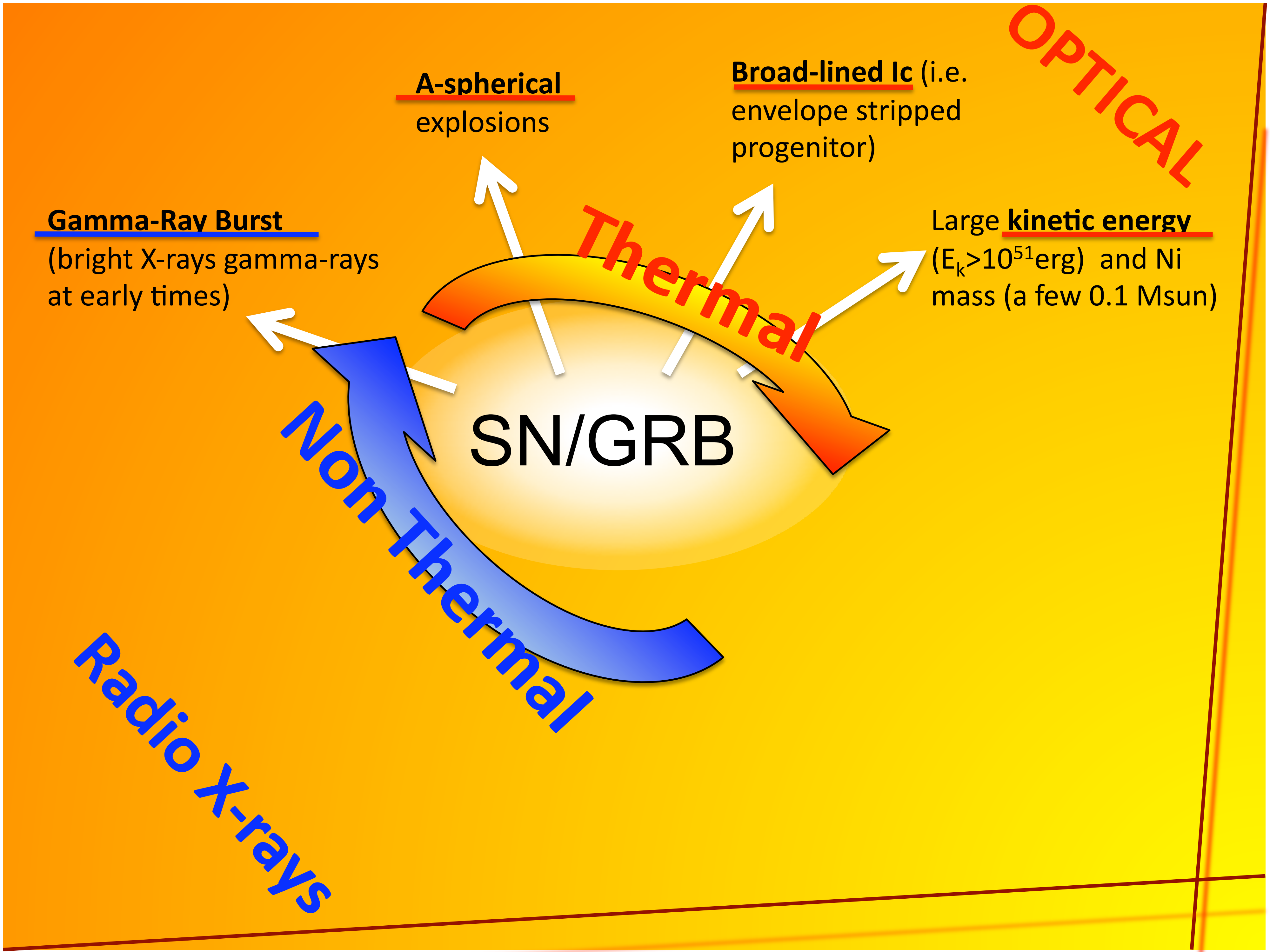

A-spherical explosions
Broad-lined Ic (i.e. envelope stripped progenitor)
Large kinetic energy (E_k>10^{51}erg) and Ni mass (a few 0.1 Msun)
Thermal
SN/GRB

A-spherical explosion from NEBULAR line





Carries
most of
the energy
SLOW ejecta
(order of ~10^3
km/s)
CE
SN
Isotropic
emission
(optical)
GRB-jet
Gamma-Rays, X-rays,
radio, optical
FAST ejecta
(relativistic)

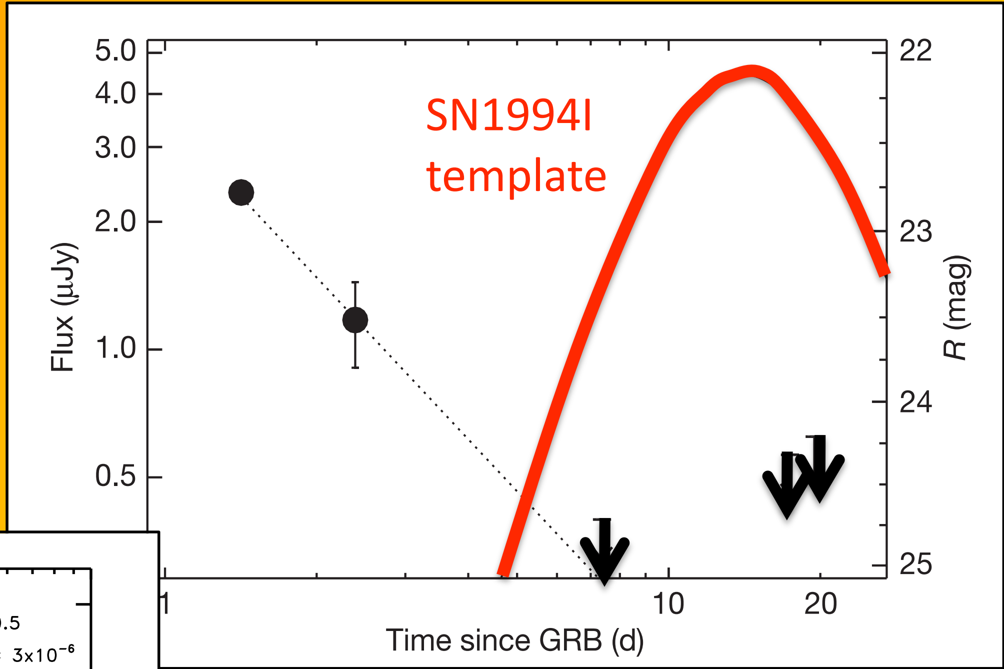


OPTICAL
A-spherical explosions
Broad-lined Ic (i.e. envelope stripped progenitor)
Gamma-Ray Burst (bright X-rays gamma-rays at early times)
Large kinetic energy (E_k>10^{51}erg) and Ni mass (a few 0.1 Msun)
Thermal
SN/GRB
Non Thermal
Radio X-rays

- Short GRBs
- SN-less “long” GRBs

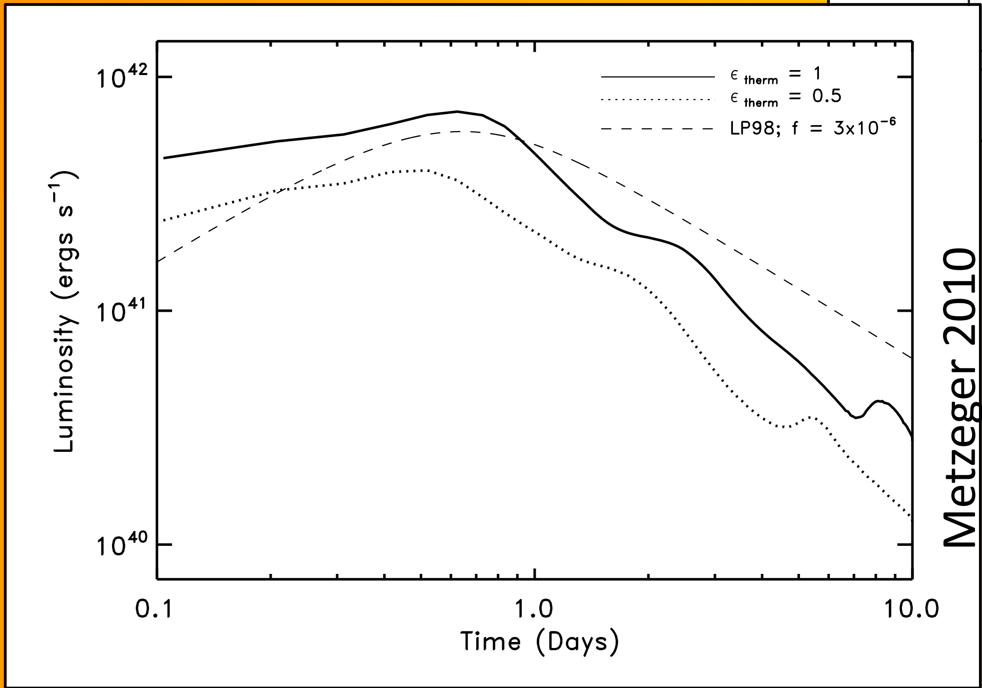
Short GRBs

GRB050709



KILONOVA

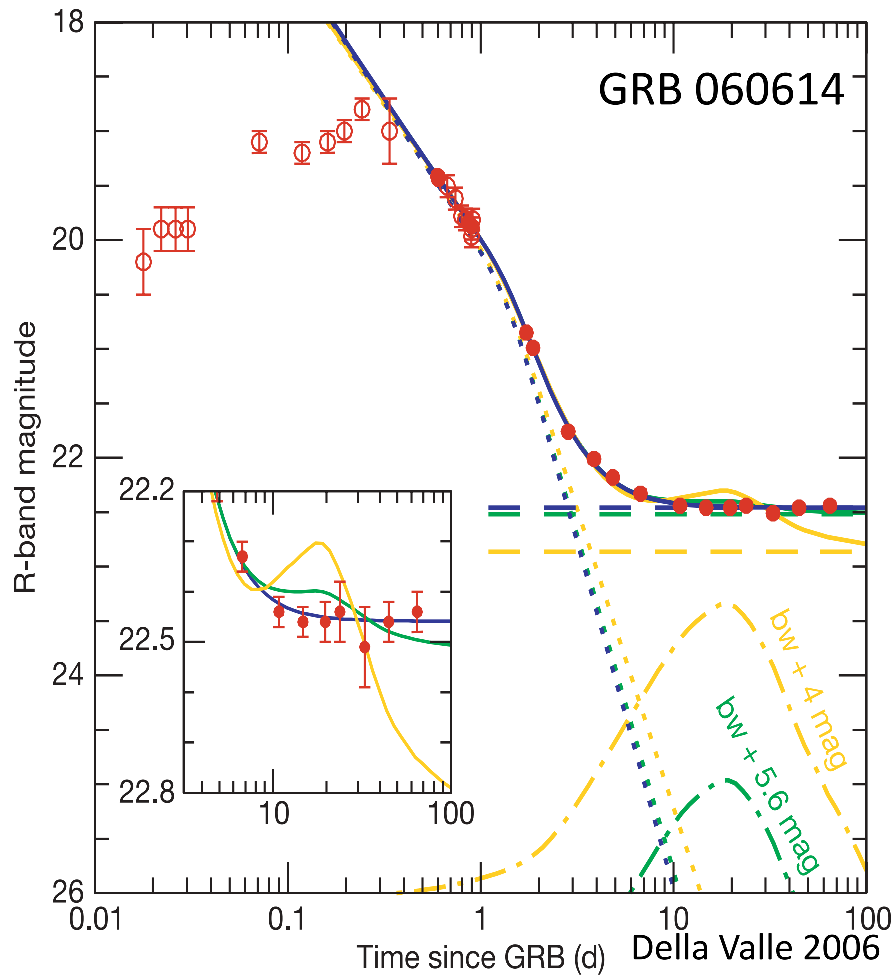
(Li & Paczynski 98)



Metzeger 2010

SN-less "long" GRBs

GRB060505 GRB0606014 XRF040701



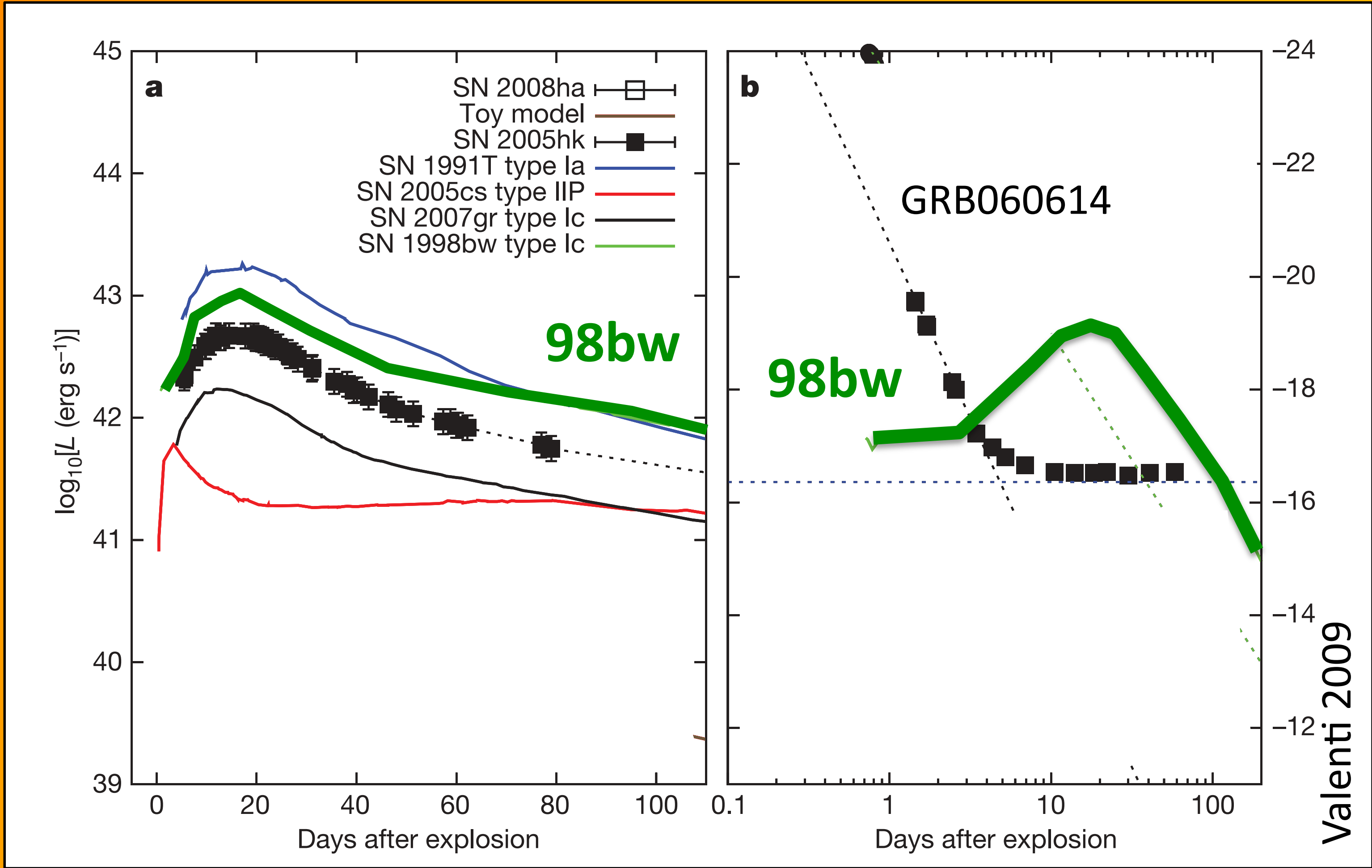
Della Valle 2006

Short GRBs "in disguise"

"Failed"-SN

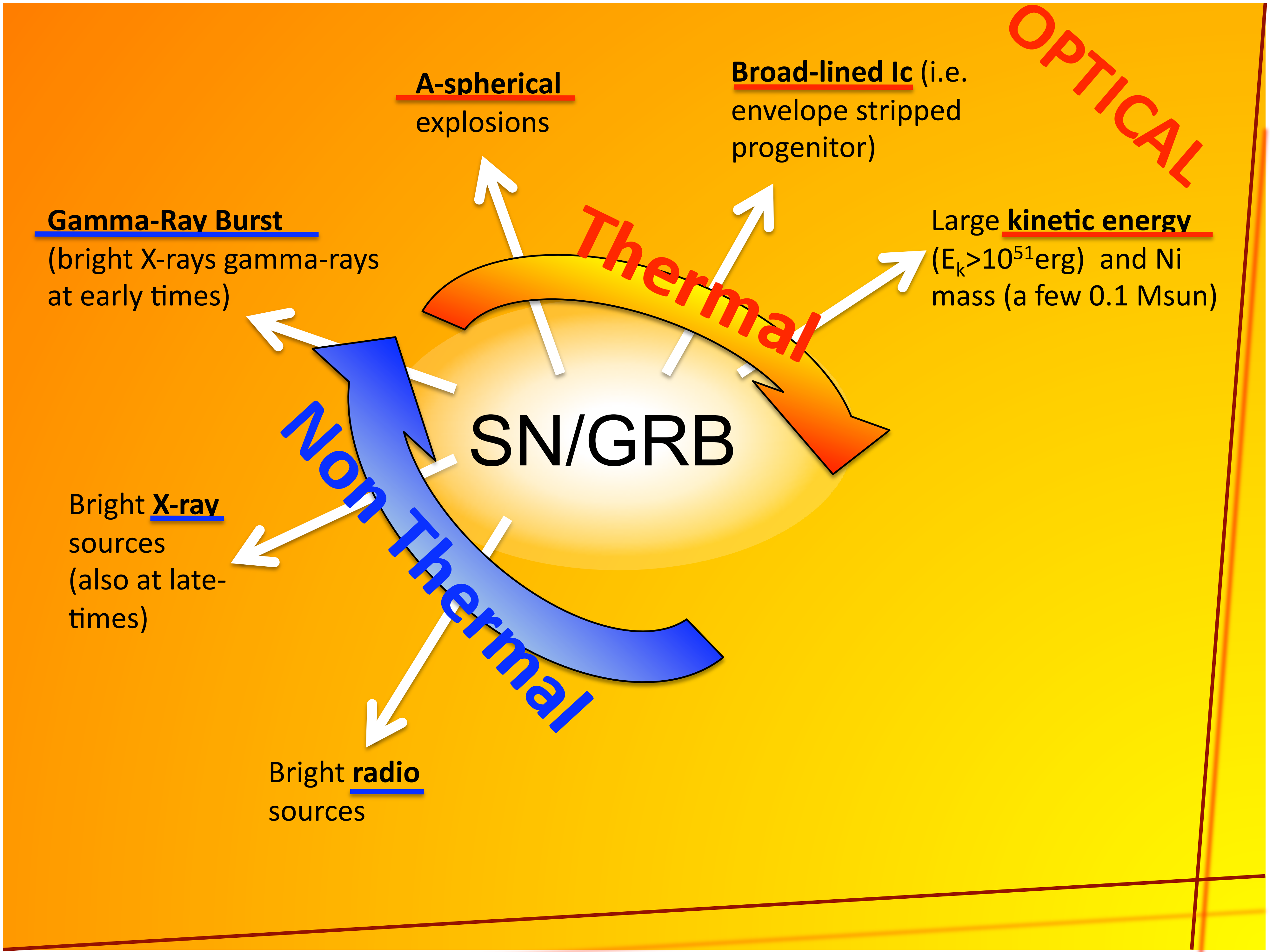
Extremely low-luminosity Ic explosions

Sub-luminous Ic explosions: SN2008ha

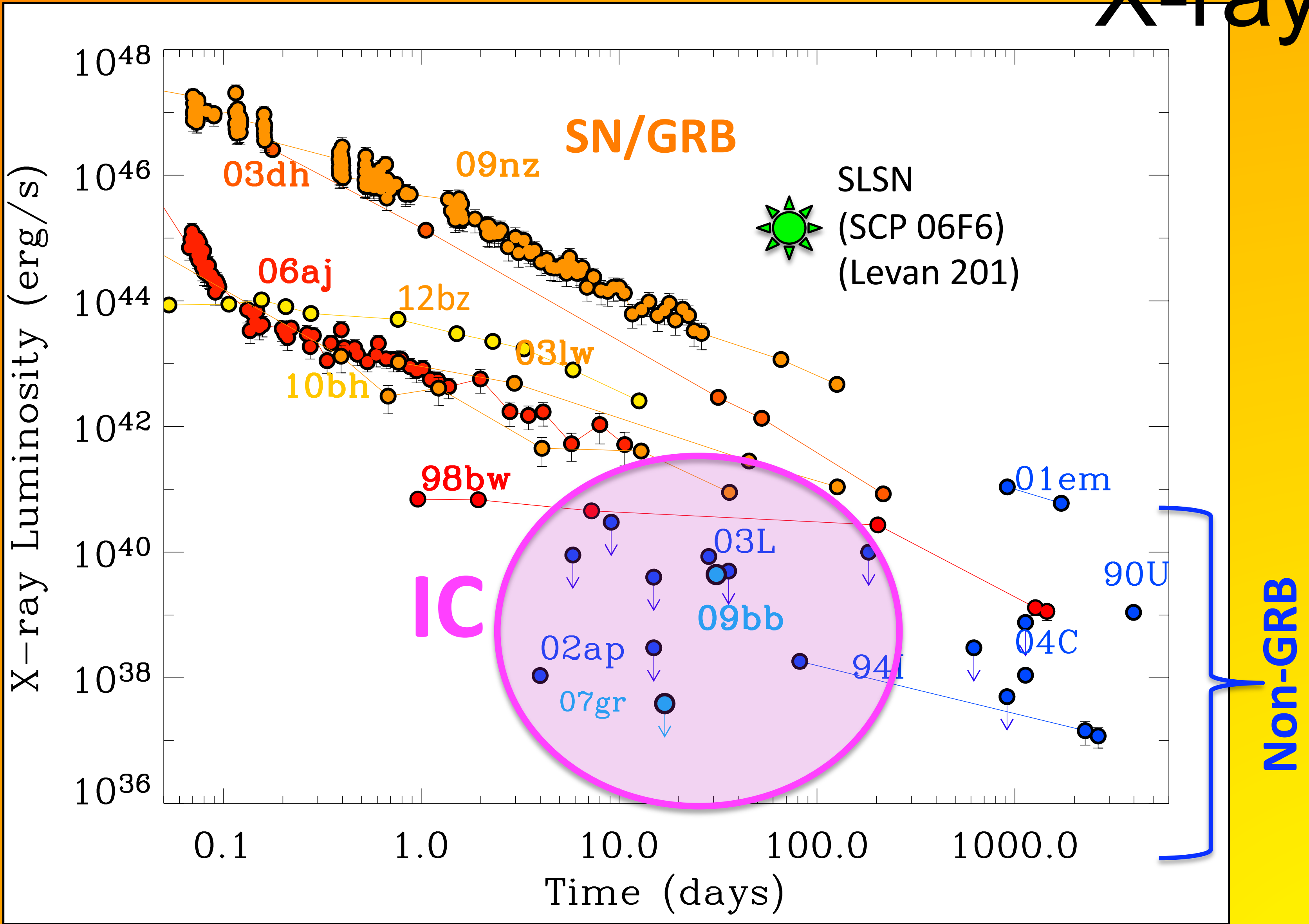


...or Ia explosion?

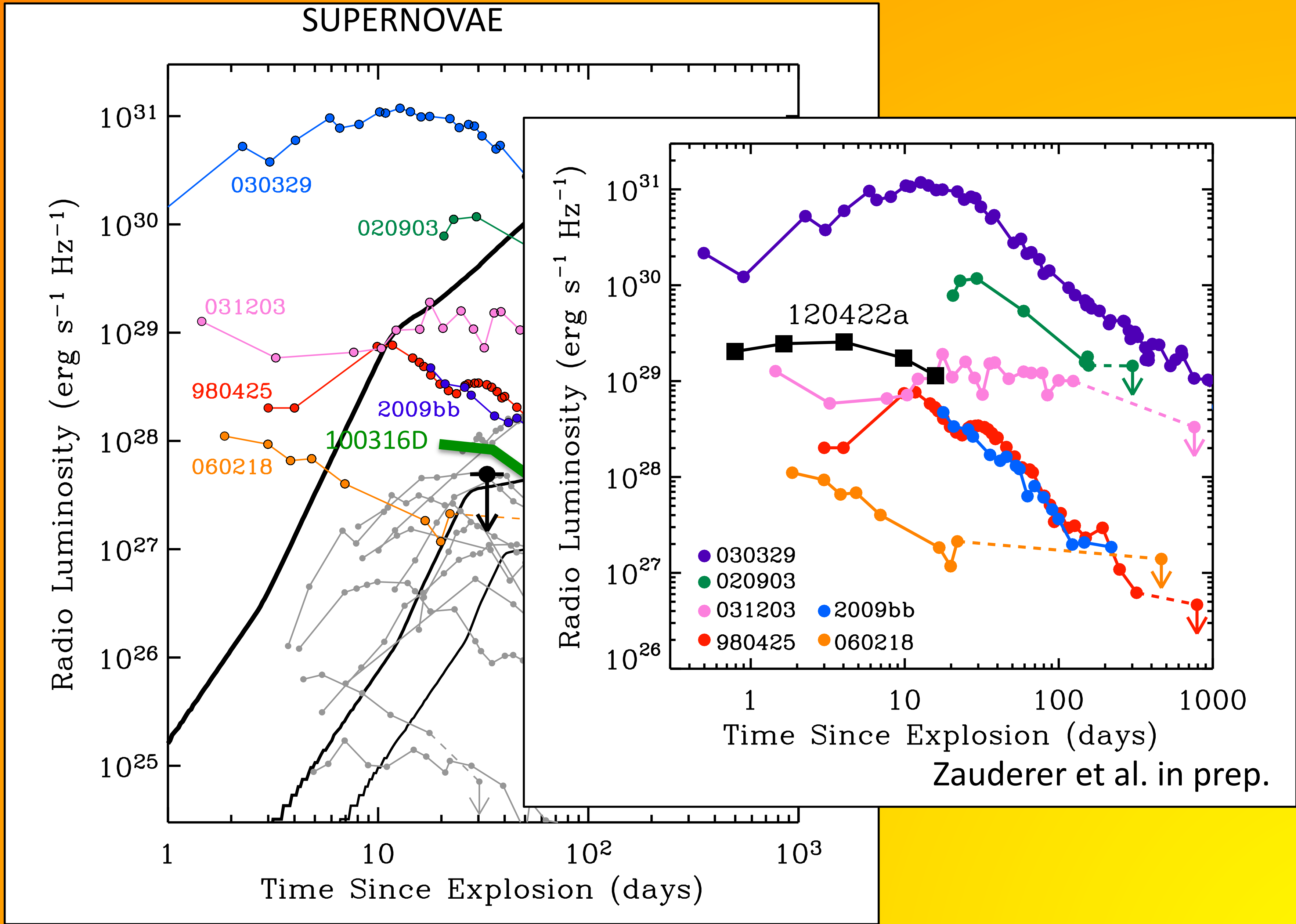
Foley 2009 AJ


OPTICAL
A-spherical explosions
Broad-lined Ic (i.e. envelope stripped progenitor)
Gamma-Ray Burst (bright X-rays gamma-rays at early times)
Large kinetic energy (E_k>10^{51}erg) and Ni mass (a few 0.1 Msun)
Thermal
SN/GRB
Non Thermal
Bright X-ray sources (also at late-times)
Bright radio sources

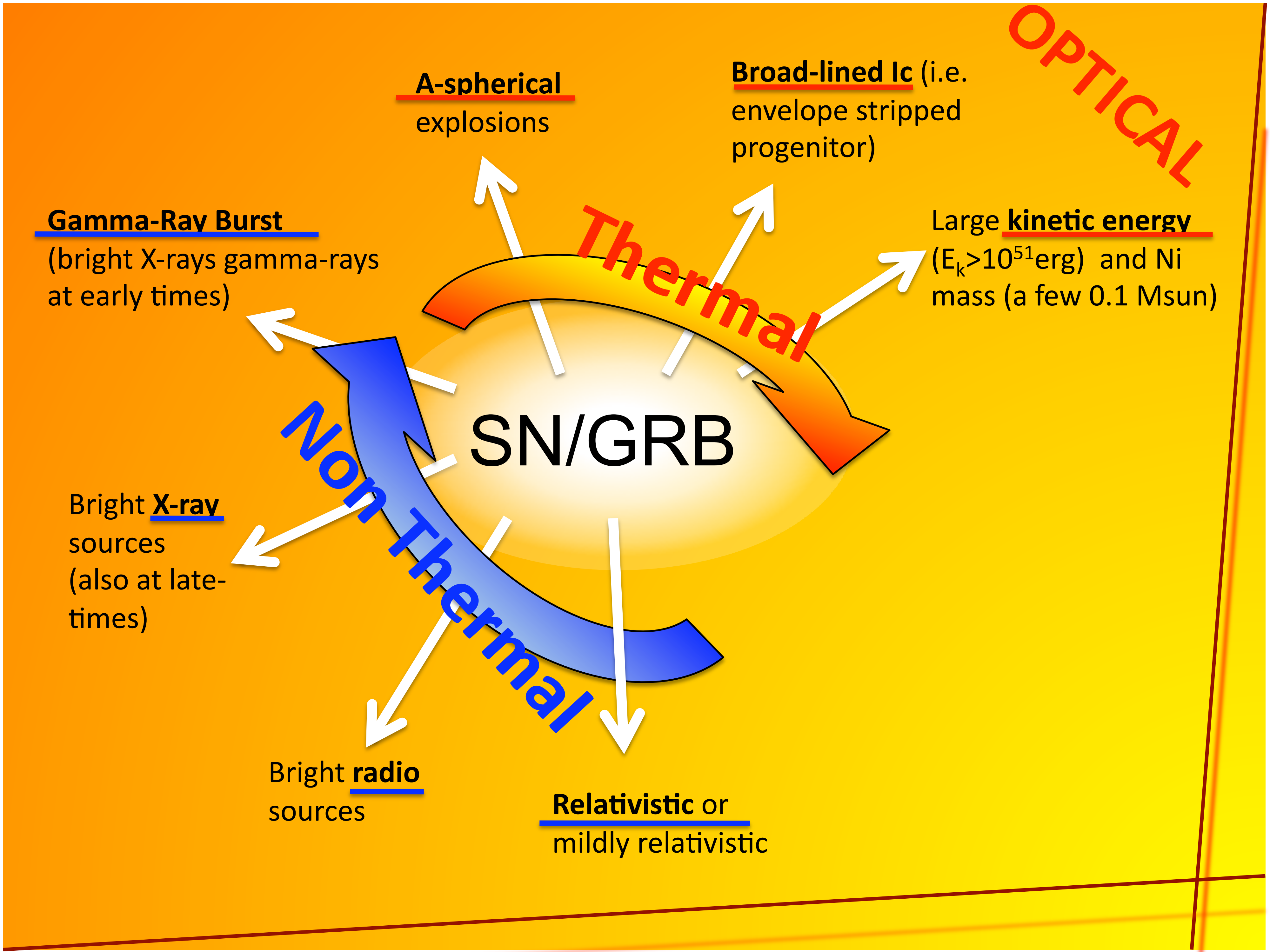
X-rays

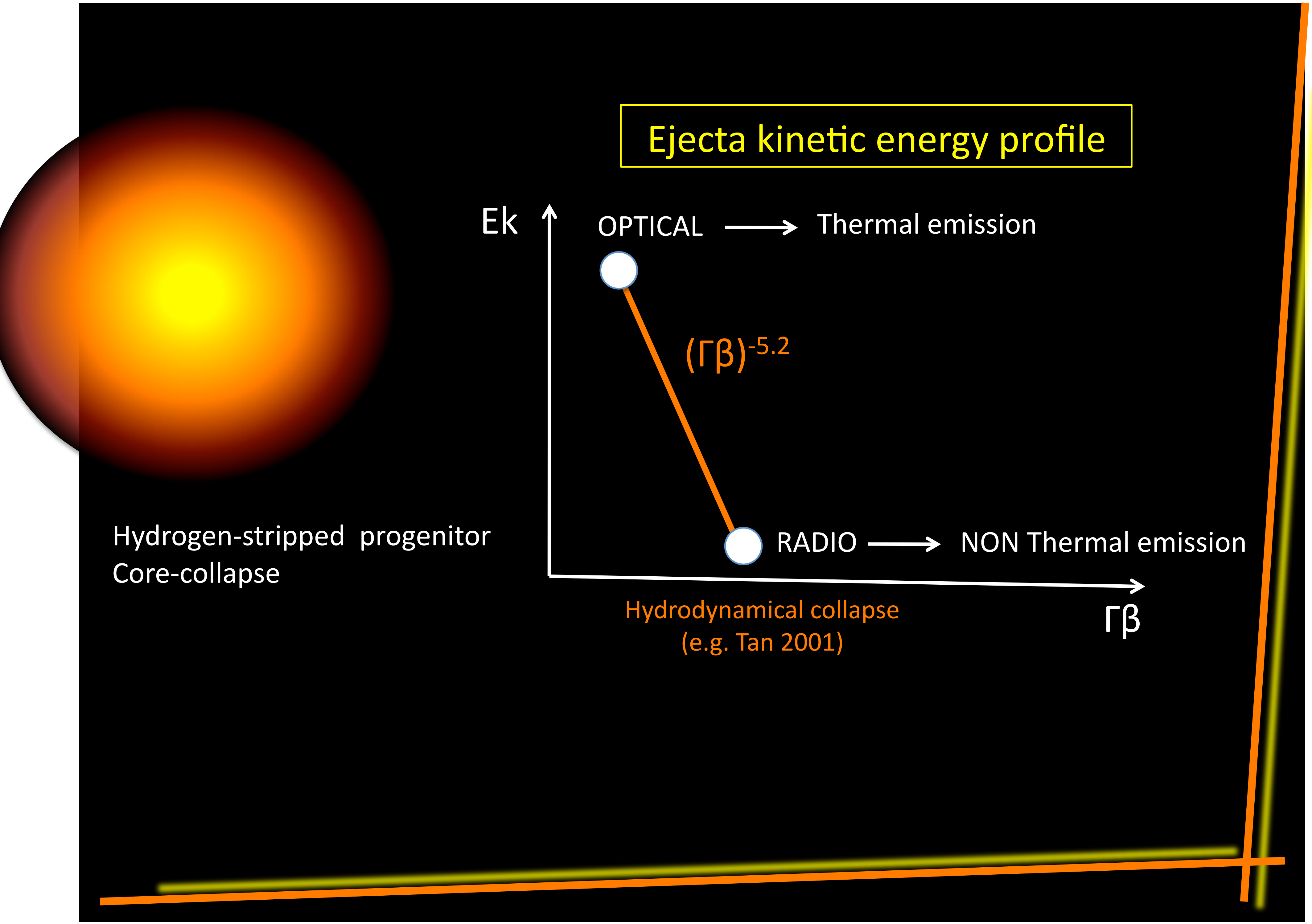


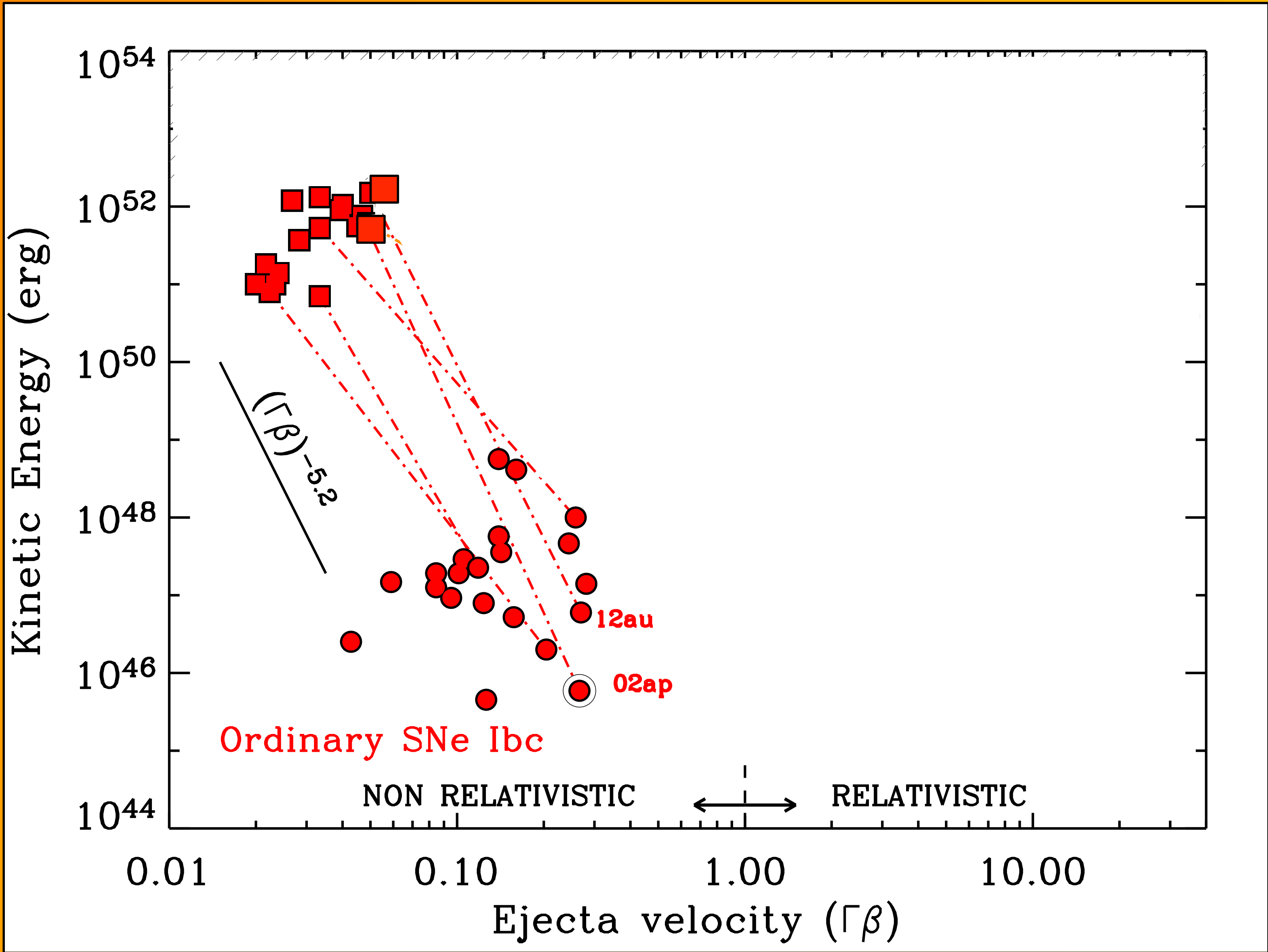
SN/GRB
SLSN
(SCP 06F6)
(Levan 201)
03dh
09nz
06aj
12bz
03lw
10bh
98bw
IC
03L
09bb
02ap
07gr
94I
01em
90U
04C
Non-GRB
X−ray Luminosity (erg/s)
Time (days)
10^48
10^46
10^44
10^42
10^40
10^38
10^36
0.1
1.0
10.0
100.0
1000.0



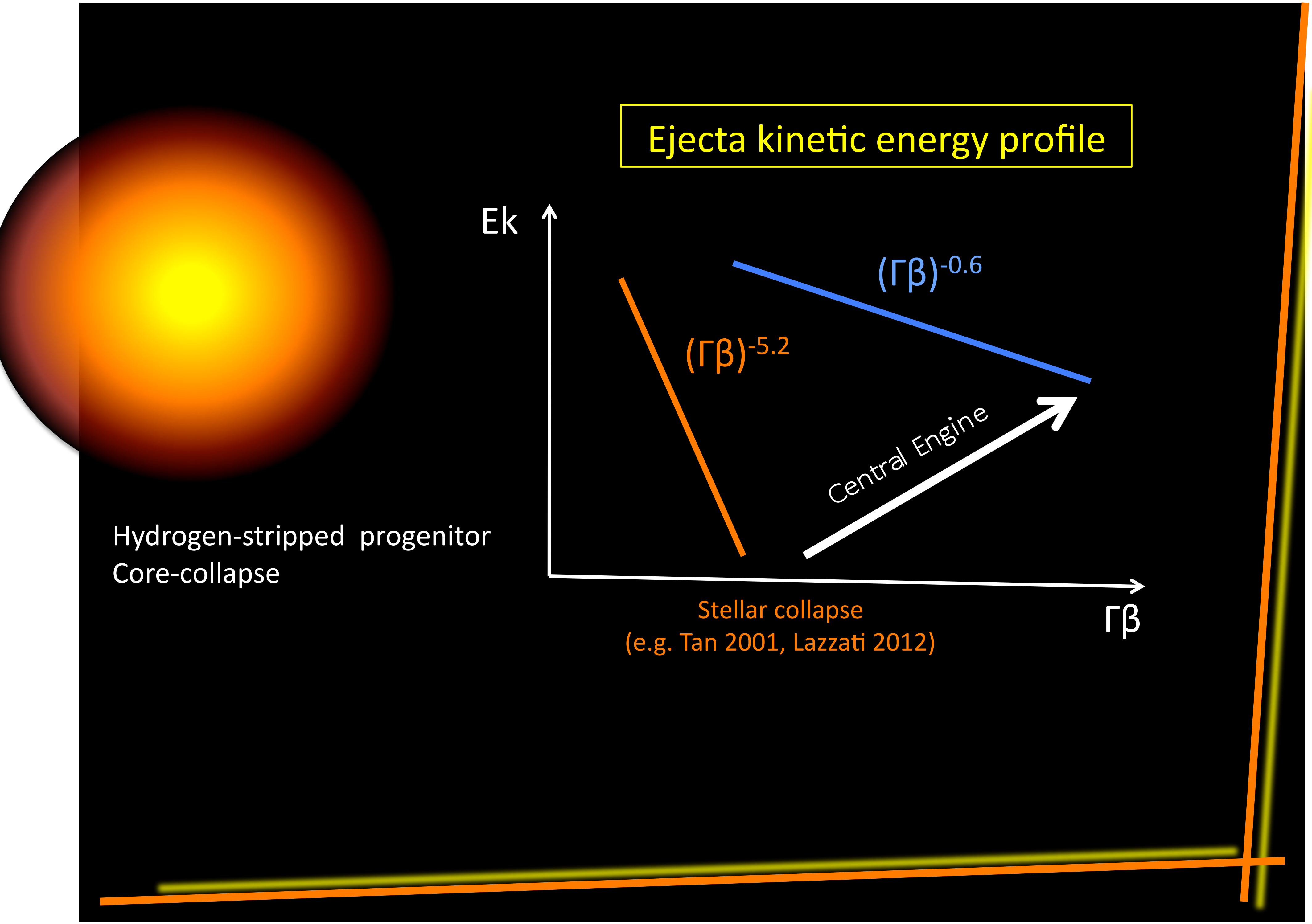
Sanders 2012


OPTICAL
A-spherical explosions
Broad-lined Ic (i.e. envelope stripped progenitor)
Gamma-Ray Burst (bright X-rays gamma-rays at early times)
Large kinetic energy (E_k>10^{51}erg) and Ni mass (a few 0.1 Msun)
Thermal
SN/GRB
Non Thermal
Bright X-ray sources (also at late-times)
Bright radio sources
Relativistic or mildly relativistic

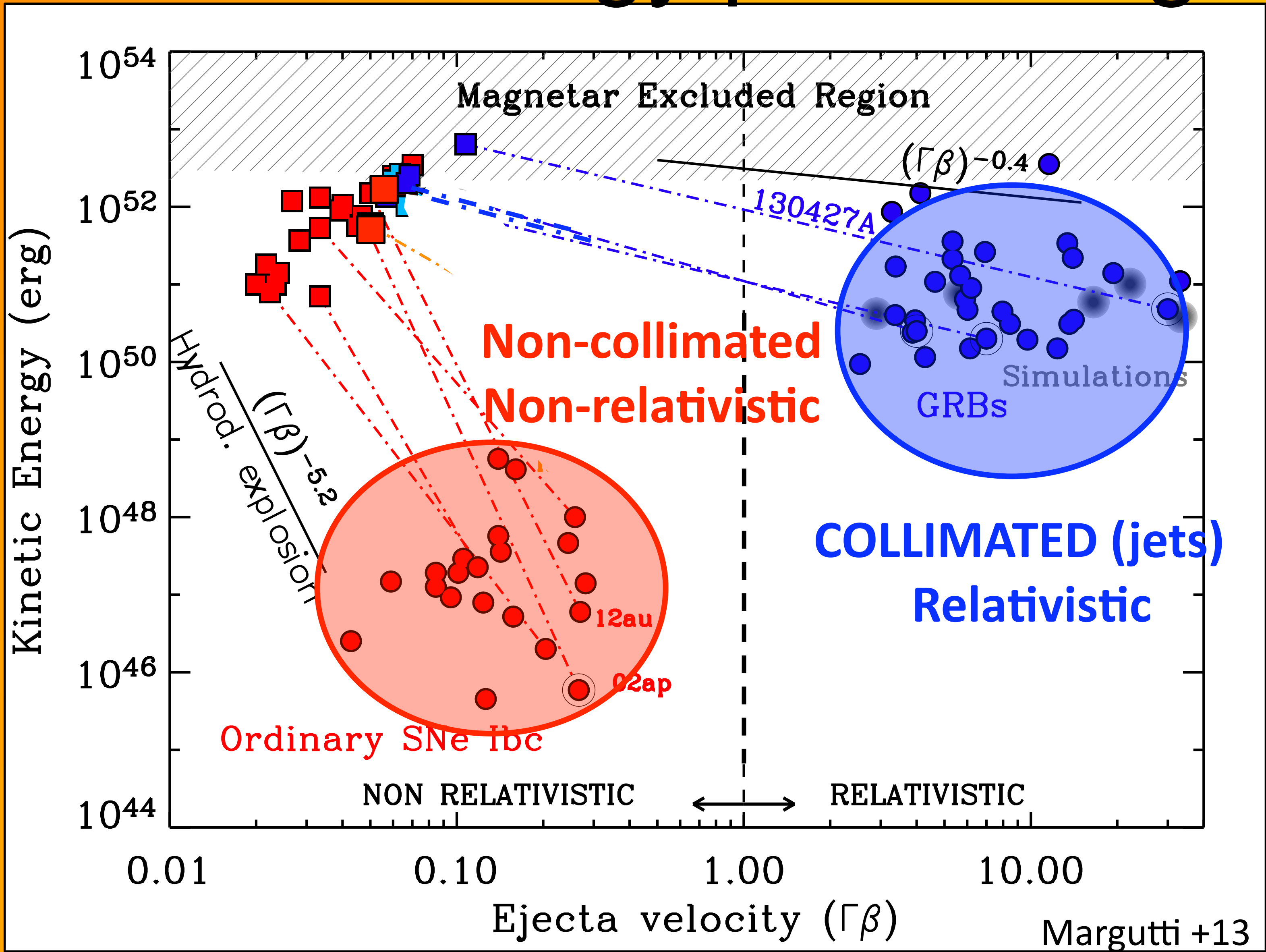

Ejecta kinetic energy profile
Ek
OPTICAL
Thermal emission
(Γβ)^-5.2
RADIO
NON Thermal emission
Γβ
Hydrodynamical collapse
(e.g. Tan 2001)
Hydrogen-stripped progenitor
Core-collapse



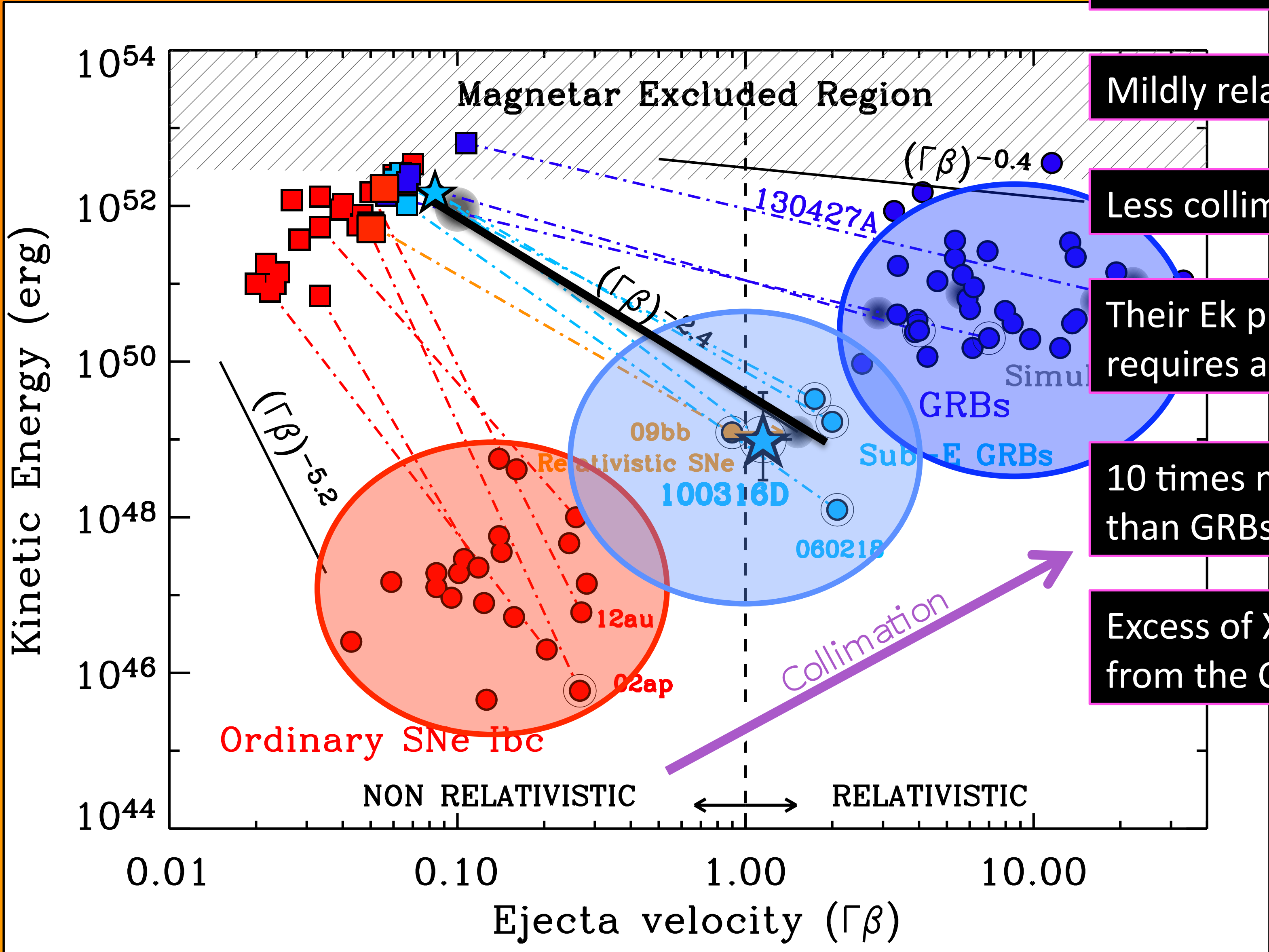
Margutti +13; Kamble +13; Soderberg +06, +10


Ejecta kinetic energy profile
Ek
(Γβ)-0.6
(Γβ)-5.2
Central Engine
Hydrogen-stripped progenitor
Core-collapse
Stellar collapse
(e.g. Tan 2001, Lazzati 2012)
Γβ

Energy partitioning



-->Continuum



Less energetic than GRBs (local universe)

Mildly relativistic

Less collimated than GRBs

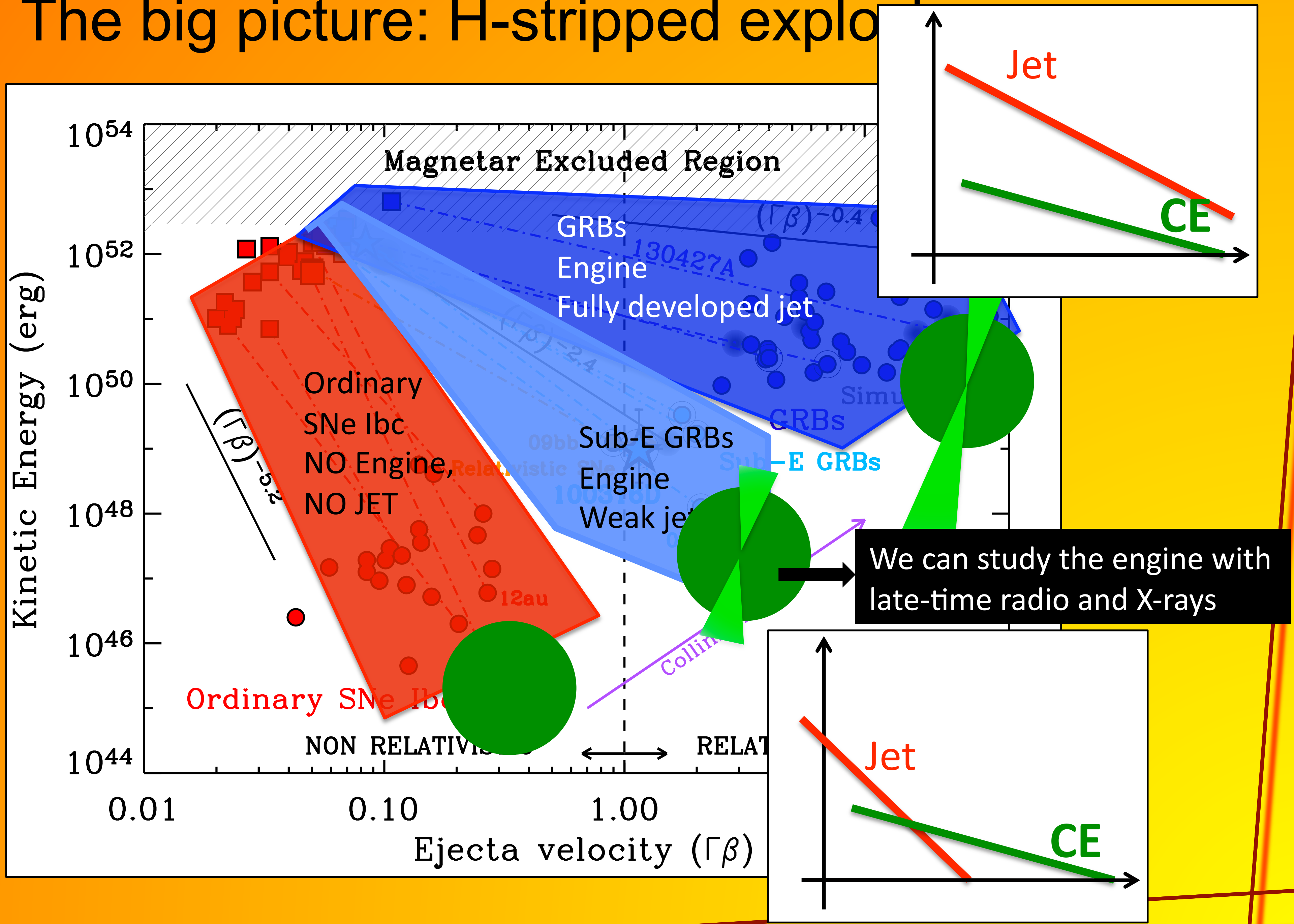
Their Ek profile still requires a CE

10 times more common than GRBs

Excess of X-ray emission from the CE

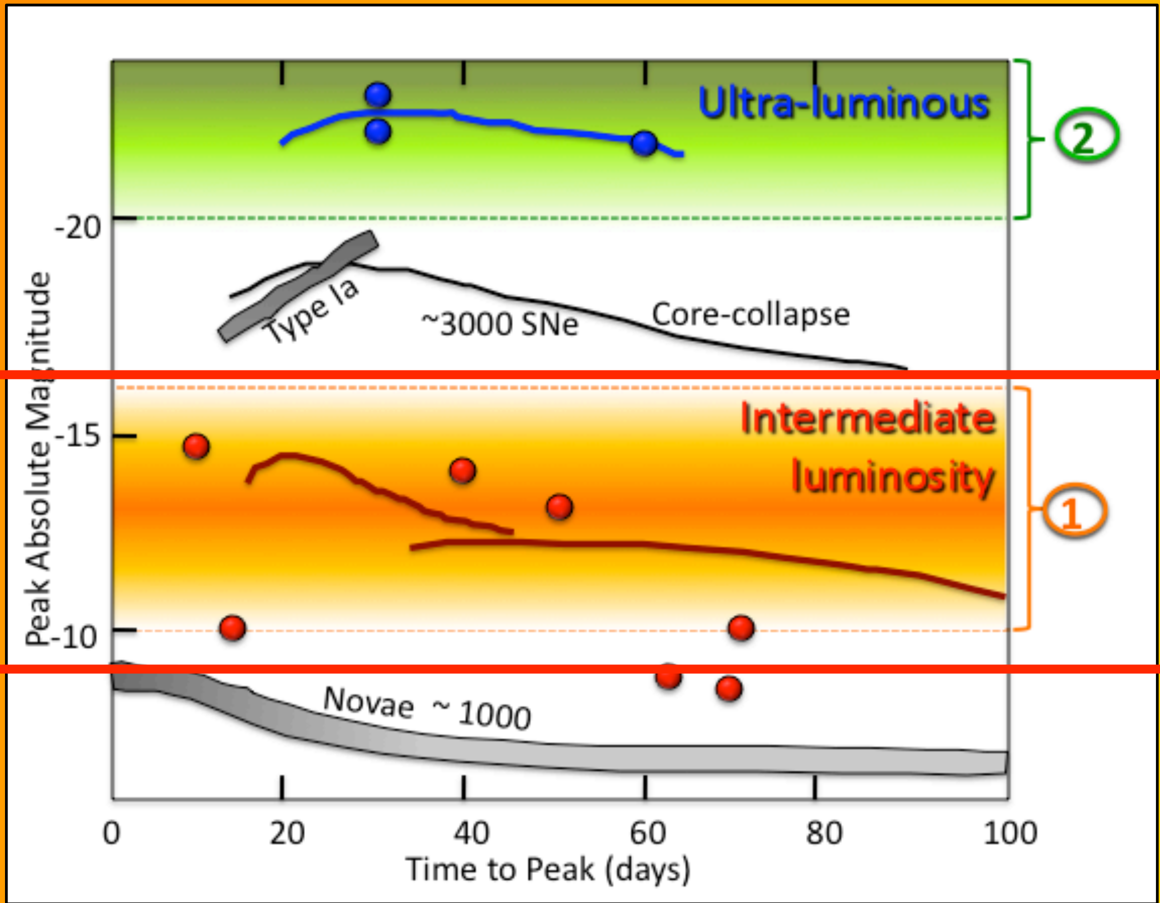
Margutti +13

The big picture: H-stripped explo



Future directions…

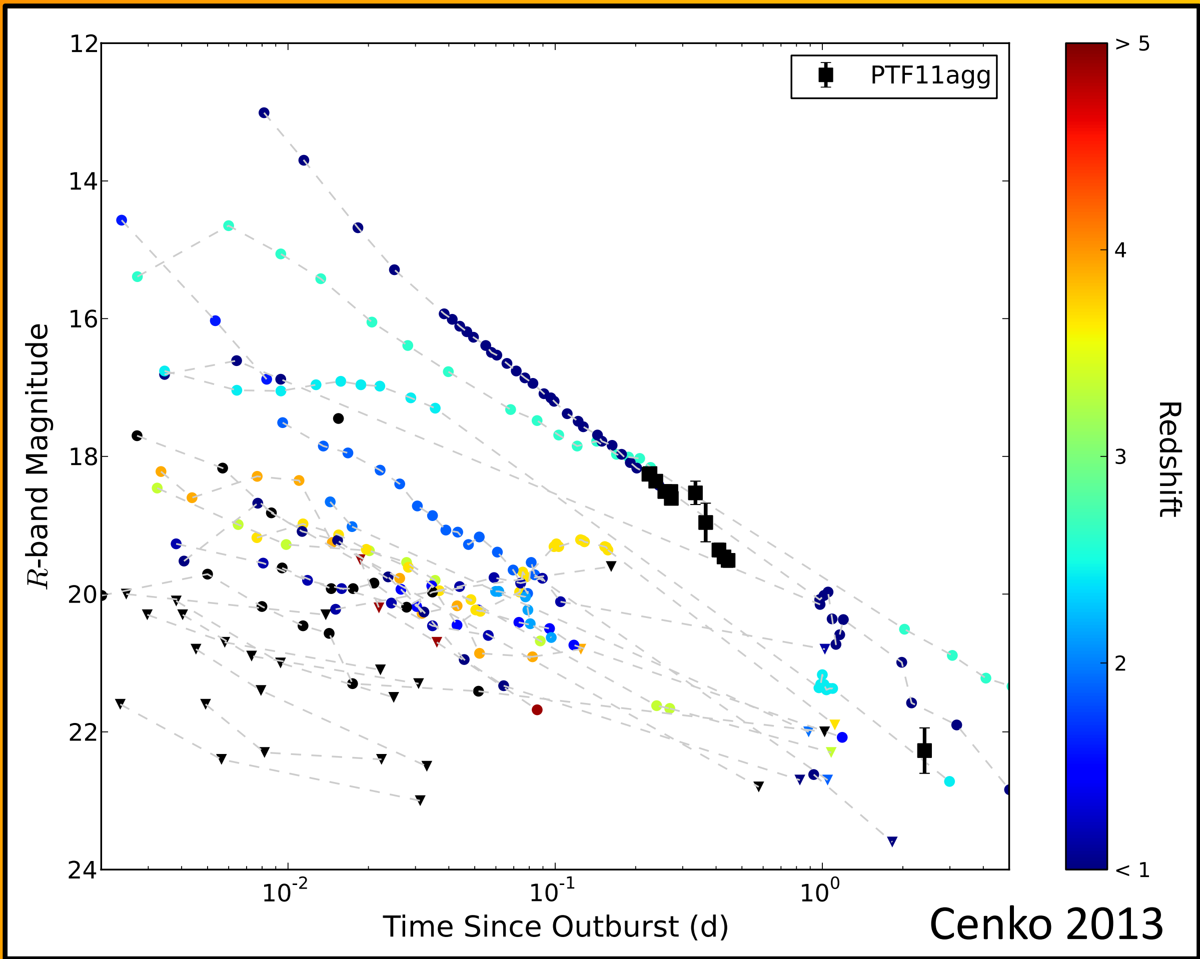
- Populate the area of FAINT transients → **KILONOVA** / **Sub-luminous Ic-SN**

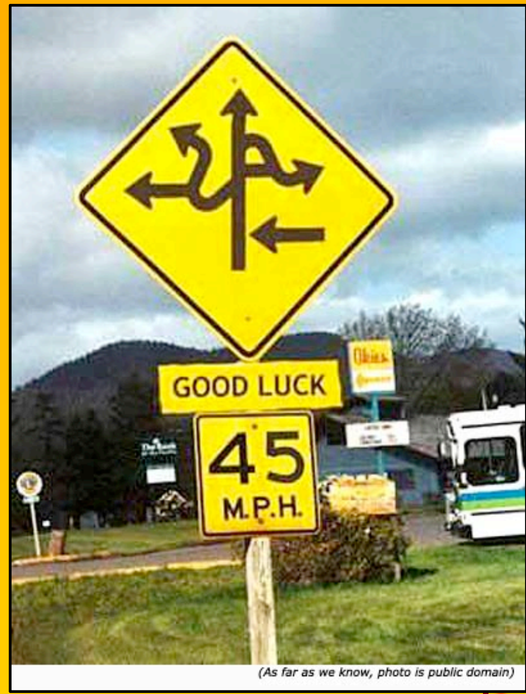


(As far as we know, photo is public domain)

Future directions…

- Populate the area of FAINT transients → **KILONOVA** / **Sub-luminous Ic-SN**
- "REVERSE" the trigger

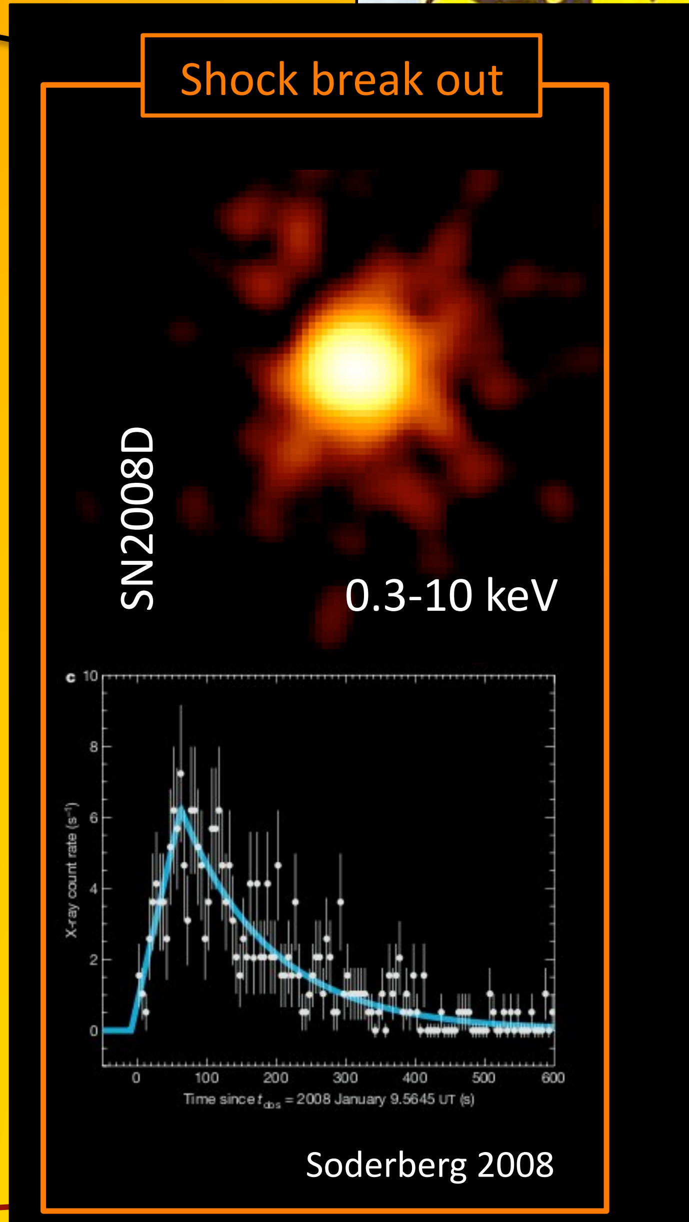




Future directions…

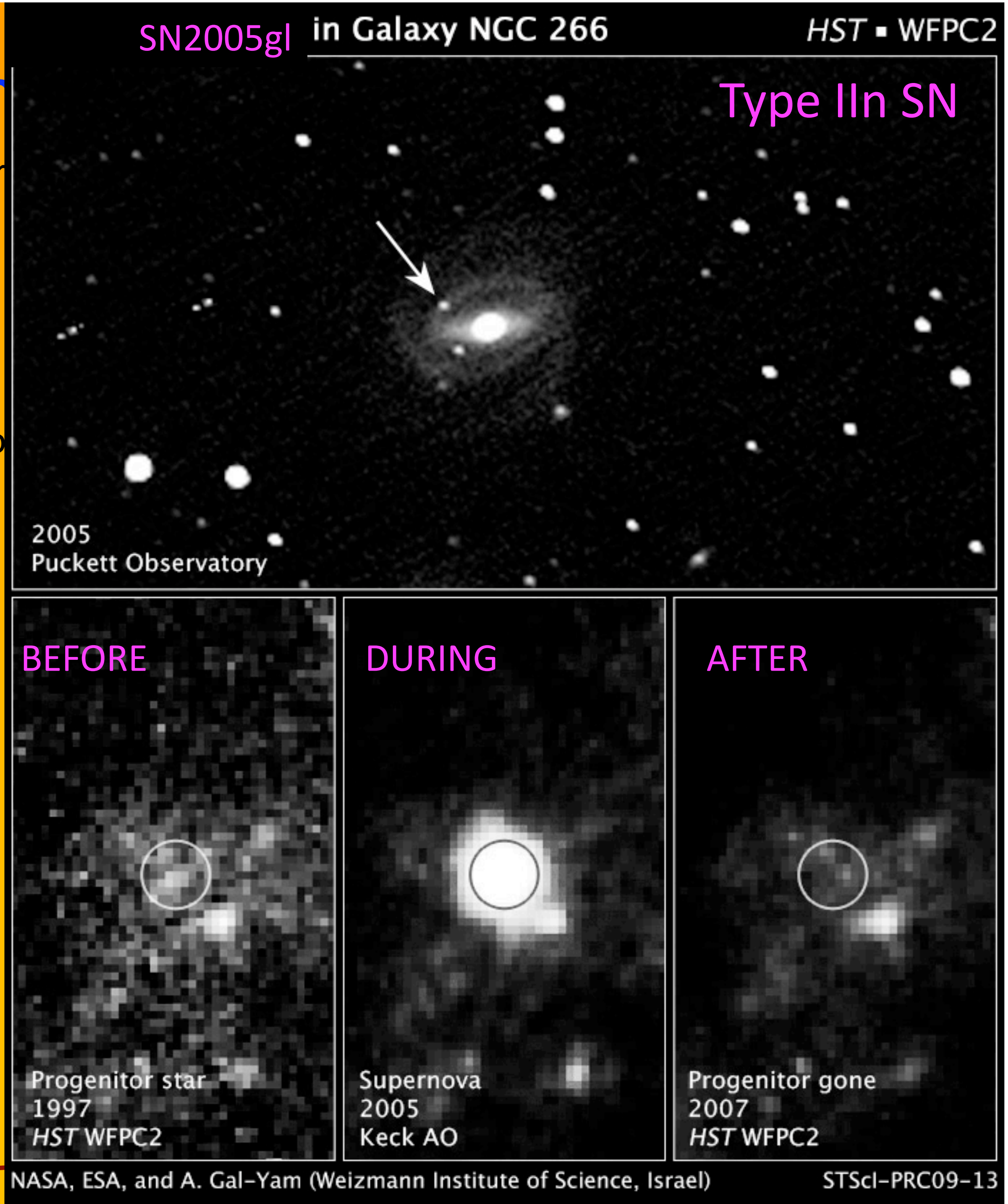
- Populate the area of FAINT transients
- “REVERSE” the trigger
- Shock break out emission of normal Ibc SN

KILONOVA



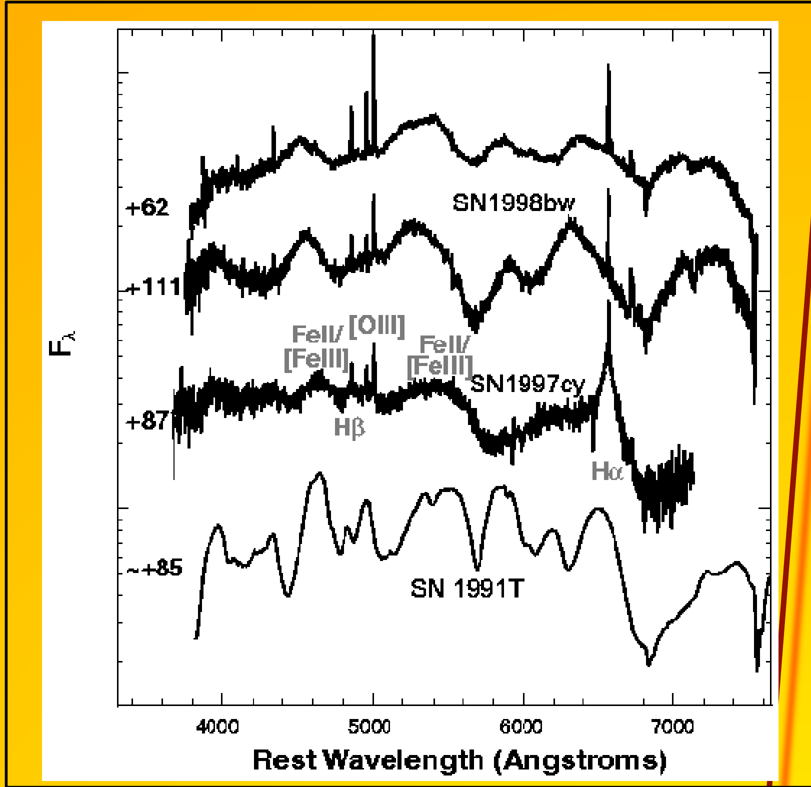
Future direction

- Populate the area of FAINT tr
- “REVERSE” the trigger
- Shock break out emission o
- Search for progenitors of type I SN: binary system?
- Mass-loss history: how stars get rid of their envelope

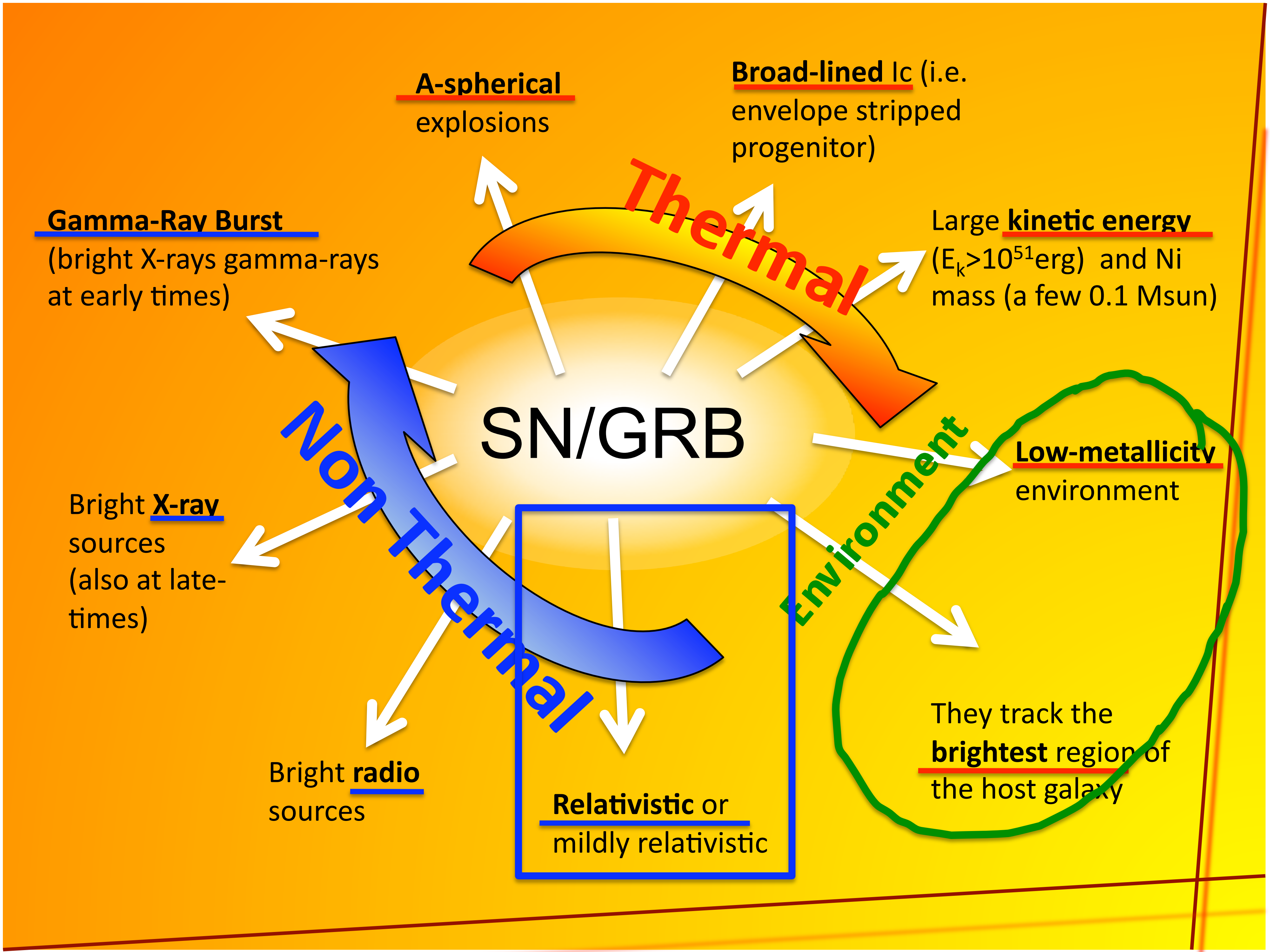


Surprises may be in store…

- "UNUSUAL" SN/GRB associations: type IIn, Hydrogen rich SN associated with GRB970514. + strange photometric bumps



- A GRB in our Galaxy?


A-spherical
explosions
Broad-lined Ic (i.e.
envelope stripped
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Thermal
Gamma-Ray Burst
(bright X-rays gamma-rays
at early times)
Large kinetic energy
(E_k>10^{51}erg) and Ni
mass (a few 0.1 Msun)
SN/GRB
Non Thermal
Environment
Low-metallicity
environment
Bright X-ray
sources
(also at late-
times)
They track the
brightest region of
the host galaxy
Bright radio
sources
Relativistic or
mildly relativistic