Constraints on Jets in Hydrogen-poor Superluminous Supernovae

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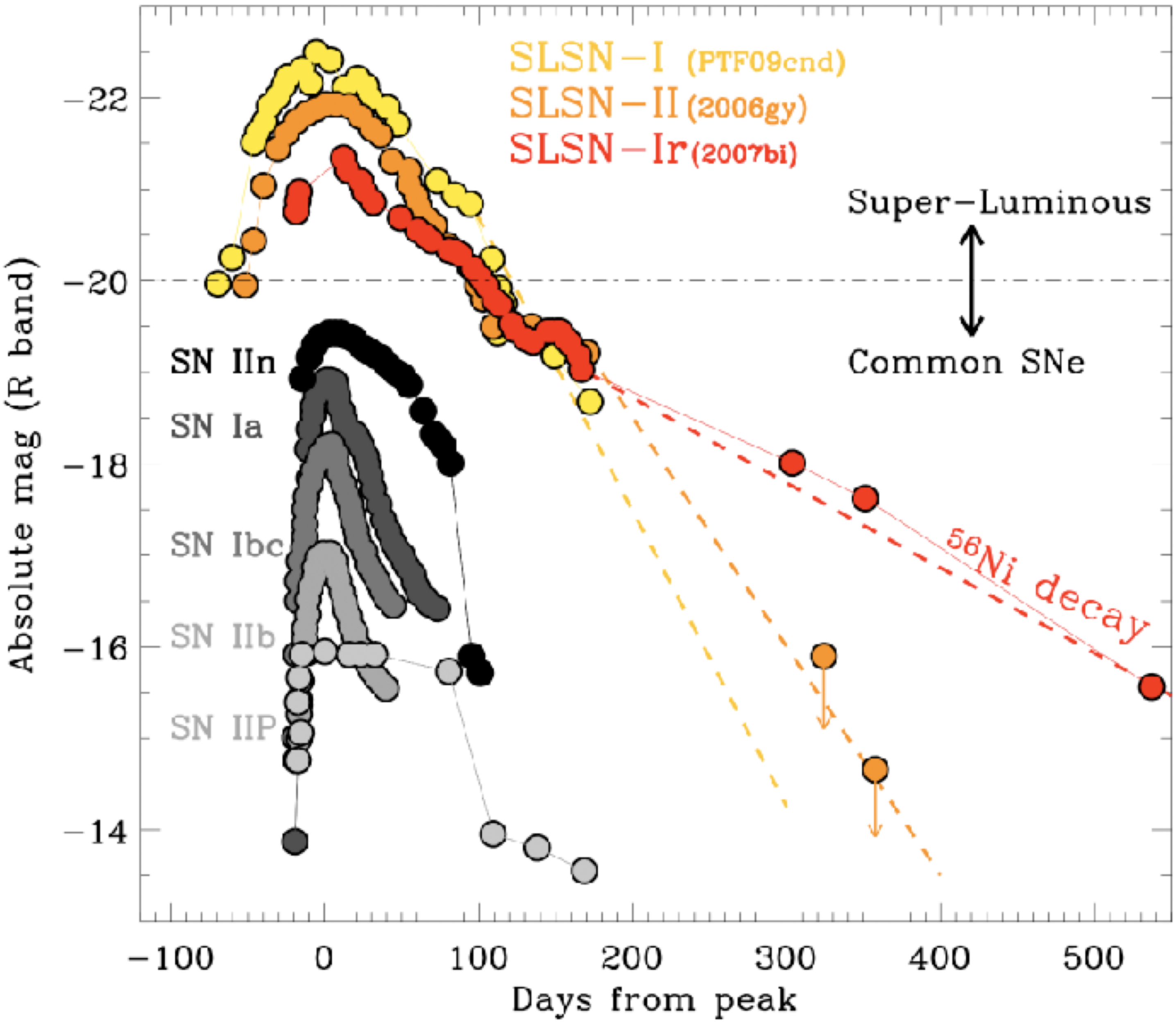
Superluminous supernovae (SLSNe)
are 10-100 x more luminous than ‘normal’ supernovae (SNe)



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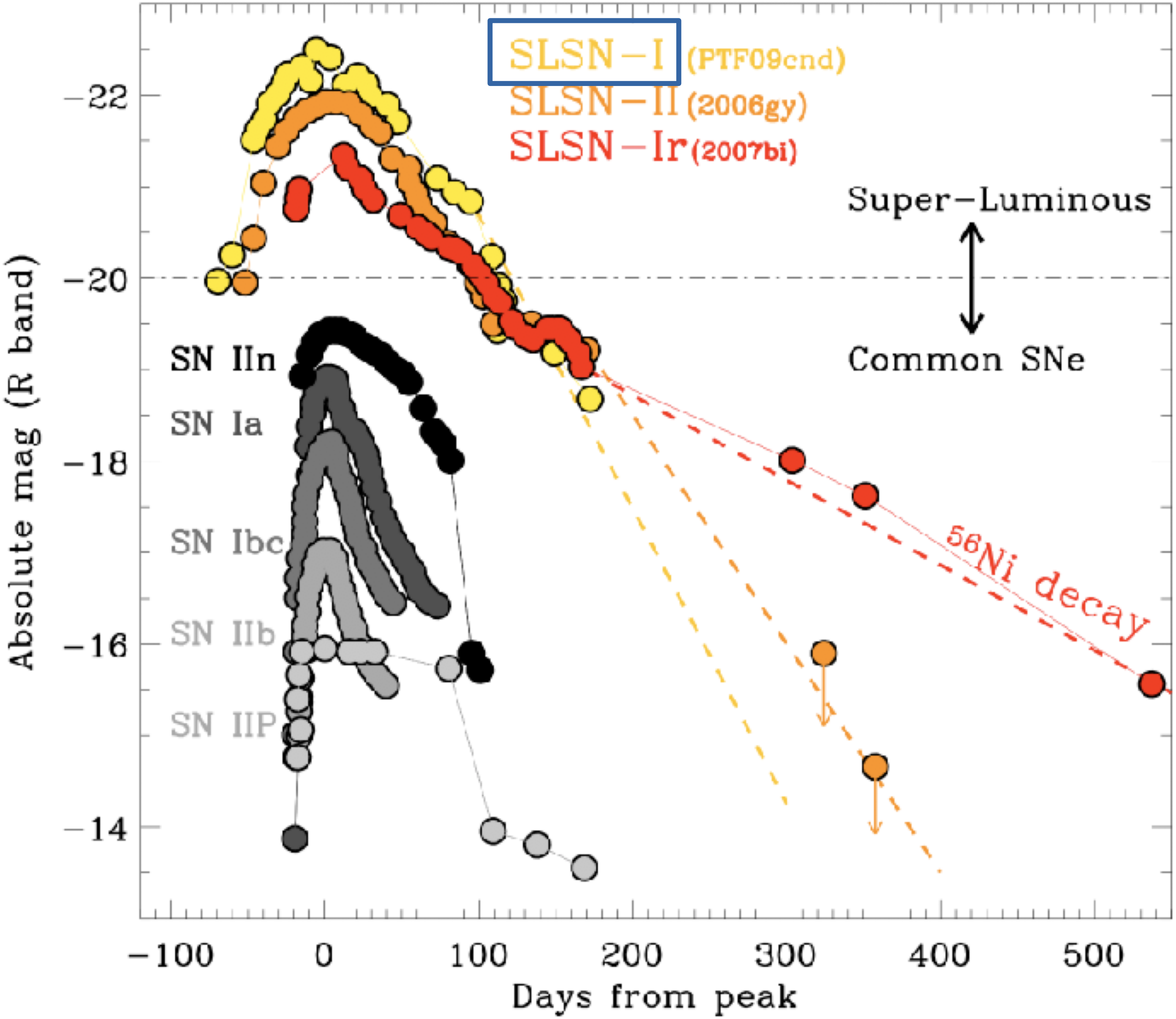

Possible powering mechanisms for SLSNe-I

Extra radioactive material | Interaction with CSM | Central engines

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- Large quantities of ^{56}Ni – “pair instability SNe”
  (Woosley+ 2007, Gal-Yam+ 2009)

- Few possible candidates
  (e.g. Gal-Yam+ 2009, Terreran+ 2017)

- From some SLSN-I, the required ^{56}Ni quantities do not match the:
  - Bright UV emission
  - Decay rate
  - Inferred ejecta mass

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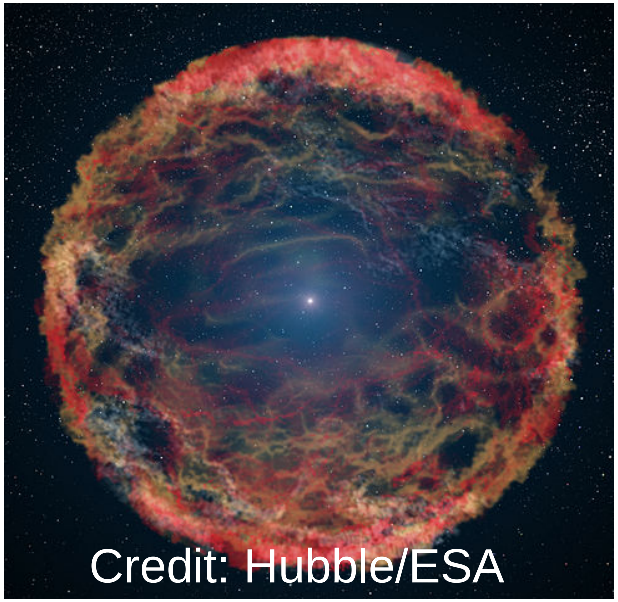
- Smith & McCray 2007; Chevalier & Irwin 2011
  Ginzburg & Balberg 2012



- Plays a role in SLSNe-II
  (e.g. Smith+ 2007, Chatzopoulos+ 2011)

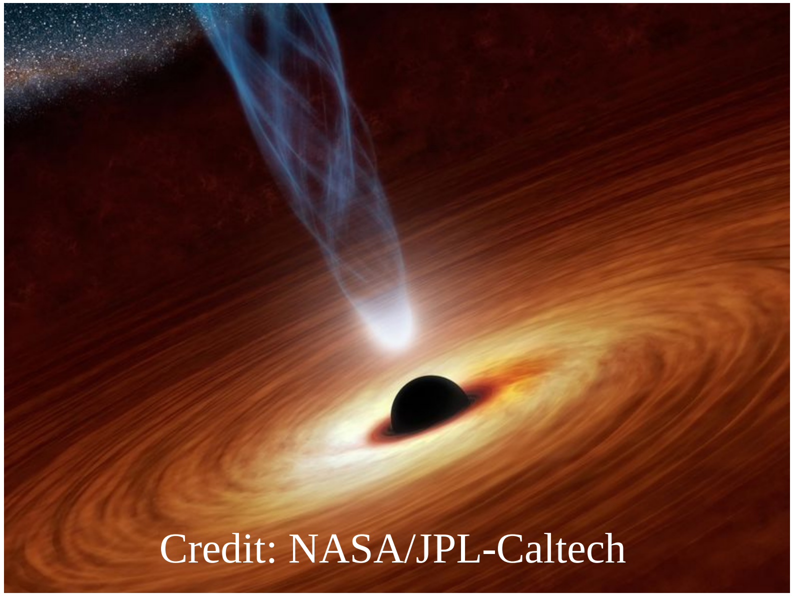
- Difficult to explain lack of narrow emission lines in SLSNe-I

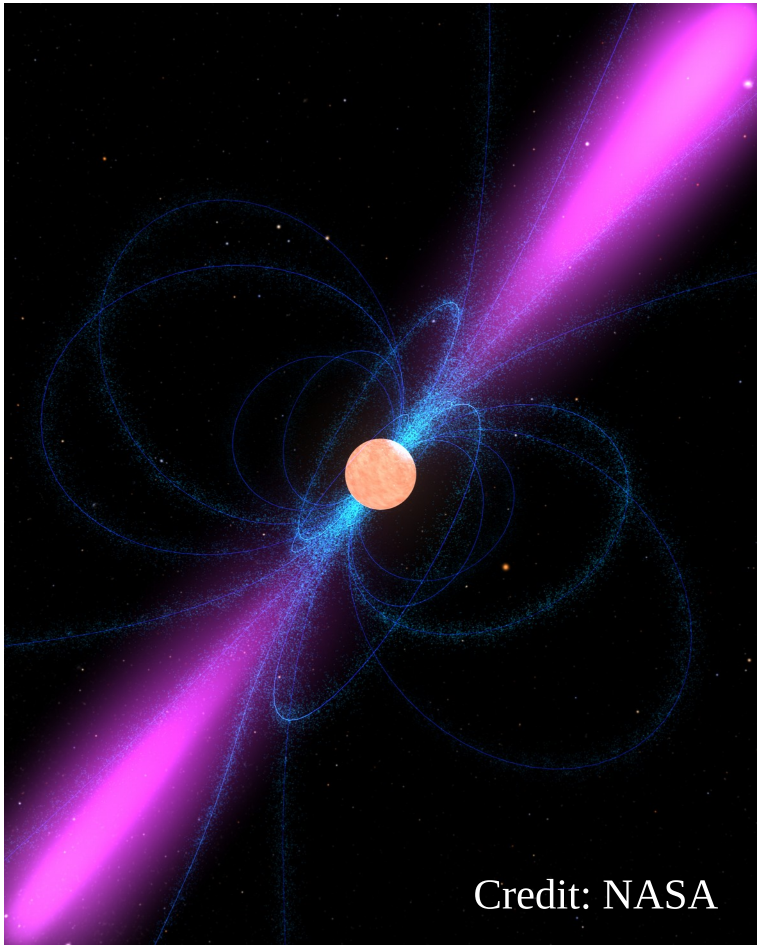
- At least some SLSN-I progenitors are likely to be compact stars surrounded by a low density medium (Margutti+ 2017)

Possible powering mechanisms for SLSNe-I

Extra radioactive material   Interaction with CSM   Central engines

Possible Mechanisms:
- Magnetar Model
  (e.g. Kasen+ 2010, Woosley 2010)
- Accretion onto a black hole
  (e.g. Dexter & Kasen 2013)





Possible powering mechanisms for SLSNe-I

Extra radioactive material | Interaction with CSM | Central engines

Evidence suggesting likely central engines (CEs):

- 1-5 ms Magnetar CEs 10^{13}-10^{15} G fit the optical light curves (e.g. Dessart+ 2012, Inserra+ 2013, Nicholl+ 2015, Lunnan+ 2016…)
- SCP06F6 (Levan+ 2013, Metzger+ 2017) and Gaia16apd (Nicholl+ 2017, see however Yan+ 2017)

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- Support for a connection between long GRBs and SLSNe-I:
  - Preference for metal-poor host galaxies (e.g. Lunnan+ 2014, …, see however Angus+ 2016)
  - Have broad spectral features (Liu+ 2017)
  - GRB associated SN2011kl (Kann+ 2016) showed SLSN features (Greiner+ 2015)
  - Similarities in nebular spectra between SLSN-I 2015bn and GRB associated SN1998bw suggest progenitor cores with a similar structure (Nicholl+ 2016)
  - Unifying model that can produce jets & SN (Metzger+ 2015, Margalit+ 2018, Soker+ 2017)

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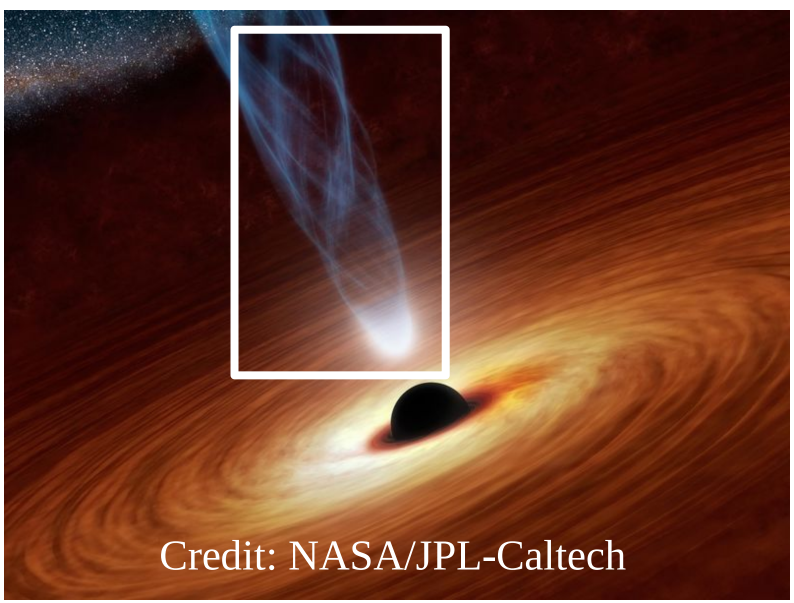
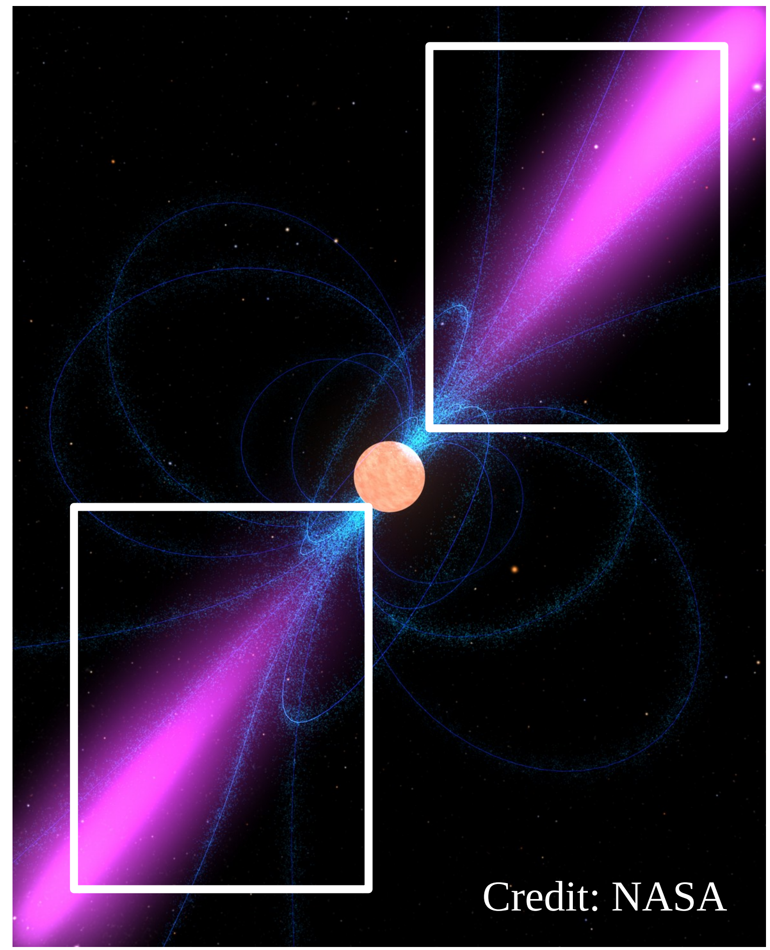




Have we seen a jet?

Problem:
X-ray and radio emission are produced by relativistically moving ejecta

X-ray

?

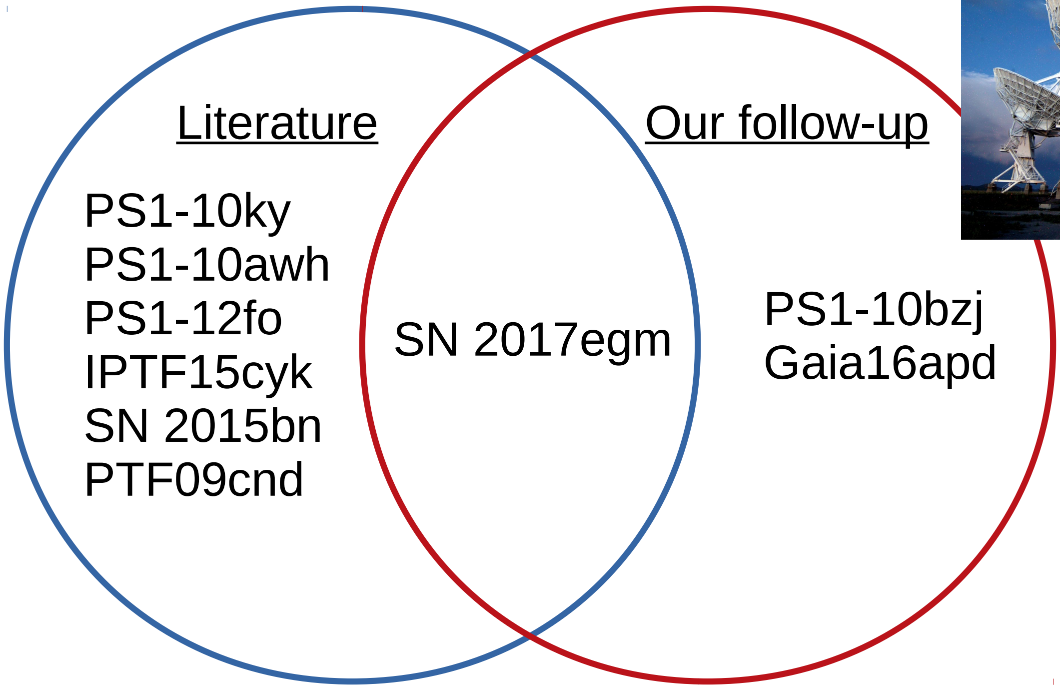
Radio

?

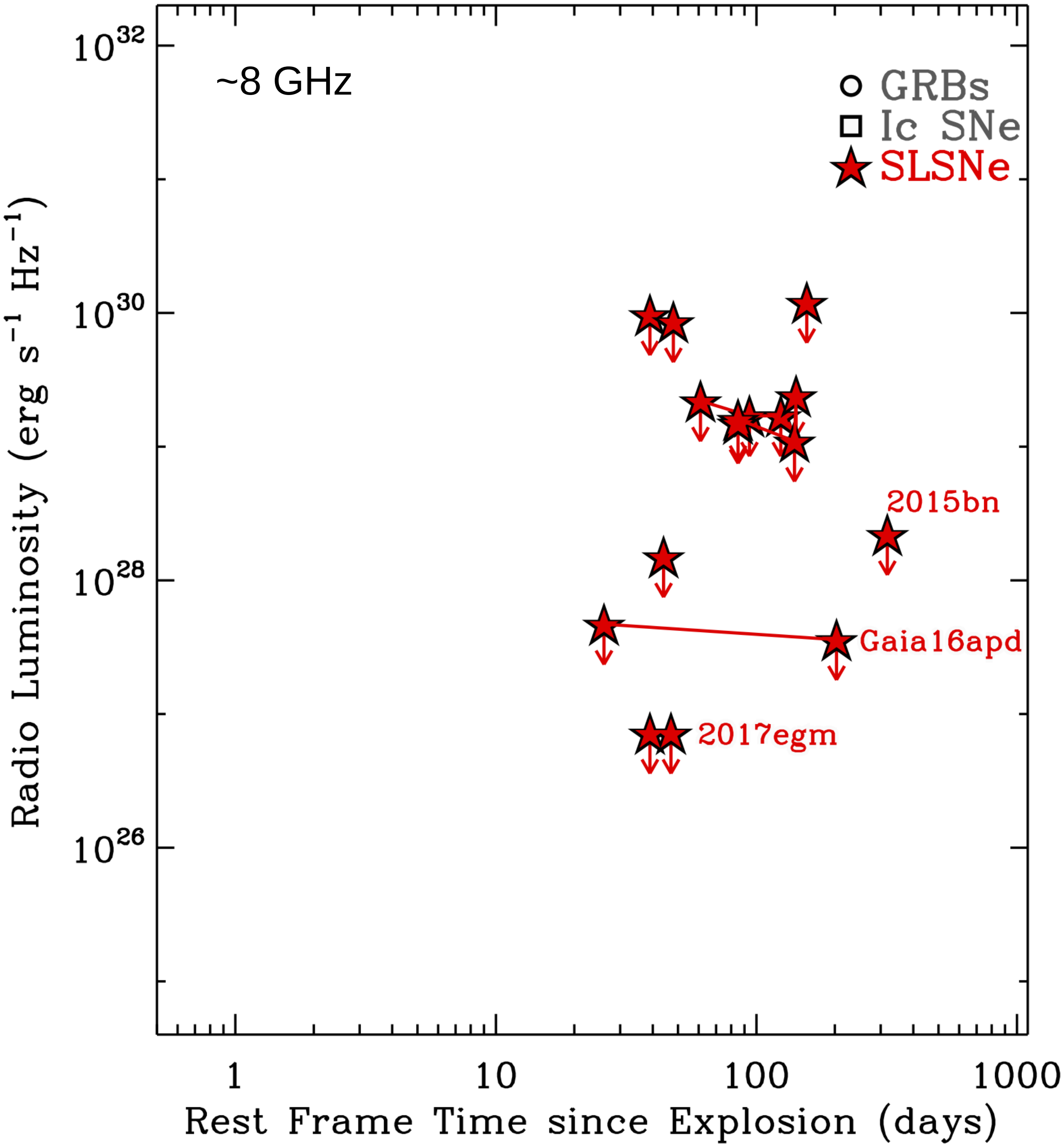
The hunt

X-ray : Margutti+ 2017

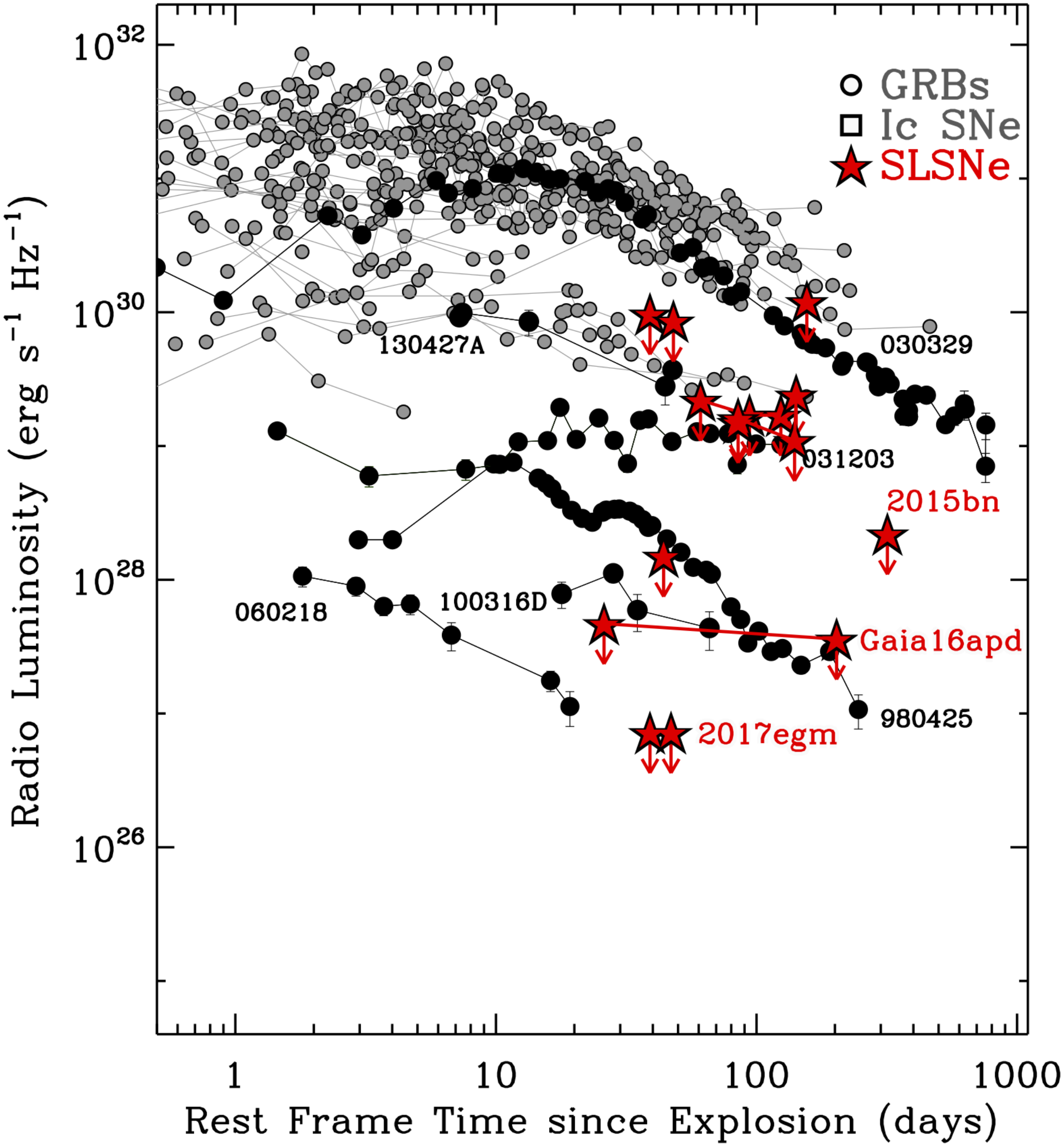
Radio: 9 SLSNe-I, 26-318 days post explosion



Comparison to other classes of massive stellar explosions from H-stripped progenitors



Modified from Coppejans+ 2018



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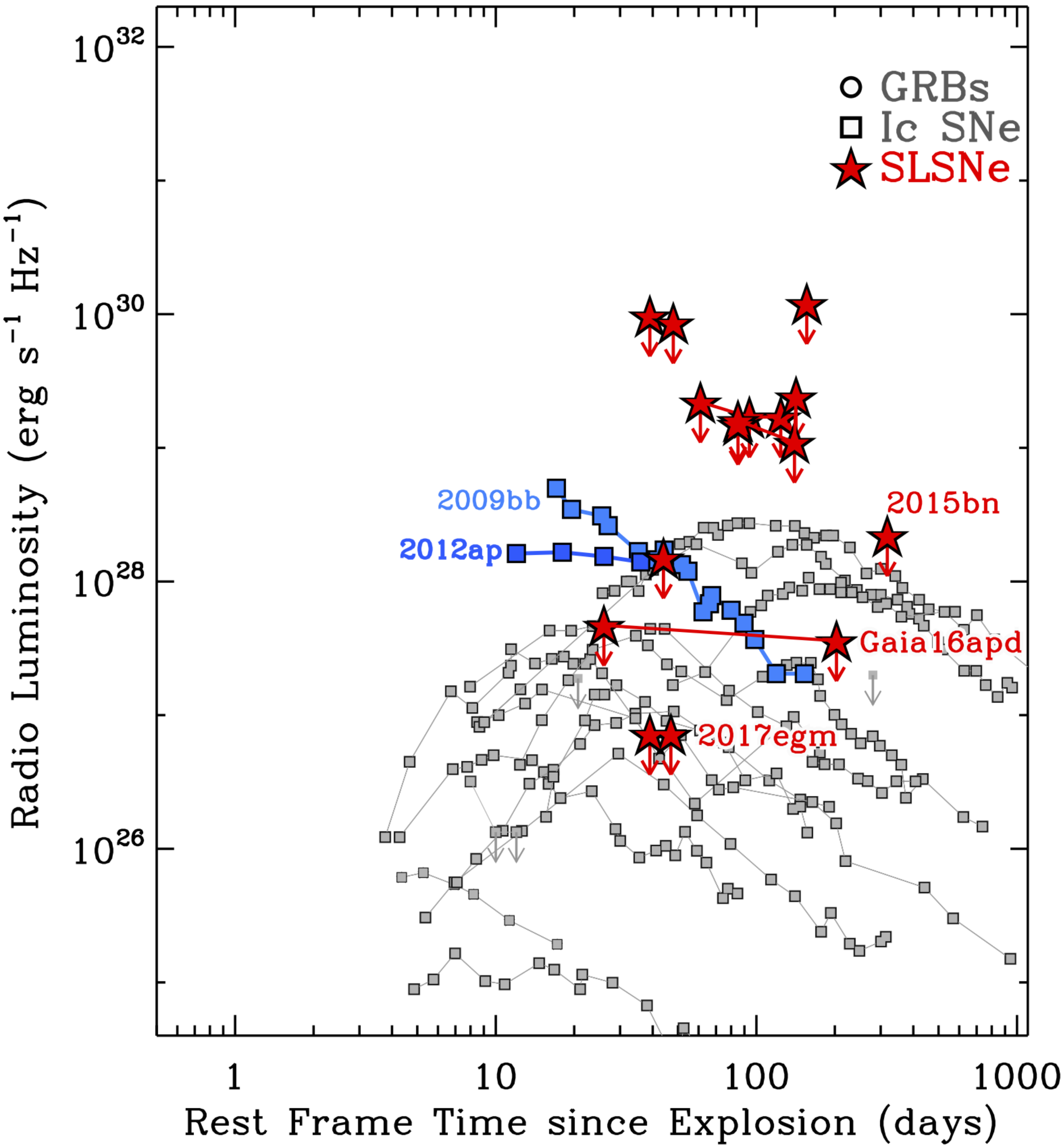

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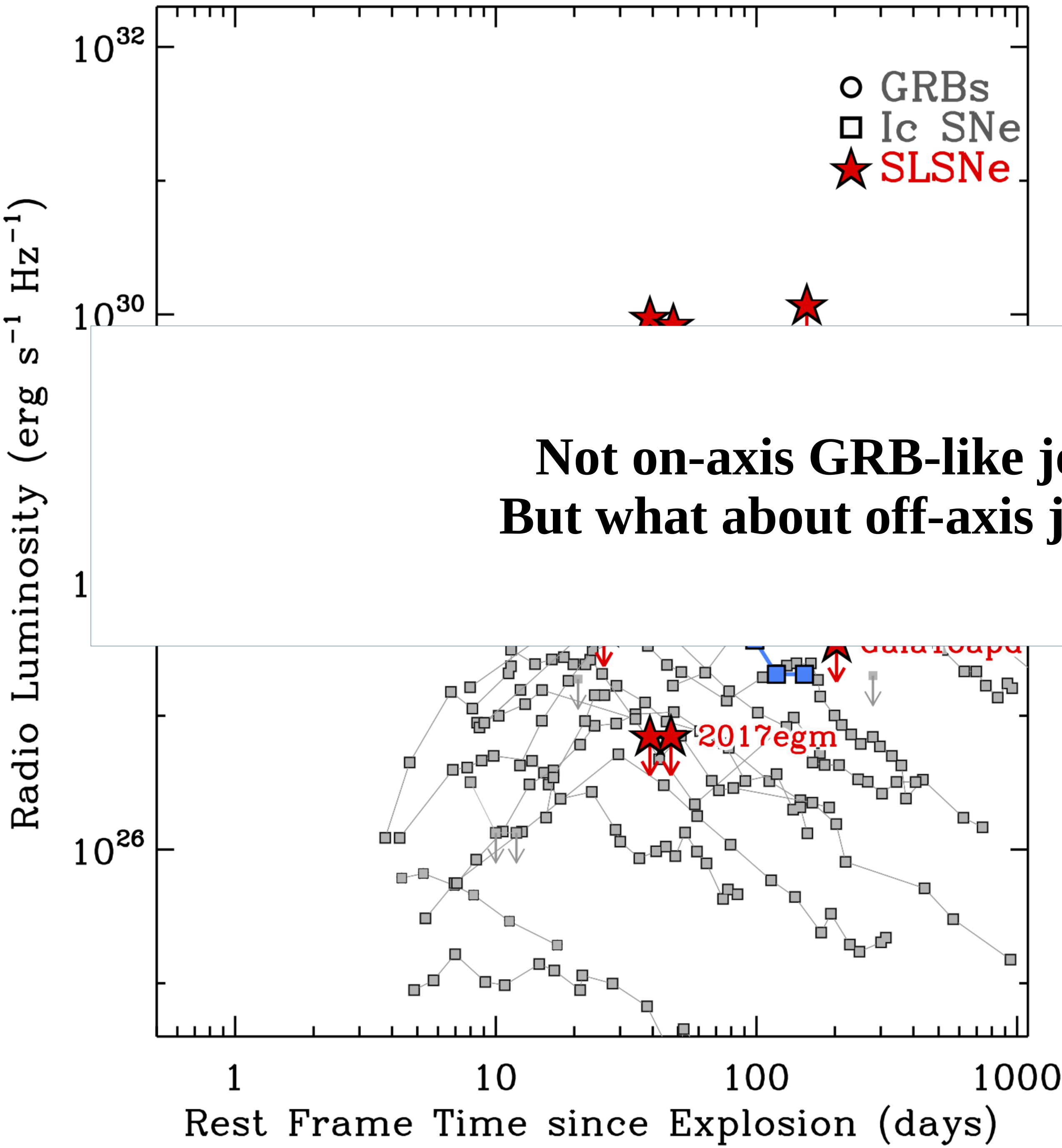
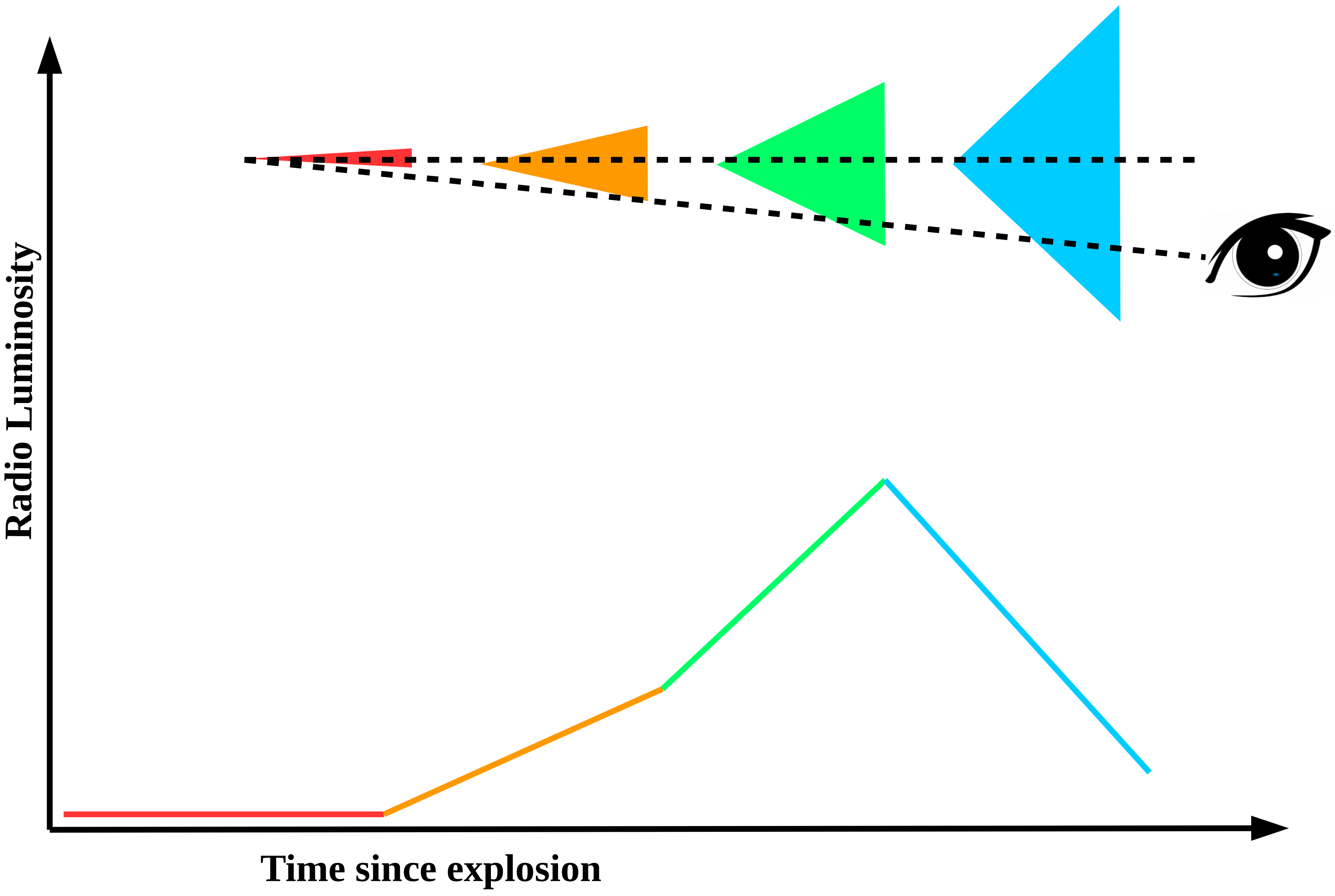


Comparison to other classes of massive stellar explosions from H-stripped progenitors

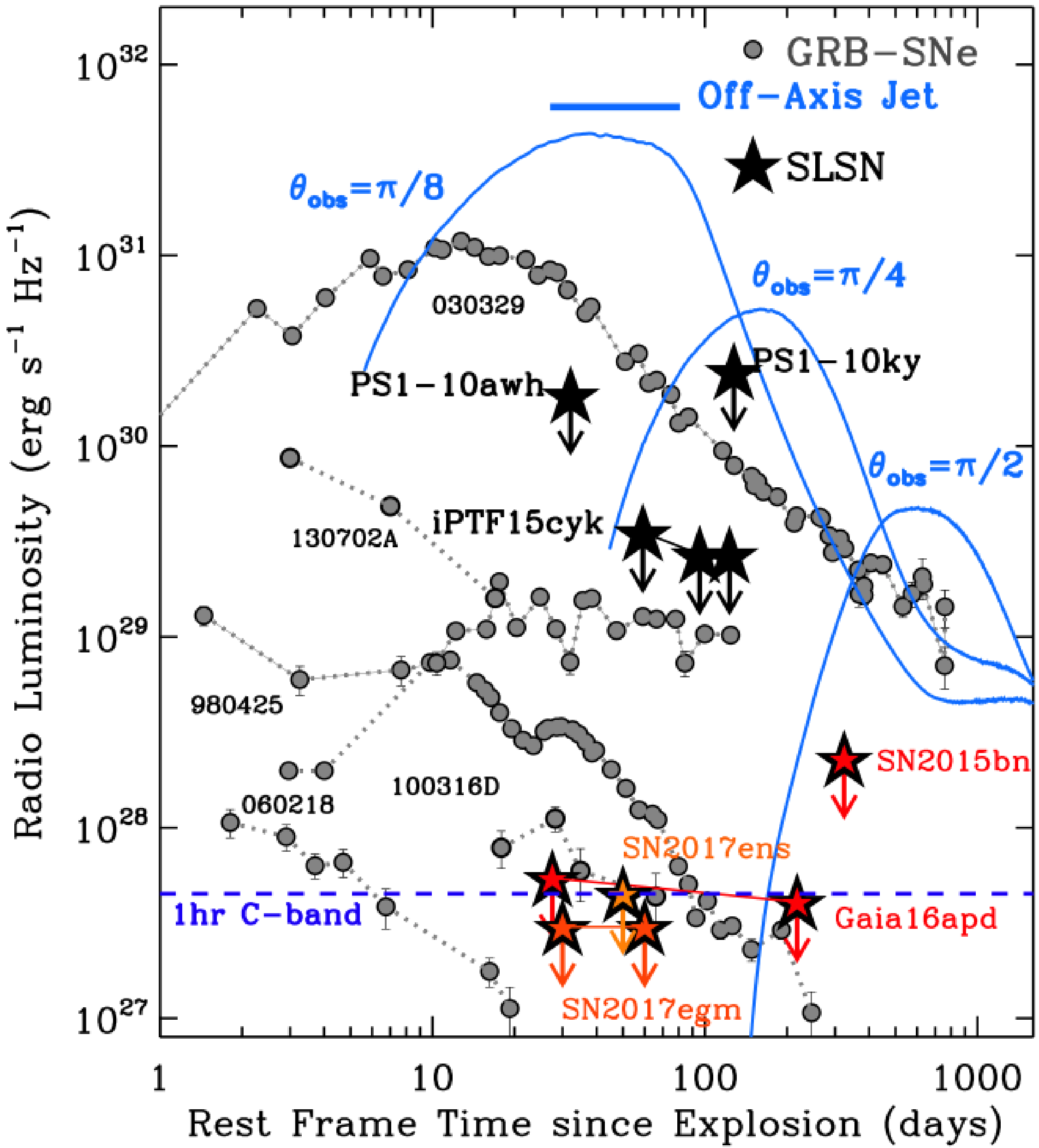
Not on-axis GRB-like jets
But what about off-axis jets?

Modified from Coppejans+ 2018

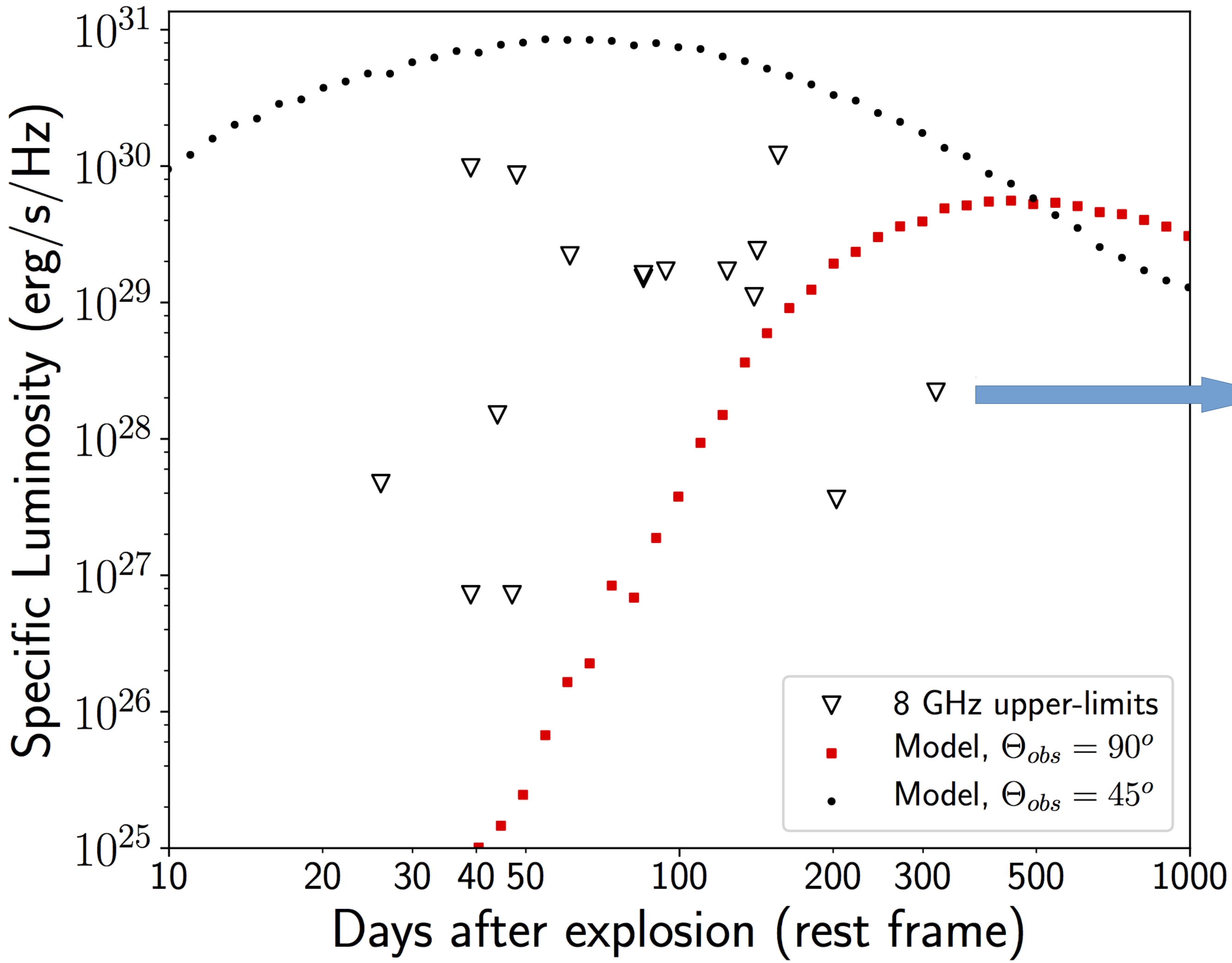
Off-axis collimated jets?



Off-axis collimated jets?



Methodology



All radio SLSNe-I observations

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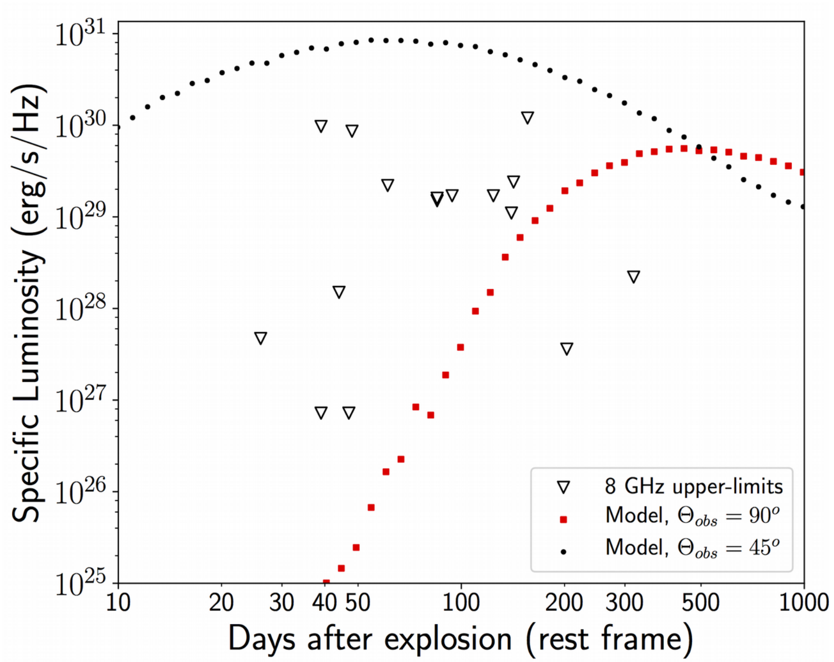
Methodology



Jet light curves depend on:

- Energy
- Collimation angle
- Density of the surrounding medium
- Density profile of the surrounding medium
- Viewing angle
- Microphysical shock parameters

Procedure:

- Modelled light curves with high-resolution 2D relativistic hydrodynamical jet simulations (Boxfit v2, van Eerten+ 2012)
- Generated a grid of models for these parameters
- Used radio limits to rule out certain parameters

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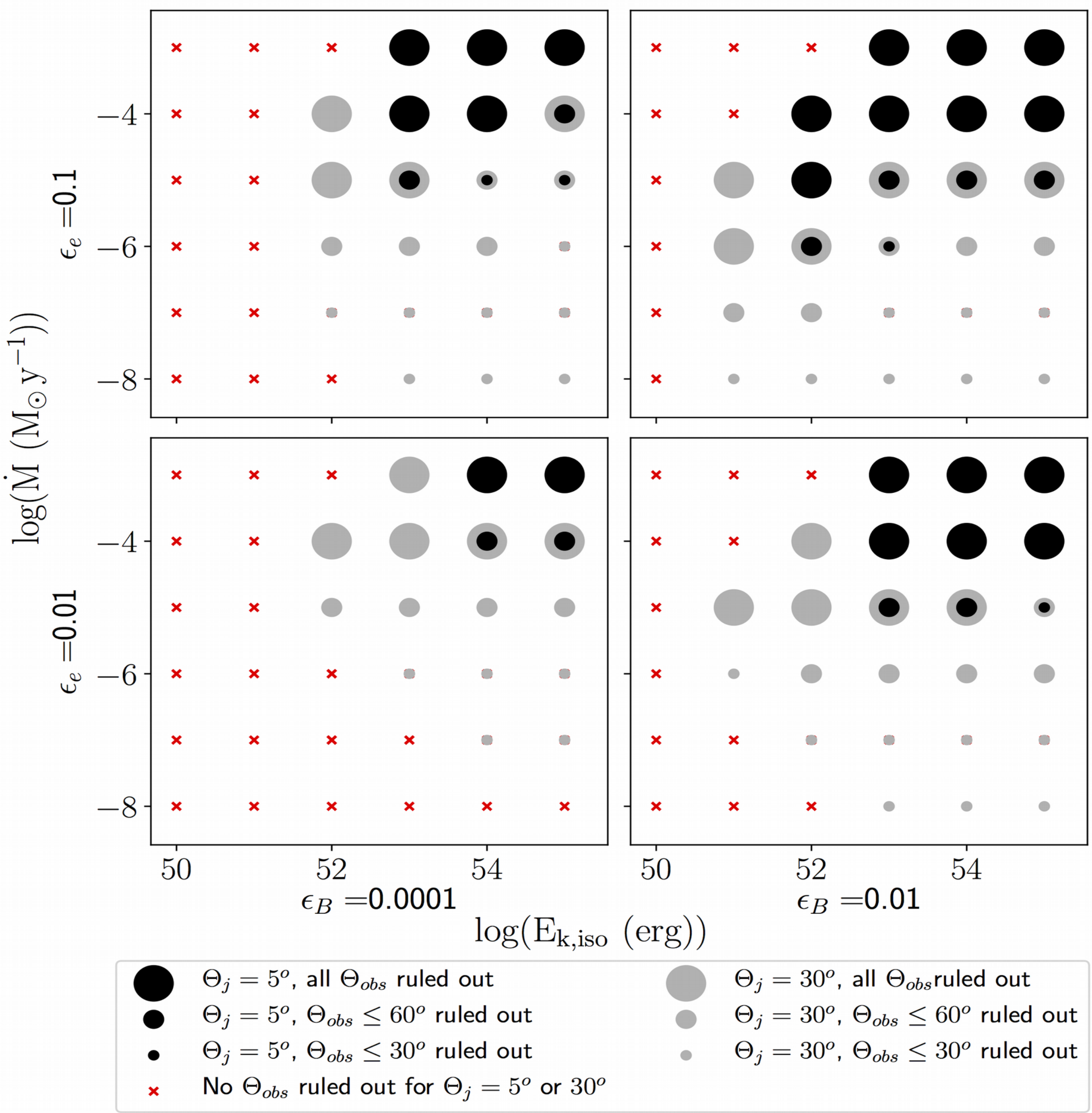
Jet constraints



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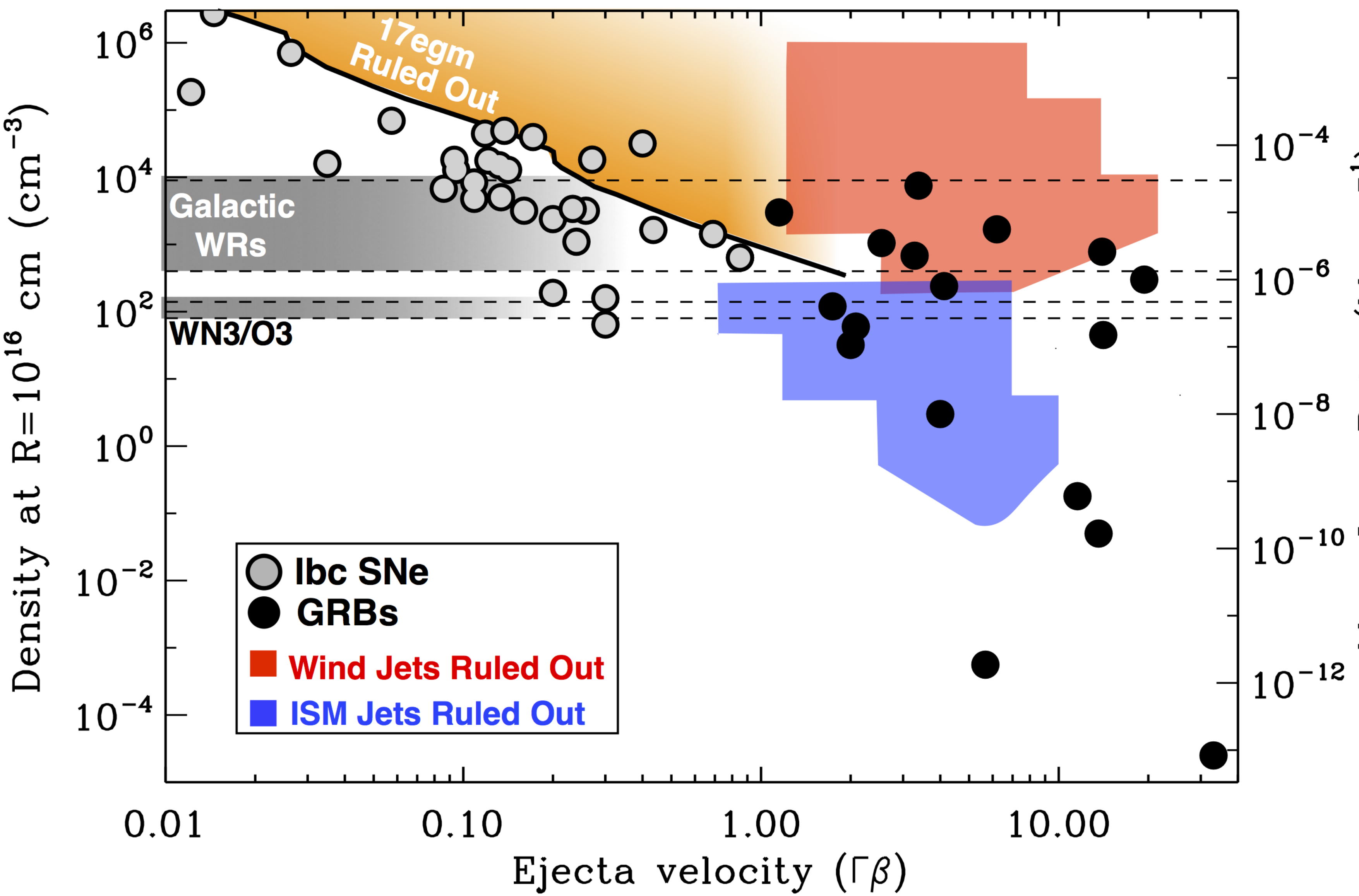
Results: Constraints on off-axis jets



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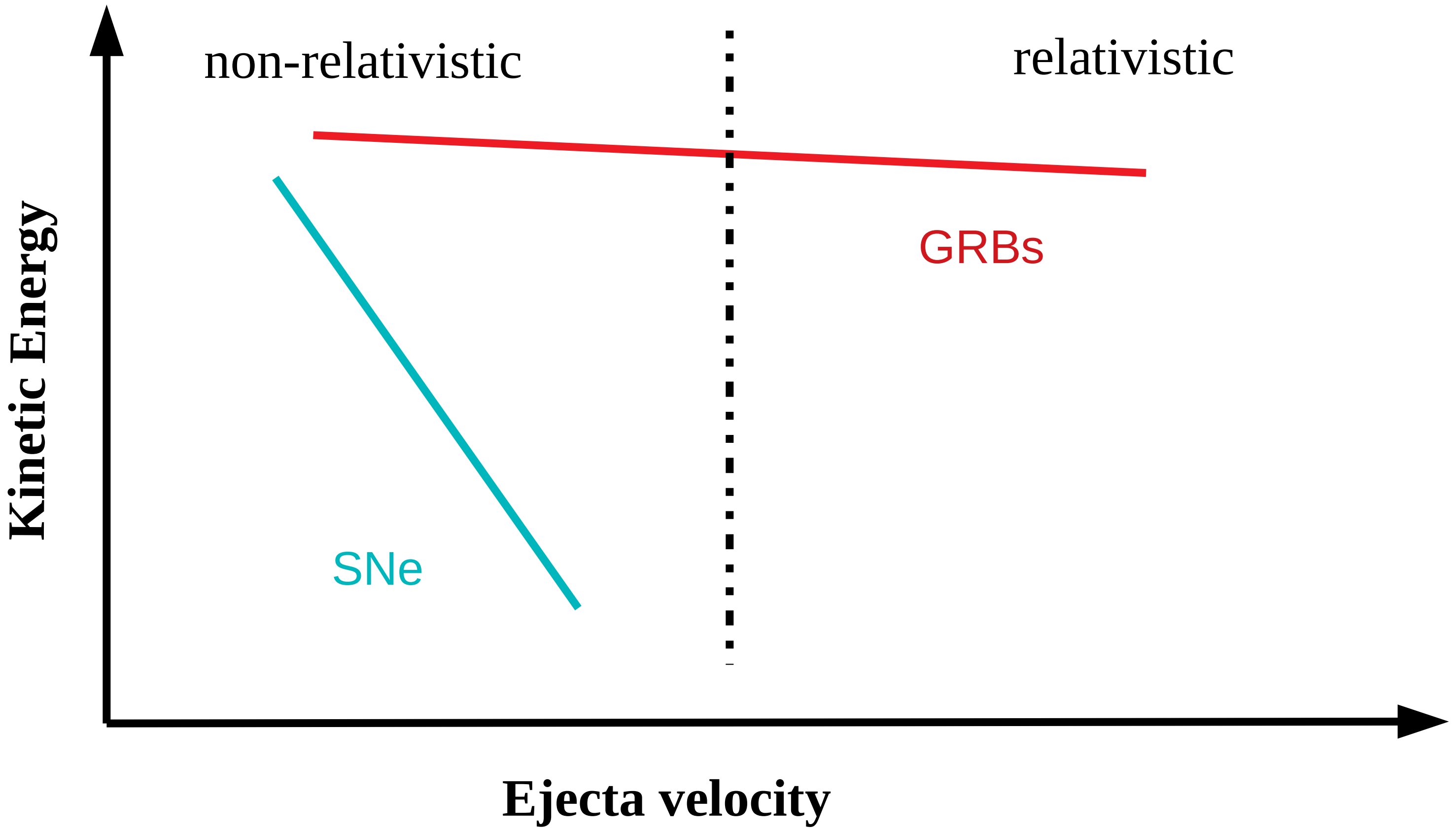
Constraints on a central engine



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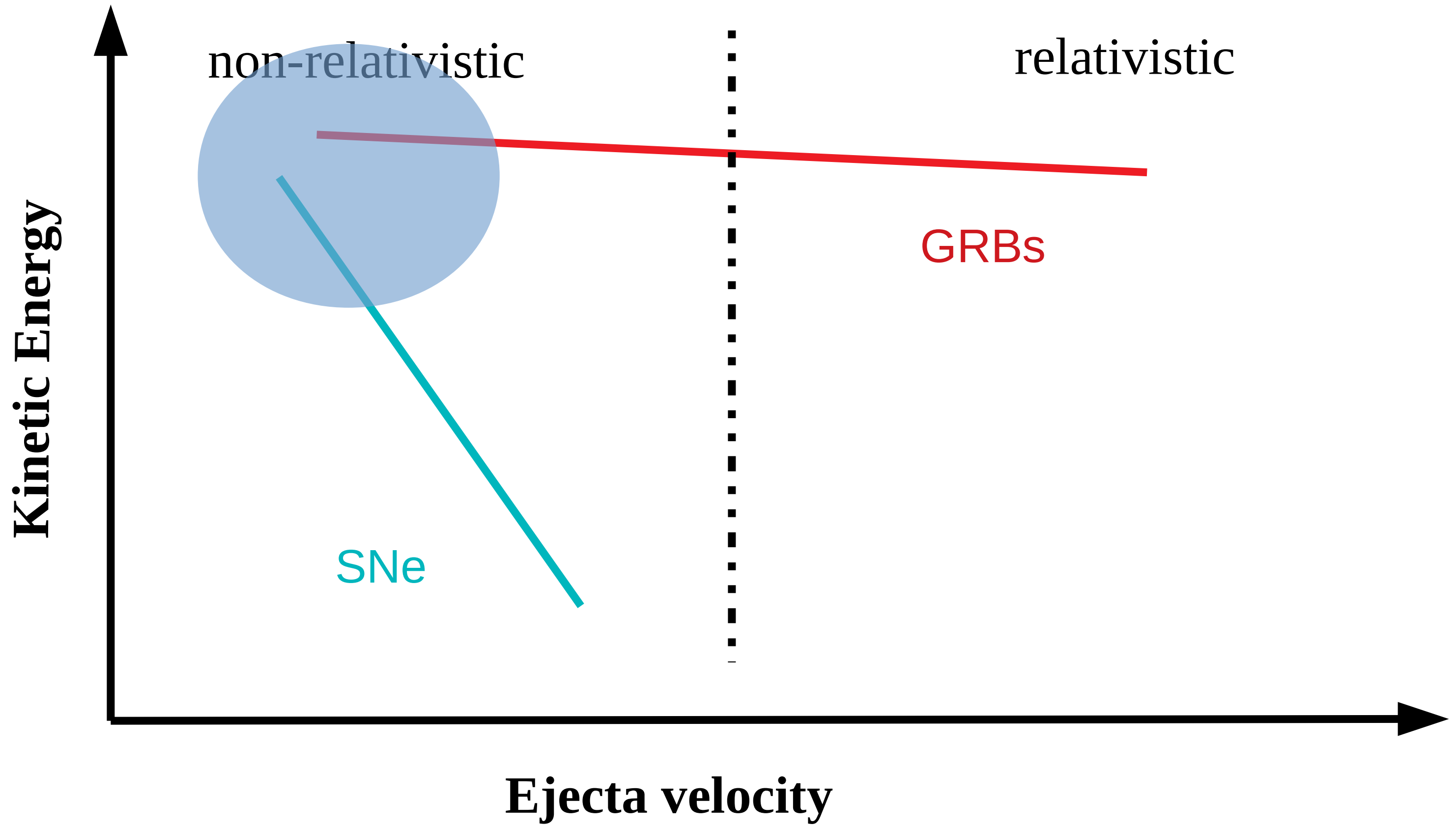

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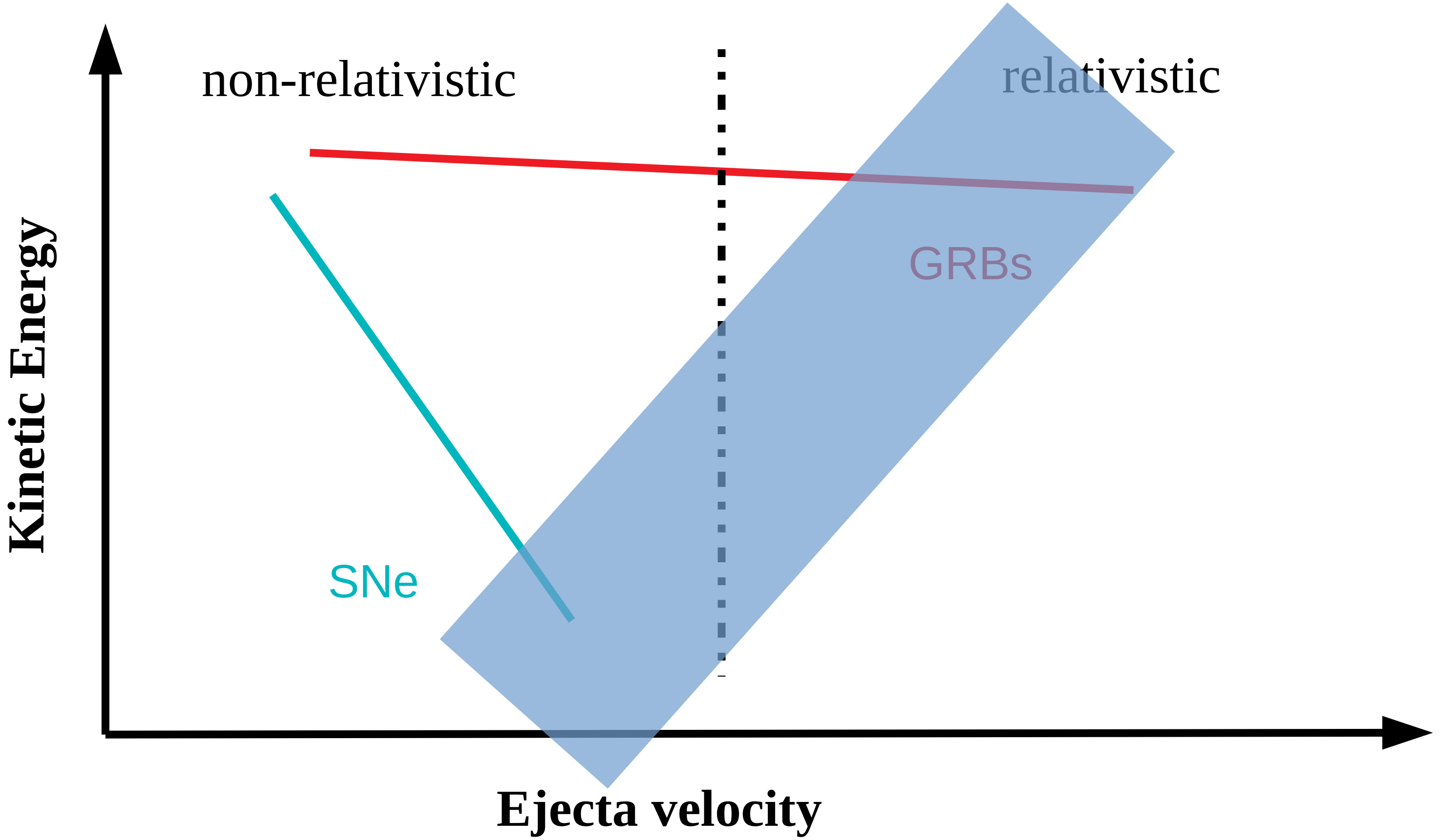

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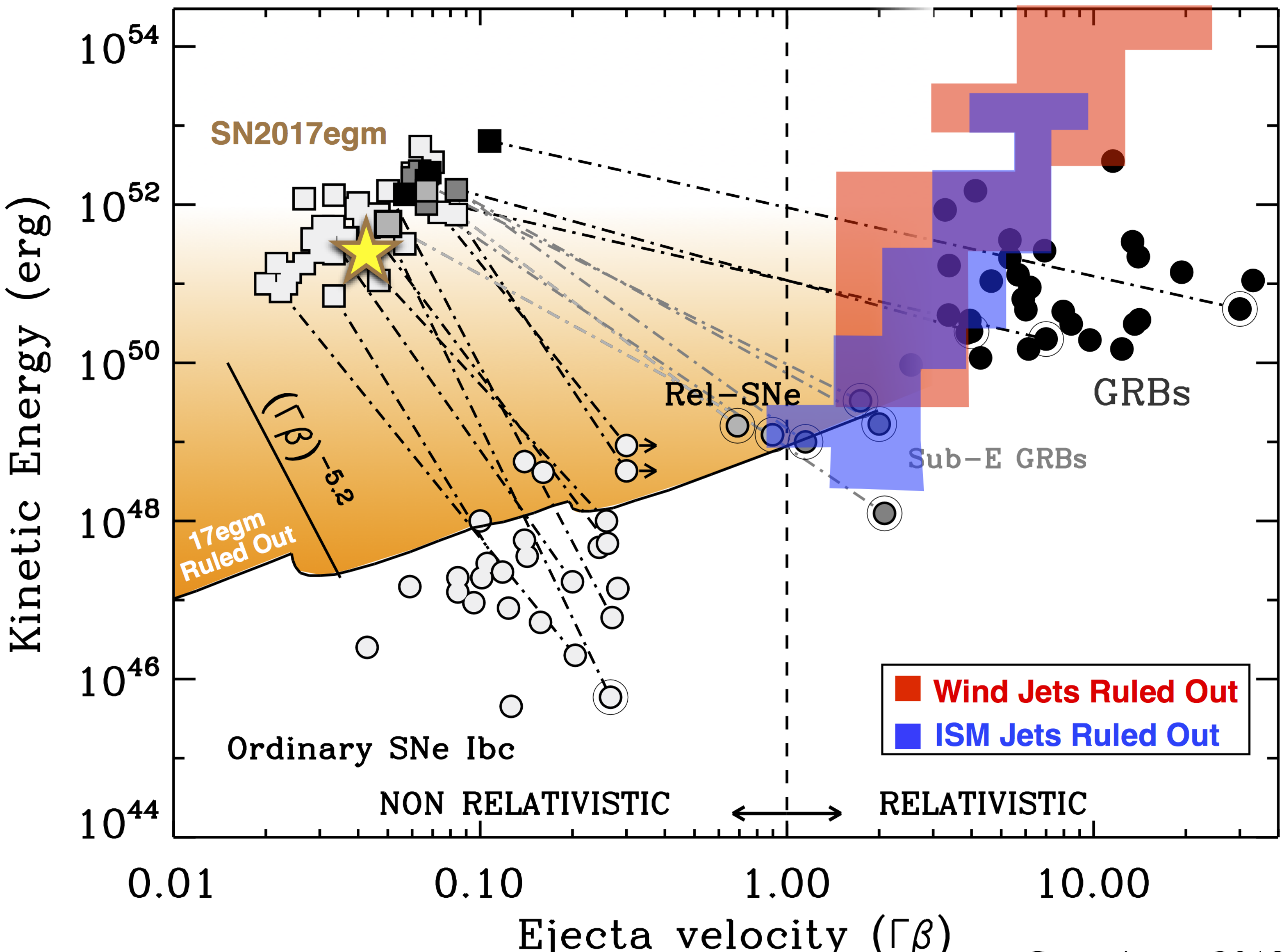

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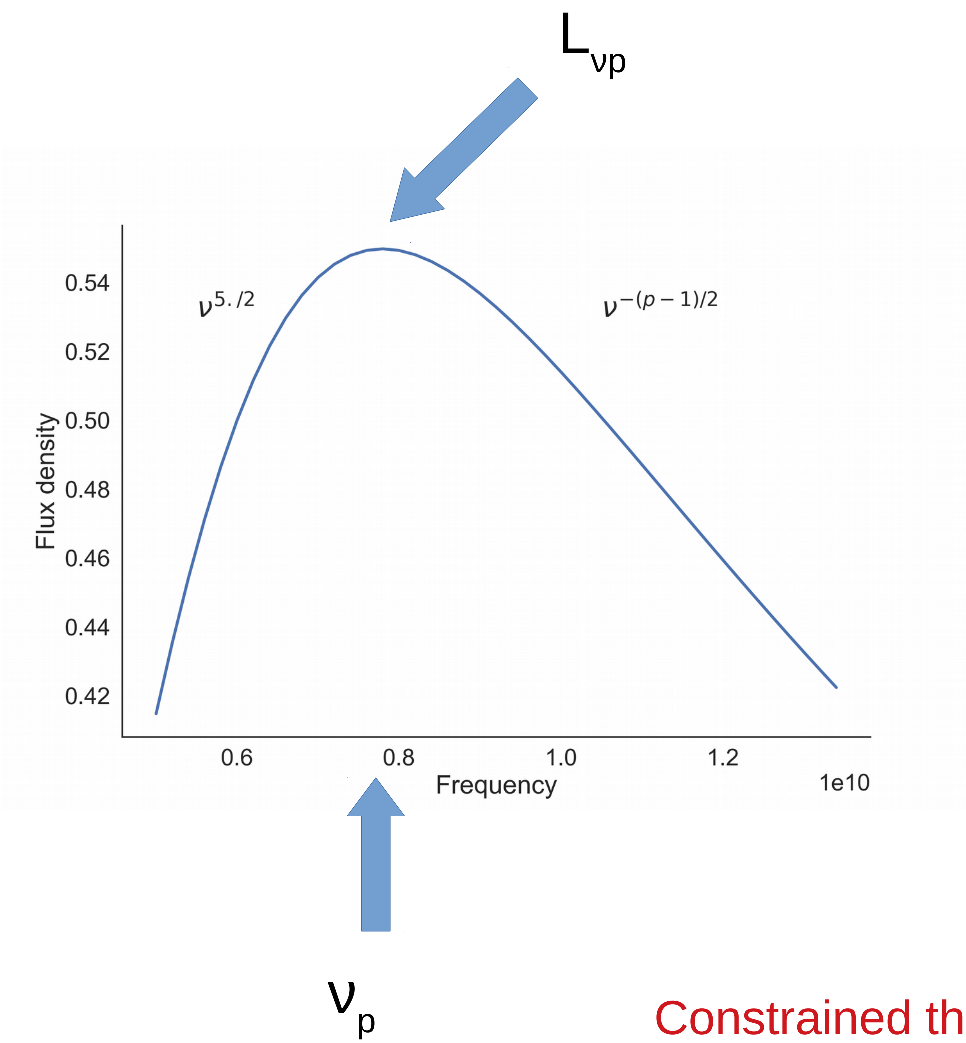
Constraints on uncollimated outflows



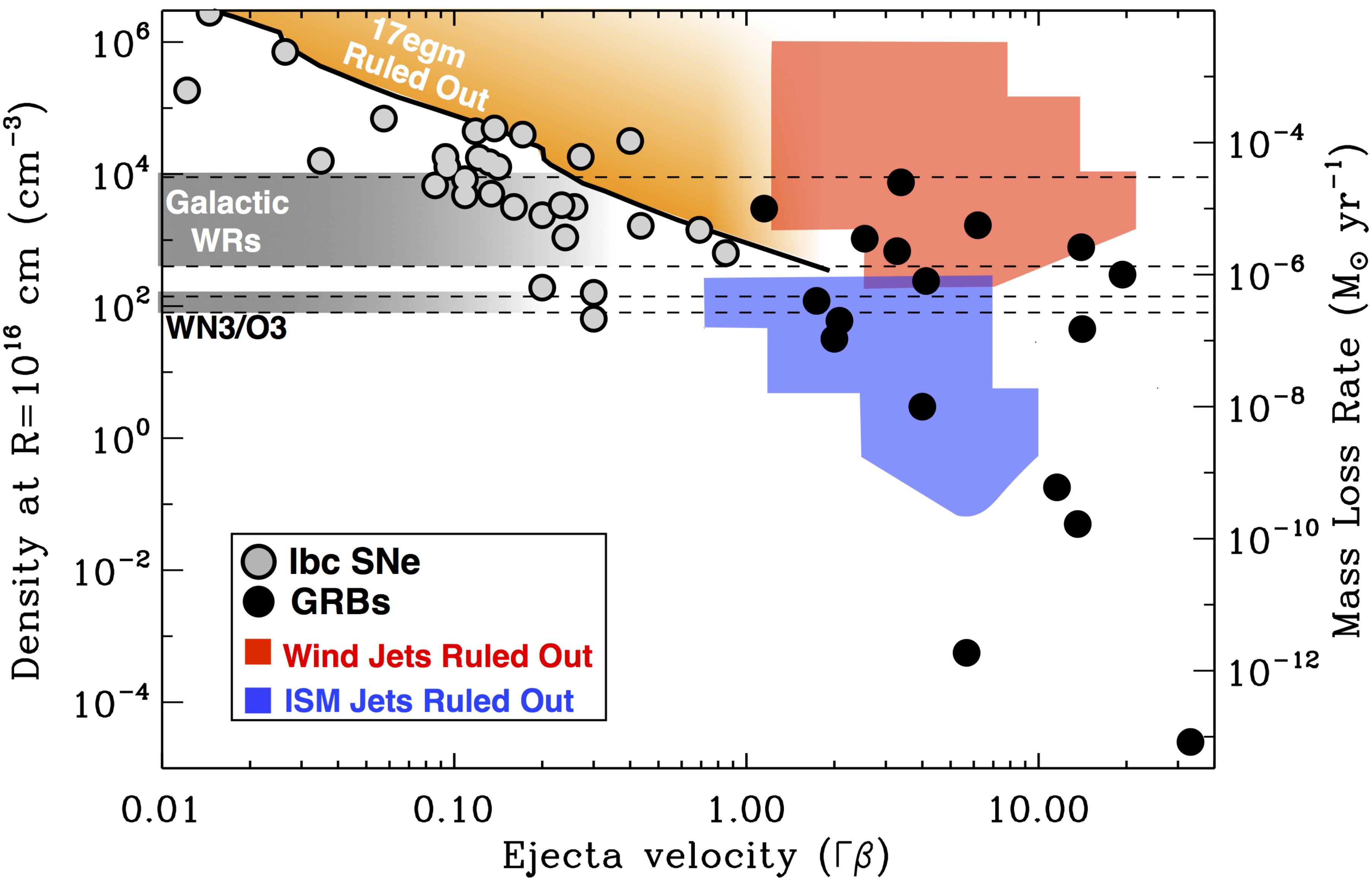
For a SSA spectrum:

- Radius ($L_{\nu p}$, ν_p)
- Magnetic field ($L_{\nu p}$, ν_p)
- Mass loss rate ($L_{\nu p}$, ν_p, t_p)

… following Chevalier 1998, Chevalier & Fransson 2006, Soderberg+ 2012

Constrained these properties with SLSN-I 2017egm

Constraints on uncollimated outflows



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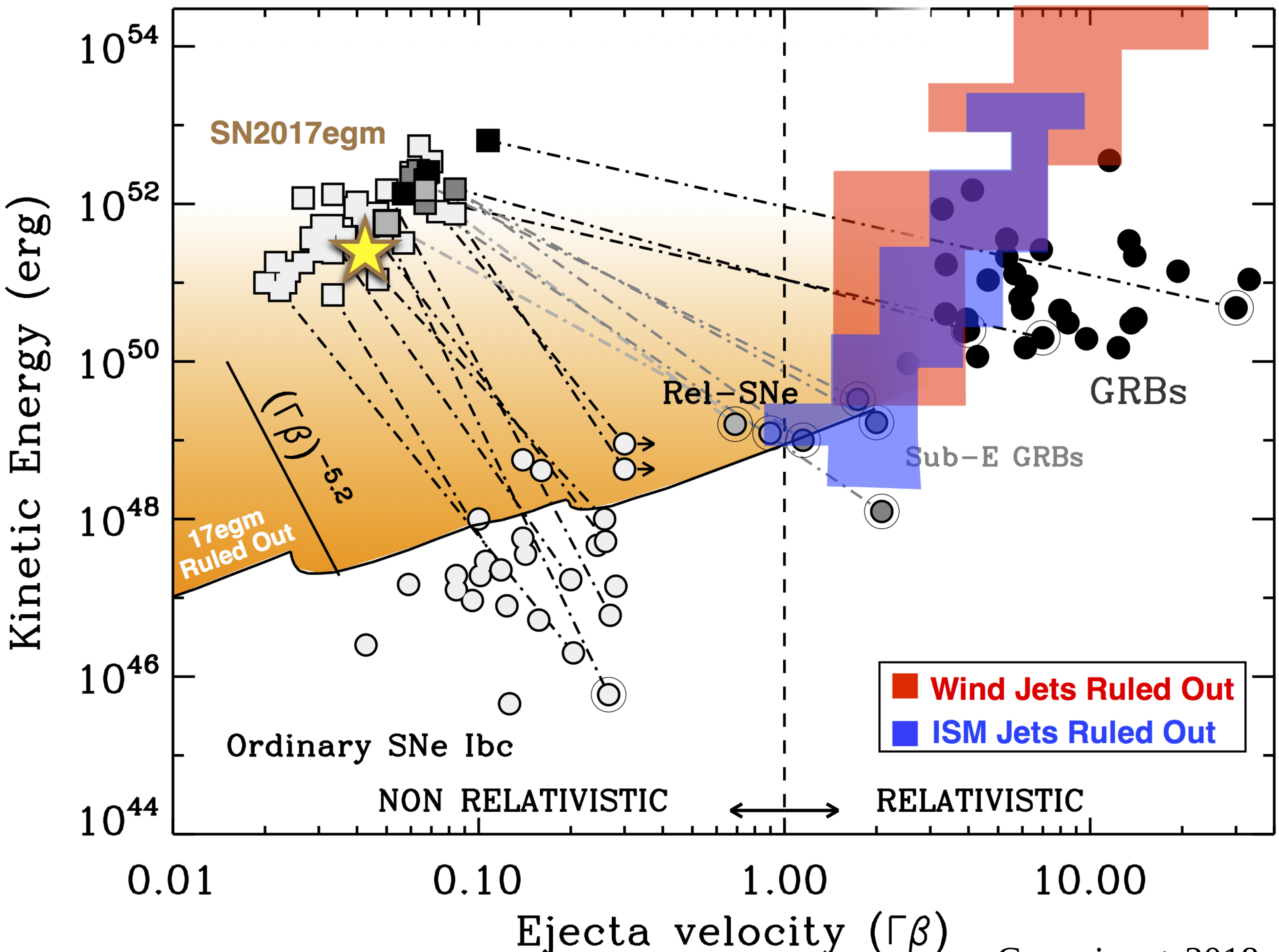

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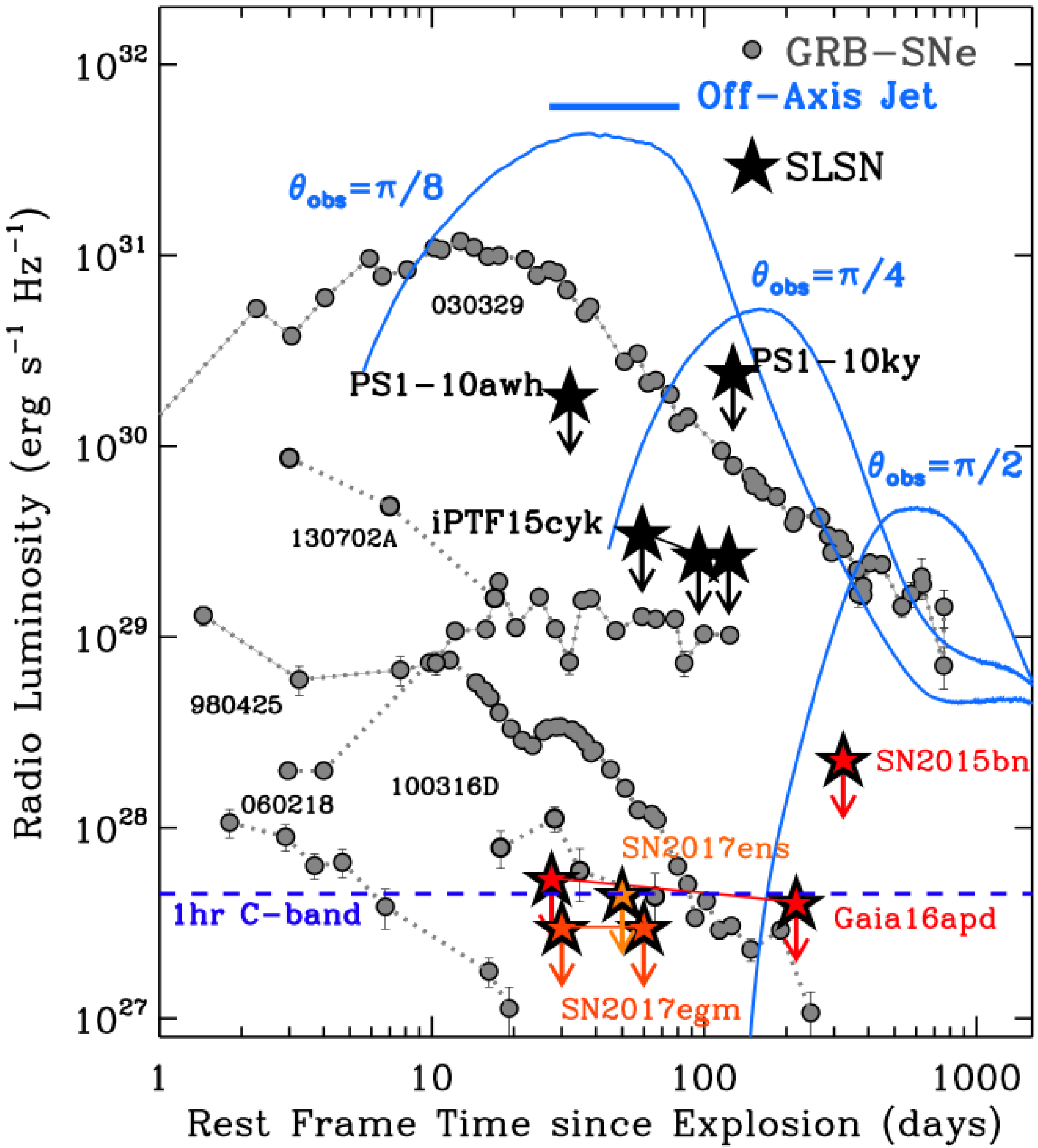
How do we proceed?



Summary

Do Hydrogen poor Super-luminous Supernovae launch jets?

- In this sample we rule out on-axis jets of the kind detected in GRBs
- If the SLSNe-I in this sample have off-axis GRB-like jets, then:
  - the jets have $E_{k,iso}$<10^{53} erg, and the progenitors had $\dot{M}$<10^{-4} $M_{o}y^{-1}$
  - we rule out off-axis jets at densities and energies equivalent to the higher end of the range shown by GRBs
- If the SLSNe-I in this sample have off-axis jets collimated to 30^{o}, then the jets have $E_{k,iso}$<10^{53} erg, and the progenitors had $\dot{M}$<10^{-5} $M_{o}y^{-1}$

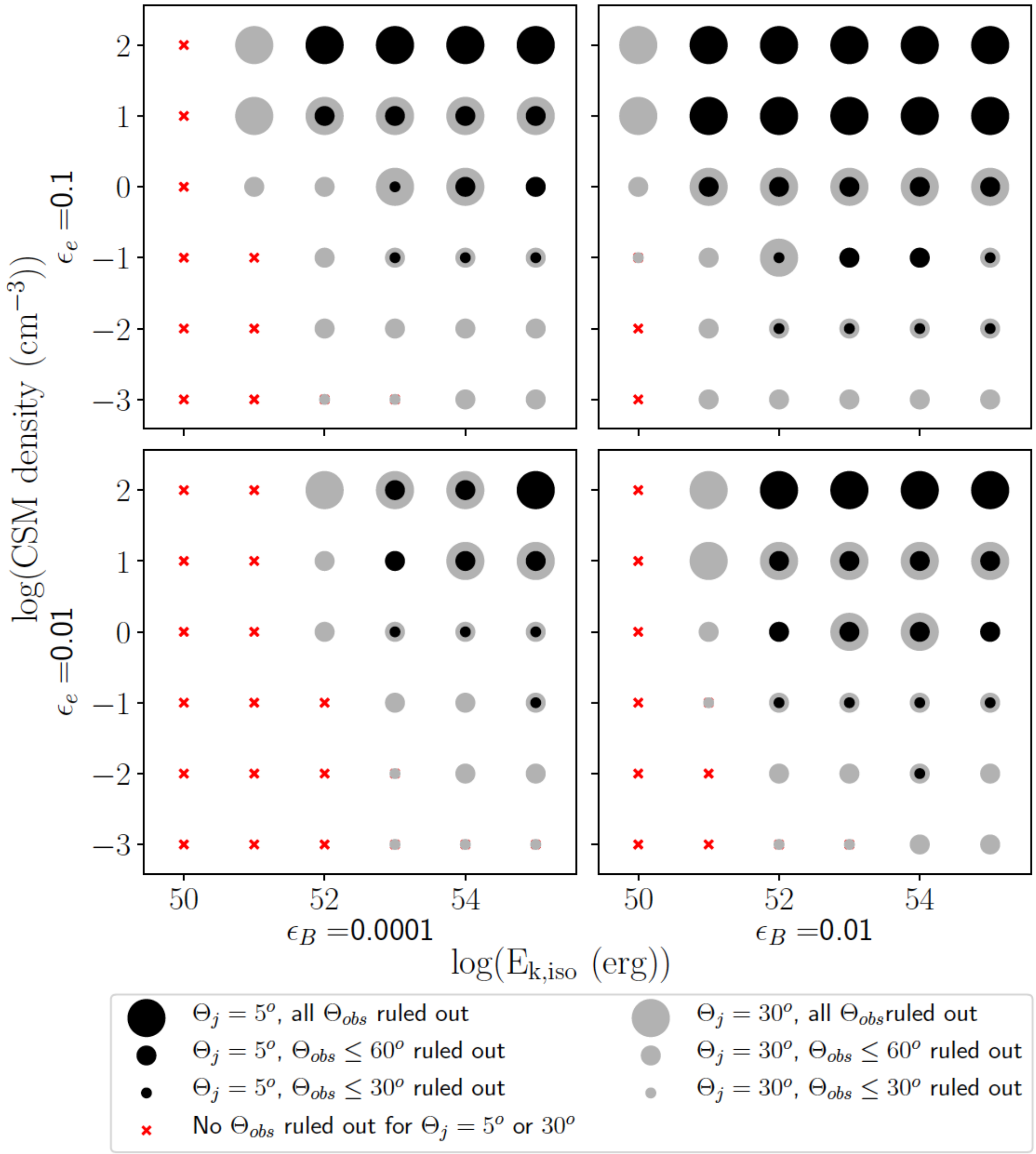
Constraints on uncollimated outflows:

- SLSNe-I radio limits rule out emission of the kind seen in relativistic SNe
- The deepest SLSN-I limits rule out emission of the kind found in faint uncollimated GRBs (except for GRB 060218) and many SNe
- If SLSN 2017egm was a spherical outflow, then it had an energy $\lesssim 10^{48}$ erg

More observations needed:

- Nearby systems
- Earlier times
- <u>Later times</u>

Extra slides



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