Core-collapse supernovae are thermonuclear explosions

Implications for nu-detection

Doron Kushnir
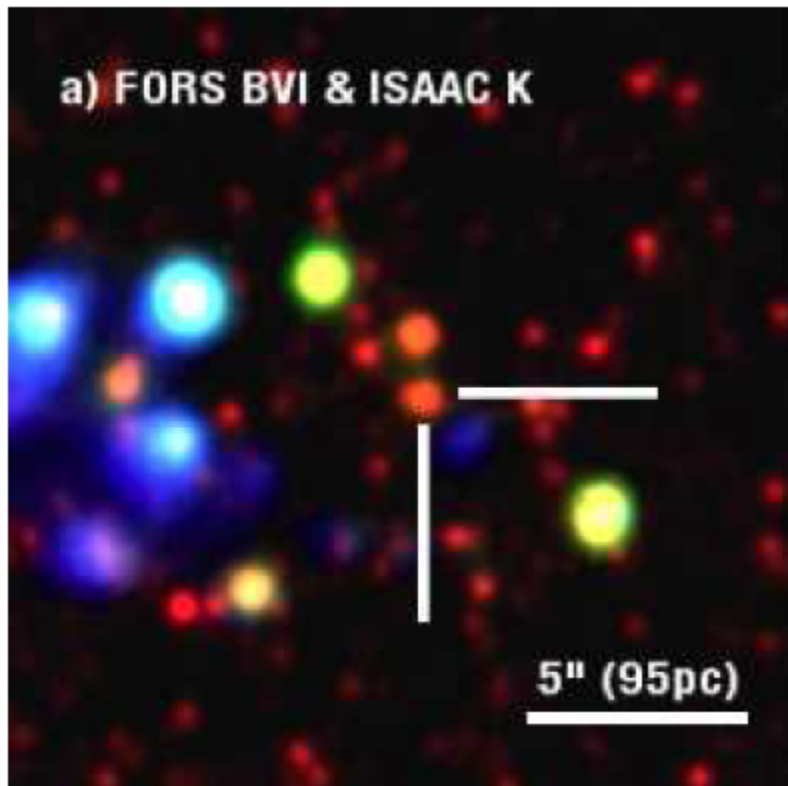
Collaborators: Boaz Katz (WIS), Kfir Blum (WIS), Roni Waldman (HUJI)

9.1.2017

The progenitors are massive stars

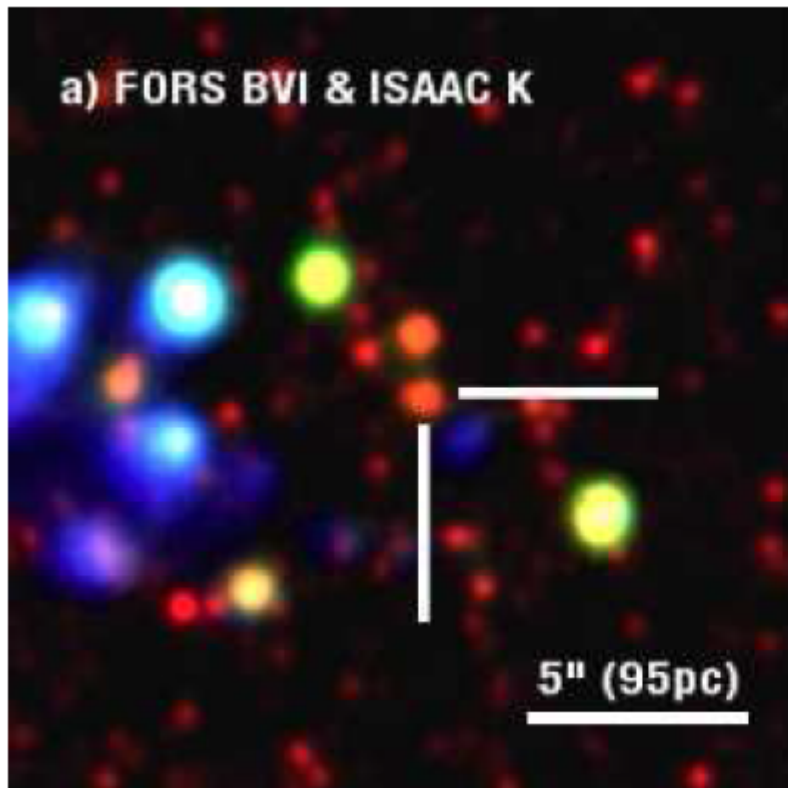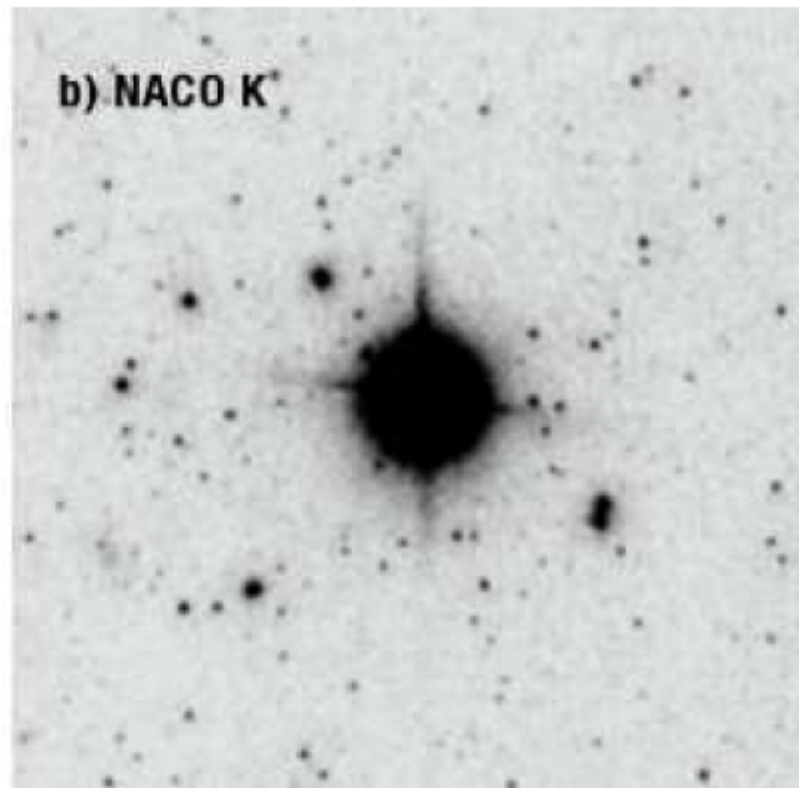**SN2008bk - Red Super Giant, $M=8.5\pm1\ M_{sun}$**

pre-explosion

a) FORS BVI & ISAAC K

5" (95pc)

Mattila et al. (2008)

The progenitors are massive stars

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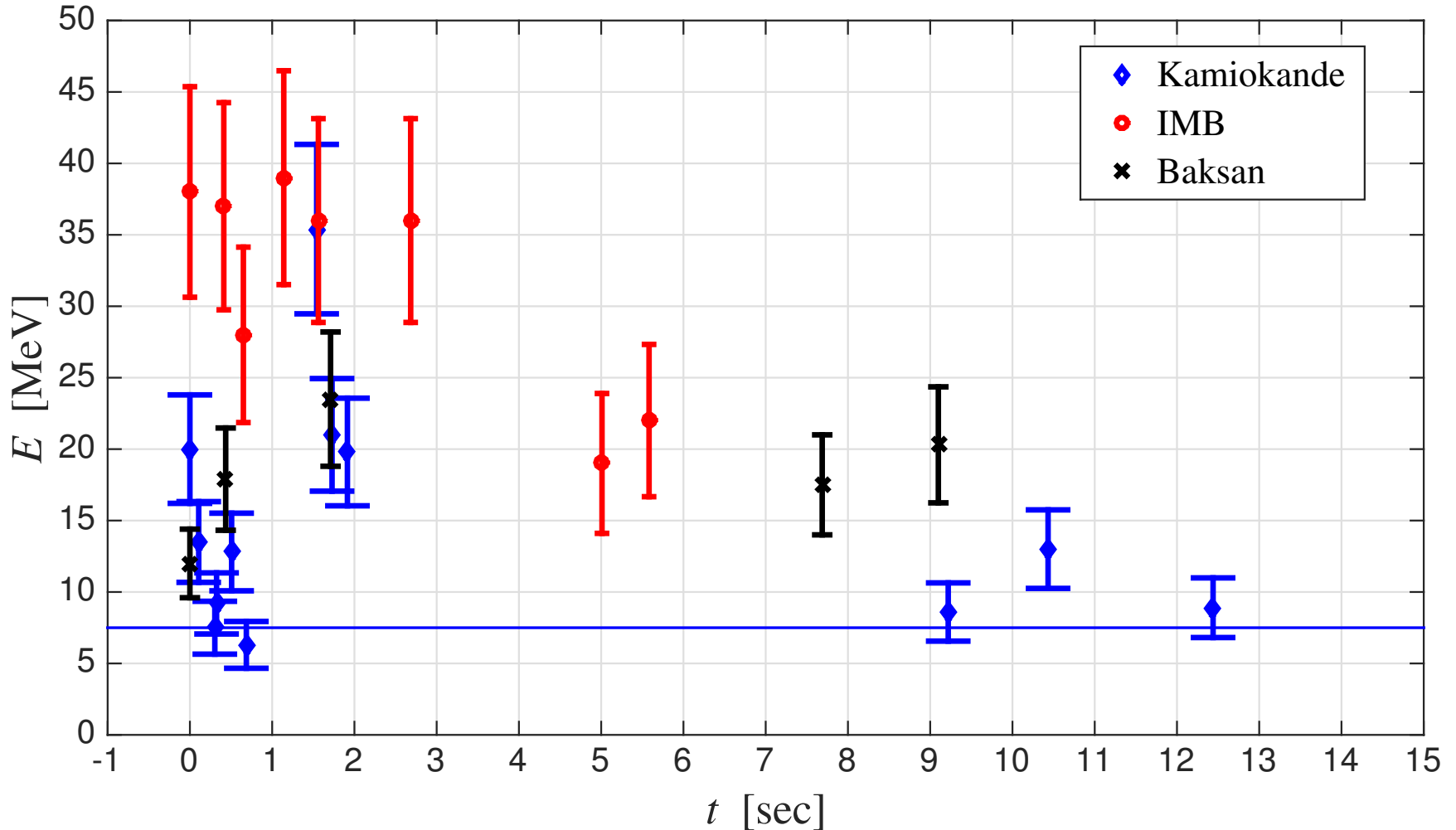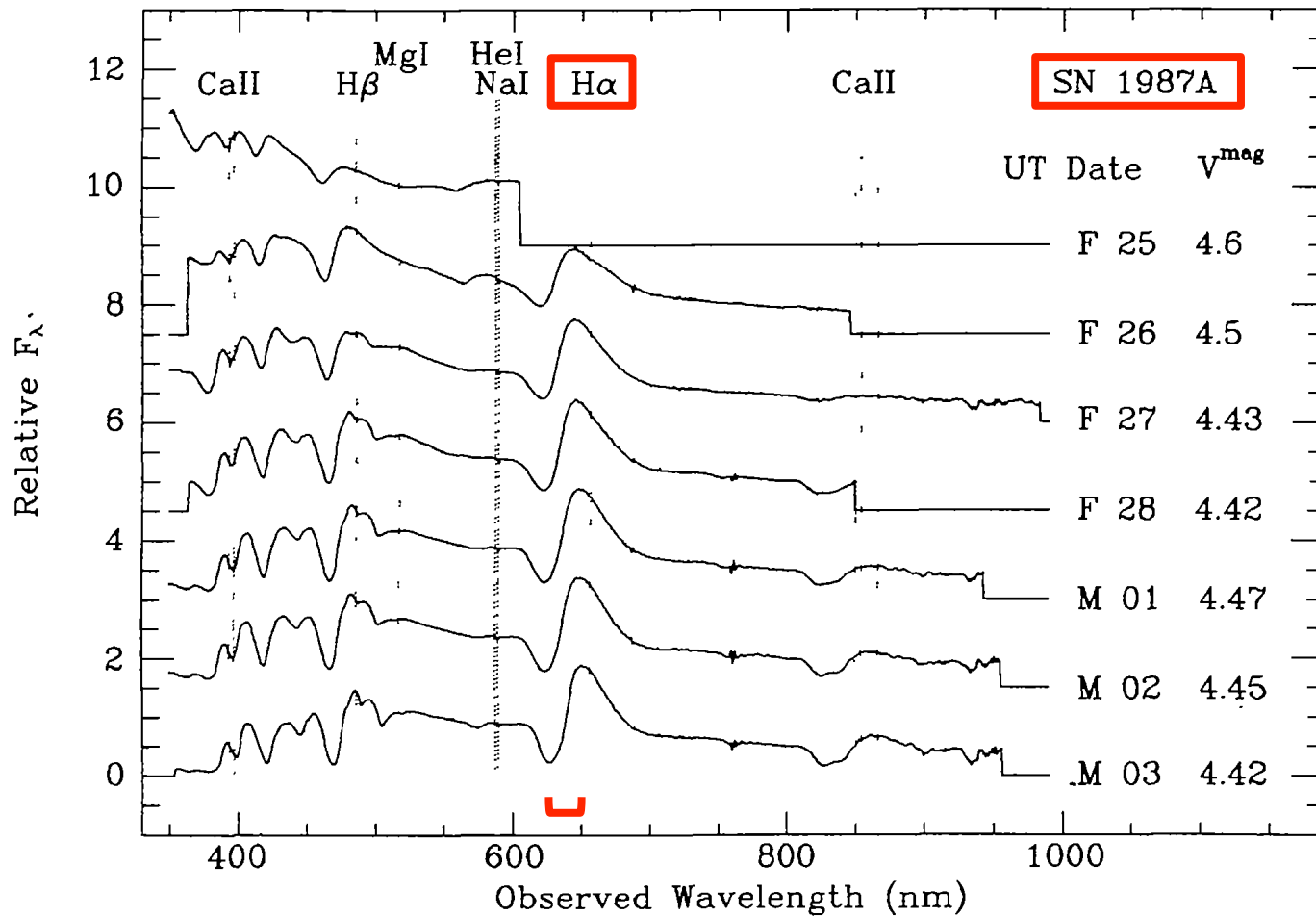
pre-explosion

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The explosion is triggered by core-collapse

SN1987A: ~10^{53} erg ~ $0.1 \times \mathrm{GeV}/m_p \times M_{\mathrm{sun}}$ released as neutrinos

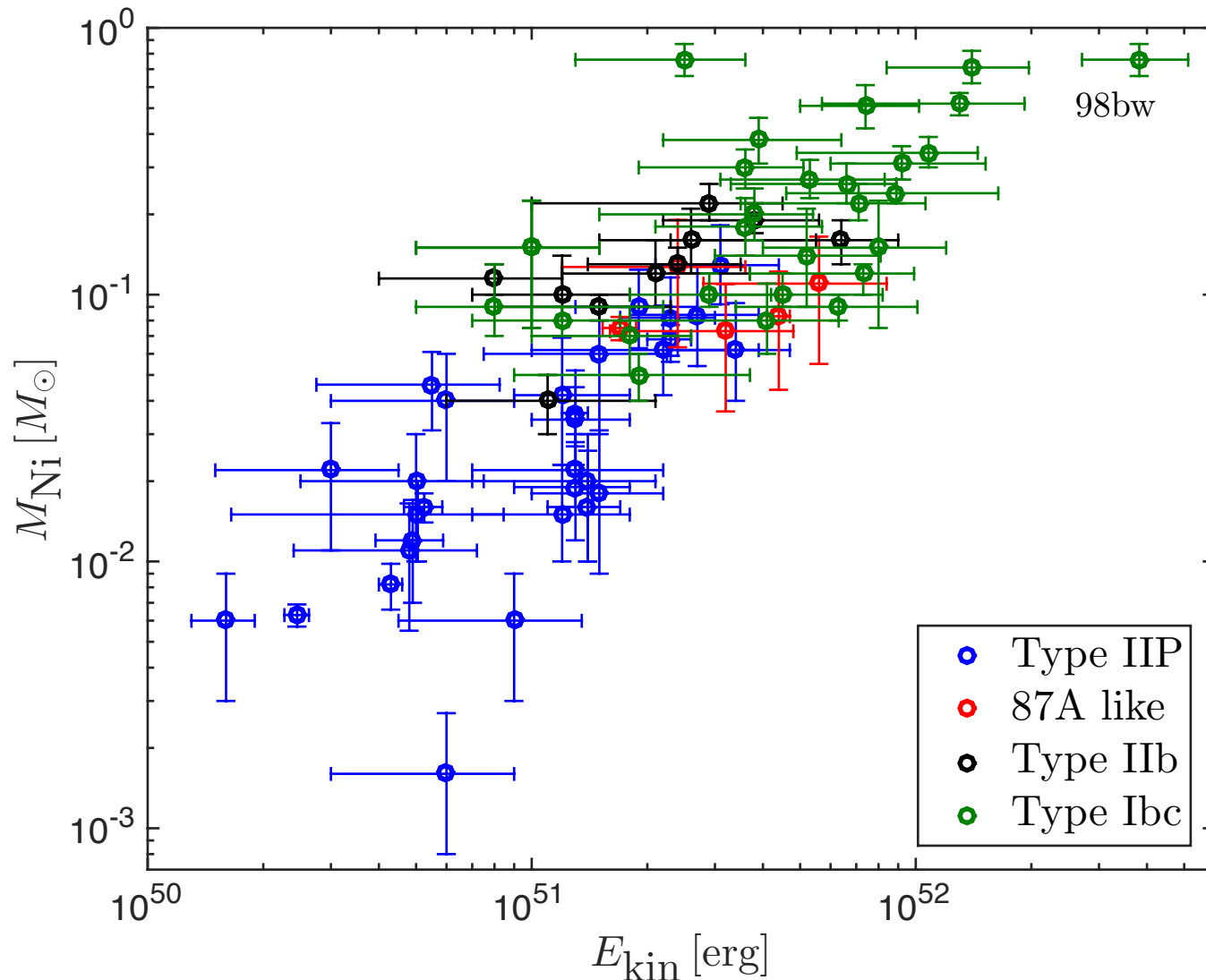# The energy scale of the ejecta is thermonuclear

$$v = \frac{\Delta\lambda}{\lambda} c \sim \frac{25}{650} c \sim 10^4 \, \text{km s}^{-1} \Rightarrow \frac{\text{MeV}}{m_p}$$

Danziger et al. (1987)

Basic parameters

- Kinetic energy of the ejecta : 10^{50} -10^{52} erg

- Ejected ^{56}Ni mass: 10^{-3} -1 $M_{\odot}$
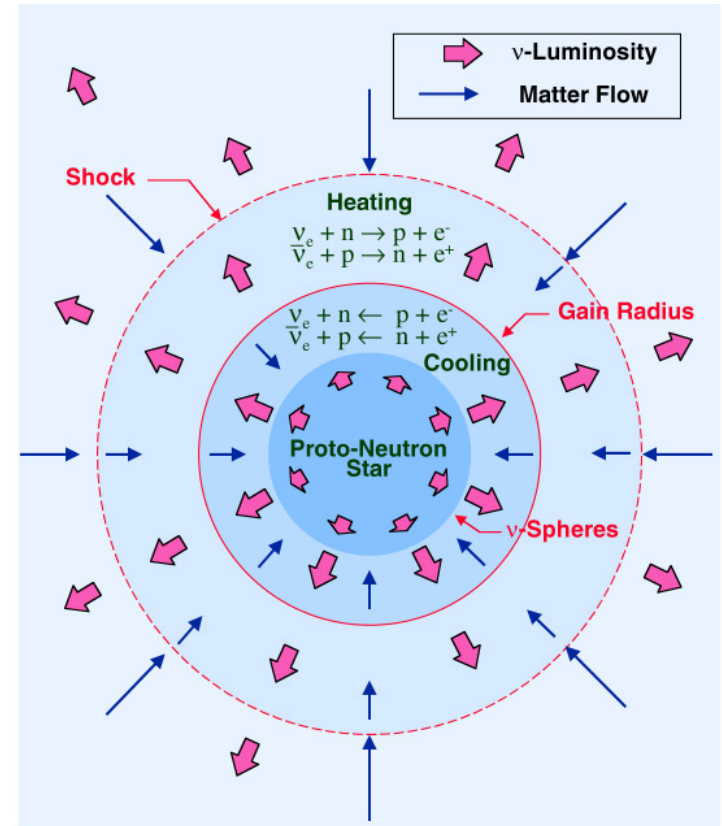
The main challenge -

Why collapse leads to an explosion?

Popular model - neutrinos

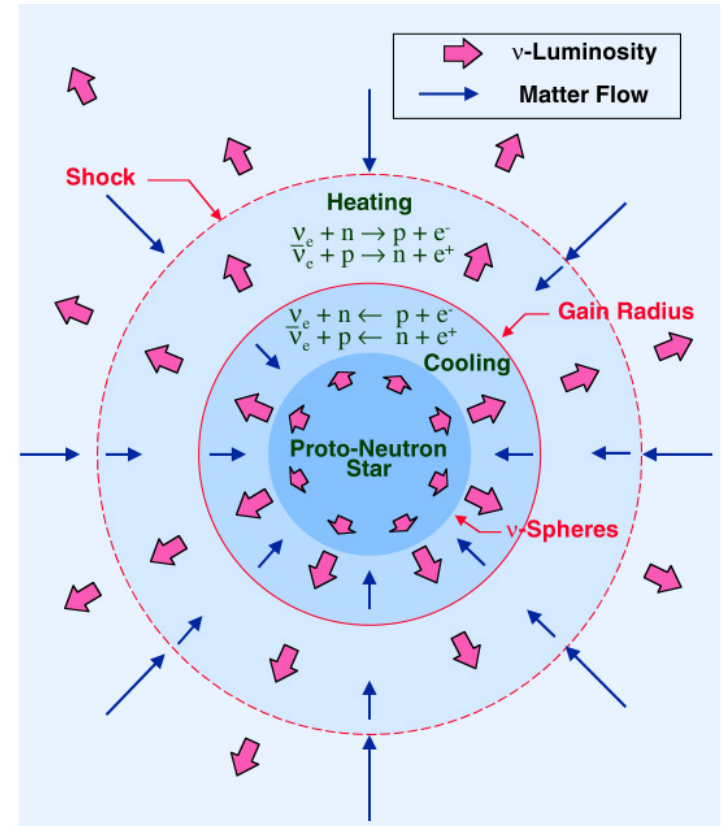- if 1% of their energy is deposited in ejecta $\Rightarrow 10^{51}$ erg

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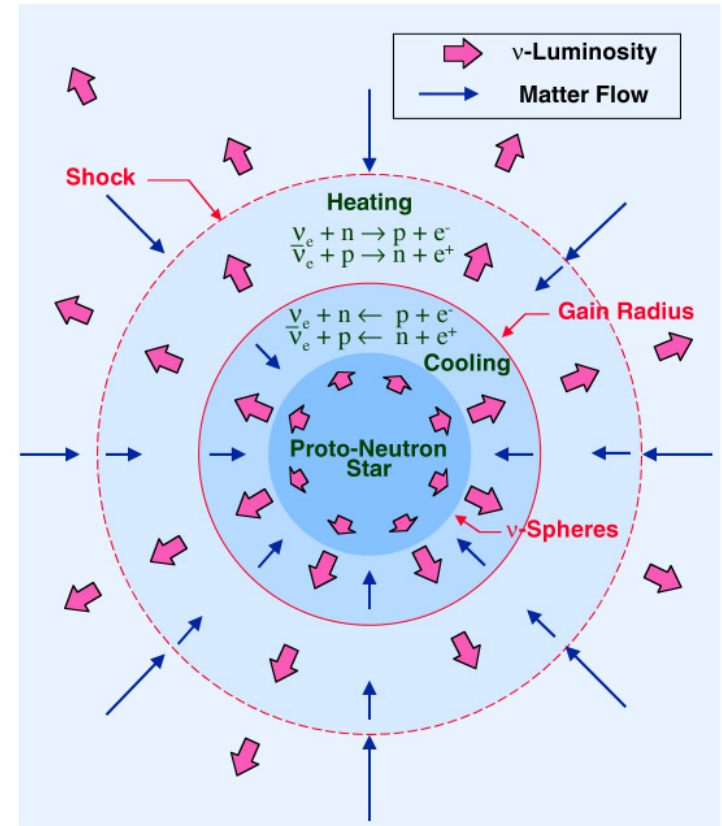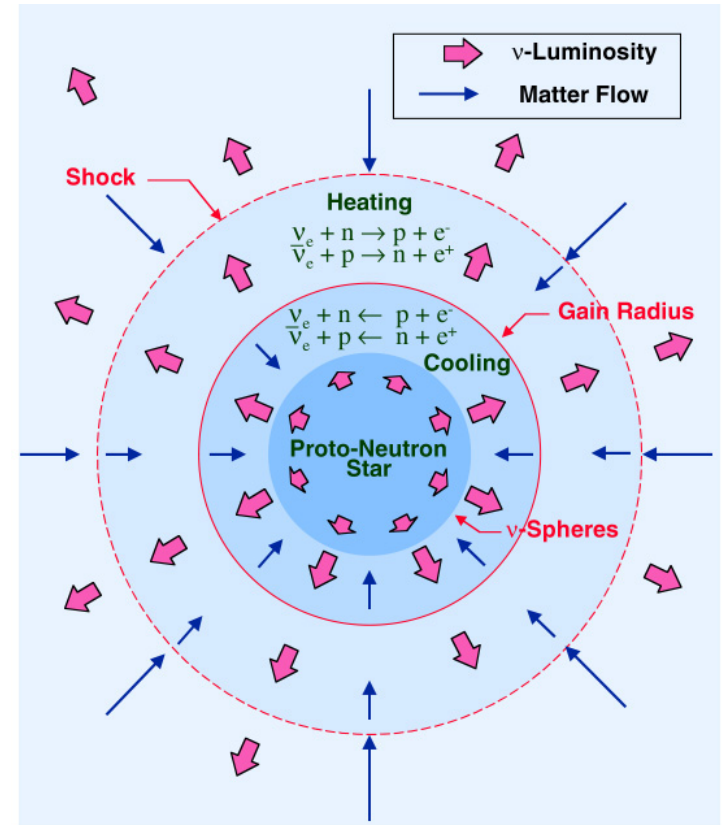
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- So far, in 3D simulations the neutrinos either failed to explode the star or produce weak ($<10^{50}$ erg) explosions.

Thermonuclear explosion of B^{2}FH

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▪ But in fact…

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  - ➢ initial burning time ≈ 10^3 s
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- Simple physics: Hydrodynamics + gravity + nuclear burning

- FLASH 4.0, $\Delta x \approx 30$ km

- Kinetic energy of the ejecta $\sim 1.3 \cdot 10^{51}$ erg

- Ejected ^{56}Ni mass: $\sim 0.08\ M_\odot$
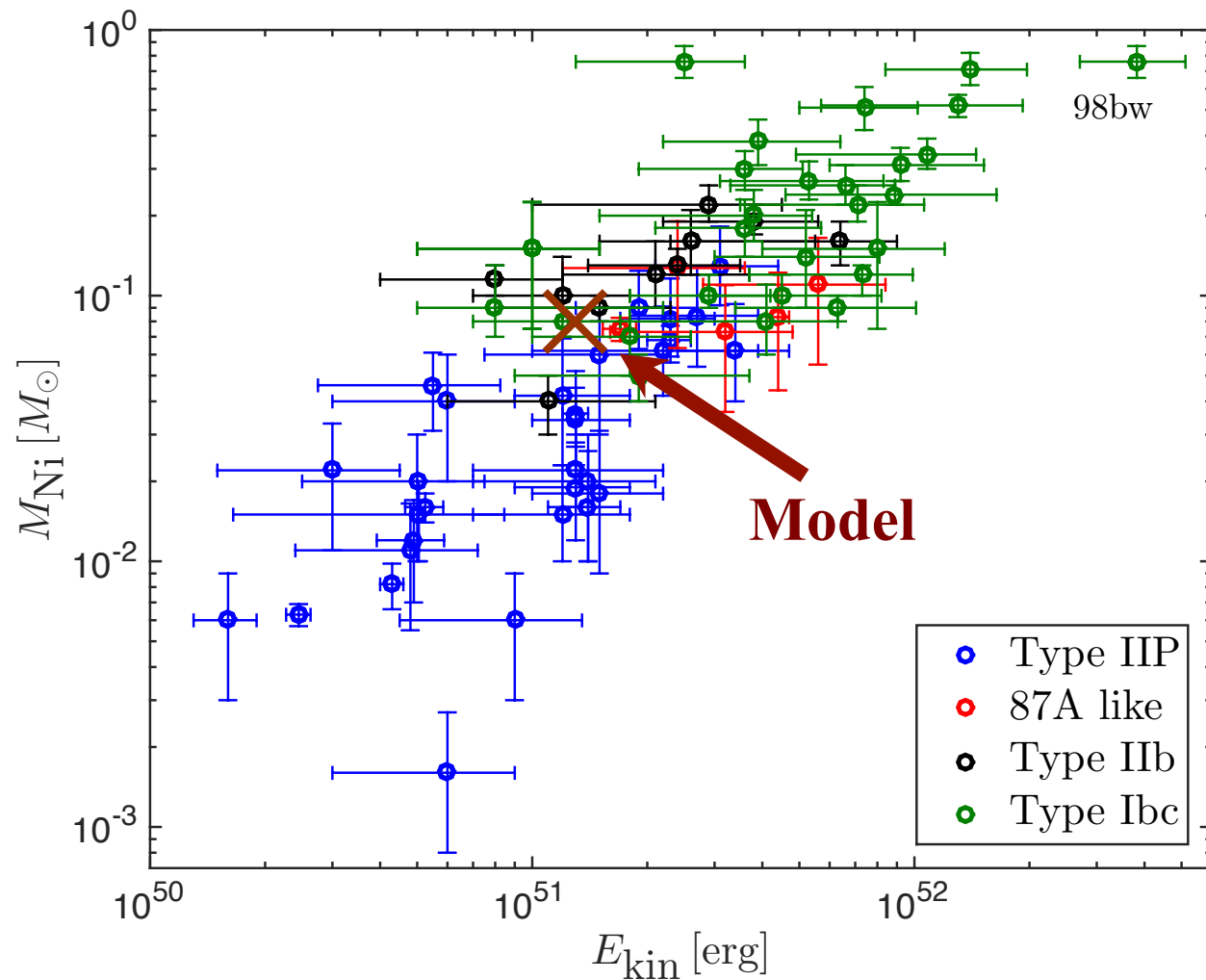
Possible!

What sets the kinetic energy?

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Thermonuclear

$$E_{dep} \approx \text{MeV}/m_p \times M_{shell}$$

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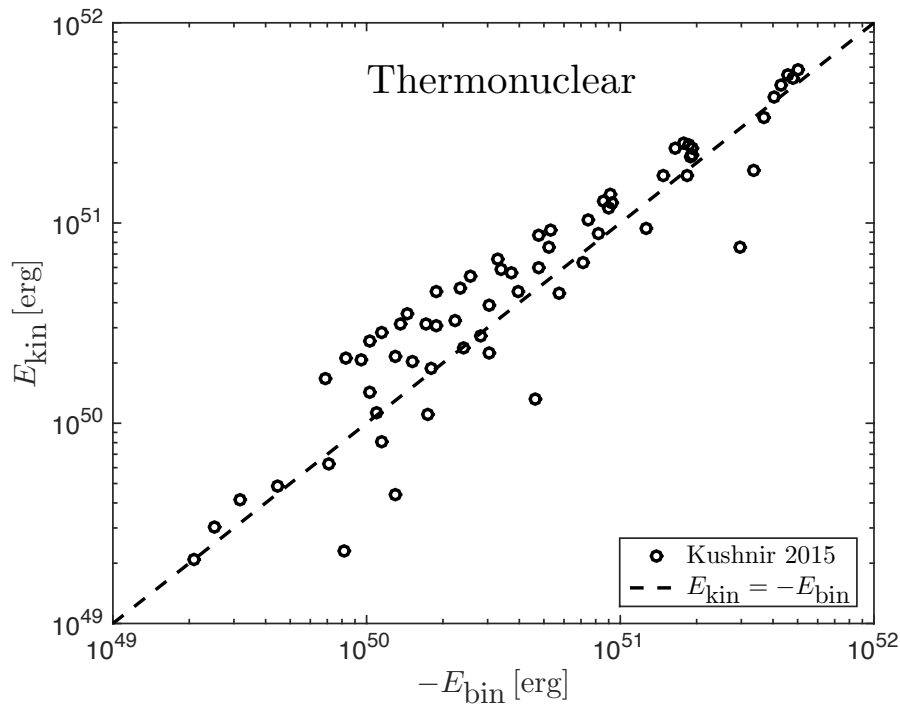
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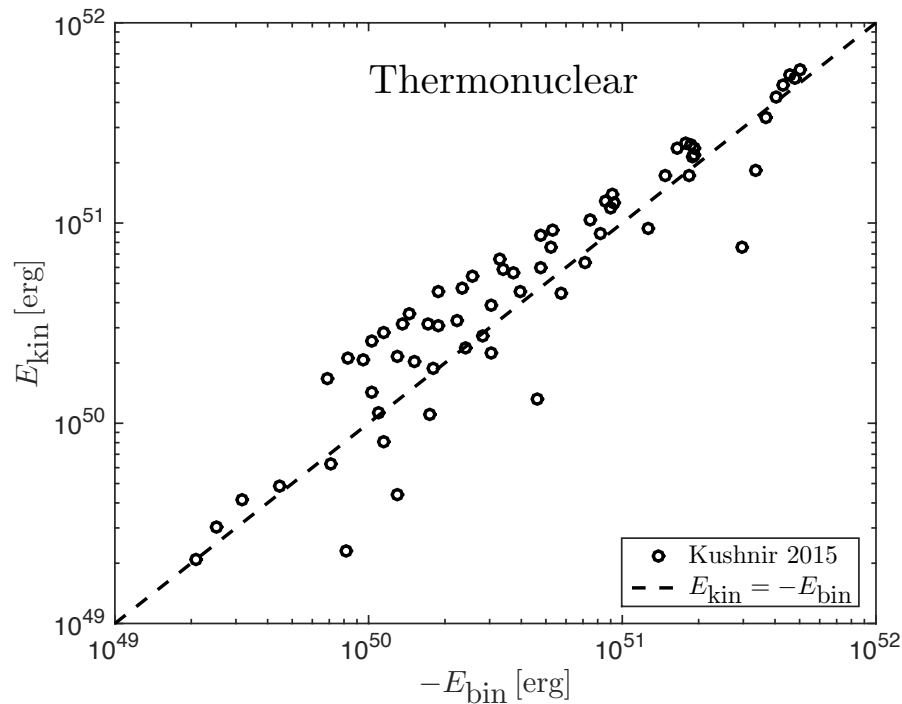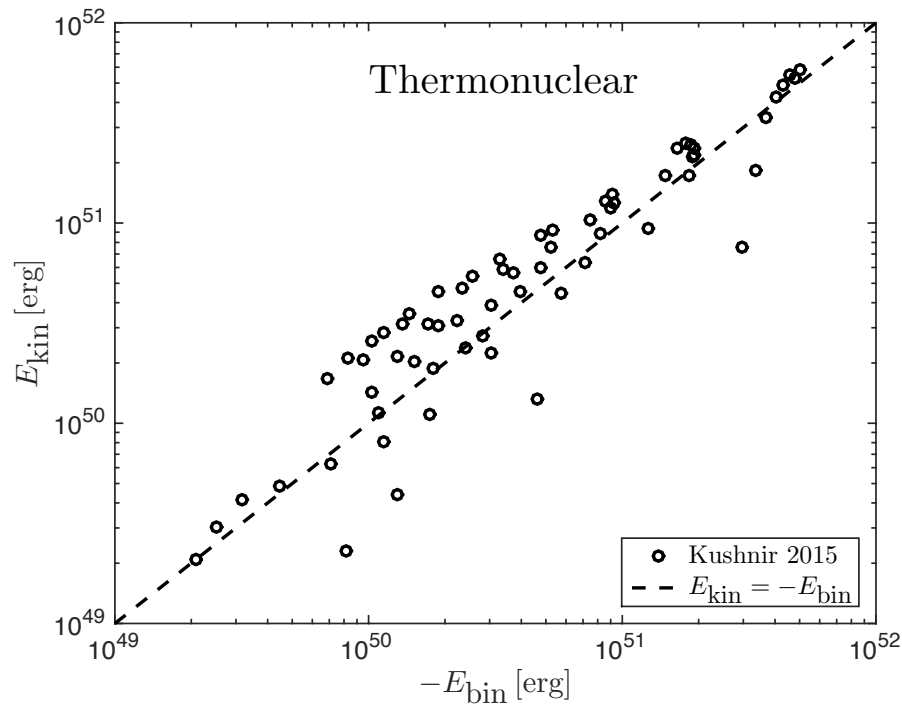$$E_{bin} \approx -GM/r \times M_{shell} \approx \text{MeV}/m_p \times M_{shell}$$

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ν-mechanism

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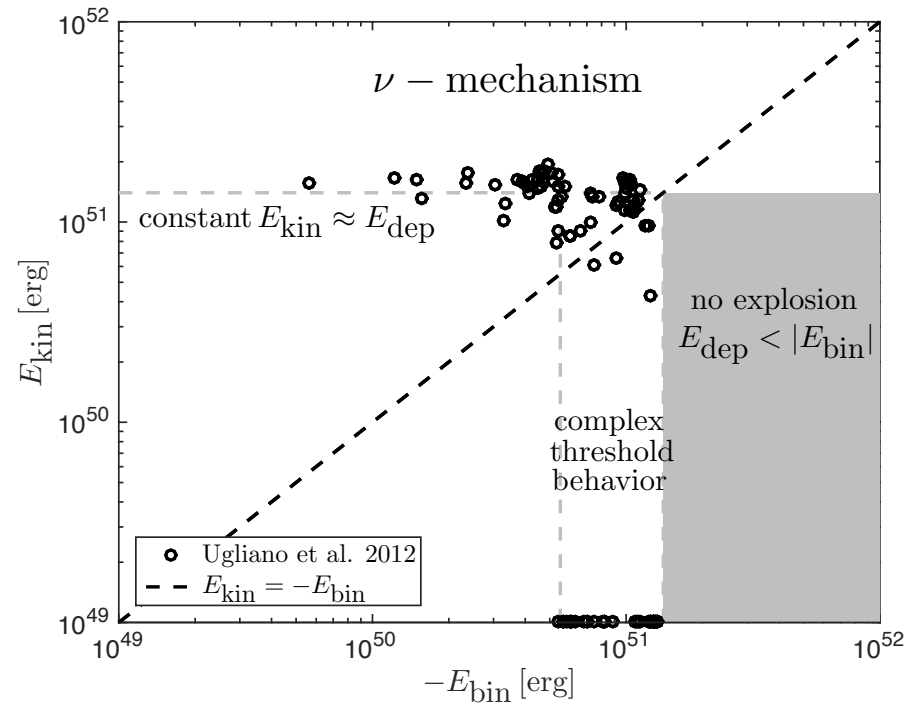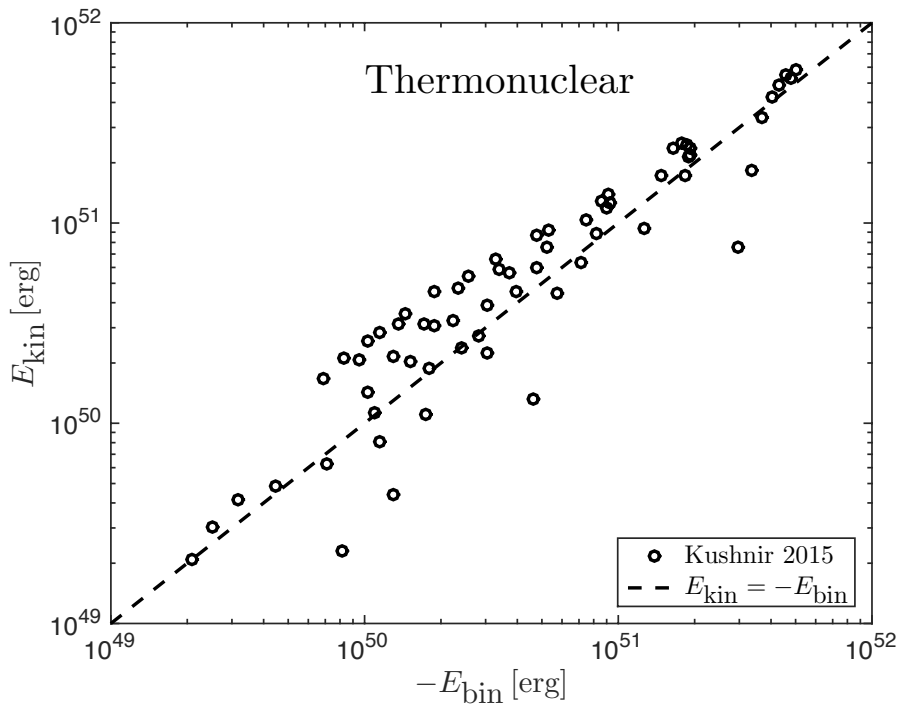
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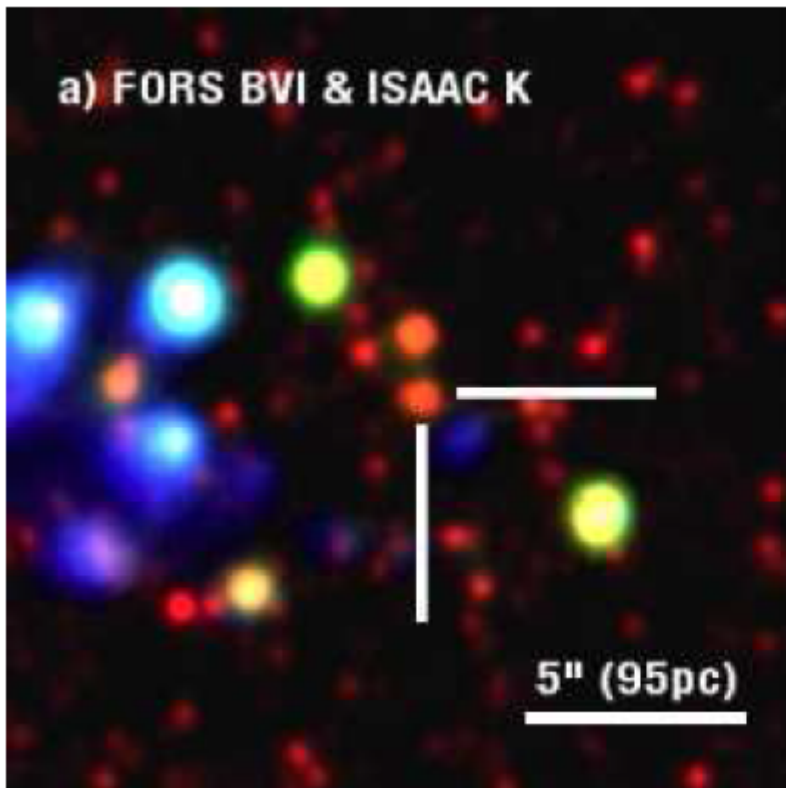
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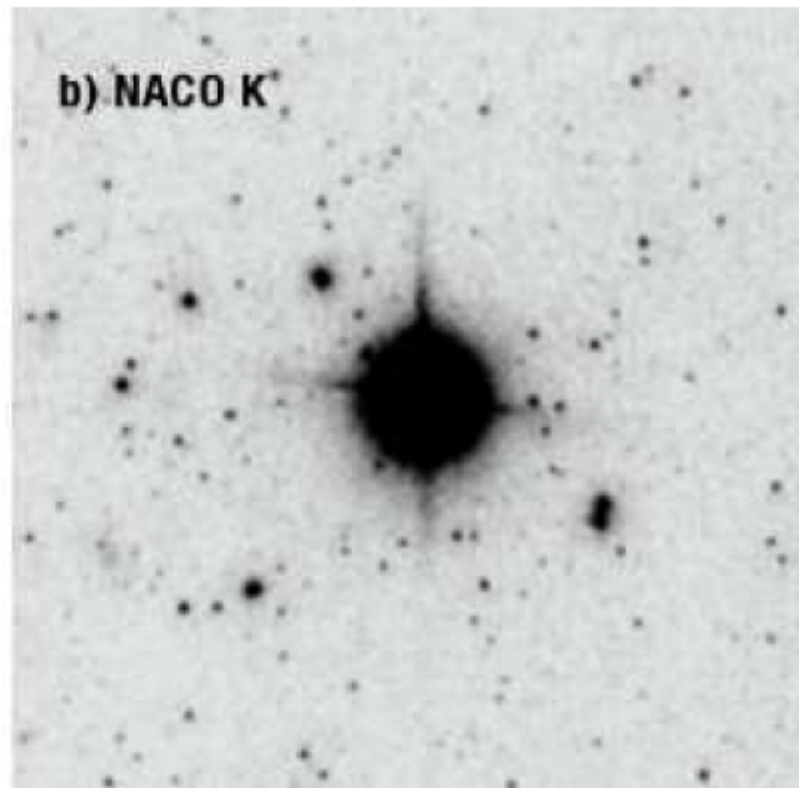E_{bin}: decreases significantly with increasing mass

For some CCSNe the massive star progenitors were observed

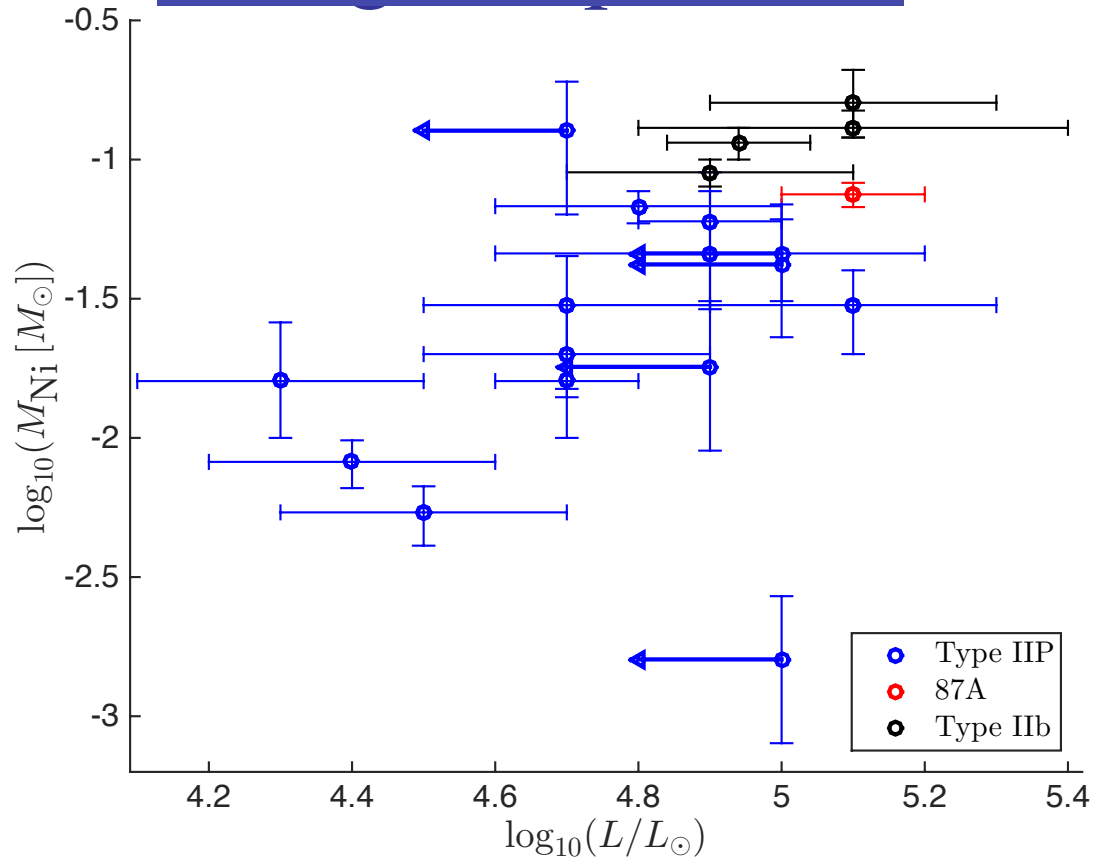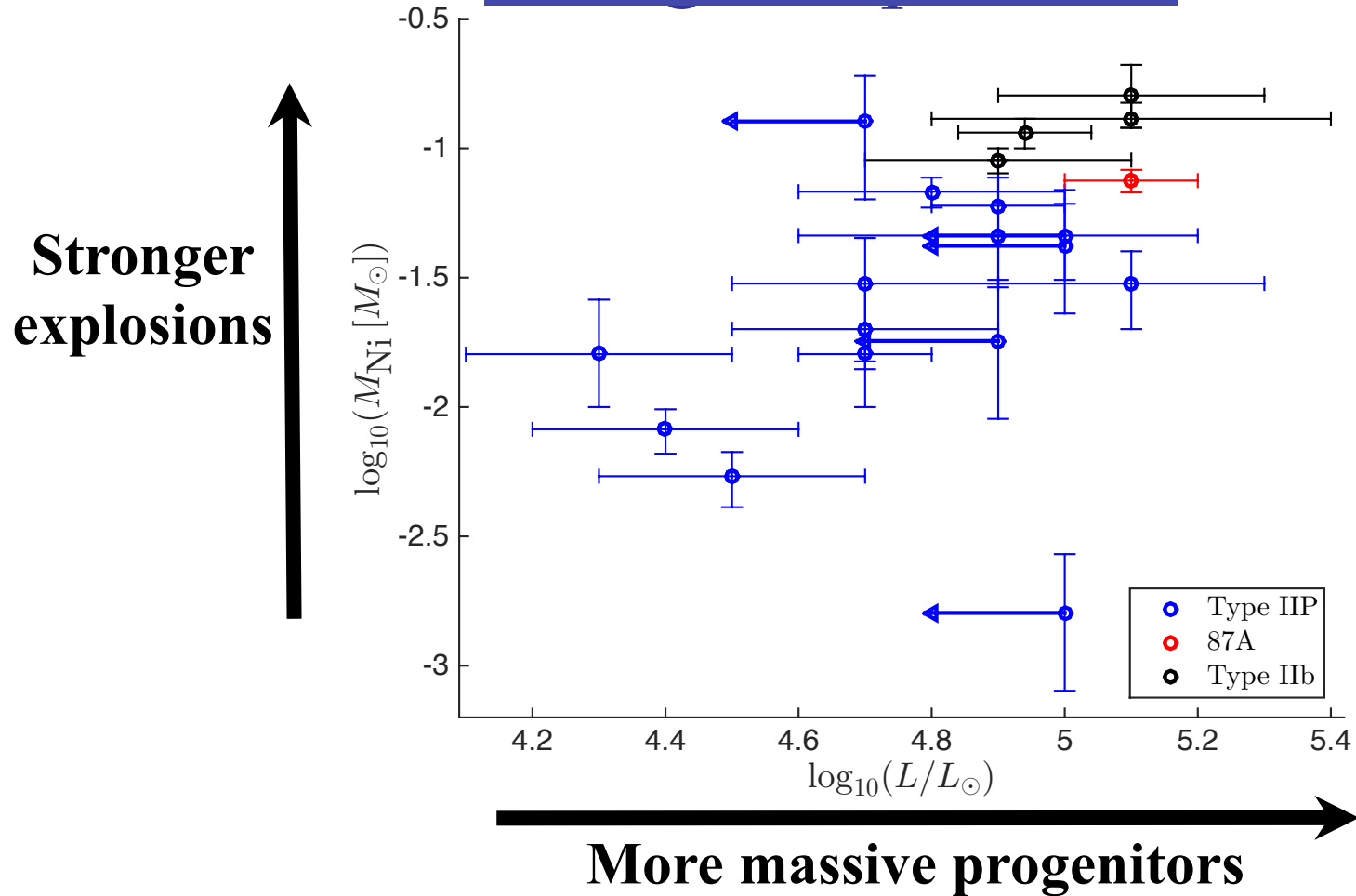**SN2008bk - Red Super Giant, $\log_{10}(L/L_\odot)=4.8\pm0.2$**
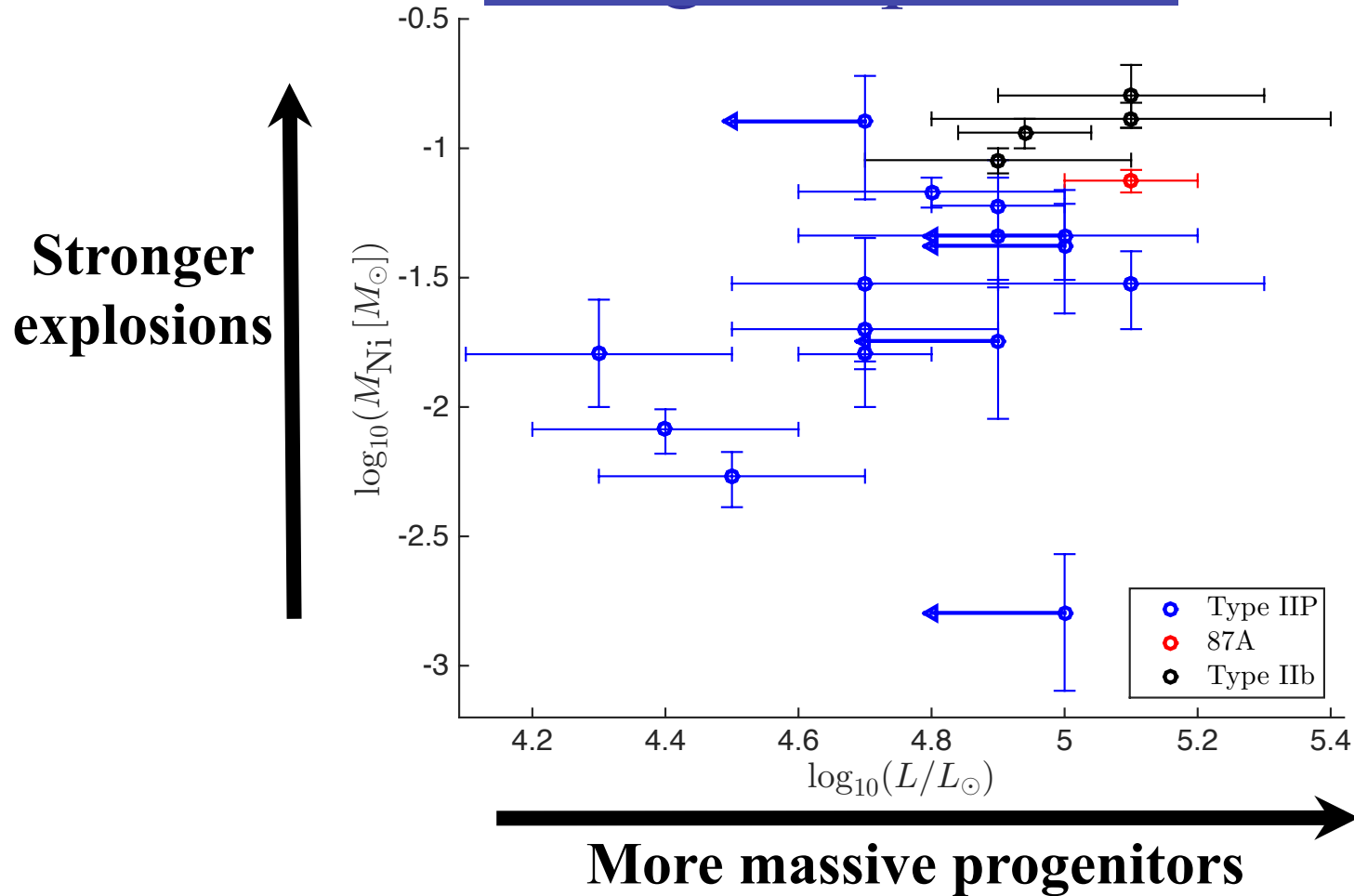
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b) NACO K

Mattila et al. (2008)

More massive progenitors lead to stronger explosions

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Stronger explosions (↑)

More massive progenitors (→)

y-axis: $\log_{10}(M_{\mathrm{Ni}}\,[M_\odot])$

x-axis: $\log_{10}(L/L_\odot)$

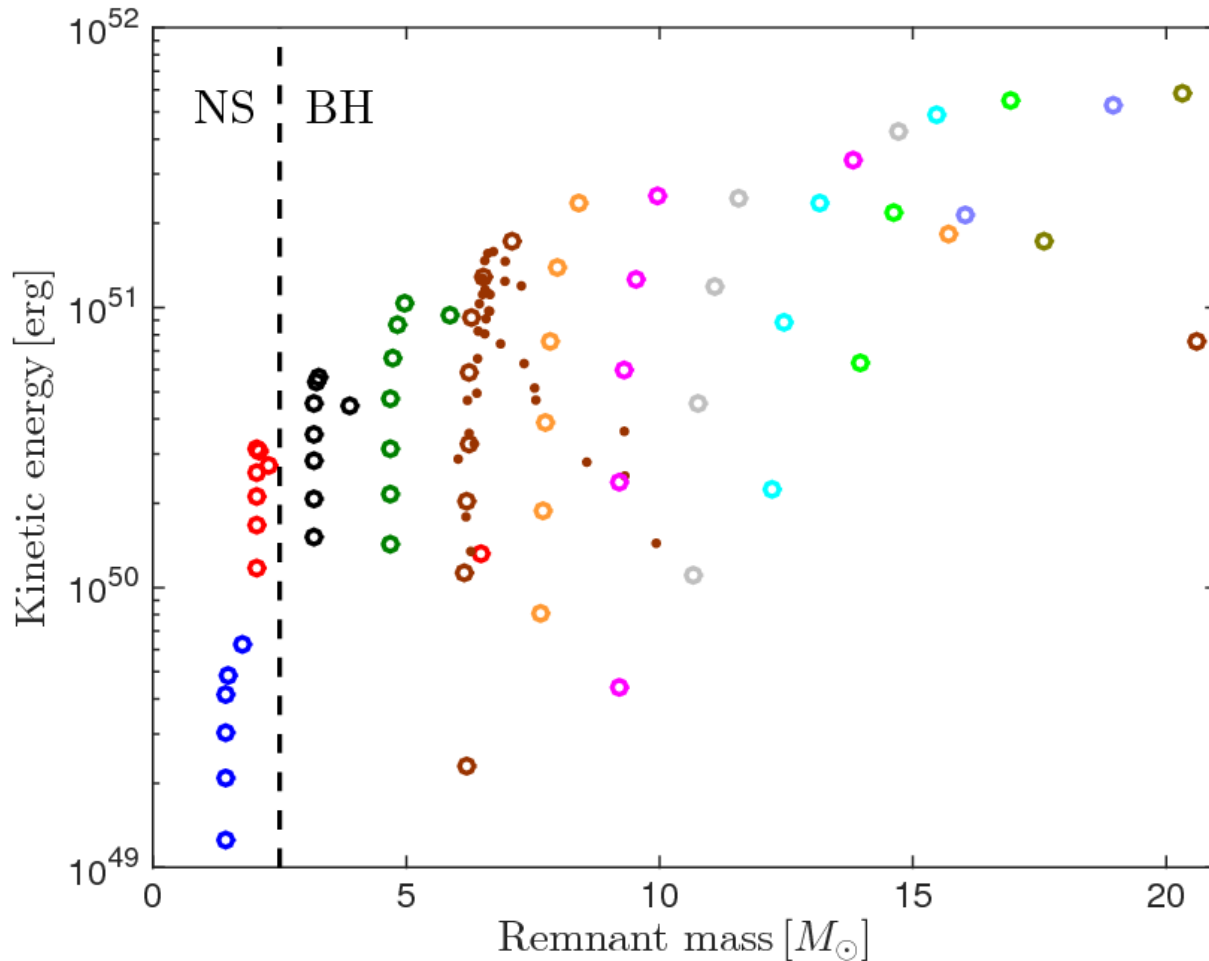Legend:
- Type IIP
- 87A
- Type IIb

More massive progenitors lead to stronger explosions

- In agreement with thermonuclear explosions
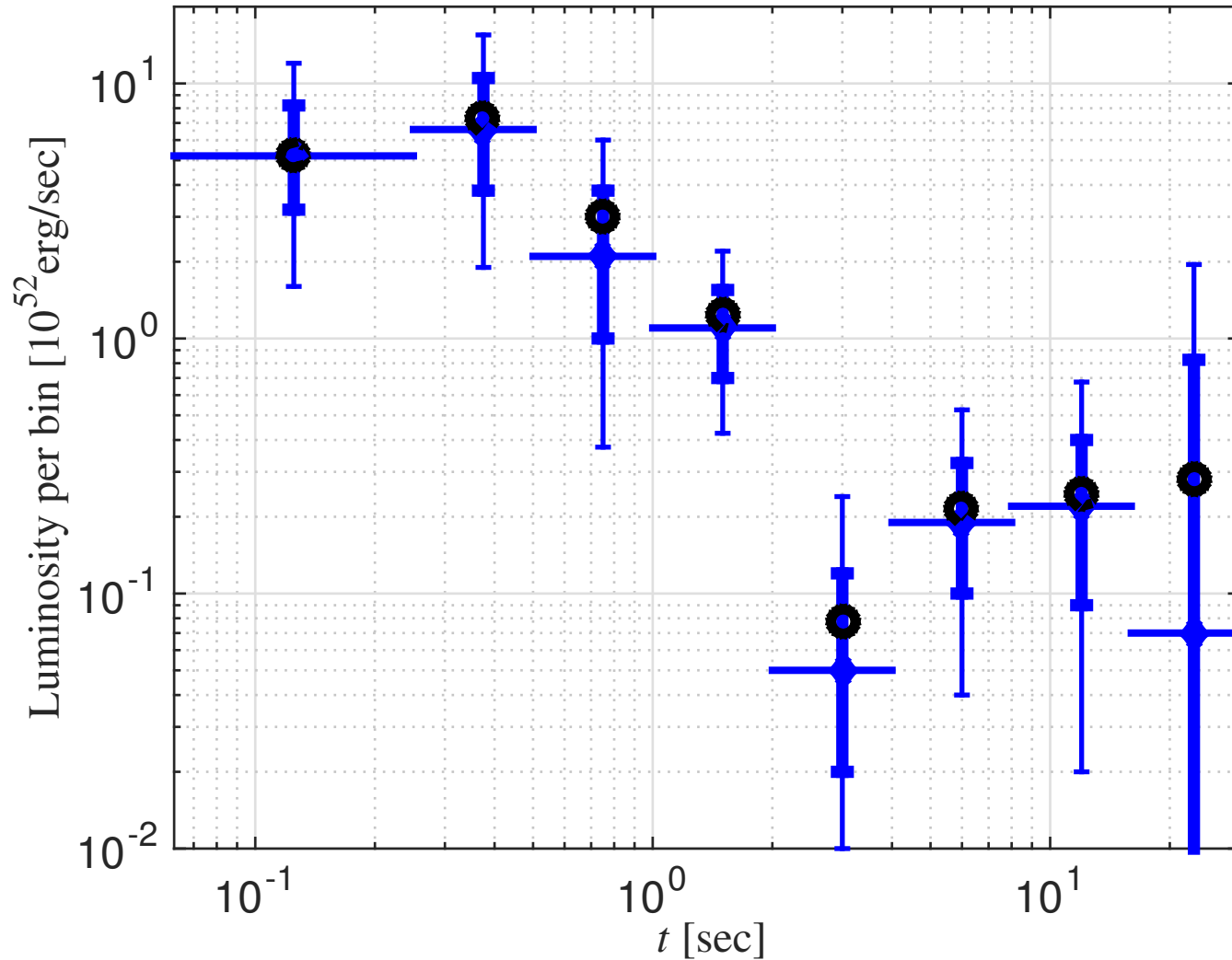- In a possible disagreement with the ν-mechanism

The remnant mass

- NSs only for weak ($<10^{51}$ erg) explosions. Strong ($>10^{51}$ erg) explosions leave BH remnants.
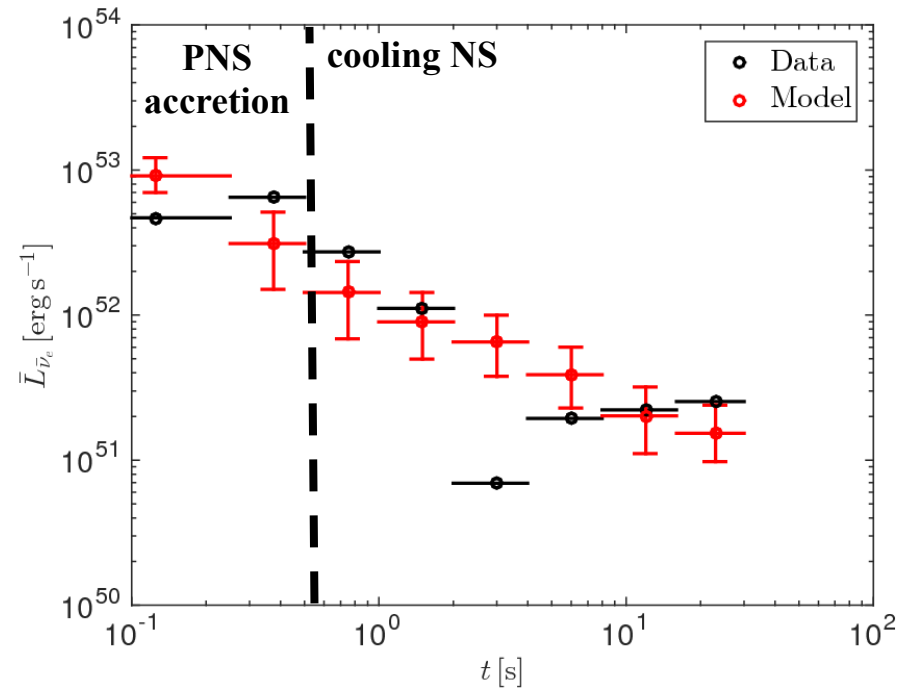
- Predicts a BH for SN1987A.

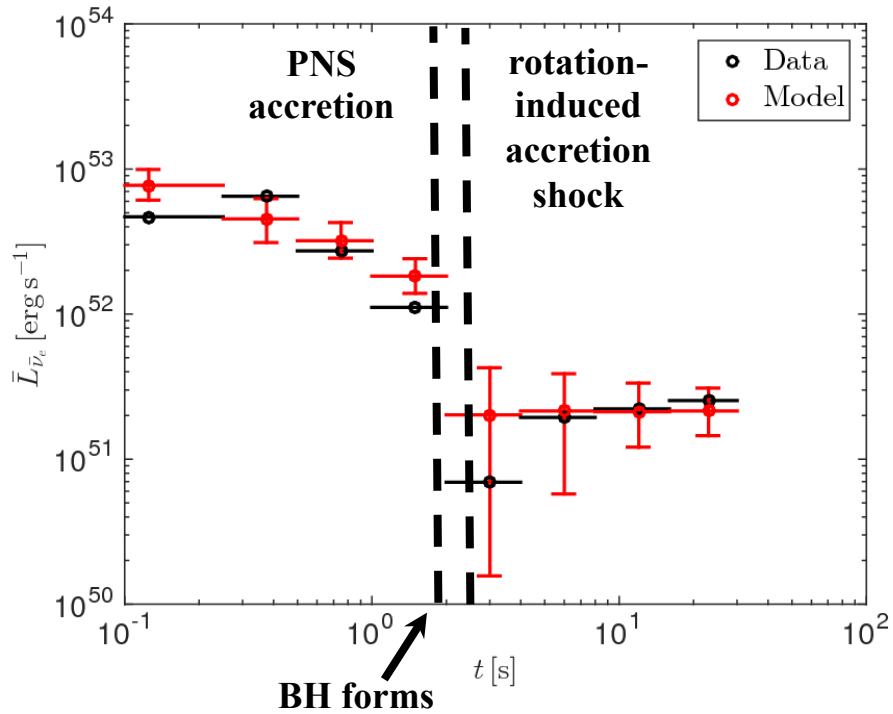# The ν signal from SN 1987A

- A luminosity drop at ~2 sec?

Blum & DK (2016)

The ν signal from SN 1987A

ν-mechanism

Blum & DK (2016)

The ν signal from SN 1987A

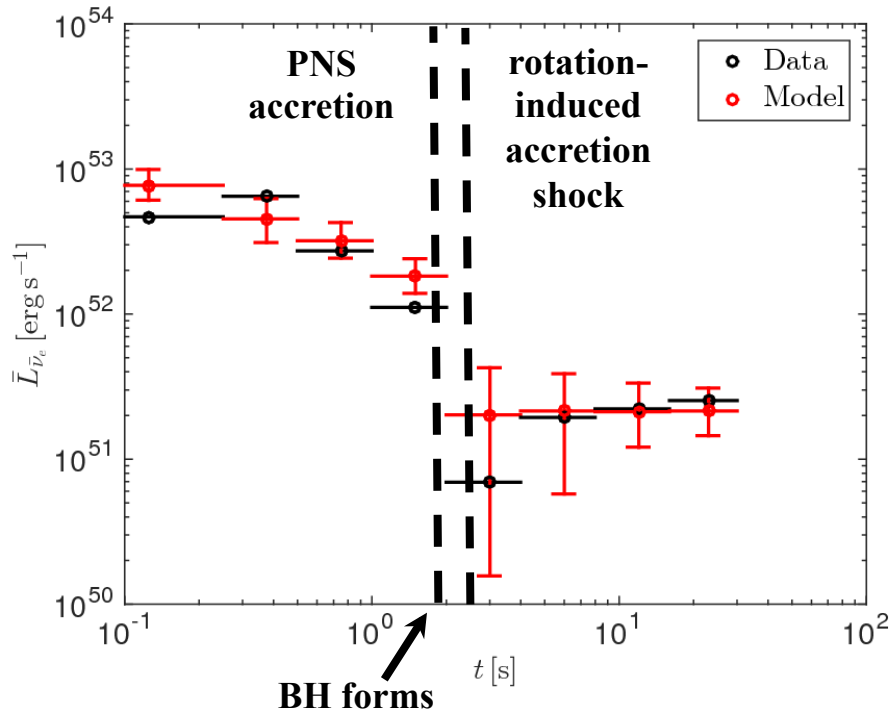**Thermonuclear**   **ν-mechanism**
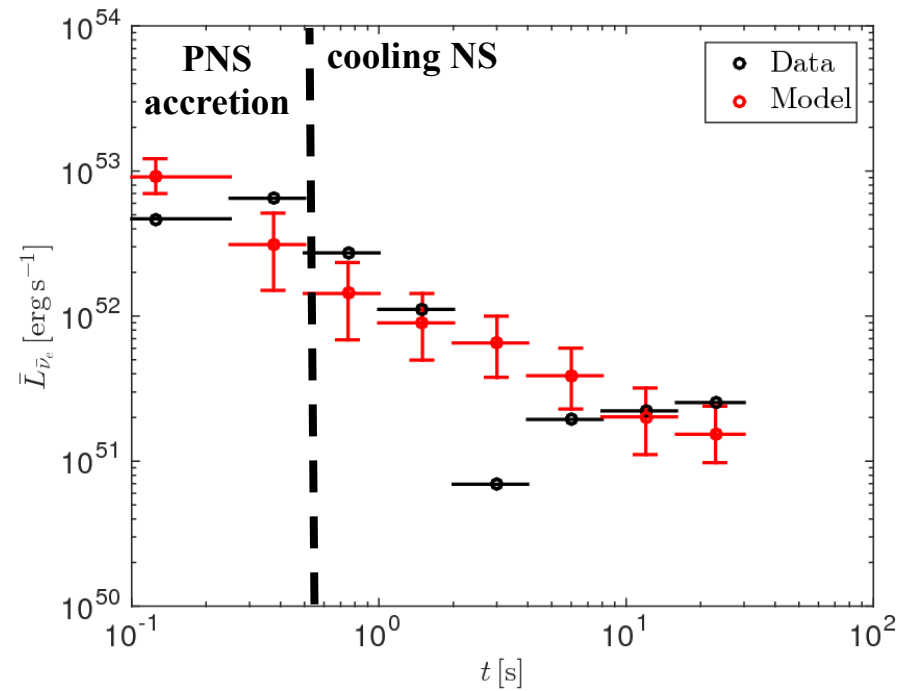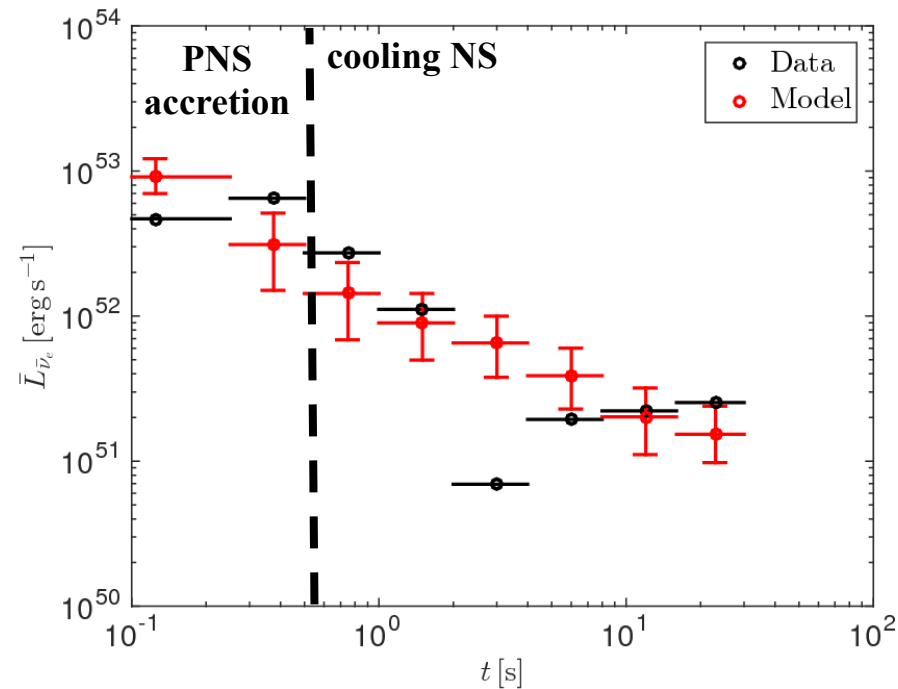

Blum & DK (2016)

The ν signal from SN 1987A

Thermonuclear

ν-mechanism

- PNS accretion for ~2 s until BH formation + rotation induced accretion shock at ~2.5 s favored by the data.

- A possible smoking gun for a thermonuclear explosion.

Blum & DK (2016)

ν - detection implications

- Fraction of CCSNe with prompt BH may be as high as ~50%

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- Unexpected discoveries (accretion induced collapse, etc.)