Circumstellar Medium of Supernovae as New Probes for BSM

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arXiv:2603.09615

@ 2026 CAU-IBS BSM workshop

Outline

01 Introduction

- Brief overview of core-collapse supernovae (CCSNe)
- Implications of BSM w/o **circumstellar medium (CSM)**

02 BSM w/ CSM

- Visible decay in CSM ➡ Heating prior to shock breakout
- Inner CSM: increasing opacity & T ☞ L_{BB} ⇧
- Outer CSM: dust resublimation

03 Application to Dark Photons

- In-medium production in PNS
- $\gamma' \to e^- e^+$ in CSM

04 Results

- None-detection of excessive precursor BB luminosity of SN 2023ixf
- [Future galatic SNe] spectral transition (IR → Optical/UV) before SBO

CCSNe & BSM w/o CSM

- Gravitational collapse of iron core & proto-neutron star formation

✓ Diffusive νenergy transport & ν-driven SN explosion

➡ **Cooling argument of novel particles in PNS & gain region**

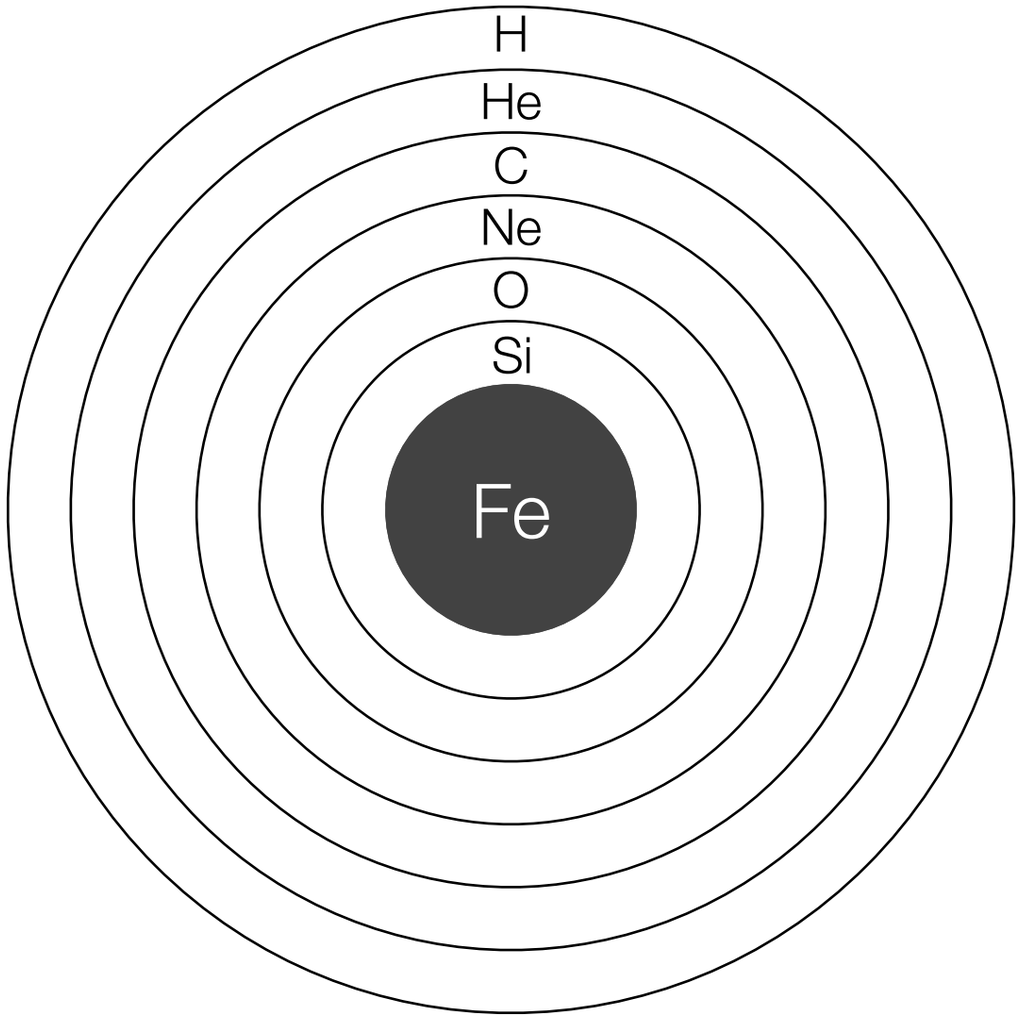
✓ Energy transport to outer regions, leading to visible signals

- **mantle: supernova explosion energy**
- **outside the progenitor: fireball formation, galactic 511keV, prompt γ-ray**

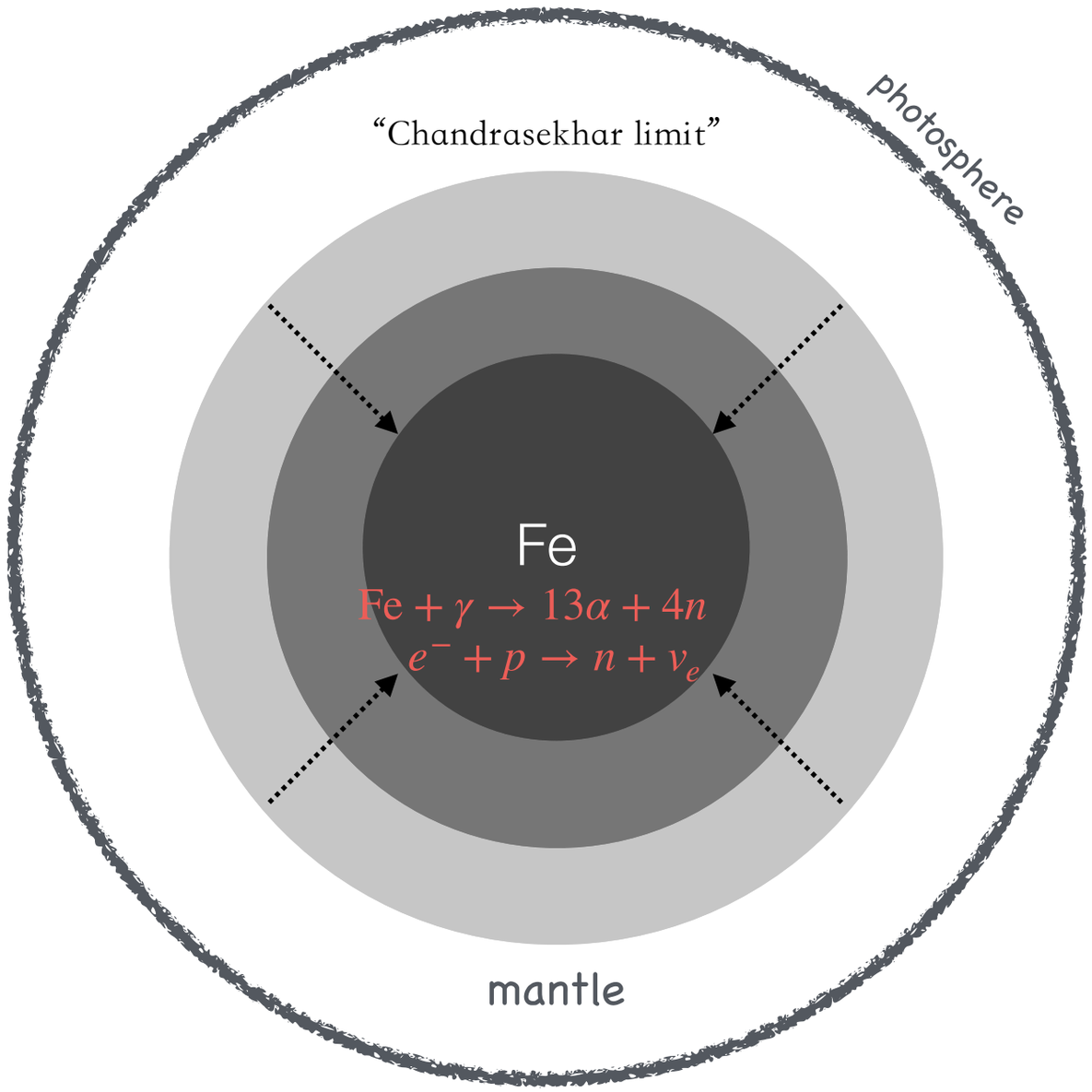
★ **conventionally, in assumption of vacuum outside progenitor**

Core-Collapse Supernova

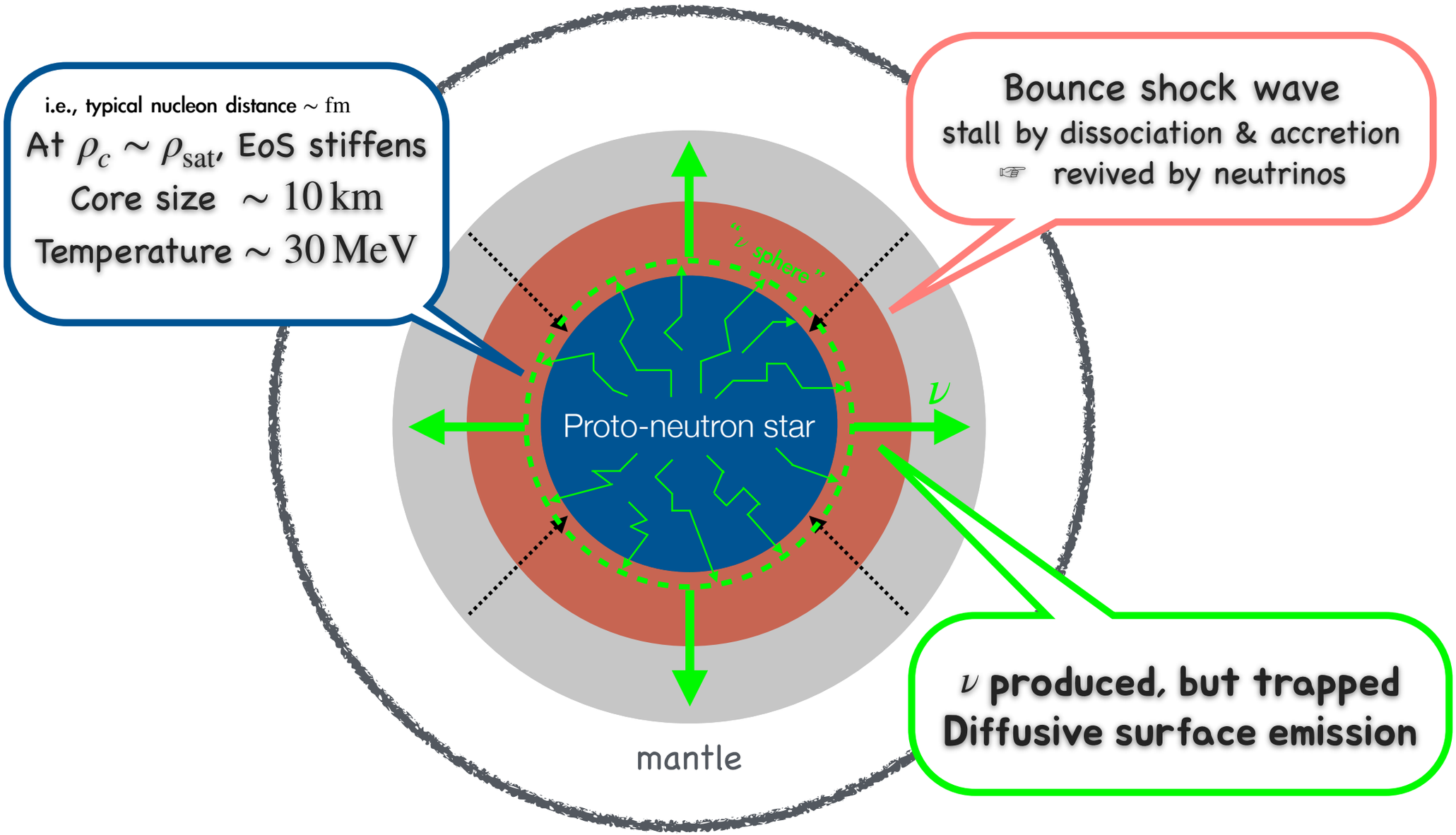
progenitor like super red-giants



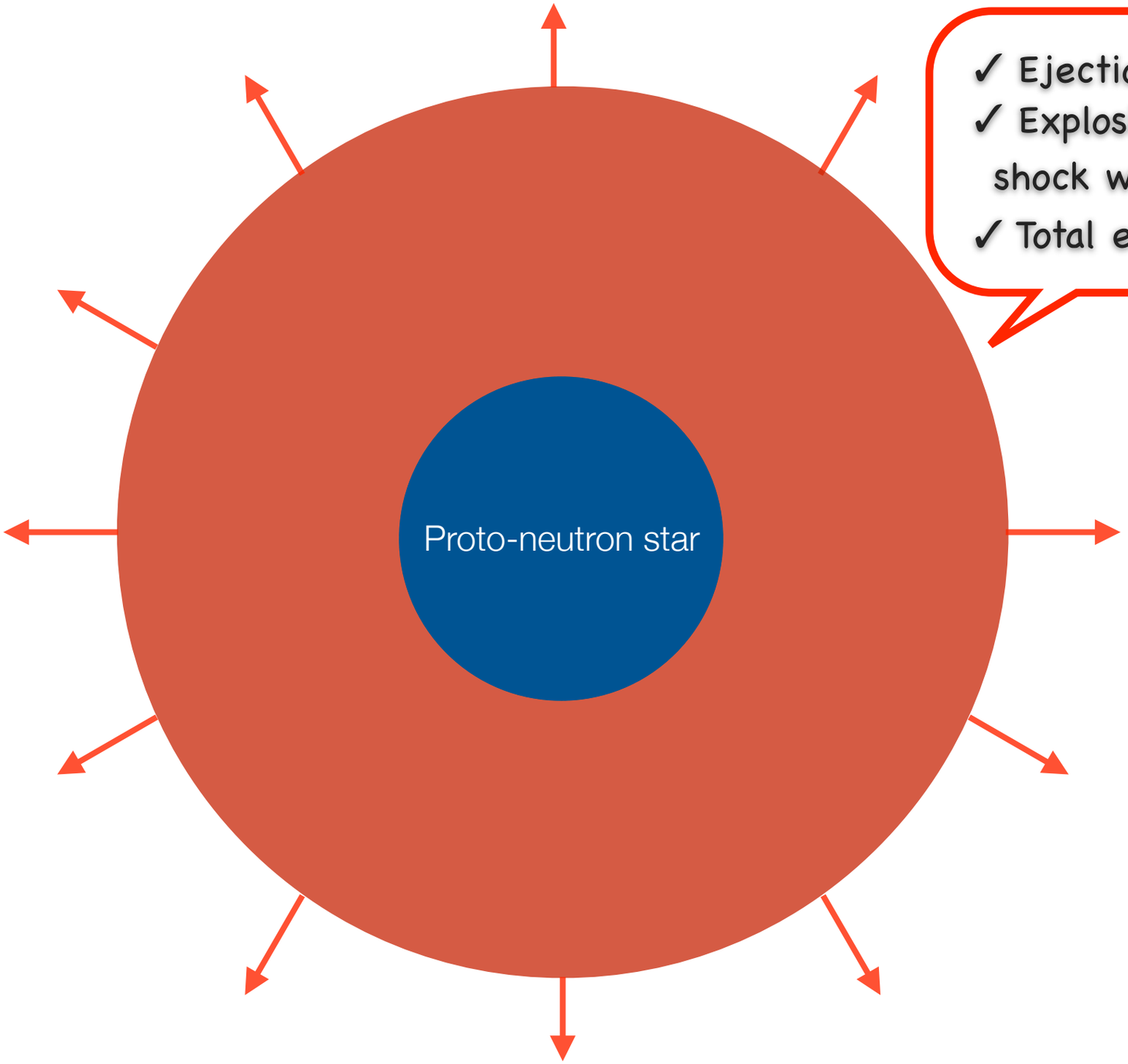
Core-Collapse Supernova



Core-Collapse Supernova



Core-Collapse Supernova



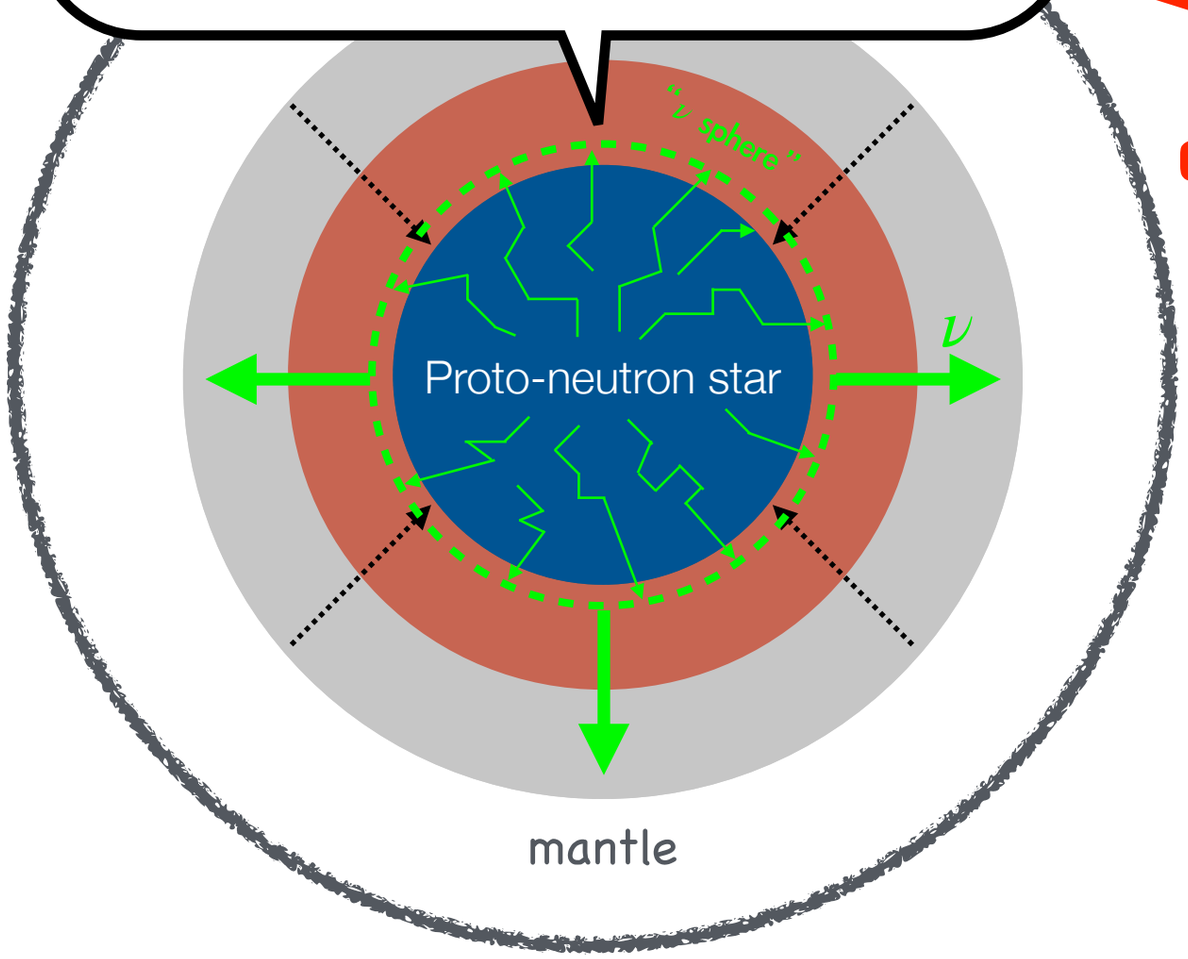
✓ Ejection of outer layer
✓ Explosion energy by
shock wave + ν transport
✓ Total energy $\sim 10^{51}$ erg

Neutrino-Cooling of Proto-Neutron Star

ν emission @ ν-sphere

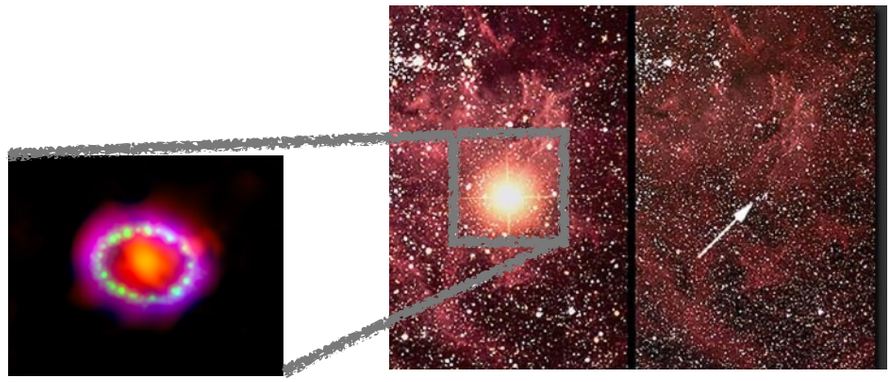
$$E_{\rm tot} \sim \frac{GM}{R_c} \sim 10^{53}\,{\rm erg} \;\&\; \mathbf{t_{diff}} \sim \frac{\mathbf{R_c^2}}{\lambda} \sim \mathbf{10}\,{\rm sec}$$

$$\Rightarrow L_\nu \sim 10^{52}\,{\rm erg\,s^{-1}}$$

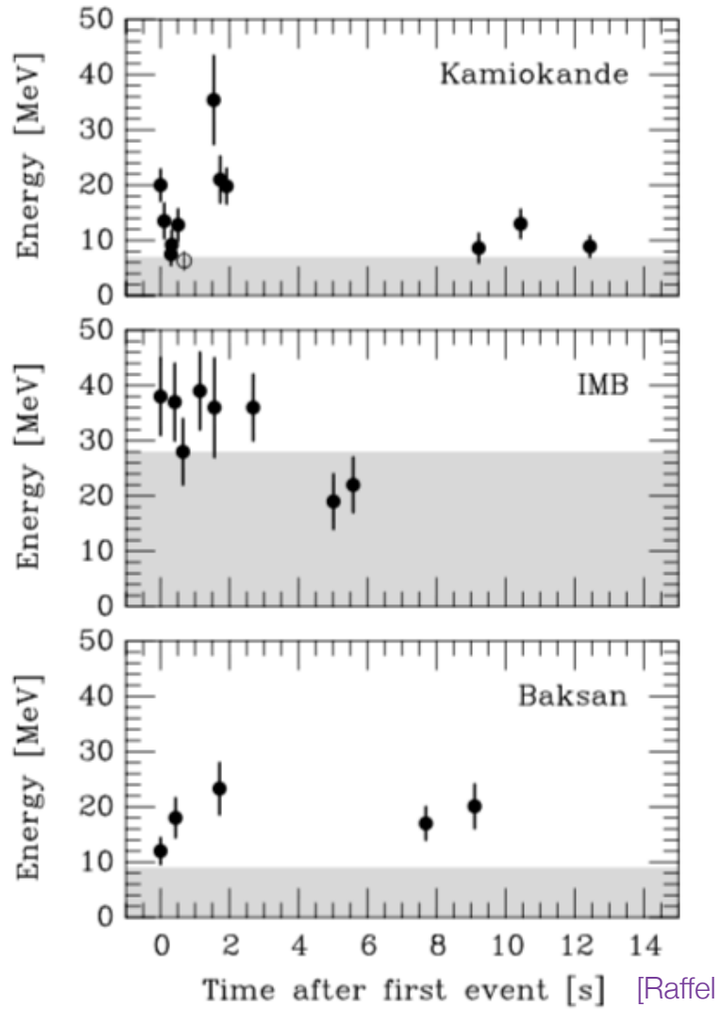


consistent!

[Chandra]

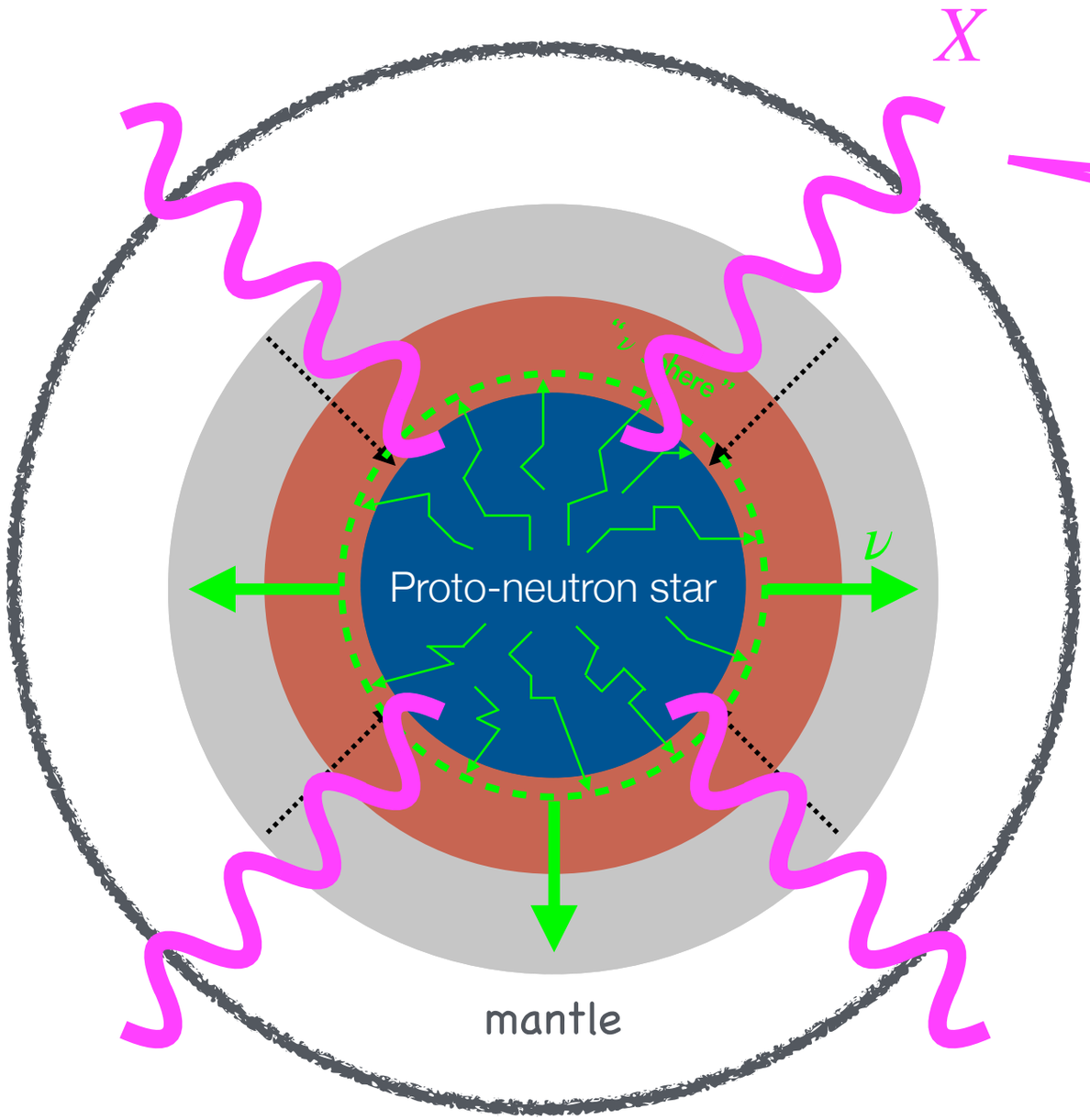


◉ neutrino flux of SN1987A



[Raffelt, 95]

Cooling Argument on SNe



- X emission as extra cooling
- free stream $\Rightarrow$ volume emit
- **Not to reduce ν-signal duration**

$$L_X \ll L_\nu \sim 10^{52}\,\mathrm{erg\,s^{-1}}$$

"Raffelt crietrion"

✓ L_X VS L_ν @ 1sec

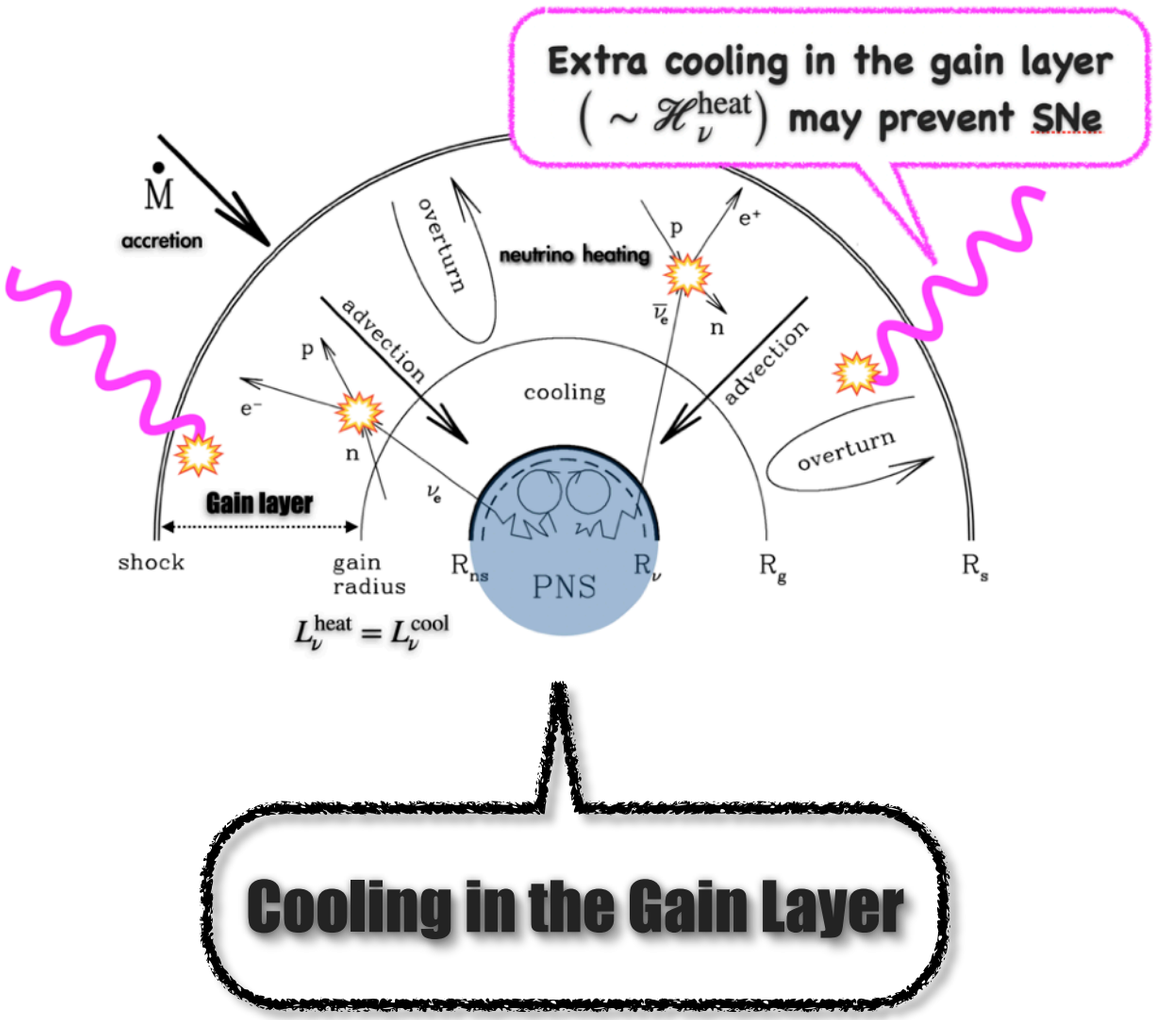
✓ No impact on earlier stage?

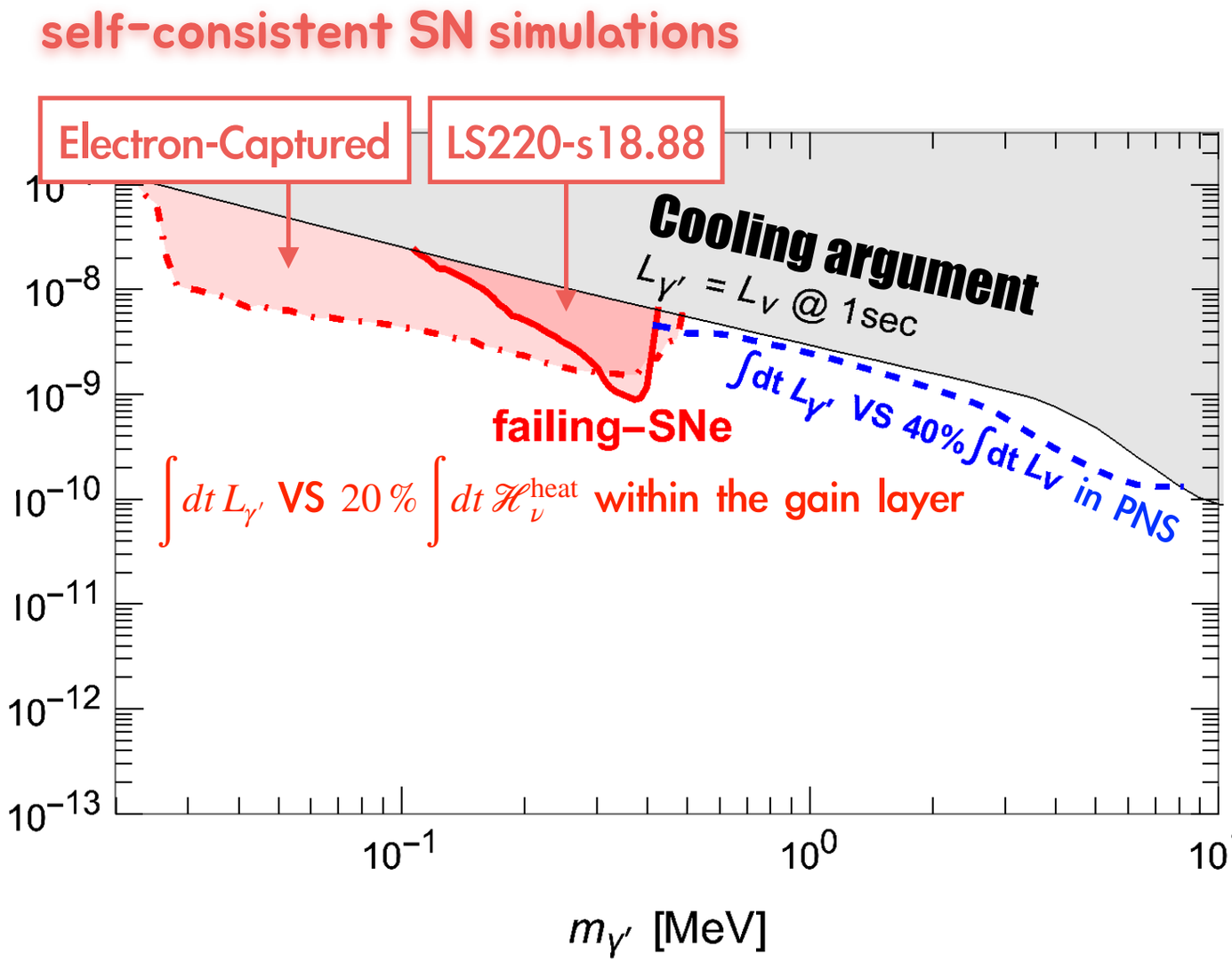
✓ Other Self-consistency?

- in particular, **explosion**?

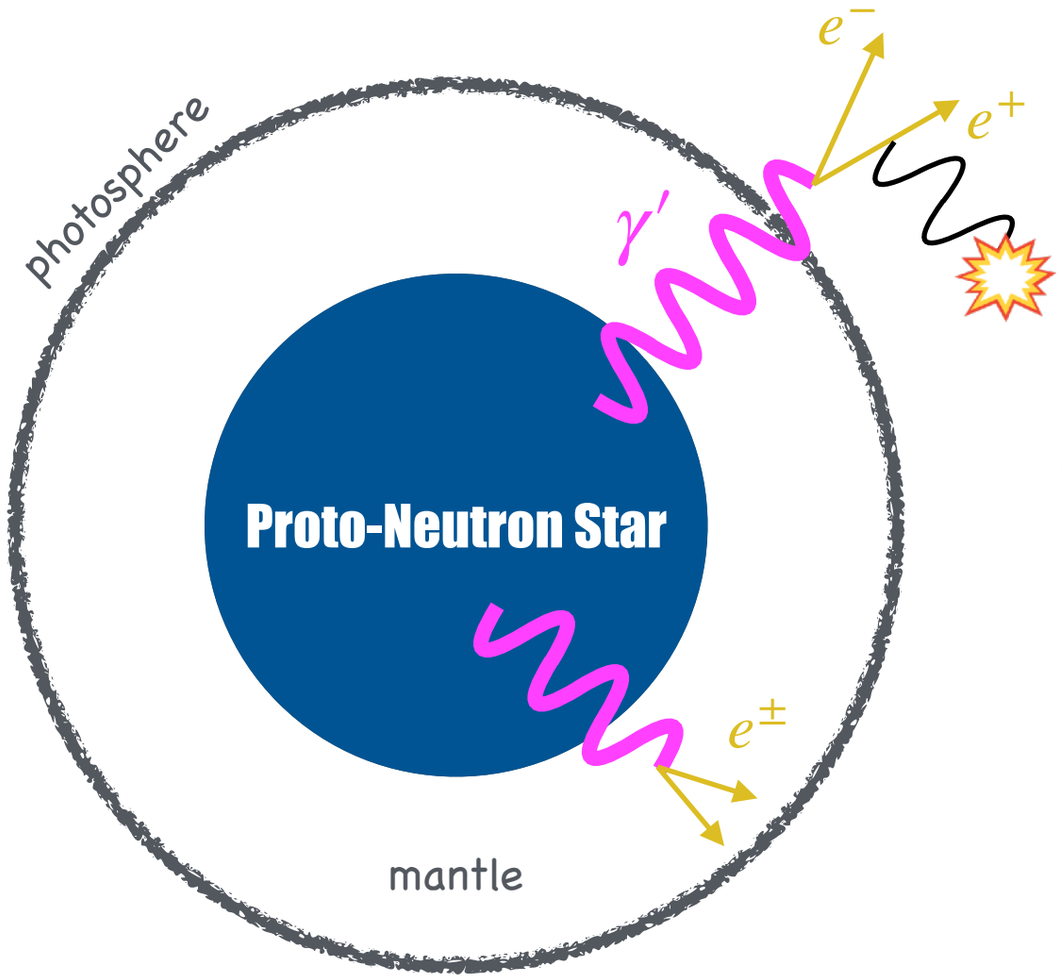
Impact on SN explosion mechanism

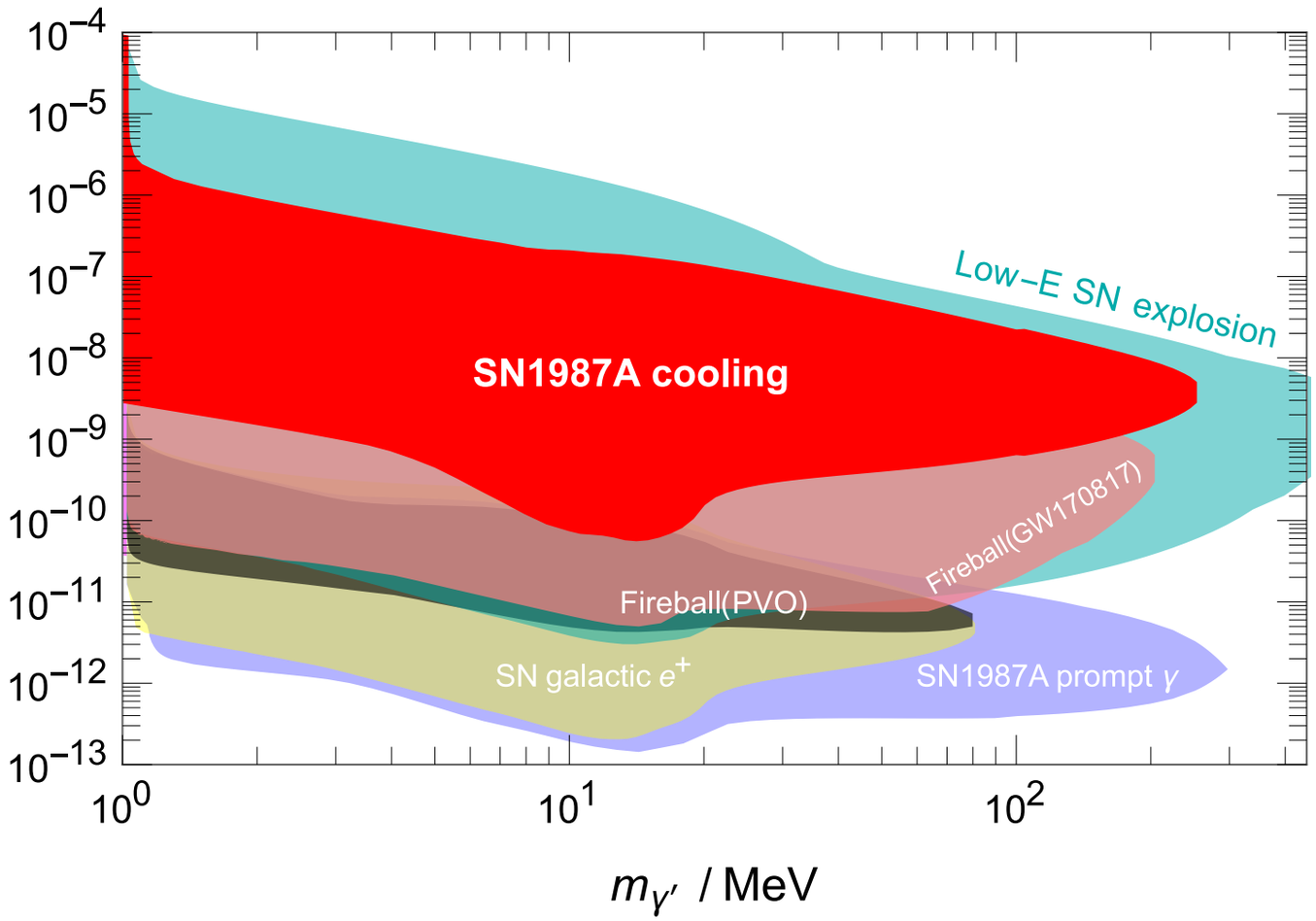
[A. Caputo, T. Janka, G. Raffelt, **SY**, 25]





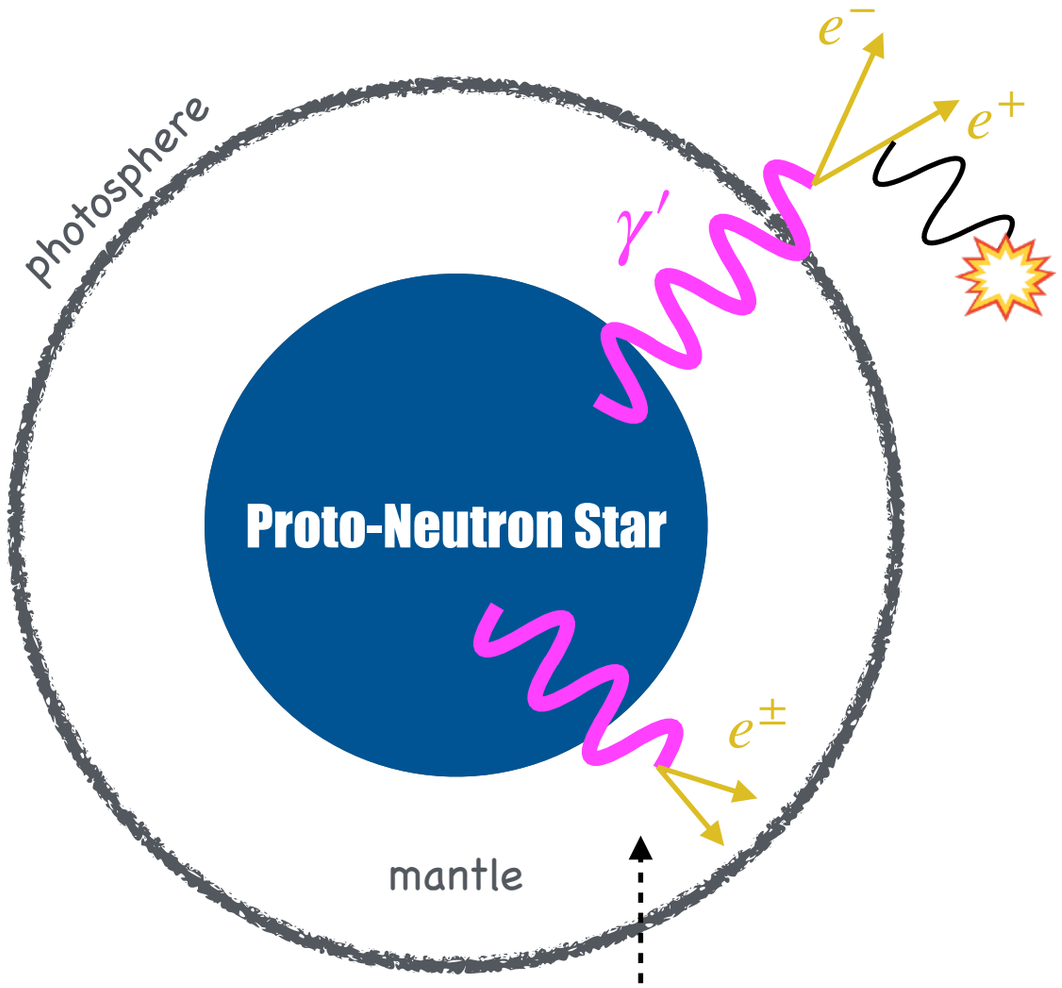
Other SN Constraints w/o CSM

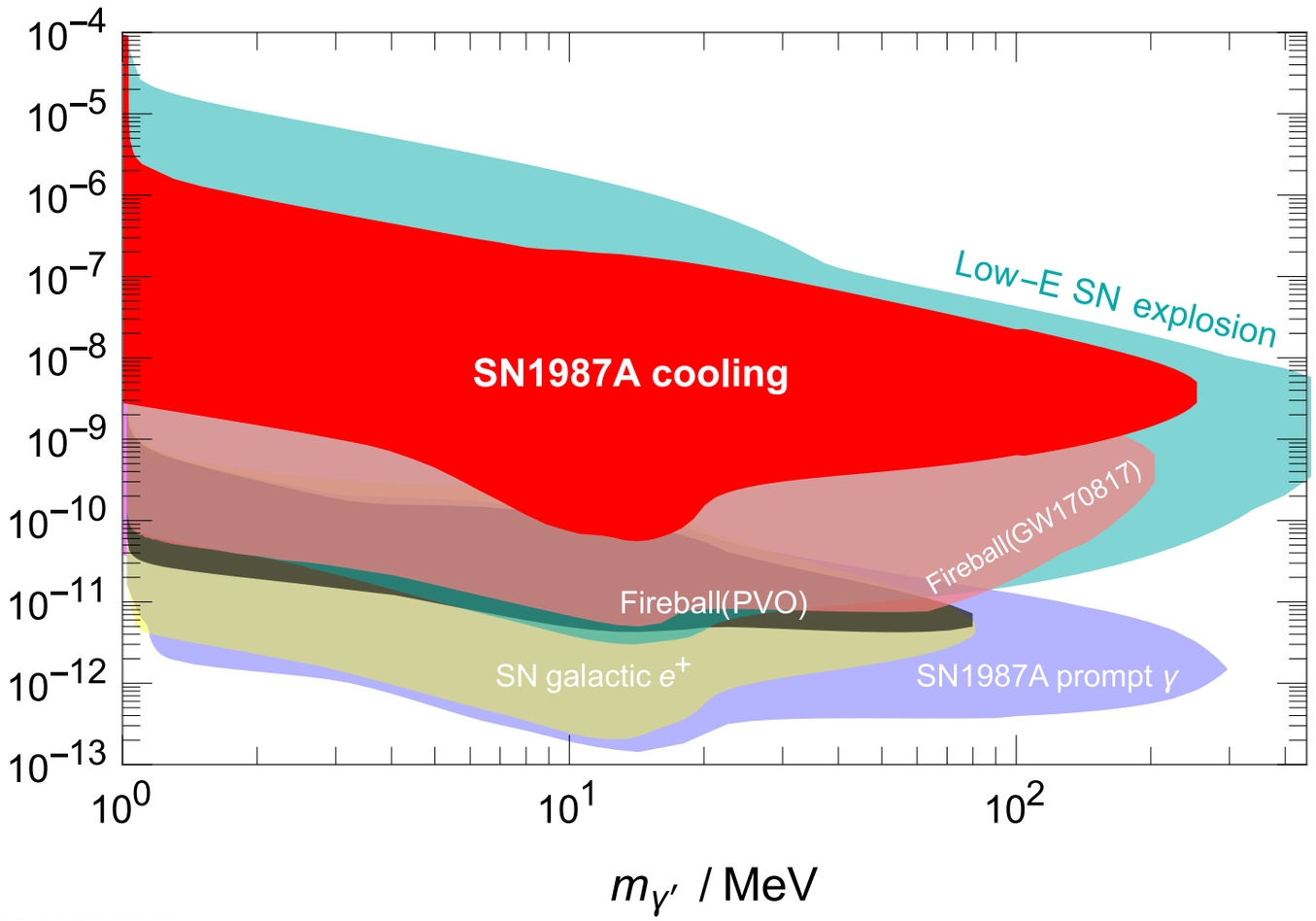




[A. Caputo, J. Park, **SY**, 26]

Other SN Constraints w/o CSM





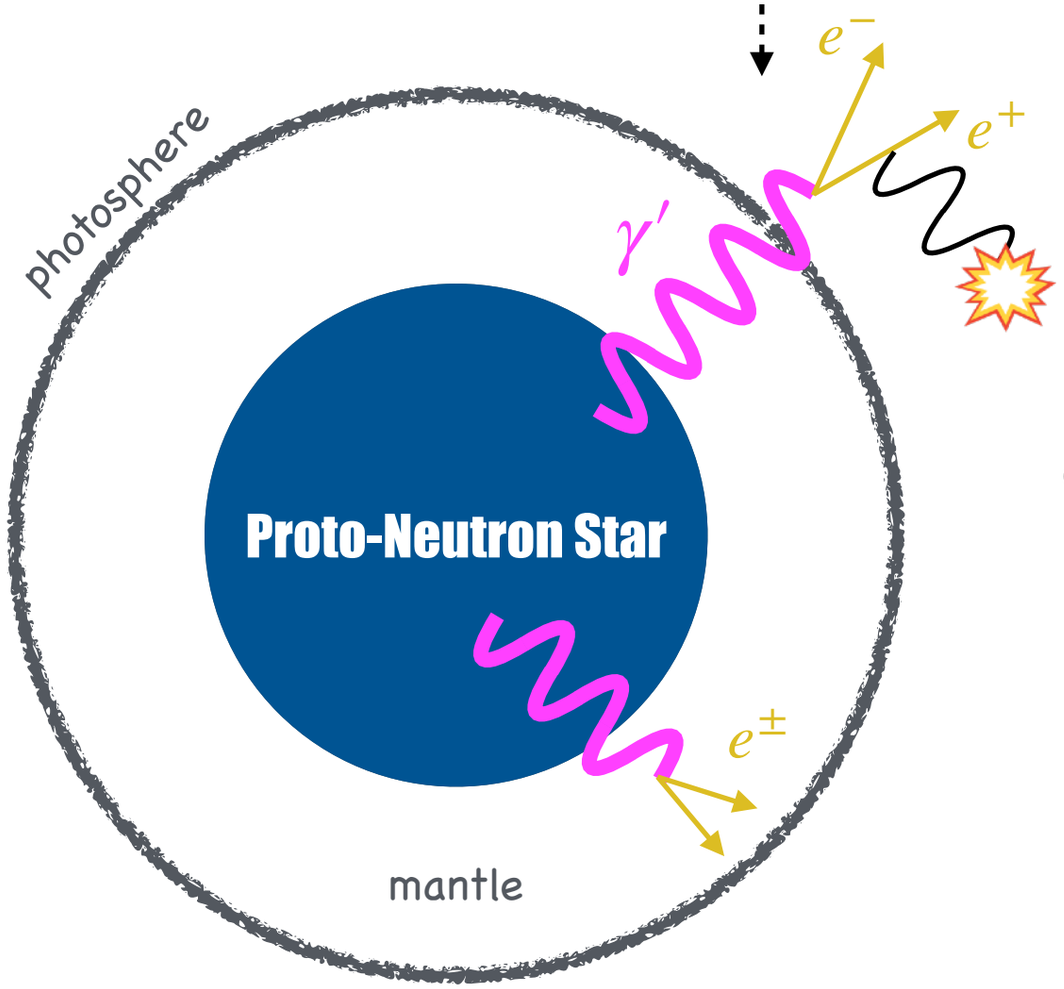
- Energy deposition into the mantle
  - ✓ Contributing to SN explosion energy

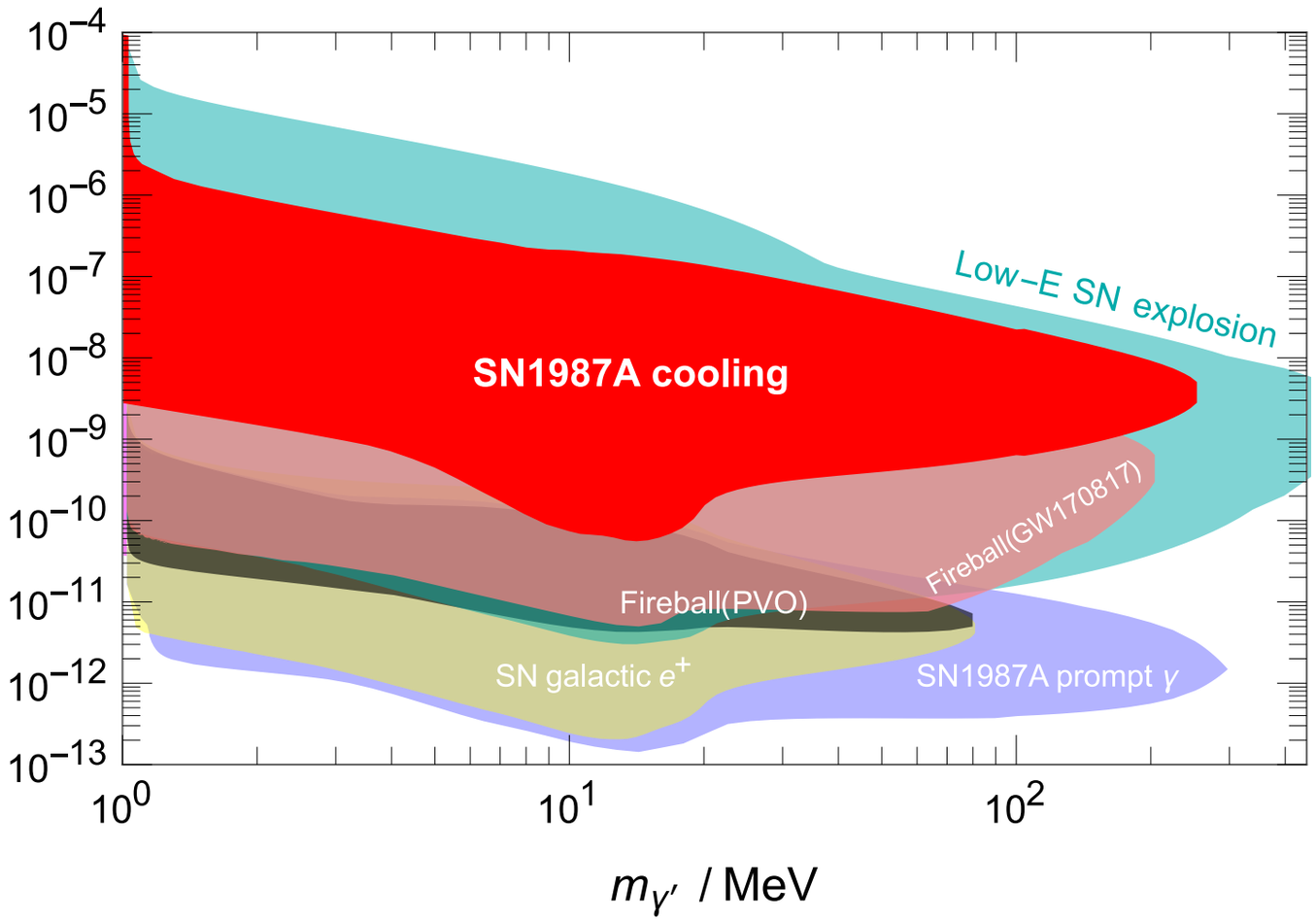
[A. Caputo, J. Park, **SY**, 26]

Other SN Constraints w/o CSM

- Energy transport outside the progenitor

✓ fireball, galactic e^+ (511keV), prompt γ-ray





[A. Caputo, J. Park, **SY**, 26]

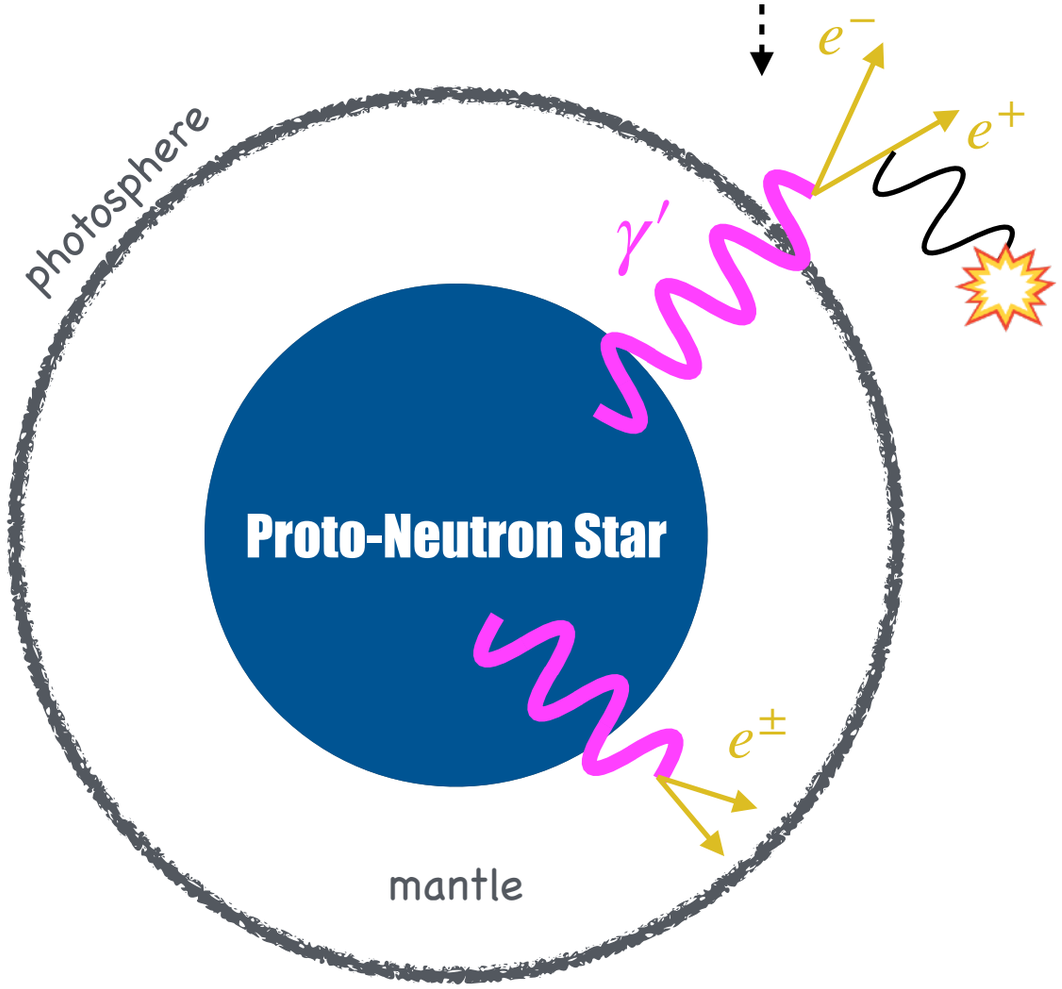
Other SN Constraints w/o CSM

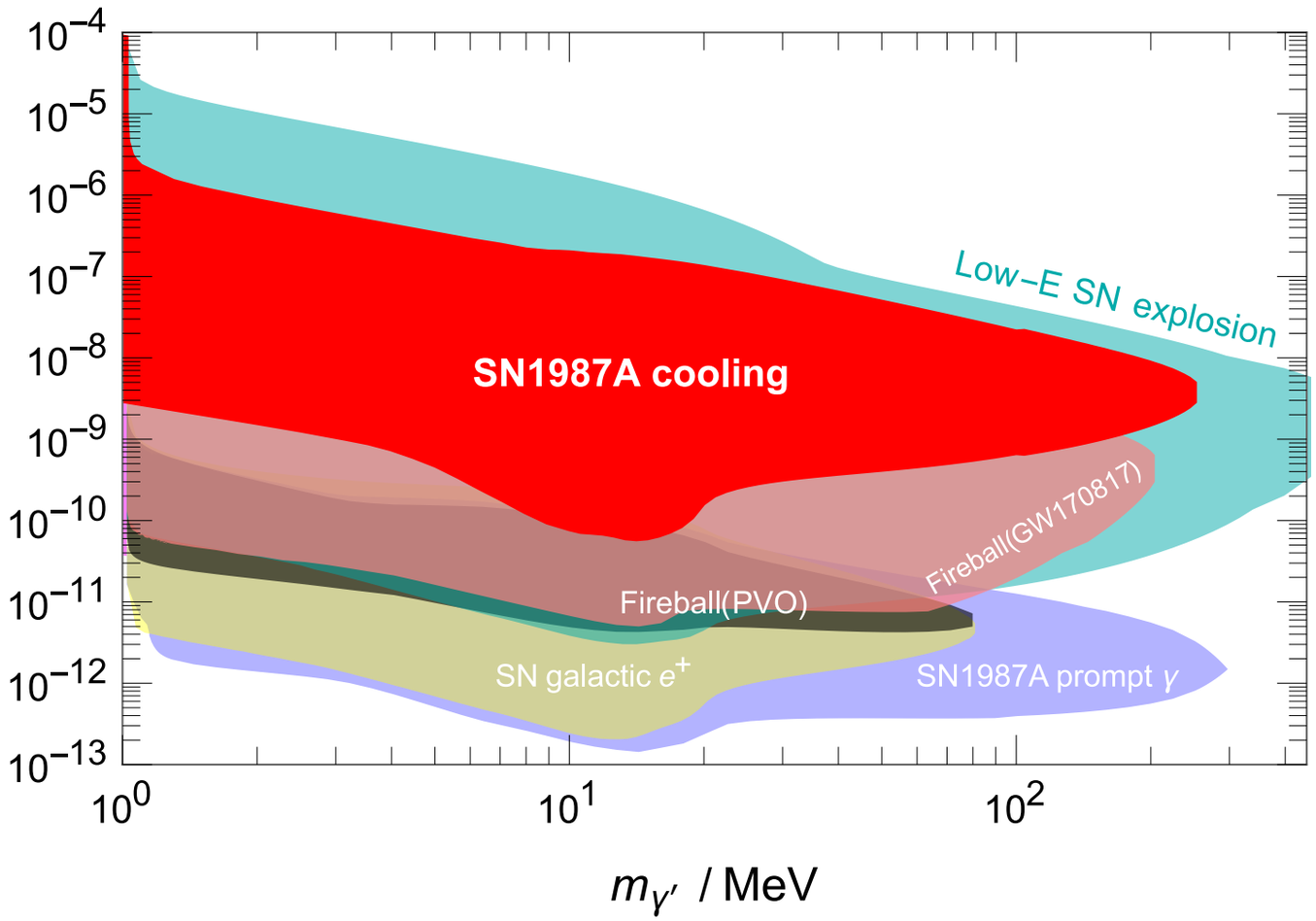
- Energy transport outside the progenitor

✓ fireball, galactic e^+ (511keV), prompt γ-ray

- conventionally - vacuum

? medium due to mass-loss

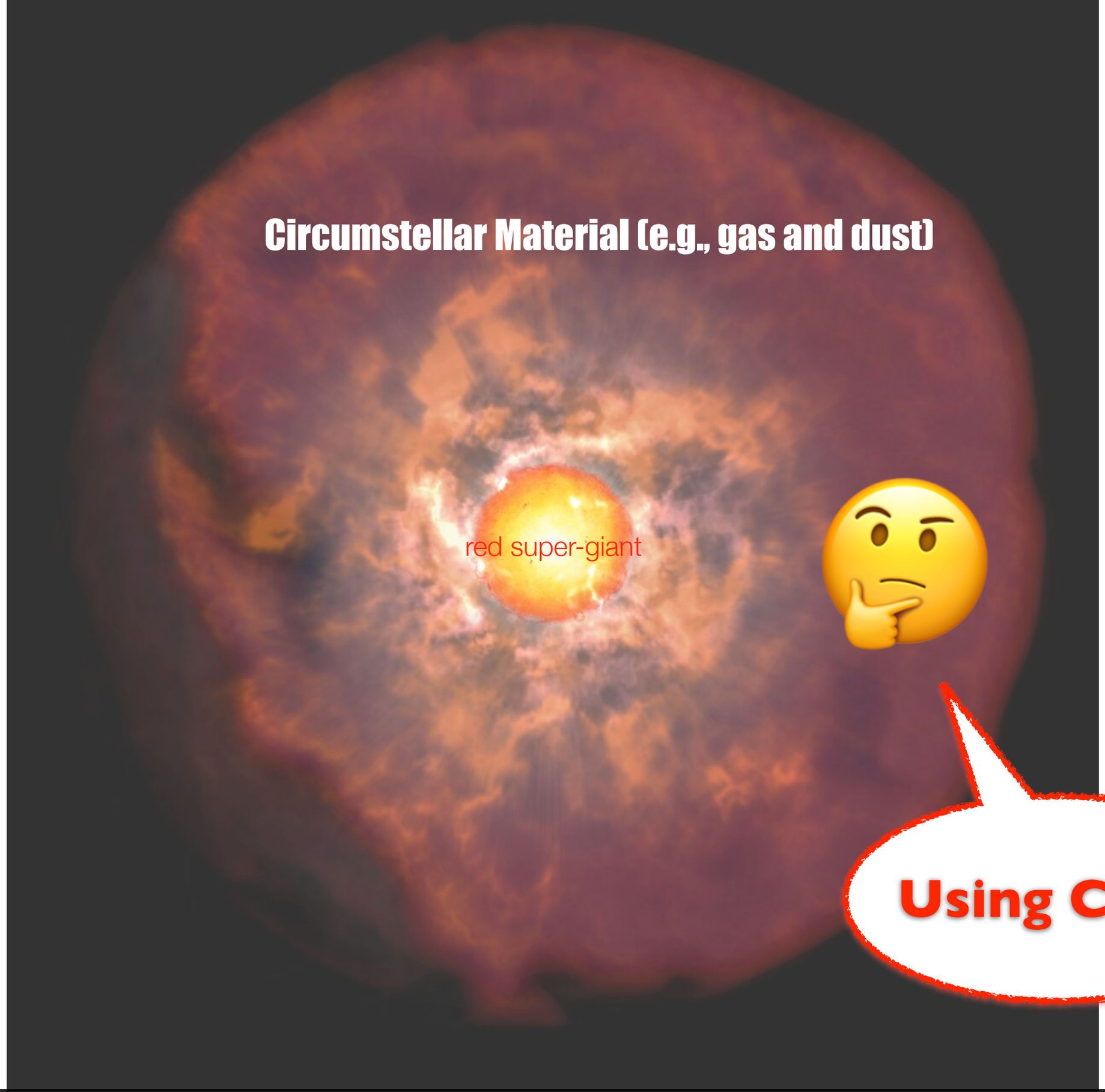




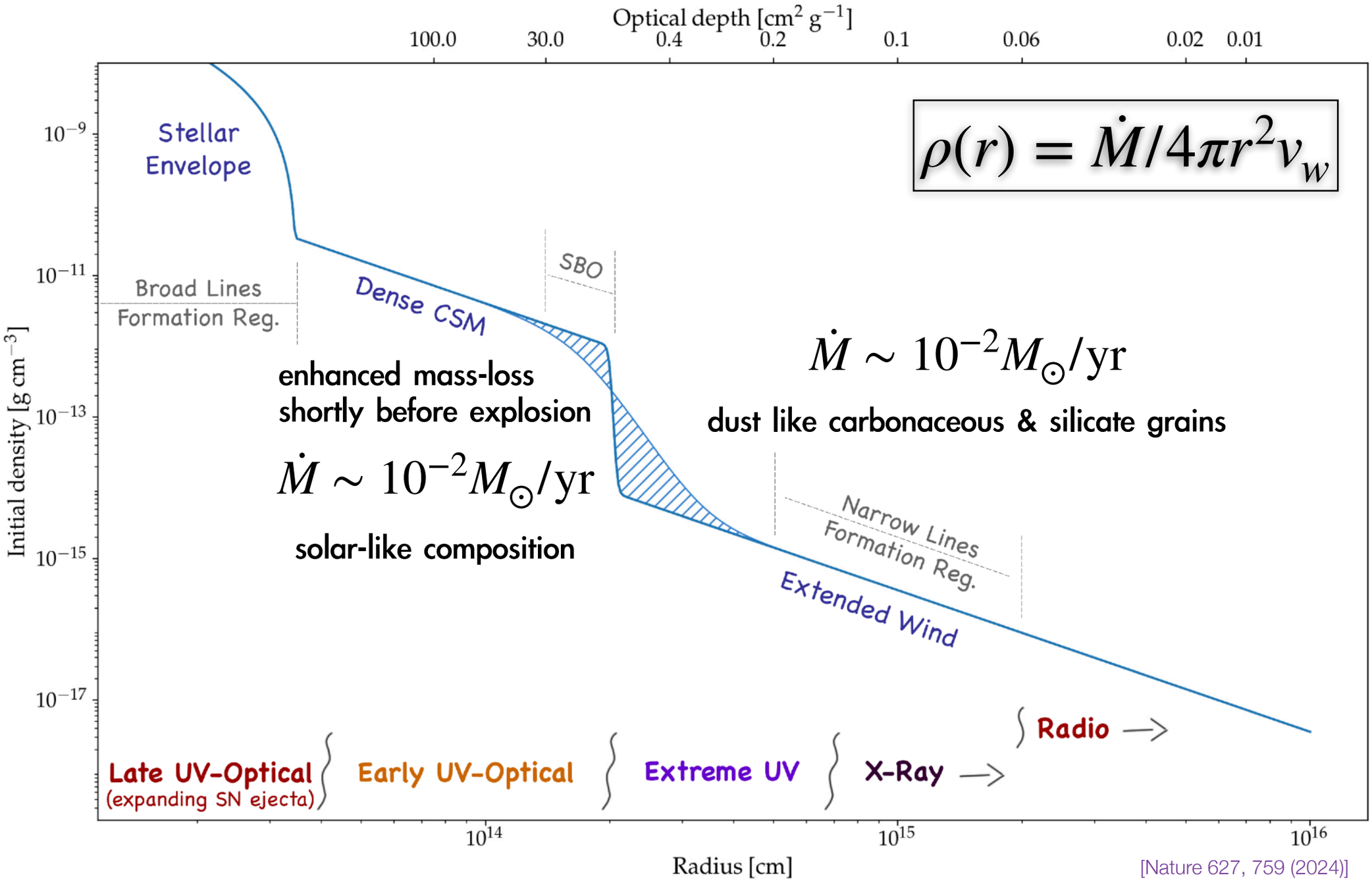
[A. Caputo, J. Park, **SY**, 26]

BSM w/ CSM

- Circumstellar medium due to mass-loss
  - ✓ Inner (dense) CSM before explosion
  - ✓ Outer (diluted) CSM like standard wind
- Energy deposition in CSM
  - ✓ Opacity & T ⬆ ☞ $L_{\rm BB}$ ⬆ - inner CSM
  - ✓ Dust sublimation - outer CSM

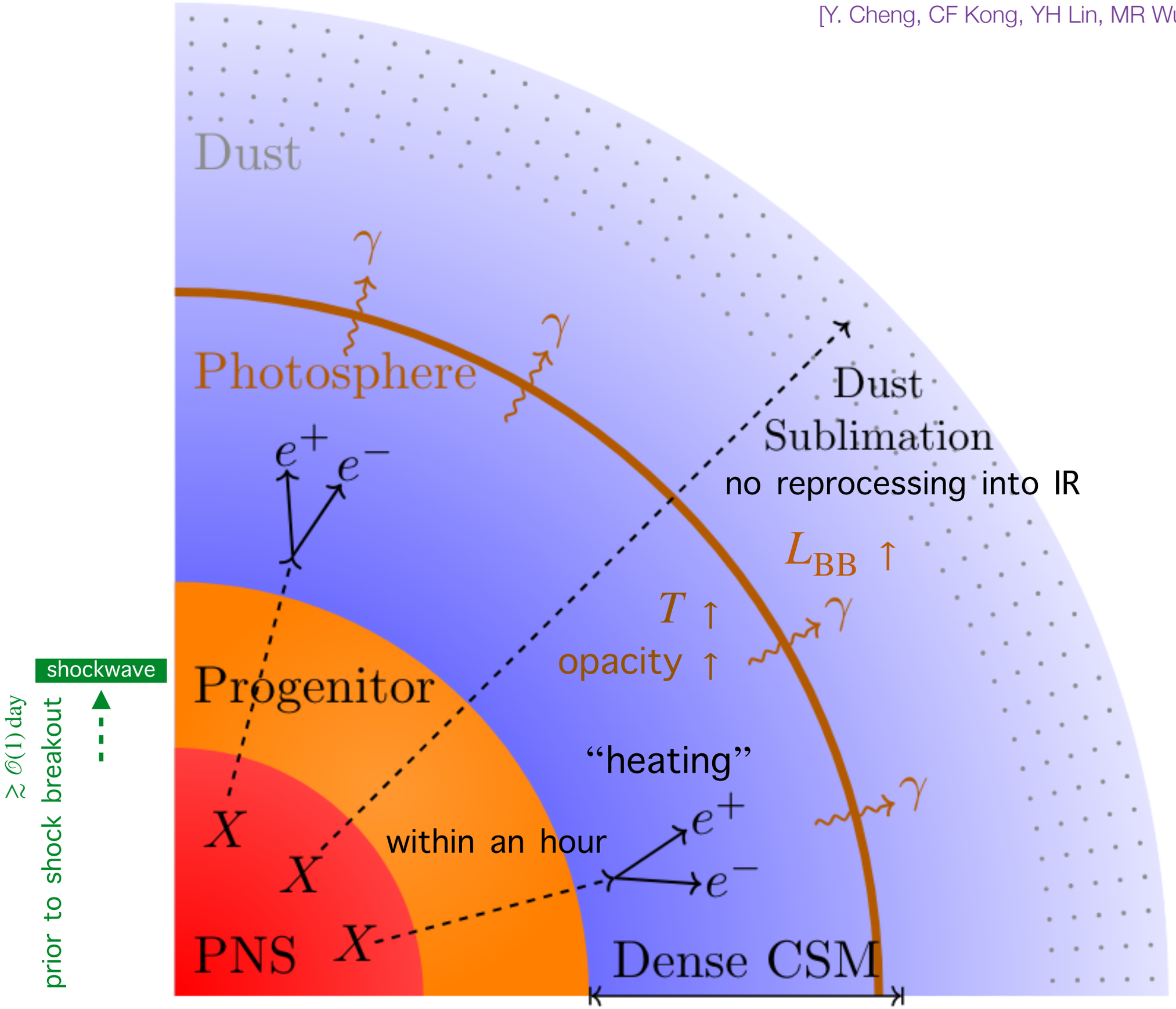

Circumstellar Material (e.g., gas and dust)
red super-giant
Using CSM?

CSM Density Profile



[Nature 627, 759 (2024)]

[Y. Cheng, CF Kong, YH Lin, MR Wu, **SY**, 26]



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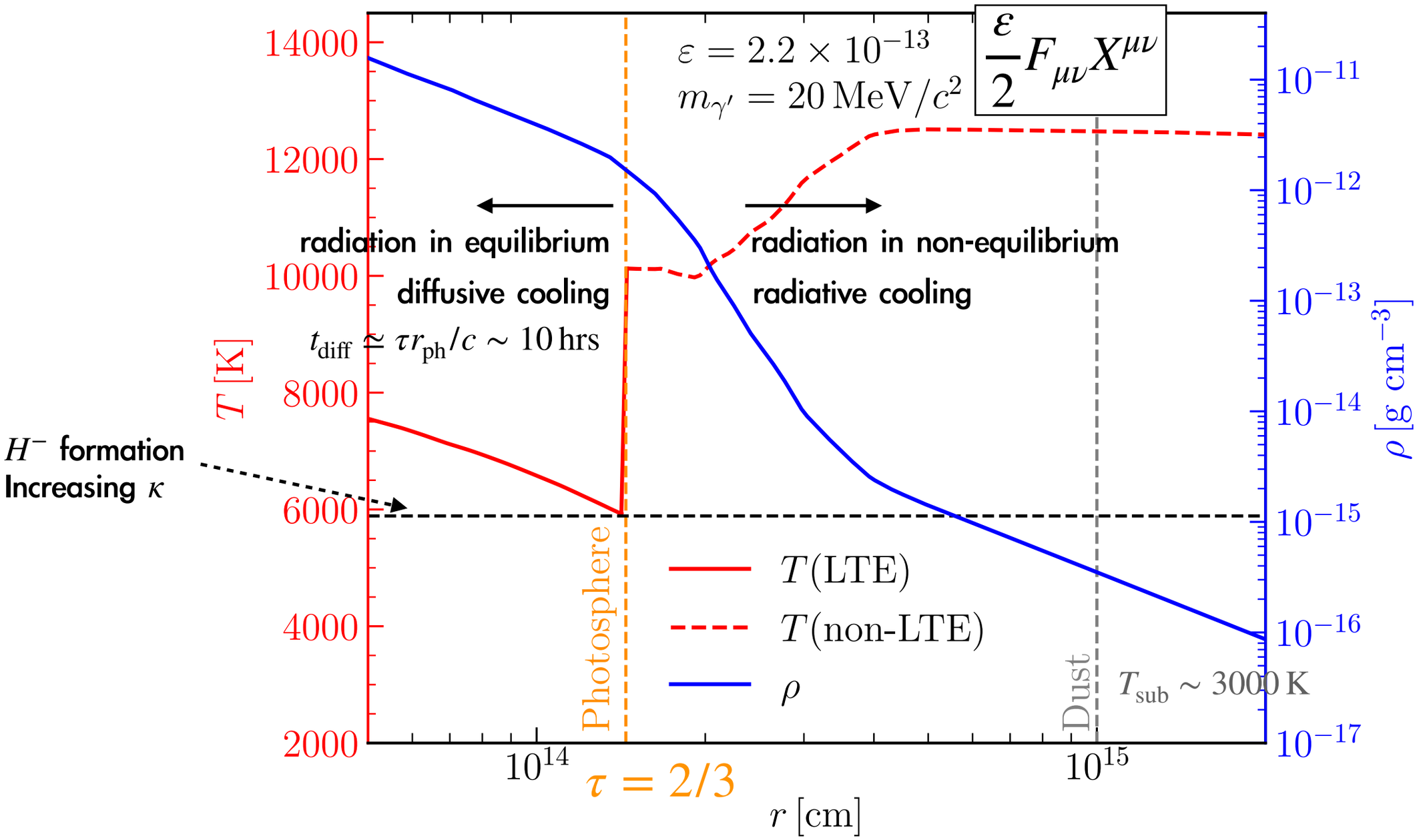
BSM-induced CSM heating



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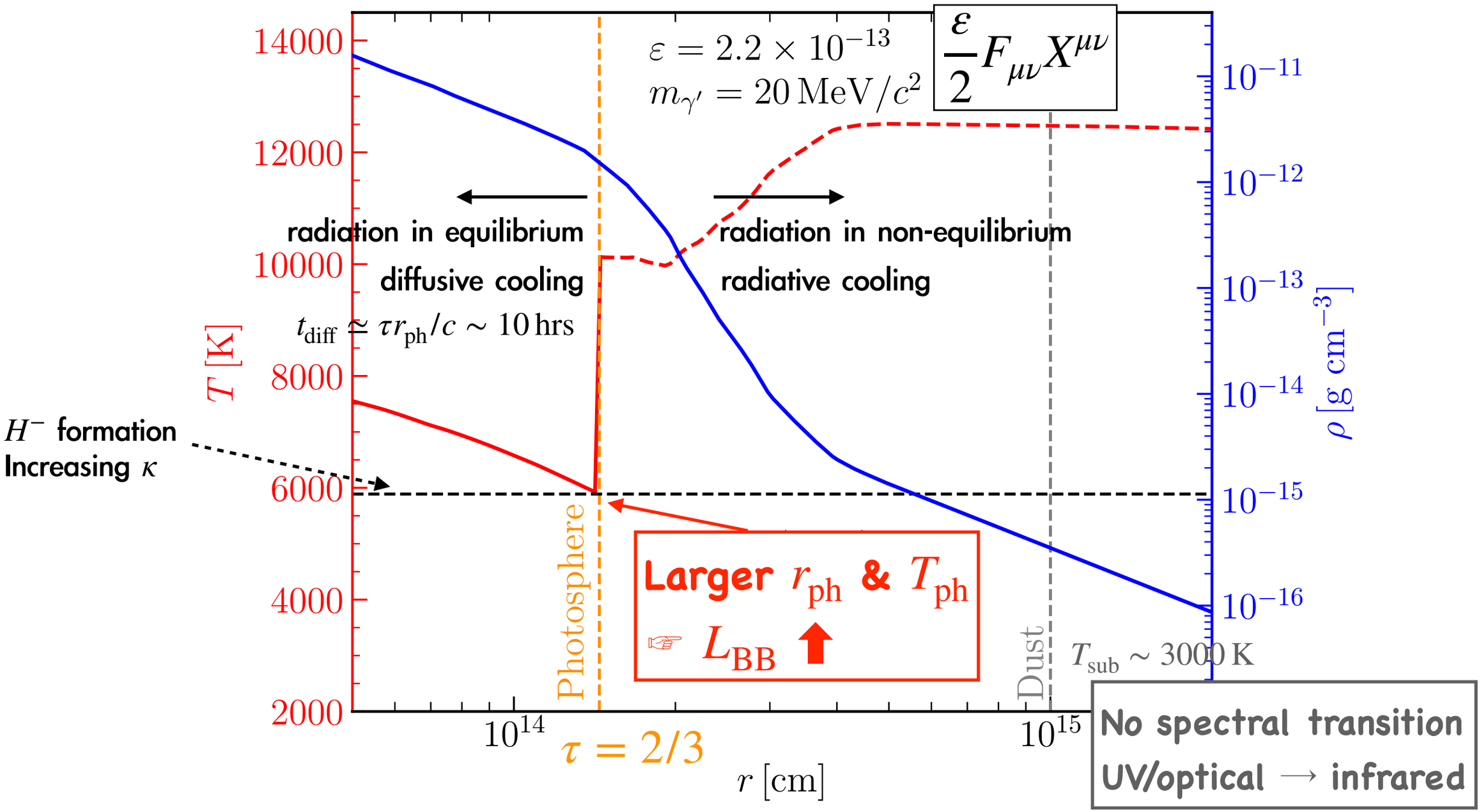

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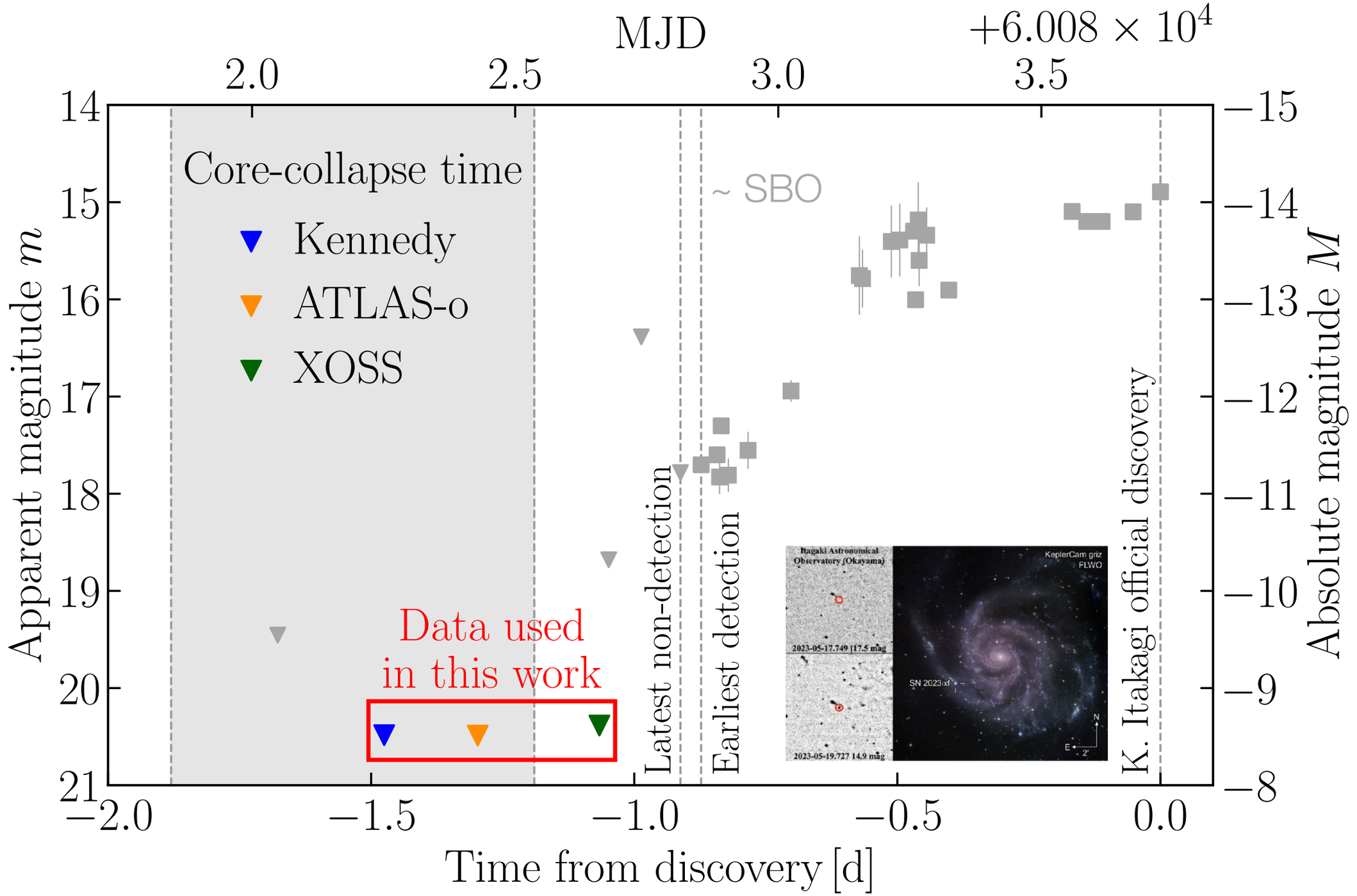
Early Time Data for SN 2023ixf



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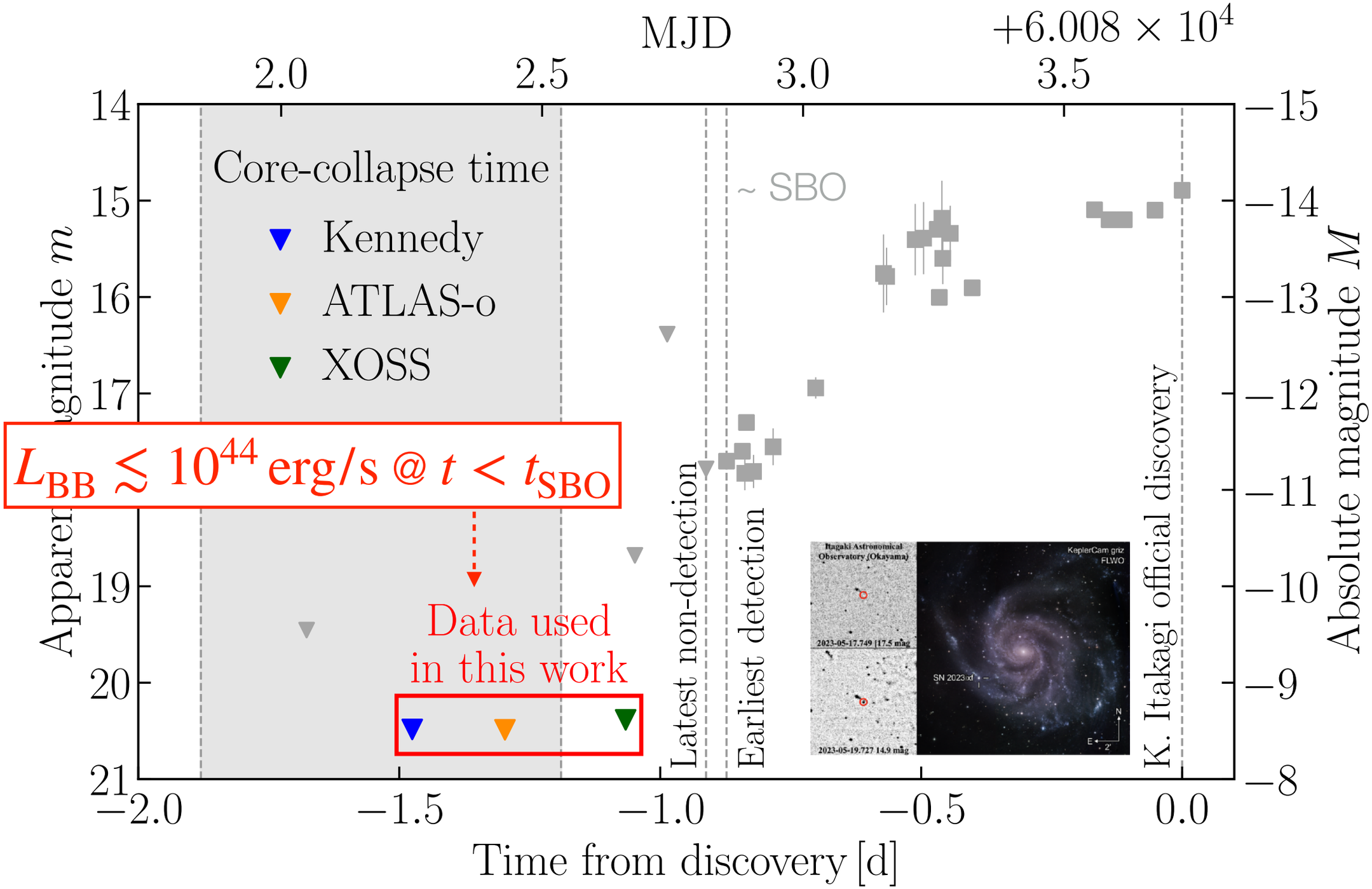

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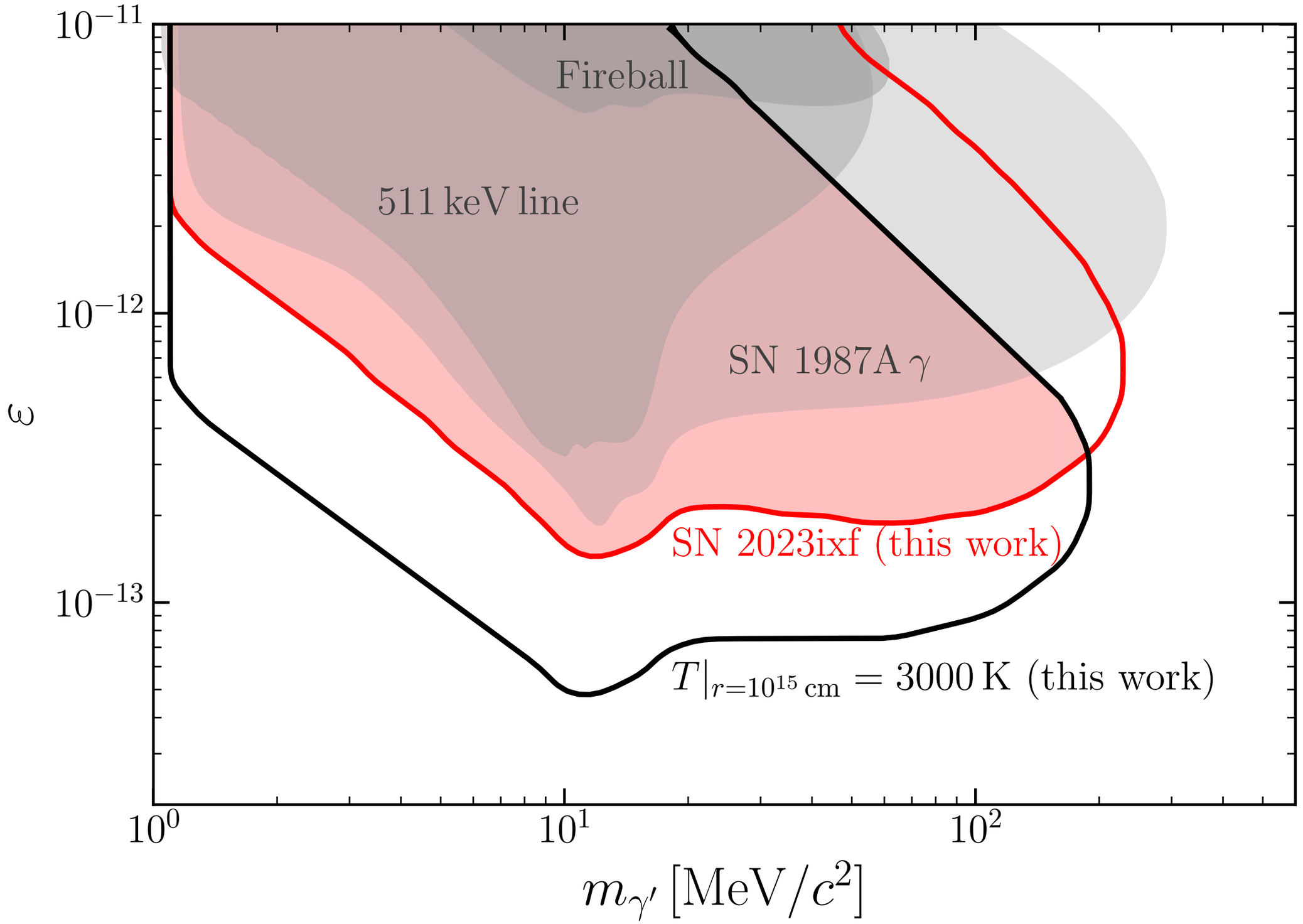

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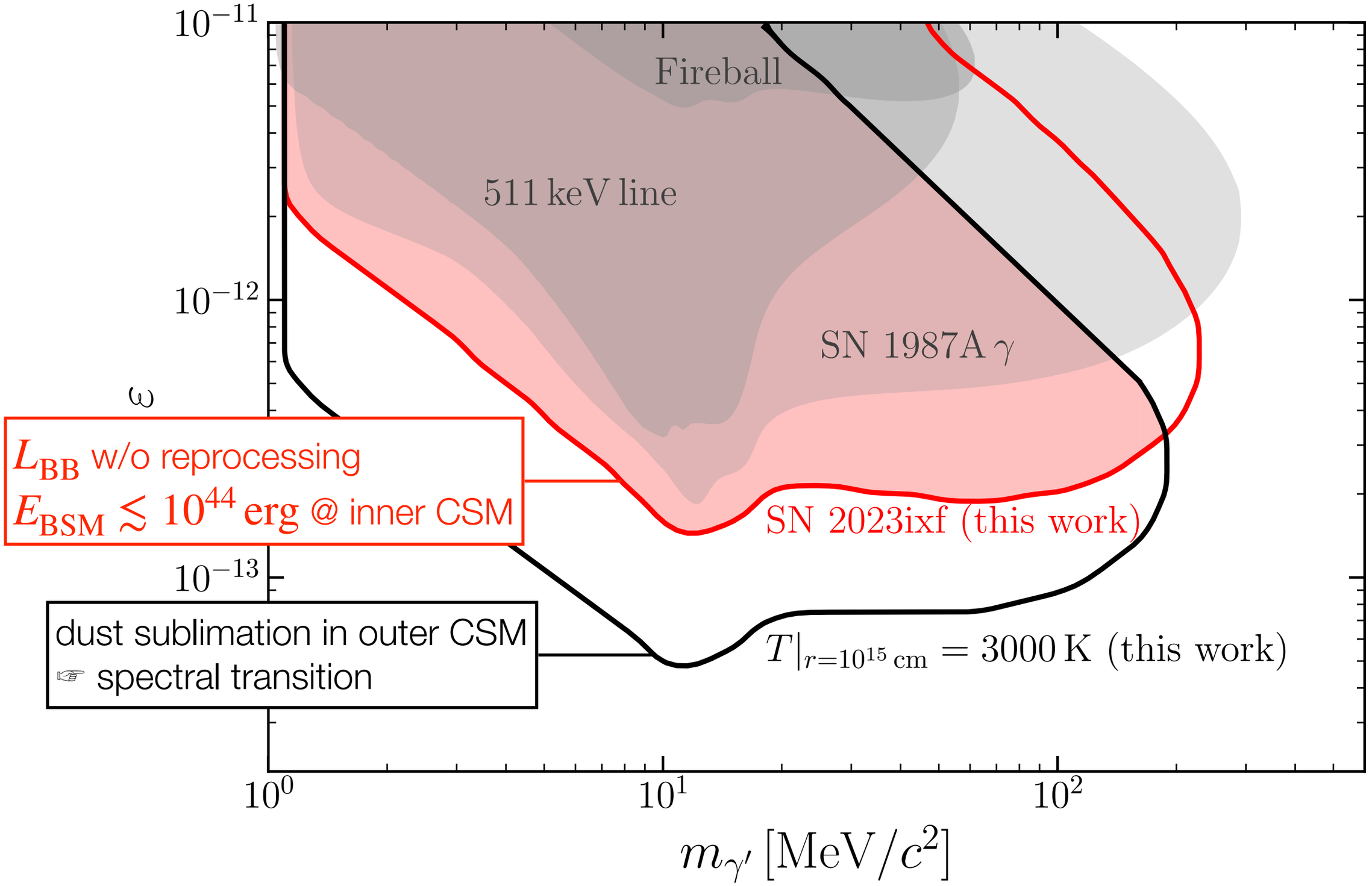

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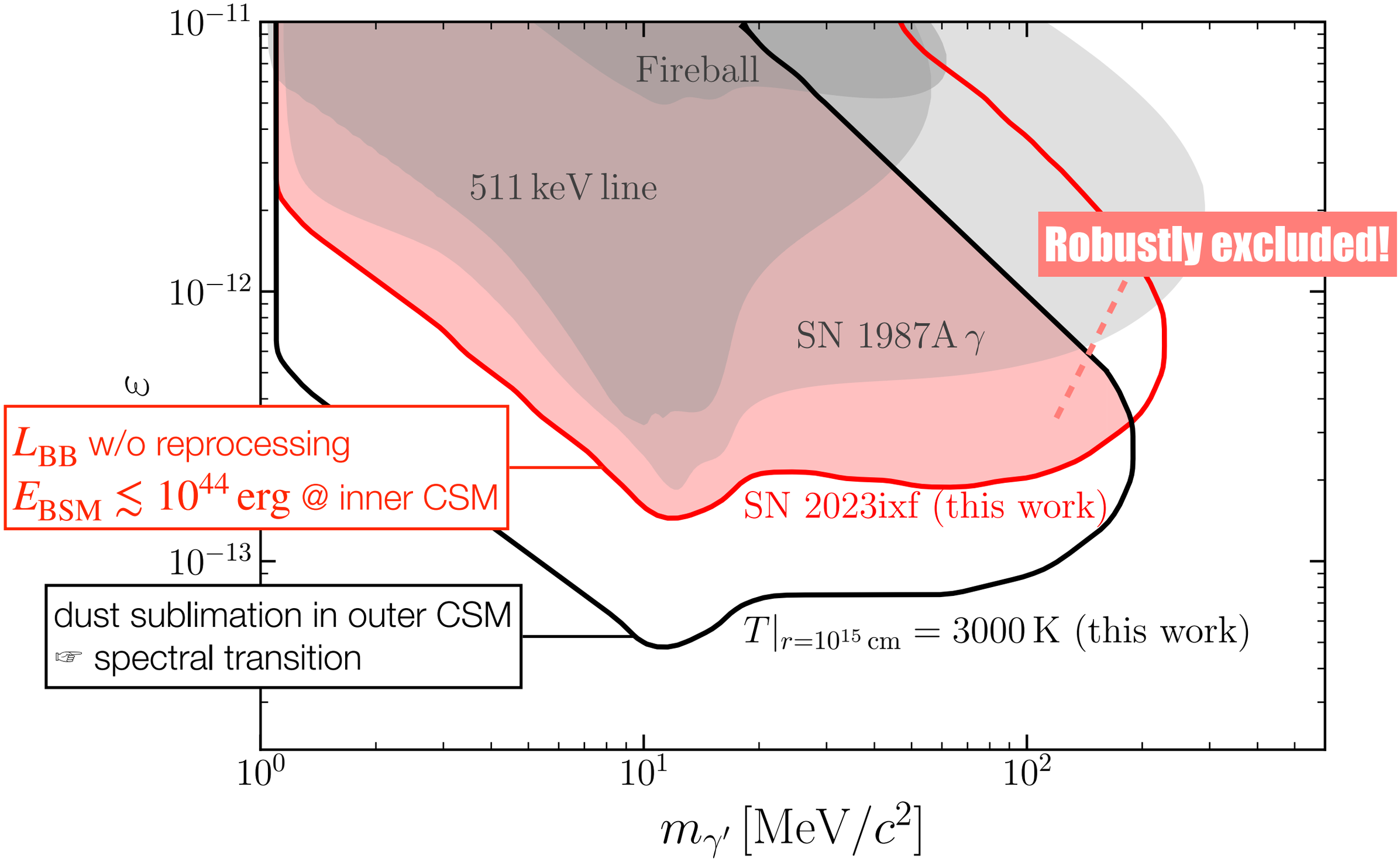

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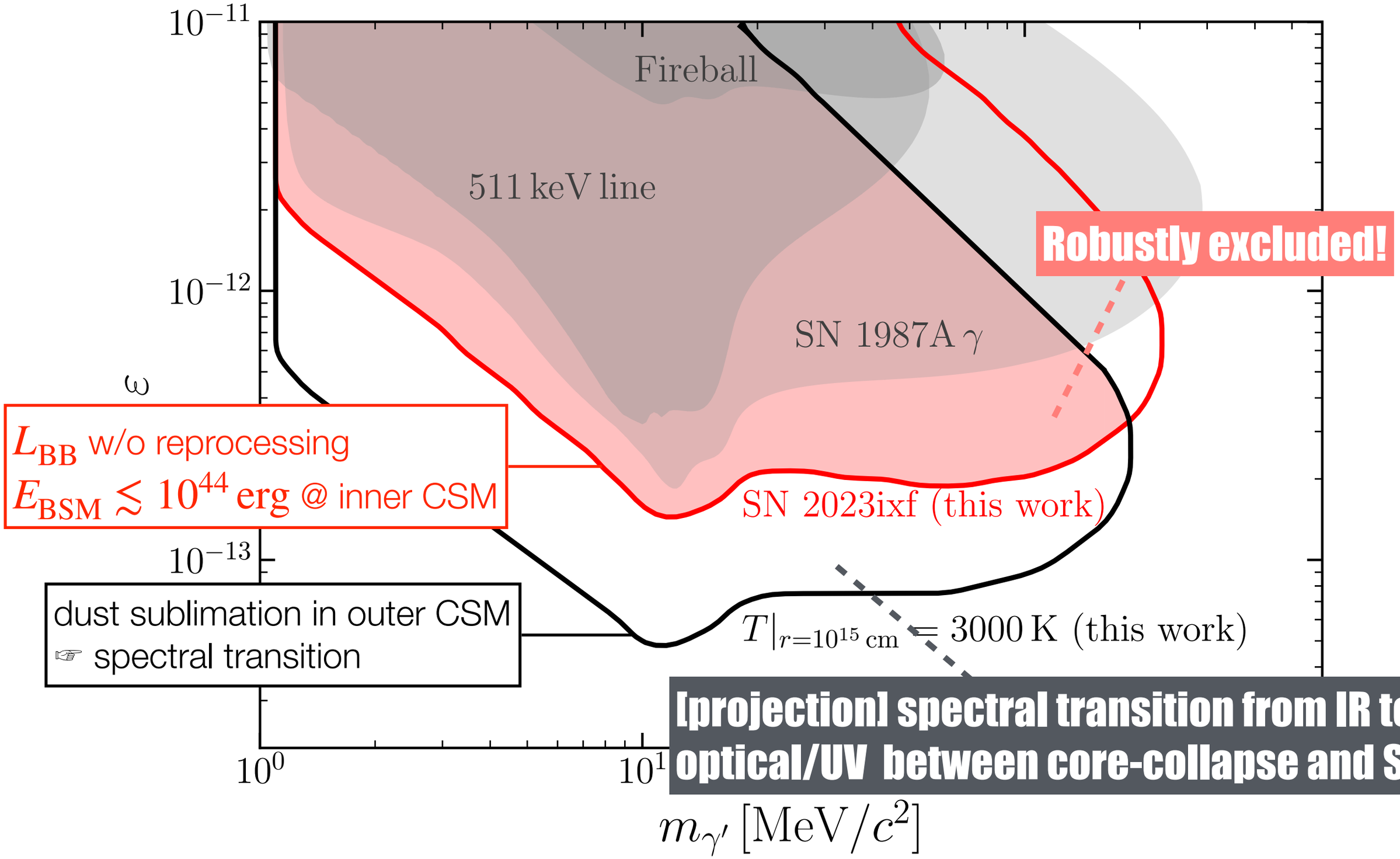
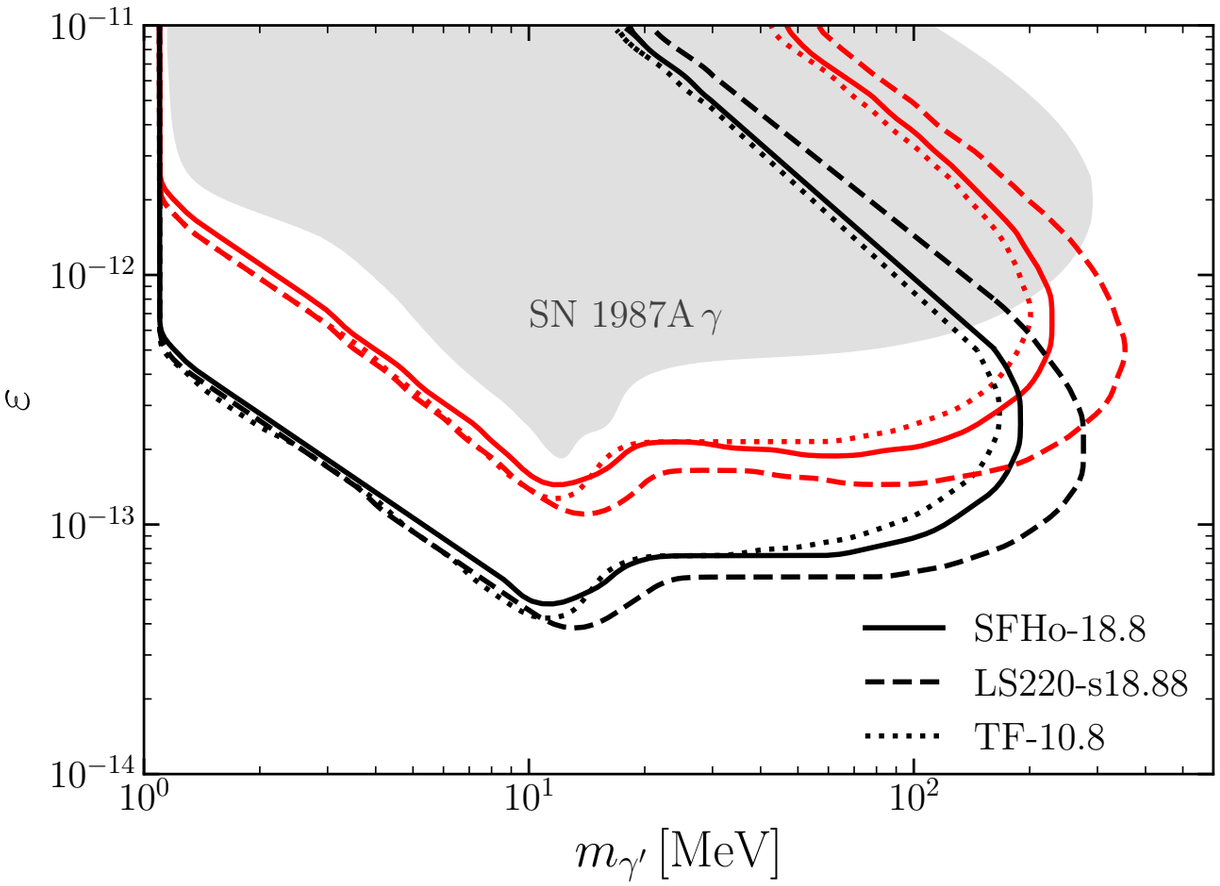


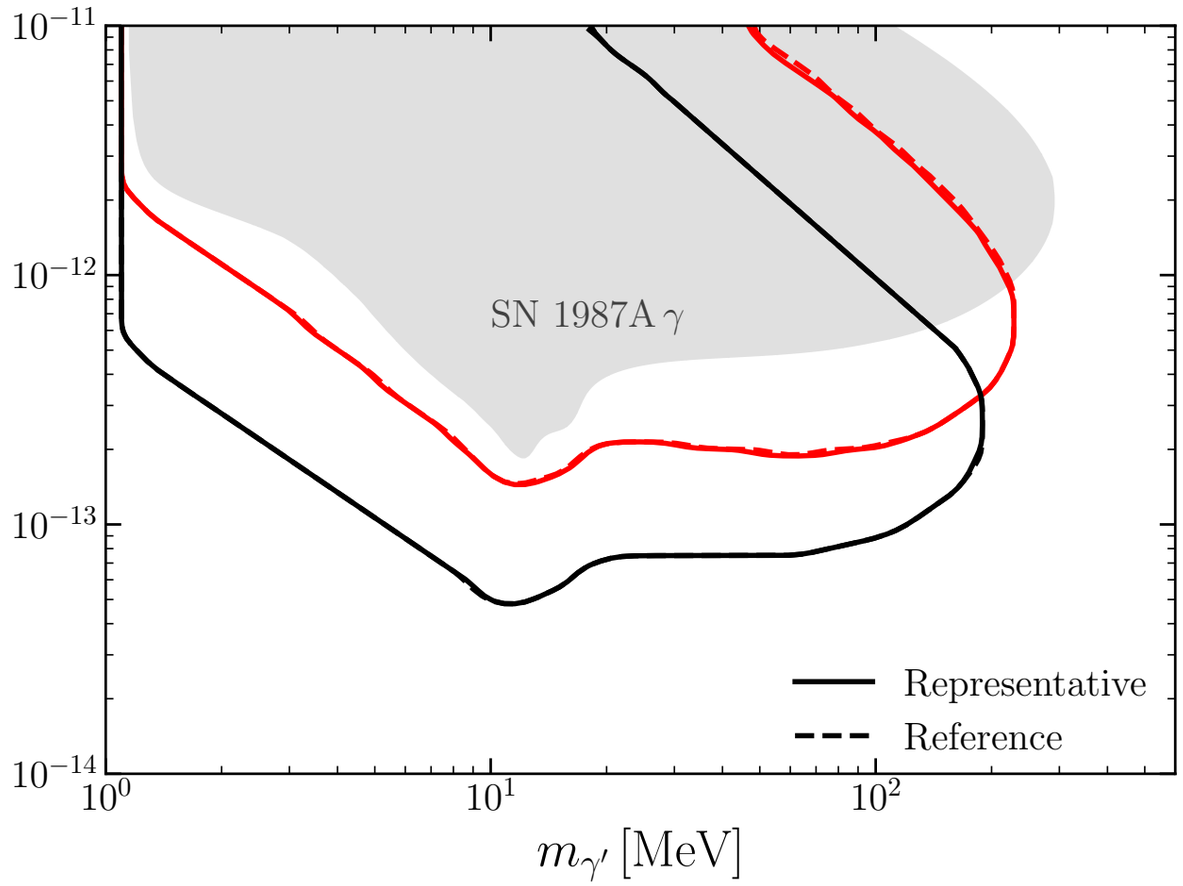
[Y. Cheng, CF Kong, YH Lin, MR Wu, **SY**, 26]

Model Dependence

◉ Core-collapse SN profiles



◉ CSM density profiles



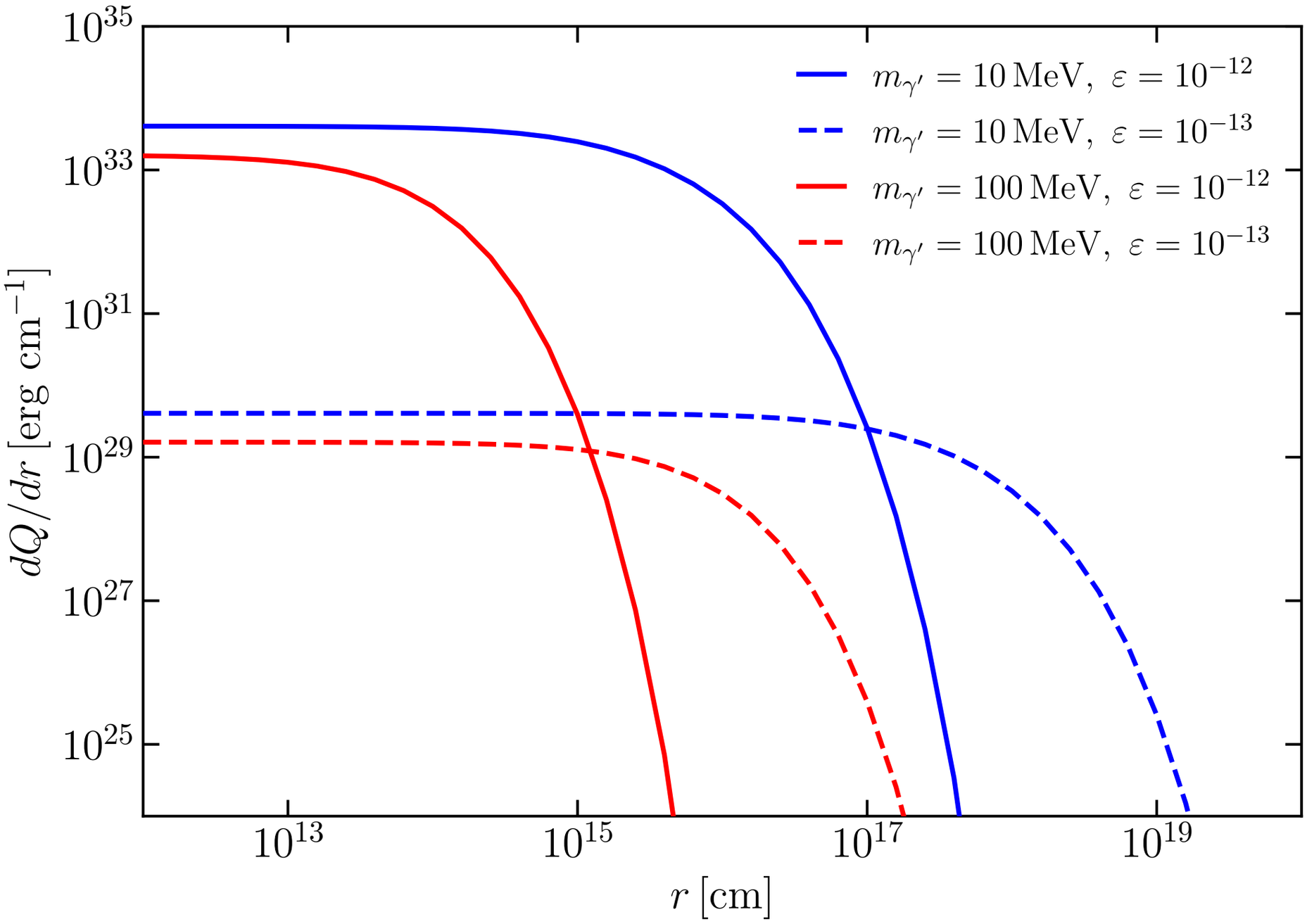
Conclusion

- CSM can provide a probe of BSM
  - production in PNS + visible decay in CSM ☞ energy deposition in CSM prior to SBO
  - @ inner CSM - increasing κ & T ☞ increasing blackbody luminosity
  - @ outer CSM - dust sublimation ☞ suppressed spectral transition (UV/optical → IR)
- Observational constraints
  - none-excessive precursor BB luminosity (SN 2023ixf)
  - for future galactic SNe, rapid spectral transition from infrared-excess to optical/UV dominance between core-collapse and SBO
  - Examine the dark photon scenario as a reference, and find the stringent constraints in the parameter space, which is previously unexplored

감사합니다!

Back up

SN γ' Energy Deposition Rate



CSM Profiles