超新星と連星系

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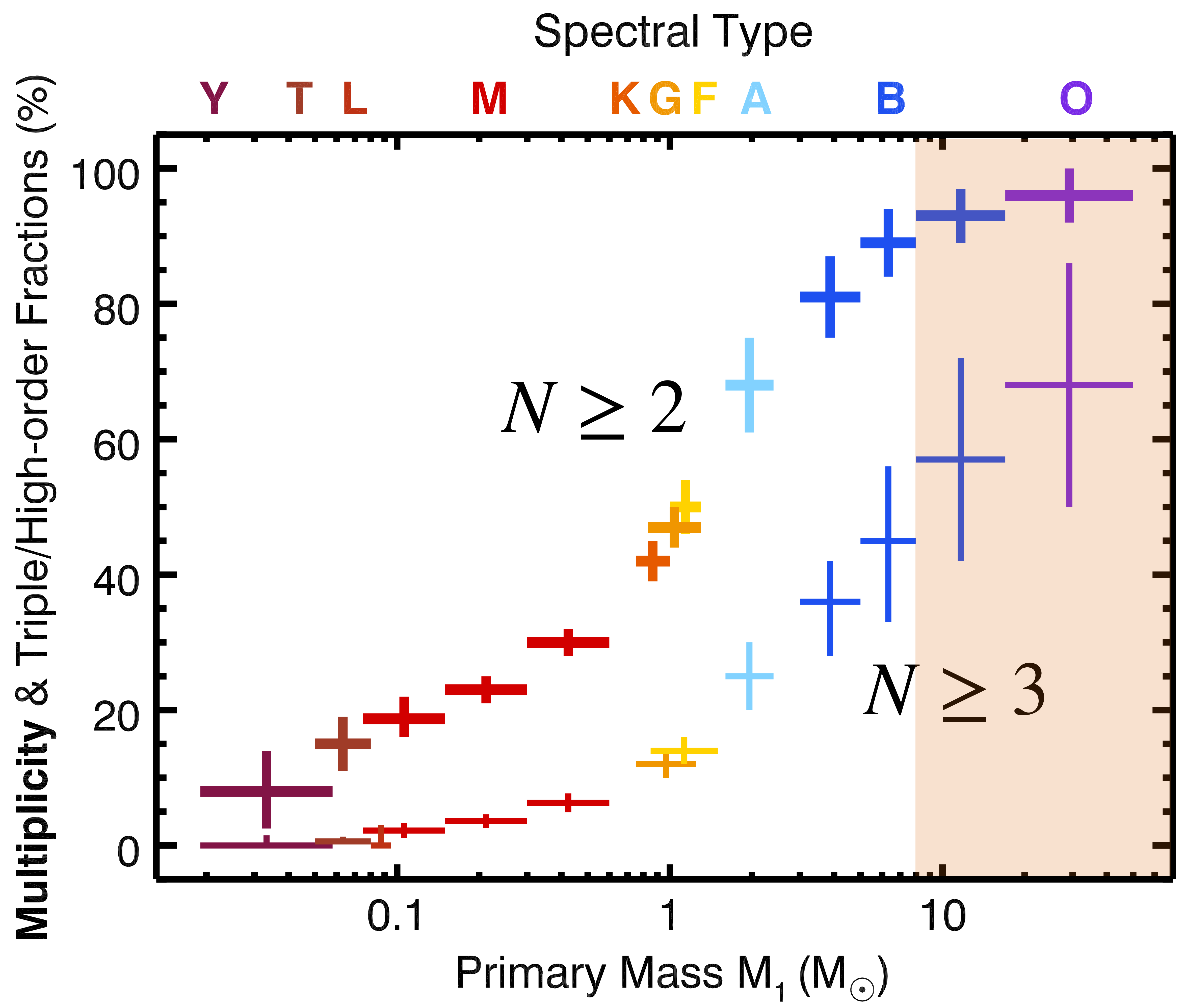
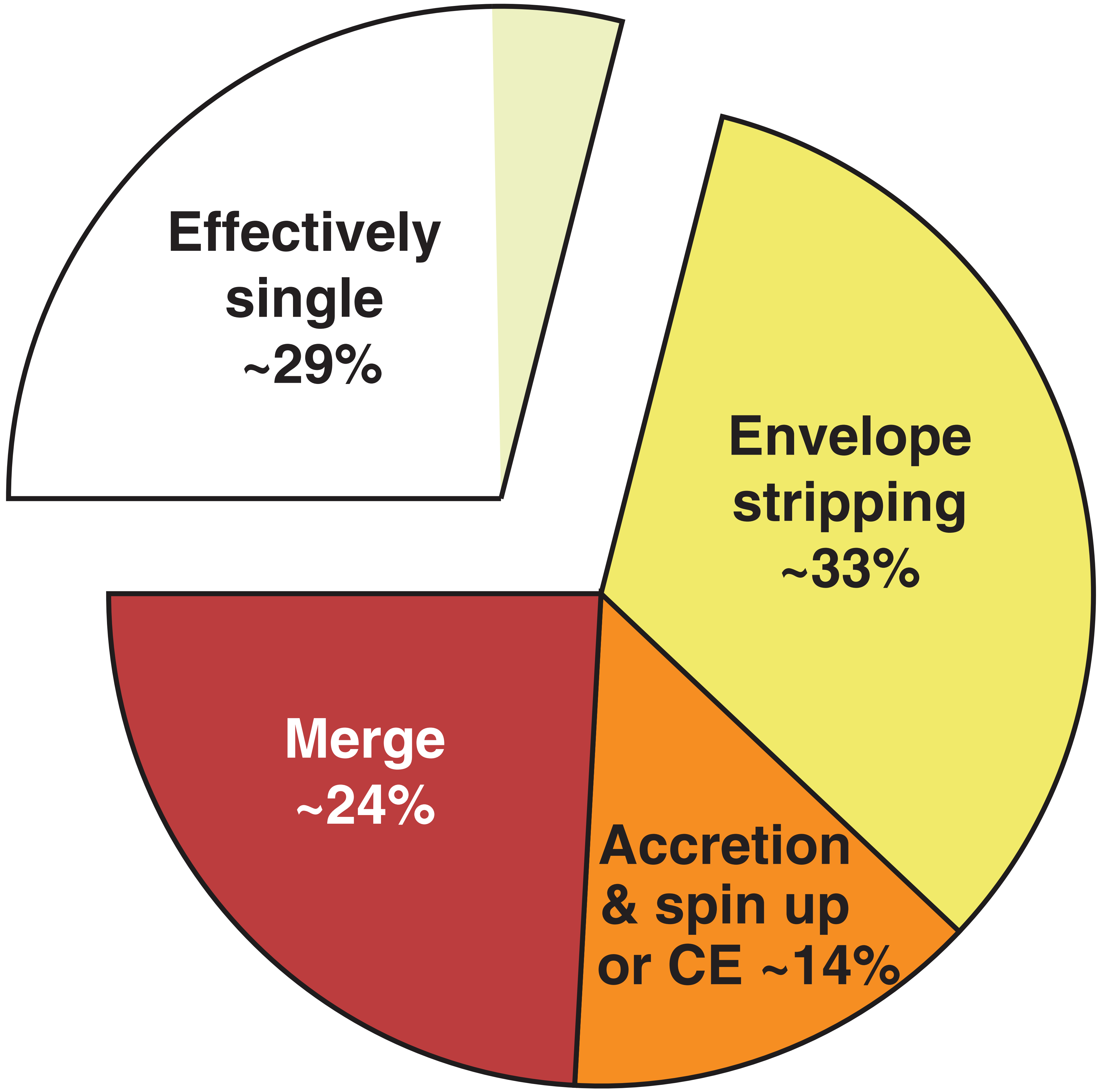
Massive stars in multiple-star systems



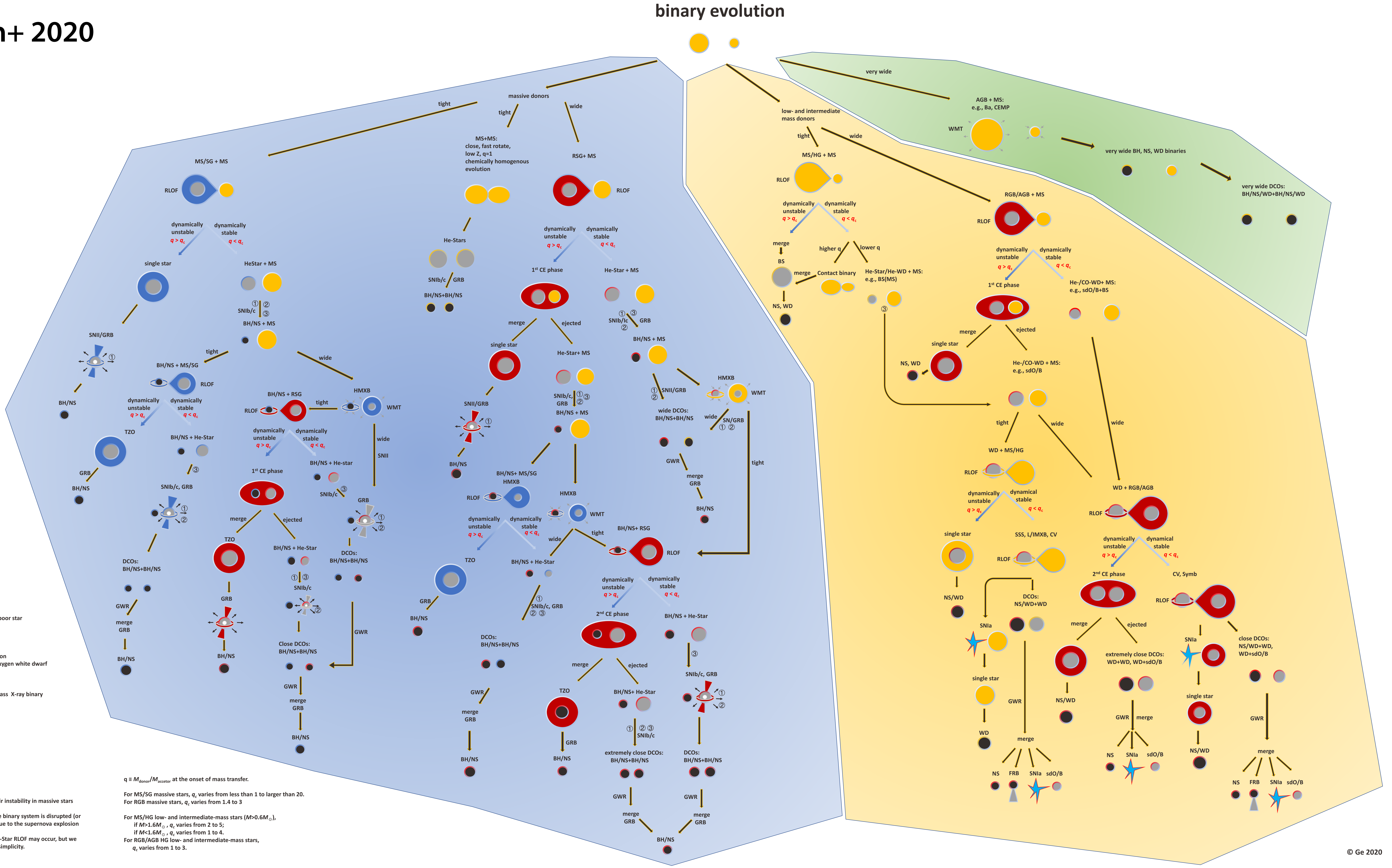
Offner+ 23



Sana+ 2012

Diversity of binary evolutions

Han+ 2020



AGB: asymptotic giant branch
Ba: barium star
BH: black hole
BS: blue straggler
CE: common envelope
CEMP: carbon enhanced metal poor star
CV: cataclysmic variable
DCOs: double compact objects
FRB: fast radio burst
GRB: gamma ray burst
GWR: gravitational wave radiation
He/CO-WD: helium or carbon oxygen white dwarf
He-Star: helium star
HG: Hertzsprung gap
HMXB: high mass X-ray binary
L/IMXB: low- or intermediate mass X-ray binary
MS: main sequence
NS: neutron star
RGB: red giant branch
RLOF: Roche-lobe over-flow
RSG: red super giant
sdO/B: hot subdwarf O/B
SG: super giant
SN: supernova
Symb: symbiotic star
TZO: Thorne-Zytkow object
WD: white dwarf
WMT: wind mass transfer

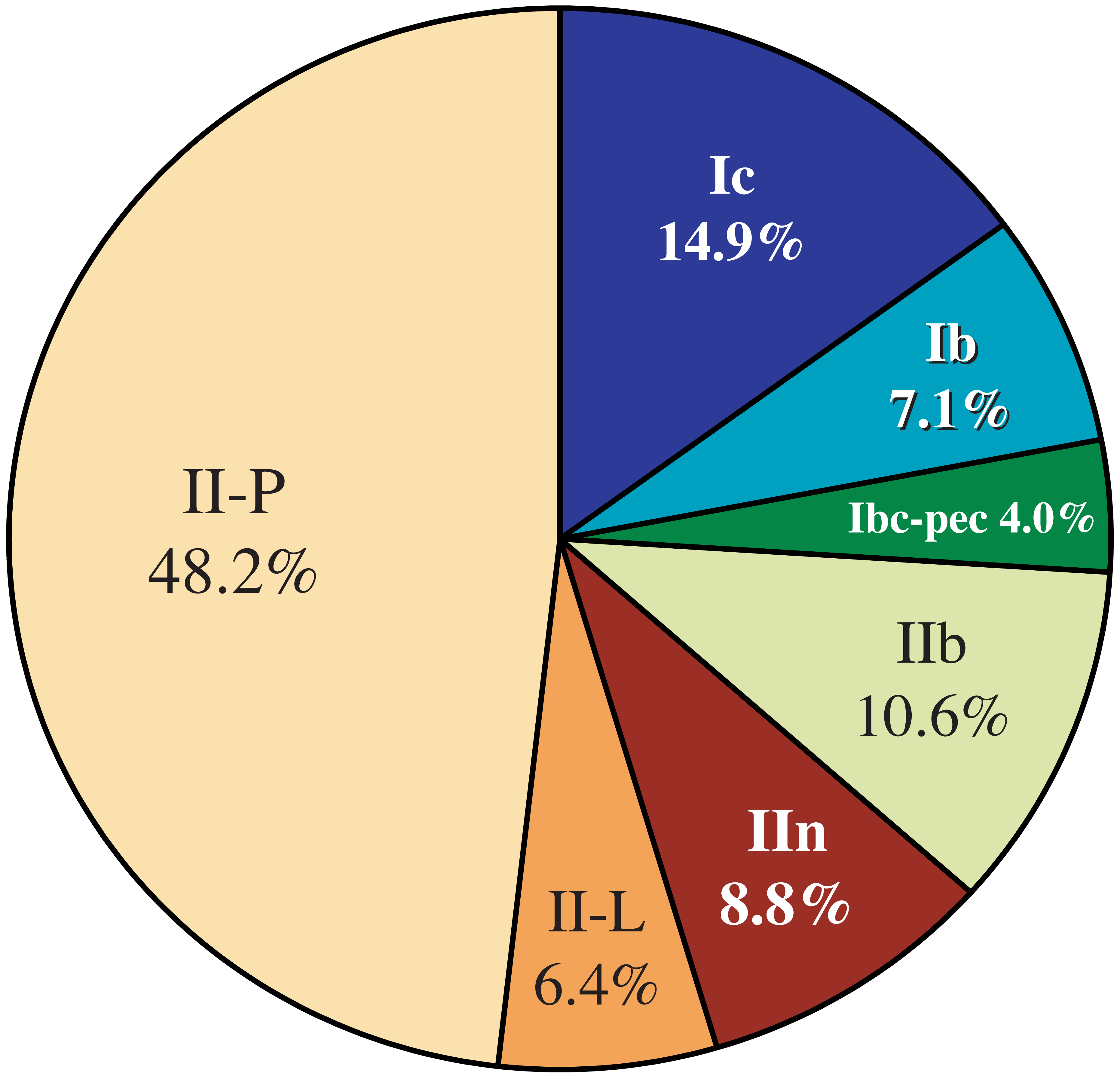
①. There is a possibility that pair instability in massive stars leaves no remnant.
②. There is a possibility that the binary system is disrupted (or becomes highly eccentric) due to the supernova explosion and its kick.
③. There is a possibility that He-Star RLOF may occur, but we omit this in the diagram for simplicity.

$q \equiv M_{donor}/M_{accetor}$ at the onset of mass transfer.

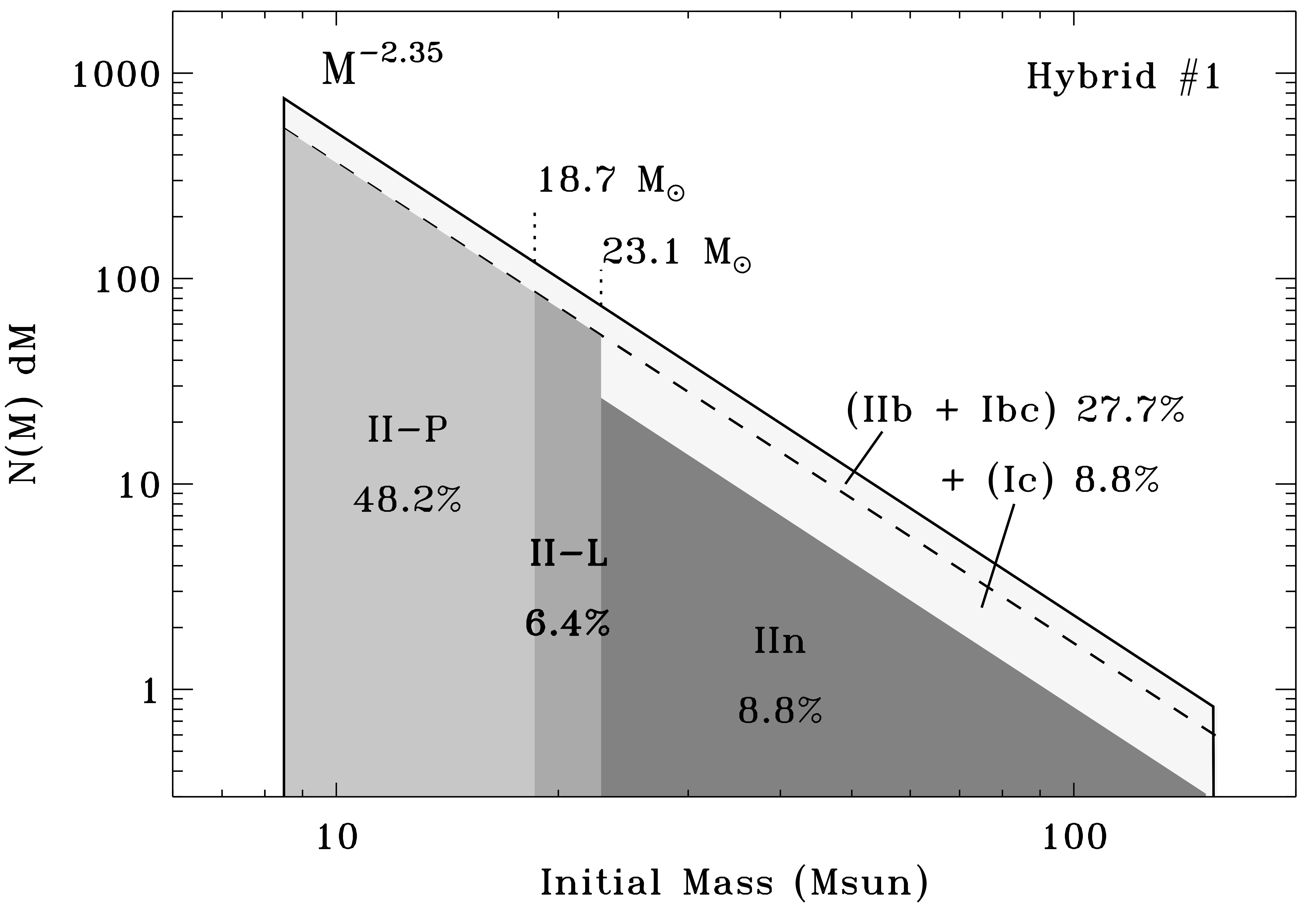
For MS/SG massive stars, q_c varies from less than 1 to larger than 20.
For RGB massive stars, q_c varies from 1.4 to 3

For MS/HG low- and intermediate-mass stars ($M>0.6M_\odot$),
if $M>1.6M_\odot$, q_c varies from 2 to 5;
if $M<1.6M_\odot$, q_c varies from 1 to 4.
For RGB/AGB HG low- and intermediate-mass stars,
q_c varies from 1 to 3.

Stripped envelope supernovae from close binaries

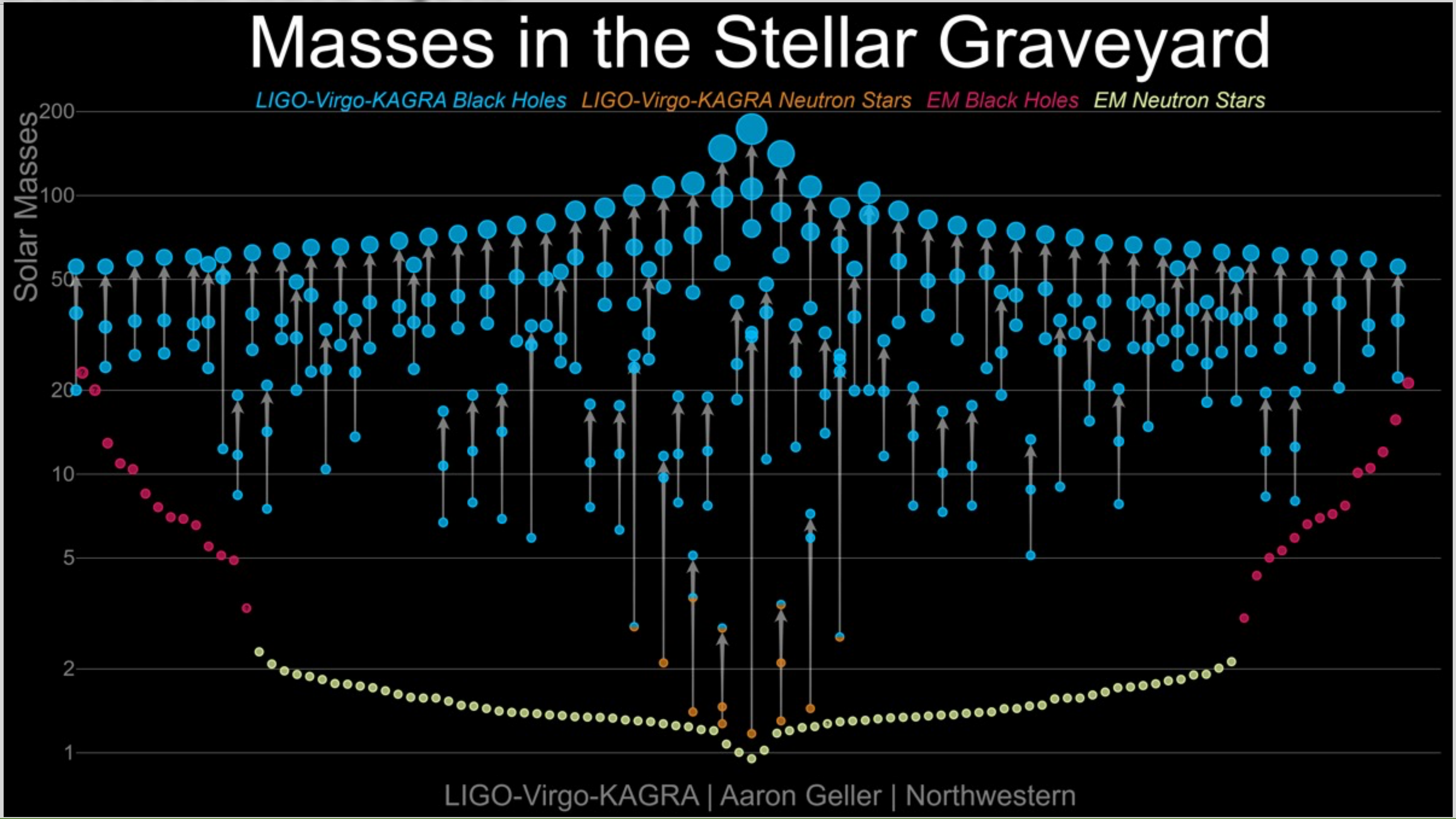


Core-Collapse SN Fractions



Smith+ 2011

Gravitational-wave objects



Double neutron stars (DNS)

* 銀河系内には19個のDNSが見つかっている (Zhu & Ashton 2020)
* 10個のDNSは宇宙年齢（13.8 Gyr）以内に合体する

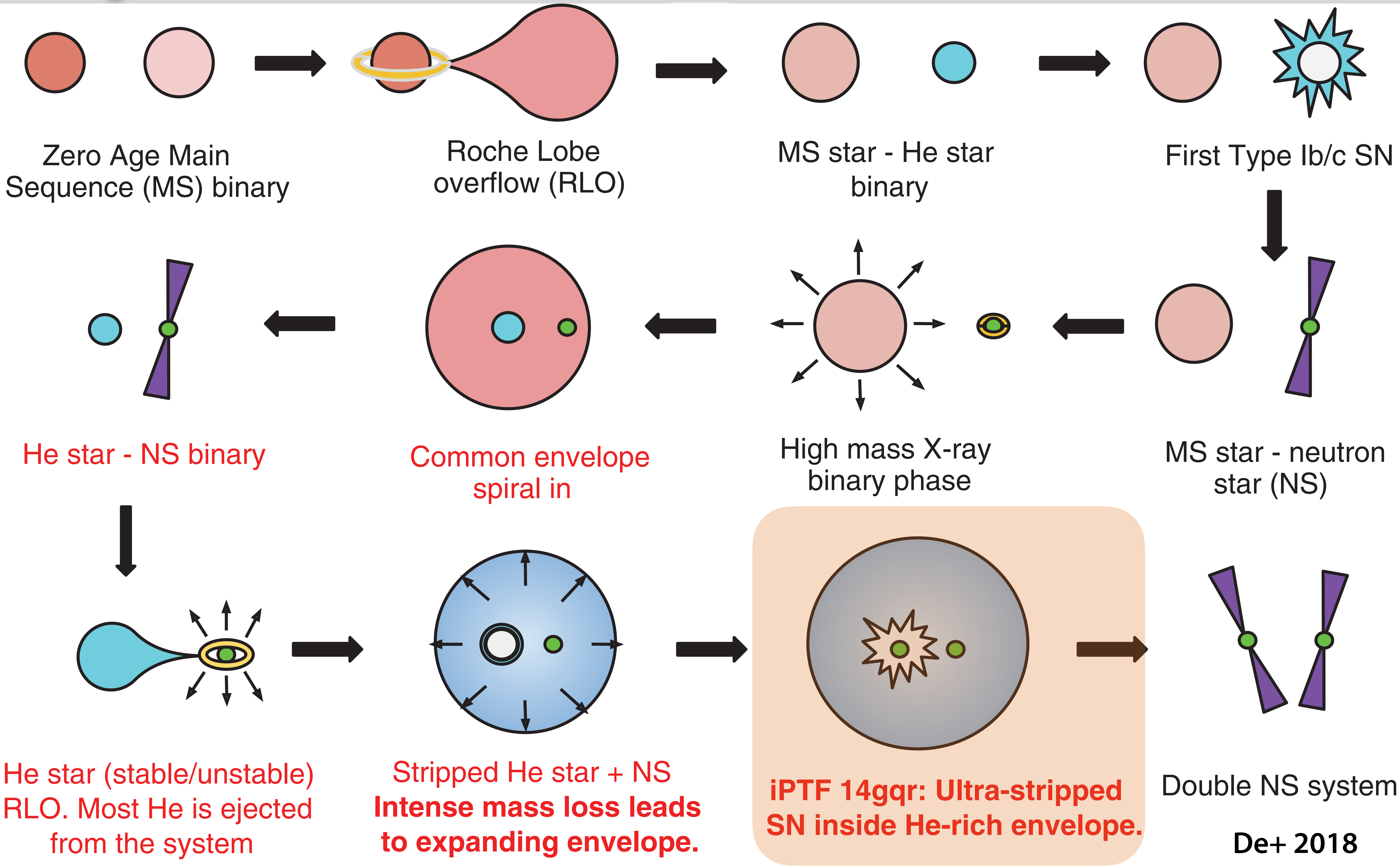
合体時間 $\tau = 1.2 \times 10^8\,\mathrm{yr} \left(\frac{a_0}{10^{11}\,\mathrm{cm}}\right)^4 \left(\frac{M_{\mathrm{tot}}}{2.8 M_\odot}\right)^{-3}$

* **いま観測されている重力波天体を説明するには** $a_0 < 3 \times 10^{11}\,\mathrm{cm}$ **が必要**

(cf. 1AU=1.5x10^{13} cm、 $R_\odot$=7x10^{10}cm)

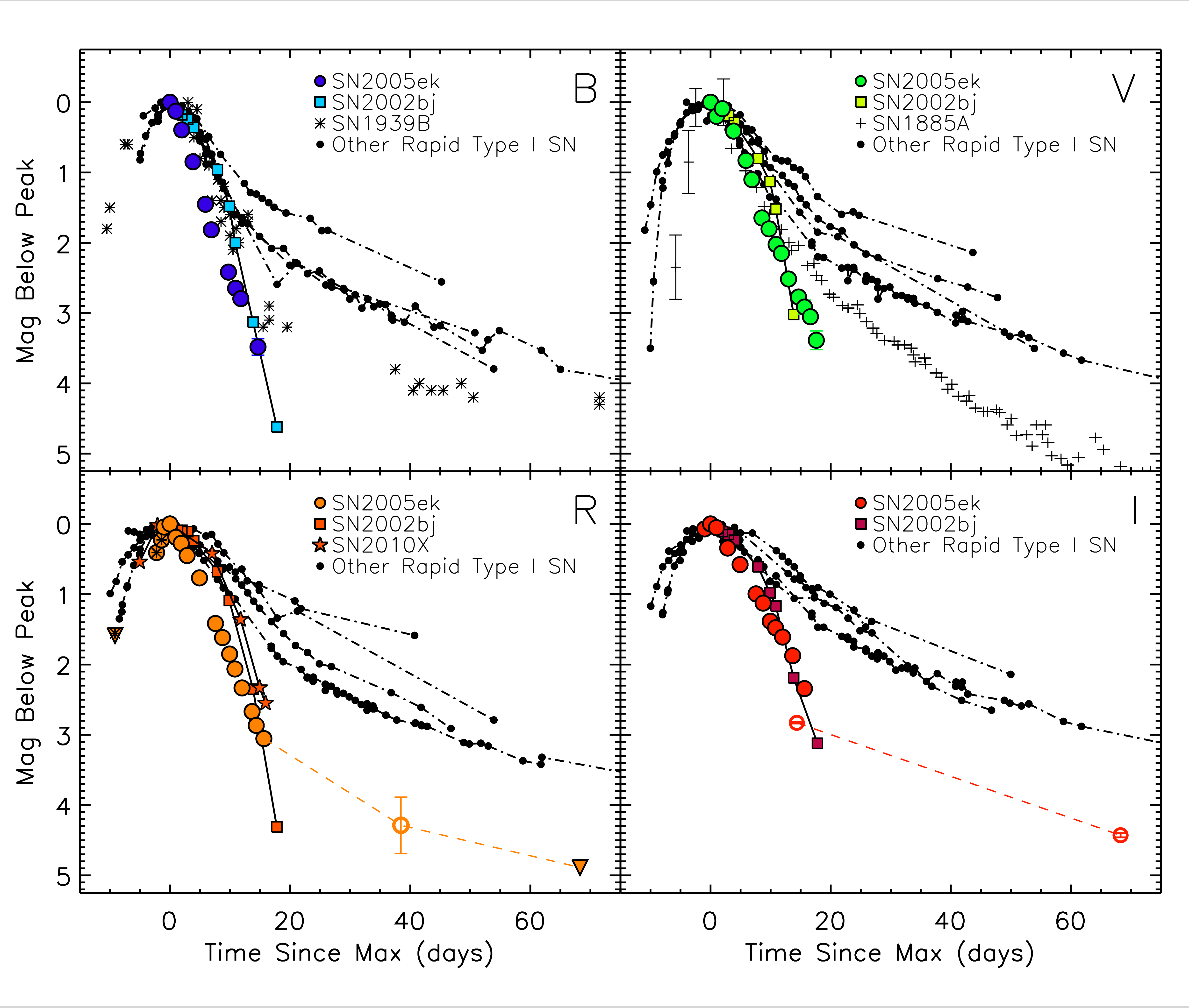
* 中性子星合体の親星は超近接連星効果を経験したはず
* **こうしたシステムから生まれる超新星はどういう超新星？**

From binary stars to DNS

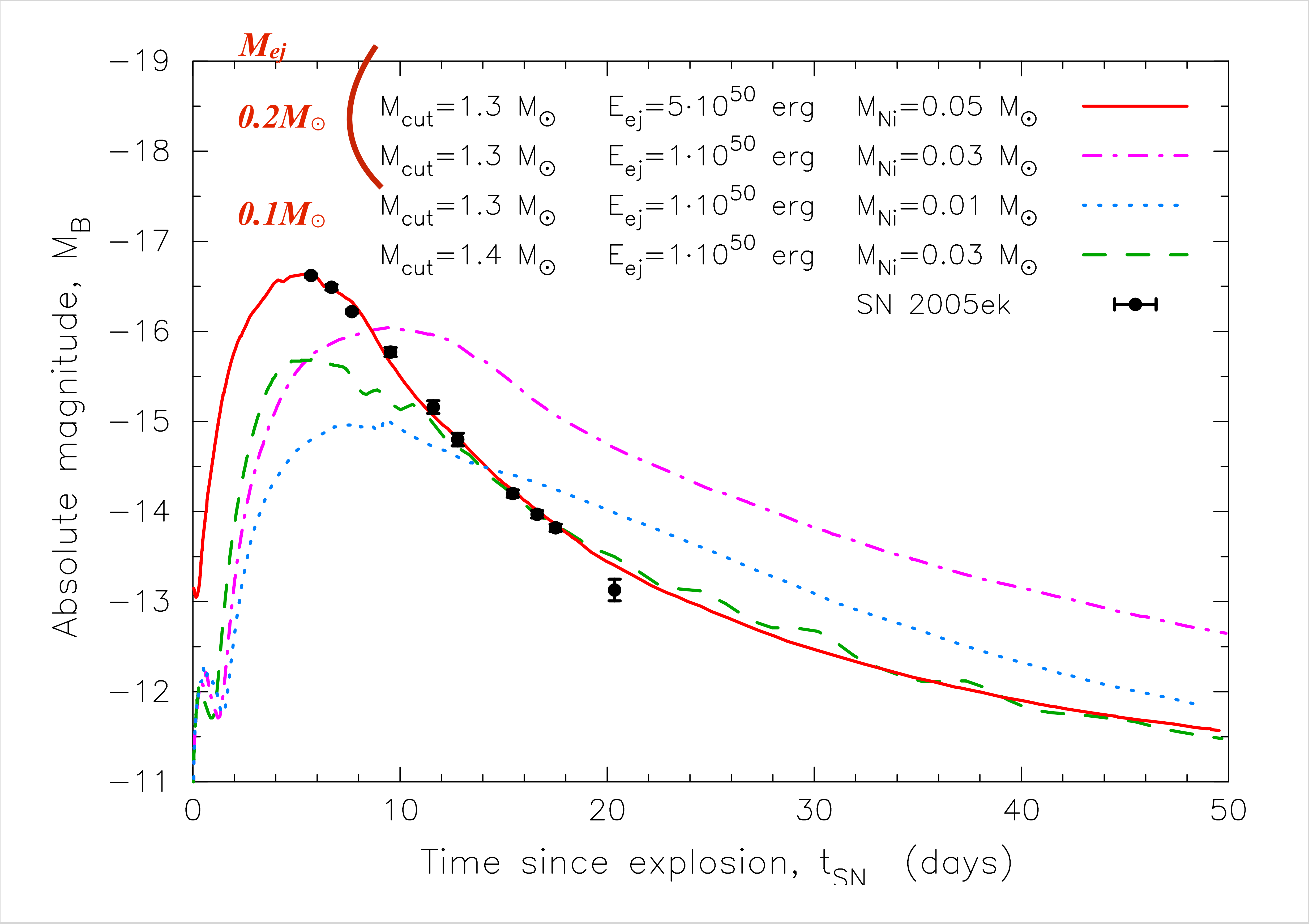


Ultra-stripped supernovae

$$\tau \sim \sqrt{\frac{\kappa M_{\rm ej}}{v_{\rm ej} c}} = 30\,{\rm day} \left(\frac{\kappa}{0.1\,{\rm cm^2/g}}\right)^{1/2} \left(\frac{M_{\rm ej}}{M_\odot}\right)^{1/2} \left(\frac{v_{\rm ej}}{10^4\,{\rm km/s}}\right)^{-1/2}$$

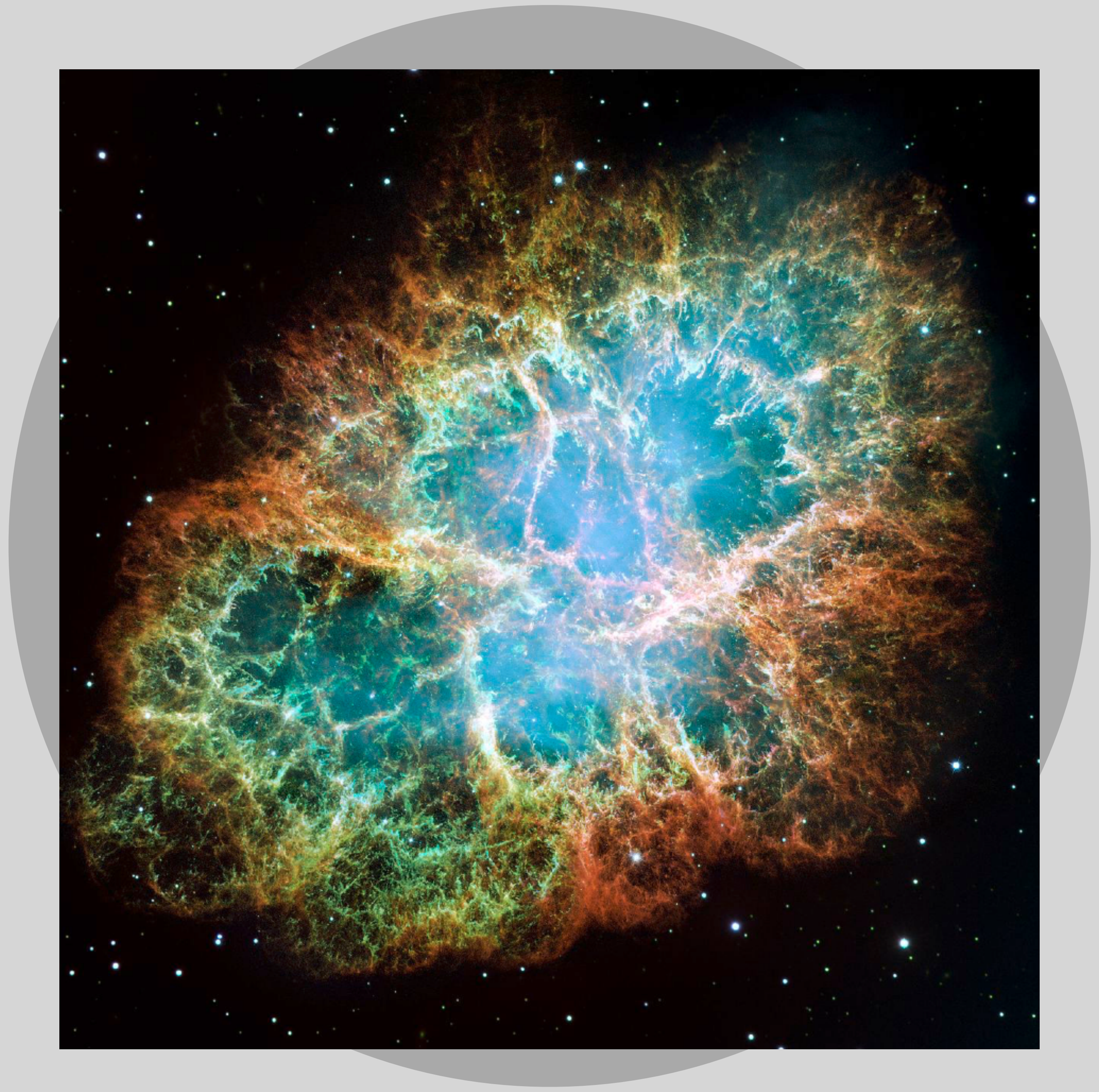


Drout+ 2013



Tauris+ 2013

Ultra-stripped supernovae

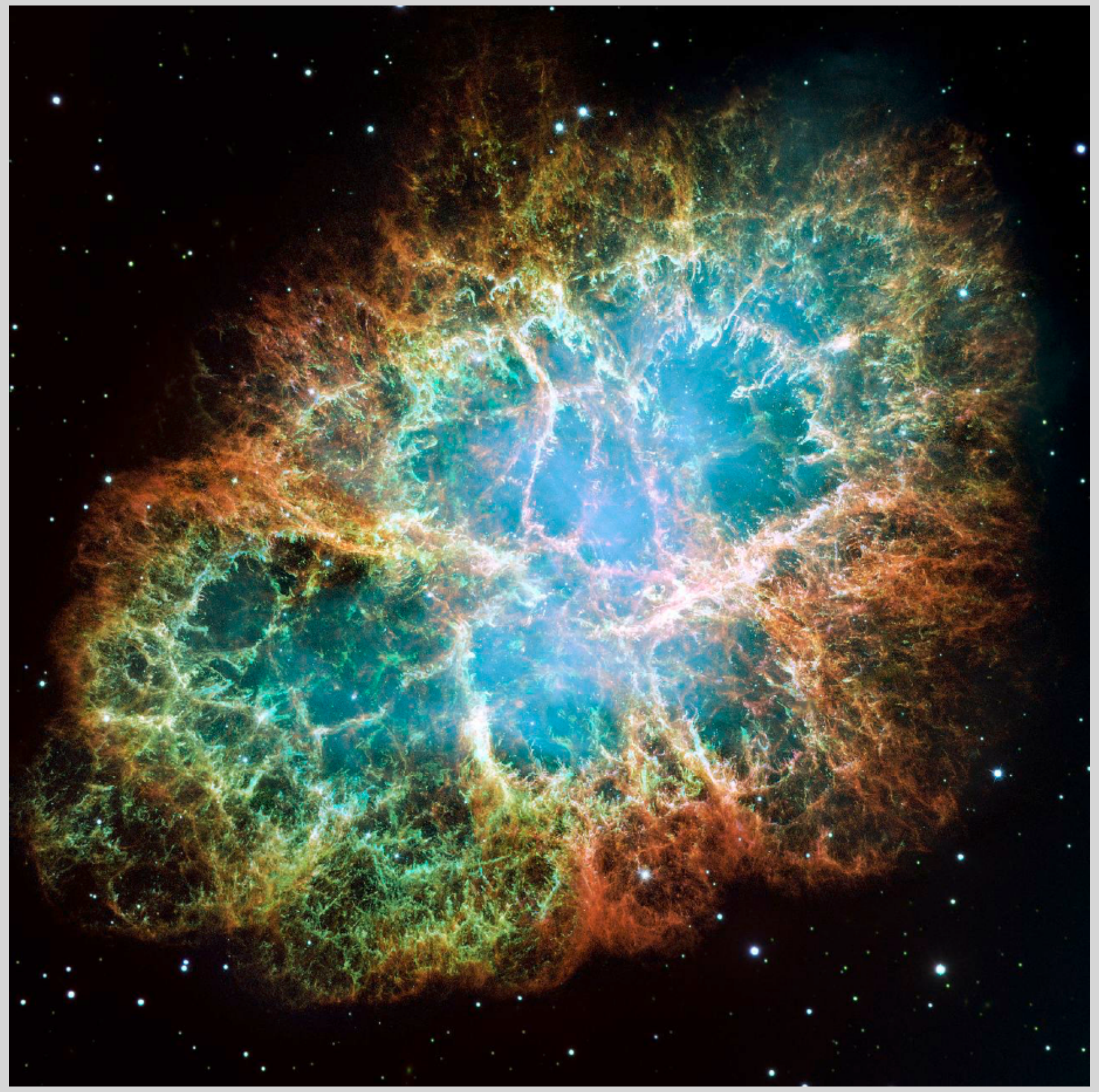


$M_{total}\sim10M_\odot$ $M_{CO}\sim3M_\odot$

type II SN
$M_{ej}\sim10M_\odot$

$M_{total}\sim5M_\odot$ $M_{CO}\sim3M_\odot$

type Ibc SN
$M_{ej}\sim3M_\odot$

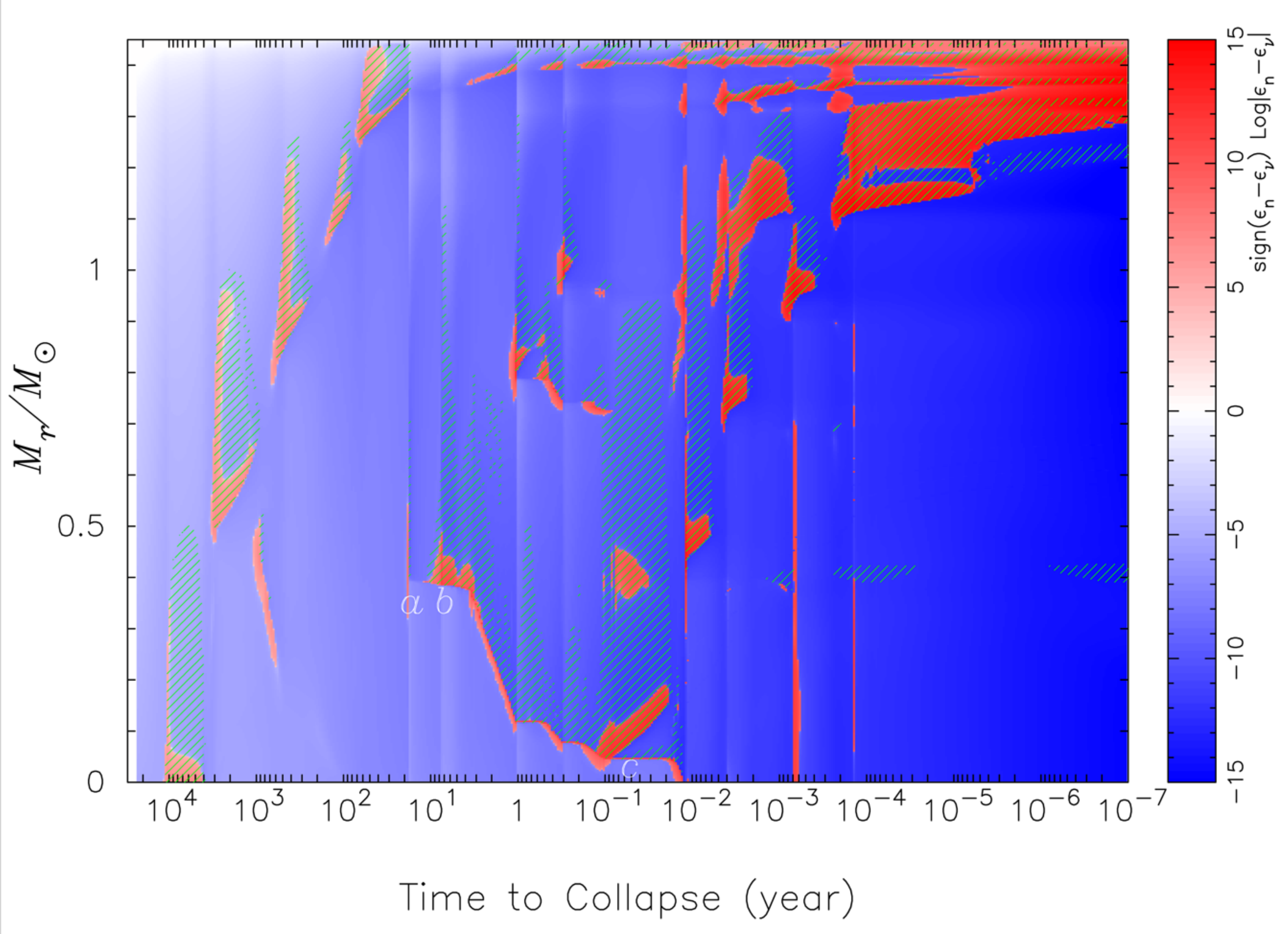


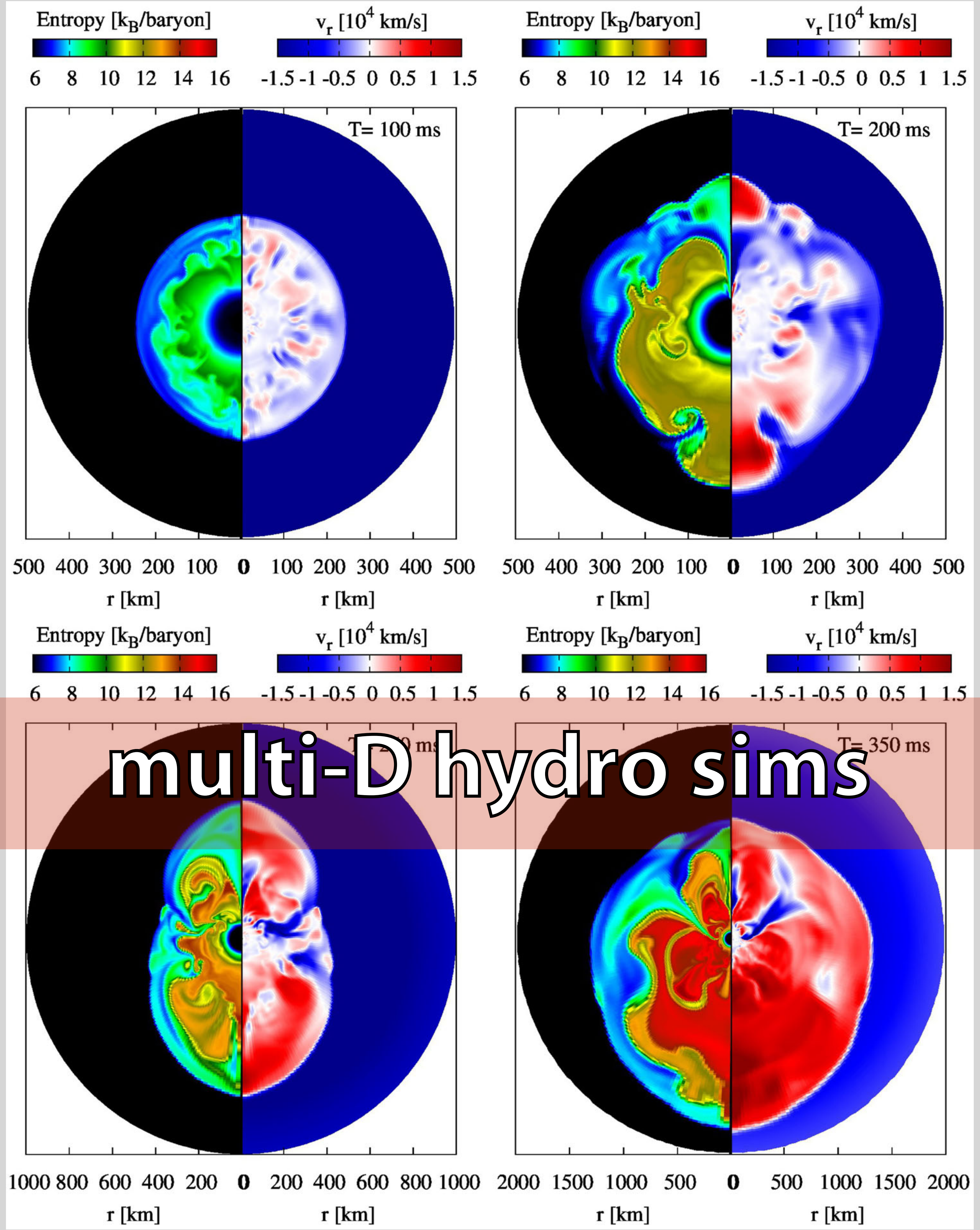
$M_{total}\sim M_{CO}\sim1.5M_\odot$

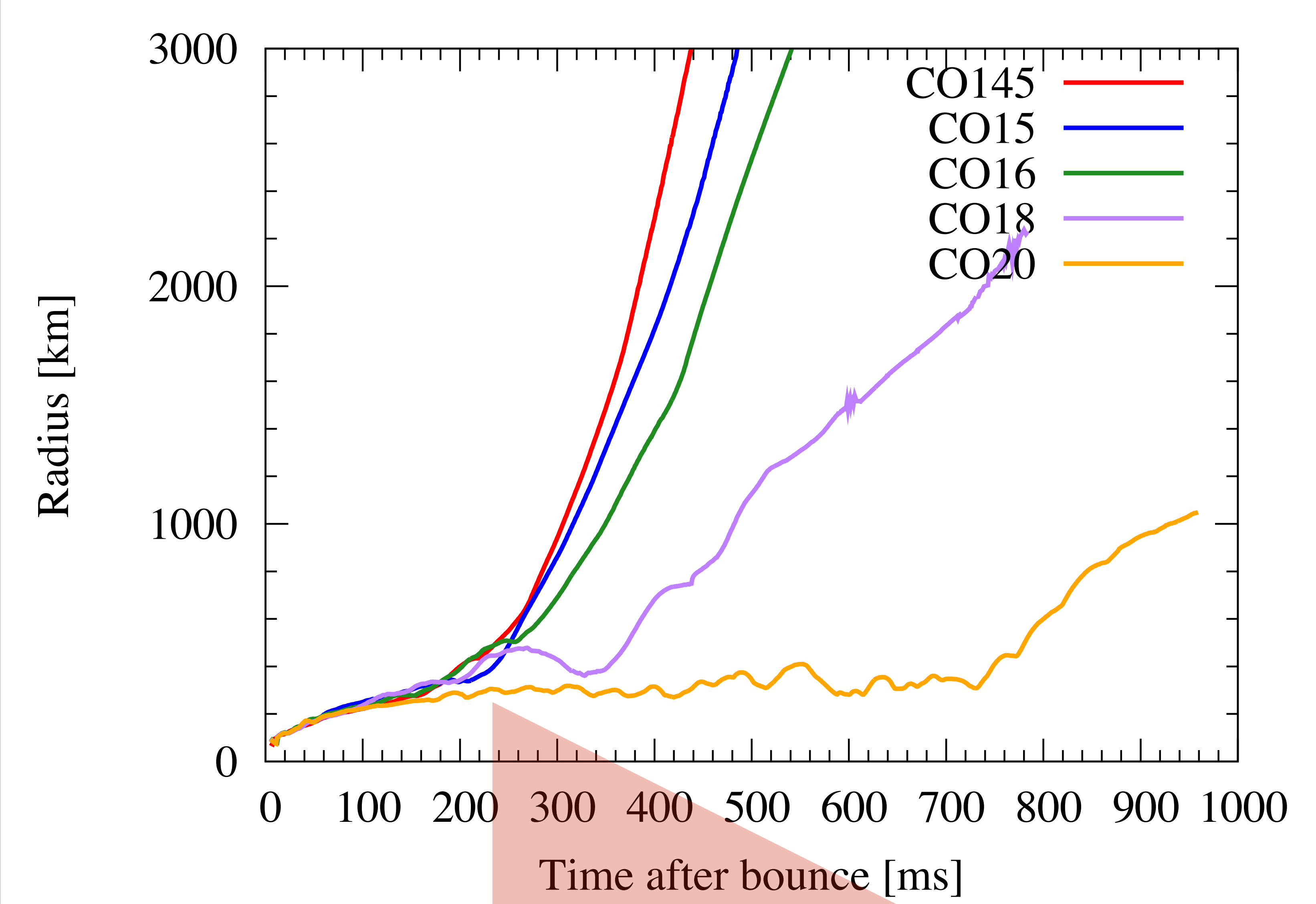
ultra-stripped SN
$M_{ej}\sim0.1M_\odot$

Neutrino-driven explosions of USSNe

[Suwa, Yoshida, Shibata, Umeda, Takahashi, MNRAS, **454**, 3073 (2015)]







stellar evolution → multi-D hydro sims → explosion

$M_{ej} = O(0.1)M_\odot$

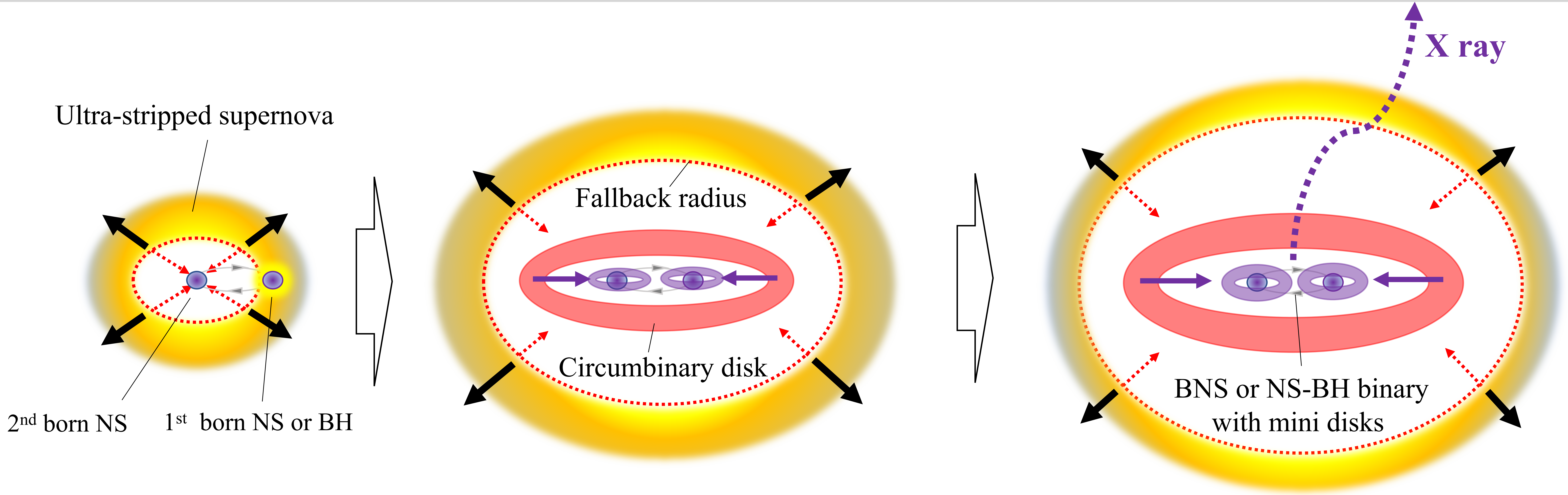
$M_{NS} \sim 1.4\ M_\odot$

$E_{exp} = O(10^{50})$ erg

$M_{Ni} = O(10^{-2})\ M_\odot$

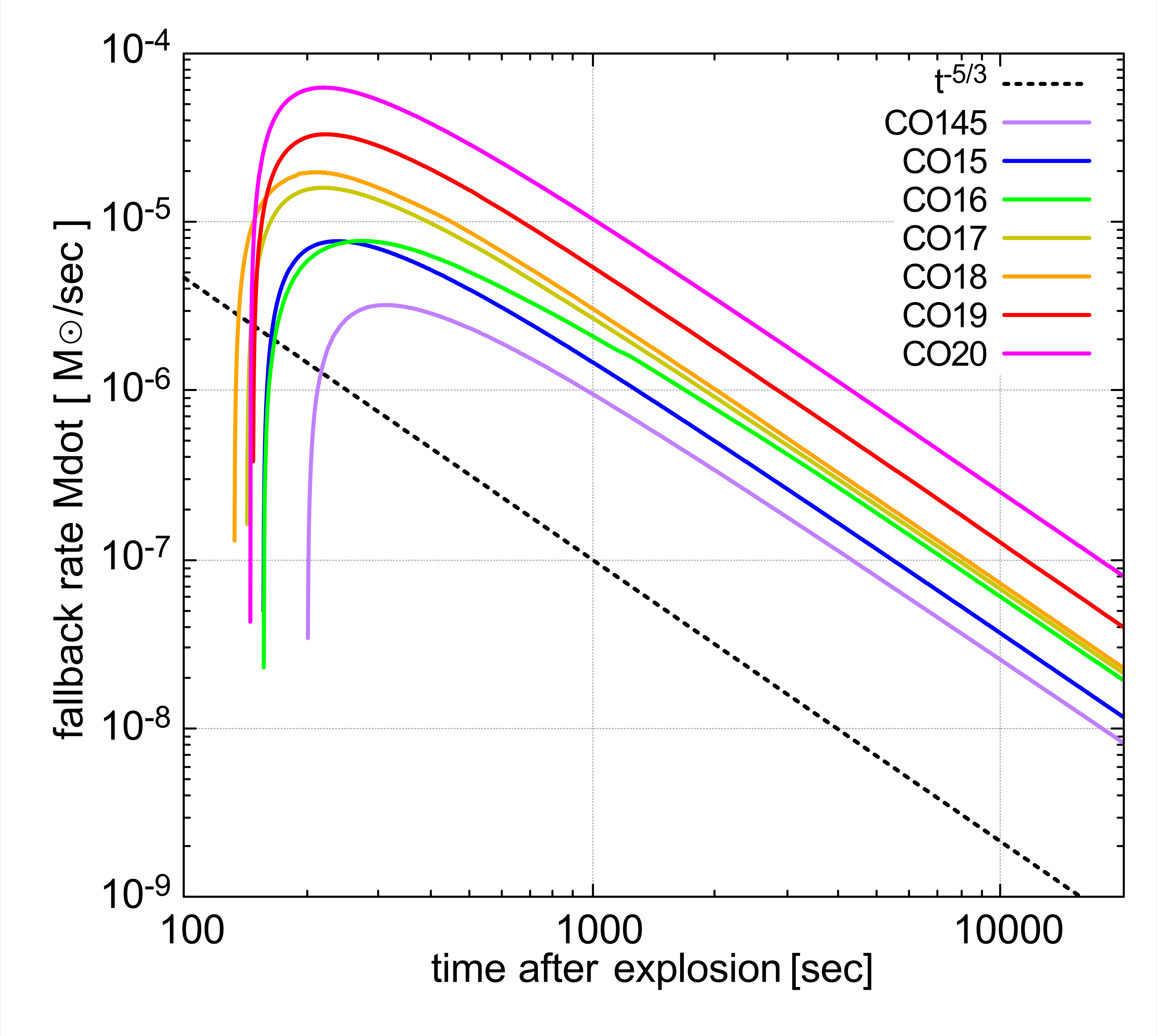
Fallback onto NSs in USSNe

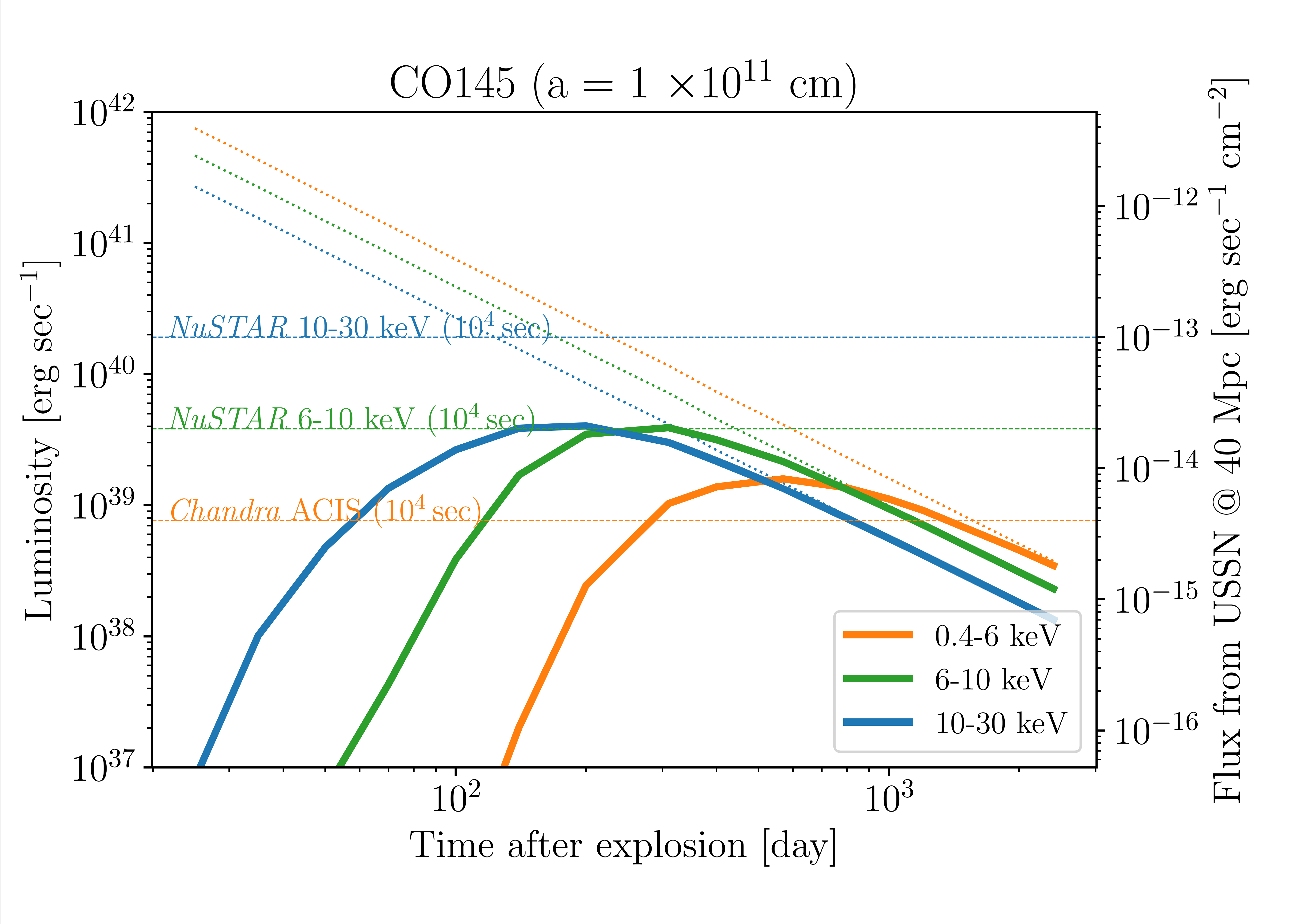
[Sawada, Kashiyama, Suwa, ApJ, **927**, 223 (2022); Kashiyama, Sawada, Suwa, ApJ, **935**, 86 (2022)]



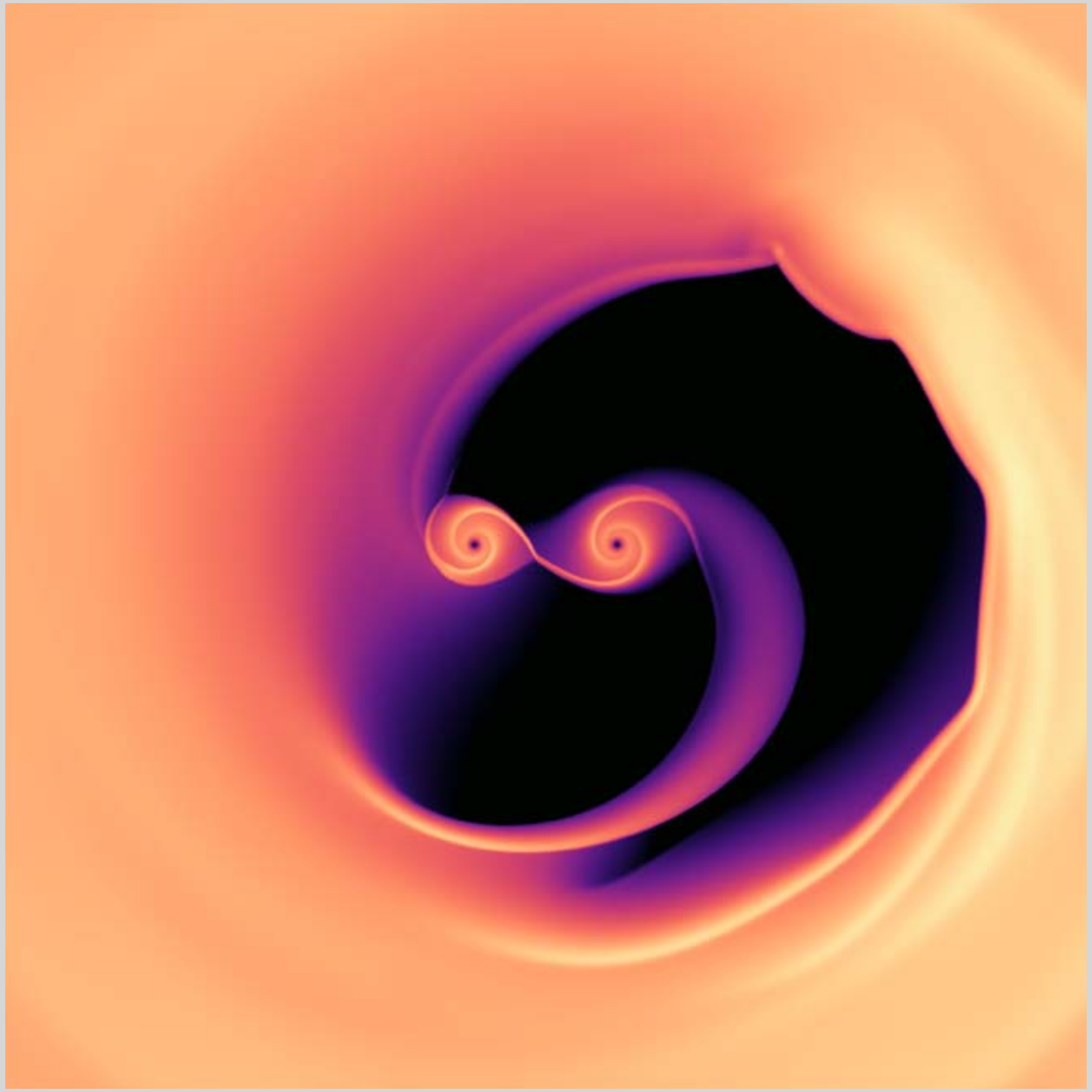
X-rays from accretion onto NS in USSNe

[Sawada, Kashiyama, Suwa, ApJ, **927**, 223 (2022); Kashiyama, Sawada, Suwa, ApJ, **935**, 86 (2022)]

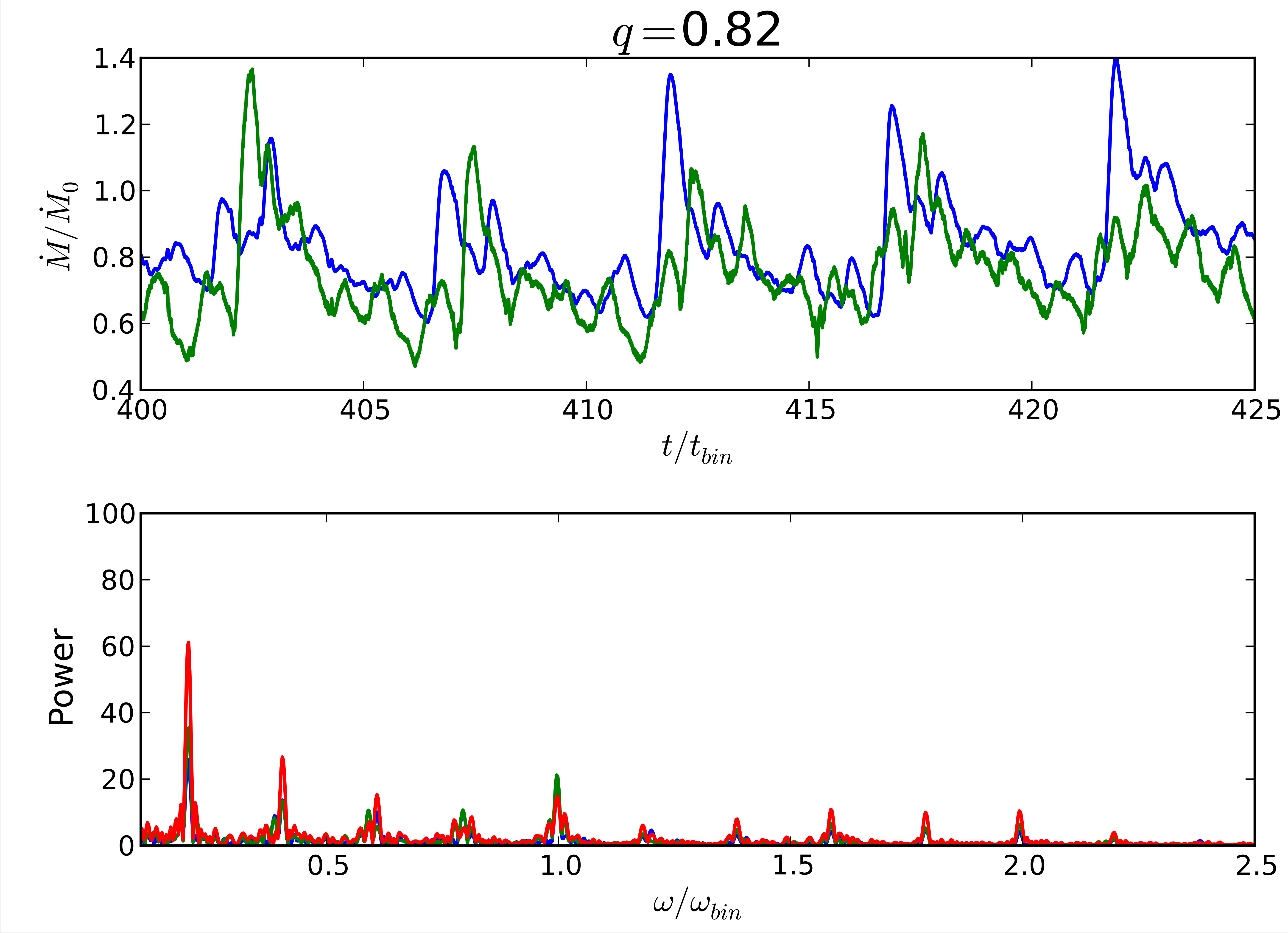




Periodic accretion onto a binary system

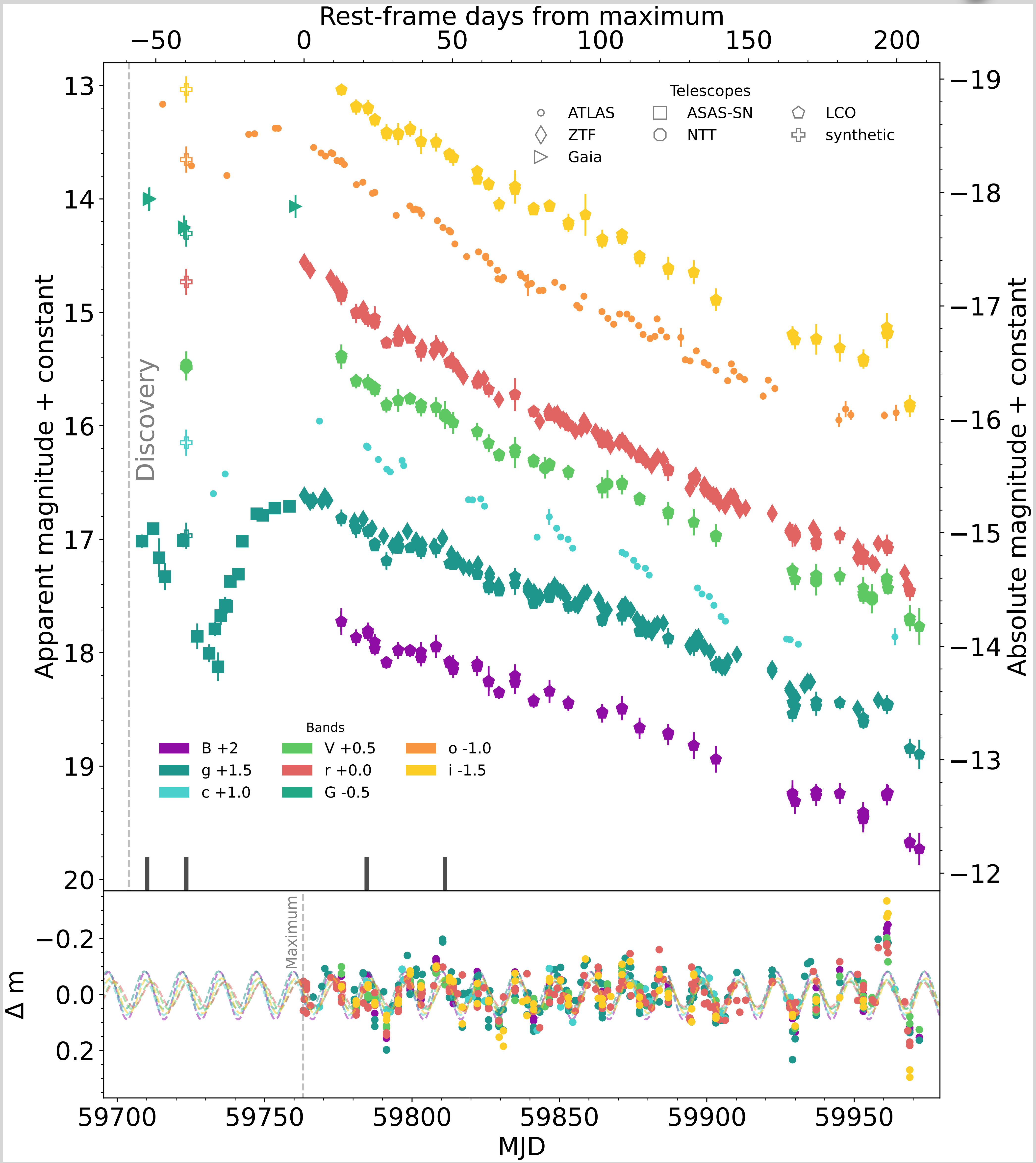


Duffell+ 2024

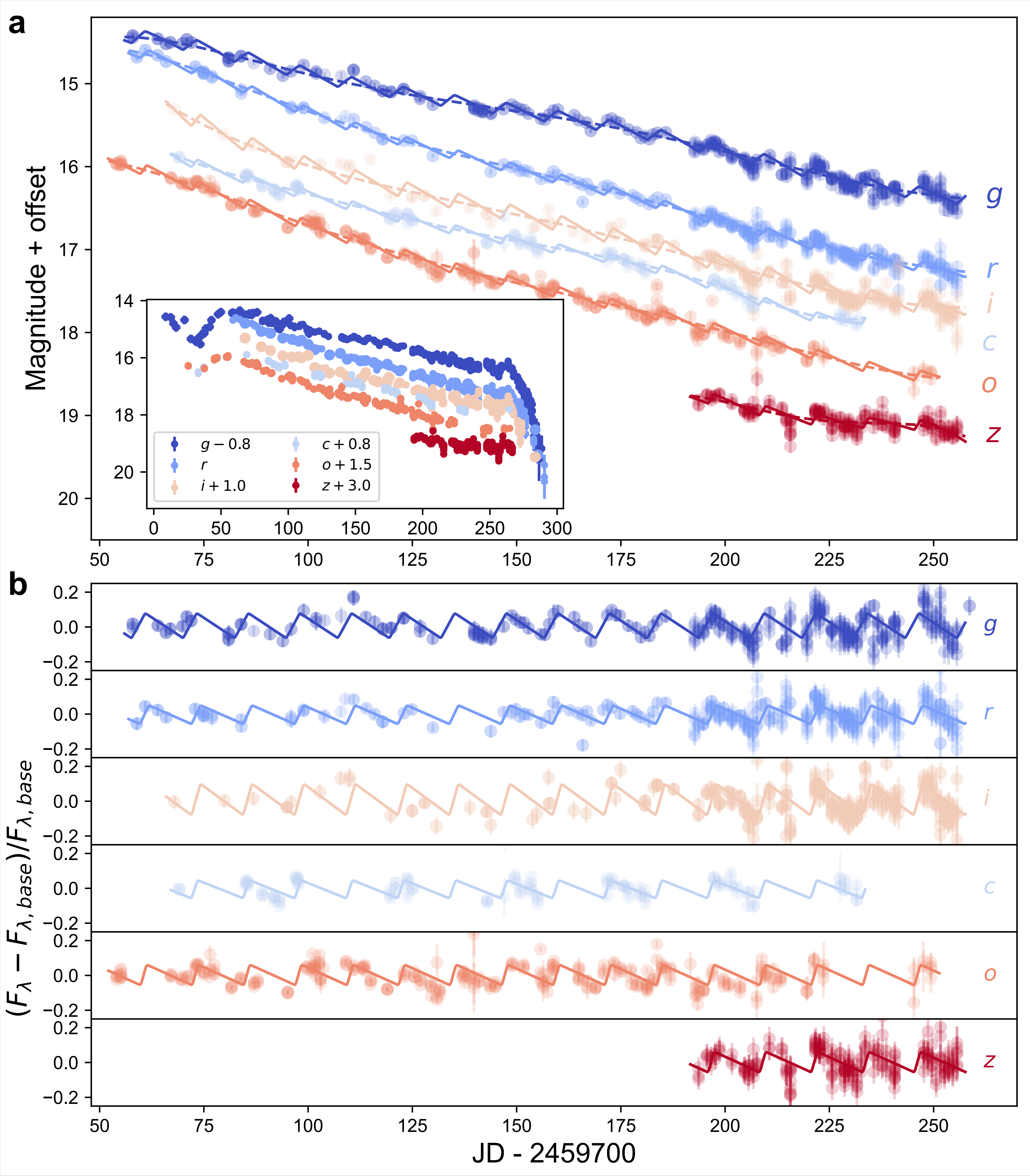


Farris+ 2014

Periodic modulation in SN 2022jli



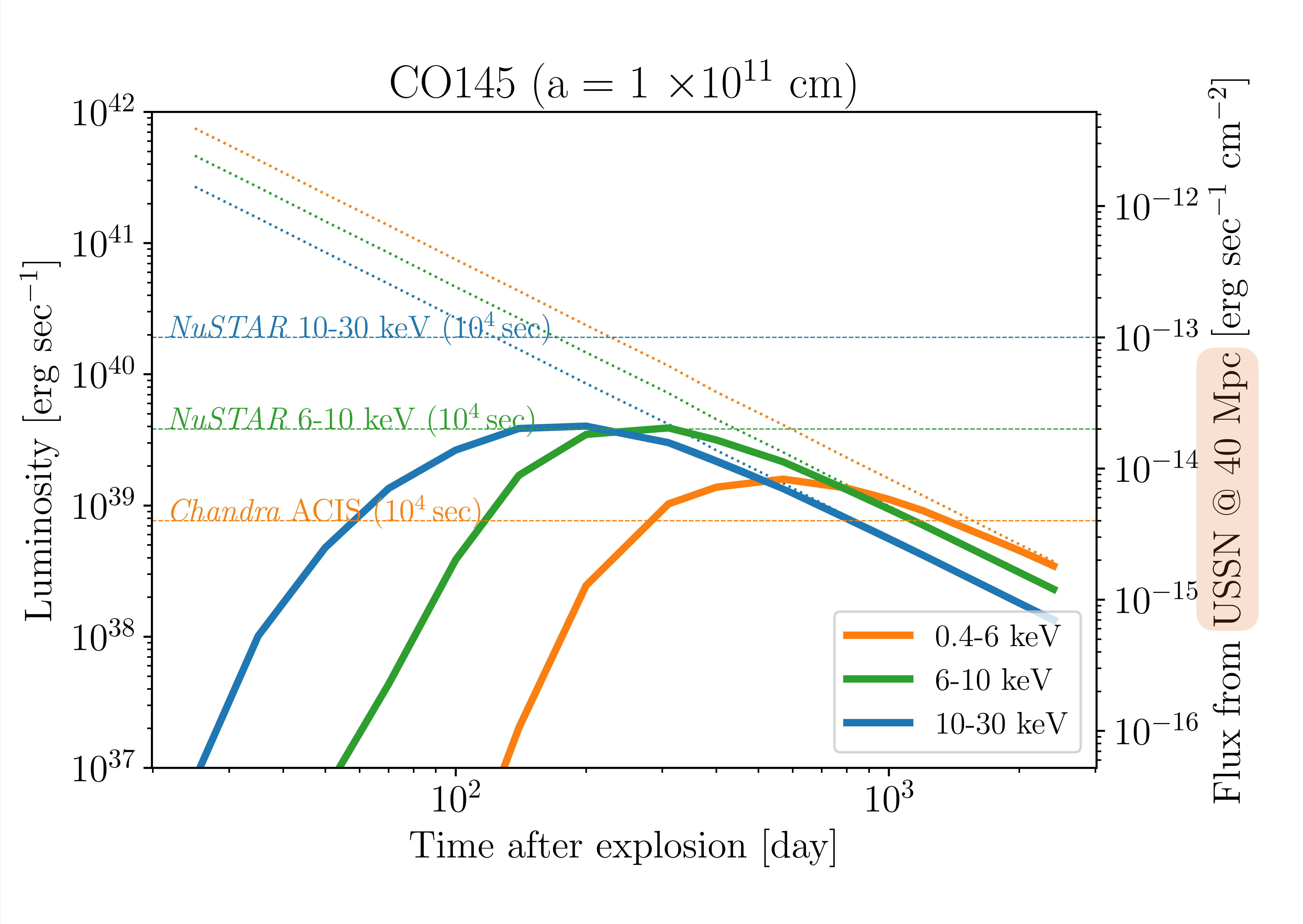
Moore+ 2023



Chen+ 2024

List of ultra-stripped SN candidates

- SN 2005ek (D~66.6 Mpc)
- SN 2010X (D~62.5 Mpc)
- iPTF14gqr (D~280 Mpc)
- iPTF15eqv (**D~26.4 Mpc**)
- iPTF16hgs (D~73.8 Mpc)
- SN 2019ehk (**D~16.2 Mpc**)
- SN 2019dge (D~93 Mpc)
- SN 2019wxt (D~154 Mpc)
- SN 2023zaw (**D~43.9 Mpc**)



Summary

* 大質量星は連星系として生まれる
* 近接連星効果が超新星の種族を決める
* 中性子星合体にいたる連星は超近接連星であり、超新星も特殊なもの（ultra-stripped SN; USSN）になる
* USSNのフォールバックによって、爆発後O(1)年後にX線が抜けてくることが期待される
* 楕円軌道の連星への降着がX線に周期的な変動をもたらす可能性
* O(10) Mpc 以内に起こる USSN の軟X線フォローアップが重要
* 軟X線の深い観測（Chandra next?）の衛星があるとよいと思います