Progenitors of Type Ia Supernovae in early type galaxies

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Type Ia Supernovae

- standard candles, important for cosmology (dark energy)
- thermonuclear explosion of a C-O white dwarf which mass reached the Chandrasekhar mass limit ($\approx 1.4\ M_\odot$)
- exact nature of progenitors still unknown
- 2 scenarios:
  - merger of two white dwarfs
  - accretion onto the WD in a close binary system

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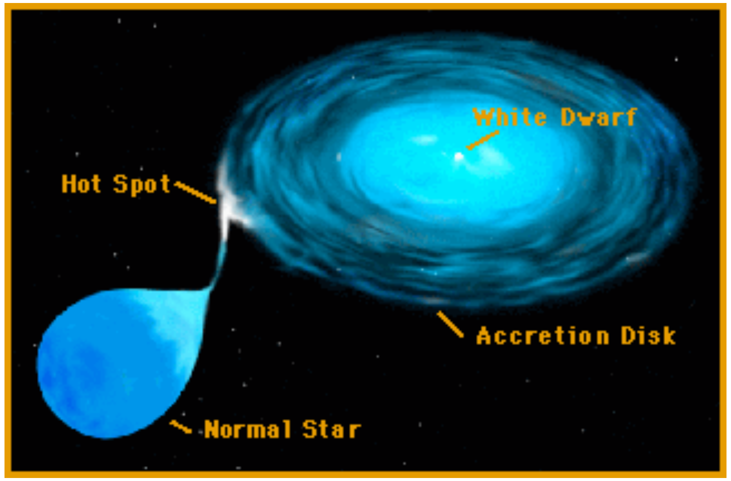
- 2 scenarios:
  - merger of two white dwarfs
  - accretion onto the WD in a close binary system **<5-10%**

Accretion scenario predicts:

- **too large** (soft) X-ray luminosity of E/S0 galaxies, **inconsistent** with **Chandra** observations
- **too frequent** Classical Novae explosions

Accretion scenario for SNe Ia progenitors



- initial white dwarf mass ~ 0.7–1.2 $M_{\odot}$
- Chandrasekhar mass limit ≈1.4 $M_{\odot}$
- need to add ≈ 0.2–0.5 $M_{\odot}$
- accretion of (hydrogen rich) material onto the WD

Energy release per one SNIa

- gravitational energy of accreted matter

$$\Delta E_{grav} = \int \frac{GM_{WD}\dot{M}(t)}{R_{WD}} dt = \int_{M_0}^{M_{Ch}} \frac{GM}{R(M)} dM \sim 4 \cdot 10^{50} \text{ erg}$$

- nuclear energy (hydrogen fusion on the WD surface)

$$\Delta E_{nuc} = \int \dot{M}(t) X_H \varepsilon_H dt = \Delta M X_H \varepsilon_H \sim 3 \cdot 10^{51} \text{ erg}$$

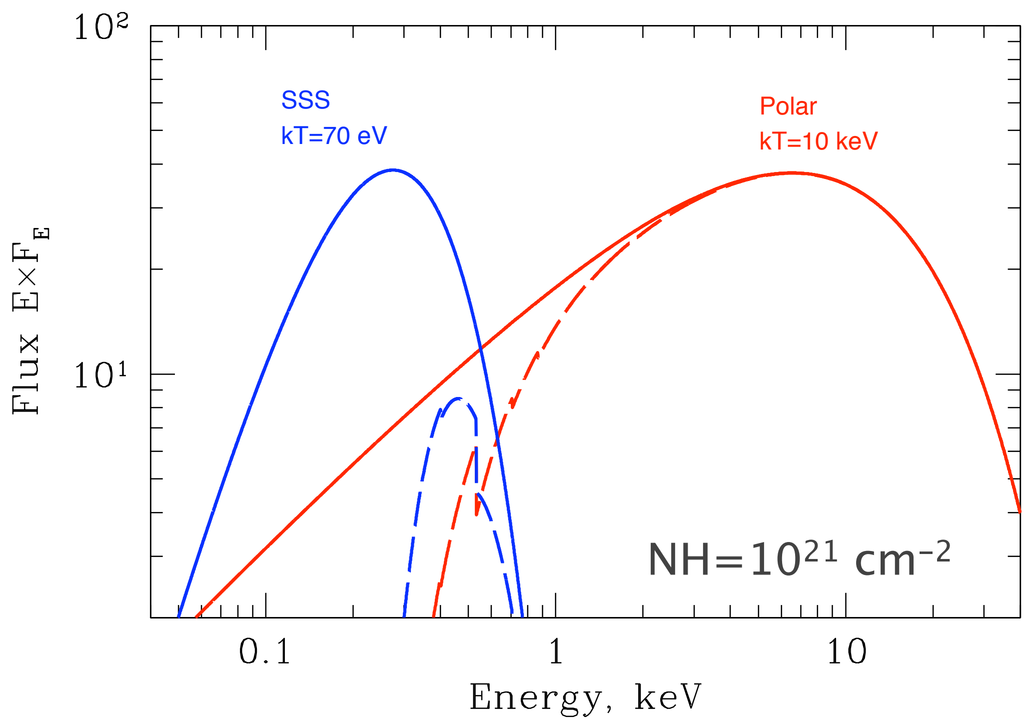
<u>prior</u> to the Supernova explosion

Combined luminosity of SNIa prog.

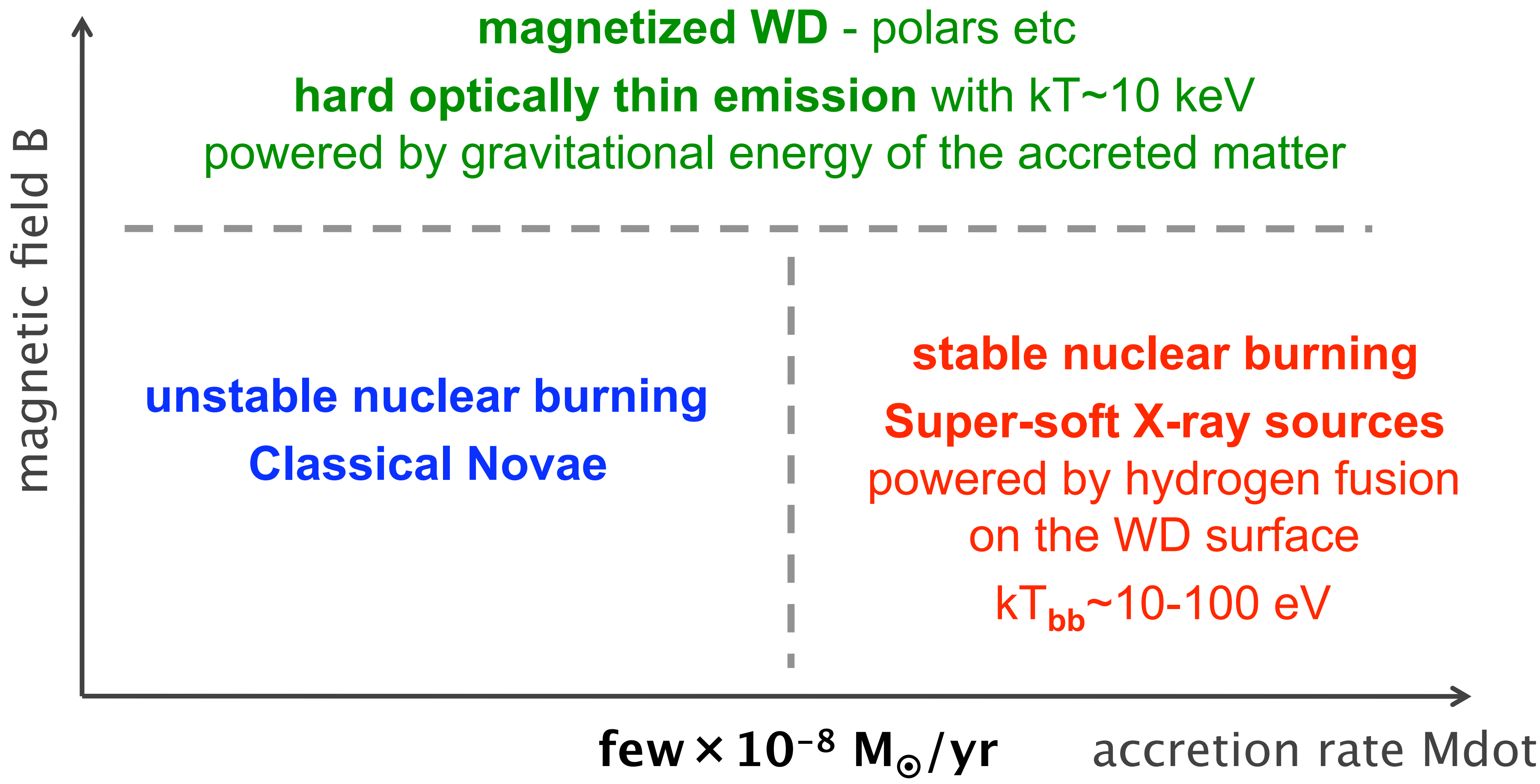
$$L_{bol} \sim (\Delta E_{grav} + \Delta E_{nuc}) \times \nu_{SNIa} \sim 10^{41-42} \text{ erg/s}$$

To compare with observations:

- absorption
- bolometric corrections
- SED of accreting WDs



Accreting white dwarfs



Accreting white dwarfs

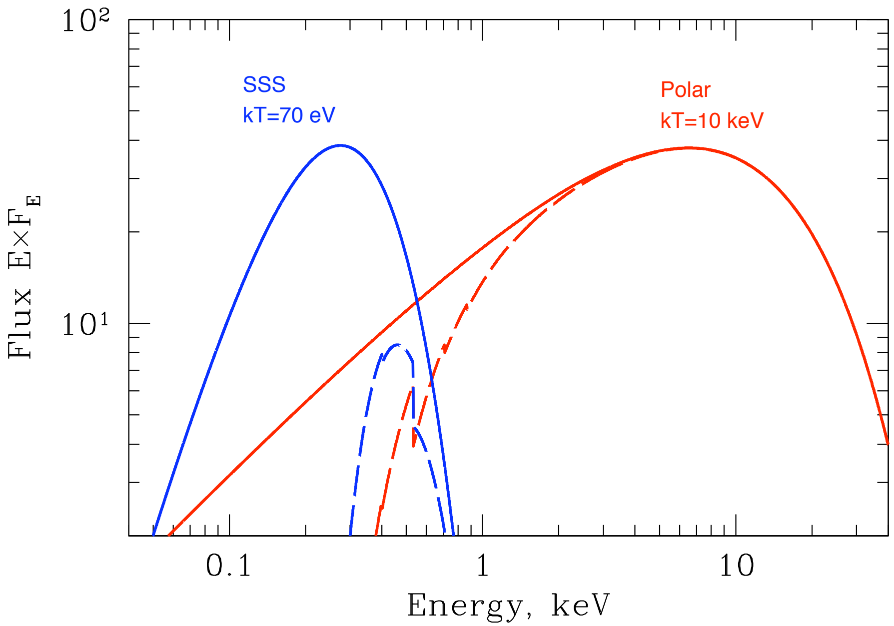
magnetized WD - polars etc

hard optically thin emission with kT~10 keV

powered by gravitational energy of the accreted matter

<1–5 %

ield B



stable nuclear burning

Super-soft X-ray sources

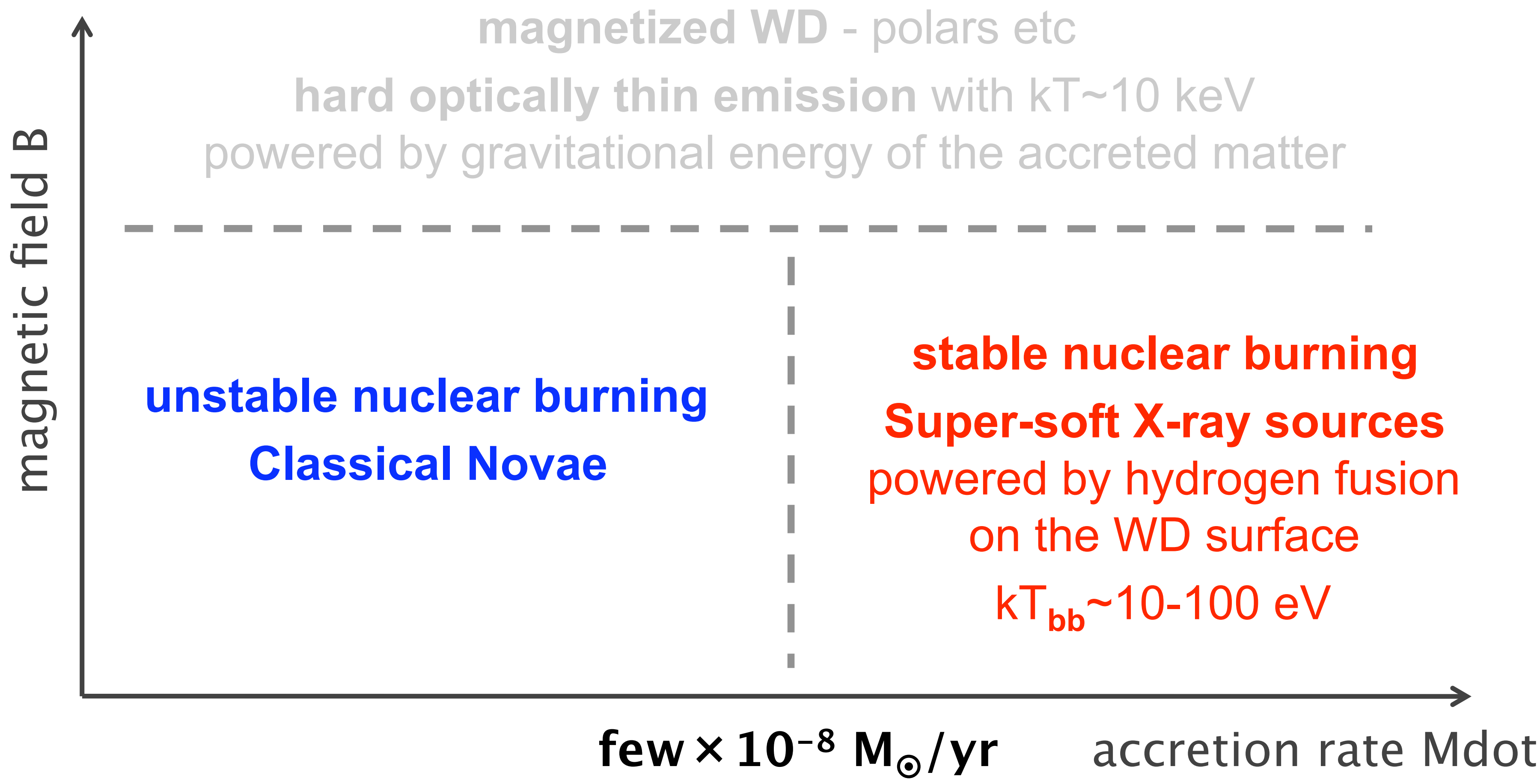
powered by hydrogen fusion on the WD surface

kT_{bb}~10-100 eV

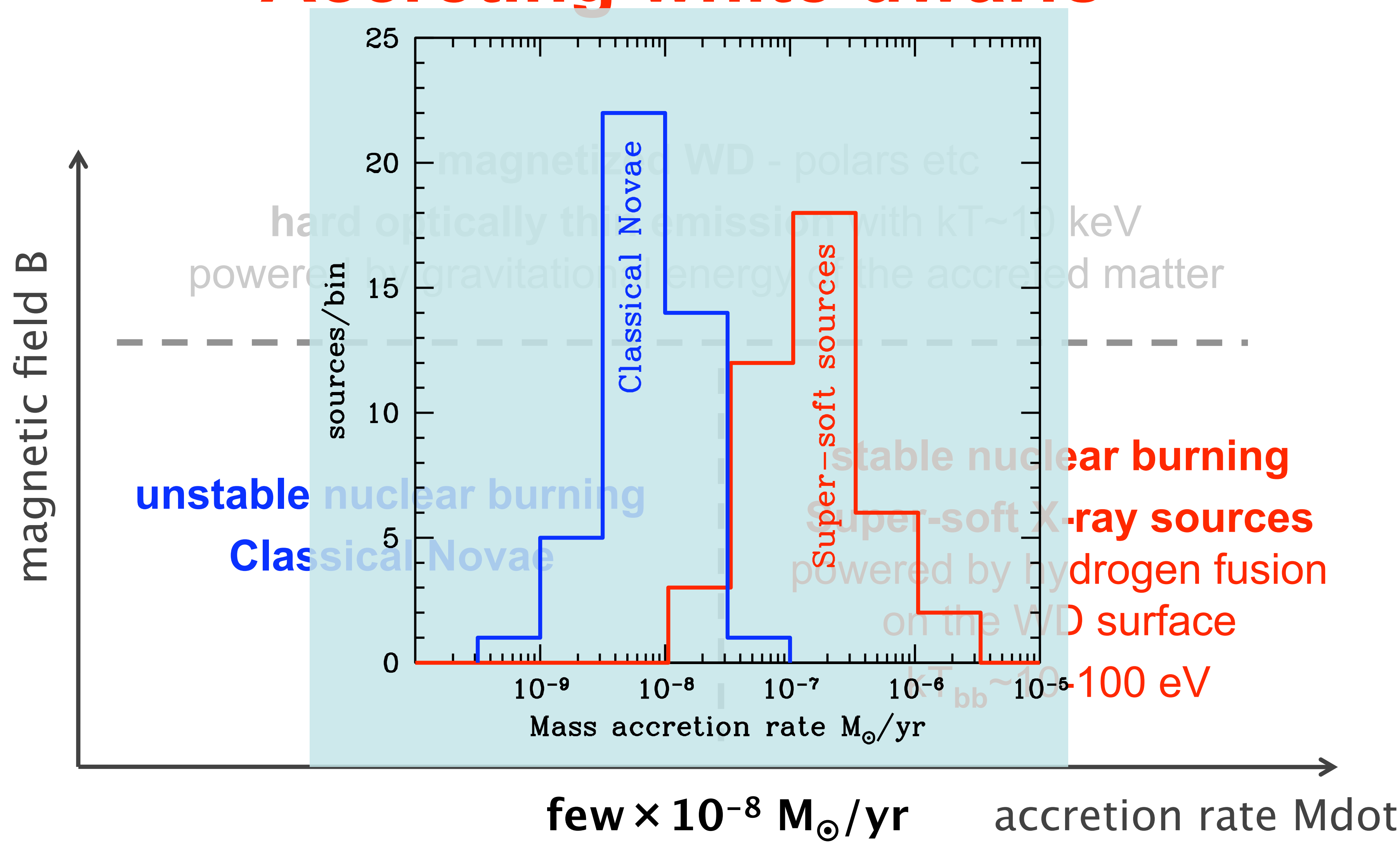
$10^{-8}\ M_\odot/yr$

accretion rate Mdot

Accreting white dwarfs



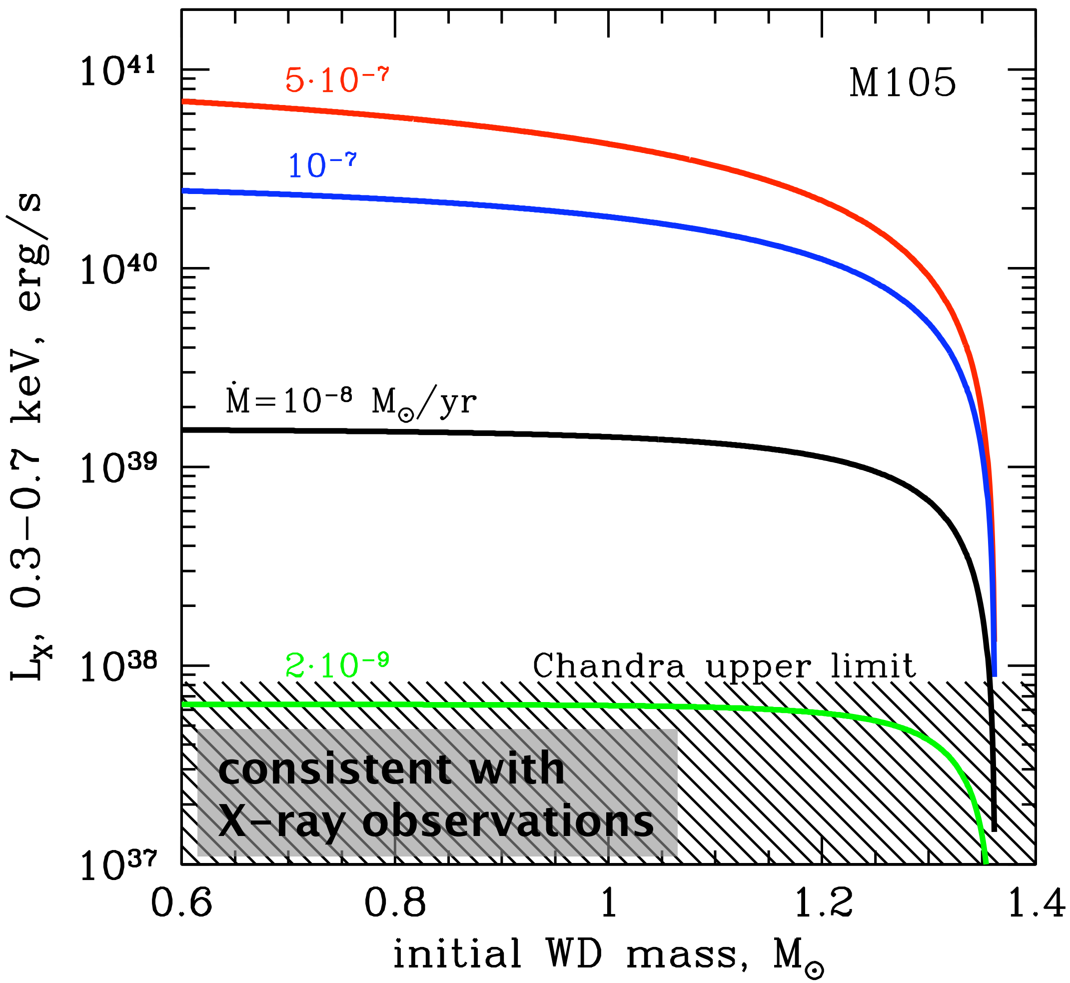
Accreting white dwarfs



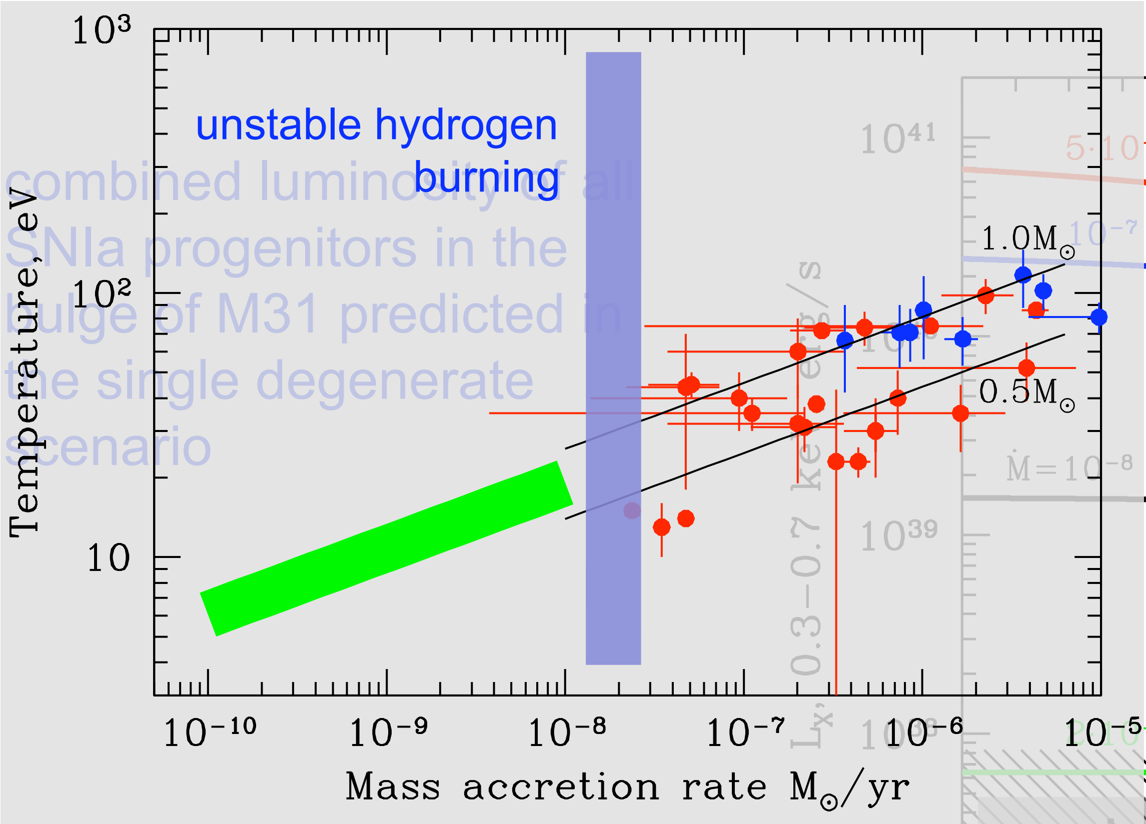
compilation of super-soft sources from Greiner, 2000
Classical Novae sample of Warner et al.

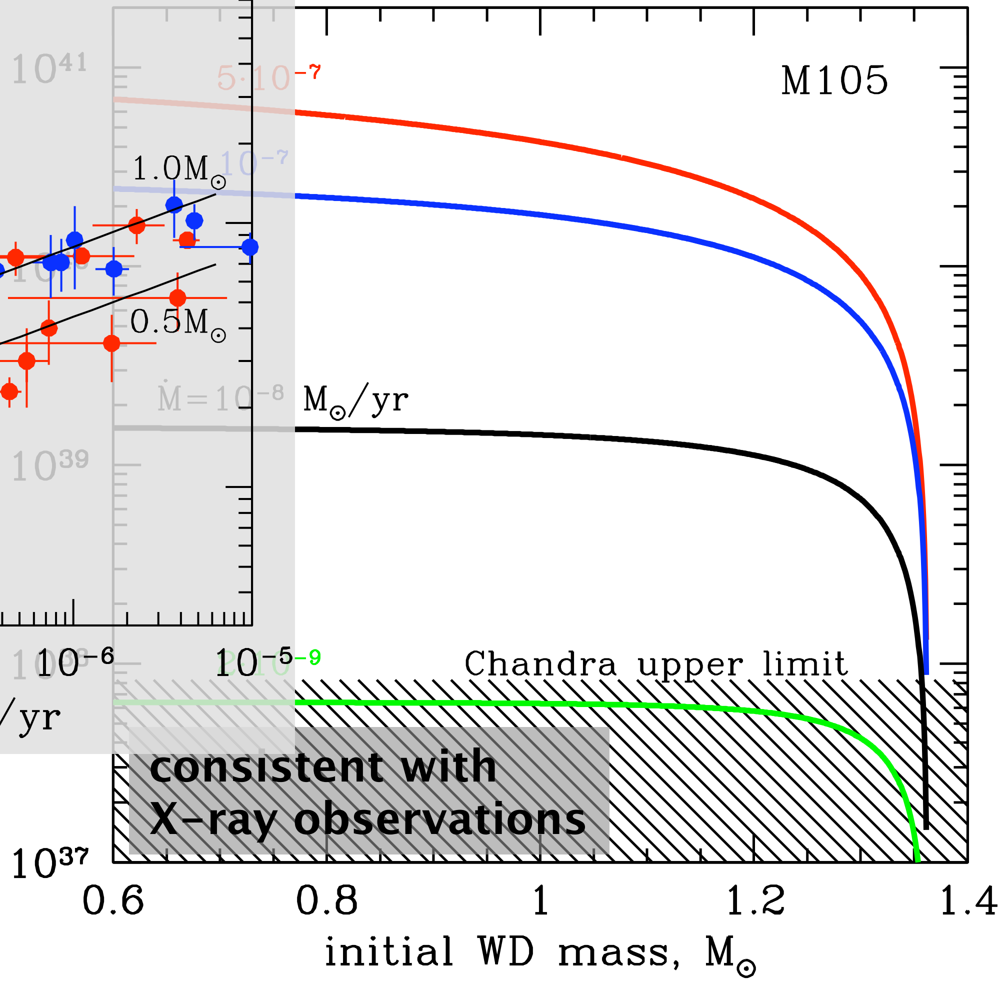
Super-soft X-ray sources

combined luminosity of all SNIa progenitors in the bulge of M31 predicted in the single degenerate scenario



Super-soft X-ray sources





compilation of
super-soft sources
from Greiner, 2000 and
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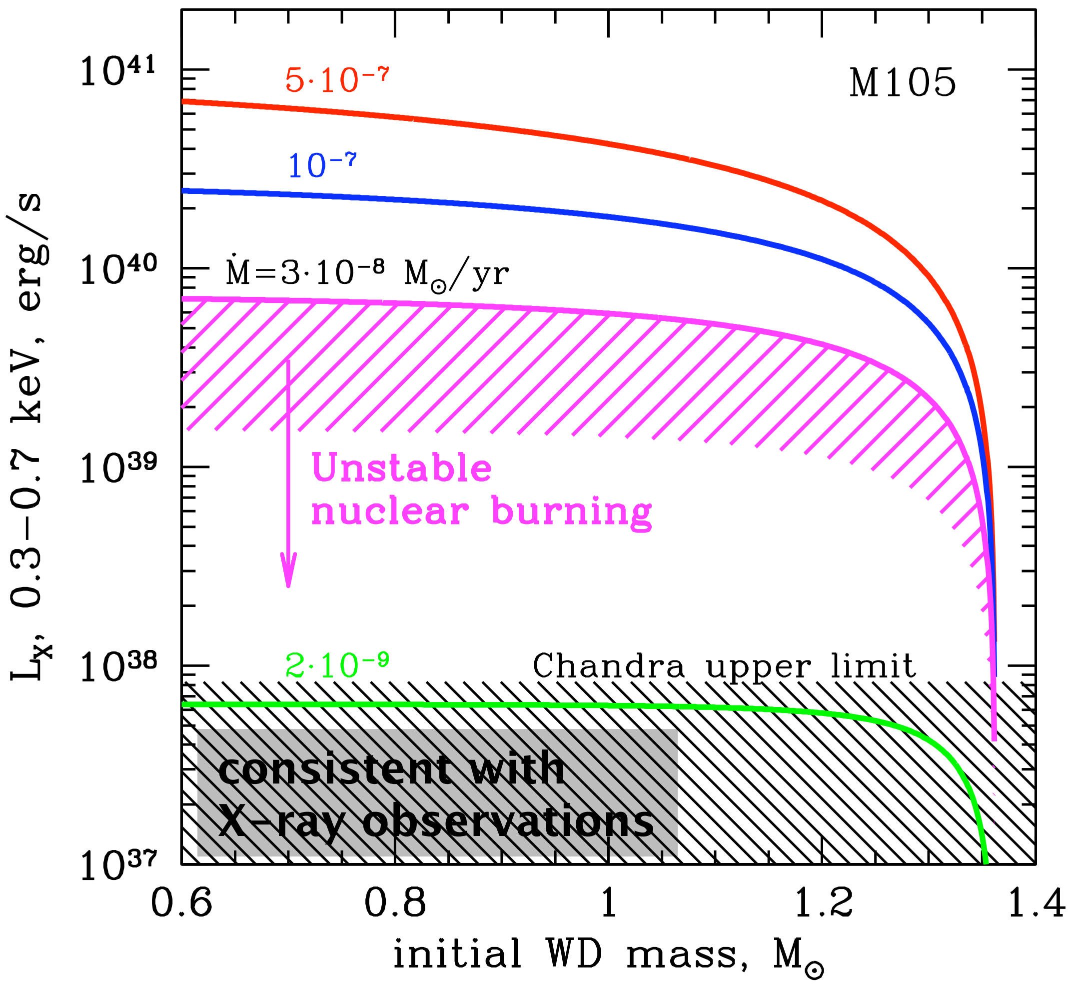
Super-soft X-ray sources

combined luminosity of all SNIa progenitors in the bulge of M31 predicted in the single degenerate scenario

SSS contribution to observed SNIa rate

<5–10 %



Classical Novae

- accreted matter is lost in CN events, **WD does not gain mass**
- independent CN frequency argument:

in the accretion scenario
CN rate ~ SN rate

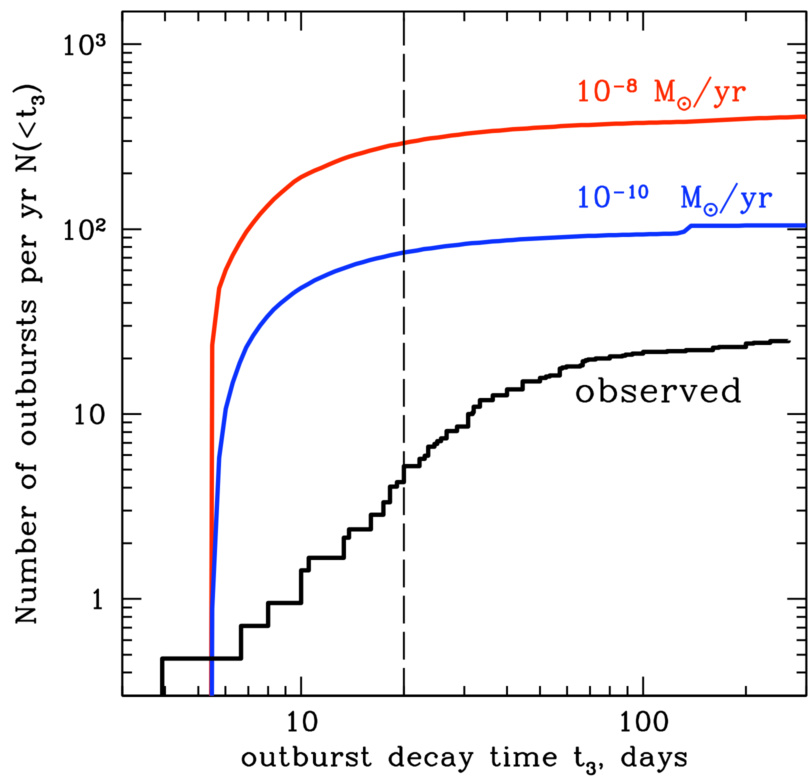
$$\Delta M_{CN}\dot{N}_{CN} \sim \Delta M_{SNIa}\dot{N}_{SNIa}$$

$$\Delta M_{CN} \sim 10^{-6} - 10^{-5} M_{\Theta}$$

$$\Delta M_{SNIa} \sim 0.3 - 0.5 M_{\Theta}$$

based on Prialnik, Kovetz et al.
observations: Arp; Capaccioli et al.

CN frequency in M31 bulge



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Classical Novae

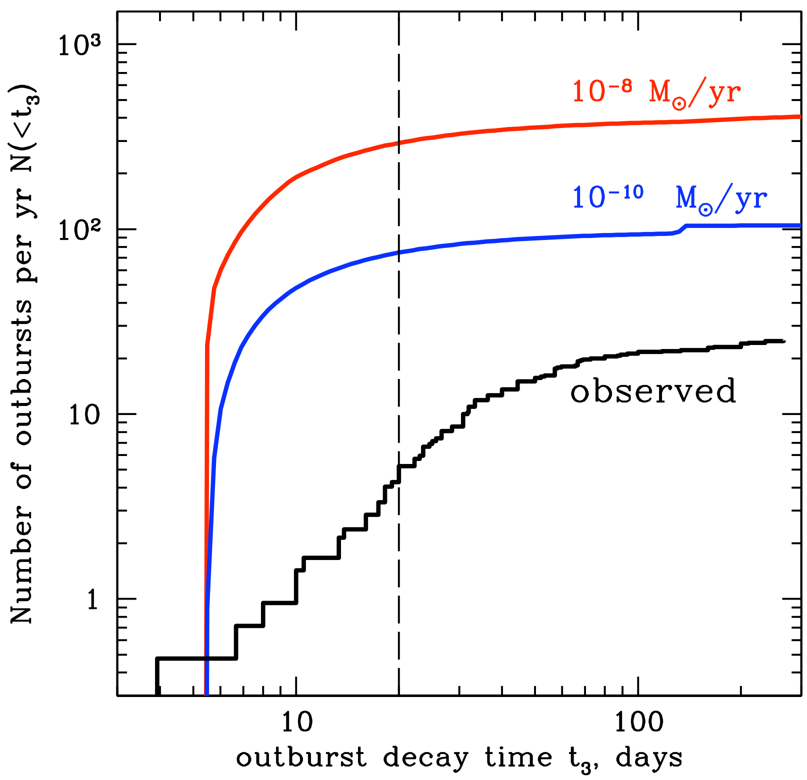
- accreted matter is lost in CN events, **WD does not gain mass**
- independent CN frequency argument:

in the accretion scenario
CN rate ~ SN rate

CN contribution to observed SNIa rate

<5–7 %

CN frequency in M31 bulge



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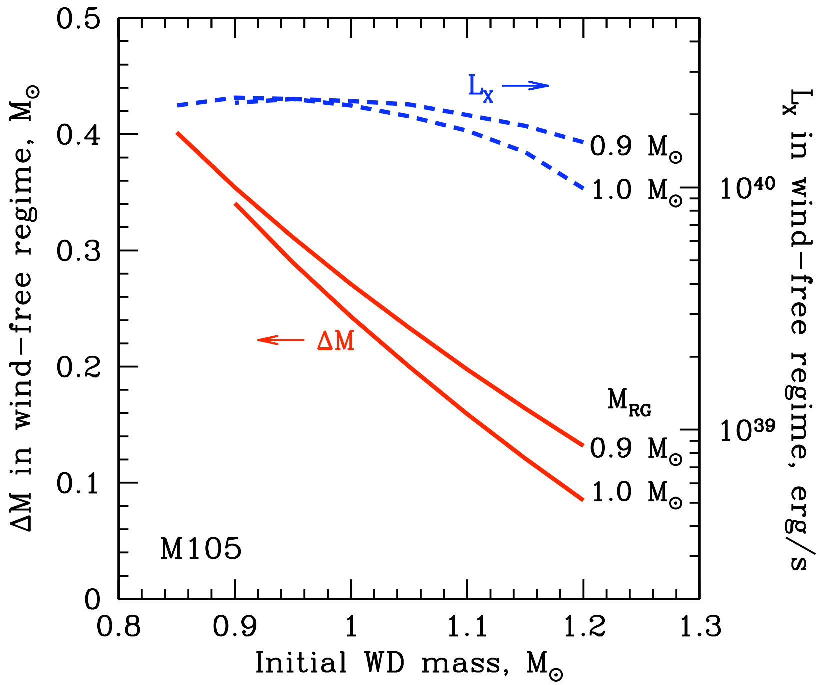
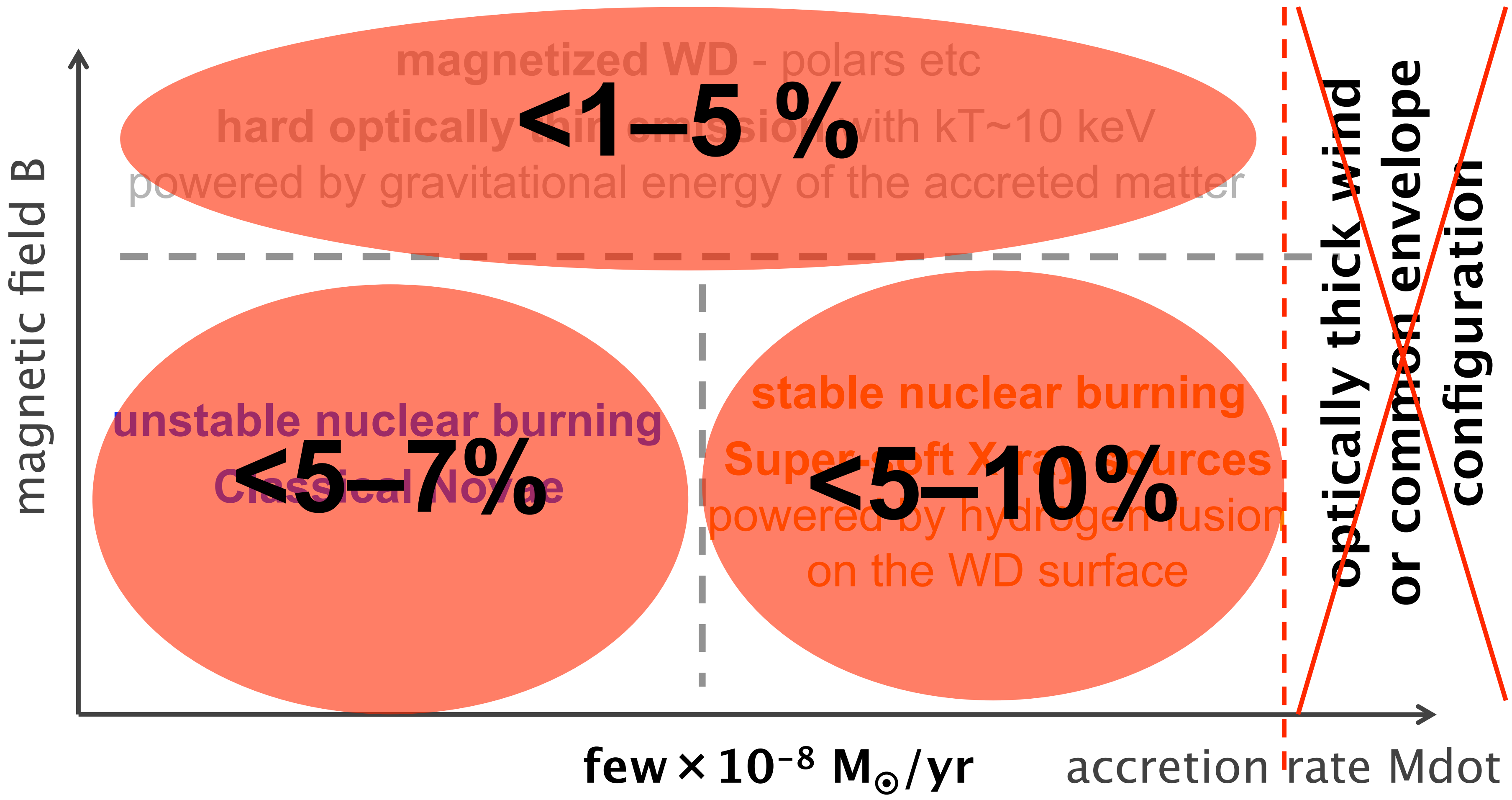
Very high Mdot regime

- common envelope configuration
- optically thick wind (Hachisu et al.)
- **low photospheric temperature** – optical, UV band

- **low mass accumulation efficiency**
- may work only with massive donor star i.e. in **young galaxies**



Contribution of accreting WD to SNIa rate in early type galaxies



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Conclusion

- **accreting WDs in binary systems can only account for <5-10 % of SNeIa in early type galaxies**

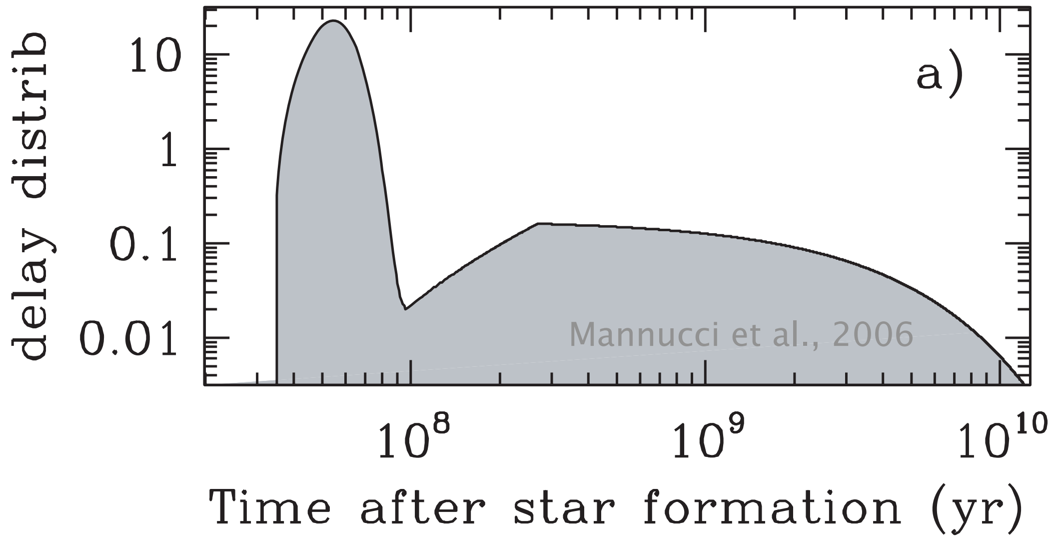
- accretion scenario predicts **too large X-ray luminosity** of SNe Ia progenitors and **too high frequency of Classical Novae**, inconsistent with observations of nearby galaxies

- unless our understanding of accretion and nuclear burning on the WD surface are fundamentally flawed

- this applies to early type galaxies (delayed SNeIa); SNIa in **star-forming galaxies (prompt SNeIa) may be different**

Thank you!

Two populations of SNIa



prompt

- t<100 Myr
- young stellar environment
- disks of spiral galaxies

delayed

- t~few Gyrs
- old stellar environment
- elliptical galaxies
  bulges of spirals

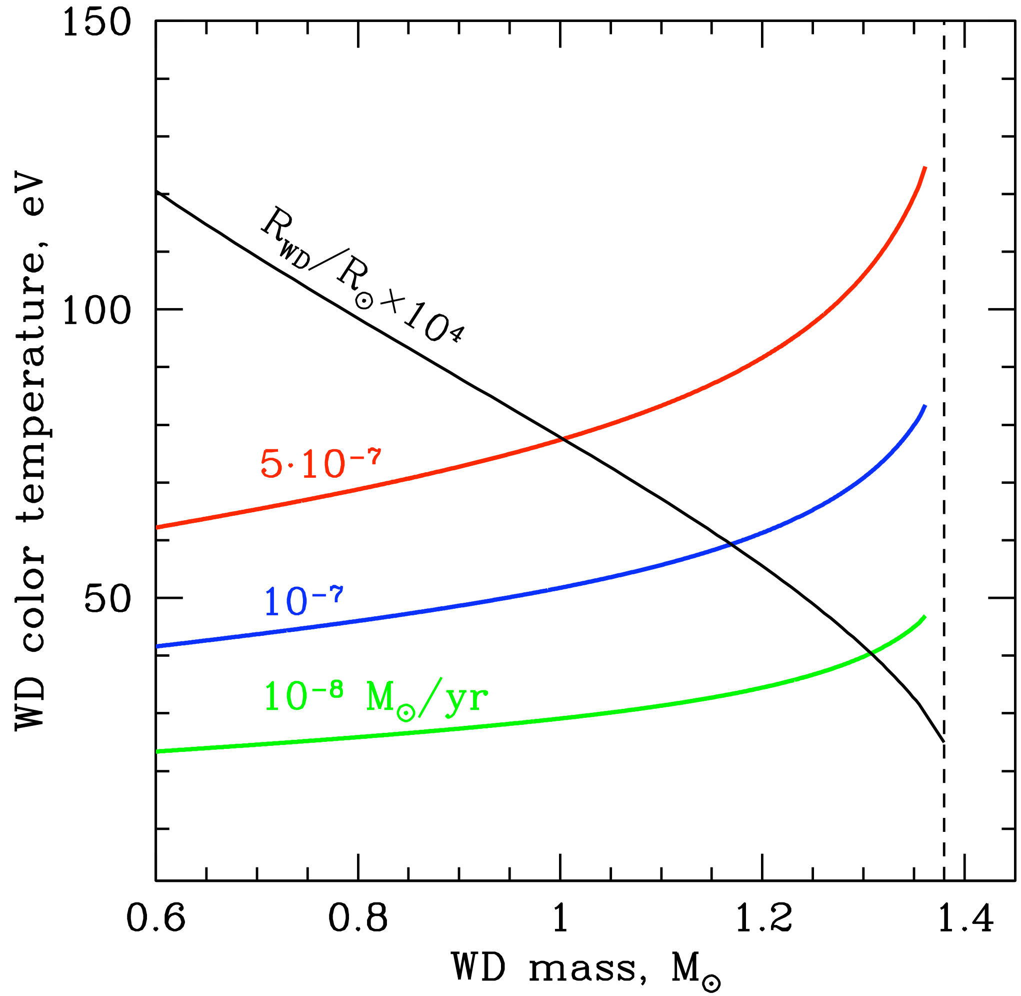
Why elliptical galaxies?

in young galaxies:

- enhanced absorption by gas and dust
- massive donor stars
  in ellipticals maximal M_{donor}~1 M_{sun}
- configurations with low mass accumulation efficiency are possible:
  - accretion from wind
  - high Mdot regime with optically thick wind

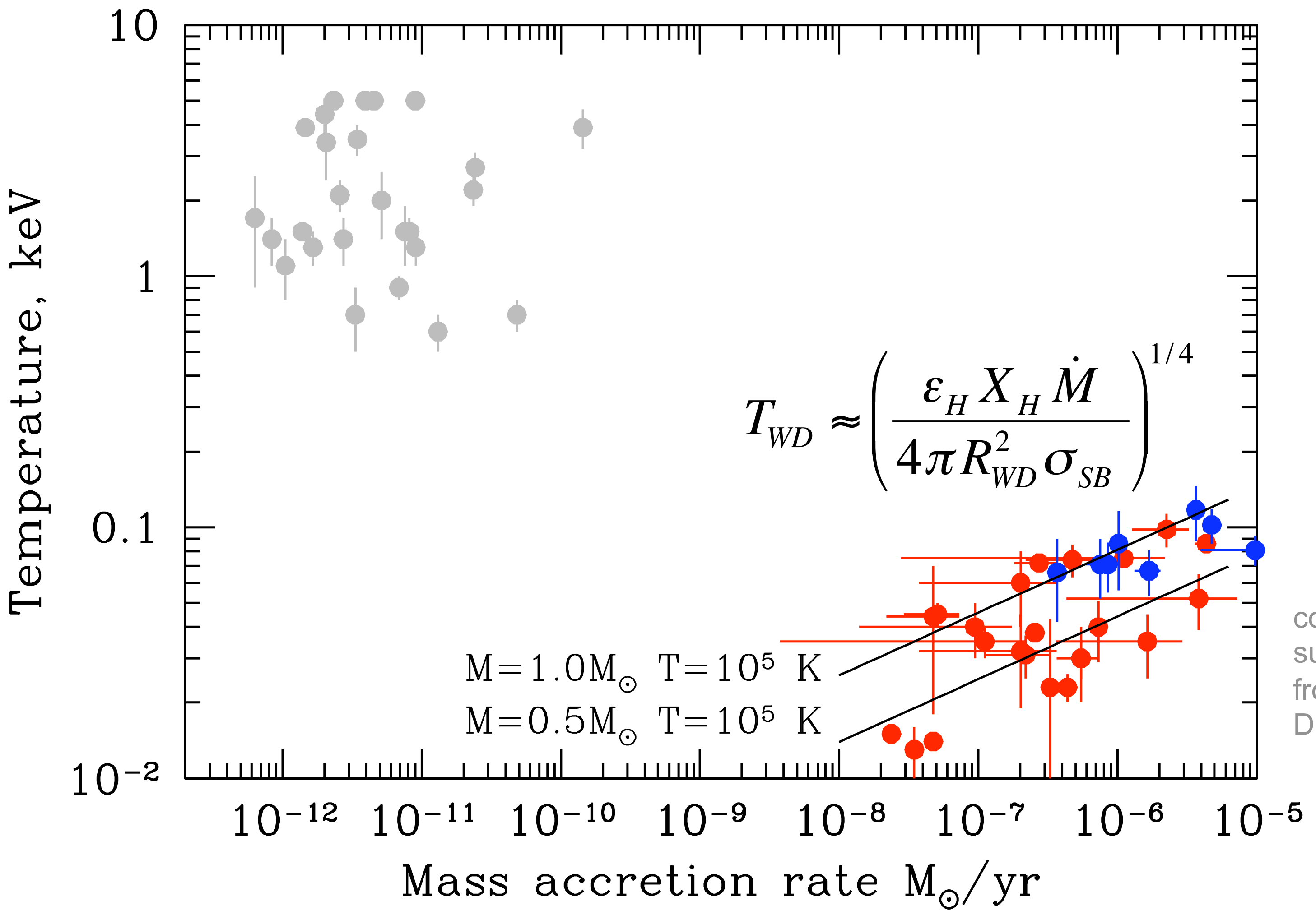
WD color temperature

$$T_{WD} \approx \left(\frac{\varepsilon_H X_H \dot{M}}{4\pi R_{WD}^2 \sigma_{SB}} \right)^{1/4}$$



WD mass-radius relation
from Panei et al., 2000

WD color temperature



compilation of
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from Greiner, 2000 and
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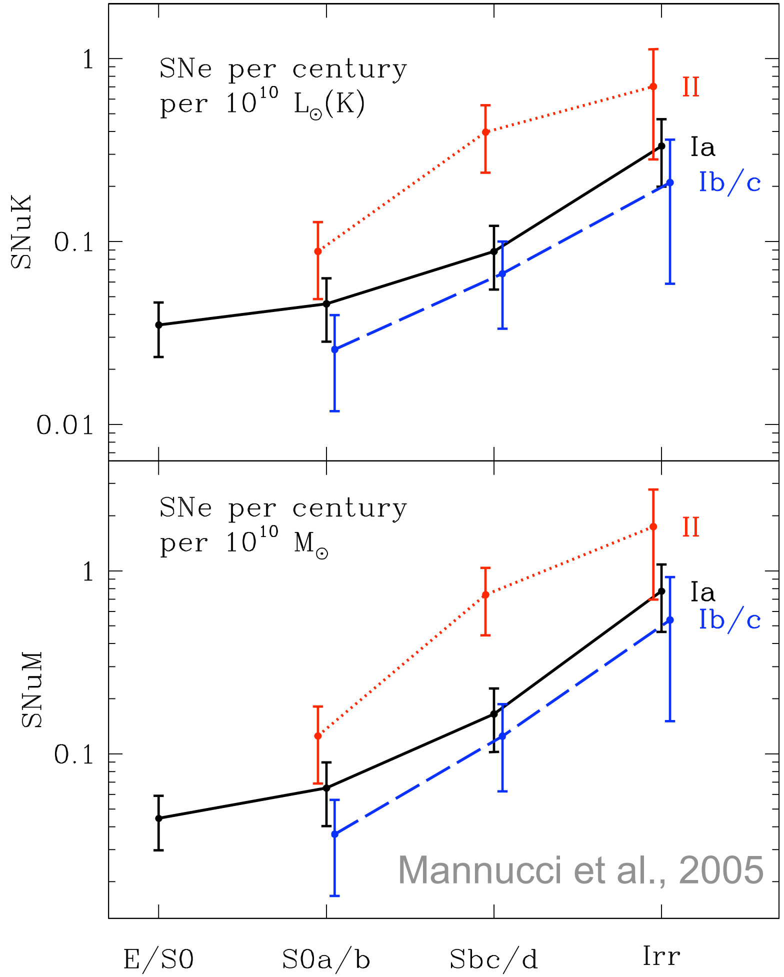
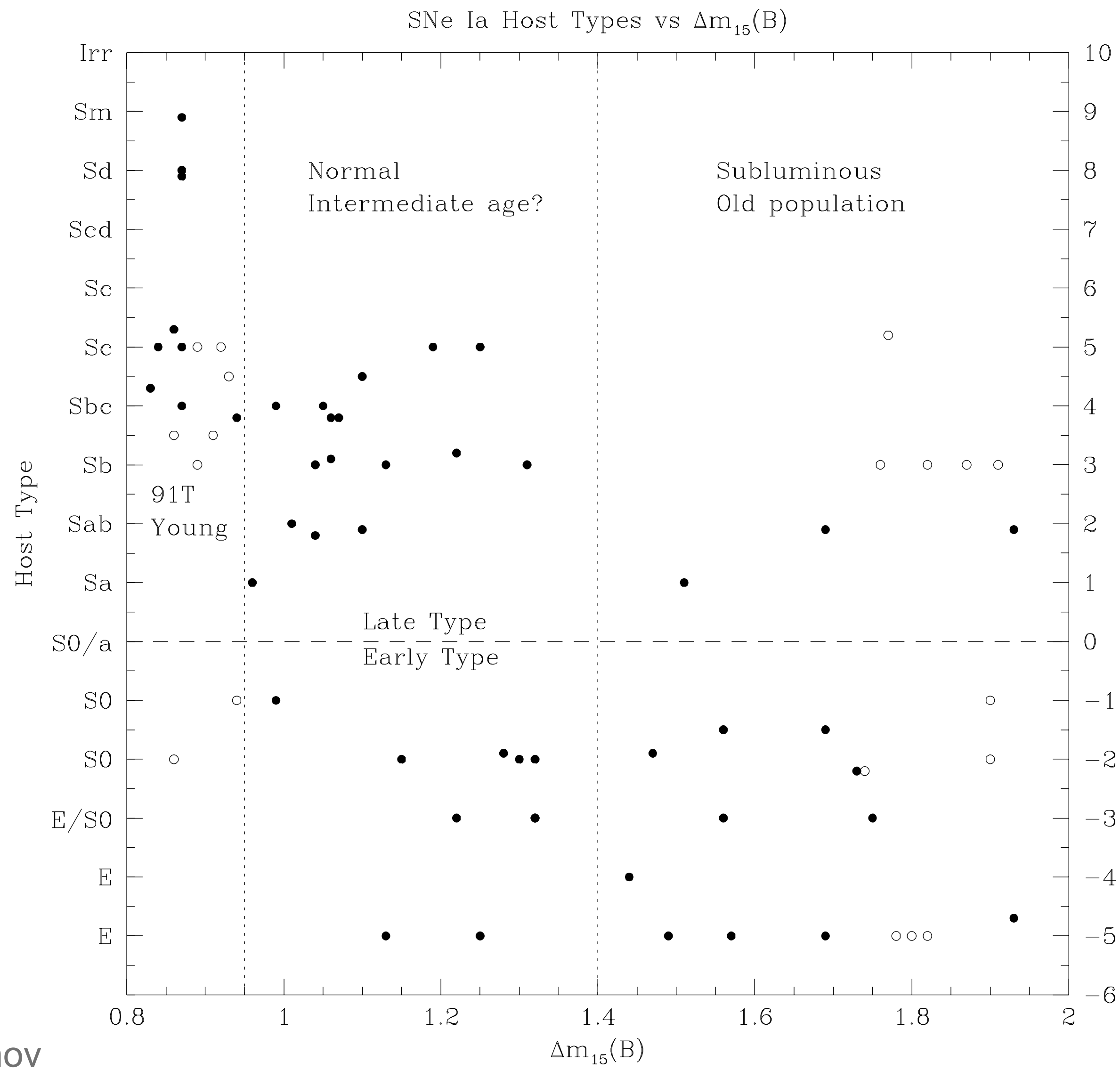
Two populations of SNIa

SNe Ia in star-forming environment tend to be:

- more frequent
- brighter
- more uniform in their parameters (as may be expected in the accretion scenario)



(at least) Two types of SNe Ia



Howell, 2001