Binary Scenarios that may Achieve Core Ignitions

Scenarios that reach $M_{chandra}$

-Single Degenerate

-Double degenerate

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> 1Msun White Dwarfs:

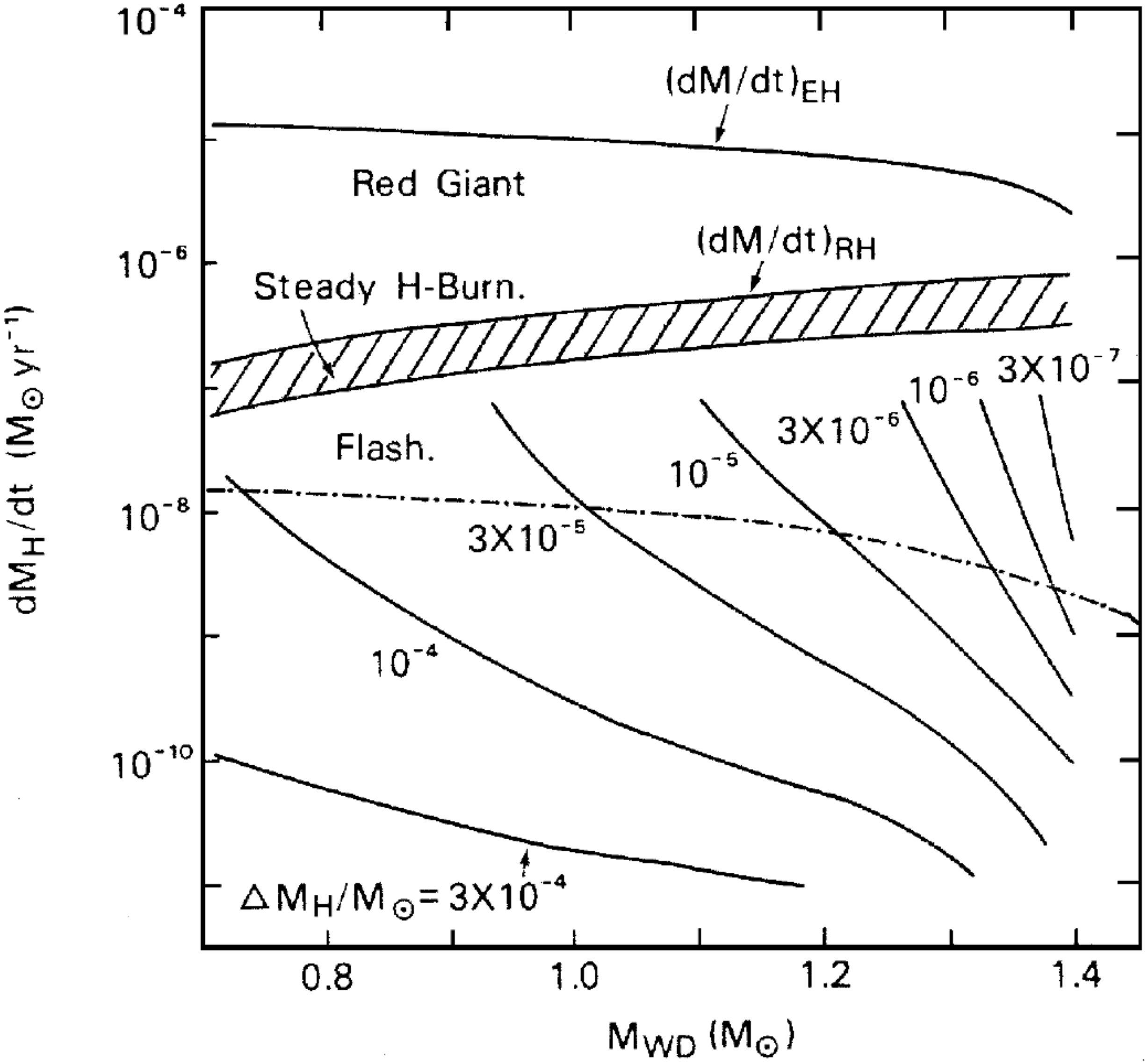


Figure 5 Regimes of steady nuclear burning, weak flashes (cyclic burning), and strong flashes (novae) in the $\dot{M}$–M_{WD} plane (cf Fujimoto 1982a,b, Nomoto 1982, DiStefano & Rappaport 1995). The ΔM_H values indicate envelope masses (for a given accretion rate) at which burning is ignited. Below the *dash-dot line*, flashes produce nova explosions.

For steady burning on the WD surface, the mass-transfer rate should be ~(1-6).10^{-7}Msun /yr. At larger rates burning is also steady, but X-rays don't come out.

For accretion rates > 10^{-8} Msun /yr, the flashes are weak and burned matter probably retained *(e.g. Kato and Hachisu,2004)*

Super Soft X-ray Sources (SSS)

-Energy generation by surface H-burning on a WD
-Source types: Close Binary SS, Symbiotics, CVs

Discovered by ROSAT (1990) thanks to its very low low-energy cut-off. Several of the sources had already been discovered by Einstein (~1981) but had been thought to be black holes in the “bright-soft” state: CAL 83 and CAL 87

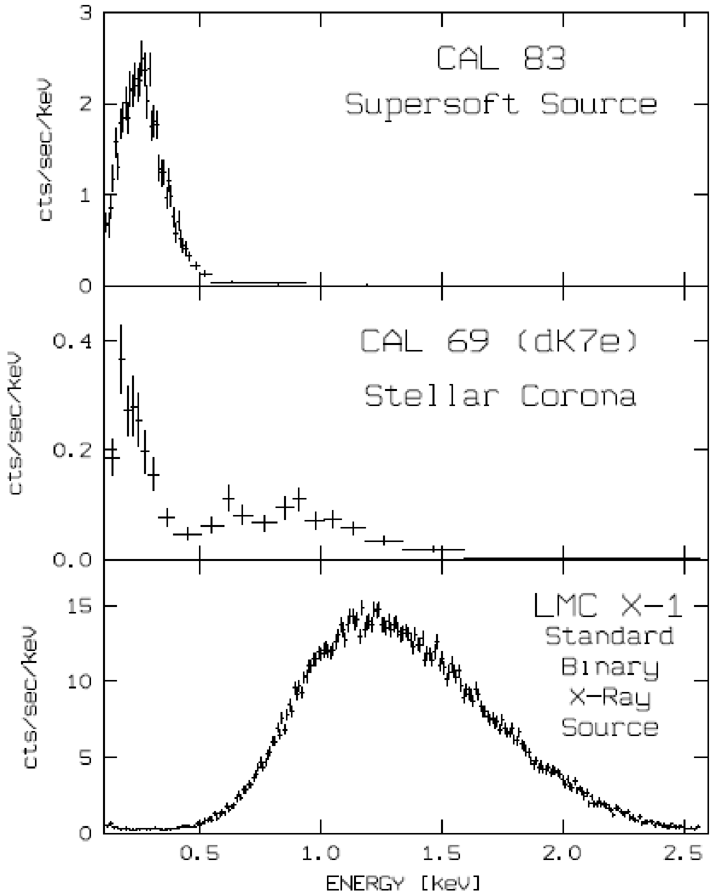


Figure 1 ROSAT PSPC count spectra of three objects in the Large Magellanic Cloud (LMC) field: the SSS CAL 83, the dK7e foreground star CAL 69, and the black hole candidate LMC X-1 (similar to Figure 2 of Trümper et al 1991).

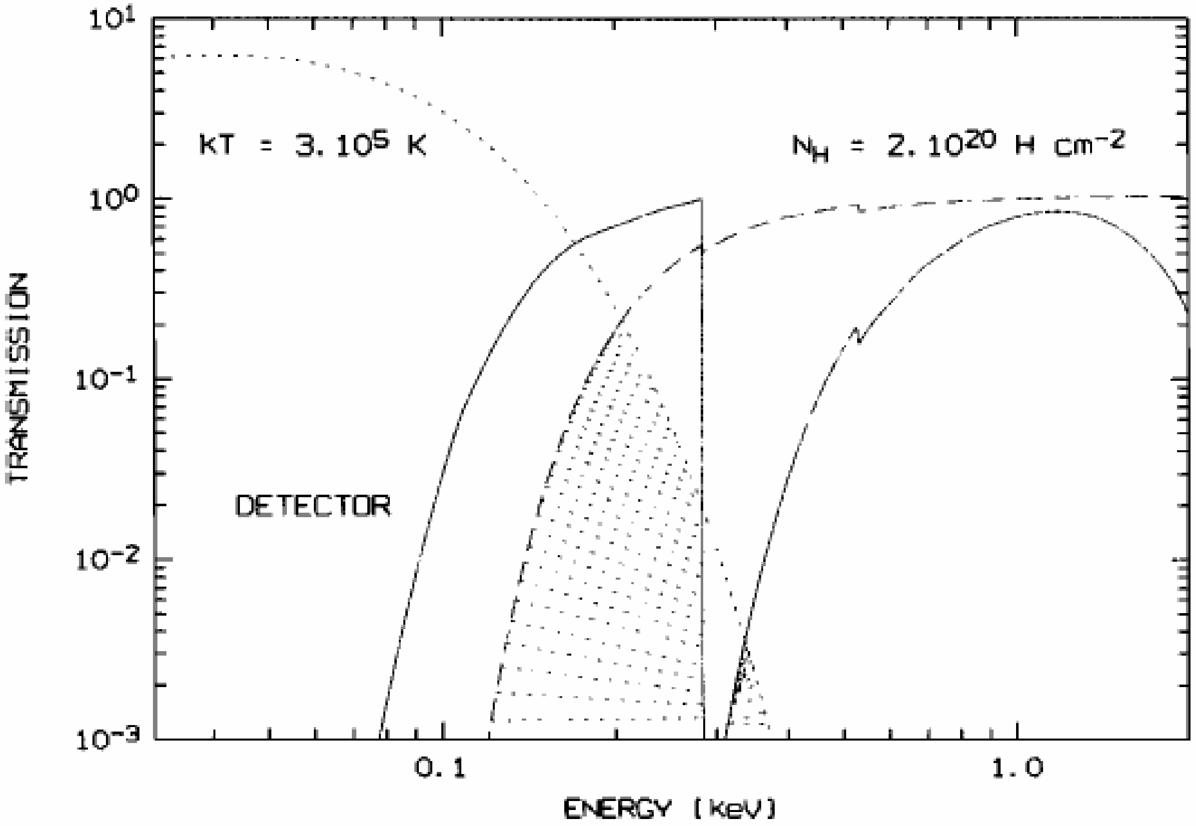
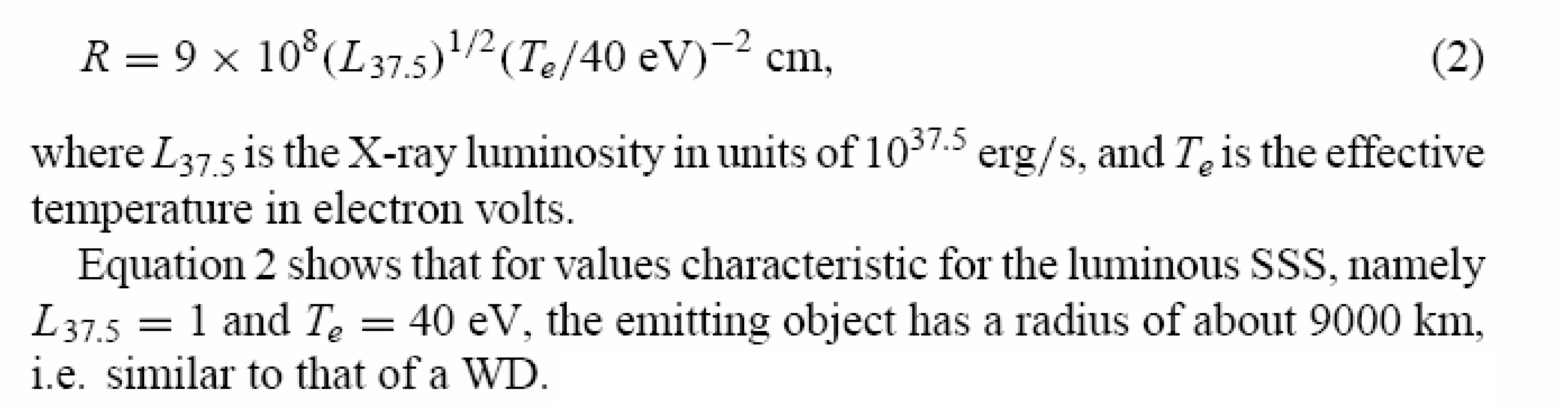


Figure 2 ROSAT PSPC efficiency (*solid curve*), transmission of ISM for hydrogen column of 2.10^{20} H atoms cm^{-2} (*dashed line*), distribution of a 3.10^{5}-K blackbody spectrum (*dotted line*) and folded (observed) distribution (*hatch marks*) (SA Rappaport, private communication).

X-ray Luminosity of LMC Supersoft sources: typically ~ $10^{37.5 \text{ to } 38}$ ergs/s



$$R = 9 \times 10^{8} (L_{37.5})^{1/2} (T_e/40\ \mathrm{eV})^{-2}\ \mathrm{cm}, \tag{2}$$

where $L_{37.5}$ is the X-ray luminosity in units of $10^{37.5}$ erg/s, and T_e is the effective temperature in electron volts.

Equation 2 shows that for values characteristic for the luminous SSS, namely $L_{37.5} = 1$ and $T_e = 40$ eV, the emitting object has a radius of about 9000 km, i.e. similar to that of a WD.

In order to generate this luminosity by accretion onto a WD, the accretion rate should be ≥ 4.10^{-6} Msun /yr. However, such an accretion rate would cause all soft X-rays to be absorbed!

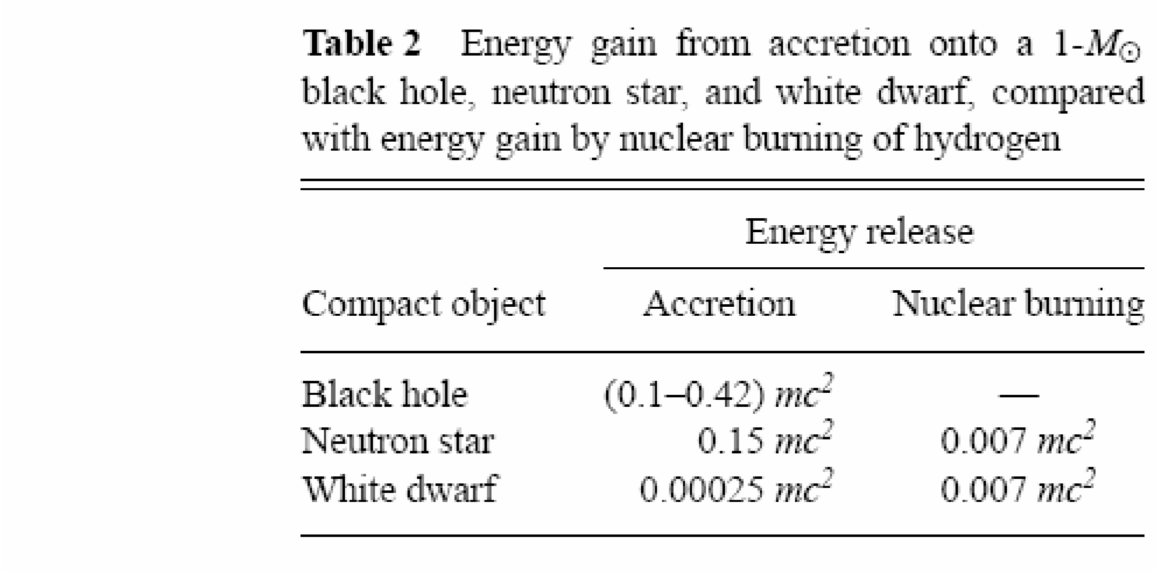


Table 2 Energy gain from accretion onto a 1-$M_{\odot}$ black hole, neutron star, and white dwarf, compared with energy gain by nuclear burning of hydrogen

	Energy release	
Compact object	Accretion	Nuclear burning
Black hole	(0.1–0.42) mc^2	—
Neutron star	0.15 mc^2	0.007 mc^2
White dwarf	0.00025 mc^2	0.007 mc^2

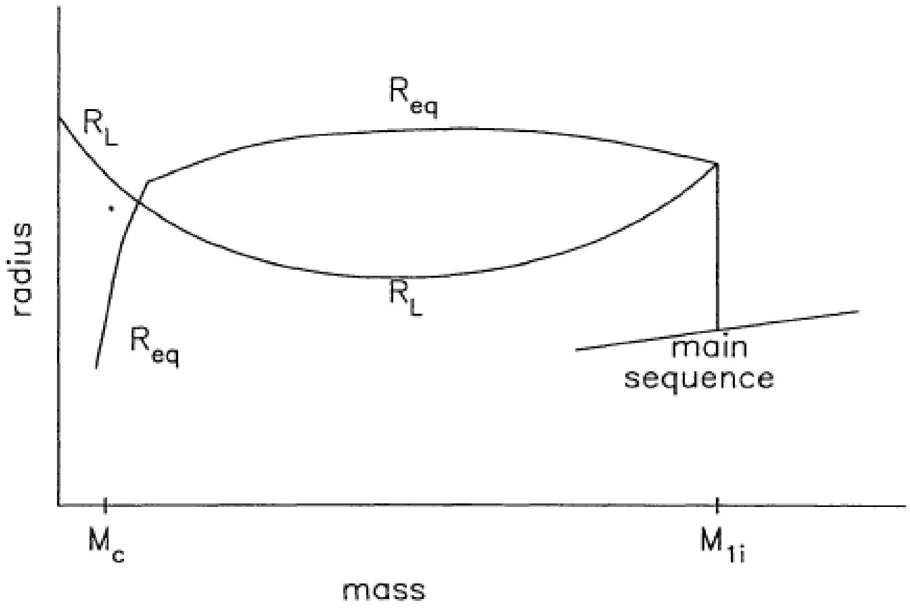
Nuclear burning of Hydrogen on the WD surface generates same X-ray luminosity at a 30 times lower accretion rate ~ 10^{-7} Msun /yr: Now the X-rays can come out!

Post-main- sequence Donor star with Radiative Envelope

Once the more massive star overflows its Roche lobe and transfers matter to its companion, its Roche-lobe radius *shrinks* while its thermal equilibrium radius stays about the same. As a result it continues to transfer matter until it has become the less massive component of the System. The entire process takes ~ τ(thermal):

$$\dot{M} \sim 0.8M/\tau_{(\mathrm{thermal})} \sim 0.8M^{3}/(3.10^{7}) \quad [M_{sun}/yr]$$

→ for $M \geq 1.5M_{sun}$, $\dot{M} \geq 10^{-7}\ M_{sun}/yr$



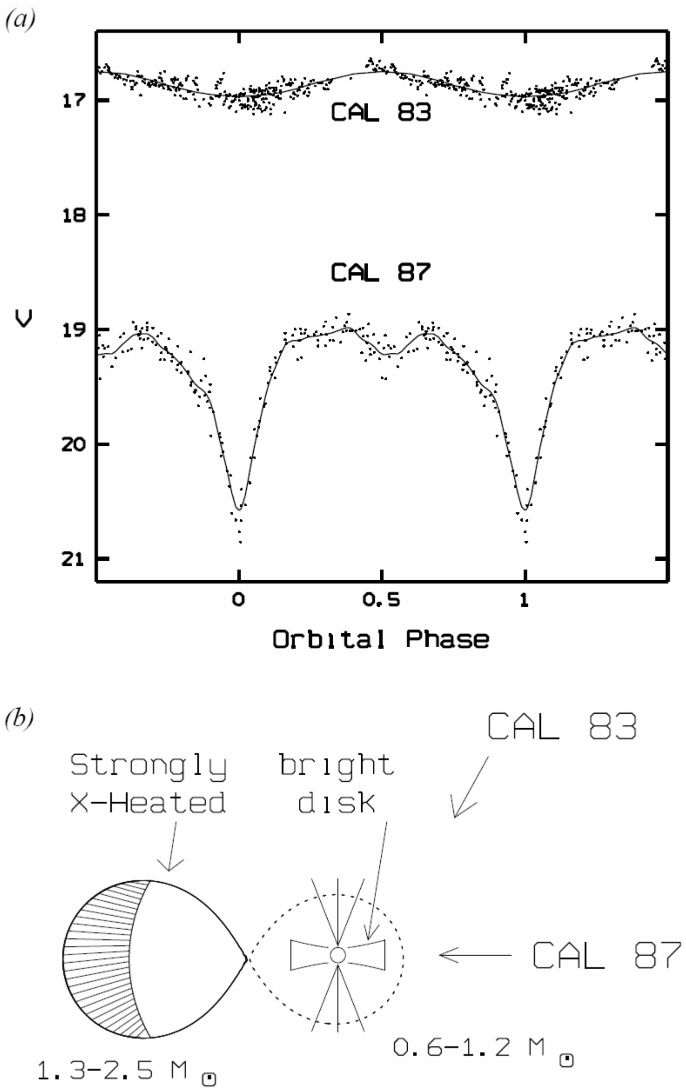


Figure 3 (*a*) Optical light curves in the Johnson V-band of CAL 83 and CAL 87 plotted on the same scale for comparison. The *solid curves* give the mean light curves. The upper light curve is adapted from Smale et al (1988), the lower light curve from Schmidtke et al (1993). (*b*) Schematic model for explaining the optical light curves of CAL 83 and 87: The main light sources in the systems are the very bright accretion disk and the X-ray heated side of the donor star. In CAL 87 the accretion disk is regularly eclipsed; CAL 83 is seen at low inclination, such that only the heating effect is observed [after van den Heuvel et al (1992); for a refined model, see S Schandl et al (1996); see also section on The "Standard" CBSS].

P_{orb} = 1.04 days

P_{orb} = 10.6 hours

The first two classical Close Binary Super Softs (CBSS), or "Algol-Supersofts"

RXJ 0513-6951 in the LMC

P_{orb} = 18,3 hours

When X-rays are “on”, the optical light is low, when X-rays are “off”, optical light is high: the energy then comes out in the optical, so accretion and burning still continue during X-ray off state!

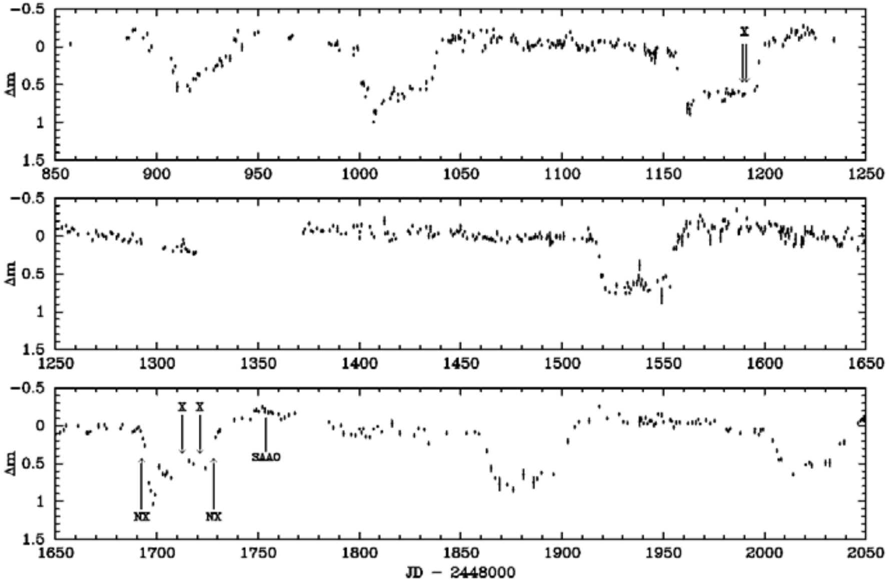


Figure 7 Optical light curve of RX J0513.9-6951 from August 22, 1992, to November 27, 1995, obtained with the MACHO project. Downward and upward *vertical arrows* indicate times at which the system was known to be on (X) or off (NX) in X rays, respectively (from Southwell et al 1996b).

Red- and Blue-shifted components of emission lines: jets with outflow velocities ~ 3800 km/s: same order as escape velocity from surface of a WD. ***Proof that SSS are WDs!***

Also the CBSS V Sagittae shows outflows, v ~ 1500km/s ***(Wood&Lockley2000)***

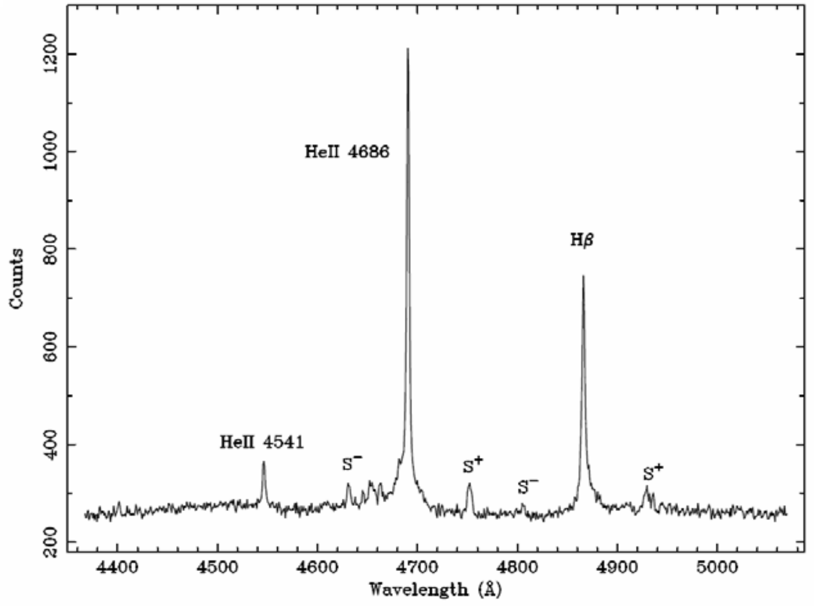


Figure 8 Average blue spectrum of RX J0513.9-6951. The principal He II and H emission features are marked, along with their associated Doppler-shifted components (from Southwell et al 1996b).

WDs grow also by the weak-flash–burning at accretion rates > 10^{-8} Msun /yr (*e.g.: Hachisu and Kato, 2004*)

At still lower accretion rates, when Nova explosions occur, still part of the accreted H may be retained and steadily burned after the explosion (Schwartzman, Kovetz and Prialnik 1994). Therefore, also in Novae (from CVs, Algols and Symbiotics) the WD may grow in mass.

Yungelson et al. (Ap.J.466,890,1996) included also these possibilities in their Population-synthesis calculations for SSS

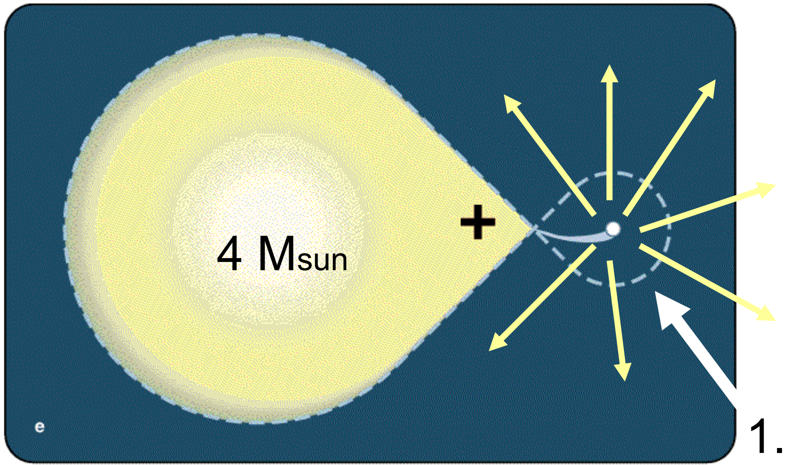
What will happen if $M_{dot} > M_{dot}(Edd,nucl) \sim 6.10^{-7}\ M_{sun}/yr$?

1. Iben and Livio (1993), Ivanova and Taam (2004):
   Red-giant envelope forms leading to Common Envelope evolution and (slow) spiral-in;

2. Hachisu, Kato, Nomoto (1996):
   Formation of a strong radiatively-driven wind which carries off the excess accreted matter with (about) the specific orbital ang.mom. of the accretor

NB: When WD is ~ 1.4Msun, its Radius is ~ 2300 km, and escape velocity from surface is ~ 12 000 km/s. Wind velocity is in general > escape velocity → pre-SN wind may stay ahead of the supernova shell.

Tauris, vdH and Savonije, 2000,Ap.J.530; (similar kinds of calculations by Podsiadlowski, King, etc.)



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1.2Msun
Neutron star

At onset of mass transfer (P_{orb} =4d), the 4Msun star has a radiative envelope, resulting in stable transfer on a thermal timescale.

The transferred mass in excess of $\dot{M}_{Edd}$ is ejected from the compact star with its specific orbital angular momentum.

For 2 million yrs, transfer rate > 2.10^{-7} Msun/yr

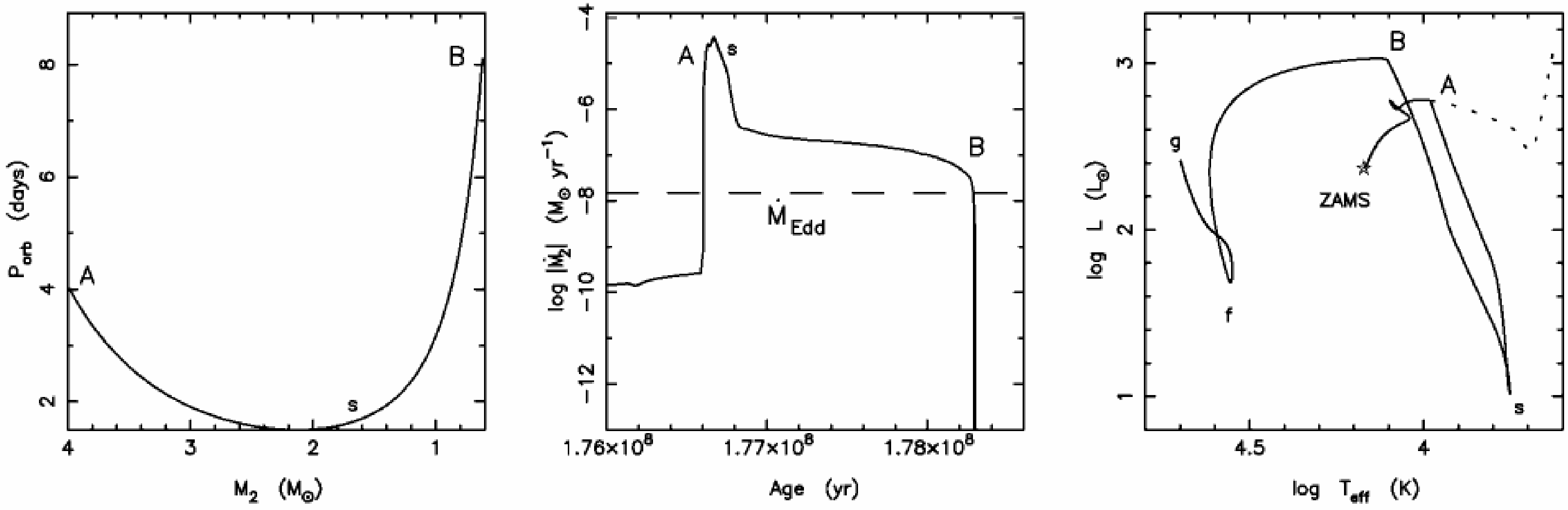


FIG. 1.—Evolution of an X-ray binary with $M_2 = 4.0\ M_\odot$ and $P_{orb} = 4.0$ days. *Left:* Evolution of P_{orb} as a function of M_2 (time is increasing to the right). *Middle:* Mass-loss rate of the donor as a function of its age since the ZAMS. *Right:* Evolution of the mass-losing donor (*solid line*) in an H-R diagram. The dotted line represents the evolutionary track of a single 4.0 $M_\odot$ star. The letters in the different panels correspond to one another at a given evolutionary epoch—see text for further explanation.

Diagram from Yungelson 2004

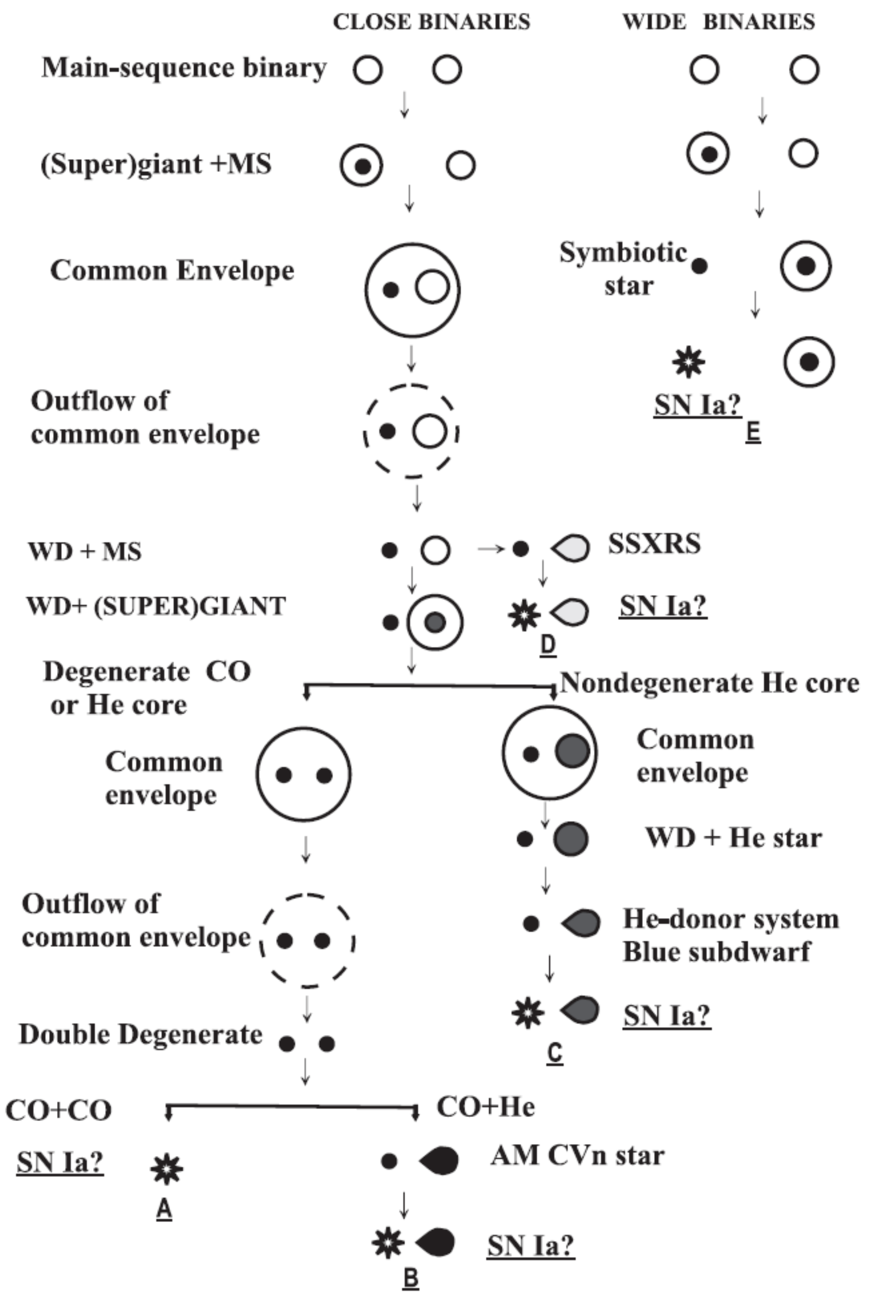


Figure 1: Evolutionary scenarios for possible progenitors of SN Ia.

Symb.SS

“Algol” and CV SS

He SS

Double Degen.

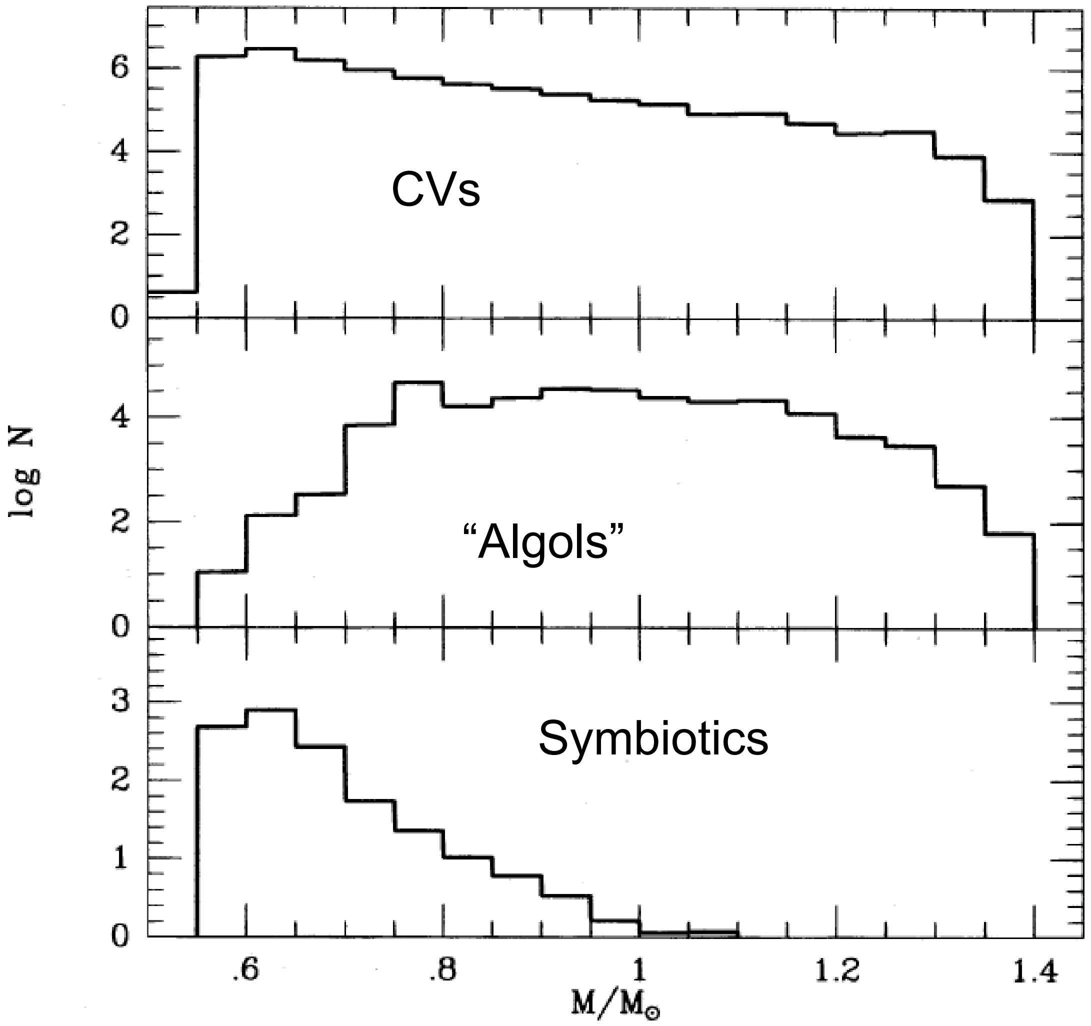
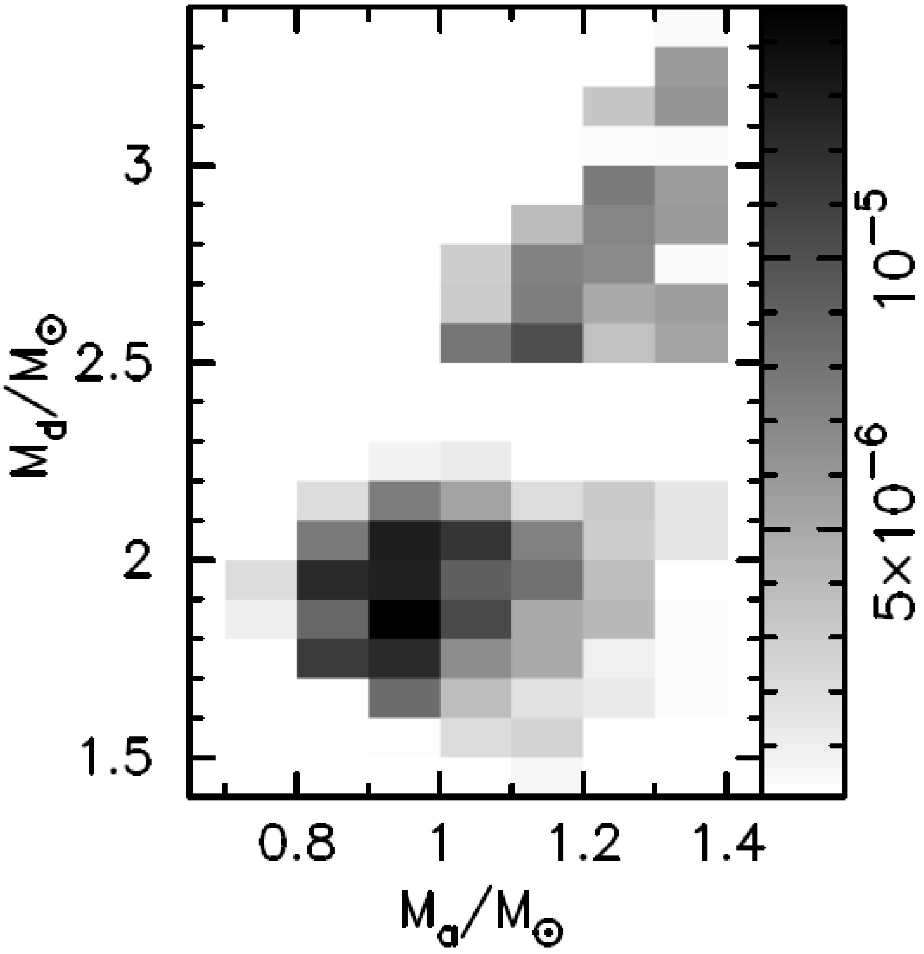


FIG. 4.—Distribution of WDs over mass in cataclysmic variables (*top panel*), systems with subgiant donors (*middle panel*), and in symbiotic binaries (*bottom panel*).

From Yungelson et al. 1996



Main seq. donors

Subgiant donors

Figure 3: The rate of accumulation of M_{Ch} in the SD-scenario (in yr^{-1}), depending on the masses of WD-accretors and MS- or SG-donors at the beginning of accretion stage. ***Yungelson 2004/ Fedorova,Tutukov and Yungelson 2004***

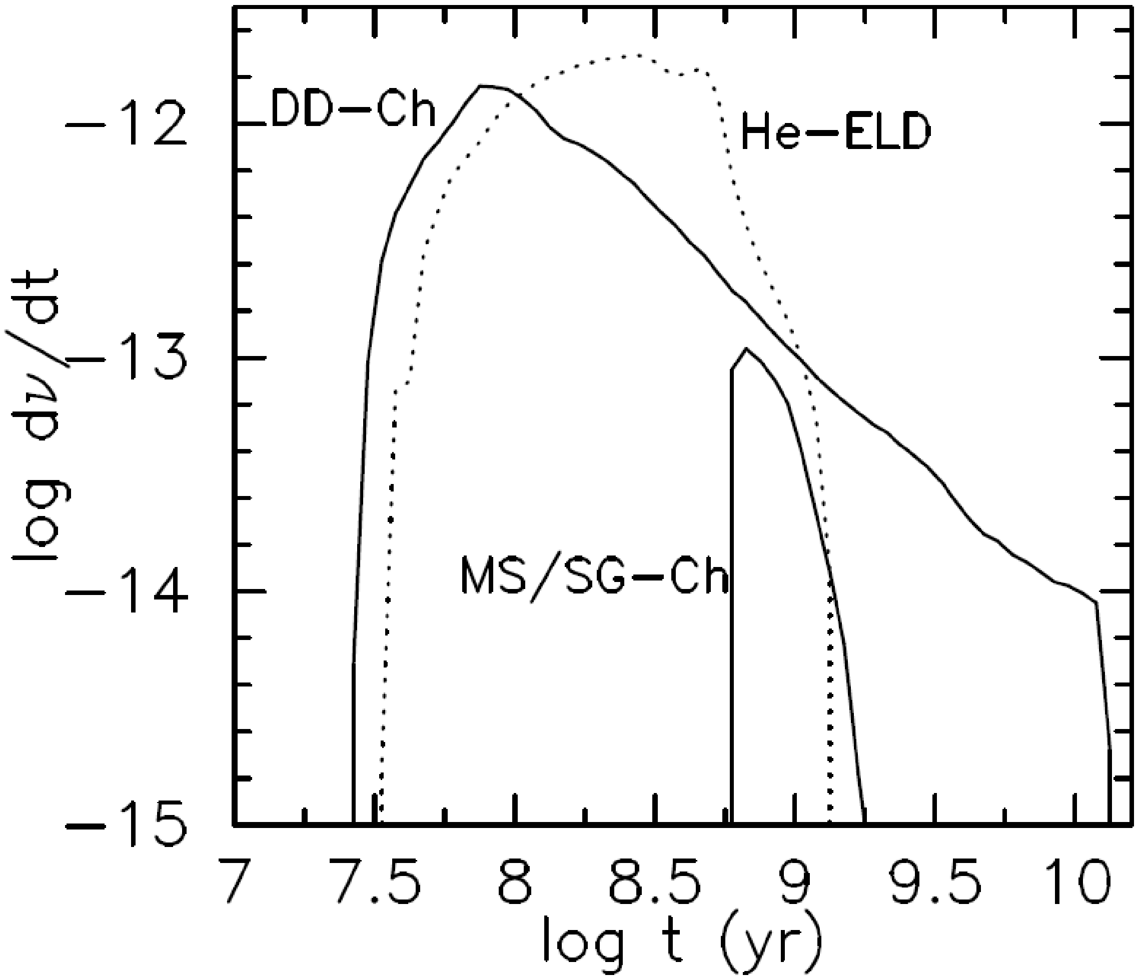
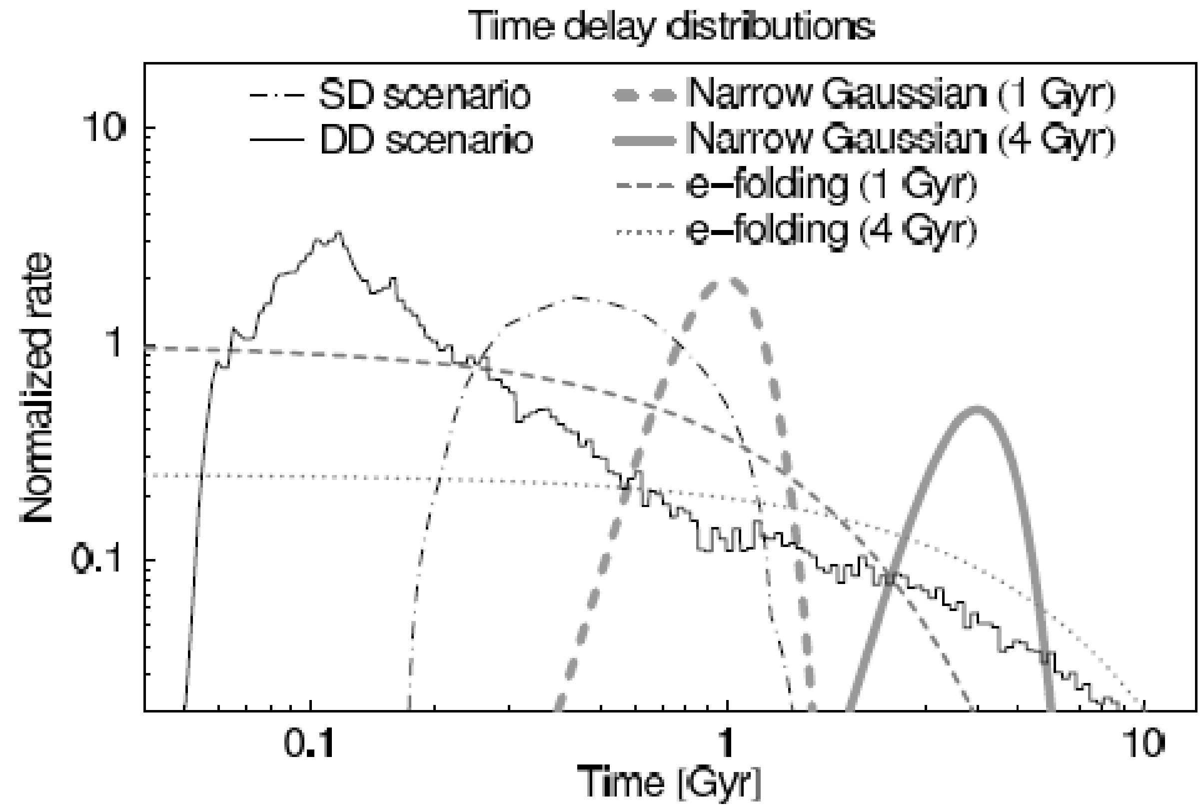


Figure 2: Rates of potential SN Ia-scale events after a 1-yr long star formation burst that produces 1 $M_\odot$ of close binary stars.

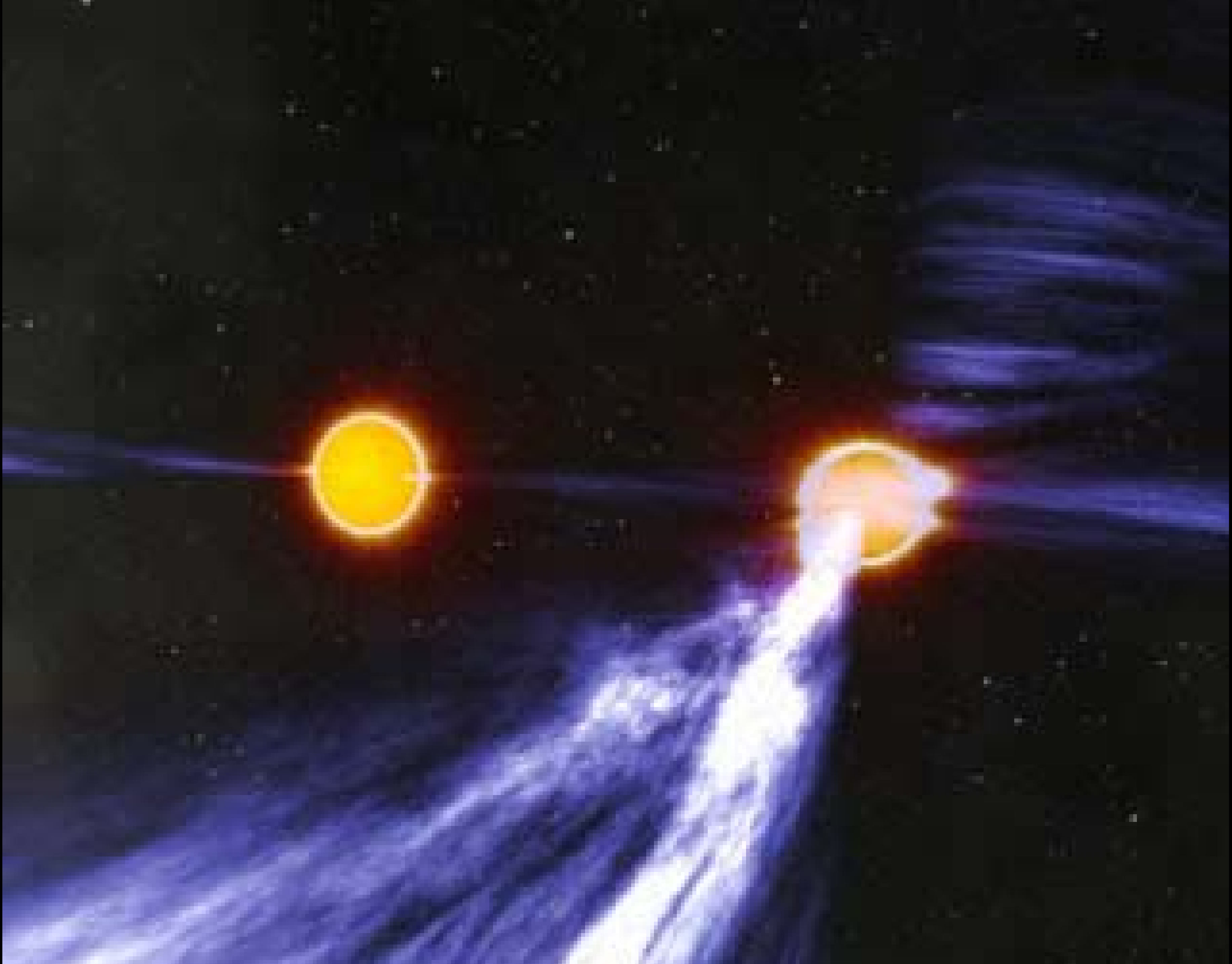
Yungelson 2004

Förster,Wolf, Podsiadlowski and Han(2006) get an ~ 5 times higher peak of the MS/SG-Ch systems than Yungelson, but *qualitatively* good agreement with these results (with a very different population synthesis program)



Time delay distributions for the SD and DD scenarios, calculated
by Förster, Wolf, Podsiadlowski and Han (2006).

These results roughly confirm those of Yungelson (2004), within factors 1-5.
Very encouraging, since the binary-population-synthesis codes of the
two groups are quite different and were developed independently!
Uncertainties come e.g. from the values of various input parameters such as α_{ce} .



Argument in favour of existence of Double WDs with total mass considerably > $M_{chandra}$:

Existence of 8 Double neutron stars in our galaxy:
5 have orbital periods < 10 hours: merge within 3 Gyr
(4 of these merge within 1 Gyr; one in 85 Myr)

These stayed together **after two supernova explosions!!**
So, it must be **EASY to keep two massive WDs together in a close binary!!**

Two close systems known consisting of a NS + massive WD:
PSRJ 1145-6545; P_{orb}=0.2 d, M_{wd}=1.00, M_{ns} = 1.28 (±0.02)M_{sun}
PSRB 0655+64 ; P_{orb} = 1.06d,M_{wd}~1.00, M_{ns}~1.30 M_{sun}.

So between these and the known D.Degen with M_{tot} <1.40 M_{sun}
there must also be many systems with M_{tot} betw. 1.4 and 2.3M_{sun}

Summary:

The results from the Moscow an Oxford groups:

1. In a population with ages between ~ 200 million and 2 billion years, "Supersoft source" binaries (including the shrouded ones) can produce between 50 (Yungelson 2004) and 90 (Förster et al. 2006) per cent of WD growing to $M_{chandra}$.
2. At other epochs the Double Degenerate mergers appear to dominate the formation rate of degenerate objects with a mass ≥ $M_{chandra}$.

3. Förster et al.(2006) conclude: it is too early to rule out any of the proposed Type Ia scenarios.