Effects of Rotation in White Dwarfs

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with thanks to:

- Rudy Knaap (Utrecht)
- Maarten Suijs (Utrecht)
- Sung-Chul Yoon (Santa Cruz)

Reasons to look at WD spin

- physics of j-transport in stars
- WD spins/ NS, pulsar spins / BH spins
- Planetary nebula shapes
- Type Ia supernovae
- long gamma-ray bursts $\leftrightarrow$ collapsars

Tool: stellar evolution code

- centrifugal force: averages on isobars (Kippenhahn and Thomas '78)
- rotationally induced transport (Heger, Langer and Woosley '00; Yoon and Langer '04)
- grav. wave radiation (r-modes) (Yoon '04)
- magnetic torques (Spruit '02)

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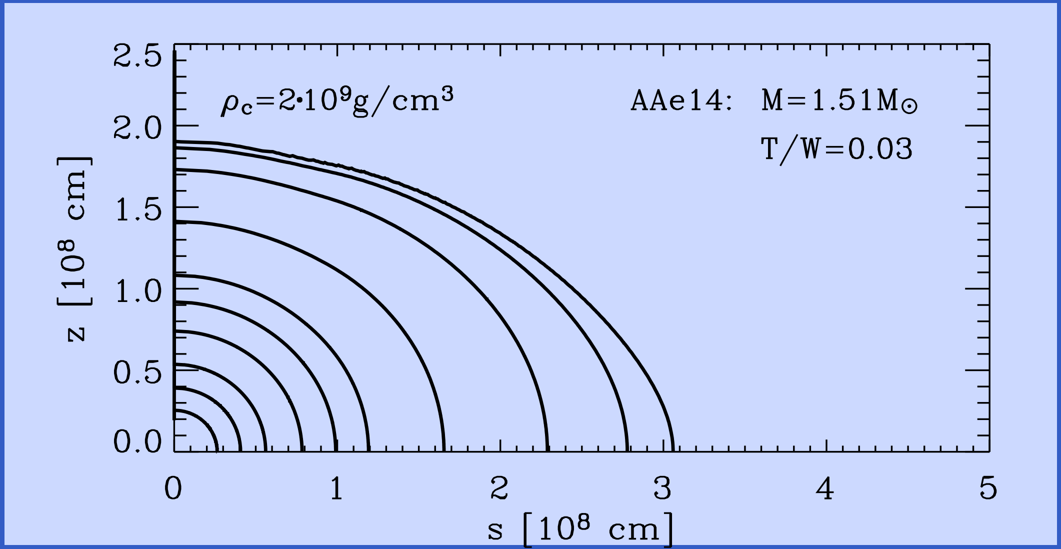
- magnetic torques (Spruit '02)
- rotationally supported mass loss (Ω-limit, Langer '98)
- mass and ang. momentum transfer (Wellstein & Langer '99)
- tidal spin-orbit coupling (Wellstein '01)

Tool: 2D WD equilibrium model

- $P = P(\rho)$; EOS of completely degenerate matter
- cylindrical rotation
- rotation law from 1D evolution models
- also: rigidly rotating models



Yoon & Langer 2005

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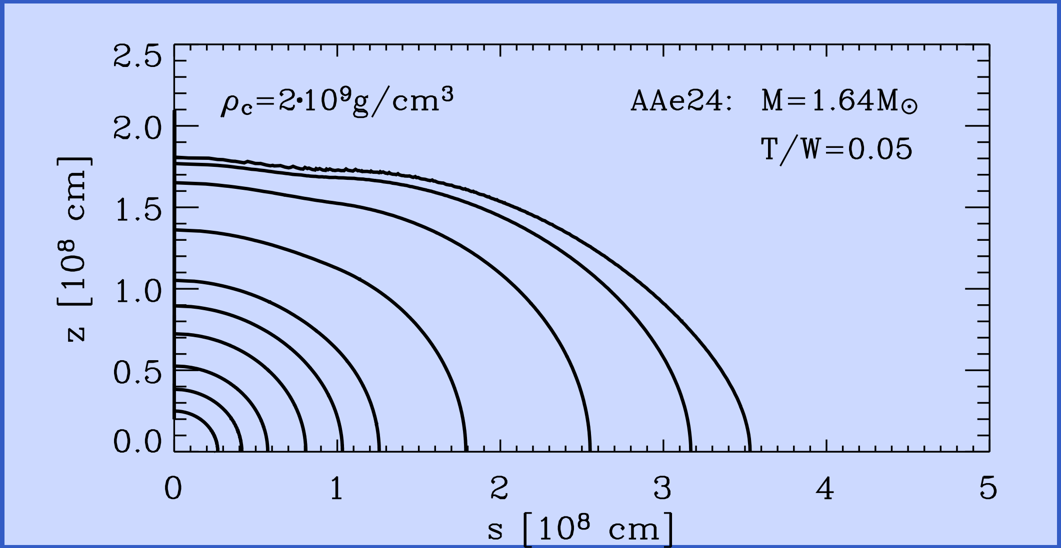

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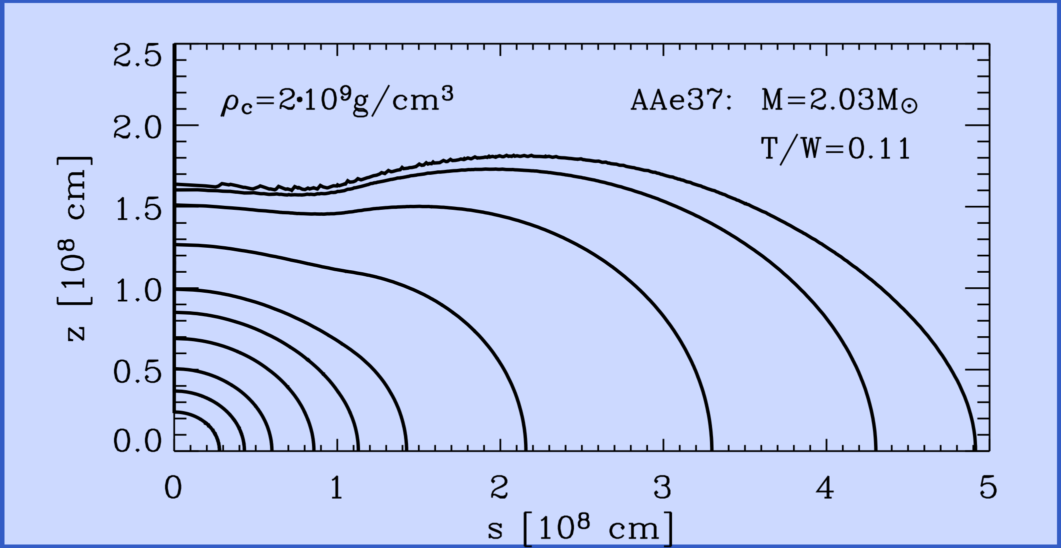
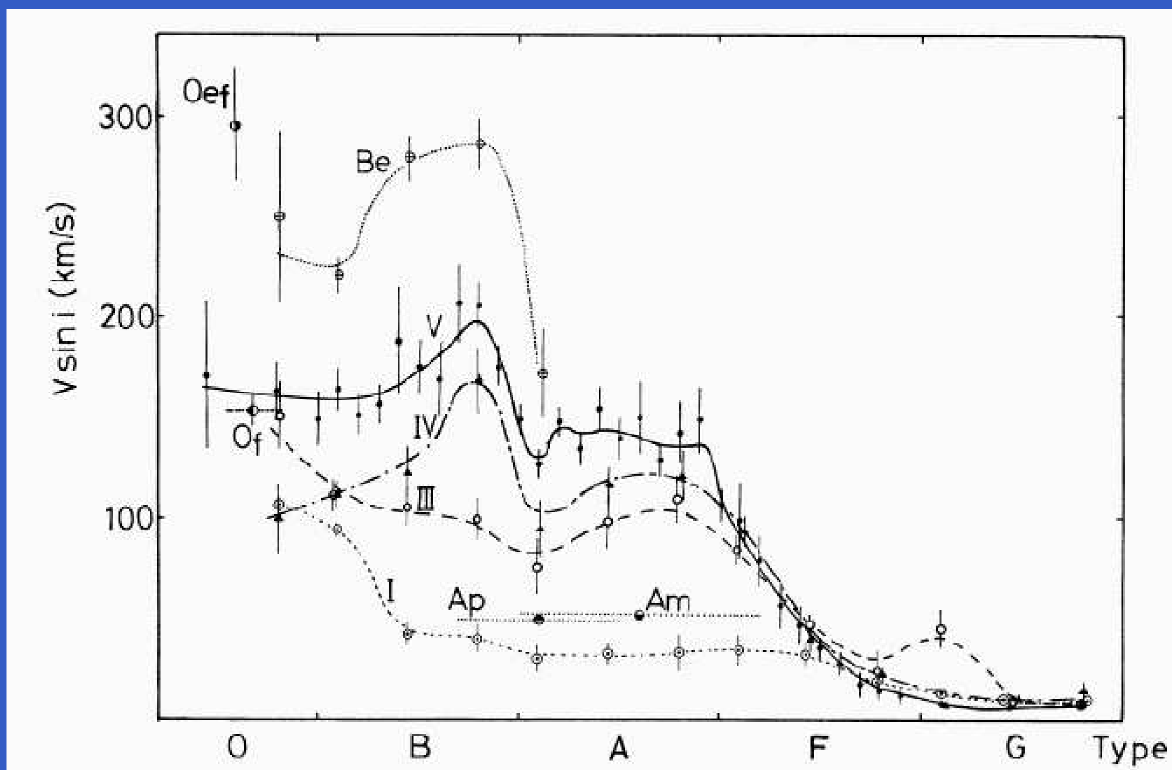


Yoon & Langer 2005

Observations: Main Sequence Rotation



Fukuda 1982

- $M < 1.2\,\mathrm{M}_\odot$

  $j \simeq 10^{16}$ cm^{2}s^{-1}

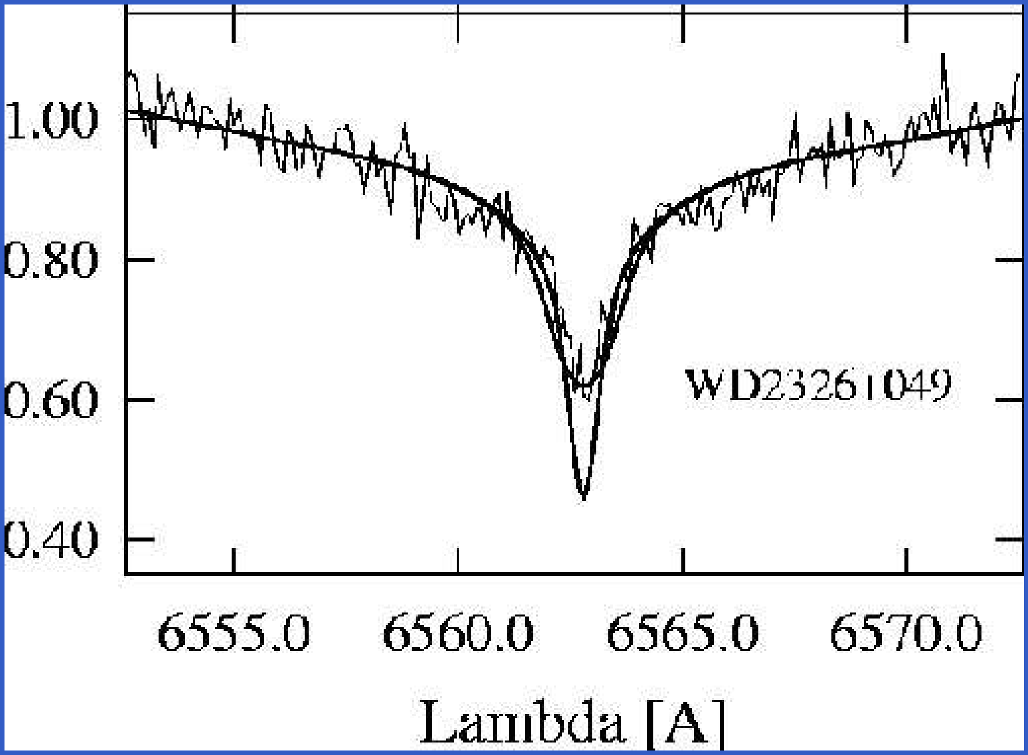
  $v_{\rm rot} \ll v_{\rm crit}$

- $M > 1.2\,\mathrm{M}_\odot$

  $j \simeq 10^{18}$ cm^{2}s^{-1}

  $v_{\rm rot} \simeq v_{\rm crit}$

White Dwarf Rotation



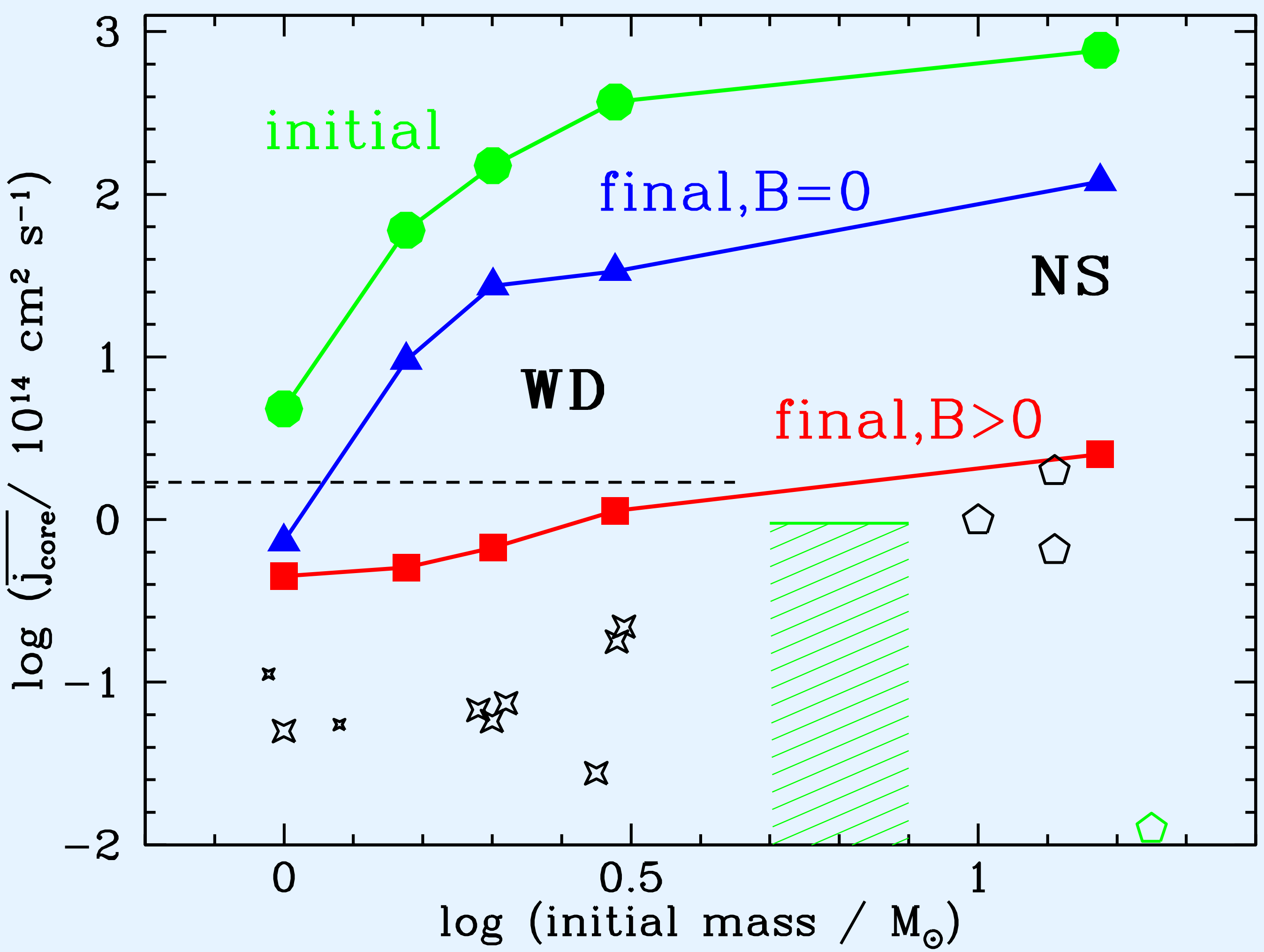
Koester et al. 1998

specific angular momentum:

- Koester et al. (1998)
- Berger et al. (2005)

$\Rightarrow j_{WD} < 10^{14}\,\mathrm{cm}^2\,\mathrm{s}^{-1}$

WD spins from single star models



Suijs et al. 2008

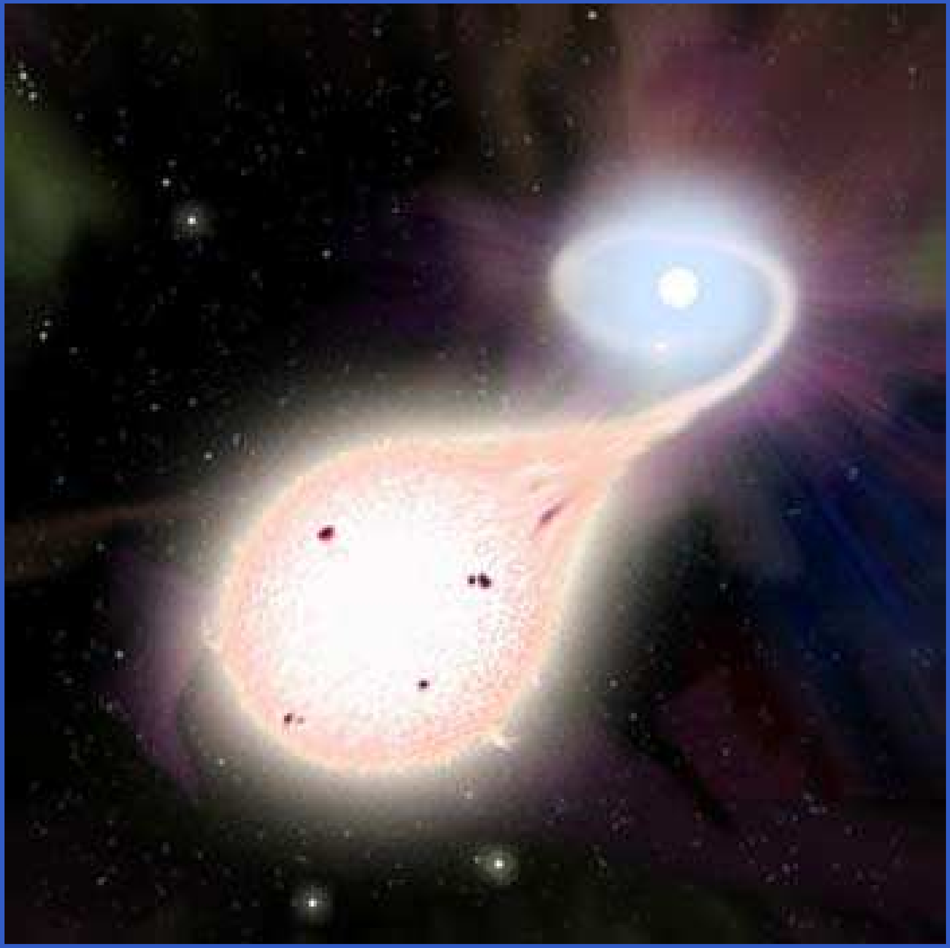
Observed spins

object	$j\,/\,\mathrm{cm^2\,s^{-1}}$	P or v_rot
MS $M < 1.2 M_\odot$	10^{16}	$v_\mathrm{rot} \simeq 2\,\mathrm{km\,s^{-1}}$
MS $M > 1.2 M_\odot$	10^{18}	$v_\mathrm{rot} \simeq 200\,\mathrm{km\,s^{-1}}$
young pulsars	$10^{13} \ldots 10^{14}$	$P = 10...100$ ms
isol. WDs	10^{13}	$v_\mathrm{rot} \simeq 1\,\mathrm{km\,s^{-1}}$

Observed spins with accretion

object	$j\,/\,\mathrm{cm^2\,s^{-1}}$	P or v_{rot}
MS $M < 1.2 M_\odot$	10^{16}	$v_{\mathrm{rot}} \simeq 2\,\mathrm{km\,s^{-1}}$
MS $M > 1.2 M_\odot$	10^{18}	$v_{\mathrm{rot}} \simeq 200\,\mathrm{km\,s^{-1}}$
young pulsars	$10^{13} \ldots 10^{14}$	$P = 10...100$ ms
isol. WDs	10^{13}	$v_{\mathrm{rot}} \simeq 1\,\mathrm{km\,s^{-1}}$
accr. WDs (CVs)	$\ldots 10^{16}$	$\ldots 1000\,\mathrm{km\,s^{-1}}$
MSP	$\sim 10^{16}$	
long GRB	$> 3\,10^{16}$	

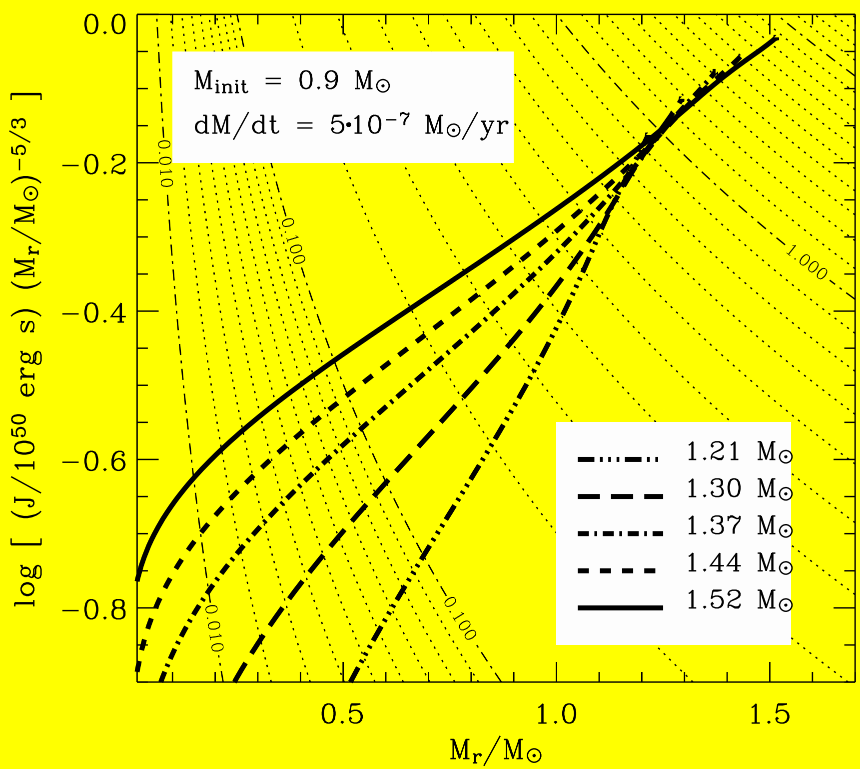
Binary mass transfer: Spin-up



Marufov, 2003

$$\dot{M} \Rightarrow \dot{J}$$

SN Ia progenitors



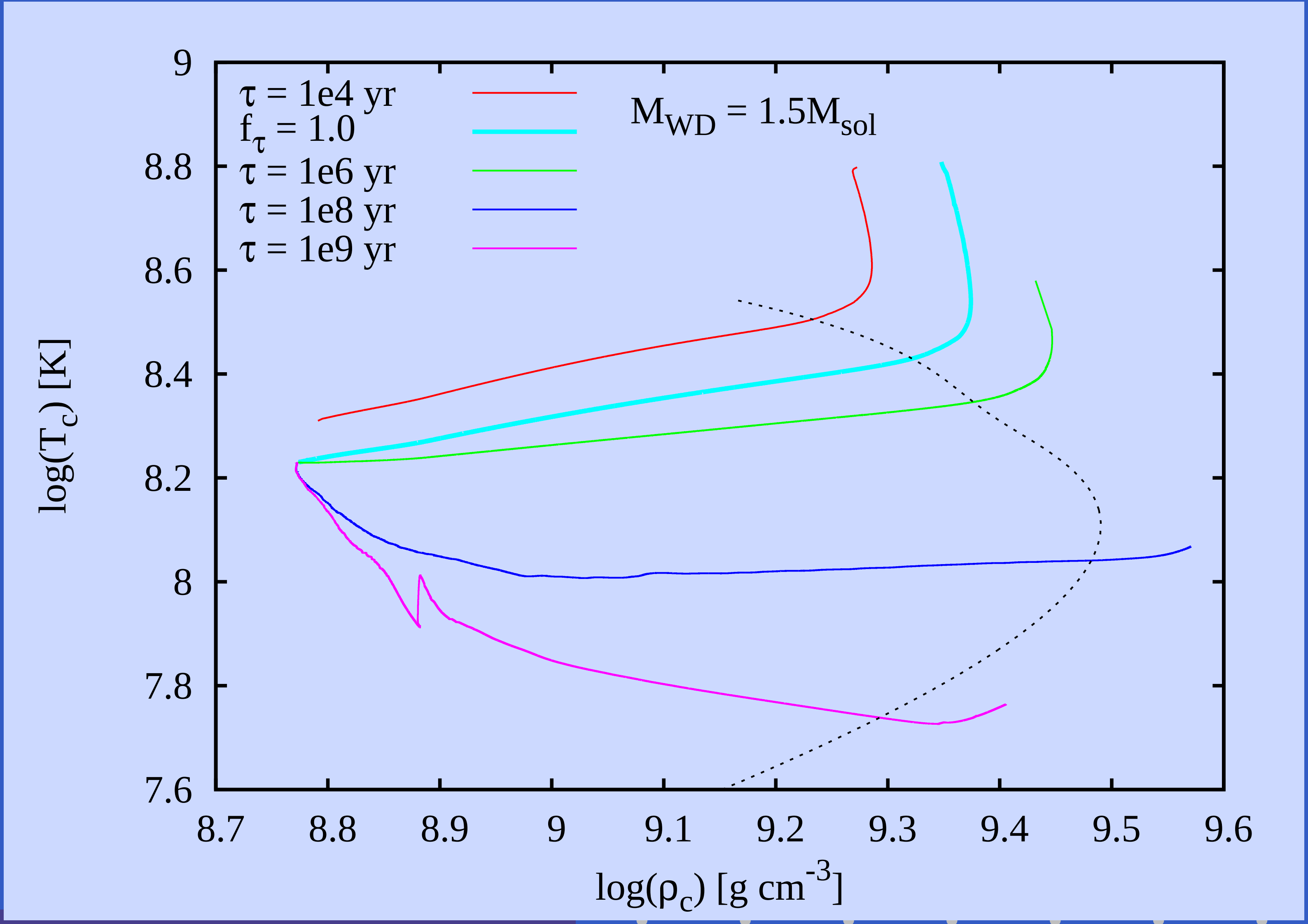
Yoon & Langer, 2004

- WD is spun-up
- differential rotation

$\Rightarrow$

increased Chandrasekhar-mass

Evolution with grav. wave radiation



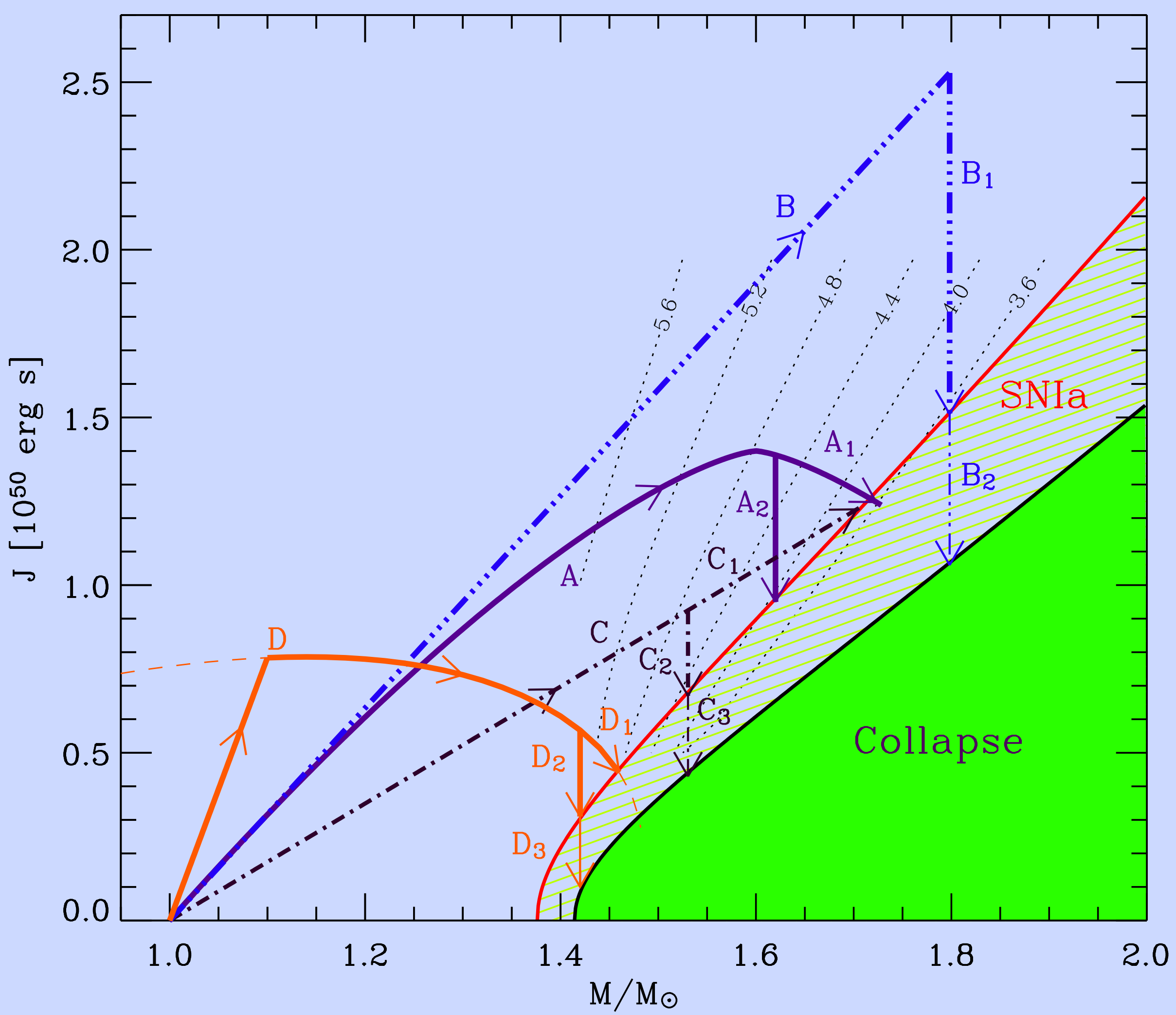
Knaap 2004

Gravitational wave signal

No.	M	$E_{\rm rot}/\|W\|$	$h_{\rm bar}$ at 10 Mpc	$f_{\rm GW}$
	$\mathrm{M}_\odot$		10^{-24}	Hz
A2	1.18	0.10	1.7	0.22
A6	1.30	0.10	2.9	0.32
A10	1.42	0.10	4.3	0.46
A2	1.34	0.14	3.7	0.32
A6	1.44	0.14	5.0	0.43
A10	1.55	0.14	7.5	0.62

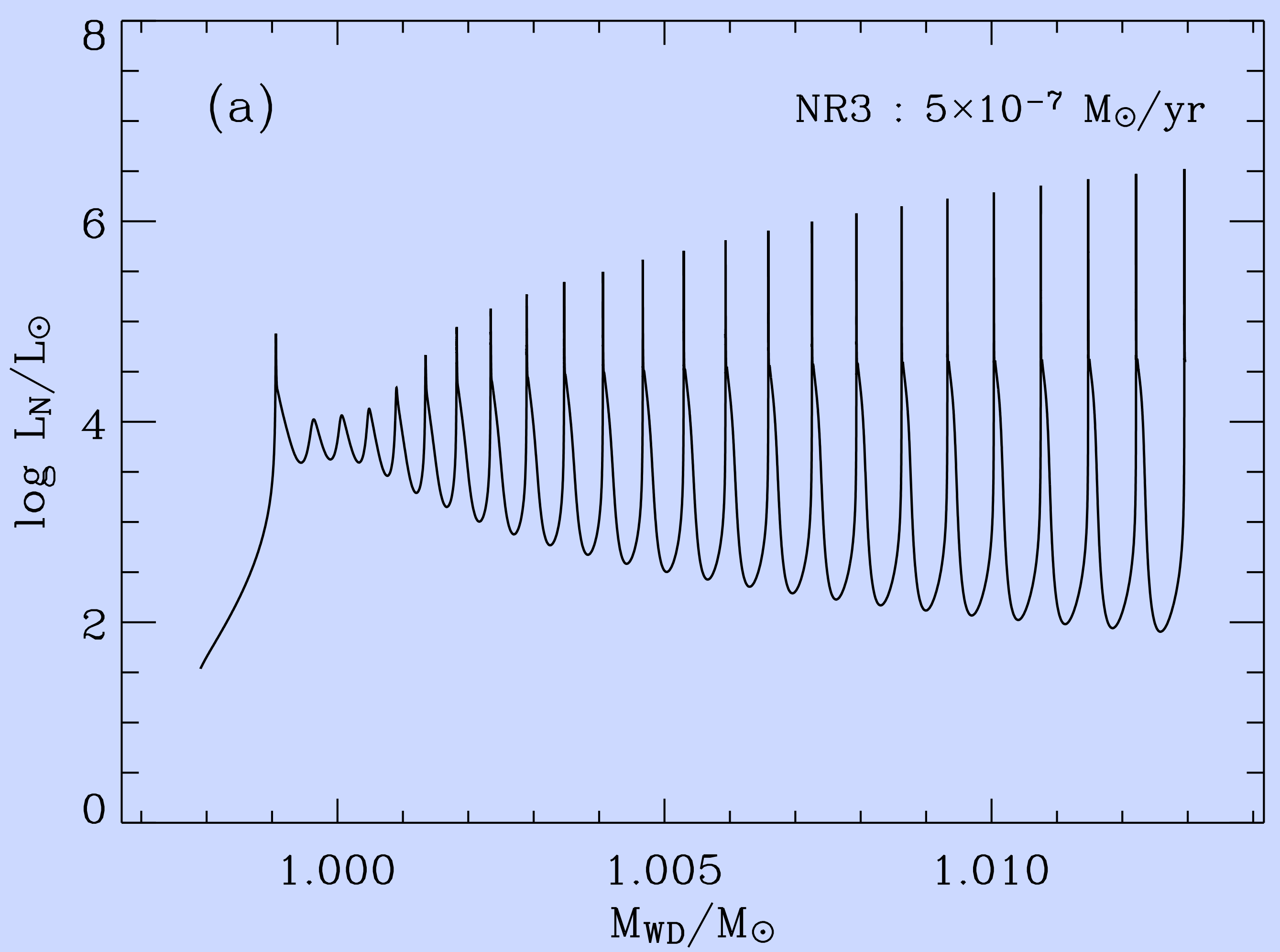
Yoon & Langer 2004

Possible paths to SNIa



Yoon & Langer 2005

Rotation stabilizes shell burning



Yoon et al. 2004

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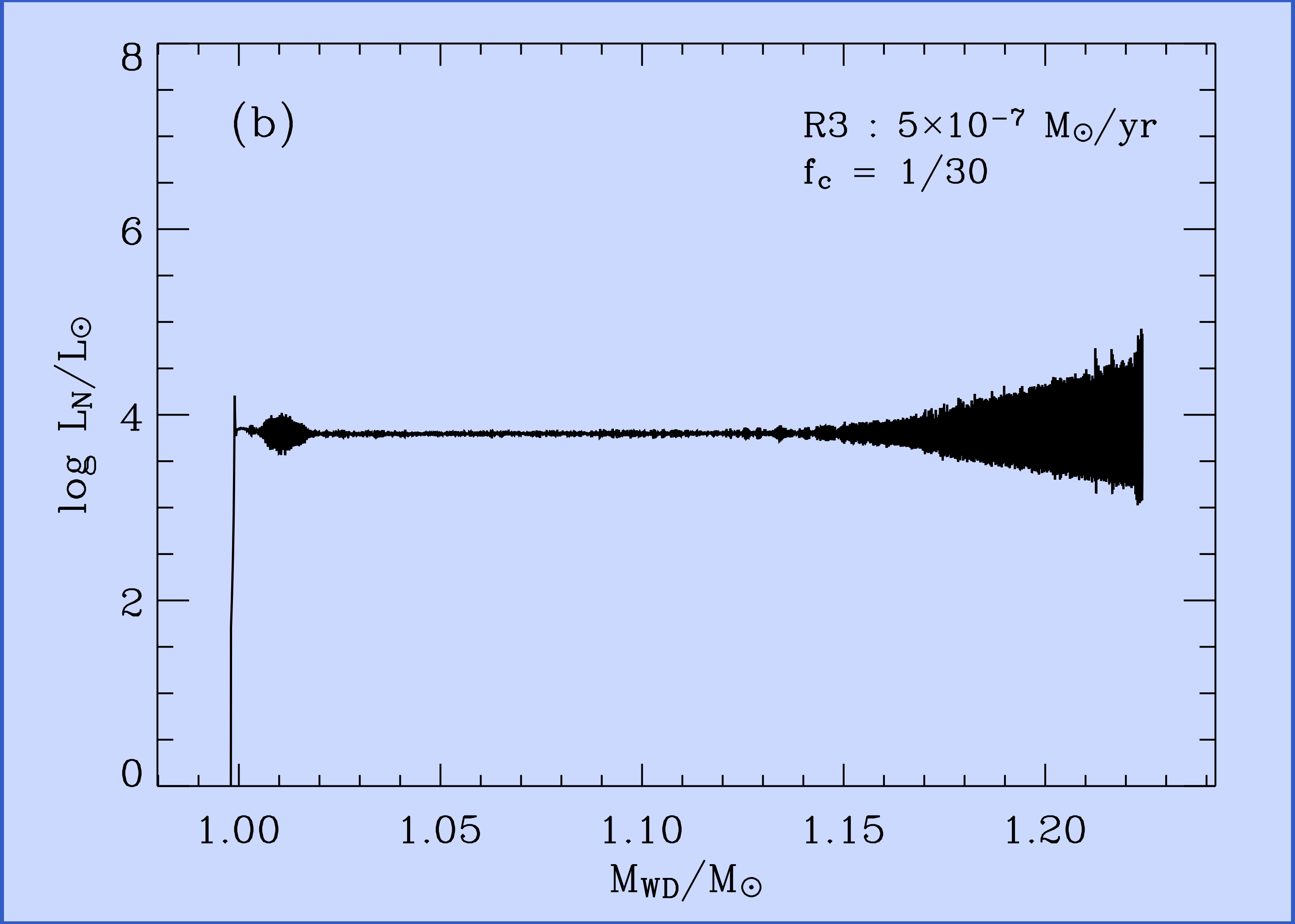

Yoon et al. 2004

Summary

- accreting WDs may be spun-up
- rotating WDs: stabilized burning shells
- rapidly rotating massive WDs: $\dot{J}$ by gravitational waves
- rapidly rotating WDs: $M_{\rm Ch} > 1.38\,{\rm M}_\odot$