The local double white dwarf population from SPY and implications for the SN Ia progenitor problem

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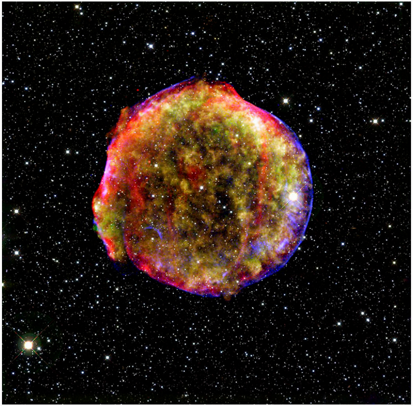
Tel-Aviv University / ESO

Maoz & Hallakoun, MNRAS, 2017, 467 (2): 1414-1425

Type-Ia supernovae are important

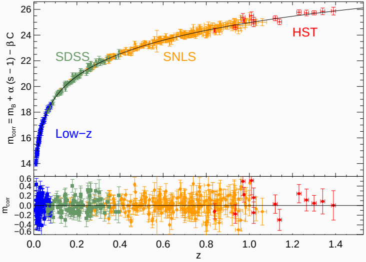
- Major source of heavy elements

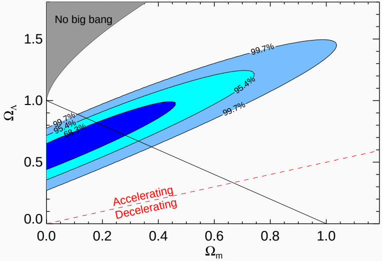


NASA/CXC/SAO; NASA/JPL-Caltech; MPIA, Calar Alto, O. Krause et al.

Type-Ia supernovae are important

- Major source of heavy elements
- Standard candles
    - Dark energy





Conley et al. 2011

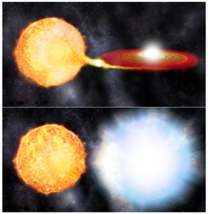
Type-Ia supernovae are important

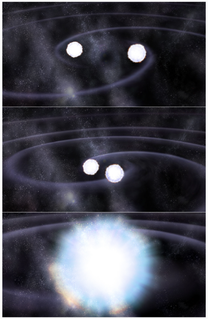
- Major source of heavy elements
- Standard candles
  - Dark energy

But, nobody knows exactly WHAT is exploding and HOW.

This is the **Type-Ia Supernova** (SN Ia) **Progenitor Problem**.

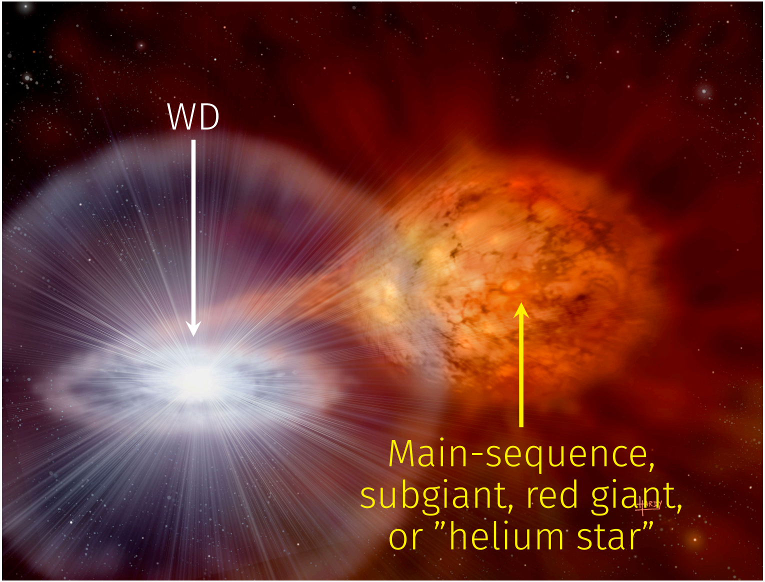
(Maoz et al. 2014, *ARAA*)





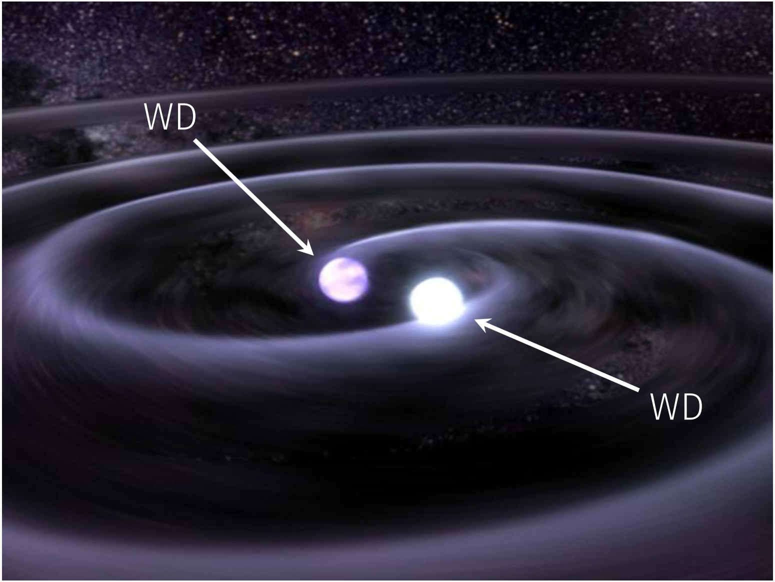
NASA/CXC/M.Weiss

”Single degenerate” (SD; Whelan & Iben 1974)



David A. Hardy/AstroArt.org

”Double degenerate” (DD; Webbink 1984, Iben & Tutukov 1984)



NASA/Tod Strohmayer (GSFC)/Dana Berry (Chandra X-Ray Observatory)

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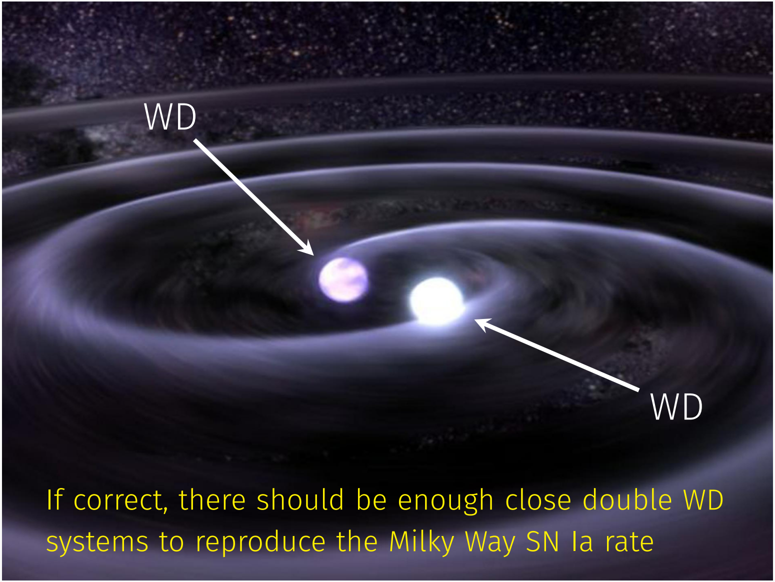


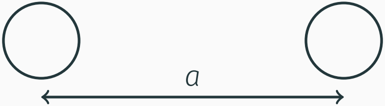
NASA/Tod Strohmayer (GSFC)/Dana Berry (Chandra X-Ray Observatory)

Gravitational wave (GW) foreground

Milky Way double WDs will also constitute the main GW foreground for *LISA*.

Assume a close-orbit double WD, e.g.:

$0.7\,M_\odot + 0.7\,M_\odot$ $\quad\quad$ $R_{WD} = R_\odot/100$



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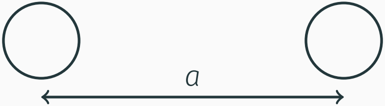


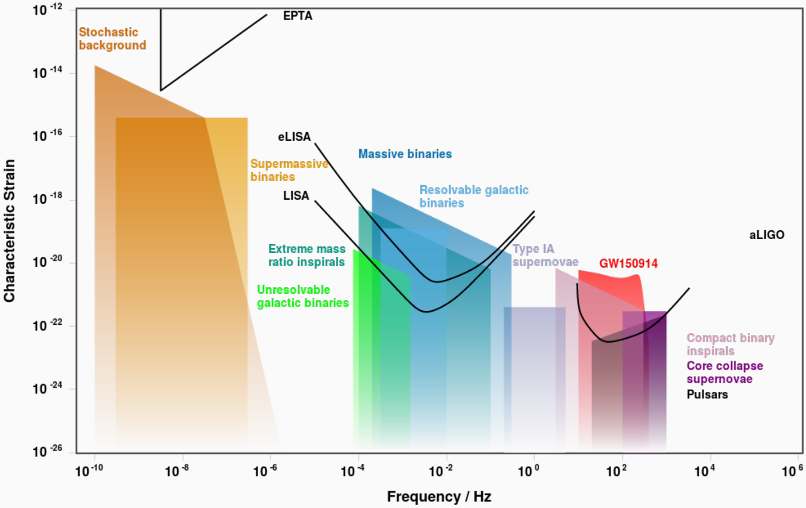
e.g. for $a < 0.3\mathrm{R}_\odot$:

$P < 0.4\,\mathrm{h}, \quad v_{\mathrm{orb}} > 470\,\mathrm{km/s}, \quad t_{\mathrm{merge}} < 1.8\,\mathrm{Myr}$

$f > 1.5\,\mathrm{mHz}$

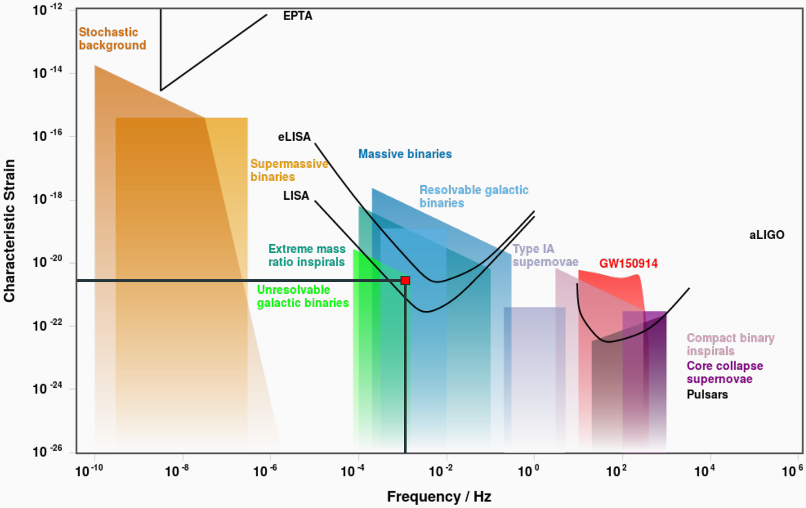
at 100 pc, $h = 5 \times 10^{-21}$

Gravitational wave foreground



Moore et al. 2014

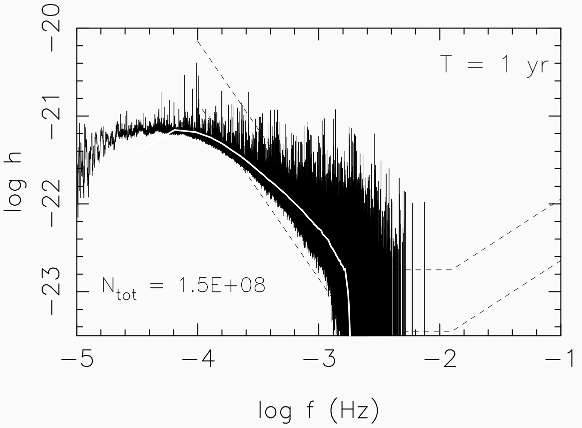
Gravitational wave foreground



Moore et al. 2014

Gravitational wave foreground

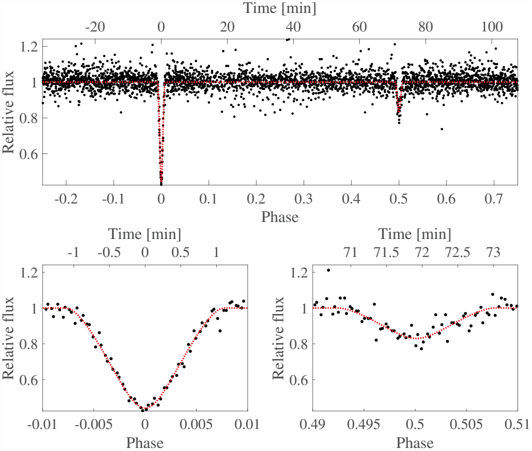
Predicted WD GW foreground is based on highly uncertain models of the double-WD population.



Nelemans et al. 2001

The search for double WDs

One method: look for **eclipsing** double WDs in photometric surveys.

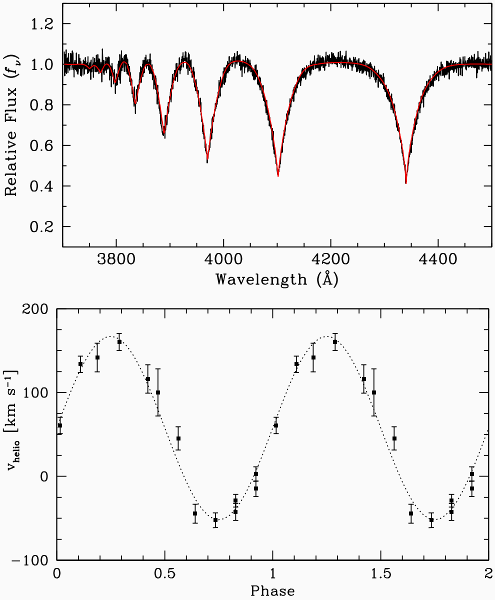


Hallakoun et al. 2016

SDSS J1152+0248: an eclipsing double WD found in *Kepler K2* data.

$P \sim 2.4\,\mathrm{h}$

The search for double WDs



SDSS J1152+0248: an eclipsing double WD found in *Kepler K2* data.

$P \sim 2.4$ h

$0.47\,M_\odot + 0.44\,M_\odot$

$a \sim 0.9\,R_\odot$

$D \sim 500$ pc

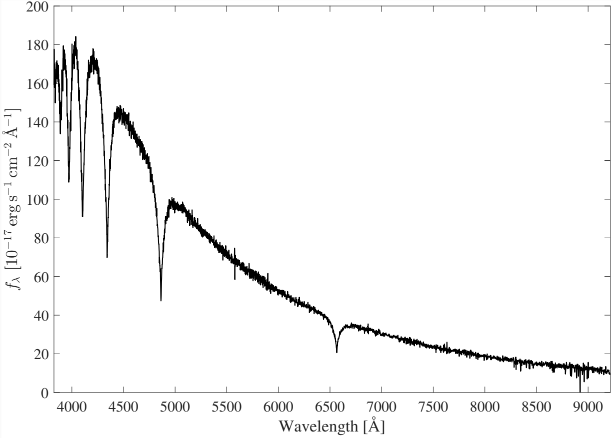
$t_{merge} \sim 460$ Myr

Hallakoun et al. 2016

The search for double WDs

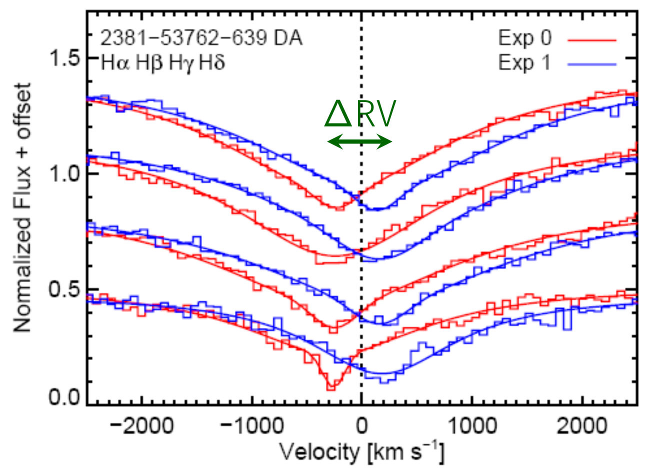
A more efficient way: look for radial velocity (RV) variations in WD spectra.

A typical WD spectrum from SDSS:

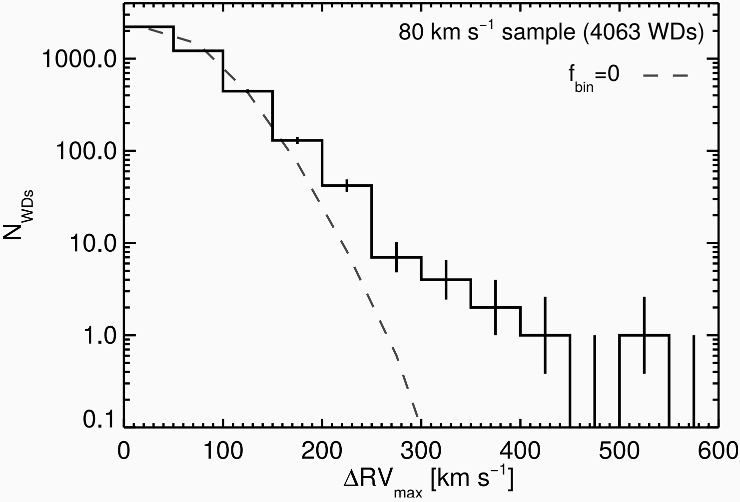


Characterizing the double-WD population using SDSS

All SDSS spectra, including $\sim 20,000$ WDs, have spectra from multiple ($2-3$) epochs:

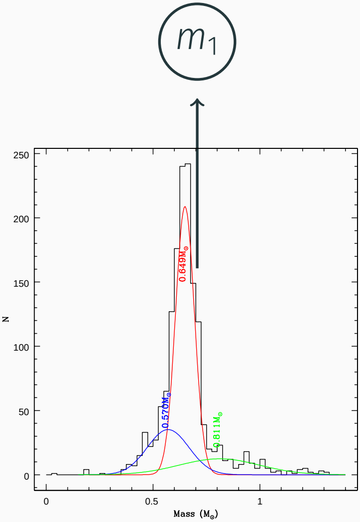


Observed RV distribution for $\sim 4,000$ WDs discriminates among models:



Adapted from Badenes & Maoz 2012

Simulating the local double-WD population



Kepler et al. 2015

Simulating the local double-WD population

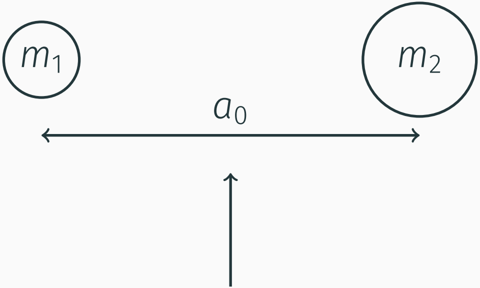
$\propto f_{\text{bin}}$

the fraction of all WDs in binaries within x AU

Simulating the local double-WD population

$$\propto \left(\frac{m_2}{m_1}\right)^{\beta}$$

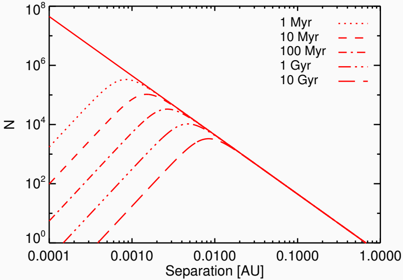
Simulating the local double-WD population

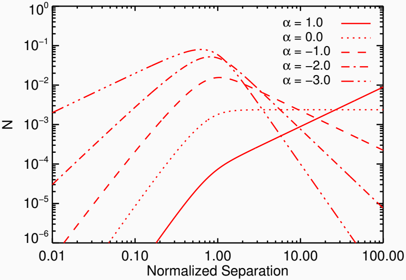


$$\frac{dN}{da_0} \propto a_0^{\alpha}$$

the separation distribution
of double WDs **at birth**

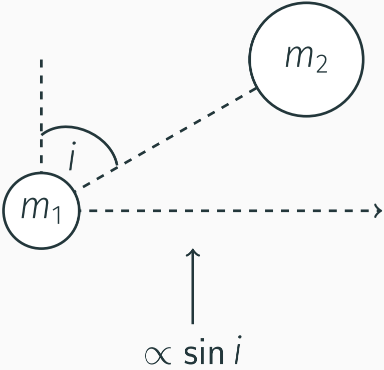
after 10 Gyr of constant star formation rate:





Maoz et al. 2012

Simulating the local double-WD population



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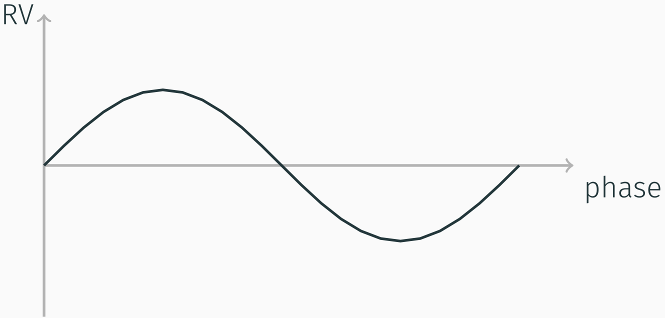

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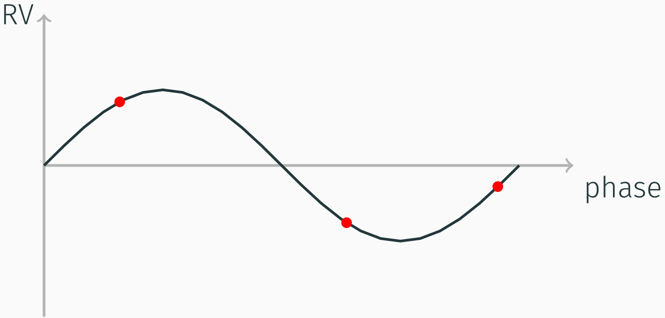

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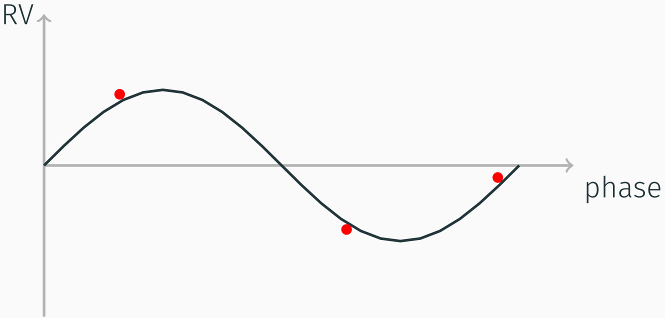

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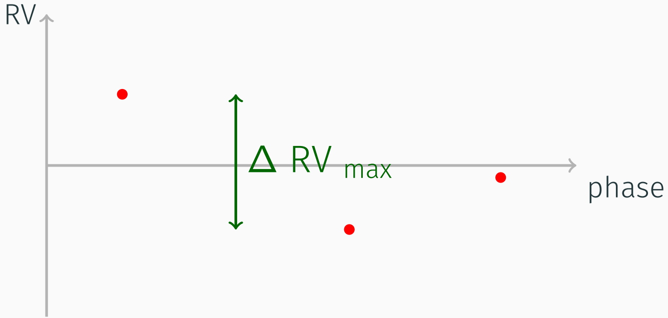


Characterizing the double-WD population using SDSS

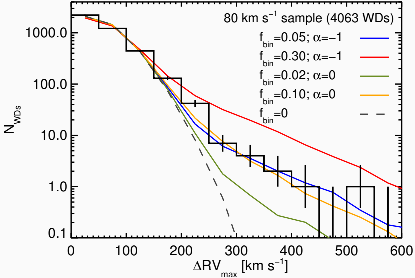
The ΔRV_{max} distribution is affected by two parameters:

f_{bin} the fraction of all WDs in binaries within a specific separation (here: 0.05 AU)

α the power-low index in

$$dN/da_0 \propto a_0^{\alpha},$$

the separation distribution of double WDs **at birth**



Badenes & Maoz 2012

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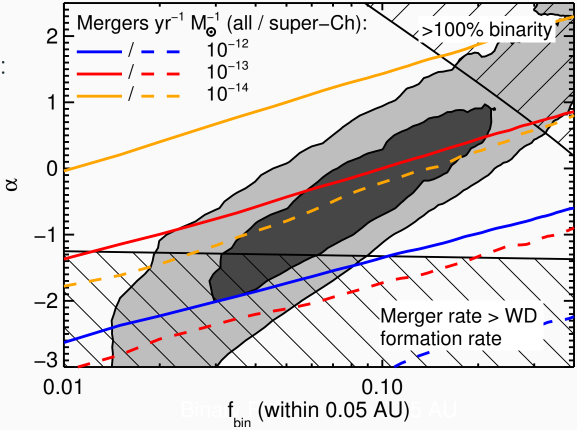


$\Rightarrow$ Total WD merger rate $\sim 1 \times 10^{-13}\,\mathrm{yr}^{-1}\,\mathrm{M}_{\odot}^{-1}$

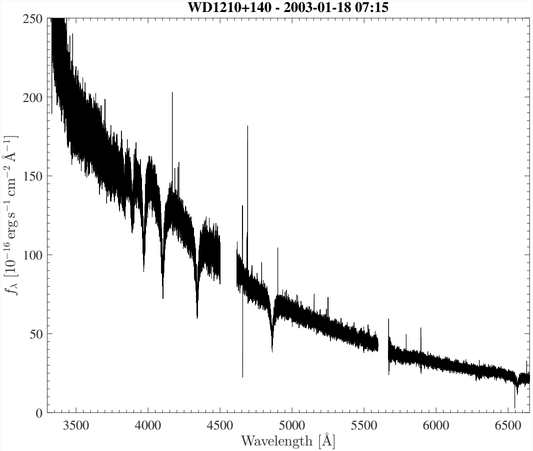
$=$ **SN Ia rate per stellar mass in Sbc galaxies (Milky Way)!**

(But uncertain: maybe 10× lower or 50× higher)

The SPY sample

The ESO VLT Supernova-Ia Progenitor surveY (SPY; 2001-2003, PI: Napiwotzki)

- High S/N spectra
- $1 - 2\,\mathrm{km\,s^{-1}}$ RV resolution
- ~ 2200 ESO-VLT/UVES spectra of ~ 800 WDs
- Clean sample: 439 WDs (DA, multi-epoch, good S/N)



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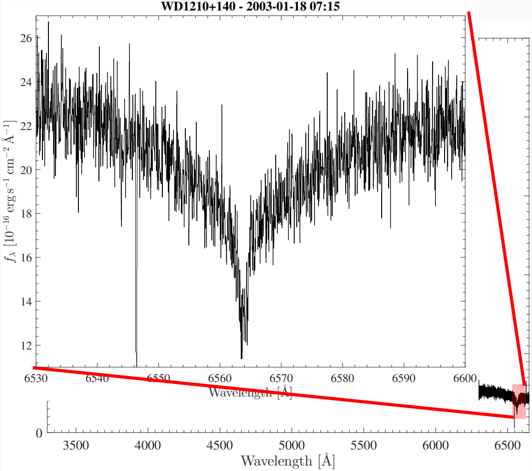

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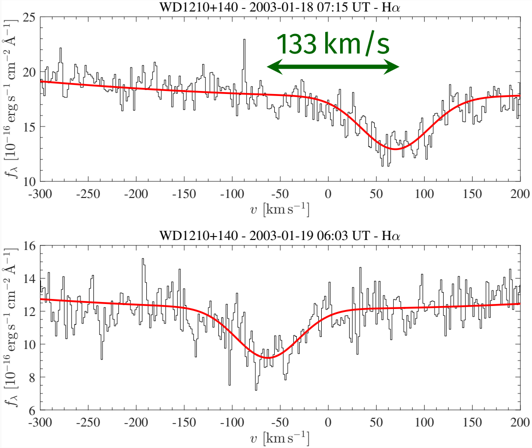
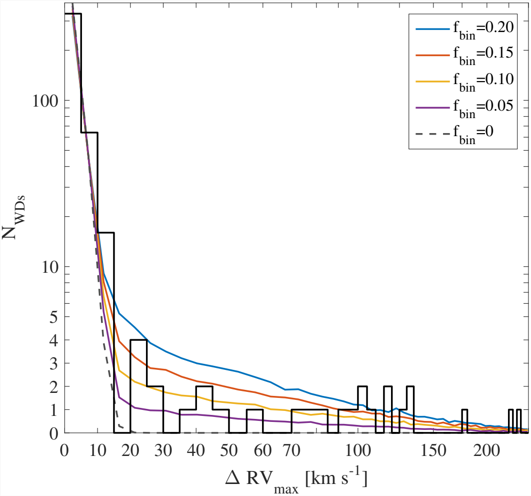


Characterizing the double-WD population using SPY

Only 439 WDs, but $1-2\,\mathrm{km\,s^{-1}}$ RV resolution.

Sensitive to double WDs out to 4 AU:

Maoz & Hallakoun 2017:



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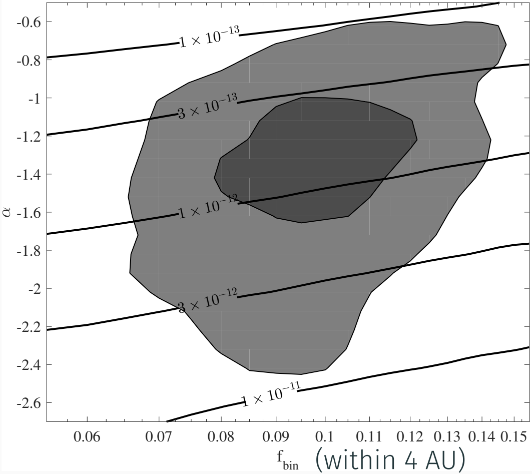

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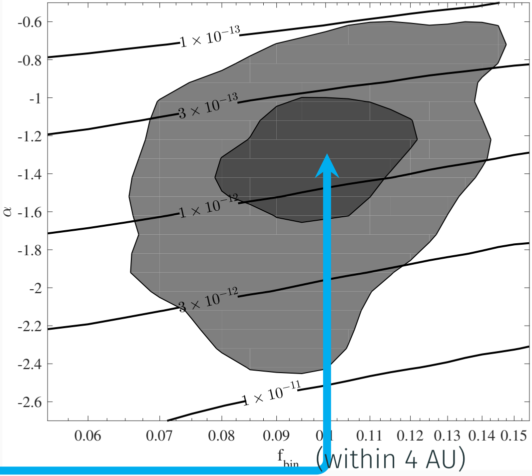

The double-WD fraction (within 4 AU) is $\sim 10\%$.

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WD merger rate $=(1-70)\times$ SN Ia rate

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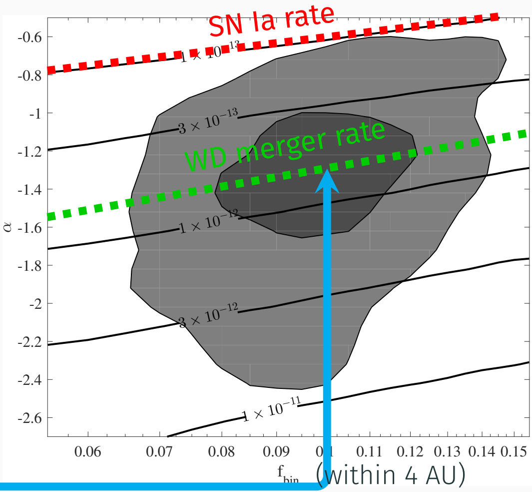

Conclusions

About 10% of WDs are in double-WD binaries with $a < 4\,\mathrm{AU}$.

Followup of candidates ongoing.

Mikly Way WD merger rate is $(1 - 100)$ / century. If a fraction of the mergers can make a SN Ia, there may be enough to reproduce the SN Ia rate.

Maoz & Hallakoun, MNRAS, 2017, 467 (2): 1414-1425