高速で自転する白色矮星と Tomo-e Gozen

fast spinning single white dwarfs and their survey with Tomo-e Gozen

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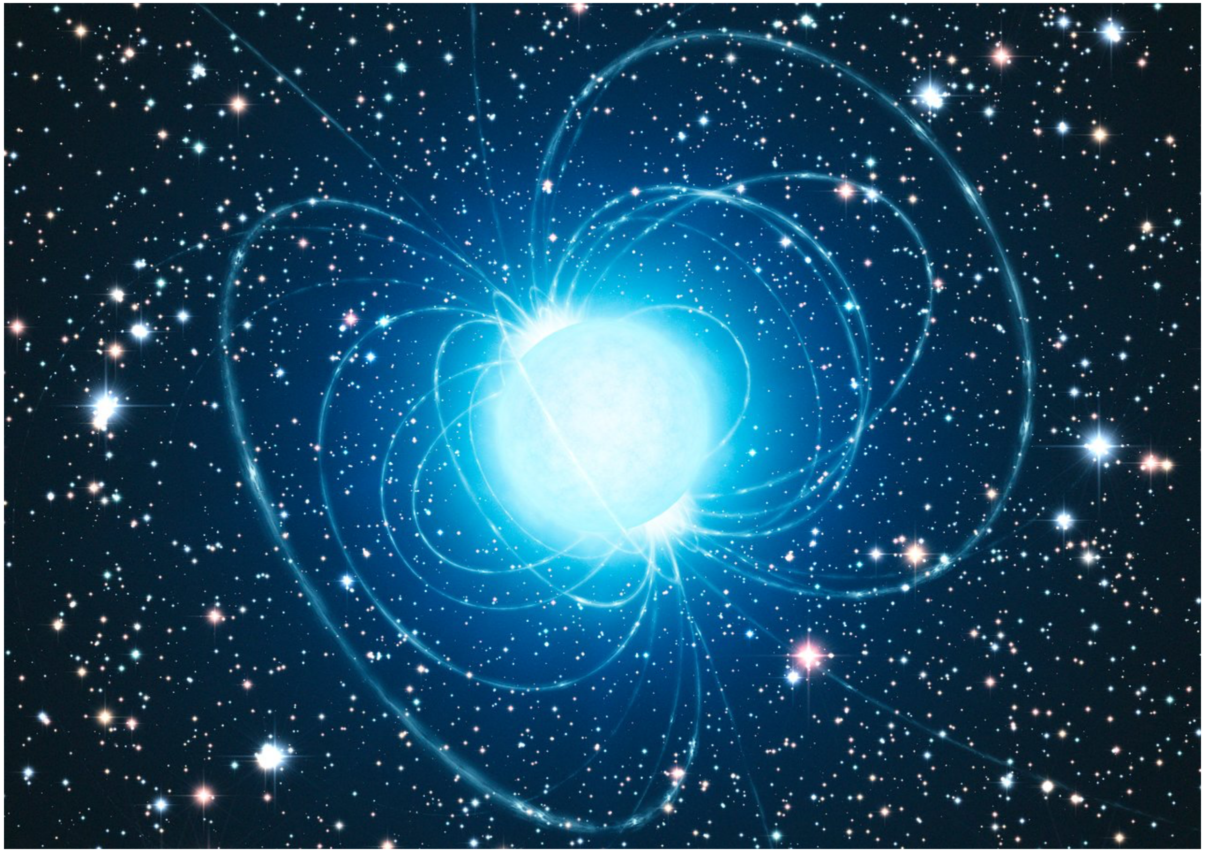
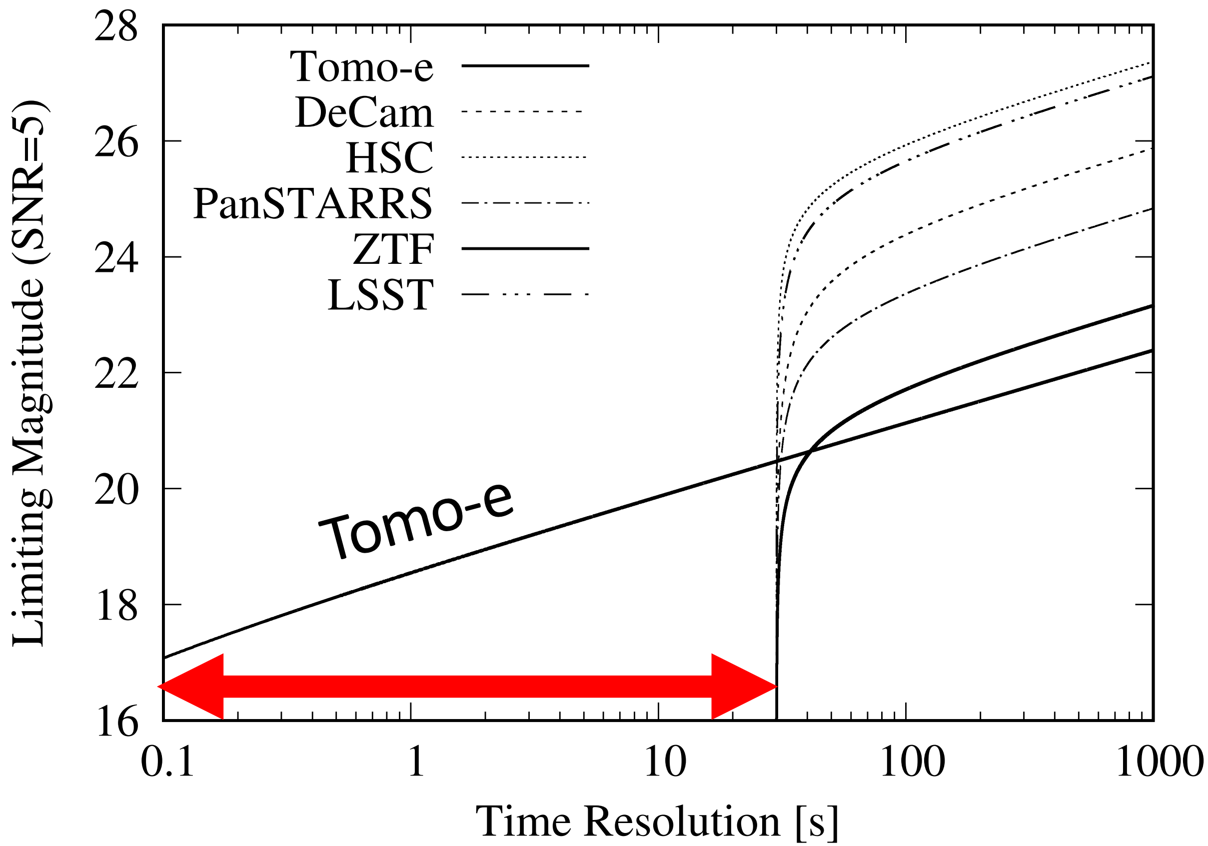
Take-home message

Let's find the fastest spinning single WDs (fssWDs) with Tomo-e Gozen short cadence survey!



Why WDs with Tomo-e?



- < 30s cadence is advantage of Tomo-e
- Tomo-e survey cadence: 0.5 sec
- Minimum spin period of WD: $P_{\rm min} \sim 1\,{\rm sec}\left(\frac{M}{M_\odot}\right)^{1/2}\left(\frac{R}{10^{8.5}\,{\rm cm}}\right)^{-3/2}$

Tomo-e observations of WDs

Target: photometric variations coming from WD spin & inhomogeneity on WD surfaces.

Sources of inhomogeneity

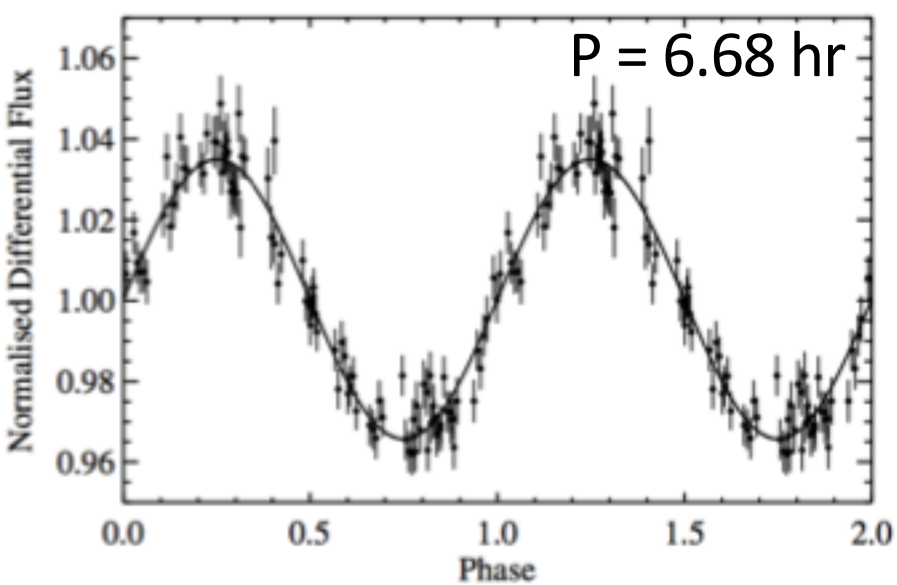
- Starspots if convective zone appears
  low T_{eff} : <12000 K for DA, < 23000 K for DB
- Strong B fields→ magnetic dichroism/hotspots
  $B \gtrsim 100$ M G
- Unknown?
  high T = 30,500 K (no convective zone) and low B = 3.5 MG

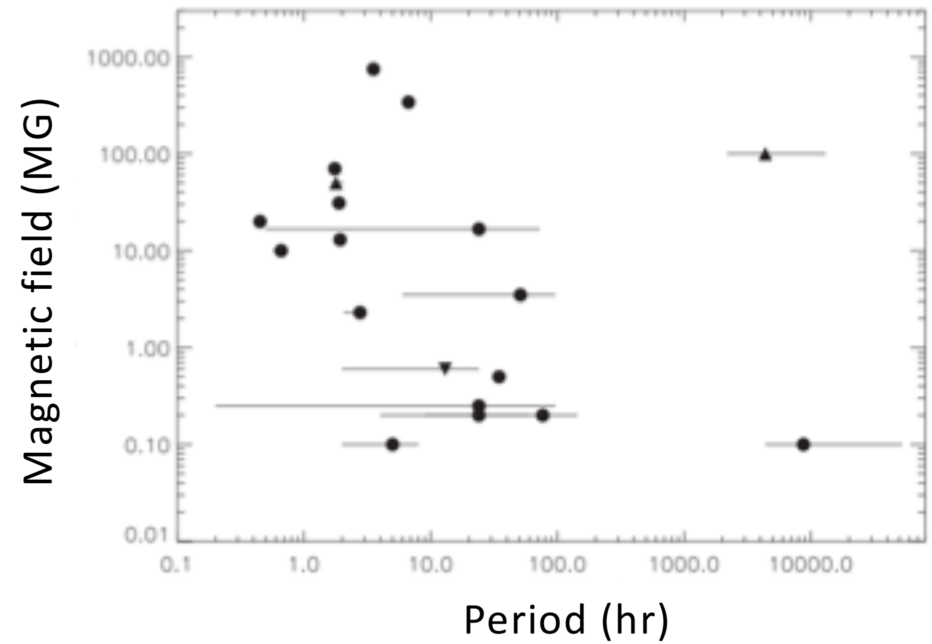
Brinkworth+ (2013)

Photometric observations of WD spins

Brinkworth+ (2013)

- Derive spin periods of 21 WDs out of 30 samples
- Photometric variation amplitude: 0.5 – 10%

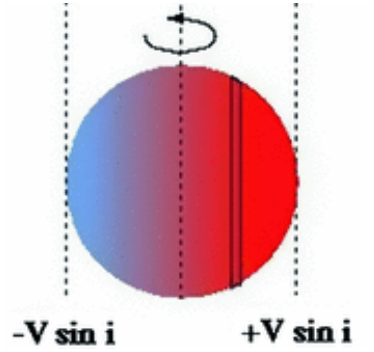




See also
- DECam minute cadence survey — Belardi+ (2016)
- Kepler/K2 observation of pulsating WD — Hermes+ (2017)

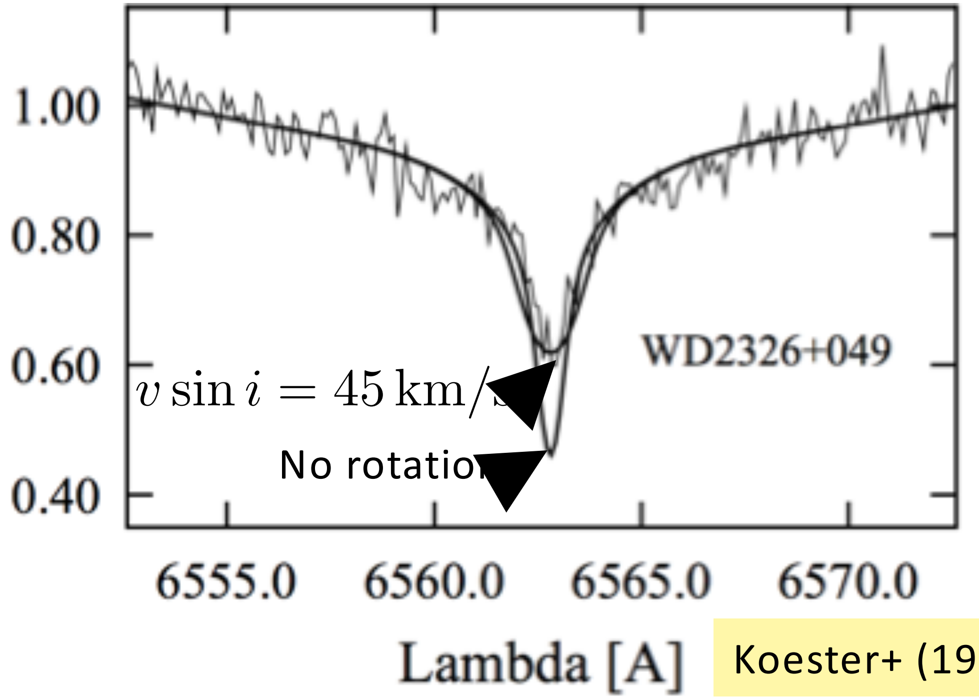
Spectroscopic observations of WD spins

Doppler broadening: $$\frac{\Delta\lambda}{\lambda} = \frac{v_{\rm rot}}{c}\sin(i)$$



SDSS DR10: ~ 43,000 WDs w/ spectroscopy Fusillo+ (2015)

But… high quality spectra with follow-up spectroscopy are needed



Koester+ (1998)

Line profiles are also affected by

- Non-LTE
- T_{eff}
- log g
- Stark broadening
  (E fields in plasma)

Q. How to form fssWDs?

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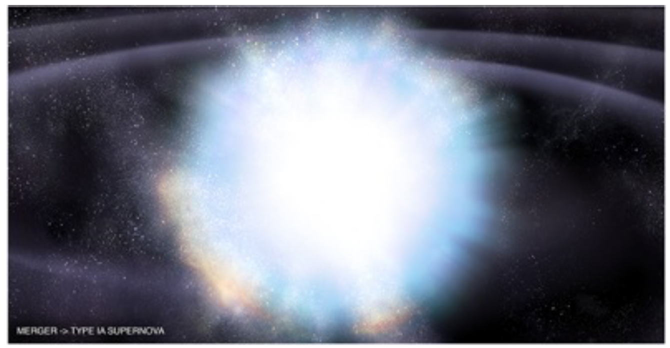
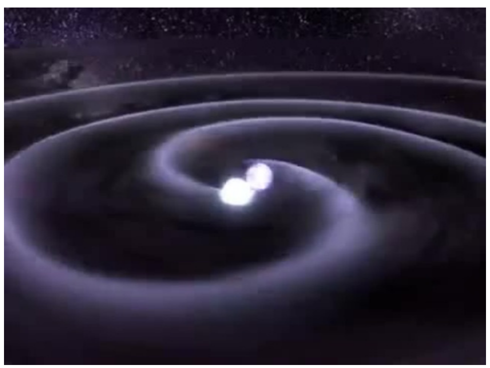
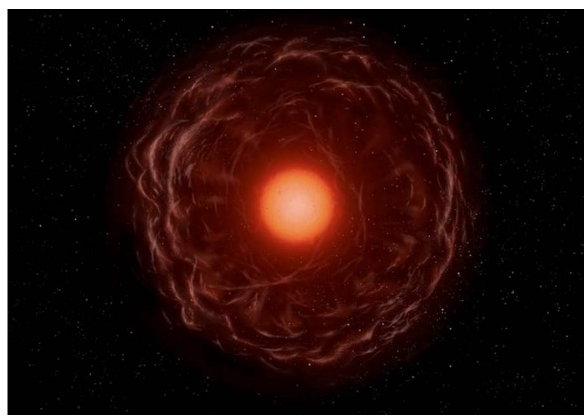
A. Double WDs mergers

Ia SNe



Double WD merger



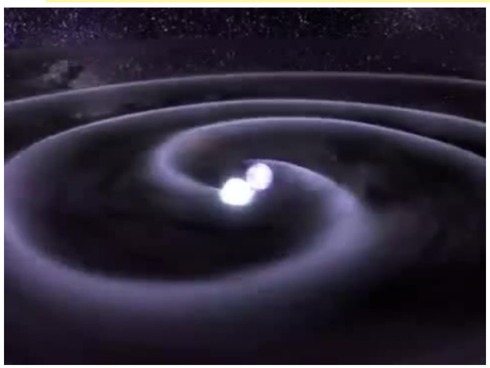


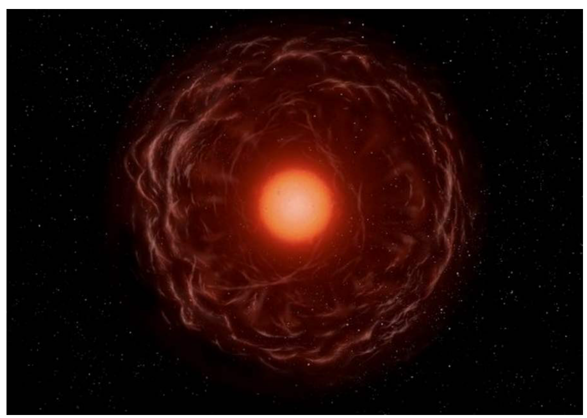
Debris expansion

KH contraction -> massive WD

Q. How to form fssWDs?
A. Double WDs mergers

We can naively expect
- fast spin ~ 1 sec ($\simeq$ mass shedding limit)
- strong B field ($B > 10^8$ G) → photometric variation

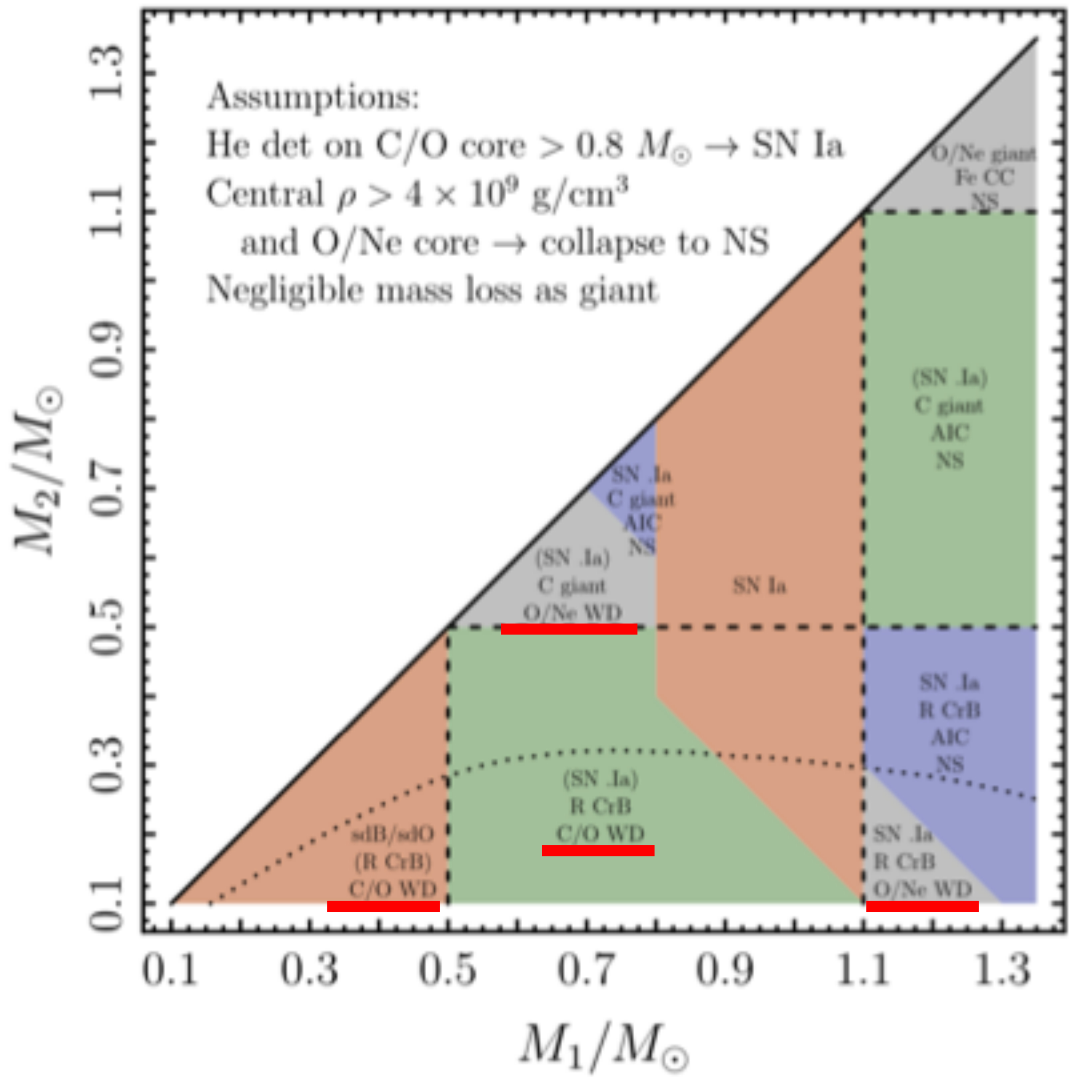




Debris expansion

KH contraction -> massive WD

Fates of double WD merger



Shen+ (2015)

A good fraction of double WD mergers leave massive WDs

How many fssWDs are there?

WD birth rate: $\dot{N}_{\rm WD} \sim 1\,{\rm yr}^{-1}\,{\rm gal}^{-1}$

Badenes & Maoz (2012)

Double WD merger rate: $\dot{N}_{\rm merger} \sim 10^{-(2\text{-}3)}\,{\rm yr}^{-1}\,{\rm gal}^{-1}$

=> Fraction of merger-origin WDs: $f_{\rm ffsWD} \sim 0.1\text{-}1\%$

Local number density of WDs from Gaia observations

$$n_{\rm WD} = 4.49 \times 10^{-3}\,{\rm pc}^{-3}$$

Hollands+ (2018)

=> We assume fssWDs density:

$$4.49 \times 10^{-5}\,{\rm pc}^{-3} \left(\frac{f_{\rm fssWD}}{1\%}\right)\left(\frac{n_{\rm WD}}{4.49 \times 10^{-3}{\rm pc}}\right)$$

Post-merger evolution model

- Assume M_{WD} = 1.0 M_{sun}, R_{WD} = 5 x 10^8 cm, CO WD
- Initial spin period: P_0 = {1, 10, 100} sec
- Spin down via magnetic dipole radiation

$$\dot{\Omega} = -\frac{R^6 \Omega^3 {B_p}^2 \sin^2\alpha}{6c^3 I}$$

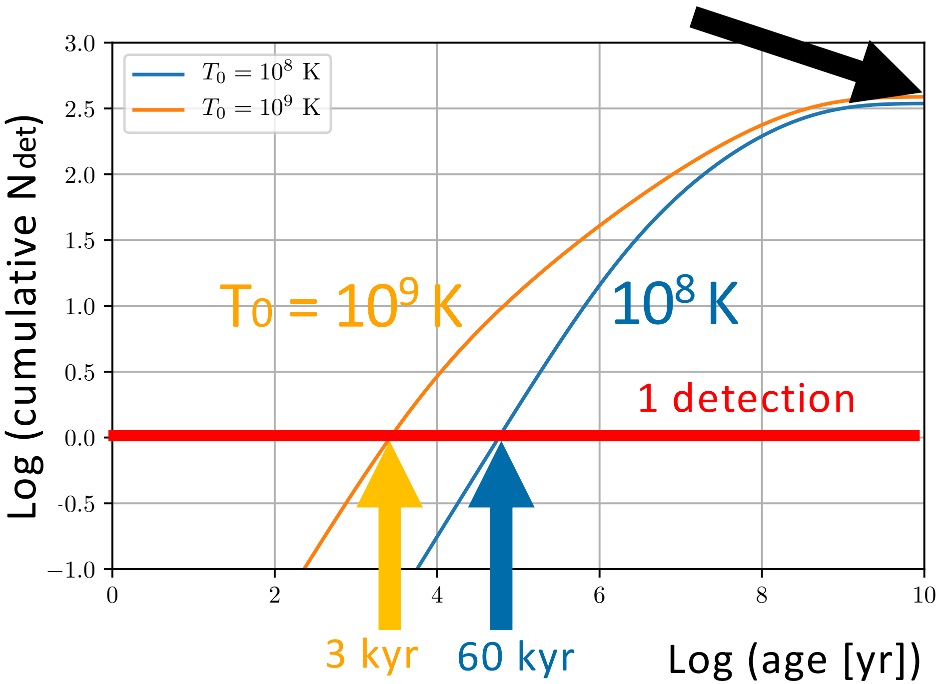
- $B_p \sin\alpha = 10^{8\text{-}12}$ G ($10^{8\text{-}9}$ G: Ji+ (2013) , 10^{12} G: $E_{grav} \sim E_B$)

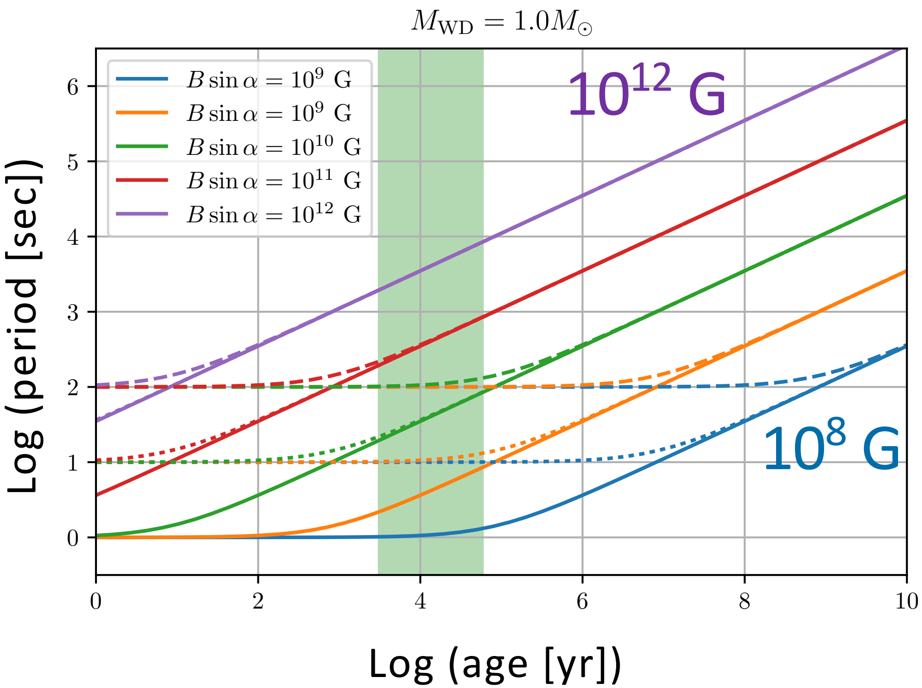
- Initial internal temperature: $T_0 = 10^{8\text{-}9}$ K
  (For $T_0 = 10^9$ K , $E_{th,0} \sim 2 \times 10^{49}$ erg, $T_{eff,0} = 10^5$ K)
- Cooling
  - Kramar's opacity: $\kappa = \kappa_0 \, \rho \, T^{-3.5}$
  - $L \propto M T_\star^{3.5}$
  - Ignoring crystallizations nor melting

fssWDs found with Tomo-e

- Limiting magnitude: g = 20, sky coverage 10,000 deg^2
- f_{fssWD} = 1%

~ 300 fssWDs would be found





- For B sin α = $10^{8\text{-}9}$ G, youngest WD have initial P $\lesssim$ 100 sec

The fastest spinning WDs observed so far

- WD: RE J0317-853 (double degenerate binary)
  - P = 725.4 sec
  - M ≃ 1.3 Msun, B ~ 300 MG
  - Double degenerate merger origin?

Barstow+ (1995), Ferrario+ (1997)

- Isolated Pulsating WD: SDSSJ0837+1856
  - P = 1.13 +- 0.02 hr
  - M = 0.87 Msun

Hermes+ (2017)

- X-ray binary: RX J0648.0–4418
  - P = 13.2 sec
  - M = 1.28 +- 0.05 Msun

Mereghetti+ (2013)

Conclusions

- Let’s find the fastest spinning single WDs (fssWDs) with Tomo-e Gozen short cadence survey!
- Double WDs mergers are plausible origin of fssWDs.
- fssWDs and distribution of WD spins are clues to fates of double WD mergers and post-merger evolutions.
- Tomo-e would detect ~ 300 fssWDs. The youngest WD has spin period of $P \lesssim 100$ sec depending on initial P and B.