Searching for the fastest spinning white dwarfs with *Tomo-e Gozen*

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Abstract

We propose to utilize second cadence photometric survey telescopes like *Tomo-e Gozen* to search for the fastest spinning single white dwarfs (fssWDs) in the Galaxy. In particular, **a remnant of a binary WD merger**, if it does not neither explode as type Ia supernova nor collapse into a neutron star, will be a strongly magnetized massive WD, which may typically rotates with a spin period of 1-10 seconds at the birth and then spins down by magnetic dipole radiation. The periodicity can be observed in the photometric data if e.g., they have hot spots on the surface as observed in strongly magnetized WDs. Considering the time evolution of the spin and thermal emission of merged WDs, we show that a **Galactic plane survey with *Tomo-e Gozen* could identify ~50 of WDs with spin periods less than 10³ seconds. Finding such WDs would unveil fates of WD mergers and various high-energy astrophysical mysteries.**

fssWD originating from double WD merger

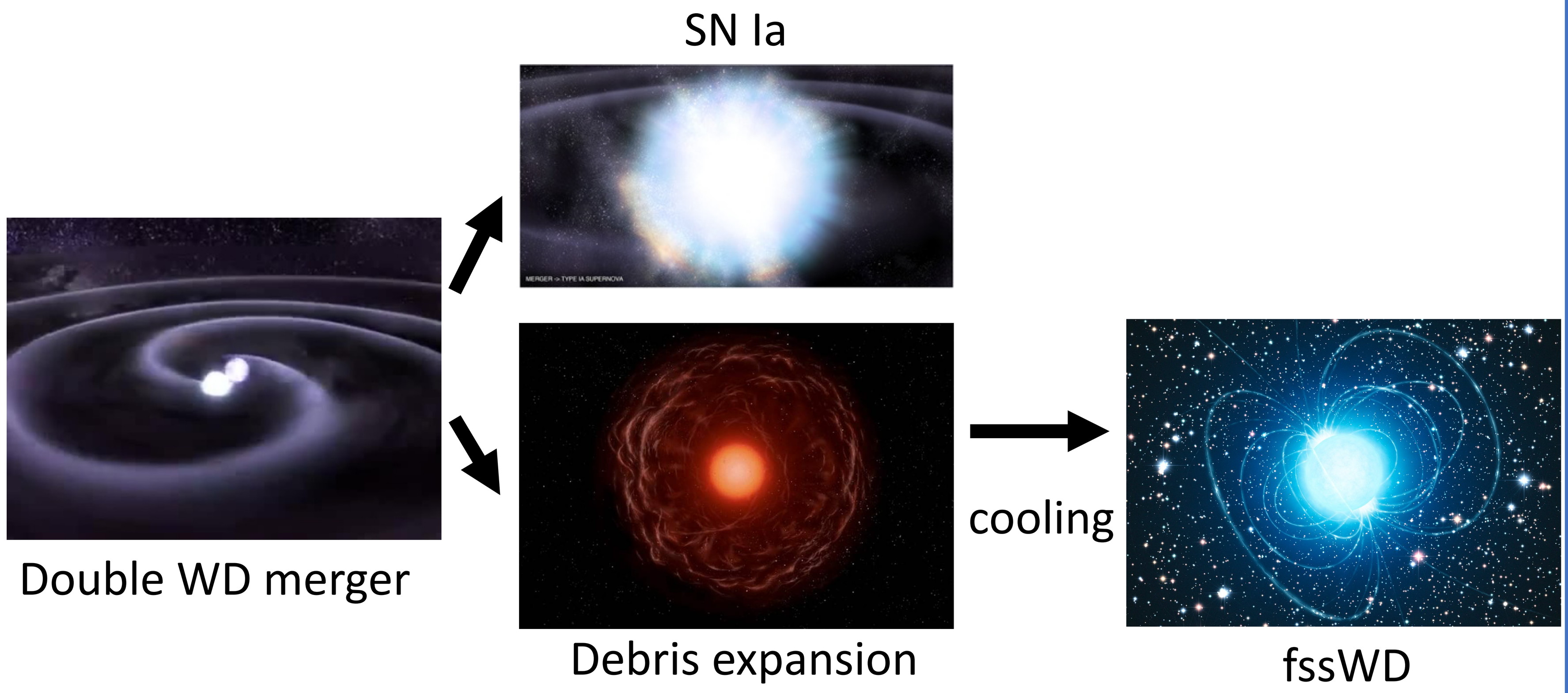

Fig. 1 Schematic flow chart on origin of fssWDs. Credit: NASA/CXC/M Weiss

A good fraction of double WD mergers do not explode as SNe Ia nor collapse into neutron stars, leaving massive remnant WDs (e.g. Shen+ 2012, Dan+ 2014). Their rotation energy of ~ 10^{50} erg could affect, once released, several high-energy phenomena, such as

- high-energy electron/positron cosmic rays (Kashiyama+ 2011)
- fast radio bursts (FRBs) (Kashiyama+ 2013)

Tomo-e Gozen & second time domain search

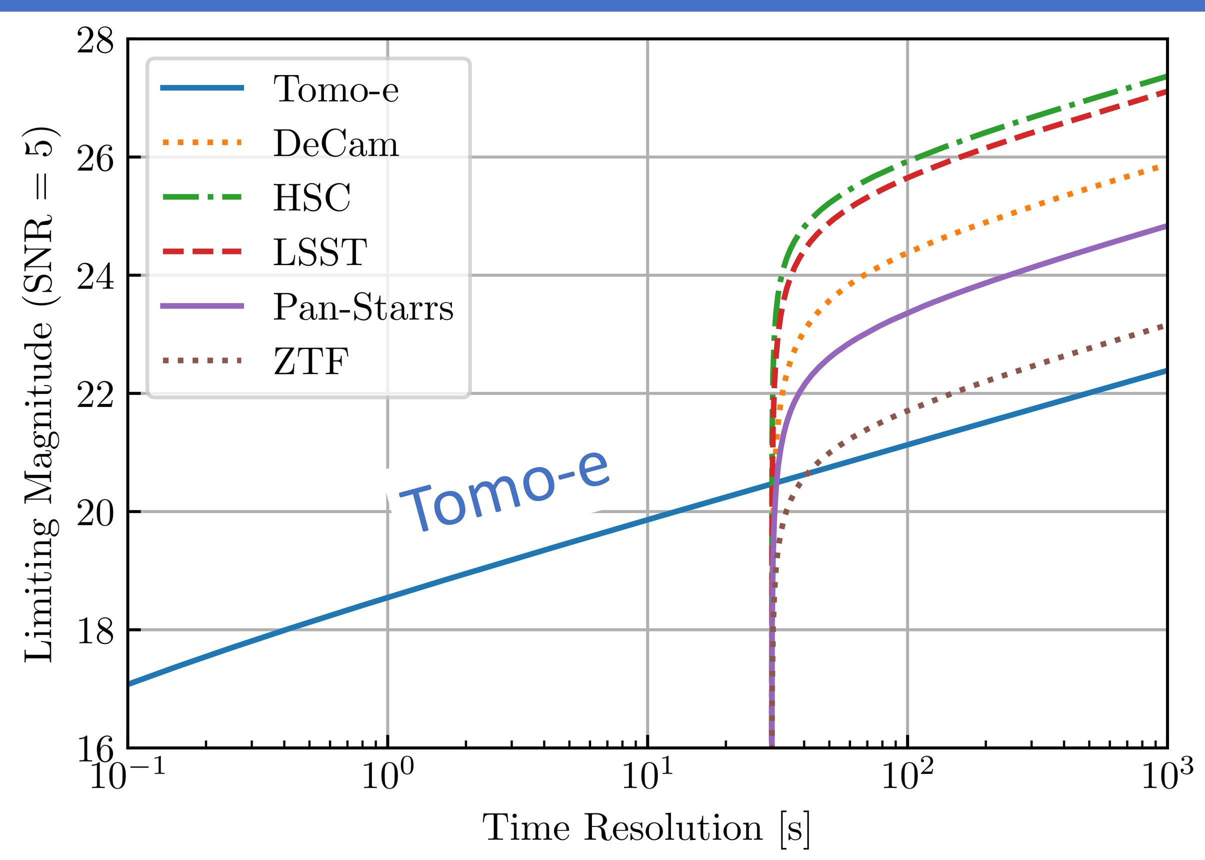

Fig. 2 Sensitivities of optical telescopes with different time resolution.

Tomo-e Gozen is a wide field optical camera mounted on 1.05m Schmidt telescope at Kiso Observatory. Its uniqueness is **high sensitivity at < 30 sec** achieved with the use of CMOS camera.

Tomo-e Gozen is suitable to survey the fastest spinning WDs rotating with mass-shedding limit velocity, whose spin period is

$$P_{\rm min} \sim 3\,{\rm sec}\left(\frac{M_{\rm WD}}{1.2\,M_\odot}\right)^{-1/2}\left(\frac{R_{\rm WD}}{5,000\,{\rm km}}\right)^{3/2}$$

Brinkworth+ (2013) observe optical photometric variation of spinning WDs arising from starspots or polar magnetic fields. But their spin periods are ≳ 30 min, which would be limited by a small number of samples and large time resolutions.

Methods

We consider spin down and cooling of WDs

Population of fssWDs

- WD birth rate: $\dot{N}_{\rm WD} \sim 1\,{\rm yr}^{-1}\,{\rm gal}^{-1}$
- Double WD merger rate: $\dot{N}_{\rm merger} \sim 10^{-(2\text{-}3)}\,{\rm yr}^{-1}\,{\rm gal}^{-1}$ Badenes & Maoz (2012)

➢ fraction of merger-origin WDs: $f_{\rm fssWD} \sim 0.1\text{-}1\%$

➢ number density:

$$n_{\rm fssWD} \sim 1.5\times10^{-6}\,{\rm pc}^{-3}\left(\frac{f_{\rm fssWD}}{0.3\%}\right)\left(\frac{n_{\rm WD}}{4.5\times10^{-3}\,{\rm pc}^{-3}}\right)$$

from Gaia observation (Hollands+ 2018)

- Assume $M_{\rm WD} = 1.2\,M_\odot$ for simplicity

Spin down

- magnetic dipole radiation: $\dot{\Omega} = -\dfrac{R^6\Omega^3 B_p^{\,2}\sin^2\alpha}{6c^3 I}$
- assuming constant strong magnetic fields: $B_p \sin\alpha = 10^{8\text{-}9}\,{\rm G}$
- Initial spin velocity: 3-30% of mass-shedding-limit velocity

Cooling

- Follow Shapiro & Teukolsky (1983)
- Composition: C 50% + O 50%
- Initial internal temperature after merger: $T_0 = 10^9\,{\rm K}$

Detection limit of *Tomo-e Gozen*

- we take g = 19 as detection limit of WD variability
- sky coverage: 10,000 deg²

Results

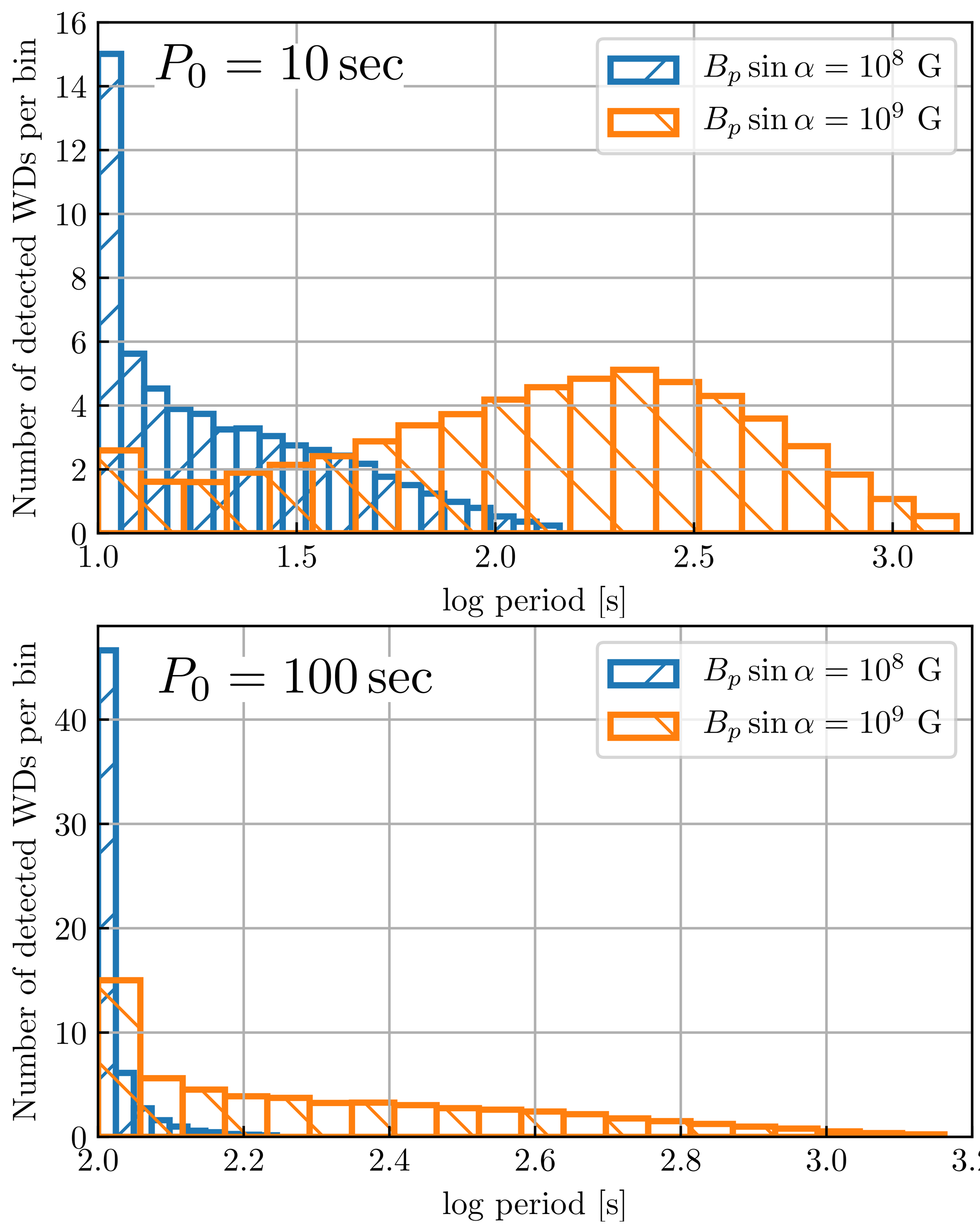

Fig. 3 Number of fssWDs detected with Tomo-e Gozen.

a: $P_0 = 10\,{\rm sec}$ or $v_{\rm rot,0} \simeq 0.3\,v_{\rm shed}$

b: $P_0 = 100\,{\rm sec}$ or $v_{\rm rot,0} \simeq 0.03\,v_{\rm shed}$

Totally ~60 fssWDs would be detected with *Tomo-e Gozen*

Current status and other sources

Installation of *Tomo-e Gozen* is going to be completed in 2019. We are developing a pipeline for *Tomo-e Gozen* to obtain photometry and variability analysis.

Our targets are not only fssWDs but also **other sources showing short time-scale variability in optical**, such as

- pulsating WDs
- asteroid disruptions by WDs like WD 1145+017
- quasars
- M-dwarfs
- …