Slowly rotating neutron stars and fast spinning white dwarfs

Kazumi Kashiyama (Tohoku. U)

based on collaboration and conversation with

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Yudai Suwa, Ryo Sawada, Masamitsu Mori (U. Tokyo), Kohta Murase (PSU),
Ryo Osawa, Aya Bamba (U. Tokyo), Hiromasa Suzuki, Takaaki Tanaka (Konan),
Shota Kisaka (Hiroshima U.), Shuta Tanaka (Aoyama), Jumpei Takata (Huazhong University of Science and Technology)

NATURE. VOL. 217. FEBRUARY 24, 1968

Observation of a Rapidly Pulsating Radio Source

by

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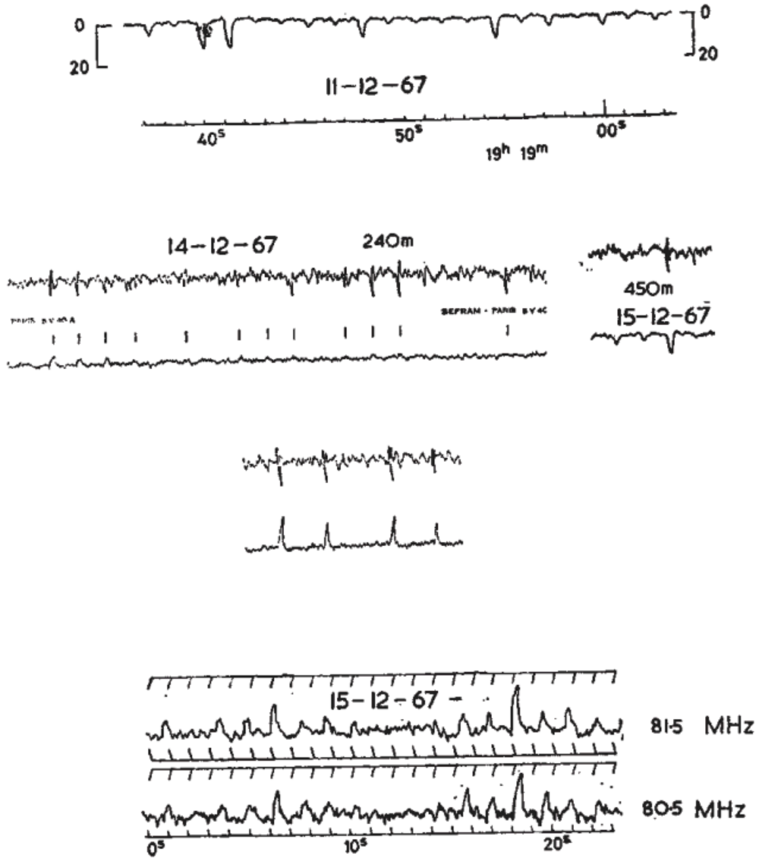
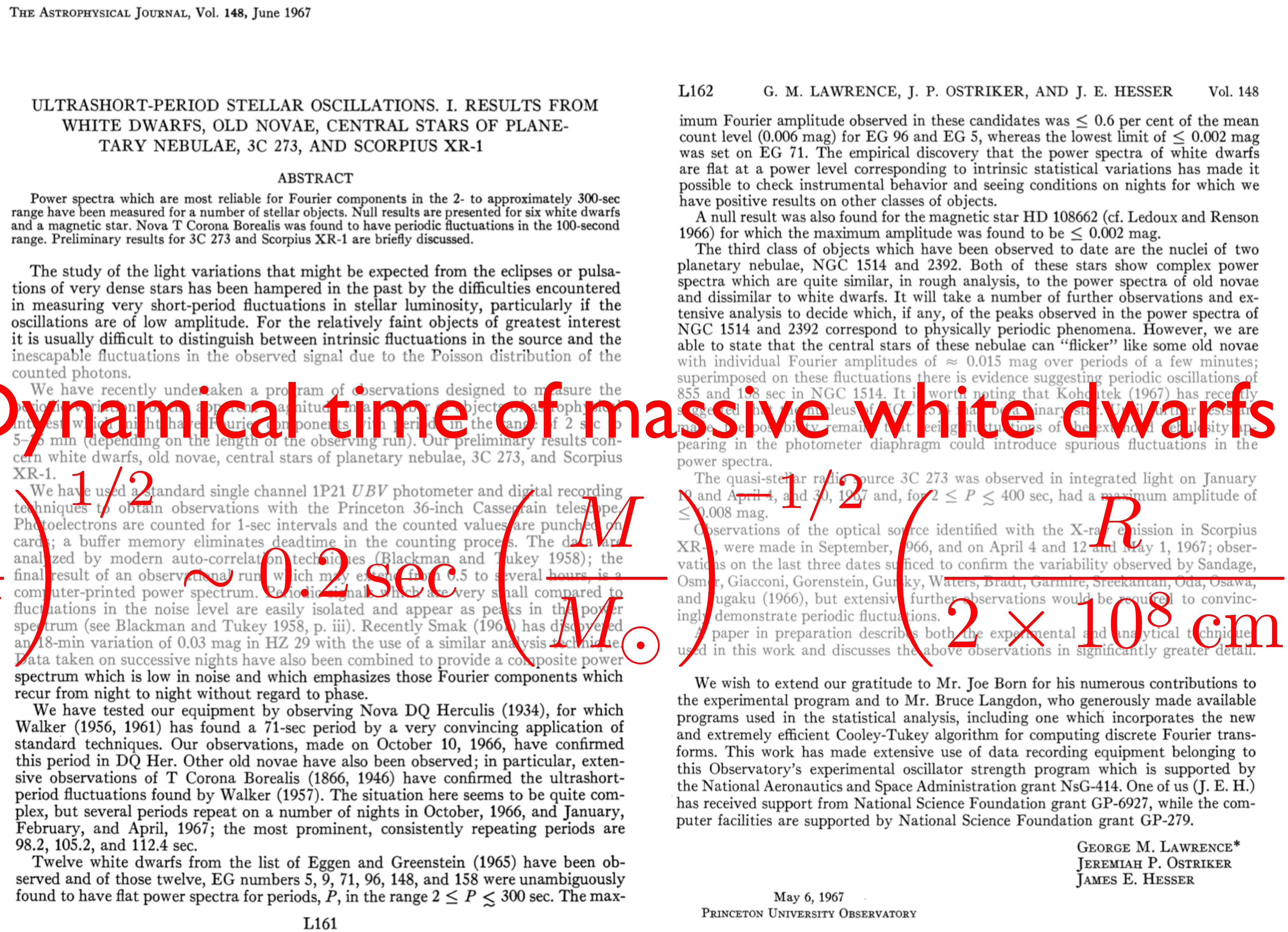
Unusual signals from pulsating radio sources have been recorded at the Mullard Radio Astronomy Observatory. The radiation seems to come from local objects within the galaxy, and may be associated with oscillations of white dwarf or neutron stars.



Dynamical time of massive white dwarfs

$$\left(\frac{R^3}{GM}\right)^{1/2} \sim 0.2\,\mathrm{sec}\left(\frac{M}{M_\odot}\right)^{-1/2}\left(\frac{R}{2\times10^{8}\,\mathrm{cm}}\right)^{3/2}$$



The Astrophysical Journal, Vol. **148**, June 1967

ULTRASHORT-PERIOD STELLAR OSCILLATIONS. I. RESULTS FROM WHITE DWARFS, OLD NOVAE, CENTRAL STARS OF PLANETARY NEBULAE, 3C 273, AND SCORPIUS XR-1

ABSTRACT

Power spectra which are most reliable for Fourier components in the 2- to approximately 300-sec range have been measured for a number of stellar objects. Null results are presented for six white dwarfs and a magnetic star. Nova T Corona Borealis was found to have periodic fluctuations in the 100-second range. Preliminary results for 3C 273 and Scorpius XR-1 are briefly discussed.

The study of the light variations that might be expected from the eclipses or pulsations of very dense stars has been hampered in the past by the difficulties encountered in measuring very short-period fluctuations in stellar luminosity, particularly if the oscillations are of low amplitude. For the relatively faint objects of greatest interest it is usually difficult to distinguish between intrinsic fluctuations in the source and the inescapable fluctuations in the observed signal due to the Poisson distribution of the counted photons.

We have recently undertaken a program of observations designed to measure the periodic variations of the apparent magnitude in a number of objects of astrophysical interest which might have Fourier components with periods in the range of 2 sec to 5–15 min (depending on the length of the observing run). Our preliminary results concern white dwarfs, old novae, central stars of planetary nebulae, 3C 273, and Scorpius XR-1.

We have used a standard single channel 1P21 *UBV* photometer and digital recording techniques to obtain observations with the Princeton 36-inch Cassegrain telescope. Photoelectrons are counted for 1-sec intervals and the counted values are punched on cards; a buffer memory eliminates deadtime in the counting process. The data are analyzed by modern auto-correlation techniques (Blackman and Tukey 1958); the final result of an observational run which may extend from 0.5 to several hours, is a computer-printed power spectrum. Periodic signals which are very small compared to fluctuations in the noise level are easily isolated and appear as peaks in the power spectrum (see Blackman and Tukey 1958, p. iii). Recently Smak (1967) has discovered an 18-min variation of 0.03 mag in HZ 29 with the use of a similar analysis technique. Data taken on successive nights have also been combined to provide a composite power spectrum which is low in noise and which emphasizes those Fourier components which recur from night to night without regard to phase.

We have tested our equipment by observing Nova DQ Herculis (1934), for which Walker (1956, 1961) has found a 71-sec period by a very convincing application of standard techniques. Our observations, made on October 10, 1966, have confirmed this period in DQ Her. Other old novae have also been observed; in particular, extensive observations of T Corona Borealis (1866, 1946) have confirmed the ultrashort-period fluctuations found by Walker (1957). The situation here seems to be quite complex, but several periods repeat on a number of nights in October, 1966, and January, February, and April, 1967; the most prominent, consistently repeating periods are 98.2, 105.2, and 112.4 sec.

Twelve white dwarfs from the list of Eggen and Greenstein (1965) have been observed and of those twelve, EG numbers 5, 9, 71, 96, 148, and 158 were unambiguously found to have flat power spectra for periods, P, in the range $2 \leq P \lesssim 300$ sec. The maximum Fourier amplitude observed in these candidates was ≤ 0.6 per cent of the mean count level (0.006 mag) for EG 96 and EG 5, whereas the lowest limit of ≤ 0.002 mag was set on EG 71. The empirical discovery that the power spectra of white dwarfs are flat at a power level corresponding to intrinsic statistical variations has made it possible to check instrumental behavior and seeing conditions on nights for which we have positive results on other classes of objects.

L161

L162 G. M. LAWRENCE, J. P. OSTRIKER, AND J. E. HESSER Vol. 148

A null result was also found for the magnetic star HD 108662 (cf. Ledoux and Renson 1966) for which the maximum amplitude was found to be ≤ 0.002 mag.

The third class of objects which have been observed to date are the nuclei of two planetary nebulae, NGC 1514 and 2392. Both of these stars show complex power spectra which are quite similar, in rough analysis, to the power spectra of old novae and dissimilar to white dwarfs. It will take a number of further observations and extensive analysis to decide which, if any, of the peaks observed in the power spectra of NGC 1514 and 2392 correspond to physically periodic phenomena. However, we are able to state that the central stars of these nebulae can "flicker" like some old novae with individual Fourier amplitudes of ≈ 0.015 mag over periods of a few minutes; superimposed on these fluctuations there is evidence suggesting periodic oscillations of 855 and 1[illegible]8 sec in NGC 1514. It is worth noting that Kohoutek (1967) has recently suggested that the nucleus of NGC 1514 may be a binary star. Until further tests are made, the possibility remains that seeing fluctuations of the extended nebulosity appearing in the photometer diaphragm could introduce spurious fluctuations in the power spectra.

The quasi-stellar radio source 3C 273 was observed in integrated light on January 19 and April 4, and 30, 1967 and, for $2 \leq P \lesssim 400$ sec, had a maximum amplitude of ≤ 0.008 mag.

Observations of the optical source identified with the X-ray emission in Scorpius XR-1, were made in September, 1966, and on April 4 and 12 and May 1, 1967; observations on the last three dates sufficed to confirm the variability observed by Sandage, Osmer, Giacconi, Gorenstein, Gursky, Waters, Bradt, Garmire, Sreekantan, Oda, Osawa, and Jugaku (1966), but extensive further observations would be required to convincingly demonstrate periodic fluctuations.

A paper in preparation describes both the experimental and analytical technique used in this work and discusses the above observations in significantly greater detail.

We wish to extend our gratitude to Mr. Joe Born for his numerous contributions to the experimental program and to Mr. Bruce Langdon, who generously made available programs used in the statistical analysis, including one which incorporates the new and extremely efficient Cooley-Tukey algorithm for computing discrete Fourier transforms. This work has made extensive use of data recording equipment belonging to this Observatory's experimental oscillator strength program which is supported by the National Aeronautics and Space Administration grant NsG-414. One of us (J. E. H.) has received support from National Science Foundation grant GP-6927, while the computer facilities are supported by National Science Foundation grant GP-279.

George M. Lawrence*
Jeremiah P. Ostriker
James E. Hesser

May 6, 1967
Princeton University Observatory

27 DECEMBER 1968

Pulsating Radio Sources near the Crab Nebula

Abstract. *Two new pulsating radio sources, designated NP 0527 and NP 0532, were found near the Crab Nebula and could be coincident with it. Both sources are sporadic, and no periodicities are evident. The pulse dispersions indicate that 1.58 ± 0.03 and 1.74 ± 0.02 × 10^{20} electrons per square centimeter lie in the direction of NP 0527 and NP 0532, respectively.*

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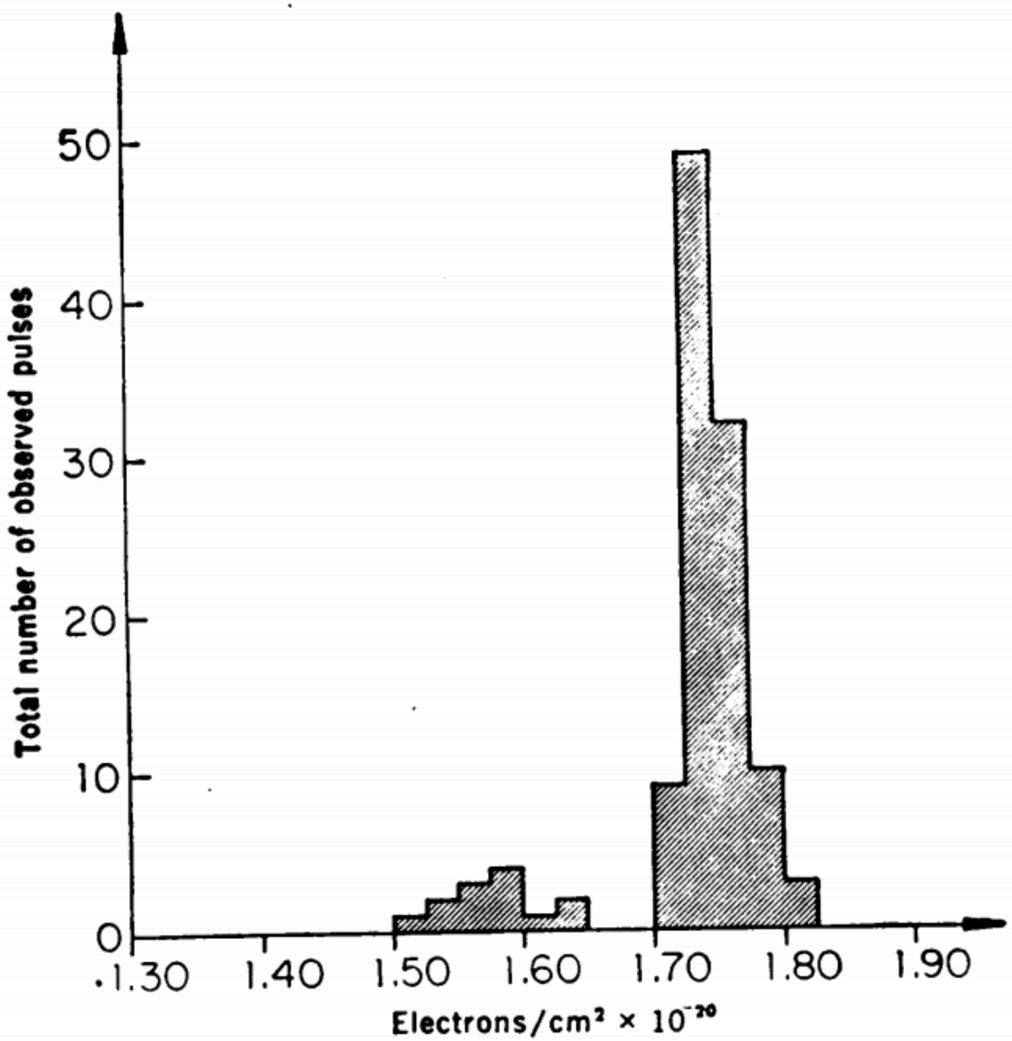


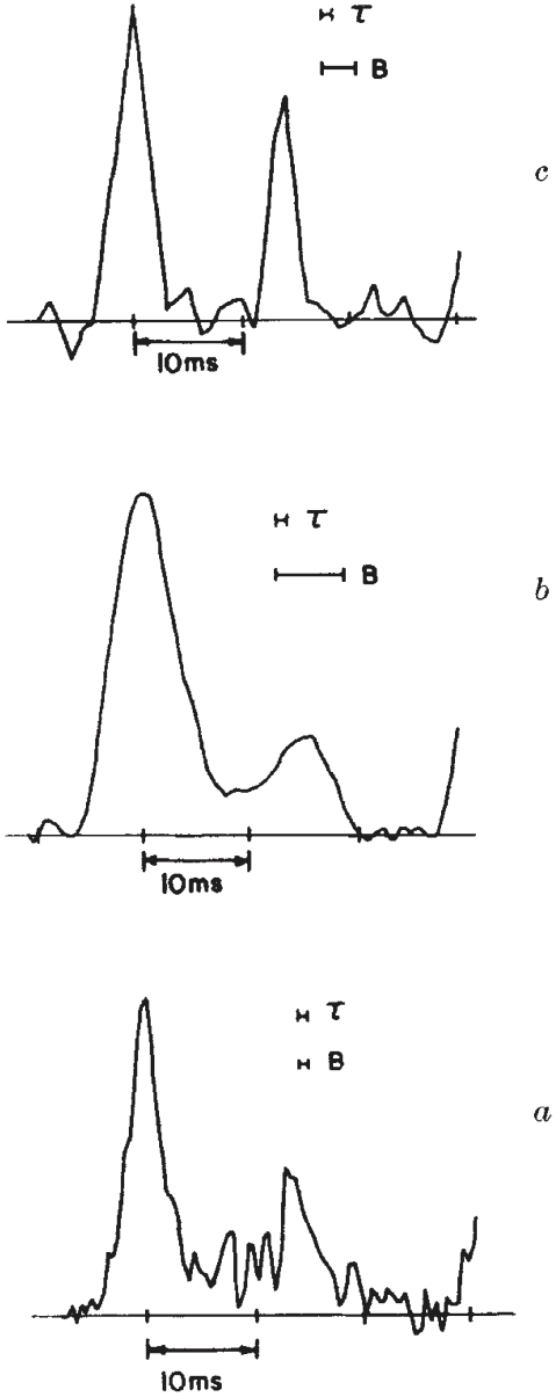
NATURE, VOL. 221, FEBRUARY 1, 1969

LETTERS TO THE EDITOR

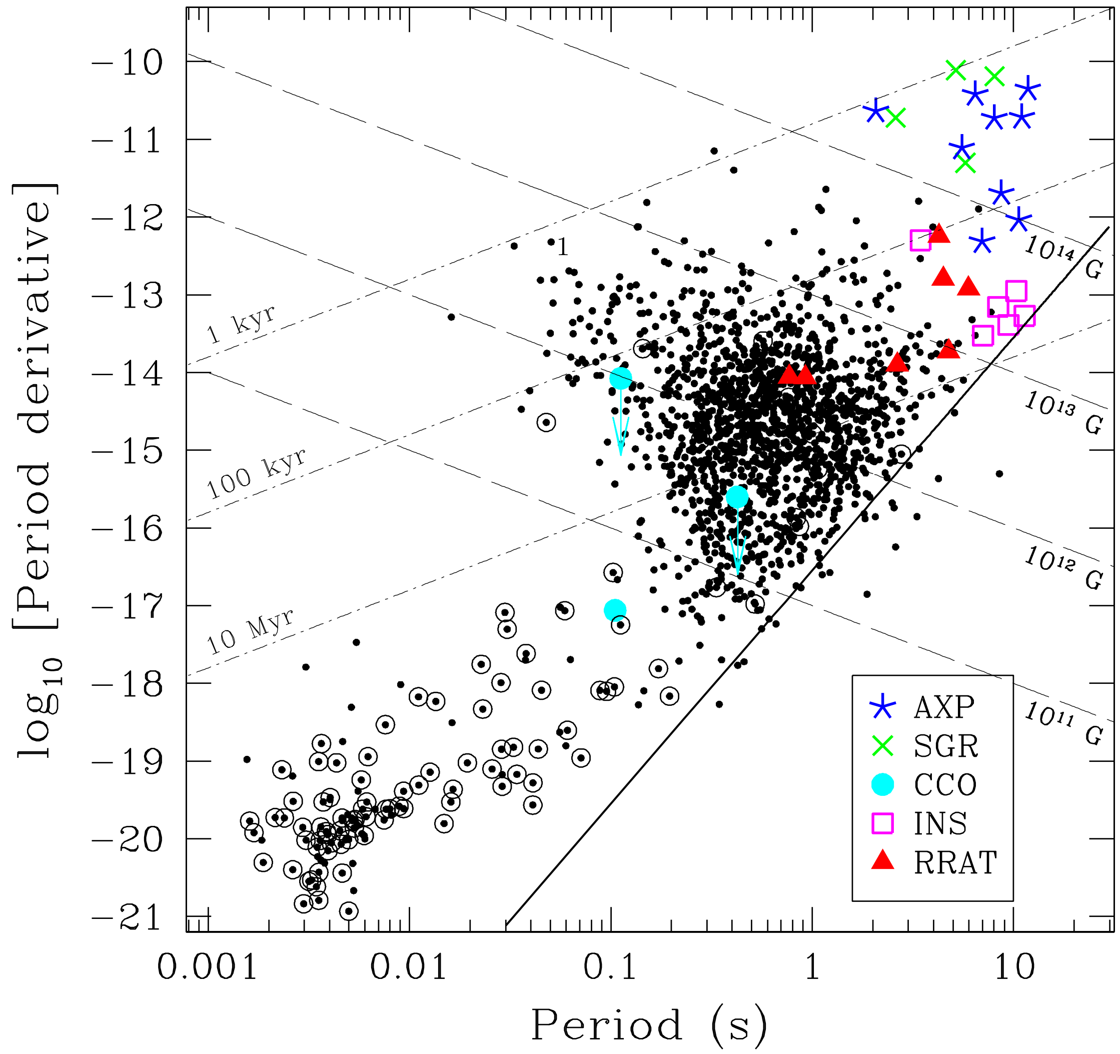
PHYSICAL SCIENCES

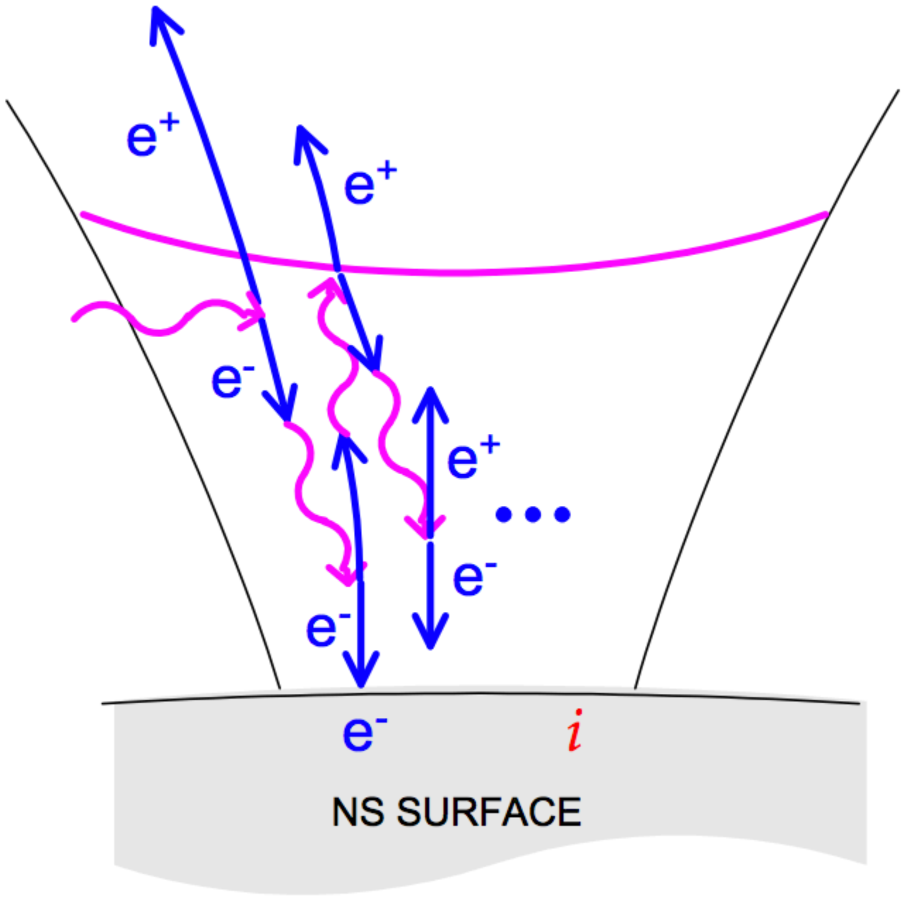
Crab Nebula Pulsar *NP* 0532

J. M. Comella
H. D. Craft, jun.
R. V. E. Lovelace
J. M. Sutton



P-Pdot diagram and pulsar death line



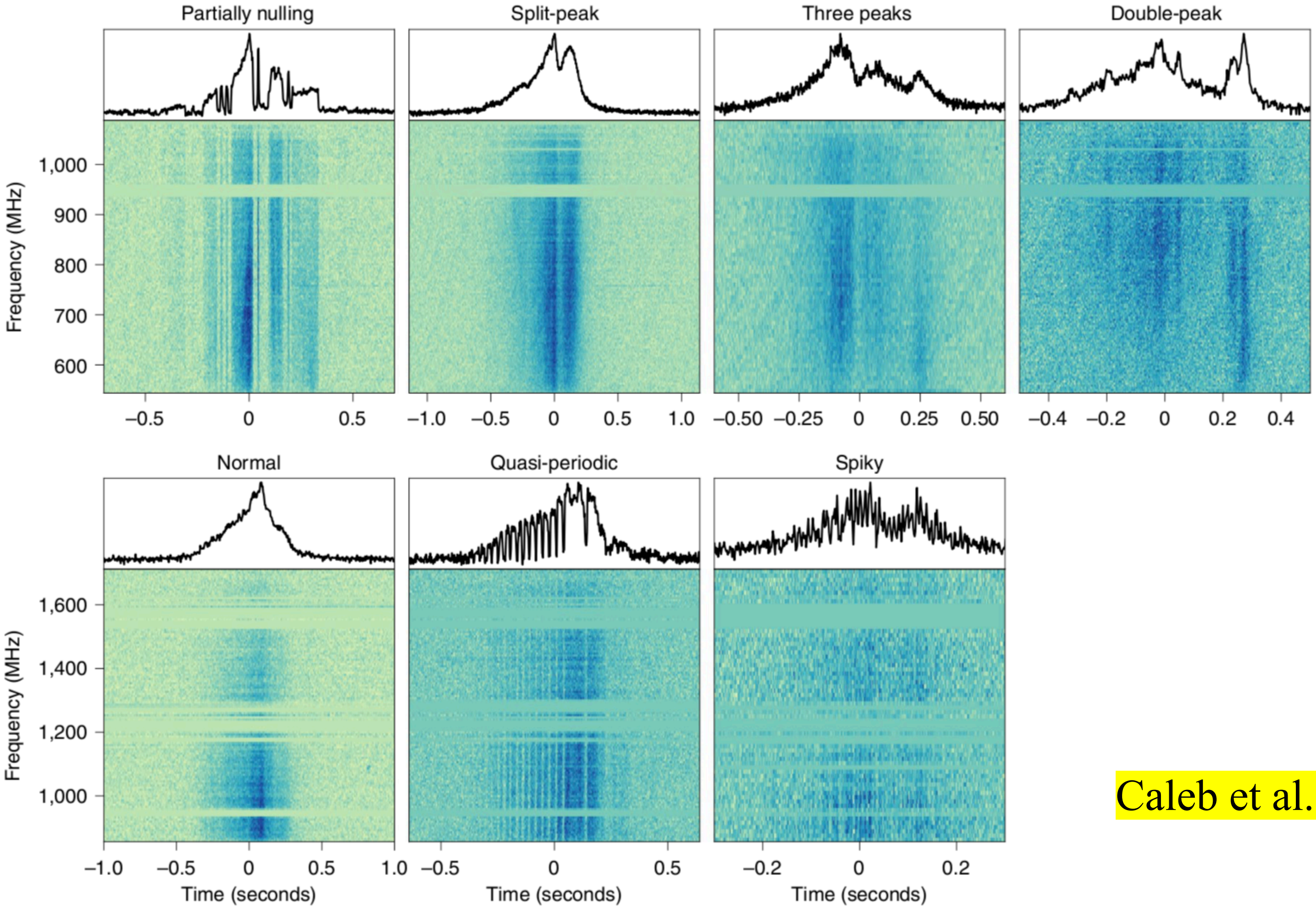


Ruderman & Sutherland 75; Chen & Rudermand 93; …

PSR J0901-4046

MEERTRAP

- $\nu \sim 1$ GHz
- DM ~ 52 pc cm^{-3}
  → d ~ 300-400 pc
- $P = 75.88$ sec
- $Pdot = 2.25\times10^{-13}$
  → $B < 1.3\times10^{14}$ G
- $Edot = 2\times10^{28}$ erg s^{-1}
- $L_{\mathrm{iso,\ radio}} \sim 10^{24}$ erg s^{-1}
- Fractional linear polarization 12%
- Fractional circular polarization 21%



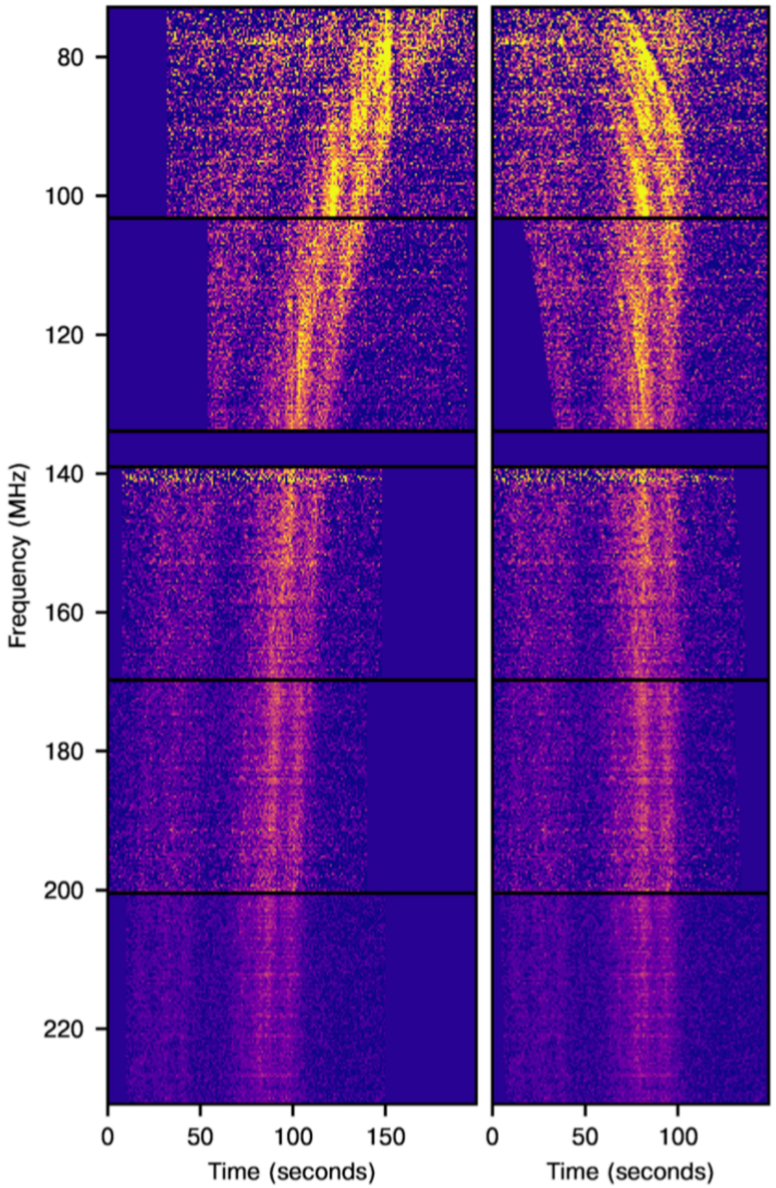
Caleb et al. 22

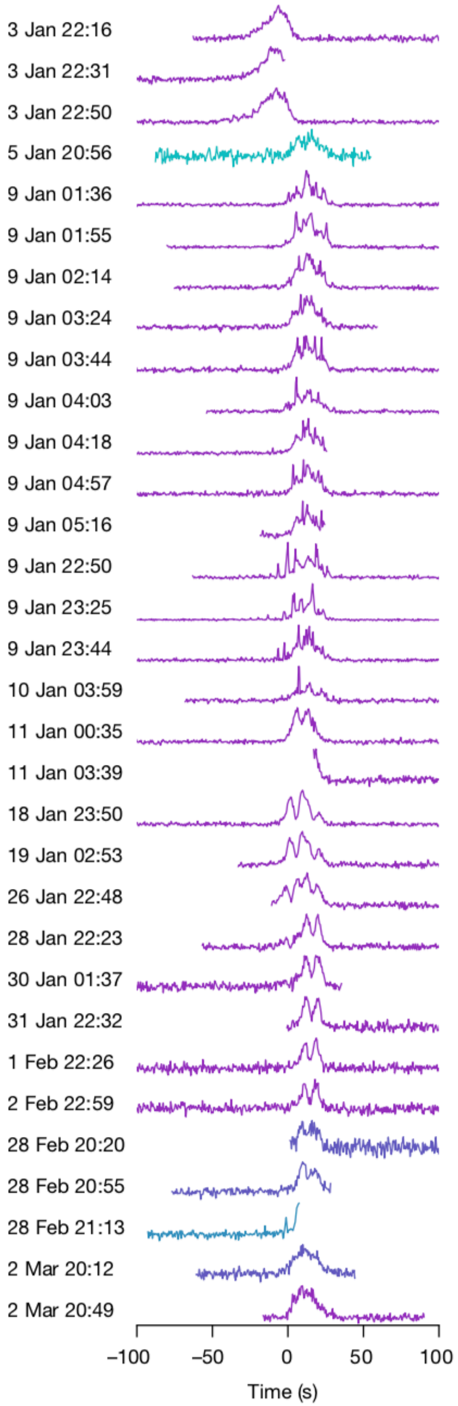
"quasi-periodicity and partial nulling"

GLEAM-X J162759.5-523504.3

- $\nu \sim 100$ MHz
- DM ~ 57 pc cm^{-3}
  → d ~ 1.3 kpc
- $P = 18.18$ min
- $0 < \dot{P} < 1.2\text{x}10^{-9}$
  → $B < 5.1\text{x}10^{16}$ G
- $\dot{E} < 1.2\text{x}10^{28}$ erg s^{-1}
- $L_{\text{peak, radio}} \sim 4\text{x}10^{31}$ erg s^{-1} >> $\dot{E}$
- high-fractional linear polarization (88 ± 1%)

Hurley-Walker et al. 22

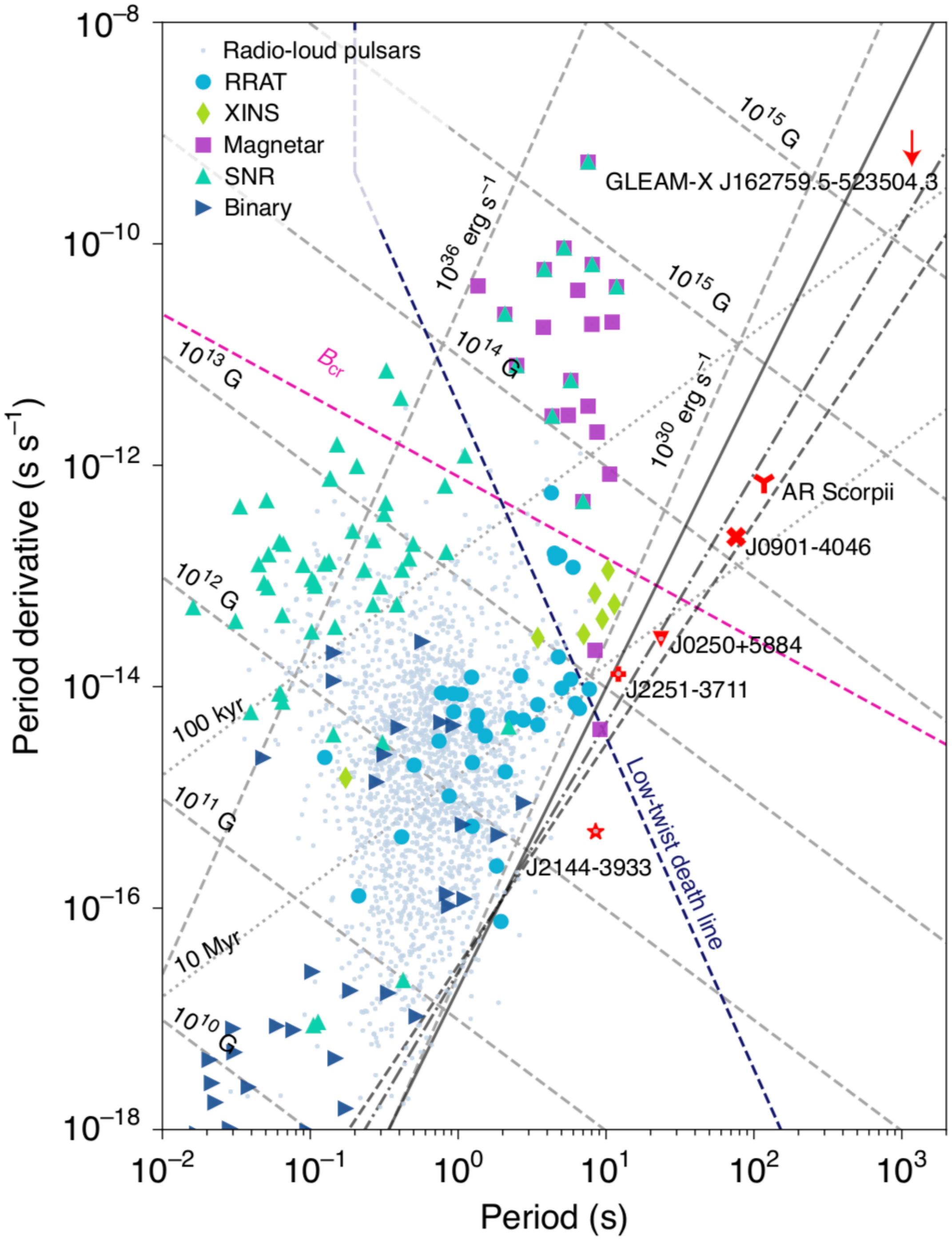




Neutron star pulsars beyond the death line?

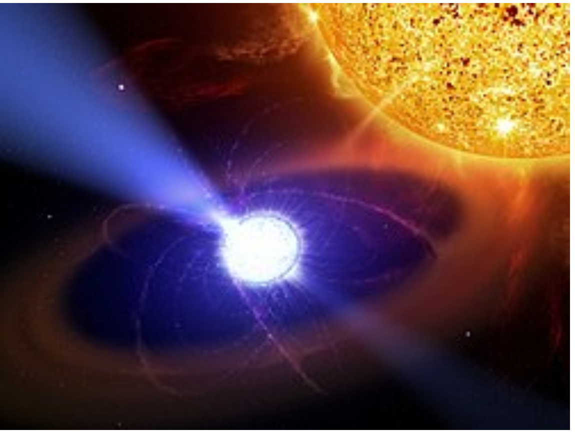
- ultra-long-period magnetars (ULPMs) above the "low-twist" death line (originally proposed for FRBs Wadiasingh et al. 20)?
- multipolar magnetic field configuration?
- many more sources like this to be found

Caleb et al. 22



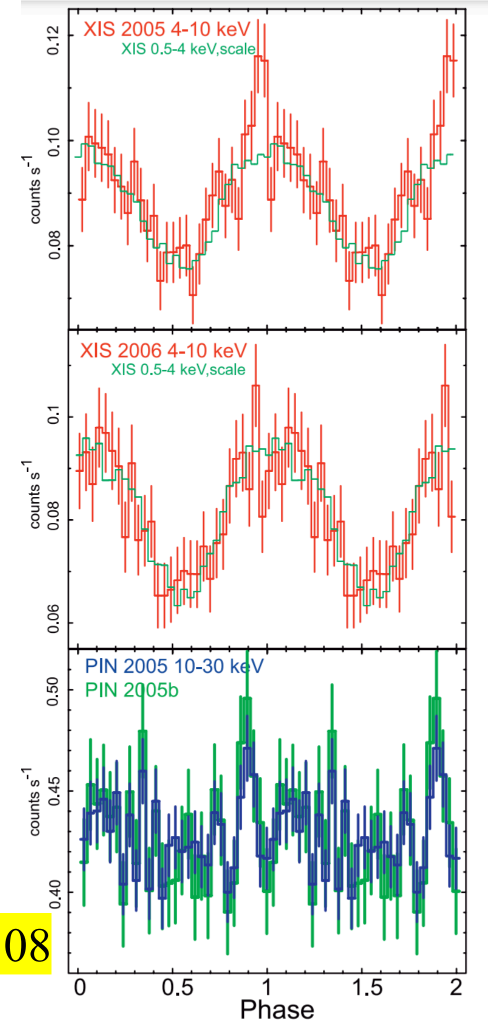
Or white dwarf pulsars?

AE aqr

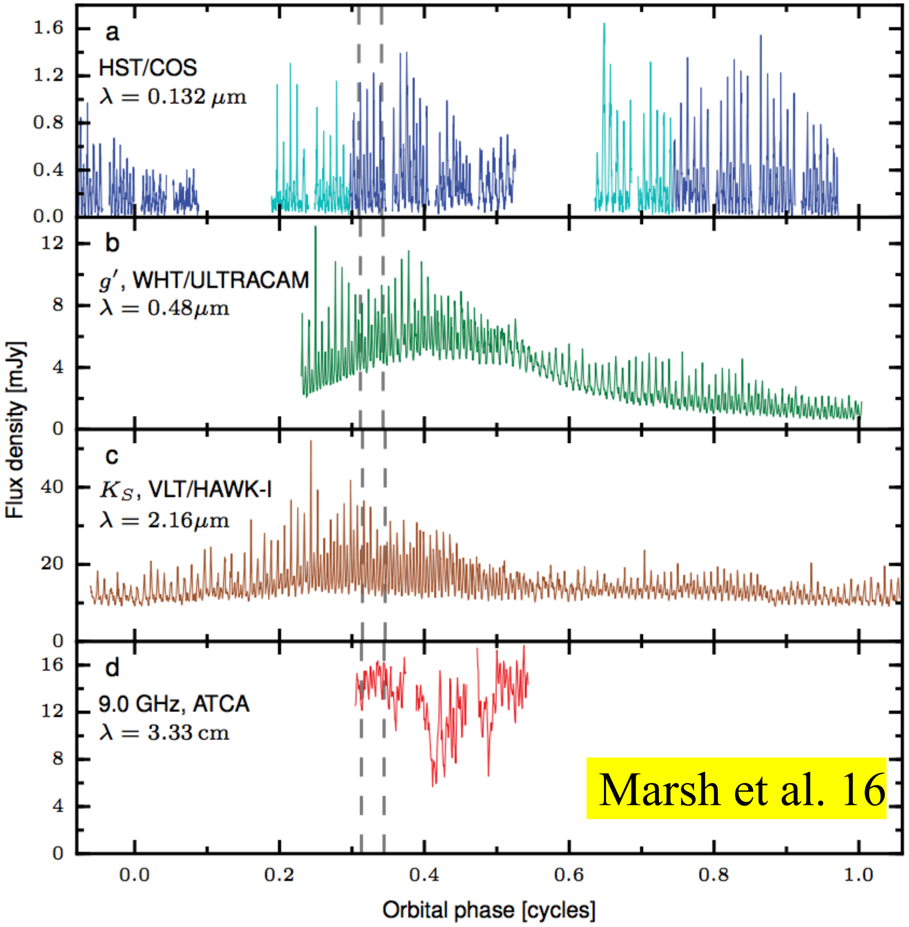


$P = 33.08$ sec

$B = 5e7$ G

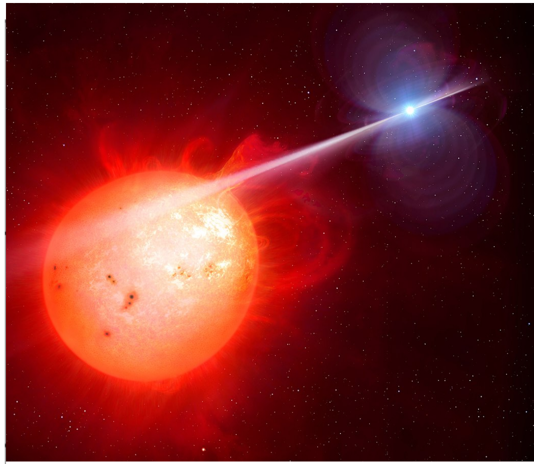


Terada et al. 08



Marsh et al. 16

AR sco

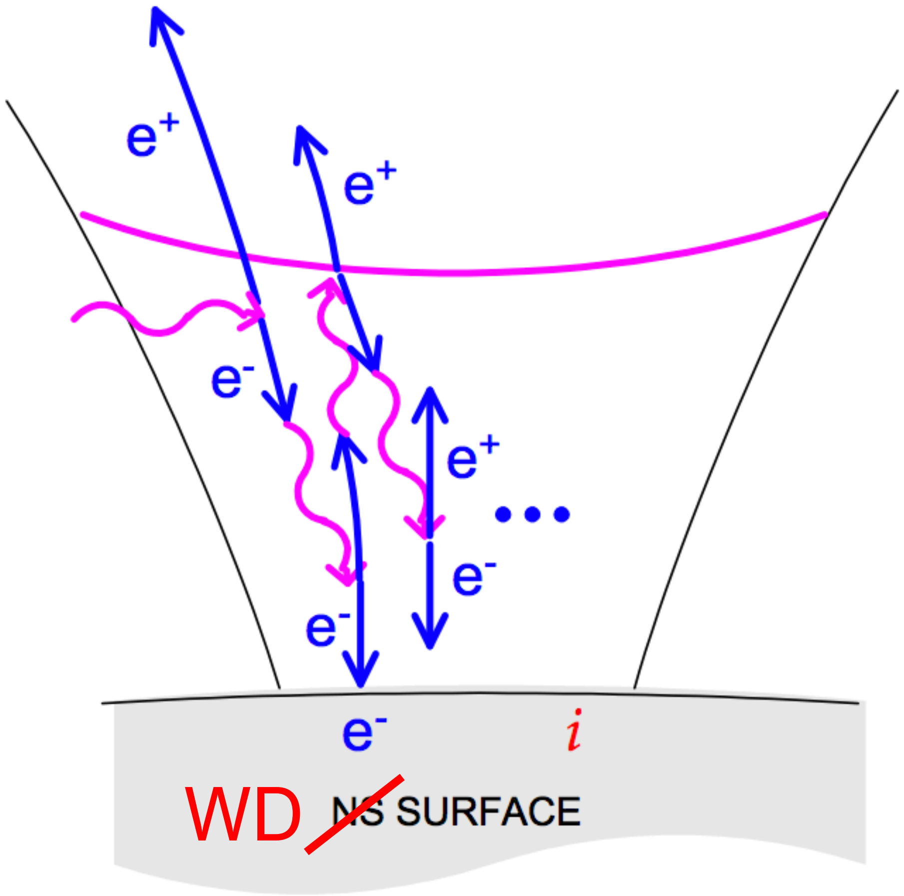


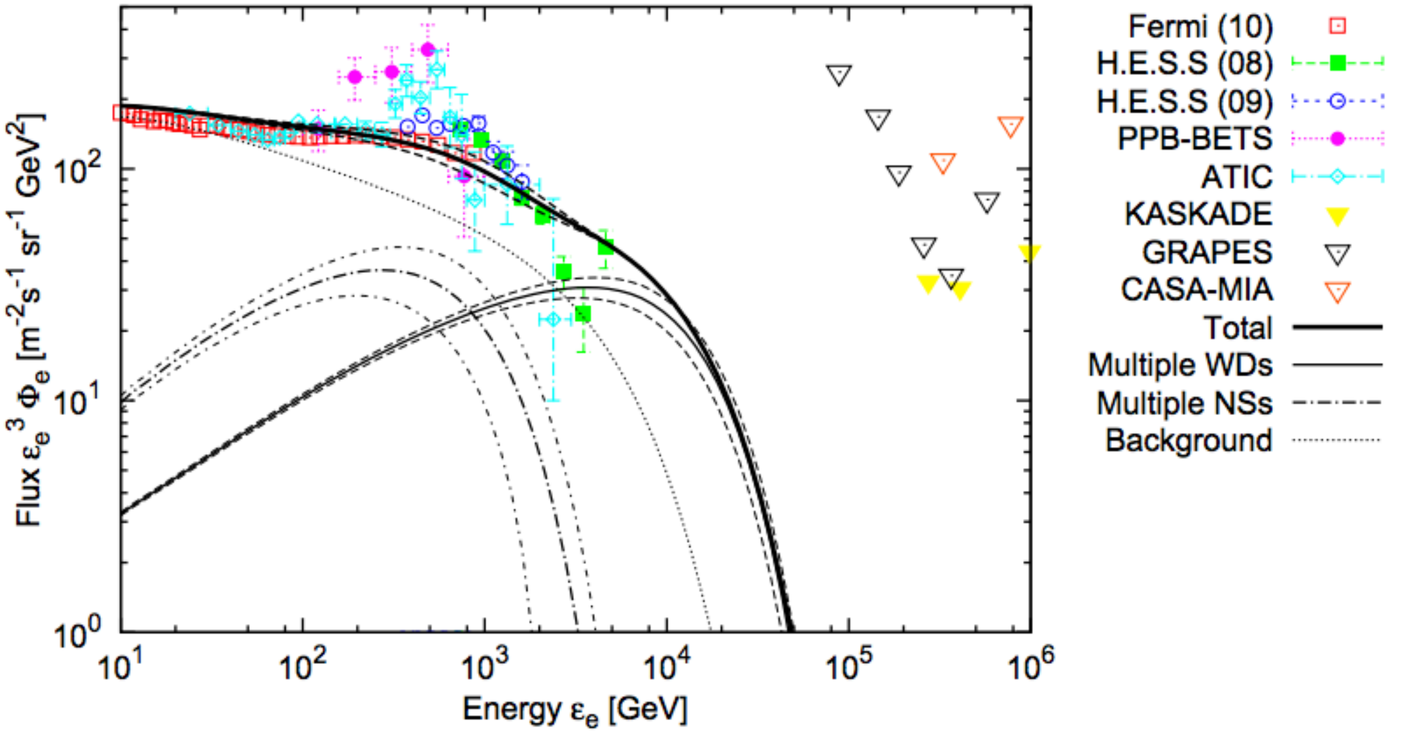
$P = 1.95$ minute

$B = 7.1e8$ G

White dwarf pulsars as CR e± factories

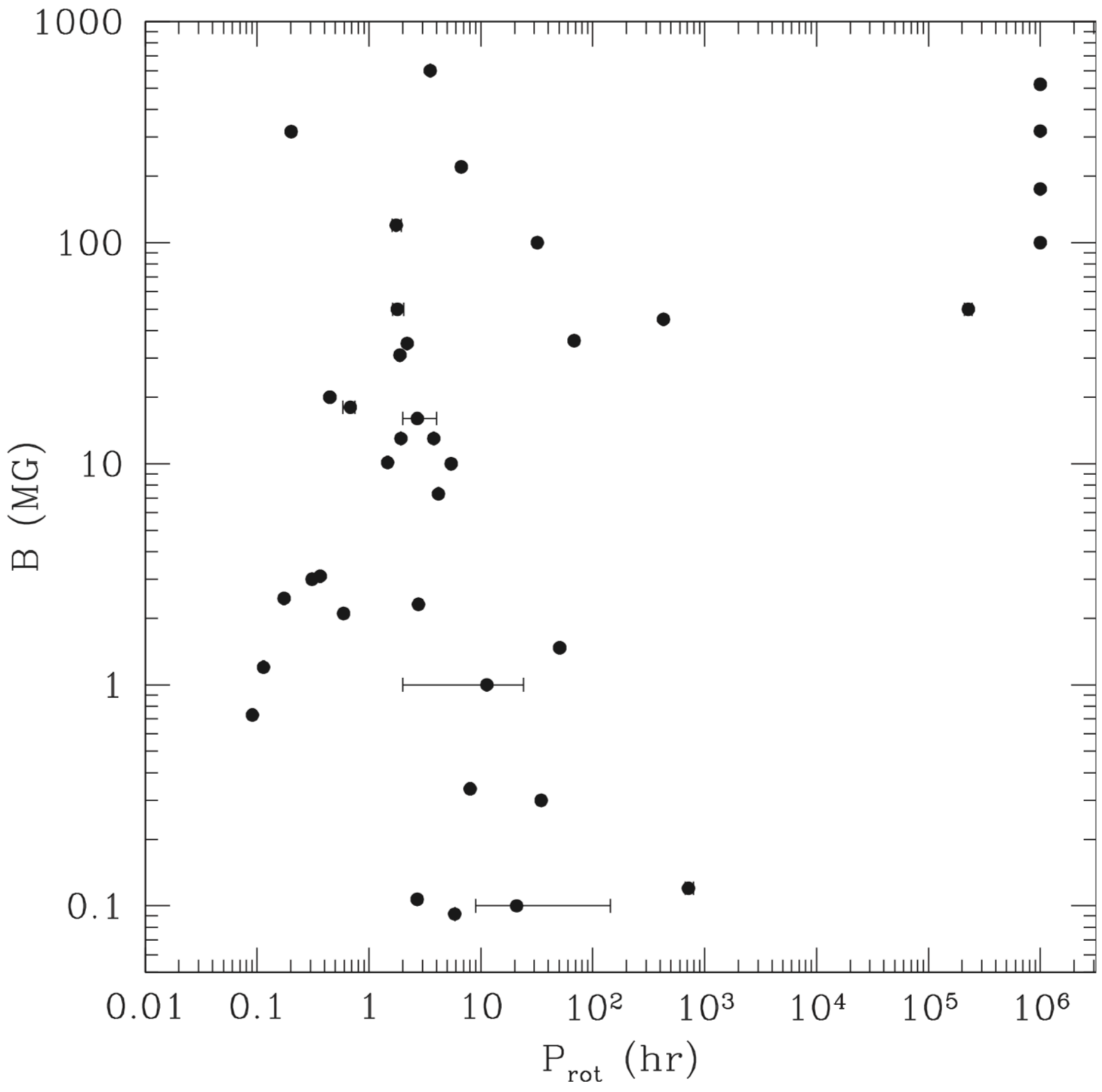
Kashiyama, Ioka, Kawanaka 10





$$\Delta V_{\mathrm{max}} = \frac{B_{\mathrm{p}} \Omega^2 R^3}{2c^2} \sim 10^{13} \left(\frac{B_{\mathrm{p}}}{10^8 \mathrm{G}}\right) \left(\frac{\Omega}{0.1 \mathrm{s}^{-1}}\right)^2 \left(\frac{R}{10^{8.7} \mathrm{cm}}\right)^3 \mathrm{Volt}$$

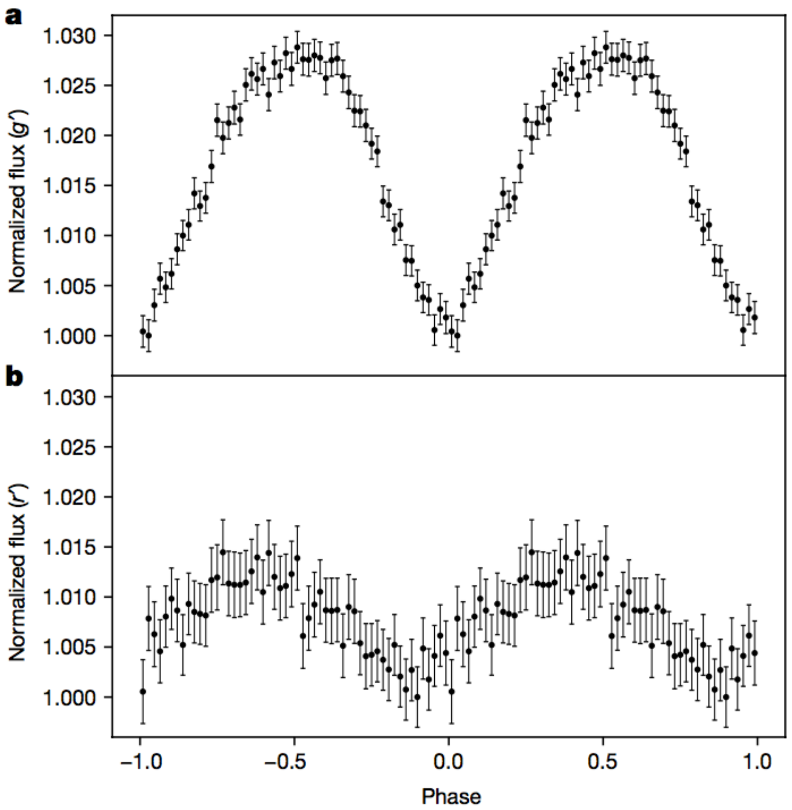
Spin periods of magnetized WDs

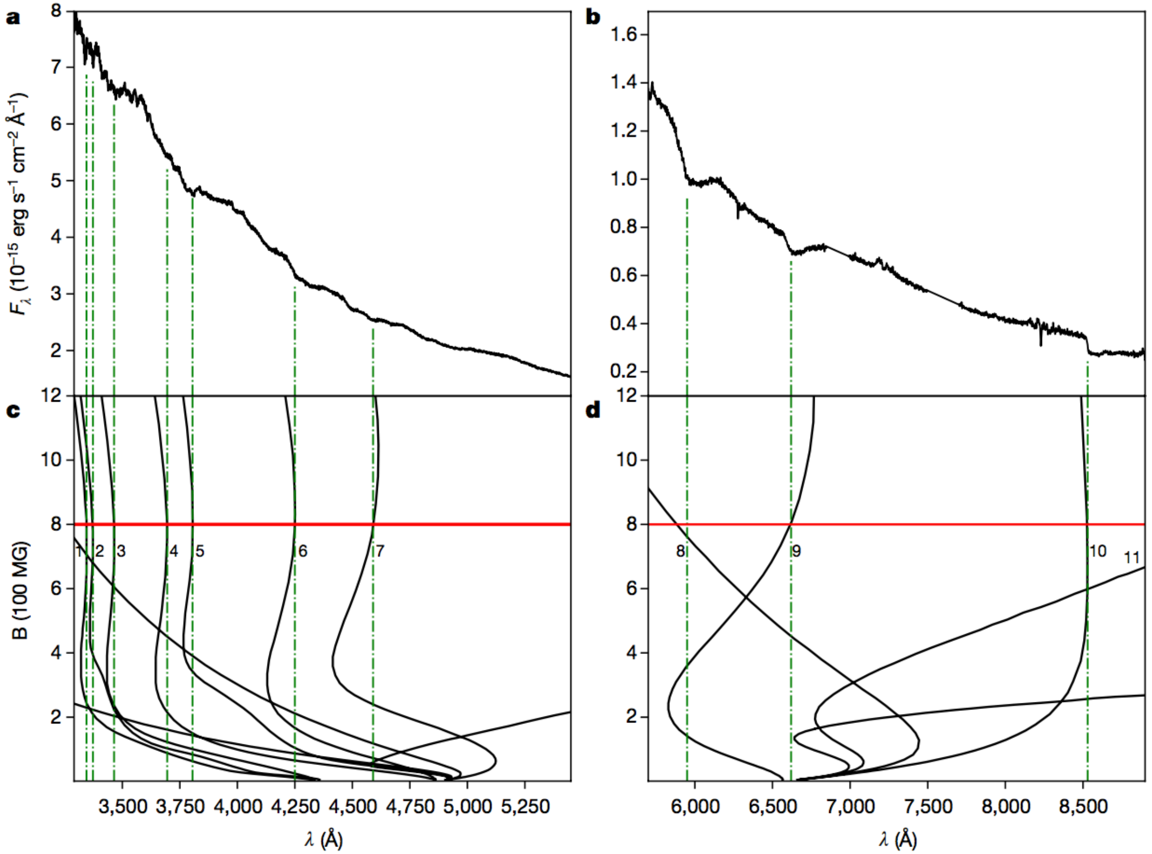


Ferrario et al. 19

ZTF J190132.9+145808.7

Caiazzo et al. 21





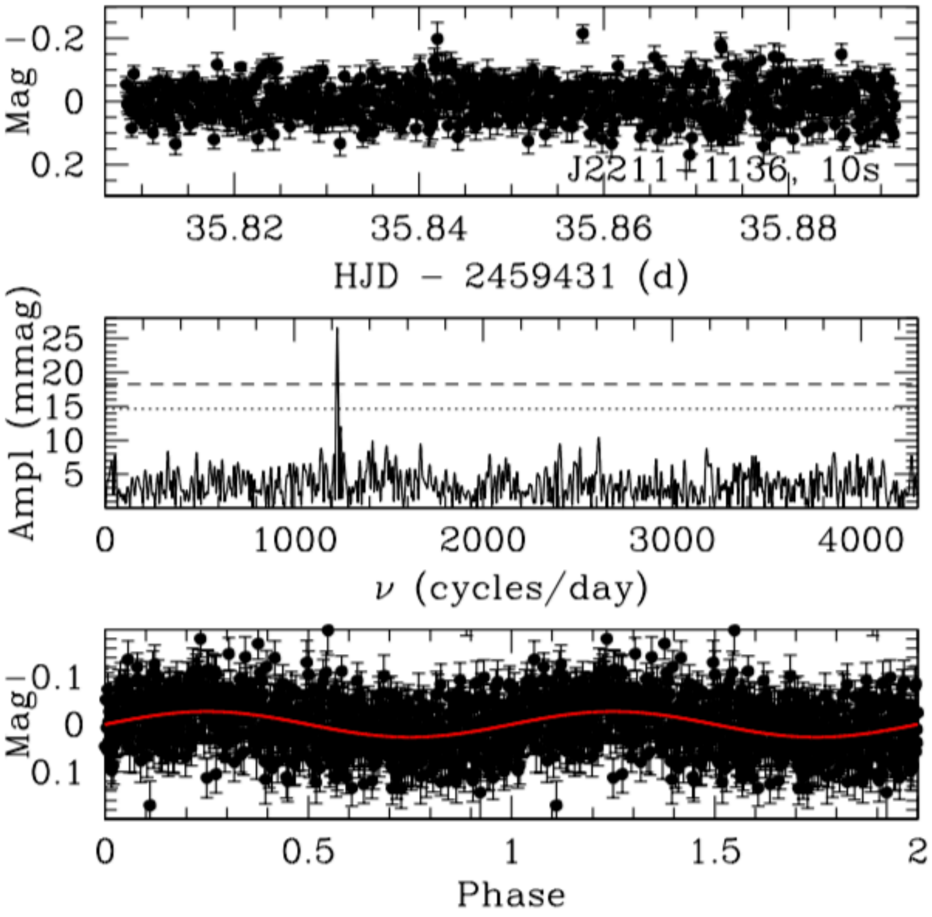
$P = 6.97$ min

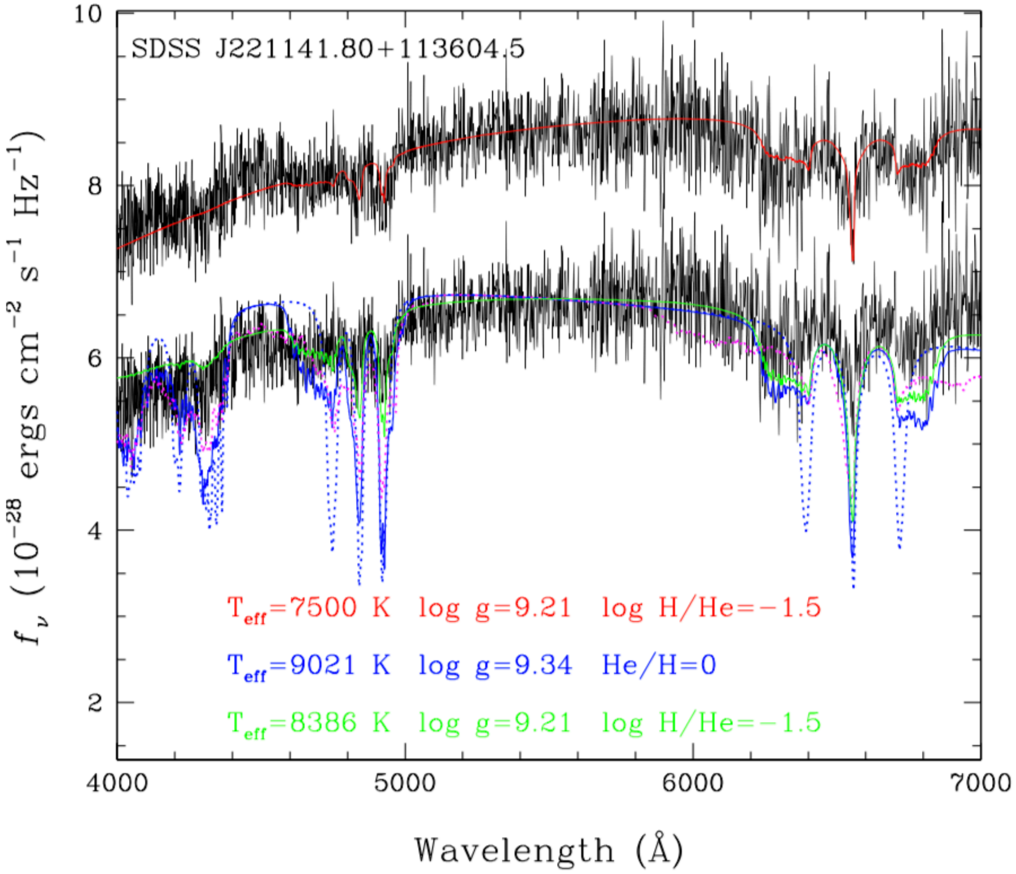
$B = 6\text{-}9\times10^{8}$ G

$M = 1.327\text{-}1.365\ M_\odot,\ T_{\rm eff} = 46{,}000$ K

SDSS J221141.80+113604.5

Killic et al. 21



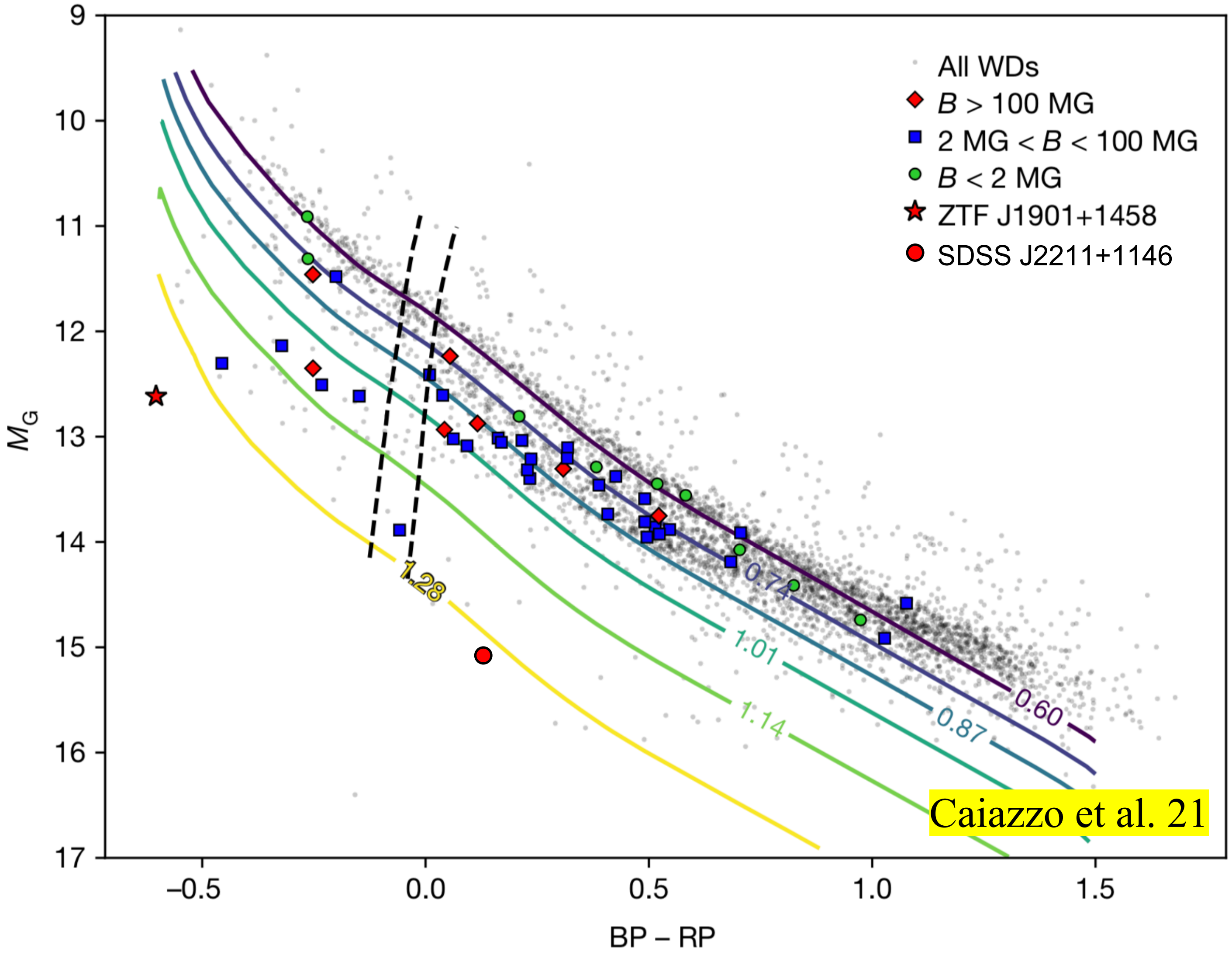


$P = 76$ sec

$B = 1.5\text{x}10^{7}$ G

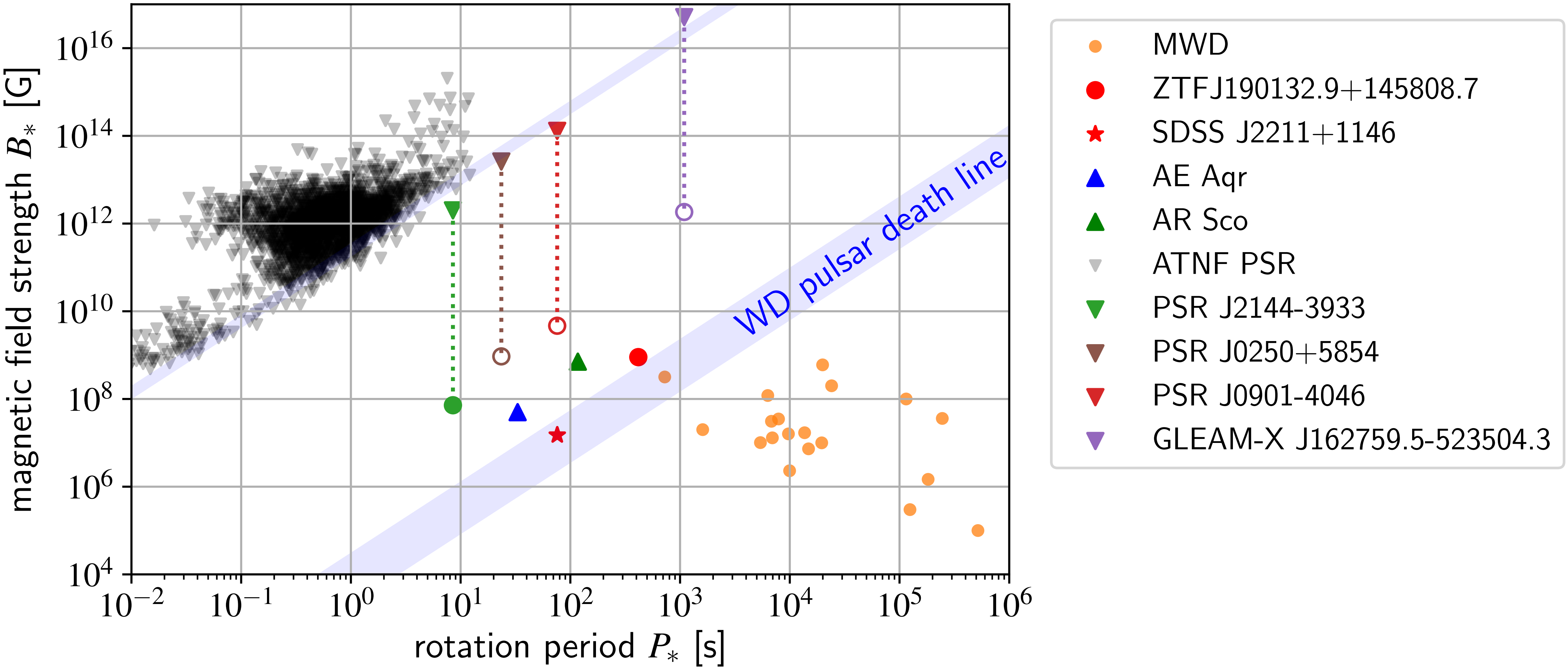
$M = 1.268\ M_\odot$, $T_{\rm eff} = 7500\text{-}8390$ K

Fast spinning WDs on the HR diagram



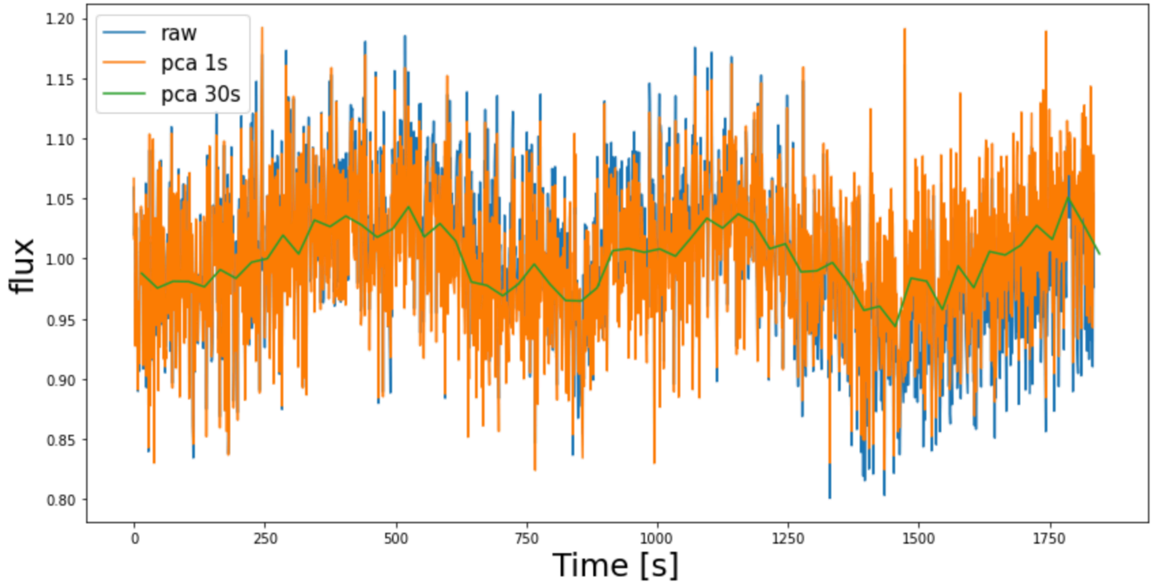
Caiazzo et al. 21

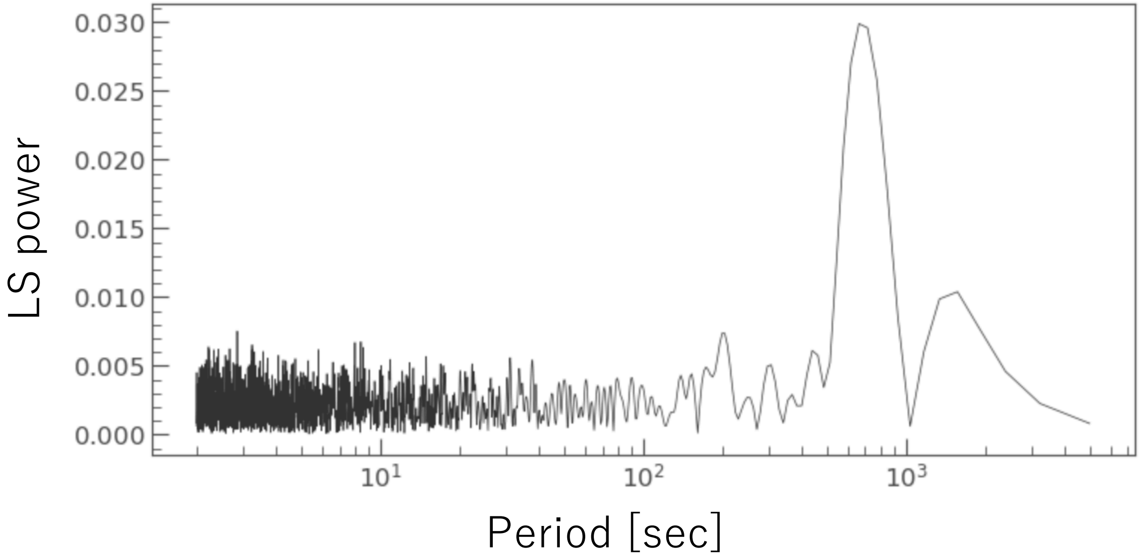
NS pulsars or WD pulsars?



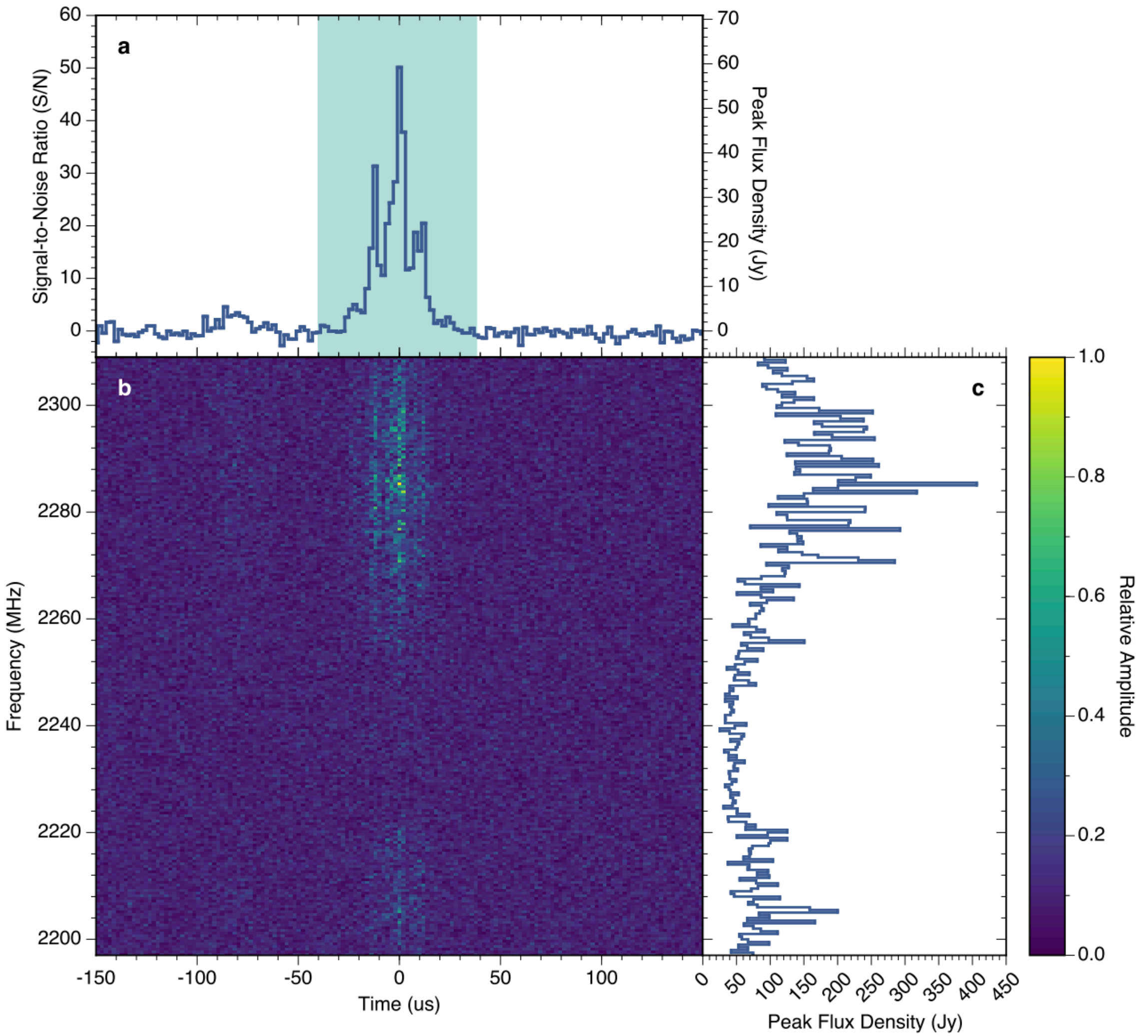
More and more fast spinning (single) WDs

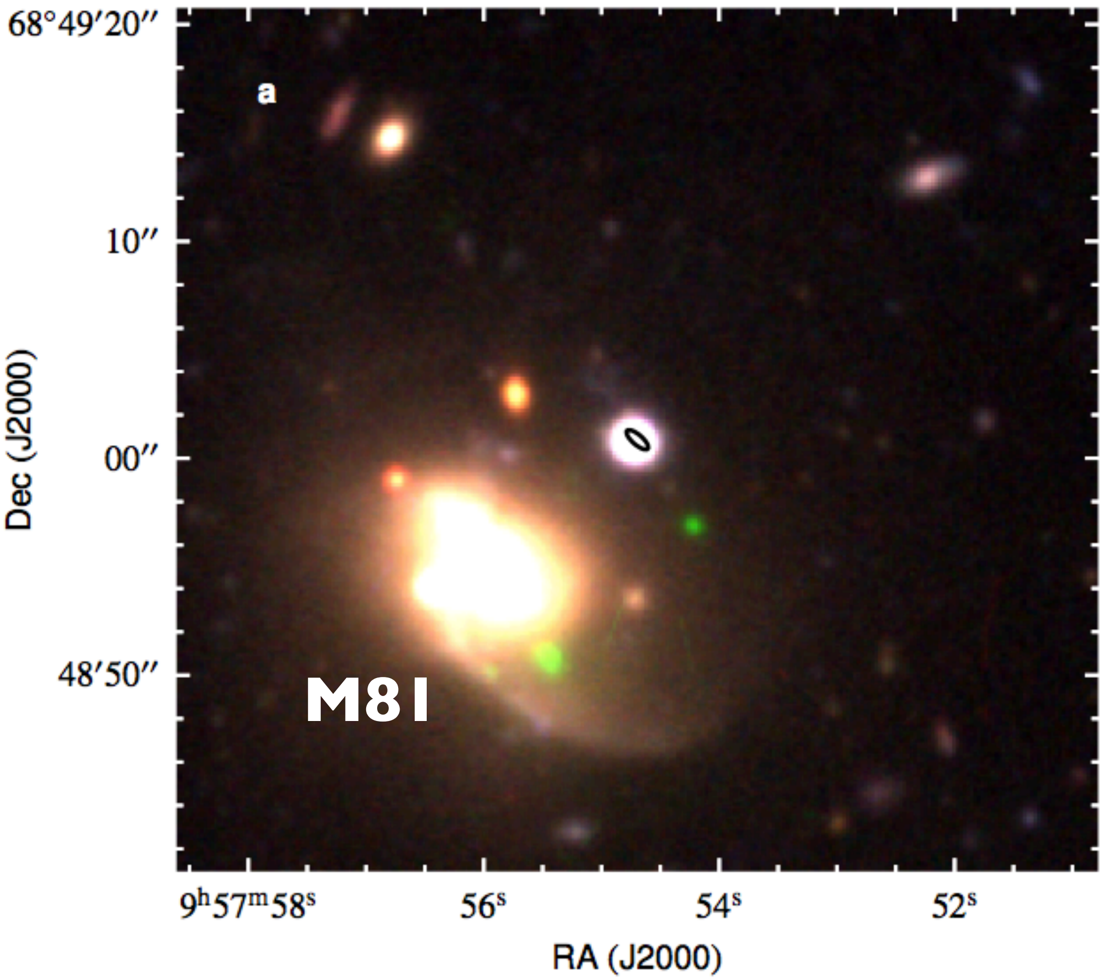
Searching for sub-min variabilities of WDs with Tomo-e Gozen and Seimei TriCCS



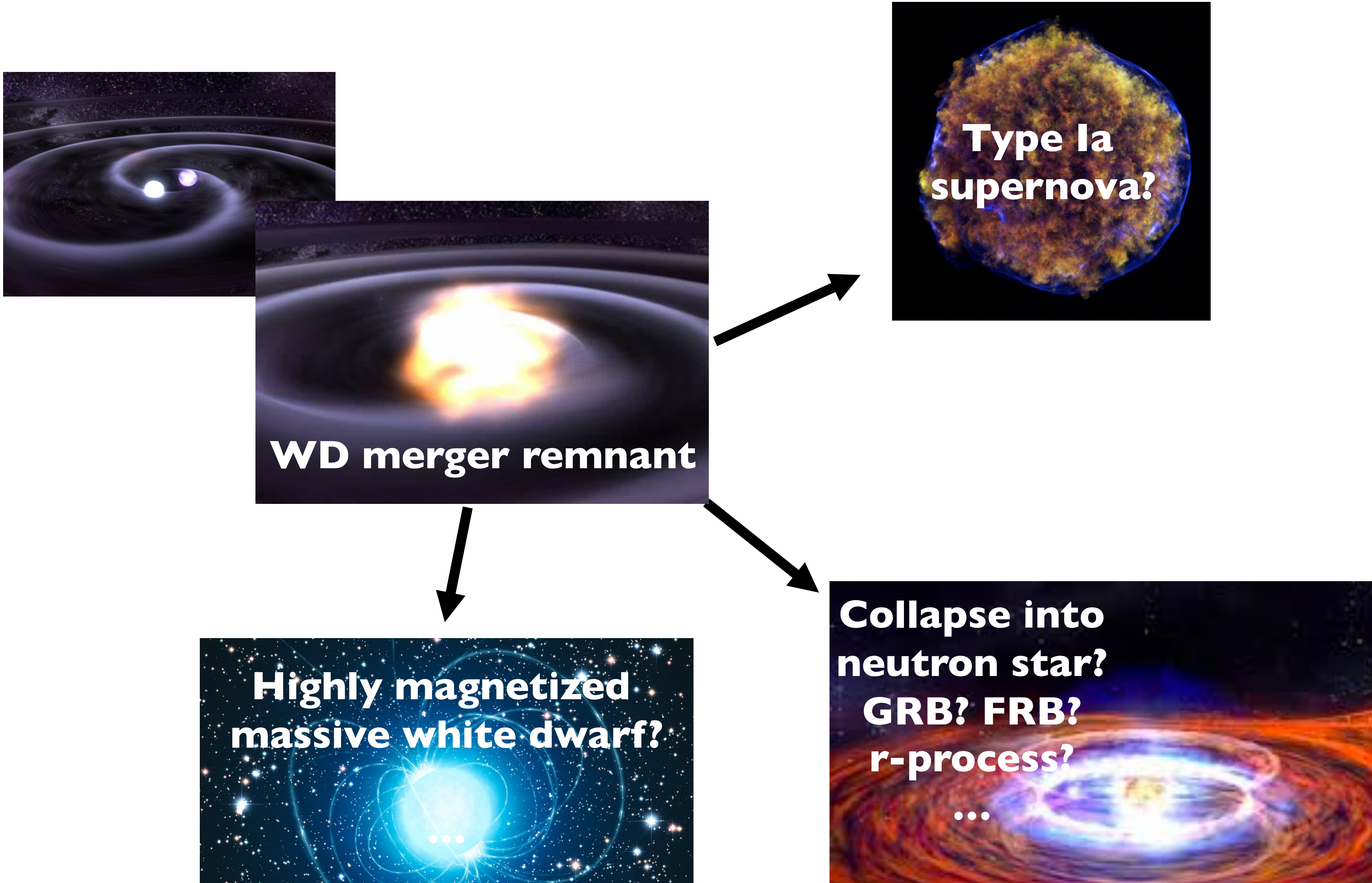


A repeating FRB source in a globular cluster





Kirsten et al. 21; Nimmo et al. 21;…



WD merger remnant

Type Ia supernova?

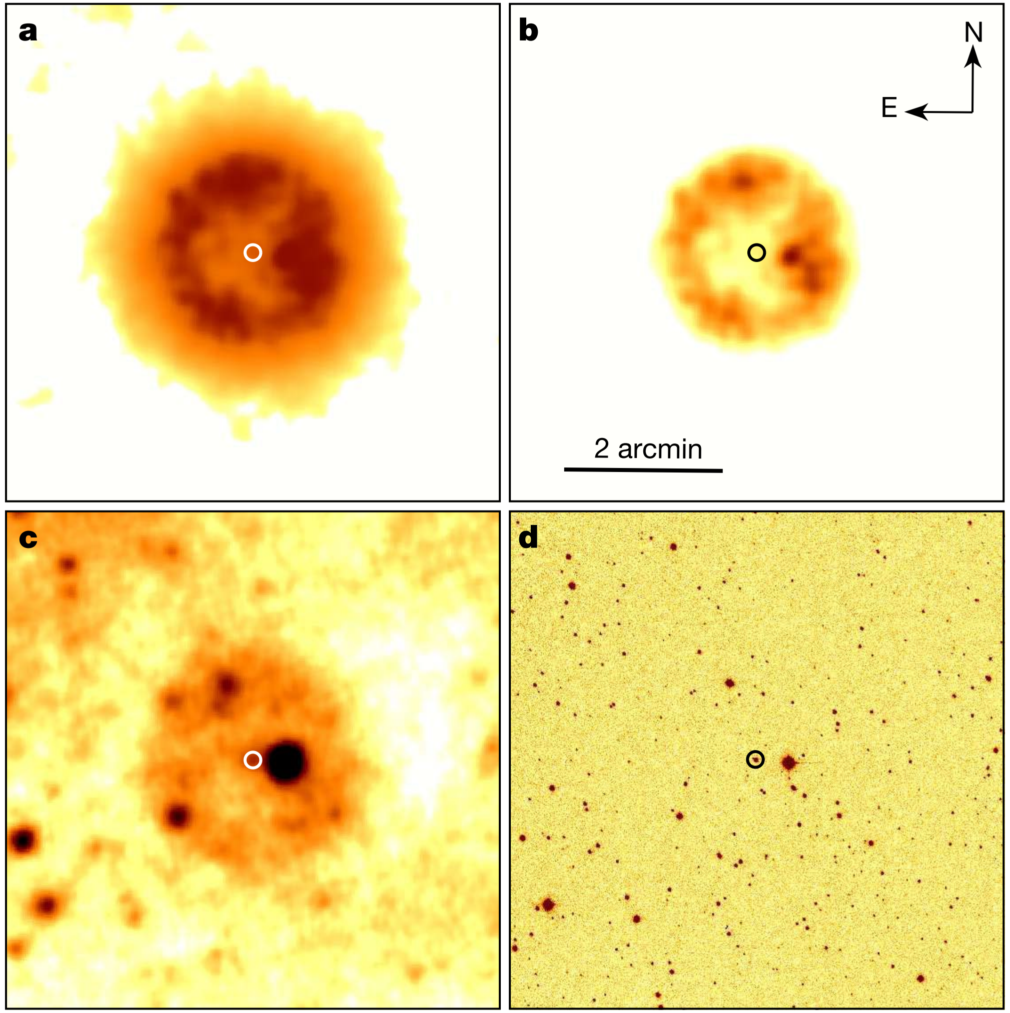
Highly magnetized massive white dwarf?

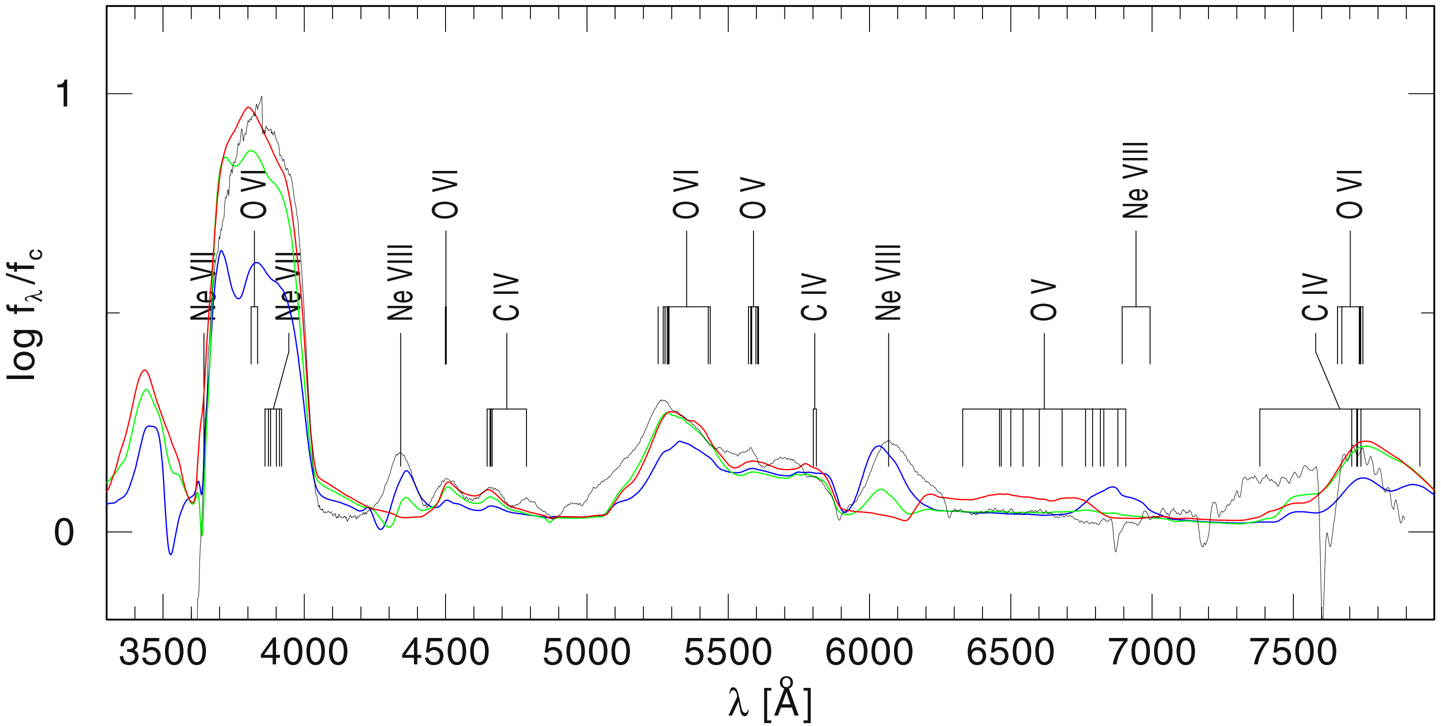
…

Collapse into neutron star?
GRB? FRB?
r-process?
…

IRAS 00500+6713

Gvaramadze et al.19





$$\dot{M} = (3.5 \pm 0.6) \times 10^{-6}\, M_\odot\, \mathrm{yr}^{-1}$$

$$v_\infty = 16,000 \pm 1,000\, \mathrm{km\, s}^{-1}$$

IRAS 00500+6713

$$T_{\rm eff} = 211,000^{+40,000}_{-23,000}\ {\rm K}$$

$$\log(L_{\rm rad}/L_{\odot}) = \ 4.60 \pm 0.14$$

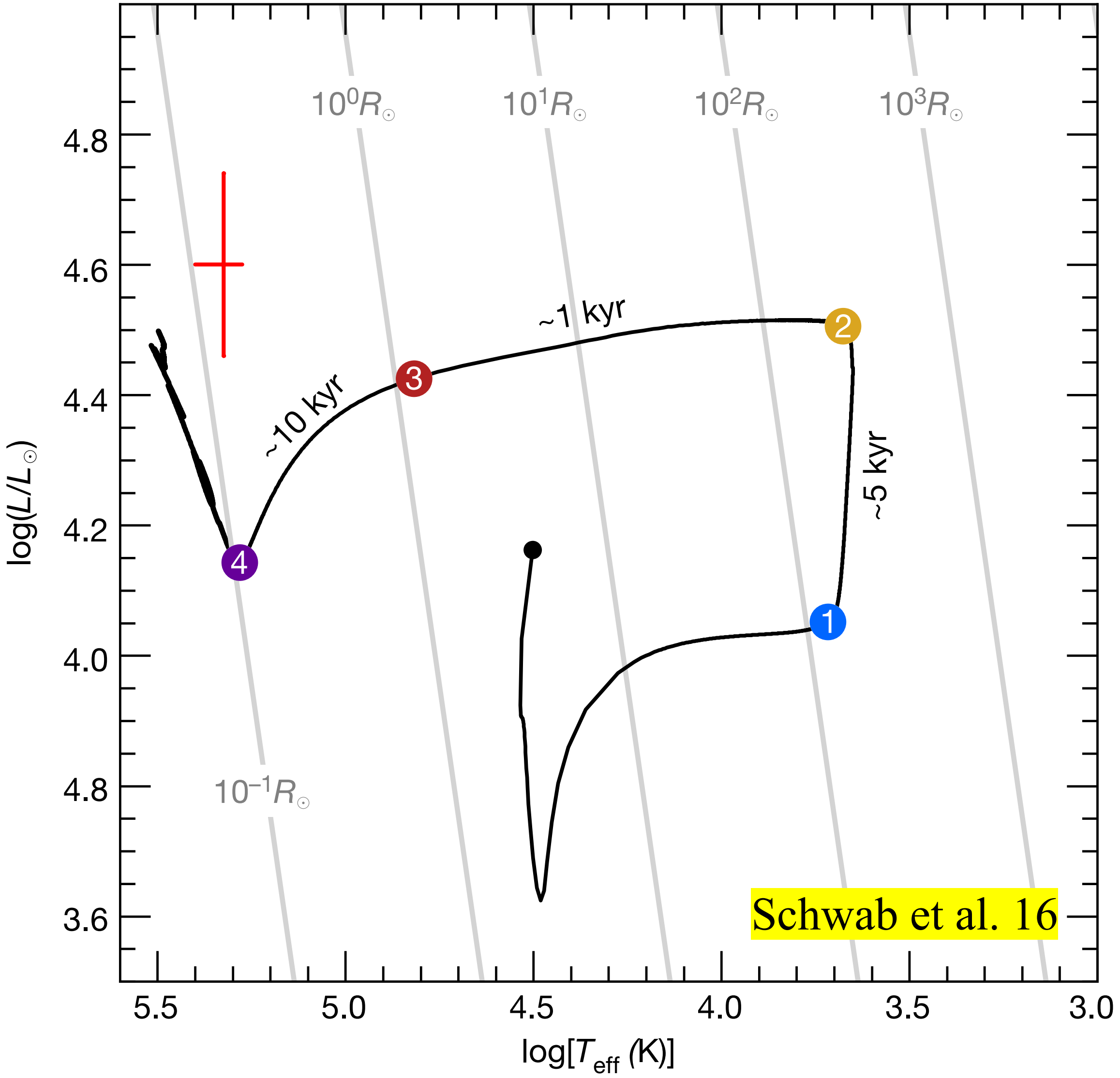
$$r_{\rm ph} = 0.15 \pm 0.04\, R_{\odot}$$

Super-Chandrasekhar mass WD eventually collapse into a NS?

Gvaramadze et al.19

Or Sub-Chandrasekhar mass WD with a fast spin and a strong B field?

Kashiyama et al.19

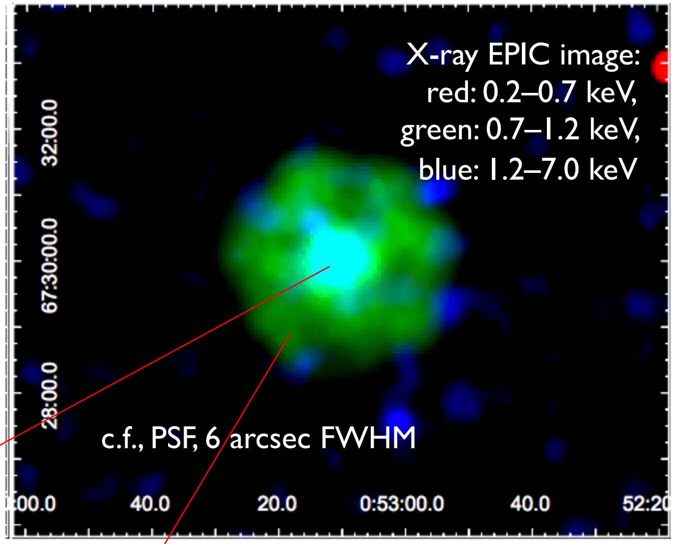


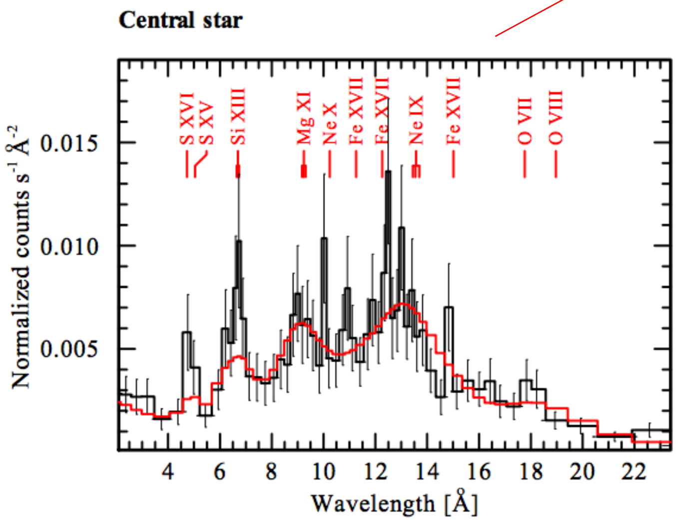
Schwab et al. 16

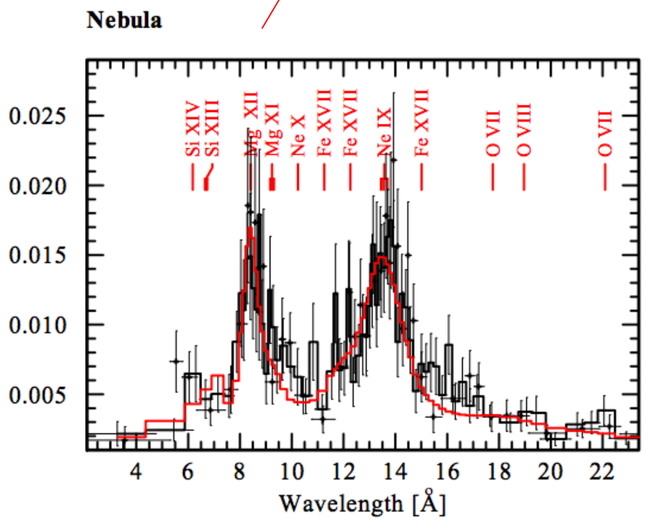
X-ray observations of IRAS 00500+6713

“Both the central star and the nebula
are detected in X-rays, heralding
the WD merger products as
a new distinct type of strong X-ray sources.”

Oskinova et al. 20



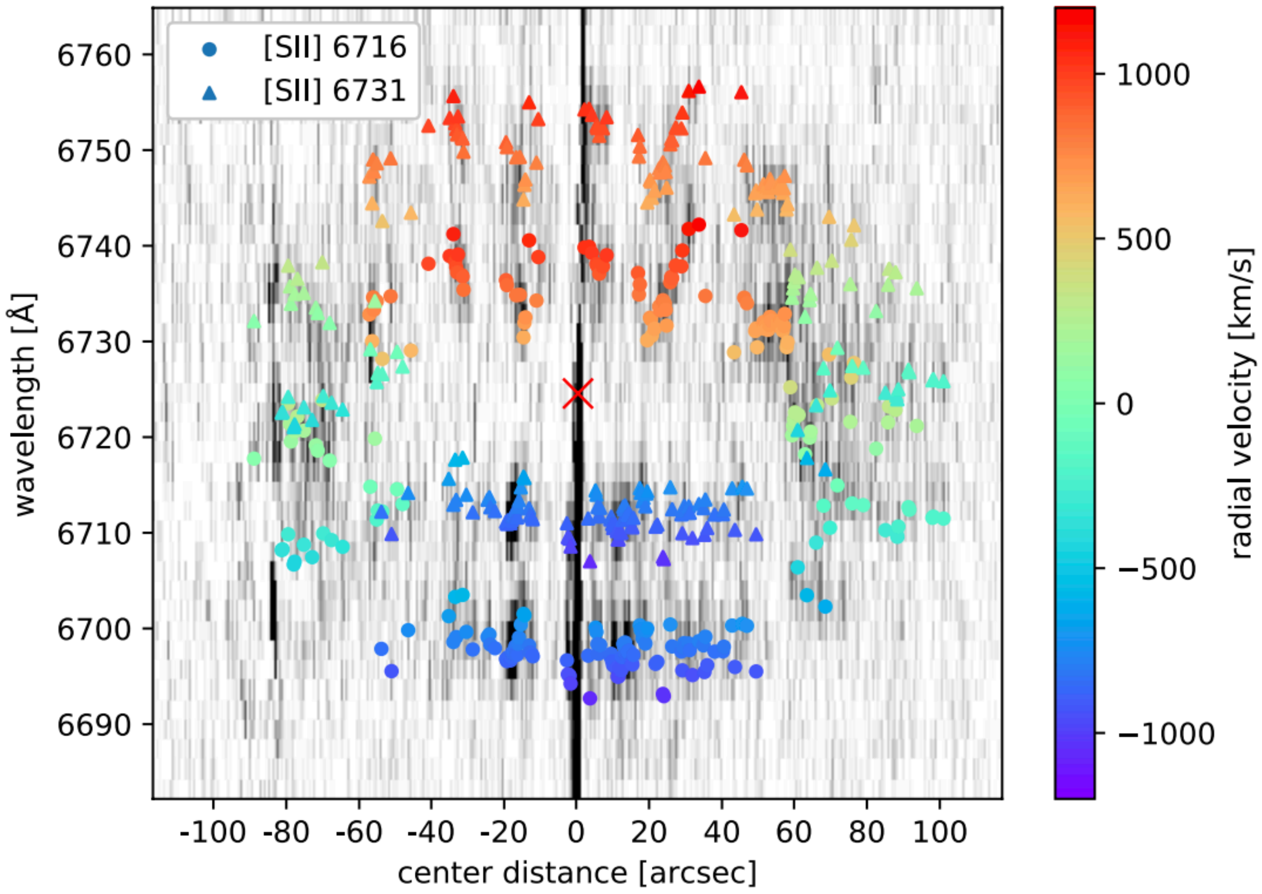




Large neon, magnesium, silicon, and sulfur enrichment of the central star and the nebula

Long slit observations with OSIRIS

on board the 10-m GranTeCan (GTC) telescope



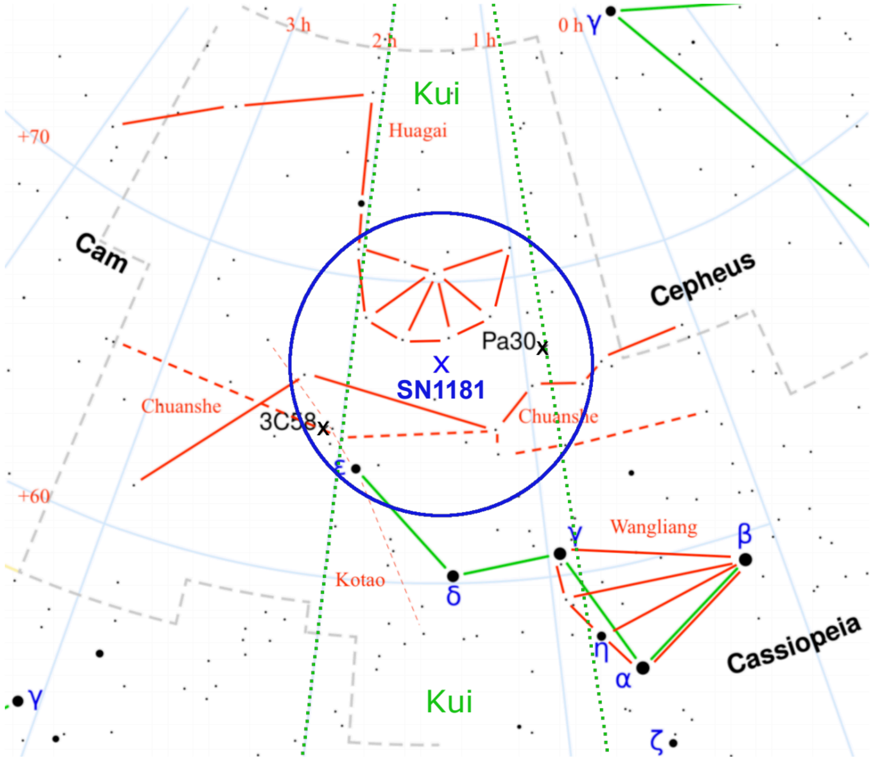
Ritter et al. 21

an expansion velocity of ~ a few 1000 km/s is inferred, which is consistent with type Iax SNe

SN 1181 → IRAS 00500+6713?

the youngest Galactic supernova
without a firmly confirmed remnant

Ritter et al. 21



「吾妻鏡」
“治承五年六月廿五日（1181年8月7日）
庚午 戌尅 客星見艮方”

- ✓ The magnitude of SN 1181 is not known
- ✓ it was compared to Saturn
- ✓ $m_V \sim -0.5$ to $+1.0$?
- ✓ $M_V \sim -14$ to -12.5?
- ✓ sub-luminous supernovae?

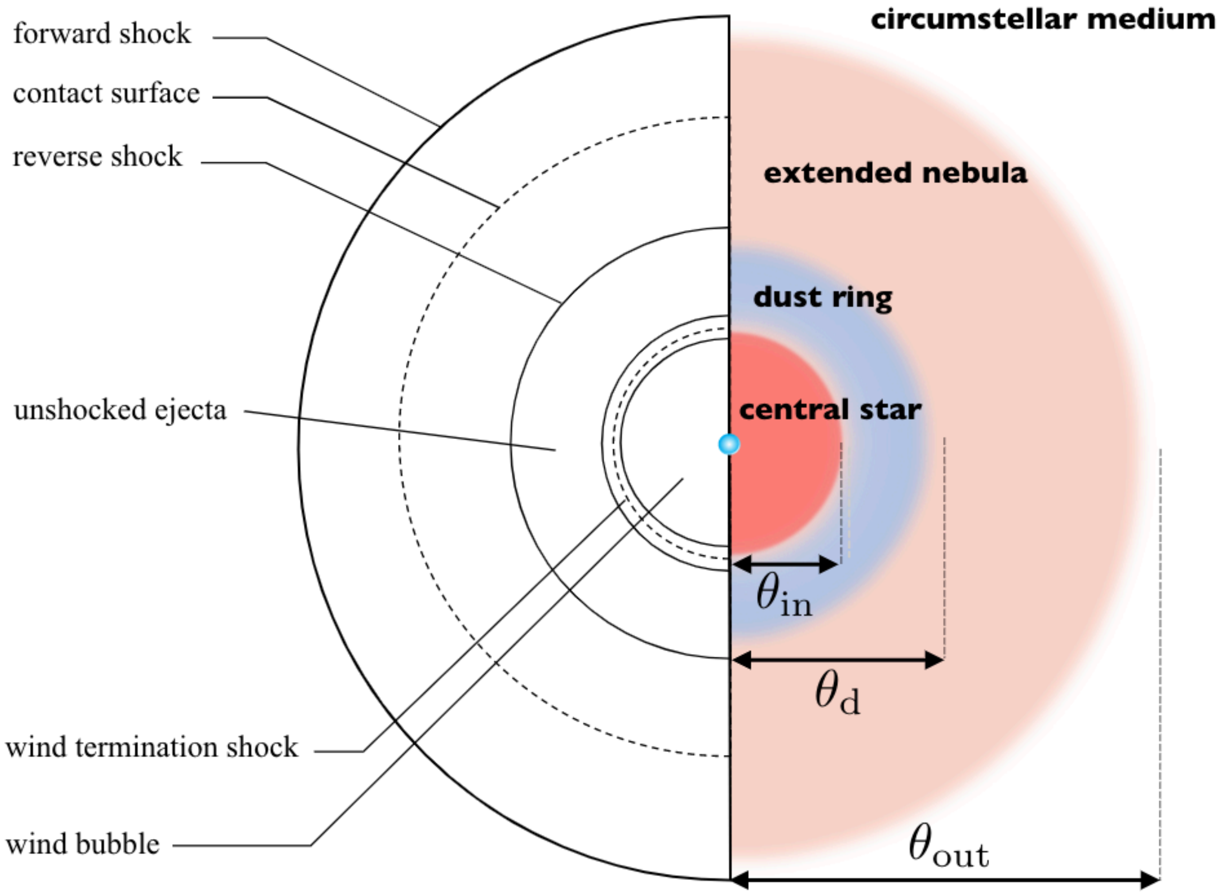
- ✓ remained visible for 185 days
- ✓ 4.5 - 6 mag of fading over this period?

A dynamical model for IRAS 00500+6713

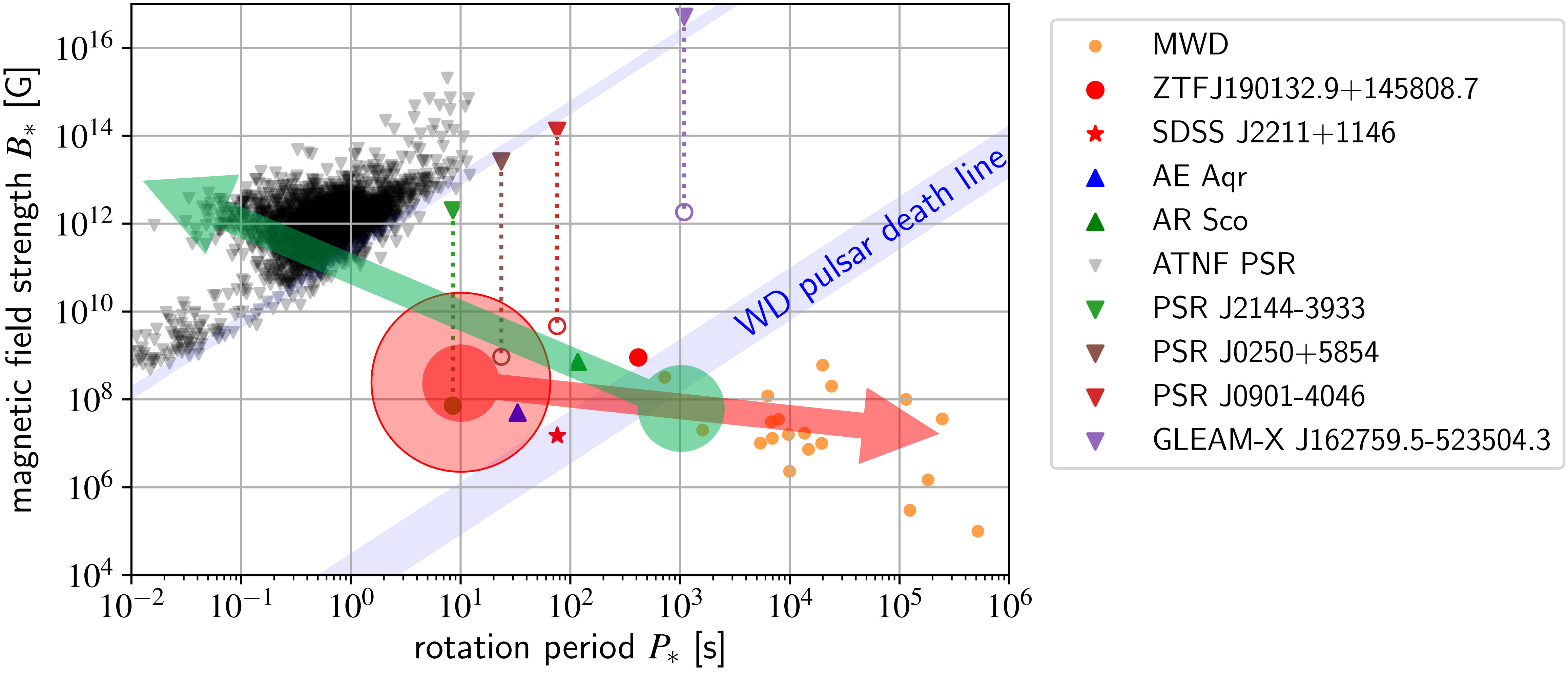
In order to consistently explain
- ✓ the nebula morphology,
- ✓ the emission measure, and
- ✓ the wind properties,

we need to consider
- a merger of a massive WD binary system with a total mass of > 1.4 Msun
- accompanied by an SN Iax like event, and
- the strong wind starts to blow ~ kyr after the merger (need fine tuning?)

Ko et al. in prep



How merged WDs spin down & collapsed into NSs?



Summary and discussion

- *Slowly rotating coherent radio emitters are being detected, and even more so in the coming era.*
- *Are they slowly rotating magnetars or fast spinning WDs?*

- *Fast spinning strongly magnetized WDs are being detected, and even more so in the coming era*
- *A good fraction of them are merger product of WDs*
- *How they evolves with time, in particular, how they spins down is likely important in the context of FRBs, SNe Ia, and so on.*