

Formation and Evolution of Close Magnetic White Dwarf Binaries

Diogo Belloni

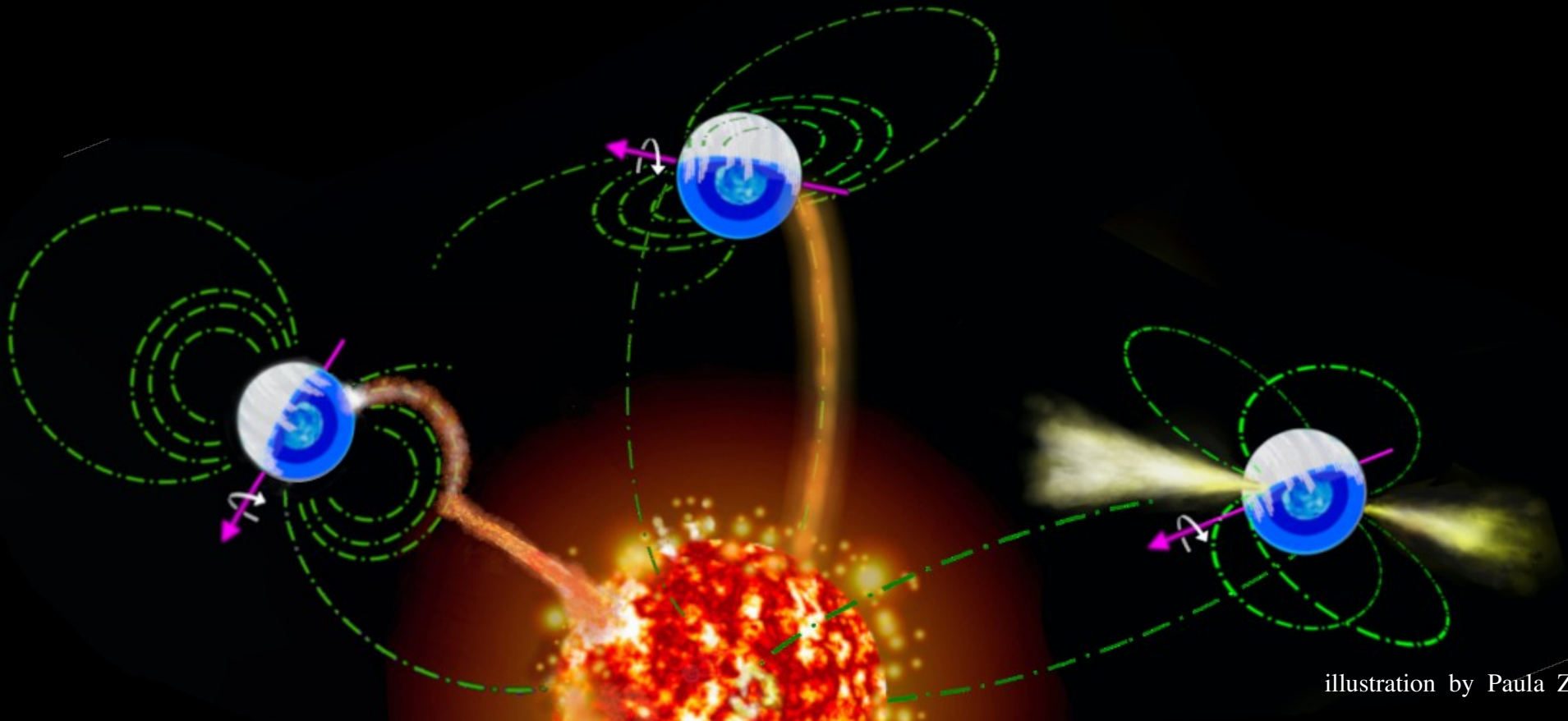


illustration by Paula Zorzi

Observational Properties of Close Magnetic White Dwarf Binaries

detached
(pre-polars + AR Sco)

semi-detached
(magnetic cataclysmic variables)

Marsh et al. (2016); Parsons et al. (2021)

Pala et al. (2020)

fraction

typical
field
strength

typical
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$\lesssim 1\%$
(only 15 confirmed)

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$\sim 30 - 40\%$

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$\sim 10 - 300$ MG

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 $\lesssim 10$ MG \lesssim

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none of the scenarios
suggested so far for
magnetic field
generation can explain
these observational
properties !!!

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THE CORE CRYSTALLIZATION SCENARIO (Isern et al. 2017)

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As a white dwarf evolves and cools down, it will eventually start to crystallize, when a sufficiently low temperature is reached

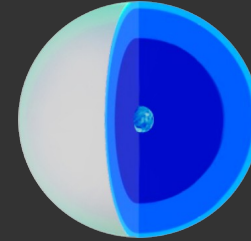


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This process leads to a solid core surrounded by a liquid convective mantle

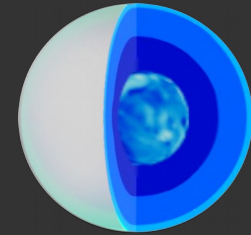
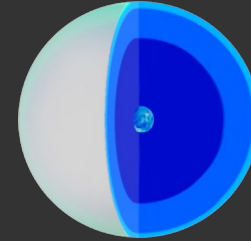


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If the white dwarf spin period is sufficiently short, the convective region can produce a dynamo able to yield magnetic fields

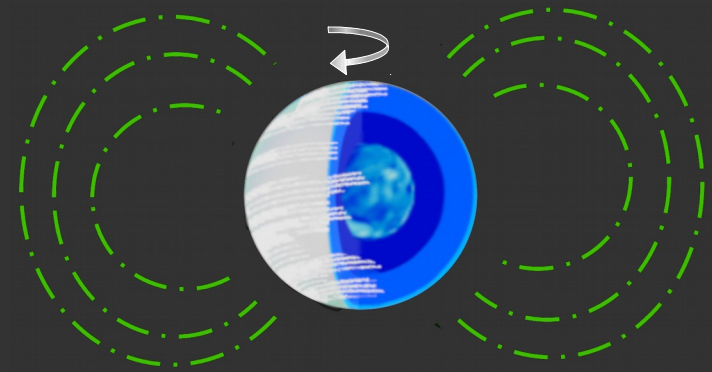
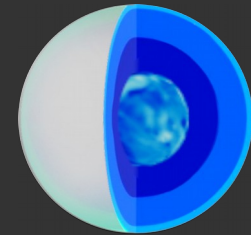
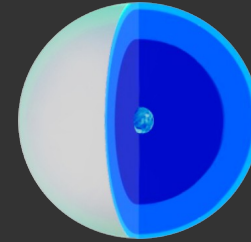
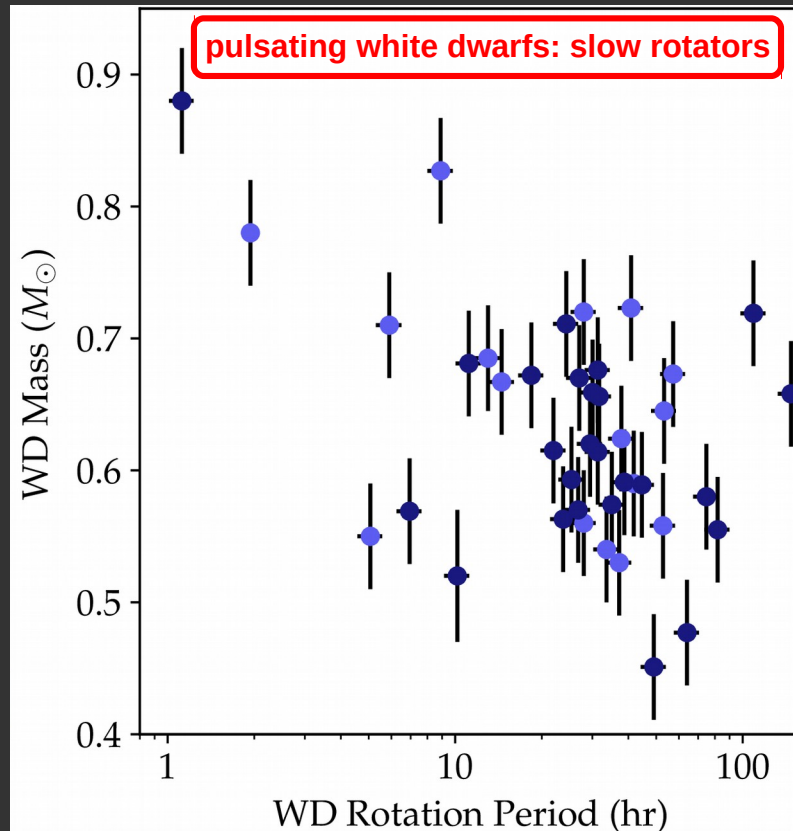


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Formation of Close Magnetic White Dwarf Binaries:

THE CORE CRYSTALLIZATION SCENARIO (Isern et al. 2017)

A potential problem?



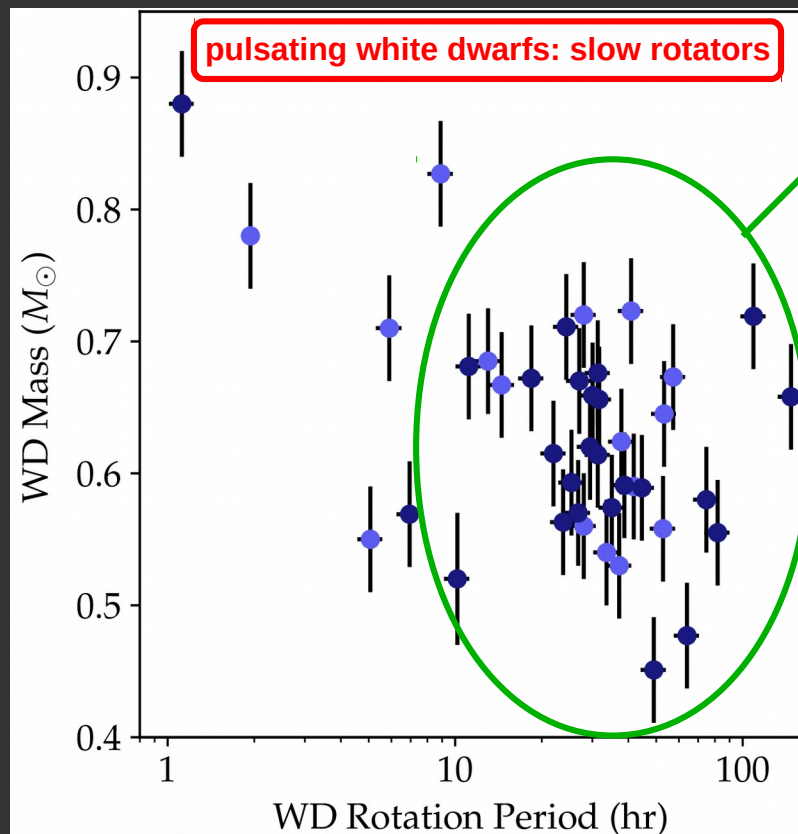
Hermes et al. (2017)

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A potential problem?

non-saturated dynamos leading to weak fields...

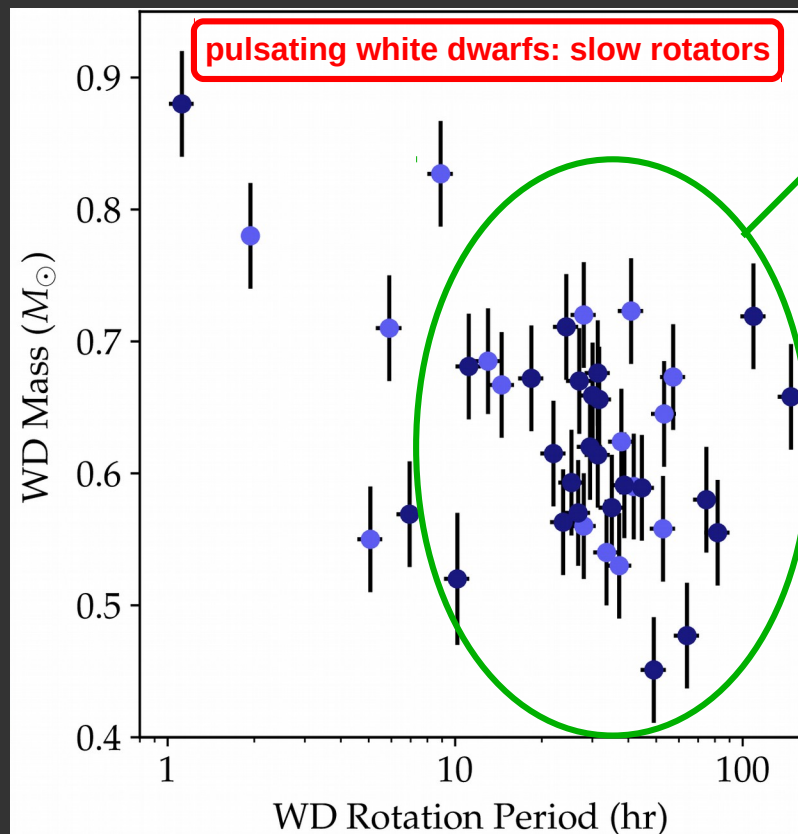


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A potential problem?



non-saturated dynamos leading to weak fields...

Not an actual problem if the white dwarf accretes angular momentum

BUT HOW?

Hermes et al. (2017)

Formation of Close Magnetic White Dwarf Binaries:

THE ROTATION- AND CRYSTALLIZATION-DRIVEN DYNAMO (Schreiber et al. in press)

ANSWER: white dwarfs accreting mass !!!!

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Key ingredient of the model proposed by Schreiber et al.

magnetic field generation in close binaries occurs during cataclysmic variable phase

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REQUIRED CONDITIONS FOR GENERATION OF STRONG FIELDS

- rapidly rotating white dwarfs (spin period shorter than ~ 1 minute)
- crystallizing white dwarfs (older than a few Gyr)

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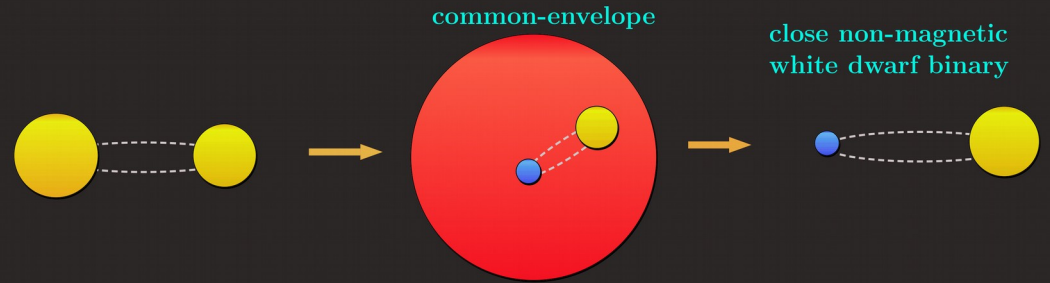
What happens before magnetic field is generated?

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formation of a non-magnetic close binary:

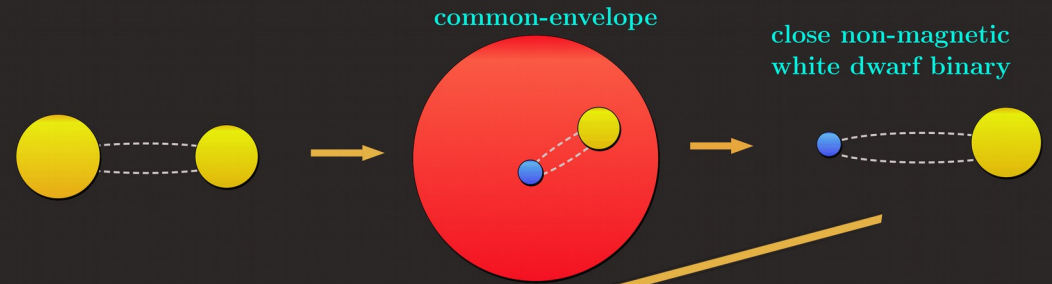


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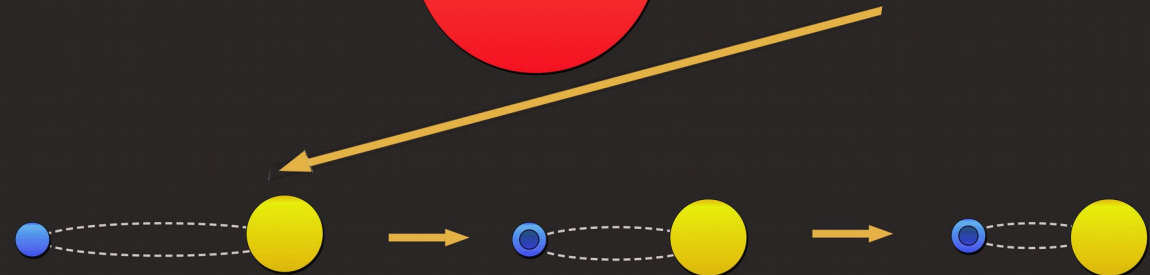
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formation of a non-magnetic close binary:



due to angular momentum loss, the orbit shrinks, and the slowly rotating white dwarf starts to crystallize during the process:

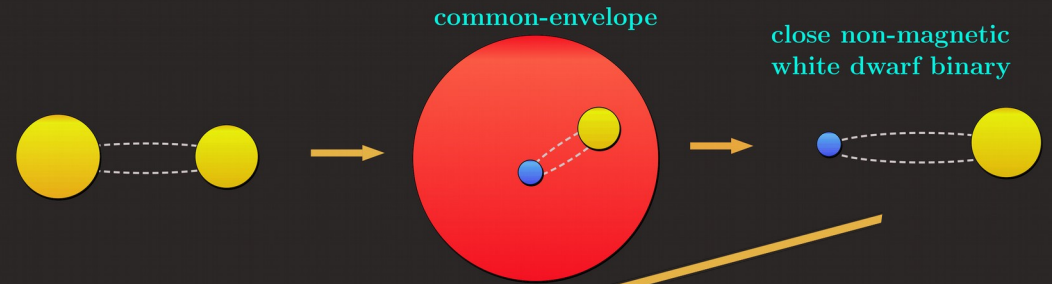


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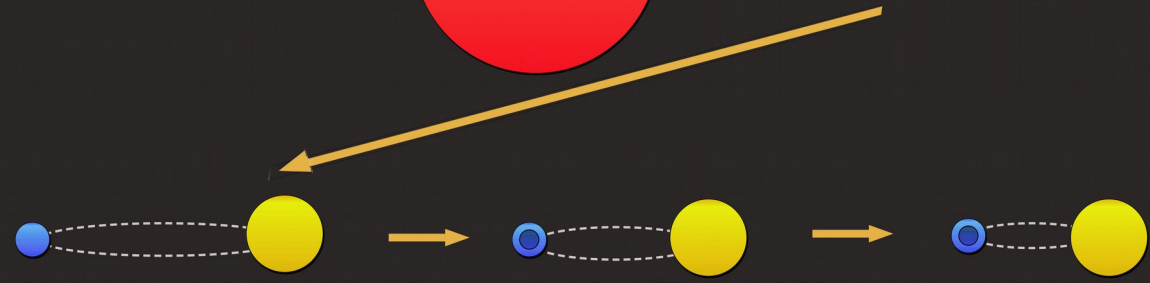
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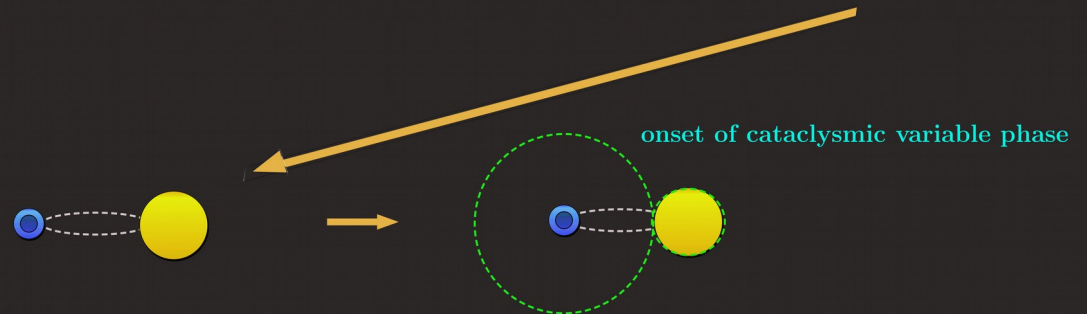
formation of a non-magnetic close binary:



due to angular momentum loss, the orbit shrinks, and the slowly rotating white dwarf starts to crystallize during the process:



the orbital separation is sufficiently small so that the secondary fills its Roche lobe:



Formation of Close Magnetic White Dwarf Binaries

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What happens before magnetic field is generated?

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accretes angular momentum, i.e. the white dwarf spin-up:

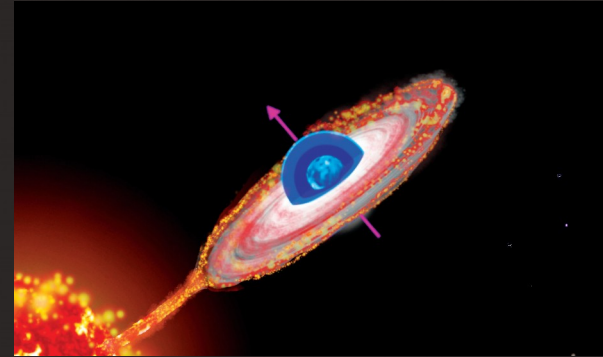


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What happens before magnetic field is generated?

during cataclysmic variable evolution, the white dwarf accretes angular momentum, i.e. the white dwarf spin-up:

when the white dwarf is rapidly rotating, the conditions for the dynamo are met, i.e.

→ crystallizing core

→ short spin period

strong magnetic field is generated:

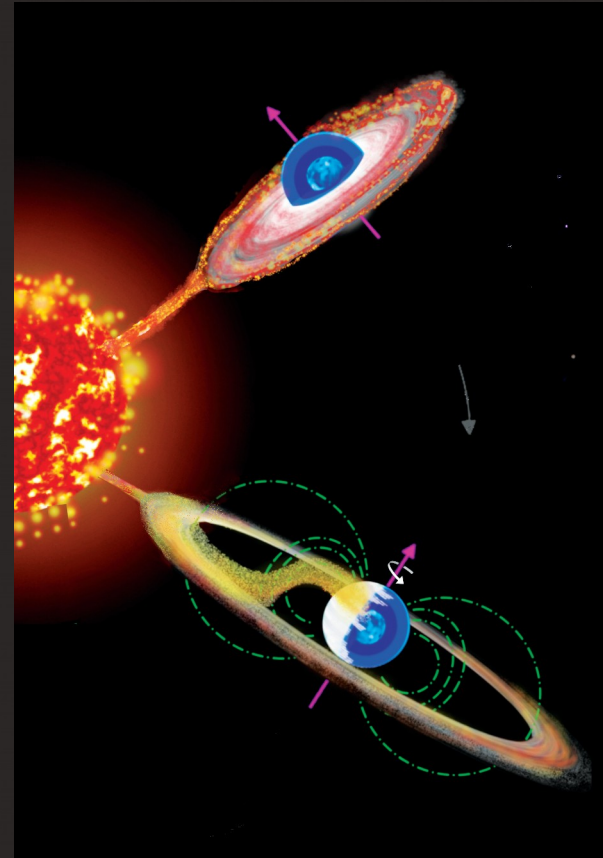


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Formation of Close Magnetic White Dwarf Binaries

THE ROTATION- AND CRYSTALLIZATION-DRIVEN DYNAMO (Schreiber et al. in press)

What happens when magnetic field is generated?

If strong enough to connect with the secondary magnetosphere

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orbital angular momentum gain vs. orbital angular momentum loss

The binary may become detached, depending on

→ white dwarf spin period

→ orbital period

→ magnetic field strength

→ angular momentum loss rate

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THE ROTATION- AND CRYSTALLIZATION-DRIVEN DYNAMO (Schreiber et al. in press)

Explaining the detached binaries (AR Sco and pre-polars)

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AR Sco → in the beginning of the synchronization, white dwarf spin period is still short (**pulsar-like**)

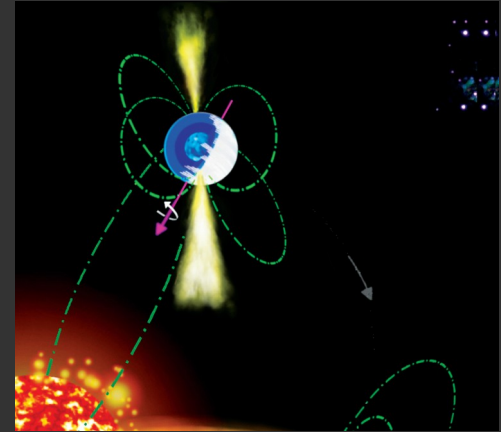


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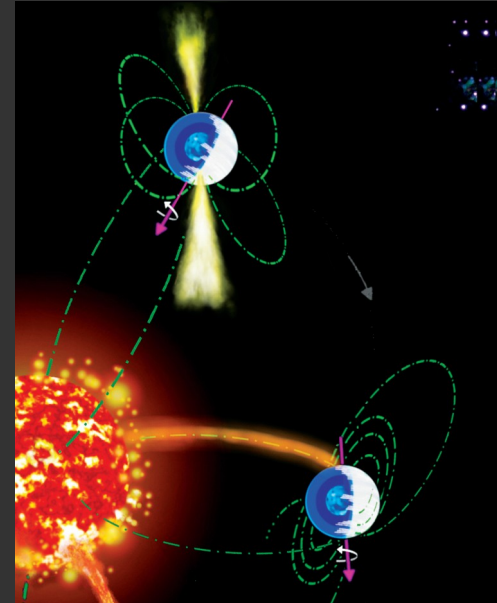


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polar → angular momentum losses keep shrinking the orbit, it becomes a semi-detached binary (**Roche lobe mass transfer**)

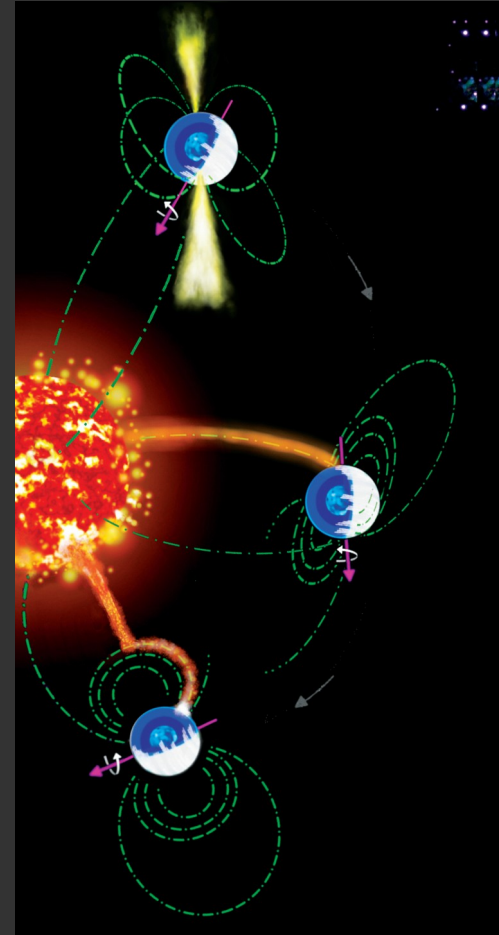


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Explaining the detached binaries (AR Sco and pre-polars)

According to this model...

AR Sco and pre-polars are not pre-cataclysmic variables !!!

They are actually post-non-magnetic cataclysmic variables !!!

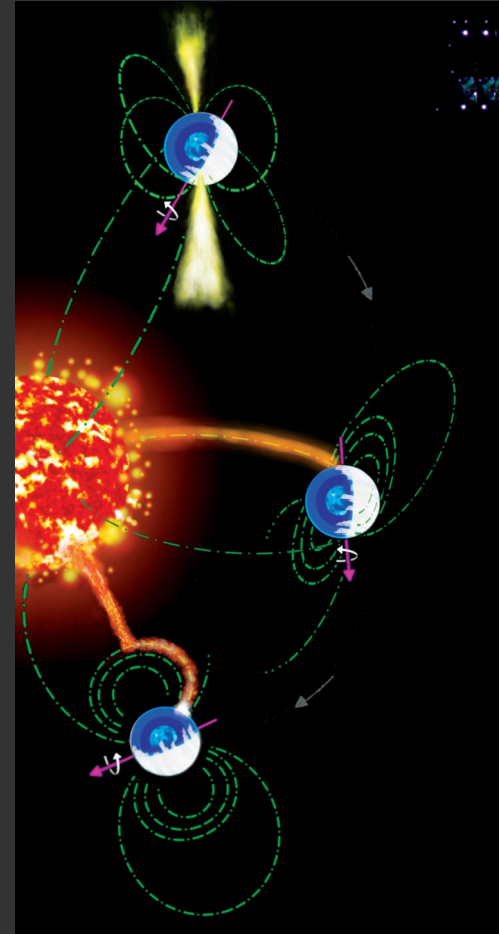


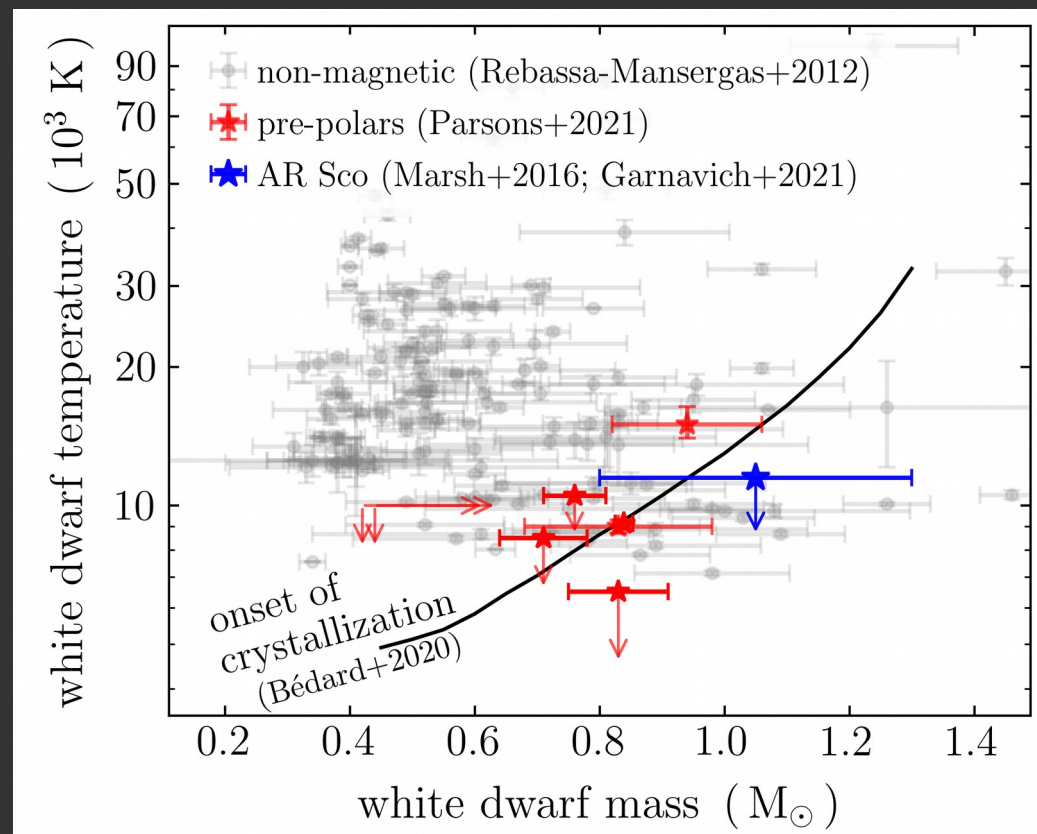
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THE ROTATION- AND CRYSTALLIZATION-DRIVEN DYNAMO (Schreiber et al. in press)

This evolutionary picture is entirely consistent with observations...

detached close binaries



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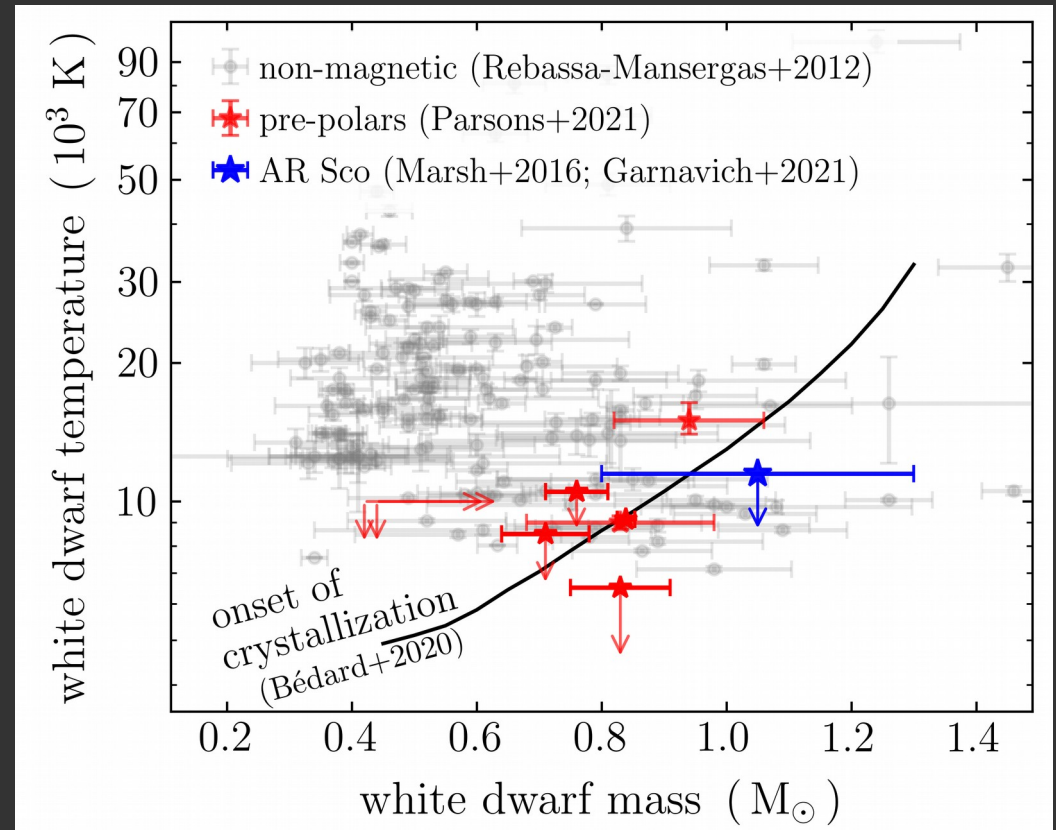
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Magnetic systems host, on average,

→ much older white dwarfs

(consistent with having crystallizing cores)

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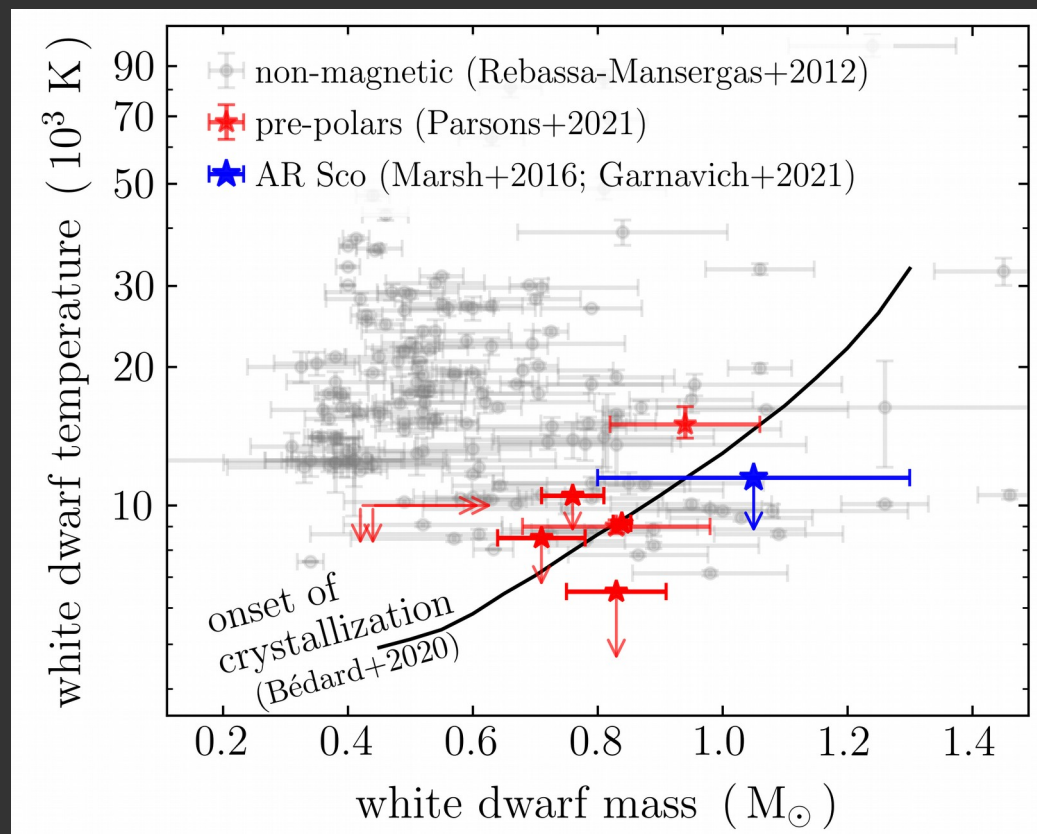
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→ more massive white dwarfs

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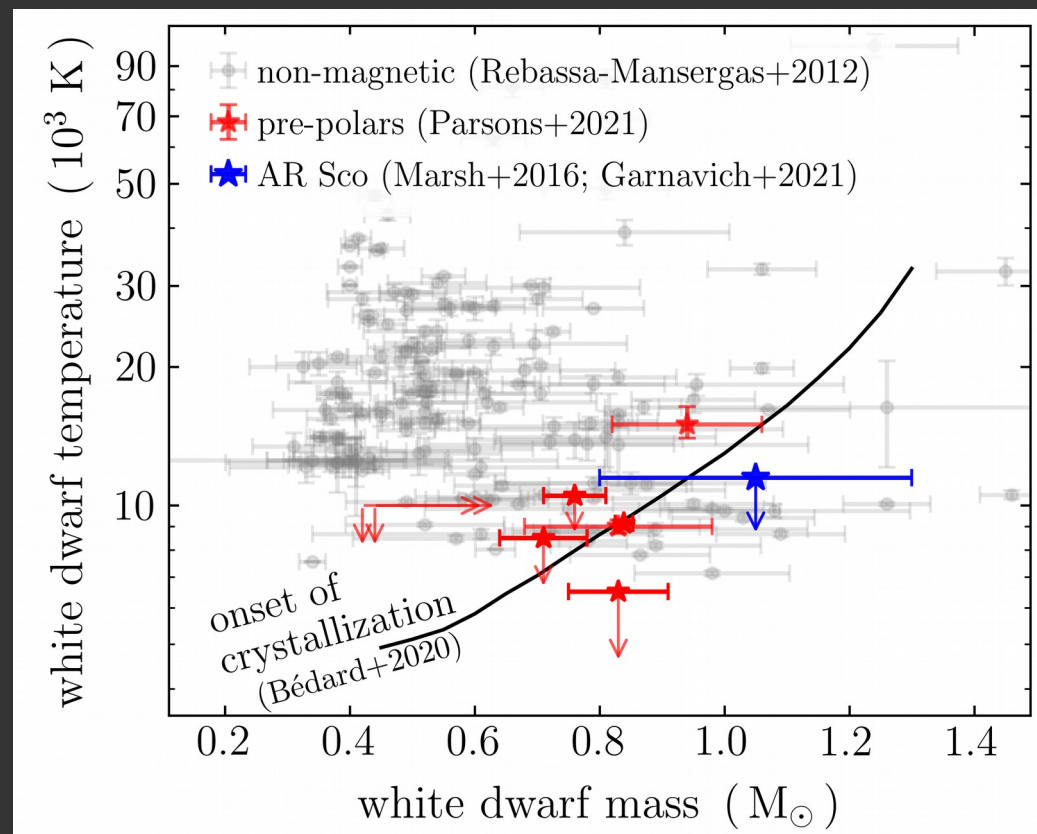
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Therefore, it makes sense that these systems have been cataclysmic variables in the past

detached close binaries

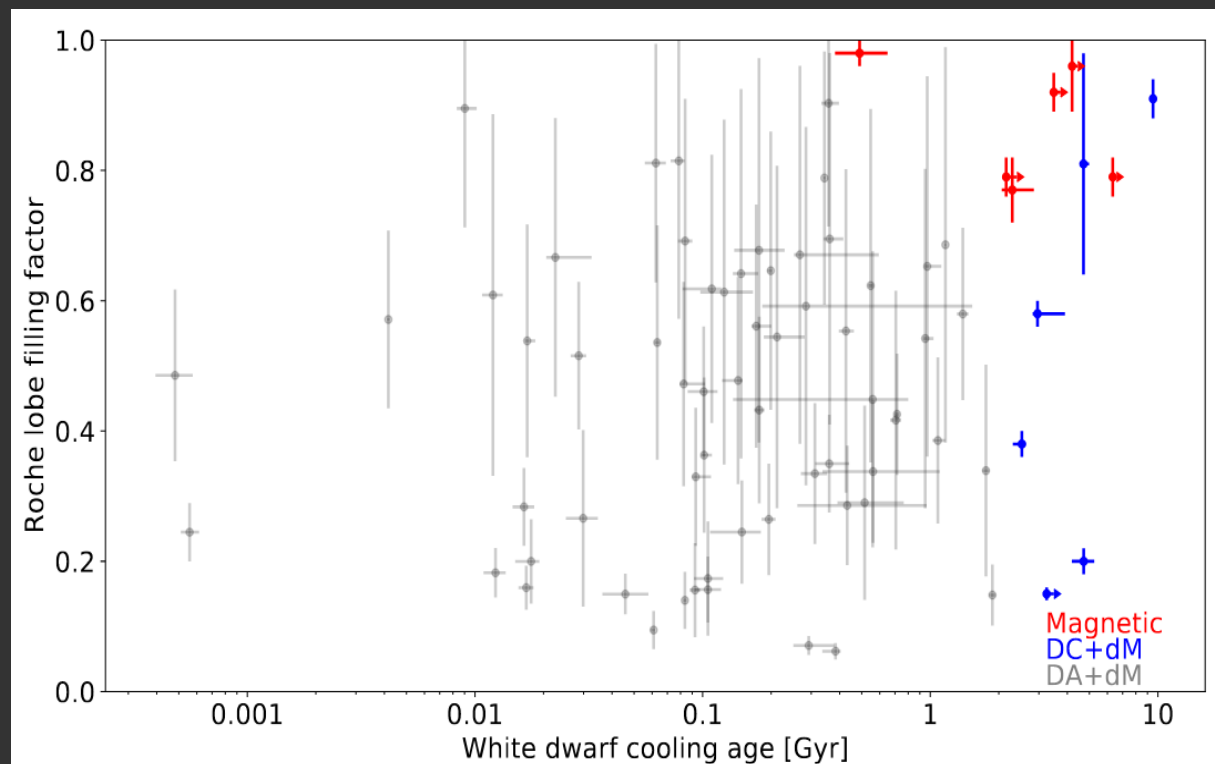


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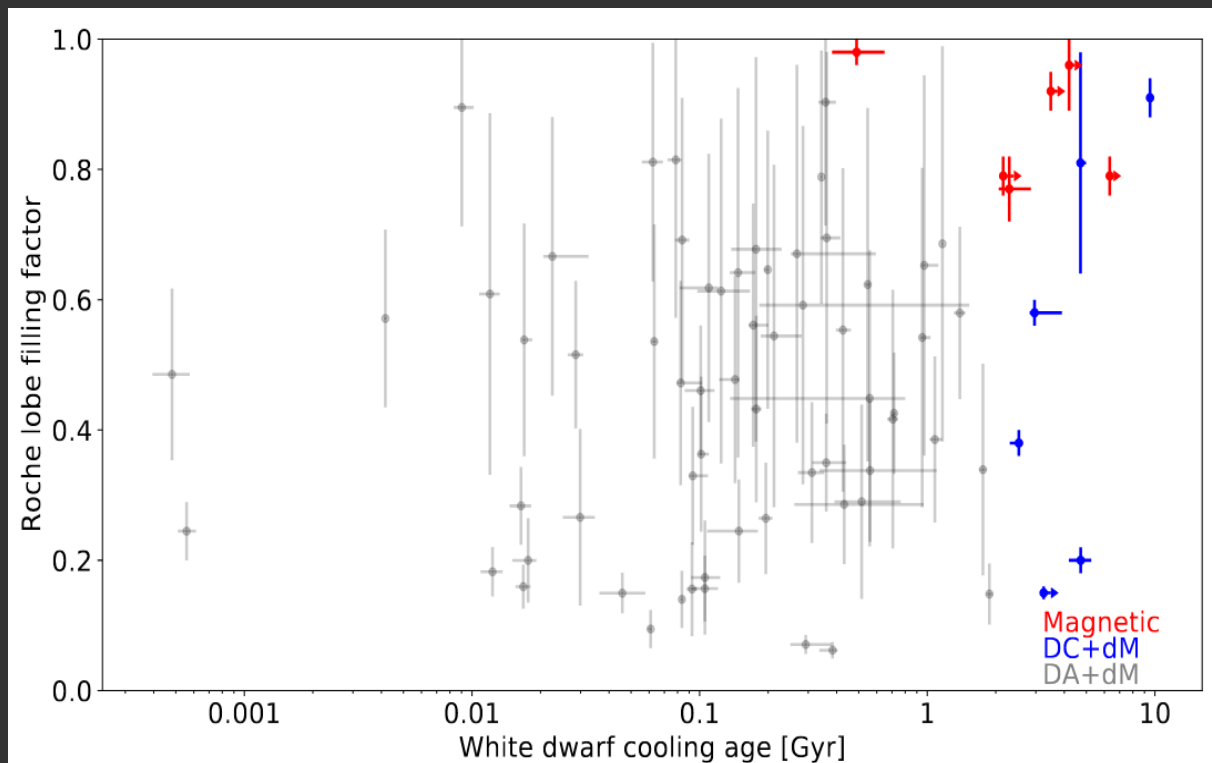
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Magnetic systems have, on average, larger Roche lobe filling factors
(consistent with having a previous phase of mass transfer via Roche-lobe overflow.)

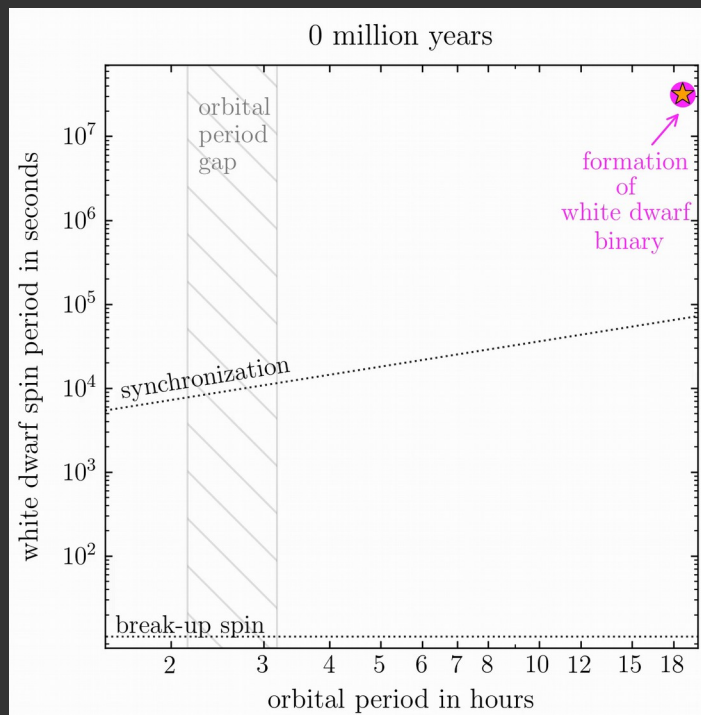
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Formation of Close Magnetic White Dwarf Binaries

THE ROTATION- AND CRYSTALLIZATION-DRIVEN DYNAMO (Schreiber et al. in press)

overall evolution



SUMMARY

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- + the existence of the radio-pulsing AR Sco
- + the relative frequency of magnetic and non-magnetic cataclysmic variables

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MANY THANKS !!