AR Sco: the first pulsing white dwarf

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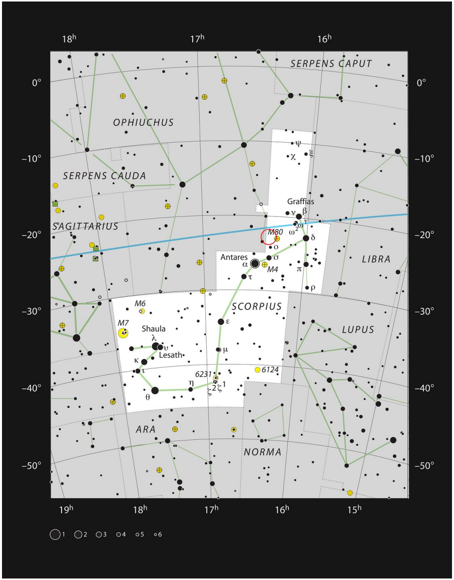
Introducing AR Scorpii

A long time ago in a star (not) far, far away…

- δ-Scutti star (Satyvaldiev 1971)
- 14.5–16.5 mag
- At 116 pc
- δ-Scutti variability:
  - Pulsations of the star's surface
  - Used as standard candles



AR Sco, a M star + white dwarf binary

- But there is a problem…

  …it is not a δ-Scutti star!

- Light-curve with large scatter

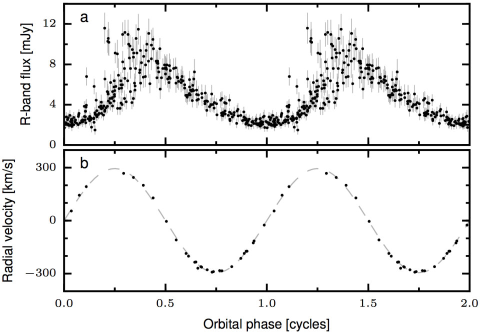
- …it's a binary!

- M star + white dwarf

  $M_1 \approx 1\mathrm{M}_\odot$
  $M_2 \approx 0.3\mathrm{M}_\odot$

- $P_{\rm orb} = 3.56$ h

- Emission from radio to X-rays



$\phi = 0.5 \Longrightarrow$ inferior conjunction

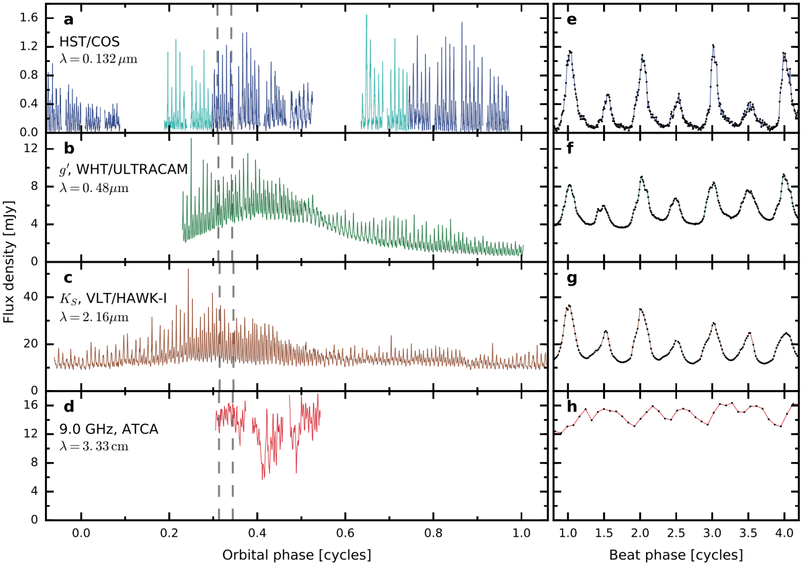
Marsh et al. (2016, Nature, 537, 374)

A piece of context

Peculiarities of AR Sco:

- Jet outflows are known in some accreting white dwarfs
  Körding et al. (2008, 2011)
- However, all ($\sim$120) but one exhibit flux densities < 1 mJy
  Barrett et al. (2017)
- **AE Aqr** is the exception:
  - Can exceed 10 mJy
  - Rapidly spinning magnetic white dwarf
  - Mass transferred from its companion is thrown out of the system
    Wynn et al. (1997), Meintjes et al. (2012)
- **AR Sco** is bright ($\sim$10 mJy)
- But does not seem to exhibit accretion...
  (faint X-ray emission, constraints to $\dot{M}$, narrow emission lines...)

AR Sco: light-curves

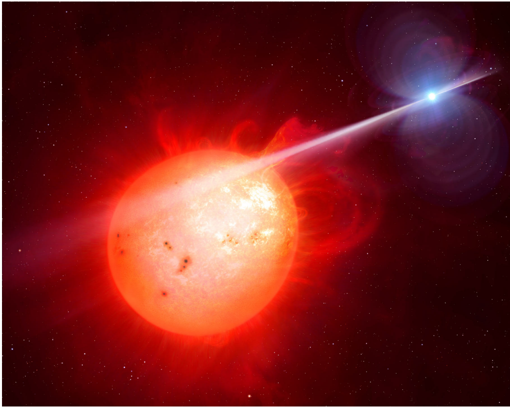


Marsh et al. (2016)

AR Sco: the first pulsar white dwarf

- Orbital period of 3.56 h
- Pulses observed every 1.97 min

  Spin period of the white dwarf (Marsh et al. 2016)
- **AR Sco is the first "so-called" pulsar white dwarf**



The origin of the emission

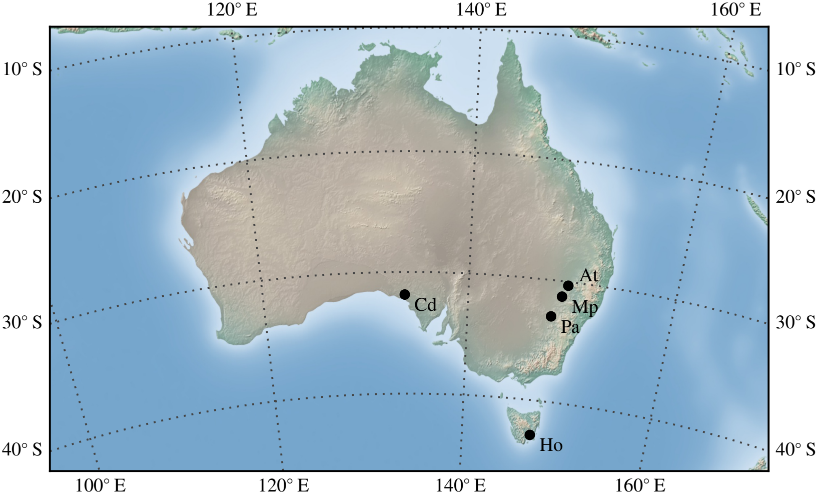
Most of the emission is likely originated in the M star's magnetosphere facing the white dwarf (Marsh et al. 2016, Katz 2017)

How the energy is transferred from the white dwarf to the M star?

Two main possibilities (focusing on the radio emission):
(Marsh et al. 2016, Buckley et al. 2017, Katz 2017)

- Collimated relativistic particle outflows
- Direct interaction between the WD magnetosphere and the M star

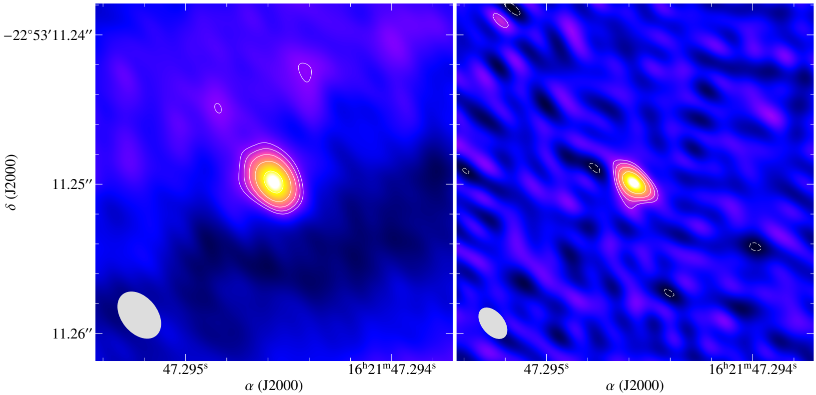
LBA radio observations



LBA observation on 20 October 2016 at 8.4 GHz

ATCA, Ceduna, Hobart, Mopra, Parkes, Katherine, [Warkworth]

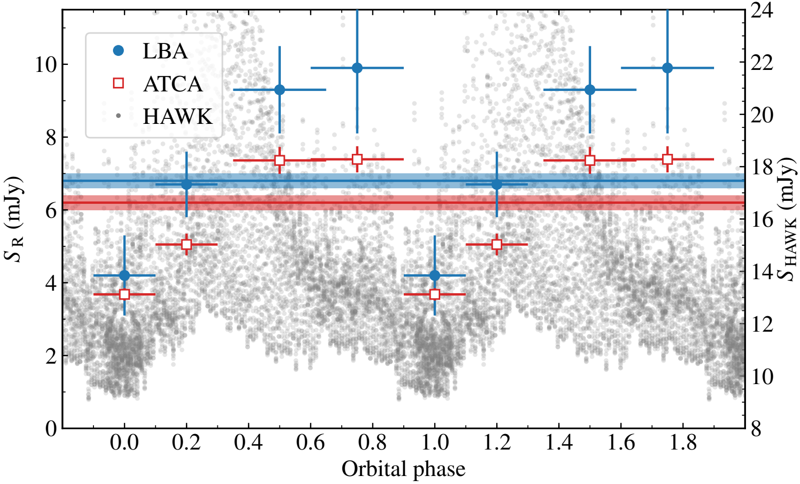
LBA Results



Natural weighting (no self-cal.) — vs — zero robust after self-cal.

Contours start at 3σ rms noise level of 0.4 mJy.

LBA Results



Light-curve of AR Sco from the LBA and ATCA data.

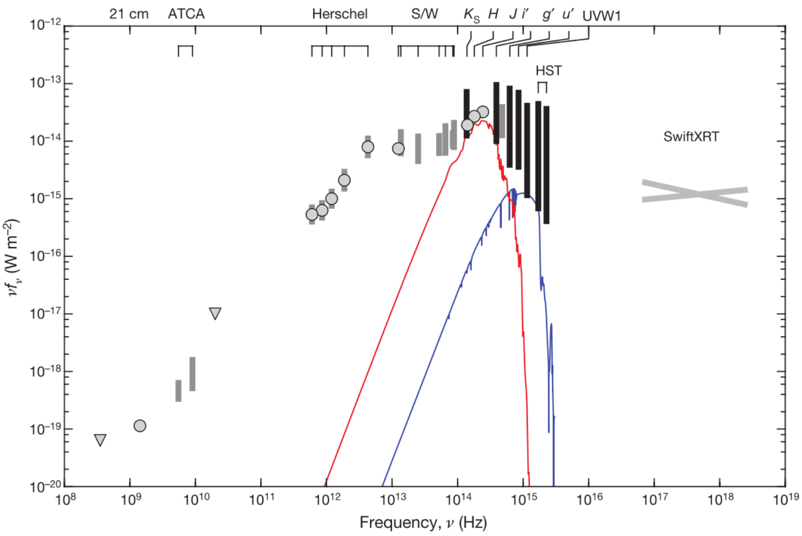
Discussion & Conclusions

- *All* emission is compact (< 0.17 mas $= 0.02$ AU $= 4\ \mathrm{R}_{\odot}$).
- Non-thermal emission ($T_b \gtrsim 5 \times 10^9$ K)
- Light-curves synchronized on $\lesssim$ 20-min timescales
- A one-zone emitting region
- Most probably scenario: emission from near the WD or at the surface of the M star

Marcote, Marsh, Stanway, Paragi, & Blanchard, A&A (submitted)

Thank you!

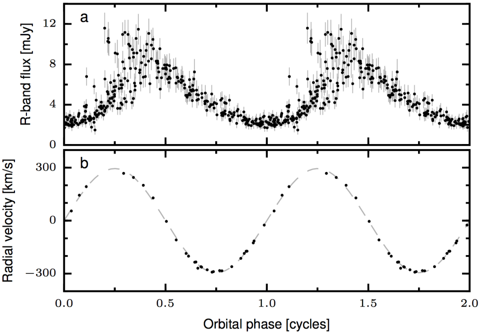
AR Sco's SED



21 cm
ATCA
Herschel
S/W
K_S
H
J
i'
g'
u'
UVW1
HST
SwiftXRT
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
νf_ν (W m^{-2})
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
Frequency, ν (Hz)

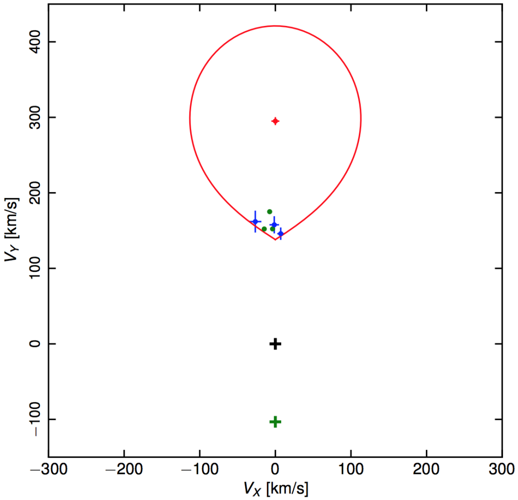
The origin of the emission

- Spin-down on 10^7-yr timescale
- Maximum 0.1 orb. phases before the inferior conjunction ($\phi = 0.5$)
- Most of the emission likely originated in the M star's magnetosphere (side facing the white dwarf)
  Marsh et al. (2016), Katz (2017)



Marsh et al. (2016)

The origin of the emission



Marsh et al. (2016)

- Roche lobe
- M star
- center of mass
- white dwarf

- SiIV and HeII lines
- $\mathrm{H}\alpha, \beta, \gamma$ lines