XMM-Newton observations of the unique binary system HD49798/RXJ0648-4418

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Why a “unique” binary?

• The only X-ray pulsar with a hot subdwarf companion

• The pulsar is the fastest spinning - and one of the most massive - white dwarf
  (Mereghetti et al. 2009, Science
Hot Sub-Dwarfs

- Low mass He-burning stars with thin H envelope
- Result of evolution involving significant mass loss
- Spectrally classified in
  - sdO (T>4 $10^4$ K)
  - sdOB (3.3 $10^4$ <T<4 $10^4$ K)
  - sdB (2.8 $10^4$ <T<3.3 $10^4$ K)
- Many are in binaries

Heber 2009, ARAA
HD 49798: the brightest sdO

- $T = 47,500$ K
- $L \sim 10^4 \ L_{\text{sun}}$
- $\log g = 4.25$

Single-lined spectroscopic binary:

- $P_{\text{orb}} = 1.55$ days
- $d = 650$ pc

Thackeray 1970
Kudritzky et al. 1978
Hamann et al. 1981
Bruhweiler et al. 1981
Stickland & Lloyd 1984
Bisscheroux et al. 1997
HD 49798:
A single-lined spectroscopic binary

HD 49798

Hot subdwarf (sdO type)
B = 8 mag

+ ?

Companion invisible in optical / UV data

S. MEREGHETTI - The X-ray Universe 2011
Berlin 28/6/2011
ROSAT discovery of pulsed soft X-ray emission

(P=13.2 s →
the companion is a Neutron Star or a White Dwarf)

Poorly constrained blackbody spectrum
→ large uncertainty on X-ray luminosity
$10^{32} - >10^{38}$ erg/s
Optical mass function

Companion mass
WD or NS?

HD 49798 mass

S. MEREGHETTI - The X-ray Universe 2011
Berlin 28/6/2011
Stellar wind from HD49798

UV spectrum of HD 49798 (Hamann 2010)

Wind from the sdO star with

\[ V = 1350 \text{ km/s} \]
\[ \dot{M} = 3 \times 10^{-9} \text{ M}_{\odot}/\text{yr} \]

Accretion luminosity:

\[ \sim 10^{34} - 10^{35} \text{ erg/s for NS} \]
\[ \sim 10^{31} - 10^{32} \text{ erg/s for WD} \]
44 ks XMM-Newton observation on May 2008

EPIC vs. ROSAT contours of $kT-N_H$

- $kT_{BB} = 40 +/- 2$ eV
- $N_H < 10^{20}$ cm$^{-2}$
- $L_{bol} \sim 10^{32}$ erg/s @ 650 pc

the companion is a White Dwarf
Time delays in X-ray pulses

- X-ray projected semi major-axis:
  \[ \text{Ax } \sin i = 9.78 \pm 0.06 \text{ light-sec} \]

- opt. mass funct. \[ q = \frac{M_{\text{HD}}}{M_x} = 1.17 \pm 0.01 \]
Optical + X-ray mass functions

\[ \frac{M_{\text{HD}}}{M_x} = 1.17 \]
Discovery of X-ray eclipse

• Eclipse duration = 1.3 hours
• Radius of HD 49798  = 1.45+/-0.25 Rsun
• \( \Rightarrow \) inclination 79—84 degrees

\[
(R_C/a)^2 = \cos^2 i + \sin^2 i \sin^2 \Theta
\]
Opt. and X-ray m.f. + inclination

$M_x = 1.28 \, \text{M}_\odot$

$M_{HD} = 1.5 \, \text{M}_\odot$
The companion of HD 49798 is a very massive WD!

**Distribution of WD masses**

Kepler et al. 2007

- **M = 1.28 +/- 0.05**

- Direct, dynamical measurement of M

- While most WD masses are derived indirectly:
  - spectroscopic and photometric methods \( \rightarrow L, T, \log g \rightarrow M/R^2 \)
  - gravitational redshift \( \rightarrow M/R \)
Summary

- Robust, dynamical determination of $M > 1.2$ $\text{M}_{\odot}$ for a white dwarf

- Post Common Envelope binary with well determined masses $\rightarrow$ optimal test-bench for evolutionary models

- The fastest spinning WD ($P=13.2$ s) $\rightarrow$ low B to avoid propeller ($< \text{few kG}$)

- Possible future evolution:
  - SN Ia with short delay time or
  - non-recycled millisecond pulsar
XMM Observations

4 short obs. in 2002 (A,B,C,D)
1 long obs. in 2008 (E)
X-rays during eclipse: emission from the sdO star!

Therm. Bremsstrahlung Spectrum with kT = 0.5 keV

\[ \text{L}_x \approx 2 \times 10^{30} \text{ erg/s} \]

First detection of X-ray emission from a hot subdwarf

\[ \frac{\text{L}_x}{\text{L}_{\text{bol}}} \approx 10^{-7} \text{ consistent with O type stars} \]
Two components with different spectral and timing properties

$kT = 39 \text{ eV}$

$\Gamma \sim 2$

BLACK BODY

POWER LAW

~60% pulsed fraction
Phase resolved spectroscopy

- Soft component: No temperature variations
- Hard component: First peak is slightly softer
Long term stability of pulse profiles

MAY 2002

SEPT 2002

MAY 2008

SOFT

HARD
No evidence for significant spin-up or spin-down

\[ -5 \times 10^{-13} \text{ s s}^{-1} < \dot{P} < 9 \times 10^{-13} \text{ s s}^{-1} \]
Small variations between 2002 and 2008

In Sept. 2002 the power law component was ~30% brighter than in 2008

Orbital or long term variability?

In May 2002 the blackbody temperature was lower than in 2008 (32 eV wrt 40 eV)
Ratio $L_{\text{soft}}/L_{\text{hard}} \sim 10$ as in several magnetic CVs...

...but:

Temperature of hard component lower than expected based on $kT$-Mass correlation

$B < 1 \text{ kG} \text{ wrt } \sim 20-200 \text{ MG in polars and } \sim 5-20 \text{ MG in Intermediate Polars}$

Variability properties are different

Accretion is through stellar wind
Conclusions

• X-ray spectral properties are similar to those of Polars and Intermediate Polars

• This is puzzling considering that this system is quite different:
  • accretes from wind and not from Roche-lobe overflow
  • $B < \text{few kG}$ rather than several MG

• First X-ray detection of a hot subdwarf $\Rightarrow$ crucial to study X-ray generation in winds of hot stars over a broader parameter space