Hot-subdwarf stars: a new class of X-ray sources…?

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Hot subdwarf stars:

Heber 2009, ARAA, 47

- Evolved low-mass stars with burning He core and thin H envelope (Heber 2009)
- Spectrally classified in: sdO (T > 40,000 K) sdB (T < 40,000 K) (Hirsch et al. 2008)
- Many in close binary systems

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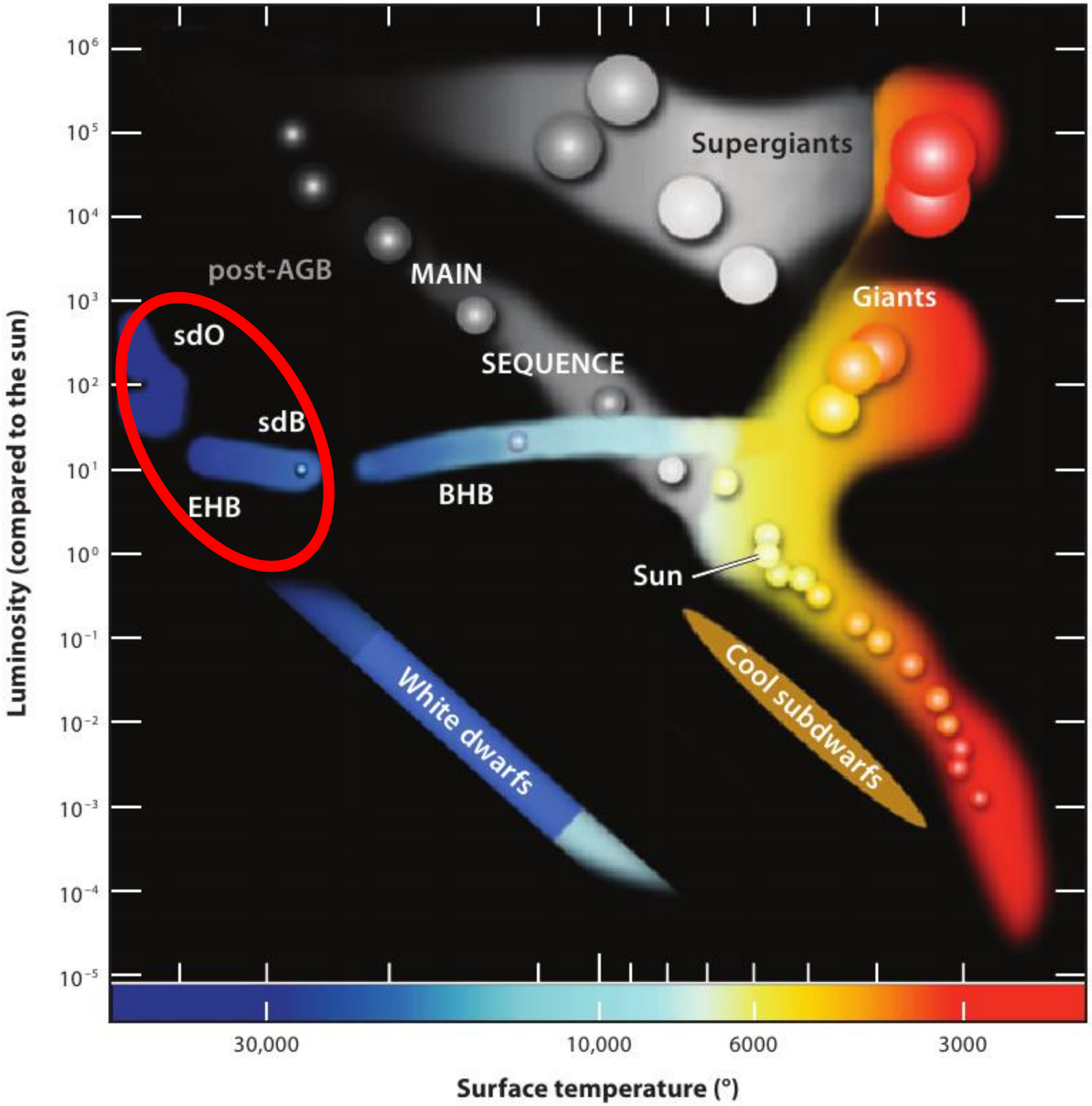
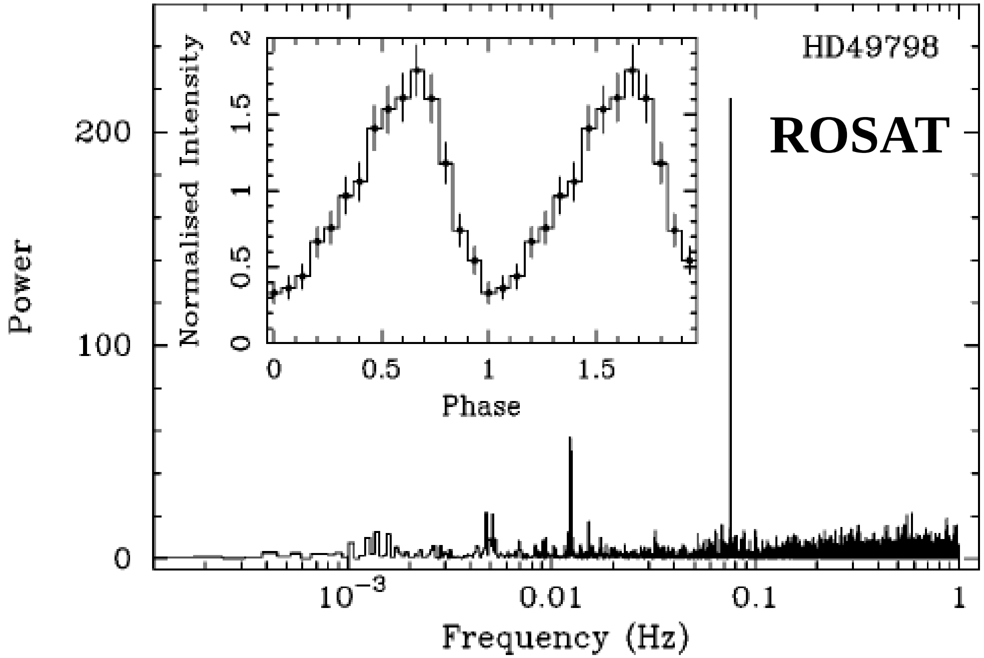
possible formation via mass loss through binary evolution

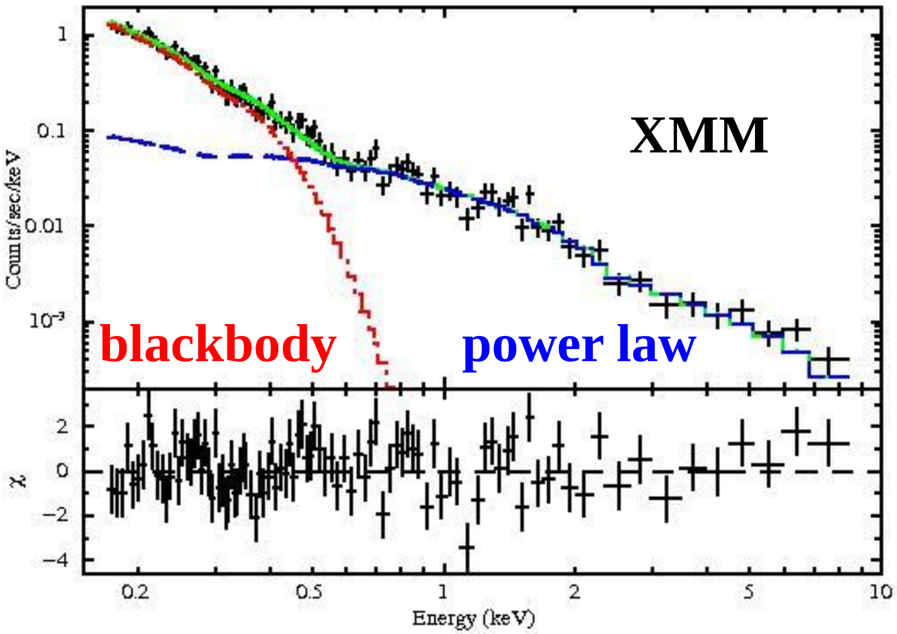


HD 49798: the first sdO star detected in X-rays

Pulsations discovered with ROSAT (Israel et al., 1997, ApJ, 474)

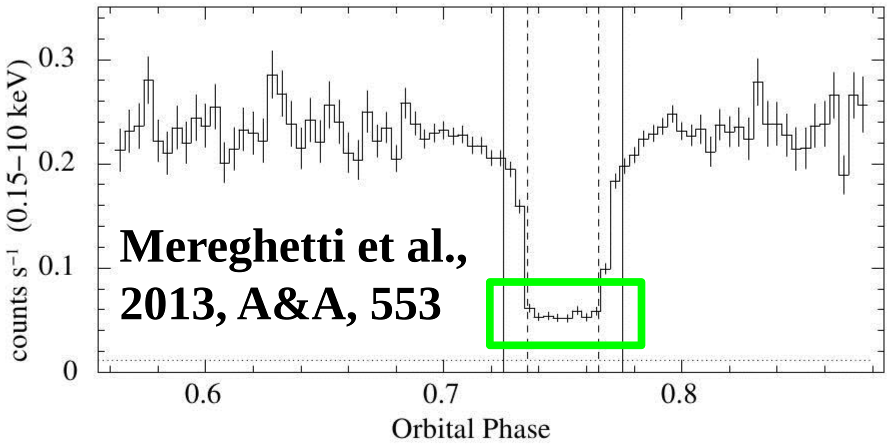


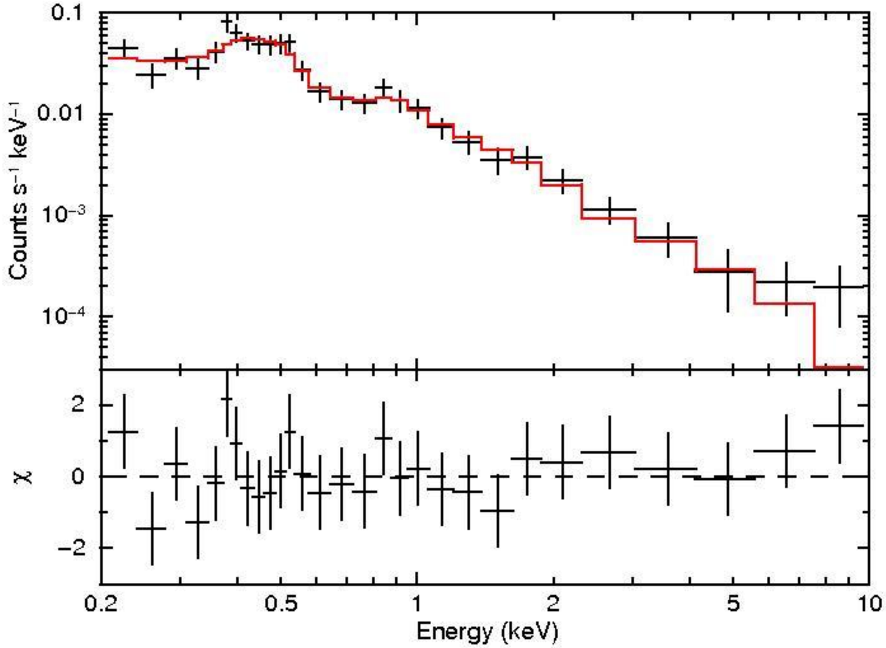
Spectrum investigated with XMM (Mereghetti et al., 2009, Science, 325)



- **Pulsed X-ray emission (P = 13.2 s)**
- **Soft X-ray spectrum (BB dominated)** ⇒ **the companion is a WD**
- **Low X-ray luminosity ($L_X \sim 10^{32}$ erg/s)**

X-ray emission during WD eclipse





- **PL + 2 narrow lines @ 0.43 & 0.5 keV (N VI & N VII)**

OR

- **3 thermal plasma components (kT = 0.14, 0.7 & 5 keV) with proper He & N abundances**

- **$L_X \simeq 3\times10^{30}$ erg/s $\Rightarrow L_X/L_{bol} \sim 10^{-7}$**

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consistent with O-type stars (Nazé 2009)

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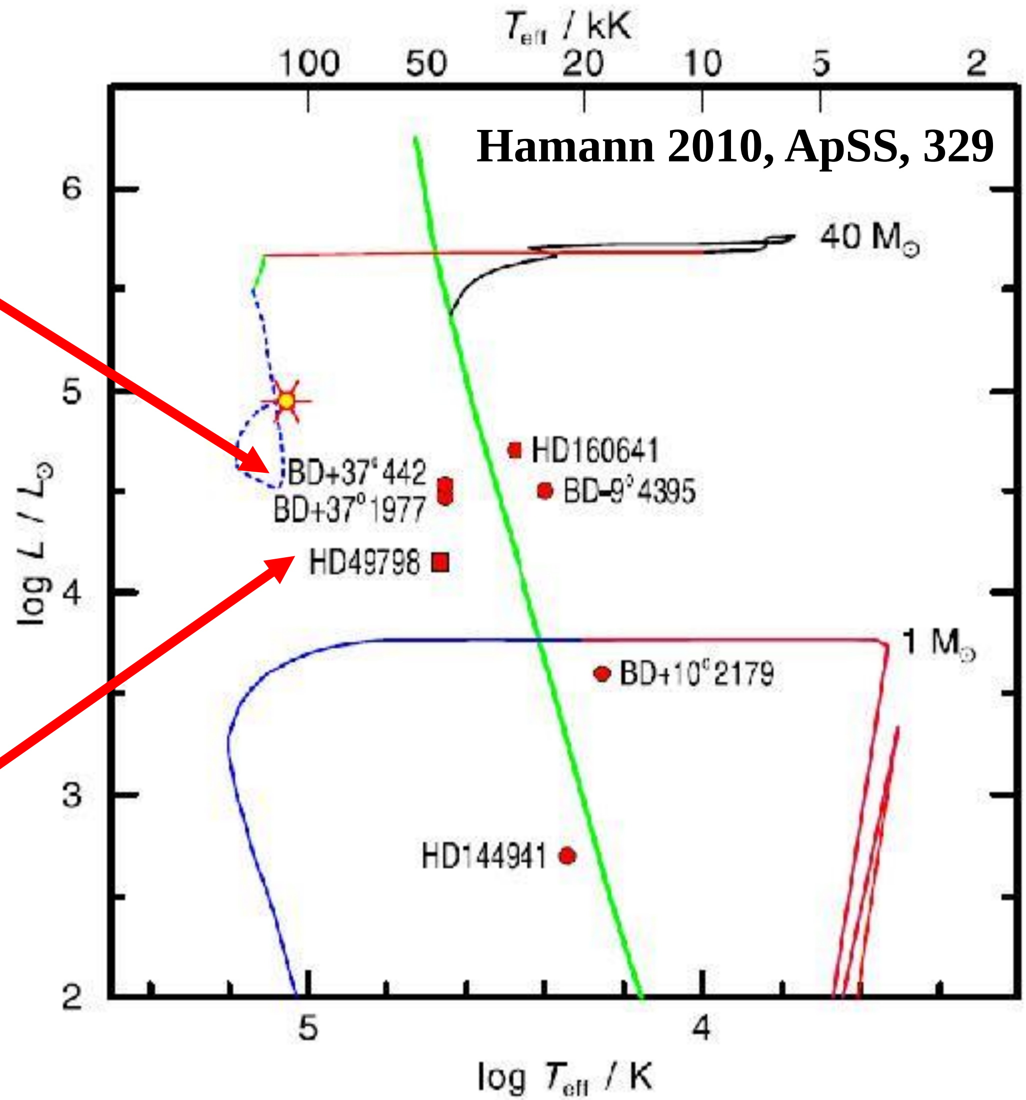
first detection of intrinsic X-ray emission from a hot subdwarf star

The Extreme Helium Star BD +37° 442

BD +37° 442
T = 48,000 K
L = 25,000 $L_\odot$
log *g* = 4.0
d = 2.0(+0.9/-0.6) kpc
$\dot{M} = 10^{-8.5}$ $M_\odot$/yr
$V_{wind, \infty}$ = 2,000 km/s

HD 49798
T = 46,500 K
L = 14,000 $L_\odot$
log *g* = 4.35
d = 650 ± 100 pc
$\dot{M} = 10^{-8.5}$ $M_\odot$/yr
$V_{wind, \infty}$ = 1,350 km/s



The Extreme Helium Star BD +37° 442

Luminous & He-rich sdO star comparable to HD 49798

Single star:

- no evidence of normal/compact companion from spectroscopic (Faÿ et al 1973; Kaufman & Theil 1980; Dworetsky et al. 1982) or photometric data (Landolt 1968, 1973)
- no infrared excess (Thejll et al. 1995)

UV spectra: N V and C IV resonance lines with P Cygni-like profiles ⇒ stellar wind (Rossi et al. 1984)

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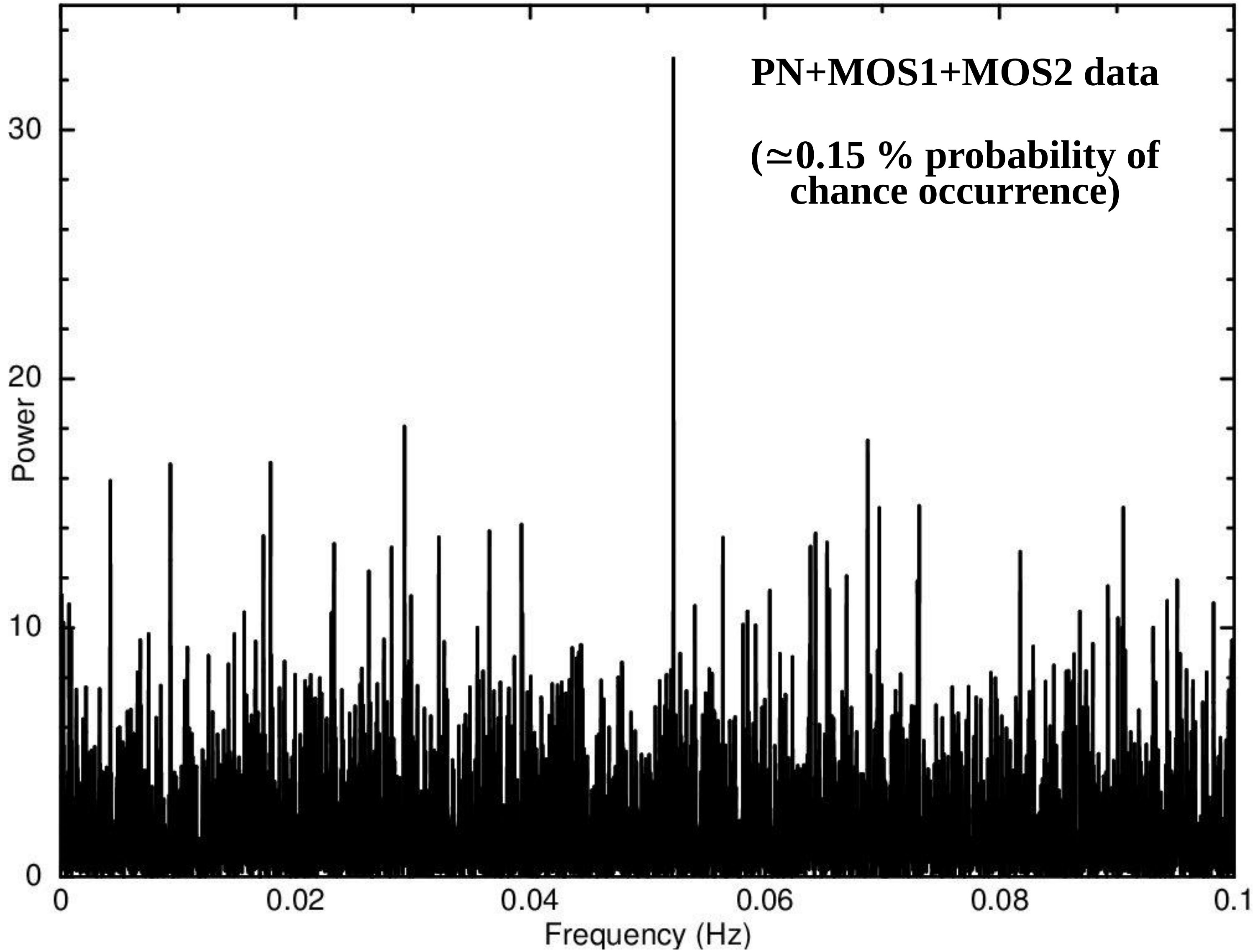
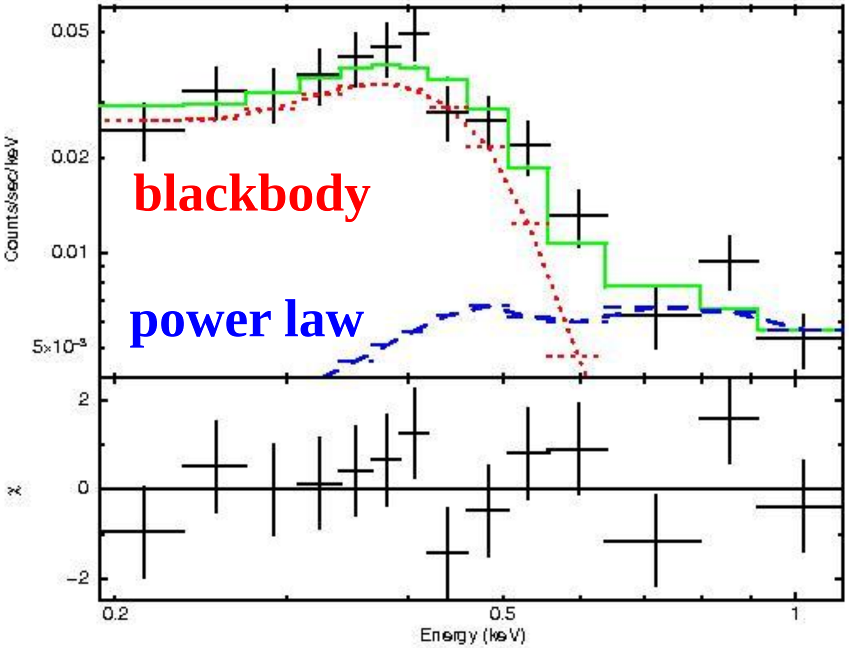
very interesting to investigate X-ray emission from sdO stars

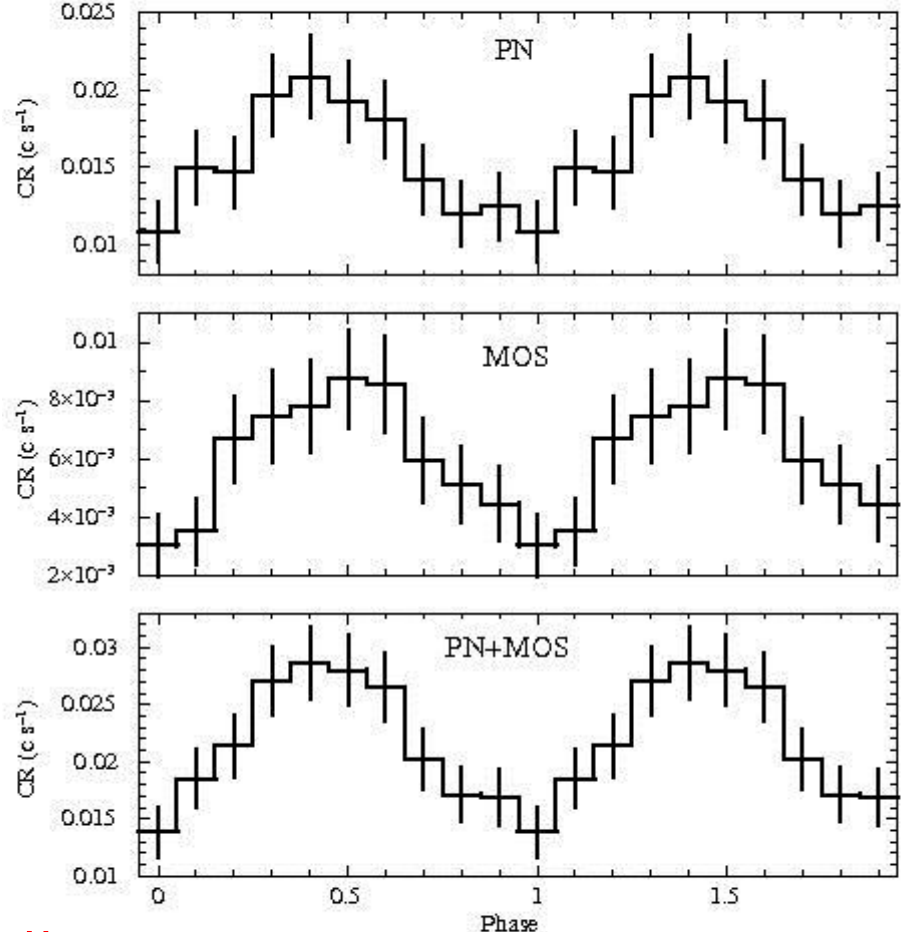
Discovery of pulsed X-ray emission



Discovery of pulsed X-ray emission



La Palombara et al., 2012, ApJL, 750



- Soft X-ray spectrum
- P = 19.156 ± 0.001 s (3 σ c.l.)
- Sinusoidal profile
- Pulsed Fraction = 31 ± 4 %

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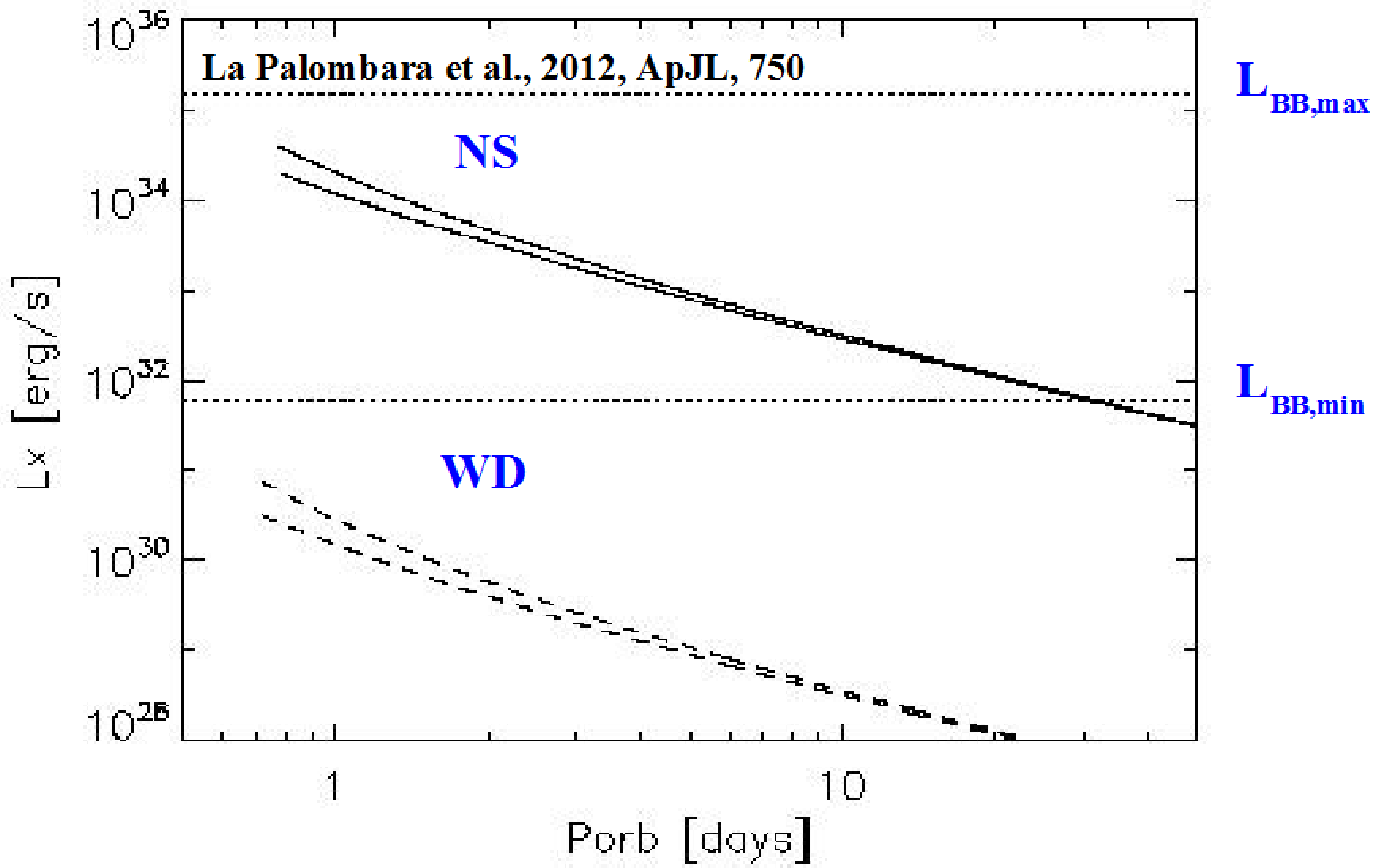
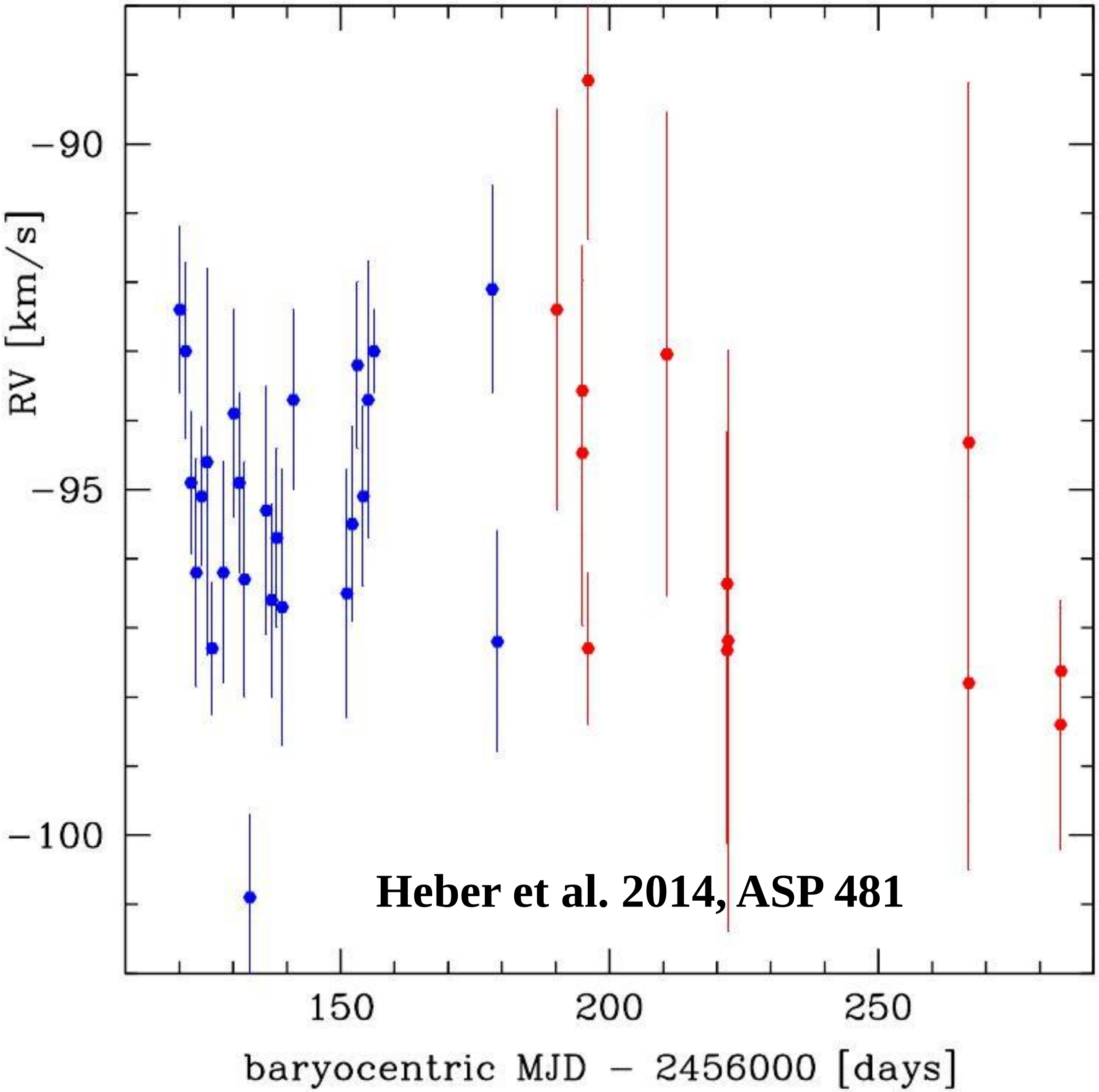
X-ray emission from a compact companion?

Nature of the compact companion of BD +37° 442



Optical spectroscopy of BD +37° 442



High-resolution time-resolved spectroscopy with CAFE (Calar Alto) and SARG (TNG)

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- **large (~ 60 km/s) projected rotation velocity (⇒ binary similar to HD 49798?)**
- **no evidence of radial velocity variations**

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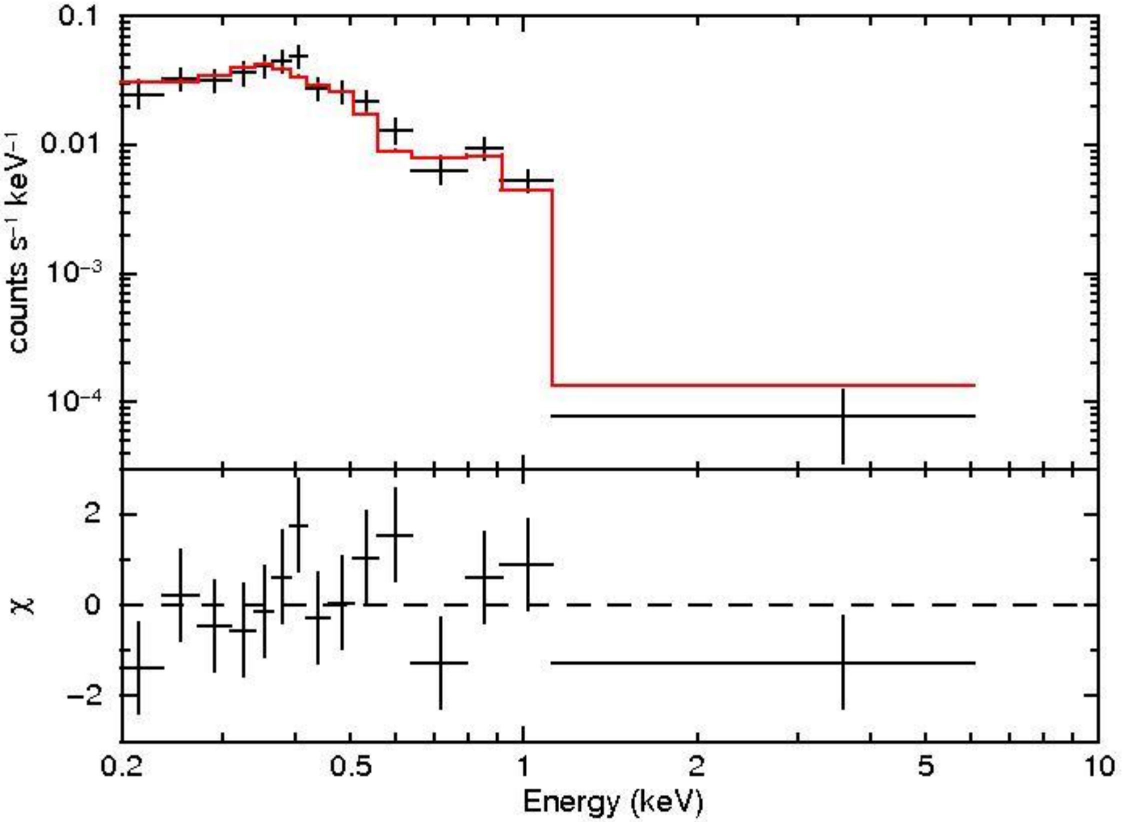
no compact companion?

Alternative for the X-ray emission of BD +37° 442



- **2 thermal plasma components (kT = 0.17 & 0.72 keV) with proper He & metal abundances**
- **$L_X \simeq 1.3 \times 10^{31}$ erg/s $\Rightarrow$ $L_X/L_{bol} \simeq 1.3 \times 10^{-7}$: consistent with O-type stars**

X-ray emission comparable to that of HD 49798 during eclipse

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intrinsic X-ray emission from the sdO star itself?

X-ray observation of other sdO stars

First systematic search of X-ray emission from a complete flux-limited sample of sdO stars:

- **snapshot observations (4 ks) with Chandra HRC-I of a sample of 19 sdO stars with V < 12 and d < 1 kpc**
- **follow-up observations of detected sources with XMM-Newton**

Approved for AO14 and performed in 2013

Name	d (pc)	V
BD+75° 325	150-280	9.55
BD+25° 4655	100-130	9.69
BD-22° 3804	230-440	10.03
BD+37° 1977	2500	10.15
BD+39° 3226	220-430	10.18
BD-03° 2179	-	10.33
BD+28° 4211	85-120	10.51
CD-31 4800	220-400	10.52
BD+48° 1777	120-250	10.74
LS V +22 38	-	10.93
LS IV -12 1	250-550	11.16
Feige 34	85-265	11.18
LSE 153	150-350	11.36
LSS 1275	< 1000	11.37
LSE 263	150-350	11.55
BD+18° 2647	600-1250	11.63
LSE 21	50	11.64
LS IV +10 9	130-330	12.05
LS I +63 198	-	12.80

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Three new X-ray detections:

- **1 luminous sdO (BD+37º 1977)**
- **2 compact sdOs (BD+28º 4211 & Feige 34)**

La Palombara et al., 2014, A&A, 566

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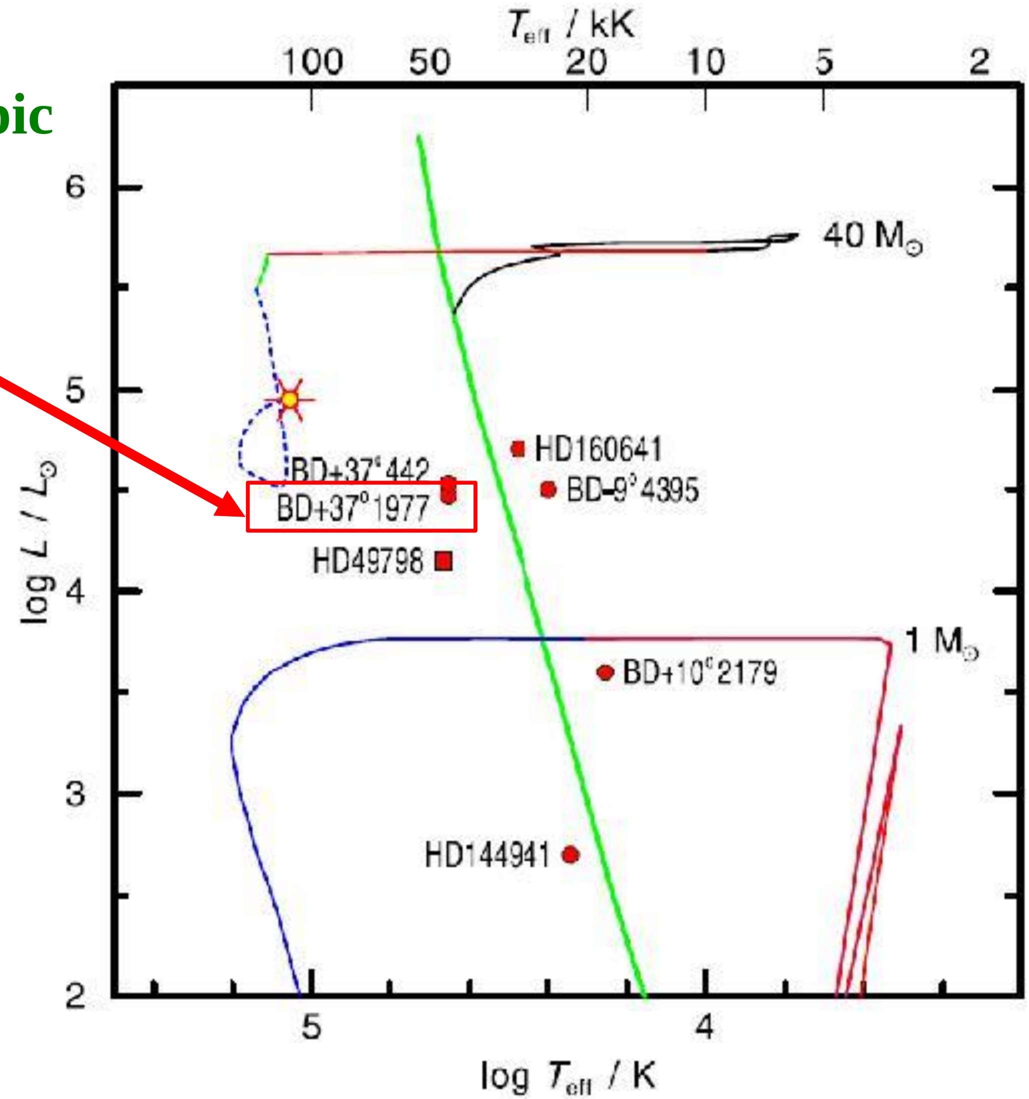
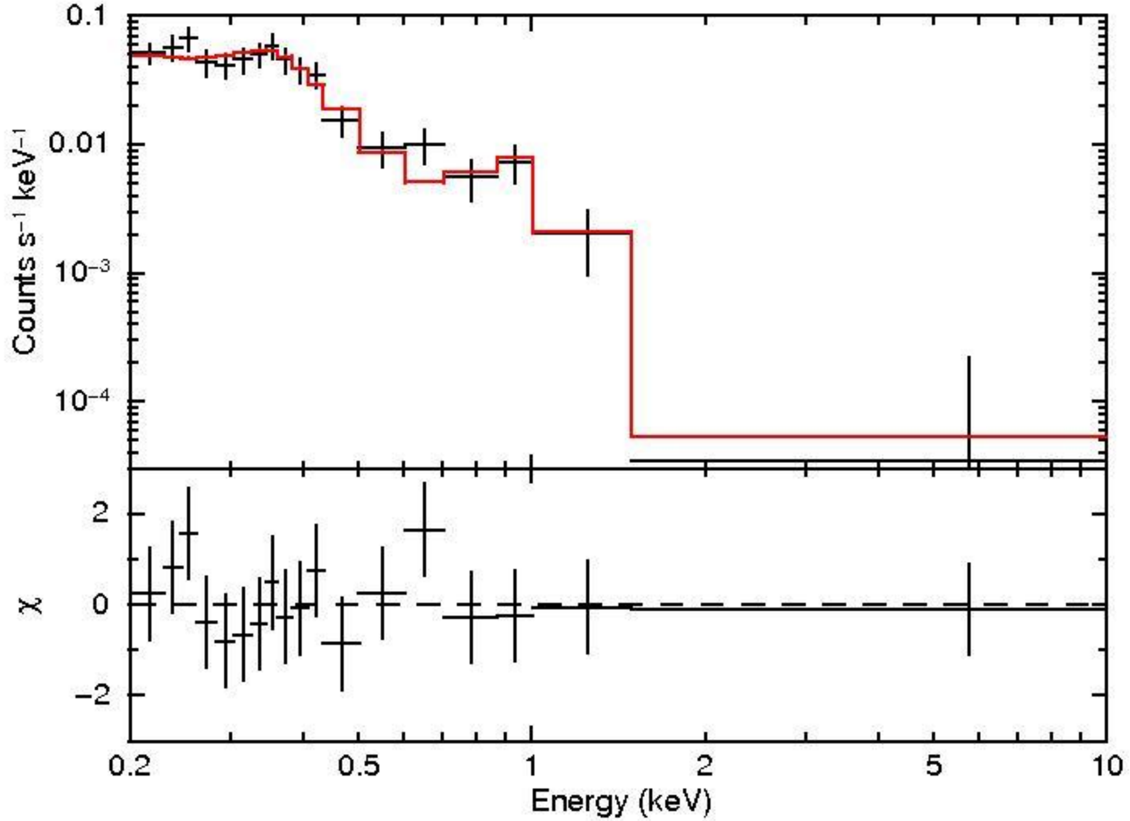
XMM-Newton observation of BD+37° 1977

BD+37° 1977 = spectroscopic twin of BD+37° 442 @ 2.6 kpc



XMM-Newton observation in April 2014 for 34 ks

XMM-Newton observation of BD+37° 1977



- **2 thermal plasma components (kT = 0.12 & 0.84 keV) with proper He & metal abundances**
- **$L_X \simeq 3.1 \times 10^{31}$ erg/s ⇒ $L_X/L_{bol} \simeq 3.5 \times 10^{-7}$: consistent with O-type stars**

X-ray emission comparable to that of HD 49798 during eclipse and that of BD+37° 442

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intrinsic X-ray emission from the sdO star itself

X-ray emission of detected luminous sdO stars

Spectra modeled with multi-temperature thermal-plasma components (*mekal*), as in normal O-type stars (Nazé 2009):

	kT1 (keV)	kT2 (keV)	kT3 (keV)	$\log(L_x/L_{bol})$
HD 49798	0.14	0.71	5 (fix)	-7.1
BD+37° 442	0.17	0.72	-	-6.7
BD+37° 1977	0.12	0.84	-	-6.5

- good spectral fit with 2/3 components
- $\log(L_x/L_{bol})$ in agreement with the typical range -6.7(±0.5)

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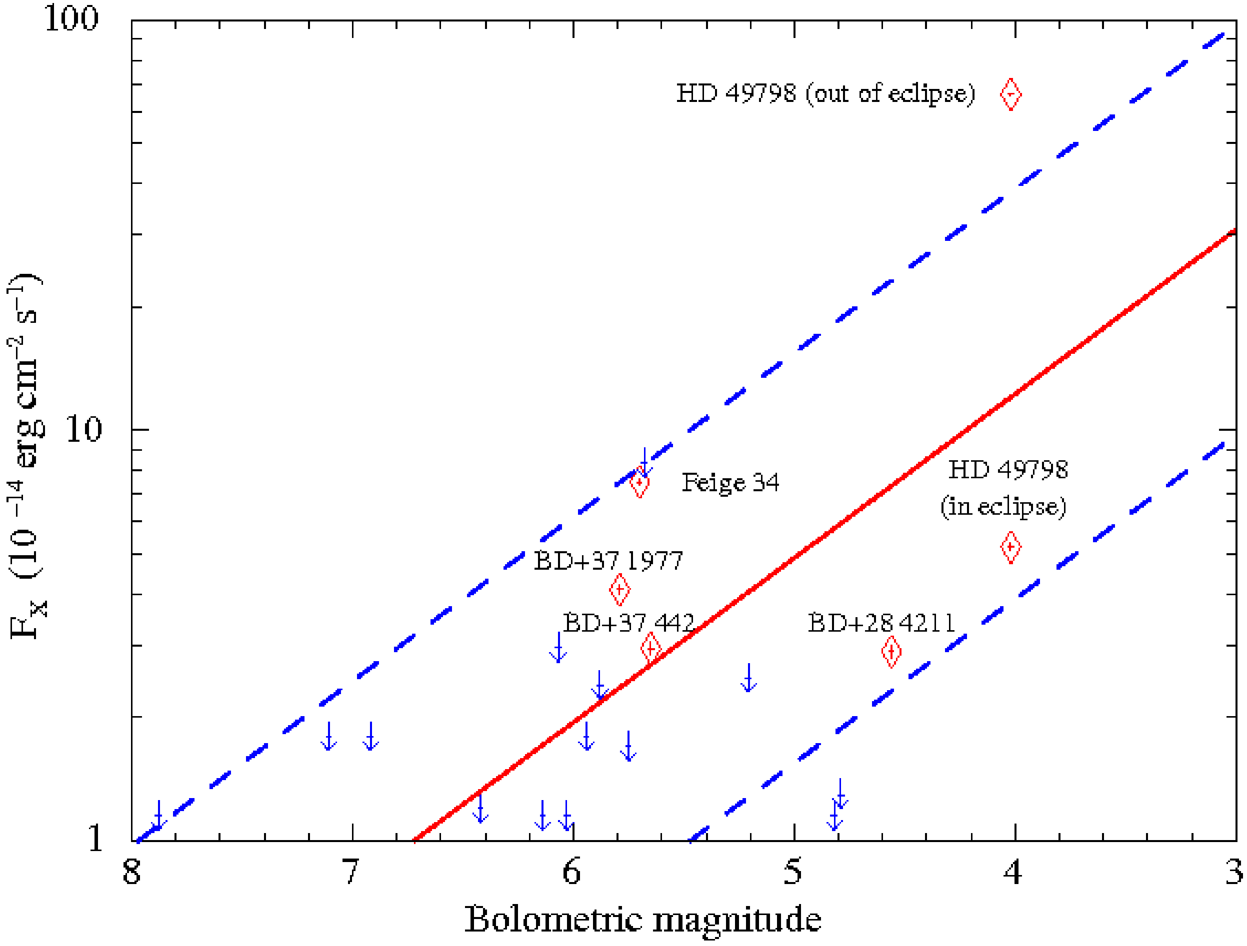
X-ray emission due to shocks in the stellar wind

(Upper Limit) X-ray flux of the observed sdO stars



$\log(L_x/L_{bol}) = -6.2$

$\log(L_x/L_{bol}) = -6.7$

$\log(L_x/L_{bol}) = -7.2$

intrinsic emission possible for almost all the observed sdO stars

Swift observations of binary sdB stars

Prediction of current stellar evolutionary models (e.g. Han et al., 2002; Han et al., 2003): most early-type subdwarf stars in close binary systems have compact companions (mainly WDs, but also NSs or BHs in some cases)

- **hypothesis difficult to test directly with optical observations**
- **X-ray observations can be a useful tool to identify systems containing a compact object (through either thermal emission from or matter accretion onto the compact-star surface)**

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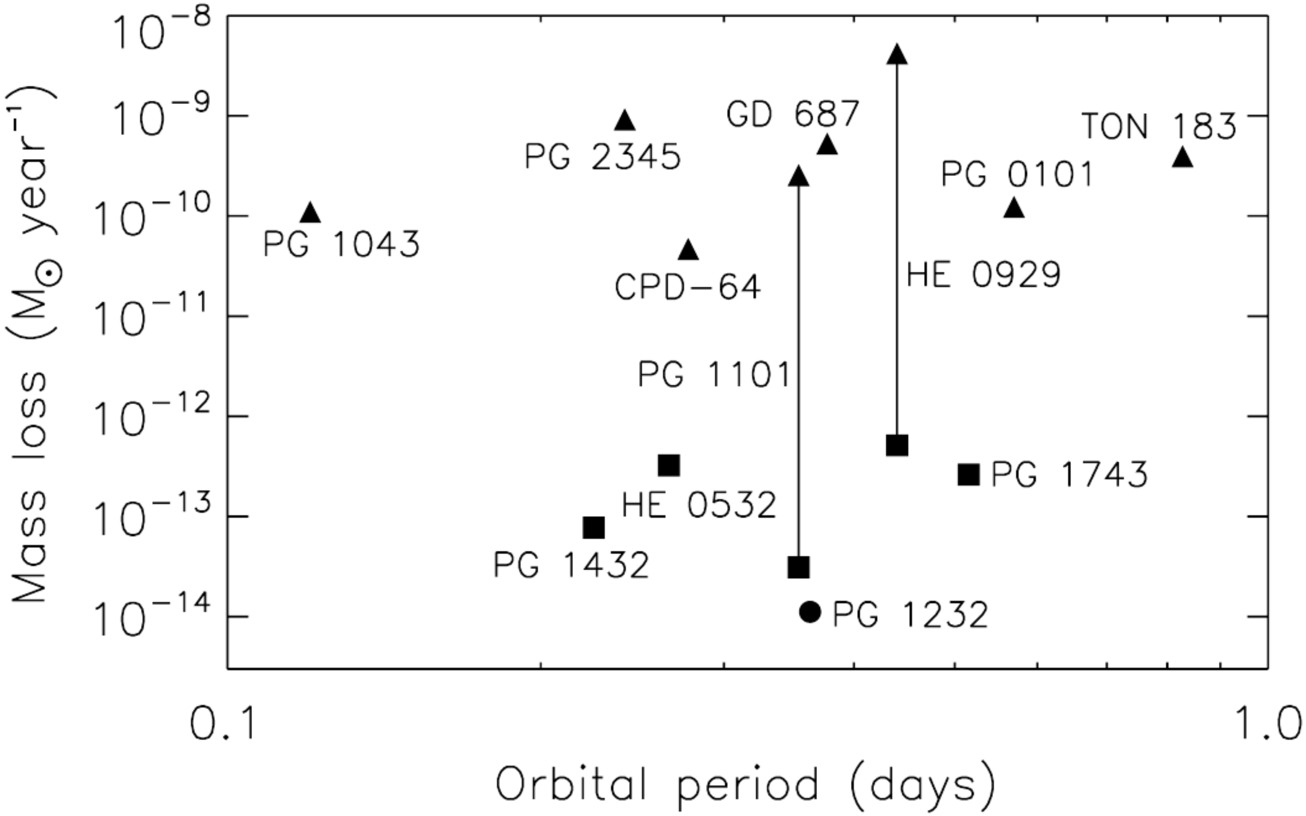
X-ray survey of a sample of candidate binary sdB star with a compact companion

Swift observations of binary sdB stars

- optical mass function + inclination (estimated assuming locked rotation) ⇒ lower limit on the companion mass
- lower limit exceeding the masses of late MS stars ⇒ compact companion (Geier et al., 2010)



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strong constraint on $\dot{M}_w$ for systems with NS/BH companion

Mereghetti et al., 2011, A&A, 536

XMM-Newton observation of CD -30° 11223

Eclipsing system sdB+WD (Vennes et al. 2012; Geier et al. 2013):

- **P_{orb} = 1.2 h (shortest P_{orb} for a sdB+WD system)**
- **$M_{WD} = 0.74\ M_{\odot}$**
- **$M_{sdB} = 0.47\ M_{\odot}$**

target observed for 50 ks by XMM

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source undetected, with luminosity upper limit = 1.5×10^{29} erg/s

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$\dot{M}_w < 3 \times 10^{-13}\ M_{\odot}$/y
much lower than for Swift sources

(Mereghetti et al., 2014, MNRAS, 441)

Conclusions

The first X-ray observations of hot-subdwarf stars have shown that:

1) sdO stars are an established class of X-ray sources, where X-ray emission can have two different origins:

- **accretion onto a compact companion**
- **internal shocks in the stellar wind**

2) sdB stars are undetected at X-rays so far:

- **no intrinsic emission for single stars (lower $\dot{M}_w$)**

Binary systems with compact objects are useful to:

- **confirm the evolutionary models**
- **probe the properties of the subdwarf wind**