The X-ray emission from hot subdwarf stars

N. La Palombara[1], Sandro Mereghetti[1], Paolo Esposito[2], Andrea Tiengo[2]
(1 - INAF / IASF Milano, 2 - IUSS Pavia)

The hot subdwarf stars

- subluminous blue stars that, in the *Hertzprung-Russell* diagram, lie between the main sequence (MS) and the white-dwarf (WD) sequence, at the blue end or beyond the horizontal branch (HB)
- progeny of low-mass (about 1 $M_\odot$) main-sequence stars that have lost most of their hydrogen envelopes during the red-giant phase, and are now burning their helium-rich core [1]
- found in both the thin and the thick discs, and in the bulge and halo populations of the Galaxy [2]
- spectroscopically classified as either sdB, with Teff < 38 kK, or sdO, with Teff > 38 kK
- sdB stars: homogeneous class, most helium poor
- sdO stars: heterogeneus group, with a wide range of effective temperatures (T_{eff} = 38-100 kK), helium abundances ($-3.5 < \log(N_{He}/N_H) < 3$), and surface gravities ($\log(g)$(cm s^{-2}) = 4-6.5)
  ⇒ He-rich or He-poor, luminous or compact
- usually investigated in optical and UV wavelength ranges, where they are bright

High sensitivity of the instruments on board *XMM-Newton* and *Chandra*
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possibility to study the X-ray emission associated to this type of stars, which can be either intrinsic or due to accretion onto a compact companion star

No sdB star detected at X-ray up to now, but X-ray emission observed for 5 sdO stars:
- 3 luminous He-rich: HD 49798 [3], BD+37° 442 [4], BD+37° 1977 [5]
- 2 compact He-poor: Feige 34 [6], BD+28° 4211 [7]

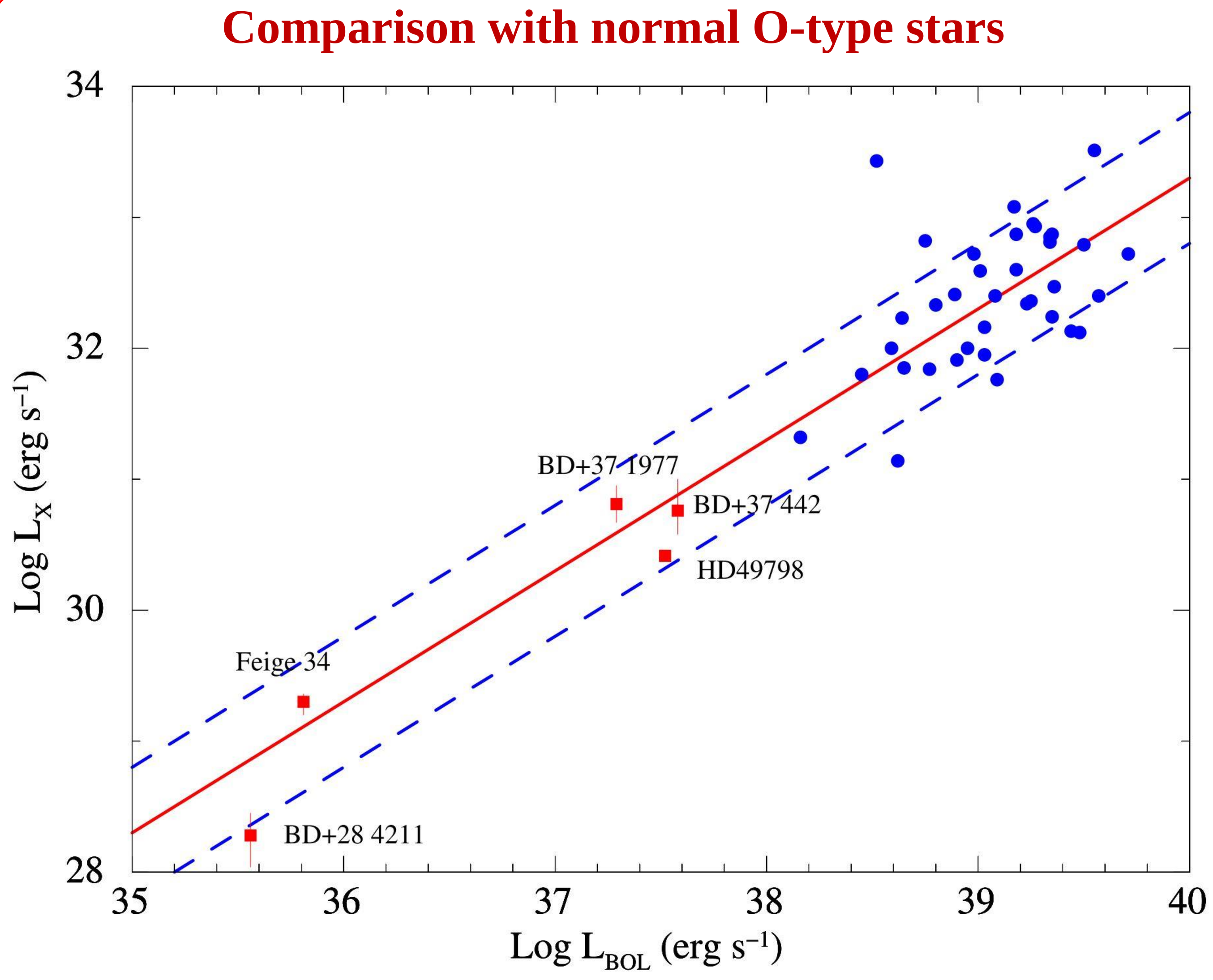
All but BD+28° 4211 spectroscopically investigated with *XMM-Newton*

The five sdO stars detected at X-rays

Parameter	HD49798	BD+37° 442	BD+37° 1977	Feige 34	BD+28° 4211
Spectral type	sdO6	sdO9	sdO5	sdOp	sdO2
log g (cm s^{-2})	4.35	4.00±0.25	4.00	5.99	$6.2^{+0.3}_{-0.2}$
T_{eff} (kK)	46.5	48	48	62.5	82±5
U	6.76	8.57	8.67	9.61	8.92
B	8.02	9.73	9.93	10.91	10.25
V	8.29	10.01	10.17	11.14	10.58
d (pc)	500^{+17}_{-16}	1230^{+320}_{-220}	1200^{+180}_{-140}	226±5	$113.3^{+1.6}_{-1.4}$
L_{bol} ($L_\odot$)	8300	9500	4900	160	90
v_W (km s^{-1})	1200	2000	2000	-	-
log $\dot{M}_W$ ($M_\odot$ yr^{-1})	-9.2	-8.5	-8.2	-10	-
f_X (x10^{-14} erg cm^{-2} s^{-1})	9.2±0.7	$3.4^{+0.3}_{-0.1}$	$4.0^{+0.2}_{-0.3}$	$3.4^{+0.5}_{-0.4}$	$1.3^{+0.6}_{-0.5}$
L_X (x10^{30} erg s^{-1})	2.6±0.2	$5.8^{+4.2}_{-2.0}$	$6.5^{+2.5}_{-1.8}$	$0.20^{+0.03}_{-0.04}$	$0.019^{+0.009}_{-0.008}$
$\log(L_X/L_{bol})$	-7.09±0.03	$-6.80^{+0.04}_{-0.01}$	$-6.46^{+0.02}_{-0.03}$	-6.48±0.06	$-7.28^{+0.17}_{-0.23}$
X_{He} (mass fraction)	0.78	0.96	0.96	0.06	0.28

Comparison of luminous He-rich stars with compact He-poor:
- different chemical composition
- lower effective temperature
- much lower surface gravity
- much higher mass-loss rate
- much higher X-ray and bolometric luminosity

Comparison with normal O-type stars



X-ray versus bolometric luminosity for the five sdO stars detected in X-rays (red squares). The blue circles show for comparison the O stars detected in the *ROSAT All Sky Survey* [8]. The continuous red line represents the best-fit relation (L_X/L_{bol} = 10$^{-6.7}$) for the main-sequence early-type stars [9], while the area between the two blue lines (L_X/L_{bol} = 10$^{-6.2}$ and L_X/L_{bol} = 10$^{-7.2}$, respectively) corresponds to the dispersion of this relation

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- Luminosities of the sdO stars consistent with an extrapolation of the average relation $L_X/L_{bol} = 10^{-6.7\pm0.5}$ followed by the more luminous O-type stars
- X-ray emission in normal O-type stars attributed to turbulence phenomena and shock episodes in the strong radiatively-driven stellar winds, with a clumped structure and mass-loss rates up to 10^{-5} $M_\odot$/yr [10,11]
- sdO stars with significantly lower luminosities ($\log(L_{bol}/L_\odot)$ = 4 instead of 5-6) but with mass-loss rates up to 10^{-8} $M_\odot$/yr

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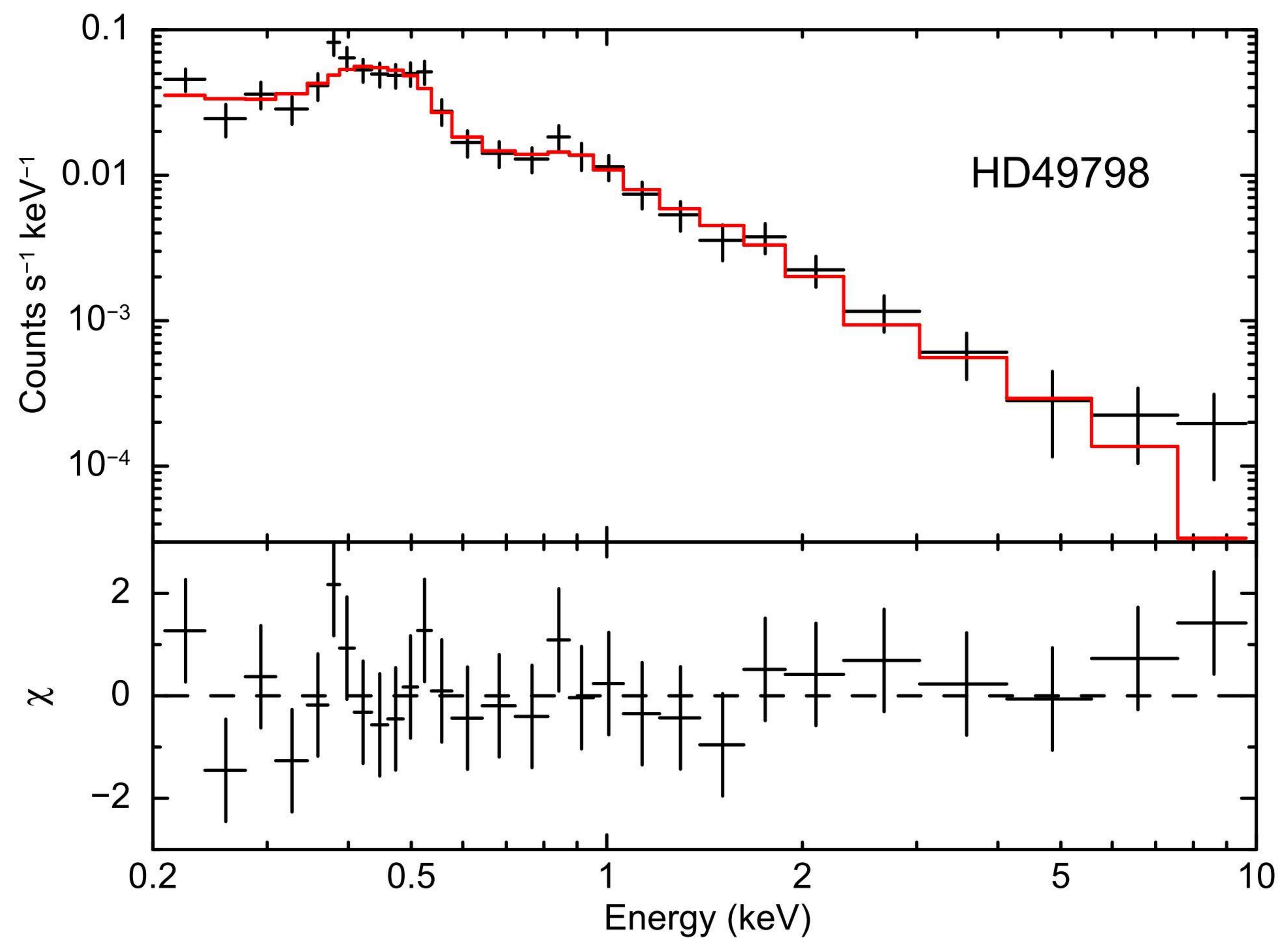
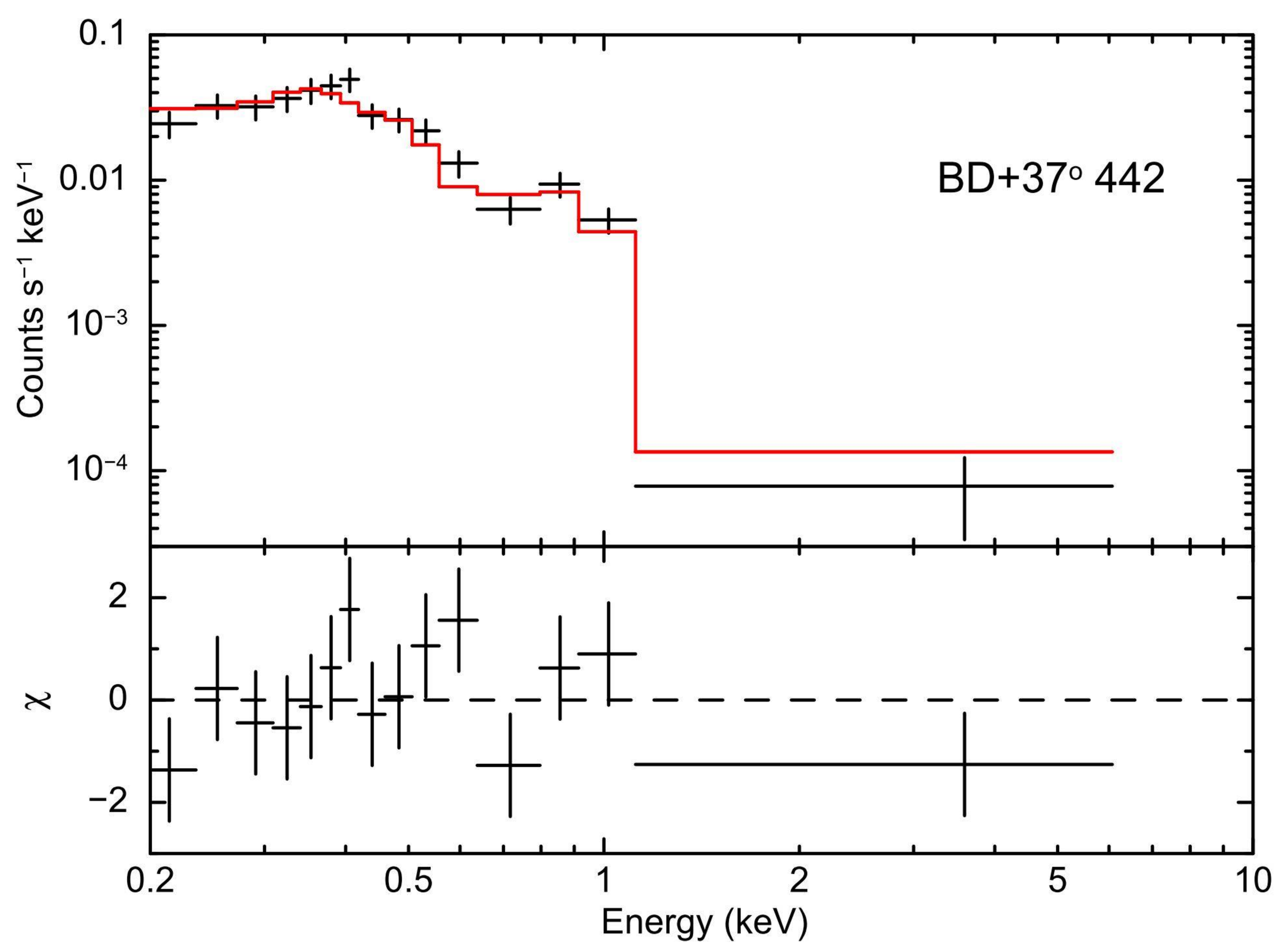
possibility that stellar wind of sdO stars can produce X-ray emitting shocks, as in more luminous O-type stars

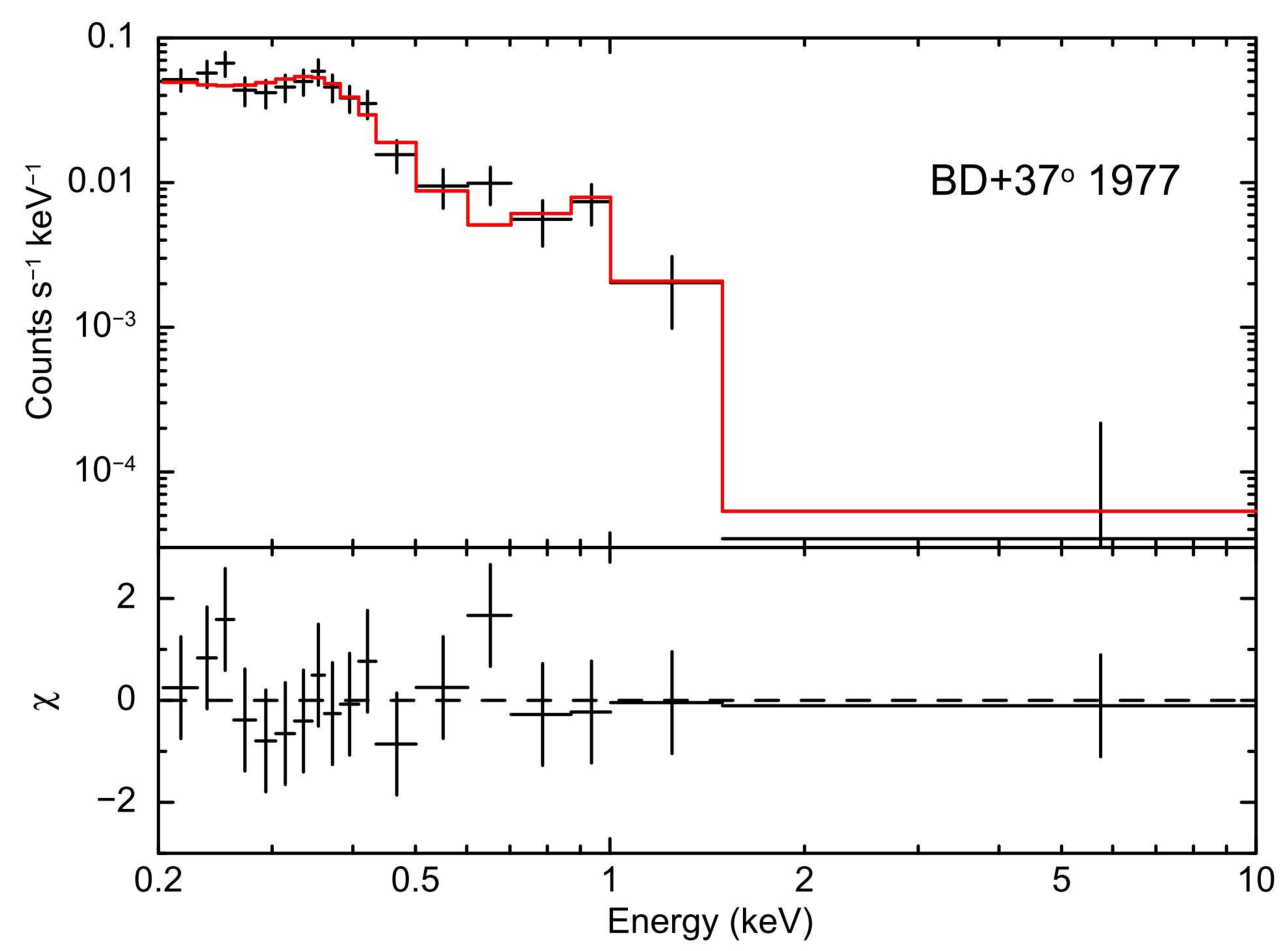
EPIC spectra of the sdO stars

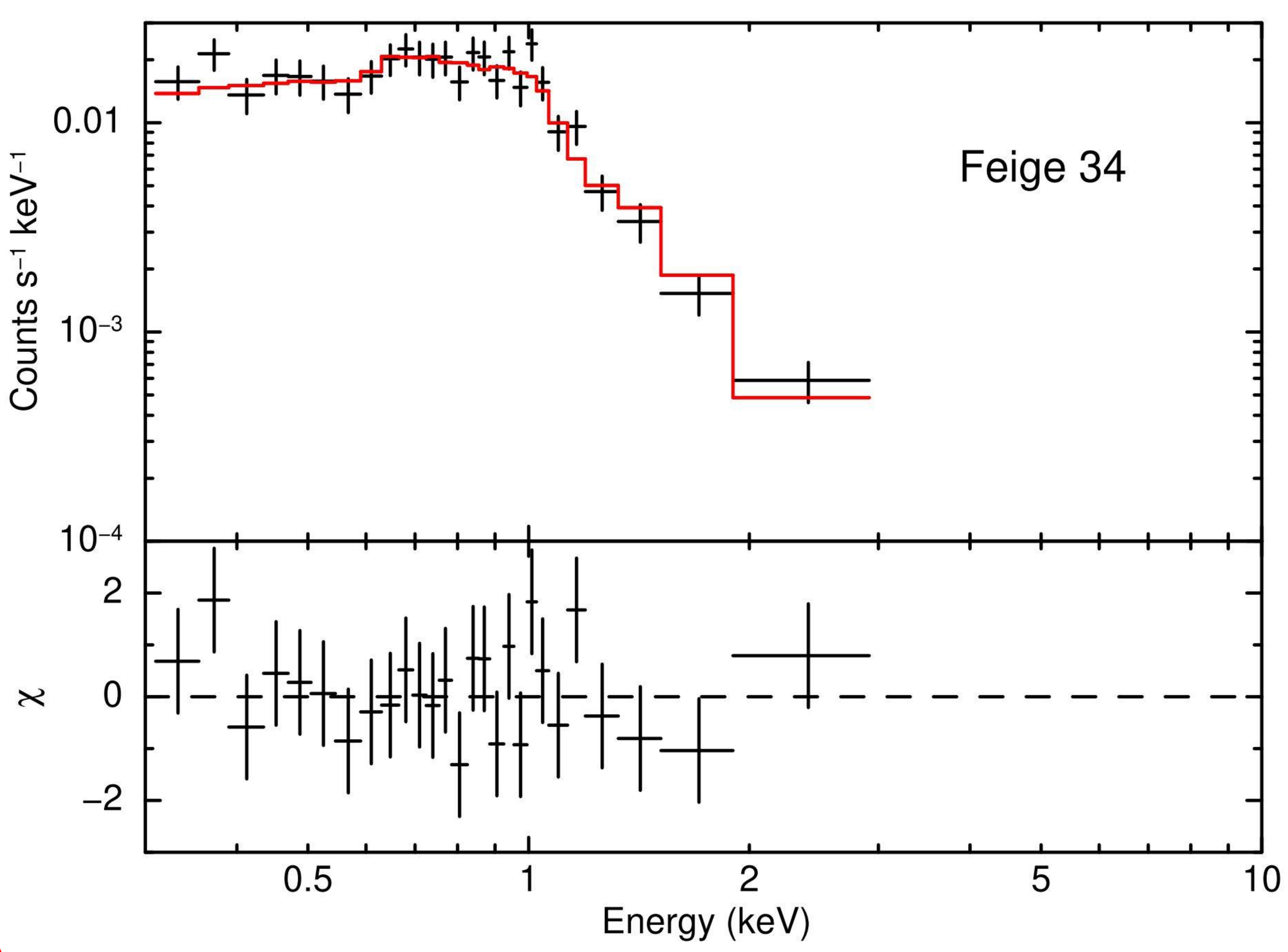
In all cases the observed spectrum can be described as the sum of two or three thermal plasma models (APEC) with different temperatures:

Parameter	HD49798	BD+37° 442	BD+37° 1977	Feige 34
kT_1 (keV)	0.11	0.11	0.13	0.30
kT_2 (keV)	0.57	0.65	0.79	1.10
kT_3 (keV)	4	-	-	-









Summary of X-ray spectral analysis

Sum of thermal plasma models with different temperatures: emission model commonly used to describe the X-ray spectrum of normal O-type stars

BUT

for the luminous He-rich stars:
- spectral fit with a multi-temperature thermal plasma model obtained considering the specific abundance of each element obtained from the spectroscopic analysis in the optical / UV domain

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consistent with the hypothesis that the observed X-ray emission originates from the hot plasma in the stellar wind

for Feige 34:
- acceptable fit only possible with subsolar metallicity, with the relative elemental abundances kept solar
- unsuccessful spectral fit with a multi-temperature thermal plasma model assuming the specific elemental abundances obtained from optical/UV data

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need of an alternative hypothesis

Alternative hypothesis for Feige 34

X-ray emission (or at least part of it) due to the late-type companion of M0 stellar type (inferred from the IR excess in the spectral energy distribution [12])
- Late-type MS stars: a well-known class of X-ray sources since the epoch of the *Einstein* satellite [13,14]
- X-ray emission due to the effect of magnetic heating of the coronal plasma (at temperatures T > 1 MK) [15,16]
- *Einstein* results: spectra of most stars well described with a two-temperature (2T) thermal-plasma model with kT_1 = 0.22 keV and kT_2 = 1.37 keV [17]
- *XMM-Newton Bright Serendipitous Survey* (XBSS): spectra of moderately active K and M-type stars described with a 2T model with kT_1 = 0.32 keV and kT_2 = 0.98 keV [18]

For Feige 34:
- Spectrum: 2T thermal-plasma model with kT_1 = 0.3 keV and kT_2 = 1.1 keV
- L_X = 2 x 10^{29} erg s^{-1} ⇒ consistent with X-ray luminosity of young M0 stars [19,20,21]
- L_X /L_{bol} = 10$^{-3.1}$ ⇒ consistent with X-ray-to-bolometric ratio of young M0 stars [22,23,24]

Conclusions and perspectives

Conclusions:
- No acceptable spectral fit when the proper elemental abundances of Feige 34 are taken into account (contrary to the case of luminous He-rich sdO stars)
- Presence of a late-type companion star of M0 spectral type suggested by the IR excess observed in the SED of Feige 34
- Properties of the observed X-ray emission consistent with those typical of young M-type stars
- sdO star Feige 67, very similar to Feige 34, undetected in our programme of snapshot observations of sdO stars performed with Chandra [7]

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our results favour the possibility that
the main source of the observed X-ray emission is the companion late-type star
(although we cannot exclude a contribution from the sdO star)

Perspectives:
- to perform a follow-up observation with *XMM-Newton* of also BD+28° 4211
- to use the *Gaia* results for the selection and observation of possible X-ray emitting sdO stars [25]
  - > 600 candidate sdO/He-sdO stars
  - ~ 60 candidate sdO/He-sdO stars at d < 1 kpc

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