PHOTOIONIZATION INSTABILITY OF WINDS IN X-RAY BINARIES

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SEVENTH FRAMEWORK PROGRAMME

STRONGGRAVITY
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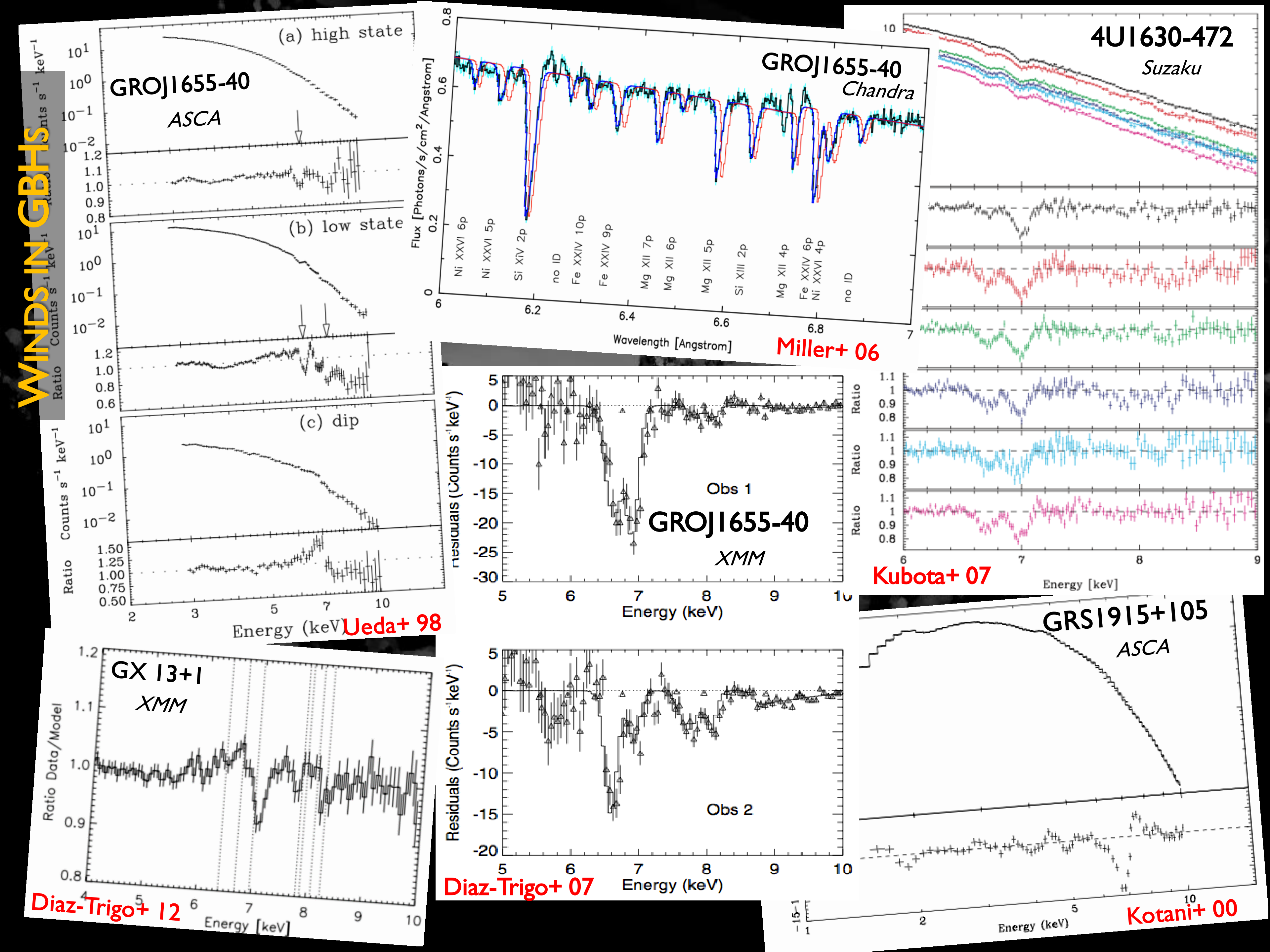

WINDS IN GBHs
GROJ1655-40
ASCA
(a) high state
(b) low state
(c) dip
Counts s^{-1} keV^{-1}
Ratio
Energy (keV)
Ueda+ 98
GROJ1655-40
Chandra
Flux [Photons/s/cm^2/Angstrom]
Wavelength [Angstrom]
Ni XXVI 6p
Ni XXVI 5p
Si XIV 2p
no ID
Fe XXIV 10p
Fe XXIV 9p
Mg XII 7p
Mg XII 6p
Mg XII 5p
Si XIII 2p
Mg XII 4p
Fe XXIV 6p
Ni XXVI 4p
no ID
Miller+ 06
4U1630-472
Suzaku
Ratio
Energy [keV]
Kubota+ 07
GROJ1655-40
XMM
Obs 1
Obs 2
Residuals (Counts s^{-1} keV^{-1})
Energy (keV)
Diaz-Trigo+ 07
GX 13+1
XMM
Ratio Data/Model
Energy [keV]
Diaz-Trigo+ 12
GRS1915+105
ASCA
Energy (keV)
Kotani+ 00

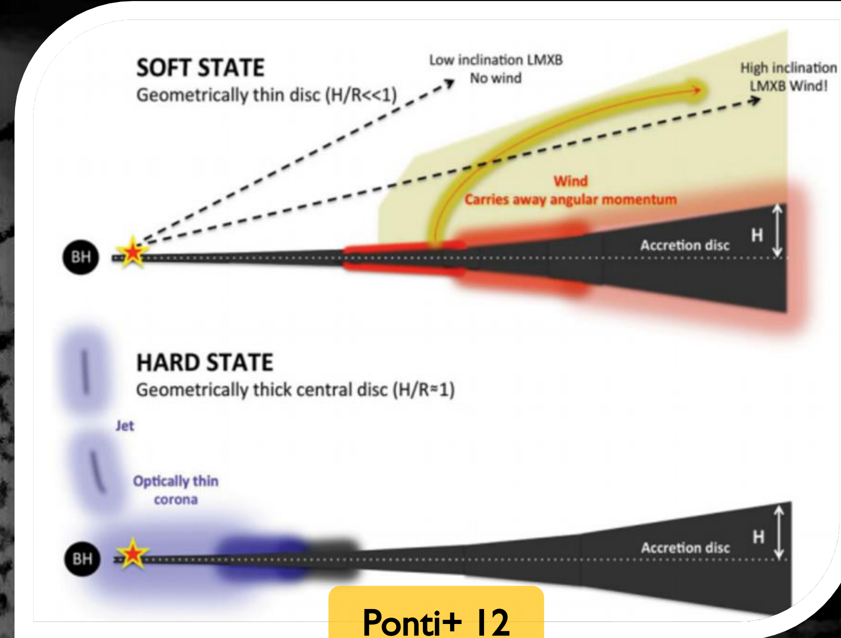
WINDS IN GBHs

Equatorial geometry

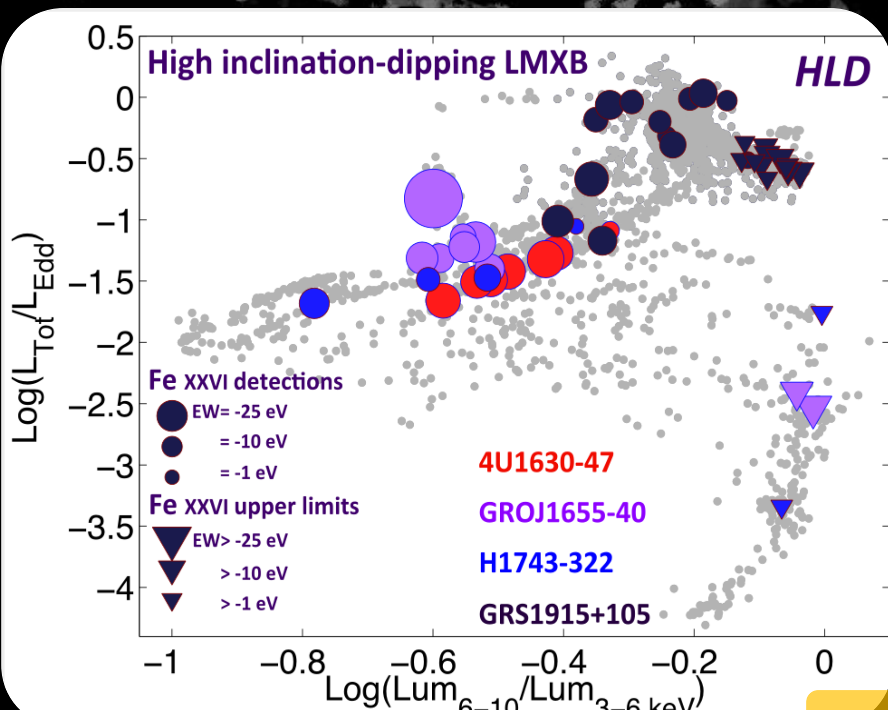
Ubiquitous in soft state (jet off)

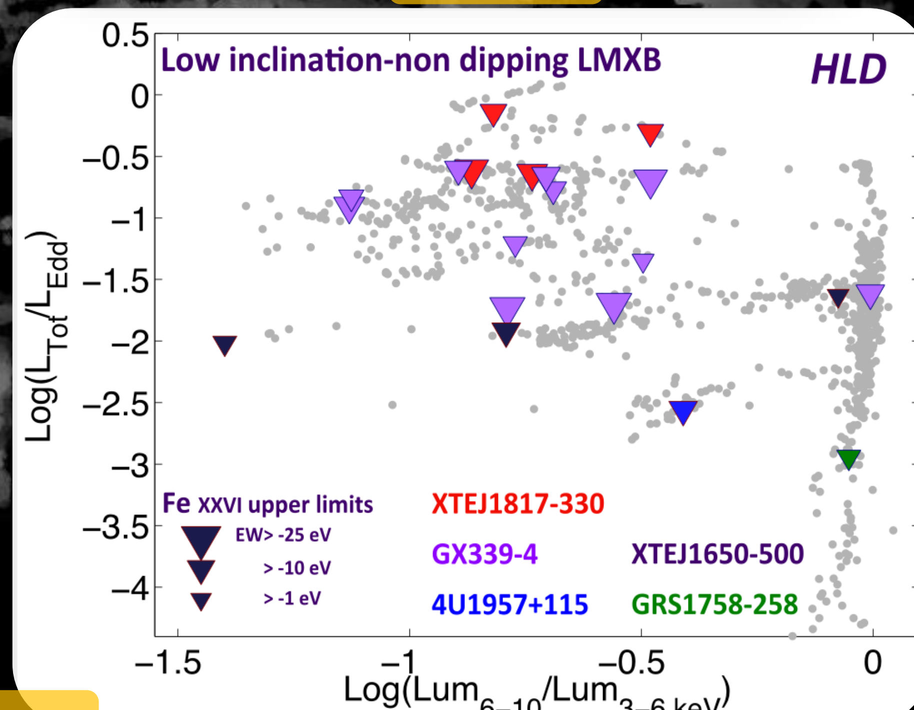
Absent in hard state (jet on)

Outflow velocities $\sim 10^2 - 10^3$ km s^{-1}



Ponti+ 12





Ponti+ 12

Winds in NS LMXBs

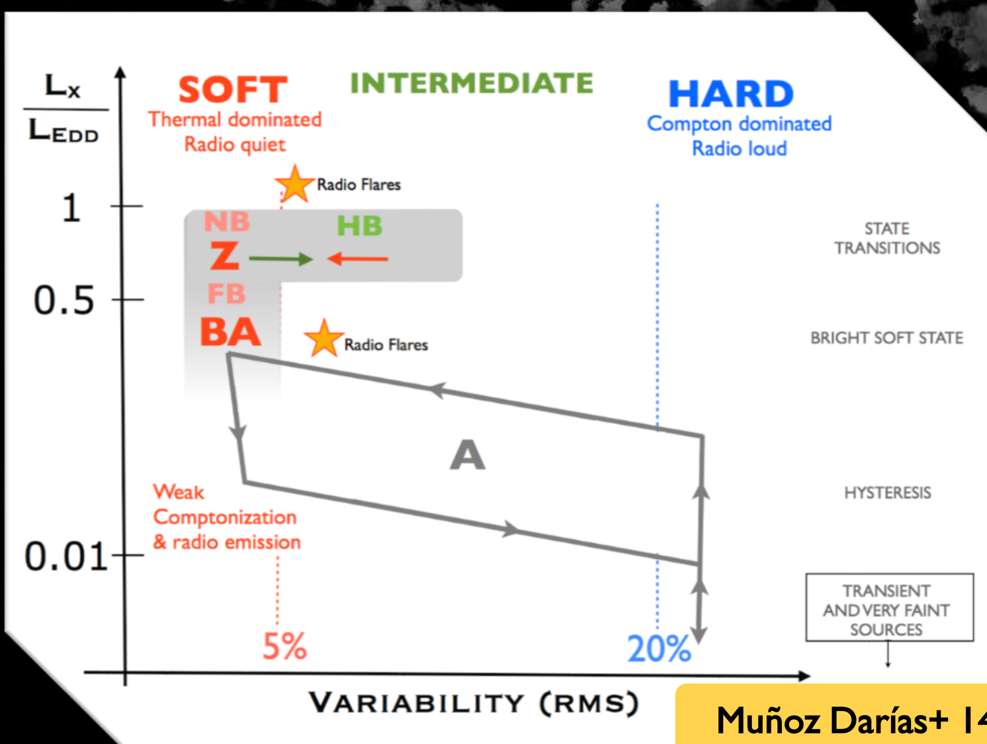
Díaz Trigo & Boirin 16

Source	P_{orb}	N_H^{Gal} [10^{21} cm^{-2}]	NS	Dips	i (°)	$\log \xi$ < 3	≥ 3	Flow
XB 1916–053	0.83 h	2.3	NS	D		x	x	atm
1A 1744–361	1.62 h	3.1	NS	D			x	atm
4U 1323–62	2.93 h	12	NS	D			x	no grat.
EXO 0748–676	3.82 h	1.0	NS	D		x	x	atm
XB 1254–690	3.93 h	2.0	NS	D			x	atm
MXB 1658–298	7.11 h	1.9	NS	D		x	x	atm
XTE J1650–500	7.63 h	4.2			> 50	?[a]	?[b]	?[c]
AX J1745.6-2901	8.4 h	12	NS	D			x	no grat.
MAXI J1305–704	9.74 h[d]	1.9		D		x		in
X 1624–490	20.89 h	20	NS	D			x	atm
IGR J17480–2446	21.27 h[e]	6.5	NS	D			x	out
GX 339–4	1.76 d	3.6			> 45[f]	x		?[g]
GRO J1655–40	2.62 d	5.2		D			x	out
Cir X–1	16.6 d	16	NS	D		x	x	out
GX 13+1	24.06 d	13	NS	D			x	out

Equatorial geometry

Outflow velocities:
$\sim 10^2 - 10^3$ km s^{-1} (*winds*)
~ 0 km s^{-1} (*disc atmospheres*)

State (jet) connection?

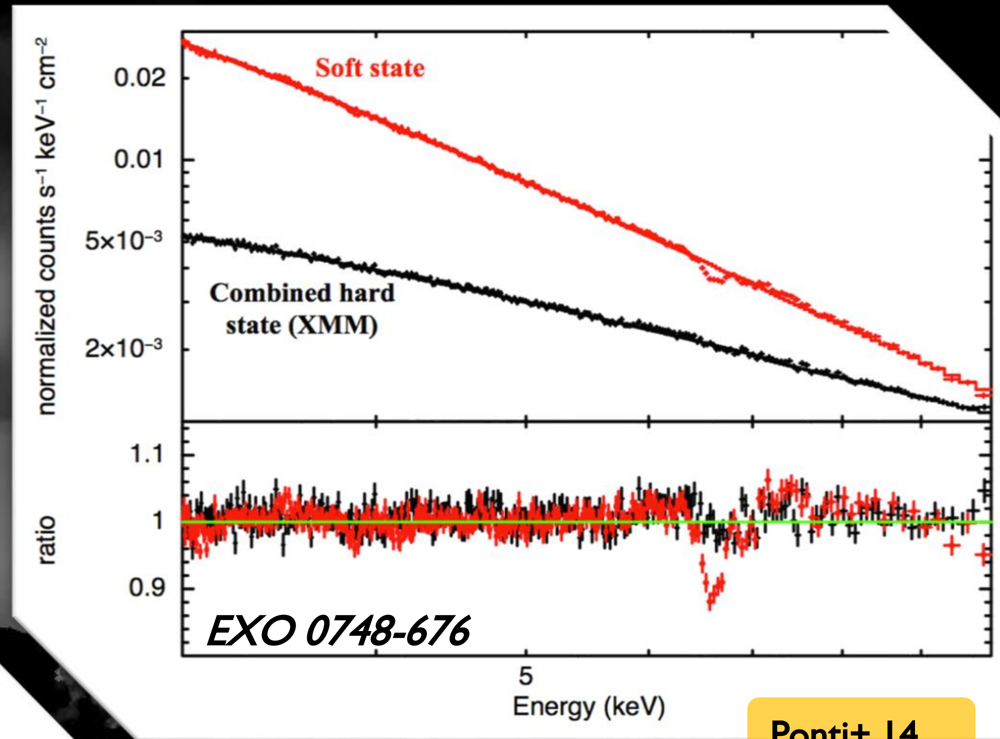


Muñoz Darías+ 14

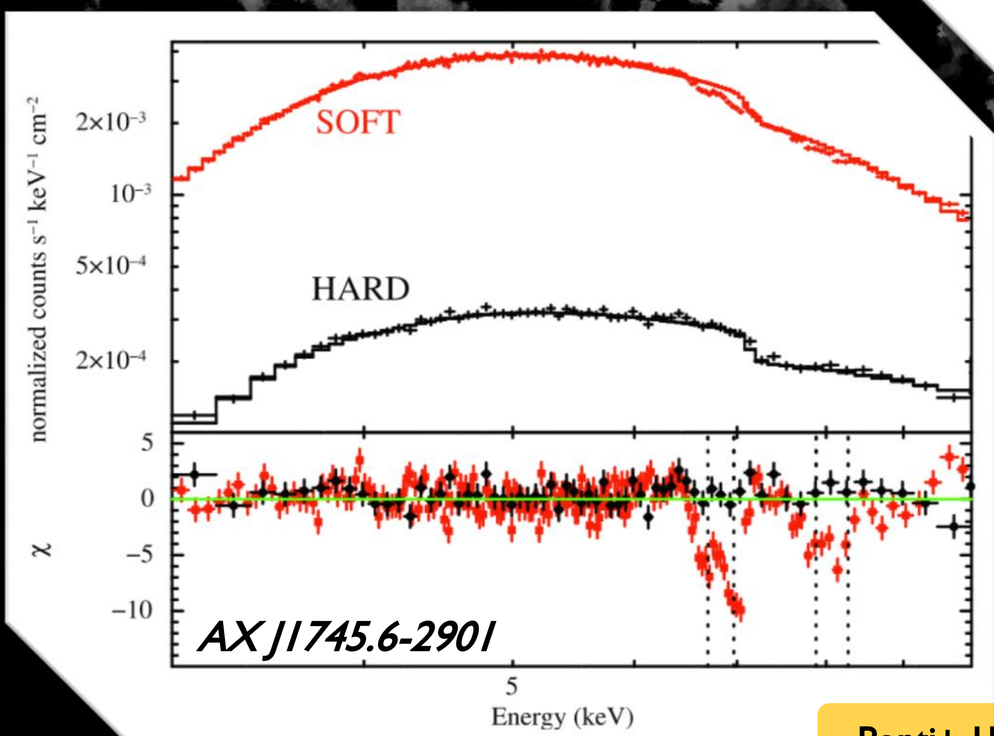
NSs LMXBs fit in the canonical state scheme of BH systems: variability is the key for classification

Only two sources have extensive monitoring campaigns

In the two best monitored NS systems, the wind is present only in the soft states, and always disappears in the hard states



Ponti+ 14



Ponti+ 15

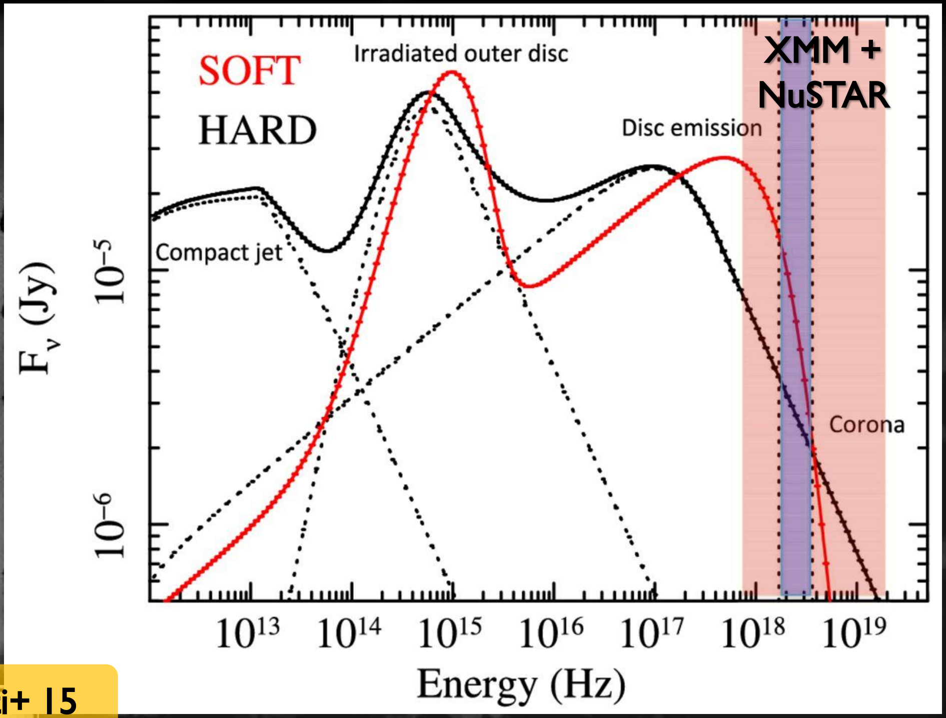
The connection between Fe K absorption and states is a general characteristic of accreting sources

AX J1745.6-2901

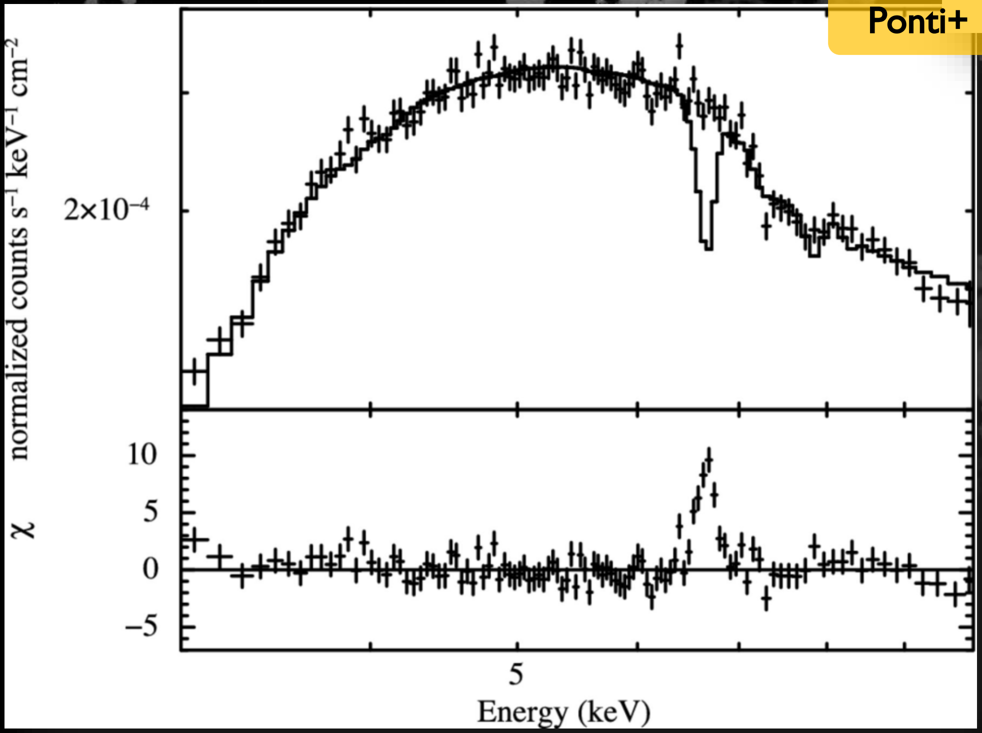
The SEDs are modelled by a multi-colour disc emission (dominant in the soft state) and a powerlaw arising from Comptonization of its seed photons (dominant in the hard state)

The optical and infrared band of the SEDs are due to emission from the irradiated disc

The contribution at radio-to-infrared frequencies from a compact jet is only added in the hard state



Ponti+ 15



If the wind retains its physical properties ($nr^2 = const$) in the hard states, it would remain detectable with the available observations

Fe K absorption does not disappear because of over-ionization in the hard state

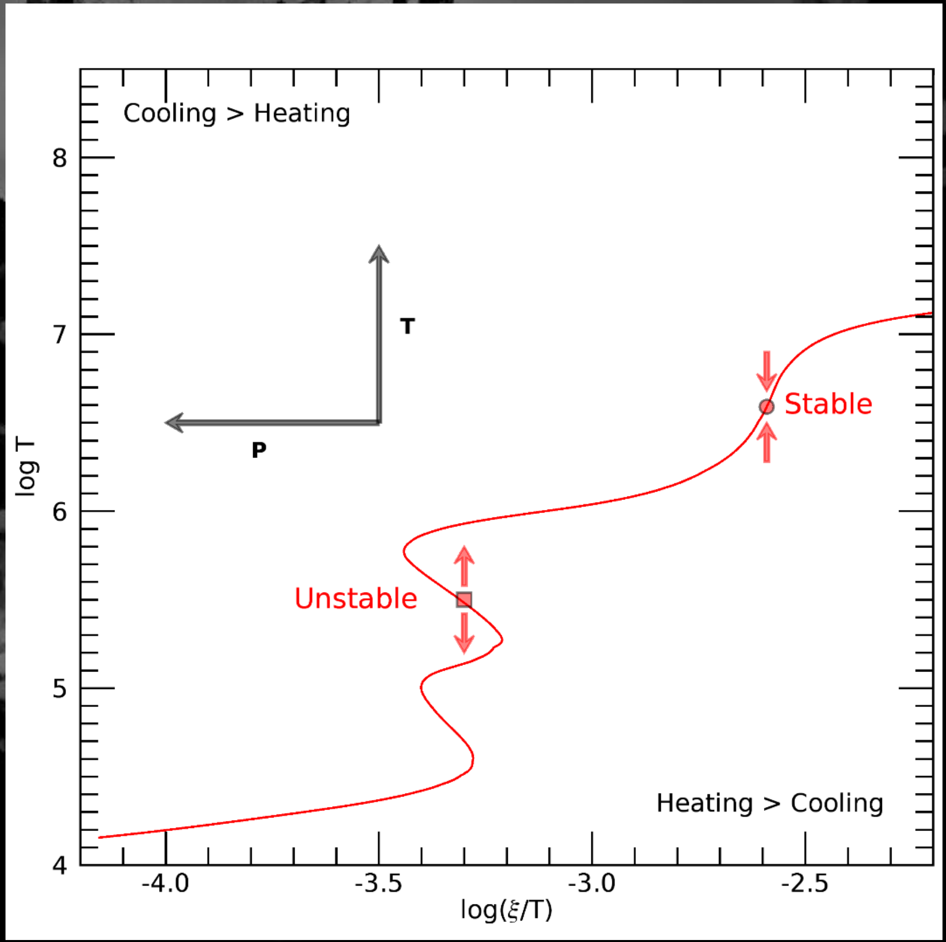
A photoionised gas will reach an equilibrium at a ionisation parameter $\xi = L/nr^2$ and temperature T, as a consequence of competing heating and cooling processes depending on its physical and chemical properties, and the illuminating radiation field

These equilibrium states can be drawn in a stability curve, where

$$\frac{\xi}{T} \sim \frac{L}{nTr^2} \sim \frac{1}{p}$$

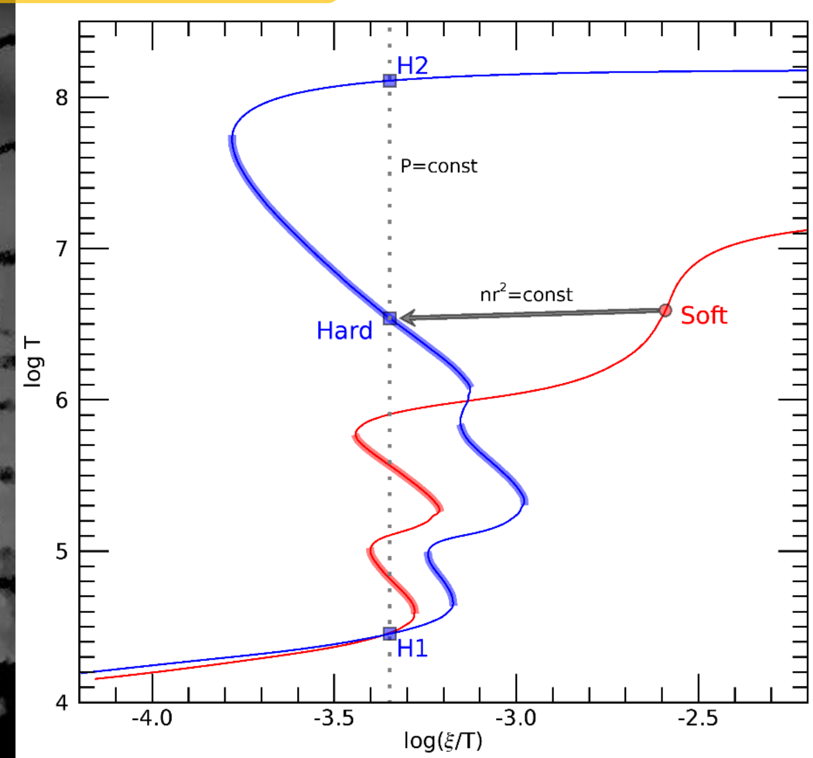
An equilibrium state where the slope of the curve is positive is thermally stable

If the slope of the stability curve is negative, the state is thermally unstable and is likely to collapse into a different stable equilibrium state

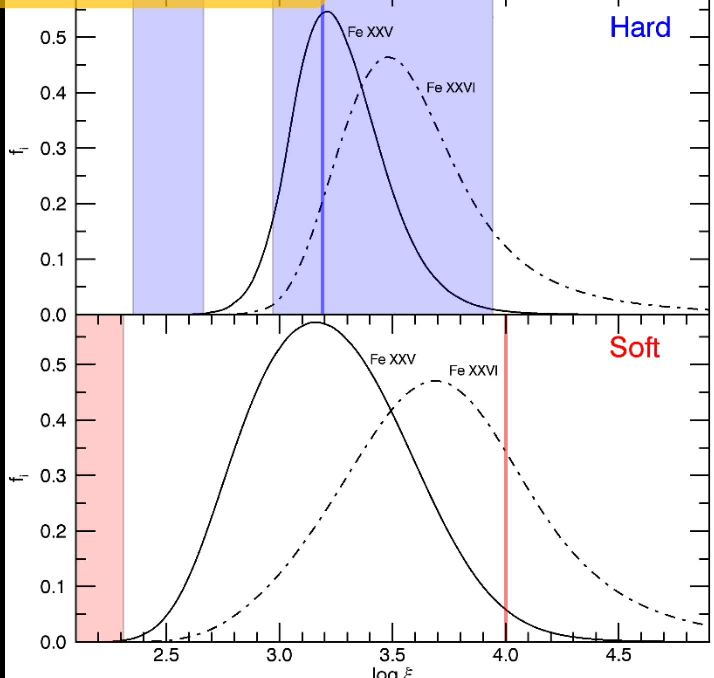


The wind observed in the soft state lies in a thermally stable branch of the stability curve
If the physical properties of the wind do not change in the hard state ($nr^2 = cost$), the different illuminating SED dramatically changes the curve, and the gas would now be in a thermally unstable branch
(see also Chakravorty+ 2013, 2016; Higginbottom+ 2015, 2016 ; Dyda+ 2016)

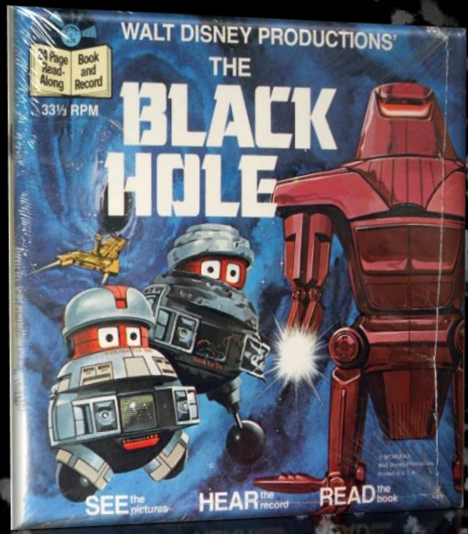
Bianchi+ in prep.



Bianchi+ in prep.



All the ionisation parameters dominated by Fe XXV and Fe XXVI are in a stable branch of the stability curve in the soft state, while they are all in unstable branches for the hard state: **the absorption features are expected to disappear**, as observed



Toy Model

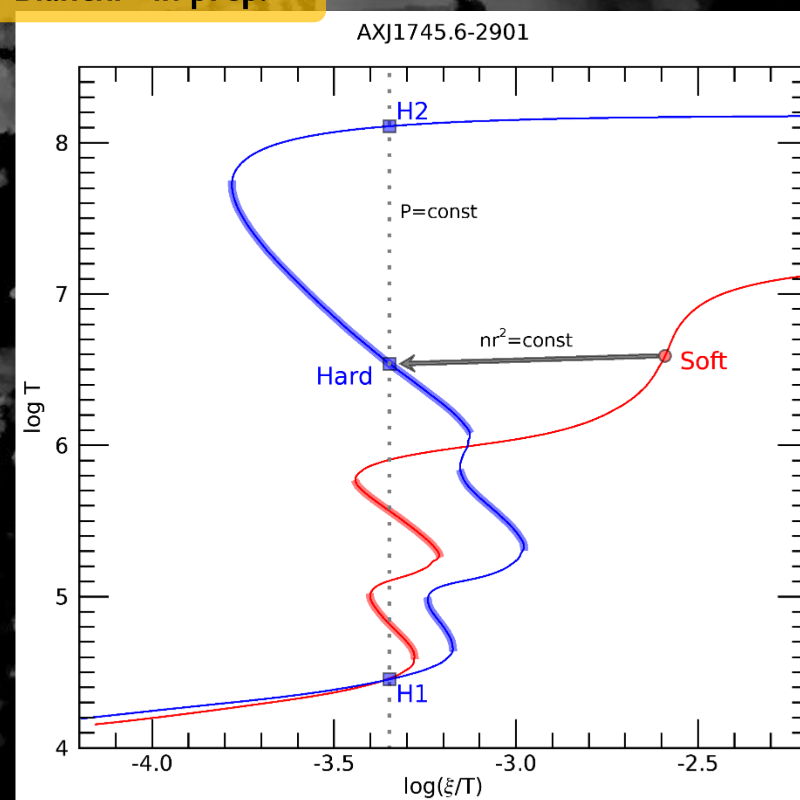
Static cloud ($v = 0$) at distance r, not replenished

After the transition from the soft to the hard state, the gas instantaneously moves to the new equilibrium state (recombination, ionization and thermal time-scales are less than tens of seconds): n and r can be assumed constant

The new equilibrium state is unstable, and any perturbation will make the gas migrate to a stable solution in few hours (dynamical time-scale)

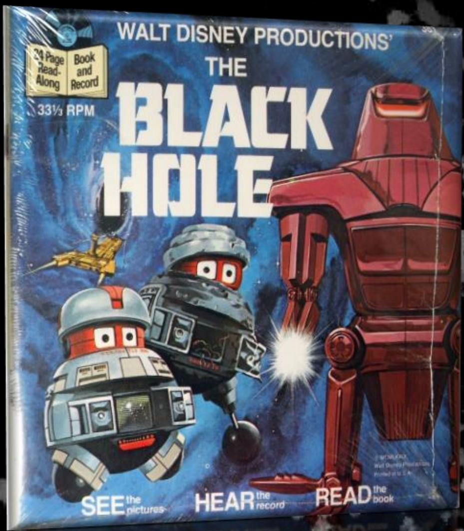
Assuming that r will not change in this time-scale, the new stable equilibrium will be characterized by different values of T, ξ, and n

Bianchi+ in prep.



Toy Model

Static cloud ($v = 0$) at distance r, not replenished

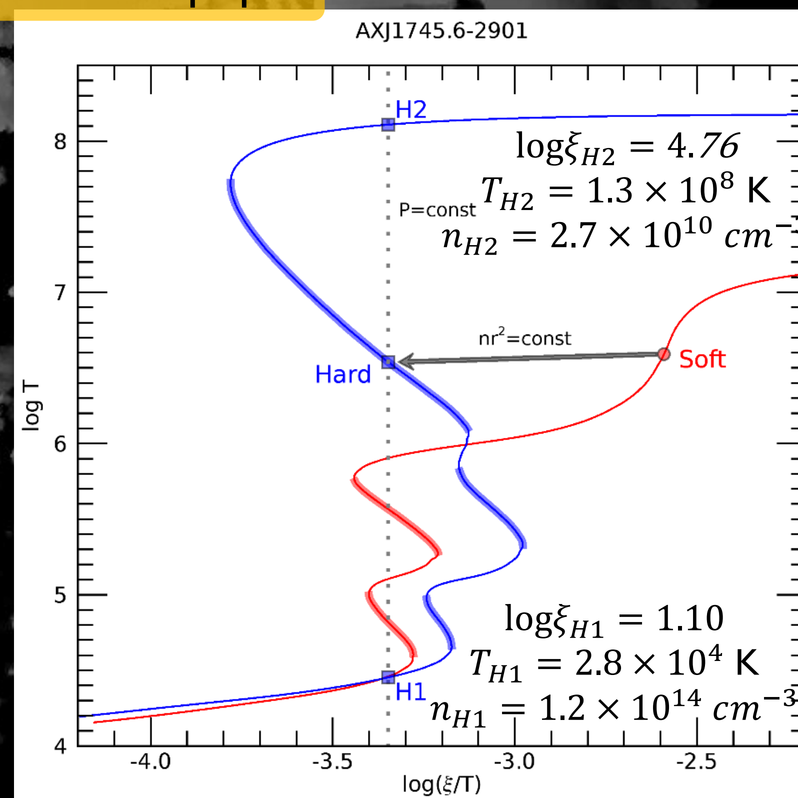


In the hard state, several phases of the gas can coexist in pressure equilibrium

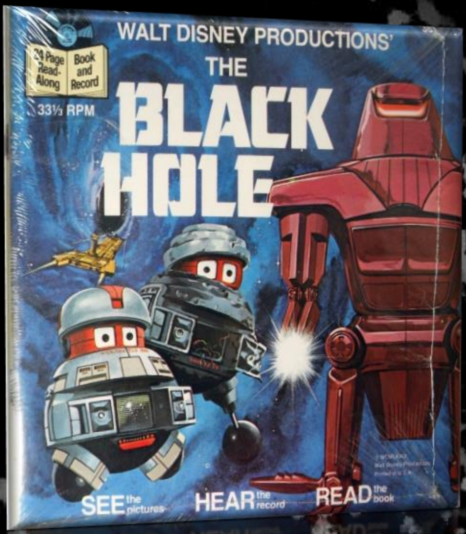
For an isobaric displacement from the initial unstable solution, we have **two stable solutions**:

$H1$ (cold, high density) and $H2$ (hot, low density)

Bianchi+ in prep.



There is no easy way to predict which stable solution the plasma will choose: hot and cold clumps can coexist adopting an unknown geometry, or a hot, dilute medium may confine cold, denser clumps, and a part of the cold phase may continuously evaporate to the hot phase and vice-versa in a dynamical time-scale



Toy Model

Static cloud ($v = 0$) at distance r, not replenished

The hot phase has a very high ionization parameter, corresponding to negligible fractions of Fe XXV and Fe XXVI: **this component of the wind will become unobservable**

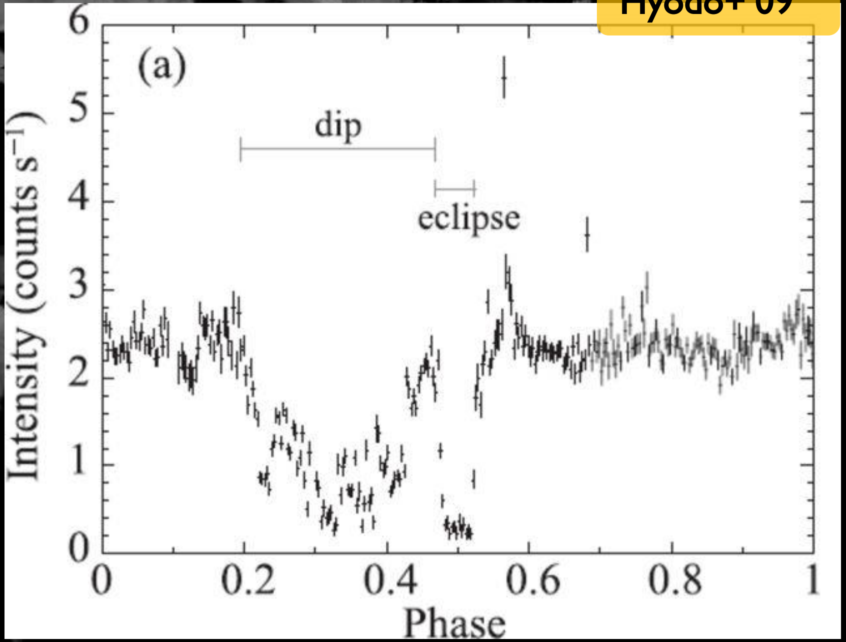
The cold phase is substantially neutral

If $logN_H = 23.5$ (as for the wind in the soft state), this would absorb the X-ray emission up to $\sim$3 keV

Incidentally, this value is the same as the neutral column density observed in AXJ both in the hard and in the soft state, so it would be only observed as a change of the persistent neutral absorption

Any connection with the dips?

Hyodo+ 09



From a Toy Model to the 'Real' World

A simple toy model explains the disappearance of Fe absorption in the hard state because of instability, but:

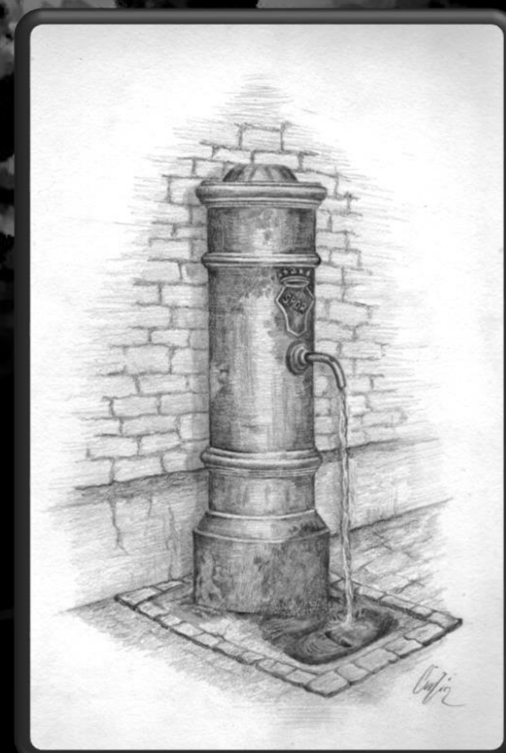
-A cold phase in the hard state is expected: is it observed? Dips are also observed in the soft state

-A static disk atmosphere is still in agreement with data in AXJ, but in other sources outflowing winds need a continuous replenishment

-With the same assumptions, we should come back to the initial wind passing from hard to soft (as observed). The hot phase will remain transparent, while the cold phase would not be ionized enough to produce Fe absorption

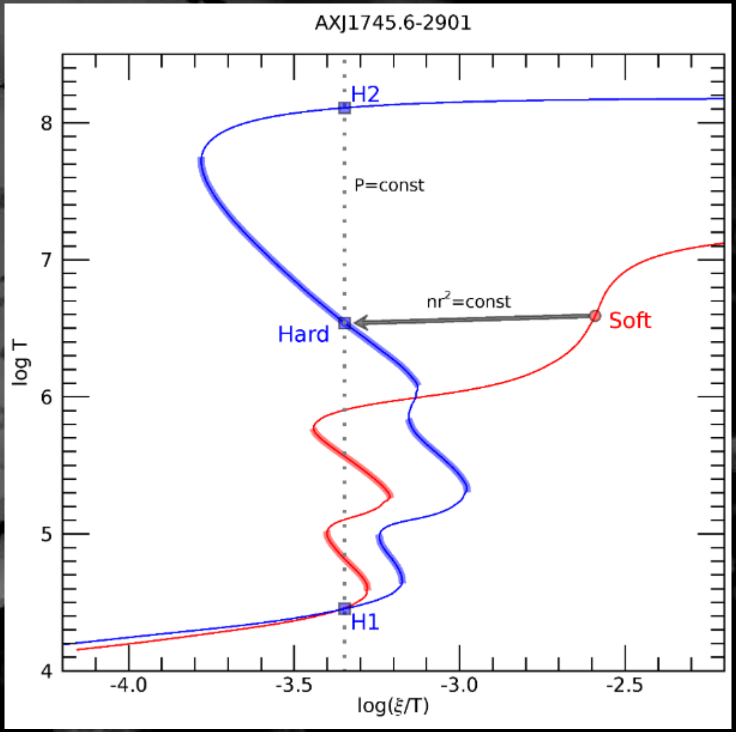
A 'fountain' is needed to re-launch the wind!

The launching mechanism must change from the soft to the hard state (see e.g. Chakravorty+ 2016)



PHOTOIONIZATION INSTABILITY OF WINDS IN X-RAY BINARIES (IN A SLIDE)

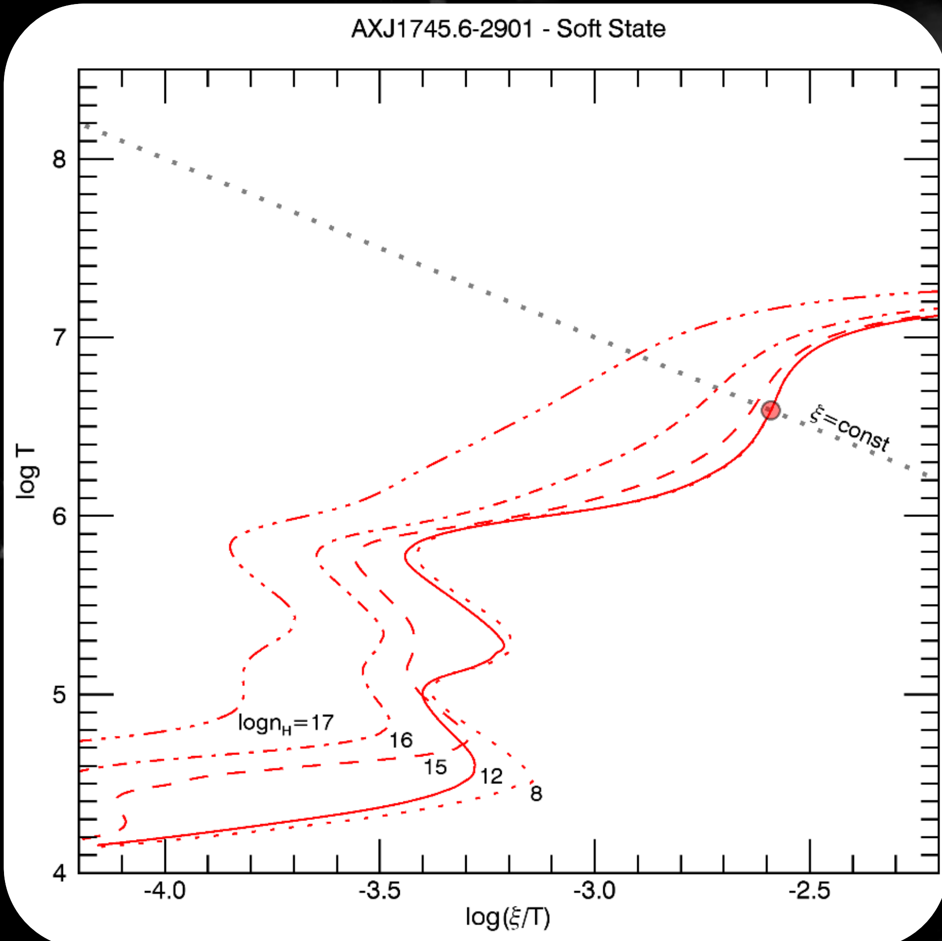
- ✓ Equatorial winds are ubiquitous in LMXBs
- ✓ The connection between Fe K absorption and states is a general characteristic of accreting sources
  - ✓ Fe K absorption does not disappear because of over-ionization in the hard state
  - ✓ **A simple toy model explains the disappearance of Fe absorption in the hard state because of photoionization instability**

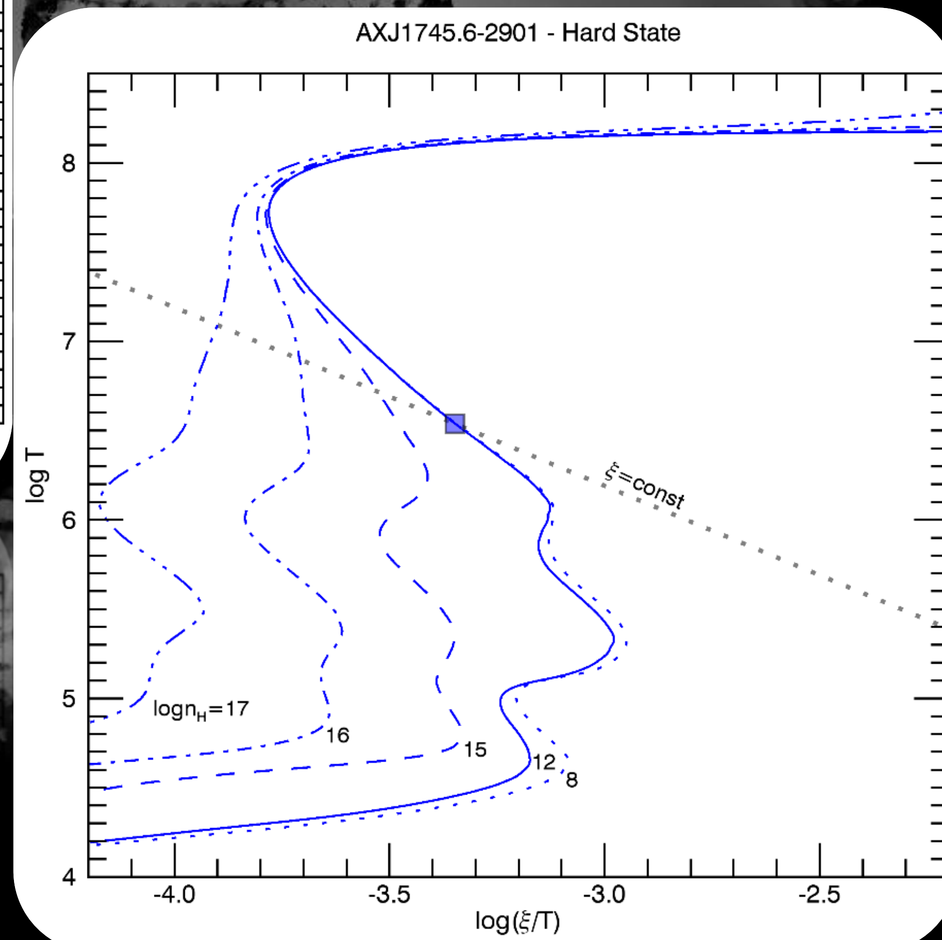


- ➢ A cold phase in the hard state is expected: is it connected to dips?
- ➢ Outflowing winds need a continuous replenishment
- ➢ **The toy model cannot reproduce the wind back to the soft state**
- ➢ **A 'fountain' is needed to re-launch the wind!**
- ➢ The launching mechanism must change from the soft to the hard state

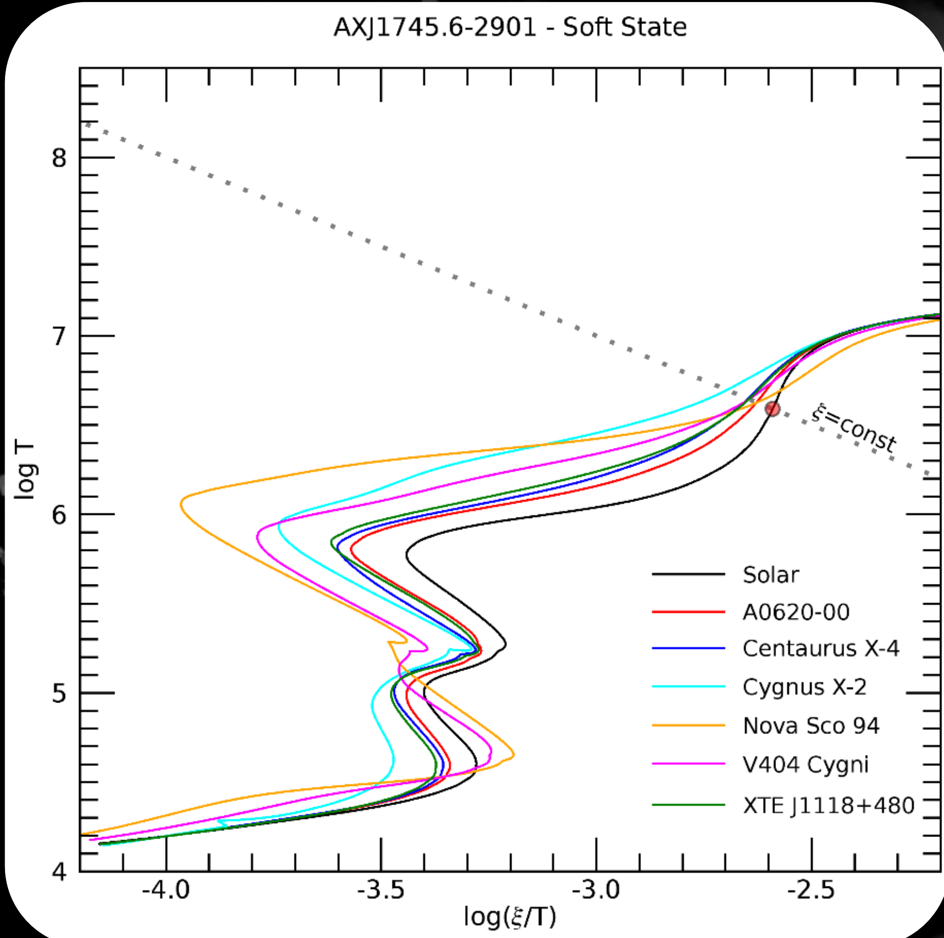

EXTRA SLIDES

Density Dependence

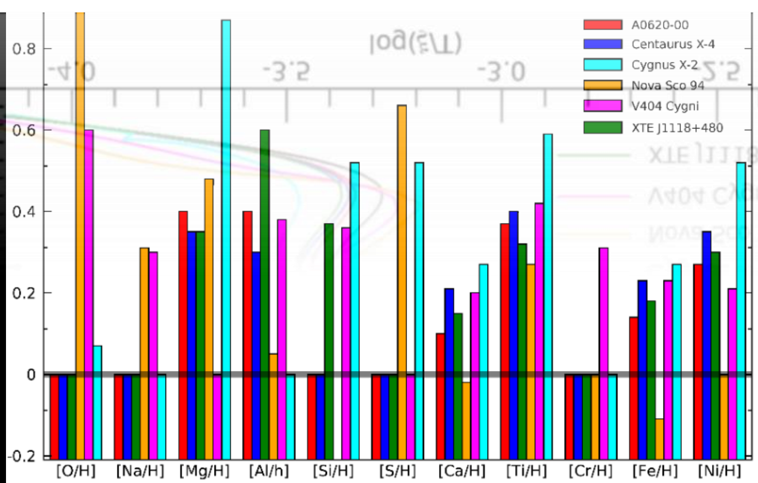




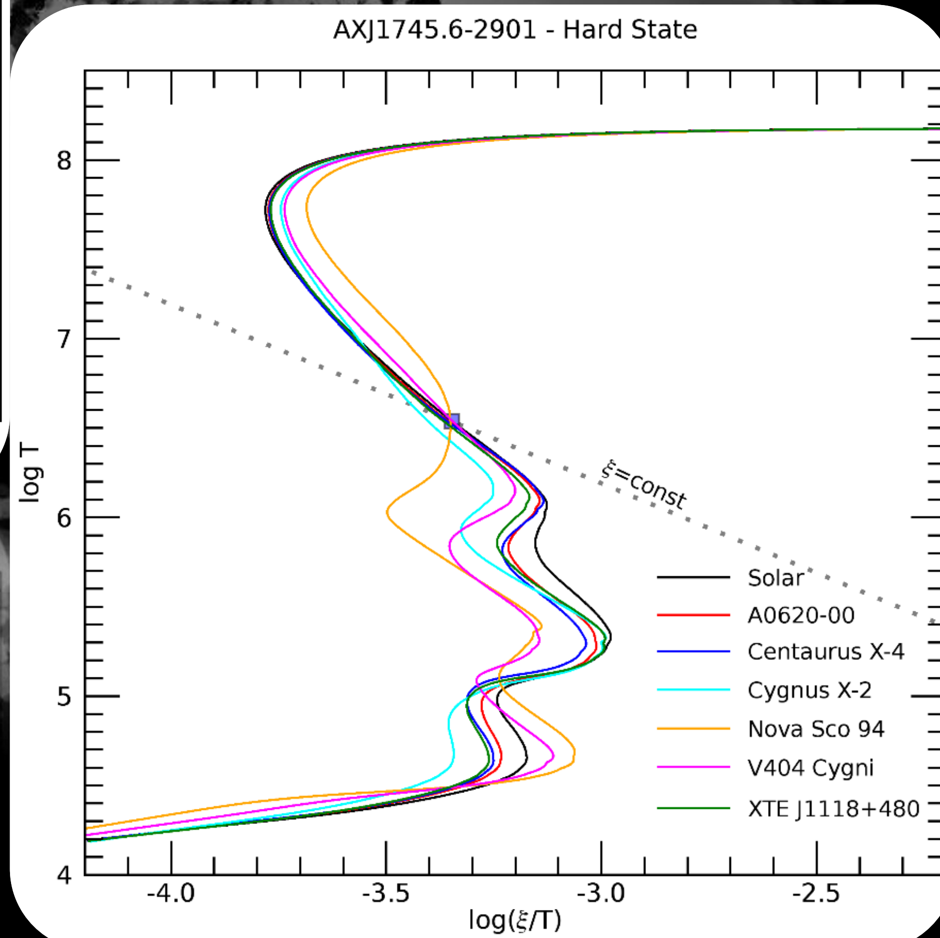
ABUNDANCES



AXJ1745.6-2901 - Soft State
log T
log(ξ/T)
ξ=const
Solar
A0620-00
Centaurus X-4
Cygnus X-2
Nova Sco 94
V404 Cygni
XTE J1118+480

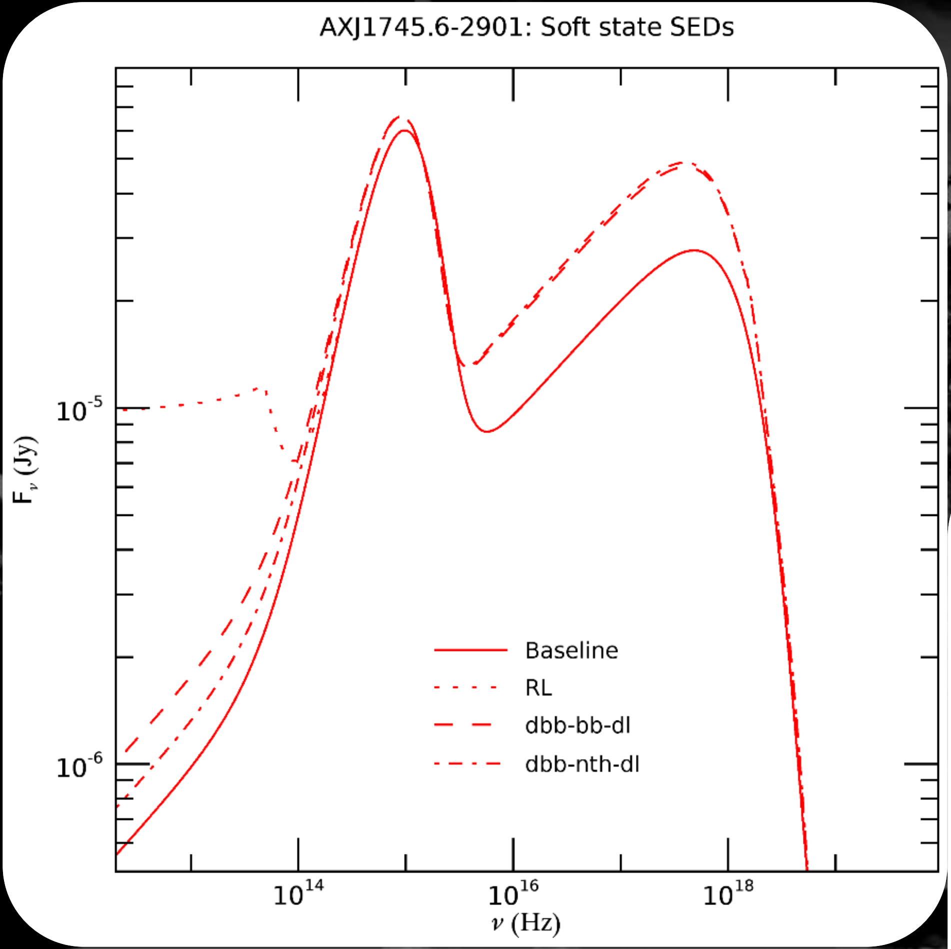


A0620-00
Centaurus X-4
Cygnus X-2
Nova Sco 94
V404 Cygni
XTE J1118+480
[O/H]
[Na/H]
[Mg/H]
[Al/h]
[Si/H]
[S/H]
[Ca/H]
[Ti/H]
[Cr/H]
[Fe/H]
[Ni/H]

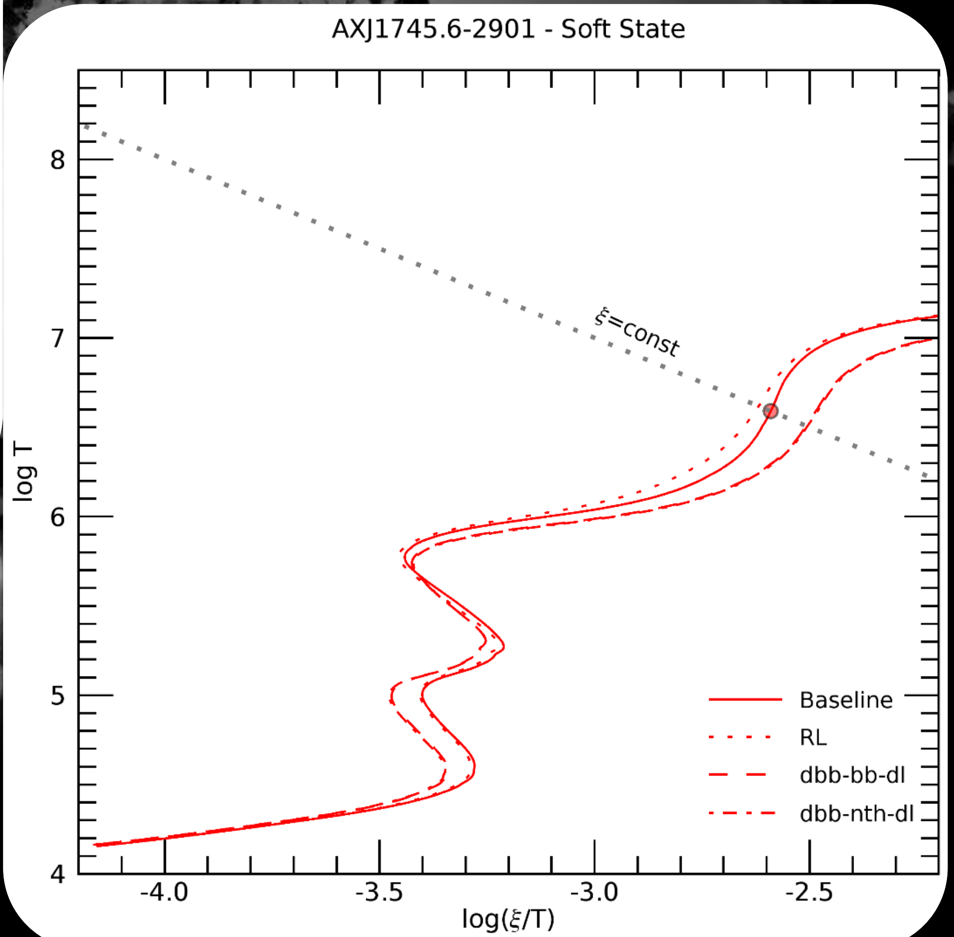


AXJ1745.6-2901 - Hard State
log T
log(ξ/T)
ξ=const
Solar
A0620-00
Centaurus X-4
Cygnus X-2
Nova Sco 94
V404 Cygni
XTE J1118+480

Other SEDs

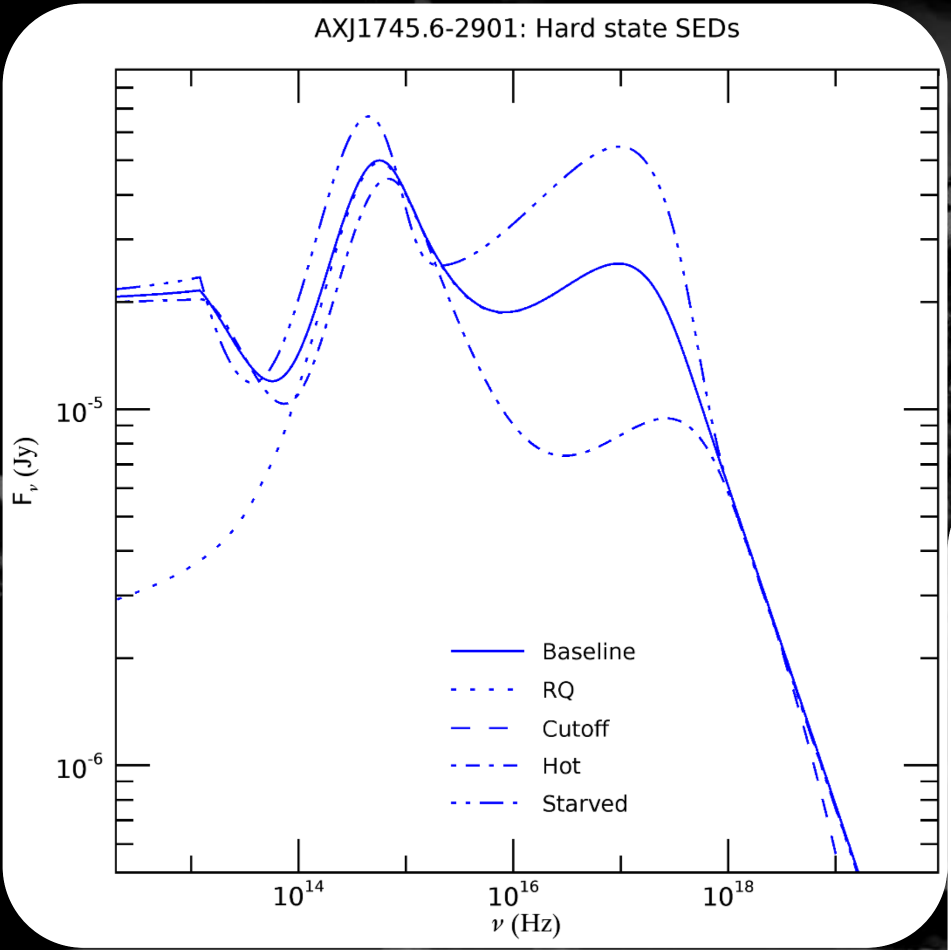


AXJ1745.6-2901: Soft state SEDs
10^{-5}
10^{-6}
F_ν (Jy)
10^{14}
10^{16}
10^{18}
ν (Hz)
Baseline
RL
dbb-bb-dl
dbb-nth-dl

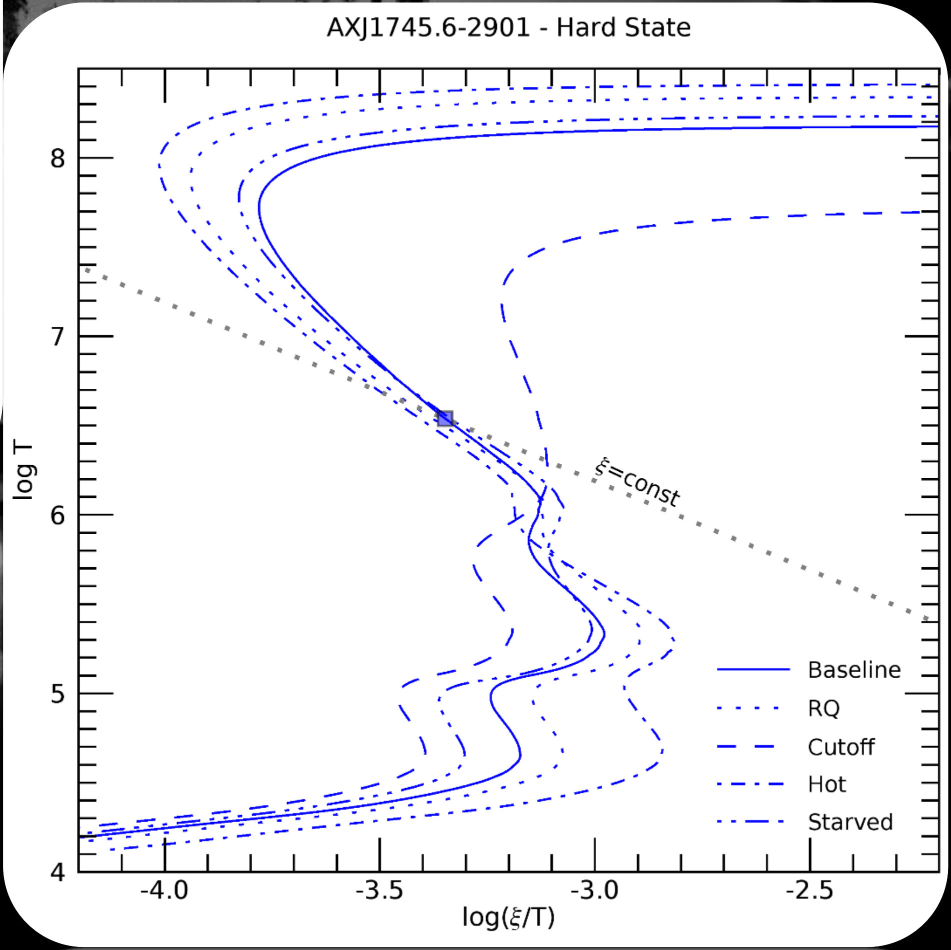


AXJ1745.6-2901 - Soft State
8
7
6
5
4
log T
ξ=const
-4.0
-3.5
-3.0
-2.5
log(ξ/T)
Baseline
RL
dbb-bb-dl
dbb-nth-dl

Other SEDs



AXJ1745.6-2901: Hard state SEDs
F_ν (Jy)
10^{-5}
10^{-6}
10^{14}
10^{16}
10^{18}
ν (Hz)
Baseline
RQ
Cutoff
Hot
Starved



AXJ1745.6-2901 - Hard State
log T
8
7
6
5
4
-4.0
-3.5
-3.0
-2.5
log(ξ/T)
ξ=const
Baseline
RQ
Cutoff
Hot
Starved