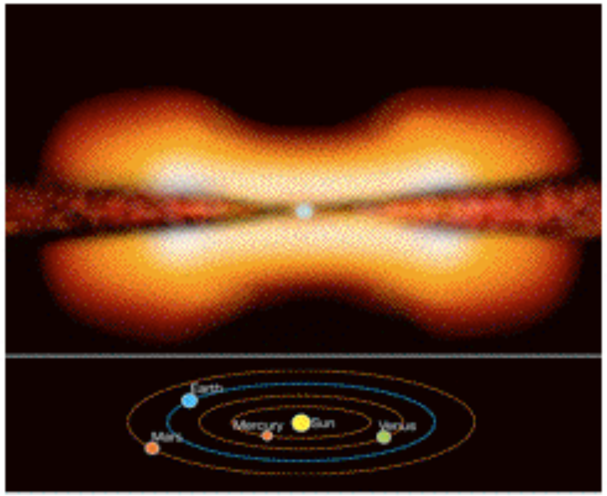
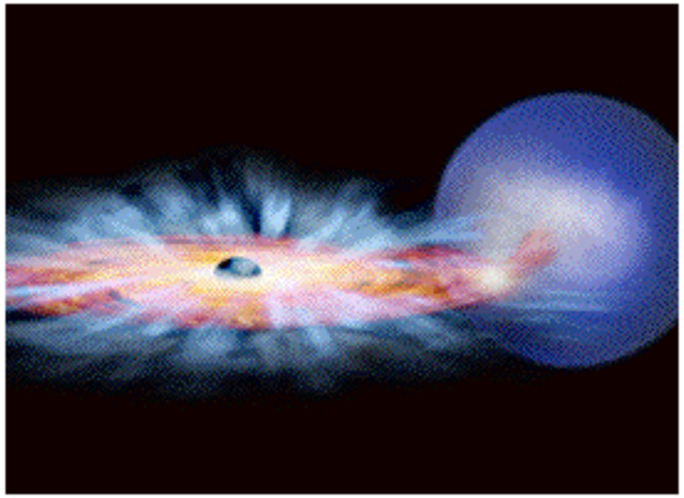
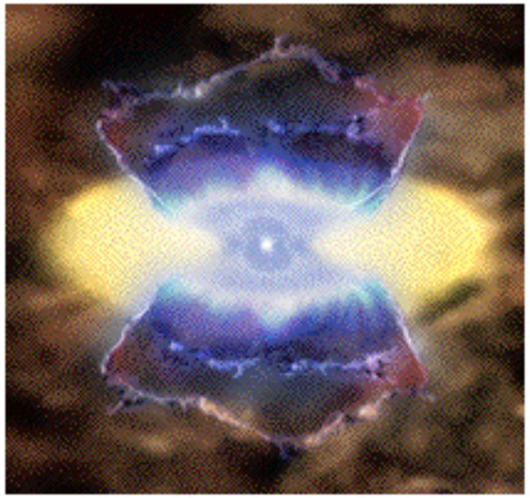
Winds in X-ray Binaries

M. Diaz Trigo (ESO)







~10^{13} cm

Young stellar object

~10^{10} cm

X-ray binary

~10^{15} cm

Supermassive black hole

Credit: ESO/VLT

Credit: NASA/CXC/M.Weiss

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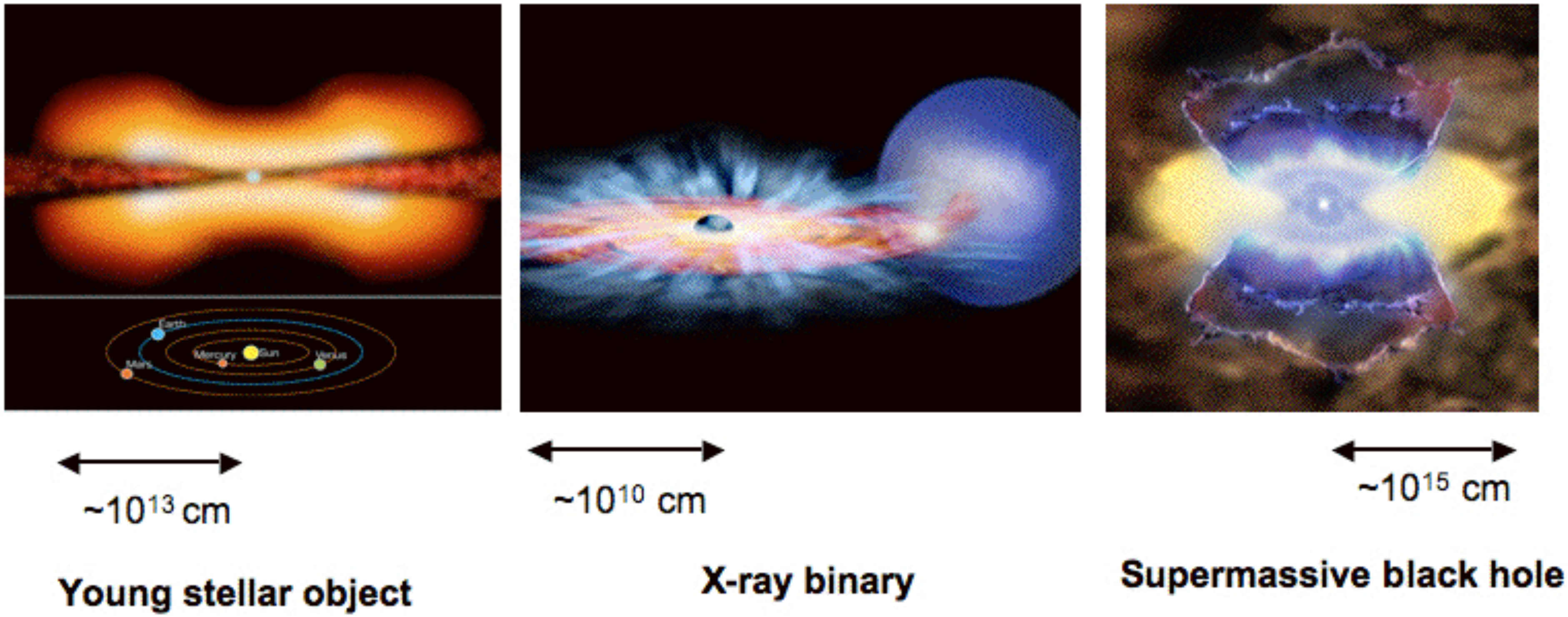


Importance of characterising the outflows:

- Dynamics of the system
- Feedback to their environment
- Our view of the innermost accretion region is limited by our understanding of winds

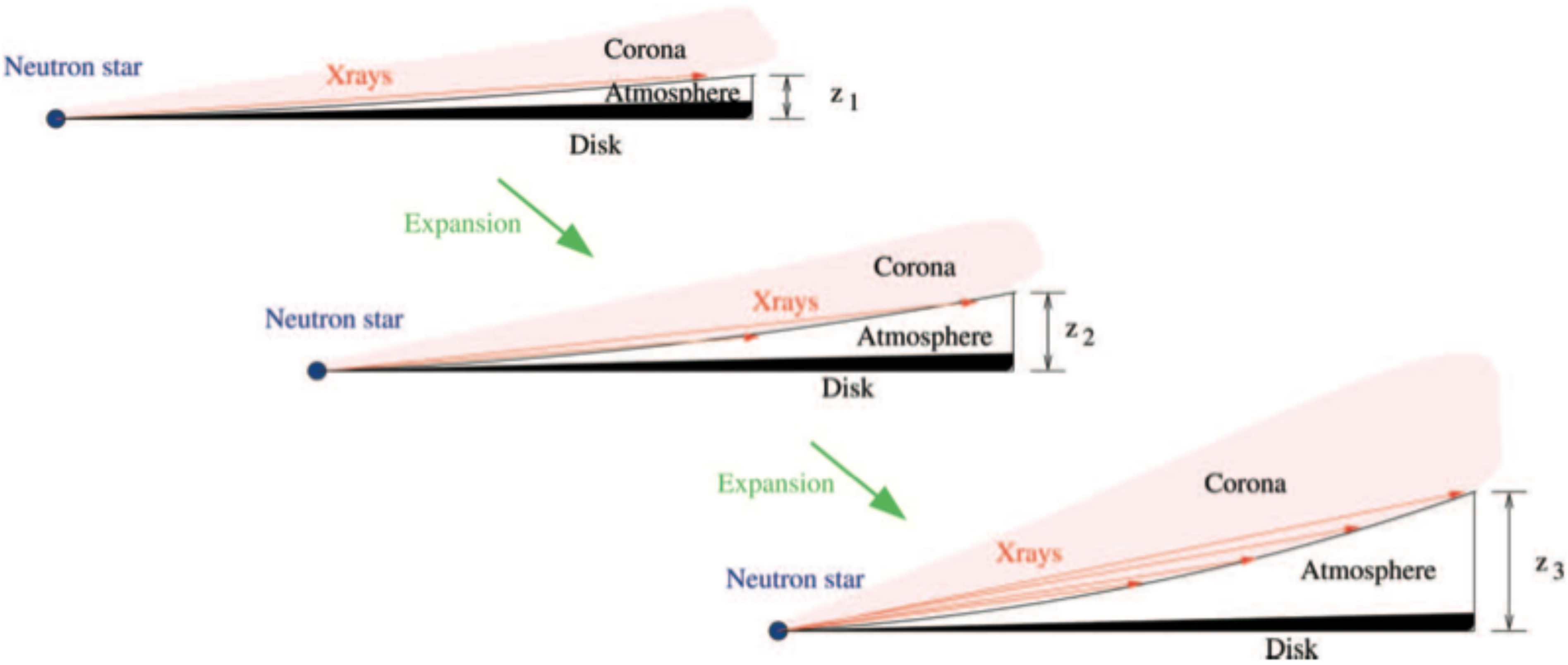
Why studying winds in XRBs?

1. Variability occurs in short timescales

2. The compact object can be a NS or a BH

    - We can isolate the role of the compact object in driving the winds: e.g. is there any evidence for an event horizon?

Some basic concepts



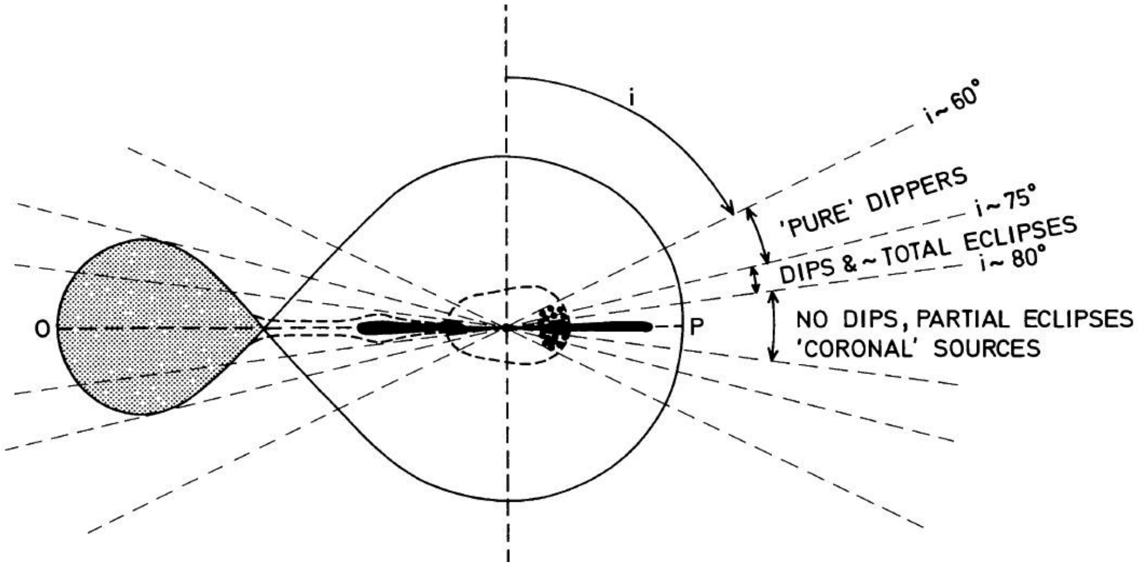
Jimenez Garate et al. 2002

Some basic concepts

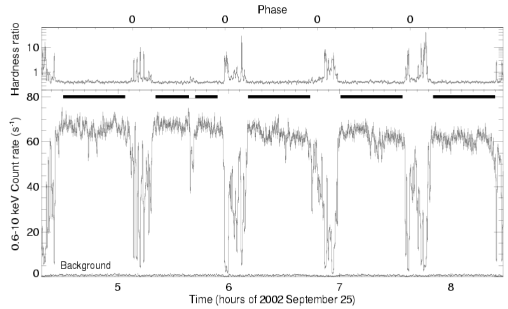
Jimenez Garate et al. 2002

- **Plasma is highly ionised**: often only Fe XXV and Fe XXVI are present (Ueda et al. 1998, Kotani et al. 2000, Sidoli et al. 2001, Ueda et al. 2001, Schulz & Brandt 2002, Parmar et al. 2002, Boirin et al. 2003, 2004, 2005…)
- **Plasma is photoionised** (based on responses to changes in continuum, triplet ratios in emitting plasma, recombination edges) (Brandt & Schulz 2001, Cottam et al. 2001, Boirin et al. 2005, Diaz Trigo et al. 2007, Kubota et al. 2007, Ueda et al. 2010…)
- **Flat ("pancake") geometry** above the disc => probably ubiquitous to all XRBs (Boirin et al. 2005, Diaz Trigo et al. 2006, Ponti et al. 2012)
- **Changes** in the plasma not only due to the change in **continuum**, but also **phase-dependent** plasma changes in column density and degree of ionisation in dipping sources (Boirin et al. 2005, Diaz Trigo et al. 2006)
- **Distance** to the central source ≈ 10^{10}-10^{13} cm (10^{4-5} r_g)

Geometry

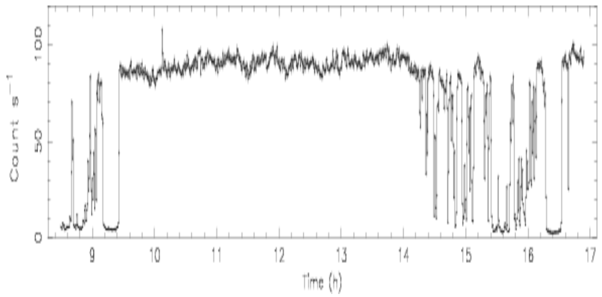


Frank et al. 1987



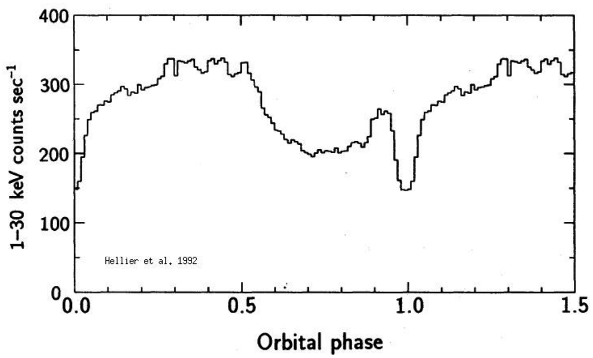
60-75 deg. 'Pure' dippers

(Boirin et al. 2004)



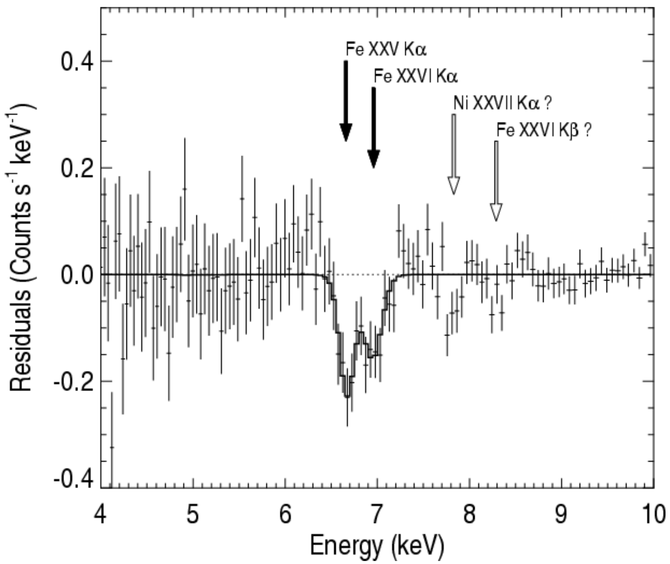
75-80 deg. Dips & ~'total' eclipses

(Sidoli et al. 2001)

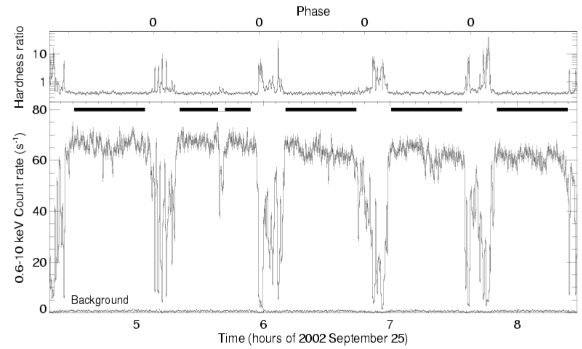


80-90 deg. No dips, partial eclipses

Geometry



4U 1916-15
Boirin et al. 2004



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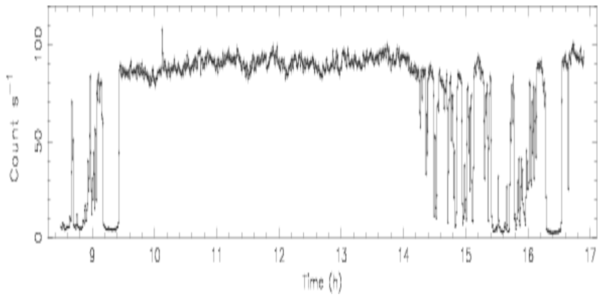

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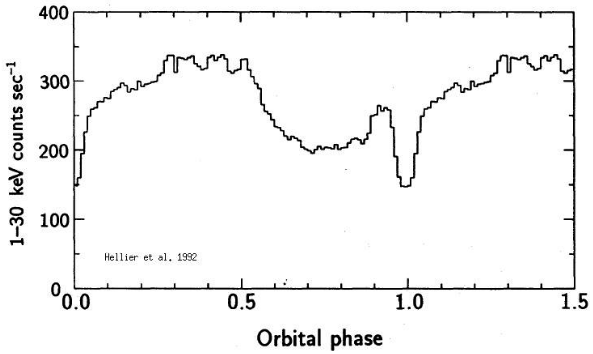
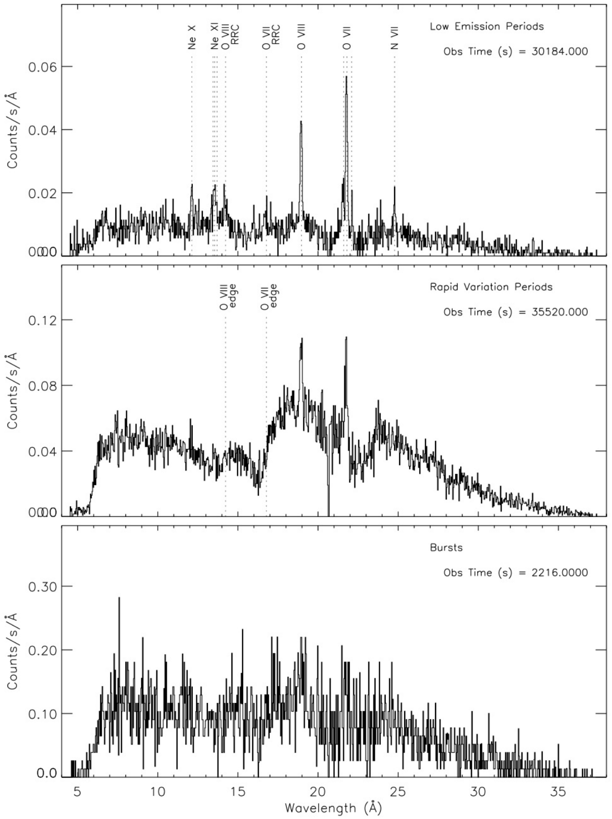
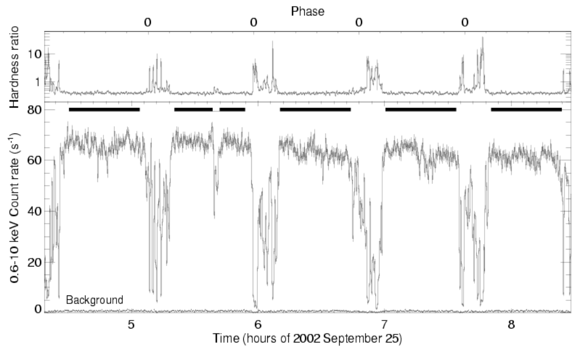


80-90 deg. No dips, partial eclipses

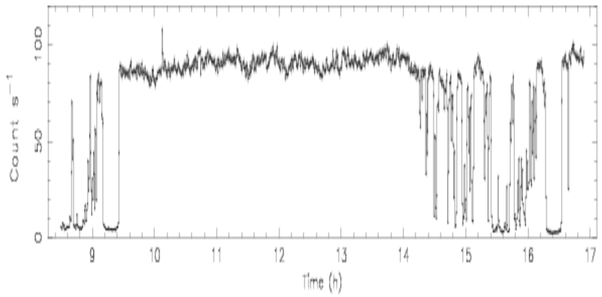
Geometry



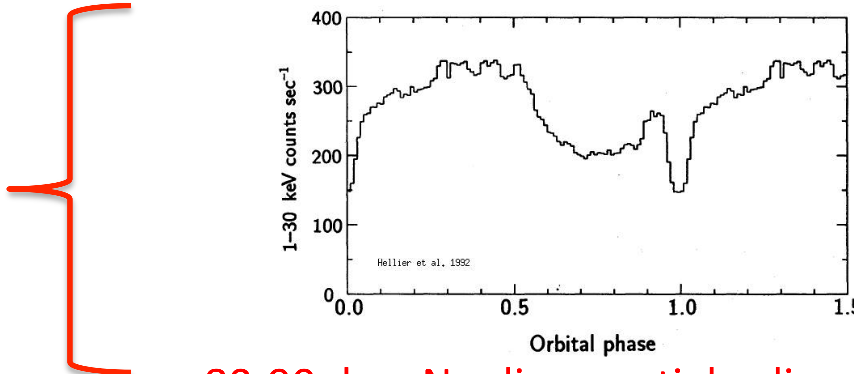
2A 1822-371, Cottam et al. 2001



60-75 deg. 'Pure' dippers

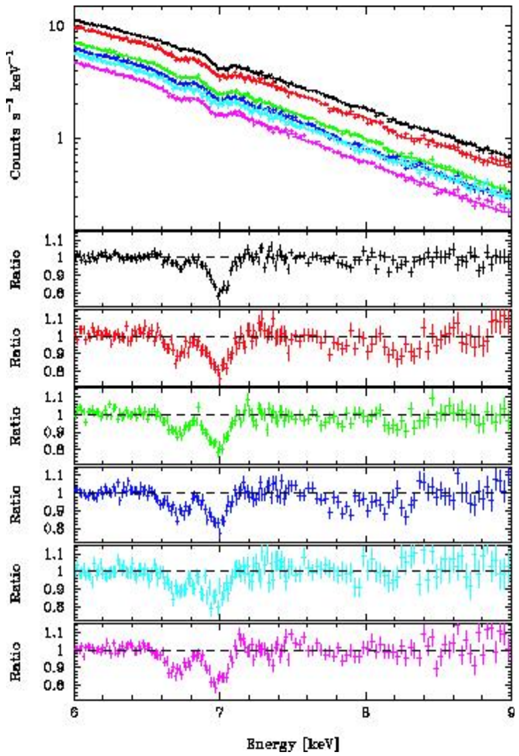


75-80 deg. Dips & ~'total' eclipses

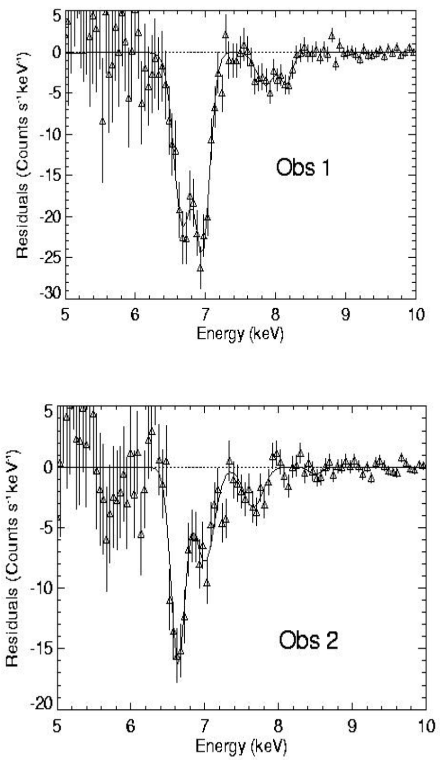


80-90 deg. No dips, partial eclipses

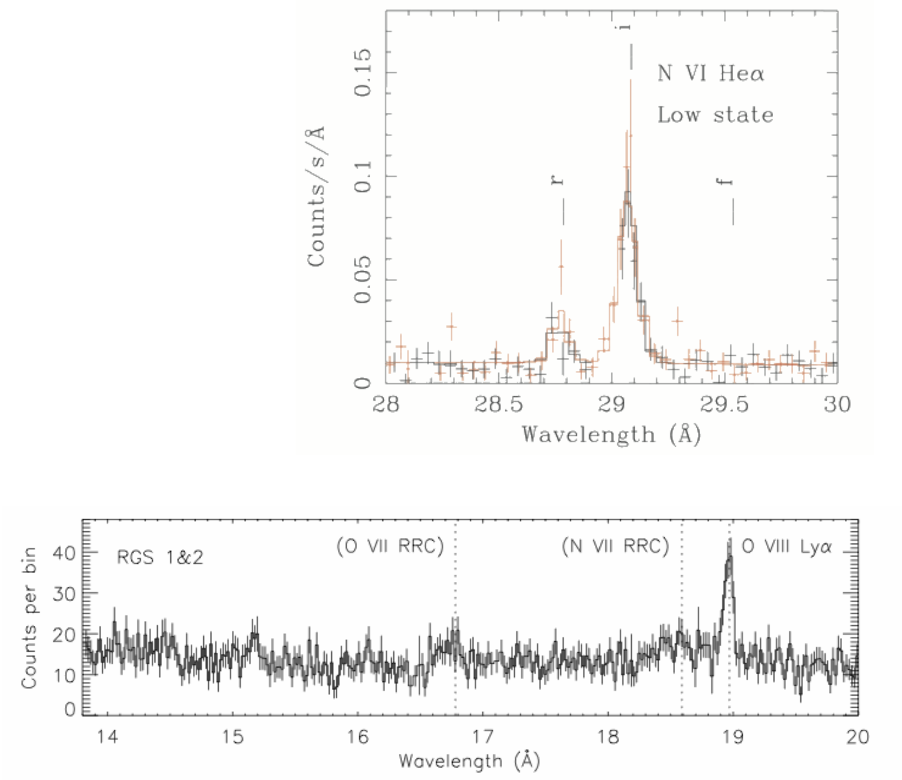
Photoionised plasma



4U 1630-472
(Kubota et al. 2007)

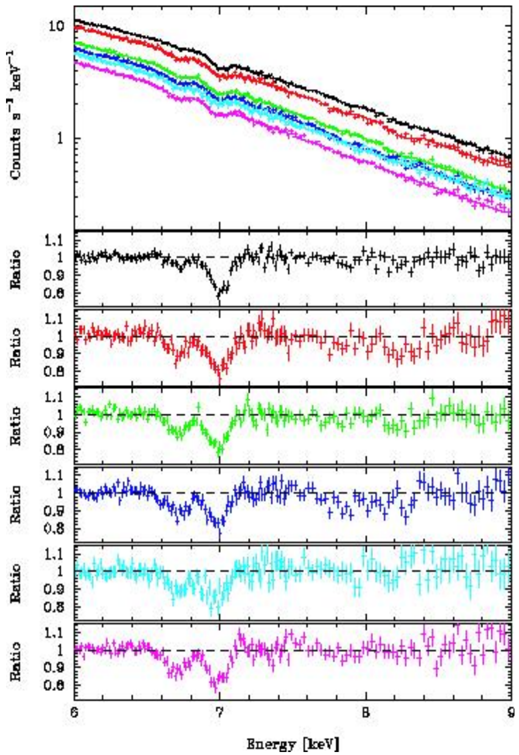


GRO J1655-40
(Diaz Trigo et al. 2007)



Her X-1
(Jimenez-Garate et al. 2001)

Photoionised plasma



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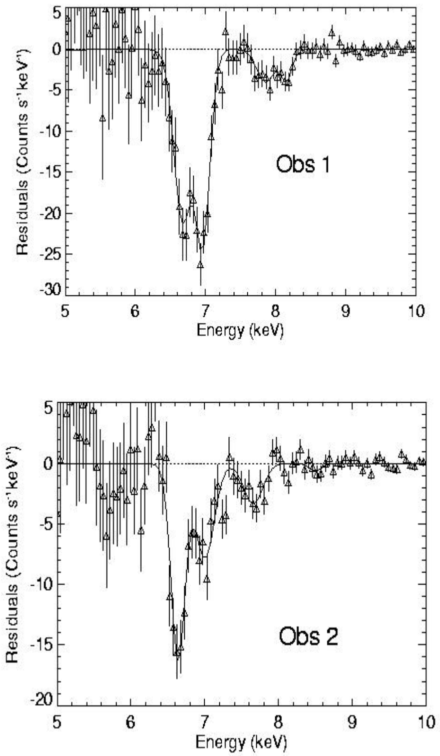

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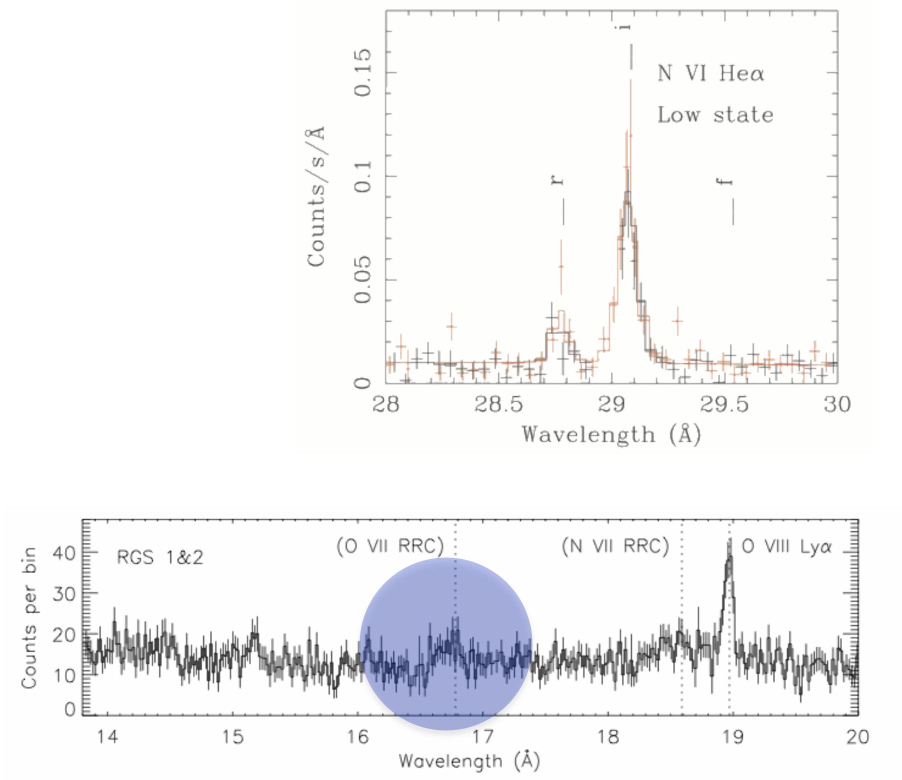

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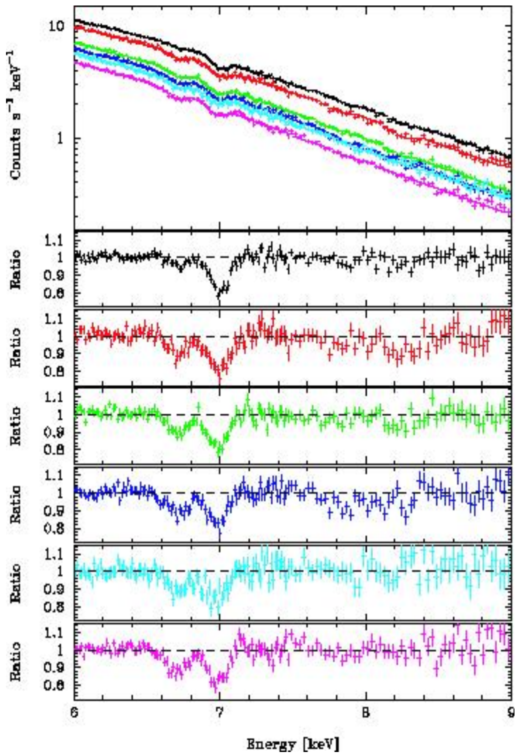

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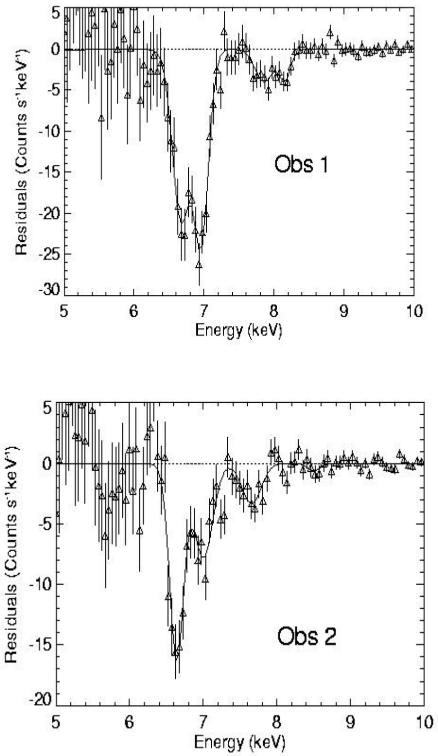

GRO J1655-40
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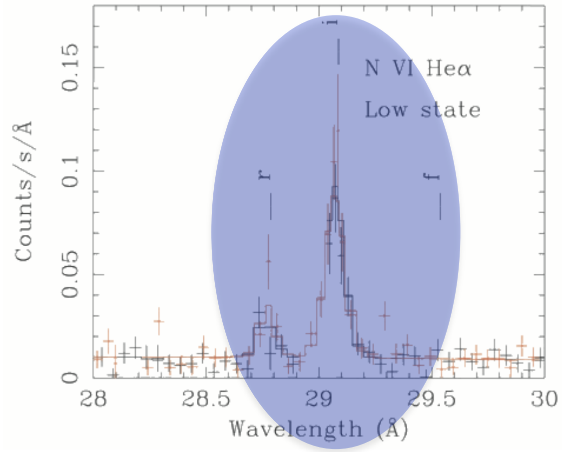

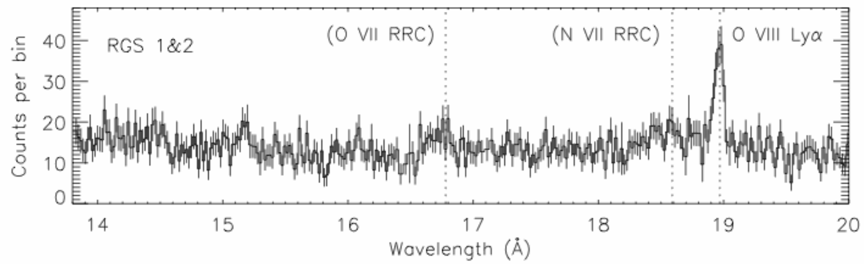

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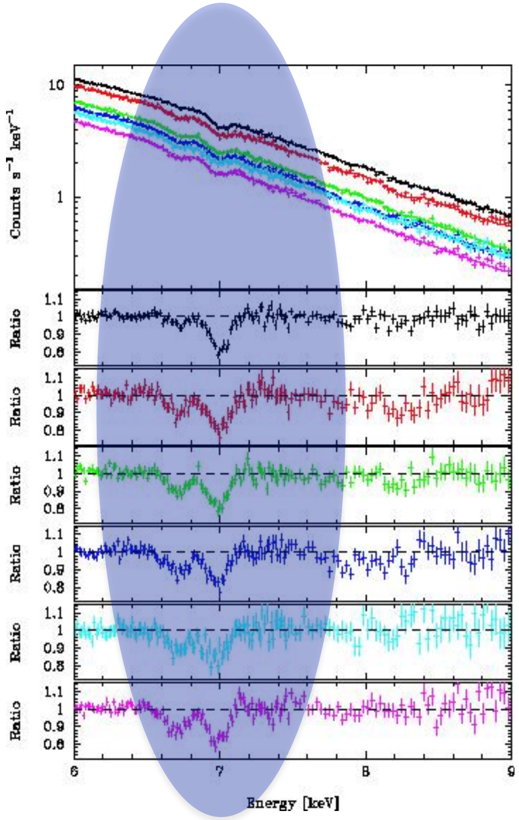
Photoionised plasma



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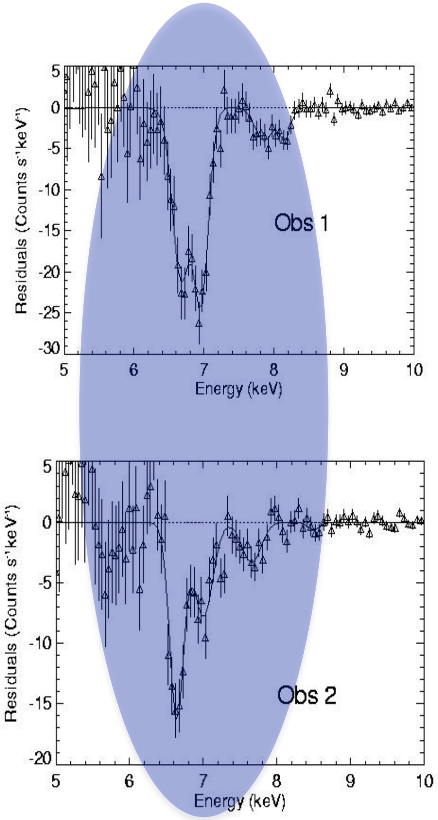

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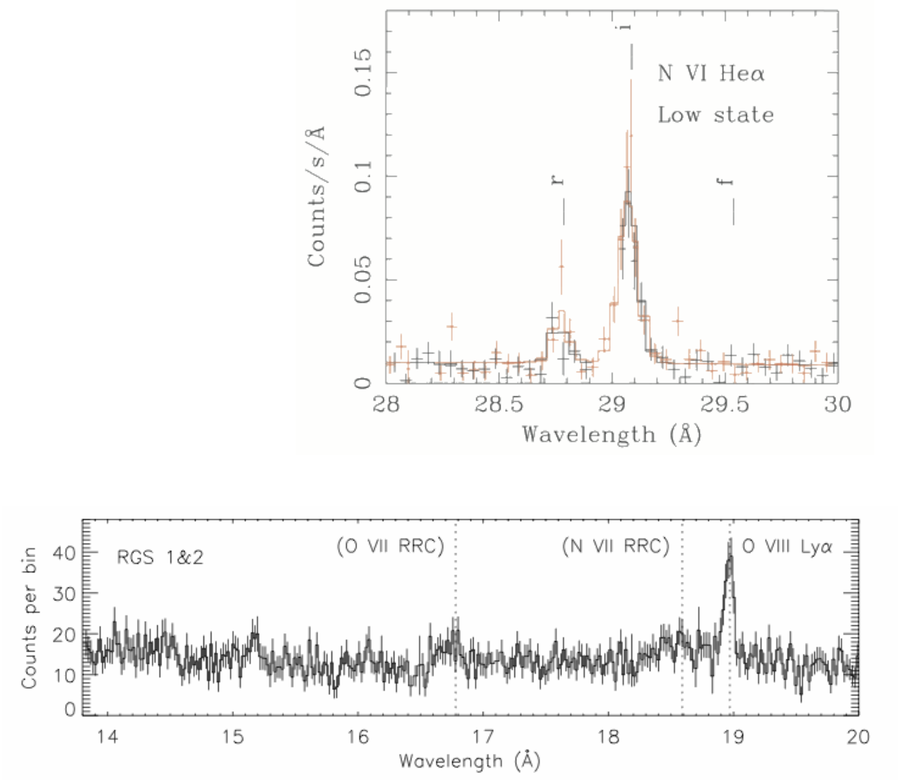


Her X-1
(Jimenez-Garate et al. 2001)

Some questions

1. Launching mechanism

2. What is the role played by the wind (if any) in the disc/jet coupling in XRBs?

3. Feedback: is the mass expelled important enough to affect the dynamics of the system or the environment?

   Yes! Mass outflow rates <~ mass accretion rates
   (e.g. Ueda et al. 2004, 2009)

1. Launching mechanism

- Magnetic
- Thermal
- Line-driven (UV opacity, radiation pressure due to line opacity)

Launching mechanism

- Magnetic
- Thermal
- ~~Line-driven~~ (Proga & Kallman 2002)

Launching mechanism

$\xi = L / n_e r^2$

Need to know launching radius

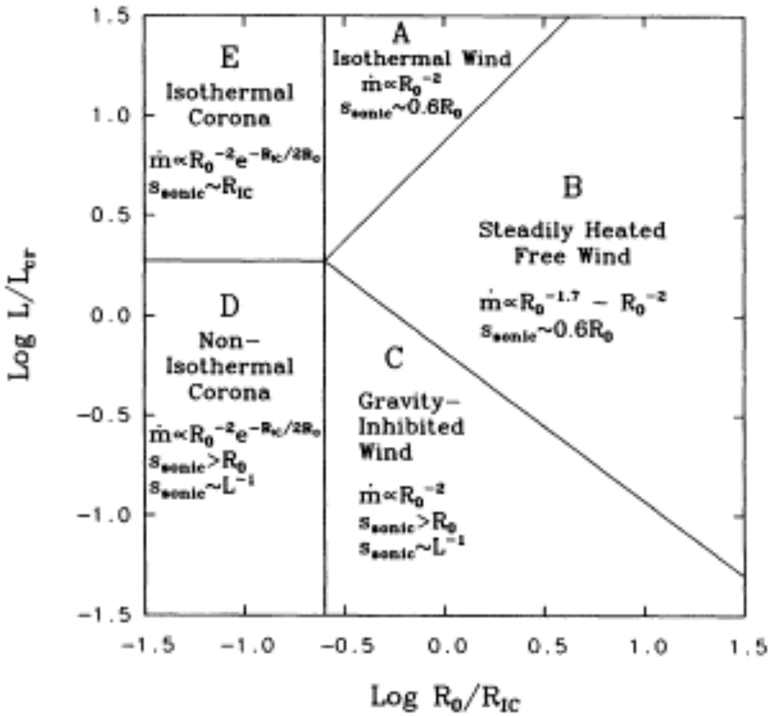
If the flux varies on a certain time the variability of the WA provides a lower limit on the density => Upper limit on the distance

Other methods: detection of excited levels associated with a given collision strength and decay rate or metastable levels

$n_e \approx 10^{12} - 10^{13}$ cm^{-3}

$r \approx 10^{10} - 10^{12}$ cm

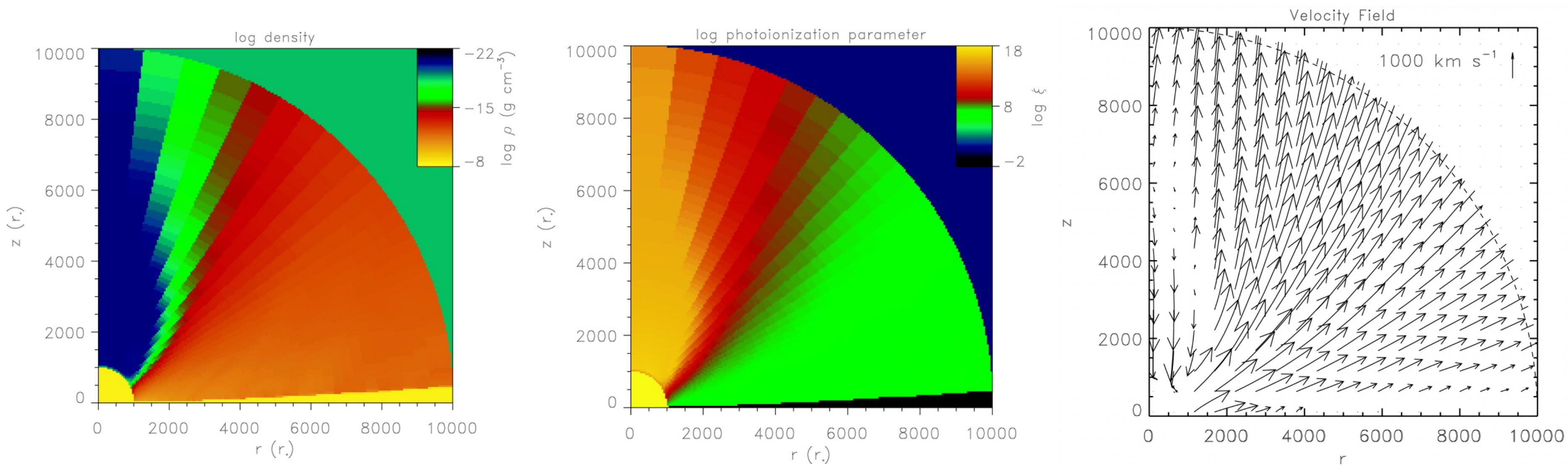
Thermal winds



Begelman et al. 1983, Woods et al. 1996

Compton radius (r_c): distance at which the escape velocity equals the isothermal sound speed at the Compton temperature

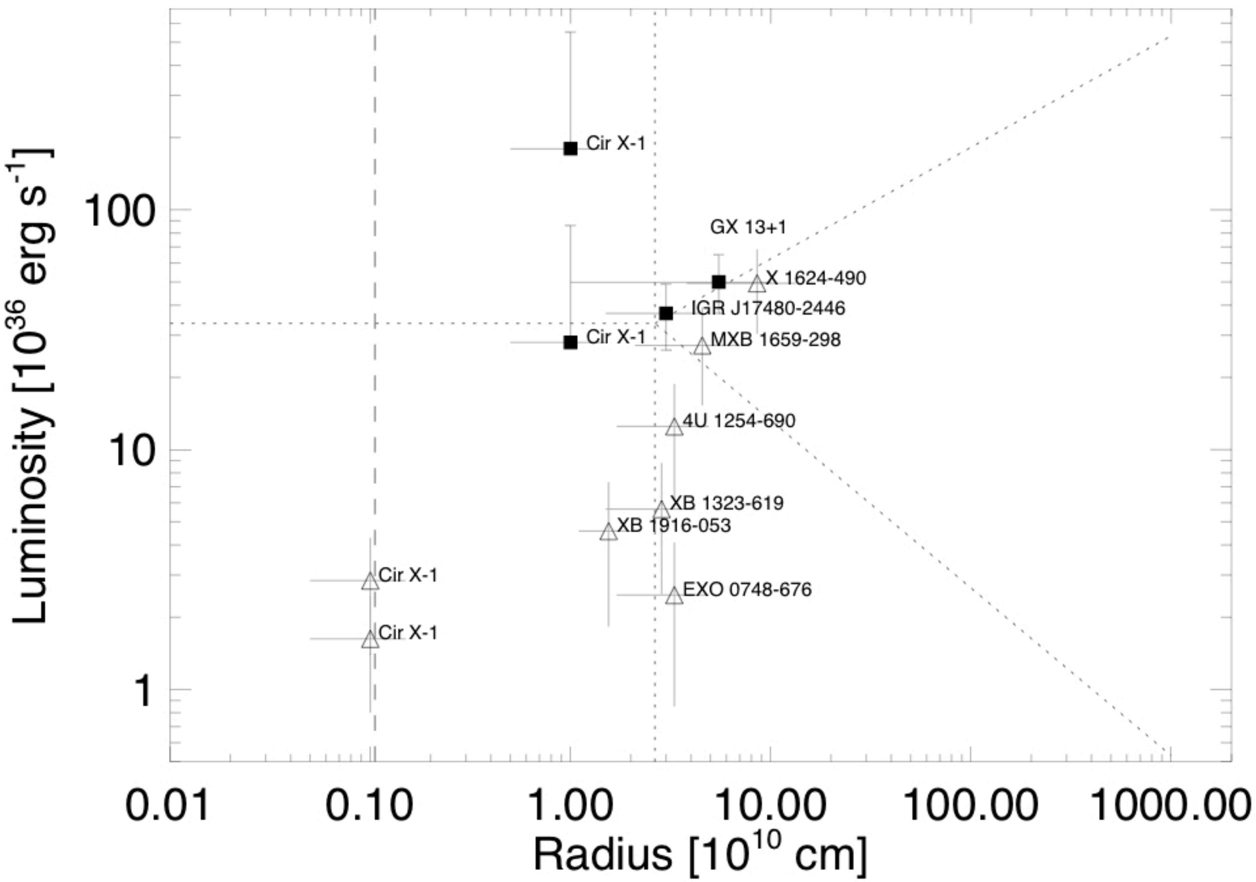
Thermal winds



Proga & Kallman 2002

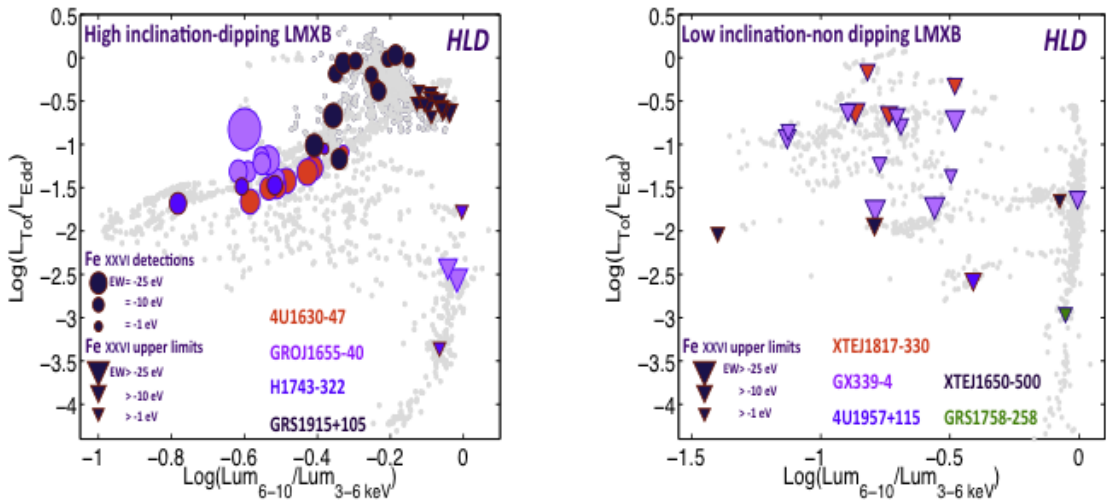
Electron radiation pressure becomes relevant at high luminosities and decreases the effective radius at which a thermal wind can be launched from ~0.25-0.1 $\mathbf{r_c}$ (Woods et al. 1996) to ~0.01 $\mathbf{r_c}$ (Proga & Kallman 2002)

Evidence for thermal winds in neutron stars



Diaz Trigo & Boirin 2012

Evidence for thermal winds in black holes



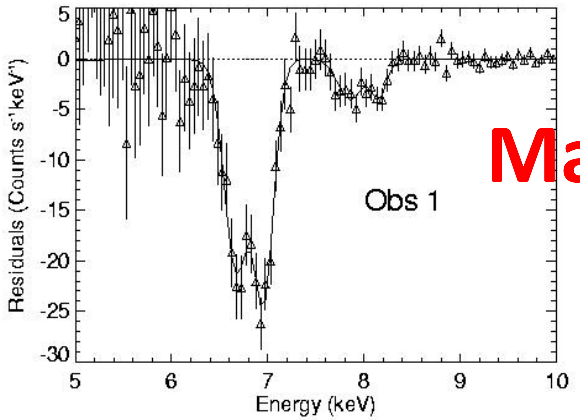
Ponti et al. 2012

Geometry: equatorial (Ponti et al. 2012, consistent with results from Diaz Trigo et al. 2006)

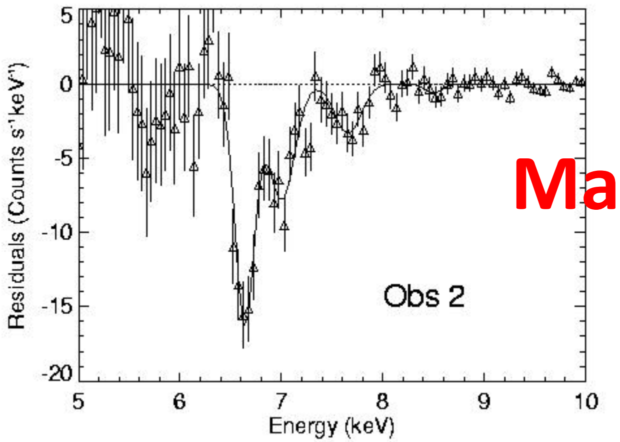
Launching radius: $10^{4\text{-}5}$ r_g (except in one case, Miller et al. 2006)

Outflow velocities: 300-1000 km/s (except in one case, King et al. 2012)

Evidence against thermal winds in black holes?

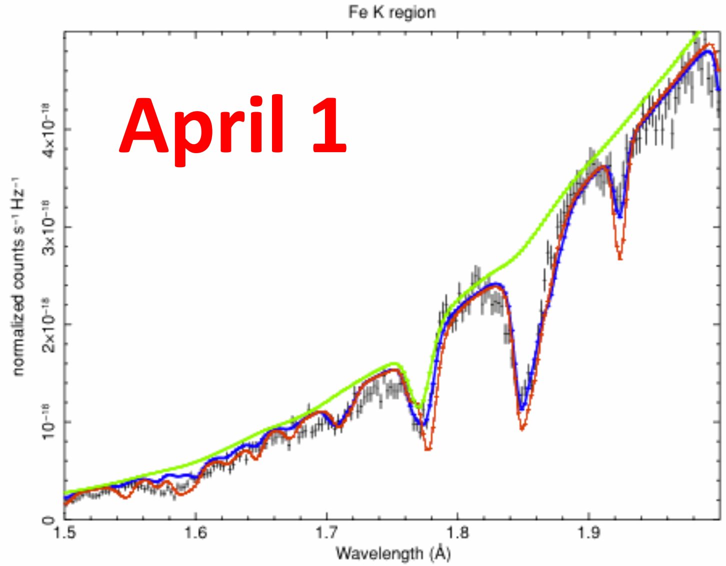


March 18



March 27

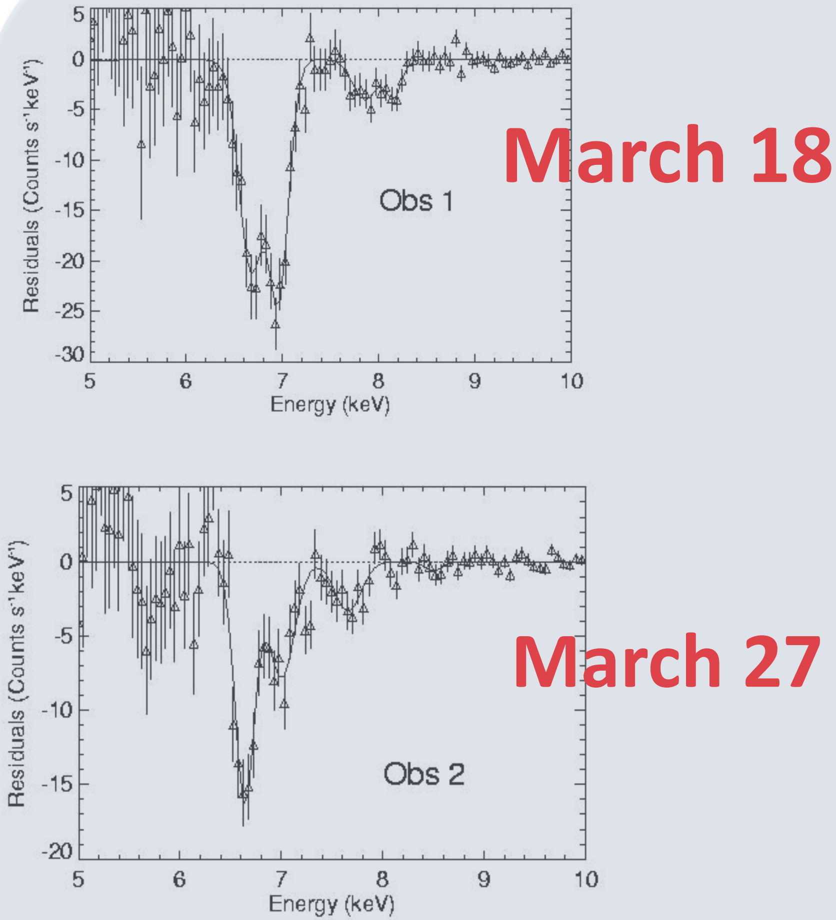
Diaz Trigo et al. 2007



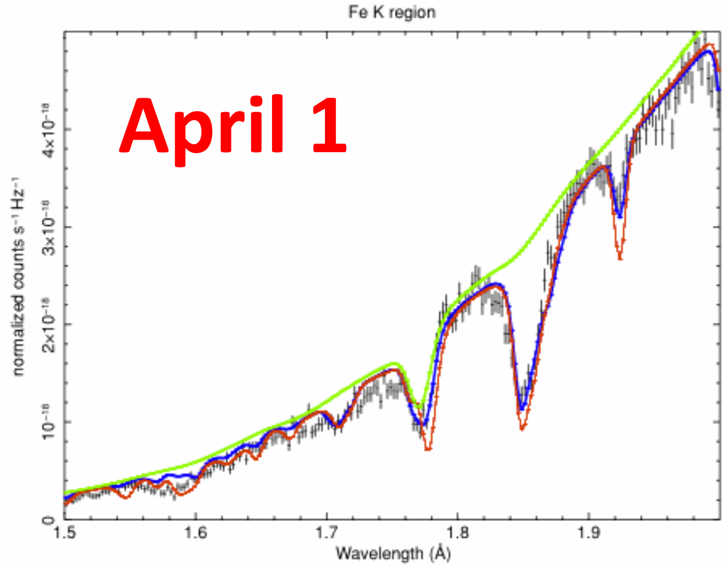
April 1

Miller et al. 2006, Kallman et al. 2009
(see also Netzer 2006, Luketic et al. 2010)

GRO J1655-40



Diaz Trigo et al. 2007



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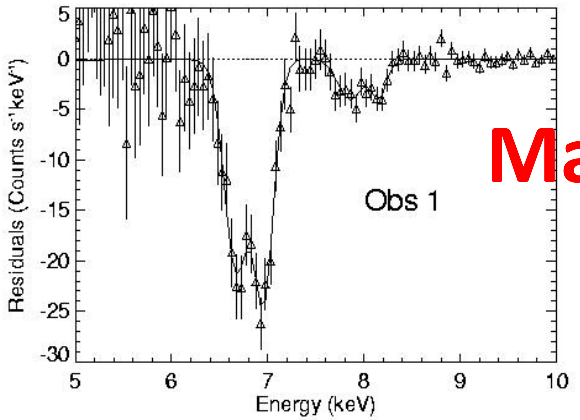

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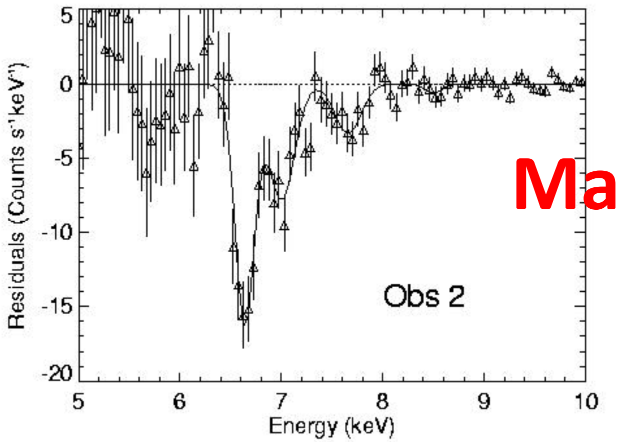
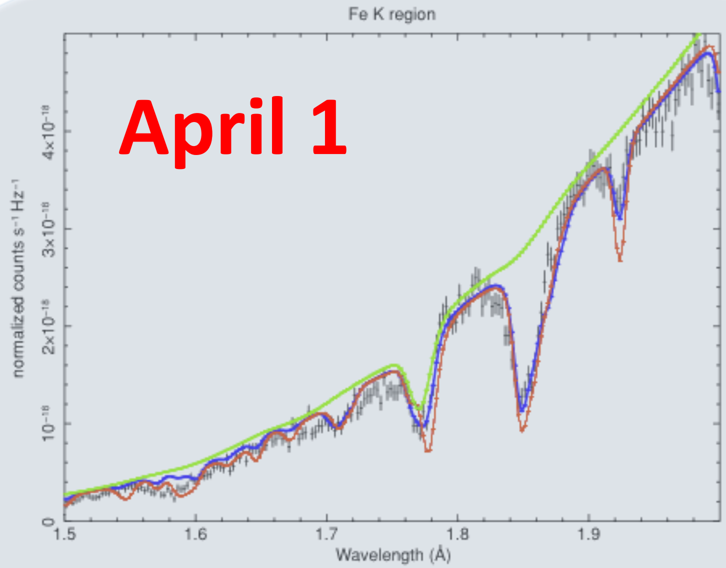


March 27

Diaz Trigo et al. 2007

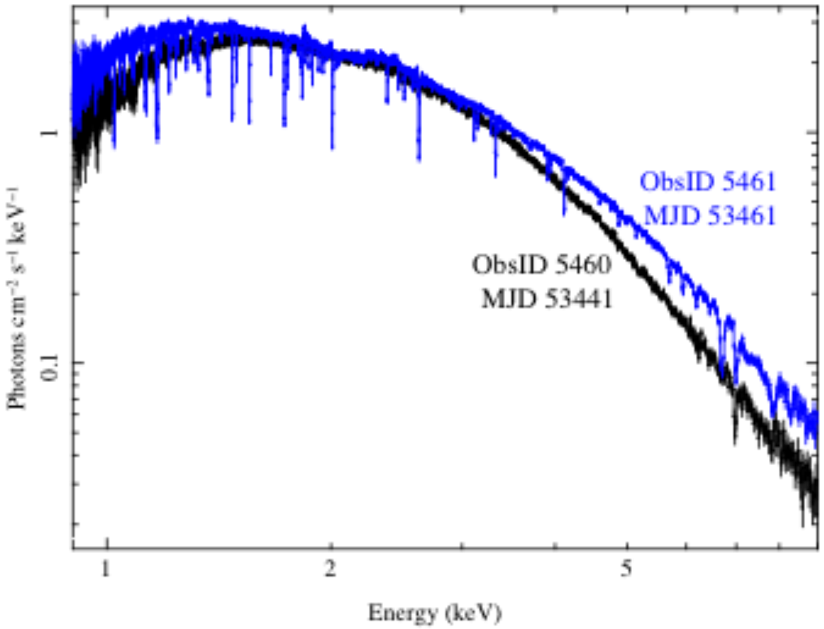


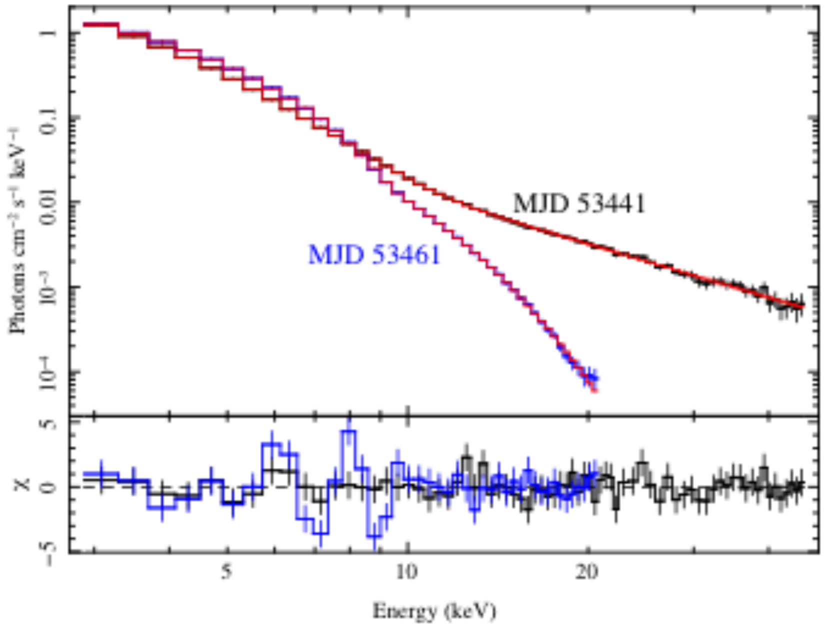
April 1

Miller et al. 2006, Kallman et al. 2009
(see also Netzer 2006, Luketic et al.2010)

r < 2x 10^9 cm => Magnetic driving
(Miller et al. 2006)
r ≈ 10^{11} cm => Thermal driving
(Netzer et al. 2006)

GRO J1655-40





Neilsen & Homan 2012

Hybrid wind: initially thermally/radiatively driven and then MHD driven

But … how realistic is the assumed SED?

The SED problem

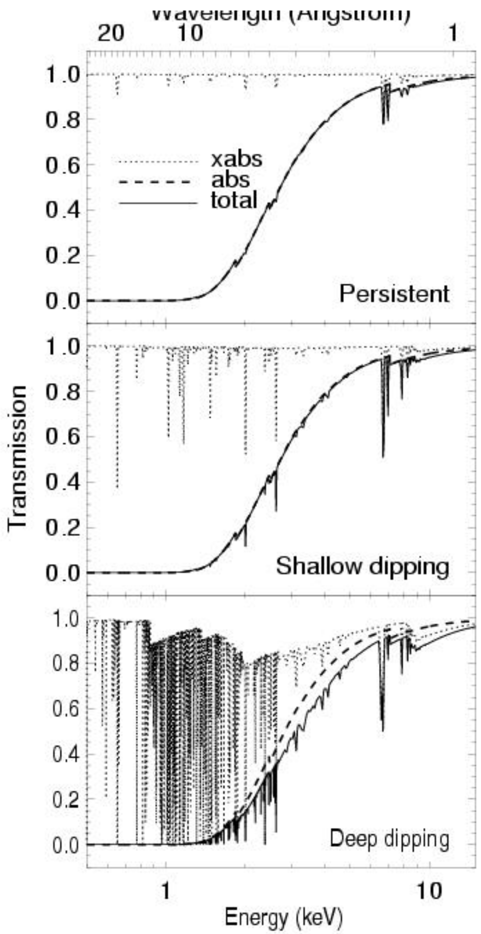
To recover the original SED we need to self-consistently take into account:

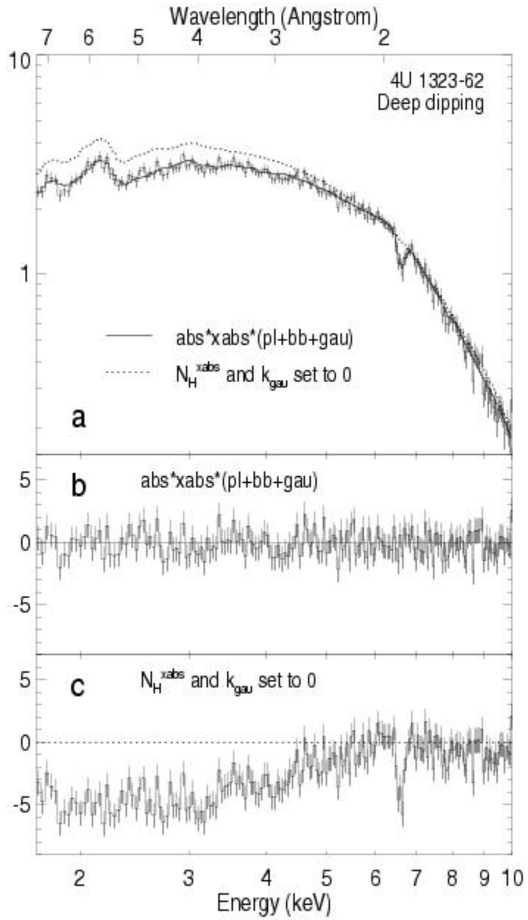
Opacity caused by wind absorption => specially relevant at low energies, energy dependent due to the Klein-Nishina formula of Compton scattering

Reprocessed component of the wind => it modifies the SED significantly

But… Chandra/XMM-Newton lack hard X-rays and RXTE/MAXI lack soft X-rays

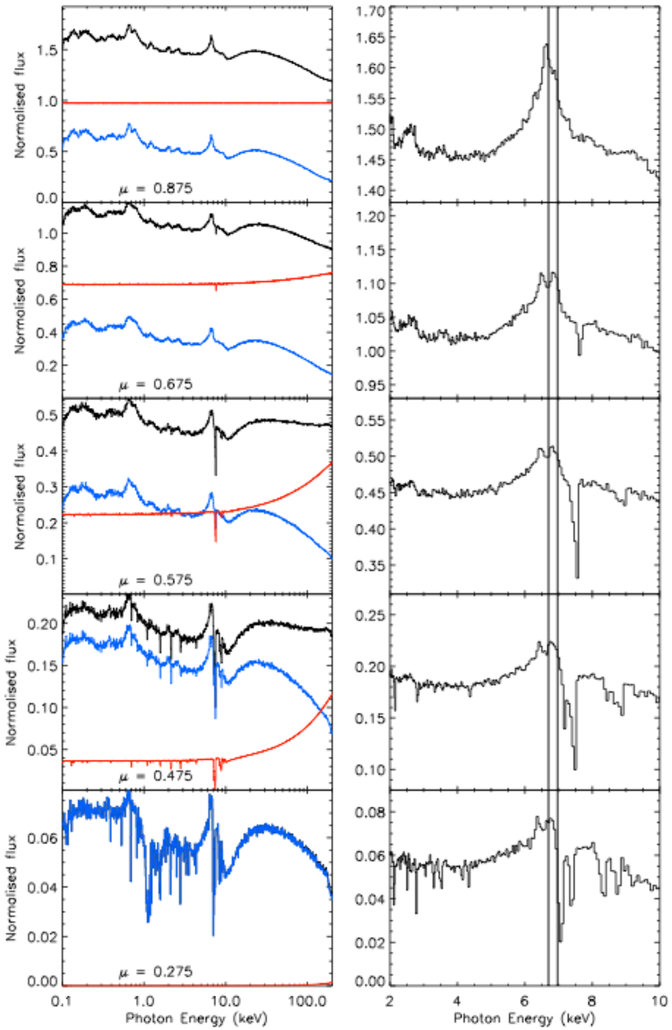
The SED problem: wind opacity





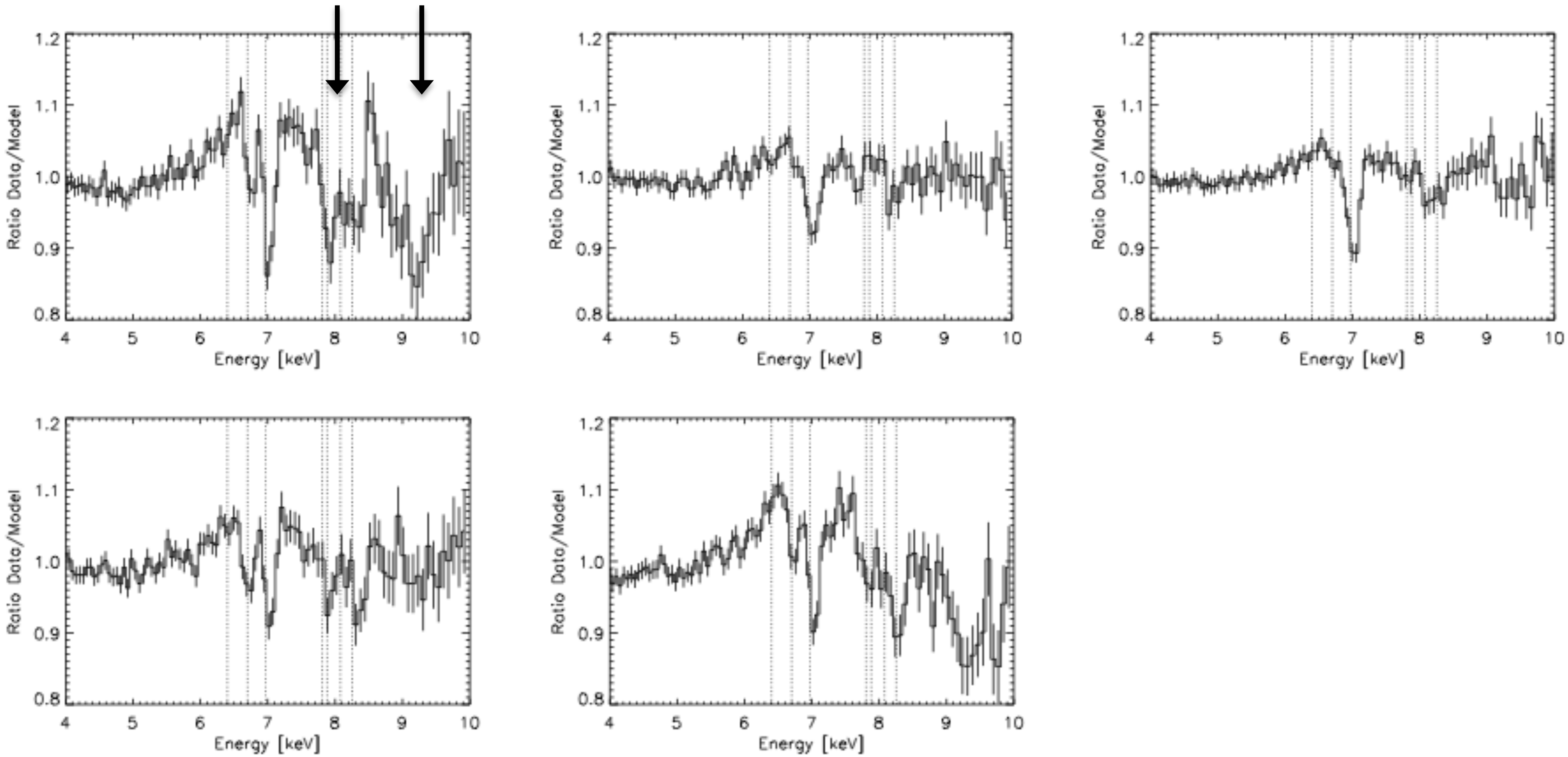
Boirin et al. 2005

The SED problem: the wind scattered component



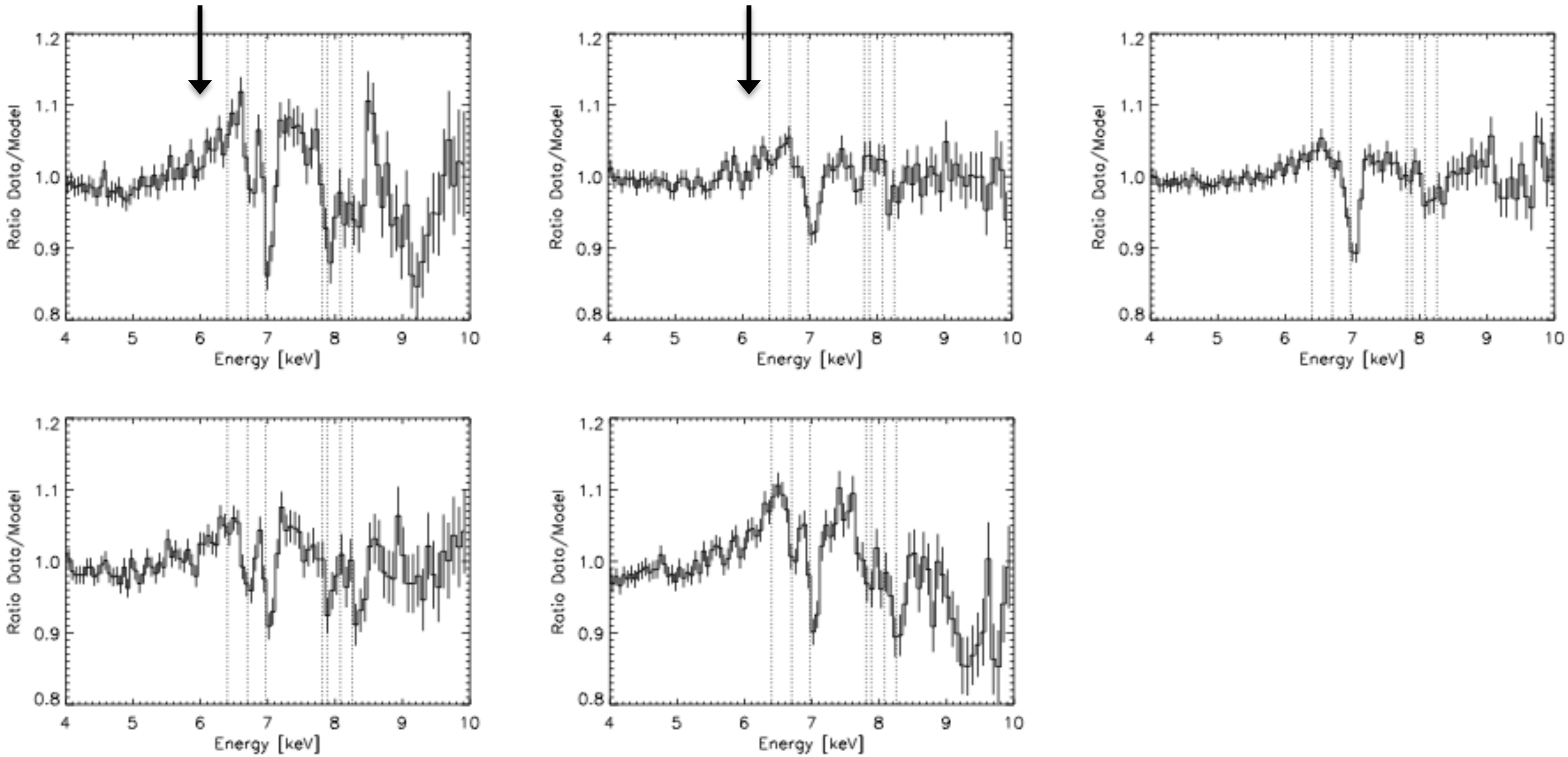
Sim et al. 2010

The SED problem: opacity & scattered component



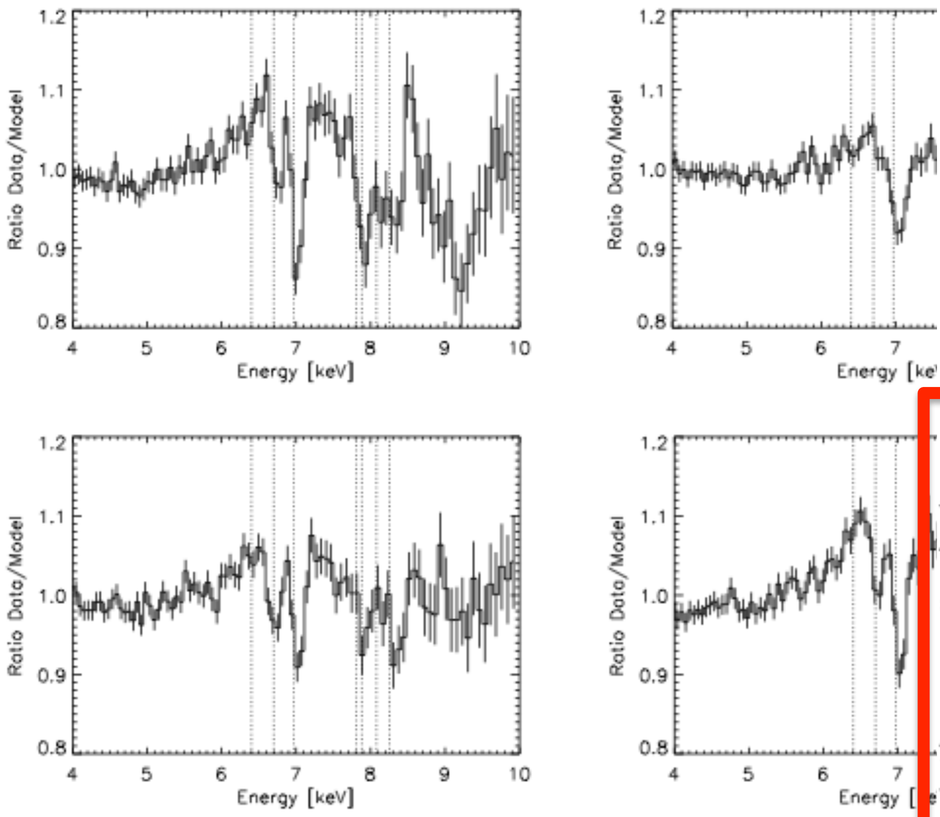
Diaz Trigo et al. 2012

The SED problem: opacity & scattered component

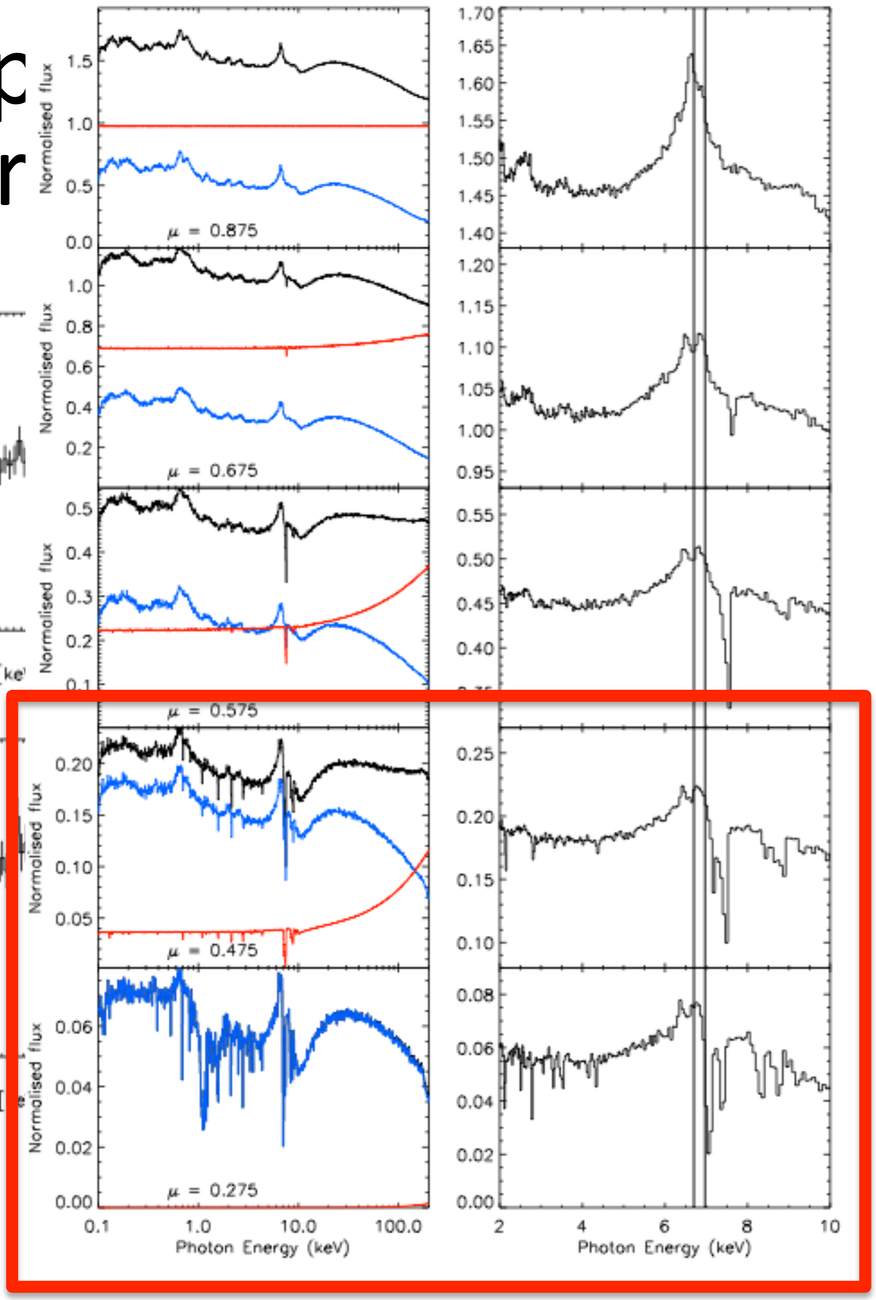


Diaz Trigo et al. 2012

The SED p
the wind scatter

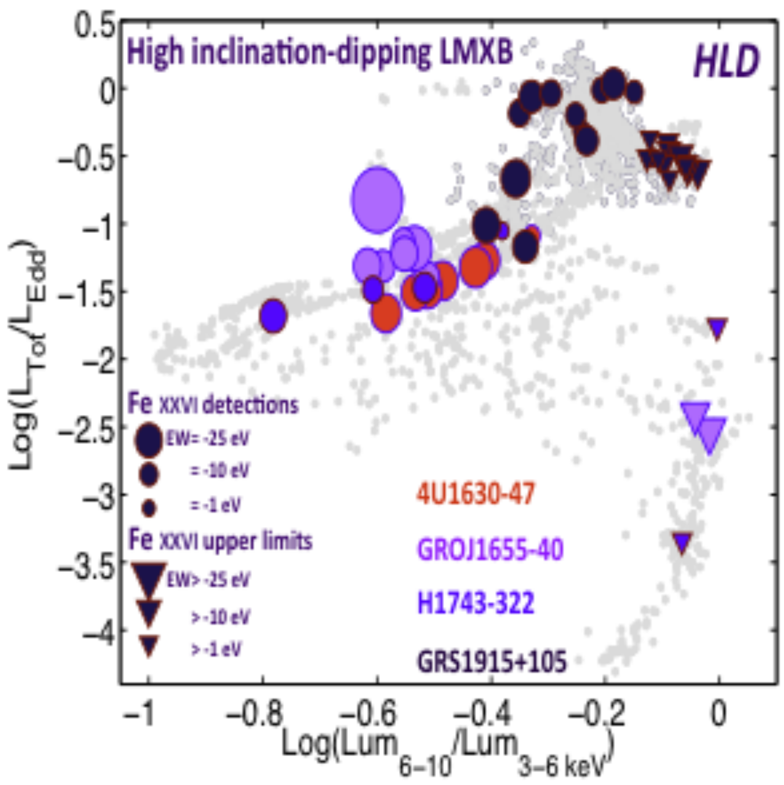


Diaz Trigo et al. 2012



Sim et al. 2010

2. Winds, jets and accretion states



Ponti et al. 2012

Winds preferentially detected during outbursts at high/soft states (but see Lee et al. 2002)

Possible interpretations:

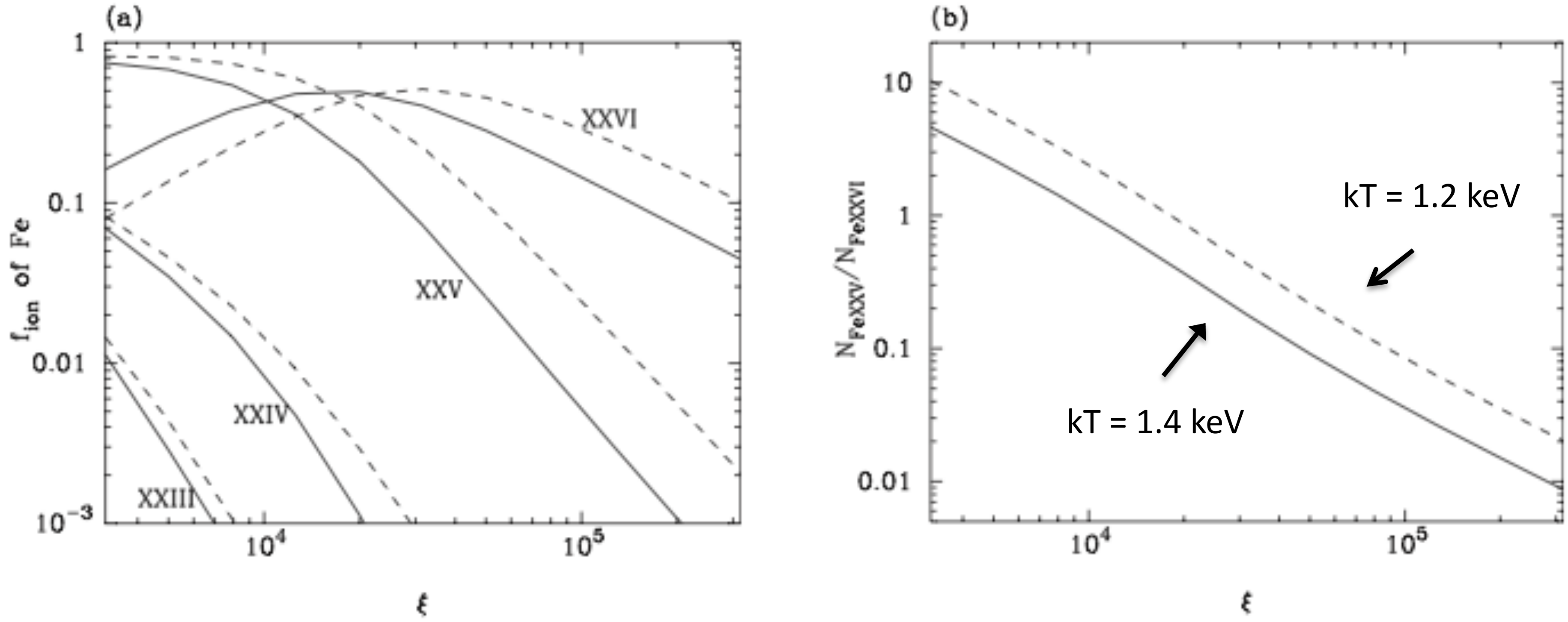
Photoionisation renders the wind transparent (e.g. Ueda et al. 2010, Diaz Trigo & Boirin 2012)

Geometrical changes in the flow (e.g. Ueda et al. 2010)

Density changes (e.g. Miller et al. 2012)

Mass depletion mechanisms (Neilsen & Lee 2009)

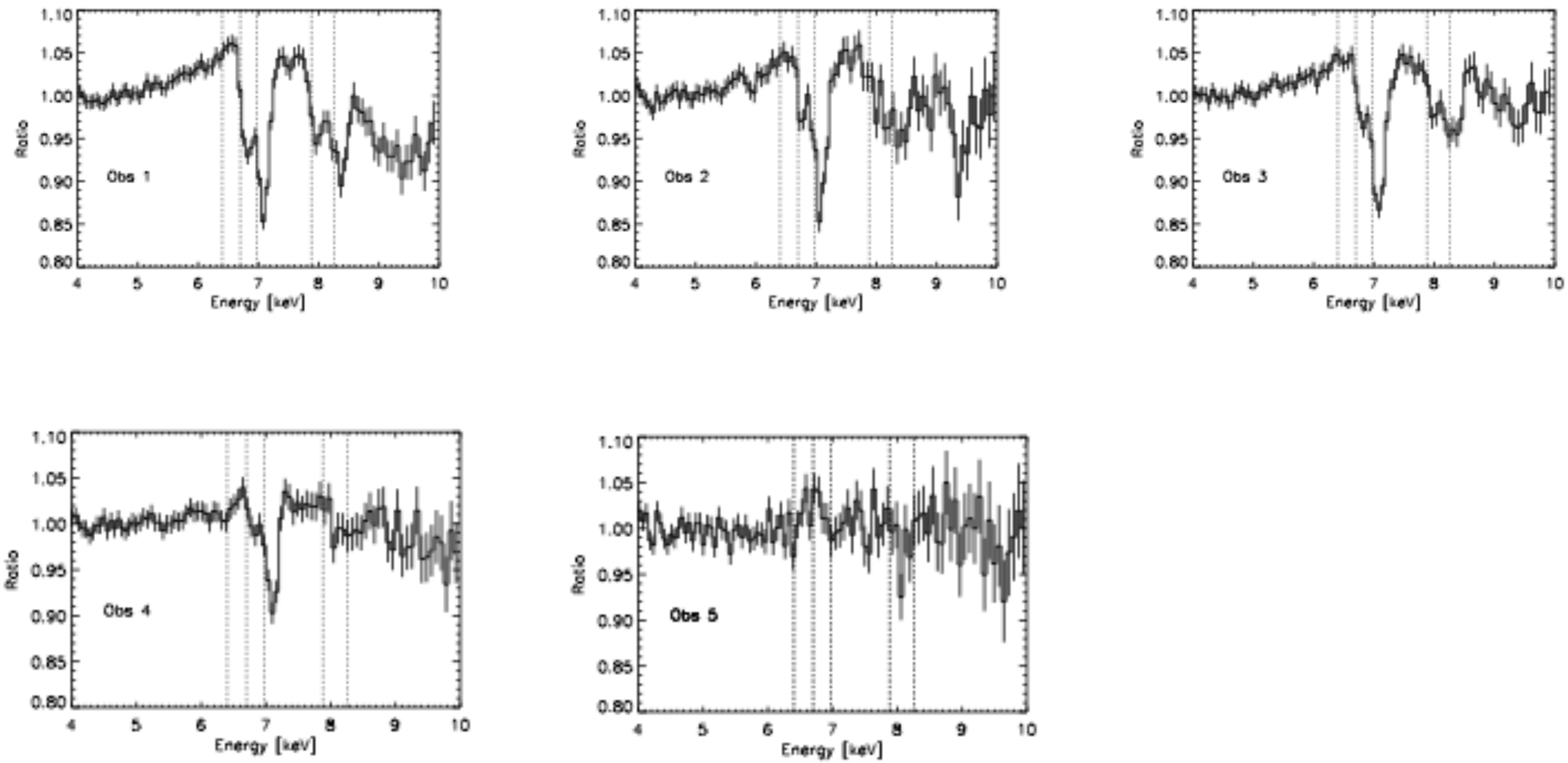
Photoionisation: the SED effect



Kubota et al. 2007

Spectral hardening causes higher ionisation **and** a decrease of column density

Wind photoionisation during HSS



Diaz Trigo et al., in preparation

Conclusions

- Launching mechanism of winds in XRBs: overwhelming evidence in favour of a thermal/radiative mechanism (one potential candidate for MHD to be studied further)
- Photoionisation is the dominant ionisation mechanism and drives changes in the wind during the high soft state of accretion
- But SED modelling and density determination are important challenges in studies of winds. Our view of the central region is significantly altered by the wind:

  Models must include Compton scattering and reprocessing in the wind and treat radiation transfer adequately for high column densities

    Luminosity may be severely underestimated

    Scattering produces broad Fe lines and modifies the continuum