An Ionised Accretion Disc Wind in Hercules X-1

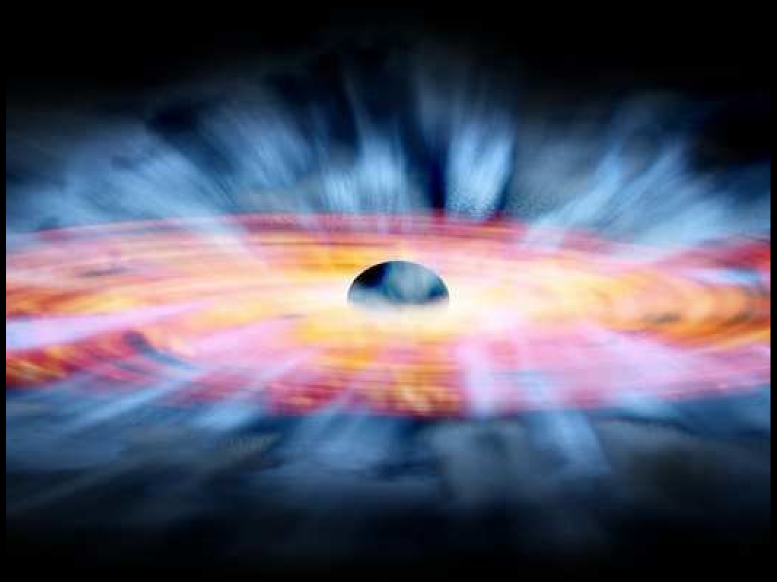
Peter Kosec

Andrew Fabian, Ciro Pinto, Dom Walton, Sergei Dyda, Chris Reynolds

Institute of Astronomy, University of Cambridge

Accretion disc winds

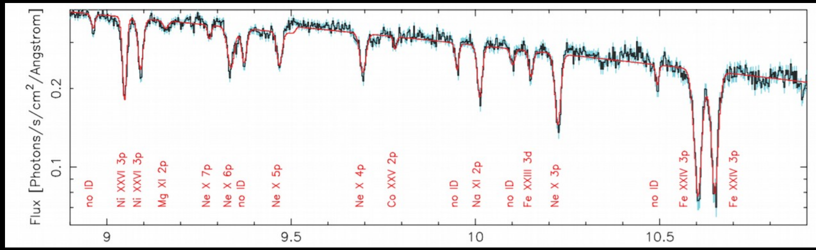
- Winds discovered in many different types of accreting systems
  - X-ray binaries, AGNs, ULXs
- The fastest outflows have potential to affect their surroundings greatly – AGN feedback + ULX bubbles
- Plethora of possible launching mechanisms
  - Radiation pressure, line driving, magnetic forces, thermal driving

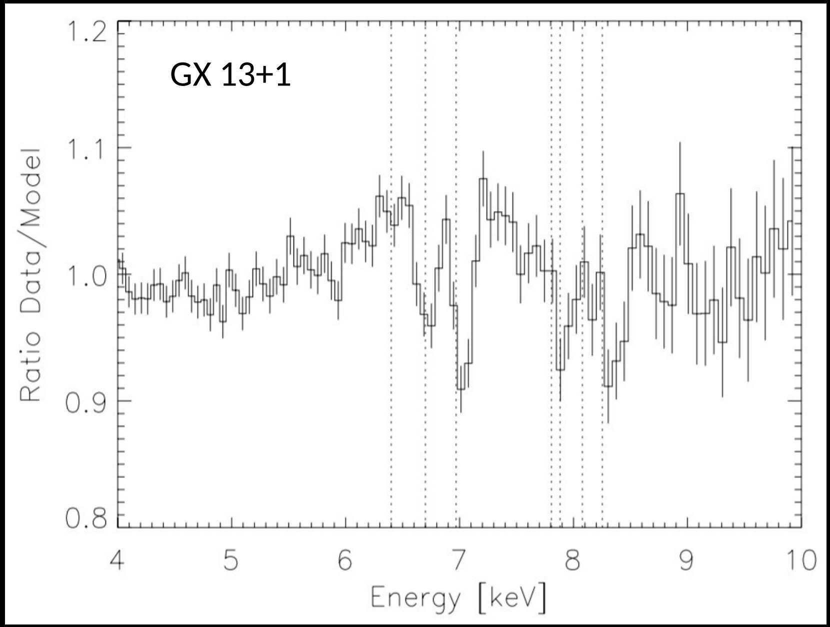


Accretion disc winds in X-ray binaries

- Blueshifted ionised absorption features ubiquitous in high inclination soft state black hole XRBs, also seen in multiple neutron star systems
- Launching mechanism
  - Radiation pressure on electrons insufficient, wind too ionised for line-driving
  - Compton heating and magnetic fields strong candidates for wind driving
- Solid angle
  - Could be as small as 5-10° from the disc
  - Governs the mass outflow rate

GRO J1655-40

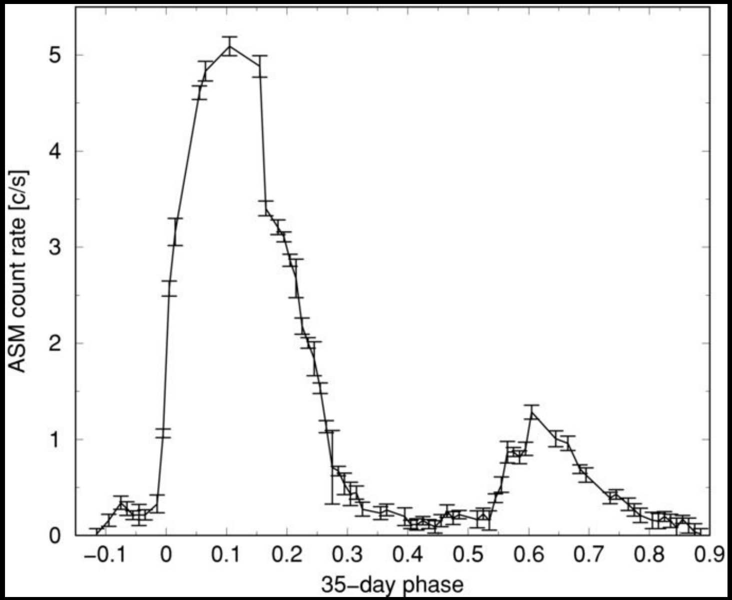


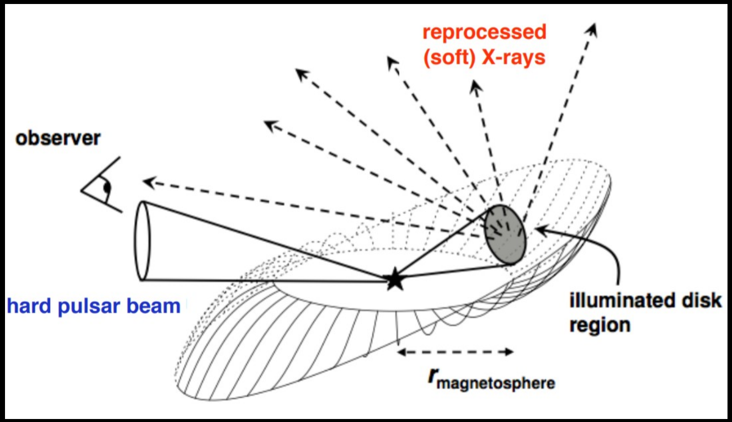


Miller et al. (2008), Ponti et al. (2012), Diaz Trigo et al. (2012)

Hercules X-1

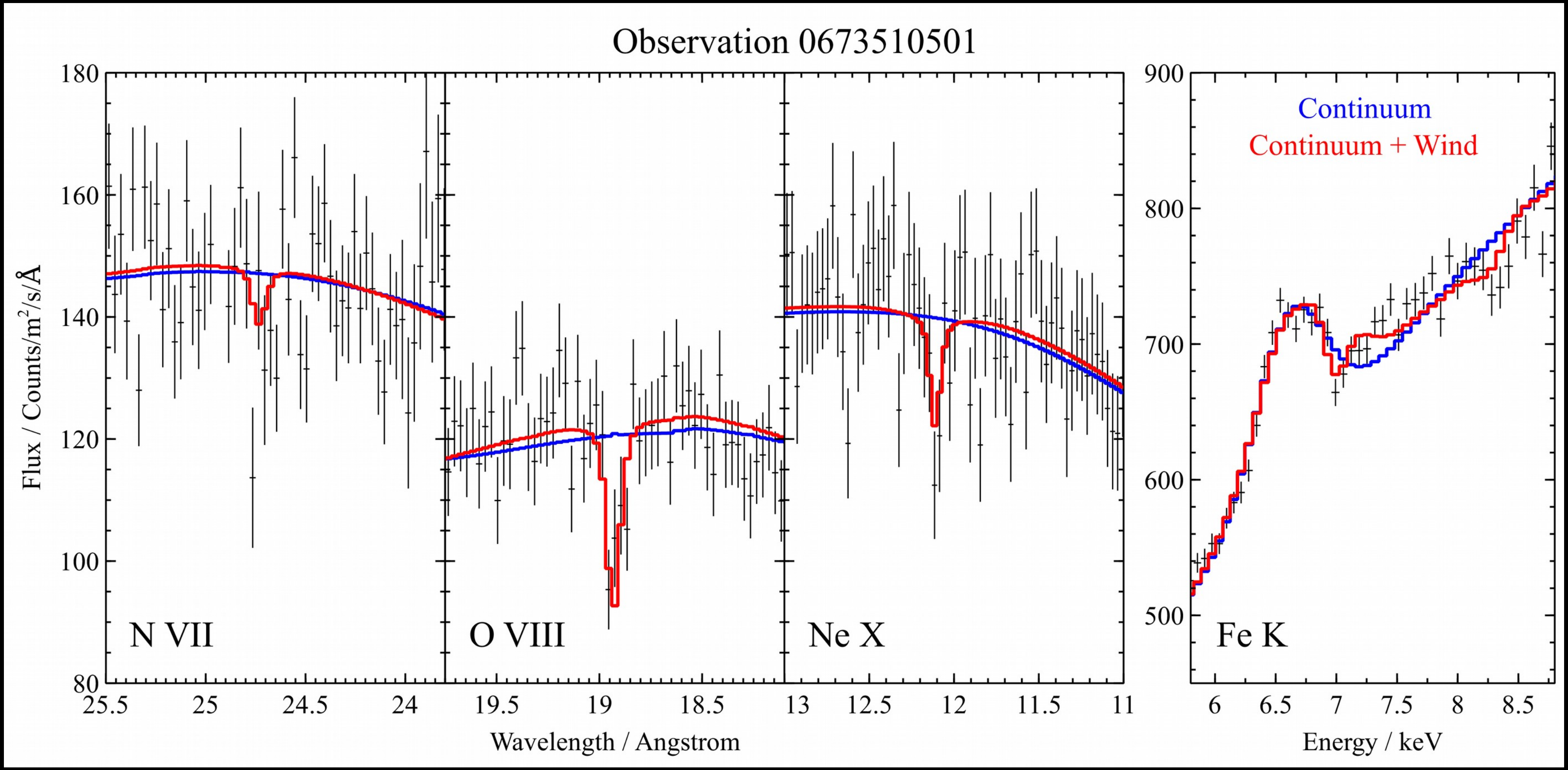
- Famous high inclination neutron star X-ray binary
- Cyclotron resonance feature at 37 keV
  - magnetic field of 10^{12} G truncating the accretion disc at ≈1000 Rg
- Characteristic 35 day period of flux variations – almost edge-on precessing warped disc
- Importantly: large archive of XMM-Newton observations



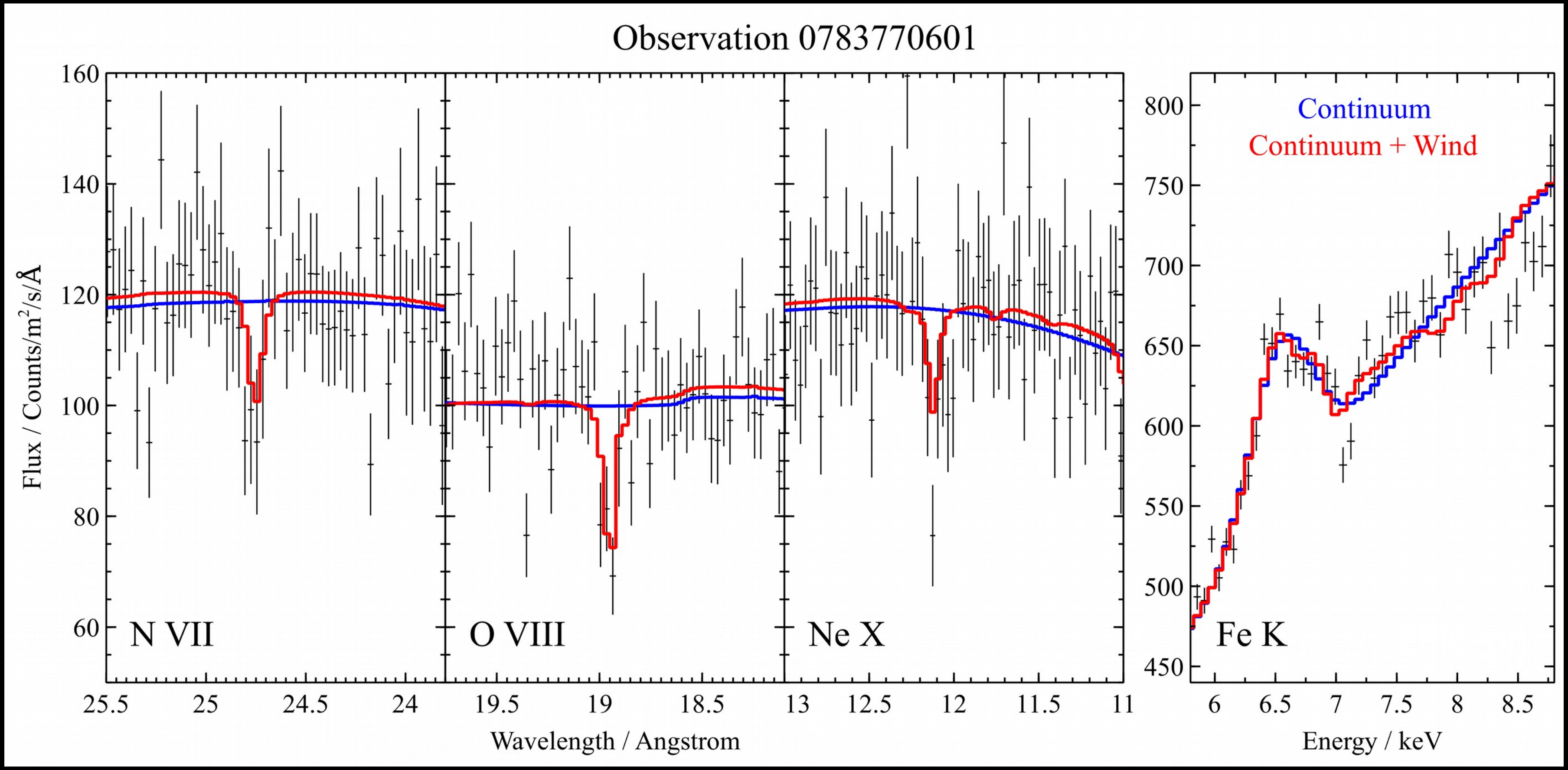


Giacconi et al. (1971), Trümper et al. (1978), Hickox et al. (2005), Leahy & Igna 2010

Absorption lines in XMM spectra

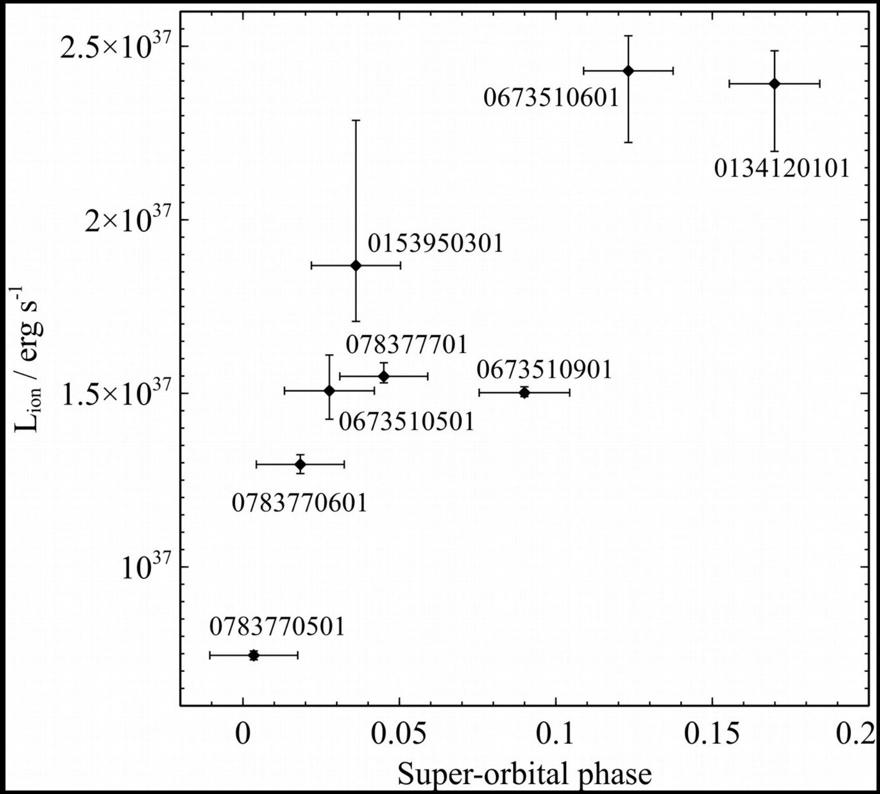


Absorption lines in XMM spectra

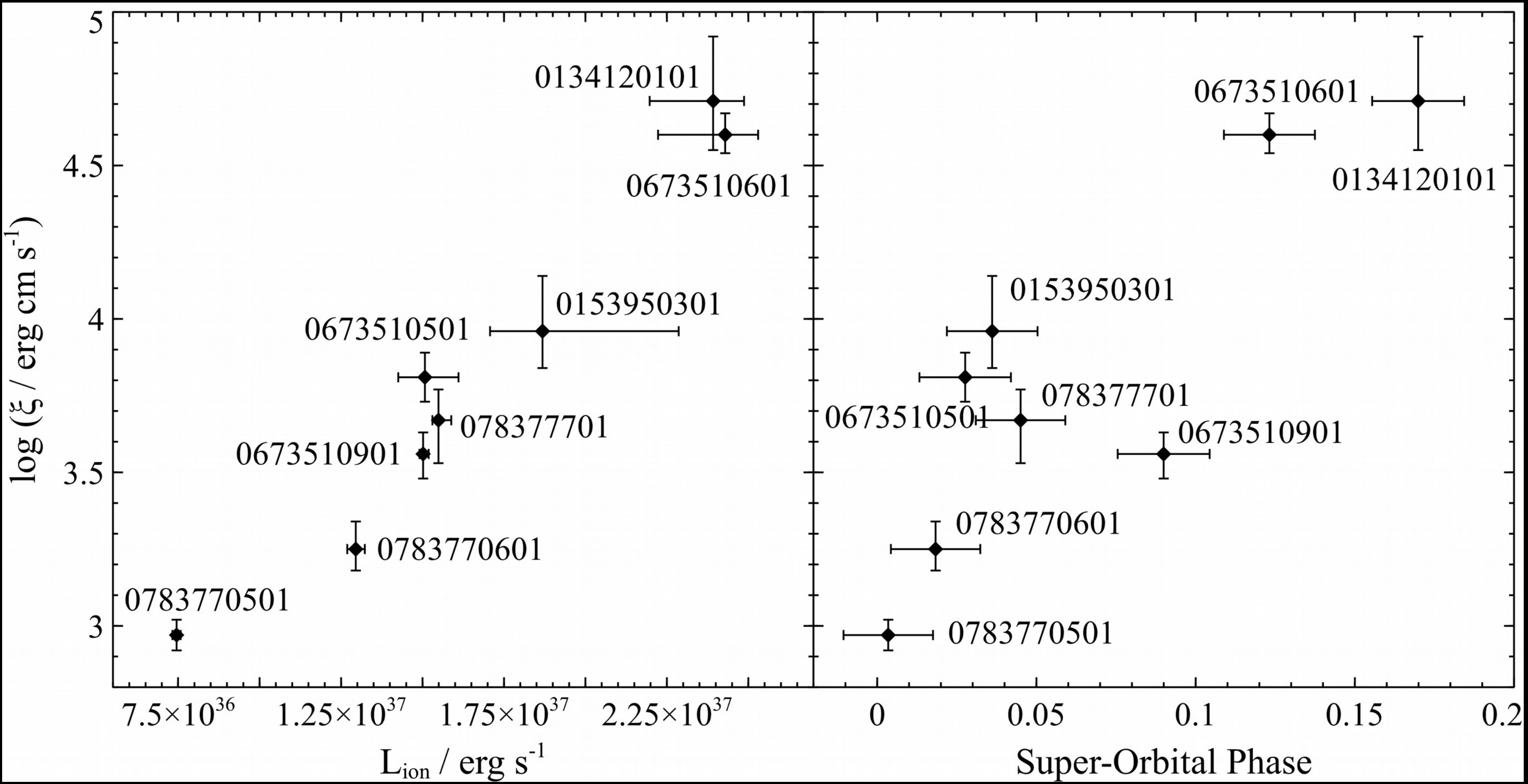


Ionised wind in the high state

- Blueshifted absorption detected in 9 out of 10 high state XMM observations
- Low state/short high observations: no significant detection in individual exposures or in stacked data
- Wind velocity between 200 and 1000 km/s
- Material highly ionised, ionisation varies between $\log \xi = 3 - 5$
- Correlations of wind properties with ionising luminosity, orbital and super-orbital phase



Ionisation parameter variation



Distance and wind mass outflow rate

- Use the ionisation parameter and column density:
  - $\xi = \frac{L_{ion}}{nr^2}$ — L_{ion} – 1-1000 Ryd luminosity
  - $n_H = n\Delta R = nR\delta R$ — δR – relative thickness of absorber

- Estimate the distance from the ionising source:
  - $R = \frac{L_{ion}}{n_H \xi} \delta R$

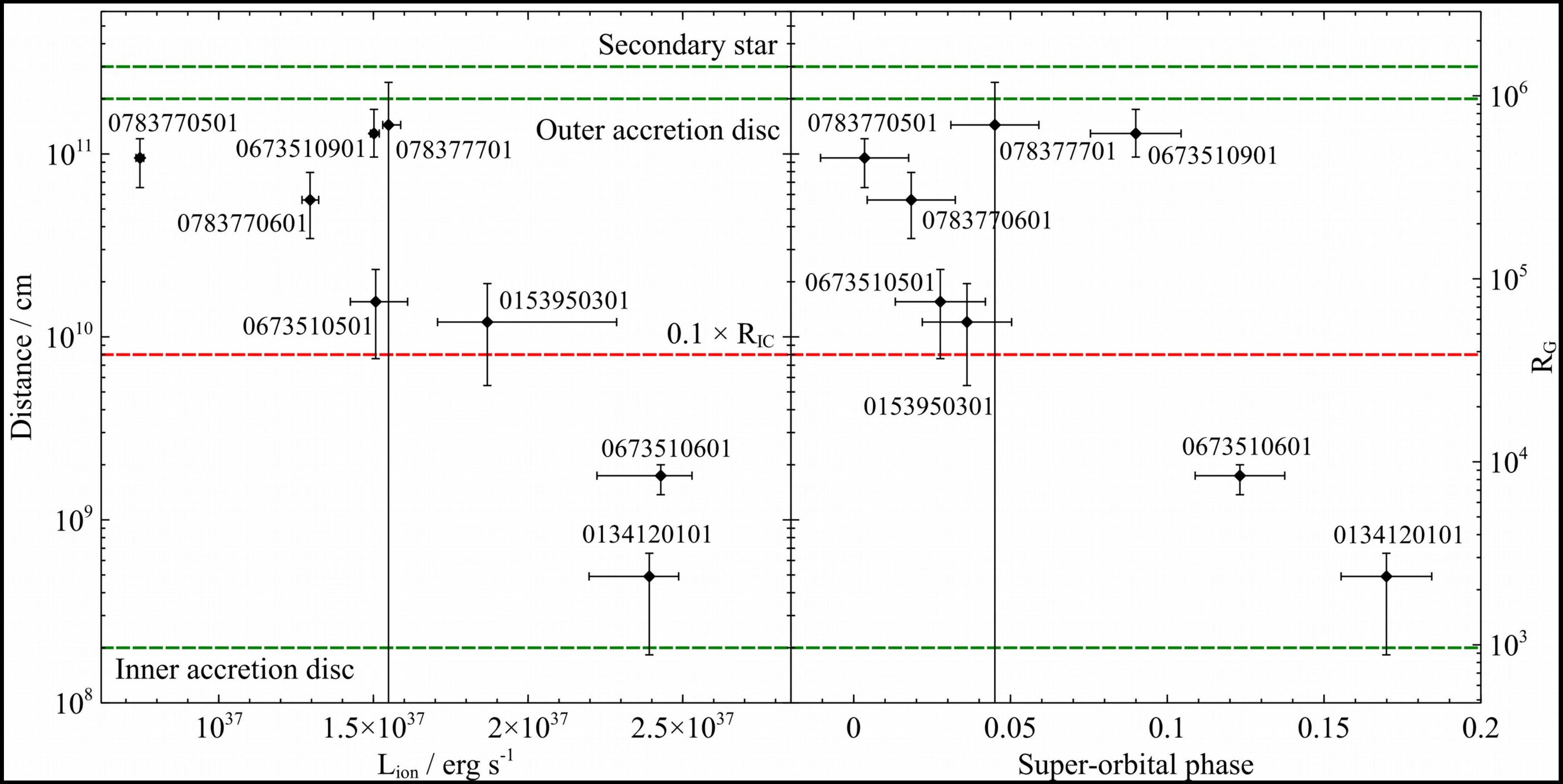
- The mass outflow rate:
  - $\dot{M} = \rho A v = C_V \mu m_p n \frac{\Omega}{4\pi} 4\pi R^2 v$
  - $\dot{M} = 4\pi \mu m_p \frac{L_{ion}}{\xi} v \, C_V \frac{\Omega}{4\pi}$

$\frac{\Omega}{4\pi}$ – wind launch solid angle

C_V – clumping factor

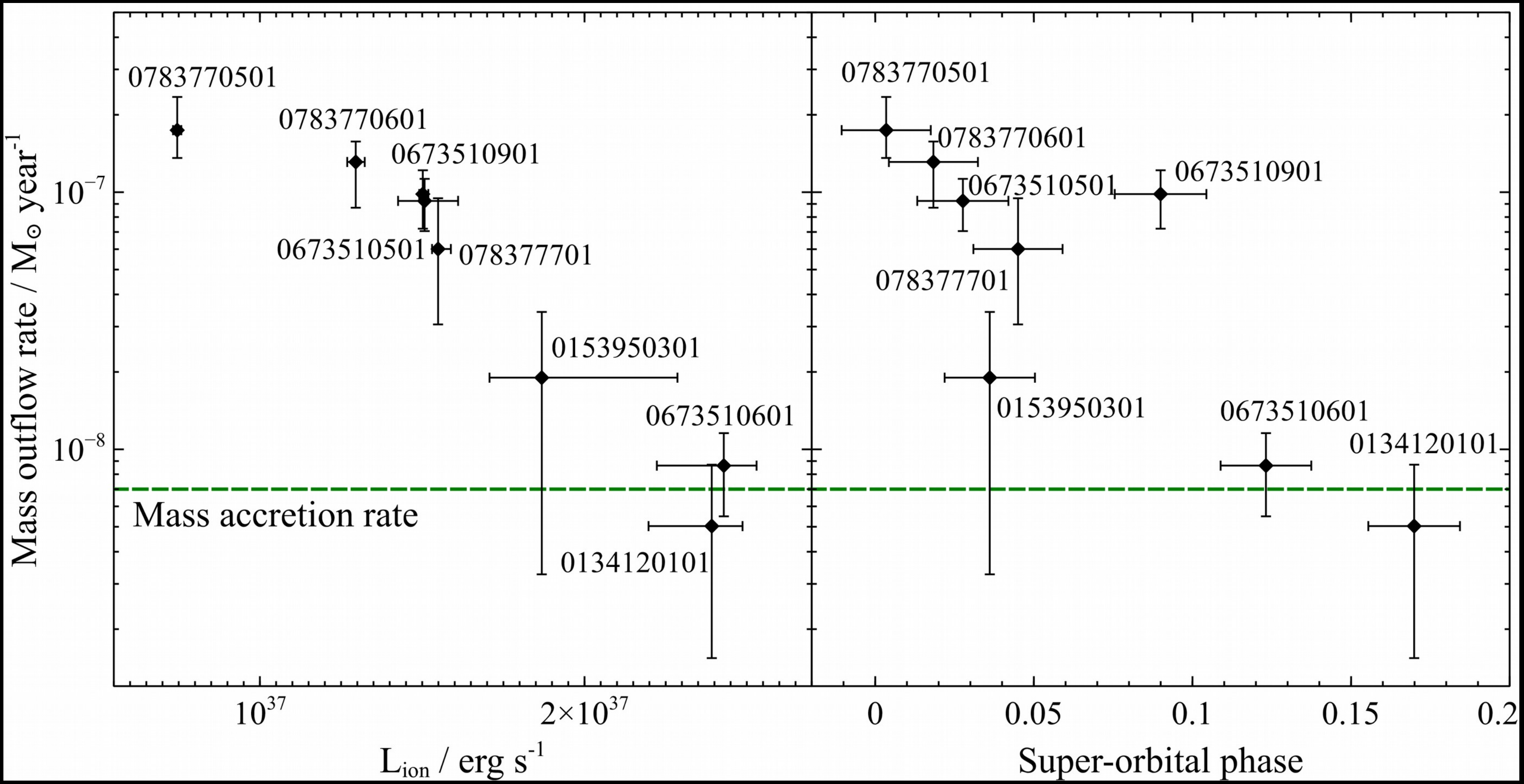
μ – mean particle weight

Distance



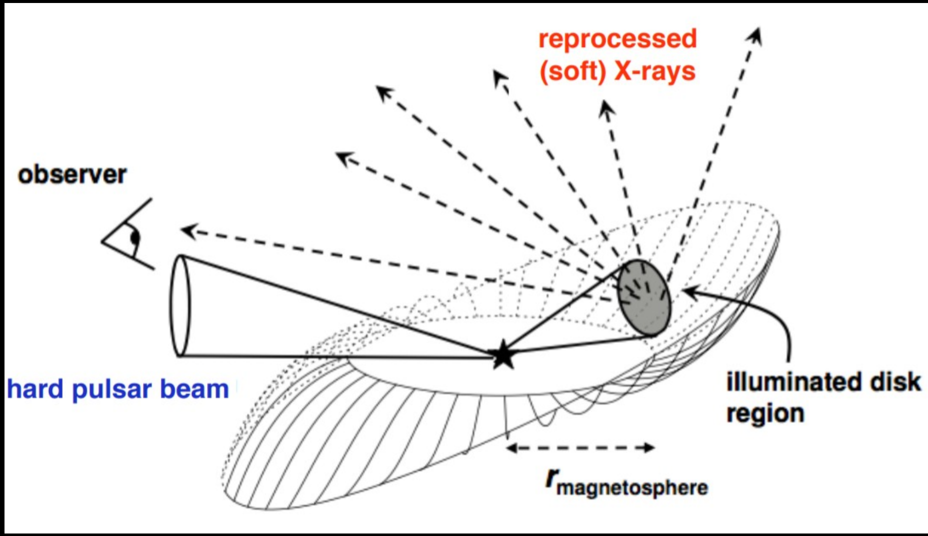
Secondary star
Outer accretion disc
0.1 × R_{IC}
Inner accretion disc
0783770501
0673510901
078377701
0783770601
0673510501
0153950301
0673510601
0134120101
Distance / cm
10^{11}
10^{10}
10^{9}
10^{8}
10^{37}
1.5×10^{37}
2×10^{37}
2.5×10^{37}
L_{ion} / erg s^{-1}
0
0.05
0.1
0.15
0.2
Super-orbital phase
R_G
10^6
10^5
10^4
10^3

Mass outflow rate



Is the super-orbital period driving the correlations?

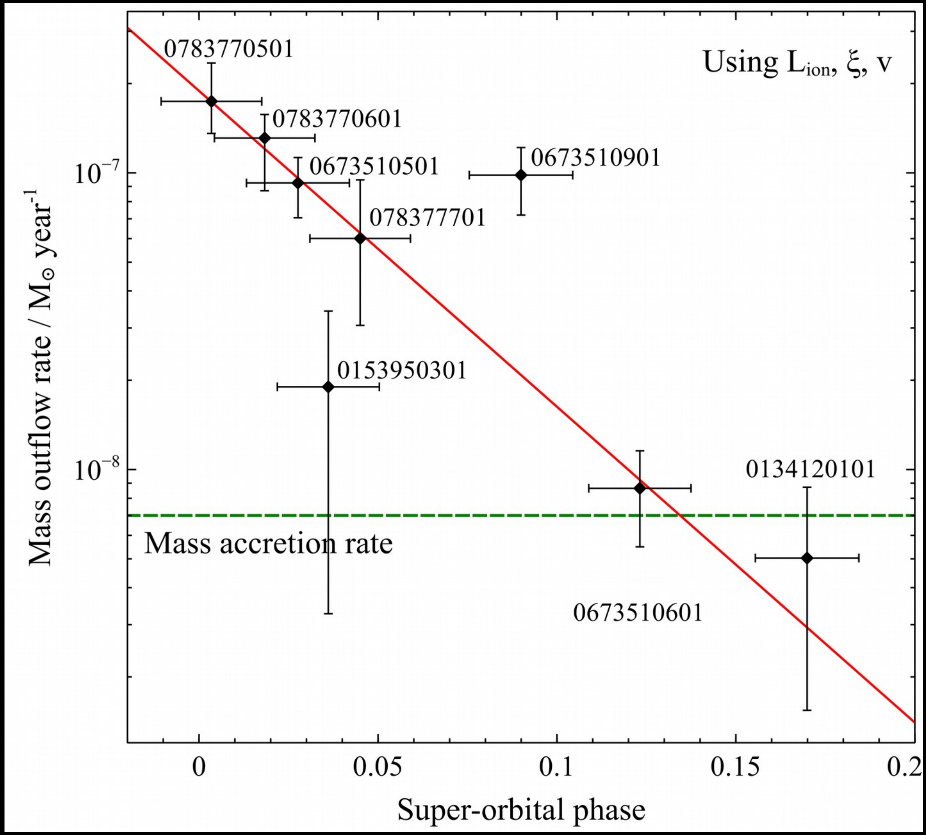
- If super-orbital variation drives the correlations, we are measuring the variation of vertical wind structure
- Can estimate the solid angle corrected mass outflow rate



Hickox et al. (2005)

Is the super-orbital period driving the correlations?

- If super-orbital variation drives the correlations, we are measuring the variation of vertical wind structure
- Can estimate the solid angle corrected mass outflow rate
- Assume a simple dependence between phase and inclination, and maximum inclination ≈ 5°
- Mass outflow rate ≈ 60-70% of mass accretion rate through the disc



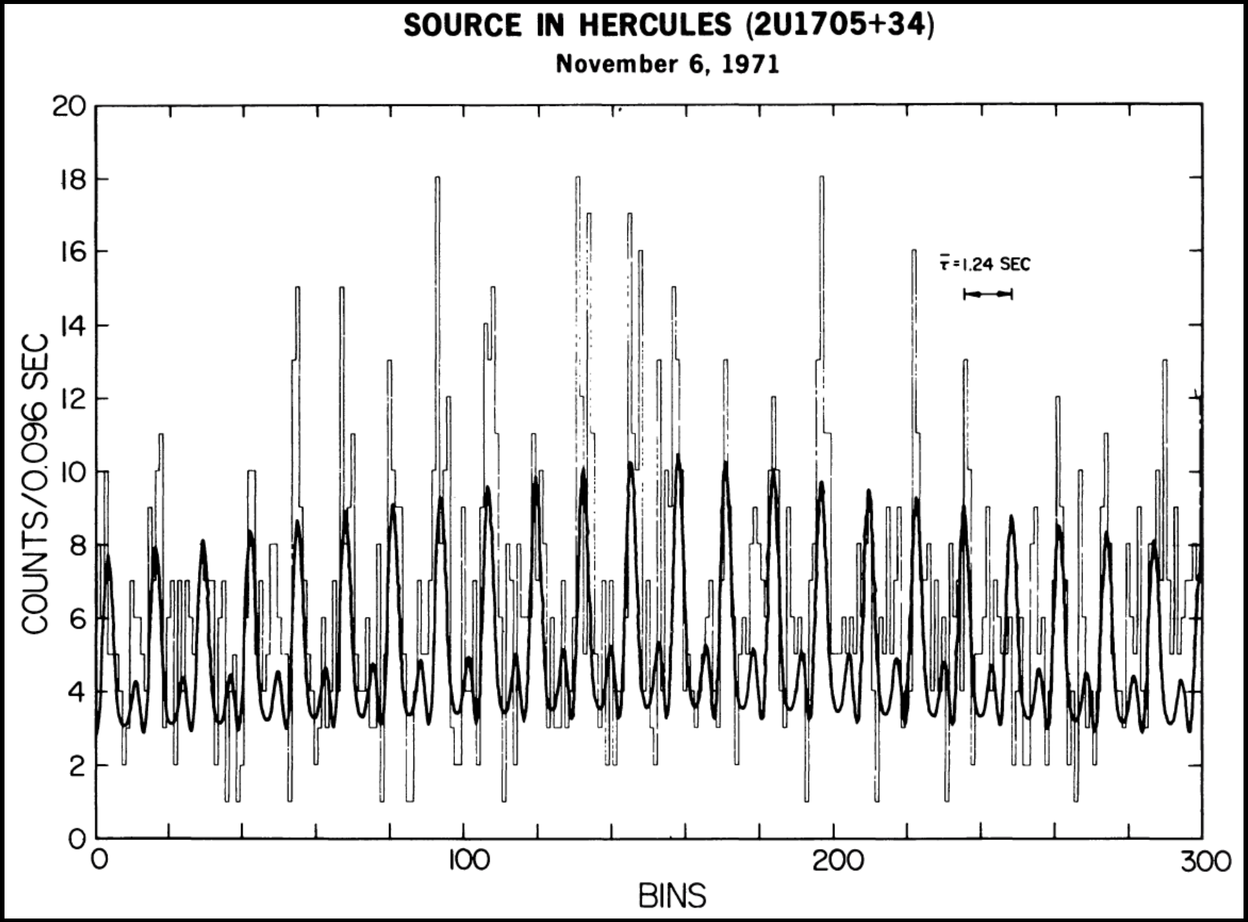
Leahy et al. (2002)

Conclusions

- We significantly detect ionised wind in the spectrum of Hercules X-1 during most XMM-Newton observations of its high state
- The wind originates in the accretion disc and is launched by Compton heating of the outer disc or by magnetic fields
- The wind ionisation varies significantly with both the luminosity and super-orbital phase of Her X-1
- If the wind variability is driven by the super-orbital phase, we are scanning variations in the wind vertical structure and can infer the solid-angle corrected mass outflow rate to be 60-70% of mass accretion rate

Extra Slides

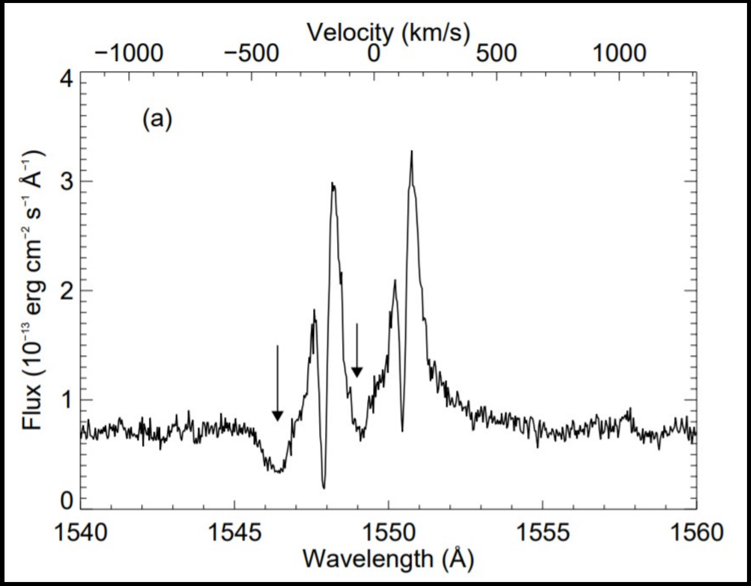
Hercules X-1

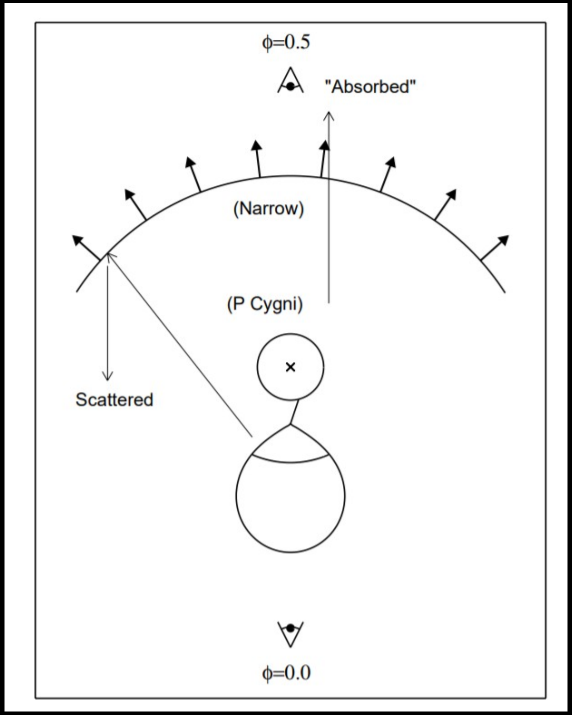


Tananbaum et al. (1972)

A circumbinary wind in Her X-1?

- Blueshifted absorption lines found in UV
- Origin: a circumbinary wind launched from the irradiated side of secondary?

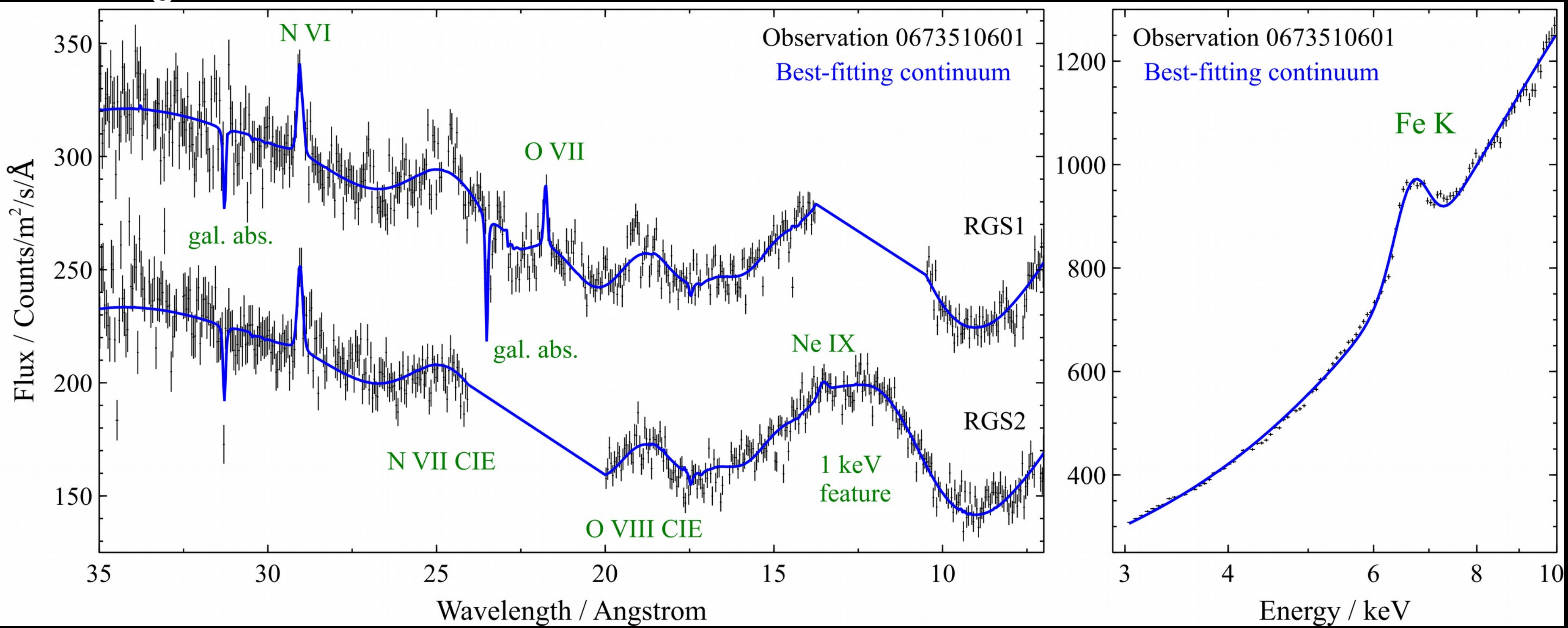




Boroson et al. (2001)

High state X-ray spectrum of Her X-1

- g



Methods and detection significance

- Fit pn and RGS data with the final continuum model:
  - $hot \times (comptt + bb + 2\ gauss + 3\ gauss + cie)$
- Fit the continuum model, recover C-stat
- Then add the photo-ionised wind component $pion$, fit and recover fit improvement ΔC-stat
- ΔC-stat determines the detection significance, ΔC-stat>25 usually considered a significant detection
- Low state observations: no significant detection in individual exposures or in stacked data

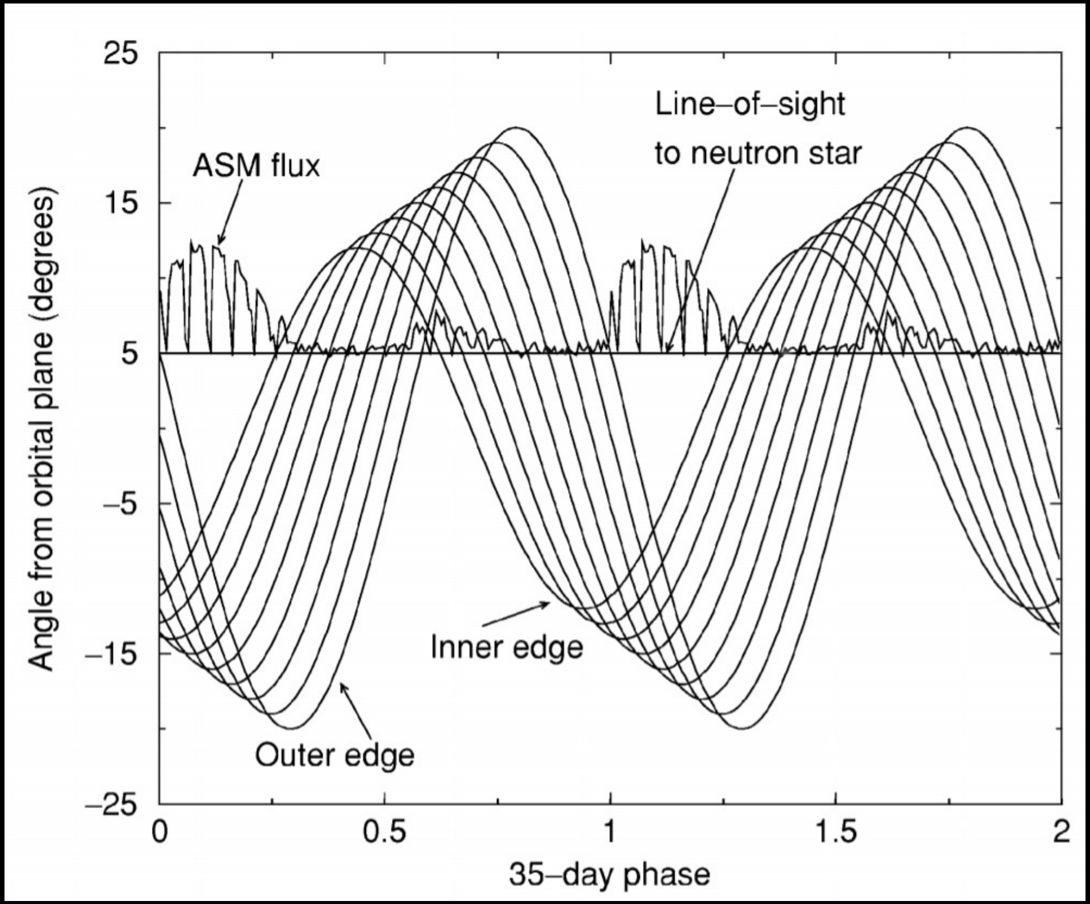
Observation ID	ΔC-stat
0134120101	10.96
0153950301	26.00
0673510501	88.20
0673510601	34.69
0673510801	2.72
0673510901	37.20
0783770501	49.86
0783770601	81.67
0783770701	15.13

Wind launching mechanism

- Compton heating of the outer accretion disc
  - A wind is launched above a critical luminosity: $L_{cr} = 0.03(T_{IC}/10^8 K)^{-\frac{1}{2}} L_E$

  where $T_{IC} = \frac{<\varepsilon>}{4k} \approx 3\ keV \approx 3.5 \times 10^7 K$
  - For Her X-1 in high state, $L_{cr} \gtrsim 1.1 \times 10^{37} erg/s$ **is satisfied**
- The wind should be launched at radii larger than:
  - $R > 0.1 \frac{GM\mu m_p}{kT_{IC}} \approx 8 \times 10^9\ cm$
- Alternatively, wind could be launched magnetically

Blandford&Payne 82; Begelman+83

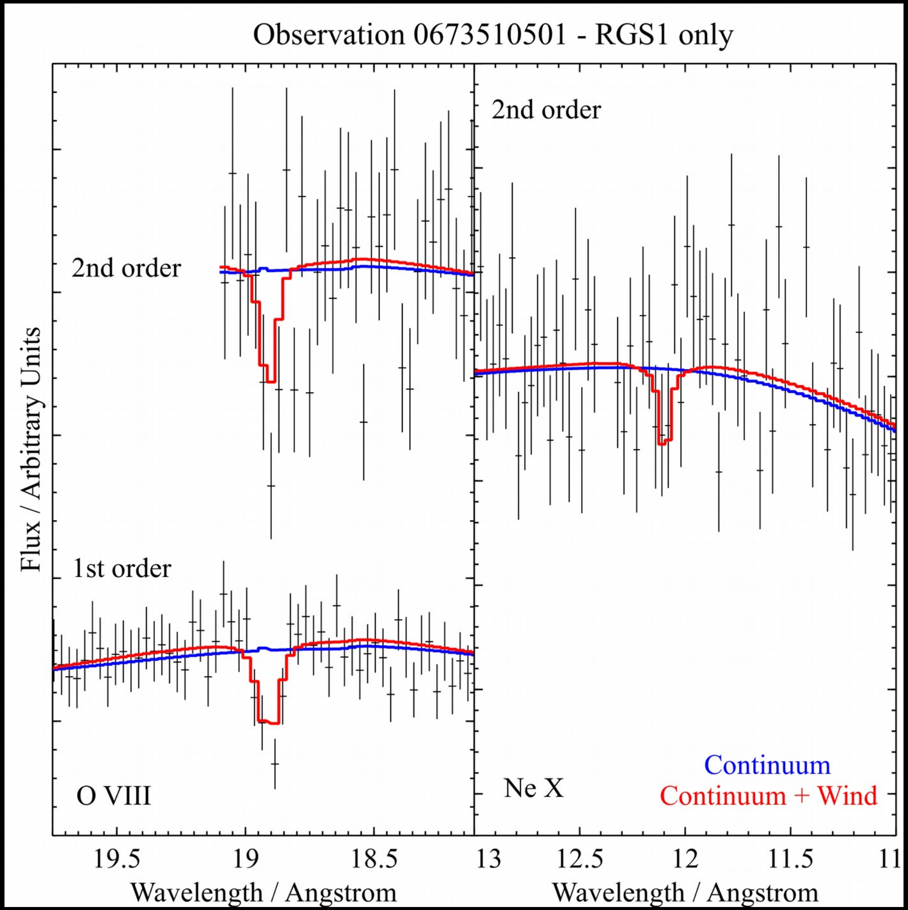


Line–of–sight
to neutron star
ASM flux
Inner edge
Outer edge
Angle from orbital plane (degrees)
35–day phase
25
15
5
–5
–15
–25
0
0.5
1
1.5
2

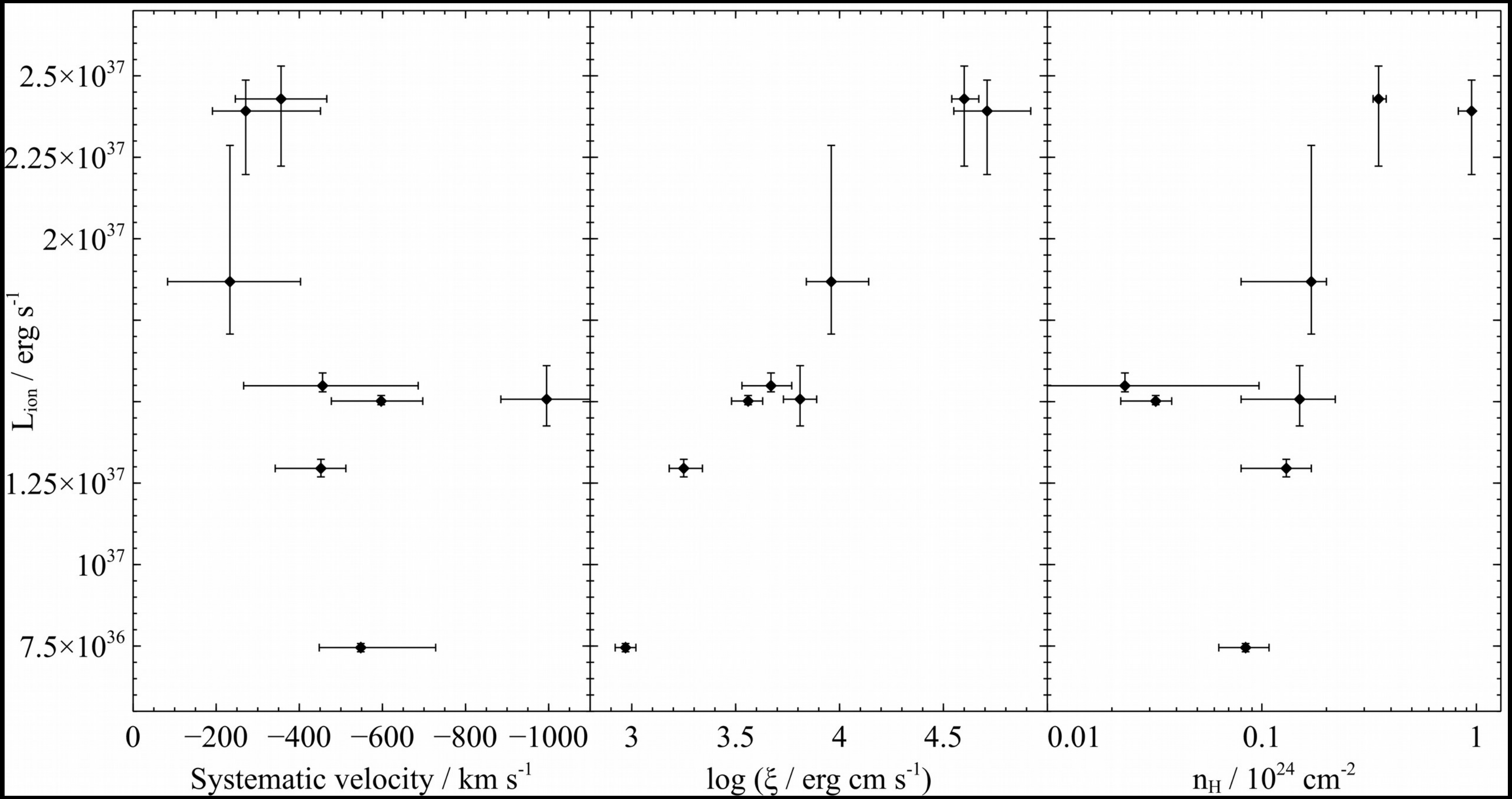
Leahy+02

Photon pile-up

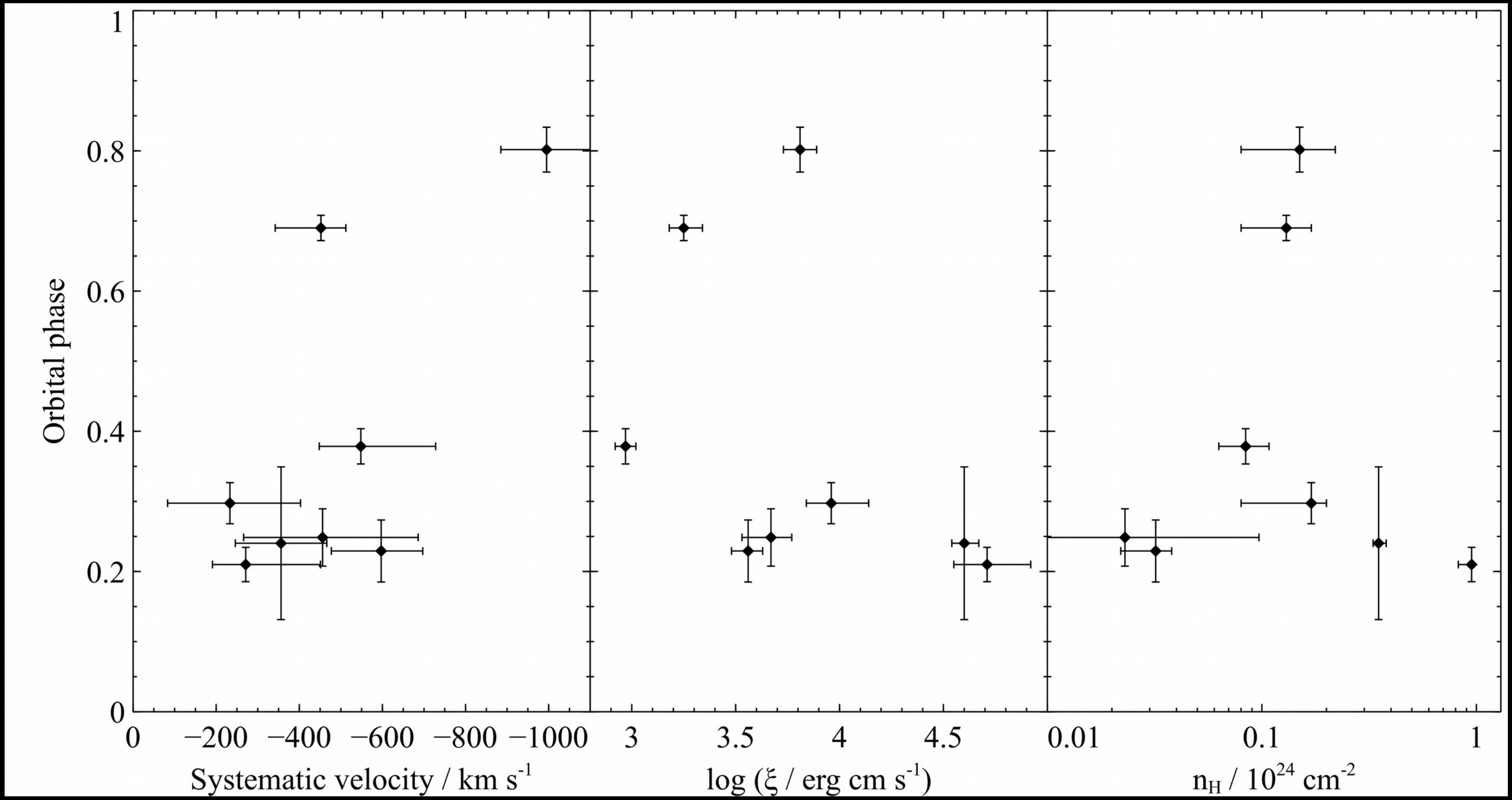
- Brightest observations could be affected by piled-up (but unlikely to introduce absorption lines)
- Average count rates up to 800 cts/s in pn (timing mode), up to 20 cts/s in RGS
- Least affected is RGS1
- Using just RGS1, at least one observation still shows significant detection of wind (ΔC-stat = 33.12)



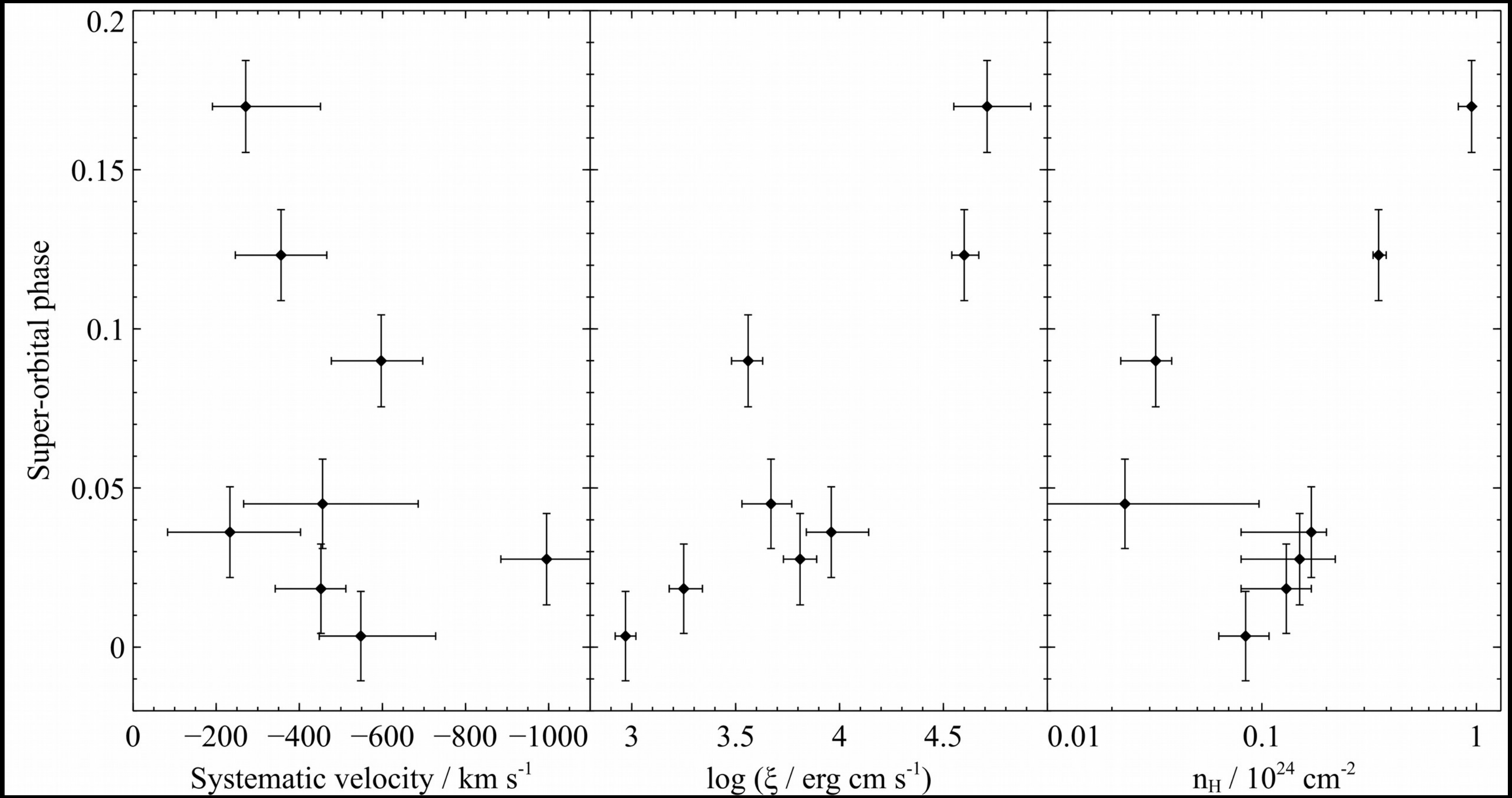
Wind parameters vs ionising luminosity



Wind parameters vs orbital phase



Wind parameters vs super-orbital phase

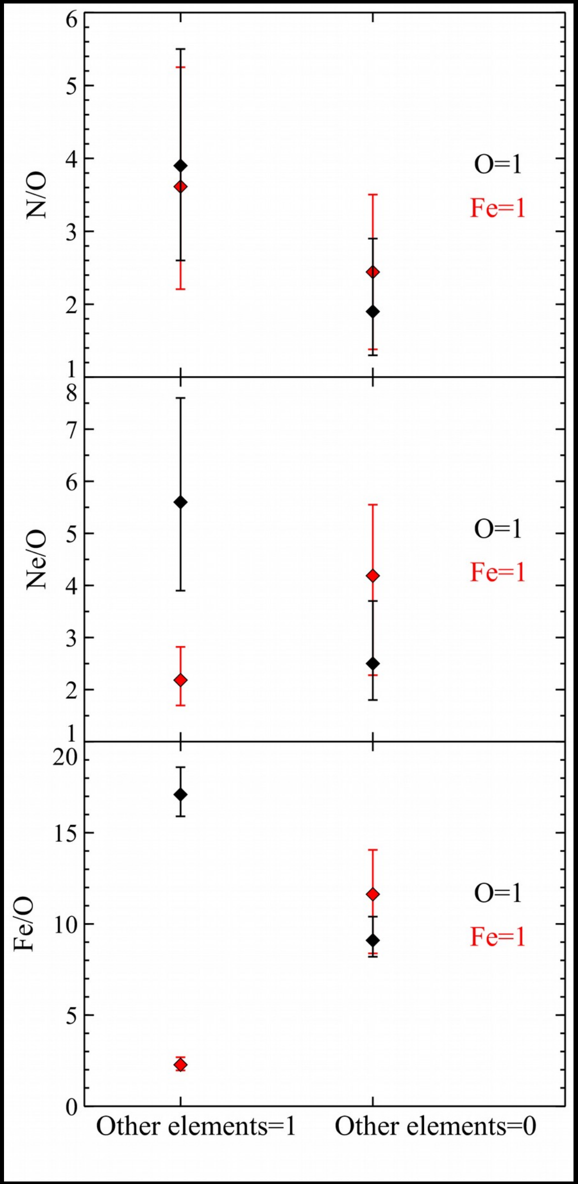


Abundance ratios in the wind

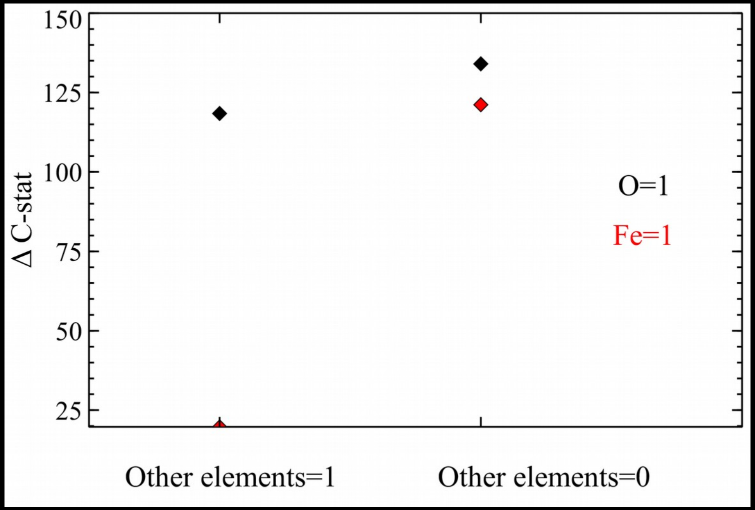
- Use the wind absorption lines to constrain the abundances in the system
- Simultaneously fit 5 observations, fit N, O, Ne, Fe (fix either N or Fe to 1), other elements fix to 1 or 0

Abundance ratios in the wind

- Use the wind absorption lines to constrain the abundances in the system
- Simultaneously fit 5 observations, fit N, O, Ne, Fe (fix either N or Fe to 1), other elements fix to 1 or 0
- Confirm the previous results of N/O≈Ne/O≈ 4
- Surprisingly also find very high Fe/O≈10



Fit improvement upon freeing abundances:



Jimenez-Garate+05