Evidence for a Variable Ultrafast Outflow in NGC 300 ULX-1

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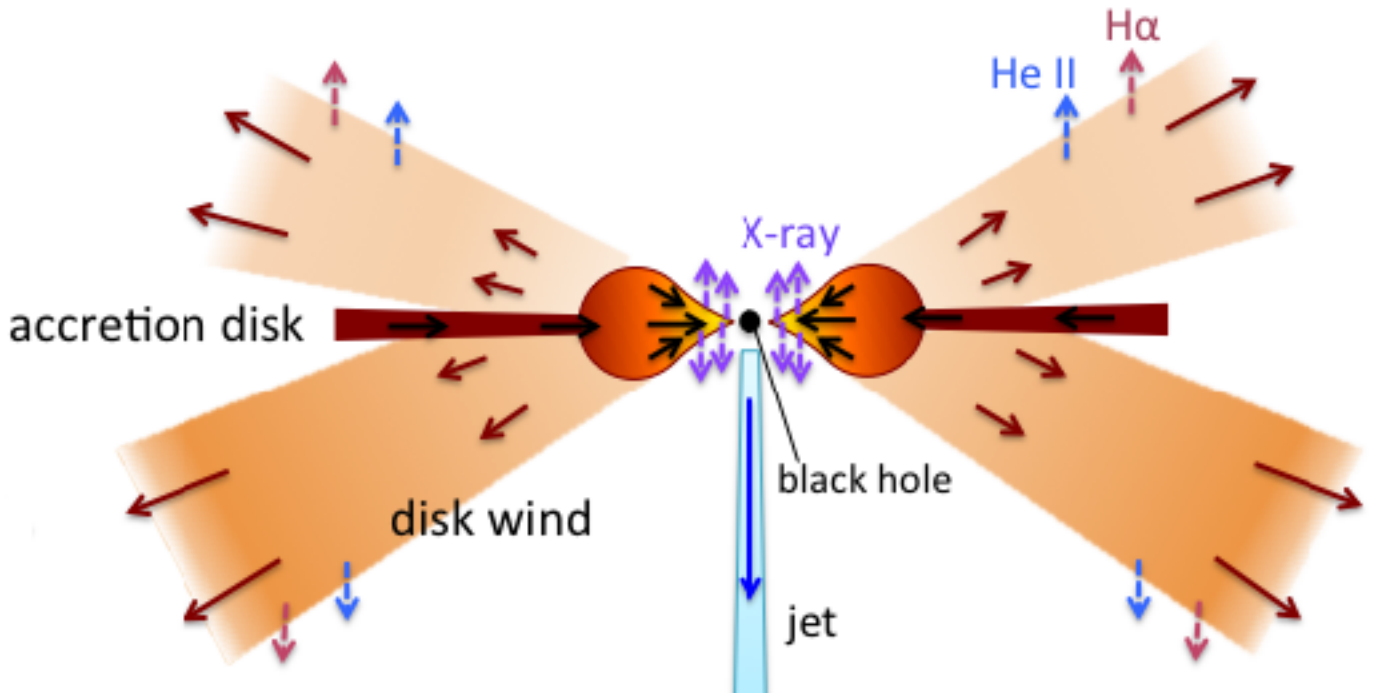
Super-Eddington Accretion and Outflows

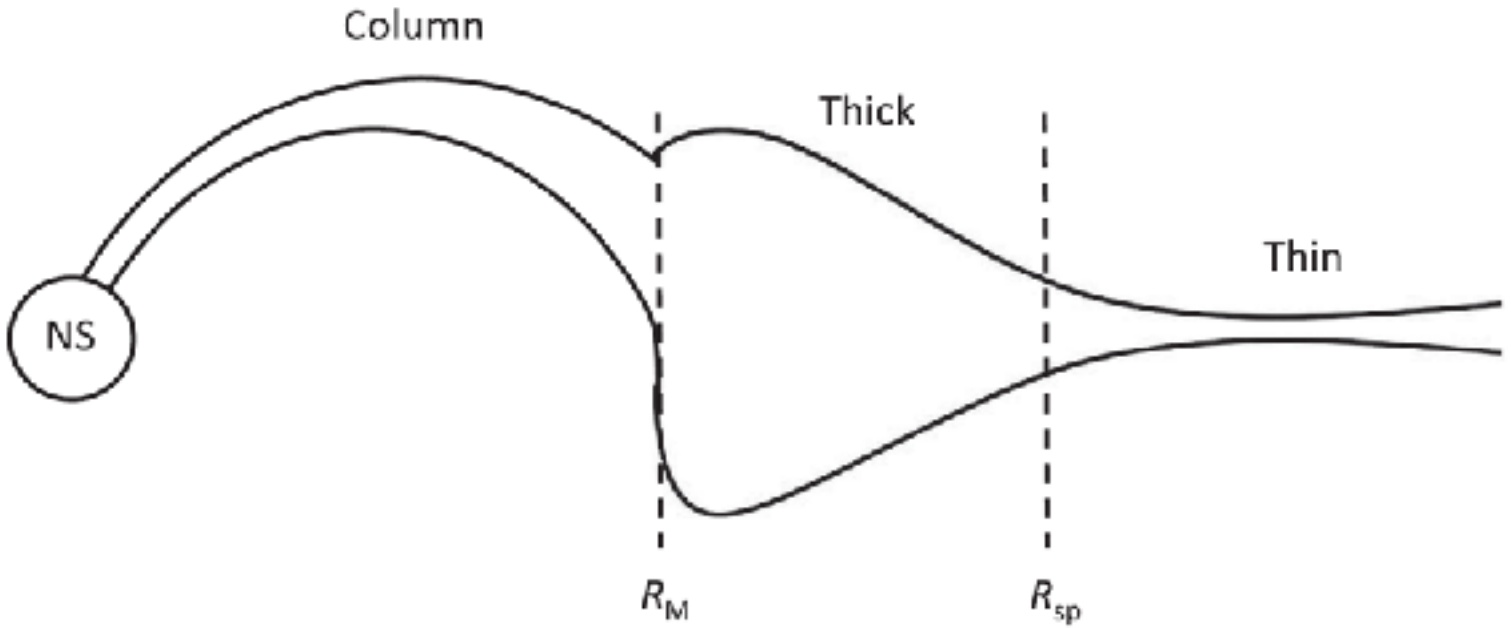


- A geometrically thick disk is required
- Crucial prediction: outflows at relativistic speeds
- Expect different observational signatures at different viewing angles

Shakura & Sunyaev 1973; Poutanen+07

Credit: Kyoto University

Super-Eddington Accretion and Outflows



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Shakura & Sunyaev 1973; Poutanen+07

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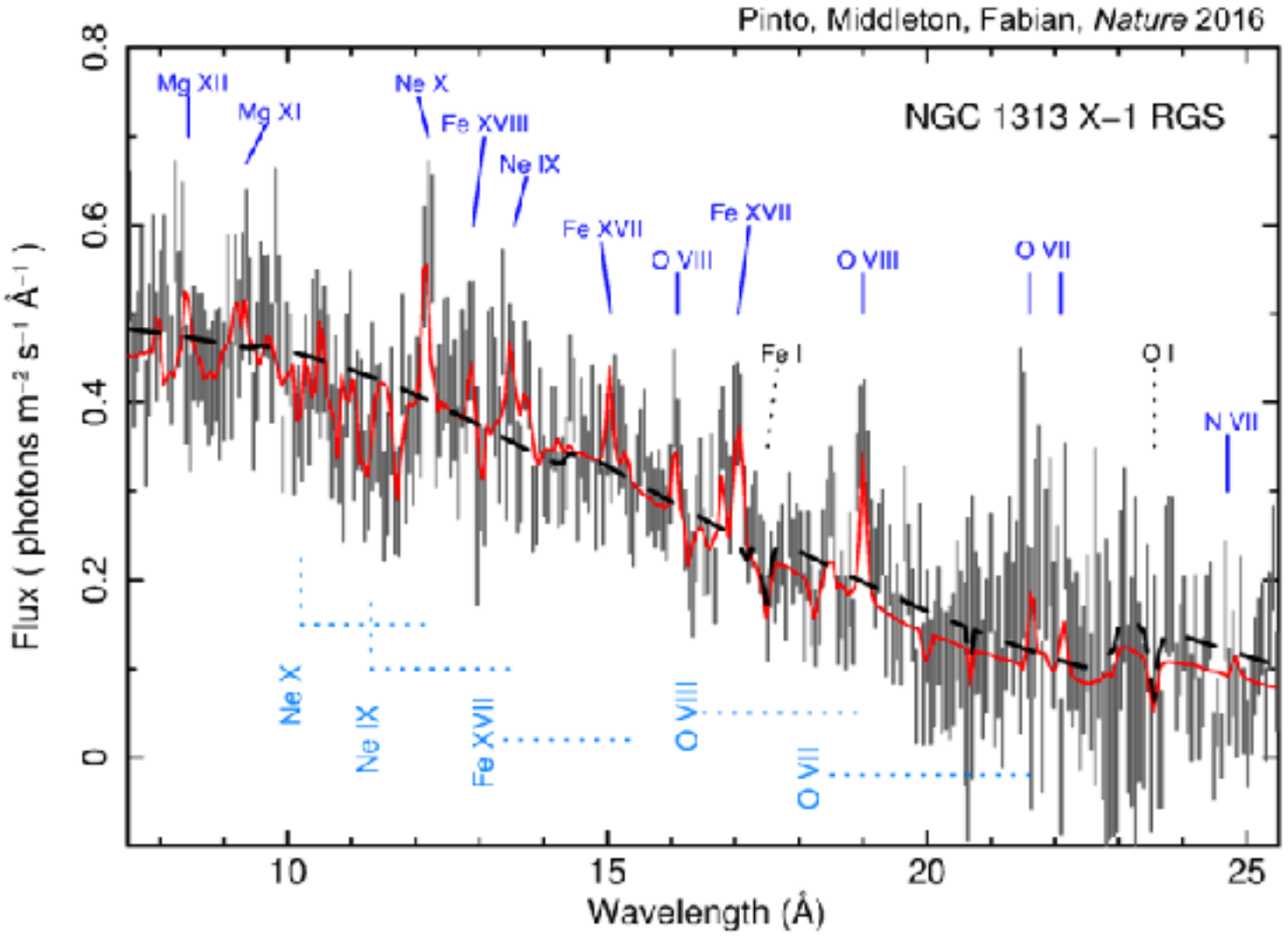
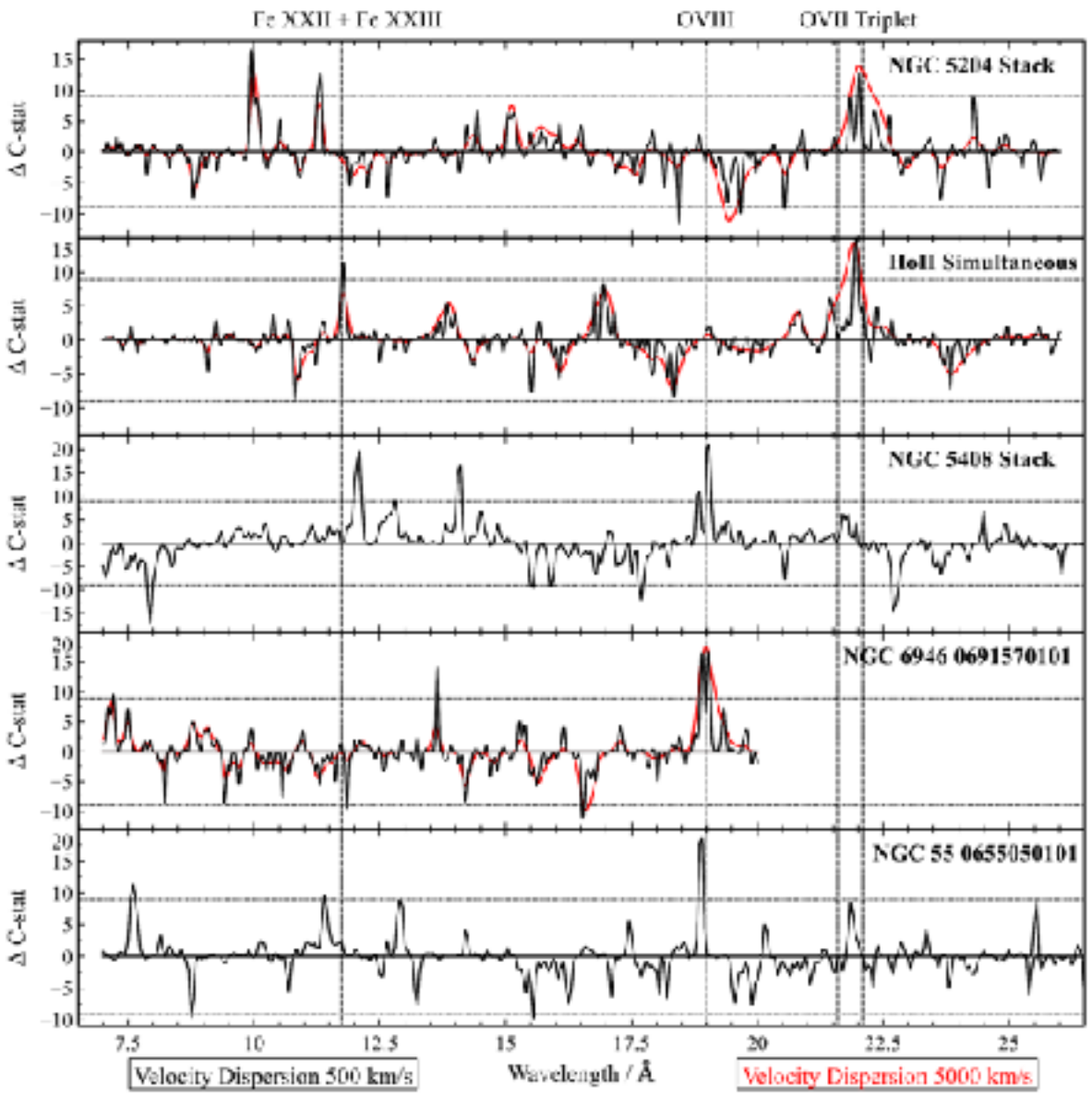
Detection of Outflows in ULXs

- Observationally challenging!
- Not possible with just X-ray CCD instruments – need high spectral resolution
- 3 objects with outflows found: NGC 1313 X-1, NGC 5408 X-1, NGC 55 ULX
- Observational signatures: blueshifted photoionised absorption + rest-frame collisionally ionised emission



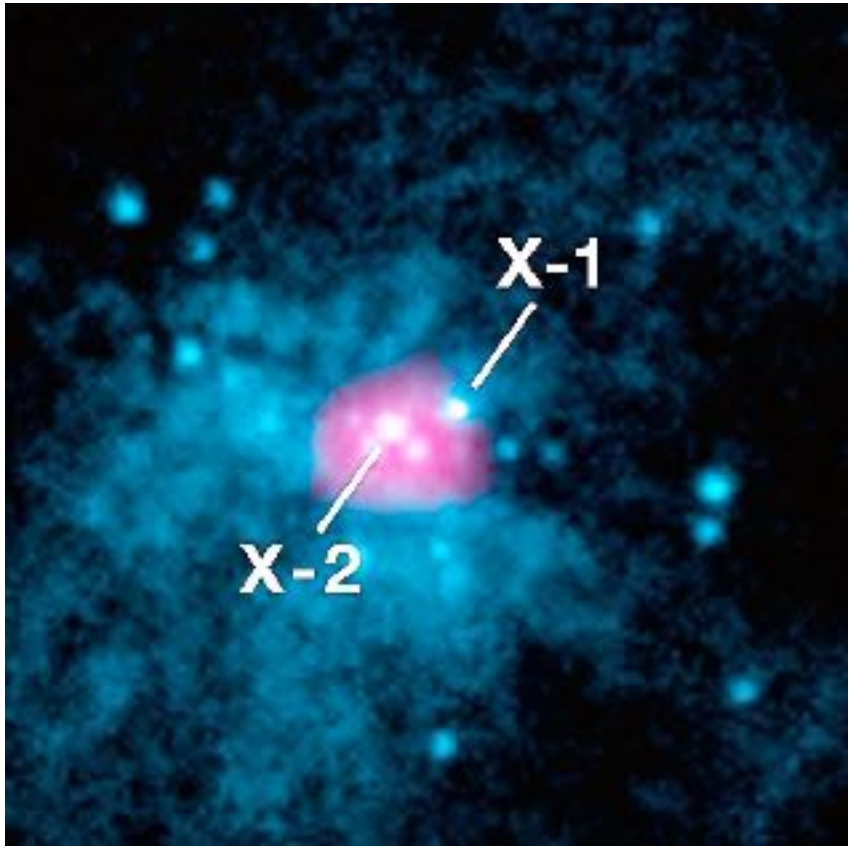
Are There More ULXs with outflows?

- Study 10 other bright ULX: current data insufficient to significantly detect more outflows
- ULXs with good quality data show oxygen emission (O VII or O VIII)
- Different line widths – shocked/ photoionised plasma around the ULX (possible contribution from nearby star-formation)
- NGC 5204 X-1: evidence (3σ) for a jet with a projected velocity of 0.34c



No Outflows in PULXs So Far…

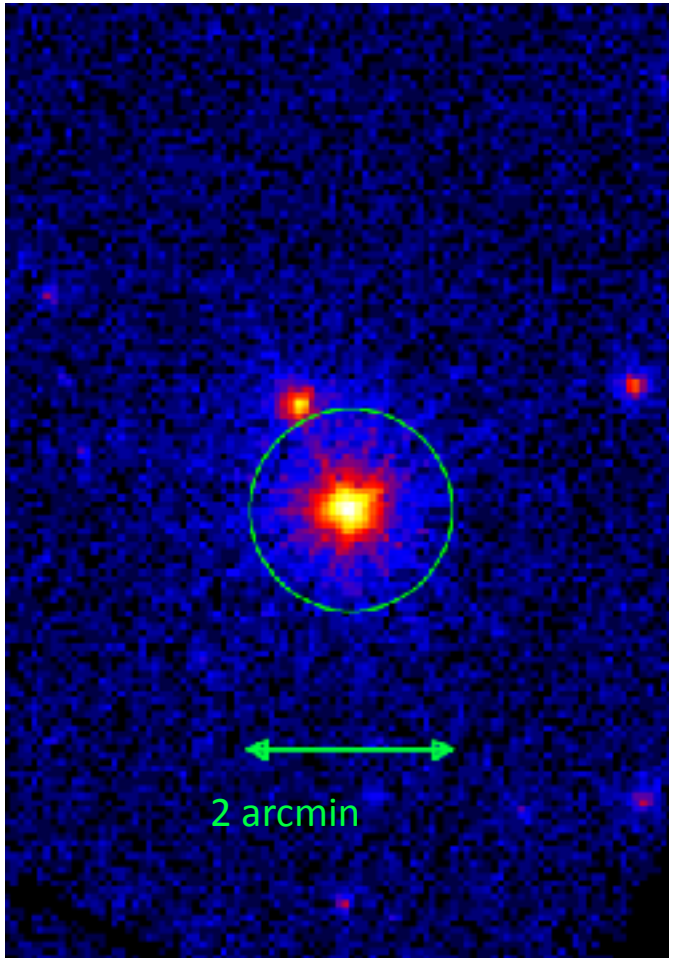
- Observational difficulties: as of Dec 2017, only 3 sources to study!
  - NGC 5907 X-1 – too distant (14 Mpc)
  - M82 X-2 – crowded field (cant study with gratings)
- Until recently, NGC 7793 P13 the only object we are able to study with gratings (work in progress)



Credit: NASA/JPL-Caltech/SAO

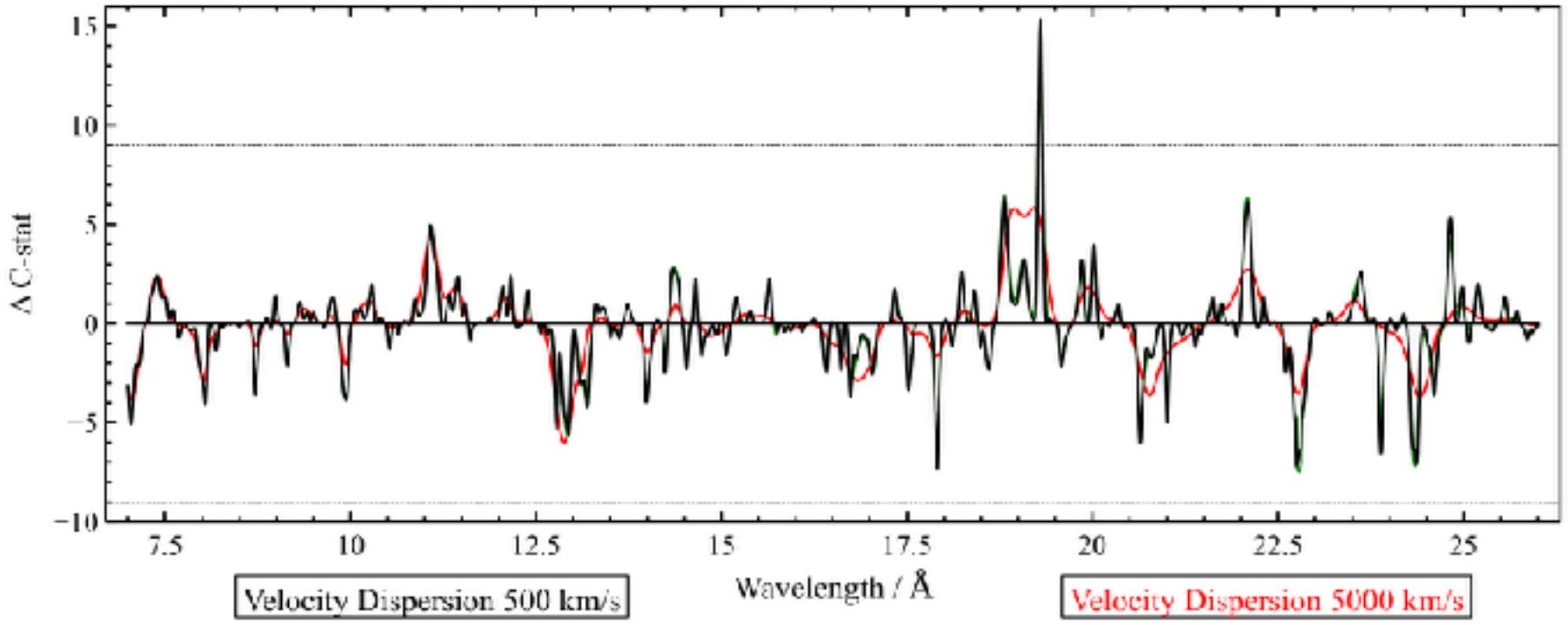
NGC 300 ULX-1: 4th ULP

- Discovered as an X-ray binary, brightened into ULX state by 2016, L≈3×10^39 erg/s
- Flux comparable to P13, not in a crowded field:
  - good candidate for a high spectral resolution study!
- In 2016, observed simultaneously by XMM-Newton (2 observations back-to-back) and NuSTAR (1 observation)
- We analyse the 2 XMM observations separately



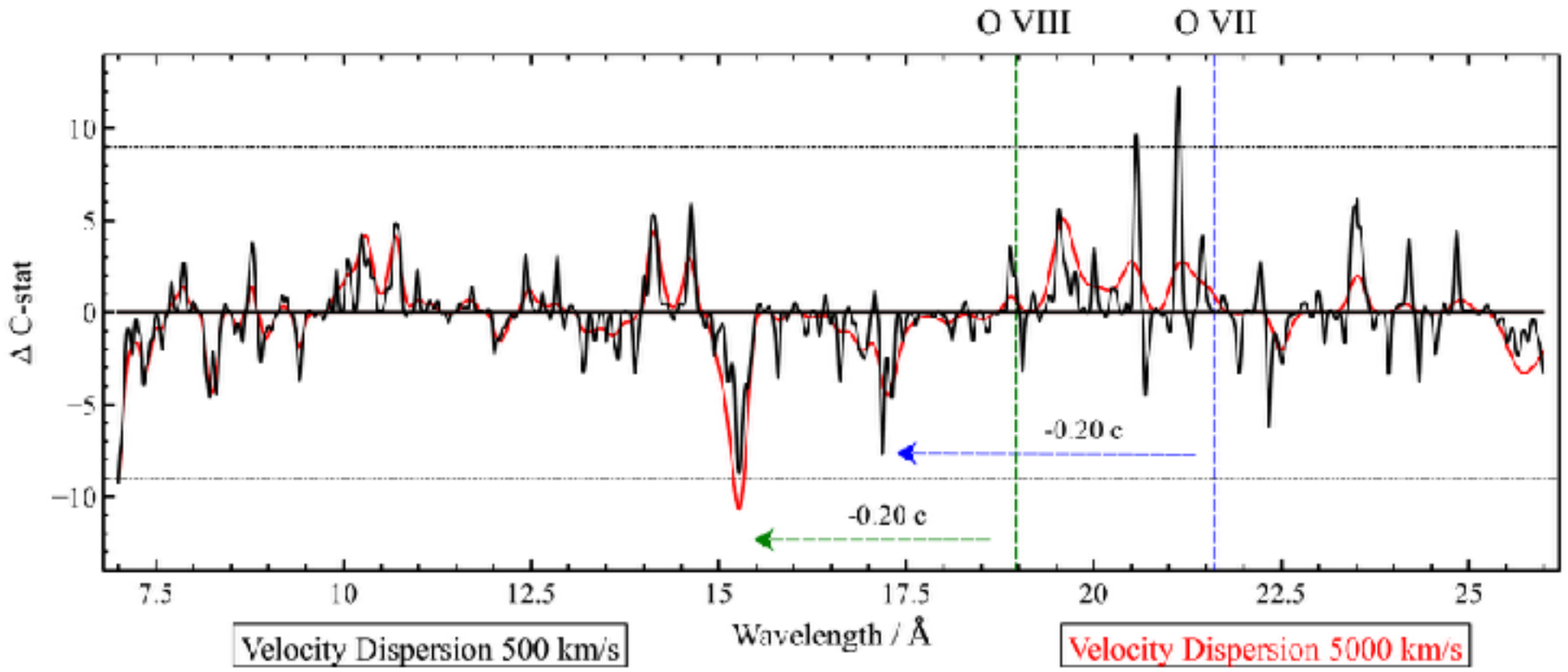
First Observation – RGS Gaussian Line Scan

- Fit the CCD and RGS continuum with a phenomenological model (blackbody, color-corrected blackbody and powerlaw) and scan the RGS energy band with a Gaussian
- No evidence for a UFO



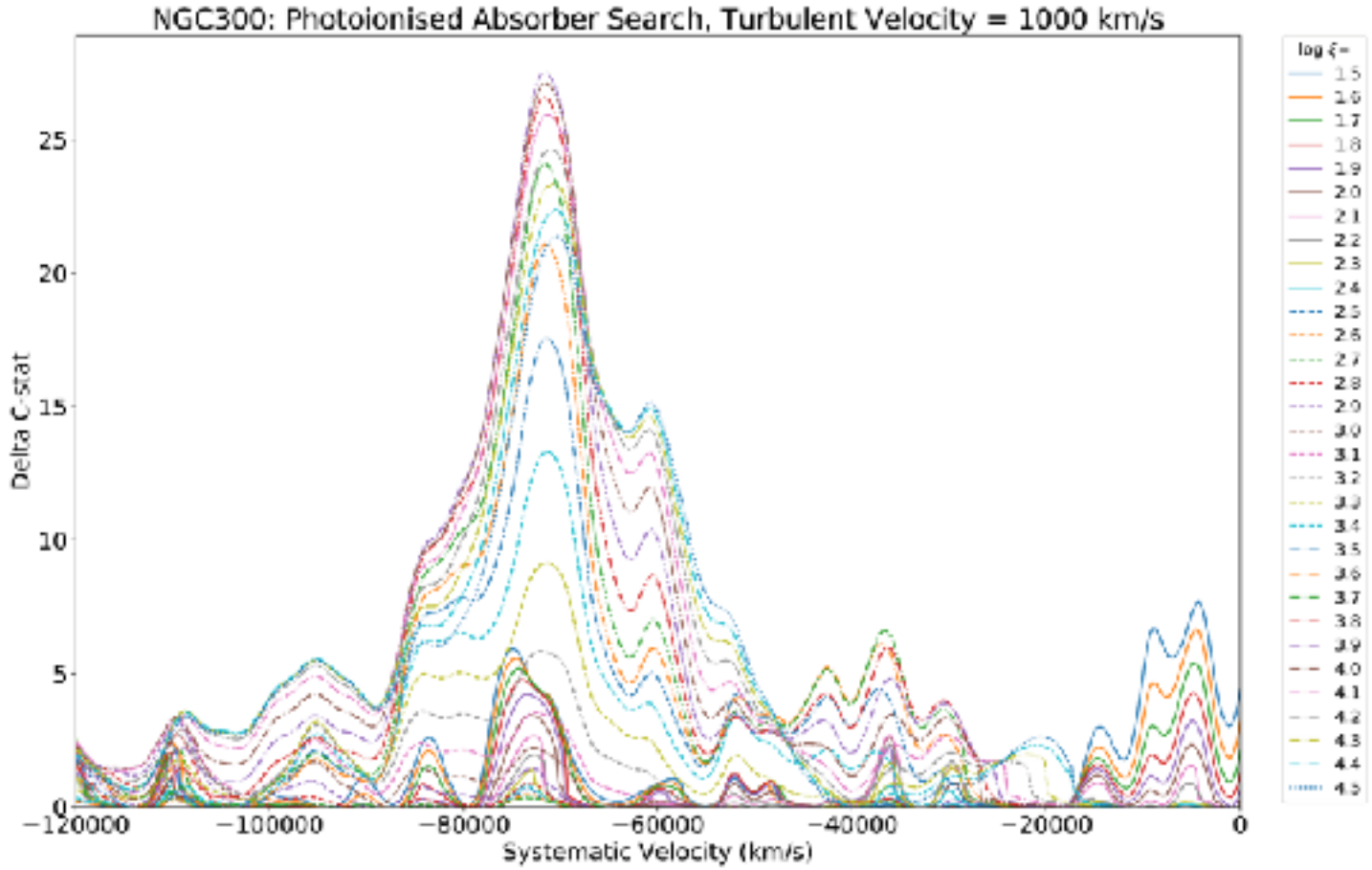
Second Observation – RGS Gaussian Line Scan

- Same steps as with the first observation
- 2 oxygen absorption features?



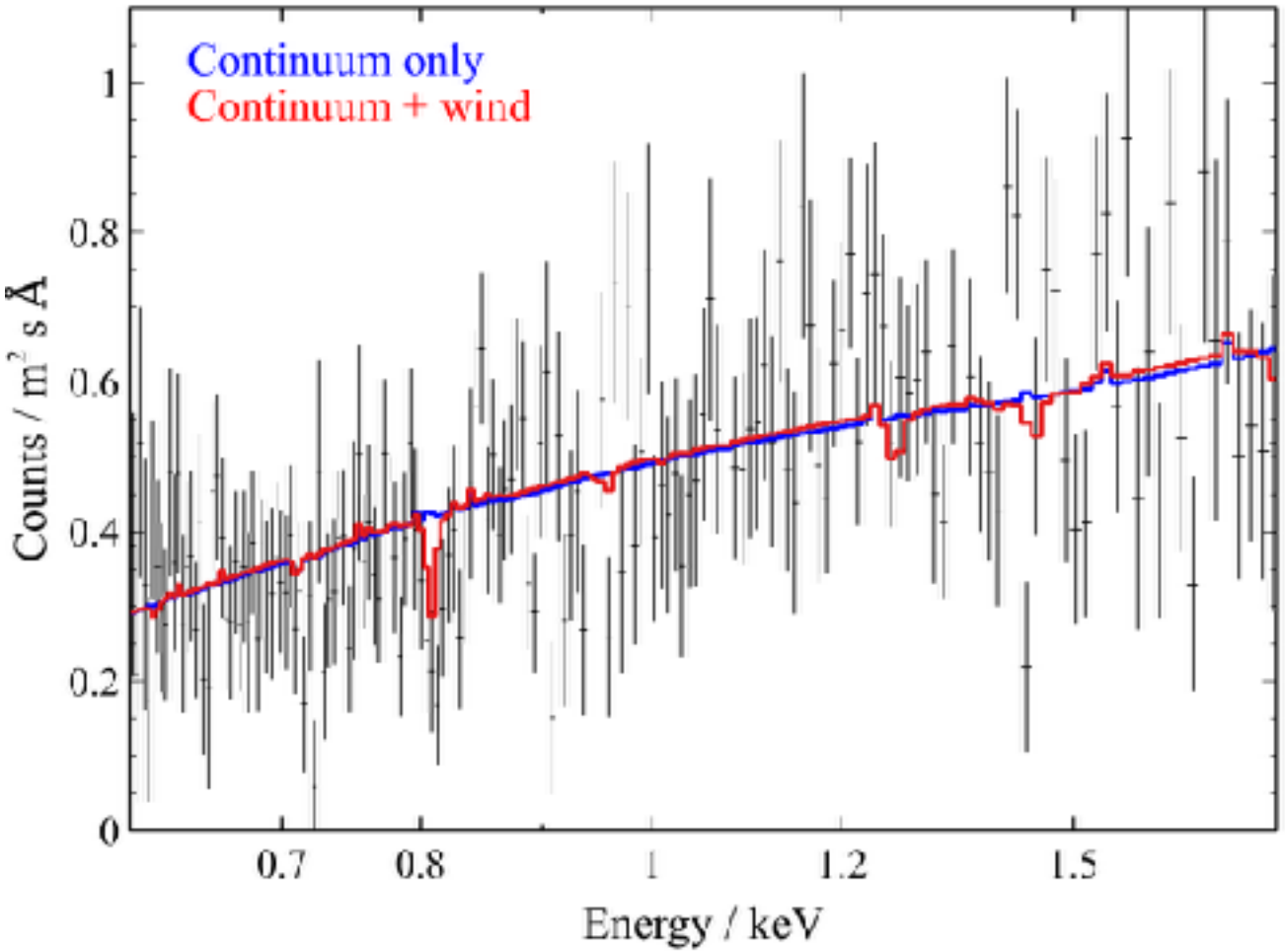
Physical Photoionized Model Search

- Now use all data: RGS, PN, MOS, FPM
- Scan the velocity parameter space with a physical photoionisation code XABS
- Scan a range of systematic and turbulent velocities, ionisation parameters, fit the column density
- Find a ΔC-stat peak at around 0.22c with ionisation parameter 3.9



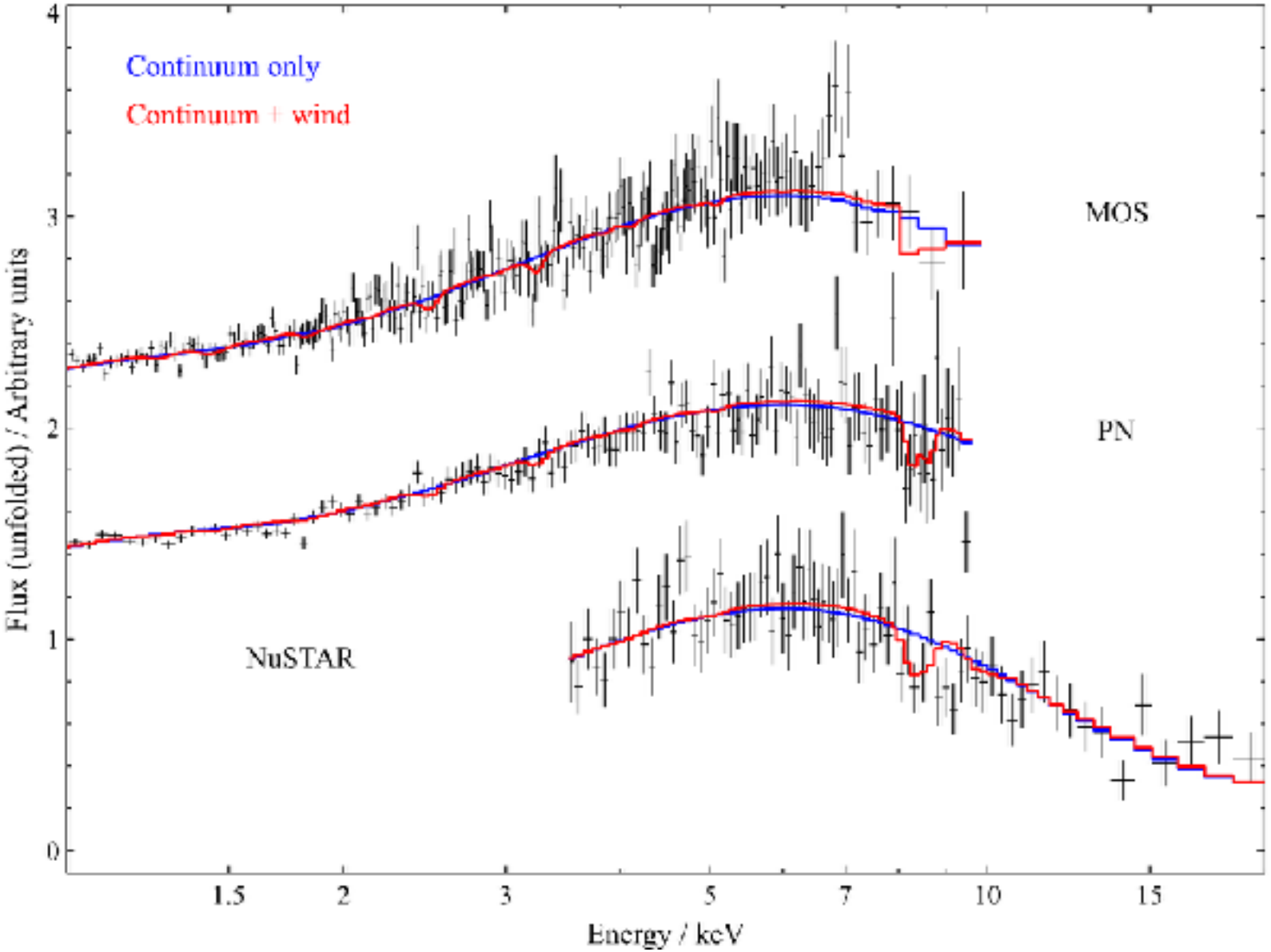
Directly Fitted UFO – RGS Spectrum

- RGS1 + RGS2 stacked
- O VIII absorption at 0.8 keV



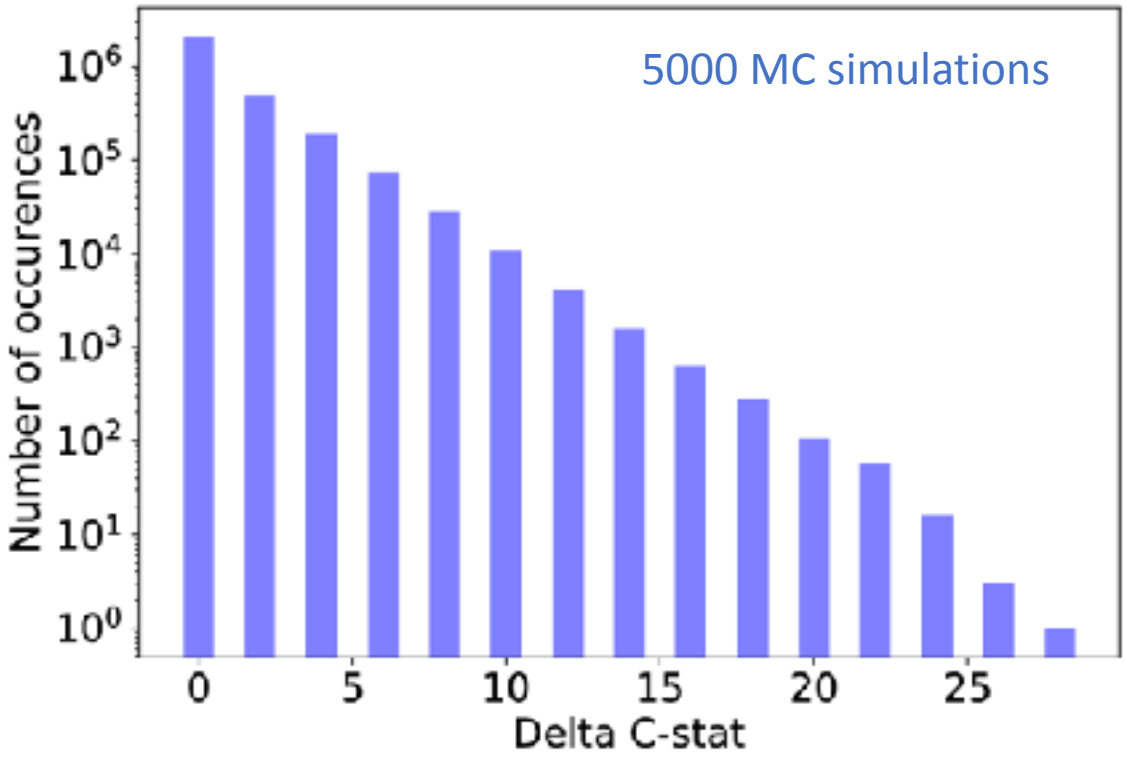
Directly Fitted UFO – CCD Spectrum

- Fe XXV and Fe XXVI absorption + unresolved lines between 2 and 5 keV
- UFO velocity: 0.22c
- Ionisation parameter: log ξ ≈ 3.9
- Column density: 10^23 cm^-2
- Turbulent velocity: 800 km/



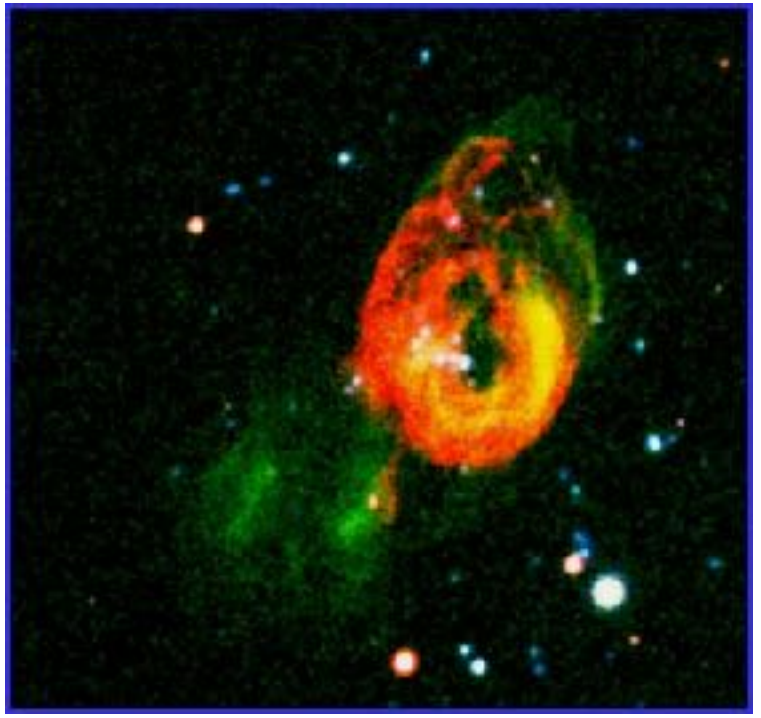
Detection Significance

- False positive rate given the number of trials – 3.1σ
- For a more robust result, perform Monte Carlo simulations – computationally expensive
- 5000 MC simulations – only 1 outlier, significance ≈ 3.7σ
- Removing any of the instruments from the analysis decreases the significance



Takeaway Message

- First UFO evidence in a ULX pulsar
- Fast variability (tens of ks) – wind is likely clumpy
- Evidence in both soft and hard X-rays – super-Eddington flow outside the magnetosphere?
- Kinetic Power inferred from the wind ionisation and speed: 10^41 erg/s, but unknown beaming factor, duty cycle
  - More than sufficient to inflate ionised bubbles around seen around other ULXs



Grise+11

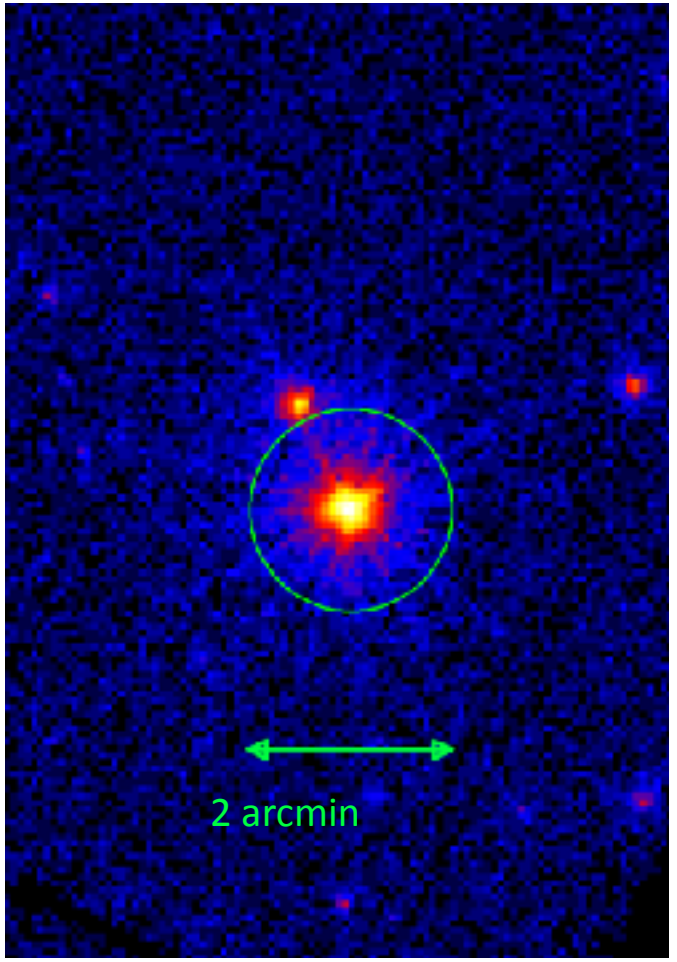
Summary

- Detect a variable UFO at more than 3σ, at a projected velocity 0.22c (65000 km/s) and ionisation parameter log ξ ≈ 3.9
- First evidence for a UFO in an ultraluminous pulsar
- UFO evidence is only present in one of the two observations – clumpy outflow?
- Future - need Chandra gratings or (better) calorimeters to resolve absorption lines above 2 keV

Bonus Slides

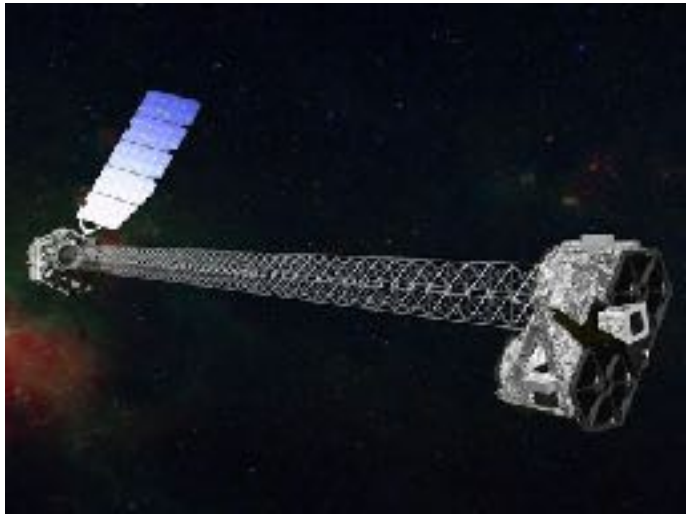
NGC 300 ULX-1: 4th ULP

- After an outburst initially mis-classified as a supernova, later classified as a B[e] high mass X-ray binary
- Brightened into ULX state by 2016, 3× erg/s
- Pulsations discovered based on observations from 2016, very large spin-up and pulsed fraction
- Flux comparable to P13, not in a crowded field: good candidate for a high spectral resolution study!



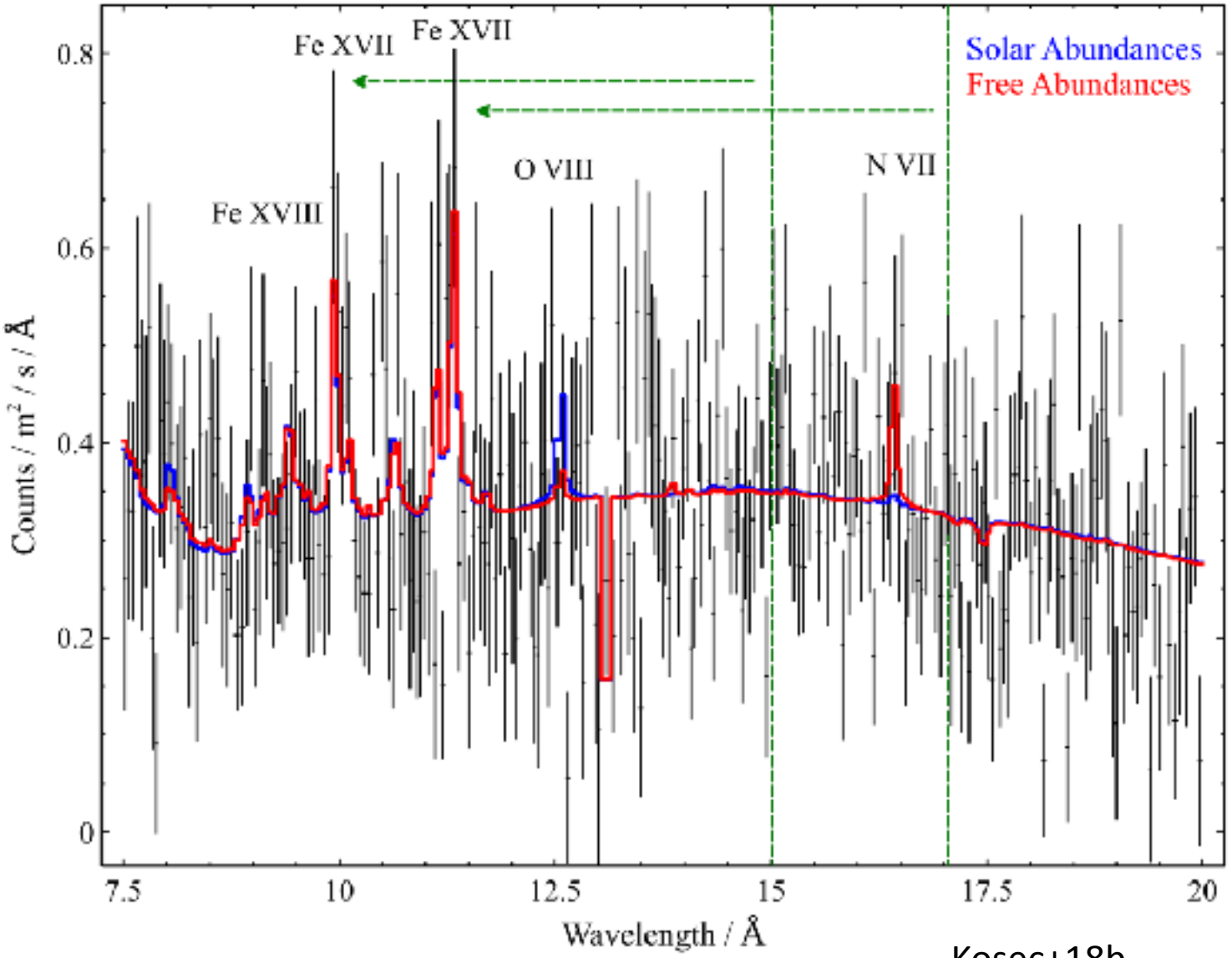
NGC 300 ULX-1: X-ray Observations

- In 2016, observed simultaneously by XMM-Newton (2 observations back-to-back) and NuSTAR (1 observation)
- Little variability in flux and spectral shape between the XMM observations
- Here we analyse the 2 XMM observations separately (with appropriate NuSTAR coverage), use all instruments (PN, MOS, RGS)
- Next part of the talk: only analyse the second XMM observation



NGC 5204 X-1: ULX with a Jet?

- Detect (3σ) blueshifted collisionally ionised plasma in the high spectral resolution RGS spectrum
- A jet at a (projected) velocity of 0.34c?
- Radio evidence for jets in ULXs (Holmberg II X-1)



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