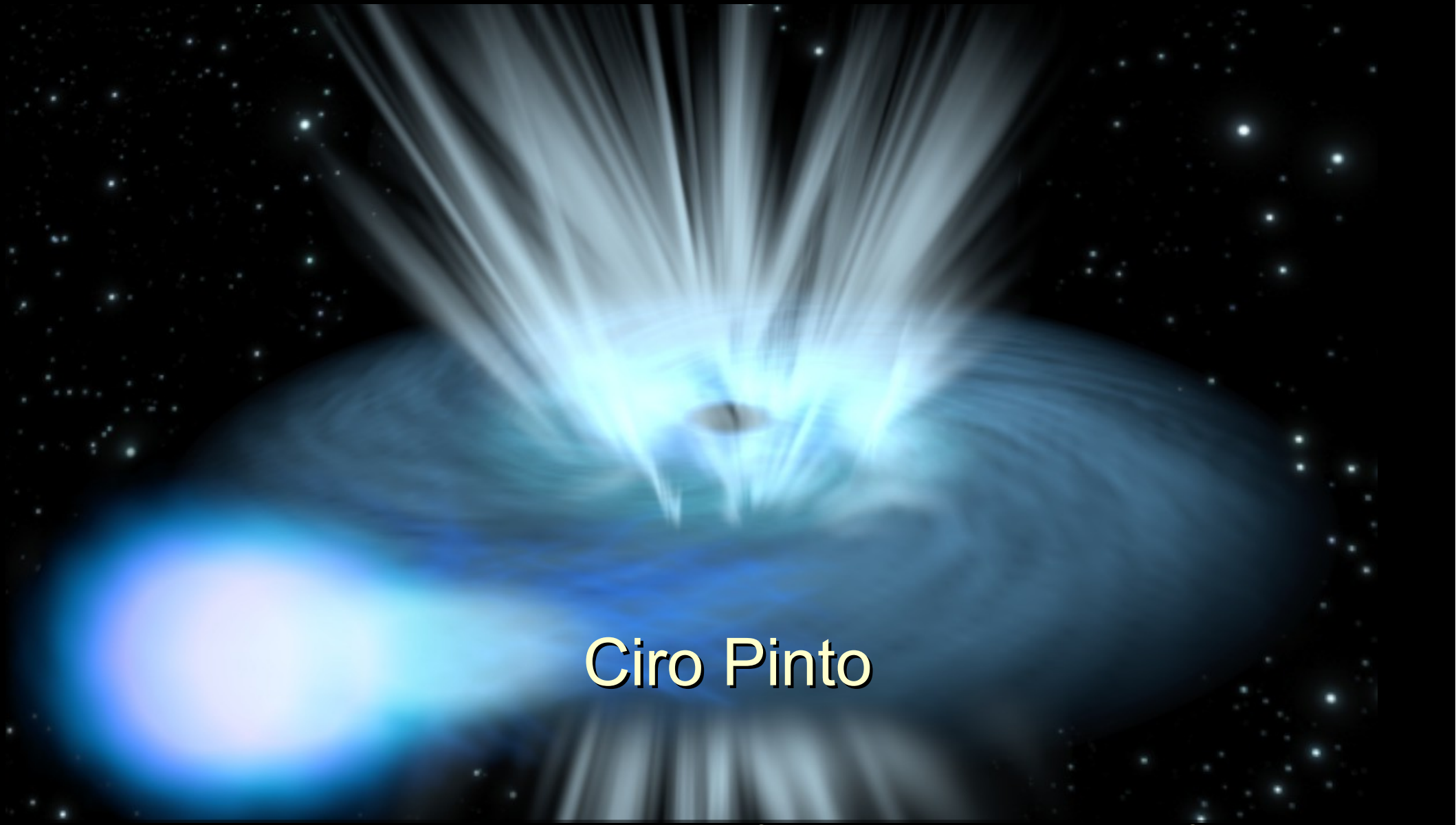
Relativistic outflows from archetypal ULXs



P. Kosec, D. Walton, W. Alston, A. Fabian, D. Fiacconi, C. Reynolds (IoA), M. Middleton (Soton), T. Roberts (Durham), H. Earnshaw (Caltech), R. Soria, R. Urquhart (Curtin), E. Kara (UMD), M. Parker (ESAC)

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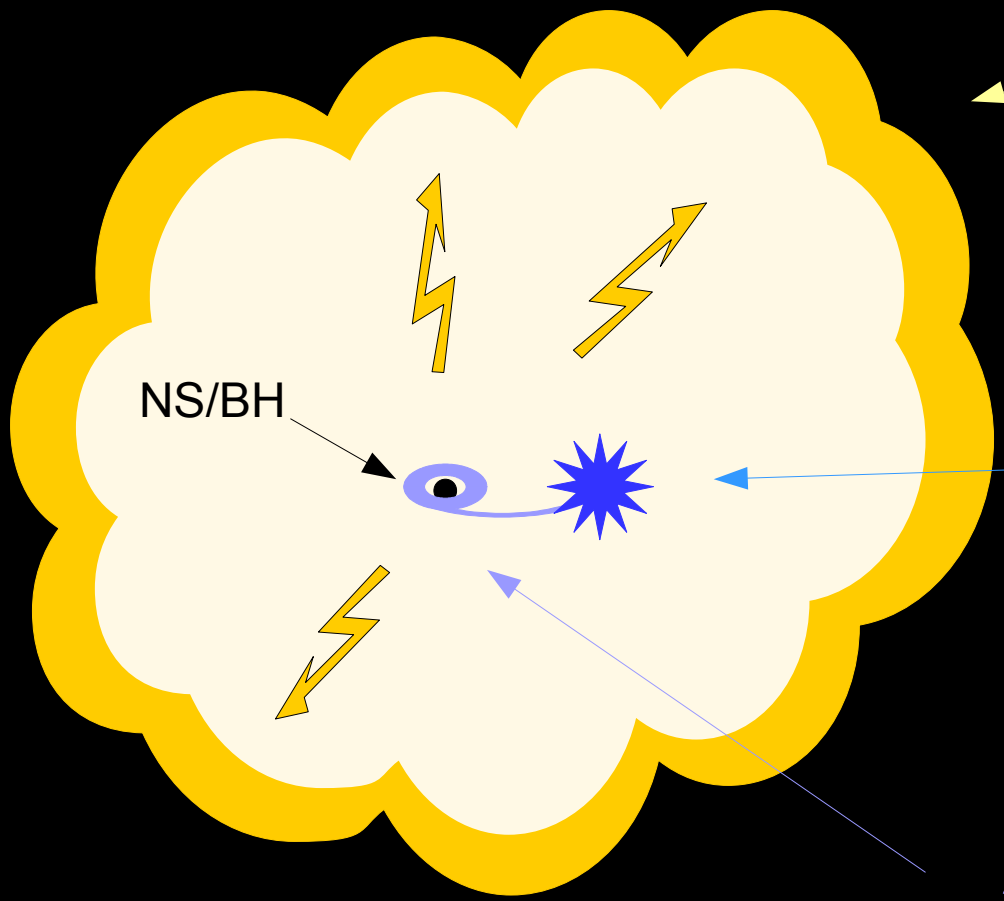
ablished by the European Commission

Image courtesy of ESA-C.Carreau from Pinto et al. (2016) Nature

Cambridge X-Ray Astronomy

ULX environment



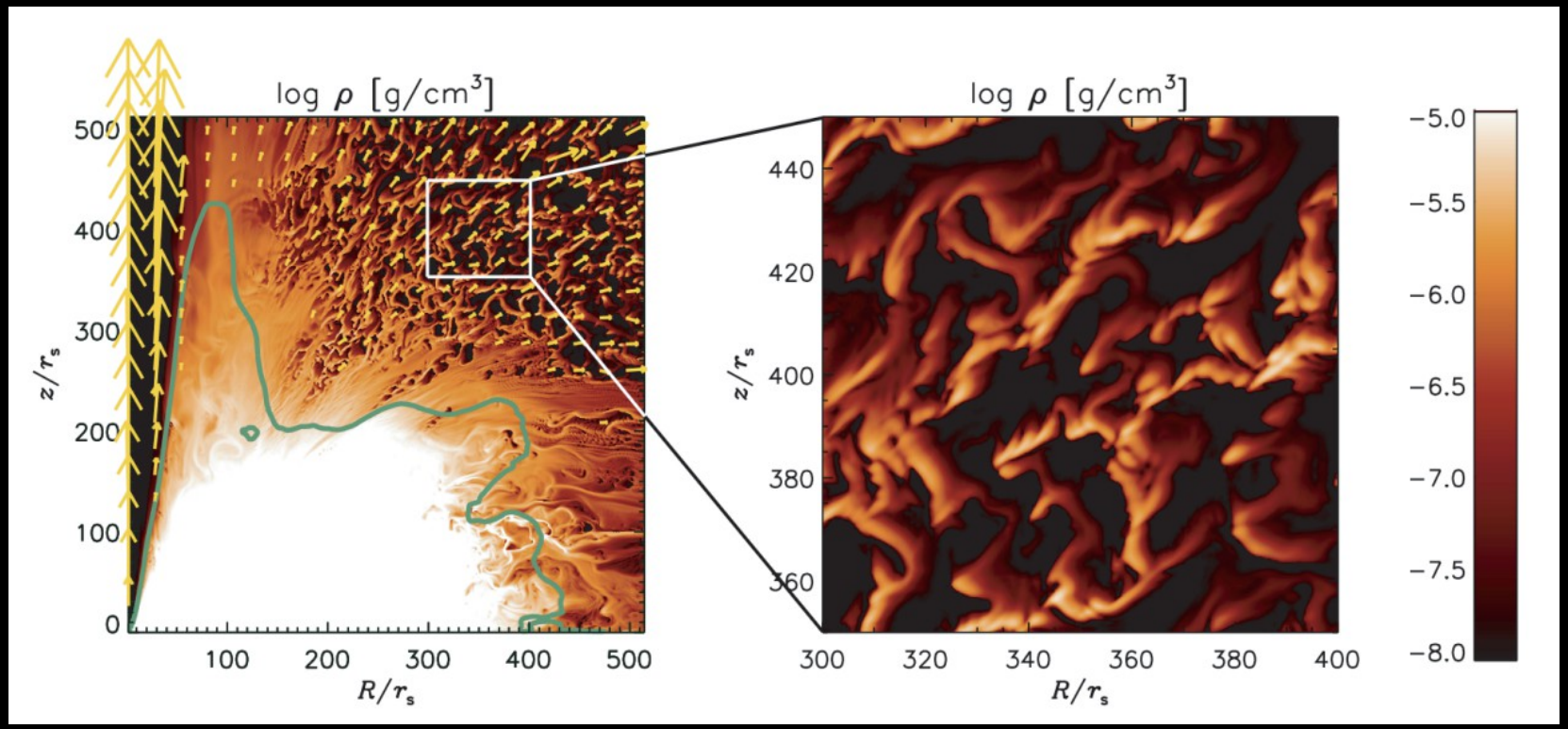
Bubble nebulae
(photo/collisionally-ionized)

High-mass star
(optical spectra & ephemerids)

Accretion disk
(accommodates high, persistent rates)

Super-Eddington radiation-driven winds

GR-MRHD simulations by Takeuchi + 13

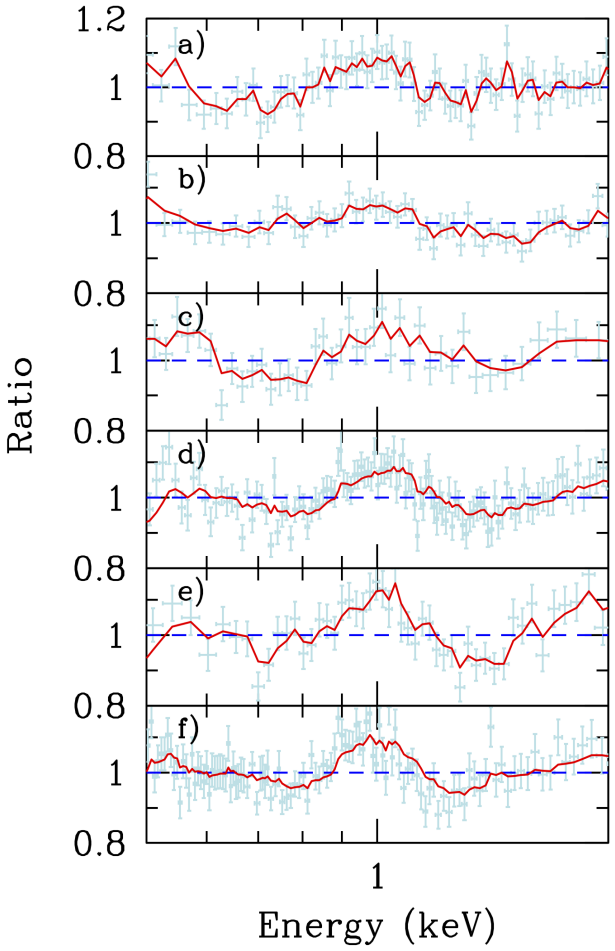


V ~ 0.1c , 10º-50º , clumpy > 250 r_s , clumps ~ 10 r_s , c_v ~ 0.3

See also Gladstone+09, Shakura & Sunyaev 73, King+01, Poutanen+07, Middleton+11-15

Early signals

Variable soft X-ray residuals in CCD spectra



NGC 1313 X-1

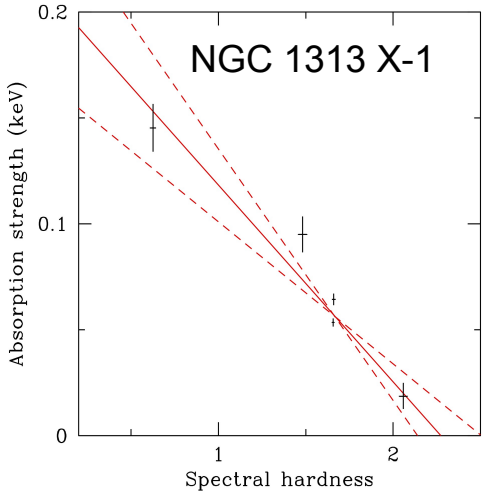
Holmberg IX X-1

Holmberg II X-1

NGC 55 ULX-1

NGC 6946 X-1

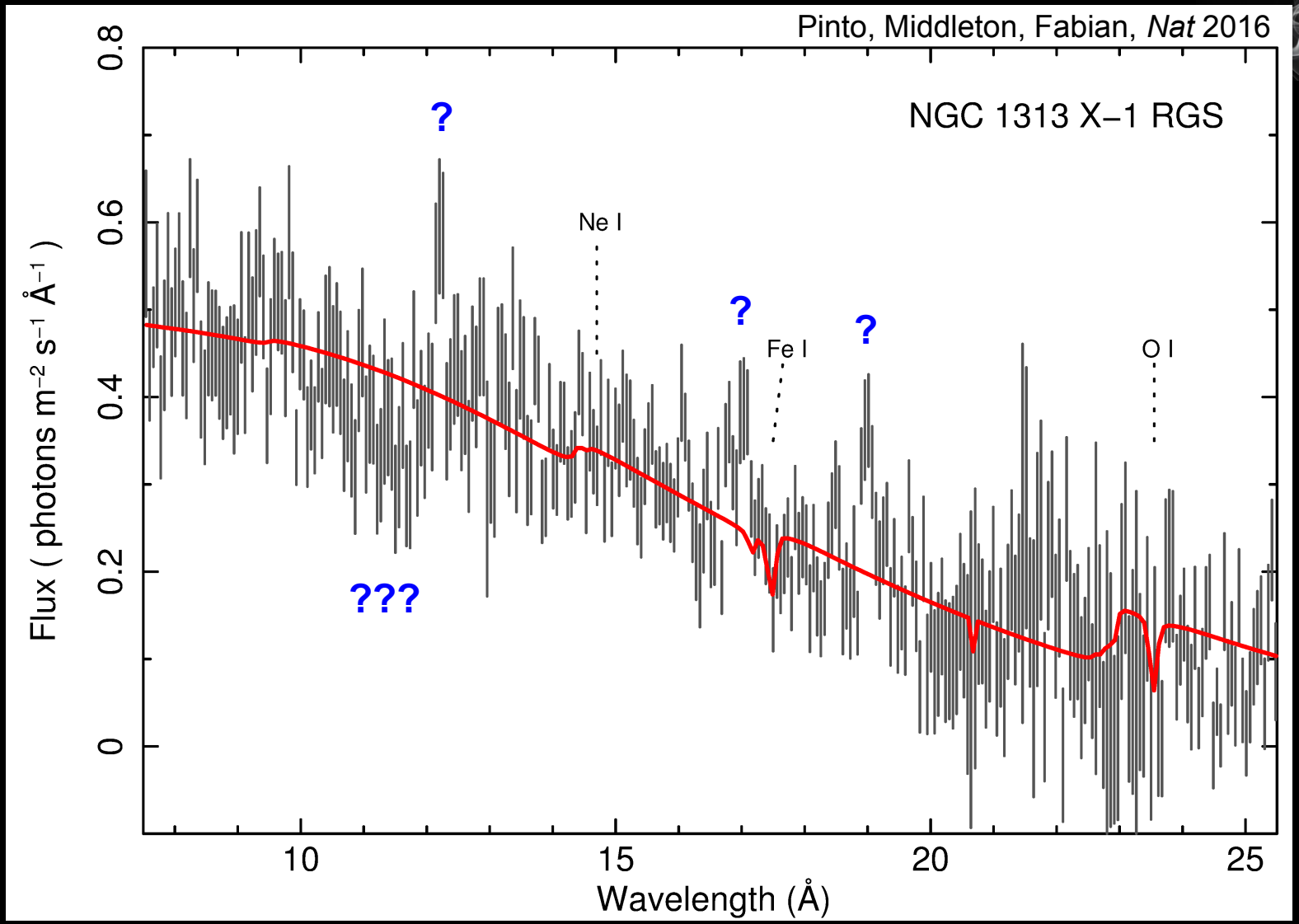
NGC 5408 X-1



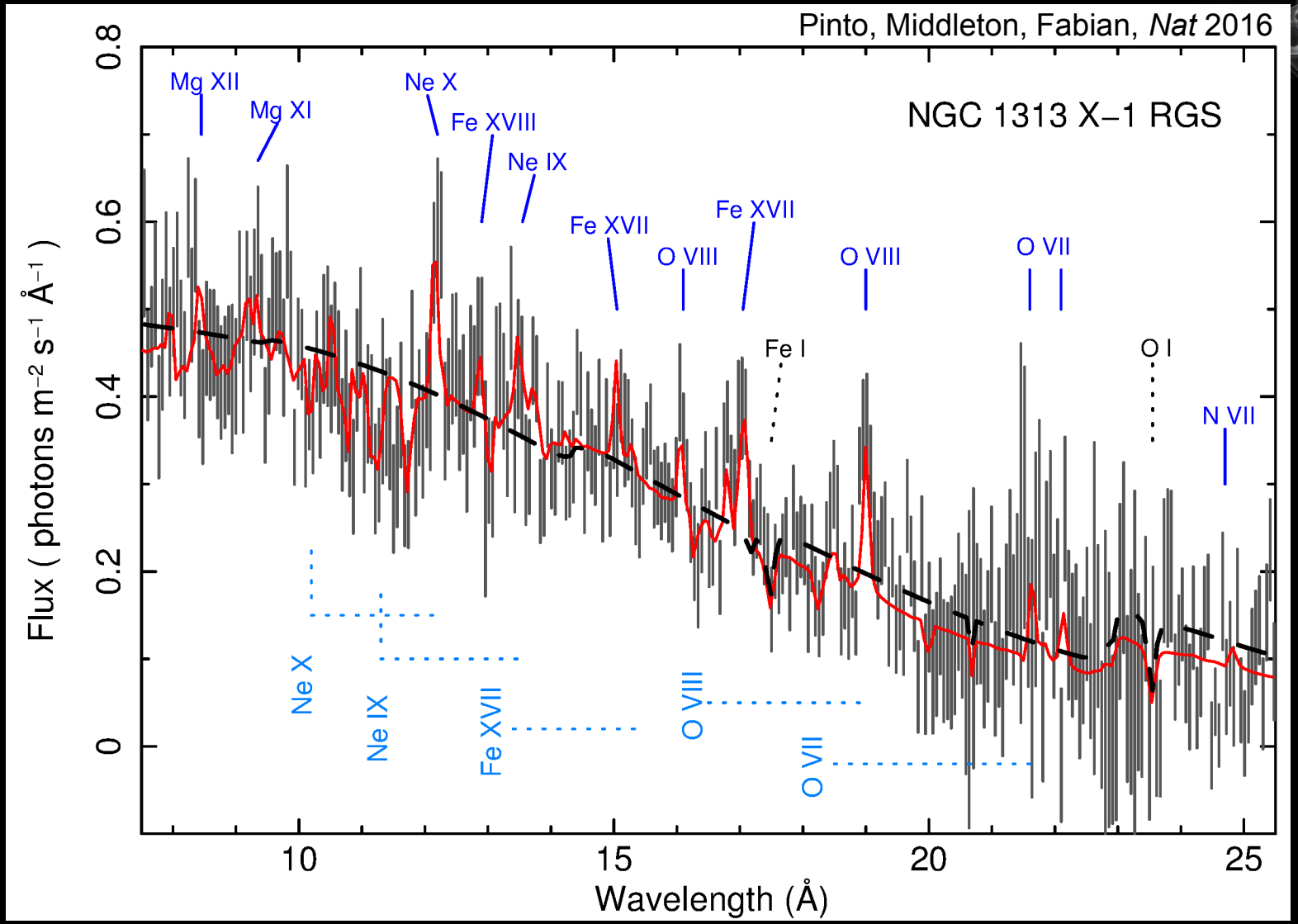
Middleton + 2015

Soria+04 ..... NGC 5408 X-1
Goad+06 ..... Holmberg II X-1
Roberts+06 ..... NGC 5204 X-1 (Chandra)
Stobbart+06 ..... Holmberg IX-II X-1
M 33 X-8, M 83 ULX
NGC 55 ULX
NGC 2403-3628-4395 X-1
NGC 1313 X-1,2
NGC 4559-4861-5204 X-1
Soria+07 ..... NGC 1365 X-1, X-2
Gladstone09 ..... Same as Stobbart +
+ IC 342 X-1, M 81 X-6
Bachetti+13 ..... NGC 1313 X-1,2
Middleton+14-15 NGC 6946-5408-1313
Sutton+15 ..... NGC 5408 X-1 (Chandra)

Smoking guns

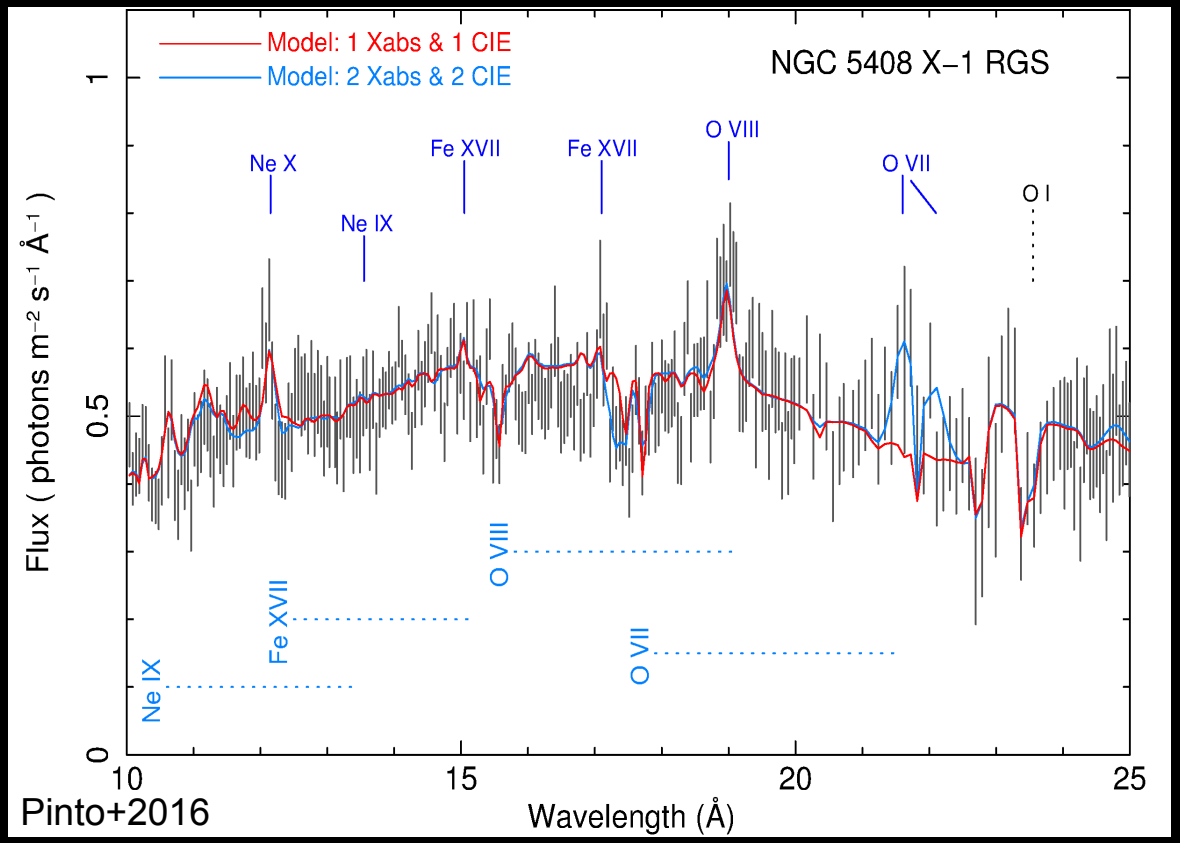


Smoking guns

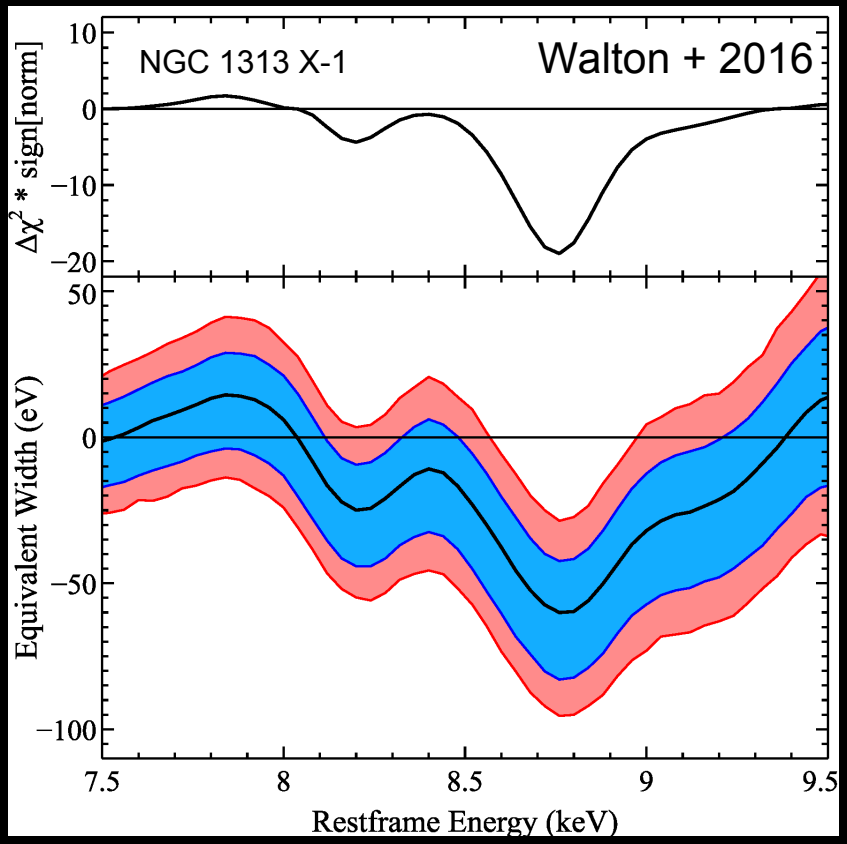


- Photoionised absorber with ~0.2c outflow velocity
- Collisionally-ionised emission at rest

Supporting discoveries

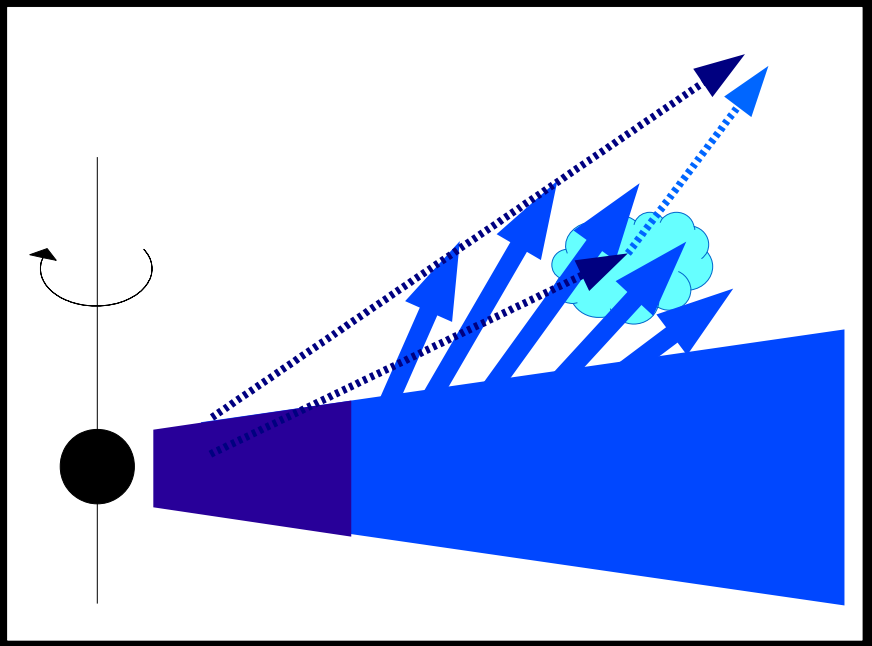


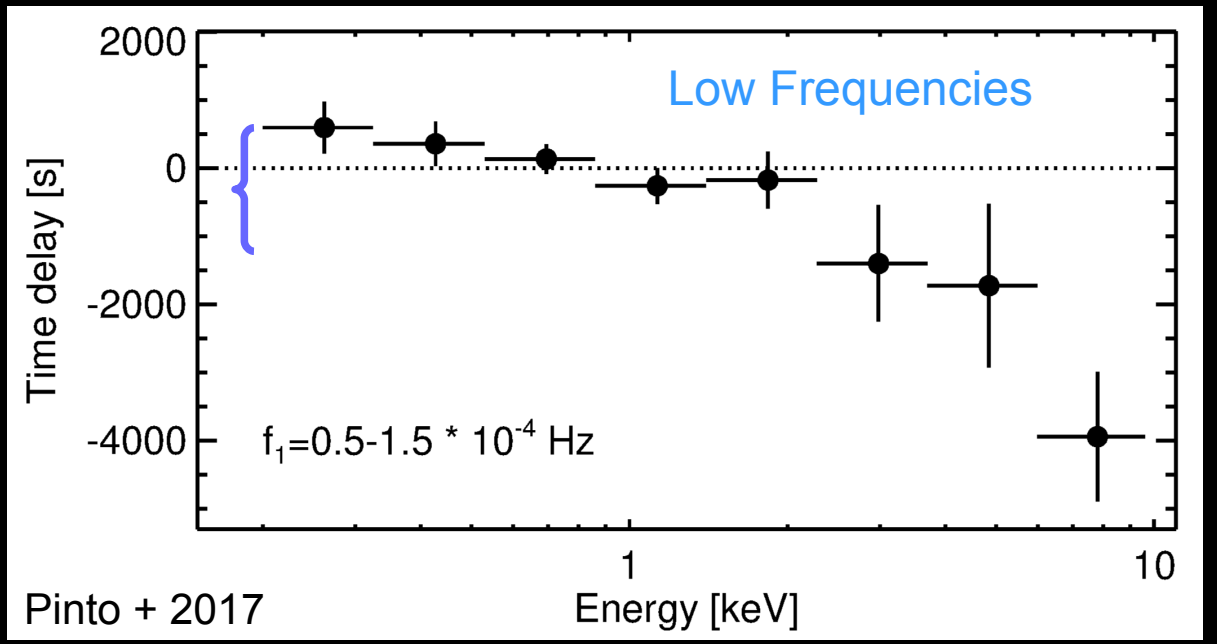
XMM / RGS gratings



XMM CCD + NuSTAR

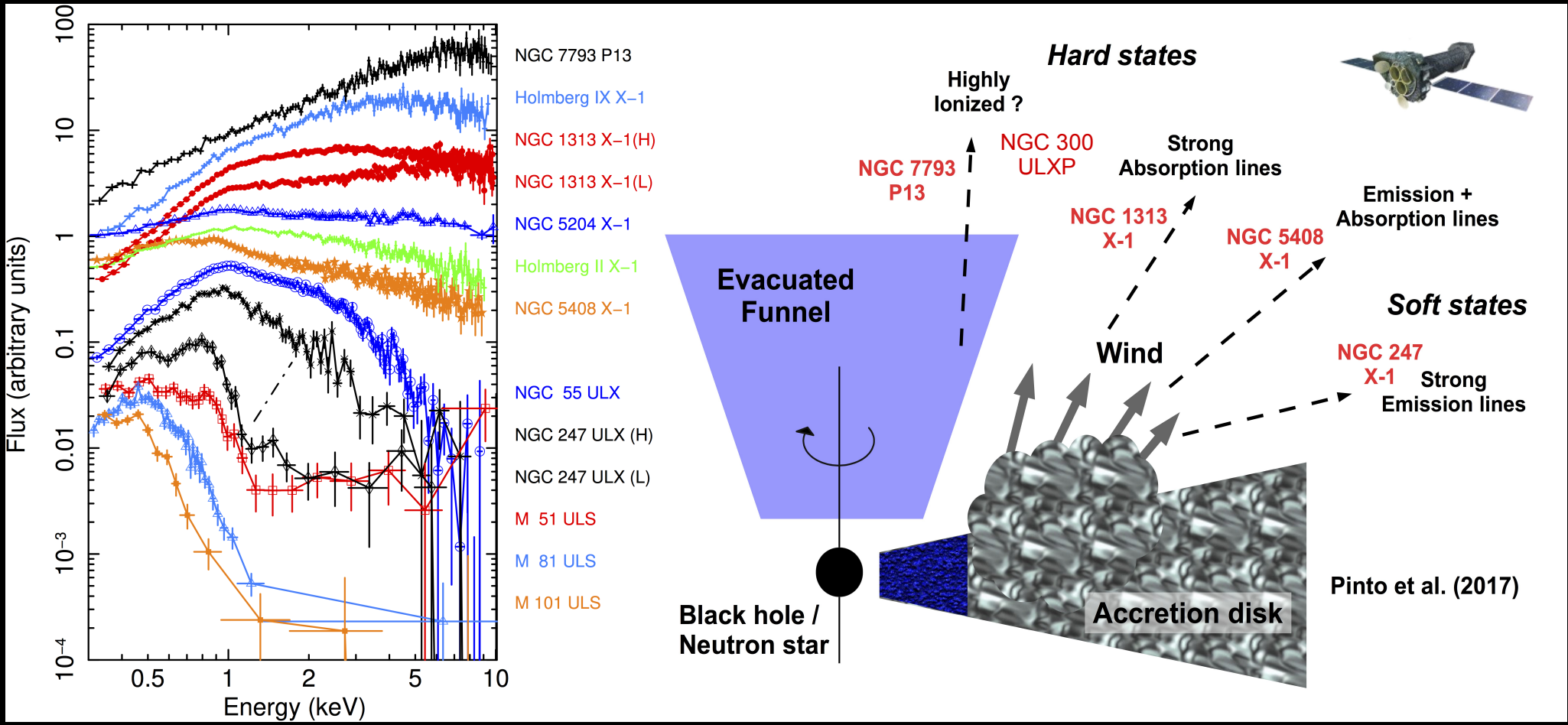
NGC 55 X-1 Time Lags





0.3 – 1.0 keV
Reference band

Wind geometry & ULX spectra



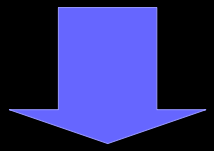
See following talk from Peter Kosec for a ULX sample

How much energy is lost in launching the winds?

Key parameter : L_{wind} / L_{bol} (AGN normally ~0.05)

$$\approx (L_X / L_{bol}) \cdot (v_{out}^3 / \xi) \cdot \Omega C_V$$

$$\approx 10 - 1000\ \Omega C_V \geq 1$$

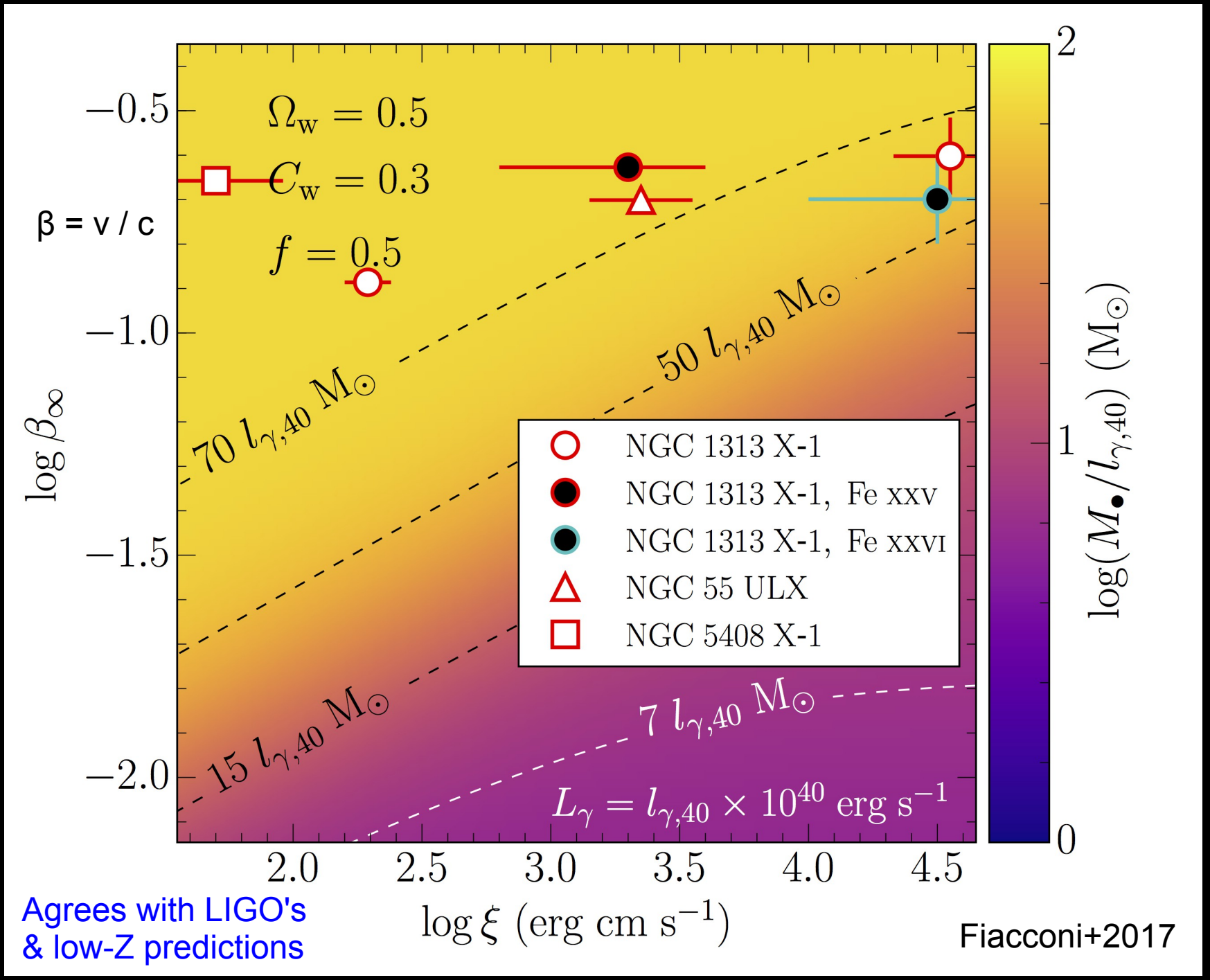


~ 50% of the total budget

in AGN UFOs normally ~ 5%

Ionisation parameter ξ = ionising photons per particle

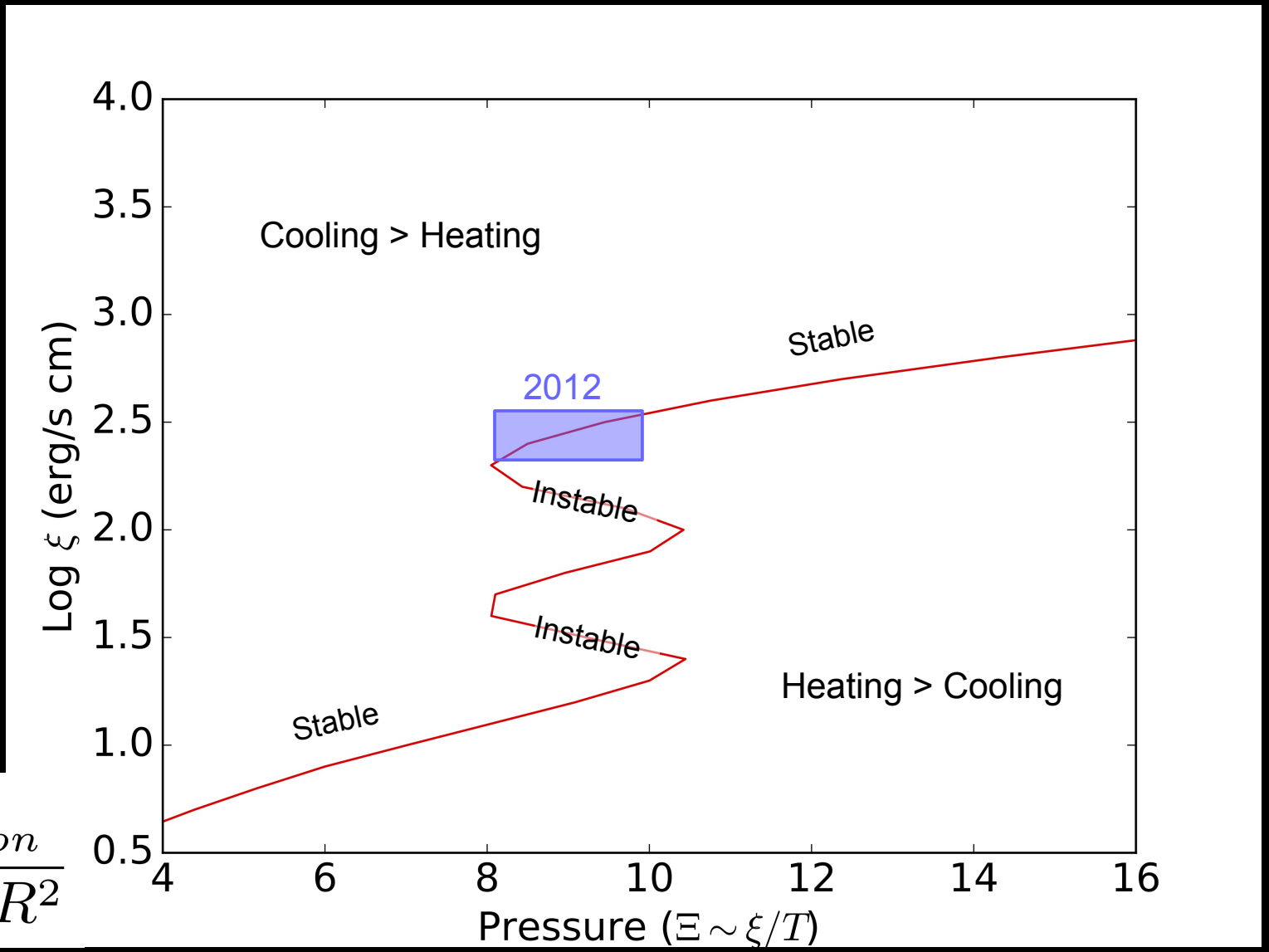
Weighing black holes (or mild-B NS?)



Agrees with LIGO's
& low-Z predictions

Fiacconi+2017

Thermal stability

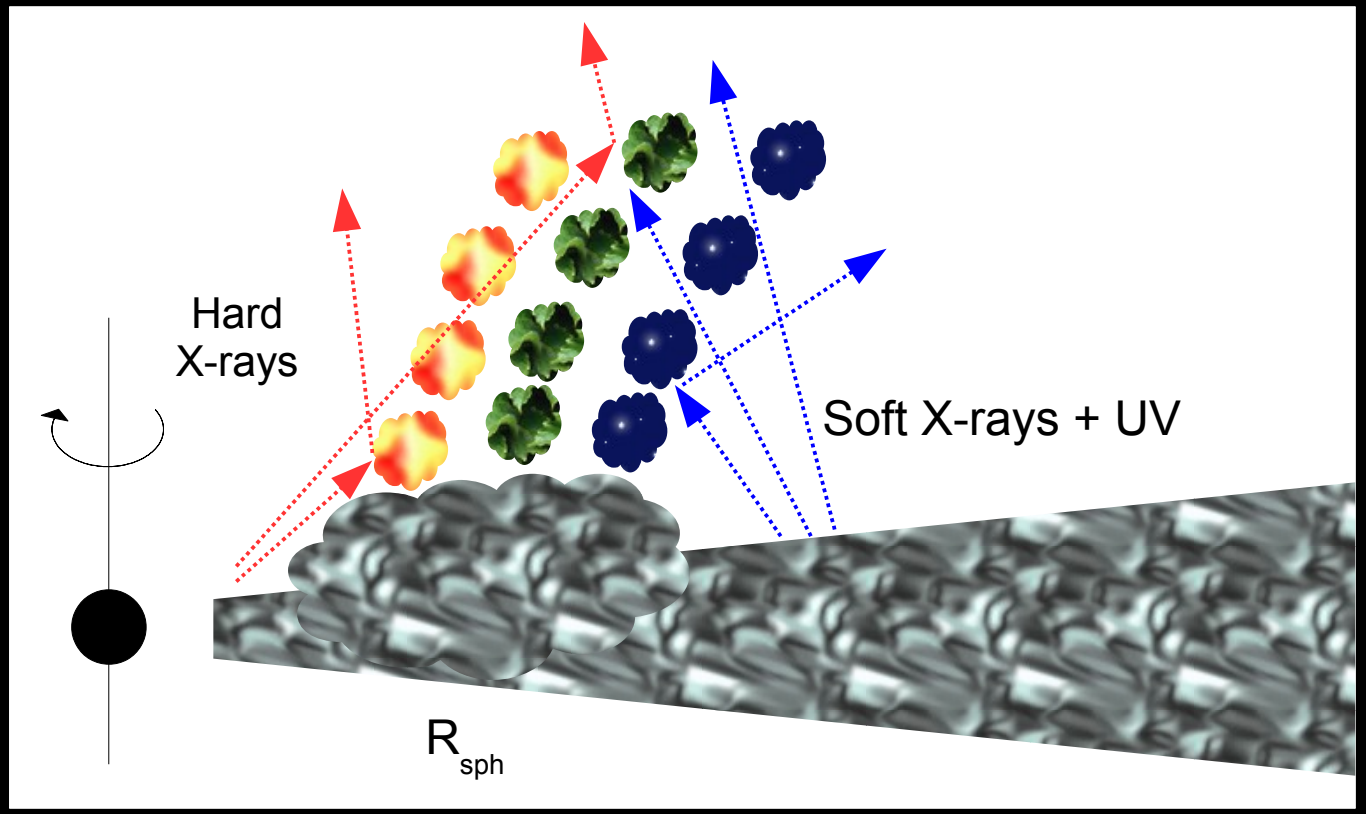


$$\xi = \frac{L_{ion}}{n_{\mathrm{H}}\, R^2}$$

Ionisation parameter ξ = ionising photons per particle

How complex can the wind be?

Self-screening

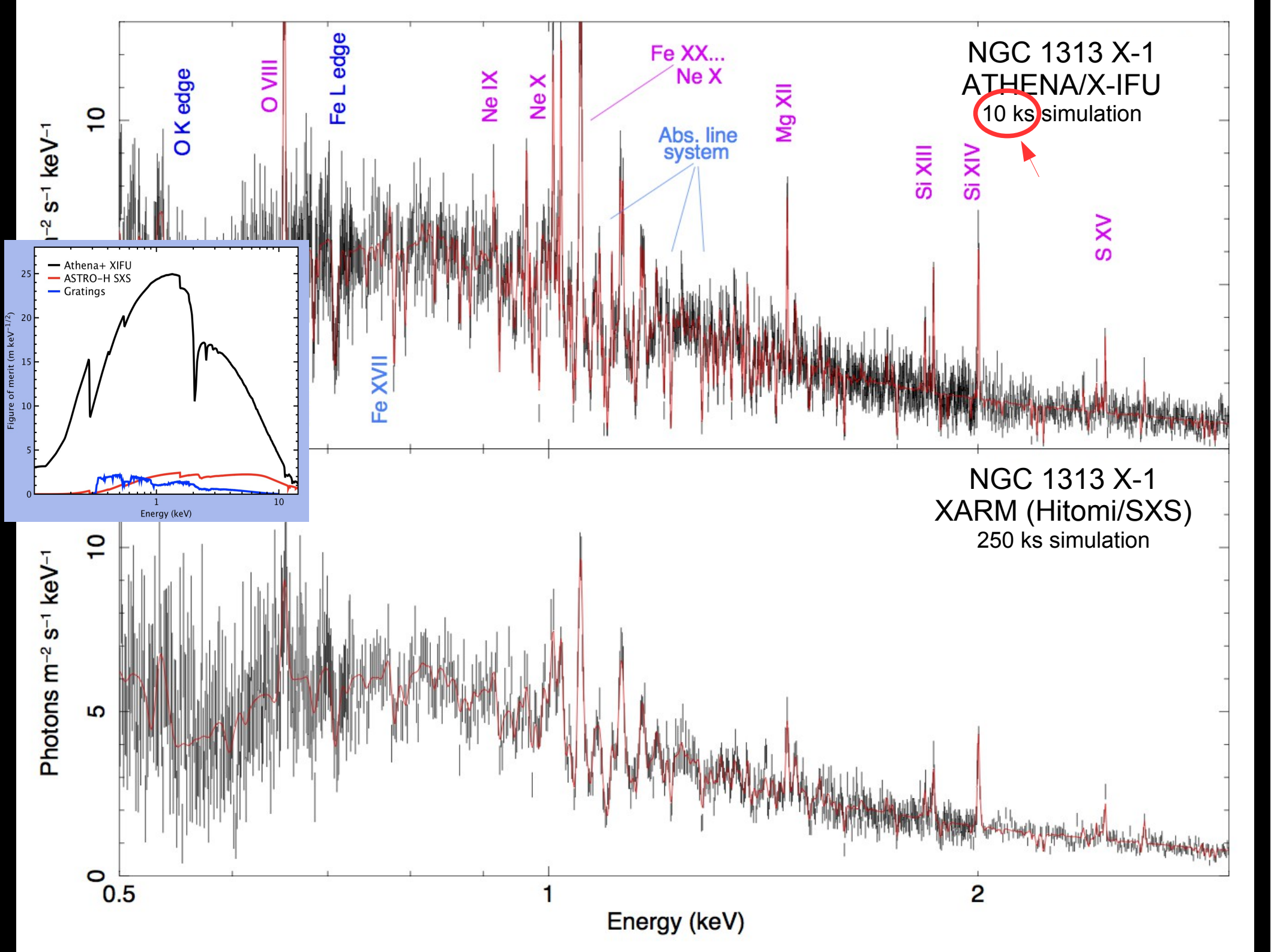


Take away message

ULXs exhibit powerful, relativistic, winds
Significant % of the energetic budget

$\dot{M}$ & Inclination with respect to the wind key parameters

ESA's XMM is still kicking after 18 years...


NGC 1313 X-1
ATHENA/X-IFU
10 ks simulation
O K edge
O VIII
Fe L edge
Ne IX
Ne X
Fe XX...
Ne X
Abs. line system
Mg XII
Si XIII
Si XIV
S XV
Fe XVII
Athena+ XIFU
ASTRO-H SXS
Gratings
Figure of merit (m keV$^{-1/2}$)
Energy (keV)
NGC 1313 X-1
XARM (Hitomi/SXS)
250 ks simulation
Photons m^{-2} s^{-1} keV^{-1}
Energy (keV)