# Obscuration in the Chandra observed sample of medium-redshift (0.5 < z < 1) 3CRR sources.

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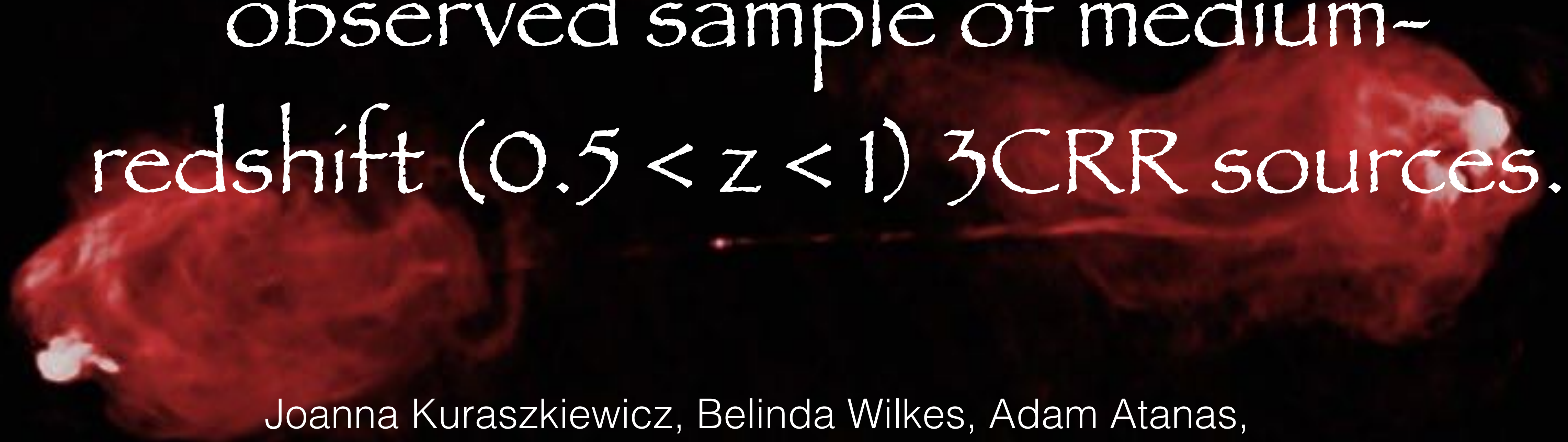


Background: Cygnus A (3C 405) - one of the brightest and closest (600 million light-years away) sources visible in radio. Radio emission extends to either side nearly 300,000 light-years powered by jets of relativistic particles. Hot spots mark the ends of the jets impacting surrounding cool, dense intergalactic medium. Image credit: NSF/NRAO/AUI/VLA

# Introduction

Obscuration in AGN is anisotropic and wavelength-dependent resulting in:

- complex selection effects for observations in most wavebands,
- AGN missed in samples traditionally selected on blue excess and strong emission lines.

Near-IR selection - 2MASS (Cutri+ 2002), and spectral surveys: Hamburg Quasar spectral survey (Hagen+1995), SDSS (Richards+ 2003) reveal significant population of red, *moderately obscured* AGN.

Multi-wavelength surveys (SWIRE, GOODS, COSMOS) including hard-X-ray (*Chandra,XMM)* and/or mid-IR selection (*Spitzer)* reveal more obscured AGN (Alexander+ 2003, Polletta+ 2006), but Compton-thick sources difficult to find.

NuSTAR COSMOS (Civano+2015) estimate ~13-20% CT.

Modeling of CXRB predicts large population of obscured sources (Gilli+2007): moderately obscured ($N_H<10^{21-23}$)/unobscured~1, Compton-thick/Compton-thin ~1

Best way to select samples unbiased by orientation/obscuration is low frequency radio (meter wavelength) where selection is based on optically thin emission from extended radio-lobes and so is independent of orientation, providing a way to assemble complete, randomly oriented sample of AGN.

# 3CRR: Low-frequency Radio-selected sample

- complete, low-frequency radio-selected at 178 MHz (brighter than 10Jy) sample of 3CRR sources observed by *Chandra*.
- medium redshift: $0.5 < z < 1$,
- highly luminous radio sources (FRII) —> all sources are AGN

Low frequency radio selection = sample with little/no orientation bias.

Radio-core fraction $R_{CD} = L_{core}(5GHz)/L_{lobe}(5GHz)$ provides estimate of orientation (Orr & Brown 1982, Ghisellini+ 1993).

Sample includes 36 AGN spanning full range of inclination angles:
- 13 broad-line RGs (quasars) —> face-on
- 22 narrow-line RGs —> edge-on
- 1 LERG

All with matched radio L. Small range of L(5GHz) ~$10^{44}$-$10^{45}$ erg/s —> orientation effects dominate distribution of properties.

Wealth of published, multiwavelength data: *Chandra, Spitzer, Herschel*

Caveat: only 10% of AGN are radio-loud - may not represent the full AGN population.

# 3CRR high-z sample (Wilkes+ 2013)

- complete, low-frequency radio-selected at 178 MHz (no orientation bias)
- $1 < z < 2$
- all FRII —> all are AGN
- observed by *Chandra*

Sample includes 38 AGN spanning full range of inclination angles:

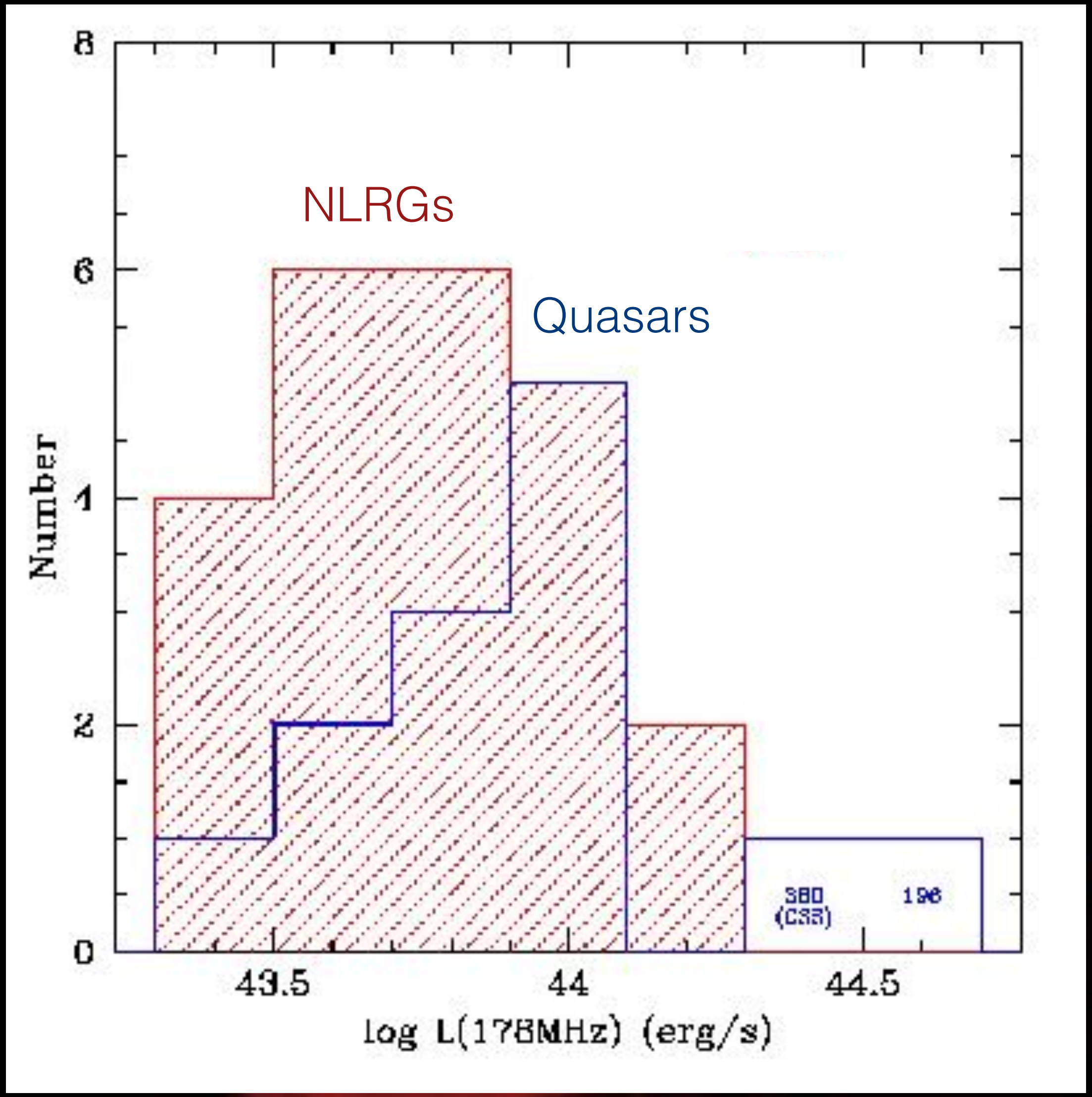
- 19 broad-line quasars —> face-on
- 3 intermediate sources (2 BLRGs + 1 NLRG; log $N_H$=22-23)
- 16 NLRGs —> edge-on

All with matched radio L.

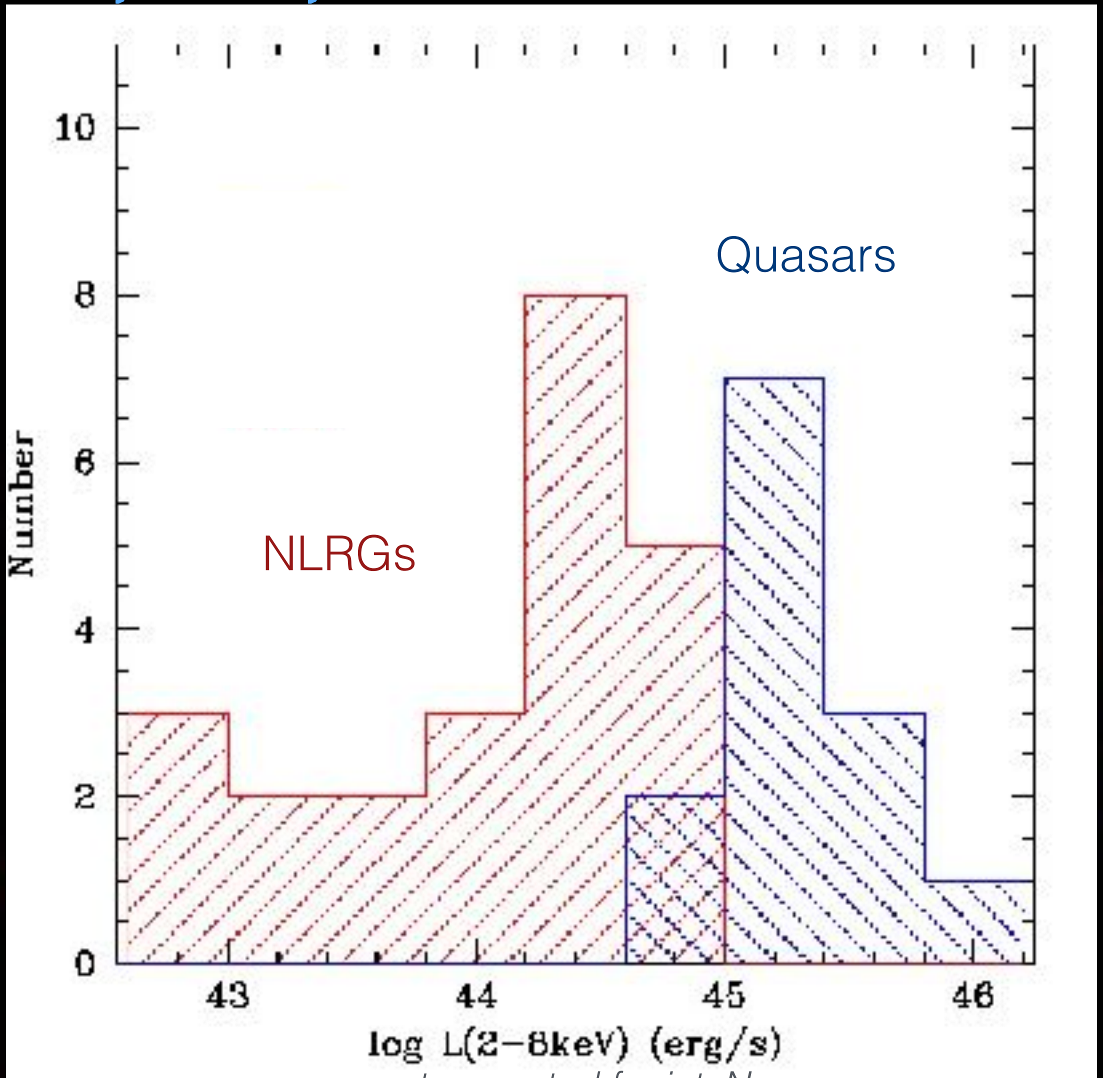
Small range of L(5GHz) ~$10^{44}$-$10^{45}$ erg/s similar to medium-z sample—> orientation effects dominate distribution of properties.

Wealth of published, multiwavelength data: *Chandra, Spitzer, Herschel*

# Chandra X-ray properties




Radio Ls match
(1 dex range)



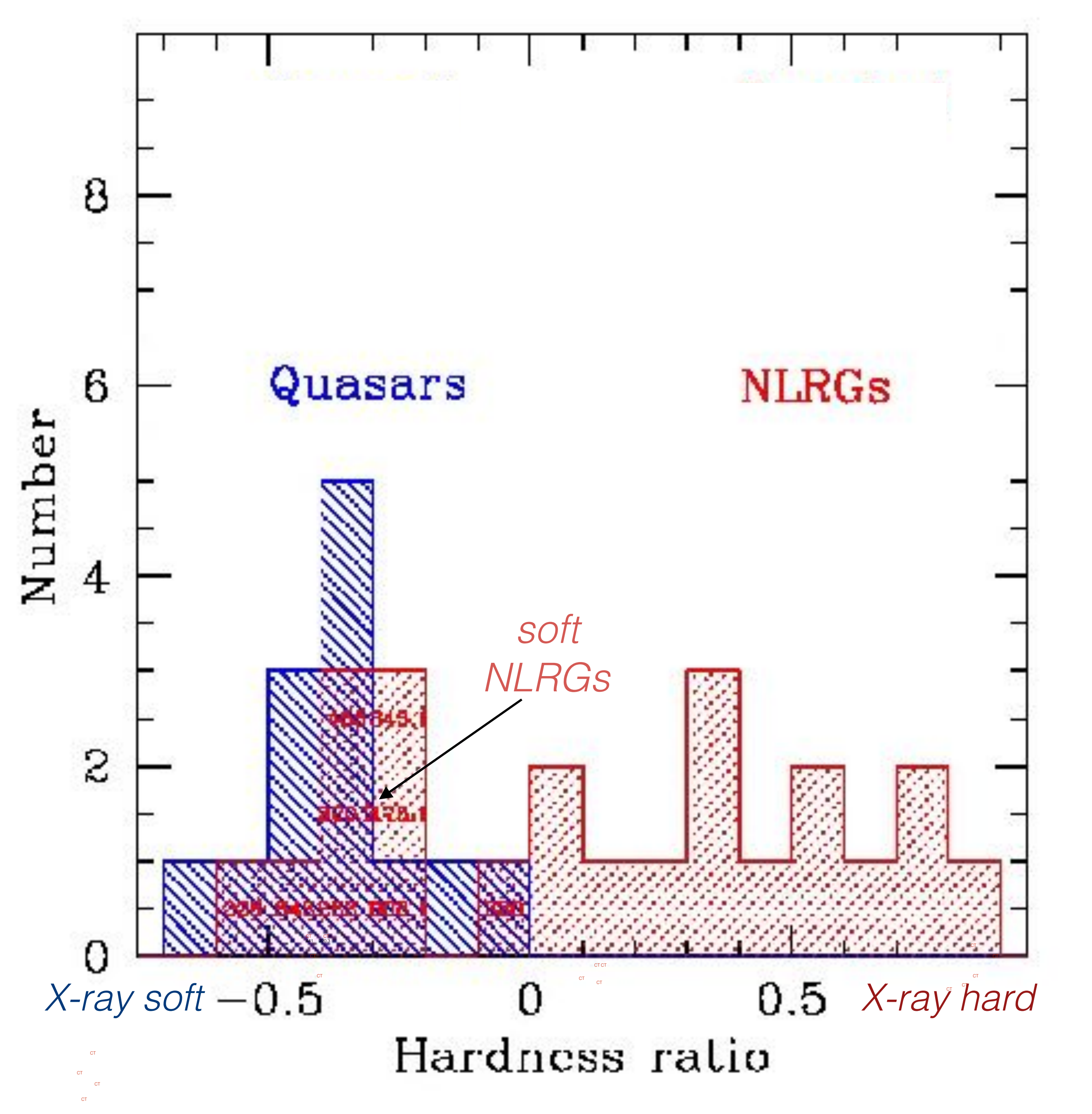

Hard-X-ray Ls don't match
(3 dex range)
NLRGs 10-1000x fainter than QSOs

Simple Unification:

QSO - face-on: X-ray bright + soft

NLRGs - edge-on: X-ray faint + hard

# Chandra Hardness Ratios

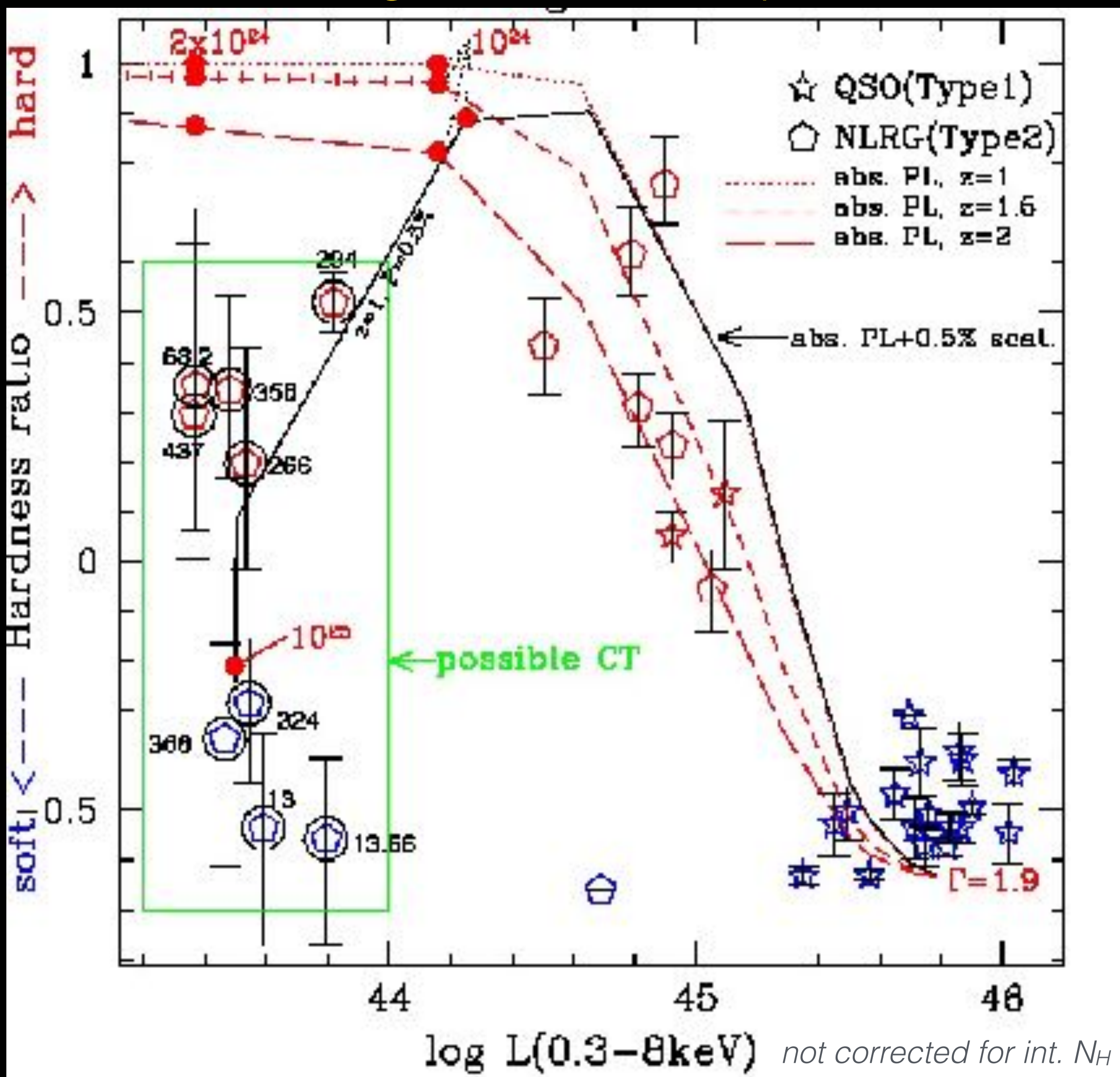



Quasars - soft HR ⟶ low $N_H$

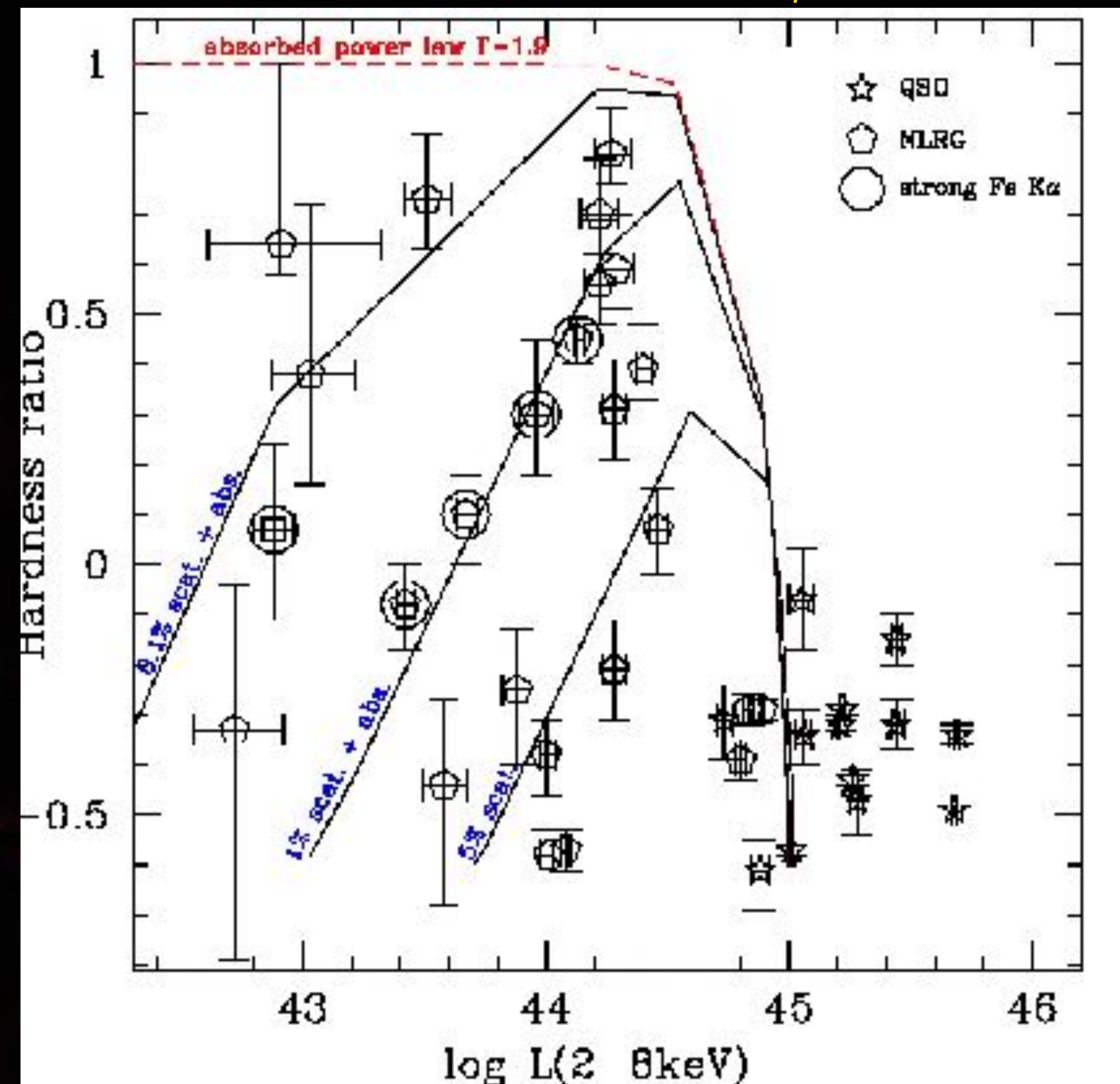
NLRGs - wide range of HR ⟶ range of $N_H$

# Hardness ratio not a high $N_H$ indicator

*High-z 3CRR sample*




*Medium-z 3CRR sample*




Obscuration ↗ → observed $L_X$ ↘ and HR gets harder

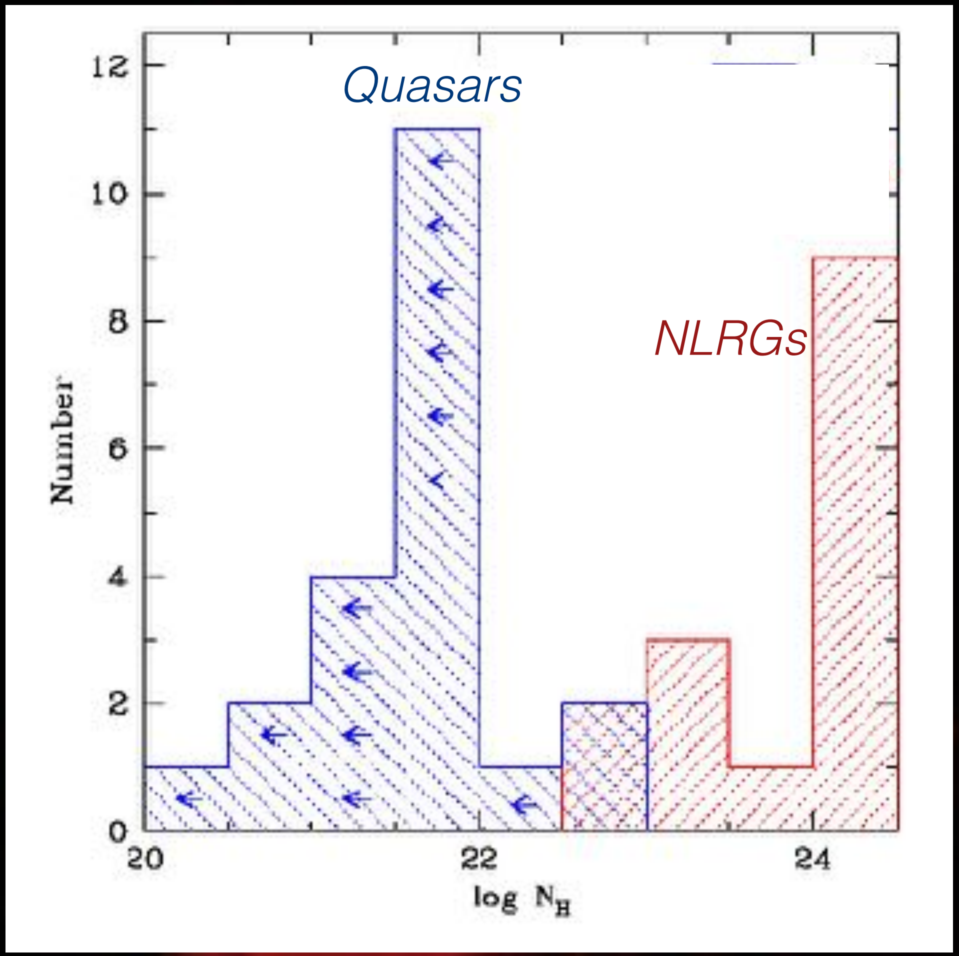
Lowest $L_X$ sources softer - require a 2nd softer component - possibly from: scattered nuclear light, extended emission or jet-related emission.

HR not a good indicator of $N_H$ at high (CT) obscuration.
$L_X$ underestimated by $10\text{-}10^3$ for ~20% using HR for $N_H$ correction → lower obscured fraction, steeper LF

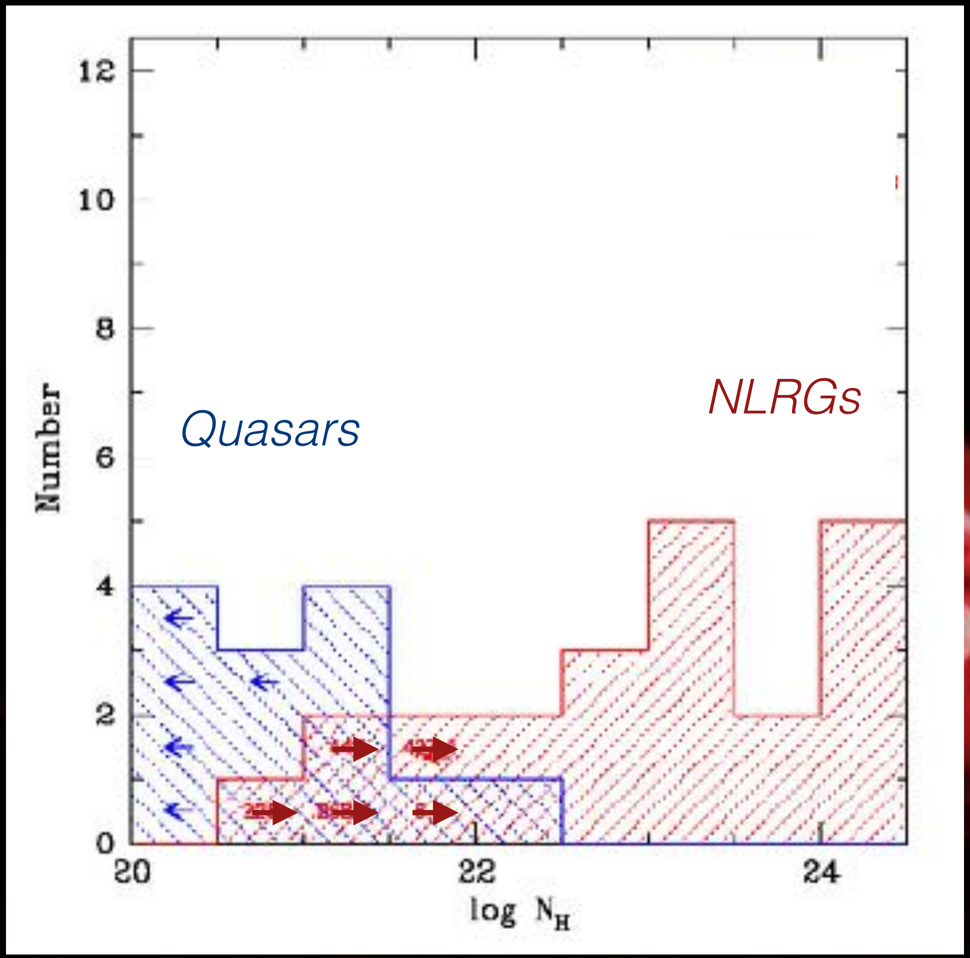
Medium-*z* more complex spectra - *Chandra* probing softer-X

# $N_H$ distribution

*High-z 3CRR sample* (Wilkes+2013)




*Medium-z 3CRR sample*



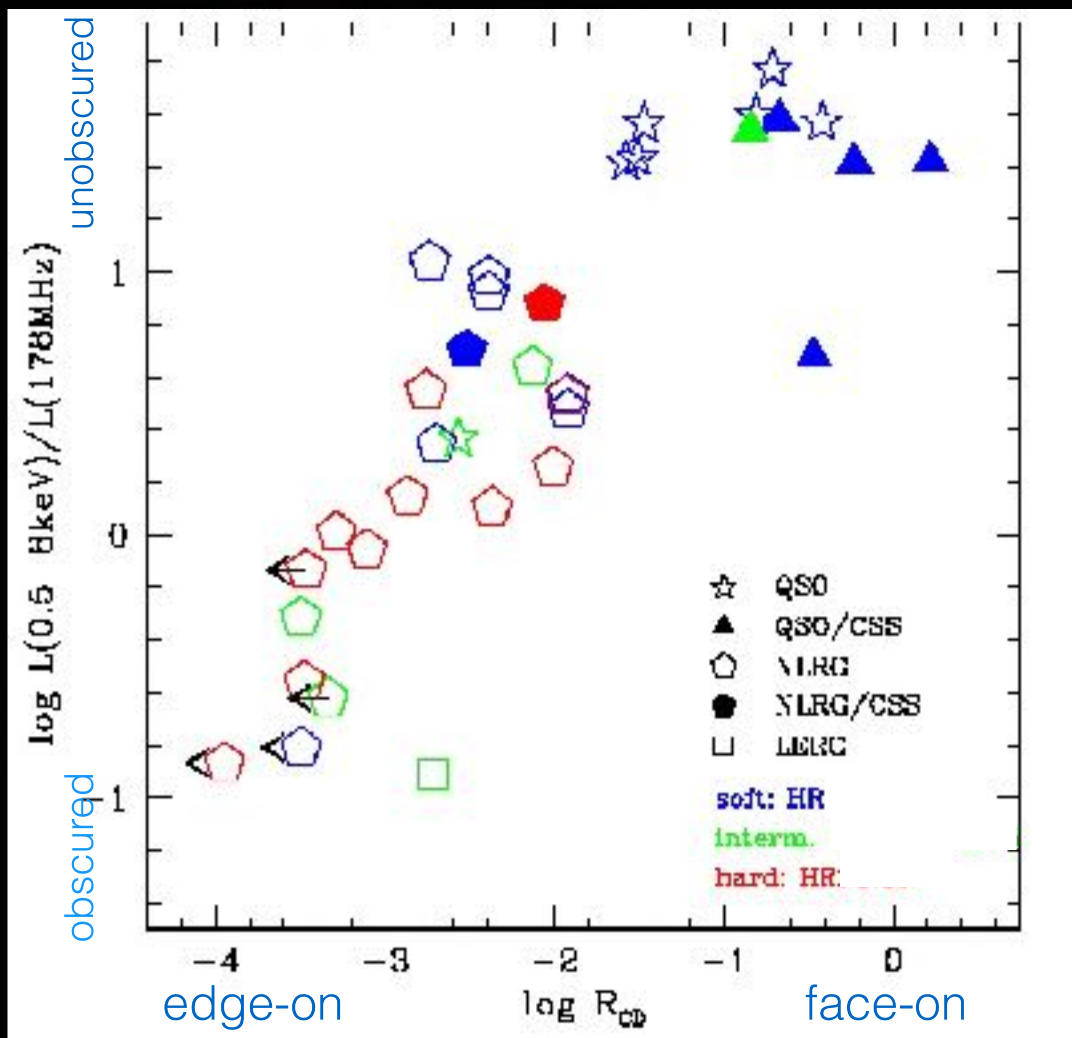

Quasars: low $N_H < 10^{22.5}$ cm$^{-2}$ in both samples.

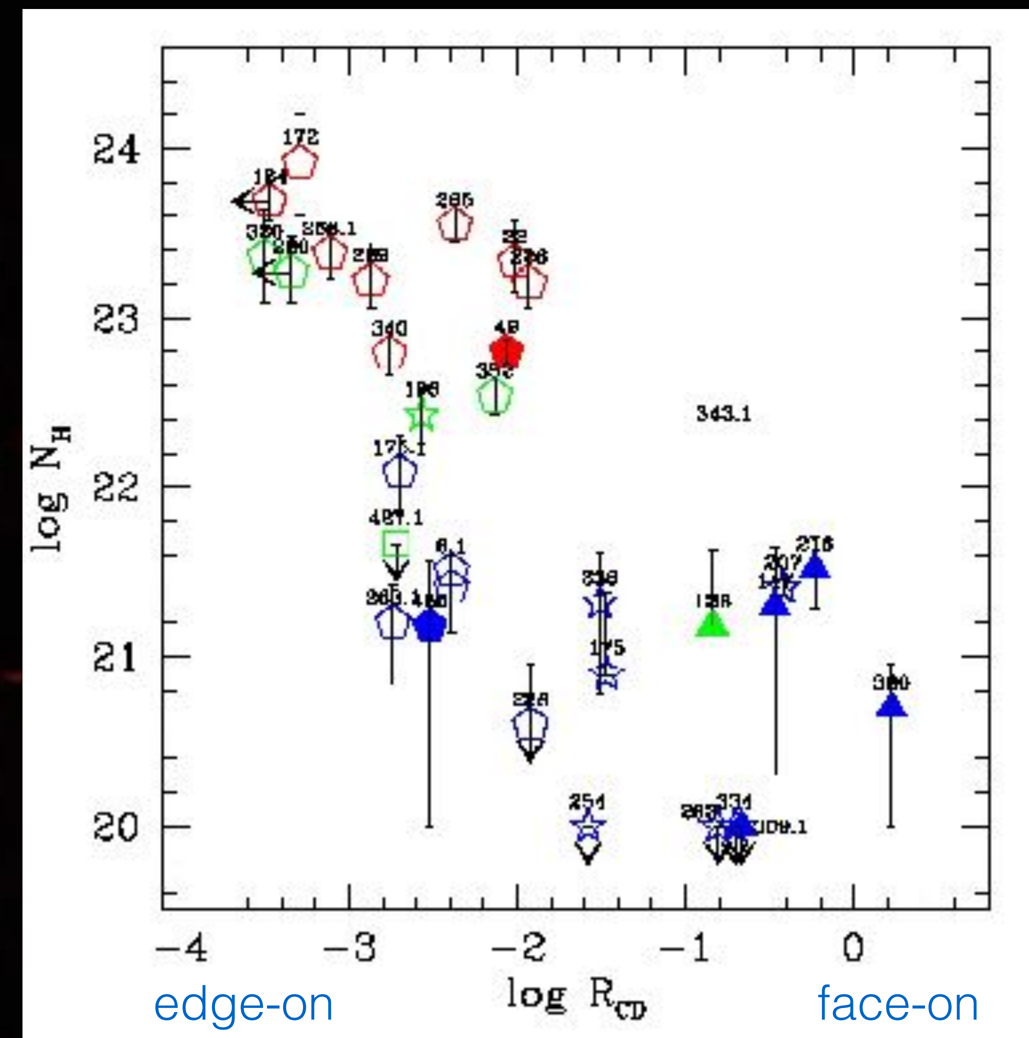
high-*z* NLRGs: high $N_H > 10^{22.5}$ cm$^{-2}$.
medium-*z* NLRGs: $N_H > 10^{21.0}$ cm$^{-2}$.

Note five low $N_H$ (~$10^{21-22}$ cm$^{-2}$) NLRGs in medium-*z* sample, absent from the high-*z* sample. *Chandra* is sampling lower energies in the medium-*z* sample -> easier to detect low $N_H$ at lower redshift, but precise estimate of low $N_H$ difficult at low S/N due to soft excess.

# Correlations with Radio Core Dominance

Radio-core fraction $R_{CD}$ ⟶ orientation



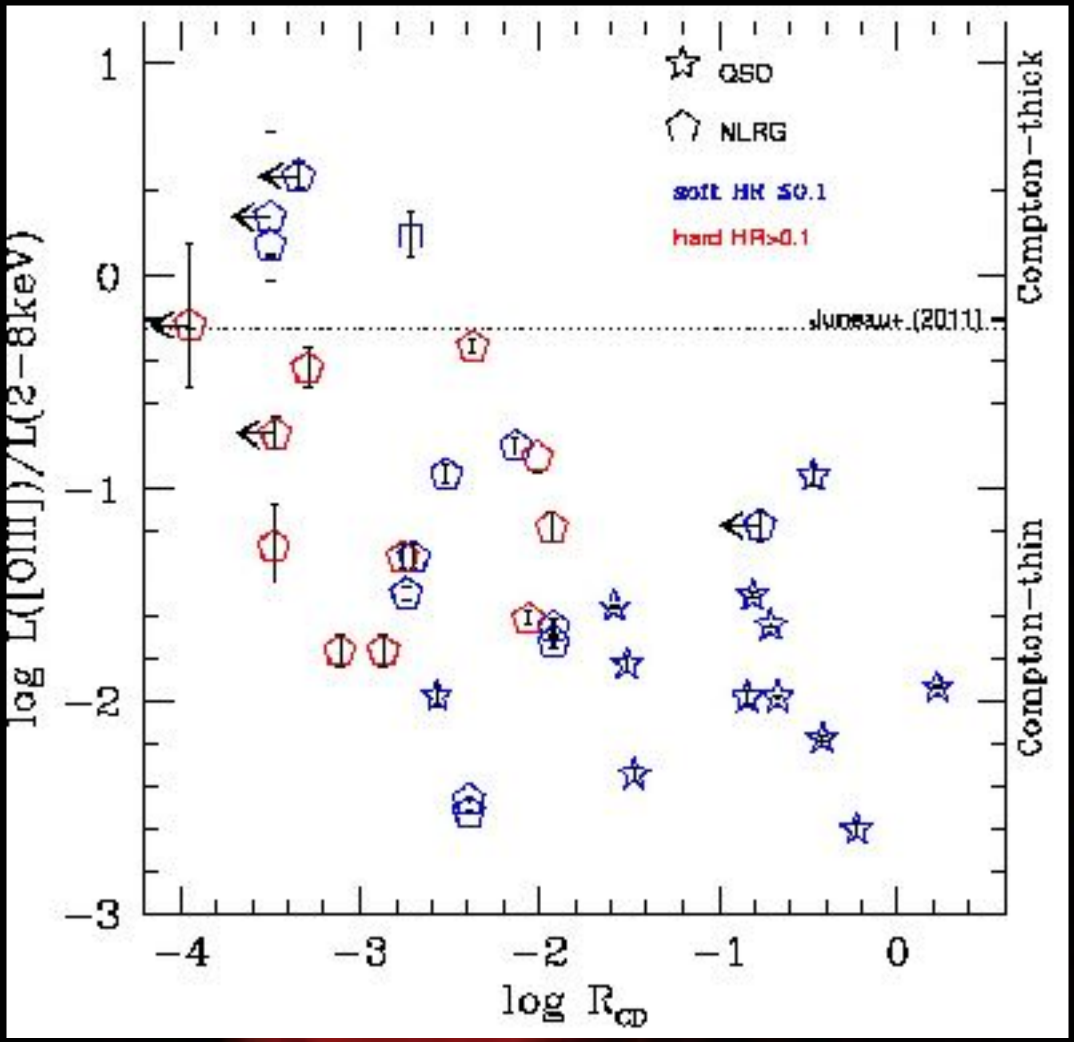



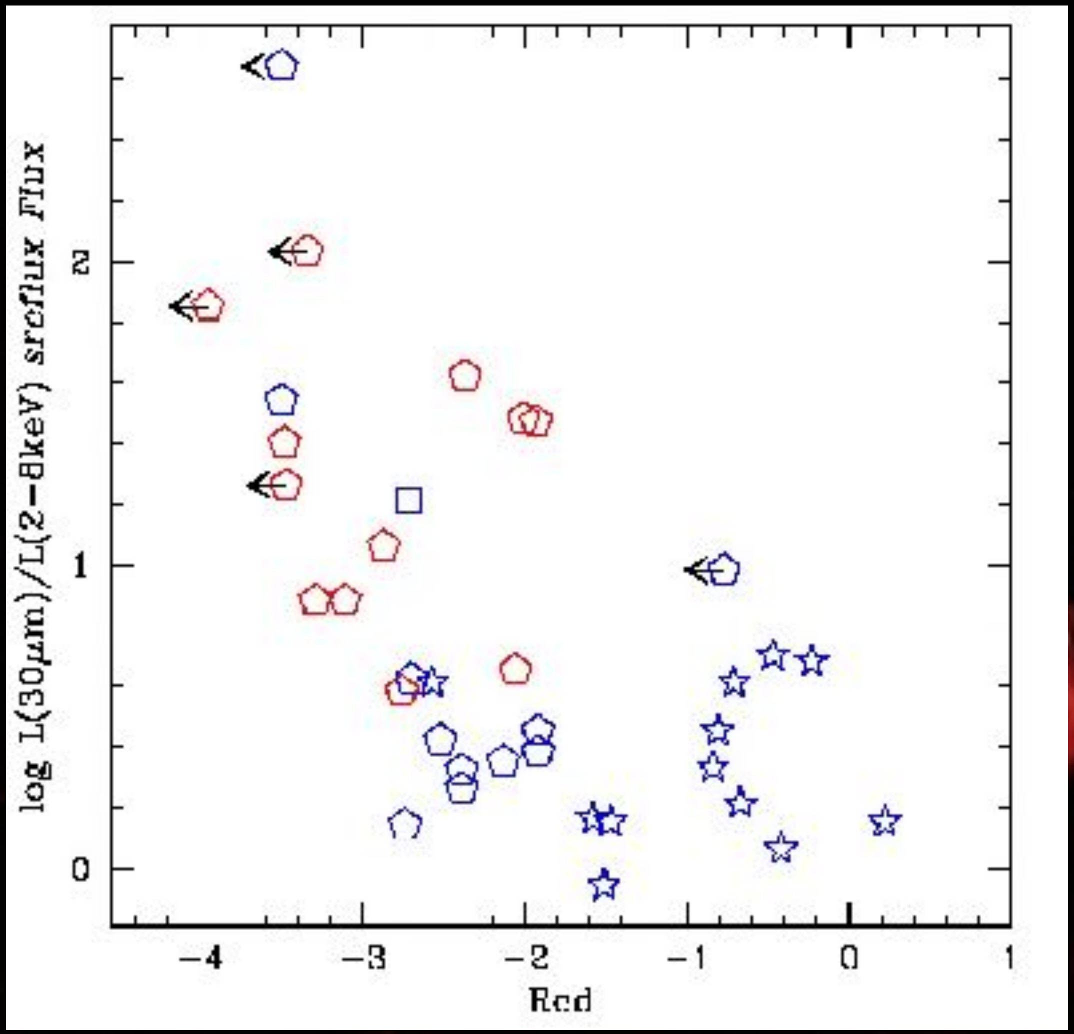

Obscuration decreases observed $L_X$

Strong dependence between $R_{CD}$ and $L_X(obs)/L_{radio}$ , $N_H$

Obscuration and orientation are strongly related ⟶ consistent with Unification models

# Compton-thick sources



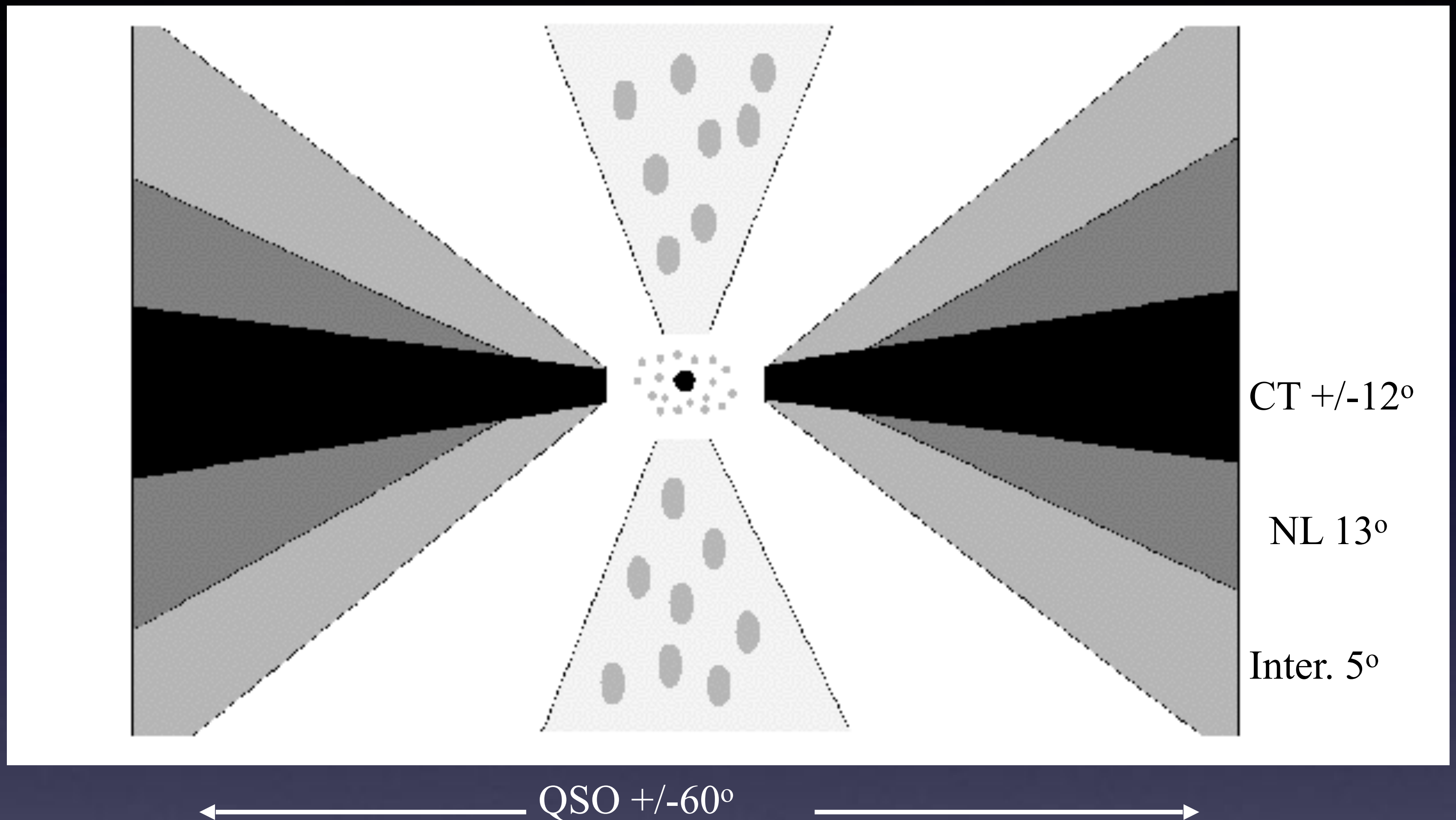

L([OIII]) tracks radio and X-ray luminosities in broad and narrow-line AGN (Jackson & Rawlings 1997, Mulchaey+ 1994) and used as indicator of intrinsic $L_X$.

High [OIII]/L(2-8keV) and/or high L(30$\mu$m)/L(2-8keV) suggest a Compton-thick (CT) source.

7-8 NLRGs are CT/borderline CT candidates i.e. 22% of the medium-*z* 3CRR sample is CT (similar to 21% at high-*z*).

# Unification Scenario

## Nuclear obscuration explains range of observed properties




**Geometry** 0.5<z<1:

- 12 (47%) QSO + 5 low $N_H$ NLRGs (log $N_H < 22$)
- 4 (11%) intermediate NLRGs (22 < log $N_H$ < 23)
- 7 (19%) NLRGs (23 < log $N_H$ < 24)
- 8 (22%) CT NLRGs (log $N_H$ > 24)

**Geometry** 1<z<2:

- 19 (50%) QSO
- 3 (8%) intermediate (2BLRG+1NLRG)
- 8 21% NLRGs
- 8 21% CT NLRGs

- unobscured ($N_H < 10^{22} cm^{-2}$) = obscured ($N_H > 10^{22}$ $cm^{-2}$) —> torus opening angle 60°
- 30% are obscured, Compton-thin ($N_H = 10^{22-24}$ $cm^{-2}$)
- 22% in both samples are CT (consistent with CXRB models; *Gilli+ 2007)*

# sources as function of obscuration -> constraints on covering factor/geometry

# Summary

We study a complete, medium redshift ($0.5 < z < 1$), low frequency (178MHz) radio selected, and so unbiased by orientation, 3CRR sample observed by *Chandra*.

3CRR quasars have:

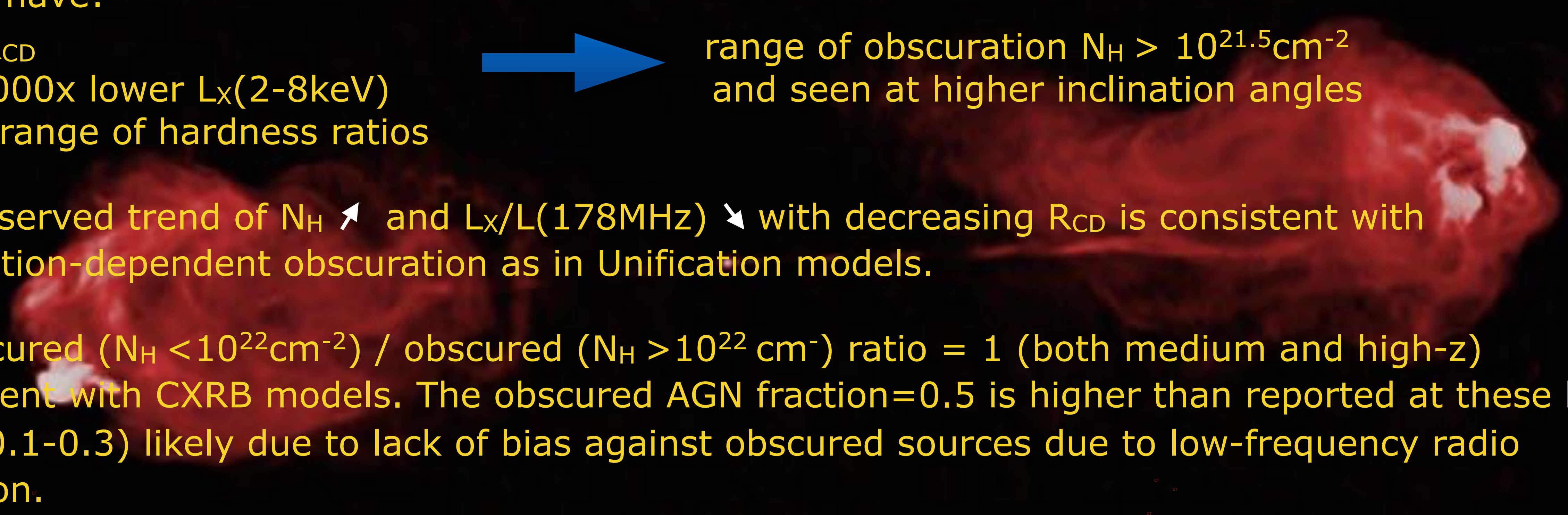
- high $R_{CD}$
- high $L_X$(2-8keV)
- soft hardness ratios

→ low obscuration ($N_H < 10^{22.5}$cm$^{-2}$) and seen face-on

NLRGs have:

- low $R_{CD}$
- 10-1000x lower $L_X$(2-8keV)
- wide range of hardness ratios

→ range of obscuration $N_H > 10^{21.5}$cm$^{-2}$ and seen at higher inclination angles



The observed trend of $N_H$ $\nearrow$ and $L_X$/L(178MHz) $\searrow$ with decreasing $R_{CD}$ is consistent with orientation-dependent obscuration as in Unification models.

Unobscured ($N_H < 10^{22}$cm$^{-2}$) / obscured ($N_H > 10^{22}$ cm$^{-}$) ratio = 1 (both medium and high-z) consistent with CXRB models. The obscured AGN fraction=0.5 is higher than reported at these high Ls (=0.1-0.3) likely due to lack of bias against obscured sources due to low-frequency radio selection.

~22% in both high and med-z samples are CT (high L[OIII]/L(2-8keV), L(30$\mu$m)/L(2-8keV)
Correcting $L_X$(obs) using $N_H$ estimated from HR results in 10-1000x underestimate of $L_X$(int).
For these highly obscured sources L(2-8keV)/$L_{radio}$ and L([OIII])/L(2-8keV) provide a better than HR measure of intrinsic absorption.

Simple geometry of obscuring material: CT obscuring disk/torus ~12° from mid-plane, additional obscuring material 18°, and half opening angle of obs. material is 60°.