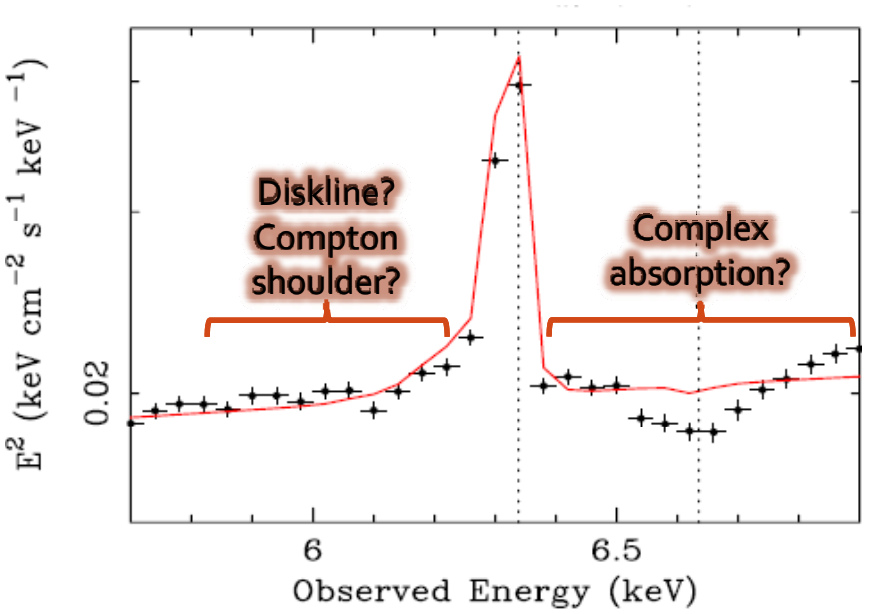
# PROBING UNIFICATION WITH HIGH-RESOLUTION IMAGING AND SPECTROSCOPY OF NGC 2110

Dan Evans (Harvard), Julia Lee (Harvard), Jane Turner (UMBC/GSFC), Kim Weaver (GSFC), Herman Marshall (MIT)

# Fe Kα Lines and Reflection: AGN Geometry

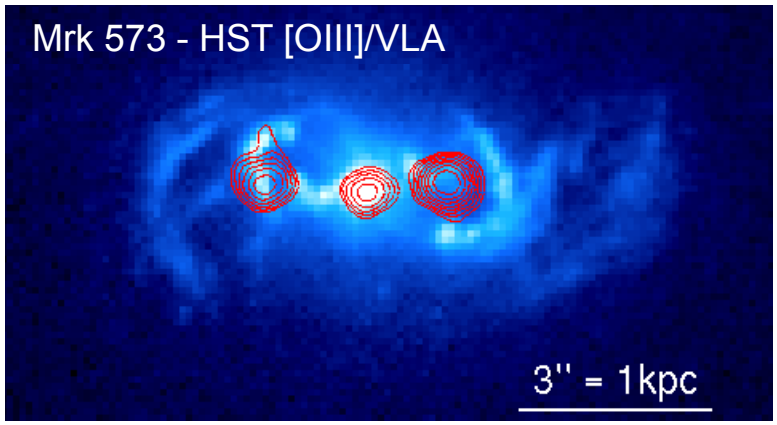
- The Fe Kα line complex in general consists of a narrow line core, possibly accompanied by broadened emission
- What is the origin of the broad emission?
  - Relativistically blurred diskline?
  - Compton shoulder?
  - Broad line region?
  - Unmodeled absorption?
- If we can deconvolve the contributions from the two, we can probe AGN geometry
- Vital to treat direct+reflected continuum and absorption effects self-consistently

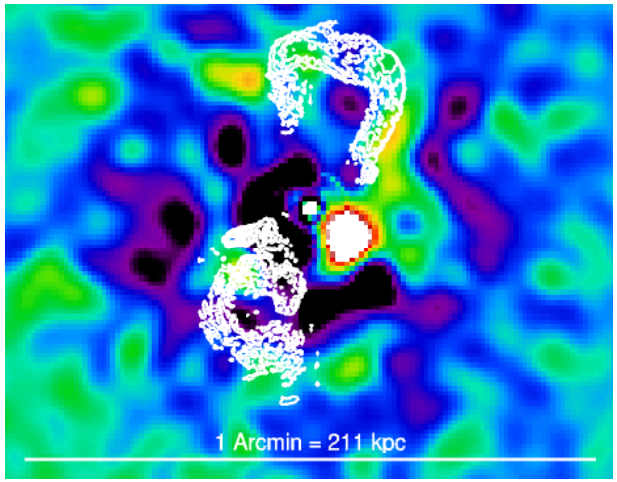



NGC 3783 (Yaqoob et al. 2005)

# Circumnuclear Environments in Seyferts

- Although Seyferts are radio quiet, many are not radio silent
- 100s-pc scale radio jet has strong influence on (E)NLR, often resulting in a disturbed environment, with prominent series of arcs, strands, and knots
- How is the emission produced? Shock heating? Photoionization? Important constraints from VLA, HST [OIII], Chandra
- To what degree is the AGN soft excess comprised of circumnuclear gas?
- What parallels can be drawn between Seyfert jets and radio-galaxy jets?




3C 123 - Chandra/VLA

# NGC 2110

Nearby ($z$=0.0076, $D_L$=33 Mpc) NELG

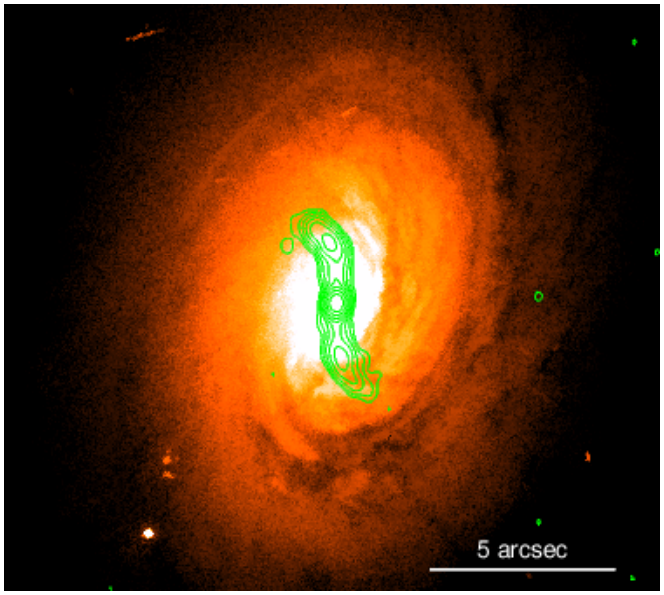
- Historical subclass of Seyferts with narrow (<600 km/s) optical lines (Seyfert 2-like) but much stronger hard X-ray emission (Seyfert 1-like)
- Flat X-ray spectra may imply they dominate XRB at low energies (e.g. Iwasawa et al. 1997)
- Transitional between Seyfert 1 and Seyfert 2? (Lawrence & Elvis 1982)

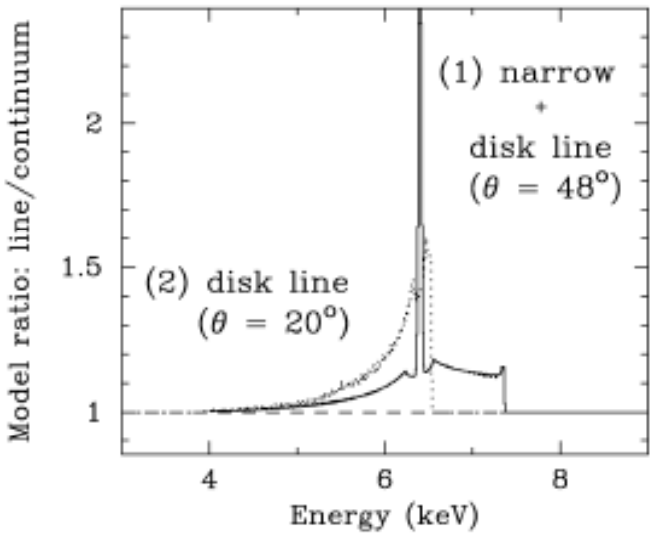
ASCA, BeppoSAX, etc. ⇒ 2-10 keV X-ray spectrum is very flat (Γ=1.4)

- Accompanied by moderate absorption ($N_H$=3x10$^{22}$ cm$^{-2}$)

ASCA Fe K complex hard to interpret

- Diskline, either oriented at intermediate angles to l.o.s. (Weaver & Reynolds 1998) or nearly face-on (Turner et al. 1998)



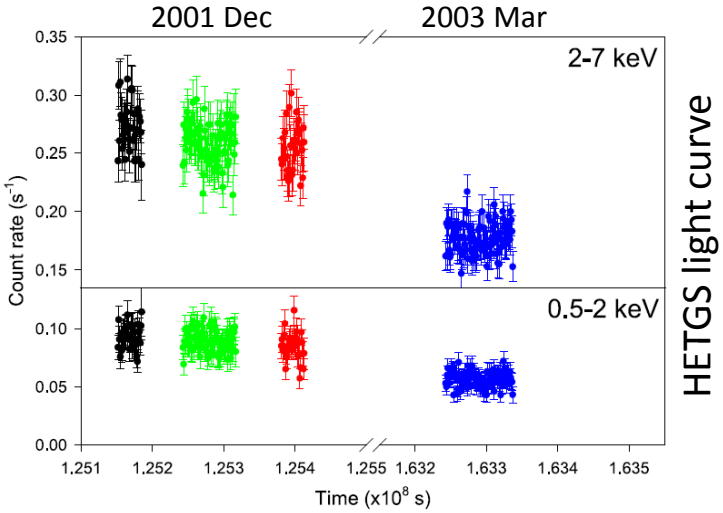



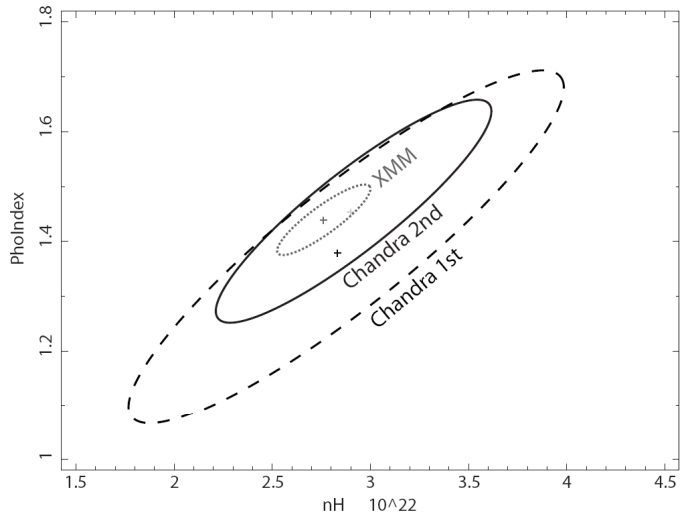
# OBSERVATIONS AND RESULTS

# Chandra and XMM-Newton

NGC 2110 was observed with Chandra for a total of 250 ks and XMM-Newton for 60 ks. An initial analysis showed variability in flux only, and so the continuum spectra were analyzed jointly.

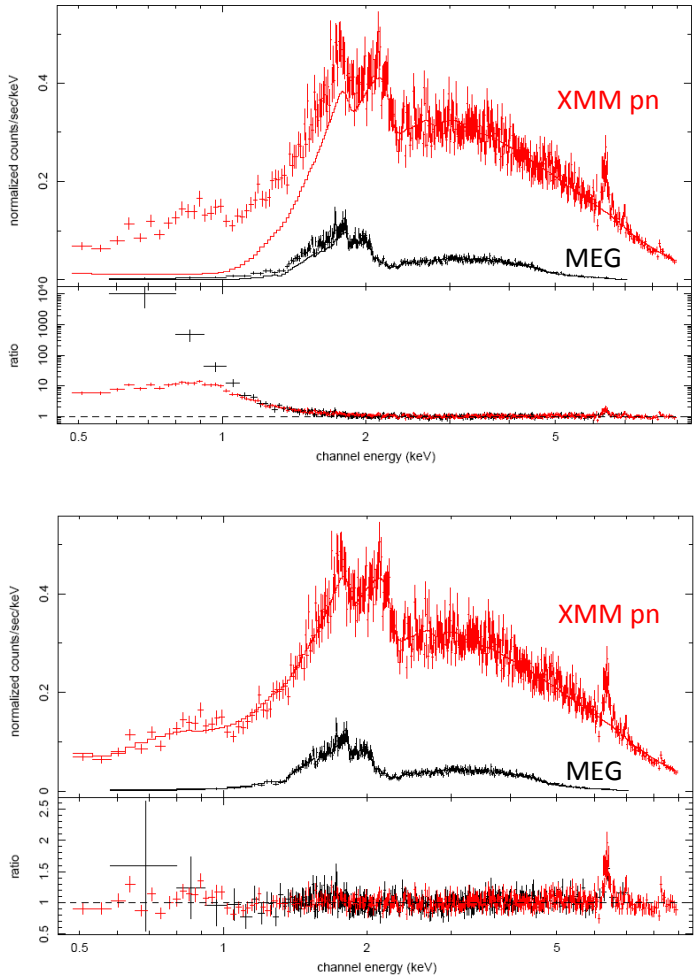
| Instrument | Date | Exposure (ks) |
|---|---|---|
| HETGS | 2001 Dec 19 | 35 |
| HETGS | 2001 Dec 20 | 80 |
| HETGS | 2001 Dec 22 | 35 |
| HETGS | 2003 Mar 05 | 100 |
| EPIC/RGS | 2003 Mar 05 | 60 |



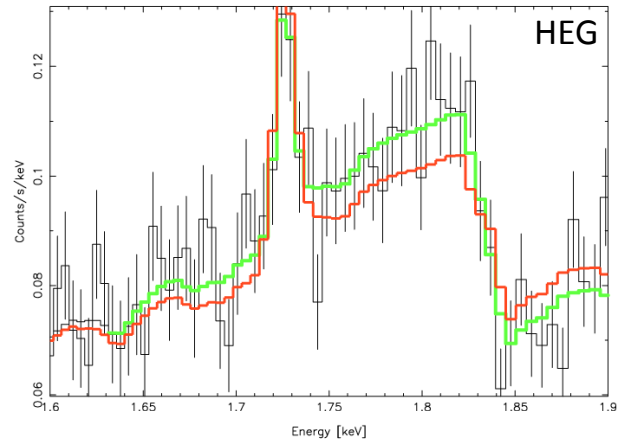
# Continuum Fitting

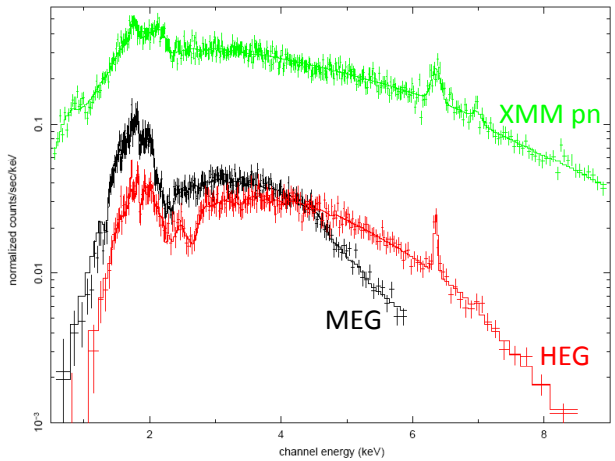
- Initial fit with single, moderately absorbed power law ($N_H$=3x$10^{22}$ $cm^{-2}$, Γ=1.4)
- Soft excess seen below 2 keV
- Significant improvement in fit with the addition of a lightly absorbed ($N_H$=7x$10^{20}$ $cm^{-2}$) power law ($\Gamma_{soft}=\Gamma_{hard}$)
- Still very flat photon index (Γ=1.4), but…



# Continuum Fitting

- Insufficient opacity at Si K and Fe K edges
- Improvement in the fit with the additional edges
- Does this imply an extra absorber?
- Significant improvement with a 3x partially covered power law
- Photon index rises to $\Gamma=1.74\pm0.05 \Rightarrow$ consistent with canonical values in Seyferts



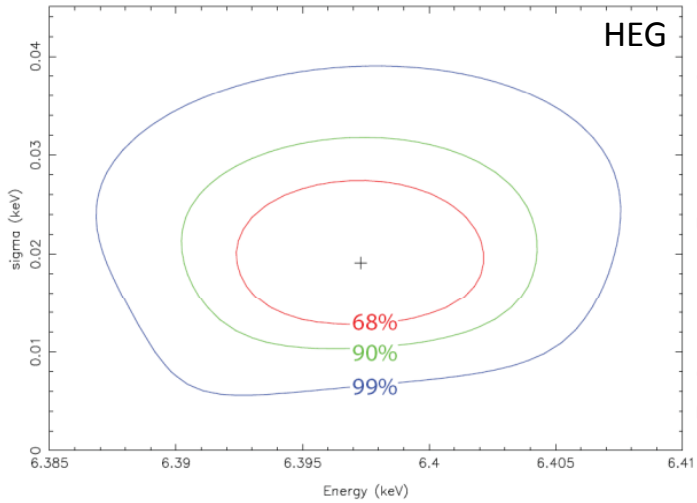

| Component | Column density ($cm^{-2}$) | Covering fraction |
|---|---|---|
| $N_{H,1}$ | $1.6x10^{23}$ | 32% |
| $N_{H,2}$ | $2.8x10^{22}$ | 96% |
| $N_{H,3}$ | $7.7x10^{20}$ | 100% |

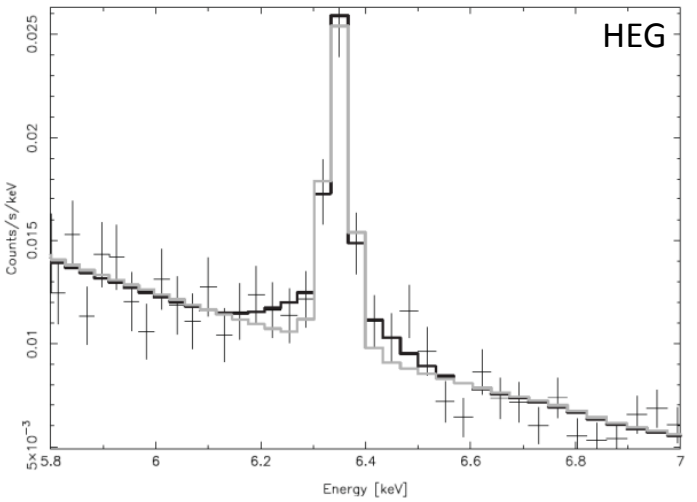
# Fluorescent Line Diagnostics

- Chandra HETGS best suited to probe narrow lines
- Neutral fluorescent Kα lines detected from Si, S, Ar, Ca, Fe
- Narrow Fe Kα and Si Kα line cores just resolved with HETGS

| Line | Energy (keV) | Width (km $s^{-1}$) | Equivalent width (eV) |
|---|---|---|---|
| Fe Kα | 6.397±0.007 | 900±500 | 80±30 |
| Si Kα | 1.740±0.002 | 600±400 | 6±2 |

- Distant, neutral fluorescing region
- No evidence for diskline
- Marginal (2.5σ) evidence for v. slight broadened base of Fe Kα

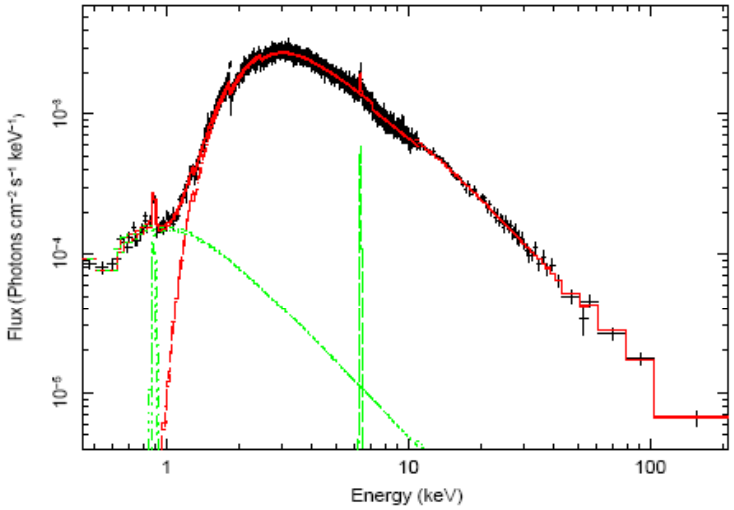


# Reflection

- Self-consistent treatment of reflection (i.e., lines+pexrav continuum)
- No change in fit parameters
- Suzaku provides vital constraints on strength of reflection
- Stringent limit of $R<0.1$ (Reeves et al. 2006; Okajima et al. 2007)
- NGC 2110 is one of the few Seyferts with no evidence for disk reflection, nor complex absorption

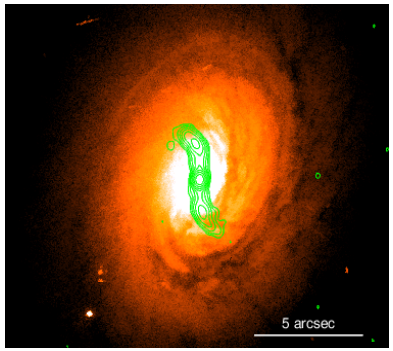
Suzaku – NGC 2110 (Reeves et al. 2006)

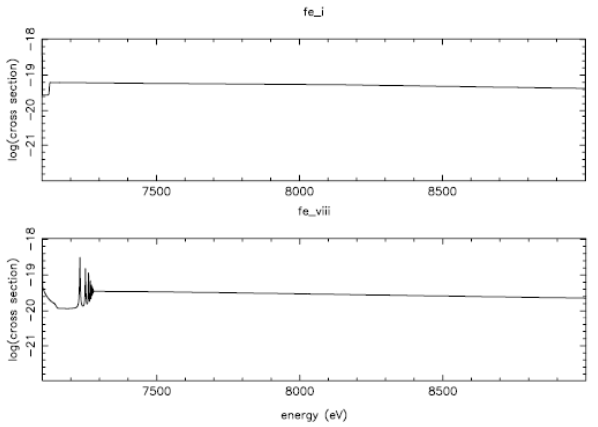


# Origins of Absorption

- Patchy $10^{23}$ cm$^{-2}$ coverer – plausibly BLR clouds?
- $10^{22}$ cm$^{-2}$ absorber likely to have
  - Flattened geometry in order to allow small-scale jet to escape
  - Significant distance from black hole in order to obscure BLR
- Alternative: ionized absorption
  - Would transmit low-energy continuum emission
  - Resonance absorption around K edge
  - No evidence in HETGS data
  - Suzaku will be able to test this further (Okajima et al., in prep.)

| Component | Column density (cm$^{-2}$) | Covering fraction |
|---|---|---|
| $N_{H,1}$ | $1.6 \times 10^{23}$ | 32% |
| $N_{H,2}$ | $2.8 \times 10^{22}$ | 96% |
| $N_{H,3}$ | $7.7 \times 10^{20}$ | 100% |



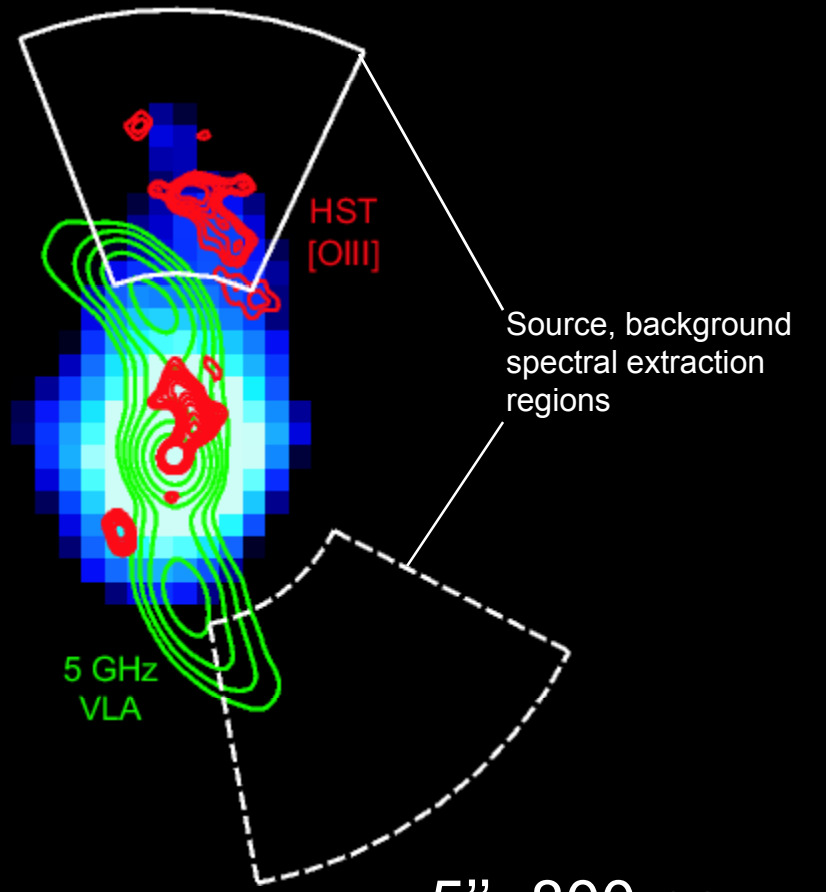




Kallman et al. (2004)

# CIRCUMNUCLEAR ENVIRONMENT

# Multiwavelength Imaging

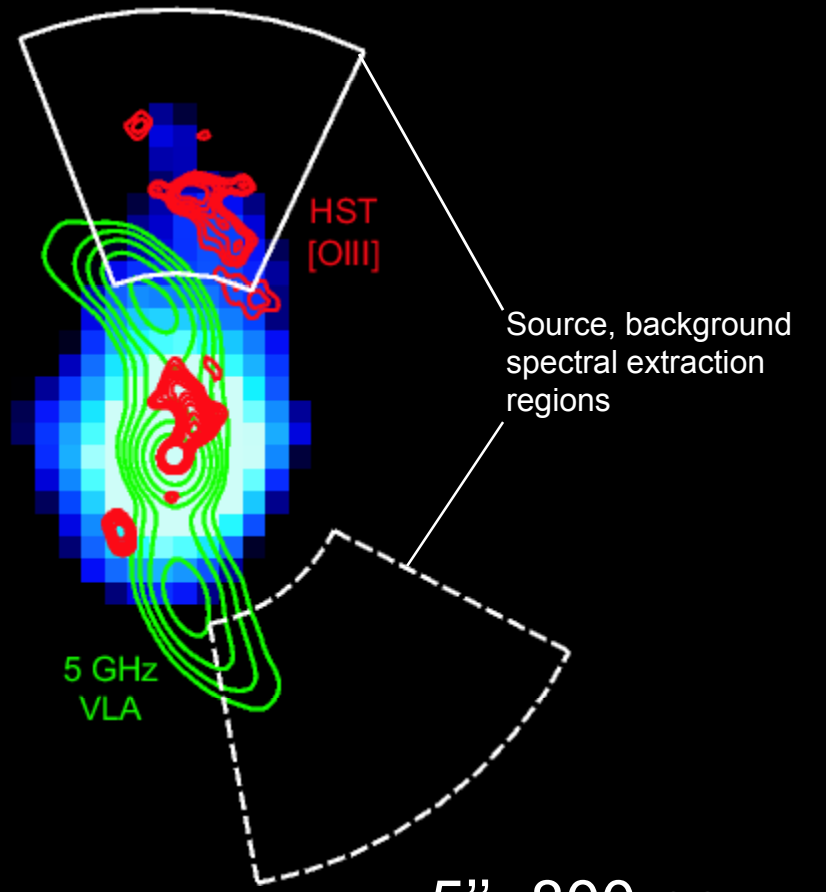
- Excellent spatial agreement between X-ray and [OIII] (Evans et al. 2006)
- Both clearly offset from radio, but extend along similar p.a.
- X-ray & [OIII] emission influenced by, but not directly associated with, radio jet?
- ACIS X-ray spectrum modeled by, e.g., two thermal plasma models ($kT_1$=0.3 keV; $kT_2$=5 keV)




Chandra (0.5-1.5 keV) / VLA / HST [OIII]

# Emission Mechanisms

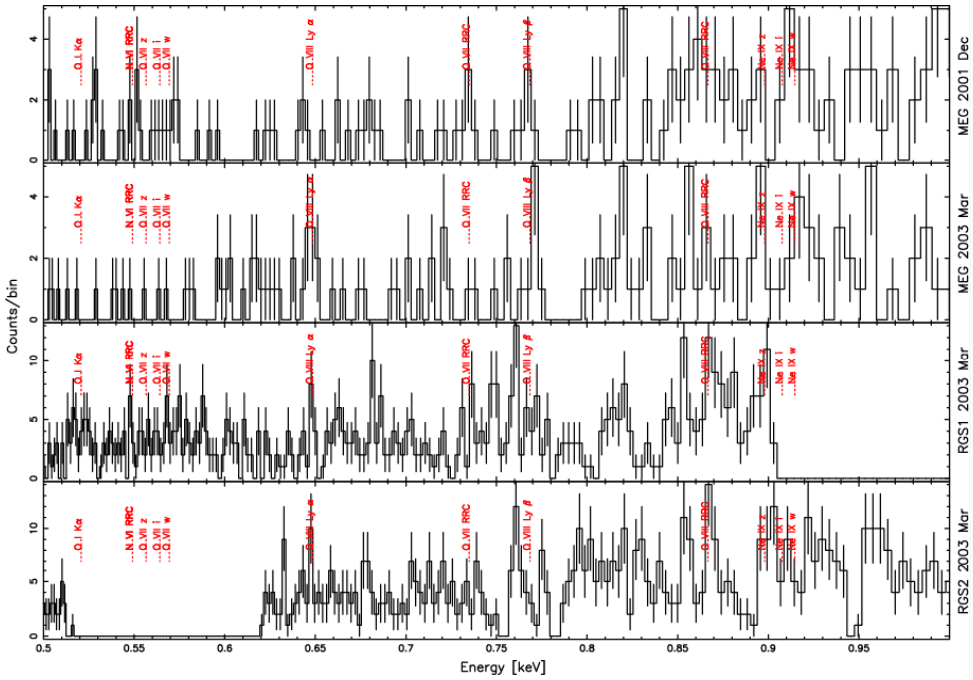
1. Shock heating
   - Minimum pressure of radio lobes, assuming $\gamma_{min}$=2 up to $\gamma_{max}$=$10^5$, is ~$10^{-10}$ Pa
   - HST [OIII] and [SII] constraints (Ferruit et al. 1999) give pressure few $10^{-10}$ Pa
   - Chandra spectrum, with plasma model, gives pressure few $10^{-10}$ Pa
2. Photoionization
   - Consider extended X-ray luminosity, and use sensible values of ionization parameter and emissivity
   - Nuclear luminosity required to photoionize gas 20x greater than that measured
   - This mechanism may be energetically viable, especially if nuclear emission emitted anisotropically
   - Also…




Chandra (0.5-1.5 keV) / VLA / HST [OIII]

# Gratings Spectrum

- High-resolution grating spectroscopy can in principle distinguish between these models
- Tentative evidence for O VIII Ly α, as well as the O VIII RRC feature first reported by Guainazzi & Bianchi (2006)
- X-ray/[OIII]/radio morphology naturally explained with shock-heating by jet




- Photoionization and collisional ionization processes both important?

# SUMMARY

# Recap

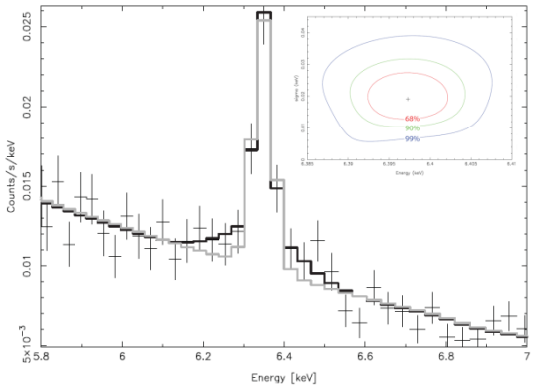
## ASCA, BeppoSAX, etc. found

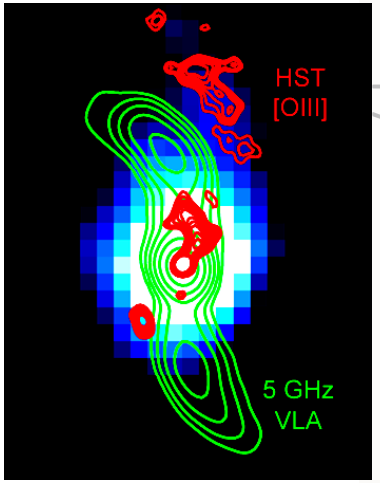
- Flat (Γ=1.4) 2-10 keV spectrum
- Moderate absorption ($N_H$=3x10$^{22}$ cm$^{-2}$)
- Diskline emission, either face-on or at intermediate angles

## Chandra, XMM-Newton (and Suzaku – Okajima et al. 2007)

- Compton-thin partial-coverer model
- Photon index 1.7-1.8
- No evidence for ionized absorption
- Marginally resolved (900±500 km s$^{-1}$) Fe Kα line core
- No evidence for disk reflection
- Multiwavelength imaging + HETGS evidence for (weak) ionized emission ⇒ extended circumnuclear environment is photoionized or collisionally ionized?

| Component | Column density (cm$^{-2}$) | Covering fraction |
|---|---|---|
| $N_{H,1}$ | 1.6x10$^{23}$ | 32% |
| $N_{H,2}$ | 2.8x10$^{22}$ | 65% |
| $N_{H,3}$ | 7.7x10$^{20}$ | 3% |



# IMPLICATIONS

- Consistent with an origin in a Compton-thin, distant (> 1pc) neutral absorber
- Orientation consistent with edge-on view
- Steepening of photon index using multiple partial-coverer model ⇒ NELGs do not have significantly flatter spectra w.r.t. Seyfert 1, 2?
- No disk reflection, unlike other Compton-thin Seyferts observed with Suzaku (Reeves et al. 2006)
- Vital to treat absorption and reflection effects in a self-consistent manner in order to evaluate AGN geometry
- High spatial and spectral resolution, together with high effective area, are key to determining the spatial distribution and energetics (collisional vs. photoionization) of circumnuclear environments in AGN