Chandra Imaging of the Nuclear Region in Nearby Seyferts: Disentangle AGN Feedback


Accretion Processes in X-Rays: From White Dwarfs to Quasars

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AGN outflow is an important part of the accretion process (cf. Proga, Chartas talks)

“AGN feedback” crucial to SMBH-galaxy co-evolution

Energy injection efficiency *often assumed*

$L_{\text{outflow}}/L_{\text{bol}} \sim 5\%-100\%$ (e.g., Scannapieco & Oh 2004; Silk 2005; see also Hopkins & Elvis 2010; Ciotti et al. 2010; Ostriker et al. 2010)

Mrk 573

HST [OIII] survey by Schmitt et al. (2003); see also Bianchi et al. (2010)
A single photoionized medium
- Overall morphology coincident with the [OIII] emission
- Poor fit to the X-ray spectra with collisionally ionized thermal plasma

- Many Seyfert galaxies host vigorous star formation and/or eject relatively weak jets
- Competing processes of AGN photoionization and shock heating

See also Evans et al. (2006); Bianchi et al. (2010); Dadina et al. (2010)
X-ray emitting hot gas may serve as the hot phase confining inter-cloud medium to the NLR cloud (Elvis et al. 1983, 1990)

[OIII] clouds $P \sim 10^{-10}$ dyne cm$^{-2}$ (Kristen et al. 1997)

Pressure equilibrium with cooler optical line-emitting gas

Hot Gas Confining the Photoionized Clouds in NGC 1365

Blue: X-rays Red: [OIII]5007

Wang et al. (2009a)
Filled circles: NGC 1365 regions
Cyan circle and line: warm Galactic halo
Blue squares: stellar yields from SNe Type I
Magenta squares: SNe Type II (Nakataki & Sato 1998 and references)

Consistent with Type II SN enrichment
Soft X-ray emission in Seyfert 2s likely dominated by photoionized gas (Guainazzi & Bianchi 2007; Guainazzi et al. 2009) Line ratio diagnostics

But ... location of the X-ray photoionized gas
e.g., Mrk 355 <0.06 pc (Longinotti+08); NGC 1068 up to 1 kpc (Evans+10) \(\rightarrow\) implications on the mass/momentum outflow

See Krongold+07; Arav+08; Steenbrugge+09; Ebrero+10
Biconical Outflow in NGC 4151 ENLR

Das et al. (2005)

Ogle et al. (2000); Yang et al. (2001)
New Results from Our NGC 4151 Project (PI: G. Fabbiano)

- ~200 ks ACIS-S 1/8 sub-array (shorter frametime)
- X-ray spectral variability of the nucleus (Wang et al. 2010a)
- Extended soft X-ray emission (Wang et al. 2010b)

50 ks HRC-I Imaging the inner-most region (Wang et al. 2009)

0.13 arcsec `pixel' but poor energy resolution (cf. 0.5″/pixel ACIS)
Wang et al. (2009); HST/FOC 502N data from Winge et al. (1997)
Enable multiwavelength view of the Jet-cloud interaction

NGC 4151


Red: HRC 0.1-10 keV
Green: optical [OIII]
Blue: radio (1.4 GHz)
Ionization parameter $\xi = L/(nr^2)$

Enhanced X-ray emission in addition to photoionization

Cloudy grid for an AGN photoionized medium (Bianchi et al. 2006) $n \propto r^\beta$
Study NGC 4151 NLR structure on physical scale of ~30 pc (0.5″ @ 13 Mpc)

Subpixel technique (Mori et al. 2001; Tsunemi et al. 2001; Kastner et al. 2002; Li et al. 2003)
Disentangle the Emission with Spatially Resolved Spectroscopy

Contours: [OIII]

Contours: 1.4 GHz

H2 emission

(Storchi-Bergmann et al. 2010)
A Full View of AGN Feeding and Feedback

Hardness ratio map of the circum-nuclear region reveal hard spectral index or high obscuration region

Bianchi et al. (2008), Wang et al. (2010)
Evidence for galaxy-scale AGN feedback?

Red: HI
Mundell et al. (1999)
Green: Hα
Blue: 0.3-1 keV

X PSF scattering
X Unresolved point sources
X Electron scattered nuclear emission

Evidence for galaxy-scale AGN feedback?
Origin of the large scale soft emission

- Relic photoionized gas from a past AGN outburst \((L \sim L_{\text{edd}} \text{ required})\)
  
  light travel time + recombination time scale
  \[ T < 2.5 \times 10^4 \text{ yr} \]

- Hot gas heated by AGN outflow
  
  Pressure \(10^{-11} \text{ dyne cm}^{-2}\)
  Additional confinement by HI gas inflow

  \[ T \sim 10^4 - 10^5 \text{ yr} \]
Conclusions

- Chandra’s high resolution images are powerful tools in studying the complex circum-nuclear regions of AGNs.
- For the NGC 1365 X-ray emission cones, we find hot gas confining photoionized clouds, likely starburst driven “superwind.”
- In NGC 4151 Chandra resolves
  - Photoionized emission. The radially constant ratio indicates a density dependence $n \propto r^{-2}$ as expected for a nuclear wind.
  - Thermal emission from interaction between radio outflow and the NLR clouds.
  - ‘Fossil’ large scale emission.

Given these diversities, we need to study individual objects in detail to learn AGN feedback physics.

**CHandra survey of Extended Emission line Regions in nearby Seyferts:**

- **CHEERS**
  - Full picture of the multiphase ISM
  - Mass-momentum outflow

Thank you!
Subpixel technique
(Mori et al. 2001; Tsunemi et al. 2001; Kastner et al. 2002; Li et al. 2003) applied