

The Chandra Survey of Outflows in AGN with Resolved Spectroscopy (SOARS)

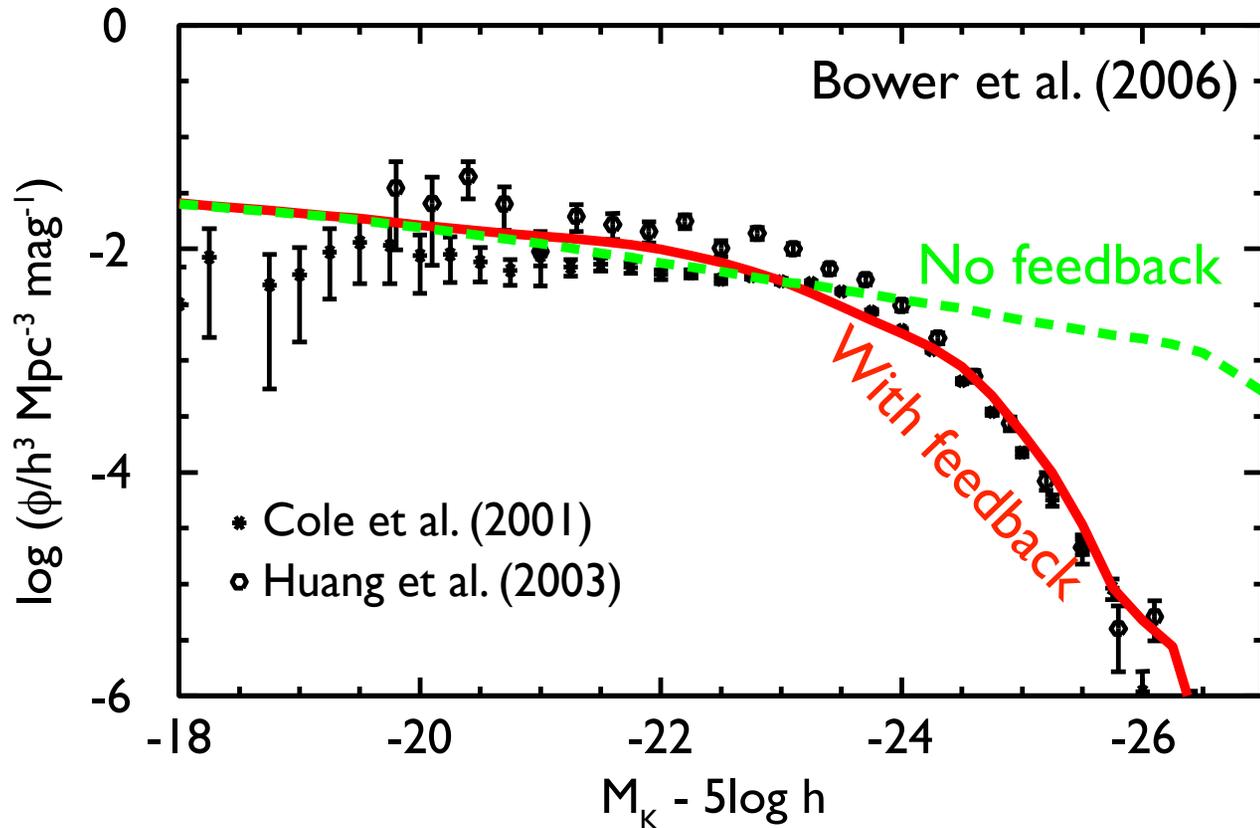


Dan Evans (Harvard-Smithsonian CfA and Elon University)

Kevin Schawinski (Yale), Herman Marshall (MIT), Stefano Bianchi (Roma Tre), Matteo Guainazzi (ESAC), Martin Ward (Durham), Ric Davies (MPE), James Reeves (Keele), Kim Weaver (GSFC), Patrick Ogle (Caltech)

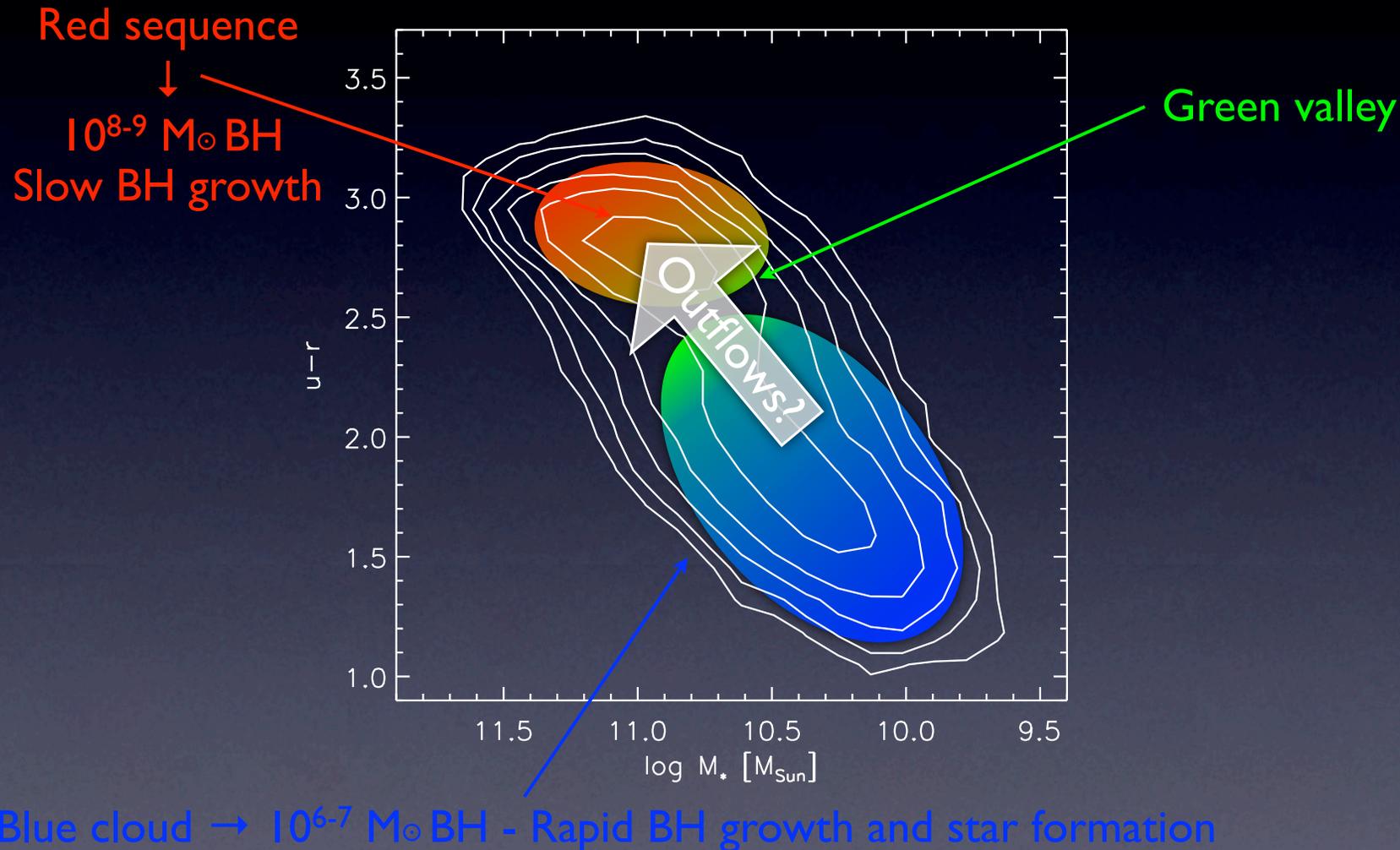


Black Holes and Galaxy Formation



Sharp cutoff at the bright end of the galaxy mass function can be solved with AGN feedback.

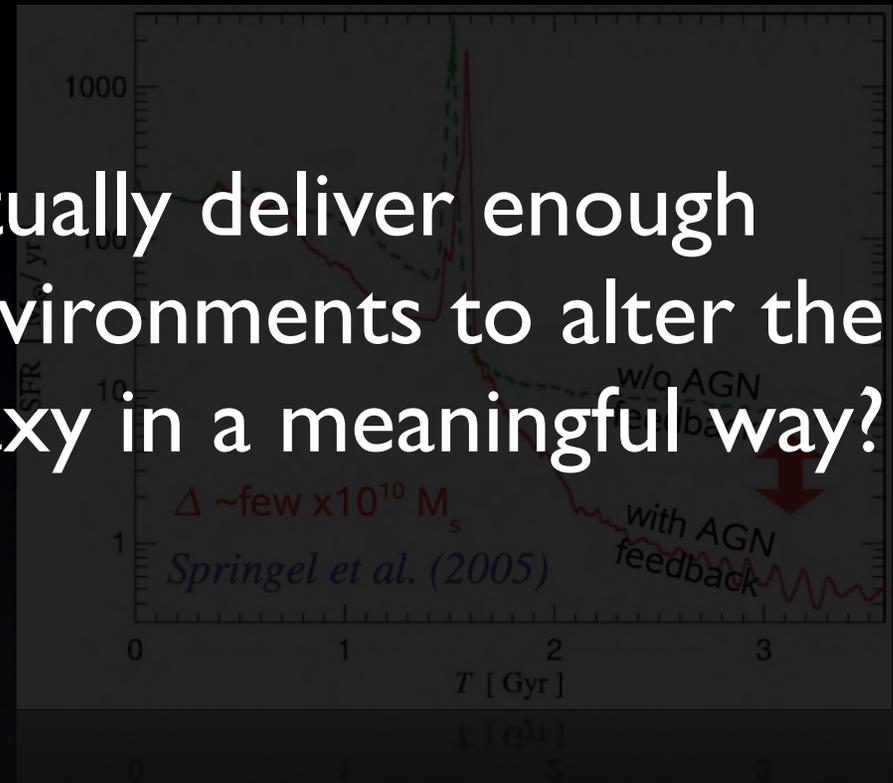
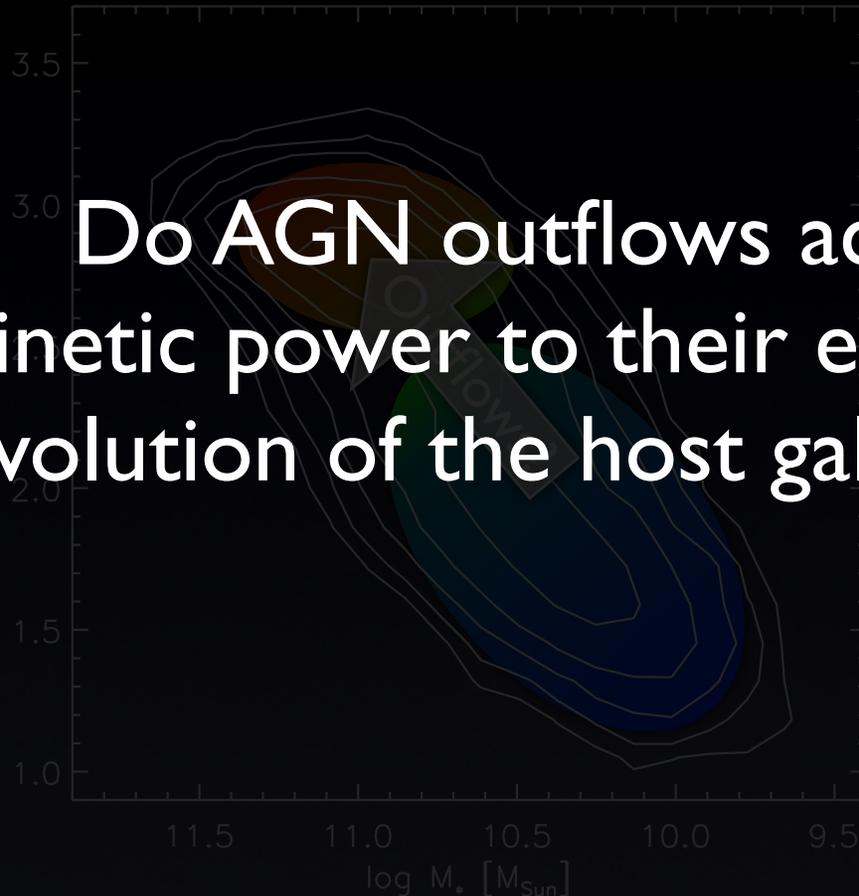
Galaxy Color-Magnitude Diagram



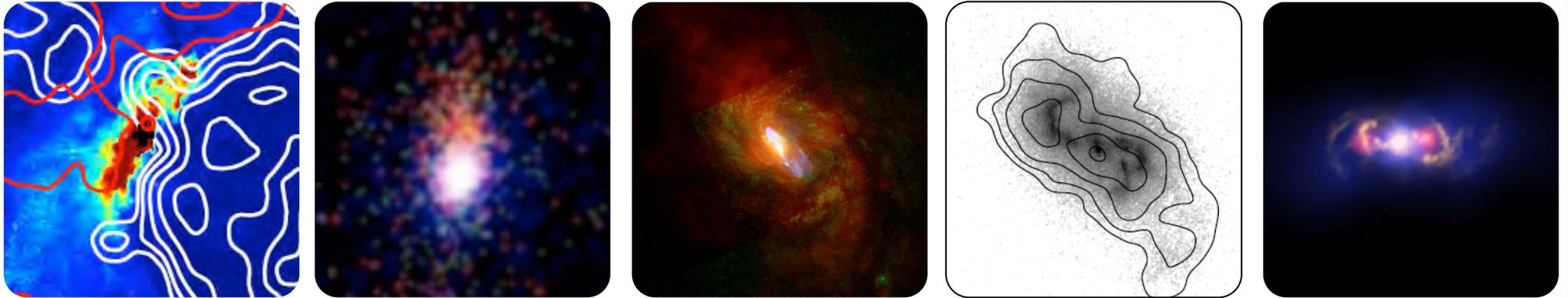
e.g. Smolcic et al. (2006), Taylor et al. (2008), Hickox et al. (2009), Schawinski et al. (2009)

Galaxy Color-Magnitude Diagram

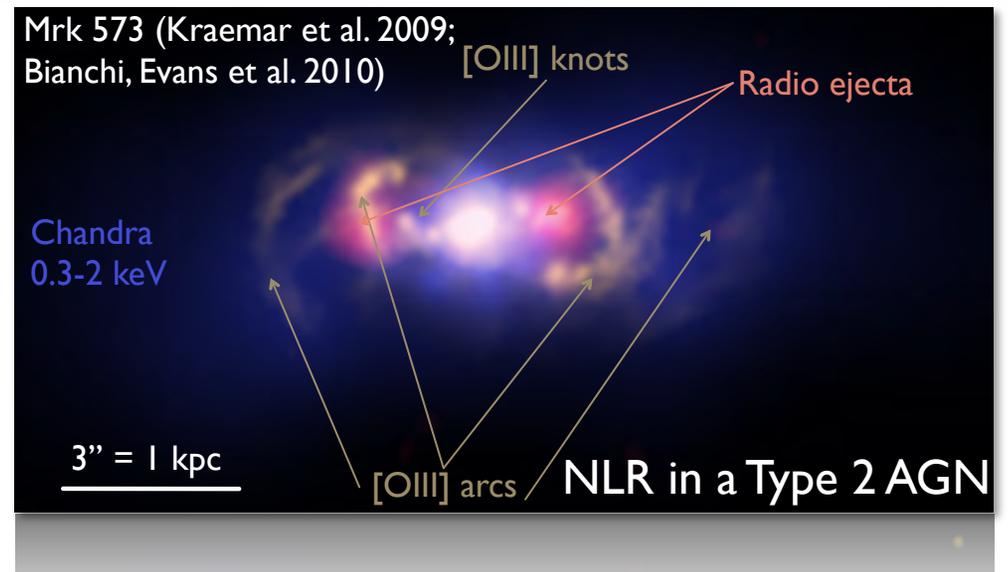
Do AGN outflows actually deliver enough kinetic power to their environments to alter the evolution of the host galaxy in a meaningful way?



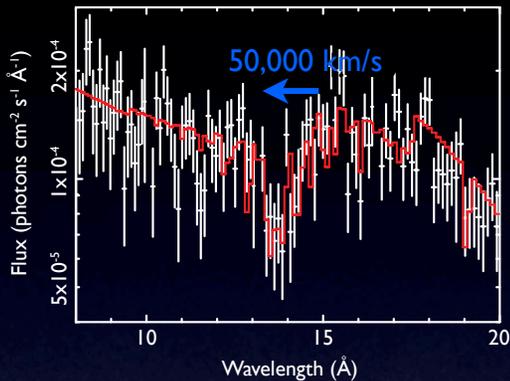
Searching For Outflows: Multi- λ Imaging



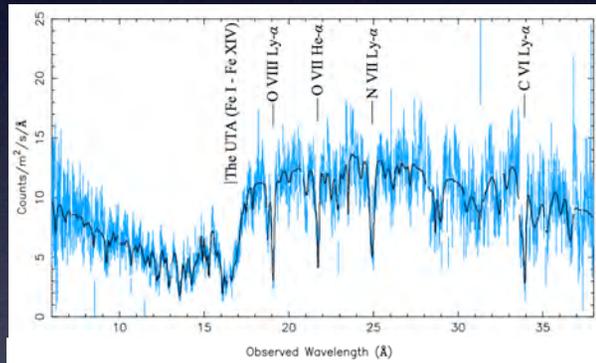
- ① Spatial relationships between nucleus, jet, warm [OIII] gas and hot X-ray gas in kpc NLR
- ② Some estimates of energy in the multiphase gas



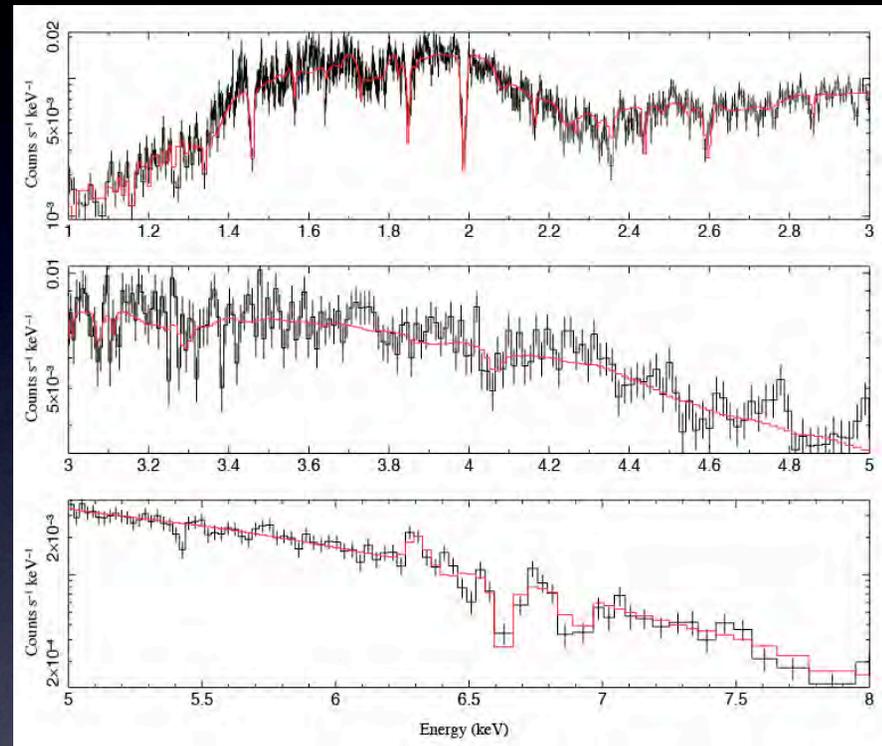
Searching For Outflows: Spectroscopy



PDS 456 - Reeves et al. (2003)



N3516 - Mehdipour et al. (2010)



ESO 323 - Evans et al. (in prep.)

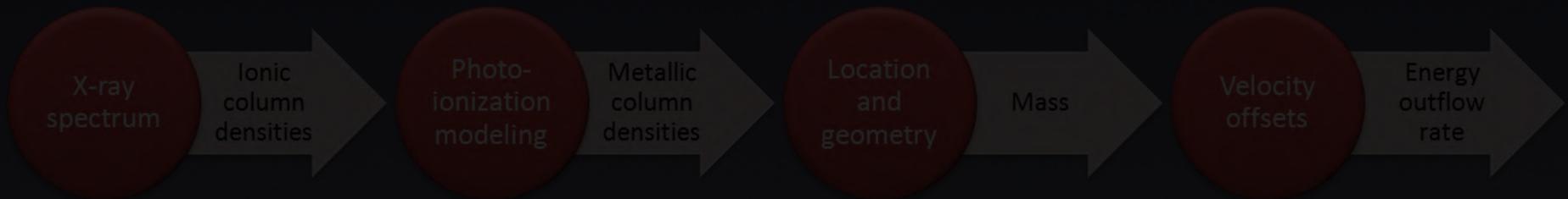
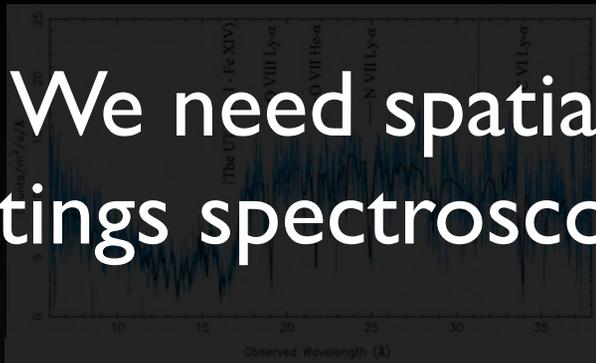
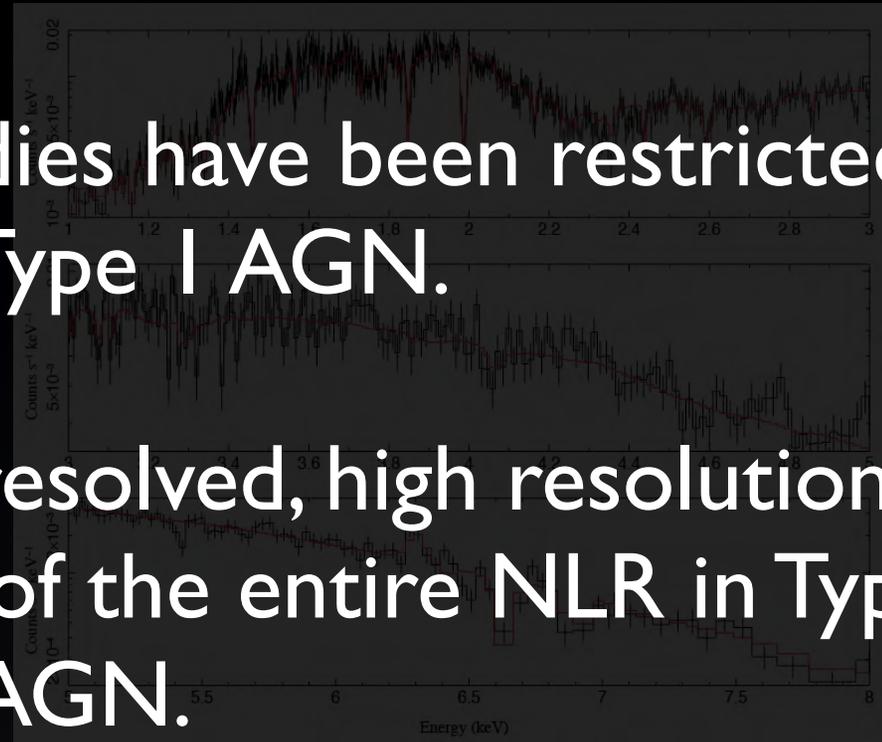
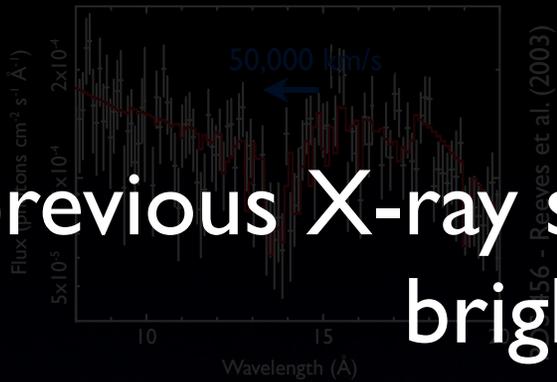


High-ionization X-ray gas has large columns and filling factors
 → may be dominant NLR component

Searching For Outflows: Spectroscopy

All previous X-ray studies have been restricted to bright, Type I AGN.

We need spatially resolved, high resolution gratings spectroscopy of the entire NLR in Type 2 AGN.

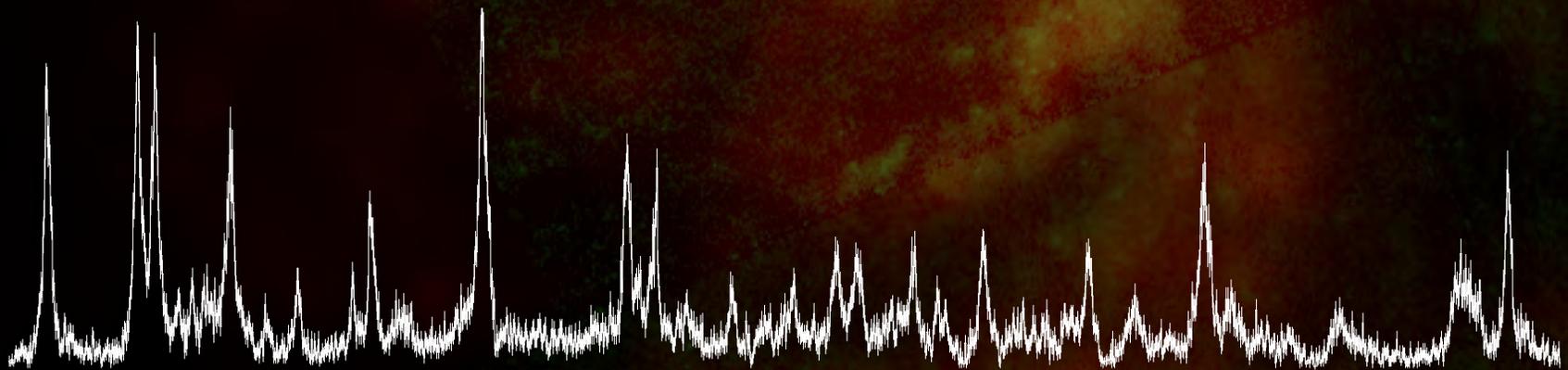


High-ionization X-ray gas has large columns and filling factors
→ may be dominant NLR component

The Chandra SOARS Project

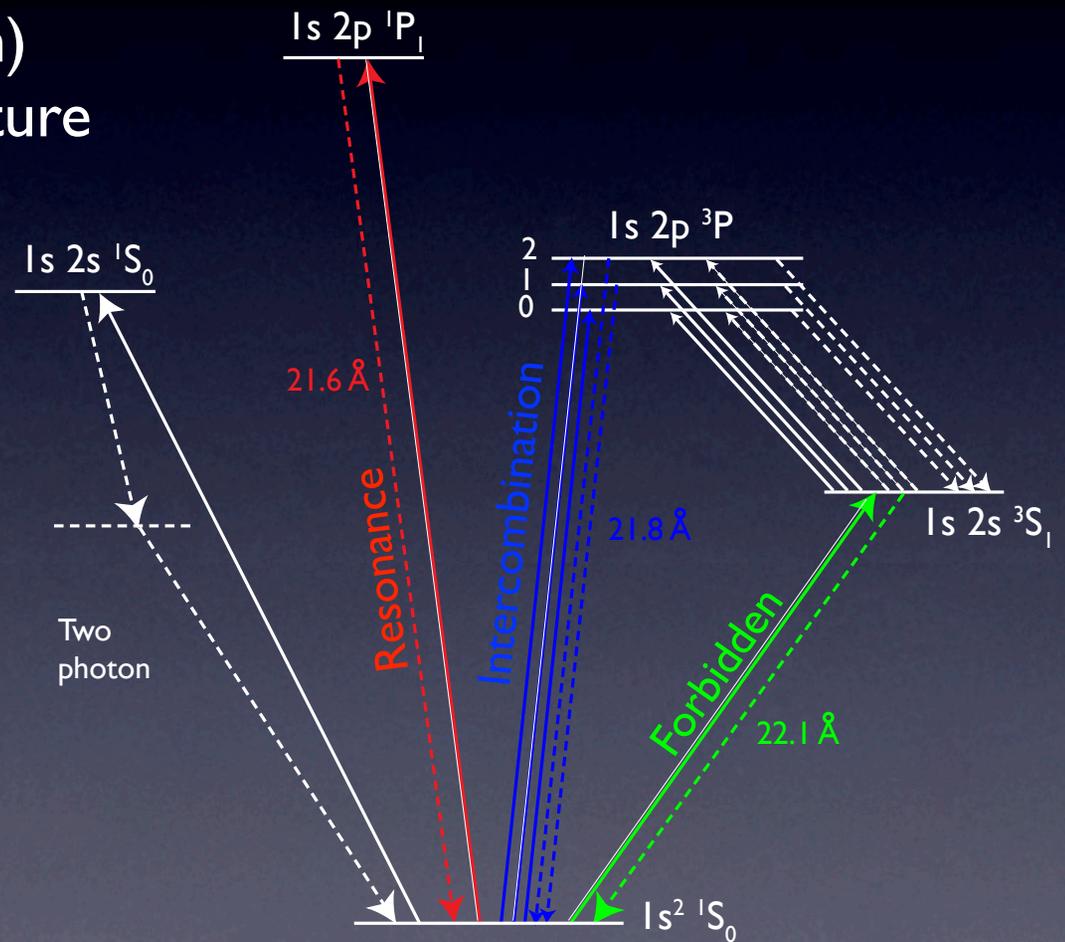
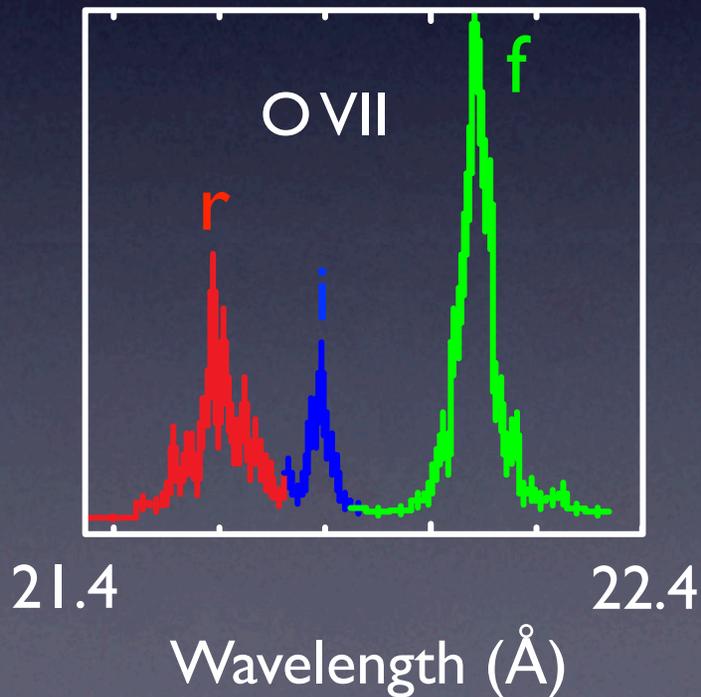
Survey of **O**utflows in **A**GN with **R**esolved **S**pectroscopy

- First spatially resolved X-ray study of kpc-scale NLR environments in type-2 AGN
- 1.5 Ms granted over multiple AOs; more on way
- Two unique advantages: high angular resolution (0.5'' FWHM) and high spectral resolution ($R \sim 1000$)

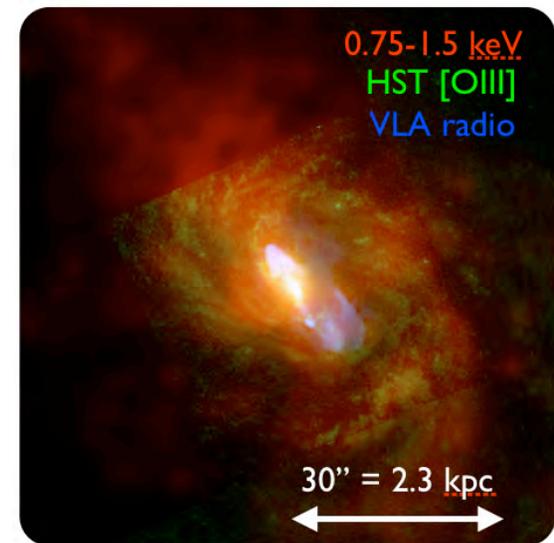
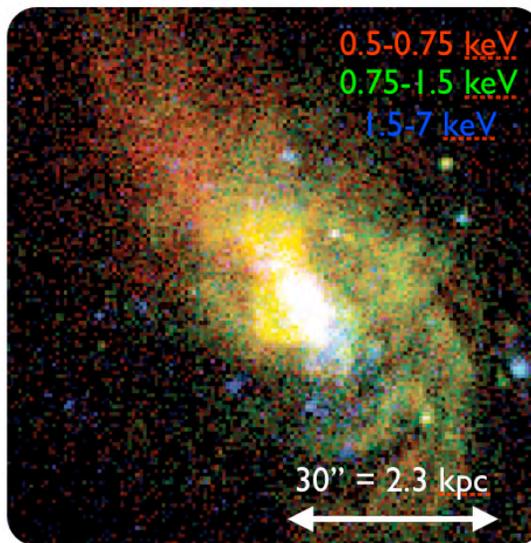
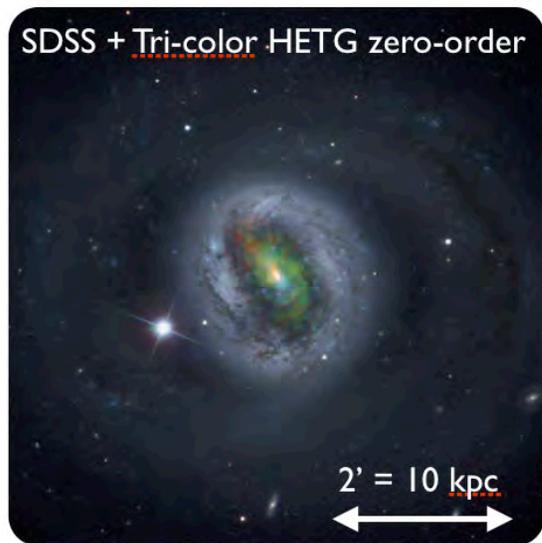


Chandra HETG and HST STIS spectroscopy

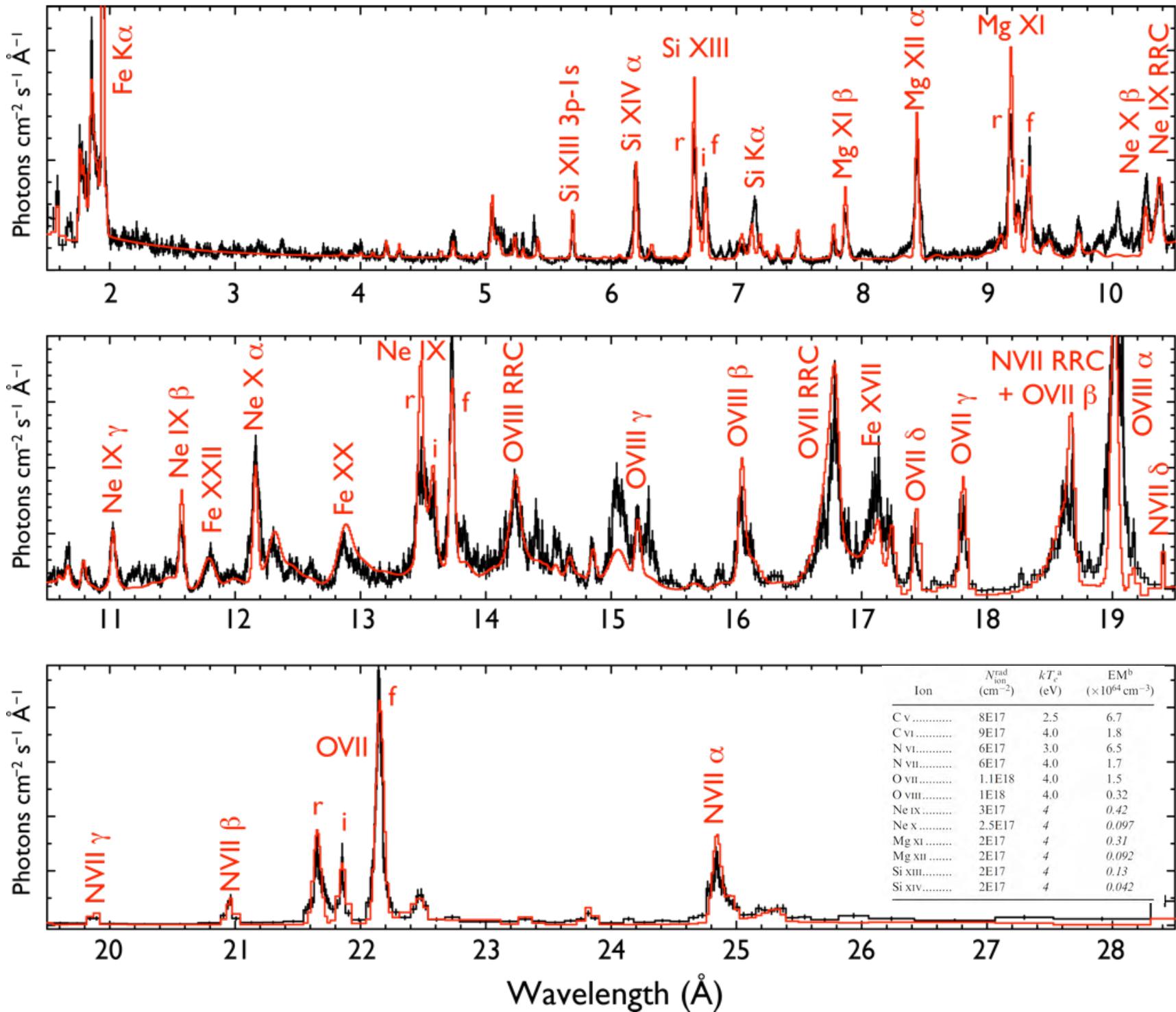
- Collisional ionization (jet) vs. photoionization (AGN radiation)
- Direct diagnostics of temperature and density



The Prototypical Example - a 440-ks Chandra HETG GTO Observation of NGC 1068 (Evans et al. 2011)



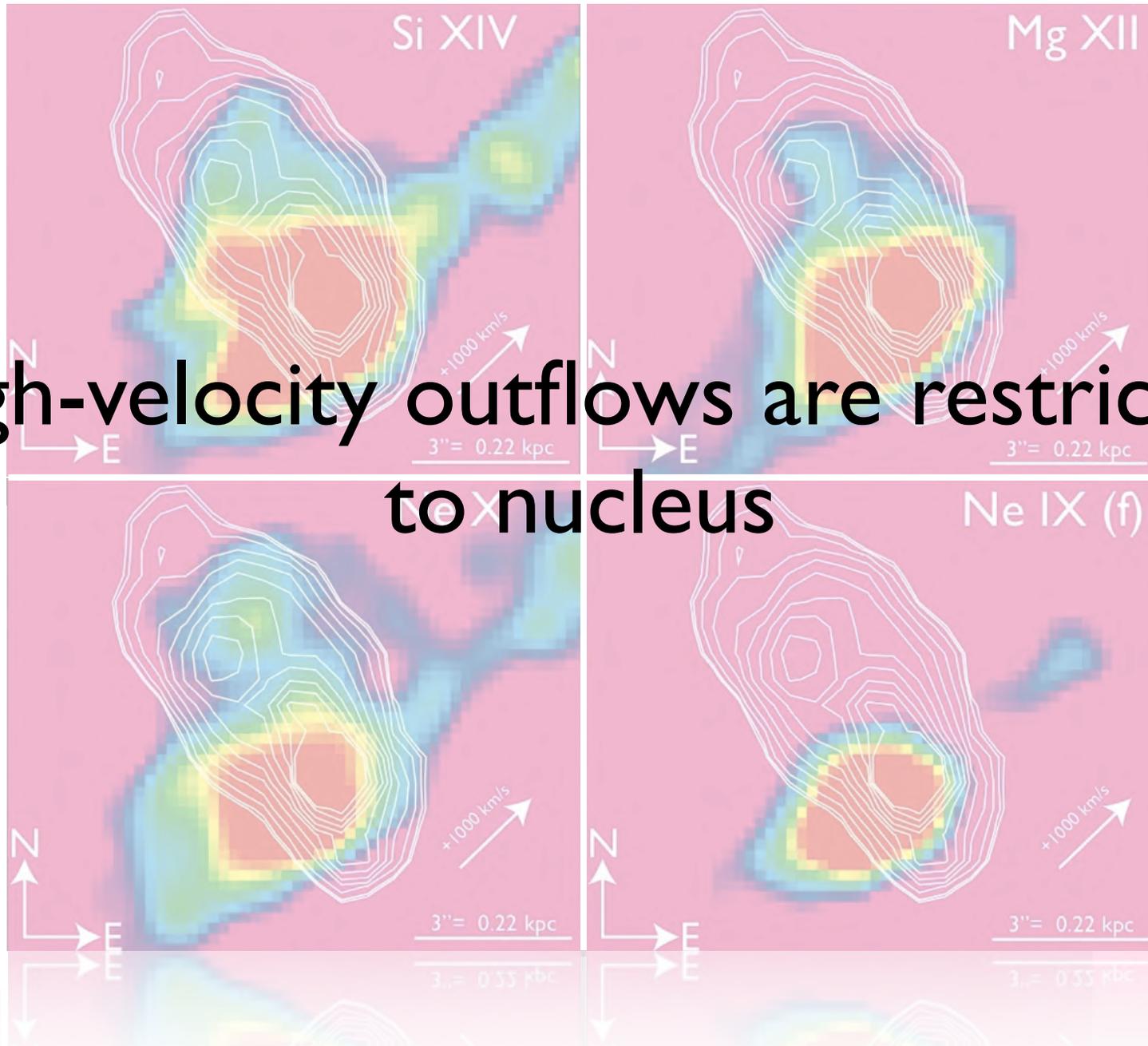
- Nearby: $z = 0.003793$, $D_L = 16.3$ Mpc, $1'' = 80$ pc ✓
- Compton-thick Seyfert 2 ($N_H > 10^{25}$ cm $^{-2}$) ✓
- Late type host galaxy ✓
- Black hole mass $\sim 10^7 M_\odot$ (e.g., Ludato et al. 2002) ✓
- Accreting at or near Eddington limit (e.g., Kishimoto et al. 1999) ✓
- Prominent kpc-scale radio jet ✓



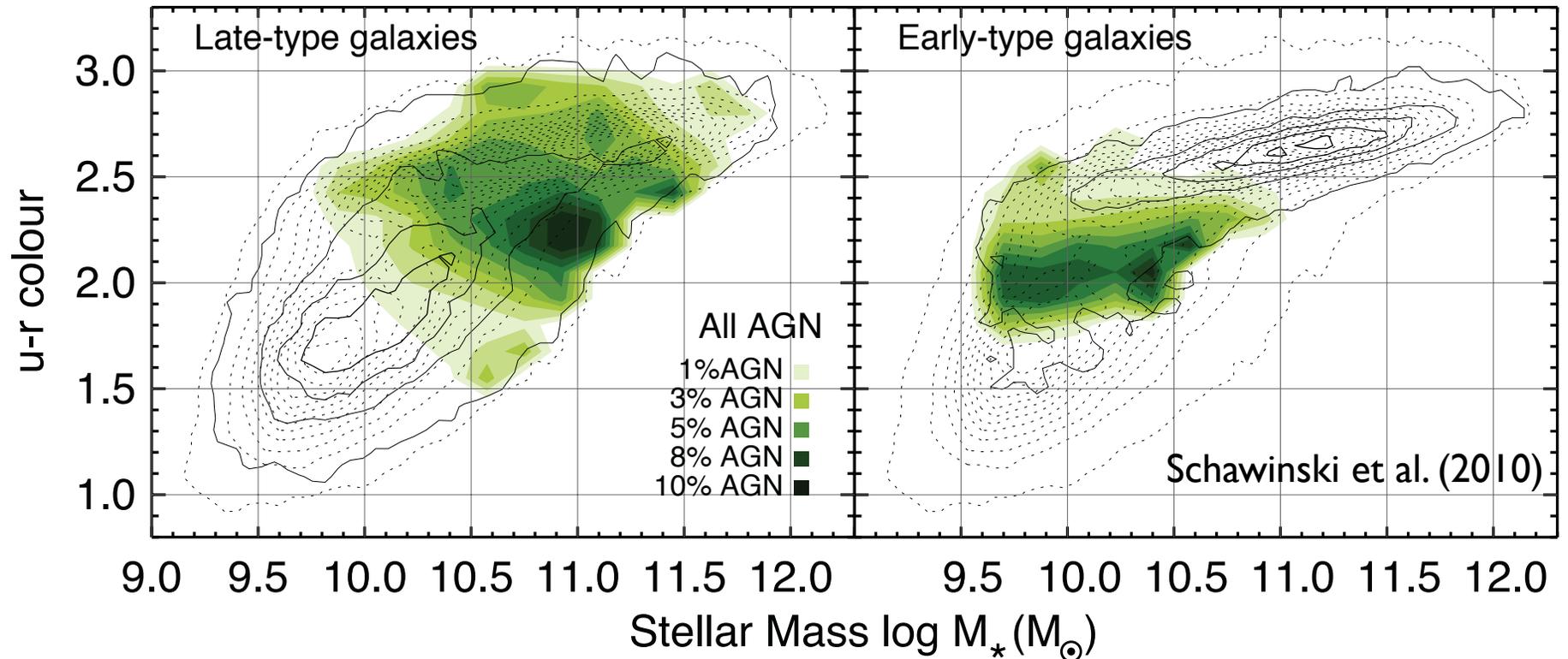
Evans et al. (2011); see also Kinkhabwala et al. (2002);
Brinkman et al. (2002); Ogle et al. (2003)

Spectral-Line Imaging

High-velocity outflows are restricted to nucleus



SOARS Synergies with Optical Surveys

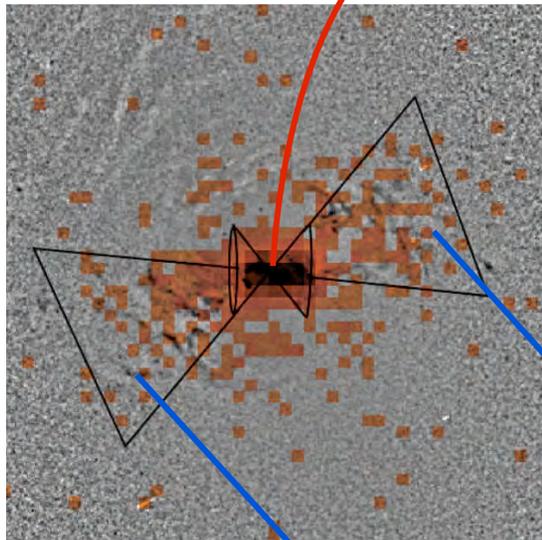


Early-type AGN are **genuinely migrating at fixed mass from the blue cloud to the low mass end of the red sequence**

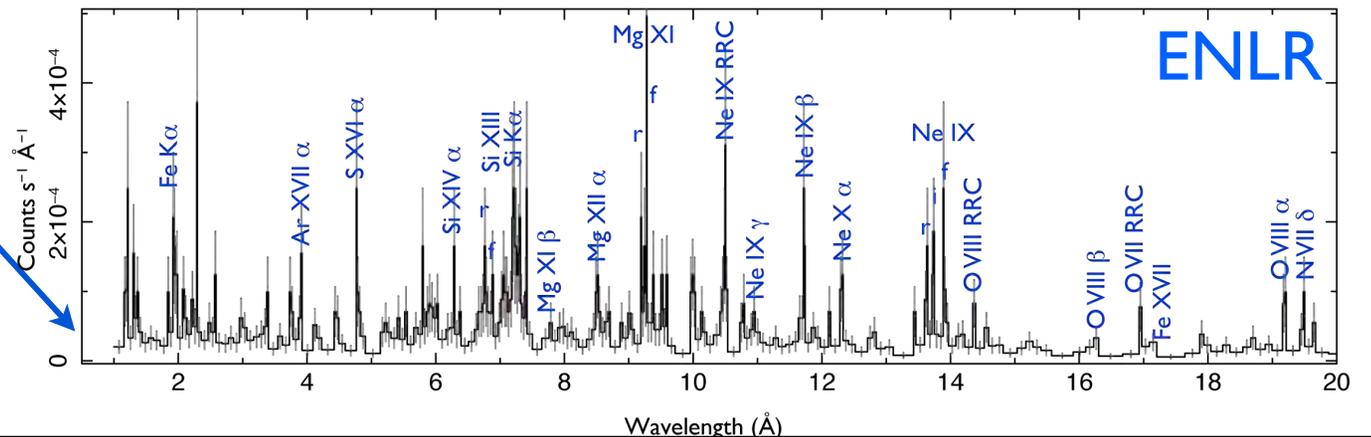
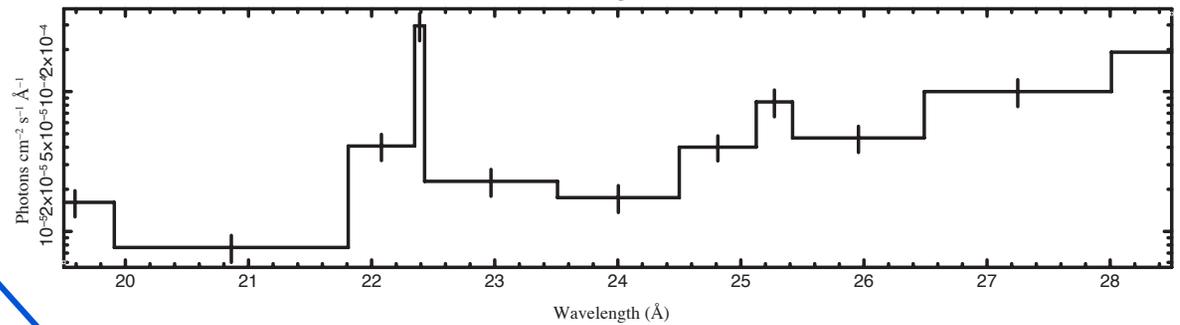
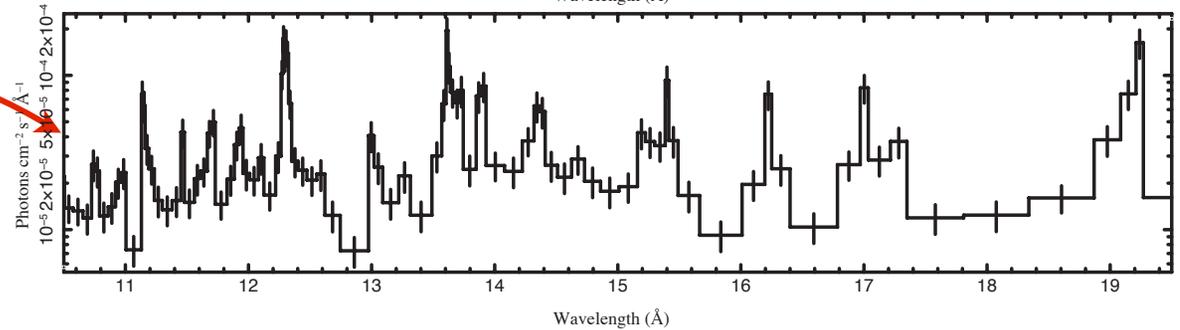
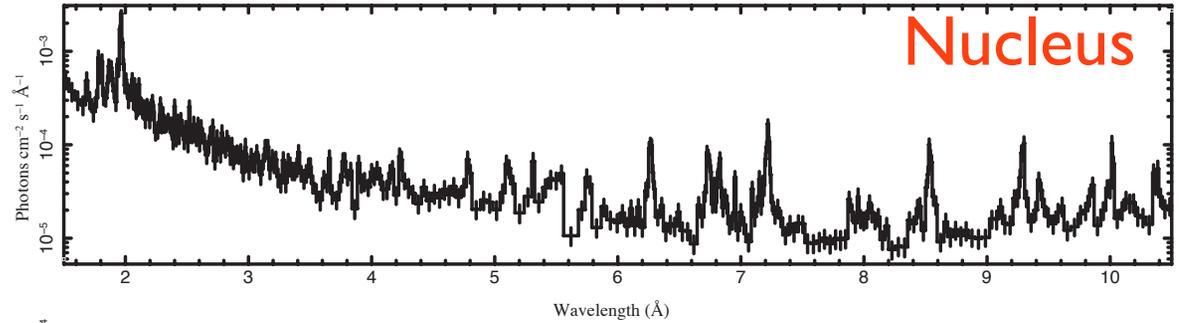
Late-type AGN have massive, highly stable stellar disks. Green host galaxy colors are **unlikely to be due to outflows**

Mrk 3

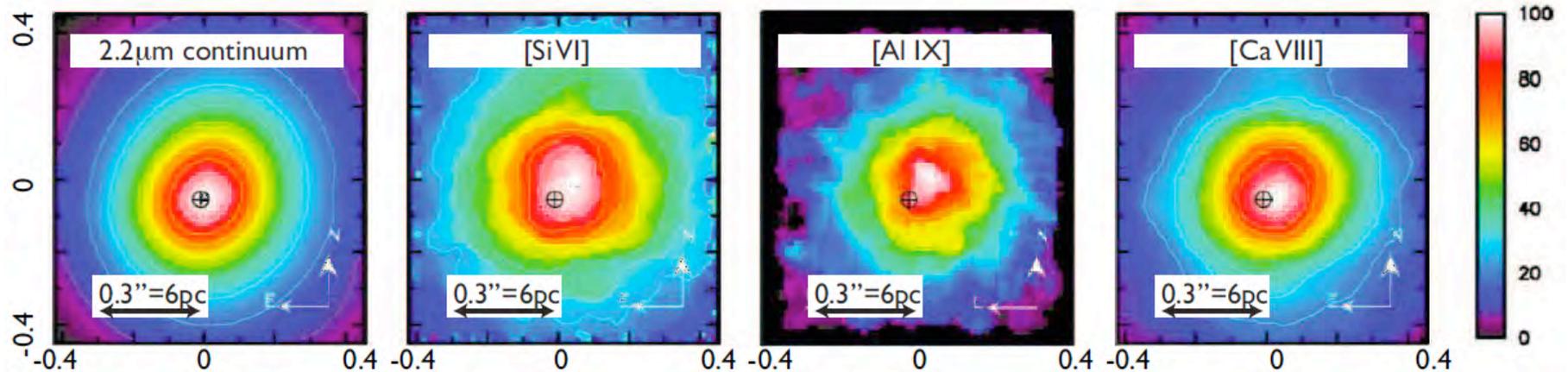
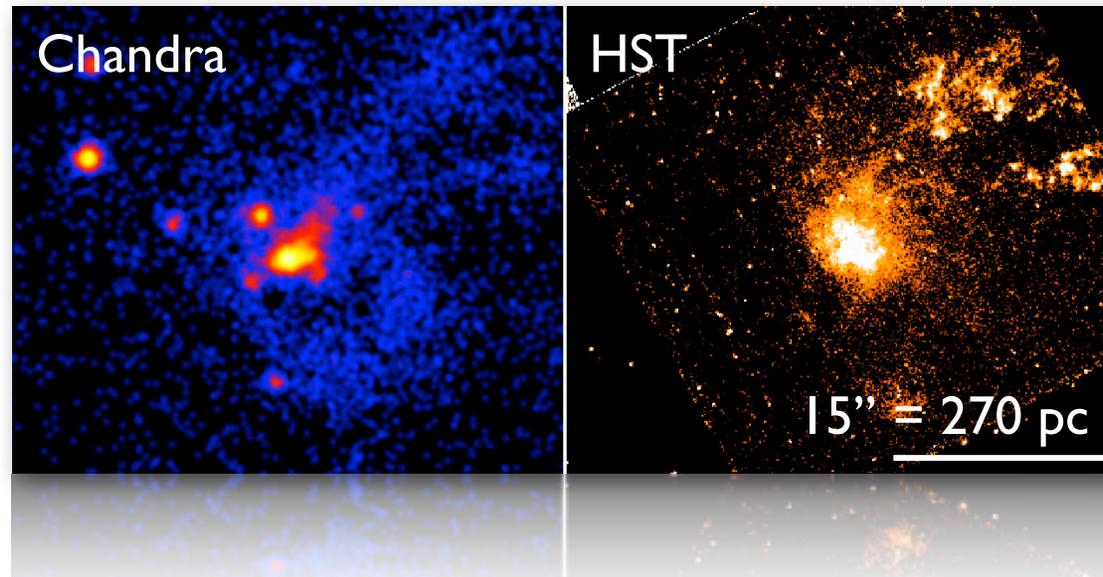
The Prototypical Early-Type Seyfert 2



HST structure map
(H. Schmitt)
+
Bicone geometry
(Crenshaw et al. 2010)
+
0.5-2 keV X-ray

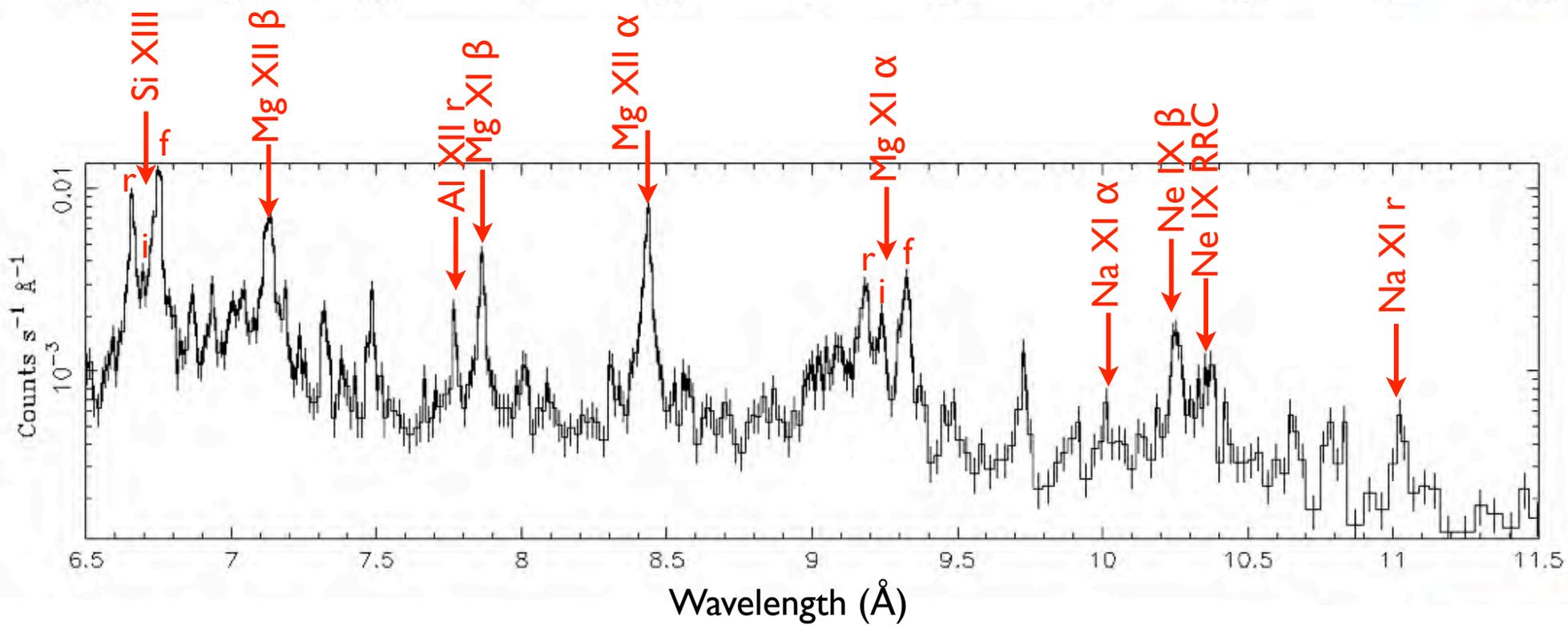
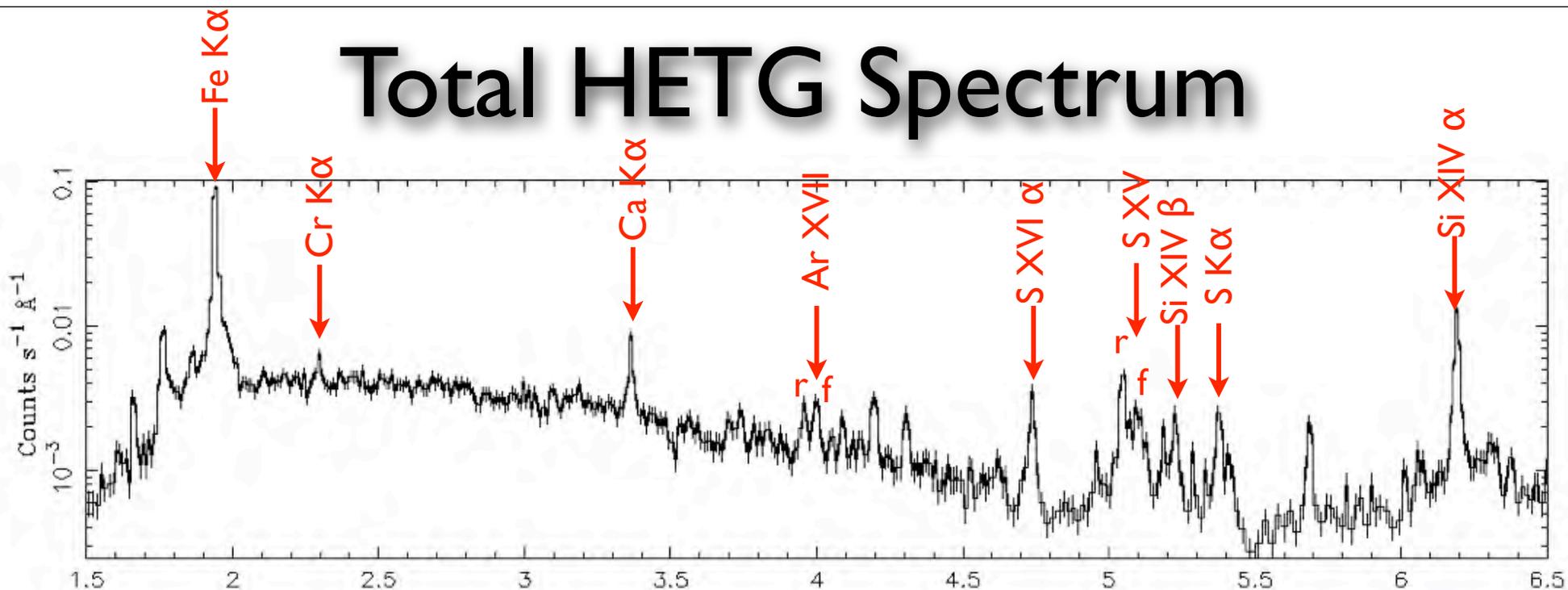


Circinus Galaxy (695 ks)

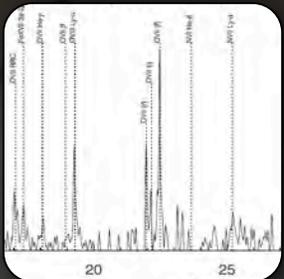
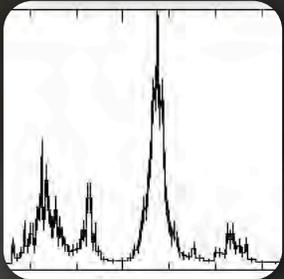
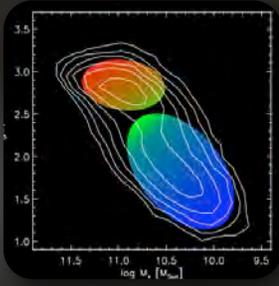


Mueller-Sanchez et al. (2006, 2011)

Total HETG Spectrum



Summary



SOARS - a better understanding **energy transport in AGN:**

- NGC 1068 has a $10^7 M_{\odot}$ black hole, which is accreting at or near its Eddington limit: it is an **ideal laboratory** to examine the role of AGN outflows and feedback on black-hole growth.
- Spatially resolved, high-resolution Chandra HETG spectra show that the **NLR is entirely photoionized**, with no indication of collisional ionization from the jet: i.e., the AGN radiation field dominates the energetics.
- **Outflows** are restricted to the nucleus, with velocities ~ 500 km/s.
- **How do early- and late-type galaxies migrate from blue to red?**