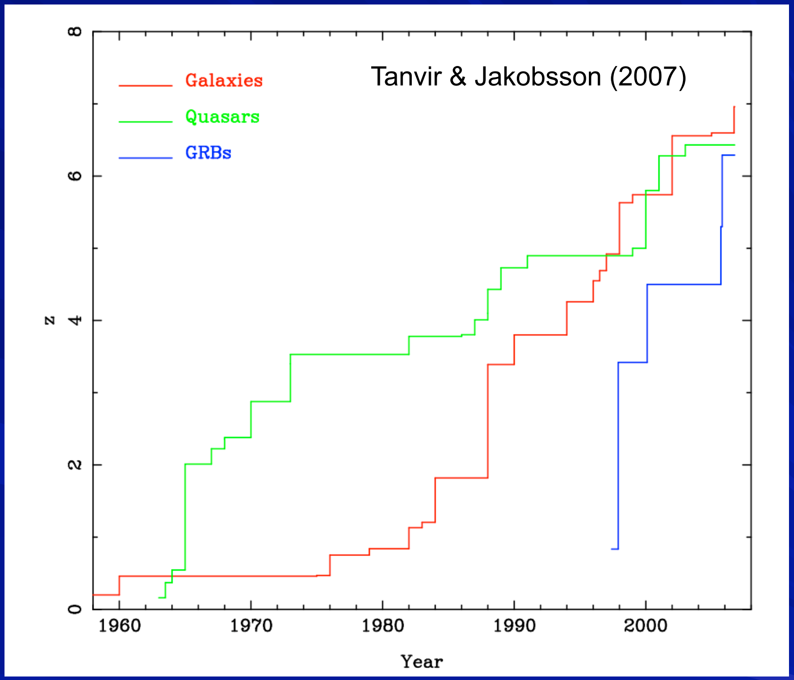
Exploring the High-Redshift X-ray Universe: Results from Snapshot to Ultradeep Surveys

Niel Brandt (Penn State)

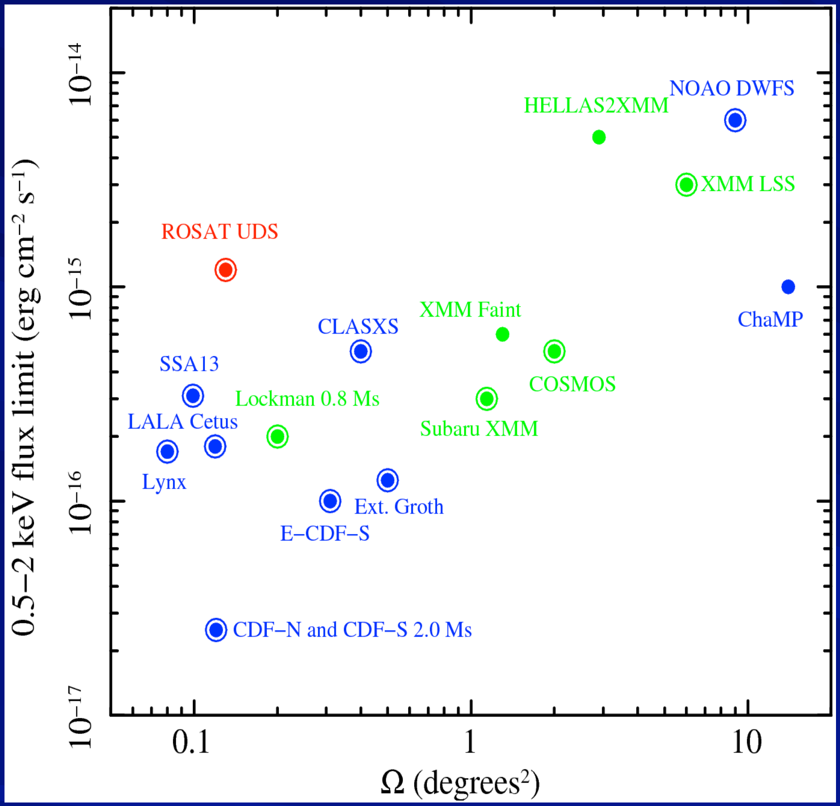


Will mostly focus on z ~ 2-6. Key growth epoch of massive galaxies.

Available X-ray targets are AGNs, galaxies, and GRBs.

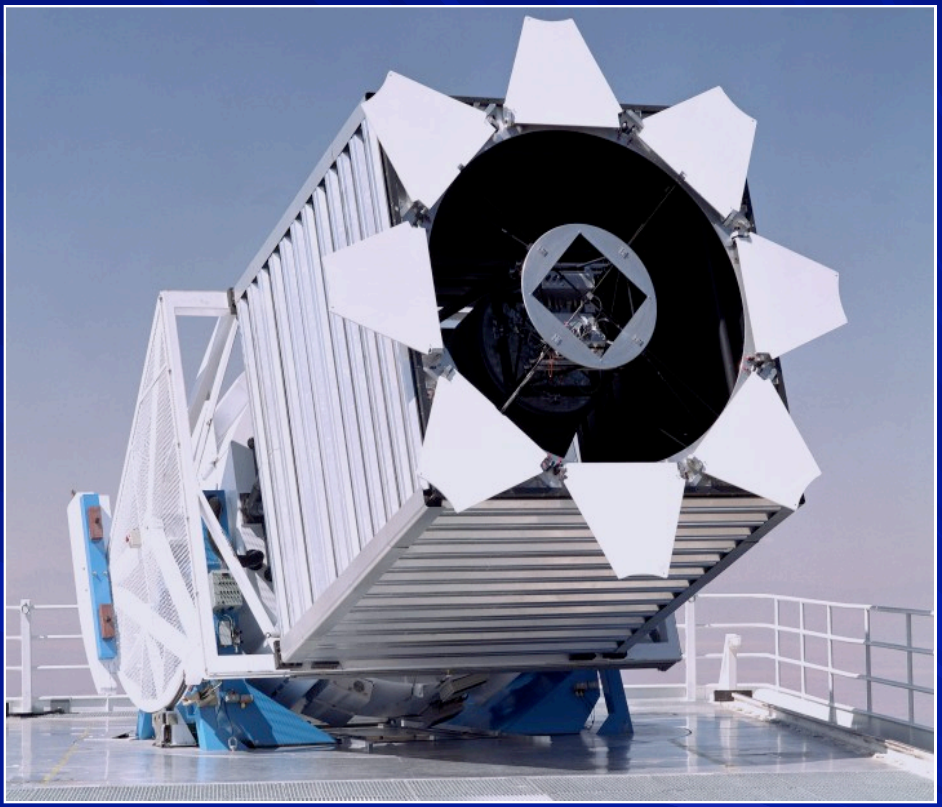
Growing Population of High-Redshift AGNs

X-ray Selection



X-ray surveys have delivered many moderate-luminosity and obscured AGNs at high redshift.

Optical / NIR Selection - e.g., SDSS

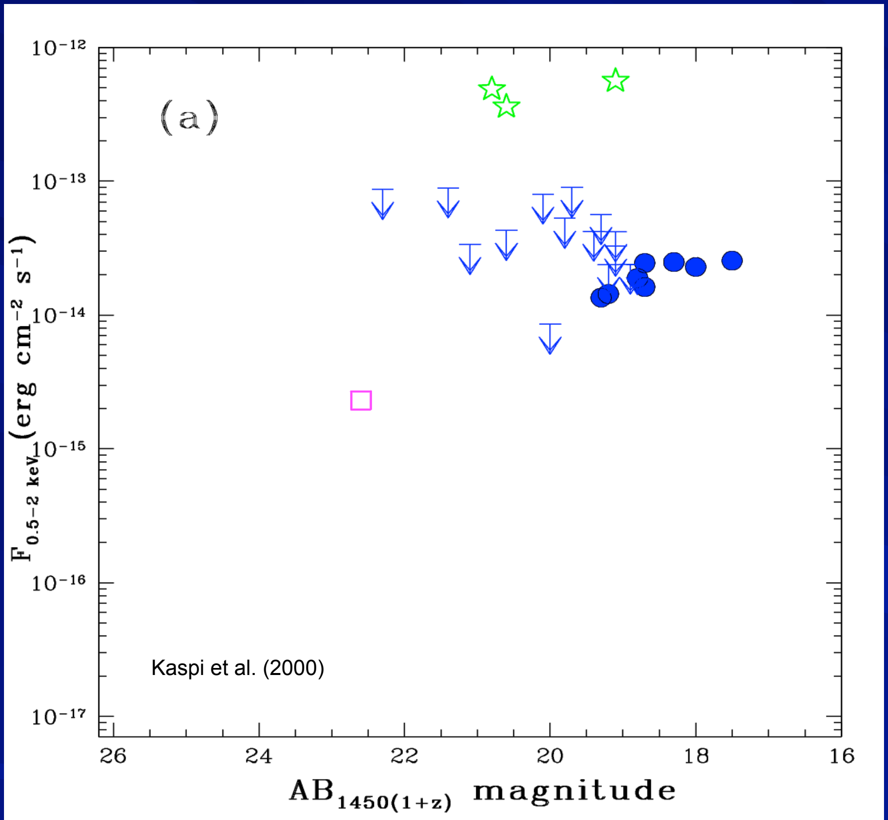


Wide-field optical / NIR surveys have delivered many rare, luminous quasars up to $z \sim 6.4$. SDSS has delivered ~ 22,000 at $z > 2$.

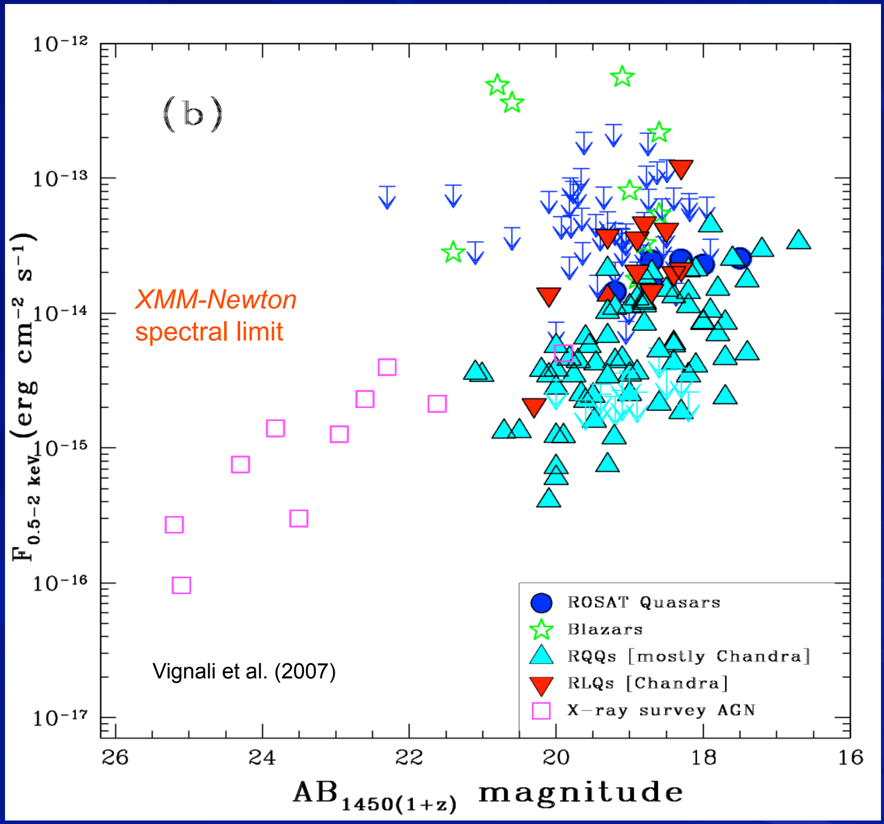
Also now selection at longer wavelengths – e.g., luminous submillimeter galaxies.

Example: Advances in X-ray Studies at *z* > 4

Status in 2000



Present Status



More than tenfold enlargement in number of X-ray detected AGNs at *z* ~ 4-6.4.

Spectroscopy difficult presently due to low X-ray fluxes - XMM-Newton has made progress at highest luminosities, but really need XEUS and Constellation-X.

Topics to be Covered

Accretion Mechanisms to High Redshift

AGN Outflows at High Redshift

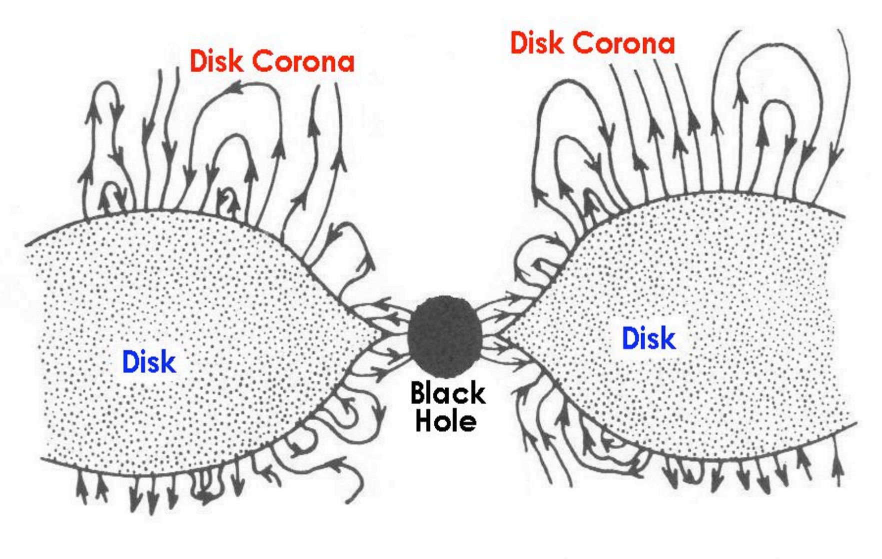
AGNs in Most-Powerful Starburst Galaxies at High Redshift

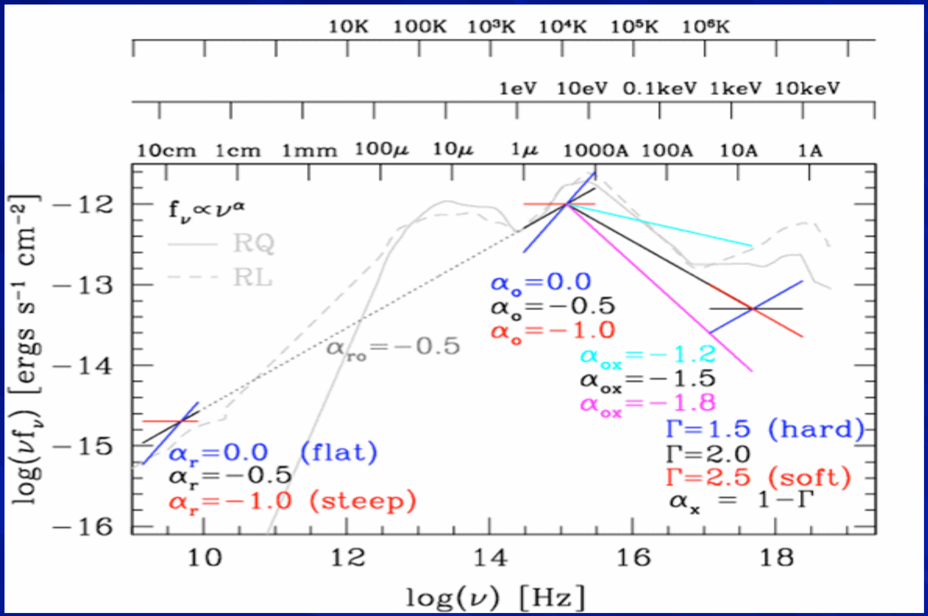
Some Prospects for XEUS and Con-X

Accretion Mechanisms to High Redshift

Accretion Mechanisms

Are high-redshift SMBHs feeding and growing in same way as local ones?





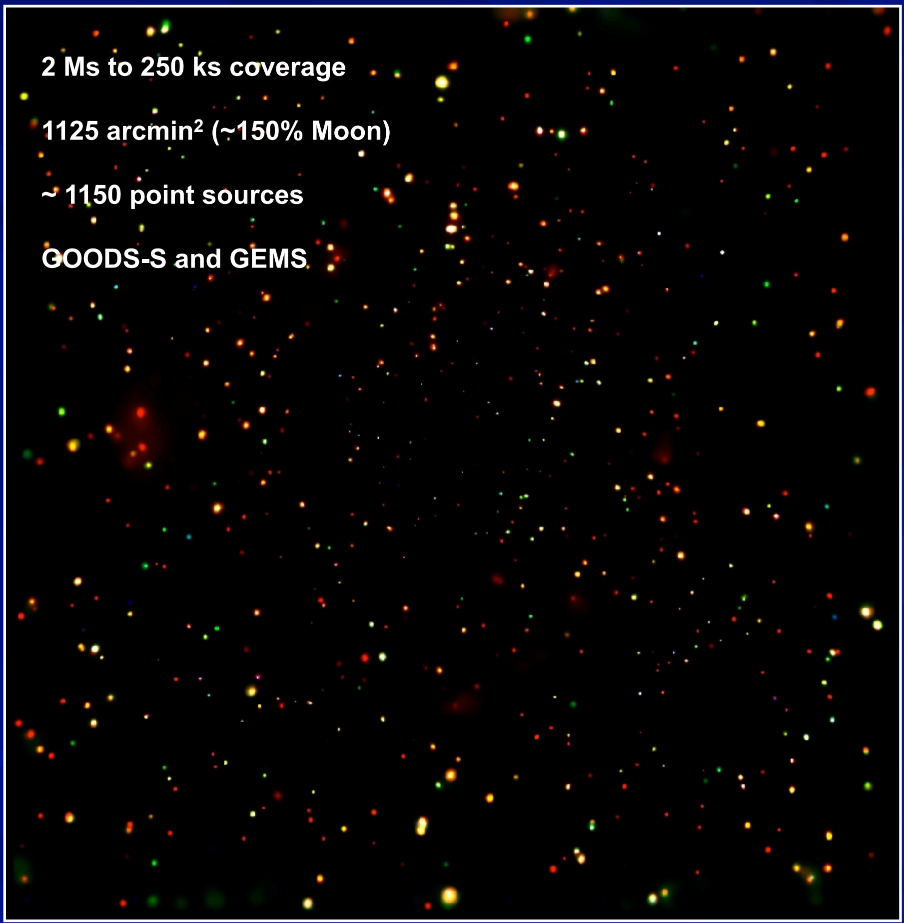
Changes in $L\,/\,L_{\mathrm{Edd}}$ have associated X-ray spectral and SED changes.

Rapid growth of first SMBHs by super-Eddington accretion?

Claims and counterclaims about SED evolution (α_{ox}) in literature.

SED Studies with Deep-Survey + Snapshot + Archive Obs.

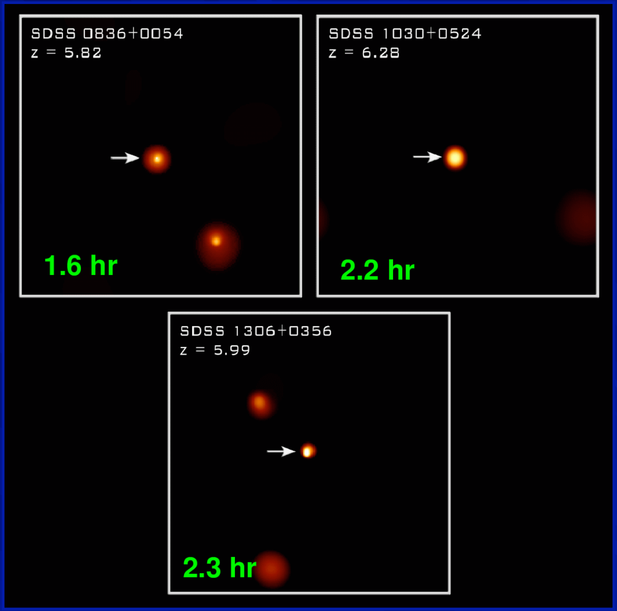
The Extended Chandra Deep Field-South



52 COMBO-17 AGN with z = 0.5-4.0; reach R = 23.

90% X-ray detection fraction.

Snapshot Observations



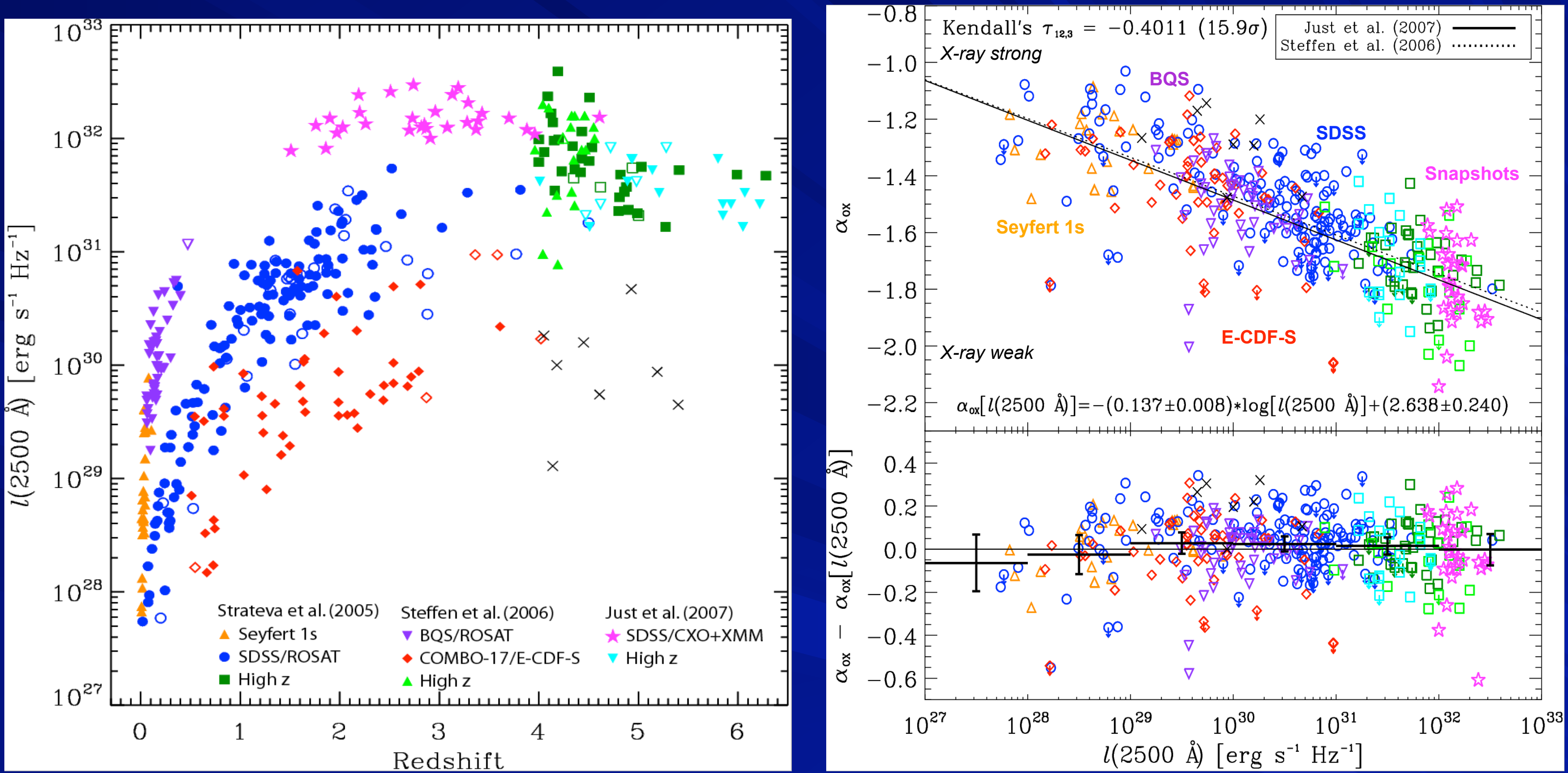
Chandra snapshots remarkably sensitive.

Observe sets of luminous quasars selected from wide-area optical surveys (4,000-20,000 deg^2).

- SDSS at z ~ 5-6.4 (e.g., Shemmer et al. 2006)
- Most luminous known at z > 4 (e.g., Vignali et al. 2005)
- Most-luminous SDSS at all redshifts (Just et al. 2007)

More than 130 snapshots executed with good success.

Accretion Mechanisms - X-ray-to-Optical SED



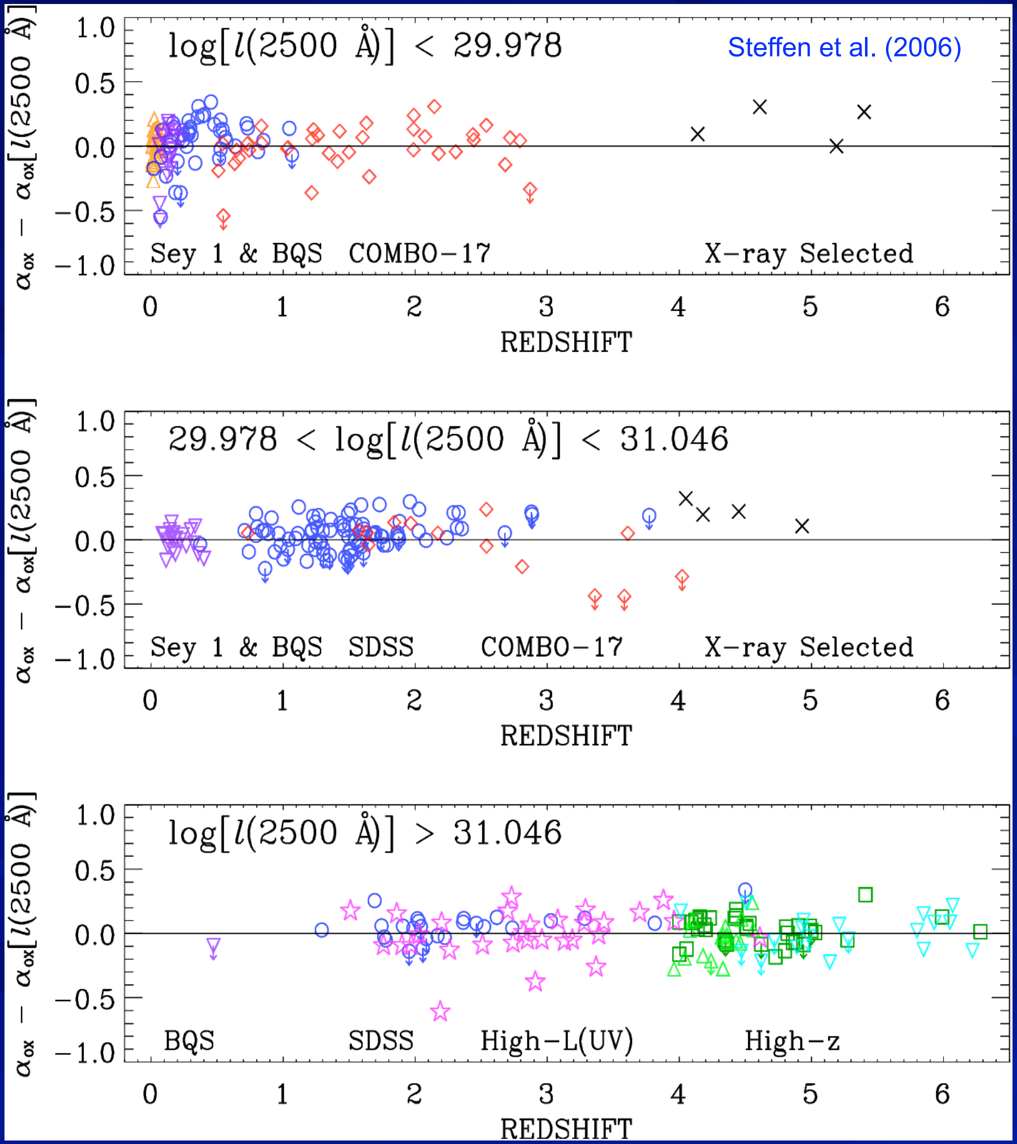
Combined AGN samples now span much of luminosity-redshift plane – much better than in past.

Partial-correlation analyses find clear luminosity dependence (16σ). X-ray fraction declines with luminosity.

Still not understood physically – hopefully future self-consistent disk + corona simulations can explain.

Important for Soltan-type arguments, AGN-wind models, X-ray universality, and selection of unusual AGNs.

X-ray Evolution Over Cosmic Time?



No detectable redshift dependence. X-ray-to-optical flux ratios of AGNs change by < 30% from z = 0-6.

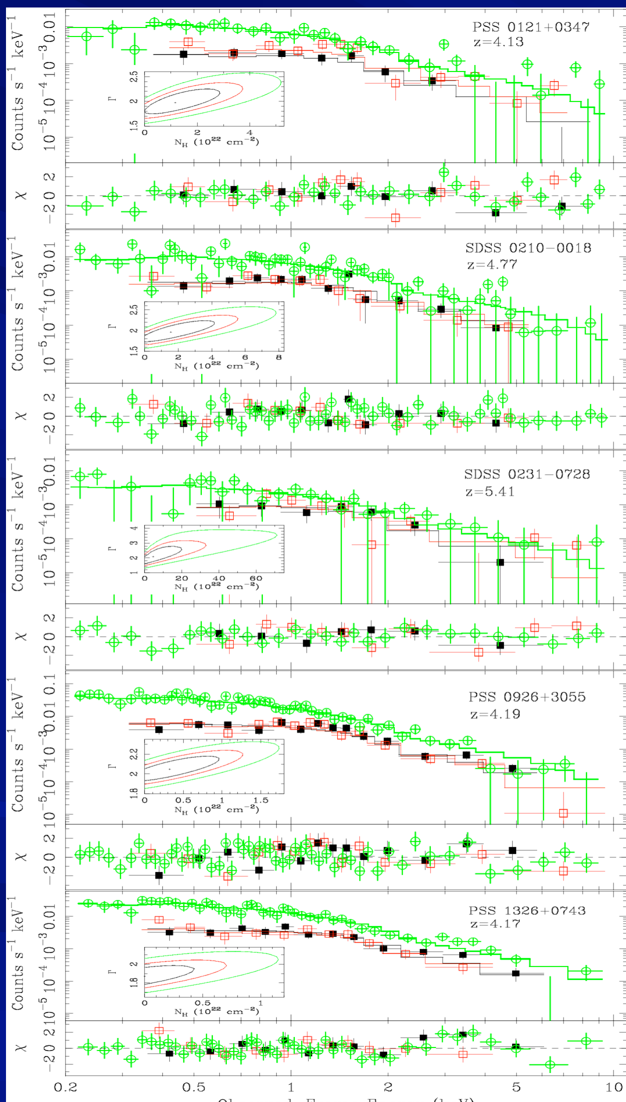
Holds for wide range of luminosity.

Basic X-ray emission processes of AGNs remarkably stable from local universe to re-ionization epoch.

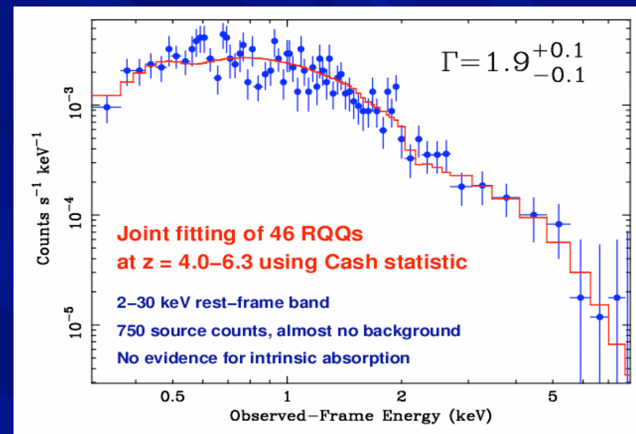
But see Kelly et al. (2007) for claimed SED evolution.

Accretion Mechanisms - X-ray Spectra

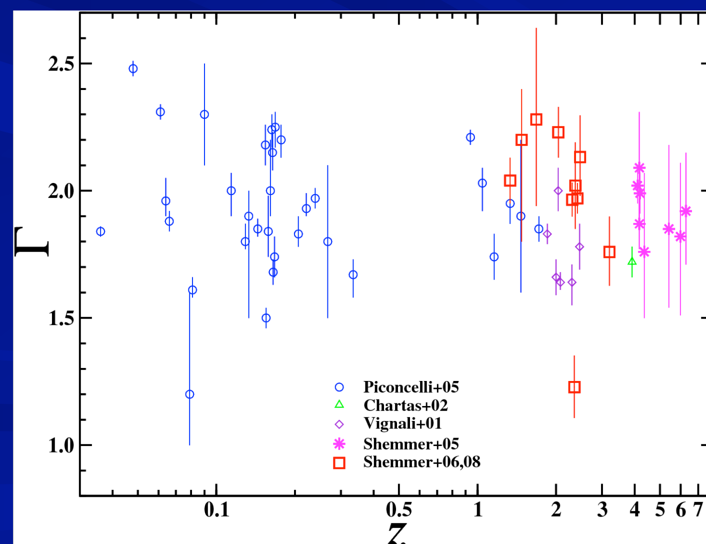
XMM-Newton Spectra – e.g., Shemmer et al. (2005)



Chandra Joint Fitting – e.g., Vignali et al. (2005)

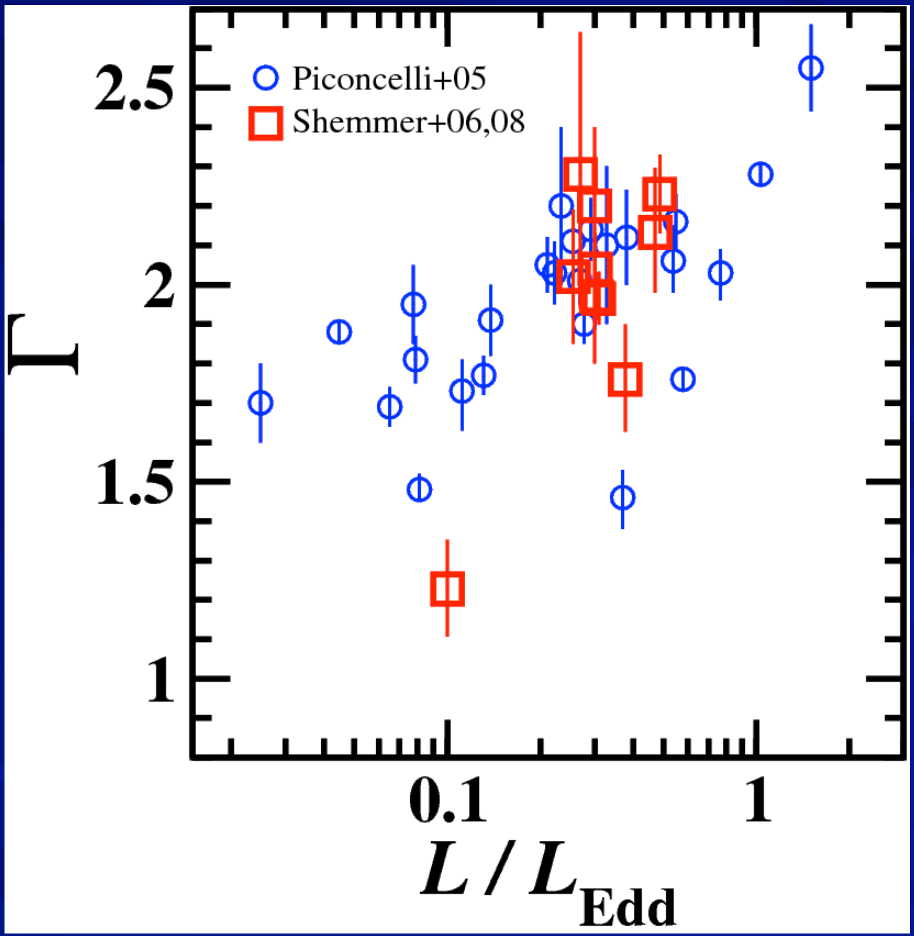


Photon index has intrinsic scatter, but no redshift dependence



Generally little Compton reflection – high luminosities.

L / L_{Edd} from Hard X-ray Spectrum



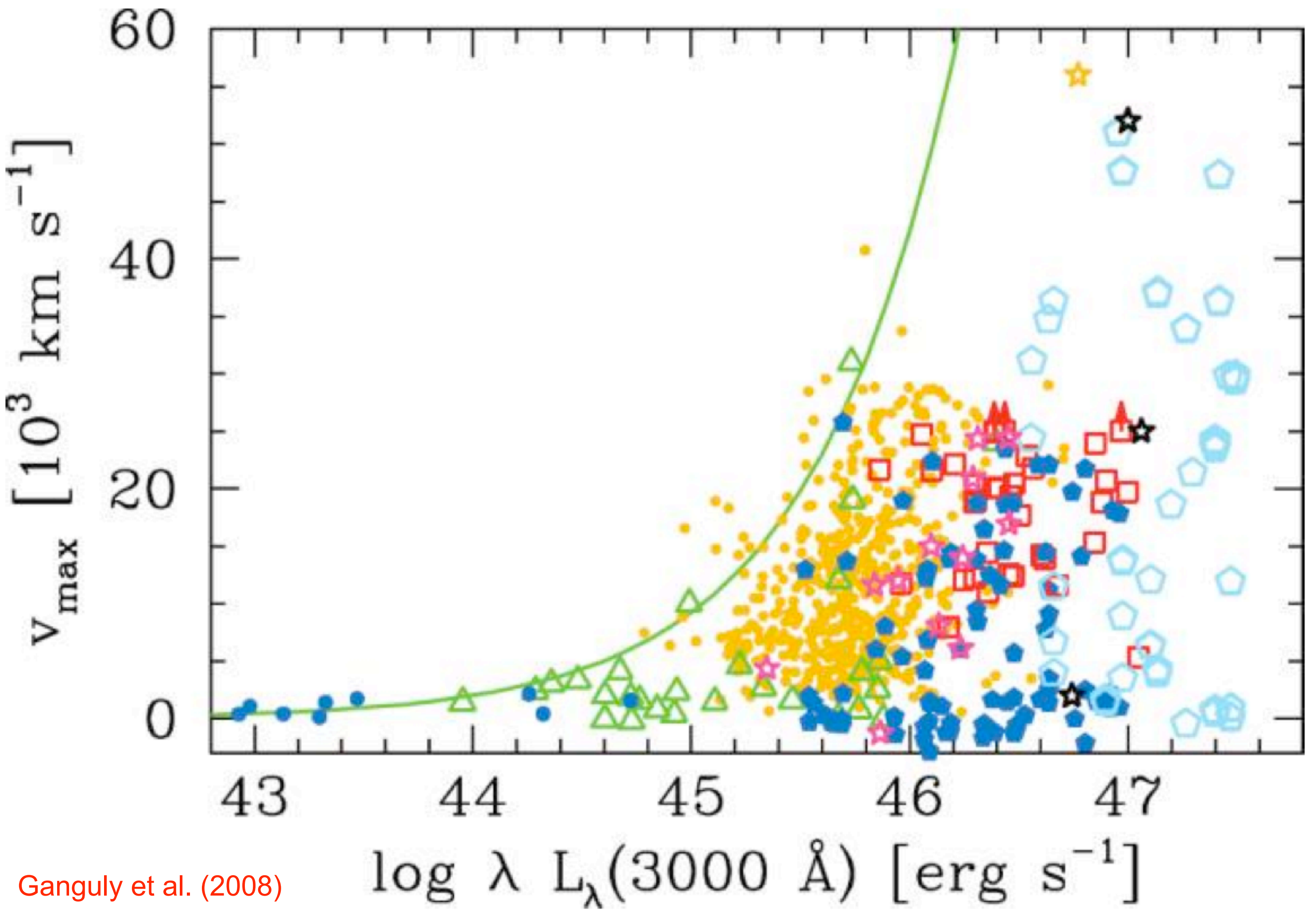
Photon index of hard X-ray power law correlates with normalized accretion rate for luminous AGNs (~ 10^3 luminosity range).

Cooling of disk corona?

X-ray based method for L / L_{Edd} estimates with factor ~ 3 uncertainty.

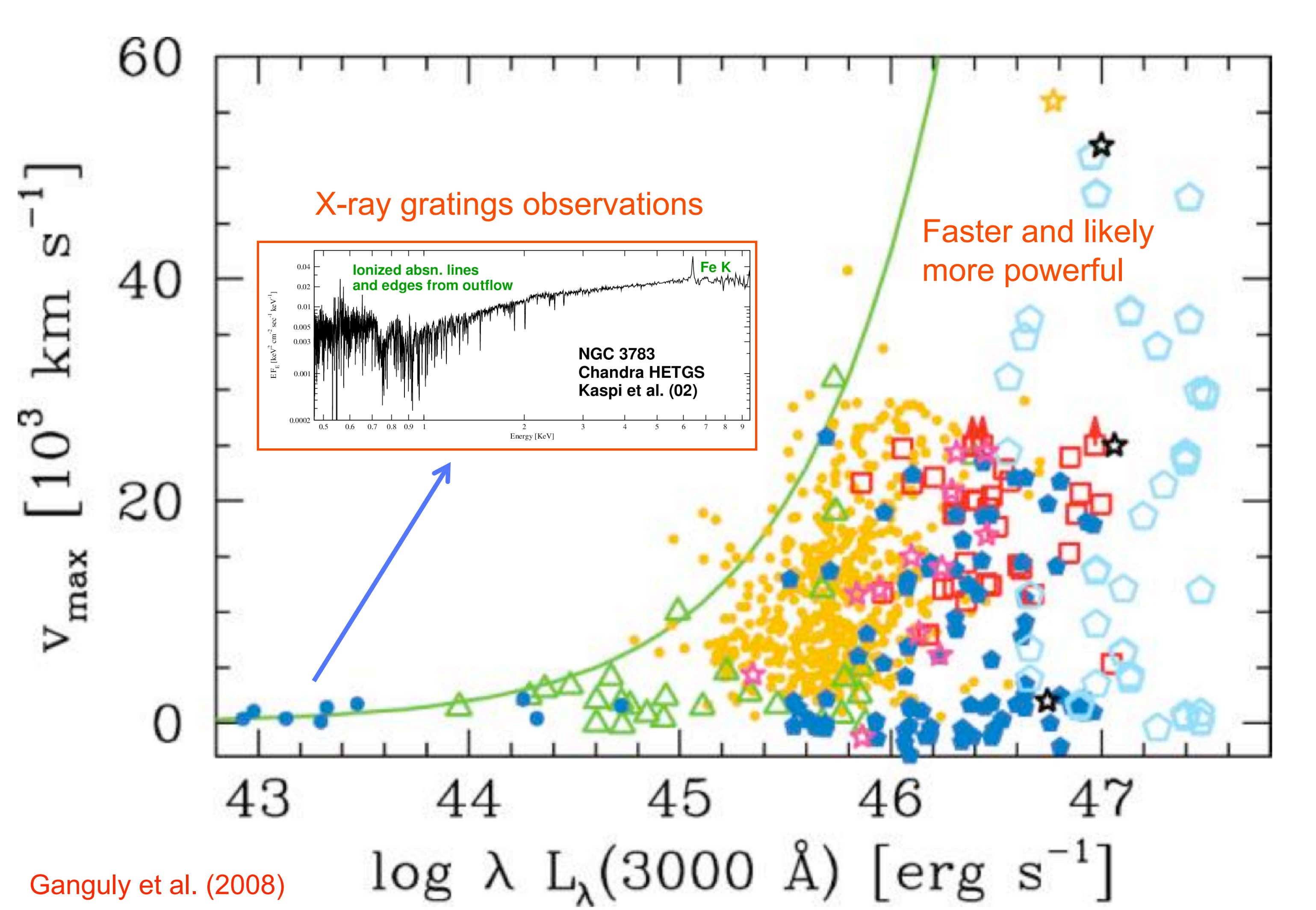
AGN Outflows at High Redshift

Universality of AGN Outflows



Ganguly et al. (2008)

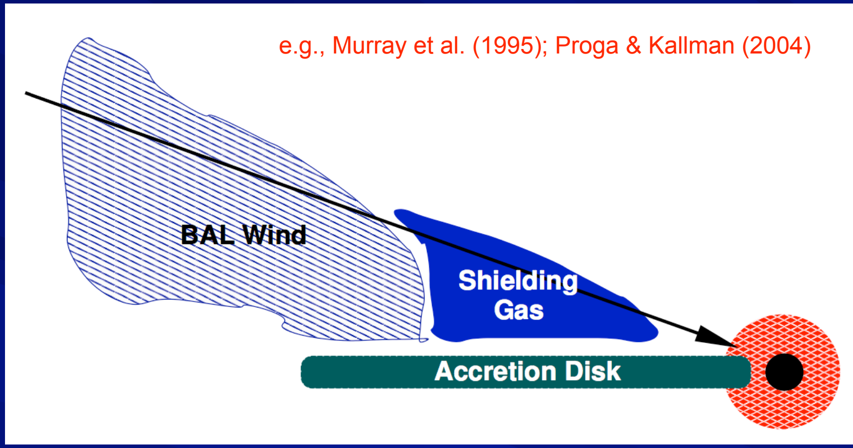
Much Still to Explore in X-rays



Ganguly et al. (2008)

Nature of BAL Quasar X-ray Absorption

Low-ionization BAL quasars appear more X-ray absorbed



This figure will appear in Gibson et al., in preparation.

Models propose X-ray absorption in “shielding gas” that protects UV wind from over-ionization.

“Faster” BAL quasars appear more X-ray absorbed

Kinematic state of X-ray absorber generally unknown for luminous BAL quasars (unlike Seyfert case).

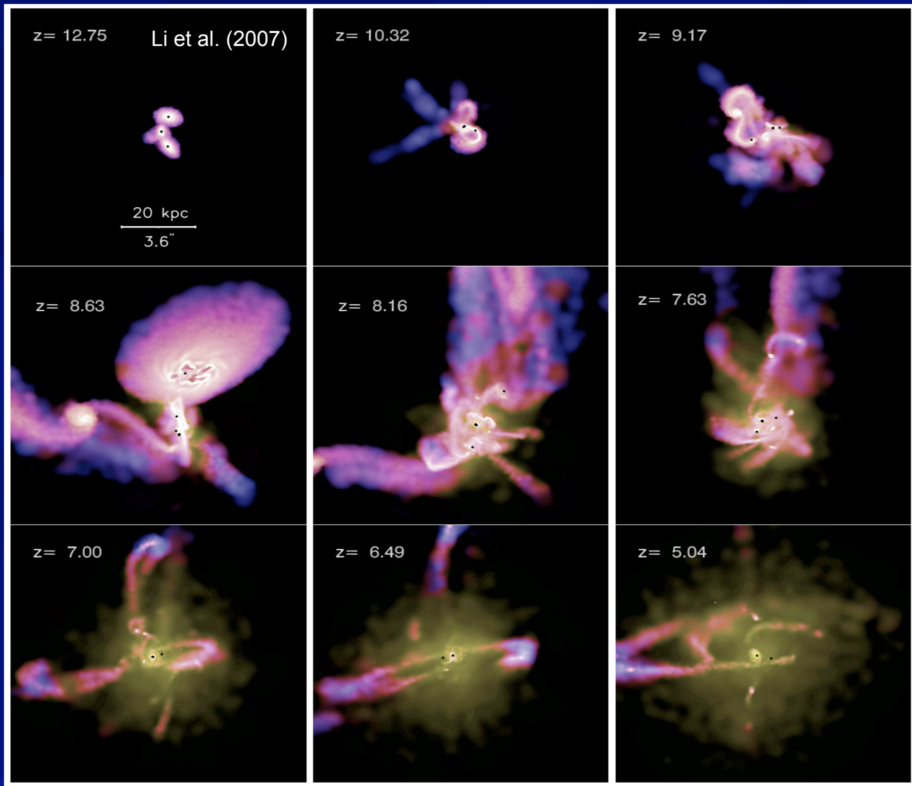
This figure will appear in Gibson et al., in preparation.

X-ray absorber could be stalled or could carry most of flow energy.

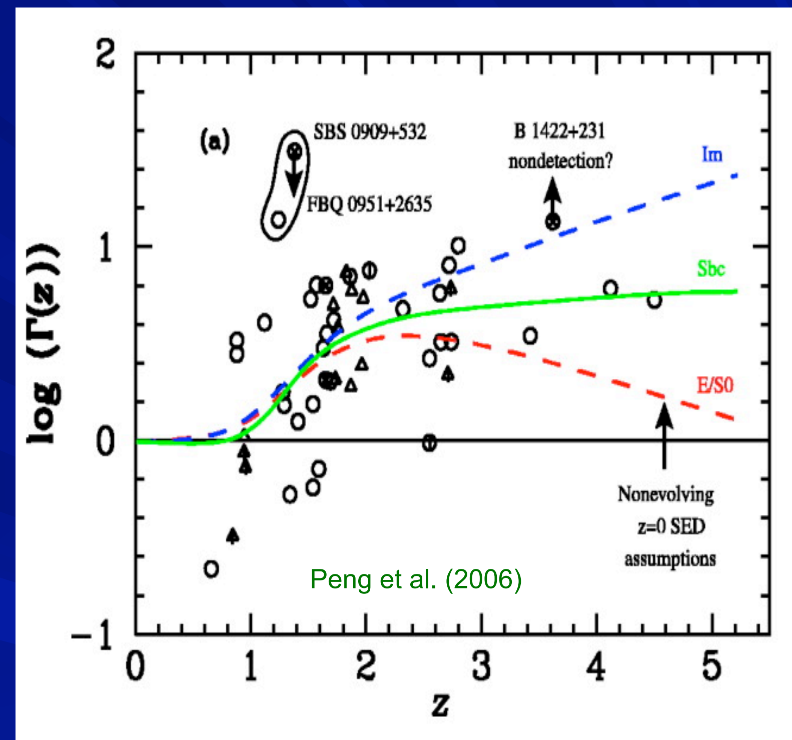
Some remarkable X-ray vs. UV relations – X-ray absorber affects the UV BAL wind.

Feedback from the Quasar Mode?

Gas density and temperature for high-redshift quasar host



M_{BH} / M_{Gal} (relative to local) versus redshift



Gas-rich mergers common in most massive halos, leading to strong starbursts and obscured AGNs.

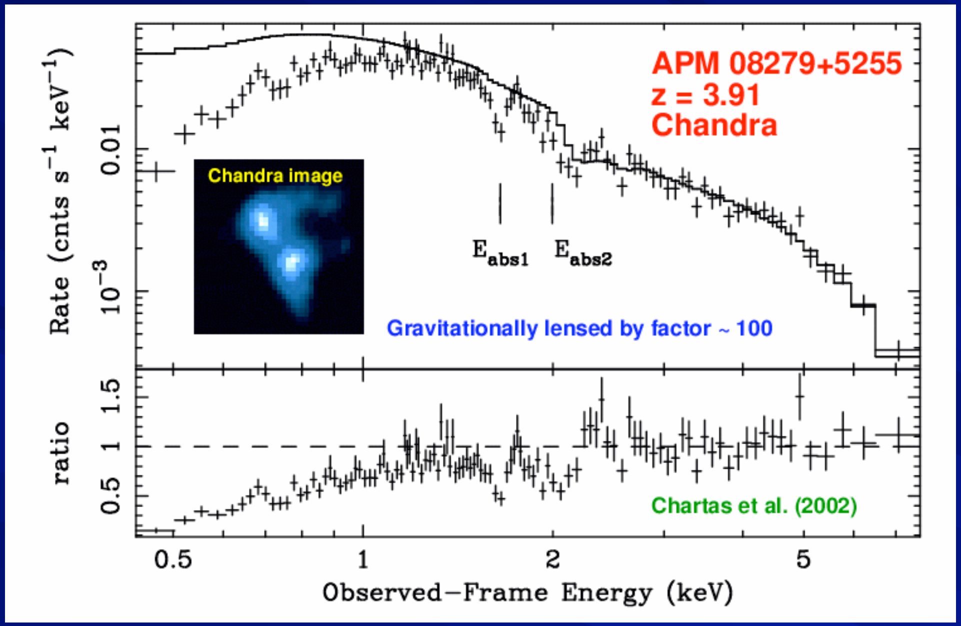
Strong SMBH-driven outflow extinguishes star formation, removes obscuration, limits SMBH growth.

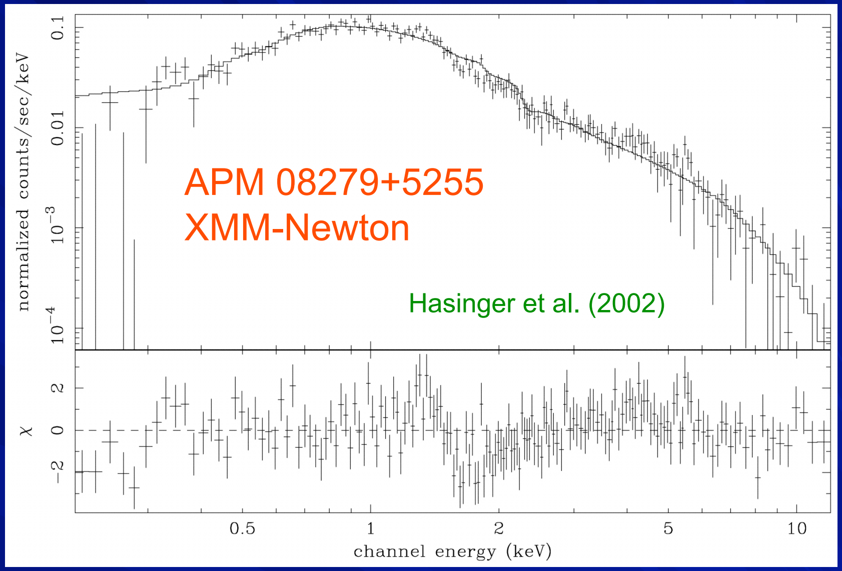
Several studies of moderate-to-high redshift AGNs suggest M_{BH} / M_{Bulge} higher in past.

SMBH-driven outflows may be particularly potent at high redshift.

Detailed observations imply this basic picture needs refinement – Can we see the feedback in action?

X-ray Absorbing Outflow from APM 08279+5255





Absorption features at 8-18 keV in rest frame - X-ray BALs from iron K?

Implied X-ray velocity is $v \sim 0.2\text{-}0.4c$ and higher. Much higher than for UV BALs.

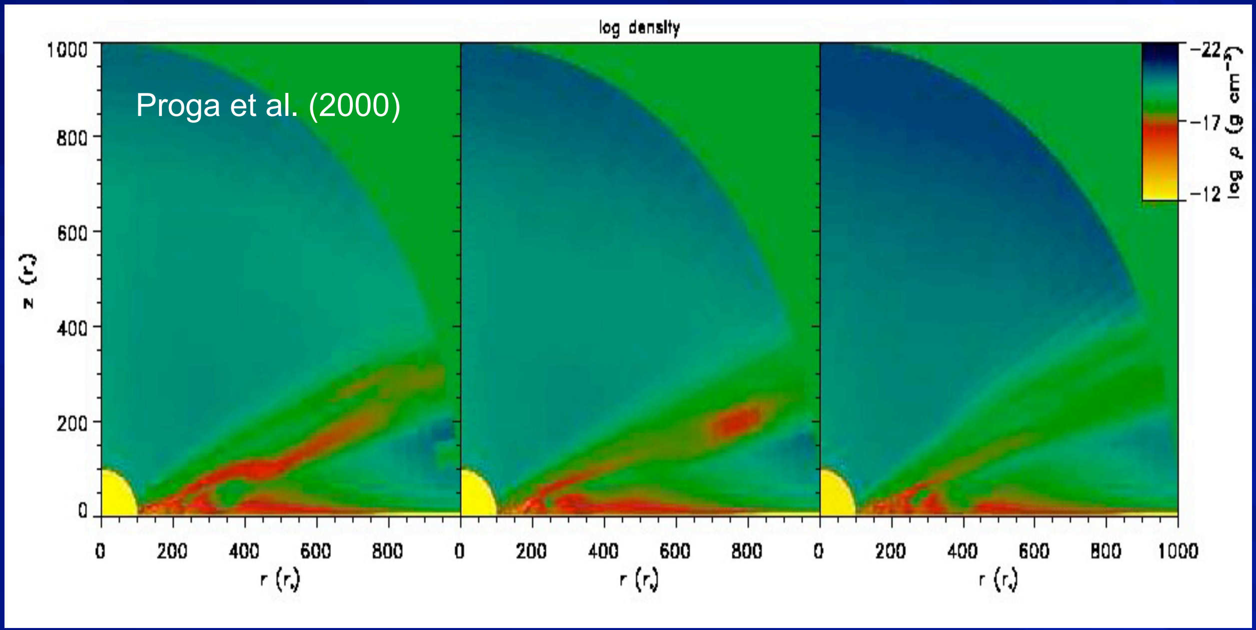
X-ray absorber in BAL quasars in state of outflow? As for Seyfert galaxies.

Kinetic power of outflows is potentially very large - High-redshift feedback in action?

Such features could be present, but undetected, in many other BAL quasars.

Expected Variability

Density changes in simulated BAL quasar wind over 3 yr



High velocity suggests small launching radius for outflow.

Variability of absorption-line profiles expected on timescales down to ~ a week.

Observed Variability - APM 08279+5255

These figures will appear in Chartas et al., in preparation.

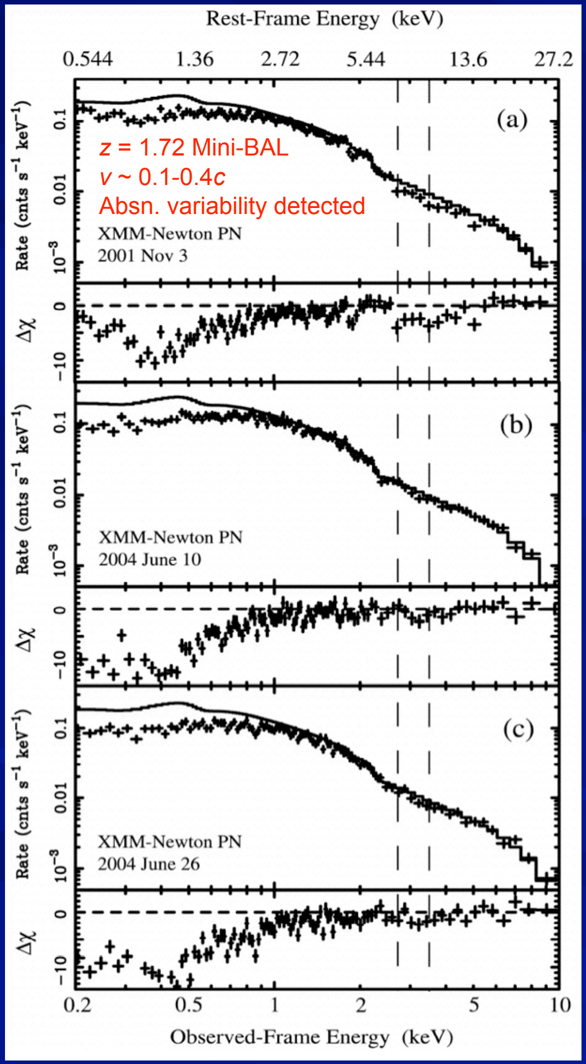
2007-2008 data confirm the absorption features.

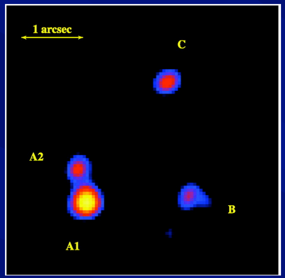
Variability now seen in multiple Chandra and XMM-Newton observations.

Line energies and strengths change on timescales down to ~ days.

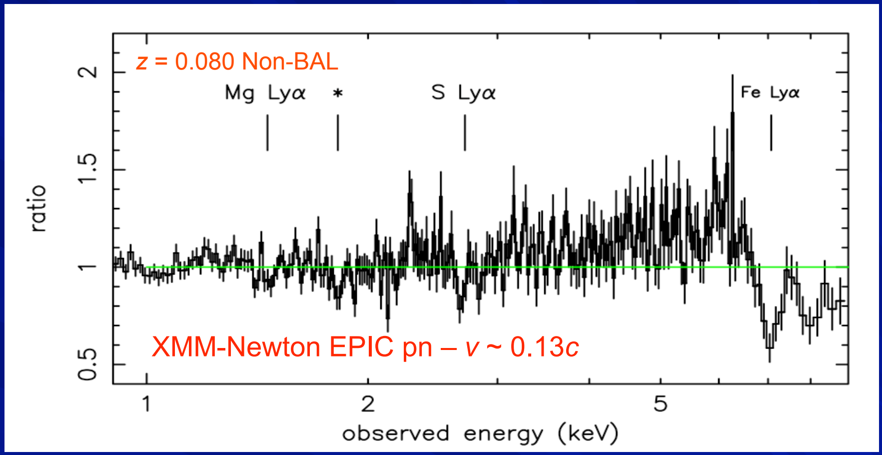
Some Additional Examples

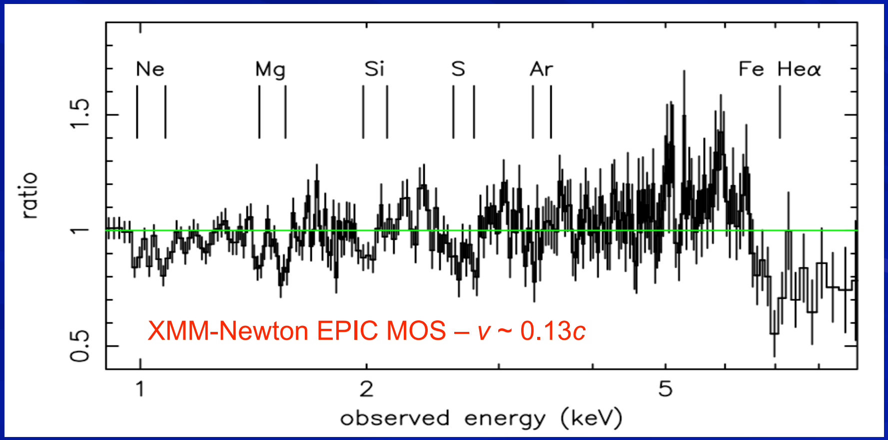
PG 1115+080 – Chartas et al. (2007)





PG 1211+143 – Pounds et al. (2007)

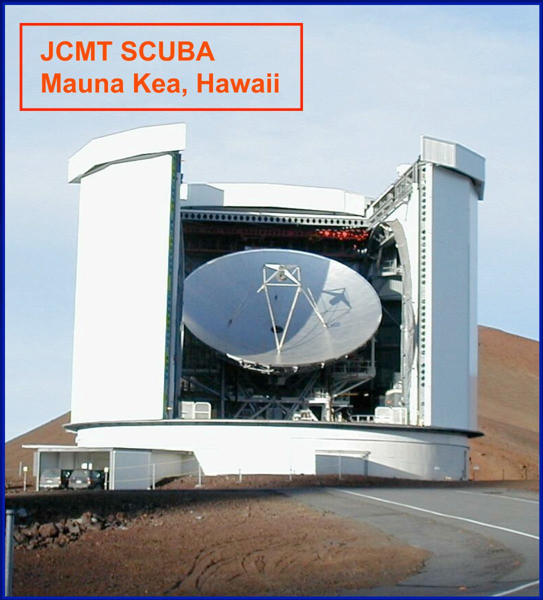




Also see Kaspi & Behar (2006)

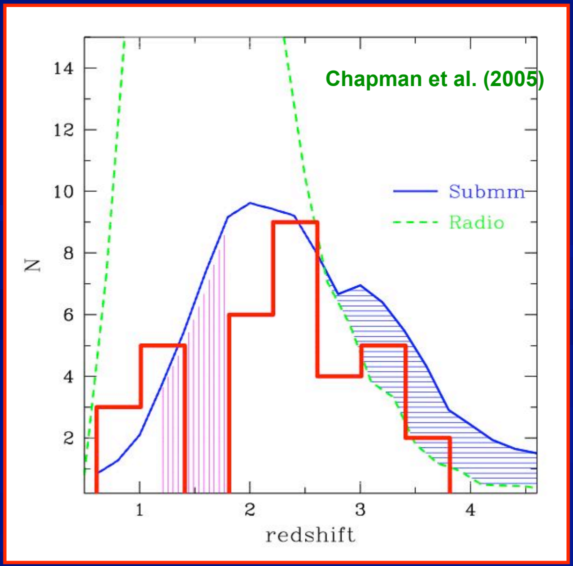
AGNs in Most-Powerful Starburst Galaxies at High Redshift

Distant Submillimeter Galaxies



Dust-shrouded starbursts forming stars at ~ 1000 solar masses / year. Optically nondescript due to extinction.

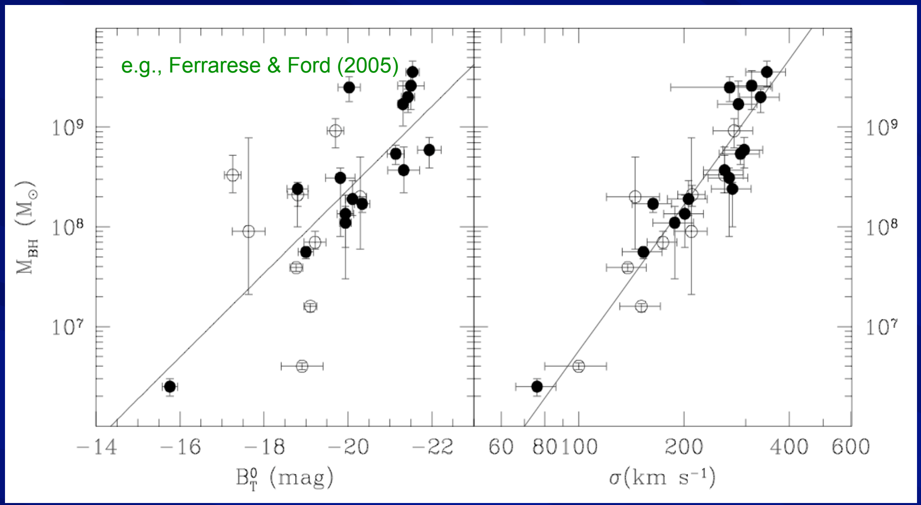
Submm / radio matching and then ultra-deep Keck spectroscopy gives redshifts for significant subset.



Typically z ~ 1.5-3 (~ 1000 times more common at z ~ 2).

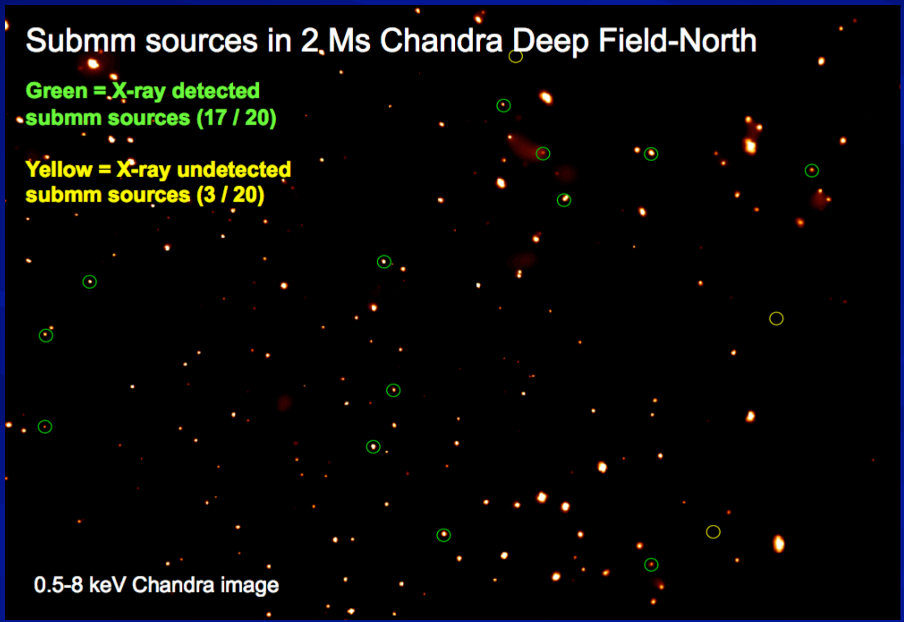
Seeing epoch of spheroid formation in massive galaxies.

SMBH-Galaxy Connections



M_{BH}-σ relation implies host-AGN connection.

Do these massive forming spheroids contain actively growing SMBHs?



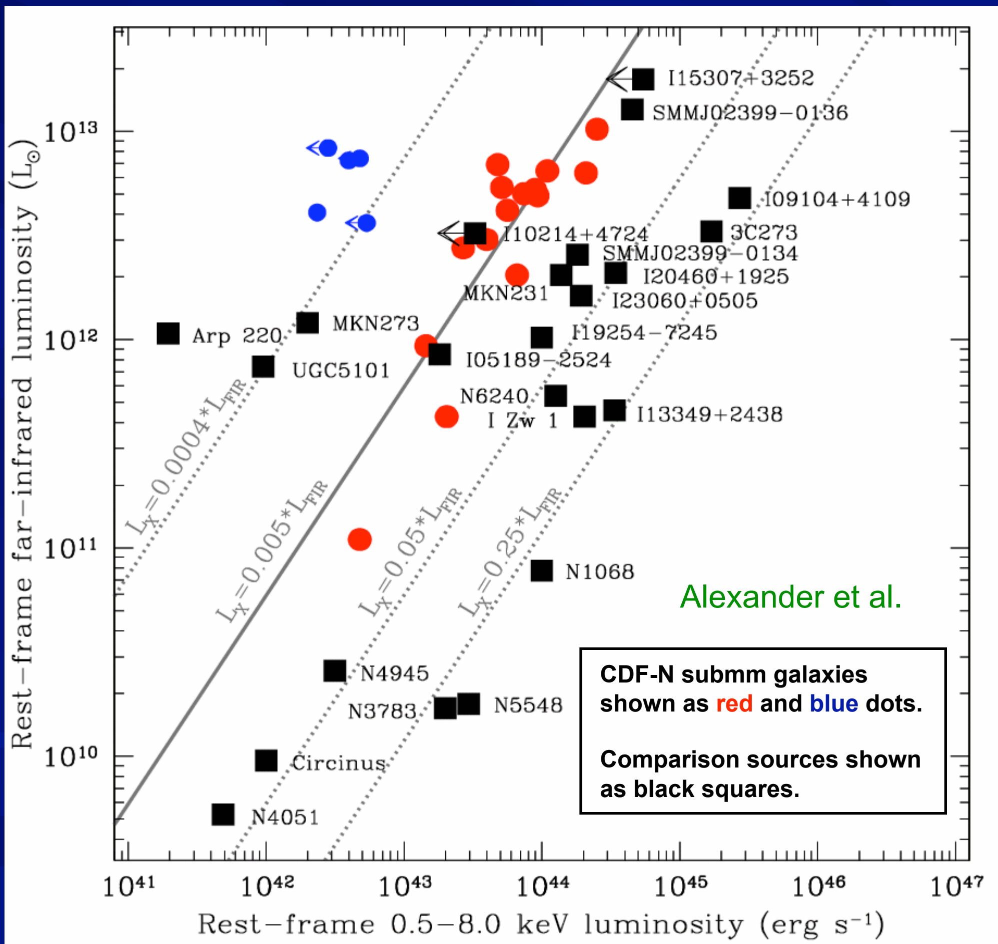
Detailed optical spectral classification often difficult due to faintness.

Thus, deepest X-ray surveys play critical role.

About 85% of CDF-N submm galaxies with precise positions have Chandra detections, often faint.

Deep X-ray Surveys Reveal the Active Galaxy Content of Submillimeter Galaxies

Far-infrared Versus X-ray Luminosity



Majority appear to contain moderate-luminosity AGN, usually obscured.

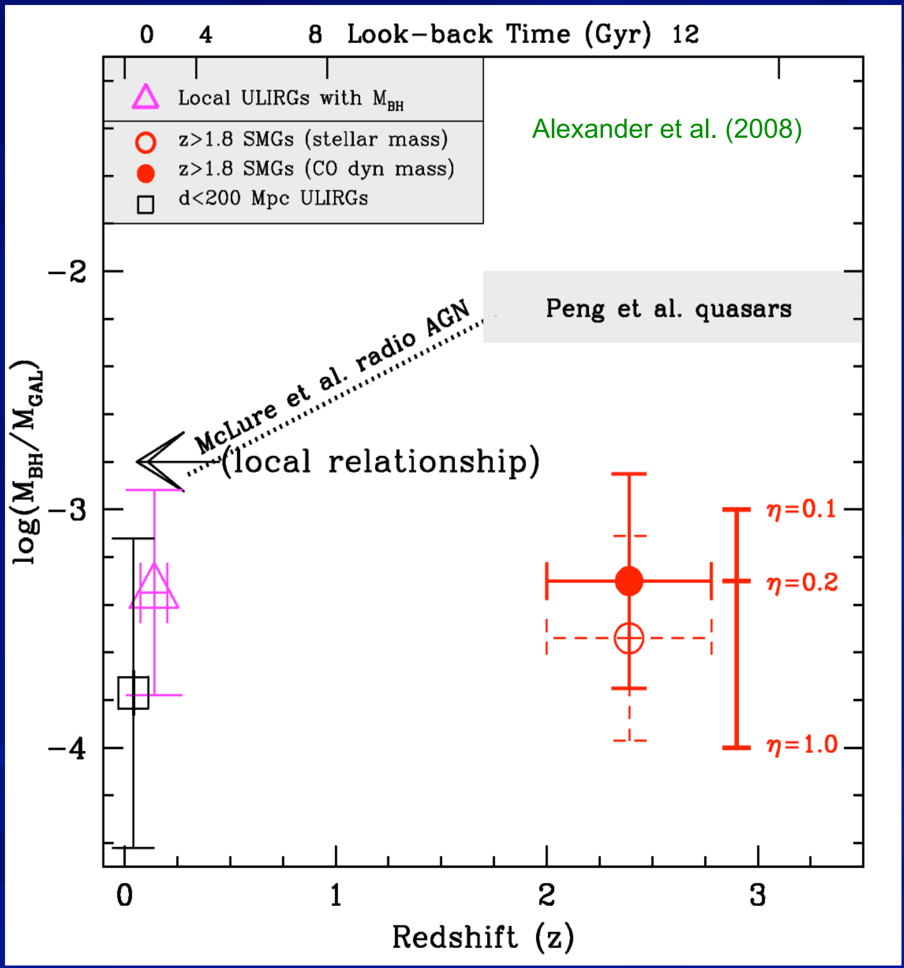
AGN fraction at least 40%, accounting for selection effects.

Much higher than any other coeval galaxy population (usually ~ 5%).

SMBHs in submm galaxies almost continuously growing during observed phase of intense star formation.

Directly seeing simultaneous growth of SMBH and spheroid.

Black-Hole vs. Host Masses in Submillimeter Galaxies – An Earlier Evolutionary Stage?



Estimate black-hole masses for 6 broad-line submm galaxies via (cautious) application of virial mass estimator.

X-ray and FIR luminosities for some of these match those of more typical submm galaxies, so apply unification model.

Available data suggest M_{BH} / M_{Bulge} is lower in submm galaxies than in z ~ 2-3 quasars (and local galaxies).

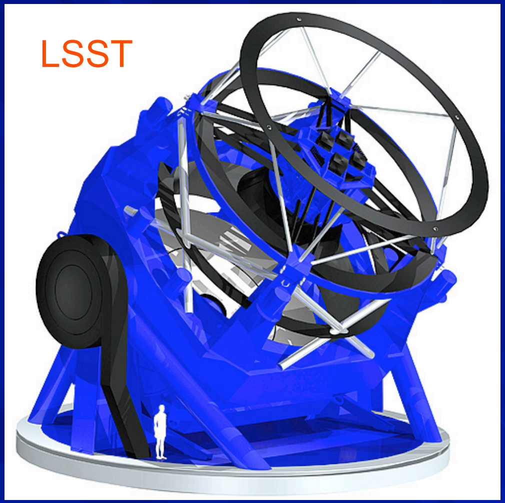
Similar results found for local ULIRGs.

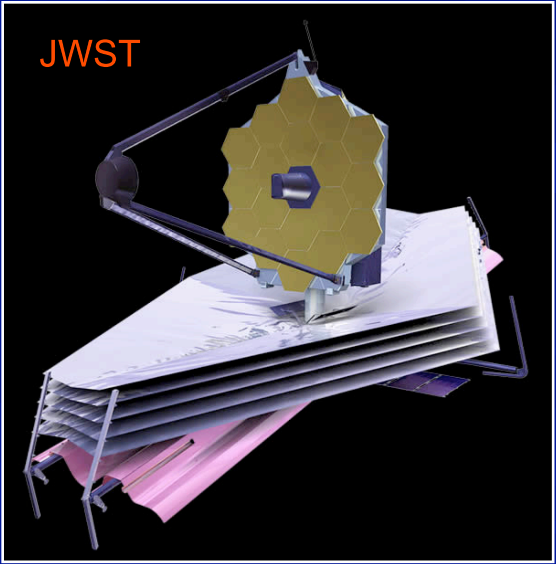
Growth of black-hole seems to lag that of host galaxy in submm galaxies.

An earlier, pre-quasar evolutionary stage?

Some Prospects for XEUS and Constellation-X

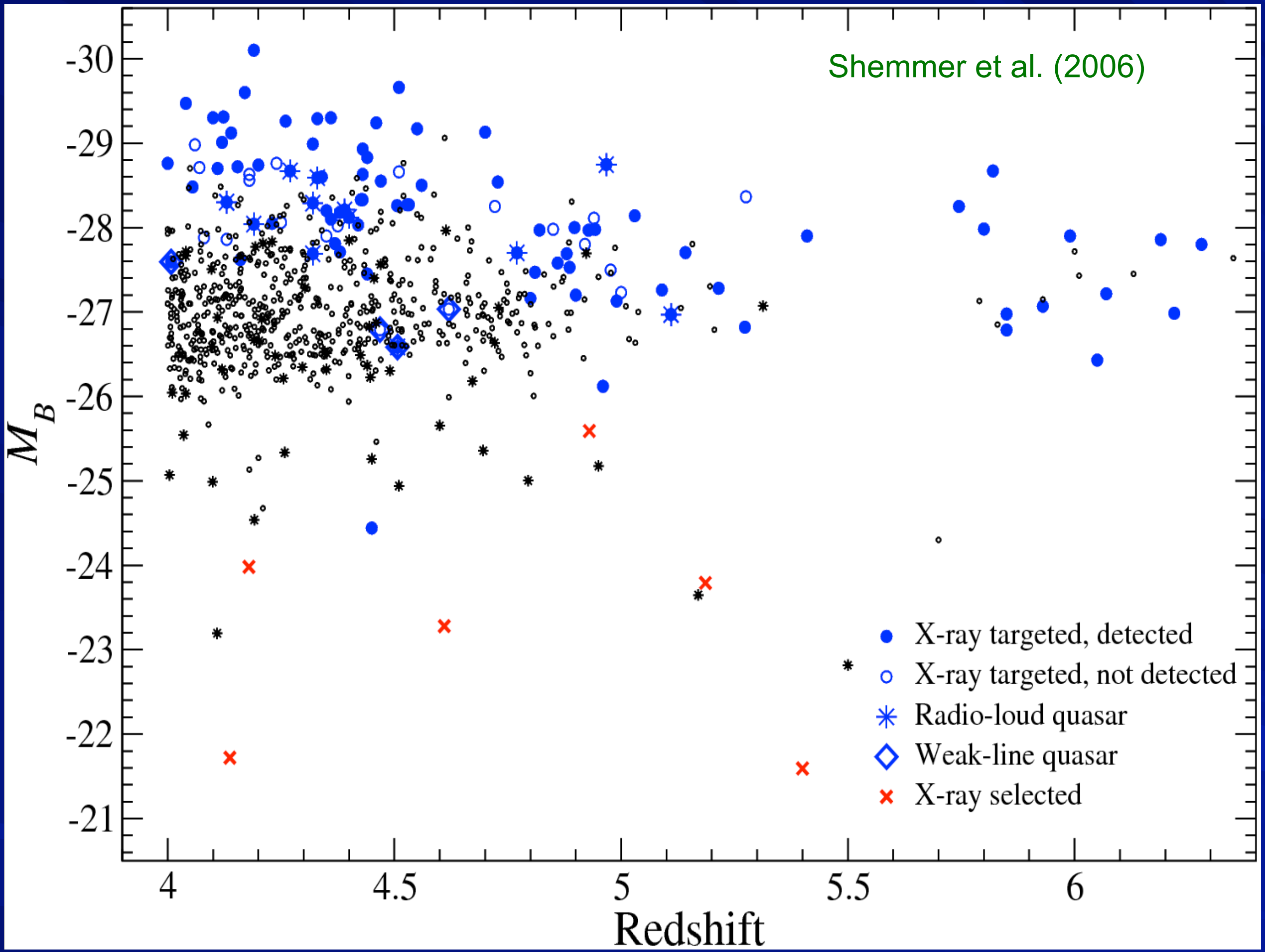
Abundant High-Redshift AGN Targets for XEUS and Con-X



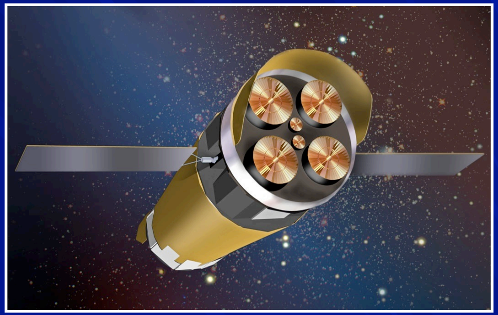


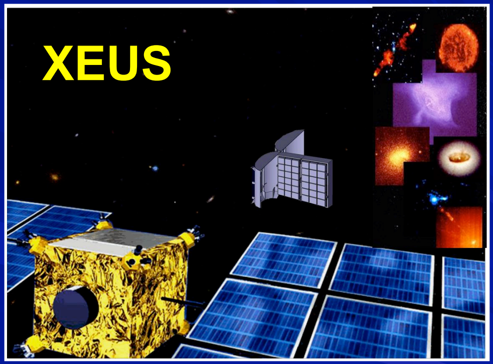
LSST alone will deliver ~ 1000 AGNs at z ~ 6.5-7.5

AGN Luminosity-Redshift Plane at z > 4



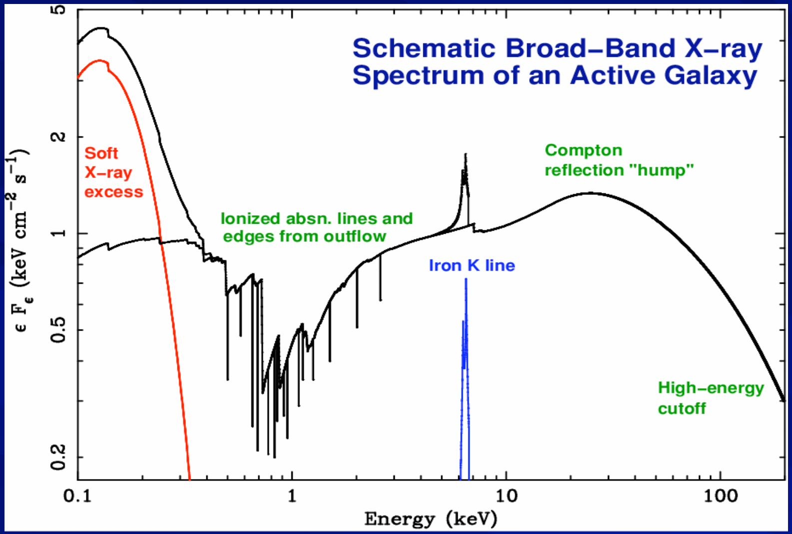
Constellation-X

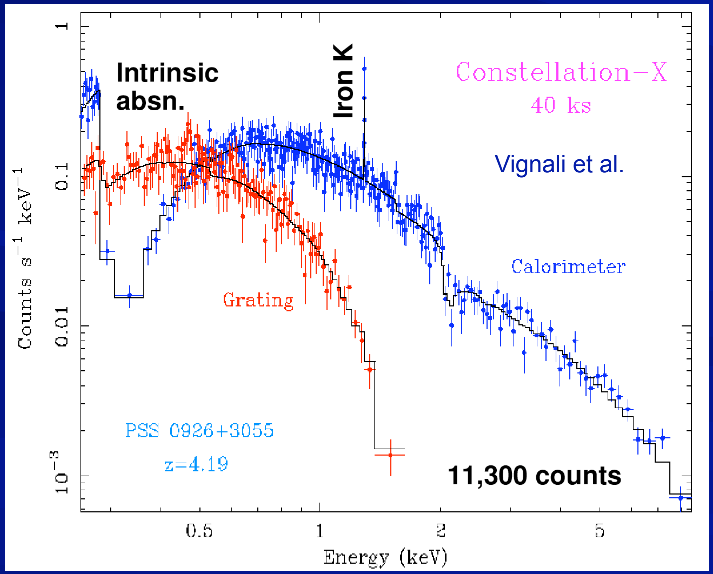




By the time XEUS and Con-X launch, this plot should have ~ 30,000 AGNs and should extend to z ~ 7.5 or higher.

Complex X-ray Spectra of AGNs





Current X-ray spectral constraints at *z* > 4 are generally crude (at most 500-1,500 counts).

X-ray continuum shape

Intrinsic absorption

X-ray BALs and NALs

Iron K lines

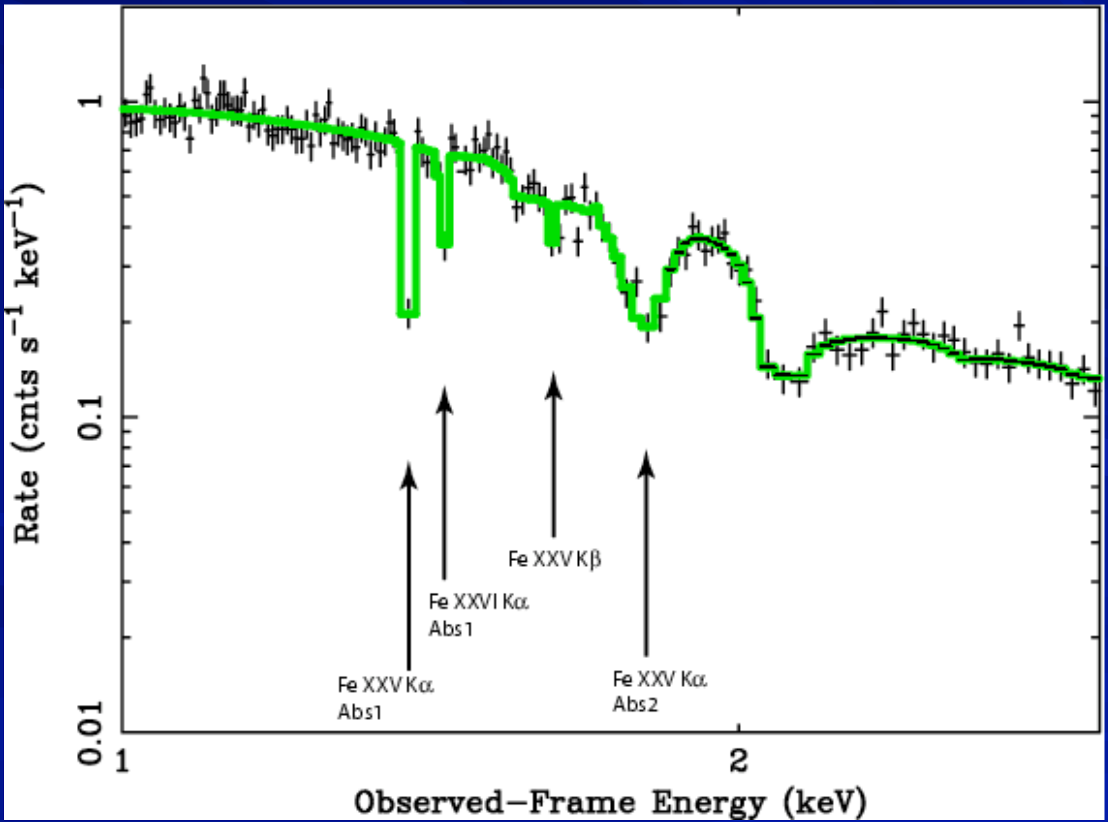
Compton-reflection continuum

High-energy cut-off

Con-X Simulation of APM 08279+5255

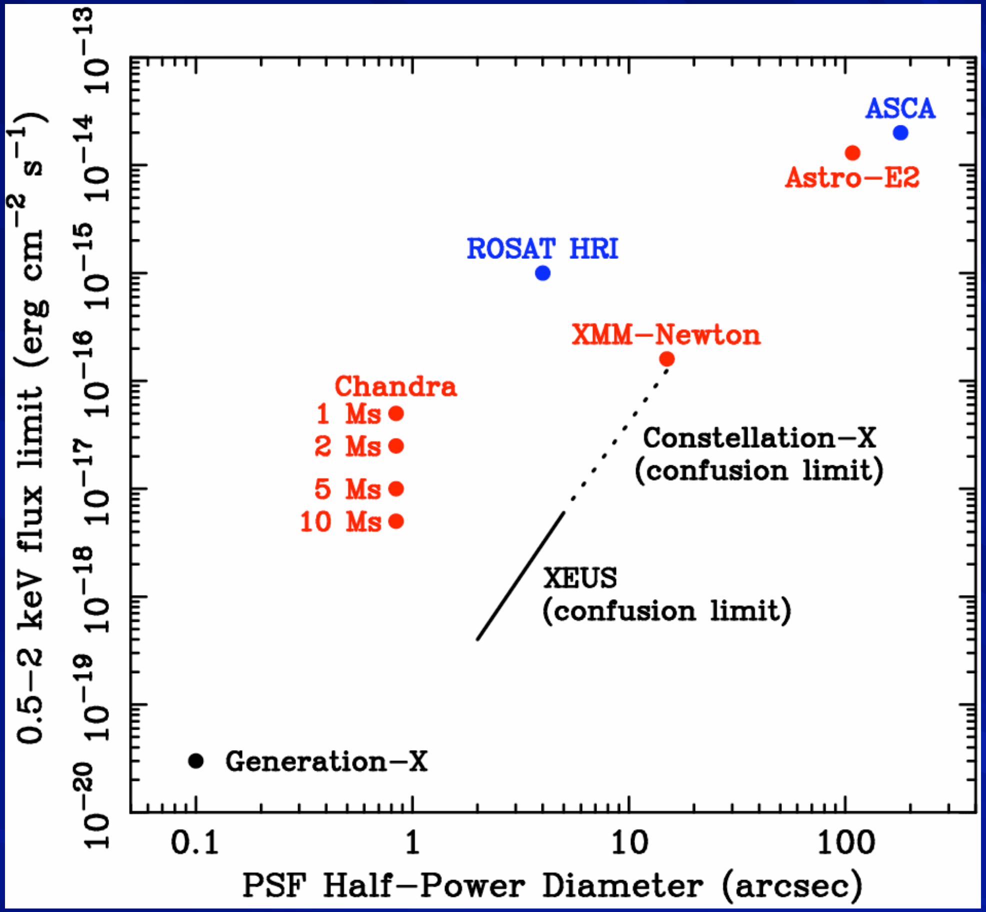
Simulated series of 10 ks Con-X observations, motivated by current Chandra and XMM-Newton data.

Variations of X-ray BALs should be straightforward to monitor, and can measure acceleration of absorbers over time.



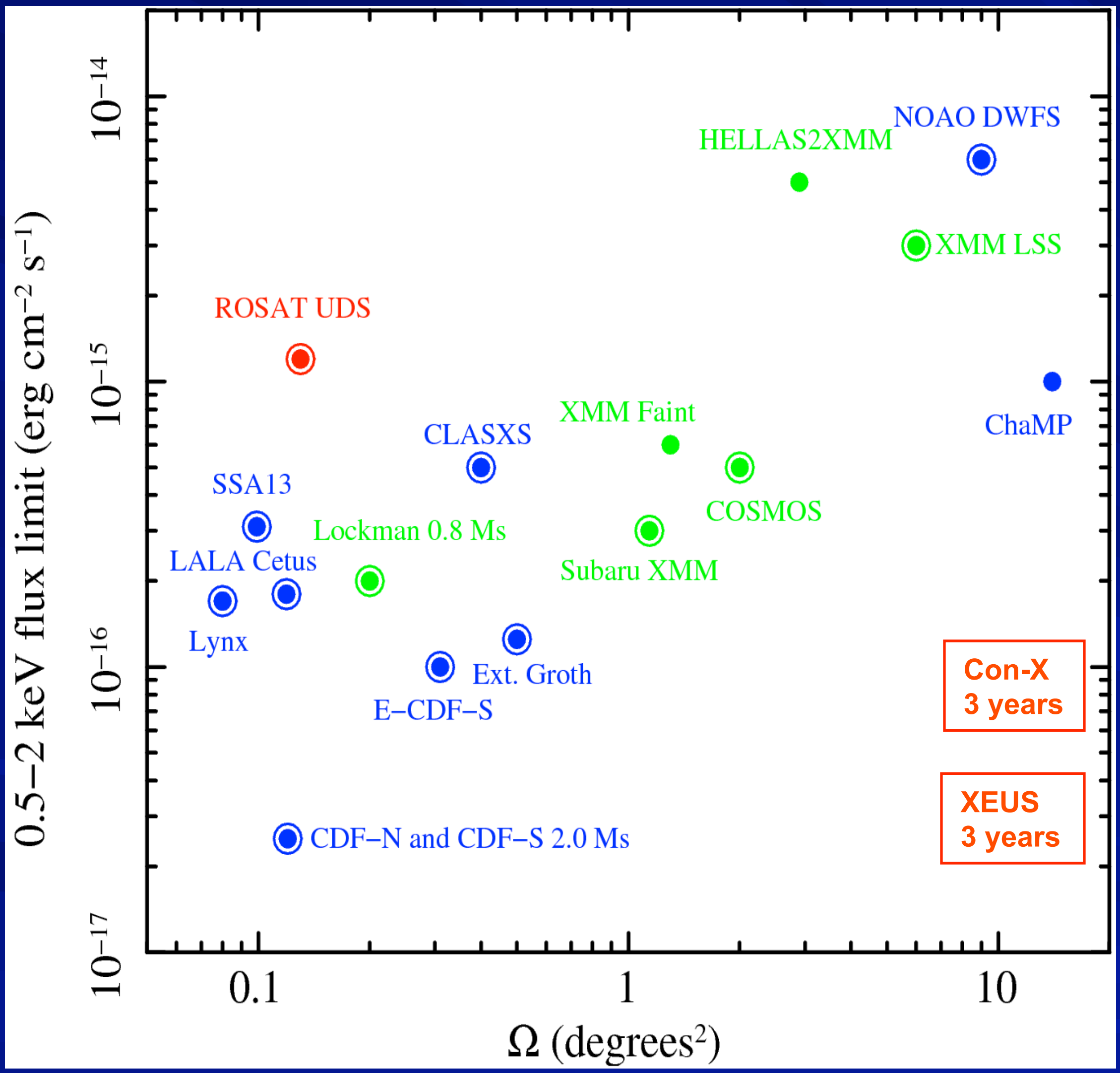
Chartas et al.

Surveys with XEUS and Con-X



Owing to large collecting areas, many XEUS and Con-X observations should approach confusion limits.

Con-X and XEUS Serendipitous Surveys at High Redshift



3-year AGN yields at $z > 4$ should be ~ 450 for Con-X and ~ 2,100 for XEUS.

Can find obscured AGNs missed by other techniques.

Fe K line redshifts can help with identifications.