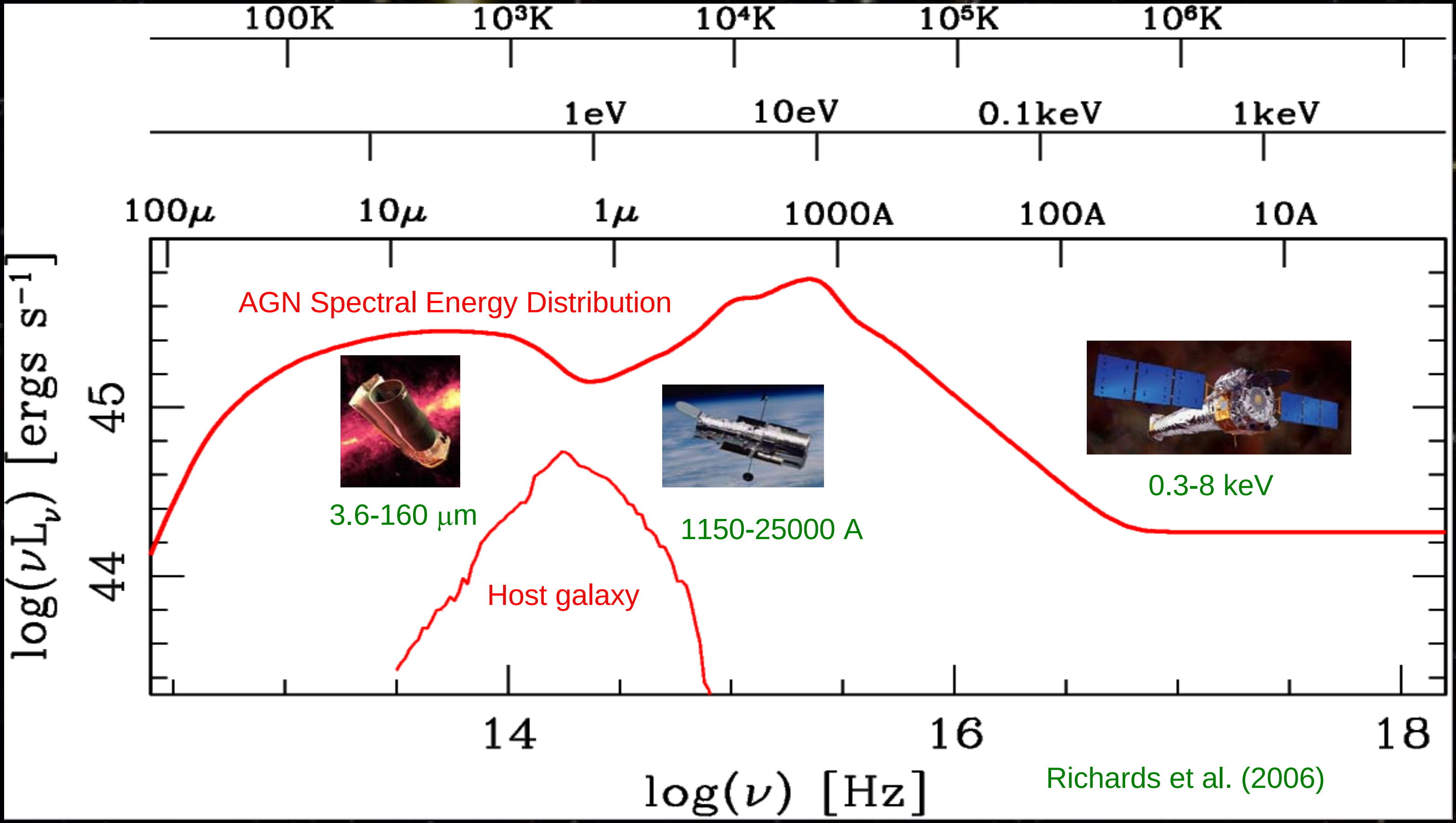
Active Galactic Nuclei: Making the Most of the Great Observatories

Niel Brandt (Penn State)



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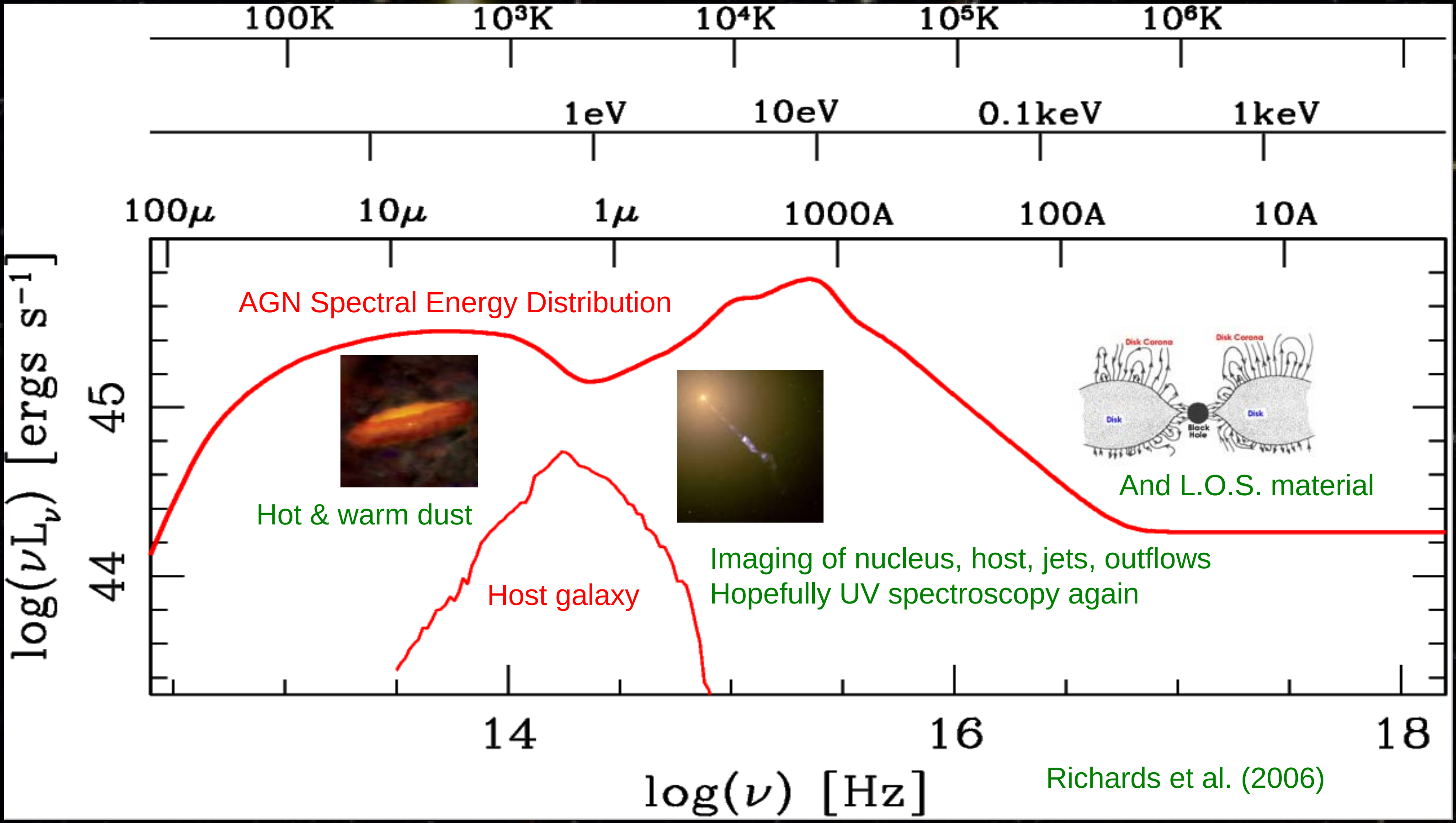
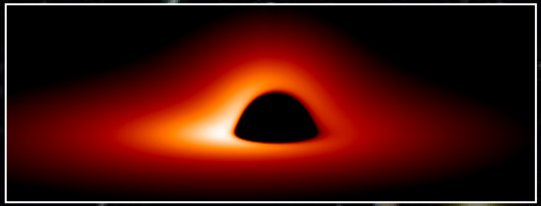


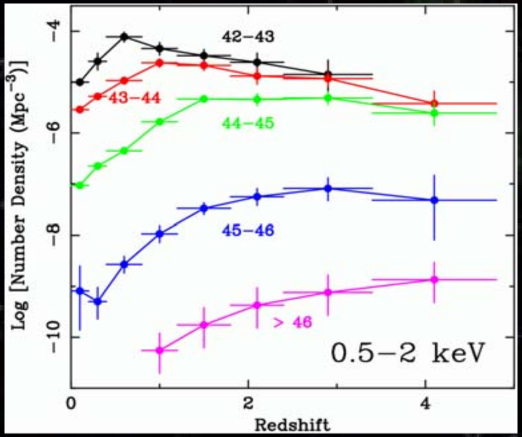
Overall Importance of AGN Studies

These three areas are inter-related.



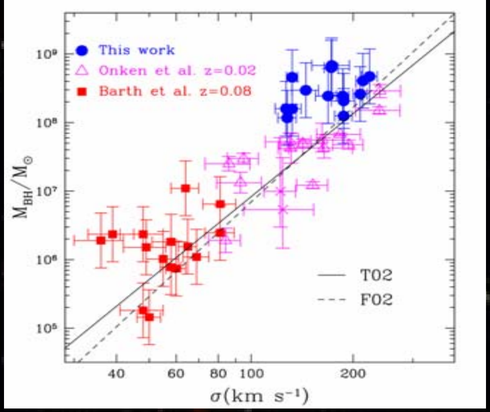
Probe among the most extreme physical environments in the Universe.

Inner disk & corona, jets, winds.



AGN surveys show how supermassive black holes (SMBHs) have fed and grown over cosmic time in a variety of environments.

Luminosity dependent AGN evolution.



AGNs are an essential part of typical galaxies, if only for small duty cycles, and they exert strong feedback on their environments.

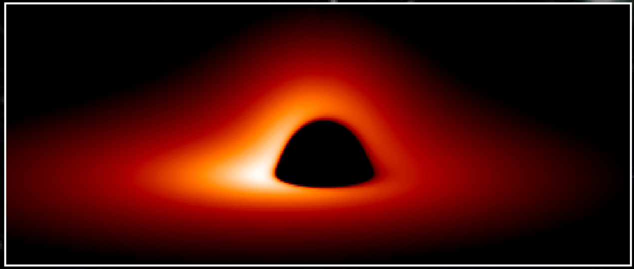
Enhanced the broad importance of AGN.

Emit ~ 5-10% of the total power in the Universe, since the formation of galaxies.

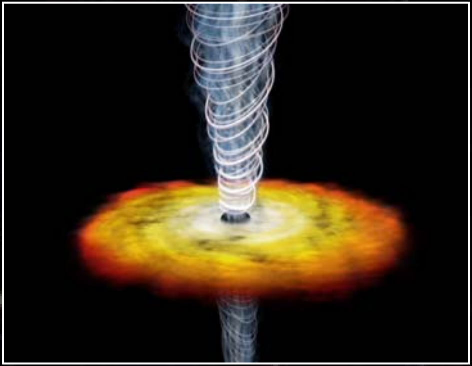
Thanks for Helpful Feedback!

George Chartas
Teddy Cheung
Moshe Elitzur
Martin Elvis
Andy Fabian
Duncan Farrah
Sarah Gallagher
Varoujan Gorjian
Paul Green
Guenther Hasinger
Ann Hornschemeier
Shai Kaspi
Mark Lacy
Charles Lawrence
Matt Malkan
Paul Martini
Chris Reynolds
Gordon Richards
Rita Sambruna
Ohad Shemmer
Aaron Steffen
Michael Strauss
Dan Weedman
Nadia Zakamska

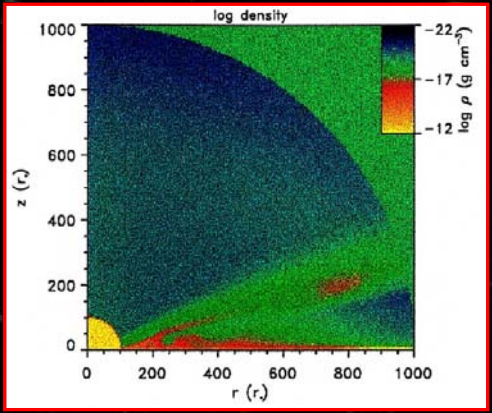
Extreme Environments



Accretion Disks



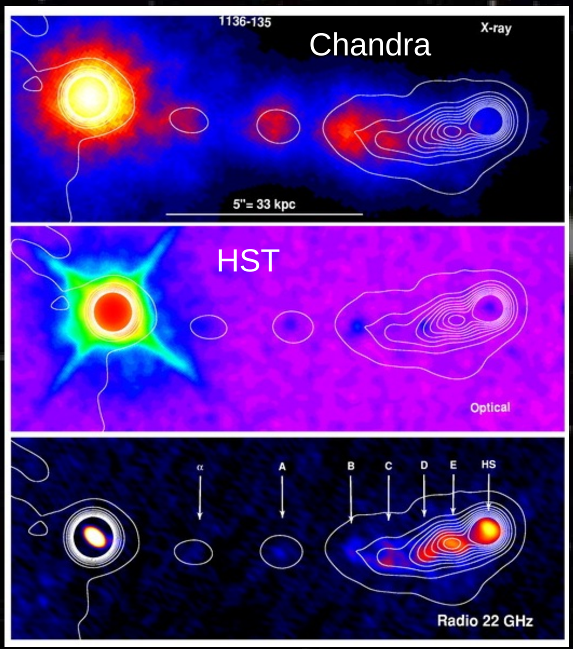
Jets



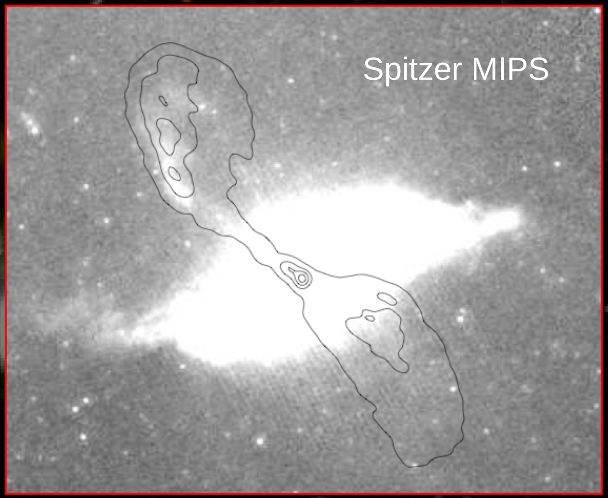
Winds

Extreme Environments: Relativistic Jets

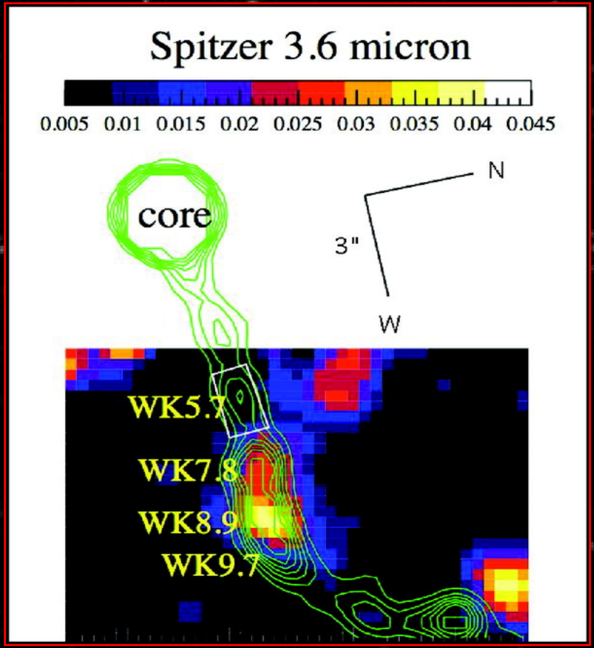
1136-135 - Sambruna et al. (2006)

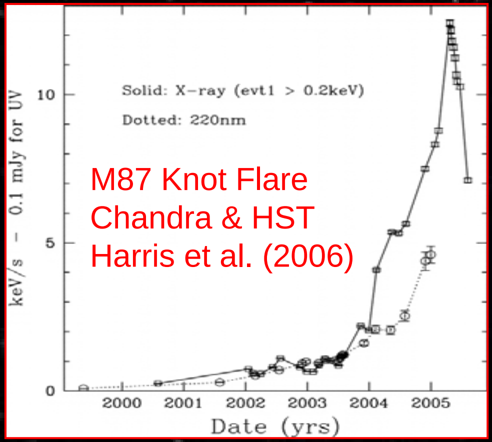


Cen A - Brookes et al. (2006)



PKS 0637-752 - Uchiyama et al. (2005)





Studies of kpc-scale jets revolutionized by Great Observatories.

HST detailed imaging, surprise Chandra detections, Spitzer constraints, and remarkable variability.

Angular resolution and multi-wavelength coverage essential for basic physical modeling. No comparable facilities for a long time.

Extreme Environments: Relativistic Jets

Some key challenges for the Great Observatories:

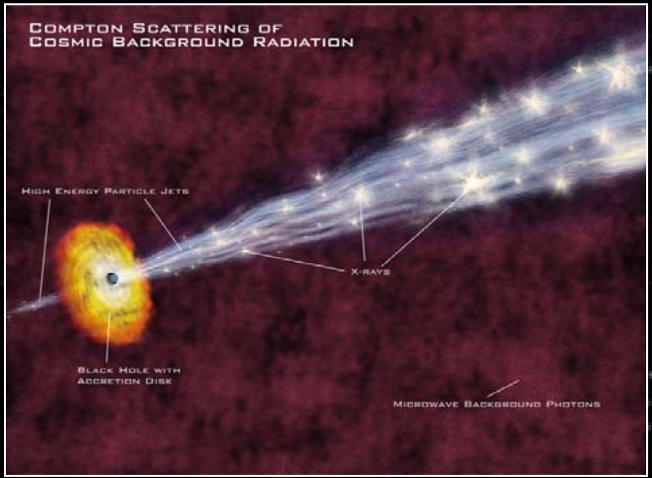
Origin of the X-ray emission for jets from powerful radio galaxies and quasars. IC/CMB? Multiple synchrotron components?

Variability monitoring of jet knots for emission-region size and beaming.

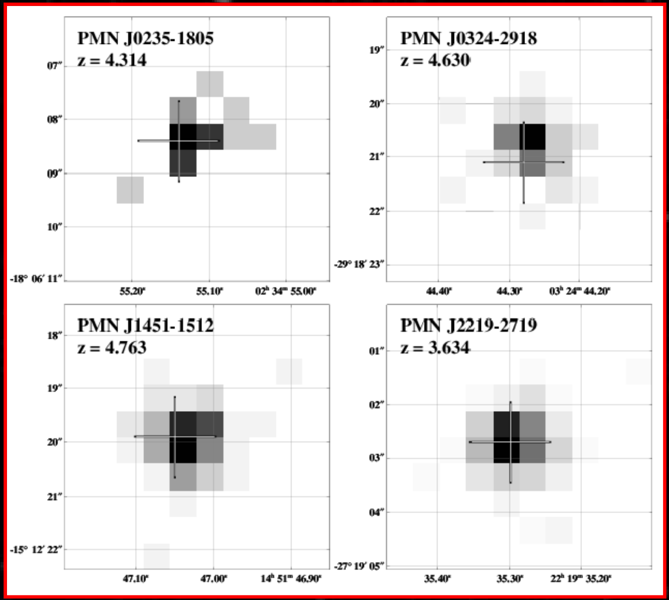
High-quality multiwavelength coverage of larger samples of sources with a range of orientation and luminosity (e.g., BL Lacs, FR I).

Role of jets at low L / L_{Edd} – dominant power output?

Lack of *highly* X-ray bright jets at high redshift. Not IC/CMB? High-redshift deceleration close to core? Intrinsic change in jet parameters?

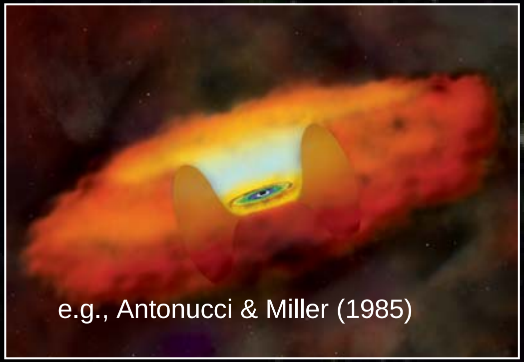


z ~ 4 RLQs with Chandra - Lopez et al. (2006)

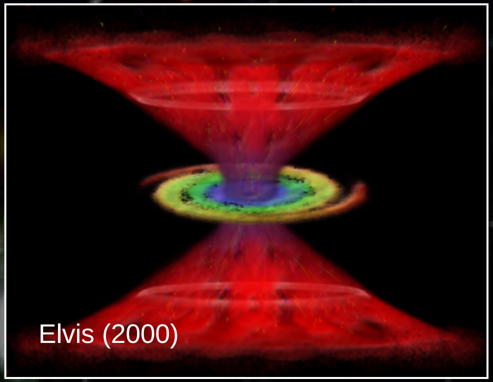


Extreme Environments: “Torus” and Winds

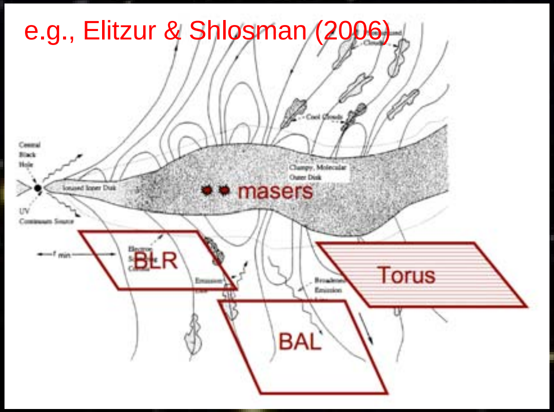
Hydrostatic “Doughnut”



Funnel-Shaped, Thin-Shell Outflow



Equatorial, Clumpy, Hydromagnetic Disk Wind



Many more!

Understanding 0.01-1 pc environment has implications for SMBH growth and AGN feedback.

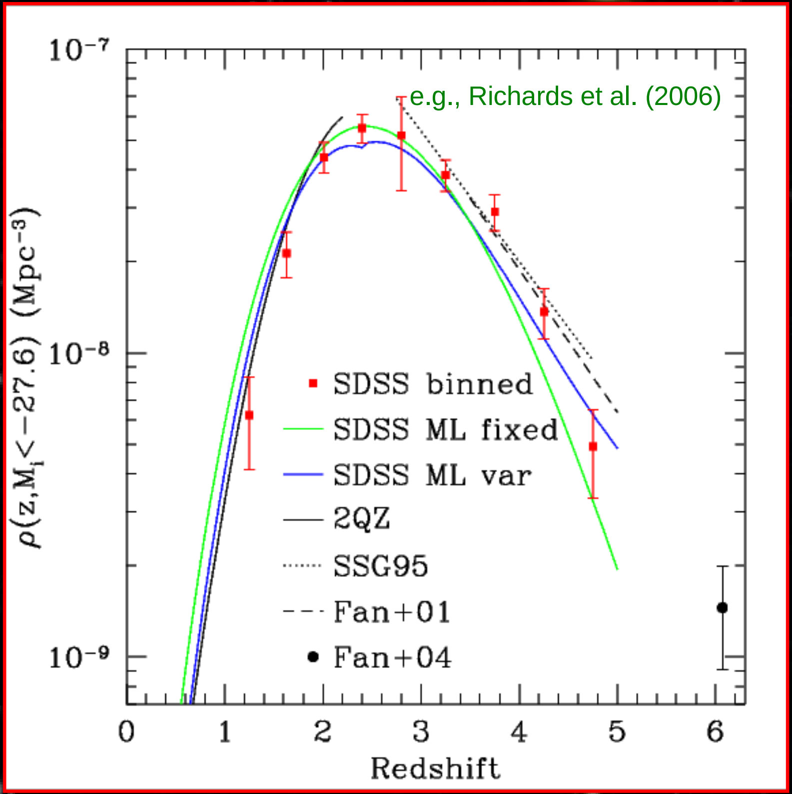
Some recent observational developments:

- Rapid X-ray absorption variability implying small scale (e.g., Risaliti et al. 2002, 2005)
- Luminosity dependence of absorbed fraction (e.g., Steffen et al. 2003)
- Small scale implies clumpiness to explain infrared emission (e.g., Elitzur 2005)

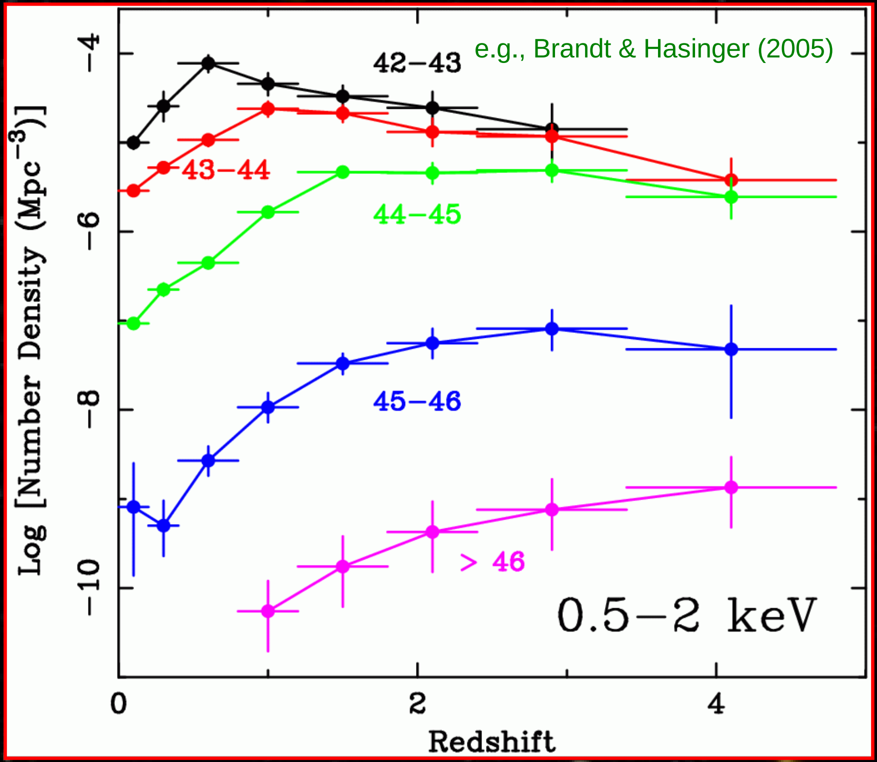
Develop further with:

- More variability monitoring, perhaps concurrently in several wavelength bands
- More and better X-ray and infrared surveys
- Checking for a “disappearing torus” at lowest luminosities
- Studies of exceptional objects (e.g., weak-line quasars)

Feeding and Growth of Supermassive Black Holes



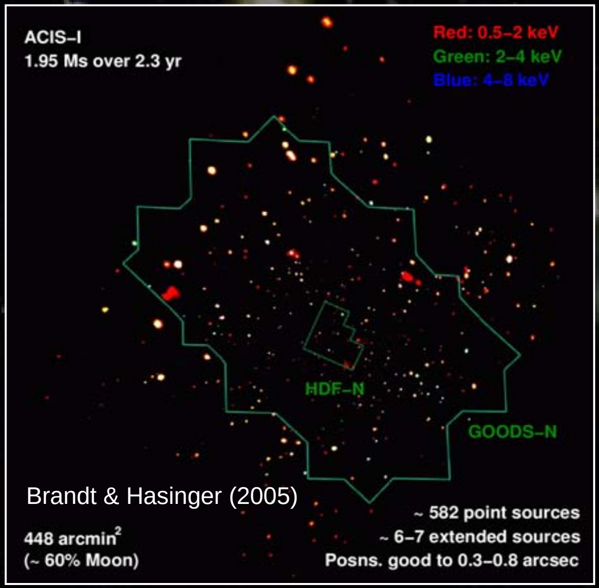
Luminous Quasar Evolution



Cosmic “Downsizing”

SMBH Growth: Complete AGN Census

Deep Chandra Fields



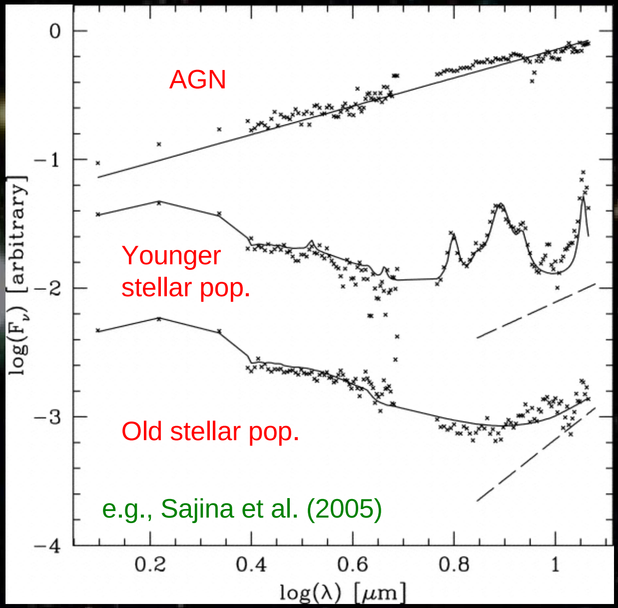
Low obscuration and host biases.

High AGN sky densities of ~ 7200 deg^{-2}.

Significant numbers of new AGNs down to faintest flux levels probed.

Only ~ 60% of 6-8 keV bkg. resolved.

Spitzer AGN Color Selection

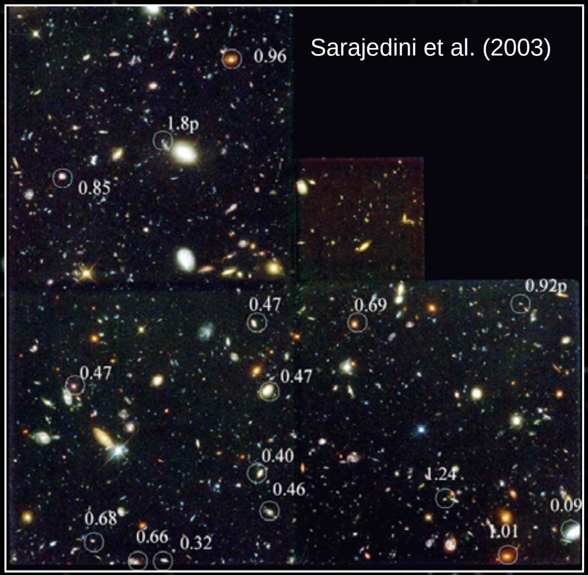


Several Spitzer + multiwavelength AGN selection techniques implemented.

Finding good AGN candidates missed even in deepest X-ray surveys - highly obscured AGNs.

Some techniques seem to work best at high AGN luminosities.

HST Variability Selection



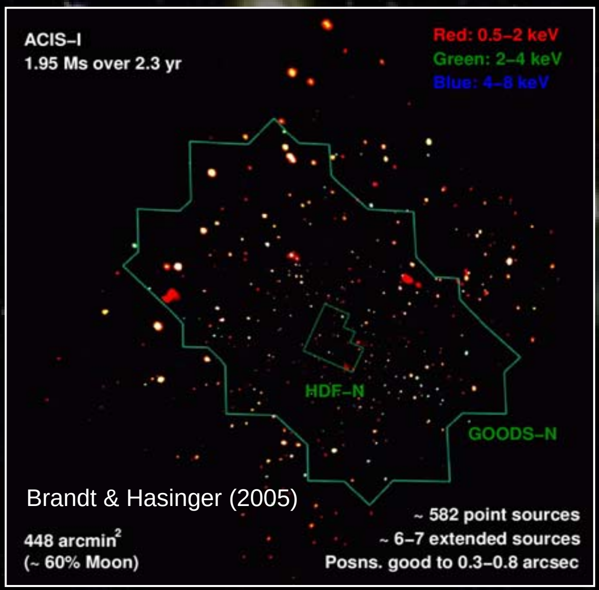
Variability selection with ultradeep HST images finds a comparable AGN density to deep X-ray surveys.

Good general overlap with X-ray selected sources, but some new ones.

Probably not highly obscured, but may be low-luminosity or intrinsically X-ray weak.

SMBH Growth: Complete AGN Census

Deep Chandra Fields

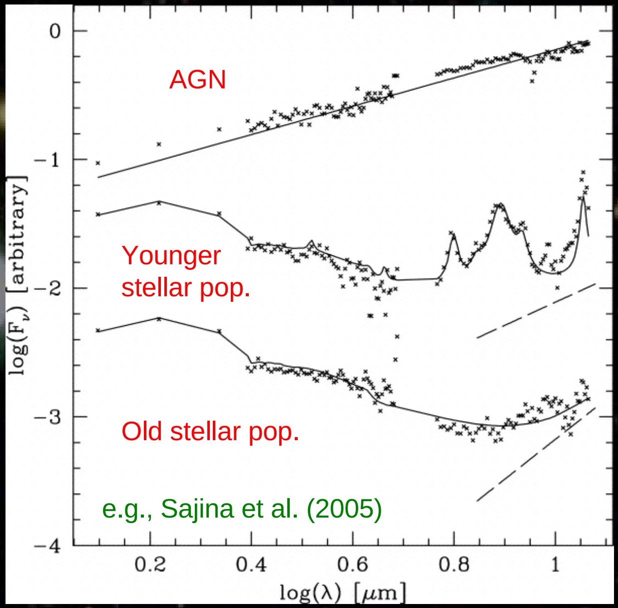


Deeper X-ray fields needed, to find the missed heavily obscured AGNs and to understand the detected AGNs better.

4-10 Ms Chandra field would be unconfused and largely photon limited.

Will not have capability again for 10-20 yr.

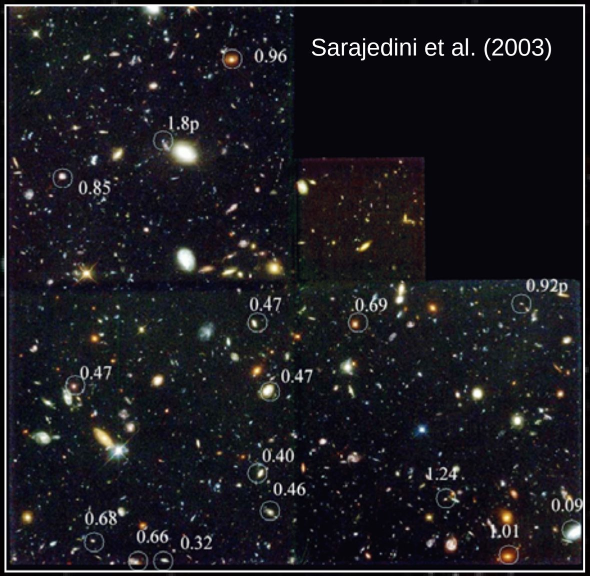
Spitzer AGN Color Selection



Refine selection methods at low AGN luminosities exploiting other information (e.g., Donley et al. 2005).

Infrared variability selection?

HST Variability Selection



More epochs on fields with deep, multi-epoch data currently (e.g., GOODS-N has ~ 12 epochs).

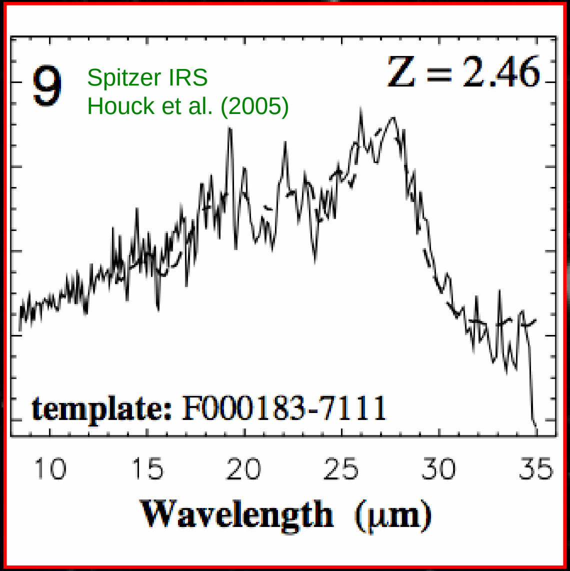
Want to move to low frequencies on the “red-noise” power spectrum.

Complementarity - supernova searches.

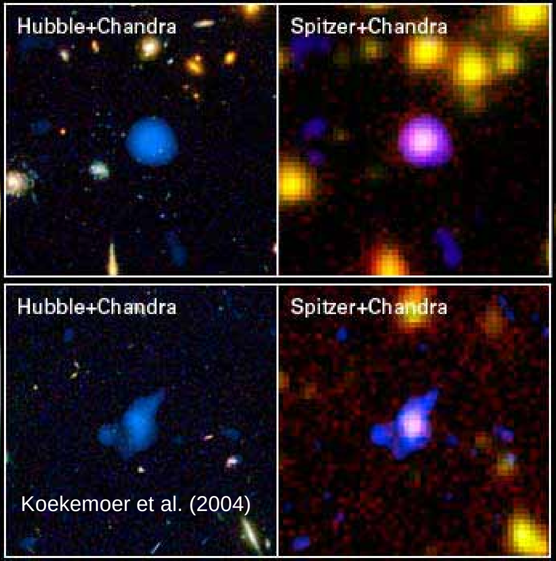
Given different AGN surveying “speeds,” ensure best possible set of matched fields. Also great local AGN sample to ~ 20 Mpc.

SMBH Growth: High-Redshift, Obscured AGNs

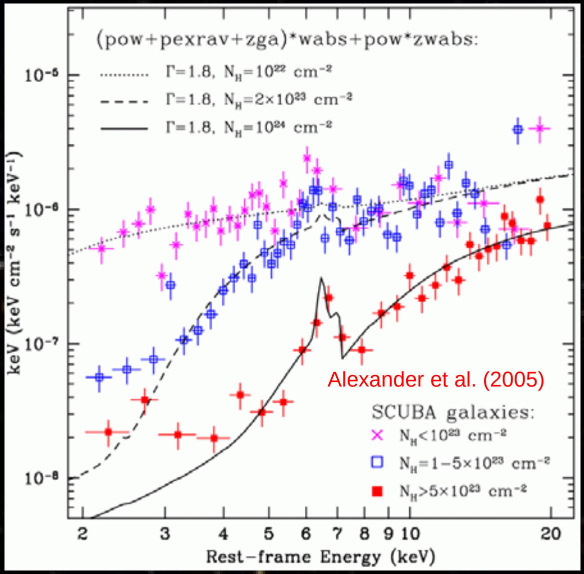
Extreme IR / Optical Sources



Extreme X-ray / Optical Sources



X-ray AGNs in Submm Galaxies



Candidates for highly obscured AGNs at z ~ 1.5-7 selected with a variety of techniques.

Outnumber classical optically selected AGNs of comparable bolometric luminosity and redshift.

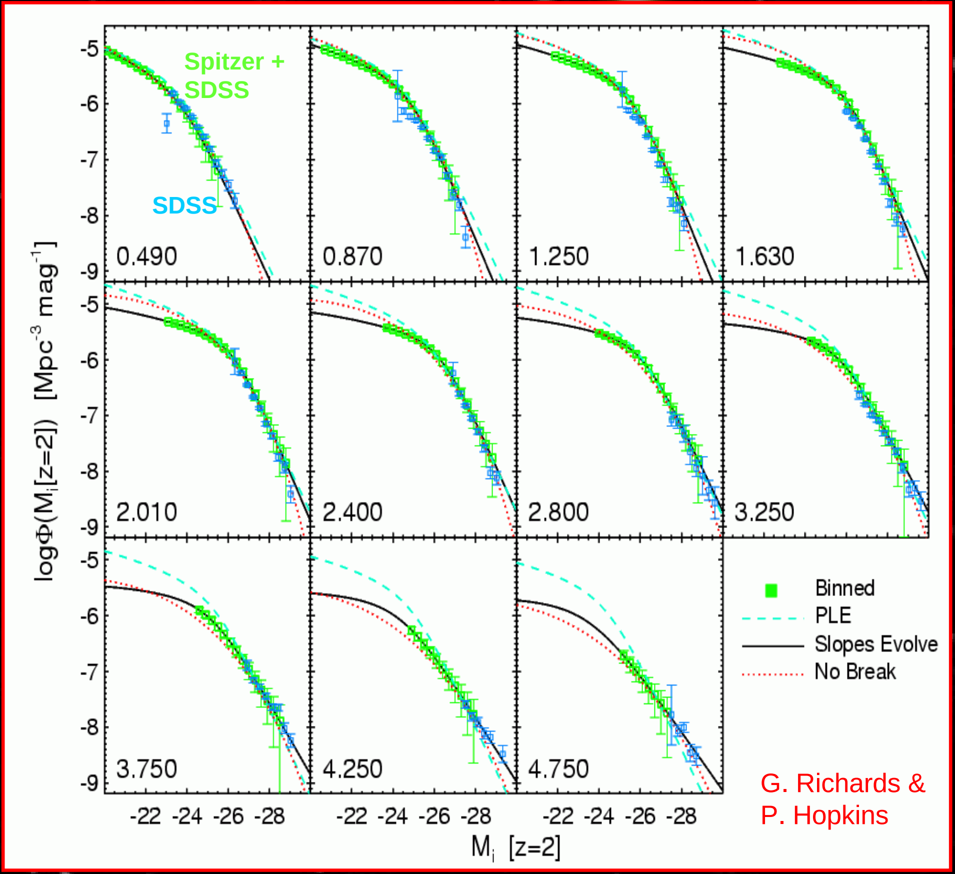
Obscured formation of SMBH and bulges in massive galaxies – pre-quasars?

Often extremely faint at optical wavelengths.

Need more effort on redshift determinations, multiwavelength coverage - AGN vs. starburst power, degree of overlap between selected populations.

SMBH Growth: Very Large Area AGN Survey with Post-Cryogen Spitzer

Simulated luminosity-function constraints from a 270 deg^2 Spitzer survey of the SDSS Southern Equatorial Stripe



Possibility of doing very large-area AGN surveys with post-cryogen Spitzer IRAC.

Could do ~ 270 deg^2 of the SDSS Equatorial Stripe to ~ 10 μJy in ~ 3.6 Ms.

With Spitzer + SDSS can push significantly further down the type 1 luminosity function (LF) than with SDSS alone.

Also ~ 30-epoch SDSS variability selection and good UKIDSS coverage.

Precision tests of luminosity-function models.

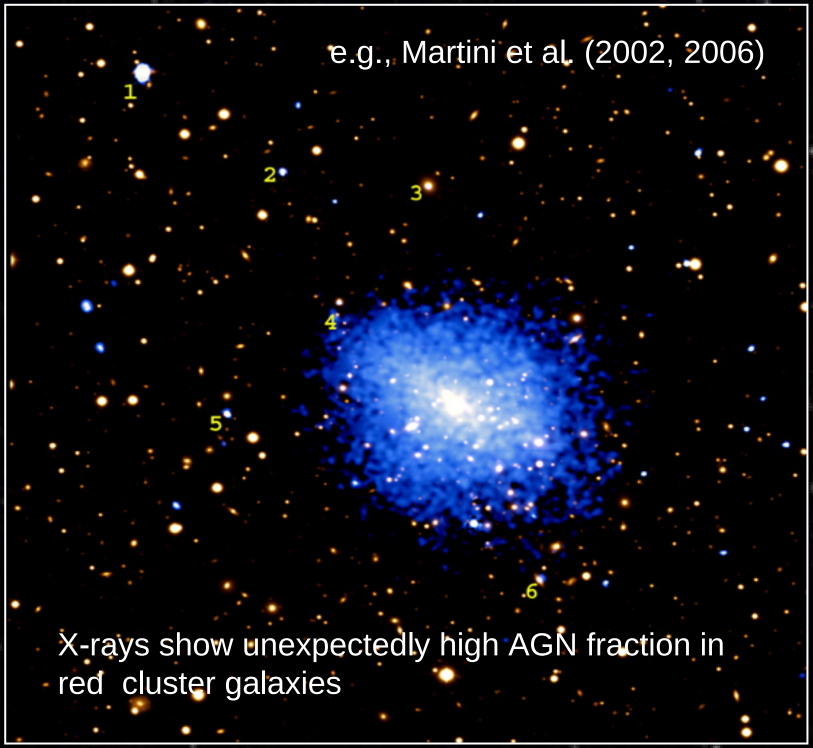
Why is the high-luminosity LF flatter at high redshift?

Massive mergers as main driver of quasar activity?

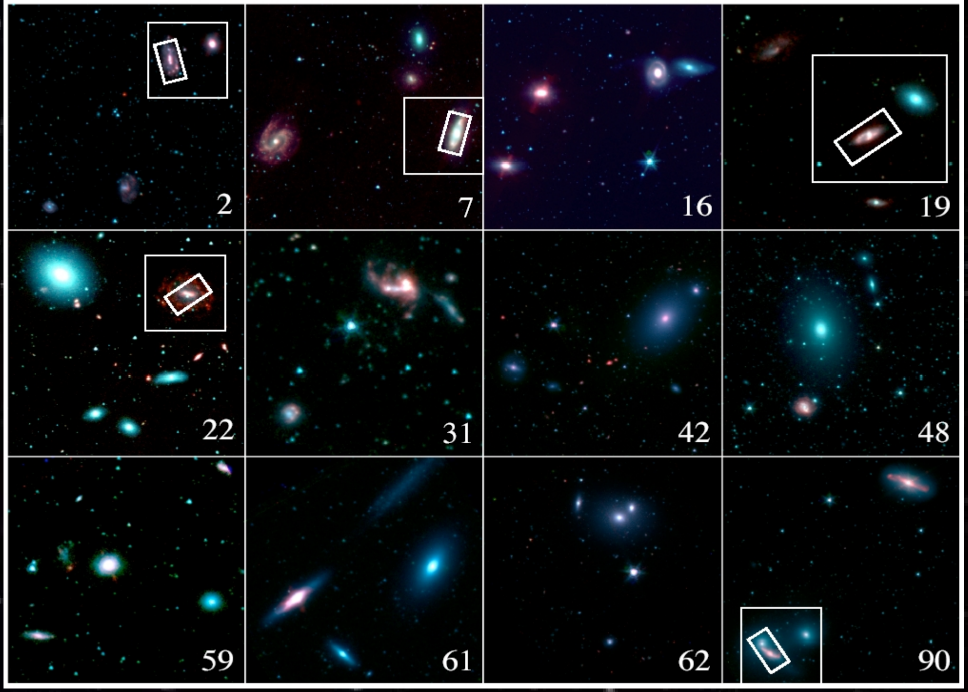
Also great for quasar clustering, rare AGNs, many non-AGN science goals.

SMBH Growth: Cluster and Group Environments

Chandra AGNs in Cluster Abell 2104



12 Hickson Compact Groups - Spitzer + HST + Chandra



Charlton, Gallagher, Johnson, Brandt, Hornschemeier, et al.

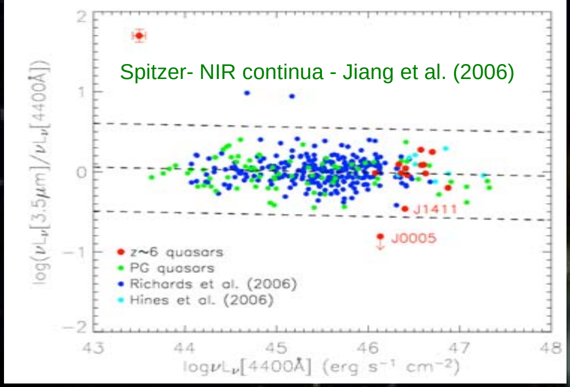
AGN content and host galaxies vs. field. AGN fraction as function of galaxy velocity dispersion.

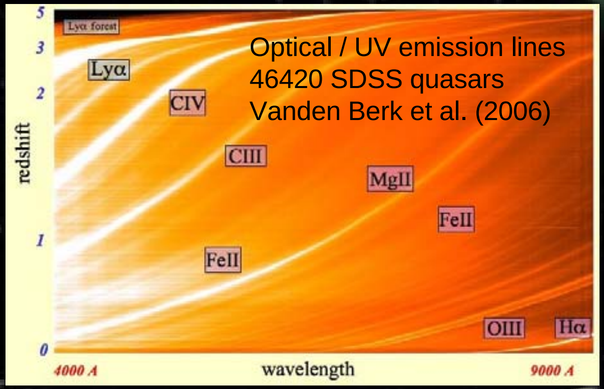
Dramatically different interaction rates and cold gas contents.

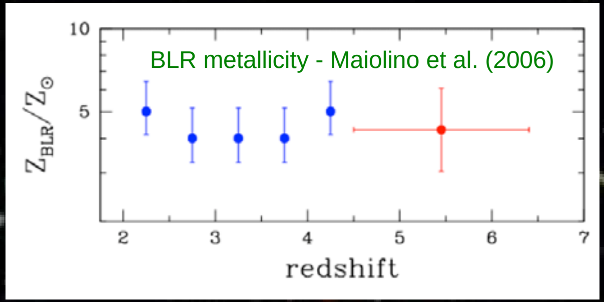
Survey cluster and group samples to low AGN luminosities using Chandra X-rays and Spitzer hot dust.

Need to probe different “evolutionary stages” of clusters and groups. Clusters from z ~ 0-0.5.

SMBH Growth: Accretion Properties Over Cosmic Time





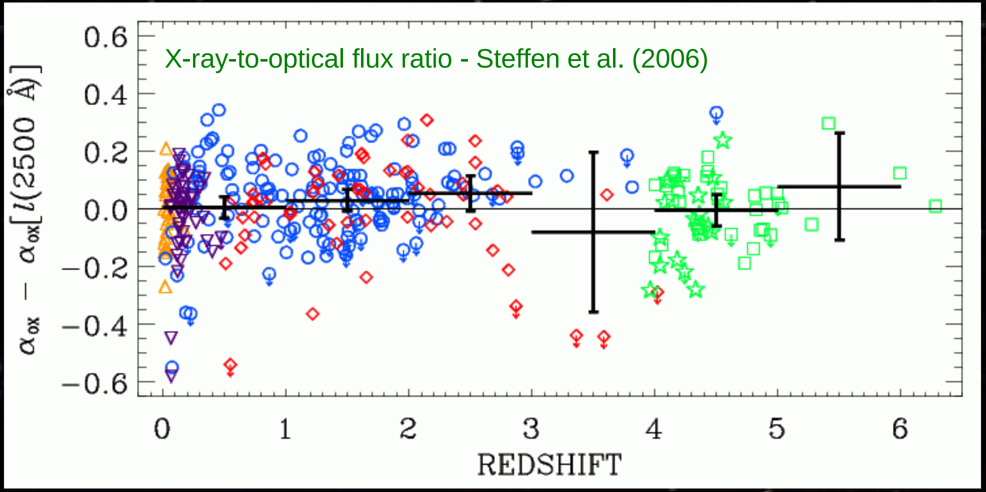


Observed AGN emission properties seem remarkably stable from z ~ 0-6, after accounting for luminosity effects.

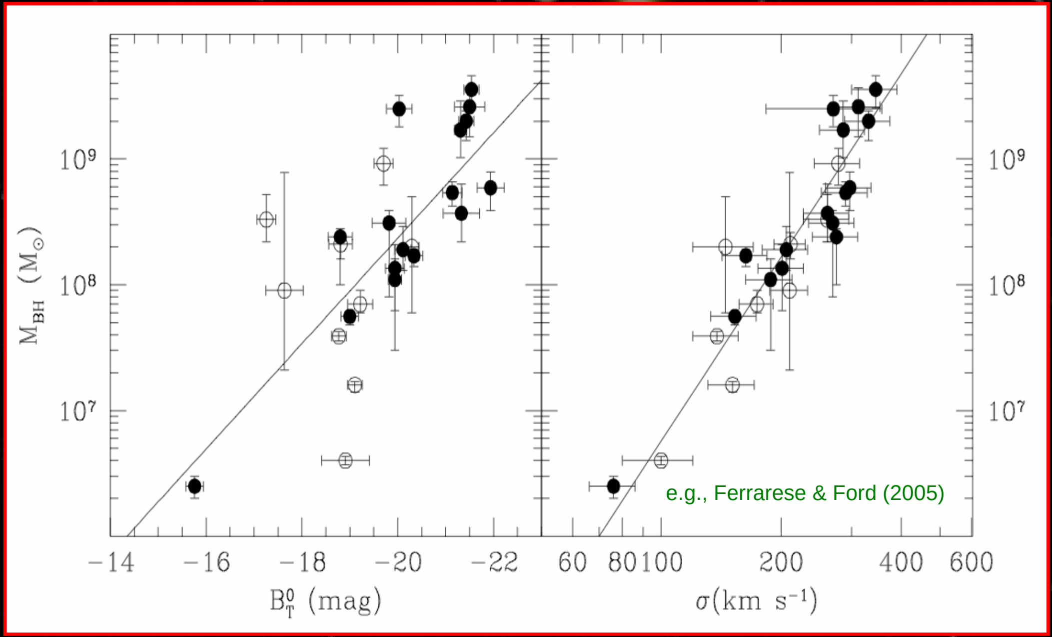
Suggests the underlying accretion properties do not change strongly over cosmic time.

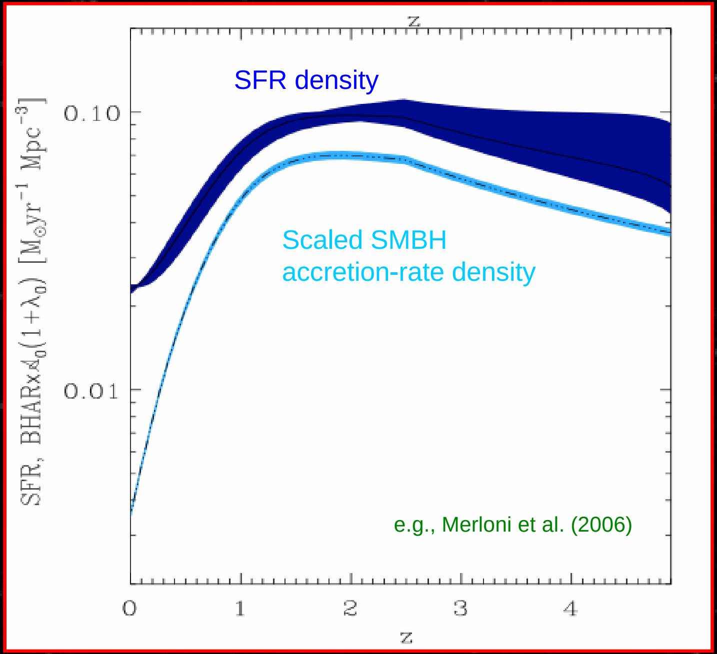
But there is still some debate, so tighter constraints needed from improved samples.

Need to fill luminosity-redshift space optimally and study more “refined” properties.



AGN-Galaxy Connections and Feedback





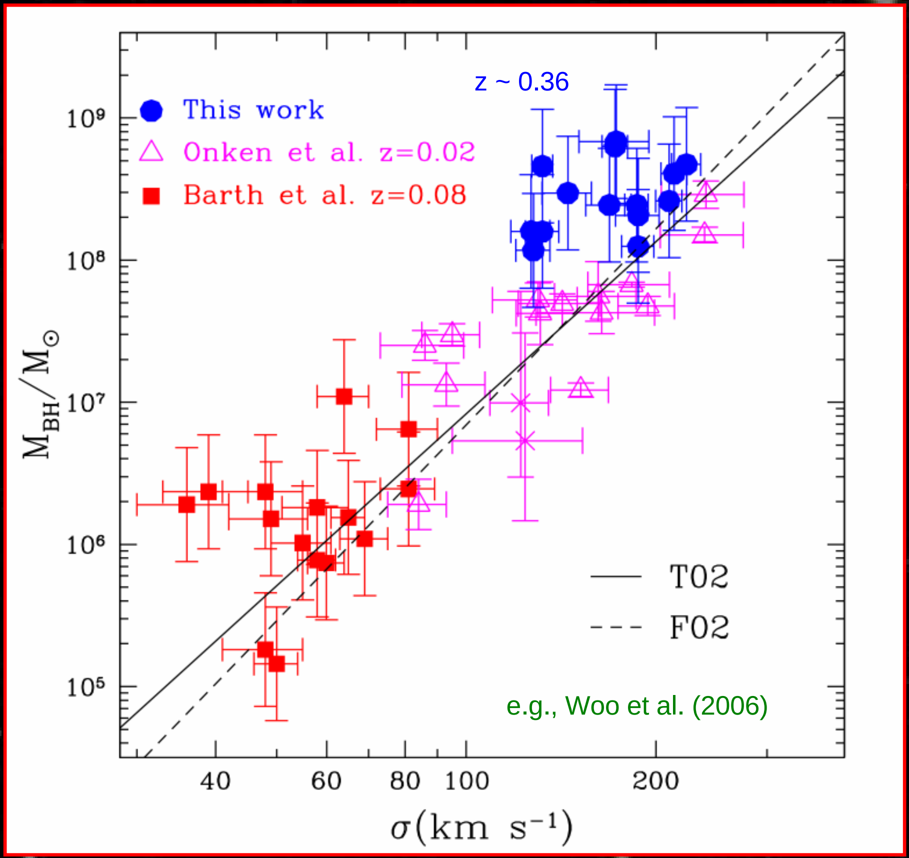
SMBH-Galaxy Relations in the Local Universe Connecting Enormously Different Size and Mass Scales

Cosmic SMBH Accretion Rate vs. Cosmic SFR

Feedback - Winds, Radiation, Jets

AGN-Galaxy Connections: SMBH-Galaxy Correlation Studies

M-σ relation for Active Galaxies



Suggestions that local M-σ relation is somewhat different for AGN vs. non-AGN – lower zero-point, shallower slope, perhaps larger scatter (e.g., Greene & Ho 2006).

Change in relation at low mass? Ongoing evolution in galaxies with currently active SMBH? BLR effect?

Evidence that M_{SMBH} / M_{Bulge} was larger in the past emerging from some observational studies (e.g., Treu et al. 2004; Peng et al. 2006; Woo et al. 2006).

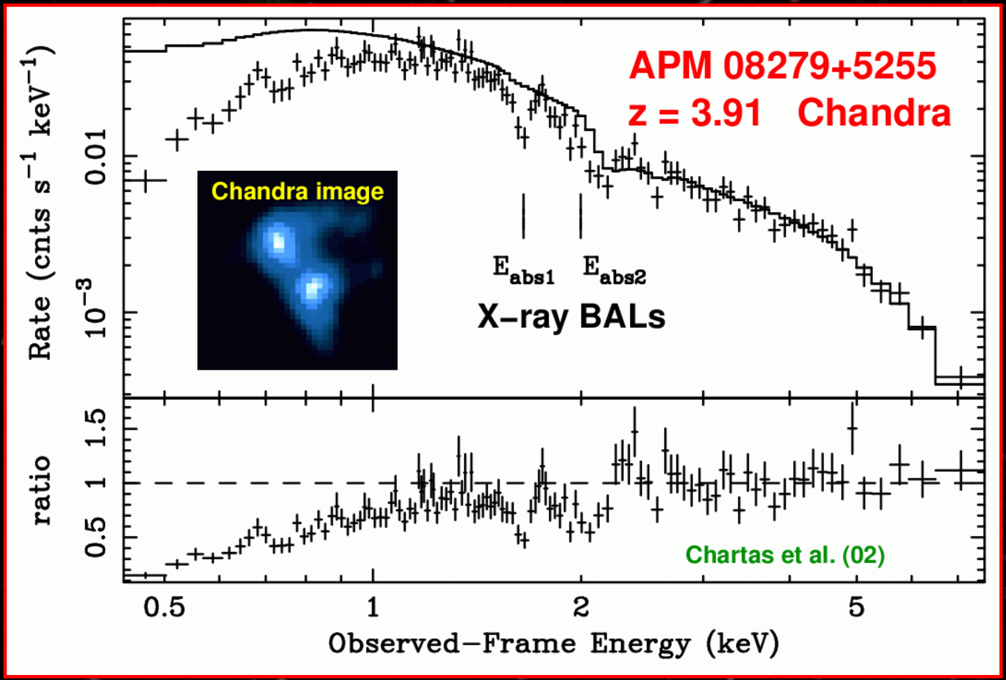
Consistent with faster drop of AGN luminosity density than SFR density (e.g., Merloni et al. 2004).

SMBH growth predates bulge assembly, at least at higher mass scales.

Better host-galaxy structural (HST) and star-formation (Spitzer) properties needed.

What fraction of dwarf AGN have classical bulges?

AGN-Galaxy Connections: Relativistic Winds Seen via X-ray BALs?



The luminous BAL quasars with the highest S/N X-ray spectra show remarkable, line-like X-ray absorption features at ~ 8-10 keV.

If due to blueshifted iron K lines, then velocities of ~ 0.1-0.3*c* implied, higher than UV velocities.

High-velocity outflow component that is too highly ionized to be seen in the UV? X-ray BALs.

Two cases of variability – weeks-to-months.

Potential to be a broadly important source of feedback, at least for massive galaxies, since majority of quasars have BAL winds. Feedback details unclear, but Di Matteo et al. (2005) argue can make M-σ relation.

Outflow efficiencies plausibly 10-20% L_{Bol}. Enough for significant feedback upon host galaxy and SMBH fueling, and higher than for local Seyfert galaxies. Luminosity dependence?

Need higher S/N X-ray spectra to test X-ray BAL interpretation and refine constraints, and also should enlarge sample of BAL quasars with sufficient-quality data.

AGN-Galaxy Connections: Radio "Bubbles" in Clusters

AGN jets commonly evacuate bubbles in the ICM filled with relativistic plasma and magnetic fields.

Buoyancy forces cause bubbles to rise in ICM, during which time they remain remarkably intact. Deposits energy and mag. fields into cluster.

Such feedback has the potential to fix the "missing cooling-flow problem" in clusters, limiting the growth of the brightest cluster galaxy.

Feedback details unclear – if bubbles transport most of the jet energy beyond the core, hard to solve the cooling problem.

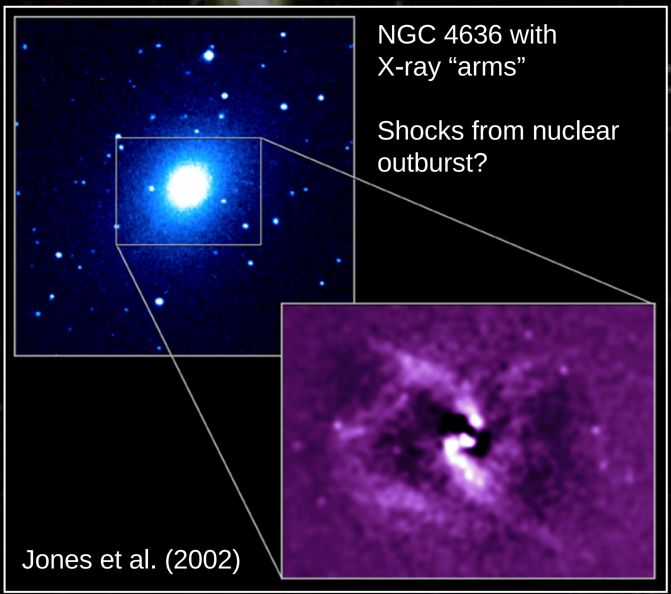
PdV work of bubble creation with viscosity? Weak shocks? Rising and sinking motions? Sound waves?

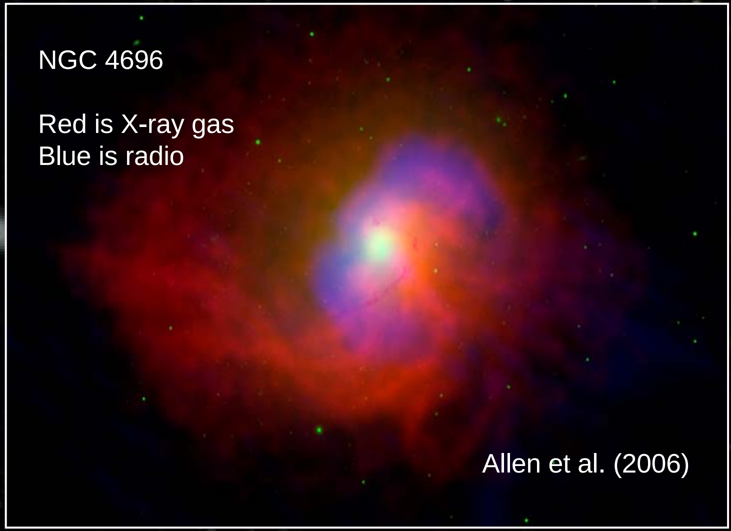
Great Observatories can help with

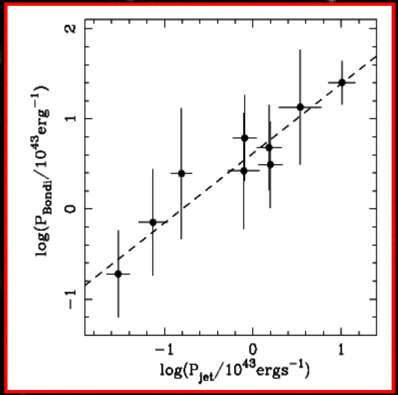
- More deep X-ray observations of cluster feedback
- Studies of cool / warm gas and dust around brightest cluster galaxies
- Larger samples of clusters with strong radio-jet feedback

Also study a few clusters with (relatively) radio-quiet quasars, to see if wind feedback on the ICM can be detected.

AGN-Galaxy Connections: Jet Feedback in Elliptical Galaxies







Many ellipticals have comparably bad “missing cooling-flow problems” to clusters.

Clear evidence for AGN feedback due to shocks (episodic nuclear outbursts?) and jets.

How does the episodic AGN feedback cycle work? Dominance of jets at low L / L_{Edd}?

Larger samples of AGN ellipticals with high-quality X-ray data on feedback and tight constraints on cold / warm nuclear gas.

Top 3 Science Priorities for the Great Observatories

Complete AGN census in variety of environments, with optimal overlap of Spitzer + Chandra + HST.

Feedback in action for the majority of AGN - winds, radiation, jets?

Nature of the obscuring material on 0.01-1 pc scales.

Notably missing - How accretion works in the black hole region at < 50 R_S.