# Who Am I

- Staff member at NASA's Goddard Space Flight Center since 1977 and a U of MD professor since October 2009
- worked on over 10 space astronomy missions (OSO-7, OSO-8, HEAO-1, Einstein, BBXRT, ASCA, XMM, Chandra, Suzaku, Swift etc) focusing on high energy astrophysics (x-ray astronomy)
- I have been the thesis advisor for 12 graduate students (11 at U of MD) and numerous post-doctoral fellows
- a member of the Astro-H science working group (a new space observatory in collaboration with Japan)
- Chair of Admission Committee


**For astrophysics research !**

# The Team

- At the University of Maryland my team consists of 2 post-doctoral fellows
  - Ranjan Vasudevan- AGN
  - Marcio Melendez- IR spectroscopy and imaging

- One researcher (sort of in residence)

  Rick Edelson- timing of AGN

We are also collaborating with Chris Reynolds group on AGN related science

For ULXs Neal Miller is leading the radio work

At GSFC I am collaborating with

Astro-H hardware team (Rich Kelley)

Dave Davis, Mike Loewenstein- clusters of galaxies

Todd Strohmayer  ULXs

# What are the major topics I have worked on 'lately'

(Graduate student involvement in red)

Nature of Ultra-Luminous X-ray Sources

X-ray Surveys (L. Trouille, Y. Yang)

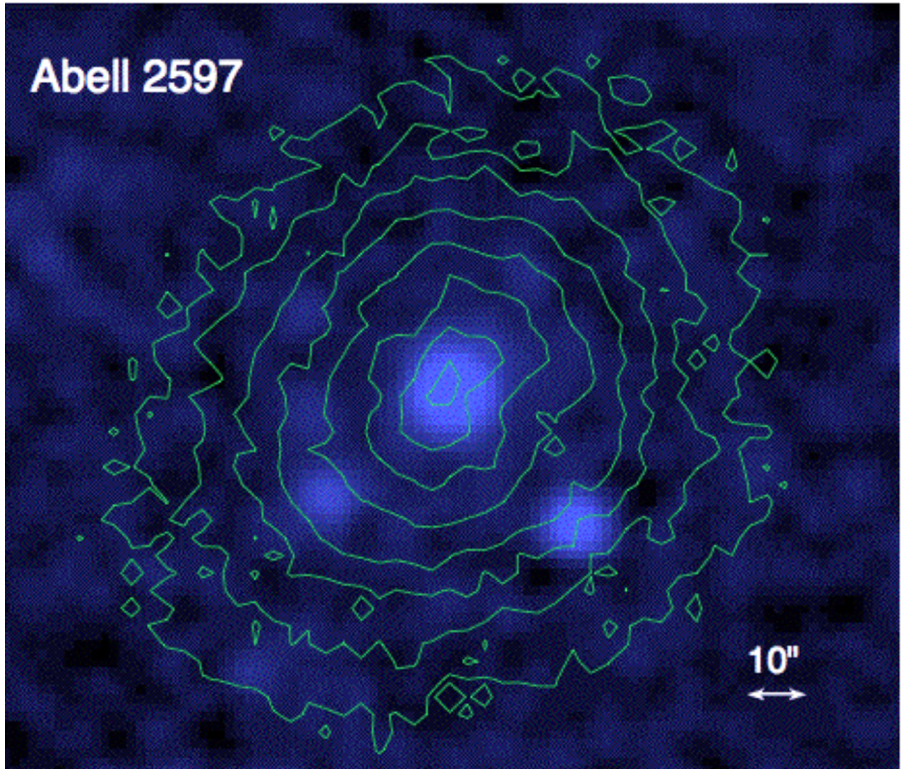
Nature of Hard X-ray Selected AGN (M. Koss)

Star Formation in Cooling Flow Clusters (M. McDonald, M Hicks)

Chemical Abundances in Clusters of Galaxies

Mass and entropy profiles of clusters (Jithin George)

Emission lines in cooling flow clusters (with M. McDonald)




Galex UV image of central Galaxy of Abell 2597 with x-ray contours overlaid

UV image is direct evidence For star formation (Hicks et al 2010- former graduate student research program fellow at GSFC)

# Where are they now? Former students in the x-ray group ( RM students)

| | | |
|---|---|---|
| Wayne Baumgartner | Univ of MD | Member Swift team at GSFC |
| David Davis | Univ. of MD | Fermi Science Center UMBC/GSFC |
| Mark Henriksen | Univ. of MD | UMBC- Professor |
| Don Horner | Univ of MD | Fermi Science Center |
| Mike Koss | Univ of MD | Univ of Hawaii post-doc |
| John McKee | Univ. of MD | Naval Weapons center |
| John Mulchaey | Univ of MD | Carnegie Observatories – staff member |
| Allyn Tennant | Univ. of MD | NASA/Marshall – staff member |
| Megan Urry | J. Hopkins U. | Yale University Professor (first woman in the physics dept) |
| Kim Weaver | Univ. of MD | NASA/Goddard staff member |
| Lisa Winter | Univ of MD | Hubble fellow at U of Colorado |
| Yuxuan Yang | Univ of MD | Post doc at U of Illinois |

Present students

| | |
|---|---|
| Jithin George | Univ of MD |
| Taro Shimizu | |

"Other" graduate students worked with in last 4 years

| | |
|---|---|
| Amelia Hicks (U of Colorado) | Marcio Melendez (Catholic Univ) |
| Laura Trouille ( U of Wisconsin) | Marco Ajello (Max Planck Garching) |
| Ranjan Vasudevan (Cambridge Univ) | |

# Galaxies, Groups and Clusters of Galaxies

(M. Loewenstein, K. Arnaud, D. Davis- U of Md research scientists and Eric Miller MIT)

Largest structures in the universe

Enriched in heavy elements-easily visible via x-ray spectroscopy

Evolution is a strong function of cosmology

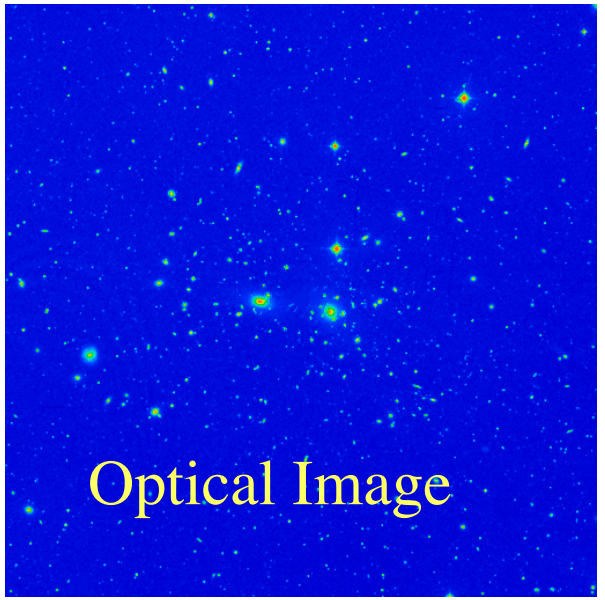
Most of baryonic mass and metals is in x-ray emitting gas

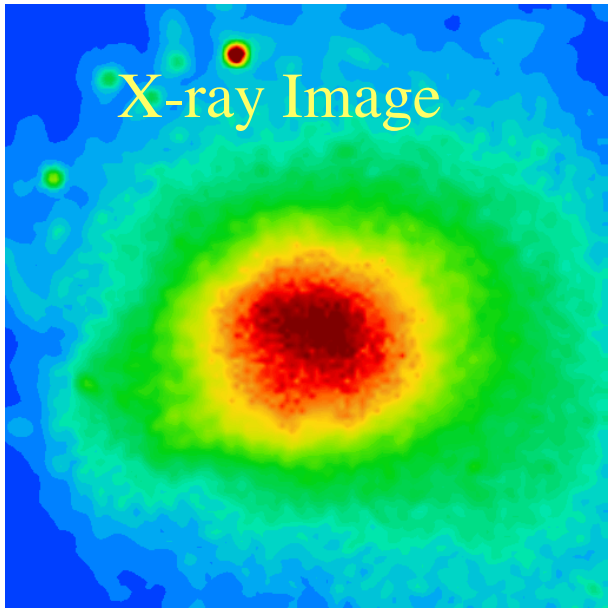
Measure integrated history of metal creation in universe

Directly measure dark matter distribution

(Last 2 Maryland PhD thesis on large survey of cluster temperatures and abundances (D. Horner, Wayne Baumgartner)

One of main Astro-H science goals is study of cluster mergers, chemical abundances and cooling flows



# Black Holes Near and Far

Graduate students Lisa Winter (graduated in 8/2008- Hubble Fellow at at Univ of Colorado),

Mike Koss graduated 7/2011

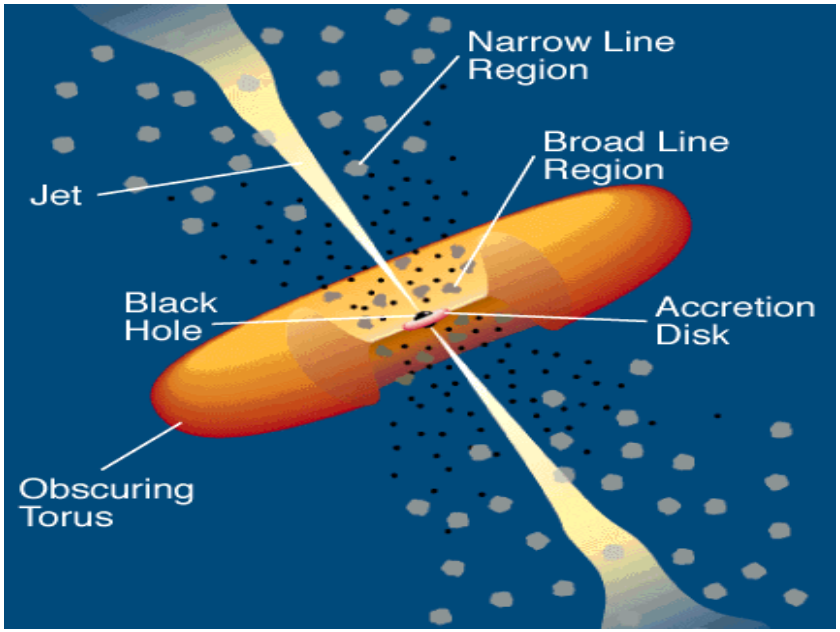
Galactic and extra-galactic black holes(AGN) including the mysterious Intermediate Mass black holes

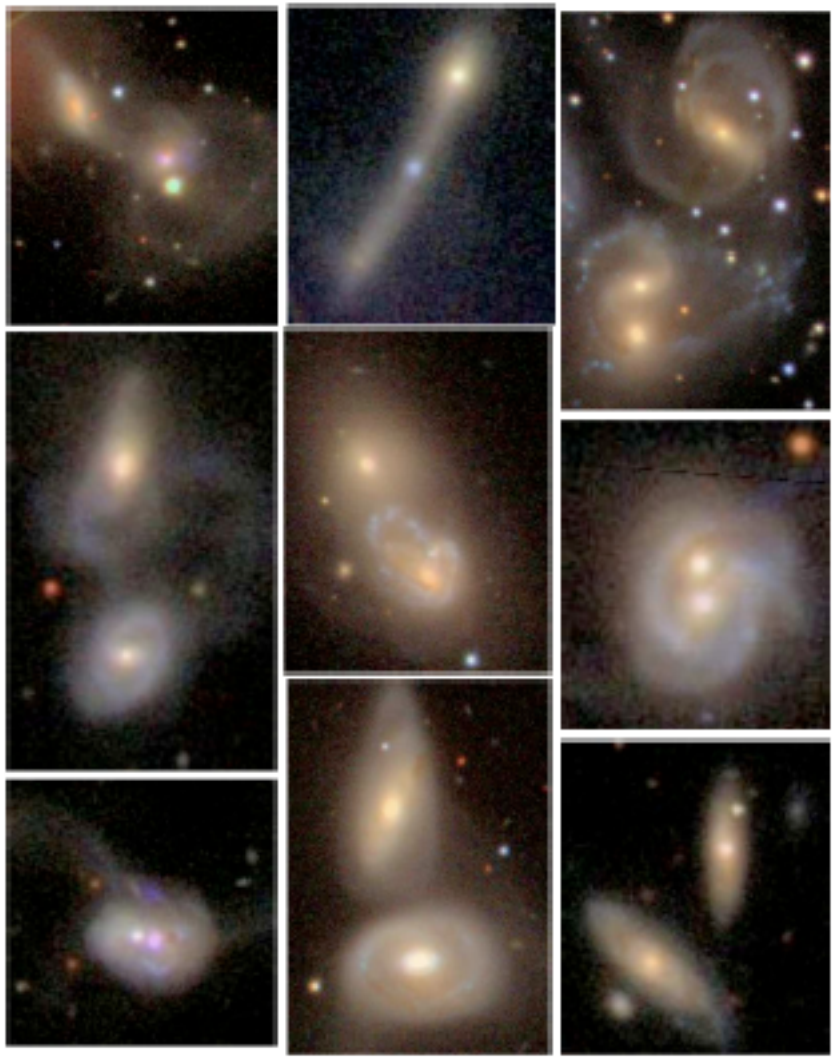
How they work and how they influence the universe

Physics of accretion, nature or region near black hole

Analysis of x-ray timing and spectral behavior and multi-wavelength observations (collaborators in Hawaii, U of Wisconsin, Catholic U, Georgia State…)

Swift, Chandra, Suzaku, XMM, Spitzer

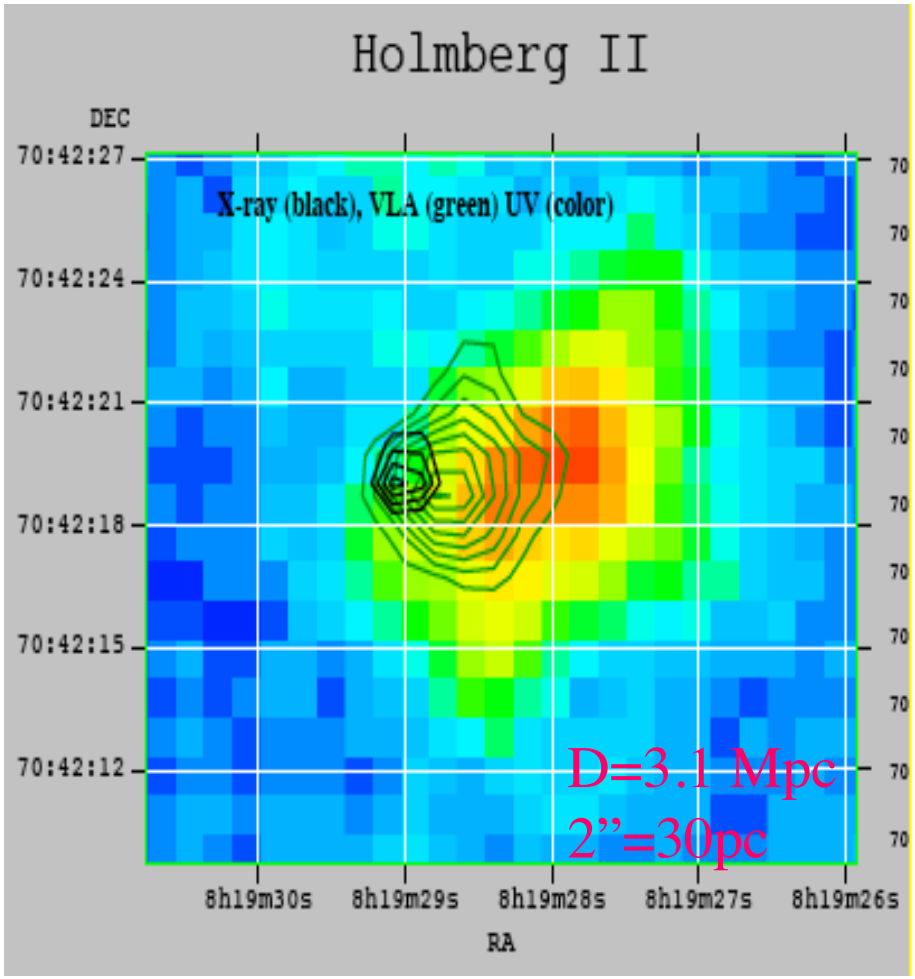


# ULXs

- ULXs are the most luminous non-nuclear sources
- Discovered via x-ray observations
- Have unusual optical properties as well (large ionized nebulae around them)
- Radio properties poorly studied- small sample (Miller et al 2005)- Neal Miller U of Md research scientist
- Collaboration with Todd Strohmayer (GSFC)
- I was organizer on a meeting on these objects held in Spain May 2010

Chandra VLA XMM UV and



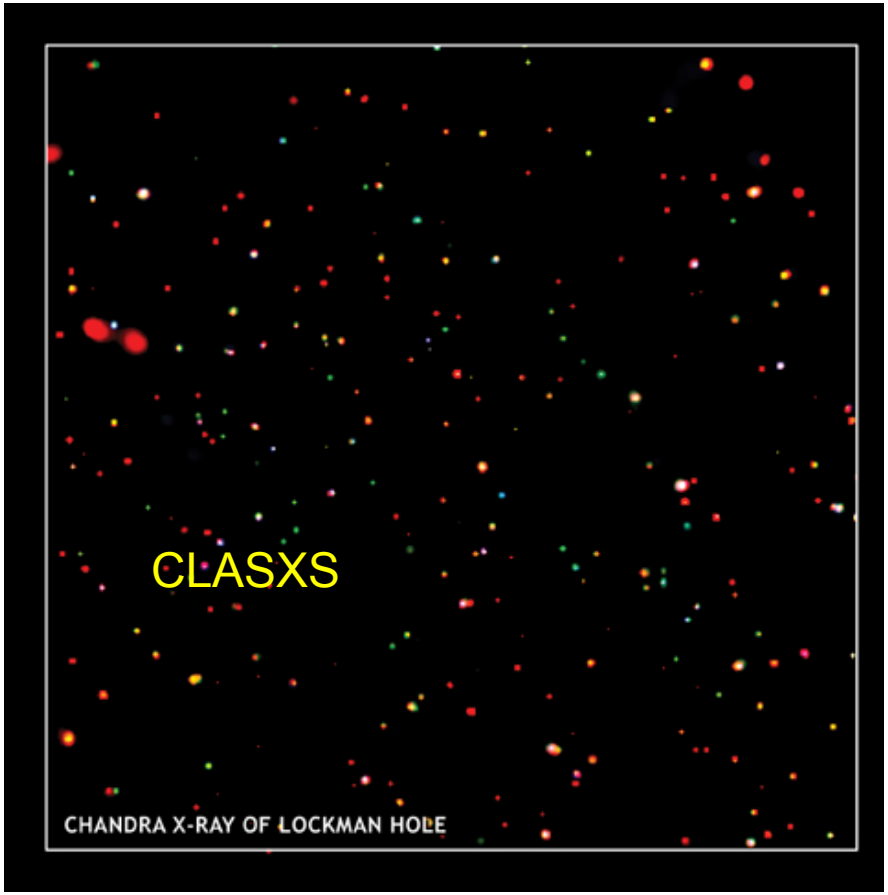

Ratio of radio to x-ray ~$5 \times 10^{-6}$

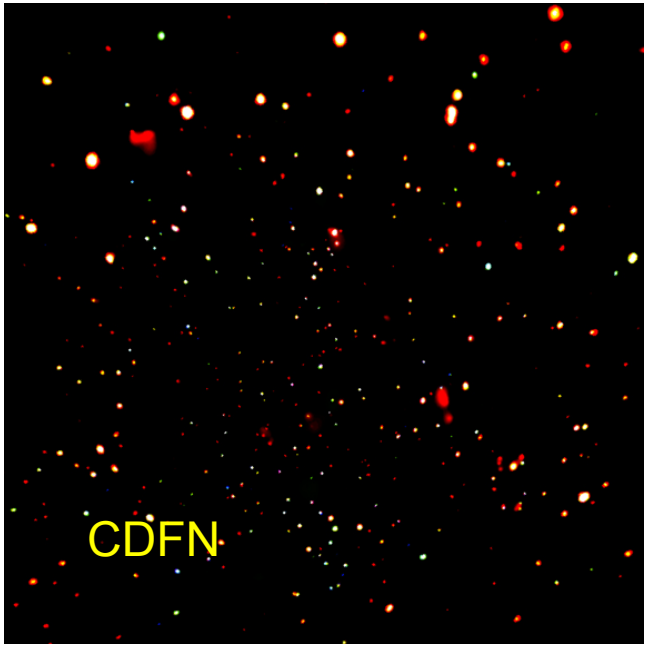
Chandra X-ray Surveys- each dot is an AGN, red blobs are clusters of galaxies

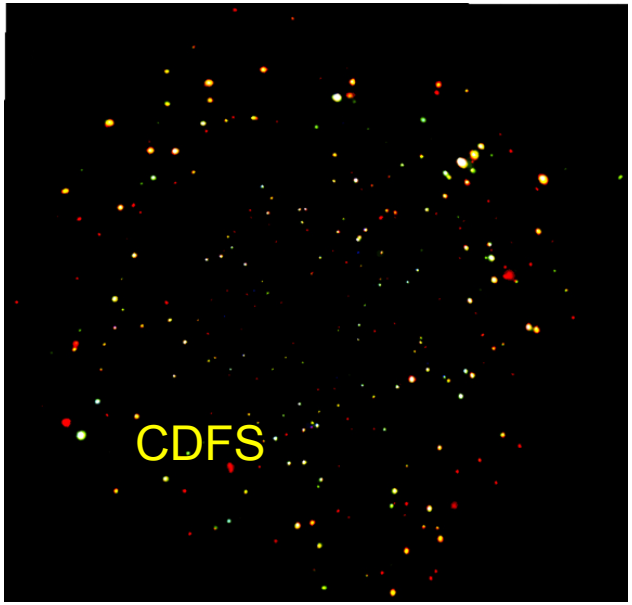
Project resulted in 3 thesis's

A. Steffen and L. Trouille (Wisconsin)

Y. Yang Maryland



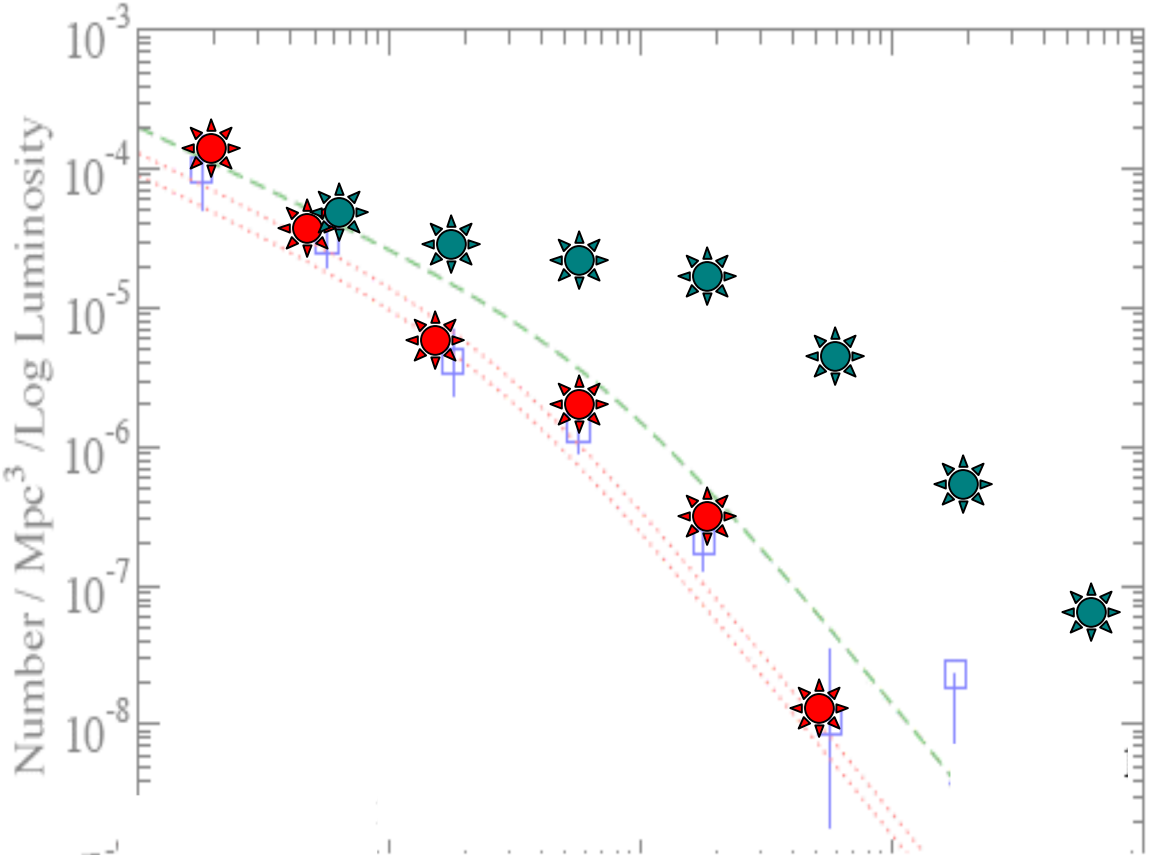




Deep Chandra images

# Form of Evolution

- the largest uniform compilation of x-ray and optical data
- form of the luminosity function changes but that the number of very low L AGN remains the same.
- incomplete (esp amongst non-broad line objects) at z>3

L. Trouille thesis
U of Wisconsin



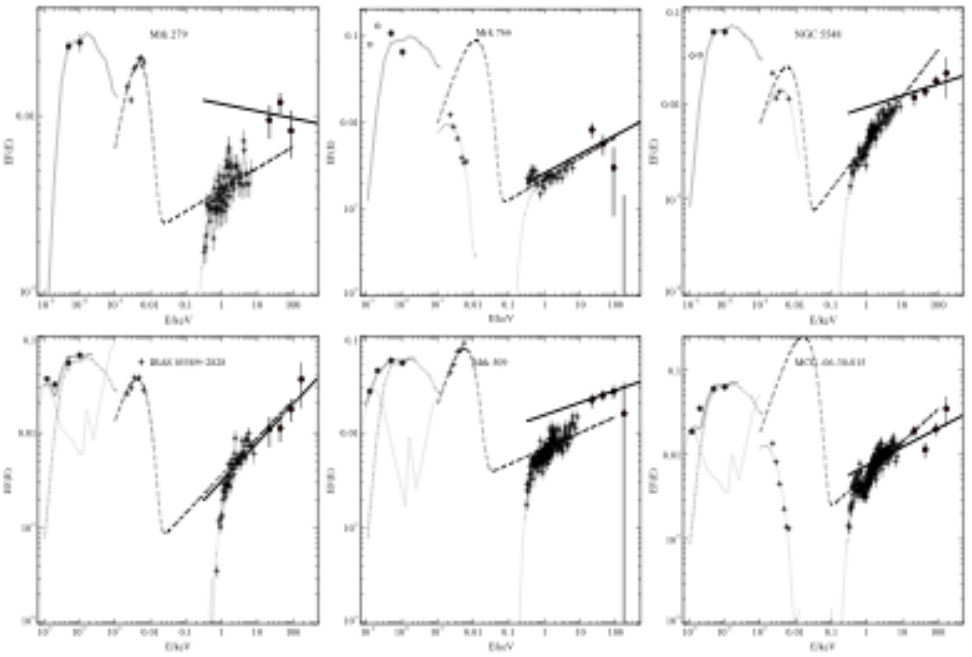

•Comparison of f(L) at 2 redshifts

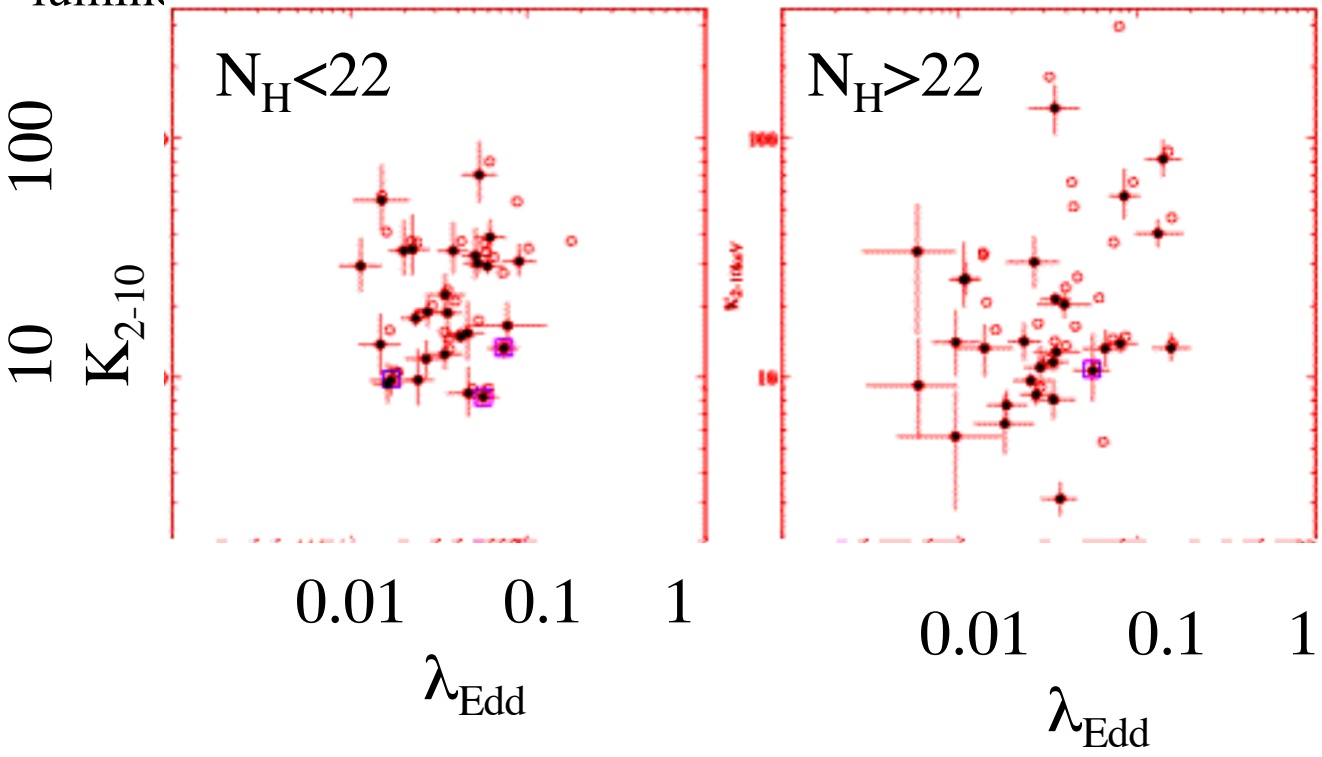
Z=0 Z=1.5-3

# Broad Band Spectral Energy Distributions

- Use of Swift BAT sample and simultaneous optical/UV data allow direct measurement of bolometric correction (Vasudevan et al 2009)

  $\kappa_{2\text{-}10}$ is the relation between the absorption corrected 2-10 kev luminosity and the bolometric luminosity

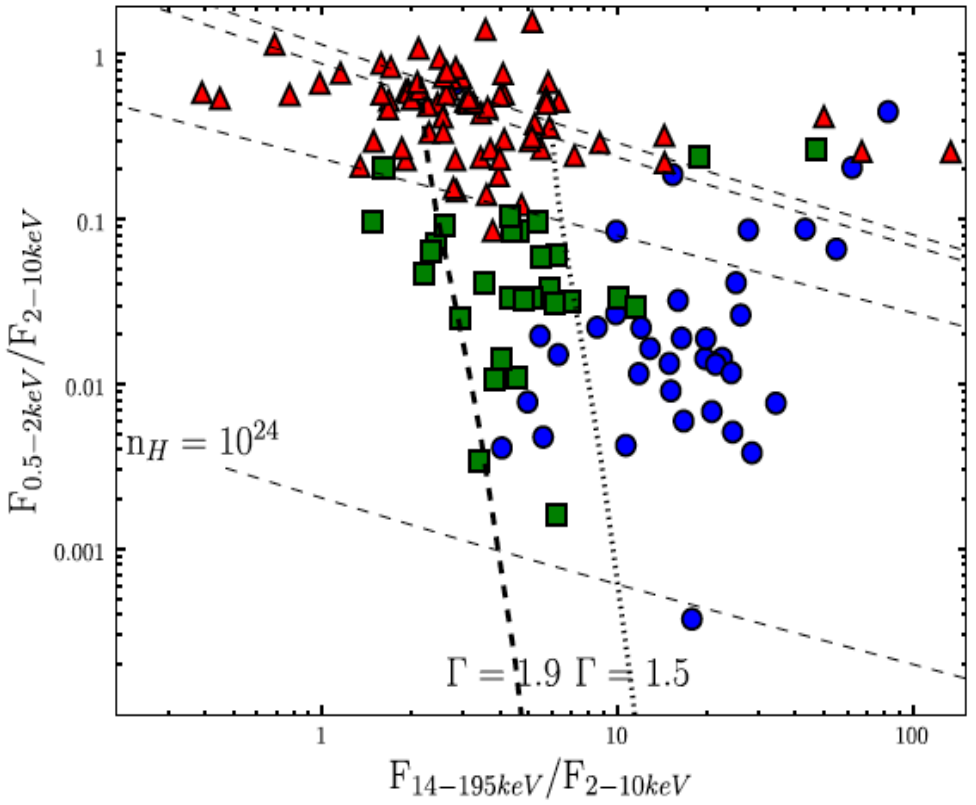


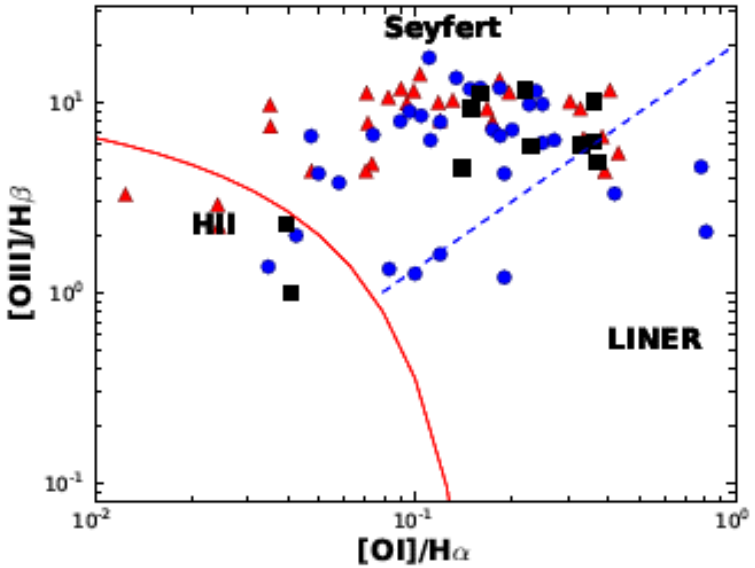



R. Vasudevan thesis Cambridge Univ

# X-ray and Optical Properties of Hard X-ray Selected AGN- **L Winter Thesis**

- We now know that most AGN are 'obscured' (that is there are large column densities of dust and gas between us and the black hole, which 'hides' the AGN in the UV, optical and soft x-ray)
- Thus a 'hard' x-ray survey is necessary to find and count 'all' the AGN.



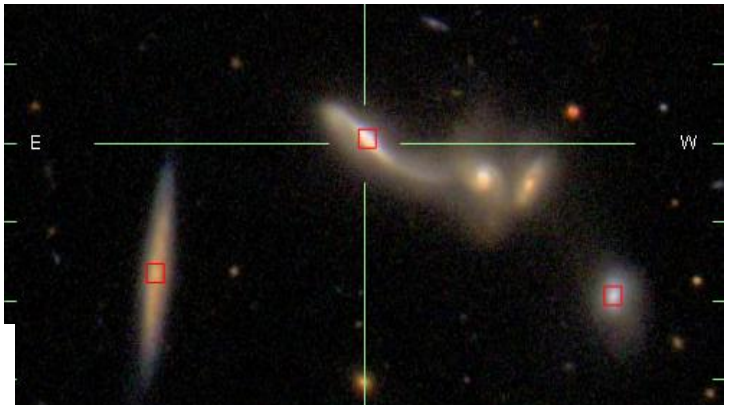



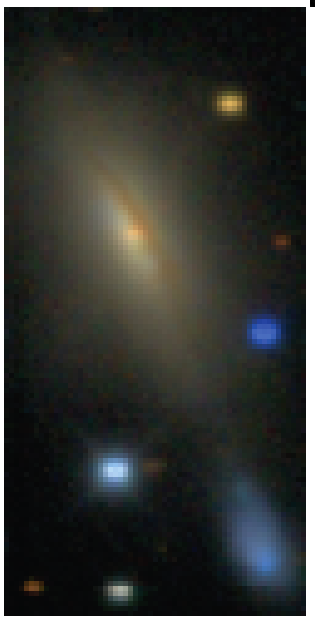

Notice that some broad line objects ▲ have narrow line ratios in the "non-AGN" part of the diagram

# The Nature of AGN Hosts-

## M Koss thesis

- Theory - AGN strongly influences galaxy formation - BAT sample perfect for testing this idea
- The BAT sample - hosts of most AGN are spiral and irregular galaxies > 30% involved in major mergers or interactions ( ~2% for 'normal' galaxies Jogee et al 2009)
- The 'colors' of the hosts are mid-way between that of 'red' and dead galaxies and active star forming galaxies
  - Chandra/XMM selected AGN at z~1 hosts are luminous red

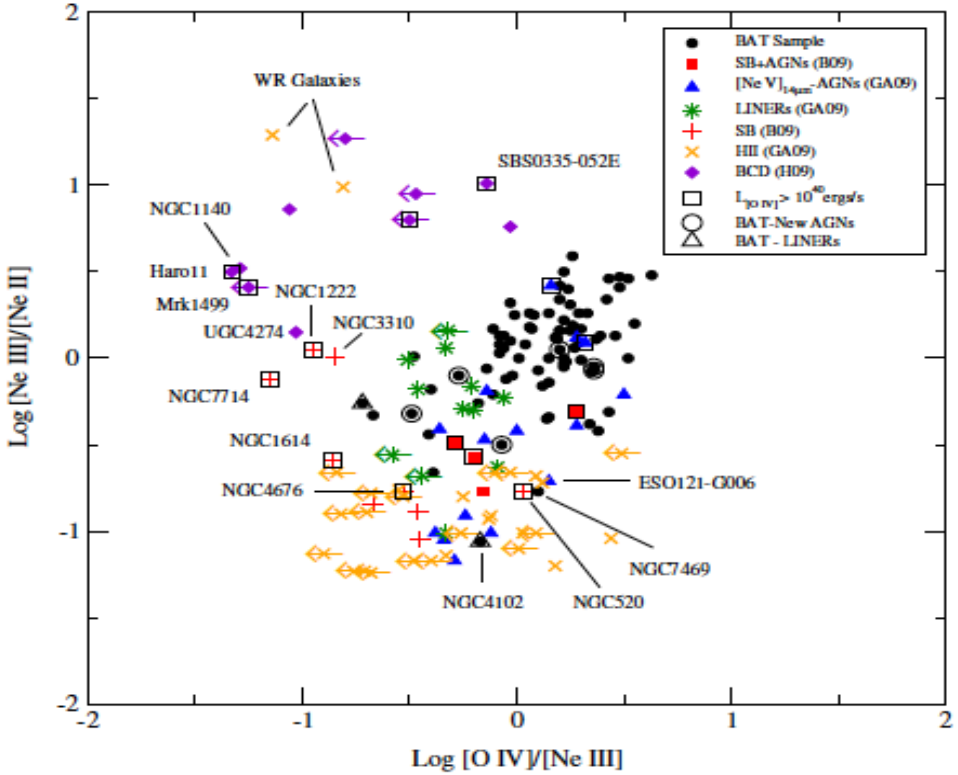


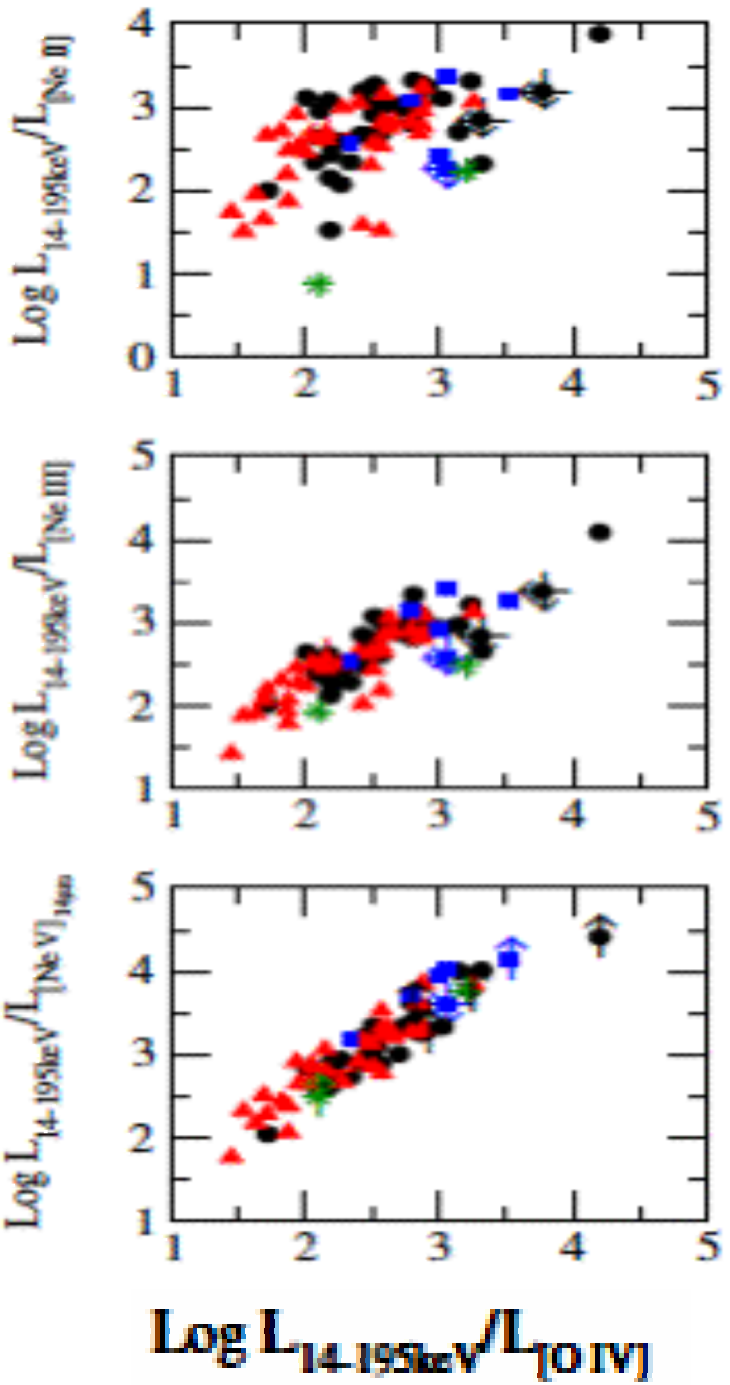



Some of the optical images of interacting galaxies from the BAT sample

# IR Spectra of Harx X-ray selected AGN-
## M. Melendez thesis Catholic U

- Spitzer IR spectra of BAT AGN show a strong relationship between OIV and hard x-rays
- Allows development of 'new' AGN diagnostics
- Identification of 'Compton thick' sources

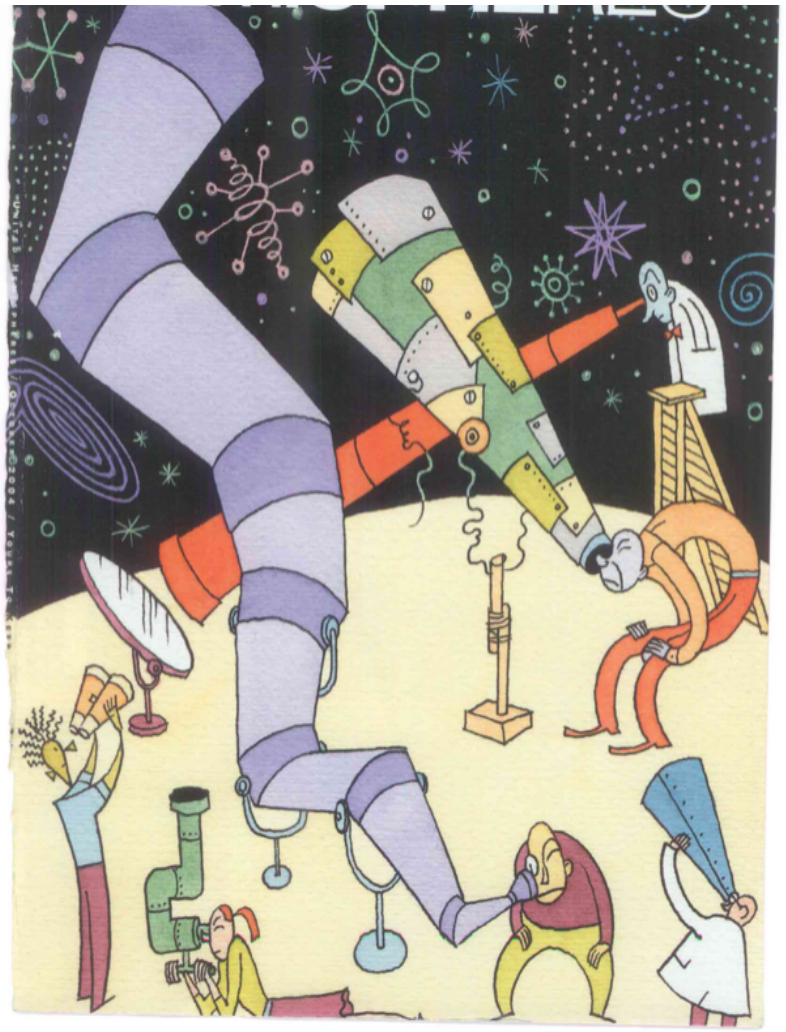


# Some Possible Projects

- Chandra and XMM high spectral resolution data for AGN and star forming galaxies
- Search for the IR counterparts of ULXs with archival Spitzer data
- Radio observations of the Swift BAT hard x-ray sources
- Analysis of the x-ray colors of the Swift AGN vs time
- Radio observations of ULXs

- <u>Proposals accepted last year</u>
  - Kepler Monitoring of the optical flux of x-ray selected AGN
  - Herschel observations of the IR emission from 300 hard x-ray selected AGN
  - Chandra observations of 12 merging AGN galaxies
  - Swift and Suzkaku monitoring of Zw229



We use a wide range of telescopes

**20 papers in the last 5 years with > 50 citations**

Awards and Other Distinctions

NASA Medal for Exceptional Scientific Achievement, 1983
GFSC Lindsay Award, for Scientific Achievement 1985
NASA Medal for Exceptional Achievement 2000
GSFC Senior Fellow 2000
ISI Highly Cited Scientist 2001
NASA Medal for Exceptional Scientific Achievement 2003
Member Astro2010 Science Panel
Robert H. Goddard Award of Merit 2010
NASA Distinguished Service Award 2011

# Extra Slides

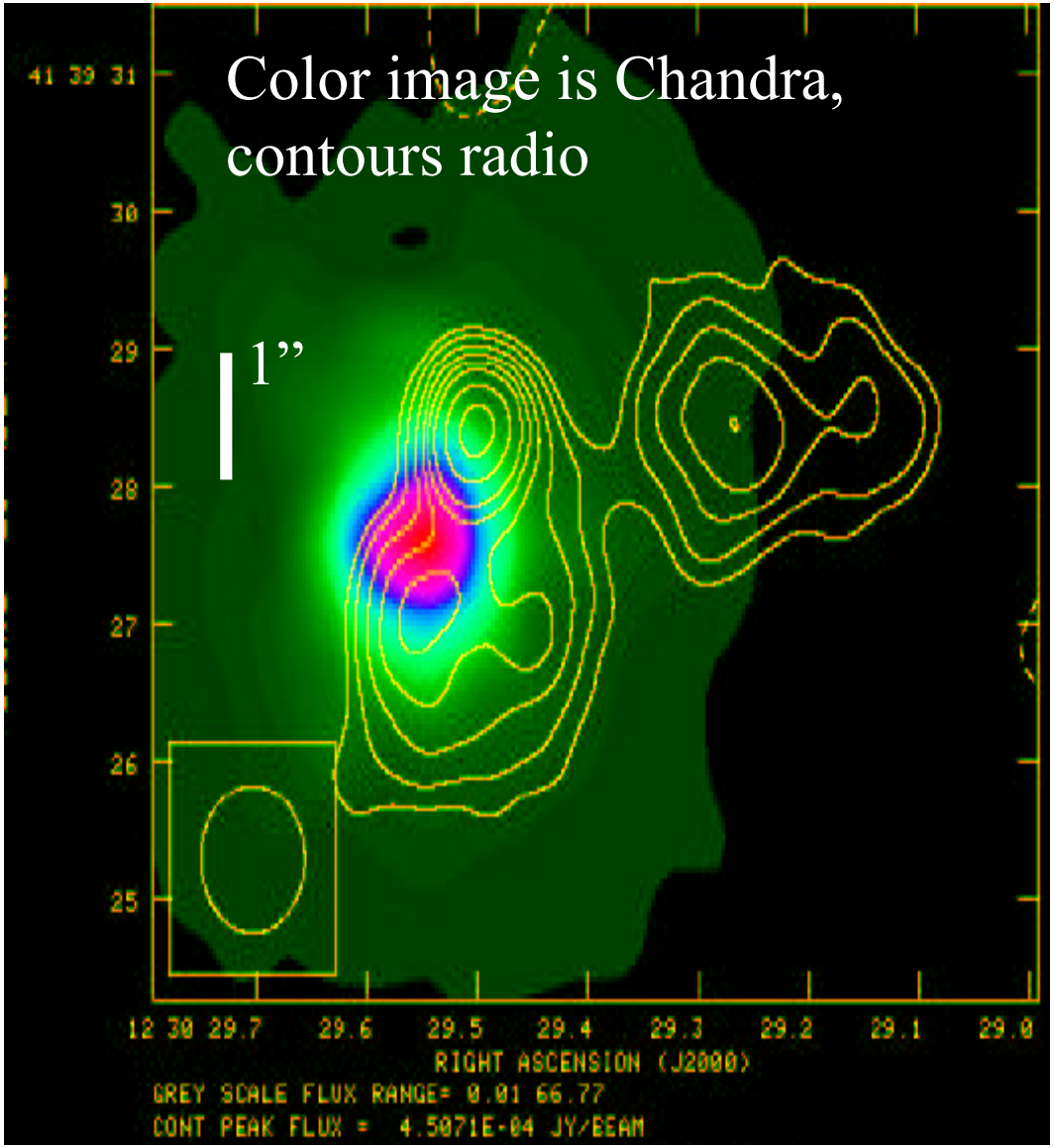
# Radio Observations of ULXs-NGC4490

- NGC4490 (D=8 Mpc 1”=39 pc) radio image with the VLA is coincident with the Chandra source (+/-0.5”)
  - source resolved 2x.4” at 4.86 Ghz about 75x150pc
  - Spectral index is flat -0.13+/-0.35
  - Flux is ~3mJy or 15x Cas-A

X-ray flux varies between Chandra and XMM epochs;

Chandra L(x) ~$8 \times 10^{38}$

~ULX inside an extended radio source-

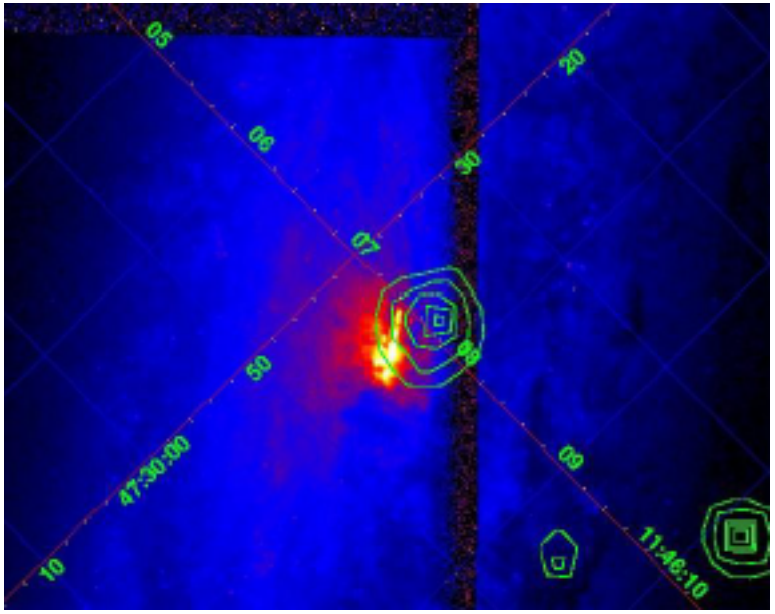


# Radio Observations of ULXs-NGC3877

- NGC3877 (D=17 Mpc 1"=83 pc)

VLA source exactly coincident with Chandra source (+/-0.5")

  - source resolved 2x.4" at 4.86 Ghz and smaller at 1.4Ghz -150x300pc (!)
  - Spectral index is flat -0.13+/-0.35
  - Flux is ~3mJy or 80x Cas-A

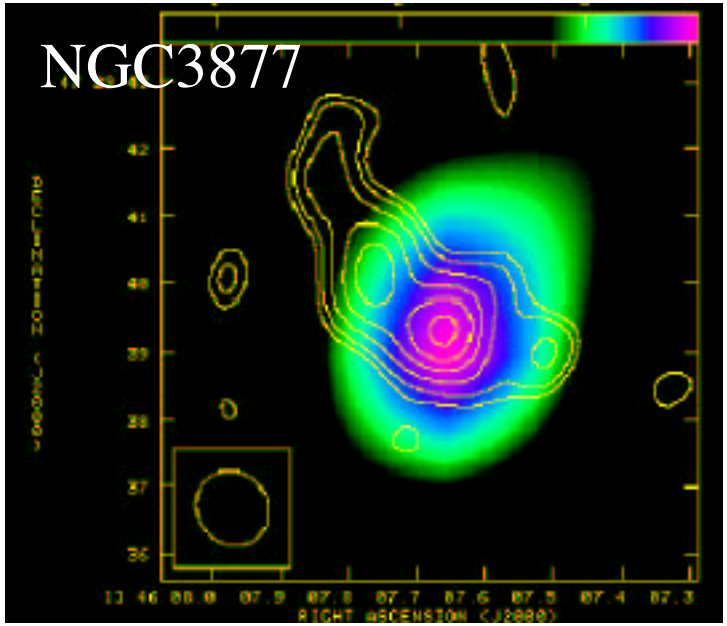


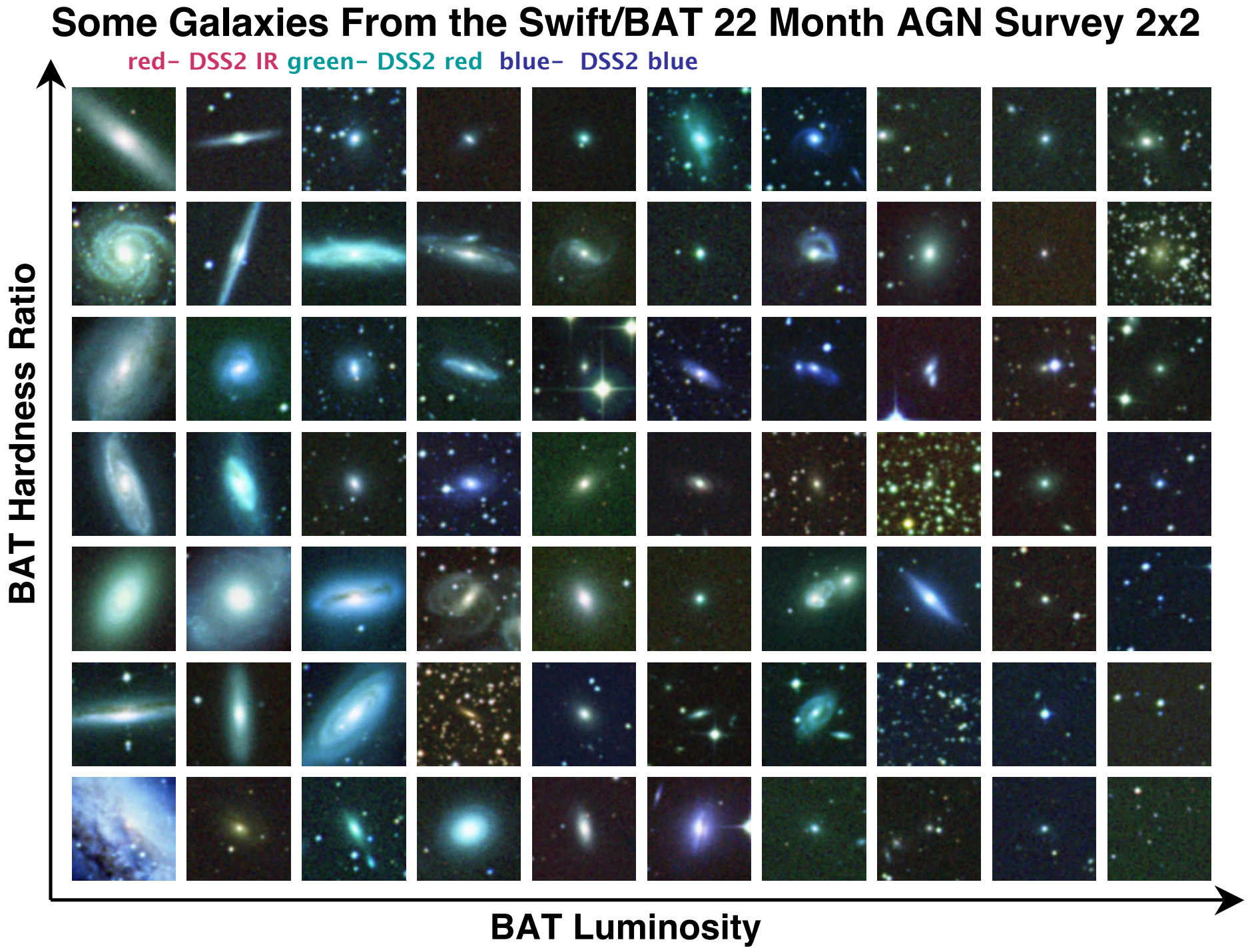

~7" away from optical nucleus -5 Chandra observations - nothing obvious in HST images

Chandra L(x) ~$6 \times 10^{38}$

Sub-luminous ULX inside an extended radio source

Miller are now analyzing the set of radio data obtaining images, spectra ; as Chandra and XMM data go public sample will increase.
Archival VLA data of very variable quality- new observations are needed
Some are bright enough for VLBI




Some Galaxies From the Swift/BAT 22 Month AGN Survey 2x2
red- DSS2 IR green- DSS2 red blue- DSS2 blue
BAT Hardness Ratio
BAT Luminosity

# Comparison of dark matter and x-ray cluster and group distribution

- Groups of galaxies

D. Davis, K.Arnaud

Extensive x-ray and optical data

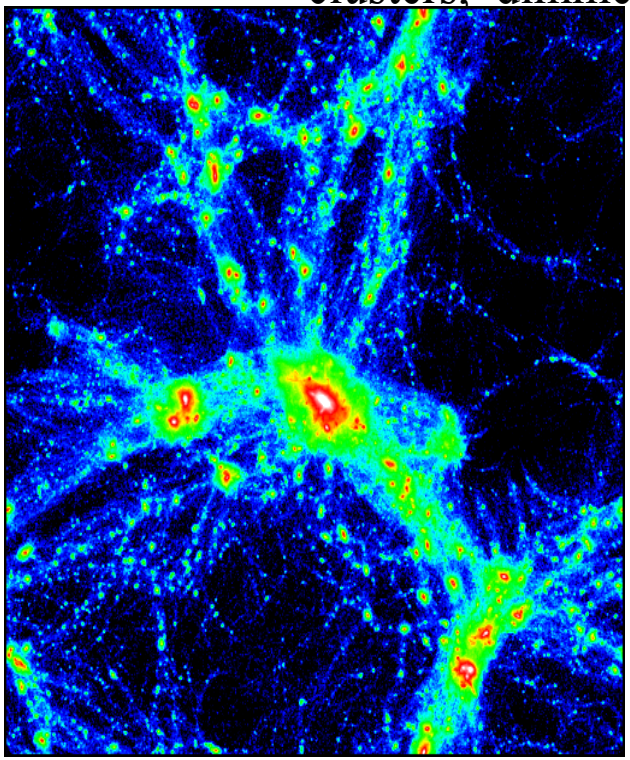
Groups are the "average" place in the universe- most galaxies live in groups

X-ray emitting gas probes the dark matter potential well- derive masses of groups

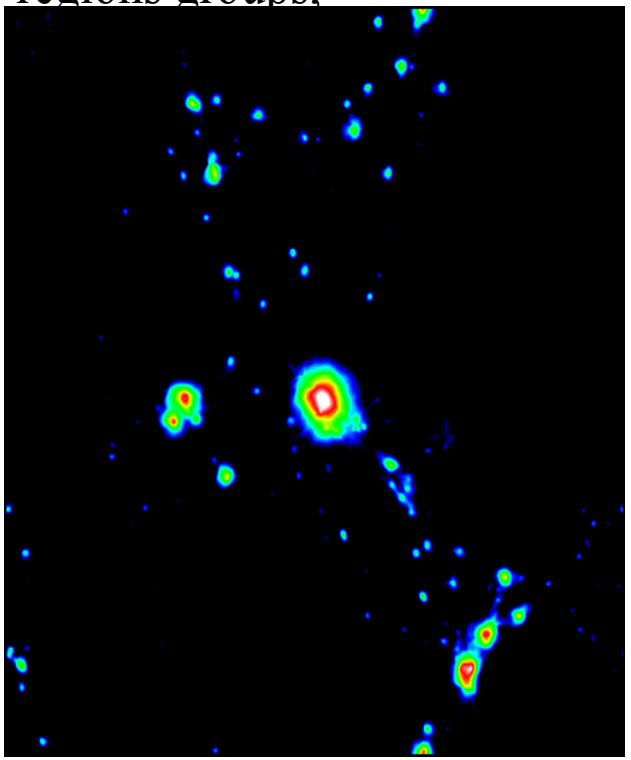
Chemical composition- and entropy ; direct signature of feedback

(former Maryland student John Mulchaey)

every bound system visible in the numerical simulation is detected in the x-ray band - bright regions are massive clusters, dimmer regions groups.



Dark matter simulation

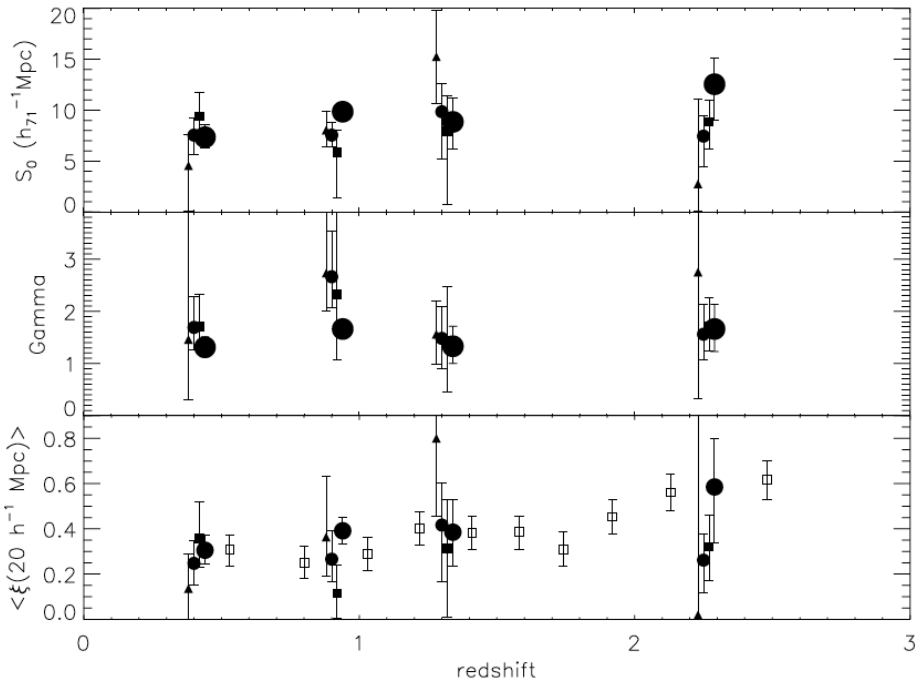


X-ray emission in simulation

Small square: CLASXS; Small triangle: SWIRE-LH;
Small Dot: LH-NW 2 fields; Large Dot: All 4 Chandra fields;
Small boxes: 2dF/2QZ;

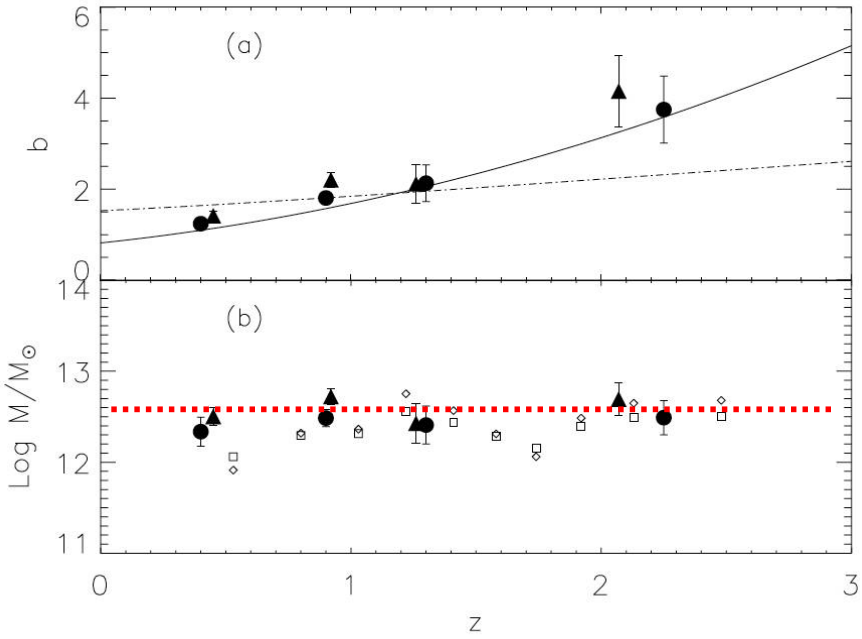
# Evolution of AGN clustering
# Y. Yang thesis

- Only mild evolution in the clustering of X-ray selected AGNs



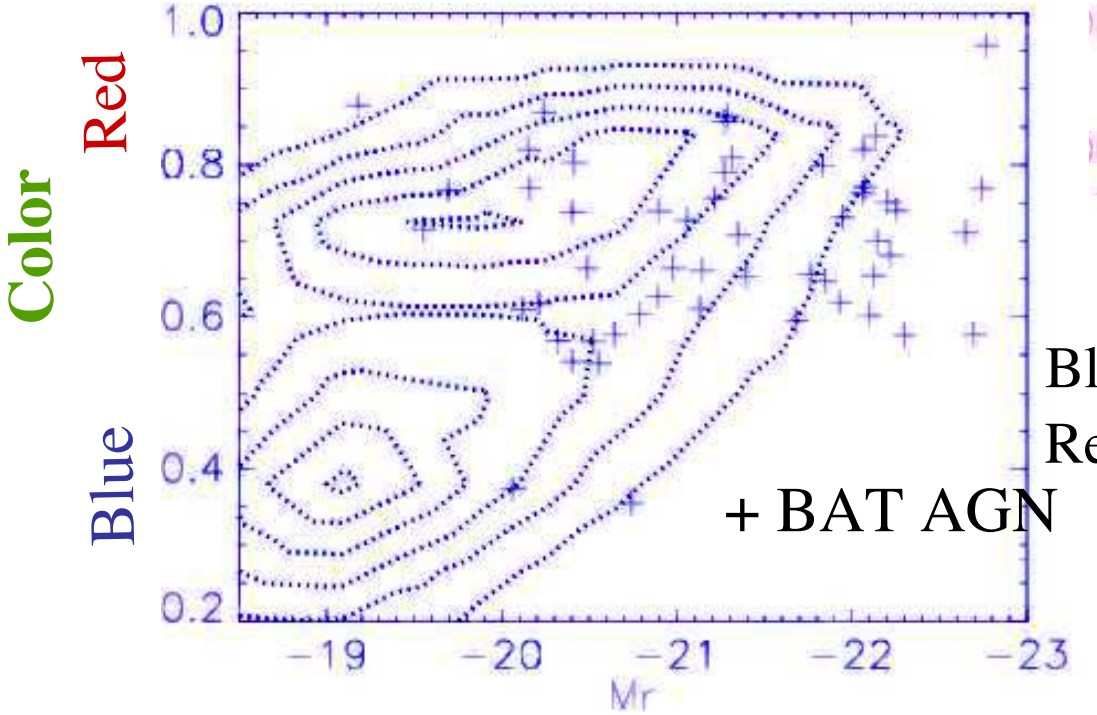

The average mass of halos which contain active galaxies does not evolve with redshift.

$$\langle M_{halo} \rangle = 2.5 \times 10^{12} M_{Sun}$$

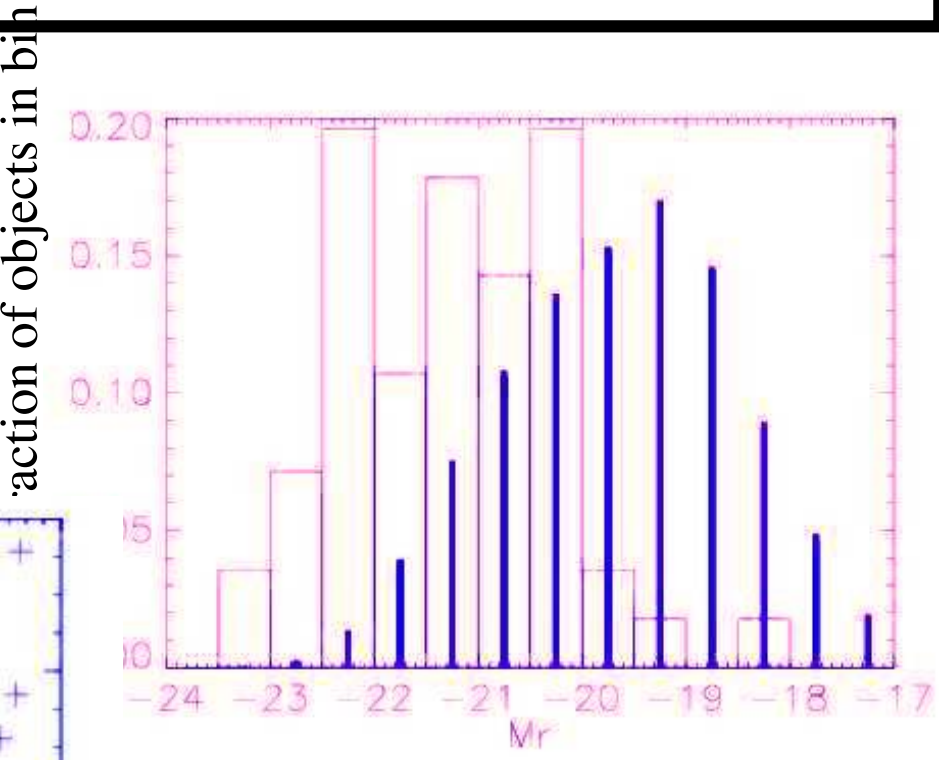


# Host Galaxies of AGN are More Luminous than Field Galaxies

- The median luminosity of BAT AGN hosts is 1.3 mag brighter than for SDSS inactive galaxies
- AGN Hosts preferentially live in 'green valley'– luminous galaxies with star formation–**Does AGN cause star formation or turn it off?- (cf. Schawinski et al 2009)**
-




+ BAT AGN



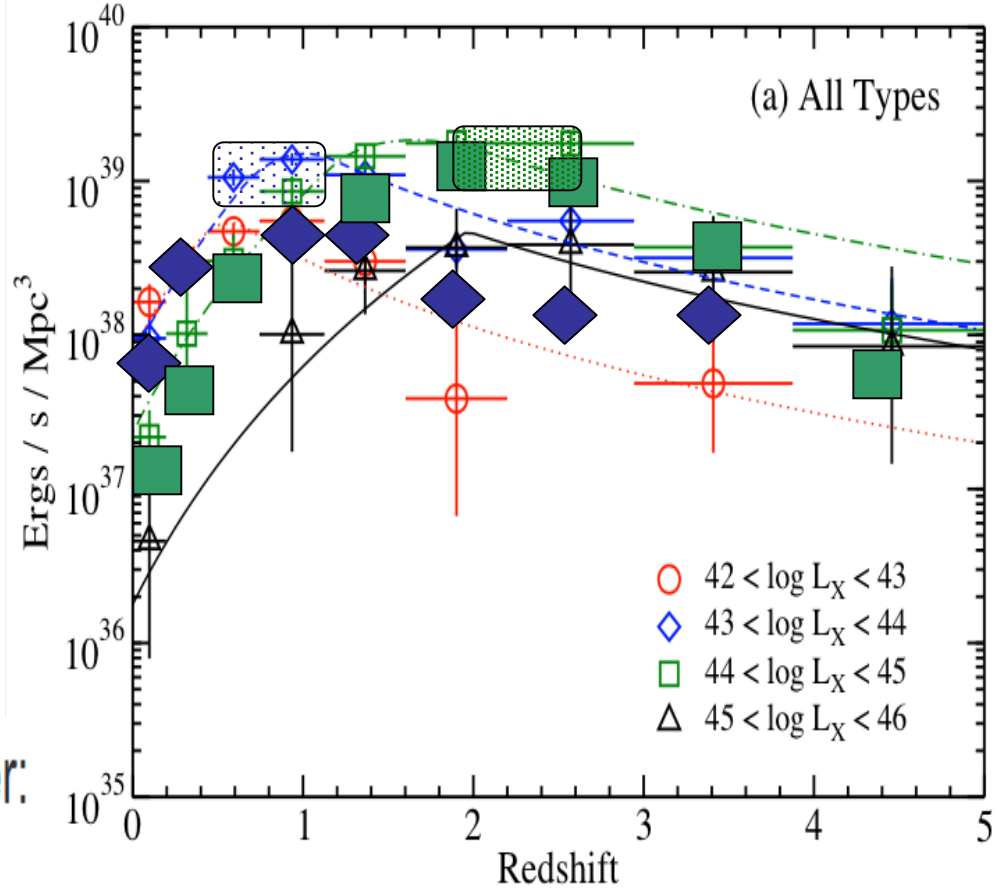

Blue line/contour - field galaxies

Red Boxes/+ AGN Hosts

Koss et al 2009

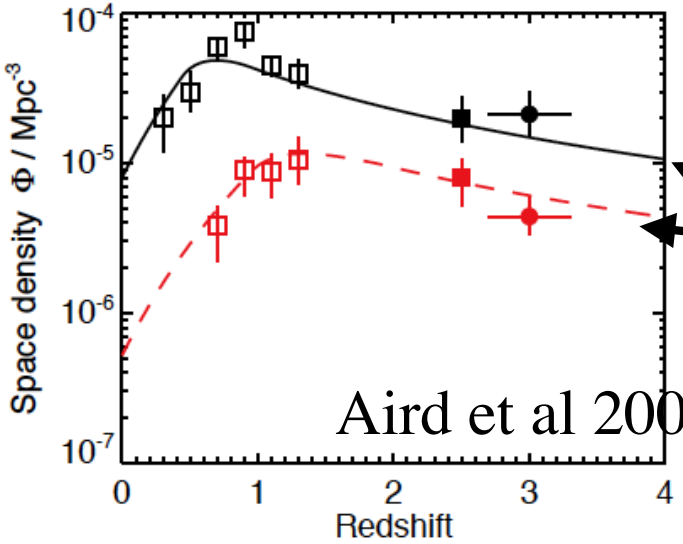
# Luminosity Density of AGN

- **Broad range in z (0.6-2)over which luminosity density ~ constant**
- At z< 1.2 most of luminosity density in log $L_x$<44 objects (Seyferts)
- At z>1.2 most of luminosity density in log $L_x$>44 objects (quasars)




L. Trouille thesis

QSOs sample ~30% of accretion power:



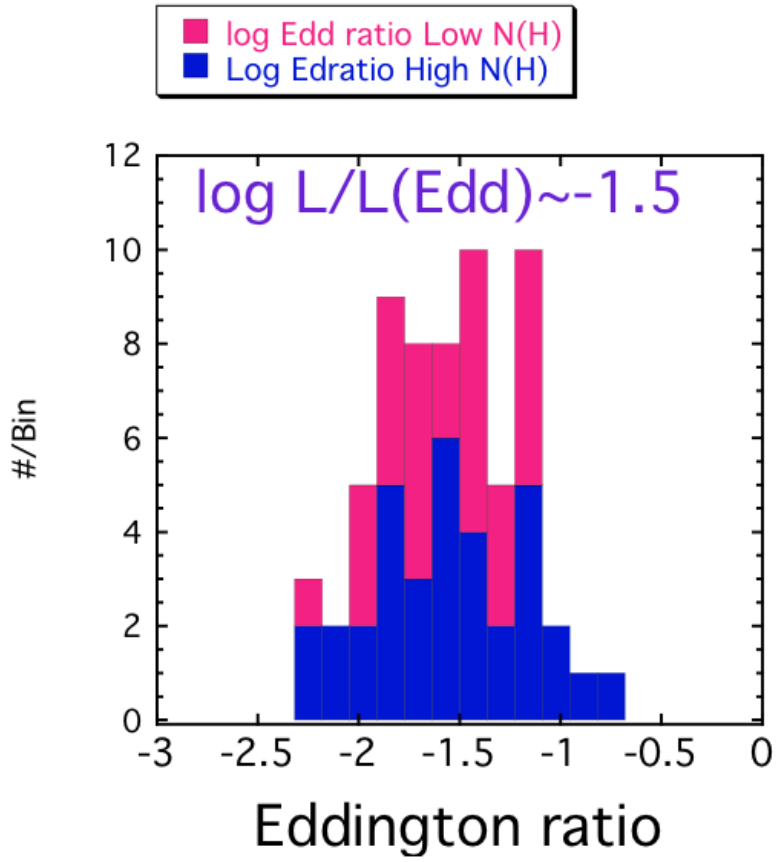

Broad line objects

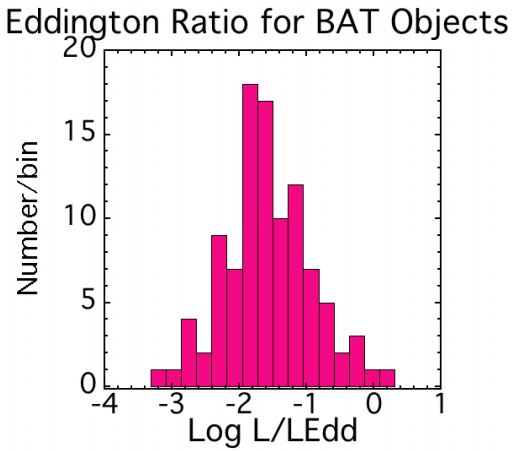
44<log $L_x$<45

43<log $L_x$<44

# Properties of Swift BAT AGN

- Sample selection and understanding of the sample is crucial:
- Previous work based on deep optical samples- tend to miss obscured objects which dominate the total accretion history
- **Swift/BAT hard x-ray sample**
  - Low redshift <z>~0.03
  - Little or no effect due to Compton thin obscuration
  - Completely identified, broad band data available for all objects
- Low z Hard x-ray selected AGN have low (~0.03) Eddington ratios




L. Winter and R. Vasudevan

# Papers in the last year from astro-ph arXiv number

1 1109.2734 Fermi/LAT Observations of Swift/BAT Seyferts: on the Contribution of Radio-quiet AGN to the Extragalactic Gamma-ray Background Stacy H. Teng R. F. Mushotzky, Rita M. Sambruna , D. S. Davis, C. S. Reynolds

2. 1107.1237 Host Galaxy Properties of the Swift BAT Ultra Hard X-ray Selected AGN M. Koss, R. Mushotzky, S. Veilleux, Lisa M. Winter, W. Baumgartner, J.Tueller, N. Gehrels, L. Valencic

3. 1106.2942 Suzaku View of the Swift/Bat Active Galactic Nuclei. IV. Nature of Two Narrow-Line Radio Galaxies (3C 403 and IC 5063) Fumie Tazaki, Yoshihiro Ueda, Yuichi Terashima, R. F. Mushotzky

4. 1106.2163 Chandra Discovery of a Binary Active Galactic Nucleus in Mrk 739 M. Koss, R. Mushotzky, E. Treister, S. Veilleux, R. Vasudevan, N. Miller, D. B. Sanders, K. Schawinski, M. Trippe

5. 1106.0310 Uncovering the Spectral Energy Distribution in Active Galaxies Using High Ionization Mid-infrared Emission Lines M. Meléndez, S.B. Kraemer, K. A. Weaver, R. F. Mushotzky

6. 1105.0893 XMM Follow-Up Observations of Three Swift BAT-Selected Active Galactic Nuclei M. L. Trippe, C. S. Reynolds, M. Koss, R. F. Mushotzky, L. M. Winter

7. 1104.2048 ORIGIN: Metal Creation and Evolution from the Cosmic Dawn J.W. den Herder, et al

8. 1104.1172 The Spin of the Supermassive Black Hole in NGC 3783 L.W. Brenneman, C.S. Reynolds, M.A. Nowak, R.C. Reis, M. Trippe, A.C. Fabian, K. Iwasawa, J.C. Lee, J.M. Miller, R.F. Mushotzky, K. Nandra, M. Volonteri

9. 1104.0665 Star Formation Efficiency in the Cool Cores of Galaxy Clusters M. McDonald, S. Veilleux, David S. N. Rupke, R. Mushotzky, C. Reynolds

10. 1102.1972 The Effect of Environment on the Formation of Halpha Filaments and Cool Cores in Galaxy Groups and Clusters M. McDonald, S. Veilleux, R. Mushotzky

11. 1101.1115 X-ray reflected spectra from accretion disk models.II. Diagnostic tools for X-ray observations J. Garcia, T.R. Kallman, R.F. Mushotzky

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