Finding Local Low-Mass Supermassive BHs

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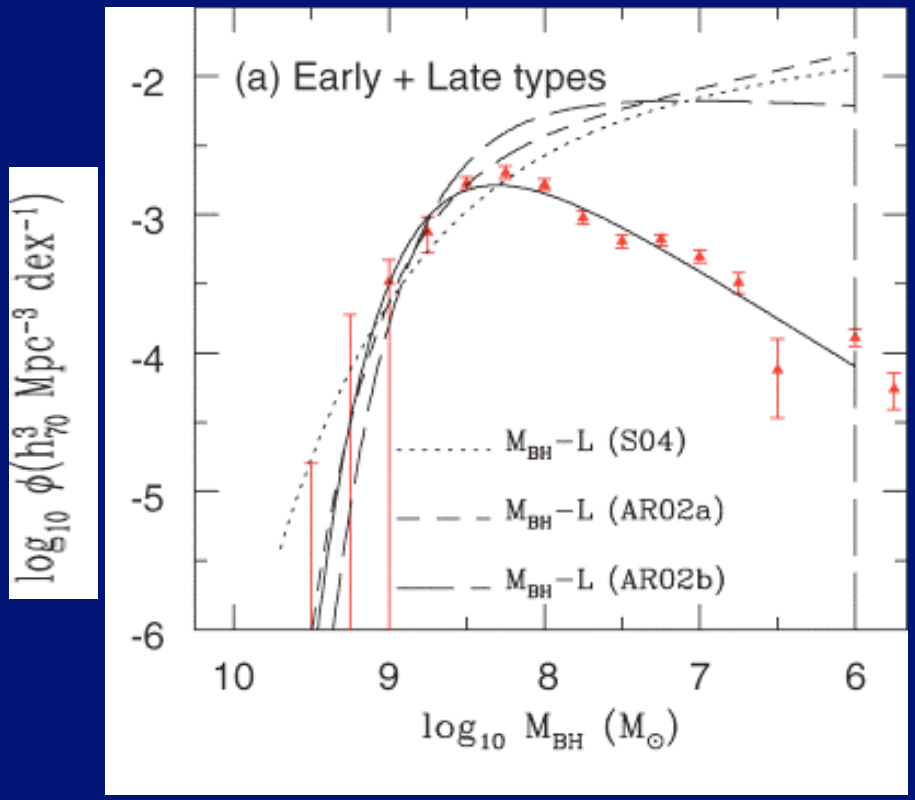
Motivation



Graham et al. 2007

- Low-mass (below 10^6 $M_\odot$) end of local SMBH mass function can constrain theories of SMBH growth.
- Do scaling relationships (e.g. M_{BH}-M_{bulge}) break down at low masses?

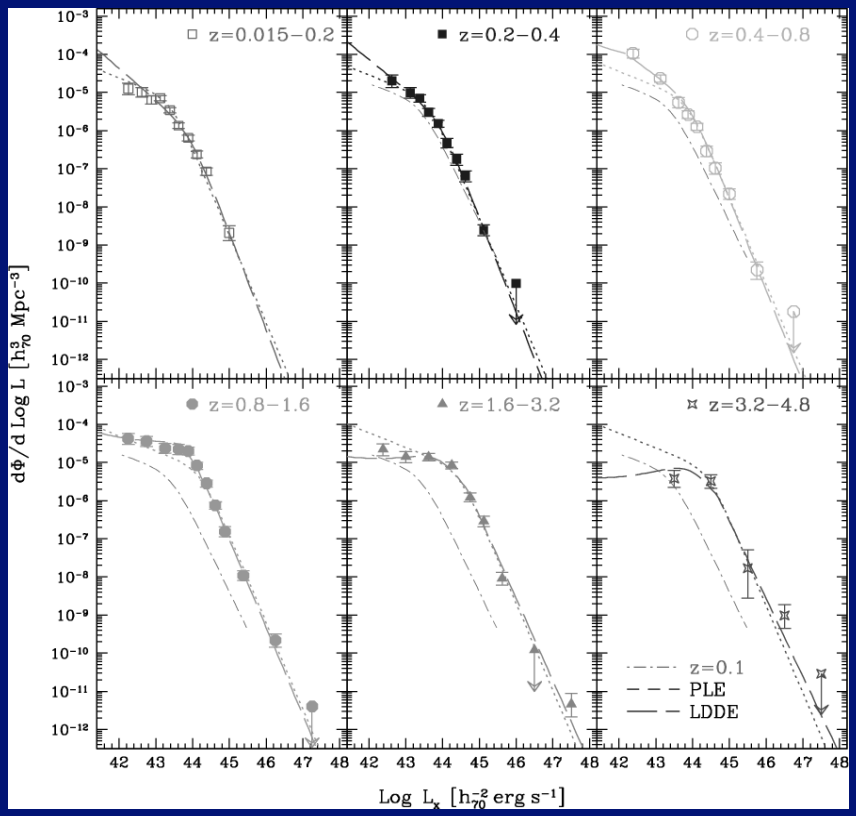
Beginning to find some

- NGC 4395 : 3×10^5 $M_\odot$ (Peterson et al. 2005)
- POX 52 : 3×10^5 $M_\odot$ (Barth et al. 2005)
- SDSS: few $\times10^5$-10^7 $M_\odot$ (Green & Ho 2004)
- NGC 3621 : > 4×10^3 $M_\odot$ (Satyapal et al. 2007)
- M31 - G1 : ~2×10^4 $M_\odot$ (Ulvestad et al. 2007)

Push to lower masses

- We aim to obtain a sample of 10^4 - 10^6 $M_\odot$ SMBH
- Using dynamical signature presently impossible. Sphere of influence of a 10^5 $M_\odot$ SMBH at 15 Mpc is ~ 3 mas
- Using AGN signature may be only viable way of detecting these SMBH

Exploit “downsizing” of AGN activity



Hasinger et al. 2005

- The lower the luminosity, the lower the redshift at which space density peaks
- Lowest luminosity AGN should be active at current epoch
- From lower mass SMBHs

Method

- Focus on late-type spirals and dE
- Use X-rays.
- Use highest angular resolution possible
- Use multi-wavelength data
- Identify false positives

Building the sample

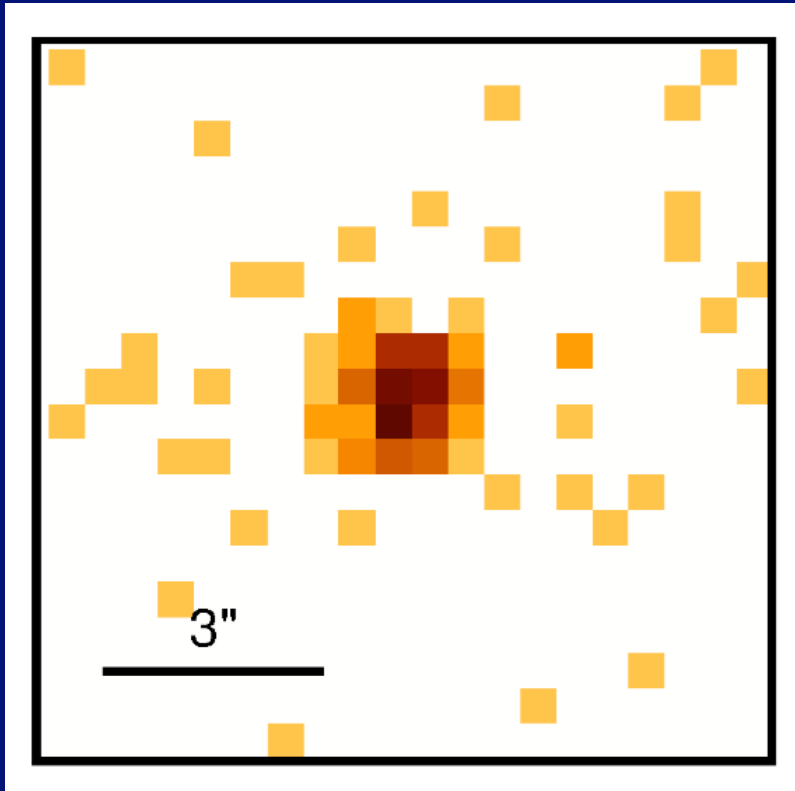
- 44 galaxies in RC3 that are:
  - face-on spirals (S0-Sdm), or dE
  - within 20 Mpc
  - NOT known to have AGN
  - not starbursts. LINERS are included.
- 6 of these already in Chandra archive

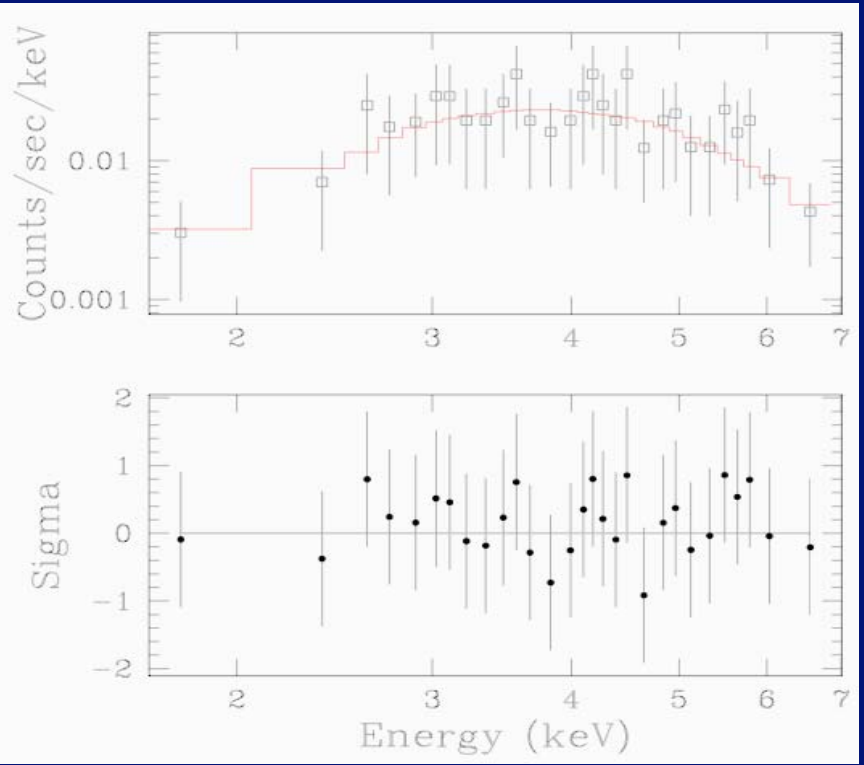
Proof of principle: Chandra archival study

- 1 Sa, 1 Sb, 1 Sc, 2 Scd, 1 Sd
- All six have a nuclear x-ray source
- NGC 3169 (Sa), 4102 (Sb) : AGN
- NGC 5457 (Scd), 3184 (Scd) : Can make a strong case for being AGN
- NGC 4713 (Sd), 4647 (Sc) : Inconclusive but can't rule out AGN
- All are candidate SMBH

NGC 3169

Sa, 20 Mpc, LINER



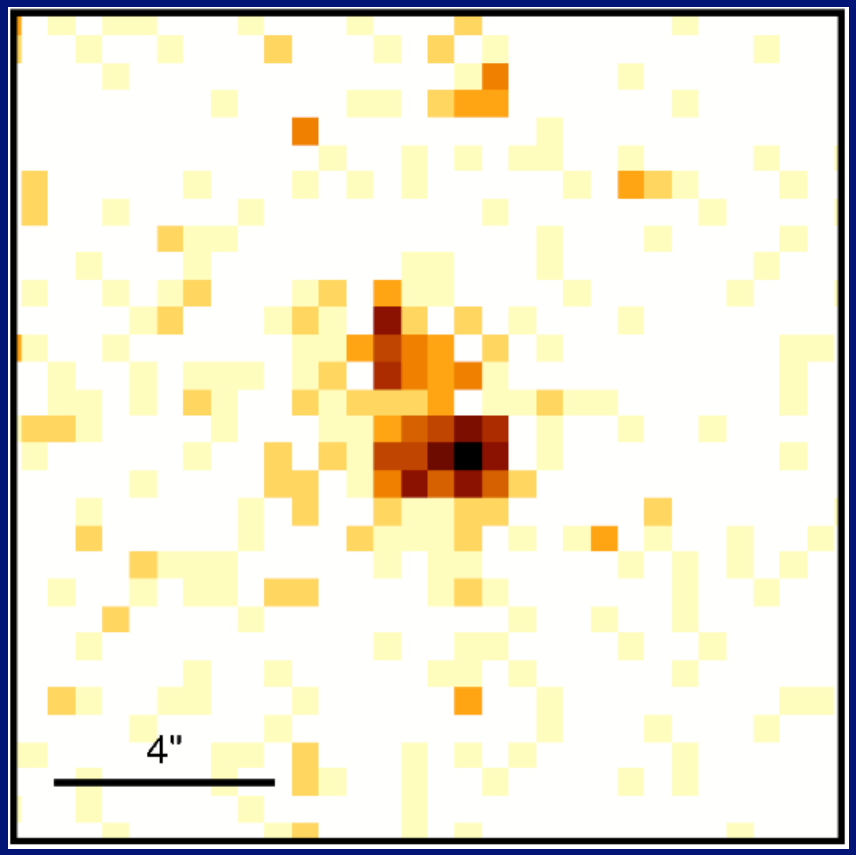


NGC 3169 (Sa)

- X-ray
  - Hard x-ray source (Terashima & Wilson 2003)
  - Absorbed power law spectrum with $\Gamma \sim 2$, $N_H \sim 10^{23}$ cm^{-2}
  - F(0.3-8 keV) ~ 10^{-11} cgs ➔ L ~ 5×10^{41} erg/s
- Radio
  - 7 mJy mas-scale radio source (VLBA, 5 GHz, Nagar et al. 2005)
- Conclusion
  - Almost certainly AGN.
  - Demonstrates power of having both X-ray & radio obs

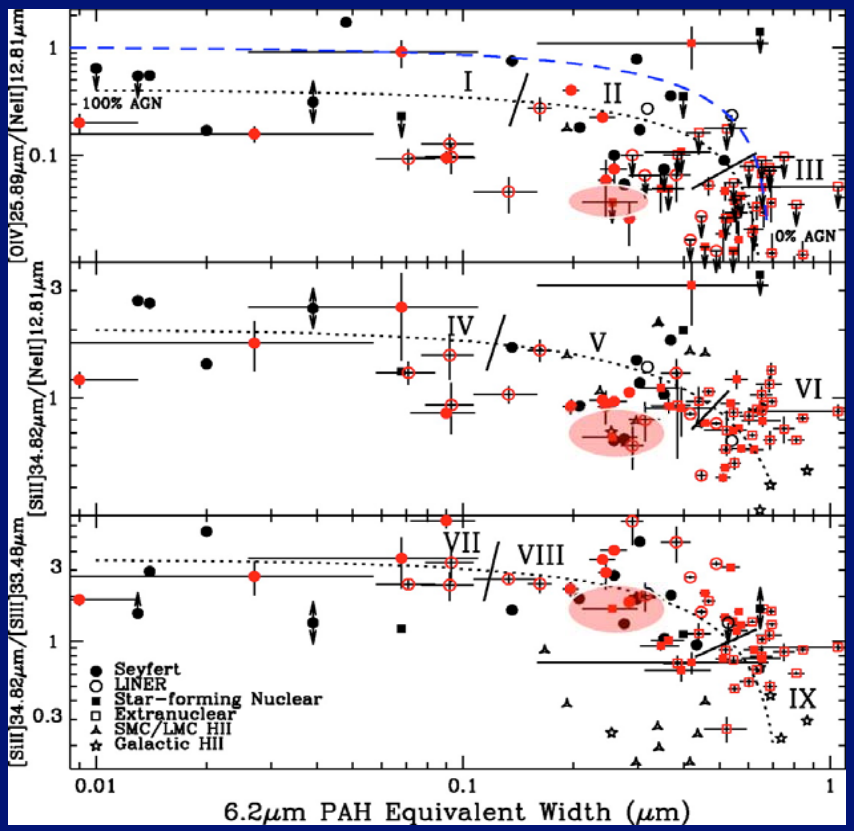
NGC 3184

Scd, 8.7 Mpc, HII



- Only 30 counts
- Soft emission
- Assuming power law, $\Gamma \sim 2$, gives L(0.3-8 keV) ~ 2×10^{37} erg/s
- No radio detection reported

NGC 3184 (Scd)



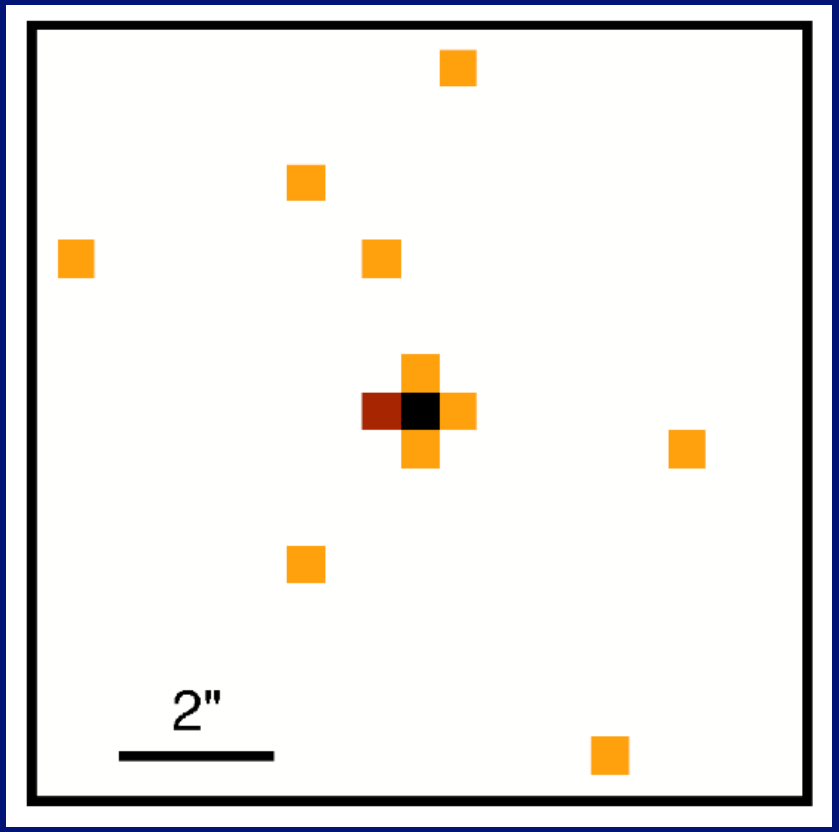
Dale et al. 2006

- IR - Spitzer
  - Falls in transition region between AGN & HII in diagnostic diagram
  - IRAC colors are redder than ~99% of normal late-type spirals (Assef et al. 2007)
- IR - 2MASS
  - $\nu L_\nu \sim 10^{41}$ erg/s difficult to produce without AGN

NGC 3184 (Scd)

- XRB?
  - would need > 1000 to produce observed bolometric luminosity
- Star formation?
  - Observed $L_{H\alpha}$ = 7×10^{38} erg/s would require ~100 O7 stars, but total bolometric luminosity would be insufficient. But possible to fine tune.
- Conclusion:
  - Probably obscured AGN.

NGC 4713
Sd, 18 Mpc, T2

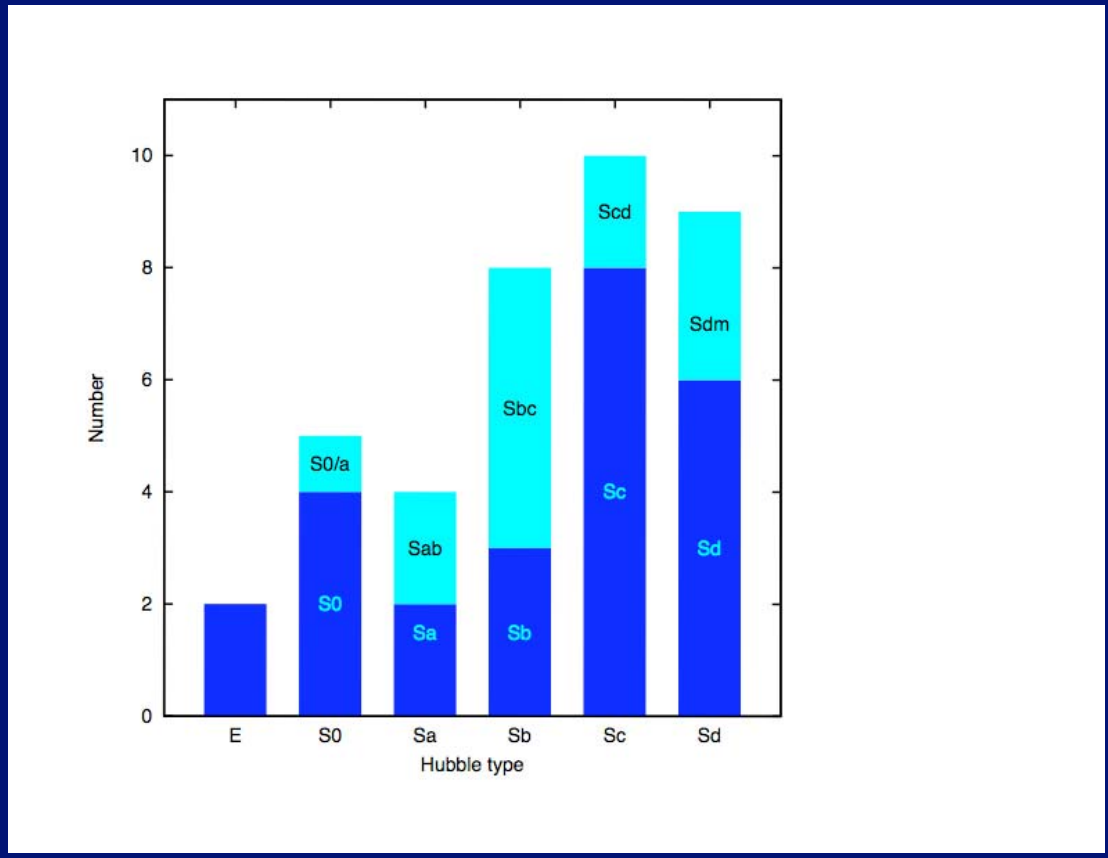


- 10 counts, 9 below 2.5 keV. Assuming $\Gamma = 2$ and Galactic absorption, L(0.3-8 keV) ~ (3-5) $\times 10^{38}$ erg/s
- Optical line ratios suggestive
- HST V band $\nu L_\nu \sim 10^{40}$ cgs
- Radio upper limit
- Inconclusive. Need more data. 70 ks XMM obs to be done.

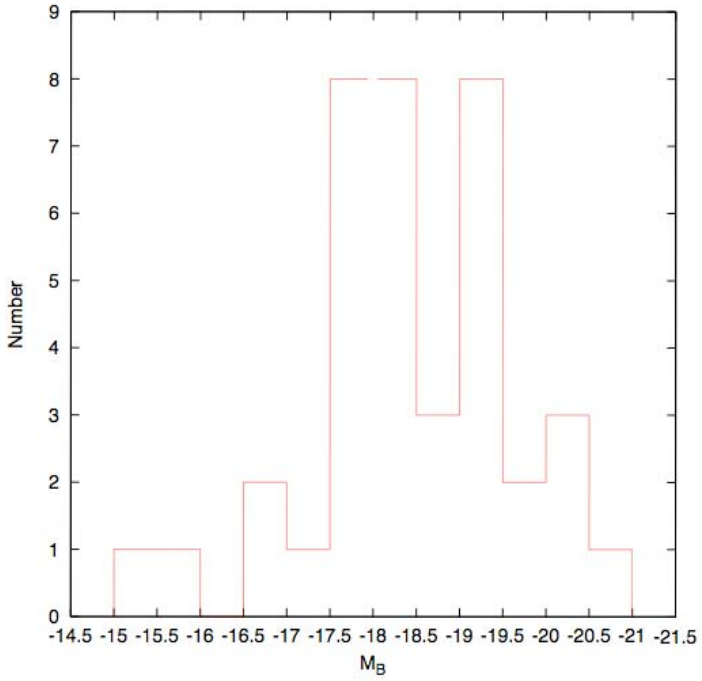
Conclusions & Future Work

- Can use x-ray to find SMBH candidates in nearby quiescent galaxies.
- High resolution & multi-wavelength coverage necessary
- Chandra survey of remaining 38 galaxies underway.
- Additional archival study of 10 galaxies from NBG (Tully 1988)
- Perform follow-up observations
- Develop diagnostics better suited for ultra-low luminosity AGN than currently exist

Survey galaxies: Hubble types



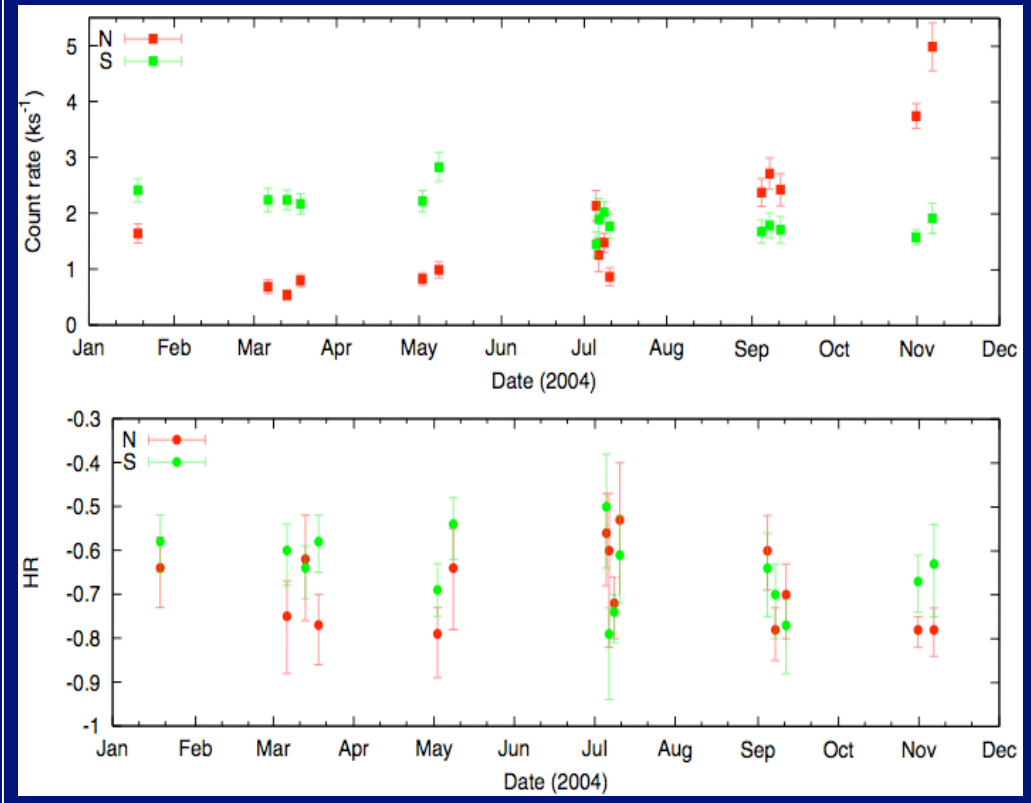
Survey galaxies: M_B



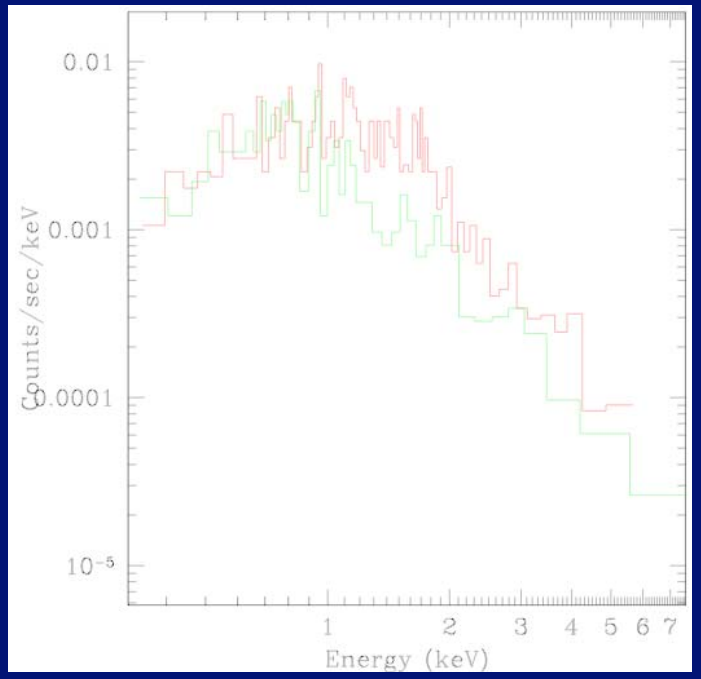
Conclusions & Future Work

- Multi-wavelength data crucial to distinguish source type
- High resolution observations crucial to avoid dilution by host galaxy light
- Need to develop diagnostics better suited for very low-luminosity AGN, e.g. using hard x-rays (10-300 keV) and FIR

NGC 5457

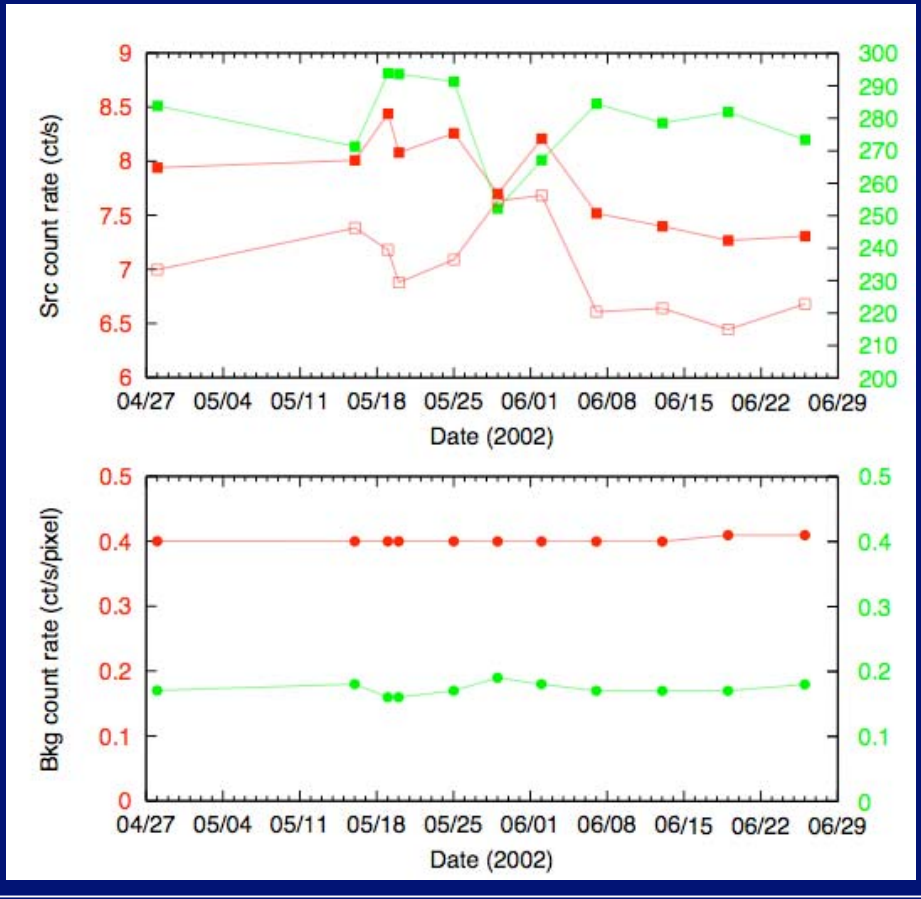


Variabilty



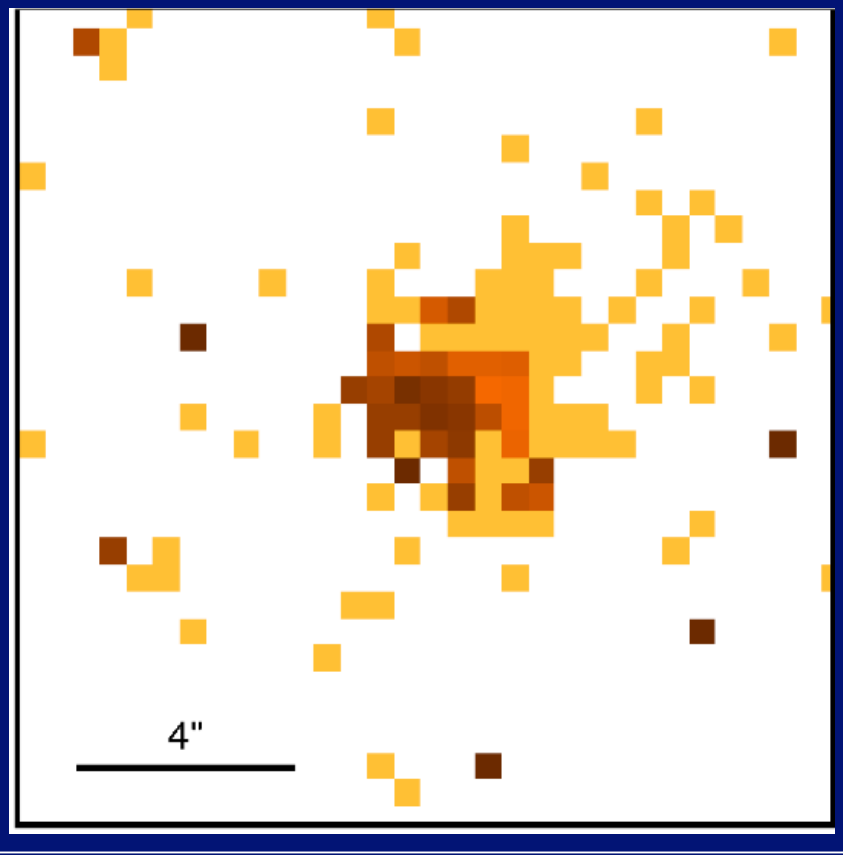
High & low state spectra

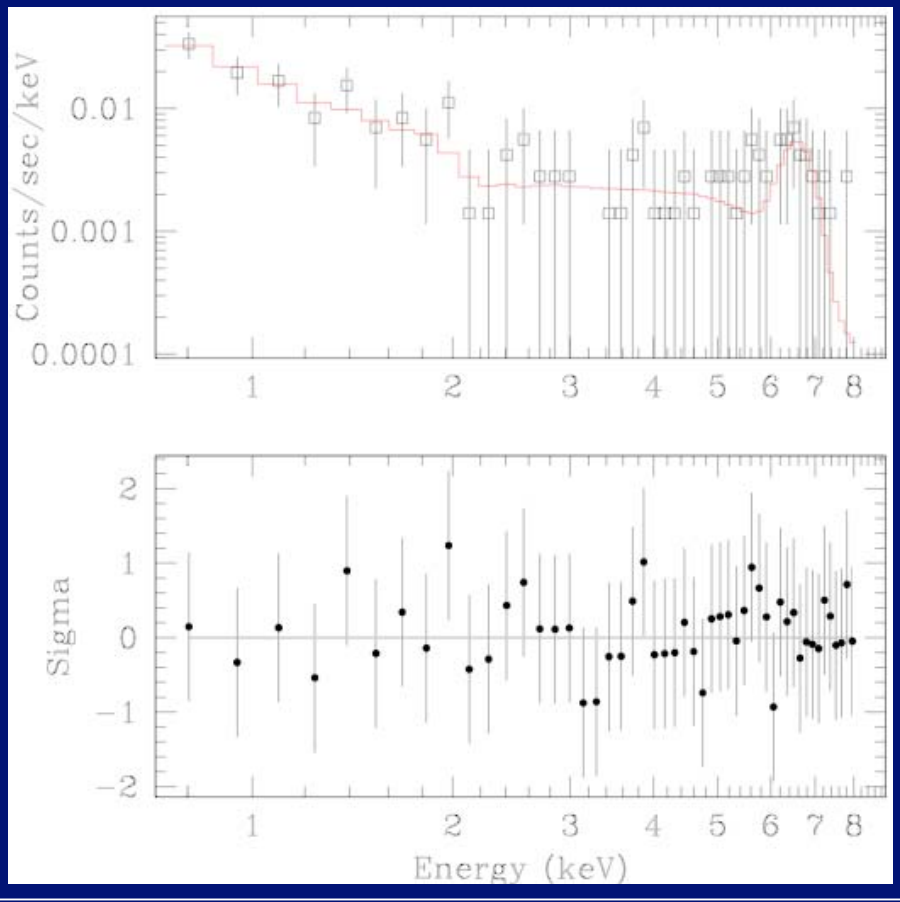
NGC 4647: variability



NGC 4102

Sb, 17 Mpc, HII





NGC 4102

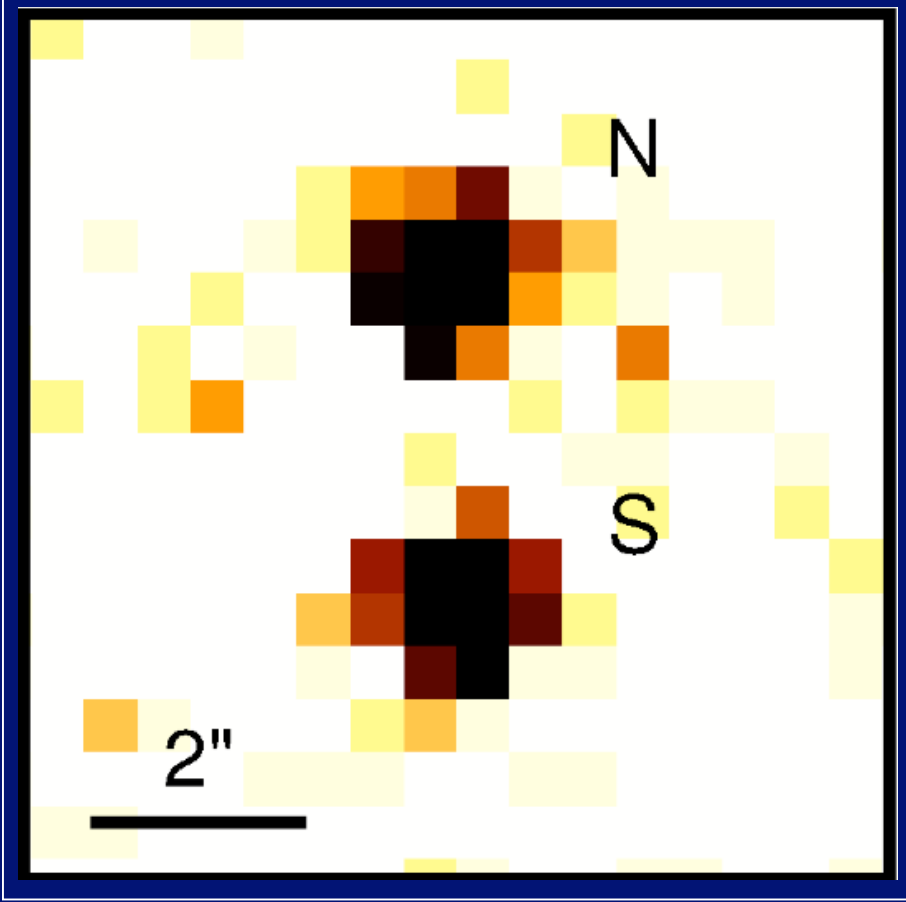
- Almost certainly AGN
- X-ray
  - Hard x-ray source
  - Possible Fe Kα line
  - Power law $\Gamma = 2.0 \pm 0.5$, Galactic absorption. Reflected light?

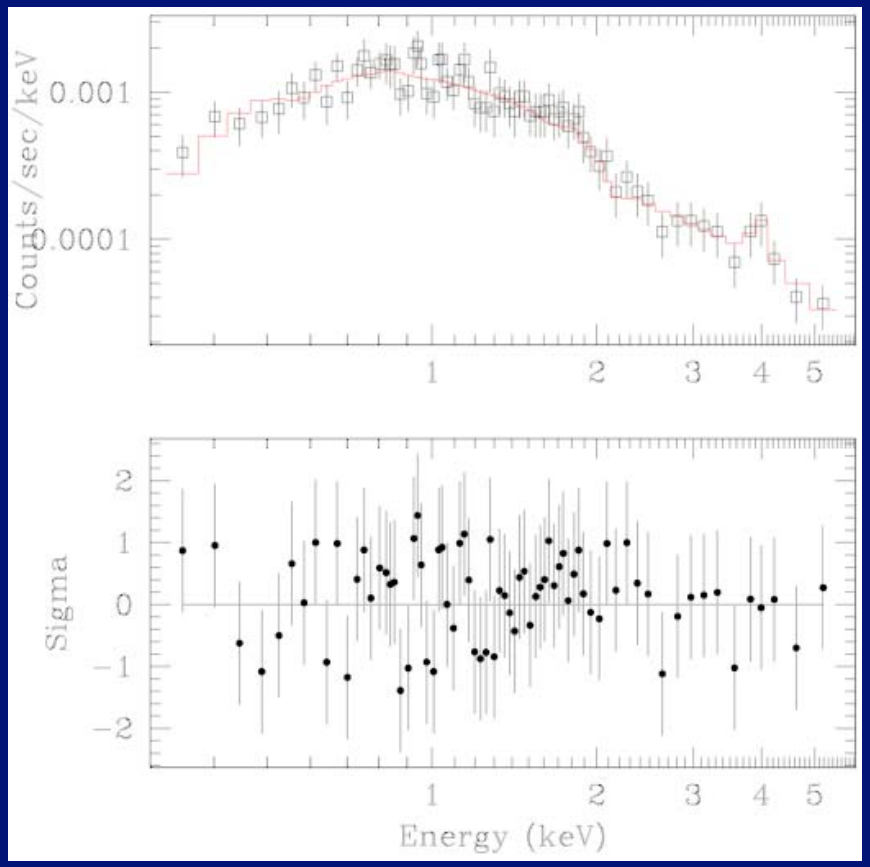
NGC 4102

- IR
  - 2MASS point source; $\nu L_\nu \sim 10^{43}$ erg/s in AGN regime
- Radio
  - FIRST detection, 167 mJy peak flux density (4”×3” beam)

NGC 5457 (M101)

Scd, 7 Mpc, HII





NGC 5457

- Probably AGN
- X-rays
  - Low luminosity (3×10^{38} erg/s) but varies by factor of 9 in 8 months
- Optical (HST)
  - α_{ox} = 1.4 similar to AGN
- IR (2MASS)
  - $\nu L_\nu \sim 10^{41}$ erg/s difficult to produce without AGN
  - α_{KX} = 1.9 similar to x-ray faint AGN (Laor et al. 1997)
- Radio
  - Upper limit $\nu L_\nu < 6\times10^{35}$ erg/s (Heckman 1980)

NGC 5457

- X-ray binary?
  - X-ray luminosity like XRB
  - BUT, bolometric luminosity implied by IR, ~10^{41} erg/s, would require implausibly high number of XRBs (10^3 - 10^4)

NGC 5457

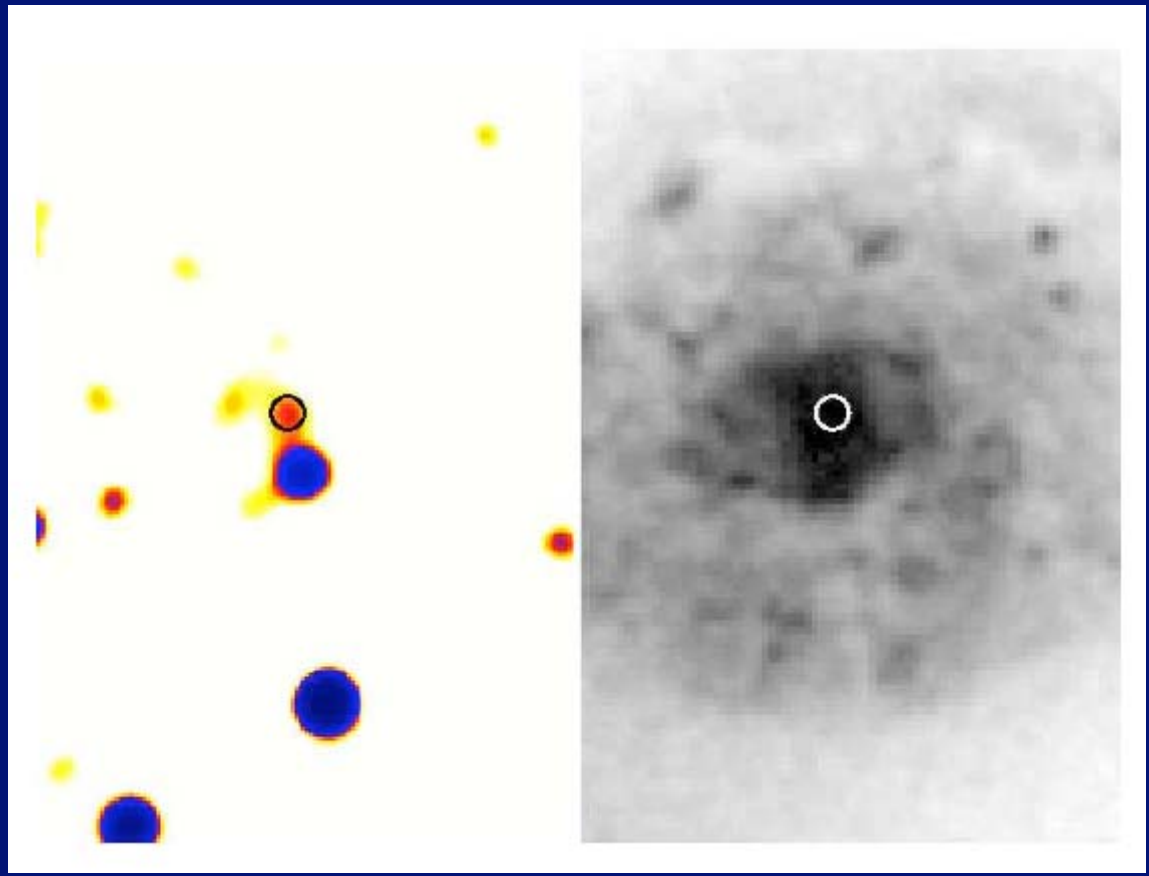
- Star formation?
  - Observed U-V = +0.30 implies E(B-V) = 0.99 - 1.1 (for LMC & Galactic reddening)
  - Requires N_H factor of 7-10 higher than obtained from spectral fitting
  - Inconsistent with E(B-V) = 0.33 obtained from $H\alpha/H\beta$ line ratio (Ho et al. 1997)

NGC 4713

- Consistent with being obscured AGN but inconclusive
- X-ray
  - Luminosity in obscured AGN / XRB range
- Optical
  - Line ratios between AGN & HII
  - HST V band $\nu L_\nu \sim 10^{40}$ erg/s
- IR
  - 2MASS $\nu L_\nu \sim 10^{41}$ erg/s
- Radio
  - Upper limit 1.1 mJy at 15 GHz (VLA) (Nagar et al. 2005)

NGC 4647

Sc, 17 Mpc, HII



NGC 4647

- Inconclusive, but intriguing signs.
- X-ray
  - Low significance Chandra detection
  - Detection (3” positional uncertainty) by XMM (Randall et al. 2006). Soft source, L(0.3-12 keV) ~ 10^{39} erg/s
- Optical
  - HST V band: variability of ~10% over 2 months

NGC 4647

- Radio
  - Not detected 5GHz with VLA (Ulvestad & Ho 2002)
  - But Willis et al. (1976) report a nuclear source with 16 mJy flux density at 1.4 GHz. Positional uncertainty ~ 12 arcseconds