PennState Eberly College of Science

NASA

Hard X-ray selected AGNs in low-mass galaxies

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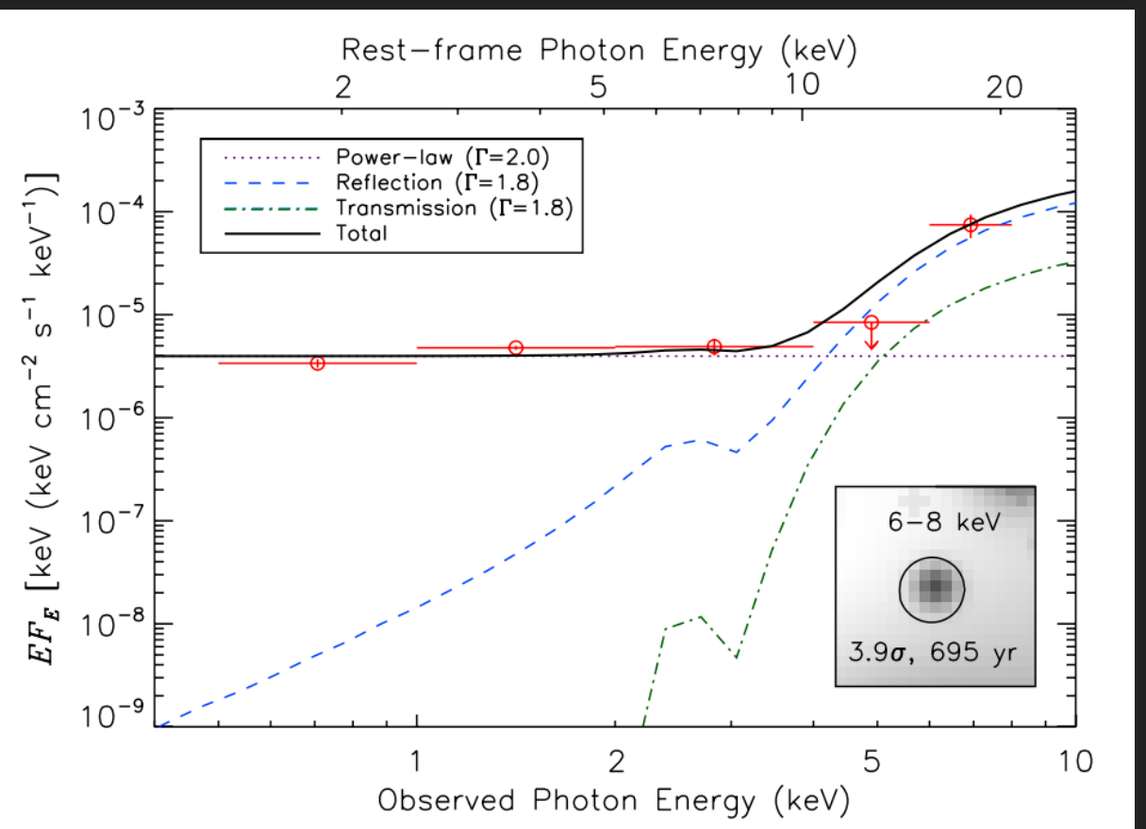
with Niel Brandt, Amy Reines, George Lansbury
Daniel Stern, Dave Alexander, and the NuSTAR Collaboration

Dwarf galaxy : $M_{star} < 3*10^9\ M_{sun}$
low-mass galaxy : $M_{star} < 10^{10}\ M_{sun}$

How many low-mass AGNs remain elusive?



- X-ray stacking results show that high redshift star-forming dwarf galaxies might have heavily obscured AGN (Xue+2012, Mezcua+2015)
- 20-25% of 6-8 keV CXB (Xue+2012)

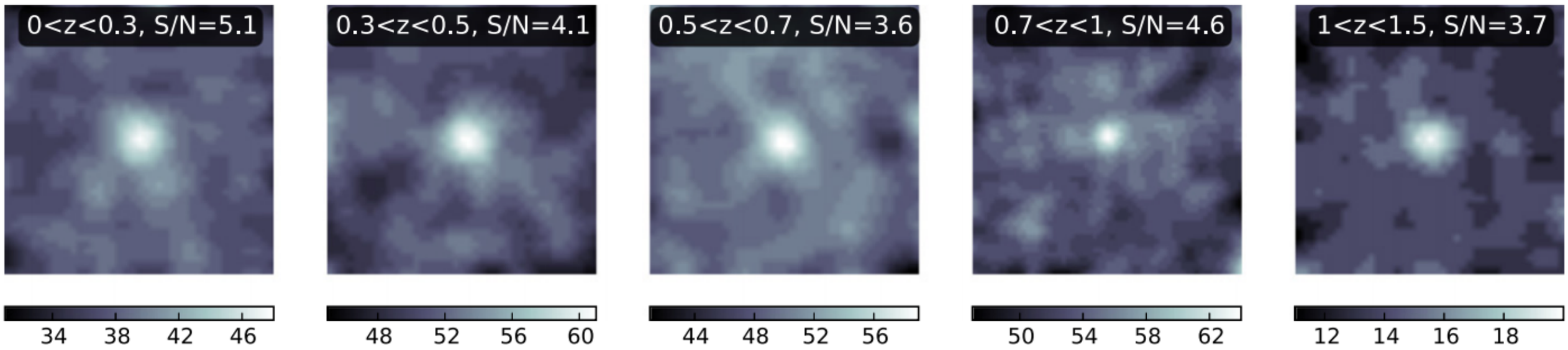
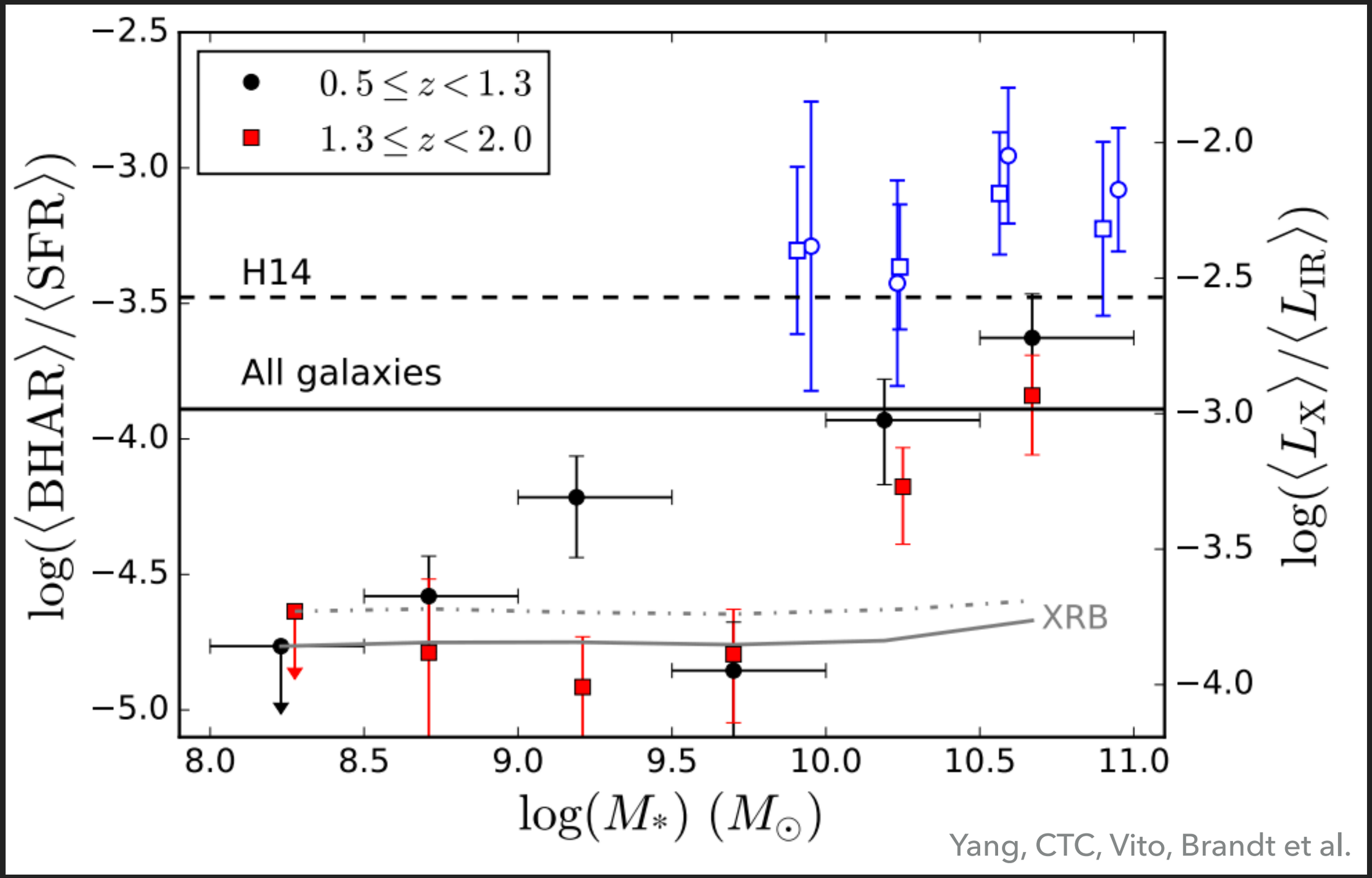


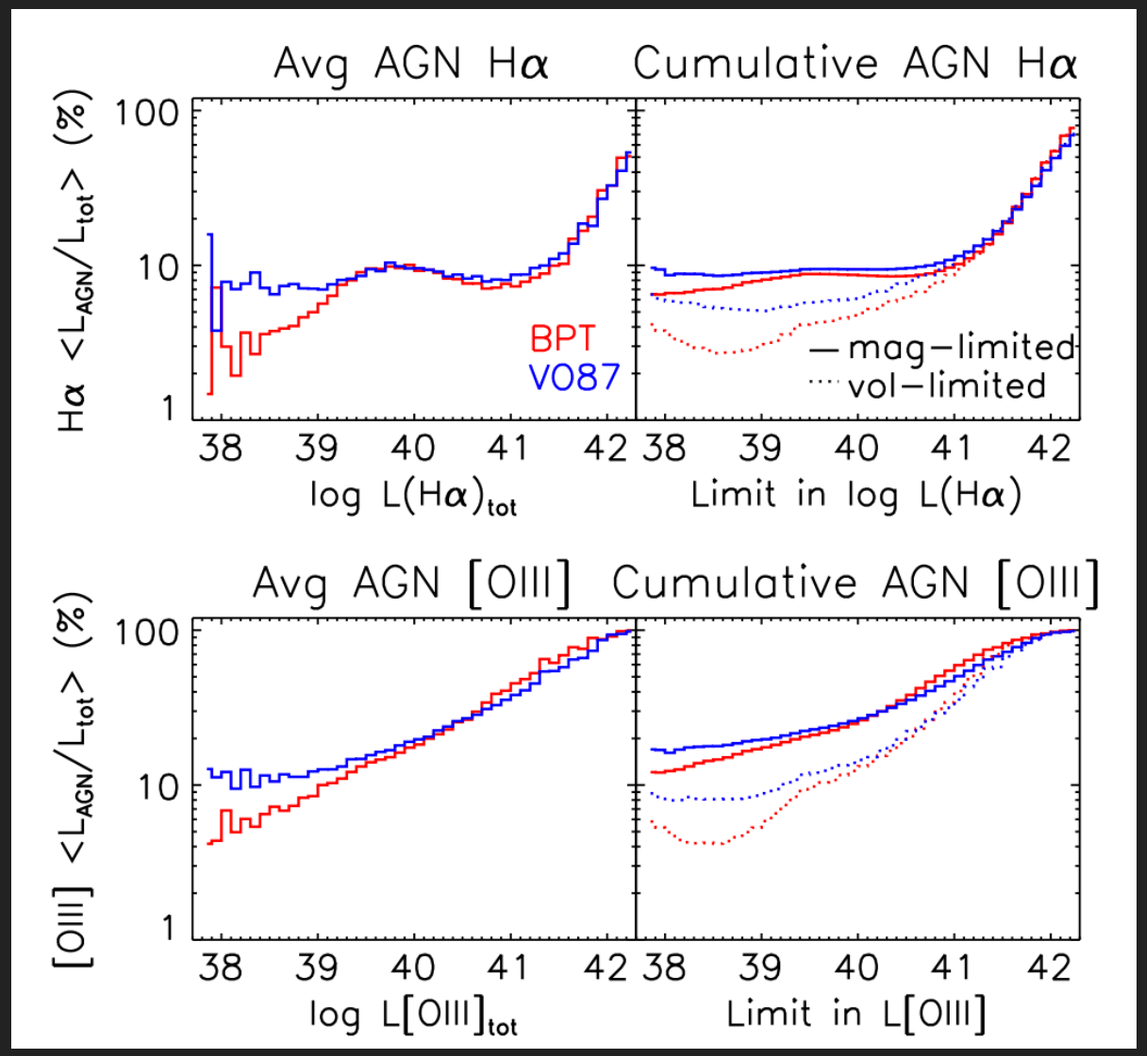
Figure 3. Stacked X-ray detections in the 0.5–2 keV band. Images have been smoothed with a Gaussian of radius = 2. Color scales are in counts.



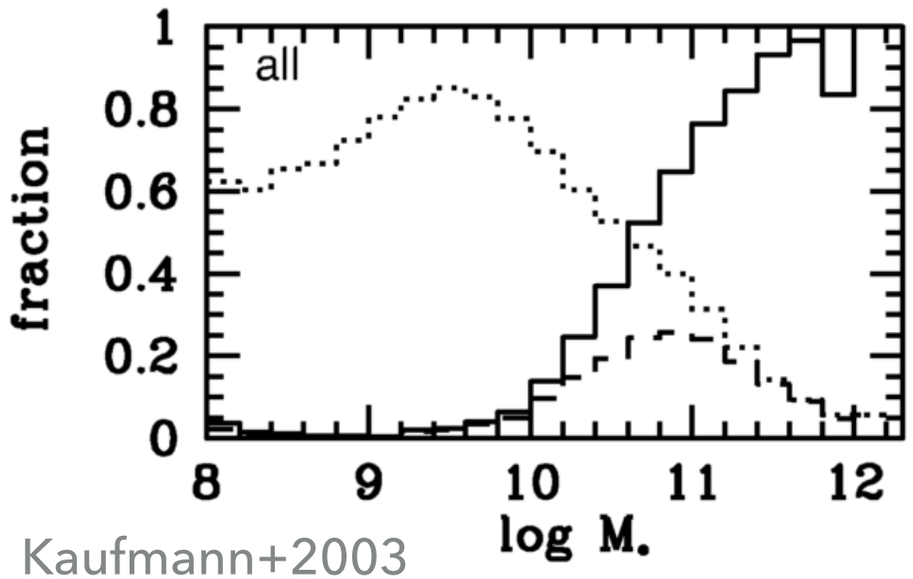
Yang, CTC, Vito, Brandt et al.

Challenges in finding obscured AGNs in dwarf galaxies

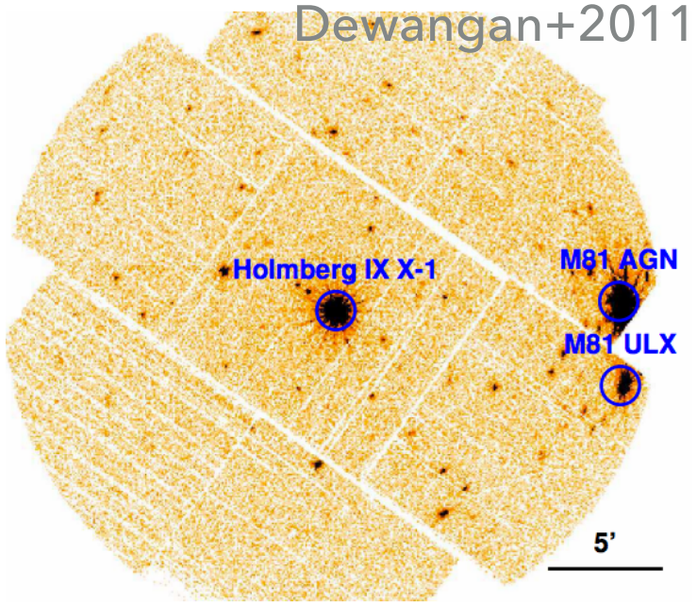
- Many AGN luminosity indicators have significant host galaxy dilution.
- Some AGNs might be ``true type 2''.
  e.g., Elitzur & Ho 2009



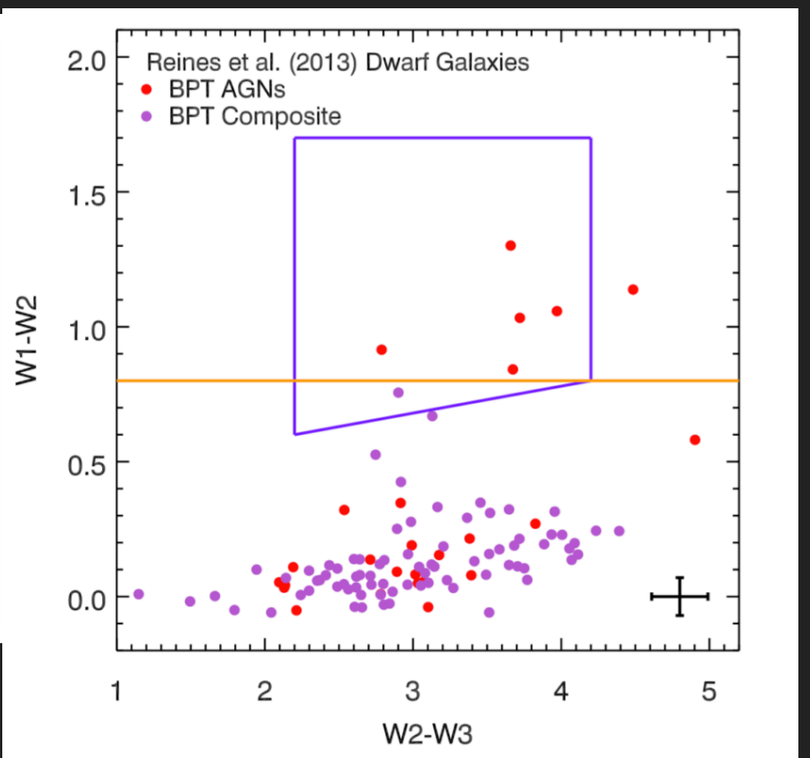
Trump+2015



Kaufmann+2003



Dewangan+2011



Hainline+2016

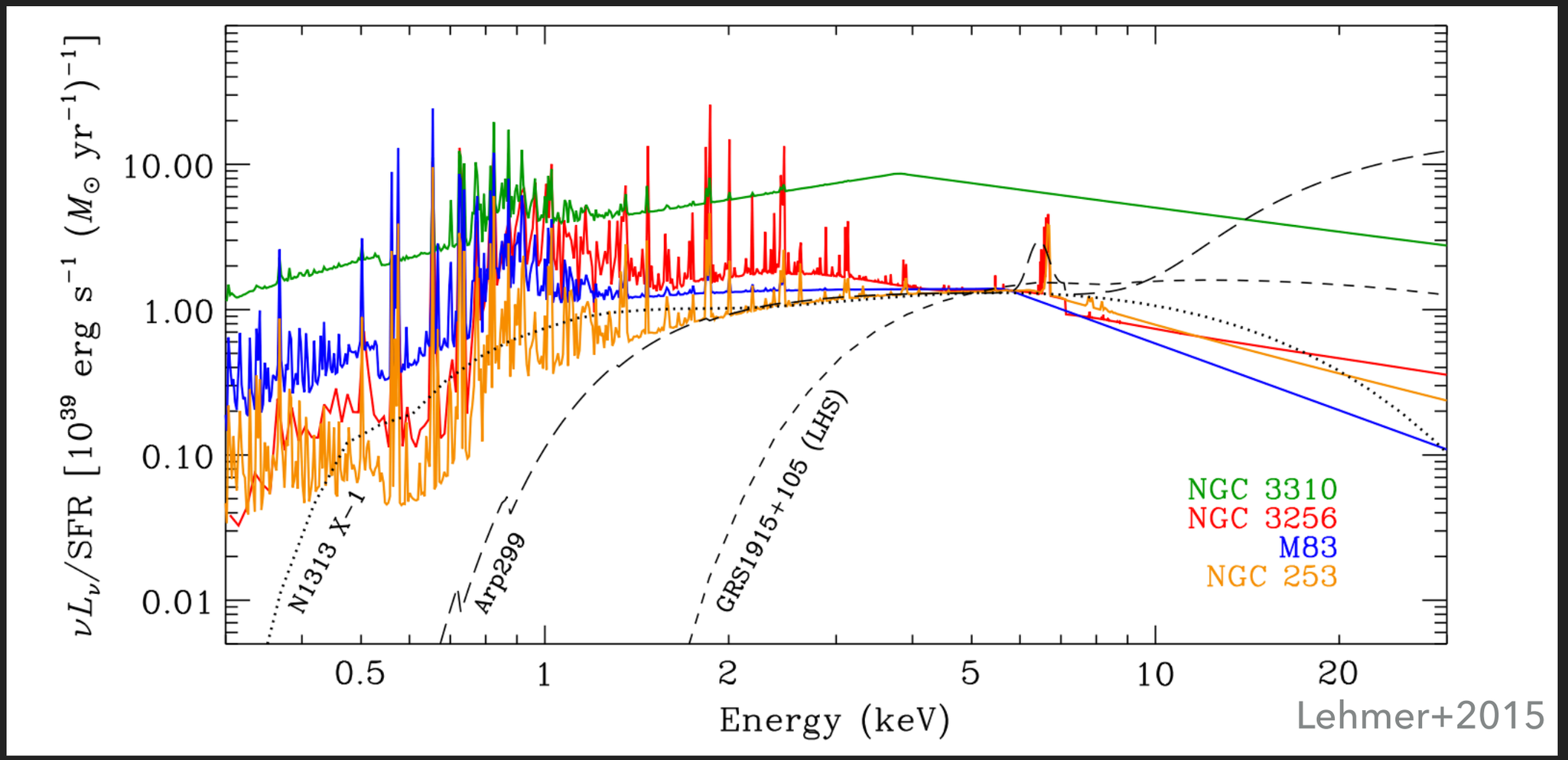
Optical spectrum : host galaxy dilution

Soft X-ray : HMXB interloper

Mid-IR color: low-metallicity dwarf starbursts interloper (Hainline et al., 2016).

Hard X-ray

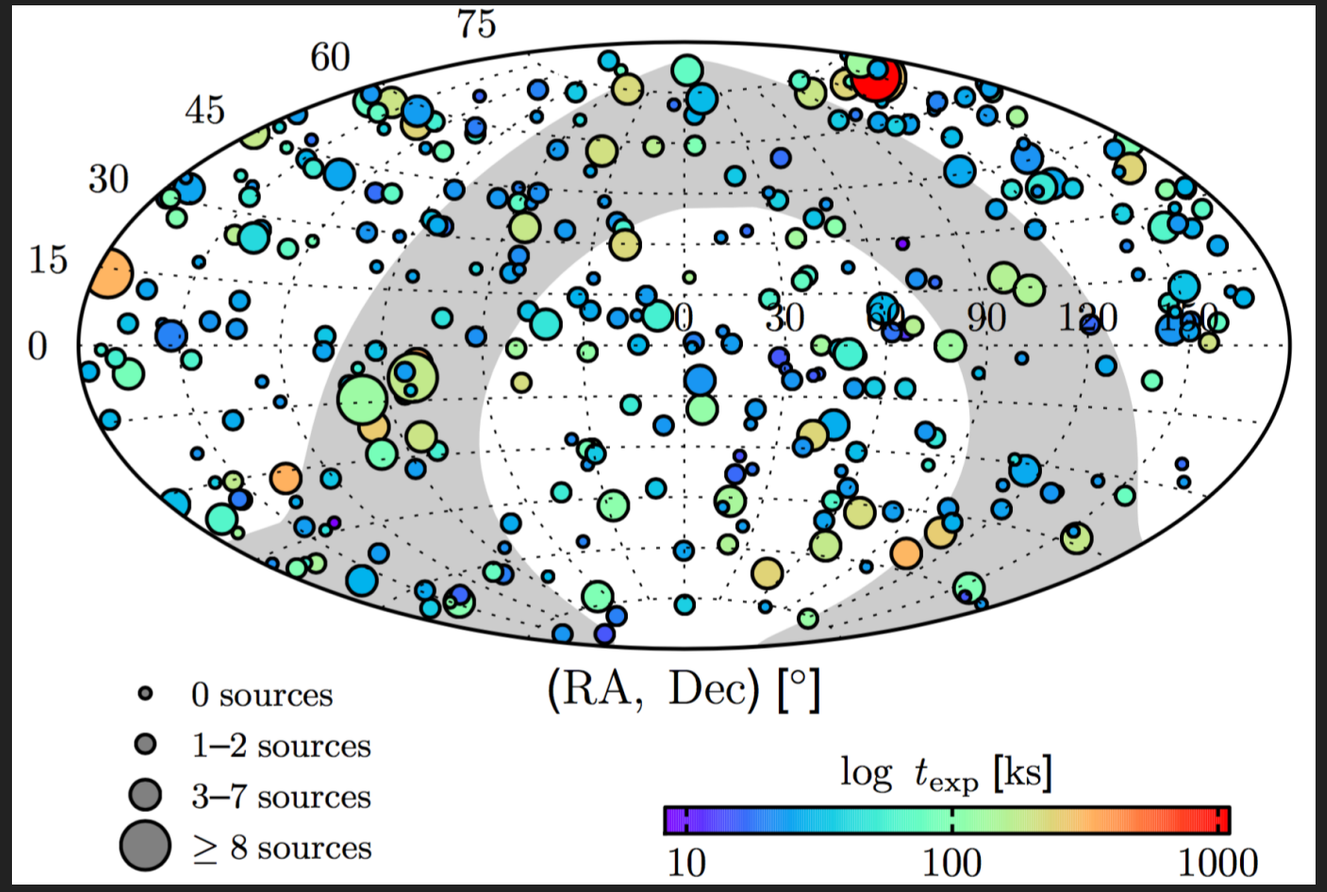
- Broad-band X-ray spectra for AGN and stellar processes are quite different:



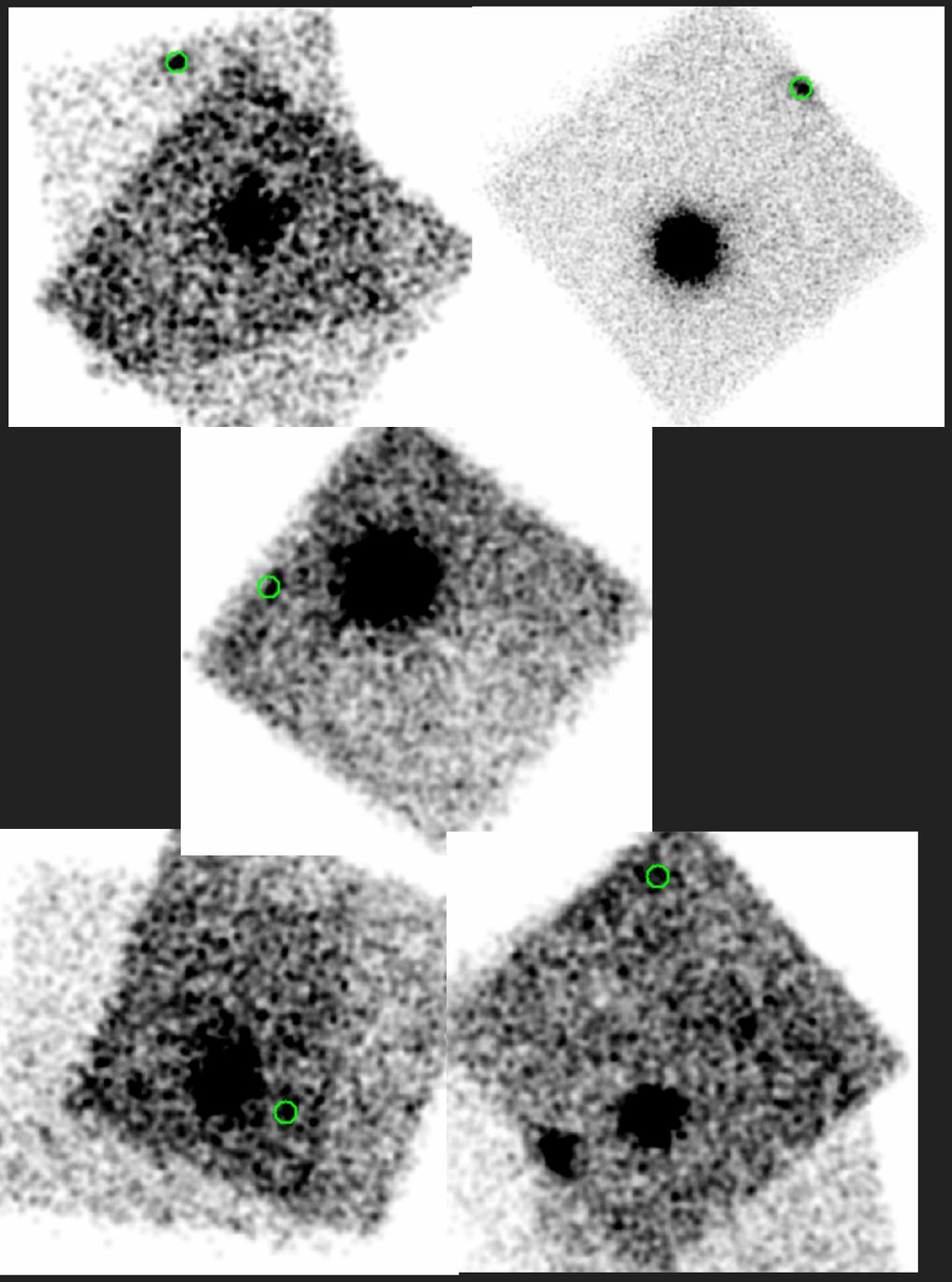
Lehmer+2015

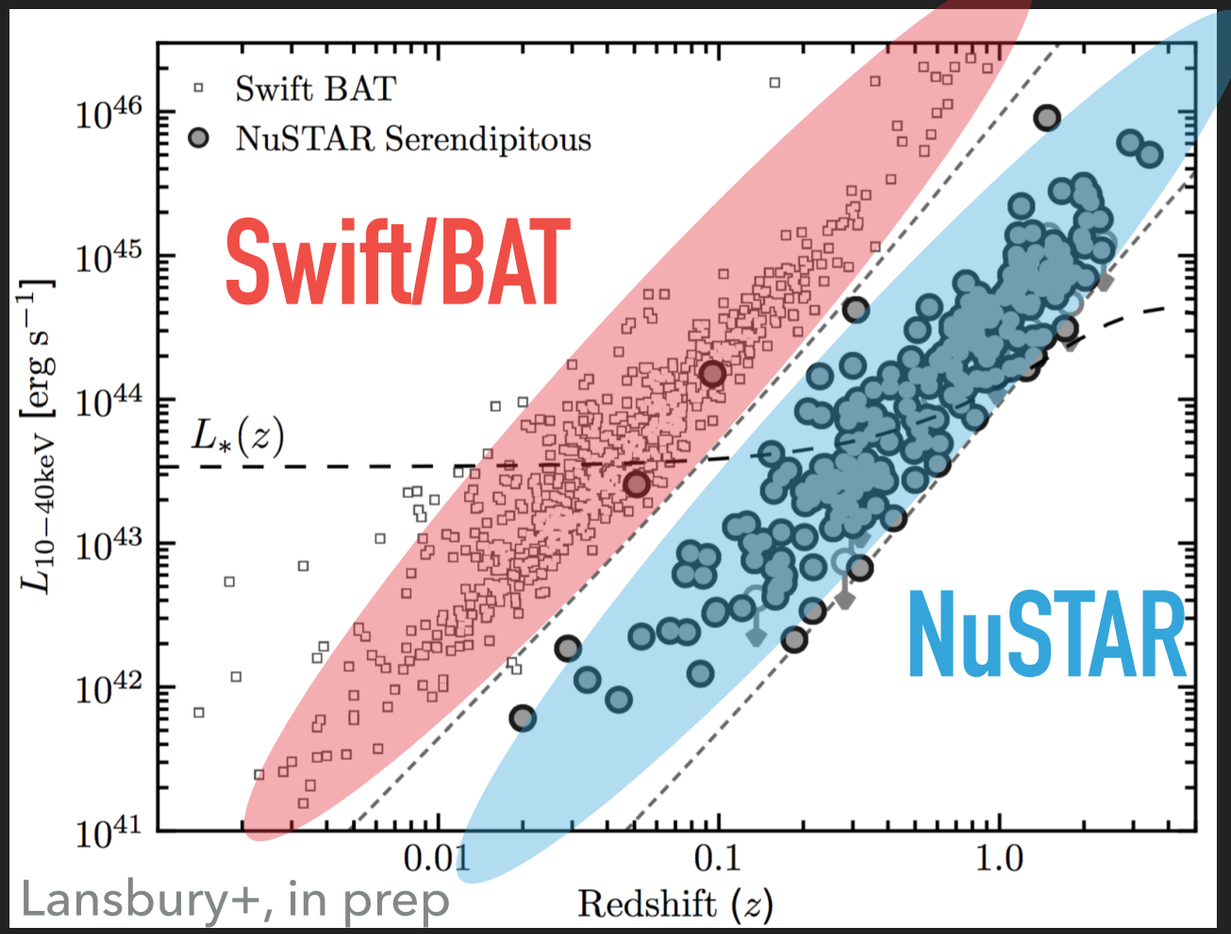
The NuSTAR serendipitous survey

- Search for serendipitous NuSTAR detections in all of the NuSTAR extragalactic pointings
- The 40-month catalog (Lansbury et al., 2017) covers ~ 13 deg^2 with ~500 detections.
- Keck/LRIS and NTT/ EFOSC2 spectroscopic follow-up observations
- A total of 248 extragalactic objects with redshifts



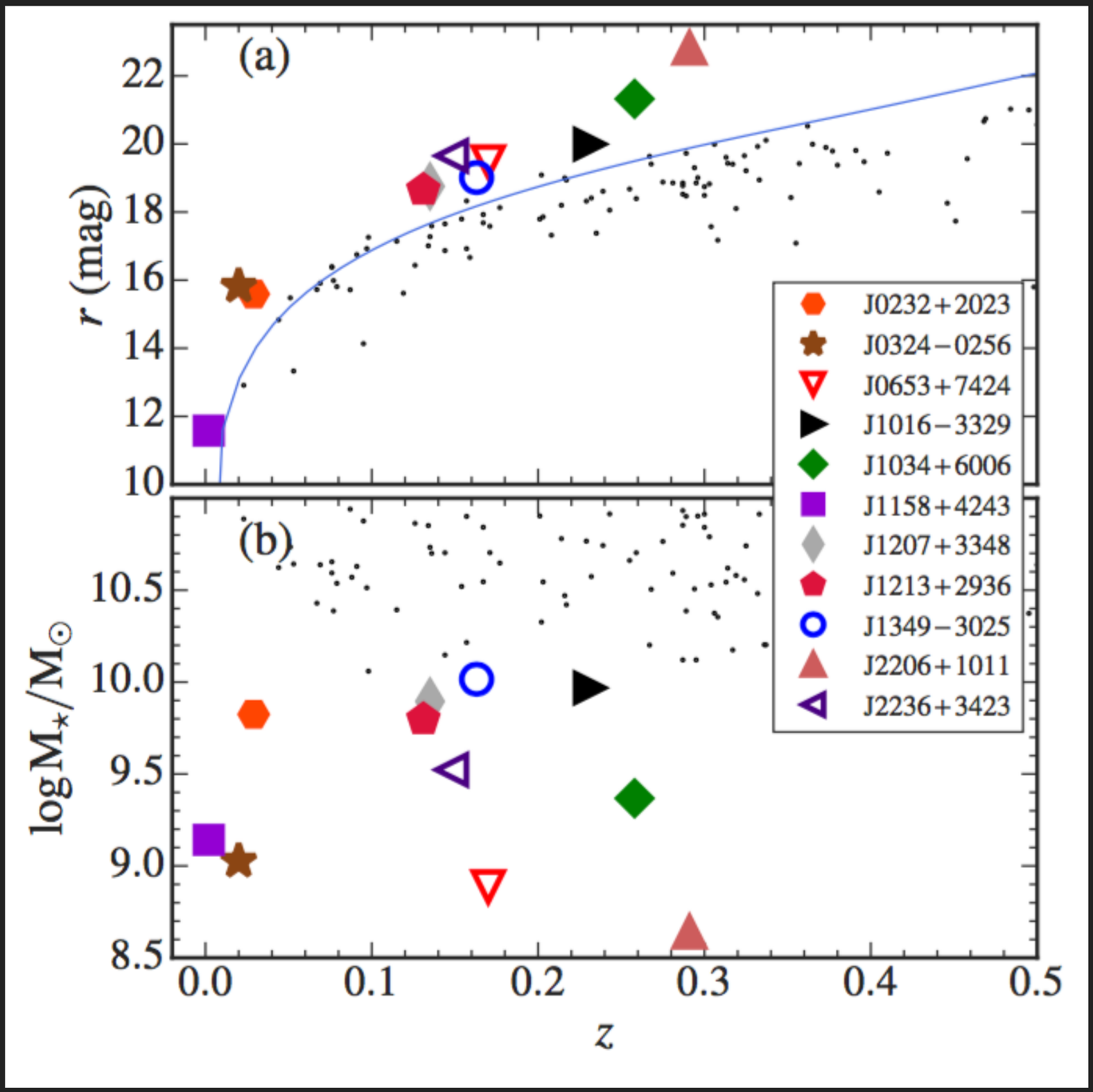
The NuSTAR serendipitous survey



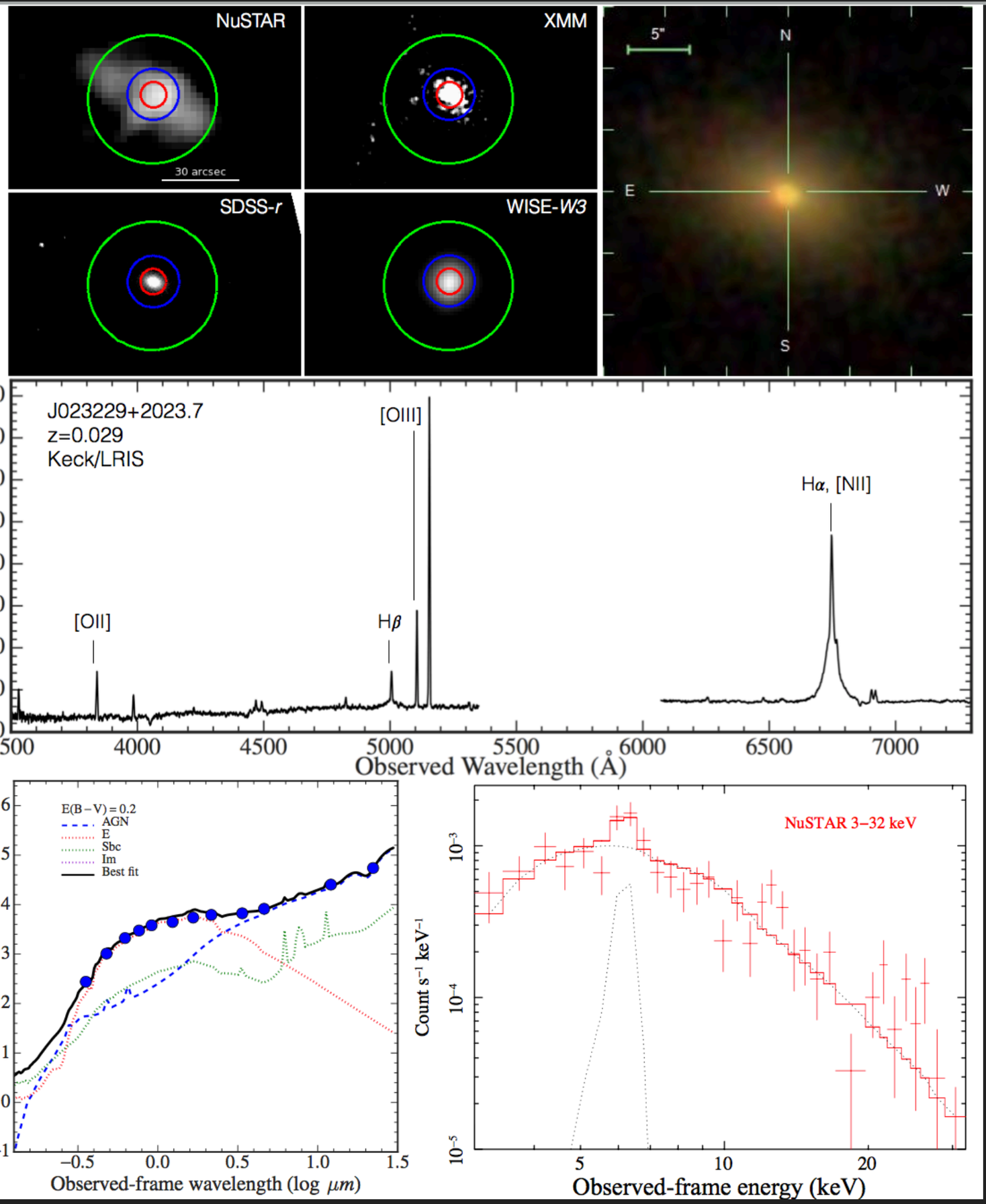


Lansbury+, in prep

11 NuSTAR selected low-mass AGNs

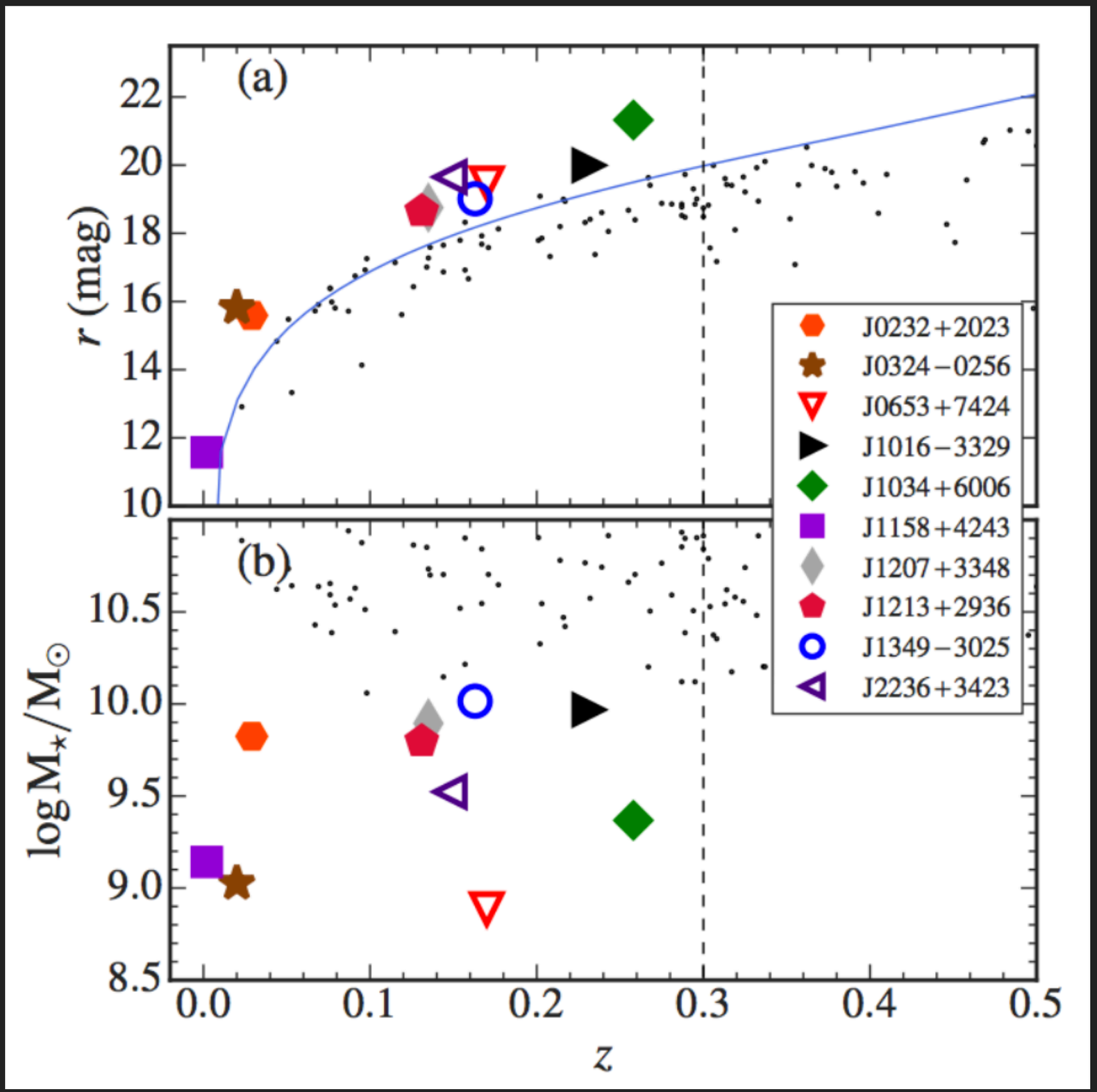


- r - r(L*) >0.5 (Kelvin+2014 LF)
- z<0.3
- 10 out of 248 extragalactic objects in the NuSTAR serendipitous survey

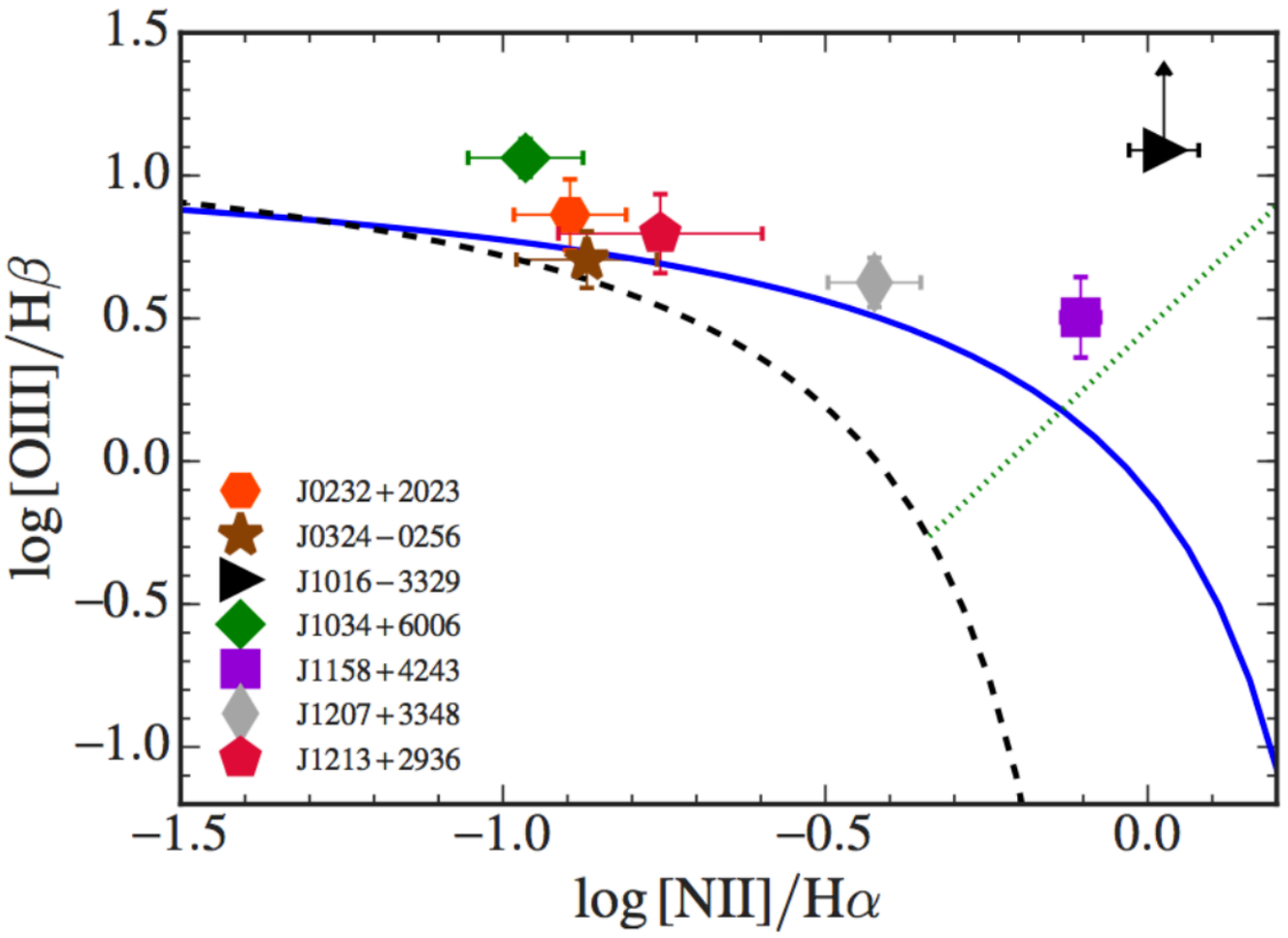


- Optical spectra
- SDSS/ SuperCOSMOS
- WISE
- 2MASS
- Soft X-ray XMM-Newton, Swift/ XRT or Chandra
- SED-fitting : M_{star}
- X-ray analysis: N_H

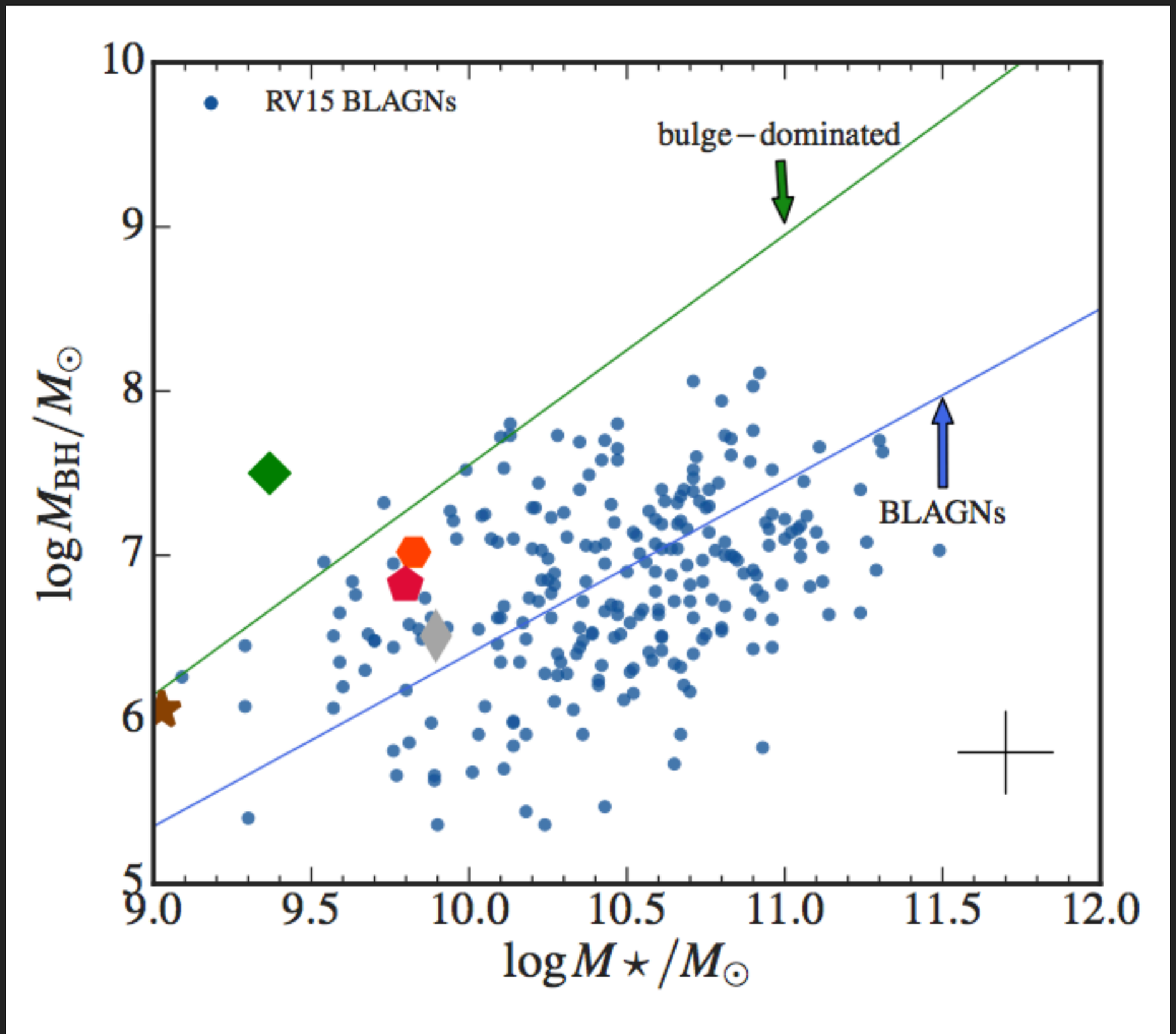
11 NuSTAR selected low-mass AGNs



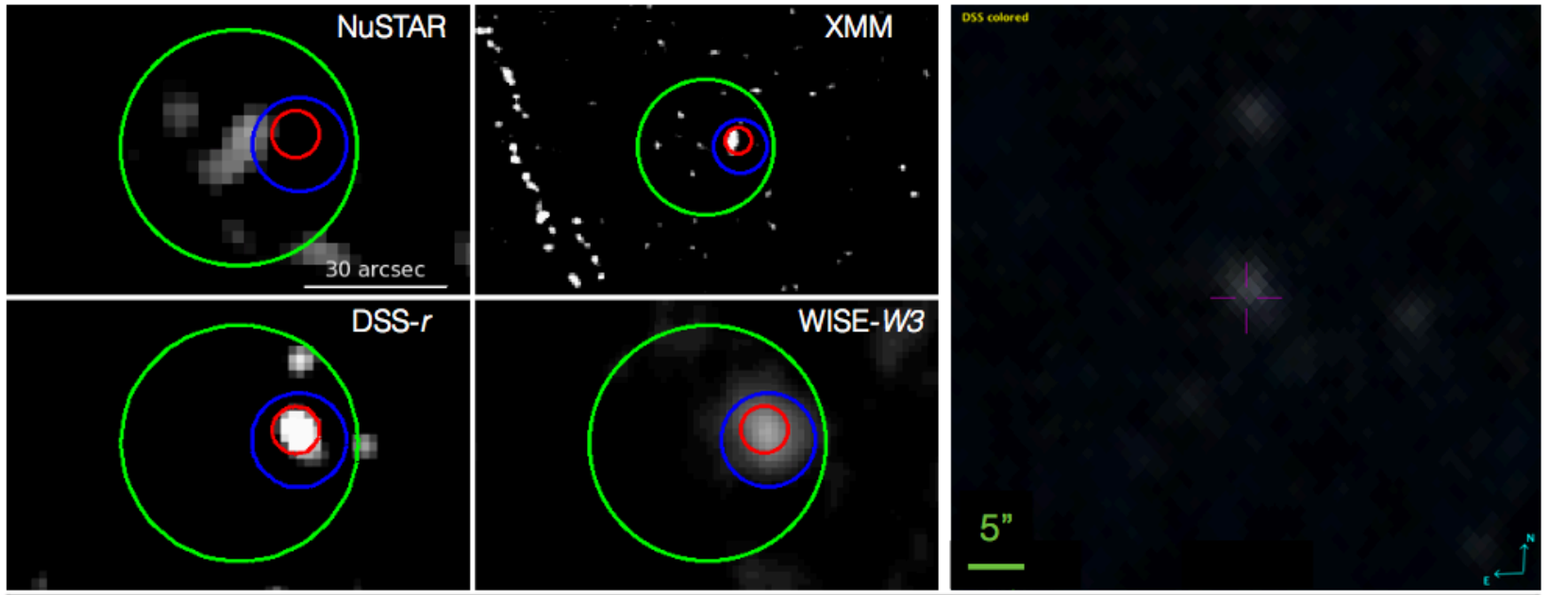
- r < r(L*) (Kelvin+2014 LF)
- 10 out of 248 extragalactic objects in the NuSTAR serendipitous survey
- $<M_{star}> = 5.9 \times 10^9\ M_{sun}$
- 7 sources have AGN-like optical spectrum
- 8 AGNs with $L_{2\text{-}10keV} > 10^{42}$ erg/s

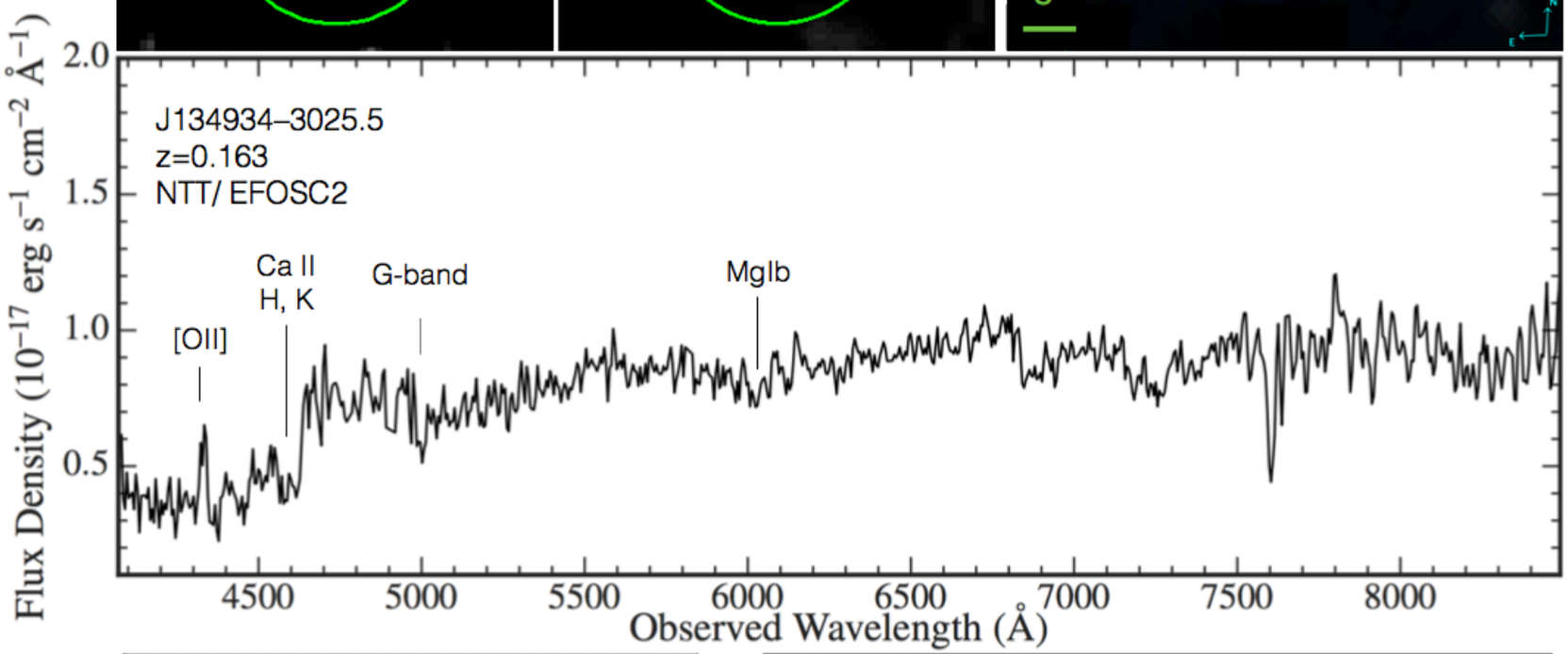

log [OIII]/Hβ
log [NII]/Hα
J0232+2023
J0324−0256
J1016−3329
J1034+6006
J1158+4243
J1207+3348
J1213+2936

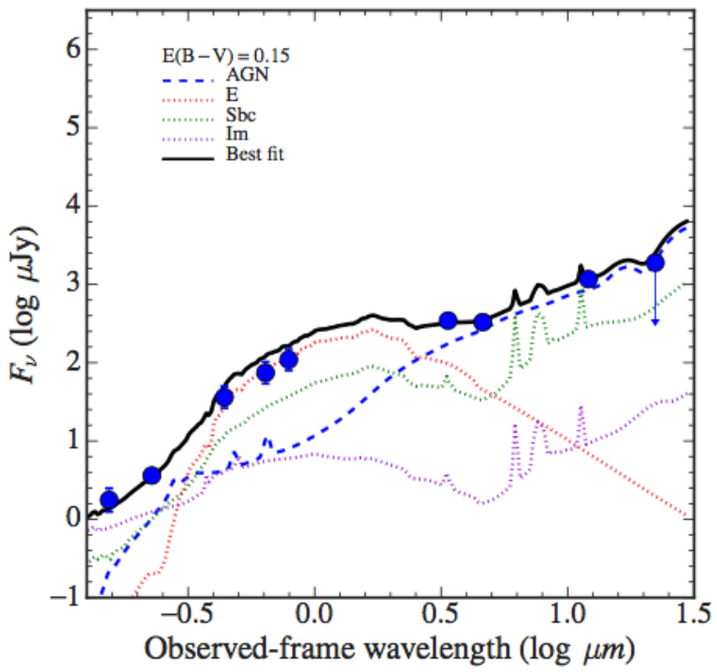
J0232+2023
FWMH:
3087 km s-1
J1207+3348
FWMH:
1427 km s-1
J0324−0256
FWMH:
1674 km s-1
J1213+2936
FWMH:
1732 km s-1
J1034+6006
FWMH:
4422 km s-1
Flux Density (10-17 erg s-1 cm-2 Å-1)
Rest Wavelength (Å)


RV15 BLAGNs
bulge – dominated
BLAGNs
10
9
8
7
6
5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
log M★/M⊙
log MBH/M⊙

- 3 of the 10 NuSTAR low-mass AGNs would not have been selected as an AGN using optical observations.



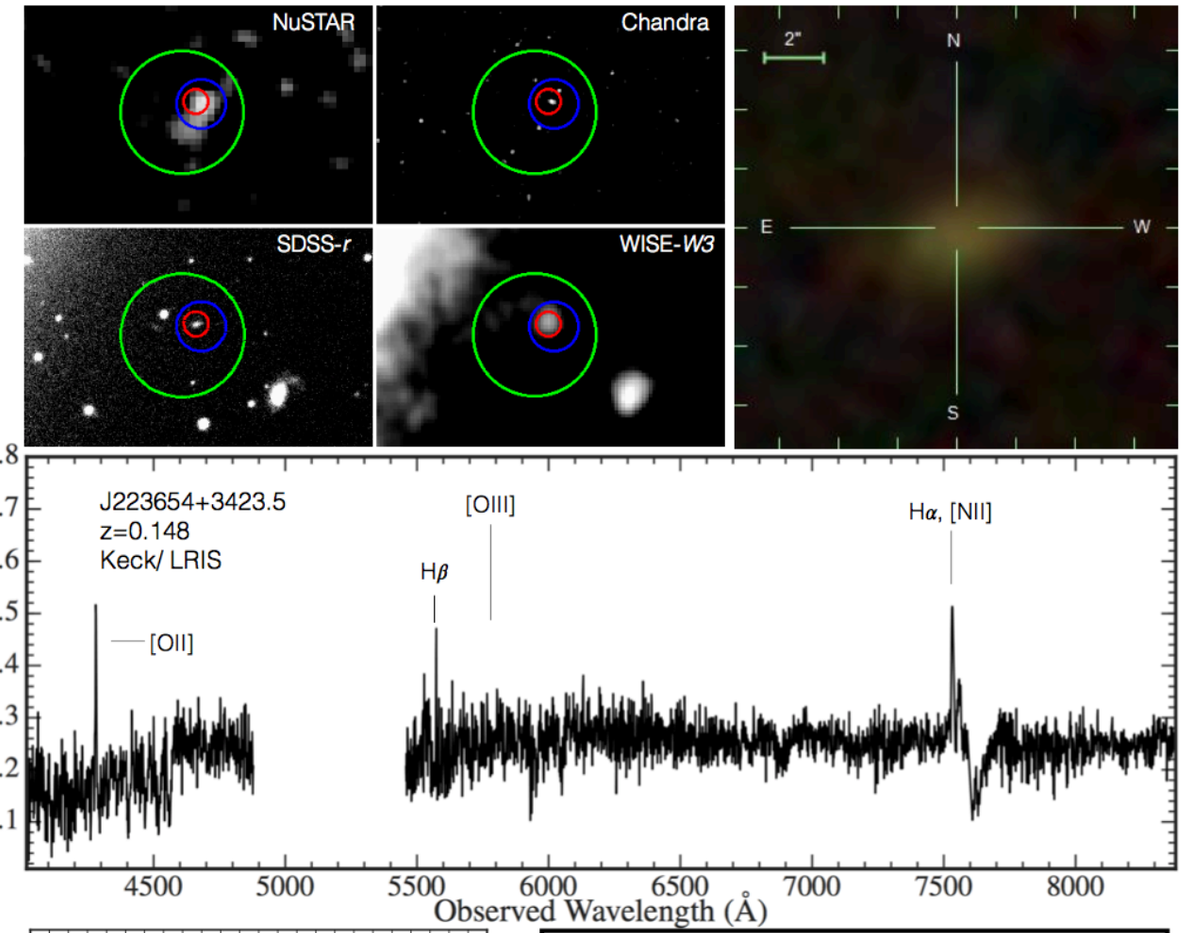


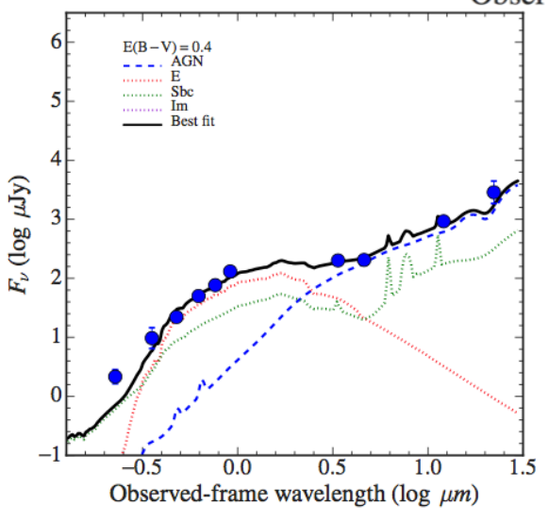


X-ray spectrum

not available

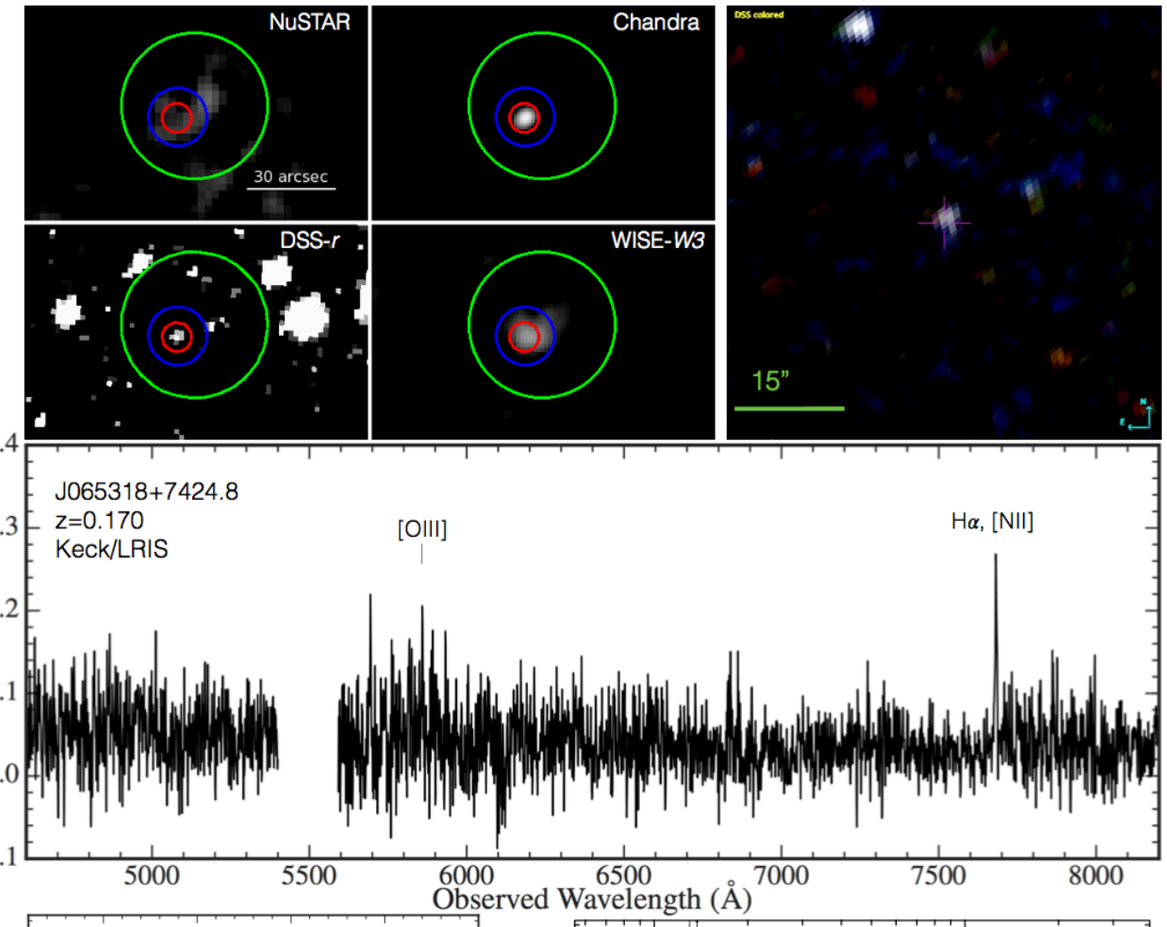
- $L_{2\text{-}10keV}=2.8*10^{42}$ erg/s
- No obvious mid-IR AGN component

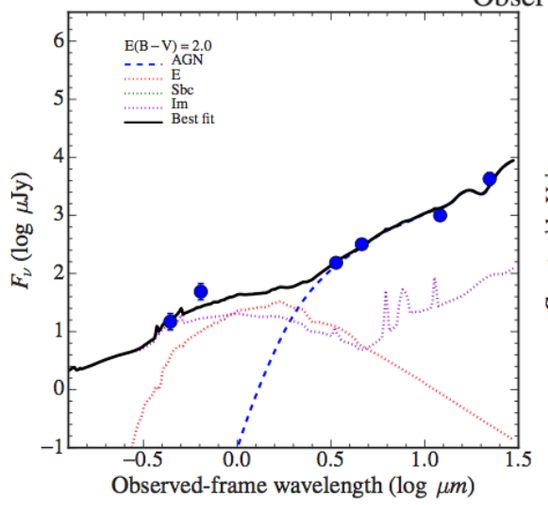


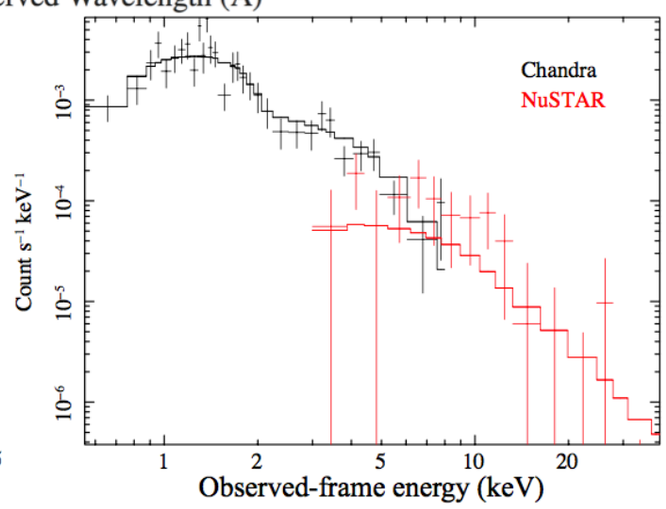


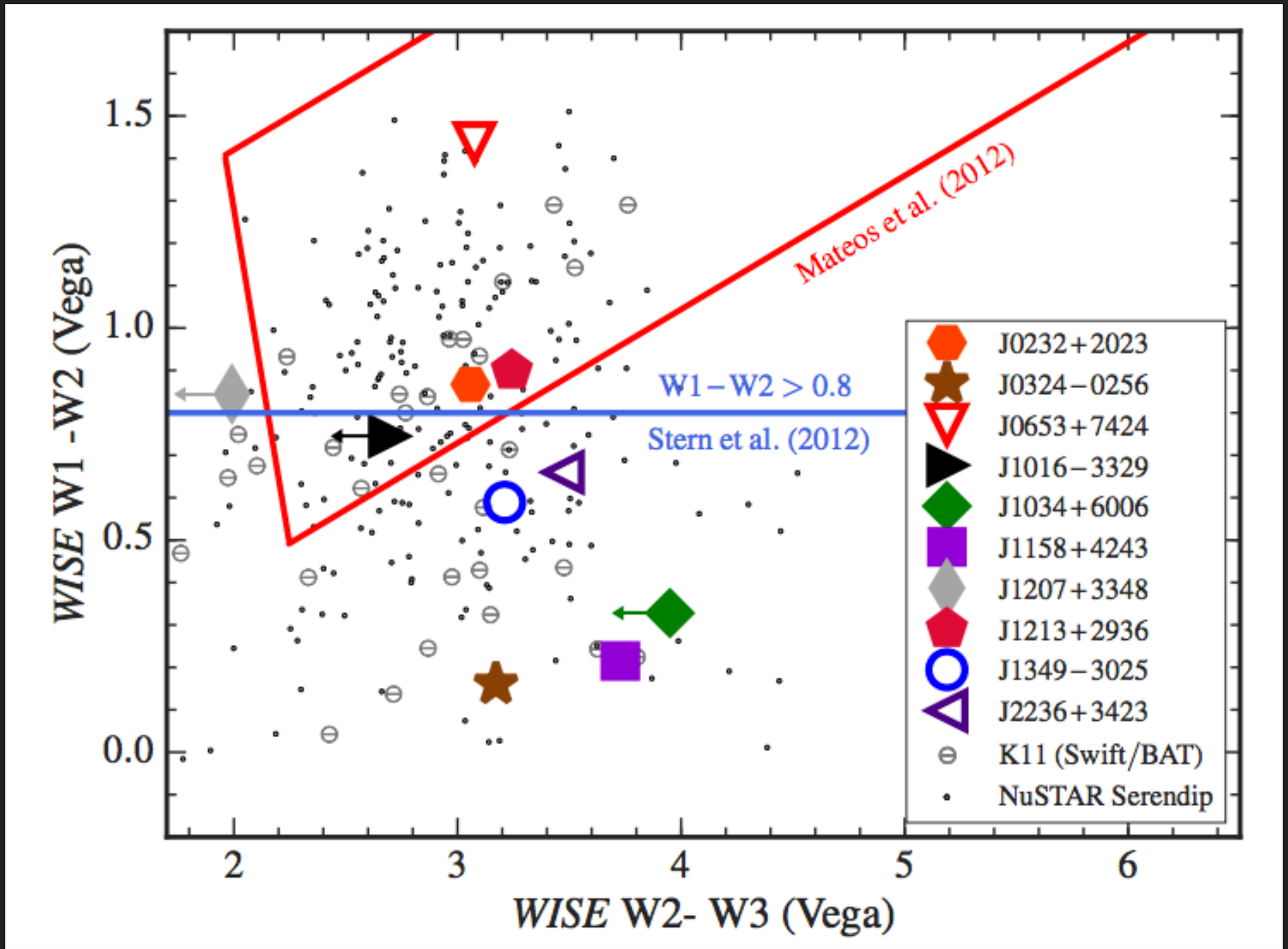
X-ray spectrum

not available



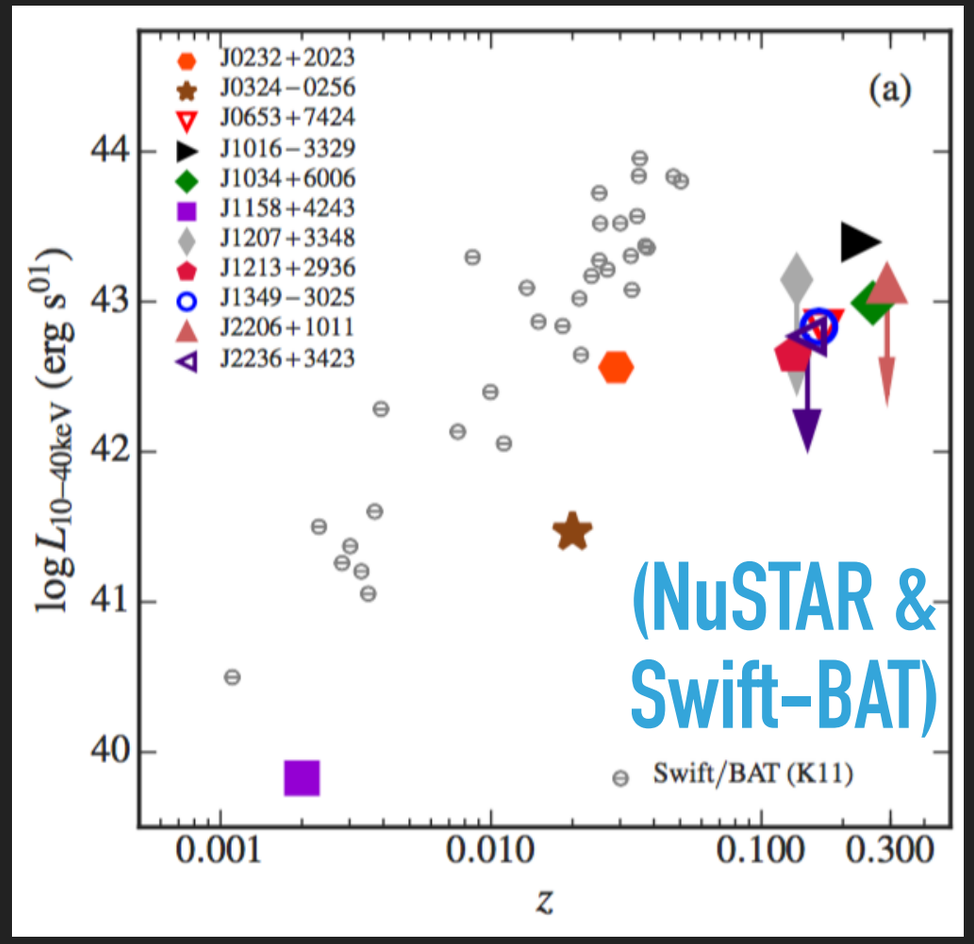


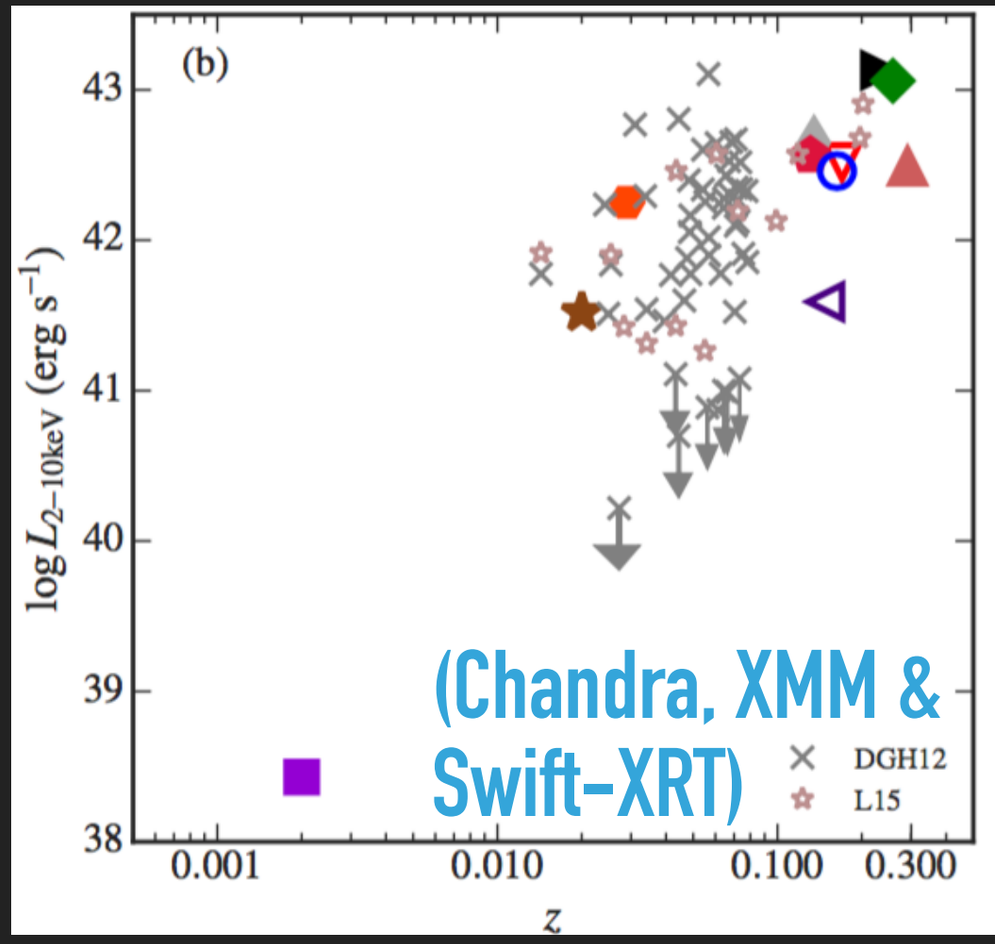



Mateos et al. (2012)
W1 − W2 > 0.8
Stern et al. (2012)
J0232+2023
J0324−0256
J0653+7424
J1016−3329
J1034+6006
J1158+4243
J1207+3348
J1213+2936
J1349−3025
J2236+3423
K11 (Swift/BAT)
NuSTAR Serendip
WISE W1 -W2 (Vega)
WISE W2- W3 (Vega)
1.5
1.0
0.5
0.0
2
3
4
5
6

Comparison to previous samples

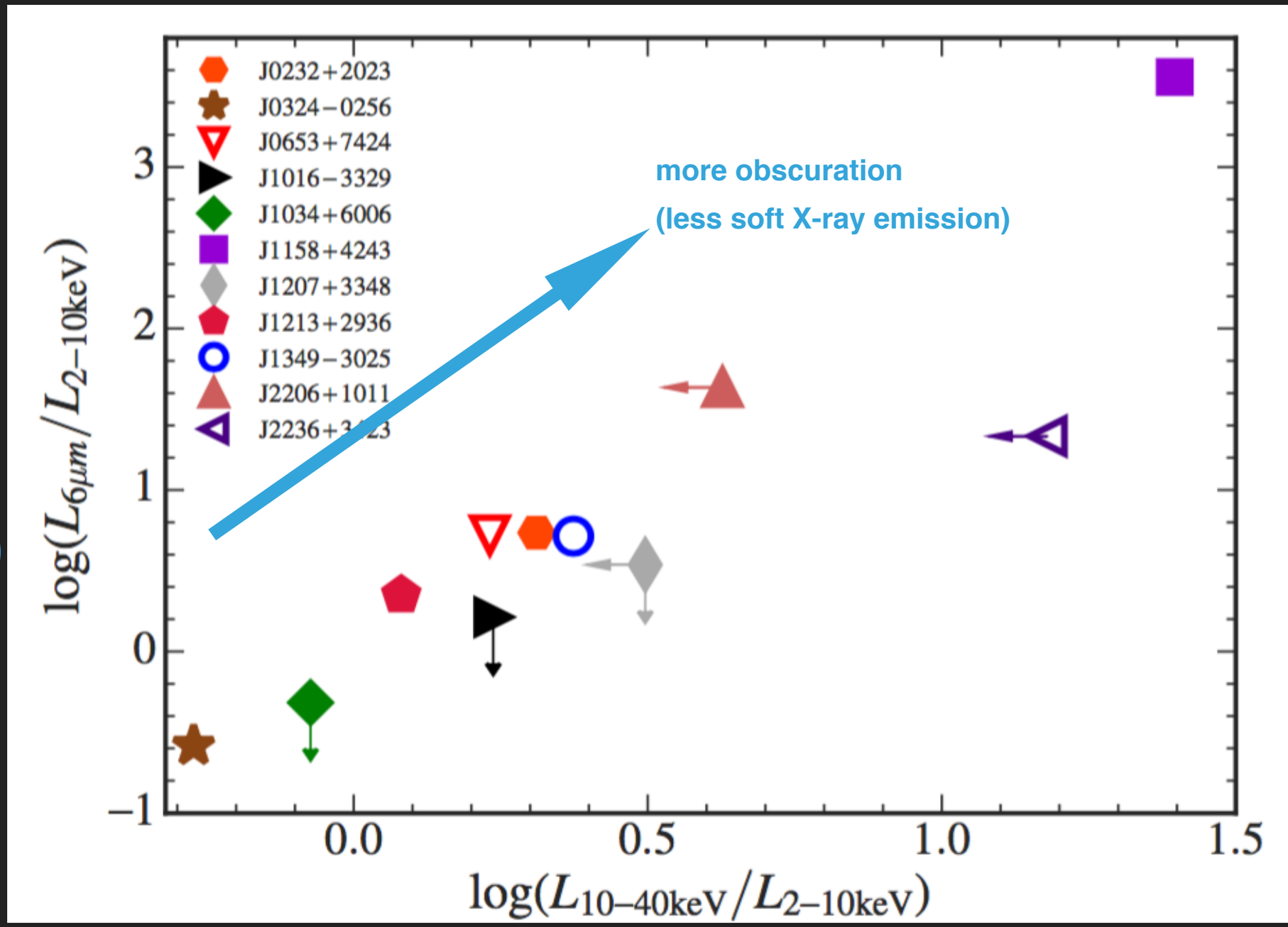
- AGNs hosted by $10^{10} M_{sun}$ galaxies in Swift/BAT sample (Koss+2011) are limited to very low-redshift or luminous sources.
- NuSTAR AGNs have soft X-ray luminosities similar to the soft X-ray follow-up observations of broad-line selected AGNs powered by IMBHs (Greene & Ho 2007, Dong et al. 2012, Ludlum et al. 2015.)





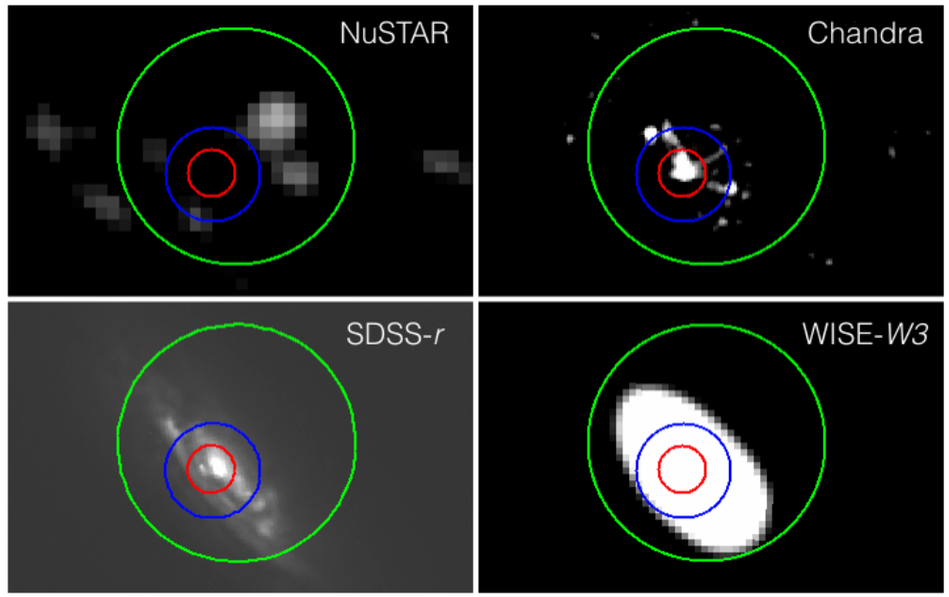
Where are the obscured AGNs?

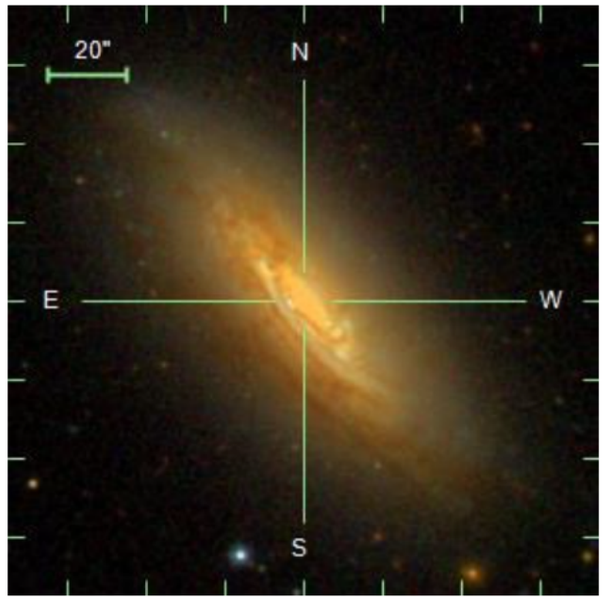
- Comparing AGN luminosity indicators – hard X-ray, soft X-ray and mid-IR

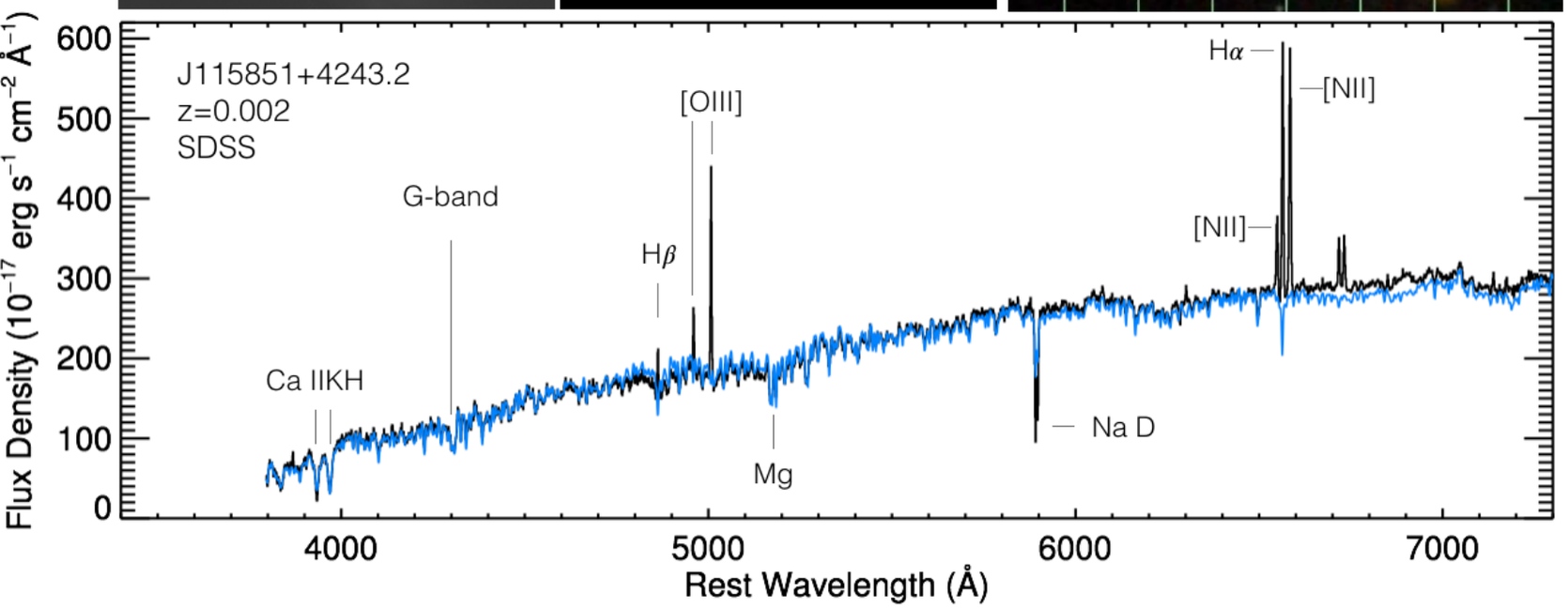


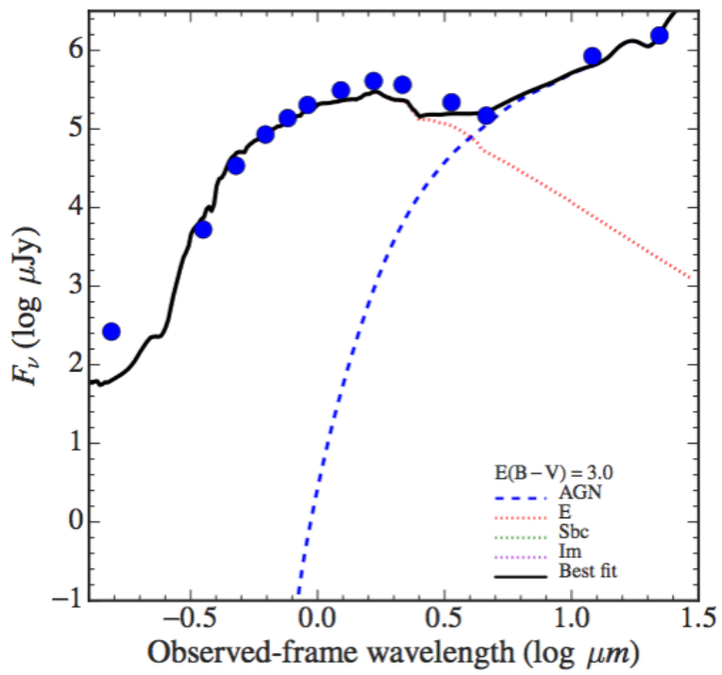
L(MIR) / L (soft X-ray)

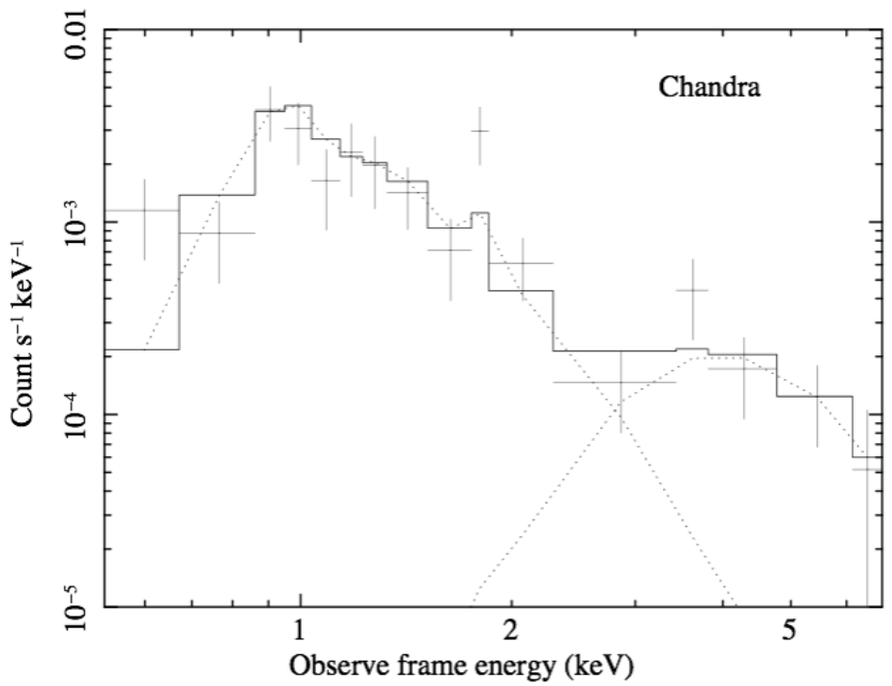
L(hard X-ray) / L (soft X-ray)



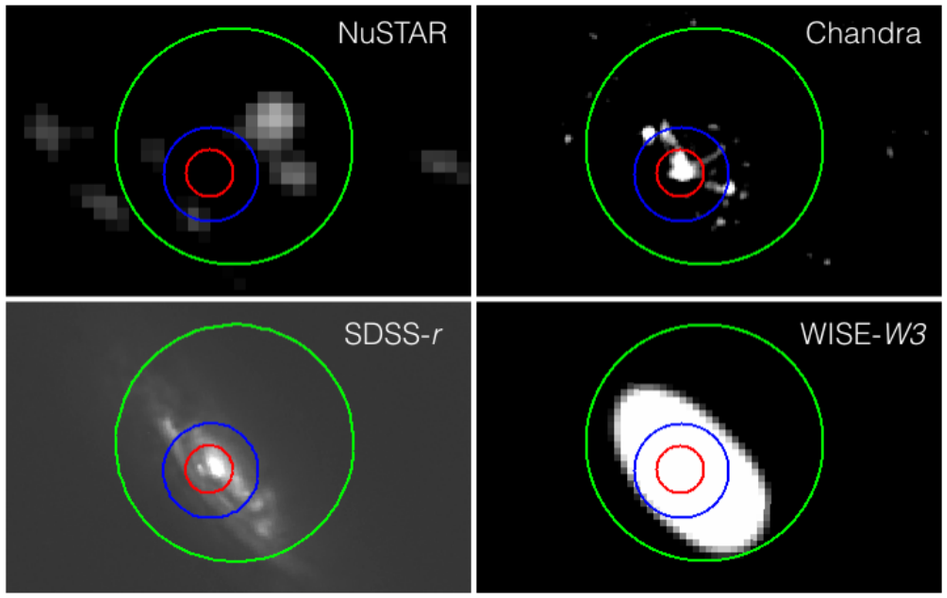


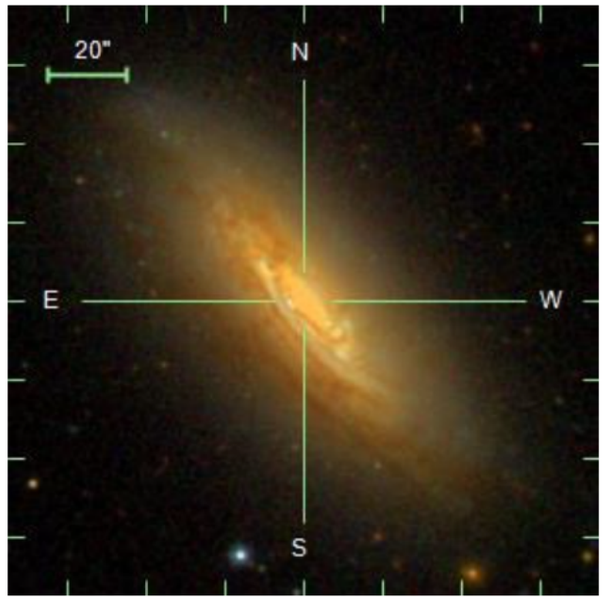


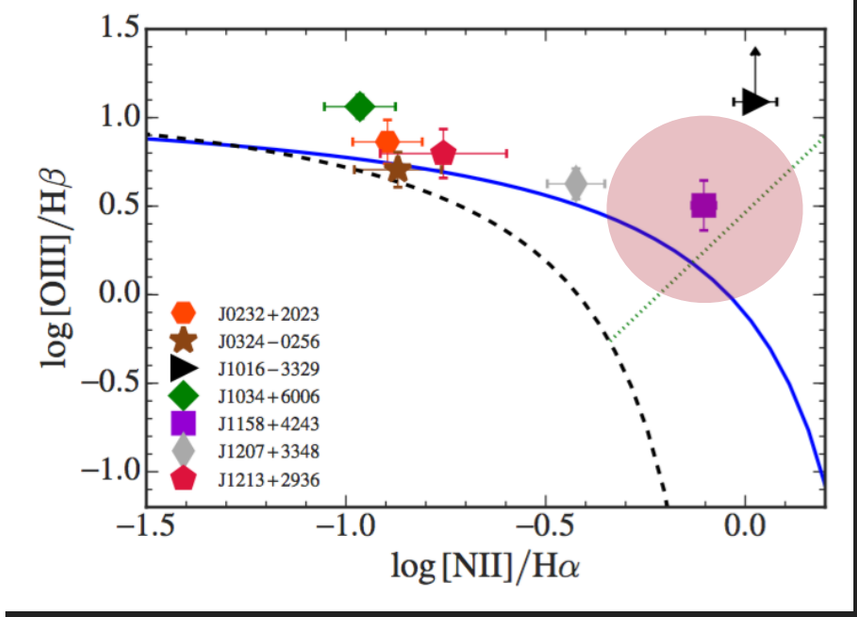


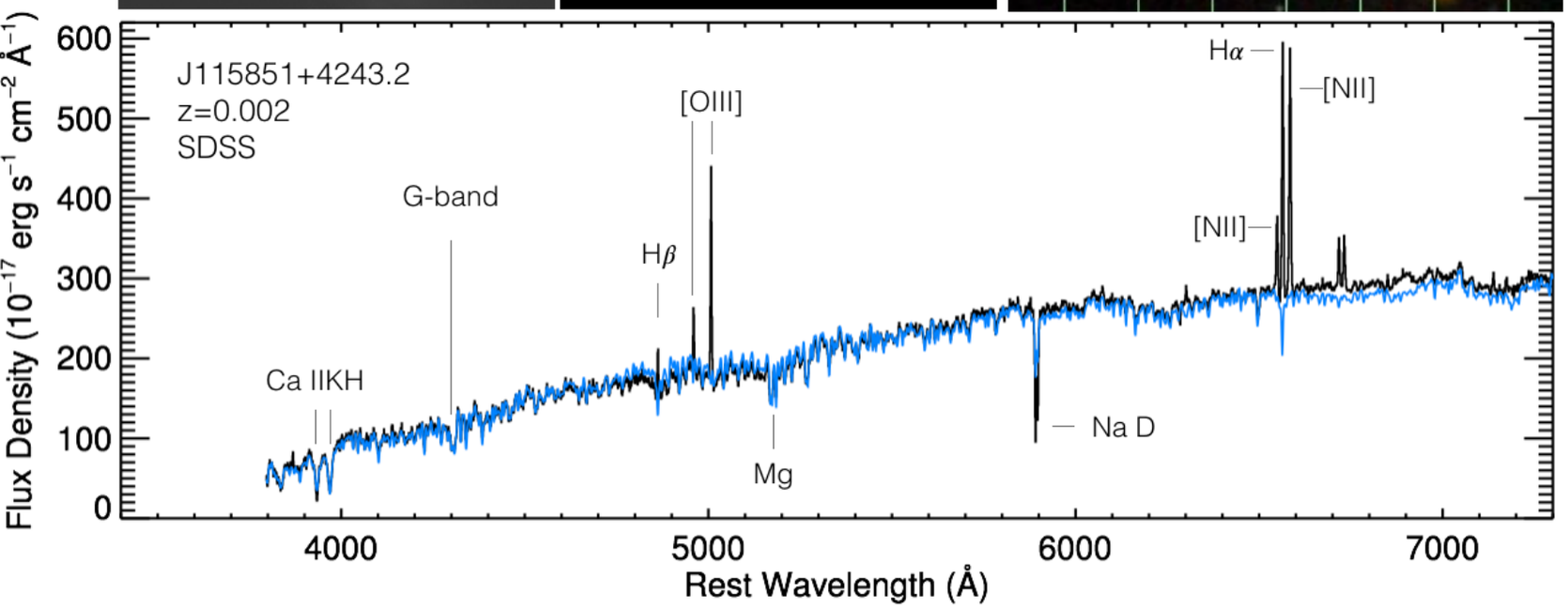


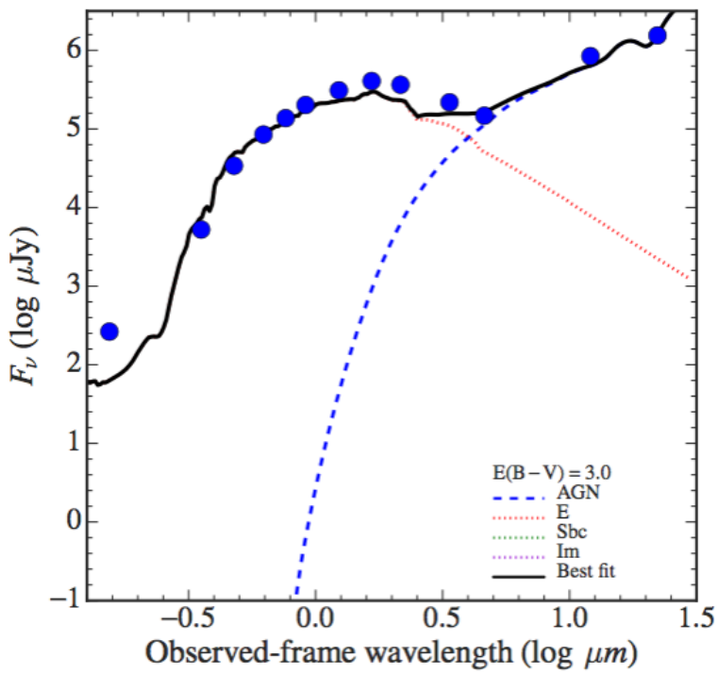
- $L_{2\text{-}10keV}=2.7*10^{38}$ erg/s
- Optical spectrum : quiescent galaxy + BPT AGN
- Mid-IR : obscured AGN
- X-ray : heavily obscured AGN
- Tentatively identified as a water maser source (Darling+ 2014)
- $N_H > 1.1*10^{23}$ cm^{-2} (TBABS(TBABS*VMEKAL+TBABS*ZPOW))

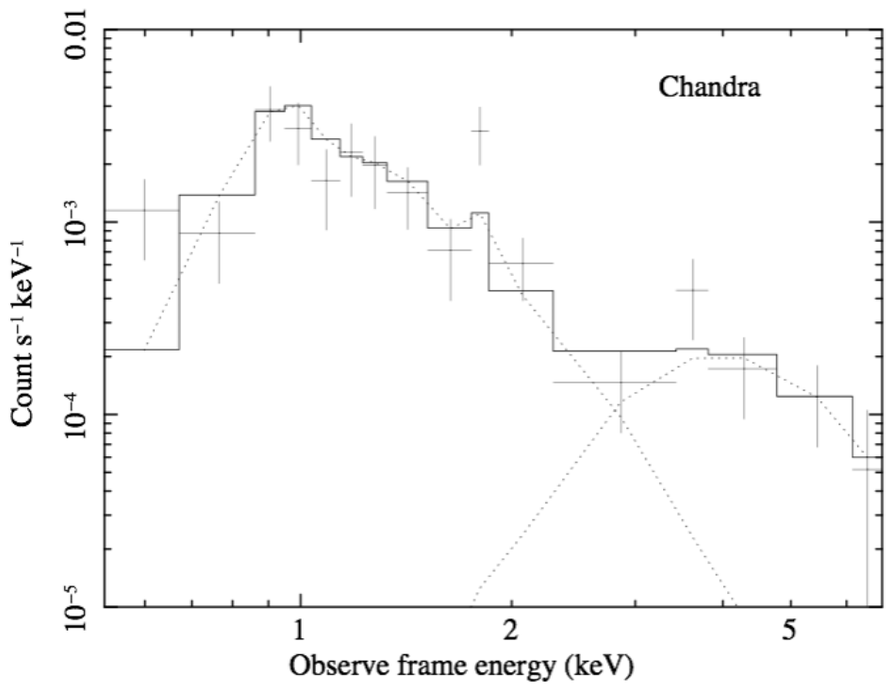












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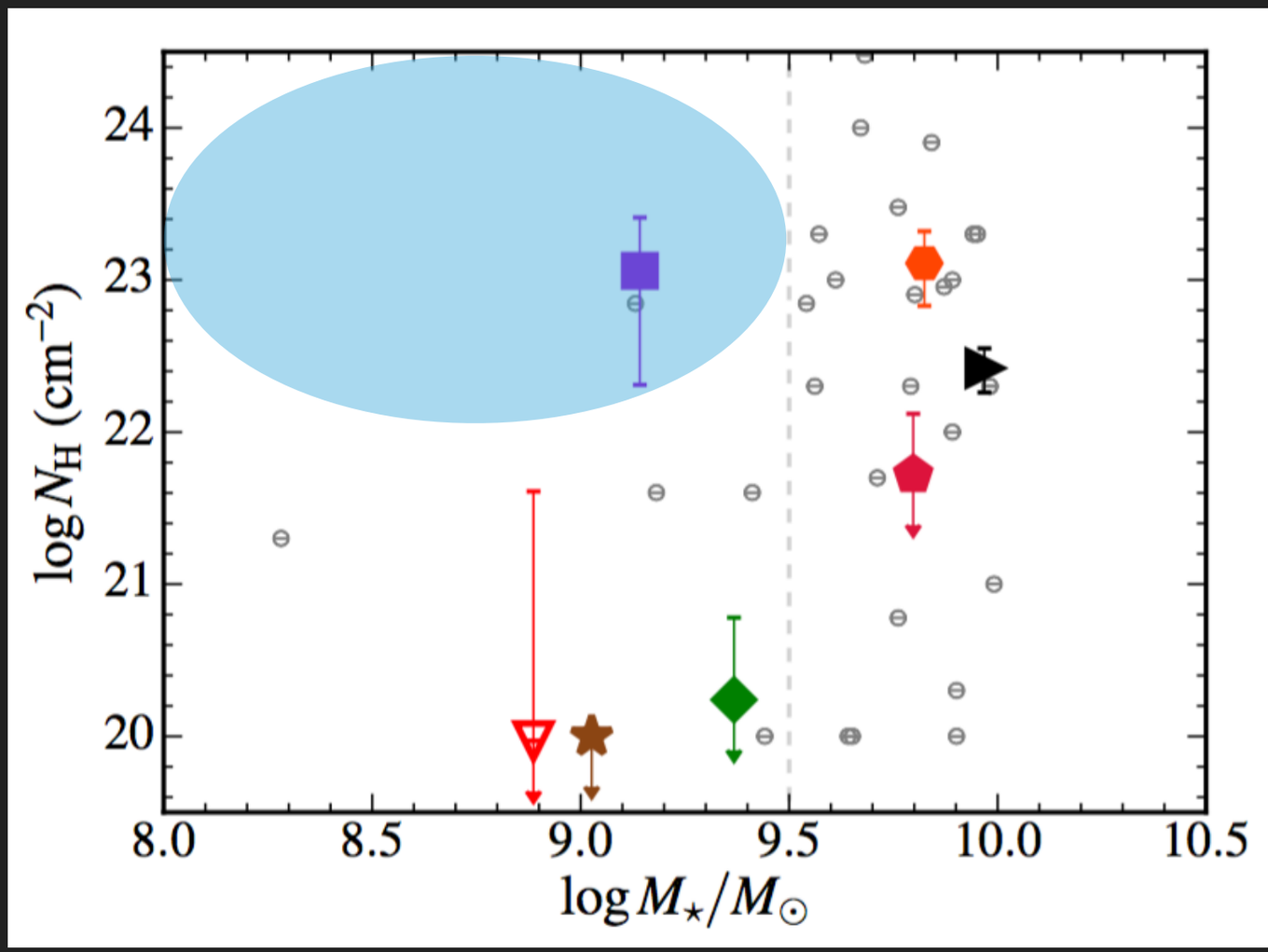
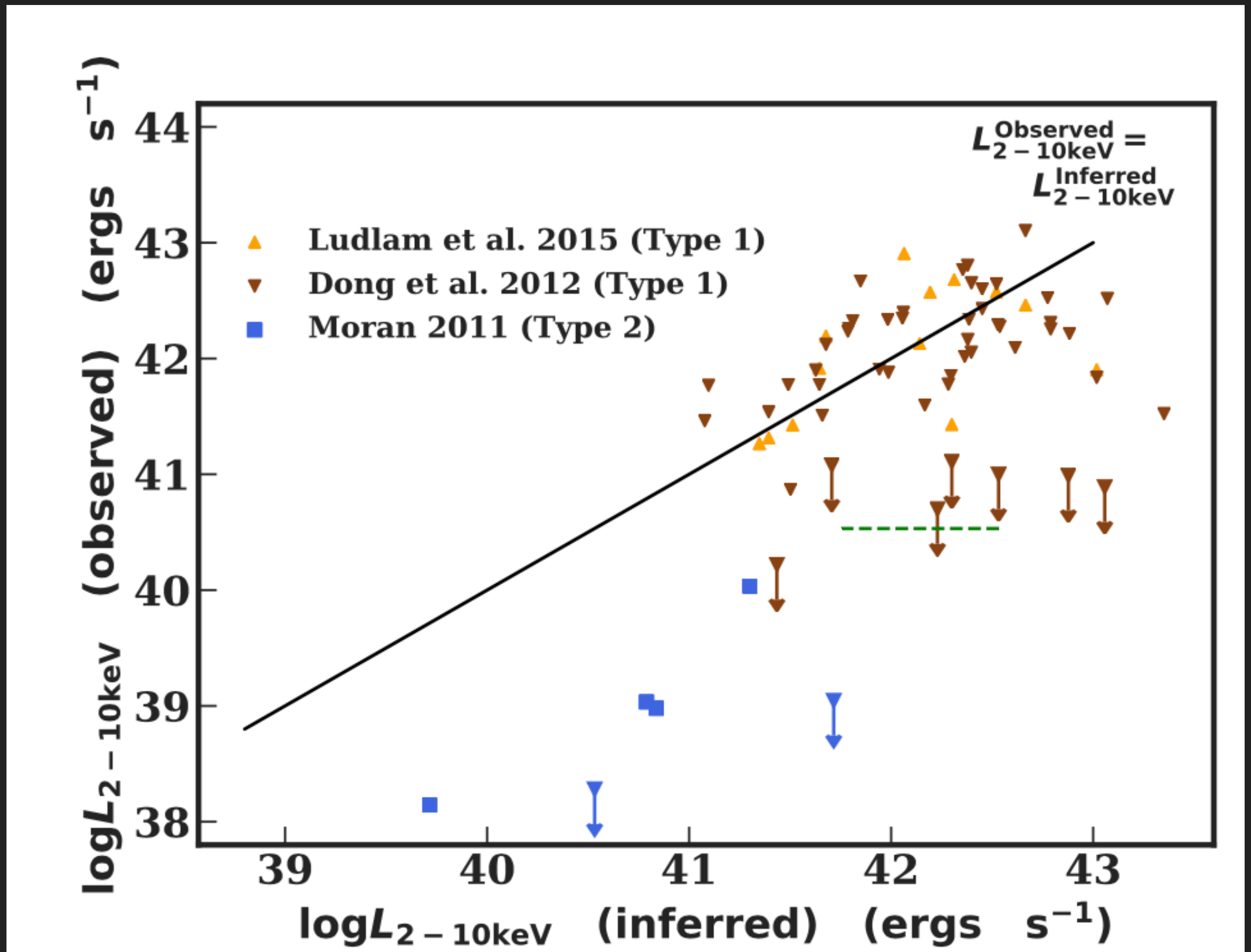
What can we learn about the agn population with the nustar sample

- Combine the 7 NuSTAR objects with the 36 Swift/BAT objects hosted by low-mass galaxies ($M_{star}<10^{10}M_{sun}$)
- NuSTAR has doubled the sample size of hard X-ray selected obscured AGN in dwarf galaxies

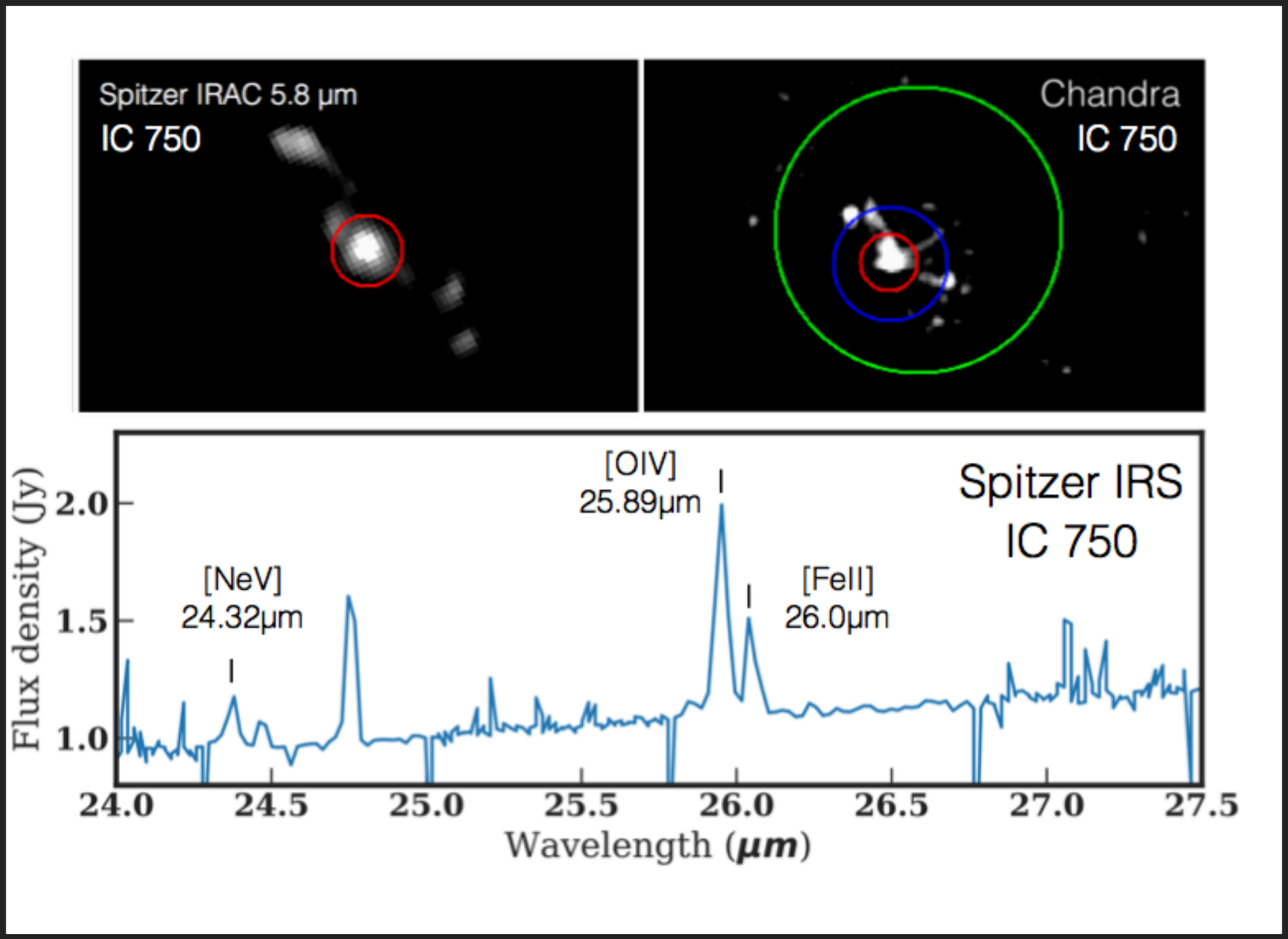
Only two objects with $N_H > 10^{22}$ cm^{-2} are hosted by ``dwarf'' galaxies



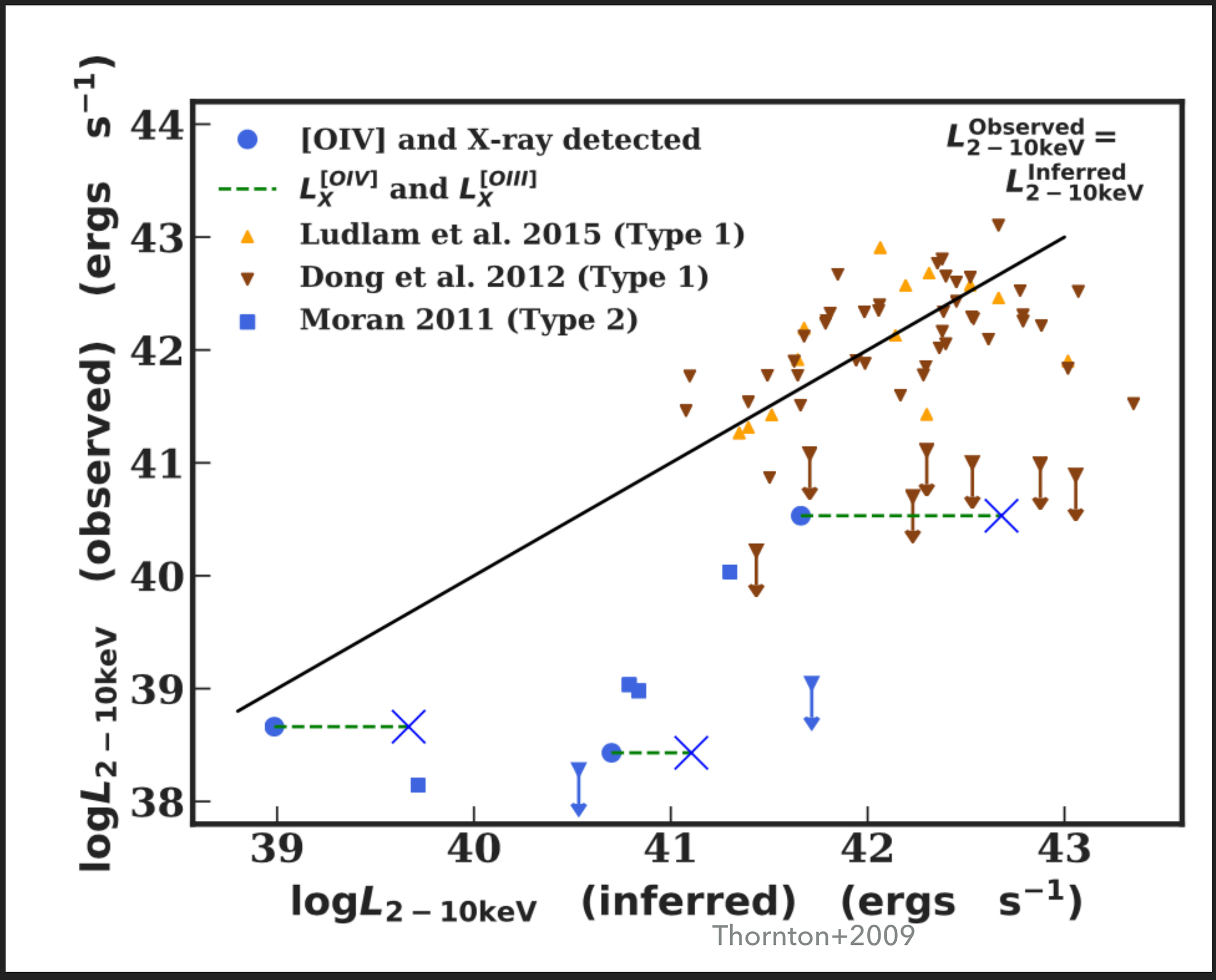
How do we find more obscured AGNs in dwarf galaxies



How do we find more obscured AGNs in dwarf galaxies



Follow up galaxies selected with Mid-IR AGN lines!



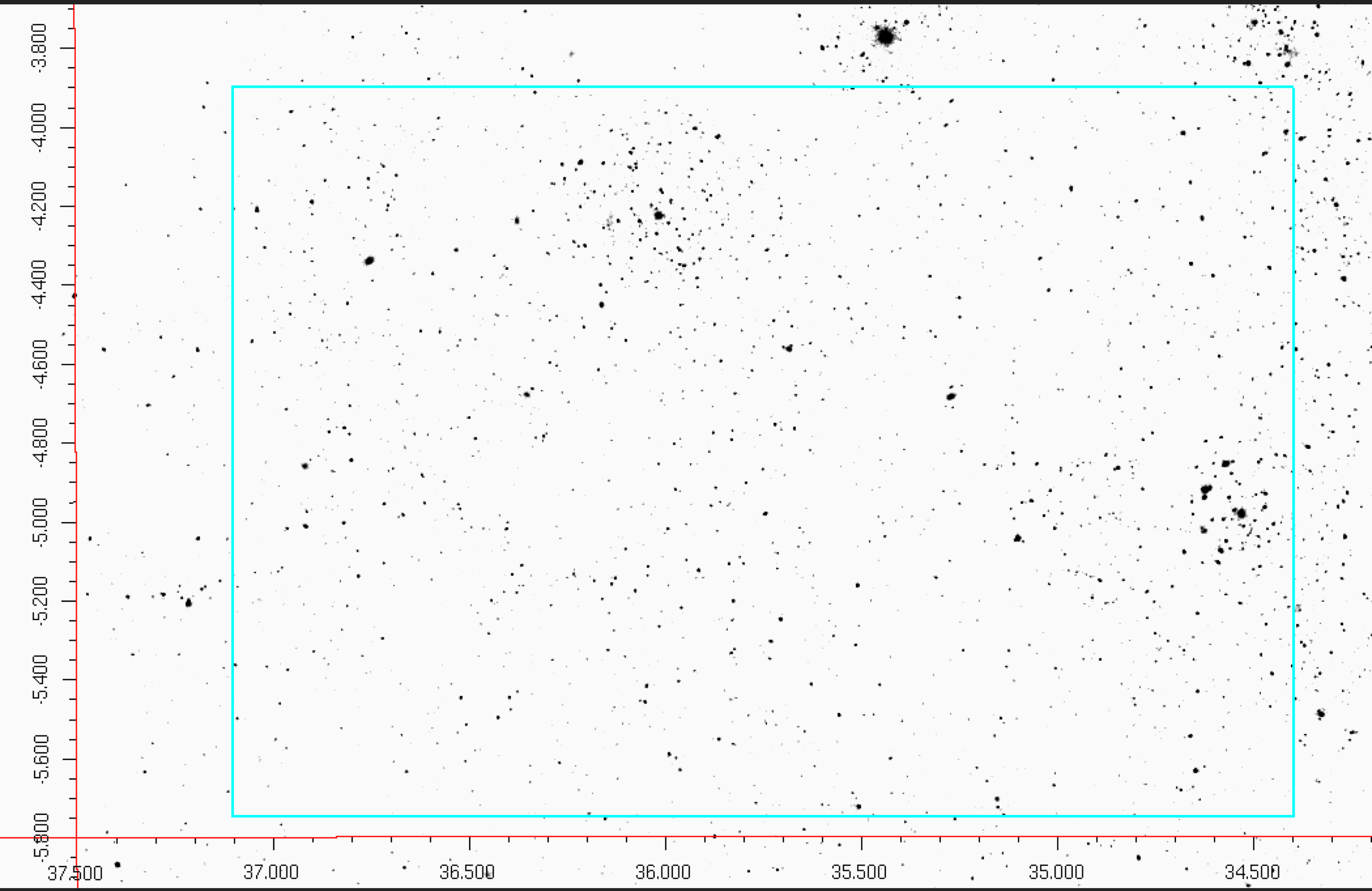
Thornton+2009

Conclusion

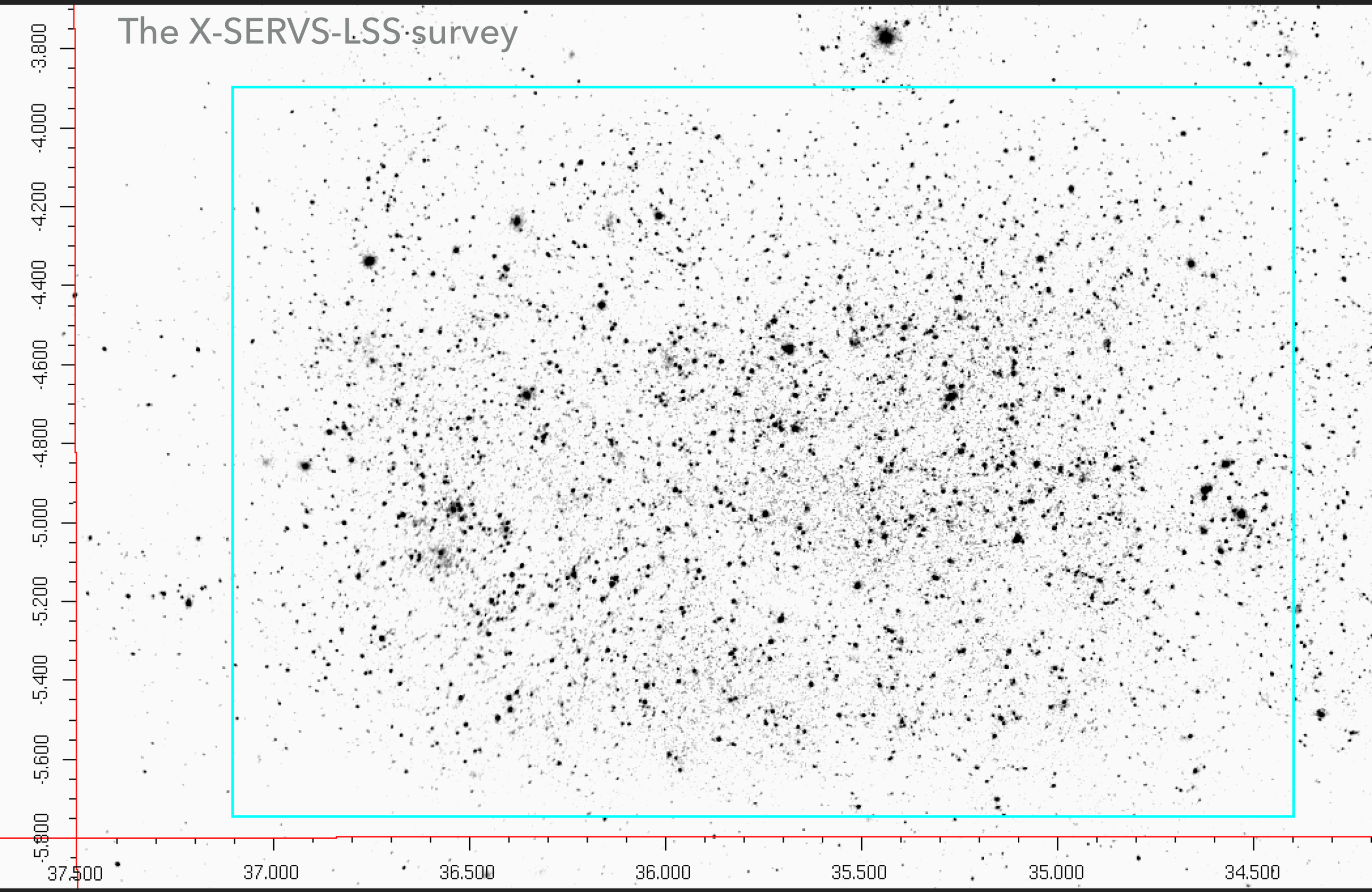
- NuSTAR survey is capable of selecting low-mass AGNs with soft X-ray luminosity similar to the broad-line AGNs hosted by dwarf galaxies.
- 3 of the 10 NuSTAR sample cannot be identified using optical emission lines
- One of the NuSTAR sample could be obscured by Compton-thick column densities.

How do we find more obscured AGNs in dwarf galaxies

- Deep-wide multiwavelength survey


-3.800
-4.000
-4.200
-4.400
-4.600
-4.800
-5.000
-5.200
-5.400
-5.600
-5.800
37.500
37.000
36.500
36.000
35.500
35.000
34.500

The X-SERVS-LSS survey



- 5.4 deg^2 XMM-Newton survey with ~10^15 erg/s/cm^2 sensitivity at 0.5-2 keV
- Exquisite multiwavelength coverage, including Spitzer SERVS, SWIRE, VIDEO, Subaru HSC, CFHTLS, Herschel HerMES, and dedicated spectroscopic campaign.