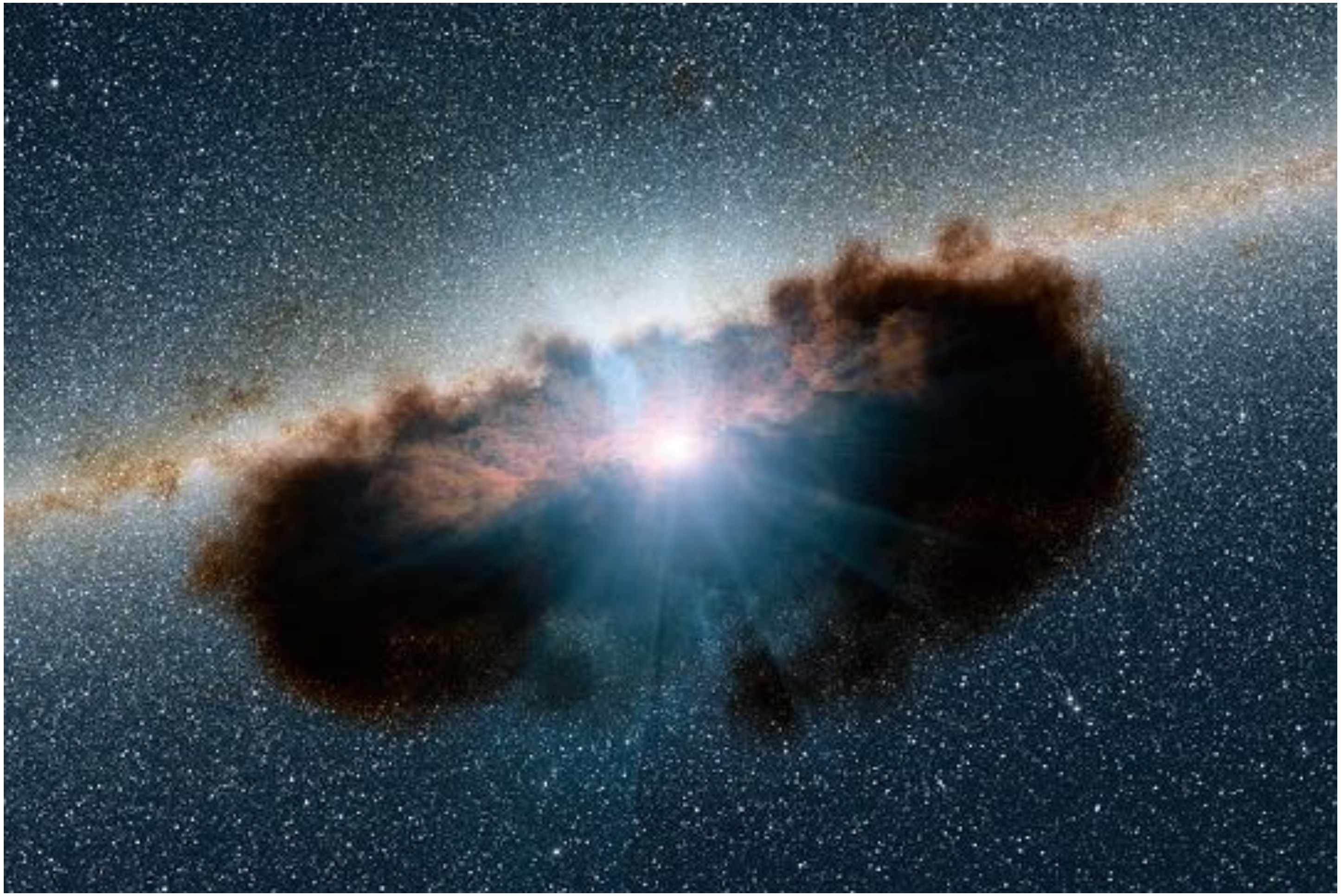


Finding Elusive AGN in the (mid)-Infrared

Almudena Alonso Herrero

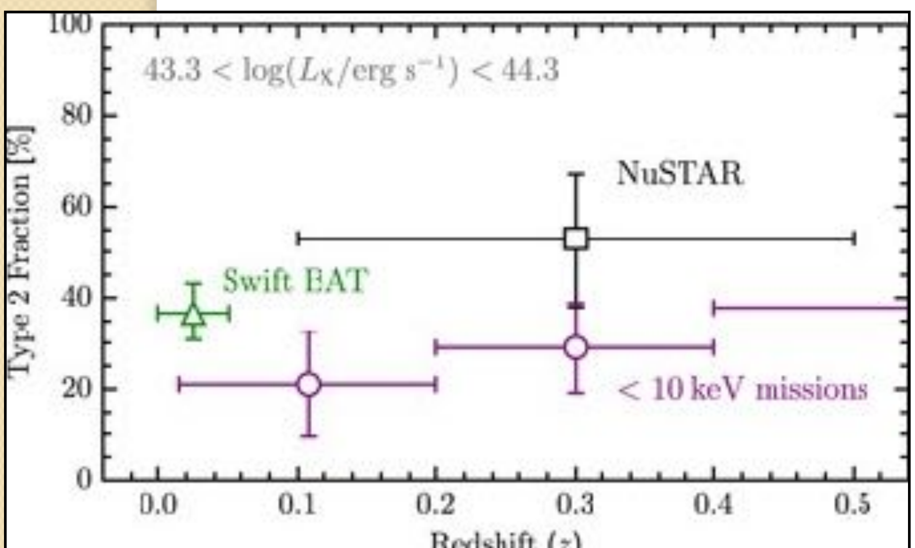
Recent evidence for missing AGN in X-ray (<10keV) surveys

A non-negligible fraction of luminous, heavily obscured (high covering factors) type-2 AGN X-ray detection (at energies < 10keV) are missing:

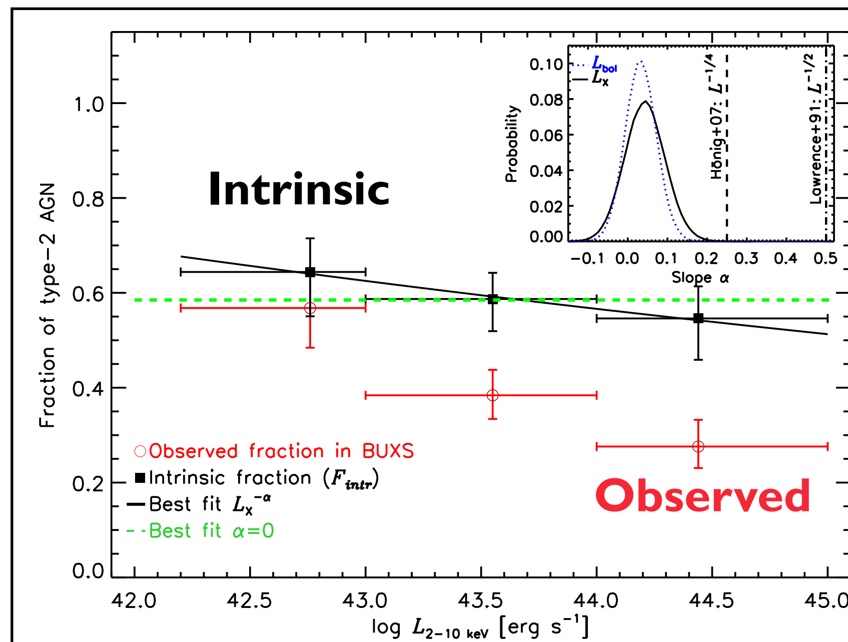
- NuSTAR Serendipitous Survey

Claudio Ricci's talk

- Comparison of optical fraction of type 1/type 2 of X-ray selected AGN with the modelled distribution of torus geometrical covering factors

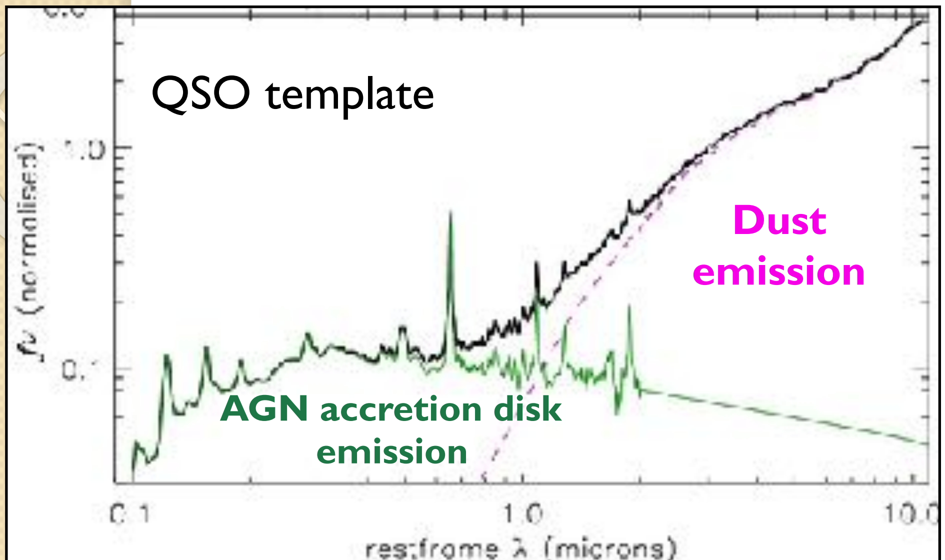


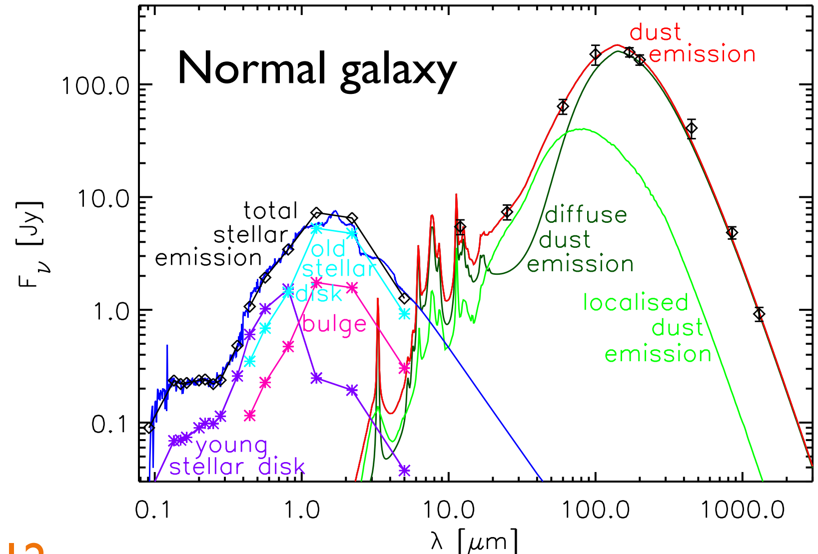
Landsbury+2017



Mateos+2017

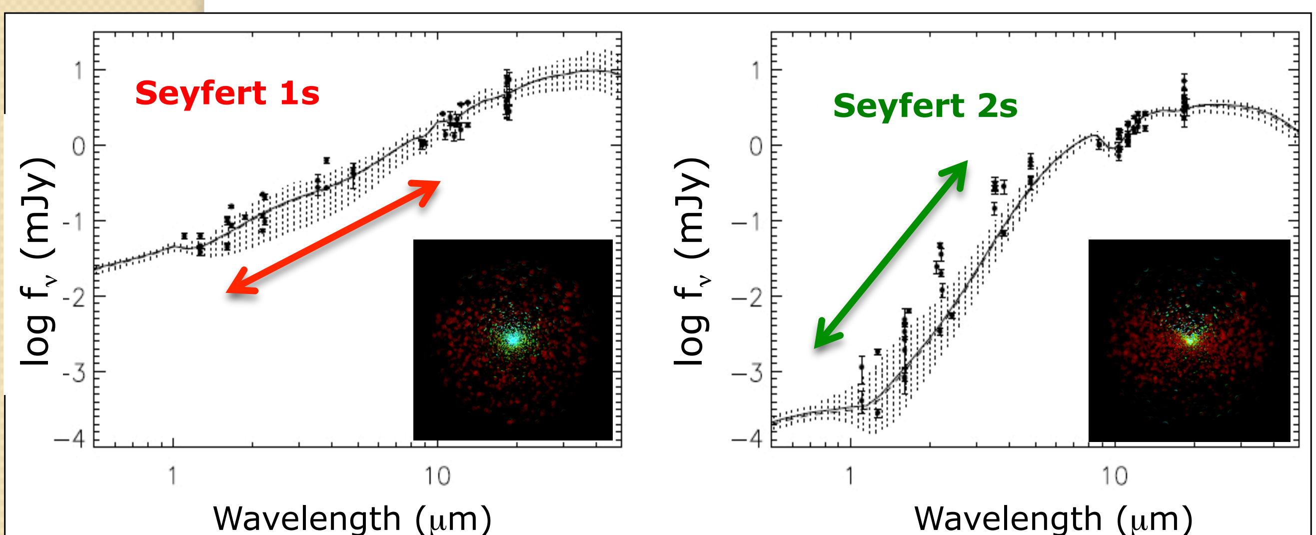
Thermal IR continuum emission of radio quiet AGN





Hernán-Caballero+2016, Elvis+1994, 2012, Glikman+2006, Richards+2001, 2006, Hill+2014, Kim+2015

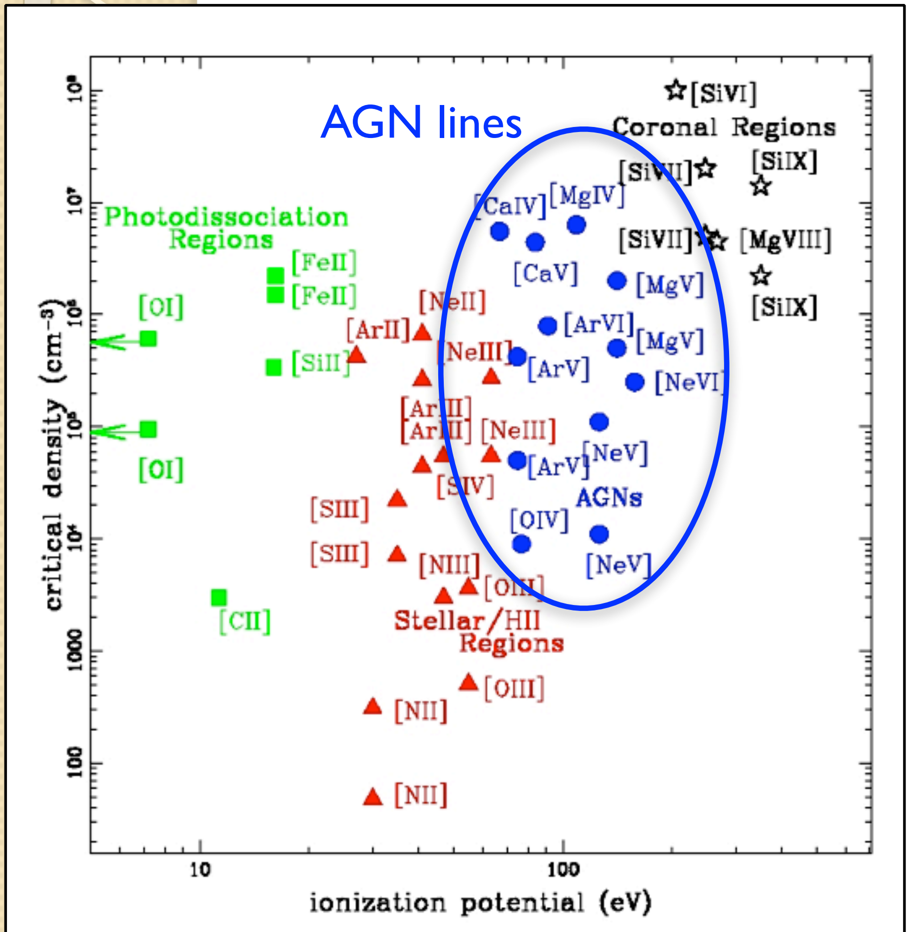
Popescu+2011



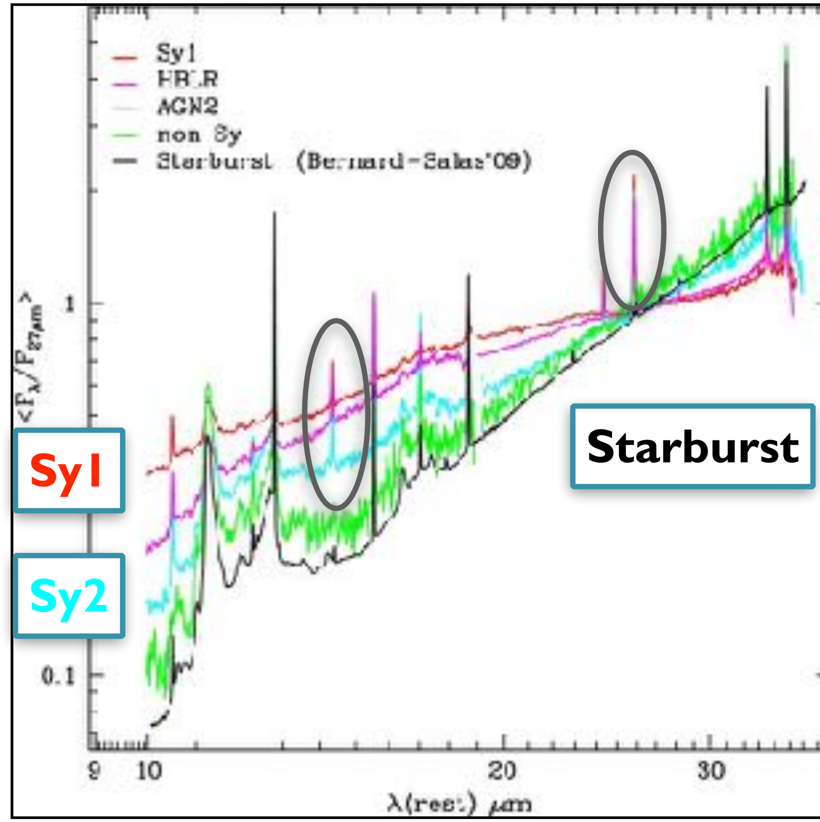
Ramos Almeida+2011, see also Alonso-Herrero+2001, 2003, 2011, 2014, Ichikawa+2016

Infrared lines in AGN

Spinoglio & Malkan 1992



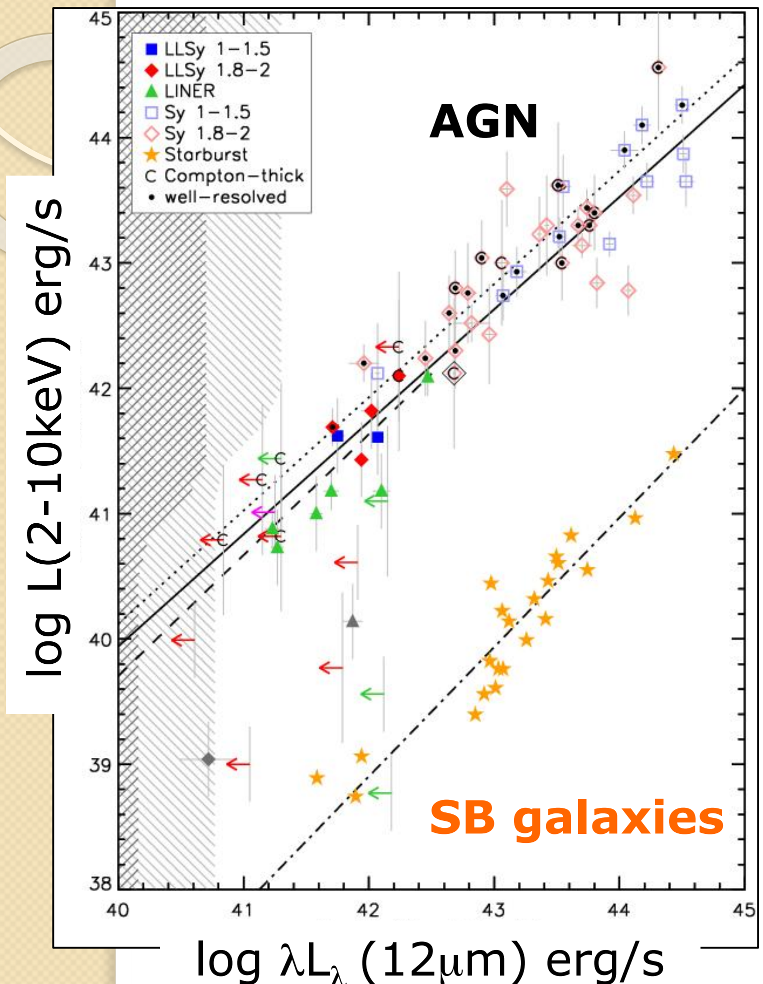
Tommasin+2010



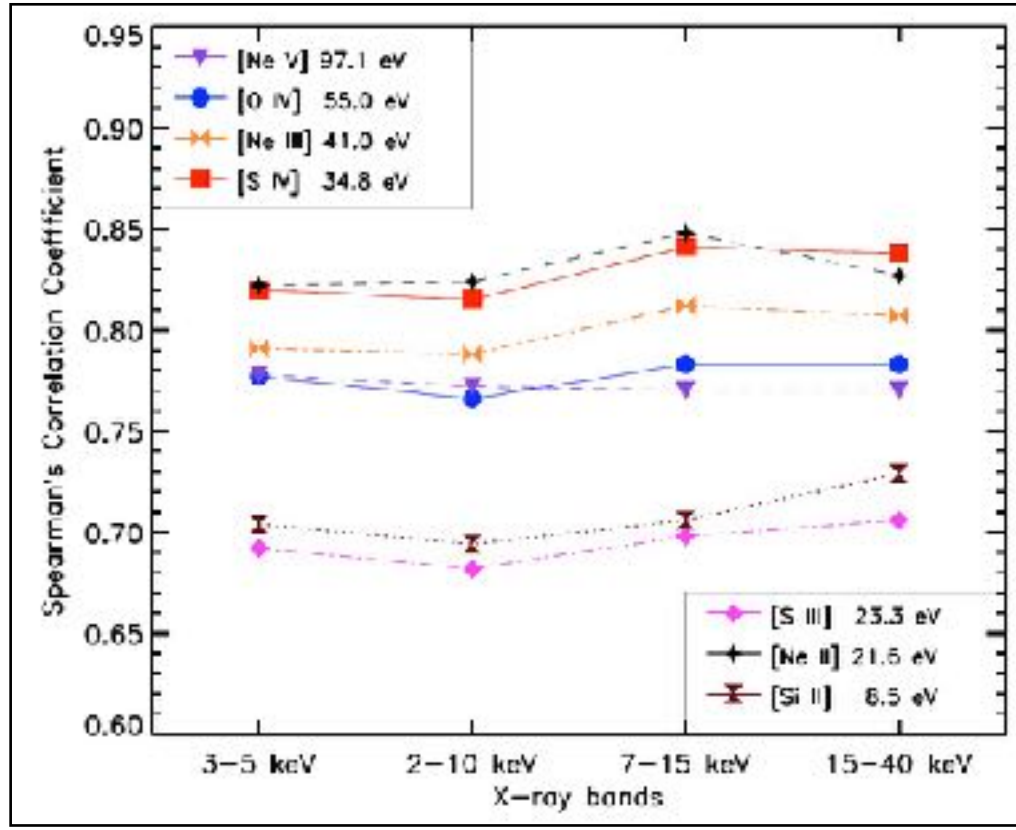
Brightest AGN lines in the mid-IR spectral range:

- [NeV] at 14.3μm and 24μm (91.7eV)
- [OIV] at 25.9μm (54.9eV)

The X-ray vs. mid-IR correlations



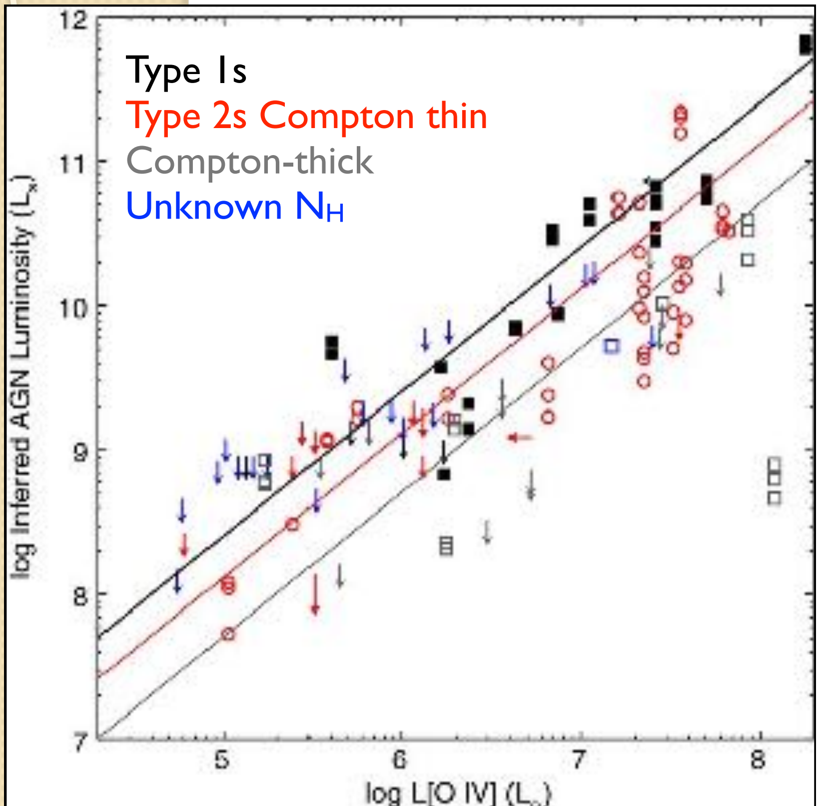
Asmus+2011,2015, see also Gandhi+2009, Levenson+2009, Mason+2012 and many more



García-Bernete+2017

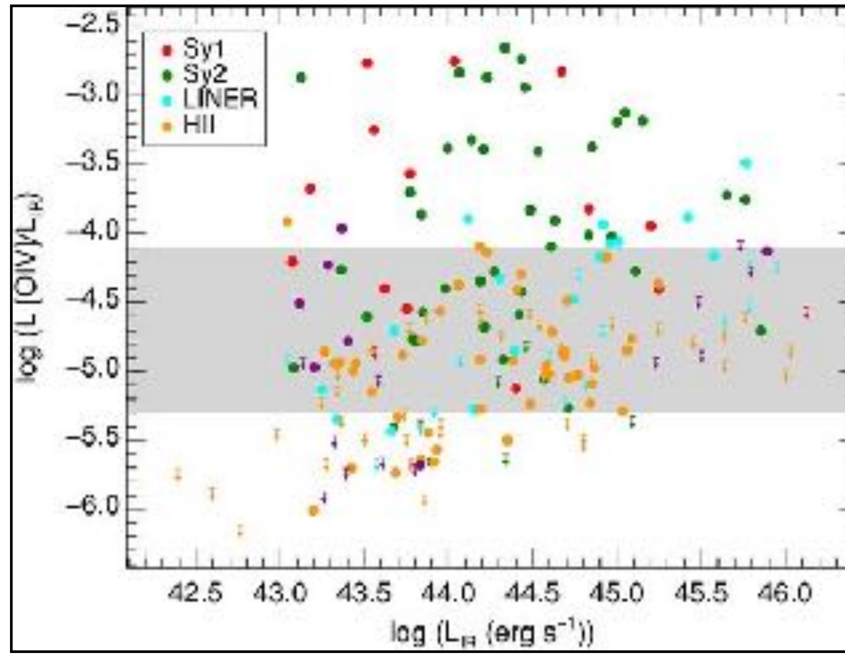
Kohei Ichikawa's talk

The [OIV] line at 25.89μm: AGN and/or SF indicator



Rigby+2009

This line could be used potentially to estimate the AGN power in very obscured and Compton-thick AGN and ULIRGs



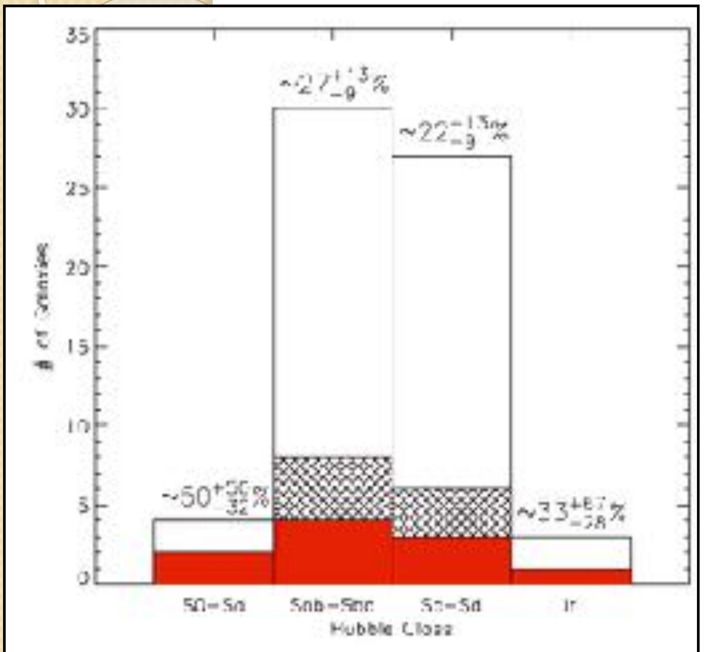
See also Melendez+2008, Diamond-Stanic & Rieke 2009

Pereira-Santaella+2010

This line can also be excited by SF activity. However, SF excitation important when SF is about x20 more luminous than the AGN

AGN fraction in nearby galaxies using the [NeV]14.3μm line

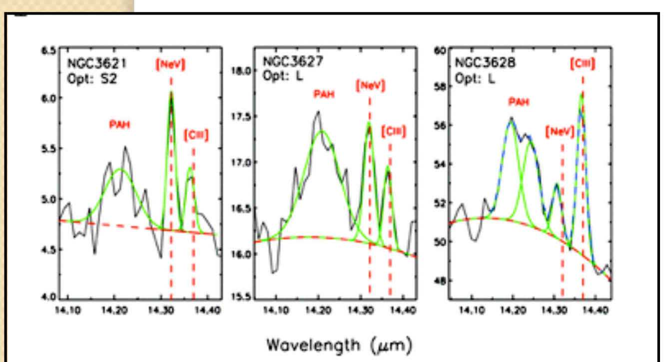
Dave Alexander's talk



Nearby galaxies: AGN fraction ~27%(+8/-6%)
-50% of these are not identified in the optical
-Strong SF activity and/or moderate extinction (a few Av)

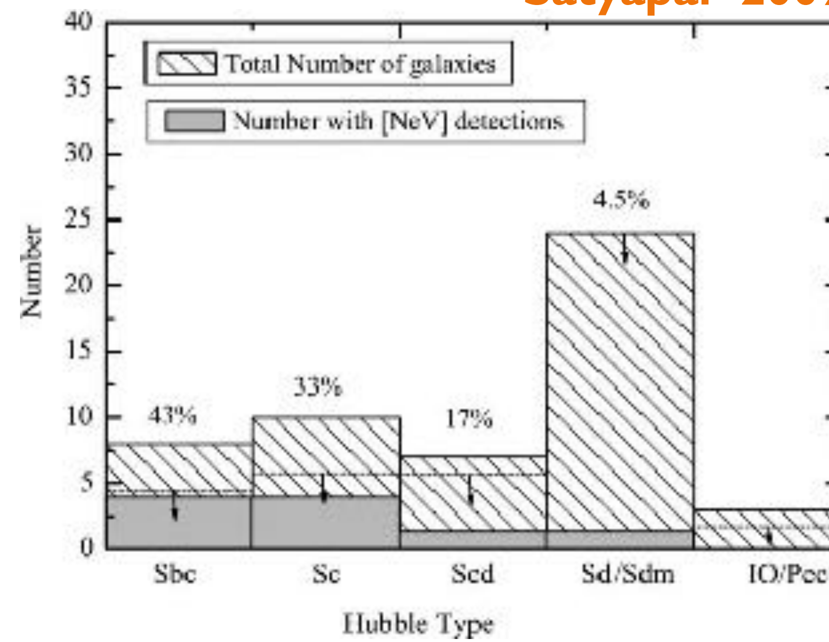
LINERs [NeV] detection rate ~40%, many without other sings of AGN activity

Bulge-less nearby galaxies AGN incidence in Sd/Sdm drops significantly. No an Av effect but due to lack of AGN



Goulding & Alexander 2009, see also Satyapal+2008, Dudik+2009

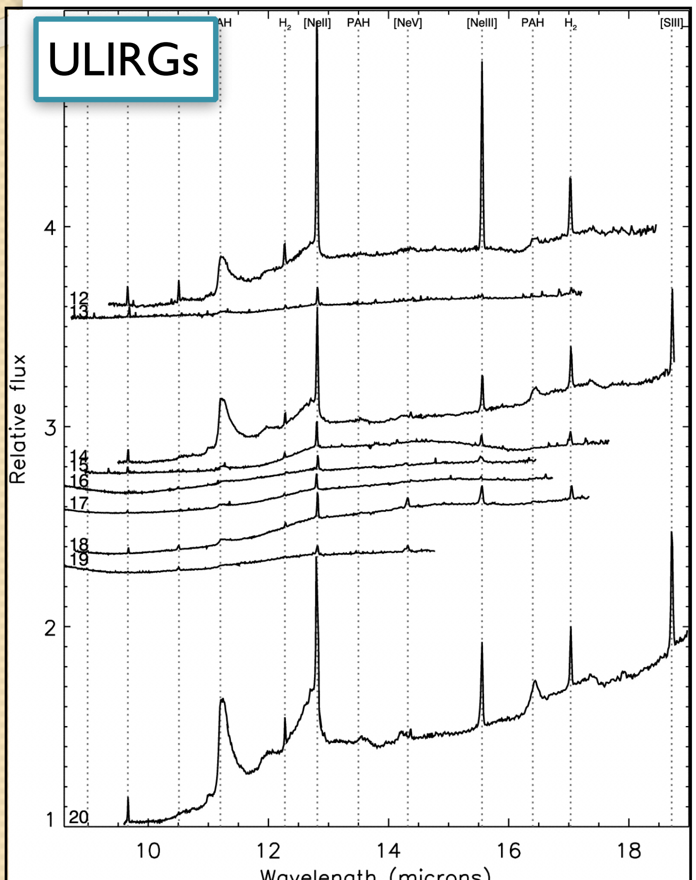
Satyapal+2009



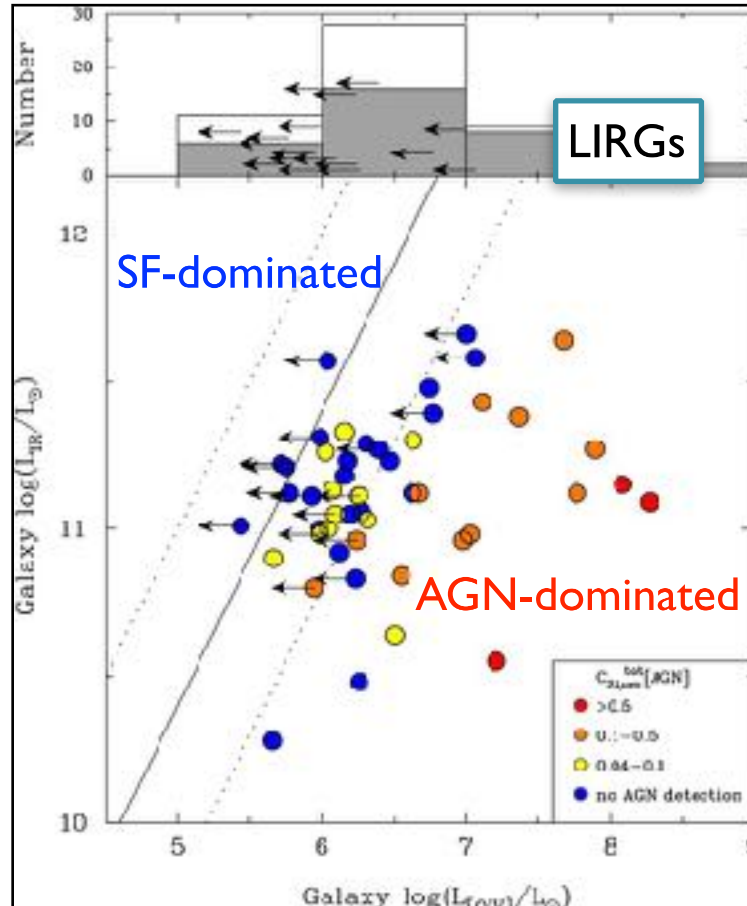
High excitation lines to identify AGN in (U)LIRGs

Local LIRGs: 50-70% with [OIV] detections and 22% with [NeV] detections

Local ULIRGs: 25-50% with [OIV] detections and 25-50% with [NeV] at 14.3μm



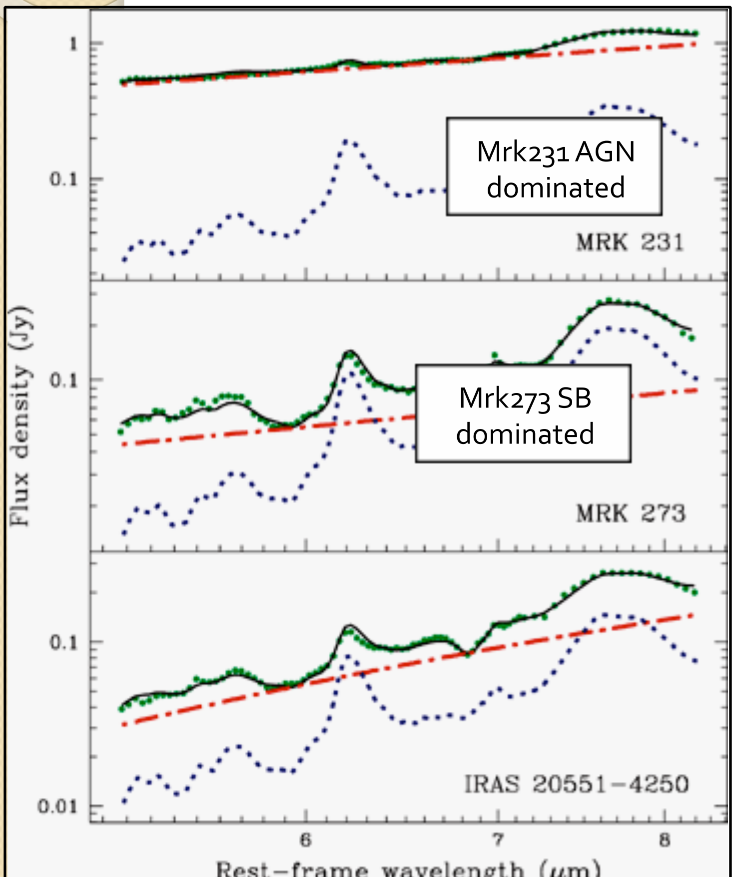
Farrah+2009, see also Armus+2006, 2007, Veilleux+2009



Alonso-Herrero+2012 and also Petric+2011

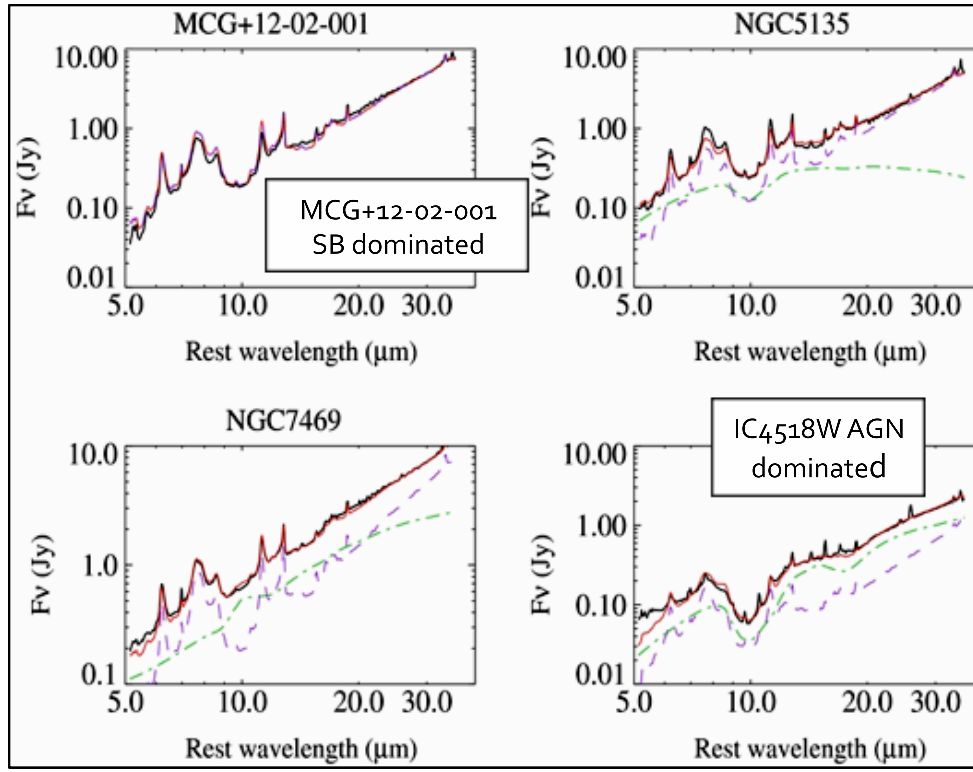
Spectral/SED decomposition methods to identify AGN

Local ULIRGs:
70% IR AGN detection rate



Nardini+2008,2009,2010

Local LIRGs:
50% IR AGN detection rate

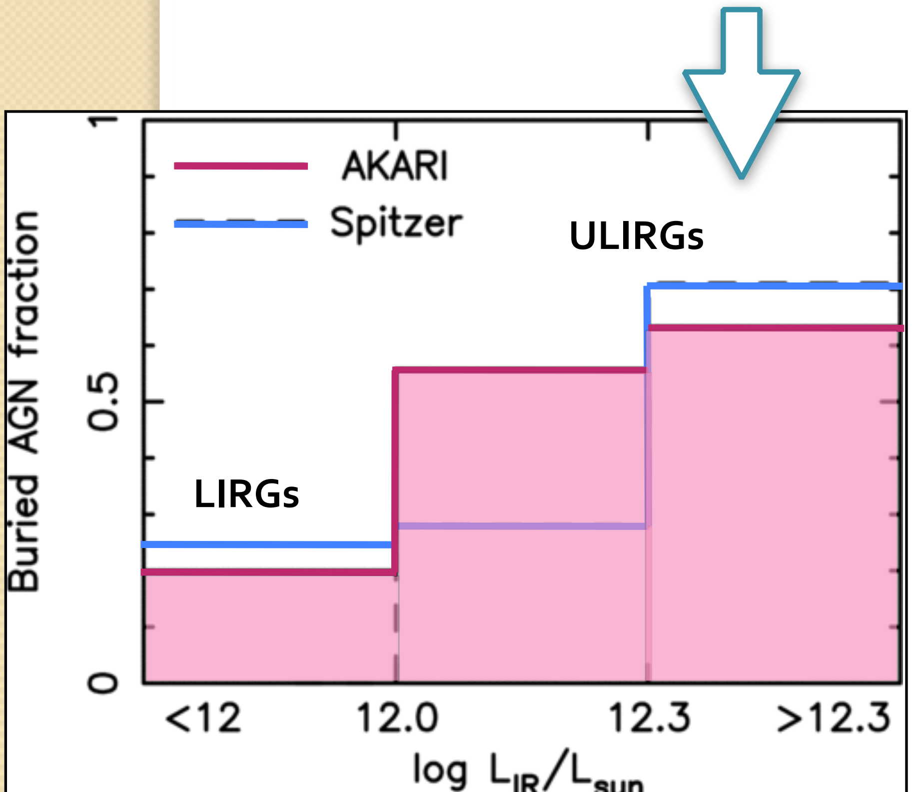


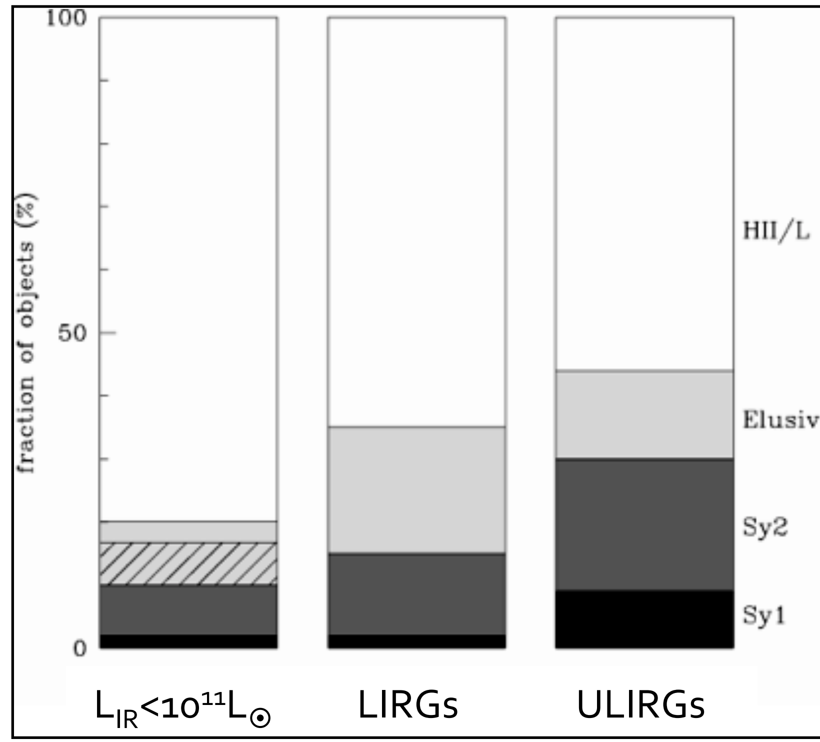
Alonso-Herrero+2012

Elusive AGN in local (U)LIRGs

IR indicators provide the fraction of buried (non-Seyfert) AGN in local (U)LIRGs that are not identified by X-rays and/or optical spectroscopy

Local **LIRGs:** Fraction of elusive (=non-Seyfert) AGN is 20-25%
Local **ULIRGs:** Fraction of elusive (=non-Seyfert) AGN is 50-70%



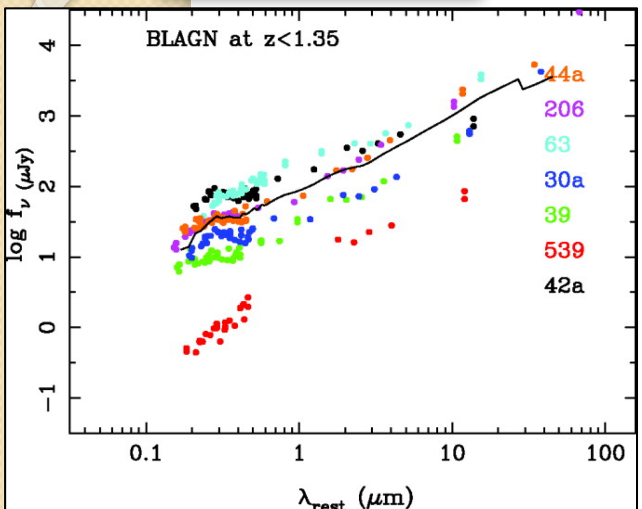


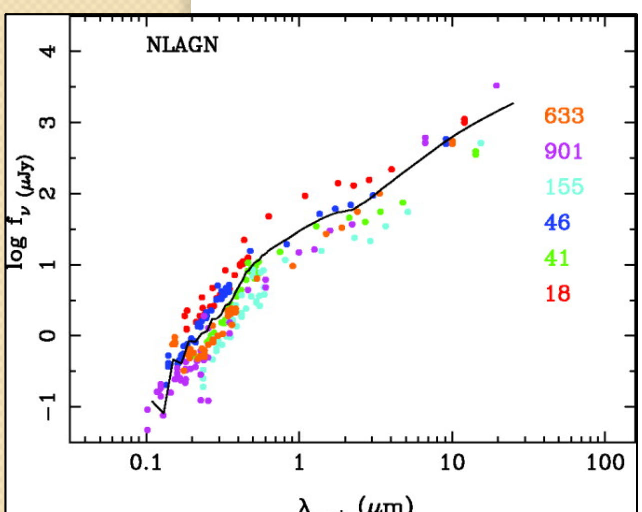
IR indicators: Imanishi+2010,2011, Alonso-Herrero+2012

X-rays: Maiolino+2003

IR power law emission as a method to select AGN

X-ray detected





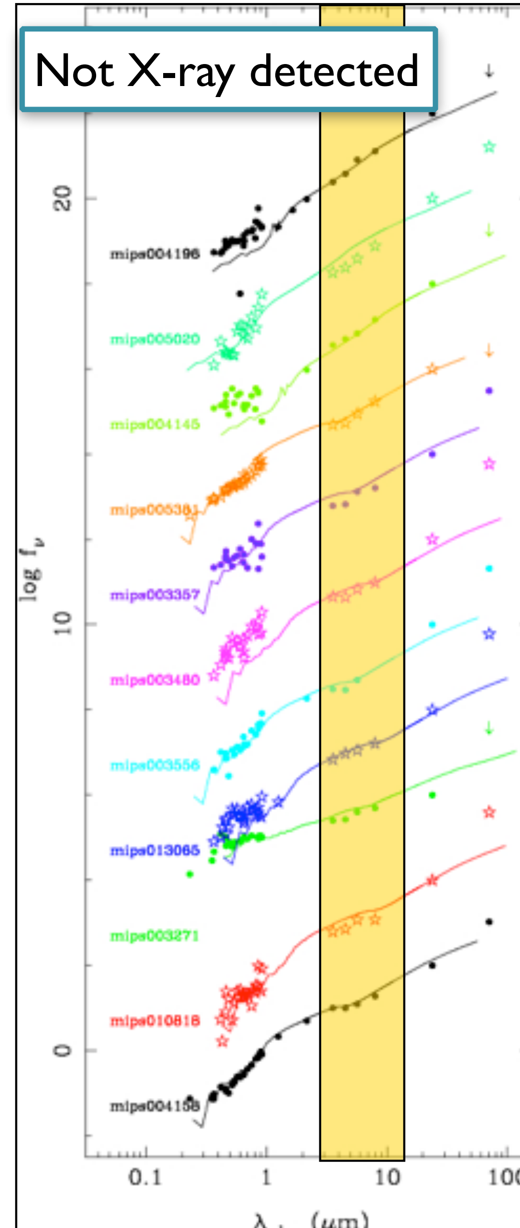
In cosmological fields with deep IRAC observations

Detection in all 4 IRAC bands with a power law continuum $f_\nu \sim \nu^{\alpha}$ in (U)LIRGs and spectral indices α <-0.5 over 3.6-8μm

Needs good estimates of photometric errors

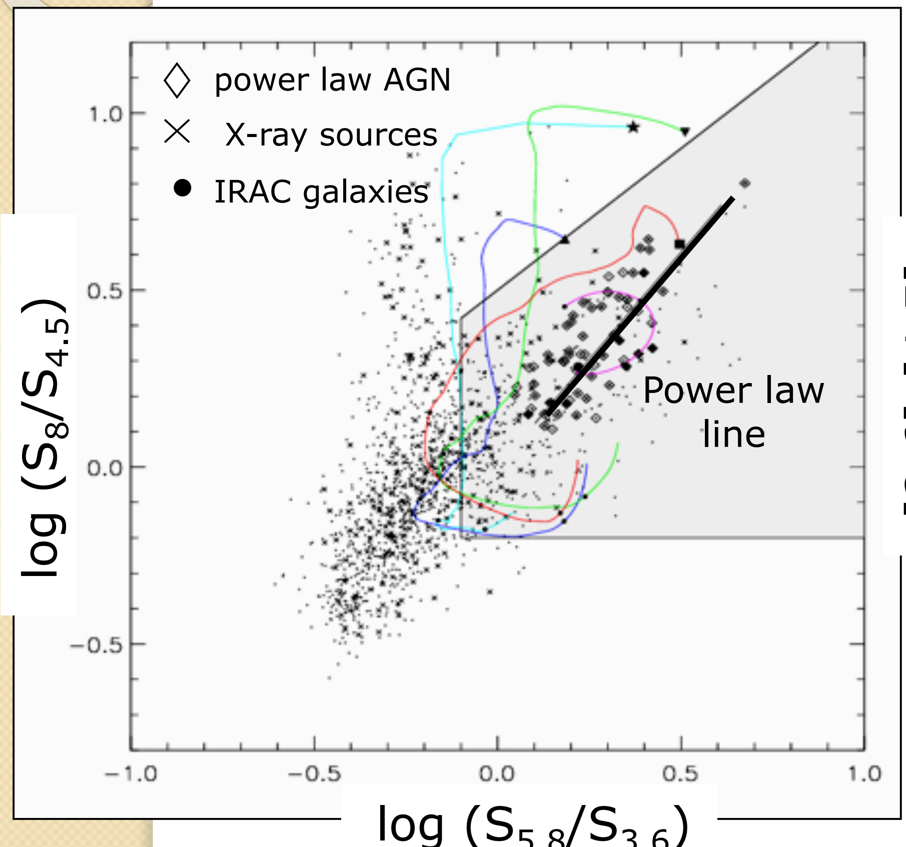
Alonso-Herrero+2006, and see also Donley+2007, 2008

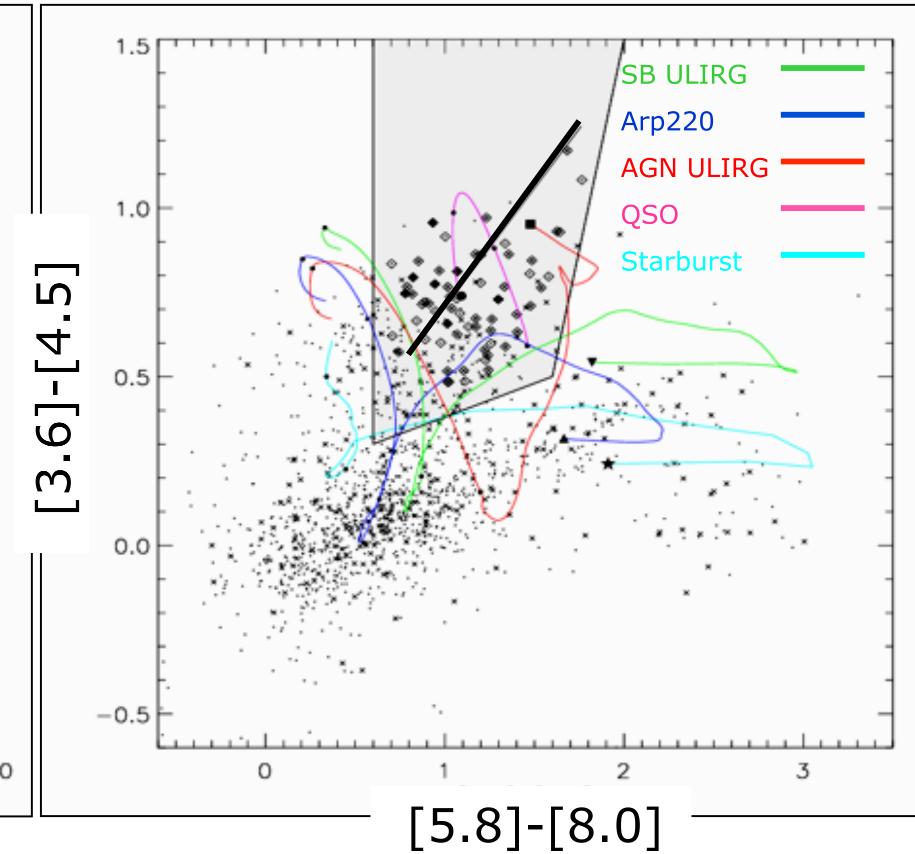
Not X-ray detected



IR color selection of AGN using IRAC data

Can be contaminated by star forming galaxies in very deep IRAC exposures



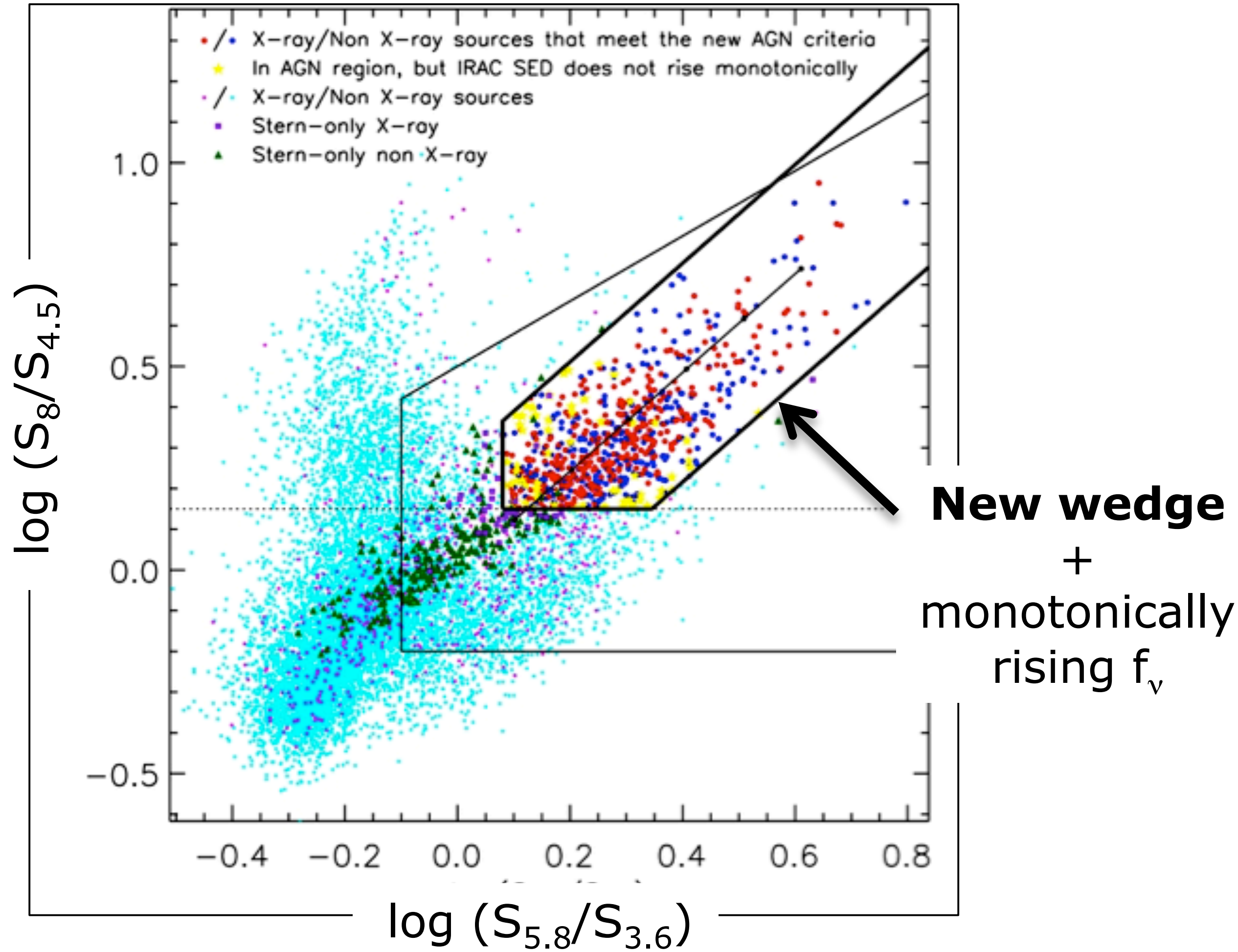


Lacy+2004, Stern+2005 and figures from also Donley+2008

IR power-law AGN selection using IRAC colors

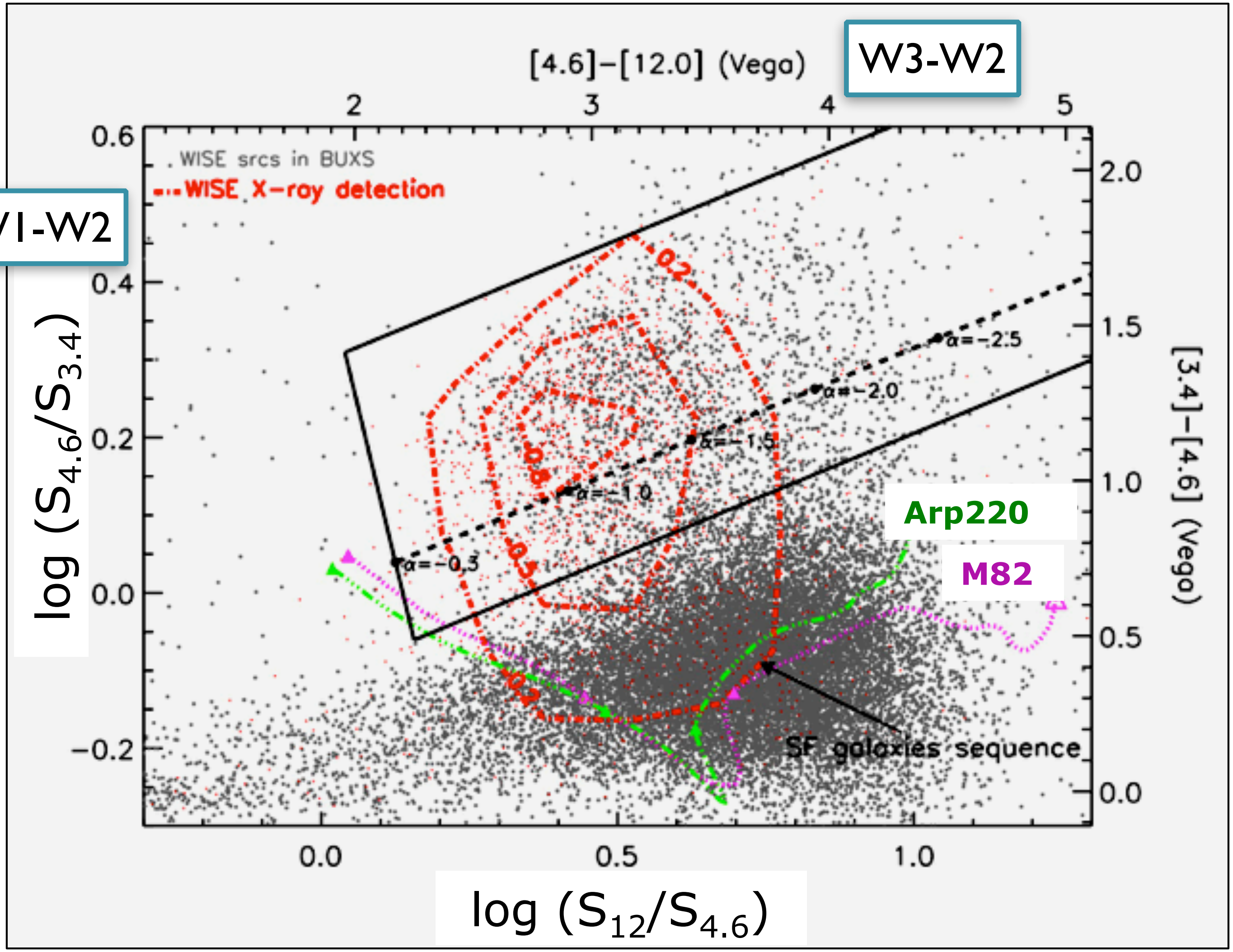
This is a more restrictive wedge which takes into account:

- typical uncertainties photometric uncertainties
- avoids contamination by high z SF galaxies in deep IRAC observations



Donley+2012

IR power-law AGN selection using WISE colors

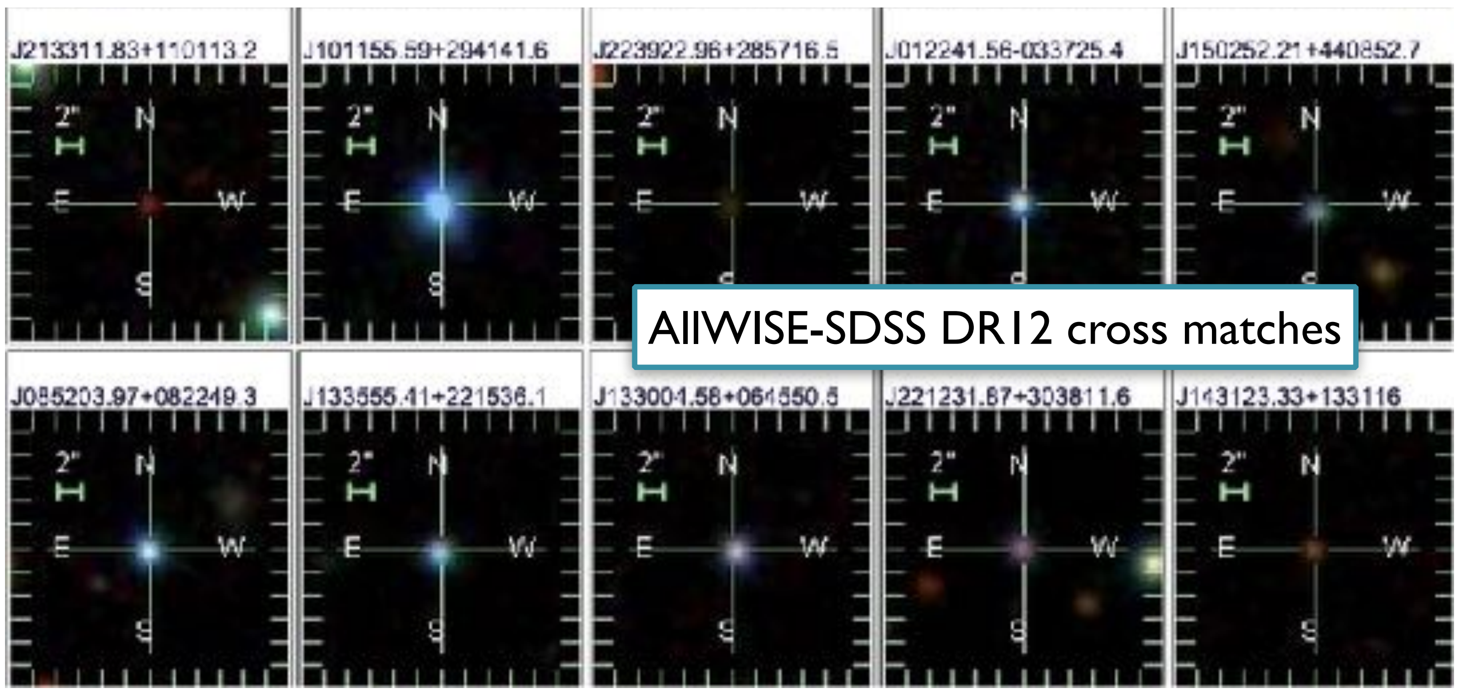


Mateos+2012, 2013 and see also Jarret+2012, Stern+2012, Assef+2013 for other WISE selections

Selecting AGN/QSO from AllWISE catalog

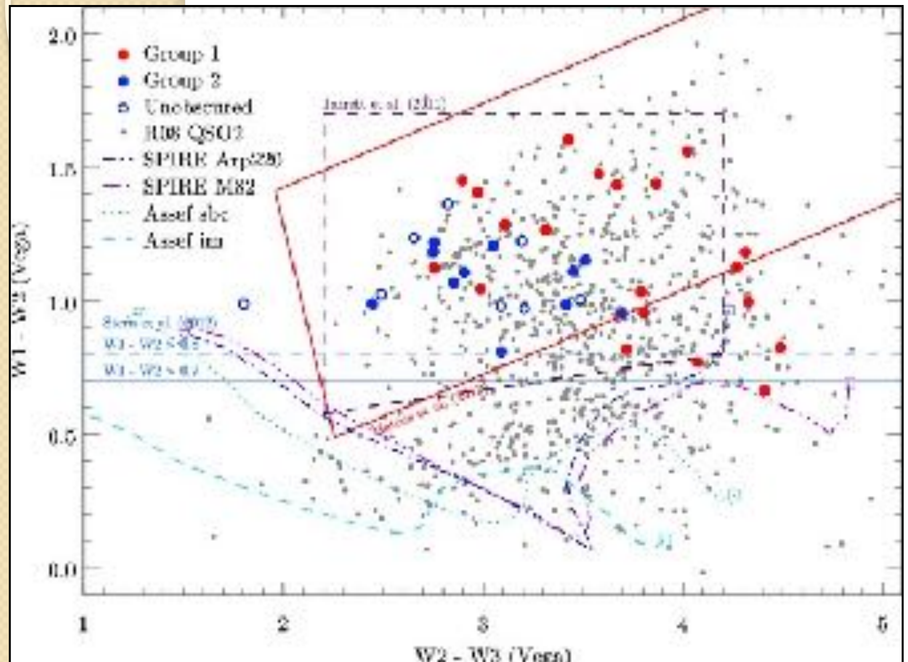
Sample of 1,354,775 AGN selected from AllWISE using Mateos+2012 criteria of which 1.1 million of these were previously uncataloged

Probability of correctly identifying a known AGN/ QSO is at least 84% for AGNs brighter than a limiting magnitude of R <19

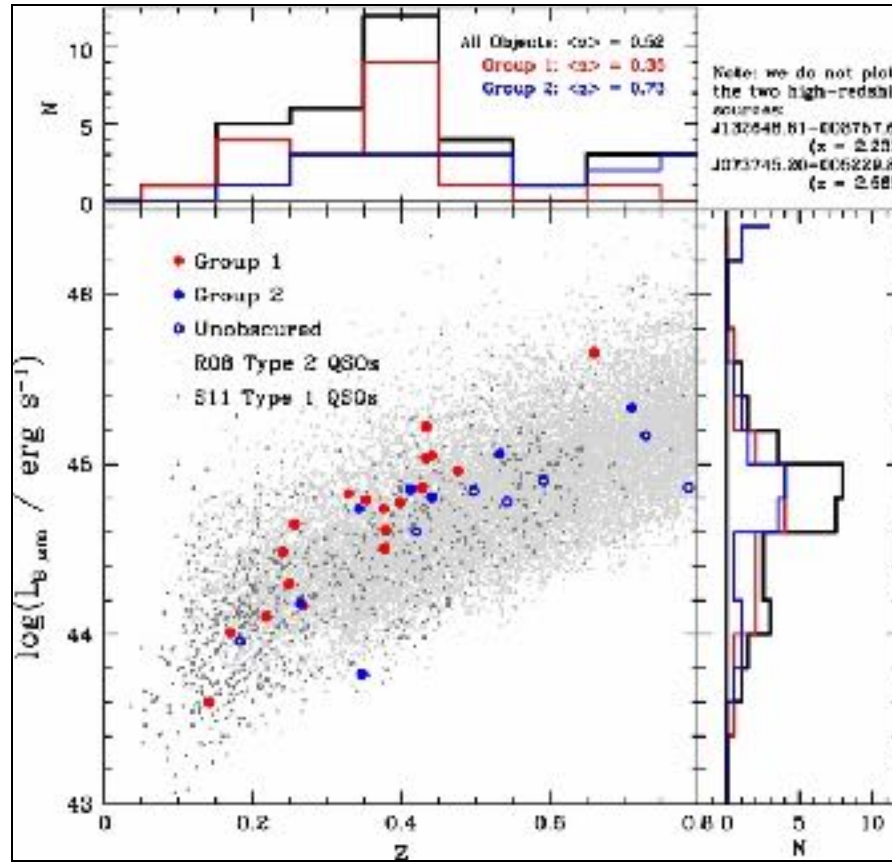


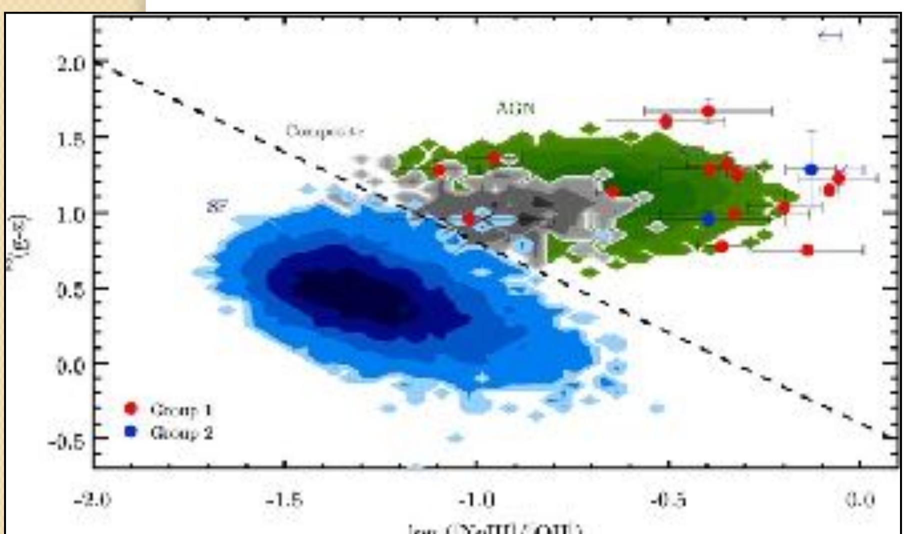
WISE+SDSS AGN: Secrest+2015, see also Mateos+2013 for detection of SDSS [OIII] selected type 2 QSO

Optical follow-up of WISE selected QSO



Of 40 targets (moderate redshifts), only 13% do not have evidence of hosting an AGN

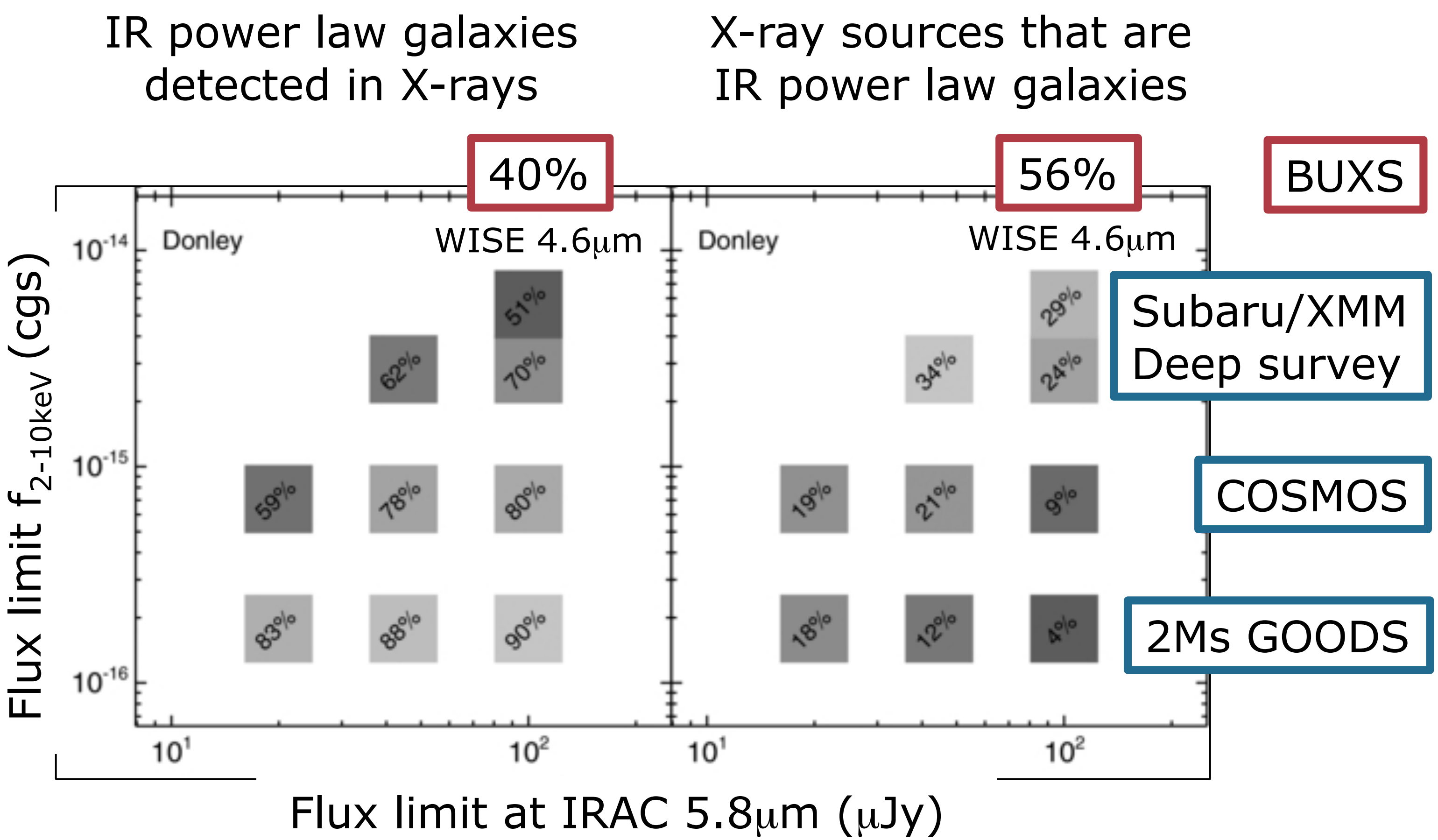




Hainline+2014. See also eg Lacy+2007 for follow-up of IRAC selected AGN

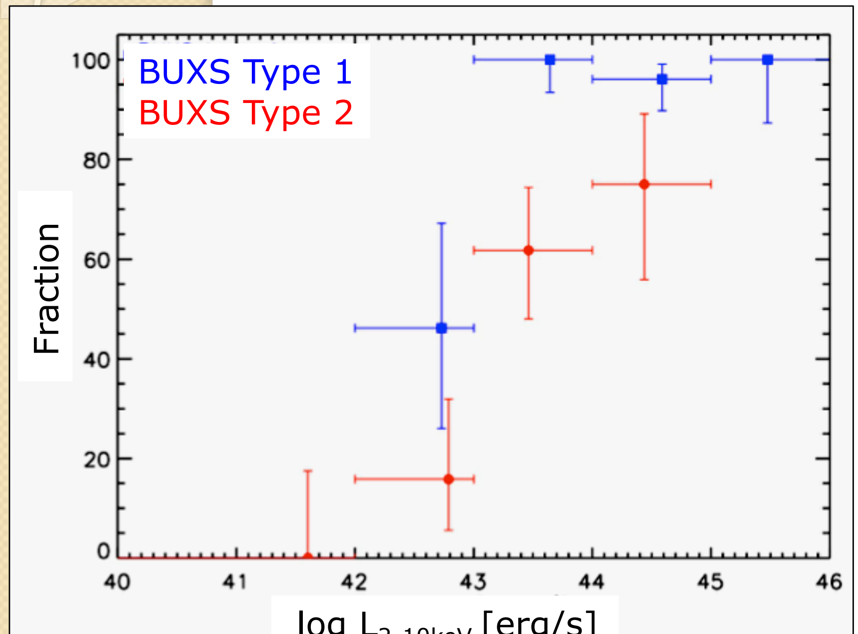
IR power-law AGN color selection vs. X-rays

Strong dependence on depth of X-ray data



IRAC selection: Mendez+2013, see also Alonso-Herrero+2006, Donley+2007,2008,2012
WISE selection: Mateos+2012, see also Assef+2013

Completeness of IR power-law AGN selection

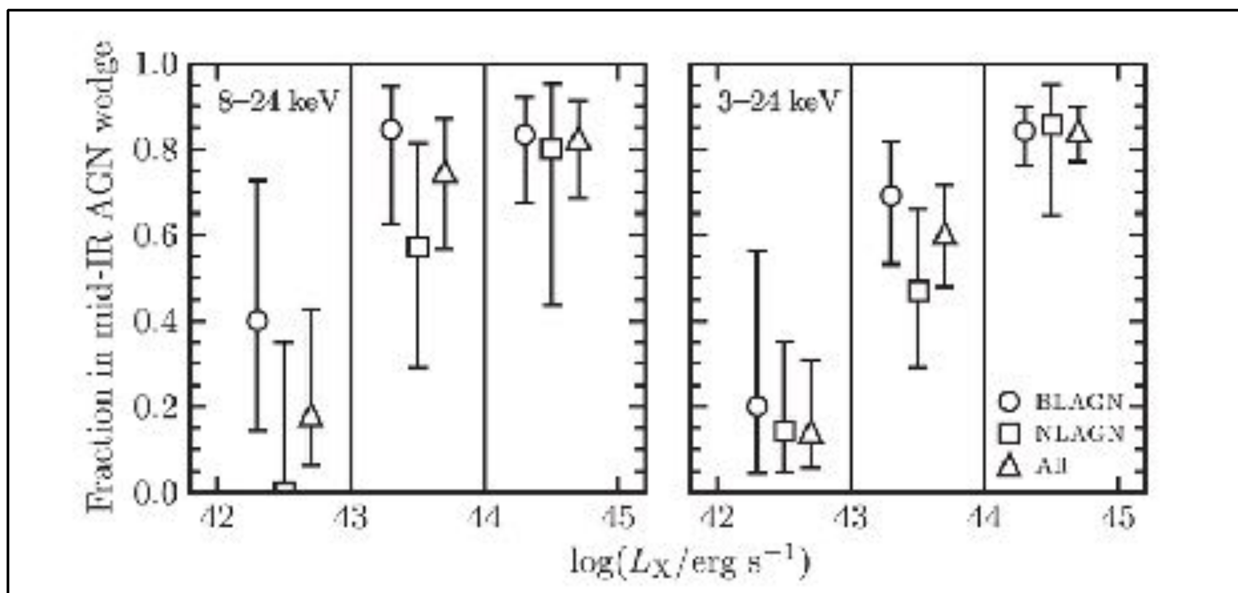


WISE colors - IR power law AGN selection using Mateos+2012 compared to a 4.5-10keV selection:

- **Highly complete for luminous type 1 AGN (Lx>10^{43}-$10^{43.5}$ erg/s)**
- Moderately complete for type 2s with Lx>10^{44} erg/s

Mateos+2012: XMM BUXS survey selected in 4.5-10keV band

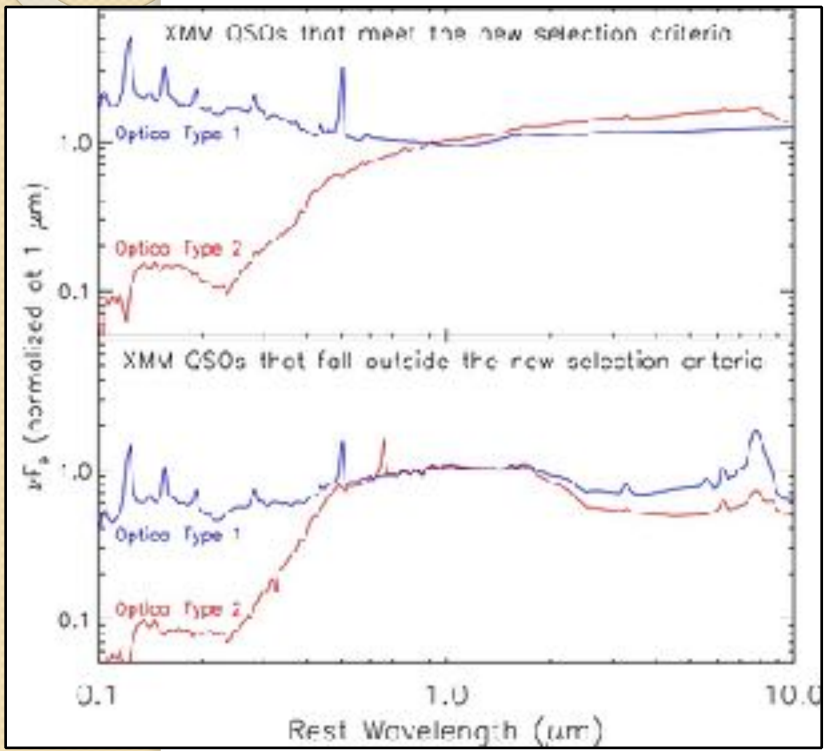
Landsbury+2017: NuSTAR serendipitous survey



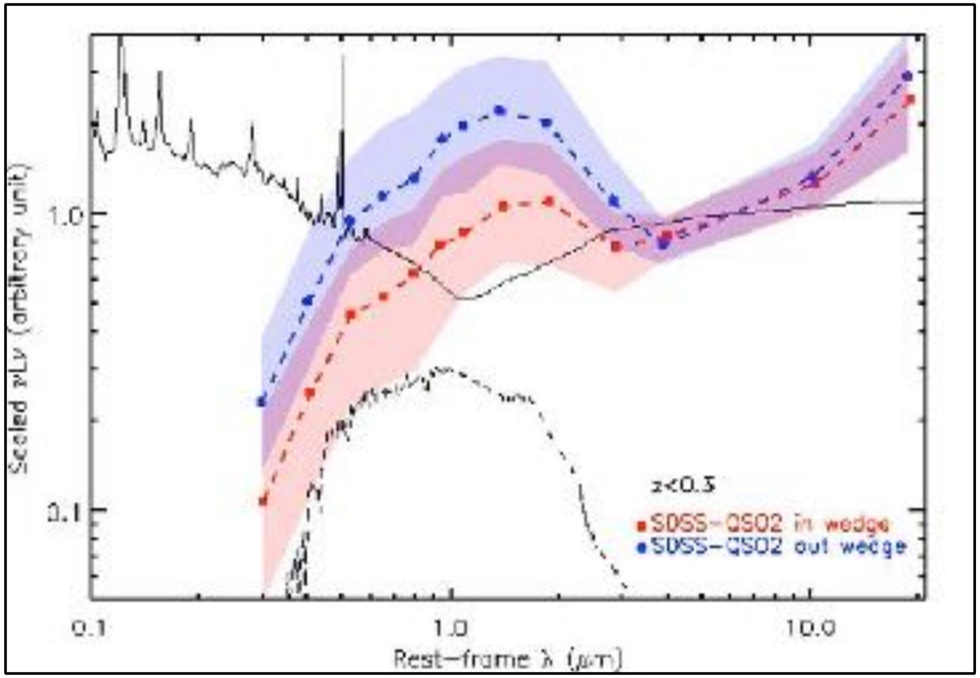
Host galaxy dilution

IRAC/WISE selections most likely to miss X-ray and optically selected AGNs:

- luminous hosts (ie, massive host galaxies)
- AGN emission is itself obscured.



Donley+2012 for IRAC selection

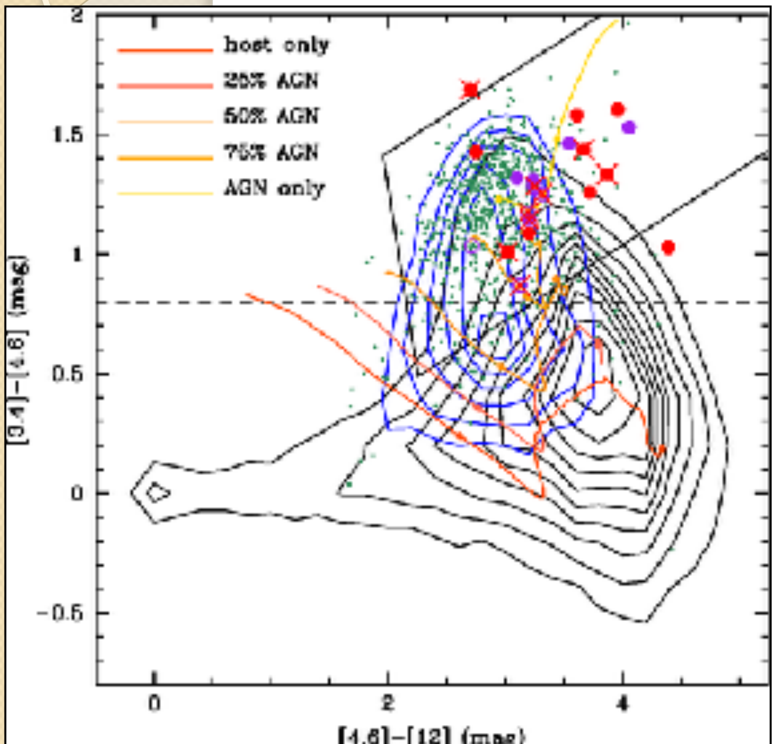


Mateos+2013 for WISE selection

See also e.g., Lazy+2007, Alonso-Herrero+2008, Hickox+2009, Mendez+2013, Messias+2014, Azadi+2017

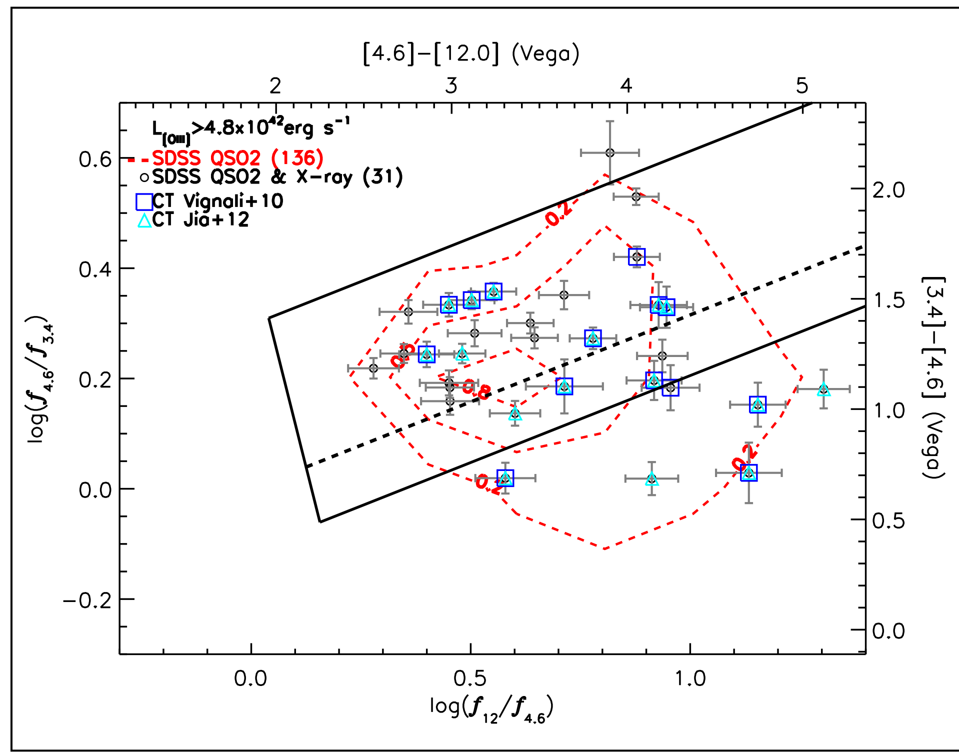
Do mid-IR criteria select obscured luminous AGN?

Rovilos+2014



20 candidates to heavily obscured AGN from combination of XMM-SDSS-WISE + SED decomposition. The majority meet the MIR-selection criteria of Stern+2012 and Mateos+2012

Mateos+2013



~ 70% of SDSS QSO 2 which are also CT candidates are in Mateos+2012 wedge

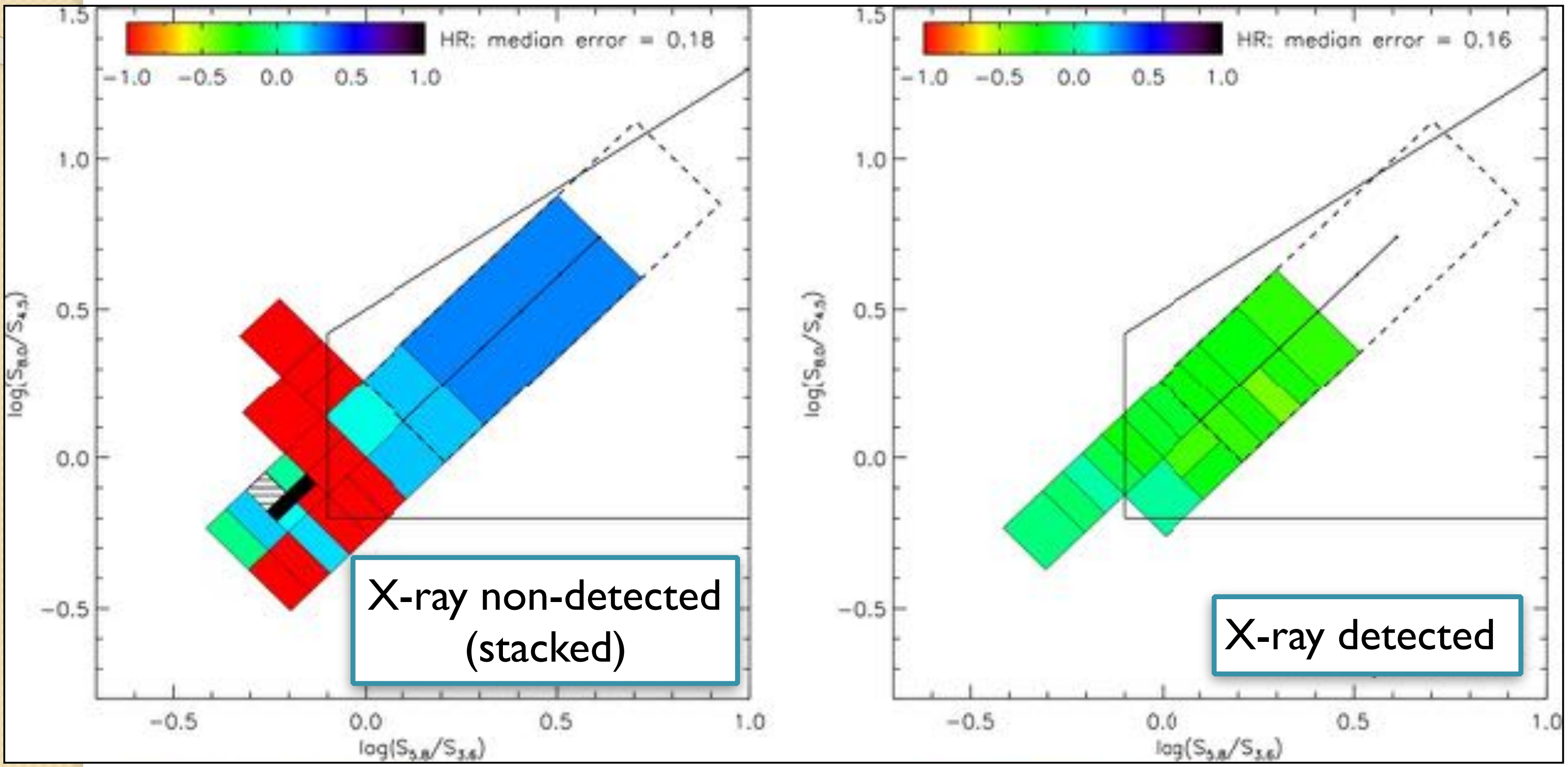
Wei Yang's poster

See also Landsbury+2014 for optical CT QSO2 candidates

Hardness ratios of IRAC selected AGN

HR =0.31 ± 0.13, column densities of log NH(cm^{-2}) =23.5 ± 0.4.

HR =−0.31 ± 0.13, column densities of log NH(cm^{-2}) =22.4 ± 0.4



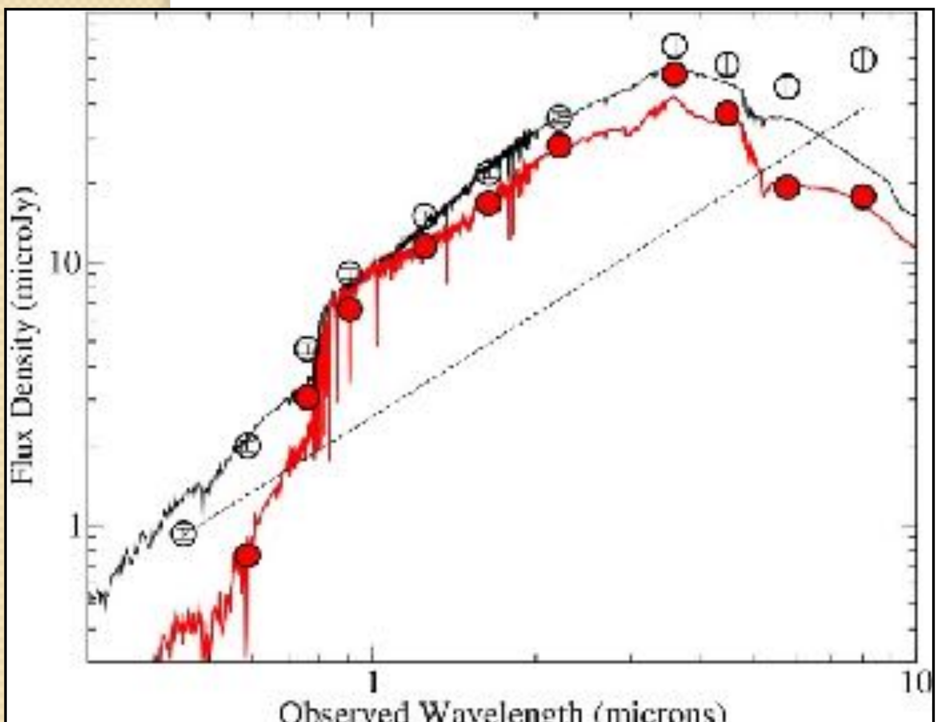
COSMOS cosmological field with Chandra data

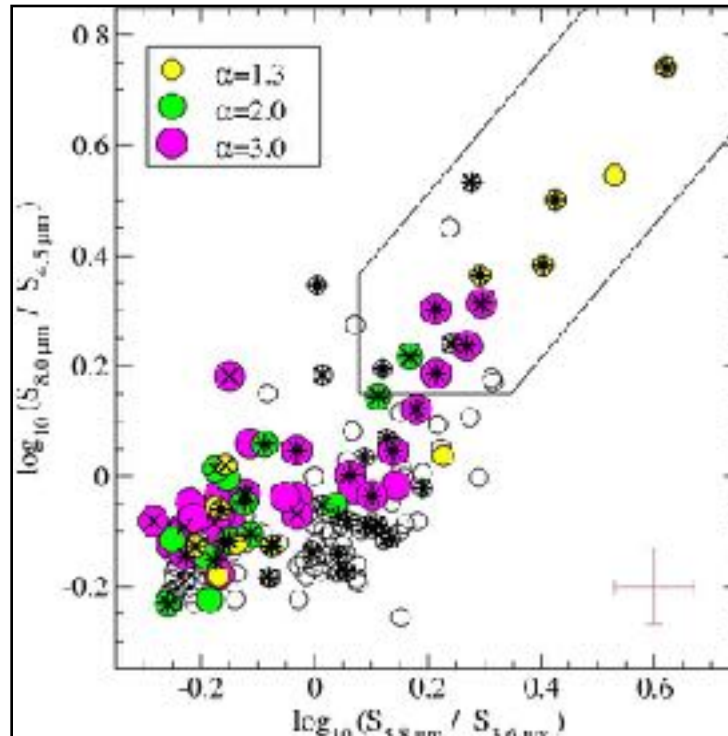
Donley+2012, see also Alonso-Herrero+2006

Looking for IR power law emission using SED decomposition

GOODS-South and Chandra 4Ms X-ray catalog:

- At z<1. 5 3/4 of the X-ray AGN are identified with this method
- At z>1.5 only 44% of X-ray AGN are identified
- **~50% of the selected galaxies at 1<z<1.5 are not identified in X-rays**

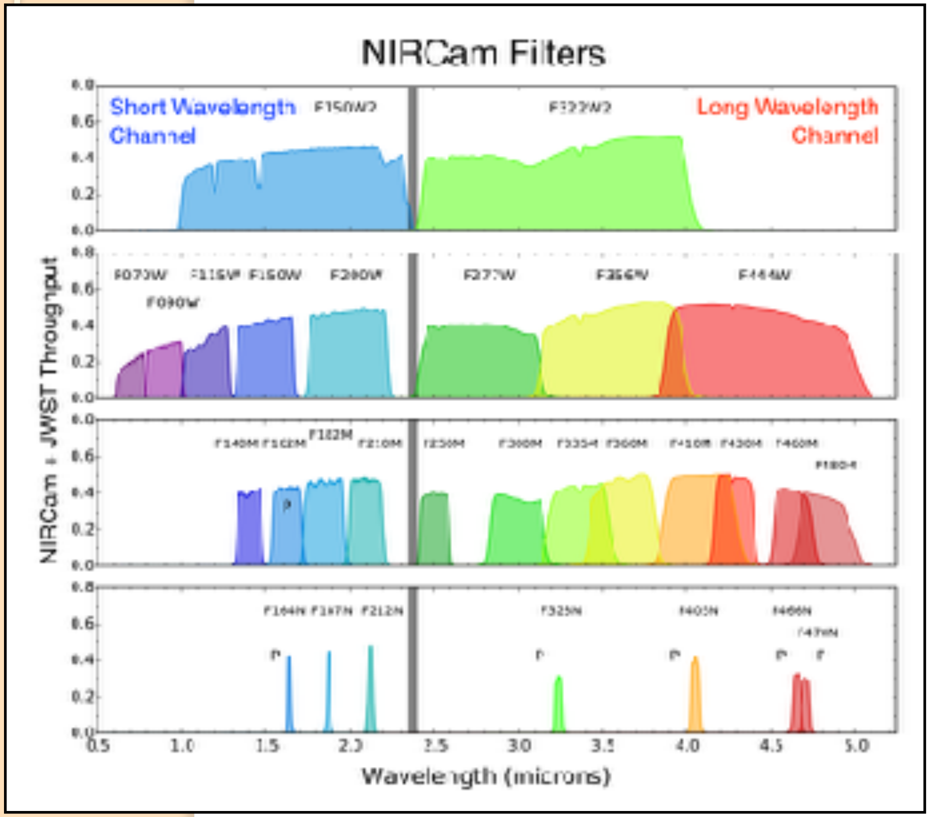




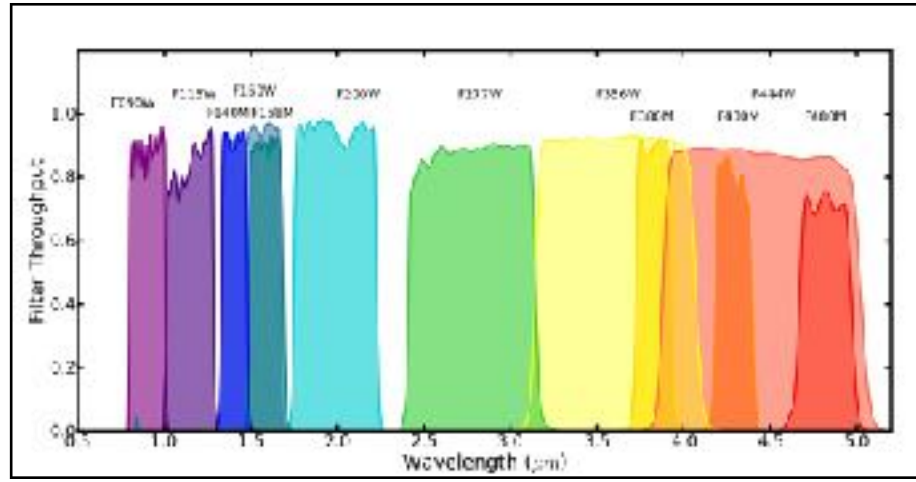
Caputi+2013, see also e.g., Daddi+2007

Chris Carroll's talk

JWST photometric filters

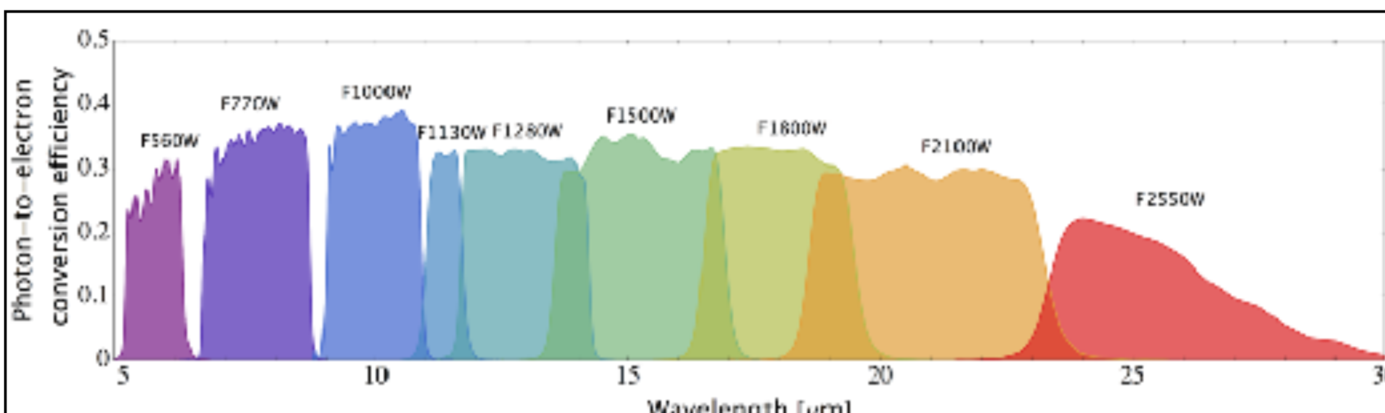


NIRISS Filters



Credit: JWST webpage at STScI

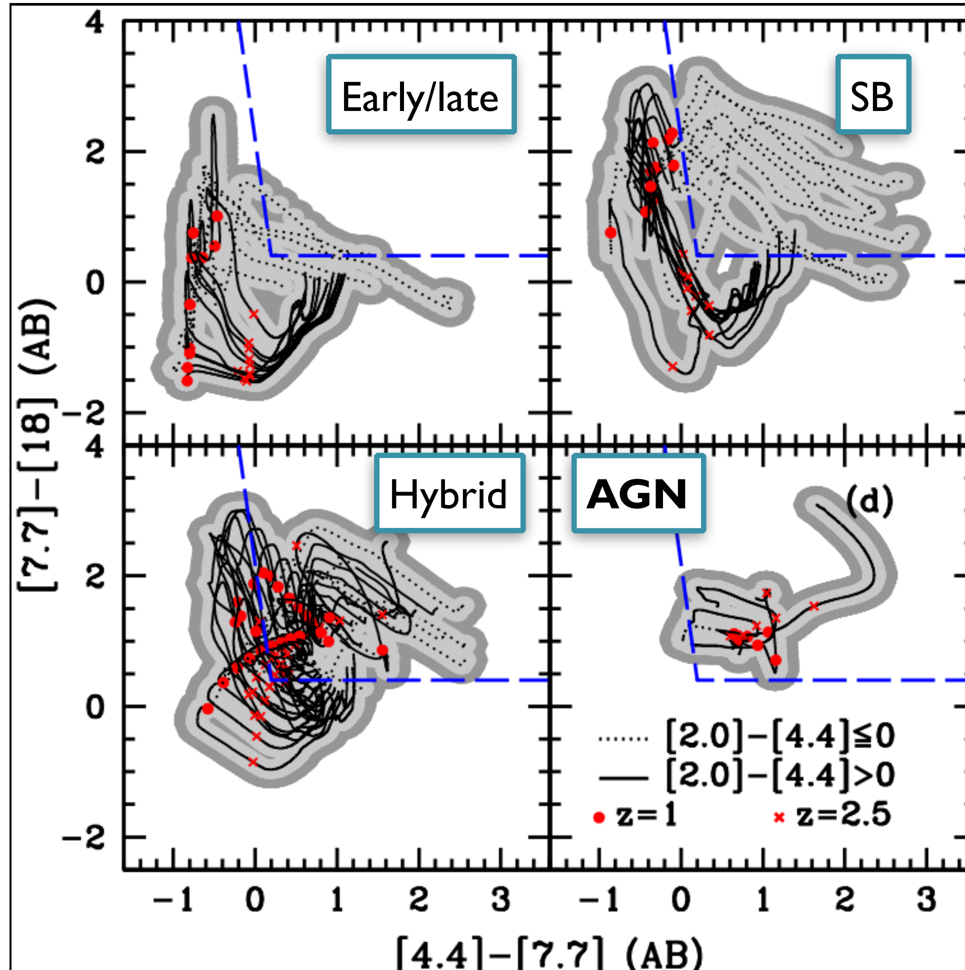
MIRI Filters



Deep surveys with JWST to select AGN

Combination of NIRCam F200W and F444W and MIRI F770W and F1800W to select AGN at z~1-2.5

Credit: Frontier Fields webpage and G. Snyder & Z. Levay (STScI)

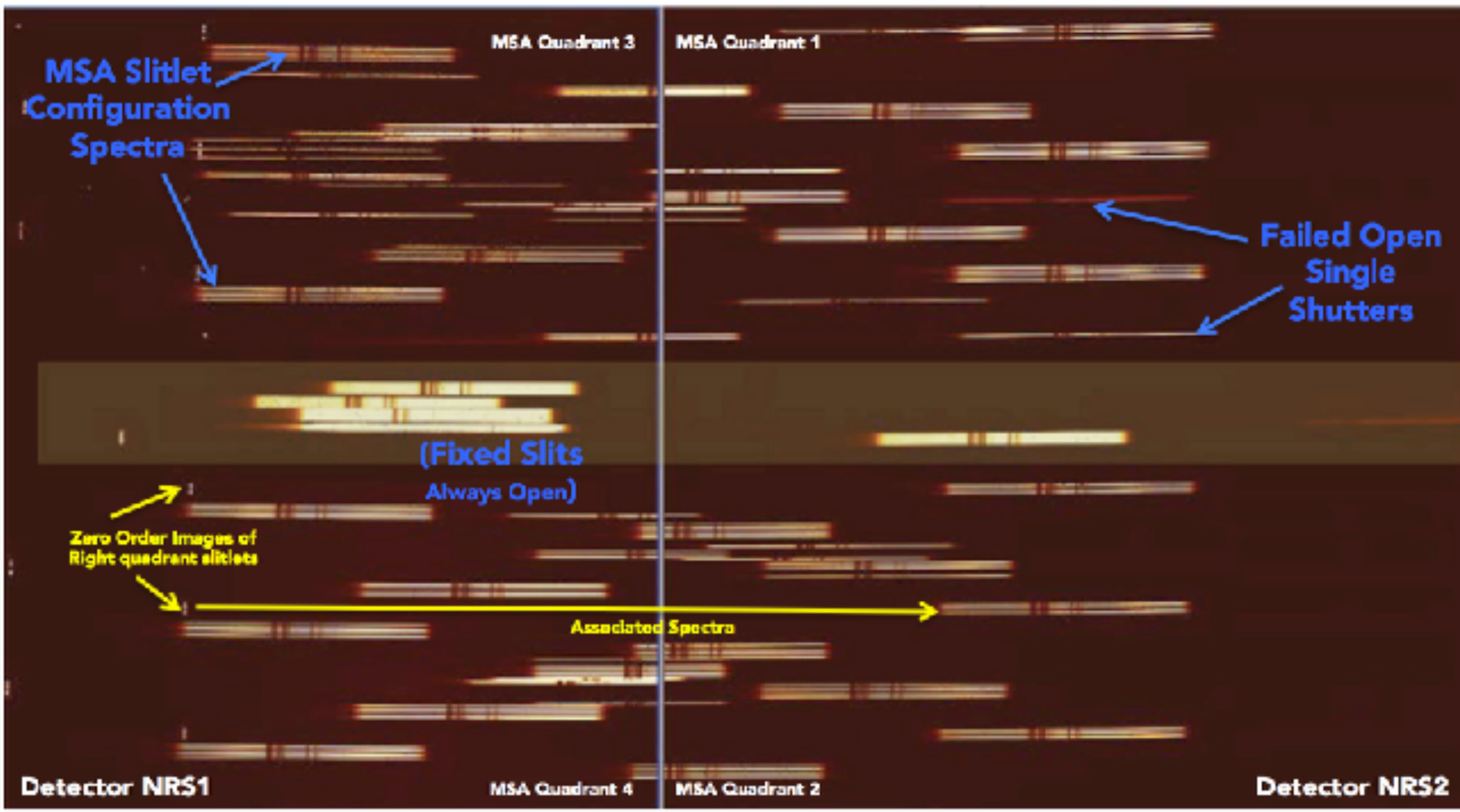


Messias+2014

Fabio Panucci's talk: detection of DCBH

JWST/NIRSpec Multi-Object Spectroscopy

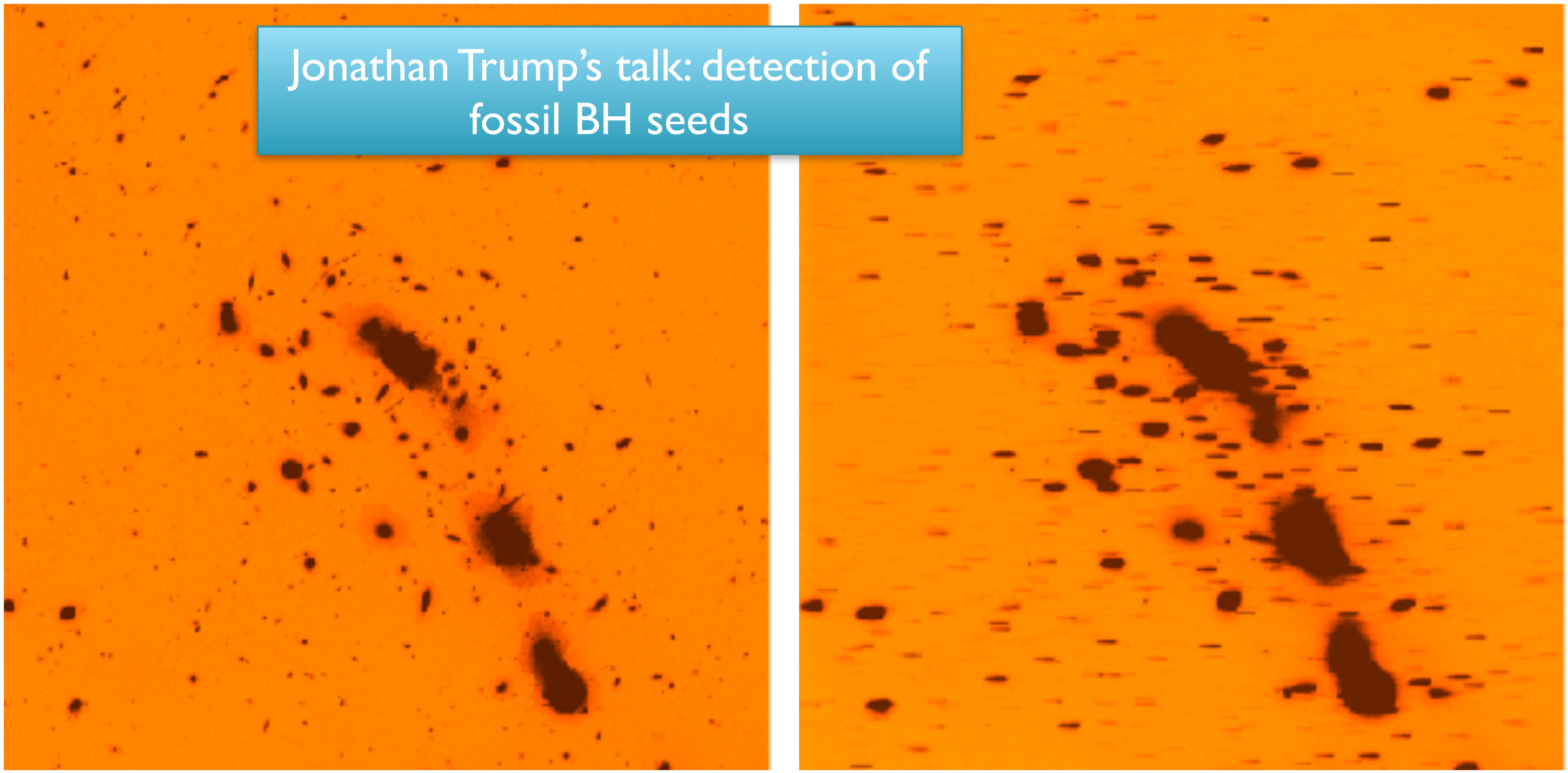
NIRSpec/MOS provides multiplexing 0.6–5.3 μm spectroscopy capabilities over a 3.6' × 3.4' field of view using configurable shutters



Credit: JWST webpage at STScI

JWST/NIRISS slitless spectroscopy

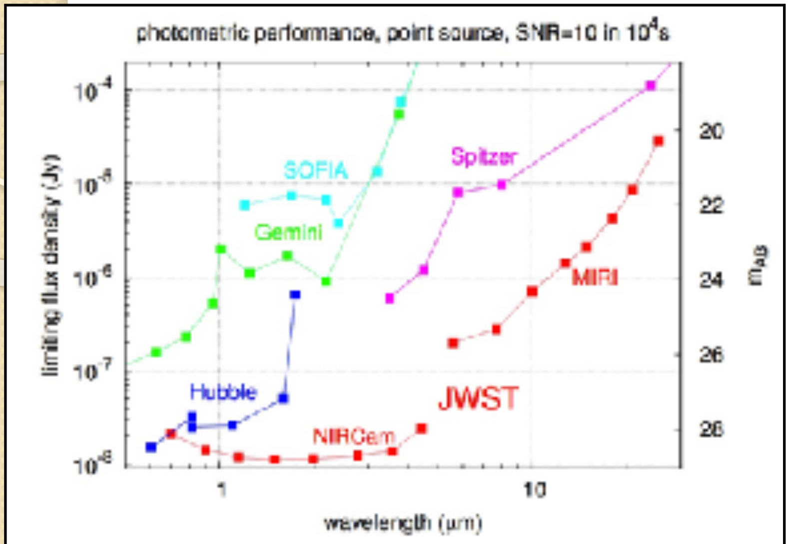
The wide field slitless spectroscopy mode of NIRISS enables low-resolution (R ≈ 150) spectroscopy over the wavelength range 0.8–2.2μm for all objects within a 2.2’ × 2.2’ field of view.

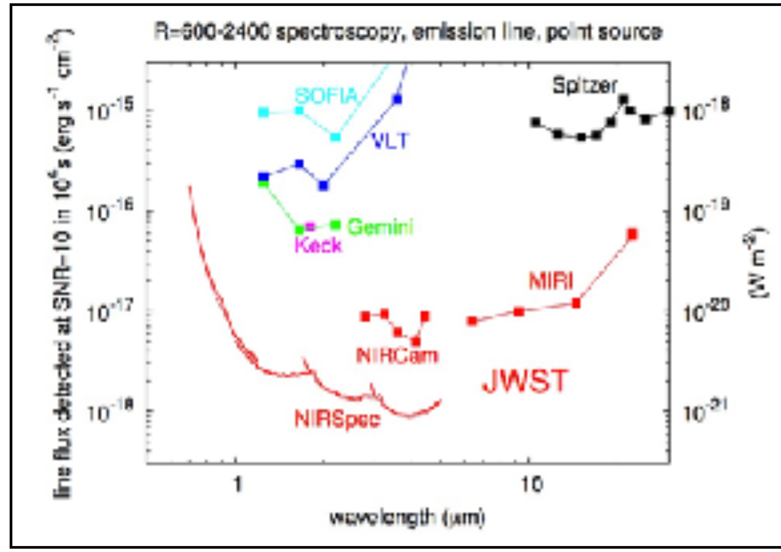


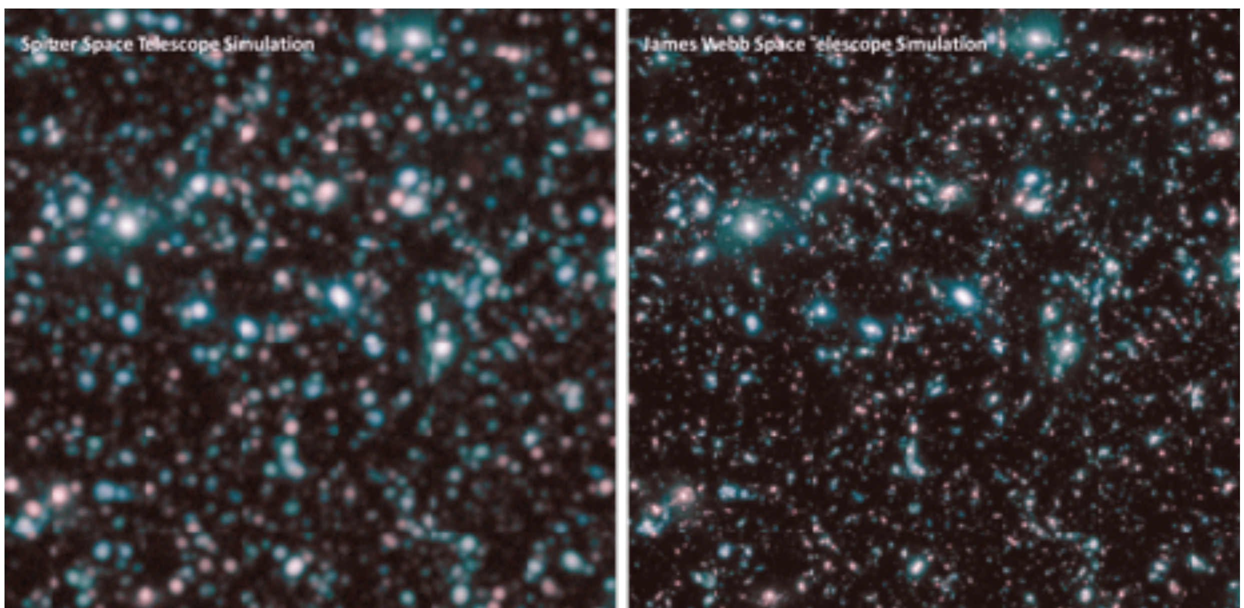
Simulated images of a lensing cluster observed with the NIRISS F115W filter and the GR150C grism and F115W blocking filter

Credit: JWST webpage at STScI

JWST sensitivity and angular resolution





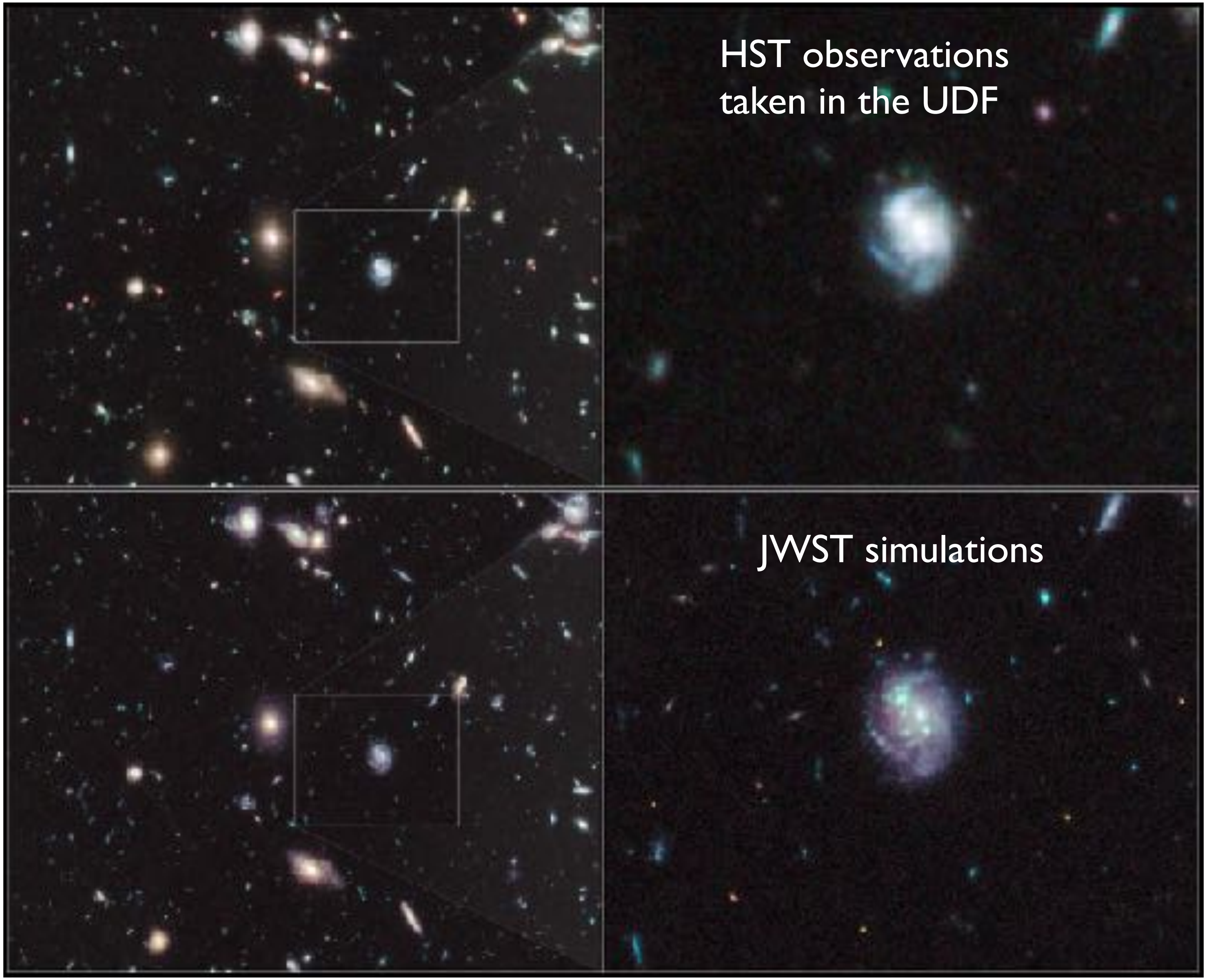


Filters:

F356W
F444W
F560W

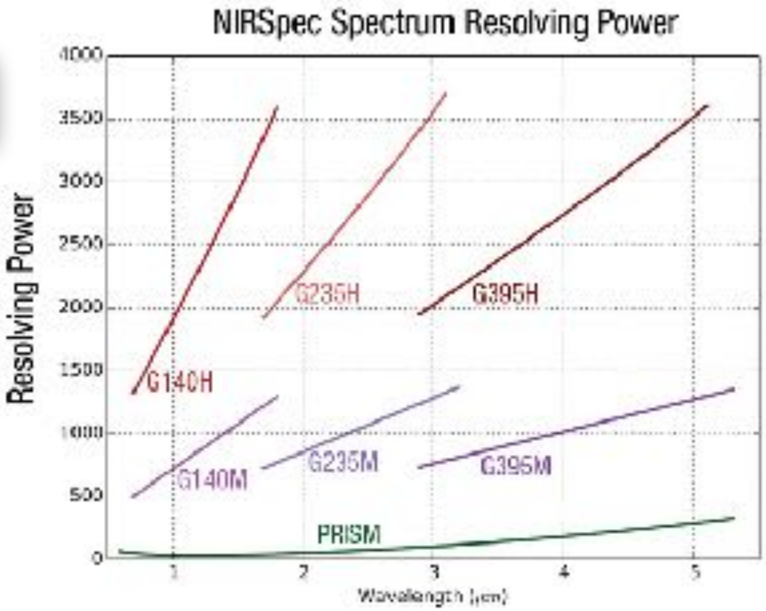
Credit: Frontier Fields webpage and G. Snyder & Z. Levay (STScI)

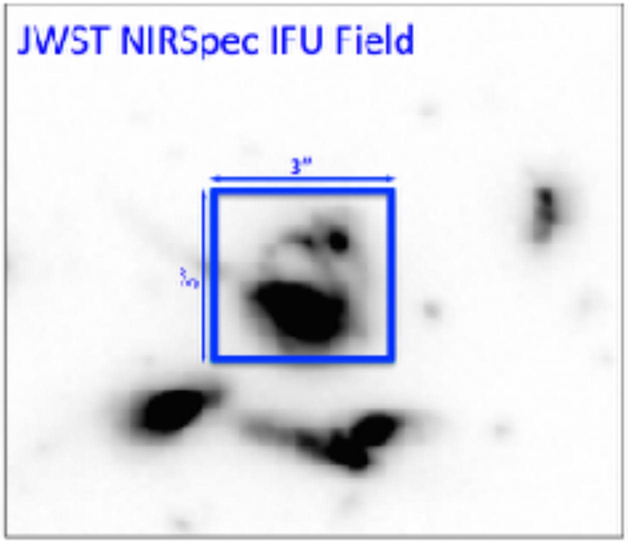
Spatially-resolved AGN selection with JWST



JWST Integral Field Units

NIRSpec

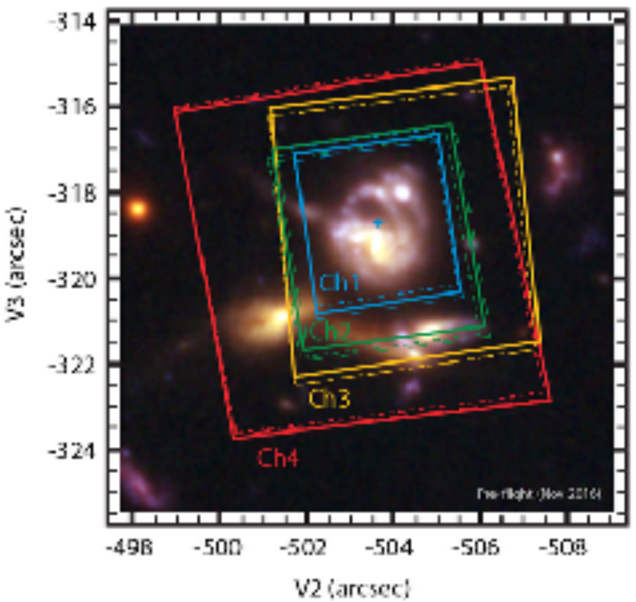




MIRI

Channel	Band	Nr. slices	Wavelength Range [μm]	Spectral Resolution	FoV [arcsec]
1	1A	21	4.88 - 5.77	~3500	3.46 x 3.72
	1B		5.64 - 6.67		3.46 x 3.72
	1C		6.50 - 7.70		3.41 x 3.72
2	2A	17	7.47 - 8.83	~3000	4.16 x 4.76
	2B		8.63 - 10.19		4.16 x 4.76
	2C		9.96 - 11.77		4.12 x 4.76
3	3A	16	11.49 - 13.55	~2600	6.00 x 6.24
	3B		13.28 - 15.66		5.96 x 6.24
	3C		15.34 - 18.09		5.91 x 6.24
4	4A	12	17.60 - 21.00	~1600	7.14 x 7.87
	4B		20.51 - 24.48		7.06 x 7.87
	4C		23.92 - 28.55		6.99 x 7.87

MIRI/MRS FoV



Credit: JWST webpage at STScI

Conclusions

IR offers a large number of tools to identify elusive AGN: emission lines, line ratios, color-color selection, SED/spectra decomposition

MIR diagnostics do not provide a complete selection of AGN but:

- High excitation lines can identify faint/buried AGN in local galaxies
- Color-color selections are highly reliable to identify luminous AGN ($L_X > 10^{43.5}$ erg/s) and possibly Compton-thick AGN
- WISE color-color selections provide large catalogs of QSO

JWST provides ALL these IR diagnostics with much higher sensitivity and angular resolution using all observing modes:

- **Imaging with NIRCam, NIRISS, MIRI**
- **MOS with NIRSpec**
- **Slit-less spectroscopy with NIRISS**
- **IFU with NIRSpec and MIRI**