The IR/X-ray connection: results from the SWIRE Legacy Survey

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Unified models for AGN: first ideas

first attempt at ‘unified model’ for quasars, Seyferts, radio-galaxies: Rowan-Robinson 1976 - Type 2 are obscured Type 1, link to 10 μm emission ?

developed into unified model (Antonucci 1993,Krolik 1999) in which different AGN types are a function of the viewing angle

Miley et al 1984: IRAS detection of mid-ir excess from AGN

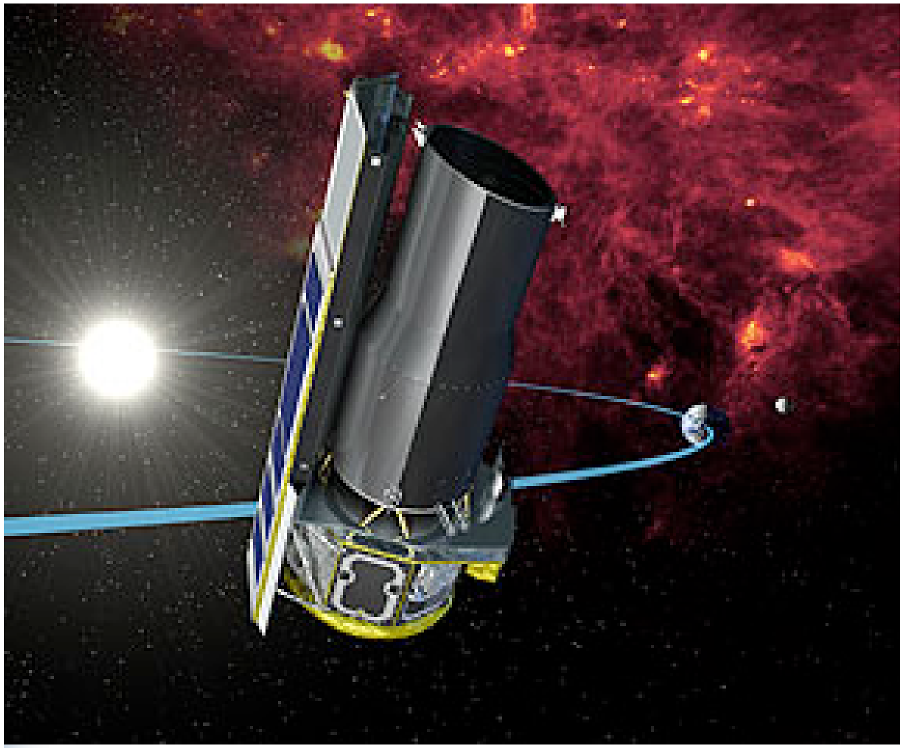
R-R & Crawford 1989: first model of this excess as dust torus around AGN

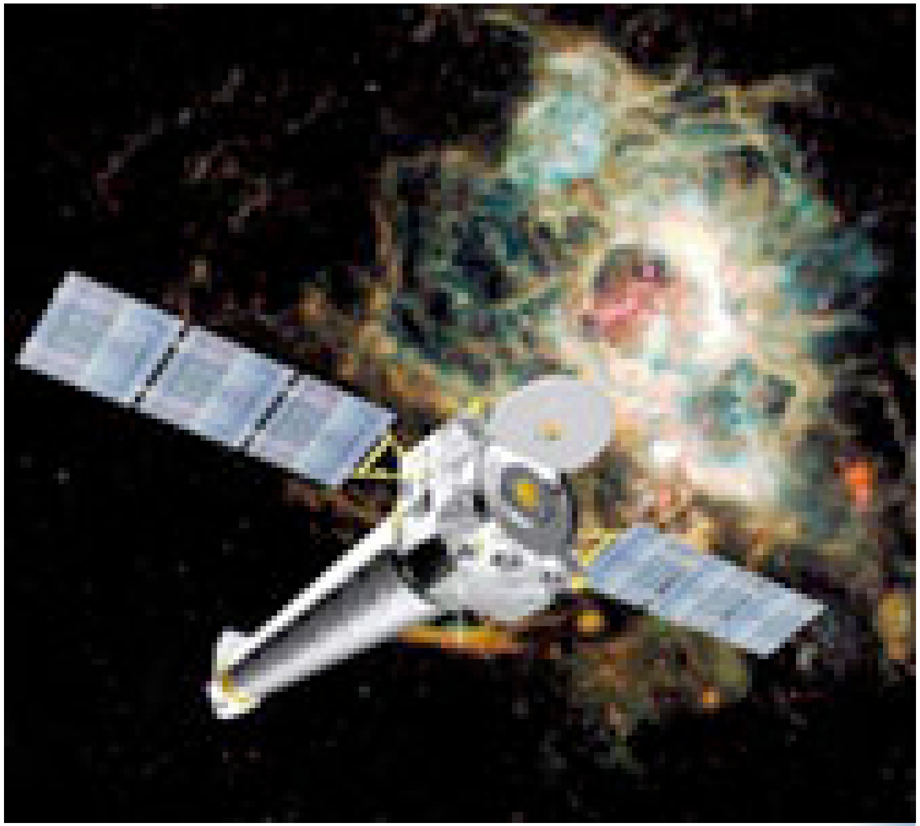
today: X-ray AGN classified as: unobscured (lg N(H)<22), Compton thin (lg N(H) = 22-24), or Compton thick (lg N(H)>24)

- these should all be detectable as dust tori in the mid-ir

Open question; could there be a major population of heavily obscured AGN, not detected at 1-10 keV in X-rays (could help explain hard-X background)

combining surveys by Chandra and Spitzer





SWIRE (Spitzer Wide-Area IR Extragalactic Survey)

- **SWIRE**: 49 sq deg in ELAIS-N1,-N2,-S1, Lockman, XMM-LSS, CDFS areas surveyed at 3.6,4.5,5.8,8.0,24,70 and 160 μm
  - Reliable catalogues released in N1, N2, XMM, Lockman, S1 (Dec 05)
  - Final catalogues will be released shortly, including photometric redshifts

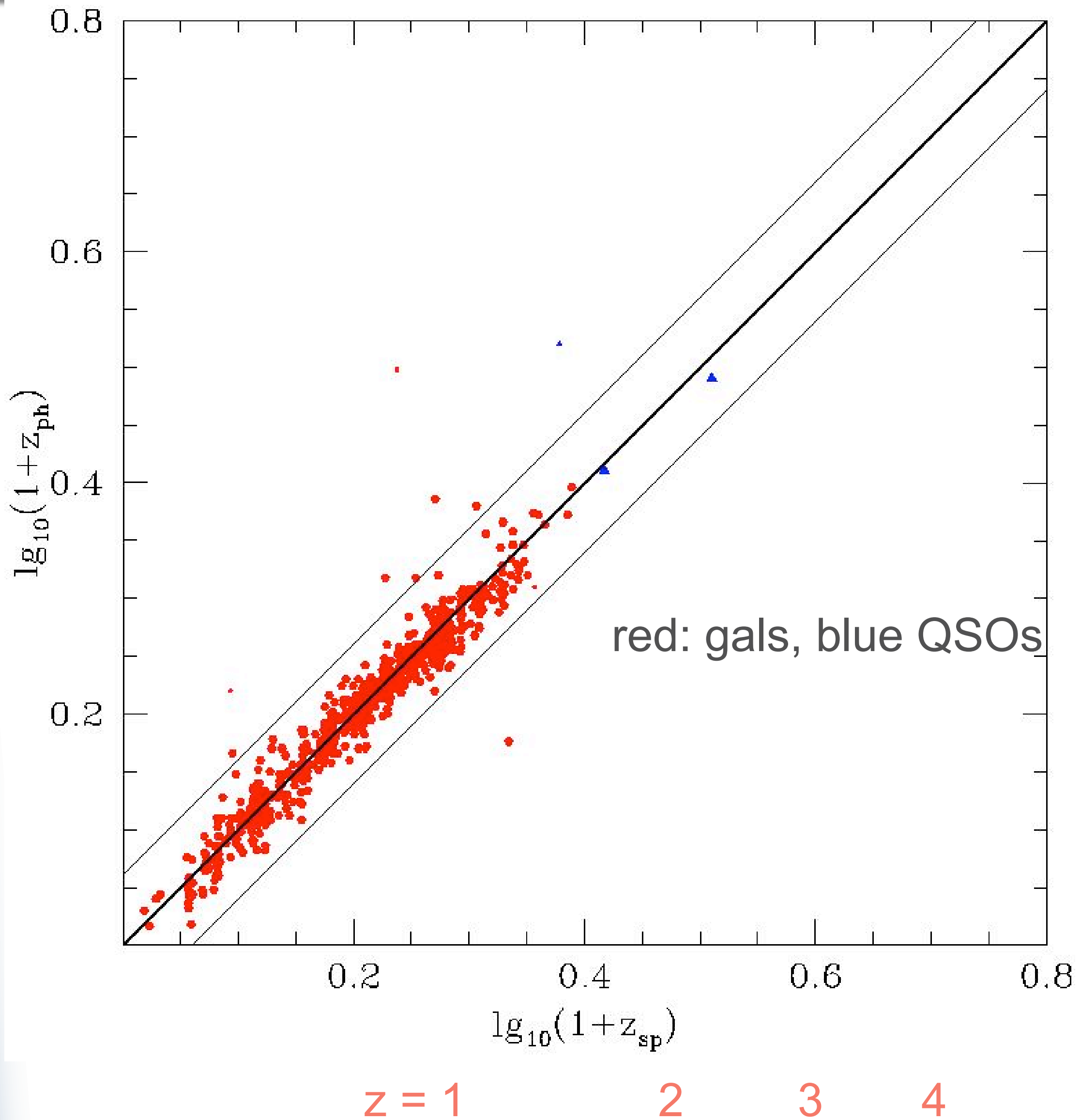
Outline

- Photometric redshifts, redshift distribution
- Optical and infrared sed modelling
- Using X-ray data to study highly obscured quasars, proportion of Type 1/Type 2 quasars

SWIRE Team and Associates

Name	Role	Institution	Associates
Carol Lonsdale	PI	IPAC, Caltech	Duncan Farrah, Maria Polletta
Harding E (Gene) Smith	Deputy PI	UCSD	Brian Siana
Michael Rowan-Robinson	Deputy PI for Science	Imperial College	Tom Babbedge, Dave Clements
Dave Shupe	Liaison Scientist	SSC/IPAC	
Jason Surace	Data Processing/IRAC	SSC/IPAC	
Kevin (Cong) Xu	Models	IPAC	
Deborah Padgett	Galactic Science/MIPS	SSC/IPAC	
Fan Fang	Simulation/Models	SSC/IPAC	
Alberto Franceschini	Spheroids/AGN	Padua	Stefano Berta, Giulia Rodighiero
Dave Frayer	EROs/MIPS	SSC/IPAC	
Glenn Morrison	Radio	IPAC	
JoAnn O'Linger	Galactic Science	SSC	
Seb Oliver	Large Scale Structure	Sussex	Malcolm Salaman, Ian Waddington
Frazer Owen	Radio Deep Survey	NRAO	
Ismael Perez-Fournon	Nearby Galaxies	IAC, Tenerife	Alejandro Afonso-Luis, Evanthia Hadtziminaoglou, Antonio Hernan-Caballero
Marguerite Pierre	X-ray/XMM-LSS	CEA, Saclay	
Gordon Stacey	Submm	Cornell	
Steve Serjeant	ELAIS	OU	
Eduardo Gonzalez-Solares	ELAIS	Cambridge	

Photometric redshifts



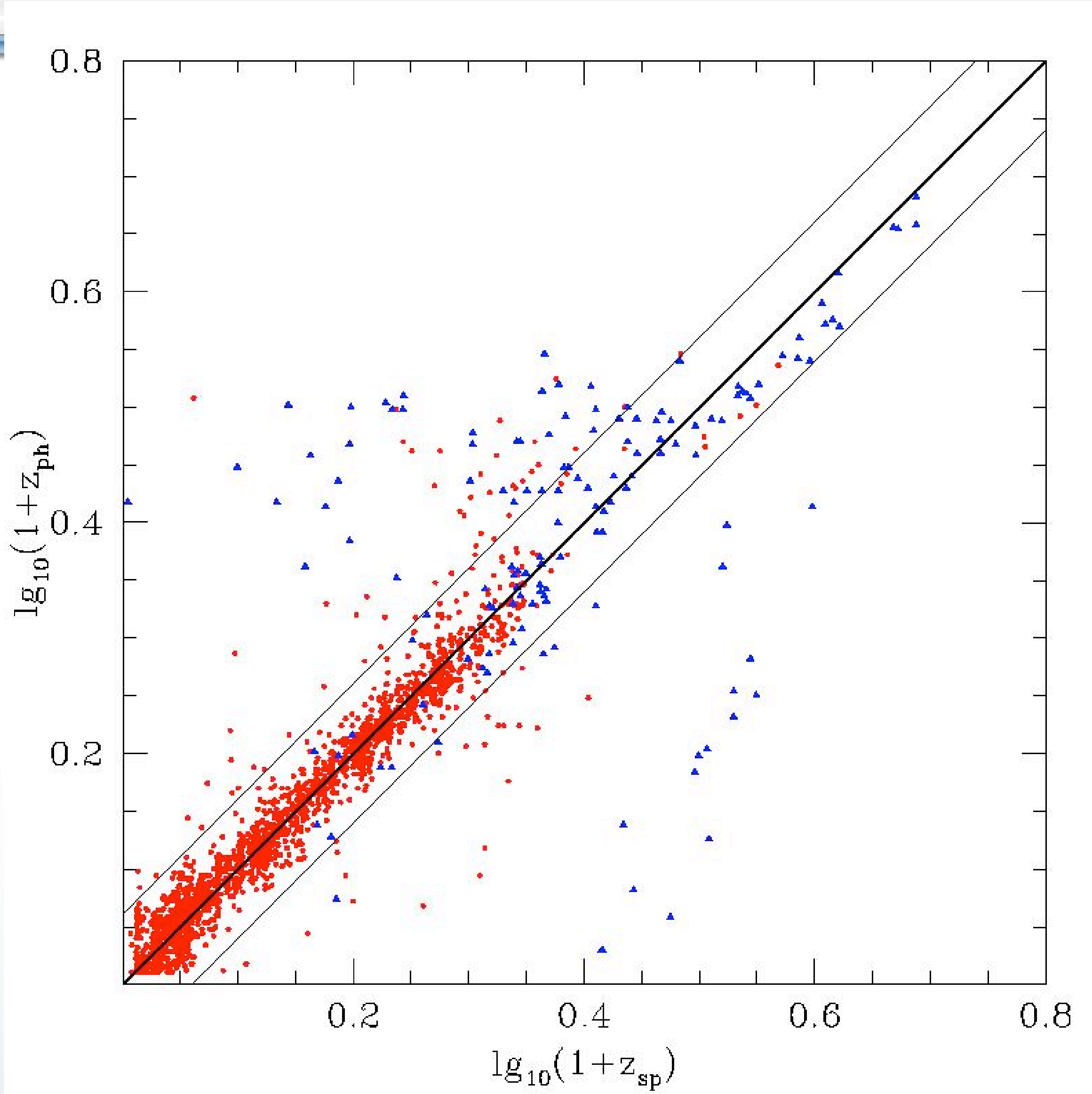
SWIRE-VVDS sample (with VVDS team, PI LeFevre)

VIRMOS-VLT Deep Survey spectra
>1000 sources
~3% *rms* in (1+z)
<2% outliers

phot z method of RR 03, Babbedge et al 04, RR et al 05, some refinements

~ IRAC 3.6 and 4.5 μm big help in reducing outliers

Photometric redshifts



z = 1 2 3 4

All SWIRE Catalogue

VVDS: 9 optical bands
N1,N2: 5 optical bands
Lockman: 3-4 optical bnds
CDFS: 3 optical bands

(Rowan-Robinson et al, 2008, MN)

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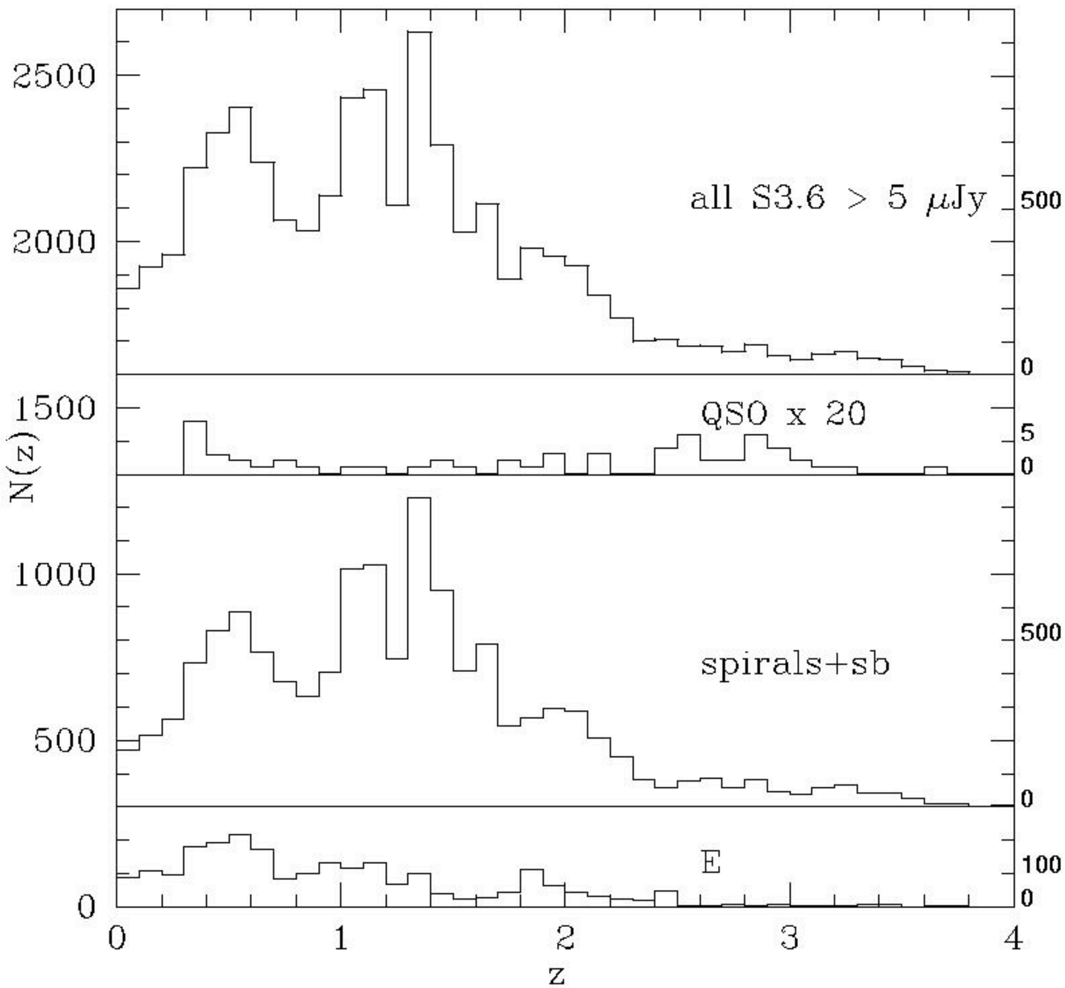
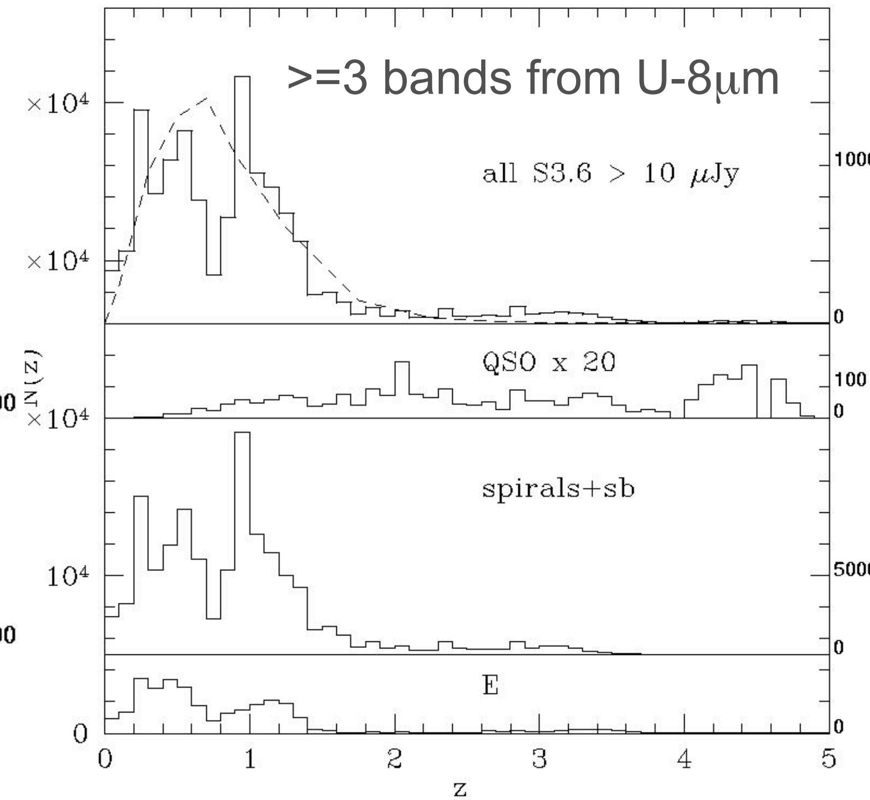
Redshift distributions



left: Suburu XDS, R<27.5

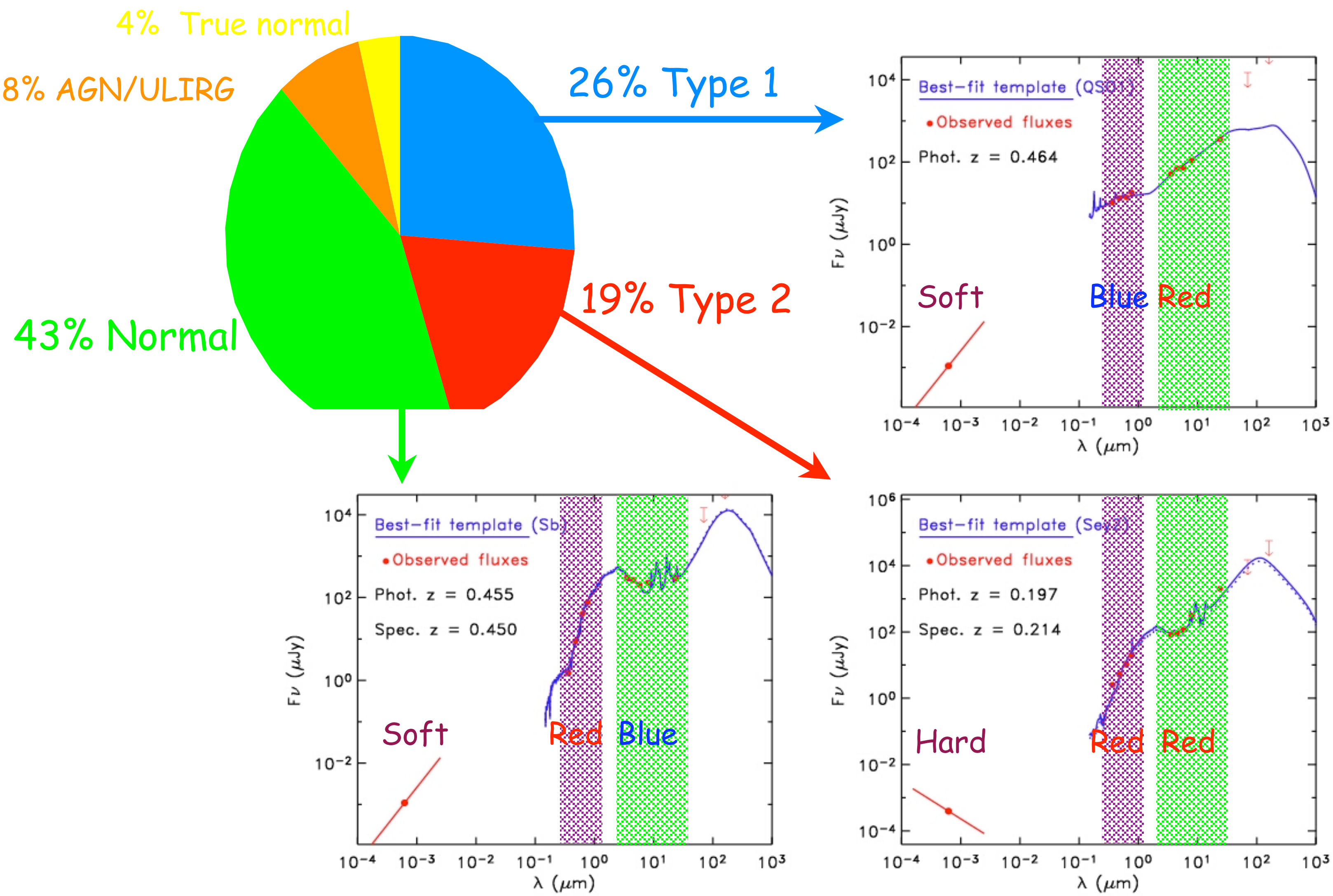
below: ELAIS-N1, r<23.5: for optically blank sources use 3.6-8 μm for phot-z



some statistics

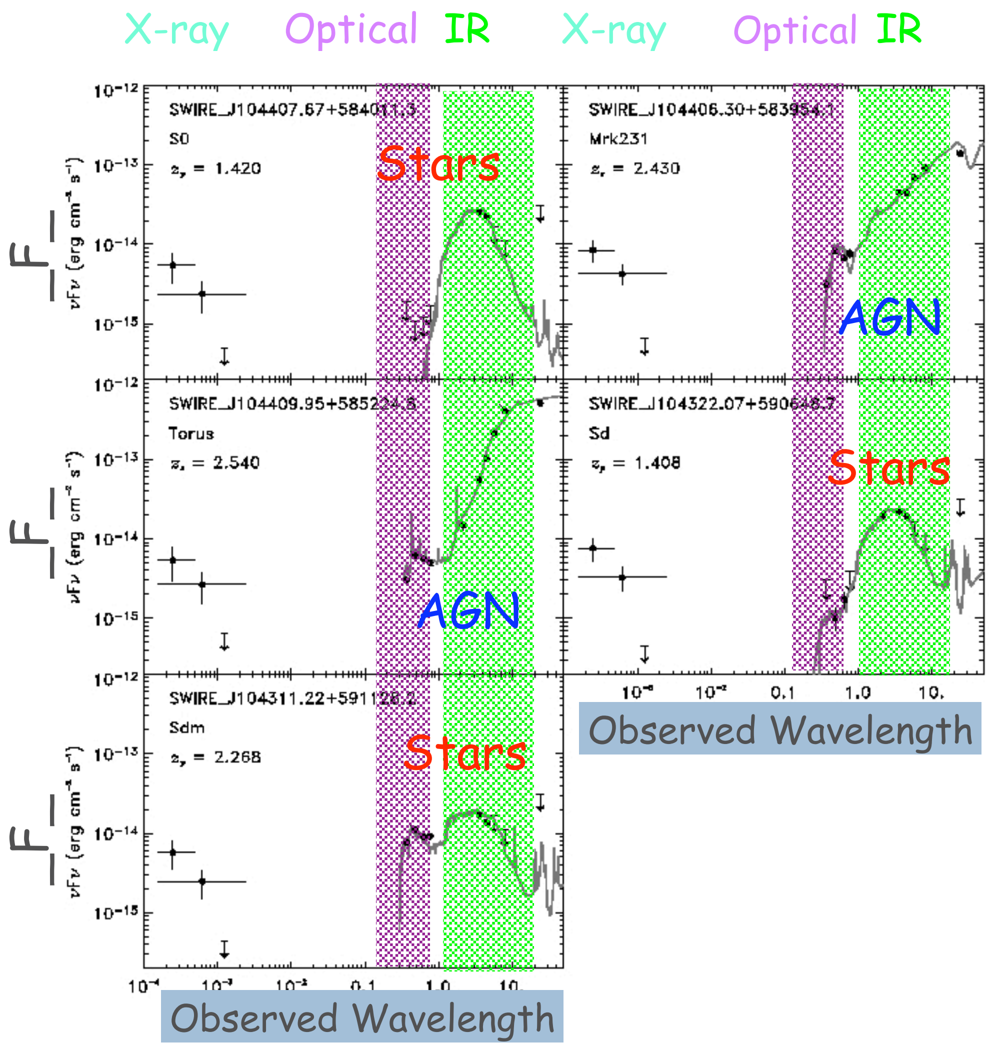
- over 1.5 million galaxies in SWIRE survey
- 10% have $z > 2$,   4% have $z > 3$
- 20% detected at 24 μm, 1% at 70 or 160 μm
- 35% of 24 μm sources are dust torus dominated at 8 μm (9% of these are QSO1, most of rest Seyfert)
- 5% of 24 μm sources are hyperluminous ($L_{ir} > 10^{13}$)
- do find some reddened QSOs, but only 5% of QSO1 have $A_v > 0.5$

Spectral energy distributions (SEDs) of a deep Lockman X-ray sample (Polletta et al 2006)



X-ray detected Compton-thick AGN

- Selection criterion:
  - HR, z ⇨ $N_H \geq 10^{24}$ cm^{-2}
  - 5 sources (z=1.4-2.5)
- SEDs:
  - 2 AGN (40%)
  - 3 normal galaxies (60%)

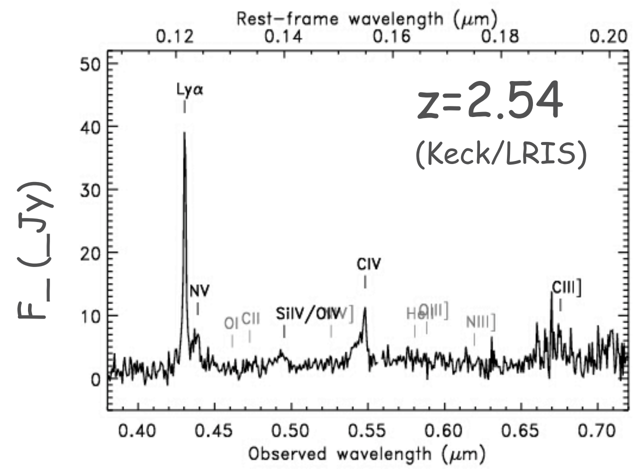


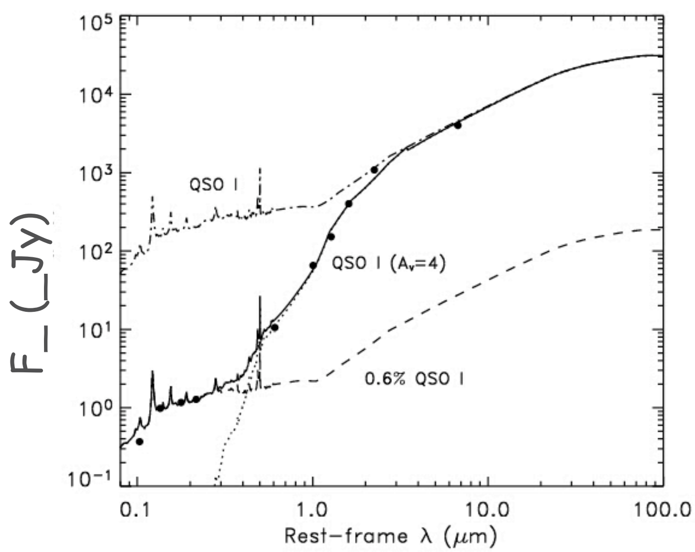
The most luminous Compton-thick quasar, z=254

- F(0.3-8 keV) = 2.7×10^{-15} erg cm^{-2} s^{-1}
- HR = 0.85 N_H= 2×10^{24} cm^{-2} & L_x= 1.2×10^{46} erg s^{-1}
- L_{bol} = 4×10^{47} erg s^{-1} & M_{BH} =3×10^{9} M_

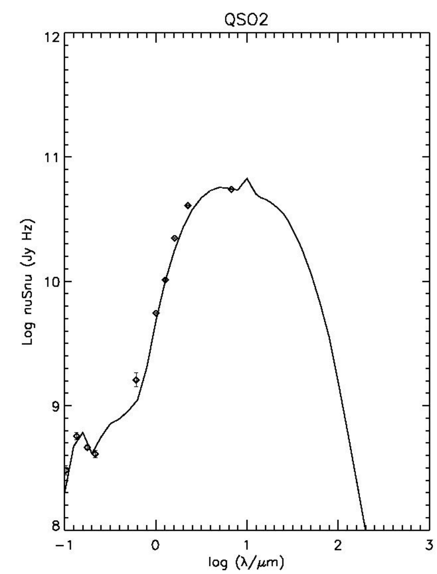
- Optical: blue with narrow lines (z=2.54) scattered light (0.6%)

- IR: red (r'-K = 4.2) model as QSO with A_V=4





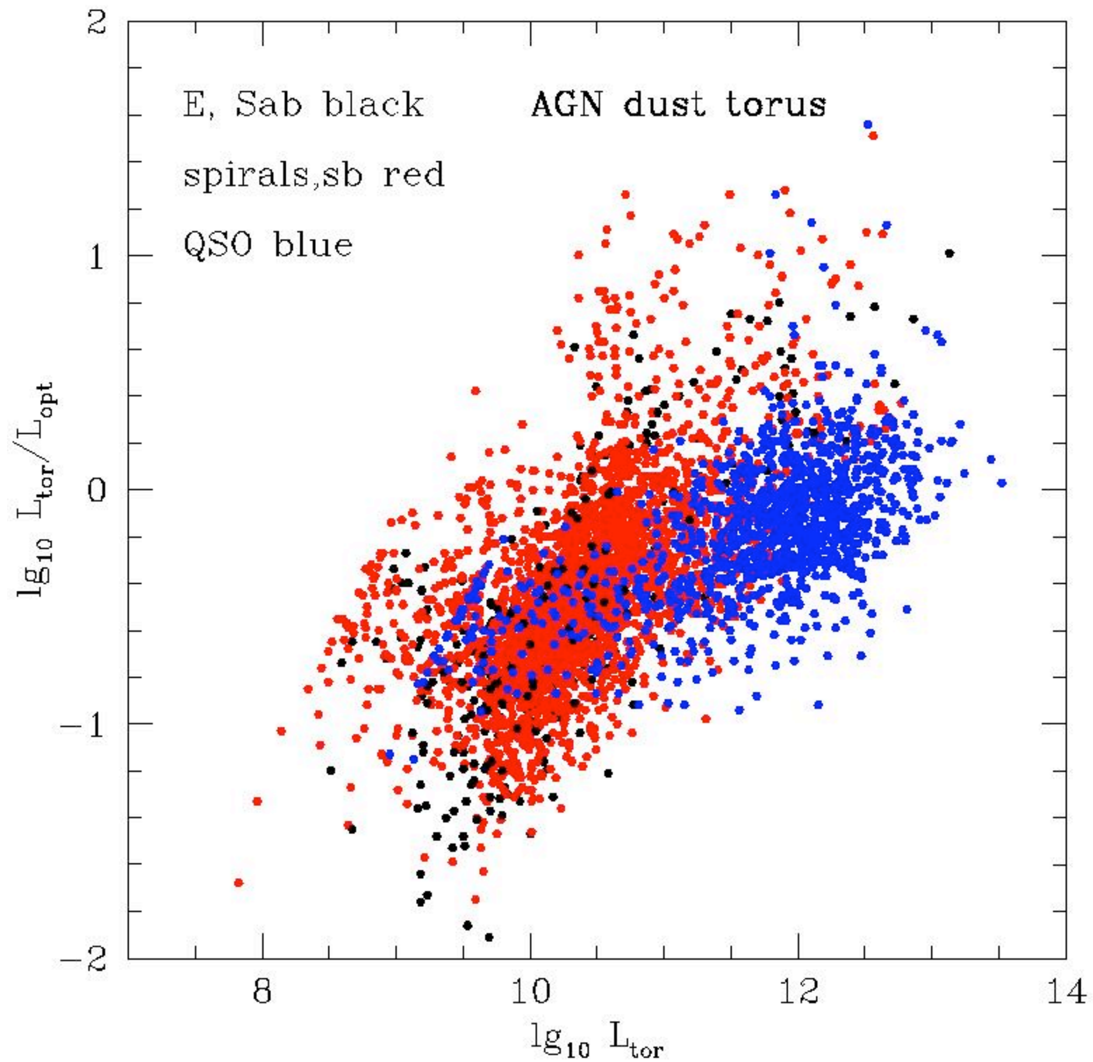
dust torus model (Eftstathiou and RR 2003)



Ltor/Lopt v. Ltor for SWIRE AGN dust tori

red: M82 sb dominated at 8 μm

blue: AGN dust torus dominated



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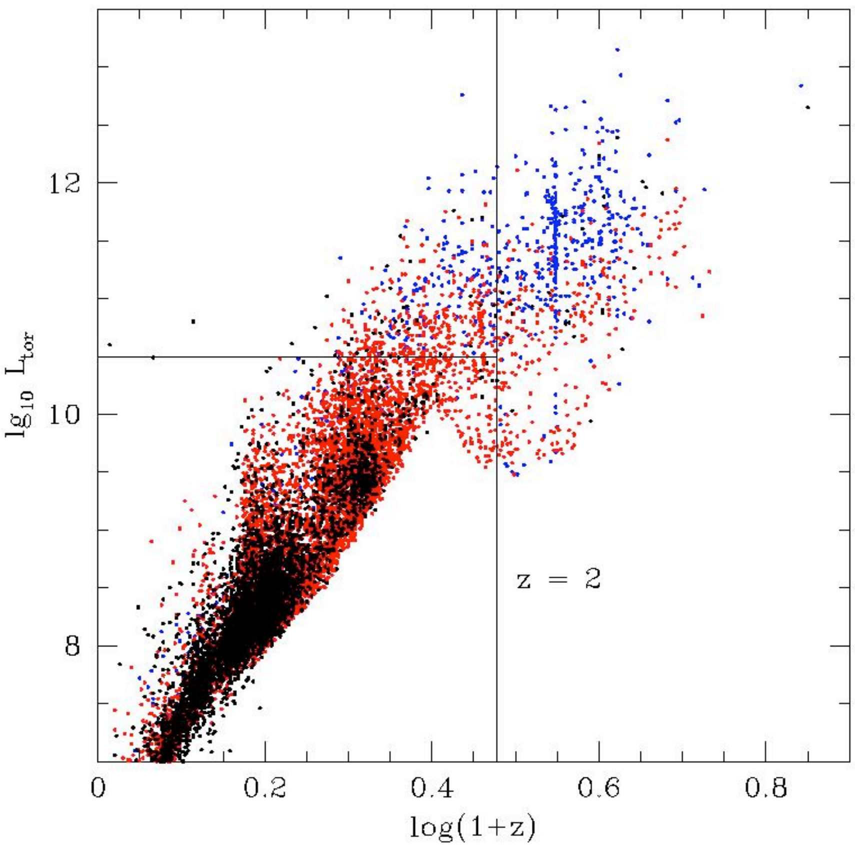
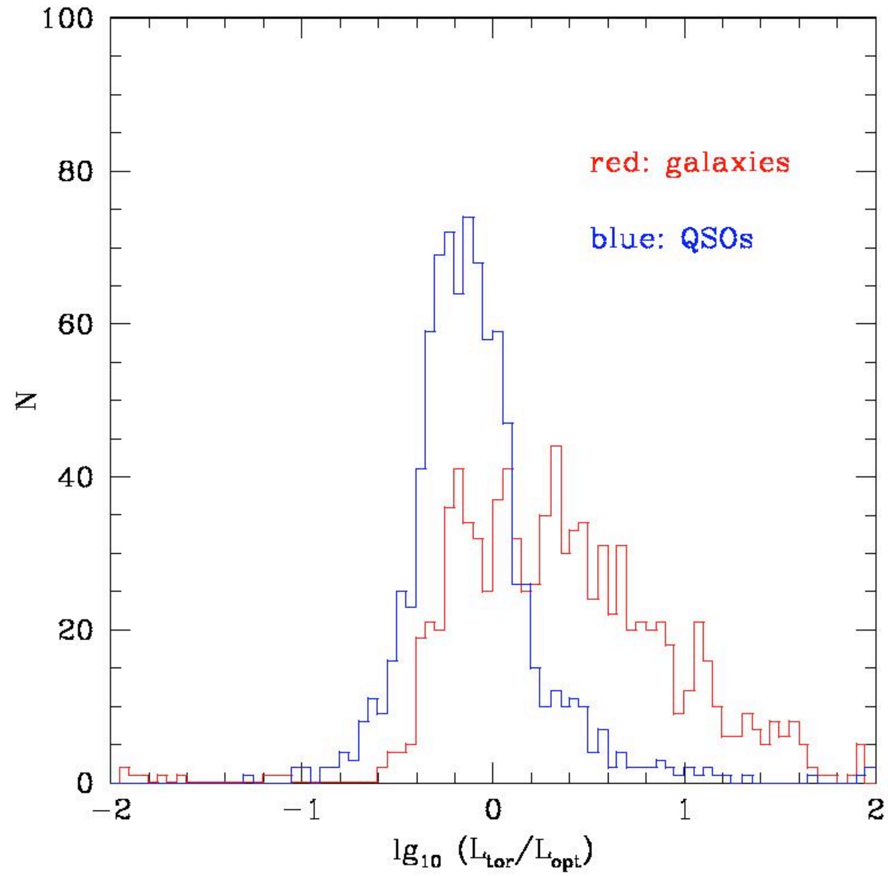
Ltor/Lopt v. Lor



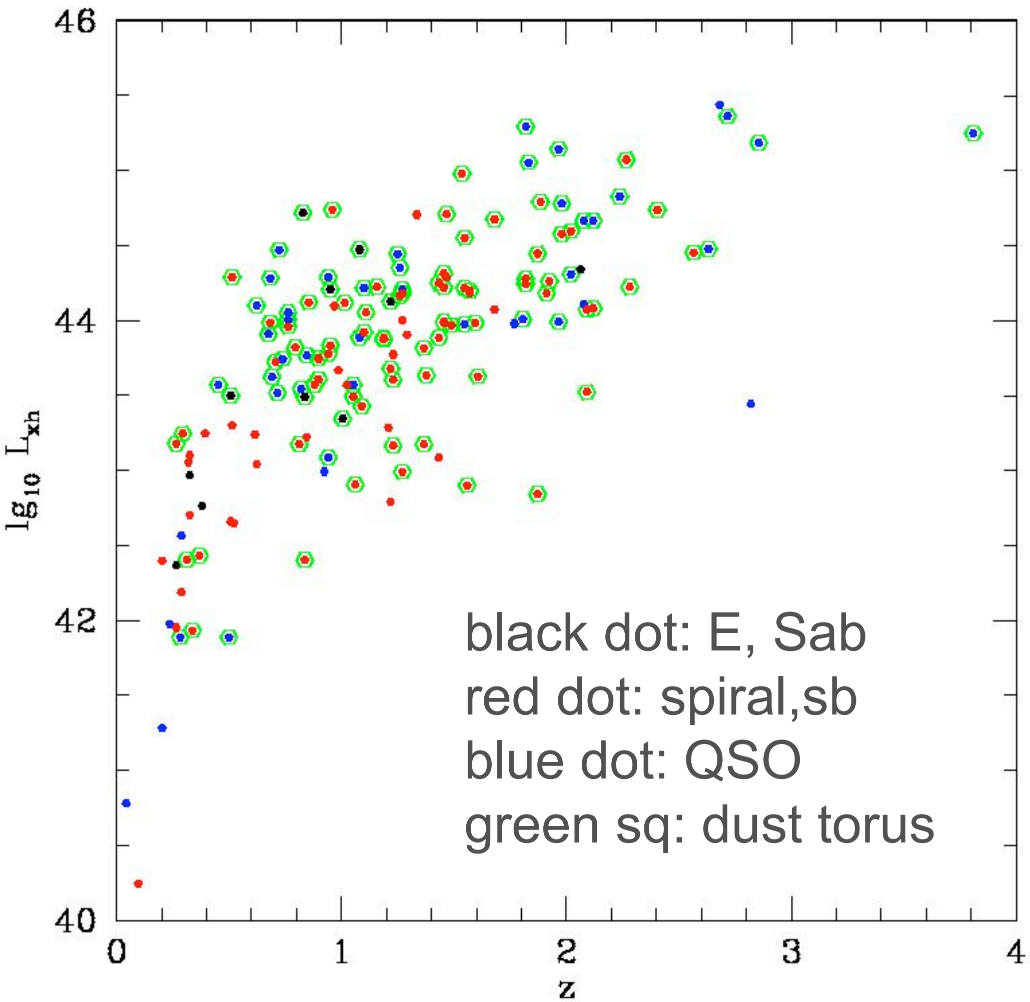


use volume limited sample of tori to quantify covering factor f=L(tor)/L(opt-uv). Find <lg10 f> = -0.4, σ=0.26, I.e. f = 0.4.

SWIRE+X-rays

CLASX Chandra X-ray survey in Lockman (Yang et al 2004), 0.4 sq deg, 426 extragalactic X-ray sources, 322 detected by SWIRE, 162 of which are QSOs or have dust tori

a further 273 SWIRE sources are QSOs or have dust tori (total SWIRE population in CLASX area: 8563)



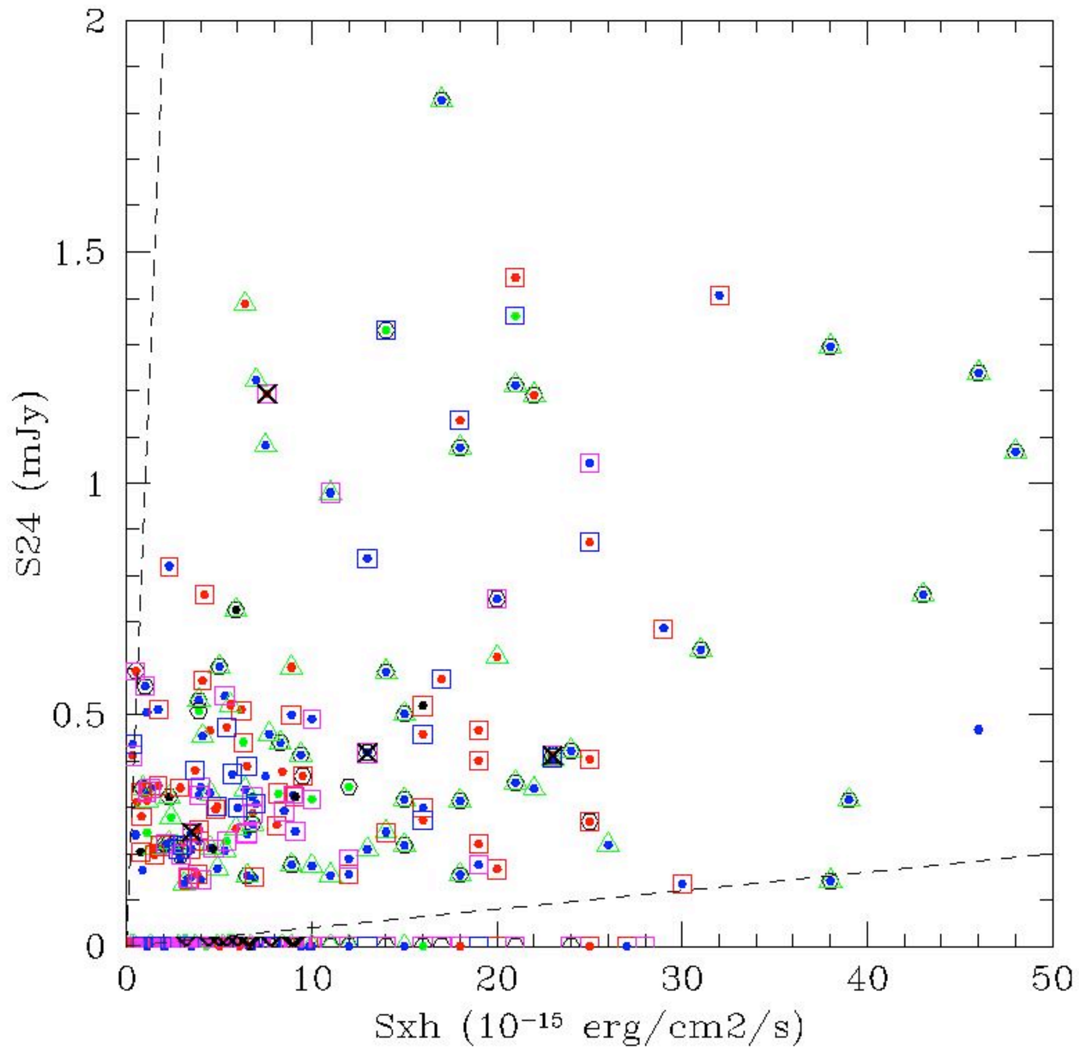
24 μm v. X-ray flux

Wide range of ratio of 24 μm flux to X-ray flux (0.004-1.0 mJy/10_{-15} erg/cm^2/s)

(Rowan-Robinson, Valtchanov, Nandra, 2008, in prep.)

green triangle: broad line
blue square: narrow line
red square:galaxy spectr.
magenta square: no spec z
black circle: optical QSO
crosses: upper limits

filled circles- ir template type
red: M82 starburst
blue: AGN dust torus
green: Arp 2200 starburst



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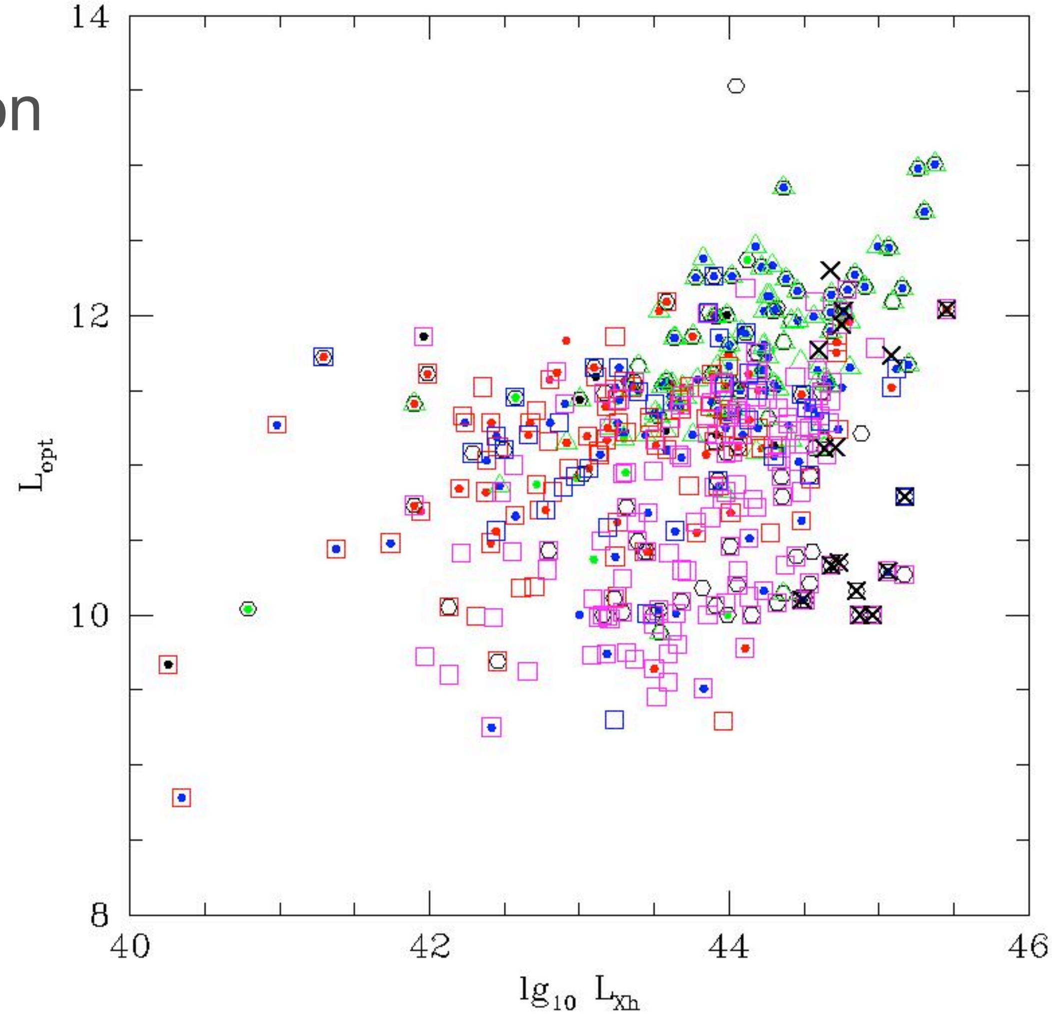
L(opt) v. L(Xh)

For type 1 QSOs, deduce X-ray bolometric correction is 23.5



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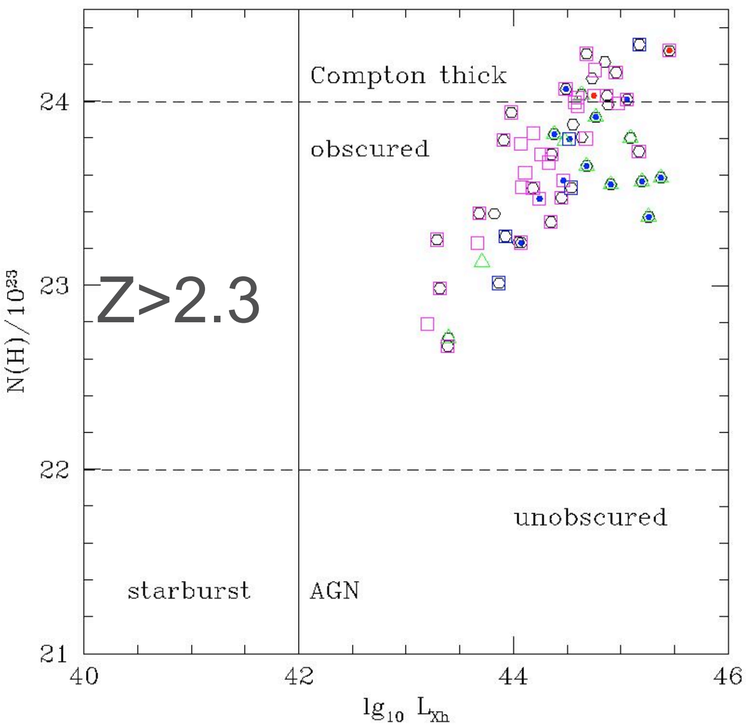
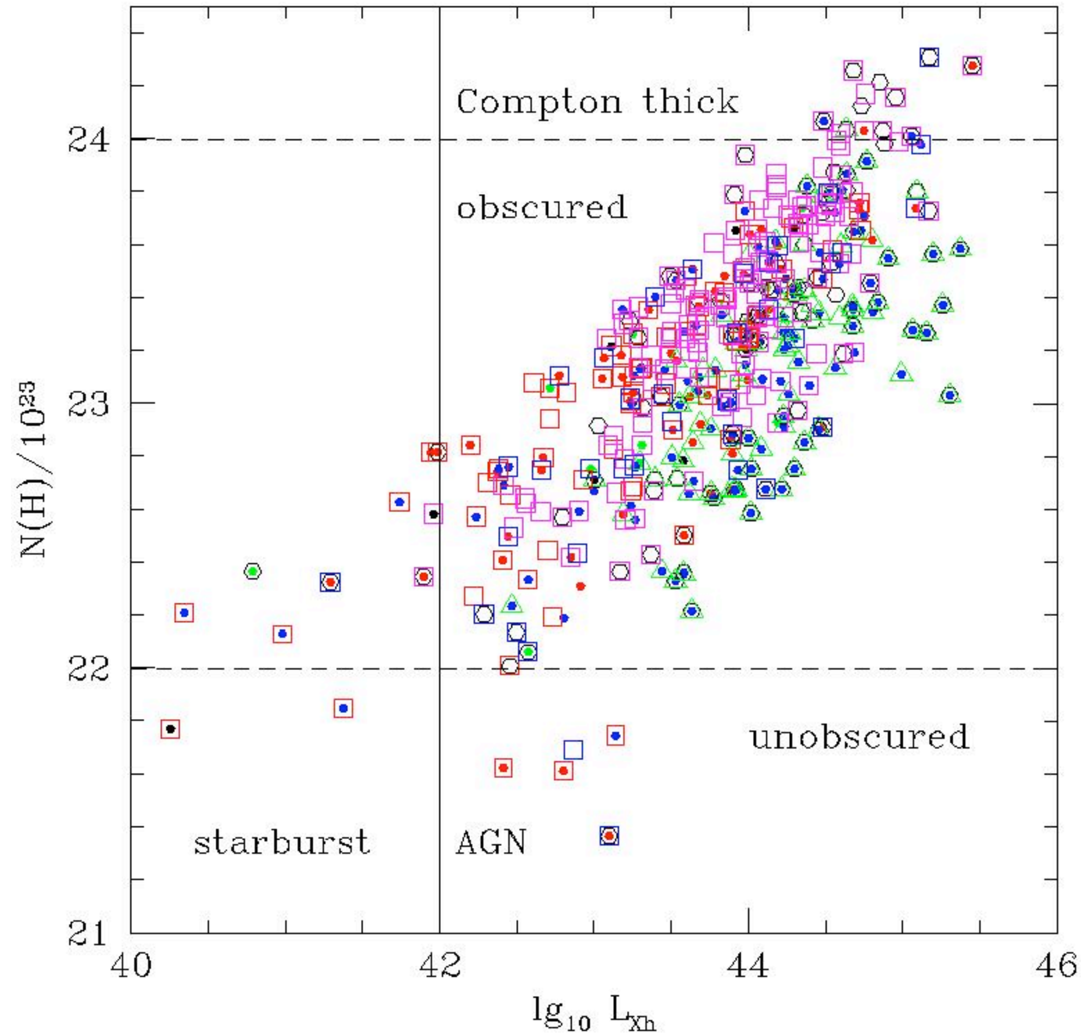
Hydrogen column-density v. X-ray luminosity

Use hard/soft X-ray flux ratio to estimate line-of-sight absorption, N(H)

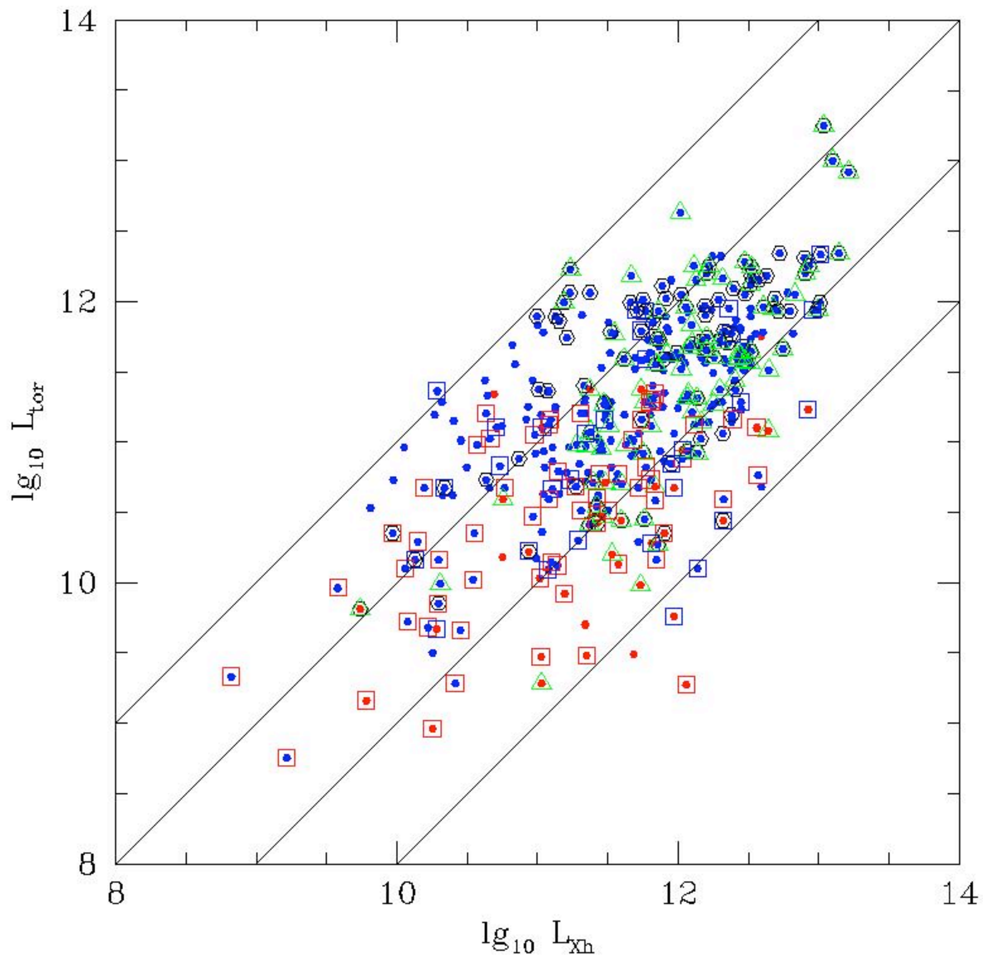




L(tor) v. L(Xh,c)

luminosity in dust torus versus X-ray luminosity

lines correspond to covering factor f = 0.01, 0.1, 1, 10
(can’t have > 1! So either X-ray bolometric correction underestimated, or there has been additional absorption in X-rays)



L(tor)/L(opt) v. L(opt)

green triangle: broad line
blue square: narrow line
red square:galaxy spectr.
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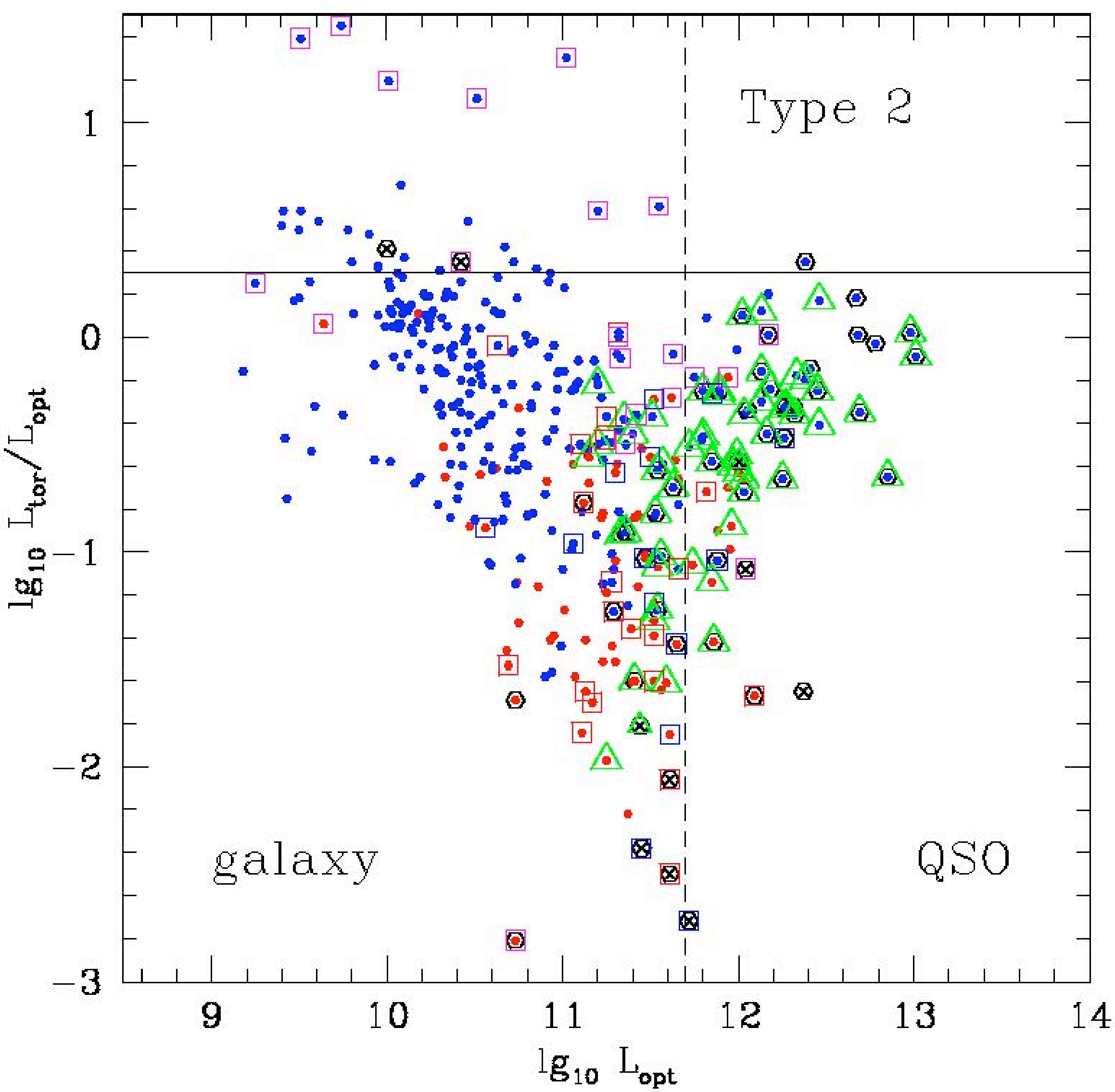
lg {L(tor)/L(opt)} ~ lg f, versus lg L(opt), (L_{sun}) for all SWIRE AGN.

we see many low-luminosity tori with SWIRE which are not detected at X-rays



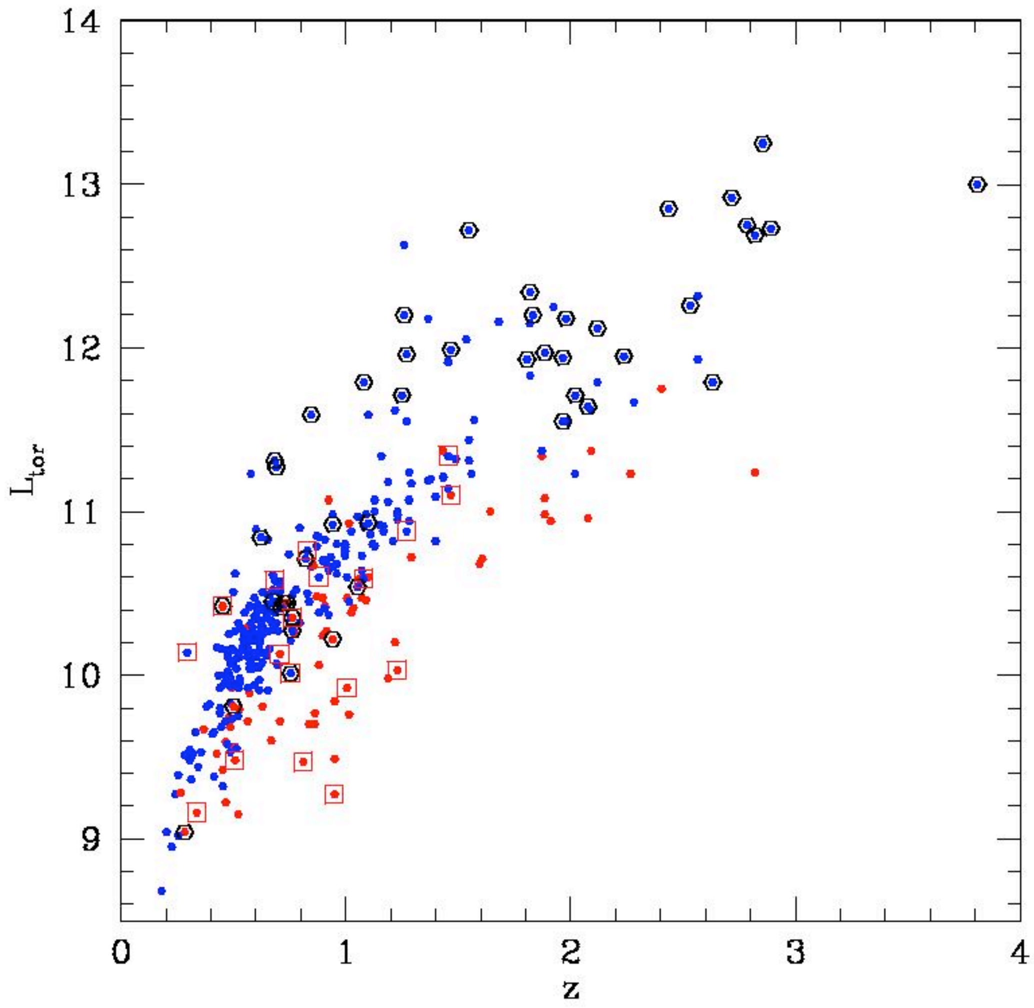
L(tor) v. z

blue square: narrow line
red square:galaxy spectr.
black circle: optical QSO

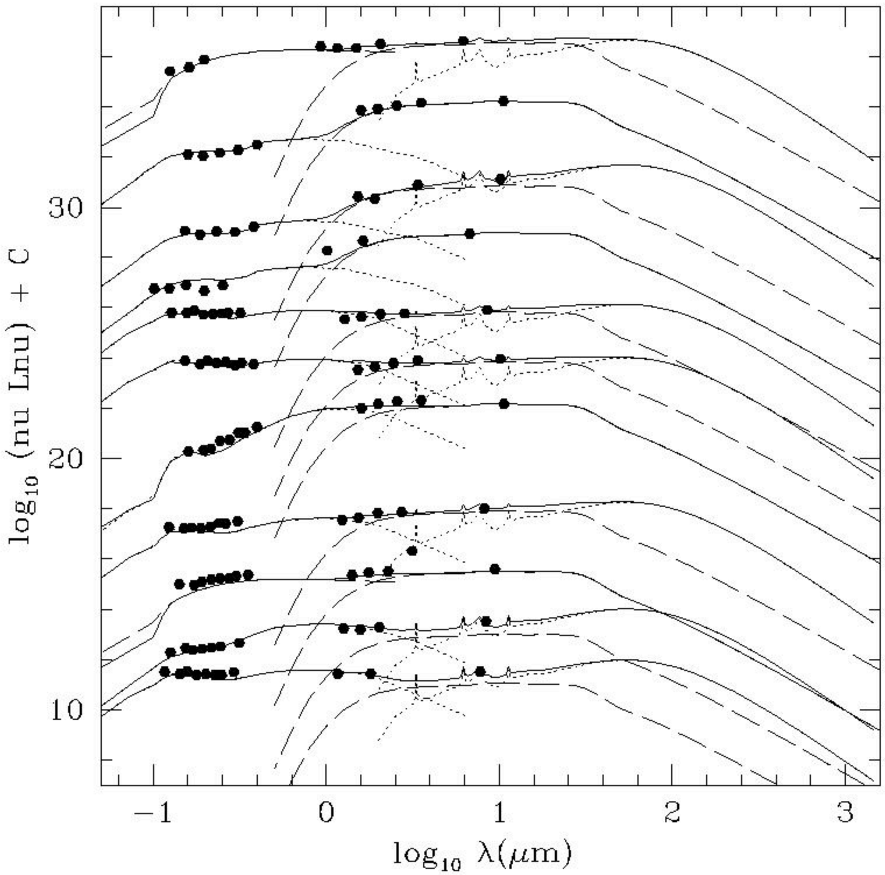
filled circles- ir template type
red: M82 starburst
blue: AGN dust torus
green: Arp 2200 starburst

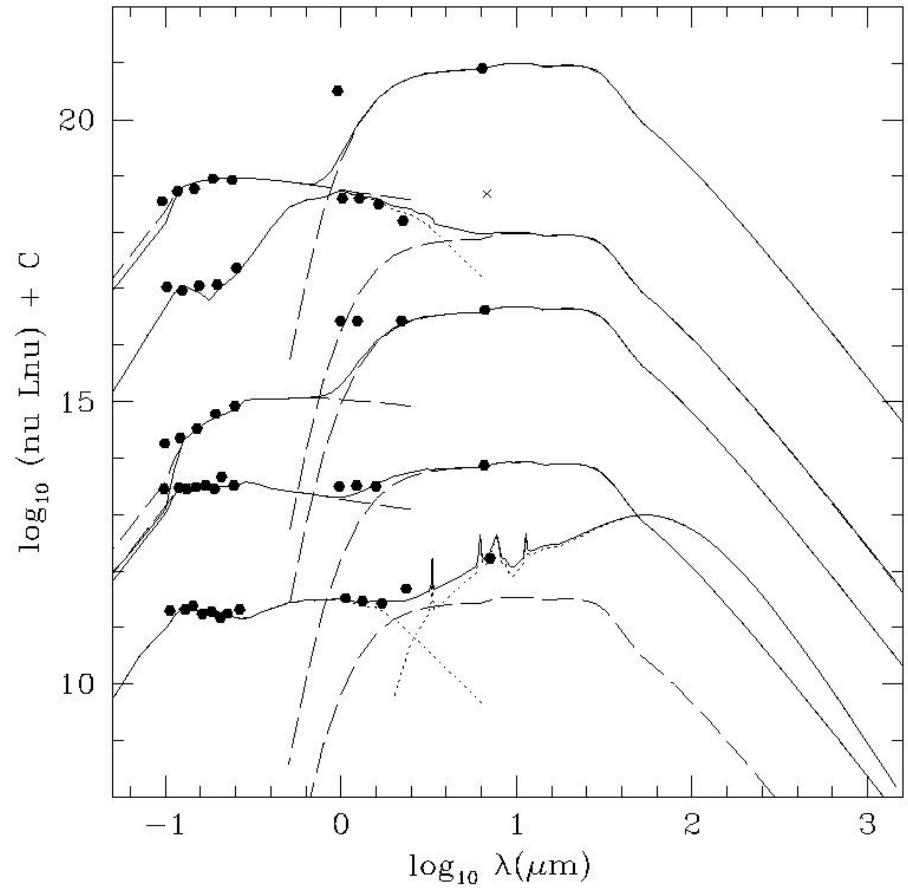
lg {L(tor)} versus z
for all SWIRE AGN.

wider dynamic range than
the X-ray luminosity,
more low-luminosity,
low-z, dust tori



very strong (Compton thick ?) tori





Left: L(tor) > L(bh) - Compton thick candidates ?

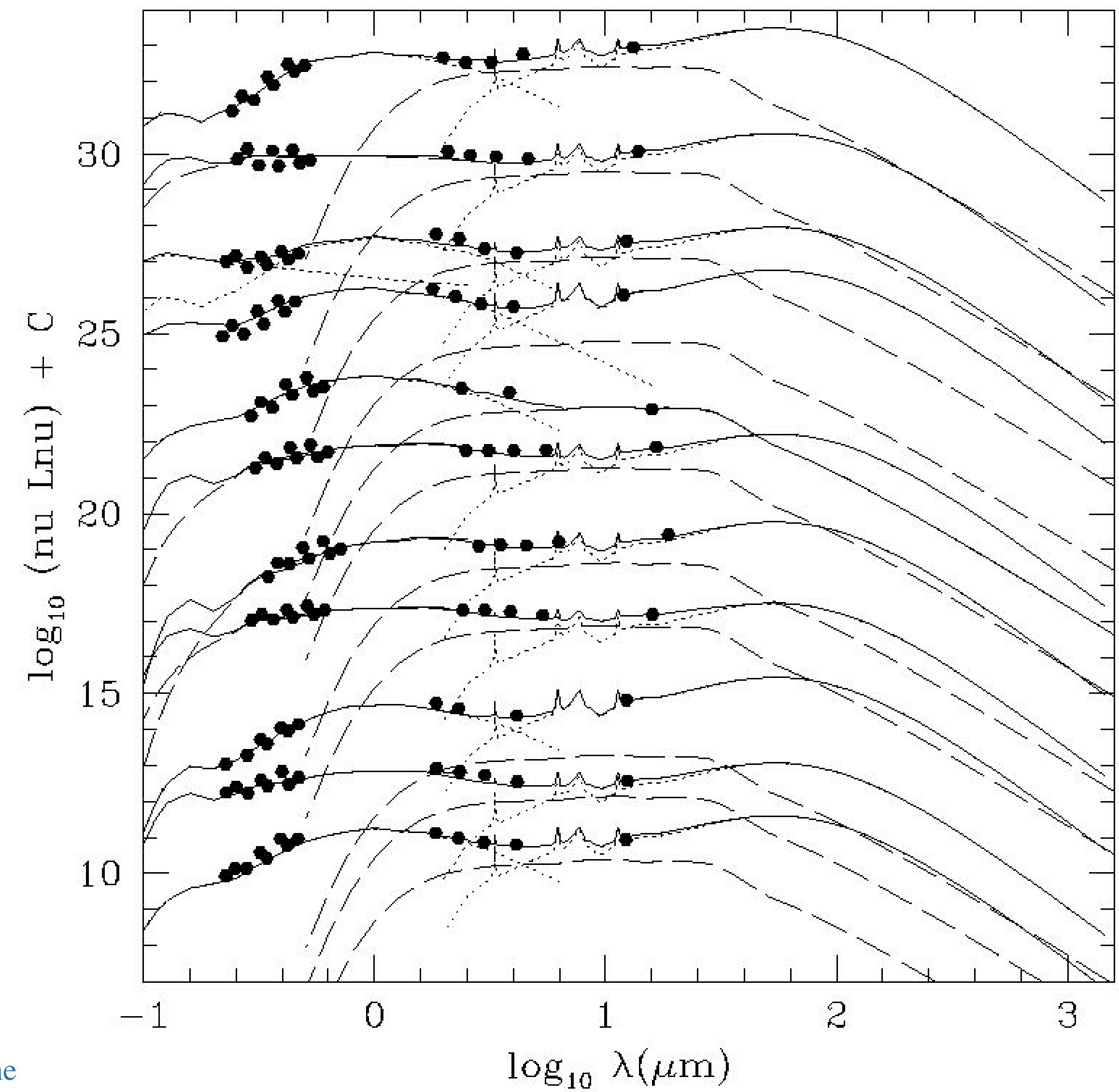
Right: lg N(H) > 24 (cm^{-2}) - Compton thick

very weak tori ?

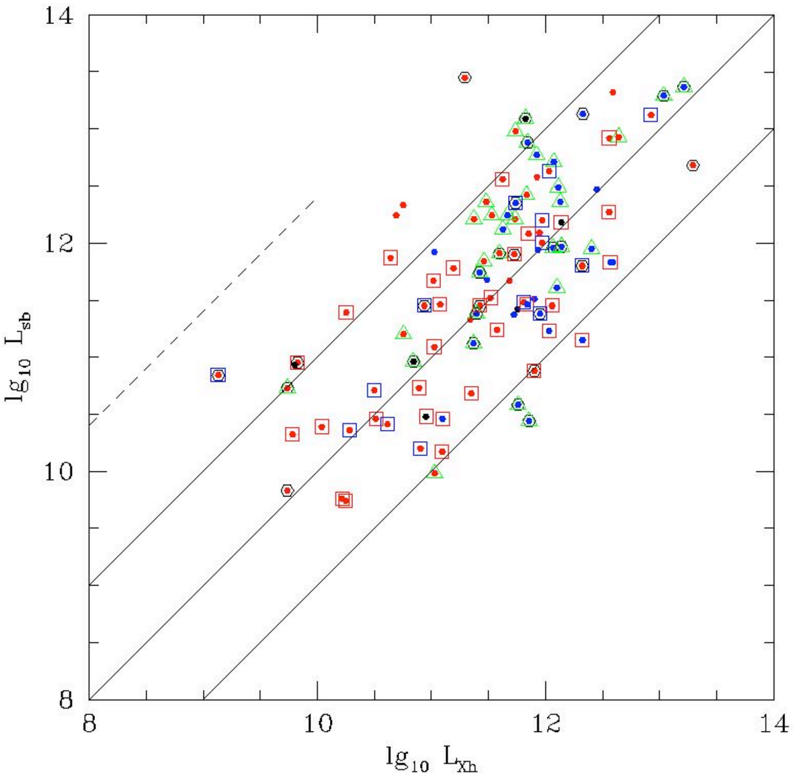
L(tor) < 0.03 L(bh) -
very weak or no tori ?

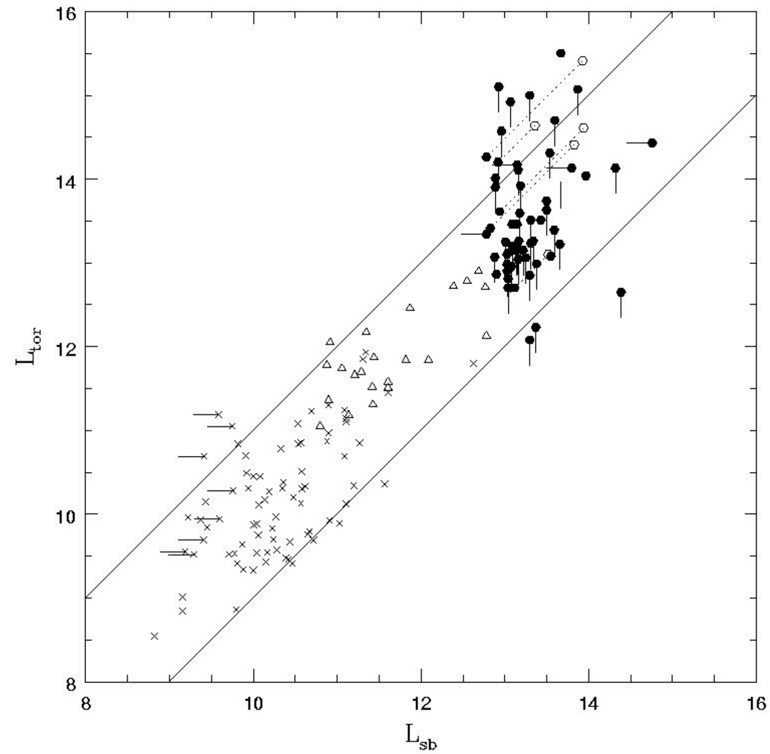
All consistent with 1-3% covering factor.

No strong evidence for < 1% covering factor



starburst-AGN connection





Left: L(sb) (measures star-formation rate) v. L(Xh,c)
[broken line - locus for X-ray starbursts].
Right: L(tor) v L(sb) - RR(2000), hyperluminous gals.
(1) Strong correlation - link between AGN and star formation
(2) these are differential versions of the Magorrian diagram (M_{bh} - M_*)

SUMMARY

- phot z
  - good accuracy and reliability with 4 or more photometric bands
  - a few red quasars with $A_V \sim 0.5\text{-}1$ (need SMC dust)

- ir template fits
  - validated by IRS
  - 35% of 24 μm sources are dust torus dominated at 8 μm (9% of these are QSO1, most of rest Seyfert: for Lir>10^{11} Lo, 60% are type 1, 40% are Type 2)

- Compton thick X-ray QSOs (NH>10^{24})
  - some are Type 1, so broad/narrow lines not indicator of dust column
  - Polletta et al (2006) found 5 in 0.6 sq deg, estimated 55 per sq deg
  - 16 found in CLASXS from S(Xh)/S(Xs), 18 candidates with L(tor) > L(XH,c), most may just be lower luminosity Type 2 objects (fraction of z>2.3 AGN: 20-40%)

- Covering factor
  - from analysis of SWIRE QSOs (Type 1) with dust tori, f =0.4
  - consistent figure from CLASX X-ray sample, f = 0.32
  - no sign of dependence of covering factor on X-ray luminosity