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Infrared SEDs and Star Formation Rates of LoBAL QSOs

Low-ionization Broad Absorption Line QSOs (LoBALs) are a rare class of objects, accounting only for 1-3% of the general population of QSOs. Their defining characteristic is the presence of high velocity (>2000 km/s) mass outflows of low- and high-ionization ions, which are evident in the very broad blue-shifted absorption troughs in their rest-UV spectra. There is some observational evidence that LoBALs at low redshifts might exclusively reside in Ultra Luminous Infrared Galaxies (ULIRGs) with disturbed morphologies and young stellar populations as a result of a recent galaxy merger. Those studies and the currently sparked interest in AGN feedback as a possible mechanism for regulating galaxy evolution have highlighted the importance of testing previous ideas proposing that BALs represent a short-lived outflow phase early in the life of QSOs. Herein we present the first results from a multiwavelength, systematic study of a complete sample of 22 LoBALs drawn from the SDSS DR3 within $0.5 < z < 0.6$. We model their optical through far-infrared SEDs using SDSS photometry, Spitzer/IRS low-resolution spectra from 7-20 microns and Spitzer/MIPS observations at 24, 70, and 160 microns. We estimate the total IR luminosities, star formation rates, and relative AGN/Starburst contribution to the FIR emission. We find that only half of the LoBALs in our sample reside in ULIRGs or HyLIRGs, while the rest of the hosts are LIRGs. We also estimate that the AGN accounts for 20-70% of the FIR luminosity. Using only the starburst contribution to the FIR luminosity, we estimate SFRs ~40-300 solar masses per year, values typical of LIRGs. In order to interpret our results, we need a control sample of classical type 1 QSOs analyzed in the same way.

Infrared SEDs and SFRs of LoBAL QSOs

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The importance of outflows in AGN

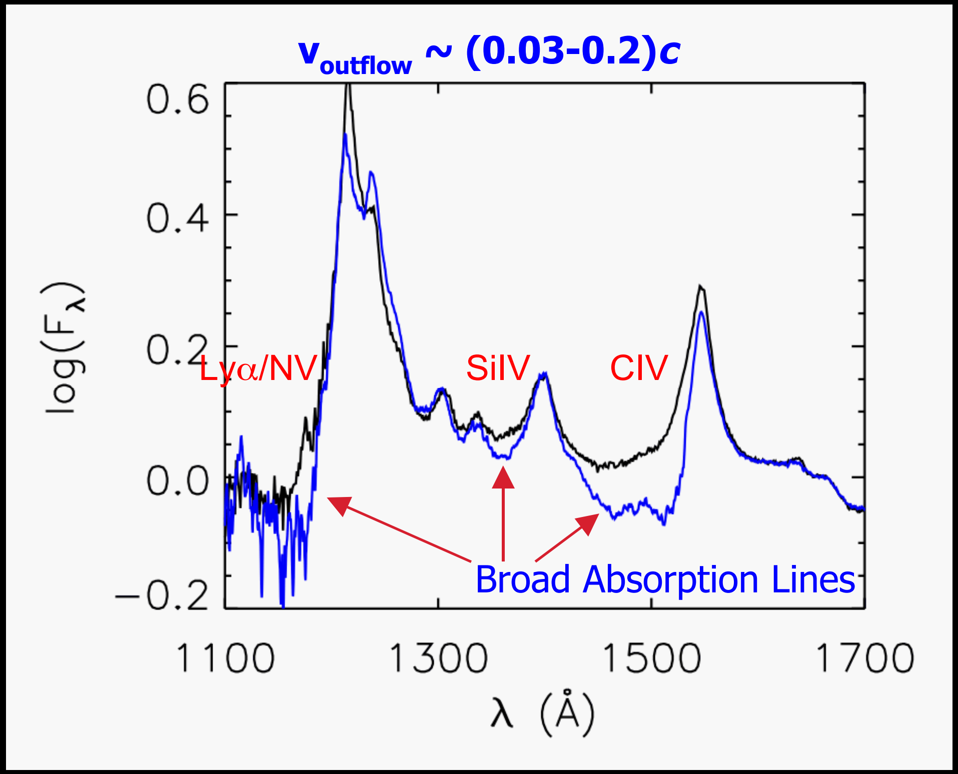
SMBH ⟷ Host galaxy connection

M_{BH} - M_{BULGE} (Kormendy & Richstone 1995; Magorrian et al. 1998)
M_{BH} - $L_{HOST\ GALAXY}$ (Laor 1998)
M_{BH} - σ (Ferrarese & Merritt 2000)
M_{BH} - M_{STARS} (Gebhardt et al. 2000)
M_{BH} - L_{BULGE} (Kormendy & Gebhardt 2001)

Quenching SF
Halting BH growth

Broad Absorption Line (BAL) QSOs

BAL widths ~ 1,000-60,000 km/s



Credit: Sarah Gallagher (U of Toronto)

BALs seen in 10% of optically-selected QSOs (Weymann et al 1991)

25% (Trump et al 2006 - redefines BAL to be> 1000 km/s)

true BAL fraction might be up to 45% (Dai et al. 2007)

The zoo of BAL QSOs

HiBALs: High-ionization BAL QSOs

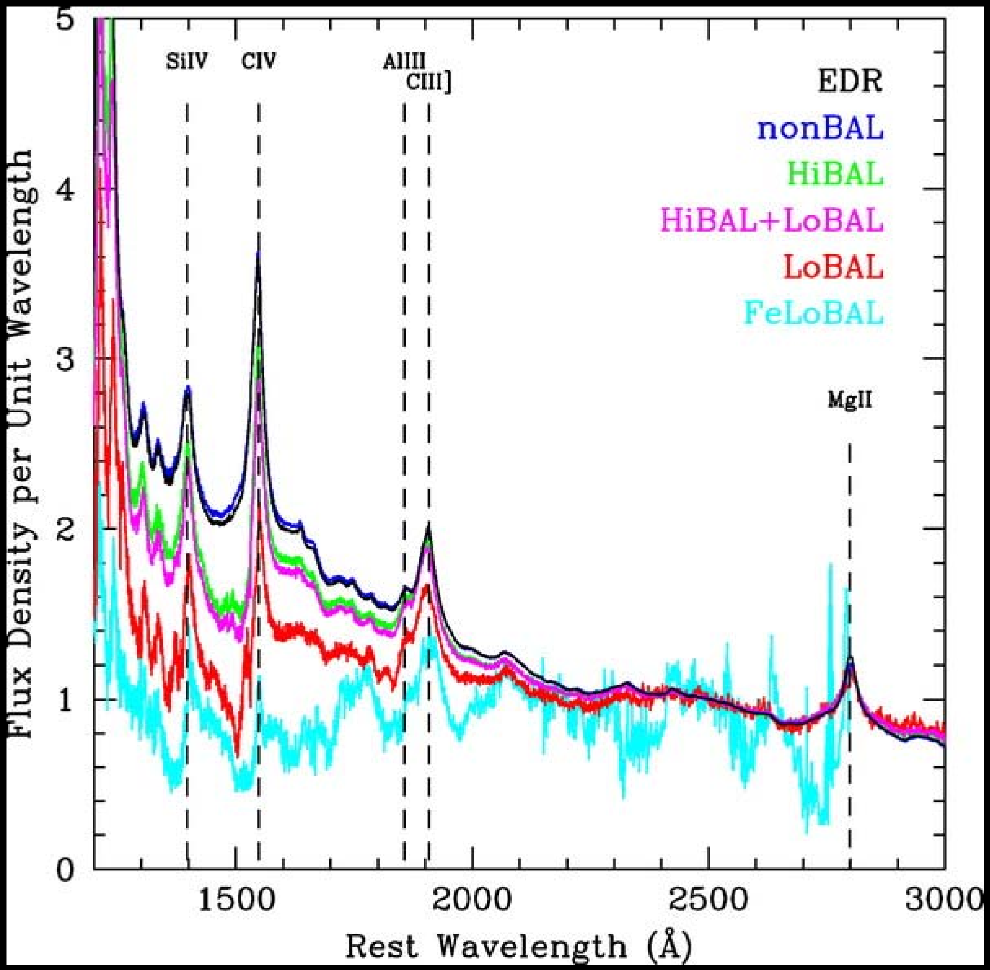
- **High-ionization BALs**
  (NV 1240, SiIV 1394, CIV 1549)
- 83% of all BAL QSOs **
- 13% of the QSOs

LoBALs: Low-ionization BAL QSOs

- **High-ionization BALs**
- **Low-ionization BALs**
  (MgII l2798, Al III l1857, Al II 1671)
- 13% of all BAL QSOs **
- 2% of the QSOs

FeLoBALs: Iron LoBAL QSOs

- **High-ionization BALs**
- **Low-ionization BALs**
- **Excited-state absorption by Fe II and FeIII**
- 4% of all BAL QSOs **
- < 1% of the QSOs



**Reichard et al. (2003)

BAL optical spectra are <u>similar</u> to non-BAL QSOs but more <u>reddened</u>

LoBALs

- LoBALs: Low-ionization BAL QSOs
  - High-ionization BALs
  - Low-ionization BALs
    (MgII λ2798, Al III λ1857, Al II 1671)
  - 13% of all BAL QSOs **
  - 2% of the QSOs

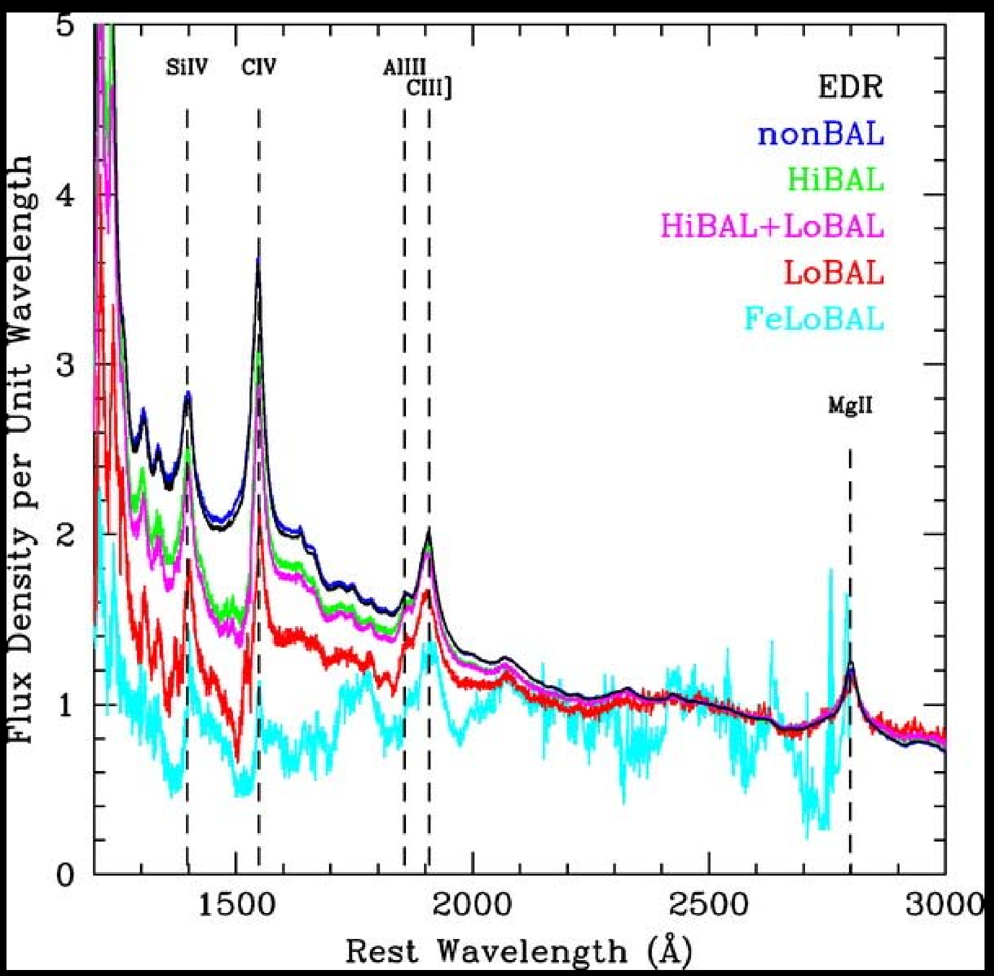
➡ low ionization parameter

➡ redder continuum

➡ weak [OIII] λλ4959,5007

➡ strong FeII (Fe II λ4570/Hβ > 1)

➡ mostly Radio Quiet



**Reichard et al. (2003)

Evolution

Orientation

Galaxy Merger

Intense star-formation

ULIRG

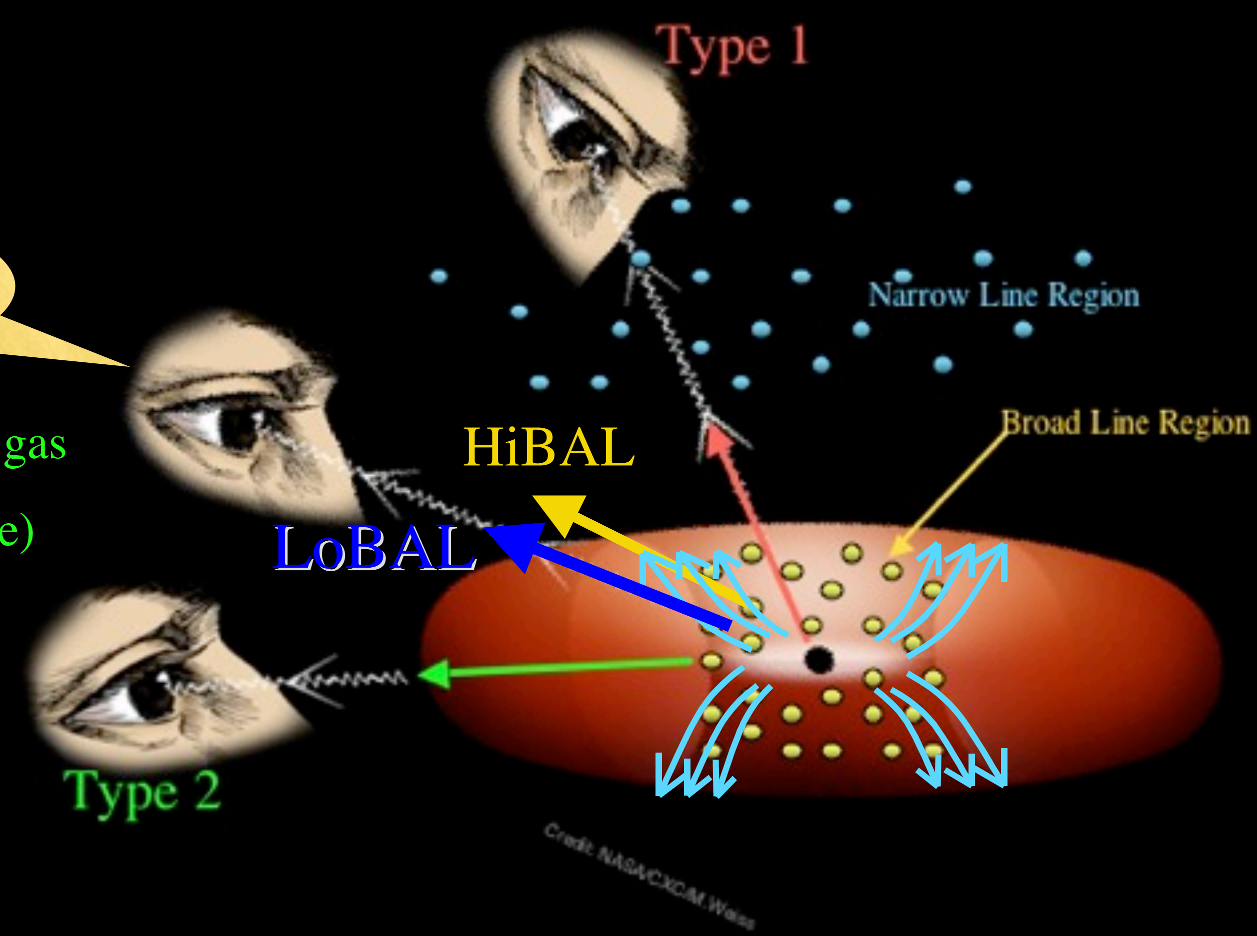
QSO

No observed winds

BAL QSO

Winds clear the enshrouding dust and gas

(end the LoBAL phase)

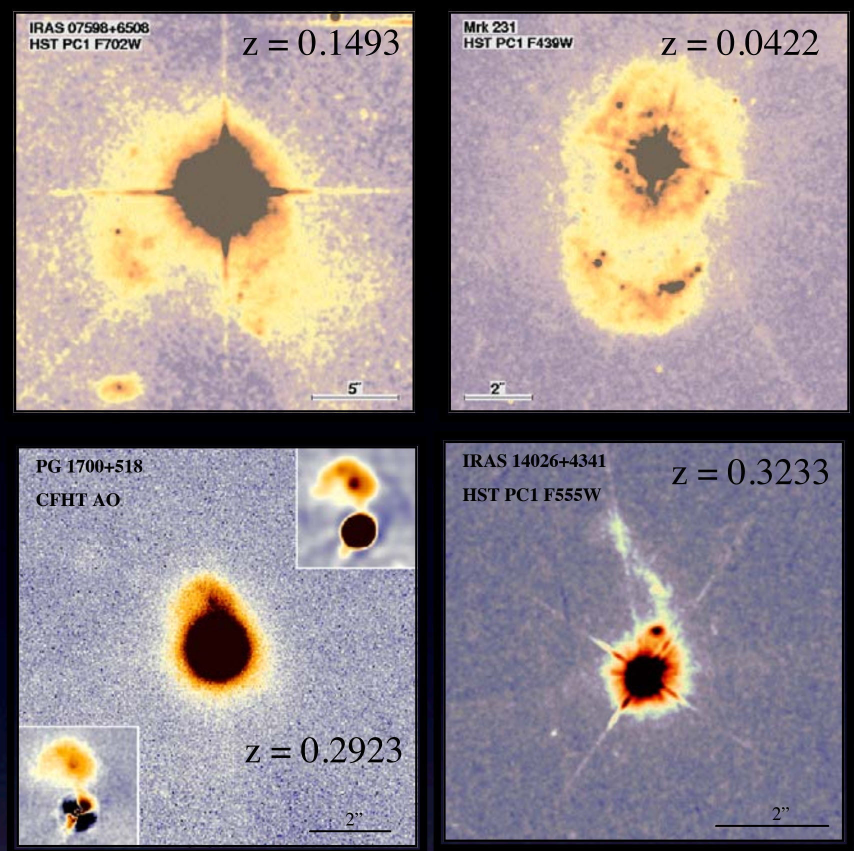


fraction of BALs => duration of outflow phase

fraction of BALs => range of viewing angles

fraction of BALs => covering factor of BAL winds

Canalizo & Stockton (2002)



the only 4 known LoBALs at z < 0.4

- ★ ULIRGs ($L_{IR} > 10^{12} L_{IR}$)
- ★ Hosts show signs of tidal interaction
- ★ Results of recent major merger
- ★ Unambiguous interaction-induced SF
- ★ Post-starburst age < 100 Myrs

Table 1: Properties of previously observed low-redshift low-ionization BAL QSOs.

Object Name	Redshift	$Log(L_{ir}/L_{\odot})$	Dynamical Age†	Starburst Age†
IRAS 07598+6508	0.1483	12.41	160	30
Mrk 231	0.0422	12.50	110	40
IRAS 14026+4341	0.3233	12.77	120	on-going
PG 1700+518	0.2923	12.58	40	85
IRAS 00275−2859 *	0.2792	12.54	130	50

† Dynamical ages (in Myr) estimated from length of tidal tails.

Motivation

Farrah et al. (2007)

- 9 FeLoBALs
- all 9 ULIRGs
- Large SB contribution to IR
- SFRs ~ 100's
- Suggest: high-z FeLoBALs are in the early stages of transition

Urrutia et al. (2009)

THE FIRST–2MASS RED QUASAR SURVEY. II.
AN ANOMALOUSLY HIGH FRACTION OF LoBALs
IN SEARCHES FOR DUST-REDDENED QUASARS

Sample

- ✓ Low-ionization BAL QSOs (i.e., confirmed MgII BALs)
- ✓ 0.5 < z < 0.6
- ✓ from the BAL QSO catalog by Trump et al. (2006)
  - BAL width > 1000 km/s
  - absorbed flux at least 10% below continuum

22 LoBALs

#	SDSS Object ID	z	$\mathrm{Log}(L_{IR}/L_{\odot})$
1	J114043.62+532439.0	0.530	13.65
2	J130952.89+011950.6	0.547	13.18
3	J112822.41+482309.9	0.543	13.15
4	J083525.98+435211.2	0.568	12.99
5	J142927.28+523849.5	0.594	12.91
6	J161425.17+375210.7	0.553	12.87
7	J085053.12+445122.5	0.541	12.24
8	J025026.66+000903.4	0.596	< 13.33
9	J204333.20-001104.2	0.545	< 13.33
10	J140025.53-012957.0	0.584	< 13.29
11	J023102.49-083141.2	0.587	< 13.20
12	J085357.87+463350.6	0.550	< 13.19
13	J101151.95+542942.7	0.536	< 13.17
14	J170341.82+383944.7	0.554	< 13.15
15	J170010.83+395545.8	0.577	< 13.10
16	J085215.66+492040.8	0.566	< 13.10
17	J142649.24+032517.7	0.530	< 13.09
18	J105102.77+525049.8	0.543	< 13.09
19	J023153.63-093333.5	0.554	< 13.04
20	J102802.32+592906.6	0.535	< 13.03
21	J141946.36+463424.3	0.546	< 13.02
22	J105404.73+042939.3	0.578	No IRAS data

The idea

(1) model IR SEDs => ULIRGs?
➡ Spitzer MIPS + IRS (16.7 hrs)

(2) image host galaxy morphology
➡ HST WFC3 UVIS / IR (23 orbits)

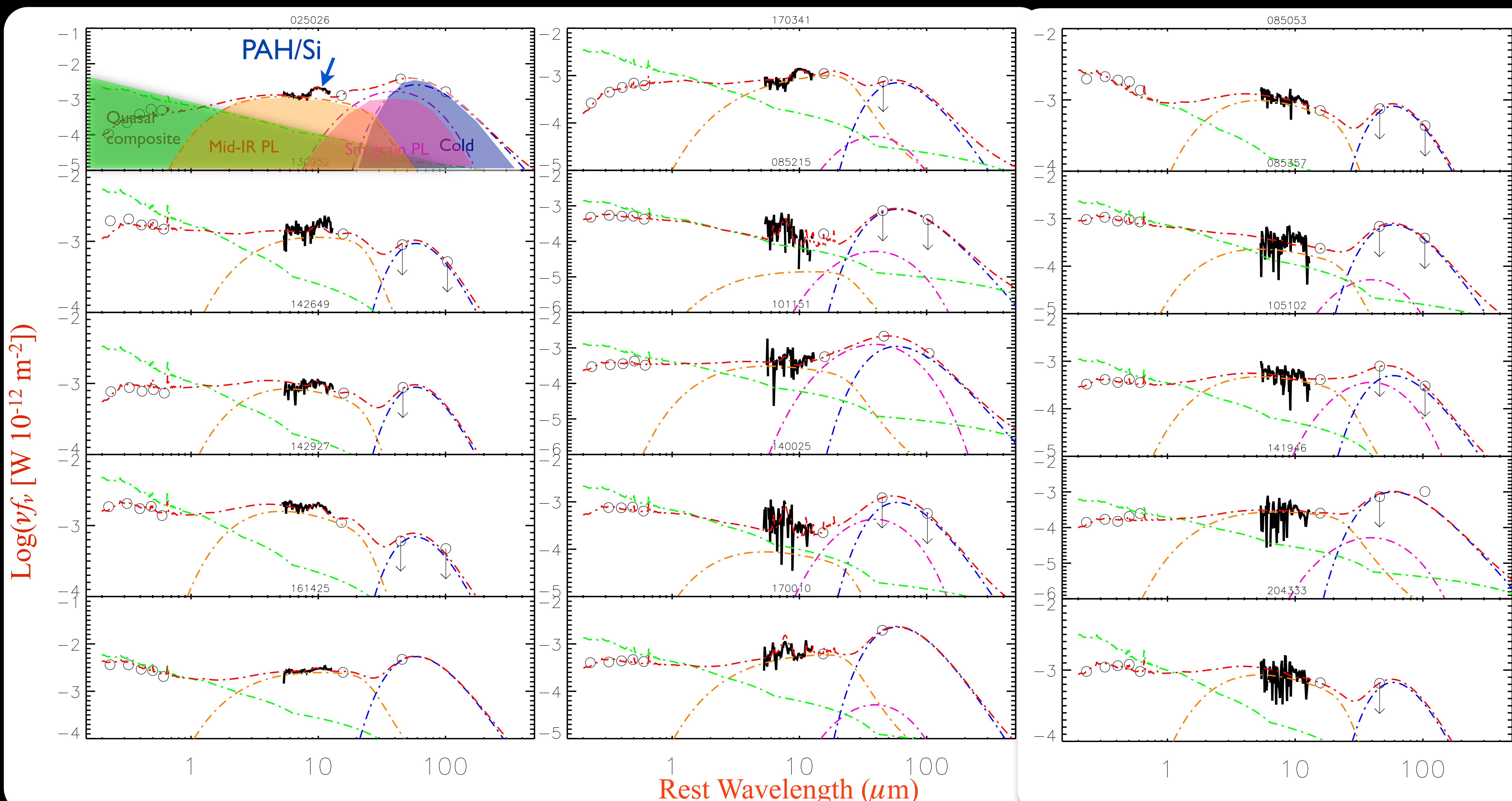
(3) model the stellar population ages
➡ Keck LRIS (2 nights)

Data

- 20 objects - Spitzer IRS spectra (SL1+LL2, 7-20 μm)
- 17 objects - Spitzer MIPS photometry (24,70,160 μm)
- 22 objects - HST WFC3 UVIS/IR images

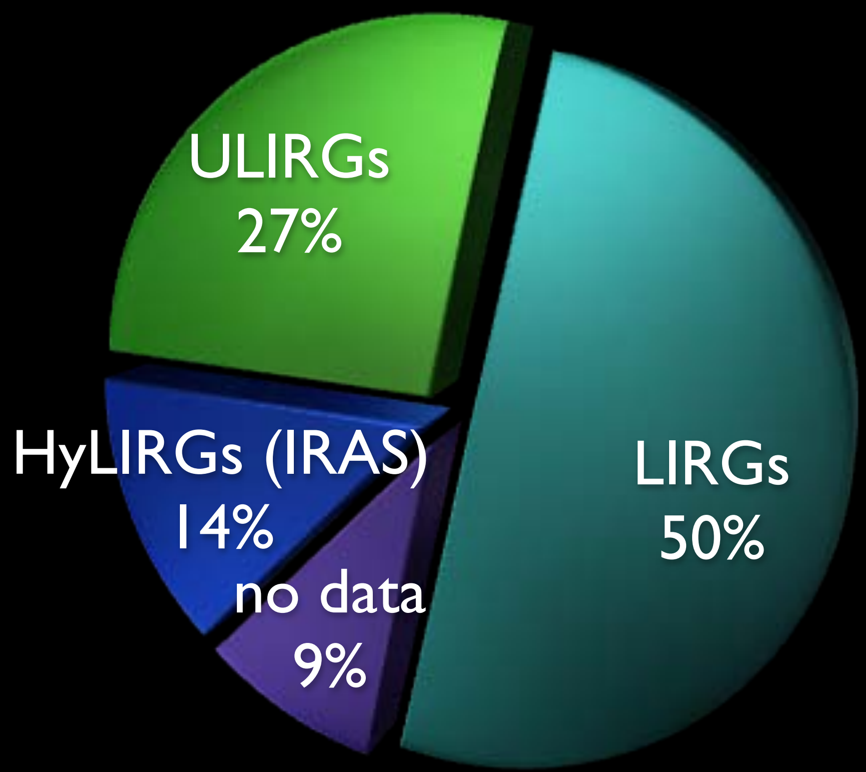
(1) optical-to-FIR SED fitting

- FIR(SB) = Warm Power Law + Cold BB(45K)

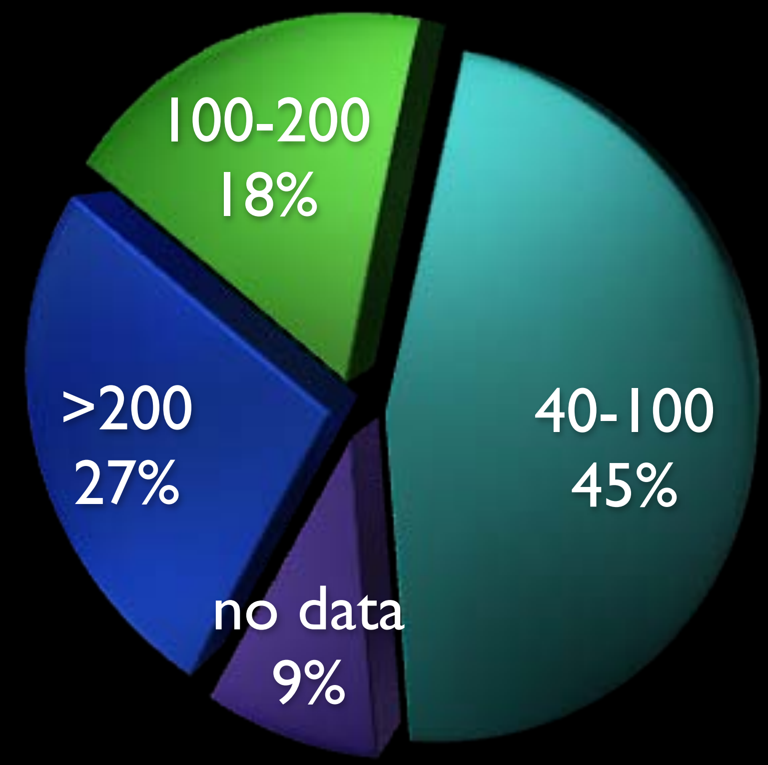


Fitting code: Sajina at al. (2006), Lacy et al. (2007)

Results from SEDs



SFRs (M⊙ yr−1)



SFR (M⊙ yr^{-1}) = 4.5 x 10^{-44} L_{FIR} (ergs s^{-1})
(Kennicutt 1998)

- 20-70% AGN contribution to FIR(8-1000 μm)
- $L_{FIR(SB+AGN)}$: $10^{11.3\ -\ 12.5}$ $L_{\odot}$
- SFRs ~ 40 - 300 $M_{\odot}$ yr^{-1}
- Median SFR ~ 50 $M_{\odot}$ yr^{-}

SFRs in QSOs

Our results

- 20-70% AGN contribution to FIR(8-1000 μm)
- 40% Hy-,U-LIRG; 50% LIRGs
- $L_{FIR(SB+AGN)}$: $10^{11.3 - 12.5}$ $L_{\odot}$
- SFRs ~ 40 - 300 $M_{\odot}$ yr^{-1}

Schweitzer et al. (2006)

- 26 PG QSOs, z<0.3
- detect PAH in 11 / 26
- PAH/FIR => 30+% SB contribution
- Higher SB % for more IR luminous QSOs
- Avg Mid-IR spectrum shows presence of PAH even for objects lacking individual PAH features
- on avg 7.7 PAH/FIR ratio same as in SB-dominated local ULIRGs

Ho (2005)

★SFRs from [OII] λ3727
★Extinction-sensitive tracer
★Assumptions (screen attenuation; Z=2$Z_{\odot}$, 1/3 of [OII] from SB)
★SFR QSOs < 20 $M_{\odot}$/yr

Hiner et al. (2010)

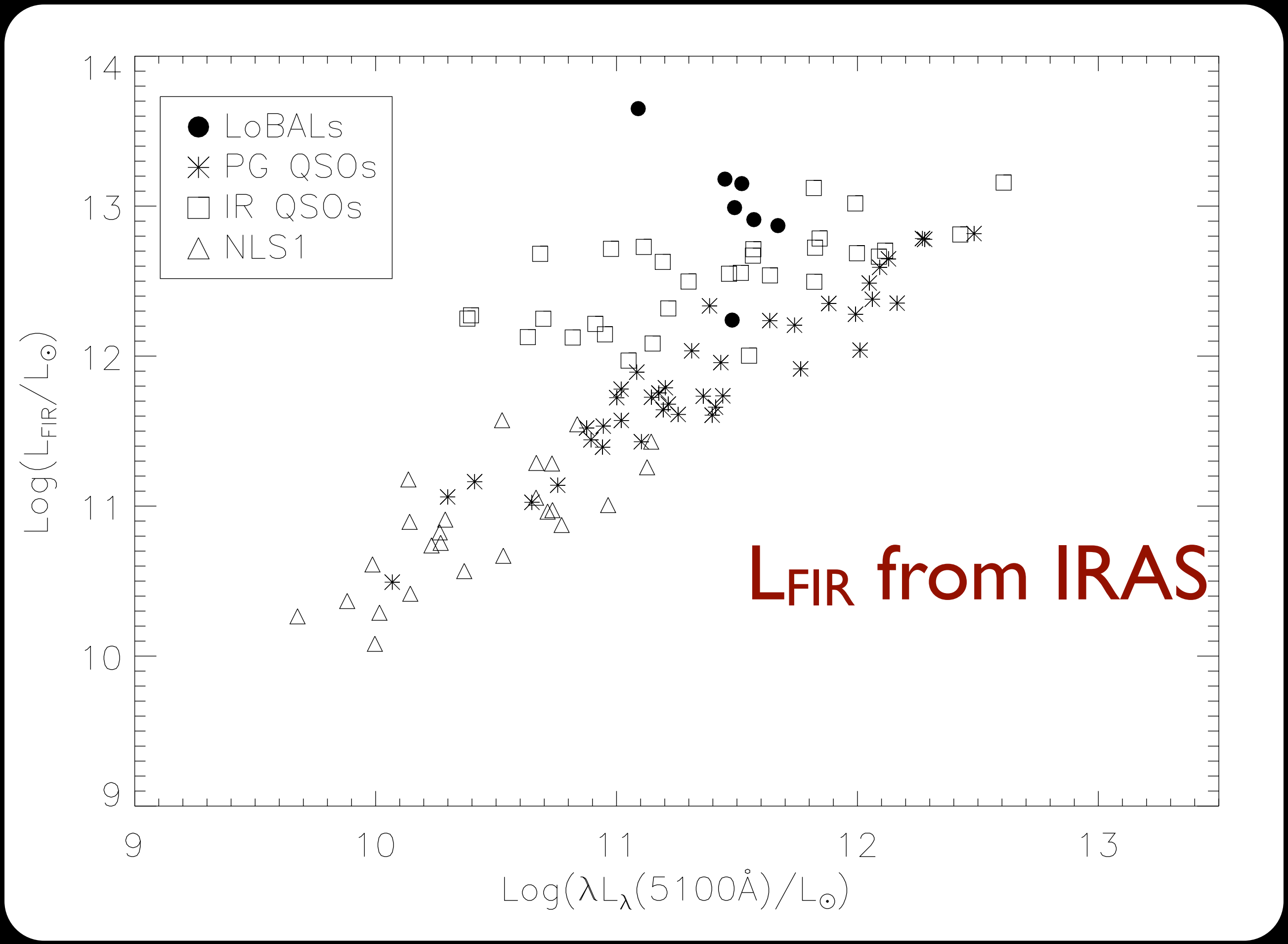
- 6 Type 1 + 6 Type 2 QSO
- 8 ULIRGs, 4 LIRGs
- 0.5 < z < 0.8
- SFR ~ 14 -180 $M_{\odot}$ yr^{-1}
- typical LIRGs SFRs ~ 20 -200 $M_{\odot}$ yr^{-1}

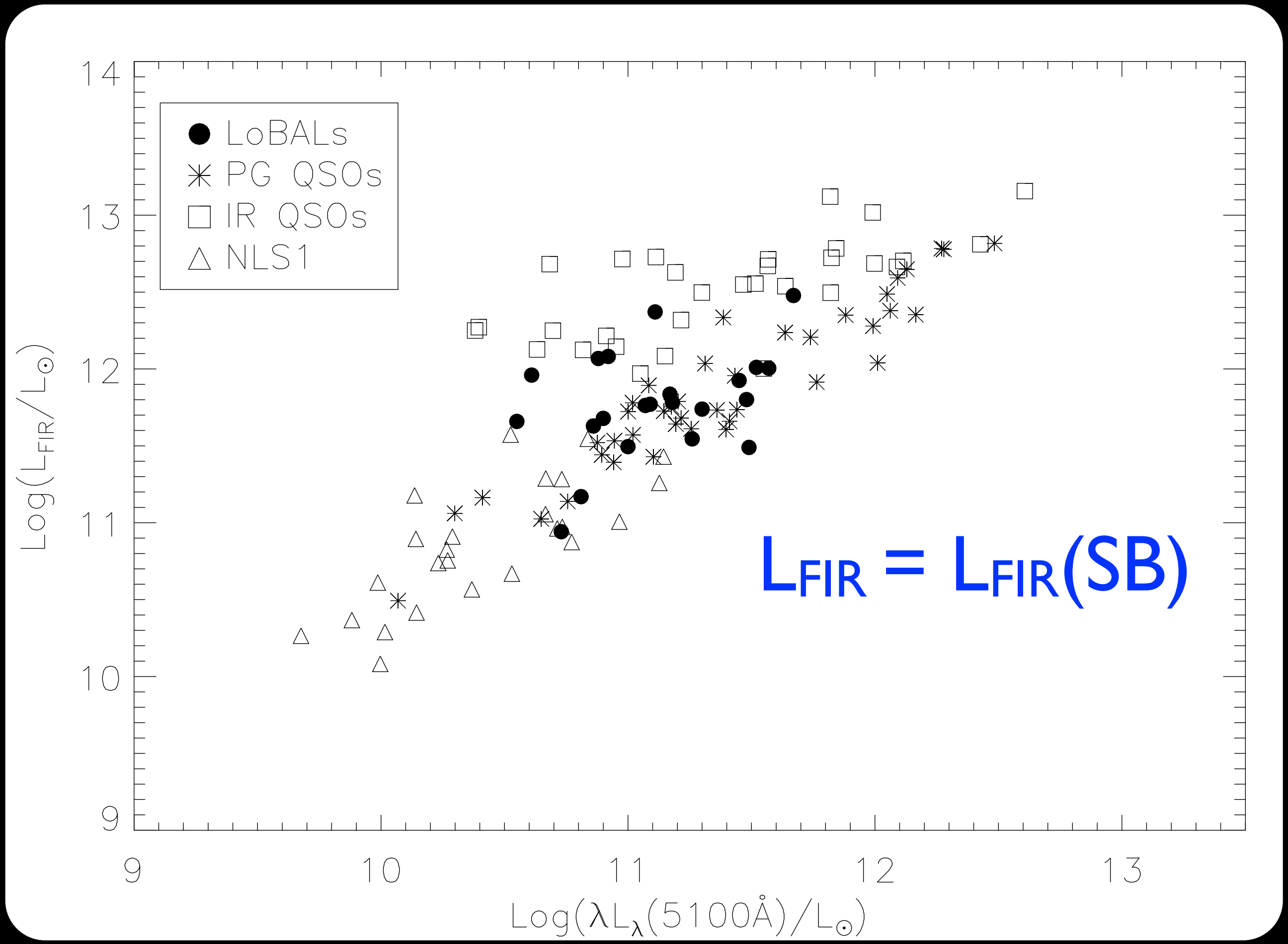
Sanders et al. (2003)

transition QSOs -- classical QSOs

IR QSOs
LoBALs

PG QSOs
NLS1



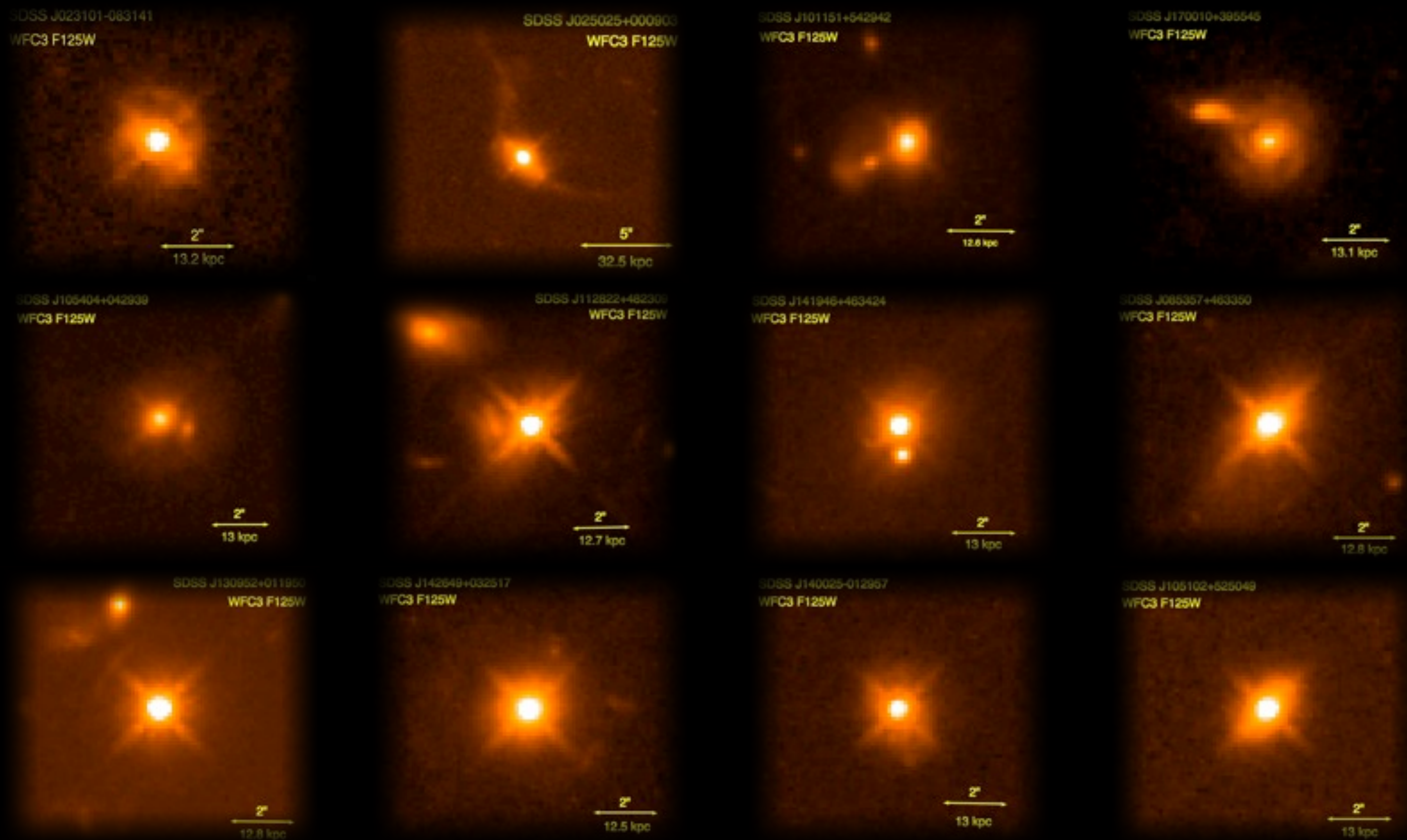


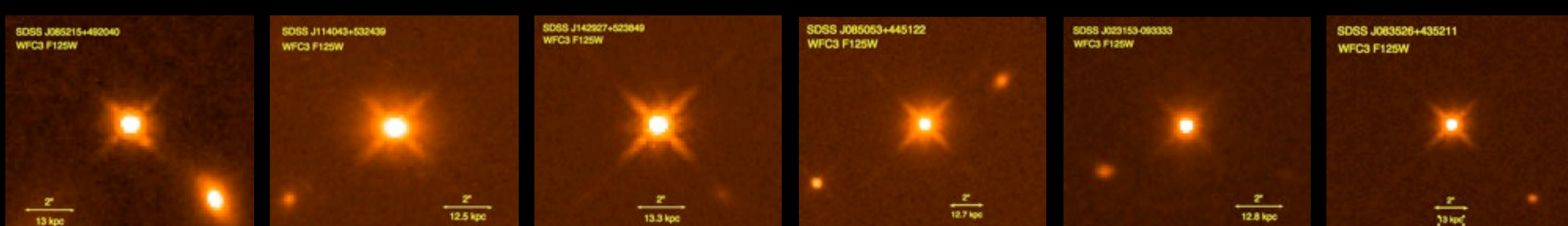
adapted from Hao et al. (2005)

Preliminary

(2) MORPHOLOGIES

HST WFC3

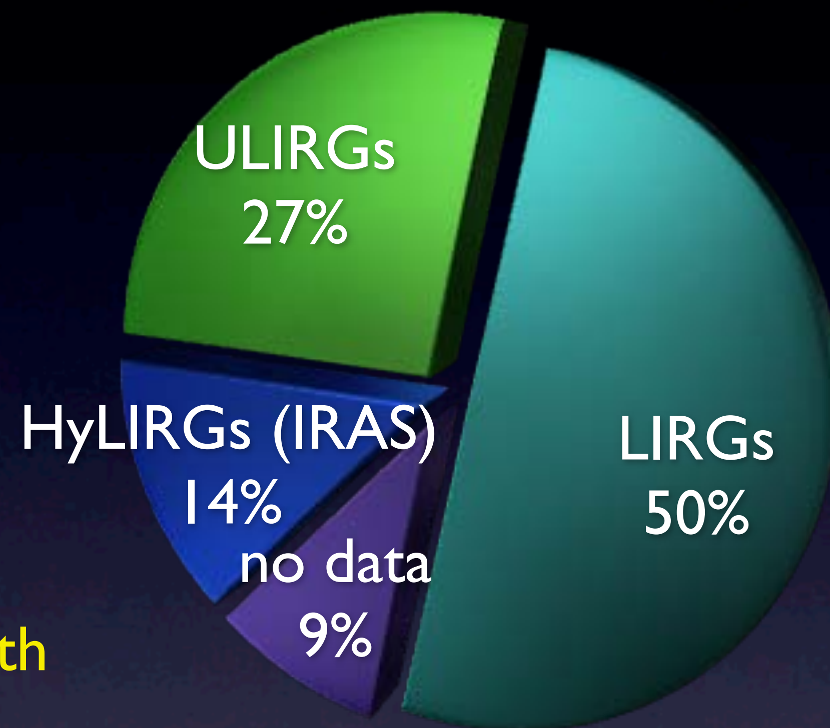




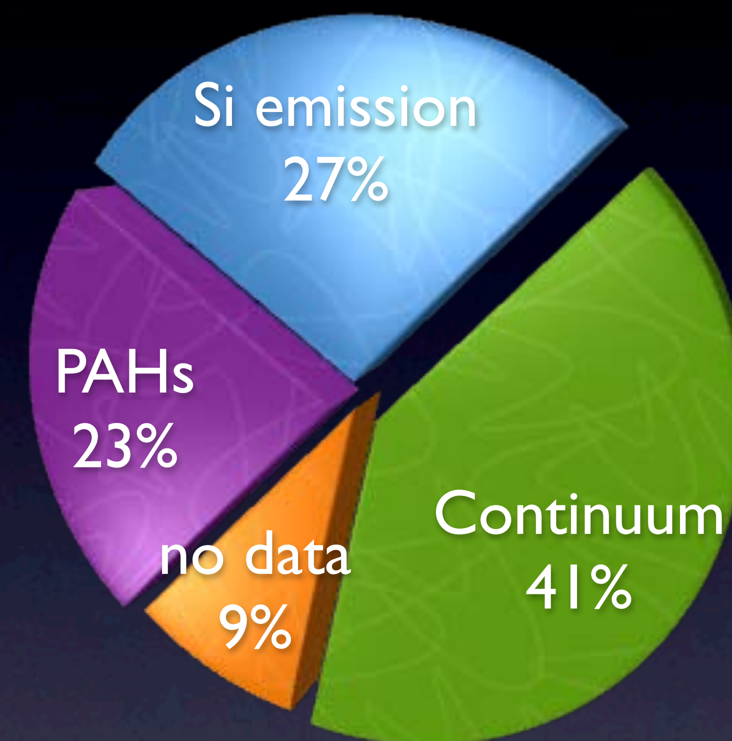
Mariana Lazarova

Summary

Complete sample of LoBALs
$0.5 < z < 0.6$
22 objects

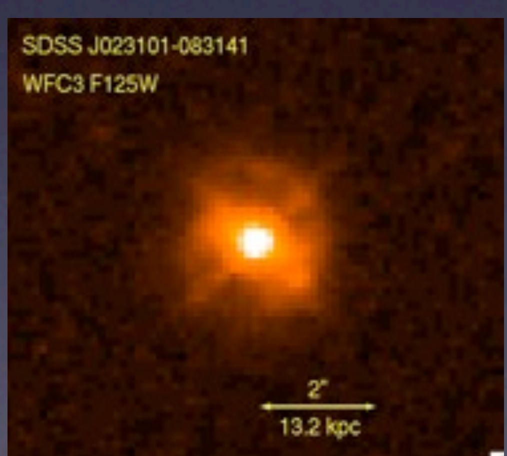


IRS spectral features



Optical to FIR SEDs modeling reveals

- ➡20-70% AGN contribution to FIR
- ➡SFRs ~ 40-300 $M_\odot$ yr^{-1}
- ➡LoBALs not exclusively associated with ULIRGs



HST Images show apparent signs of tidal interaction in 50% of the sample => disturbed morphologies, tails, shells or companions

Future work

- ➡SED fitting of comparison sample of classical QSO: SFRs
- ➡GALFIT the HST images: classify morphologies
- ➡Keck LRIS spectra of hosts: model stellar populations