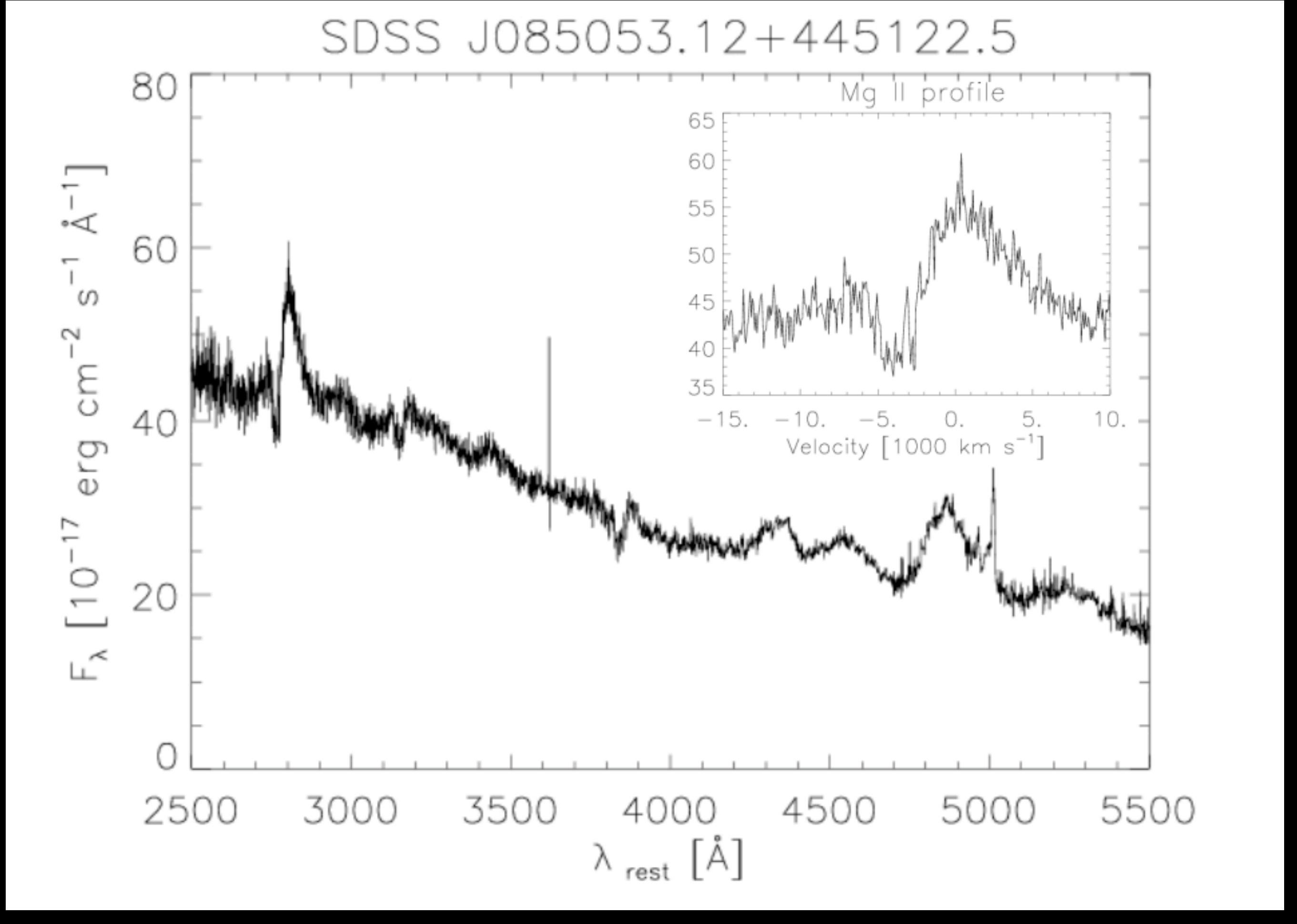
SEDs and MIR spectral properties of LoBAL QSOs

Mariana Lazarova

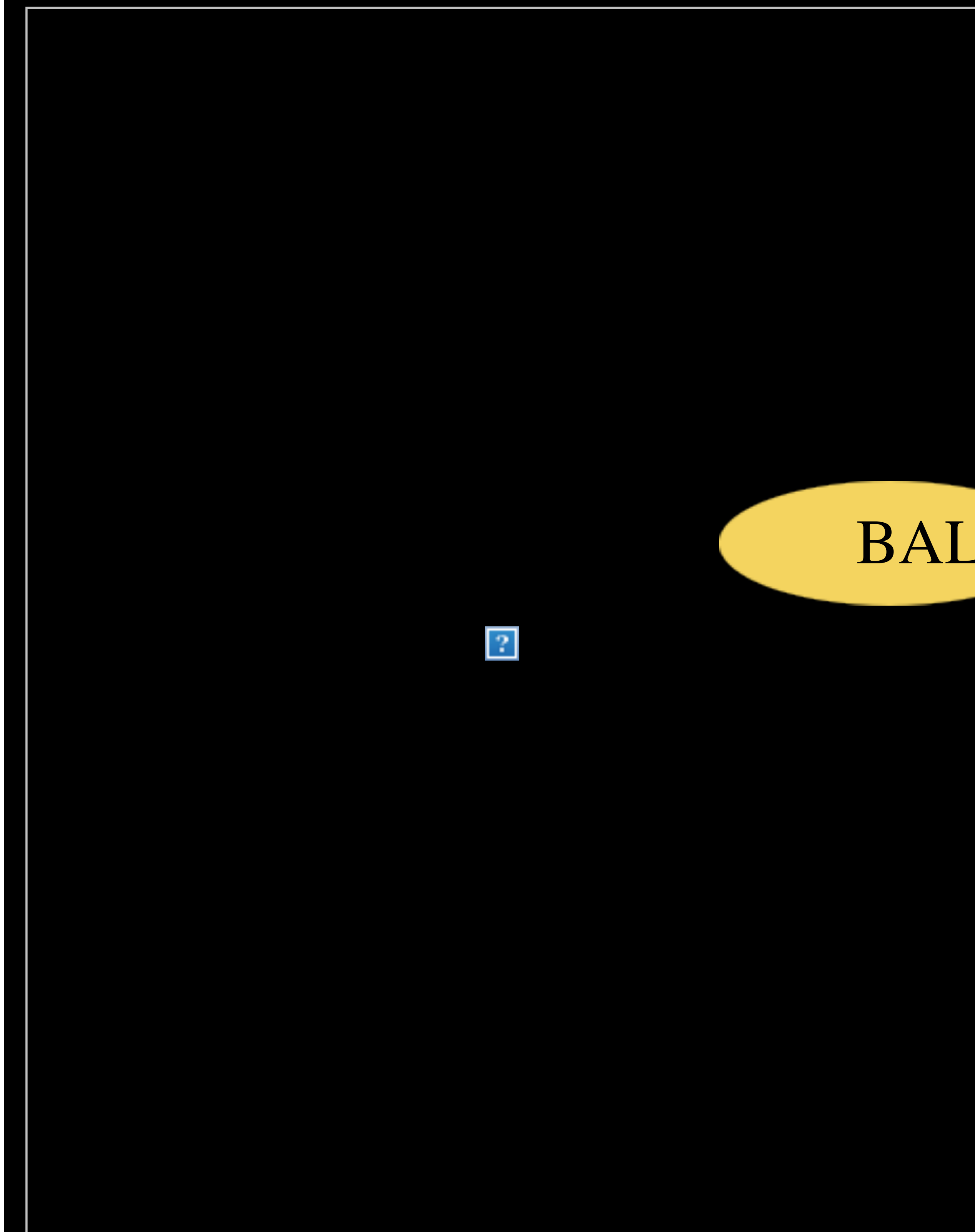
LoBAL = Low-ionization Broad Absorption Line QSO



LoBALs are type-1 QSOs...

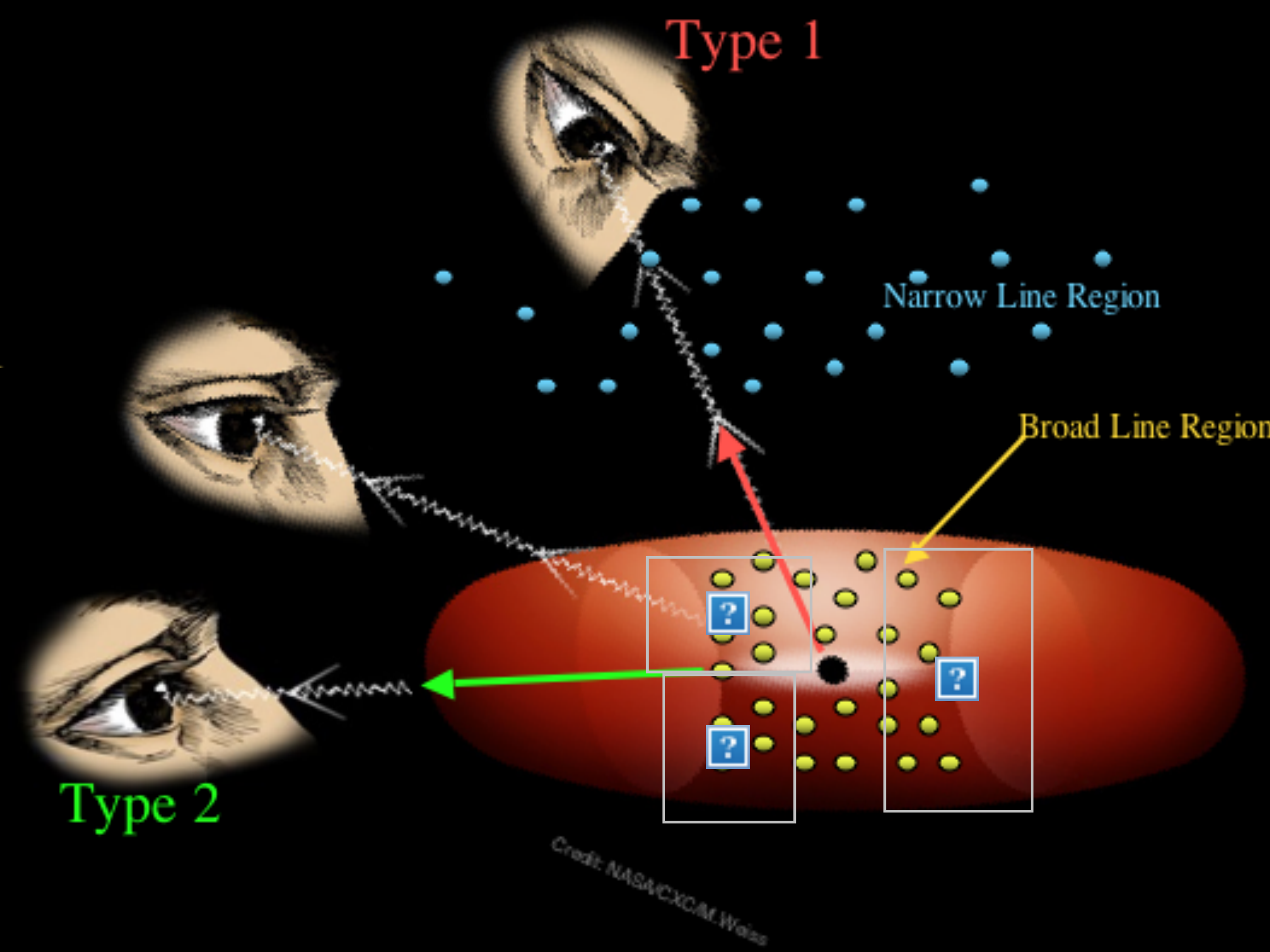
- rare: 1-3% of all opt. QSOs
- redder than type-1 QSOs
- weak [OIII] lines

Evolution vs. Orientation

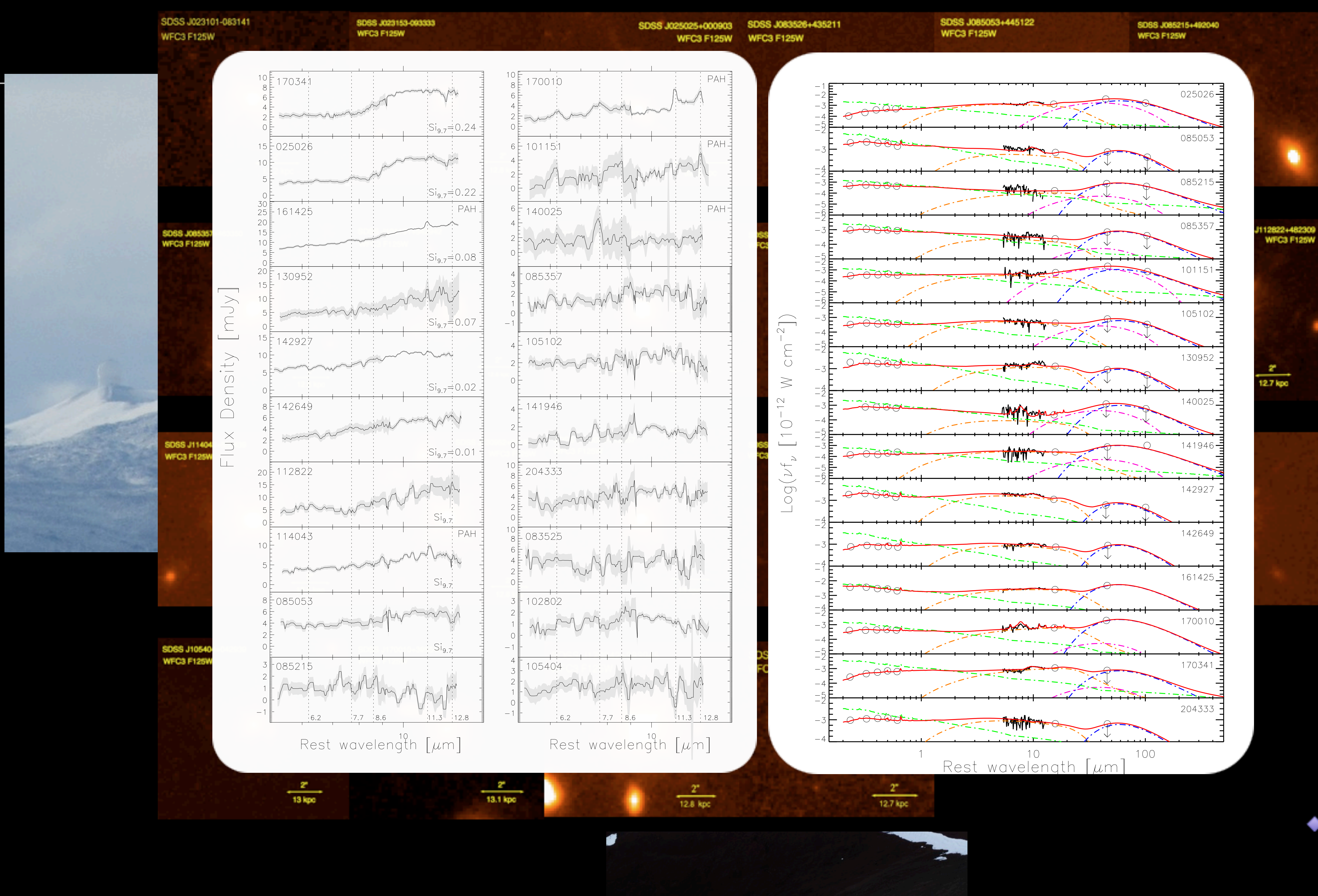


Credit: Volker Springel

BAL Q



Are LoBAL QSOs a transition phase?



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SEDs and mid-infrared spectral properties of LoBAL QSOs

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Abstract

We present Spitzer IRS spectra and MIPS photometry for a volume-limited sample of 22 SDSS-selected Low-ionization Broad Absorption Line QSOs (LoBALs) at 0.5 < z < 0.6. By comparing their mid-IR spectral properties and far-IR SEDs with those of a control sample of type-1 QSOs, we test the hypothesis that LoBALs are a transition phase from dust-embedded, ultra-luminous infrared QSOs toward unobscured type-1 QSOs. The presence of current star-formation in the LoBAL host galaxies is inferred by the appearance of weak PAHs in one quarter of the IRS spectra. Silicate dust at 9.7 microns is exclusively seen in weak emission in half of the objects, a trend typical of type-1 QSOs. We model their SEDs and decouple the AGN and starburst contributions to the FIR luminosity. As many as 80% of the LoBALs have infrared luminosities comparable to those of type-1 QSOs. However, at least 20%, and as much as 60%, of the LoBALs reside in ULIRGs. The star formation rates (SFRs) corrected for AGN contribution to the FIR flux in most LoBALs are comparable to those found in type-1 QSOs. However, the ULIRG LoBALs have SFRs three times higher than the most star-forming type-1 QSOs. The median contribution of star formation to the total FIR flux in LoBALs is estimated to be 60%, while for type-1 QSOs we find 30%, in agreement with previous results for PG QSOs. Our results show that, while the majority of the LoBALs are similar to type-1 QSOs in terms of their mid- and far-infrared properties, at least some of the LoBALs are characterized by higher infrared luminosities and star formation rates. Statistical tests accounting for the preponderance of upper limits in the FIR fluxes show that the observed differences in the infrared luminosities of LoBALs and type-1 QSOs are statistically significant only at the 1-sigma confidence level, and it is possible that the two samples are drawn from the same parent population.

IRS spectra

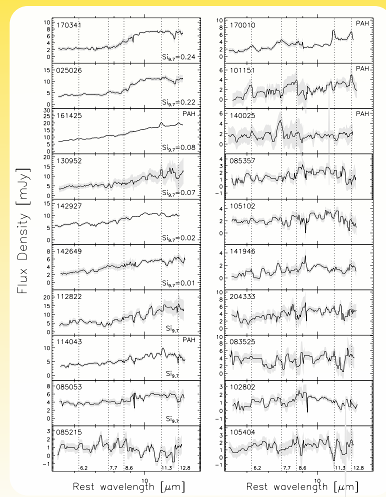


Figure 1: Low-resolution Spitzer IRS spectra of our LoBAL sample. Vertical dotted lines at 6.2, 7.7, 8.6, 11.3, and 12.8 μm indicate the peaks of prominent PAH features. The objects in the left column show silicate emission at 9.7 μm, in order of decreasing strength from top to bottom. The top three objects in the right columns show the strongest PAH features. All objects labeled 'PAH' in the top right corner show at least one of the PAH lines.

Si emission

Silicate dust shows emission in the mid-IR at $\lambda \sim 10\,\mu$m and 18 μm.

- **45% (9 of 20) of the LoBALs with IRS spectra show weak 9.7 μm silicate features, *exclusively in emission***
- The emission peaks at ~11 μm, either due to dust grain size and composition (e.g., Bouwman et al. 2001) or radiative transfer effects in a clumpy dust geometry (e.g., Nikutta et al. 2009)
- previous studies support a dichotomy in the Si emission, with type-1 QSOs characterized by Si emission (e.g., Hao et al. 2005) and type-2 QSOs showing mostly Si absorption (e.g., Zakamska et al. 2008)

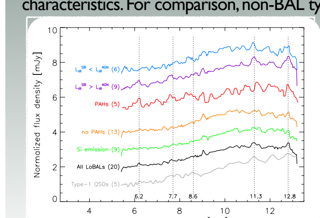
PAHs

The presence of polycyclic aromatic hydrocarbon molecules (PAHs) is used as a tracer of current star formation (e.g., Genzel et al. 1998).

- **25% (5 of 20) of the LoBALs show weak PAH emission**

Composites

S/N-weighted average spectra of the LoBALs, grouped according to shared characteristics. For comparison, non-BAL type-1 QSO average is plotted in gray.



- **The mean of all LoBALs shows very weak PAH emission at 6.2, 11.3 and 12.8 μm**
- The mean of objects with **$L_{IR}^{SB} > L_{IR}^{AGN}$ shows stronger PAHs than the 'PAH' composite**, suggesting the FIR emission is from star-formation rather than an extended dust torus

SEDs

LoBALs — non-BAL type-1 QSOs

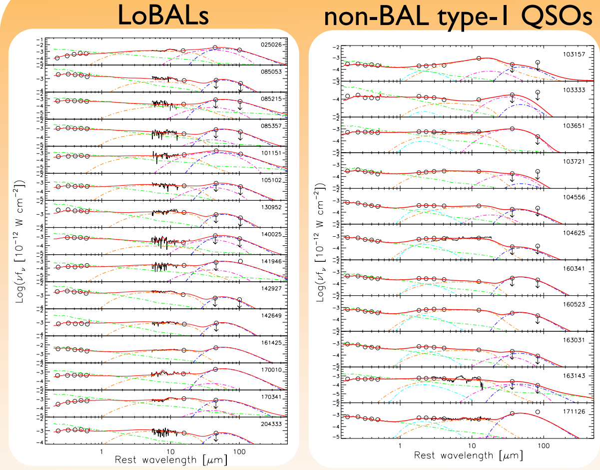
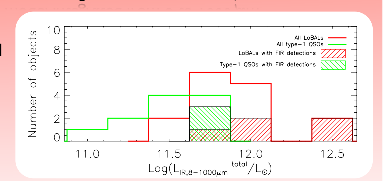


Figure 2: Model fits to the SEDs of the 15 LoBALs in the sample with available Spitzer IRS observations and to a control sample of 11 non-BAL type-1 QSOs. The solid black lines are the Spitzer IRS spectra and the open black circles are SDSS *ugriz* and Spitzer MIPS photometry at 24, 70, and 160 μm. The overall fit to the SED is plotted with a solid red line. The individual components to the fit are plotted with dot-dash lines, color-coded as follows: unreddened SDSS quasar composite in green; mid-IR power-law component in orange; warm small grain dust in magenta; and 45K modified black body component in blue. Down arrows indicate 3σ upper limits.

Infrared luminosities

Total infrared luminosities are estimated from the SED model integrated from 8 to 1000 μm

- The LoBALs in our sample are **not exclusively associated with ULIRGs** ($L_{IR} > 10^{12} L_\odot$), a trend found for anecdotal studies of LoBALs are lower redshifts.
- However, at least 20% (and as many as 60%) of the LoBALs are ULIRGs.
- All the non-BAL type-1 QSOs of the control sample reside in luminous IR galaxies ($L_{IR} = 10^{11-12} L_\odot$)

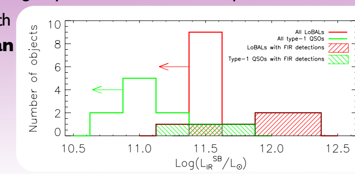


- **We do not find statistically significant differences between the total IR luminosity of LoBALs and type-1 QSOs**

Starburst luminosities

Starburst infrared luminosities (L_{IR}^{SB}) are estimated by summing only the warm and cold components of the model

- **among the FIR-detected objects** (~25% in both samples), **LoBALs** ($L_{LoBAL}^{SB} \sim 11.9$) **have higher median L_{IR}^{SB} than non-BAL type-1 QSOs** ($L_{type-1}^{SB} \sim 11.5$)
- if considering the entire samples, the majority of which are dominated by upper limits, LoBALs and type-1 QSOs have comparable medians, $L_{IR}^{SB} \sim 11.5$



SFRs

SFRs are estimated from the starburst IR luminosity using the Kennicutt (1998) relation

- only four LoBALs (20%) have SFRs ~150 - 300 $M_\odot$/yr
- the median SFRs of LoBALs and non-BAL type-1 QSOs are comparable at ~50 $M_\odot$/yr
- among the objects with FIR MIPS detections, the median SFR of the LoBALs (~145 $M_\odot$/yr) is three times higher than in the non-BAL type-1 QSOs (~54 $M_\odot$/yr)

Why LoBALs?

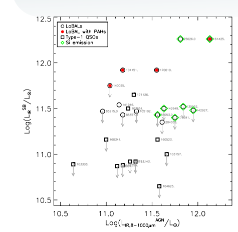
- LoBAL = Low-ionization Broad Absorption Line type-1 QSO
- LoBALs are identified by broad, blueshifted MgII 2800Å absorptions, indicative of gas outflows at >2,000 km/s
- LoBALs are rare in optically-selected QSO samples, comprising only10-30% of the QSOs
- **low redshift (z<0.4) LoBALs are found to be associated with ULIRGs, major merger remnants, and young stellar populations** (Canalizo & Stockton 2002)
- The AGN-driven outflows observed in BAL QSOs are a promising candidate for the feedback mechanism which regulates the growth of galaxies and their central black holes, inferred from the observed $M_{BH} - \sigma$ relationship

Goal

We test the hypothesis that LoBALs are an early, short phase in the evolution of QSOs, a transition from a dust-enshrouded young QSO observed as a ULIRG, toward an unobscured type-1 QSO, by comparing the SEDs, FIR luminosities, and SFRs of a complete volume-limited sample of LoBALs to a control sample of non-BAL type-1 QSOs.

Conclusions

- **While the majority of LoBALs are not statistically different from non-BAL type-1 QSOs in terms of their IR luminosities and mid-IR spectral properties, a fraction of the LoBALs are characterized by much higher starburst luminosities.**
- In the context of an evolutionary paradigm, this would imply that LoBALs are rapidly transitioning from a ULIRG phase to a more quiescent phase with star formation activity typical of type-1 QSOs.



Si emission is favored in the LoBALs with the highest AGN IR luminosities ($L_{IR}^{AGN} > 10^{11.55} L_\odot$)

PAH features are detected in the LoBALs with the highest starburst IR luminosities ($L_{IR}^{SB} > 10^{11.75} L_\odot$)

Coming up soon...

- ***HST*/WFC3** images of this entire sample reveal that most of the host galaxies have undergone a recent tidal interaction
- ***Keck* LRIS** spectra of at least some of the host galaxies show Balmer absorption lines, indicating dominant post-starburst stellar populations; we have obtained spectra of seven hosts and proposed for the rest of the sample

Acknowledgements

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References: Bouwman et al. 2001, A&A, 375, 950; Canalizo & Stockton, 2002, ASPC, 255, 195; Genzel et al. 1998, ApJ, 498, 579; Hao et al. 2005, ApJ, 625, 78; Kennicutt 1998, ARAA, 36, 189; Nikutta et al. 2009, ApJ, 707, 1550; Zakamska et al. 2008, AJ, 136, 1607