Fast outflows in BAL quasars and their connection with CSS/GPS sources

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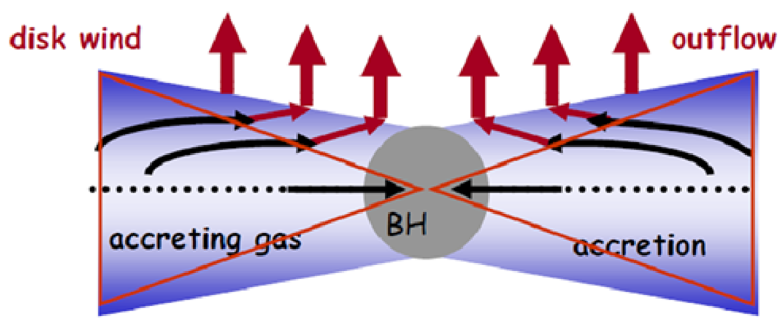
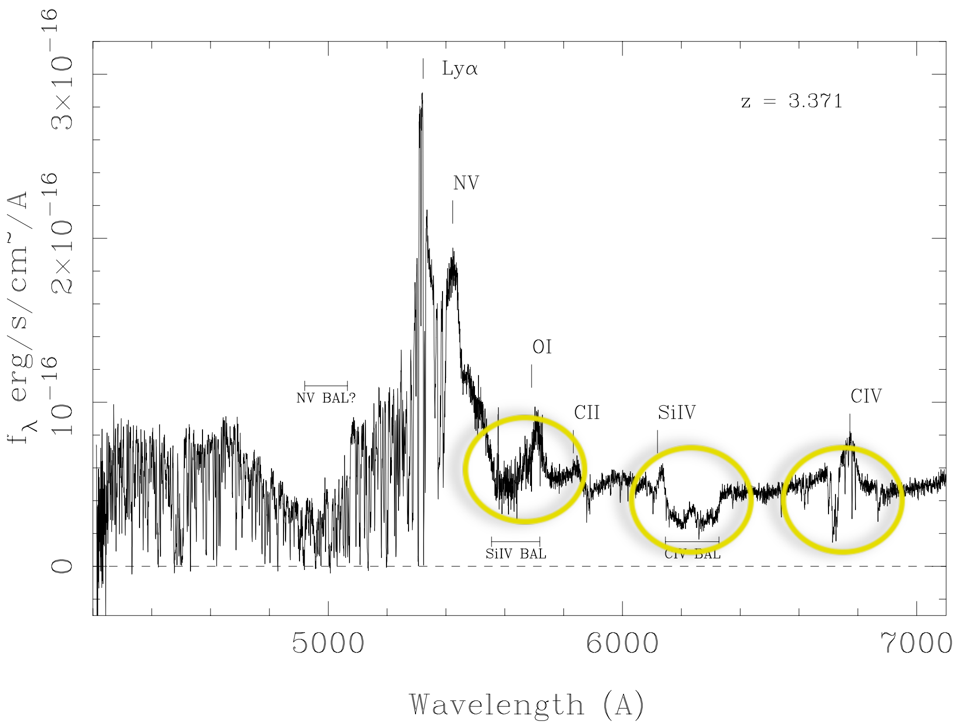
Outflows facts

- Present in most of the accreting objects, at various scales (from proto-stars to AGNs)
- Different launching mechanism (thermal, radiation pressure, magnetic fields)
- Can reach relativistic velocities
- Strong effect/feedback on surrounding AGN environment (e.g. star formation inhibition, Tombesi et al. 2015)
- Detected in different bands (UFOs in X-ray, BALs in UV/Optical…)



Ohsuga et al. 2014

What do we call BAL QSO?



- Broad absorption lines in the blue side of UV lines (C_{IV}, Si_{IV}, Mg_{II})
- Velocities up to 0.2c
- Present in 20% of QSOs
- Mild increase with redshift (Allen et al. 2011)
- Variable on secular timescale (Filiz Ak et al. 2012)

BAL QSOs *vs* "normal" QSOs

<u>X-Rays:</u> Emission intrinsically similar, BAL QSOs more absorbed (Green et al. 2001, Gallagher et al. 2007)

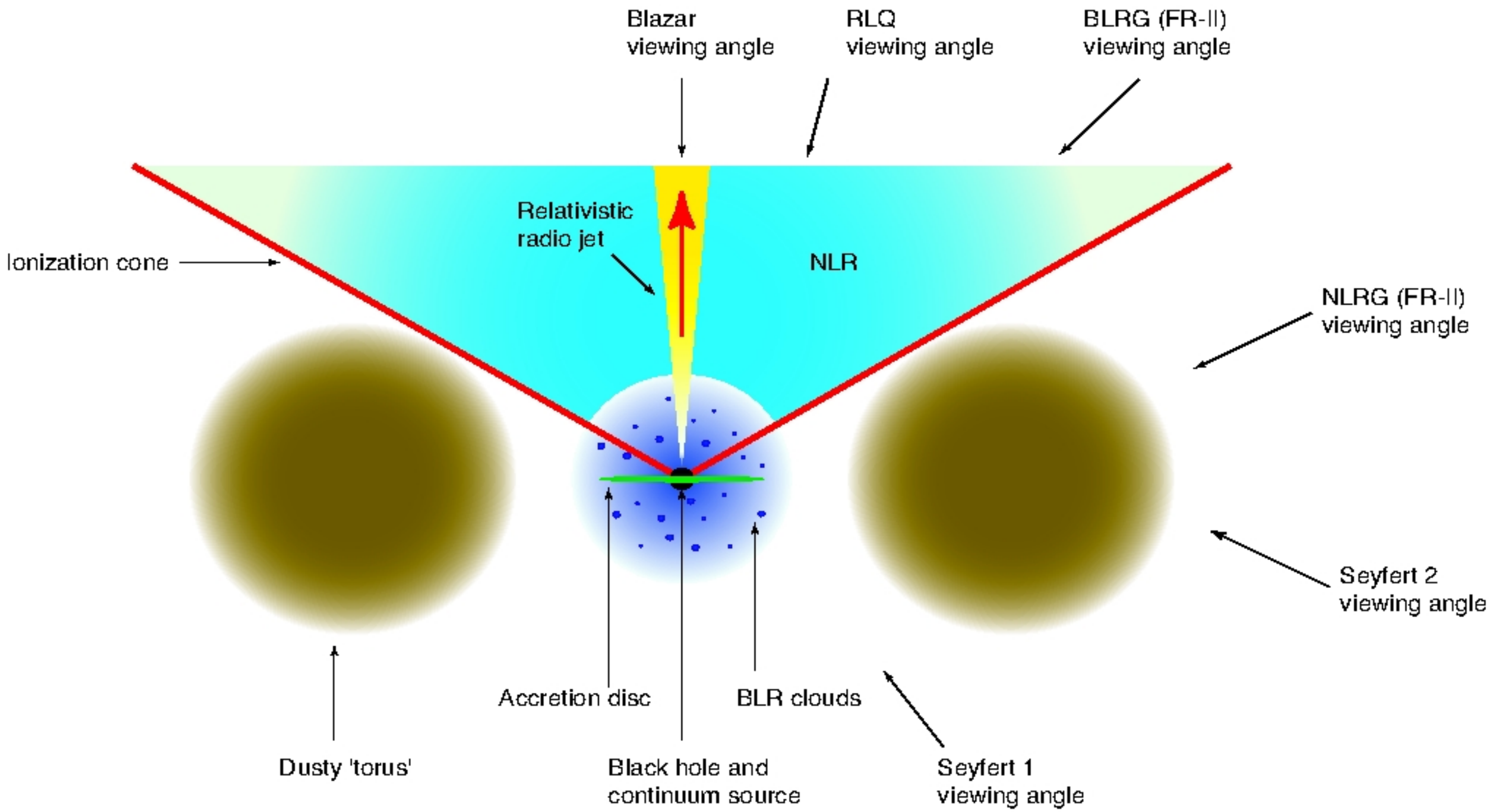
<u>Optical:</u> BALs more reddened, more highly polarized, UV absorption (Goodrich 1997, Krolik & Voit 1998)

<u>Near-IR:</u> Similar properties (Bruni et al. 2014, Rochais et al. 2014)

<u>Mid-IR:</u> Similar properties (Gallagher et al. 2007)

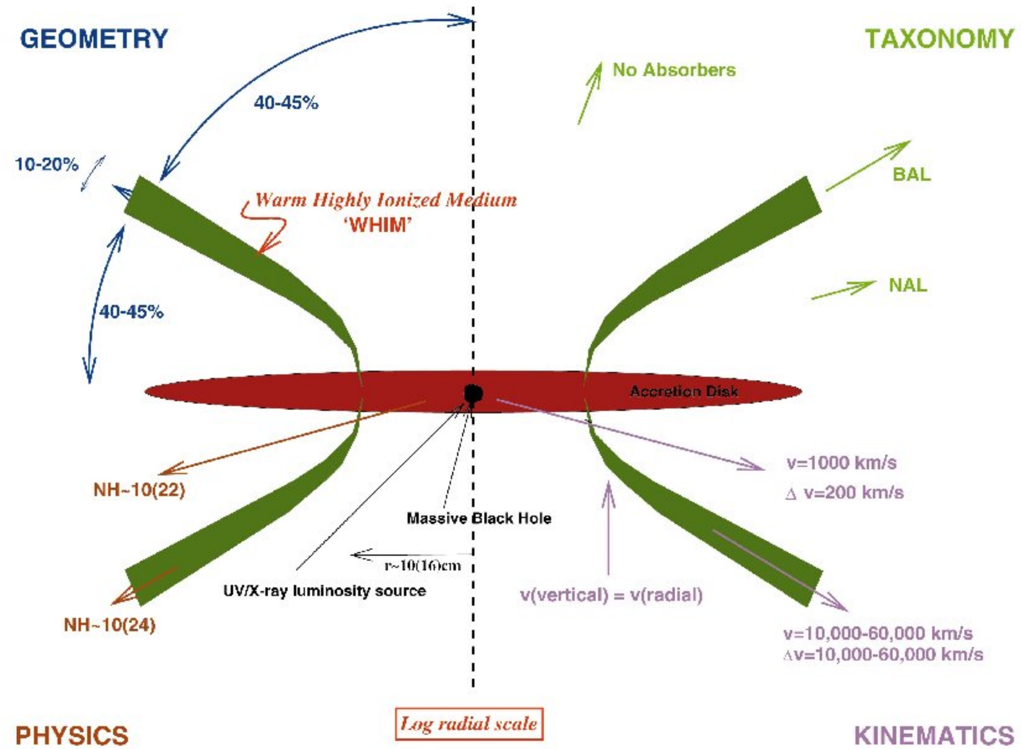
<u>Sub-mm, mm:</u> No differences (Lewis et al. 2003, Willott et al. 2003, Priddey et al. 2007)

Unification scheme of AGN



Explanations for the BAL phenomenon

Orientation Scenario (Elvis 2000)



Explanations for the BAL phenomenon

PRO:

- Naturally explains why BAL/non-BAL QSOs are so similar
- Explains higher reddening/obscuration in BAL QSOs
- Explains higher polarisation (optical band) via resonant scattering

CONTRA:

- Variety of radio spectral indices
  (Becker et al. 2000, Montenegro-Montes et al. 2008, DiPompeo et al. 2011, Bruni et al. 2012)
- Found both edge-on (FR II) and polar (strongly beamed) BAL QSOs
  (e.g., Gregg et al. 2006, Zhou et al. 2006)

Explanations for the BAL phenomenon

Evolutionary Scenario

Young or recently refueled quasars
(Briggs et al. 1984; Lipari and Terlevich 2006)

PRO:

- Anticorrelation between radio-loudness and the BAL phenomenon (Gregg et al. 2006)

CONTRA:

- Same cold and warm dust properties of BAL/non-BAL QSOs (Becker et al. 2000; Gregg et al. 2000, Kunert-Bajraszewska & Marecki 2007, Willott et al. 2004, Bruni et al. 2015)

Our observational campaign

- Radio continuum & polarization (Effelsberg, VLA, GMRT)
- Morphology & orientation (EVN, VLBA)
- Dust detection: (IRAM 30-m, APEX)
- Infrared spectroscopy: central BH mass estimation (TNG)

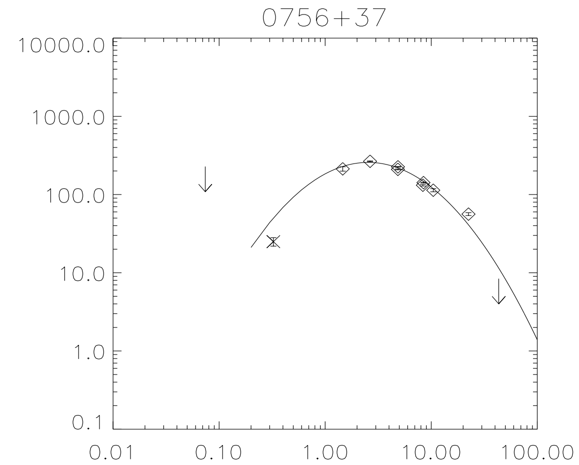
Results

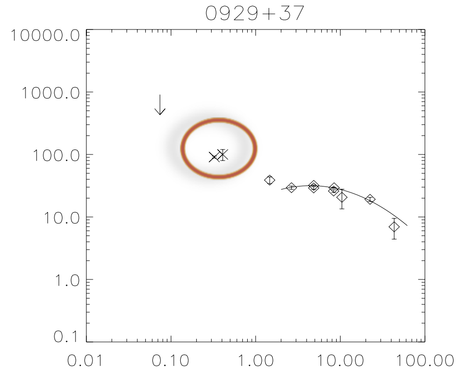
SED fitting

- Both for BAL (25) and non-BAL (34) samples
- Determination of the peak frequency

GPS: 32% BAL QSOs
23% non-BAL QSOs

- Evidence of low-frequency (older) components in some cases
(12% BAL QSOs, 18% comparison QSOs)





Bruni et al. 2012

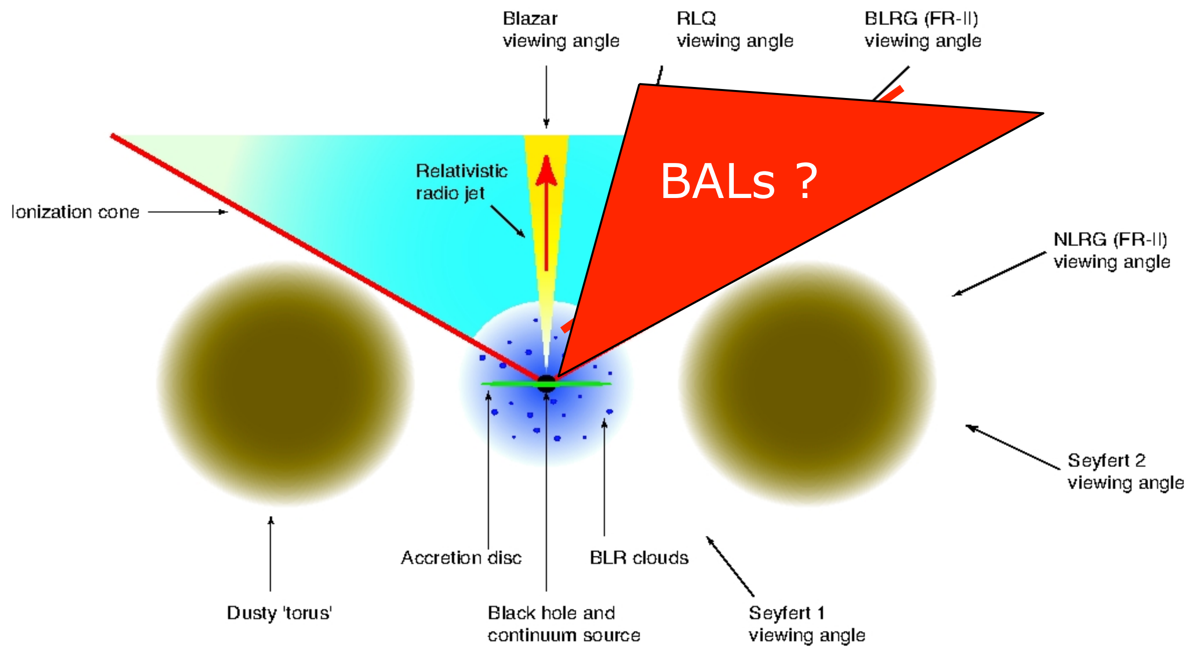
Results

SED fitting

- Spectral index

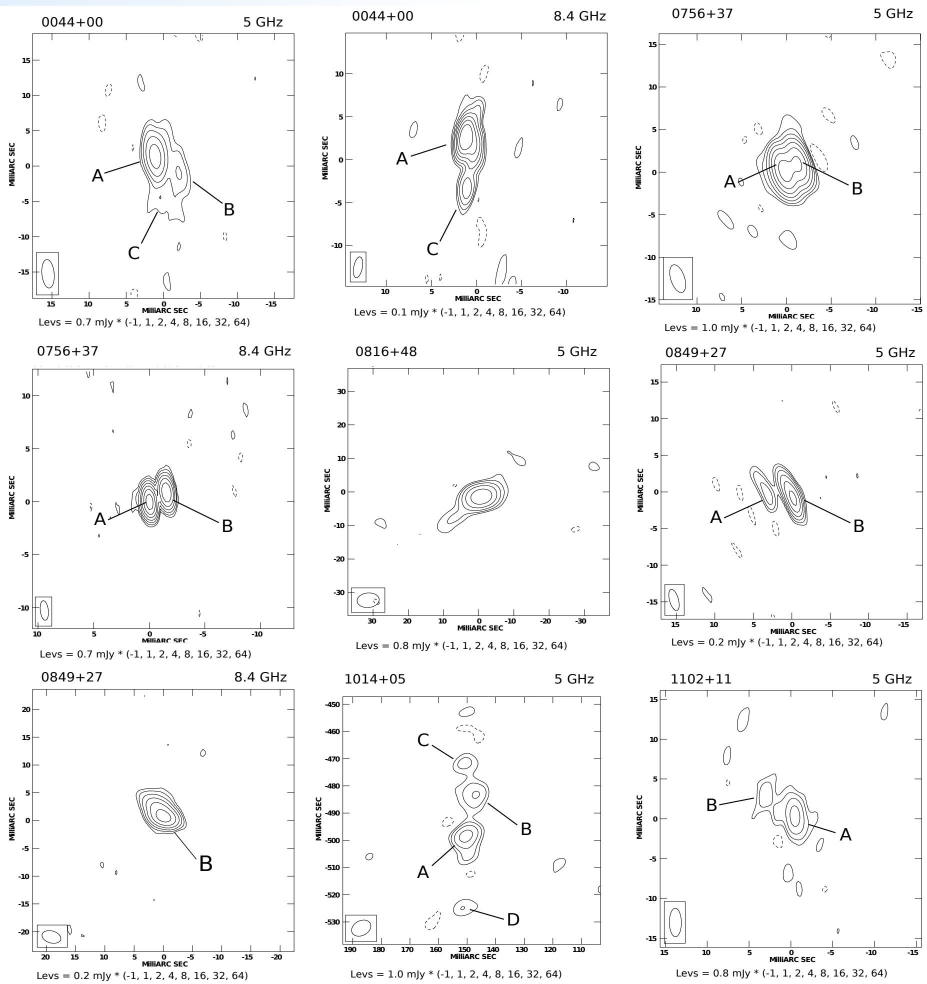
steep:	68% BAL QSOs
	50% non-BAL QSOs

- Wide range of orientations



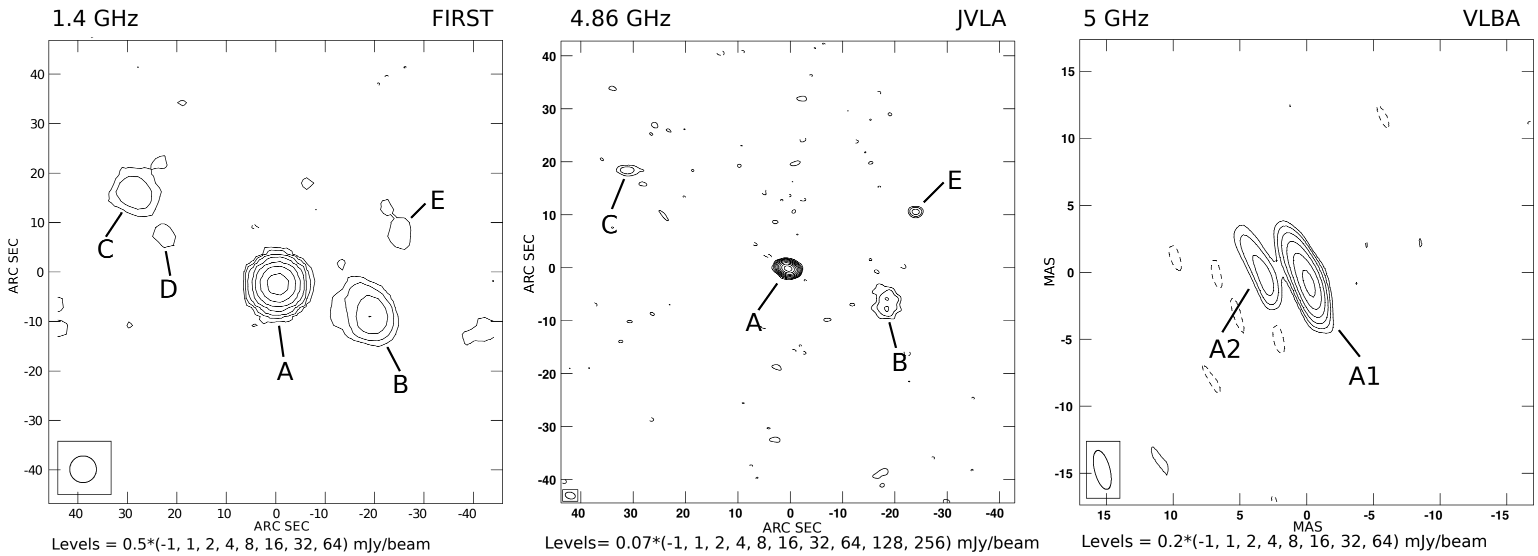
Results

pc-scale morphologies from VLBI



Bruni et al. 2013

Results



In some cases a complex morphologies, at also different scales, is present. Project size up to ~200 kpc.

Different radio phases?

Results

NIR helps…

BAL QSOs are less common in RL QSOs (Becker et al. 2001; Gregg et al. 2006)

…we compared 16 RL vs 18 RQ BAL QSOs, through NIR spectra:

- BH mass distributions do not significantly differ
- Similar Eddington ratios → similar accretion rates
- Similar dimensions for BLRs

No clear differences in the central engine geometry / physics:
same objects presenting BALs can become/have been RL?

Bruni et al. 2014

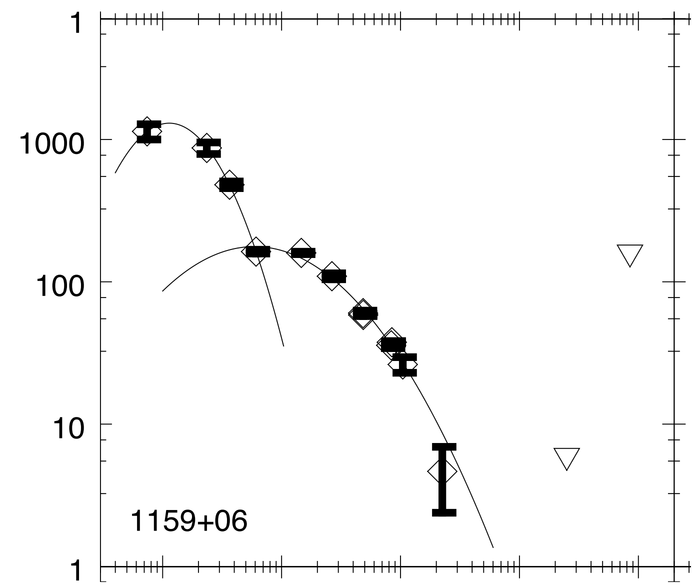
Results

New constraints from GMRT…

- CSS components arise when extending SED coverage
- Most of objects (~80%) are in a GPS or GPS+CSS phase
- CSS, older component suggests a restarting activity

Not so dusty

- Only 1/17 (6%) sources observed at mm wavelengths present emission due to dust vs ~26% found by Omont et al. (2003) for QSOs
- BAL are dust-poor w.r.t. other QSOs?
- Possible feed-back on star formation?



Bruni et al. 2015

Conclusions

- No particular orientation, only steep-spectrum majority
- Indications of a young/restarting phase in radio-loud BAL QSOs
- Different morphologies, sizes from ~10 pc to ~200 kpc
- Dust-poor objects w.r.t. general QSOs, possible feed-back on star formation
- Same BH masses, BLR gemetries, Eddington ratios

Are accretion-disk outflows precursors of radio jets?

Thank you!

Conclusions

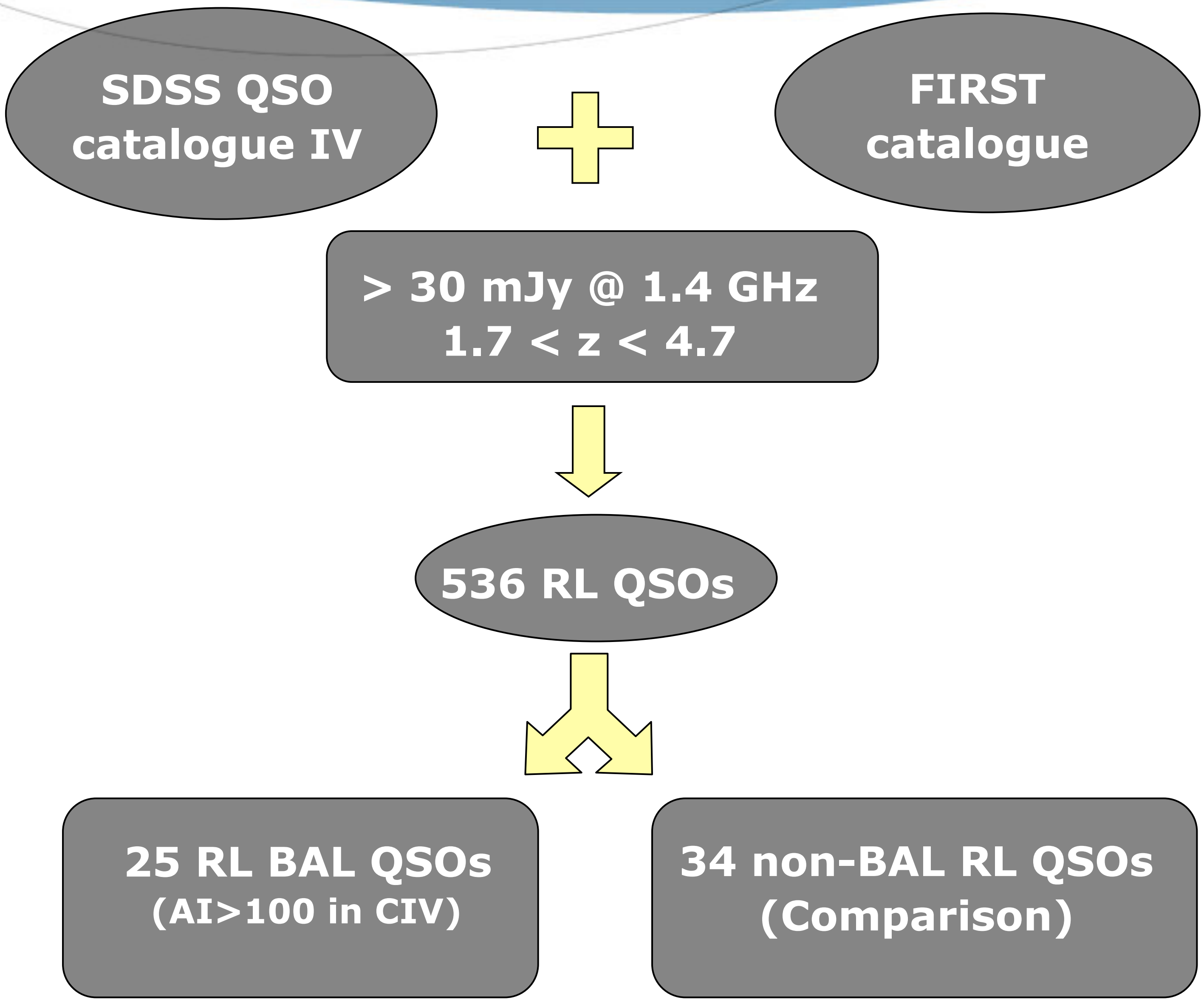
The BALs are most probably produced by outflows, but:

① with different possible orientations (recollimated outflows?)

② Present in different evolutionary stages of the QSO

③ Probably as an intermittent phenomenon (Filiz Ak et al. 2012)

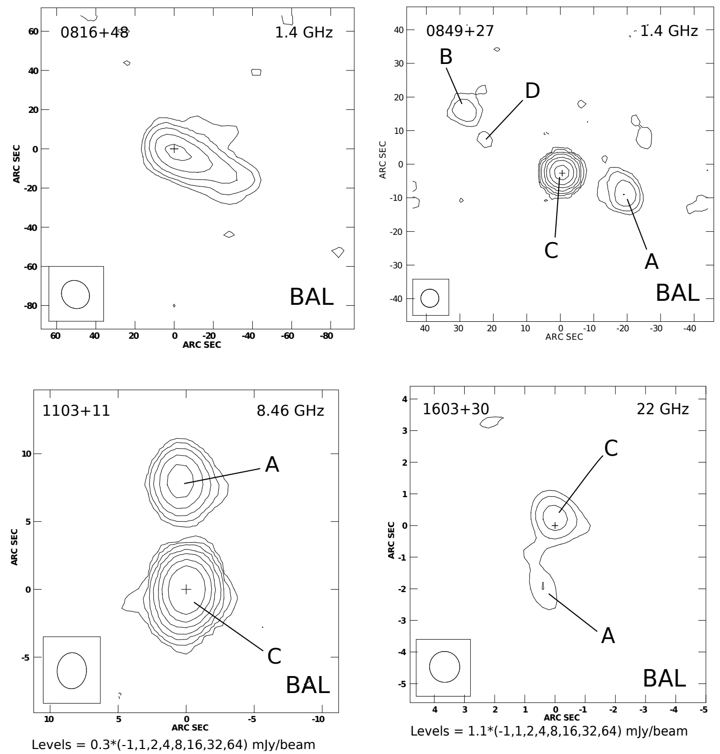
Sample selection



Results

1) Morphology

- 8 resolved source with the VLA:
  4 BAL + 4 non-BAL QSOs (16% vs 12%)
- Linear sizes from 20 to 400 kpc for both
- Similar morphologies



Results

2) Variability

- Calculation of the flux-density variability (4.8 and 8.4 GHz; Var>20%; σ_{var}>4)

$$Var_{\Delta S} = \frac{S_{max} - S_{min}}{S_{min}}$$

$$\sigma_{Var} = \frac{|S_2 - S_1|}{\sqrt{\sigma_1^2 + \sigma_2^2}}$$

- 1 BAL vs 3 non-BAL QSOs present variability

- Results confirmed by the variability study of the RBQ sample (20% vs 14%) (Montenegro-Montes e al. 2008)

→ Polar orientation is not preferred

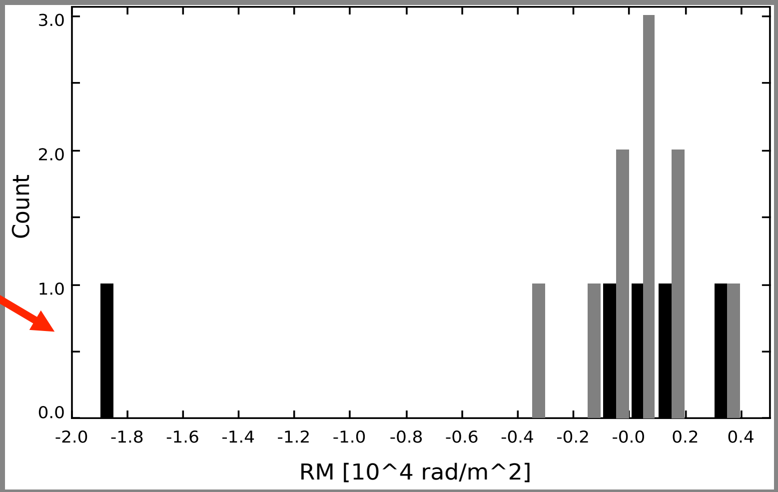
Results

5) Polarimetry

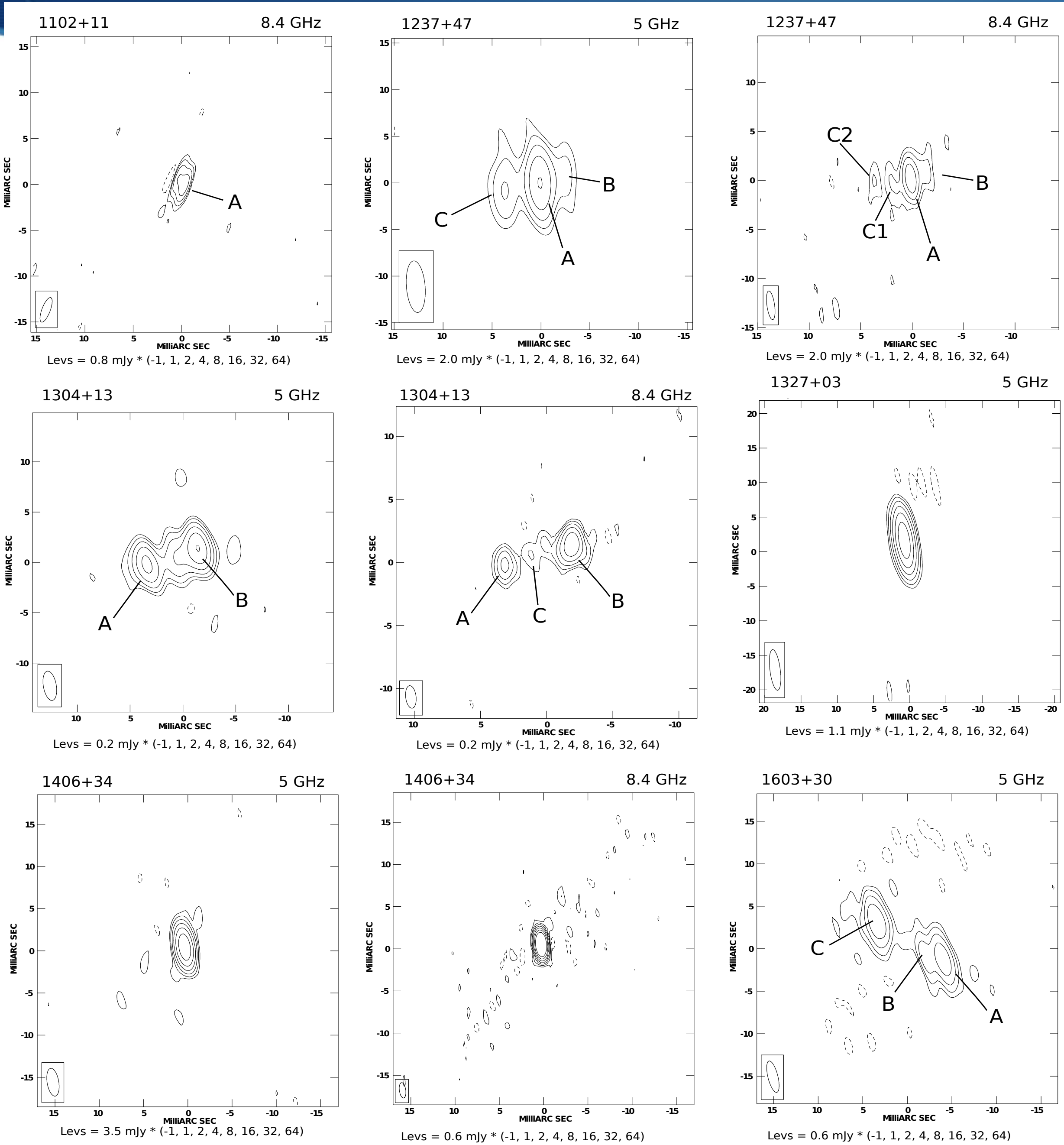
- Polarisation percentage — ~ 1-10% — Similar to non-BAL QSOs
- Rotation Measure — 800<|RM|<3500 rad/m^2 , 1 outlier

$$RM = 8.1 \times \int (n_e \cdot B_{\parallel}) dL \quad [rad \cdot m^2]$$

Benn et al. (2005)
(-18350±570 rad/m^2)



Bruni et al. 2012



- 4 core-jet
- 2 doubles
- 3 symmetric
- 2 unresolved (18%)

- 10<LS<100 pc

Bruni et al. 2013

Results

- 82% of sources are resolved at pc-scale
- Different morphologies imply different possible orientations
- Missing flux in some cases, possibly due to extended components.
- Linear sizes up to 200 kpc from previous VLA observations: not all sources are young/compact.

Why are RL BAL QSOs rare?

- BAL QSOs are 4 time less common among QSOs with R*>2 (Stocke et al. 1992)
- FR II BAL QSOs found by Gregg et al. (2006) with strong anticorrelation between Radio-Loudness and BAL strength

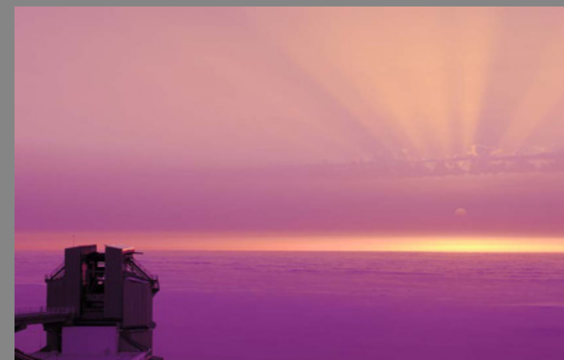
Evolutionary track?

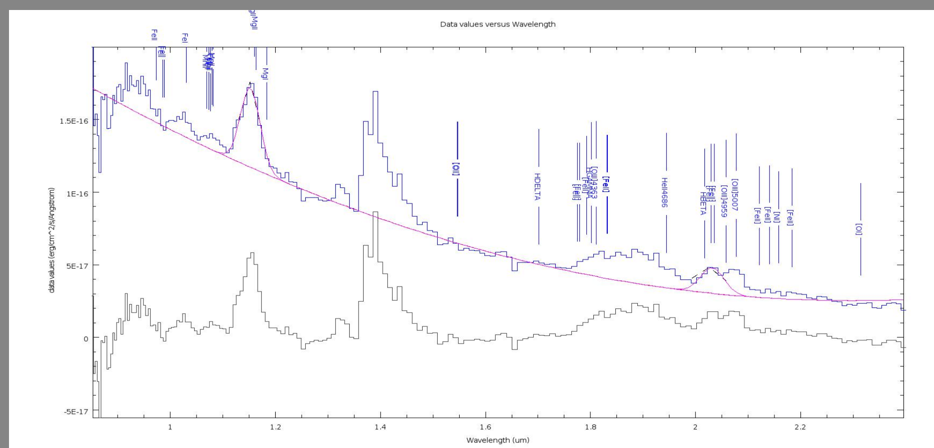
BAL QSOs → RL QSOs

Near-Infrared observations

- TNG-NICS spectroscopic observations of 16 RL + 18 RQ BAL QSOs, optically bright (r<19)

- Low resolution (R~50) but high-sensitivity, with the AMICI prism (0.85-2.4 microns).





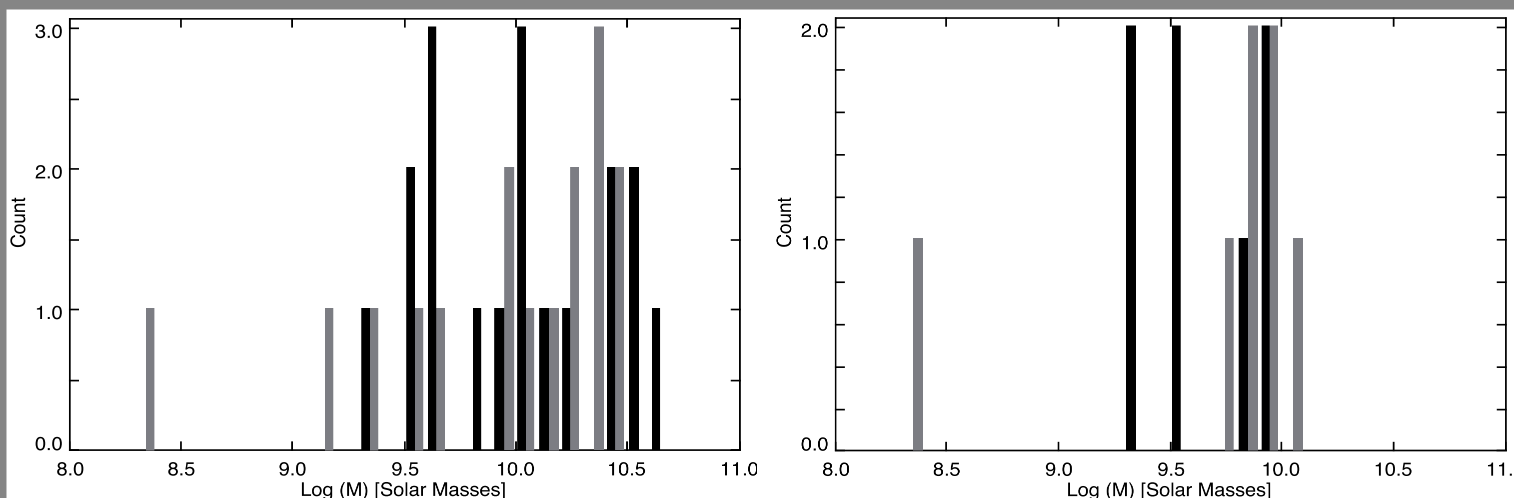
Mass of the BH from FWHM of MgII and H_β

$$M_{\rm BH}\ [M_\odot] = 10^{6.86} \left[\frac{\rm FWHM(MgII)}{1000\ km\ s^{-1}}\right]^2 \left[\frac{\lambda L_\lambda(3000\ \text{Å})}{10^{44}{\rm erg\ s^{-1}}}\right]^{0.50}$$

Vestergaard et al. 2006

$$M_{\rm BH}\ [M_\odot] = 10^{6.91} \left[\frac{\rm FWHM(H\beta)}{1000\ km\ s^{-1}}\right]^2 \left[\frac{\lambda L_\lambda(5100\ \text{Å})}{10^{44}{\rm erg\ s^{-1}}}\right]^{0.50}$$

Vestergaard & Osmer 2009



Eddington ratio and BLR radius

$$\frac{L_{bol}}{L_{Edd}} \approx 0.13 \left(\frac{\lambda L_\lambda (5100\,\text{Å})}{10^{44}\,\text{ergs}\,\text{s}^{-1}} \right)^{0.5}$$

Kaspi et al. 2000

$$R_{BLR} = A \cdot \left[\frac{\lambda L_\lambda (5100)}{10^{44}\text{erg s}^{-1}} \right]^{0.5} \text{lt} - \text{days}$$

Kaspi et al. 2000, 2005
Bentz et al. 2006

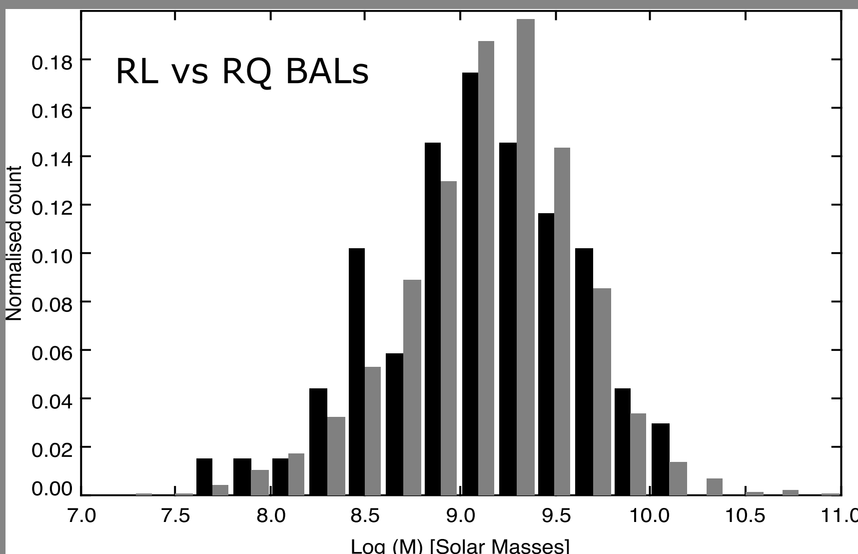
- Similar values for Eddington ratios:
  1. all super-Eddington (selection effect)
  2. mean values of 2.41 vs 2.92

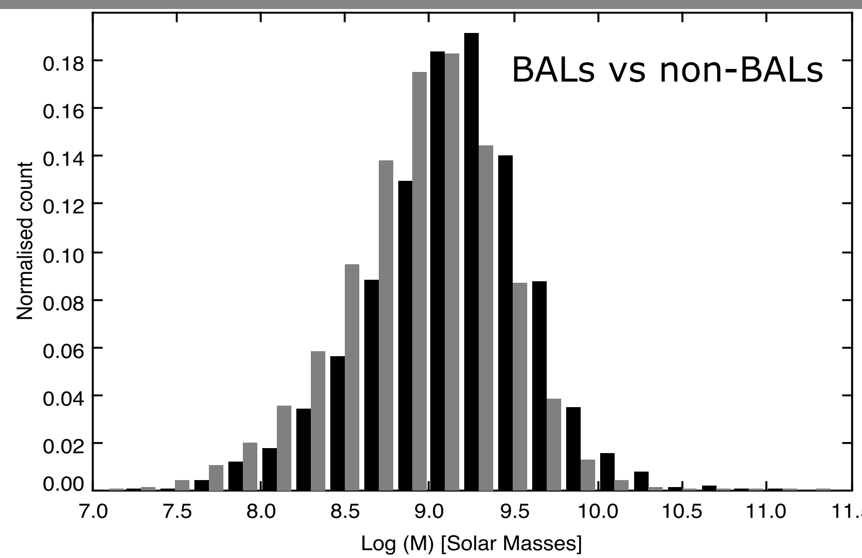
- Similar values for BLR: 427±191 vs 501±155 light-days

Results from the SDSS DR7 QSO catalogue

(Shen et al. 2011)

- 69 RL vs 3369 RQ BAL QSOs
- 3650 BAL vs 79650 non-BAL QSOs
- means within ±1 sigma for RL vs RQ BAL QSOs





Results from the SDSS DR7 QSO catalogue

Excess of super-Eddington objects among BAL QSOs:

13% vs 2%	26% vs 13%
BALs vs non-BALs	RL BALs vs RQ BALs

- High accretion rates required to trigger the BAL phenomenon?
- BH mass is not responsible for the rarity of RL BAL QSOs

(Bruni et al. 2014, in prep.)