Extended Lyα Emission around High z Radio Loud QSOs

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Outline

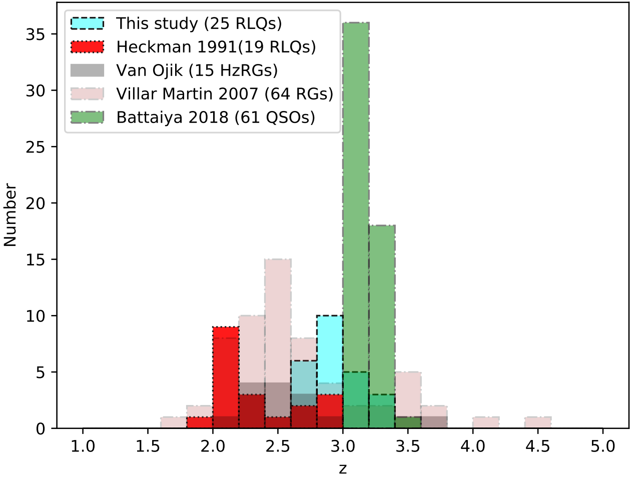
Motivation and Aim

- Detection rate of extended Lyα halos around QSOs
- Characterize the halo properties:
  - Gas extent
  - Radial profile
  - Velocity field
- Origin of Lyα emission
- Connect absorption and emission
- Study correlations between radio properties and optical properties of extended emission

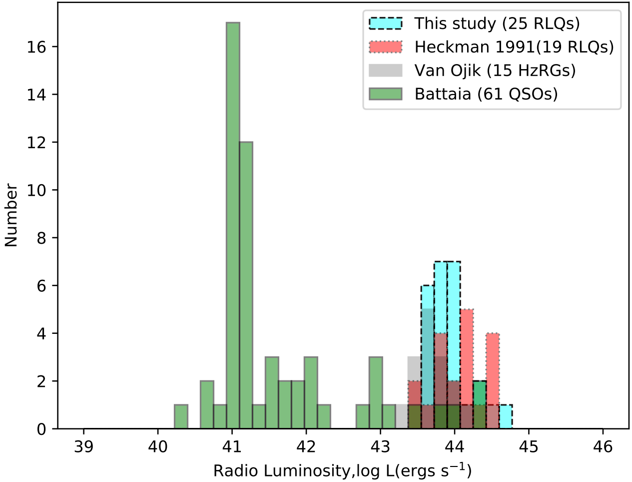
Sample and Observations

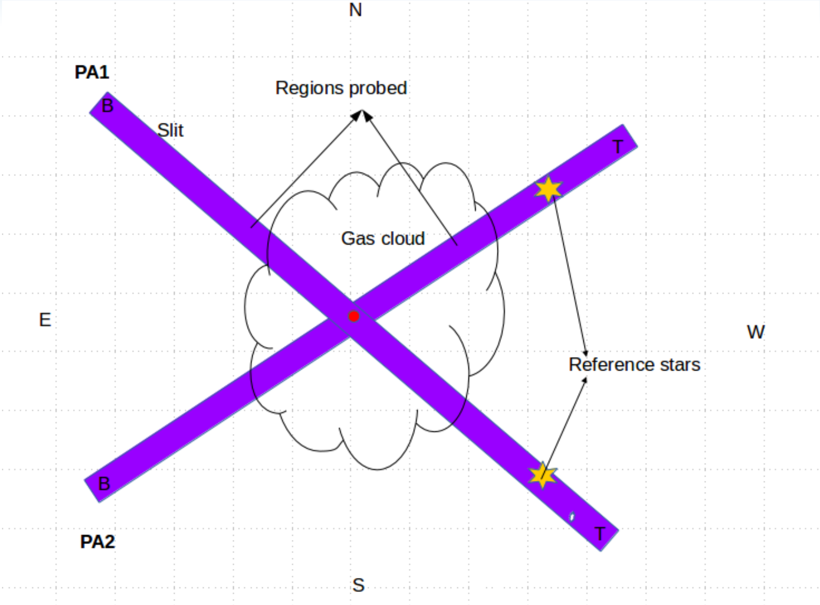
- QSO sample selected from MeerKAT Absorption Line Survey (MALS) lead by Neeraj Gupta
- 200 targets observed, 25 targets b/w 2.75$< z_{em} <$3.35 observed with SALT
- QSOs have radio flux, f$_{1.4GHz}$ $>$ 200mJ and radio luminosity $> 7 \times 10^{40}$erg s^{-1}
- Observing each target at 2 PAs using longslit at RSS/ SALT
- Radio maps obtained using GMRT

Histogram of redshift



Histogram of Radio Luminosity

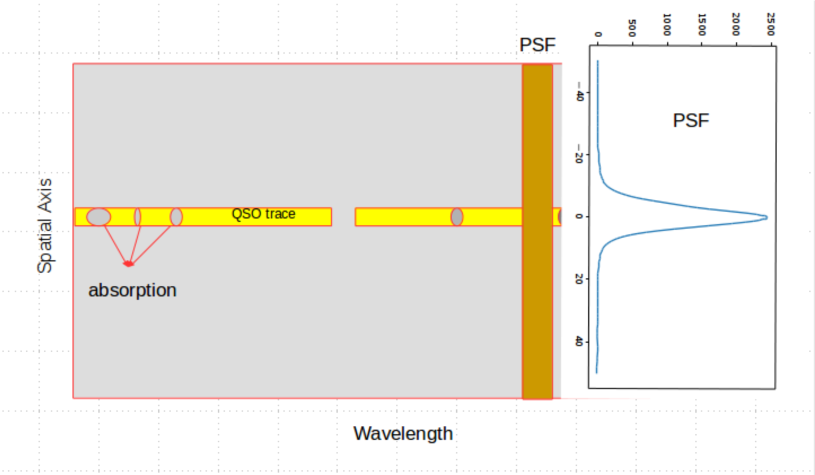



N
PA1
Regions probed
B
Slit
T
Gas cloud
E
W
Reference stars
B
T
PA2
S

Analysis

1. QSO Properties
   - Extract the 1D spectra
   - Find out the z_{em}, L_{bol}, M_{BH}
   - Emission lines
2. Characterize the halo properties
   - Find SPSF
   - Create a 2D continuum spectra from the PSF
   - Extract Lyα emission from continuum subtracted spectra
   - Find out the extent and surface brightness of the extension
3. Understand the correlation between radio jets and extended emission

What is SPSF?


PSF
QSO trace
absorption
Spatial Axis
Wavelength
PSF
0
500
1000
1500
2000
2500
−40
−20
0
20
40

Why constructing a well defined global SPSF is challenging?

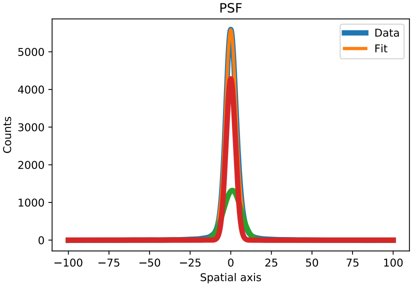
- Varies with wavelength
- Problematic due to tilt in the spectrum
- Strong emission and absorption create problems
- Shape often varies and is asymmetric

How to Extract SPSF?

- Use reference star or data to extract SPSF
- PSF should be extracted from redward absorption and emission free wavelength region
- Use a double gaussian fit to the spectrum, for low SNR data
- Use the PSF extracted from emission or absorption free region of the spectrum for high SNR data

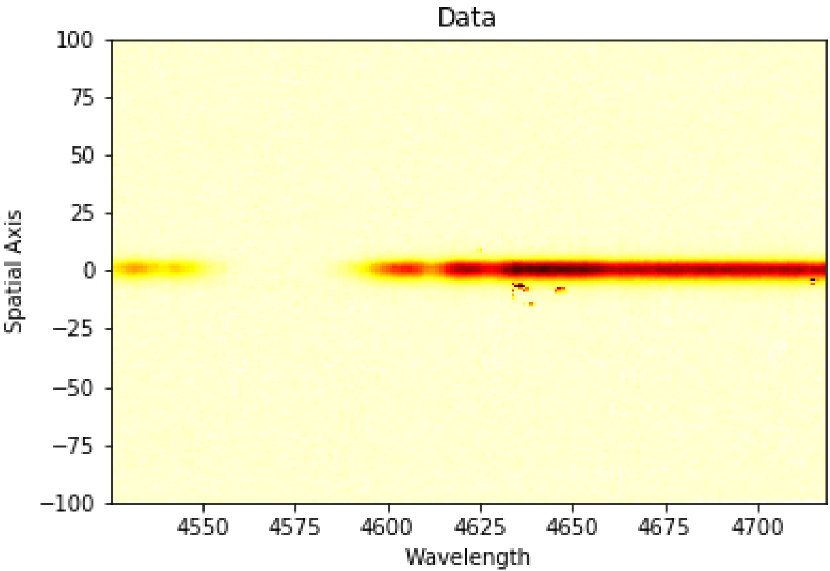
Why a double gaussian fit is appropriate?

- SPSF has a broad and narrow components
- Double gaussian fit is required for both narrow and broad profiles

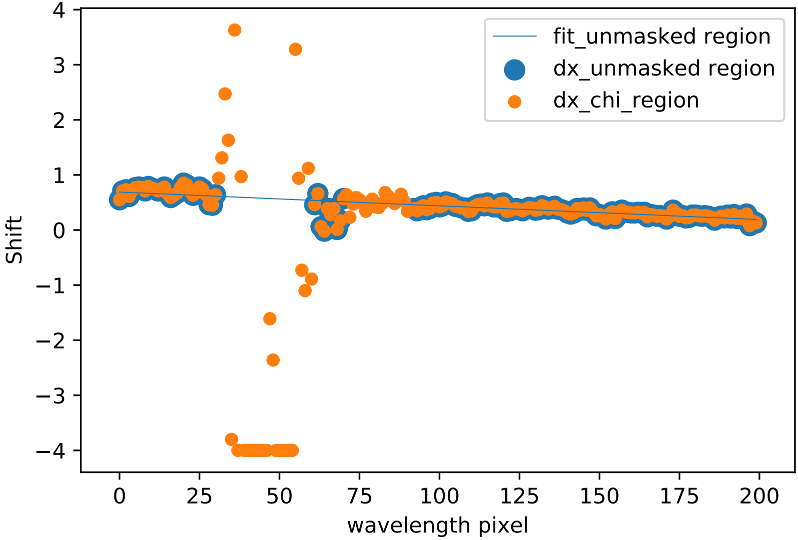


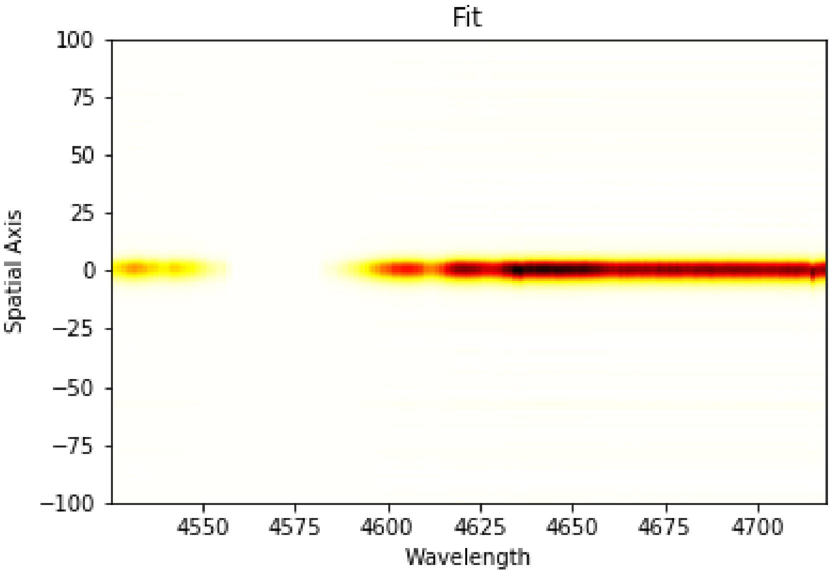
2D continuum model

- Trace the peak of QSO trace at each wavelength
- Fit the peak with a straight line
- Apply the appropriate shift to the SPSF to match the peak at each wavelength
- χ^2 minimize the amplitude of SPSF w.r.t. data



Data
100
75
50
25
0
−25
−50
−75
−100
Spatial Axis
4550
4575
4600
4625
4650
4675
4700
Wavelength


fit_unmasked region
dx_unmasked region
dx_chi_region
Shift
wavelength pixel
4
3
2
1
0
−1
−2
−3
−4
0
25
50
75
100
125
150
175
200

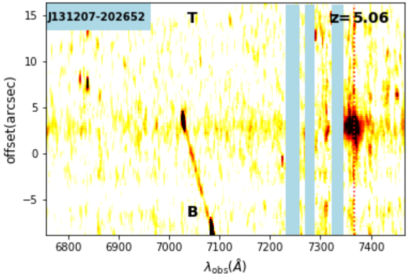

Fit
Spatial Axis
100
75
50
25
0
−25
−50
−75
−100
4550
4575
4600
4625
4650
4675
4700
Wavelength

Few Interesting Targets

Table: SALT/RSS Log of observations and QSO sample

QSO	Grating	$\Delta\lambda$ (km s^{-1})	λ ($\AA$)	DoO	ET (s)	Seeing ($''$)
J1312-2026	PG0900	282	4486−7533	2015-06-19	570.2	2.16
J1142-2633	PG0900	274	4627−7668	2018-02-27	1200.216	1.46
J1513-2524	PG0900	282	4486−7533	2017-05-18	1200.207	1.32
J2101-1747	PG0900	296	4203−7261	2017-05-22	1300.218	2.11
J2154-3826	PG0900	296	4061−7124	2018-07-04	1200.216	1.49

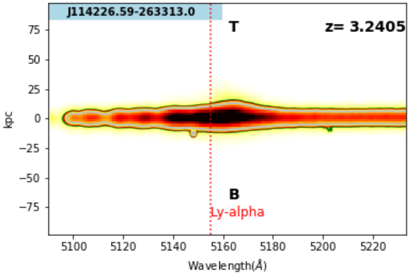
J1312-2026

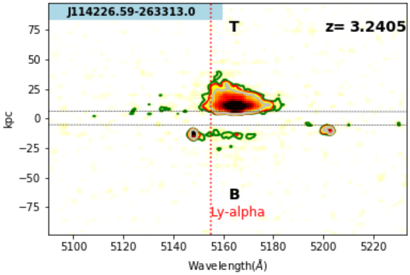


- Most Luminous RLQ detected till date at z>5
- Emission is reproduced in 2 set of observations with different setup
- LLS is found at z=5.0
- $L_{1.4GHz} = 1.2 \times 10^{29}$ W Hz^{-1}
- No radio structure present

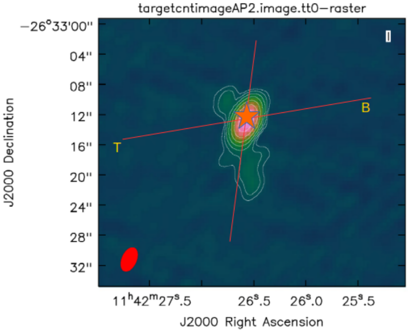
J1142-2633

PA=100





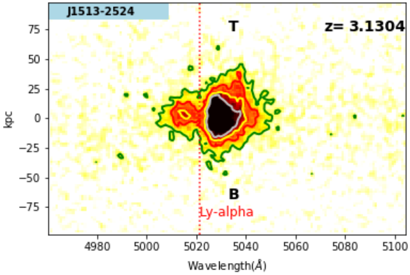
RADIO IMAGE

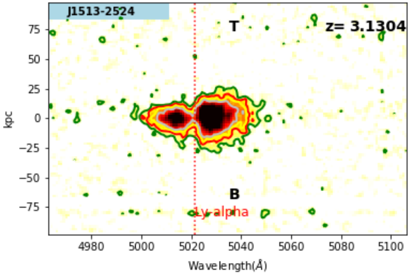


- Asymmetric Lyα emission extending upto 35 kpc
- Could be extended upto 150 kpc if reach a lower SB limit for $\mathrm{SB(r)} \propto \mathrm{r}^{-1.8}$ (Arrigoni-Battaia 2018)
- Extended emission seems to correlate with the radio jet direction
- Need NB observations to study the gas distribution

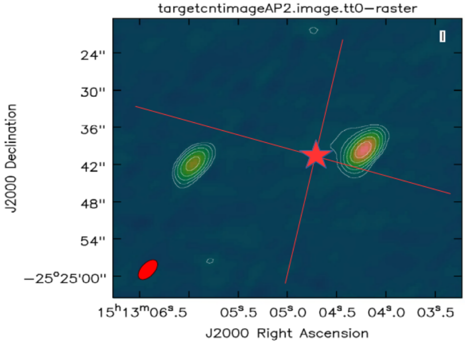
J1513-2524

PA=72,350





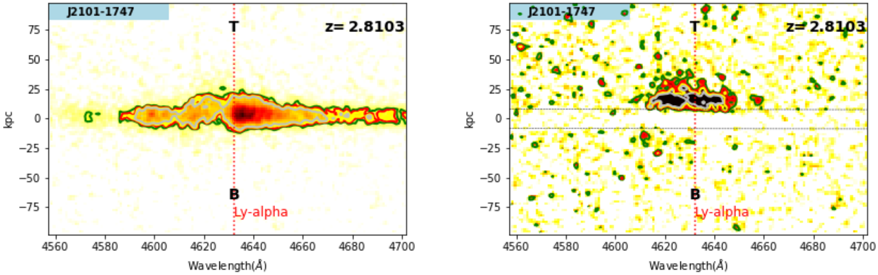
RADIO IMAGE



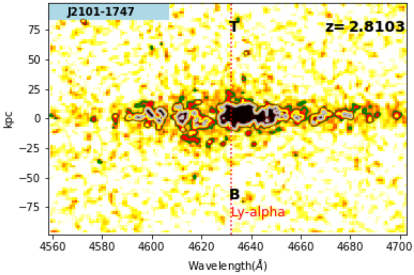
- A radio galaxy with no optical counterpart
- Only Lyα, CIV and HeII lines detected without any continuum
- 2 PAs show asymmetric emission
- Extent of emission is $\approx$ 80 kpc
- A double lobed radio quasar with faint nucleus
- A potential candidate for ELAN

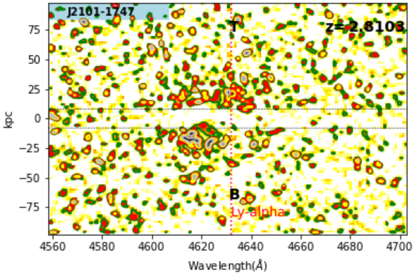
J2101-1747

PA=112

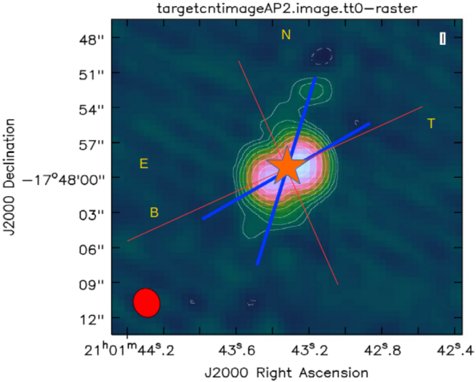


PA=30


J2101-1747
T
z= 2.8103
B
Ly-alpha
kpc
Wavelength(Å)


J2101-1747
T
z= 2.8103
B
Ly-alpha
kpc
Wavelength(Å)

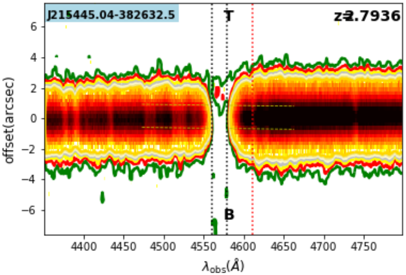
RADIO IMAGE

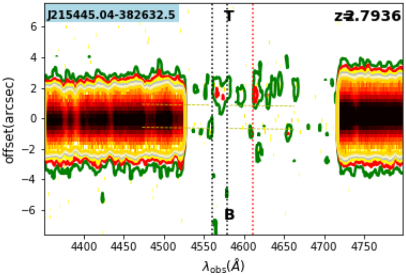


- Lyα halo at both PAs
- Two episodes of radio activity
- Strong core-jet structure along South-East
- A weaker jet along North-South
- Emission at PA=112 is anti-correlated with the jet direction

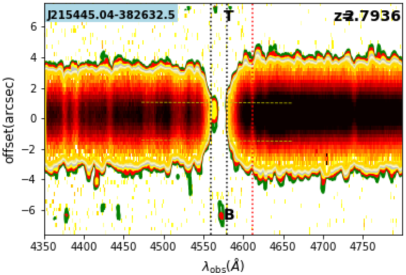
J2154-3826

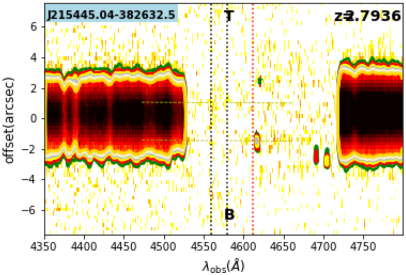
PA=45



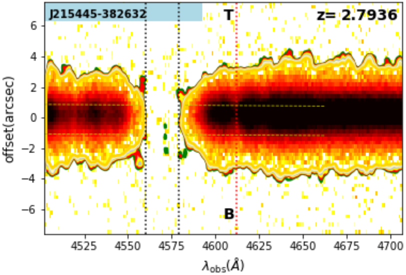


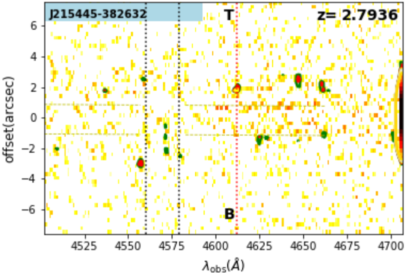
PA=135


J215445.04-382632.5
T
B
z=2.7936
offset(arcsec)
$\lambda_{obs}(\AA)$


J215445.04-382632.5
T
B
z=2.7936
offset(arcsec)
$\lambda_{obs}(\AA)$

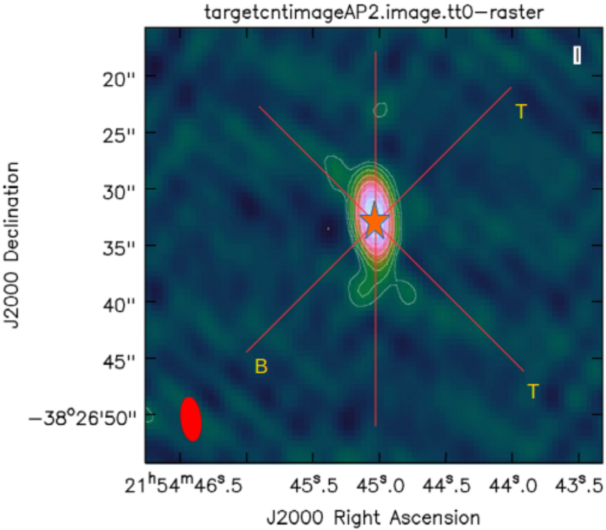
PA=0





- An emission from DLA at PA=45 with 7σ significance
- $\Delta V = -2685$ km s^{-1}
- $M_{BH} = 2.4 \times 10^9 M_\odot$
- $R_{BLR} = 106$ light days
- $L_{Ly\alpha} = 2.3 \times 10^{42}$ erg s^{-1}, $\sigma_v = 712$ km s^{-1}
- $L_{1450} = 1.29 \times 10^{44}$ erg s^{-1}Å^{-1}
- $L_{912} = 1.32 \times 10^{31}$erg s^{-1}Hz^{-1}

RADIO IMAGE


targetcntimageAP2.image.tt0−raster
I
T
T
B
20"
25"
30"
35"
40"
45"
−38°26'50"
J2000 Declination
21h54m46s.5
45s.5
45s.0
44s.5
44s.0
43s.5
J2000 Right Ascension

Some Measurements

Table: Measurements from our analysis

Target	z_{em}	L_{bol} (erg s^{-1})	M_{BH} ($M_\odot$)	$L_{Ly\alpha}$ (erg s^{-1})
J1513-2524	3.1304	7.5×10^{46}	5.8×10^{8}	6.87×10^{44}
J2154-3826	2.7936	7.90×10^{47}	2.4×10^{9}	3.13×10^{43}
J1142-2633	3.2405	1.32×10^{47}	1.05×10^{9}	7.48×10^{43}
J2101-1747	2.8103	1.2×10^{46}	9.6×10^{7}	2.66×10^{43}

Table: Targets with extended Lyα emission

Target	SB $(\mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}})$	$\mathrm{SB_{lim}}$ $(\mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}})$	S/N
J1513-2524	7.65×10^{-16}	8.40×10^{-18}	90
J2154-3826	2.80×10^{-17}	4.56×10^{-18}	6
J1142-2633	1.70×10^{-16}	1.50×10^{-18}	100
J2101-1747	8.37×10^{-17}	4.14×10^{-18}	20

Plans for future observations with SALT

- Observed 13 targets at two PAs
- 8 are observed at only one PA
- 4 targets need to be observed at two PAs
- Observing few sources with narrow band imaging

Summary

- All the QSOs seem to host MBH at the centre with mass range b/w $10^6 - 10^9 M_\odot$
- FWHM of the PSF ranges b/w 1.2″-2 ″, allows to detect extended emission beyond 15kpc
- 60-70% of QSOs seem to have asymmetric extended emission
- With limiting surface $\approx 10^{-18}$ erg s^{-1} cm^{-2} $arcsec^{-2}$, detecting bigger halos extending upto 30-80kpc
- We are possibly witnessing Lyα fluorescence
- There might be a correlation b/w extended emission and HeII emission
- Statistical correlation is important to understand the origin of extended emission