Revealing the Powering Mechanism of Lyman α Blob via Polarimetry

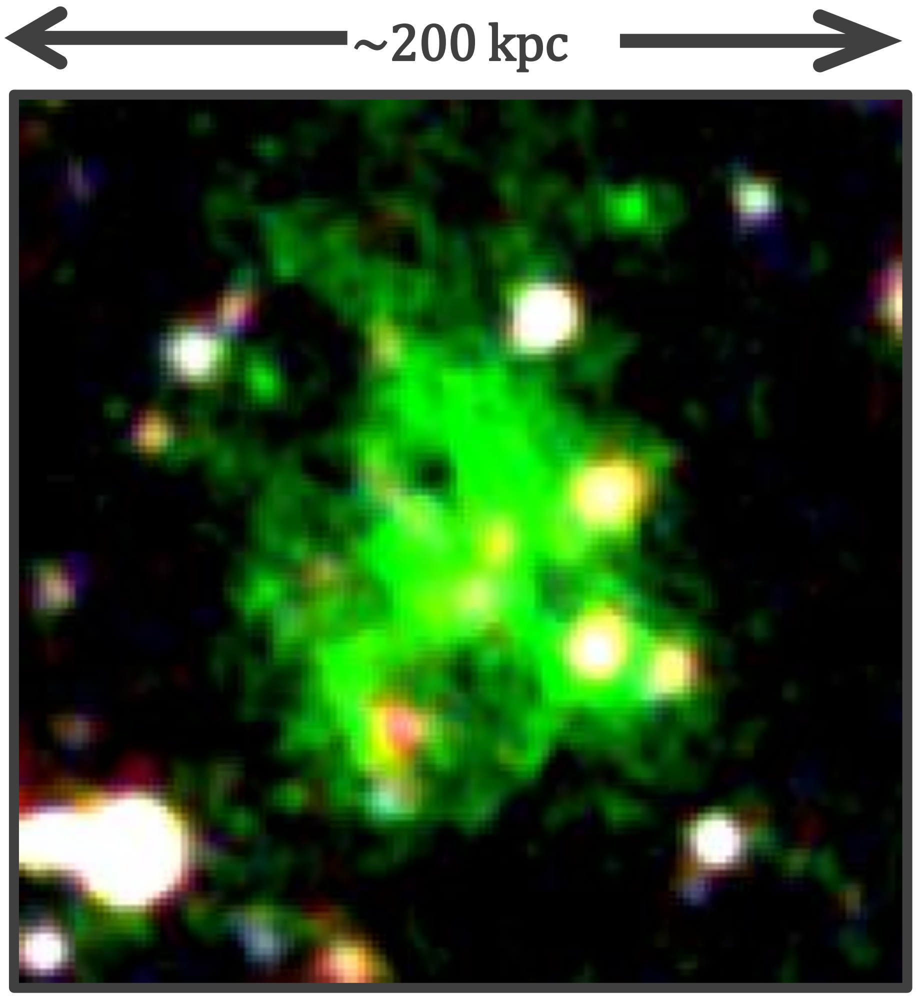
Eunchong Kim (SNU, KASI)

Advisors:
Myung Gyoon Lee (SNU), Yujin Yang (KASI)

Collaborators:
Ann Zabludoff, Paul Smith
Buell Jannuzi, Chang You (Arizona)

1 What are Lyman α blobs?

Introduction



Steidel blob1, z = 3.1
(Matsuda et al. 2004)

- Discovered by narrowband imaging at z= 2~6
- Extended more than embedded galaxies
- Reside in overdense region and massive dark matter halo
- Clue for formation of galaxy group or galaxy cluster

What causes the Lyman α blobs to glow?

1. Gravitational cooling radiation by gas infalling
   (Haiman et al.2000; Fardal et al. 2001; Goerdt et al. 2010)
2. Shock-heating from starburst driven winds
   (Taniguchi & Shioya et al. 2000; Mori et al. 2004)
3. Photo-ionizing radiation from AGN
   (Haiman et al. 2000, Yang et al. 2014a)
4. Resonant scattering
   (Steidel et al. 2011, Hayes et al. 2011)

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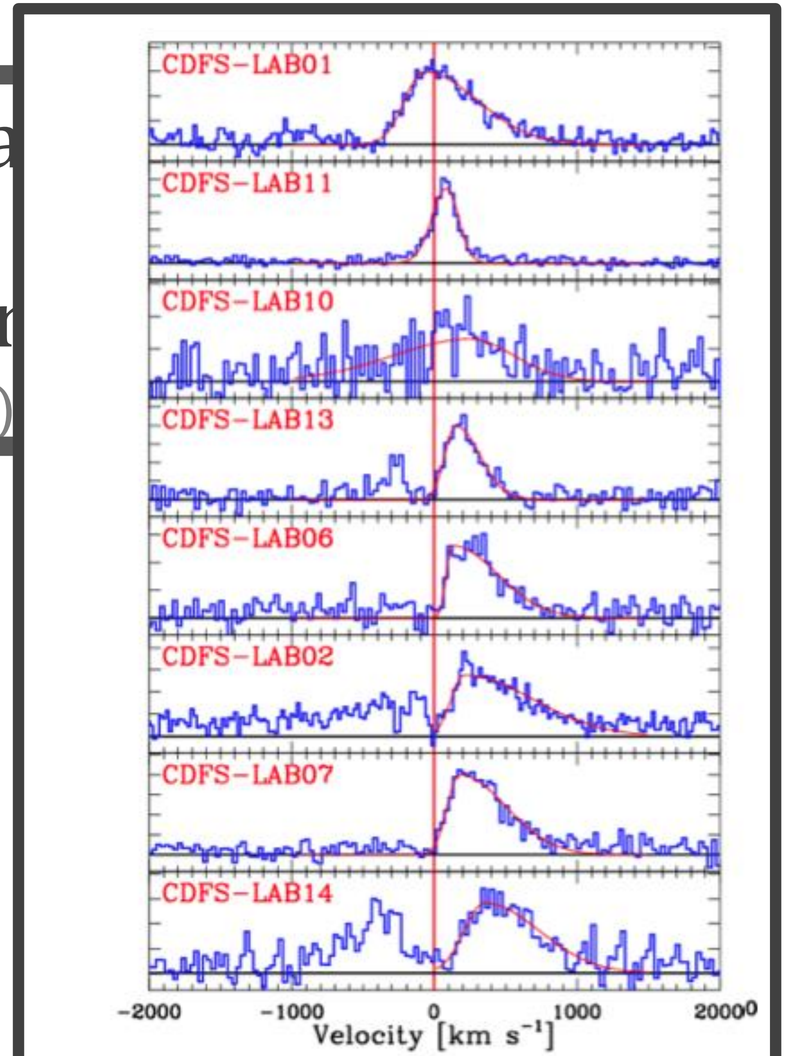
Modest outflow (~100km/s) rather than Galactic super wind (~1000km/s) or gas infall

Lyα profile



Yang et al. (2011, 2014b)

1

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→ Evidence for hard ionizing source (s):
He II λ1640, C IV λ1640 emission lines are detected.
(F. Arrigoni-Battaia et al. 2016)

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3. Photo-ionizing radiation from AGN

(Haiman et al. 2000, Yang et al. 2014a)

→ Evidence for hard ionizing source (s):
He II λ1640, C IV λ1640 emission lines are detected.
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→ Only 17 % of blobs have strong X-ray AGN
(Geach et al. 2009)

→ No clear evidence of **global photo-ionization**

What causes the Lyman α blobs to glow?

4. Resonant scattering

(Steidel et al. 2011, Hayes et al. 2011)

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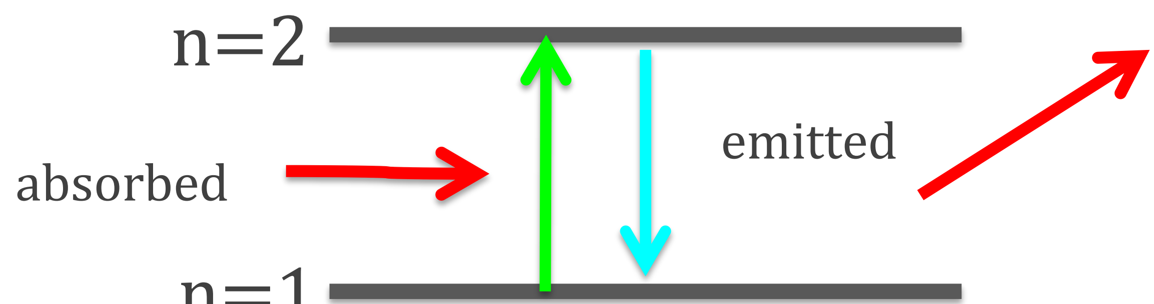
Resonant scattering



No energy change, **Only direction changes**

Photons are produced by an embedded central source, **scattered by surrounding gas, and transported to outer radii.**

What causes the Lyman α blobs to glow?

Resonant Scattering VS **Photo-ionization**

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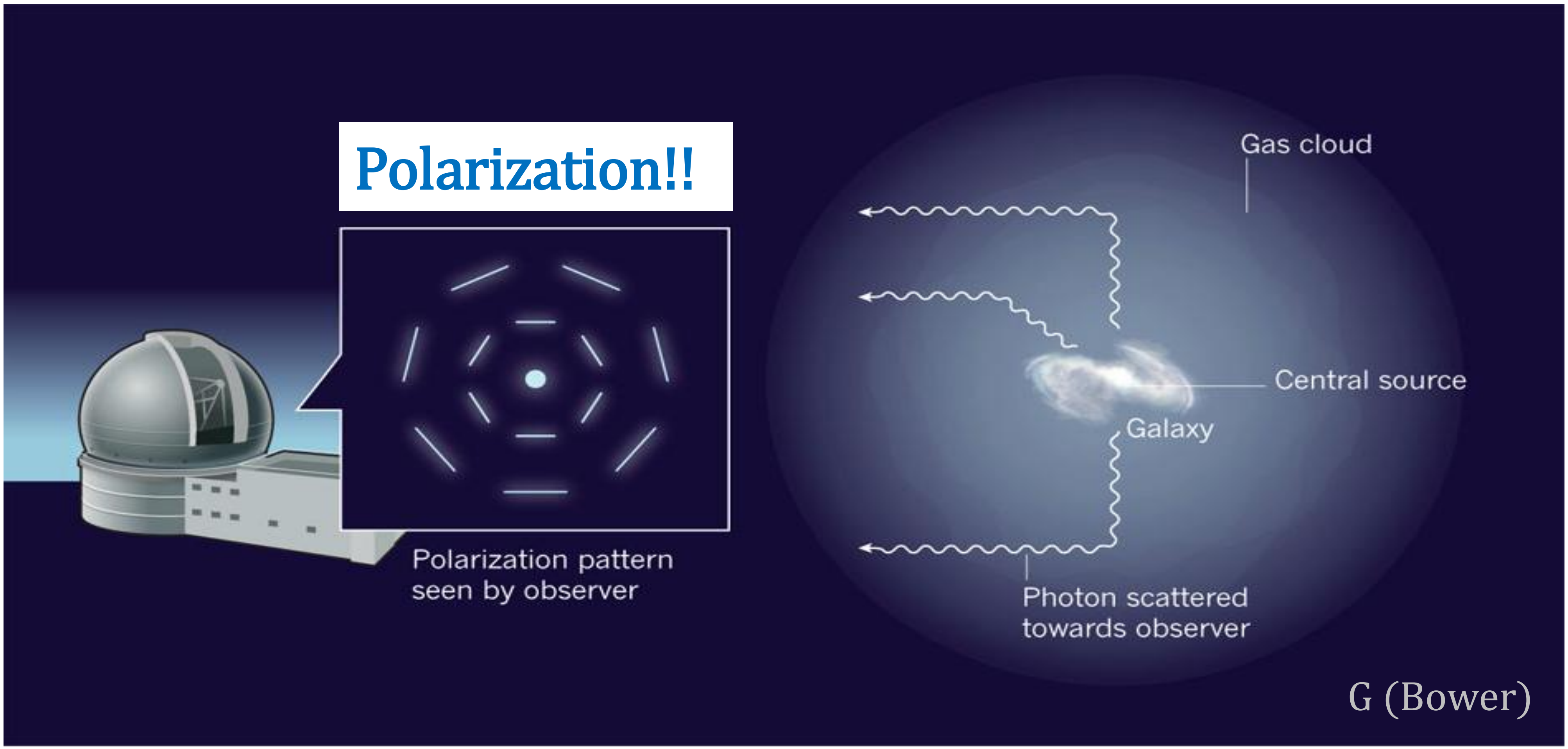
Resonant Scattering VS Photo-ionization



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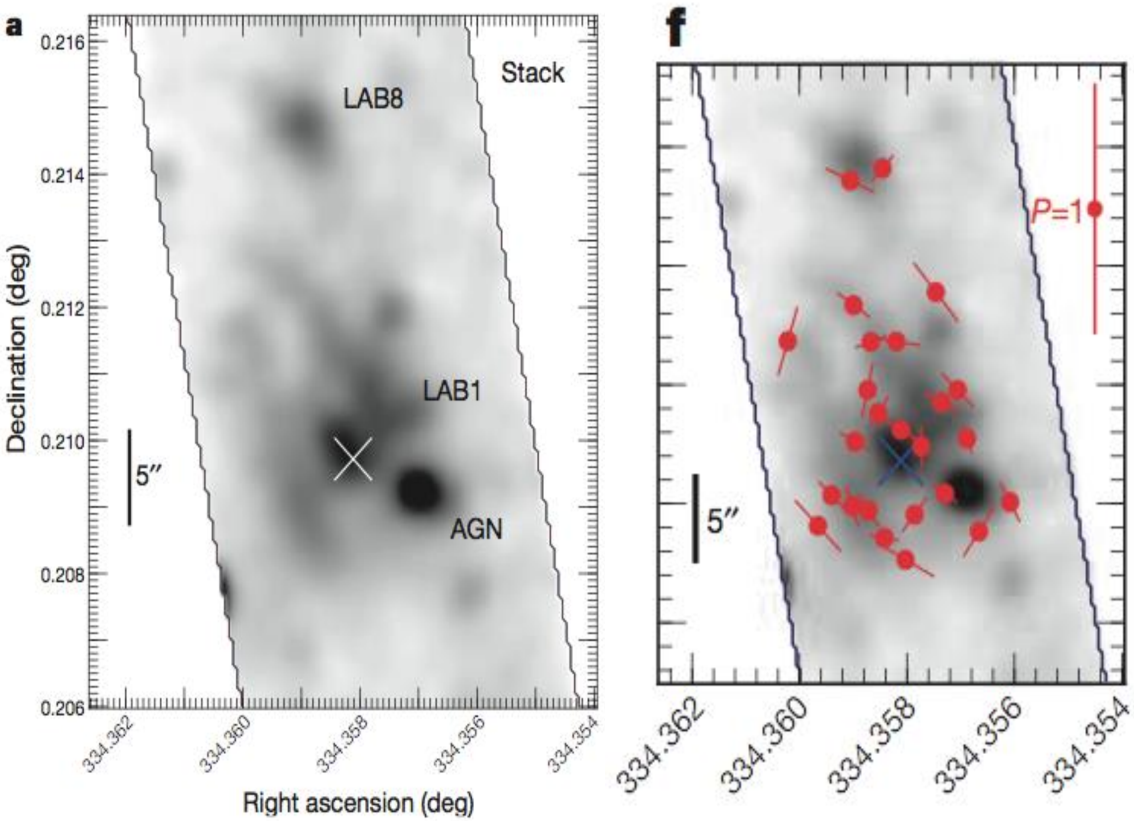
Resonant Scattering VS Photo-ionization

1 A previous study for Lyman α blobs via Polarization

Introduction



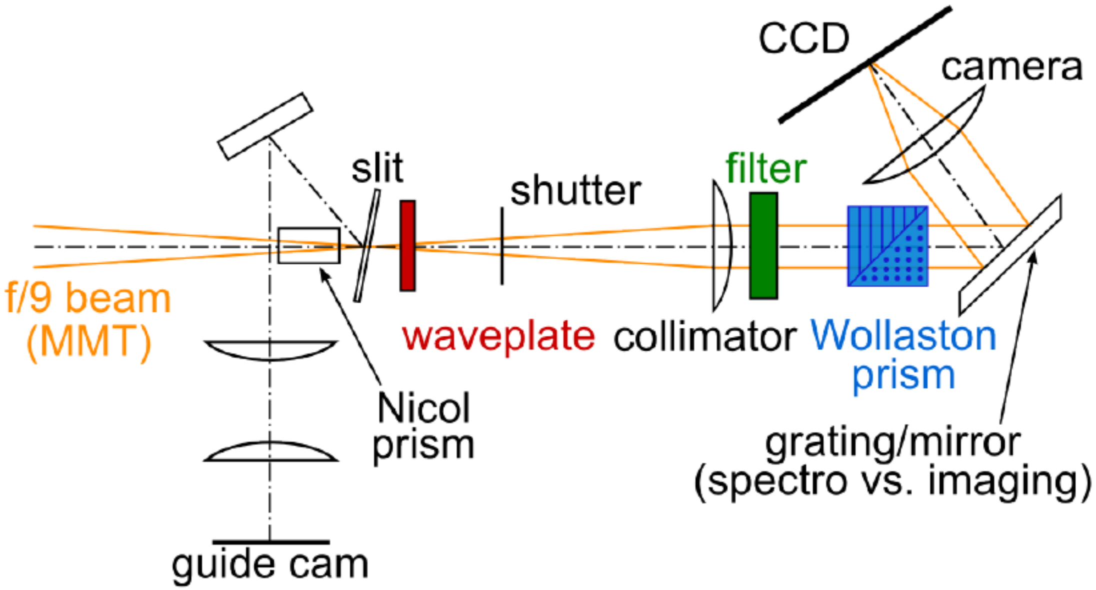
Hayes et al. 2011

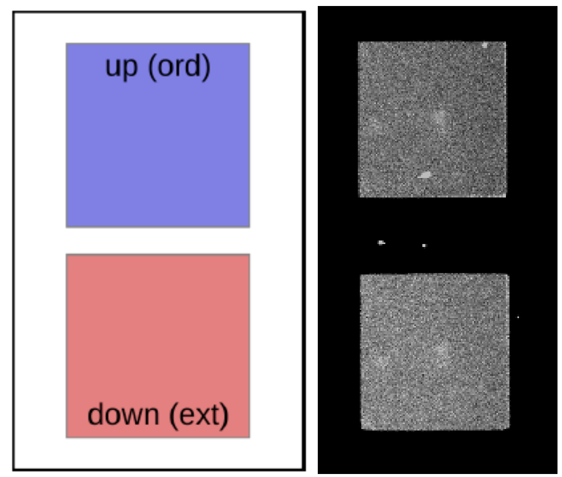
- LAB1 using VLT FORS2
- Relatively low polarization ~7% at the center and increase along the radius (~20%).
- **Concentric ring pattern**
- **Supporting resonant scattering scenario**

2 MMT/SPOL Imaging Polarimetry

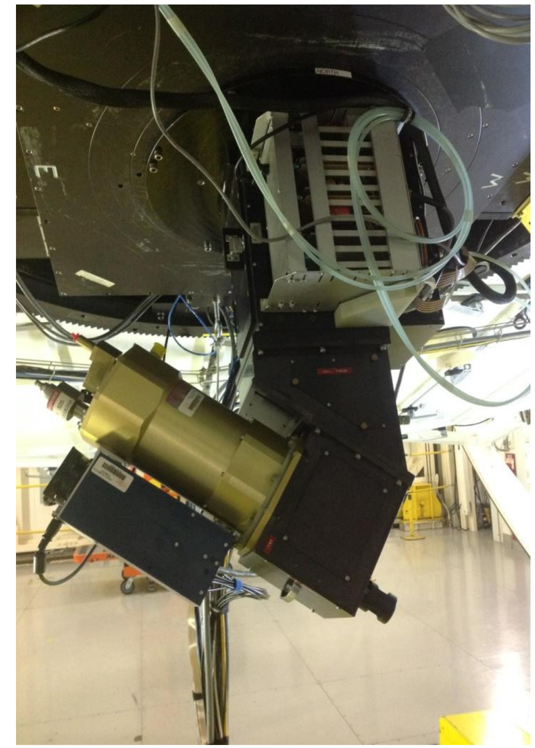
Dual beam polarimeter for Stokes

Observation





Raw Image of FLS-LAB1



MMT/SPOL

- 6.5m telescope
- <0.1% Instrumental polarization

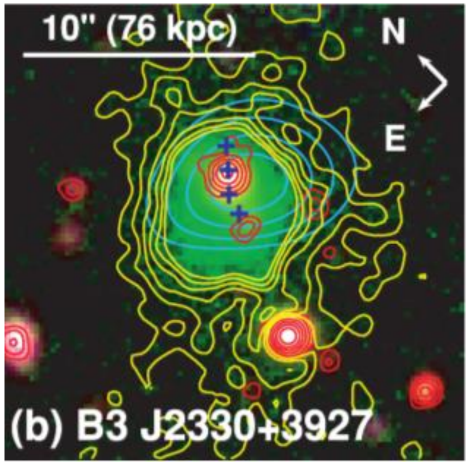
2 Polarimetric Survey of Lyman α blobs

Observation

	Redshift	Type	Total Exp. Time	K-GMT science program?
B3 J2330 +3927 (Mastuda et al. 2009)	3.08	Radio-loud AGN	9.3 hours	
FLS-LAB1 (Smith et al. 2007)	2.83	No AGN, Cold accretion?	16.5 hours	Partial
LABd05 (Dey et al. 2005)	2.65	Obscured AGN	11 hours	Partial
SSA22-SB3-LAB1 (Mastuda et al. 2011)	3.1	Radio-loud QSO	6.13 hours	Partial
4C41.17 (Reuland et al. 2003)	3.79	HzRG	10.38 hours	Partial

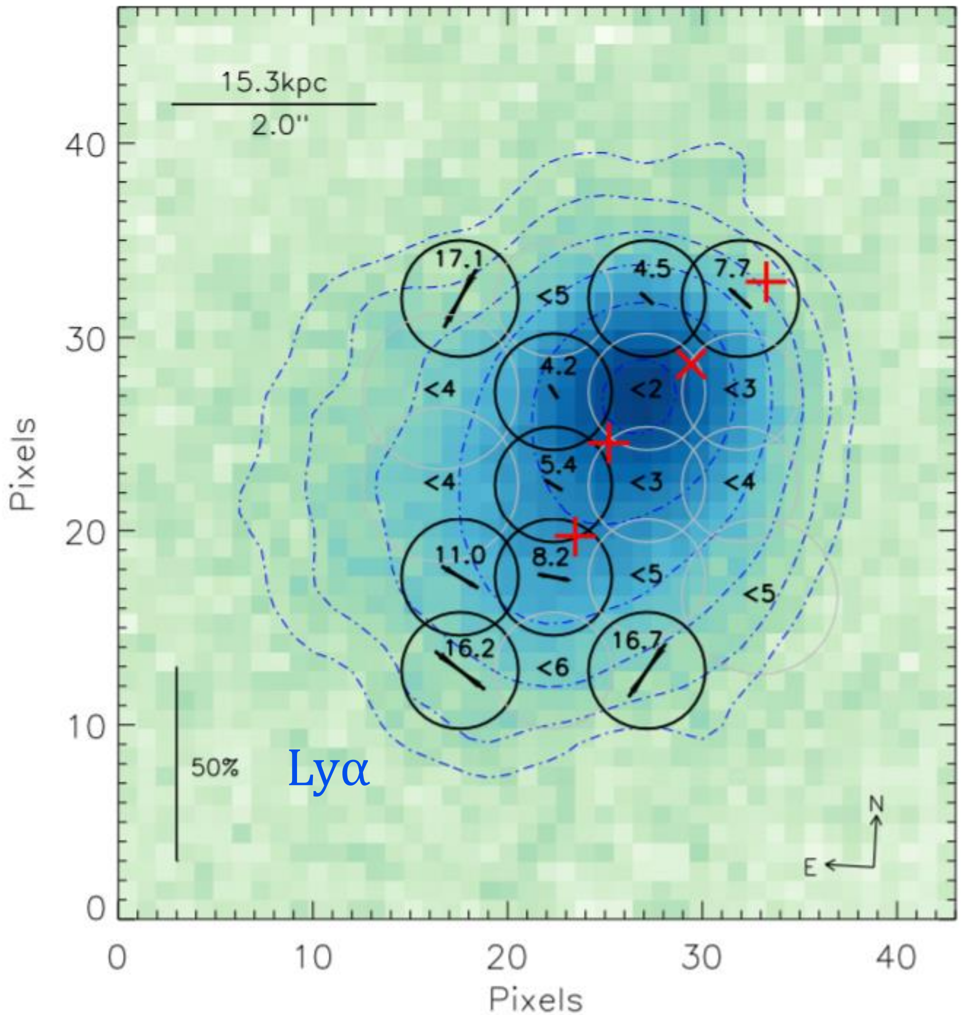
3 B3 J2330+3927

Result



Matsuda et al. 2009

- z = 3.087
- Size ~ 130 kpc
- L(Lyα) ~ 10^{44} erg/s
- Radio loud AGN, with radio lobe

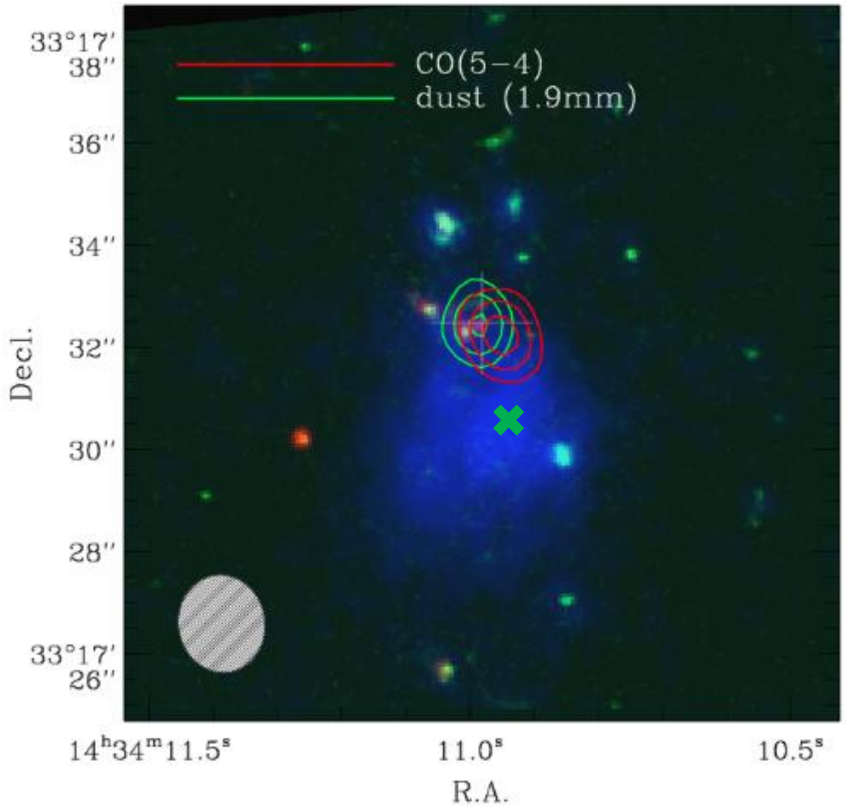


C.You, Zabludoff, Y.Yang, **E.Kim**, M.G.Lee et al. 2017

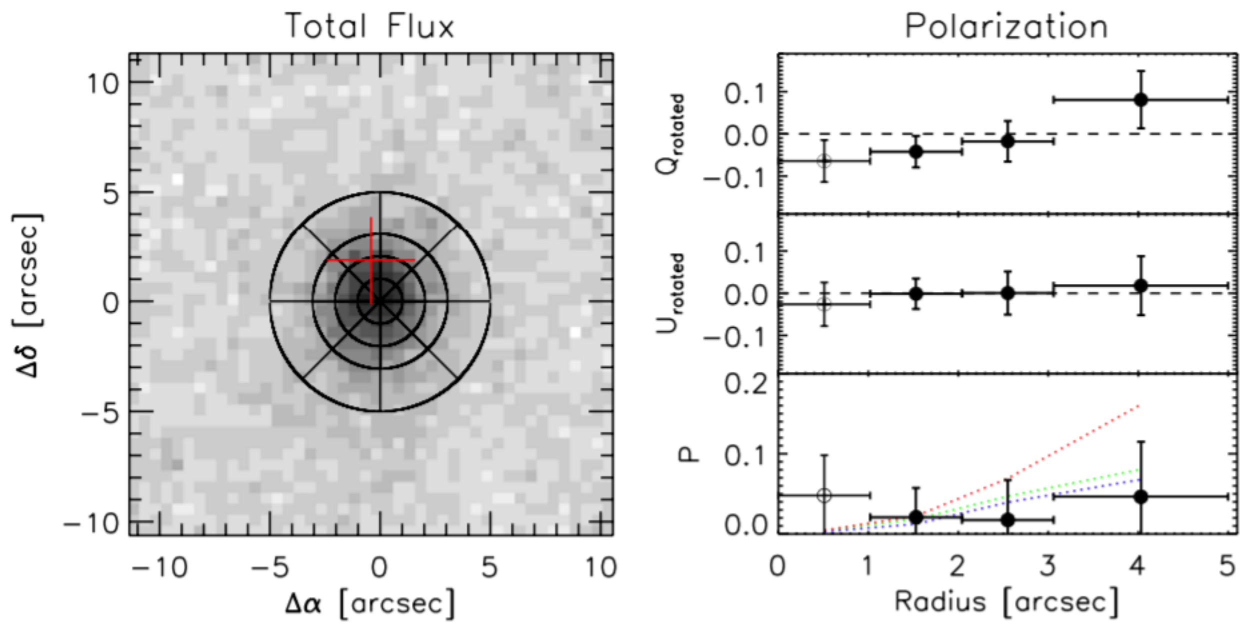
- First detection of Lyα polarization from radio-loud Lyα blob using **MMT/SPOL**
- Detection of polarization 5% (at 5kpc) – 20% (at 30kpc)
- Polarization mostly along the jet (major axis of nebula)
- Polarization angle perpendicular to the jet direction
- **Believed that photo-ionization dominant (radio jet and lobe) , but polarized!**

3 LABd05

Result



HST Image: Prescott et al. 2012
CO map: Yang et al. 2014



Prescott et al. 2011

- Using Bok 2.3m telescope/SPOL
- Total P = 2.6 ± 2.8 (%): (Null detection)

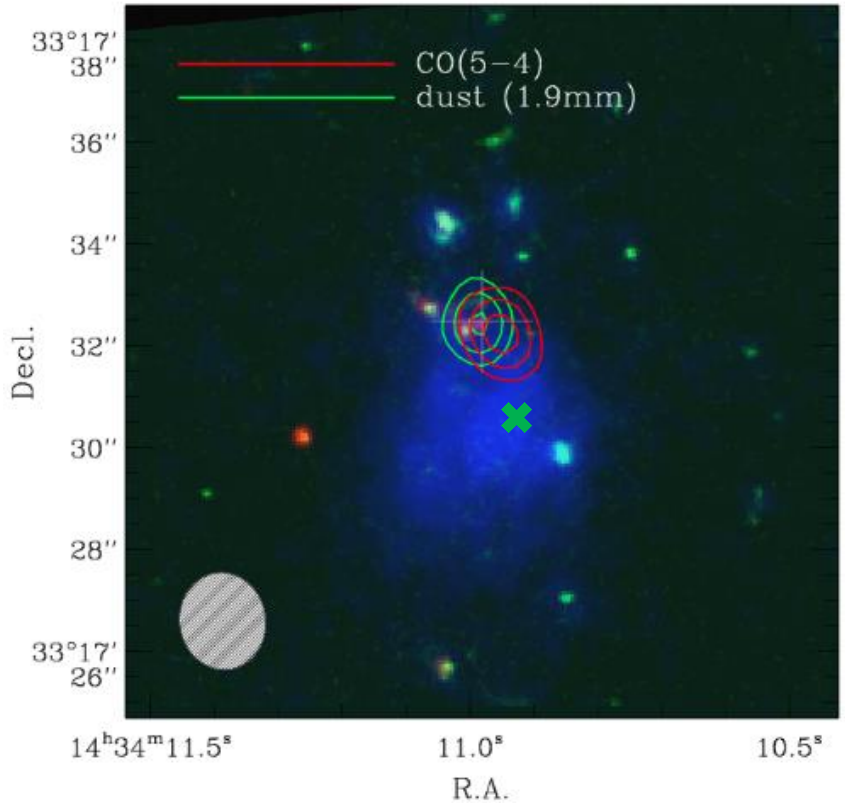
z = 2.656, Size = ~160 kpc
L(Lyα) = ~2x10^{44} erg/s

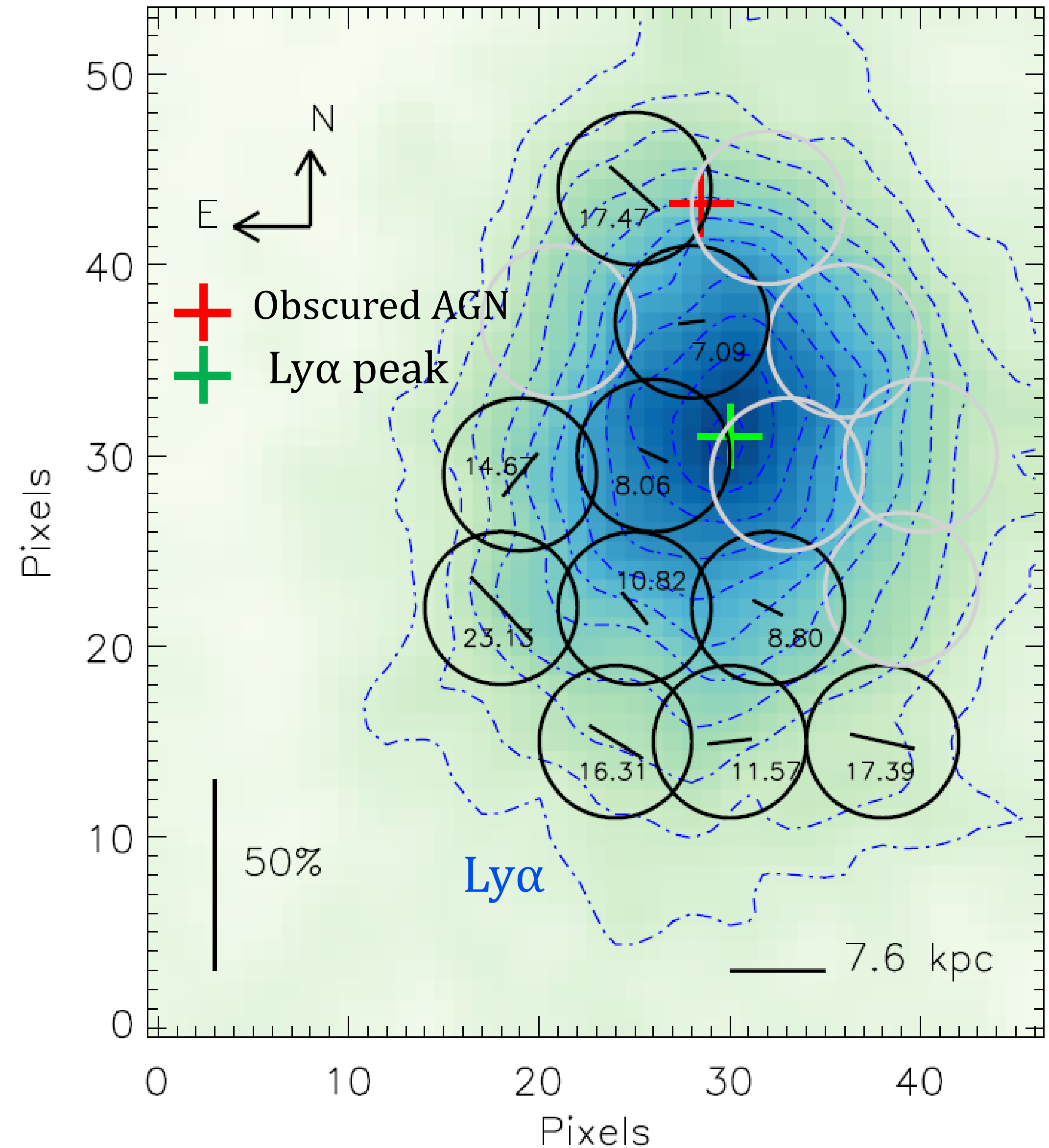
Spatial offset between obscured AGN and Lyα peak
→Photo-ionization dominant?

3 Result

LABd05

Preliminary result, (E. Kim et al. in prep.)

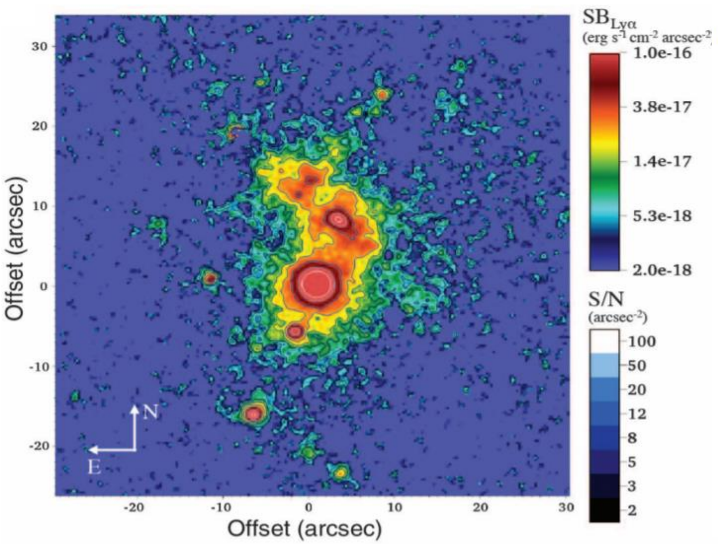




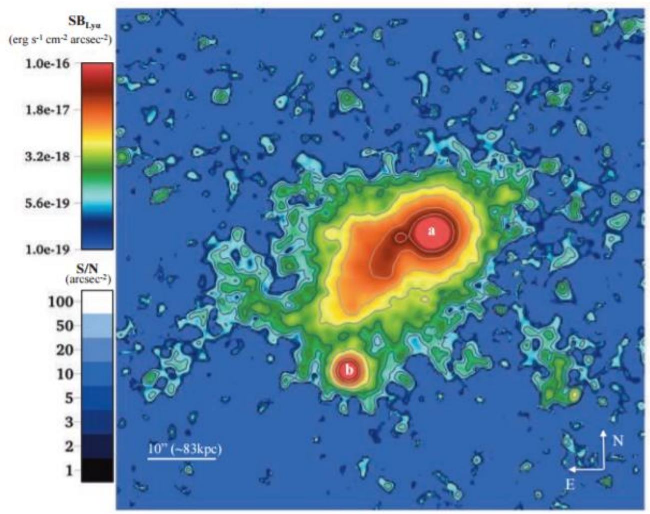
- Detection of polarization
  8% (at peak of Lyα) – 23% (at ~20 kpc)

4 Polarimetric Survey of Lyman α blobs (Plan)

Future Plan



Jackpot



Slug

- Jackpot (SDSS J0841 + 3927, Hennawi et al. 2015): **z ~ 2.046**, L~1.16x10^{45}erg/s size ~ 37.13 arcsec
- Slug (LBQS 0049 +0045, Cantalupo et al. 2014): **z ~ 2.279**, L~1.43x10^{45}erg/s size ~ 55.97 arcsec

- Upgrade the **MMT/SPOL**'s blue band sensitivity (Dr. Sung-Joon Park & Woong-Seob Jeong at KASI)
  → Lower z (and thus brighter) Lyman α blobs
- **Spectro-polarimetry** for Lyman α blobs: kinematics of Lyman α blobs
- Comparison with **numerical calculation** of polarization (Hee-won Lee & Seok-Jun Chang at Sejong Univ.)

5 Conclusion & Summary

Summary

- **Polarimetric survey** of the brightest Lyman α nebulae with various radio, AGN, and host galaxy properties (K-GMT science program & U Arizona).

- Significant level of Polarization in **B3 J2330+3927** and **LABd05** using **MMT/SPOL** (up to 20% and 23%)

- Upgrade the **MMT/SPOL**'s blue band sensitivity
  → Expand survey to lower z sample of Lyman α blob

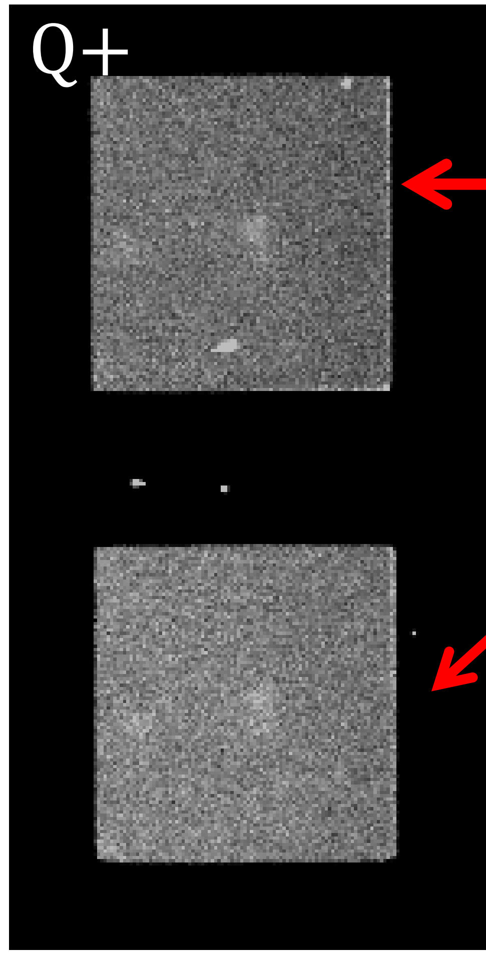
2 The Observation of Polarization

Observation

Measuring Stokes parameters

$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} \text{Total intensity} \\ I(0\ \text{deg}) - I(90\text{deg}) \\ I(45\ \text{deg}) - I(135\text{deg}) \\ \text{Circular polarization} \end{pmatrix}$$

Position angle of wave plate	Sequence
0°,90°,180°,270°	Q+
45°,135°,225°,315°	Q-
22°.5,112°.5,202°.5,292°.5	U+
67°.5,157°.5,247°.5,337°.5	U-



(I + Q)/2

(I - Q)/2

Raw Image of FLS-LAB1

$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$

$$\theta = \frac{1}{2} \arctan \frac{U}{Q}$$