Extended Lyα Nebulae at z=2.3: Tracers for High-Redshift Protocluster?

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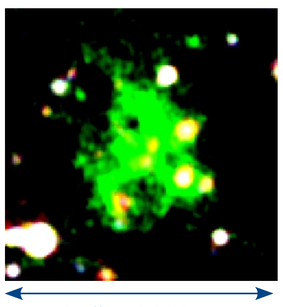
Abstract **Radio-quiet Lyα nebulae (aka "blobs"), extended sources at z = 2-5 with typical sizes of ~100 kpc, are among the most mysterious of astronomical objects. While the nature of these blobs has been hotly debated, they are likely the sites of massive galaxy formation. To understand their abundances and environments, we carried out two complimentary narrowband imaging surveys targeting blobs at z=2.3: one shallow but ultra-wide survey (with Steward Bok-2.3m) and the other deeper survey but with smaller sky coverage (with NOAO 4m telescopes). After searching over ~5 deg^2 on the sky, we found a pair of radio-quiet blobs that are separated only by 70" (550 kpc) on the sky and have almost identical redshifts (<350 kpc), suggesting that they are strongly clustered. Furthermore, from the deeper survey searching four 30'×30' fields (CDFS, CDFN, two COSMOS subfields), we discovered ~six largest/brightest blobs (area > 16 □") only in one survey field (CDFS). This strong field-to-field variation indicates that these extended Lyα nebulae occupy high density regions and perhaps they are the precursors of brightest cluster galaxies. Spatial distribution of compact Lyα emitters in CDFS confirms the presence of large-scale belt-like structure, possibly a proto-cluster, with 10×40 comoving Mpc in size.**

1. What Are Lyα Blobs (Lyα Nebulae)?



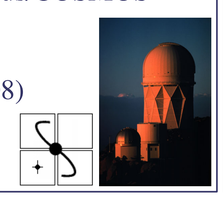
25" ~ 200kpc
Steidel blob 1
(from Matsuda+ 04)

Lyα blobs have been discovered by narrowband imaging surveys and are extended over ~10" (100 kpc) with Lyα luminosity of 10^{44} ergs/s. While blobs may represent an important phase of massive galaxy formation, their energy sources (e.g., AGN, superwind, cold accretion), kinematics of their surrounding gas (infall vs. outflow), and what they will turn into at the present-day universe are poorly understood. Nonetheless, our study (this poster) will show that blobs are strongly clustered populations at z=2.3, therefore, likely tracers for protoclusters at the high redshifts.

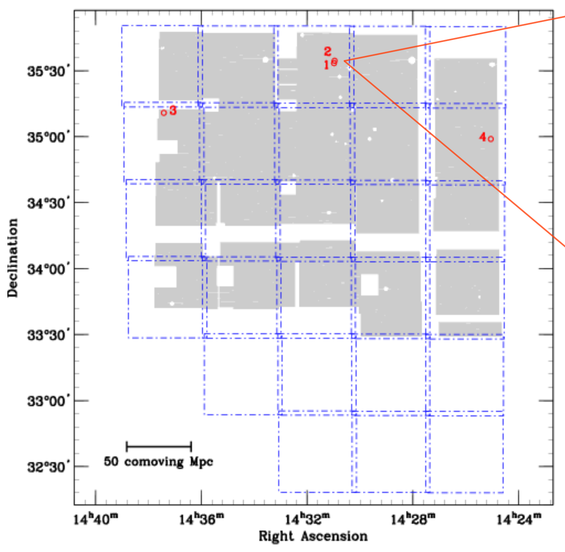
2. Blind Surveys for Lyα Blobs

• Identify Lyα blobs in blank fields at key redshift (z=2.3) to constrain number density/environment/clustering

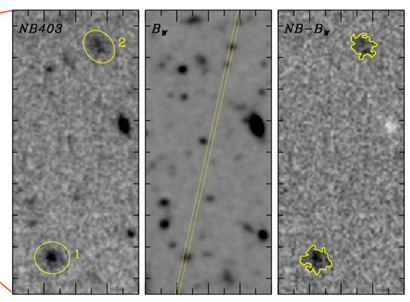
	Wide-field survey	Deep survey
Telescope	Bok2.3m+90Prime (1□° FOV)	KPNO/CTIO-4m+MOSAIC
Target	bright (10^{44} ergs s^{-1}) blobs	intermediate (< 10^{43} ergs s^{-1})
Fields	NOAO Bootes/Cetus/COSMOS	CDF-S/CDF-N/COSMOS 1&2
Exposure	6–20 hours	~10 hours
	45 nights (2007-08)	15 nights (2007 & 2009)
Area	6+4+2 □°	4 × (35' × 35')



3. Close Pair of Blobs from Wide-Field Survey



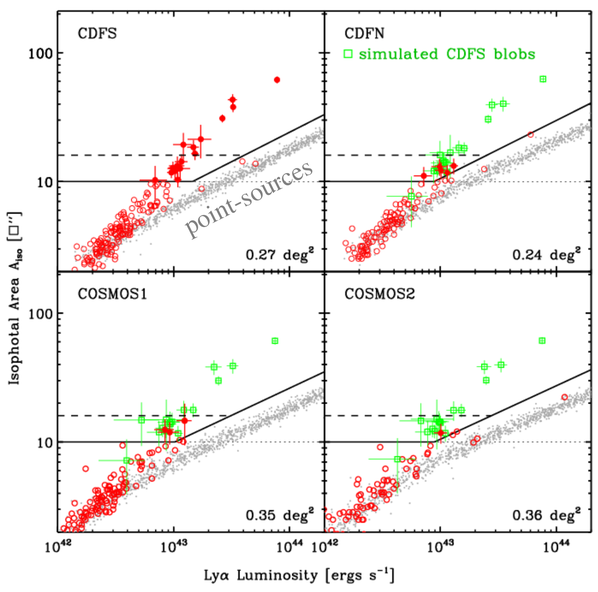
Sky coverage of wide-field survey in NOAO Bootes field.



$\delta\theta$=70"
~ 550 kpc
δz = 360 kpc

- Total sky coverage = 4.82□°
- Line-of-sight depth: Δz ~ 0.04 = 50 cMpc
- Survey volume = 2.1×10^6 Mpc^3
  Widest-FOV narrowband survey to date
- **After searching over ~5 □°on the sky, we discover a pair of radio-quiet blobs that are separated only by 70" on the sky and have almost identical redshifts, suggesting that Lyα blobs are strongly clustered.**

4. Strong Field-to-Field Variation of Blobs



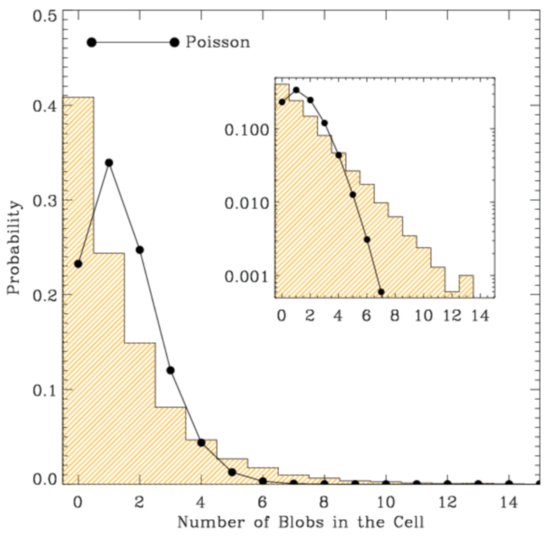
Lyα Blob Selection Criteria (•)
- EW$_{obs}$ (Lyα) > 100Å
- Distinguishable from point-sources
- A$_{iso}$ > 10 □" above 5×10^{-18} ergs/s/cm^2/□"

Green squares (■) :
Simulated [A$_{iso}$, L(Lyα)] of 16 CDFS blobs if they were observed in the other three fields.

Six most luminous (L > 1.5×10^{43} ergs/s) and largest (>16□") Lyα blobs lie only in the CDFS, although we should have been able to detect such blobs in the CDFN and COSMOS fields. This strong field-to-field variation also suggests that the brightest blobs are strongly clustered populations specific to the highest density regions, perhaps the precursors of brightest cluster galaxies.

	CDFS	CDFN	COS1	COS2
N(Aiso > 16)	6	0	0	0
N(Aiso > 10)	14	5	3	1

5. Dark Matter Halo Mass of Lyα Blobs



Counts-in-cells distribution of blobs from N-body simulation (L=1 Gpc)
Cell size = 50 cMpc

With the number density and the clustering of blobs in hand, we can now constrain the mass of dark matter halos where blobs reside, therefore how blobs will evolve into the present-day universe.

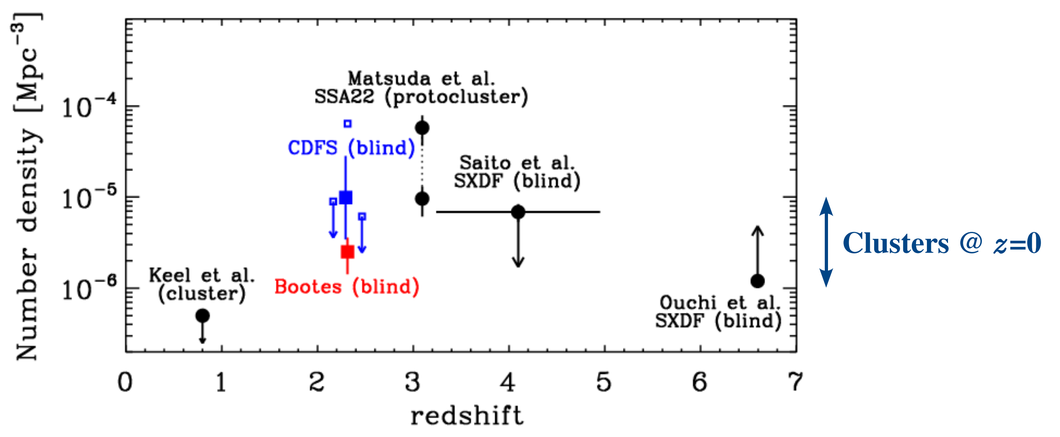
The abundance (1.2×10^{-5} Mpc^{-3}) and *100% duty cycle* requires DM halos with

$M_{halo} \geqslant 1\times10^{13}\,M_\odot$ at z =2.3

(→ ~1×10^{14} M$_\odot$ at z=0), which exhibits the strong cosmic variance (σ_v=100%; see left).

Probability of finding 6 or more blobs in one field but none from other three fields is Prob(6, 0, 0, 0) = 0.5 – 1.5% : plausible!

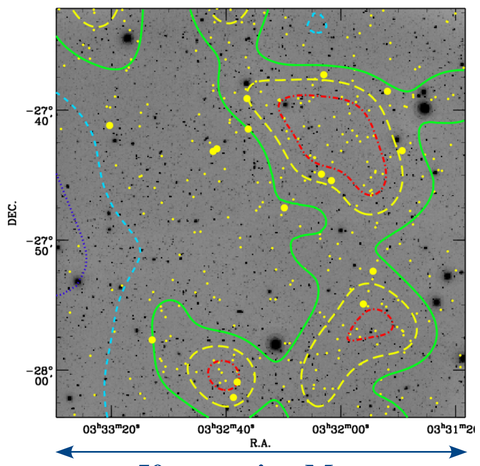
6. Lyα Blob: Tracer for High-z Protocluster?



- **Extremely Rare:** n = 3–12 × 10^{-6} Mpc^{-3}, consistent with cluster number density
- **Strongly Clustered:** close pair of blobs, strong field-to-field variation
- **Occupying Massive Halos:** **$M_{halo} \geqslant 1\times10^{13}\,M_\odot$ at z =2.3**

- **Lyα blobs are precursors of brightest cluster galaxies in proto-clusters?**

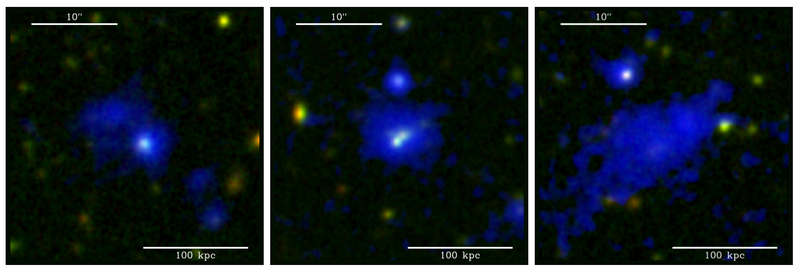
7. So... Did We Find a Proto-cluster in CDFS?



- Small dots (·) : Compact Lyα emitters
- Large dots (●) : Lyα blobs

- Large-scale structure over ~50 cMpc
- Blobs reside in the over-dense region

- Effective technique to find proto-clusters at high-z if wide-FOV tunable filters are employed?



CDFS-LAB01 CDFS-LAB02 CDFS-LAB03

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