Galaxy Formation and Evolution probed with Intermediate-band Survey for LABs

TOMOKI SAITO (NAOJ)

-31 Jan. 2007 Subaru Users' Meeting-

Collaborators

SXDS team

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Kyoto 3DII team

H. Sugai, A. Kawai, A. Shimono, K. Matsubayashi (Kyoto-U), T. Hattori (NAOJ)

Others

Y. Matsuda (Kyoto-U)

Other countries

J. P. U. Fynbo, et al. (Denmark)

Contents

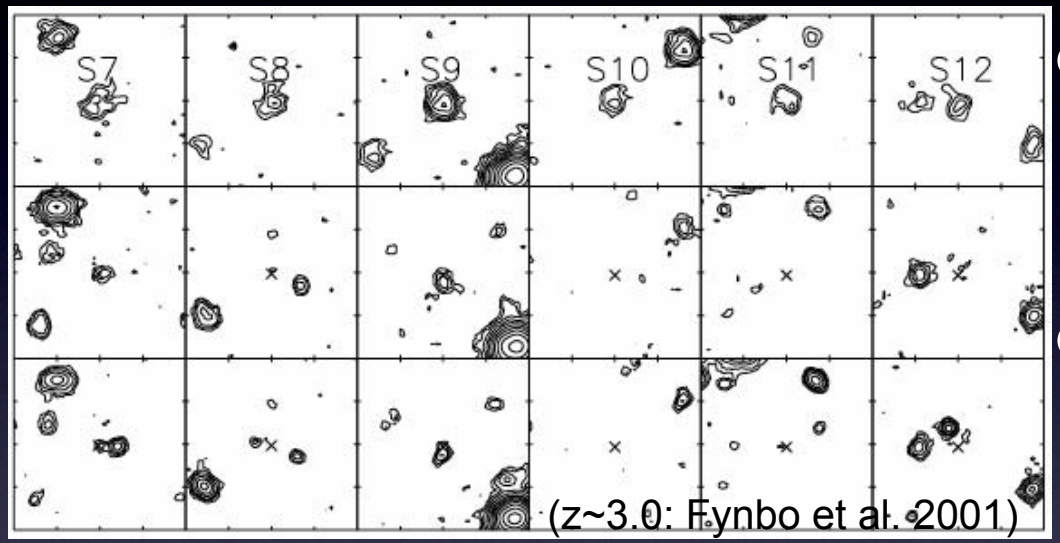
- Introduction: Extended Ly α Sources
- Intermediate-band survey with Subaru
  - Details of the survey
  - Photometric properties of the sample
- Follow-up spectroscopy with VLT
  - Spectral properties
- Further follow-up studies

Ly α Emitters (LAEs) at high redshifts

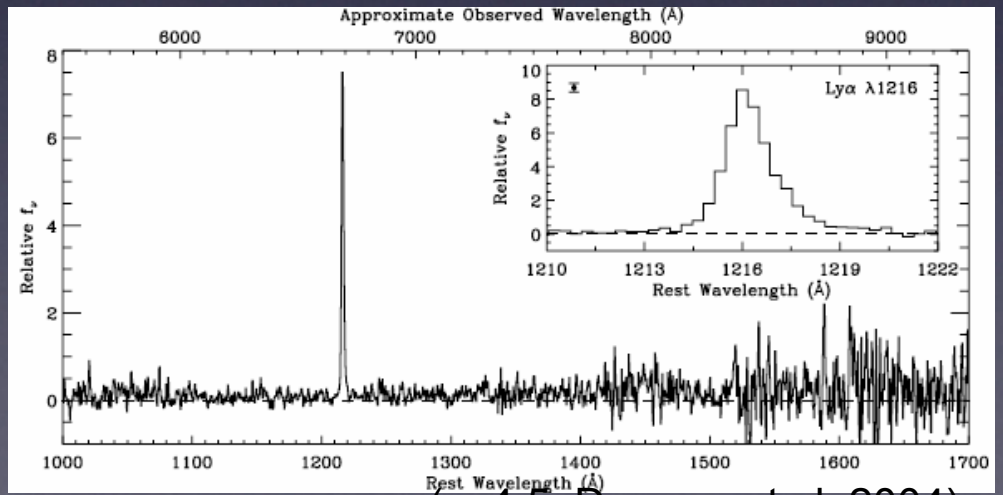
Ly α

B

I



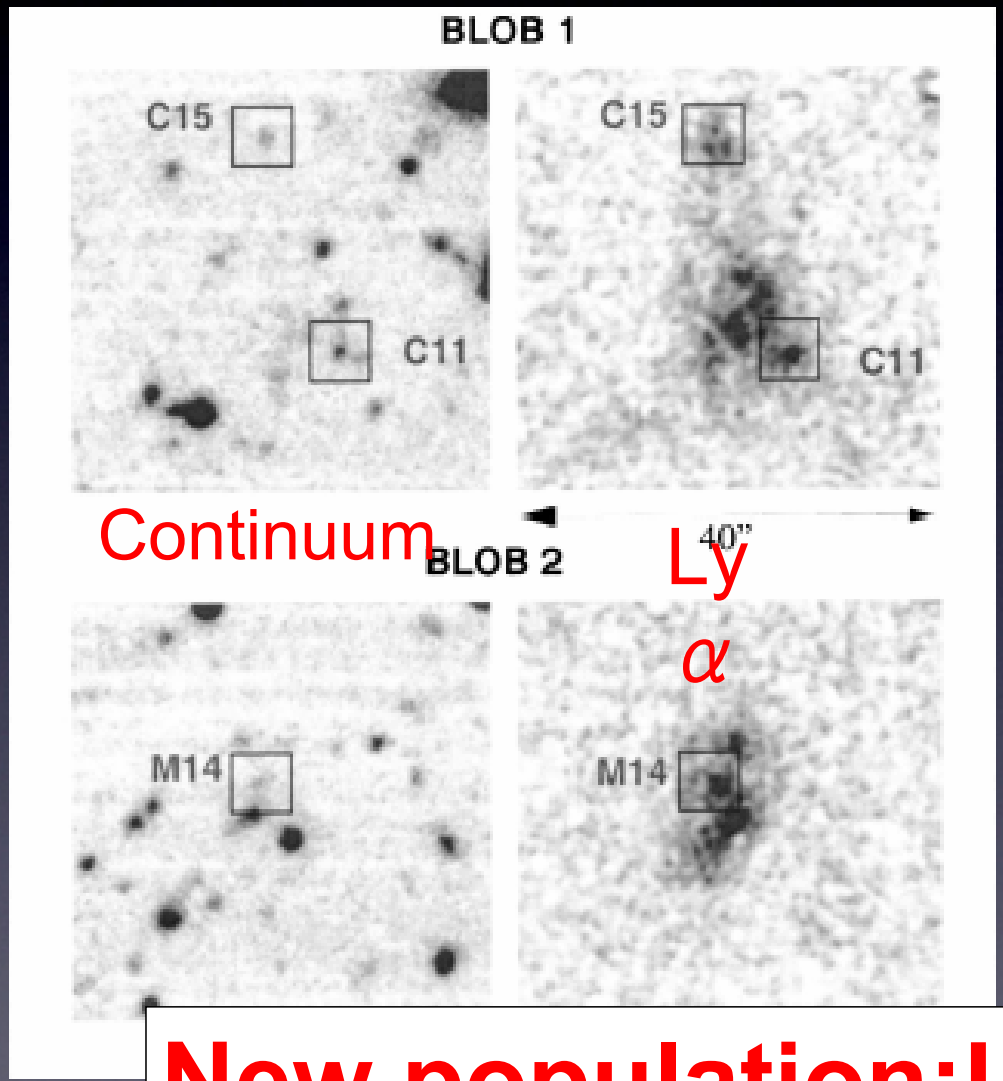
(z~3.0: Fynbo et al. 2001)



(z~4.5: Dawson et al. 2004)

- Young starbursts emit strong Ly α (e.g. Partiridge & Peebles '67; Charlog & Fall '93)
- Identified w/ narrowbands: thousands@z~2-7
- Some objects have LARGE EWs ➔young?
- Some exceeds ~240A (e.g. Malhotra & Rhoads '02;Dawson+'04)

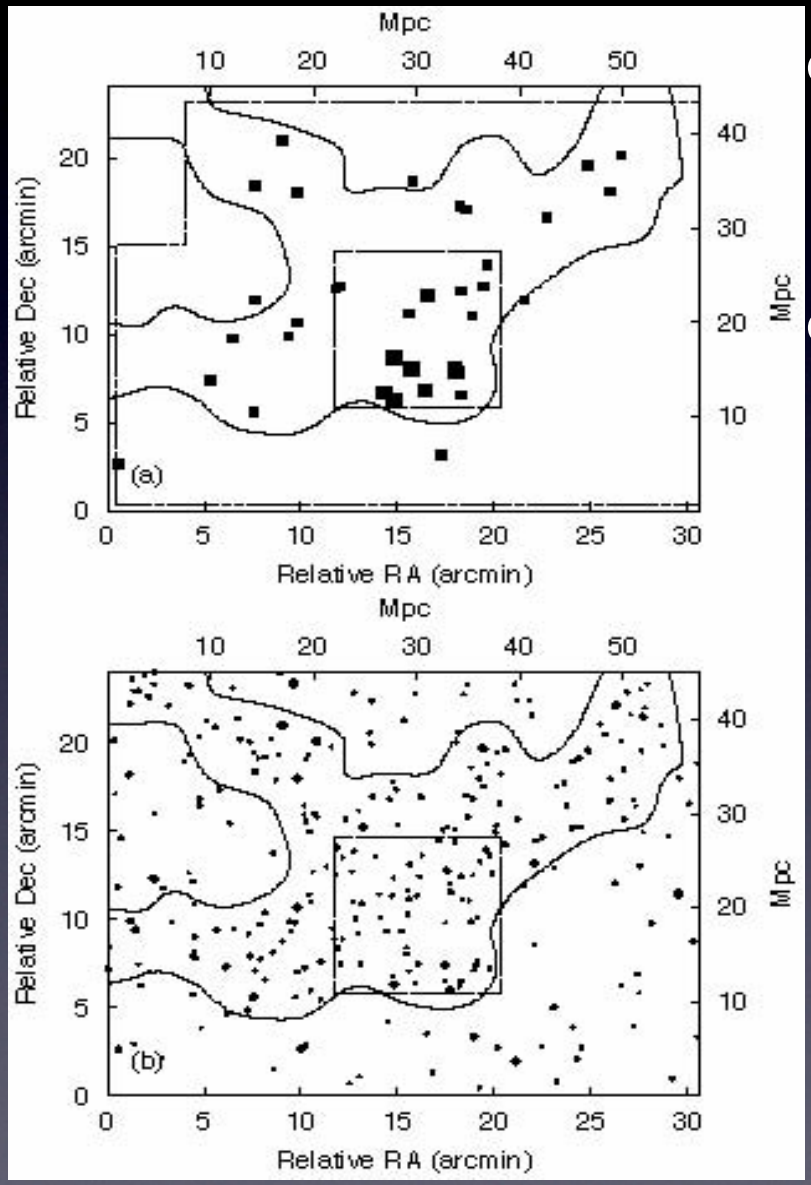
Ly α Blobs (LABs):
first examples



- Most of LAEs are COMPACT.
- Steidel+(2000): Spatially extended LAEs@z~3.1
  - Strong Ly α
    - L(Ly α) ~ 10^{44} ergs/s
    - size ~ 100 kpc
  - Faint/Compact in UV Cont.

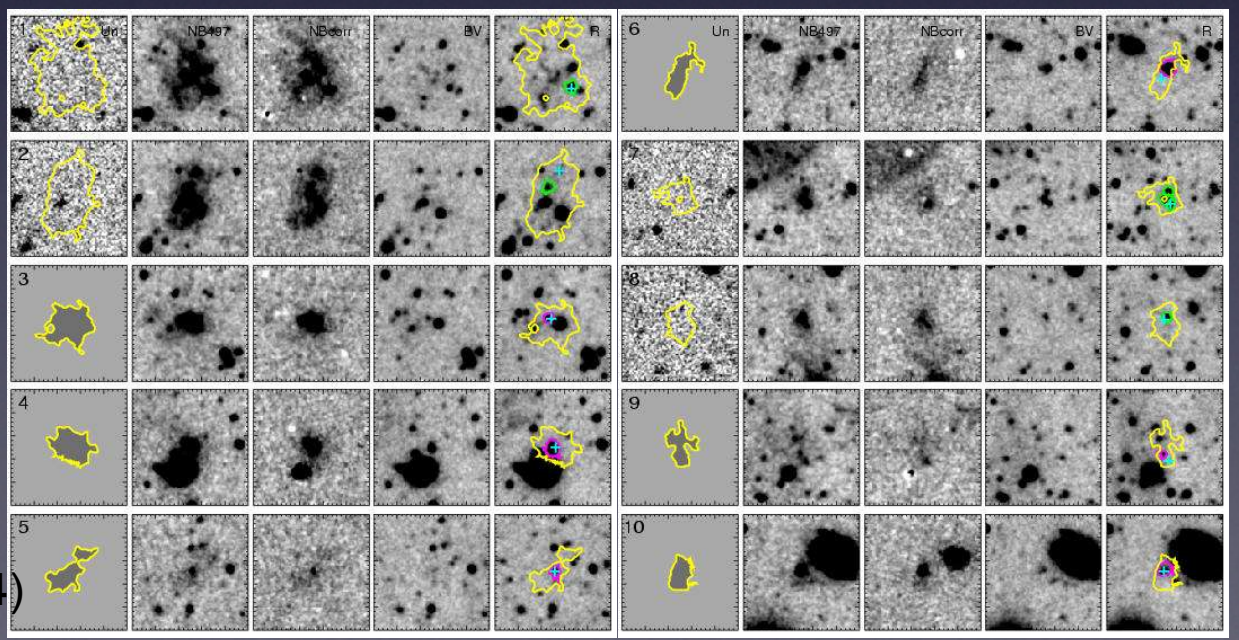
New population:Ly α Blobs (LABs)

LABs known to date



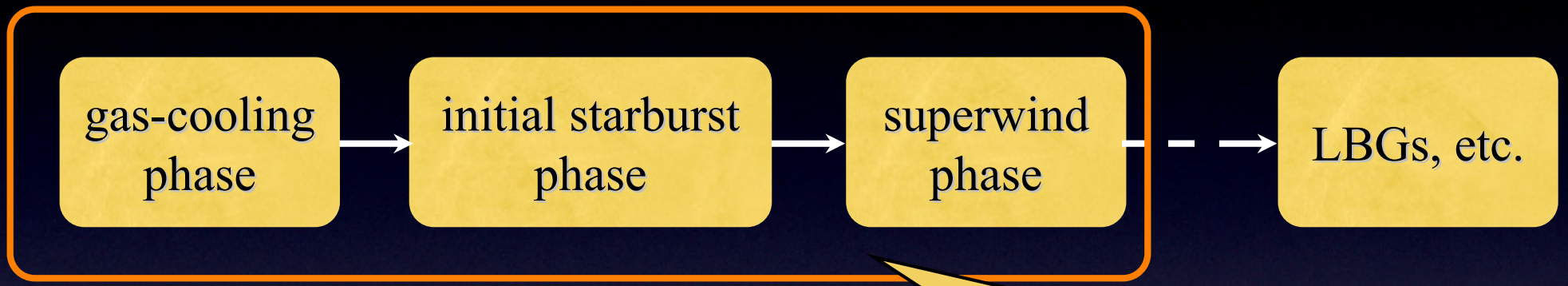
(Matsuda et al. 2004)

- Steidel+'00; Francis+'01; Dey+'05; Nilsson+'06; Keel+'99 →**RARE OBJECTS!**
- Systematic search: Matsuda+'04
  - Suprime-Cam+NB497 (λ c=4977A, $\Delta\lambda$ =77A)
  - Identified 35 LABs @z=3.1 proto-cluster



Physical origins

--extremely young galaxies?



Matsuda et al.(2004) covers only z~3.1

Extended in Lyα
Faint/Compact in UV

- Almost no unbiased surveys have ever been made!
  - **Are they common in the early Universe?**
- Their origins are totally unknown!
  - **What drives the extended Lyα emission?**

Survey strategy

- Sample selection

Subaru + Suprime-Cam + Intermediate-bands

- Survey area

Subaru/XMM-Newton Deep Field (SXDF)

- Follow-up Spectroscopy (multi-object)

Low-resolution: Subaru + FOCAS (R~500)
High-resolution: VLT + VIMOS (R~2000)

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Observations:

Intermediate-band Imaging Survey

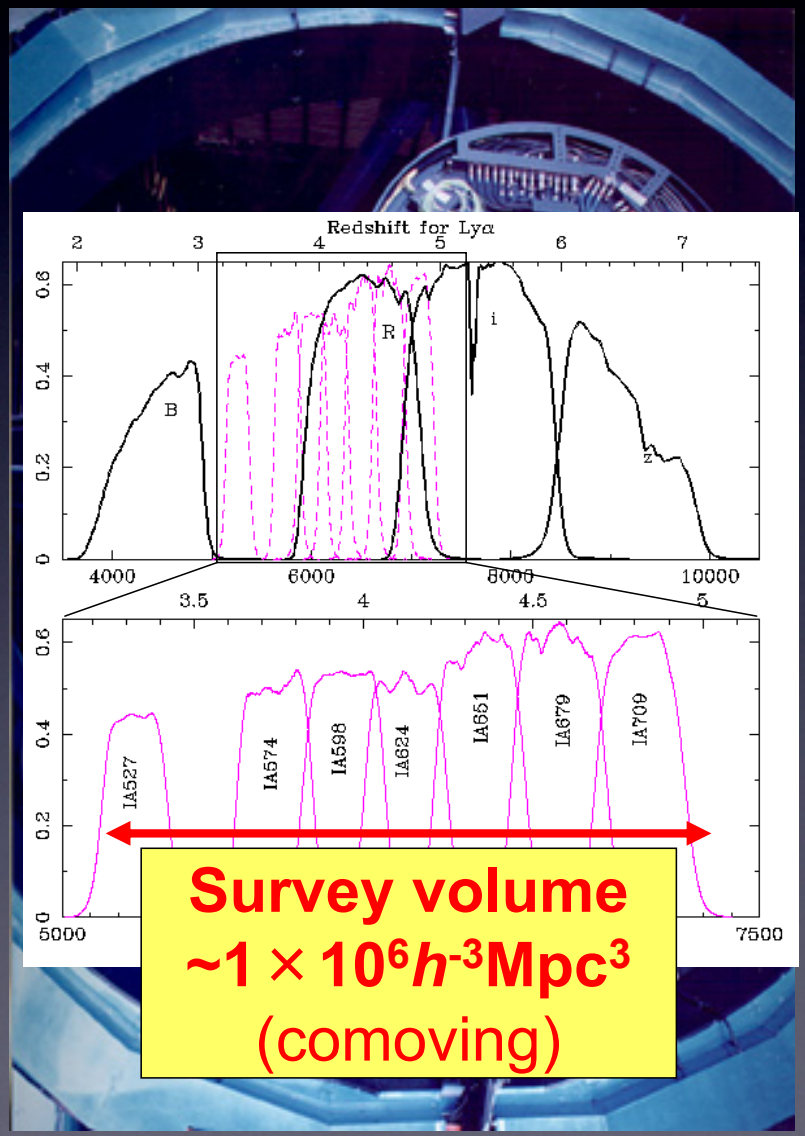
- Deep & Wide survey with Subaru + Suprime-Cam
- Covers a wide range of redshift
- Efficiently collects large-EW objects.

Intermediate-band (IA) x7: 26.5-26.8 mag
(S02B-163: Kodaira et al.)

→Ly α at z~3-5

Broadbands x4: *R*27.4mag
(SXDS: Sekiguchi et al.)

→Colour selection



Field & Survey data

- Field: SXDF-S α =2h18m00s, δ =-5d25m00s
- FoV: 33'x25' (~825 arcmin^2)

band	exposure	$m_{lim}(3\sigma)$
IA527	5280s	**26.8**
IA574	7200s	**26.5**
IA598	6720s	**26.5**
IA624	10560s	**26.7**
IA651	6500s	**26.7**
IA679	10560s	**26.8**
IA709	11520s	**26.6**
B	18000s	**28.2**
R	12000s	**27.4**
i'	13200s	**27.0**
z'	5700s	**25.8**

>60000 objects (>3σ)

Sample selection

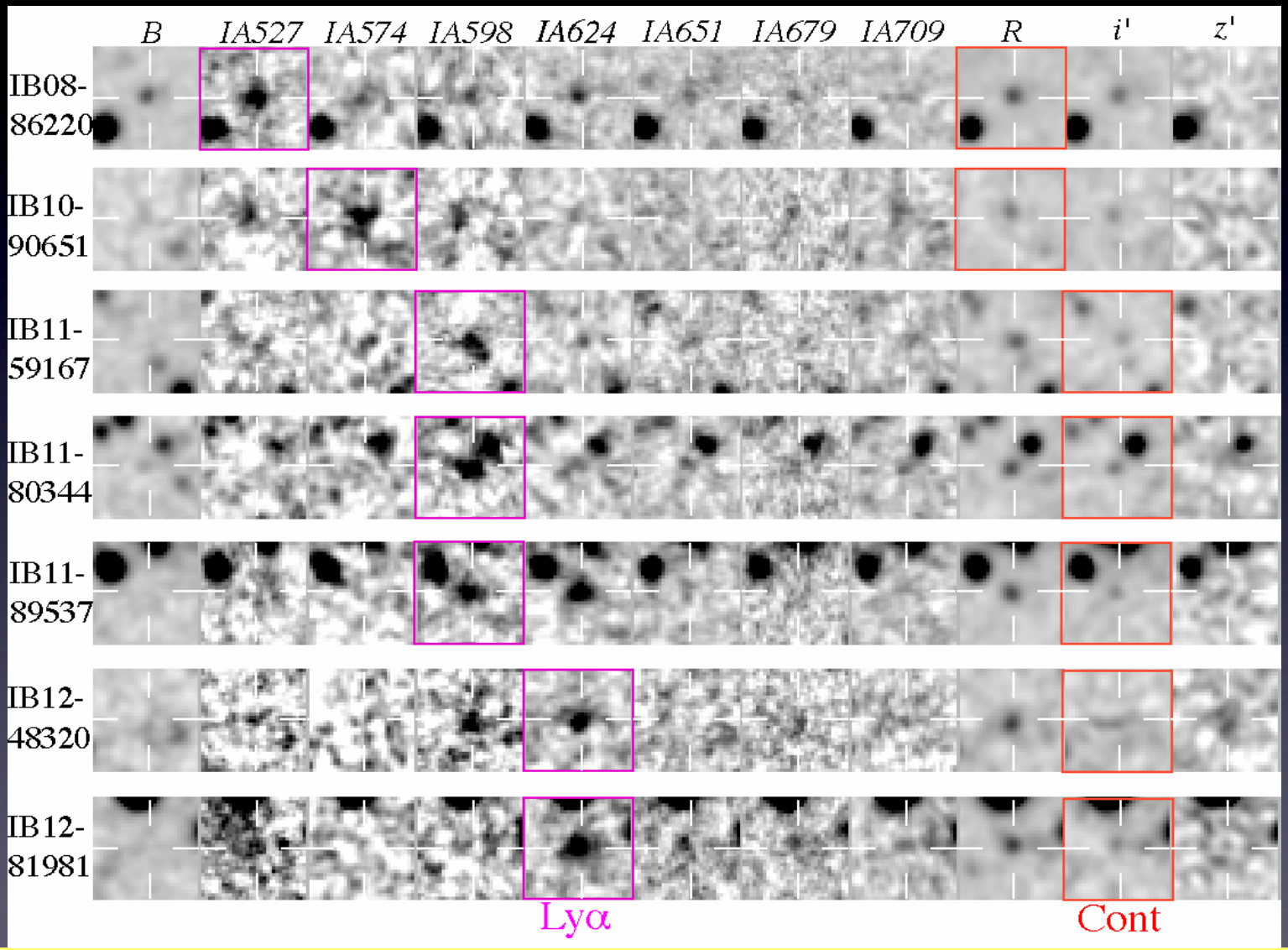
- B-band dropout / non-detection
- IA(Ly α) excess: Cont. - IA $\geq$ 0.75

→ “normal” LAEs: ~140

- Spatially extended in Ly α
  - FWHM(IA) > 1.4"
- Compact and/or Faint in Continuum
  - FWHM(Cont.)<1.2" or Cont. < 3 σ

→ 41 LABs

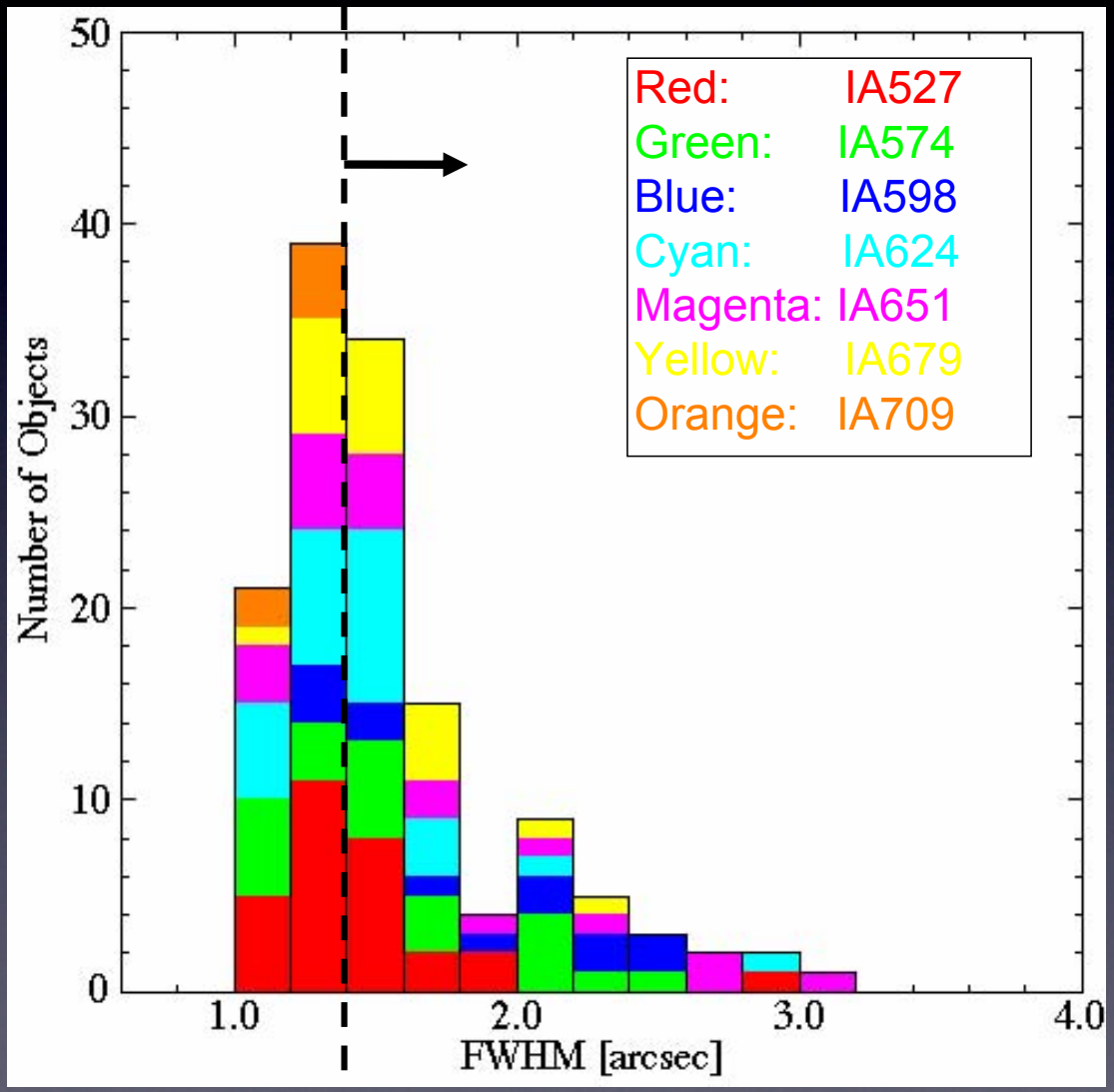
Images (examples)



(Saito+ 2006)

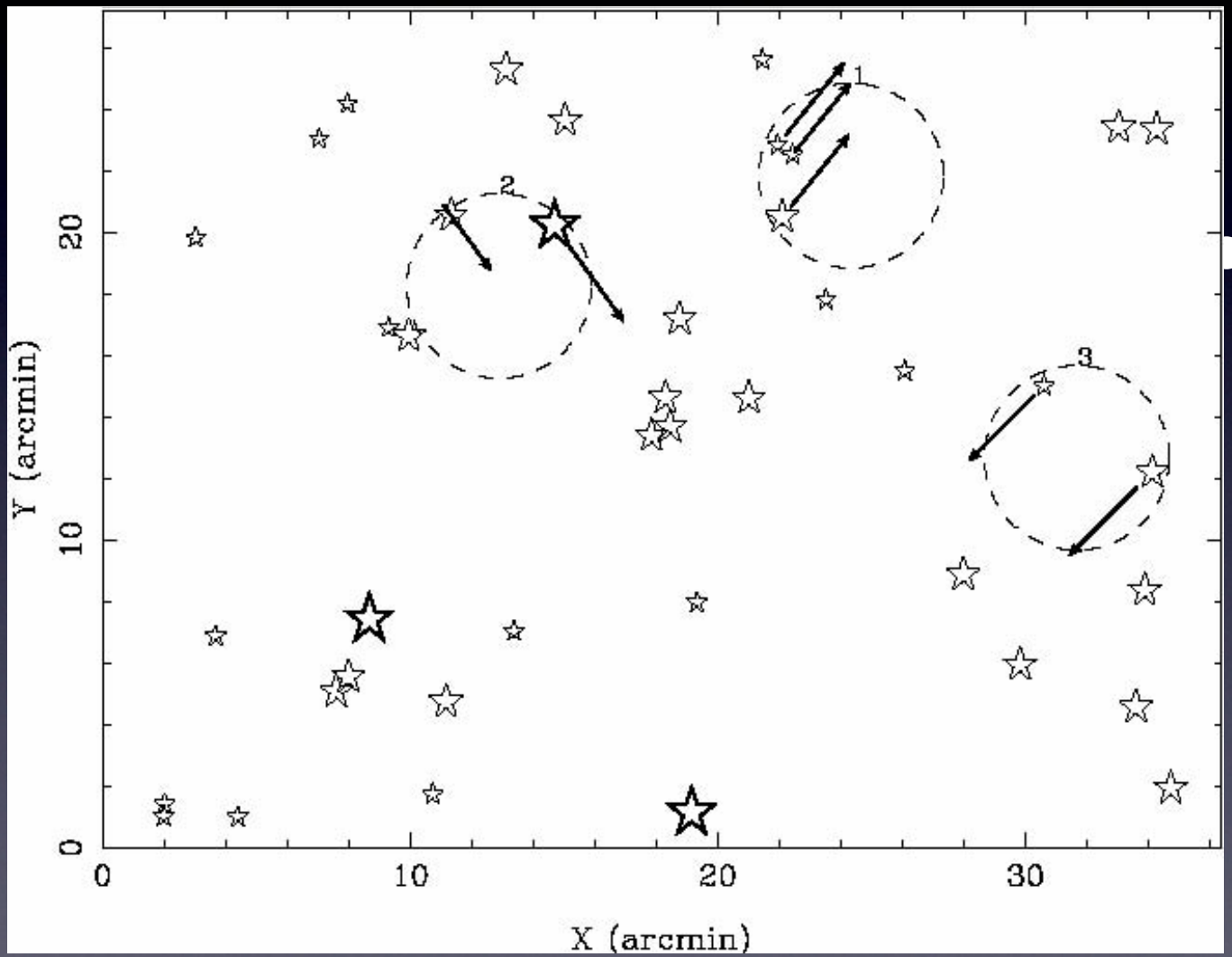
- **Extended in Ly α , Faint/Compact in UV**

Size distribution



- Size > PSF + 2pix
- Typically ~1.5"-2" (~PSFx1.5, including seeing)
- Maximum ~3"

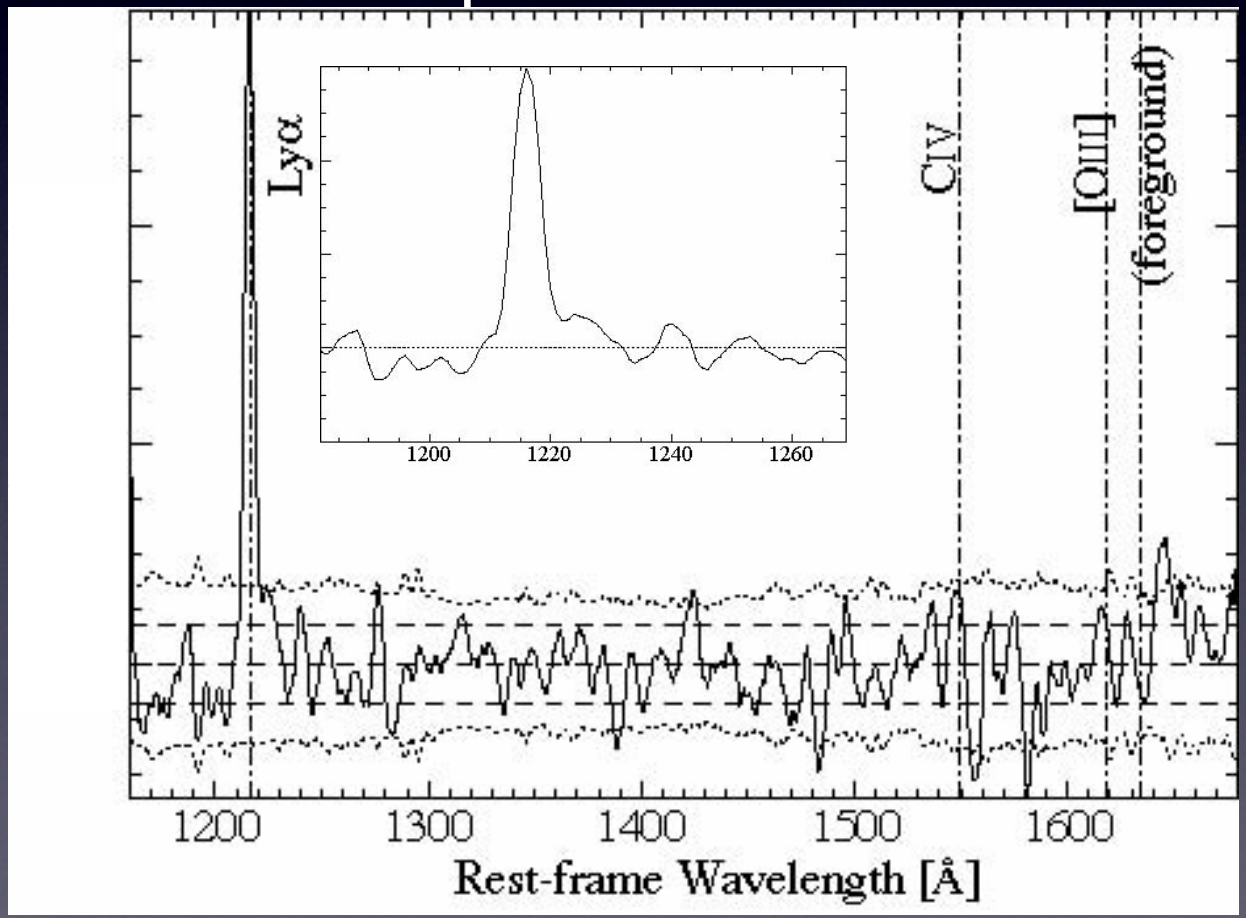
Sky distribution



- Almost uniformly distributed over the sky.
- Spectra are taken for 7objects
  - Instrument:FOCAS
  - Resolution: R~500
  - Exposure: 1.5-2.5 hrs

FOCAS spectra (7 objects)

Stacked spectrum–(Saito et al. 2006)



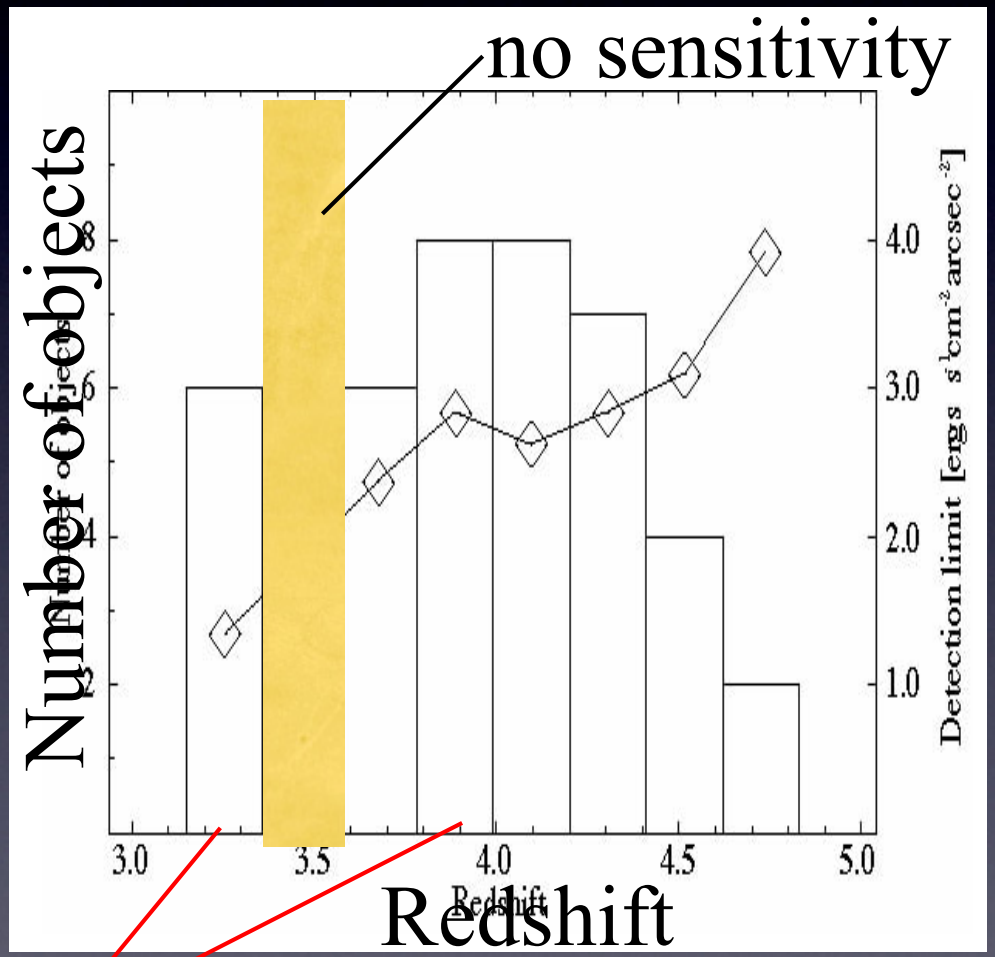
- All have large EWs (>80A)
- 3 are clearly single-line objects
- Marginal signature of asymmetric profiles

They are all LAEs!
(almost no contamination)

Redshift distribution

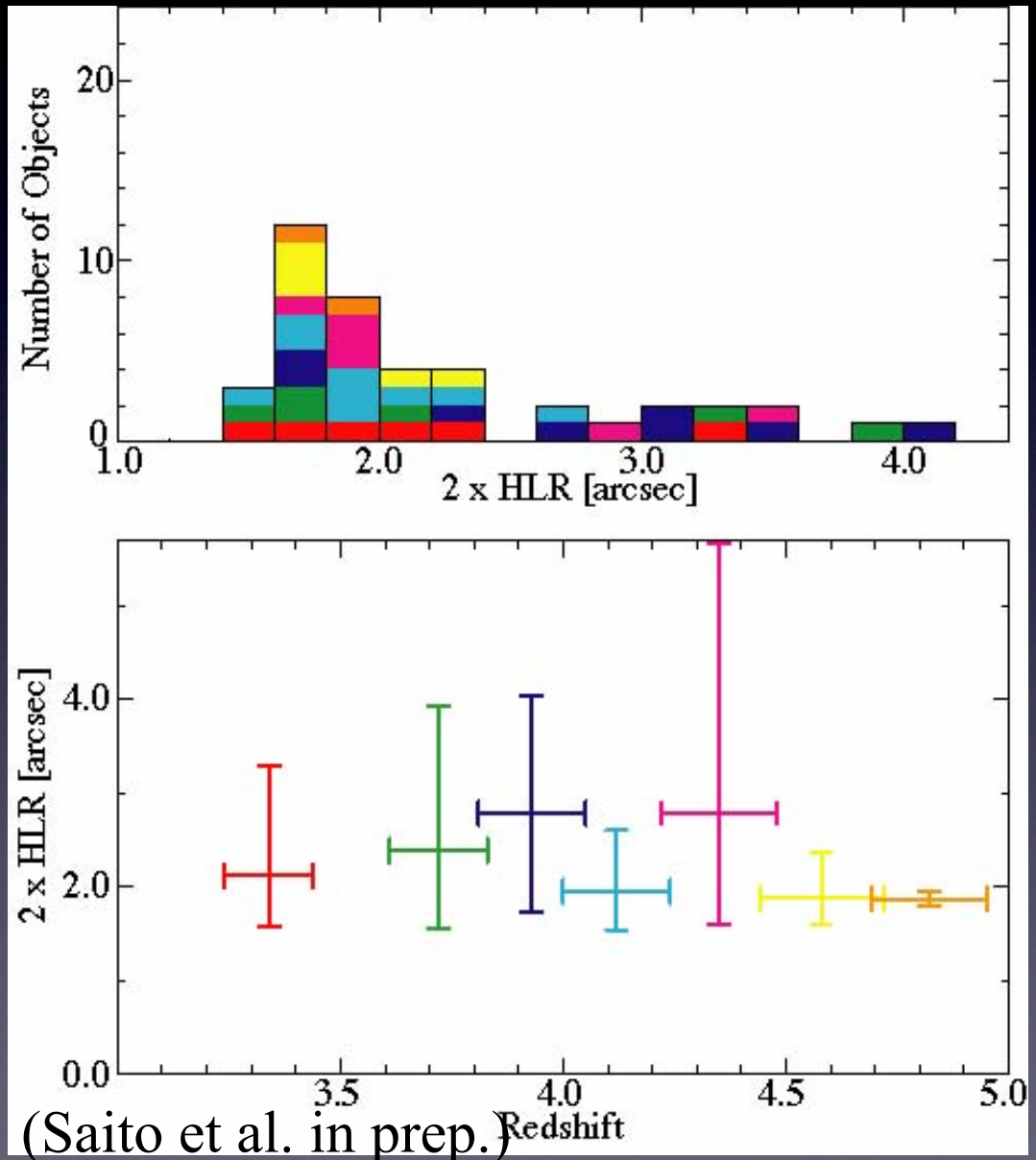
- Almost uniformly distributed over z~3-5 *NOT strictly "uniform"
- Number density (lower-limit) ~4x10-5h^3Mpc^{-3}

LABs are common even beyond z~3.1



Spectroscopic sample

Size distribution

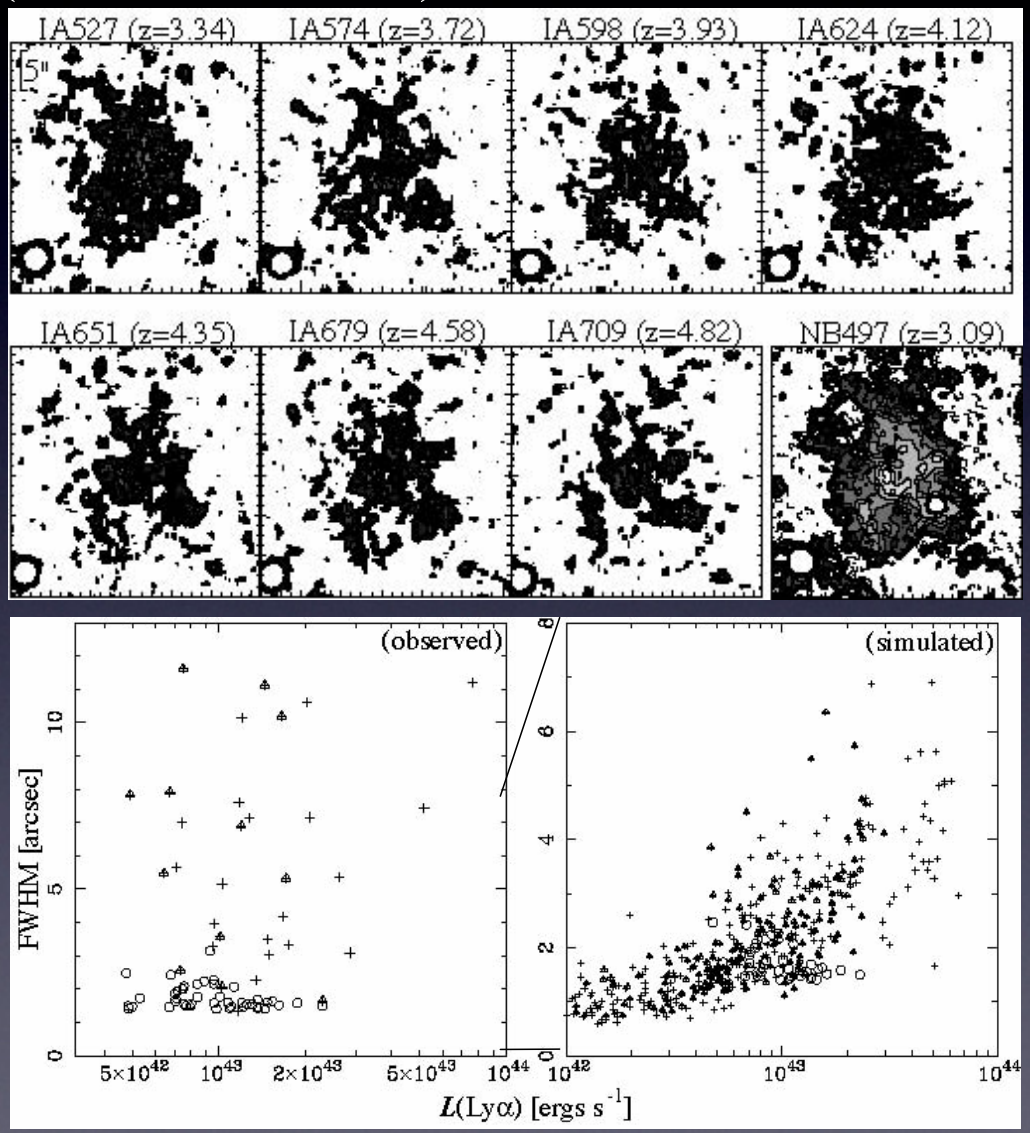


(Saito et al. in prep.)

- Typical sizes ~1".6 - 2".0 (~10-15kpc)
- Maximum ~4".2 (~30kpc)
- No significant dependence on the redshifts

Imaging simulation

(Saito et al. 2006)



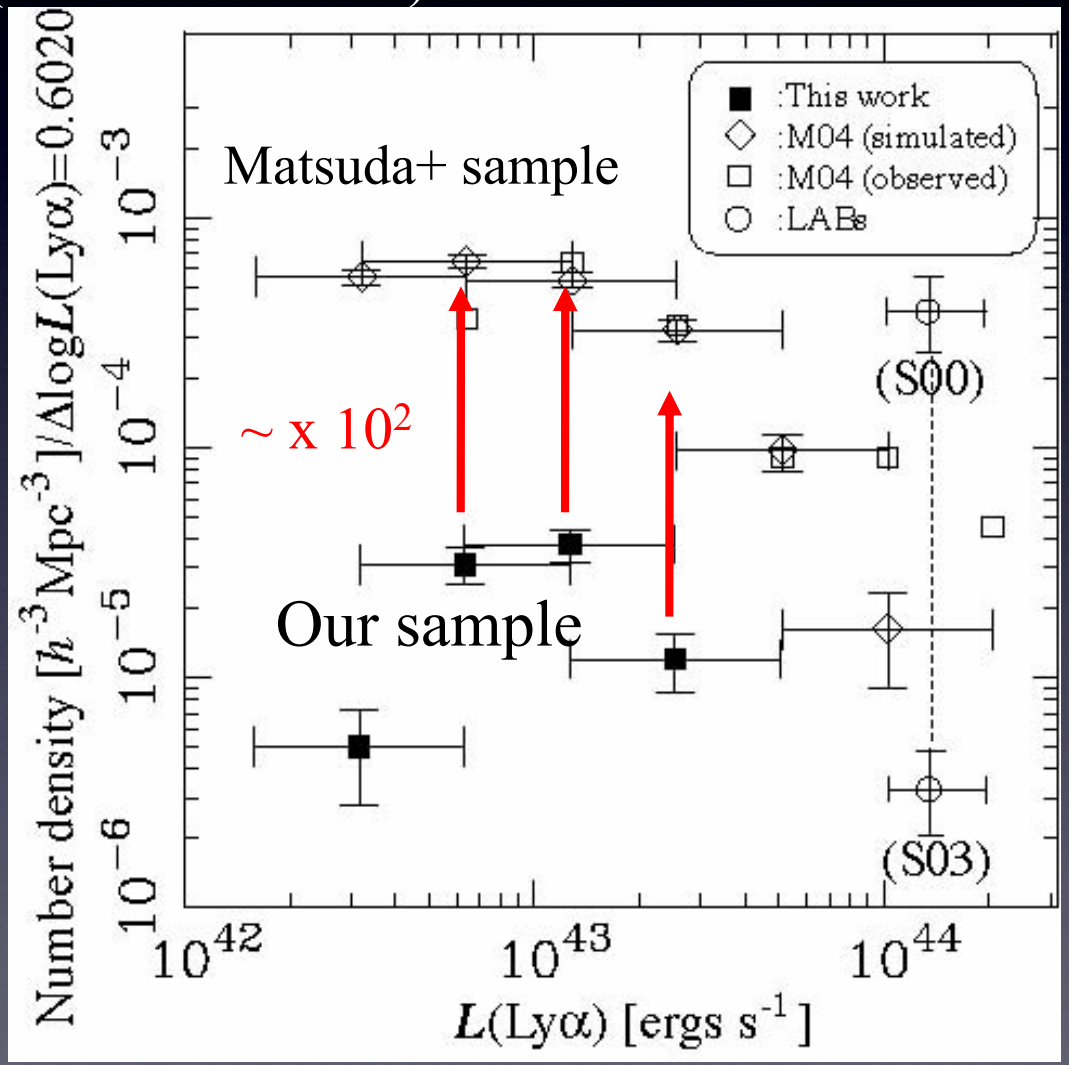
(narrowband image: Matsuda+'04)

- Original data: z~3.1 LABs
  → simulate as if they are…
  - Located at higher redshifts
  - and Observed with IA filters
- Source extraction with the same manner as the IA data
  - diffuse components cannot be seen
  - Extended objects are divided into two or more segments

LABs become apparently smaller
Our objects≈LABs@high-z

Luminosity function

(Saito et al. 2006)



- ~1/100 times less-numerous than Matsuda+ sample.
- No such large objects like LAB1/2 were found.

LABs are clustered in overdensities

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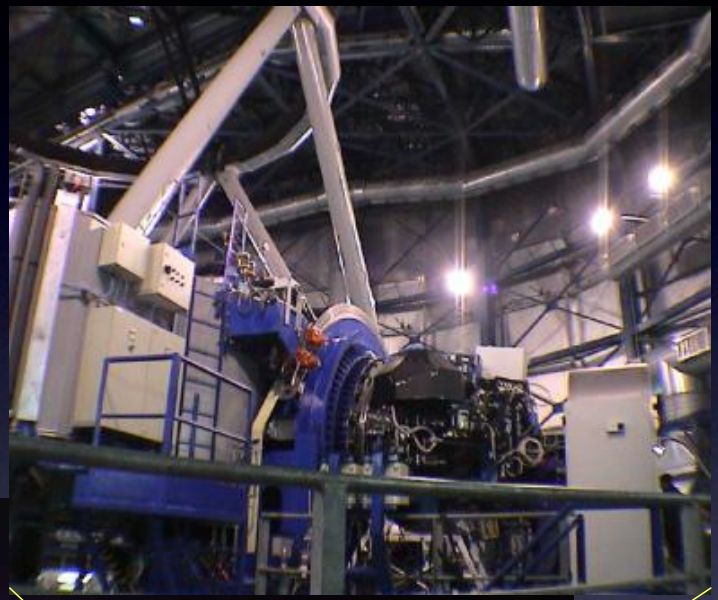
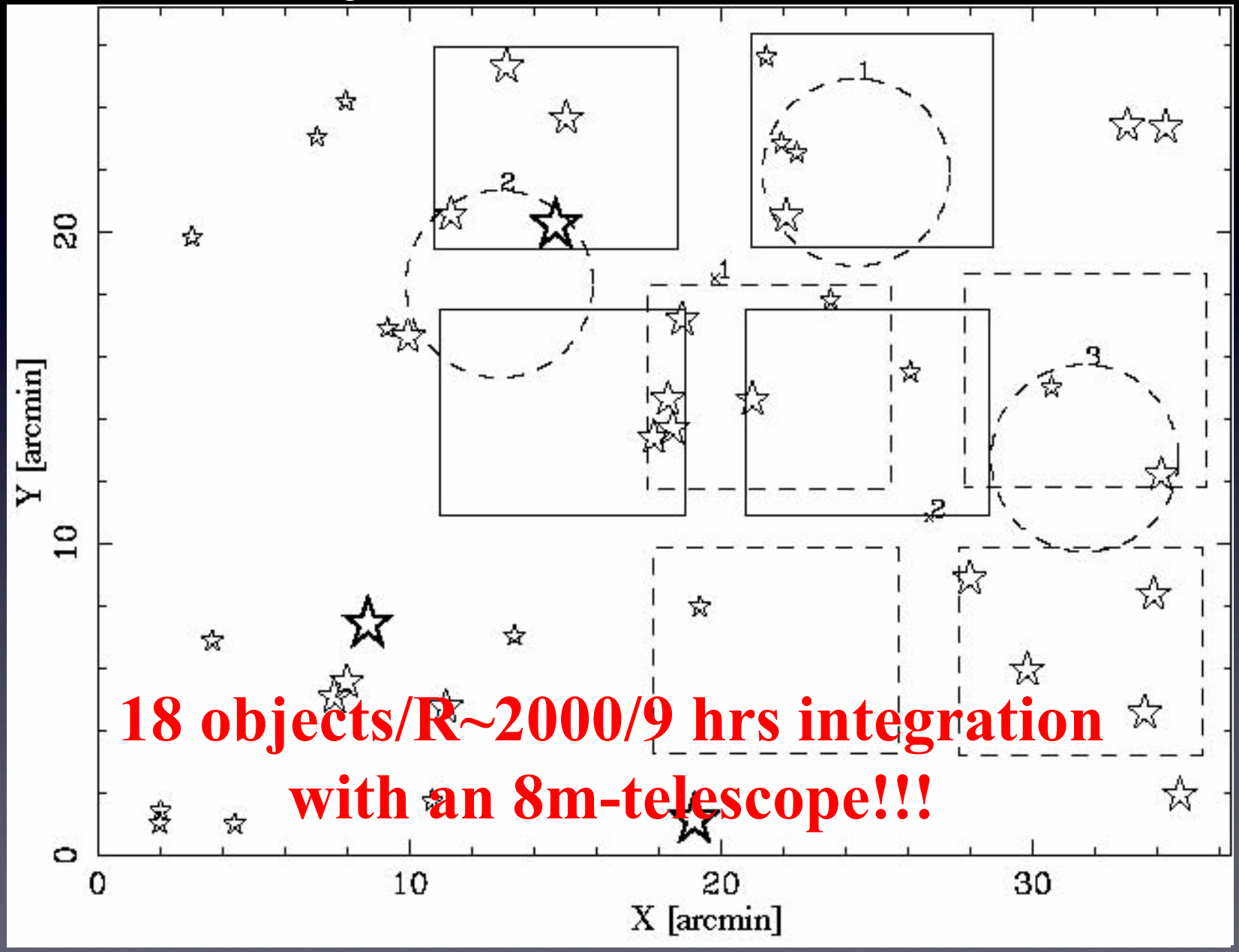
Observations:
high-resolution spectroscopy

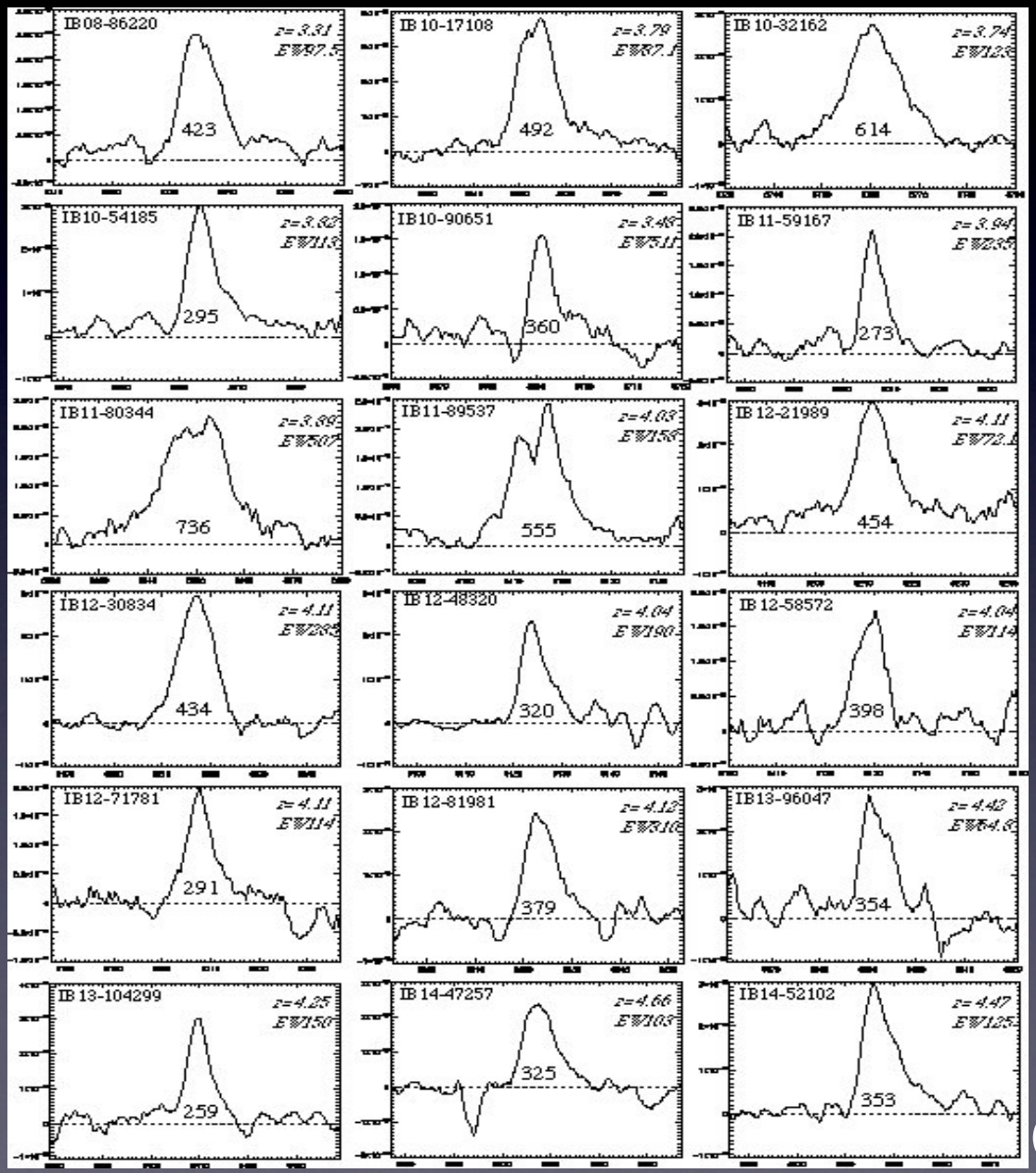


- Date: Nov. 2004
- Instrument: **VLT/VIMOS**
  - Grism: HR-Orange
  - Filter: GG435
- 2 MOS masks **(18objects)**
- Resolution: **R~2100 (<150 km/s)**
- Exposure: **6.5-9.5 hrs**
- Sensitivity:
  1 σ ~1×10^{-19} erg/s/cm^2/A
  (~26 mag in *V*)

Sky distribution



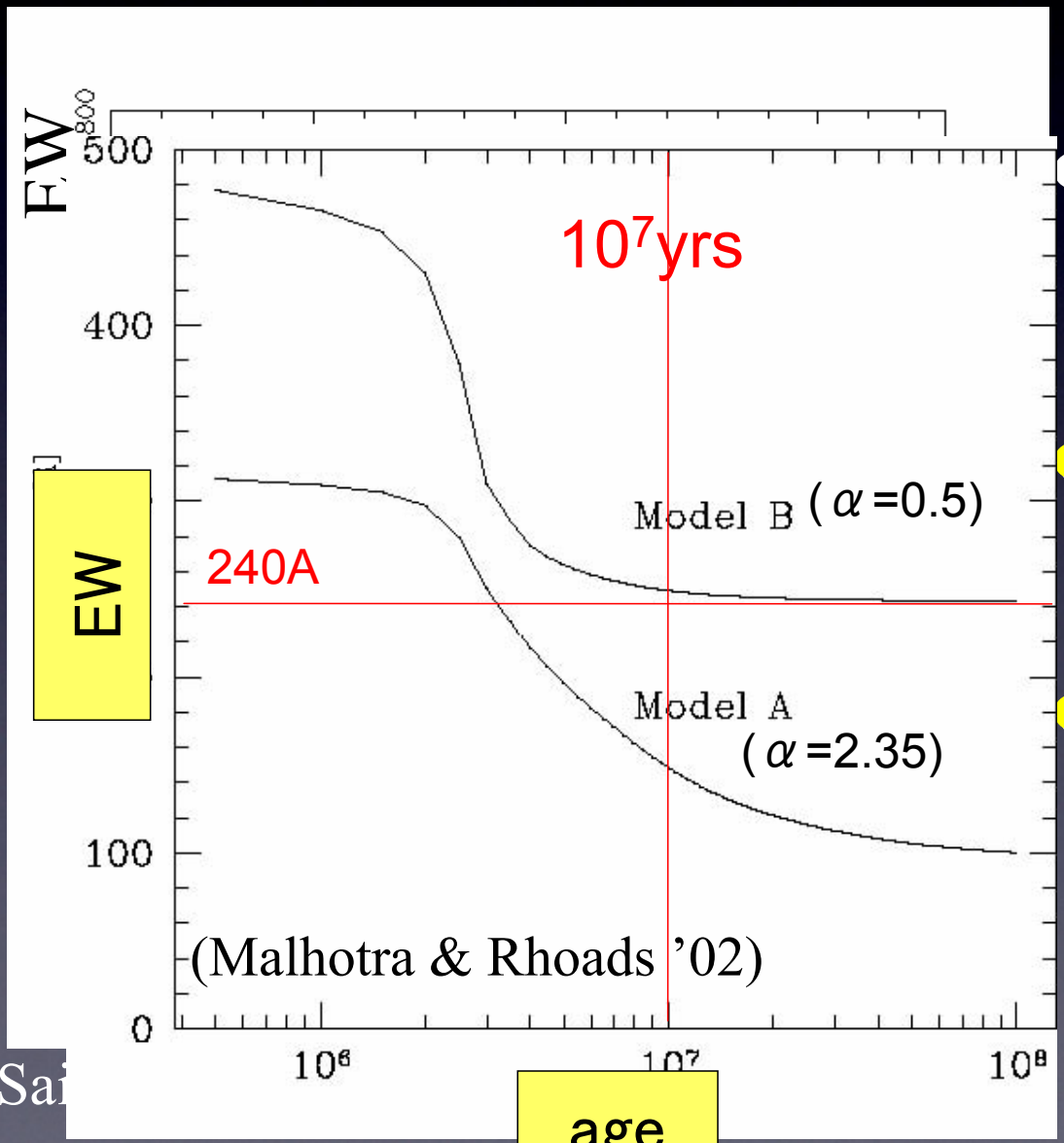
Spectral data: overview



- Line profiles
  - Mostly simple.
  - 2objects: double-peaked
  - Some have asymmetric wing.
- Velocity widths
  - 4 objects: >500km/s
  - 14objects: ~270-490km/s
- EWs(rest-frame)
  - 9objects: 100-200A
  - 9objects: >200A

(Saito et al. in prep.)

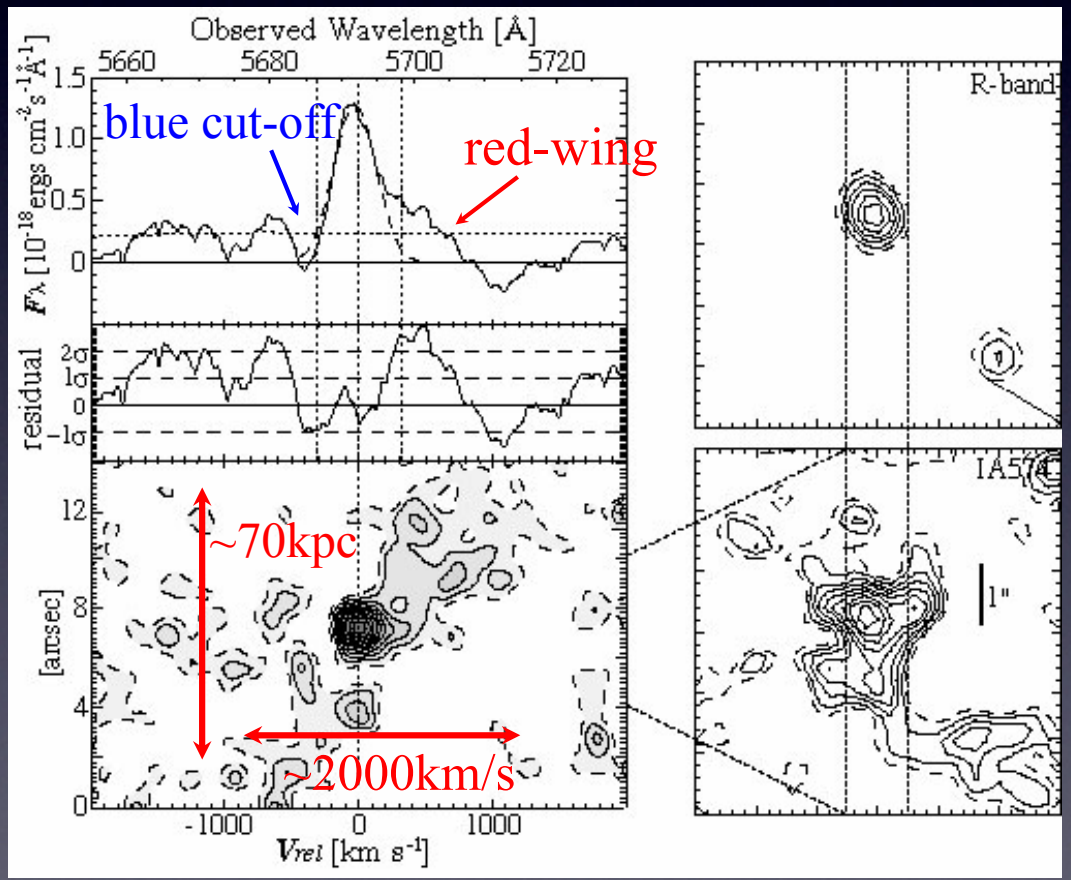
Equivalent widths



- 9objects: EW_{rest}~100-200A
  - Regime of stellar photo-ionization
- **9objects: EW_{rest}>200A**
  - Cannot be starbursts with α>1.5 IMF (Charlot & Fall 1993)
- **8objects: EW_{rest}>240A**
  - Cannot be starbursts with α>0.5 IMF (Malhotra & Rhoads 2002)

Profiles & 2-d spectra

Conspicuous asymmetry: IB10-90651 @ z=3.68

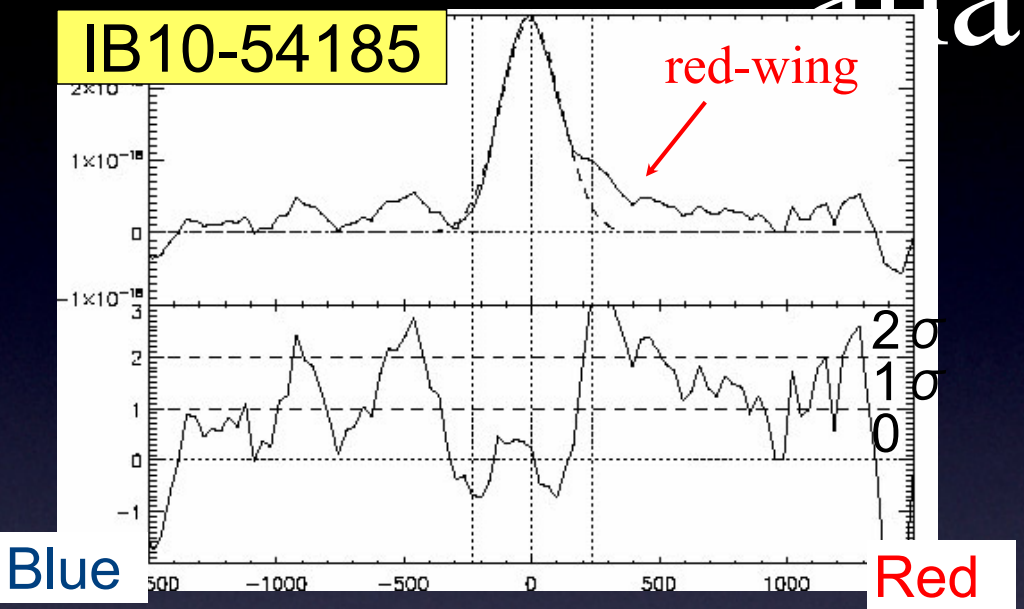


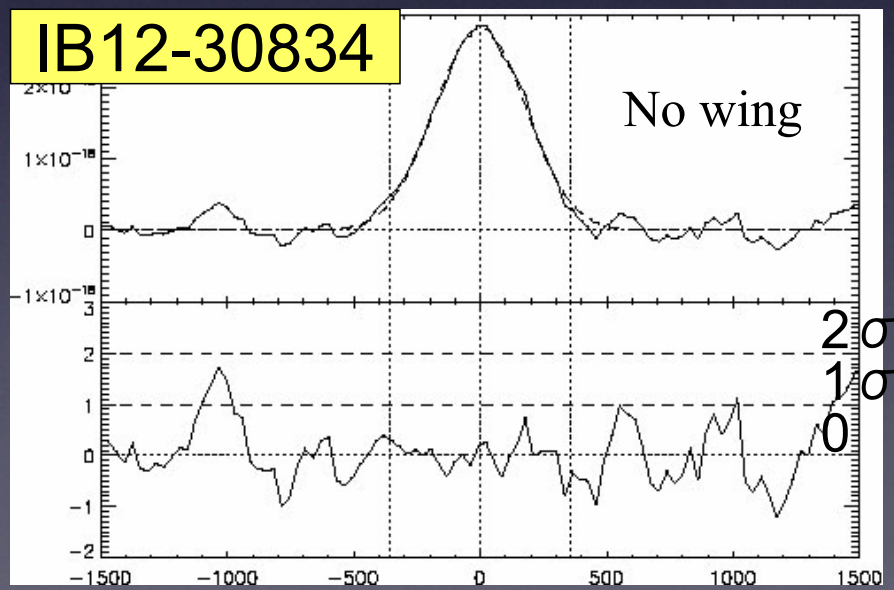
(Saito 2006, PhD thesis)

- Size of diffuse emission: ~70kpc
- Velocity extent of the wing ~2000km/s
- EW ~870A
- Line profile: red-wing + blue cut-off

Superwind ?

Wing-component analysis





(Saito 2006, PhD thesis)

- For each object,
  - Fit the profile with a simple Gaussian function
  - Plot the residual aganst the line-of sight velocity
- If, Excess (>2 σ) raised from <2 σ -width extends up to~500km/s, we refer to as **"wing emission"**

Identified wing emission from 5 objects (~30%)

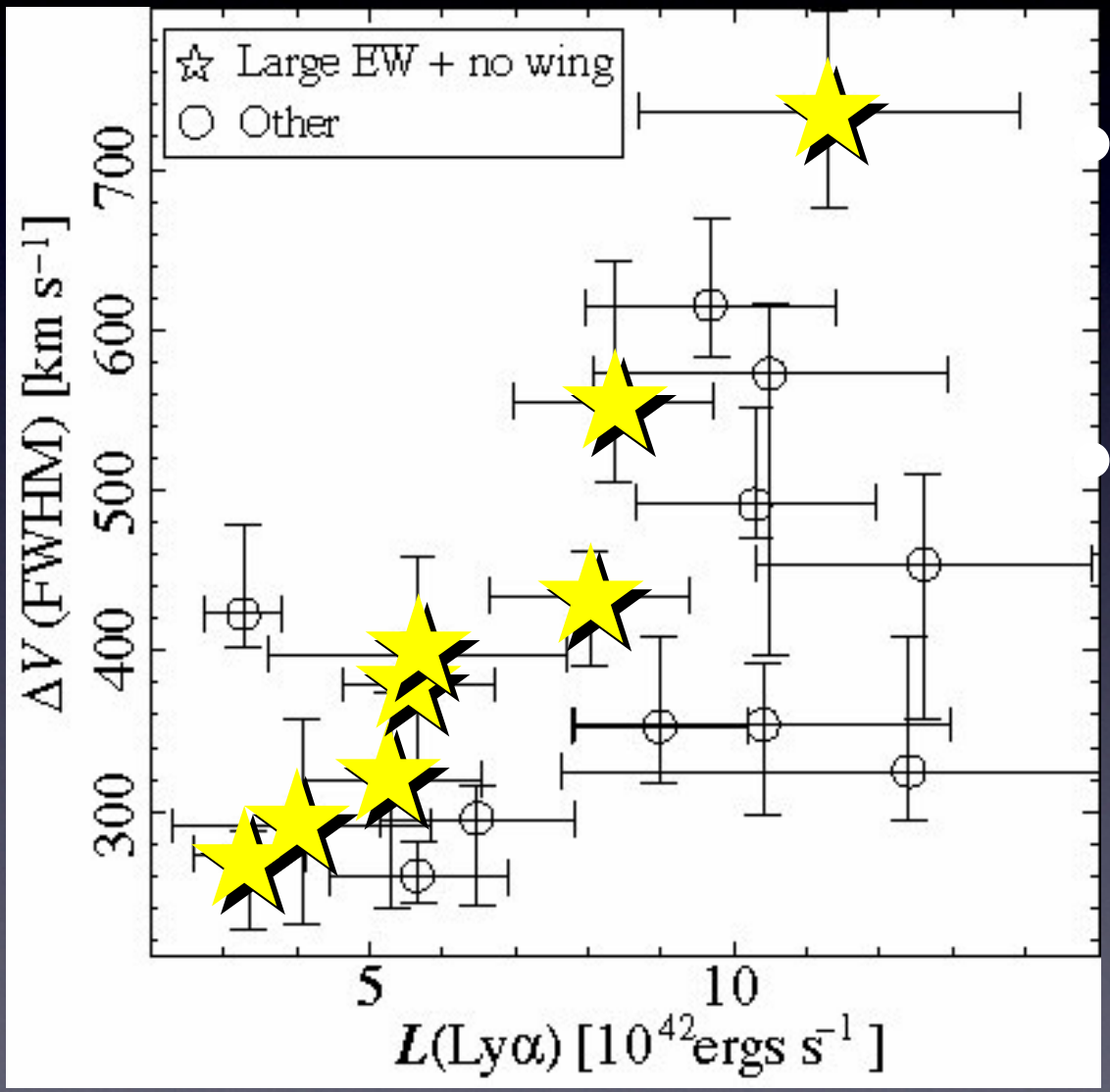
Spectral properties
(summary)

Object ID	*EW*	Δ *V*	wing
IB11-59167	265	270	--
IB11-80344	569	740	--
IB11-89537	458	560	--

Object ID	*EW*	Δ *V*	wing
IB12-30834	357	430	blue?
IB12-48320	318	320	red?
IB12-58572	208	400	blue?
IB12-81981	500	380	red?
IB13-104299	303	260	--

How about the remaining eight... ?

Diagnostic: L- ΔV relation



If, cooling clouds, there should be ***L*(Ly α)- Δ *V* correlation**

8 objects clearly show positive correlation.

Candidates for Forming-Galaxies

(Saito et al. in prep.)

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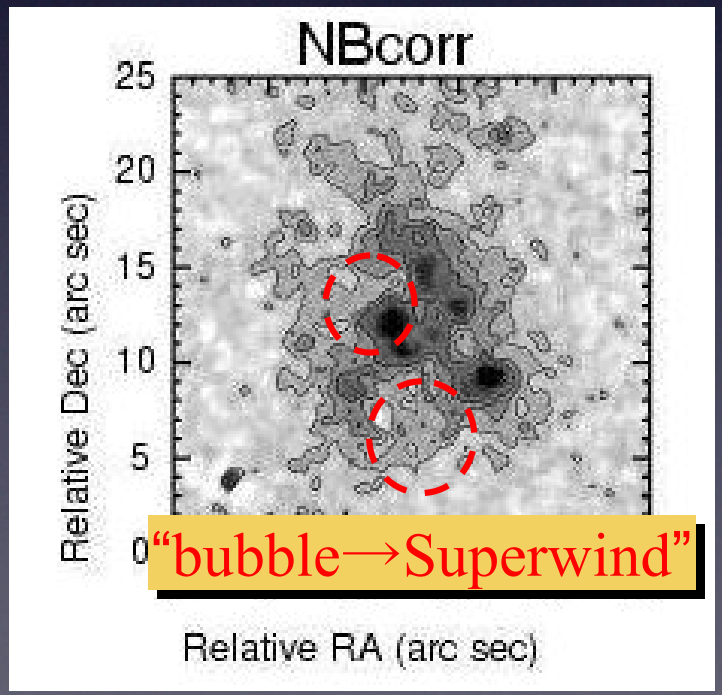
Observational constraints on the physical origins

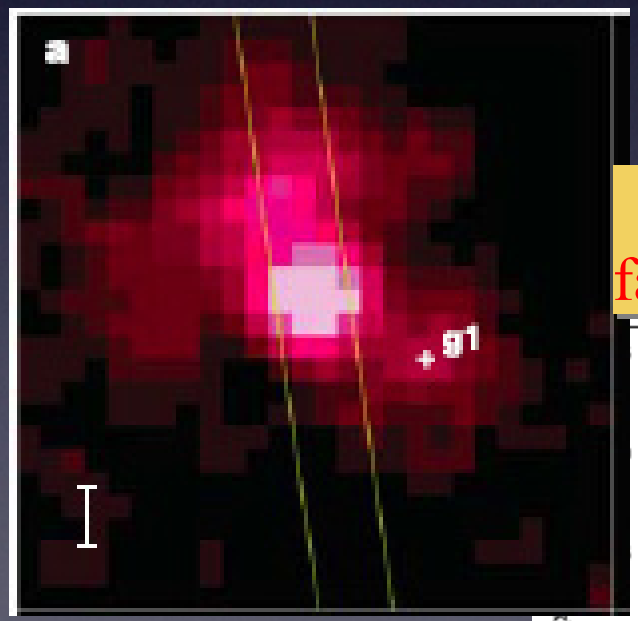
Morphology & Surface brightness profiles

↓

Must reflect the ionizing mechanisms

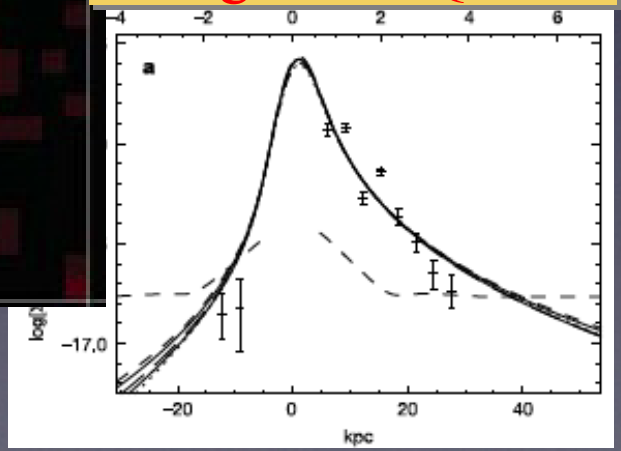


(Matsuda+'04)

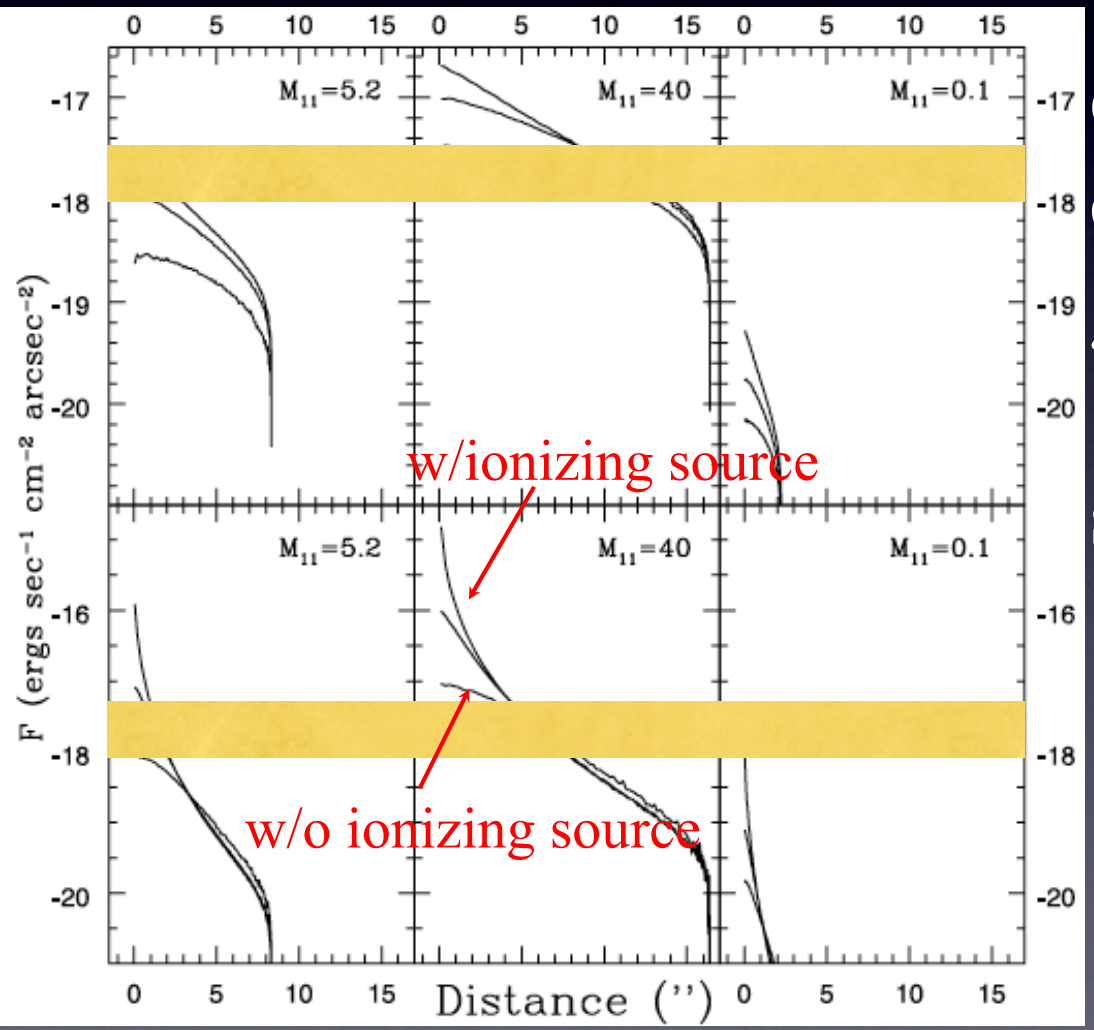


(Weidinger+'04)

"infalling HI gas falling into a Quasar"



Observational constraints on the physical origins



existence of ionizing sources
cooling radiation parameters
gas dynamics, etc.

should affect the profiles
(Dijkstra+'06a,b)

↓

DEEPER IMAGING!

Observational constraints on the physical origins

(Page 1)

Subaru Telescope
National Astronomical Observatory of Japan

Semester	S06B
Proposal ID	S06B098N
Received	03/13/2006

Application Form for Telescope Time

1. Title of Proposal
Deep Narrowband Imaging of Extended Lyα Sources in SXDF

2. Principal Investigator

Name:	Saito	Tomoki	
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Mailing Address:	Department of Astronomy, University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan		
E-mail Address:	tsaito@astron.s.u-tokyo.ac.jp		
Phone:	03-5841-4267	Fax:	03-5841-7644

3. Scientific Category
- ☐ Solar System
- ☐ Normal Stars
- ☐ Extrasolar Planets
- ☐ Star and Planet Formation
- ☐ Compact Objects and
- ☐ Nearby Galaxies
- ☐ Clusters of Galaxies
- ☐ Large-Scale Structure

4. Abstract (approximat
Spatially extended Lyα s
high redshifts. They may
extended emissions are t
using Suprime-Cam and
VLT/VIMOS, and showe
protogalaxies in the very
We propose deep follow-
and NB570 on Suprime-C
spatial extents, morphol
will be able to put const
galaxy formation, and p

5. Co-Investigators

Name			
K. Shimasaku			
S. Okamura	University of Tokyo	A. Shimono	Kyoto University
M. Ouchi	STScI	T. Hattori	Subaru, NAOJ
H. Sugai	Kyoto University	M. Yoshida	Okayama, NAOJ
Y. Matsuda	Kyoto University	SXDS Team	

6. List of Applicants' Related Publications (last 5 years)
1) Saito et al. 2005, "Systematic Survey of Extended Lyα Sources over $z \sim 3-5$", submitted to ApJ
2) Matsuda et al. 2004, "A Subaru Search for Lyα Blobs in and around the Protocluster Region at Redshift $z = 3.1$", AJ, 128, 569
3) Matsuda et al. 2005, "Large-Scale Filamentary Structure around the Protocluster at Redshift $z = 3.1$", ApJ, 634, L125
4) Ouchi et al. 2005, "The Discovery of Primeval Large-Scale Structures with Forming Clusters at Redshift 6", ApJ, 620, L1
5) Shimasaku et al. 2004 "Large Cosmic Variance in the Clustering Properties of Lyα Emitters at $z \simeq 5$", ApJ, 605, L93
6) Shimasaku et al. 2003 "Discovery of a Large-Scale Structure of Galaxy Distribution at Redshift ~ 5", ApJ, 586, L111
7) Sugai et al. 2004, "Test observations of the Kyoto Tridimensional Spectrograph II at the University of Hawaii 88-in and Subaru Telescopes", SPIE, 5492, 651

Last modified 10/01/04

Proposal (S06B-098)

Deep Narrowband Imaging with Kyoto-3DII + S-Cam

Cancelled.

Fucking earthquake!

ng probe
wide

3 nights for Kyoto-3DII !

Summary

- Intermediate-band (IA) deep imaging survey for extended Lyα sources.
  - IA filters can effectively collect LAEs with large EWs over a wide range of redshift.

We've made a
Uniquely large sample of LABs

- Follow-up spectroscopy with VLT/VIMOS
  - They are candidates for Cooling Clouds, PopIII-dominated galaxies, or Superwinds.

Direct observations of the
very first stage of galaxy formation