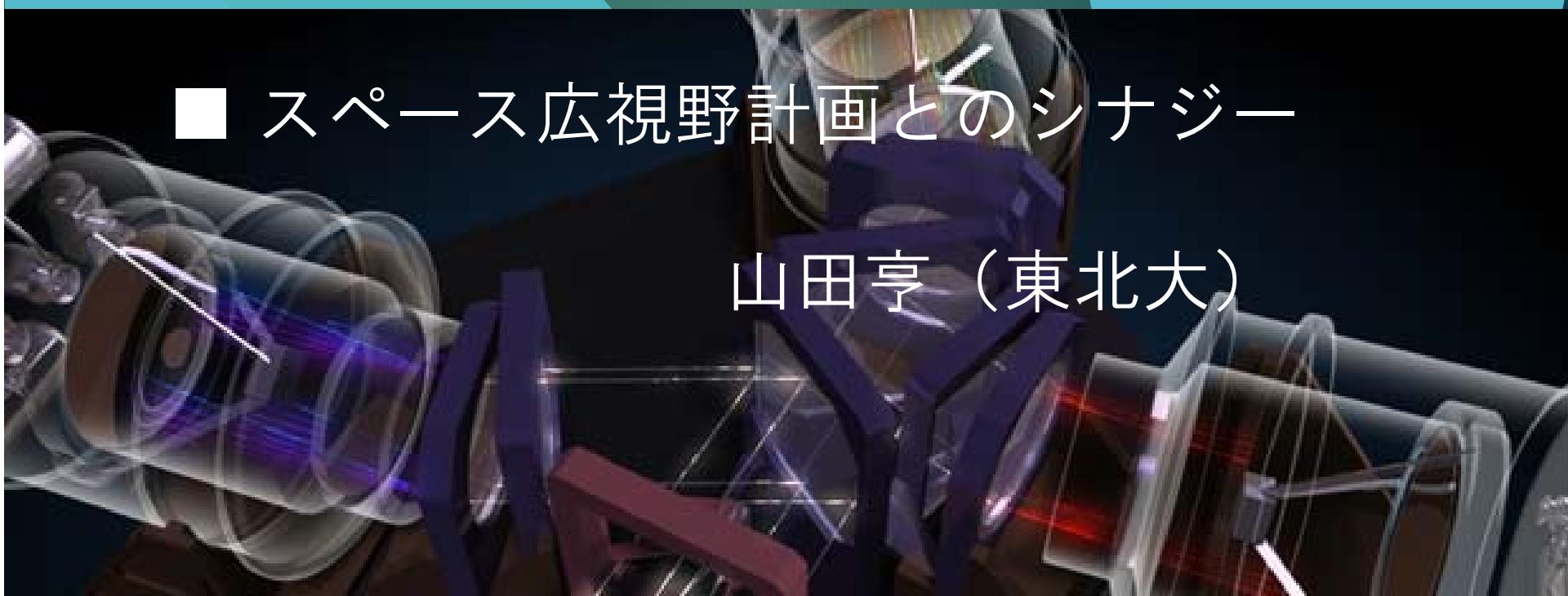


# PFS広視野分光サーベイと 銀河形成進化研究：

■ 広視野分光サーベイ と銀河進化

■ スペース広視野計画とのシナジー

山田亨（東北大）



# 広視野・多天体観測による 銀河形成進化研究

- 十分に制御されたサーベイ
- 非常に高い統計精度
- さまざまな密度環境
- 希少な天体
  - 本当に希少な天体
  - 時間スケールの短い現象
    - + さまざまな現象の「時間分解能」

$$N_{\text{obs}} = \Phi_{\alpha, z_1} \Delta t / t_H V_{\text{obs}} \cdot F_{\text{sel}}$$

$$N_{\text{obs}} = \Phi_{\text{host}} \Delta t / t_{\Delta z} V_{\text{obs}} (\Delta z)$$

$$\Delta z \sim 1 \rightarrow t_{\Delta z} \sim \text{a few} \times 10^9 \text{ yr}$$

$$V_{\text{obs}} (\Delta z) \sim 10^7 \text{ Mpc}^3 / 1 \text{ deg}^2$$

$$\Phi_{\text{host}} = 10^{-3} / \text{Mpc}^3$$

$$N_{\text{obs}} \sim 100 \rightarrow$$

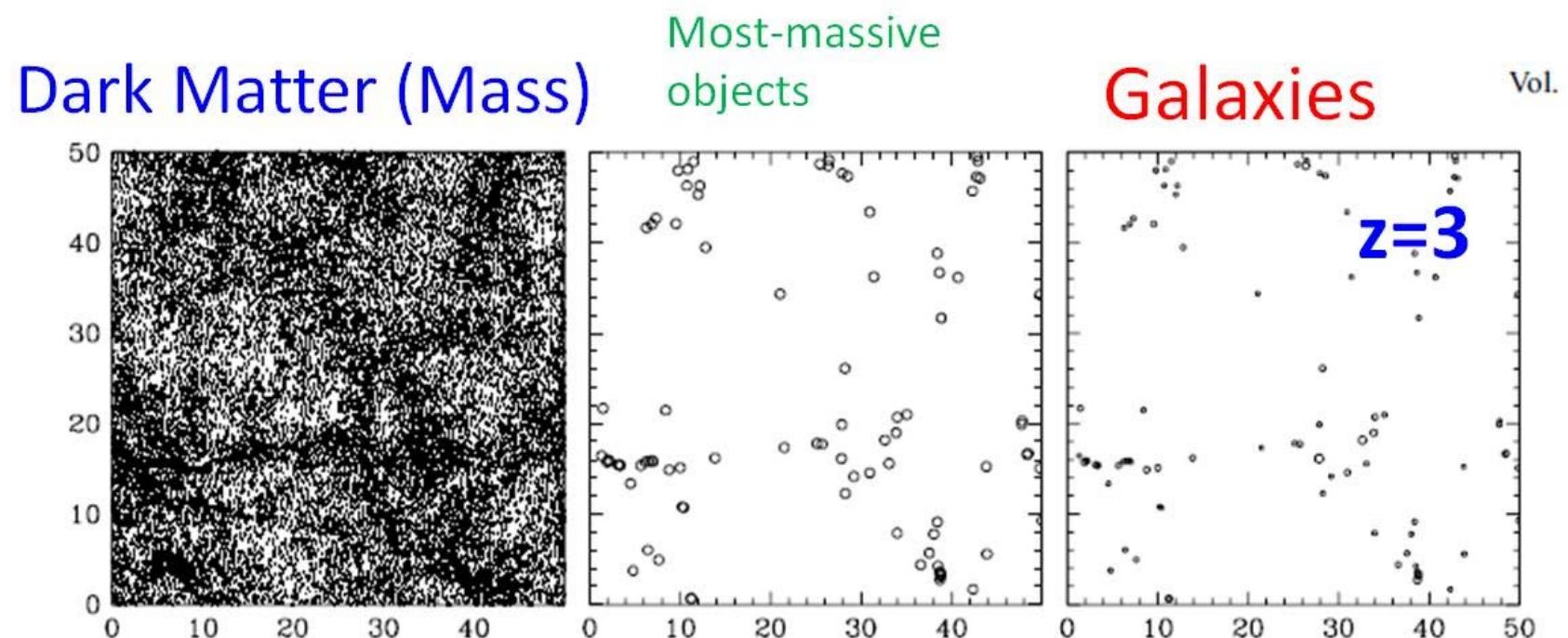
$$\Delta t \sim \text{a few} \times 10^7 \text{ yr} \quad \text{for } 1 \text{ deg}^2$$

$$\text{a few} \times 10^6 \text{ yr} \quad \text{for } 10 \text{ deg}^2$$

# バイアスされた銀河形成過程と 銀河形成・非形成領域観測

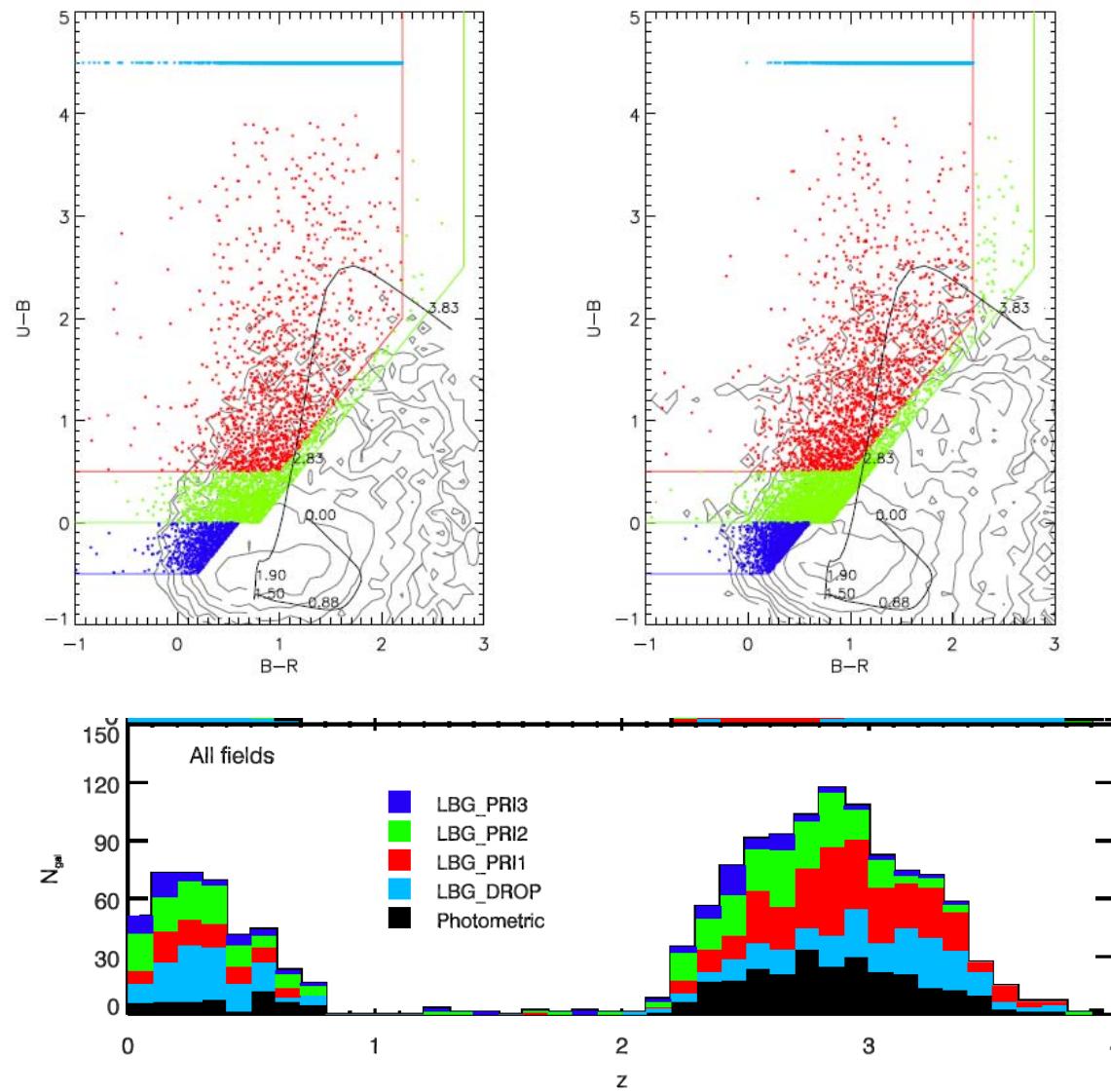
# ■ 密度環境

高赤方偏移 顕著な銀河形成バイアス



e.g., Weinberg et al. 2004: N-body + semi-analytic simulation

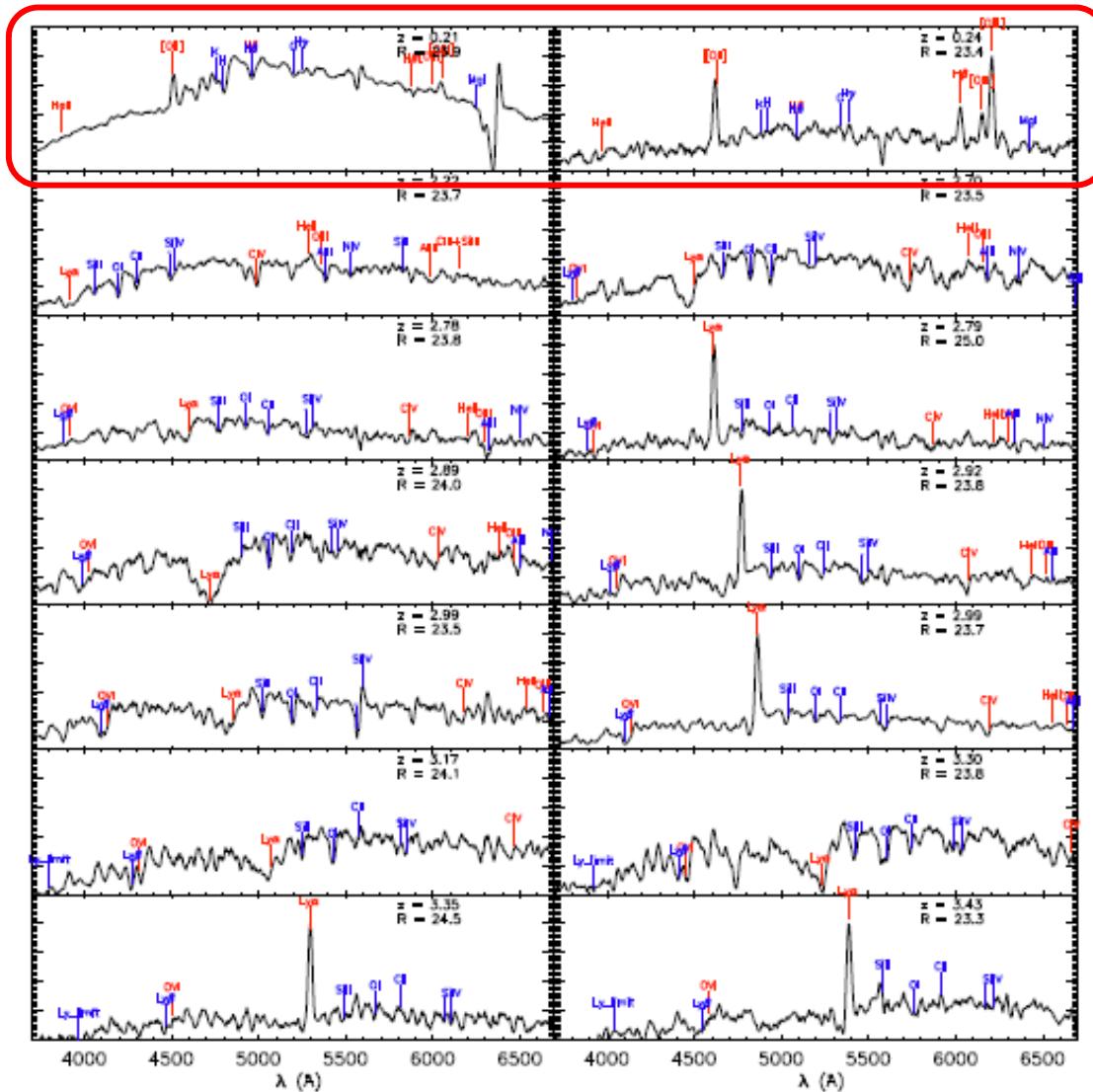
VLT による最近の Lyman Break Galaxy 分光サーベイ  
 $z=2\sim3$  ~1000 galaxies Bielby et al. 2010



$36' \times 36'$   
 $R < 25$

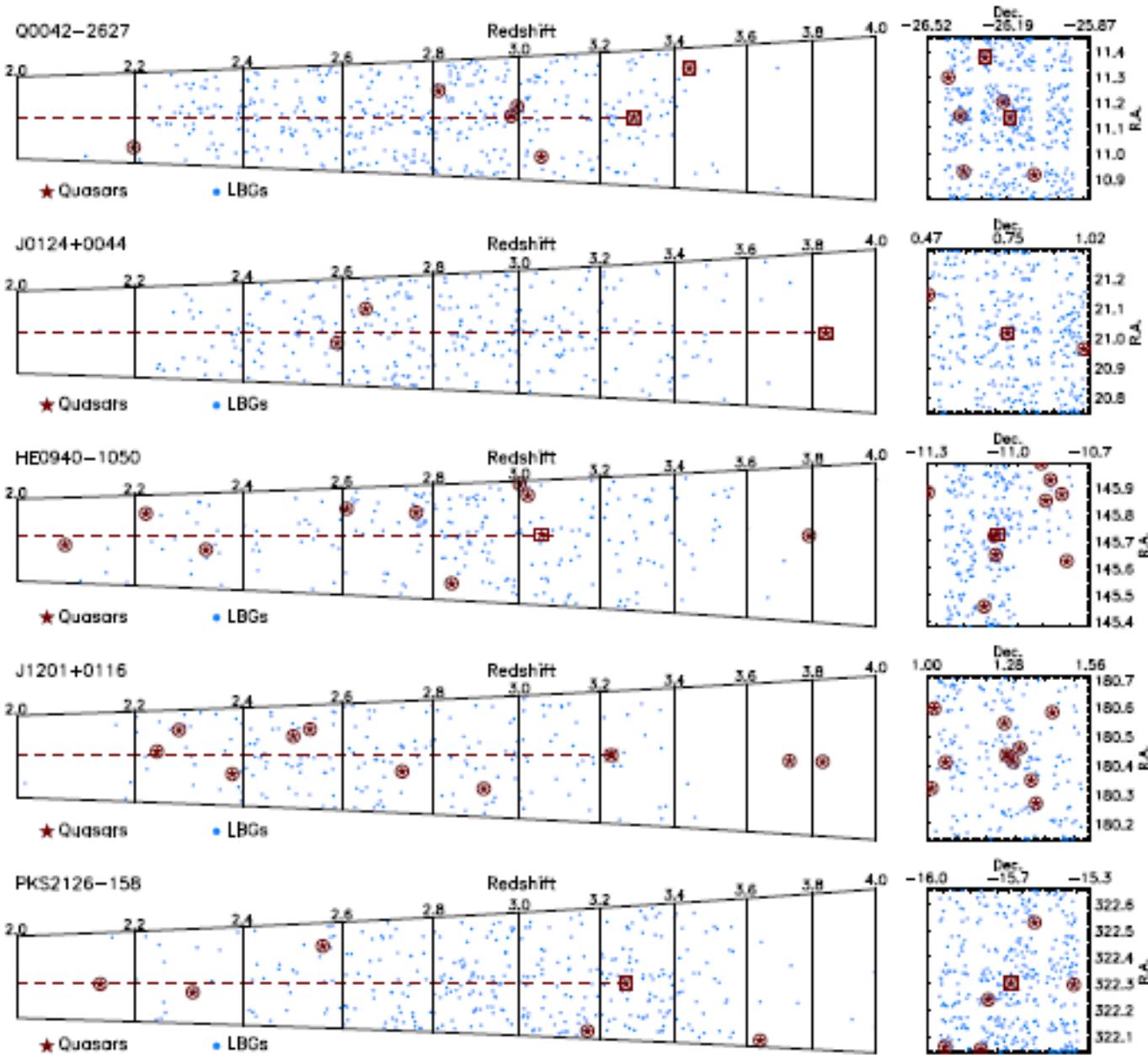
# VLT VIMOS による分光スペクトル

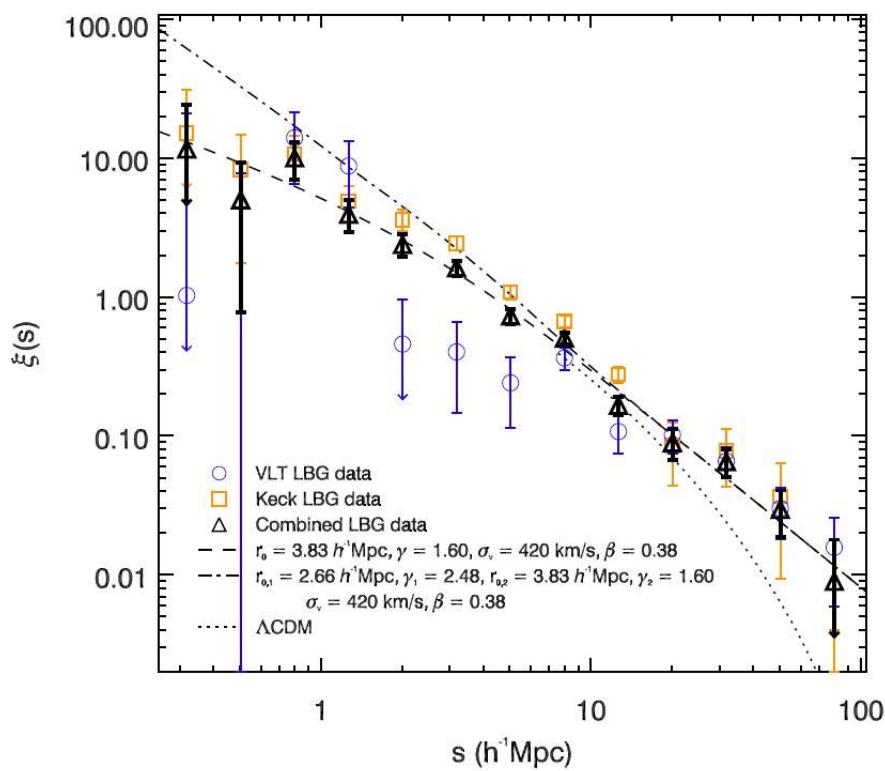
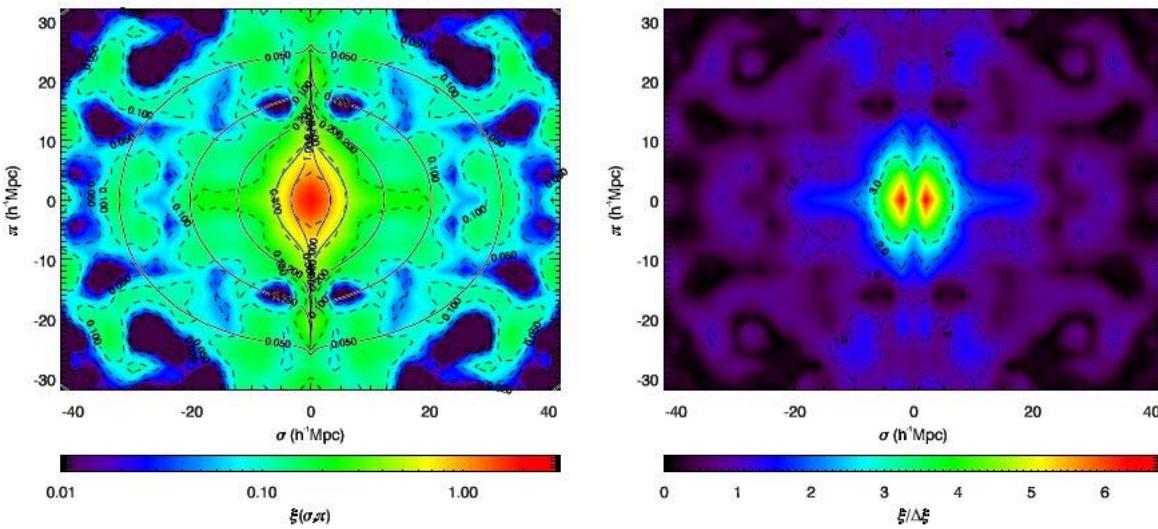
積分時間 ~10000sec =3時間程度     $2 < z < 3.5$



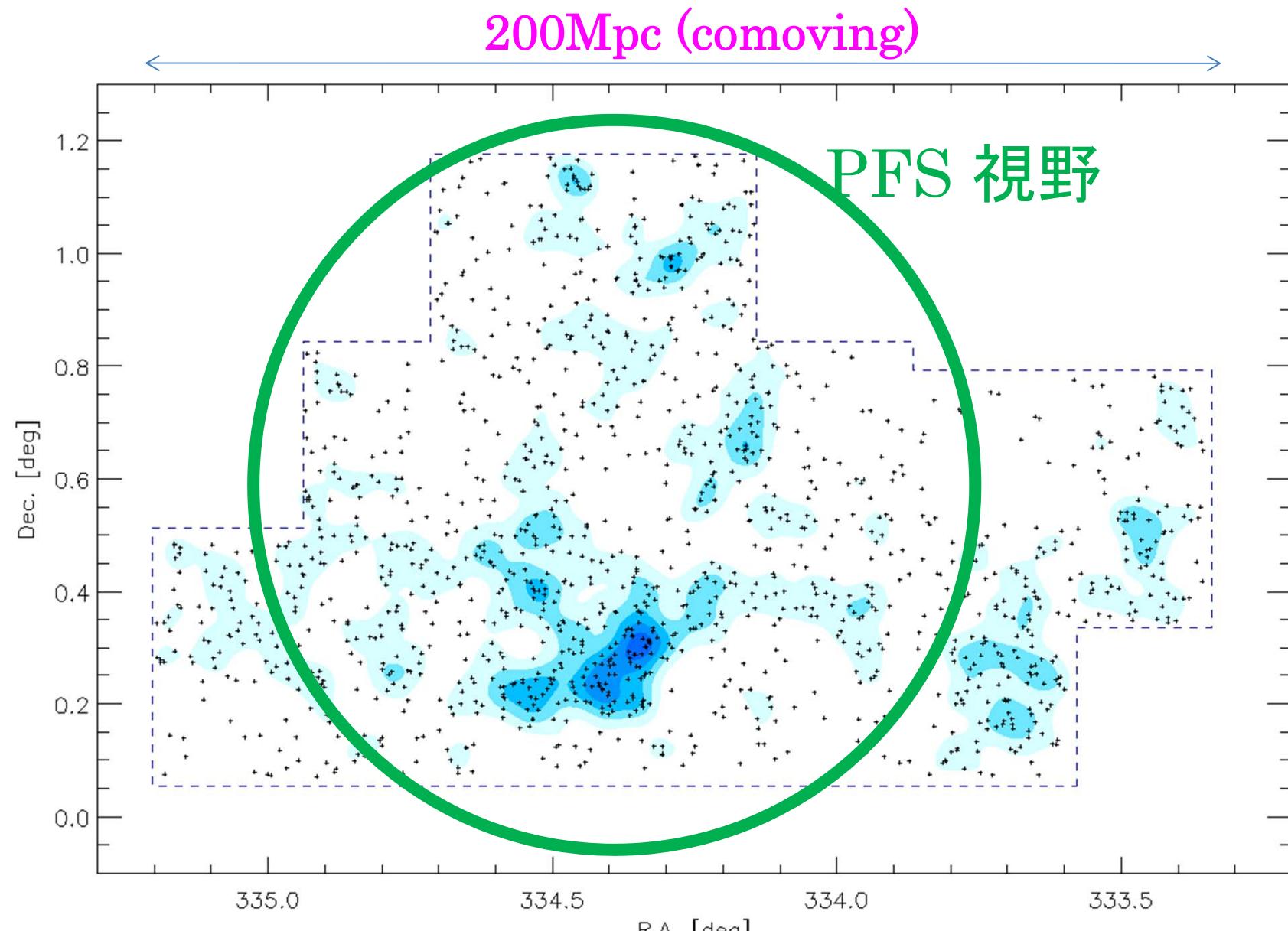
近傍銀河  
(contamination)

Success rate  
~30%





# Redshift 3.1: distribution of $\sim 1500$ Ly $\alpha$ emitters



TY et al. 2012

Depth 60Mpc

200Mpc (comoving)

← →

CfA REDSHIFT SURVEY SLICES

45

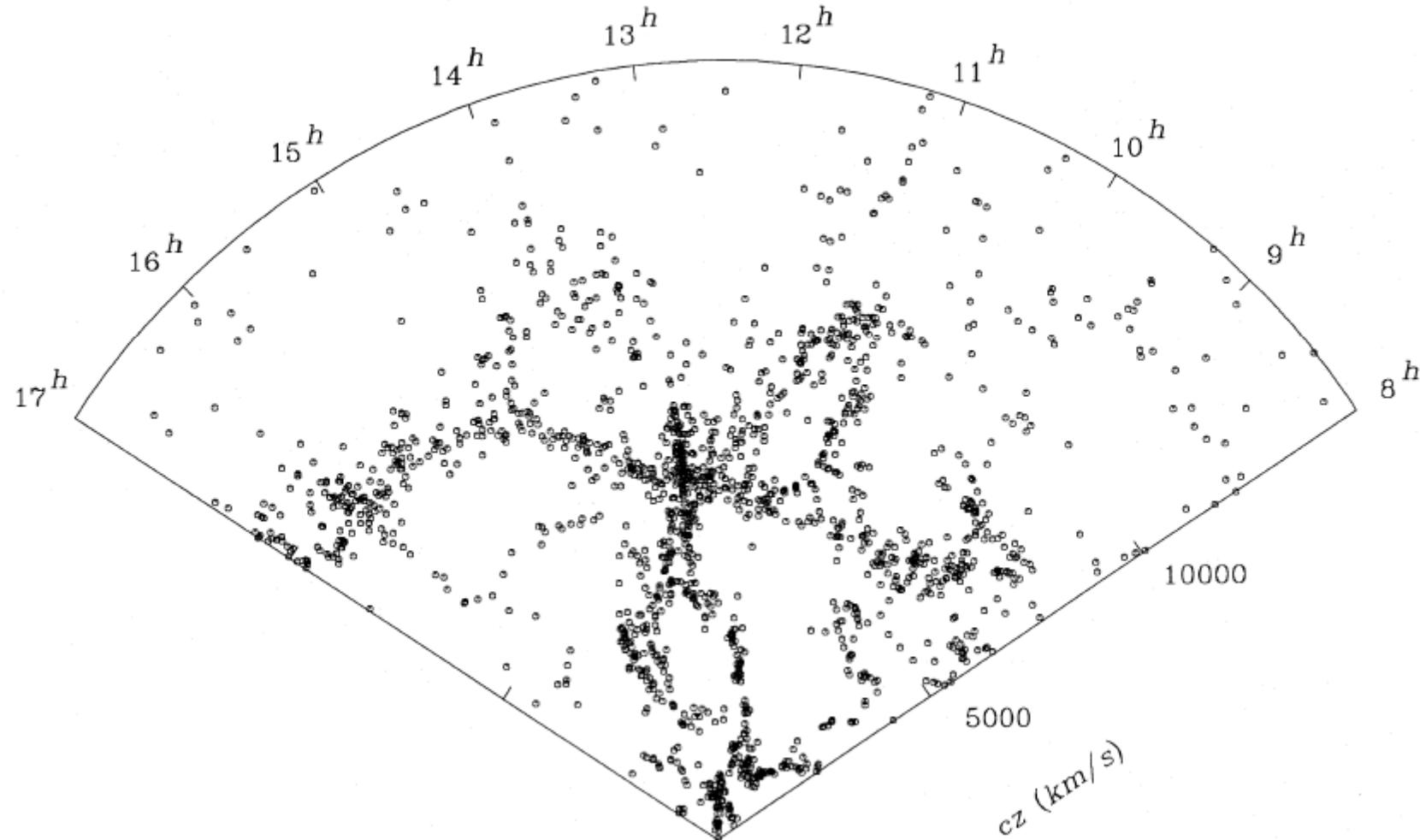
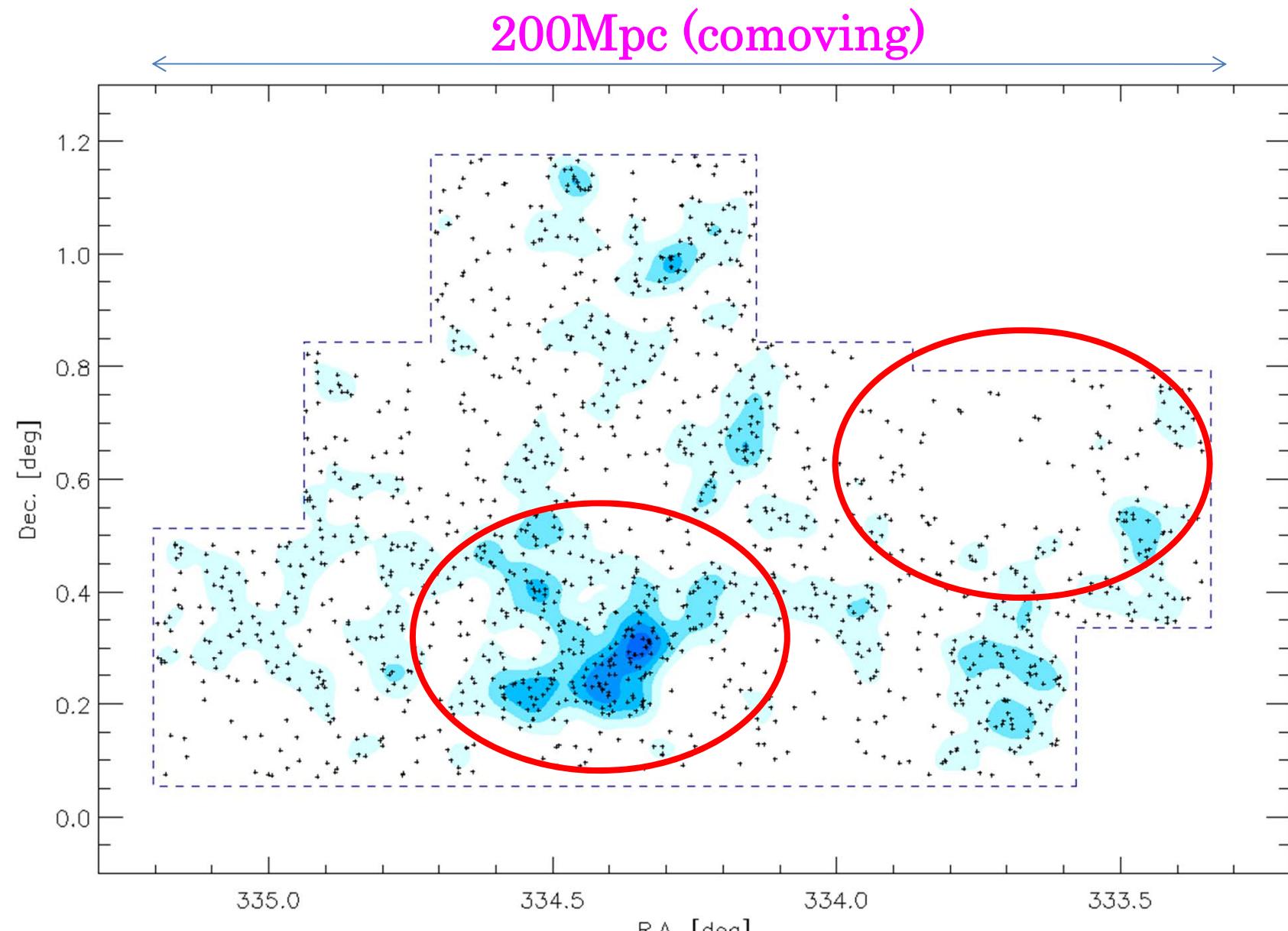


FIG. 1.—Map of the galaxy distribution in right ascension and velocity in the  $12^\circ$  strip limited by  $m_{B(0)} \leq 15.5$ . The declination range is  $26^\circ 5 \leq \delta \gtrsim 38^\circ 5$ . This map contains 1761 galaxies.

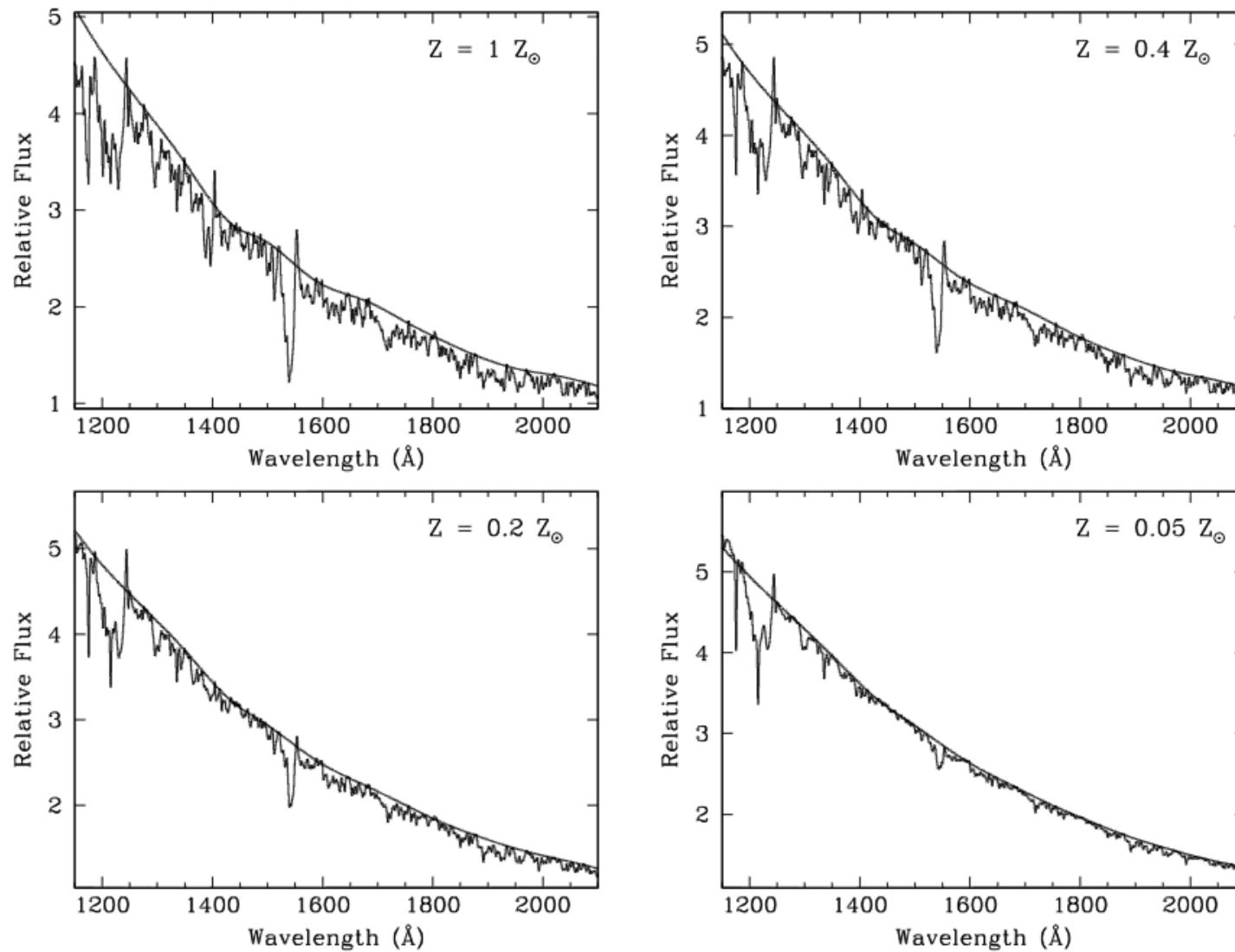
De Lapparent et al. 1988

# Redshift 3.1: distribution of $\sim 1500$ Ly $\alpha$ emitters



TY et al. 2012

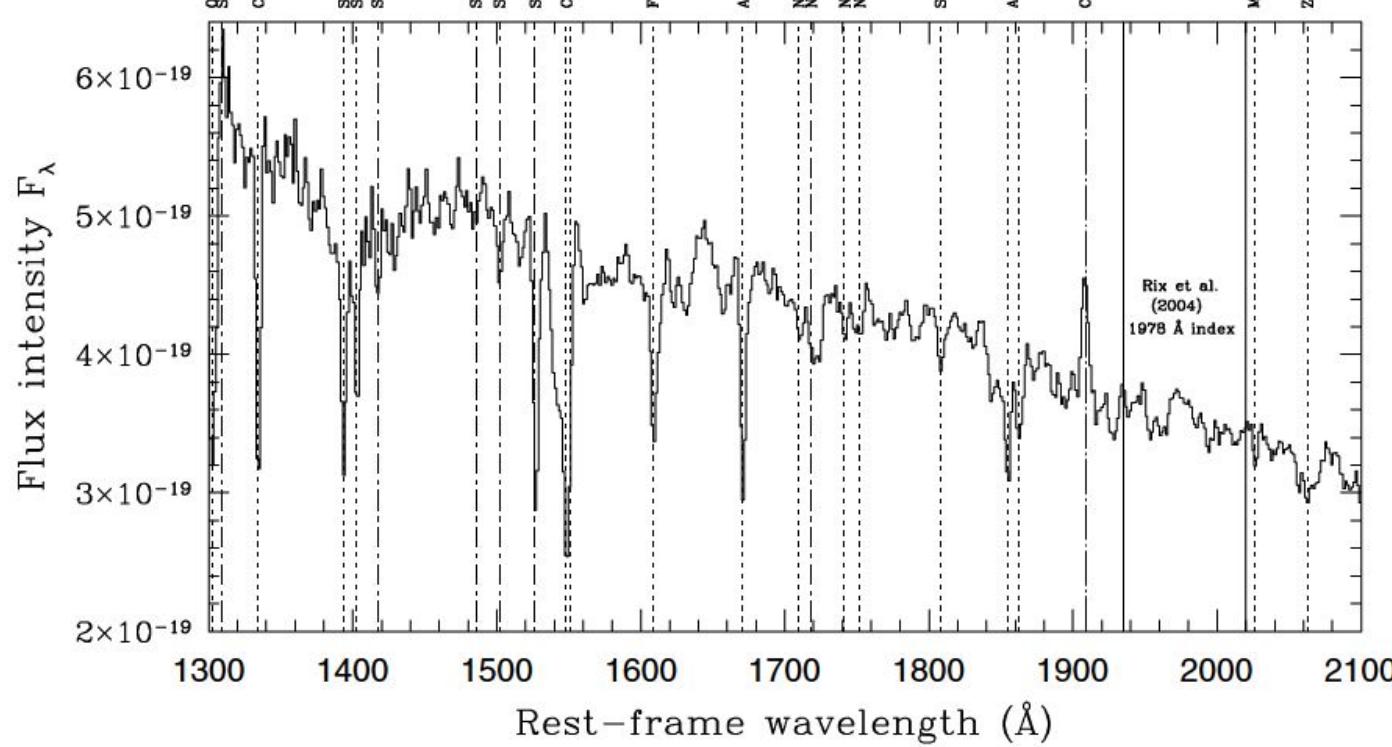
# Metallicity dependence of UV stellar spectra of LBGs



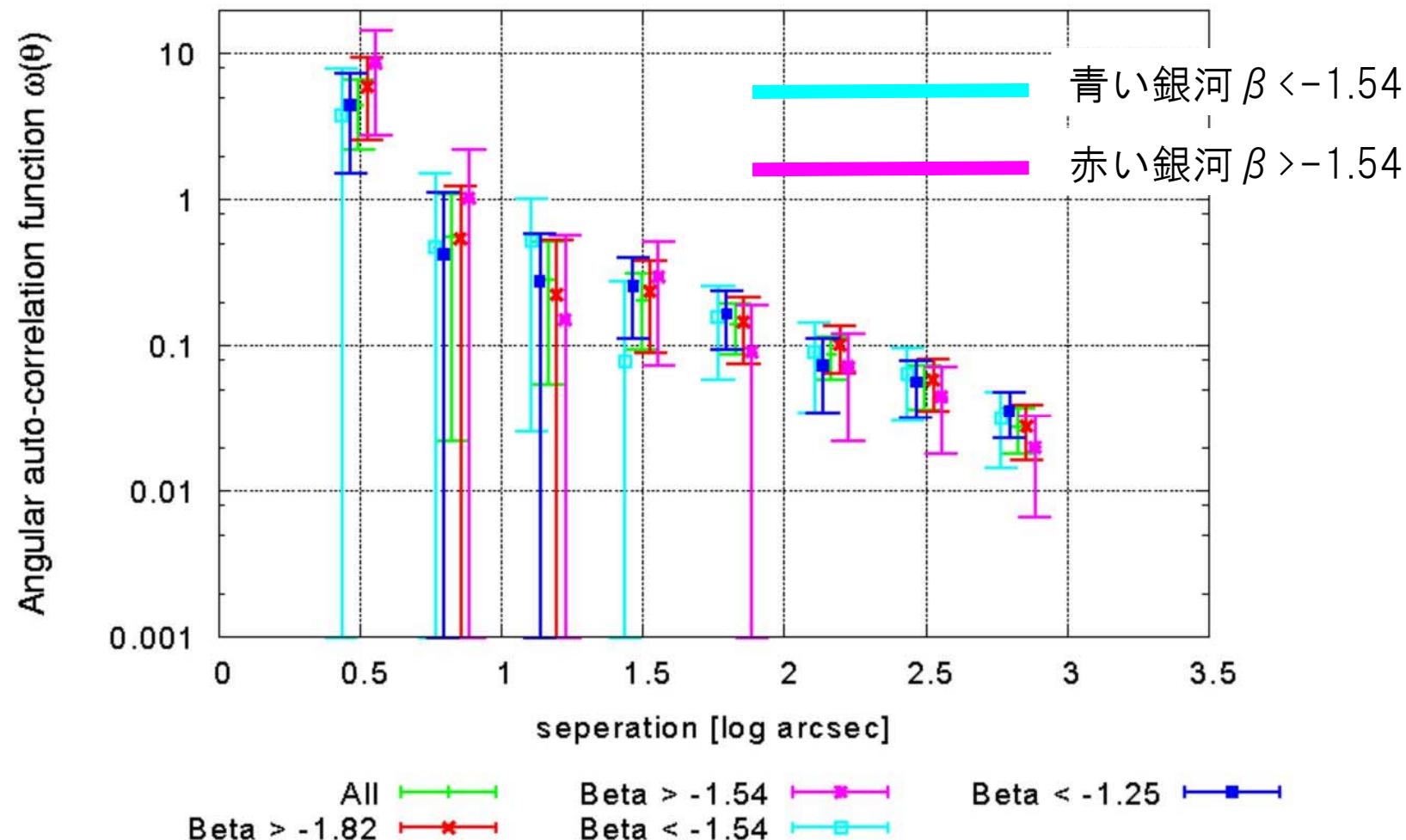
VLT 75gal stack

Effective 1750hours (~30h integration)

B<26.5 & I<26.5 + IRAC



# $z \sim 4$ LymanBreak Galaxies 紫外線連續光スロープ $\beta$ と空間分布



# 高赤方偏移銀河のクラスタリング (銀河形成バイアス) と銀河の性質

高赤方偏移  
高い測光精度  
広視野撮像  
+  
広視野分光 \*\*MUST\*\*



# 銀河形成初期の「時間分解」

$$N_{\text{obs}} = \Phi_{\text{host}} \Delta t / t_{\Delta z} V_{\text{obs}}(\Delta z)$$

$$\Delta z \sim 1 \rightarrow t_{\Delta z} \sim \text{a few} \times 10^9 \text{ yr}$$

$$V_{\text{obs}}(\Delta z) \sim 10^7 \text{ Mpc}^3 / 1 \text{ deg}^2$$

$$\Phi_{\text{host}} = 10^{-3} / \text{Mpc}^3$$

$$N_{\text{obs}} \sim 100 \rightarrow$$

$$\Delta t \sim \text{a few} \times 10^7 \text{ yr} \quad \text{for } 1 \text{ deg}^2$$

$$\text{a few} \times 10^6 \text{ yr} \quad \text{for } 10 \text{ deg}^2$$

# 銀河形成における短時間 ( $\sim 100\text{Myr}$ ) 現象

- 爆発的星形成の初期
- マージング過程 (e.g., ISM large-scale shock)
- 星形成の quenching
- 巨大ブラックホール合体過程

## 短時間 ( $\sim 100\text{Myr}$ ) 分解したい銀河形成過程

- 爆発的星形成期
- 初期の円盤形成期

# 高赤方偏移銀河： 時間スケールが短い「現象」（銀河進化段階）をとらえられるか？

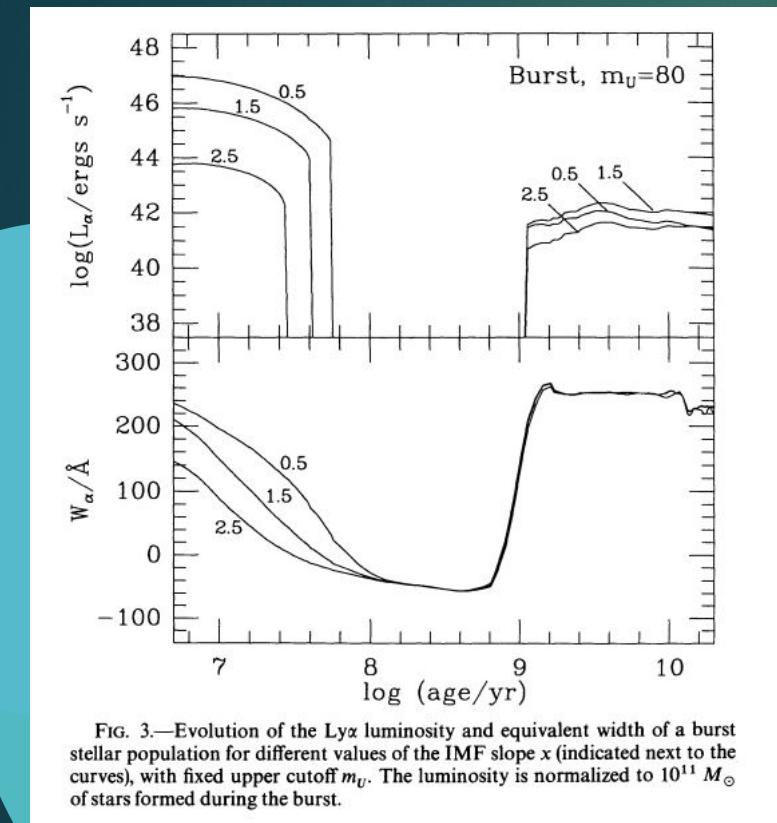
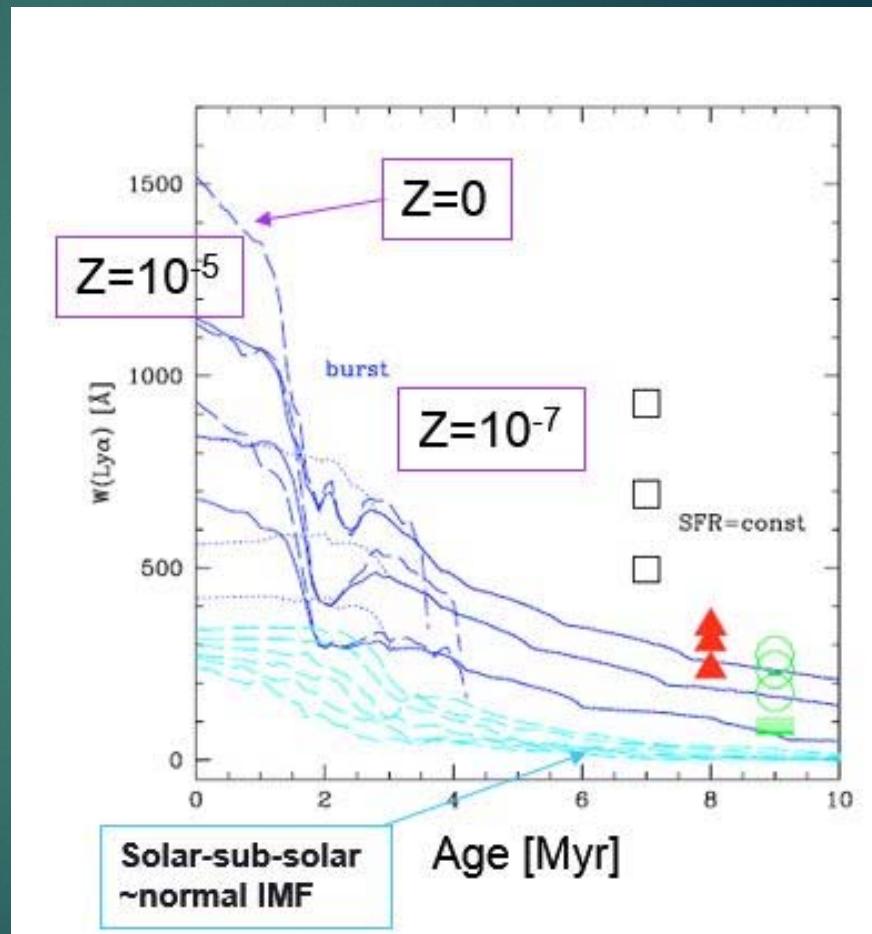


FIG. 3.—Evolution of the Ly $\alpha$  luminosity and equivalent width of a burst stellar population for different values of the IMF slope  $x$  (indicated next to the curves), with fixed upper cutoff  $m_u$ . The luminosity is normalized to  $10^{11} M_\odot$  of stars formed during the burst.

Charlot and Fall 1993



Schaerer 2003



PFS スペース広視野計画とのシナジー

# スペース広視野計画とのシナジー

## 2020's の光赤外広視野スペース計画

Mission	特徴	Status
WISH	1 – 5 $\mu\text{m}$ 100平方度 28AB	2020-21 打上を目指すJAXA 戦略ミッションに推薦されなかった。
WFIRST	1-2(2.4) $\mu\text{m}$ 2200平方度 26-27AB (高黄緯、南天主体計画) Grism 1.35-1.89 $\mu\text{m}$	米国NASA のJWST に次ぐ 2020's の戦略基幹ミッション
Euclid	可視広帯域、NIR 1-1.8 $\mu\text{m}$ 15000平方度 24AB	~2020-2021打上予定
SPICA	~1-10 平方度 赤外分光・撮像サーベイ	2016-17 ESA M5 competition



WFIRST

- 口径2.4m の望遠鏡 (Hubble Space Telescopeと同じ口径)
- 広視野 近赤外
- JWST に続く NASA の戦略ミッション
- 2023–2025年以降の打ち上げを目指している

<http://wfirst.gsfc.nasa.gov/>

[http://wfirst.gsfc.nasa.gov/science/sdt\\_public/](http://wfirst.gsfc.nasa.gov/science/sdt_public/)

# WFIRST 日本の取組

- ・ WFIRST SDT 住貴宏 2010-2011  
WFIRST-AFTA(2.4m) 山田亨 2013-2015 (JAXA rep.)
  - ・ WFIRST 連絡会 (2012~)
  - ・ コロナグラフ開発 WACO Working Group 主査 田村元秀  
(小規模・国際協力クラス)
- WFIRST Working Group 申請中 主査 住貴宏



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## Foreign Interest in WFIRST-AFTA



# Interests by Foreign Groups for Potential Contributions



- Japan
  - WFI: Could provide coordinated ground-based observations (wide and deep spectroscopy and deep optical imaging) and microlensing/galactic bulge science imaging processing pipeline & precursor ground observations
  - CGI: Interested in a polarization module, mask fabrication, analysis/algorithm support, PIAA module
- Canada
  - Strong science interest in SN and WL surveys as well as coronagraphy
  - WFI: Interested in the IFU, FGS, photometric calibration (pre-flight or flight), UV/blue wide-field instrument
  - CGI: Interested in the IFS, EMCCDs, LOWFS, filter/mask wheels, data reduction pipeline, data processing, and archiving
- UK and Europe
  - WFI: Interested in the IFU and opto-mechanical systems and associated electronics, ground processing of spectroscopy data, image/data processing and analysis pipeline, lenses and mounts, and calibration hardware
  - CGI:
    - Expertise in flight instruments, high contrast test bed for testing coronagraphs and post-coronagraphic techniques and detector technology
    - Interested in LOWFS design, optical element, CCDs and associated camera
- Korea
  - No formal statement in the report, discussions are at the very early stages, but strong interest & possible funding, likely centered around the HgCdTe detectors



# Initial Thoughts on Foreign Contributions



- WFI
  - IFU: Canada, Europe
  - FGS: Canada
  - Opto-Mechanical Systems: Europe
  - Calibration system: Canada, Europe
  - Data Processing: Canada, Europe, Japan
  - Ground-based observations: Europe, Japan
- CGI
  - IFS: Canada
  - Detectors: Canada, UK
  - Filter/mask wheels: Canada
  - Operational algorithms: Japan
  - Polarization module: Japan

Study Office is preparing a recommendation that balances the advantages with the associated risks

## WFIRST とすばるサーベイ

- Subaru HSC SSP (~2019?)
- Subaru PFS SSP (~2019-2024??)

→ WFIRST で最初期に  
観測すべき天域

- WFIRST 観測天域（一部、北天～赤道）  
→ Subaru HSC/PFS/Ultimate観測  
SSP に次ぐサーベイに期待

# PFS + WFIRST Science

WFIRST for PFS (~DEIMOS観測とCANDELS)

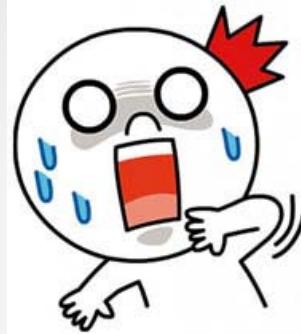
- PFS分光天体 の高解像度画像
- PFS分光天体 の星質量
- その他サンプルセレクション

PFS for WFIRST

- WFIRST photo-z キャリブレーション
-

# WFIRST 観測視野案（これまで）

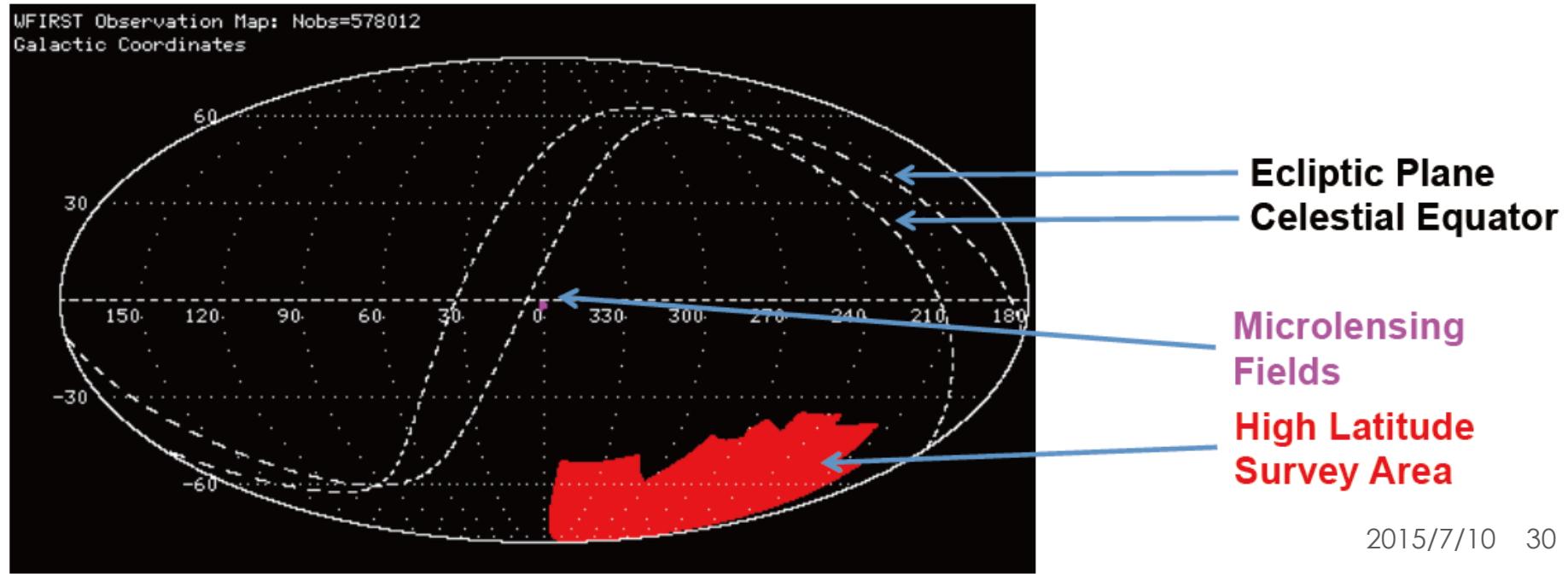
# このままでは すばるもTMTも見えない！！



2014/11/17-20

WFIRST Workshop @ Pasadena

AFTA で観測計画を議論する機会か



# 広視野・多天体観測による 銀河形成進化研究

- 十分に制御されたサーベイ
- 非常に高い統計精度
- さまざま密度環境
- 希少な天体
  - 本当に希少な天体
  - 時間スケールの短い現象
    - + さまざまな現象の「時間分解能」

## PFS スペース広視野計画とのシナジー

- WFIRST との互恵関係
- JWST ヘターゲット供給
- SPICA dust/gas survey とのシナジー



# Capabilities



## WFI:

Imager	<b>0.76-2.0 microns</b> 0.28° FoV, 0.11" pixel scale
Filters:	z (0.76 - 0.98), Y (0.93-1.19), J (1.13-1.45), H(1.38-1.77), F184 (1.68-2.0), W149 (0.93-2.00)
Grism:	<b>1.35-1.89 microns</b> 0.28° FoV, R=461λ, 0.11" pixel scale
IFU:	<b>0.6-2.0 microns</b> 3" & 6" FoV, R~100, 0.075" pixel scale

## Coronagraph:

Imager:	<b>0.43-0.97 microns</b> 1.63" FoV (radius), 0.01" pixel scale, 1k x 1k EMCCD, $10^{-9}$ final contrast, 100-200 mas inner working angle
IFS:	<b>0.60-0.97 microns</b> 0.82" FoV (radius), R~70

**Field of Regard:** 54° - 126° 60% of sky



# DRM Yields



## Attributes

Imaging survey

Slitless spectroscopy

Number of SN Ia SNe

Number galaxies with spectra

Number galaxies with shapes

Number of galaxies detected

Number of massive clusters

Number of microlens exoplanets

Number of imaged exoplanets

## WFIRST-AFTA Yields

J ~ 27 AB over 2200 sq deg

J ~ 29 AB over 3 sq deg deep fields

R~461λ over 2200 sq deg

2700 to z~1.7

$2 \times 10^7$

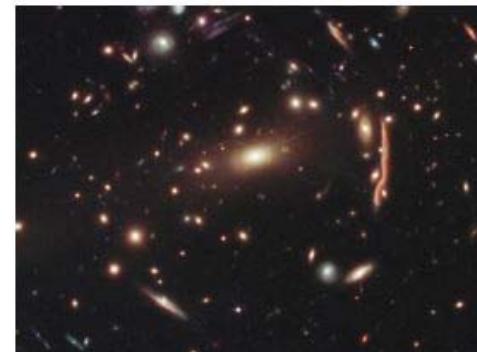
$4 \times 10^8$

$\text{few} \times 10^9$

$4 \times 10^4$

2600

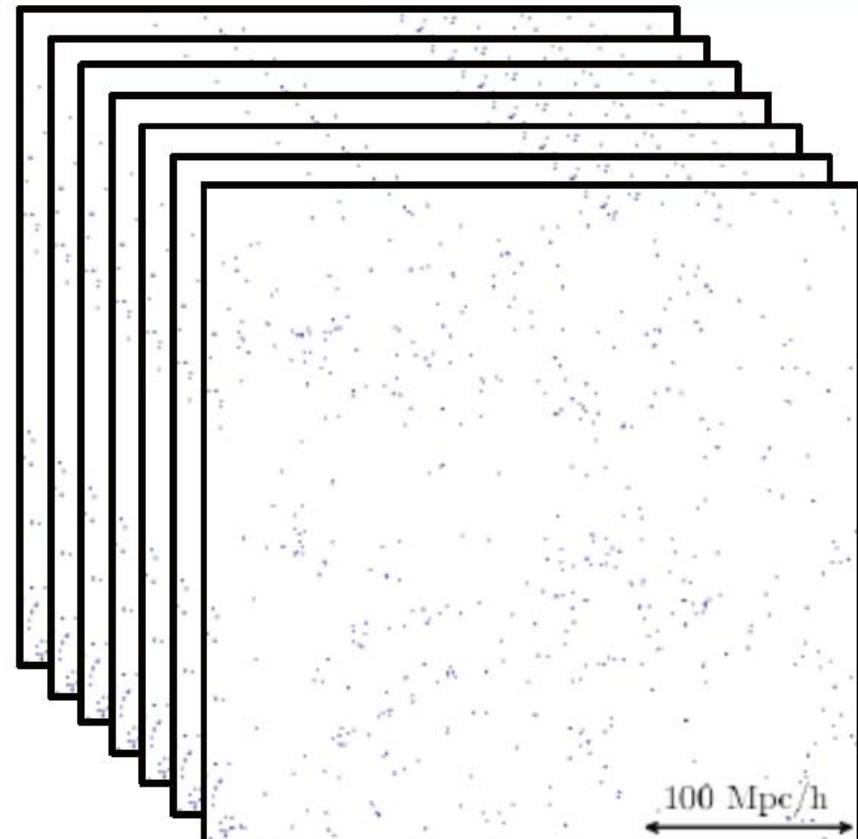
10s



# WFIRST vs Euclid

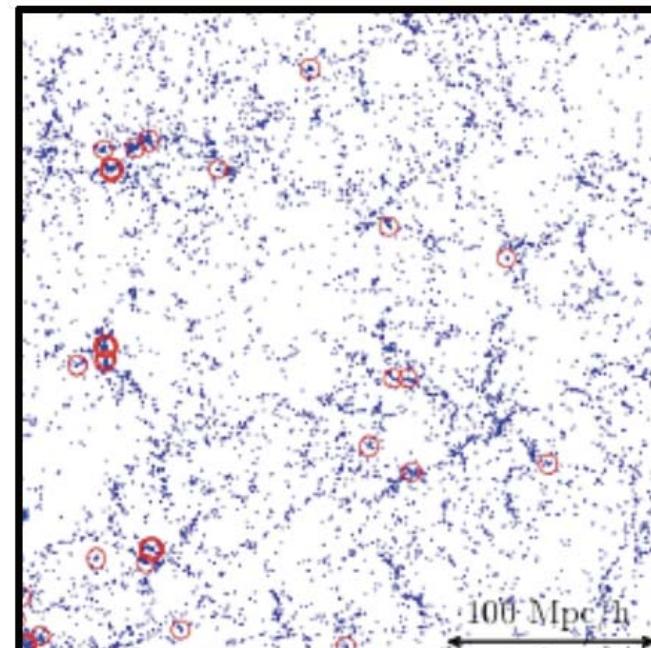


## Detailed 3D Map of Large Scale Structure at $z = 1-2$



**Euclid**  
**15,000 deg<sup>2</sup> @ 1700 gal/deg<sup>2</sup>**

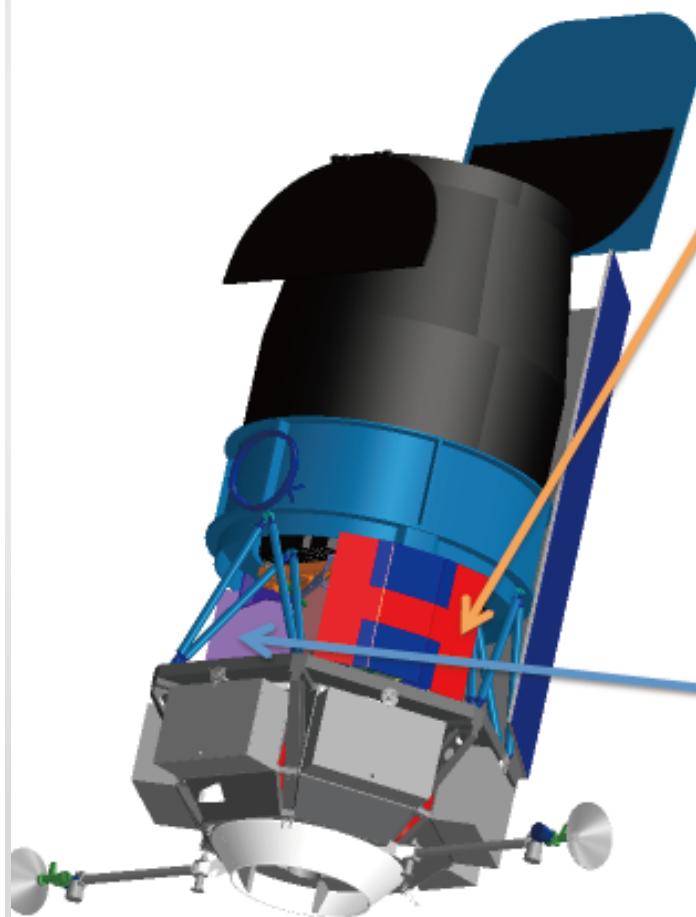
Large scale structure simulation showing 0.1% of the total WFIRST-AFTA Galaxy Redshift Survey Volume



**WFIRST**  
**2,400 deg<sup>2</sup> @ 12,600 gal/deg<sup>2</sup>**

*Large scale structure simulations from 2013 SDT Report – courtesy of Ying Zou* 2015/7/10 34  
*Thin and thick red circles mark clusters with masses exceeding  $5 \times 10^{13} M_{\text{Sun}}$  and  $10^{14} M_{\text{Sun}}$ , respectively*

# WFIRST-AFTA 観測装置の概要



## Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 deg<sup>2</sup> FoV (100x JWST FoV)
- 18 H4RG detectors (288 Mpixels)
- 6 filter imaging, grism + IFU spectroscopy

## Coronagraph

- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- $\leq 10^{-9}$  contrast (after post-processing)
- 100 milliarcsec inner working angle at 400 nm

# WFIRST-AFTA観測計画概要

宇宙論サーベイ ( $\sim 2.5$ 年)

= High Latitude Survey (HLS)

$\sim 2200$ 平方度、**撮像**(YJH) + **分光** ( $R \sim 800$ )

$Y < 26.7, J < 26.9, H < 26.7,$

$F184W < 26.2$

+ Supernova Survey

$5, 9, 27$ 平方度 (DMW)

**撮像モニタリング** + **IFU分光** ( $R \sim 100$ )

(最終的な深さ)  $H < 28.9$  (deep)

重力レンズ、クラスタリング、Ia超新星

-

+

系外惑星マイクロレンズ(~1年)  
銀河中心方向、軌道半径大きい地球型

系外惑星コロナグラフ観測(~1年)  
可視、コントラスト  $10^{-9}$ , IWA 0.2”

Guest Observer 観測 (25%, 1.5年)