The Subaru Deep Field
~ 6 years journey ~

Nobunari Kashikawa
(National Astronomical Observatory of Japan: NAOJ)
Subaru Deep Field (SDF) Project

- Systematic imaging+spectroscopic survey to explore the universe as deep as, and as early as possible with Subaru.

- The major goal is to sample and understand the high-z (4<z<7) populations

- Conventional methods of “Lyman-drop” and “narrow-band”

- Taking advantage of a wide FoV of Suprime-Cam

- Measuring the fundamental observables such as LF, CF

- Subaru Observatory Project;
  ~30nights /2years +5nights (Intensive, PI: Y.Taniguchi)

- SDF (Subaru Deep Field Project) deeper

- SXDS (Subaru/XMM Deep Survey) wider
SDF team are

N.Kashikawa\textsuperscript{1}, M.Ajiki\textsuperscript{2}, M.Akiyama\textsuperscript{3}, H.Ando\textsuperscript{1}, K.Aoki\textsuperscript{3}, M.Doi\textsuperscript{4}, S.Fujita\textsuperscript{2}, H.Furusawa\textsuperscript{3}, T.Hayashino\textsuperscript{2}, H.Karoji\textsuperscript{1}, F.Iwamuro\textsuperscript{5}, M.Iye\textsuperscript{1}, N.Kobayashi\textsuperscript{4}, T.Kodama\textsuperscript{1}, K.Kodaira\textsuperscript{6}, Y.Komiya\textsuperscript{1}, Y.Matsuda\textsuperscript{2}, S.Miyazaki\textsuperscript{3}, T.Morokuma\textsuperscript{4}, K.Motohara\textsuperscript{4}, T.Murayama\textsuperscript{2}, T.Nagao\textsuperscript{1,7}, K.Nariai\textsuperscript{8}, S.Okamura\textsuperscript{9}, M.Ouchi\textsuperscript{10}, T.Sasaki\textsuperscript{3}, Y.Sato\textsuperscript{1}, K.Shimasaku\textsuperscript{9}, Y.Shioya\textsuperscript{2}, H.Tamura\textsuperscript{2}, I.Tanaka\textsuperscript{3}, Y.Taniguchi\textsuperscript{2}, T.Yamada\textsuperscript{3}, N.Yasuda\textsuperscript{11}, M.Yoshida\textsuperscript{9}

and

Subaru Telescope, Mitaka Subaru office, Subaru Telescope builder

1. NAOJ, mtk
2. Tohoku U.
3. NAOJ, Hawaii
4. Tokyo U., IoA
5. Kyoto U.
6. GUAS
7. INAF
8. Meisei U.
9. Tokyo U.
10. STScI
11. Tokyo U., ICRR
Subaru Deep Field (SDF)

- \( \alpha 13:24:21.38 \quad \delta +27:29:23.0 \)
- 34'x27' FOV

- Previous deep NIR imaging 2'x2' \( K<25.35 \) (9.7hrs)
- No nearby bright stars
- No known cluster of galaxies
- Low galactic HI column density
- Easy to access from Mauna-Kea

GOODS-N-FOV size

HDFN-FOV size

real SDF image
Optical imaging with S-Cam
Suprime-Cam 1-FOV (34'×27')
- B<28.5 (9.91hr integ.)
- V<27.2 (6.0hr)
- R<27.4 (10.0hr)
- i'<27.5 (11.25hr)
- z'<26.6 (9.4hr)

- NB816<26.8 (10.0hr)
- NB921<26.5 (15.0hr)

(AB, 2σ, 2″φ)

http://soaps.naoj.org/sdf/
Galaxies at 4<z<7 on SDF

- Lyman alpha emitters (LAEs)
  - NB816-selected galaxies → z=5.7 LAEs (z=5.71 ± 0.05)
  - NB921-selected galaxies → z=6.6 LAEs (z=6.57 ± 0.04)

- Lyman break galaxies (LBGs)
  - BRi’-selected galaxies → z~4 LBGs (z~4.0 ± 0.5)
  - Vi’z’-selected galaxies → z~5 LBGs (z~4.7 ± 0.5)
  - (i’z’-selected galaxies → z~6 LBGs)
SDF optical images
effective area 773 arcmin$^2$

- LAE@$z=6.6$
- LAE@$z=5.7$
- (LBG@$z\sim6$)
- LBG@$z\sim5$
- LBG@$z\sim4$

They are waiting for spectroscopy!!!

cf.
HDF-N (WFPC2)

GOODS
~160sqmin x 2 fields
Follow-up Observations

- **Optical Spectroscopy**
  - Subaru/FOCAS (PI: H.Karoji, T.Nagao, NK)
  - KeckII/DEIMOS (PI: M.Malkan)

- **NIR**
  - deep images in 3 2’x2’ fields w/ Subaru/CISCO
  - wide images w/ UKIRT/WFCAM ~400arcmin² (PI: K.Motohara)
  - deep Subaru/MOIRCS (PI: K.Motohara)
  - [deep HST/NICMOS] (PI: E.Egami)

- **MIR**
  - wide Spitzer/IRAC+MIPS (PI: M.Malkan)
  - deep Spitzer/IRAC+MIPS (PI: E.Egami)

- **UV**
  - GALEX (PI: M.Malkan)

- **AO imaging** (PI: Y.Yoshii)

- **NB imaging**
  - N711/N703 imaging (K.Shimasaku,M.Ouchi),
  - N973 imaging (PI: M.Iye)

- ✓ X, Radio --- no plan
Scientific Results from the SDF

- Subara Deep Survey I. Near-Infrared Observations, Maihara+ 01
- Infrared Star-Count Models and Their Application to the Subaru Deep Field, Nakajima+ 00
- Diffuse EBL versus Deep Galaxy Counts in the SDF: Missing Light in the Universe?, Totani+ 01
- NIR Faint Galaxies in the SDF: Comparing the Theory w/ Obs. for N(m), Colors, and Size Distrib. to K~24.5 Totani+ 01
- HEROs in the SDF: Evidence for Primordial Elliptical Galaxies in the Dusty Starburst Phase, Totani+ 01
- Galaxy Number Counts in the SDF: Multiband Analysis in a Hierarchical Galaxy Formation Model, Nakajima+ 02
- SDS. II. Luminosity Functions and Clustering Properties of Ly α Emitters at z=4.86 in the SDF, Ouchi+ 03
- SDS. III. Evolution of Rest-Frame LFs Based on the Photometric-z for a K'-Band-Selected Galaxy Sample, NK+ 03
- SDS. IV. Discovery of a Large-Scale Structure at Redshift ~5LSS at z=5, Shimasaku+ 03
- The Discovery of Two Lyman α Emitters beyond Redshift 6 in the SDF, Kodaira+ 03
- SDS. V. A Census of Lyman Break Galaxies at z~4 and 5 in the SDFs: Clustering Properties, Ouchi+ 04
- SDS. VI. A Census of Lyman Break Galaxies at z~4 and 5 in the SDFs: Photometric Properties, Ouchi+ 04
- Large Cosmic Variance in the Clustering Properties of Ly α Emitters at z ~ 5, Shimasaku+ 04
- A Strong Ly α Emitter at z = 6.33 in the Subaru Deep Field Selected as an i'-Dropout, Nagao+ 04
- Submillimetre constraints on hyper-extremely red objects in the Subaru Deep Field, Coppin+ 04
- The Subaru Deep Field: The Optical Imaging Data, NK+ 04
- Subaru Super Deep Field with Adaptive Optics. I. Observations and First Implications, Minowa+ 05
- New High-Redshift Galaxies at z = 5.8-6.5 in the Subaru Deep Field, Shioya+ 05a
- The SUBARU Deep Field Project: Lyman α Emitters at a Redshift of 6.6, Taniguchi+ 05
- Number Density of Bright Lyman-Break Galaxies at z ~ 6 in the Subaru Deep Field, Shimasaku+ 05
- A Survey of NB921 Dropouts in the Subaru Deep Field, Shioya+ 05b
- Spectroscopy of i'-Dropout Galaxies with an NB921-Band Depression in the Subaru Deep Field, Nagao+ 05
- Properties of Stars in the Subaru Deep Field, Richmond+ 05
- Clustering of LBGs at z = 4 and 5 in the SDF: Luminosity Dependence of the Correlation Function Slope, NK+ 06a
- Ly α Emitters at z = 5.7 in the Subaru Deep Field, Shimasaku+ 06
- The End of the Reionization Epoch Probed by Ly α Emitters at z = 6.5 in the Subaru Deep Field, NK+ 06b
- A galaxy at a redshift z = 6.96, Iye+ 06
- The LF and Star Formation Rate between Redshifts of 0.07 and 1.47 for Narrow-band Emitters in the SDF, Ly+ 07
- Luminosity Functions of Lyman Break Galaxies at z~4 and z~5 in the Subaru Deep Field, Yoshida+ 07
- High-z LAEs w/ a large EW Properties of i-dropout galaxies w/ an NB921-depression in the SDF, Nagao+ 07
- Luminosity Dependent Clustering of Star-Forming BzK Galaxies at Redshift 2, Hayashi+ 07
z>4 studies

Scientific Results from the SDF

- Subaru Deep Survey I. Near-Infrared Observations, Maihara+ 01
- Infrared Star-Count Models and Their Application to the Subaru Deep Field, Nakajima+ 00
- Diffuse EBL versus Deep Galaxy Counts in the SDF: Missing Light in the Universe?, Totani+ 01
- NIR Faint Galaxies in the SDF: Comparing the Theory w/ Obs. for N(m), Colors, and Size Distrib. to K~24.5 Totani+ 01
- HEROs in the SDF: Evidence for Primordial Elliptical Galaxies in the Dusty Starburst Phase, Totani+ 01
- Galaxy Number Counts in the SDF: Multiband Analysis in a Hierarchical Galaxy Formation Model, Nagashima+ 02
- SDS. II. Luminosity Functions and Clustering Properties of Ly α Emitters at z=4.86 in the SDF, Ouchi+ 03
- SDS. III. Evolution of Rest-Frame LFs Based on the Photometric-z for a K’-Band-Selected Galaxy Sample, NK+ 03
- SDS. IV. Discovery of a Large-Scale Structure at Redshift ~5LSS at z=5, Shimasaku+ 03
- The Discovery of Two Lyman α Emitters beyond Redshift 6 in the SDF, Kodaira+ 03
- SDS. VI. A Census of Lyman Break Galaxies at z~4 and 5 in the SDFs: Clustering Properties, Ouchi+ 04
- SDS. V. A Census of Lyman Break Galaxies at z~4 and 5 in the SDFs: Photometric Properties, Ouchi+ 04
- Large Cosmic Variance in the Clustering Properties of Ly α Emitters at z ~5, Shimasaku+ 04
- A Strong Ly α Emitter at z = 6.33 in the Subaru Deep Field Selected as an i’-Dropout, Nagao+ 04
- Submillimetre constraints on hyper-extremely red objects in the Subaru Deep Field, Coppin+ 04
- The Subaru Deep Field: The Optical Imaging Data, NK+ 04
- Subaru Super Deep Field with Adaptive Optics. I. Observations and First Implications, Minowa+ 05
- New High-Redshift Galaxies at z = 5.8-6.5 in the Subaru Deep Field, Shioya+ 05a
- The SUBARU Deep Field Project: Lyman α Emitters at a Redshift of 6.6, Taniguchi+ 05
- Number Density of Bright Lyman-Break Galaxies at z ~ 6 in the Subaru Deep Field, Shimasaku+ 05
- A Survey of NB921 Dropouts in the Subaru Deep Field, Shioya+ 05b
- Spectroscopy of i’-Dropout Galaxies with an NB921-Band Depression in the Subaru Deep Field, Nagao+ 05
- Properties of Stars in the Subaru Deep Field, Richmond+ 05
- Clustering of LBGs at z = 4 and 5 in the SDF: Luminosity Dependence of the Correlation Function Slope, NK+ 06a
- Ly α Emitters at z = 5.7 in the Subaru Deep Field, Shimasaku+ 06
- The End of the Reionization Epoch Probed by Ly α Emitters at z = 6.5 in the Subaru Deep Field, NK+ 06b
- A galaxy at a redshift z = 6.96, Iye+ 06
- The LF and Star Formation Rate between Redshifts of 0.07 and 1.47 for Narrow-band Emitters in the SDF, Ly+ 07
- Luminosity Functions of Lyman Break Galaxies at z~4 and z~5 in the Subaru Deep Field, Yoshida+ 07
- High-z LAEs w/ a large EW Properties of i-dropout galaxies w/ an NB921-depression in the SDF, Nagao+ 07
- Luminosity Dependent Clustering of Star-Forming BzK Galaxies at Redshift 2, Hayashi+ 07
and ... Stay tuned

- Subaru Super Deep Field using Adaptive Optics
  Minowa, Y.
- Formation and Evolution of the Star-Forming Galaxies at z~2
  Hayashi, M.
- Galaxies at z~7: Evolution, Probing Re-Ionization of the Universe
  Ohta, K.
Data release

http://soaps.naoj.org/sdf/

2004.11.01 The final data/catalogs release
details --- NK+04, PASJ, 56, 1011

SDF Data Products (Version 1)

--- We plan to release another set of data products reduced with good PSF exposures only. ---

README
Download Tips Is a RFC Observation paper (pdf, ps.gz)
Images (FITS: about 373MB each)
broad-band: B V R c i' z'
narrow-band: NB816 NB921

Catalogs (gzipped ASCII: about 14-17MB each)
B selected V selected R selected i' selected z' selected NB816 selected NB921 selected

sample file (ASCII)

Detection (source selection) and photometry (magnitude measurement) were performed separately with the SEtractor program.

Use reading software (below) to eliminate sources in the low quality area.

The Galactic extinction (below) is not corrected in the listed magnitudes.
Press/ Web releases

- 2006 Cosmic Archeology Uncovers the Universe’s Dark Ages
- 2005 Young Galaxies Grow Up Together in a Nest of Dark Matter
- 2005 Subaru Obtains the Deepest Infrared Image of the Universe
- 2003 Subaru Telescope Detects the Most Distant Galaxy Yet, part 2
- 2003 The Universe Had Large Scale Structure at a Very Early Age
- 2003 Subaru Telescope Detects the Most Distant Galaxy Yet
- 2001 Discovery of Seven New Distant Supernovae
- 2001 Light From All the Galaxies in the Universe
- 1999 Subaru Deep Field
Press/Web releases

2006 Cosmic Archeology Uncovers the Universe's Dark Ages

2005 Young Galaxies Grow Up Together in a Nest of Dark Matter

2005 Subaru Obtains the Deepest Infrared Image of the Universe

2003 Subaru Telescope Detects the Most Distant Galaxy Yet, part 2

2003 The Universe Had Large Scale Structure at a Very Early Age

2003 Subaru Telescope Detects the Most Distant Galaxy Yet

2001 Discovery of Seven New Distant Supernovae

2001 Light From All the Galaxies in the Universe

1999 Subaru Deep Field
2005 ASJ PASJ Award (日本天文学会 欧文研究報告論文賞)
Maihara et al. 2001

2004 ASJ PASJ Award (日本天文学会 欧文研究報告論文賞)
Kodaira et al. 2003
A Map of the Universe

Gott III et al., 2005, APJ, 624, 463
STRENGTHS
- Project lead by Japan/Subaru
  - global consensus as the Subaru’s work
  - It is not a “Subaru follow-up” of “XXX survey”!
- Prompt data analysis, data release, result output
  ← small membership & clear objectives

WEAKNESSES
- Poor initial organization for multi- $\lambda$ observations.
  - Follow-up observations with our own efforts
  - insufficient outputs except high-z sciences
STRENGTHS

- Project lead by Japan/Subaru
- Global consensus as the Subaru's work
- It is not a "Subaru follow-up" of "XXX survey"!
- Prompt data analysis, data release, result output

← Small membership & clear objectives

WEAKNESSES

- Poor initial organization for multi-observations.
- Follow-up observations with our own efforts insufficient outputs except high-z sciences

SDF Pros & Cons
The first one small step, but one giant leap for Subaru

Sincerely respect to CISCO team who first observed the SDF where nobody has set foot in 6 years ago.