Subaru Wide-Field Variability Survey

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- Summary
Subaru telescope

- 8.2-m aperture
- Mt. Mauna Kea (~4,200m) in Hawaii Big Island
  - 3 other 8-m class telescopes: Gemini-N, Keckx2
- Optical-infrared telescope
- Operated by National Astronomical Observatory of Japan (NAOJ)
- Multi-purpose: 10 instruments
- First light: 1999
Subaru telescope

- Optical-infrared telescope
- 8.2-m aperture
- Located on Mauna Kea (~4,200m) in Hawaii, Big Island
- Operated by National Astronomical Observatory of Japan (NAOJ)
- Multi-purpose with 10 instruments
- First light in 1999

The diagram shows the primary mirror and various instruments:
- S-Cam
- FMOS
- Ns IR
- IRCS
- HiCIAO
- AO188
- Ns Opt
- HDS
- Cs Opt
- FOCAS
- Kyoto3DII
- Cs IR
- MOIRCS
- COMICS
Suprime-Cam

- Prime-focus optical imager: 3600–10000\(\text{\AA}\)
- Based on development experience of mosaic CCD wide-field imagers at Kiso
- Much widest field-of-view among 8-m class telescopes: 34'x27' ~ full moon
- 10 Hamamatsu CCDs (upgraded August 2008)
  - QE improvement around ~1\(\text{\um}\)
- Most popular instrument: ~20% share
Suprime-Cam

The much widest field-of-view among current 8-m class/space telescopes: 34′x27′ ~ full moon

~1,000,000 objects
Suprime-Cam

- prime-focus optical imager: 3600–10000A
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- much widest field-of-view among 8-m class telescopes: 34′x27′ ~ full moon
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Variable Object Surveys w/ Subaru/Suprime-Cam

- Subaru is a multi-purpose telescope (10 instruments). Not a dedicated telescope.
- Large survey has not been so easy
- But we could conduct variability surveys

Subaru Observatory Projects + Intensive Programs since 2001 + Guaranteed Time

Subaru Deep Field (SDF)

Subaru/XMM-Newton Deep Survey (SXDS)
Flux Variability Detection

- simple photometry can NOT detect variability for extended sources such as faint AGN in bright galaxies and supernovae in extended galaxies.
- due to time-varying seeing size (ground-based observation)

Image subtraction method
Survey for Variables

- Variability Survey (TM+2008a)
- Active Galactic Nuclei (AGN)
  - Variability-Selected AGN (TM+2008b)
- Supernovae
  - Supernova Rate (Poznanski+2007)
  - Delay Time Distribution of SNe Ia in early-type galaxies (Totani, TM+2008)
  - Supernova Spectra w/ Subaru/FOCAS (TM+2010)
  - SN Ia Cosmology (Amanullah+2010)
  - Delay Time Distribution of SNe Ia (Okumura, Totani+2010, in prep.)
  - SN Ia Cosmology (Suzuki+2010, in prep.)
- High Proper Motion Stars
  - High Proper Motion Stars 1 (Richmond, TM+2009)
  - High Proper Motion Stars 2 (Richmond, TM+2010)
Survey for Variables

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Subaru/XMM-Newton Deep Survey (SXDS)

- X-ray (XMM-Newton/EPIC, 50-100ks, Ueda+2009)
  - 1e-15 erg s⁻¹ cm⁻² @0.5-2.0keV
  - 3e-15 erg s⁻¹ cm⁻² @2.0-10.0keV
- mid-infrared (Spitzer/IRAC): 3.6μm-band ~ 22.0mag
- spectroscopic follow-ups with many 8m-class telescopes
- optical (Subaru/Suprime-Cam, Furusawa+2008)
  - B(28.2mag), V(27.2mag), R(27.6mag), I(27.5mag), Z(26.5mag)
- optical variability (Subaru/Suprime-Cam, TM+2008a,b)
  - multi-epoch 8-10 times during 2002~2005
  - Timescale: 1 day - 3 years
  - \( i_{AB} \sim 26\text{mag} \) (each epoch)
  - \( i_{AB,\text{vari}} \sim 25.5\text{mag} \)
  - (flux of variable components = flux difference between epochs \( \Delta f = |f_1 - f_2| \))
- 1,040 variable objects over 0.918 deg²
- ~500 AGN selected by optical variability
- ~50 SNe Ia with good light curves

Suprime-Cam 5 fields

XMM-Newton 7 pointings
(02h18m00s, -05:00:00) in J2000
(l,b) = (169°,-60°)
Supernova rates

Ihara+2010 in prep.
SXDS (~1 deg²), ~50 SNe Ia by photometric typing

<table>
<thead>
<tr>
<th>Redshift</th>
<th>0</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
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</thead>
<tbody>
<tr>
<td>Rate (10^{-4} yr^{-1} Mpc^{-3})</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Ihara+09 (Photometric sample)
Rates increasing

Dahlen+08 (Spectroscopic sample)
Flat rates from z~0.8 to 1.2

The nearby rate is well fitted by our rate function.

SN Ia rates trace star formation rates → With short delay time (<~2-3 Gyr)

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SN Ia Delay Time Distribution

Totani, TM+2008
SN Ia@early-type gals

Okumura+2010, in prep.
SN Ia@all gals
Optical Variability of AGN

- all (type-1) AGN show detectable variability in optical. (Hawkins 1993, Hook+1994, Giveon+1999, many SDSS studies ...).
- fainter AGN show larger variability amplitudes.

- Subaru (Suprime-Cam): Totani+2005, TM+2008a,b

- significant fractions (~50%) of AGN w/o X-ray detections

Optical variability can be a good tracer for low-luminosity AGN.

- Subaru (Suprime-Cam): Totani+2005, TM+2008a,b

• (low-luminosity) type-1 AGN (up to z~5)
• ~580 AGN / deg²
• significant fractions (~50%) of AGN w/o X-ray detections

classical optical color selection does NOT suit for low–L AGN search.

Vanden Berk+2004
AGN samples

X-ray

- obscured (type-2)
  - 238 (36)
  - \( \langle z \rangle = 1.48 \)

- unobscured (type-1)
  - 89 (35)
  - \( \langle z \rangle = 1.82 \)

optical variability

- unobscured (type-1?)
  - 122 (9)
  - \( \langle z \rangle = 1.32 \)
properties of variability-selected AGN

differential flux between maximum and minimum
low differential flux ~ low AGN flux
properties of variability-selected AGN

- X-ray undetected optical-variability-selected AGN
- not optical color selection

differential flux between maximum and minimum
low differential flux ~ low AGN flux
What is the nature of this kind of low-luminosity AGN???
- HST imaging
- Deep spectroscopy (maybe stacking analysis necessary) to search for AGN features and also apply AGN identification diagnostics based on emission line ratios.
- Environmental dependence?
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- HST imaging
- Deep spectroscopy (maybe stacking analysis necessary) to search for AGN features and also apply AGN identification diagnostics based on emission line ratios.
- Environmental dependence?

- faint AGN (~-18 mag) in bright galaxies (e.g. Totani+2005)
- elliptical galaxies at $z_{\text{photo}} \sim 0.5$
- flare-up? radiatively inefficient accretion flow (RIAF)?
- radio-mode feedback?
- nearby LINER analogous? (Maoz +2006)
- $\sim 10^8 M_{\odot}$ SMBHs
- ending phase of mass accretion?
- 5-10% of bright galaxies show variability
  $\rightarrow$ several tens percent in total?
  (unknown detection efficiency...)
Hyper Suprime-Cam (HSC)
Hyper Suprime-Cam

ACS

34 arcmin

27 arcmin

Suprime-Cam

1.5deg
Hyper Suprime-Cam

ACS

27 arcmin
Suprime-Cam

LSST

3.5deg

1.5deg

Hyper Suprime-Cam

34 arcmin

Primary
S-Cam
FMOS

Ns IR
IRCS
HICIAO
RCA

Ns Opt
HDS

Cs Opt
FOCAS
Kyoto3DII

Cs IR
MOIRCS
COMICS
HSC specification

- field-of-view: 1.5 degree in diameter (1.77 deg²)
  - 7 times larger than Suprime-Cam (5 times smaller than LSST...)
- 600mm focal plane
  - 116 CCDs (incl. 4 auto-guider, 8 auto-focus)
- 1 gigapixel
- 0.17 arcsec/pixel (typical seeing @ MK ~0.7 arcsec)
- high QE CCDs (Hamamatsu)
- readout ~20sec
- 6 broad-band filters (ugrizy) + several narrow-band filters
- seeing-limited image quality
- first light: 2011 fall
- data access?
Hyper Suprime-Cam (HSC)

Camera

NAOJ
U-Tokyo
KEK
ASIAA
Princeton
Hyper Suprime-Cam (HSC)
HSC Strategic Observations

“Legacy” survey

spend ~300 nights over ~5 years (maximum)

cannot be achieved by individual proposals

We will start HSC strategic observation in 2012 summer.

Japan-Taiwan-Princeton collaboration

3 layers: wide/deep/ultradeep

weak lensing, galaxy evolution, SN Ia cosmology, high-z (z>6.5) quasars

cadence is very important for “us”
## HSC Strategic Survey: 3 layers

<table>
<thead>
<tr>
<th>layer</th>
<th>wide</th>
<th>deep</th>
<th>ultradeep</th>
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</thead>
<tbody>
<tr>
<td># of nights</td>
<td>200</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>area [deg²]</td>
<td>1300 (734)</td>
<td>28 (16=4x4)</td>
<td>3.5 (2)</td>
</tr>
<tr>
<td>(HSC FoVs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>filters</td>
<td>grizy</td>
<td>(u)grizy+3NBs</td>
<td>(u)grizy+6NBs</td>
</tr>
<tr>
<td>t_exp [min]</td>
<td>10-20</td>
<td>120-180</td>
<td>540-1620</td>
</tr>
<tr>
<td>science</td>
<td>weak lensing, galaxy cluster, quasars, ...</td>
<td>high-z galaxy, SNe, quasars, GRBs, ...</td>
<td>high-z galaxy, SNe, GRBs, AGN, ...</td>
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</tbody>
</table>

# all the numbers are tentative.
# HSC Strategic Observation (tentative)

<table>
<thead>
<tr>
<th></th>
<th>u</th>
<th>g</th>
<th>r</th>
<th>i</th>
<th>z</th>
<th>y</th>
<th>NBs</th>
<th>area</th>
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<tr>
<td>wide</td>
<td>-</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>-</td>
<td>1300</td>
</tr>
<tr>
<td>deep</td>
<td>120</td>
<td>180</td>
<td>180</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>3</td>
<td>28</td>
</tr>
<tr>
<td>ultradeep</td>
<td>-</td>
<td>540</td>
<td>540</td>
<td>1080</td>
<td>1620</td>
<td>1620</td>
<td>6</td>
<td>3.5</td>
</tr>
</tbody>
</table>

- **wide**: weak lensing, galaxy clusters, high-z quasars, ...
  - take all the data during one lunar phase (around new moon)
  - examine variability within a day
- **deep**: high-z galaxy, supernovae, quasars, GRBs, ...
  - ~10 epochs over 3 years
- **ultradeep**: high-z galaxy, supernovae, GRBs, AGN, ...
  - ~20 epochs over 5 years

# exposure time in minute
# area in deg2
# limiting magnitude measured within 2 arcsec aperture, 5 sigmas
HSC Science: Transients

time scale: an hour - years

- Supernova
  - type Ia: cosmology, rate, host galaxy, progenitor
  - core-collapse: rate, host galaxy, progenitor (@preimage)

- GRB
  - optical orphan afterglow: mechanism
  - ToO follow-up (?)

- AGN
  - low-L quasar (M1450 ~ -23mag)@z>3: LF, evolution
  - low-L AGN@z<1: environmental effect

- High Proper Motion Stars

- Solay system bodies
Summary

Subaru/Suprime-Cam variability survey found \( \sim 1,000 \) variable objects over \( \sim 1 \text{ deg}^2 \) (\( i<26 \text{mag} \)).

SN Ia at \( z>1 \). Rate is increasing. Higher-redshift?

Among the AGN sample (\( \sim 500 \) objects), a significant fraction of AGN are not detected in deep X-ray data (XMM-Newton).

They are low-L AGN without X-ray detection (\(<10^{-15} \text{ erg/s/cm}^2\)) at \( z\sim0.5 \). LINER analogous?

Subaru/HSC will be completed and get its first light on 2011 fall.

HSC Strategic Survey will start on 2012 summer and spend \( \sim 300 \) nights over 5 years (3 layers: wide/deep/ultradeep).

Many science including SN, GRB, and AGN will be intensively done using Subaru/HSC.
~ End ~

Thank you !!!