An overview of Deep Etragalactic Survey with AKARI and the Lessons Learned for WISH

WISH Science Workshop
2-3 December, 2013, NAOJ

Hideo Matsuhara
(ISAS, JAXA)
& NEP deep survey team
List of my Talk

- **NEP Deep Multi-wavelength Survey**
  - Overview and Status

- **AKARI All-Sky Survey**
  - Current Topics

- **NEP is uniquely high visibility region with Euclid, SPICA and WISH!!**
NEP-Deep: Contributors

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- NOAO
  - Hanae Inami
- INAF
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NEP Deep Survey
Main Science Goal

- Cosmic Star-formation History from `violent epoch’ @ z=1–2 to present
The `Violent Epoch’

- Universe at $z=1\sim2$: evolution of both galaxies and AGN peaks
- Decelerating expansion to accelerating expansion due to the dark energy

- More Intense Starburst, the more deeply embedded in the dust
- AGN are heavily obscured at their youngest, Compton thick age

Ueda et al. (2003)

Hopkins & Beacom (2006)
The Violent Epoch

- Universe at $z=1\sim2$: evolution of both galaxies and AGN peaks
- Decelerating expansion to accelerating expansion due to the dark energy

More Intense Starburst, the more deeply embedded in the dust
- AGN are heavily obscured at their youngest, Compton-thick age

Goto et al. 2010
NEP Deep Survey
(Updated) Main Science Goals

- Cosmic Star-formation History from "violent epoch" @ z=1–2 to present

- Previous Work: Star-formation Density was estimated based on MIR luminosity density only, not entire bolometric luminosity

- Current Work:
  - Direct measurement at FIR-submm $\rightarrow L_{\text{TIR}}$ $\rightarrow$ 
    $\text{IR8}=L_{\text{TIR}}/L(8)$
“Infrared Main Sequence”
an outcome from Spitzer + Herschel
Elbaz, D. + (2011)

IR8 = 4 (σ=1.6) is universal for star-forming galaxies independent of luminosity and redshift.

Compact (U)LIRGs in the Local Universe are ‘outliers’ — intense starburst red filled circles

\[
\text{IR8} \equiv \frac{L_{\text{IR}}^{\text{tot}}}{L_8}
\]
NEP Deep Survey
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- Current Work:
  - Direct measurement at FIR-submm $\rightarrow L_{\text{TIR}}$ $\rightarrow$ IR8=$L_{\text{TIR}}/L(8)$
  - Dust attenuation : unobscured SFR / unobscured SFR
  - Need to measure contribution from accretion energies to SMBH (dust torus of AGN) by using Chandra and AKARI data
AKARI NEP Deep Survey: Uniqueness

- Continuously covers 9–24 μm with 5 wavebands, filling the gap of Spitzer
SED Diagnostic: dusty AGN or starburst?

Data Points:
z=1.25 AGN

Dotted Line: Starburst Model

10^{-2}
10^{-4}
10^{-6}
10^{-8}

Flux [Jy]

0.1 1.0 10.0

Wavelength [\mu m]

Broad, Continuous wavelength coverage is essential!

Red AGN, no PAH

PAH

ID10

z_{\text{phot}}=0.6
\chi^2/\nu=2.08
The NEP Survey - footprints

- Deep: 0.38 deg$^2$ (259 pointing)  Wada et al. 2008
- Wide: 5.8 deg$^2$ (446 pointing)    Lee et al. 2009

Imaging with nine IRC wavebands
(N2, N3, N4, S7, S9W, S11, L15, L18W, L24)
NEP-Deep

AKARI/IRC 2,3,4μm colour image

Large 15 & 18 μm selected galaxy sample

>20,000 NIR sources
5000-8000 MIR sources
(about a half is inside the Subaru/S-cam deep image)
Opt.-NIR imaging follow-ups

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Band</th>
<th>Wavelength (μm)</th>
<th>Sensitivity (AB mag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MegaCam (CFHT)</td>
<td>u*</td>
<td>0.37</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>0.49</td>
<td>27.1</td>
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<tr>
<td></td>
<td>r</td>
<td>0.63</td>
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<td></td>
<td>i</td>
<td>0.78</td>
<td>25.6</td>
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<tr>
<td></td>
<td>z</td>
<td>1.17</td>
<td>24.5</td>
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<tr>
<td>SuprimeCam (Subaru)</td>
<td>B</td>
<td>0.43</td>
<td>28.4</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>0.54</td>
<td>28.0</td>
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<tr>
<td></td>
<td>R</td>
<td>0.65</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>0.80</td>
<td>27.0</td>
</tr>
<tr>
<td></td>
<td>z</td>
<td>1.17</td>
<td>26.2</td>
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<tr>
<td>WIRCam (CFHT)</td>
<td>Y</td>
<td>1.02</td>
<td>23.9</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>1.25</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>2.15</td>
<td>23.0</td>
</tr>
</tbody>
</table>

MegaCam: 2011A  WIRCam: 2010A
- Queue mode (PI: T. Goto)
- Oi, N. et al. (2013) submitted
Multi-wavelength Follow-ups

Radio: WSRT & GMRT
WSRT: 1.4GHz 21mJy
Xray: Chandra
  - Suprime-cam field
  - 0.5–7keV, 260 ksec

Karouzos, M.. et al. (2013)
submitted
Far-IR: Herschel data
(PI: Steve Serjeant)

- **SPIRE**
  - 250, 350, 500 microns
  - GT & PV data: 400-900 arcmin$^2$
  - OT2 data: 160x160 arcmin$^2$

- **PACS**
  - 100, 160 microns
    - 8 " @ 100 micron
    - ~1000 sources detected
Recent Progress
(2012-2013)

- Exploration of Star Formation and AGN activity at \( z = 0.4-2 \) by using the \( 1.6 \mu m \) Bump and PAH features (Hanami et al. 2012)
- A multicolour star-galaxy separation from the NIR and MIR AKARI data (Solarz et al. 2012)
- AKARI Observation of the North Ecliptic Pole (NEP) Supercluster at \( z = 0.087 \): Mid-infrared View of Transition Galaxies (Ko et al. 2012)
- The North Ecliptic Pole Wide survey of AKARI: a near- and mid-infrared source catalog (Kim et al. 2012)
- AKARI North Ecliptic Pole Deep Survey, Revision of the catalogue via a new image analysis (Murata et al. 2013)
- Optical – Near-Infrared Catalog for the North Ecliptic Pole Deep Field (Oi et al. 2013 submitted)
- A TALE OF TWO FEEDBACKS: STAR-FORMATION IN THE HOST GALAXIES OF RADIO-AGN (Karouzos et al. 2013, submitted)
- AGN fraction / PAH deficit (Murata et al. 2013 , paper in prep.)
- Mass vs Metalicity at \( z=0.8 \) …..
- Deeply Obscured Galaxies …..
- Clustering of 24 miron selected galaxies (Solaz et al. 2013, paper in prep.)
Improvement of AKARI Images and Catalogues (Murata et al. 2013 A&A, 559)

open to public!!
http://www.ir.isas.jaxa.jp/AKARI/Archive/Catalogues/NEPD_V2/

- Improved analysis methods and source extraction from the AKARI/IRC images have been developed.

The total number of detected objects was increased by ~2000 compared with the previous version of the catalogue; it now has 9560 objects.

MegaCam / Suprime-cam / WIRCam magnitudes are also merged into the catalogue.
Deeply Obscured Galaxies (DOGs)

- Physical quantities (Total IR Luminosity, Stellar Mass, AGN fraction, Dust attenuation etc.) are estimated for 63 DOGs in NEP–Deep field by using CIGALE

Matsuhara, H., Oi, N., et al. in prep.
AKARI All-Sky Survey
Uniqueness

• Large Area IR surveys
  – Spiter (SWIRE): 50 deg²
  – Herschel (H-ATLAS): 500 deg² FIR
  – WISE: All Sky in MIR

• AKARI All-Sky survey, namely at 90 (140 micron), is still filling unique parameter space in the depth vs area diagram.
FIS catalogue data reduction team

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S. Serjeant (Open, UK)
G.J. White (Open, UK)
C. Pearson (RAL, UK)
R. Savage (Sussex, UK / Warwick, UK)
N. Rahman (Sussex, UK / Maryland, USA)
M. Thomson (Sussex, UK)
S. Oliver (Sussex, UK)
L. Wang (IC, UK)
M. Rowan-Robison (IC, UK)
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Th. Müller (MPE, Germany)
M. Cohen (UCB, USA)

FIS H/W team

AKARI operation team
Public release: March 2010
http://www.ir.isas.jaxa.jp/AKARI/Observation/

<table>
<thead>
<tr>
<th>Wavelength (µm)</th>
<th>MIR</th>
<th>FIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sources</td>
<td>9, 18</td>
<td>65, 90, 140, 160</td>
</tr>
<tr>
<td>Detection limit</td>
<td>50 &amp; 130 mJy</td>
<td>3.2, 0.55, 3.8, 7.5 Jy</td>
</tr>
<tr>
<td>Flux uncertainty</td>
<td>5–20 %</td>
<td>20 ~ 30 %</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~7 arcsec</td>
<td>~1 arcmin</td>
</tr>
<tr>
<td>Position uncertainty</td>
<td>1–3 arcsec</td>
<td>~6 arcsec</td>
</tr>
</tbody>
</table>
“Treasure Hunting”
by using FIS BSC ver.1
(Koyama, S. et al. in prep.)

- Arp220–like ULIRGs Candidate Search by using FIS Wide–S & WISE W3, W4

Template SEDs

Arp220
NGC6240
M82

$S(90)/S(12)$ vs. $S(90)/S(22)$

Arp220
NGC6240
M82
“Treasure” Candidates

- $|b| > 30\text{deg}$ (LMC is also masked), WISE ext\_flag=0 (point-like)
  - 15% match (1705 AKARI sources in Northern Hemisphere)

- color-color cut & sources with existing SDSS imaging data (but no SDSS spec-z)

<table>
<thead>
<tr>
<th>photo-z</th>
<th>luminosity distance [Mpc]</th>
<th>$\nu L_\nu \left[ L_\odot \right]$</th>
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<tbody>
<tr>
<td>0.148</td>
<td>702</td>
<td>4.62e11</td>
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<tr>
<td>0.274</td>
<td>1399</td>
<td>1.01e12</td>
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<td>0.387</td>
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<td>0.224</td>
<td>1113</td>
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<td>0.215</td>
<td>1063</td>
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<tr>
<td>0.143</td>
<td>677</td>
<td>2.89e11</td>
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<tr>
<td>0.266</td>
<td>1352</td>
<td>1.18e12</td>
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<tr>
<td>0.217</td>
<td>1074</td>
<td>7.28e11</td>
</tr>
</tbody>
</table>
Products under construction

- **Bright Source Catalogue version 2**
  - Uniform sensitivity (per single scan)
    - More scans, more reliability
  - Catalogue open to public in the end FY2014

- **Faint Source Catalogue version 1**
  - More scans, more sensitivity
    - Sensitivity depends on scan density
  - Catalogue open to public in mid FY2015
FSC Test Processing vs BSC_V1

50x50 deg$^2$ region around Ecliptic poles (Galactic coordinates)

Issei Yamamura

AKARI conference2 2012/02/27
FSC Test Processing vs BSC_V1

- Source count in the region $|\beta| \geq 80$ deg
- The sensitivity is improved as expected from the number of scans

![Graph showing source count and sensitivity comparison between FSC Test and BSC_V1.]

0.2 Jy

0.8 Jy

Typical scan density @ 85 deg ~ 40

$\sqrt{40/3} \sim 3.7$
AKARI NEP & All-Sky Surveys
Summary

• The NEP-Deep Survey
  – provides us with several thousands of 15 μm or 18 μm selected sample of galaxies, which is the largest sample ever made at this wavelengths.
  – A continuous filter coverage in the mid-IR wavelength (2.4, 3.2, 4.1, 7, 9, 11, 15, 18, and 24 μm) is unique and vital to diagnose the contributions from starbursts and AGNs in the galaxies at the violent epoch.

• The AKARI All Sky Survey
  – unique science products namely in FIR
  – Treasures are hidden!
  – Faint-Source catalogue will be released in FY2015

*The 3rd Int’l AKARI conference will be held in Oxford, 9-11 July, 2014*
Lessons Learned?

- NEP Deep: multi-wavelength ancillary data are extremely useful for any sciences
  - For WISH: mandatory to organize the coordinated and follow-up study with other observatories to study WISH high-z sources
  - Caveat: don’t duplicate the same thing as that other observatories will do. Such functions should be dropped or regarded as lower-priority ones.
- AKARI launched in Feb. 2006, long after numerous Spitzer deep surveys were already undertaken. Thus the NEP deep data are NOT attractive except for AKARI’s unique 9–24 micron coverage
Lessons Learned ? (cont.)

- Far-IR All Sky Survey: this certainly was the main goal of AKARI mission, and although by now its uniqueness was not widely recognized, but the science potential is very large, and will be the main unique product from AKARI.

  → For WISH: I recommend to stick on the main science goals, and the instrumentation should be optimized to perform these main goals.

  - A Far-IR All Sky surveyor with much better sensitivity than AKARI is NOT yet planned / proposed. → Plan after SPICA?