Publications of the Korean Astronomical Society
32: 213 ∼ 217, 2017 March

pISSN 1225-1534
eISSN 2287-6936
https://doi.org/10.5303/PKAS.2017.32.1.213

OVERVIEW OF NORTH ECLIPTIC POLE DEEP MULTI-WAVELENGTH SURVEY (NEP-DEEP)

H. Matsuhara[1,18], T. Wada[1], N. Oi[1], T. Takagi[1], T. Nakagawa[1], K. Murata[1,18], T. Goto[2], S. Oyabu[3], T. T. Takeuchi[3], K. Małek[3], A. Solarz[3], Y. Ohyama[4], T. Miyaji[5,7], M. Krumpe[6,7,17], H. M. Lee[8], M. Im[8], S. Serjeant[9], C. P. Pearson[9,10,16], G. J. White[9,10], M. A. Malkan[11], H. Hanami[12], T. Ishigaki[12], D. Burgarella[13], V. Buat[13], and A. Pollo[14,15]

[1] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, , Kanagawa 229-8510, Japan
[2] Institute of Astronomy, National Tsing Hua University, Hsinchu, Taiwan 30013, R.O.C
[3] Graduate School of Science, Nagoya University, Nagoya, Aichi 464-8602, Japan
[4] Academia Sinica, Institute of Astronomy and Astrophysics, Taiwan
[5] Instituto de Astronomia, Universidad Nacional Autonoma de Mexico, Ensenada, Baja California, Mexico
[6] Max-Planck-Institut für extraterrestrische Physik, Giessenbachstraßè, 85748 Garching, Germany
[7] University of California, San Diego, Center for Astrophysics and Space Sciences, La Jolla, CA, USA
[8] Department of Physics & Astronomy, FPRD, Seoul National University, Seoul 151-742, Korea
[9] Department of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK
[10] Rutherford Appleton Laboratory Oxon, OX11 0QX, UK
[11] University of California, Los Angeles, CA 90095-1547, USA
[12] Iwate University, 3-18-34 Ueda, Morioka, Iwate 020-8550, Japan
[13] Aix-Marseille Université, CNRS, LAM, UMR7326, 13388, Marseille, France
[14] National Center for Nuclear Research, Poland
[15] Jagiellonian University Observatory, Poland
[16] Oxford Astrophysics, Denys Wilkinson Building, University of Oxford, Keble Rd, Oxford OX1 3RH, UK
[17] ESO Headquarters, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany
[18] Department of Space and Astronautical Science, The Graduate University for Advanced Studies, Japan

E-mail: maruma@ir.isas.jaxa.jp

(Received September 3, 2015; Revised October 24, 2016; Accepted October 24, 2016)

ABSTRACT

The recent updates of the North Ecliptic Pole deep (0.5 deg^2, NEP-Deep) multi-wavelength survey covering from X-ray to radio-wave is presented. The NEP-Deep provides us with several thousands of 15 μm or 18 μm selected galaxies, which is the largest sample ever made at these wavelengths. A continuous filter coverage in the mid-infrared wavelength (7, 9, 11, 15, 18, and 24 μm) is unique and vital to diagnose the contributions from starbursts and AGNs in the galaxies out to z=2. The new goal of the project is to resolve the nature of the cosmic star formation history at the violent epoch (e.g. z=1–2), and to find a clue to understand its decline from z=1 to present universe by utilizing the unique power of the multiwavelength survey. The progress in this context is briefly mentioned.

Key words: infrared: galaxies — galaxies: starburst — AGN — dust

1. INTRODUCTION

The mid- and far-infrared (MIR and FIR) wavelengths are quite important probes to explore the star formation and growth of super-massive black holes (SMBHs) in the universe, since the early stages of the star-formation and interacting processes with active galactic nuclei (AGN) most likely take place within nuclear regions obscured by dust. The North Ecliptic Pole (NEP) survey (Mat-

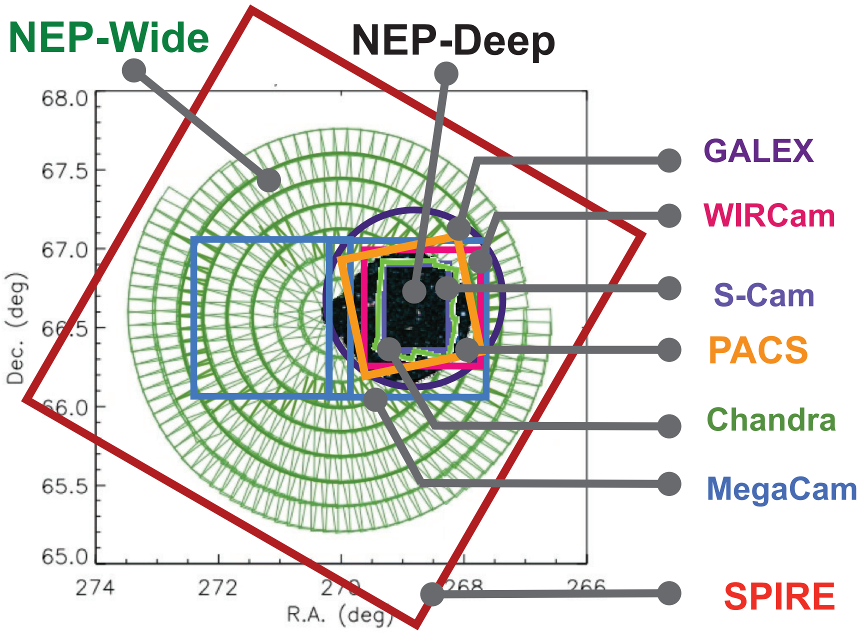

Figure 1. Sky coverage of the multi-wavelength data around NEP. See Table 1 for more information (e.g. areas, depths). New optical-NIR data is also shown in Figure 2.

suhara et al., 2006) was one of the large area surveys of the AKARI/IRC, and is optimally designed to explore the dust obscured universe up to $z \sim 2$, with unique, unpararelled continous wavelength coverage over the 8-24 μm wavelength gap of the *Spitzer*, namely by the existence of 9, 11, 15, and 18 μm bands. The AKARI NEP survey consists of two survey projects; deeper one is 'NEP-Deep' (0.5 deg^2, Wada et al., 2008) while a shallower but wider one is 'NEP-Wide' (5.4 deg^2, Lee et al., 2009). In order to effectively utilize the value of unique MIR data of AKARI, numerous multiwavelegth data, from X-ray to radio-wave, were obtained. The status of multi-wavelength data available for NEP-Deep at the time of the 2nd AKARI conference was presented in Matsuhara et al. (2012). This paper aims to describe the major updates over the last few years.

It is noteworthy to put a few sentences on the science goal of this mutltiwavelength survey projects. One of our major science goals was "to reveal the cosmic star-formation (CSF) history at z=1–2", and this has been already achieved to some extent: in case of AKARI, Goto et al. (2010) presented. After the launch of Herschel the understanding of CSF history, based on other multiwavelength survey projects (GOODS, COSMOS, etc.) has been extended to $z \sim 4$ (Burgarella et al., 2013; Madau & Dickinson, 2014). Therefore, we now set the new goal as "to resolve the nature of CSF at the violent epoch (e.g. z=1–2), and to find a clue to understand the decline of CSF from z=1 to present universe", by using the power of the NEP multiwavelength survey data: for example, we can classify the dusty AGN and starburst from the MIR spectral energy distributions (SEDs), evaluate the star-formation strength (starburstiness) with the ratio of total IR luminosity and rest 8 μm luminosity (Elbaz et al., 2011), and estimate the dust attenuation from UV to FIR SED fitting. In section 3, we also briefly highlight them.

2. RECENT PROGRESS IN MULTIWAVELENGTH DATA

Sky coverage of the multi-wavelength data around NEP is shown in Figure 1. A zoom-up view around the NEP-Deep survey area with areal coverage of the new optical-NIR images is given in Figure 2. A list of currently available multiwavelength data is shown in Table 1. Note that the list focuses on the NEP-Deep although the survey area of some data covers the NEP-Wide as well. The data with major updates are shown in boldface. The quality of the nine AKARI/IRC band images has been greatly improved and a new band-merged catalogue was created with improved depth ($\sim$ 20%) and reliability (Murata et al., 2013). The catalogue was opened to public in October 2013 through the ISAS DARTS archive. As for the optical-NIR data, new band-merged catalogue (u^*, g', r', i', z', Y, J, $K_{\rm s}$) was generated from

Table 1
The NEP-Deep Multi-wavelength data. Recent (last two years) progress are highlighted in boldface.

Observatory/Instrument	Band/Filter	Sensitivity	Area/Target	Status (Sep. 2014)
AKARI/IRC	2.4-24 μm, 9 bands	90μJy@15μm	0.5 deg^2	**updated, published**[1]
AKARI/IRC (Spec.)	2.4-12 μm, 9 bands	$\sim$1mJy@9 μm	$\sim$100 sources	paper in prep.
Subaru/SuprimeCam	$BVRi'z'$, NB711	B =28 ABmag	$27' \times 34'$	paper in prep.
Subaru/**HSC**	r	r =27.2 ABmag	5.4 deg^2	analysis on-going
Subaru/FOCAS	optical spec.	$R \sim 24$ ABmag	57 sources	paper in prep.
Subaru/**FMOS**	JH spec.	$J \sim 19$ ABmag	$\sim$700 sources	paper in prep.
Keck/DEIMOS	opt. spec.(July 2008)	$R \sim 24$ ABmag	420 sources	analysis completed
	opt. spec.(July 2011)		$\sim$600 soures	analysis on-going
	opt. spec.**(Aug. 2014)**		$\sim$200 soures	analysis on-going
MMT,WIYN	optical spec.		5.4 deg^2	**published**[2]
GTC/OSIRIS-MOS	optical spec.		190 sources	analysis on-going
CFHT/MegaCam	g' r' i' z'	$r' \sim 25$ ABmag	2 deg^2	published[3]
	u^* g' r' i' z'	$r' \sim 26.5$ ABmag	1 deg^2	**published**[4]
CFHT/WIRCam	YJK_s	$K_s \sim 24$ ABmag	0.5 deg^2	**published**[4]
KPNO 2.1m/Flamingos	JK_s	K_s=20 Vega mag	$25' \times 30'$	published[5]
KPNO 4m/NEWFIRM	HK_s	K_s=22 ABmag	$27' \times 27'$	analysis completed
Chandra/ACIS-I	0.5-7 keV	(30-50ksec)	0.34 deg^2	**published**[6]
GALEX	NUV, FUV	NUV$\sim$26 AB mag	circular, 1.0 degϕ	paper in prep.
Herschel/SPIRE	250, 350, 500 μm	$\sim$10 mJy	7.1 deg^2	**paper in prep.**
Herschel/PACS	100, 160 μm	5-10 mJy	0.5 deg^2	**paper in prep.**
JCMT/SCUBA-2	450, 850 μm	$\sim$ 1mJy	0.25 deg^2	analysis on-going
WSRT	1.5GHz	0.1 mJy	$\sim$1.7 deg^2	published[7]
GMRT	610MHz		$\sim$0.5 deg^2	analysis on-going

[1] Murata et al. (2013); [2] Shim et al. (2013); [3] Hwang et al. (2007); [4] Oi et al. (2014); [5]Imai et al. (2007); [6] Krumpe et al. (2014); [7] White et al. (2010)

newly obtained deep images with CFHT/MegaCam and WIRCam (Oi et al., 2014). The 300 ks Chandra X-ray image data are also published in Krumpe et al. (2014). Regarding the FIR/submm data Herschel/PACS observations could be undertaken just before the running out of the cryogen for Herschel. The imaging data analysis for both PACS and SPIRE has been done to some level (see the paper by Pearson et al. in this proceeding). Significant progress was also seen in the spectroscopic follow-up; Keck/DEIMOS optical spectroscopic observations were undertaken for $\sim$1000 sources, and also a GTC/OSIRIS-MOS observing run was successful. NIR (1.0-1.8 μm) data with Subaru/FMOS were also successful and good spectra were obtained for $\sim$100 sources.

3. RECENT SCIENTIFIC PROGRESS

Great progress was seen in the study of dusty star-formation and AGN activity out to z=2 by mainly utilizing the unique AKARI/IRC photometry data covering continously 2.4-24 μm wavelengths. Hanami et al. (2012) showed that the rest-frame 8 μm and 5 μm luminosities are good tracers of star-forming and AGN activities from their Polycyclic Aromatic Hydrocarbons (PAH) and dusty tori emissions, respectively. As for the AGN dominated MIR-selected sources (inferred from their MIR SEDs), Krumpe et al. (2014) found a high ($\sim$ 40%) X-ray detection rate, while sources without any sign of AGN activity in their MIR SEDs have a very low X-ray detection rate of 3%. They also concluded that roughly 30% of IR-selected AGN are strong Compton-thick AGN candidates; this is about to be verified by rest-frame X-ray stacking (Miyaji et al. in prep.). On the other hand, Murata et al. (2014) extracted the pure starburst sources after excluding the AGN candidates by the SED fitting. They found that rest-frame 8 μm / 5 μm luminosity ratio (e.g. a proxy of PAH equivallent width) is not proportional to the starburstiness (specific star-formation rate (sSFR) normalized by that of the main-sequence) at higher starburstiness, indicating the PAH feature deficit under the intense starburst.

Many on-going projects will lead to publications in the near future. NIR spectroscopic follow-up of MIR selected sources provides the opportunity to investigate metallicity of $z \sim 0.8$ dusty IR luminous galaxies by

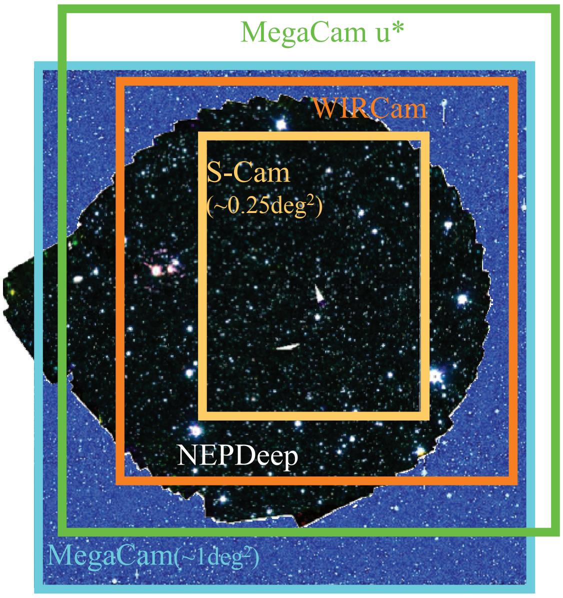

Figure 2. Sky coverage of optical-NIR images recently obtained with CFHT (Oi et al., 2014): WIRCAM Y, J, K_s and MegaCam u^*, g', r', i', z', overlayed on the AKARI NEP-Deep false-colour image (dark-black background).

[N II]/H_α ratio (Oi et al., in prep.). The sSFR and dust attenuation evolution can be studied by using the rest-frame 8 μm selected sample out to z=2 (see Buat et al. paper in this conference), where sSFR and dust attenuation are derived by the SED fitting with CIGALE (Code Investigating GALaxy Emission, http://cigale.lam.fr). It is notable that (U)LIRGs' SED characteristics is under careful investigation using CIGALE fitting (Malek et al. in prep.). By using the New FIR (PACS) photometry data re-analysis of sSFR of the MIR-selected galaxies, and of AGN fraction by also using the X-ray (Chandra) data is on-going (Ishigaki et al. in prep.). By using 24 μm selected galaxies at different redshift, evolution of clustering is examined (Solaz et al. 2014, submitted), and stellar mass dependence of sSFR between NEP (AKARI) and SXDF (Spitzer) is examined (Fujishiro et al. paper in this conference).

4. SUMMARY AND FUTURE PROSPECTS

The recent updates of the NEP-Deep multi-wavelength survey covering from X-ray to radio-wave is presented. For existing data, a few catalogue papers were published, while new multiwavelength surveys (Subaru/HSC, JCMT/SCUBA-2) have been undertaken. Significant progress was seen in the dusty AGN/starburst classification (or determination of AGN fraction for each MIR-selected source), and determination of radiation hardness or star-formation mode by using the UV-submm SED. These outcomes are useful to perform the new goal of the project, 'to resolve the nature of the CSF history at the violent epoch, and to find a clue to understand its decline from z=1 to present universe.' In the near future, we aim to obtain multiband photometry data with Subaru/HSC (and CFHT/MegaCam u^*) over 5.4 deg^2 NEP-Wide survey area in order to significantly increase the number of (U)LIRGs with accurate redshift, sSFR, and AGN fraction.

It is also noteworthy that the NEP is the legacy field thanks to its high visibility by the space observatories, such as eROSITA, Euclid, JWST, and SPICA. SPICA, the next generation 3 m class cooled space telescope is extremely powerful to study the rise and fall of the CSF in the universe via the PAH equivallent width diagnostics (see Wada et al. paper in this conference).

ACKNOWLEDGMENTS

We would like to thank all *AKARI* team members for their support on this project. The AKARI NEP-Deep survey project activities are mainly supported by a JSPS grant 23244040, and also partly supported by the Chandra Guest Observer support GO1-12178X, CONACyT grant 83564, and the Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency.

REFERENCES

Burgarella, D., Buat, V., Gruppioni, C., et al., 2013, The Local Universe as Seen in the Far-Infrared and Far-Ultraviolet: A Global Point of View of the Local Recent Star Formation, A&A, 554, A70

Elbaz, D., Dickinson, M., Hwang, H. S., et al., 2011, GOODS-Herschel: an infrared main sequence for star-forming galaxies, A&A, 533, A119

Goto, T., et al., 2010, Evolution of infrared luminosity functions of galaxies in the AKARI NEP-deep field. Revealing the cosmic star formation history hidden by dust, A&A, 514, A6

Hanami, H., Ishigaki, T., Fujishiro, N., et al., 2012, Star Formation and AGN Activity in Galaxies Classified Using the 1.6 μm Bump and PAH Features at z = 0.4-2, PASJ, 64, 70

Hwang, N., et al., 2007, An Optical Source Catalog of the North Ecliptic Pole Region, APJS, 172, 583

Imai, K., Matsuhara, H., Oyabu, S., et al., 2007, J- and Ks-Band Galaxy Counts and Color Distributions in the AKARI North Ecliptic Pole Field, AJ, 133, 2418

Krumpe, M., Miyaji, T., Brunner, H., et al., 2014, Chandra Survey in the AKARI North Ecliptic Pole Deep Field. I.X-ray Data, Point-like Source Catalog, Sensitivity Maps, and Number Counts, MNRAS, in press (arXiv:1409.7697)

Lee, H. M., Kim, S. J., Im, M., et al., 2009, North Ecliptic Pole Wide Field Survey of AKARI: Survey Strategy and Data Characteristics, PASJ, 61, 375

Madau, P. & Dickinson, M., 2014, Cosmic Star-Formation History, ARAA, 52, 415

Matsuhara, H., et al., 2006, Deep Extragalactic Surveys around the Ecliptic Poles with AKARI (ASTRO-F), PASJ, 58, 673

Matsuhara, H., Wada, T., Takagi, T., et al., 2012, Overview of the North Ecliptic Pole Deep Multi-Wavelength Survey NEP-DEEP, PKAS, 27, 123

Murata, K., Matsuhara, H., Wada, T., et al., 2013, AKARI North Ecliptic Pole Deep Survey. Revision of the catalogue via a new image analysis, A&A, 559, A132

Murata, K., Matsuhara, H., Inami, H., et al., 2014, Polycyclic aromatic hydrocarbon feature deficit of starburst galaxies in the AKARI North Ecliptic Pole Deep field, A&A, 566, A136

Oi, N., Matsuhara, H., Murata, K., et al., 2014, Optical - near-infrared catalog for the AKARI north ecliptic pole Deep field, A&A, 566, A60

Shim, H., Im, M., Ko, J., et al., 2013, Hectospec and Hydra Spectra of Infrared Luminous Sources in the AKARI North Ecliptic Pole Survey Field, ApJS, 207, 37

Wada, T., et al., 2008, AKARI/IRC Deep Survey in the North Ecliptic Pole Region, PASJ, 60, 517

White, G. J., et al., 2010, A deep survey of the AKARI north ecliptic pole field . I. WSRT 20 cm radio survey description, observations and data reduction, A&A, 517, A54