Current Status of NEP Survey Large Program

Hyung Mok Lee
KASI

Hyunjin Shim*
Kyungpook National University

*PI of the SCUBA-2/NEP Survey Program

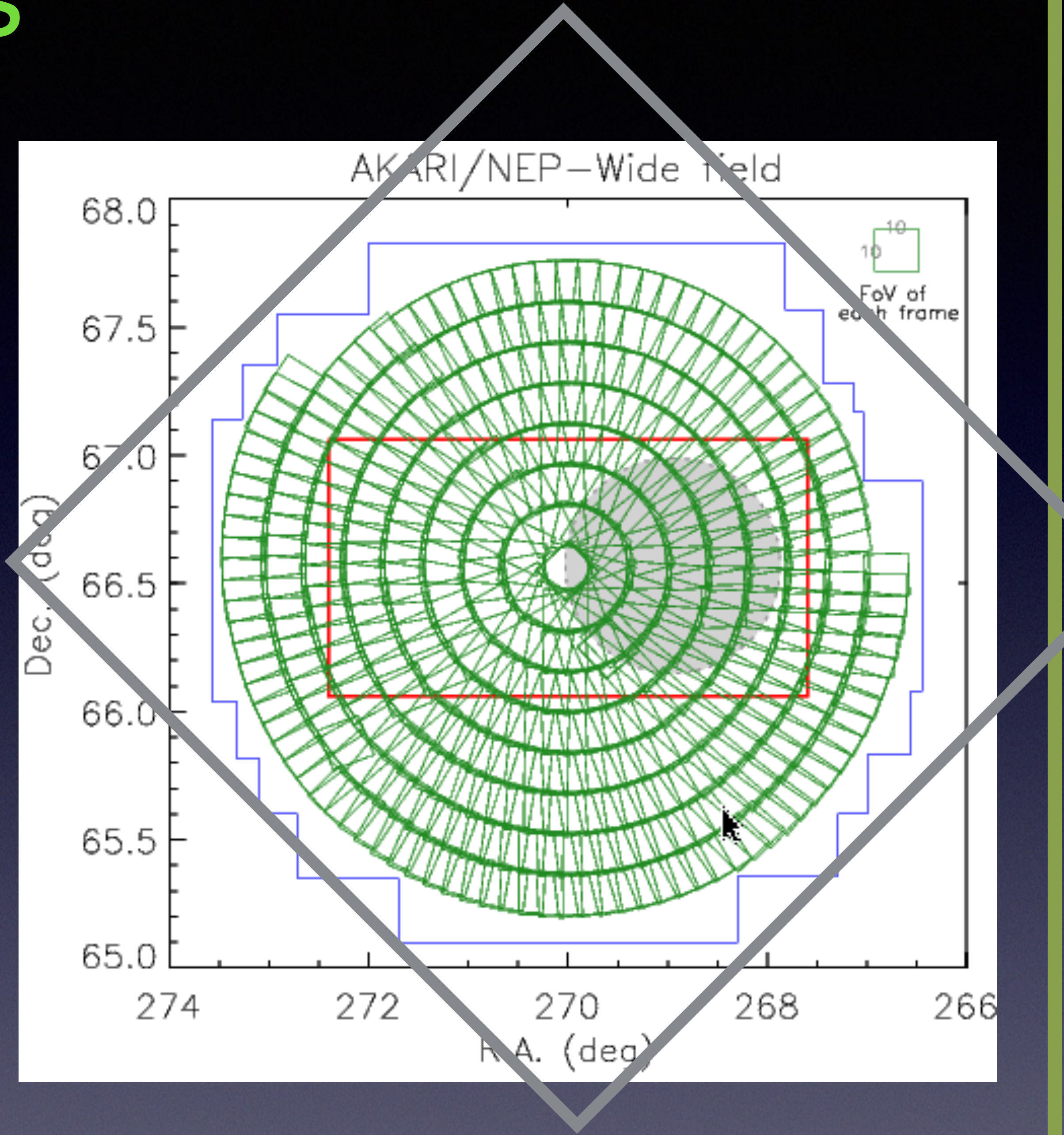
NEP-Wide Surveys at Various Wavelengths

- ✦ AKARI's Legacy Program

  Survey area : 5.4 sq. deg

  446 pointing observations with IRC in 2 - 25 μm

- ✦ Ancillary data
  - ✦ Optical – CFHT, Maidanak (Hwang et al. 2007)
  - ✦ NIR: Kitt Peak FLAMINGOS: (Jeon et al. 2014.)
  - ✦ MMT/Hectospec and WYIN/Hydra Spectroscopic Surveys (Shim et al. 2013)
  - ✦ Herschel/SPIRE (Pearson et al. in preparation)
  - ✦ Hyper Spreme Cam (HSC) Survey with *grizy*
  - ✦ JCMT 850 μm: this talk

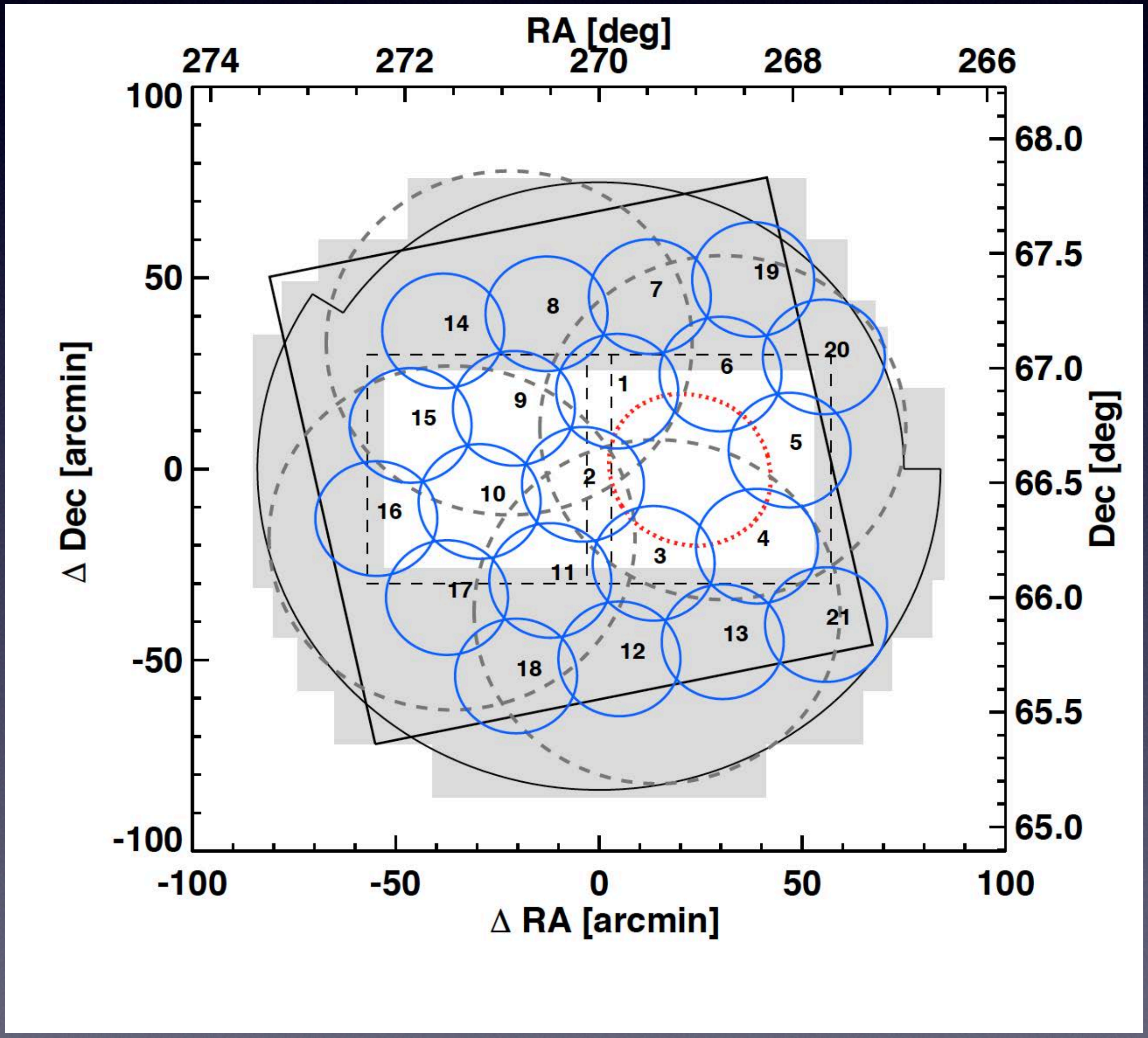


Summary of Proposed Survey with SCUBA2

- Inner 1 sq. degree was covered by Cosmological Large Survey (CLS, Geach et al. 2017)
- Our survey aims to observe remaining ~4 sq. deg. with SCUBA2 at 850 µm

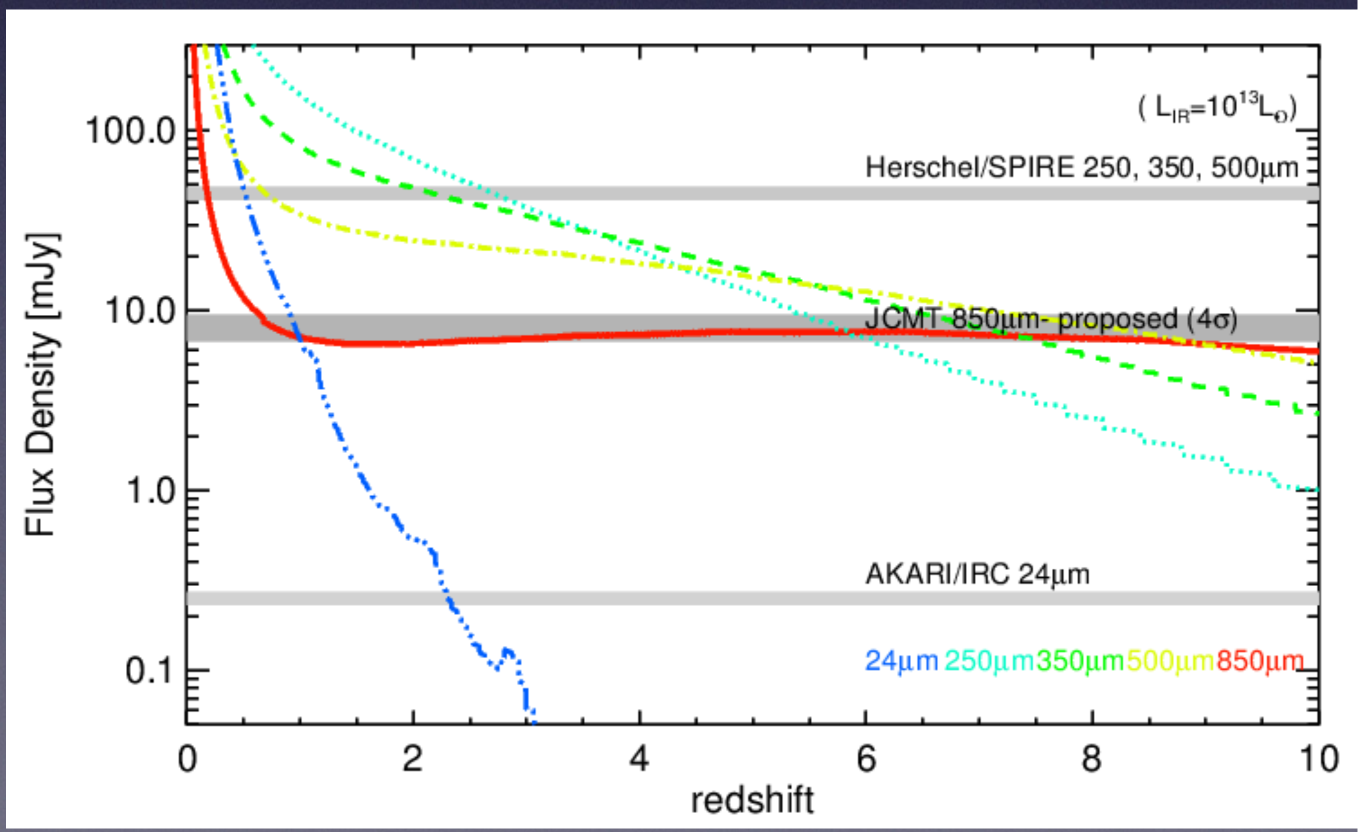
PONG1800 observations: 1-σ sensitivity of 1.83 mJy

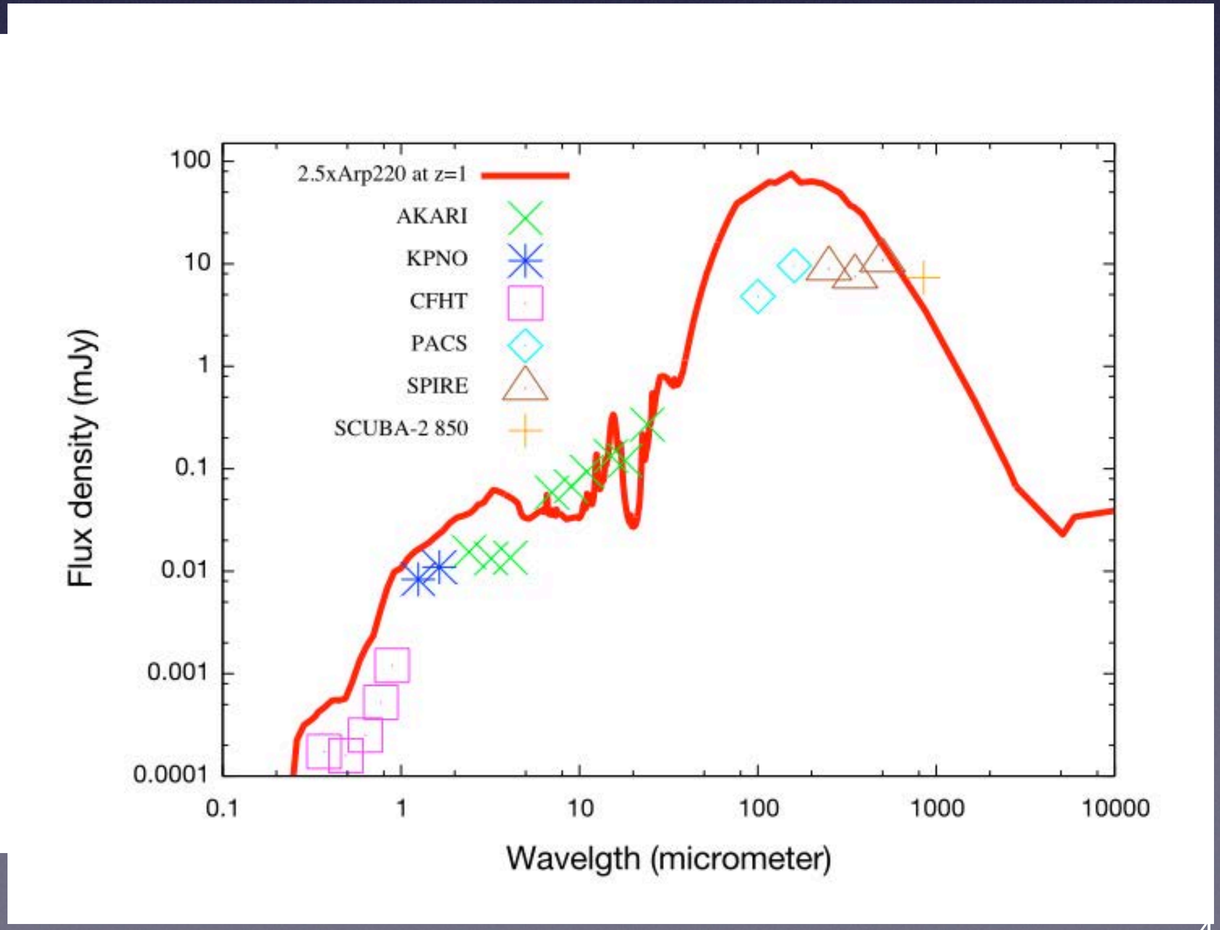
Expected Observing time: 400 hours



Rationale

- The uncertainty of the infrared SED is mainly due to the dust temperature
- Long wavelengths data in the Rayleigh-Jeans side of the infrared SED peak are crucial for reliable infrared SED fitting
- Advantage
  - At 850 μm, the expected flux density remains constant from z ~ 1 to 8





Regional Coordinators

- Korea: Hyunjin Shim (hjshim@knu.ac.kr, PI)
- China: Haojin Yan (yanhaojing@gmail.com)
- Japan: Hideo Matsuhara (maruma@ir.isas.jaxa.jp)
- Taiwan: Tomotsugu Goto (tomo@phys.nthu.edu.tw)
- UK: Stephen Serjeant (stephen.serjeant@open.ac.uk)
- Canada: Douglas Scott (dscott@astro.ubc.ca)

Member Summary (May 15, 2018)

Please provide numbers for:	CN	JP	KR	TW	CA	UK
Registered Members	11	17	15	4	5	15
Institutes	7	4	5	2	3	5
Graduate Students	2	3	2	0	3	2
Postdocs/Fellows	1	4	4	2	0	4
Professors	8	9	9	2	2	9

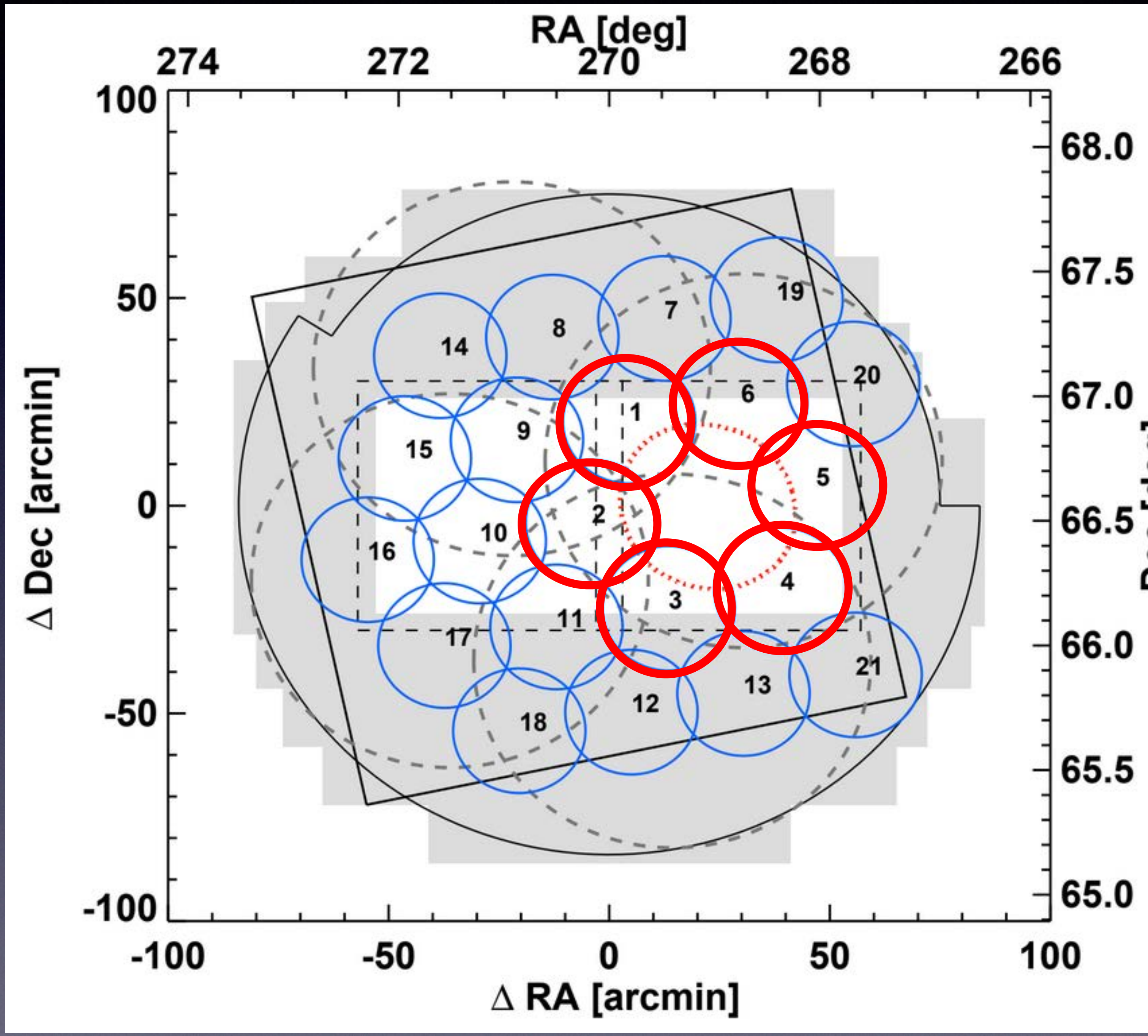
67 members from 6 regions and 26 institutes. There are a few other members from outside of EAO/JCMT partners

Current Status of the Observations

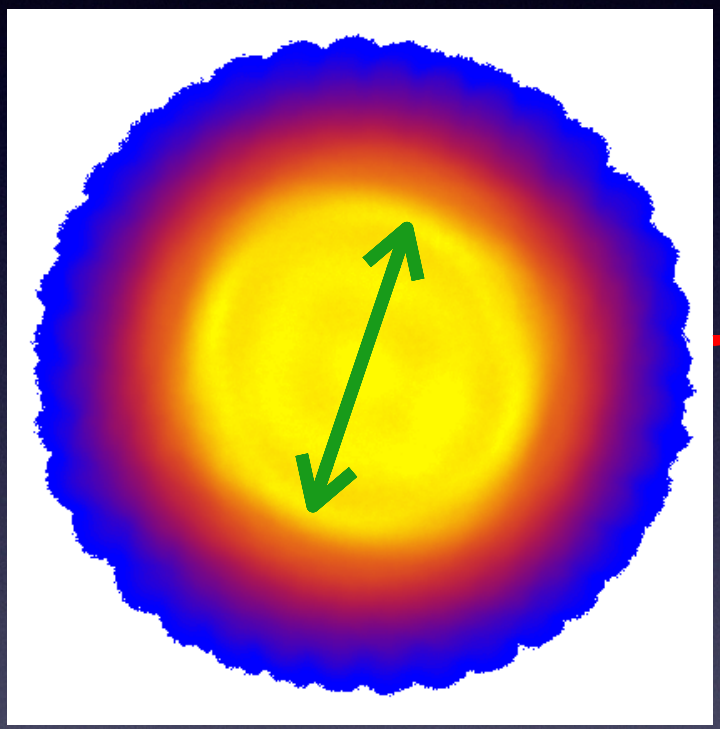
Progress of the Survey

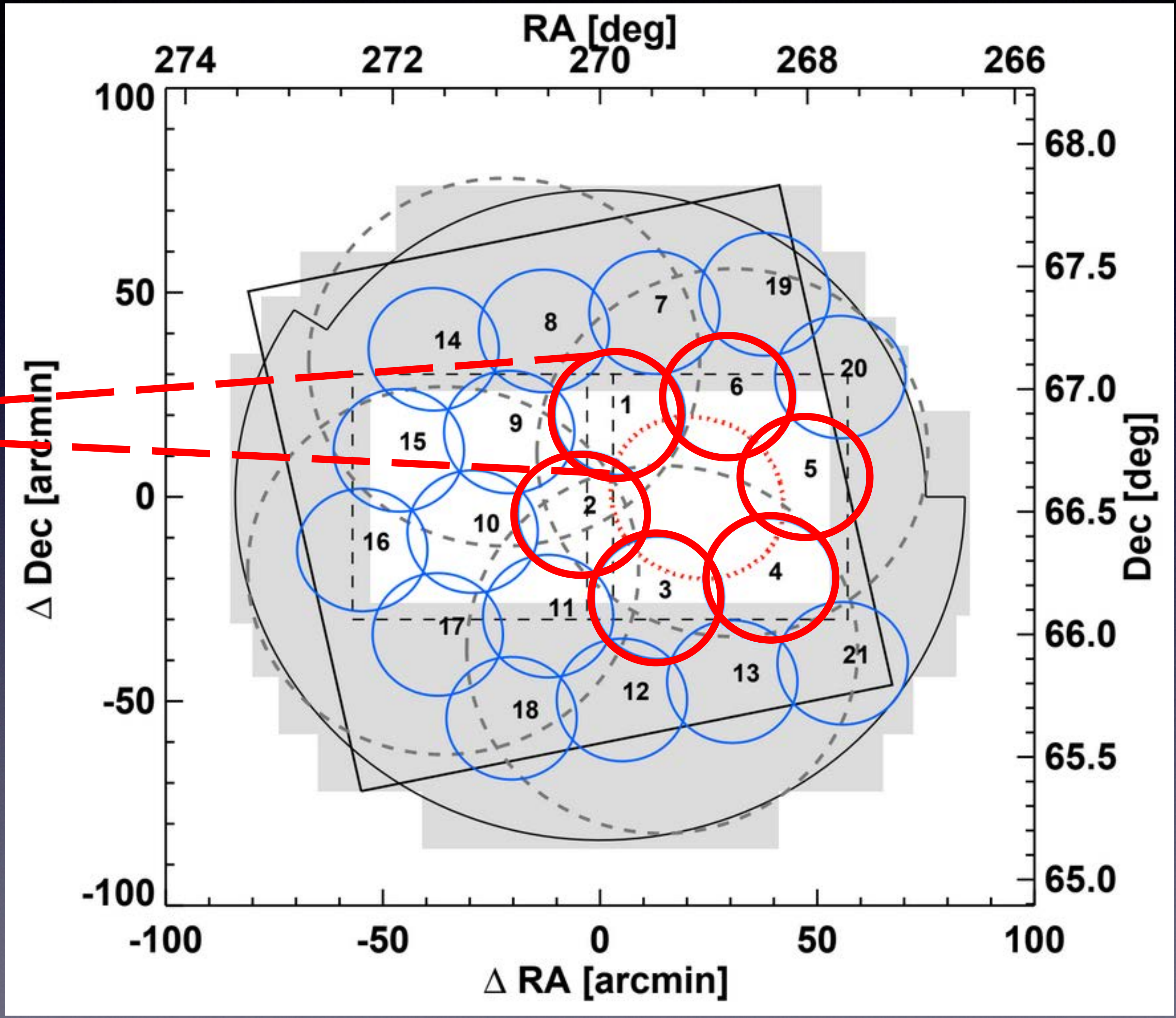
- 400 hrs allocated
- We asked to tile the map in order as written in the plot, NEP1, 2, 3…
- Observation started in late July 2017, but progress until late 2018 was very slow

  ~33% complete by May 12, 2019
- Currently NEP1 to NEP6 are completed, NEP7 is 25% completed.



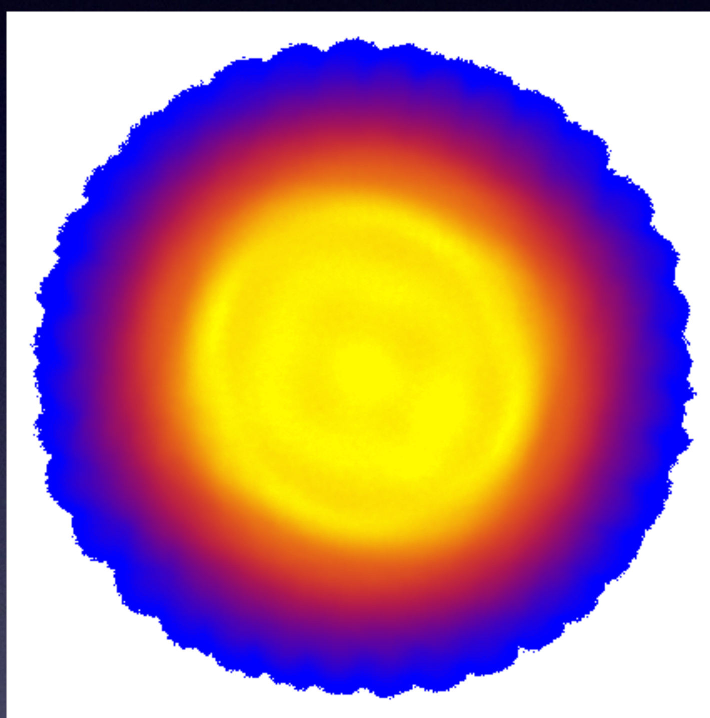
Observing mode: PONG1800

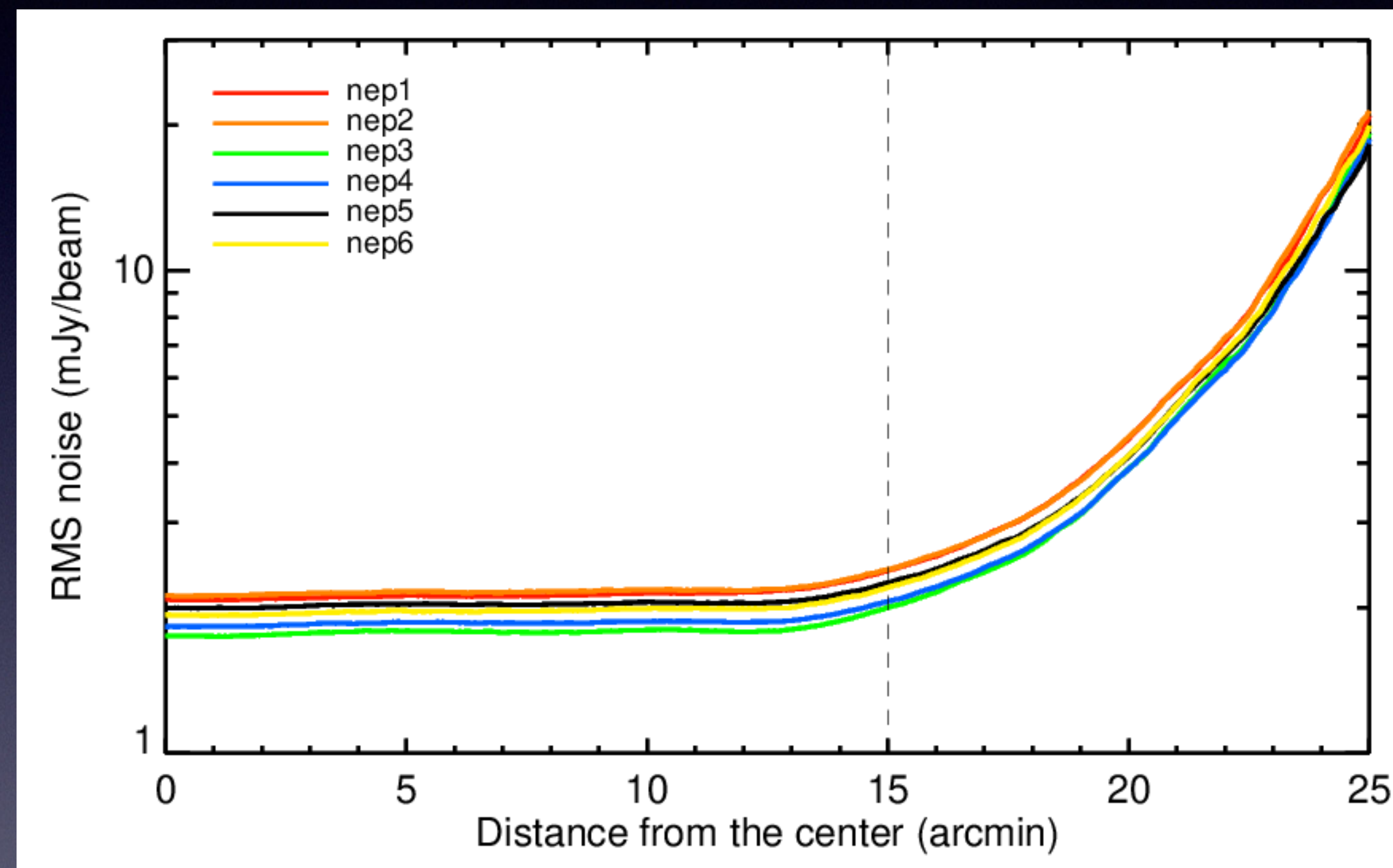




~1800 arcsec (i.e., 30 arcmin) diameter shows fairly uniform rms.

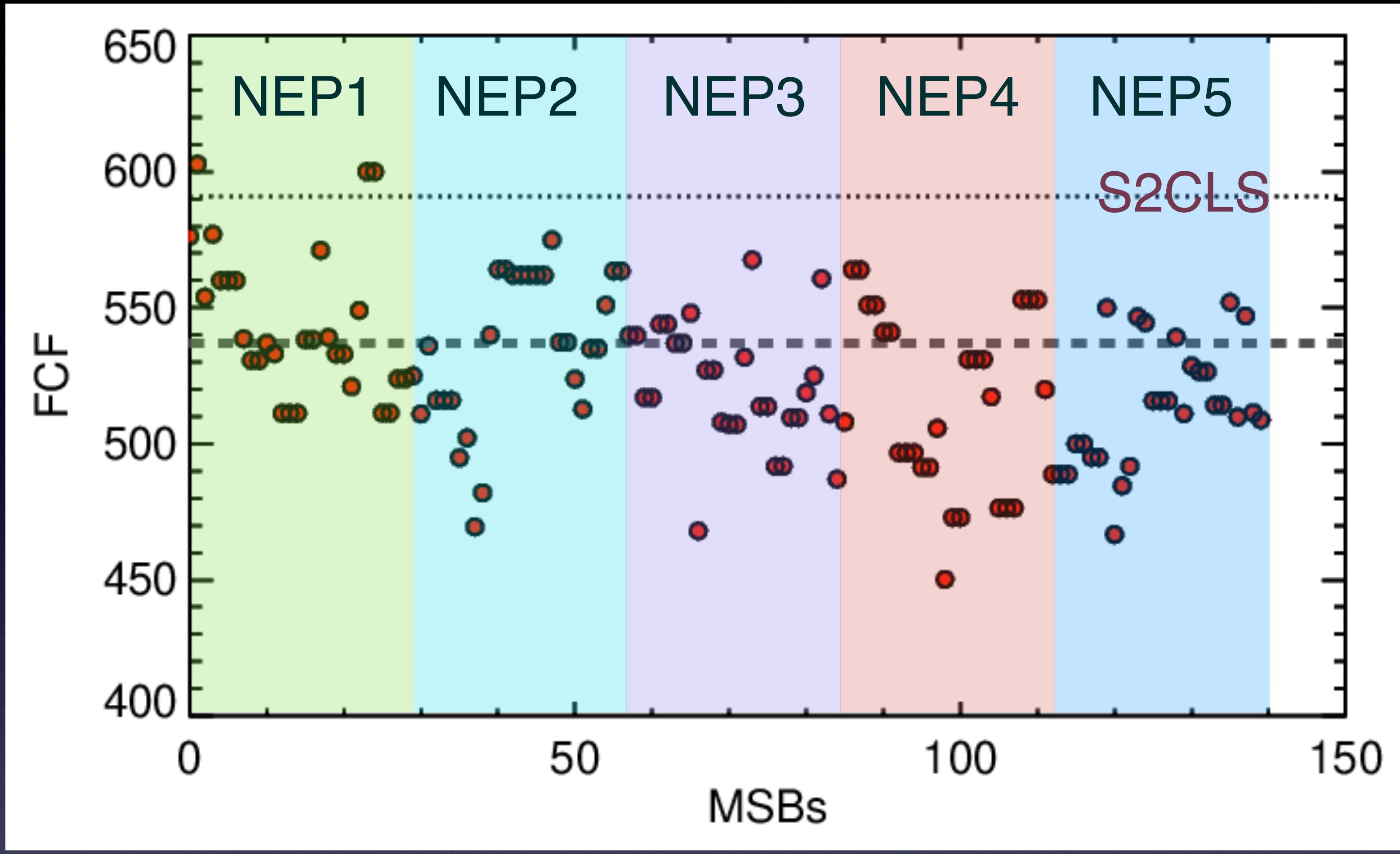
RMS noise distribution with radius: NEP1~6





NEP3 & NEP4 (obtained Feb-Mar 2019) are slightly deeper than other fields.

Flux Conversion Factors



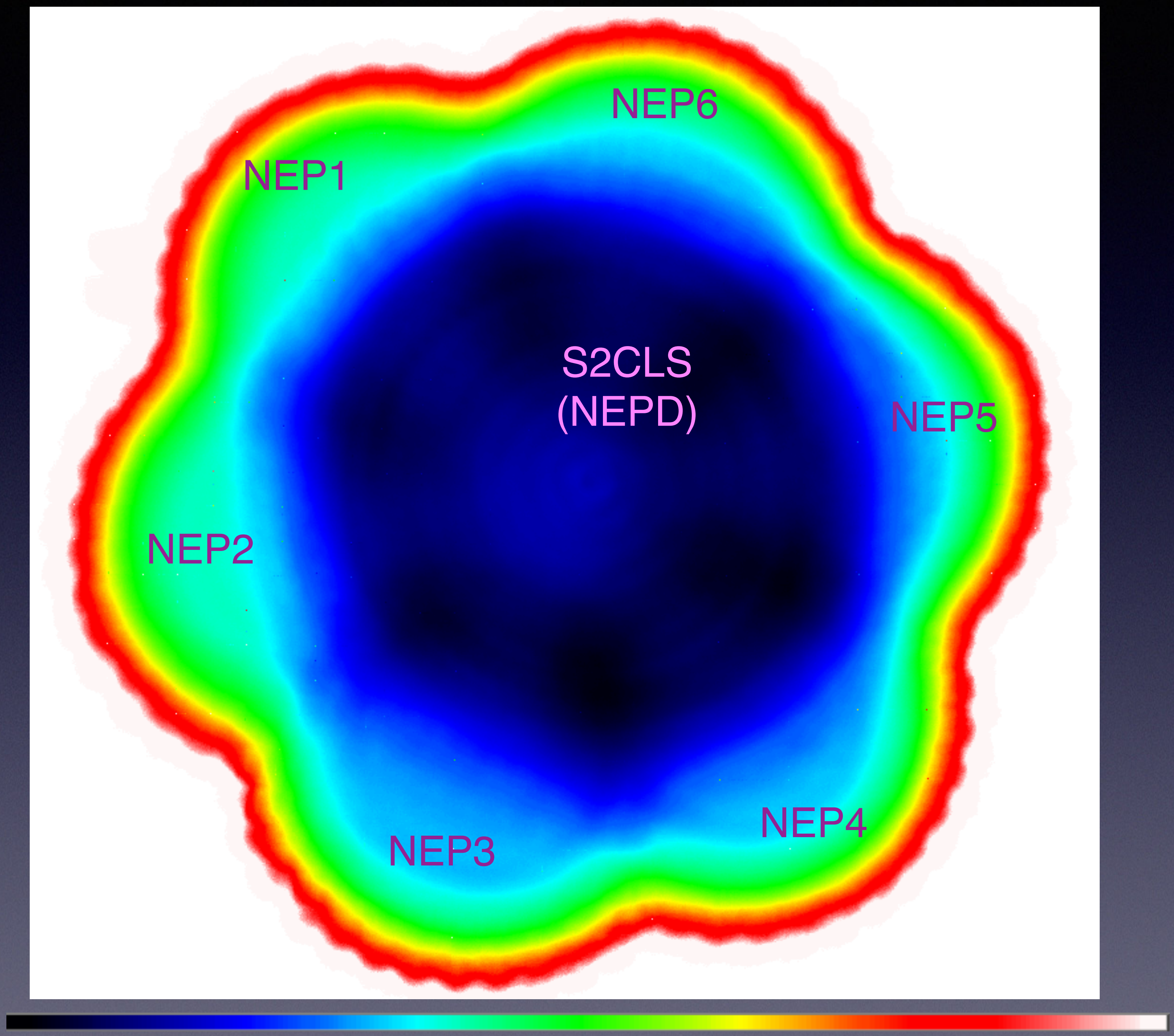
Reference (standard) 850um FCF of SCUBA-2
(1 pixel size, Dempsey+2013, in SCUBA-2 reduction manual)

- Flux Conversion Factor (FCF) coverts SCUBA-2 data (pW) into mJy/beam
- FCF seems to be decreasing slowly: long-term effect related to the instrument, or this is due to the time of observation
  In general, images obtained right after the sunset requires higher FCF values
  NEP1&2 data were mostly obtained summer-autumn, while NEP3, 4, & 5 were obtained in winter-spring.

Survey depths in the combined mosaic image

- S2CLS + NEPs : ~0.92 mJy/beam at the deepest (overlapping area)
- S2CLS : ~1.0-1.2 mJy/beam
- NEP : ~1.7-2.1 mJy/beam

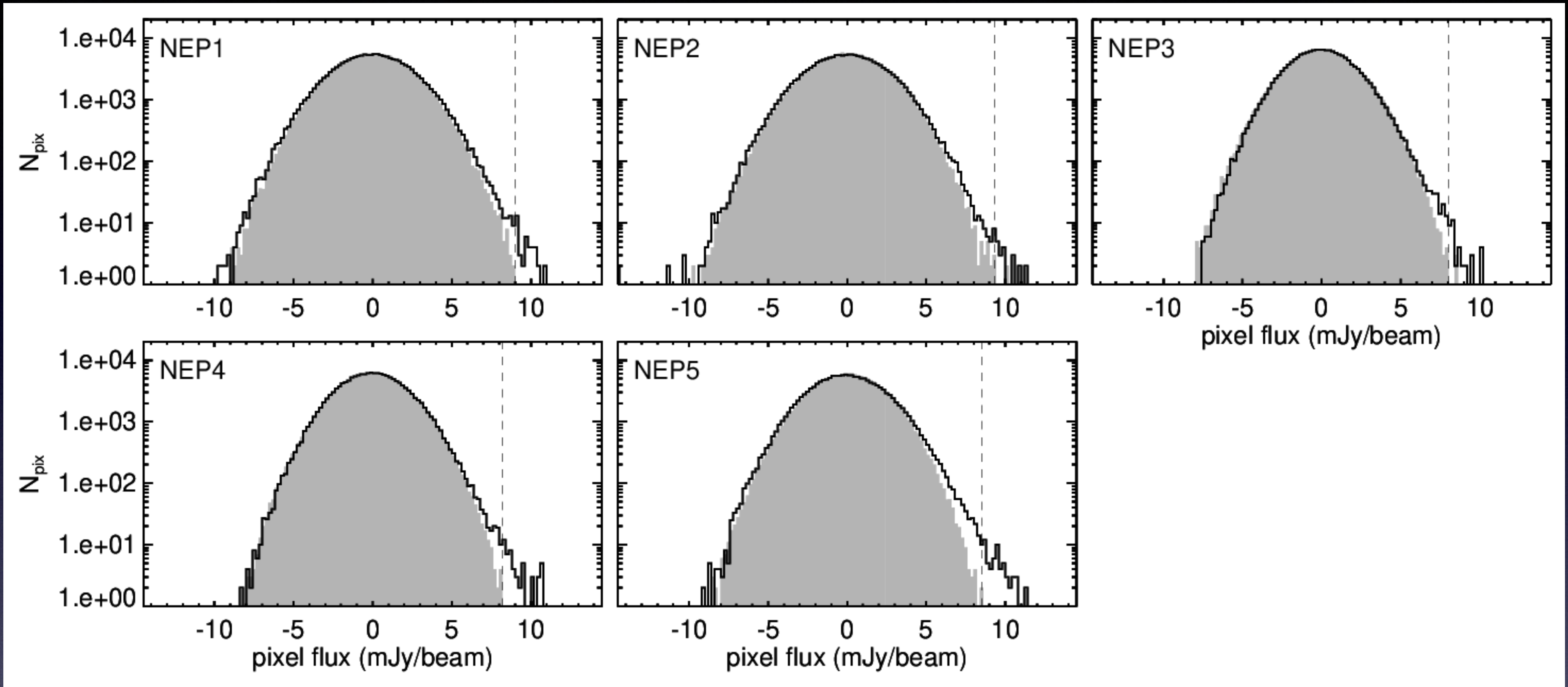
updated 2019.05.13



Construction of the Noise Map

1. Randomly divide flux density maps into two groups (groupA, groupB)
2. Construct mosaic images (mosaicA, mosaicB)
3. Take the differences between the two mosaic (mosaicA - mosaicB) (i.e., jackknife image) - this removes contribution from sources, to produce 'source-free' noise maps
4. Scale the jackknife noise map, by multiplying $\frac{1}{\sqrt{t_1 + t_2}} = 1/\sqrt{2t}$ for $t_1 = t_2 = t$
5. Use the "filtered" noise map in followings (using SCUBA2_MATCHED_FILTER) since we will use filtered flux map in source detection

Pixel Value Distribution

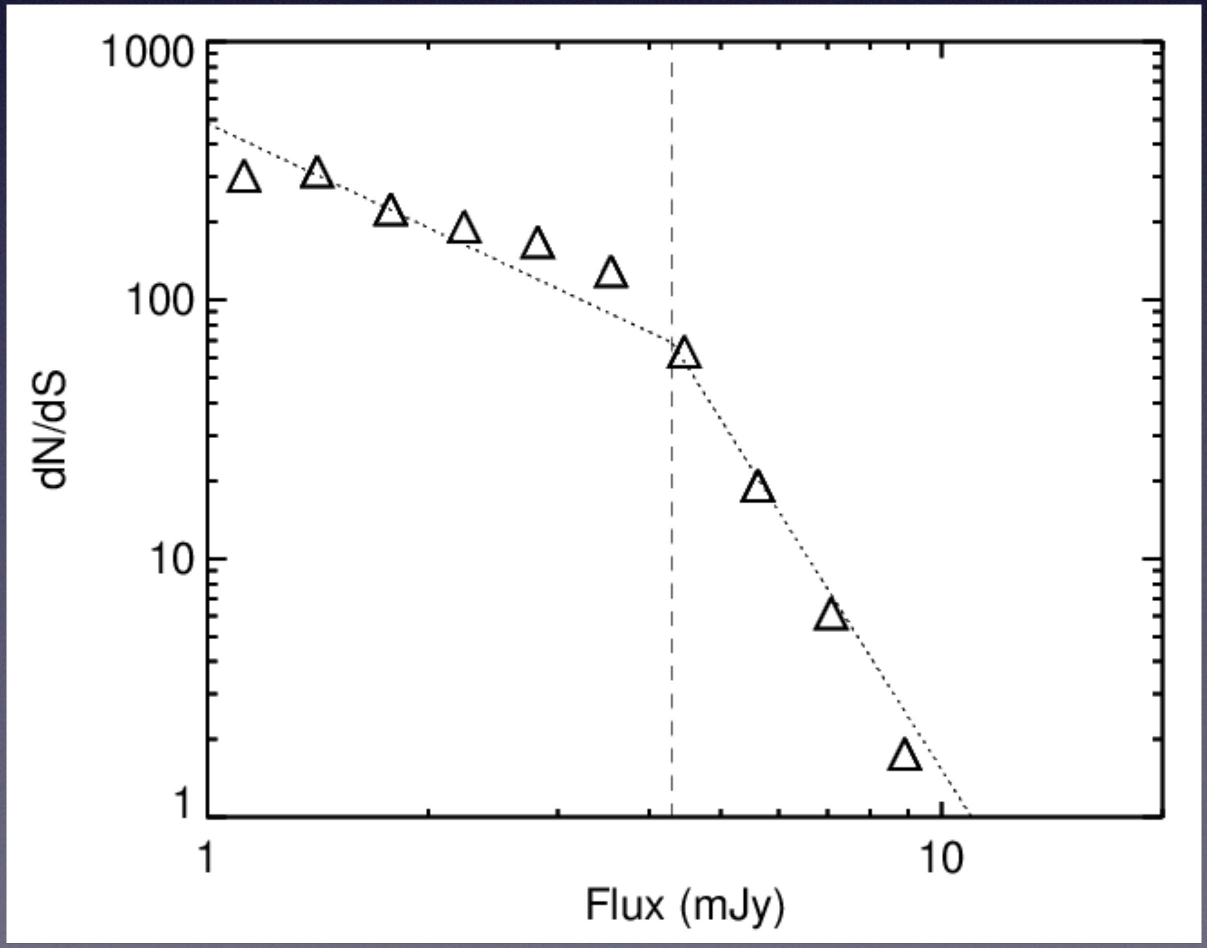


- Solid lines: flux density of the observed images
- Envelope of shades: equivalent distribution in the noise map.
- The “tail” in positive side appears due to the submm sources.

Note that the vertical line may be considered as flux limit.

Monte Carlo Simulations (using Noise Map + artificial sources)

1. Generate catalog of artificial sources with assumed flux density distribution



Flux density distribution based on the previous results (e.g., Casey et al. 2013; double power-law)

$$\frac{dN}{dS} = \begin{cases} \frac{N_0}{S_0}\left(\frac{S}{S_0}\right)^{-\alpha} & : S \leq S_0 \\ \frac{N_0}{S_0}\left(\frac{S}{S_0}\right)^{-\beta} & : S > S_0 \end{cases}$$

Uniform spatial distribution

Monte Carlo Simulations
(using Noise Map + artificial sources)

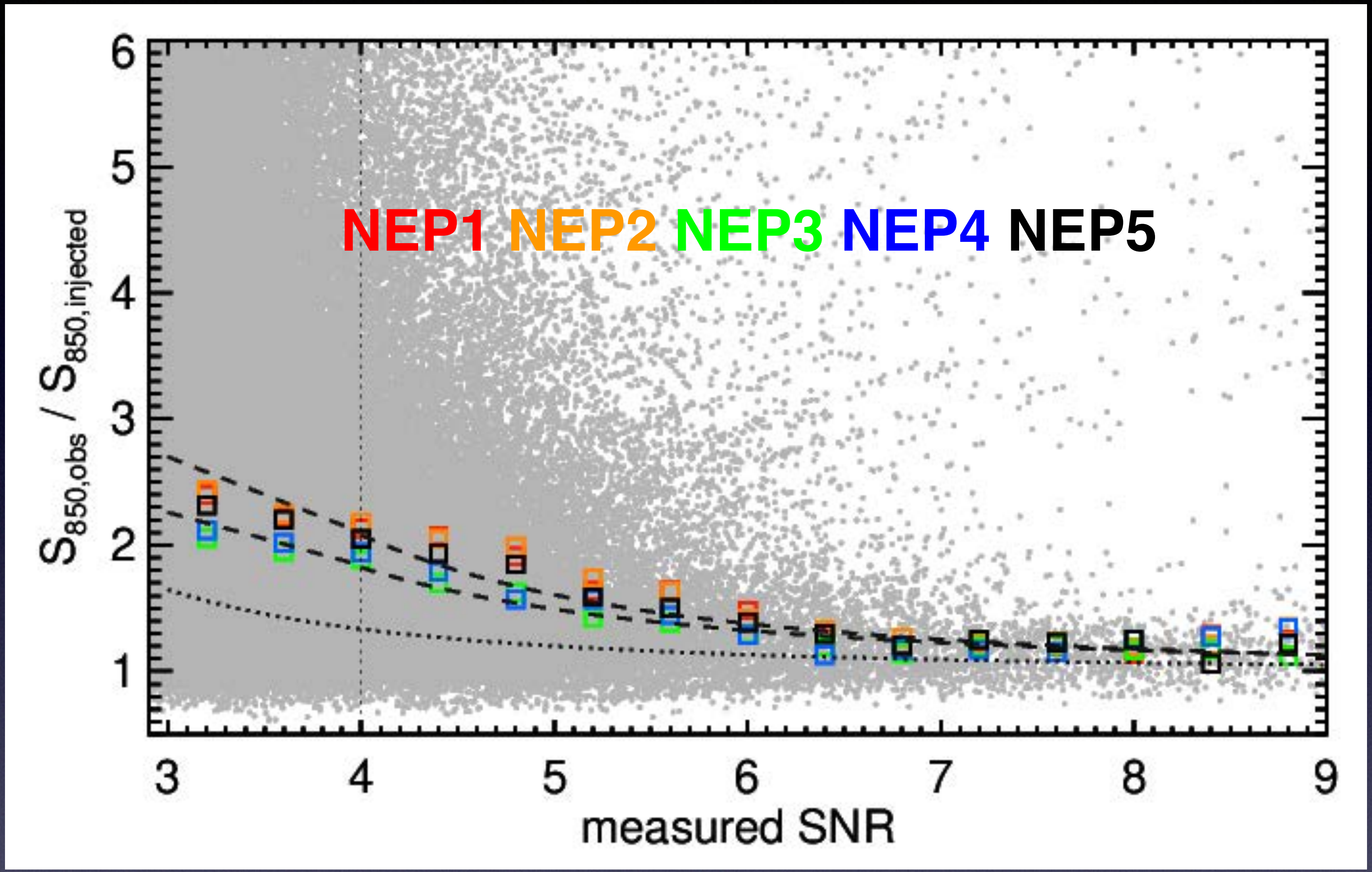
2. Add the artificial sources in the noise map (jackknife image) to produce simulated images

   - 20 random catalog x 10 random noise maps
   - used psf file

3. Perform source detection using the same parameter setting used in the source detection in real flux density map

4. Based on the result, we can (1) calculate deboost factor (=observed flux/injected flux) as a function of SNR, (2) check the positional uncertainty, and (3) estimate the completeness by deriving the recovery rate

Deboost Factors



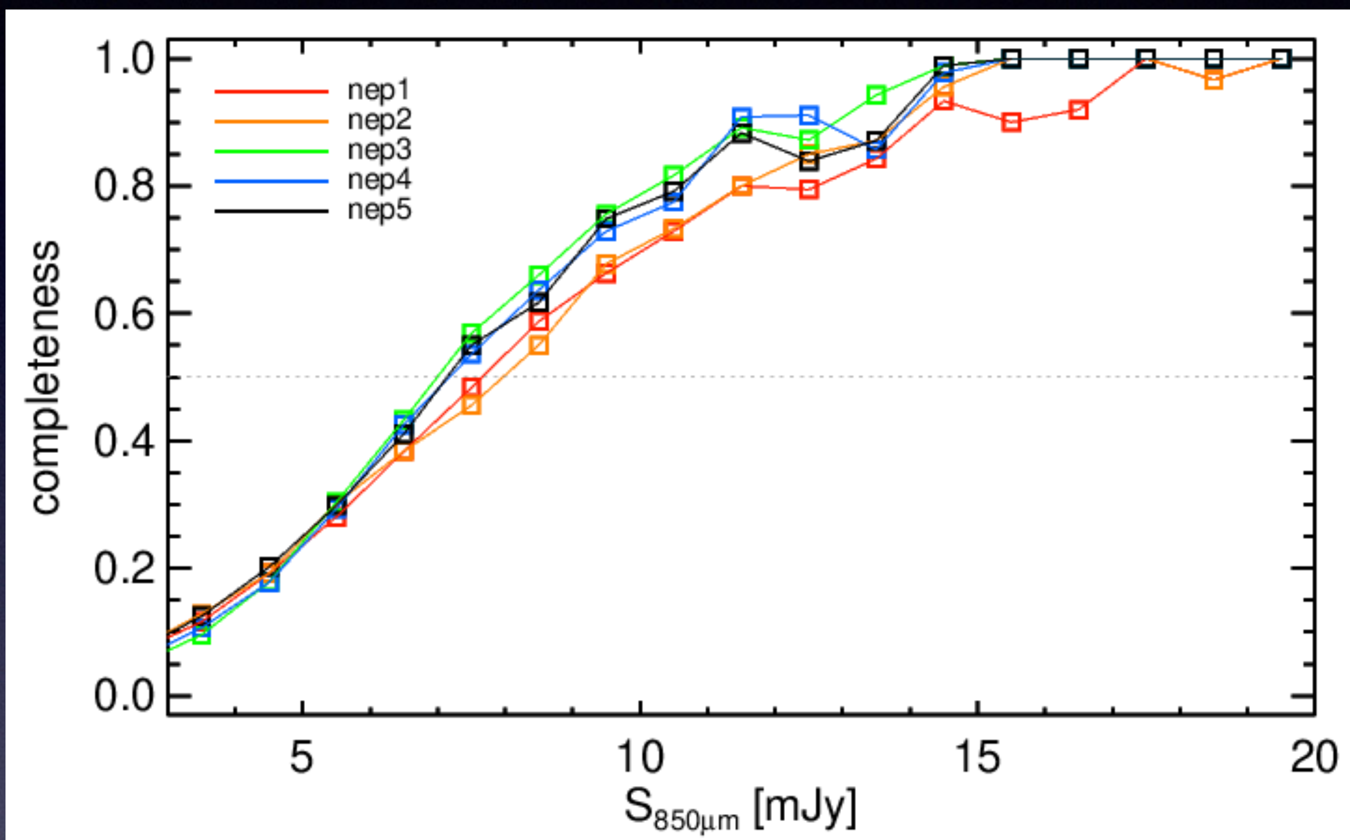
$$\mathcal{B} = 1 + 0.2\left(\frac{\mathrm{SNR}}{5}\right)^{-2.3}$$

Geach et al.(2017), power-law description of deboost factor *B* (dotted line)

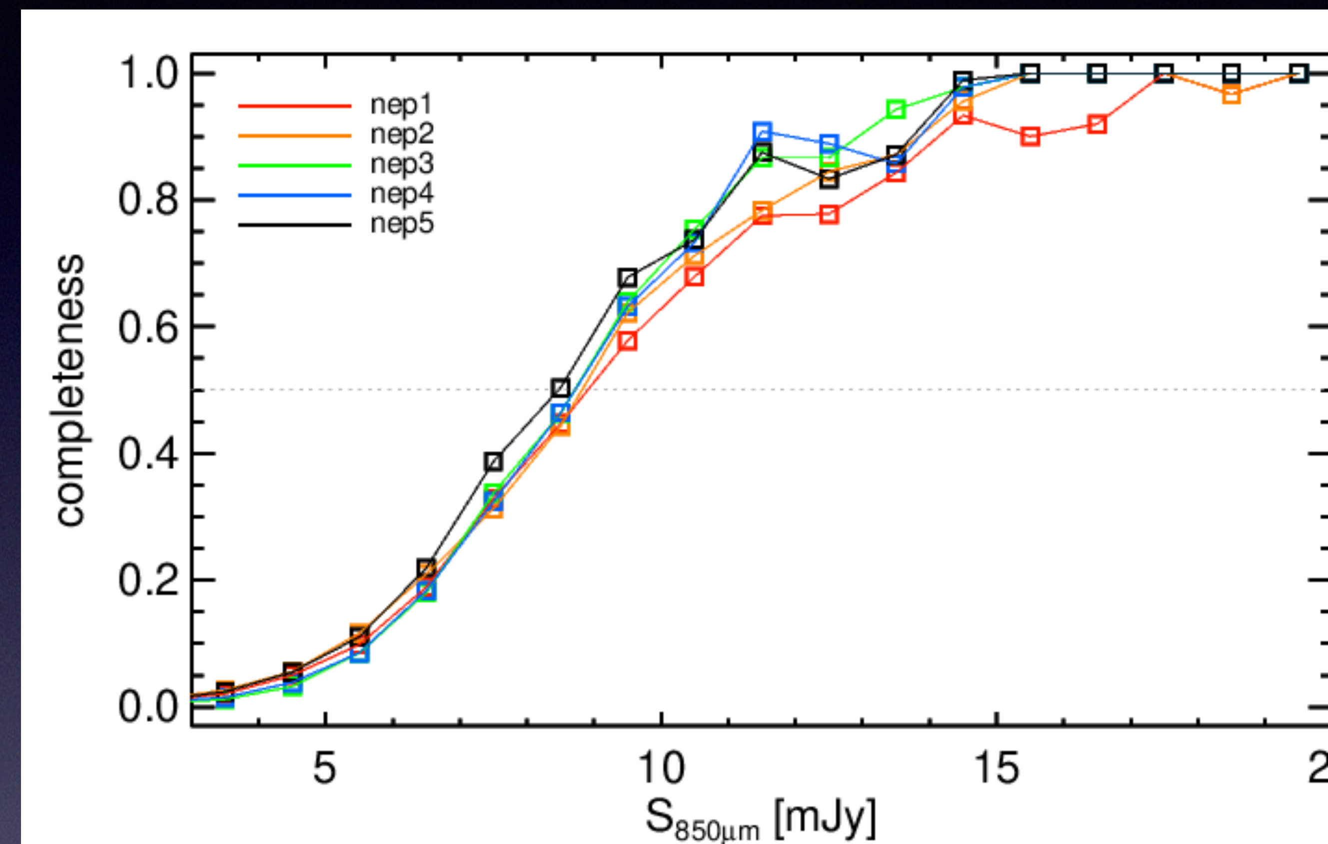
Dashed lines are deboost factors that will be applied to NEP3/4 and NEP1/2/5.

- **Eddington bias**: statistical variation tends to around the sources tend to make the estimated fluxes of fainter sources brighter than the intrinsic fluxes
- **Source confusion**: superimposed signals from faint, unresolved sources make the measured fluxes of the detected sources brighter.
- We estimated deboost factor through Monte-Carlo simulations.
- At SNR>4, the deboost factor can be described as a power-law function of SNR.

Estimation of the Completeness



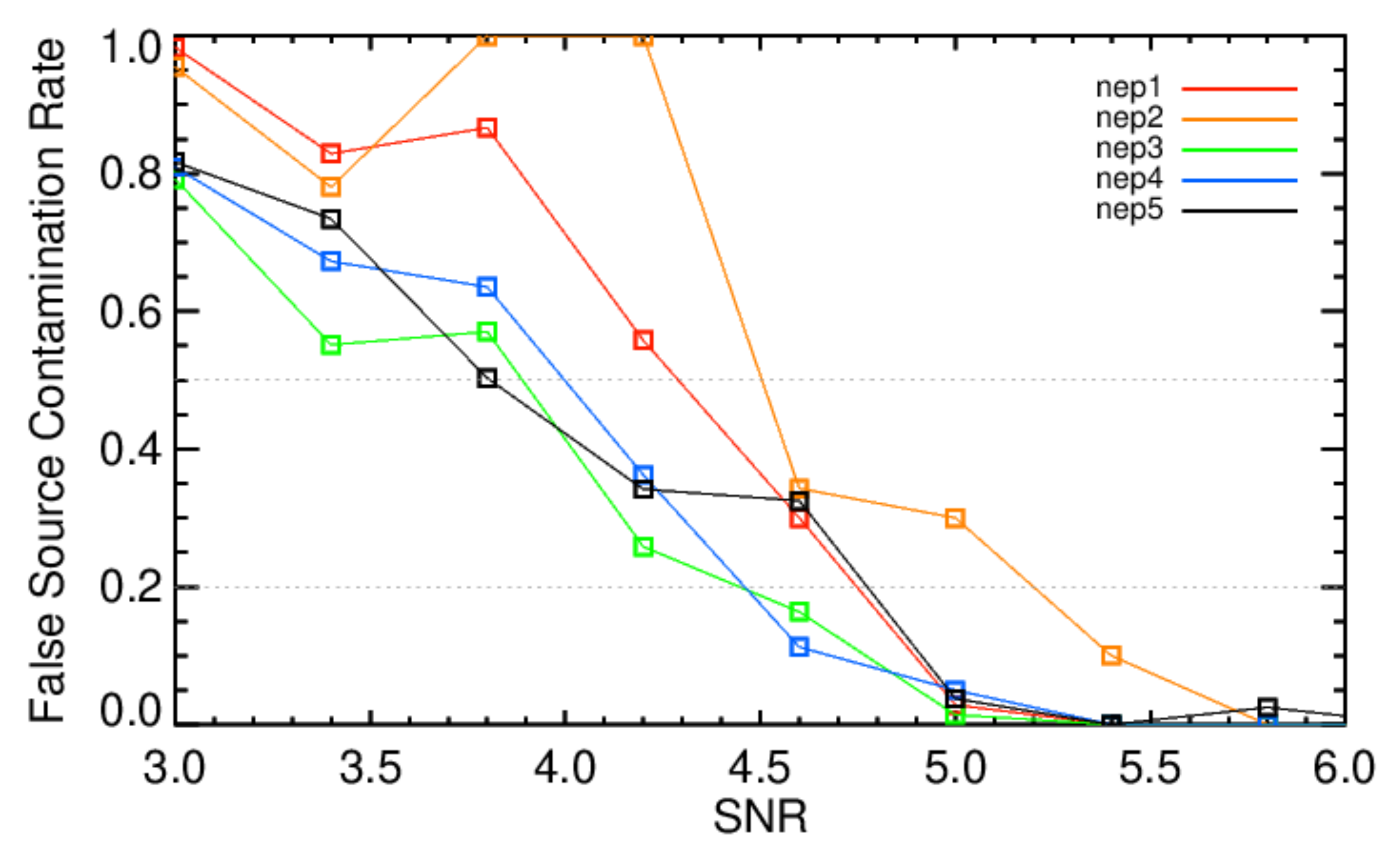
Completeness estimation (recovery rate) with SNR > 3 σ.



Completeness estimation at 4 σ detection.

~50% completeness at ~9mJy

False Detection Rate



False detection rate

= (Number of sources detected in the jackknife noise map)/(Number of sources detected in the real image)

The safe cut would be SNR>4. At SNR>4.5, most of the detected sources would be real sources.

Photometry

- dual-mode detection and measurement using SNR map as a detection image
- SExtractor output FLUX_MAX for peak flux

1. all (faint) submm galaxies are considered as “non-resolved” sources, thus peak flux in the image with [mJy/beam] unit is considered as the flux density of the source.

2. used SExtractor to detect sources and extract the flux density

Source Catalog (updated 2019.05.13)

S2CLS (NEP-Deep)

0.6 deg^2
330 sources (>3.5σ)

- Geach+2017, publicly available
- Flux density in the provided catalog slightly differs (by ~0.15mJy) from the value from the mosaic map provided, but the difference is within the error limit.

NEP-individual

~1.1 deg^2
223 sources (>4σ)

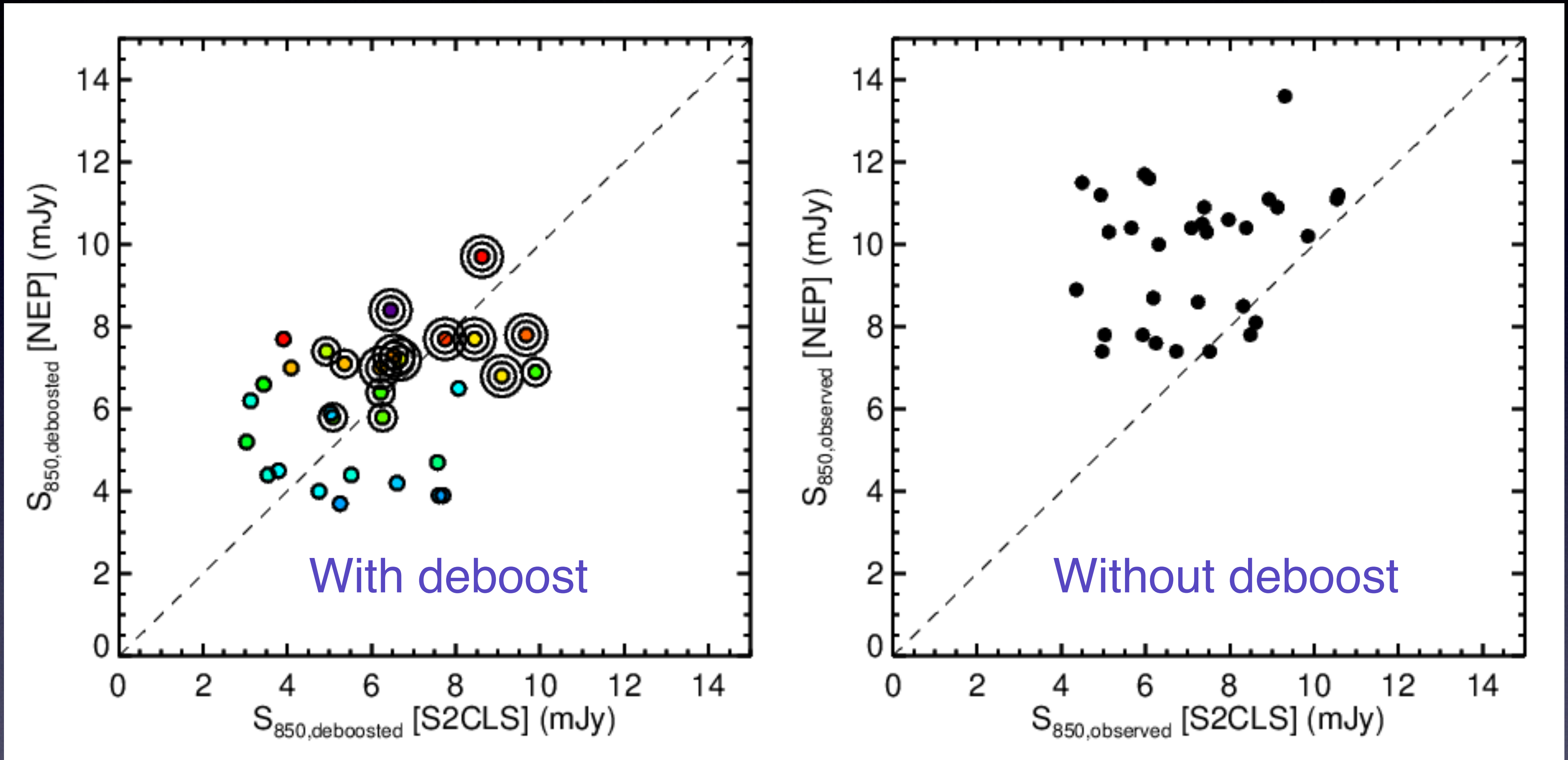
- 229 sources, with 6 objects being detected twice. Thus there are 223 unique sources

NEP-mosaic (S2CLS + NEP)

~1.6 deg^2
873 source (>3.5σ)

- Should be used with care (uncertainty in deboosting factor as a function of location).

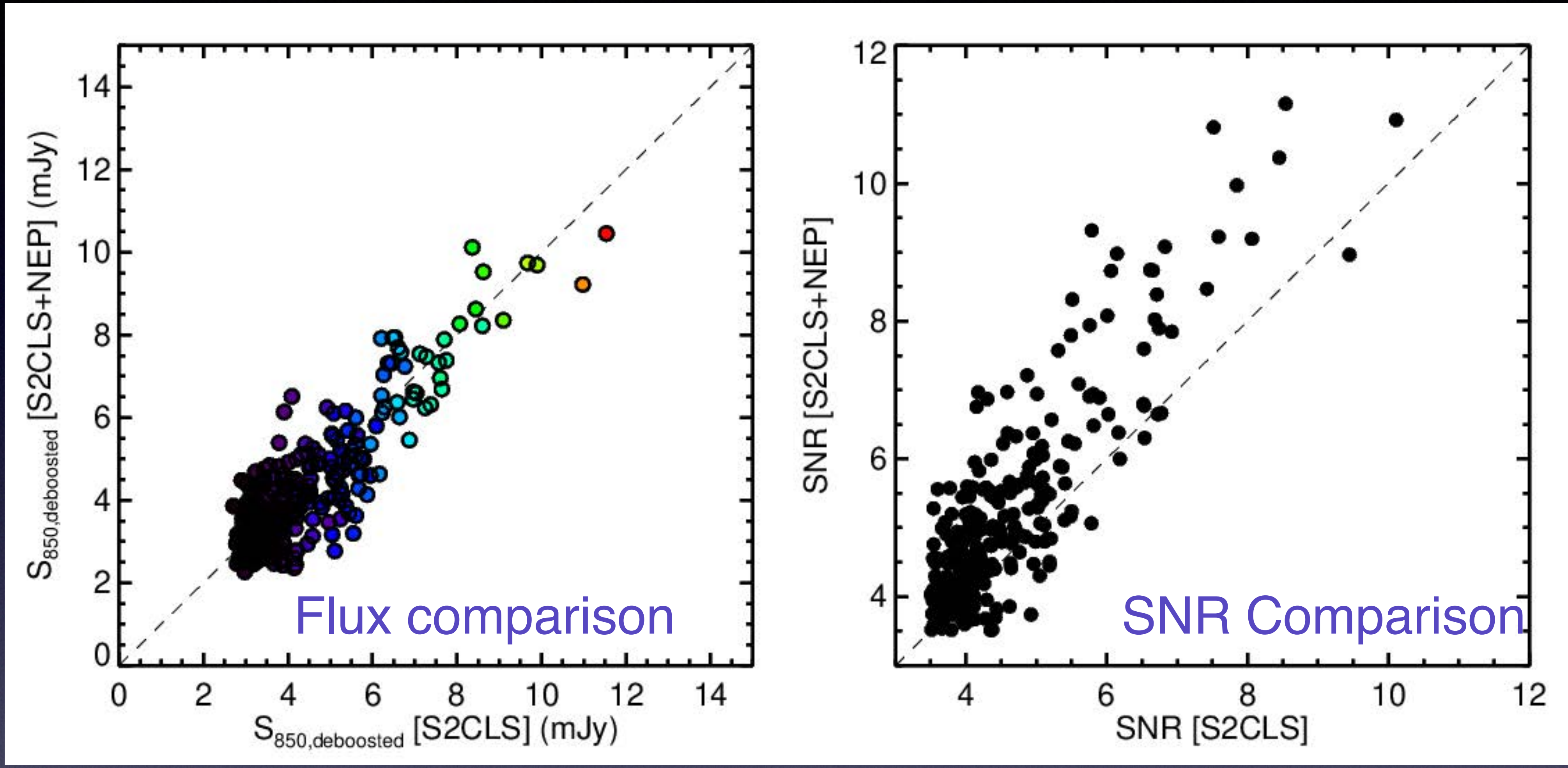
Comparison with S2CLS in Individual Fields



- S2CLS (NEP-Deep) versus NEP-individual (4σ cut) - we have **42** common objects. Their observed fluxes are very different (see right), but after the deboosting, they converge to $y=x$ line.

- "Single" Open circle : objects detected with SNR > 4.5 in both S2CLS and NEP indiv.
- "Double" Open circle : objects detected with SNR > 5 in both S2CLS and NEP indiv.

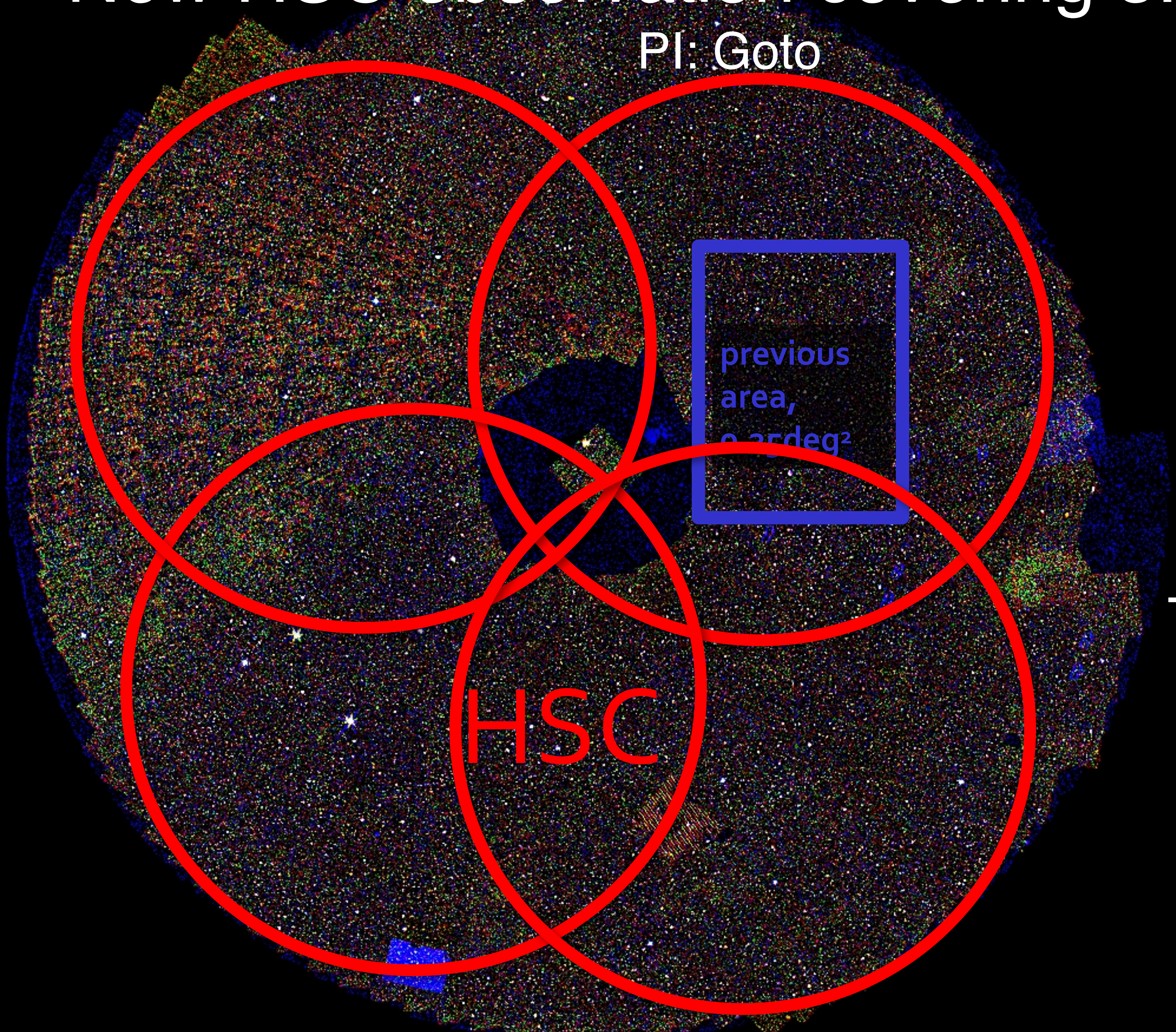
Comparison with S2CLS in Combined Image



- **251** objects (out of 330 in S2CLS catalog) are matched.
- ~80 objects are 'missed' in the combined image, because
  1. In the coadding process, edges in NEP pointing increased rms for some points
  2. Some sources are fake ones due to the fluctuation (~20% expected at 3.5σ limit).
- [S2CLS] and [S2CLS+NEP] fluxes are consistent, within the rms error.
- Same sources are detected with larger SNR in [S2CLS+NEP] combined image

New HSC observation covering 5.4deg^2,

PI: Goto



x20

larger

area

HSC grizy data over 5.4deg^2

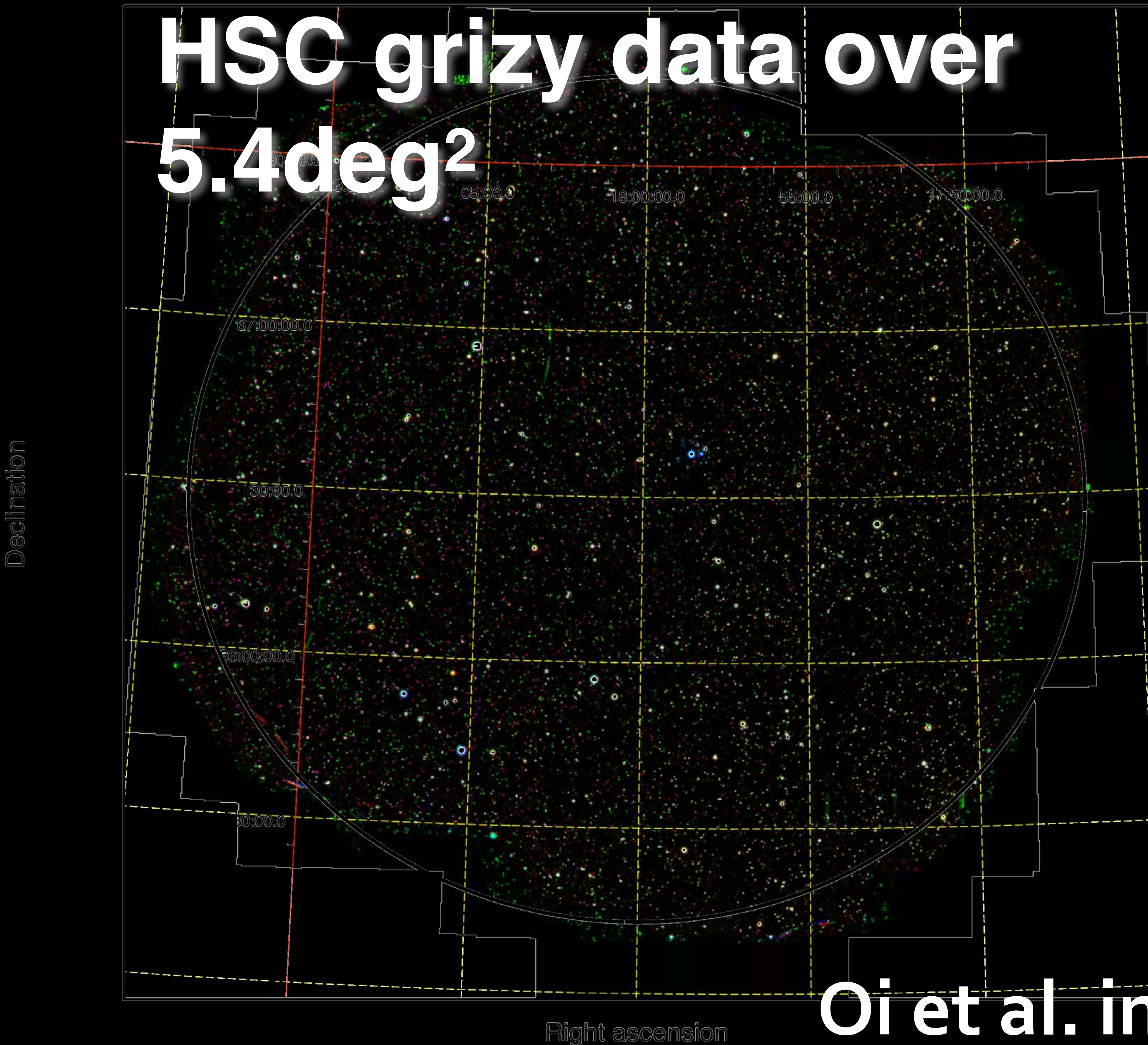
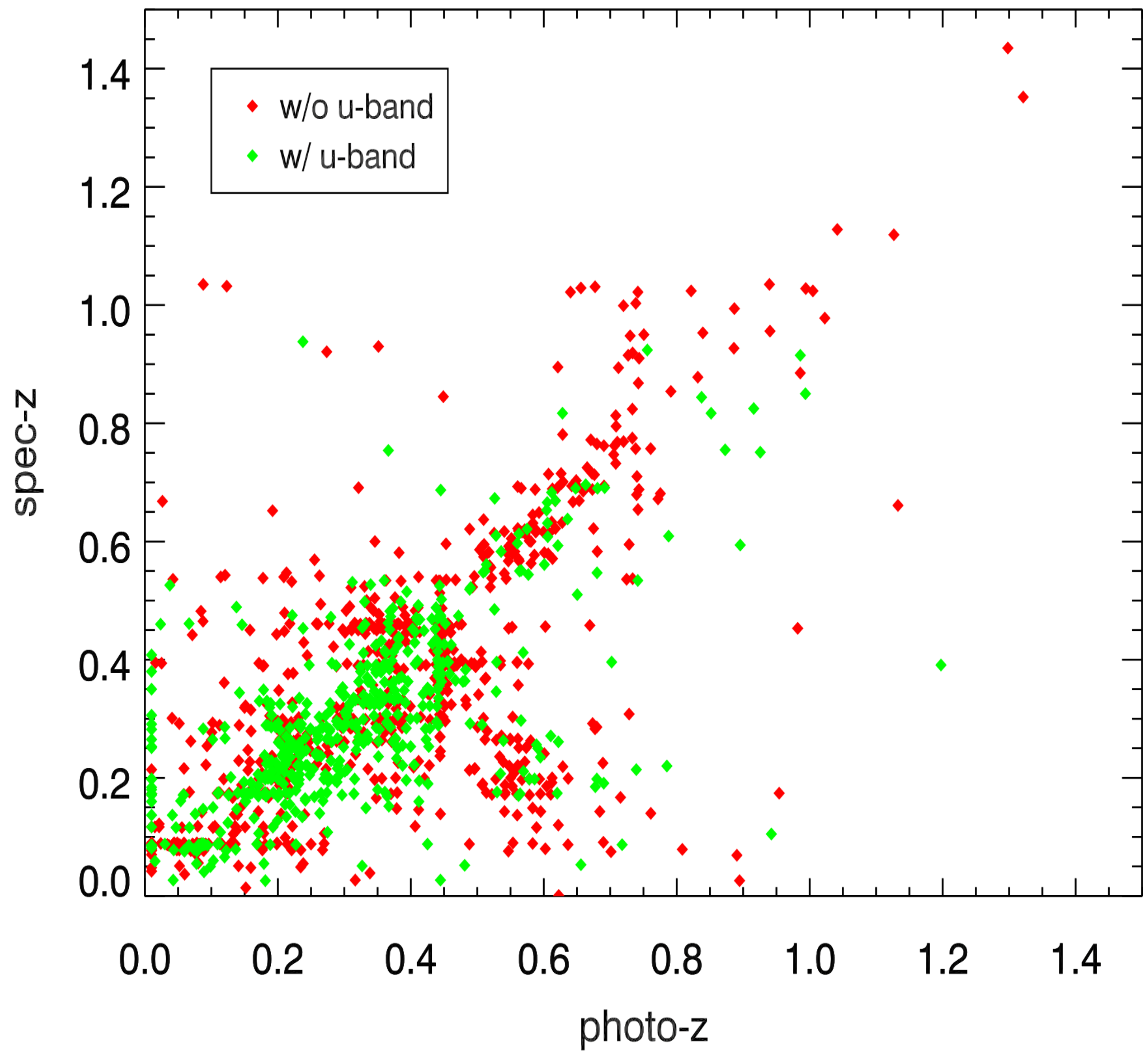


Fig. 1. HSC three color (g, r, i) composite image of the NEP wide field (5.4 deg^2). The AKARI NEP wide data exist within the white circle.

g' 27.5mag
r 26.5
i' 25.4
z' 24.7
y 24.3

Oi et al. in prep

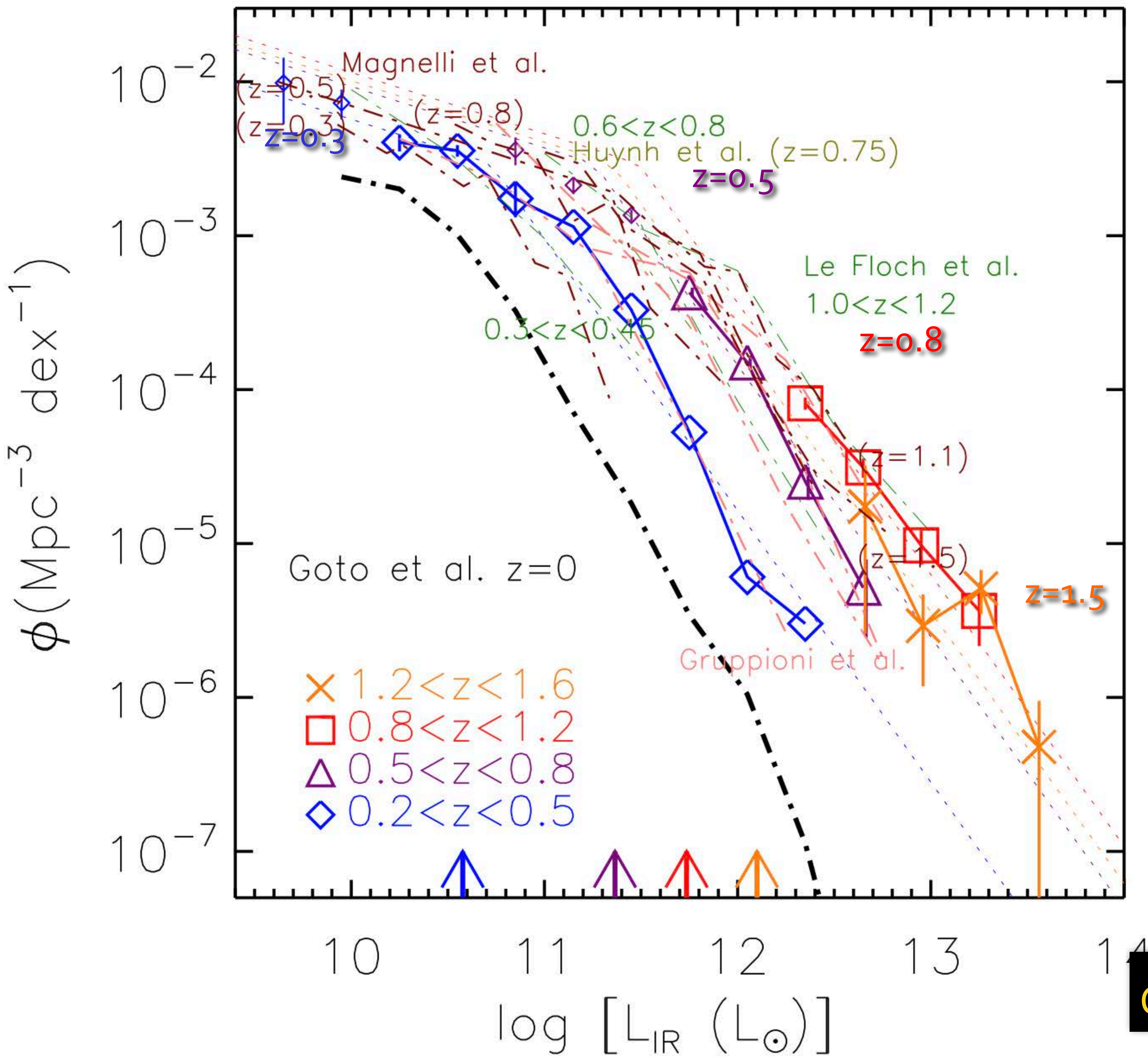
Photo-z computed for 180,000 AKARI sources in NEP Wide



With u-band,
Dispersion σ~0.036
Catastrophic rate
η~12.8%

Thanks to spec-z from Shim et al. (2013) and Shogaki, Takagi, Matt, Helen (DEIMOS), Nagisa (FMOS)…etc.

Total IR LF



- x20 larger sample
- Smaller errorbar

Goto et al. 2019

More to Come…

- Cross identification with HSC [MIR-based] catalog : ~200 sources newly discovered (not in S2CLS). Among these, ~40 are detected in Herschel SPIRE images. 2 bright z~1.5 AGNs, …
- At least ~50 (actually more) sources are not matched with HSC [MIR-based] catalog - (if these are real sources and not a false detection) due to the limited AKARI IRC depth? Cross-identification with deep HSC images would be essential.
- In principle 850 µm survey can detect high-z star forming galaxies, but current sensitivity is good for only for very bright galaxies ($L_{IR}>10^{13}\ L_{\odot}$)
- We have not reached confusion limit of 0.8 mJy/beam yet!

Publication Plan (based on discussion during Jan. F2F Meeting in 2018)

1. 850um mosaic and catalog (blind and band-merged) of the NEP-Wide: Data release paper (Hyunjong Seo [KR] et al., will be prepared after the completion of the survey)
2. Testing cosmic IR background fluctuation models with 850um and NIR/MIR dat (Hyunjong Seo [KR] et al., checking feasibility)
3. Properties of red galaxies (DOGs, DRGs, EROs) – extinction, SFR, stellar mass, Tdust, … (number of members mentioned that they are interested, thus will be arranged once the data acquisition is resumed)
4. PAH-FIR correlation (Tomotsugu Goto [TW], Seongjin Kim [TW] et al.)
5. Dust-obscured AGNs and hidden star formation (Hideo Matsuhara [JP] et al.)
6. Rare objects (e.g., z>3-4 massive dusty starbursts) (Woong-Seob Jeong, Hyunjin Shim et al. [KR])
7. Clusters and proto-clusters around submm sources (can be done before the completion of the survey)
8. Angular (Spatial) correlation of the 850um sources (will be done after the completion of the survey)
9. Dust properties of the optically selected galaxies (will be done after the completion of the survey
10. Dust-to-gas ratio of star-forming galaxies (Zheng Zheng [CN] et al.)
11. NEP supercluster environments and galaxies (TBD)
12. Evolution of massive galaxies in terms of AGN contribution (Hyunjong Seo [KR] et al.