NEAR INFRARED BACKGROUND RADIATION OBSERVED BY AKARI

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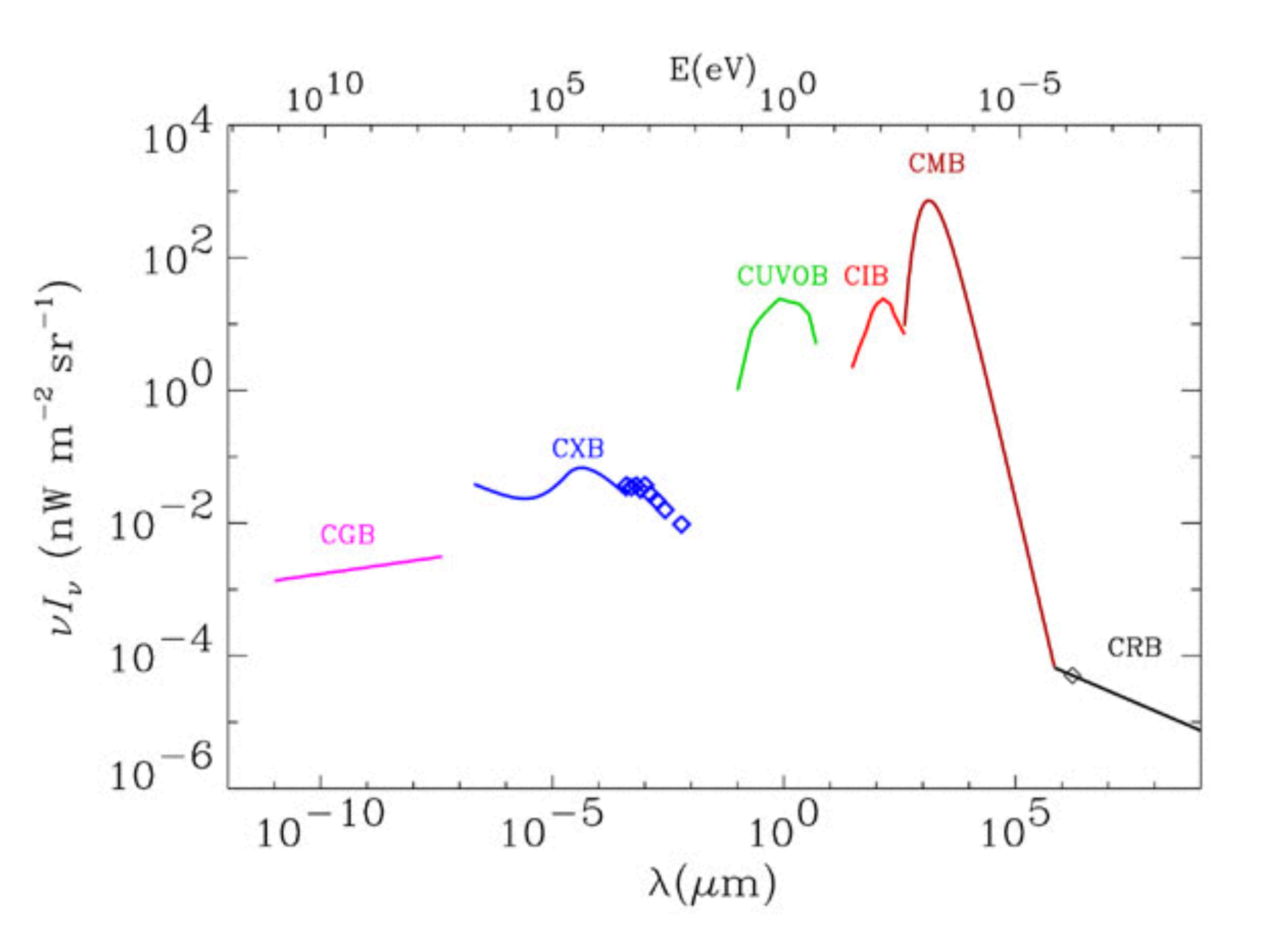
OUTLINE

- Introduction
- Fluctuation measurements with AKARI
  - Monitor field
  - NEP-deep field
- Origin

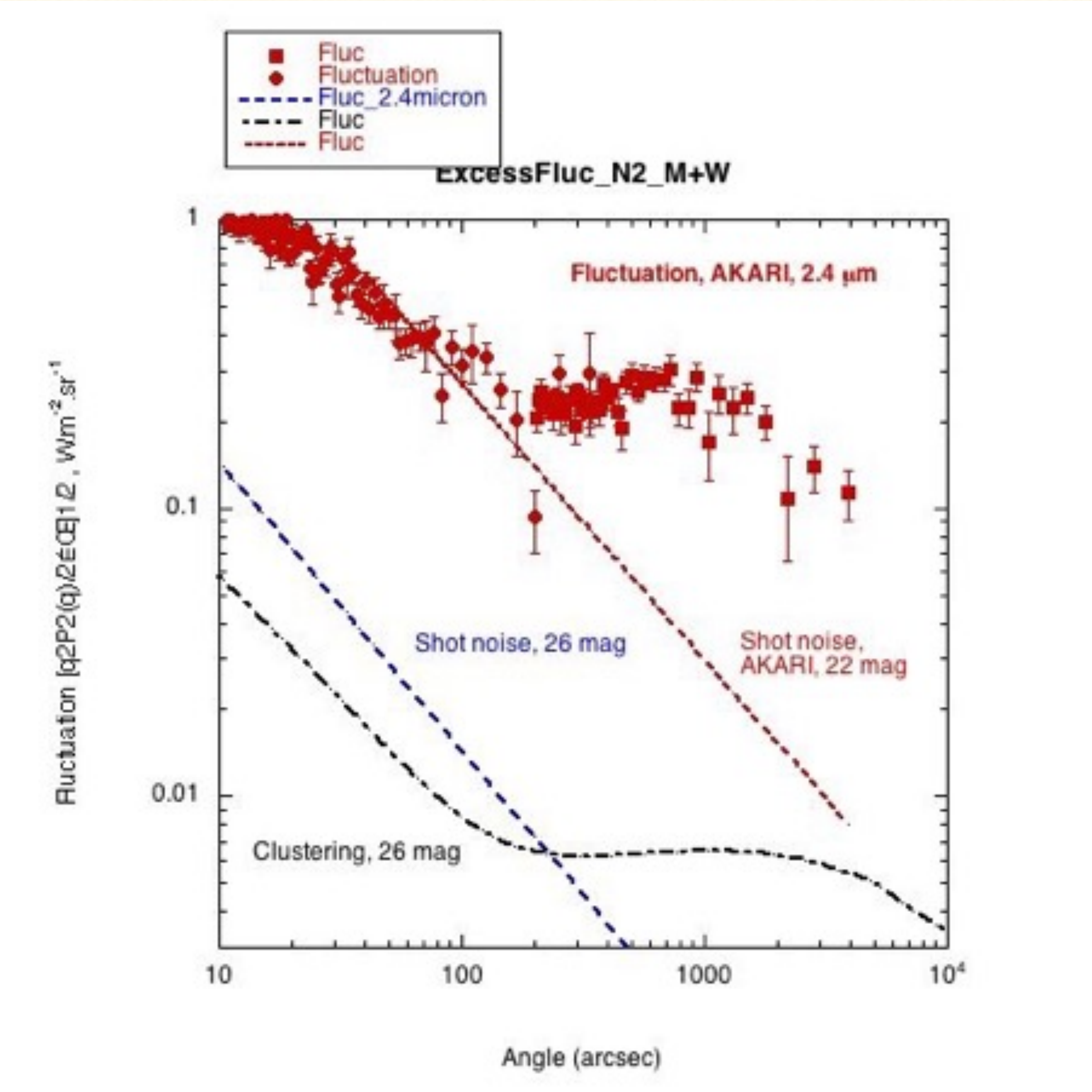
BACKGROUND RADIATION OVER WIDE SPECTRAL RANGES



Hauser & Dwek 2001, ARAA

COSMIC INFRARED BACKGROUND RADIATION (CIRB)

- Residual light in long exposure IR image after removal of contribution from all known sources
  - Stars
  - Galaxies
  - Diffuse Galactic light
  - Zodiacal light
- Issues
  - Accuracy of measurement
  - Origin



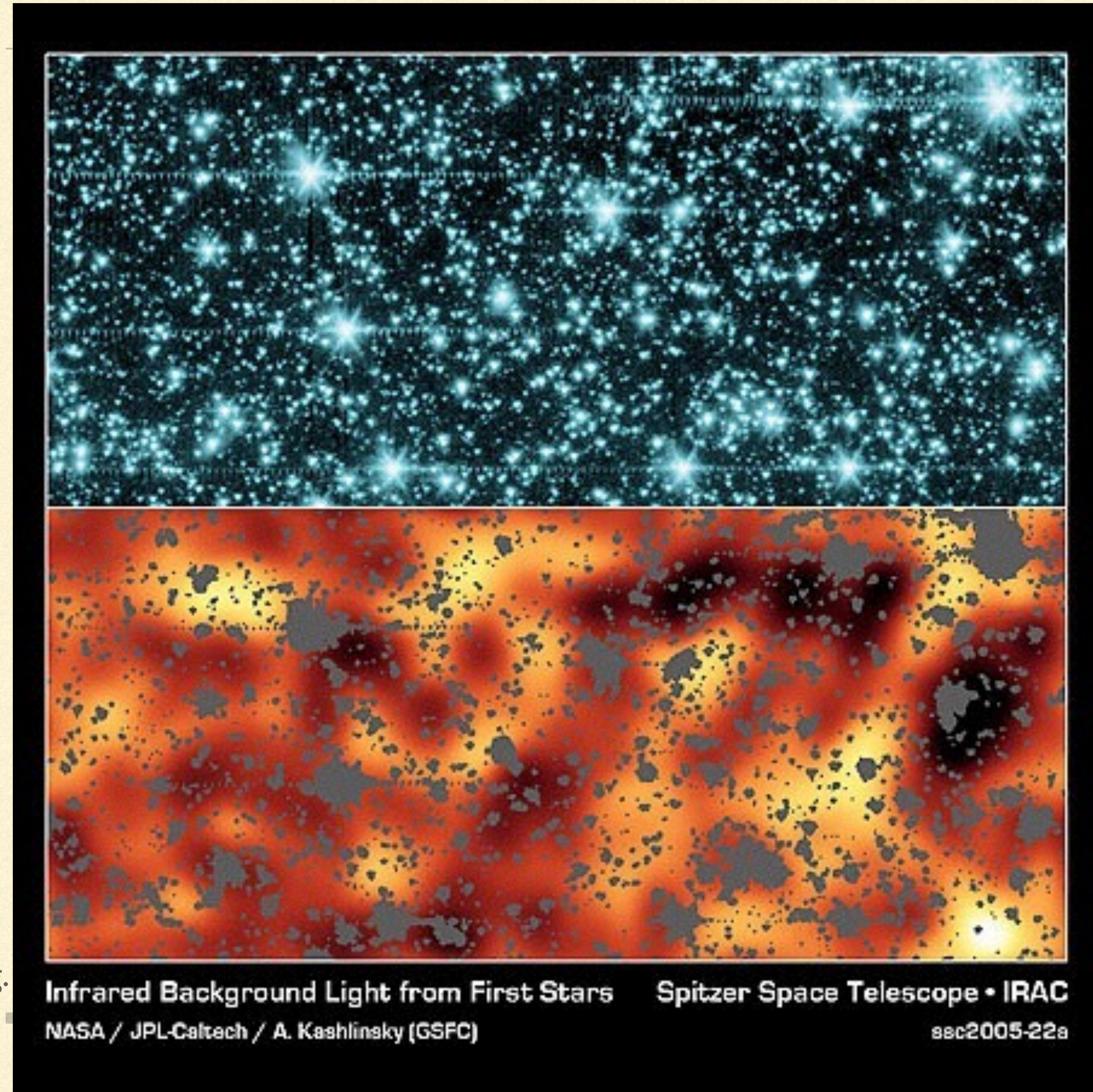
RELEVANT STUDIES

- COBE
  - Hauser et al. (1998): excess emission in near to far IR
  - Cambresy et al. (2001), Levenson et al. (2007): Existence of CIRB in NIR
- IRTS
  - Matsumoto et al. (2005): spectrum from 1.6-4 micron
- Spitzer
  - Kashlinsky et al. (2005, 2007, 2012): significant fluctuations at 100-300 arcsec scale
- More recently
  - AKARI: Monitor Field (Matsumoto et al. 2011), NEP-Deep (Seo et al. 2015)
  - CIBER: NEP area (Zemcov et al. 2014)

CONTROVERSY

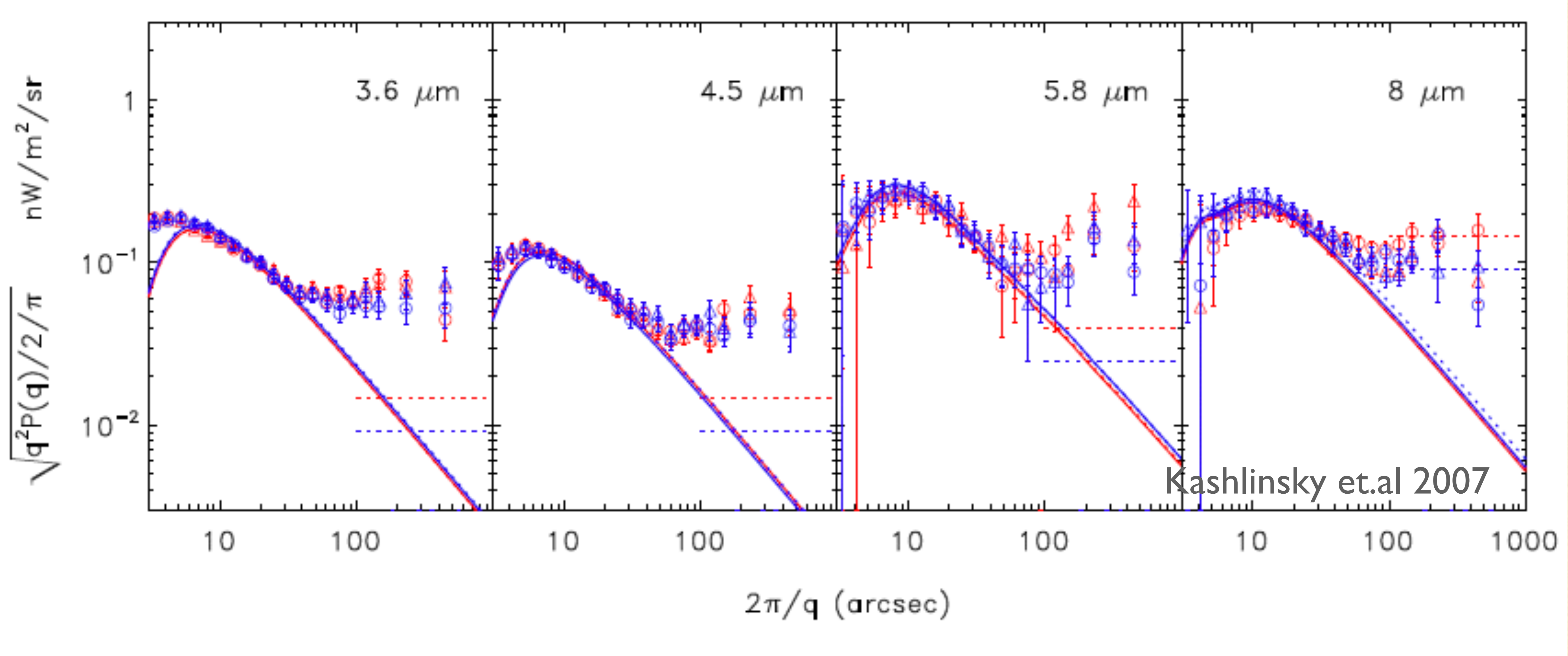
- Uncertainties in foreground Zodiacal Light
- TeV γ-ray Blazar spectrum favors no excess above the contributions from faint galaxies (Ahronian et al. 2005, Mazin & Raue 2007)
- Energetics: claimed background light means too much generation of Pop. III stars (Madau & Silk 2005)
- Large angular scale fluctuations

CAREFUL MEASUREMENT OF THE BACKGROUND RADIATION



- Kashlinsky et al. 2005 using Spitzer telescope data

FLUCTUATION ANALYSIS OF SPITZER DATA



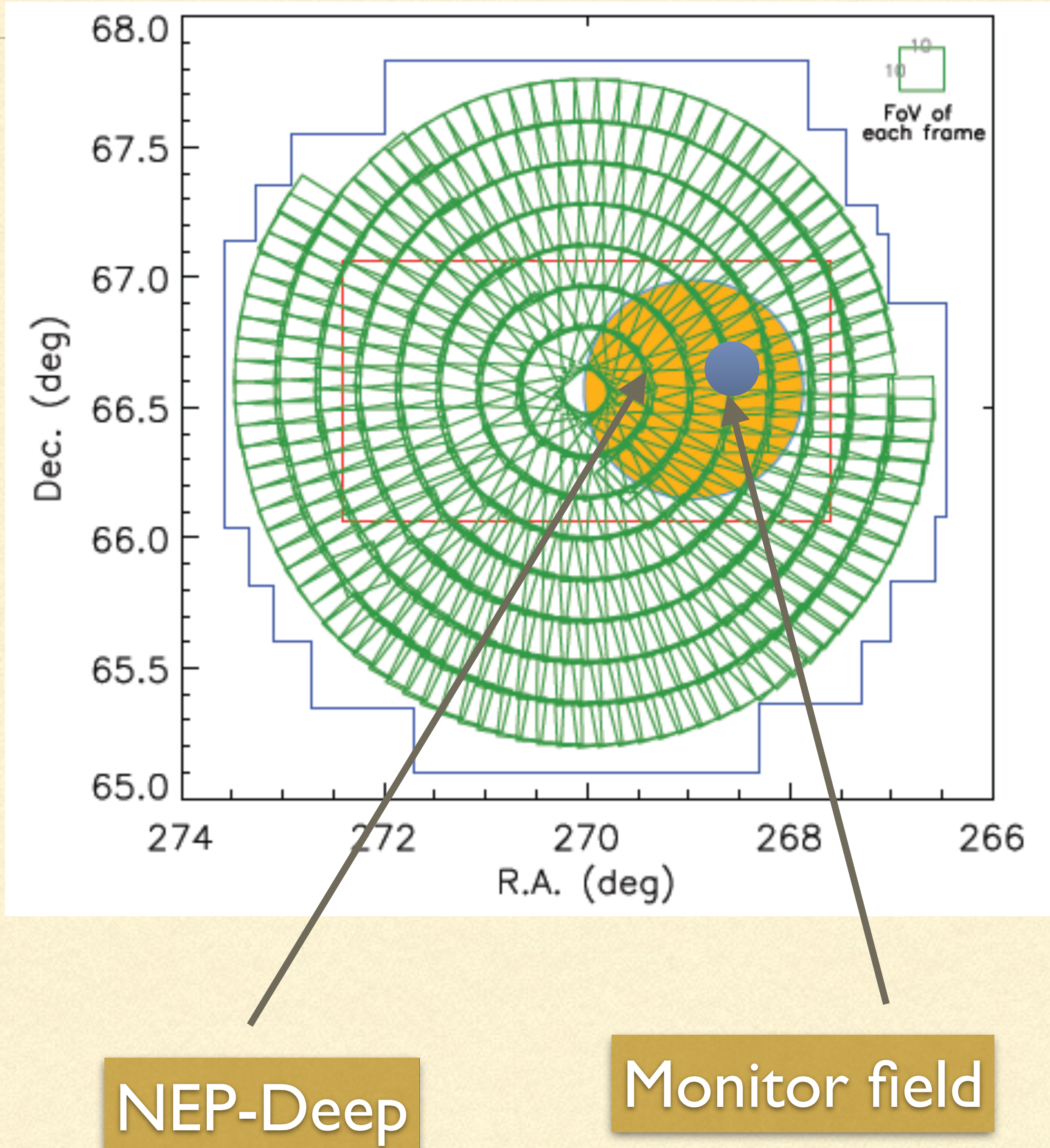
Kashlinsky et.al 2007

NEW MEASUREMENT WITH AKARI

- Cold shutter ⇒accurate determination of dark current
- Deep and Wide Surveys
- Wavelength coverage to shorter wavelength
- Other ancillary data available: optical, ground based high resolution near-IR, mid-IR

FIELDS

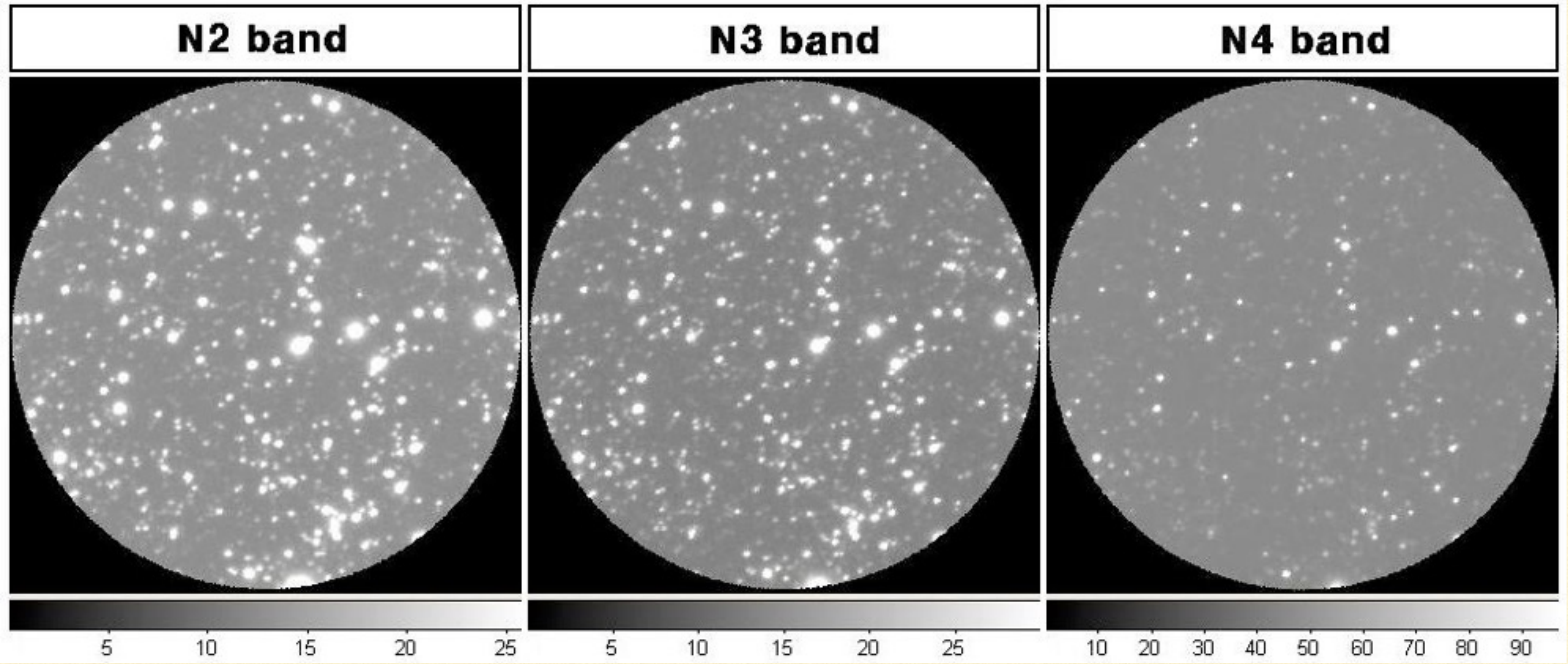
- Observed areas
  - Monitor field (Matsumoto et al. 2011)
    - circular field with10 arcmin radius, used for the performance of the instruments
  - NEP-Deep (Seo et al. 2015)
    - Blank field survey area of ~0.6 sq. deg.



Summary of Monitor Field Data

Band	N2 (2.4μm)	N3 (3.2μm)	N4 (4.1μm)
Position (J2000)	RA 268.8500 DEC 66.6256		
Observation	14 pointed observation (2006.9 – 2007.3)		
Number of image frames	40	39	28
Integrated exposure time	**1776 sec**	**1732 sec**	**1243 sec**
Pixel scale (″)	1.46		
FOV of stacked image	10' diameter (412pixel diameter)		
Limiting magnitude (AB)	21.7	21.4	20.7

Stacked (original) images

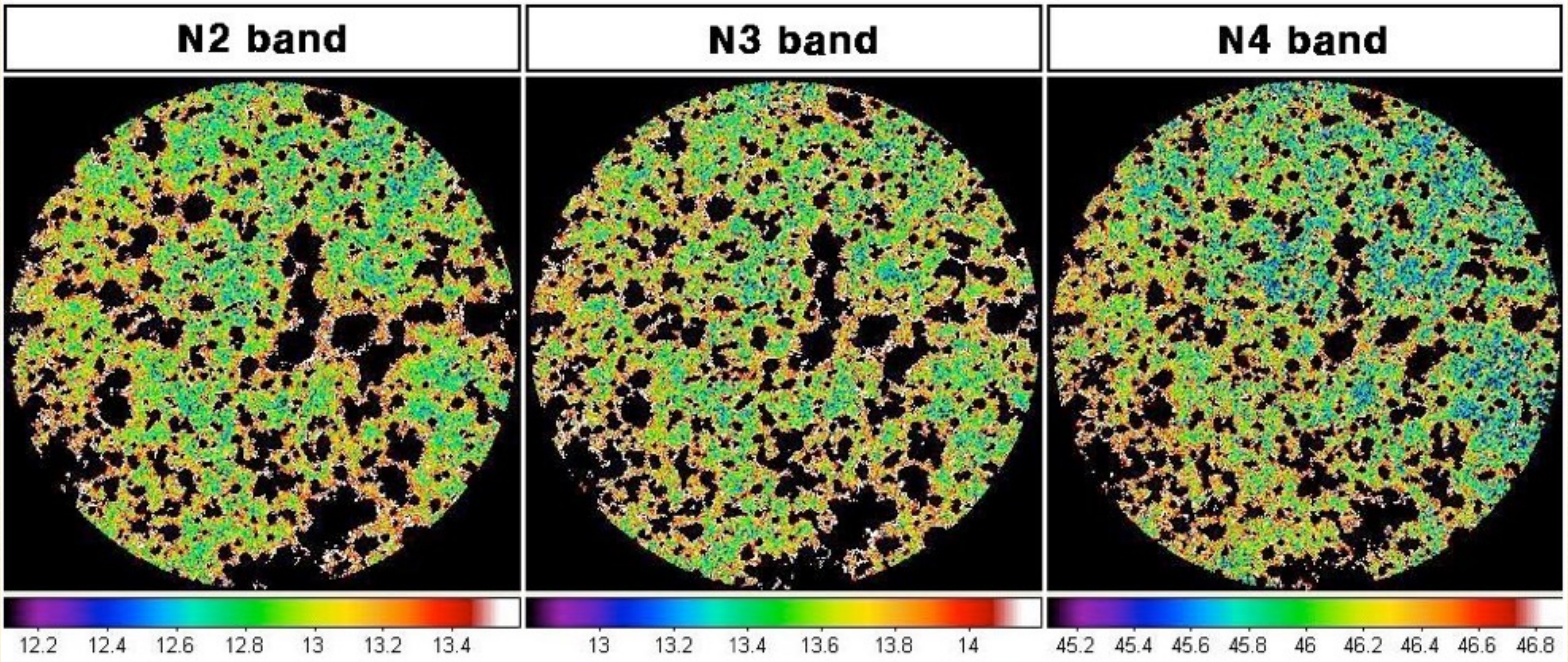


※ The number in the scale bar is ADU scale.

REMOVING FOREGROUND SOURCES

1. 2σ Clipping: Removing pixels above or below the average by 2σ. Repeat this process 10 times.
2. Subtraction of outer part of point source using carefully modeled PSF
3. Subtraction of outer part of extended sources identified by CFHT optical catalogue. Their Flamingo images (higher spatial resolution at K band) are convolved with AKARI PSF and subtracted.
4. In order to make contribution of identified sources negligible, we masked a layer of one pixel around masked region.
5. For sources that are not masked in step 1 but for which step 2 or 3 were applied, we masked 8 neighboring pixels around the center of these objects.

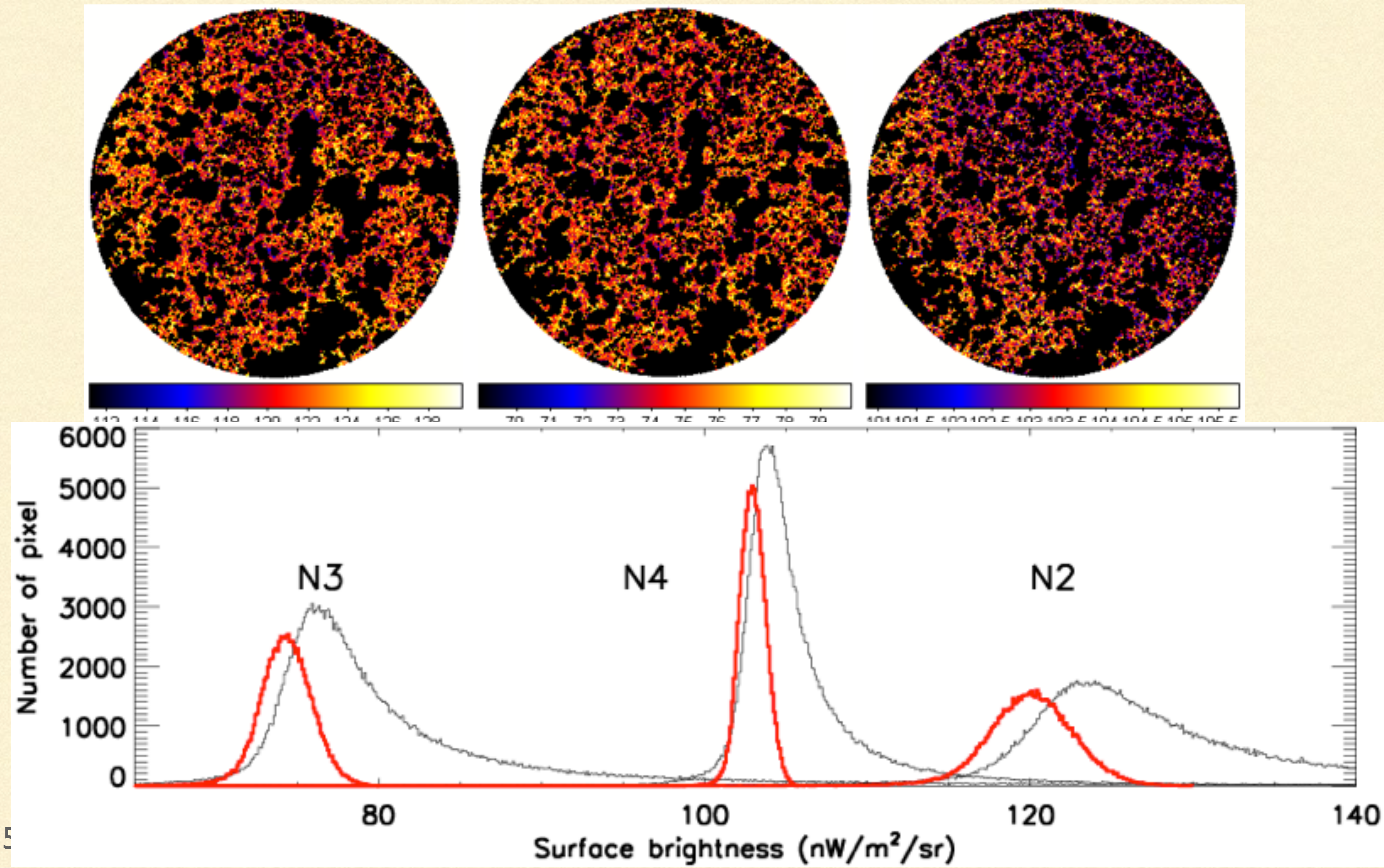
Images after 2σ clipping



※ The number in the color bar is ADU scale.

Final images

2.4 μm, 39.8%	3.2 μm, 39.3 %	4.1 μm , 36.8 %



FLUCTUATION ANALYSIS

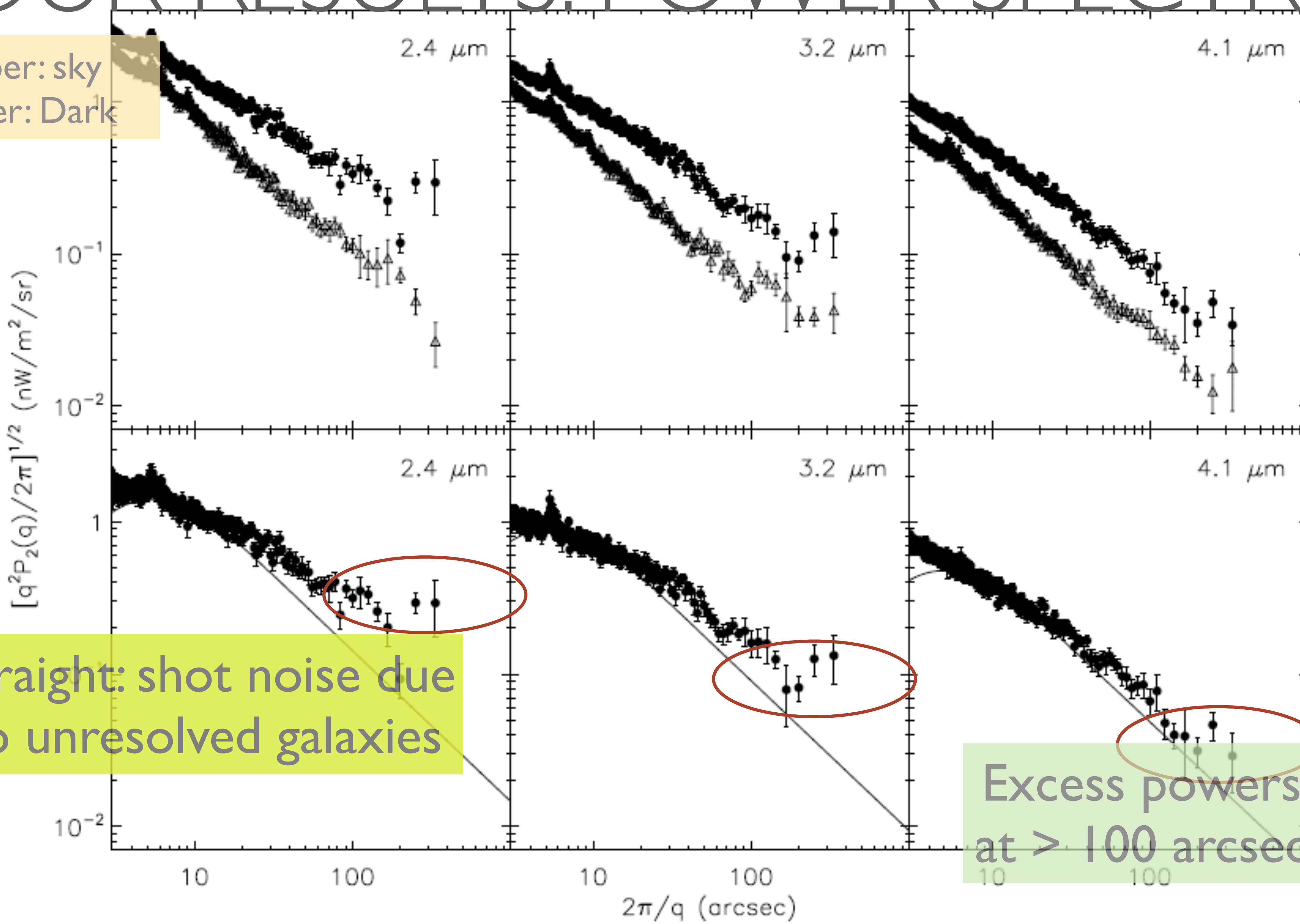
- Absolute level of the CIRB is difficult to determine because of uncertainties in diffuse component (especially Zodiacal light)
- Fluctuation analysis is another powerful method since diffuse component is thought to be rather smooth (Kashlinsky et al. 2007)

$$f(q) = \int \delta F(x) \exp(-ix \cdot q) d^2 x$$

$$P_2(q) = < |f(q)^2| >$$

⇒ Typical fluctuation flux = $\sqrt{q^2 P_2(q)/2\pi}$

OUR RESULTS: POWER SPECTRA



Upper: sky
Lower: Dark

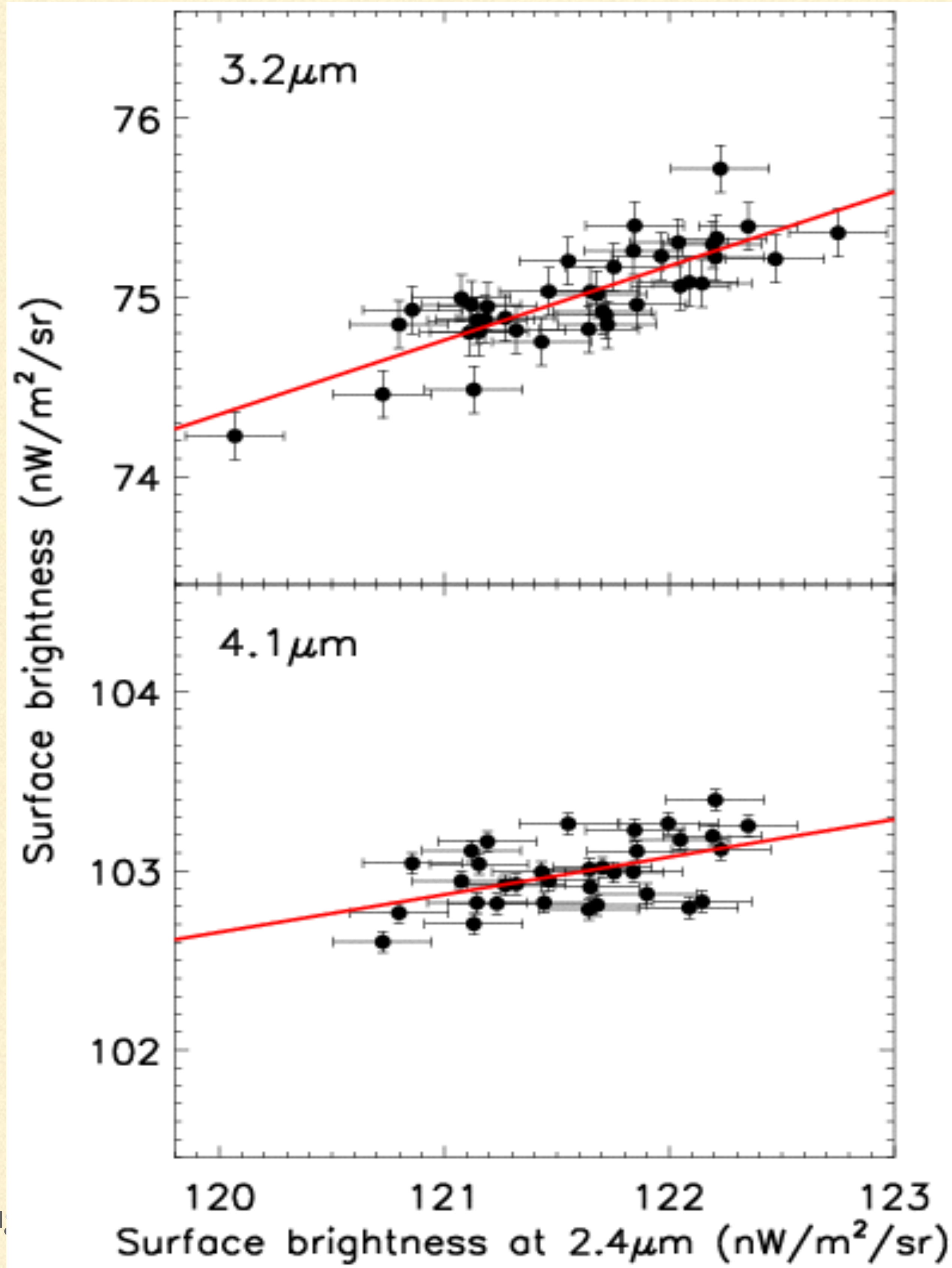
Straight: shot noise due to unresolved galaxies

Excess powers at > 100 arcsec

Au

Matsumoto, Seo, Lee, et al. (2011)

PIXEL CORRELATION BETWEEN DIFFERENT BANDS

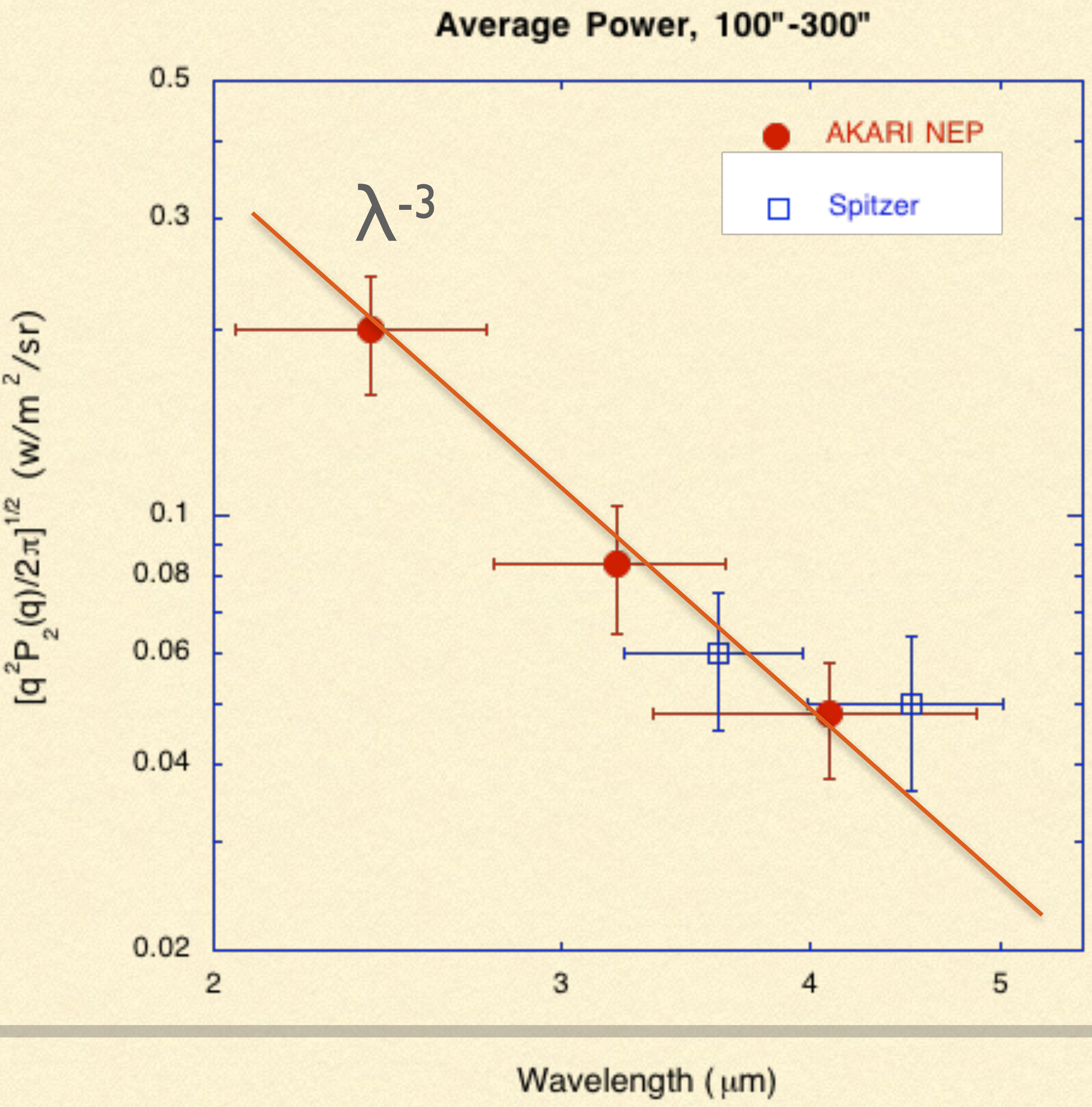


Correlation coefficient ~ 0.8

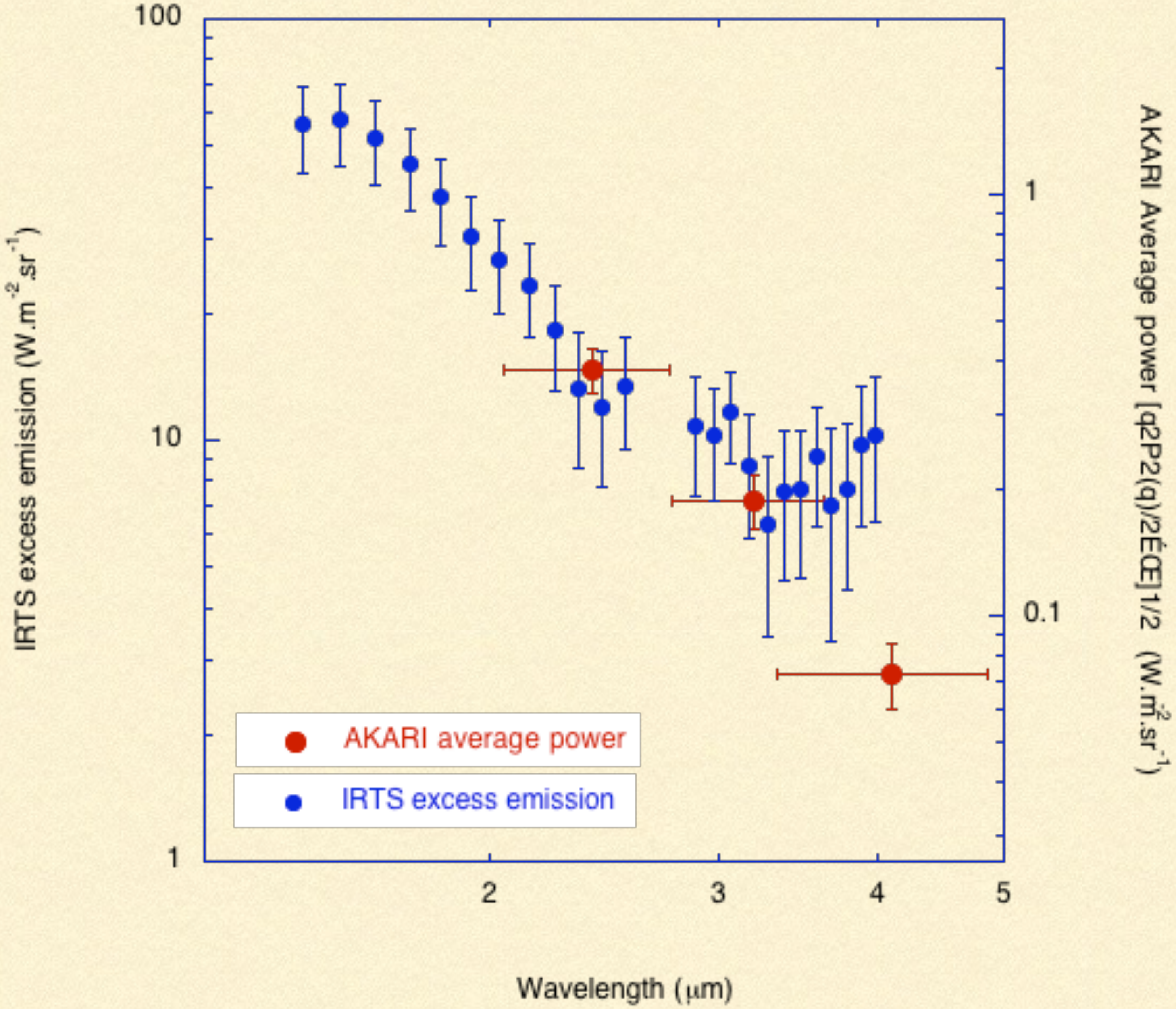
Correlation coefficient ~ 0.5

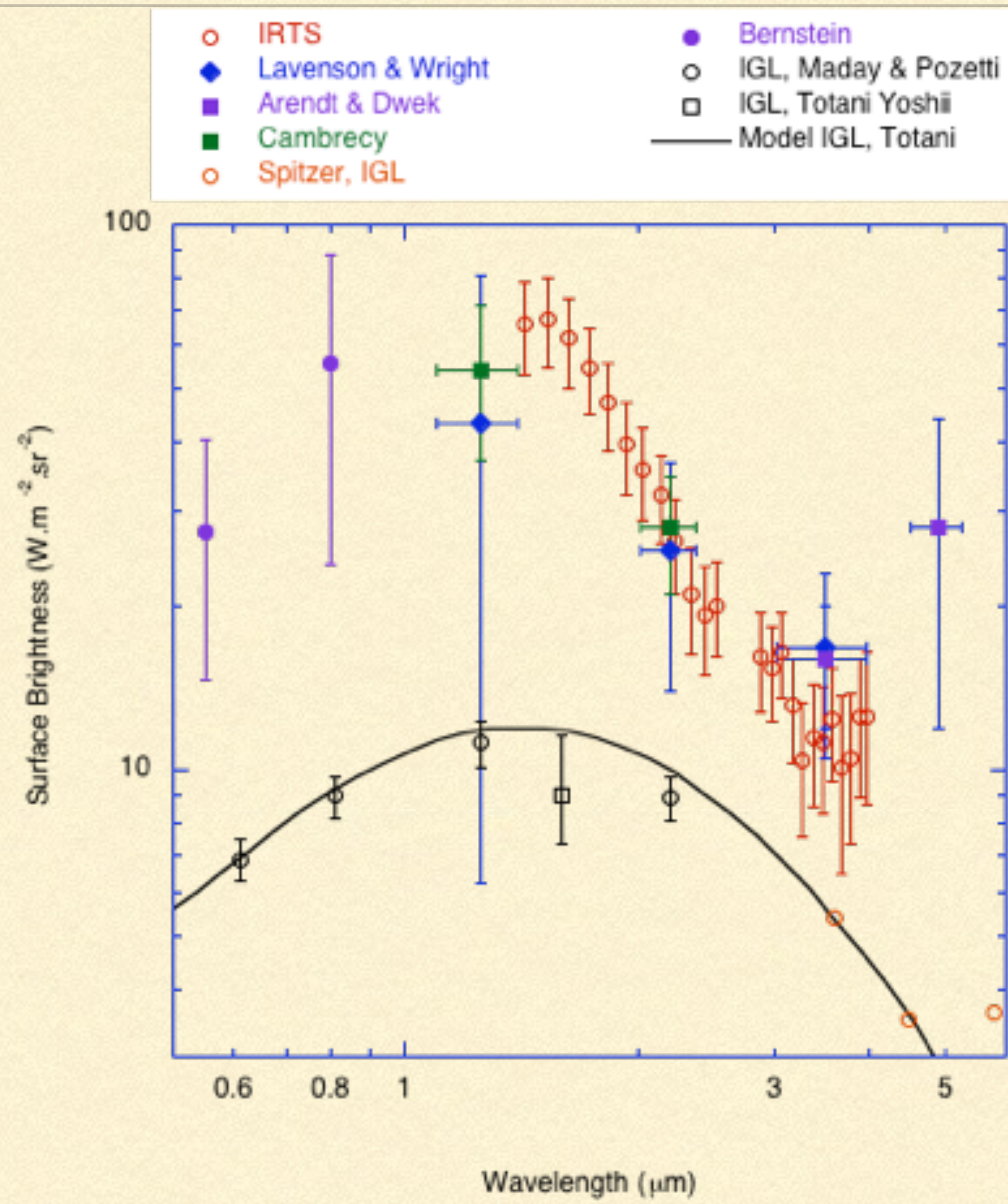
SPECTRUM OF FLUCTUATING COMPONENT

- Average value of power at 100”<θ<300”
- Rayleigh Jeans like blue spectrum (∝ λ-3)

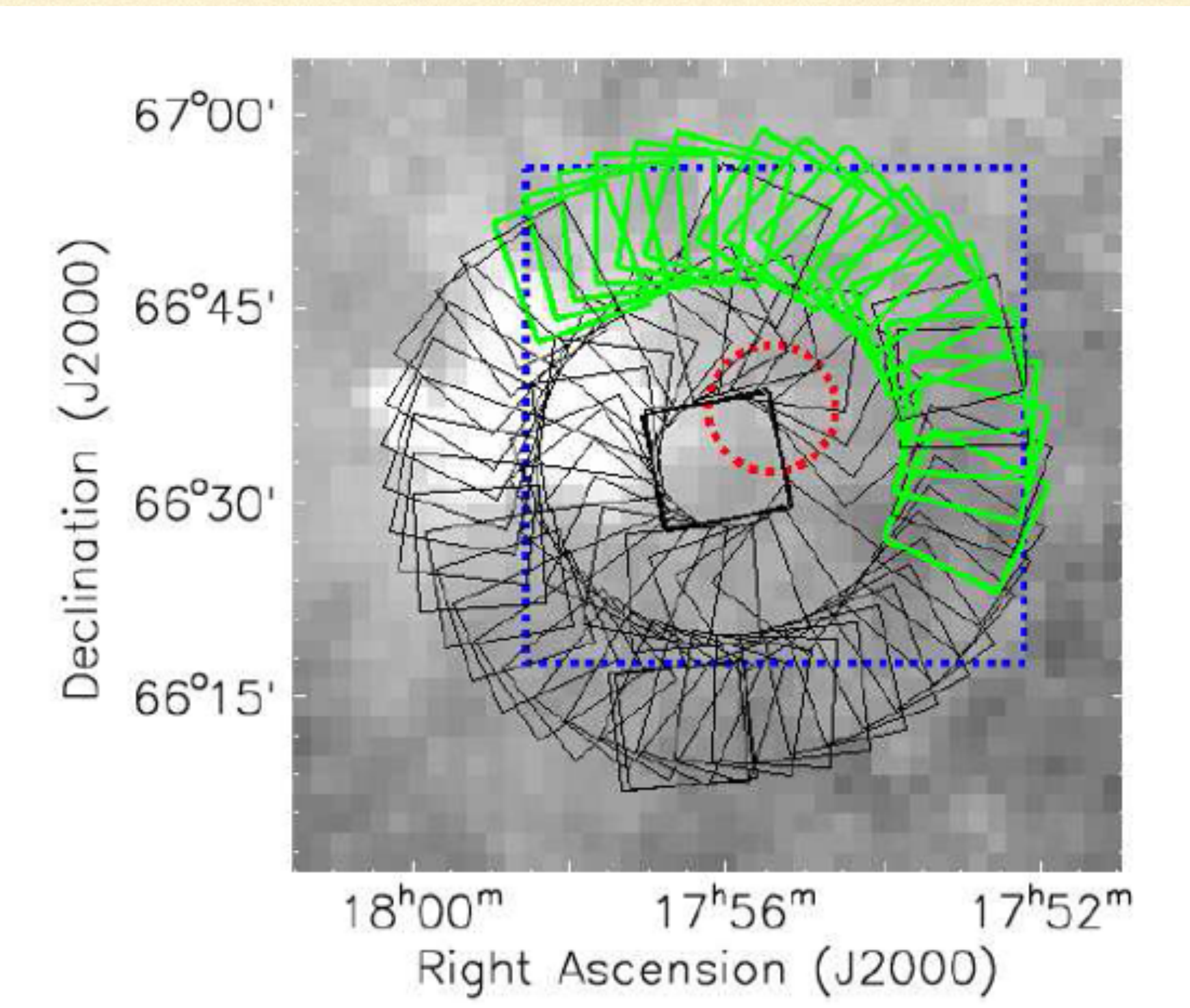


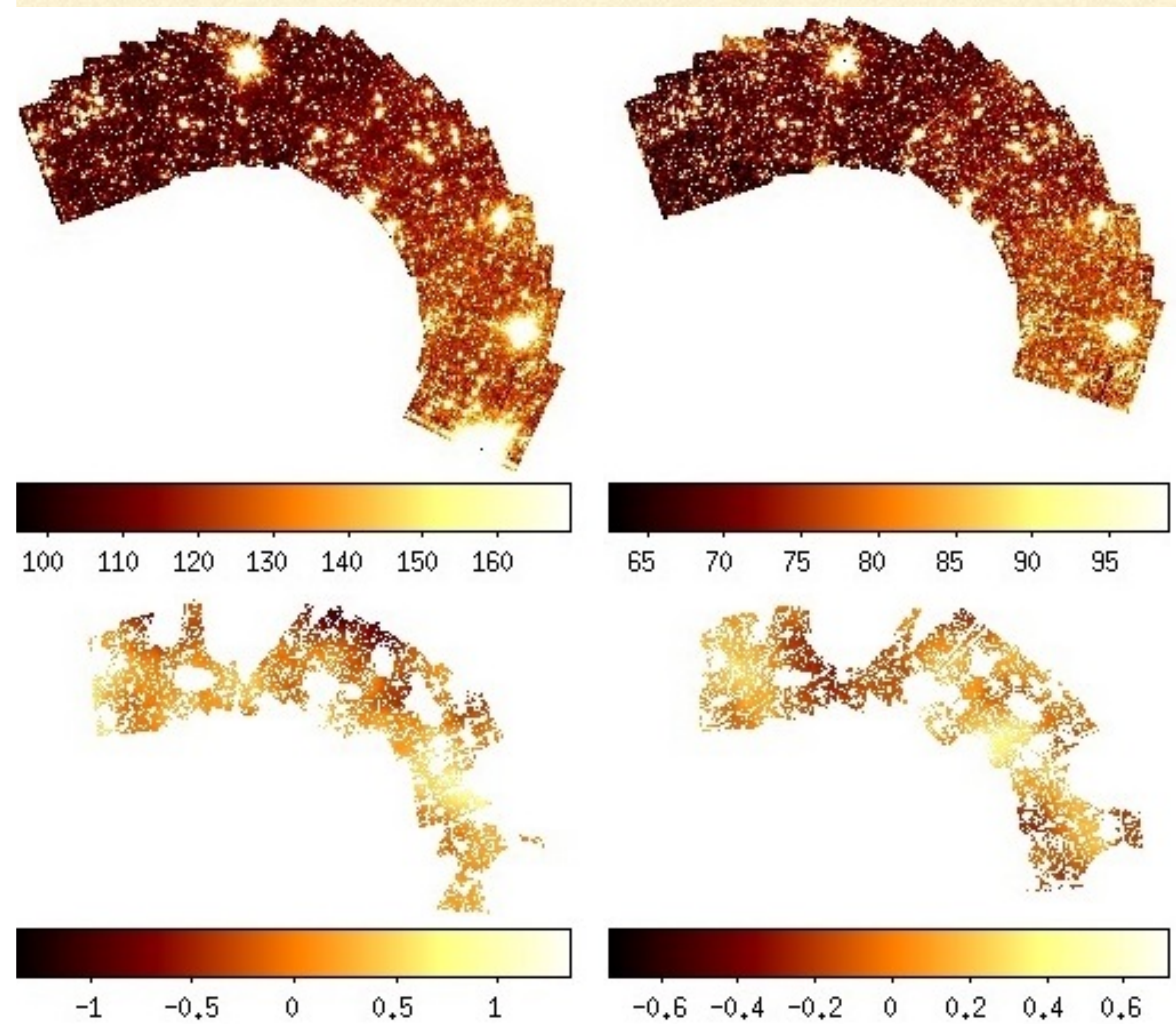
COMPARISON WITH OTHER MEASUREMENTS





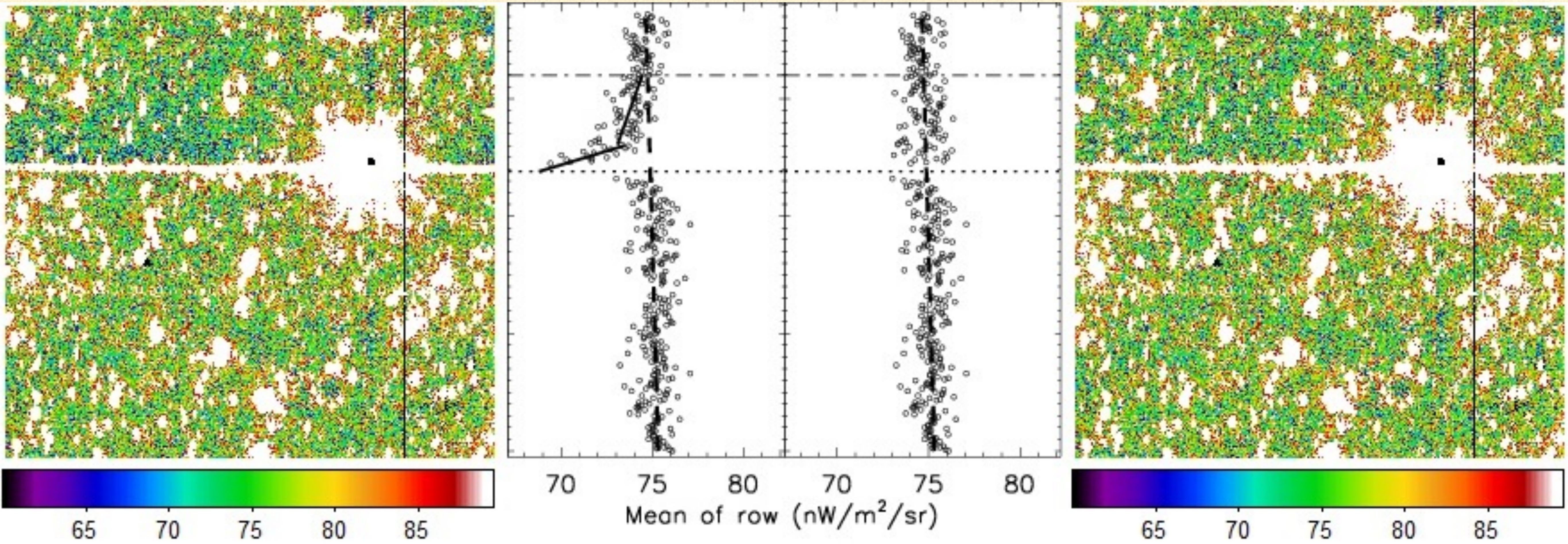
LARGER ANGULAR SCALE STUDY: NEP-DEEP FIELD





2.4 µm 3.2 µm

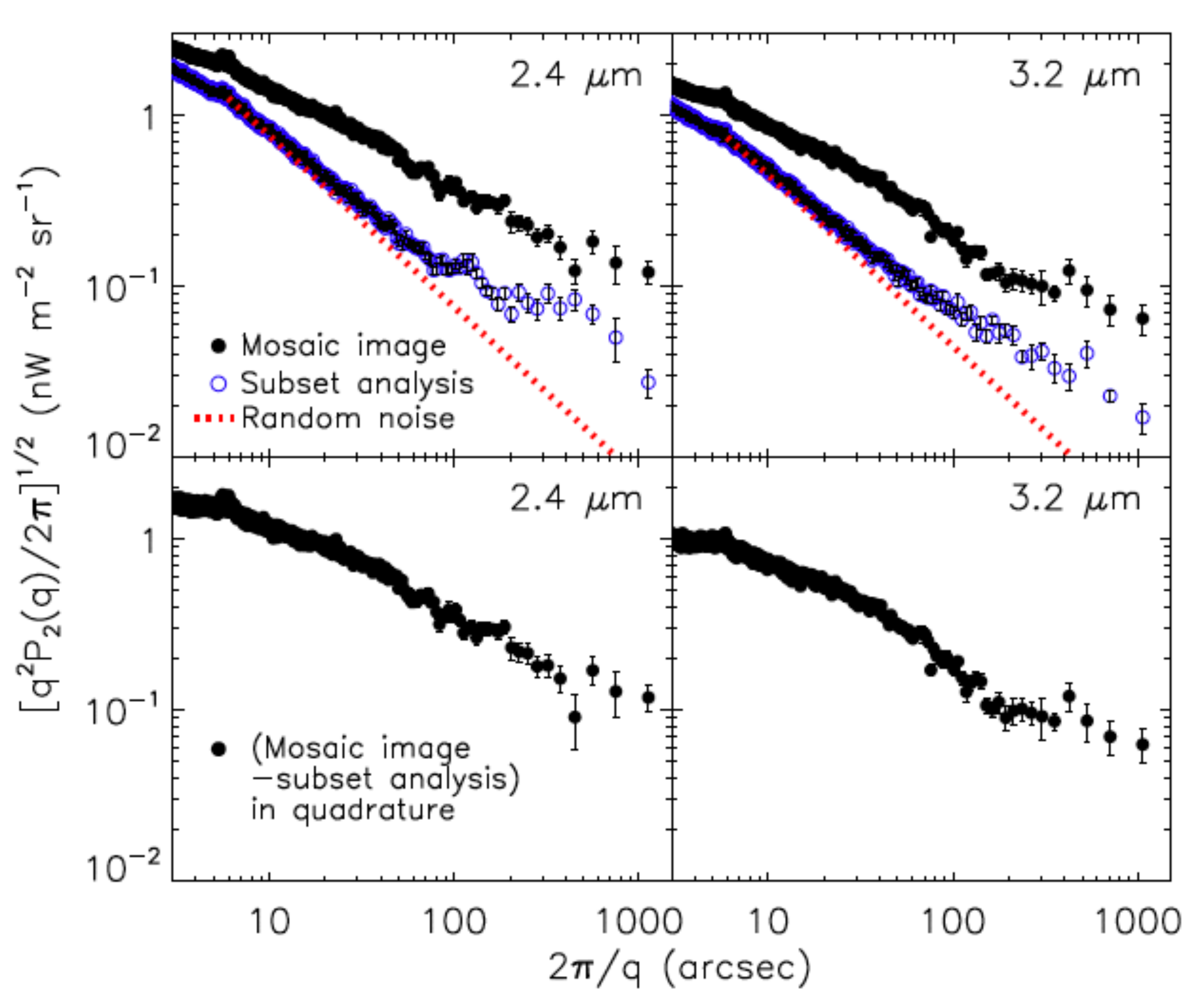
CORRECTION FOR THE INSTRUMENTAL EFFECTS



- MUXbleed caused sudden changes in background: we corrected it by fitting the average background to the linear function

FLUCTUATION SPECTRA

- Noise power was obtained by computing the fluctuation power for the difference images of two subsets of stacked images
- True fluctuation was obtained by quadratically subtracting the powers of mosaic and the subset
- Excess fluctuation power over all angular scales



CORRECTION FOR INSTRUMENTAL AND SYSTEMATIC EFFECTS

- The computed power can be affected by
  - Masking: too much masking could cause artificial fluctuations (mode coupling)
  - Map making procedure: adjustment of background level of adjacent images (map-making transfer)
  - Finite beam size: smear out fluctuations in small angular scale (beam transfer)

$$\tilde{P}_2(q) = M(q)T(q)B(q)P_2(q)$$

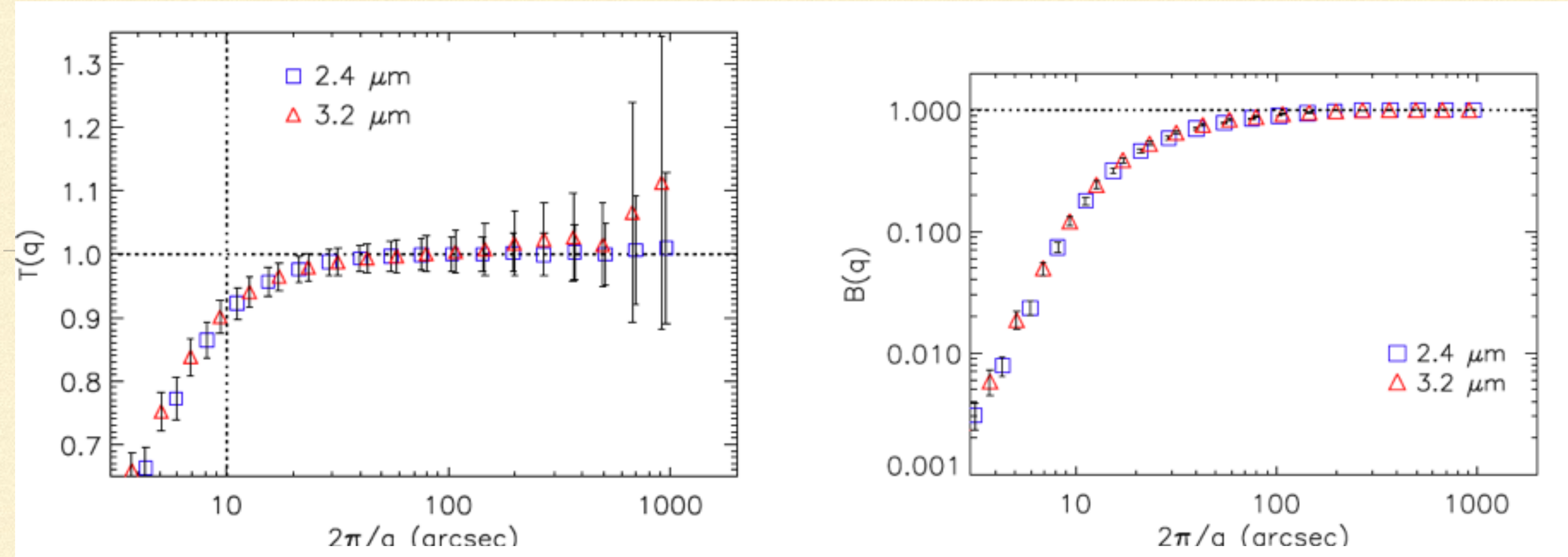
Computed power → $\tilde{P}_2(q)$

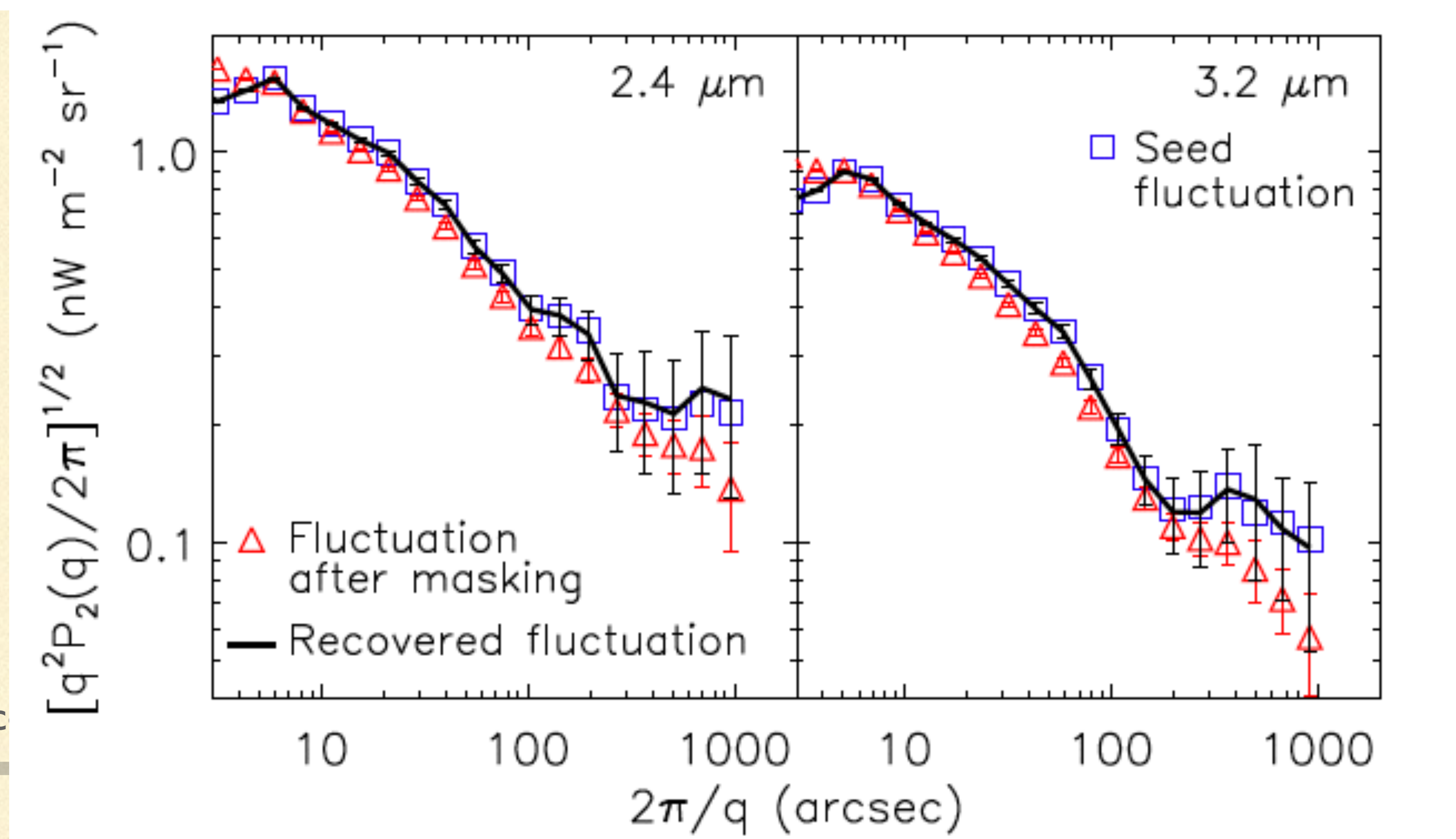
True power → $P_2(q)$

Mode coupling → $M(q)$

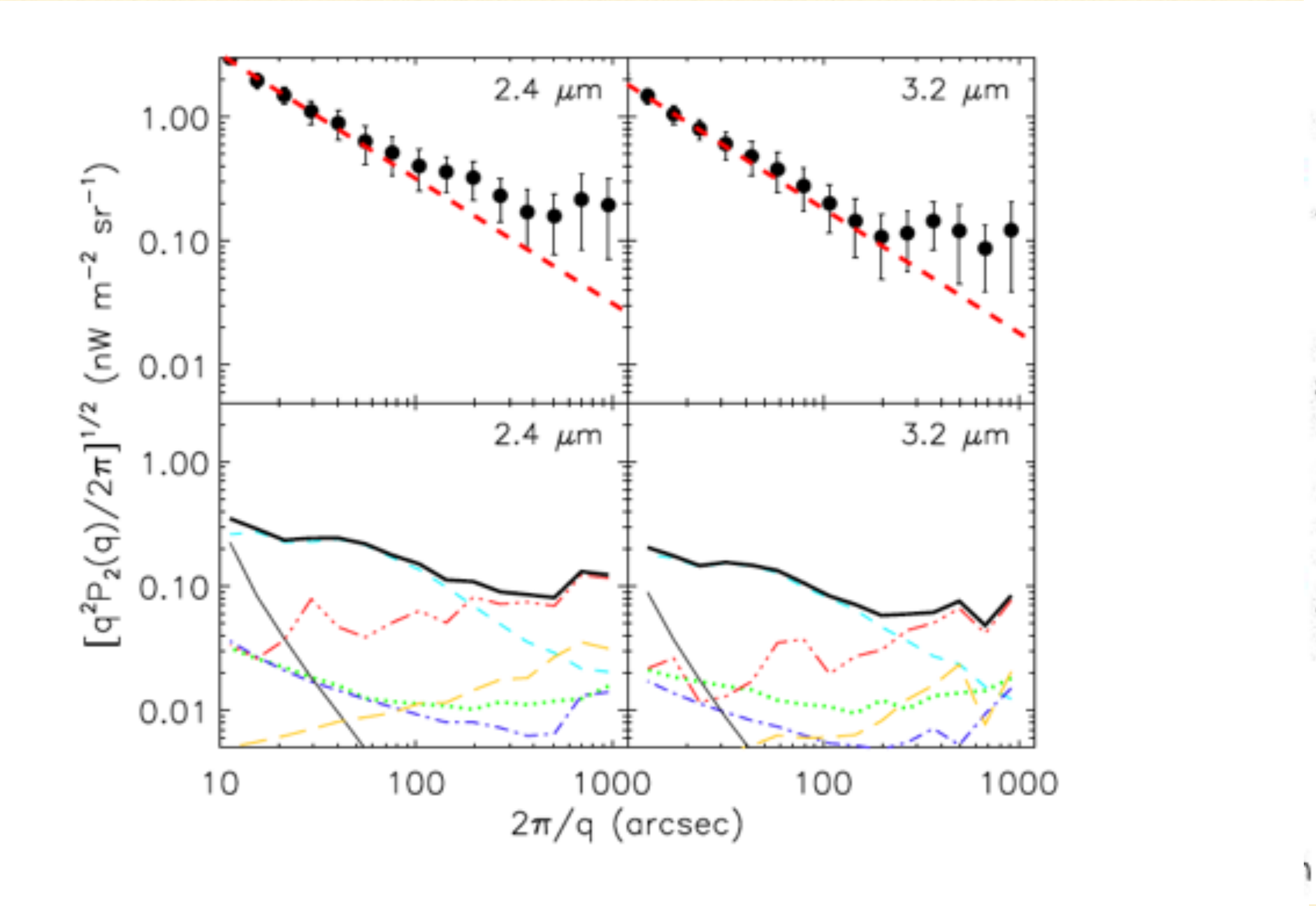
map making transfer → $T(q)$

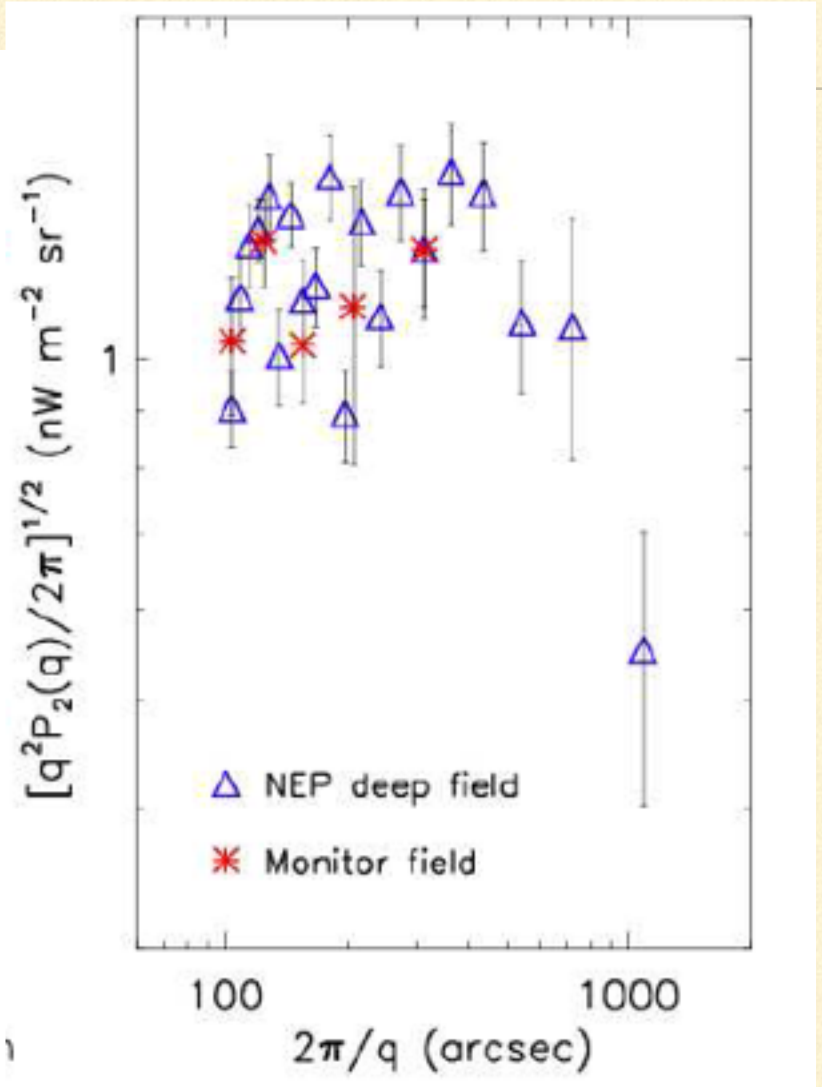
beam transfer → $B(q)$


T(q)
2.4 μm
3.2 μm
2π/q (arcsec)
B(q)
2.4 μm
3.2 μm
2π/q (arcsec)


[q²P₂(q)/2π]^{1/2} (nW m⁻² sr⁻¹)
2.4 μm
3.2 μm
Seed fluctuation
Fluctuation after masking
Recovered fluctuation
2π/q (arcsec)

ESTIMATED FLUCTUATION SPECTRA



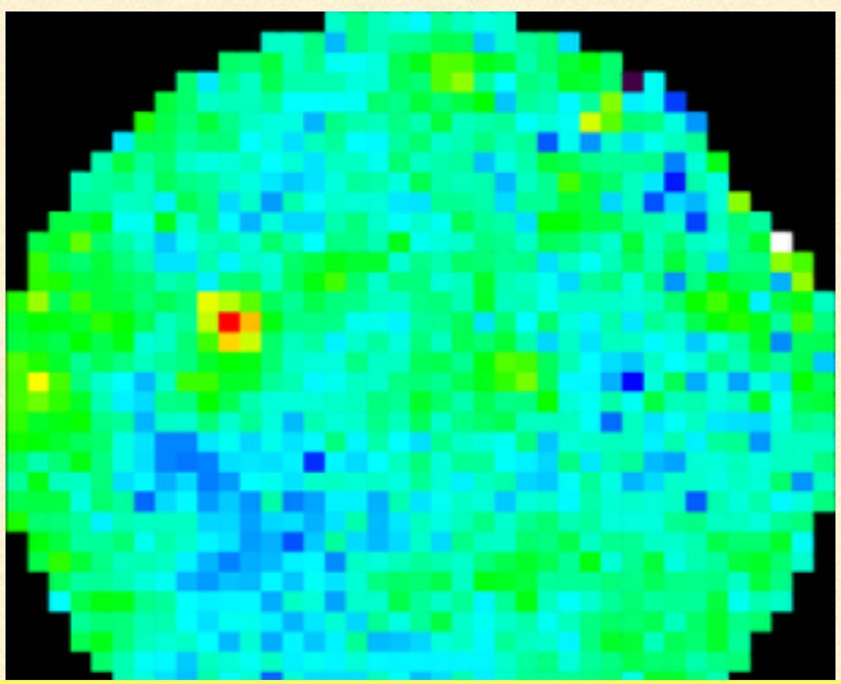


- Excess fluctuation power over shot noise up to ~1000 arcsec.
- Smooth continuation from Monitor Field Results

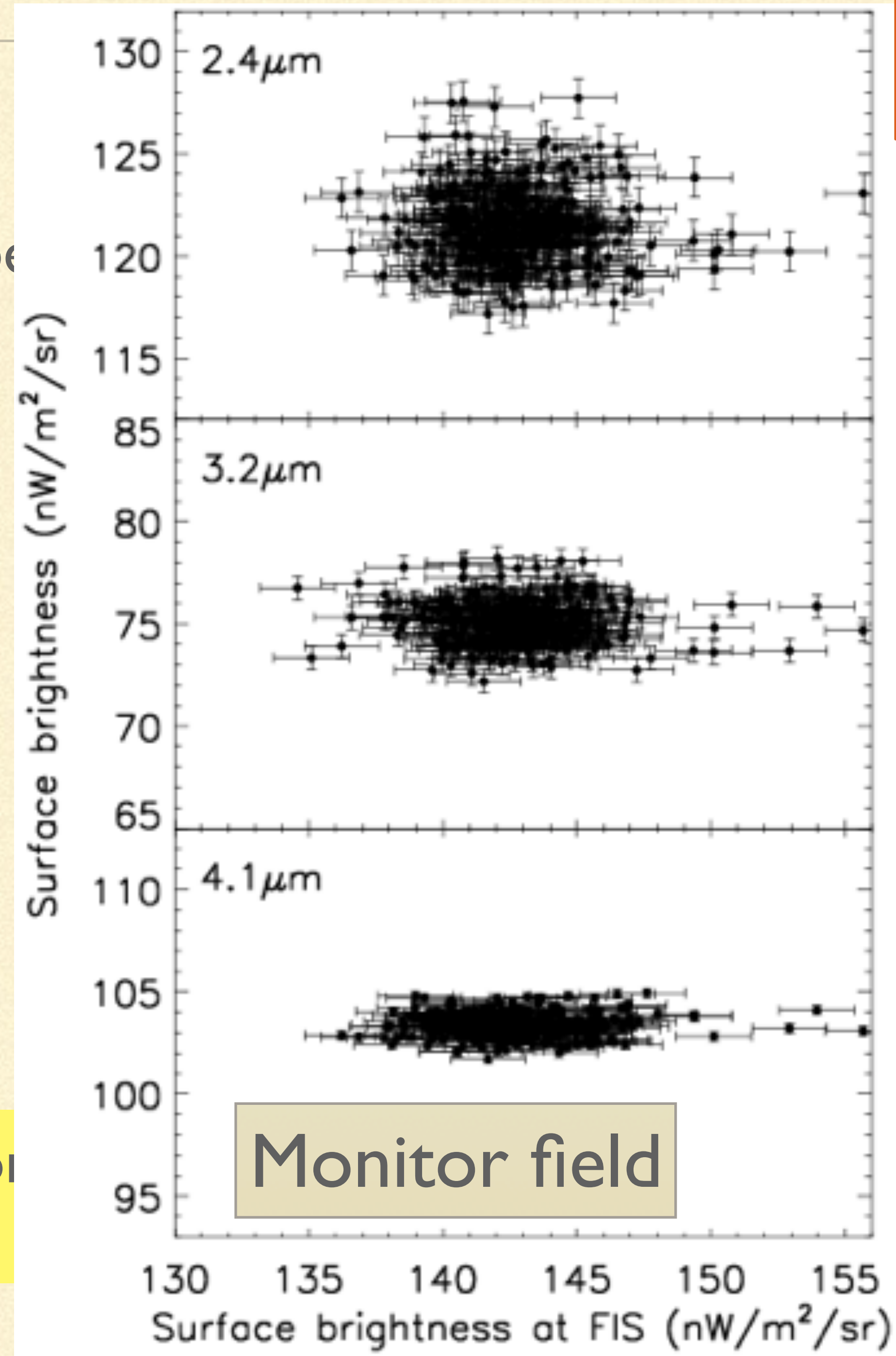
DIFFUSE GALACTIC LIGHT (DGL)?

- DGL: Scattered stellar light
- FIR Emission: Thermal emission

⇒DGL and FIR emission should be well correlated

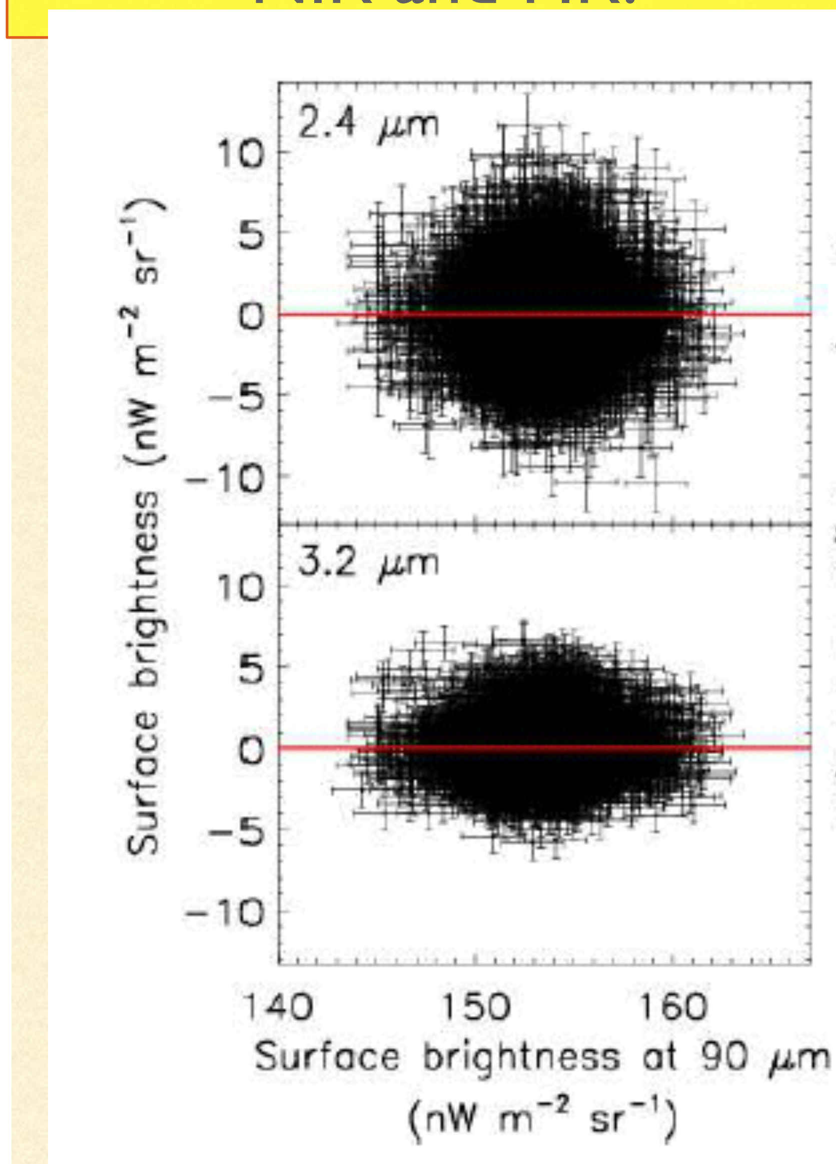


AKARI 90 μm image at Monitor field (Matsuura et al. 2010)



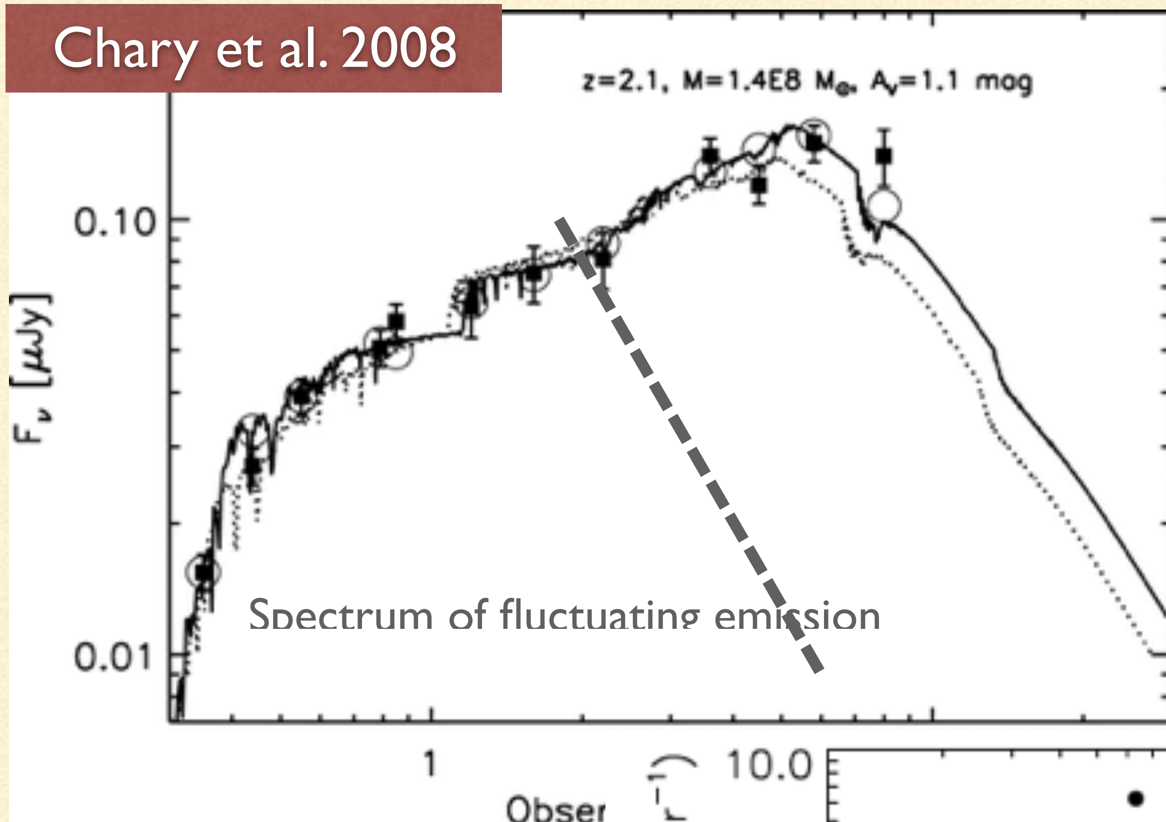
Monitor field

No correlation between NIR and FIR!

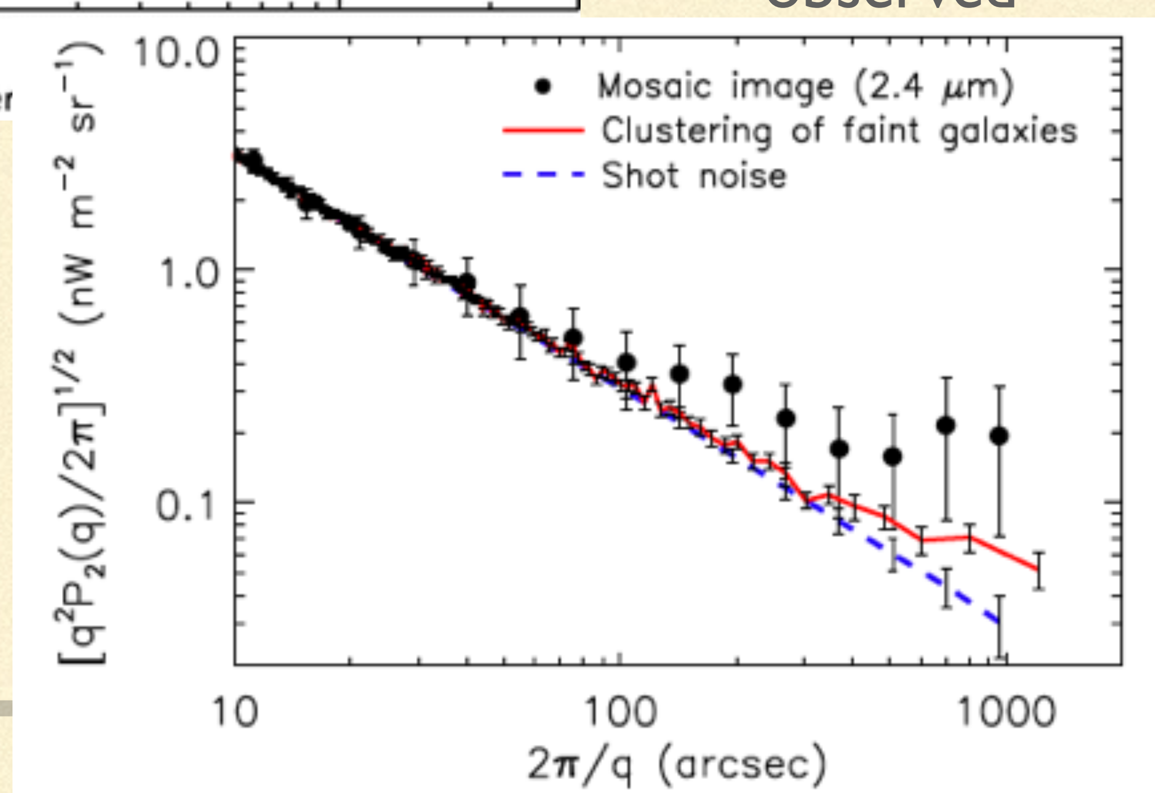


NEP-Deep field

CLUSTERING OF FAINT GALAXIES AT Z=2~3?



- Spectrum of red dwarf galaxies is red at near infrared (Chary et al. 2008)
- Expected fluctuation of galaxies fainter than Ks(Vega)>21 mag : 0.03 nW $m^{-2}sr^{-1}$ at 600”
- AKARI observation at 2.4 μm: nW m^{-2} sr^{-1}
- Estimated fluctuation power is lower than observed

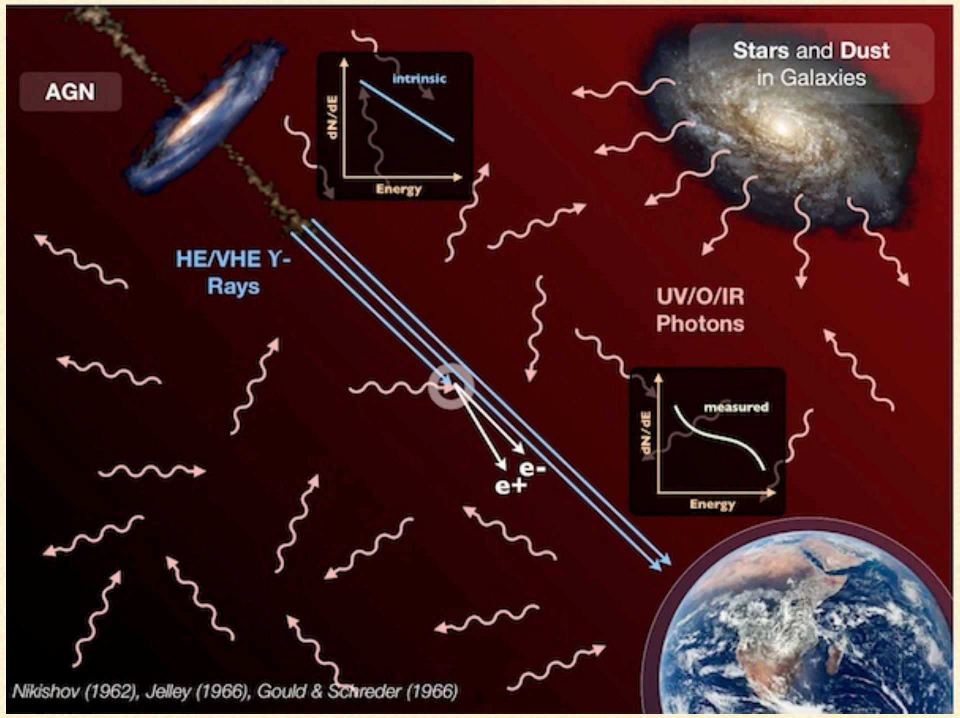


POP III STARS?

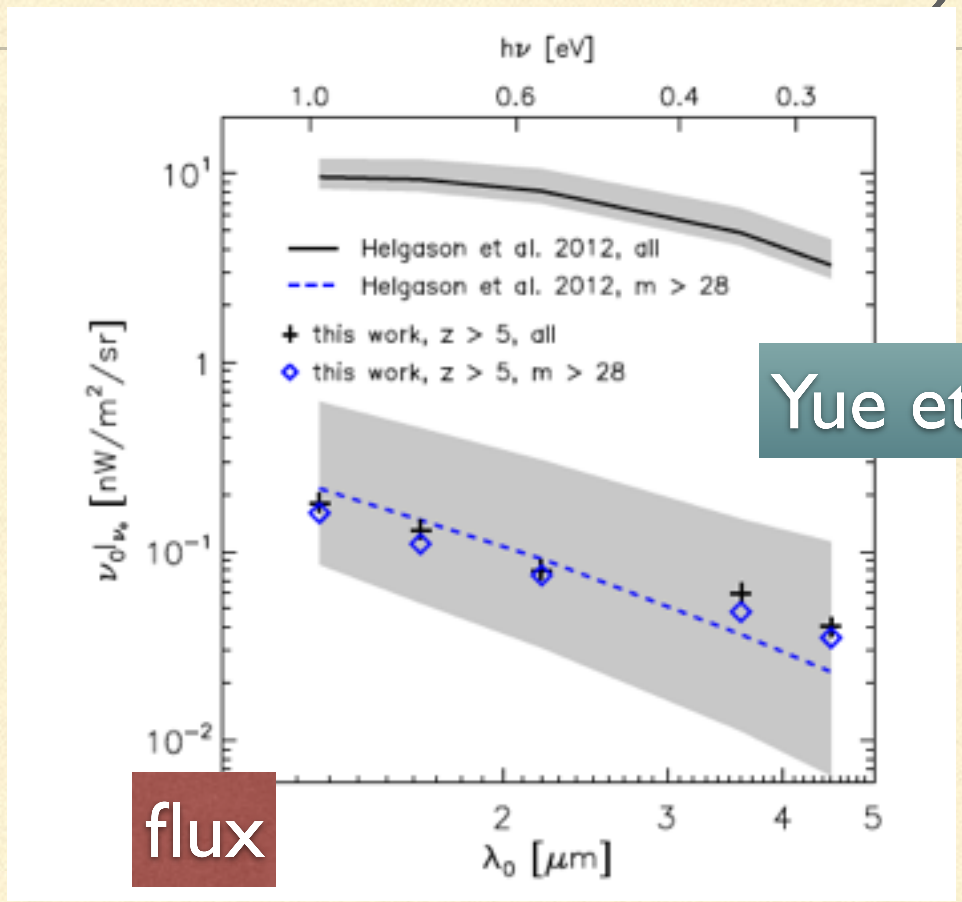
- Difficulty in explaining the TeV γ-ray spectra
  - γ-ray photons experience inverse compton scattering with IR background radiation
  - However, intrinsic spectra of TeV γ-ray galaxies are not known.
- Too much metal production (Madau & Silk 2005)

$$\Omega_* \approx 0.045\Omega_B \left(\frac{F_J}{2.5\mathrm{nW/m^2/sr^{-1}}}\right)$$

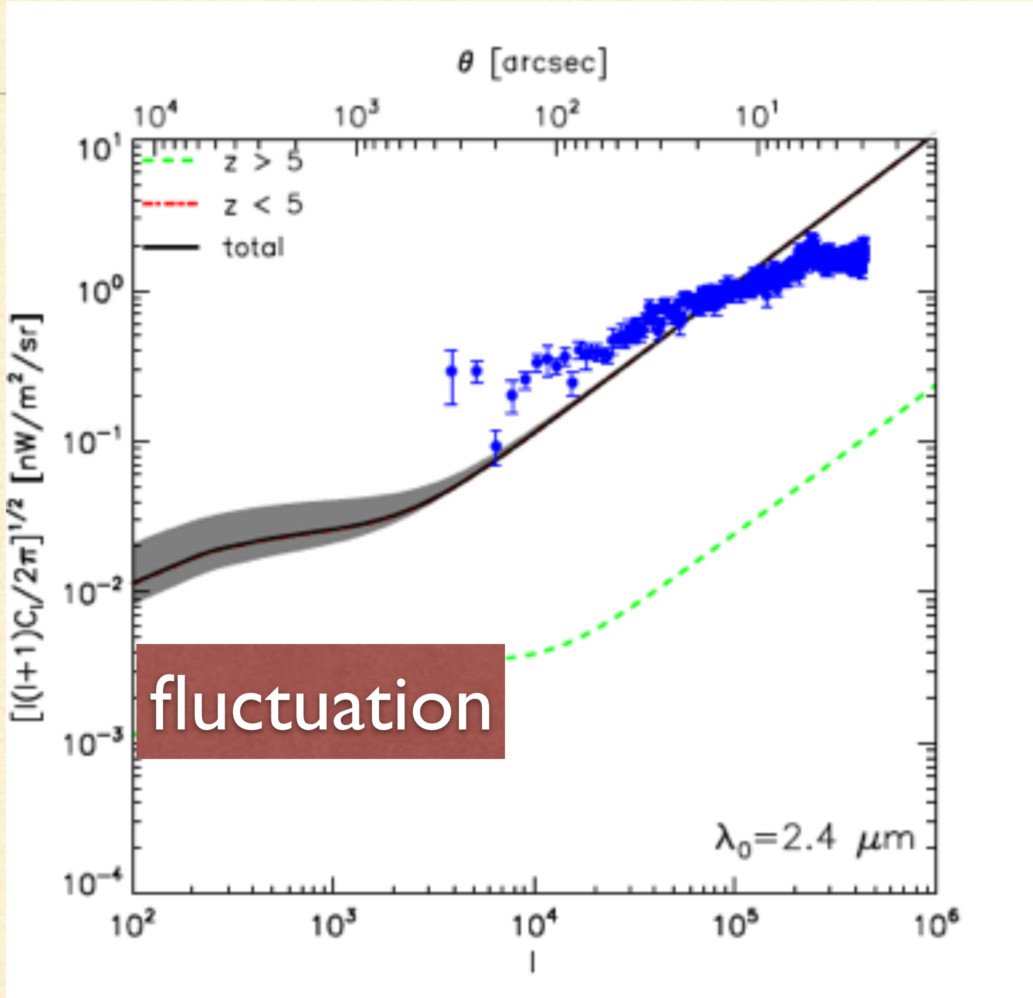
  - Absolute level uncertain
  - Collapse into black hole?



HIGH-Z GALAXIES (INCLUDING POP III STARS)?



Yue et al. 2012

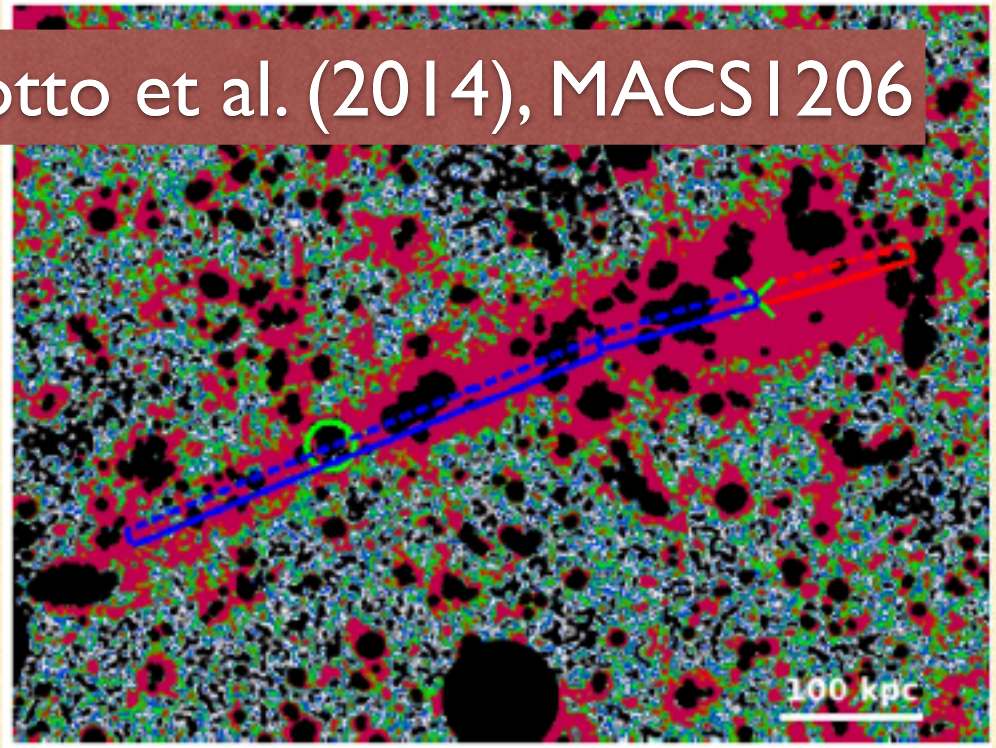


- Background flux level can be explained by combination of low and high-z galaxies
- However, fluctuations at 100-1000 arctic cannot be explained by 'known' components

INTRA HALO LIGHT (IHL)

- Diffuse light in intracluster has been found (IHL or ICL)
- The fraction and origin of IHL are not well known: accretion or in-situ
- IHL becomes an interesting component in understanding the formation and evolution of galaxies

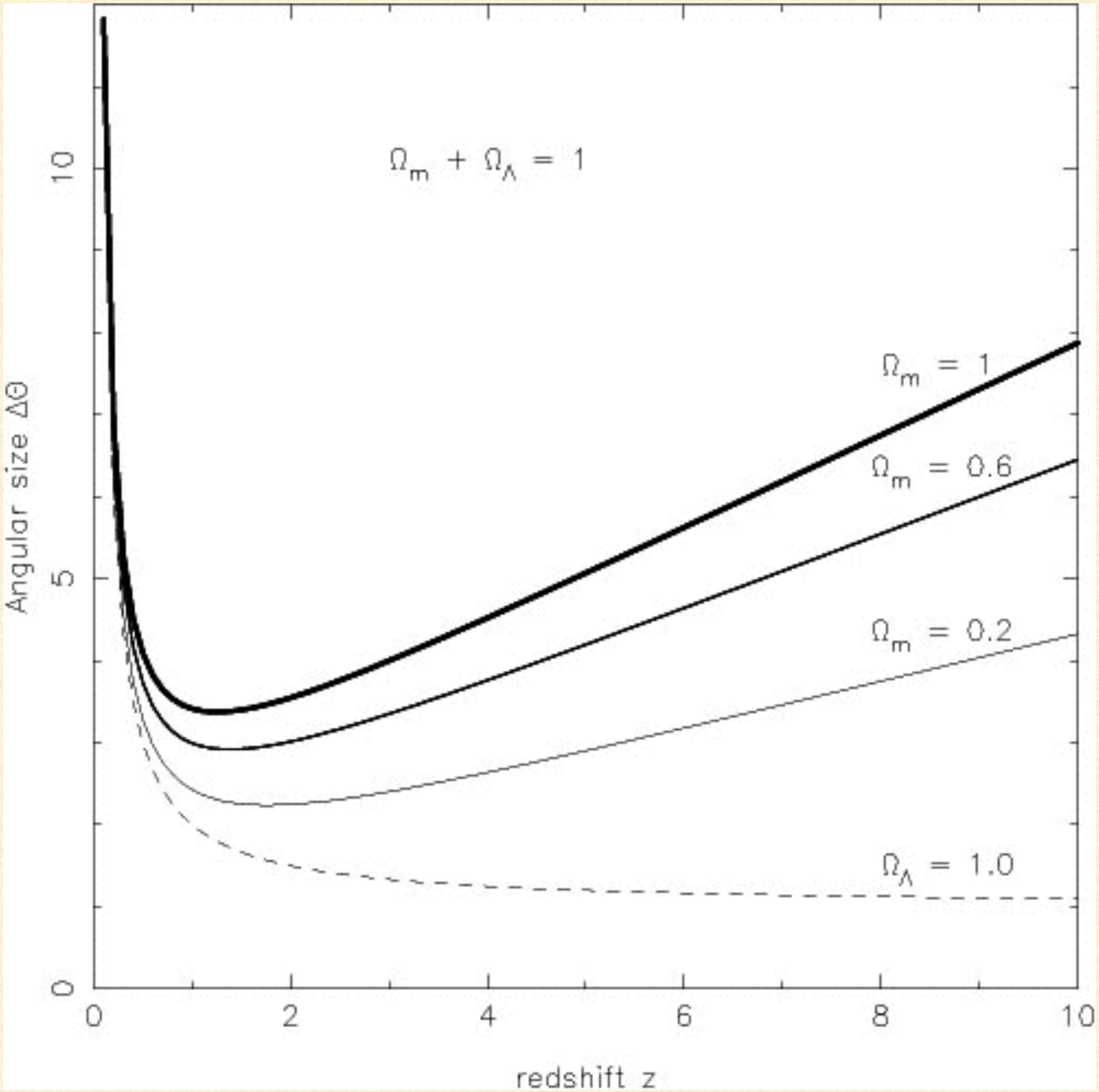

Mihos et al. (2005), Virgo



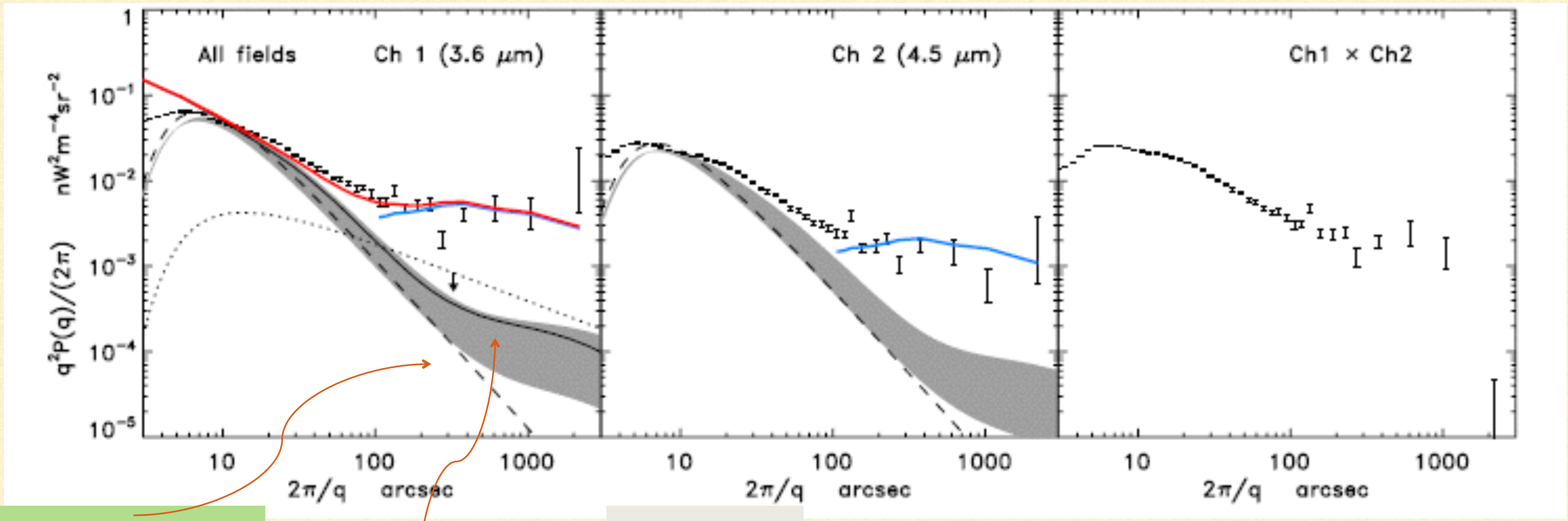
Presotto et al. (2014), MACS1206

IHL AS SOURCE OF IR BACKGROUND

- Larger fluctuation means strong clustering
- Clusters are known to show strong clustering than galaxies
- Angular scale distance varies slowly from z>1
  - Larger fluctuation is expected from



LARGE SCALE FLUCTUATION FROM SPITZER



Shot Noise

Known galaxies fainter than detection limits

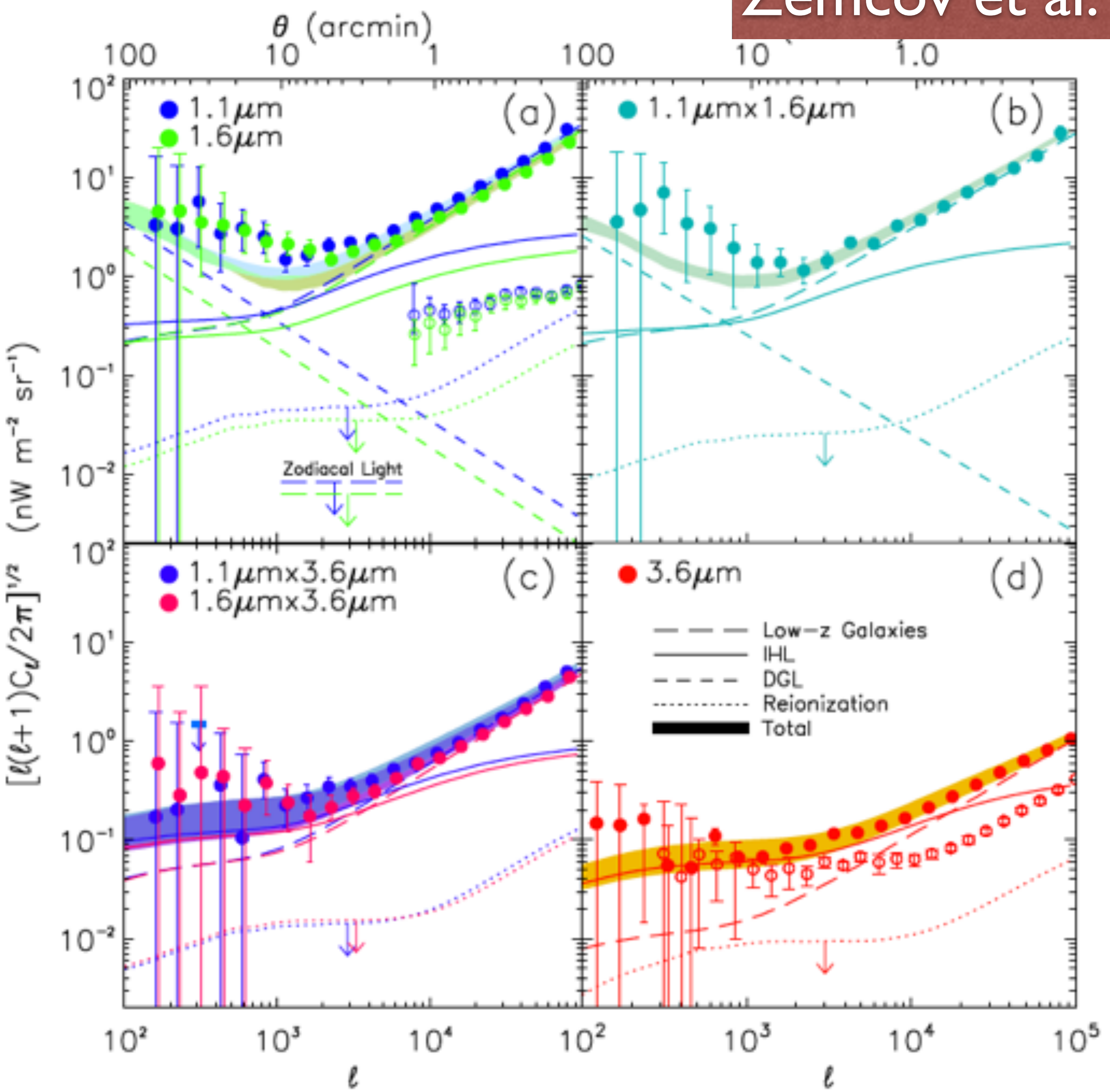
Red: Total

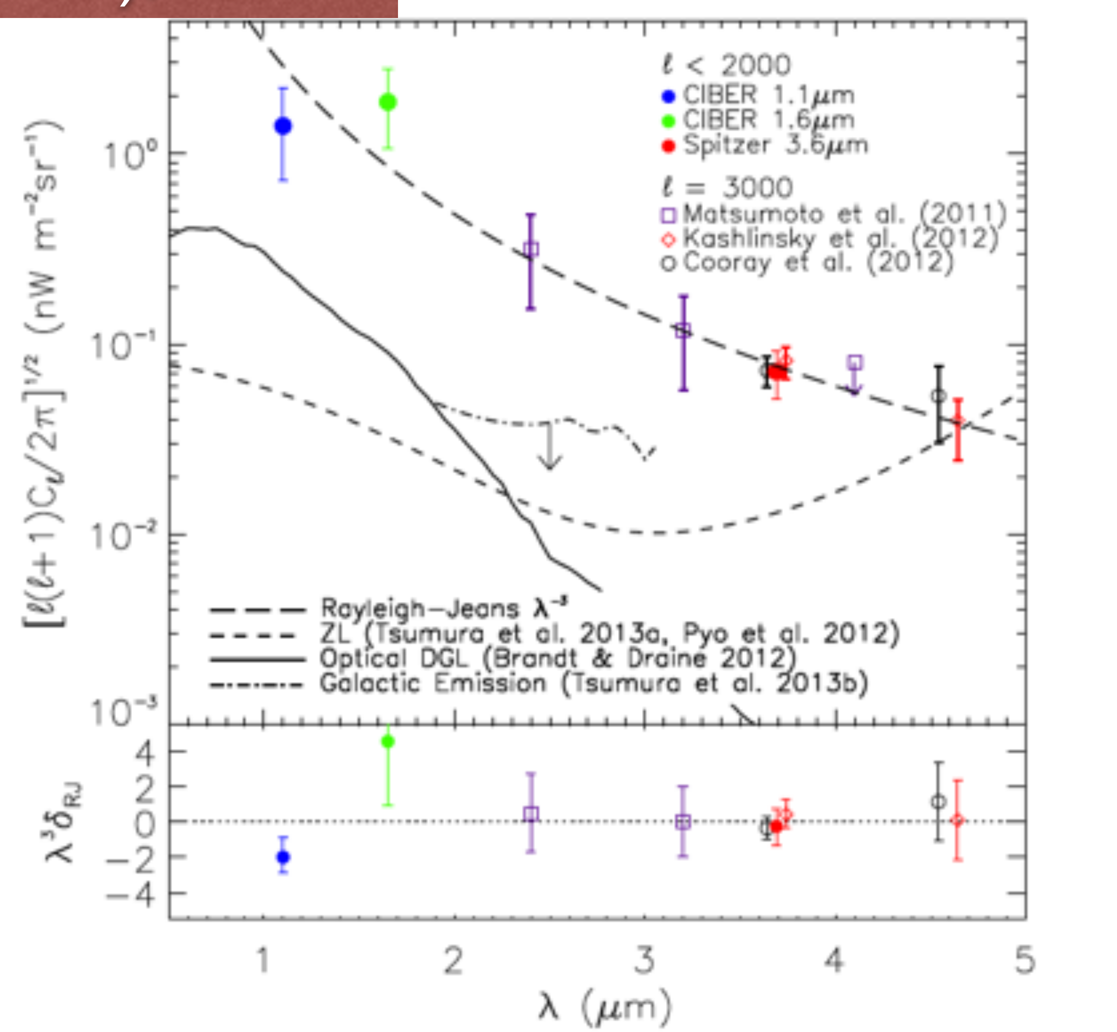
Blue: High-z ΛCDM

Kashlinsky et al. 2012

INTRA-HALO LIGHT (IHL) AND OBSERVED FLUCTUATIONS

Zemcov et al. (2014), CIBER



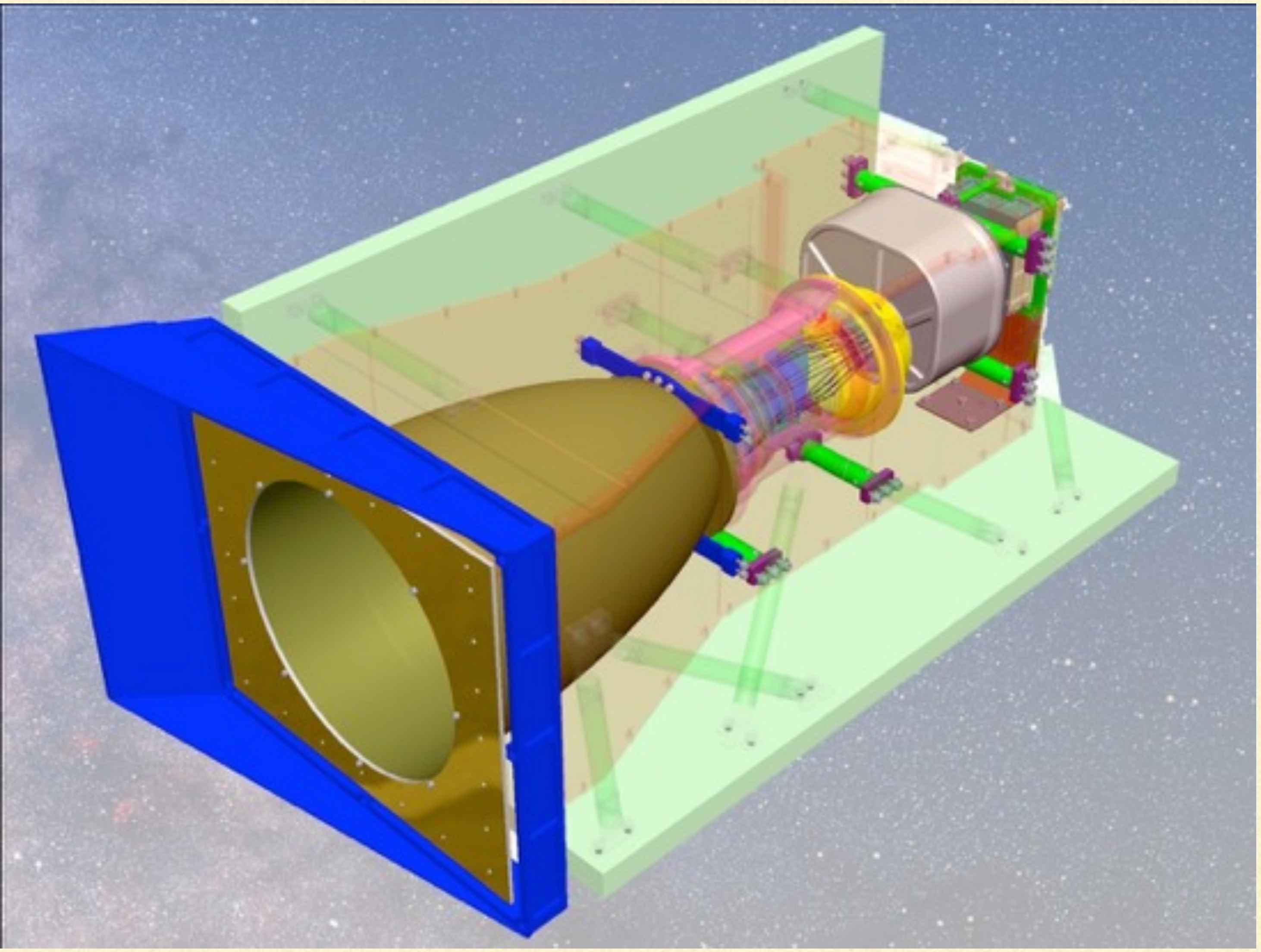


- IHL may be able to account for most of the fluctuation at 10-100 arcmin.

WHAT ELSE DO WE NEED?

- Current measurement extends to ~1 degree
- Recent analysis of IRTS data by Matsumoto et al. (private comm.) shows excess power up to ~40 degree (tentative)
  - Such a large scale structure due to the same component?
  - Very local?
- MIRIS will filll the gap of 1-10 degree fluctuations

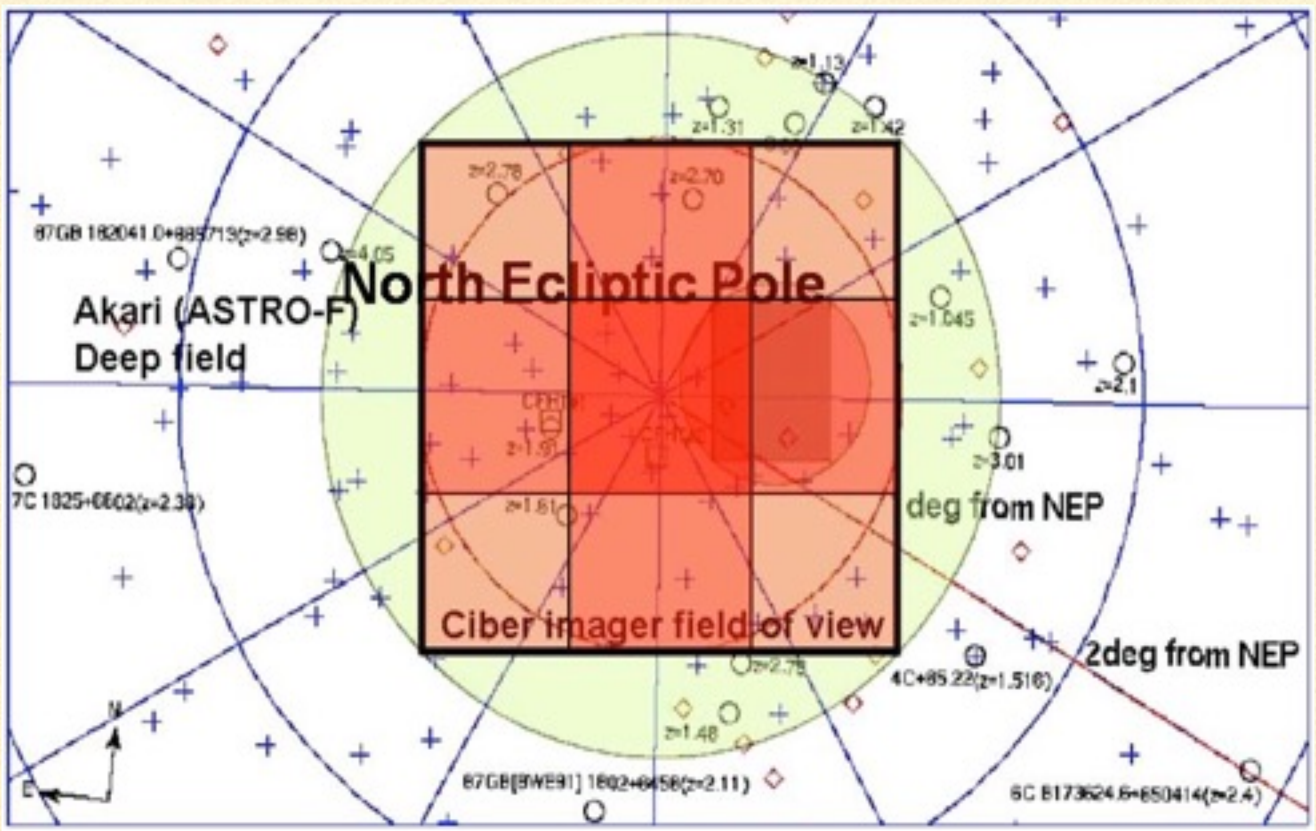
MIRIS CONCEPT

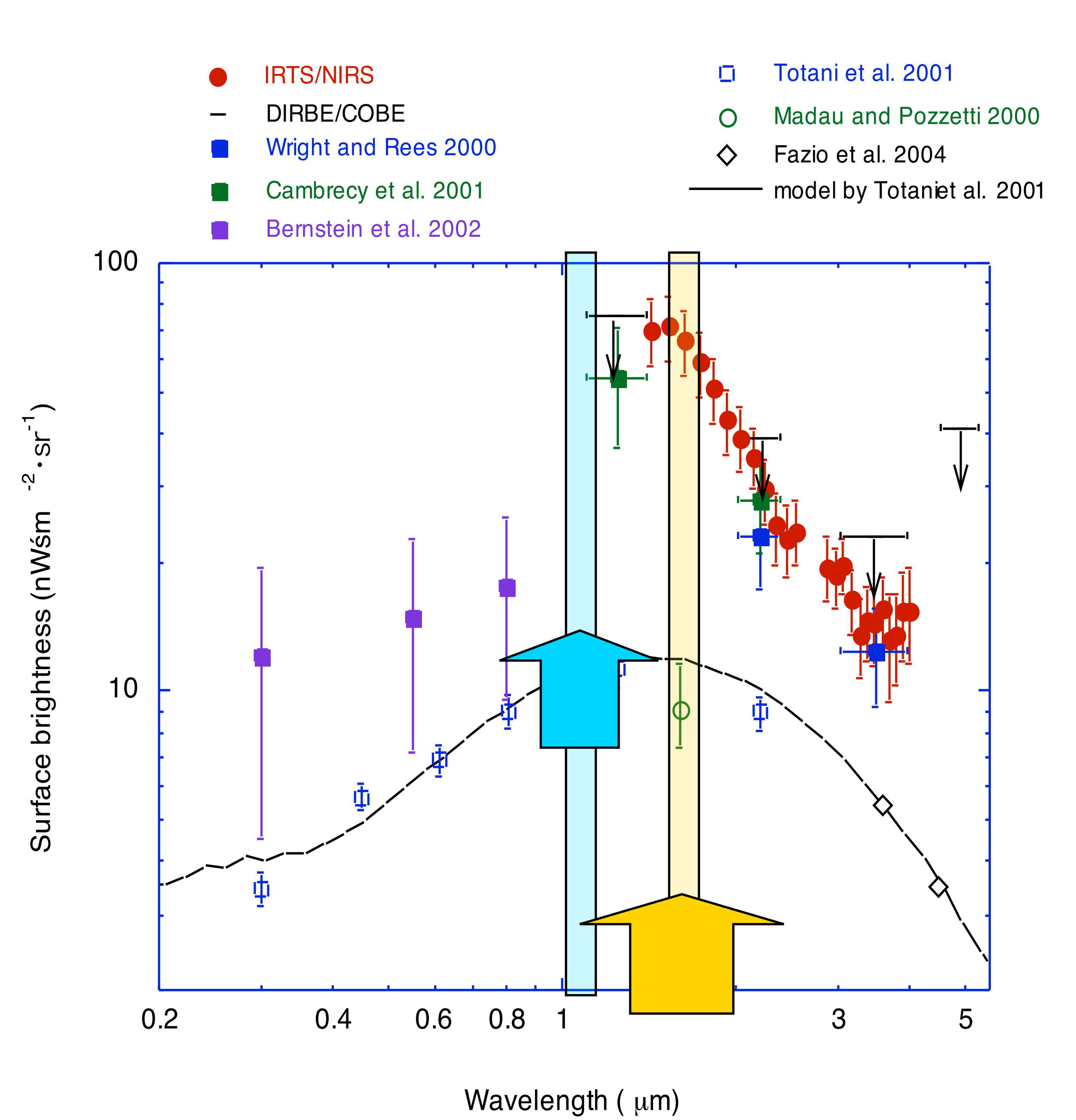


- Optics
  8cm aperture, F2
  Refractive optics
- Picnic array:
  51.6” pixel scale,
  3.67° x 3.67°
- Telescope is passively cooled by radiation to ~180K
- Mission period: Nov. 2013 - early 2015

COSMIC NEAR-INFRARED BACKGROUND: MIRIS OBSERVATION

- I & H bands
- NEP (North Ecliptic Pole): > 10° x 10° (FOV = 3.67o x 3.67o)





SUMMARY

- Unambiguous detection of Cosmic Infrared Background (CIRB) from various surveys
  - Spitzer: GOODS , UDS, EGS
  - AKARI's Monitor field and NE-Deep field
  - CIBER: NEP
- Excess powers 100-1000 arc second
- Nearly Rayleigh-Jeans SED with possible peak around ~ 1.8 μm
- Difficult to explain with zodiacal light, diffuse galactic light or low-z faint galaxies
- Possible explanations
  - Pop III stars, and epoch of reionization? Maybe difficult
  - IHL appears to be a viable candidate
- Future
  - Measurements at larger angular scale (~up to 10 degrees) and spectrum will help to understand the origin