Cosmic Near Infrared Background Radiation from AKARI Surveys as an Indicator the First Galaxies

Hyung Mok Lee (Seoul National University)

In collaboration with T. Matsumoto (ASIAA), H. Seo (SNU), W. Jeong (KASI), K. Wada, S. Oyabu, S. Matsuura (ISAS/JAXA), and more

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

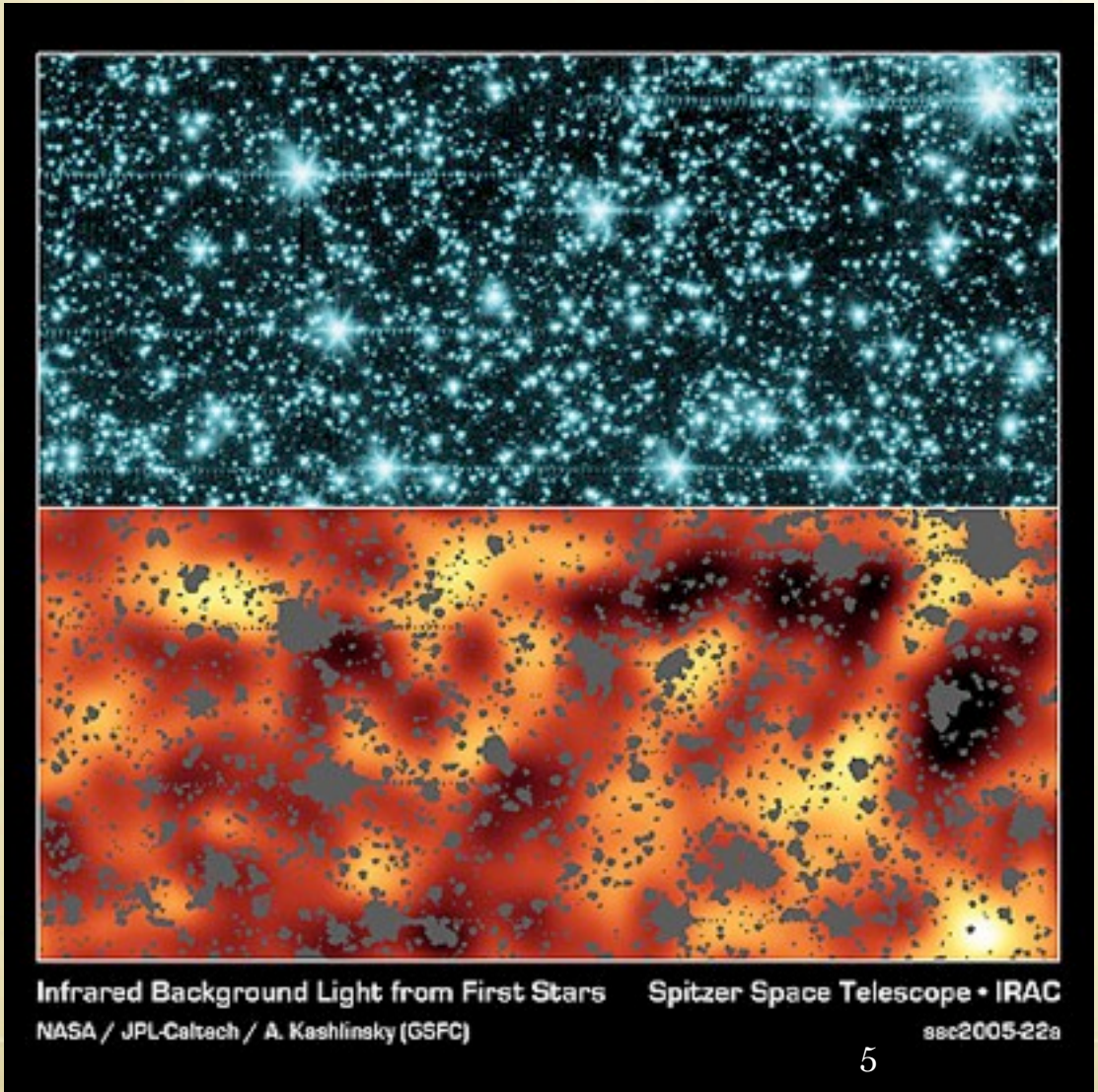
Previous Measurements

- 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

Controversy

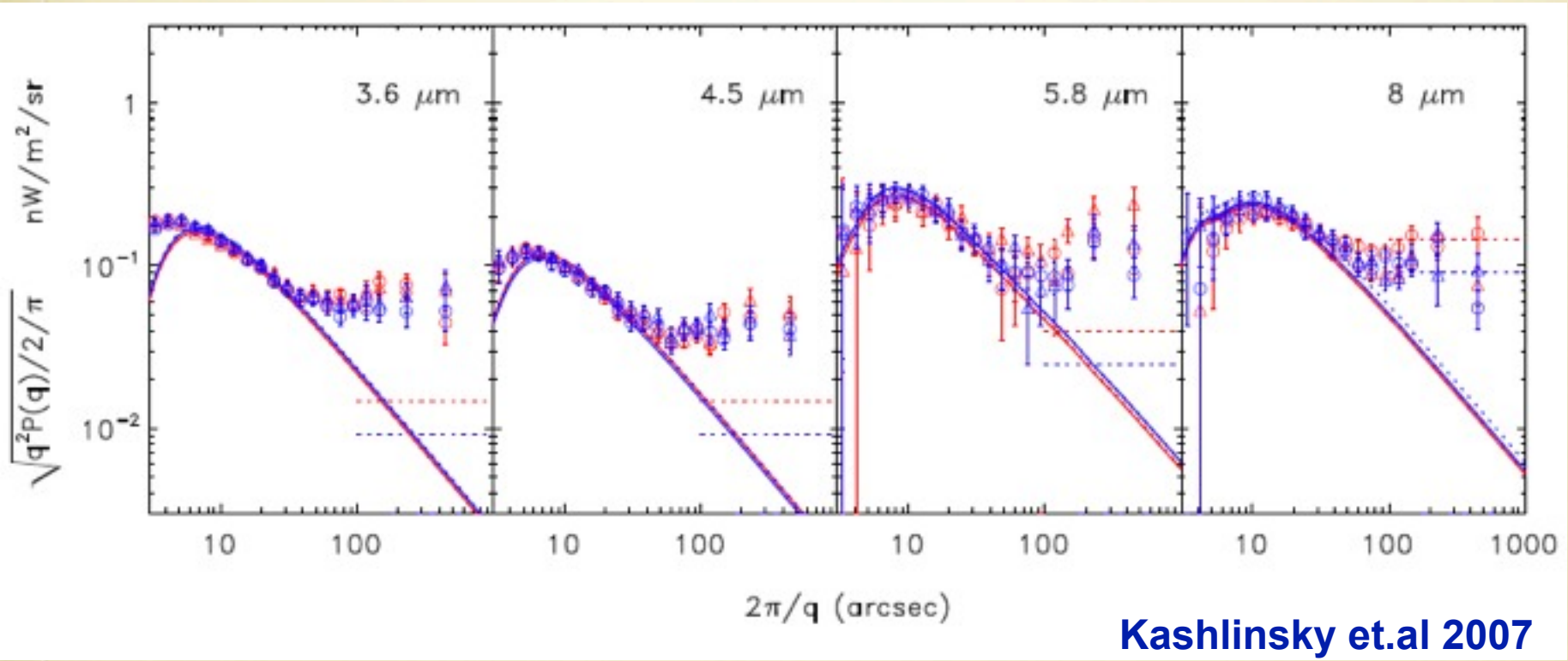
- Uncertainties in foreground Zodiacal Light
- TeV γ-ray Blazar spectrum favors no excess above the contributions from faint galaxies (Ahronian et al. 2005, Mazin & Raue 2007)
- Energetics: claimed background light means too much generation of Pop. III stars (Madau & Silk 2005)

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

AKARI

- Space Mission by Japan Aerospace Exploration Institutes (JAXA)/Institute for Space and Aeronautical Science (ISAS) with ESA support
- International Collaboration

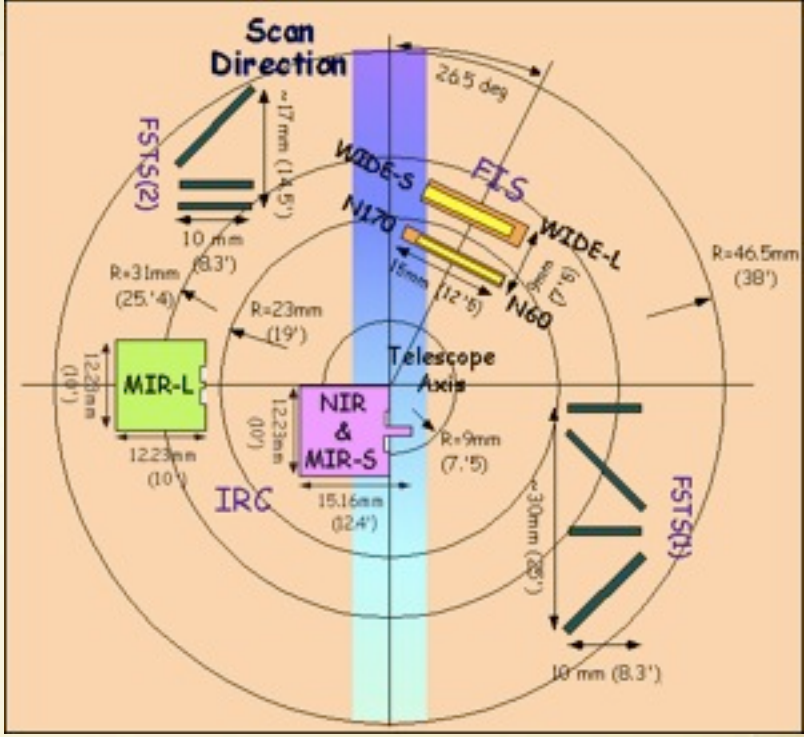
- Seoul National University

- European Consortium (Imperial, Open Univ., Sussex, Groningen)

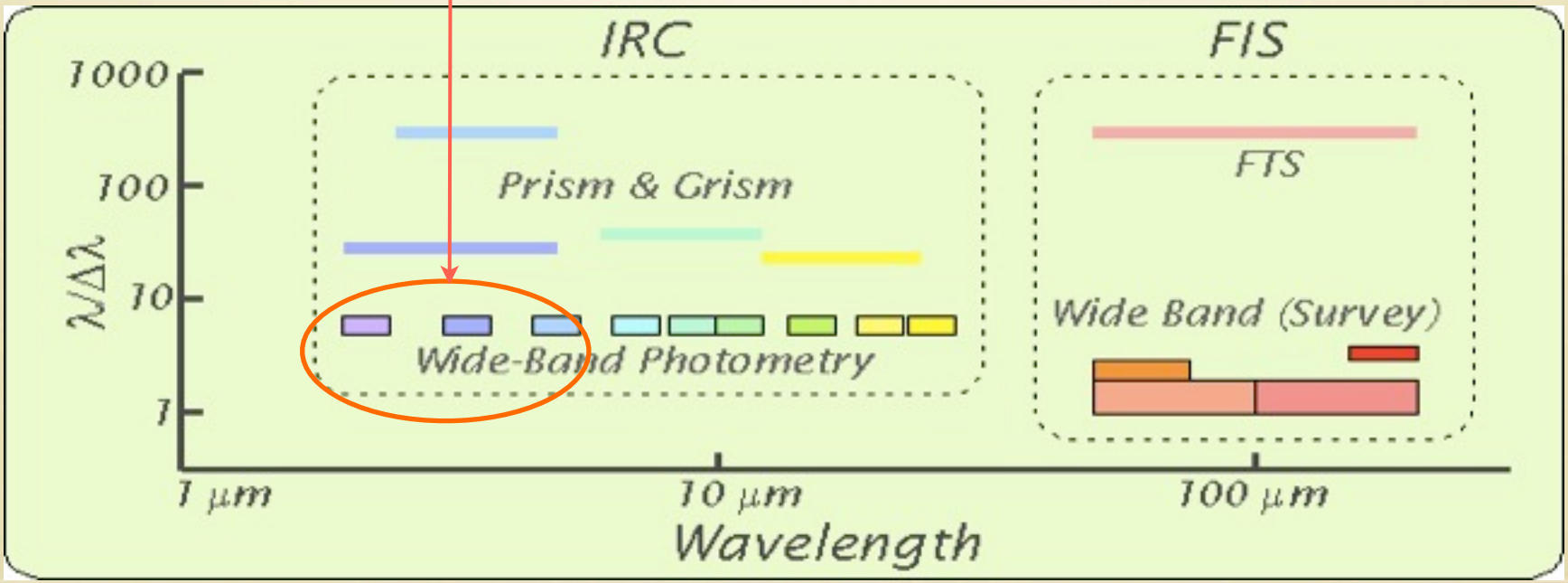
Launched on Feb. 22, 2006

Focal Plane Instruments

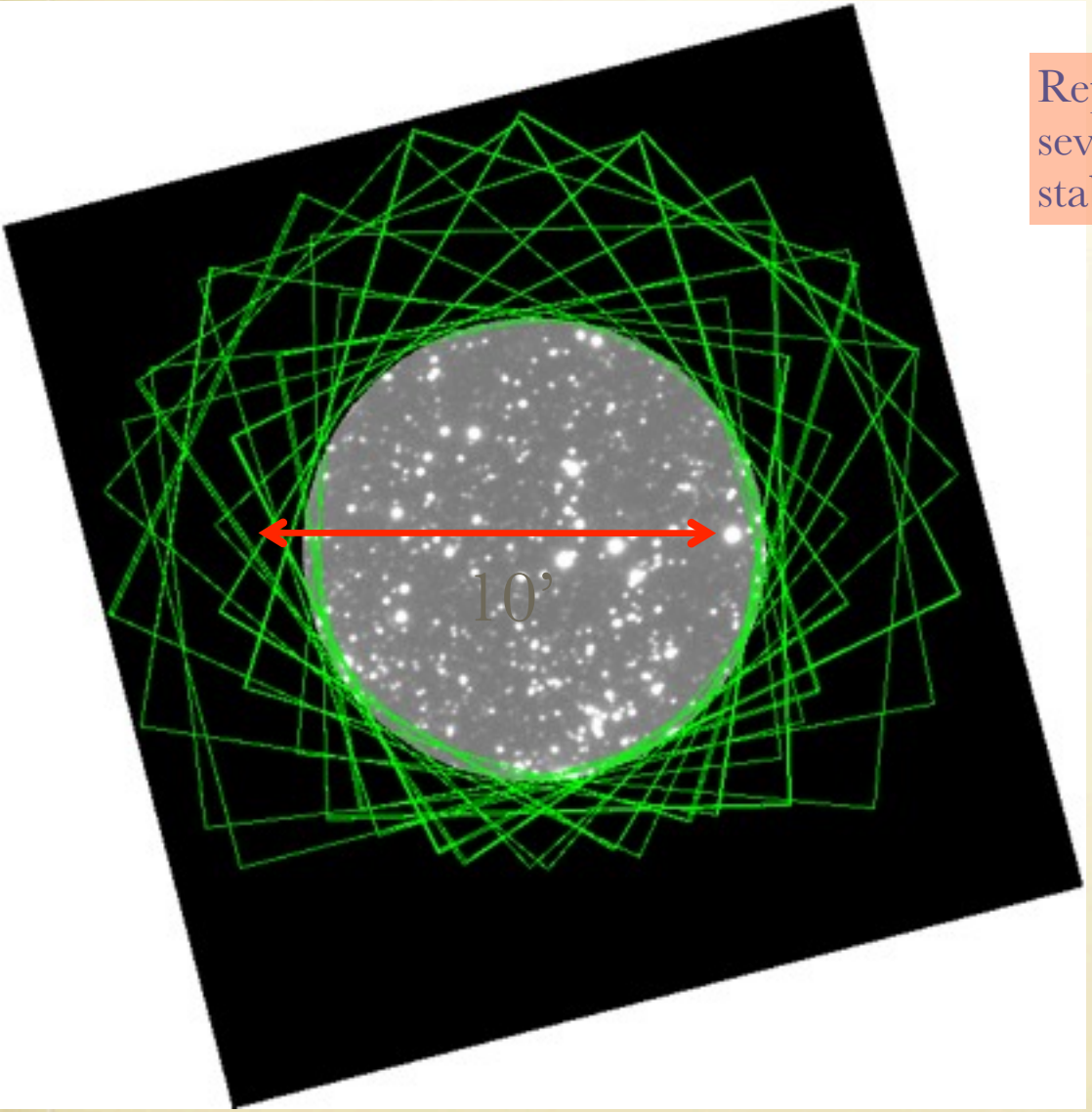
- IRC: *Near- and Mid-IR Camera*
- FIS: *Far-IR Surveyor*



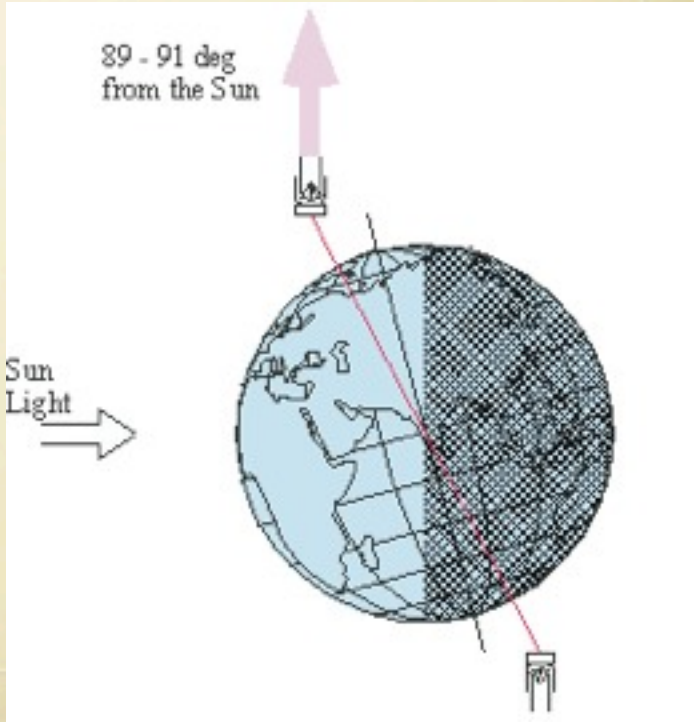
We used there 3-bands for CIRB



Monitor Field near the NEP



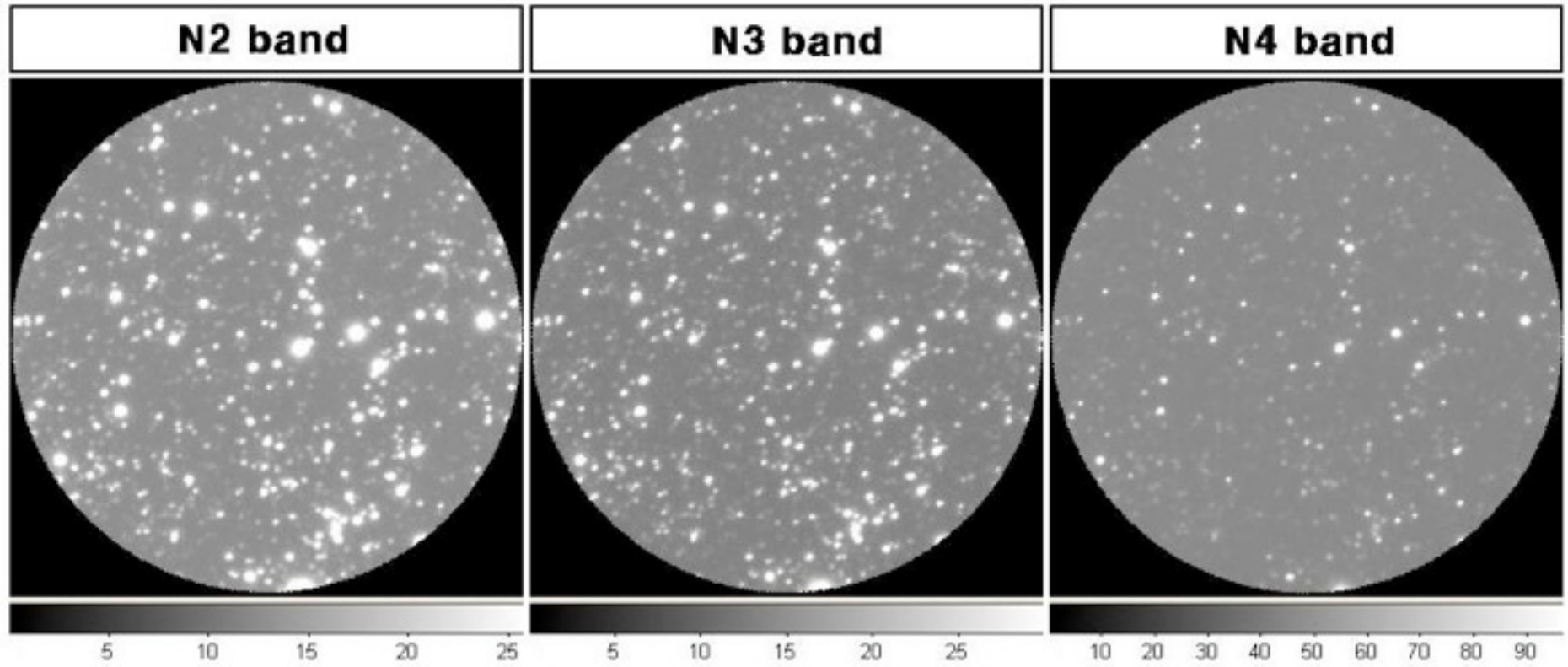
Repeated measurements over several months to check the stability of the instrument



Summary of Monitor Field Data

Band	N2 (2.4 μm)	N3 (3.2 μm)	N4 (4.1 μm)
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

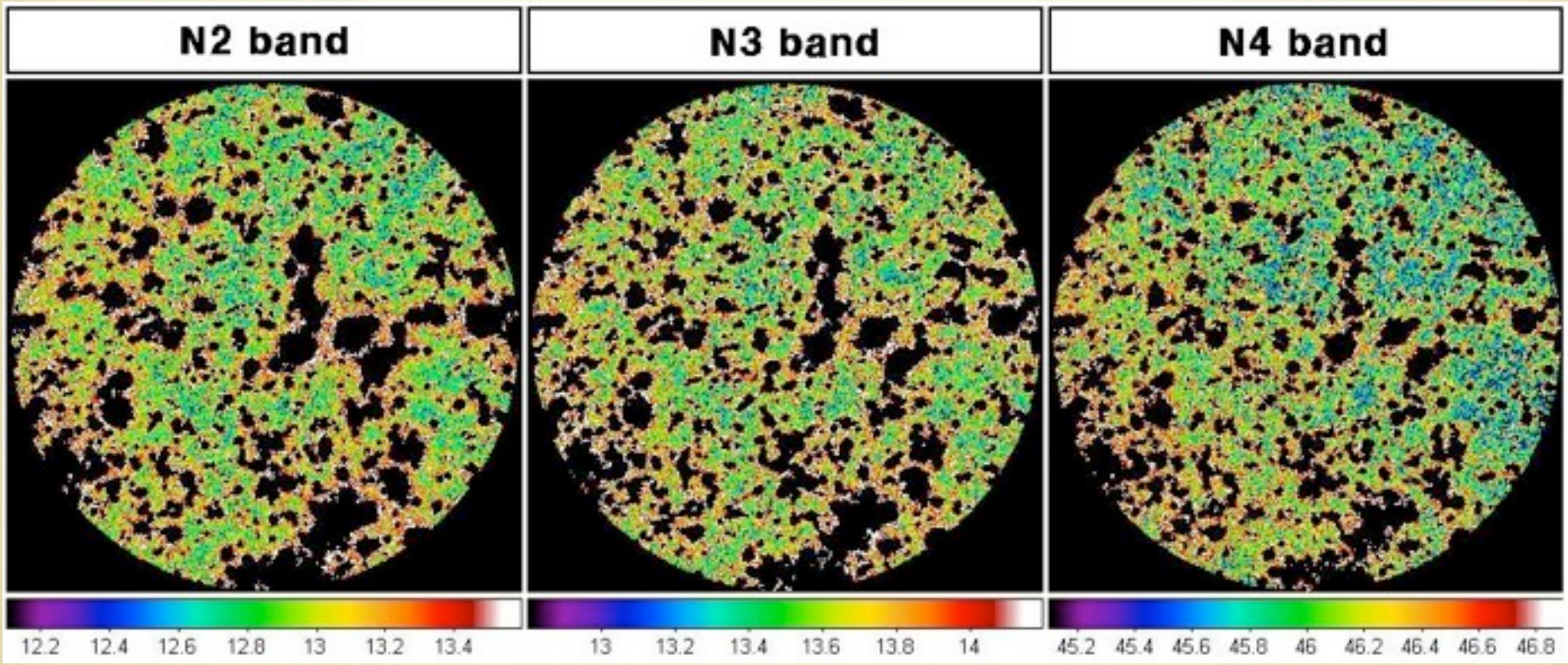


※ **The number in the scale bar is ADU scale.**

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.

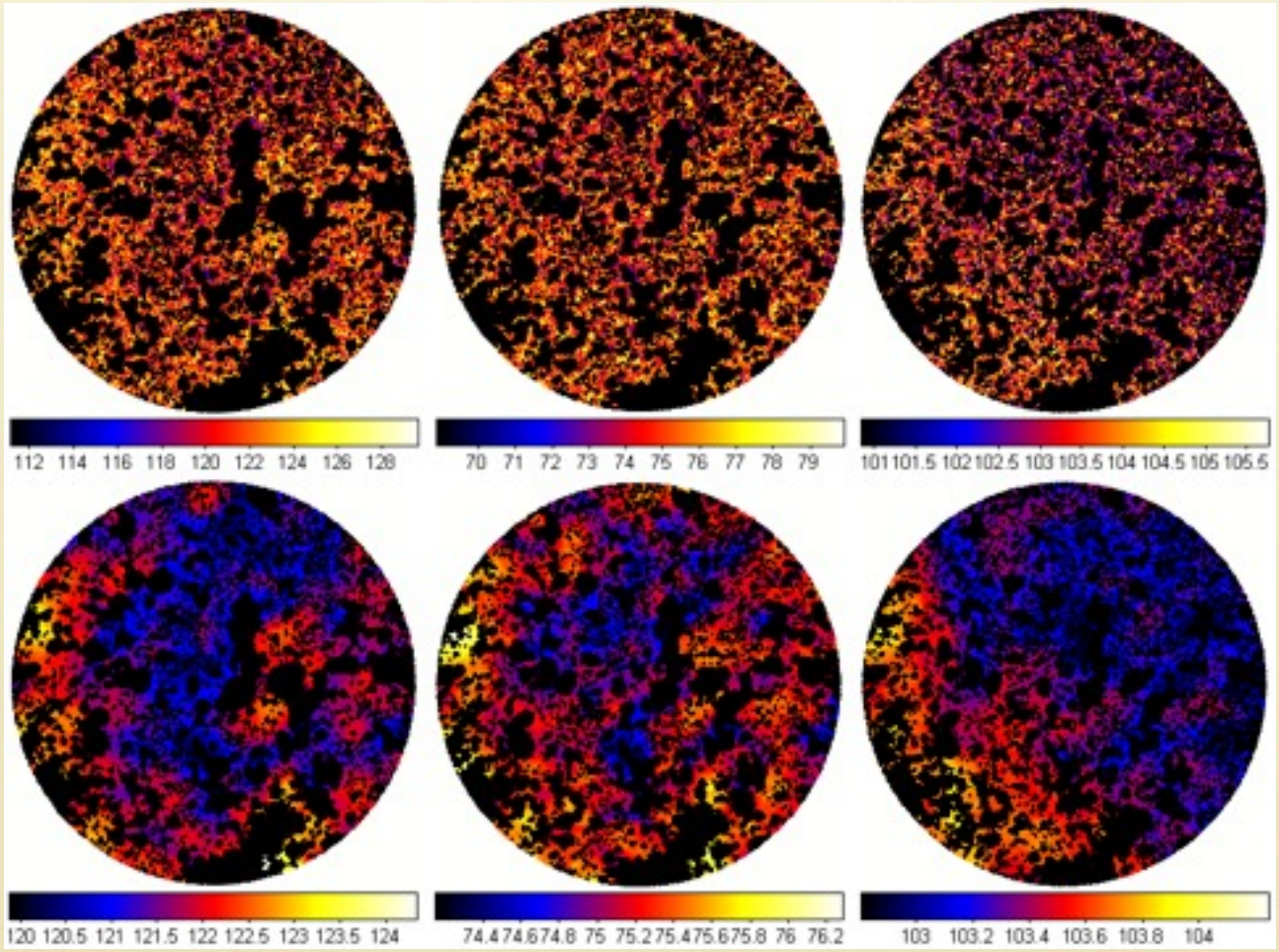
Images after 2σ clipping



※ **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 %



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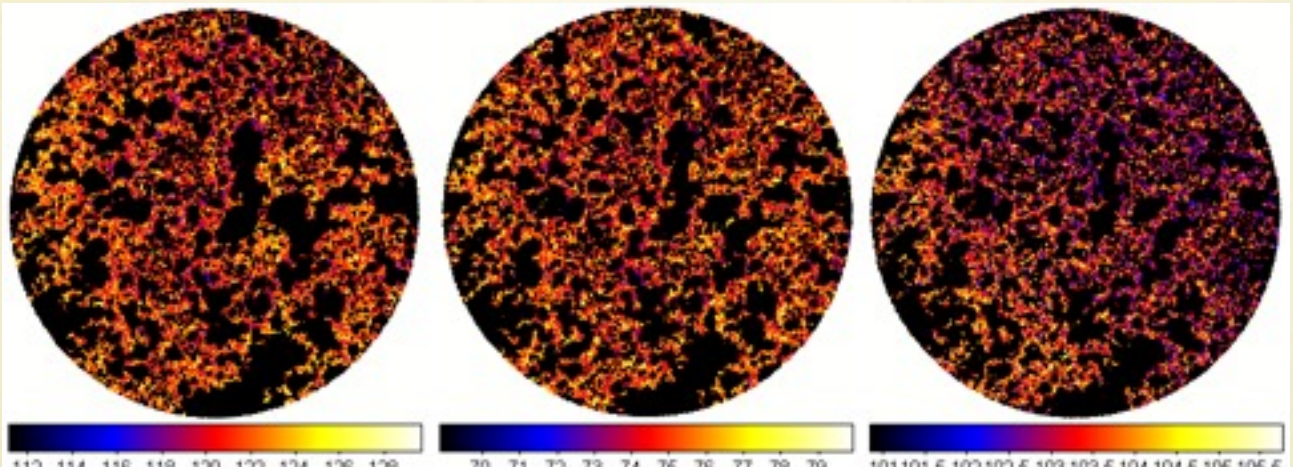
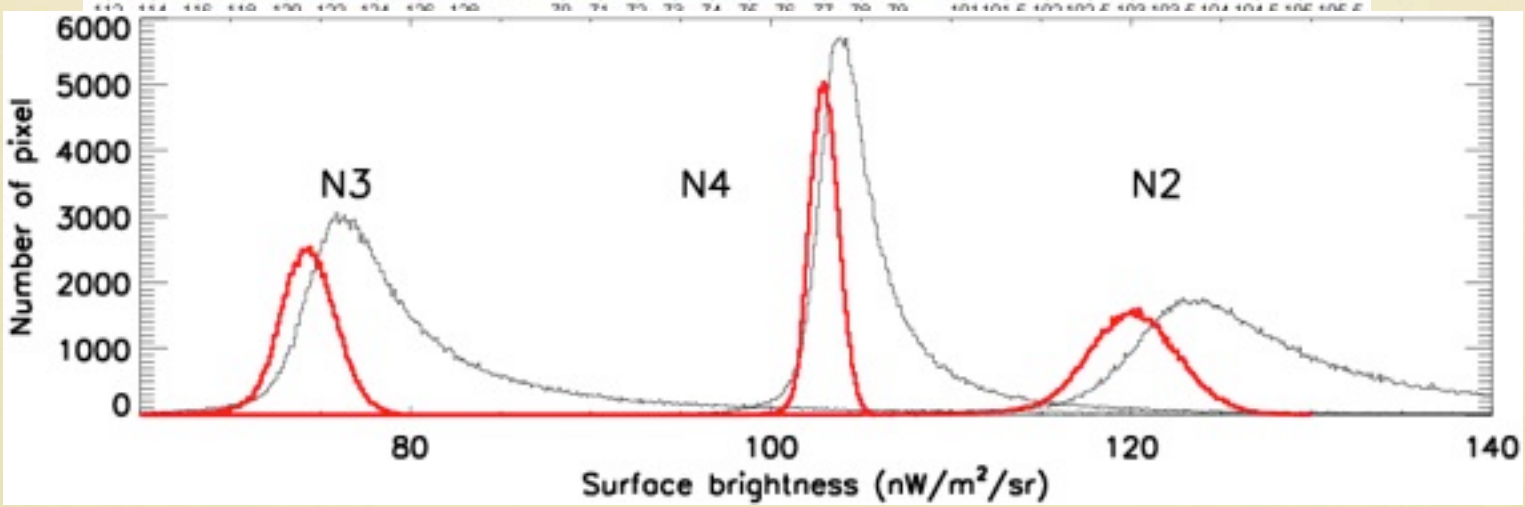




Fluctuation Analysis

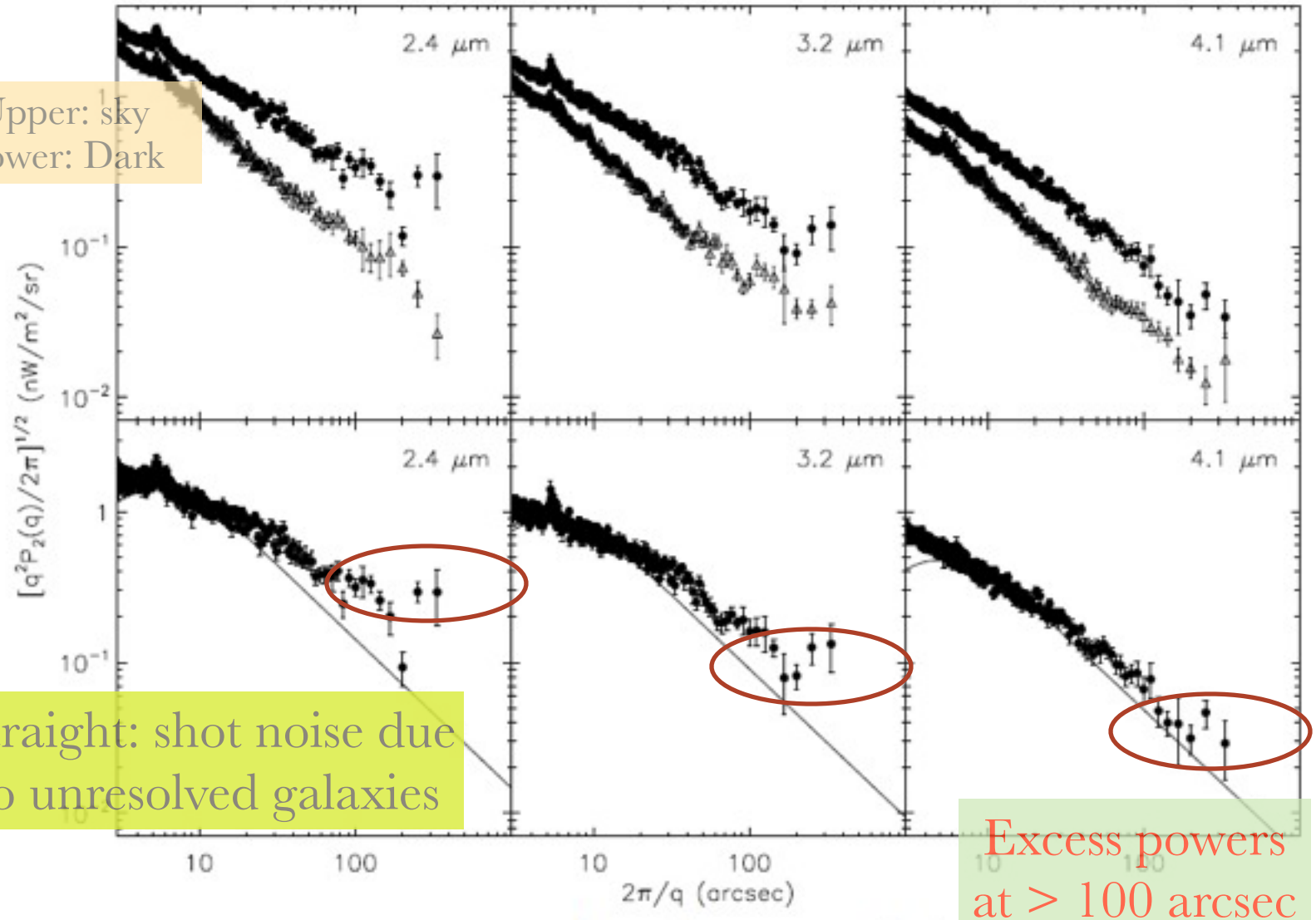
- Absolute level of the CIRB is difficult to determine because of uncertainties in diffuse component (especially Zodiacal light)
- Fluctuation analysis is another powerful method since diffuse component is thought to be rather smooth (Kashlinsky et al. 2007)

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

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

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

Our Results: Power Spectra



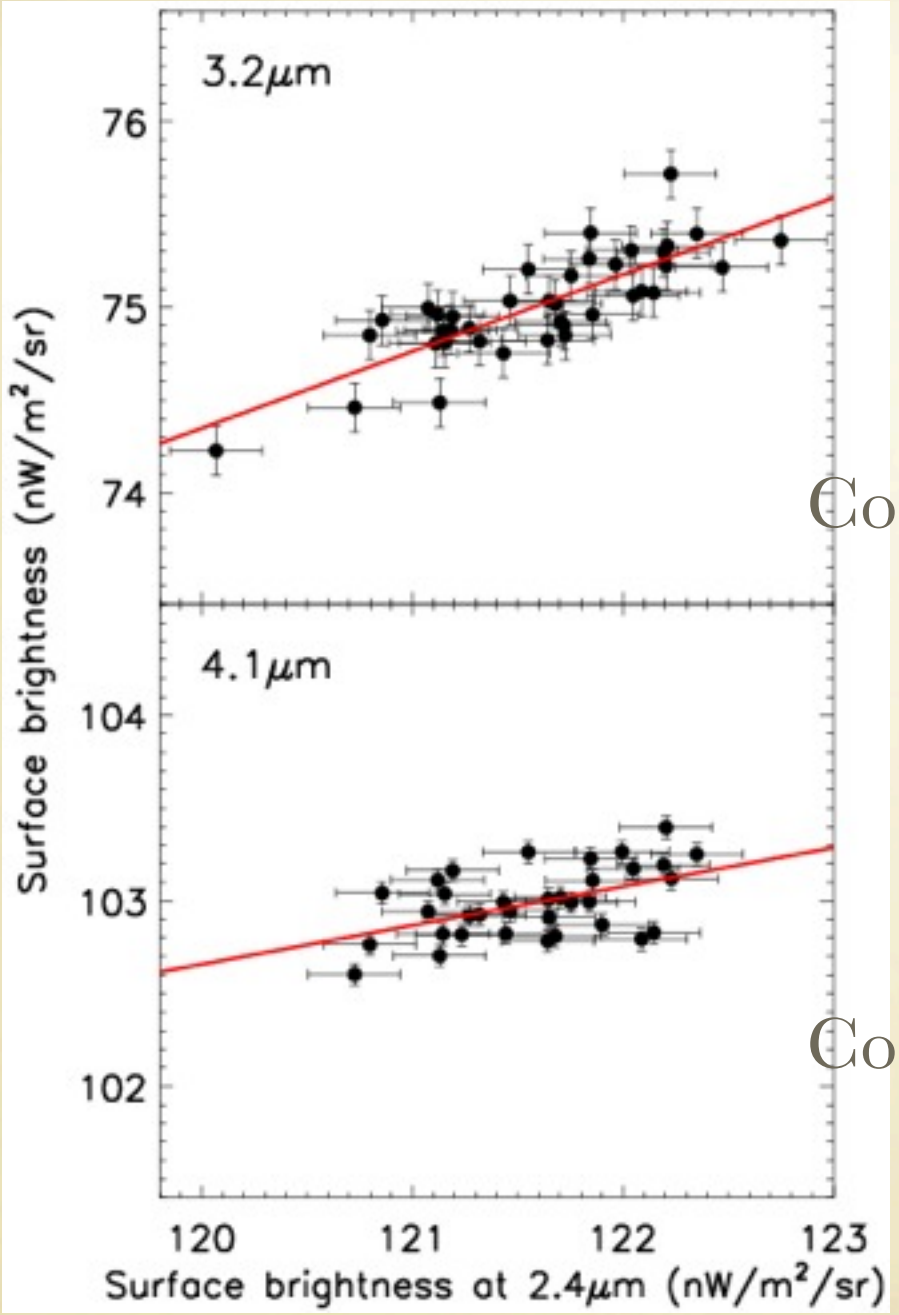
Upper: sky
Lower: Dark

Straight: shot noise due to unresolved galaxies

Excess powers at > 100 arcsec

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

Pixel correlation between wavelength bands

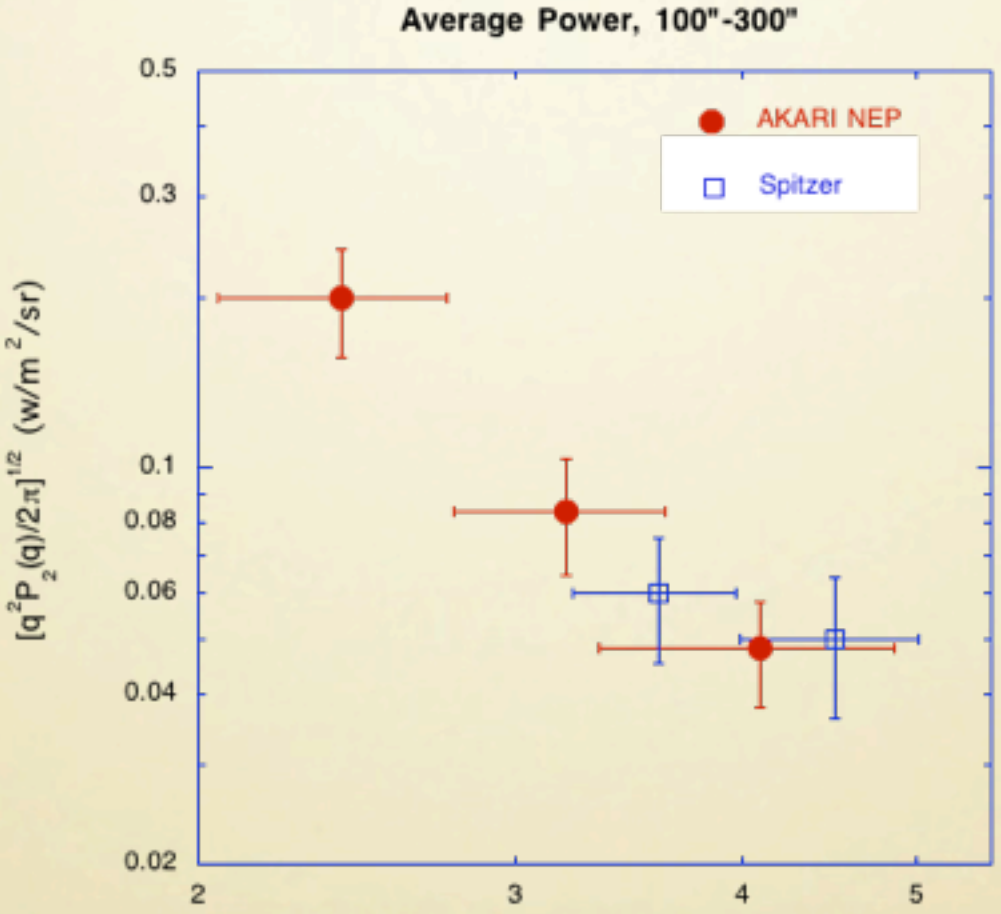


Correlation coefficient ~ 0.8

Correlation coefficient ~ 0.5

Spectrum of fluctuating component

- Average value of power at 100"<θ<300"
- Rayleigh Jeans like blue spectrum ($\propto \lambda^{-3}$)



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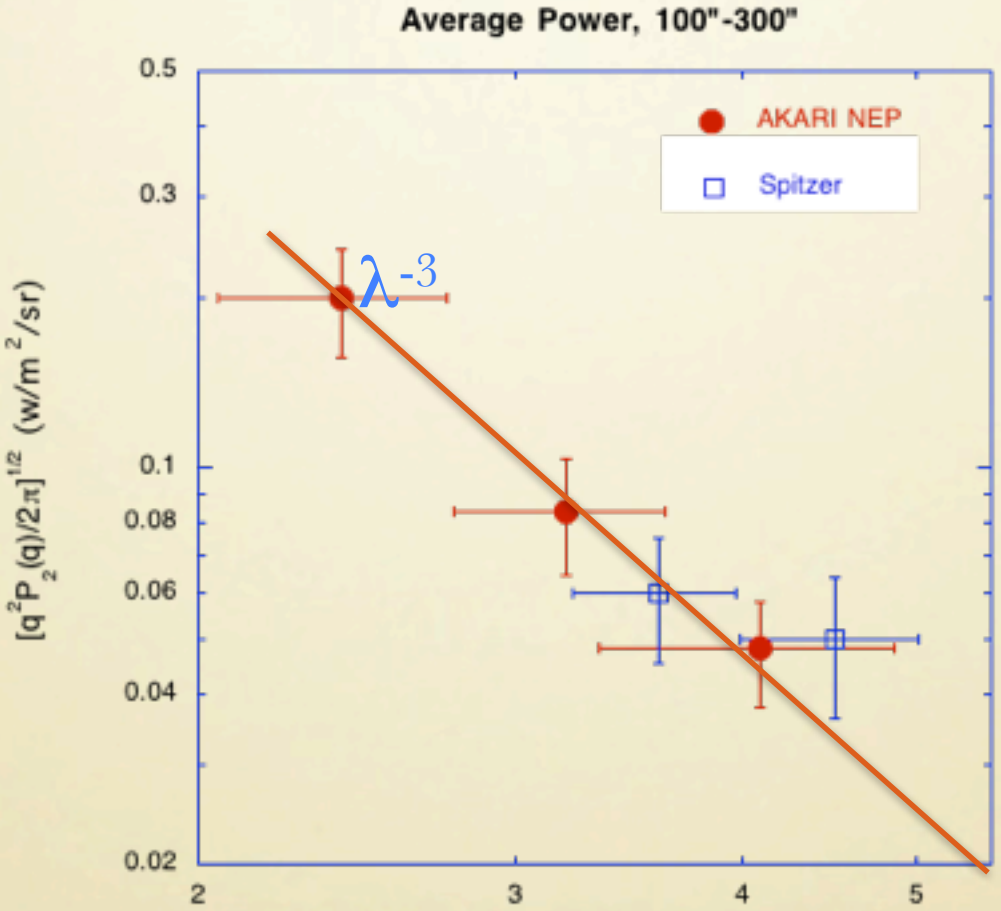
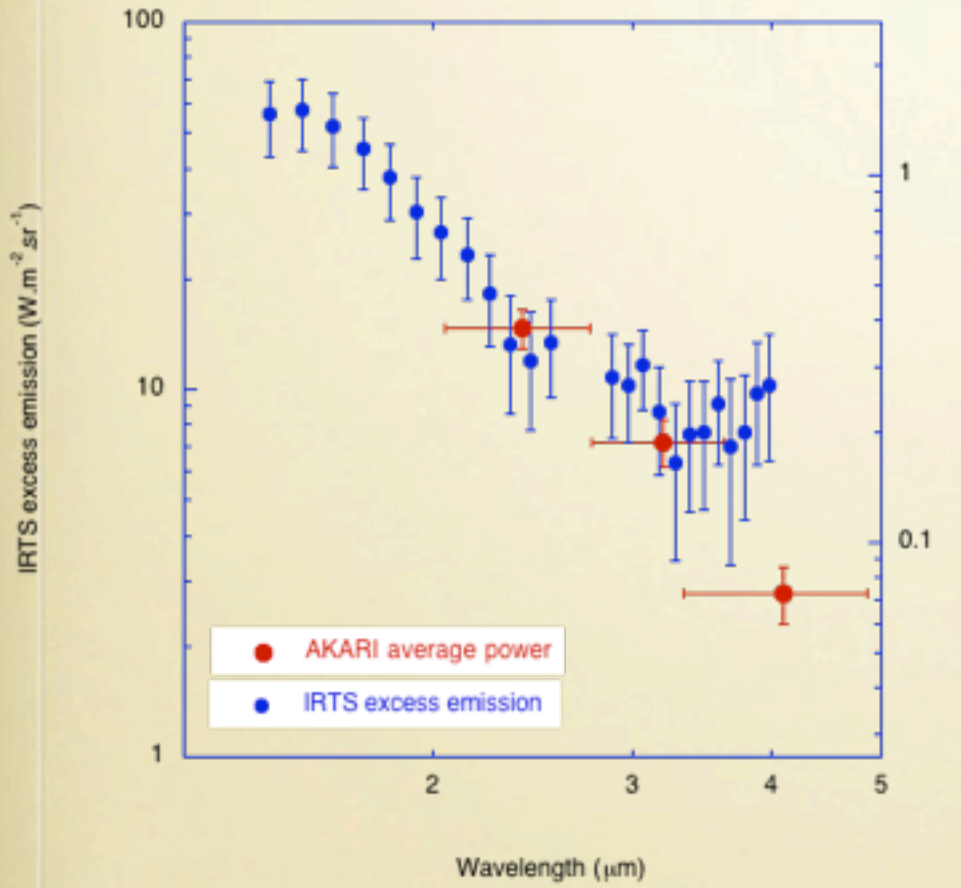
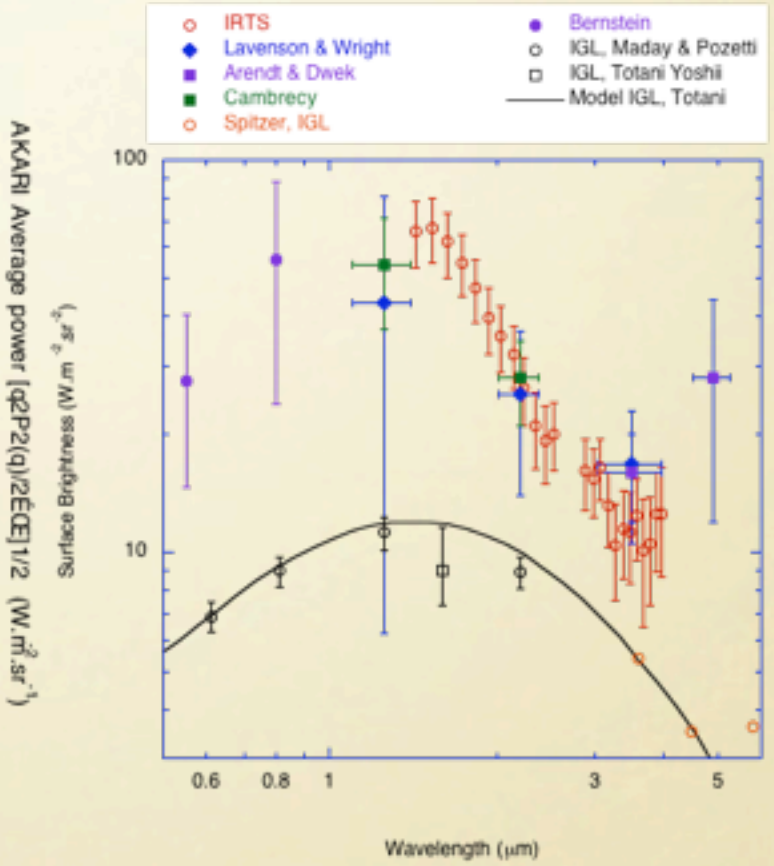
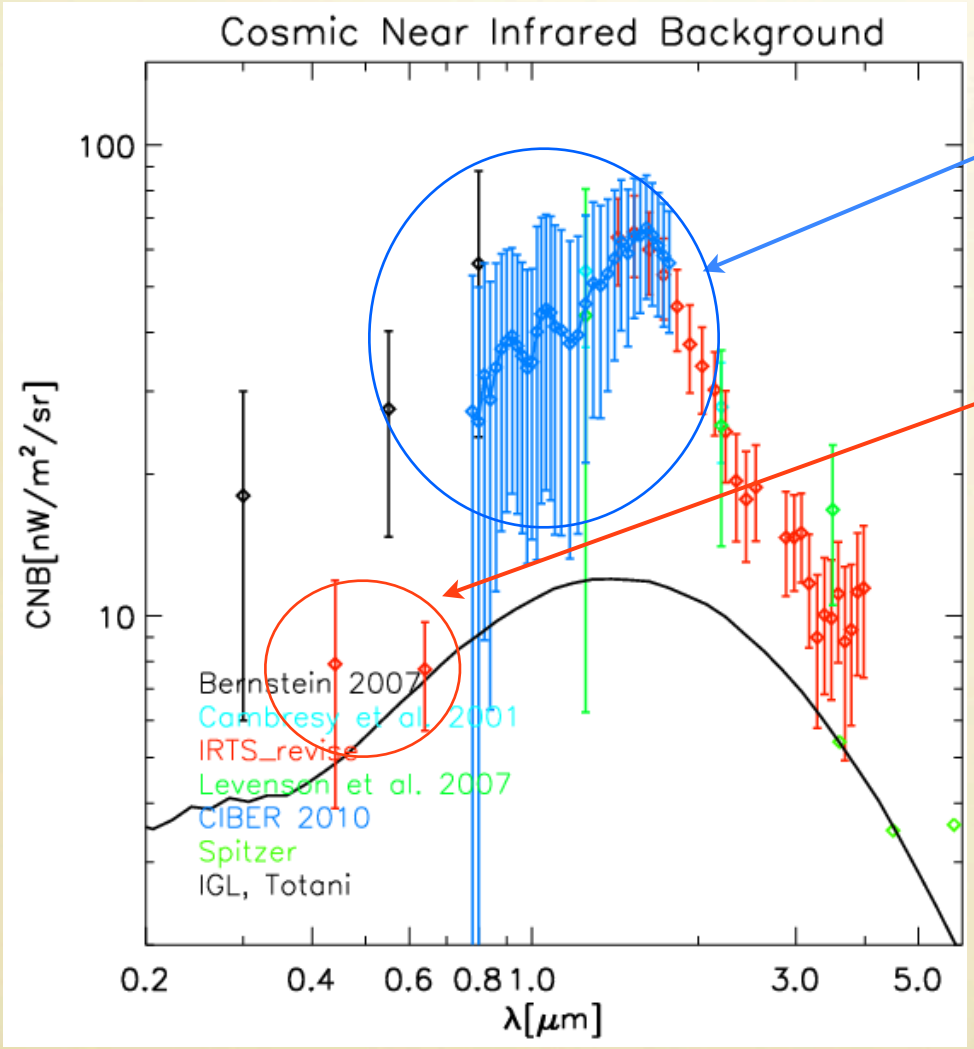


Comparison with IRTS Spectrum





More Recent Data



CIBER's LRS Data (Kim et al. in prep.)

Matsuoka et al. (2011), Matilla et al. (2011)

- Peak at λ~1.8 μm: Lyman-α of the most distant component z<15?
- Gradual decrease toward short λ: Lyman-α forest at 7<z<15?
- Lyman break at λ~0.7μm, z~7?
- Rapid decrease toward mid-IR: Stellar continuum

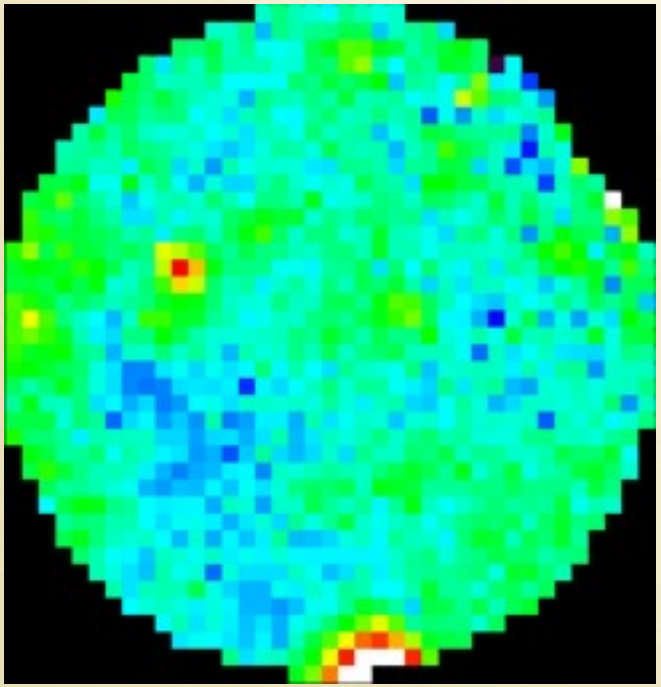
Origin of fluctuations

- Zodiacal light?
  - Zodiacal light is expected to be very smooth
- Diffuse galactic light (DGL)?
  - No correlation with FIR background
- Clustering of galaxies faint (red dwarf) galaxies at z=2~3? (Chary et al. 2008)
  - Fluctuation spectrum is blue, but faint galaxies should be red

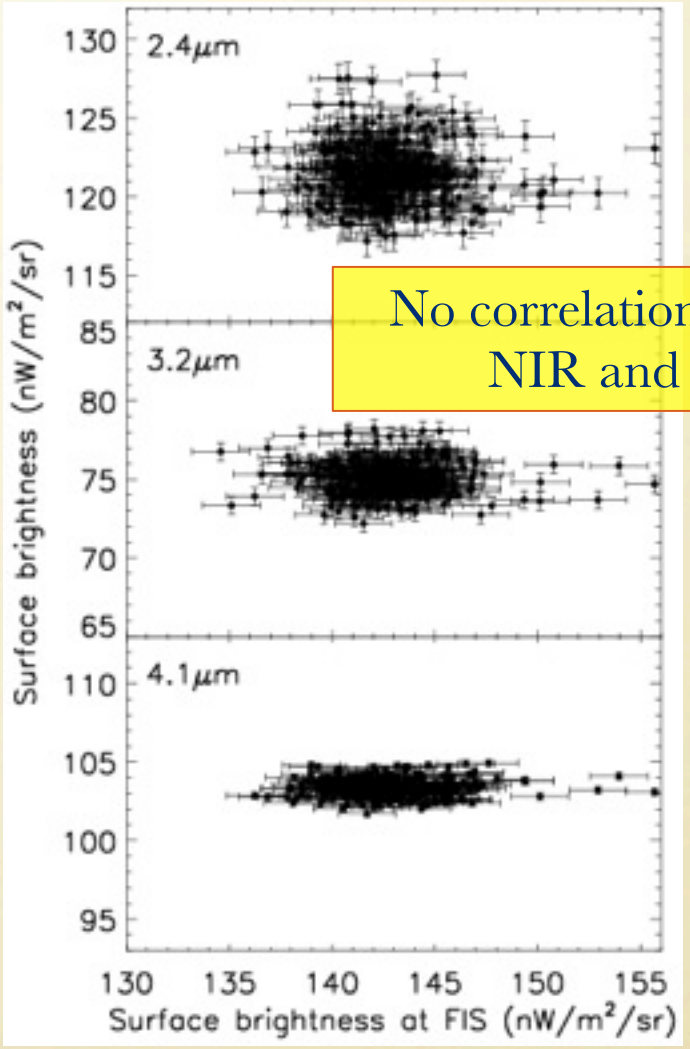
Diffuse Galactic Light (DGL)?

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

→DGL and FIR emission should be well correlated

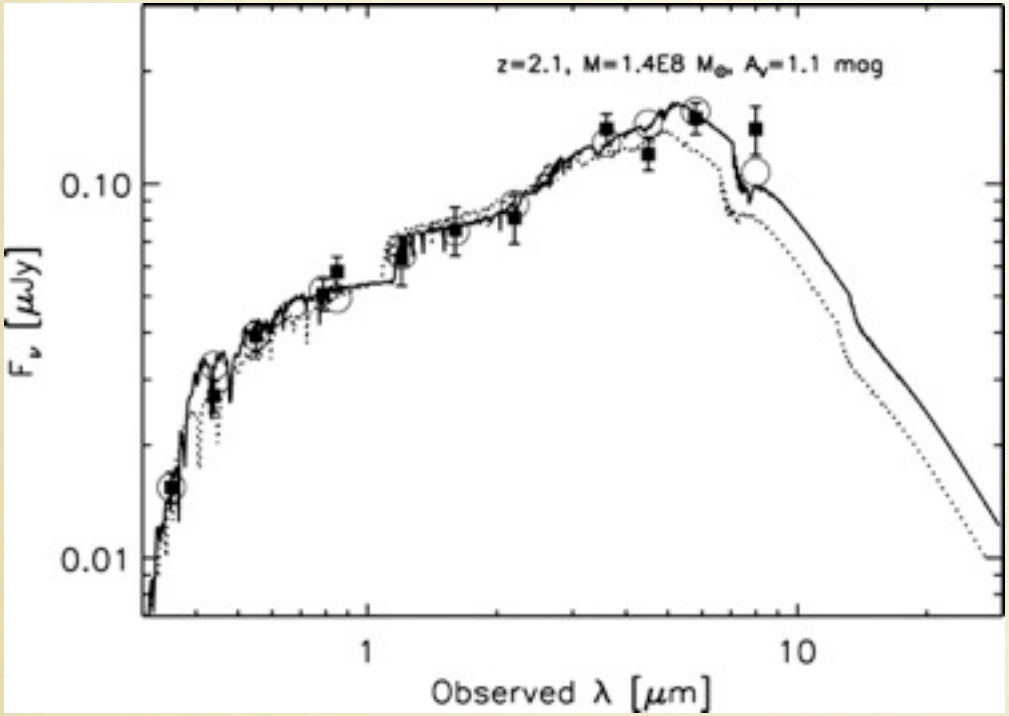


AKARI 90 μm image at Monitor field (Matsuura et al. 2010)



No correlation between NIR and FIR!

Clustering of faint galaxies at z=2~3?

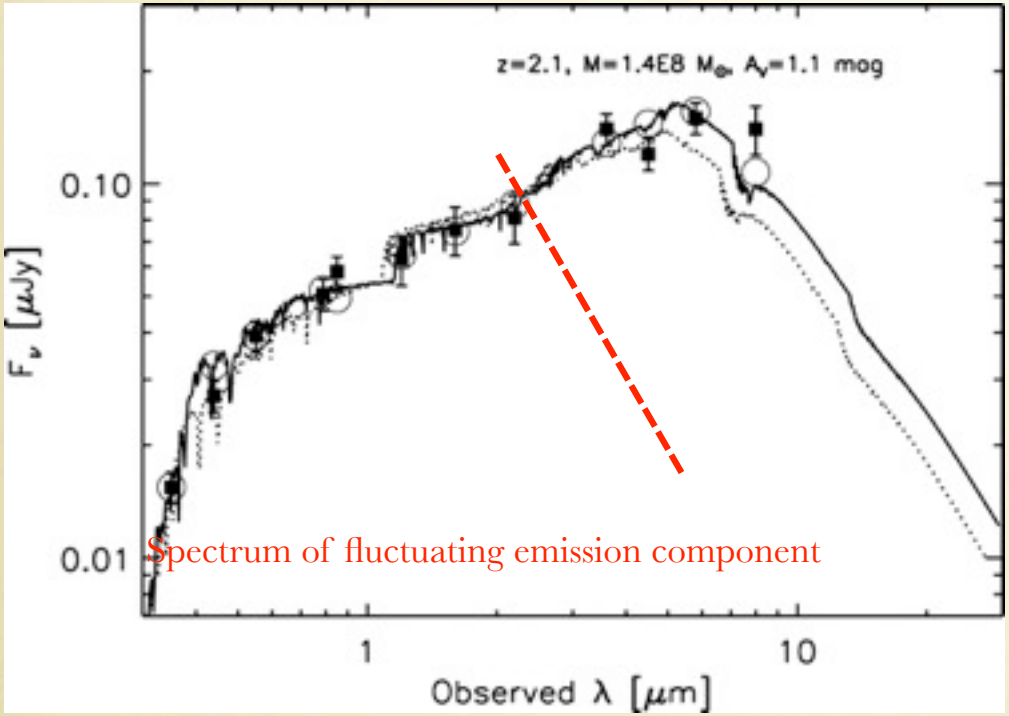


Chary et al. 2008

- **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:**

0.2 nW .m^{-2}.sr^{1}

Clustering of faint galaxies at z=2~3?



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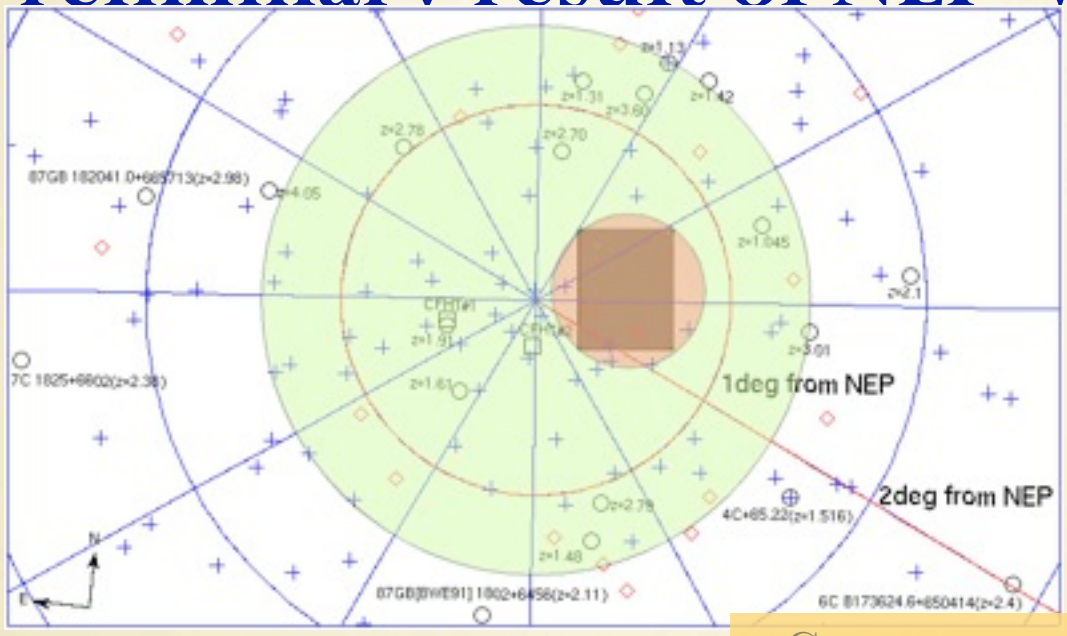
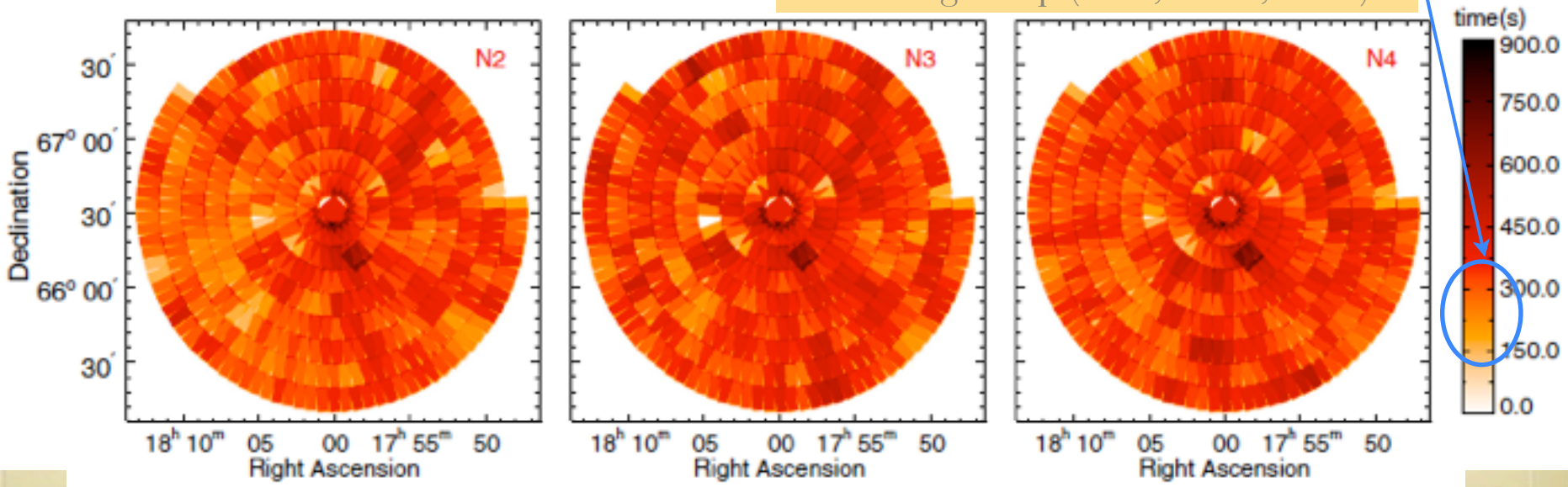
Preliminary result of NEP-Wide Field



~2.5 degree in scale

Typical exposure time of 180-400 sec

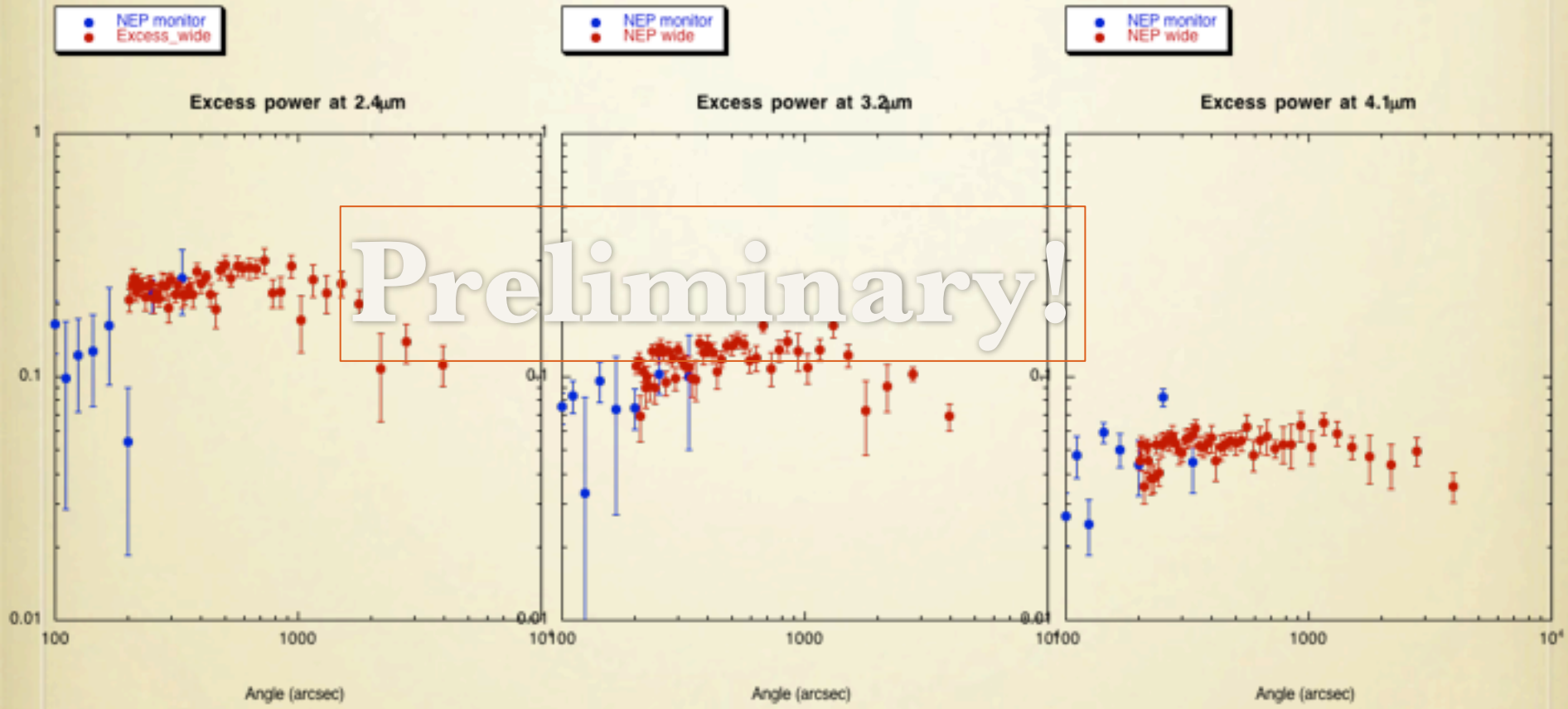
Coverage map (Kim, Lee+, 2012)



Additional careful analysis!

- Seasonal variation of zodiacal light
  - Subtracted zodiacal light with sinusoidal fitting
- Subtraction of dark level
  - Dark level was estimated based on the masked region
- More accurate flat field
- Muxbleed problem:
  Masked affected pixels

Power spectrum at large scale [NEP-Wide]

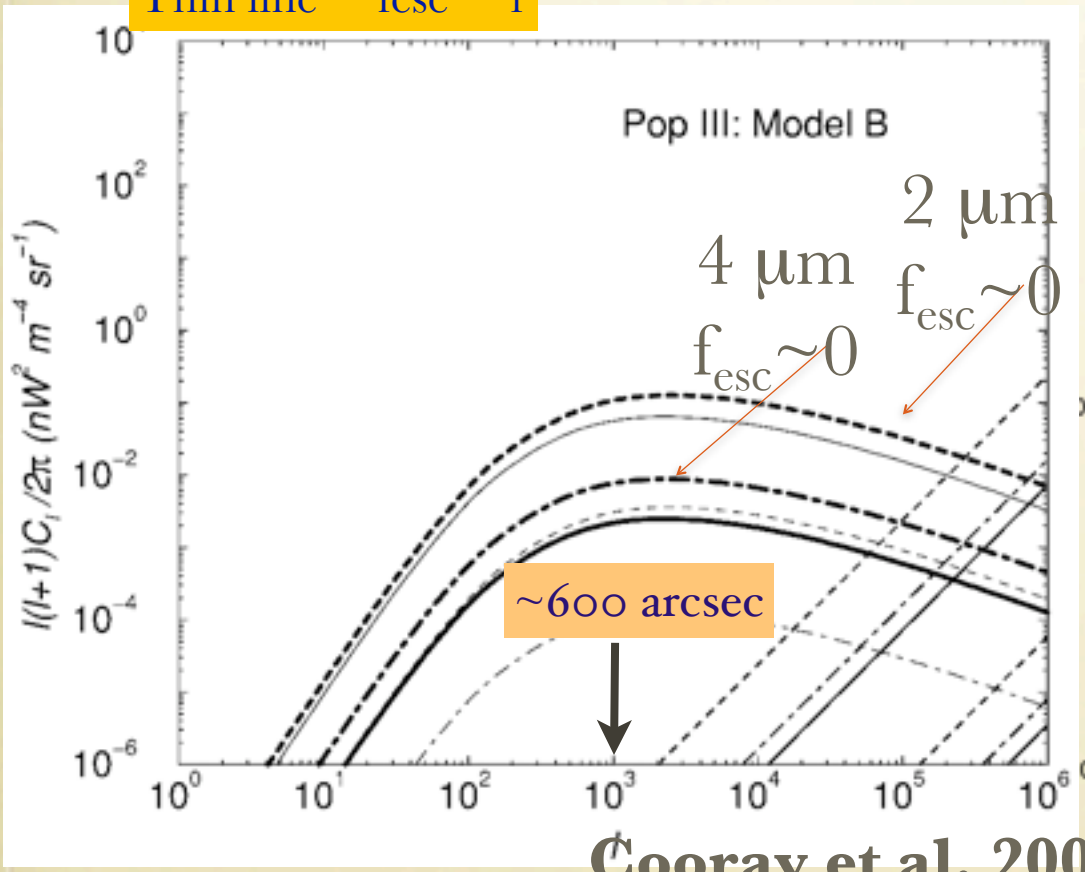


2.4 μm 3.2 μm 4.1 μm

Seo,in preparation

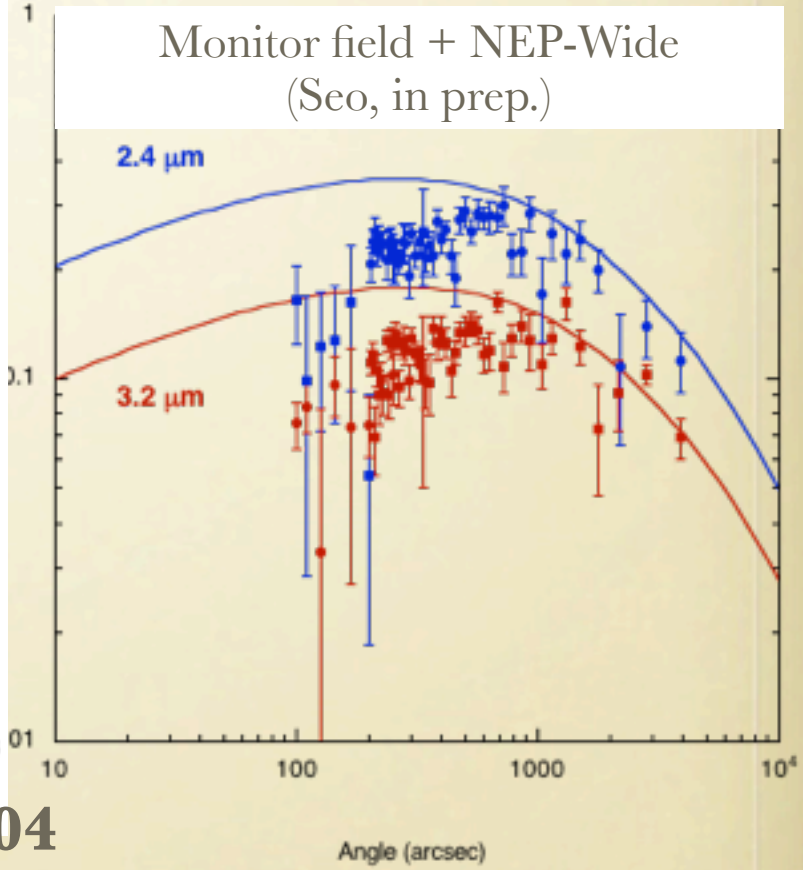
Comparison with theory

Thick line fesc ~ 0
Thin line fesc ~ 1



Comparison with the theory (Cooray et al. 2004)

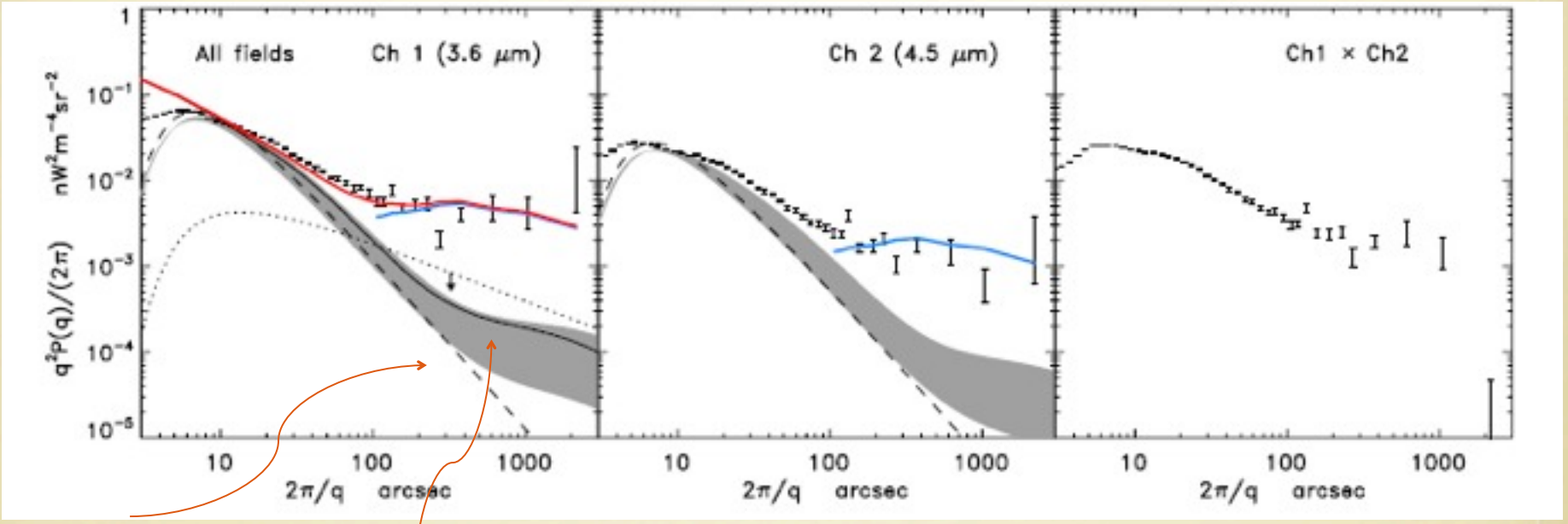
Monitor field + NEP-Wide
(Seo, in prep.)



Cooray et al. 2004

Peak (turn over) at several tens arcminutes

Large scale fluctuation from Spitzer



Shot Noise

Red: Total

Known galaxies fainter than detection limits

Blue: High-z ΛCDM

Kashlinsky et al. 2012

Discussions

- Uncertainties in zodaical Light: may have little effect on the fluctuations
- TeV γ-ray Blazar spectrum: intrinsic spectrum is not well known
- Energetics: too much star formation? Too much formation of heavy elements?

$$\Omega_* \approx 0.045\, \Omega_B\, (F_J / 2.5\ \mathrm{nW\ m^{-2}\ sr^{-1}})$$ Madau & Silk (2005)

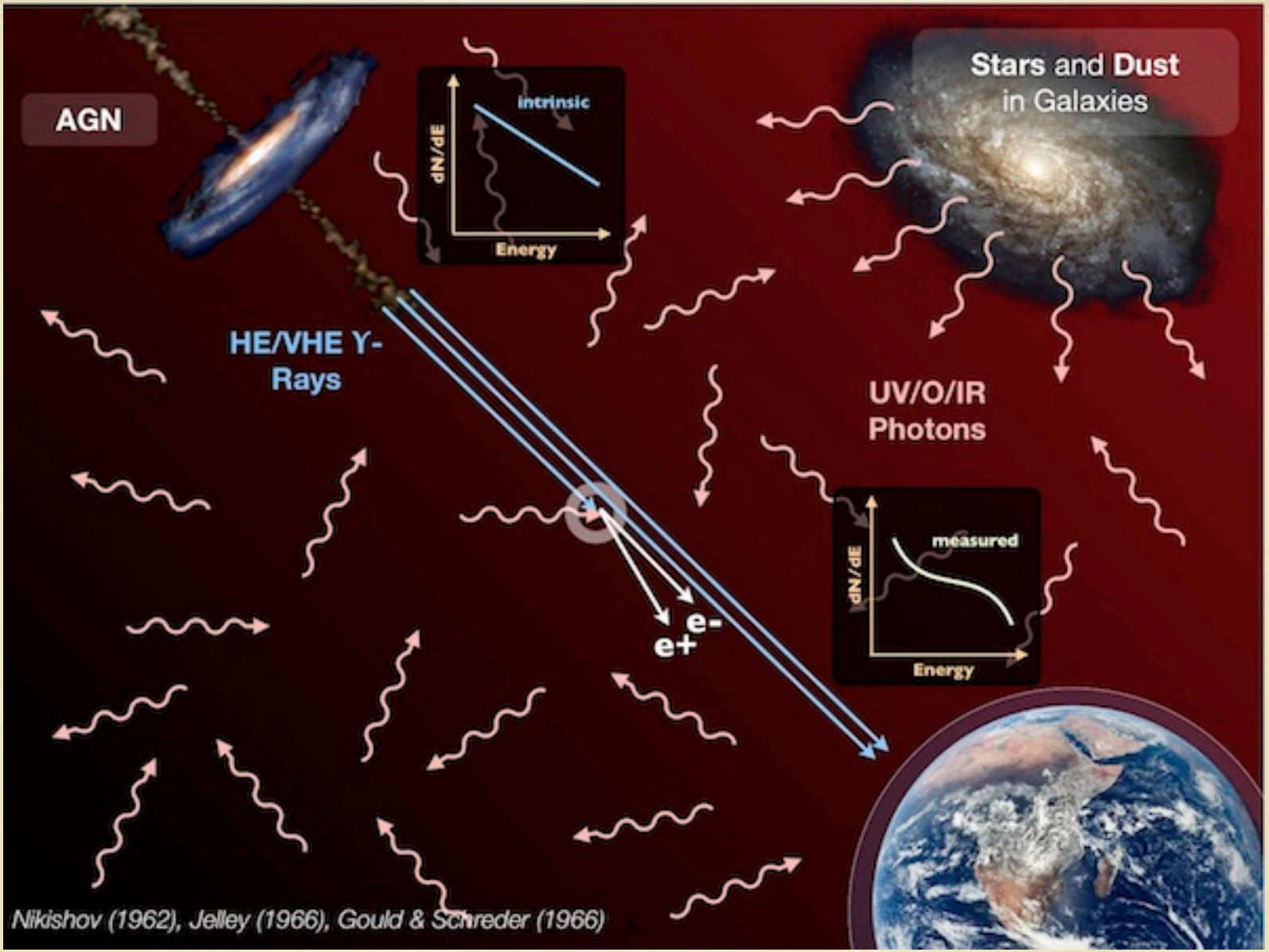
Ω_*: Density parameter in stars

Ω_B: Density parameter in baryon

F_J: J-band background intensity

➔ (1) Absolute level of the background intensity is uncertain

(2) The mass function in high-z could be different from today.


AGN
intrinsic
dN/dE
Energy
Stars and Dust
in Galaxies
HE/VHE γ-
Rays
UV/O/IR
Photons
e+
e-
measured
dN/dE
Energy
Nikishov (1962), Jelley (1966), Gould & Schreder (1966)

Further Efforts

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- CIBER II: Rocket experiments among US, Japan and Korea (on-going): spectrum of CIRB

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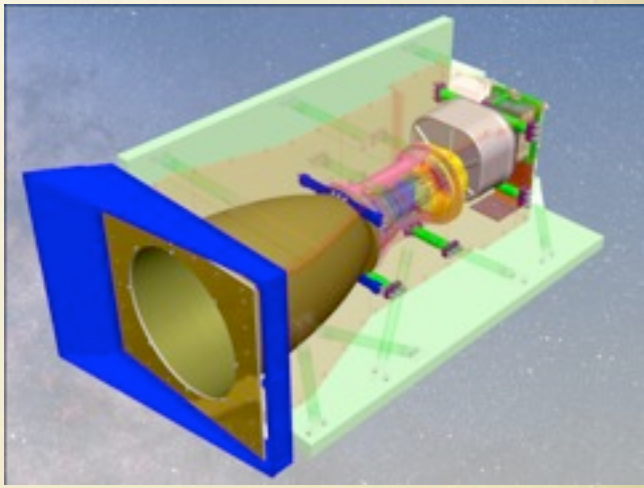
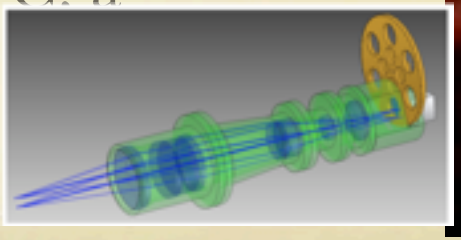
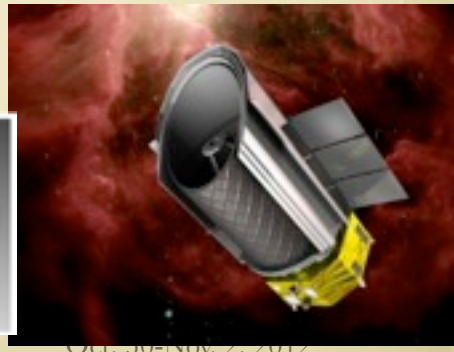
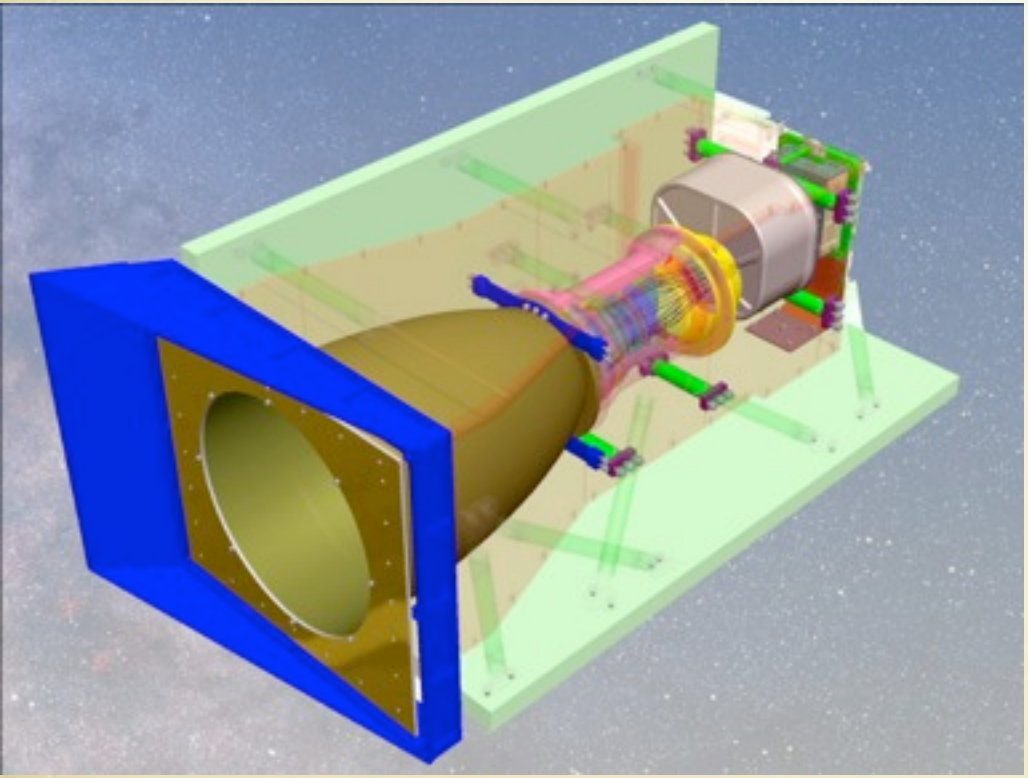
- MIRIS: Small infrared space telescope will be launched soon (2012) to study large scale fluctuation
- SPICA: Large Space Infrared Telescope project among Japan, Europe and Korea (~2021): more accurate measurements using FPC, a Korean-led instrument









MIRIS concept

Optics:

- 8cm aperture, F2 refractive optics

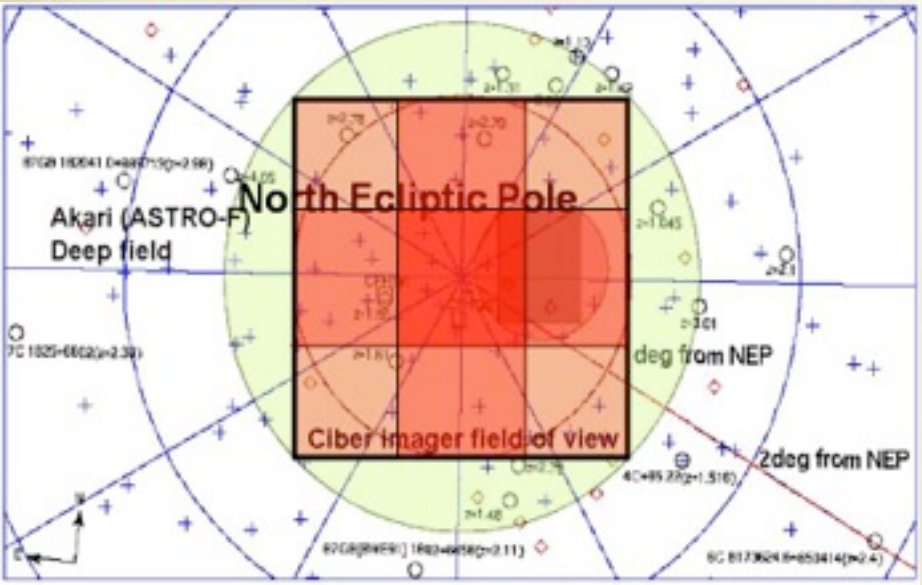
Picnic array:

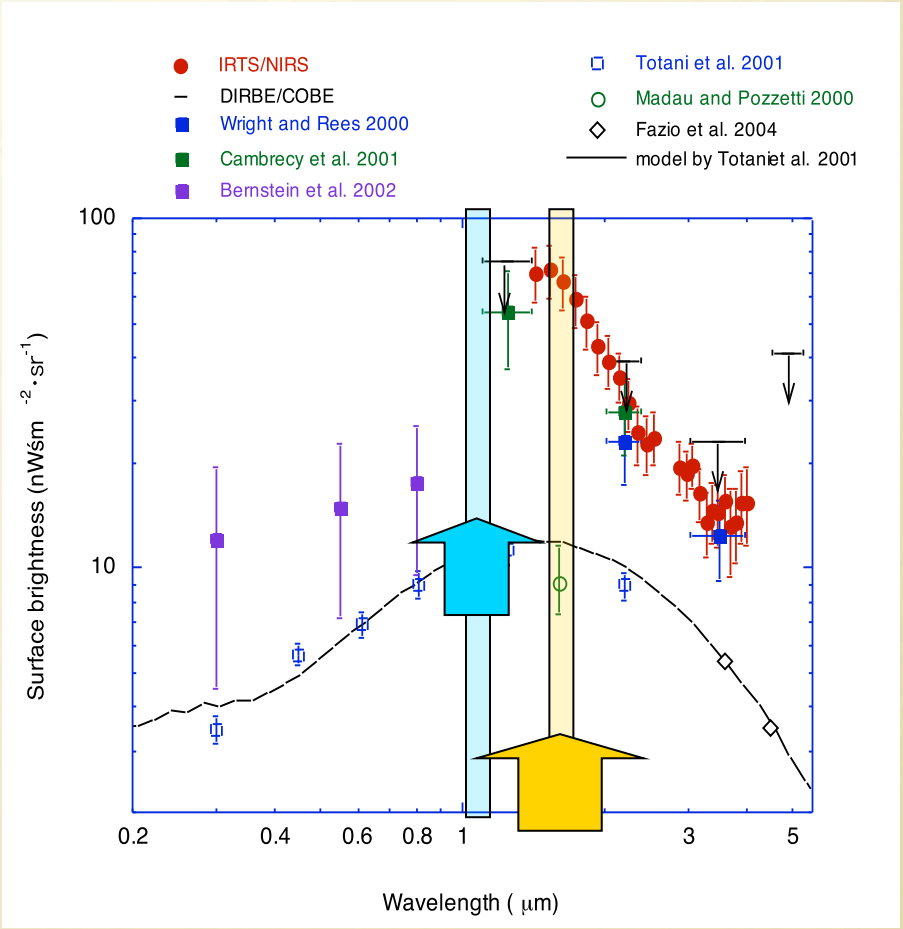
- 51.6” pixel scale, 3.67° x 3.67° frame

Telescope is passively cooled by radiation to ~180K

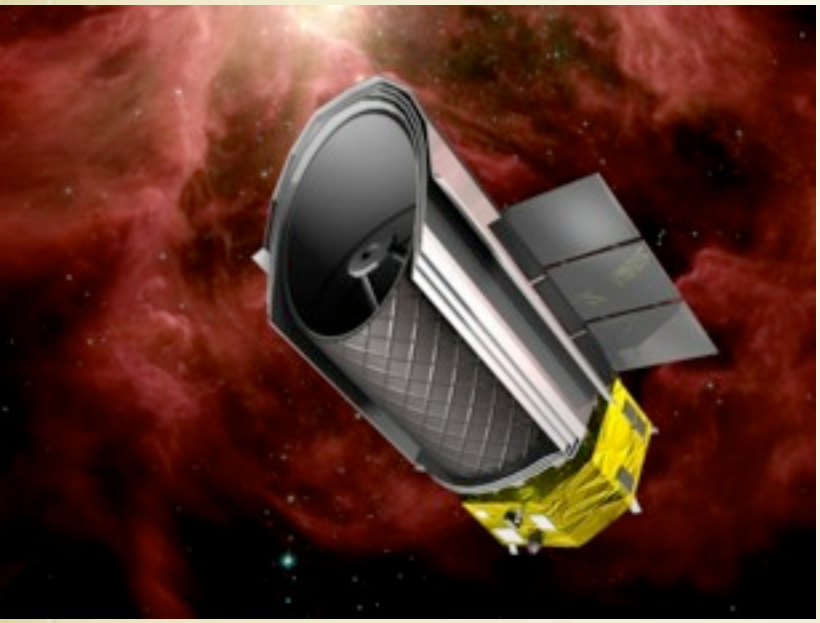
Cosmic Near-infrared Background: MIRIS Observation

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





SPICA



- 3m class cooled telescope (4.5K)
- L2 halo orbit
- Launch ~ 2020

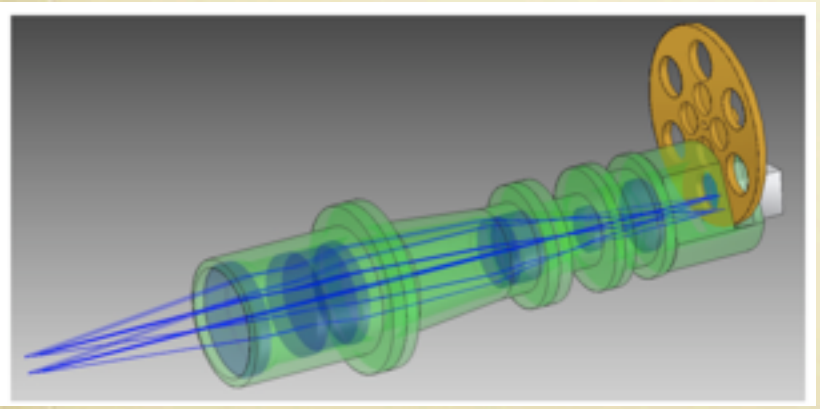
International collaboration

ESA: Telescope & FIR instrument

NASA: Submillimeter instrument?

Korea: NIR camera (FPC)

- **0.5-5 μm with large FOV**
- **large throughput compared with JWST**
- **LVF (Linear Variable Filter) + step scan**
- **absolute spectrum and**
- **small angle fluctuation of CNB**



Summary

- Unambiguous detection of Cosmic Infrared Background (CIRB)
- Strong power at 100-200 arcsecond
  - 200 arcsec = 9 Mpc at z=10
  - clusters of galaxies scale?
- Nearly Rayleigh-Jeans SED with peak ~ 1.8 μm

  Pop. III stars at z<15?
- NIR Spectrum with CIBER: Lyman-α emitters in z=7-15?
- Wide field survey data being analyzed. Preliminary results show excess power up to ~1 deg beyond shot noise
- CIBER, MIRIS, SPICA projects will deliver more accurate information on absolute brightness, spectrum, large scale structure, etc.