Cosmic Near Infrared Background Radiation and the First Galaxies

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Cosmic Infrared Background Radiation (CIRB)

- Residual light after removal of contribution from all known sources
  - stars
  - galaxies
  - diffuse Galactic light
  - Zodiacal light
- Issues
  - Accuracy of measurement
  - Origin

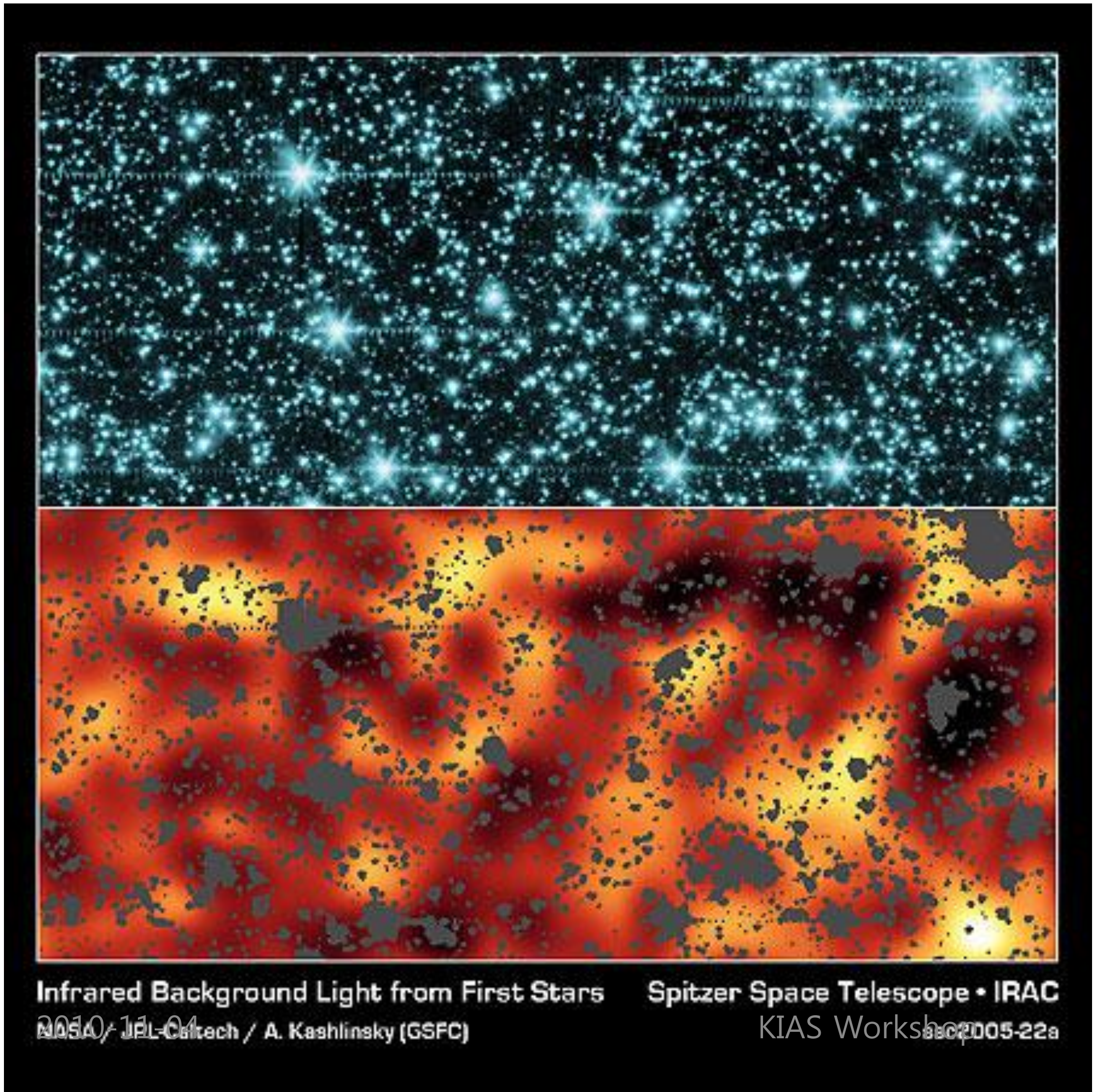
Previous Measurements

- 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): significant fluctuations at 100-300 arcsec scale

Controversy

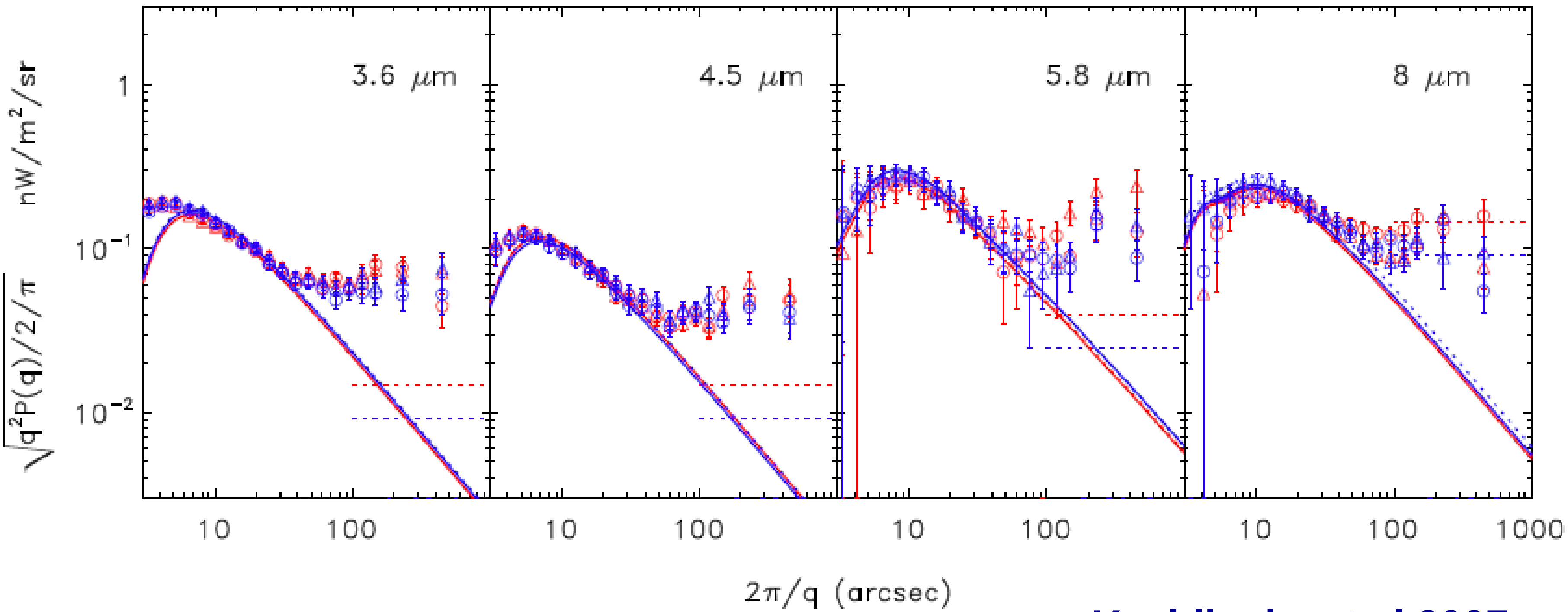
- Uncertainties in foreground Zodiacal Light
- TeV γ-ray Blazar spectrum favors no excess above the contributions from faint galaxies (Ahronian et al. 2005, Mazin & Raue 2007)
- Energetics: claimed background light means too much generation of Pop. III stars (Madau & Silk 2005)

Careful measurement of the background radiation



- Kashlinsky et al. 2005 using Spitzer telescope data

Fluctuation Analysis of Spitzer data



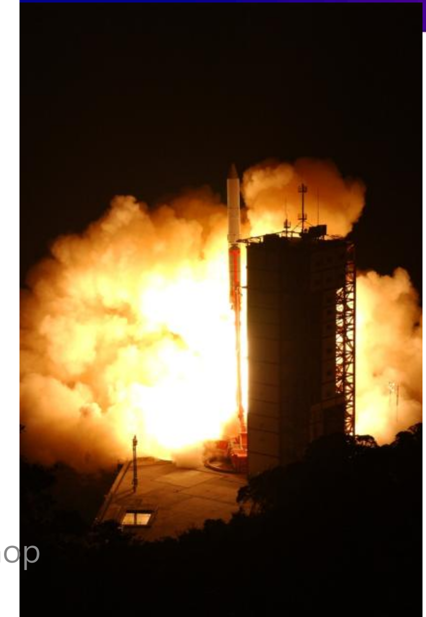
Kashlinsky et.al 2007

New measurement with AKARI

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

The AKARI Project

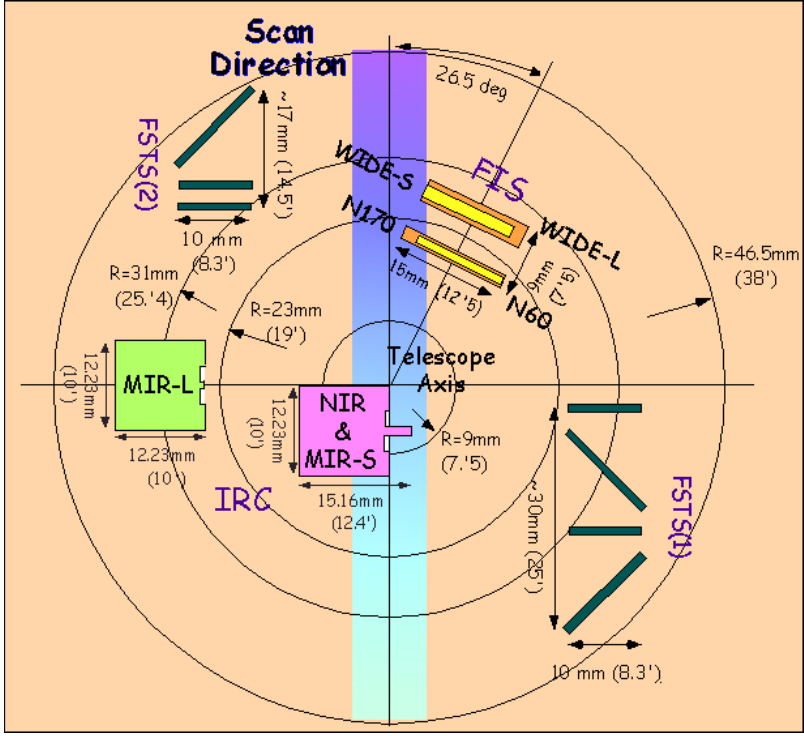
- Space Mission by Japan Aerospace Exploration Institutes (JAXA)/Institute for Space and Aeronautical Science (ISAS) with ESA support
- International Collaboration
  - Seoul National University
  - European Consortium (Imperial, Open Univ., Sussex, Groningen)

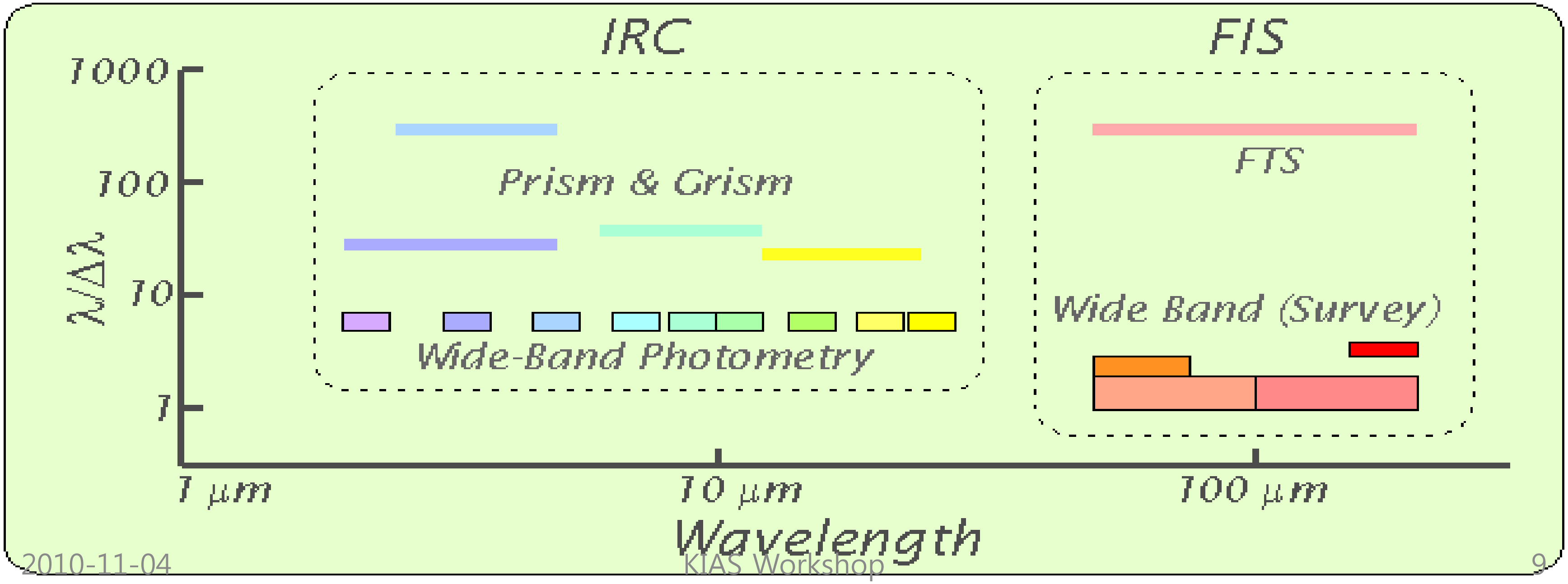


Launched on Feb. 22, 2006

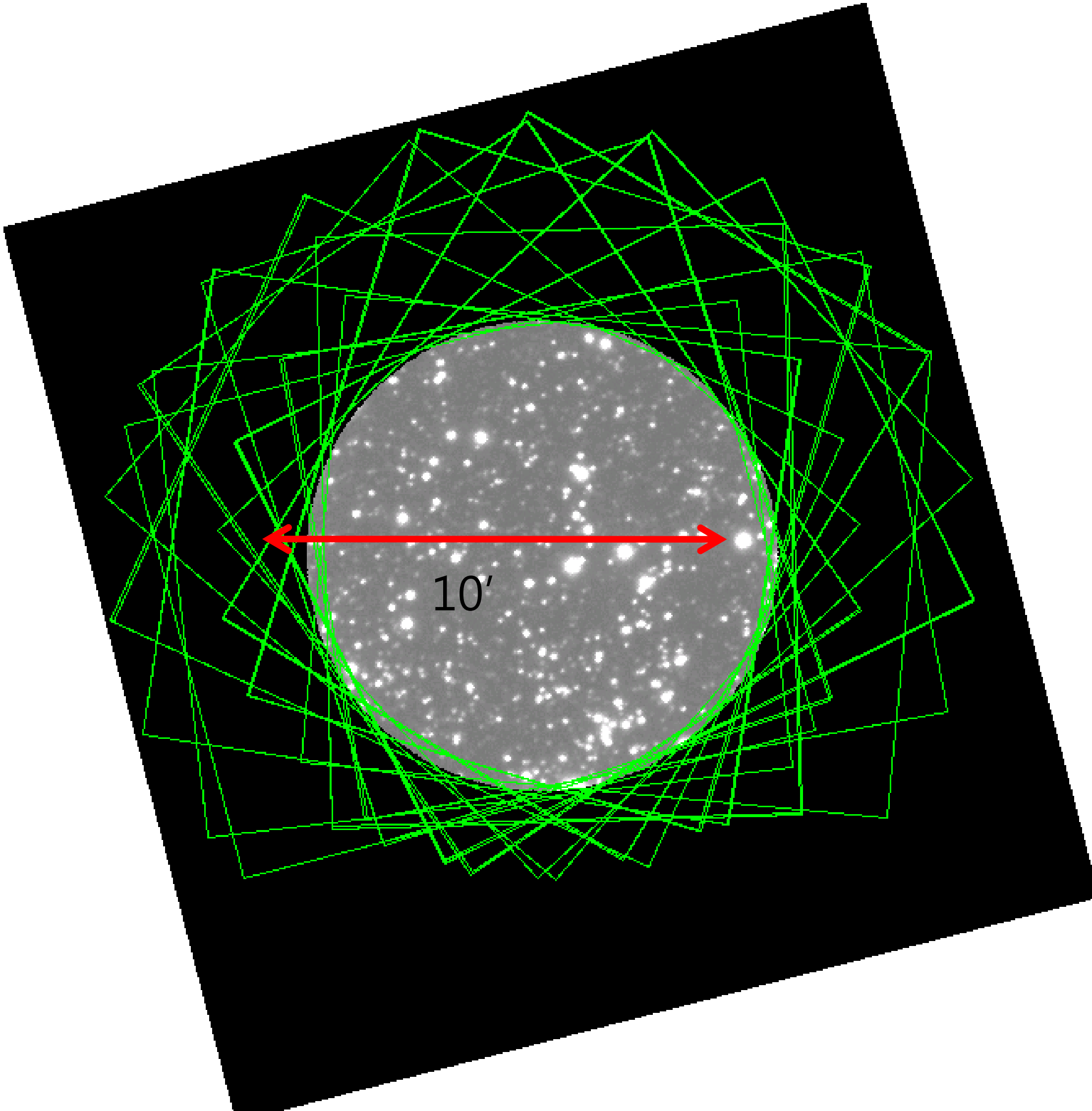
Focal Plane Instruments

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

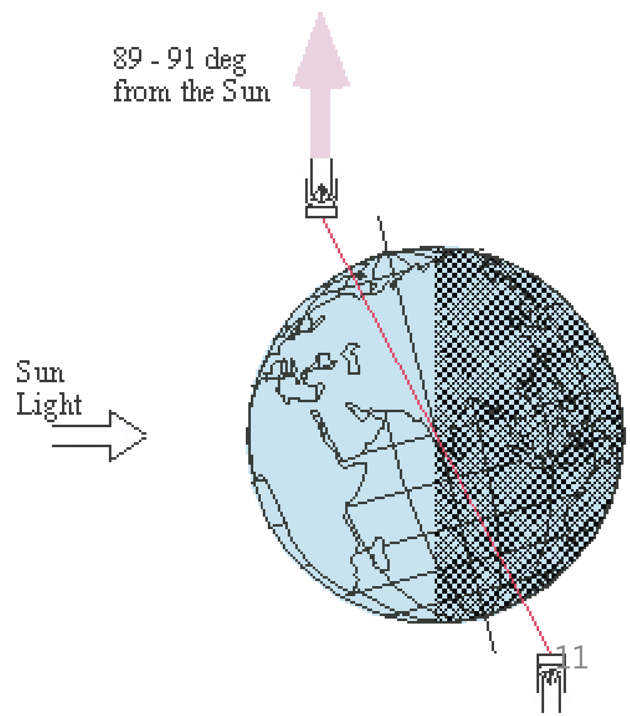




Monitor Field near the NEP



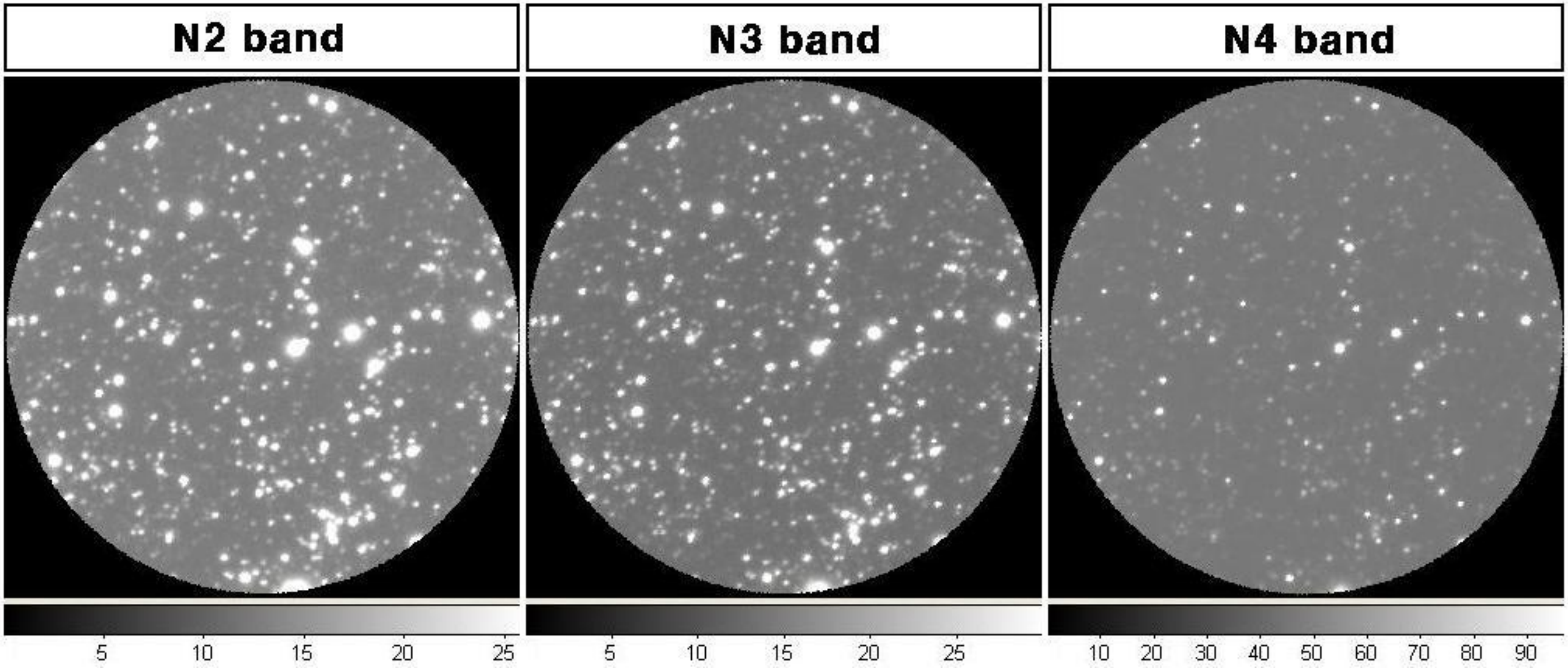
Repeated measurements over several months to check the stability of the instrument



Summary of Monitor Field Data

Band	N2 (2.4㎛)	N3 (3.2㎛)	N4 (4.1㎛)
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

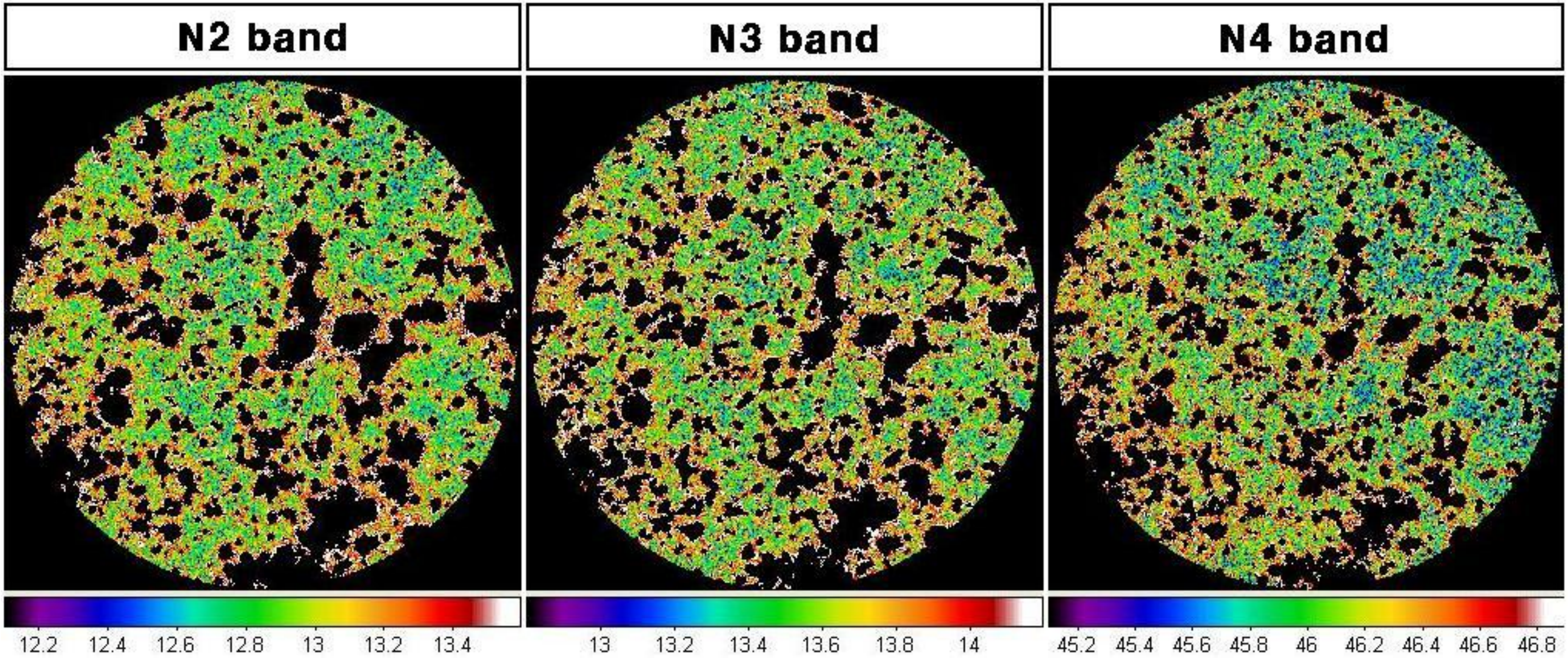


※ The number in the scale bar is ADU scale.

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.

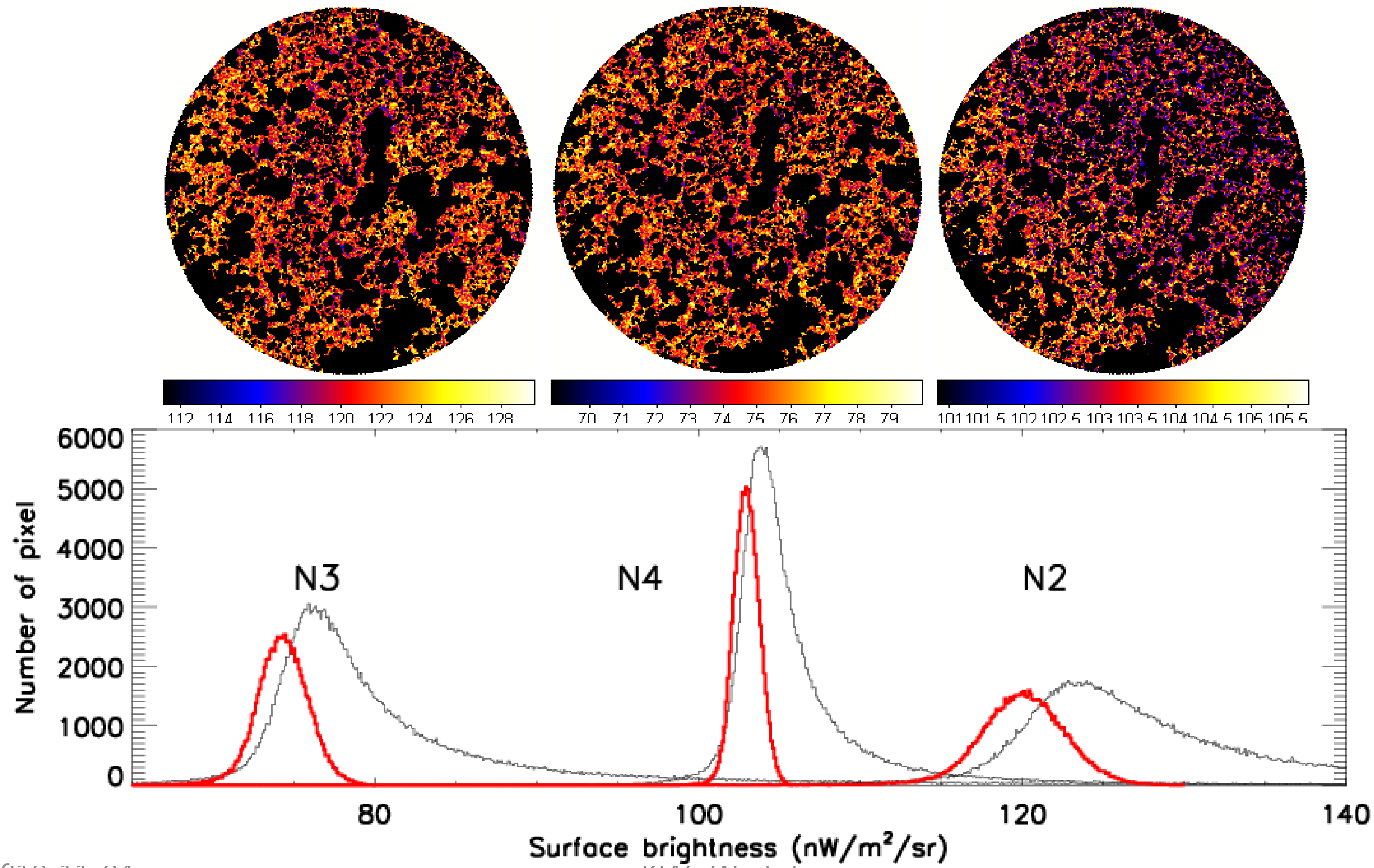
Images after 2σ clipping



※ **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

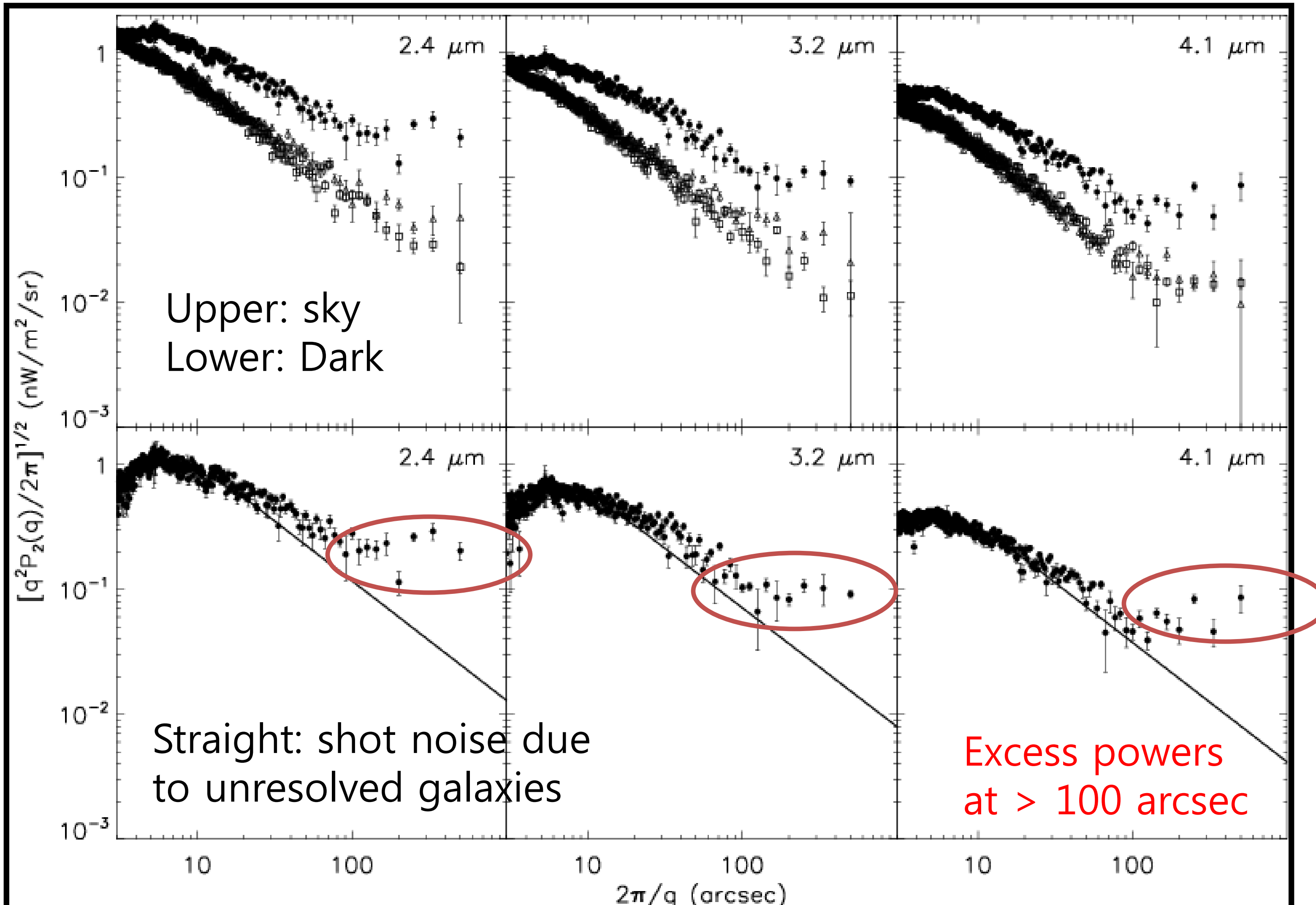
- Absolute level of the CIRB is difficult determine because of uncertainties in diffuse component (zodiacal light)
- Fluctuation analysis is another powerful method since diffuse component is thought to be rather smooth (Kashlinsky et al. 2007)

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

$$P_2(q) = \langle |f(q)^2| \rangle$$

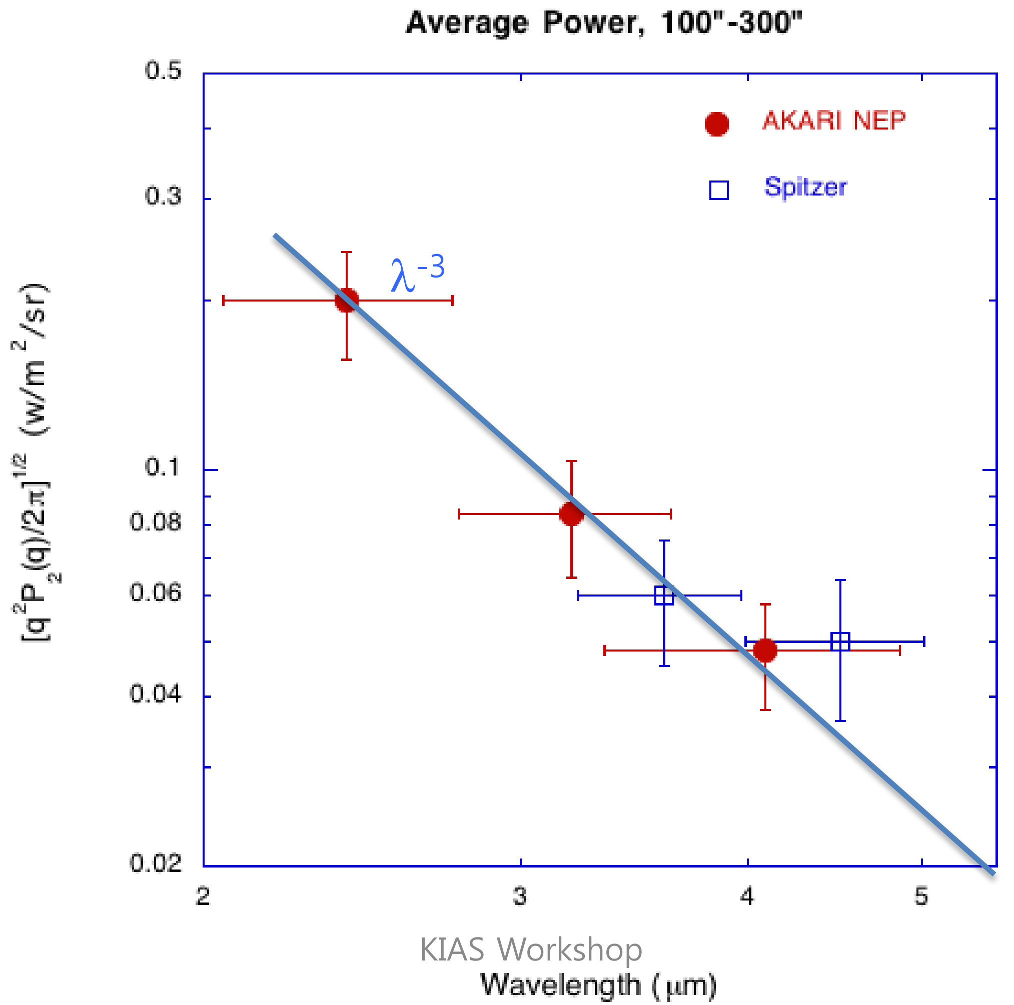
→ Typical fluctuation flux = $\sqrt{q^2 P_2(q)/2\pi}$

Our Work: Power Spectra

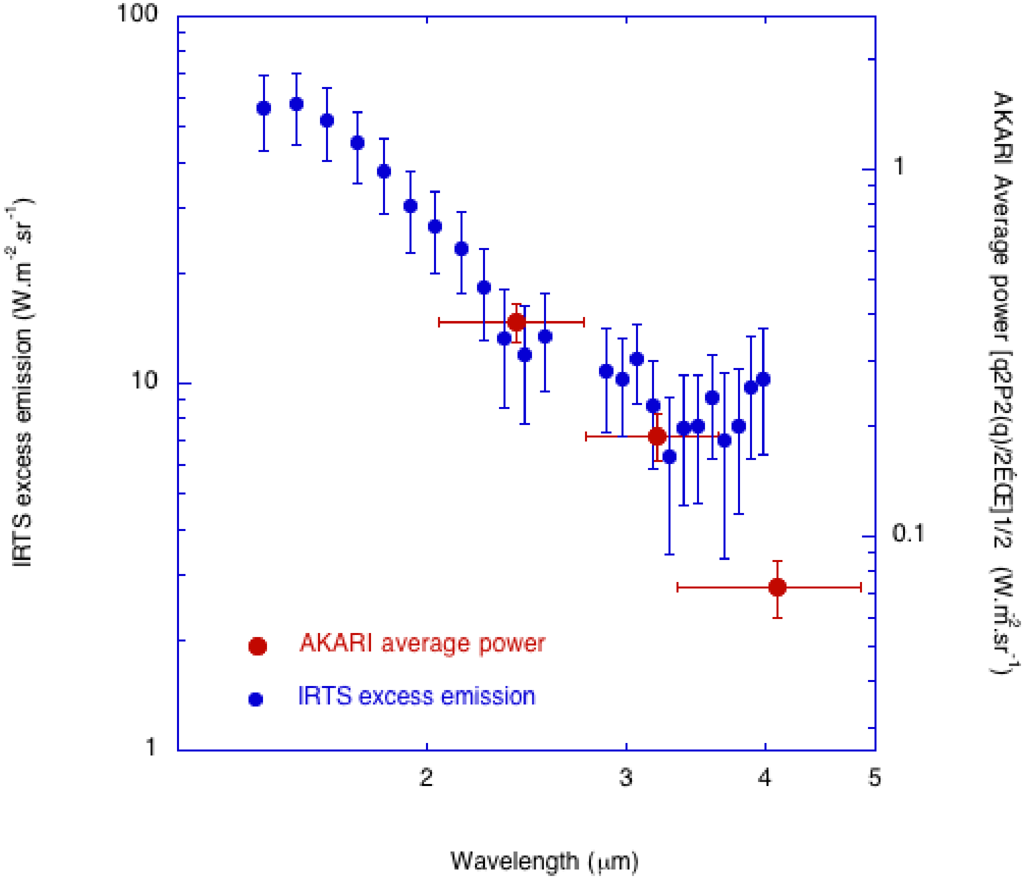


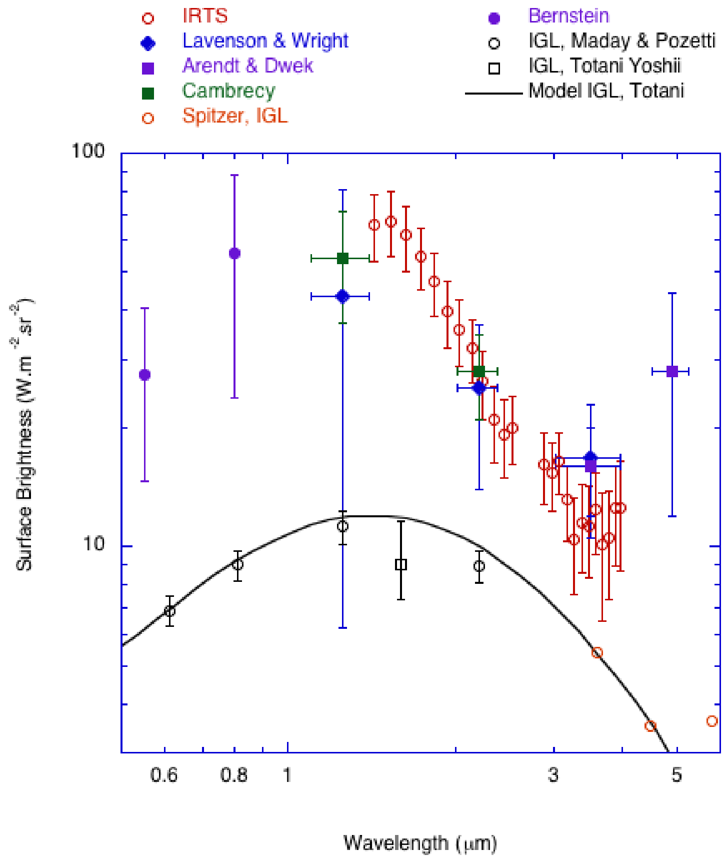
Spectrum of fluctuating component

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

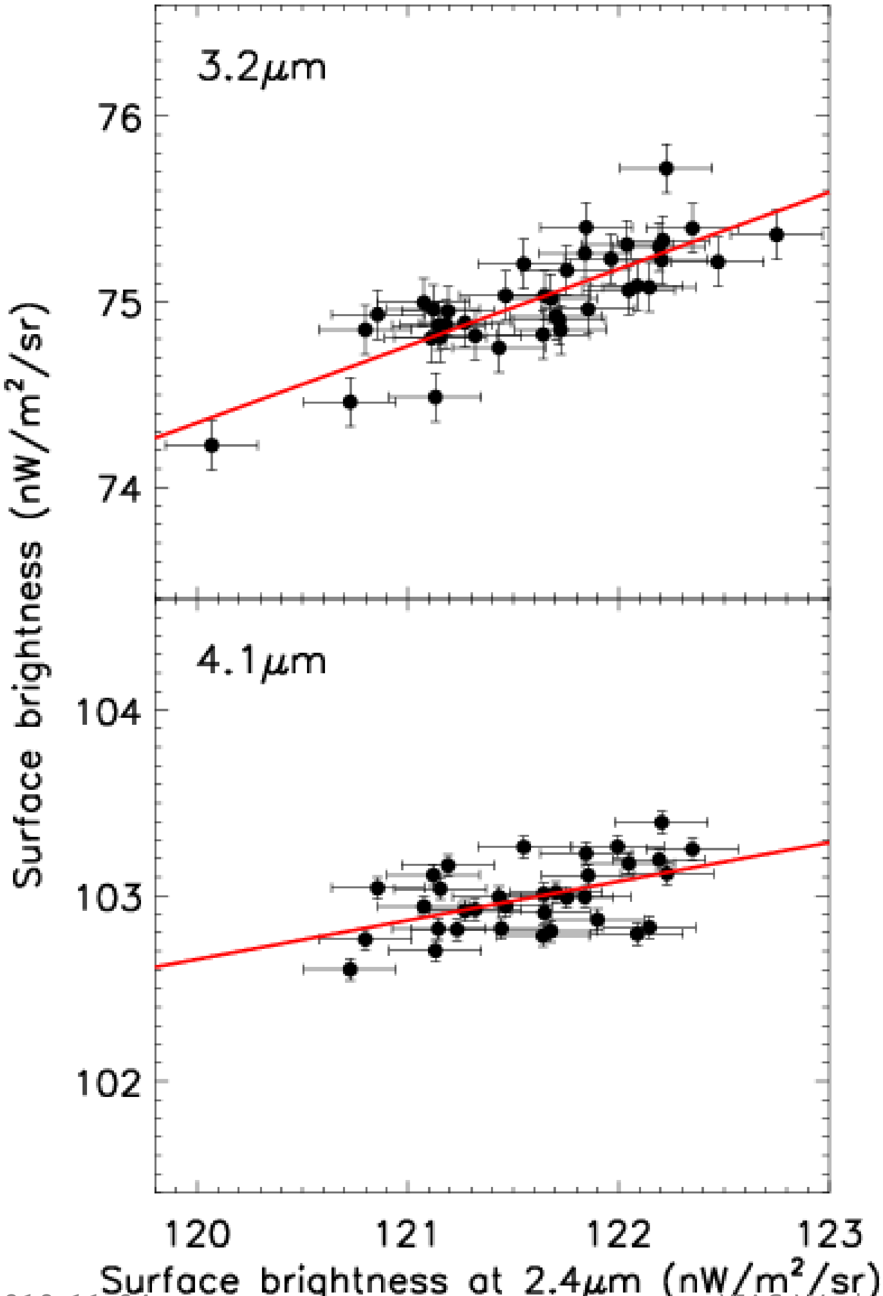


Comparison with IRTS Spectrum





Pixel correlation between wavelength bands



Correlation coefficient ~ 0.8

Correlation coefficient ~ 0.5

Origin of fluctuations

- Zodiacal light?
- Diffuse galactic light?
- Clustering of galaxies faint (red dwarf) galaxies at z=2~3? (Chary et al. 2008)

Zodiacal light is very smooth!

- Pyo et al. (2010) used the seasonal variation of zodiacal emission to derive upper limits of fluctuations
  - NIR fluctuation of zodiacal light is < 0.14%
  - MIR fluctuation of zodiacal emission is < 0.013 %
- Stacking process reduces the fluctuation further.

Upper Limits of ZL Fluctuations

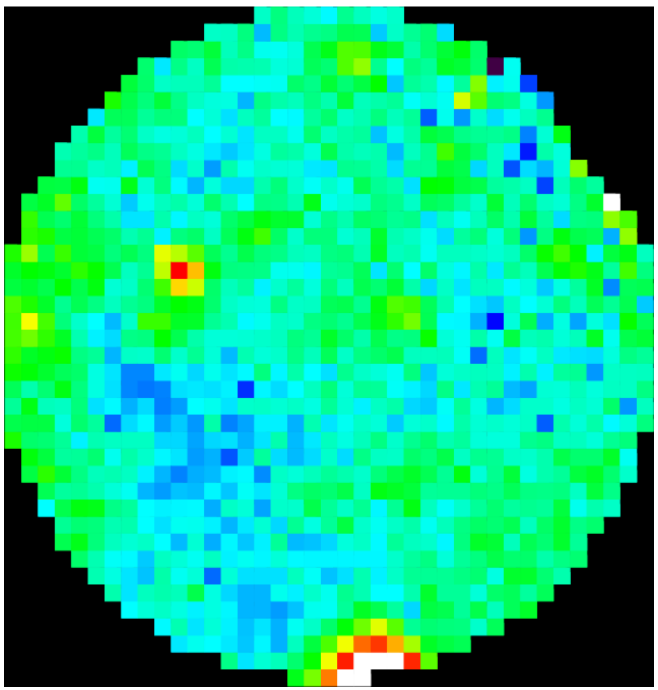
λ (μm)	**2.4**	**3.2**	**4.1**
Relative Fluctuation (%)	0.0021	0.0021	0.0025
Fluctuation power (nW m^{-2} sr^{-1})	0.0025	0.0016	0.0025
Observed power	0.19	0.08	0.051

- **Observed fluctuation is much larger than that of zodiacal light!**

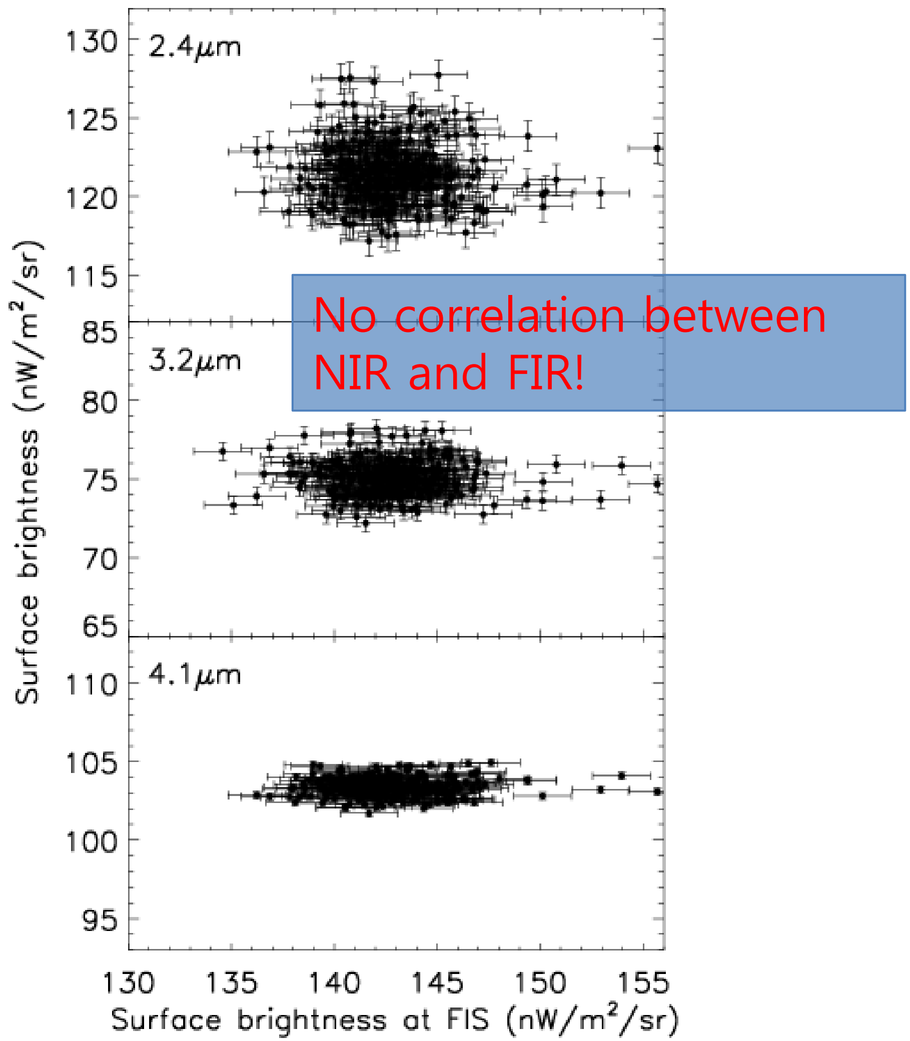
Diffuse Galactic Light (DGL)?

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

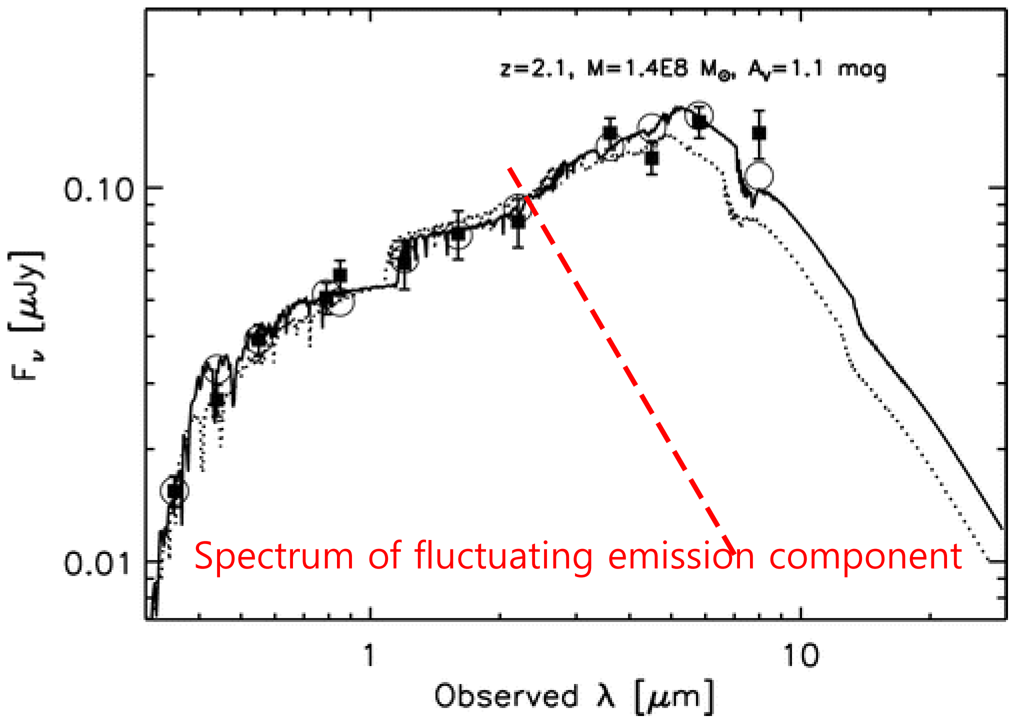
→ DGL and FIR emission should be wee correlated



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



Clustering of faint galaxies at z=2~3?

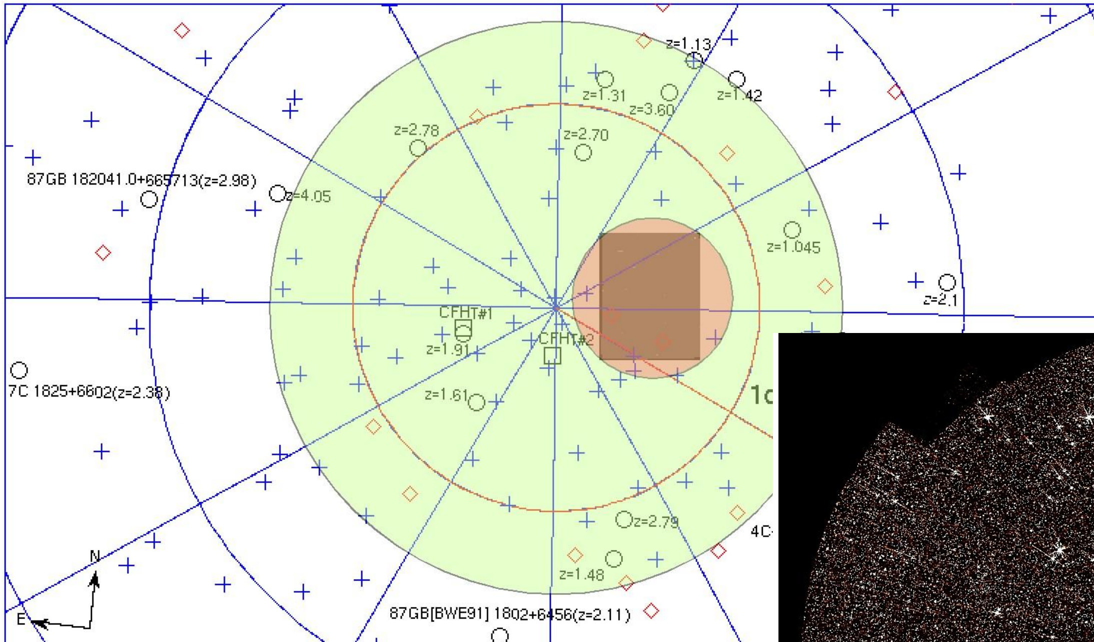


Chary et al. 2008

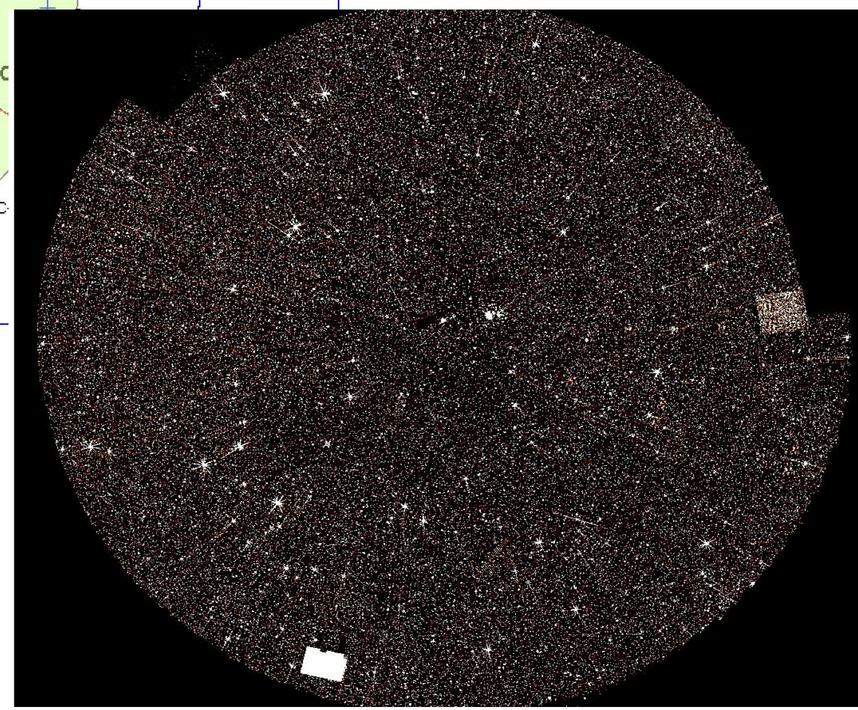
- **Spectrum of red dwarf galaxies is red at near infrared (Chary et al. 2008)**
- **Expected fluctuation of galaxies fainter than Ks(Vega)>21 mag : 0.03 $nW.m^{-2}.sr^{-1}$ at 600"**
- **AKARI observation at 2.4 μm:**

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

Preliminary result of NEP-Wide Field



~2.5 degree in scale



Band-merged Image

Additional careful analysis!

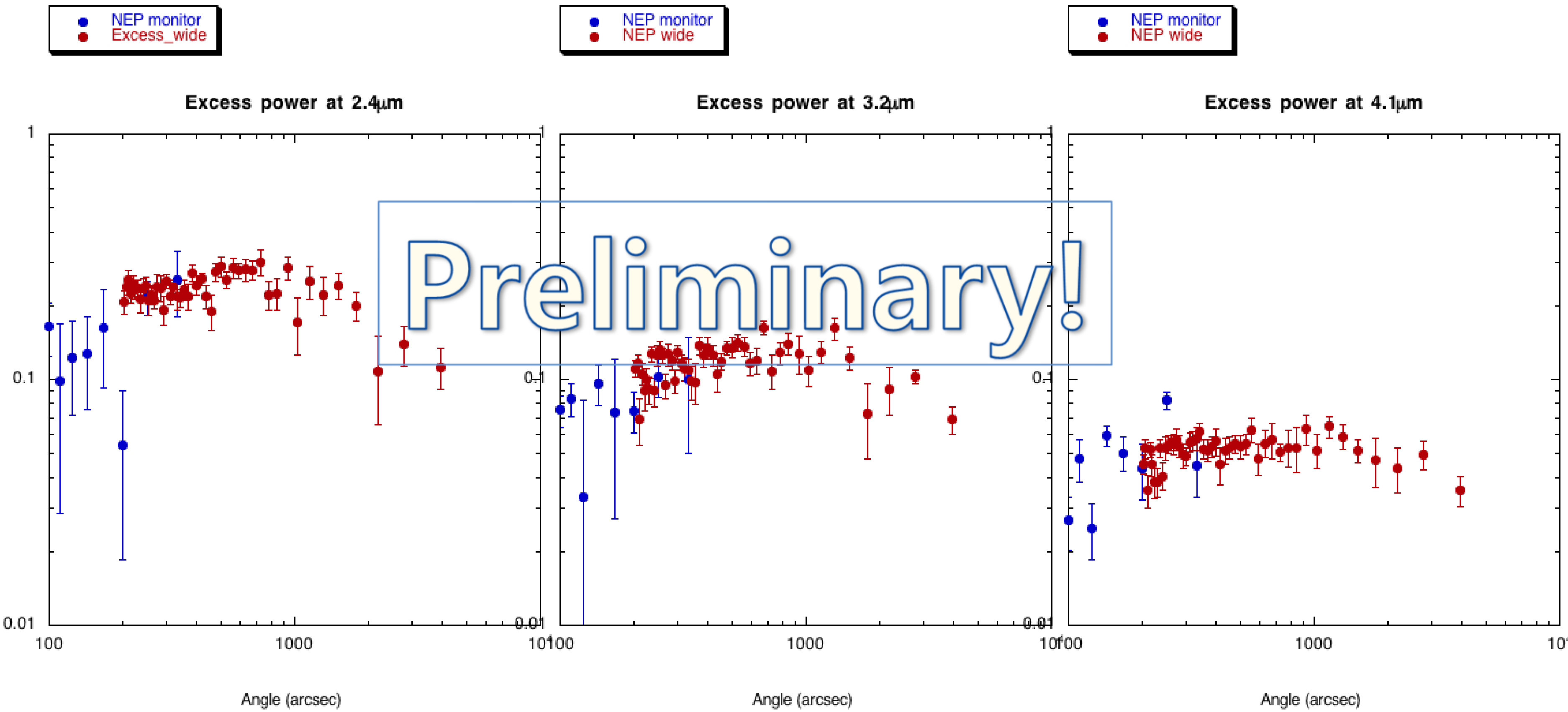
- Seasonal variation of zodiacal light
  Subtract zodiacal light with sinusoid
al fitting

- Subtraction of dark level
  Dark level was estimated based on t
he masked region

- More accurate flat field

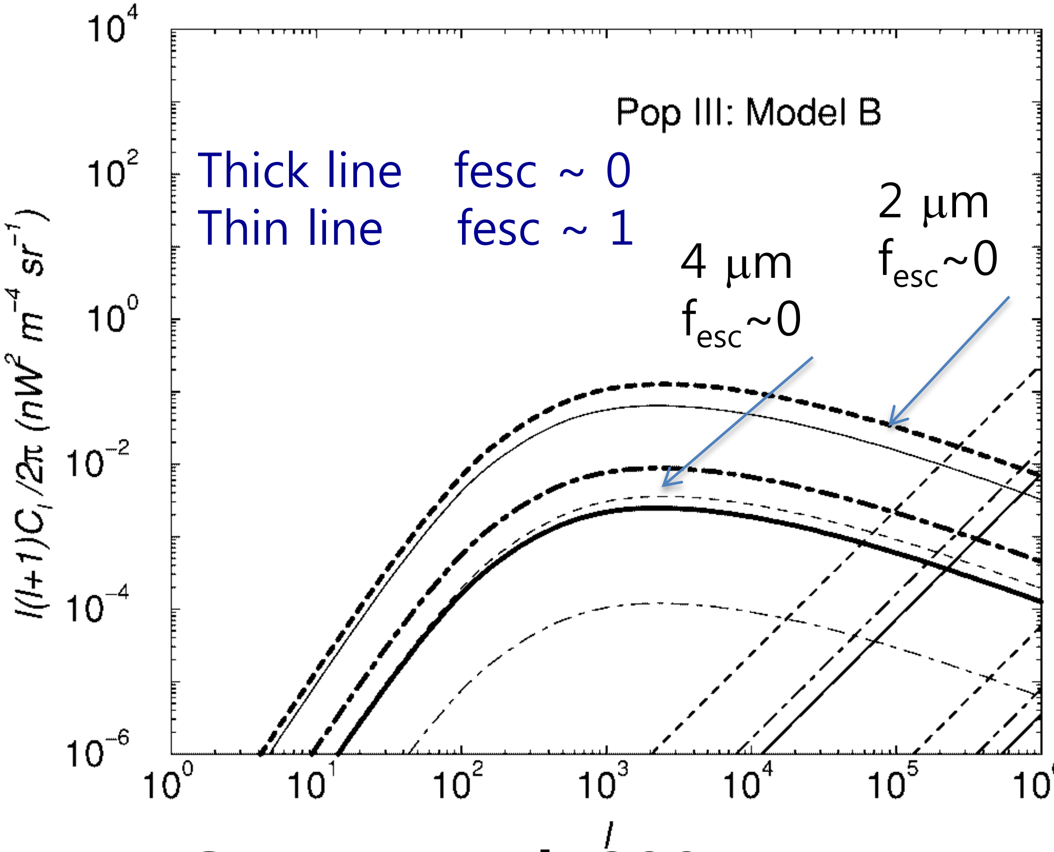
- Muxbleed problem:
  Masked affected pixels

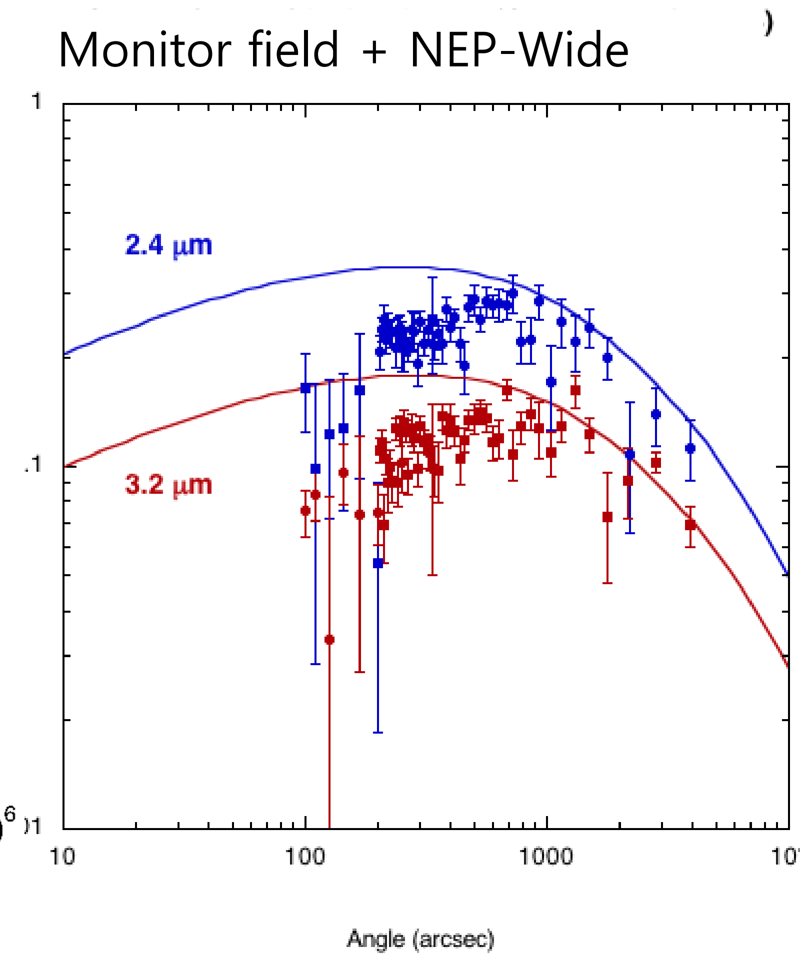
Power spectrum after subtracting shot noise



2.4 μm   3.2 μm   4.1 μm

Comparison with theory



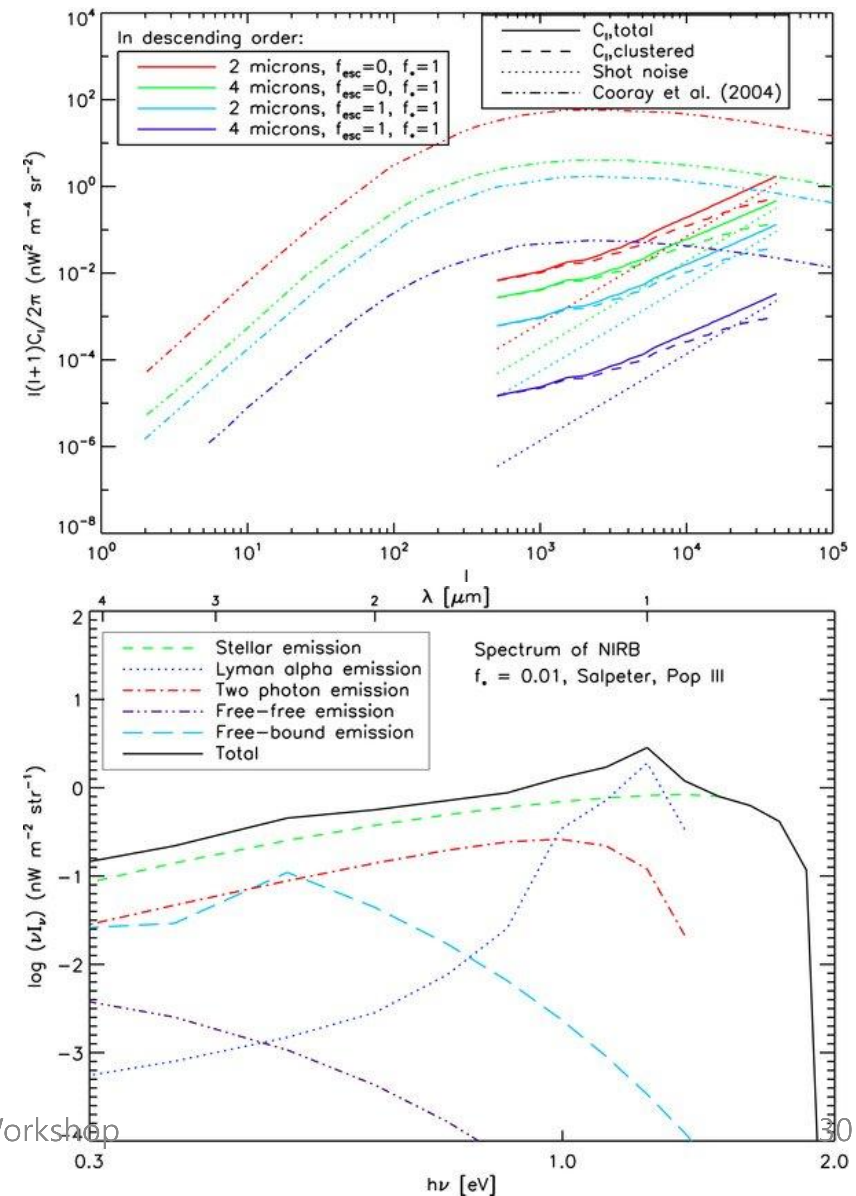


Cooray et al. 2004

Peak (turn over) at several tens arcminutes

More recent models

- Fernandez et al. (2010) does not predict a turnover at large angular scale
- The predicted spectrum is also different ($\nu I_\nu \sim \lambda^{-2}$ instead of our result of λ^{-3})



Discussions

- Uncertainties in zodaical Light: may have little effect on the fluctuations
- TeV γ-ray Blazar spectrum: intrinsic spectrum is know well known
- Energetics:

  $\sim 30(h^2\Omega_B/0.024)(\Delta X/0.05)(10/1+z_f)$ $nW.m^{-2}.sr^{-1}$

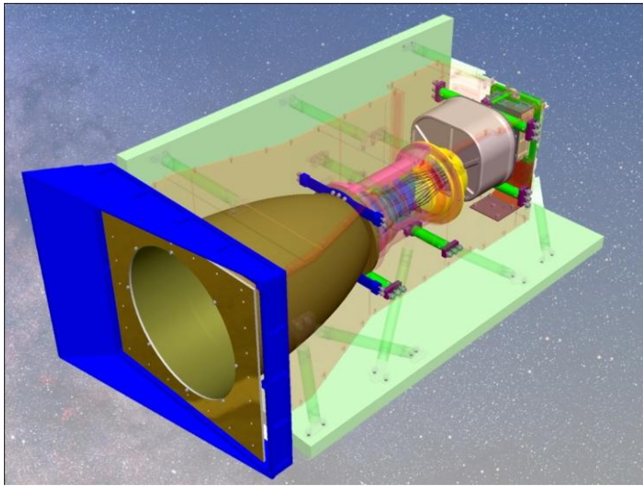
  Ω_B : Baryon density

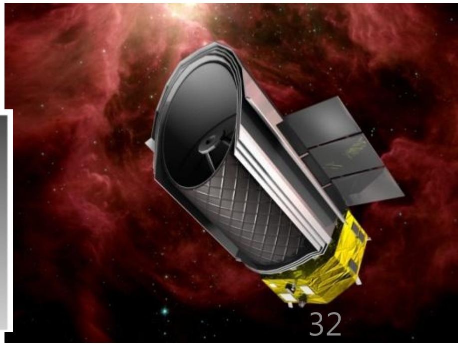
  ΔX : ratio of burned hydrogen to total hydrogen

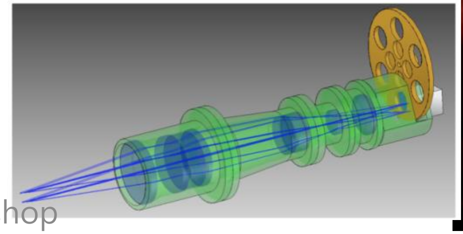
➔~5 % of hydrogen must be processed to Helium and beyond: Produced metal must be confined in black holes

Further Efforts

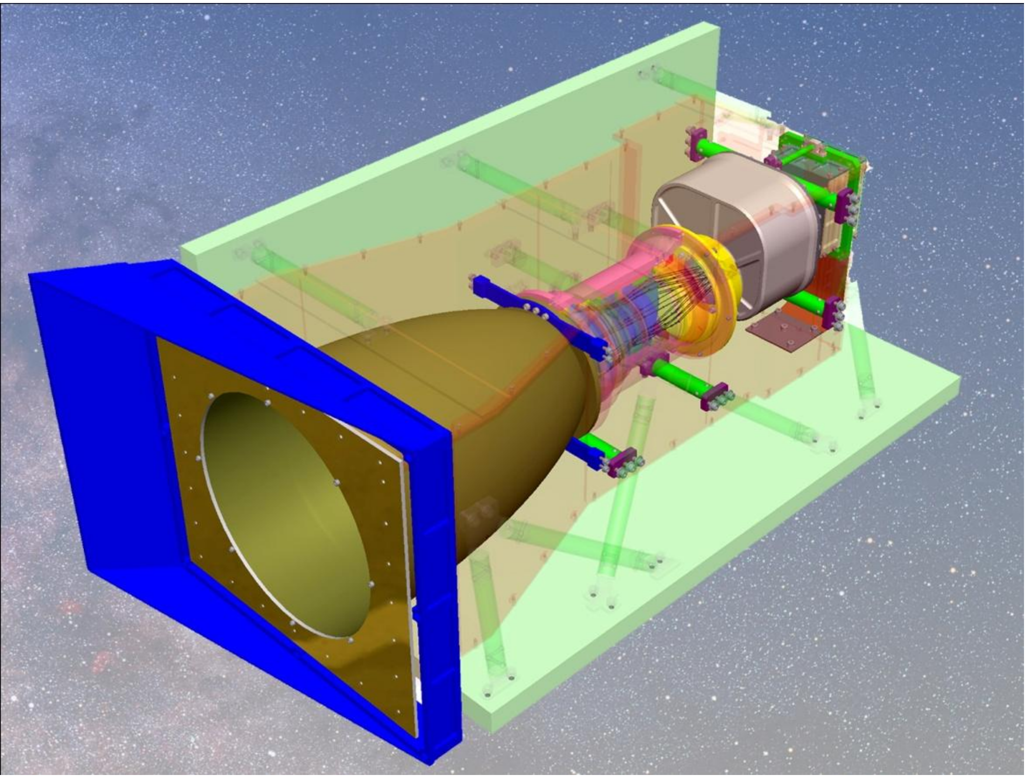
- CIBER: Rocket experiments among US, Japan and Korea (on-going): spectrum of CIRB
- MIRIS: Small infrared space telescope being built in Korea with Japanese collaboration (~2012): large scale fluctuation
- SPICA: Large Space Infrared Telescope project among Japan, Europe and Korea (~2018): more accurate measurements







MIRIS concept



Optics:

8cm aperture, F2 refractive optics

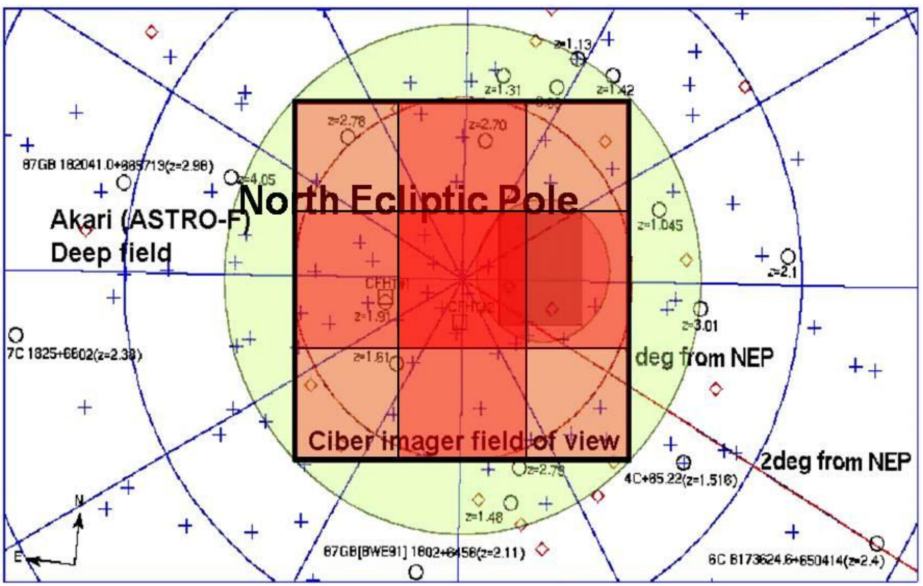
Picnic array:

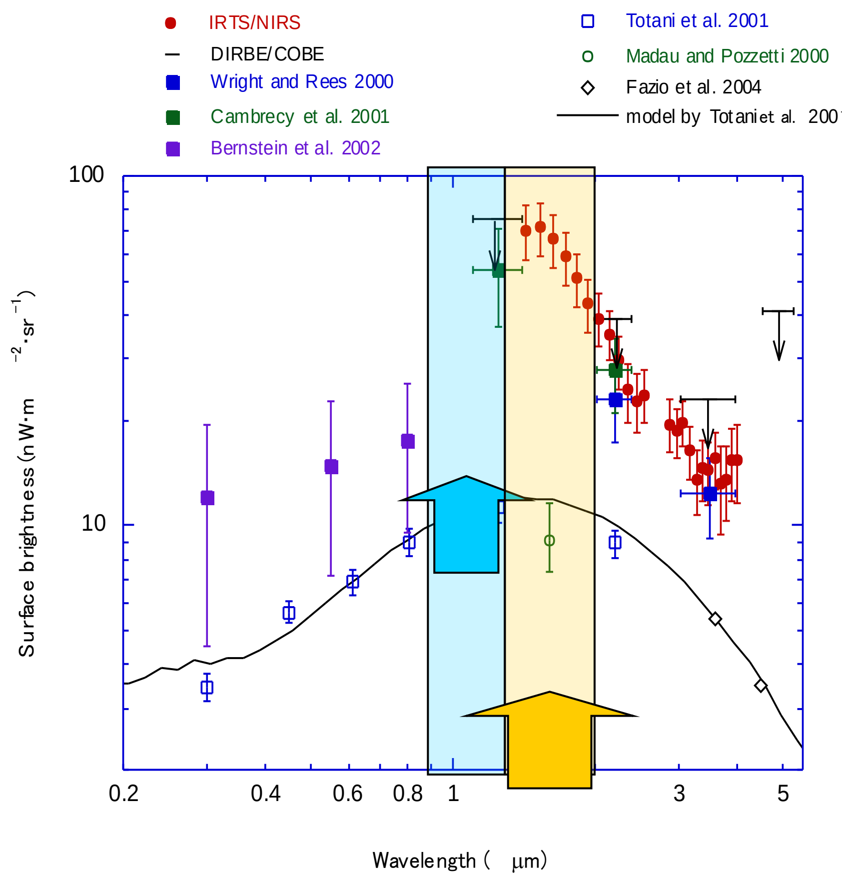
51.6″ pixel scale, $3.67^o \times 3.67^o$ frame

Telescope is passively cooled by radiation to ~180K

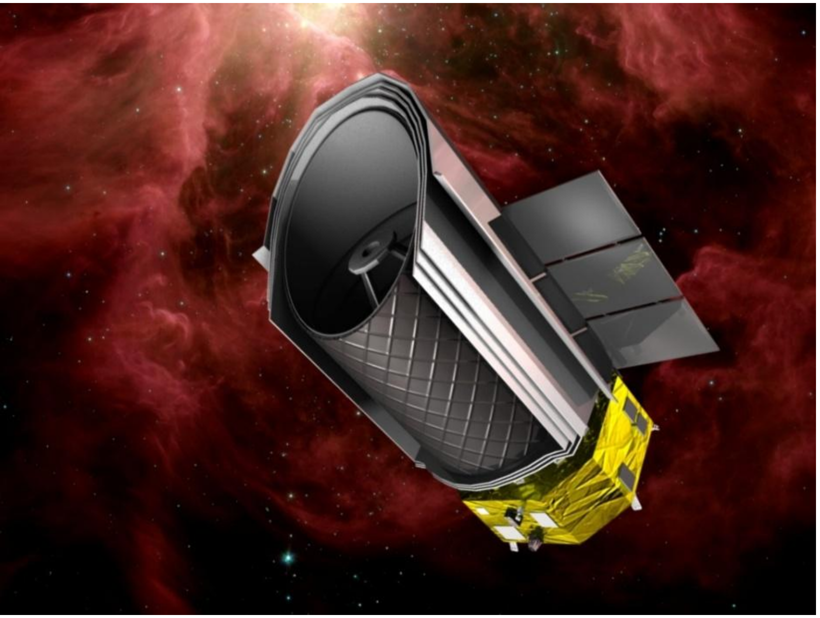
Cosmic Near-infrared Background: MIRIS Observation

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





SPICA



- 3m class cooled telescope (4.5K)
- L2 halo orbit
- Launch 2018

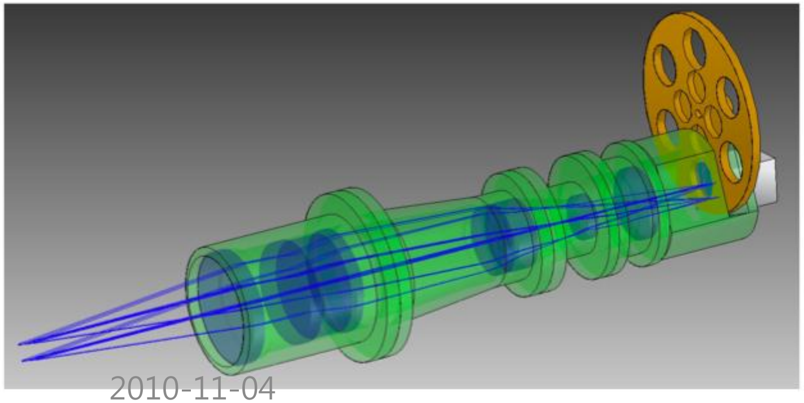
International collaboration

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 CIRB
- Strong power at 100-200 arcsecond
  - 200 arcsec = 9 Mpc at $z=10$
  - clusters of galaxies scale?
- Nearly Rayleigh-Jeans SED with peak $< 2\mu m$

  Pop. III stars at $z<15$?
- Wide field survey data being analyzed. Preliminary results show excess power up to ~1 deg beyond shot noise.
- CIBER, MIRIS, SPICA projects will deliver better information on absolute brightness, spectrum, large scale structure, etc.