TCHoU Seminor

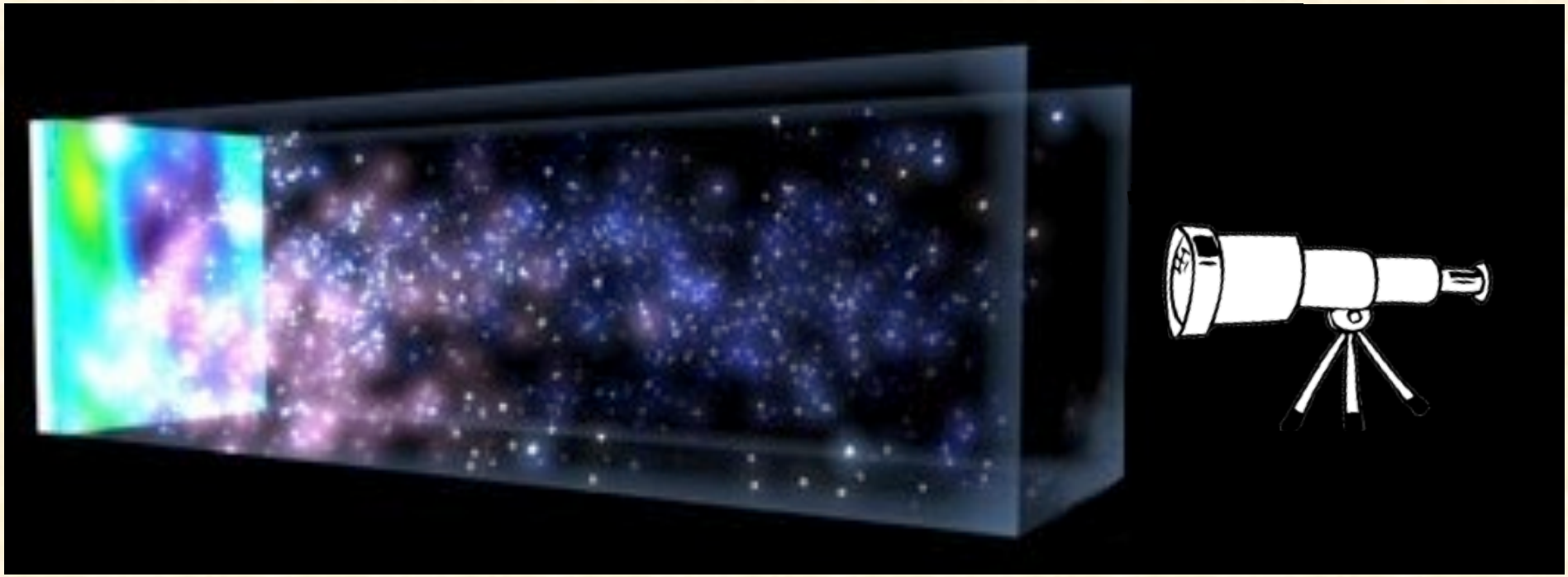
What is the origin of the Cosmic Near-Infrared Background ?

~ from recent result of the CIBER experiment ~

Shuji Matsuura
(Kwansei Gakuin University)

Cosmic Background Radiation

- Cosmic Background Radiation – the total integrated light emitted and absorbed along the line of sight.
- Measurement of the cosmic background gives constraints on the cosmic evolution history as global mean.



Cosmic Microwave Background (CMB)

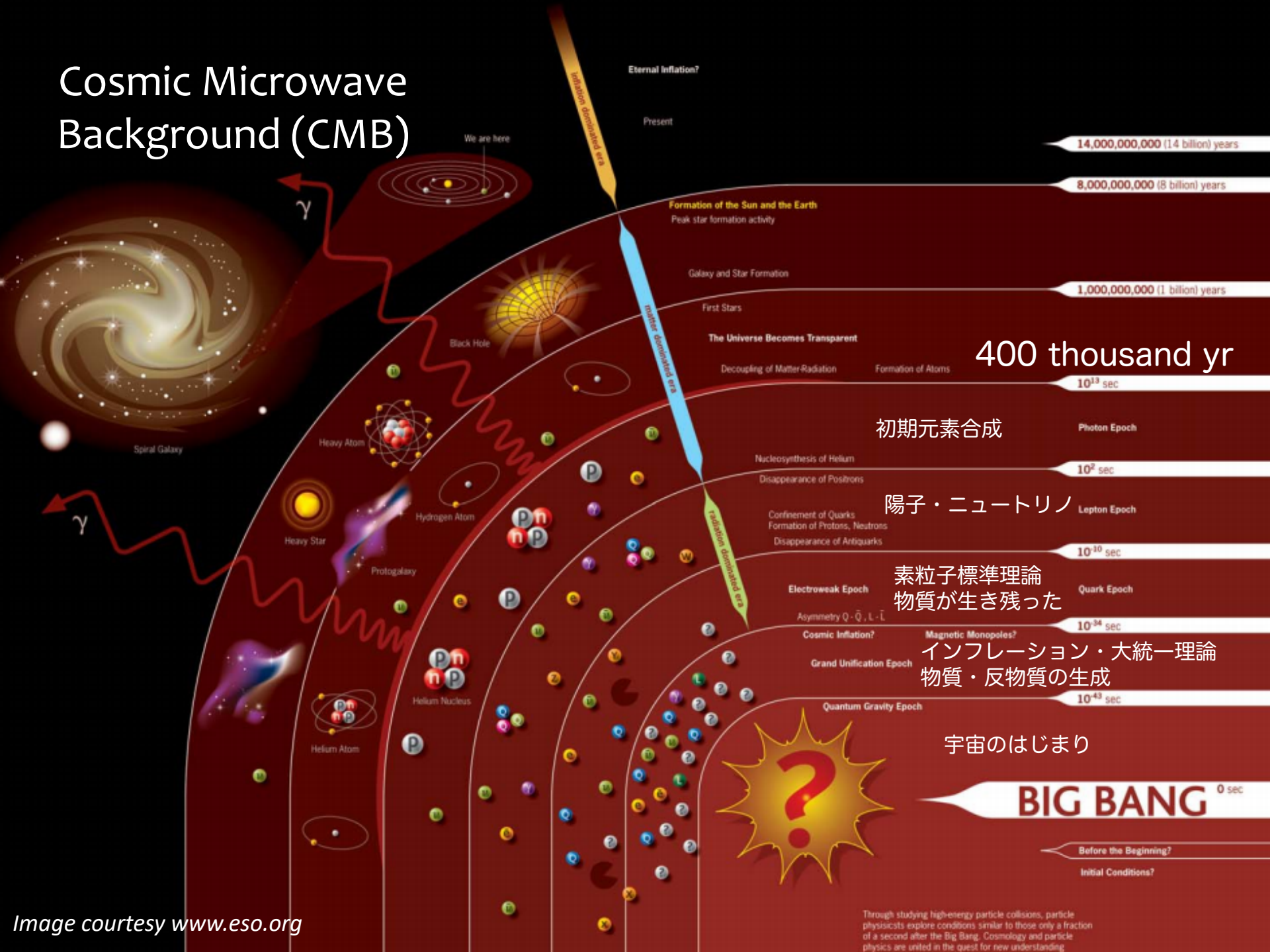
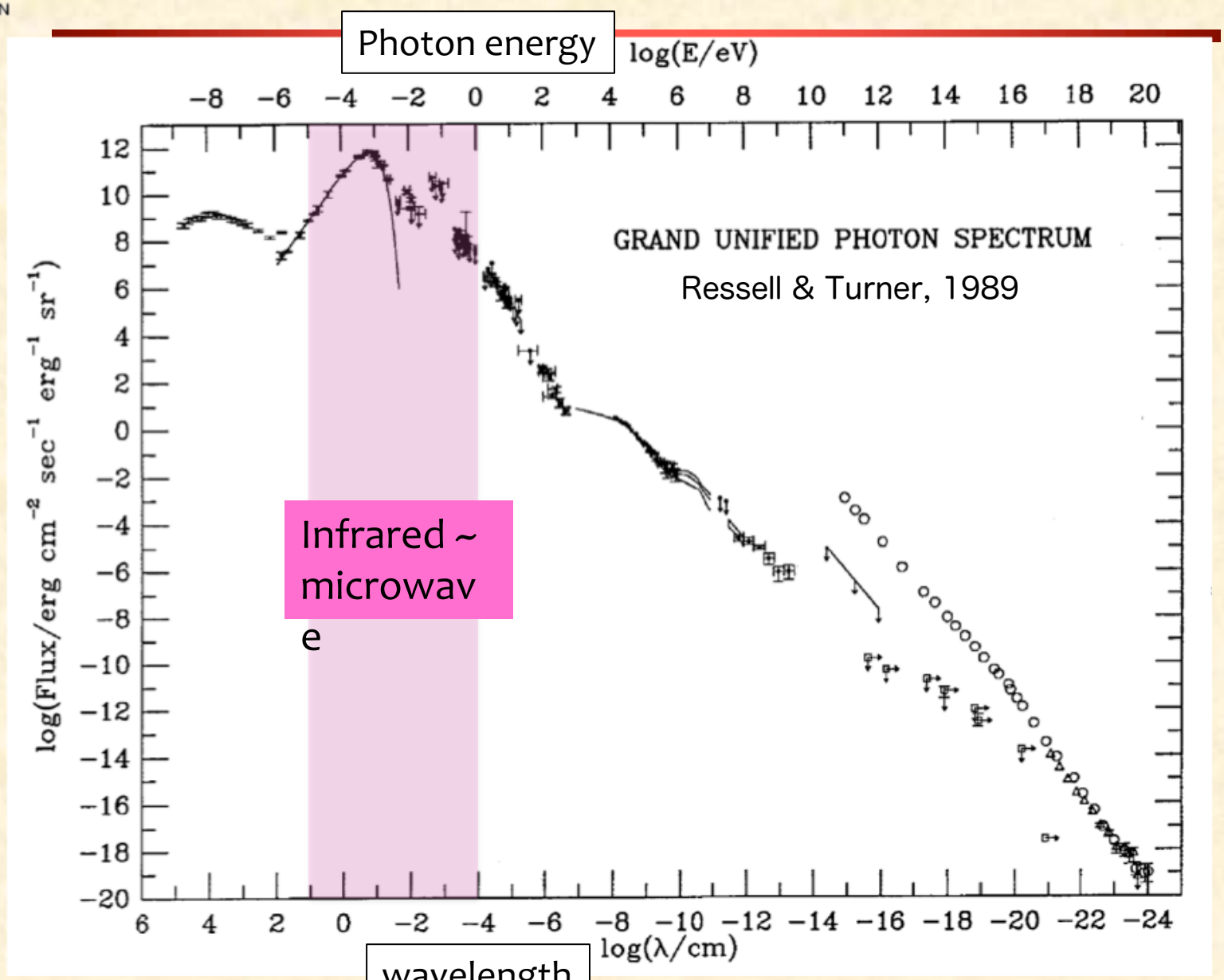
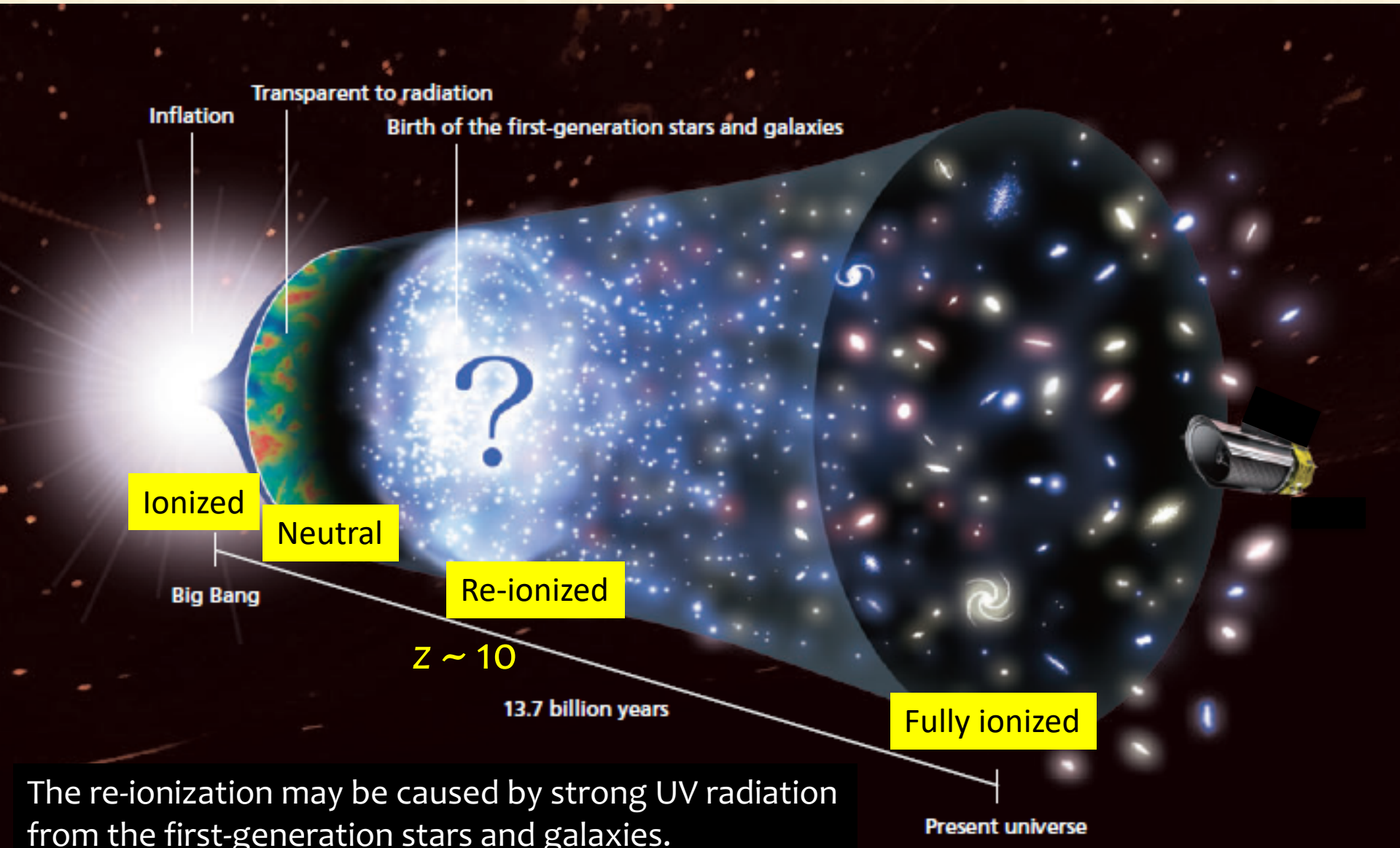


Image courtesy www.eso.org

Cosmic background radiation



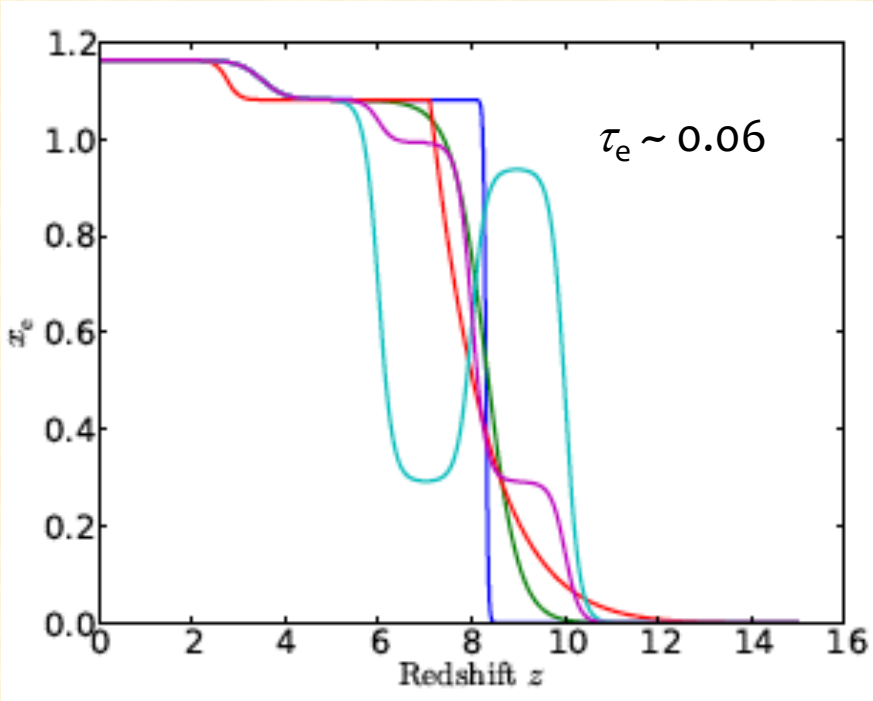
Universe was re-ionized

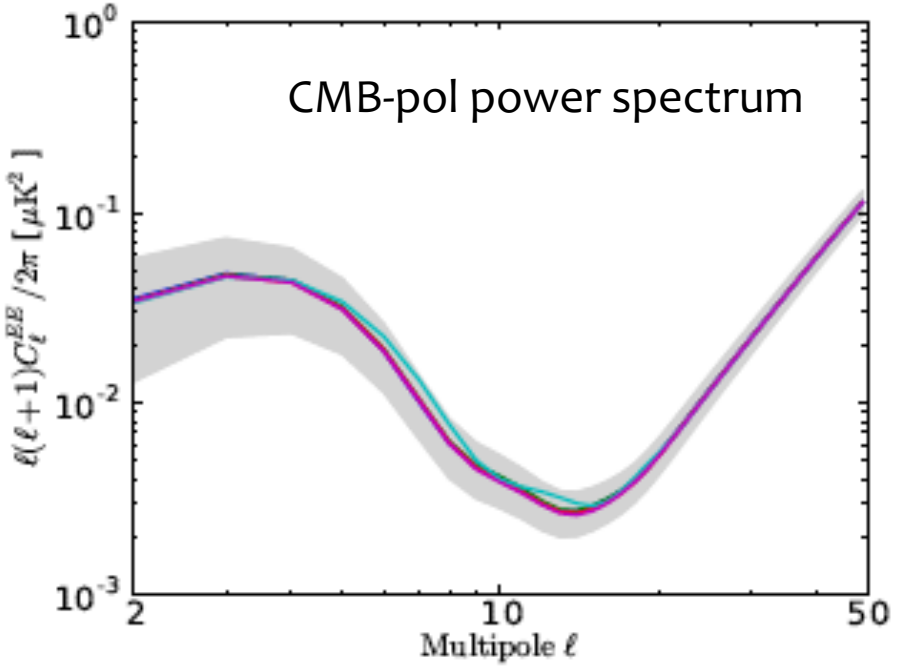


The re-ionization may be caused by strong UV radiation from the first-generation stars and galaxies.

Result of the CMB-pol measurement

- Thomson scattering optical depth in ionized IGM in LoS (τ_e) is derived from the CMB polarization measurements (EE-mode)
- τ_e ~ 0.09/0.06 from WMAP/Planck
- Re-ionization redshift z_{re} ~ 8 - 10

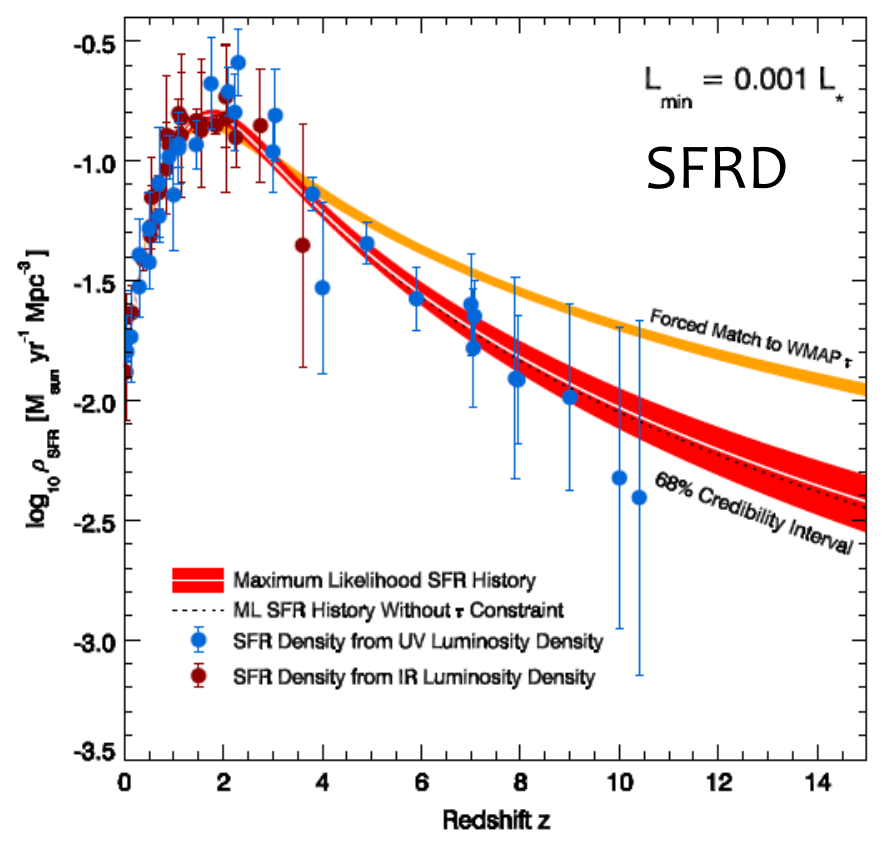


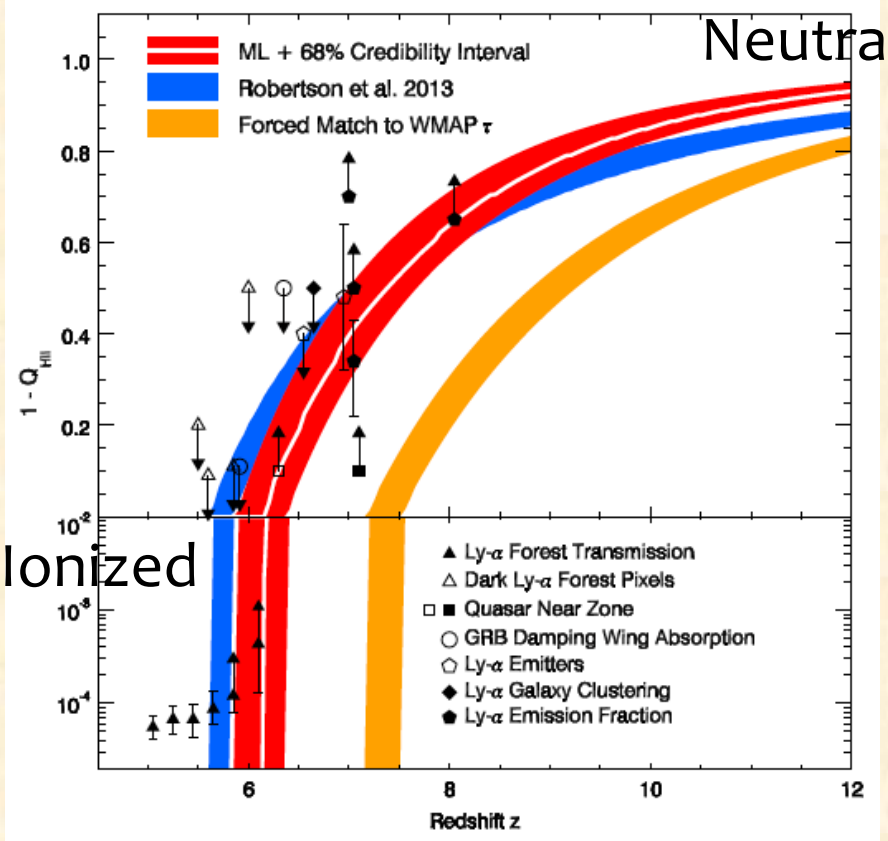


Planck 2016

IGM neutrality from galaxy observations

- Neutrality of IGM can be estimated from star formation rate density from redshift distribution of distant galaxies.
- Planck result does NOT require additional re-ionization sources.

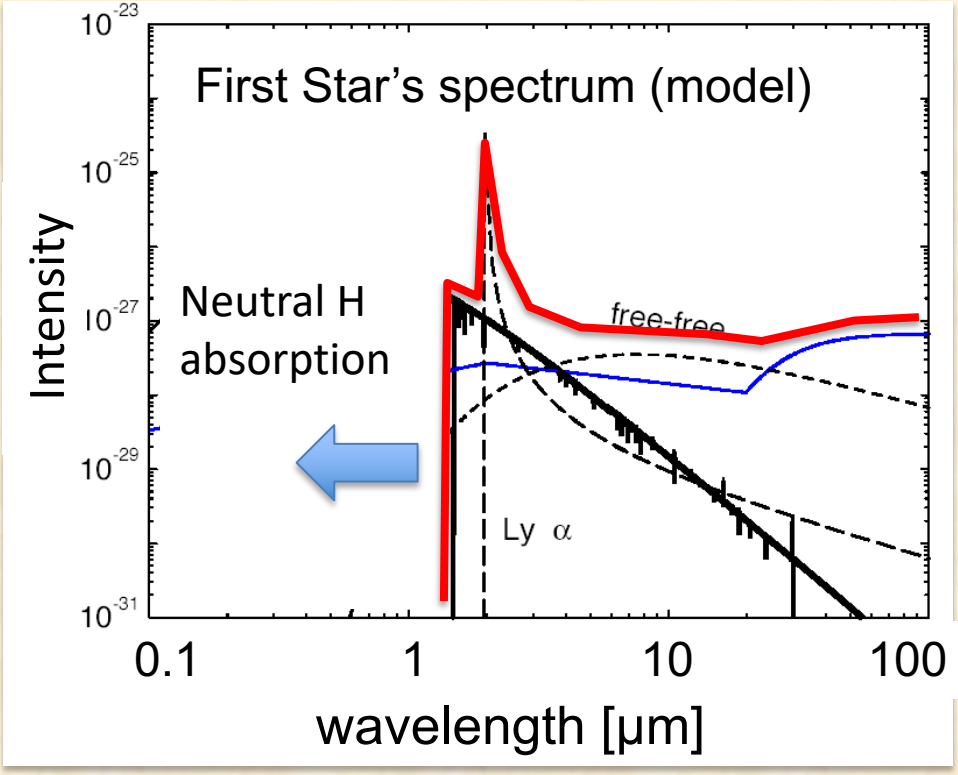




Robertson et al. ApJL 2015

First-generation Stars

- First stars are thought to be extremely massive.
- They emit strong UV light, that may ionize intergalactic medium.
- The UV radiation is redshifted into the near-infrared.
- Radiation spectrum indicates sharp edge due to IGM absorption.

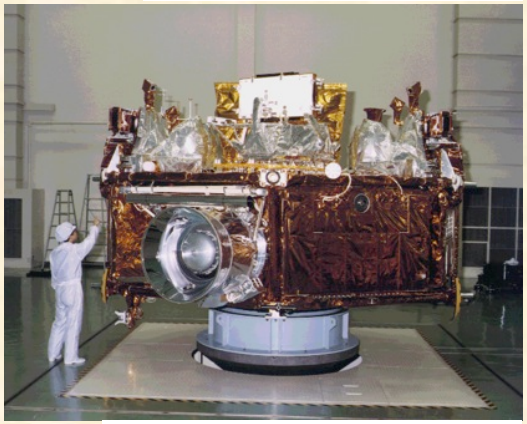


Cooray&Yoshida 2004 (MNRAS, 351, L71), Santos et al. 2002 (MNRAS, 336, 1082)

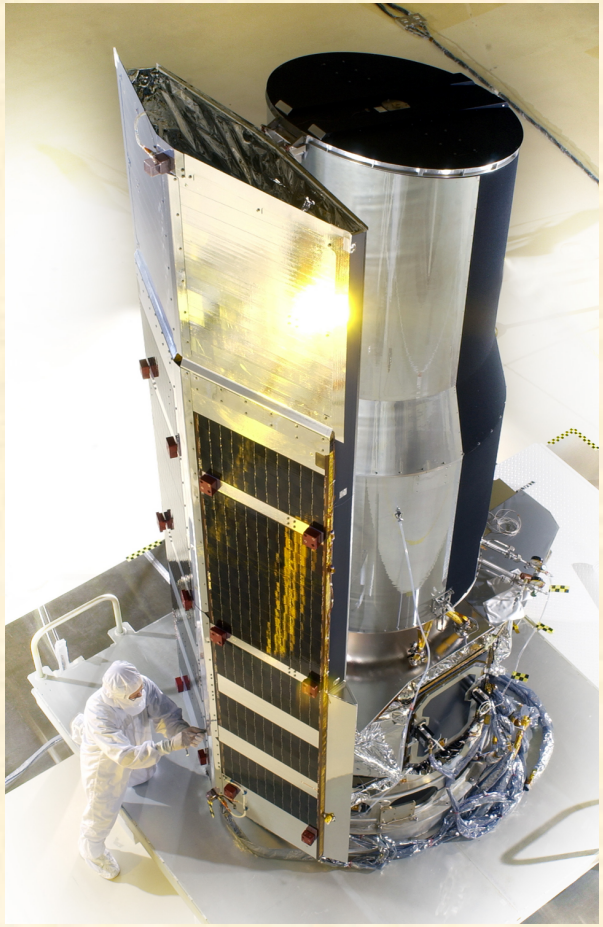
Observations of the infrared background

- Precise measurements of the near-infrared background were carried out by space infrared telescopes.

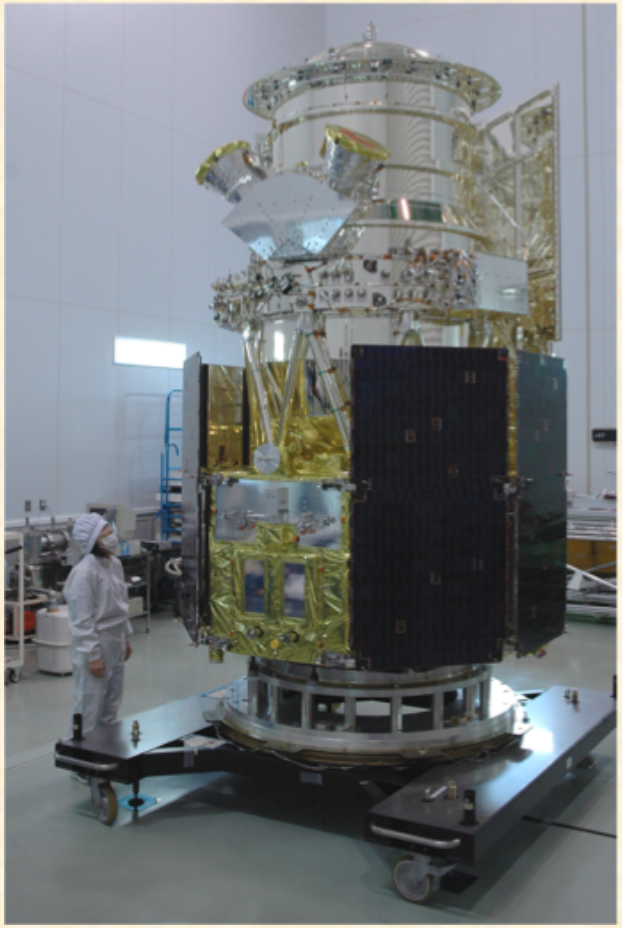
COBE (NASA) 1989



IRTS/SFU (ISAS) 1995



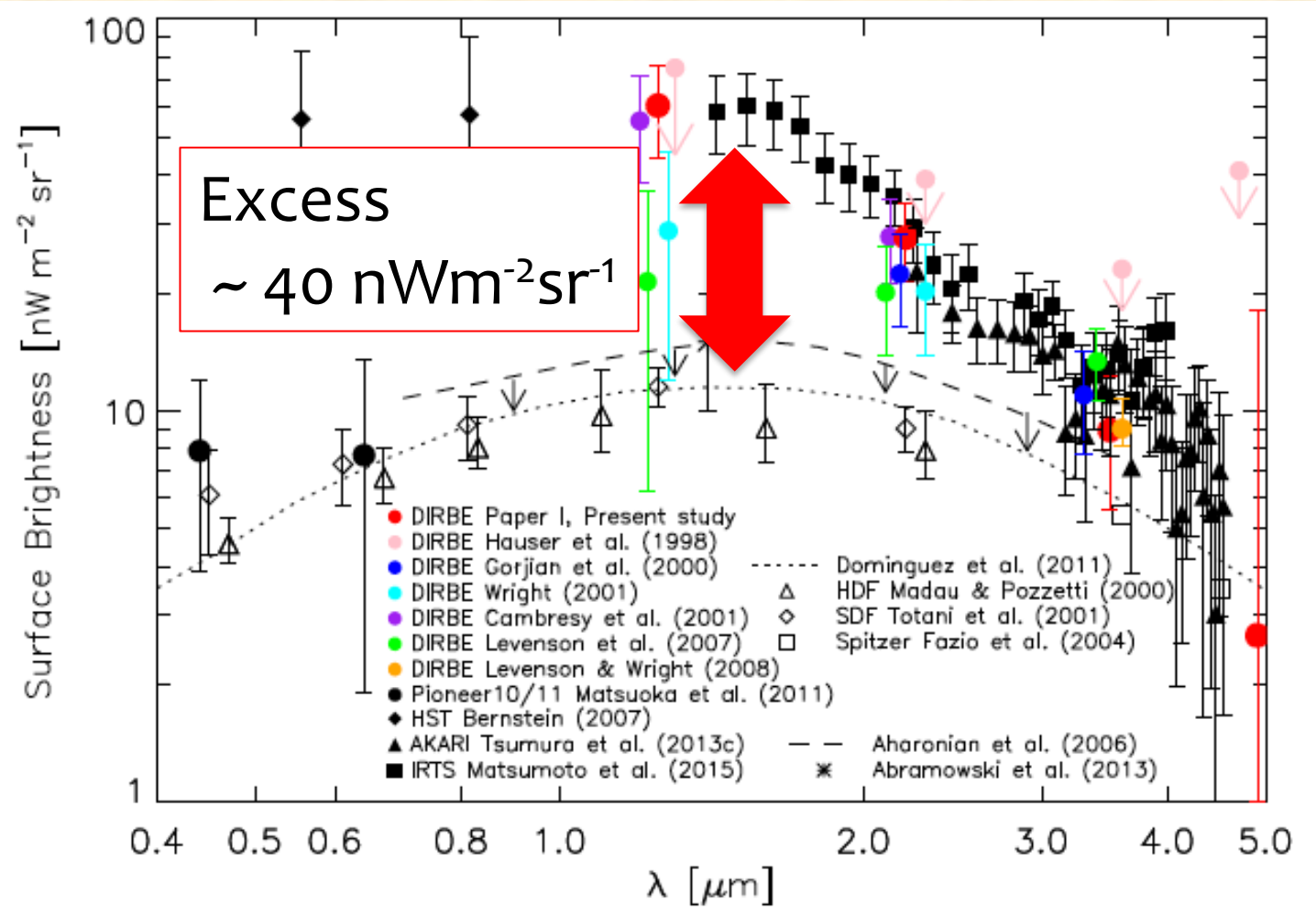
Spitzer (NASA) 2004



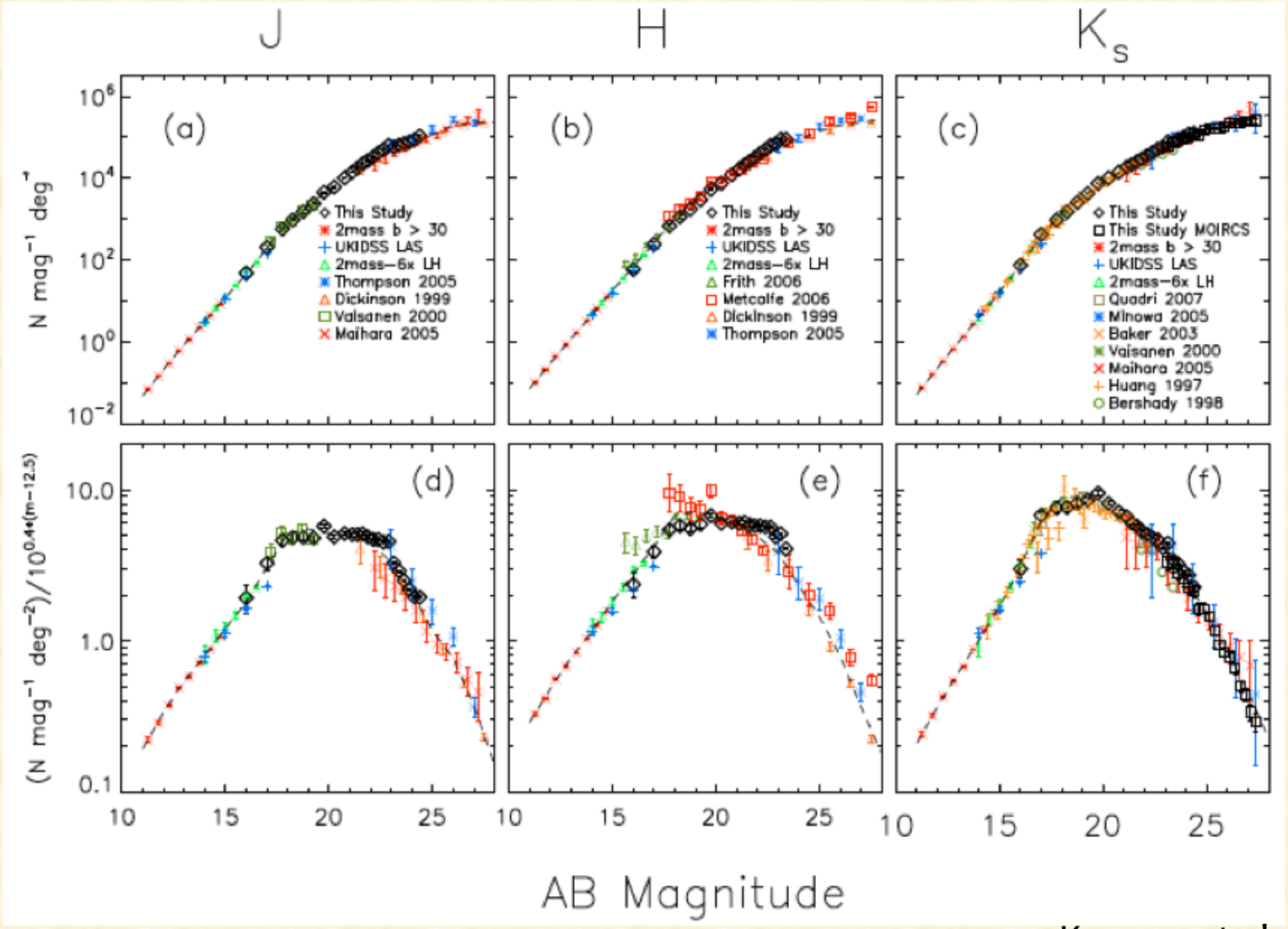
AKARI (ISAS) 2006

Observed near-infrared background

- Clear discrepancy between the measured background and the expected levels of the integrated galaxy light.



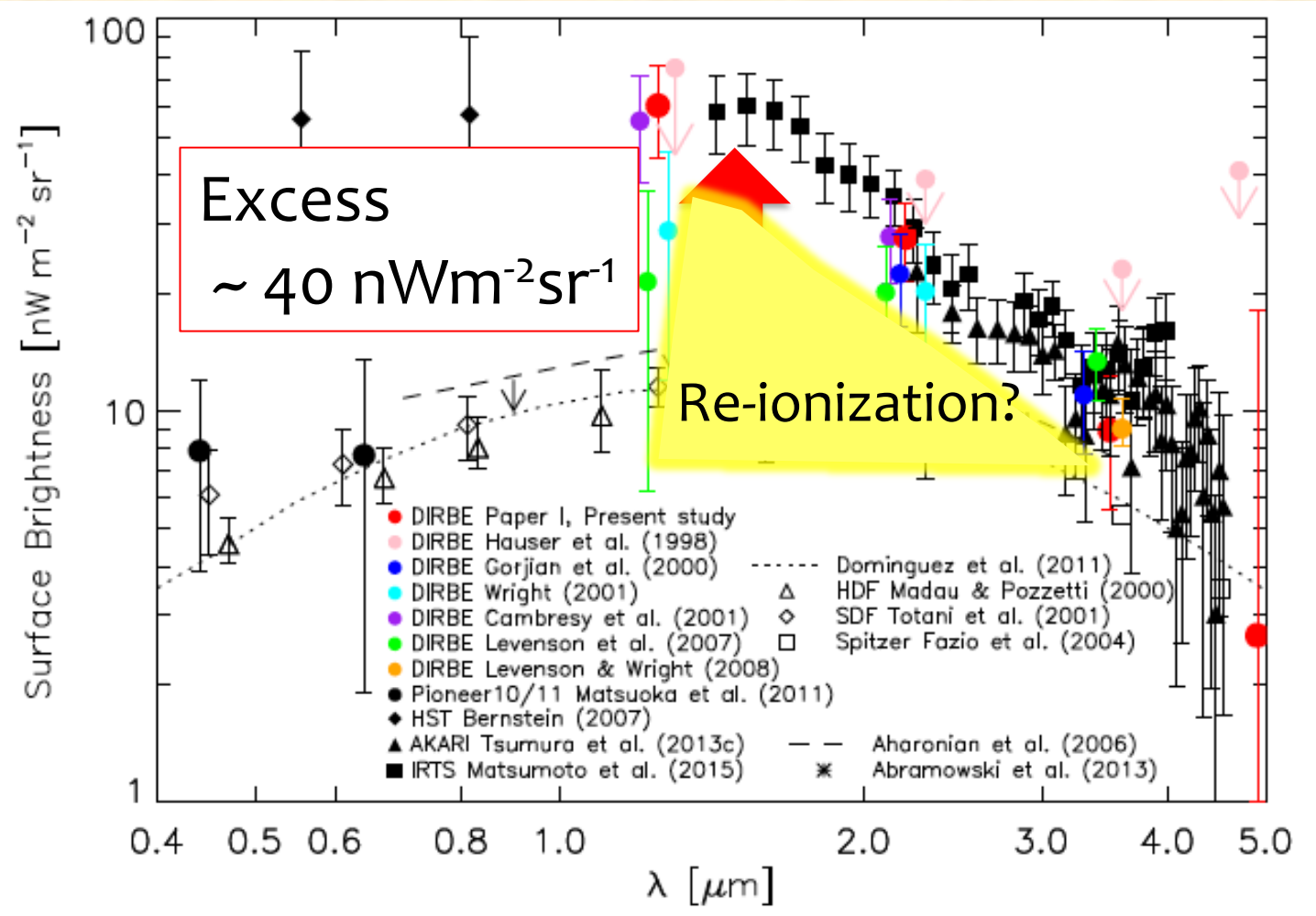
Deep galaxy counts



Keenan et al., ApJ, 2010
MOIRCS / SUBARU

Observed near-infrared background

- Clear discrepancy between the measured background and the expected levels of the integrated galaxy light.



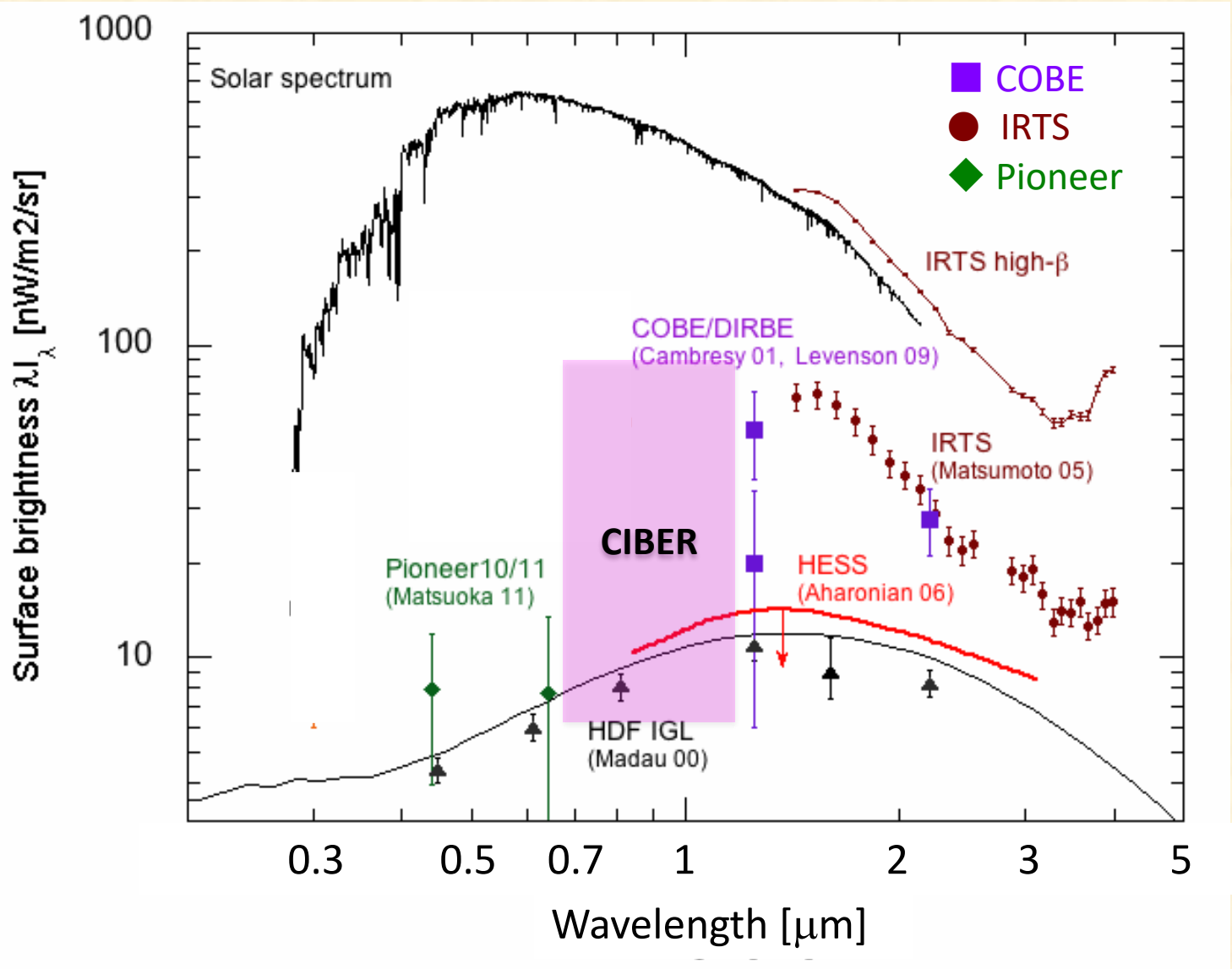
Foreground subtraction

- To measure the background radiation, subtraction of the foreground radiation from the observed total brightness is necessary.

Total sky = Zodiacal light (interplanetary dust) ~80%
+ Galactic light (starlight and dust) ~10%
+ Integrated light of external galaxies ~5% (?)
+ additional isotropic background ?

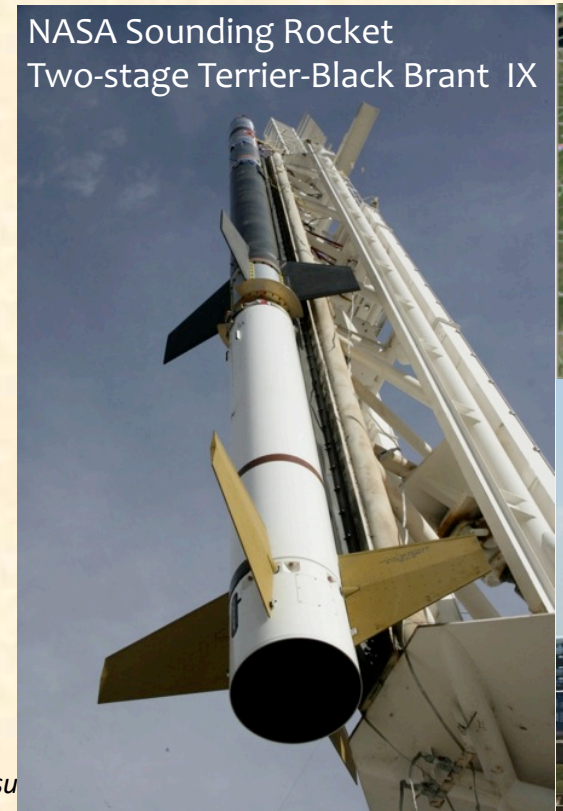
- Underestimate of ZL is most plausible

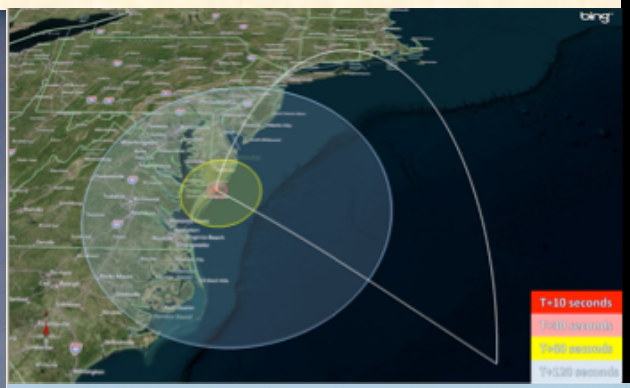
Zodiacal light is strong

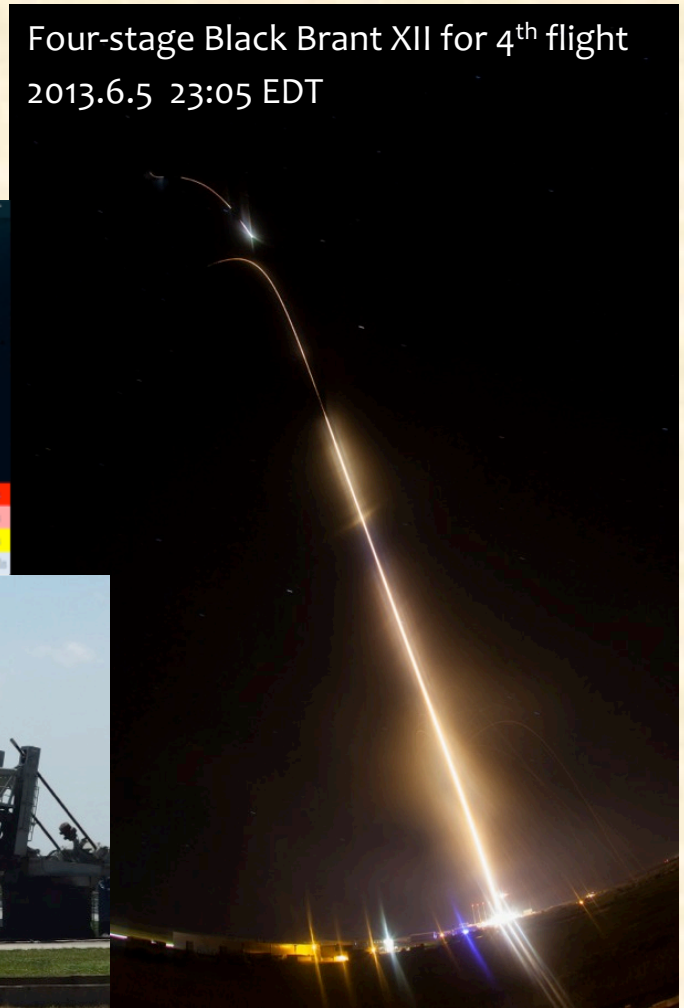


Rocket experiment CIBER

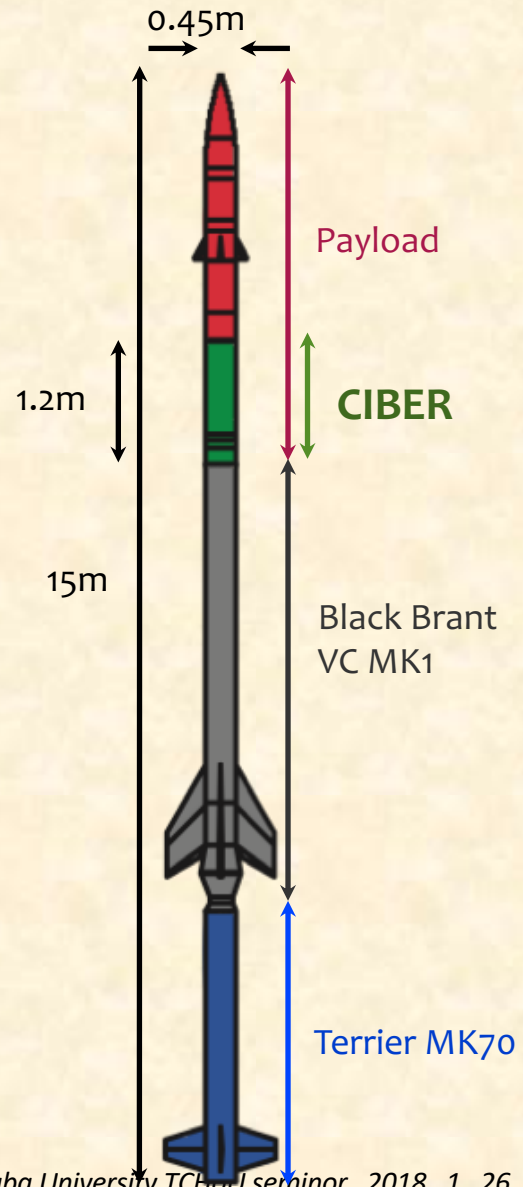
- We have already flown CIBER four times.
  (Feb 2009, Jul 2010, Mar 2012, and June 2013)
- All flights were successful.
- NASA team award

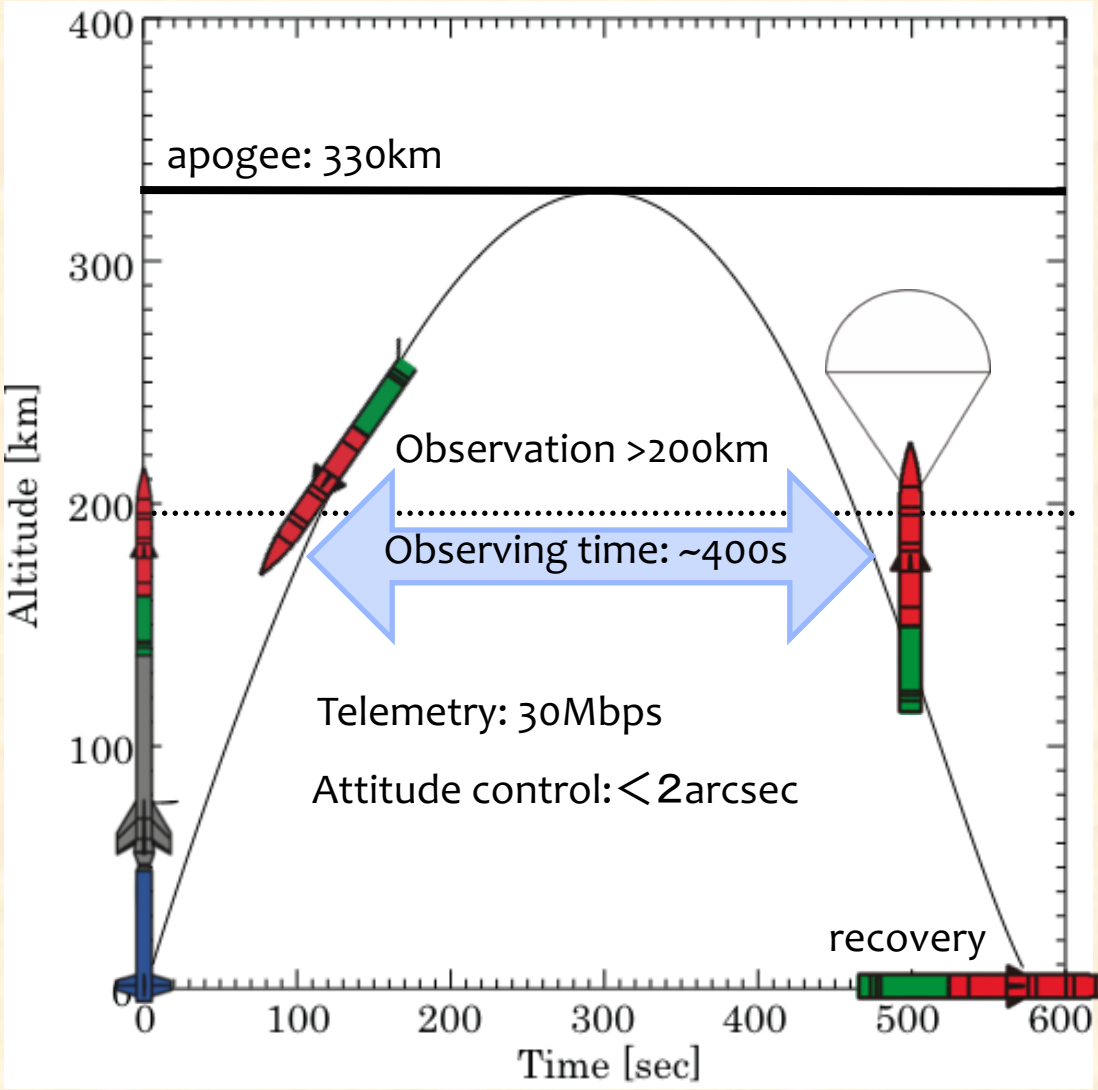

NASA Sounding Rocket
Two-stage Terrier-Black Brant IX



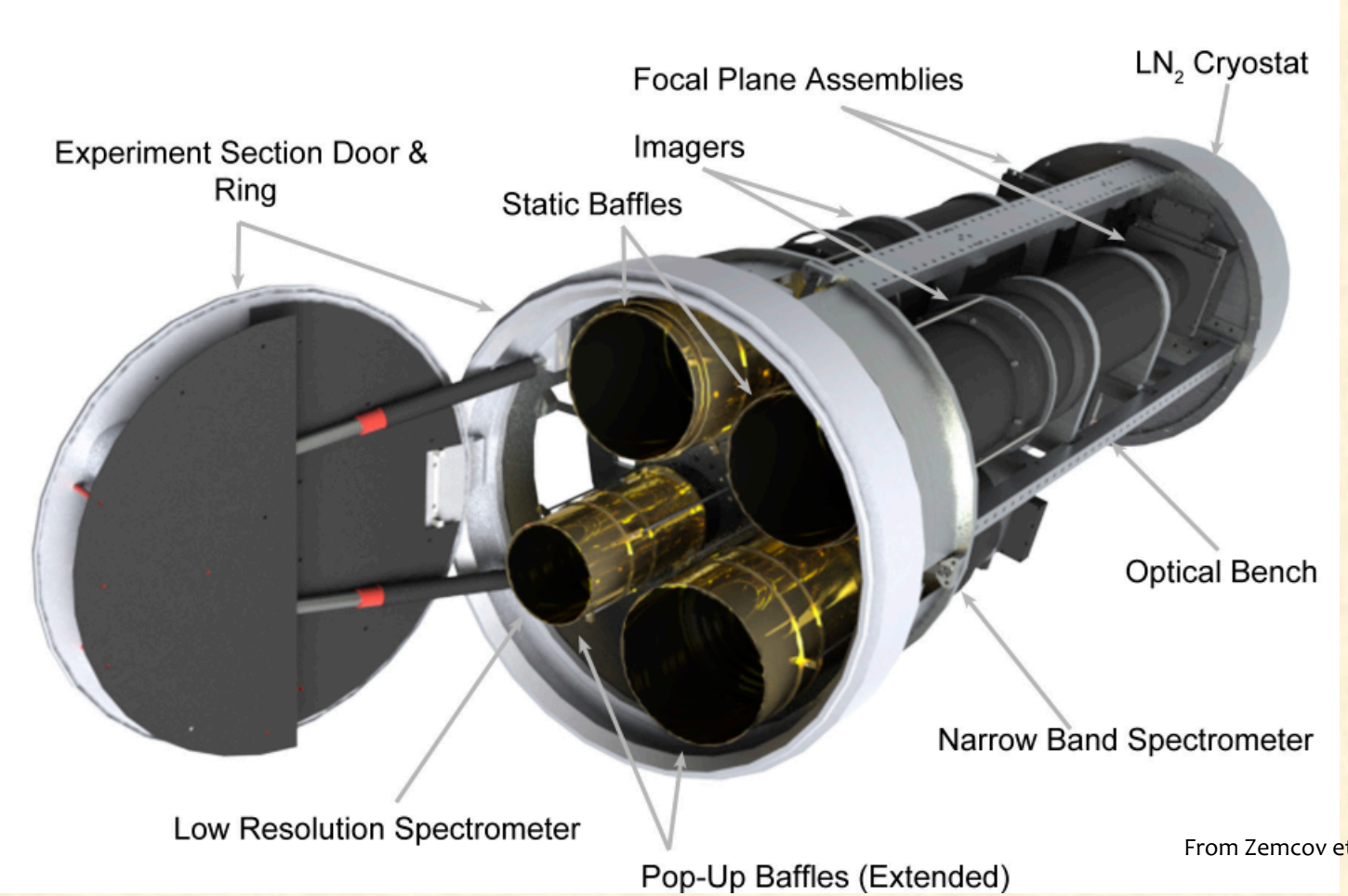

Four-stage Black Brant XII for 4th flight
2013.6.5 23:05 EDT

Launch vehicle & orbit





CIBER payload



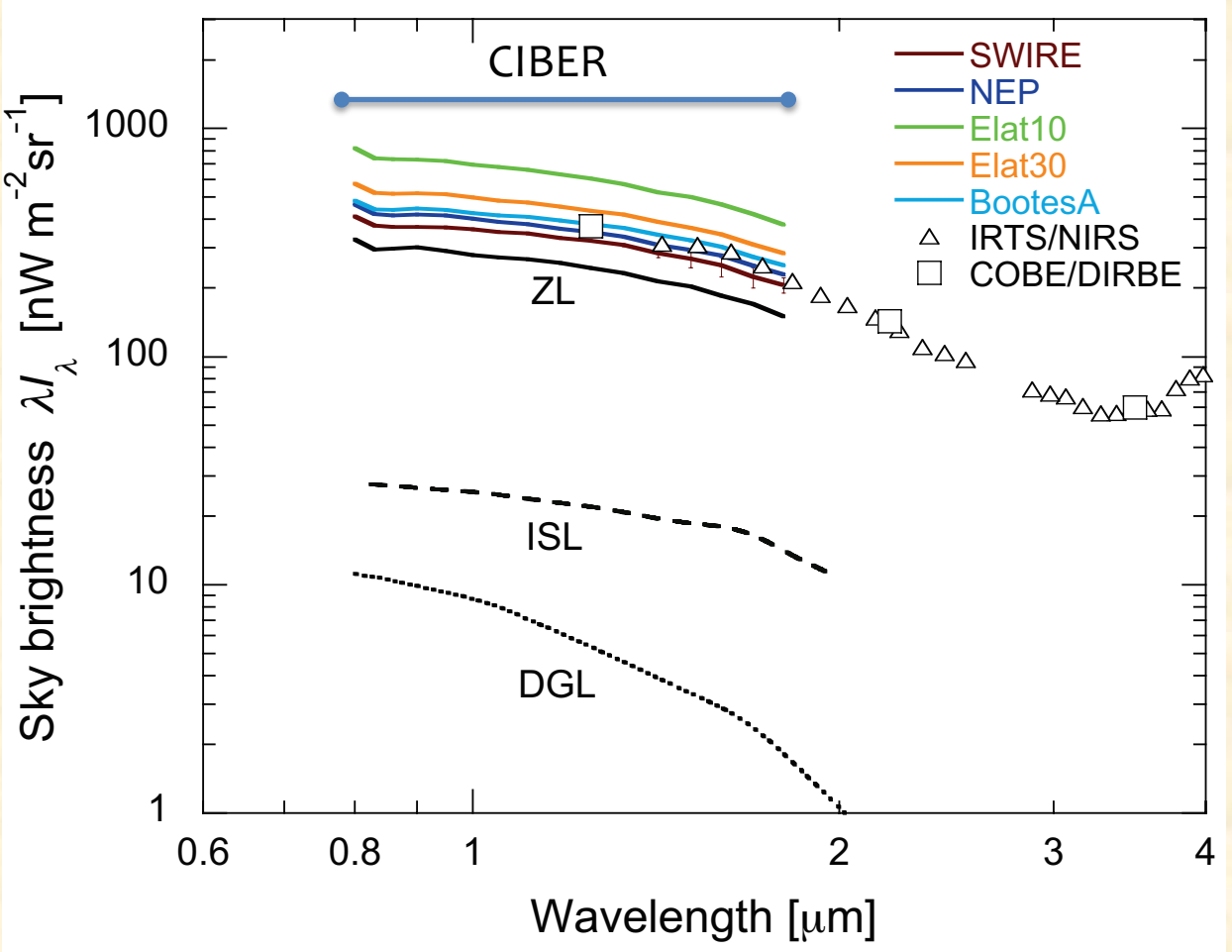
From Zemcov et al. (2012)

Observed sky brightness

Sky brightness levels are similar to previous observations

Extragalactic background
= Sky - foregrounds

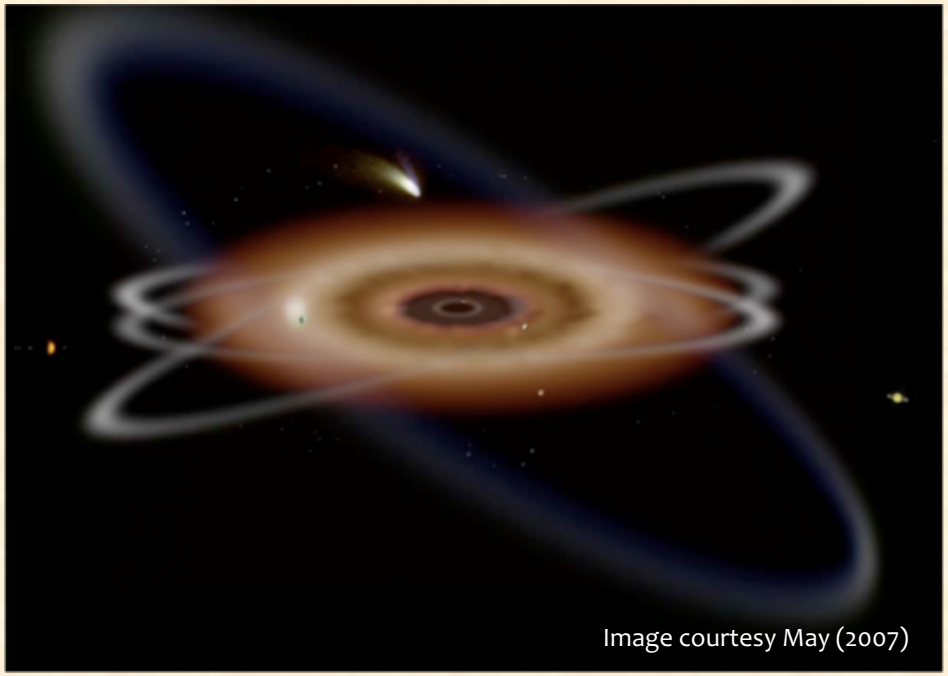
Foregrounds
- zodiacal light (ZL)
- integrated star light (ISL)
- diffuse galactic light (DGL)



Matsuura et al. 2017, ApJ accepted

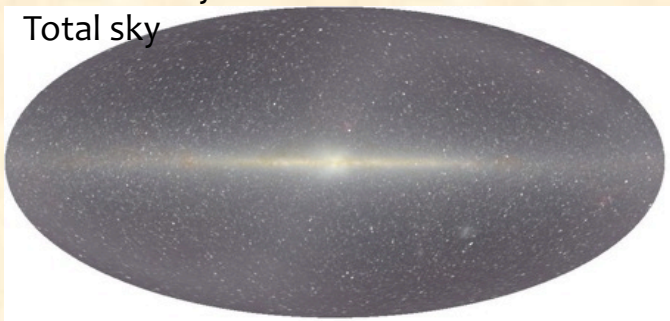
Zodiacal light – major foreground

- Zodi dust cloud has complex structure, not easy to model
- COBE team constructed complex but reliable model of ZL
- But, we still need better understanding of the ZL spectrum



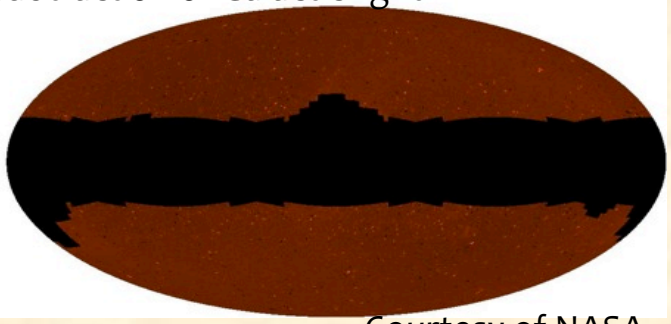
COBE all-sky observation

Total sky



After subtraction of Zodiacal light

After subtraction of Galactic light

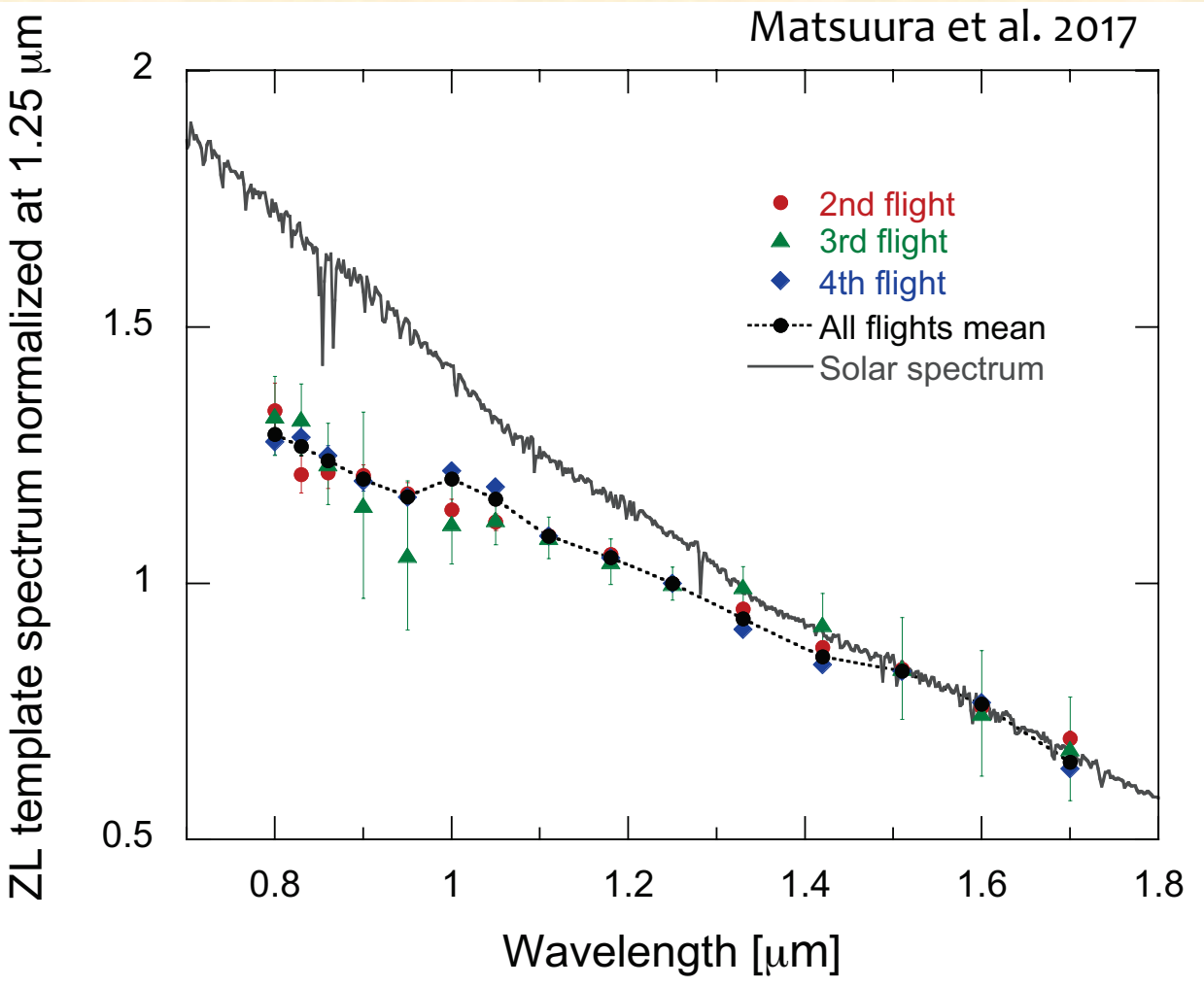


Courtesy of NASA

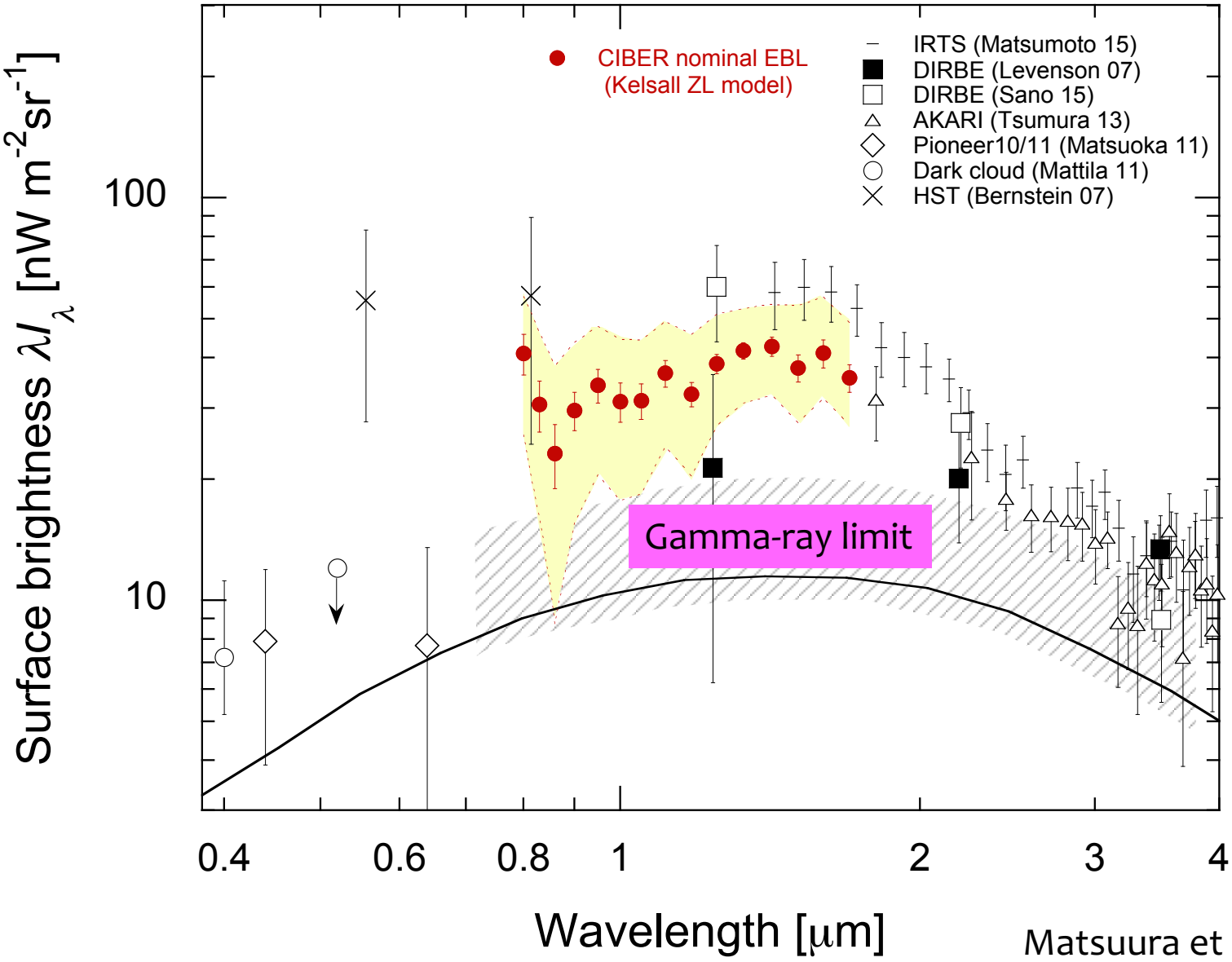
Zodiacal light spectrum

- ZL spectrum – difference of sky spectra (Sky-ISL-DGL) at different ecliptic latitudes, cancelling out any isotropic offset.

- Slightly redder than the solar, but similar.
- This is the first measurement of ZL spectrum in this region.
- Subtracted ZL using the COBE model of ZL distribution.

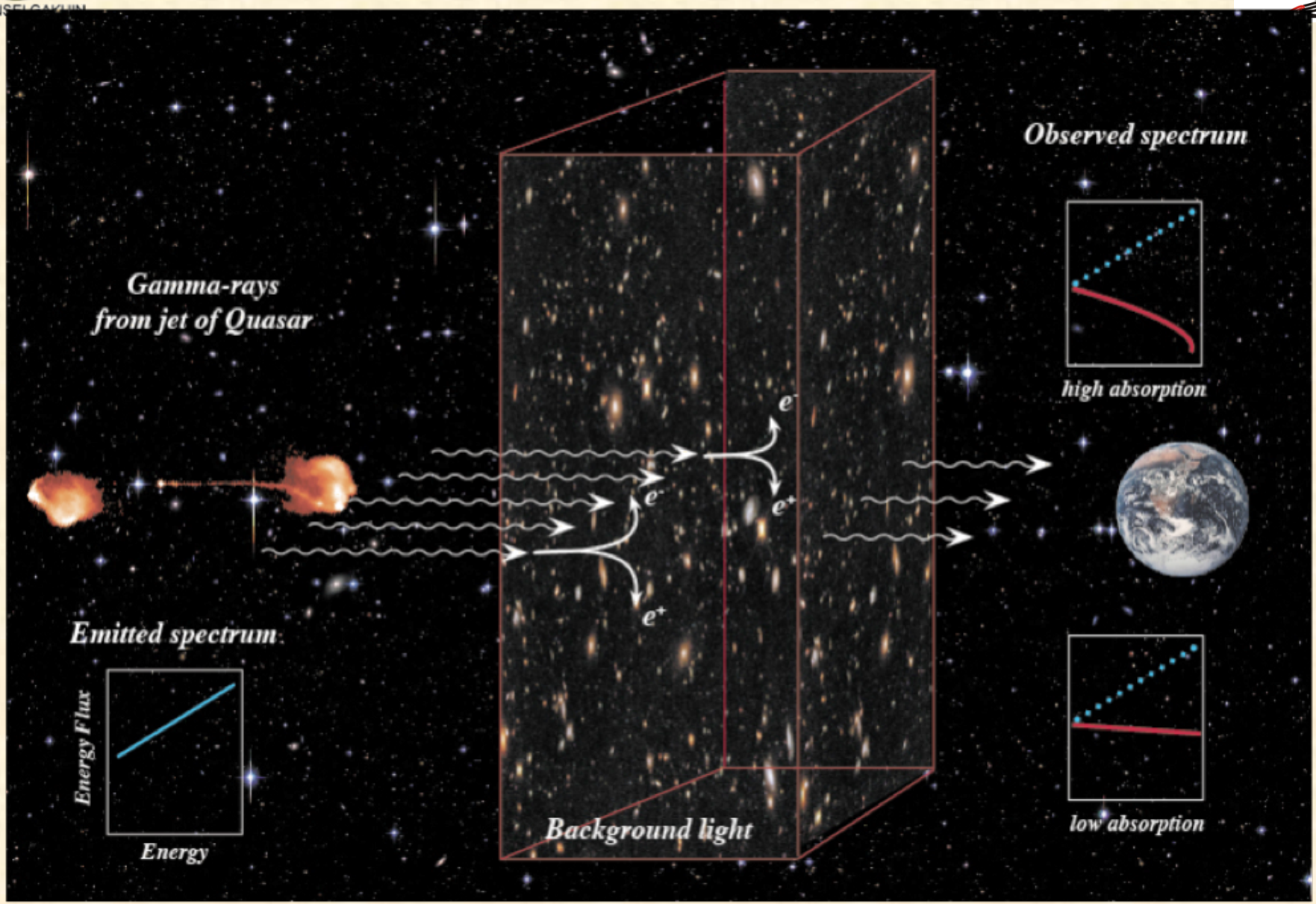


CIBER background result



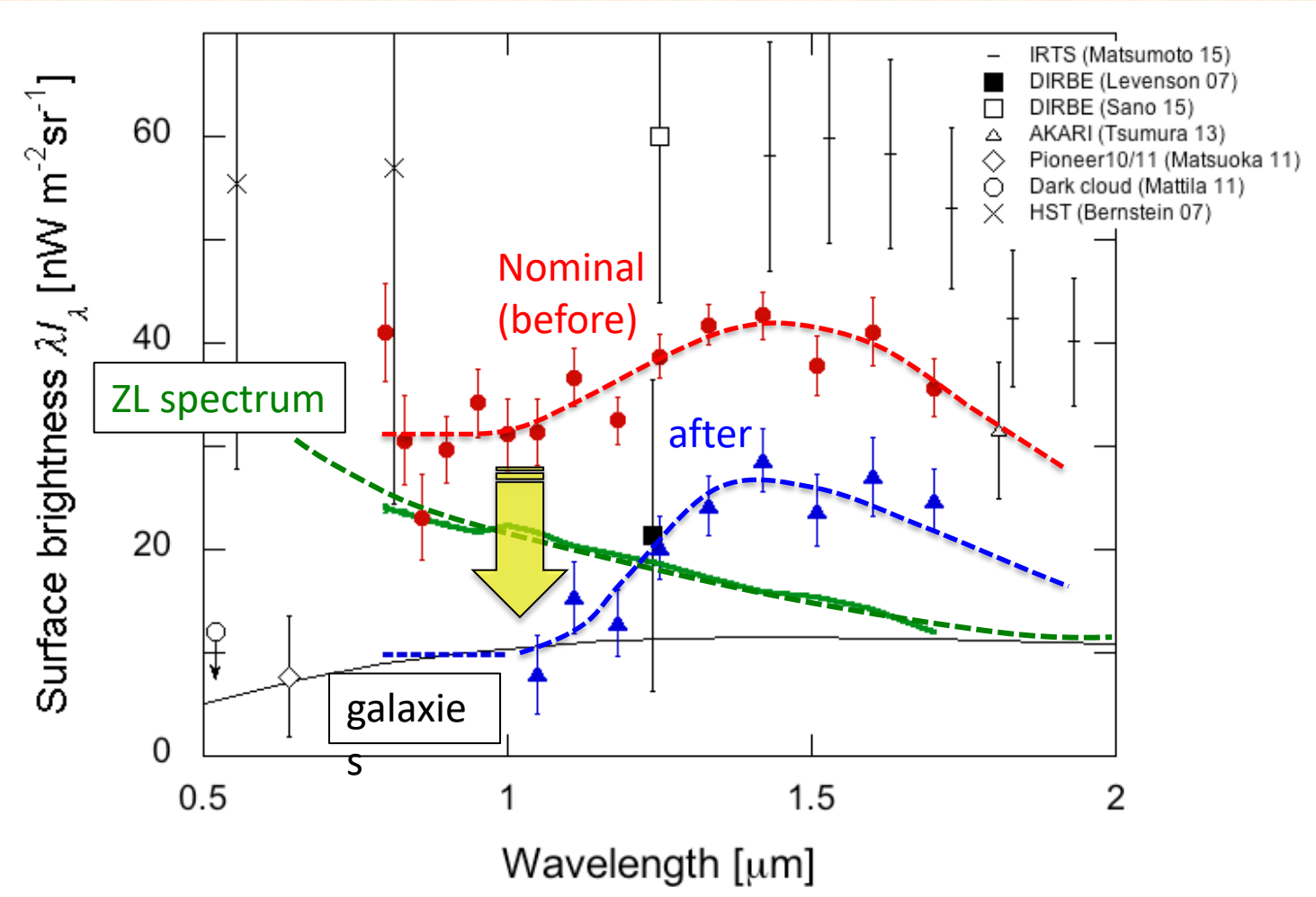
Matsuura et al. 2017

IGM absorption of TeV γ-rays by NIR EBL

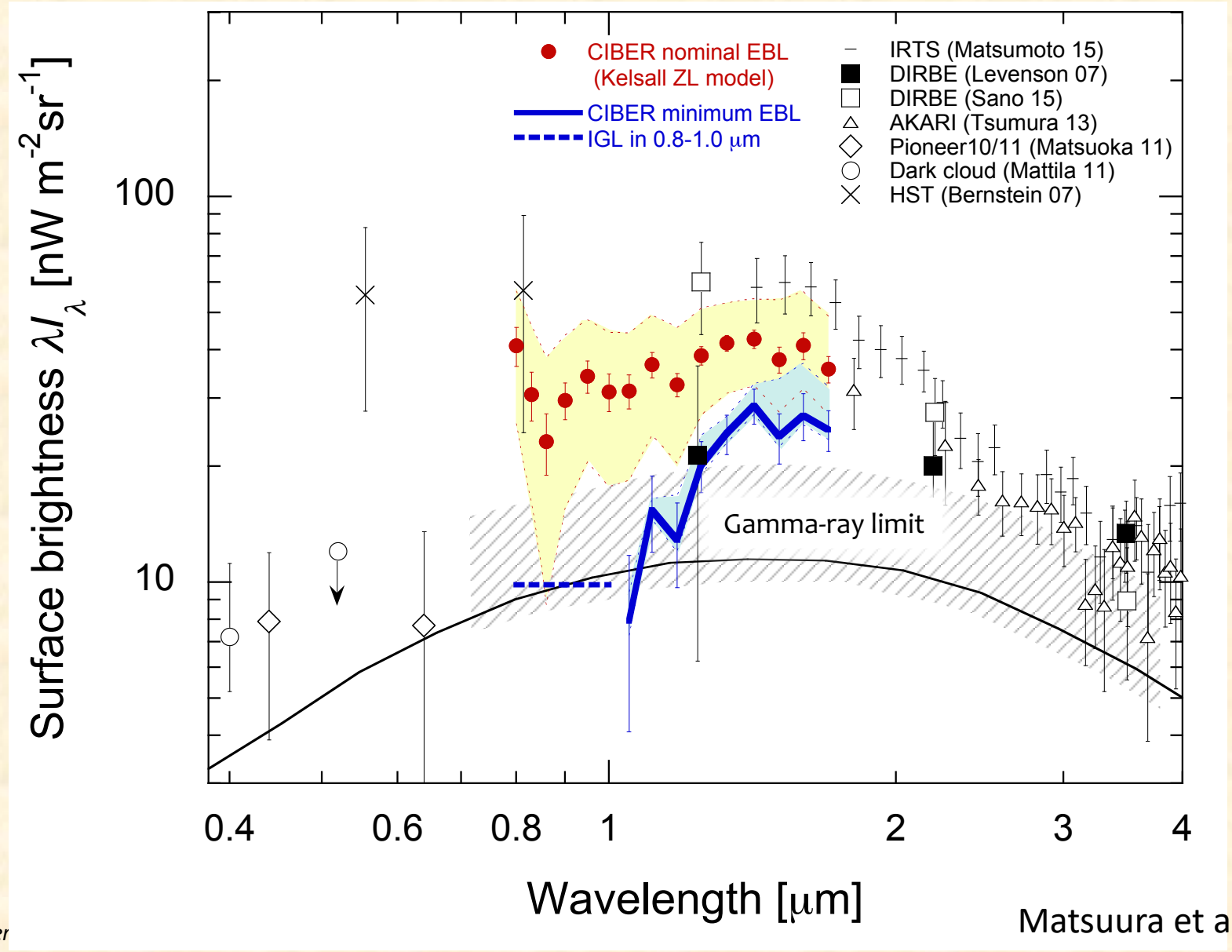


Model-independent minimum CIB

- Subtraction of "Quasi-isotropic" ZL component
- 5% more subtraction than nominal case (Kelsall et al. ZL model)



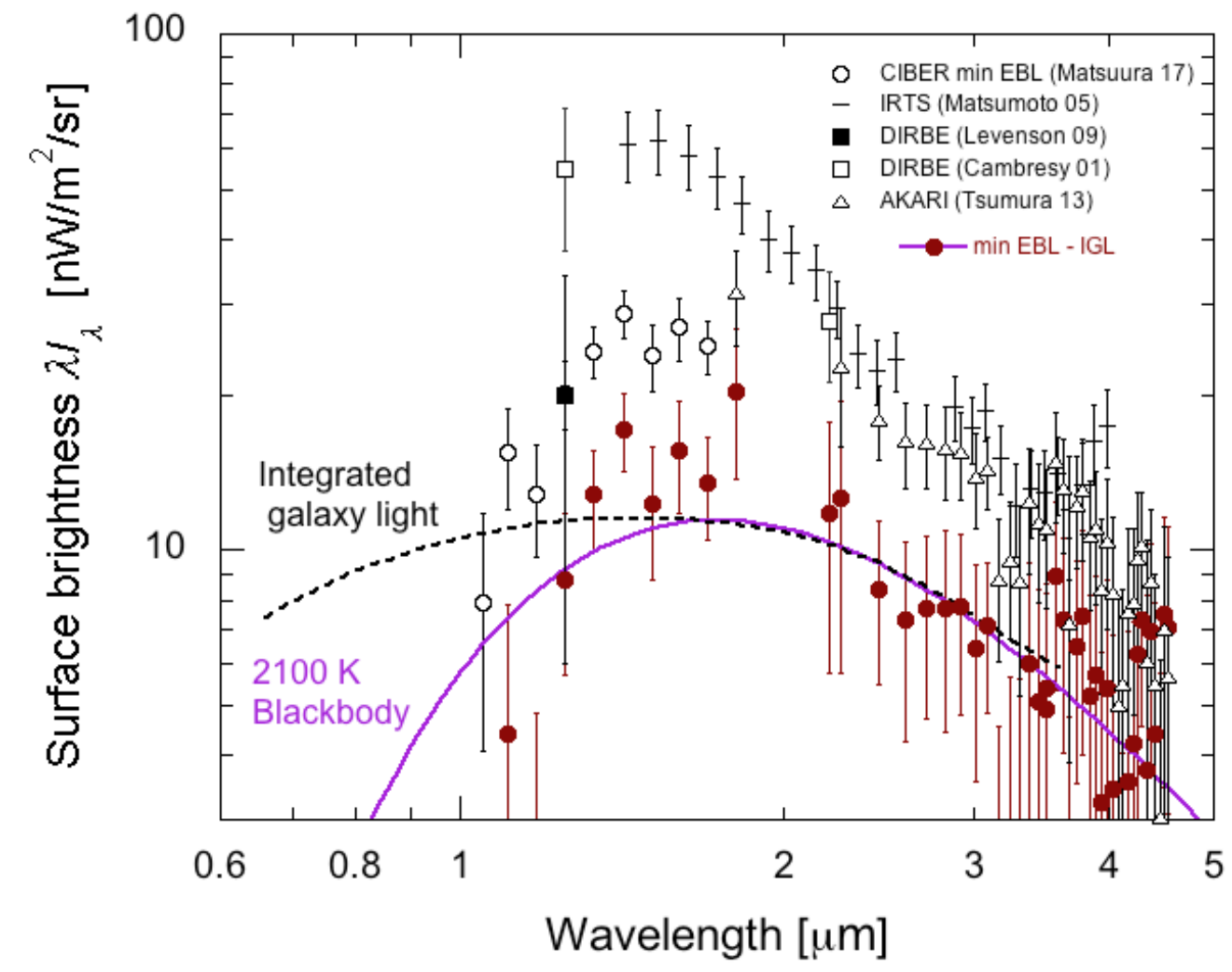
CIBER background result



Matsuura et al. 2017

CIBER – AKARI combined result

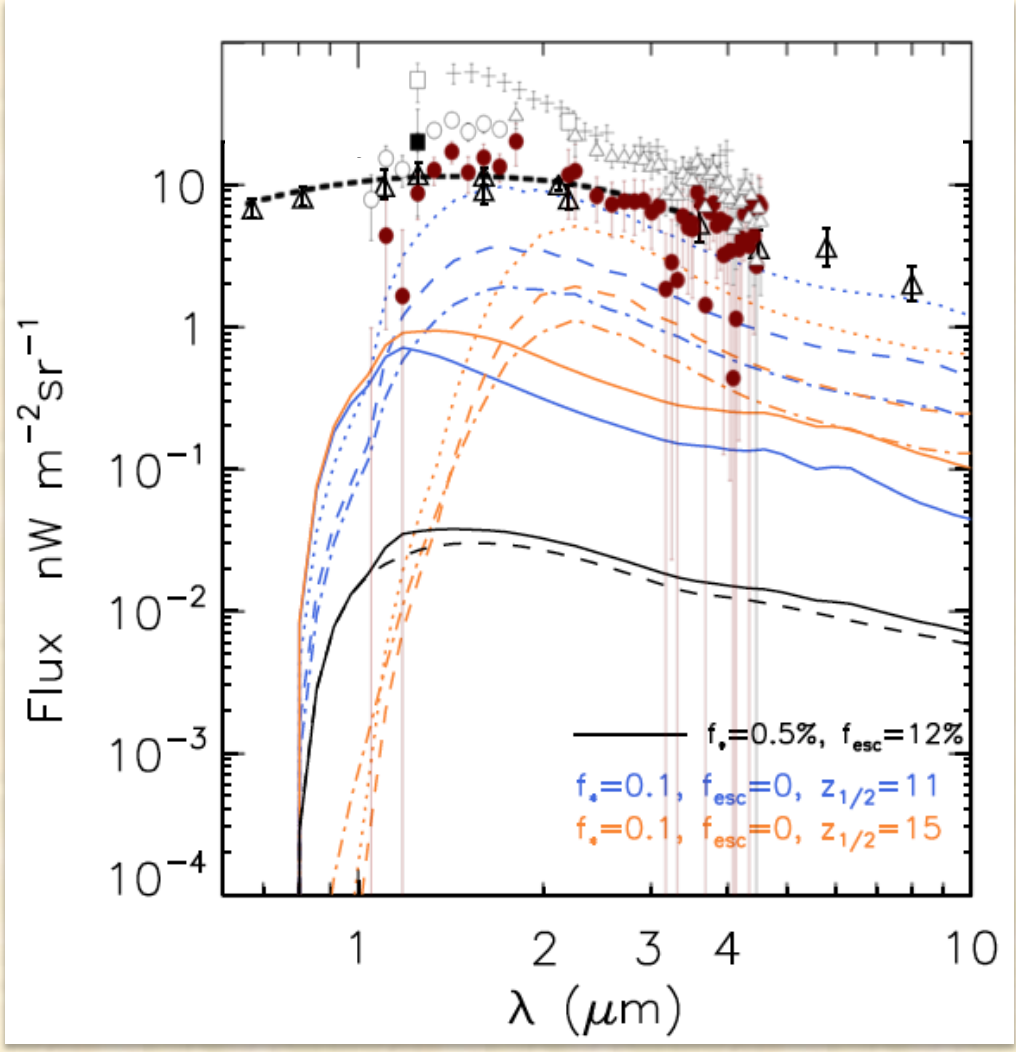
- Minimum CIB result – Integrated galaxy light



First stars ?

- Comparison of the CIBER minimum CIB with models of early stars at z>8
- A maximum model can explain the observed level.
- assumes a Top-heavy IMF, extremely high star-formation efficiency, and deep obscuration within neutral gas, to be consistent with the electron optical depth from WMAP/Planck.

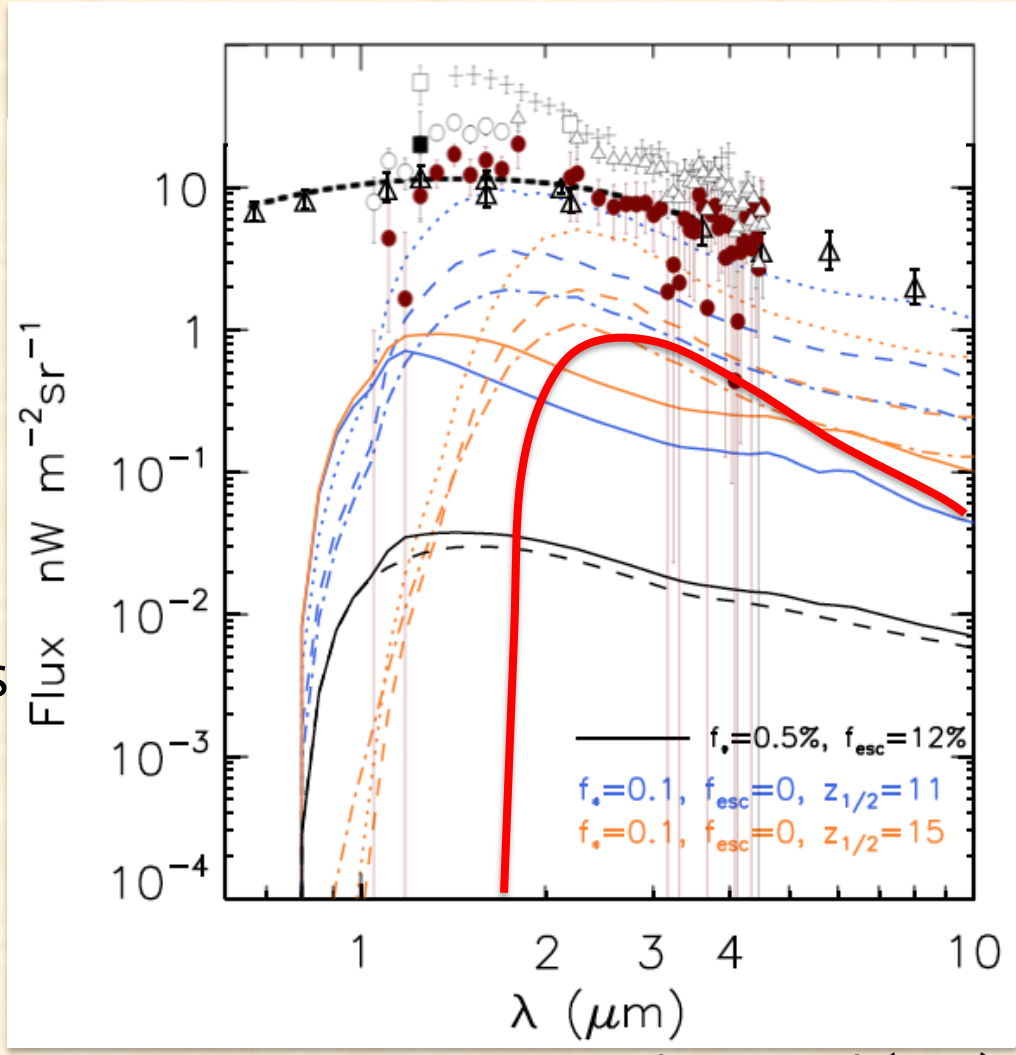
  ($f_* >> 0.1$, $f_{esc} \sim 0$)



Helgason et al. (2016)

Early black holes ?

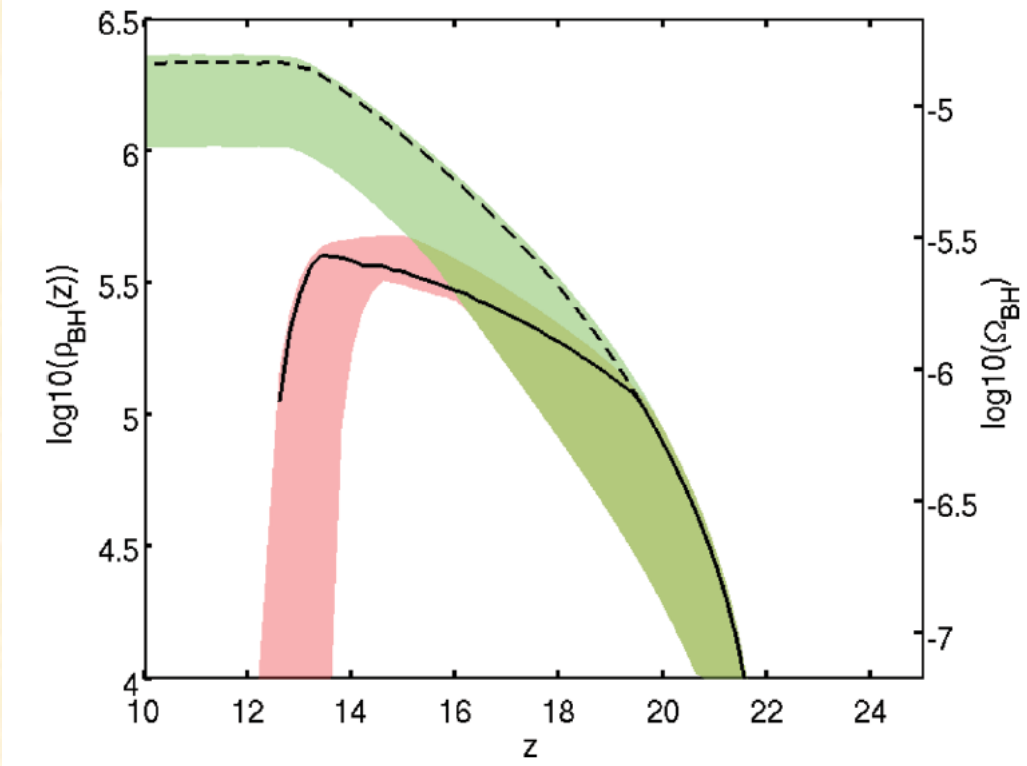
- Direct Collapse Black Hole (DCBH) may solve the problem
- Intermediate mass (< 10^6) BH formed by direct gas collapse
- Radiation efficiency is high enough to account for large part of the background excess
- highly obscured as Compton-thick AGN not to be in conflict with CXB

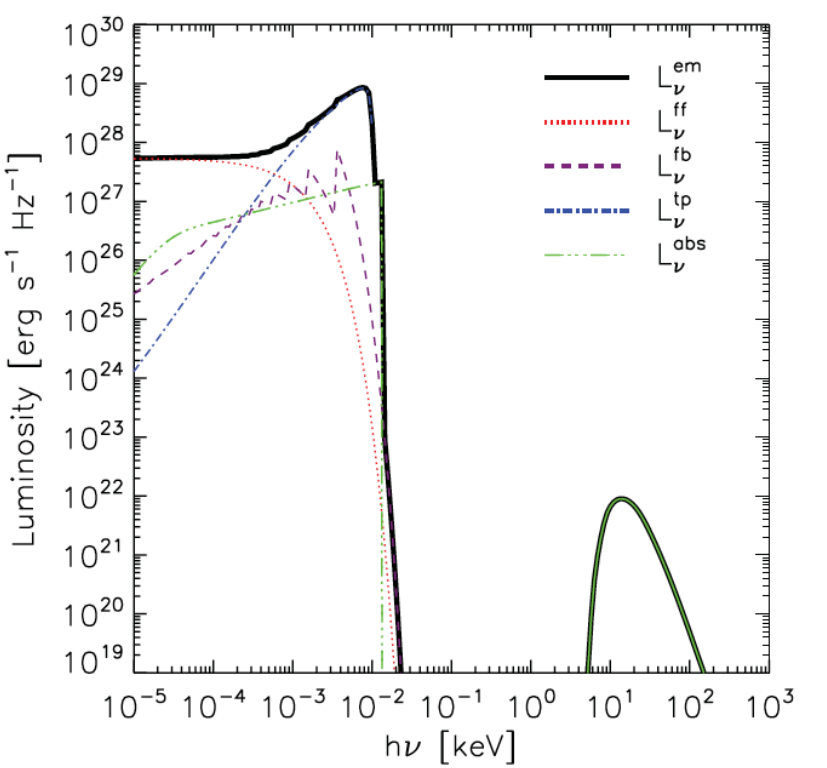


Helgason et al. (2016)

DCBH density & SED

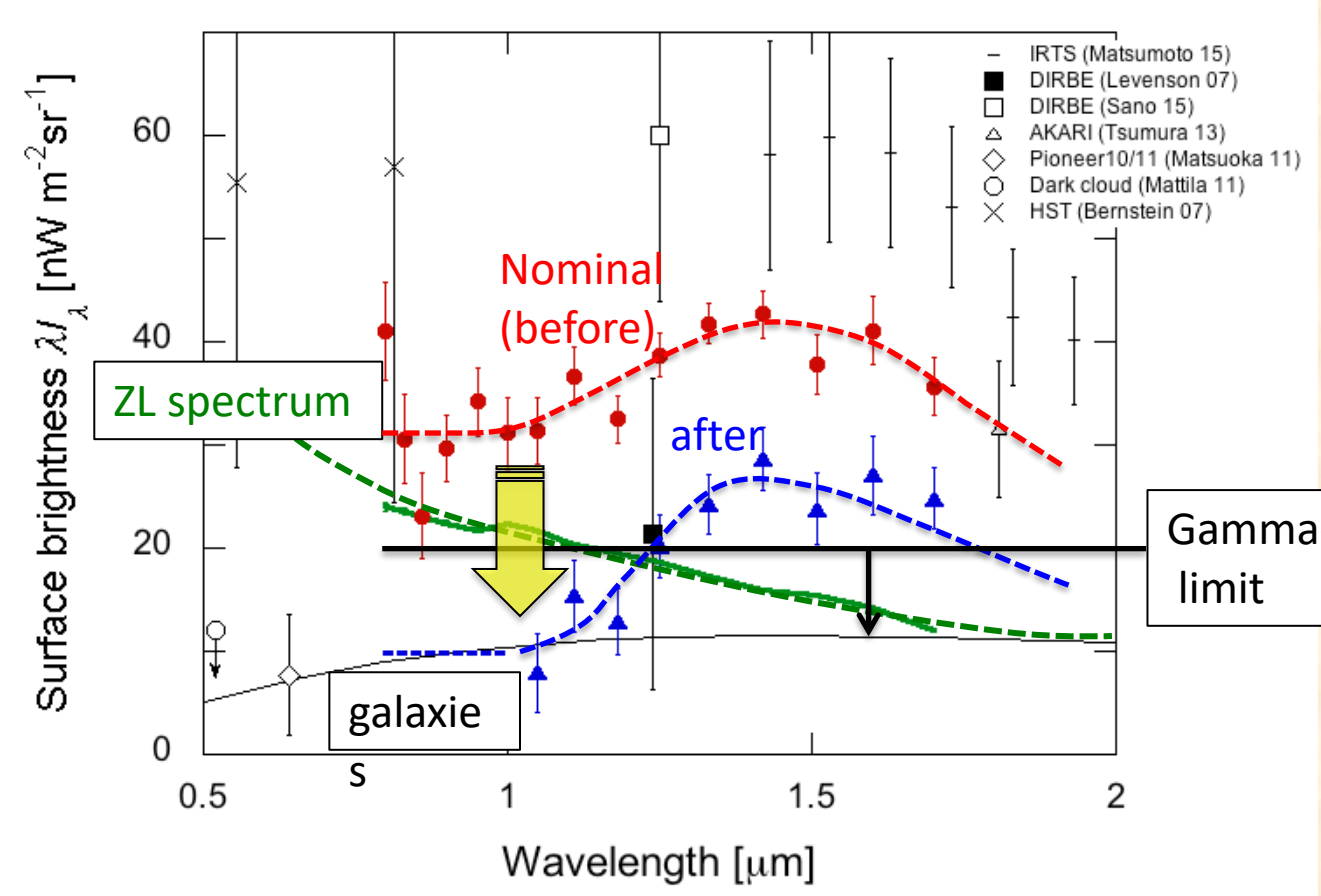
- Cumulative mass density of Direct Collapse Black Holes (DCBH) and the accreting one.
- The accretion is necessary for contributing to CIB.





ZL is still suspect

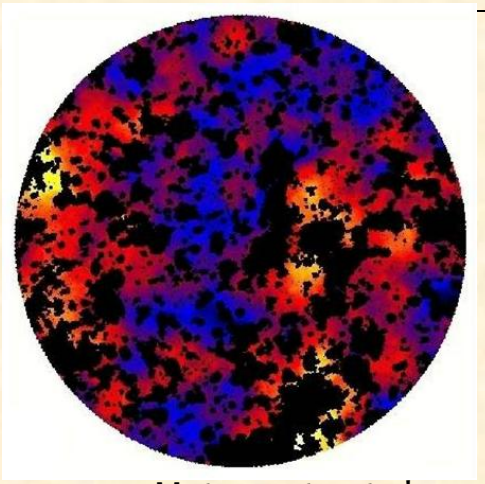
- It might be ZL with isotropic distribution, though the spectrum should be extraordinary, i.e., ZL should have similar spectral shape to the nominal.



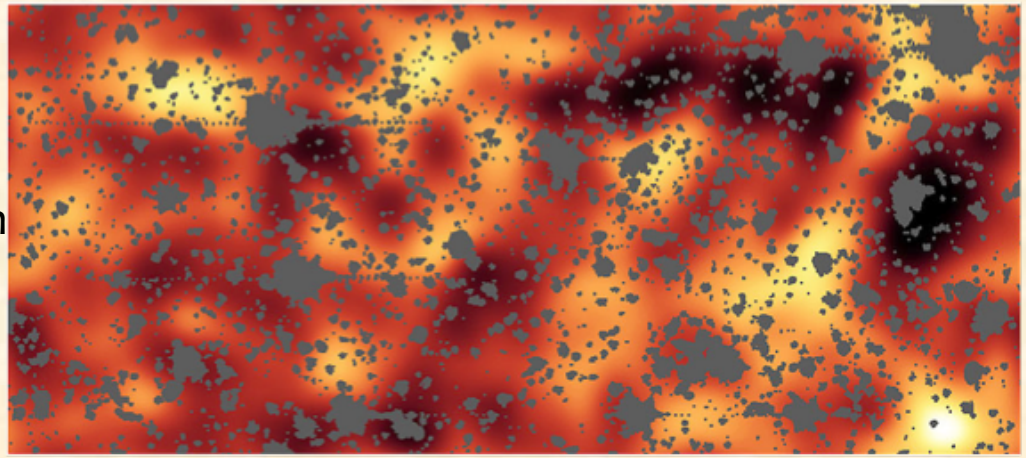
CIB Fluctuation measurements

AKARI 2.4μm

Spitzer 3.6μm

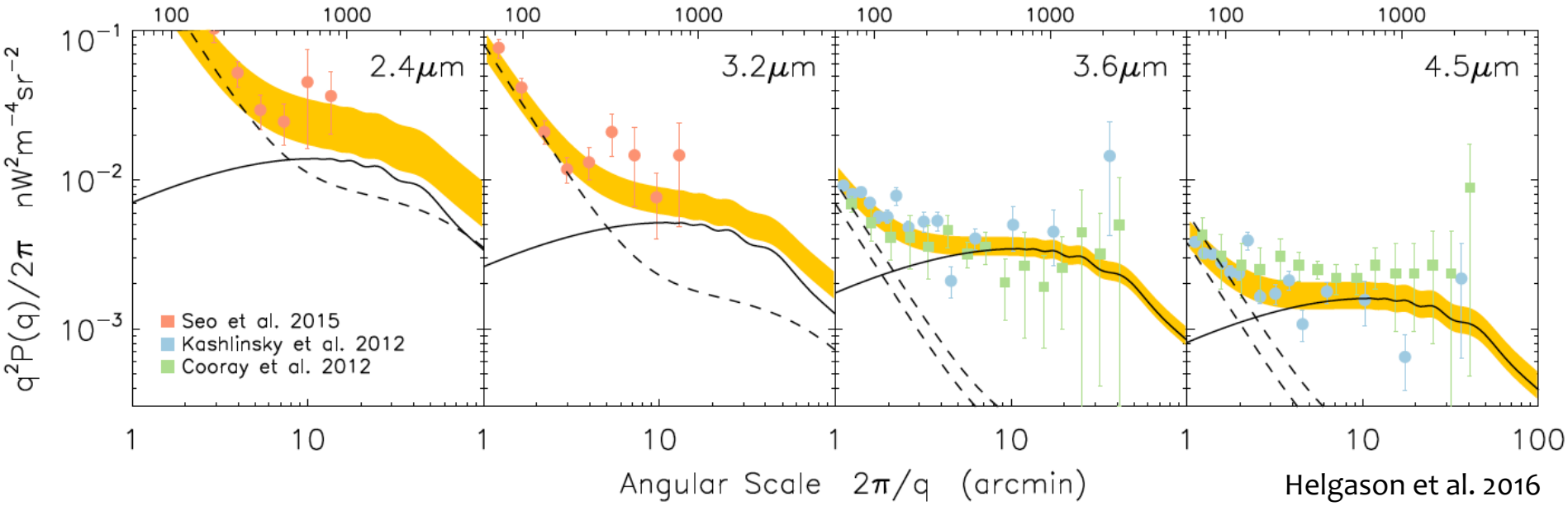


10 arcmin



Matsumoto et al. 2011

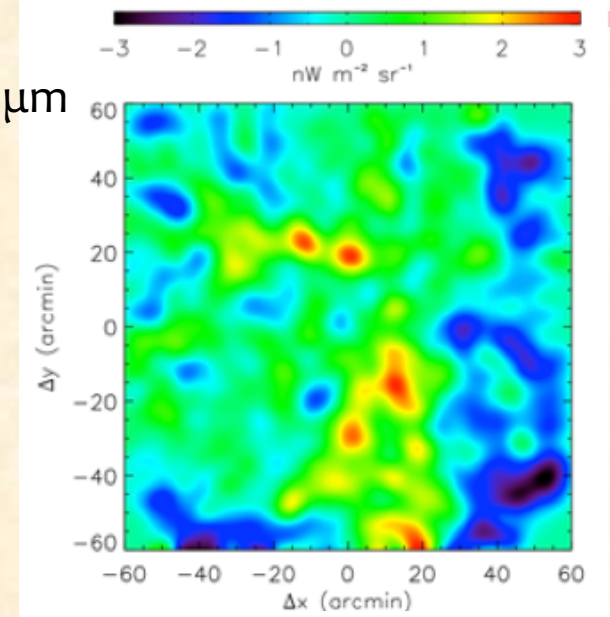
Kashlinsky et al. 2005, 2007



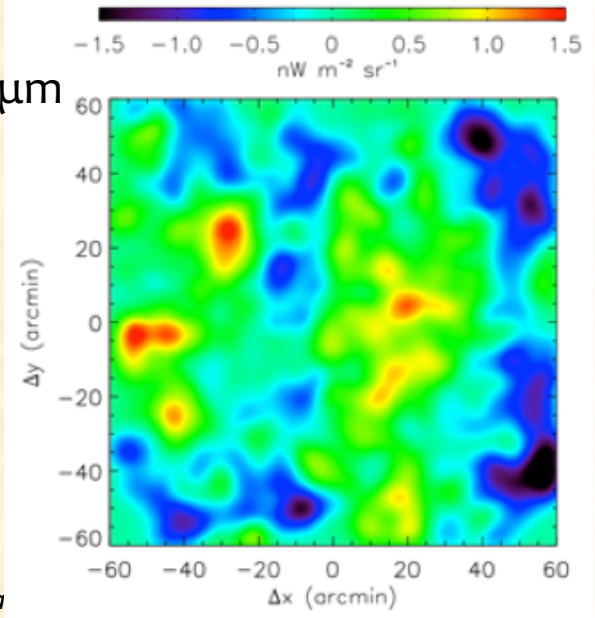
Helgason et al. 2016

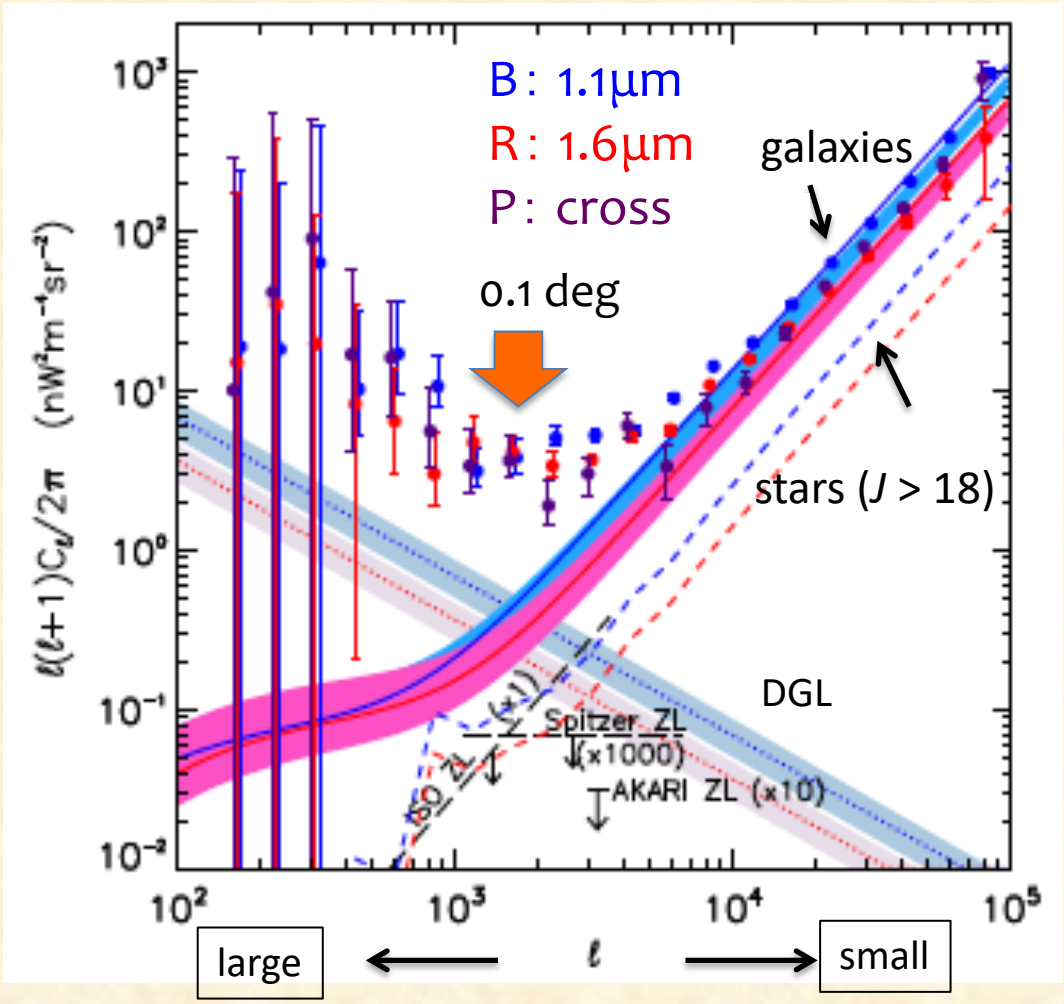
CIBER observed fluctuation power

1.1μm



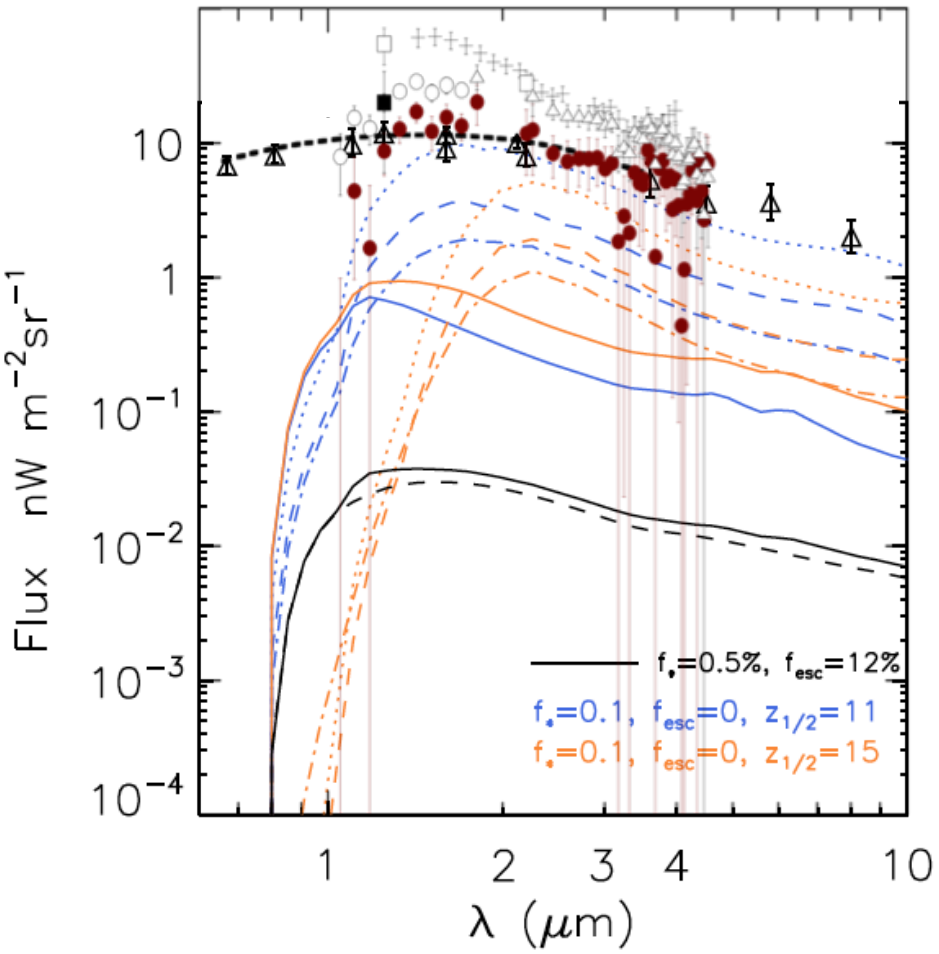
1.6μm



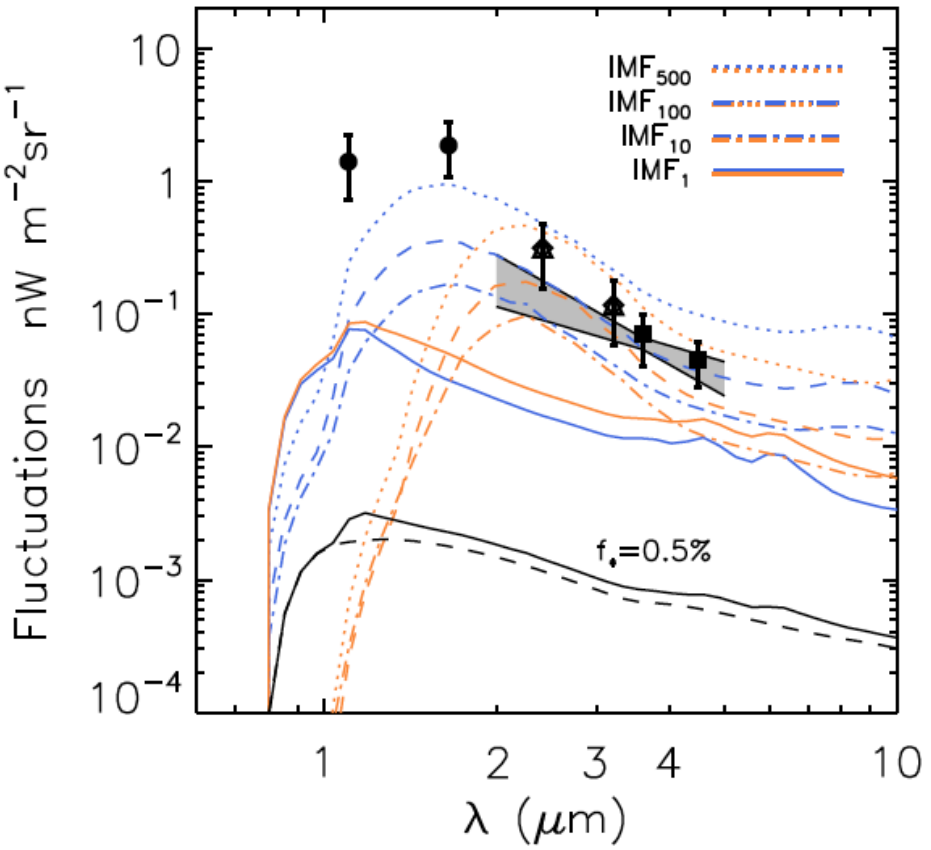


First stars ?

- Comparison of the lower limit from CIBER with a model of early stars at z>8

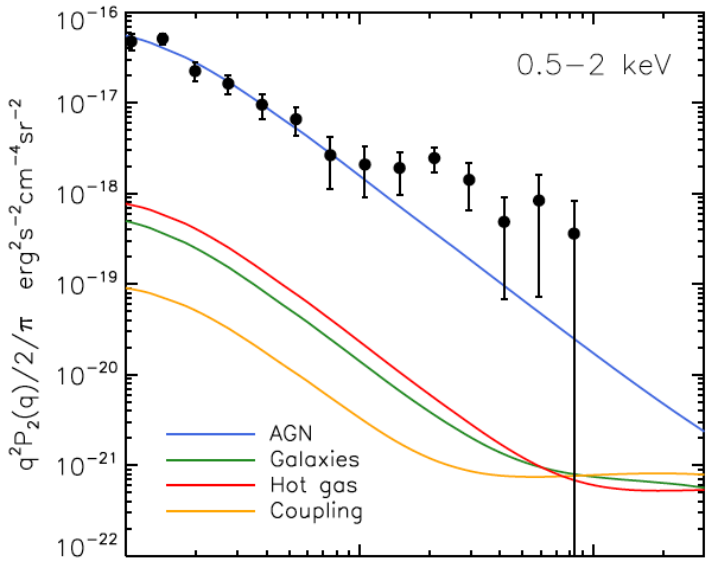


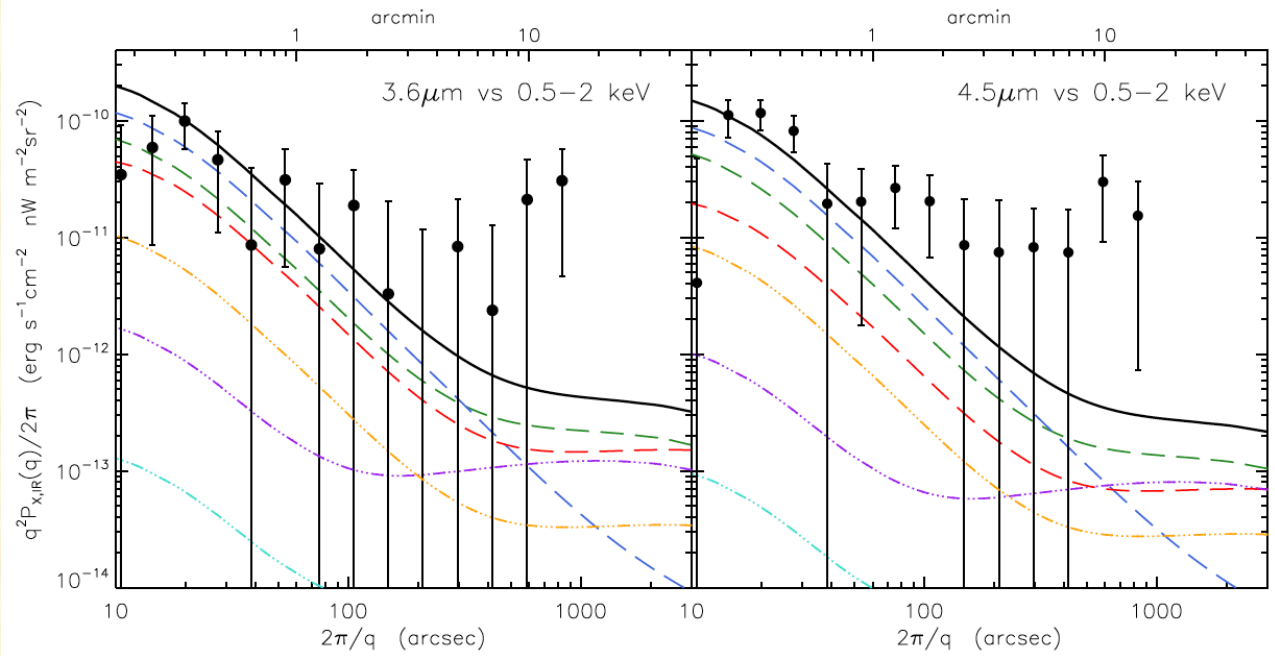
Helgason et al. (2016)



Early black holes ?

- CIB-CXB cross-power spectra show that small-scale CIB fluctuations are associated with AGNs.
- Large-scale clustering of CXB may contribute to CIB fluctuations.

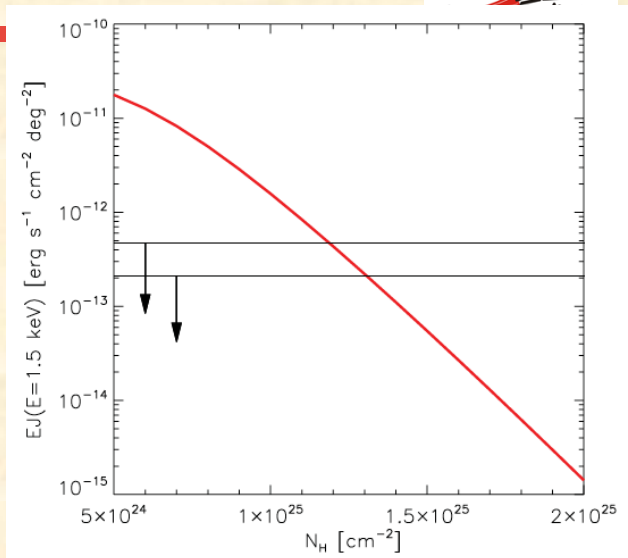


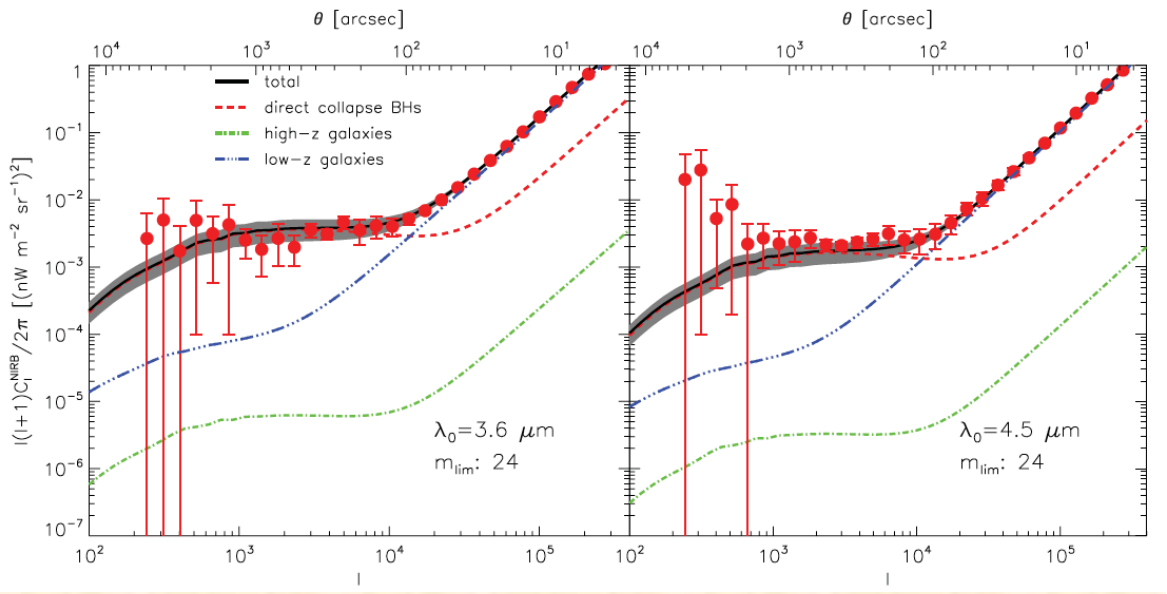


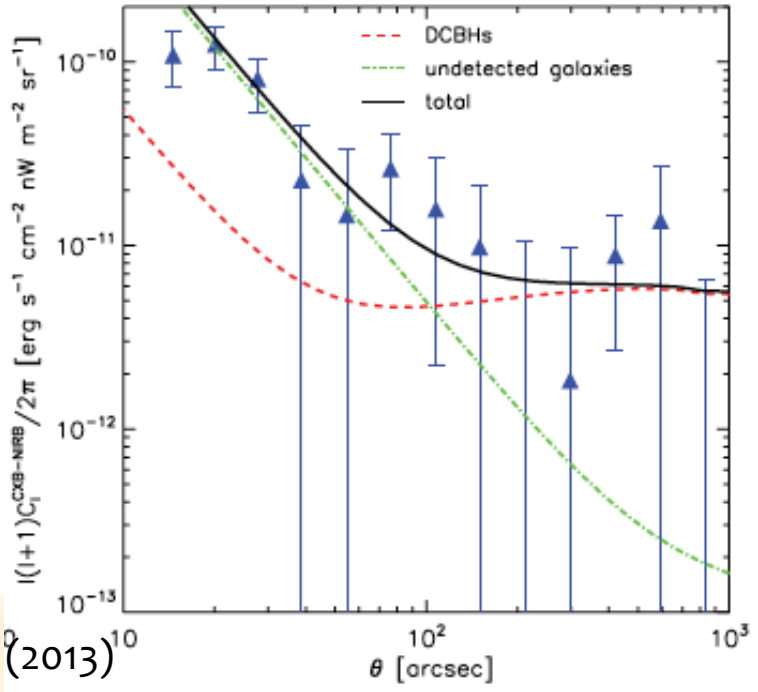
Helgason et al. (2014, 2016)

Early black holes ?

- DCBH model can explain both CIB and CXB fluctuations.
- constrained by CXB intensity
- N_H > 10^25 cm^{-2} is required



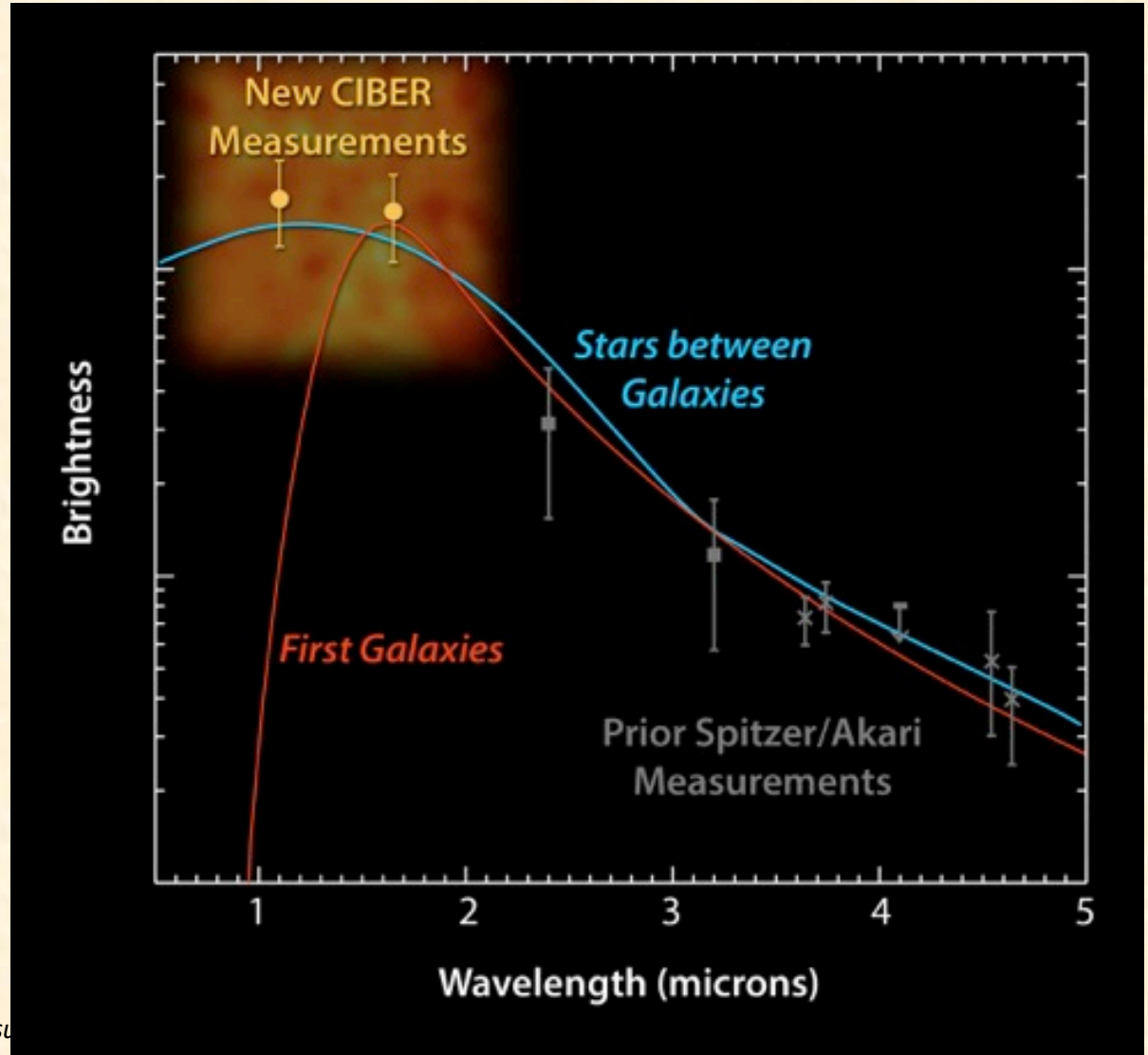


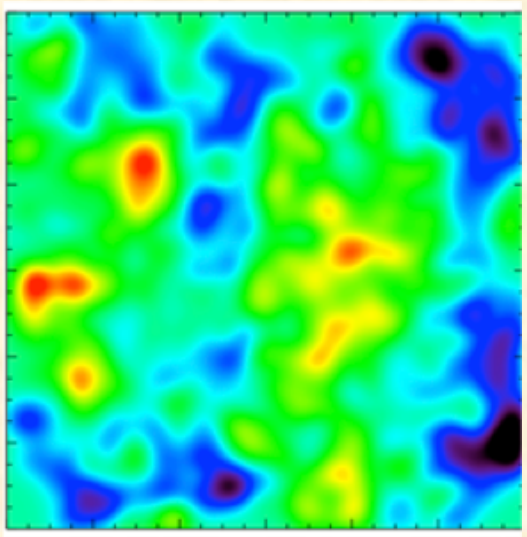


Yue et al. (2013)

SED of CIB fluctuations

Intrahalo light(IHL) of nearby galaxies rather than high-z objects ?

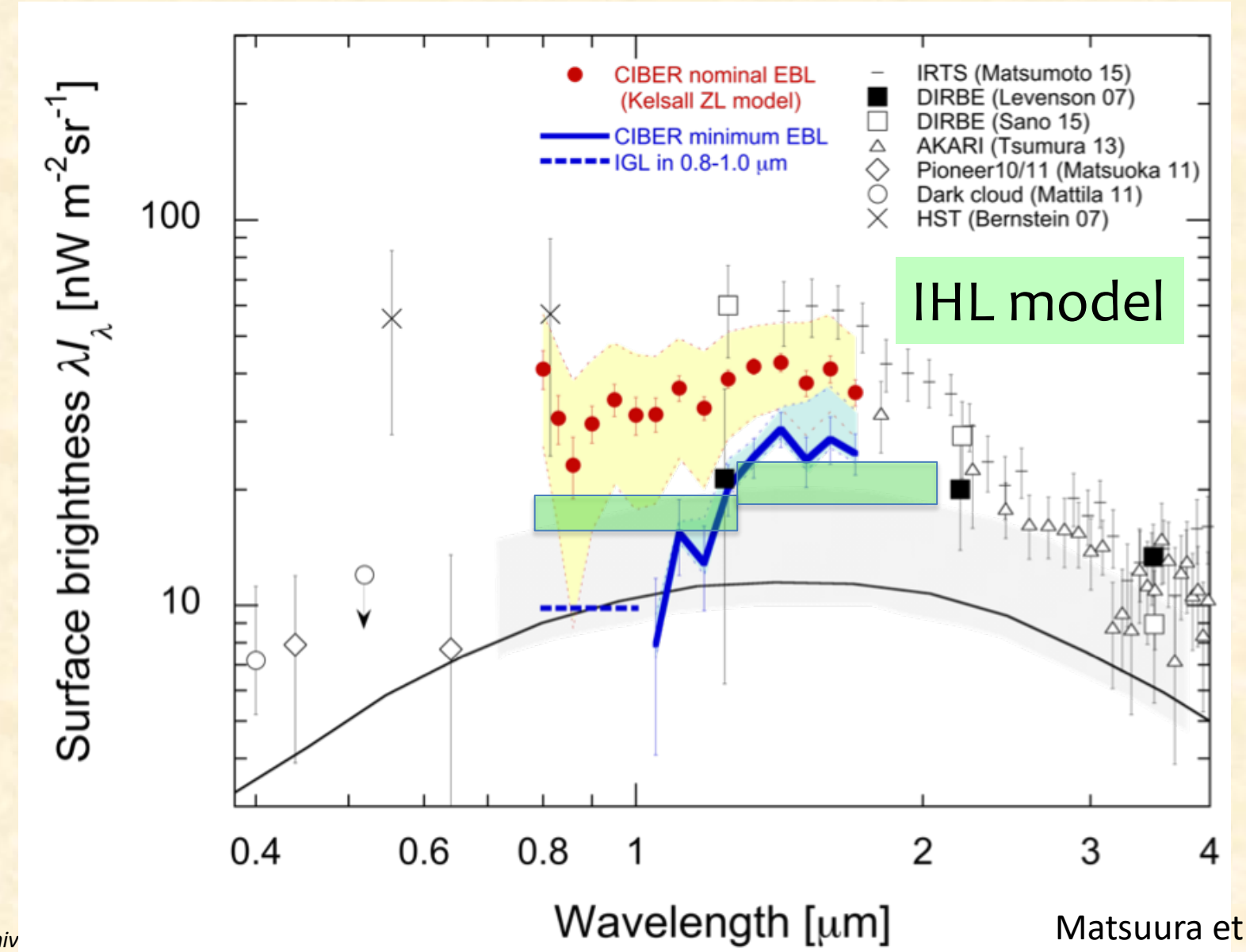




CIBER Imager FoV 2 degrees

Zemcov *et al*. *Science* (2014)

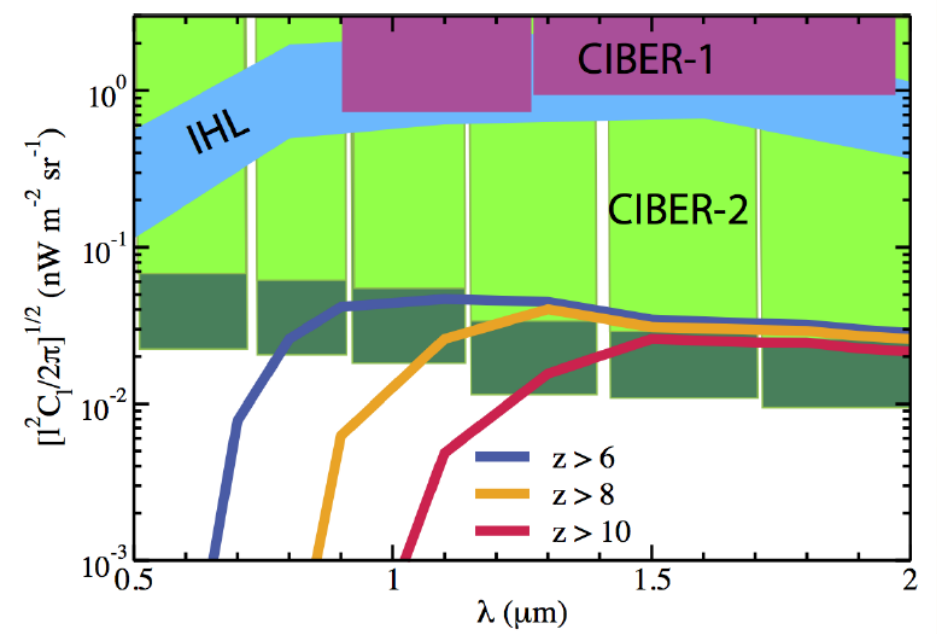
IHL model fits mean intensity ?

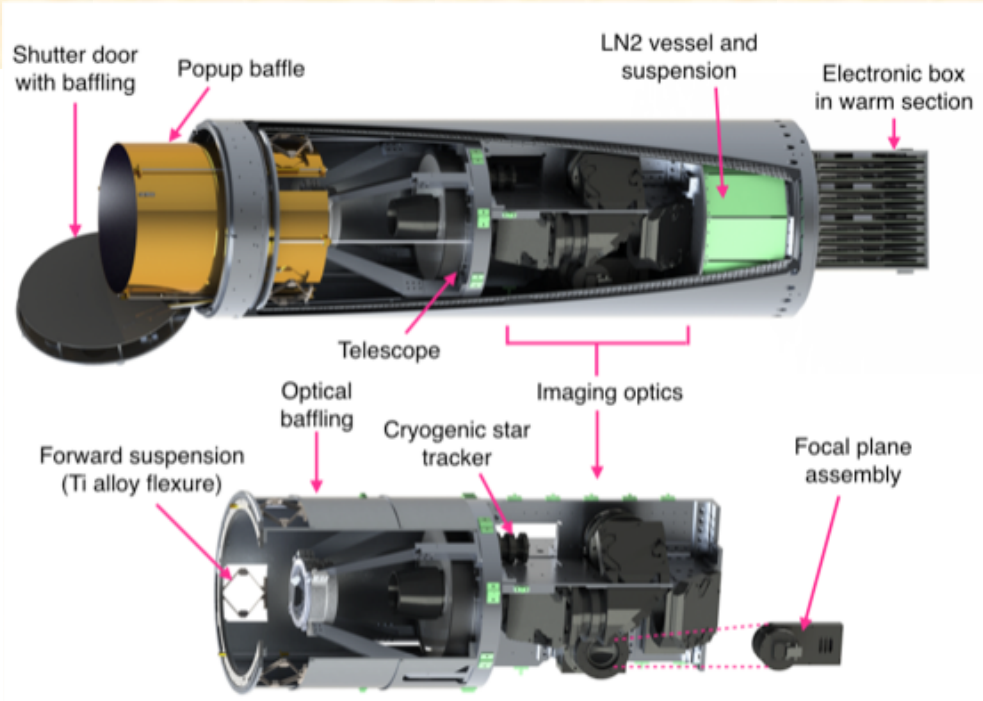


Matsuura et al. 2017

CIBER-2 experiment

- >10 times better sensitivity than CIBER
- Measuring the optical background for accurate ZL sub
- Measuring the spatial fluctuation in 6 wave-bands
- Plan to launch in 2018 !

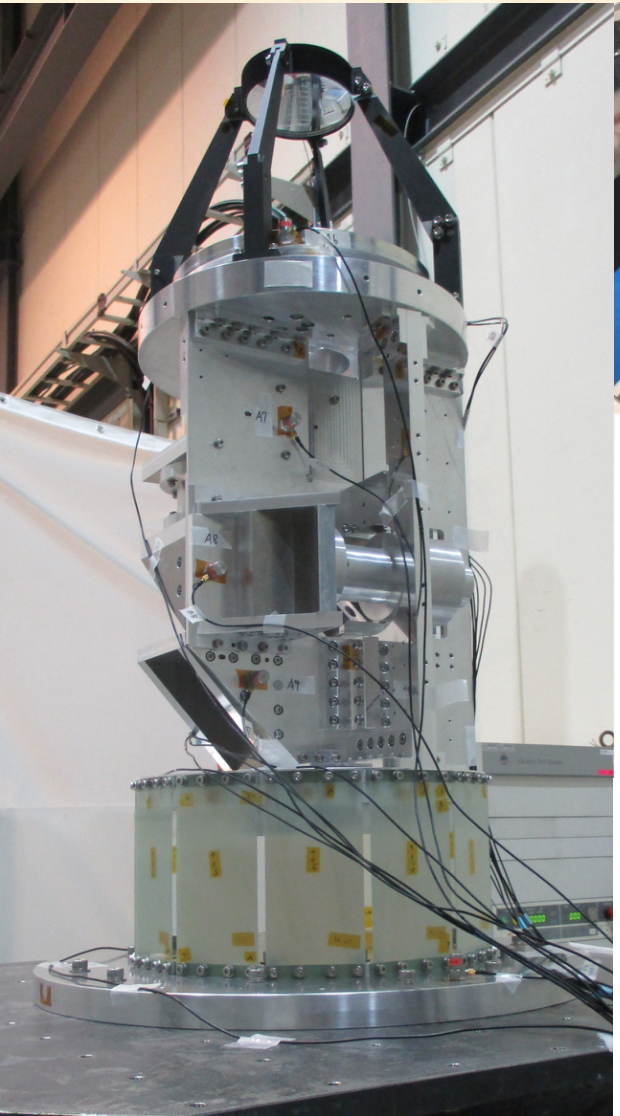


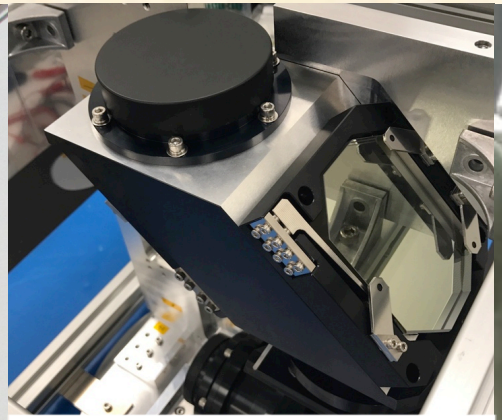


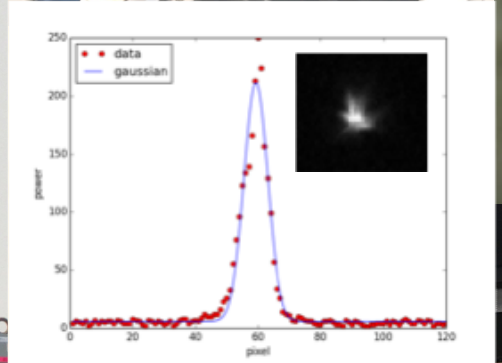
CIBER-2 payload model

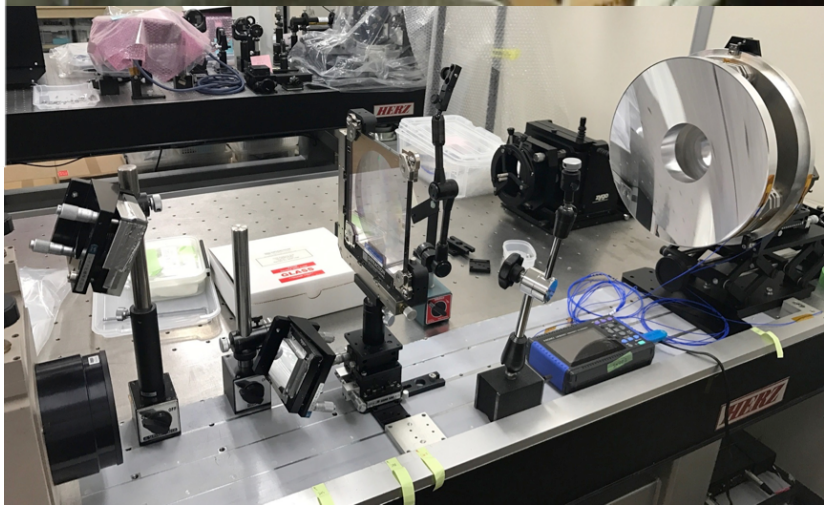
Hardware work on CB2 in progress

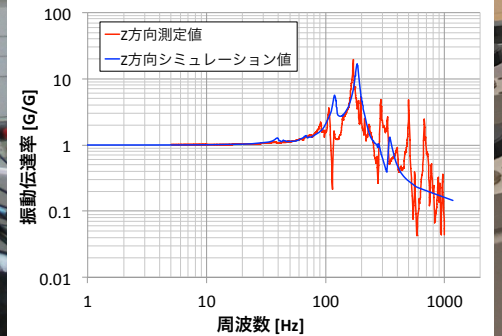
- Optics fabrication and testing





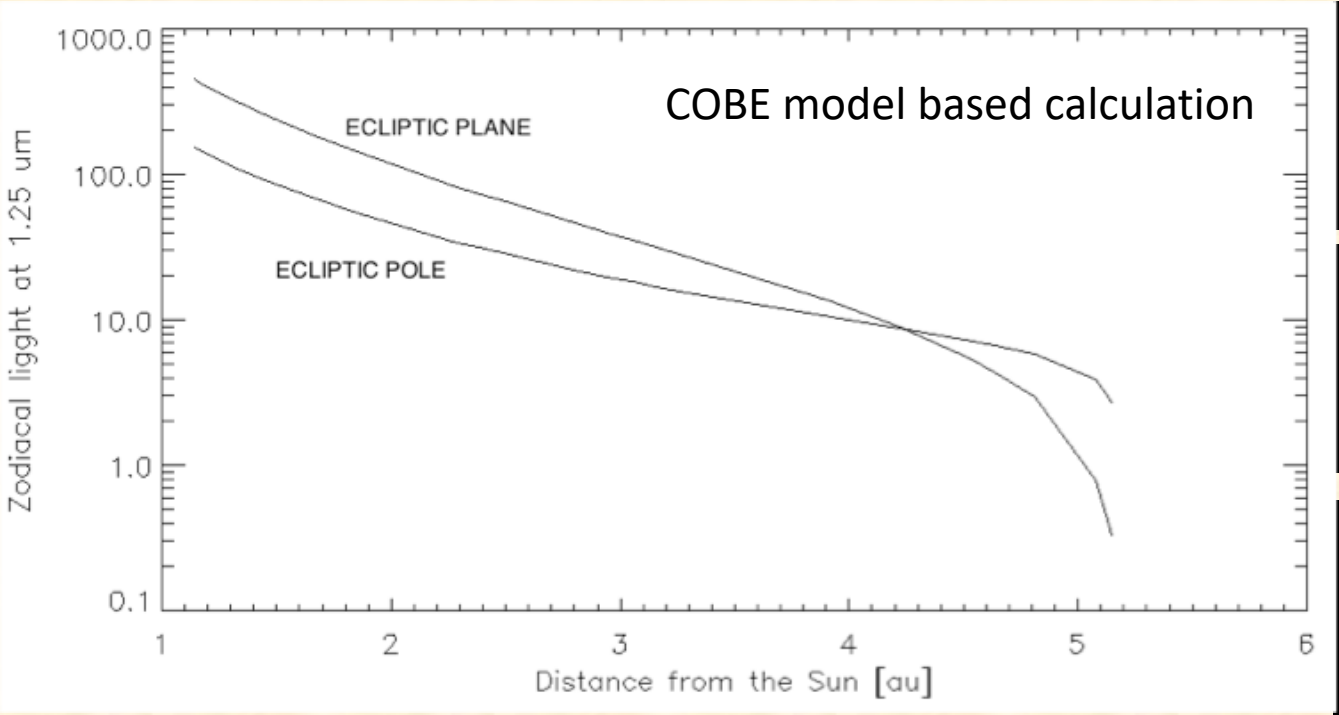


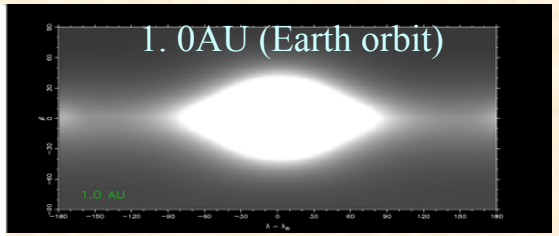


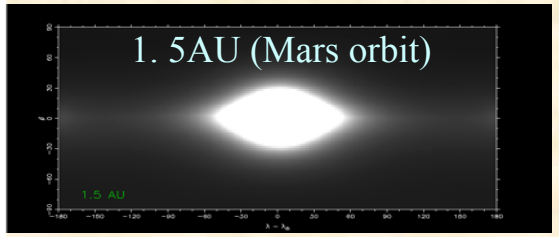


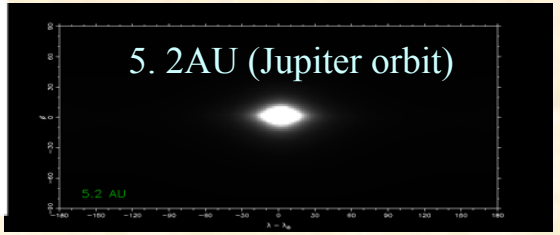
ZL decreases with heliocentric distance

- Best solution to mitigate ZL is interplanetary mission
- If the model is true, we have chance to see naked extragalactic background with no ZL contamination.





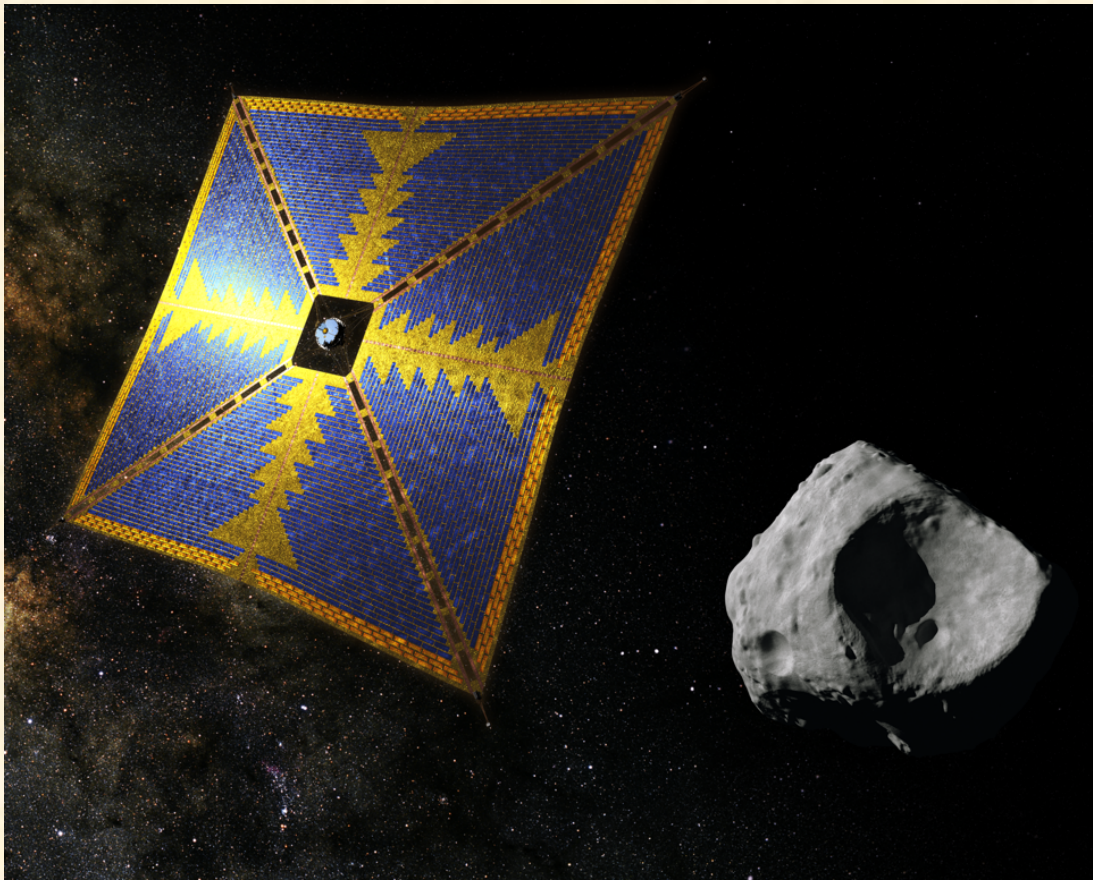




OKEANOS - Solar Power Sail

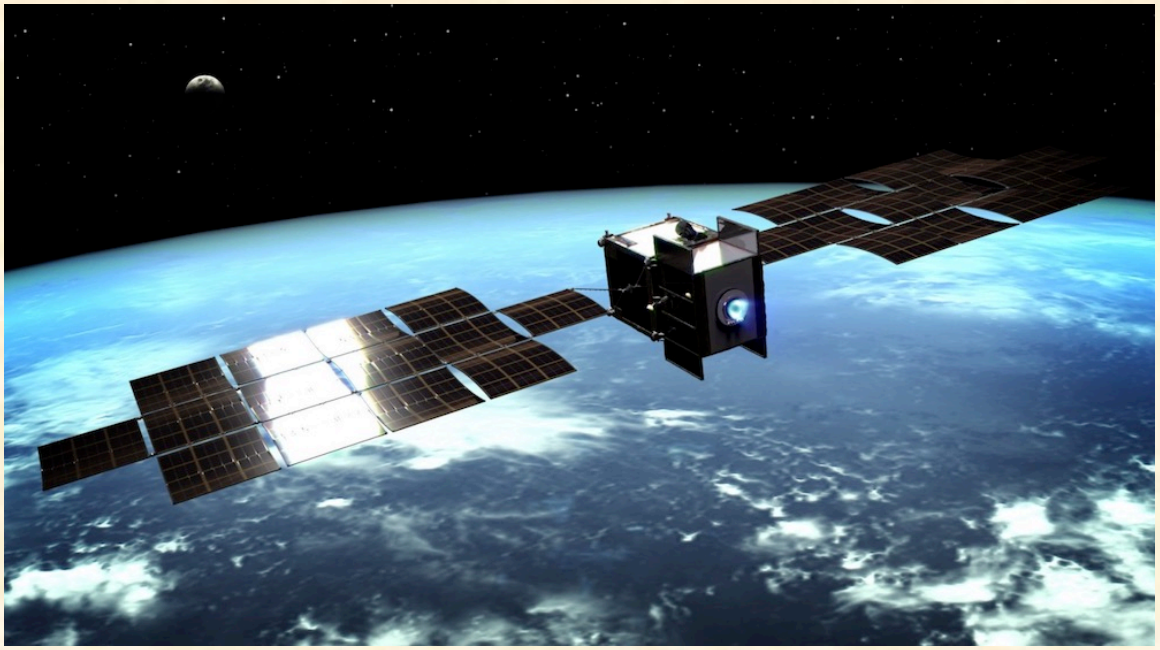
OKEANOS (The Oversized Kite-craft for Exploration and Astronautics in the Outer Solar System)

- Mission to explore Jupiter-Trojan asteroid
- Proposed as a candidate of ISAS M-class and on the way to be real project
- We plan to measure CIB in cruising phase with a science instrument (EXZIT: Exo-Zodiacal Infrared Telescope).
  - Passively cooled 10cm telescope

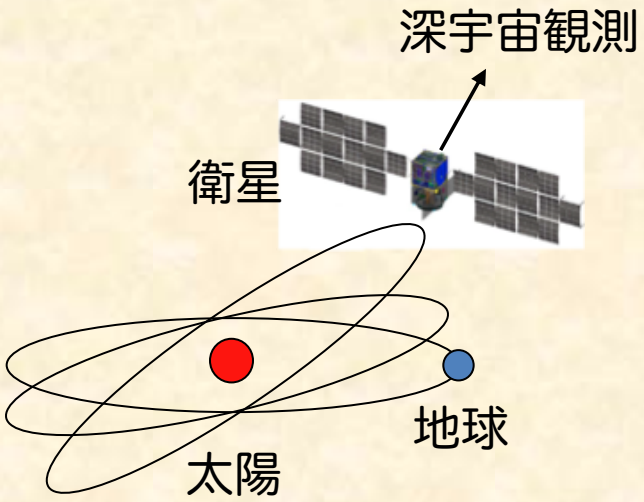


DESTINY-Z

- ISAS小型衛星計画 DESTINY+　小惑星Phaeton探査機
- 同探査機システムを黄道面外へ (DESTINY-Z !)
  - ダスト密度が指数的に低下
  - 地球スイングバイによる傾斜角増大
  - 黄道面外~1AU軌道



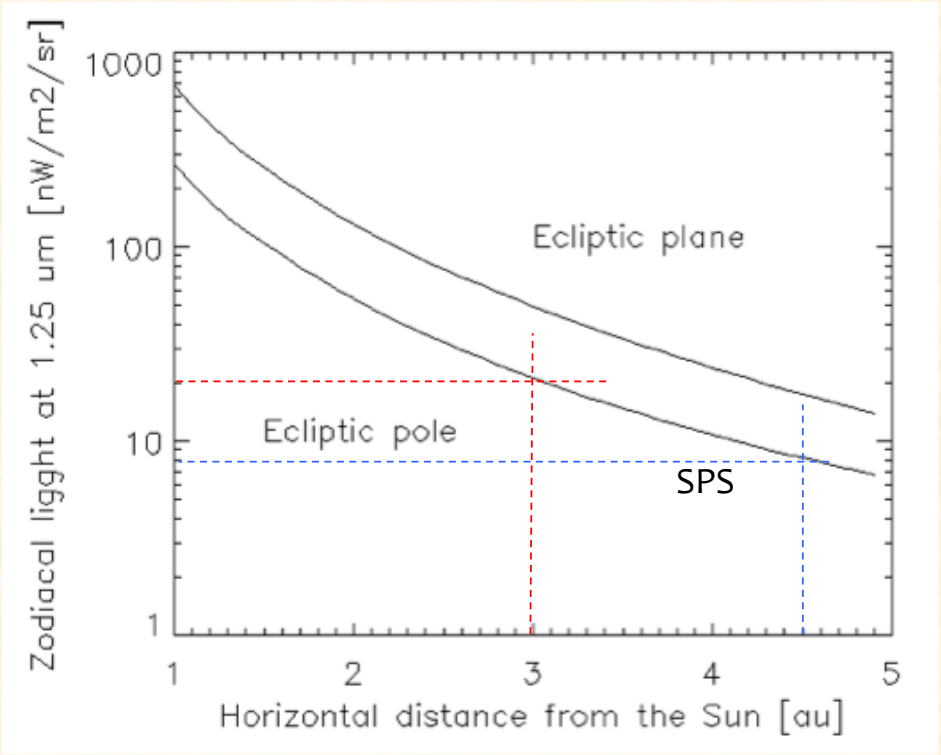
高軌道傾斜角　黄道面脱出

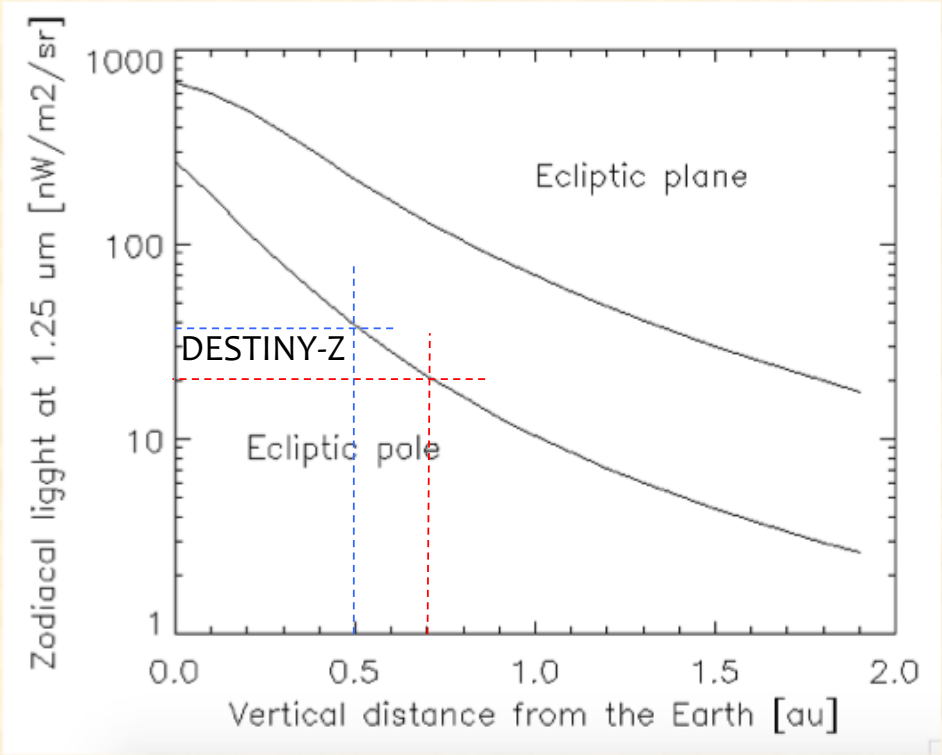


黄道光の位置変化

惑星間ダスト分布モデルからの予測

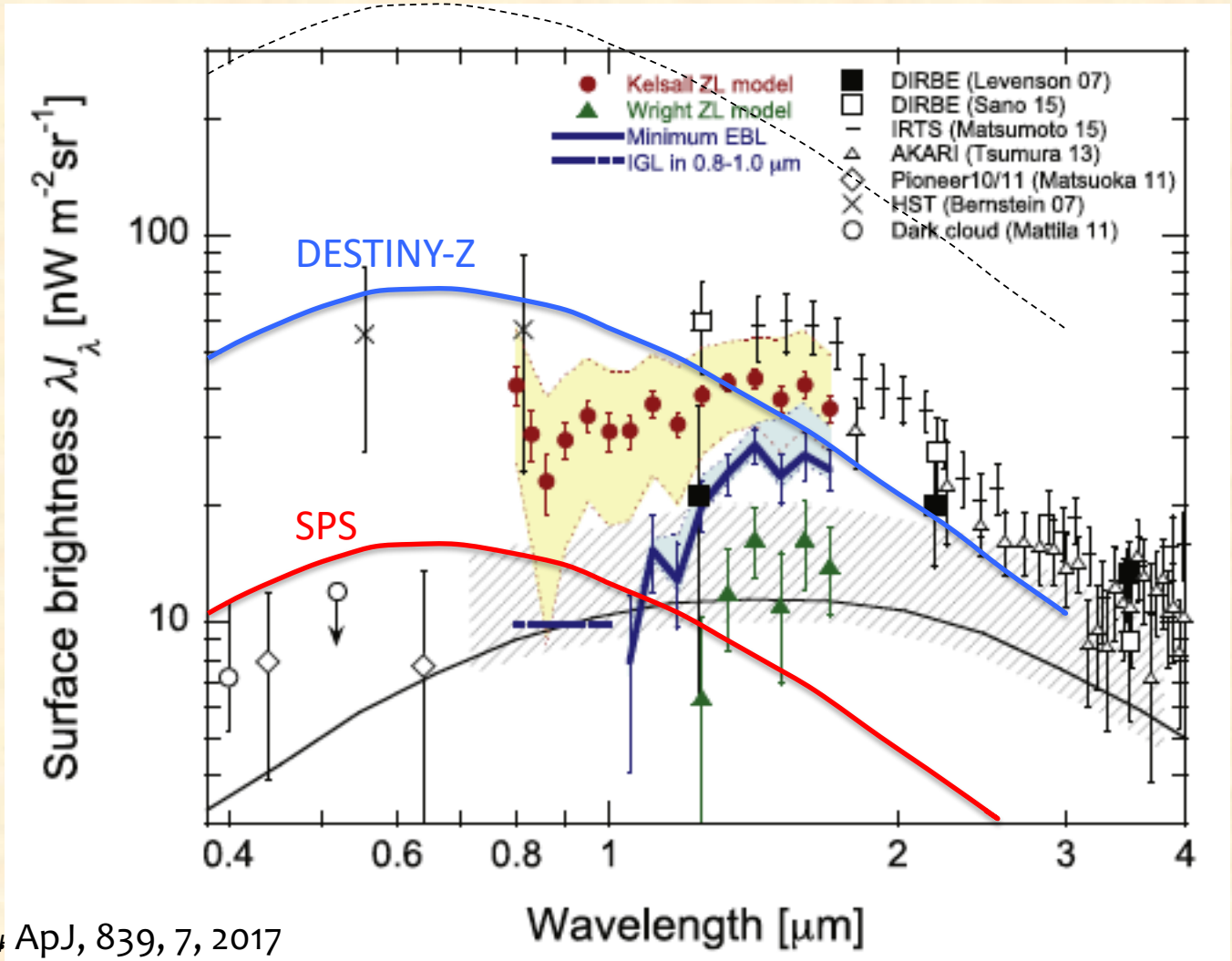
- 小惑星帯(3AU)や黄道面外(0.7AU)では10分の１以下に





EXZIT – 惑星間ダスト雲からの脱出

EXZITでは地球軌道と比べて，黄道光差引きによる
系統誤差の著しい低減が期待される.



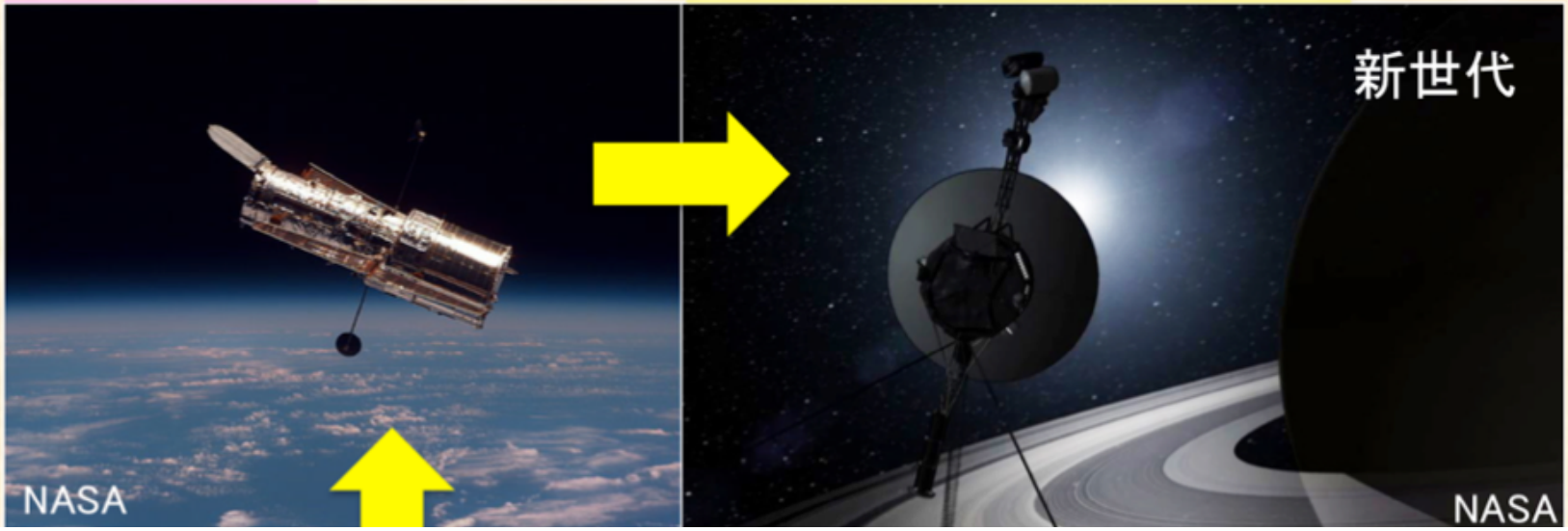
Matsuura et al. ApJ, 839, 7, 2017

Interplanetary Space Telescope (IPST)

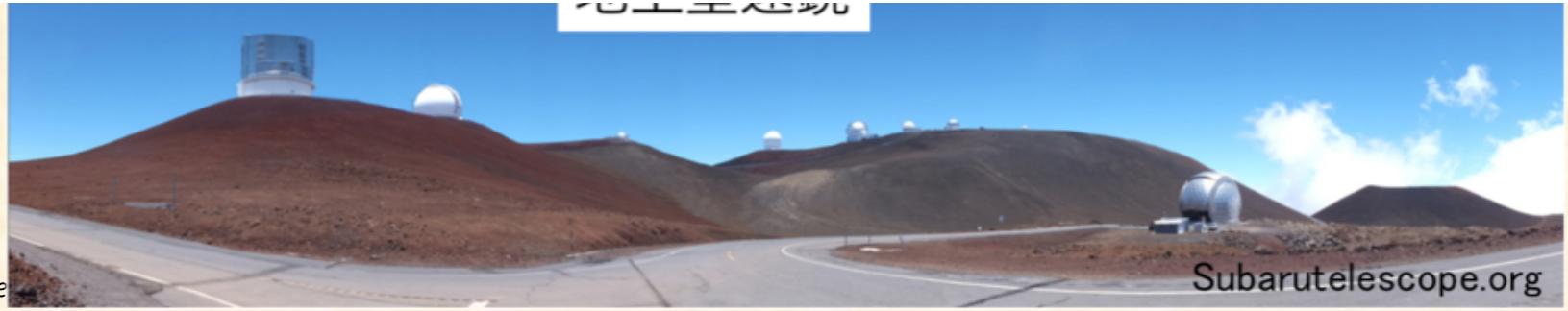
新たな望遠鏡サイトの開拓

宇宙望遠鏡

惑星間空間望遠鏡 (IPST)



ご清聴ありがとうございました。



Summary

- CIBER measured CIB mean intensity after foreground subtraction based on the COBE ZL model is consistent with previous satellite results.
- We derived a ZL model-independent CIB lower limit from CIBER data, and it is marginally consistent with the gamma-ray limit.
- First star and DCBH models may explain the derived CIB lower limit and observed CIB fluctuations, but extreme condition has to be assumed to avoid conflict with Planck electron scattering optical depth.
- Need more observations to test varieties of theory.

KWANSEI GAKUIN

EXZIT DARK AGE EXPLORATION FROM SAU

CIBER

END