Infrared Background

Asantha Cooray

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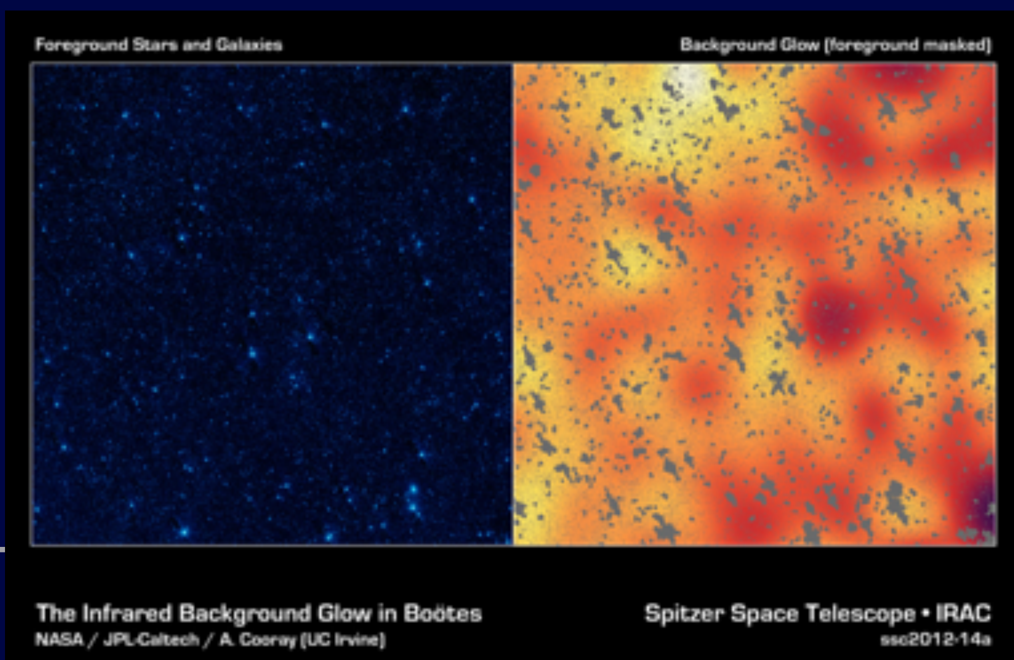
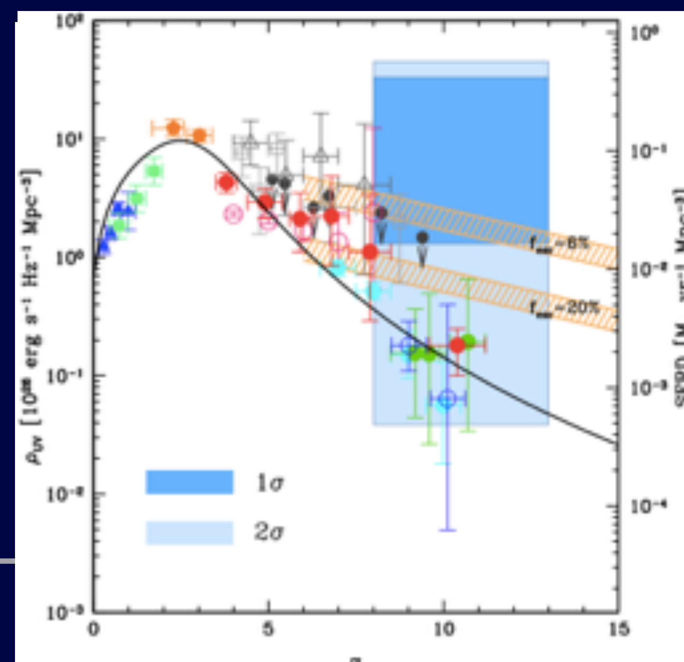


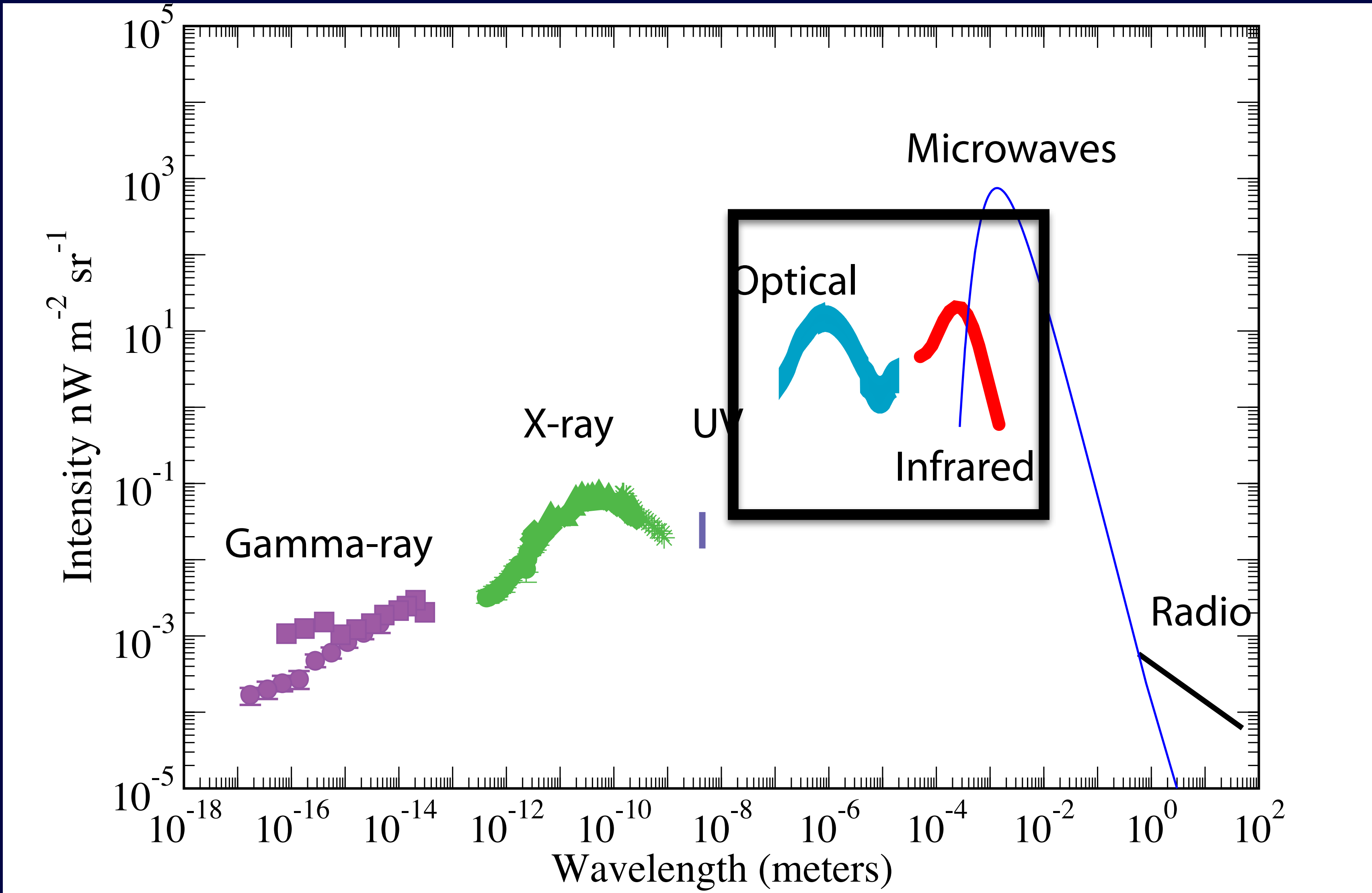


Outline

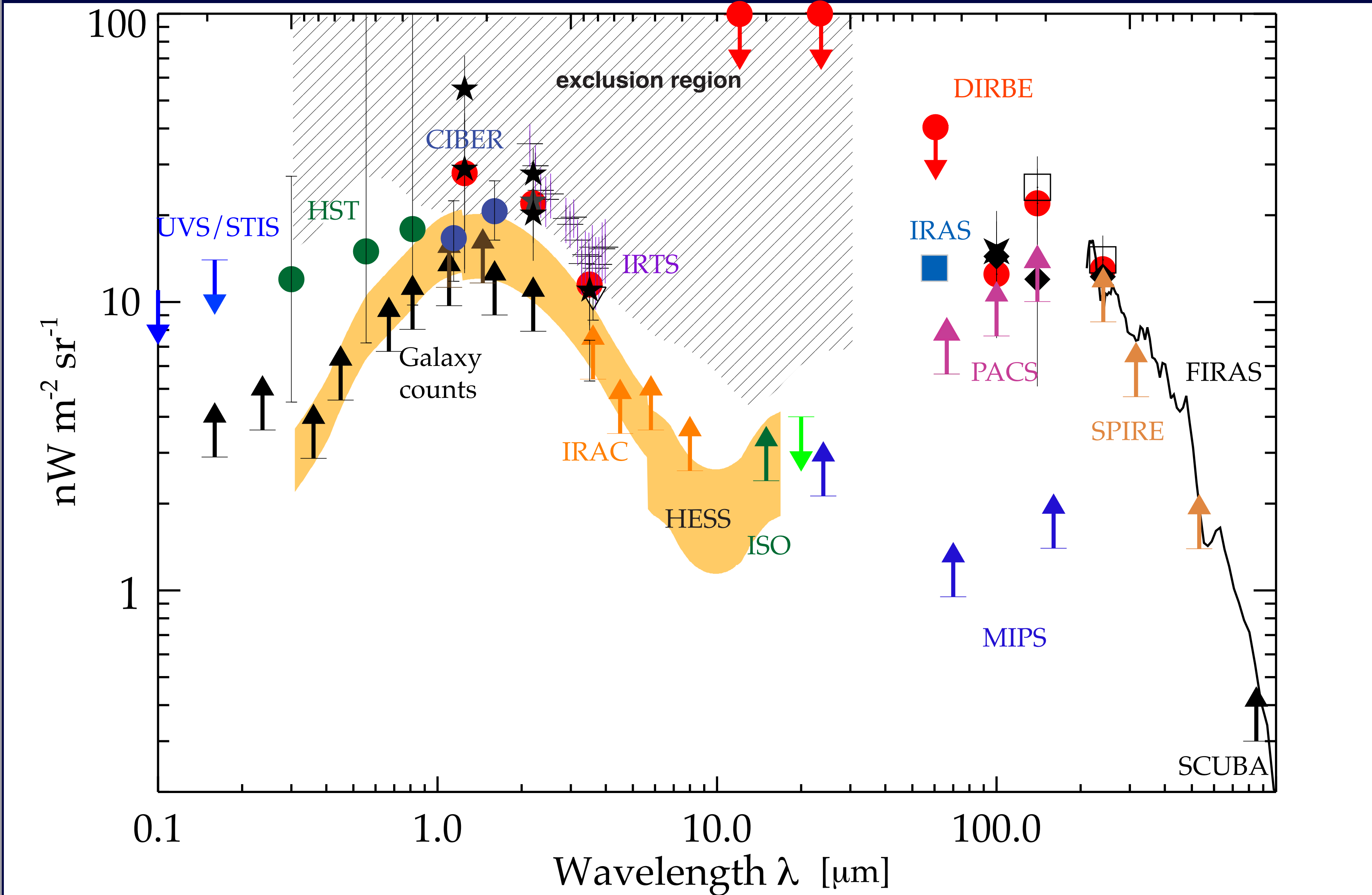
- Extragalactic Background Light/Cosmic Infrared Background
- Spatial Fluctuations in the IR background
- ***New results from HST/CANDELS***
- ZEBRA - a small instrument to the outer Solar system

Key coauthors/collaborators on research discussed today:

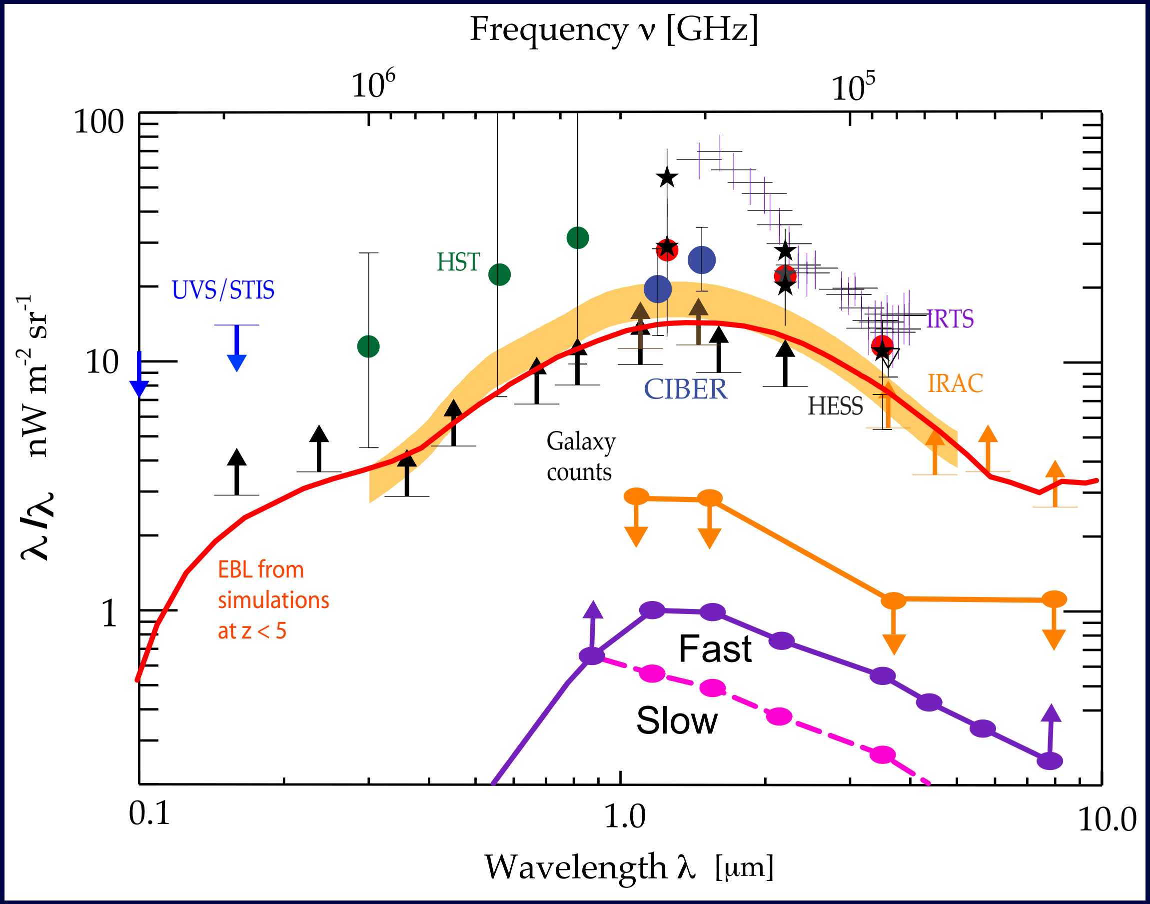
Ketron Mitchell-Wynne (grad student), Yan Gong (postdoc)
Joseph Smidt (former grad student)
CIBER Science Team
HST/CANDELS EBL Team

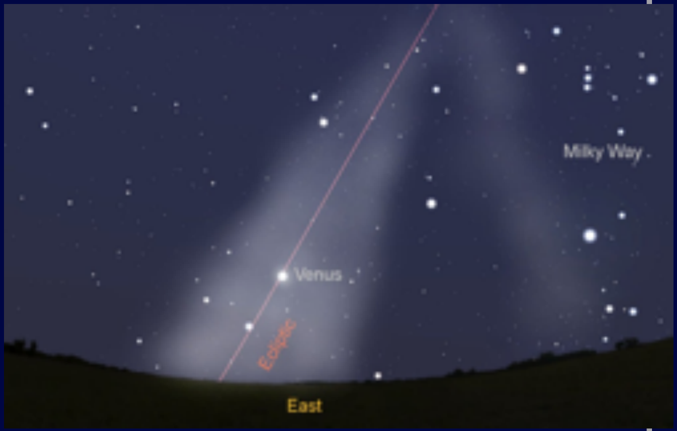


The extragalactic background spectrum



The extragalactic background spectrum

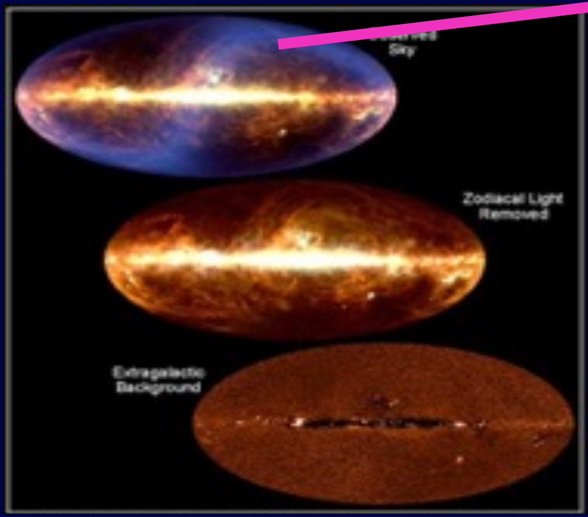


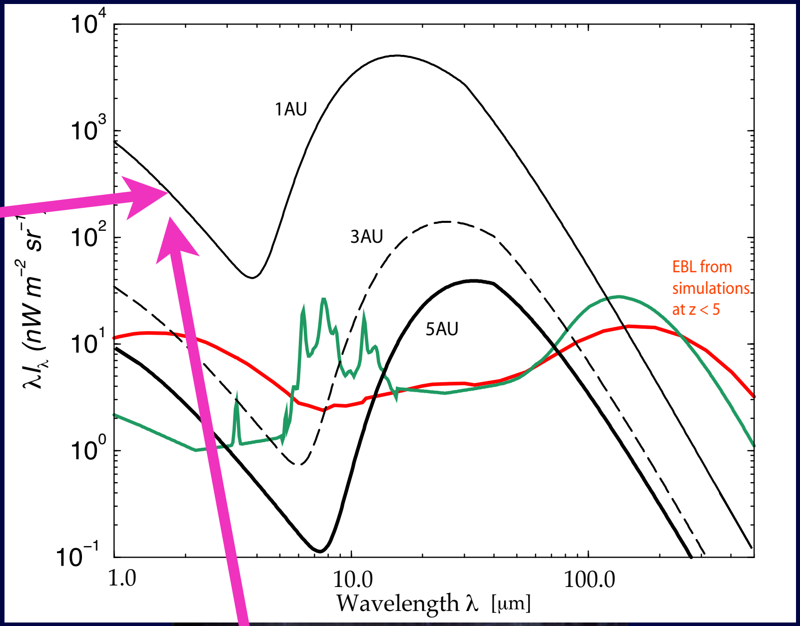


Absolute measurements are limited by Zodiacal light

Status of Cosmic IR Background Measurements

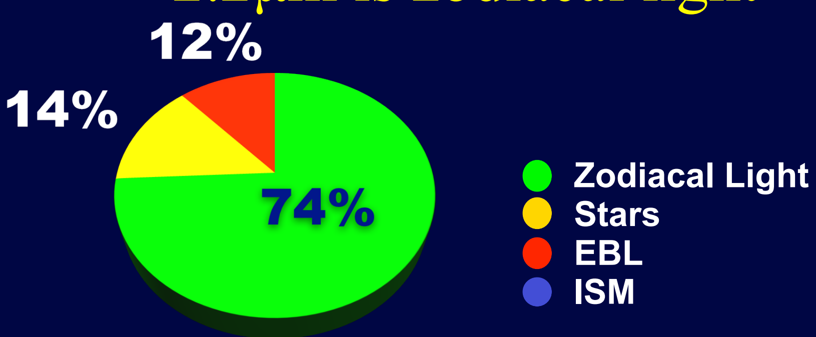
Why is the UV to IR EBL is hard to measure?



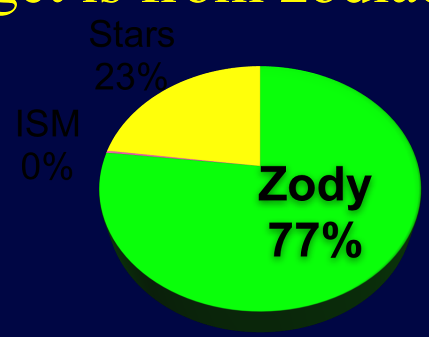


Extragalactic Background Light =
Total sky brightness – Stars – Zodiacal light – ISM

74% of the sky brightness at 2.2μm is zodiacal light

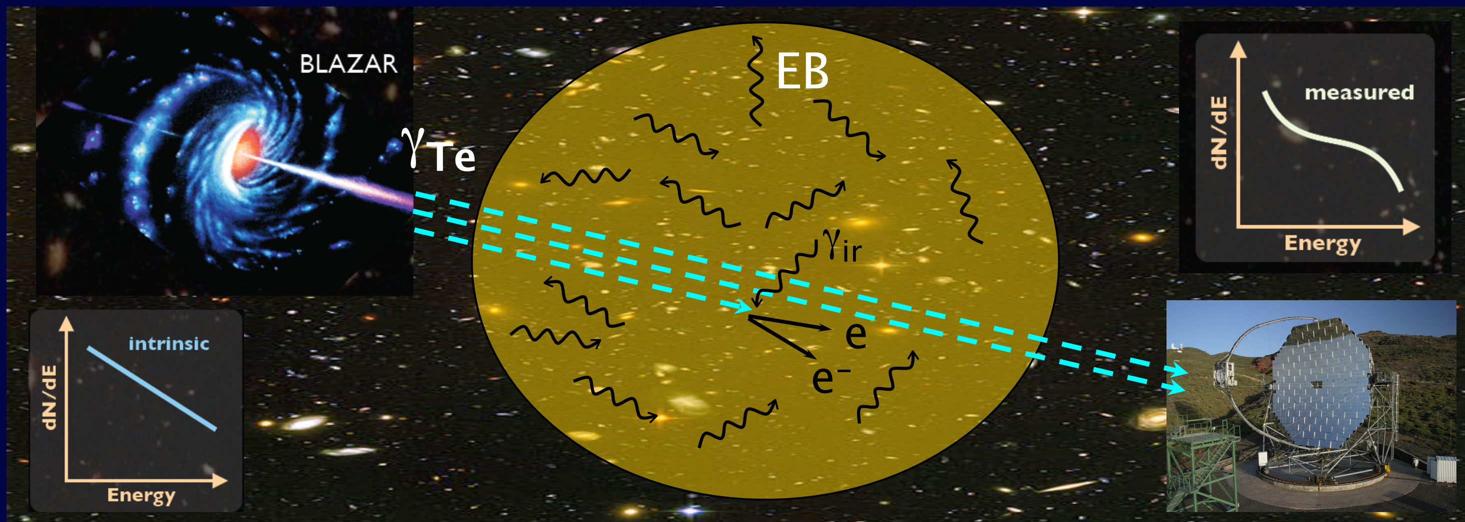


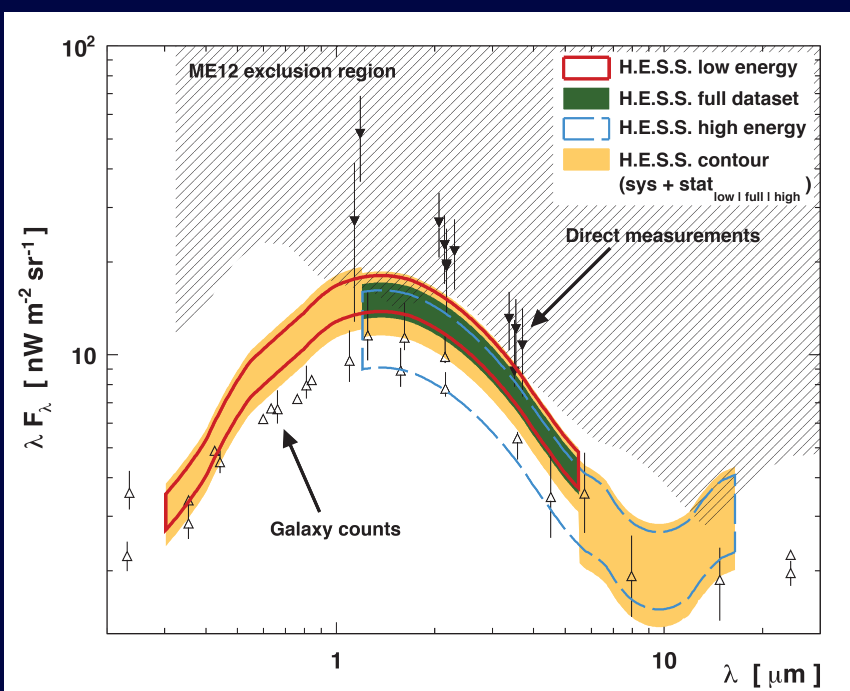
77% of the 2.2 μm EBL error budget is from zodiacal light



Indirect methods to constrain optical-IR EBL

TeV absorption





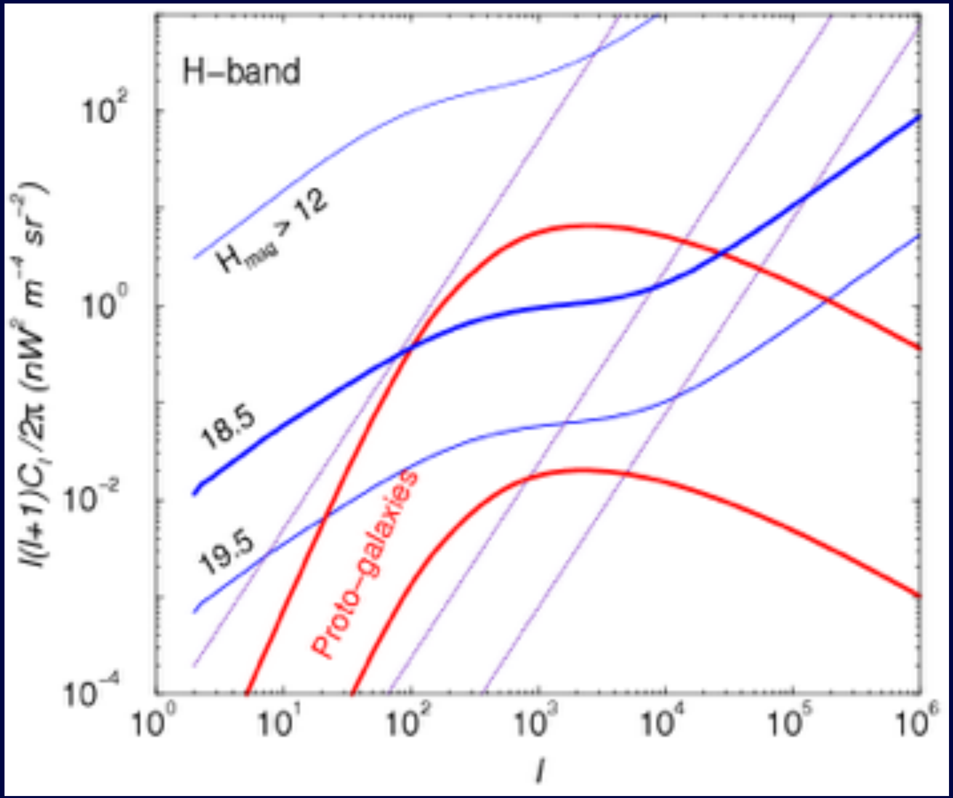
(a) TeV photons are attenuated via pair production with IR photons

(b) Imprint of the IR photon density in the measured TeV spectra

(c) However, intrinsic spectrum is not measured!

High-z galaxies?

Study IRB anisotropies.



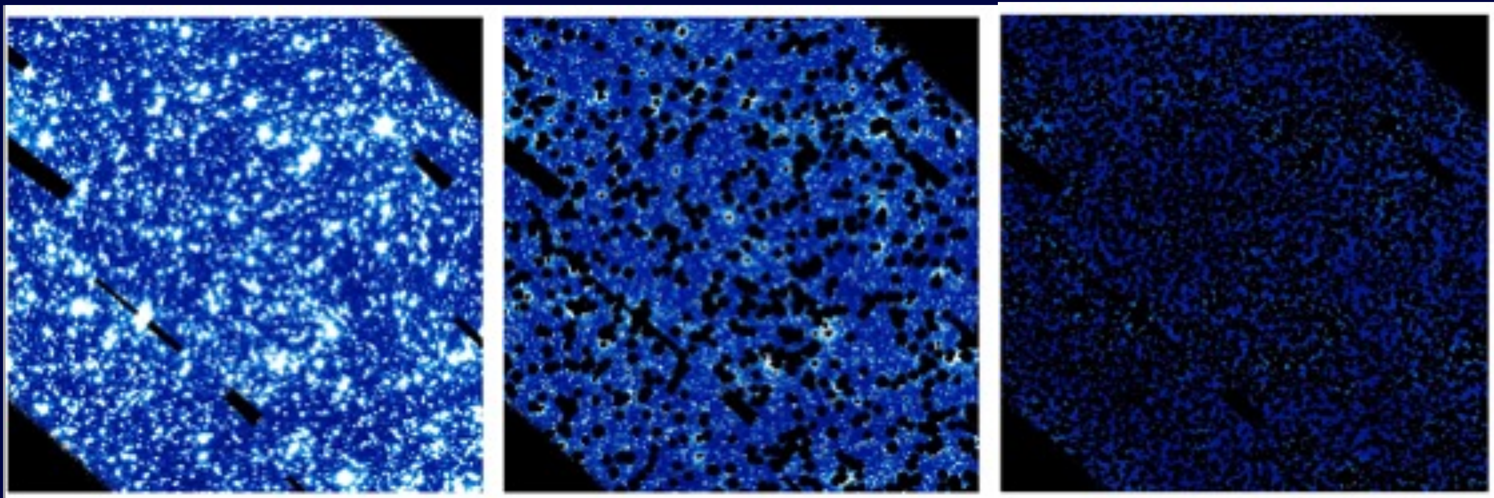
Instead of the absolute total IRB intensity, measure anisotropies or fluctuations of the intensity (just like in CMB).

IRB anisotropies probe substantially below 0.1 nW/m2/sr intensity.

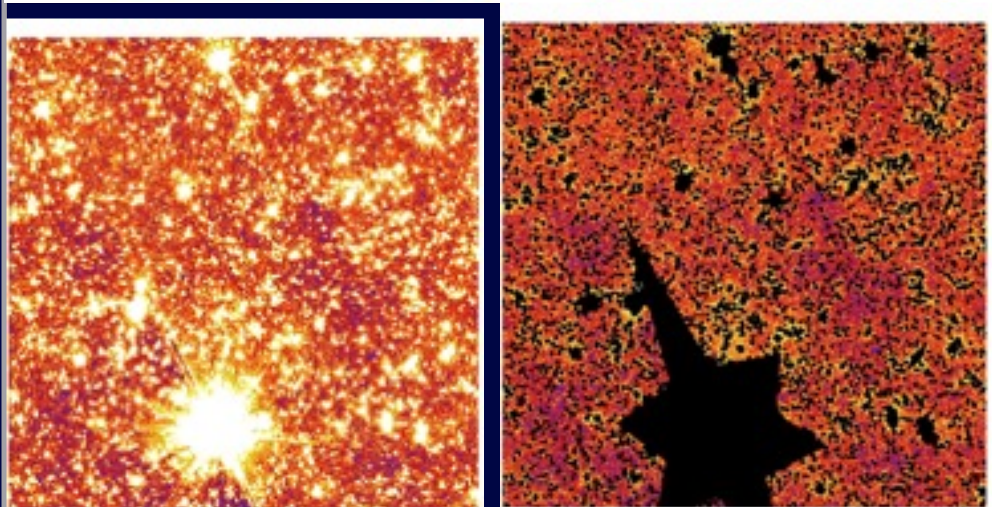
(Cooray, Bock, Keating, Lange & Matsumoto 2004, ApJ)

IR Background Fluctuations Measurements

IR Background Fluctuations Measurements



GOODS CDF-S



COSMOS

What do we do?

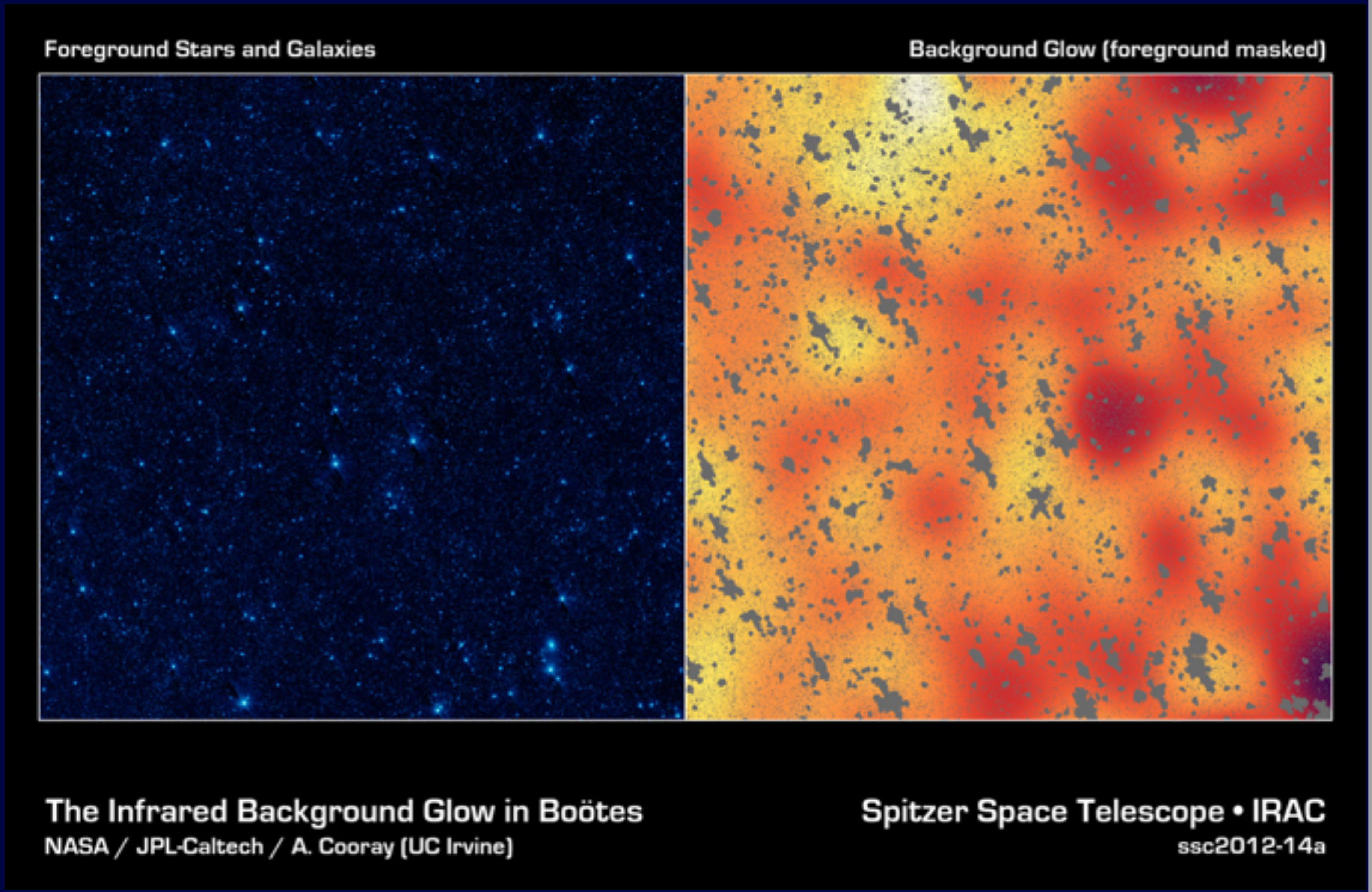
Measure statistics of “empty” pixels.

If unresolved faint galaxies are hidden in noise, then there is a clustering excess above noise

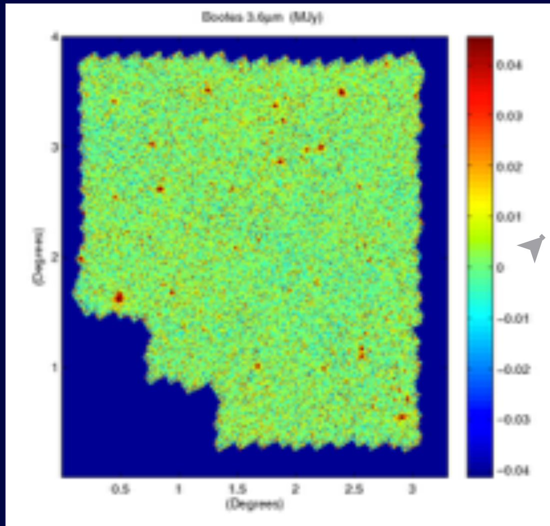
Challenges: > 10 million of pixels (higher complexity than analyzing CMB data.)

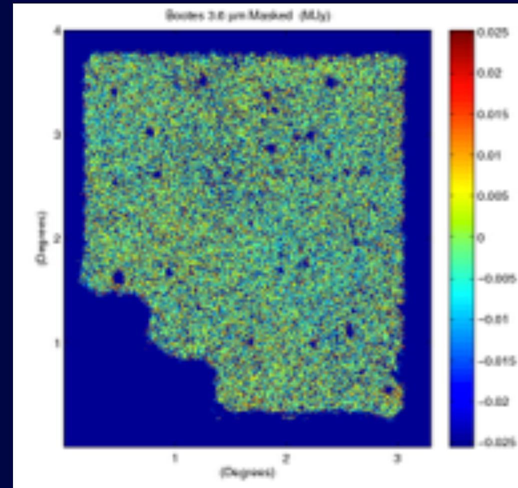
We also mask > 50% of pixels (GOODS we masked 70% of pixels).

Techniques to handle mask - borrowed from CMB analyses.



Intra-halo light





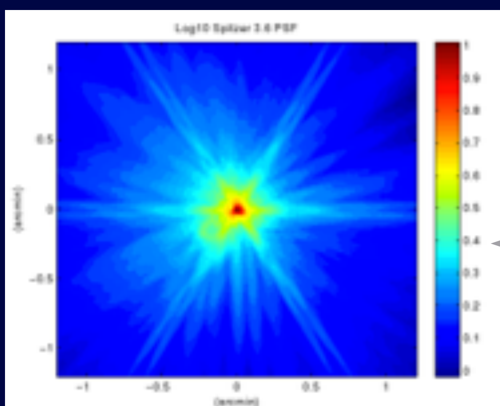
Mask map. (Sextractor)

Epoch 1 + Epoch 2

X

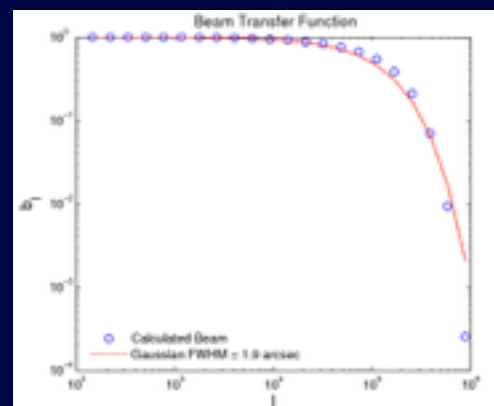
Epoch 3 + Epoch 4

Cross-Correlate Coadded Epochs



PSF

Fourier Transform



BEAM TRANSFER FUNCTION

Epoch 1 - Epoch 2

X

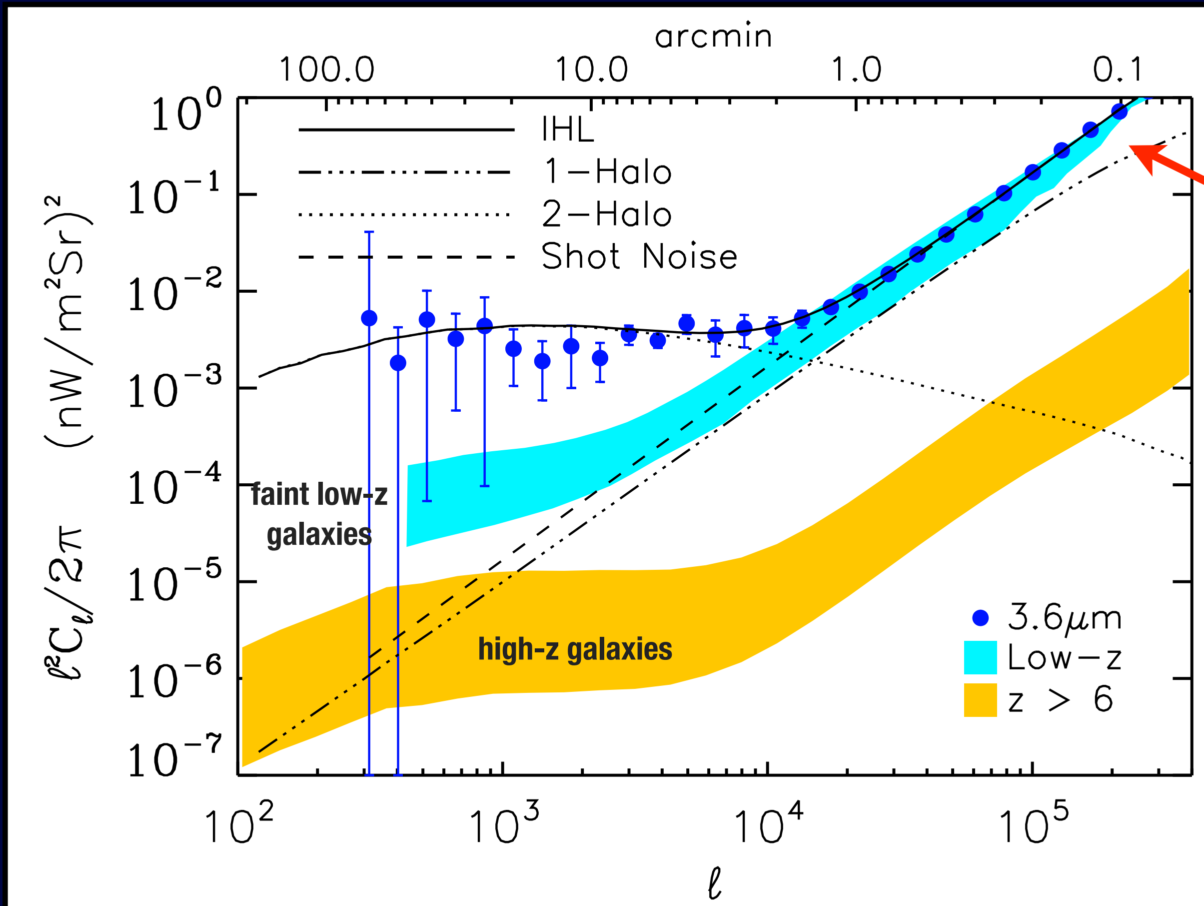
Epoch 3 - Epoch 4

Jackknife For Noise Errors

Spitzer Background Fluctuations in SDWFS

Cooray et al. 2012, Nature, 490, 514

What is the origin of these IR fluctuations?



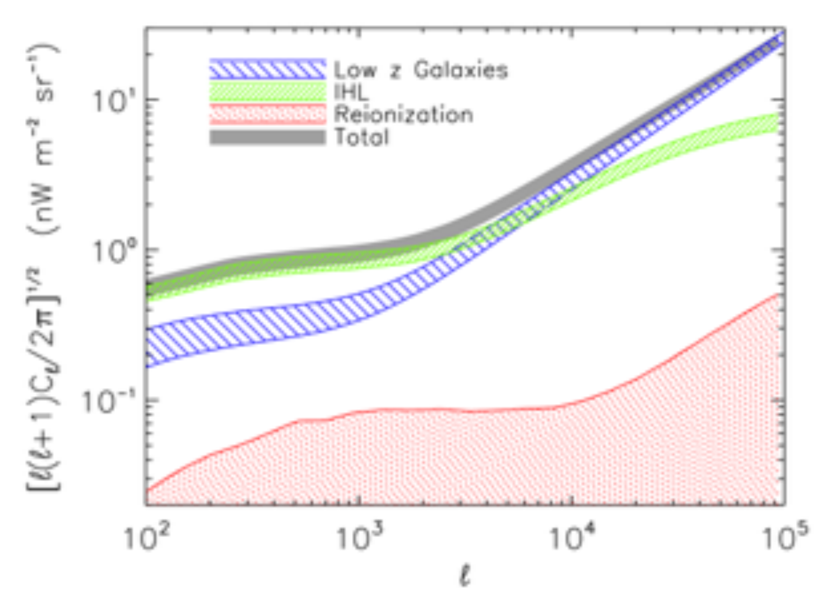
Measured shot-noise agrees with prediction for faint galaxies below the detection threshold (Helgason et al. 2012)

Argues against a new source population to explain the observations

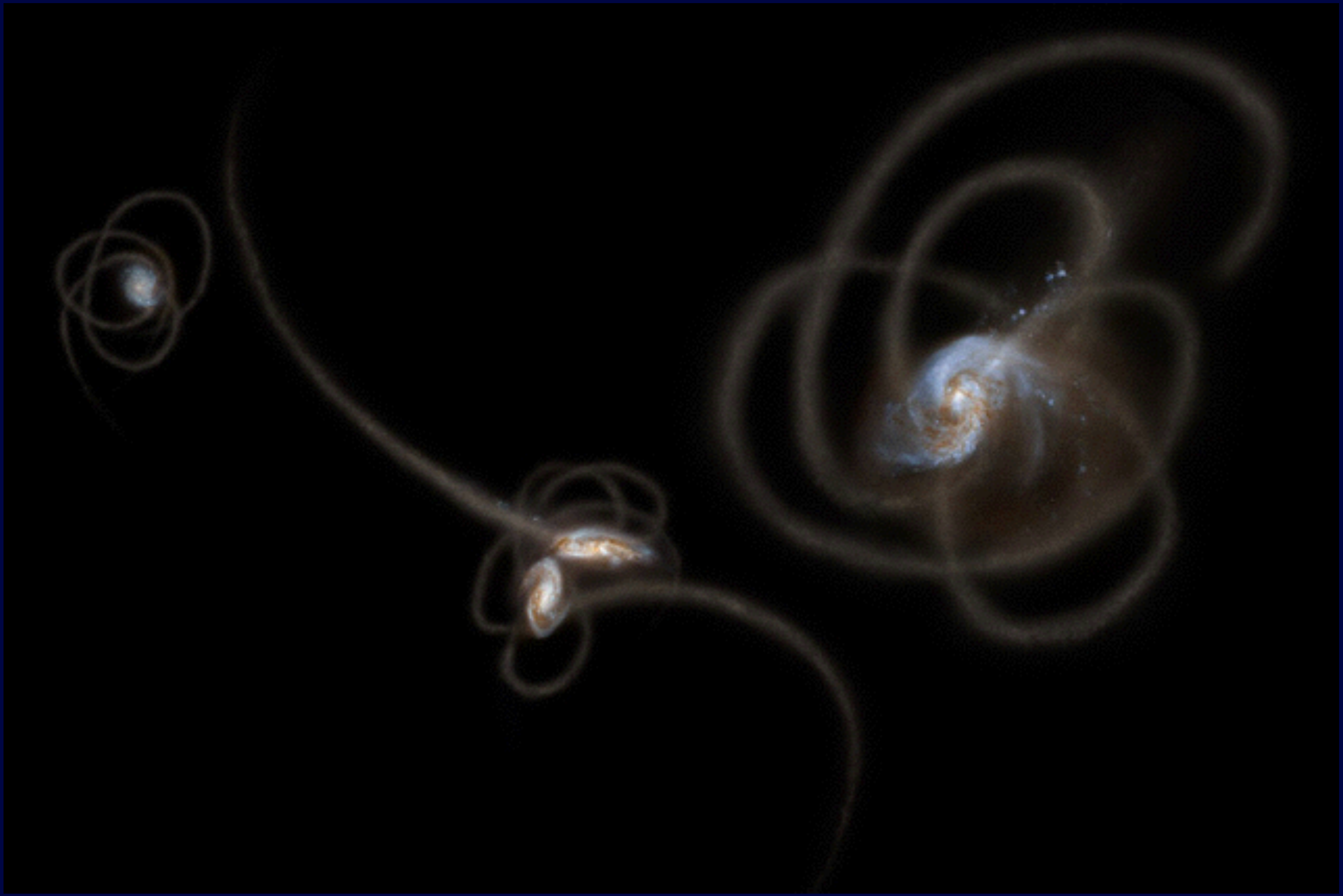
Spitzer Background Fluctuations in SDWFS

Cooray et al. 2012, Nature, 490, 514

Intra-halo light (IHL): stars which have been tidally stripped from their parent galaxies during galaxy mergers and go onto form an extended diffuse sea of stars in dark matter halos.



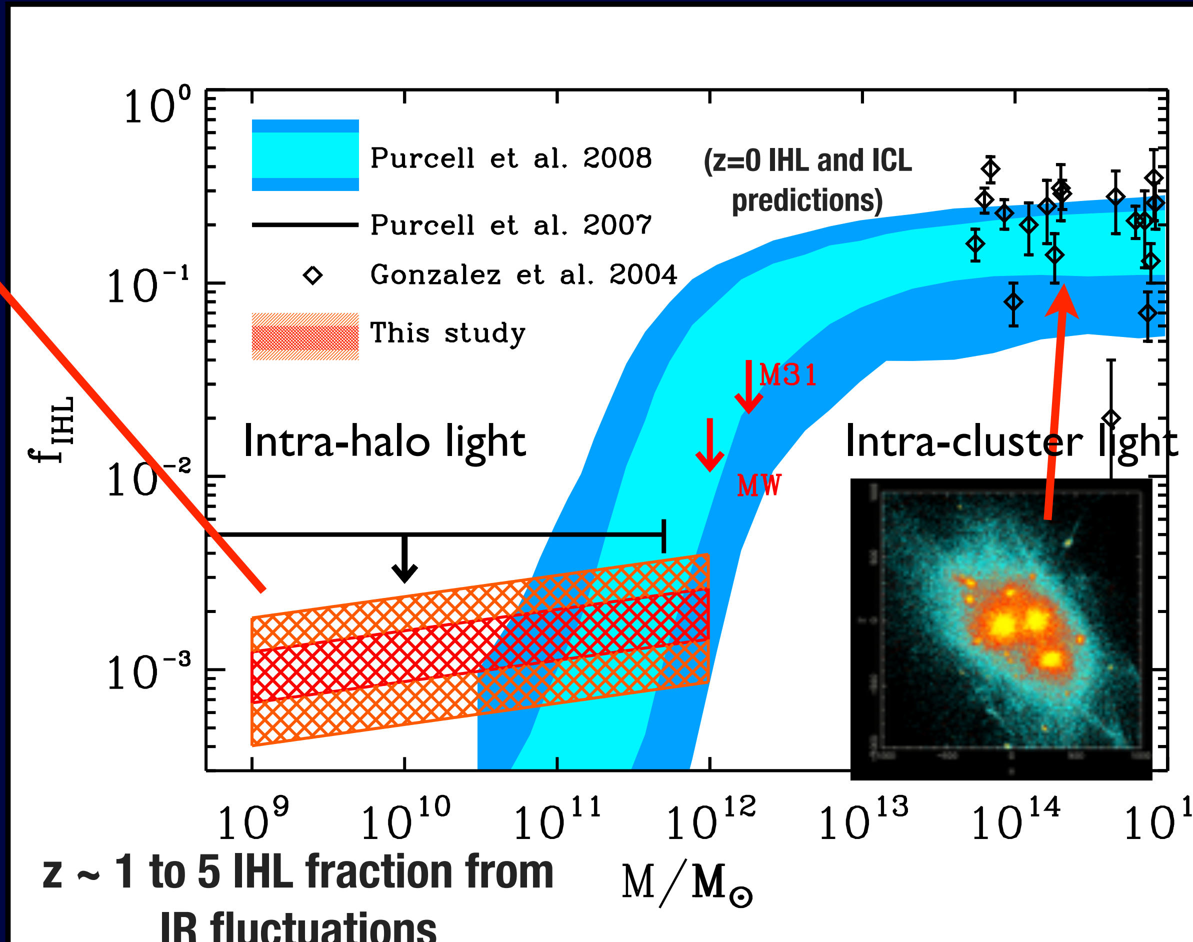
Intra-halo light



Intra-halo light

What is the origin of these IR fluctuations?

Intra-halo light



Intrahalo light:
stars outside of the galactic disks and in the outskirts of dark matter halos due to tidal stripping and galaxy mergers.

Simulation/theory predictions:
Purcell et al. 2007
Watson et al. 2012

Intra-halo light in galaxy-scale dark matter halos

Cooray et al. 2012, Nature, 490, 514

COSMOLOGY

Infrared light from wandering stars

An explanation has been proposed for the observed excess of cosmic light at infrared wavelengths. It invokes stars that are cast into the dark-matter haloes of their parent galaxies during powerful galaxy collisions. SEE LETTER P.514

ANDREA FERRARA

Ever since the collective infrared light from cosmic sources was found[1] to exceed the expected emissions from known galaxies, researchers have considered[2–6] whether the excess might comprise radiation from distant stars and galaxies too faint to be detected individually. However, on page 514 of this issue, Cooray *et al.*[7] suggest instead that the excess signal could be provided largely by nearby stars that were stripped from the main body of their parent galaxies during collisions.

According to the standard Big Bang model, cosmic structures originated from tiny lumps of unseen dark matter in the early Universe that grew large enough to collect the normal (baryonic) matter from which stars eventually formed. On theoretical grounds[8], it is believed that the first stars were 10–100 times more massive than the Sun, because their parent gas clumps would have been poor in metals (elements other than hydrogen and helium), enabling them to avoid fragmentation into smaller clumps.

M. LIVIO/HUBBLE HERITAGE TEAM (STSCI/AURA)/ESA/NASA

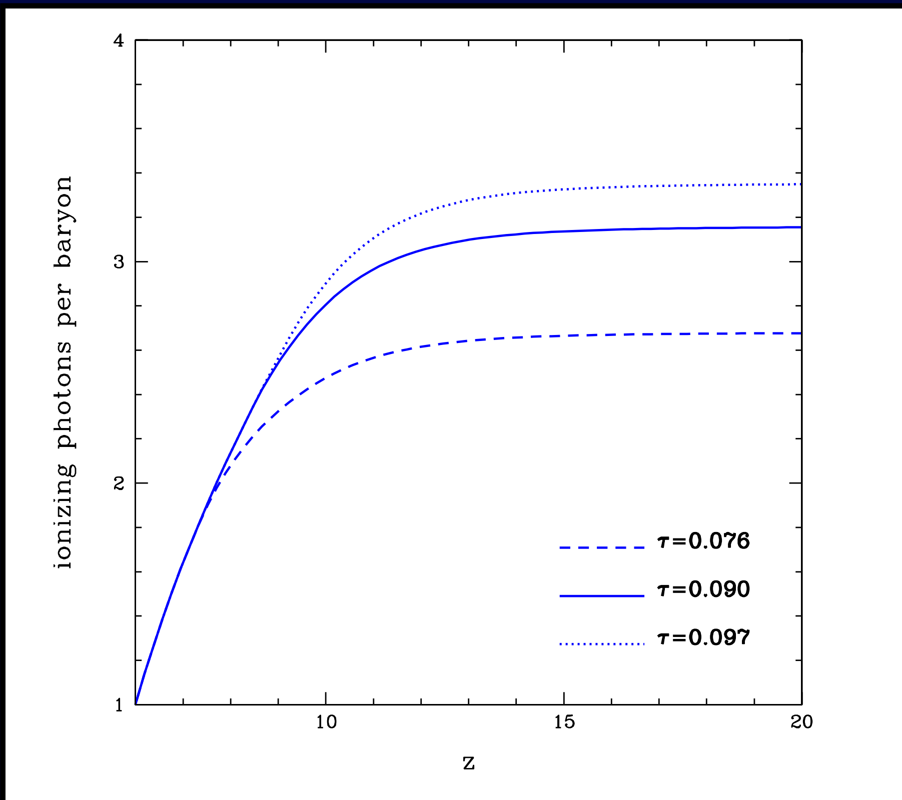
Intra-halo Light

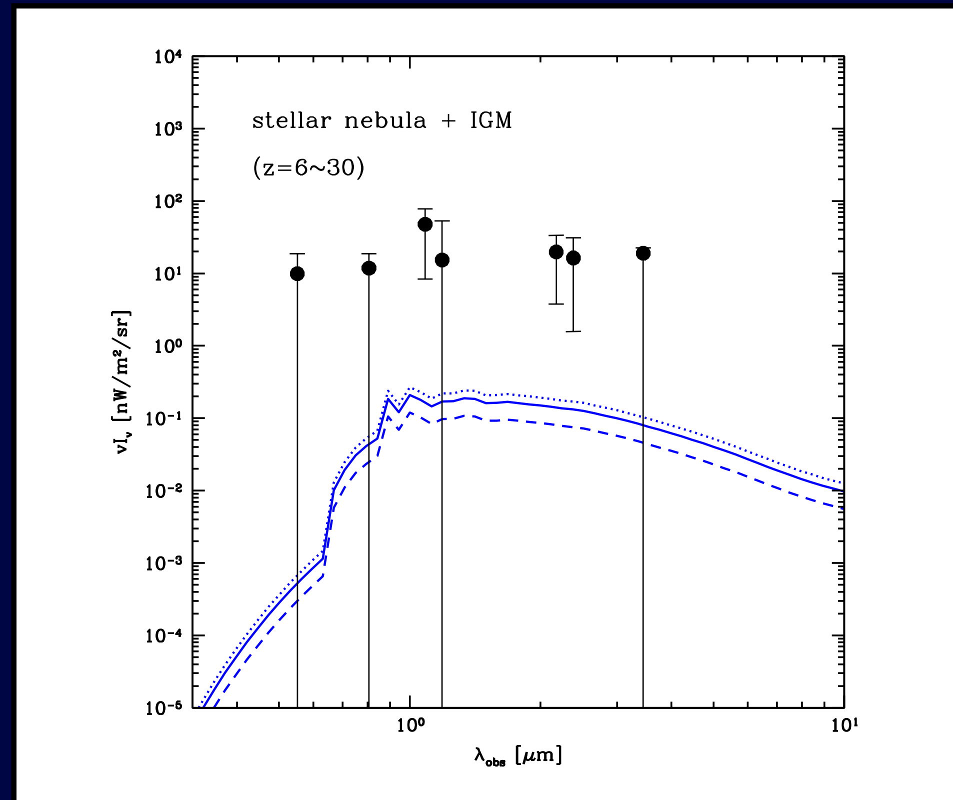
(z=0 IHL and ICL predictions)

Cooray et al. 2012, Nature, 490, 514

EBL should contain sources from reionization

Even if faint sources are individually undetected, their presence is visible in the EBL





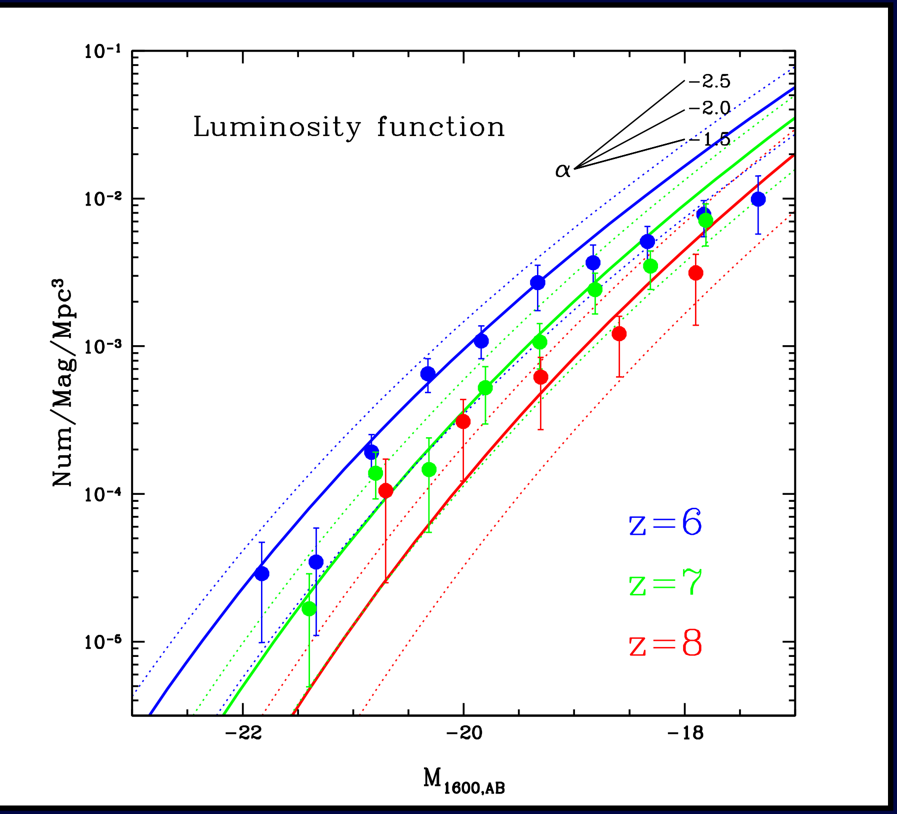
Two key features of the EBL reionization spectral signature:

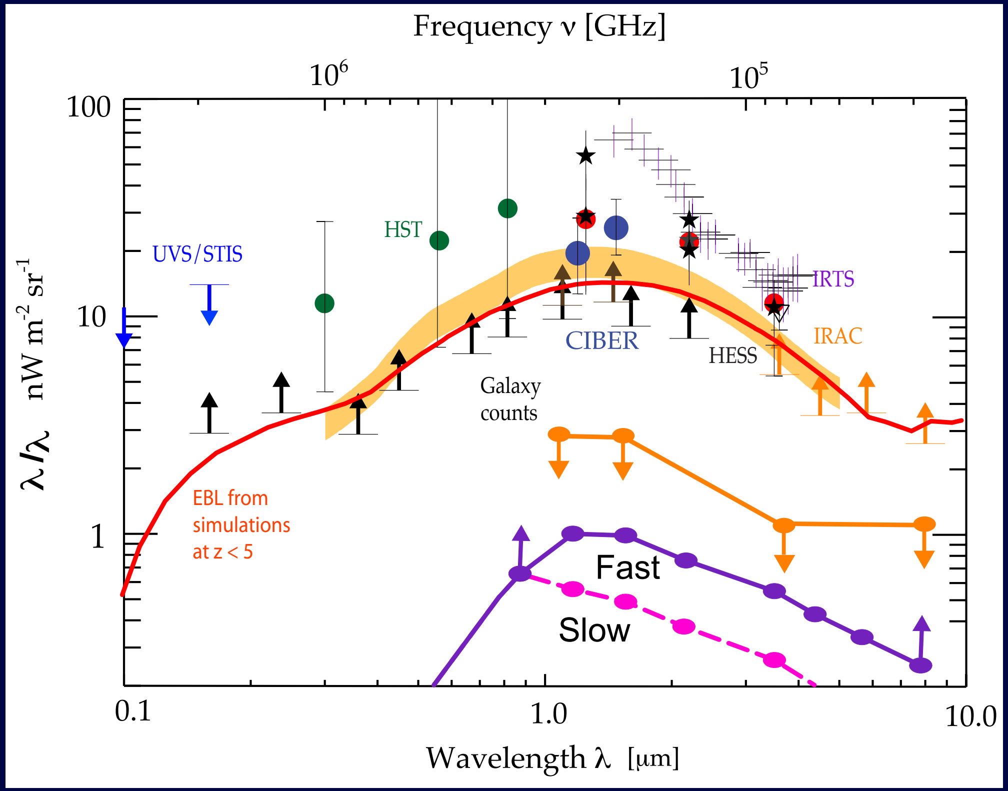
(a) Amplitude of the spectral signature probes the integrated SFR during

(b) Width of the spectral signature probes the duration of reionization

Near-IR background Light is a probe of reionization

Even if faint sources are individually undetected, their presence is visible in the absolute intensity of the near-IR background.



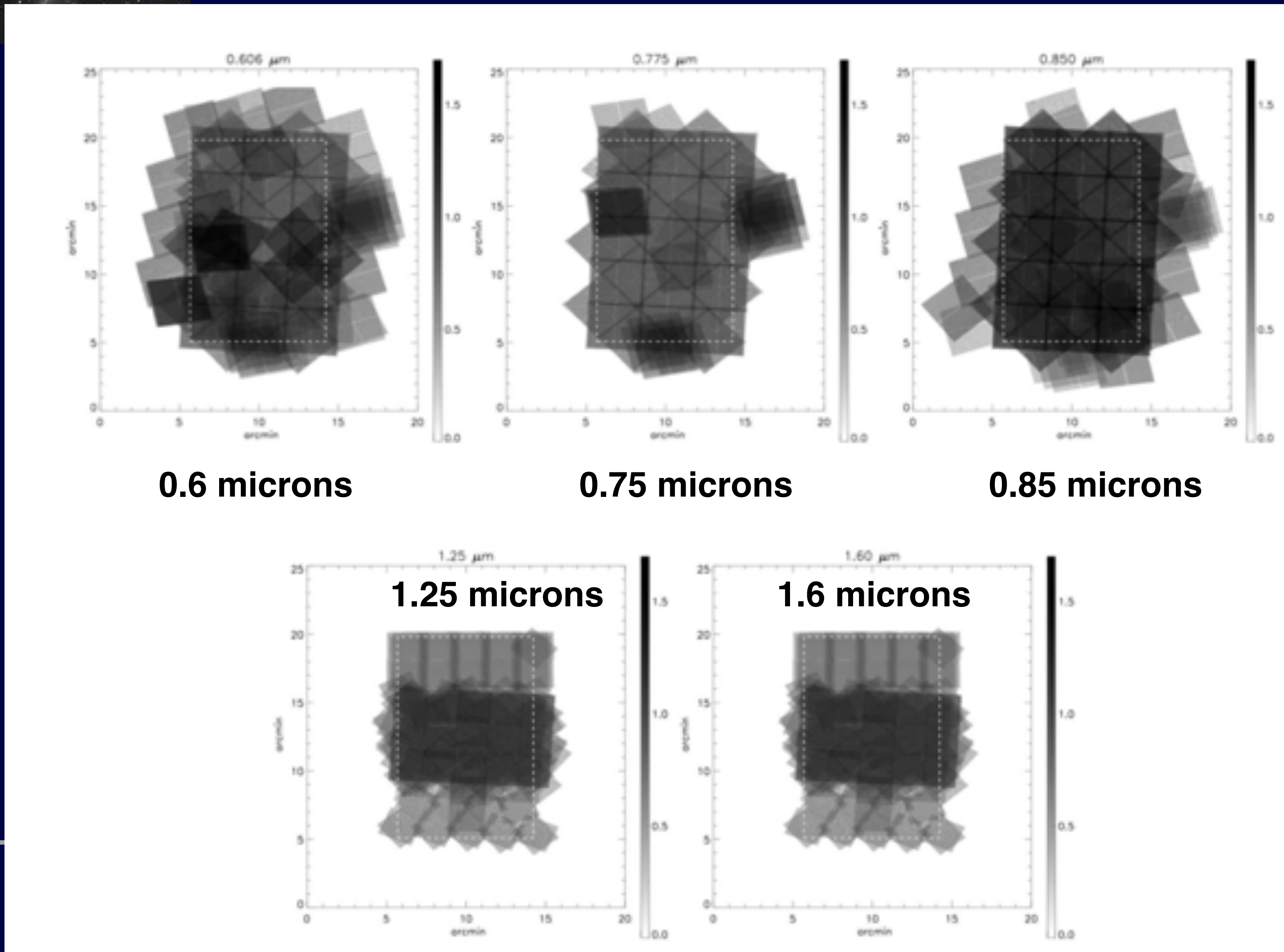


- ***The predicted $z > 8$ background intensity ~ 0.1 to 0.8 nW/m2/sr between 1 to 3 microns.***
- A small instrument outside of the zodiacal light cloud > 5 AU (ZEBRA)

Reionization signal in IR fluctuations?

Field	Area	Program ID	Dates
UDS	210 sq arcmins	12064	11/08/10-11/25/10
		12064	12/27/10-01/10/11
EGS	90 sq arcmins	12063	04/02/11-04/08/11
		12063	05/22/11-06/02/11
COSMOS	210 sq arcmins	12440	12/06/11-02/25/12
		12440	01/23/12-04/16/12
COSMOS	1.8 sq degrees	9822/10092	10/03-5/04

Reionization signal in IR fluctuations?



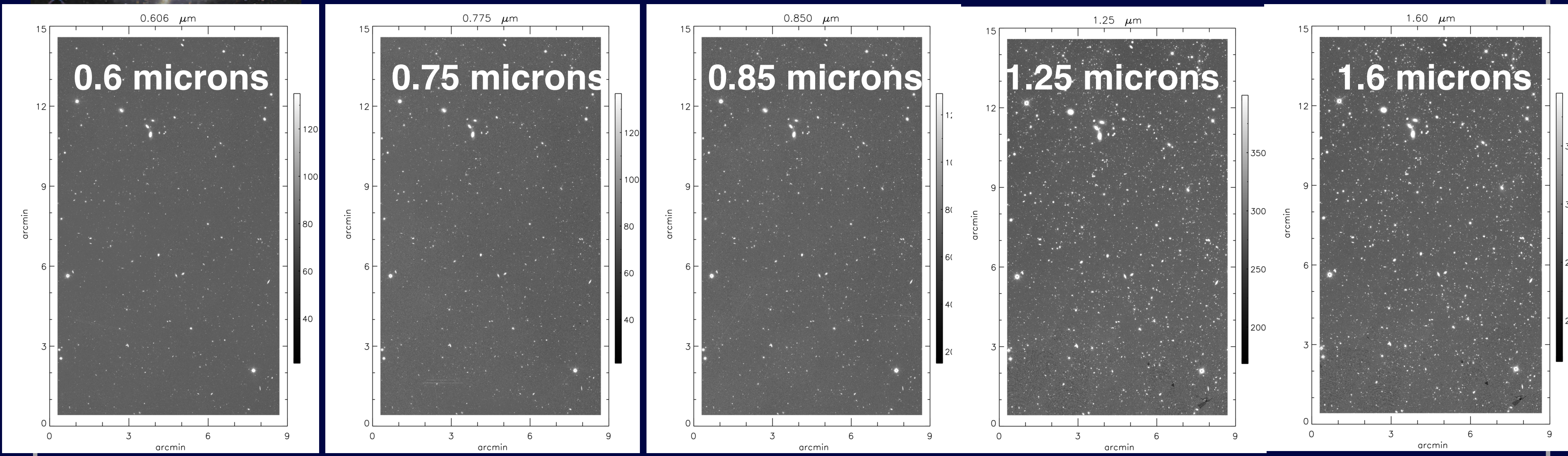
Reionization signal in IR fluctuations?

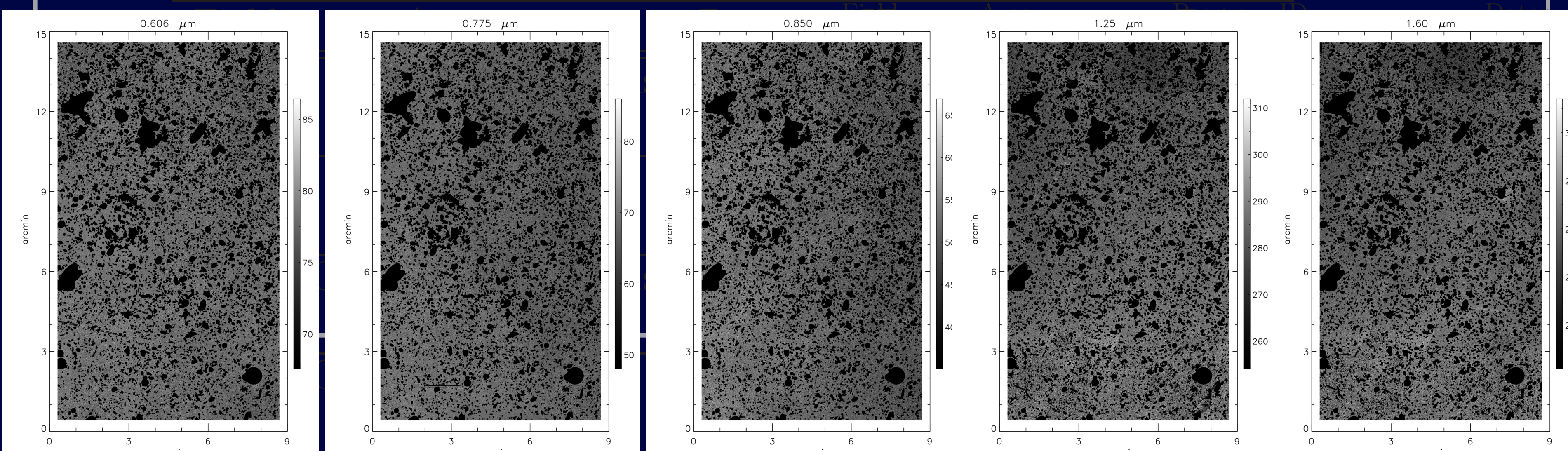
11 years of Hubble Space Telescope data 2002-2013 taken by 10 different proposal PIs

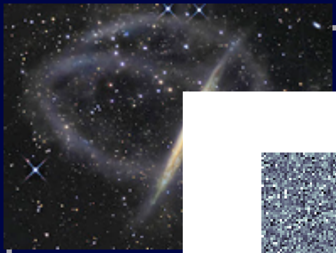
Filter	Proposal	IDs							
F775W	9575								
F850LP	9500	9978	10086						
ACS	9425	9803	10189	10258					
WFC3	11359	12060	12061	12062					
F606W	9500	9978	11563	12007	12060	12062	12099	12461	12534

Table 1: Proposal ID's for each filter. The ACS and WFC3 rows show the proposals which are common between all the bands in each instrument. For each proposal we did not necessarily use all the frames, specifically those from deep surveys.

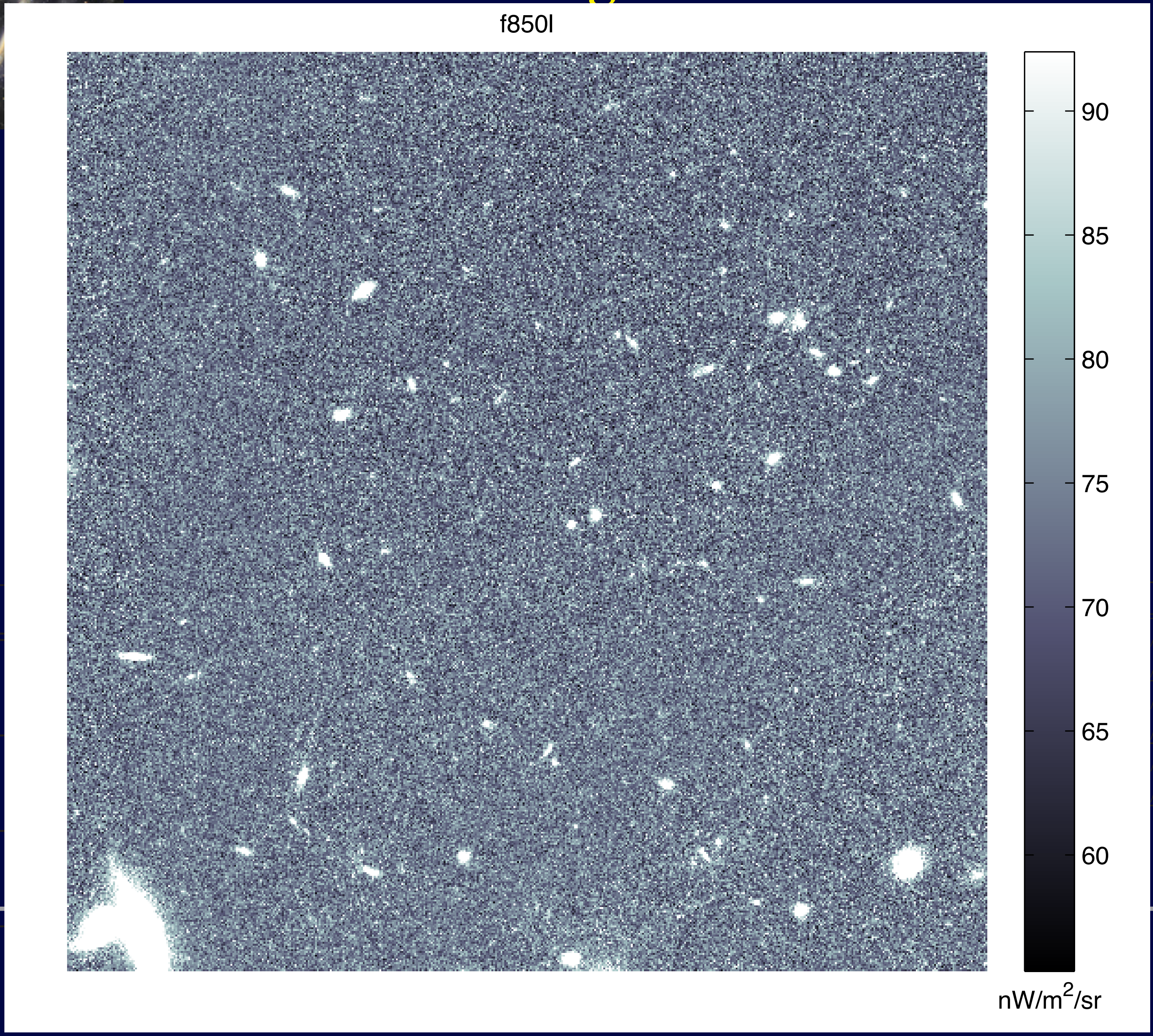
Reionization signal in IR fluctuations?







Reionization signal in IR fluctuations?



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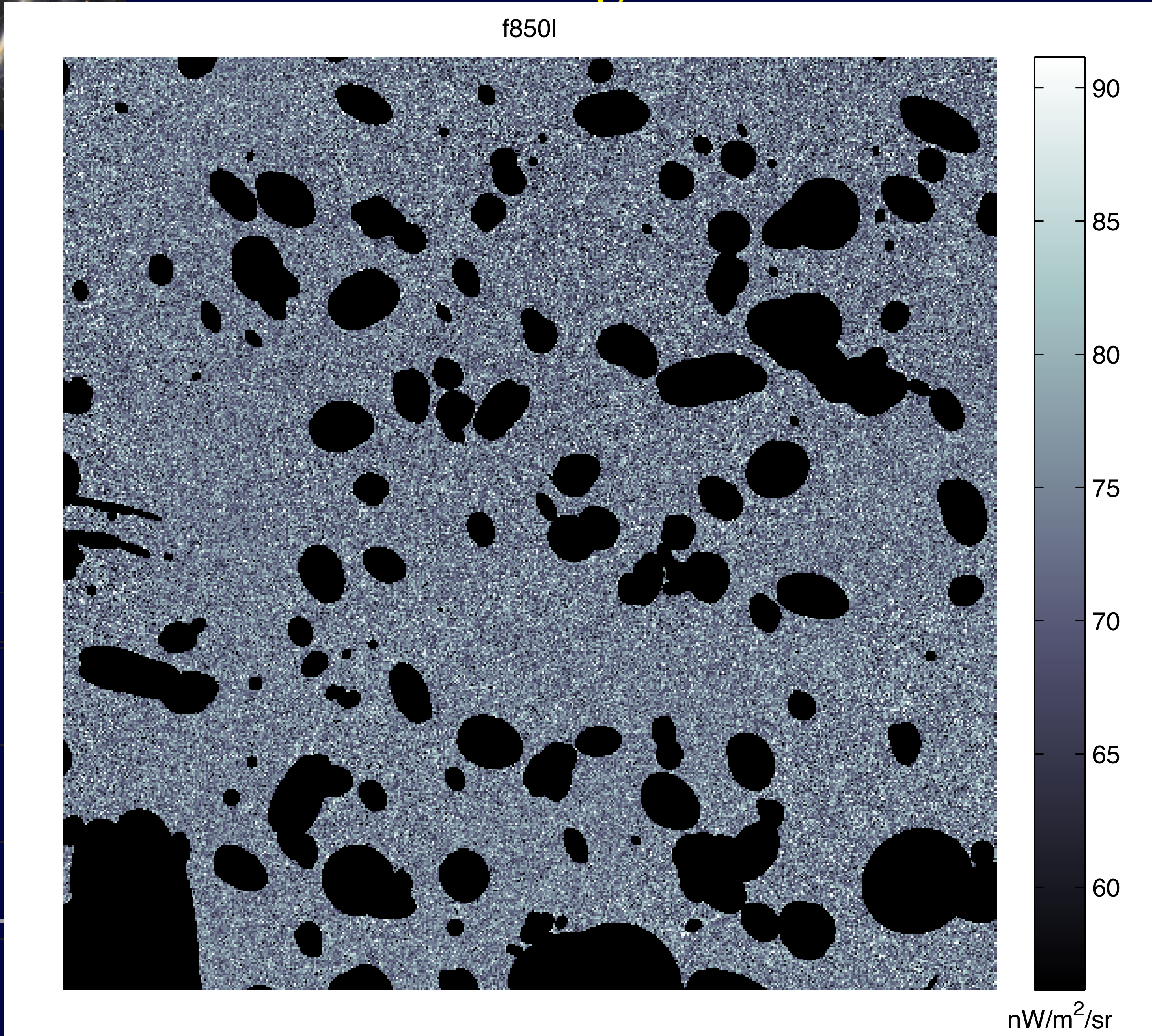
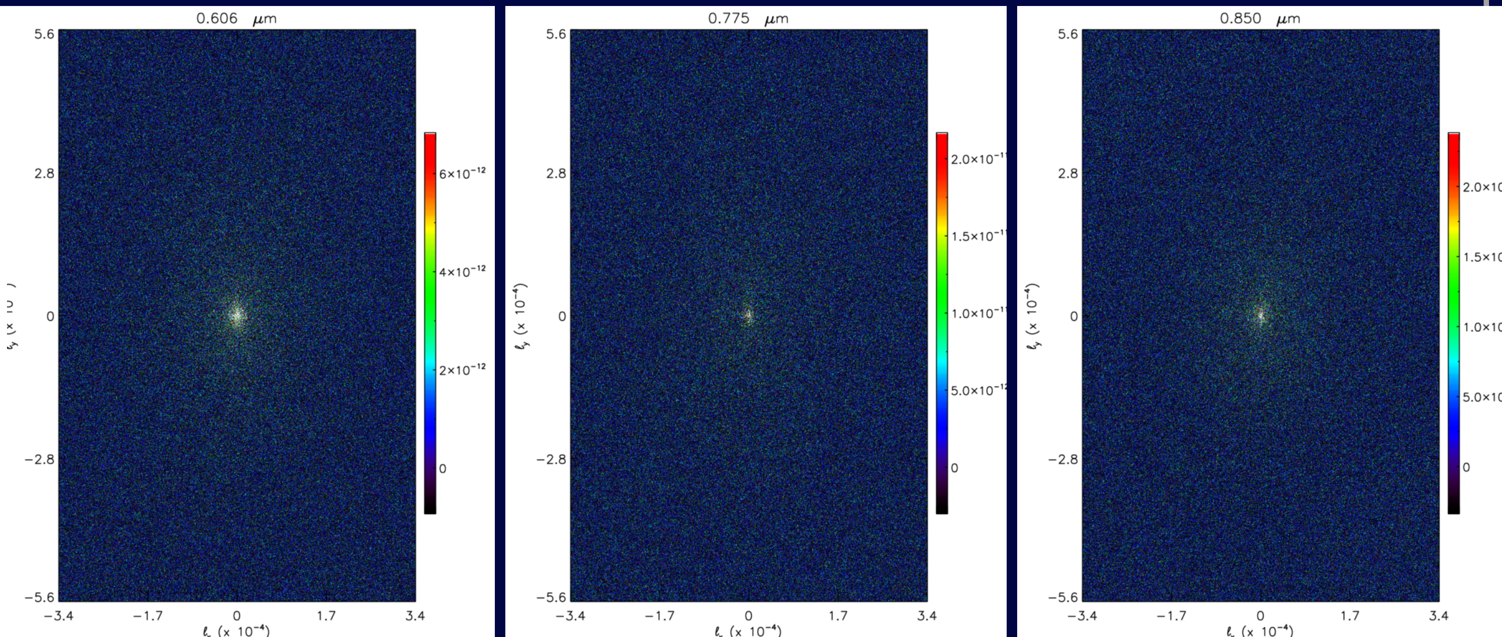


Reionization signal in IR fluctuations?

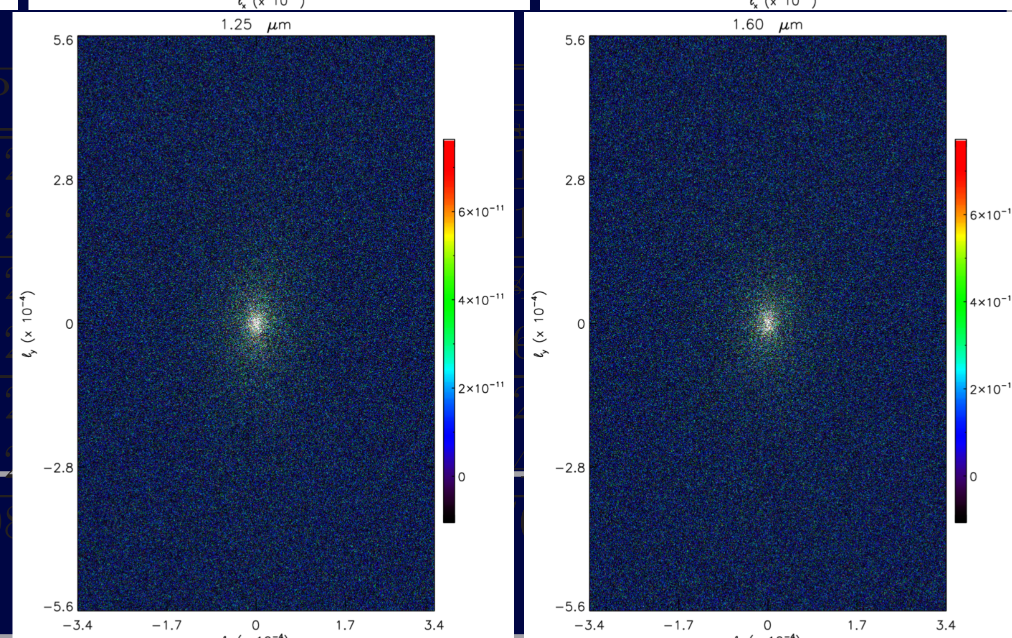
- Made 2 mosaics per band ("A" and "B") each with half the FLTs

- Source masks generated from Guo+ 2013, using the CXX, CYY, CXY parameters to incorporate source shapes.

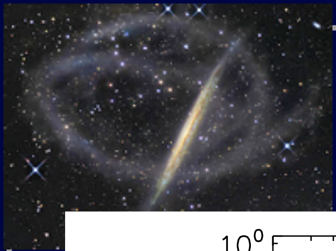


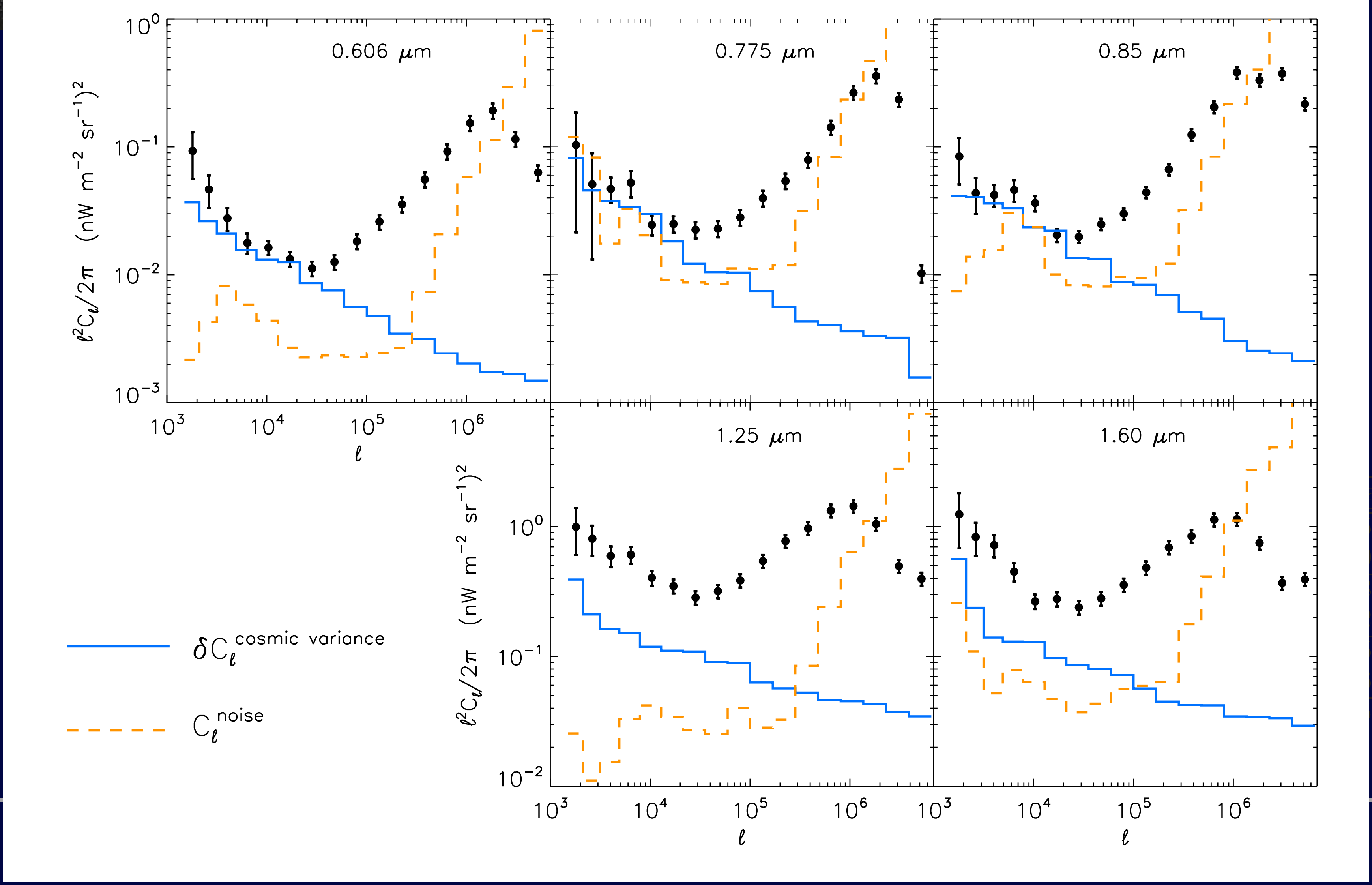
- Also ran SExtractor on (A+B)/2 map in each band, took the union of all 6 masks as the final mask.

- No need to Fourier mask as auto spectra (A x B) have no structure in Fourier space, only Gaussian noise.



Reionization signal in IR fluctuations?

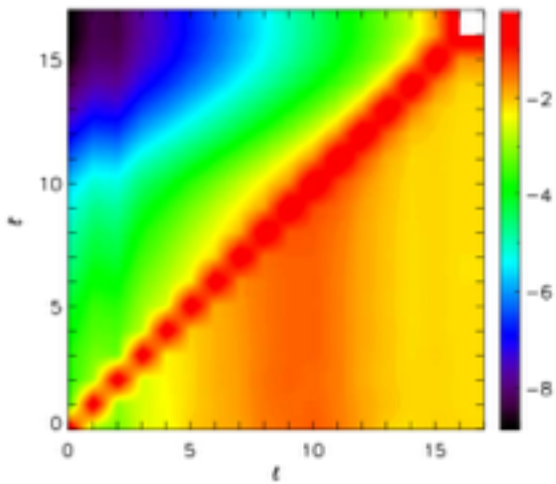


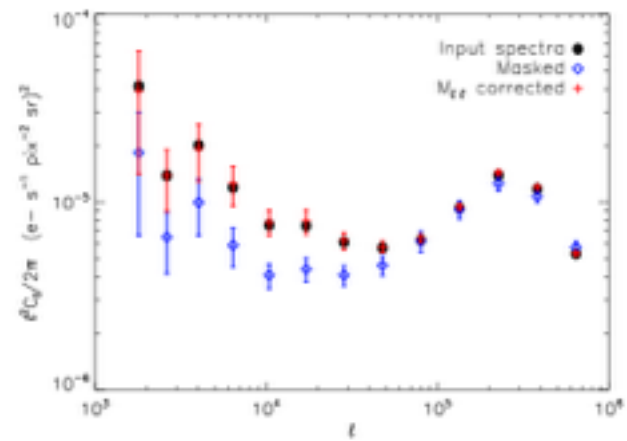


Corrections -- $M_{ll'}$ and Beam

Mask Correction

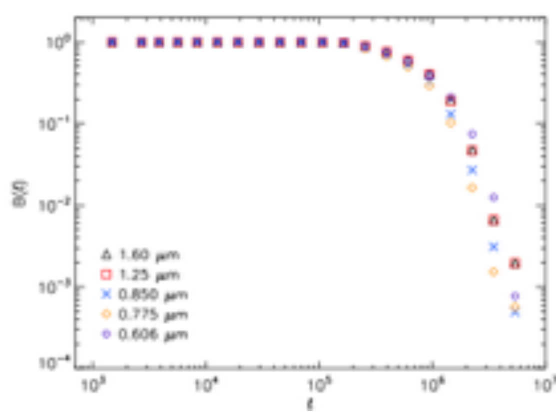
One common mask for all 5 bands, so one common $M_{ll'}$ correction. Matrix generated computationally mode by mode.
Cooray+ 2012, Zemcov+ 2014

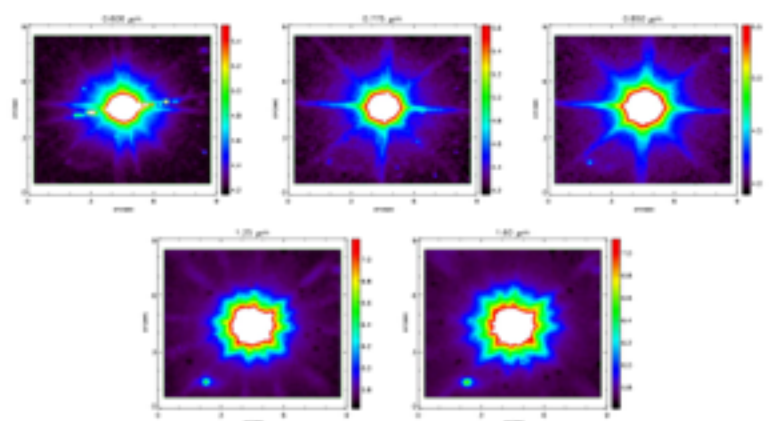




Beam Correction

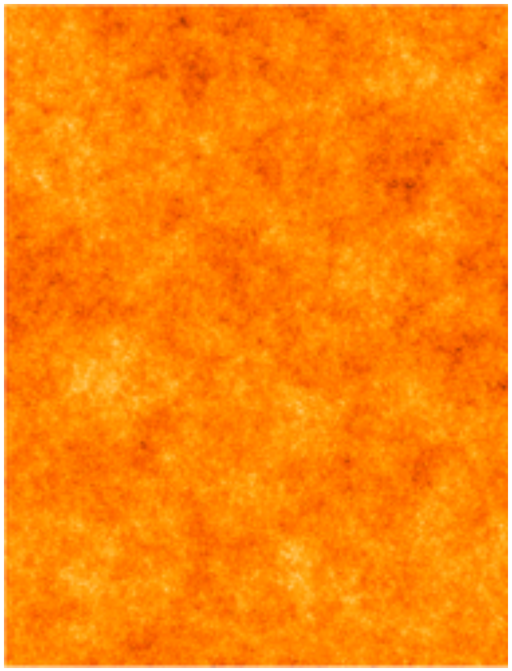
- Stacked sources across the map to get the PSFs in each band (right).
- Measure the PSFs in harmonic space to get the beam transfer function B(l).





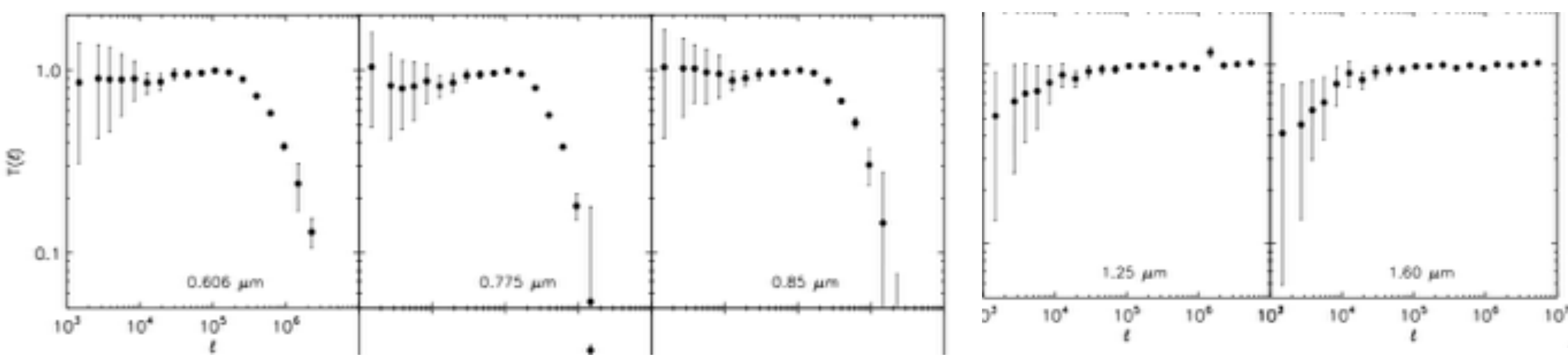
Corrections -- T(l)

Input simulated map

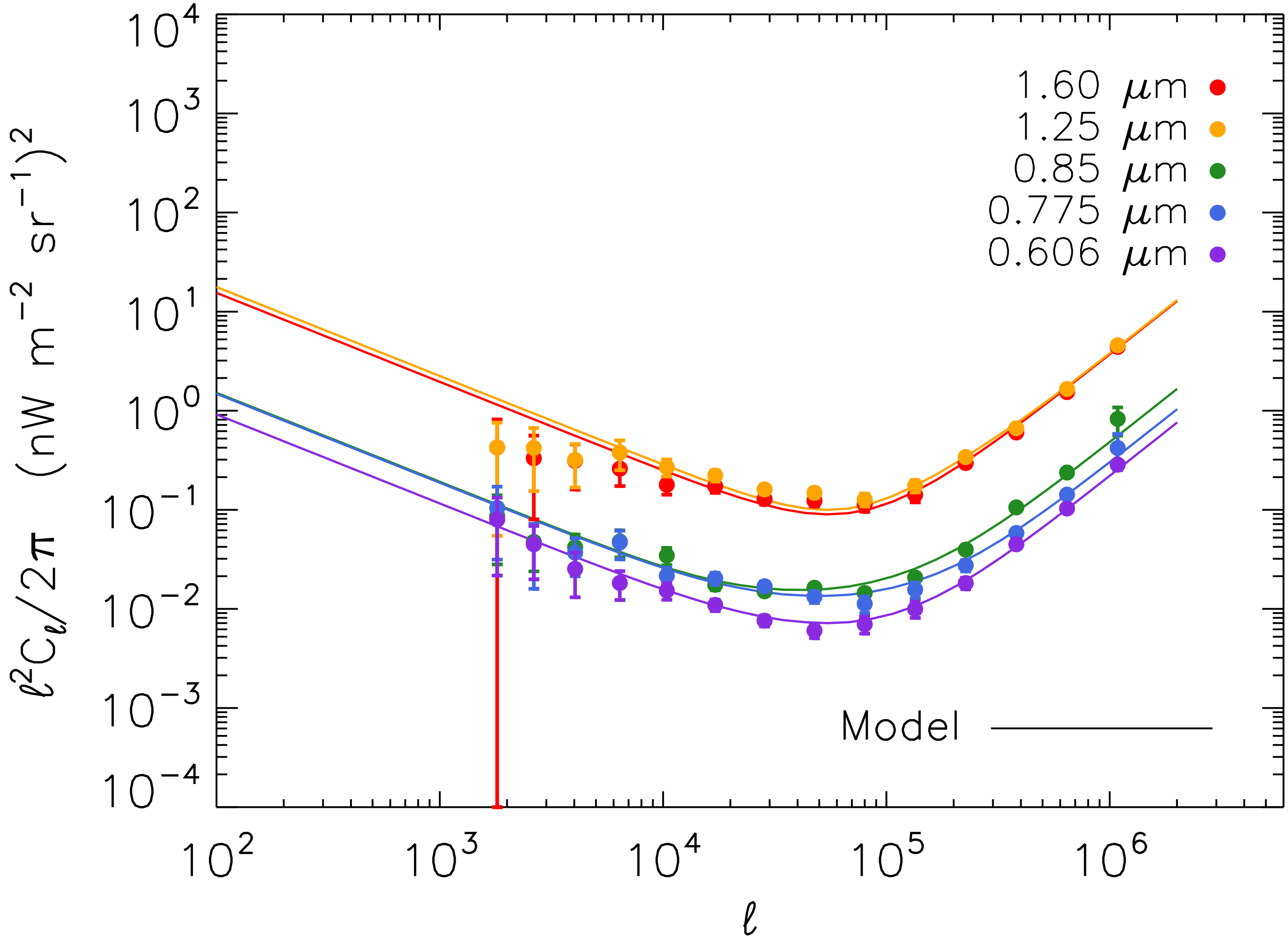


- Extract flux from simulated input map at each flight image pixel position.
- Add noise proportional to inverse square root exposure time.
- Add an overall offset equal to the median of the flight image to account for background variations.
- Feed to SelfCal and generate mosaic. Repeat 50-100 times.

Output simulated map



Reionization signal in IR fluctuations?



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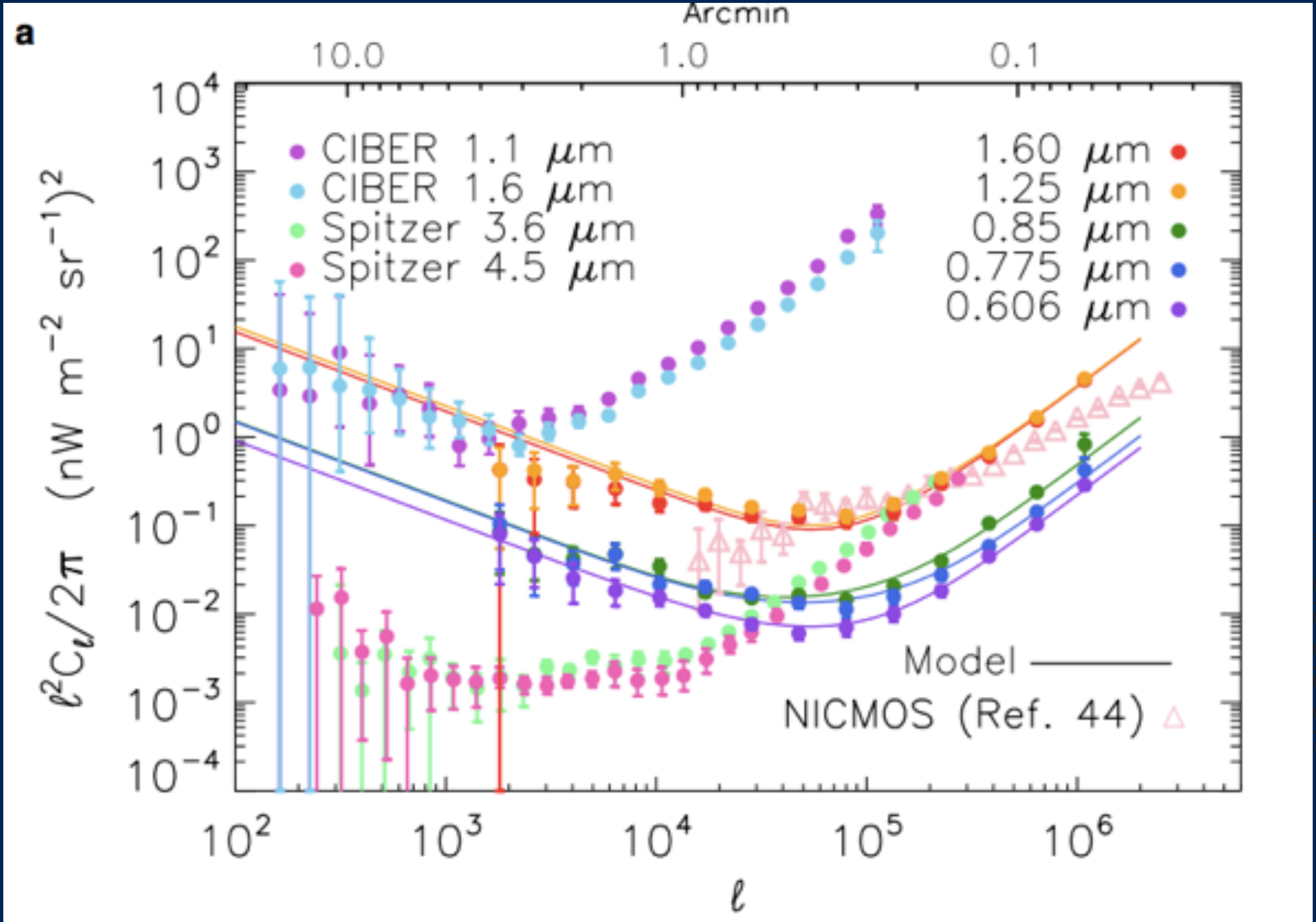


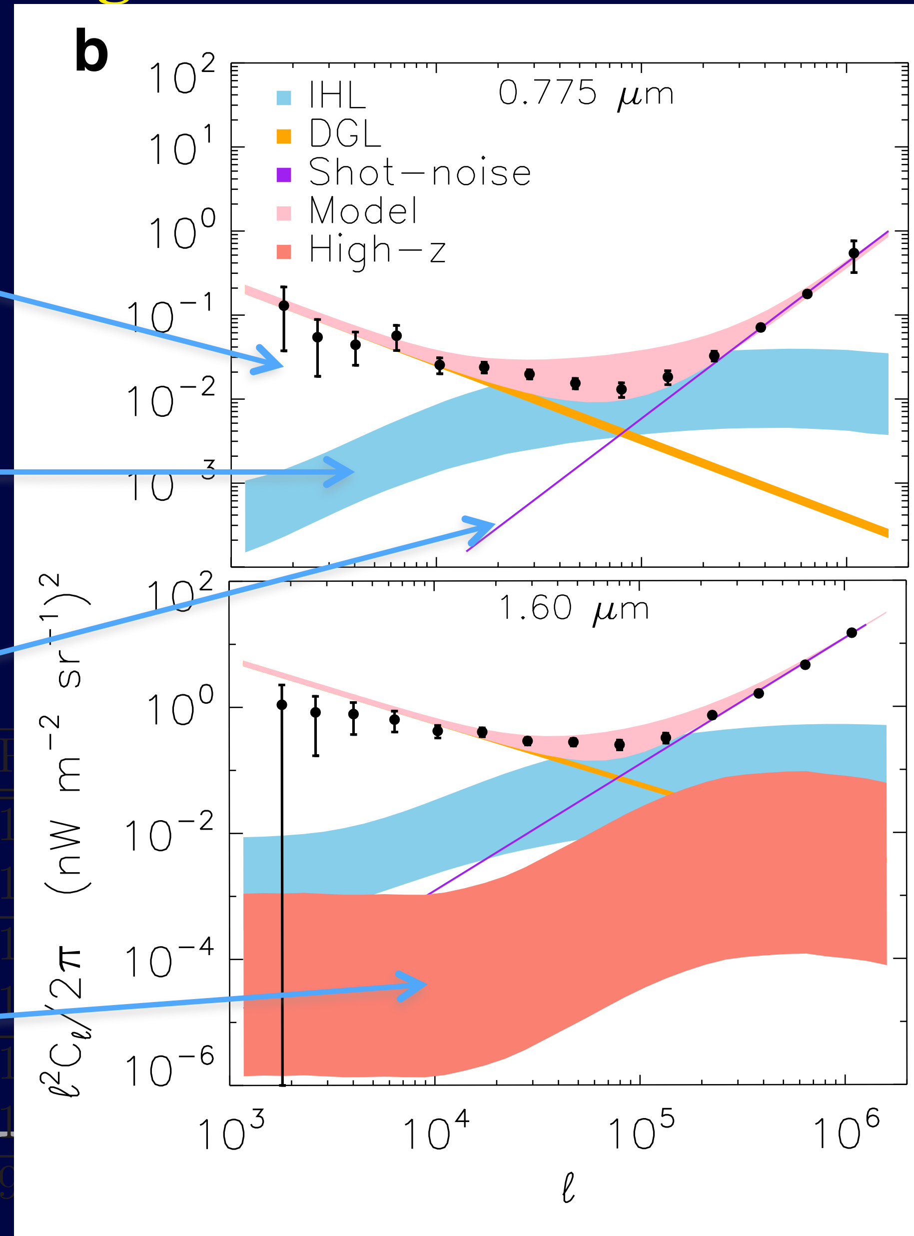
Reionization signal in IR fluctuations?

DGL (?) Component

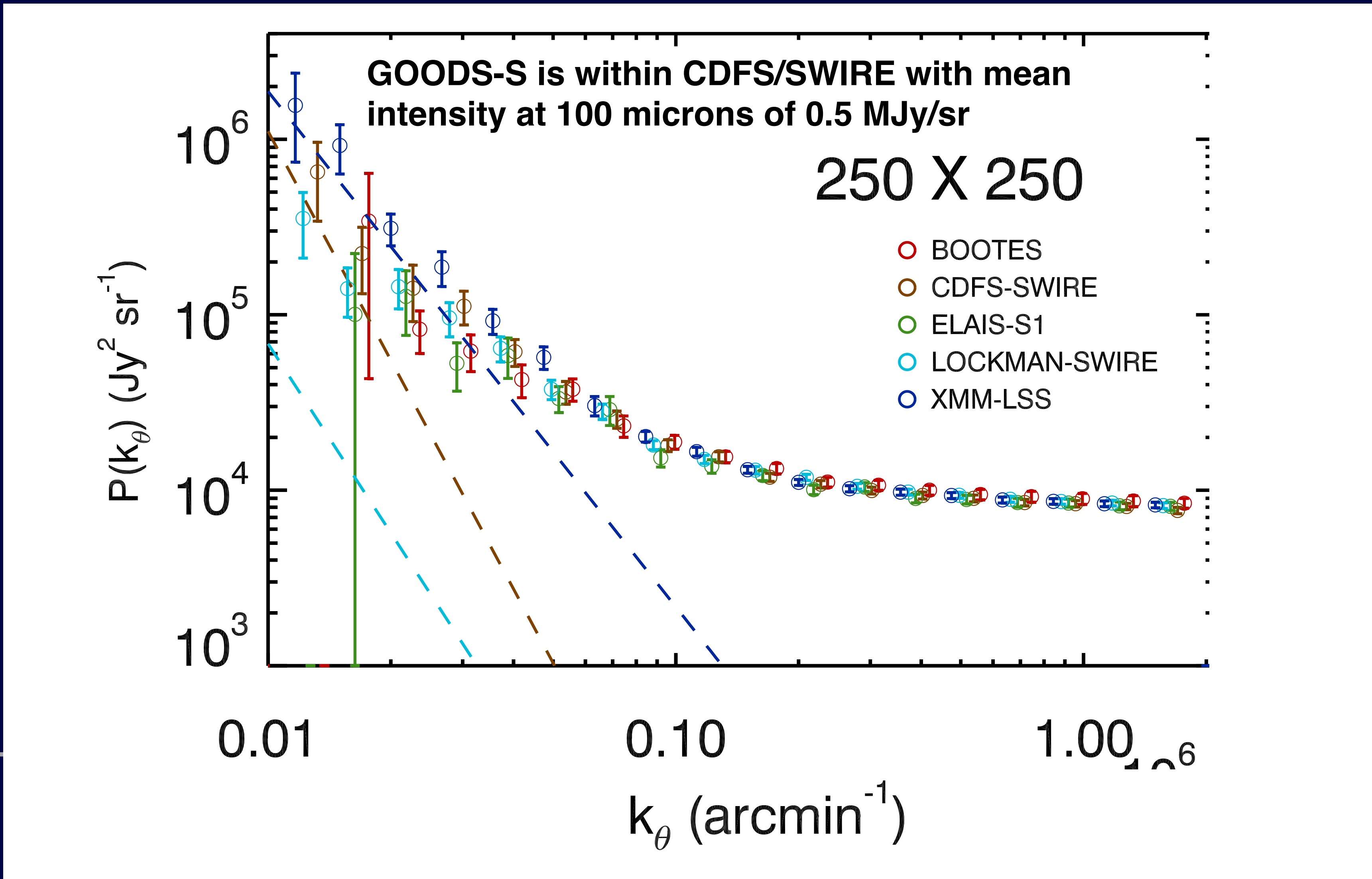
IHL Component

Shot-noise from low-z galaxies

High-redshift galaxies



What's happening at low ell? From CMB/far-IR dust emission. At optical/near-IR dust-scattered interstellar light (Diffuse Galactic Light)



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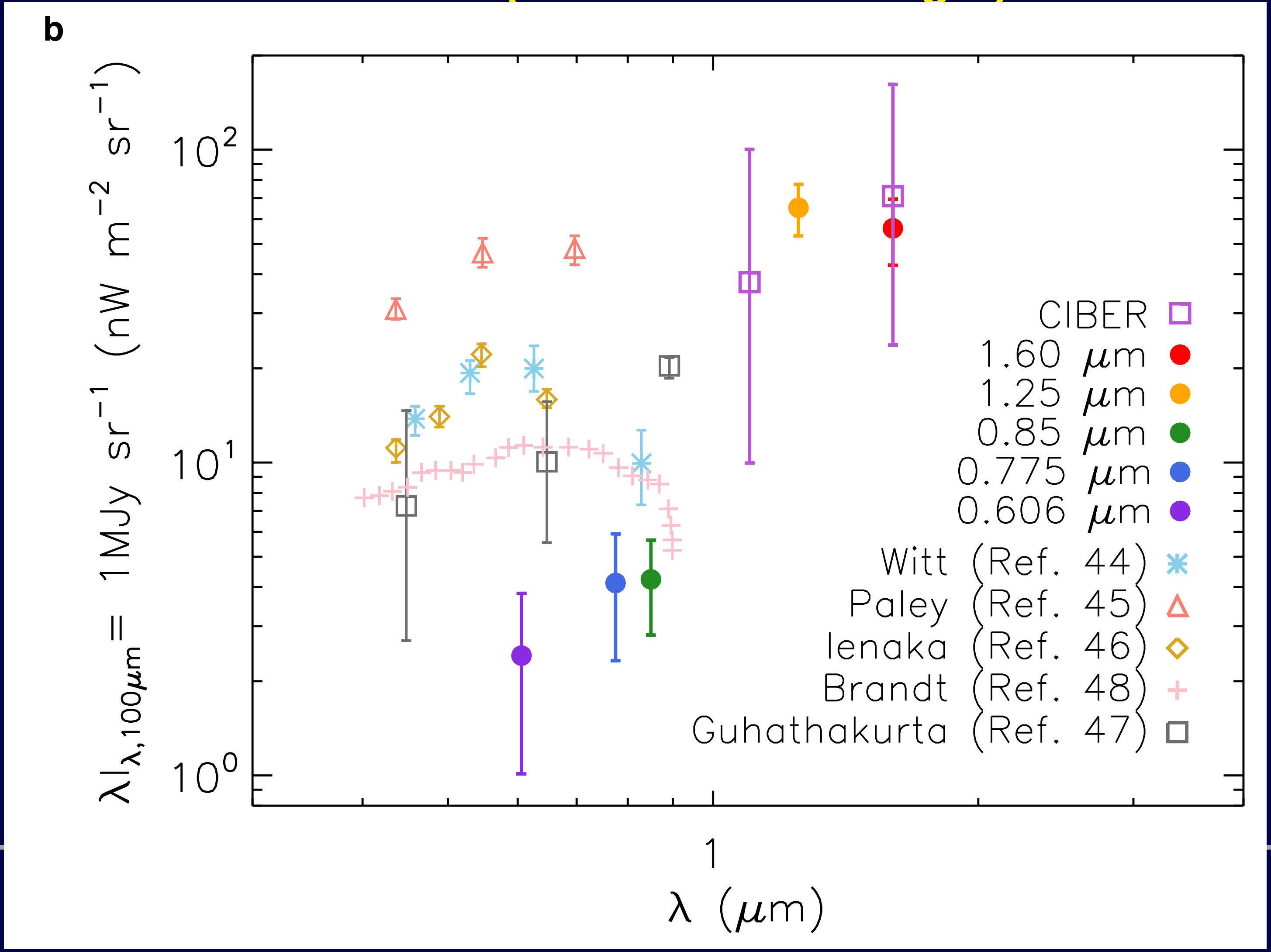

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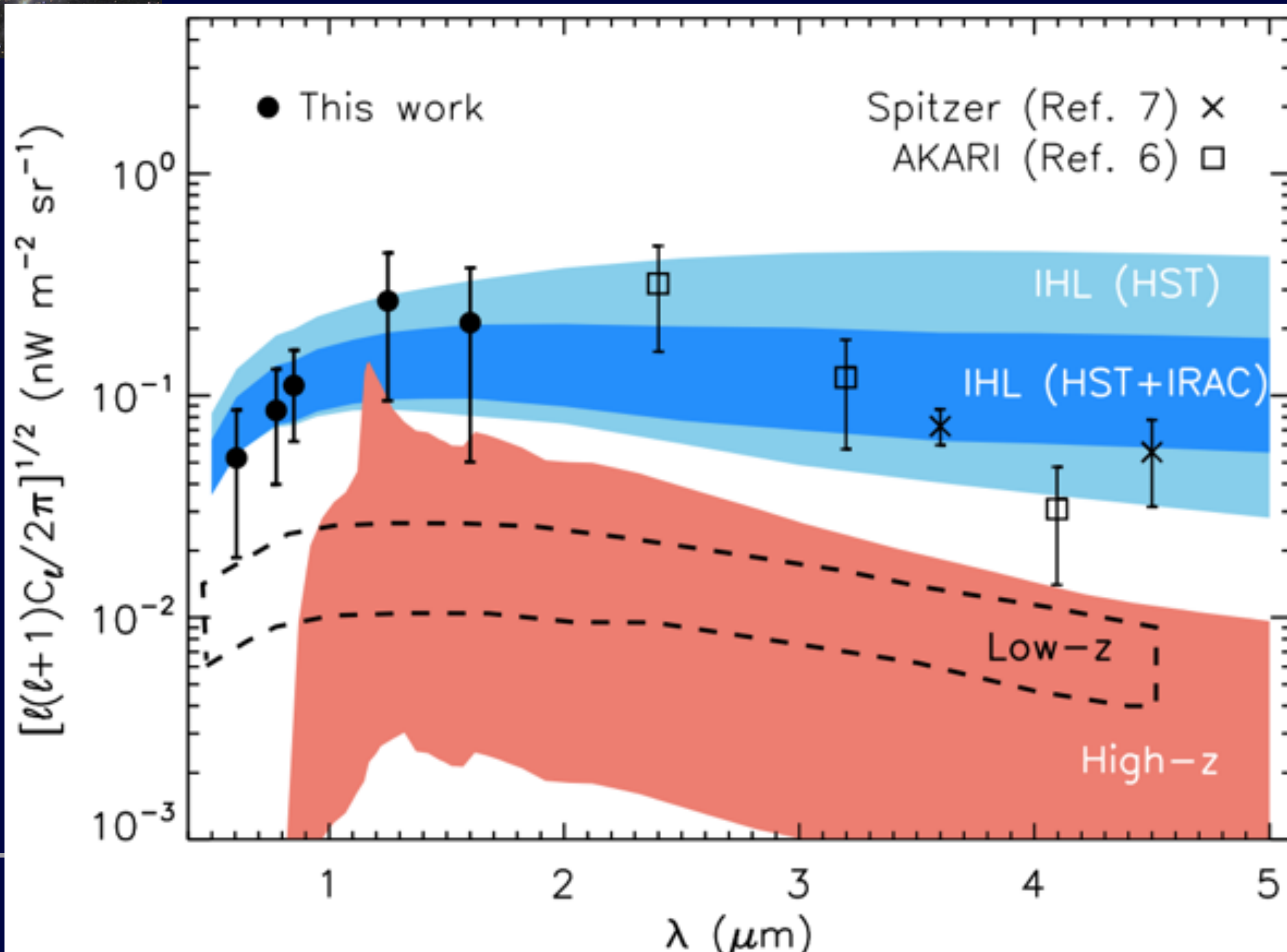
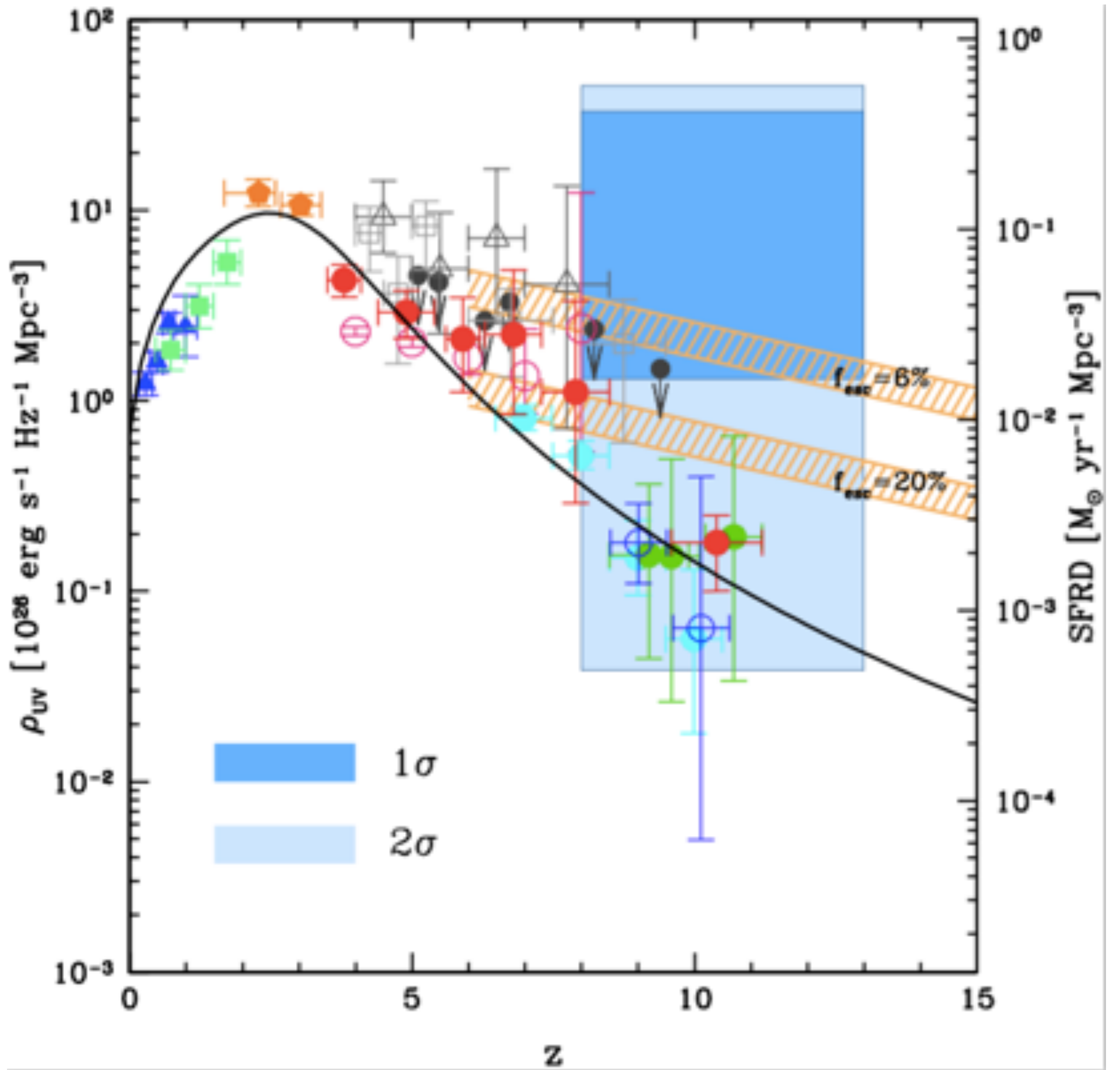
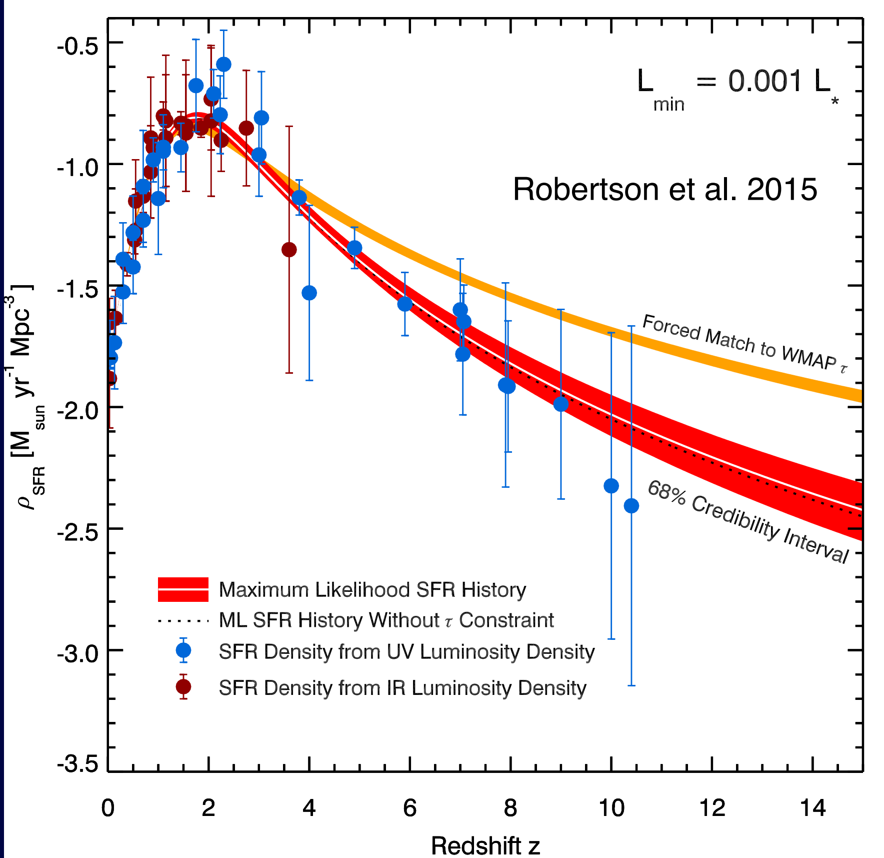


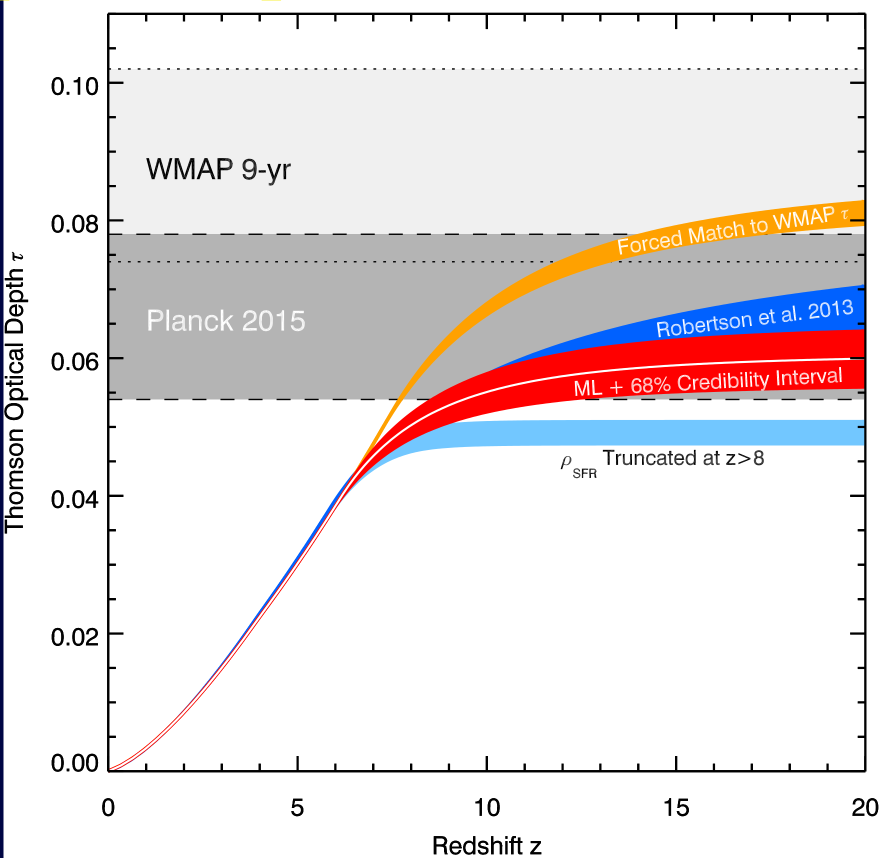
Reionization signal in IR fluctuations?



Mitchell-Wynne et al. 2015
Nature (Communications), in press

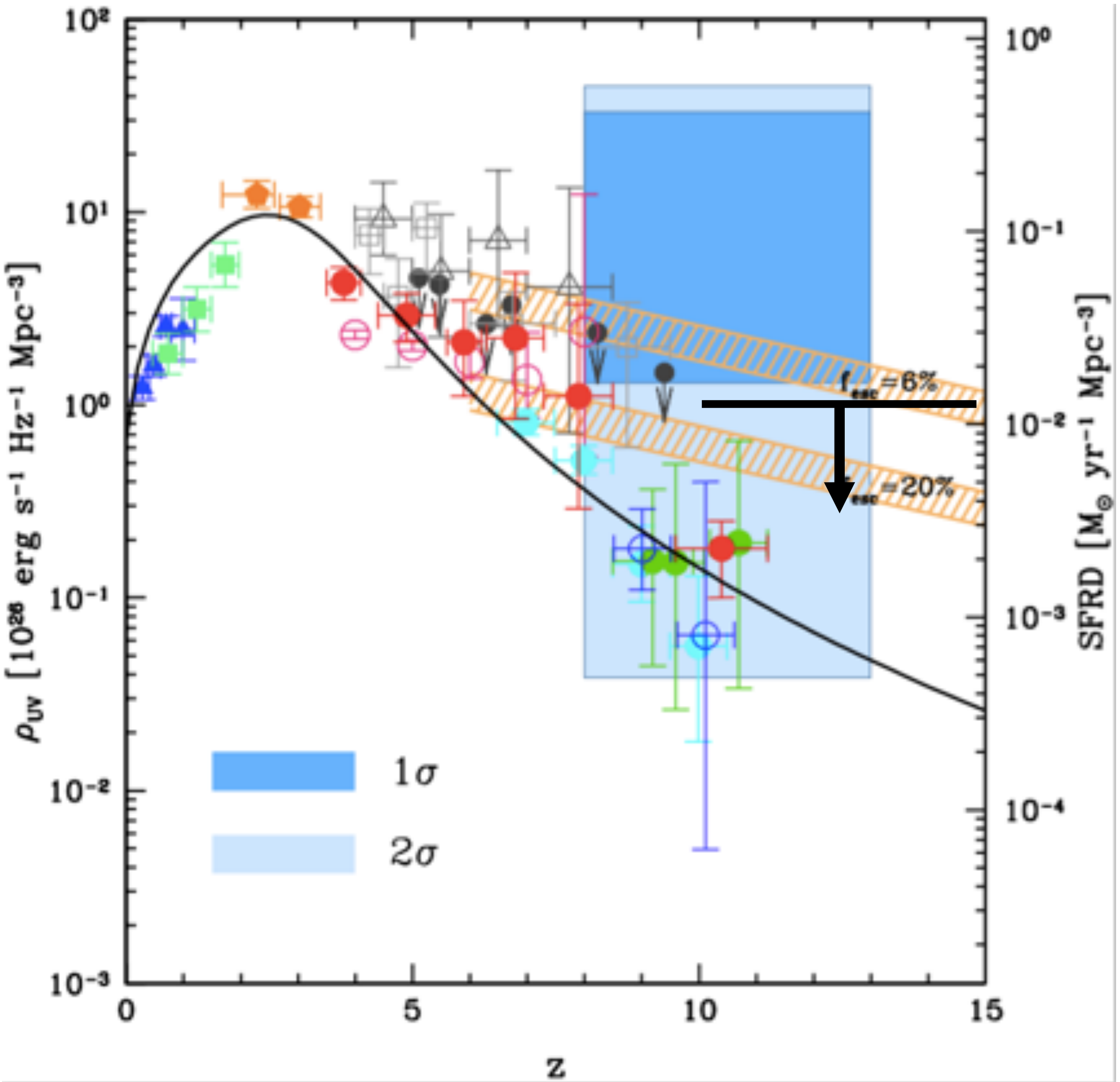
Implications for reionization (especially given low Planck optical depth)





Assuming Planck optical depth of 0.066 from early this year.
Two weeks ago optical depth increased to 0.077.

Implications for reionization (especially given low Planck optical depth)



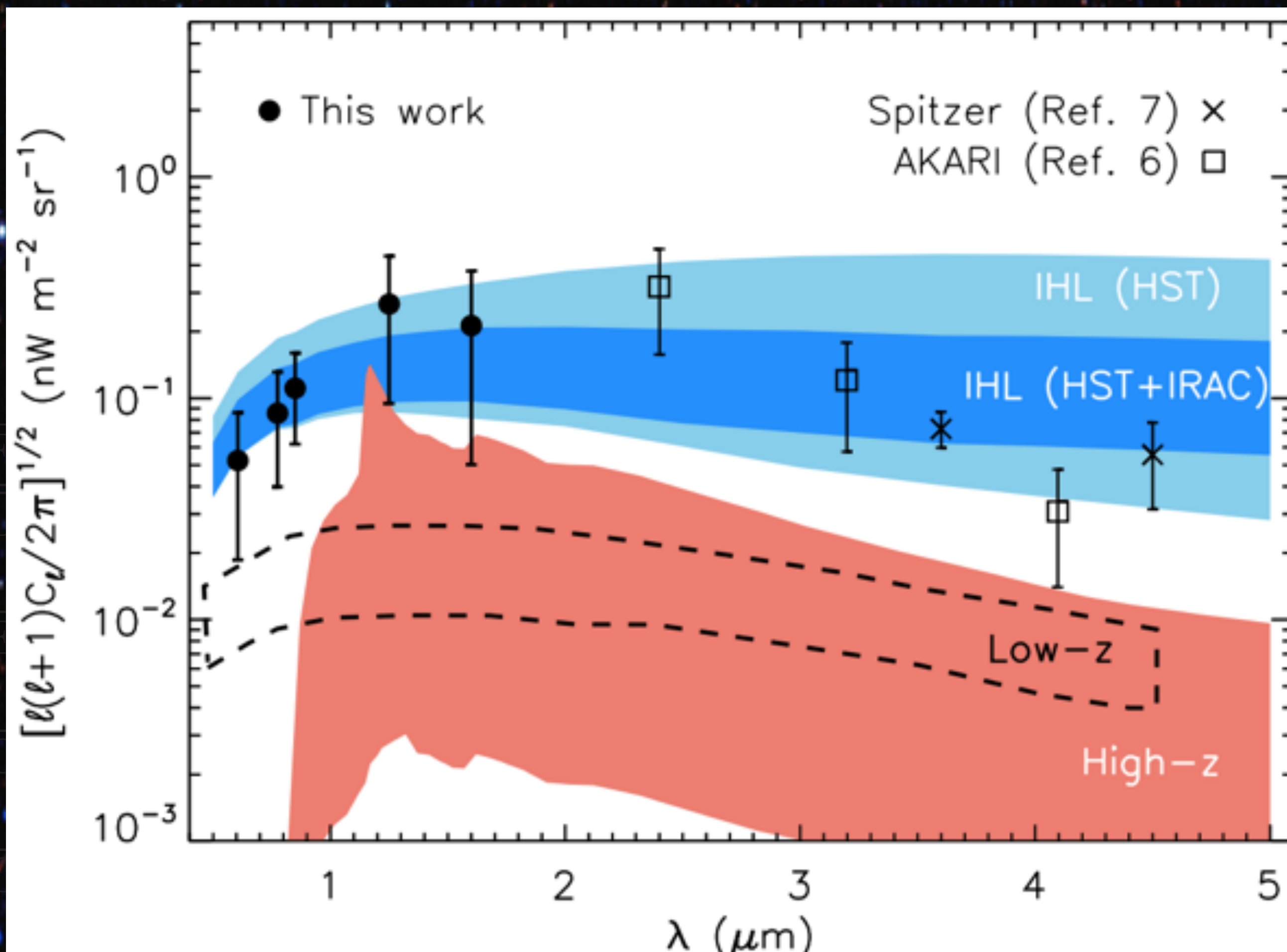
Upper limit on the z > 10 SFRD to be consistent with Planck (Robertson+ 2015) assuming f_{esc}=0.2

Fluctuations implied SFRD is 1sigma higher.

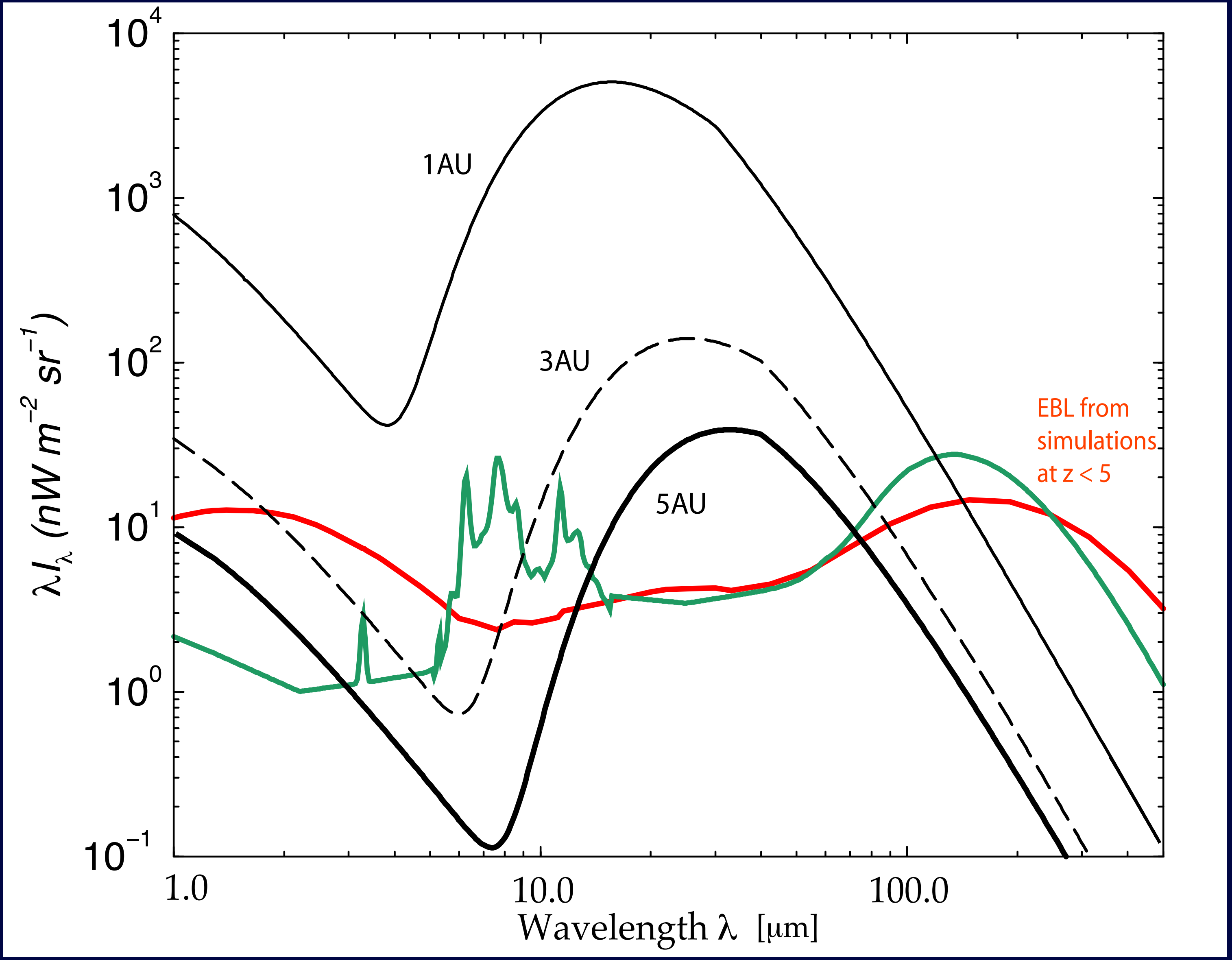
Solutions:
C/f_{esc} large (need f_{esc} < 0.05)

Future (…. HST ….)

Fill existing HST gap between 0.85 and 1.25 microns with F098M and F105W filters. This will separate 6 < z < 11 to two bands 6 < z< 8, 8 < z < 11



Can we measure EBL to sub-1% accuracy?



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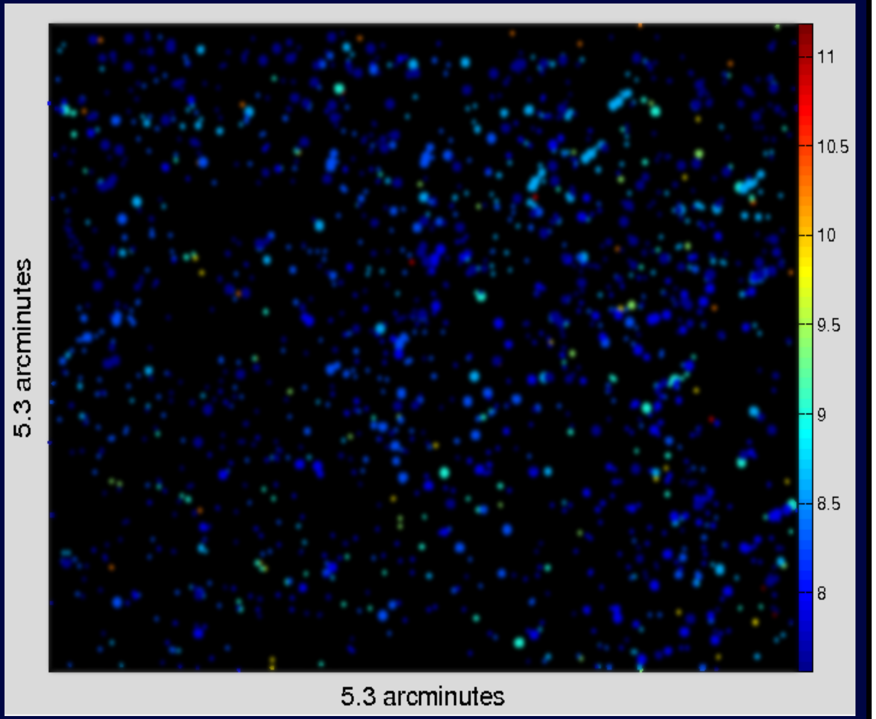
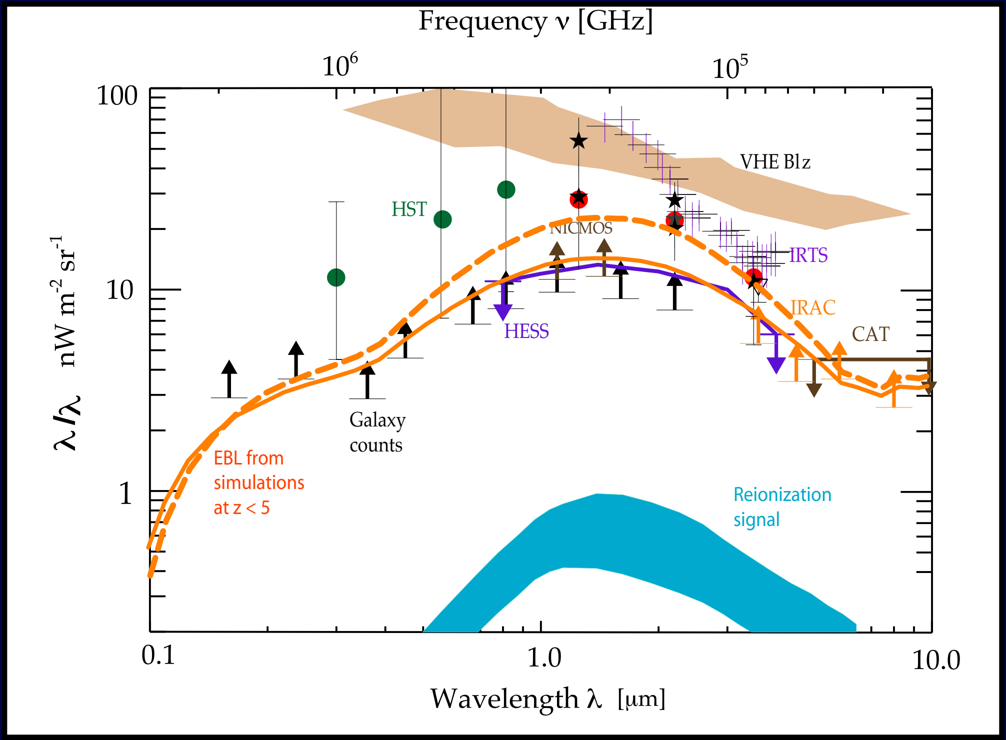
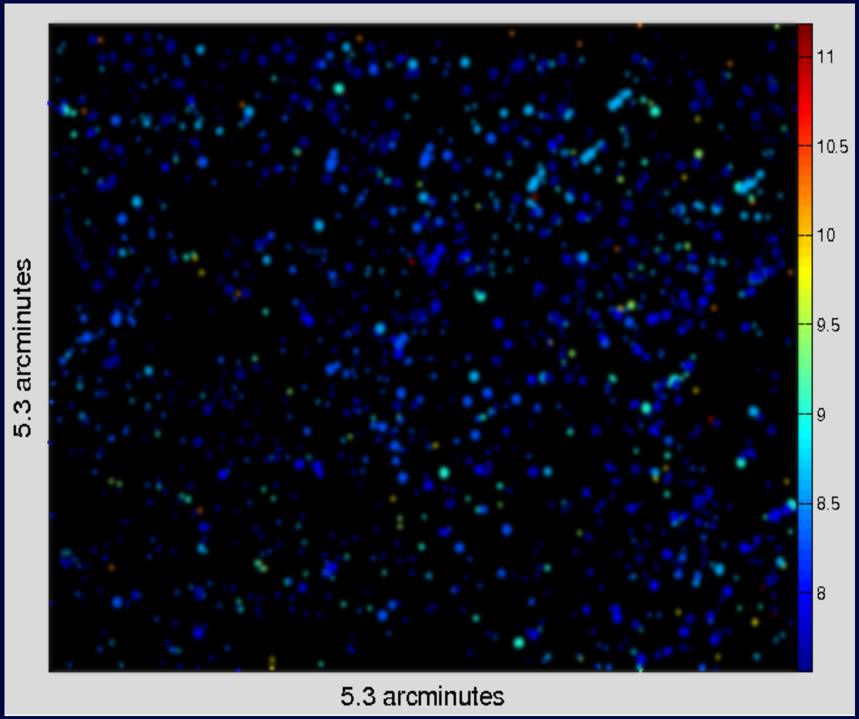


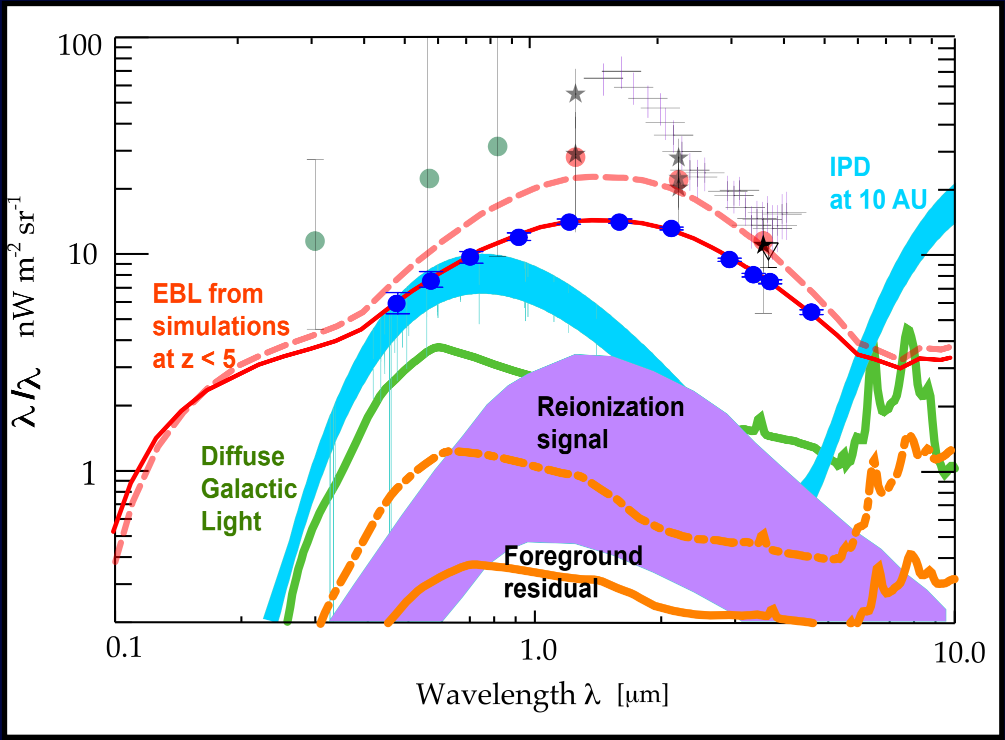


What do we need:

A small aperture telescope with multi-wavelength coverage observing outside of 5 AU

Can we measure EBL to sub-1% accuracy?





What do we need:

A small aperture telescope with multi-wavelength coverage observing outside of 5 AU

ZEBRA Mission Concept Study

Concept Study for Strategic Space Flight Science Missions

ZEBRA

ZODIACAL DUST, EXTRAGALACTIC BACKGROUND AND REIONIZATION APPARATUS

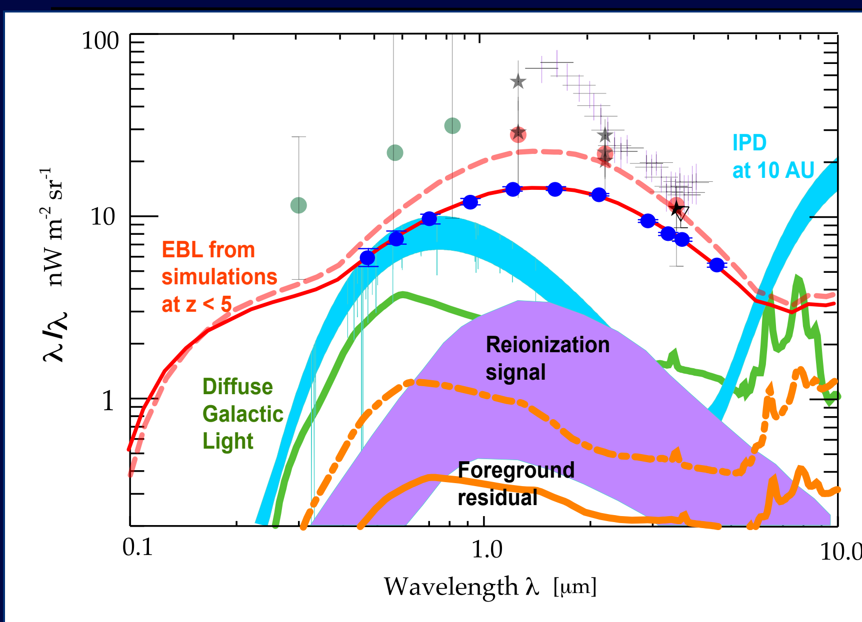
A Science Enhancement Option for an Outer Planet Discovery Mission

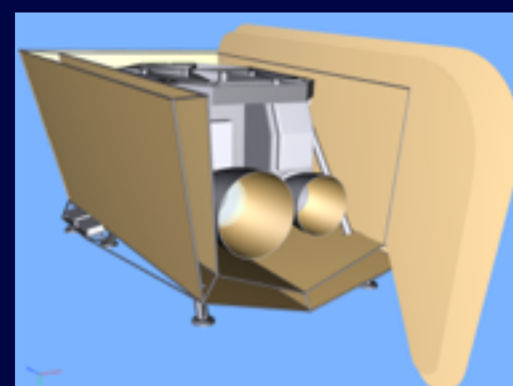
ZEBRA

Two Fundamental Science Goals in One Instrument to the Outer Planets

- **Extragalactic Background Light**
  - Measures galaxy history
  - Epoch of reionization galaxies
- **Zodiacal Dust**
  - Structure and origin of solar system dust
  - Detect and map Kuiper belt dust

- Platform: Outer planets mission to Saturn
- Description of payload instrumentation: Optical to near-infrared absolute photometer with 15 cm telescope; Wide field optical camera with 3 cm telescope
- Mission duration: 5-year outer planets cruise-phase
- Temperature: 50 K
- Pointing requirements: 0.5″ stability over 500 s.
- Data rate to ground (kbits/day): 0.5 Mbpd





Optics: 15 cm & 3 cm off-axis
Wavelengths: 0.4 – 5 μm
Cooling: Passive to 50 K

ZEBRA is a high-TRL instrument with minimum impact to host mission
- All key technologies demonstrated
- Well-defined interfaces
- ZEBRA engineers offset to net mass

Summary

Infrared background is a probe of high-z galaxies and low-z intra-halo light.

From Spitzer fluctuations at 3.6 microns, a 0.1 to 0.5% of IHL fraction in z~1 to 5 Milky Way-like galaxies. CIBERI has extended fluctuations to 1.1 microns, with strong evidence for IHL; CIBERII upgrade in progress, flights from mid 2017.

From Hubble/CANDELS, a measure of total UV luminosity density of the Universe at z > 8 with fluctuations.

An instrument like ZEBRA observing from outer Solar system needed to precisely measure the EBL at optical and infrared wavelengths.