Measuring Light From the Epoch of Reionization with the Cosmic Infrared Background Experiment (CIBER)

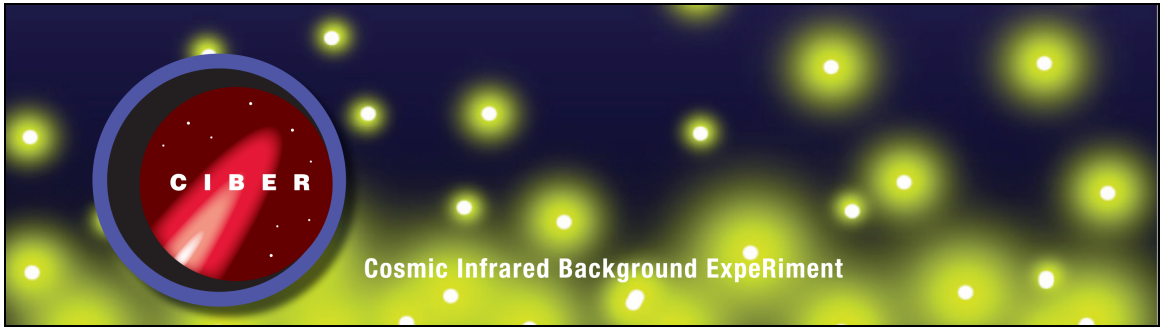
Michael Zemcov for

the CIBER Collaboration

Near Infrared Background and the Epoch of Reionization

Austin, Texas

May 14, 2012



The CIBER Collaboration

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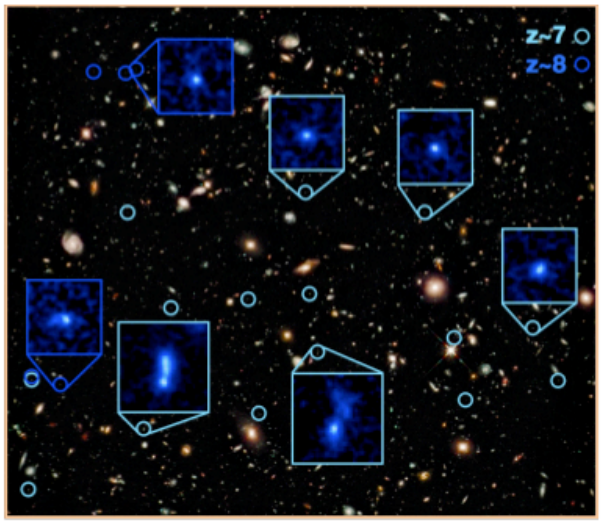
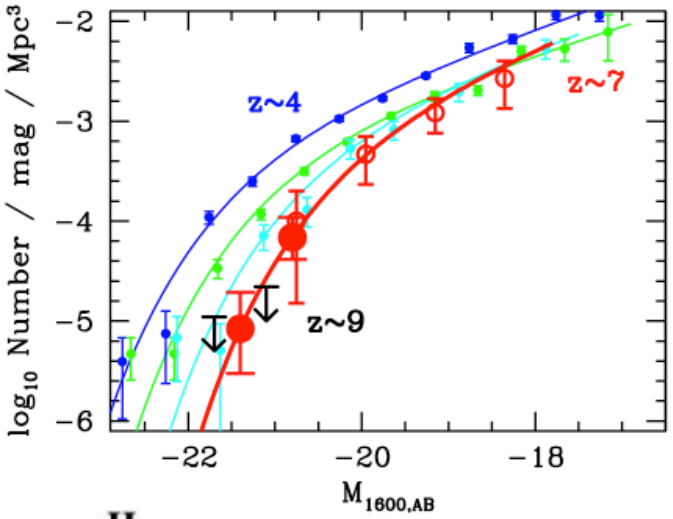
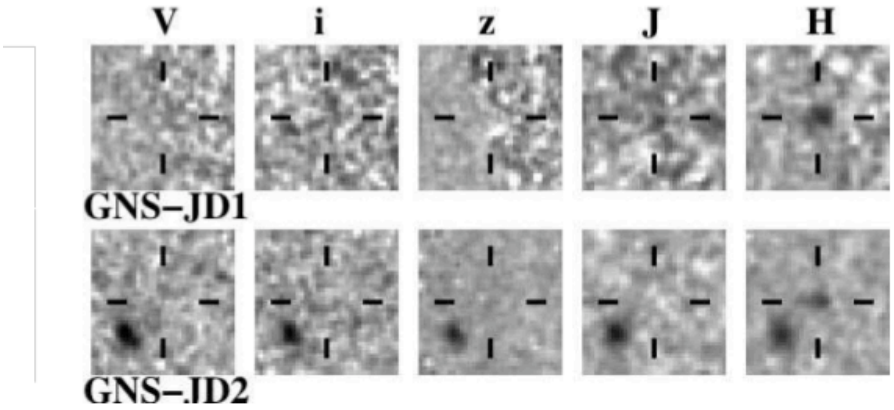
Searching for the Sources Responsible for Reionization

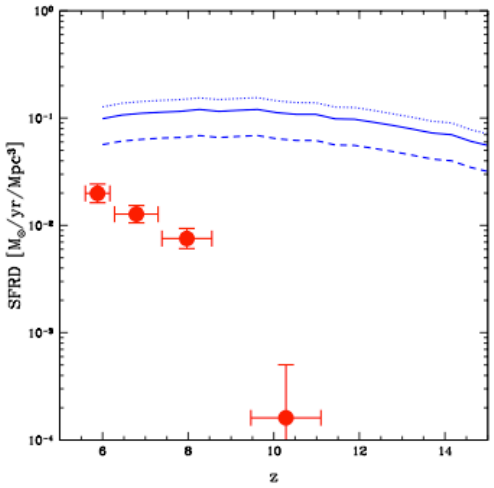


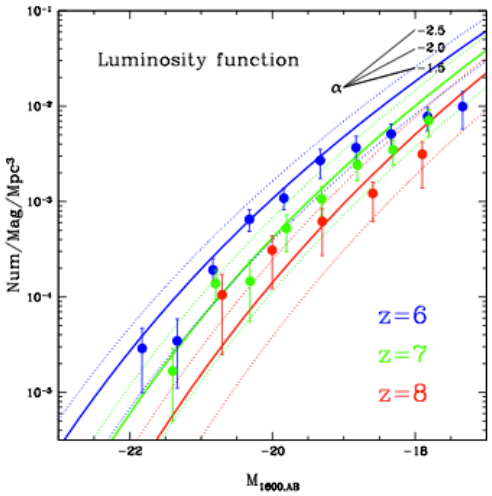




From Bouwens et al. (2010)

Why CIBER?

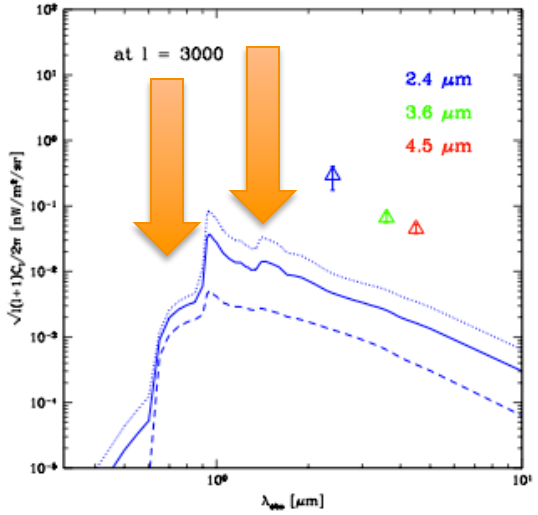


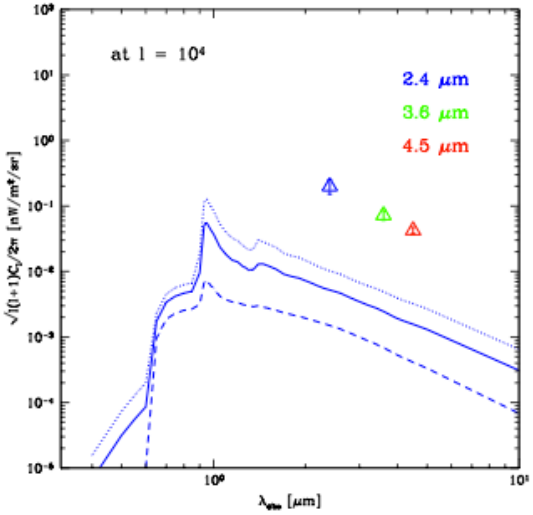


Deficit in inferred SFRD - reionized by lots of faint sources?

Large uncertainty in the faint end slope of the UV luminosity function – the faint sources dominate the integrated light.

Measuring fluctuation power at different wavelengths discriminates foregrounds; amplitude traces minimum halo mass at reionization.



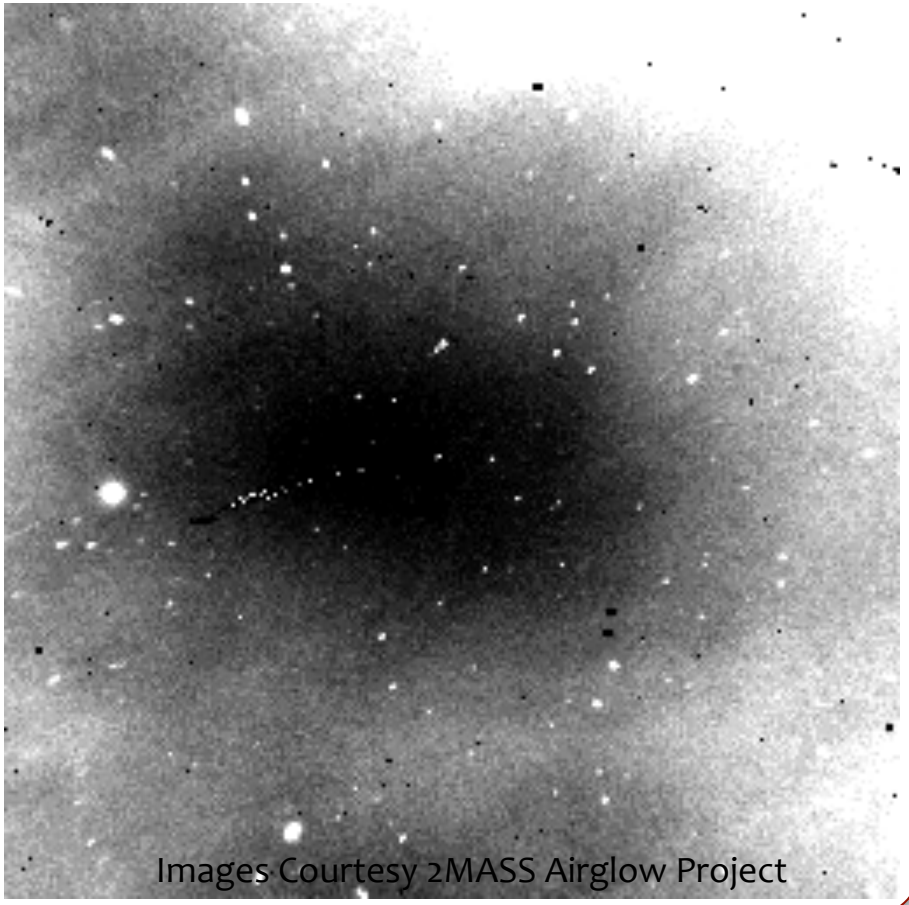


So Why Hasn't This Been Done From The Ground?

Airglow!

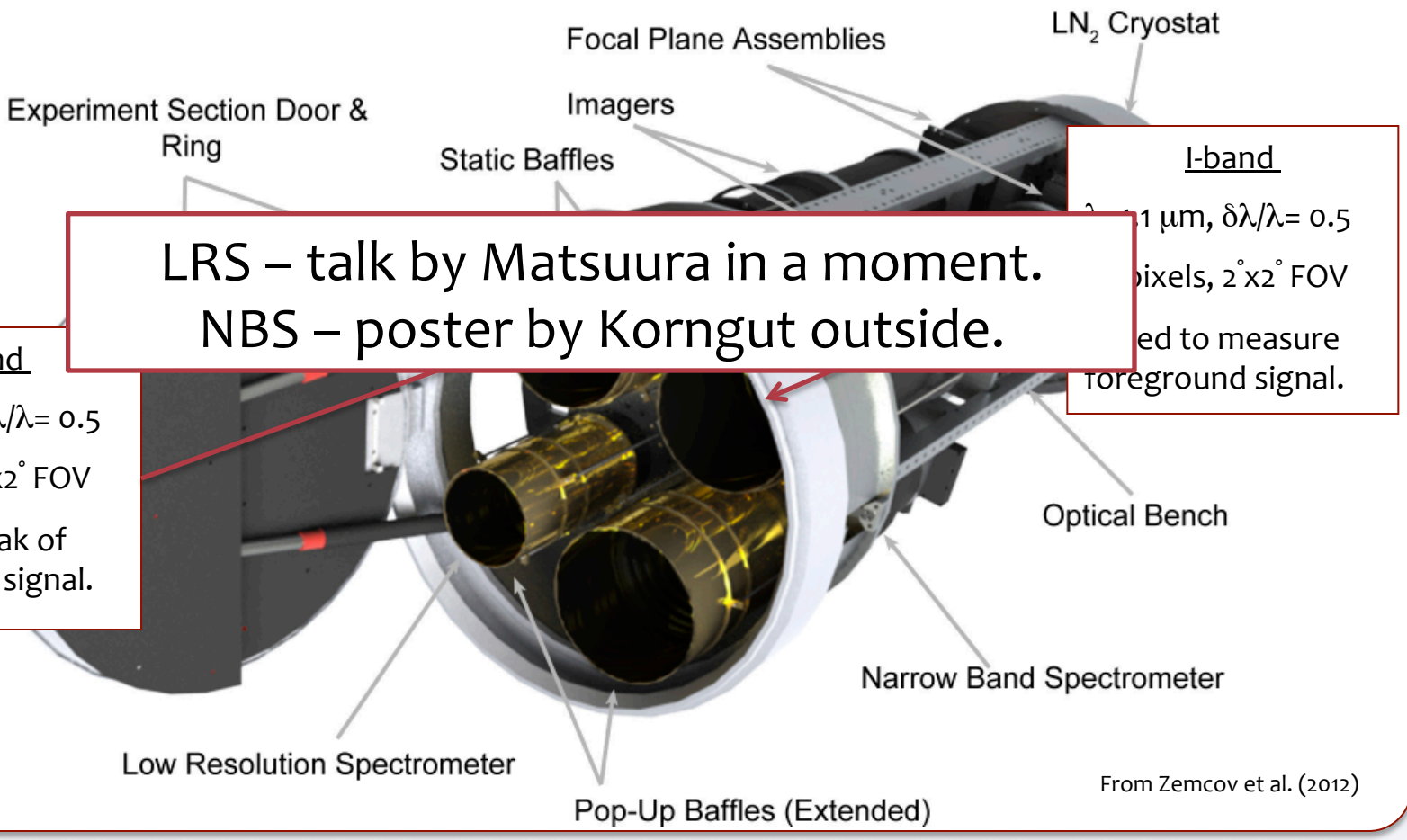
- Due to hydroxyl (OH) molecules in the atmosphere.
- Atmosphere is 500-2500 times brighter than the astrophysical sky around 1 micron.
- Airglow fluctuations in a 1 degree field are 10^6 times brighter than CIBER's sensitivity in a 50s integration.
- The brightest airglow layer is at an altitude of ~100km - even balloons are inadequate.

H-band 9x9 degree^2 image over 45 minutes at Kitt Peak



Images Courtesy 2MASS Airglow Project

The Cosmic Infrared Background ExpeRiment (CIBER)



LRS – talk by Matsuura in a moment.
NBS – poster by Korngut outside.

H-band

λ=1.6 μm, δλ/λ= 0.5

7" pixels, 2˚x2˚ FOV

Tuned to peak of reionization signal.

I-band

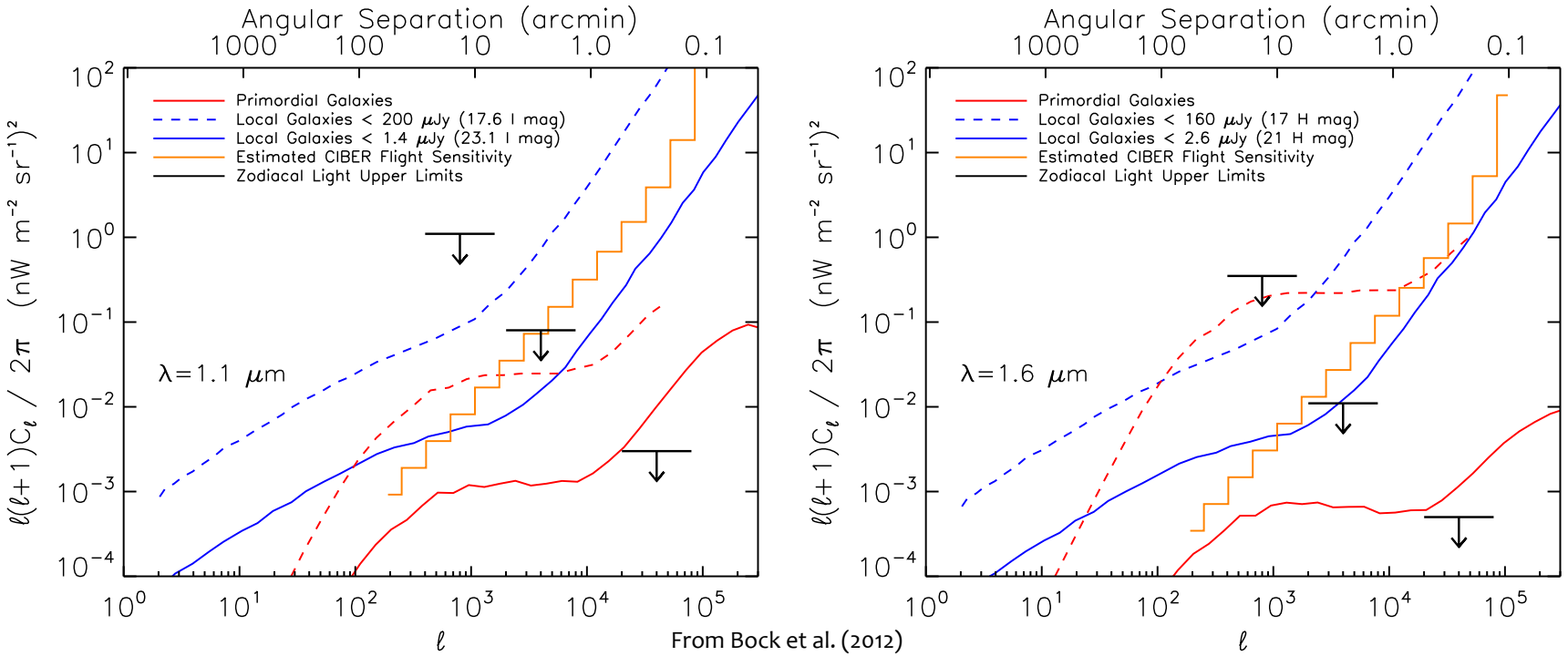
λ=1.1 μm, δλ/λ= 0.5

7" pixels, 2˚x2˚ FOV

Tuned to measure foreground signal.

From Zemcov et al. (2012)

Near IR EBL Power Spectra

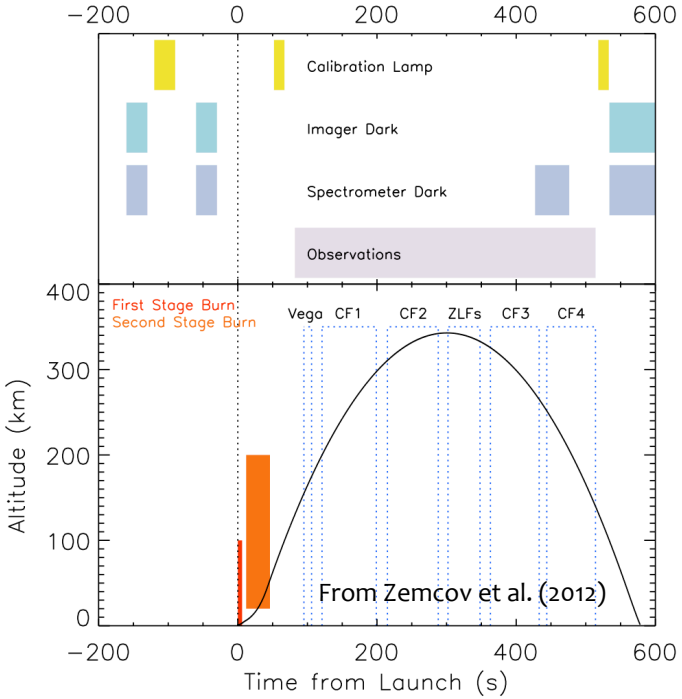


From Bock et al. (2012)

- CIBER's statistical uncertainties allow a high confidence measurement of REBL fluctuations at bright reported levels.
- If fluctuation power is below brightest levels, CIBER will provide strong upper limit on minimum reionization models.
- Cross correlations with measurements at other wavelengths allow strong systematic error checks (see talks from Matsumoto, Joseph Smidt).

Observation Strategy

- Flight is typically 15 mins long with ~425s of data acquisition.
- Have flown CIBER three times; first in Feb 2009, then in July 2010 and finally Mar 2012.
- Data quality from first flight was marginal, but second two flights very good.



Ancillary Data

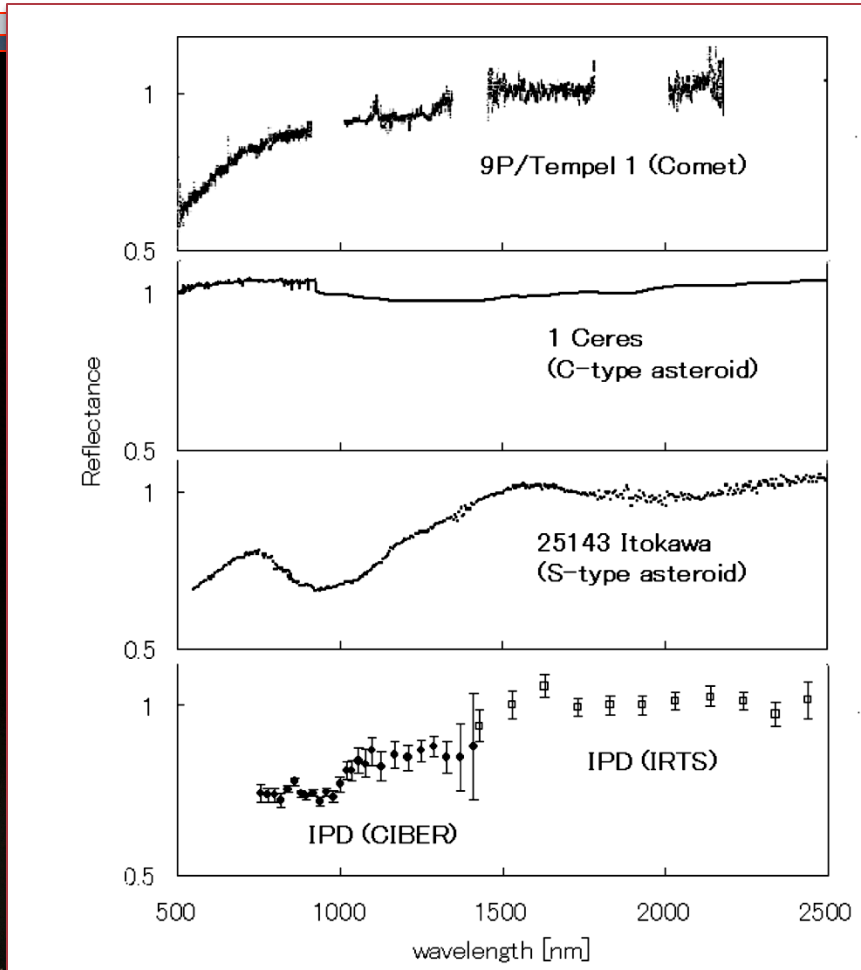
	R 0.6 μm	I 0.8 μm	J 1.3 μm	H 1.6 μm	K 2.2 μm	L 3.5 μm
SWIRE-N1	24.0	23.0	22.0		21.0	19.0
NEP	23.8	23.0	20.5		19.0	
Bootes	26.0	25.5	21.0	19.6	20.0	19.5
Lockman			22.0		21.0	19.0
XMM-LSS	26.0	25.8	23.5	22.7	21.8	19.0
CDFS	24.8	23.6	23.5	22.7	21.8	19.0
SWIRE-S1	24.5	24.0	23.5	22.7	21.8	19.0

Estimated 5σ flux limit in Vega magnitudes

Why CIBER is robust to systematic errors:

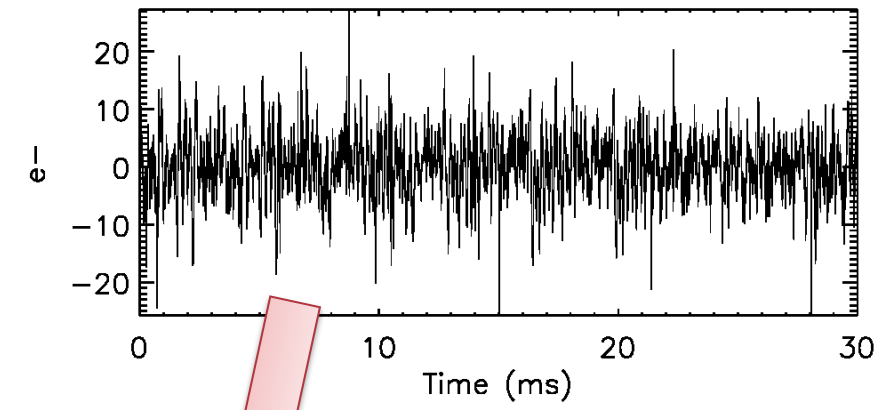
• Zodiacal Smoothness?	Observe same sky in two different seasons.
• Flat Field?	Use diff. images, lab flat, Season1 x Season2.
• 1/f noise?	Assess using sky diffs, remove in x-correlations.
• Galaxies?	Large ℓ separation from EOR.
• Foregrounds?	EOR has very different colors.
• Anything else?	Cross-correlate with Spitzer.

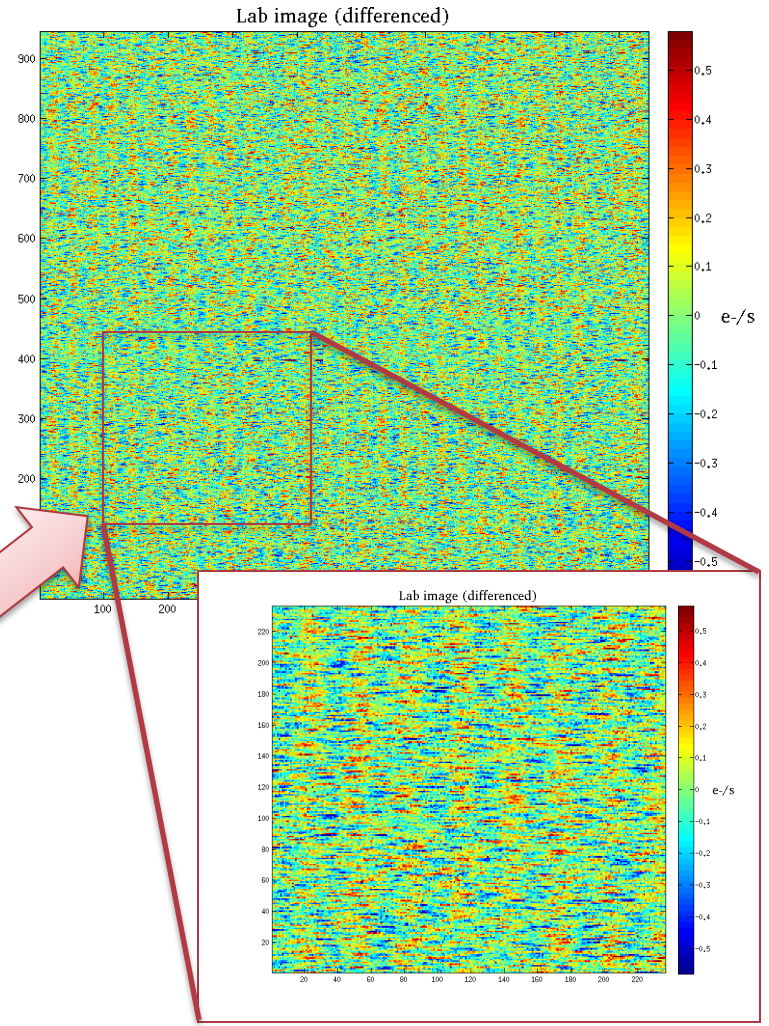
Flying CIBER



Zodiacal light spectrum result from Tsumura et al. (2010) "Observations of the Near-Infrared Spectrum of the Zodiacal Light with CIBER", 2010, ApJ, 719, 394

Imager Data Properties





From Bock et al. (2012)

Imager Data Properties

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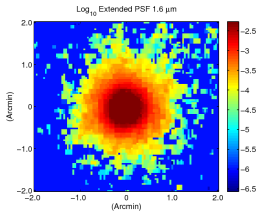
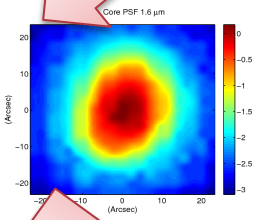
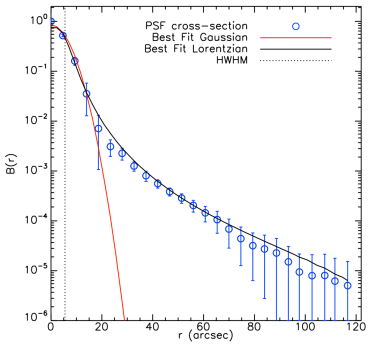
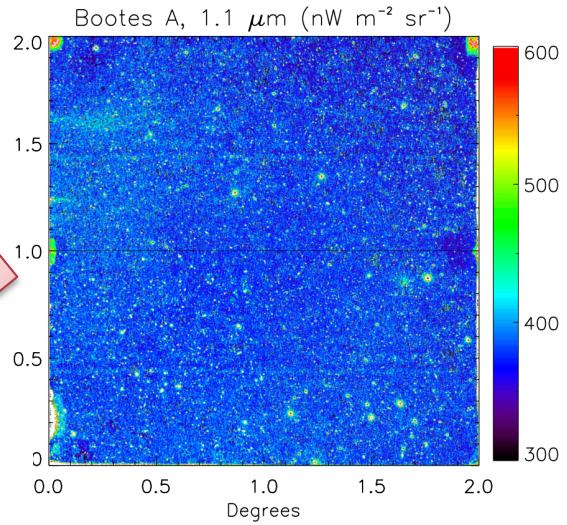
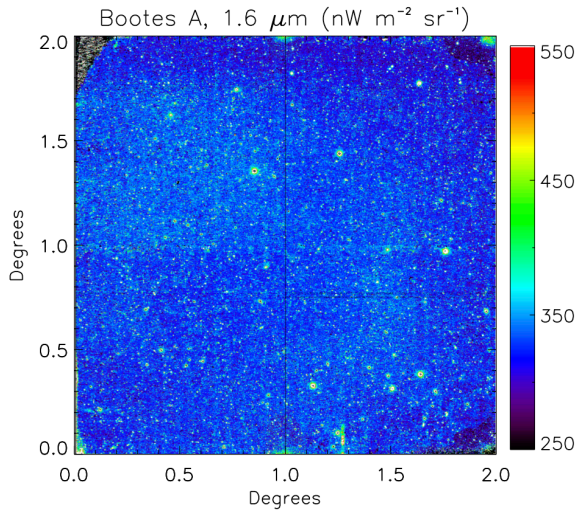
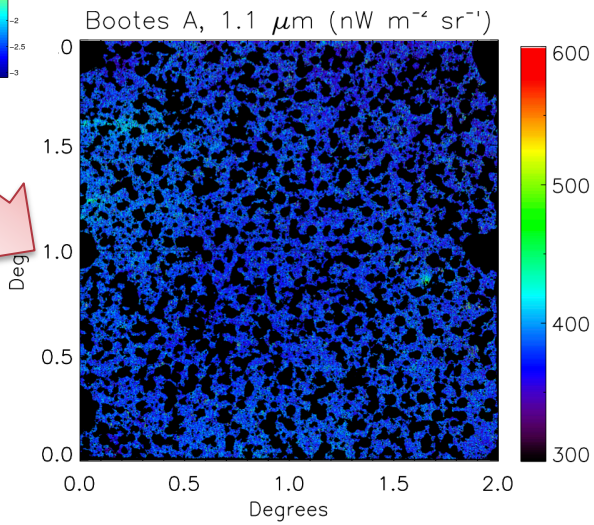


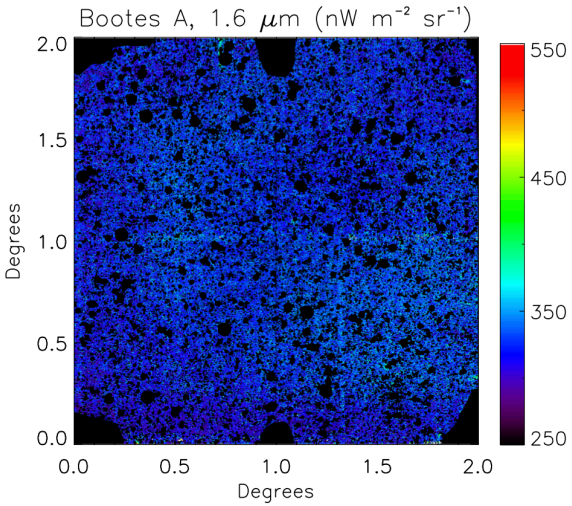








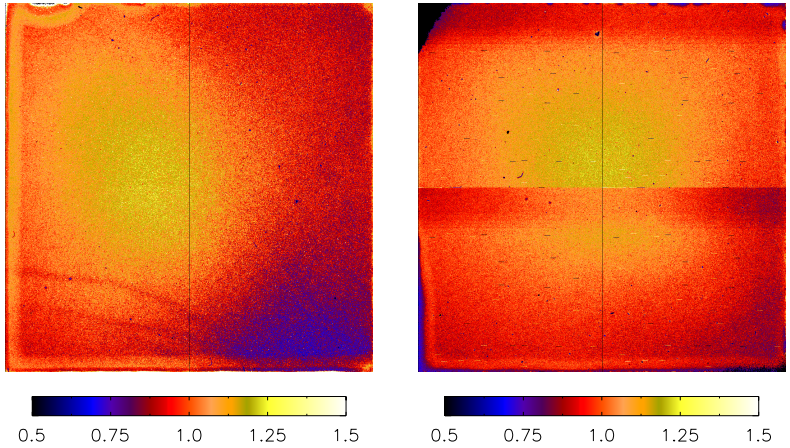


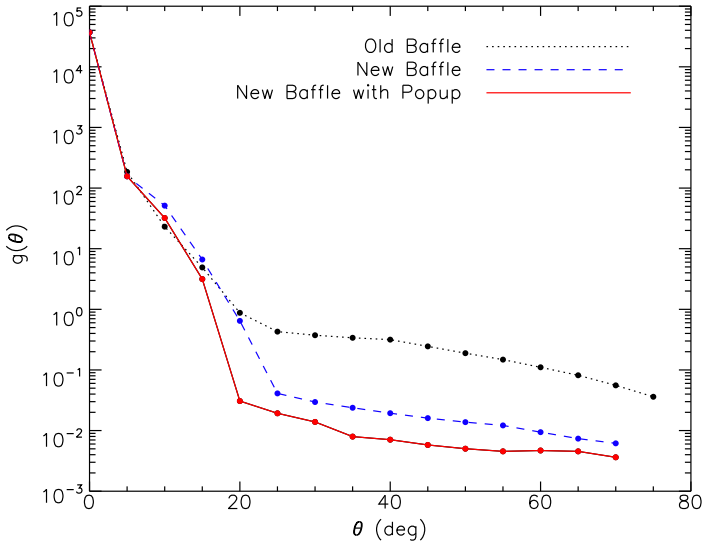


Imager Laboratory Data

Absolute Calibration
- From stacks on sources in flight.
- Verified using NIST system in the lab.

Flat Fielding
- Calculated from median of source masked flight images.
- Verified from measurements in the lab.

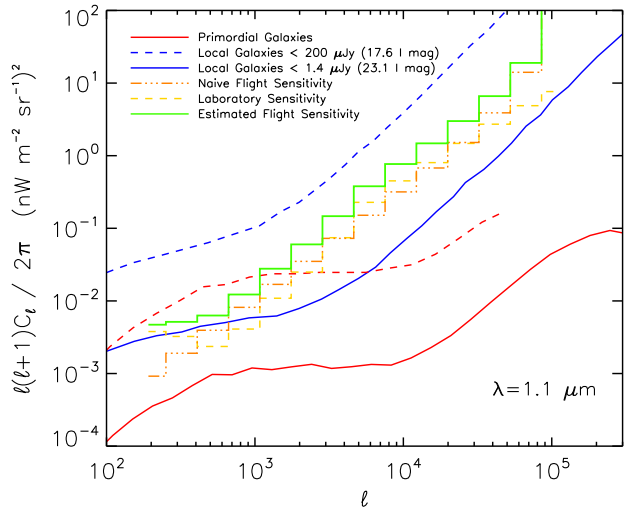


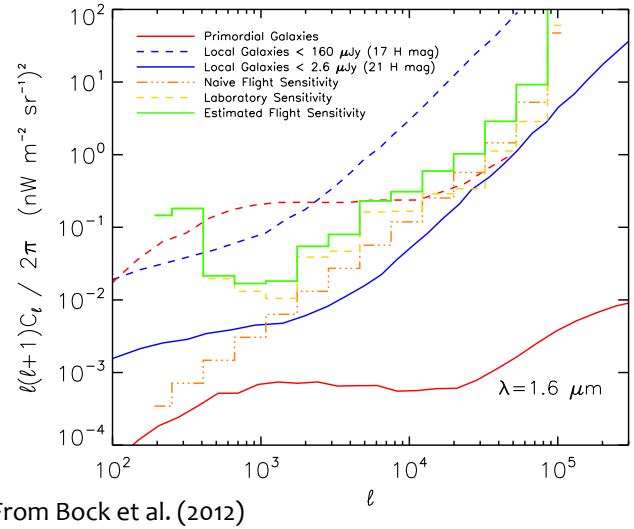


Noise Properties
- Estimated from time PSD, field differences.
- Noise model will allow calculation of uncertainties in flight data.

Stray Light
- Determined from laboratory off-axis light measurements.

Achieved Performance





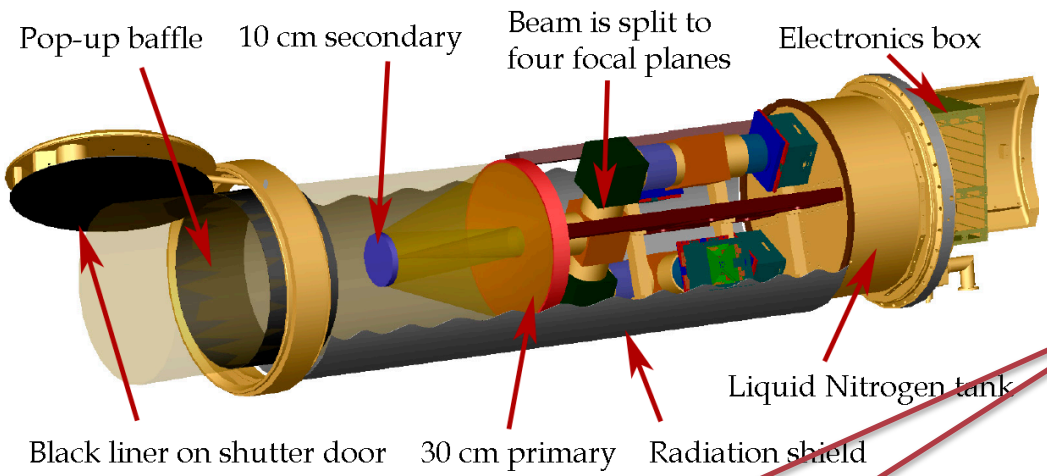
From Bock et al. (2012)

- Surface brightness sensitivity very slightly larger than predicted due to correlated noise in detectors.
- Calculation of auto spectrum flight sensitivities similar to pre-flight estimates.

Table 4: Calculated and Achieved Sensitivities in a 50 s Observation.

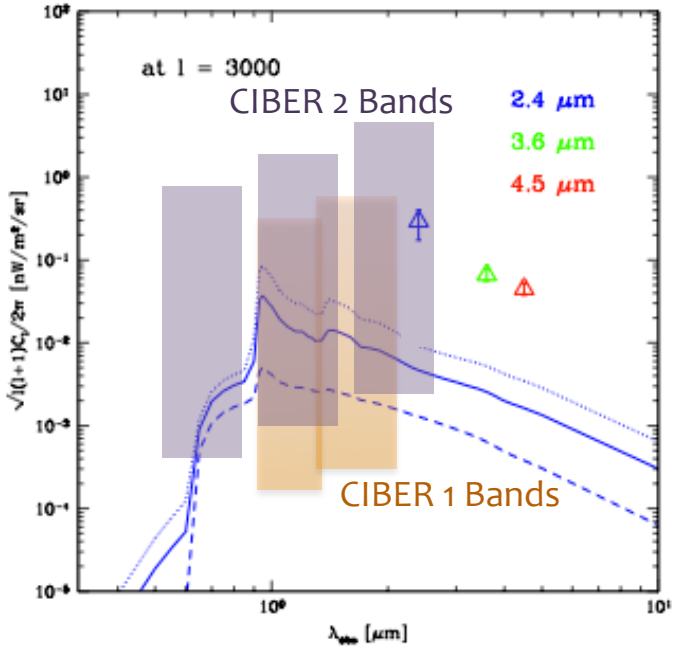
	1.1 μm Imager		1.6 μm Imager		
	Predicted	Achieved	Predicted	Achieved	
Sky brightness	450	420	300	370	nW m^{-2} sr^{-1}
Photo current	4.4	4.9	8.2	11.0	e$^-$/s
Responsivity	10	11	28	31	me$^-$ s^{-1} / nW m^{-2} sr^{-1}
Current Noise	0.31	0.35	0.41	0.45	e$^-$ s^{-1} (1σ/pix)
$\delta\lambda I_\lambda$	31.7	33.1	15.1	17.5	nW m^{-2} sr^{-1} (1σ/pix)
δF_ν	18.5	18.4	18.2	17.8	Vega Mag (3σ)

CIBER-2



CIBER-2 improves on CIBER-1 with 3 bands and ~10x greater AΩ which maximizes sensitivity to ℓ modes of interest.

Aperture	30			cm
Pixel Size	4			arcsec
FOV	2.3 x 2.3			degrees
λ (Δλ/λ)	0.6 (0.4)	1.3 (0.4)	2.05 (0.35)	μm
Array	H2RG	H2RG	H2RG	2048² format
νI_ν (sky)	850	600	200	nW m^{-2} sr^{-1}
$\delta\nu I_\nu$ (1σ/pix)	32	25	11	nW m^{-2} sr^{-1}
δF_ν (3σ)	21.0	18.3	17.8	Vega mag
F_ν @ 20% cut	25	23	22	Vega mag



Summary

• The sources responsible for reionization are typically intrinsically faint and even the most powerful planned telescopes will have difficulty resolving all of them.

• Measuring fluctuations in the near IR EBL can provide important information about these early galaxies and their effect on the process of reionization.

• CIBER will measure spatial anisotropies in the IR EBL caused by large scale structure in the range $8 < z < 20$ using two broadband imaging instruments.

• **CIBER has flown three times and our release of a fluctuations result is imminent.**