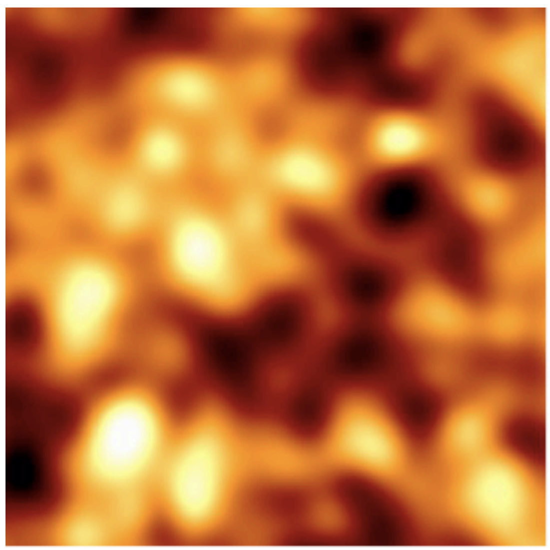
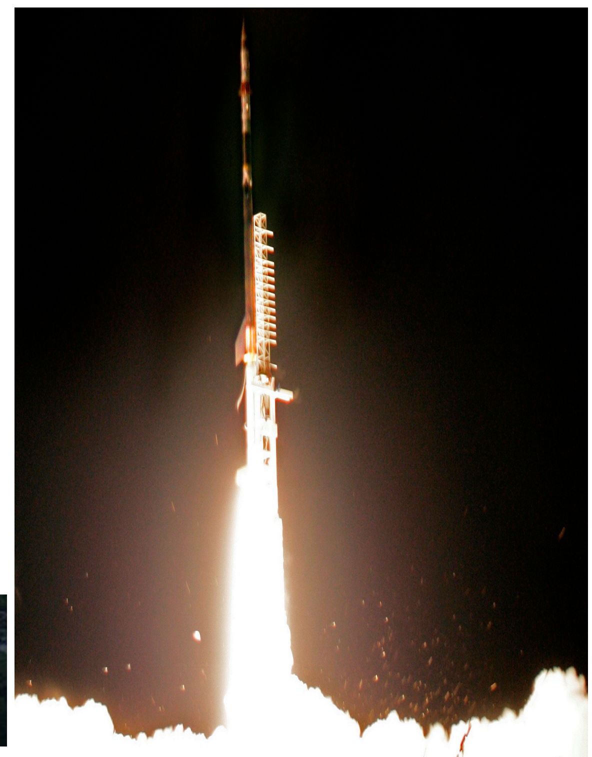
Searching for Signatures of Reionization in the Cosmic Infrared Background

Asantha Cooray

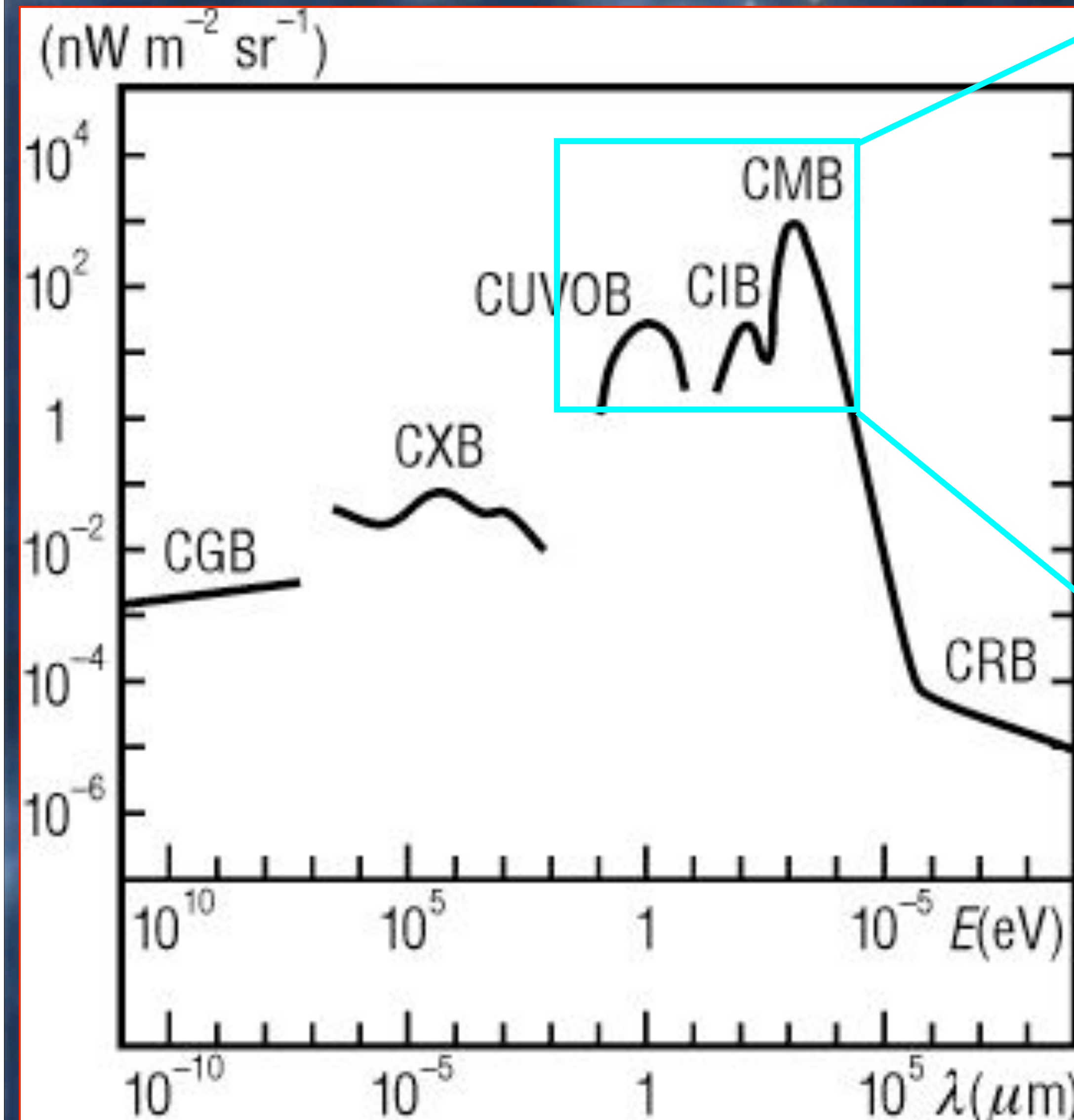
UCIrvine
University of California, Irvine

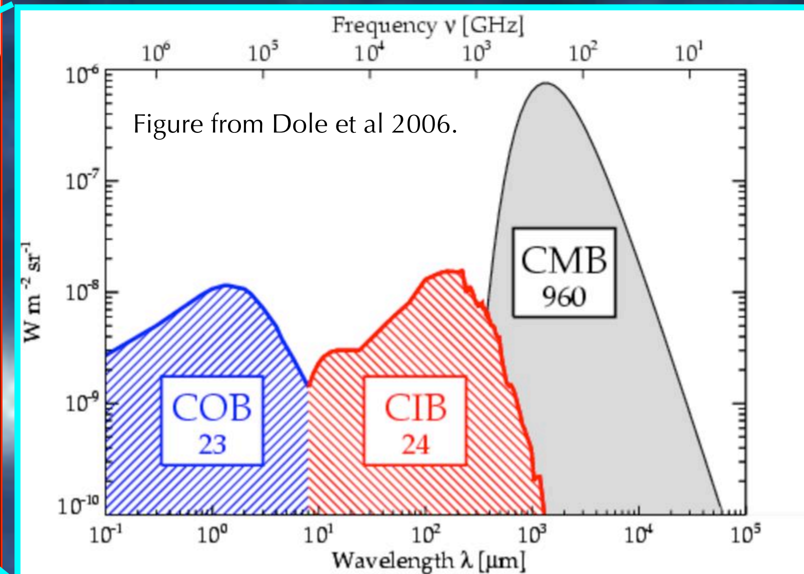


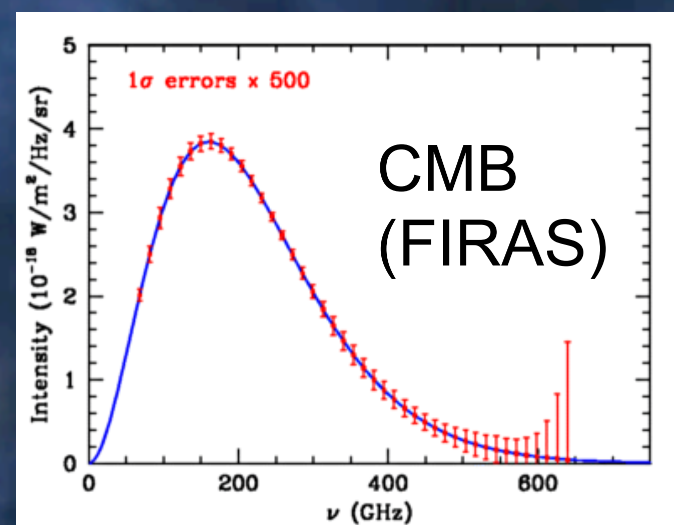


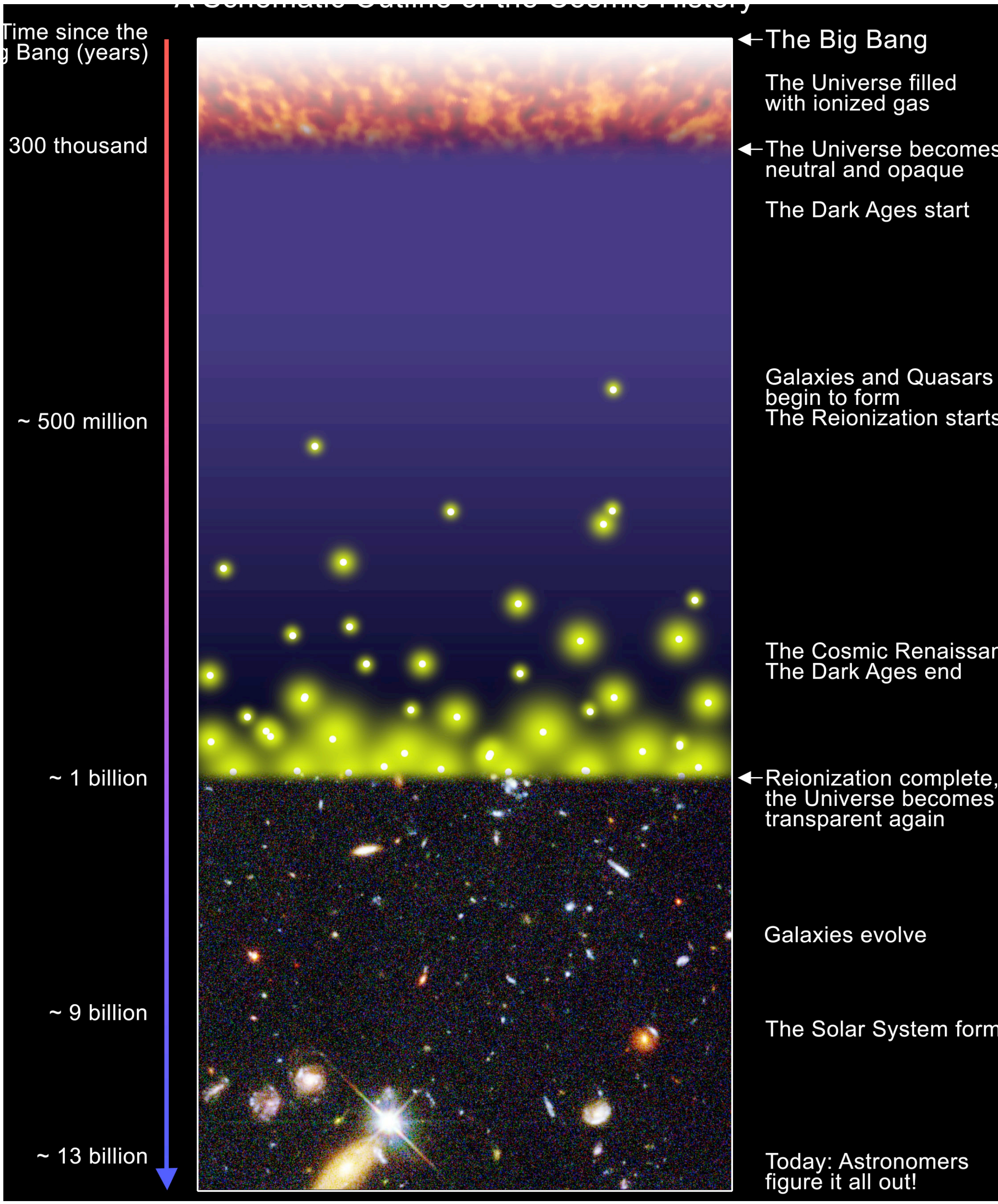
CIBER
Cosmic Infrared Background ExpeRiment

The Extragalactic Background Light Spectrum









Why study the Extragalactic Background Light?

The sum of light from all nucleosynthesis in stars since the Big Bang, a quantity of fundamental interest in cosmology

What do we learn from the EBL?

Amplitude and spectrum constrain galaxy formation and evolution over cosmic time

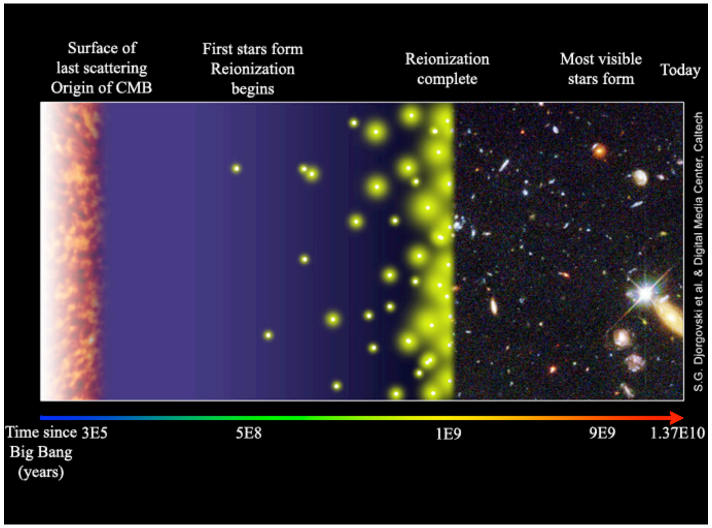
If properly measured, EBL spectrum provides a key anchor to separate competing models of structure formation

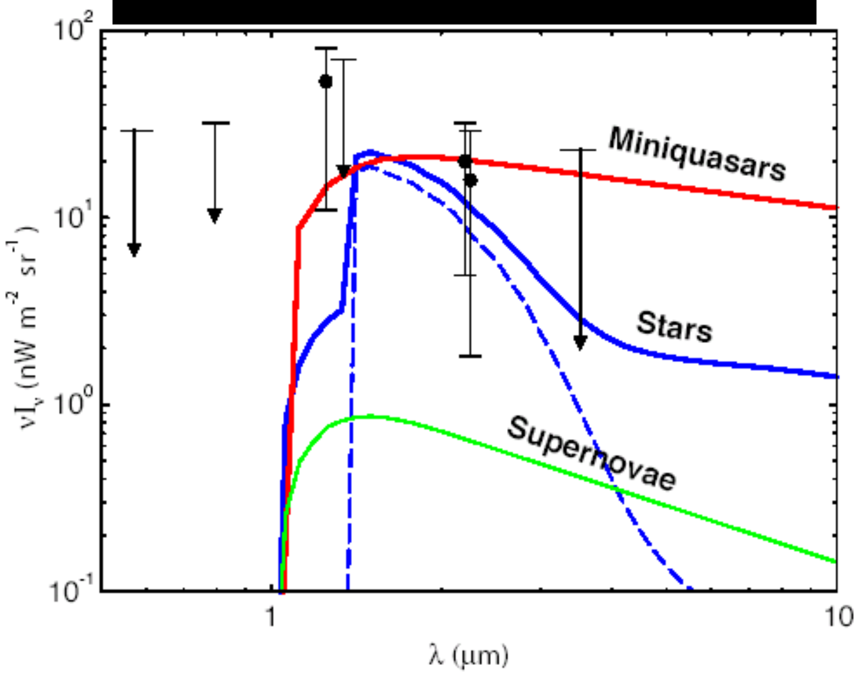
The background may contain “hidden” source populations

Near-infrared EBL needed to interpret spectra of gamma-ray sources

EBL at IR wavelengths captures sources even present during reionization.

Could Exotic Sources Produce the IRB Excess?





Santos *et al*. 2002; Salvaterra & Ferrara 2003;
Magliocchetti *et al*. 2003; Cooray & Yoshida 2004

Yes! …but there are difficulties

Do not need large IRB to explain WMAP

for τ_e = 0.1 +/- 0.03

-need $n_\gamma = 2\ C_{IGM}\ (\tau_e / 0.10)$ [γ/baryon]

-IRB excess: $n_\gamma = f_{esc}\ (1+z)\ u_J / 0.7\ E_a\ n_b = 4000\ f_{esc}$

Population III Stars

-Must convert 5-10 % of Baryons into Pop III stars
- High star formation fraction in collapsed structures
- Many recombinations to suppress Ly continuum

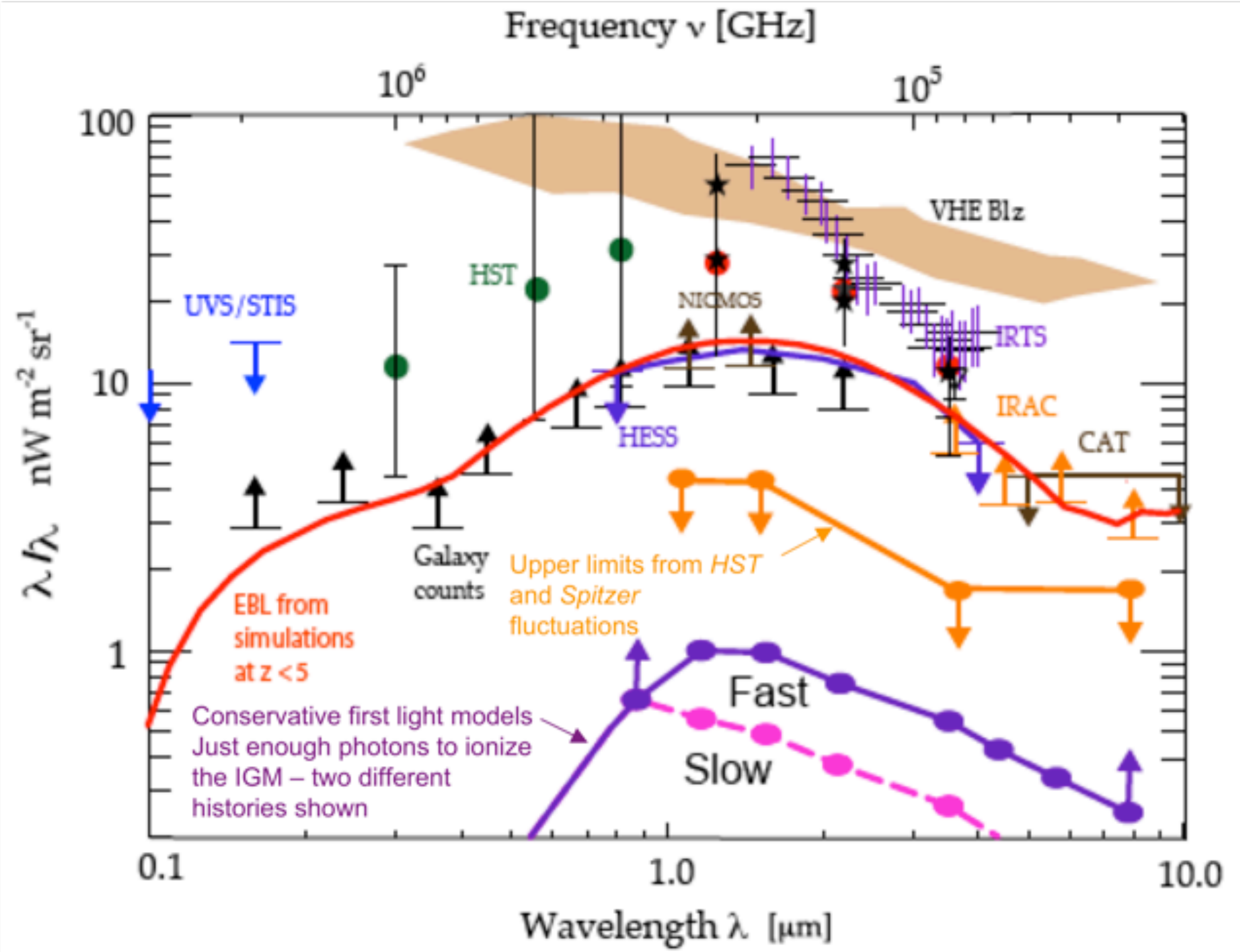
-Hard to avoid metal overproduction
- Stars between 140 – 260 solar masses give PISN, eject half the star's mass in metals

Mini-Quasars

-Need 1/3000th the formation rate of Pop III stars, but
- Overproduce SXB unless very X-ray quiet
- Exceed current estimated black hole densities

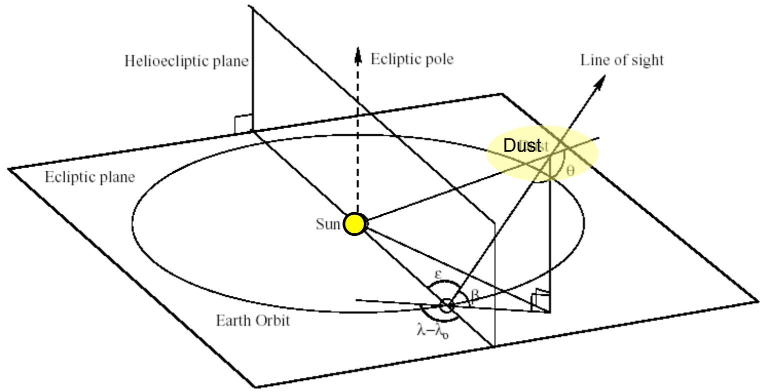
Madau & Silk 2004

State of NIR/Optical Extragalactic Background Measurements



Absolute measurements completely limited by Zodiacal foreground removal

Is the DIRBE excess a zodiacal light residual?



<u>Zodiacal Light is just scattered sunlight</u>

DIRBE team used a multi-component model (aka Kelsall model, but model may undercount scattered zodi)

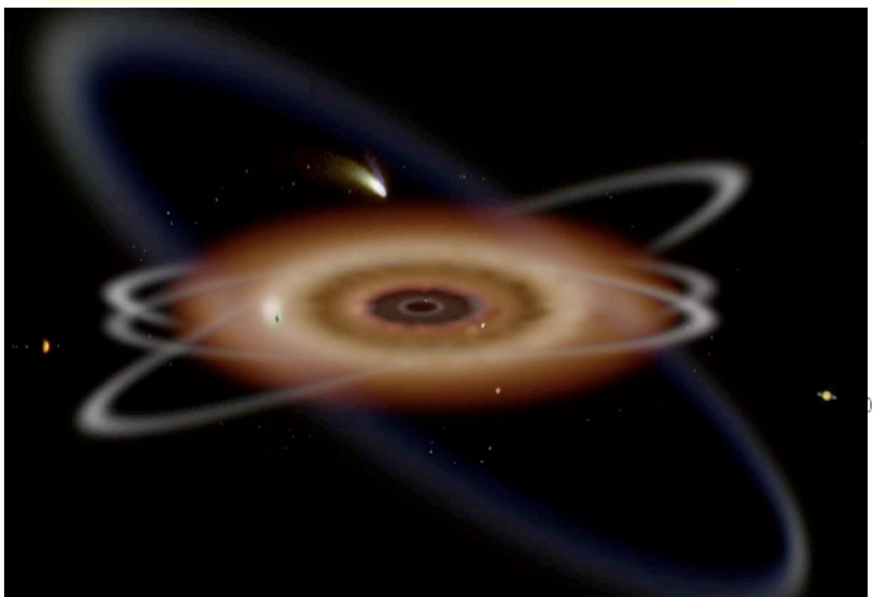
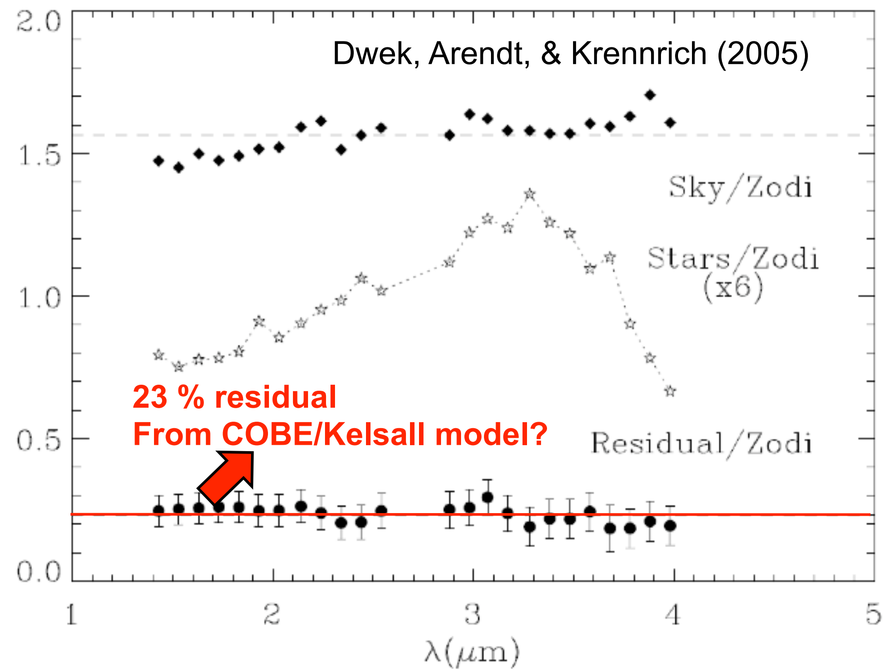
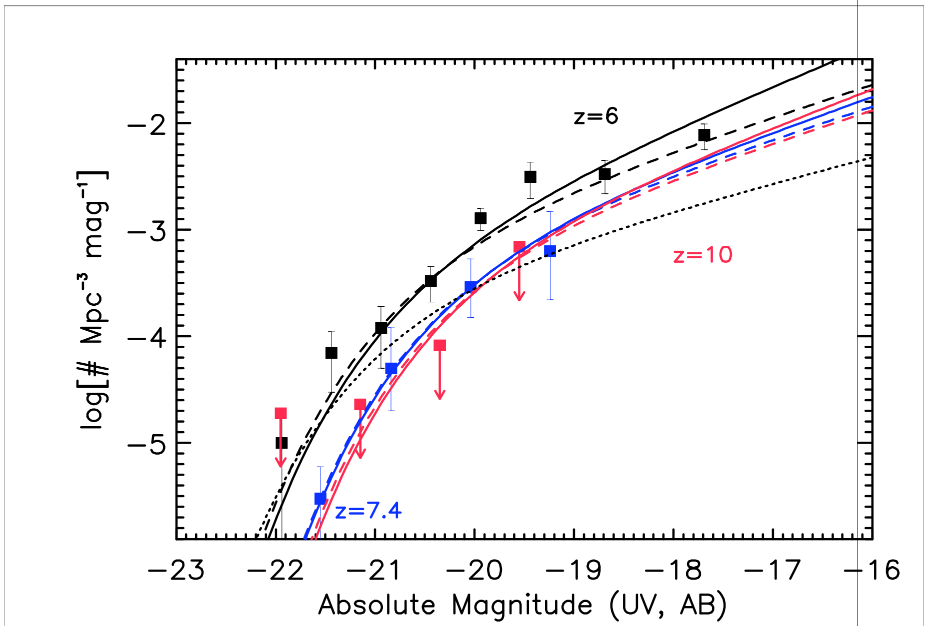
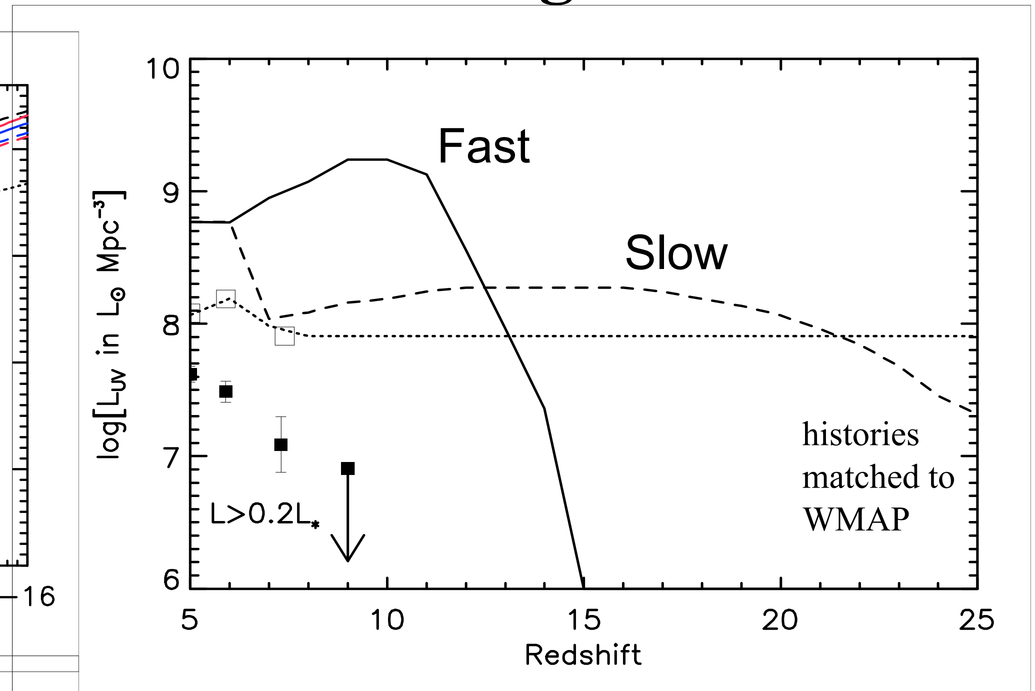


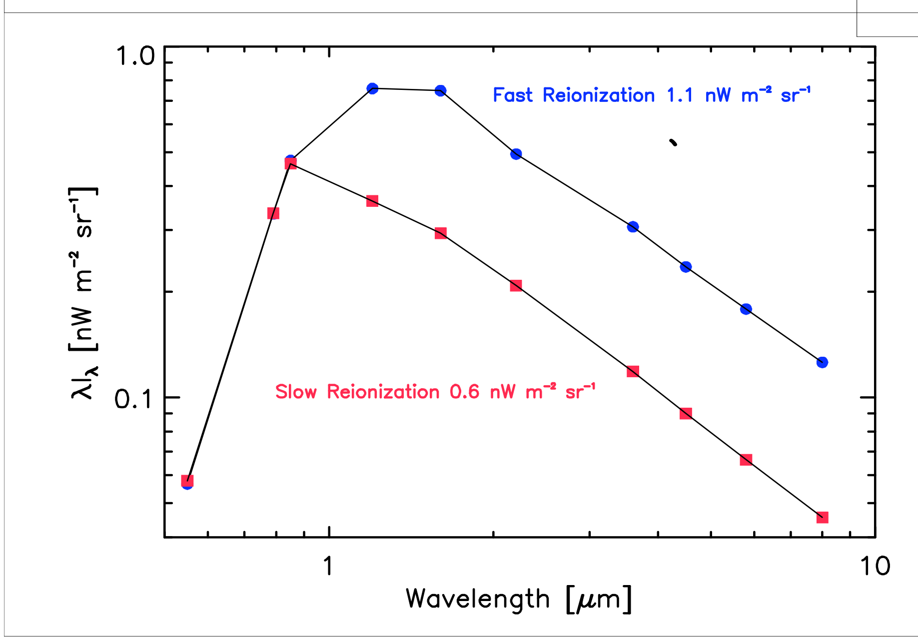
Image courtesy Brian May (PhD, 2007)



A lower-bound on reionization signature







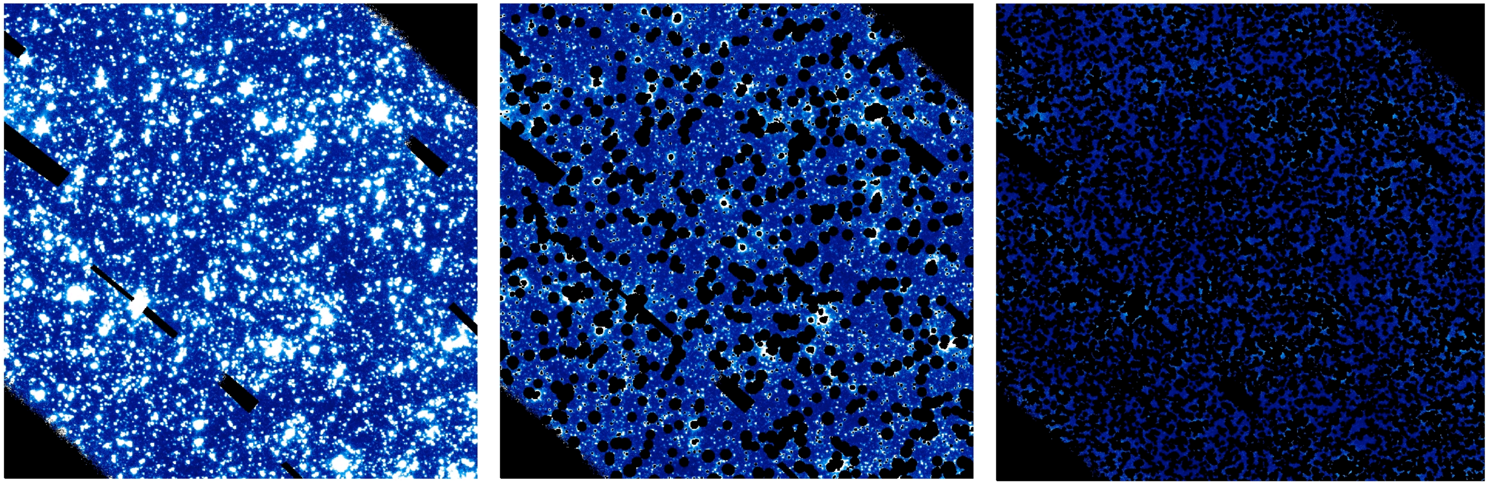
reionization dominated by L ~0.001 L_* or below, unlikely to be resolved by even JWST @ z~10

Reionization EBL is far below the DIRBE excess

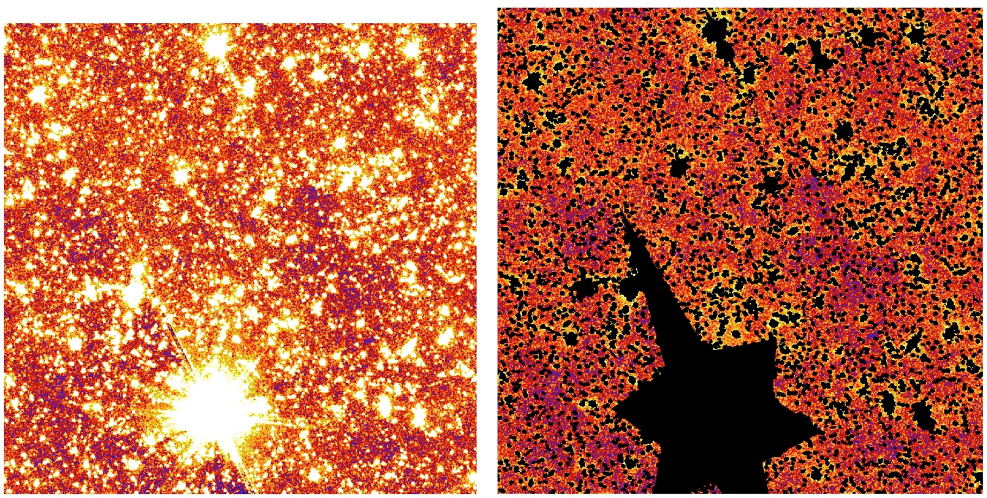
Existing fluctuation measurements can already constrain “fast” models of reionization

Chary & Cooray 2010, in prep

Clustering of Unresolved Fluctuations



GOODS CDF-S



COSMOS

What do we do?

Measure statistics of “empty” pixels.

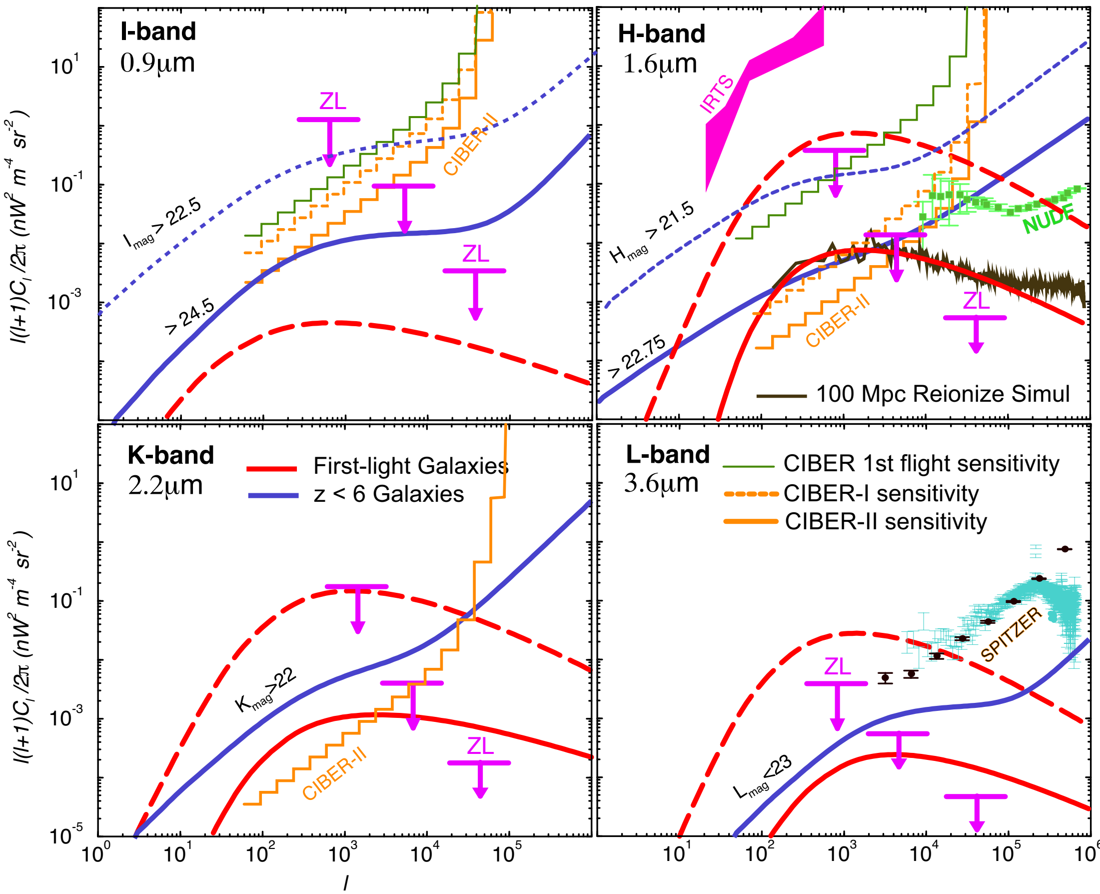
If unresolved faint galaxies are hidden in noise, then there is a clustering excess above noise

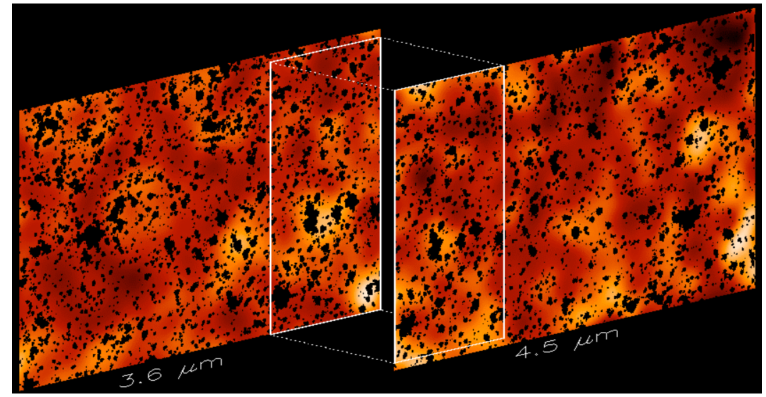
Challenges: > 10 million of pixels (higher complexity than analyzing WMAP data.)

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

Techniques to handle mask - borrowed from CMB analyses. (e.g., MASTER algorithm from Hivon et al.)

Status of excess IR Background Fluctuations





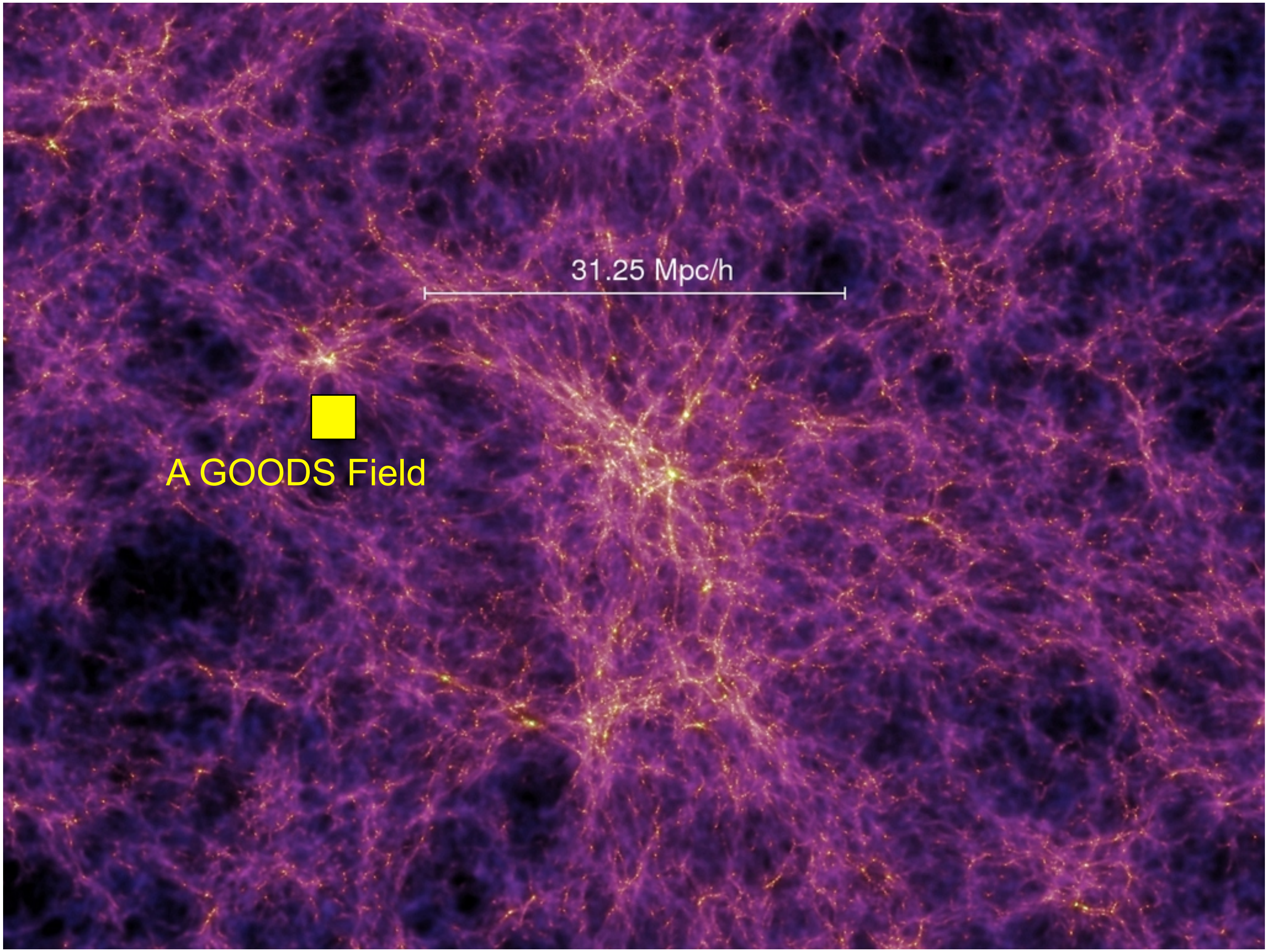
- **First detection reported by Kashlinksy *et al.* 2005**. Interpreted as evidence for a z > 8 first-light component responsible for reionization
- **Could it be partly due to undetected dwarf galaxies at moderate redshifts of 1 to 3?** Cooray *et al*. 2006; Chary et al. 2008 using fluctuations and a stacking analysis; we can account for ~50% of the fluctuations.
- **Thompson *et al*. 2007 report upper limits** with HST/ NICMOS, argued to be inconsistent with a z > 8 source interpretation.

Characteristic features (Cooray et al. 2003):
(a) bump around $l \sim 10^3$ (~50 Mpc clustering scale at z~10-12)
(b) non-linear corrections at $l > 10^4$ (seen in numerical simulations)

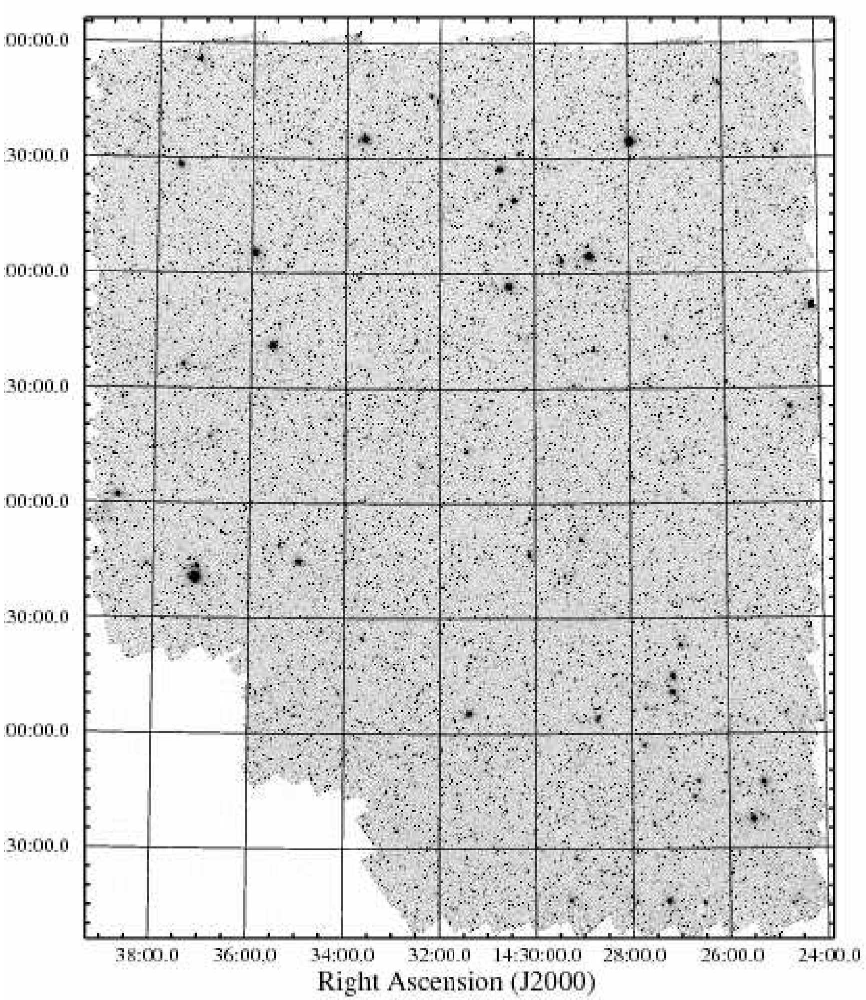
The full spectrum cannot be reproduced by a galaxy population at low redshifts!
(at z < 1 to 2, diffuse intra-cluster light can, but amplitude is small given existing measurements)

Cosmic Variance is a problem for all studies, so far

2 deg

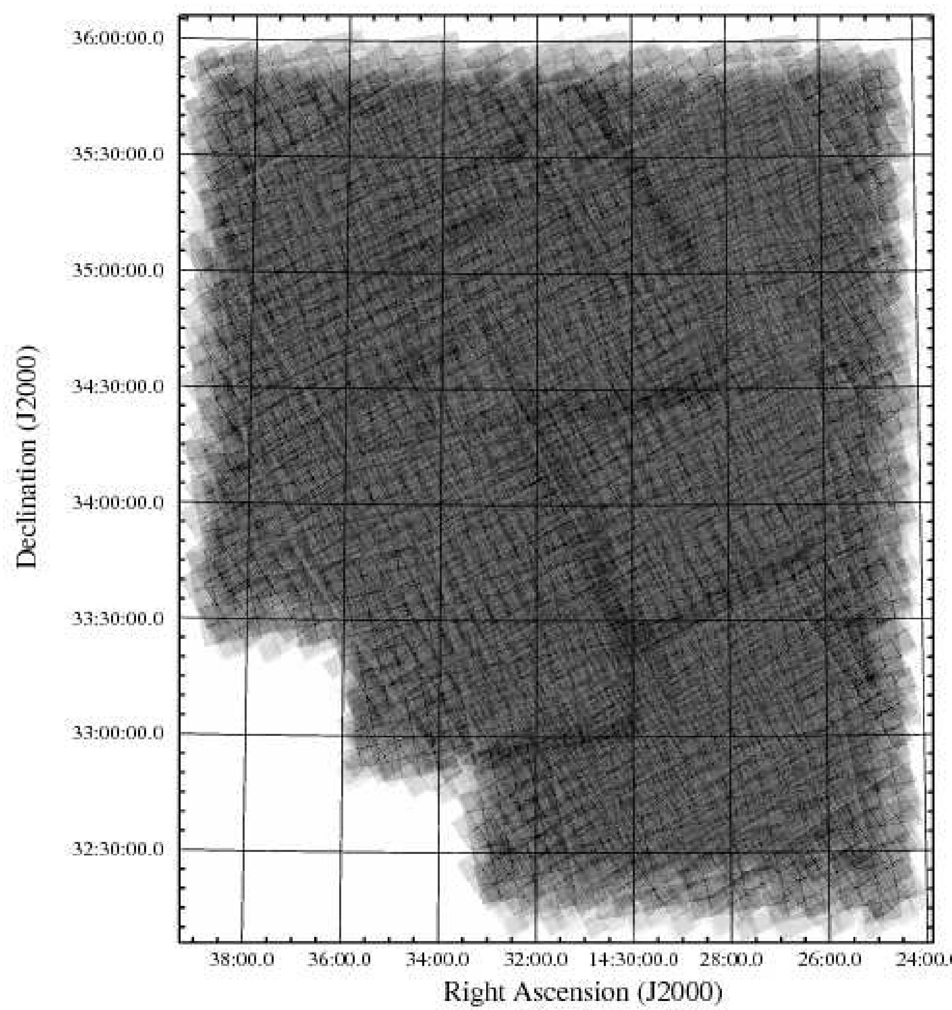


We need fields that span couple of degrees, not small GOODS-like fields!



IRAC Spitzer Bootes field

8.5 square degrees



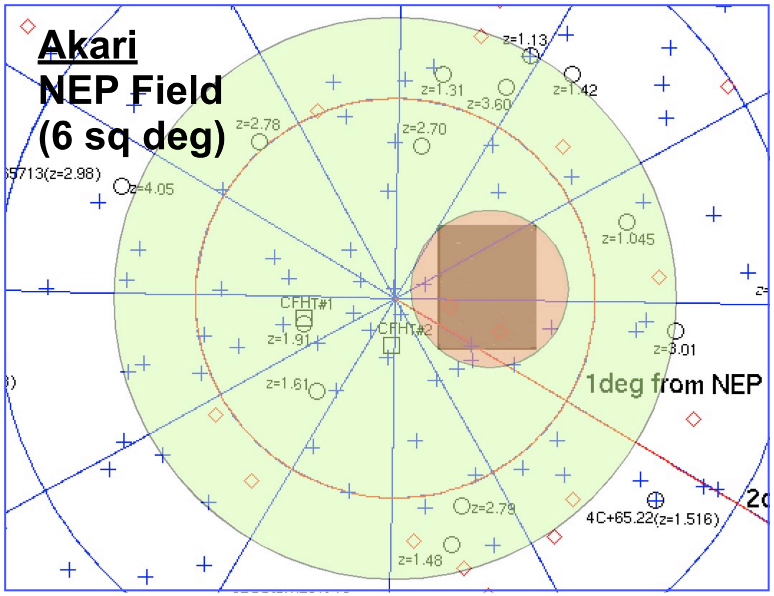
Deconvolve the coverage map!!

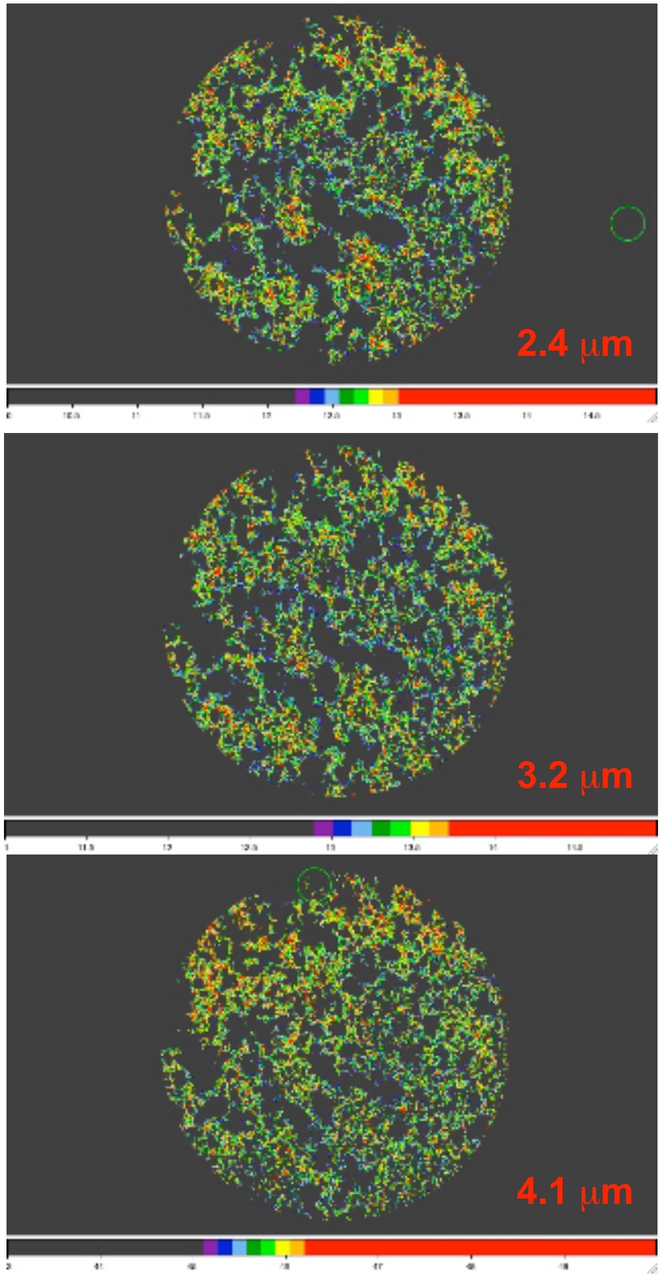
(not so easy)

Sam Kim, in preparation

Akari Background Fluctuations! (sees the characteristic bump at ell of 1000)

Akari team's (Matsumoto et al.) poster at this conference





2.5micron fluctuations out to a degree scale for the first time! consistent with a power spectrum expected from model predictions.

Should we believe it? If from reionization, a multi-wavelength cross-correlation of optical and Akari IR data should be zero.

CIBER: A sounding rocket for the background light

The Cosmic Infrared Background ExpeRiment

JPL / Caltech
John Battle
Jamie Bock
Louis Levenson
Ian Sullivan
Mike Zemcov

UC Irvine
Asantha Cooray
Sam Kim

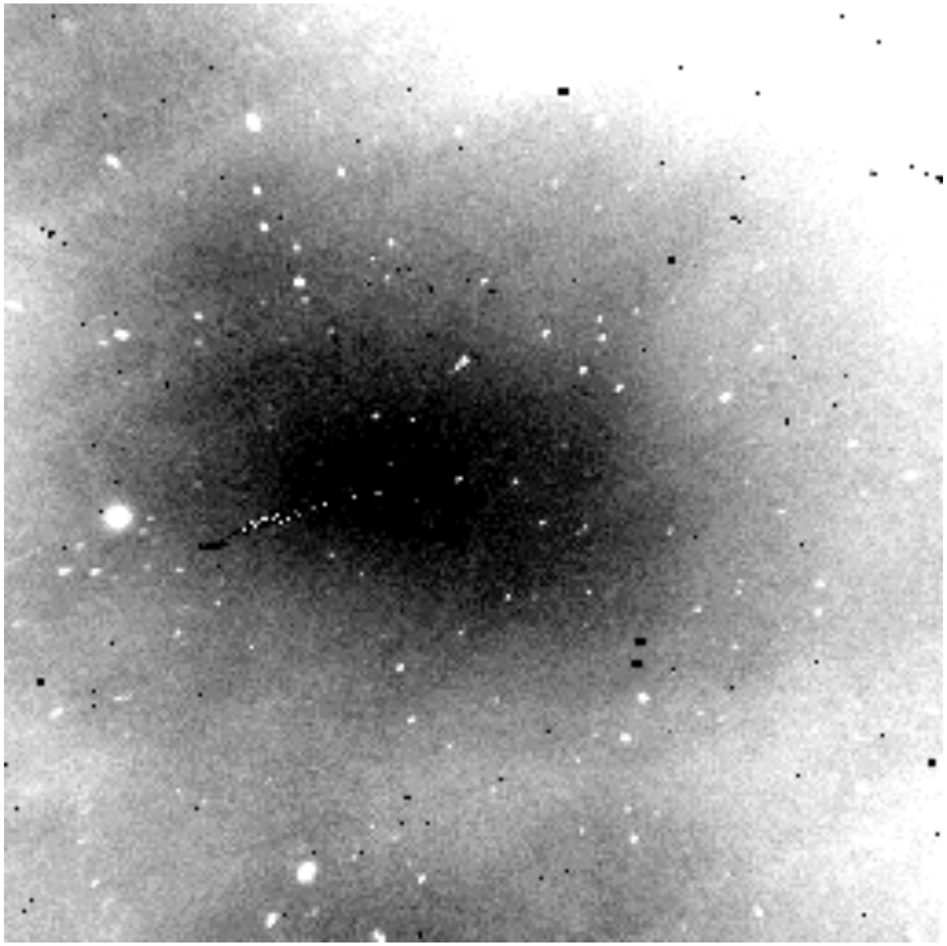
UC San Diego
Brian Keating

ISAS / JAXA
Toshio Matsumoto
Shuji Matsuura
Kohji Tsumura
Takehiko Wada

Nagoya U.
Mitsunobu Kawada

KASI
Dae-Hee Lee

The Case for Space



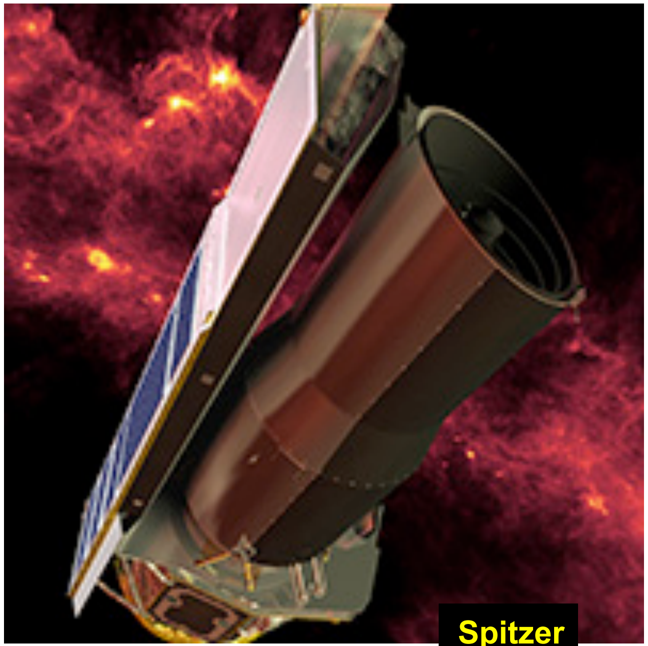
Airglow Emission

- Atmosphere is **500 – 2500** times brighter than the astrophysical sky at 1-2 μm
- Airglow fluctuations in a **1-degree** patch are **10^6** times brighter than CIBER's sensitivity in 50 s
- Brightest airglow layer at an altitude of **100 km**… can't even use a balloon

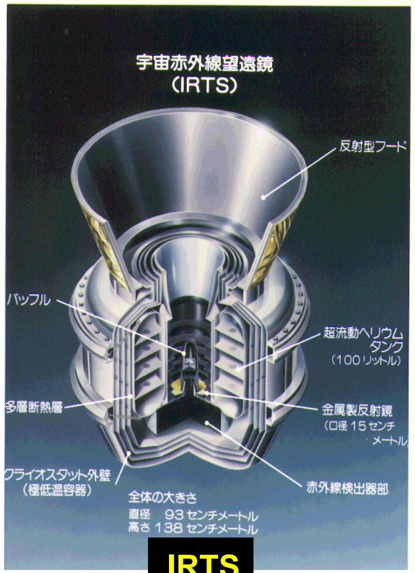
H-band 9º x 9º image over 45 minutes from Kitt Peak

Wide-field airglow experiment: http://pegasus.phast.umass.edu/2mass/teaminfo/airglow.html

How can a rocket experiment compete with these?

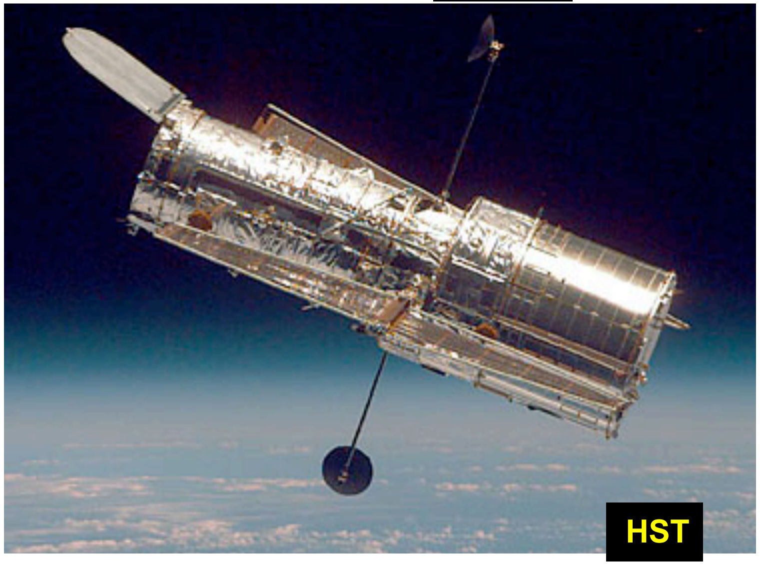


Spitzer



IRTS

Akari



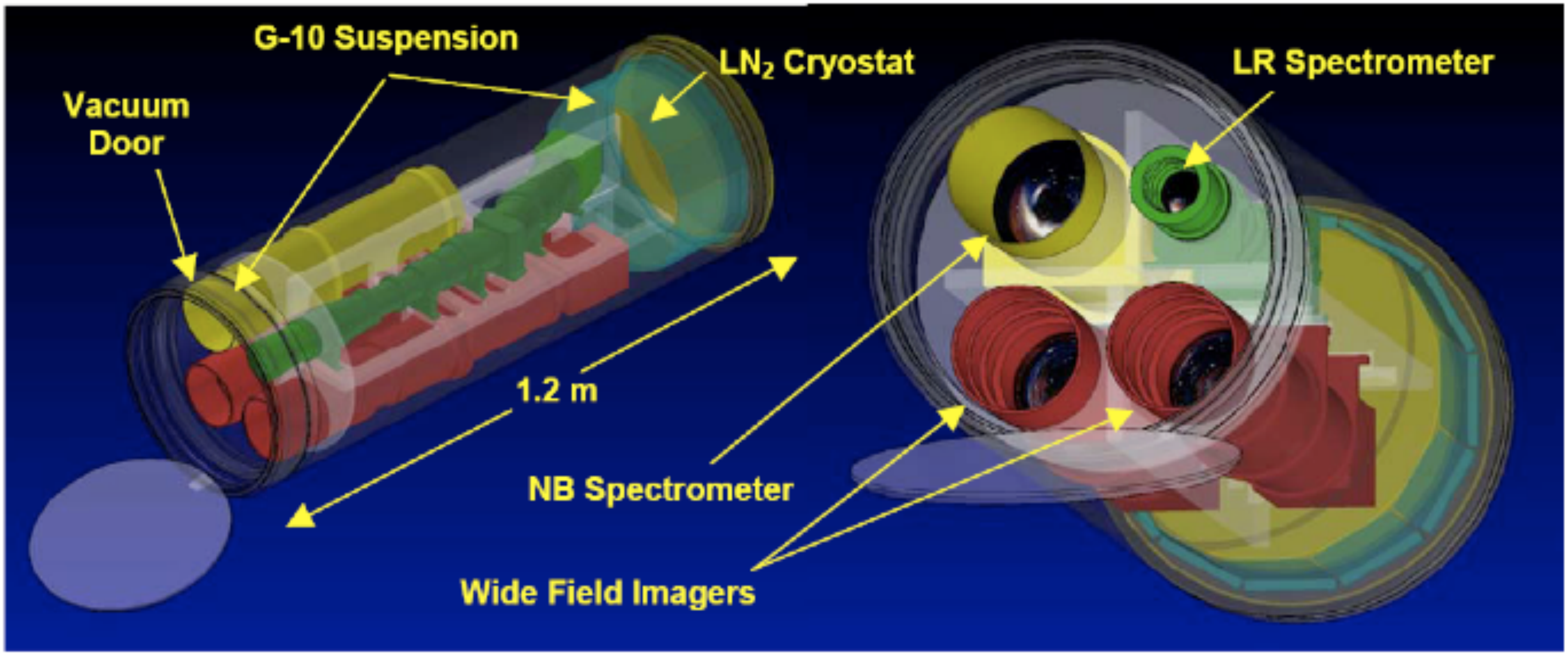
HST

Table 5.2 Comparison with Existing Instruments

Instrument	Bands [μm]	FOV	Sub-fields	Etendue
CIBER2	0.6, 0.9, 1.4, 2.1	85' x 85'	1	1
CIBER1	0.9, 1.6	120' x 120'	1	0.1
NICMOS	1.1, 1.6, 2.1	1' x 1'	9900	0.002
WFC3	0.6, 1.0, 1.4, 1.6	2' x 2'	1500	0.01
Akari	2.3, 3.2, 4.1	12' x 12'	50	0.02
Spitzer	3.6, 4.5	5' x 5'	270	0.01

Notes: Etendue = Area x Ω x Simultaneous Bands
Sub-fields = number of pointings to cover 2 sq. degrees

CIBER Science Goals



Dual Wide-Field Imagers

λ= 0.8 μm & 1.6 μm $\lambda/\Delta\lambda$ = 2

2° x 2° FOV   7" pixels

• Measure power spectrum from 7" to 2 degrees

Low-Resolution Spectrometer

λ = 0.8 – 2.0 μm $\lambda/\Delta\lambda$ ~ 20

4° x 4° FOV   60" pixels

• Search for Ly cutoff feature in 0.8 – 1.2 μm region

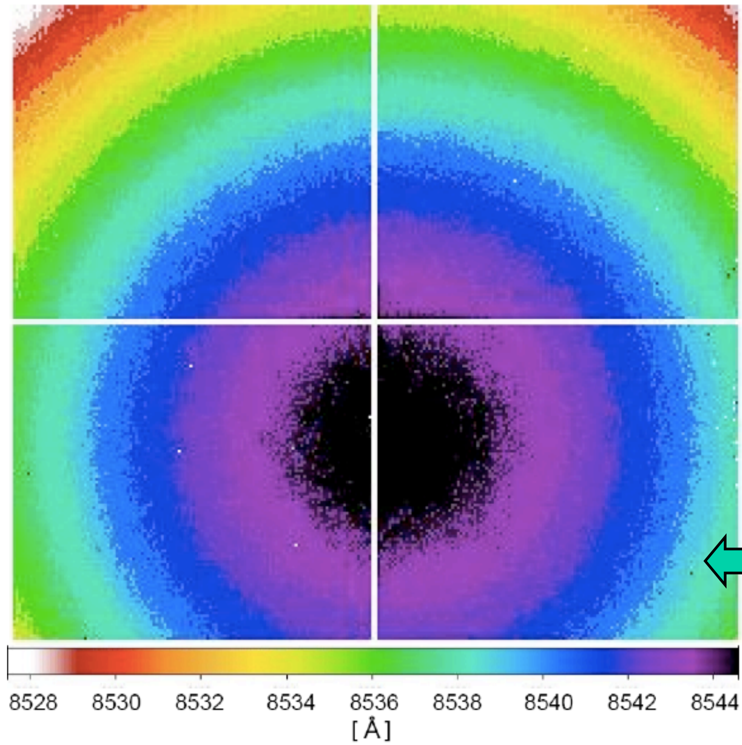
Narrow-Band Spectrometer

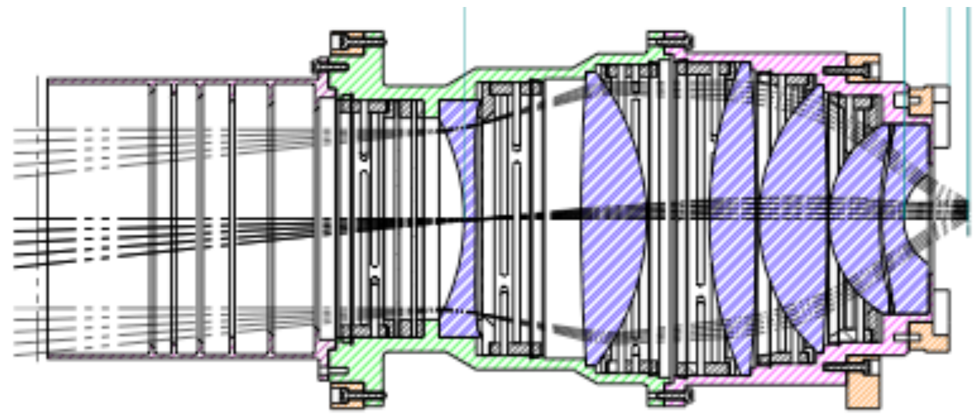
λ= 0.8542 μm $\lambda/\Delta\lambda$ = 1000

8° x 8° FOV   120" pixels

• Use Fraunhofer lines to measure absolute Zodiacal intensity

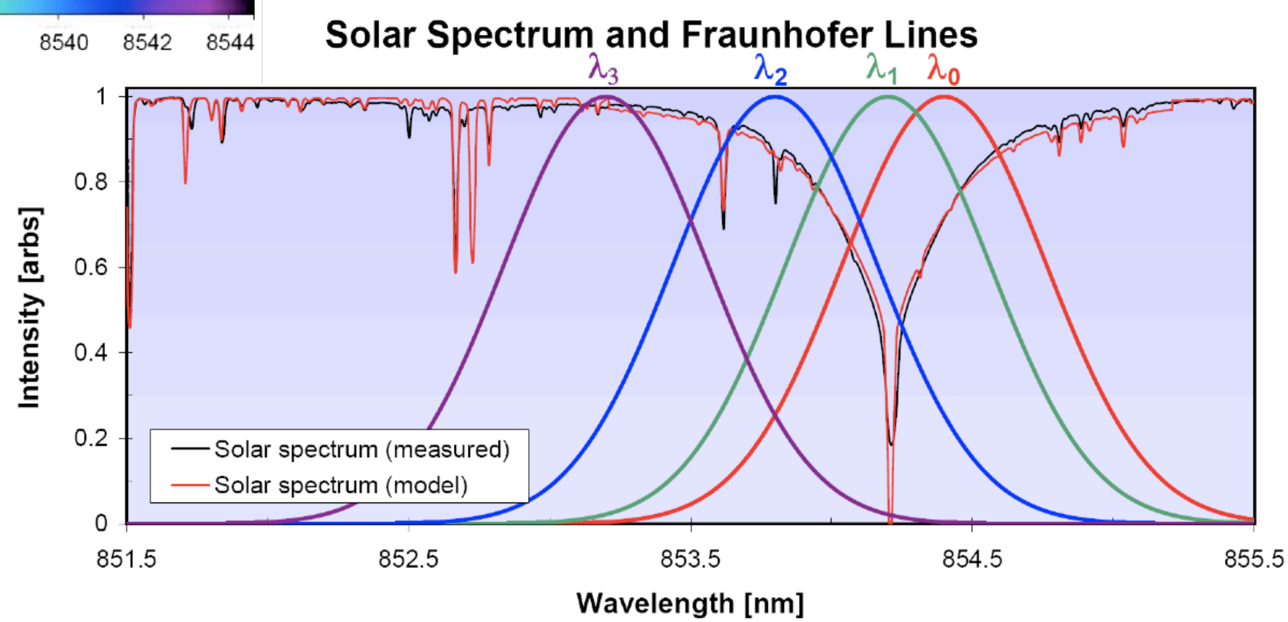
Narrow-Band Spectrometer





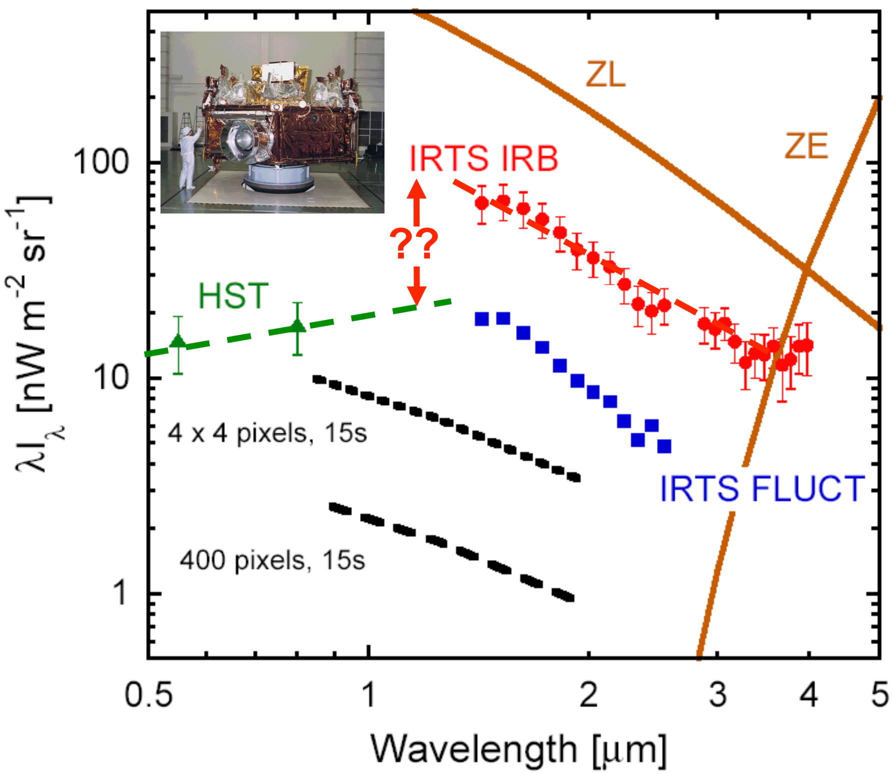
NIST calibration data
I(photo) ~ 30 e-/s

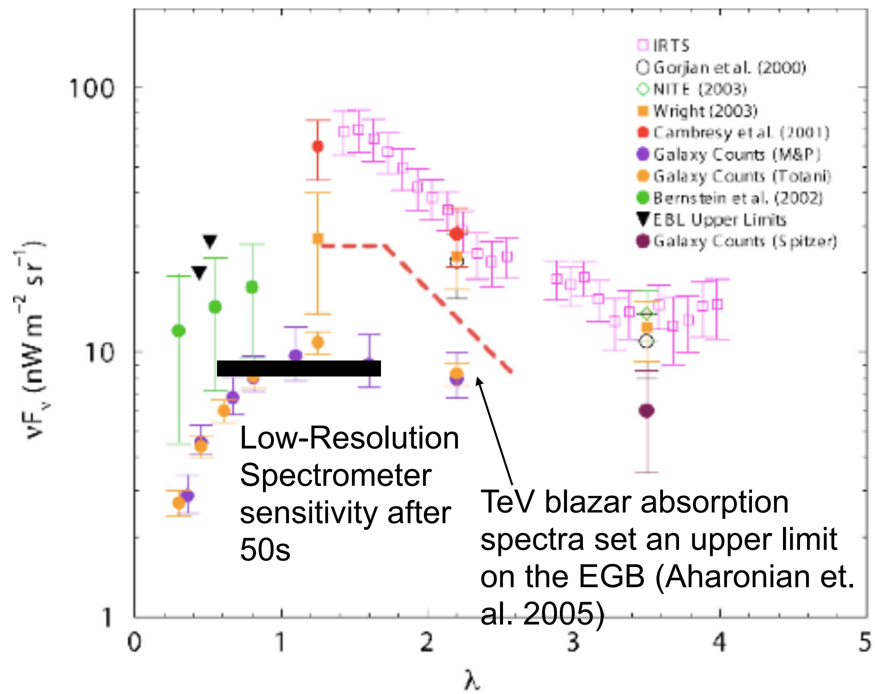
<u>Science Goal</u>:
Measure Fraunhofer Ca II 854.2 nm line EW to 1 % absolute



Low-Resolution Spectrometer Science

Spectrometer Sensitivity





Is the gap between IRTS/DIRBE and HST real?

CIBER would see it easily, *without any* Zodiacal subtraction

Precisely measure Zodiacal color, link with narrow-band spectrometer

Low-resolution spectrometer sensitivity is 1-2 nW m^{-2} sr^{-1}

NB Spectrometer Zodiacal zero point is 3 nW m^{-2} sr^{-1} at 0.85 μm

Excess at J-band is ~30 nW m^{-2} sr^{-1}

CIBER timeline

CIBER-I first flight launched successfully February 25, 2009

First flight constituted a test flight of the instrument, but adequate science data!

An unexpected discovery with CIBER-I (nothing to do with cosmology)
(CIBER is the first experiment to do a spectral study of the EBL and zodi between 0.6 and ~2 microns and we already have a result related to dust in the inner Solar system; paper recently submitted)

Second flight June 2010.

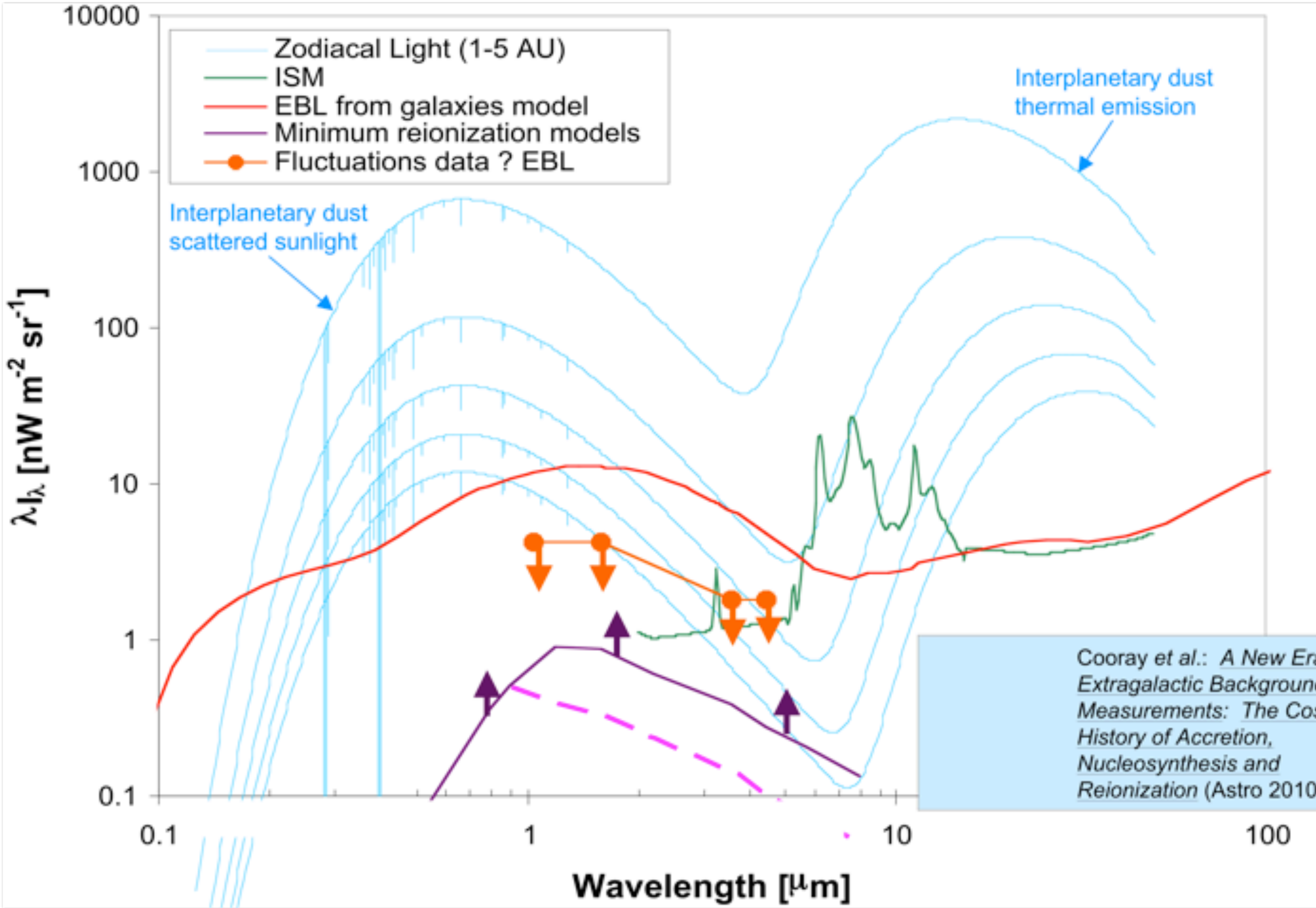
CIBER-I will fly a total of 4 times. Last flight in fall 2011 will be a long duration flight with a launch from Alaska (payload drops to Pacific ocean).

Goal: reliable EBL (best we can do at @ one AU) after about 4 flights.

CIBER-II: upgrade with 2048x2048 arrays with flights starting 2013. Focus more on fluctuations.

CIBER program funded till 2015.

A Unique Opportunity to Measure the EBL at 5 AU

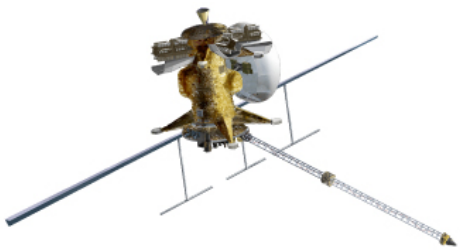


Cooray *et al.*: *A New Era in Extragalactic Background Light Measurements: The Cosmic History of Accretion, Nucleosynthesis and Reionization* (Astro 2010)

Out-of-Zodi EBL Explorer?

Small instrument attached to an outer (≥ Jupiter) planets mission

- **- support from planetary community (study dust in the Solar System)**
- **- could be cheap/small/simple**
- **- upcoming Outer Planet Mission opportunity (AO in 2011) to Europa.**
- **- Also Discovery opportunity, AO coming out later this year.**

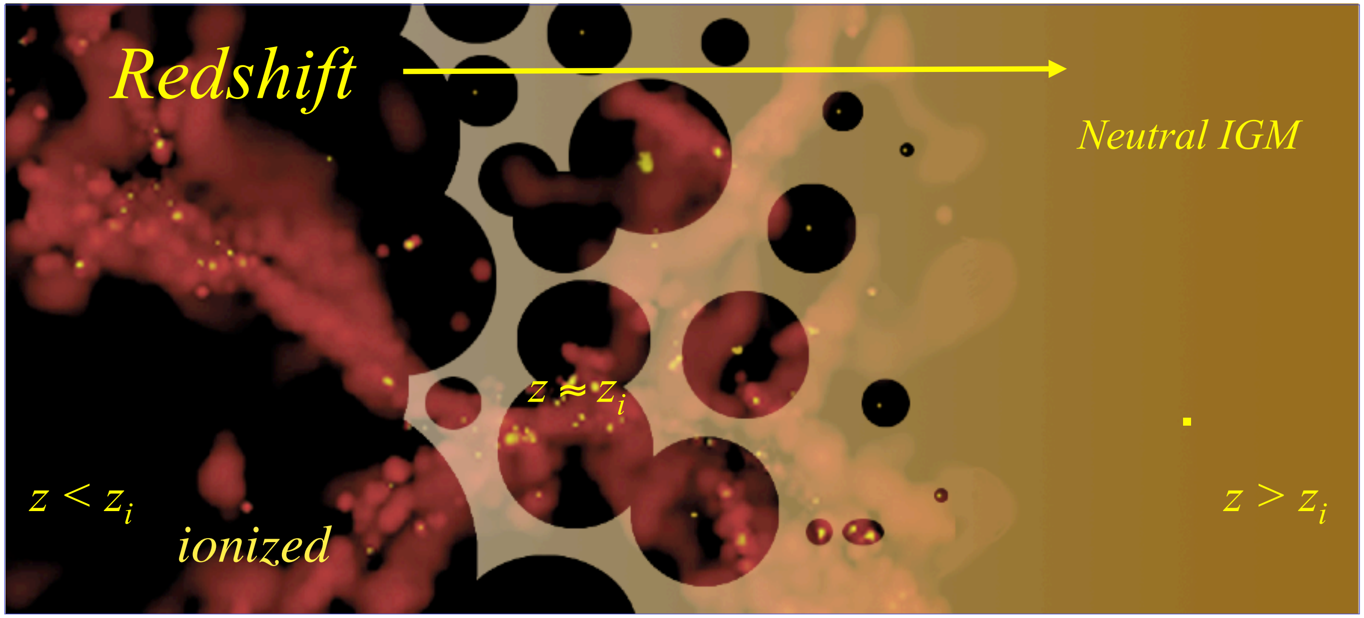


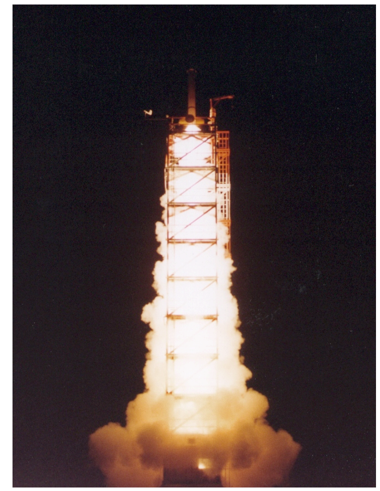
Jupiter-Europe Orbiter (JEO)

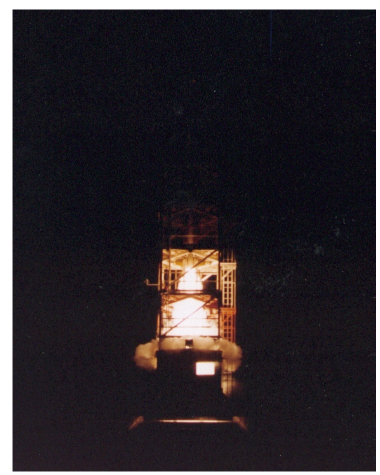
- Launch Mass Capability, 5040 kg
- Launch Vehicle Adapter, 123 kg
- Flight System Mass, 1367 kg
- Propellant (for 2260 m/s), 2646 kg

  Astrophysics requesting to install ~25 kg instrument in the focal plane for EBL
- *Under discussions*
- *Workshop at National Academies' Beckman Center March 25-26 to discuss the way forward*

Conclusions







Infrared backgrounds are cosmologically important

Current measurements are wanting in near-IR

- fluctuations
  - limited in l range, now extended to 2 degrees.
  - cross-correlations important
- absolute spectroscopy of sky from 0.8 – 1.4 μm
- uncertainty in Zodiacal light subtraction
- CIBER will remeasure the IR EBL
- 5 AU EBL Explorer for reionization signature!