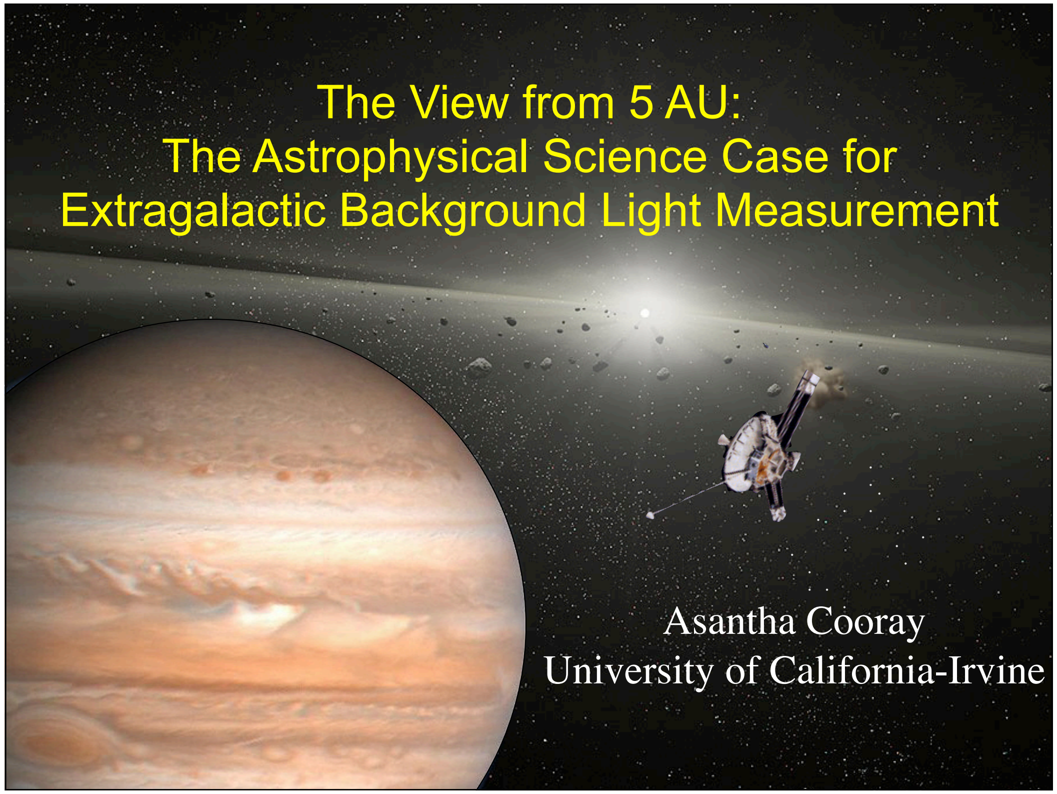

The View from 5 AU:
The Astrophysical Science Case for
Extragalactic Background Light Measurement
Asantha Cooray
University of California-Irvine

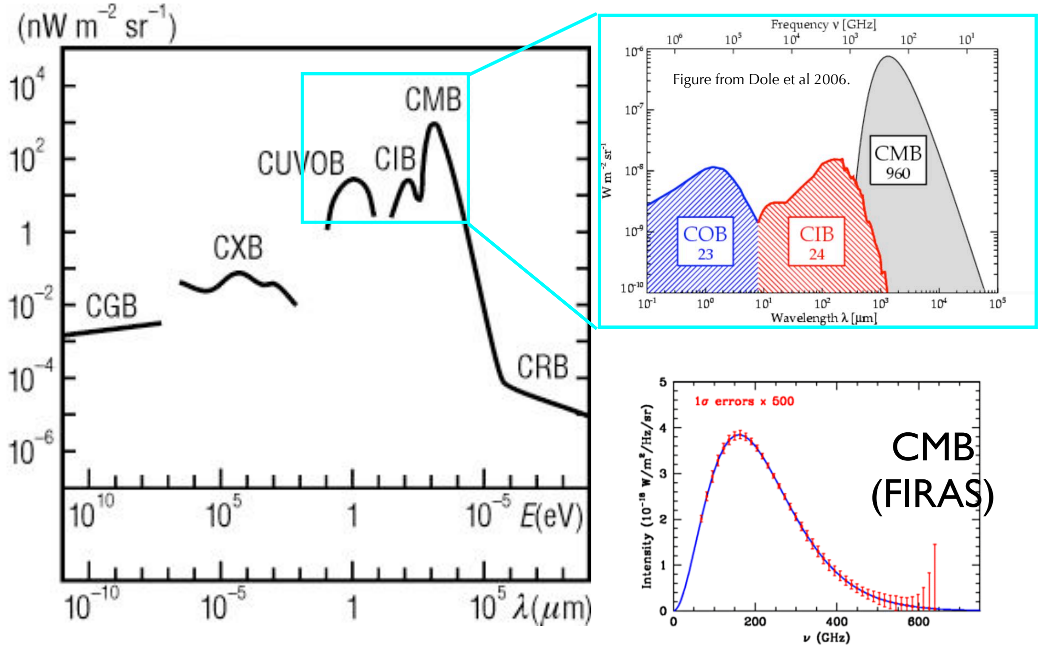
Heinrich Olbers
1758-1840

“Why is the night sky dark?”

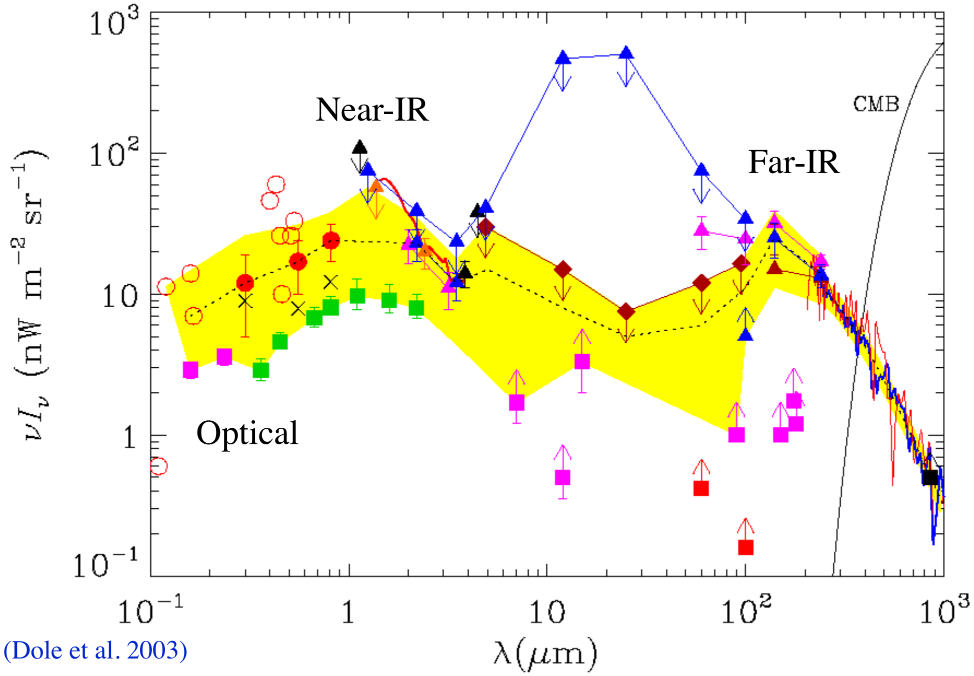
21st century version:

What is the spectrum of the background light in the Universe?

The Extragalactic Background Light Spectrum



Optical and IR EBL Spectrum

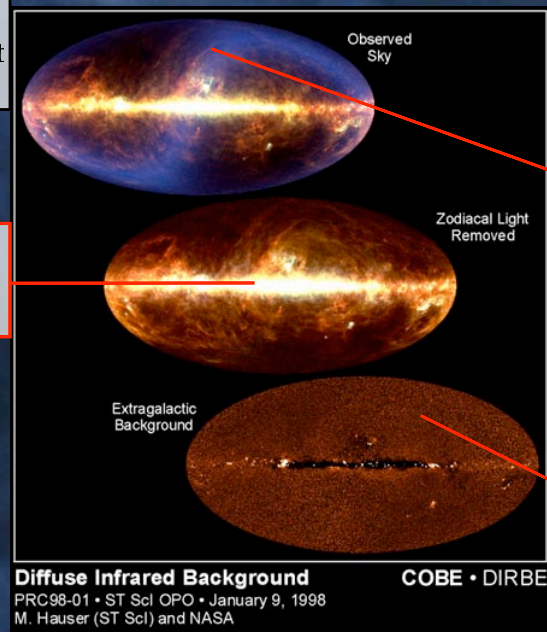


(Dole et al. 2003)

Why is the absolute optical/IR background uncertain?

Our viewpoint of the Universe is not typical

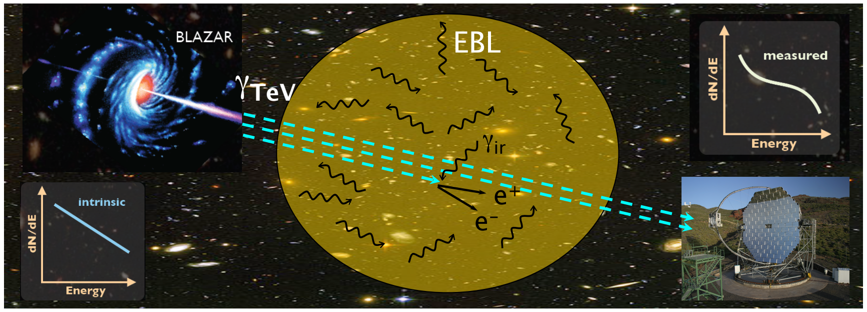
...stars and starlight in the galaxy...



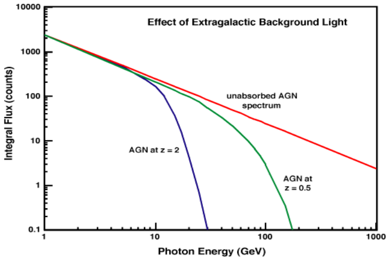
...Zodiacal light (ie dust in the solar system scattering sun light)...

DIRBE EBL is sensitive to how foregrounds are accounted for!

Indirect Limits on IR EBL: Attenuation of GeV–TeV photons



- During transit, TeV photons are attenuated via pair production with IR photons
- Imprint of the IR photon density in the measured TeV spectra
- However, intrinsic spectrum is not measured!!!!
- (If IR EBL known exactly, study TeV source astrophysics)



Joel Primack's talk

Is there a need for a new direct EBL measurement?

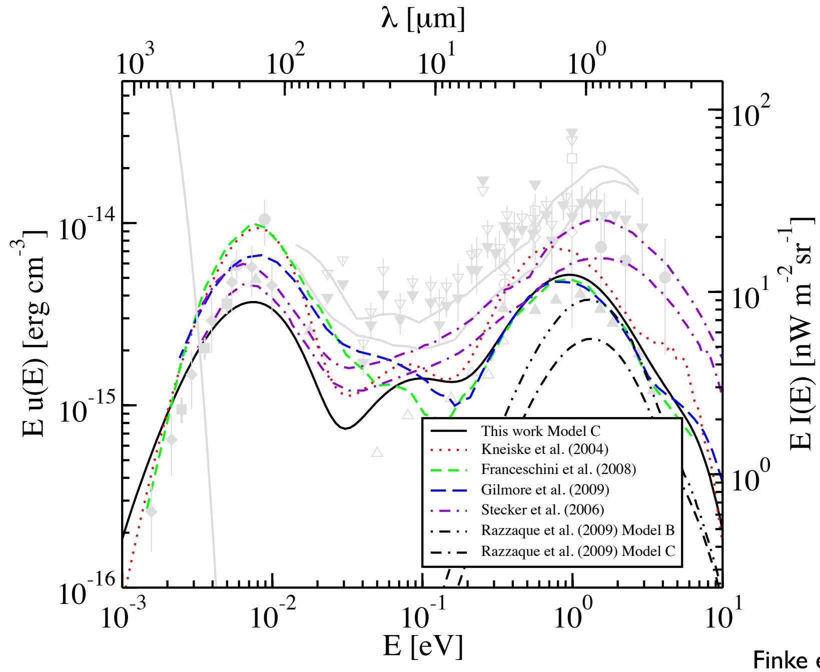
A New Era in Extragalactic Background Light Measurements:

The Cosmic History of Accretion, Nucleosynthesis and Reionization

Asantha Cooray[1,*] Alexandre Amblard[1], Charles Beichman[2], Dominic Benford[3], Rebecca Bernstein[4], James J. Bock[2,5], Mark Brodwin[6], Volker Bromm[7], Renyue Cen[8], Ranga R. Chary[2], Mark Devlin[9], Timothy Dolch[10], Hervé Dole[11], Eli Dwek[3], David Elbaz[12], Michael Fall[10], Giovanni Fazio[13], Henry Ferguson[10], Steven Furlanetto[14], Jonathan Gardner[3], Mauro Giavalisco[15], Rudy Gilmore[4], Nickolay Gnedin[16], Anthony Gonzalez[17], Zoltan Haiman[18], Michael Hauser[9], Jiasheng Huang[13], Sergei Ipatov[19], Alexander Kashlinsky[3], Brian Keating[20], Thomas Kelsall[3], Eiichiro Komatsu[7], Guilaine Lagache[11], Louis R. Levenson[2], Avi Loeb[13], Piero Madau[4], John C. Mather[3], Toshio Matsumoto[21], Shuji Matsuura[21], Kalevi Mattila[22], Harvey Moseley[3], Leonidas Moustakas[5], S. Peng Oh[23], Larry Petro[10], Joel Primack[4], William Reach[2], Tom Renbarger[20], Paul Shapiro[7], Daniel Stern[5], Ian Sullivan[2], Aparna Venkatesan[24], Michael Werner[5], Rogier Windhorst[25], Edward L. Wright[14], Michael Zemcov[2,5]

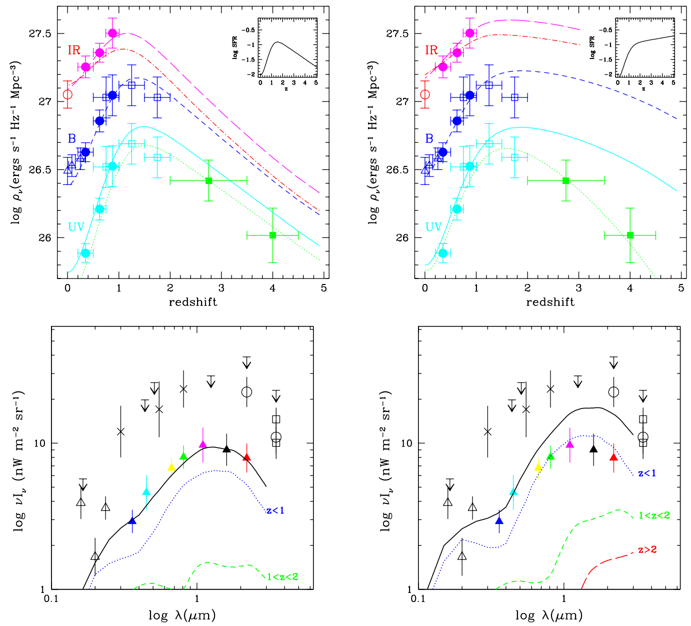
Science Program White Paper for Astro-2010 Decadal Survey
arXiv:0902.2372

Understanding Galaxy Formation with EBL?



Finke et al. 2009

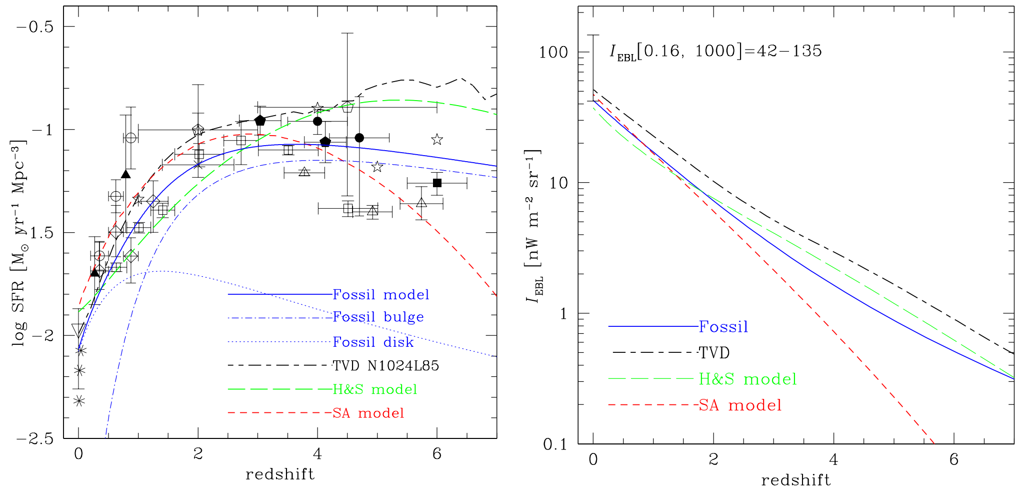
EBL as an independent probe of SF history of the Universe



Madau et al.

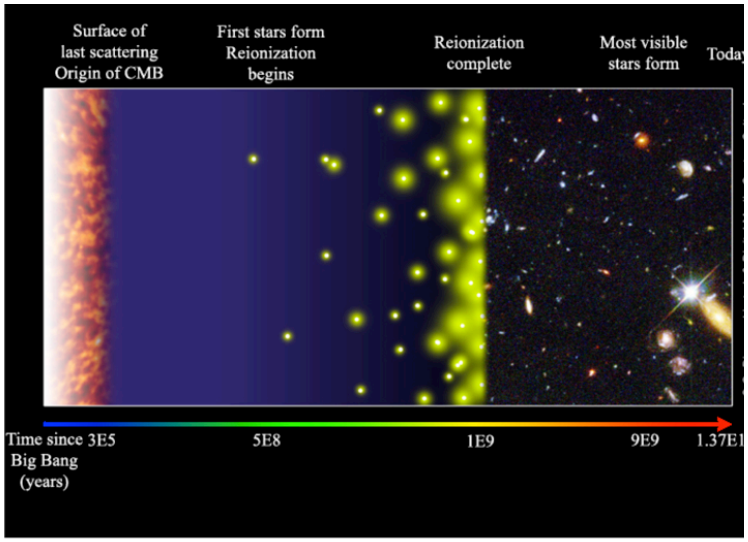
EBL as an independent probe of SF history of the Universe

Nagamine et al.

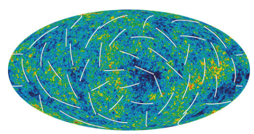


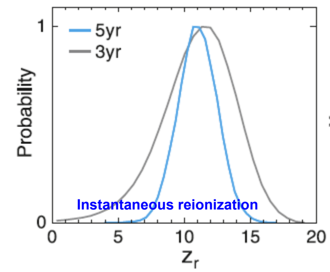
EBL from known galaxy populations at $z > 4$ is less than 3 nW m^2 sr^{-1}

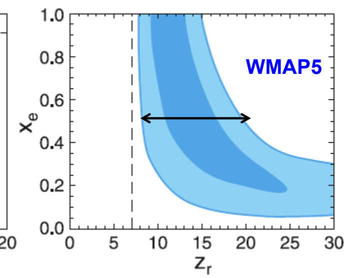
The epoch of reionization and a spectral signature in EBL



When did the reionization take place?





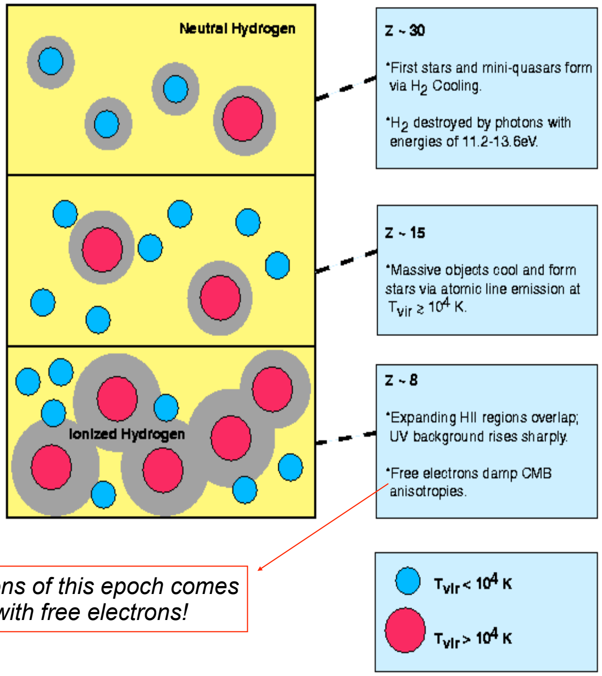


Data rejects instantaneous reionization at z~6-7
Process is likely extended over 6<z<20
CMB studies do <u>not</u> pinpoint the responsible cosmic sources

What Reionized the Universe?

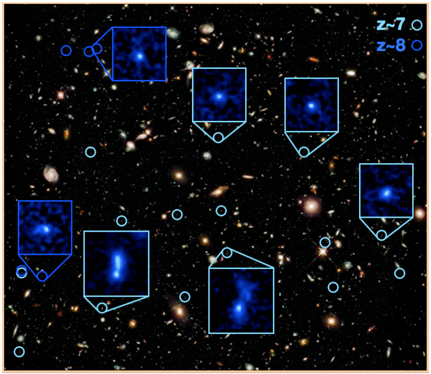
<u>Leading candidates</u>

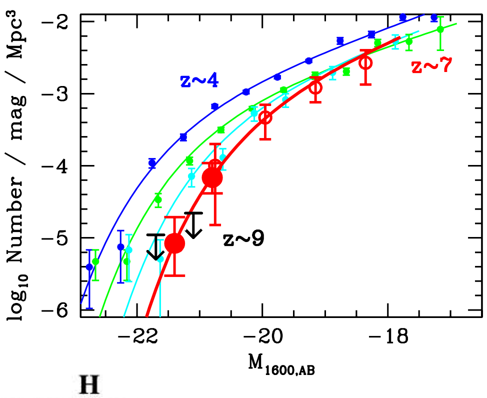
- Star formation
  - high mass stars?
  - two bursts?
- Stellar remnants
  - aka 'mini-quasars'
- Supernovae
  - PISN produce metals
- Exotic scenarios
  - Decaying dark matter

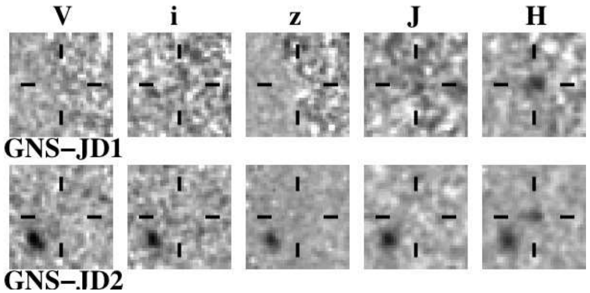


To date, the only direct observations of this epoch comes from interaction of CMB photons with free electrons!

Searching for sources responsible for reionization

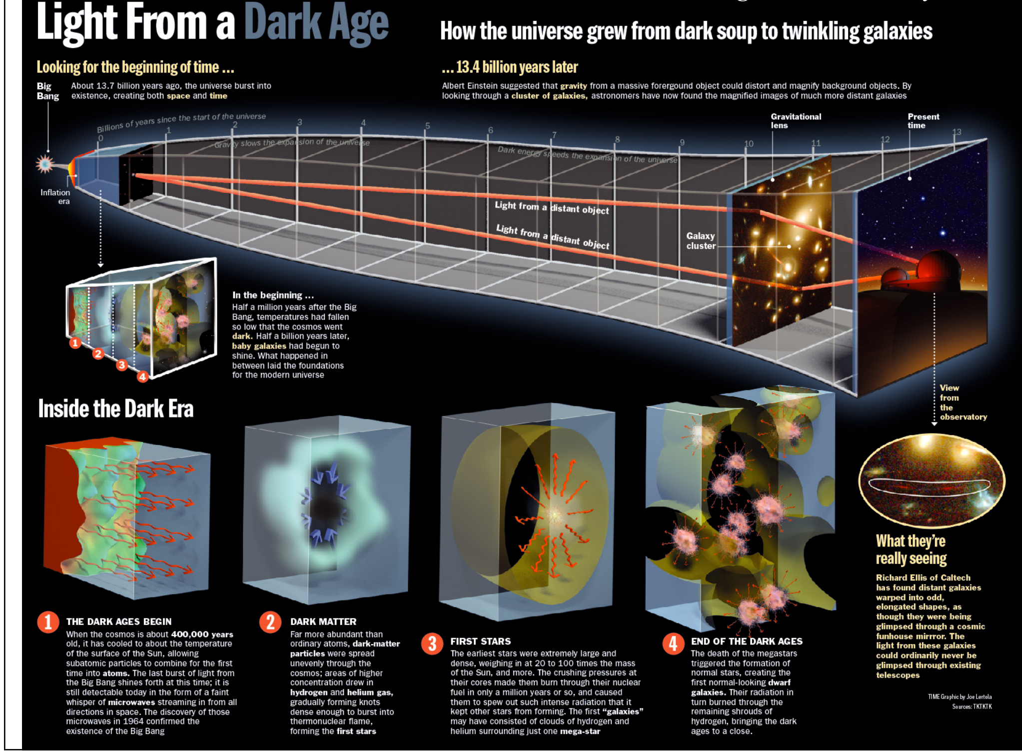




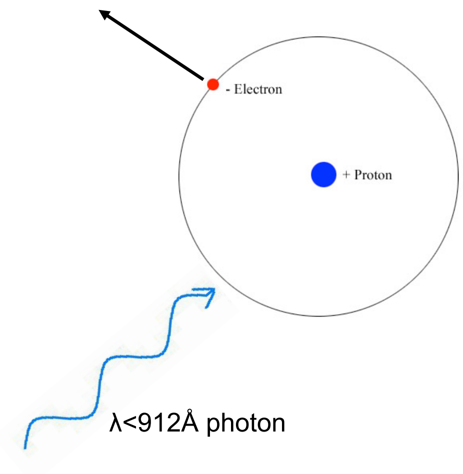


Bouwens et al.

TIME Magazine cover story, 9/06



Need 1 photon to start reionization



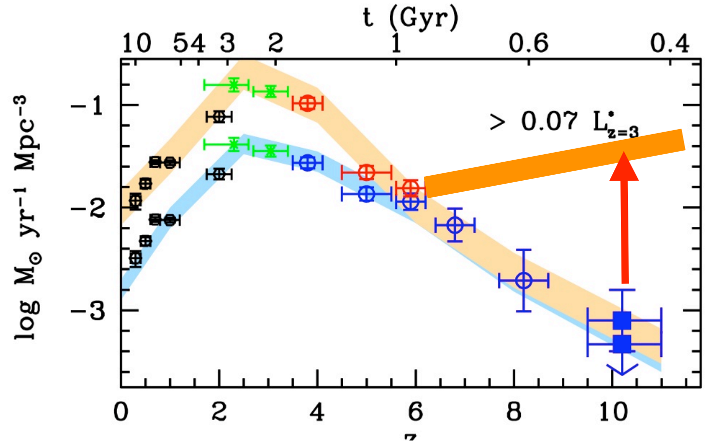
$$R = n_e n_{\mathrm{H\,II}} \alpha_{\mathrm{B}} C \text{ s}^{-1} \text{ Mpc},^{-3}$$

Sensitive to:

1. Clumpiness of the gas
2. Temperature of the gas
3. Co-moving electron density

Need ~few photons to maintain ionized hydrogen due to recombinations

Have we seen sources responsible for reionization?

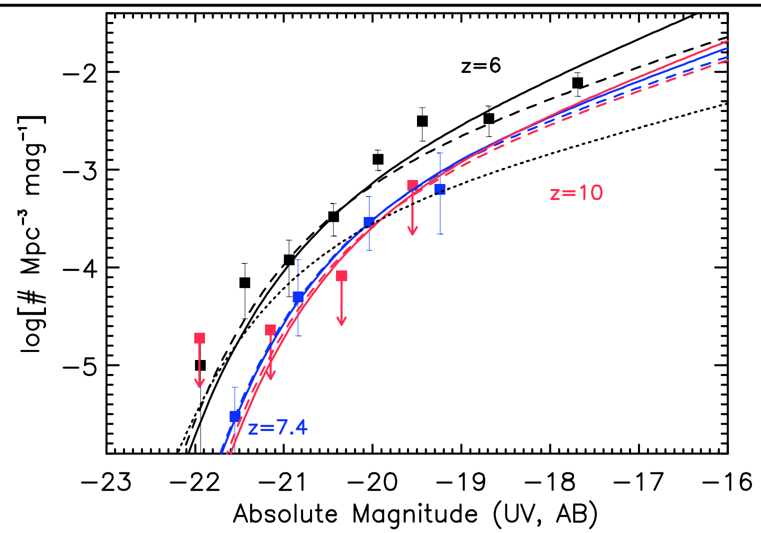


NO!

$$\dot{\rho}_{\rm SFR} \approx 0.013 f_{\rm esc}^{-1} \left(\frac{1+z}{6}\right)^3 \left(\frac{\Omega_b h_{50}^2}{0.08}\right)^2 C_{30} M_\odot \, {\rm yr}^{-1} \, {\rm Mpc}^{-3}$$

Reionization dominated by very faint, sub-dwarf galaxies!!!

Can we hide the sources?

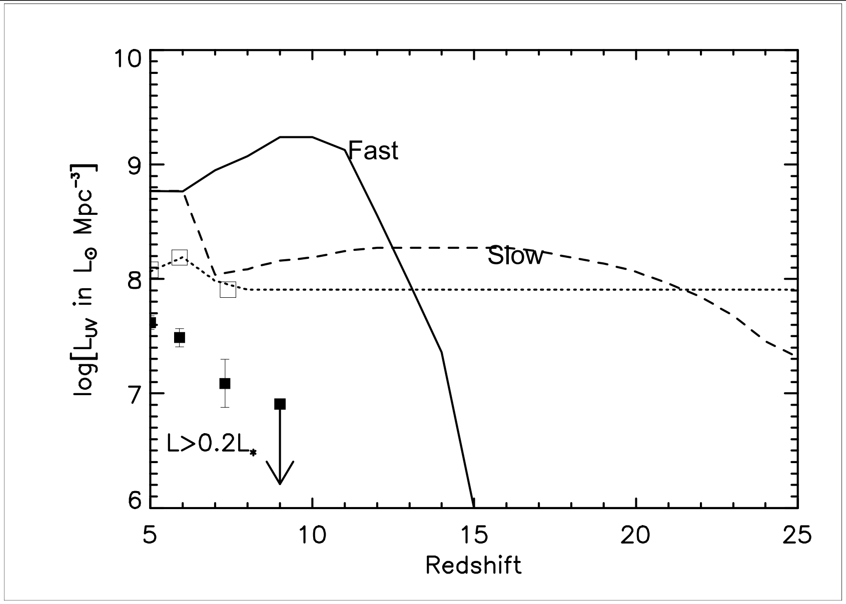


Solid lines: Required for Reionization
Dashed lines: Measured

Data/fits from
Bouwens et al. 08

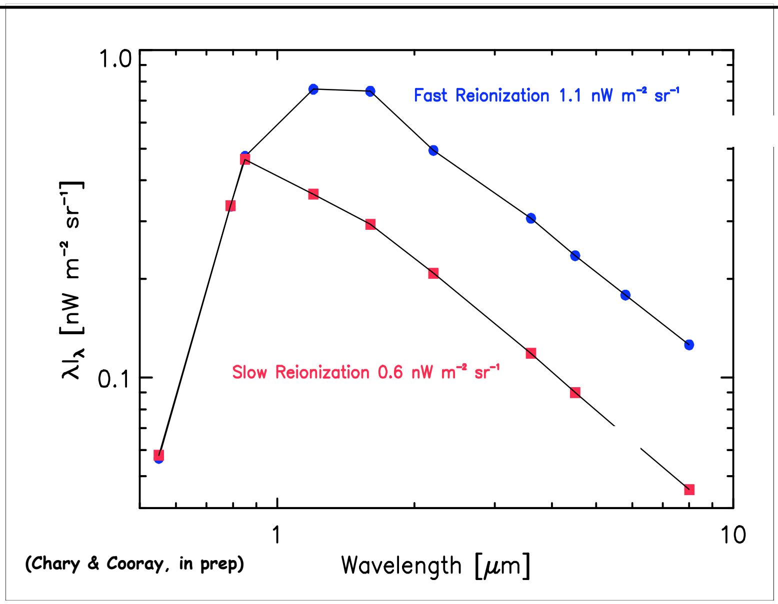
Large uncertainty in the faint end slope of the UVLF
the faint sources dominate the integrated light!

The UV photon luminosity density for reionization



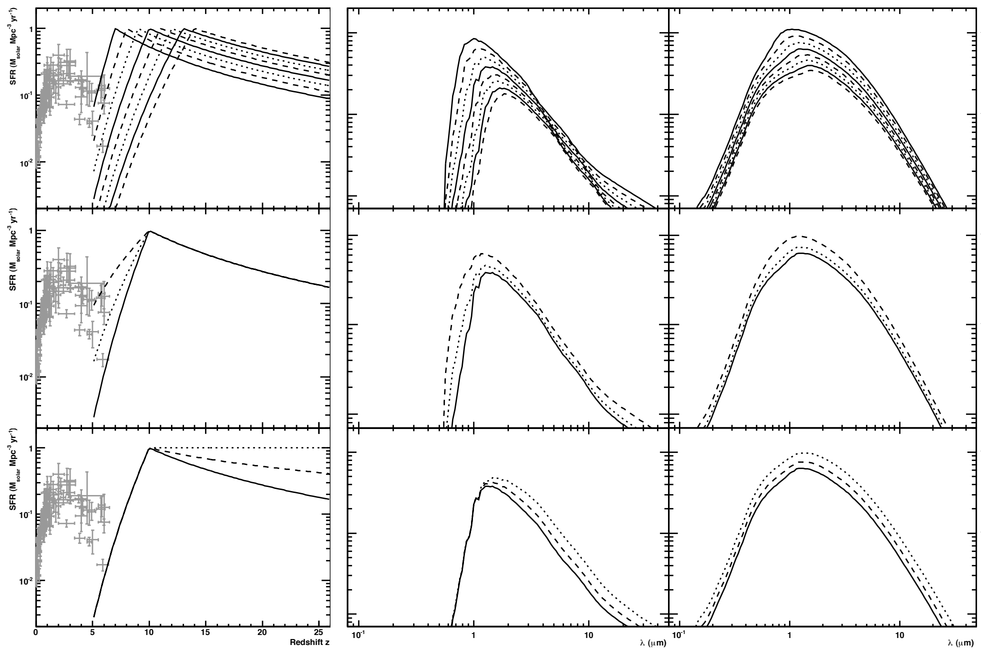
reionization dominated by L ~0.001 L* or below

A minimum level of EBL from reionization



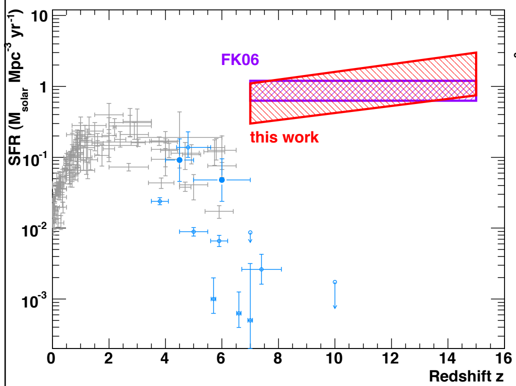
Calculation consistent with all existing data, including stellar mass density at z of 6 with Spitzer. If EBL is higher, more massive stars with end stage going to black holes.
It is safe to consider this EBL as a lower limit.

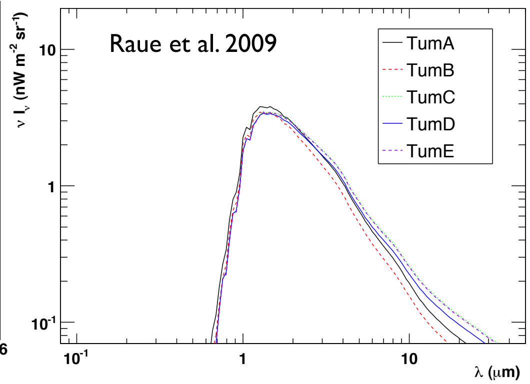
But, there could be more high-redshift star-formation



Raue et al. 2009

Spectral Signature in EBL from Reionization





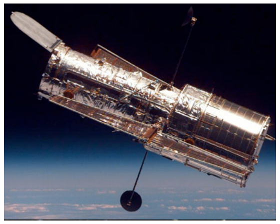
Two key features of the EBL reionization spectral signature:

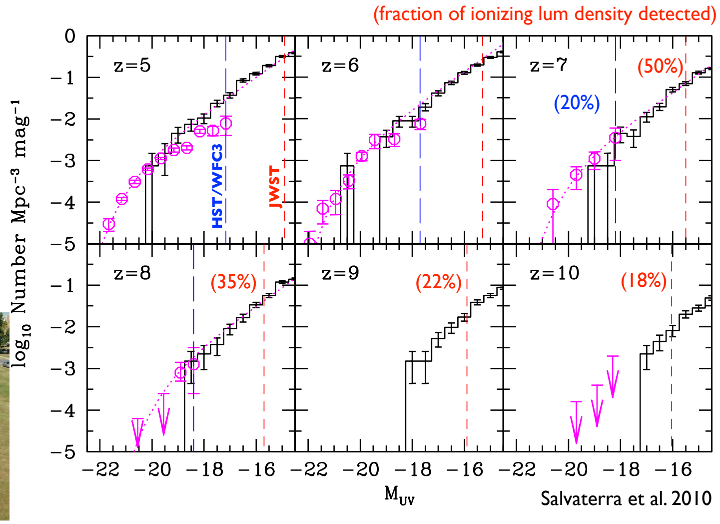
(a) Amplitude of the spectral signature probes the integrated SFR during reionization

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

These are complimentary to information from CMB polarization and 21-cm background studies of neutral H

Will JWST see the faint reionizing sources?

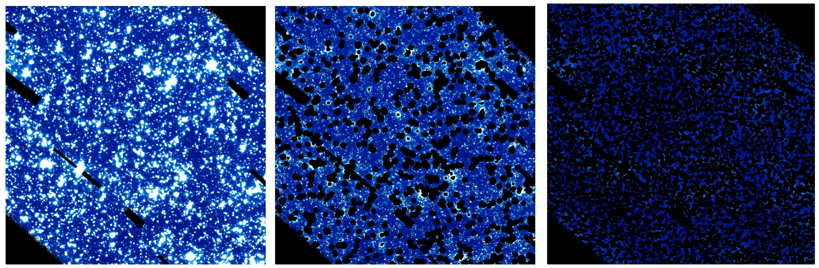




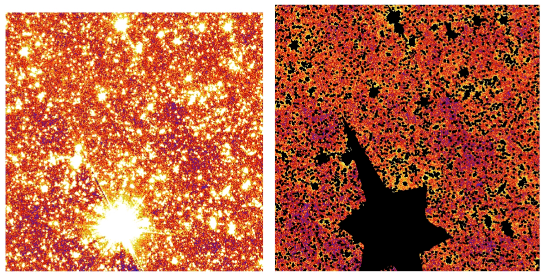
JWST: a deep 10^6 sec exposure
1nJy detection in J-band
(equivalent to a HDF
with JWST)

LFs are steep (~-2), luminosity density is dominated by sources at the faint-end.
JWST is not the final answer to studying reionization!

Searching for faint sources hidden in noise!



GOODS
CDF-S



COSMOS

What is done?

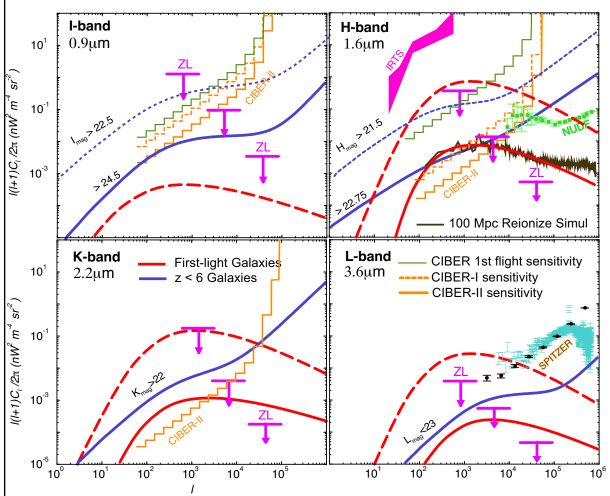
Measure statistics of “empty” pixels.

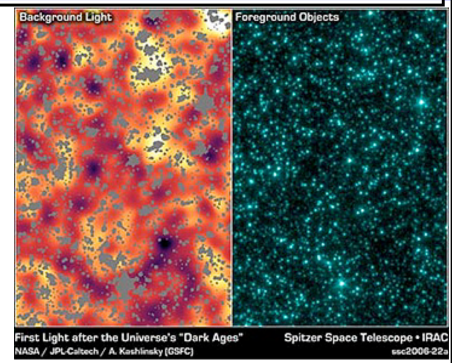
If unresolved faint galaxies are hidden in noise, then there is a clustering excess above noise

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

Mask > 50% of pixels (GOODS we masked 70% of pixels), but techniques to handle mask well developed for CMB analyses. (e.g., MASTER algorithm from Hivon et al.)

Searching for faint sources hidden in noise!



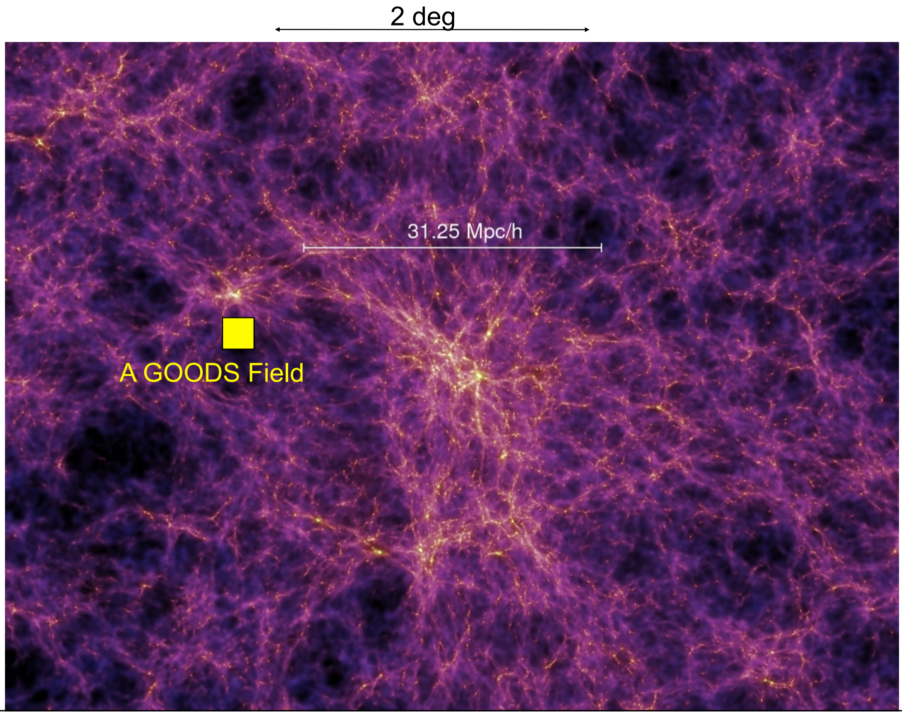


- **Kashlinksy *et al.* 2005**. Interpreted as evidence for a z > 8 first-light component responsible for reionization
- **Some uncertainty with undetected dwarf galaxies at moderate redshifts of 1 to 3?** Cooray *et al*. 2006; Chary et al. 2008 using fluctuations and a stacking analysis; account for ~50% of the fluctuations.

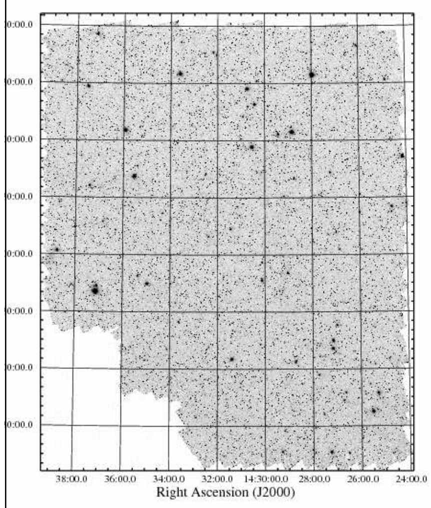
Characteristic features (Cooray et al. 2003):
(a) bump around $l \sim 10^3$ (~50 Mpc clustering scale at z~10-12)
(b) non-linear corrections at $l > 10^4$ (seen in numerical simulations)

The full spectrum over a few degree angular scales cannot be reproduced by low redshift populations!
(at z < 1 to 2, diffuse intra-cluster light can, but amplitude is small given existing measurements)

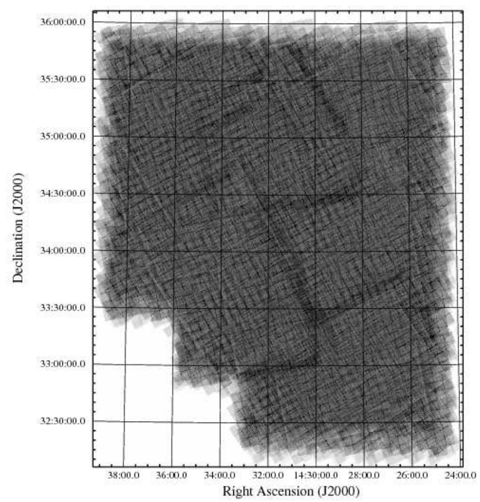
Cosmic Variance is a problem for fluctuation studies, so far



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



IRAC-Bootes, 8.5 square degrees



Challenges: Deconvolve the coverage map!!

Other opportunities: Akari, SEDS w/IRAC (>2 microns),
WFC3/MCT (Ferguson-Faber program)
CIBER, and in near horizon JDEM

Fluctuations vs. Mean Intensity

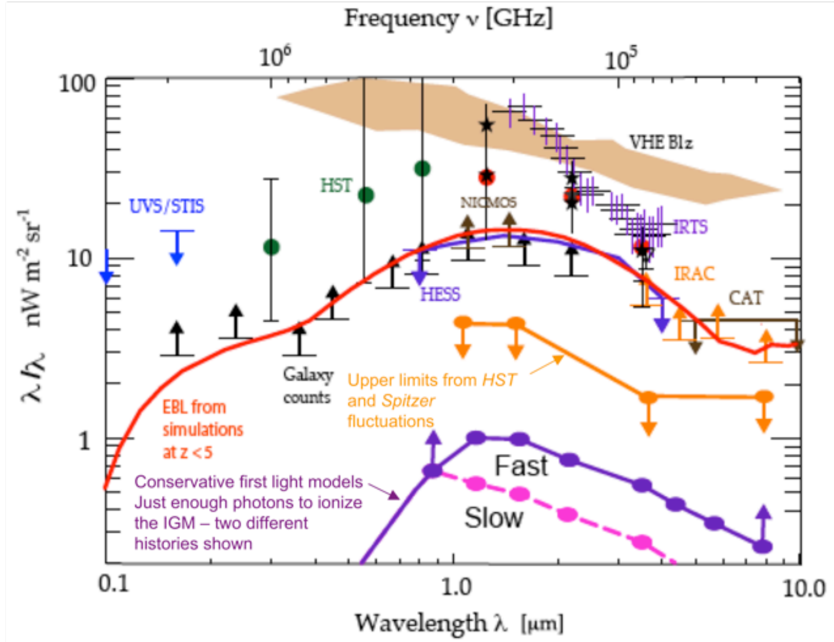
Fluctuations alone cannot establish the integrated SFR during reionization - degeneracies between various model parameters from mass scale of reionization, mean redshift of reionization, duration of reionization etc.

Sources in more massive dark matter halos at a lower redshift can be tuned to produce the same level of fluctuations as sources in less massive halos at a higher redshift.

However, the two scenarios will have two different EBL amplitudes.

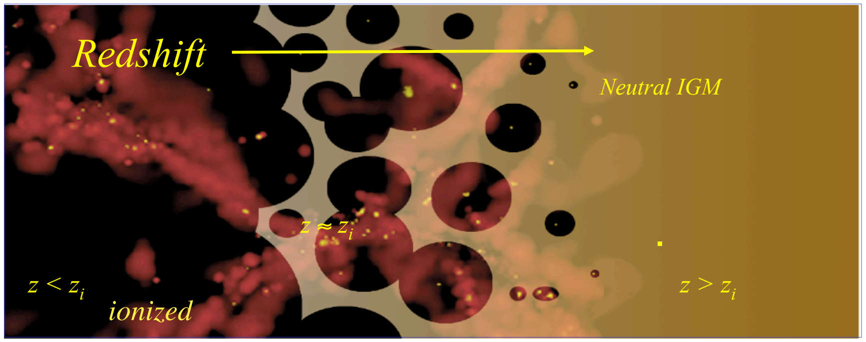
Thus, a precise EBL spectrum must be combined with fluctuations to properly constrain the astrophysics of of reionization.

State of NIR/Optical Extragalactic Background Measurements



Absolute measurements completely limited by Zodiacal foreground removal

Summary



Infrared background is cosmologically important, a spectral signature from sources present during reionization.

The optical to IR extragalactic background light is highly uncertain

More precise measurements are wanted in near-IR

- absolute spectroscopy of sky from 0.8 – 3.0 μm with an ability to account for zodiacal light properly.
- fluctuation studies extending to 2 degrees or more with multi-wavelength coverage for cross-correlations
- in combination, establish reionization history, mass scale, duration!