

The View from 5 AU:
The Astrophysical Science Case for
Extragalactic Background Light Measurement



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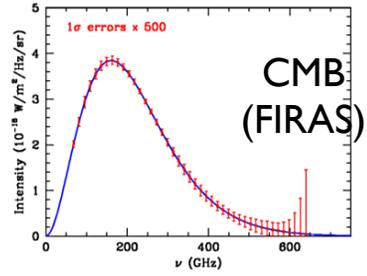
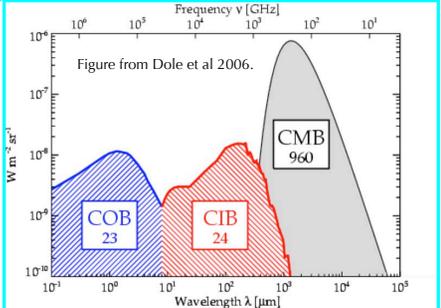
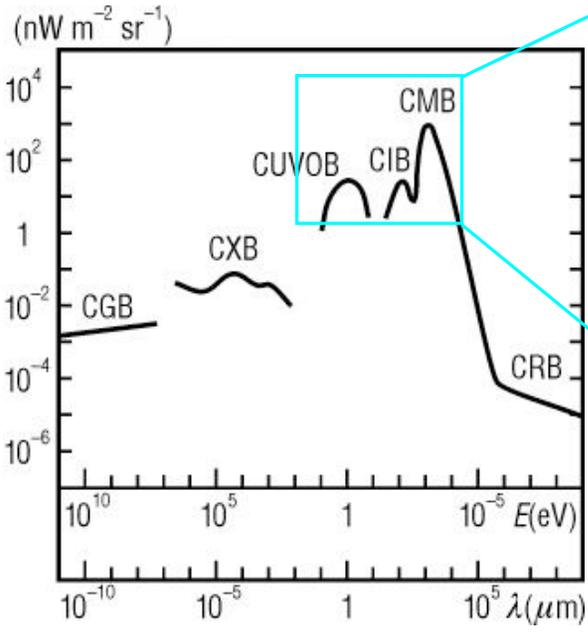
Heinrich Olbers
1758-1840

“Why is the night sky dark?”

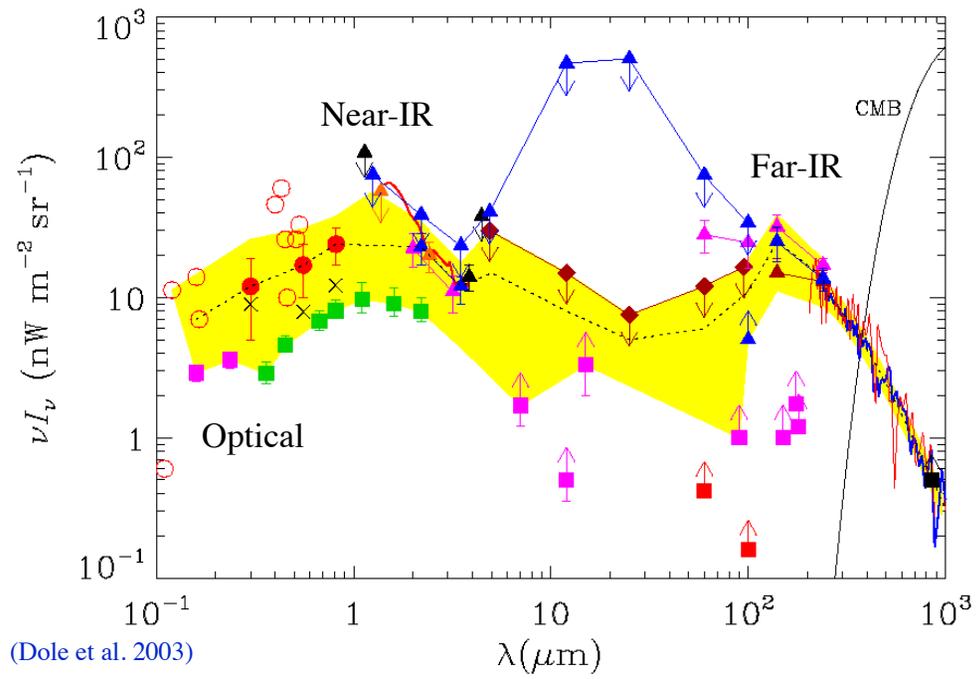
21st century version:

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

The Extragalactic Background Light Spectrum



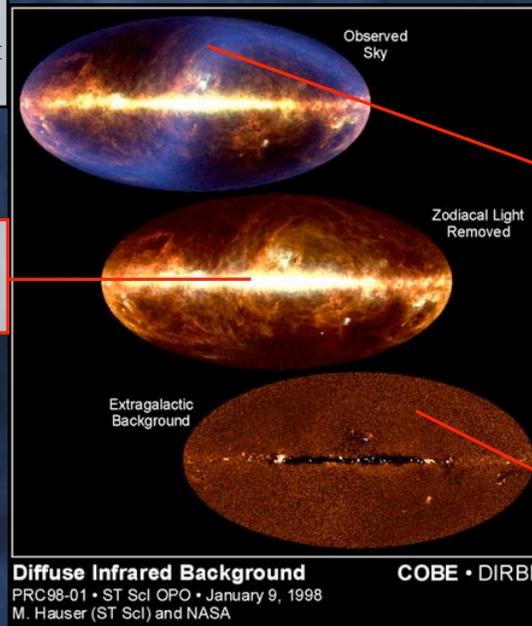
Optical and IR EBL Spectrum



Why is the absolute optical/IR background uncertain?

Our viewpoint of the Universe is not typical

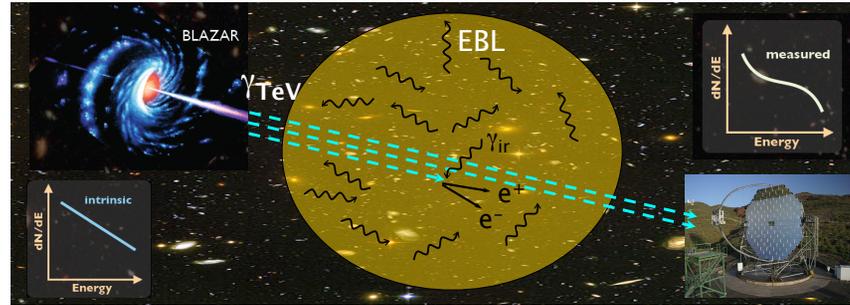
...stars and starlight in the galaxy...



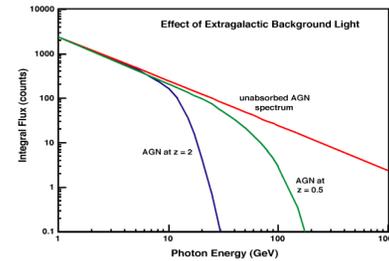
...Zodiacal light (ie dust in the solar system scattering sun light)...

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

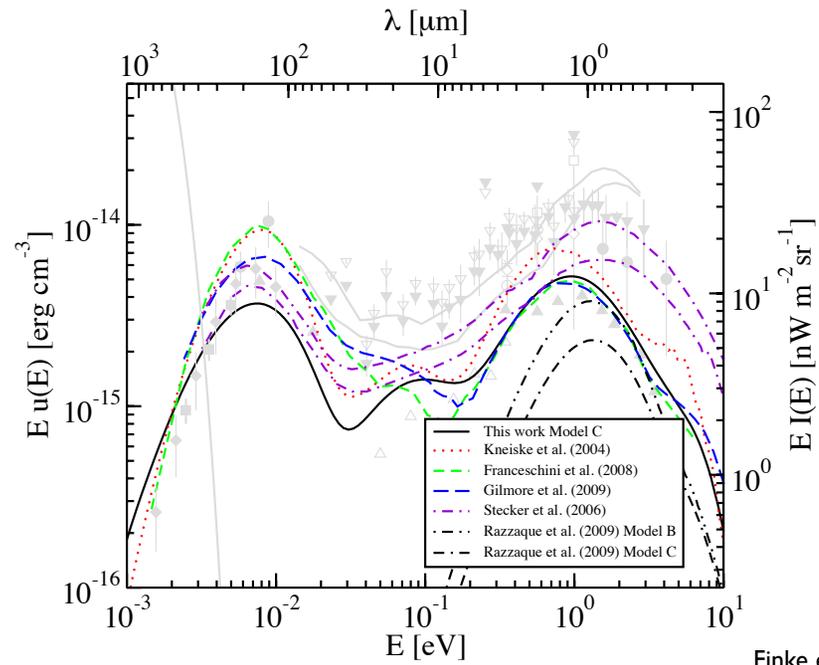
Is there a need for a new direct EBL measurement?

A New Era in Extragalactic Background Light Measurements: The Cosmic History of Accretion, Nucleosynthesis and Reionization

Asantha Cooray^{1,*}, Alexandre Amblard¹, Charles Beichman², Dominic Benford³, Rebecca Bernstein⁴, James J. Bock^{2,5}, Mark Brodwin⁶, Volker Bromm⁷, Renyue Cen⁸, Ranga R. Chary², Mark Devlin⁹, Timothy Dolch¹⁰, Hervé Dole¹¹, Eli Dwek³, David Elbaz¹², Michael Fall¹⁰, Giovanni Fazio¹³, Henry Ferguson¹⁰, Steven Furlanetto¹⁴, Jonathan Gardner³, Mauro Giavalisco¹⁵, Rudy Gilmore⁴, Nickolay Gnedin¹⁶, Anthony Gonzalez¹⁷, Zoltan Haiman¹⁸, Michael Hauser⁹, Jiasheng Huang¹³, Sergei Ipatov¹⁹, Alexander Kashlinsky³, Brian Keating²⁰, Thomas Kelsall³, Eiichiro Komatsu⁷, Guilaine Lagache¹¹, Louis R. Levenson², Avi Loeb¹³, Piero Madau⁴, John C. Mather³, Toshio Matsumoto²¹, Shuji Matsuura²¹, Kalevi Mattila²², Harvey Moseley³, Leonidas Moustakas⁵, S. Peng Oh²³, Larry Petro¹⁰, Joel Primack⁴, William Reach², Tom Renbarger²⁰, Paul Shapiro⁷, Daniel Stern⁵, Ian Sullivan², Aparna Venkatesan²⁴, Michael Werner⁵, Rogier Windhorst²⁵, Edward L. Wright¹⁴, Michael Zemcov^{2,5}

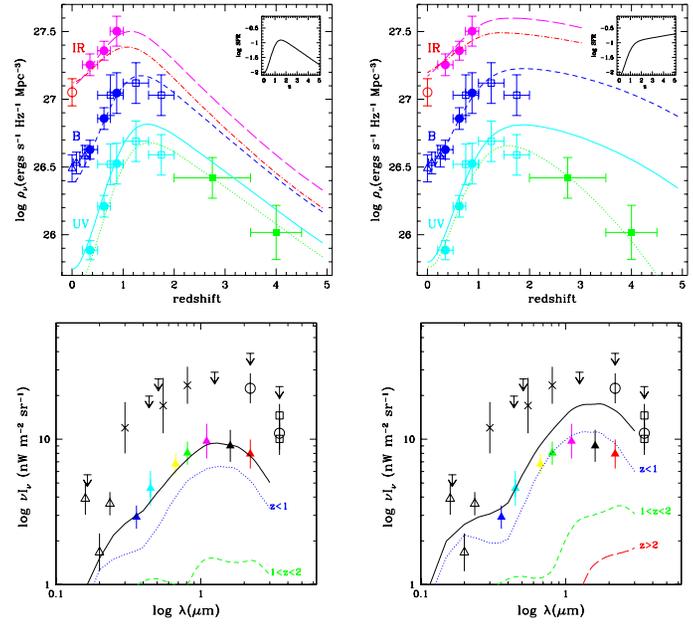
Science Program White Paper for Astro-2010 Decadal Survey
arXiv:0902.2372

Understanding Galaxy Formation with EBL?



Finke et al. 2009

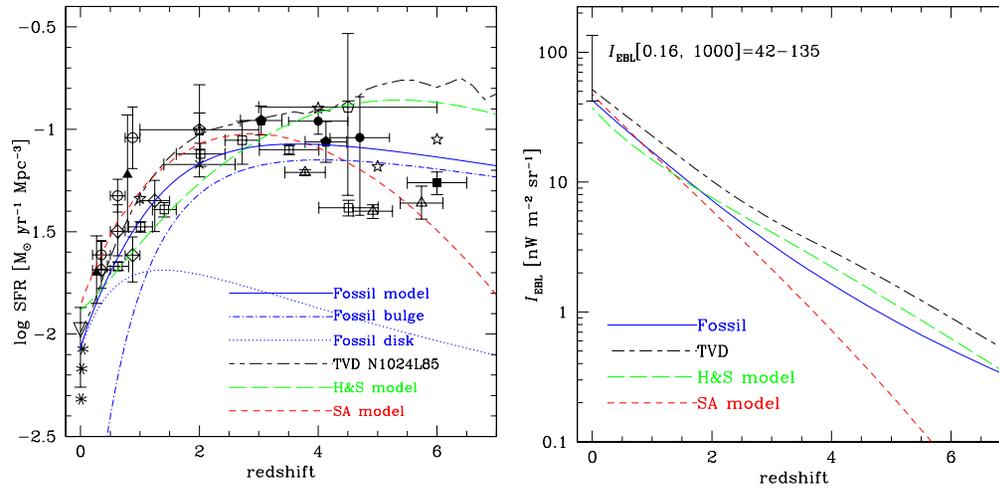
EBL as an independent probe of SF history of the Universe



Madau et al.

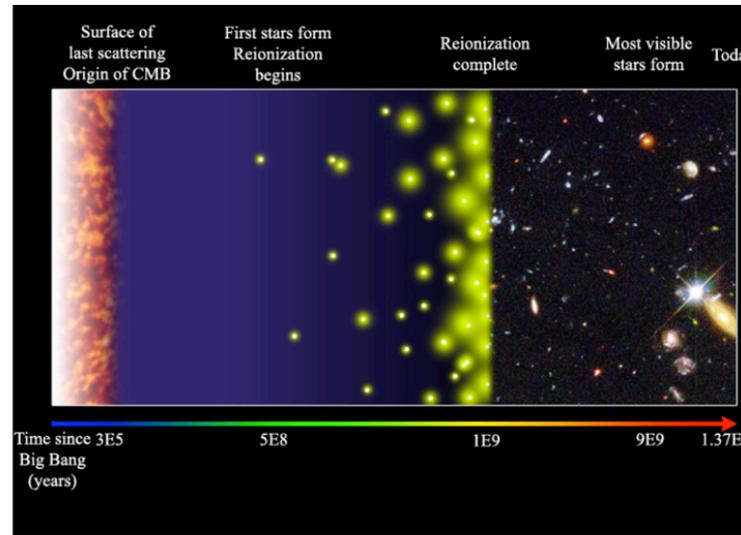
EBL as an independent probe of SF history of the Universe

Nagamine et al.



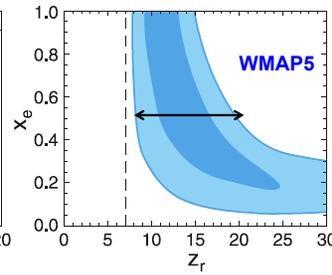
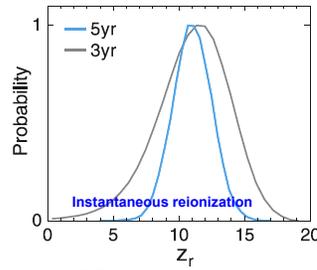
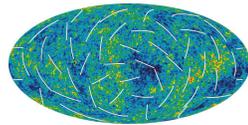
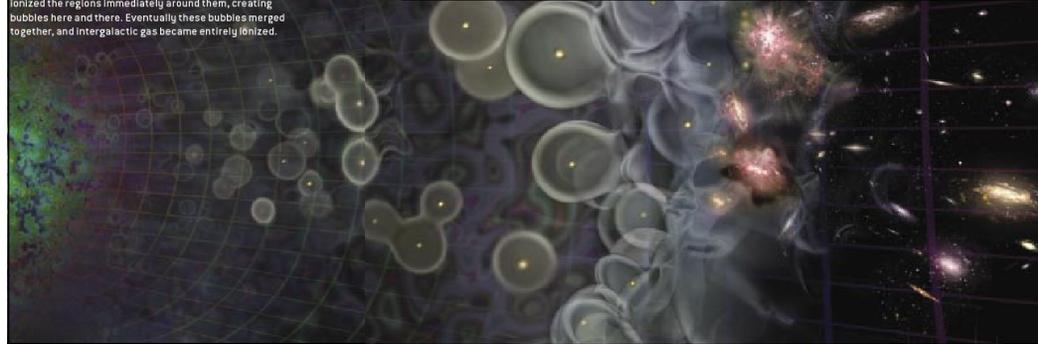
EBL from known galaxy populations at $z > 4$ is less than $3 \text{ nW m}^2 \text{ sr}^{-1}$

The epoch of reionization and a spectral signature in EBL



In the beginning of the Dark Ages, electrically neutral hydrogen gas filled the universe. As stars formed, they ionized the regions immediately around them, creating bubbles here and there. Eventually these bubbles merged together, and intergalactic gas became entirely ionized.

When did the reionization take place?

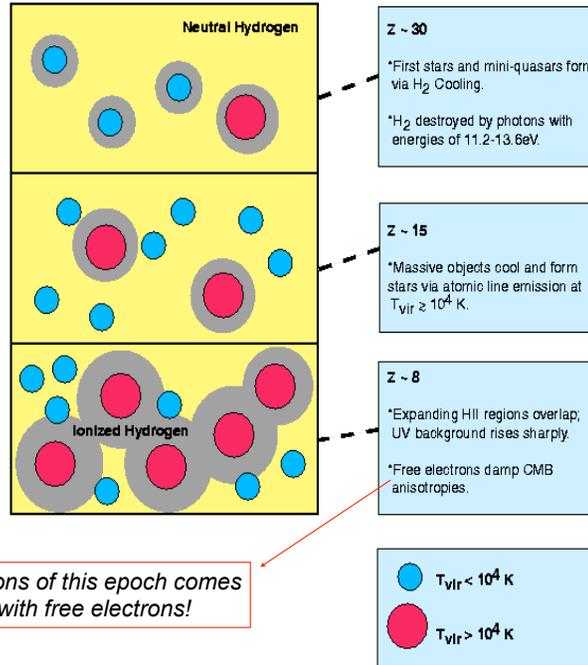


Data rejects instantaneous reionization at $z \sim 6-7$
Process is likely extended over $6 < z < 20$
CMB studies do not pinpoint the responsible cosmic sources

What Reionized the Universe?

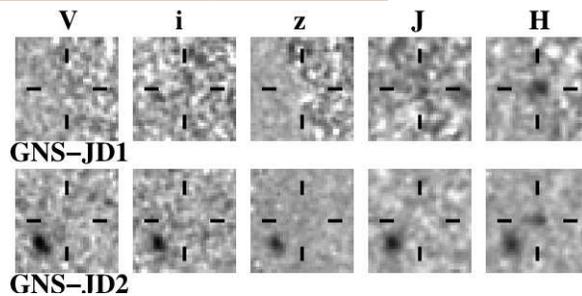
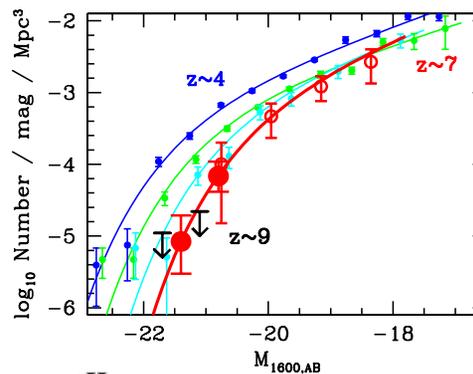
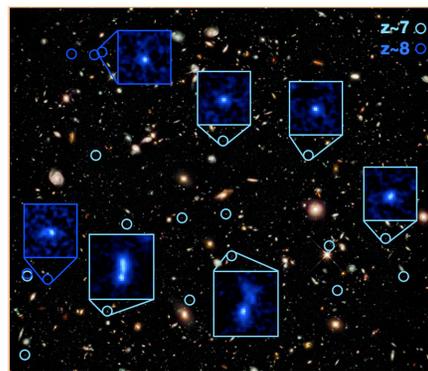
Leading candidates

- 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



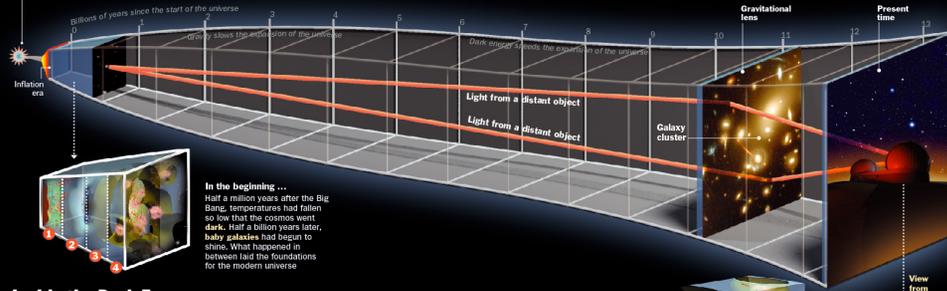
Bouwens et al.

Light From a Dark Age

How the universe grew from dark soup to twinkling galaxies

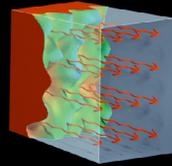
Looking for the beginning of time ...

Big Bang About 13.7 billion years ago, the universe burst into existence, creating both space and time

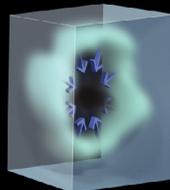


In the beginning ...
Half a million years after the Big Bang, temperatures had fallen so low that the cosmos went dark. Half a billion years later, baby galaxies had begun to shine. What happened in between laid the foundations for the modern universe.

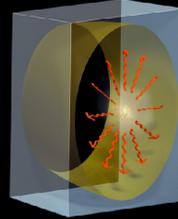
Inside the Dark Era



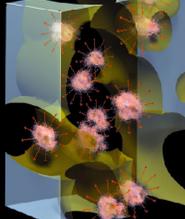
1 THE DARK AGES BEGIN
When the cosmos is about 400,000 years old, it has cooled to about the temperature of the surface of the Sun, allowing subatomic particles to combine for the first time into atoms. The first burst of light from the Big Bang shines forth at this time; it is still detectable today in the form of a faint whisper of microwaves streaming in from all directions in space. The discovery of those microwaves in 1964 confirmed the existence of the Big Bang.



2 DARK MATTER
For more abundant than ordinary atoms, dark-matter particles were spread unevenly through the cosmos; areas of higher concentration drew in hydrogen and helium gas, gradually forming knots dense enough to burst into thermonuclear flame, forming the first stars.



3 FIRST STARS
The earliest stars were extremely large and dense, weighing in at 20 to 100 times the mass of the Sun, and more. The crushing pressures at their cores made them burn through their nuclear fuel in only a million years or so, and caused them to spew out such intense radiation that it kept other stars from forming. The first "galaxies" may have consisted of clouds of hydrogen and helium surrounding just one mega-star.



4 END OF THE DARK AGES
The death of the megastars triggered the formation of normal stars, creating the first normal-looking dwarf galaxies. Their radiation in turn burned through the remaining shrouds of hydrogen, bringing the dark ages to a close.

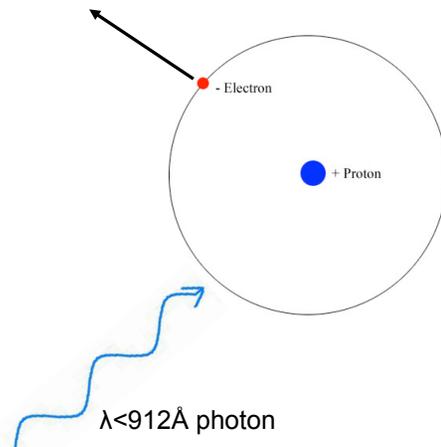


What they're really seeing

Richard Ellis of Caltech has found distant galaxies warped into odd, elongated shapes, as though they were being glimpsed through a cosmic funhouse mirror. The light from these galaxies could ordinarily never be glimpsed through existing telescopes.

TIME Graphics by Jon Landis
Science: NEXTER

Need 1 photon to start reionization



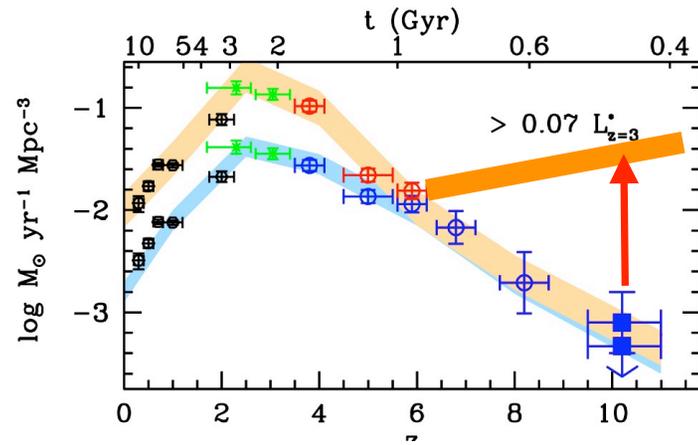
$$R = n_e n_{\text{H II}} \alpha_B C \text{ s}^{-1} \text{ Mpc}^{-3}$$

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?

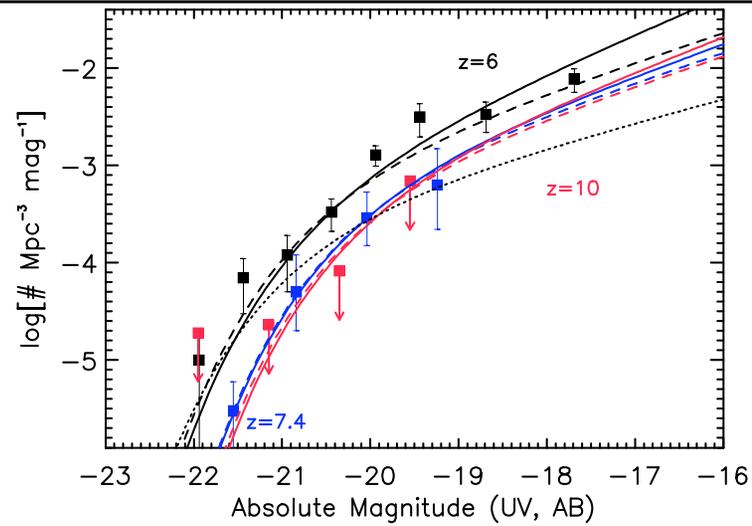


NO!

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

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

Can we hide the sources?

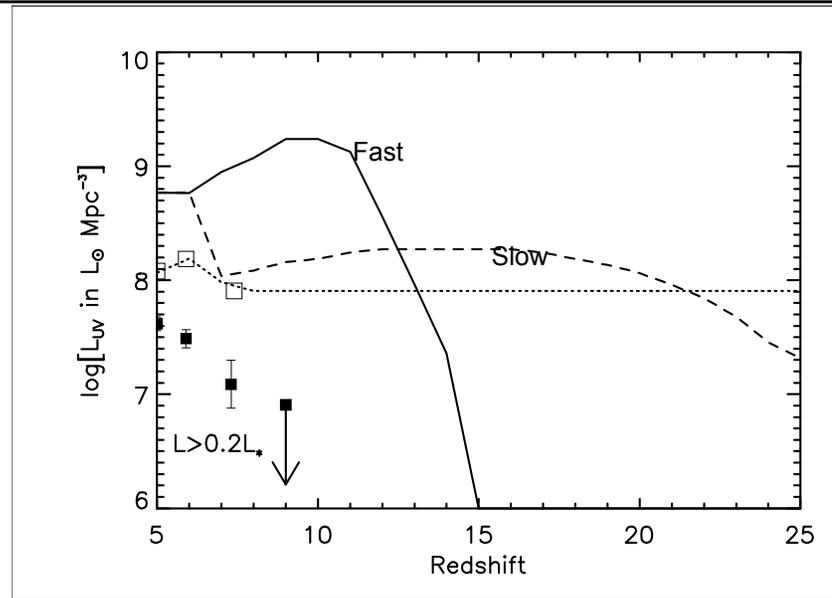


Solid lines: Required for Reionization
Dashed lines: Measured

Data/fits from
Bouwens et al. 08

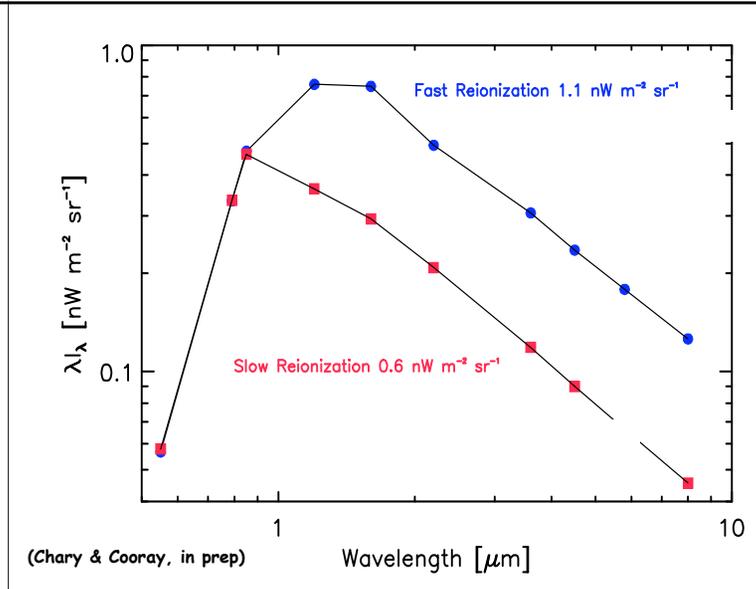
Large uncertainty in the faint end slope of the UVLF
the faint sources dominate the integrated light!

The UV photon luminosity density for reionization



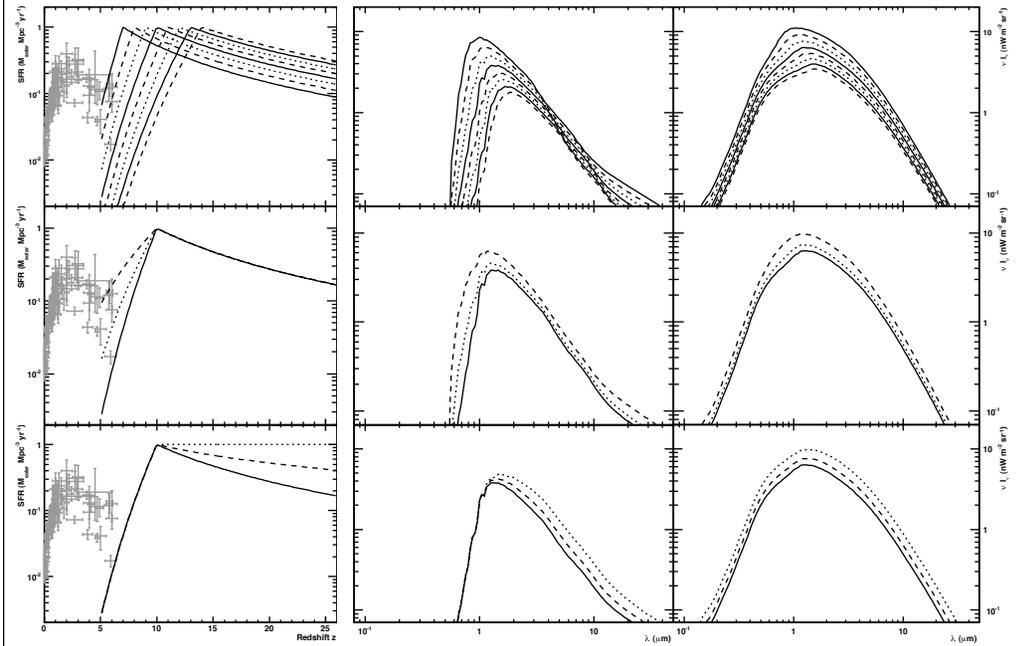
reionization dominated by $L \sim 0.001 L_{\odot}$ or below

A minimum level of EBL from reionization



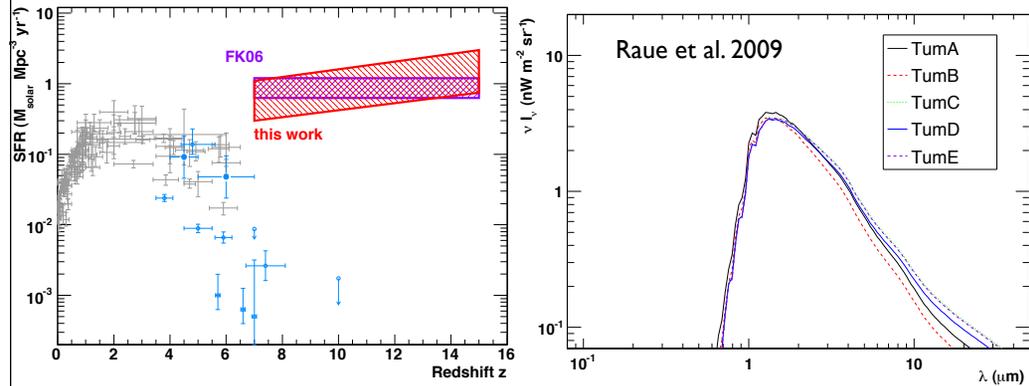
Calculation consistent with all existing data, including stellar mass density at z of 6 with Spitzer. If EBL is higher, more massive stars with end stage going to black holes.
It is safe to consider this EBL as a lower limit.

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



Raue et al. 2009

Spectral Signature in EBL from Reionization

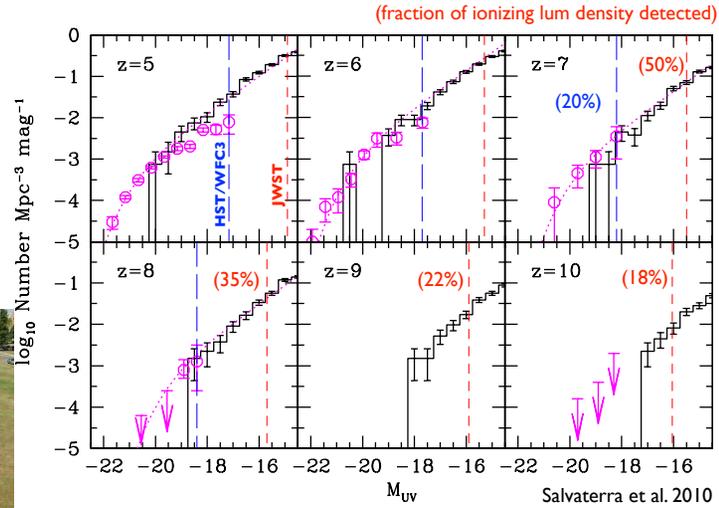


Two key features of the EBL reionization spectral signature:

- (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 complementary to information from CMB polarization and 21-cm background studies of neutral H

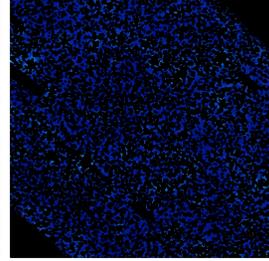
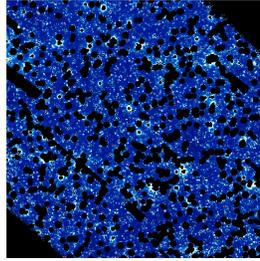
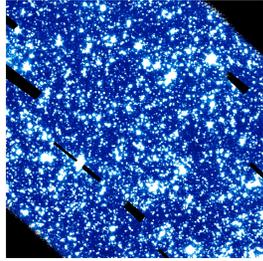
Will JWST see the faint reionizing sources?



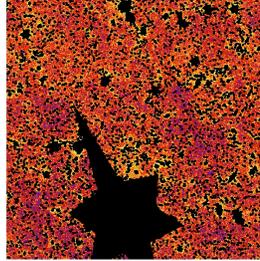
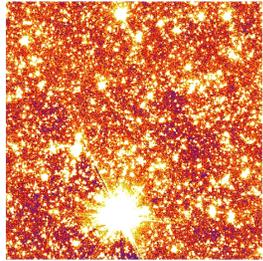
JWST: a deep 10^6 sec exposure
 InJy detection in J-band
 (equivalent to a HDF
 with JWST)

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?

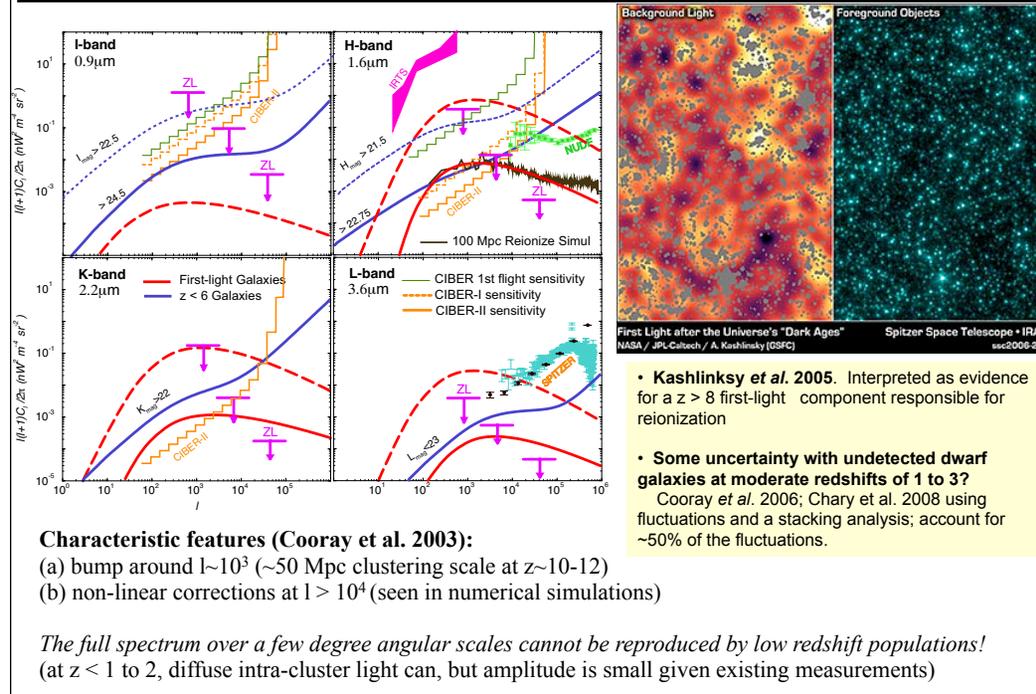
Measure statistics of “empty” pixels.

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

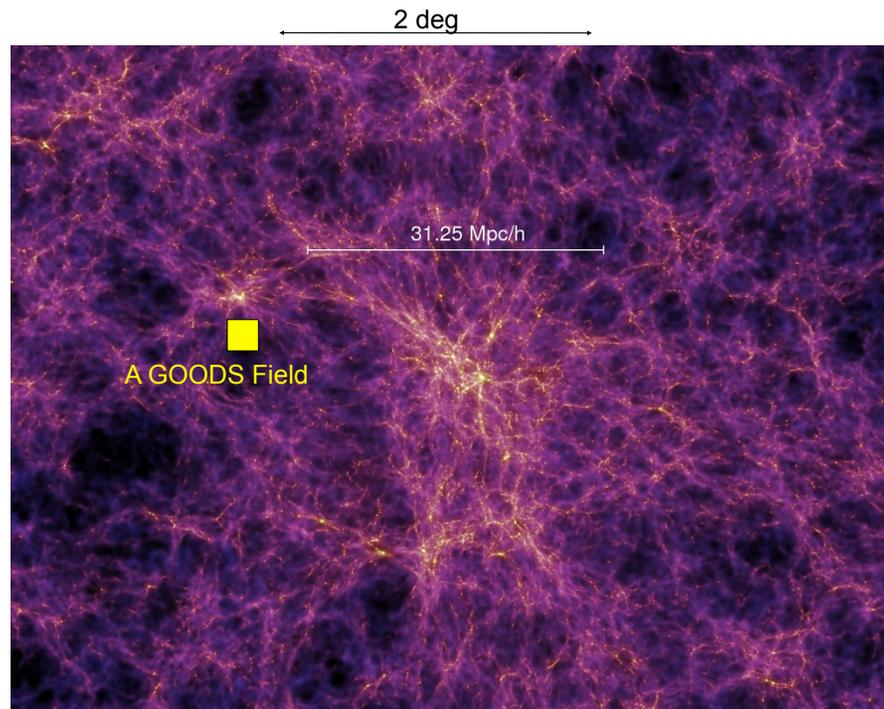
Challenges: > 10 million of pixels (higher complexity than analyzing WMAP data.)

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.)

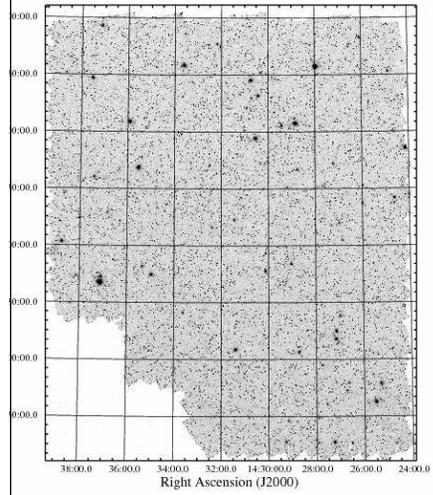
Searching for faint sources hidden in noise!



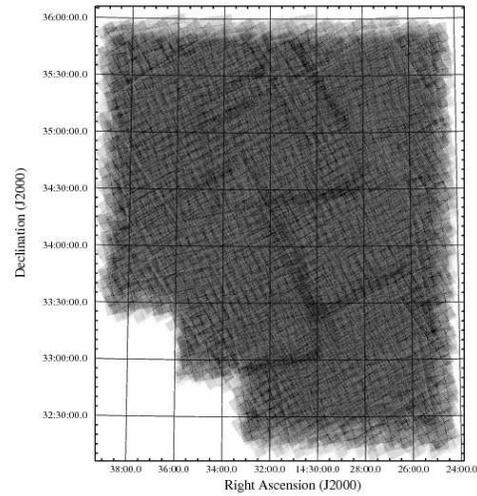
Cosmic Variance is a problem for fluctuation studies, so far



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

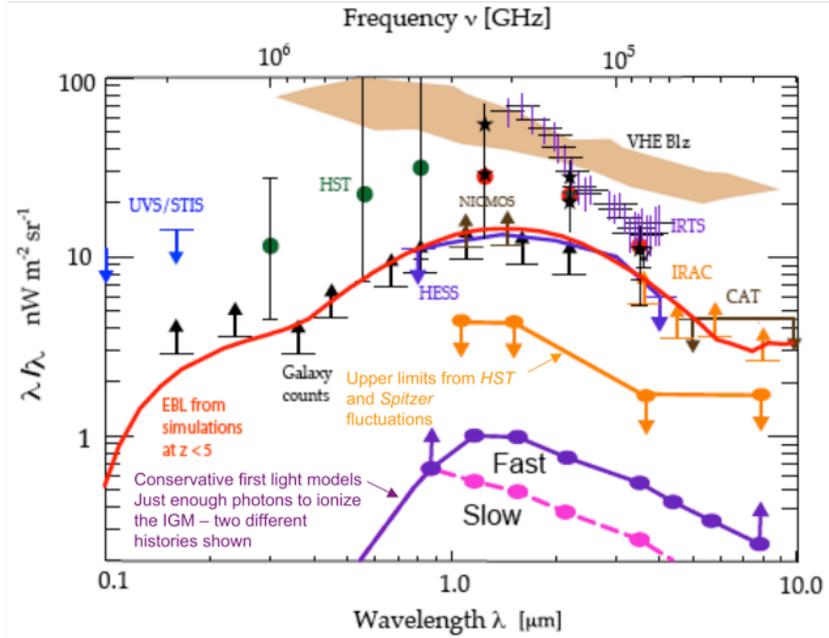
Fluctuations alone cannot establish the integrated SFR during reionization - degeneracies between various model parameters from mass scale of reionization, mean redshift of reionization, duration of reionization etc.

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.

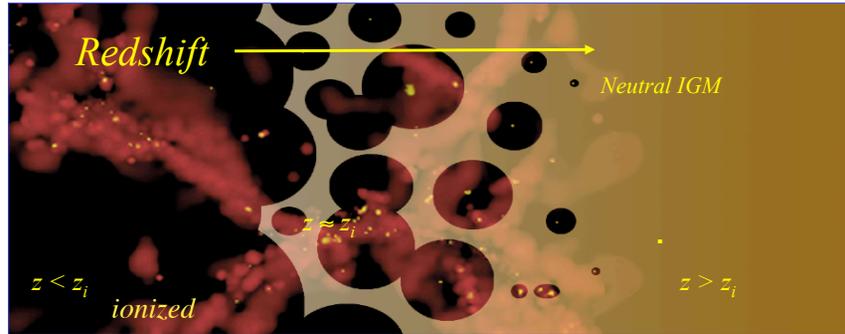
Thus, a precise EBL spectrum must be combined with fluctuations to properly constrain the astrophysics of reionization.

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!