Reionization And The Infrared Background

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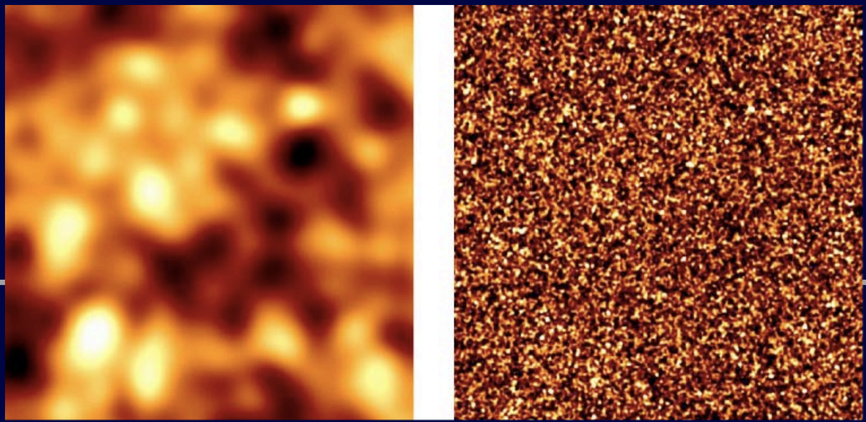


Outline

- Reionization and the Absolute Intensity of the Cosmic Infrared Background
- Spatial Fluctuations in the near-IR background

more details in arXiv.org:1205.2316 *(and this is probably not the last word on the subject)*.

Key coauthors/collaborators on research discussed today:

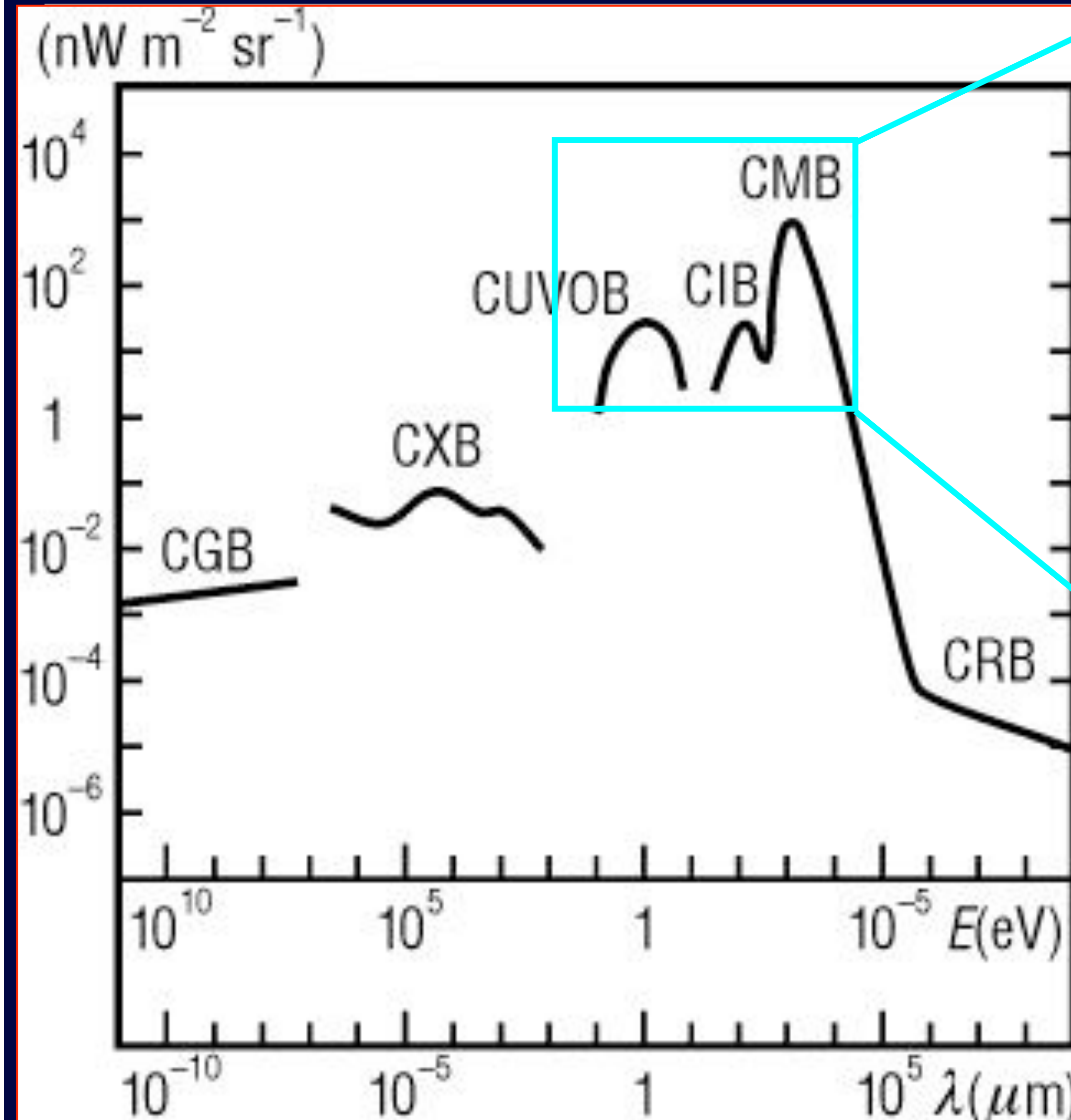
Joseph Smidt (grad student)

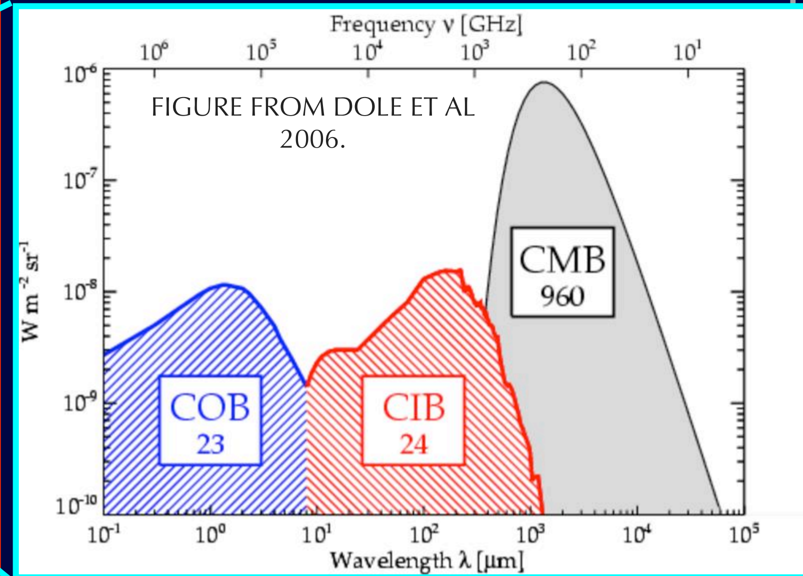
Yan Gong, Francesco De Bernardis (postdocs)

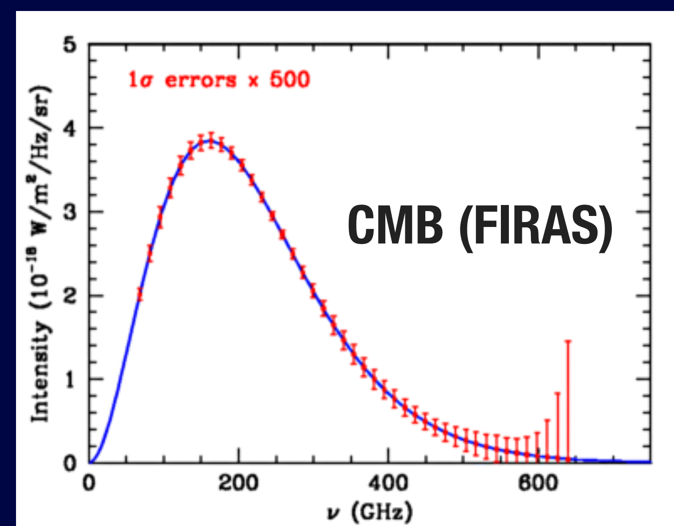
CIBER Team *ZEBRA Team*

(Jamie Bock PI on both, Mike Zemcov Project Scientist)

HST/CANDELS EBL working group

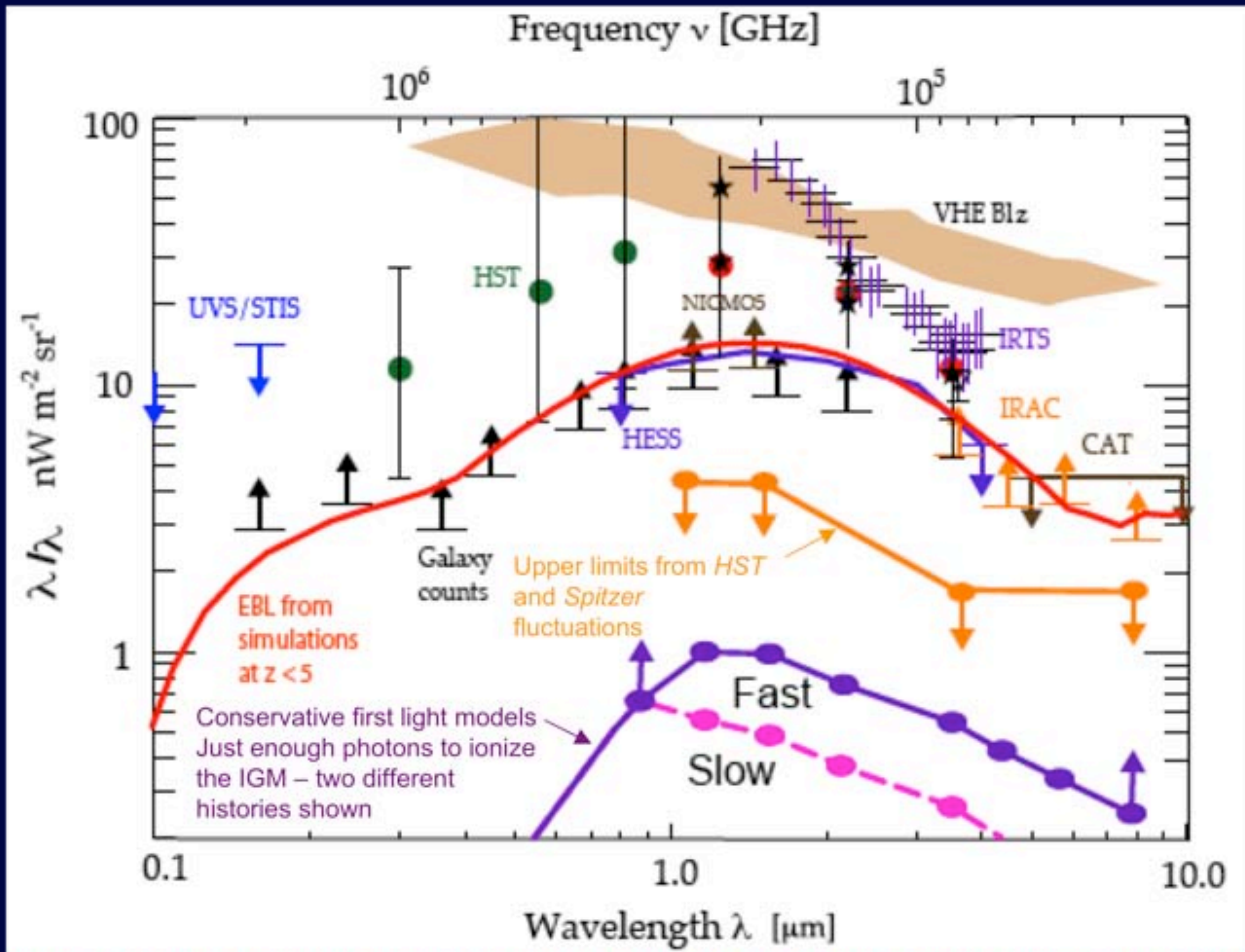






The extragalactic background spectrum

State of NIR/Optical Extragalactic Background Measurements



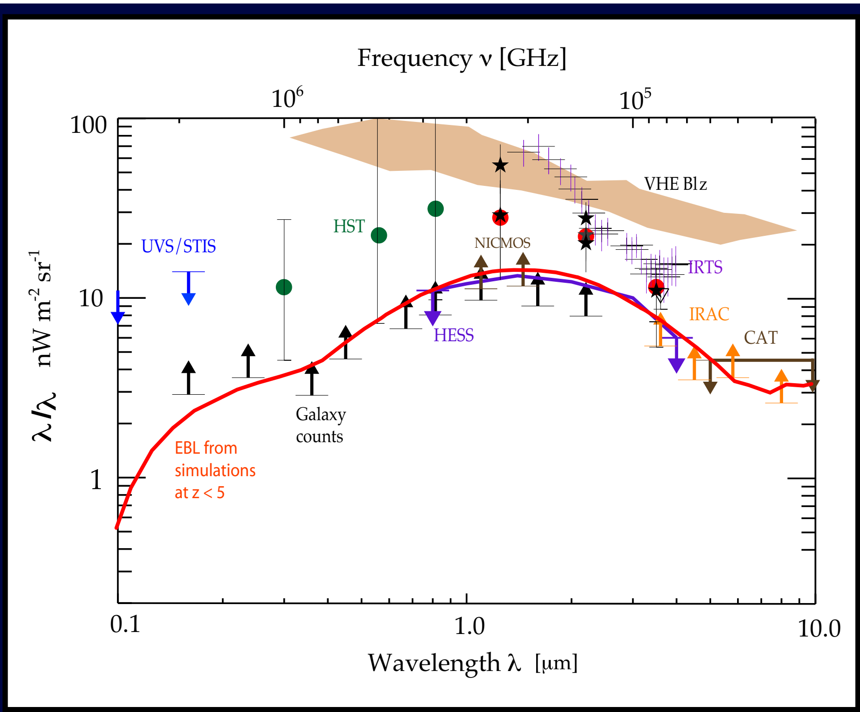
Absolute measurements completely limited by Zodiacal foreground removal

Status of Cosmic IR Background Measurements

Indirect methods to constrain EBL

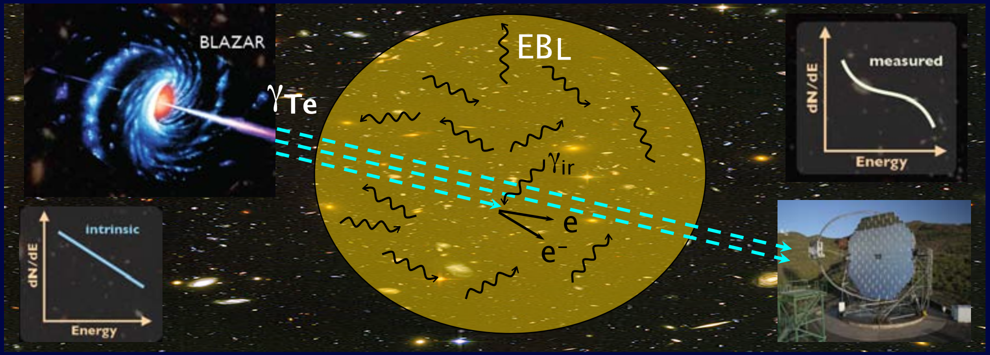
1. **Integrated Galaxy Light (IGL)** =
Sum over light from all detected galaxies

IGL ≤ EBL?



(a) Are we missing sources and/ or flux, especially in the wings?
(b) Precise EBL and IGL together can constrain any diffuse light component

2. TeV absorption



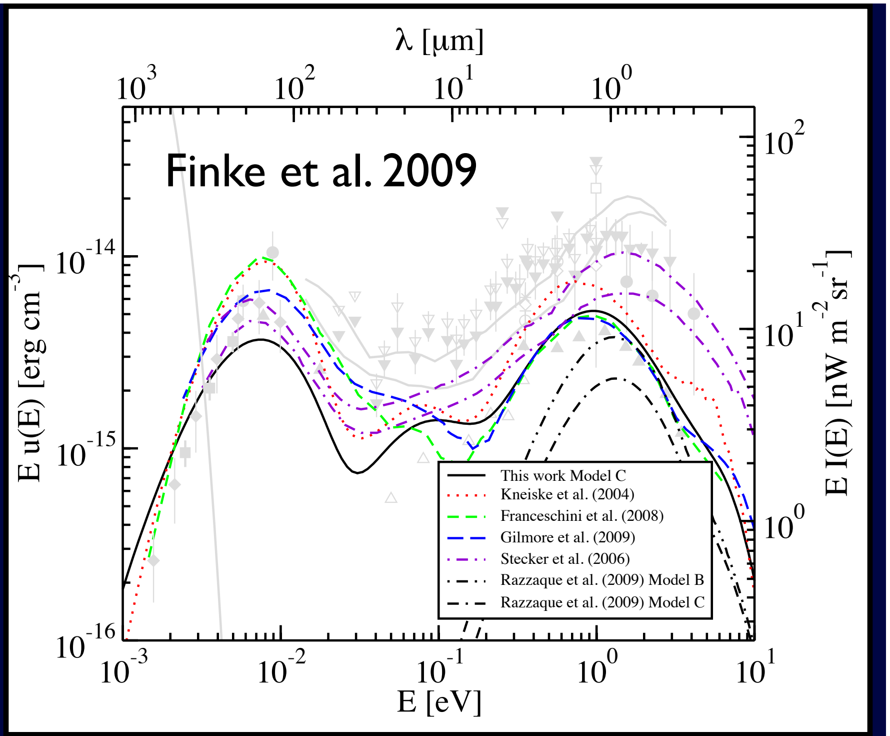
(a) TeV photons are attenuated via pair production with IR photons
(b) Imprint of the IR photon density in the measured TeV spectra
(c) However, intrinsic spectrum is not measured!

Why measure EBL to 1%?

I. Understand galaxy evolution

EBL provides an anchor that all theories of galaxy formation and evolution must satisfy.

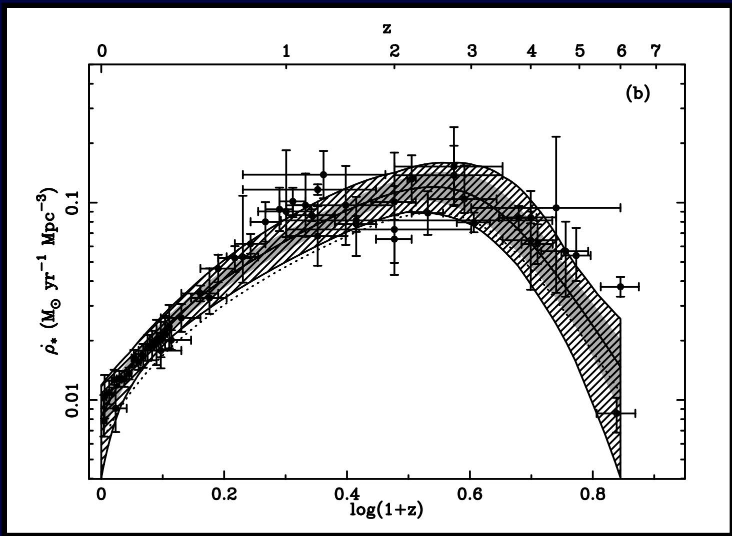
EBL can distinguish between different models of galaxy formation and evolution

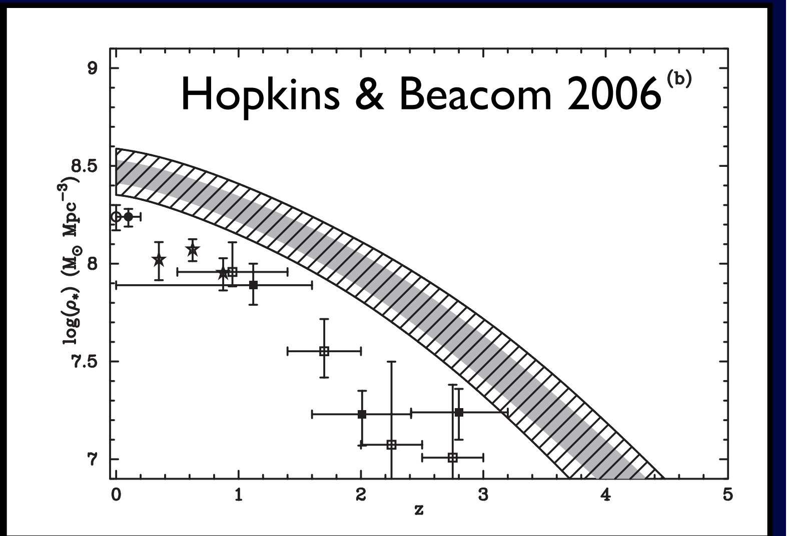


Star-formation history is inconsistent with stellar mass density at all redshifts: is the IMF of stars evolving?

Are we missing stars in low mass halos?

A precise EBL can solve this outstanding puzzle!



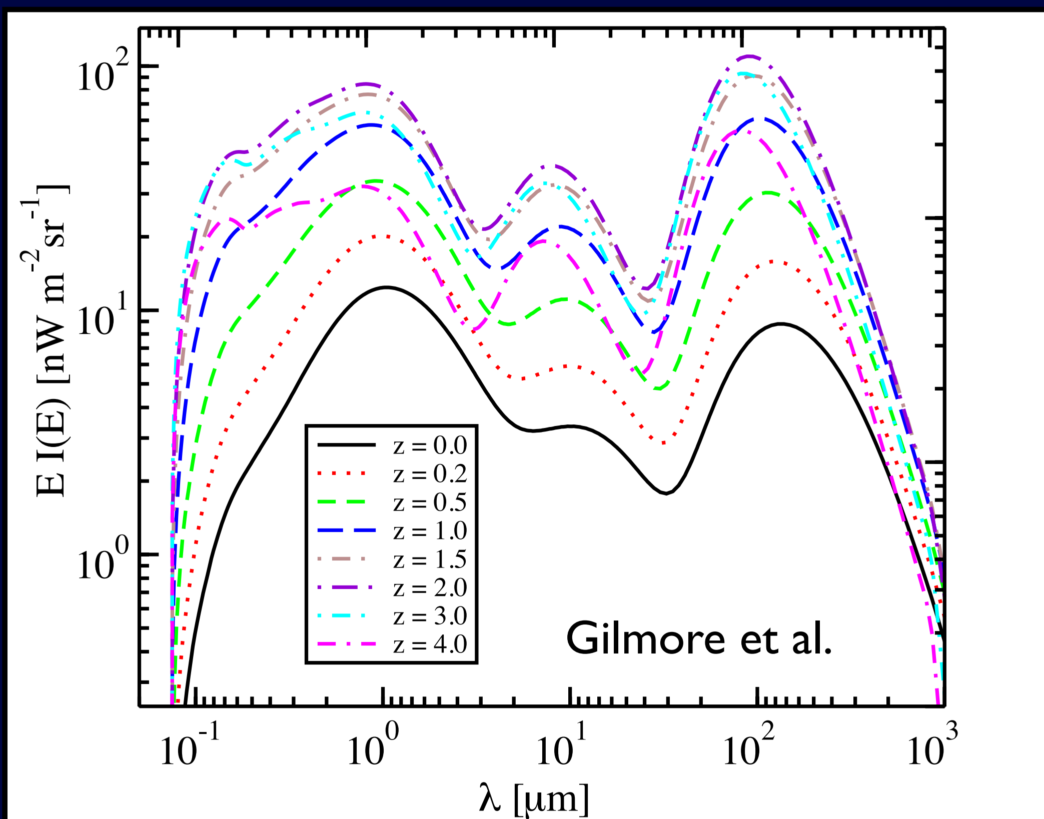


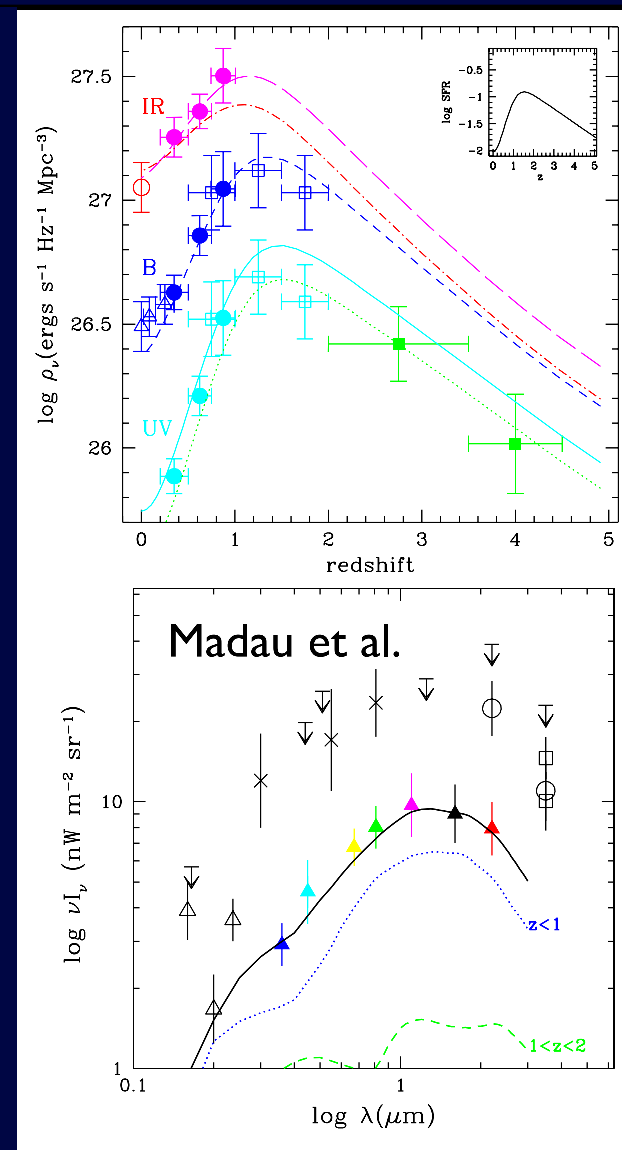
Why measure EBL to 1%?

II. EBL provides an independent probe of star-formation history of the Universe

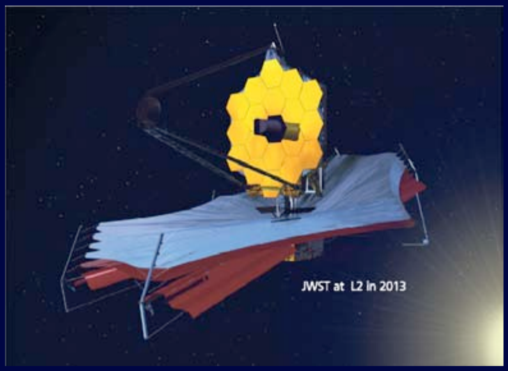
Is there significant star-formation at z > 6?

What is the fraction of EBL as a function of the redshift when combined with deep galaxy surveys?

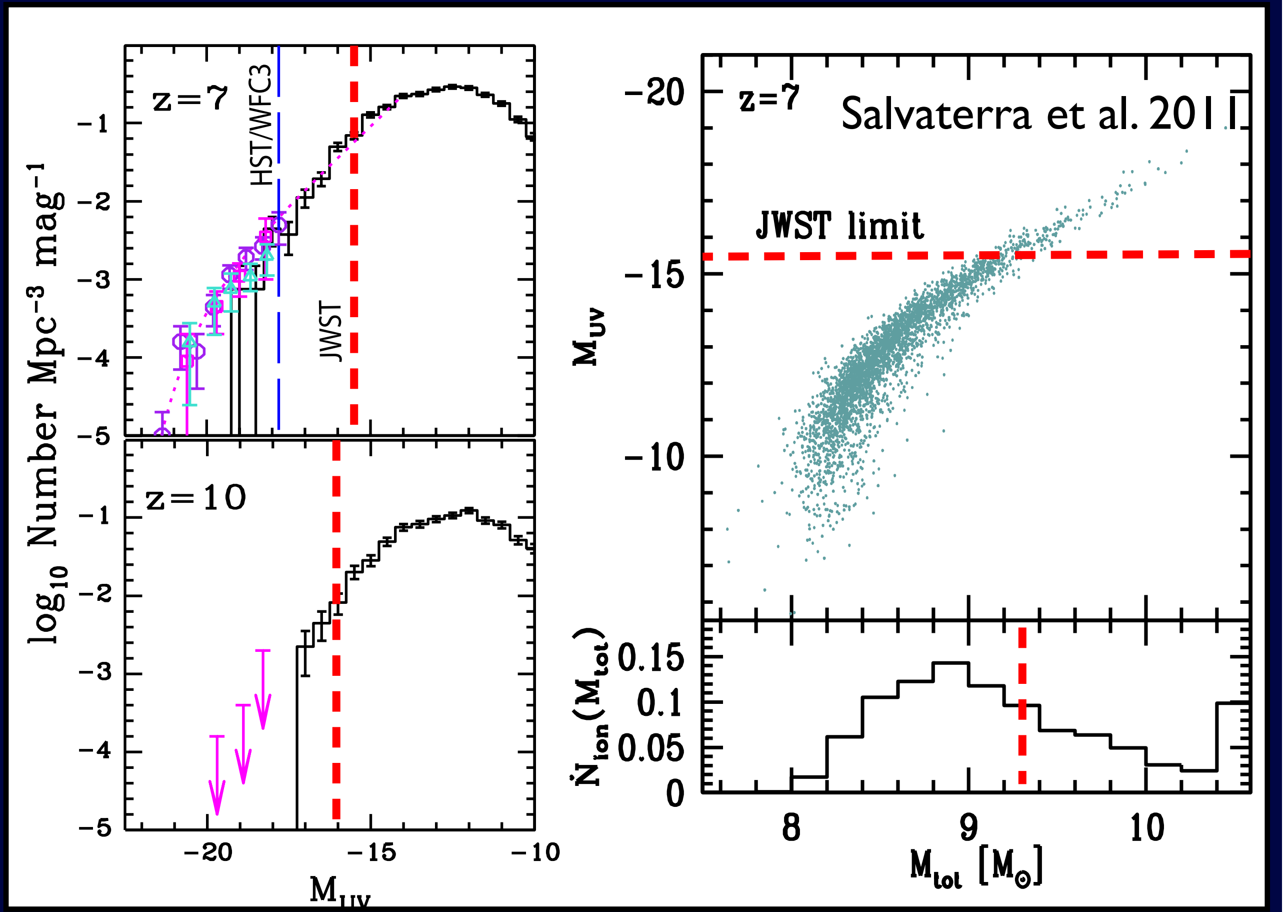




JWST will not image all sources responsible for reionization



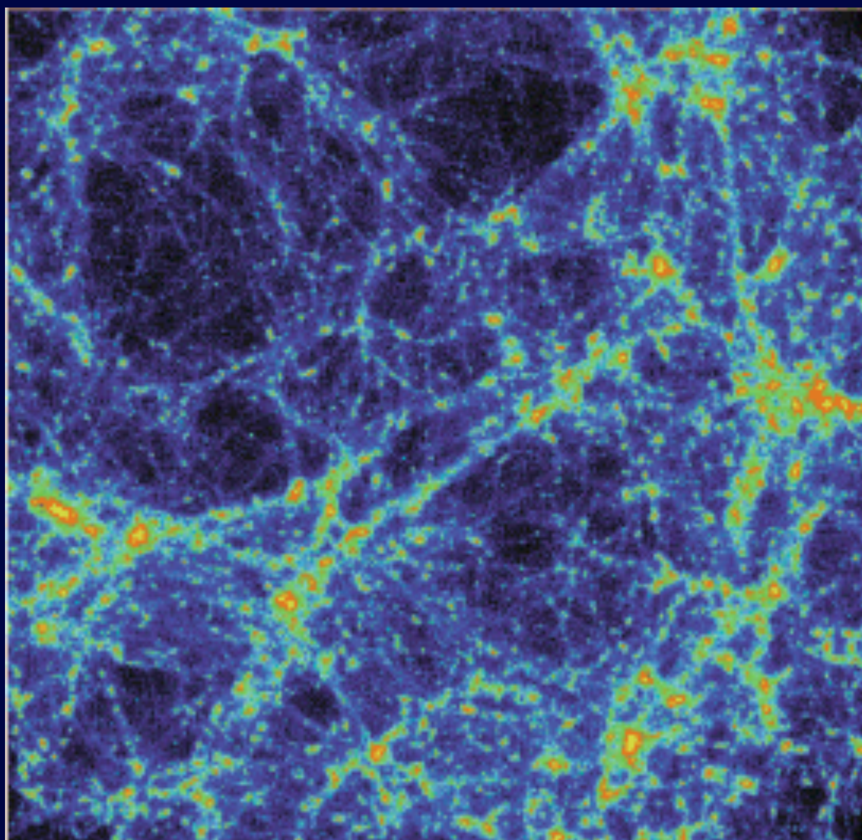
JWST: a deep10^6 sec exposure
1 nJy detection in J-band
(equivalent to a UDF
with JWST)

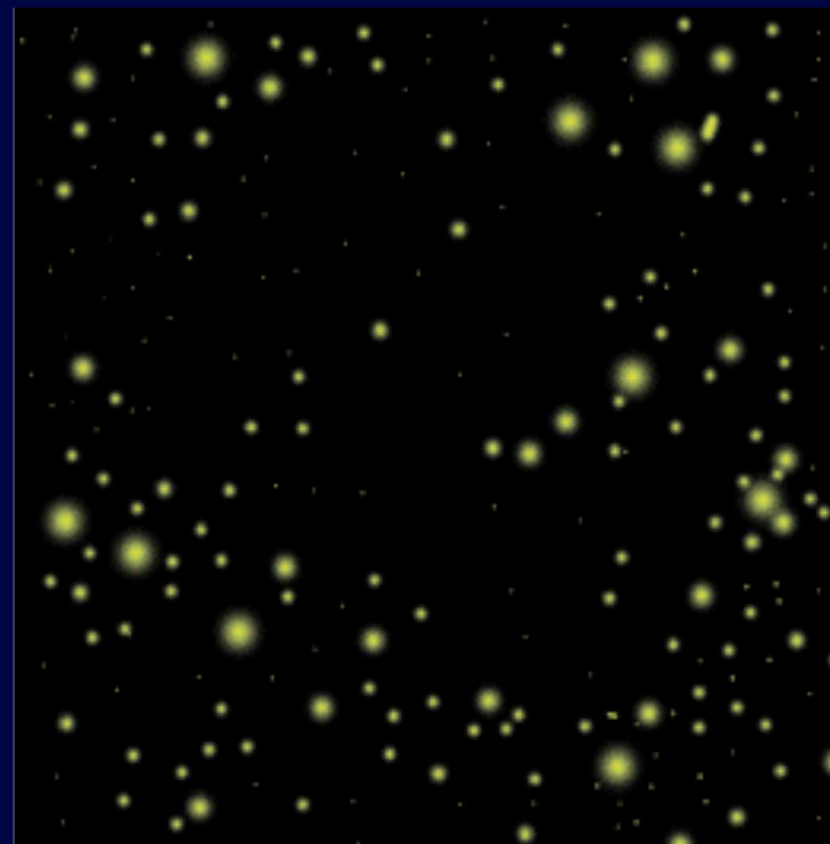


(a) Even at z~7 JWST will only detect galaxies with absolute magnitudes brighter than -15.5 in rest UV (observed J-band)
(b) LFs are steep, luminosity density is dominated by sources at the faint-end.
(c) JWST is not the final answer to understanding reionization!

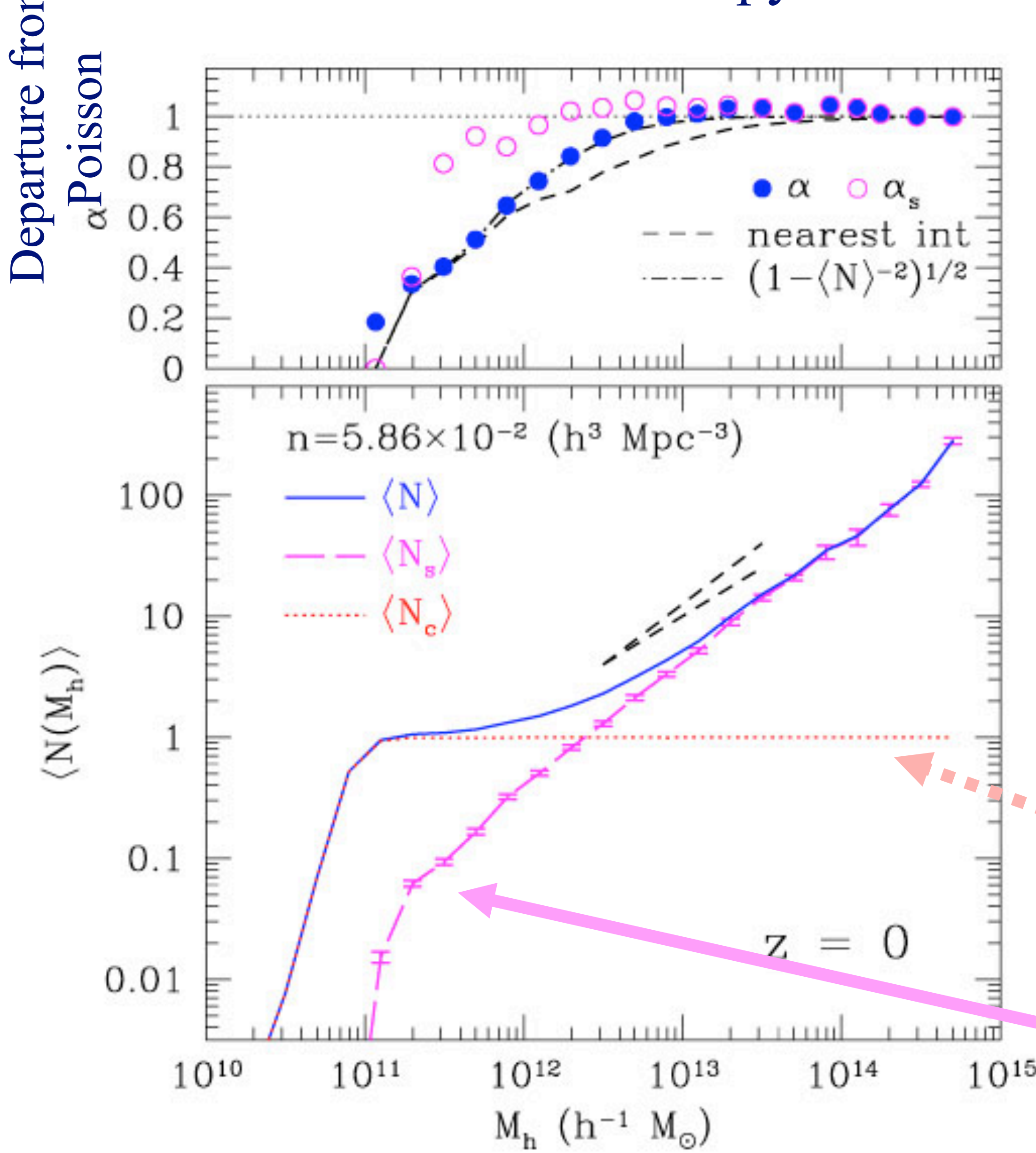
Model predictions

We have a amazingly very good model for dark matter halo density and dark matter halo evolution.
The assumption that galaxies form in dark matter (ie halo model; Cooray & Sheth 2002), works amazingly well at explaining galaxy density, LFs, clustering out to z ~ 5.5.
There is no reason to assume different formation scenarios at z > 6!





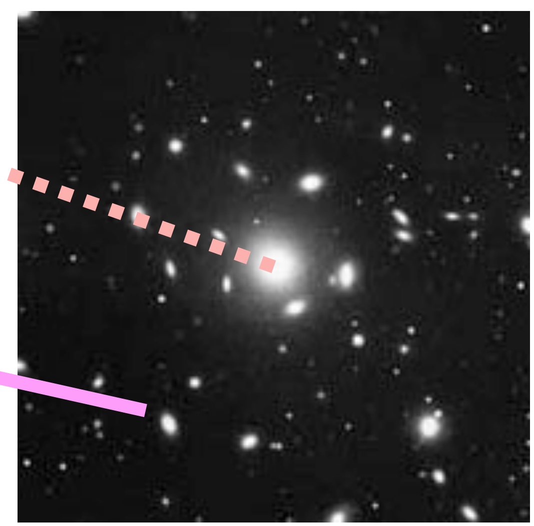
How Galaxies Occupy Halos?



Separate halo occupation statistics to central and satellite galaxies.

A central galaxy always form when M> M_{cut}

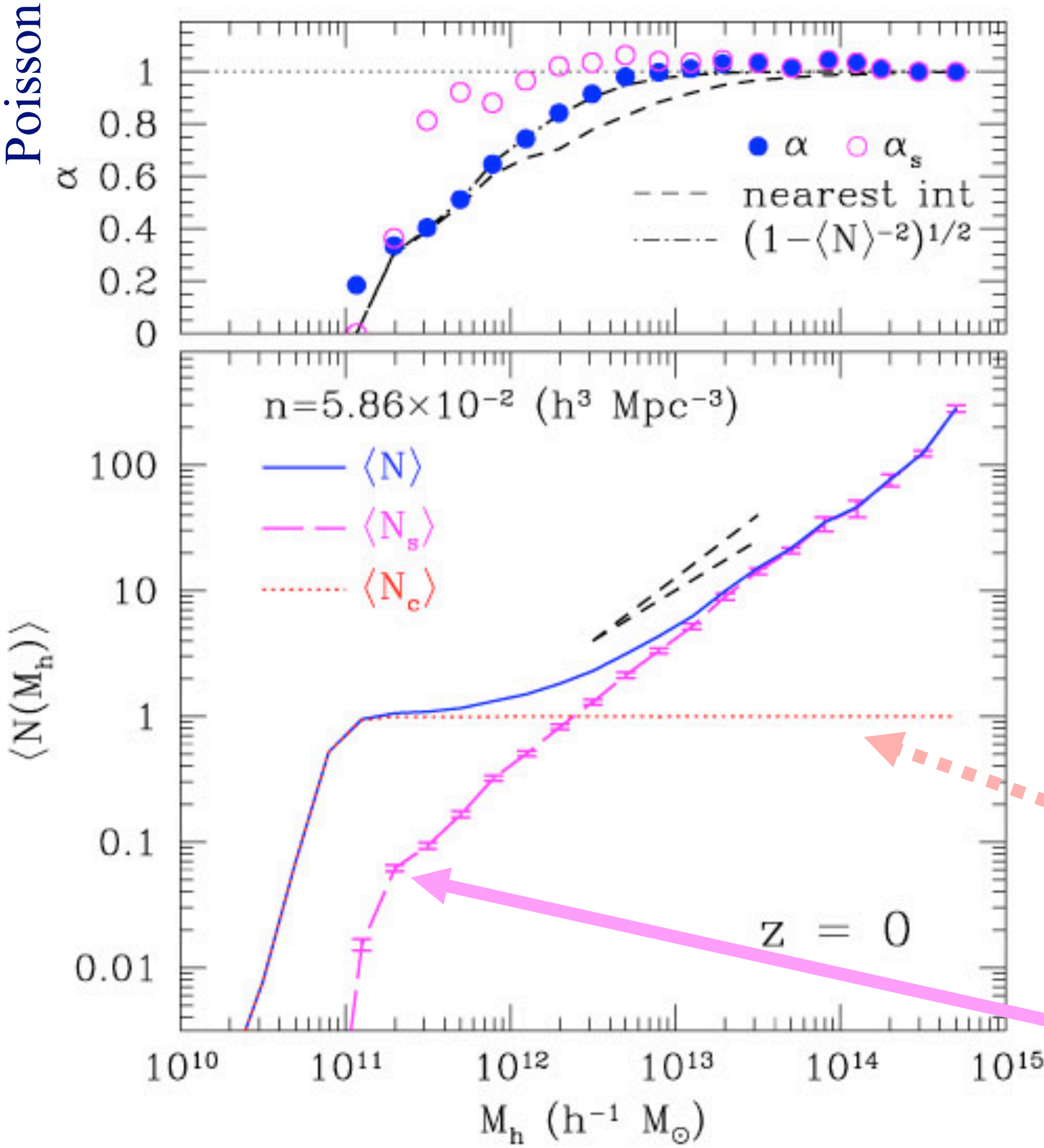
For massive halos, $<N_{sat}(M)> \sim M$



Kauffmann et al. 2001; Cooray 2002; Kravtsov et al. 2003

How Galaxies Occupy Halos?

Departure from Poisson



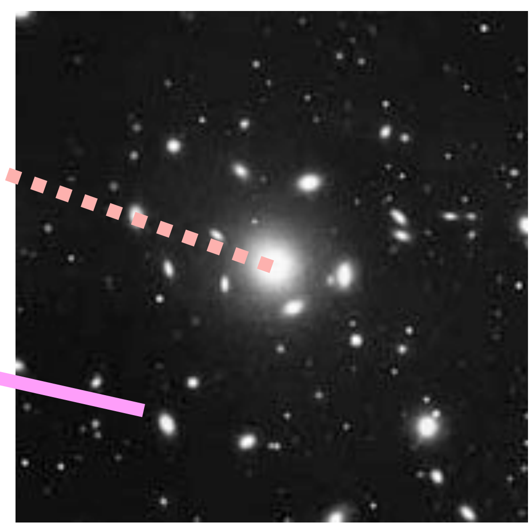
Kauffmann et al. 2001; Cooray 2002; Kravtsov et al. 2003

Problems with the HOD

Treats all galaxies same, regardless of properties (*there is no freedom to separate galaxies based on luminosity, color etc)*

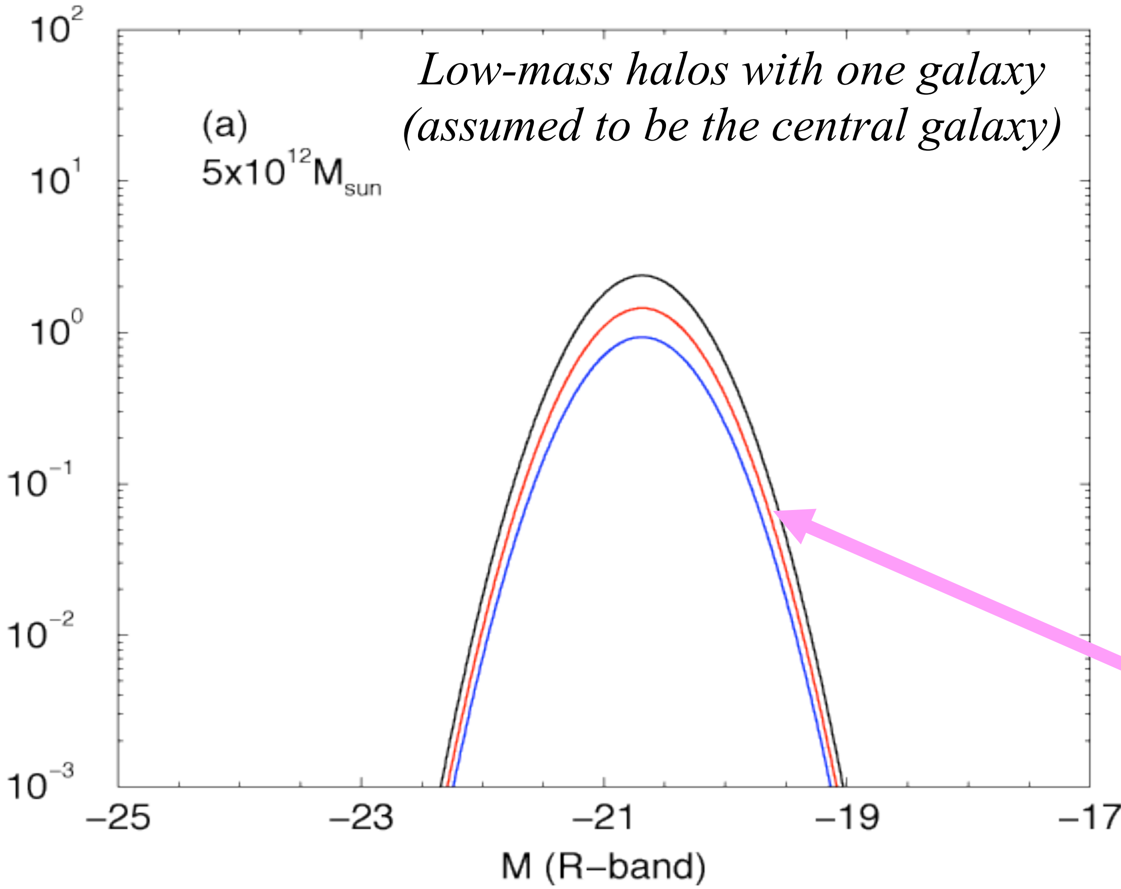
Cannot describe the LF

Need an improved model based on luminosities



Improved Halo Model: Occupation Conditioned in Luminosity

Conditional Luminosity Functions

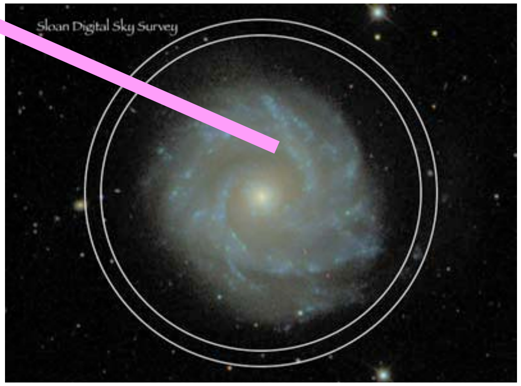


Central galaxy: log-normal with scatter from L(M) relation

Separate halo occupation statistics to central and satellite galaxies.

$$\Phi(L \mid M) = \frac{d\langle N_{gal}(M)\rangle}{dL}$$

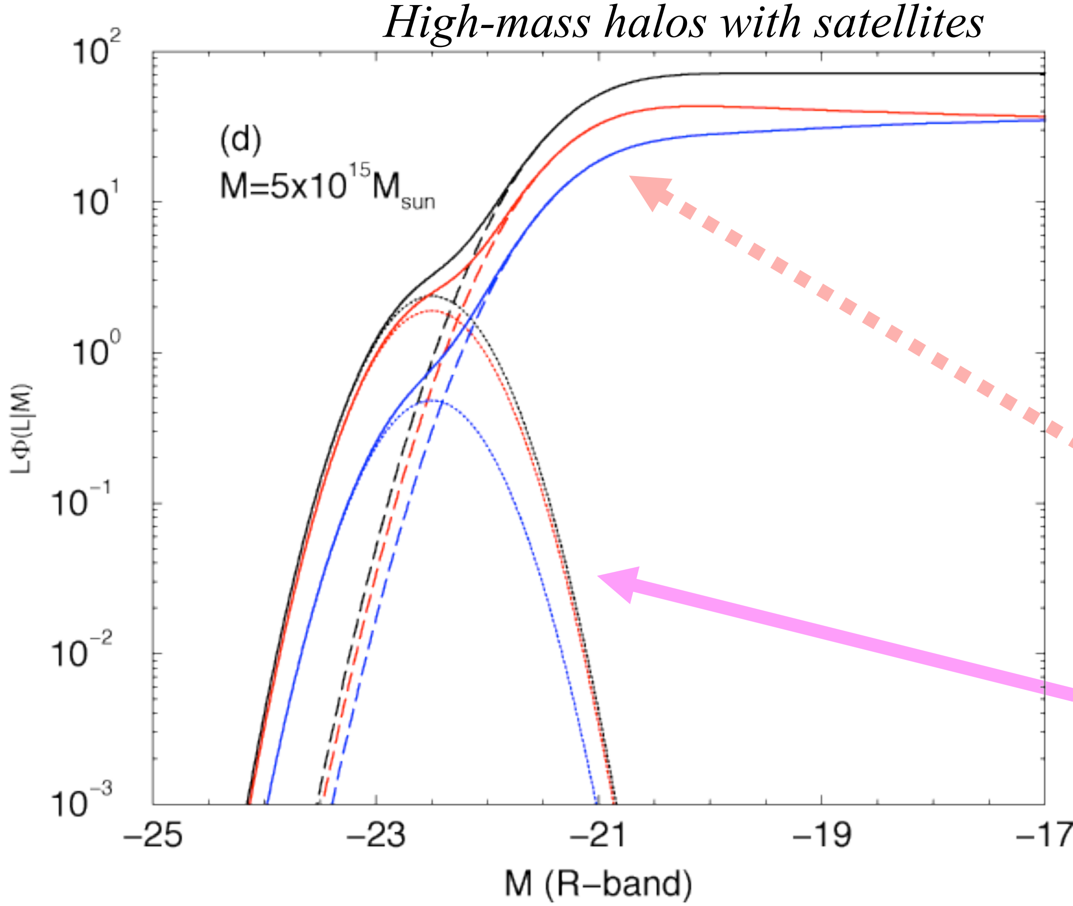
Yang et al. 2003
Cooray & Milosavlejvic 2005



Improved Halo Model: Occupation Conditioned in Luminosity

Conditional Luminosity Functions

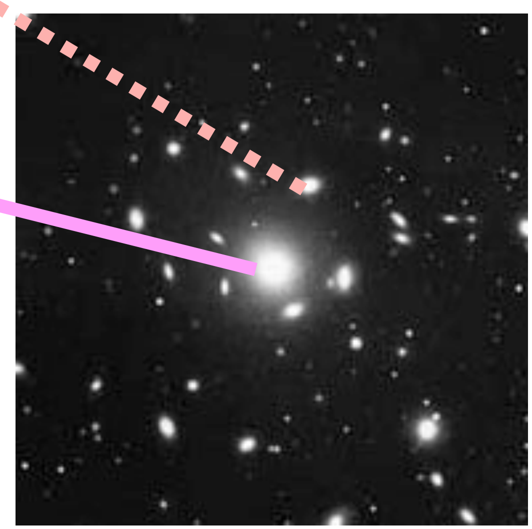
High-mass halos with satellites



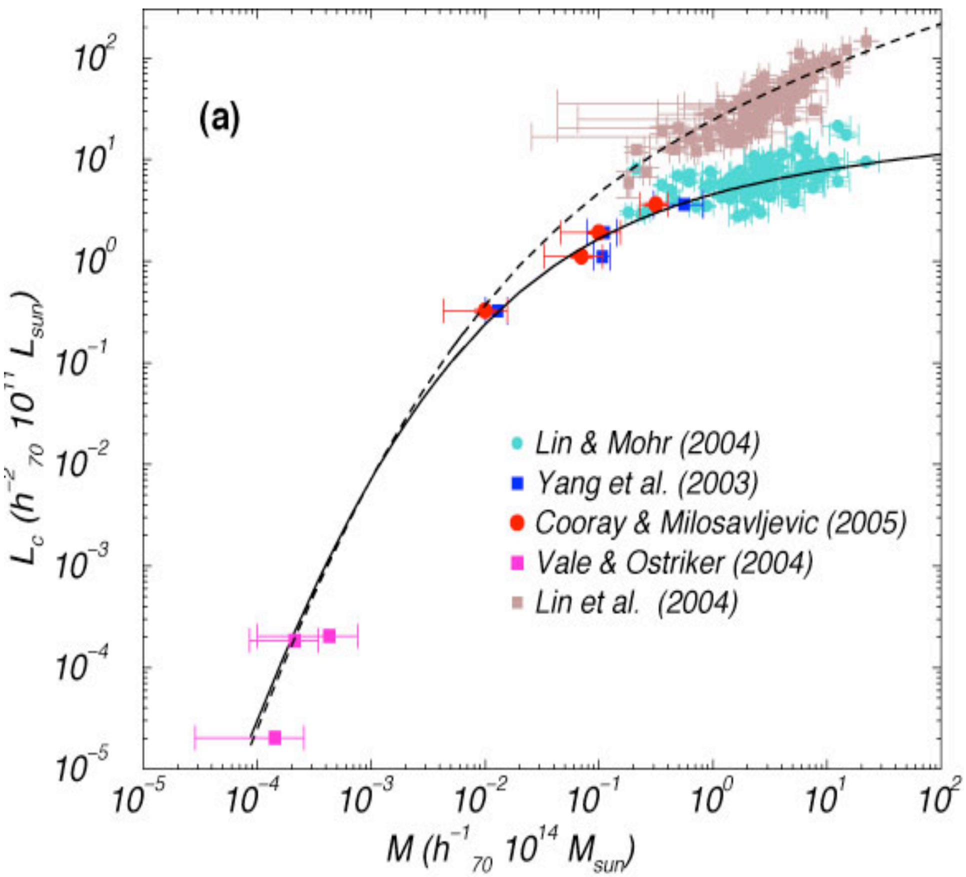
Central galaxy: log-normal with
scatter from L(M) relation
Satellites: power-law (or the subhalo mass function)

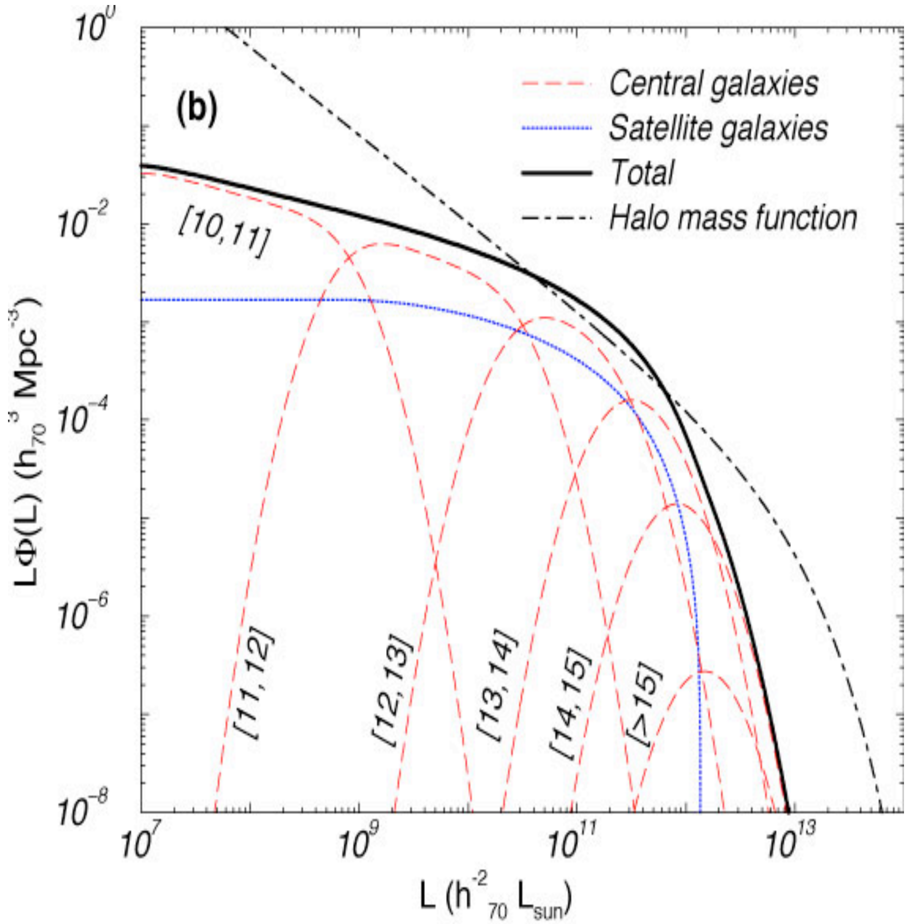
Separate halo occupation statistics to central and satellite galaxies.

$$\Phi(L\,|\,M) = \frac{d\langle N_{gal}(M)\rangle}{dL}$$



Finally, what shapes the luminosity function?





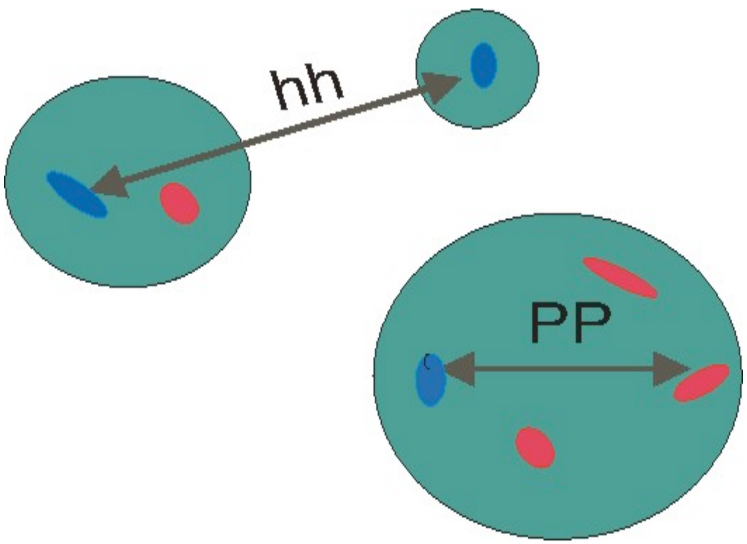
$$\Phi(L) = \int \Phi(L \mid M) \frac{dn}{dM} dM$$

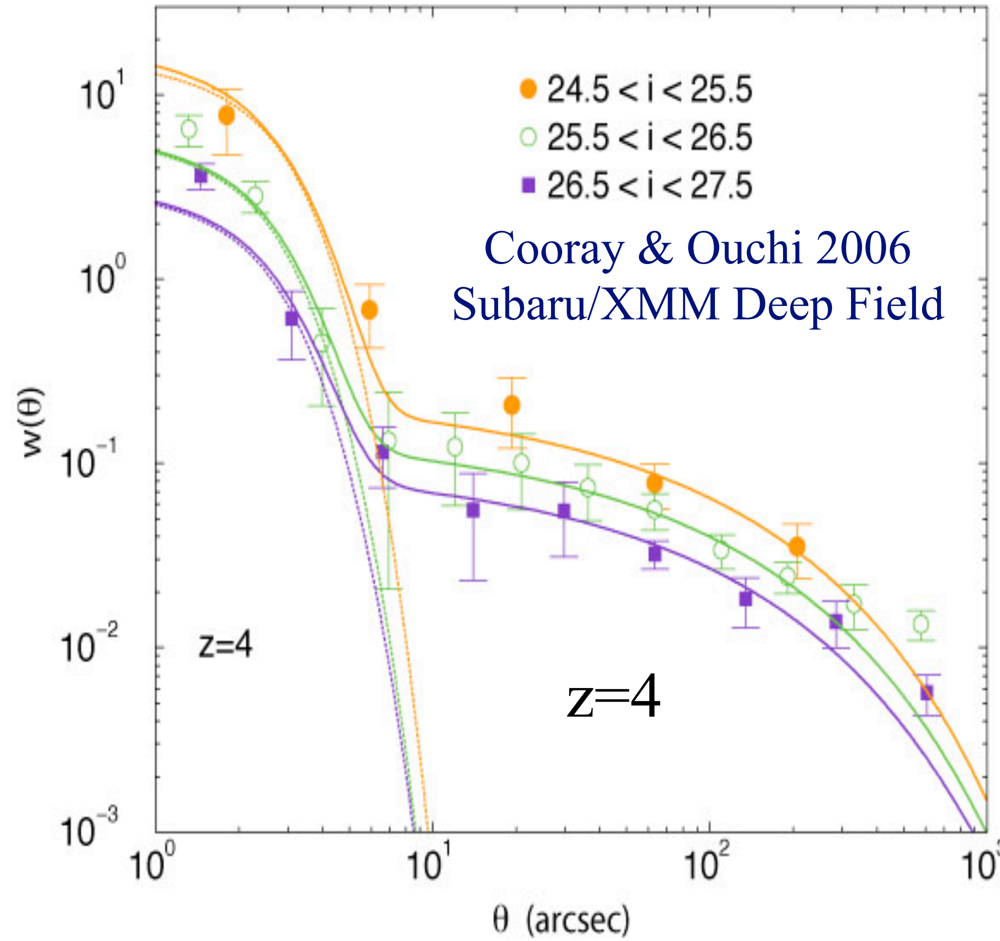
L_* when

$$\frac{d \ln L_c(M)}{d \ln M} \sim \ln(10)\sigma_{cen}$$

Cooray & Milosavljevic 2005b

Galaxy Clustering

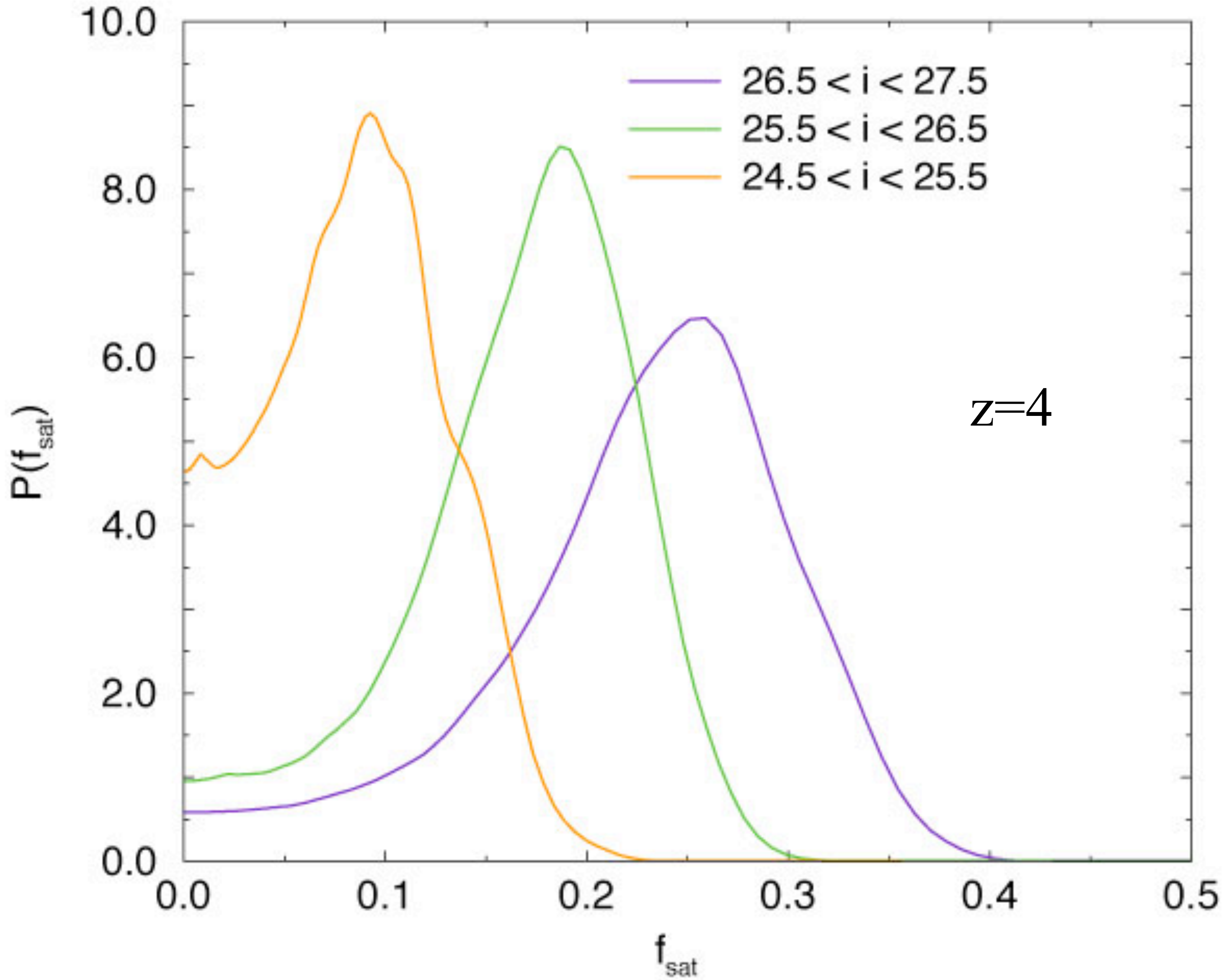




Large-scales: Correlations between galaxies in two different halos
Small-scales: Correlations between galaxies in the same halo

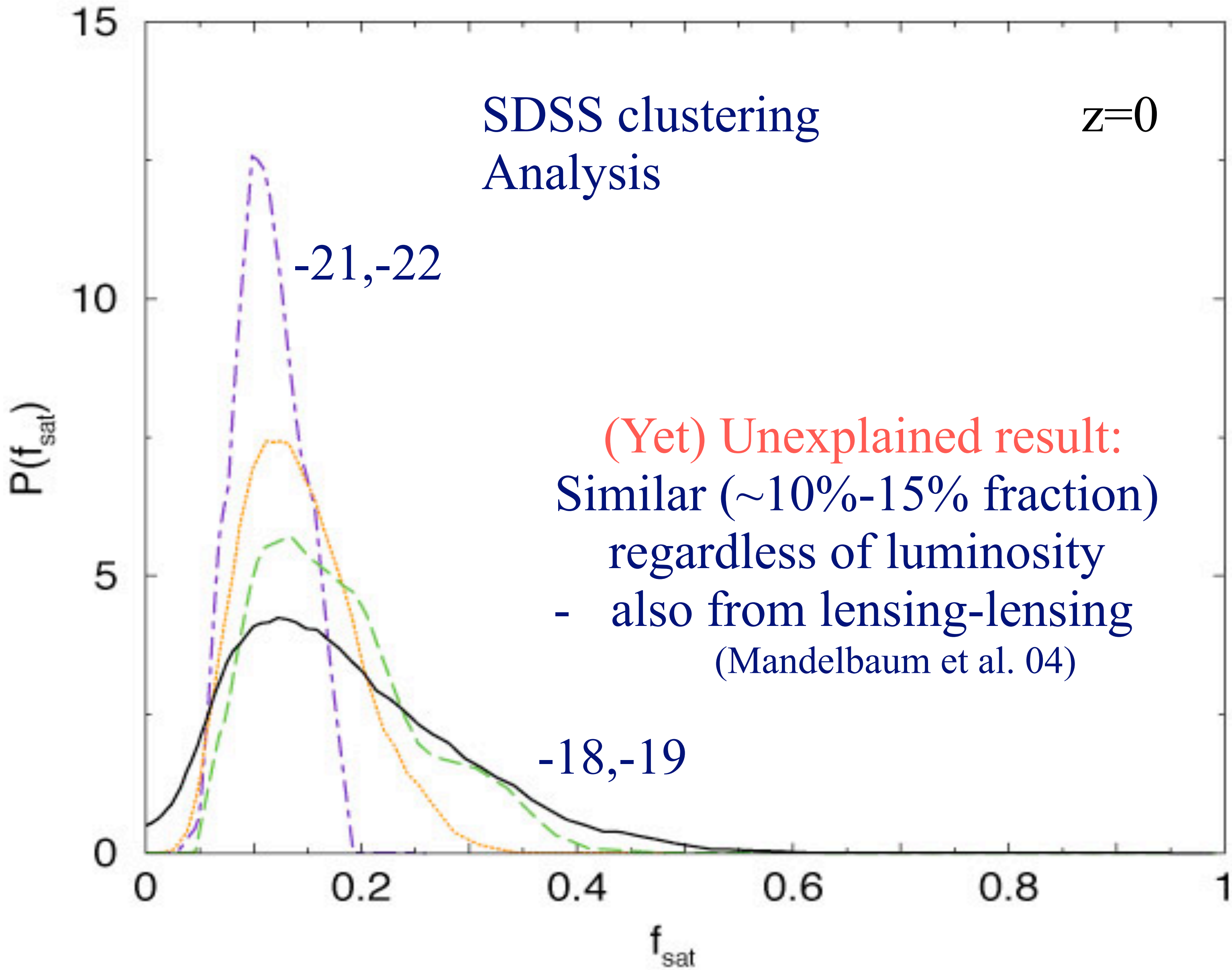
Distinct transition in the correlation function between the two terms

What fraction of galaxies are satellites? (at a given luminosity)



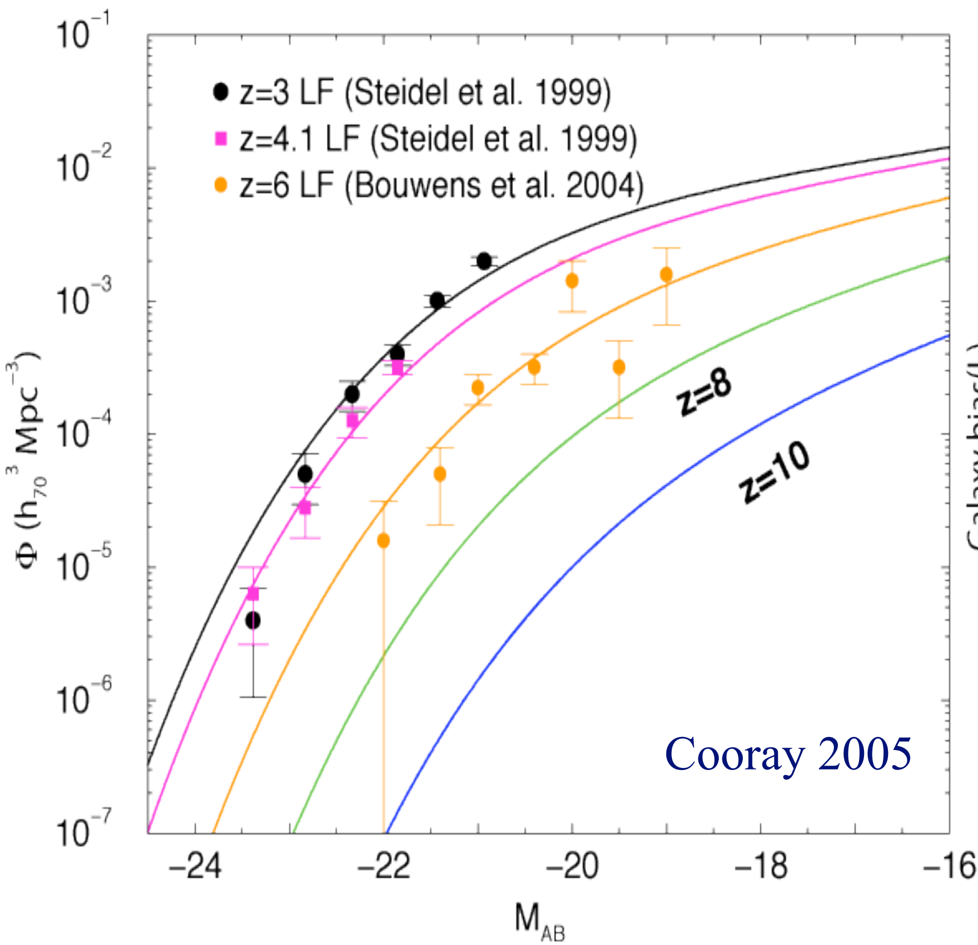
Fainter galaxies: 25% satellites; Brighter galaxies < 10% satellites

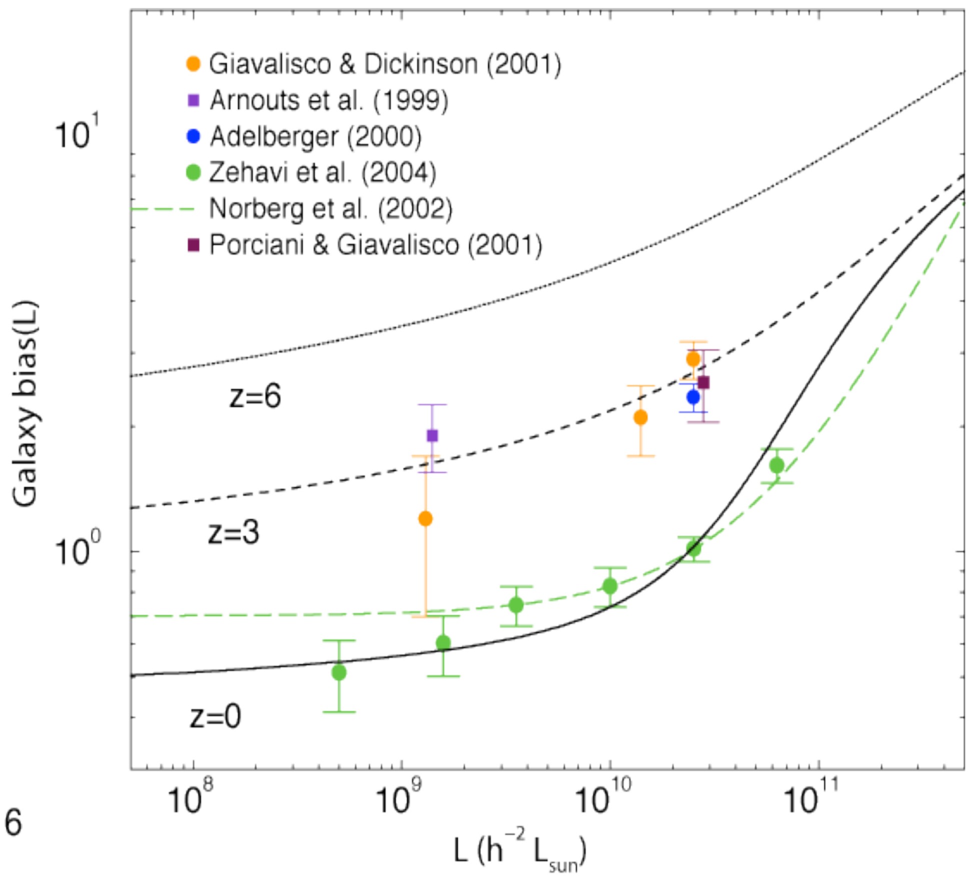
What about z=0 (results from SDSS)



Explains the steepening of the LF at high-redshifts

High-redshifts within a single framework



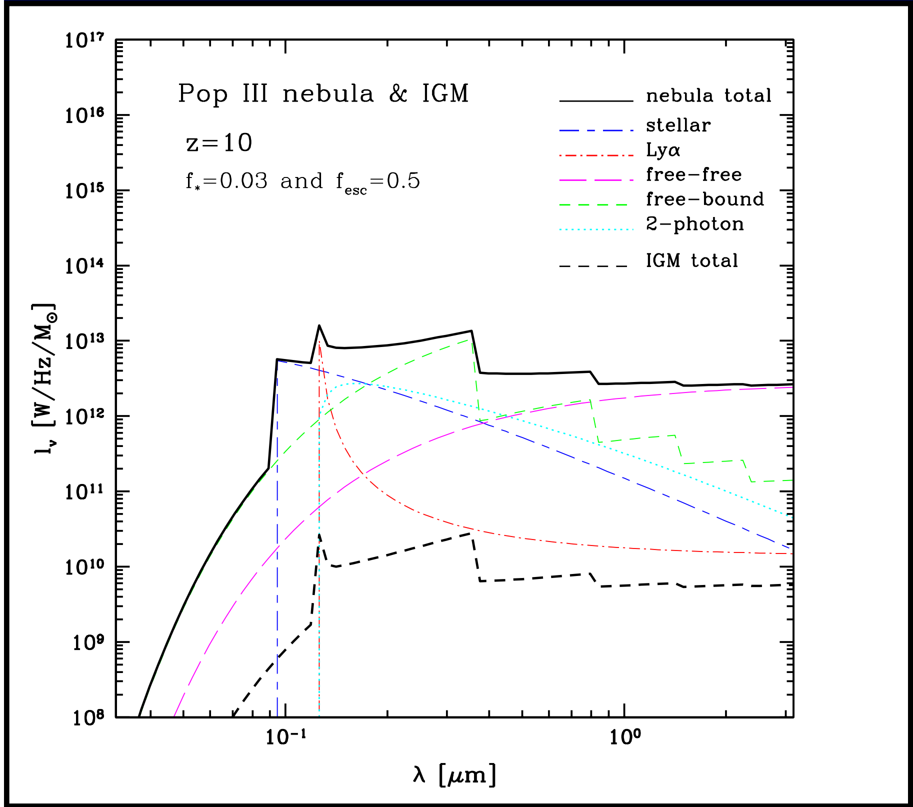


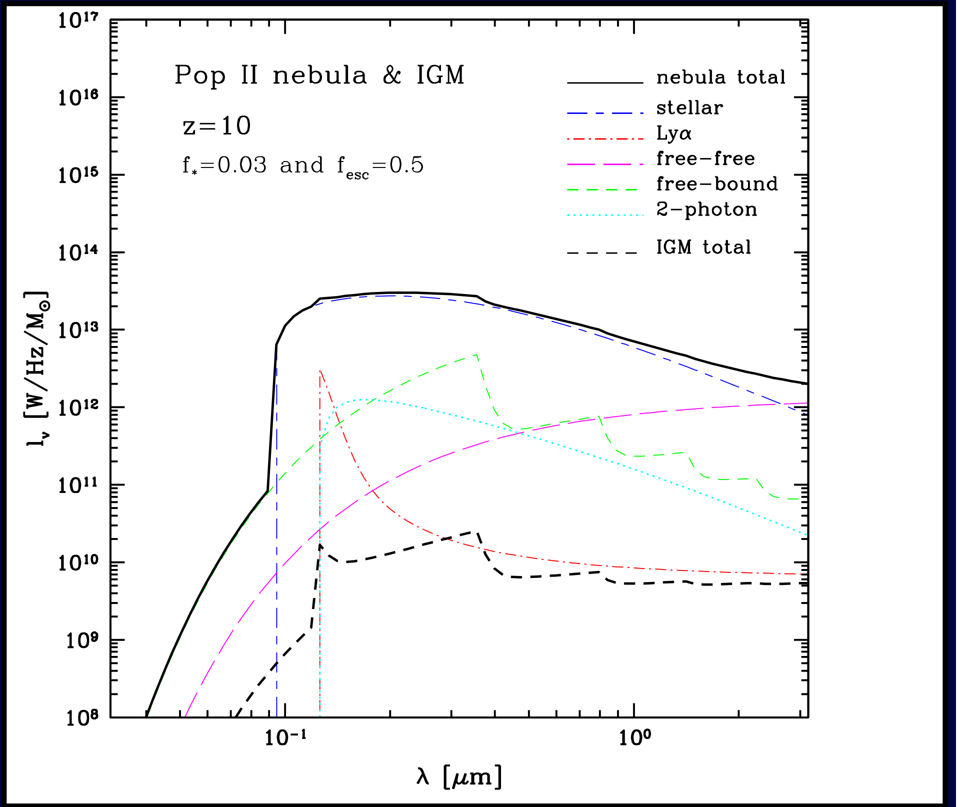
Simple mass-dependent evolution predicts even higher redshift LFs (now in rest UV). *2005 predictions for expectations on z=8 and 10 z=6 LFs are now tested with WFC3 results!*

Also, agreement with bias factors (tested with GOODS at z~6 now)

EBL is a probe of reionization

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





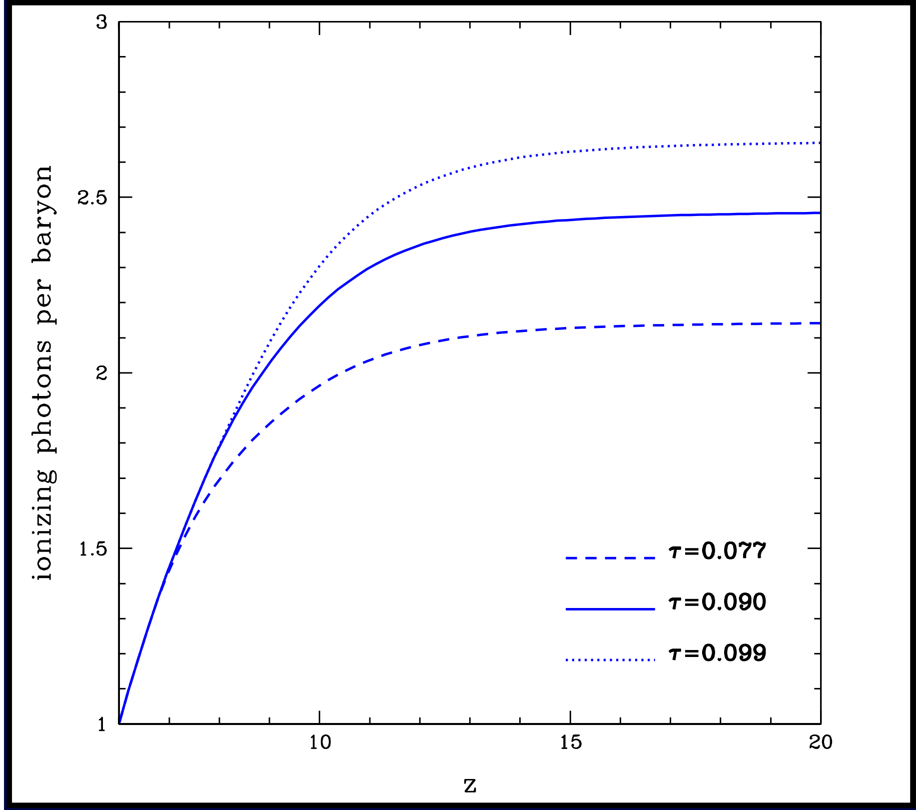
PopII stars are likely to be equally or more important than PopIII stars

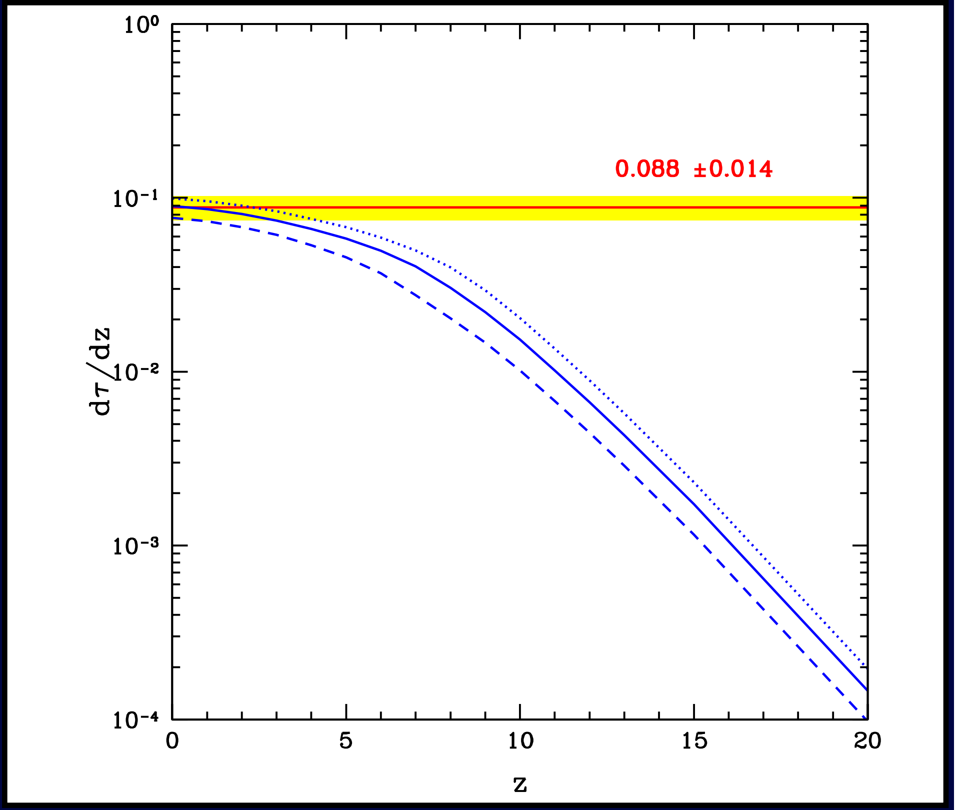
Fernandez & Komatsu 2006

Model predictions

Connect galaxy UV LFs with a reionization model.

One does not need more than ~3 hydrogen-ionizing photons-per-baryon to explain reionization. (it is definitely below 5, if one takes an extreme view on escape fraction and gas clumping)





If the absolute intensity is as high as 2.5 nW/m2/sr, then photon-to-baryon ratio of ~4000.
Various problems with metal abundance and X-ray background. Madau & Silk 2005

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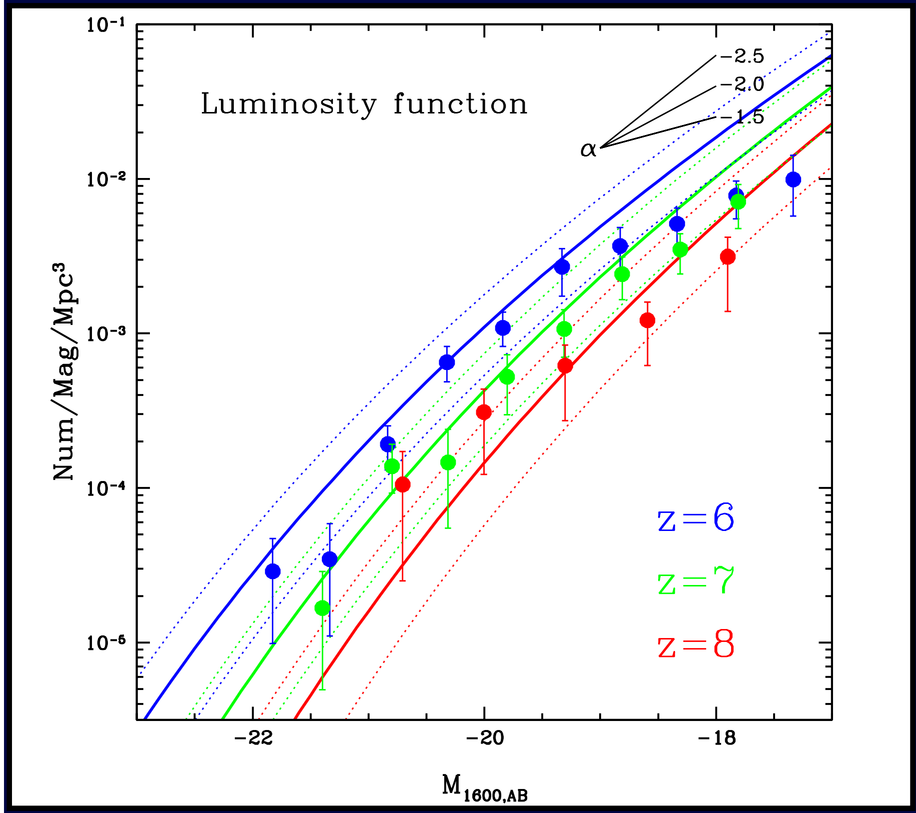

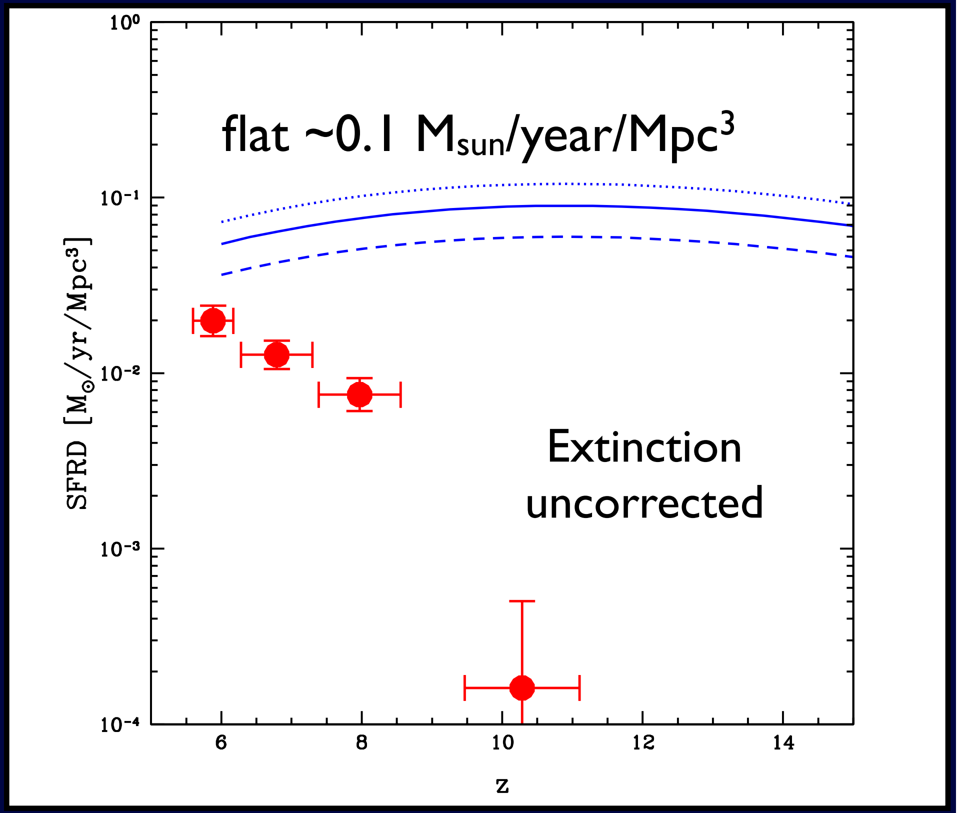

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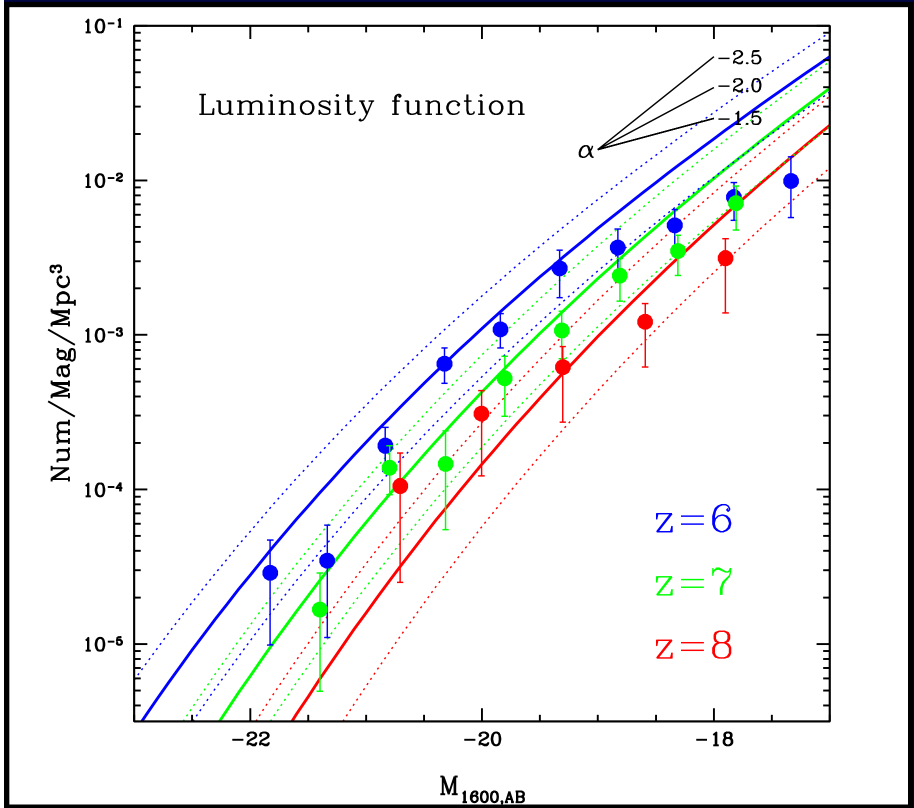
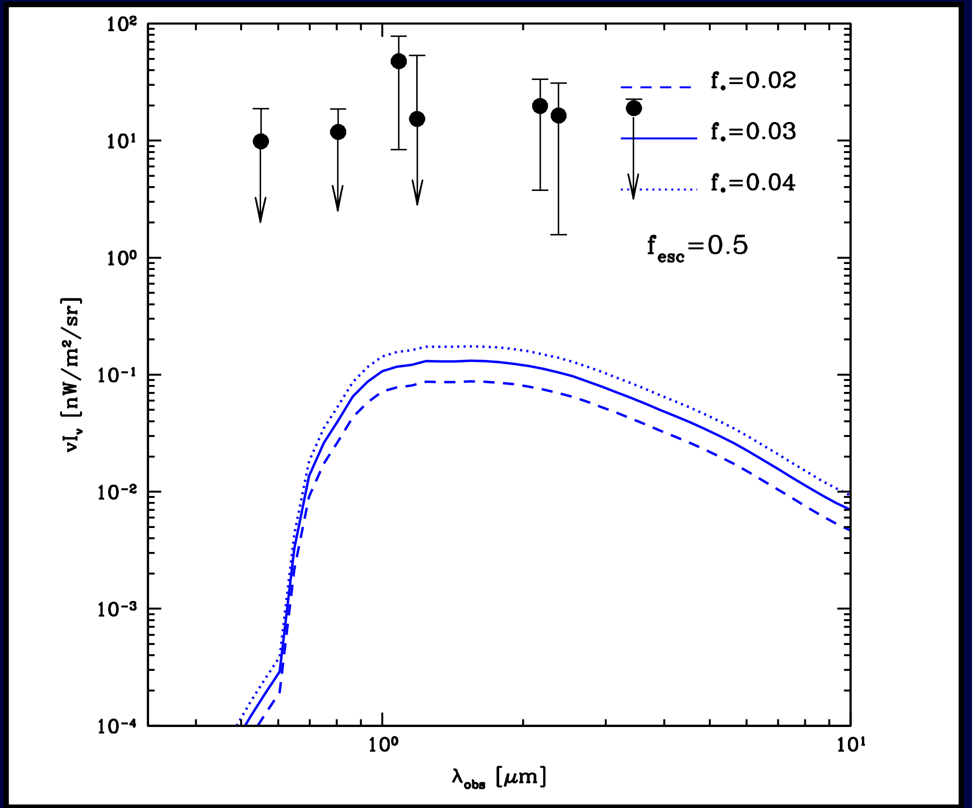
Various problems with metal abundance and X-ray background.   Madau & Silk 2005

Model predictions

> 80% of the reionizing UV photons are in M(AB) > -18 galaxies.
Universe was dominated by many faint galaxies; they are satellites of bigger halos!





Reionization absolute intensity is no more than 0.3 nW/m2/sr at 1.6 micron. Such an intensity is permissible given the arguments in Madau & Silk (2005).

Model predictions

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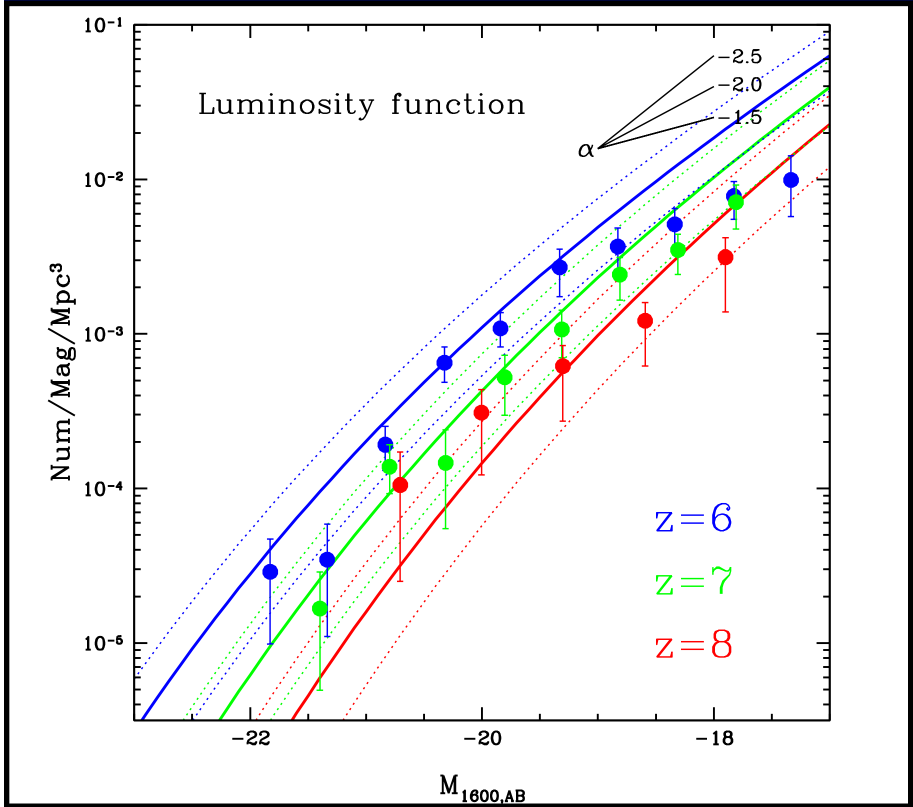
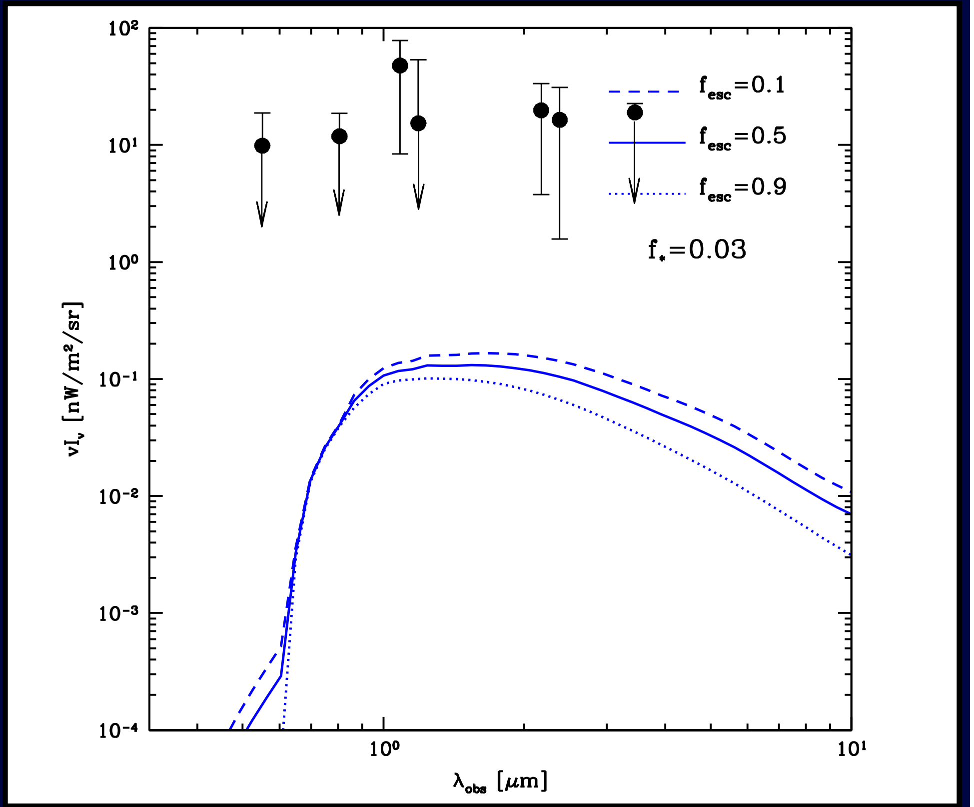
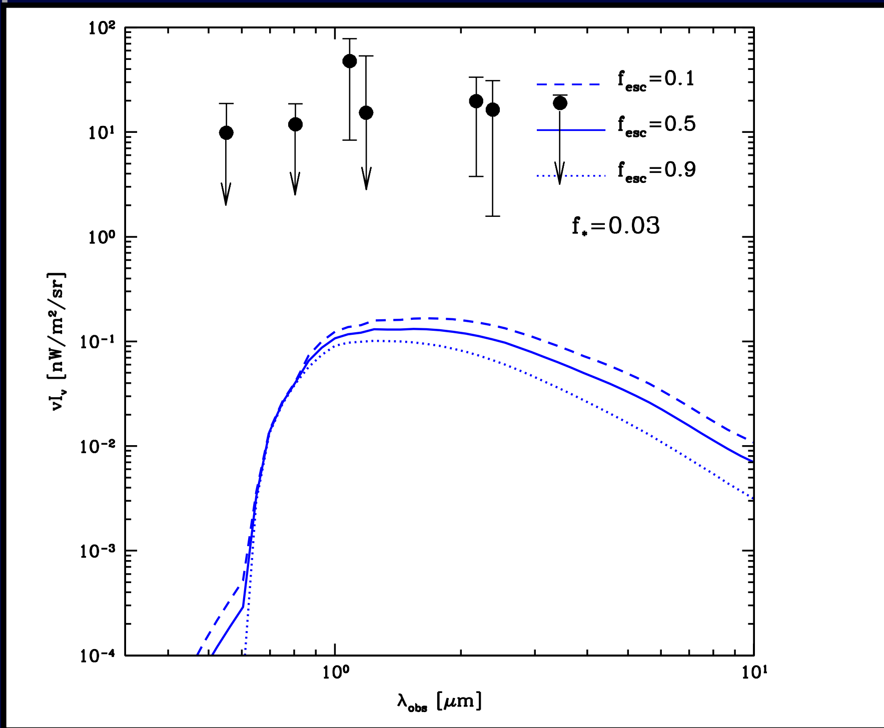
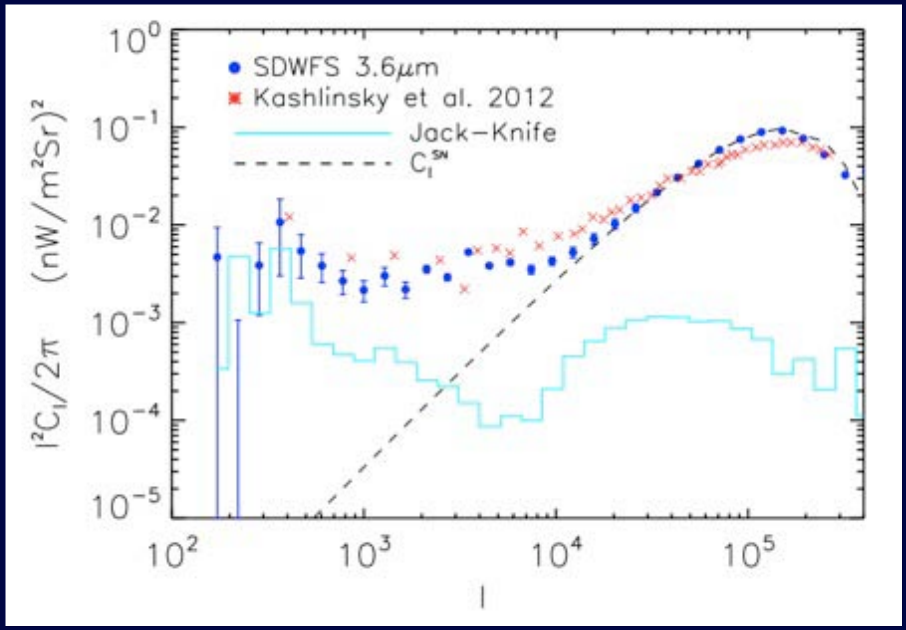




A lower escape fraction makes the background intensity larger.
We have not done any dust corrections; dust may make intensity smaller (but dust abudnance at z > 6?).



High-z galaxies? Study IRB anisotropies.

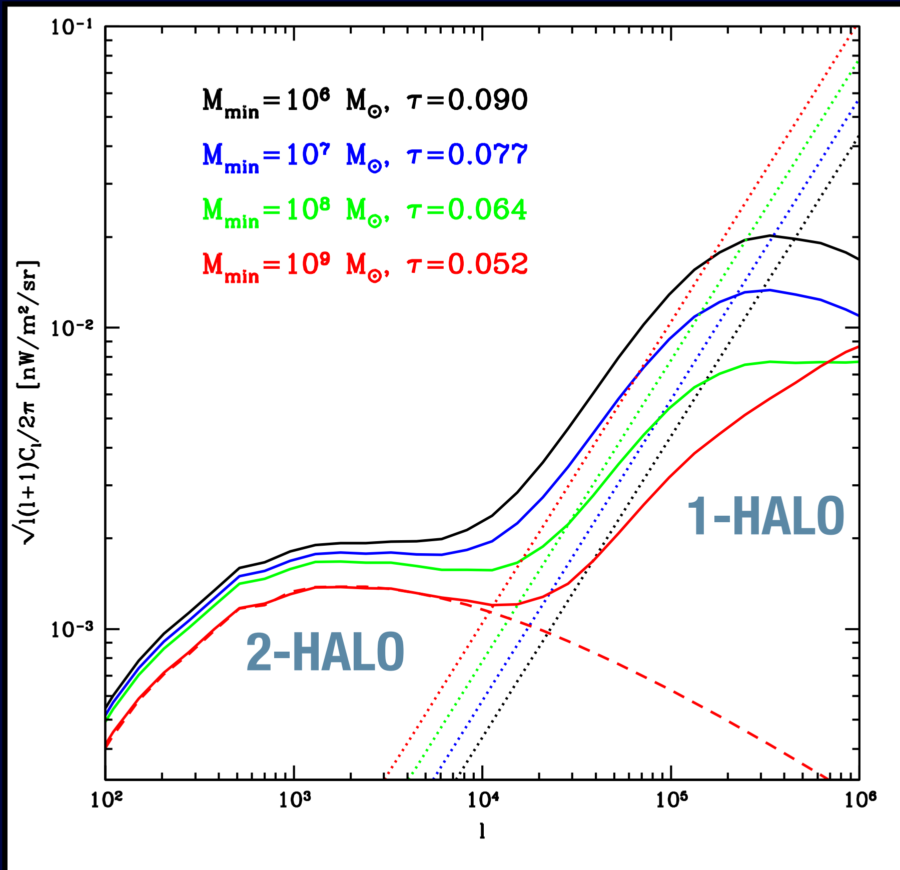


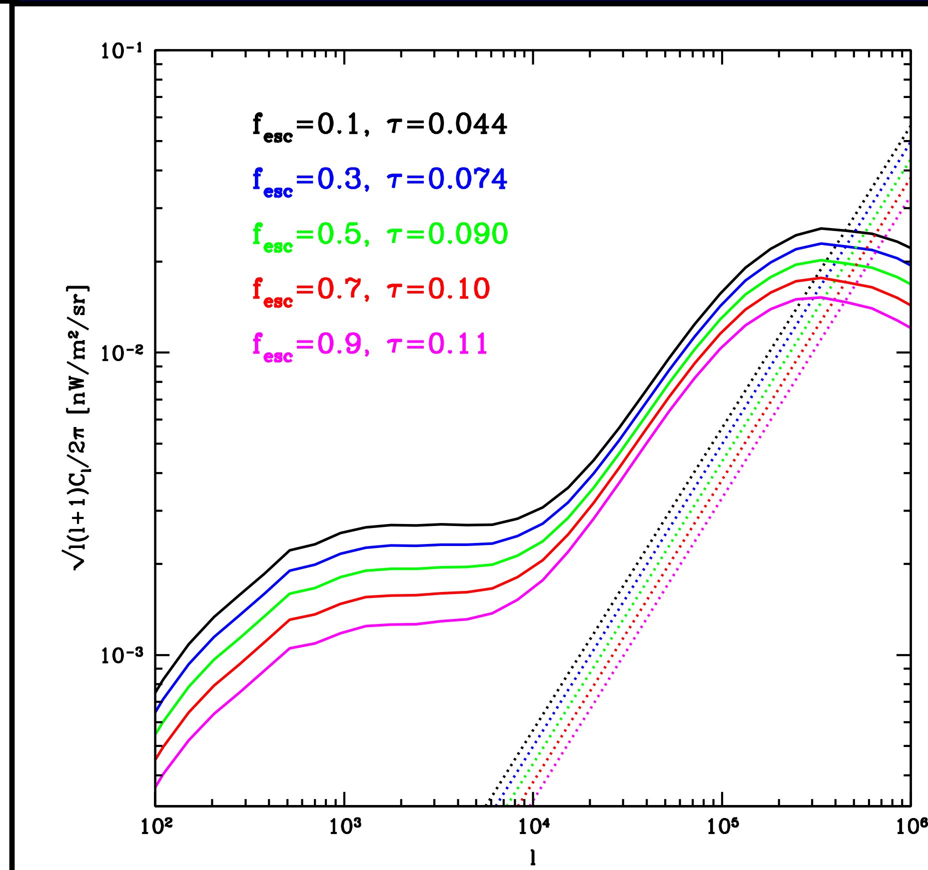
To study the origin of IRB light, instead of the absolute total IRB intensity, measure anisotropies or fluctuations of the intensity (just like in CMB).

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

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

IR Background Fluctuations



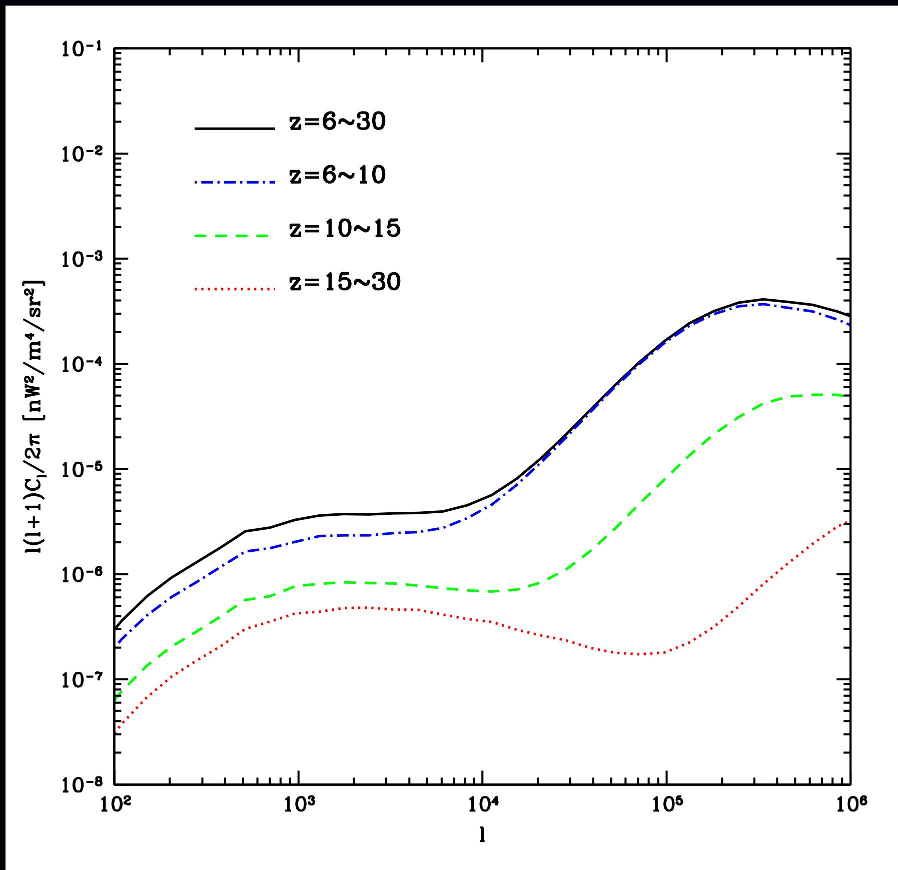


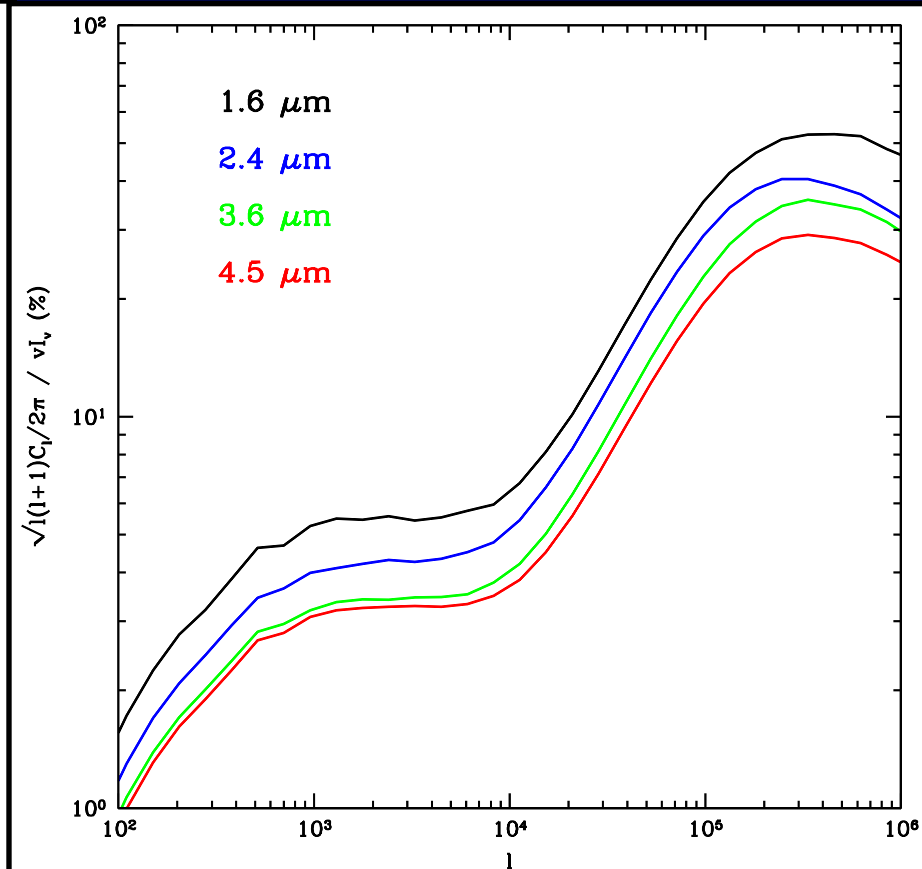
Calculation based on a halo model for first galaxies:

(a) Large scale-bias factor sensitive to minimum halo mass

(b) 1-halo term (non-linear power) sensitive to minimum halo mass to host satellites

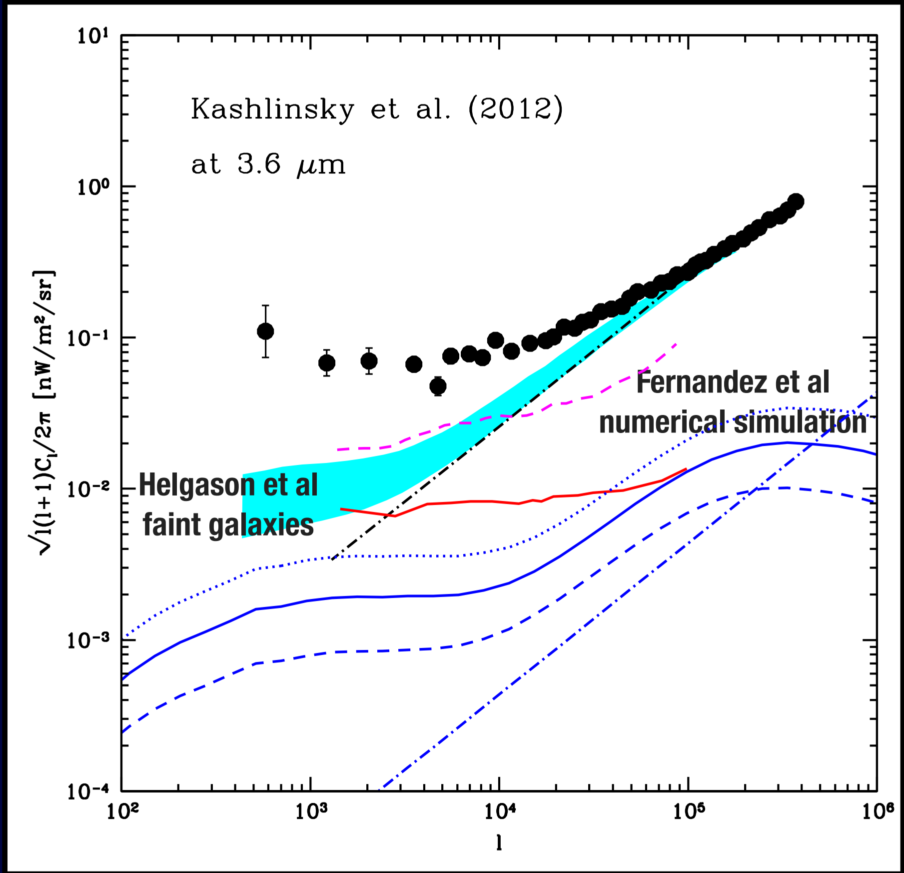
Expected Power Spectrum Amplitude

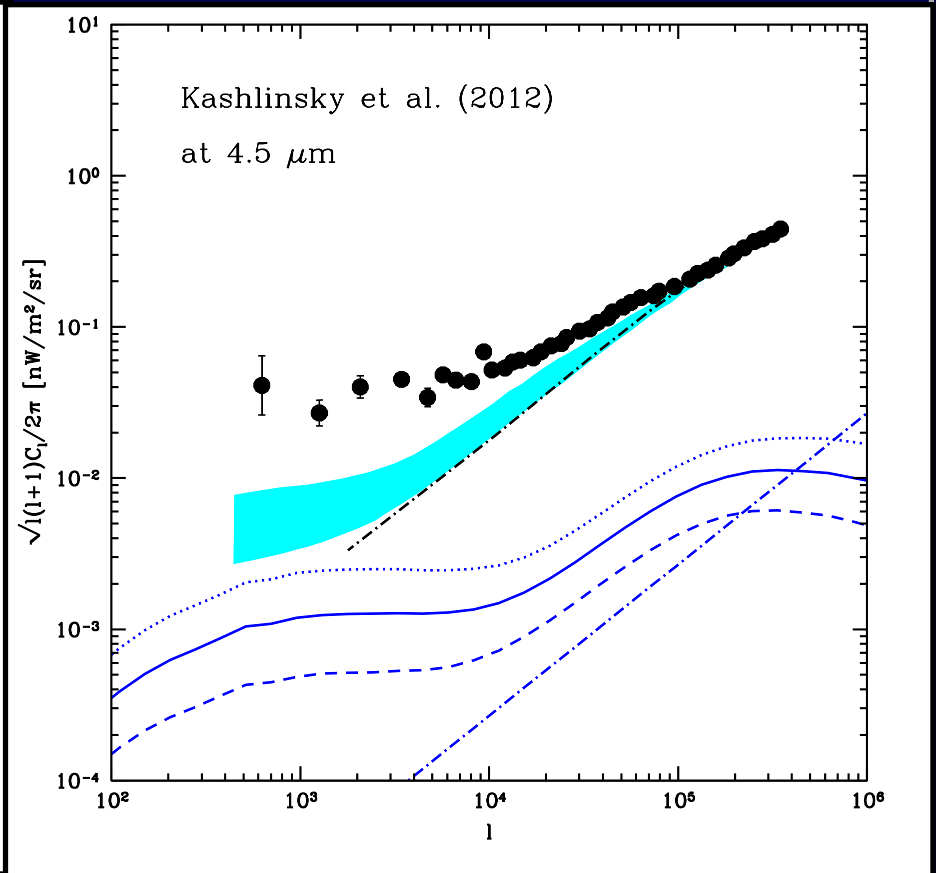




< 10% rms fluctuations relative to absolute intensity at tens of arcminute scales; ie the background is very smooth, produced by many fainter sources, not a few rare bright sources.

Expected Power Spectrum Amplitude





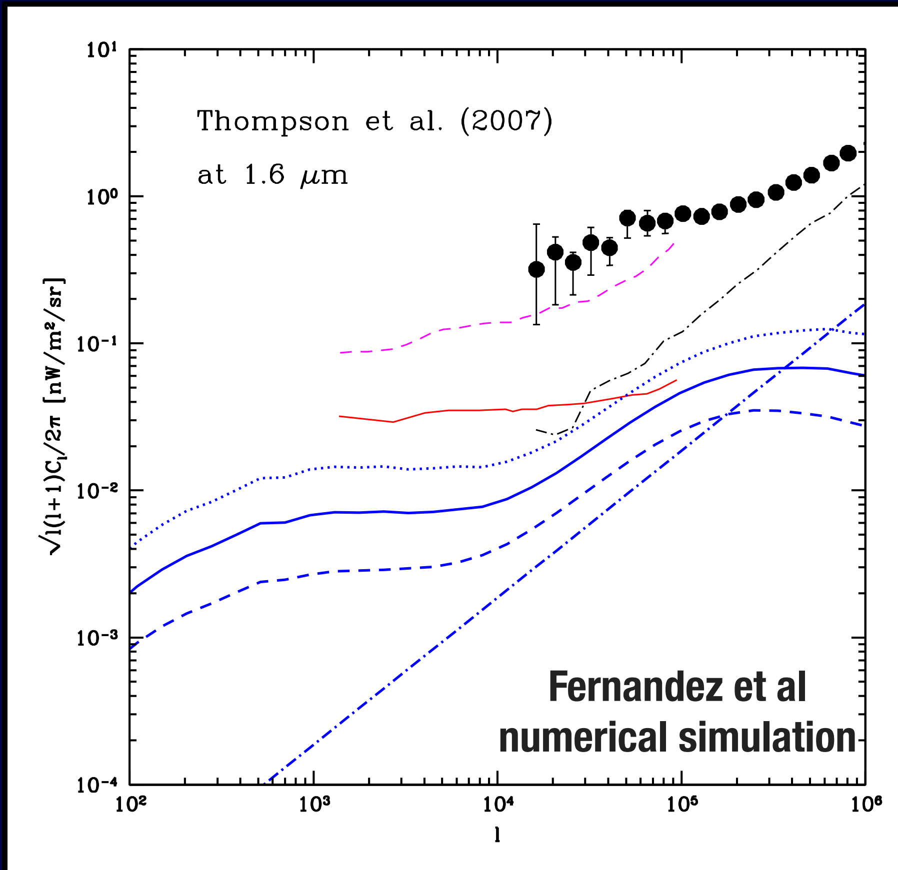
Kashlinsky et al. (2012) from new SEDS data.

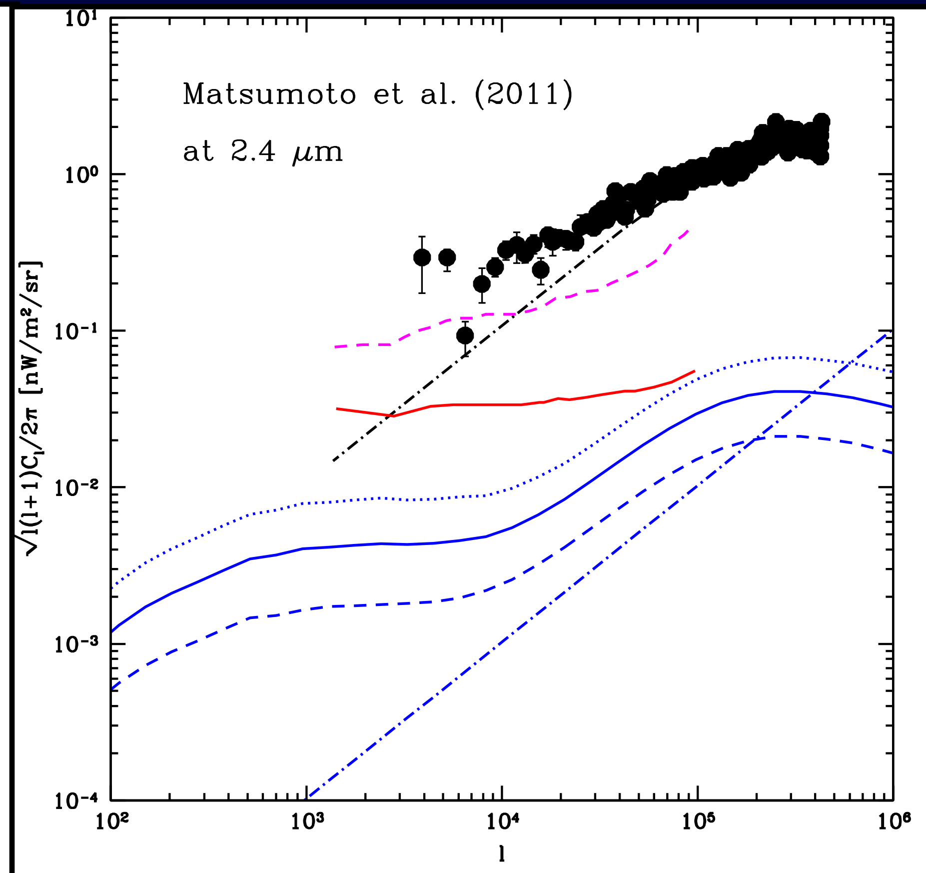
Clear excess above low-z faint galaxy clustering (shaded blue; Helgason et al 2012).

New high-z reionization models are about a X30 below the measurements.

Absolute intensity must be ~2 to 2.5 nW/m2/sr at 3.6 microns to fit the data.

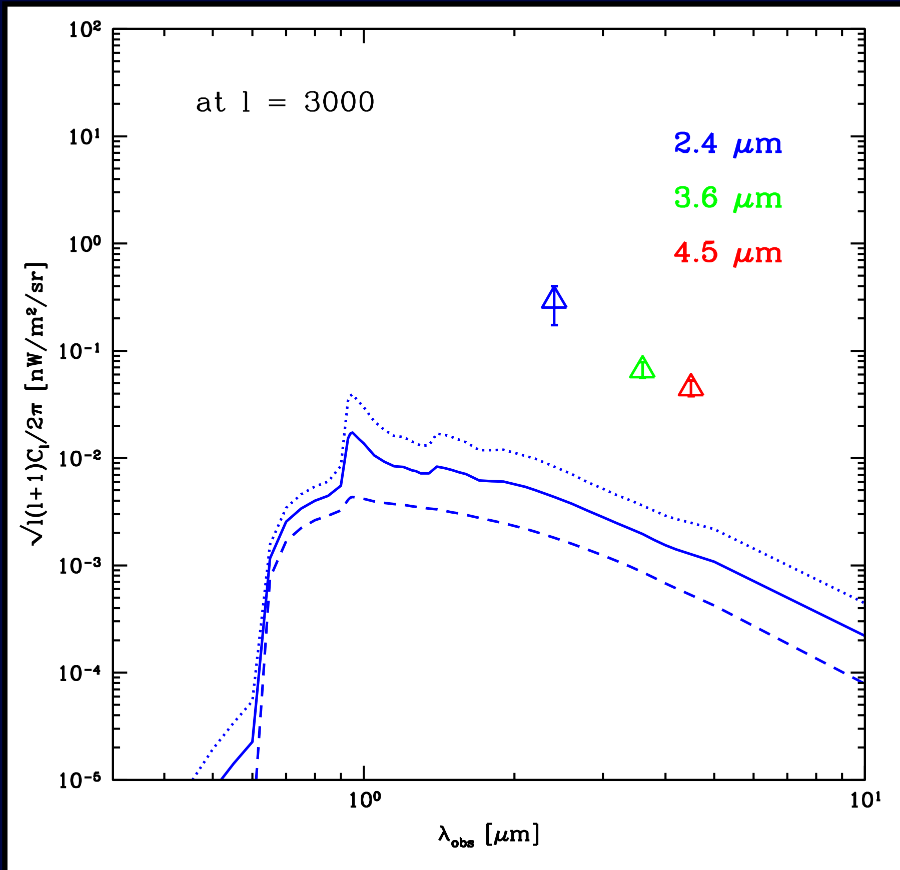
Spitzer Background Fluctuations in SDWFS

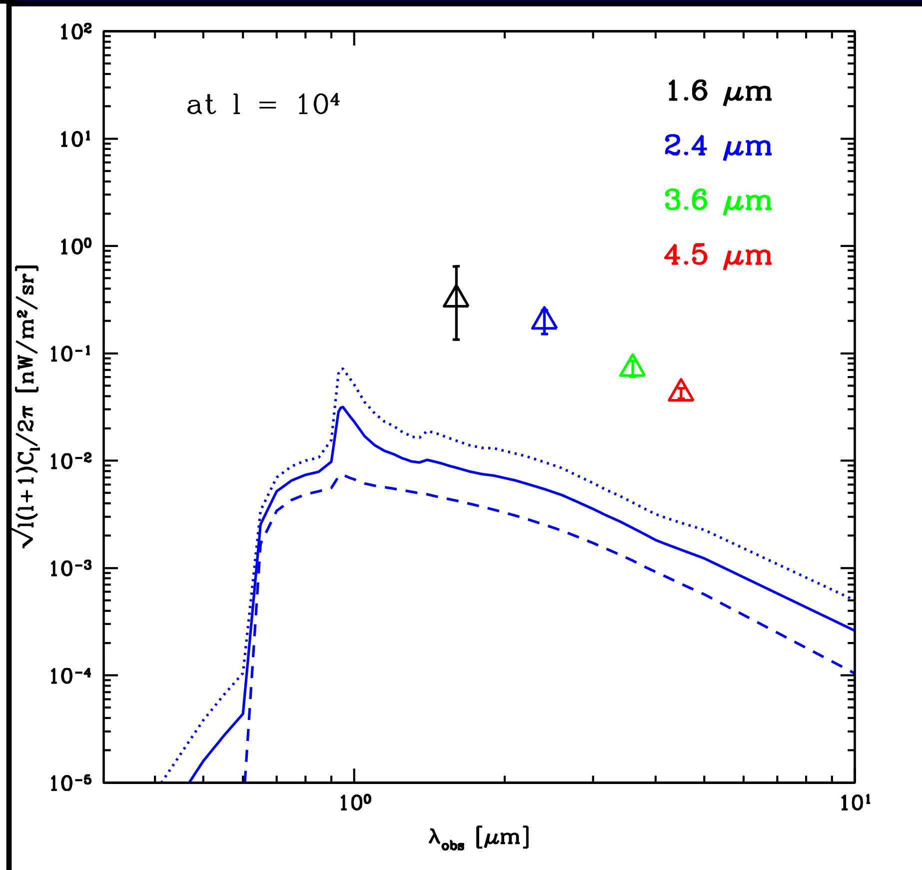




Thompson et al. (2007) with NICMOS UDF (~5 arcmin image).
Matusmoto et al. (2011) with AKARI (multi-wavelengths)

HST and AKARI Background Fluctuations

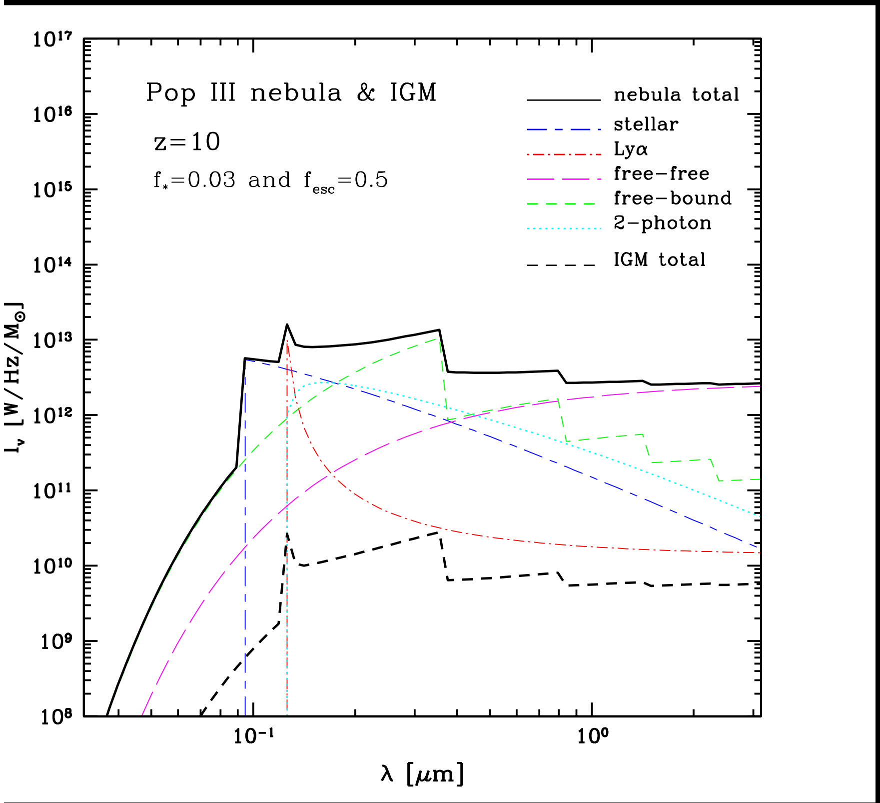


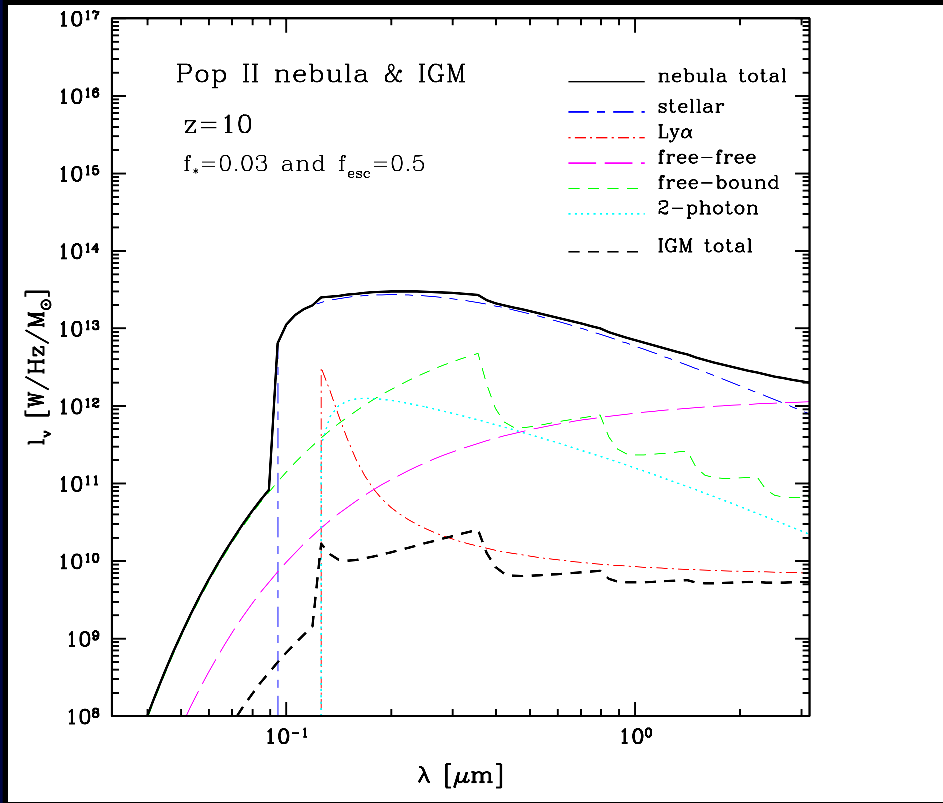


What does all of this mean in terms of z > 6 galaxies?
x20-30 higher UV photon-density than necessary to reionize.
Photon-to-baryon ratio~60 to 90 vs 3?

SED of near-IR background Anisotropies

So how can we fix this difference?



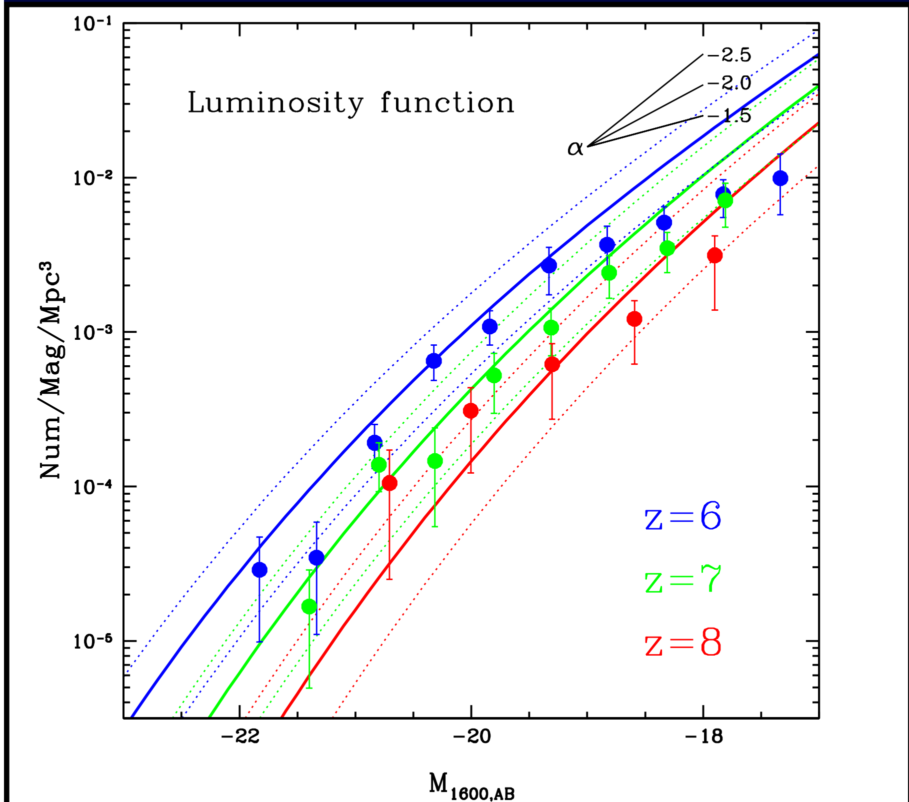


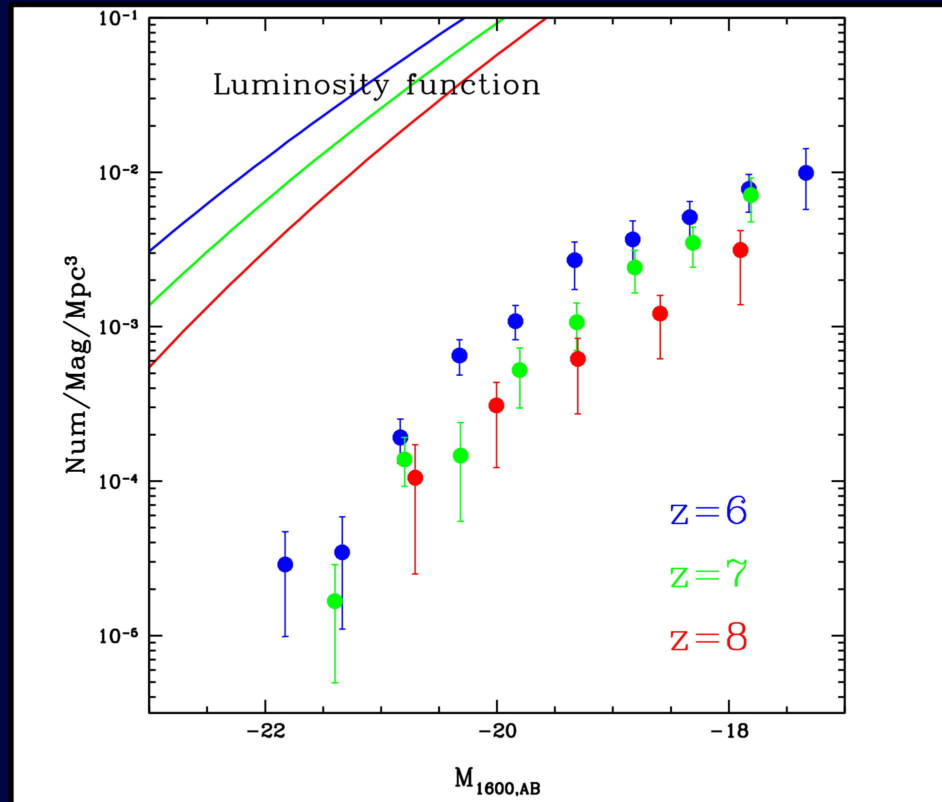
SEDs of $z > 6$ galaxies must be made very steep from rest-UV to rest-optical. Make all stars more like PopII instead of hotter PopIII?

however, WFC3 rest-UV LFs are at rest ~0.16 microns and the LFs constrain how much of a boost you can make to the SEDs (or boost will reduce stellar collapse fraction and back to the same low EBL intensity).

Changing mass-to-light ratios cannot change the fit to all of LFs, optical depth and clustering.

If measured fluctuations are indeed from z > 6......



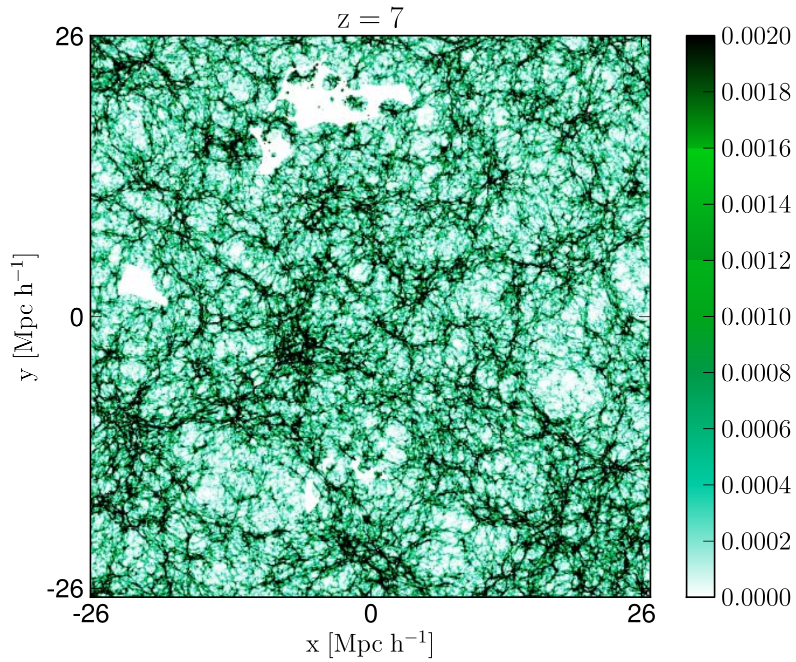


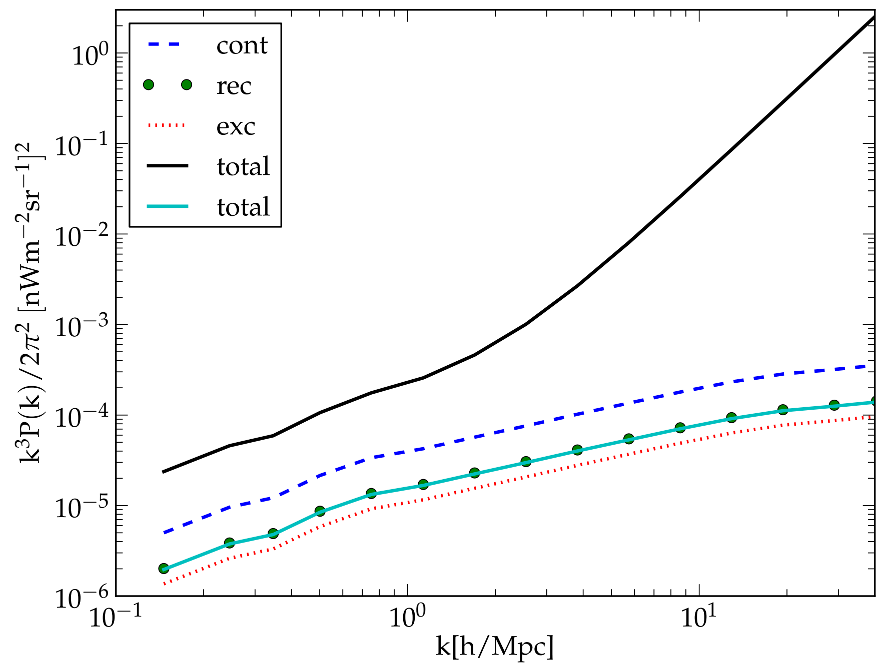
Where are the luminous Lyman-dropout galaxies in WFC3?

William of Ockham (1285-1349) was a Franciscan monk and philosopher who embraced the virtues of simplicity in science and in life.

"One should not increase, beyond what is necessary, the number of entities required to explain anything"

Universe is 13.6 billion years old, instead of focusing on 0.5-0.8 billion years, astrophysics over the last 12.5 billion years may explain the fluctuations.





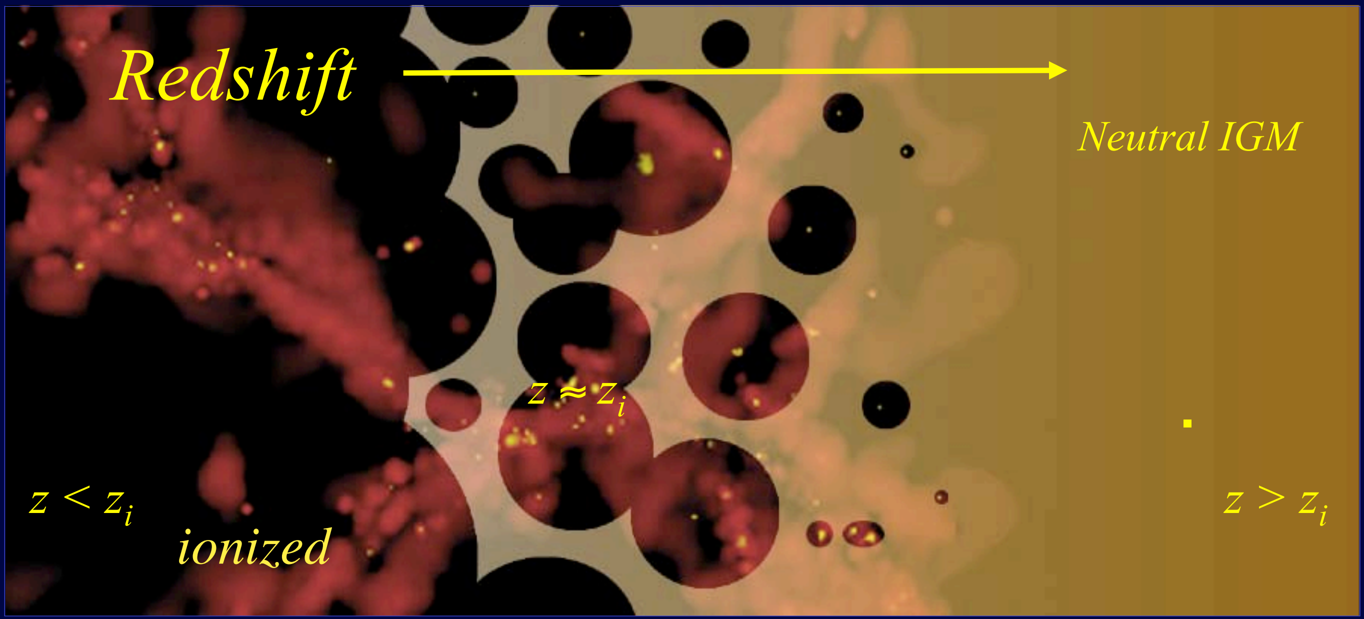
Attach a redshift to near-IR fluctuations observationally.

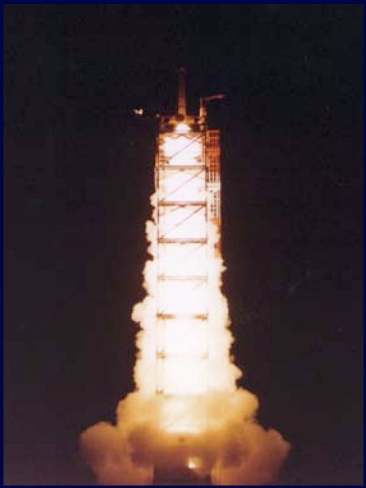
So narrow-band spectral imaging in the near-IR for intensity mapping of the Lyman-alpha line. Silva et al. 2012

See Mario Santos' talk later today for more details.

How to make a "perfect" claim of a reionization detection?

Conclusions





Infrared background is cosmologically important

Current measurements are wanting in near-IR

- fluctuations
  - limited in l range, now extended to 2 degrees.
  - *Origin is still a mystery.*
- absolute spectroscopy of sky from 0.5 – 5 μm
- uncertainty in Zodiacal light subtraction
- ZEBRA 5-10 AU EBL explorer for reionization signature!