Fluctuations in the Near Infrared (and X-ray) Background

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&

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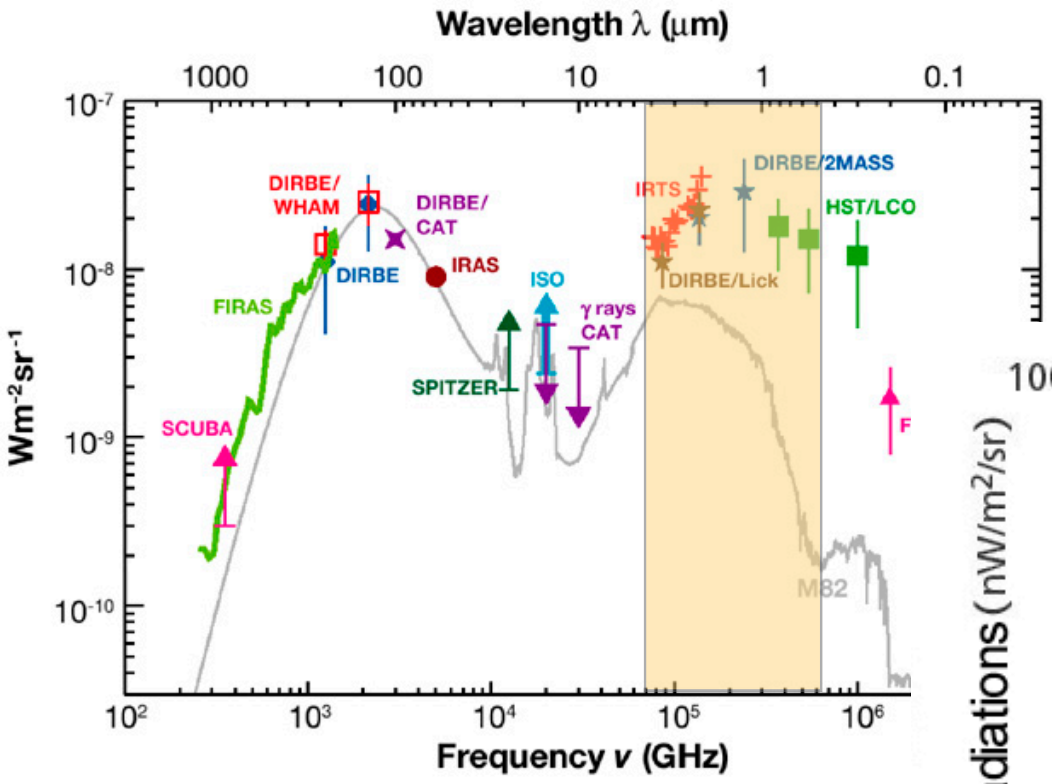
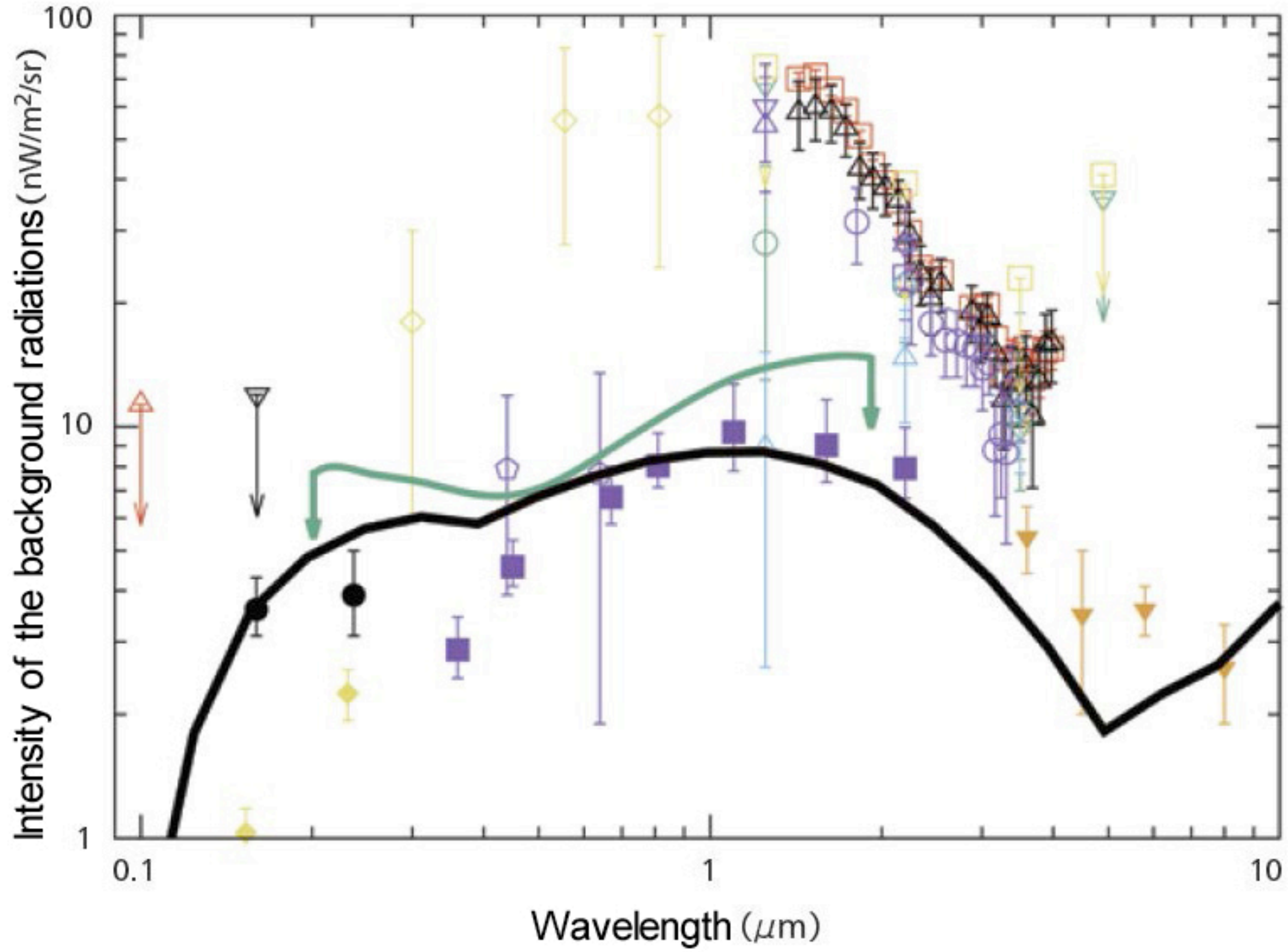
NIRB intensity

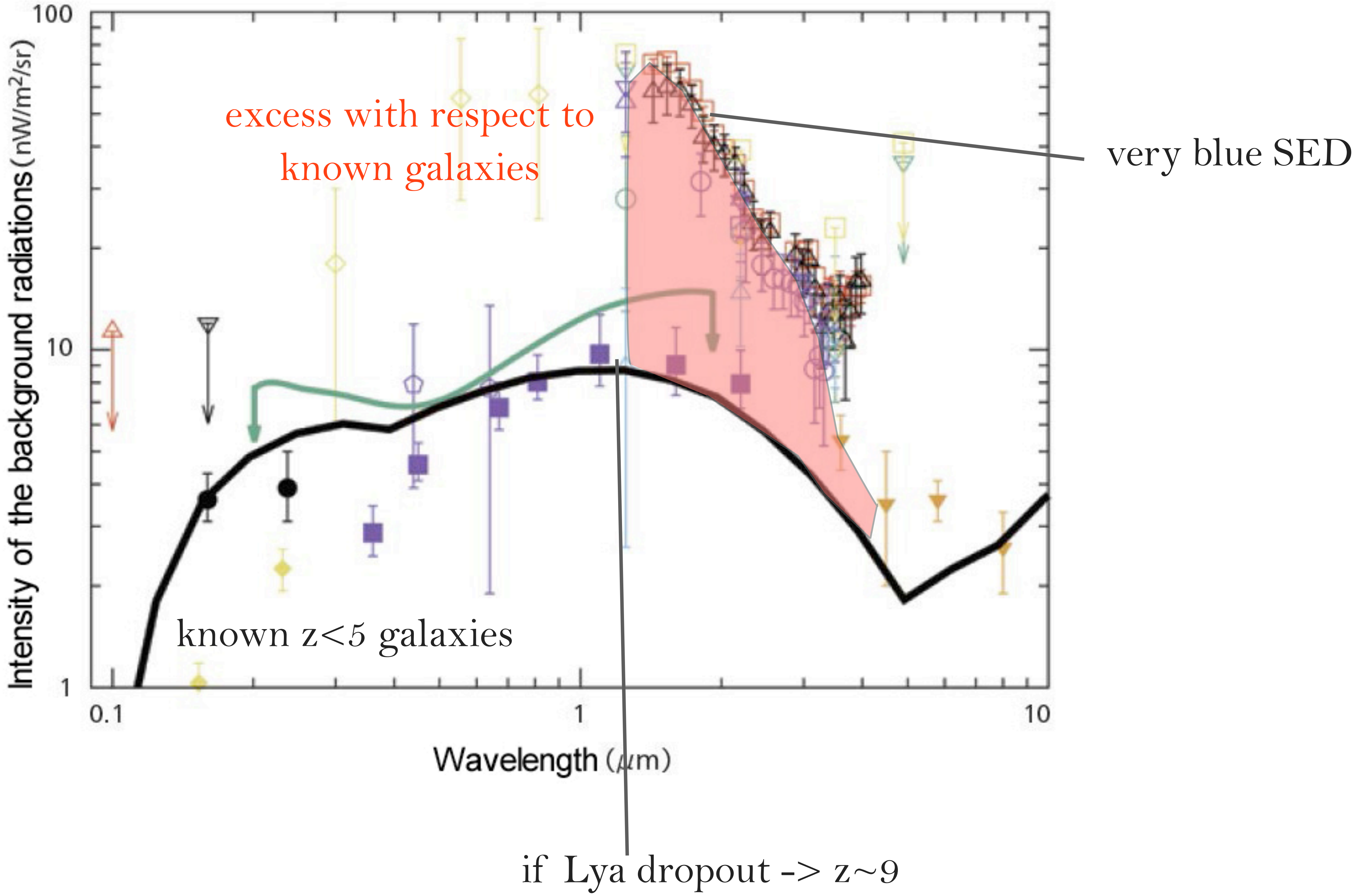
the Near Infrared Background



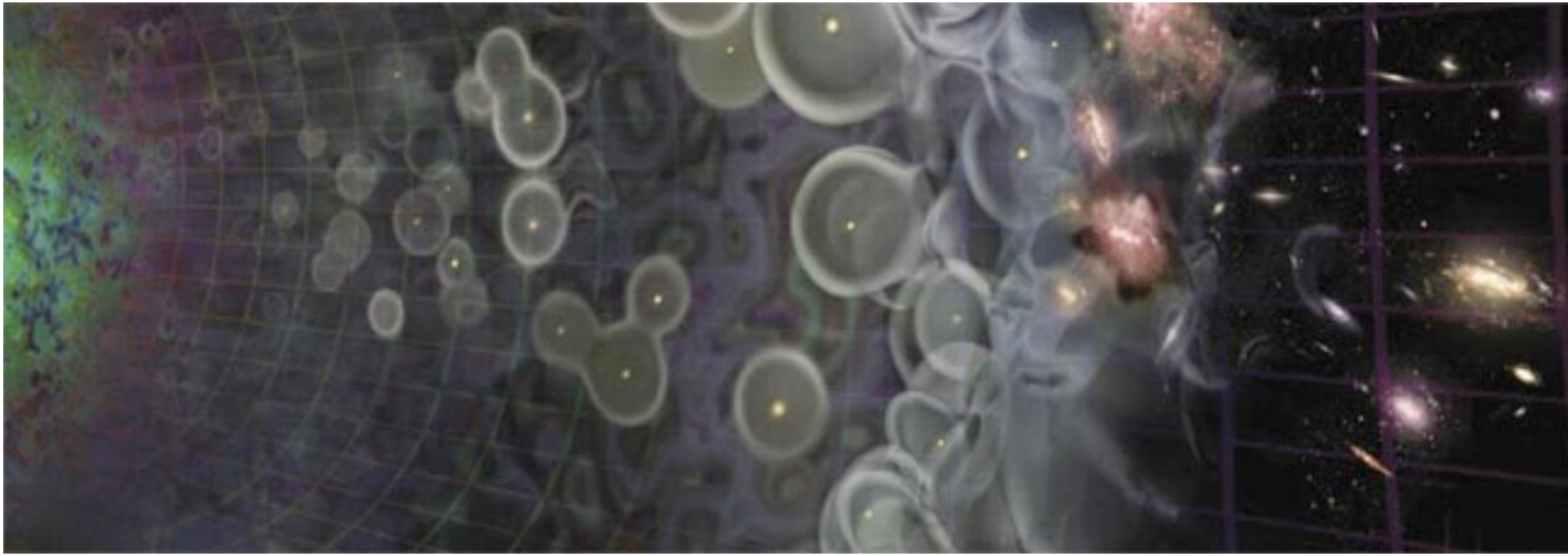


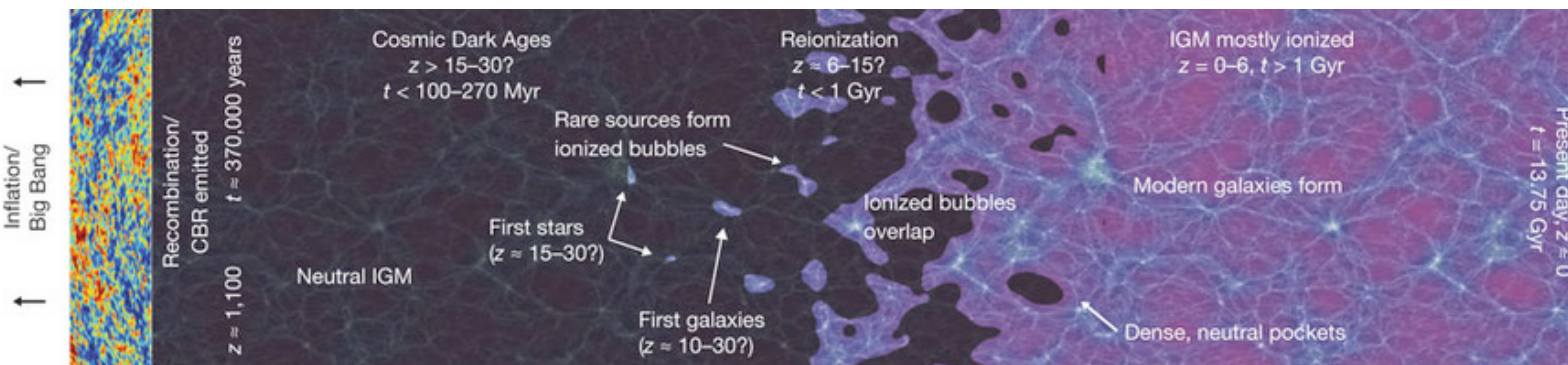
Matsumoto+2005, Matsumoto+2015

the intensity excess



the cosmic dark-ages

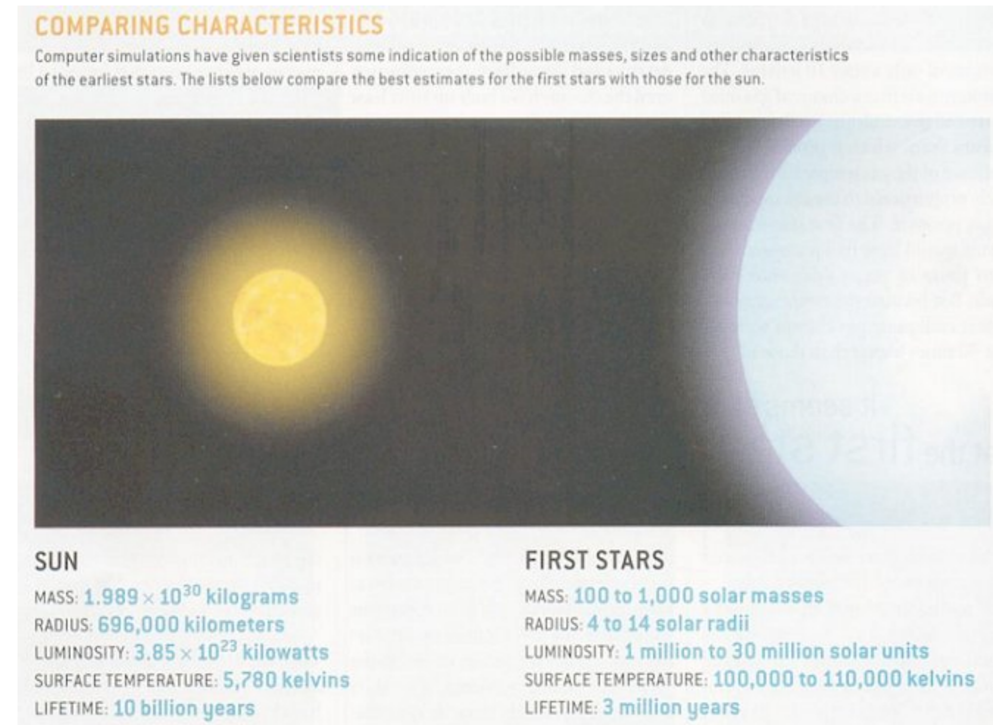




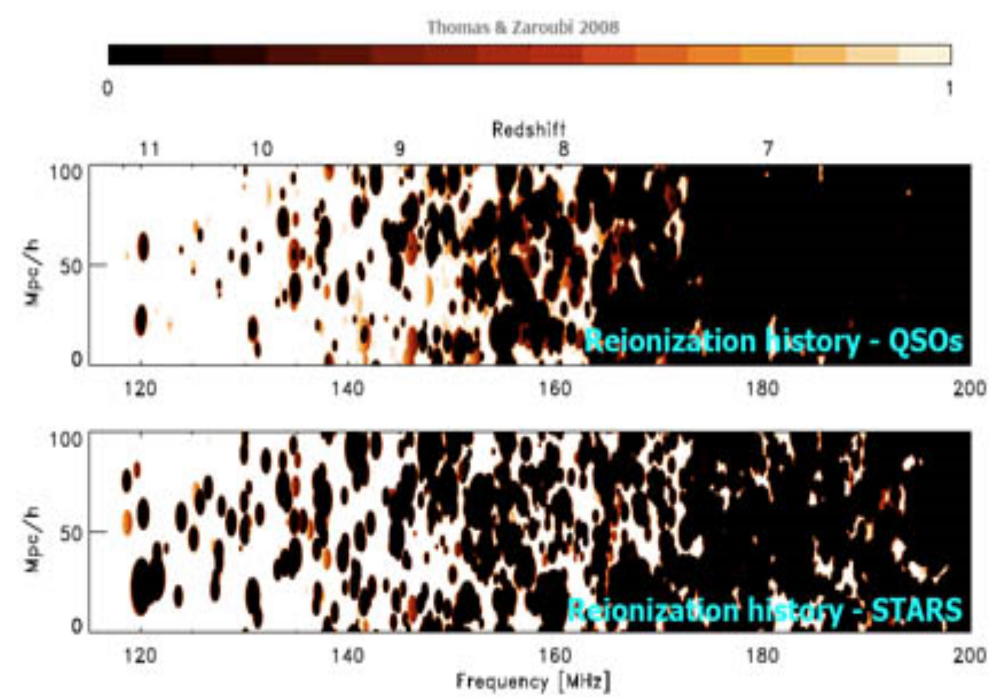
formation of first stars, first galaxies and first (massive) BHs

why is it interesting?

the Universe experienced two fundamental transitions:

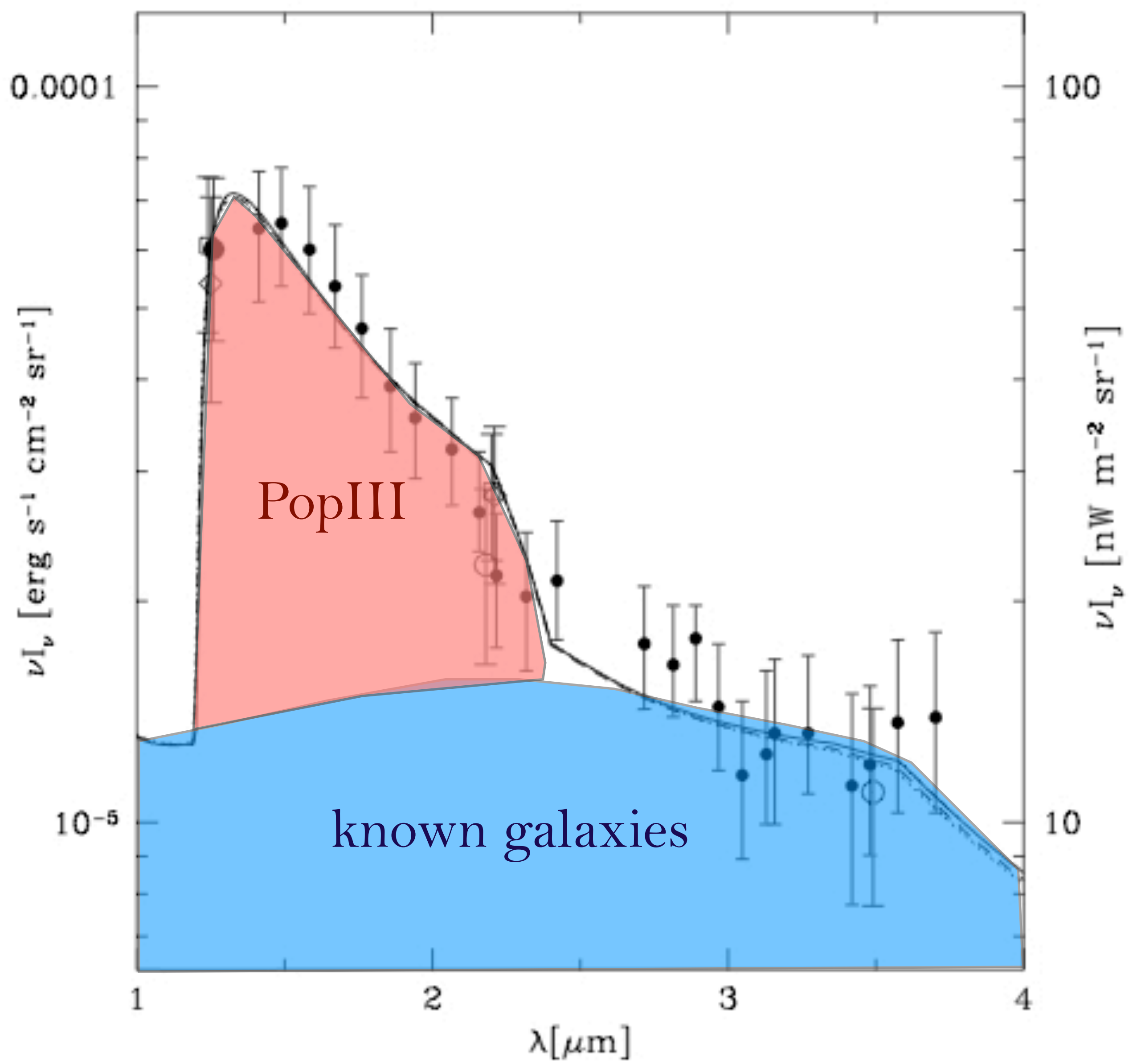


- transition in the star-formation mode:
from massive, metal-free PopIII stars to a normal (Salpeter-like) second generation of stars (PopII)
the transition is governed by metals and dust



- transition in IGM state/reionization:
from a neutral to a ionized intergalactic medium

PopIII interpretation feasible...



NIRB requires

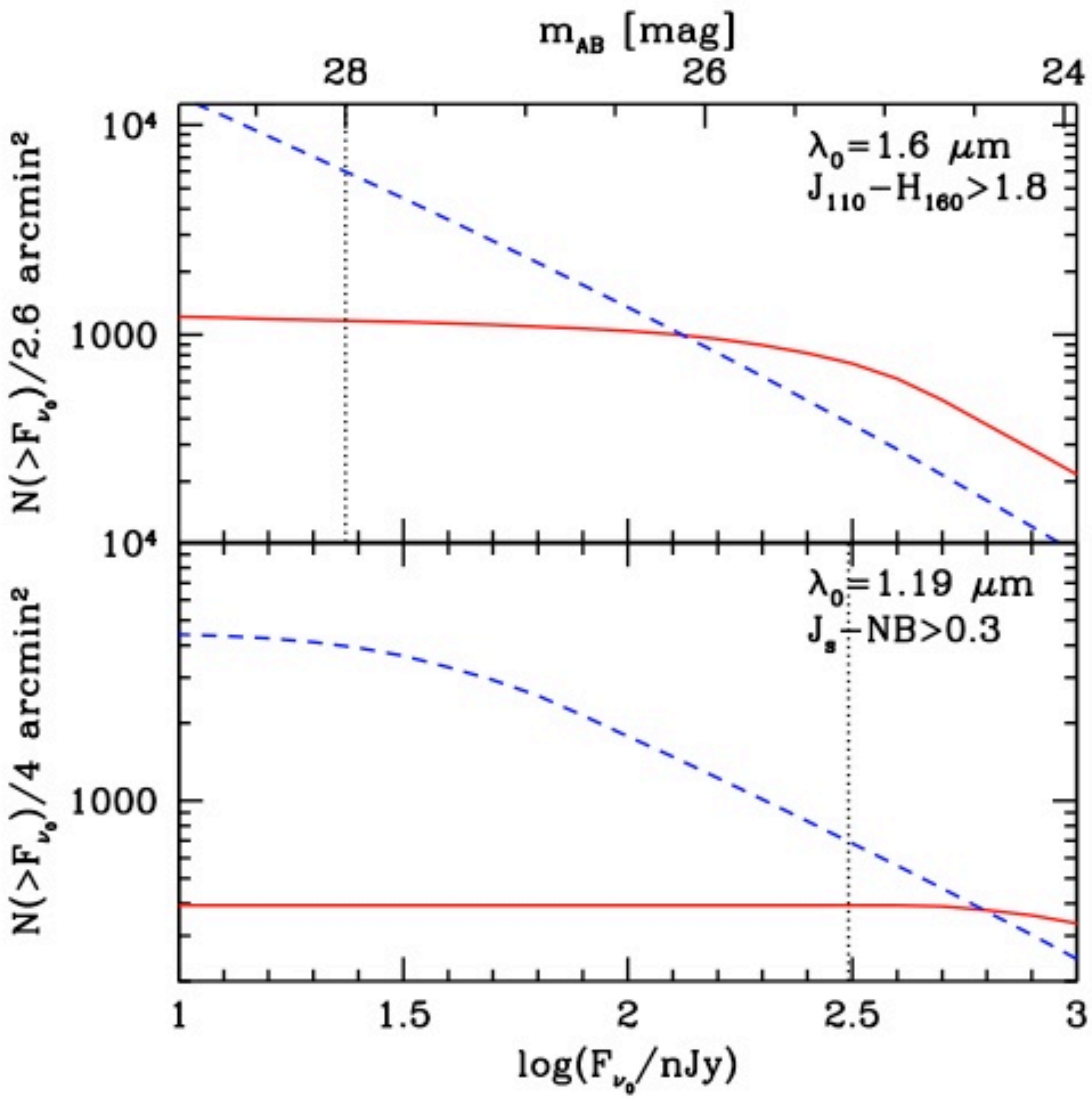
$z_{end} \sim 8.8$

$f_{\star} \sim 30\%$

also high-z, metal poor, PopII galaxies can do the job (e.g. Fernandez+2012)

Salvaterra+ 2003, Santos+ 2003, many others

... but unrealistic!



it predicts very large H-band dropouts in the HUDFs

high-z galaxies can not contribute more than 1% of the NIRB

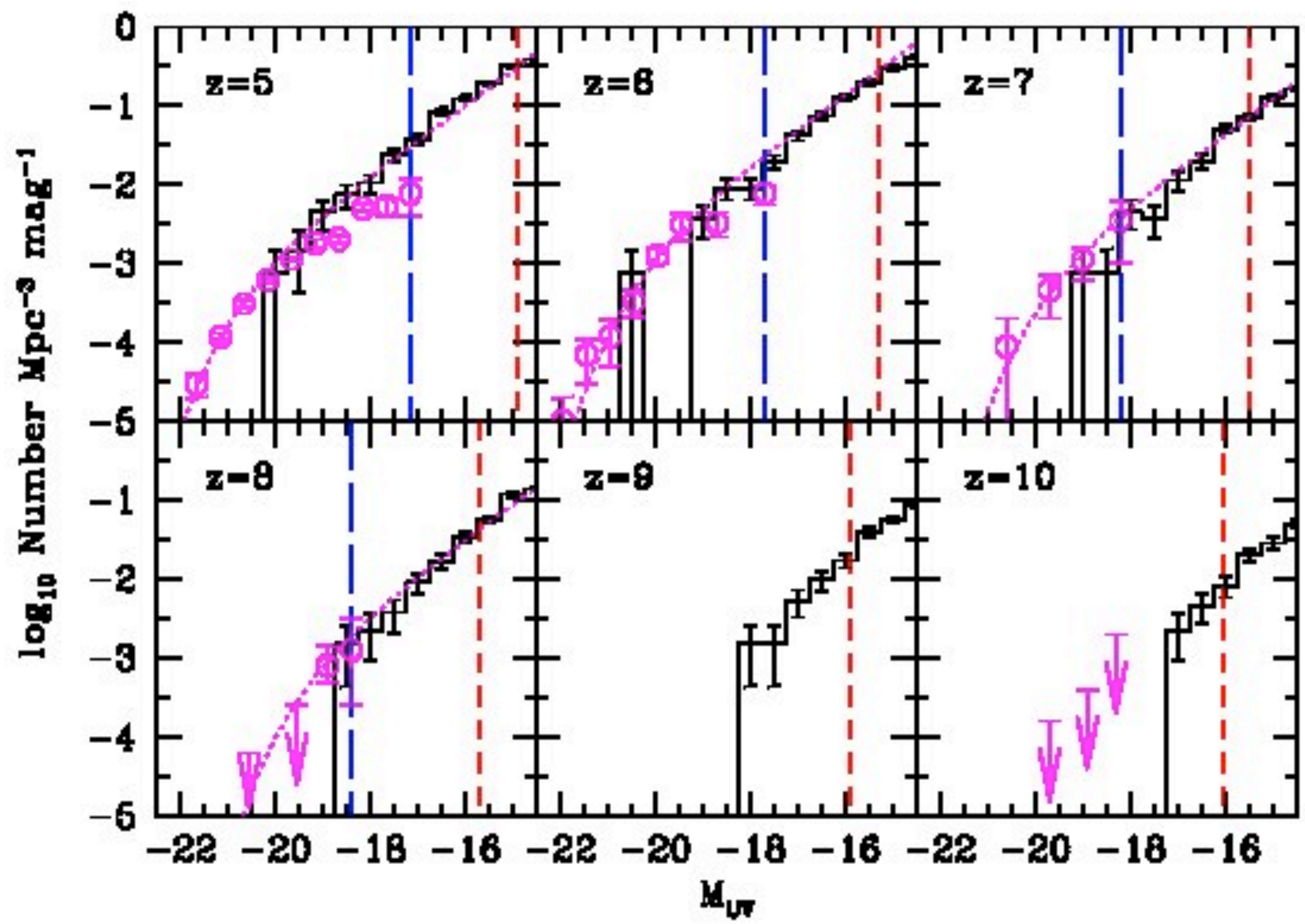
Salvaterra+2006

a modern approach

bright galaxies are now observed up to z~10 and the LF measured up to z~7-8 (Bouwens+2015, etc)

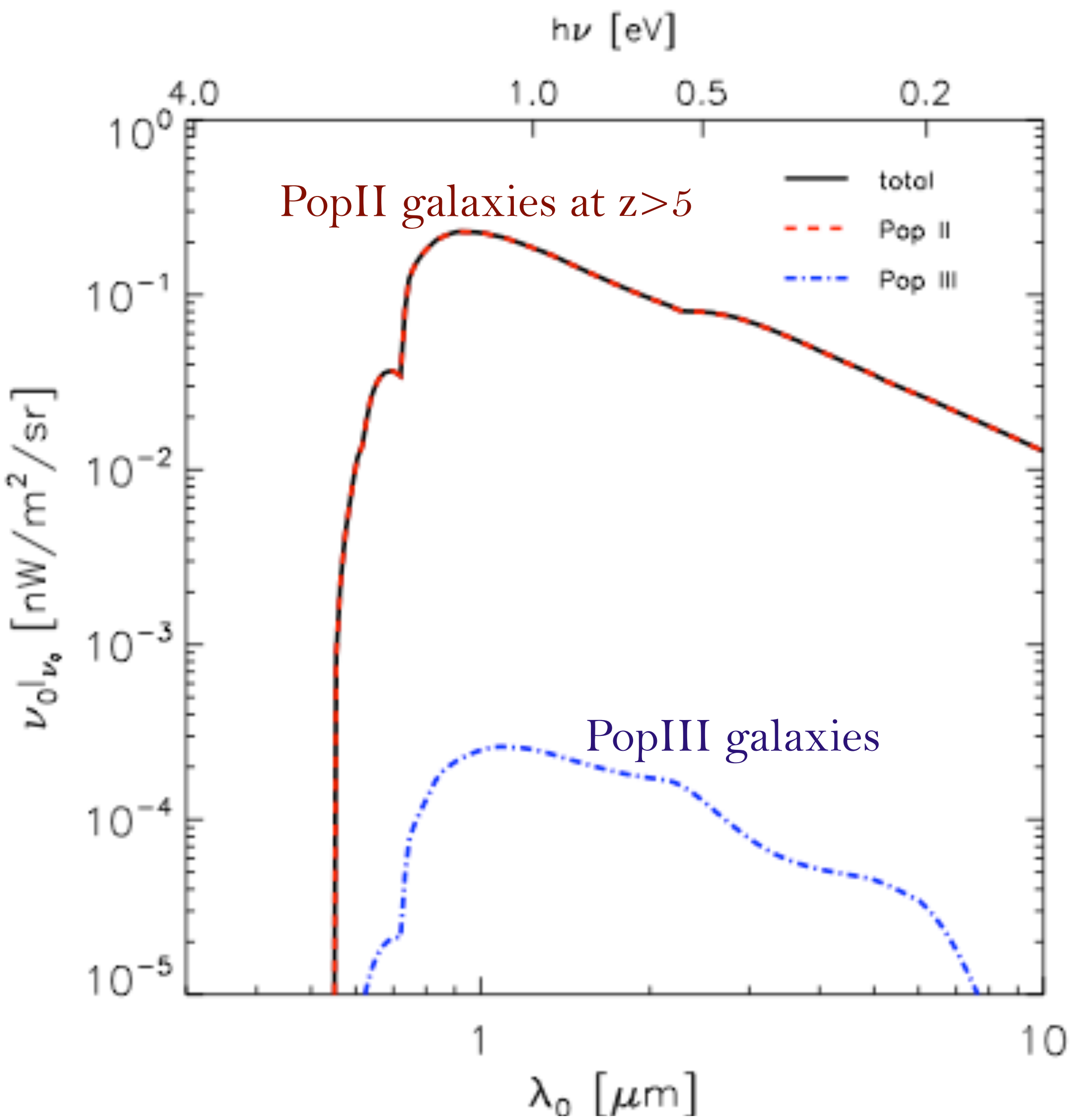
we use the state-of-the art of numerical simulation of structure formation at high-z including all relevant physical process (e.g. chemical, mechanical and radiative feedback) with SEDs computed with starburst99 template taking into account age, metallicity and PopIII fraction

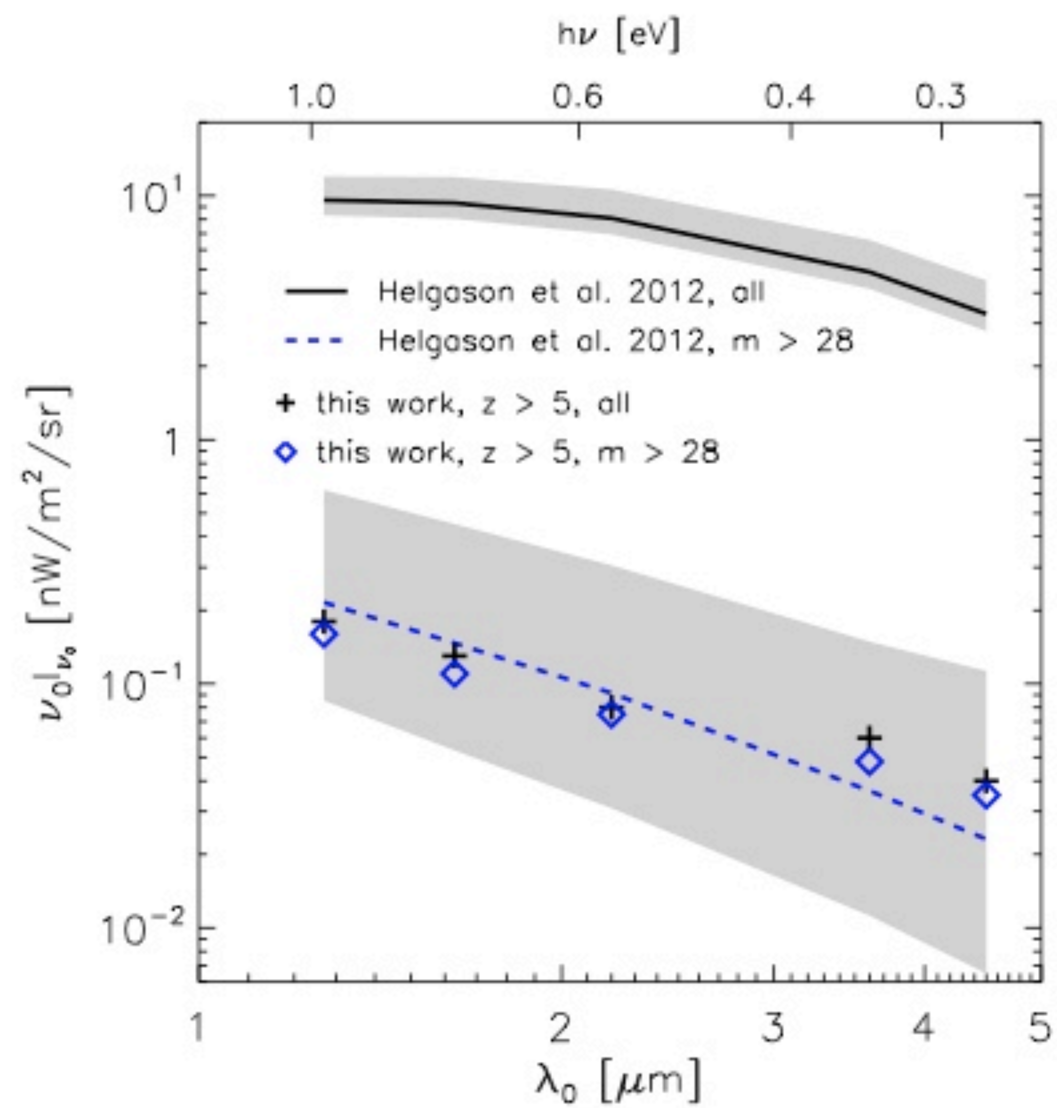
it provides a very good description of the observed galaxy LF at z>6 without any fine-tuning of simulation parameters



Salvaterra+2011

contribution of high-z galaxies

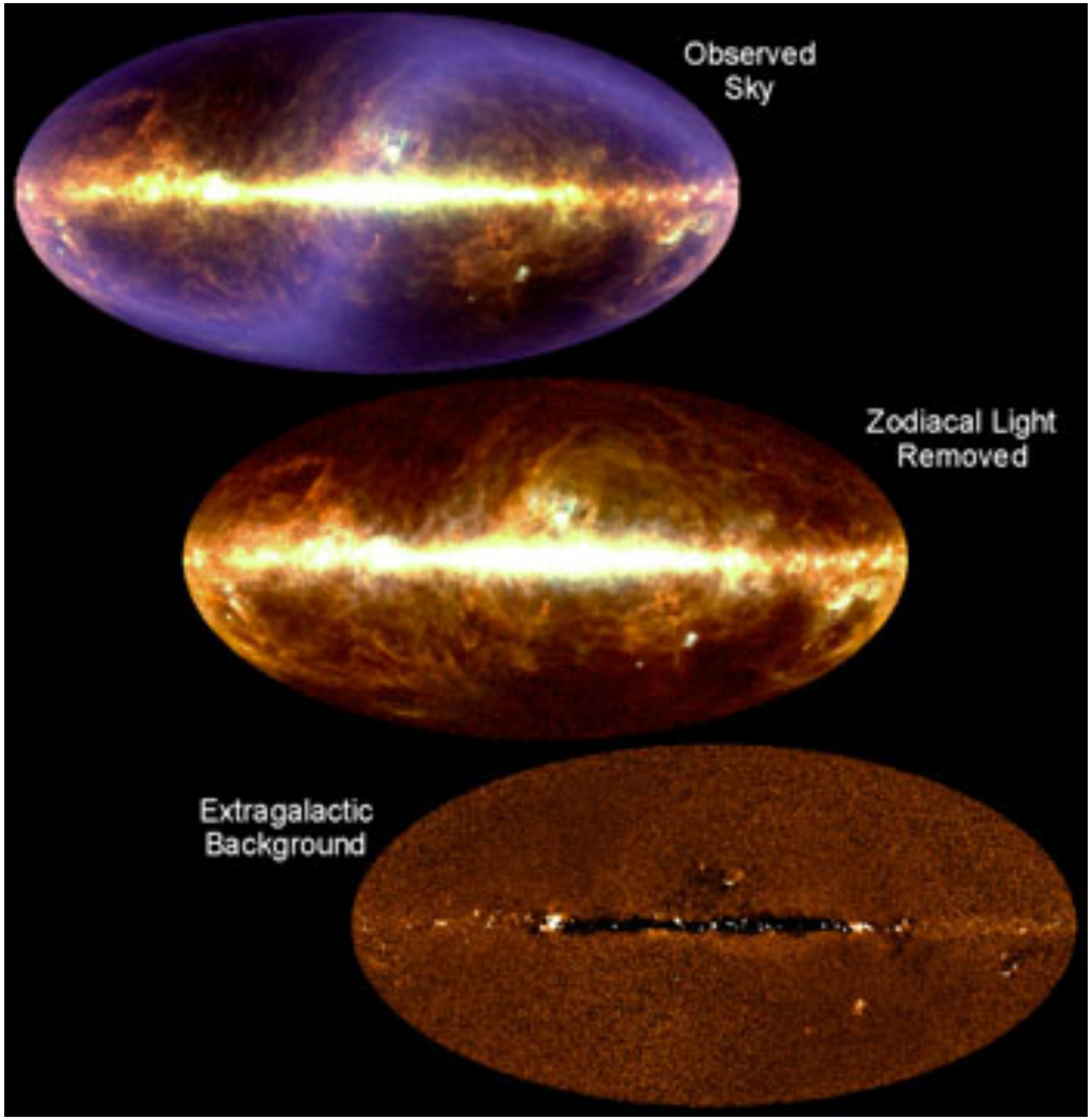




the contribution of z>5 galaxies is very low (<1 nW/m²/sr) but it can be isolated in the NIRB by subtracting sources down to m~28

Yue+2012

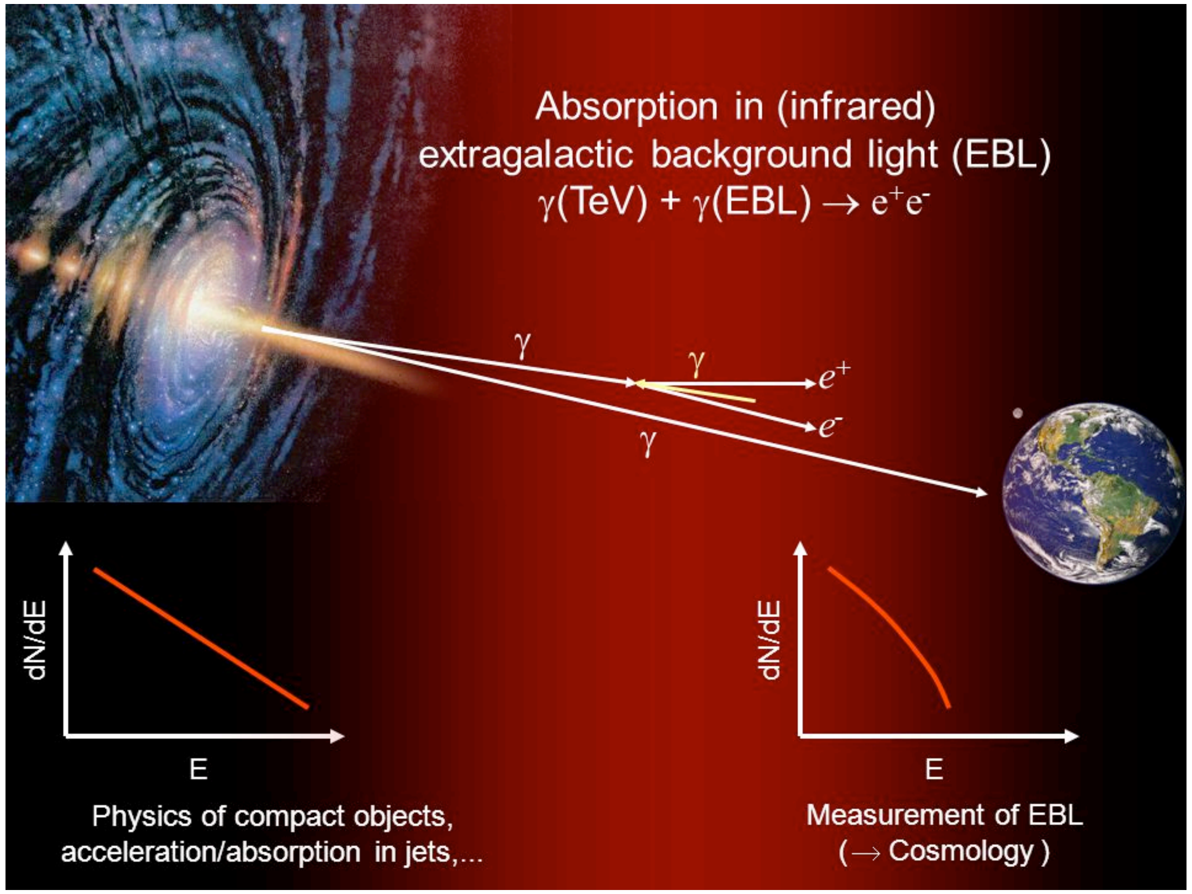
zodiacal light



total sky brightness
= zodiacal light 90%
+ galactic light 5%
+ integrated light of galaxies 5%

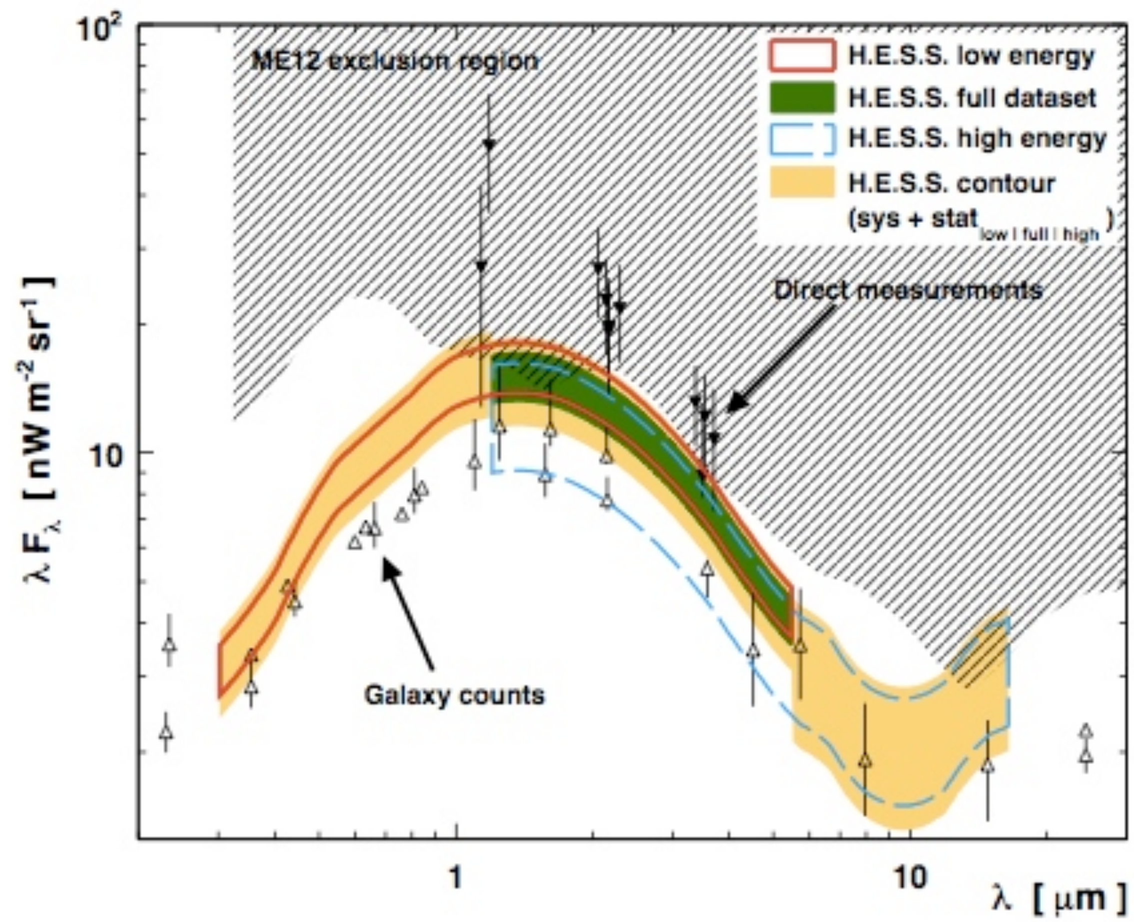
main foreground is zodiacal light:
sunlight scattered by
interplanetary dust

indirect probes



γ-γ absorption of distant γ-ray sources (both single than statistically) can provide an indirect measure of the NIRB intensity

γ-ray detector (HESS, Magic, Fermi/LAT) data are inconsistent with very large excess

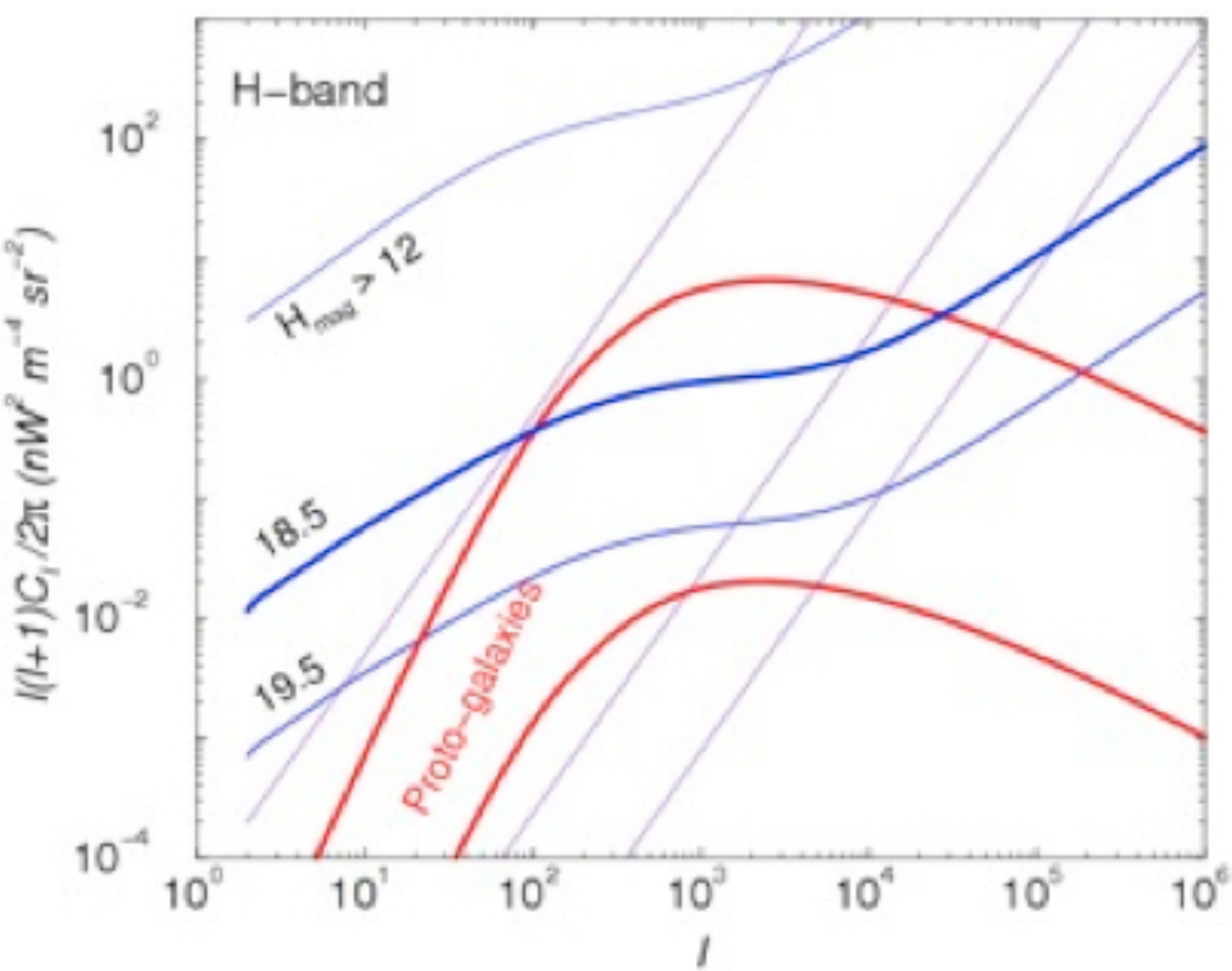


Abramowski+2013, Ackerman+2012, ...

NIRB anisotropies

why fluctuations?

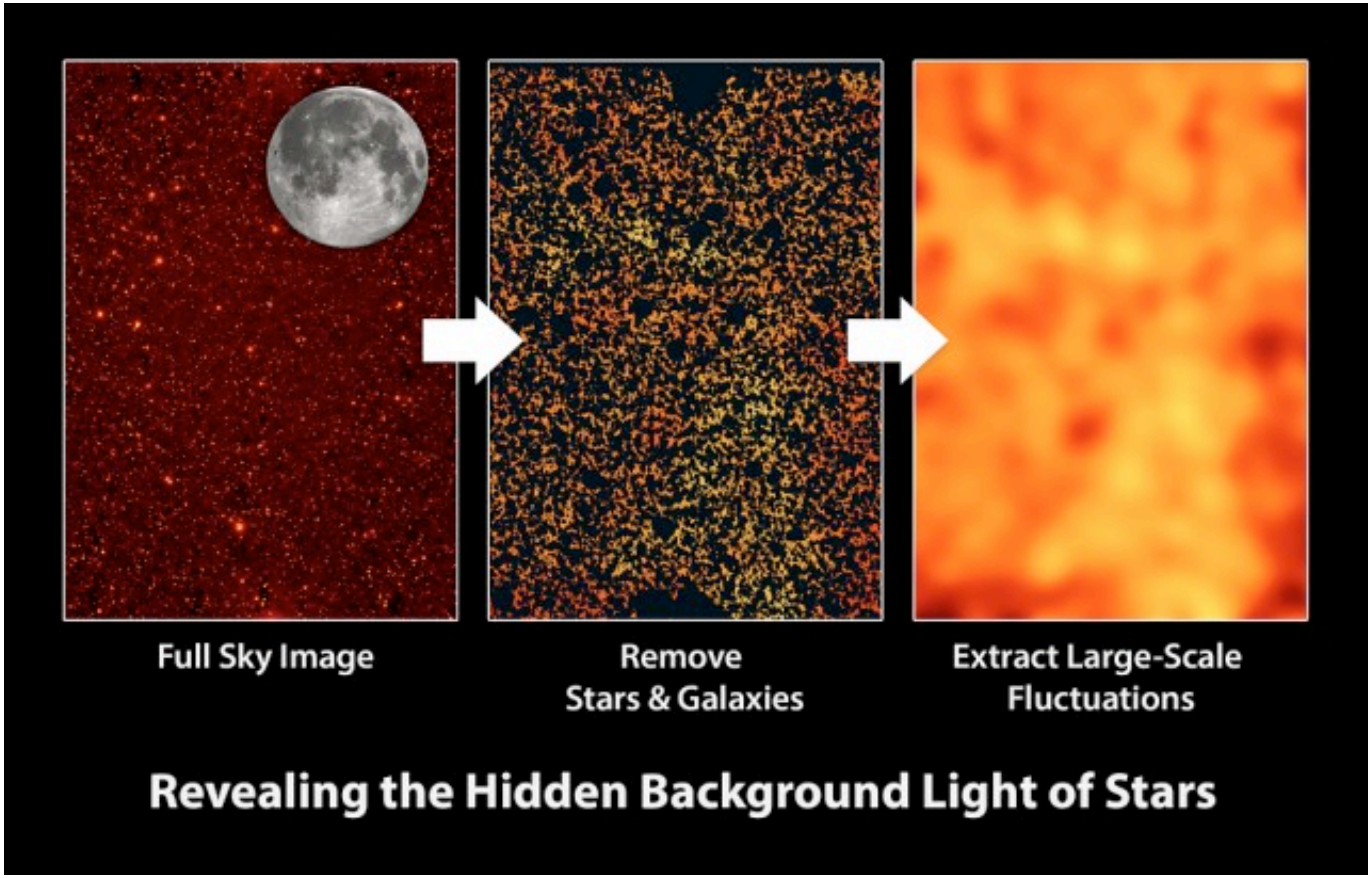
ZL smooth (fluctuation <0.03%)



high-z galaxies are highly biased with respect to the density field,
trace the linear regime of clustering at tens of arcminute scales when projected on the sky today.

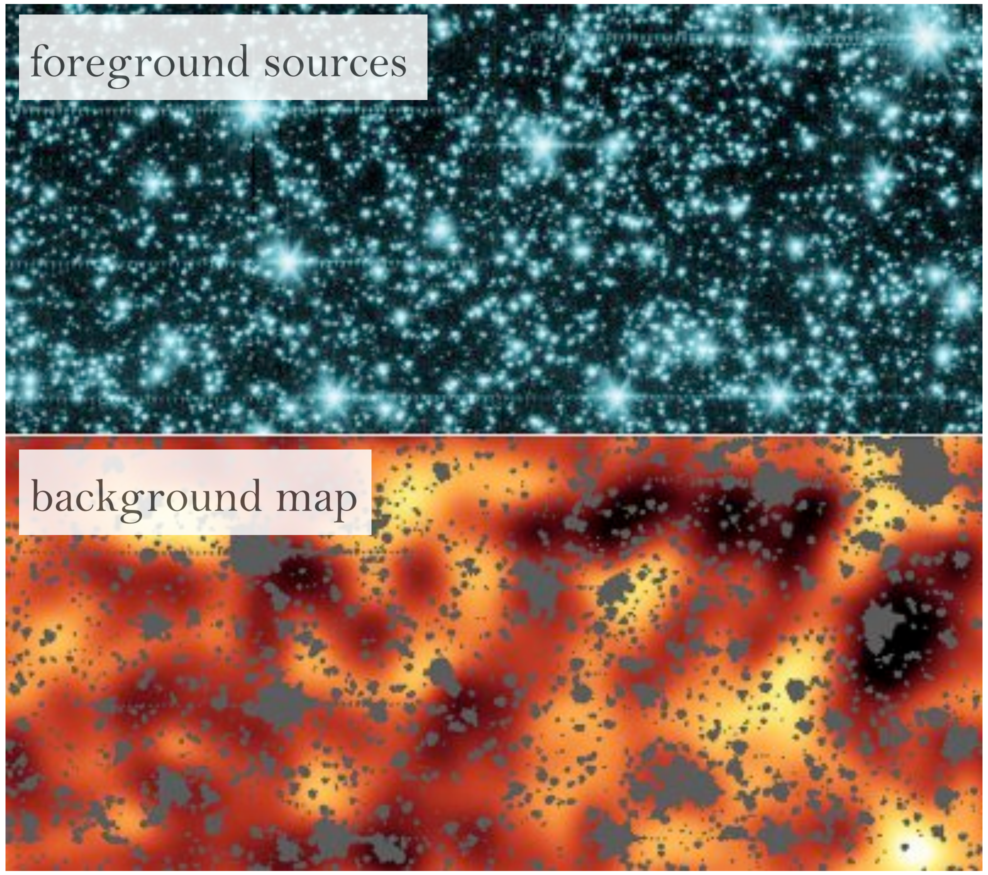
Cooray+2004

how it works?

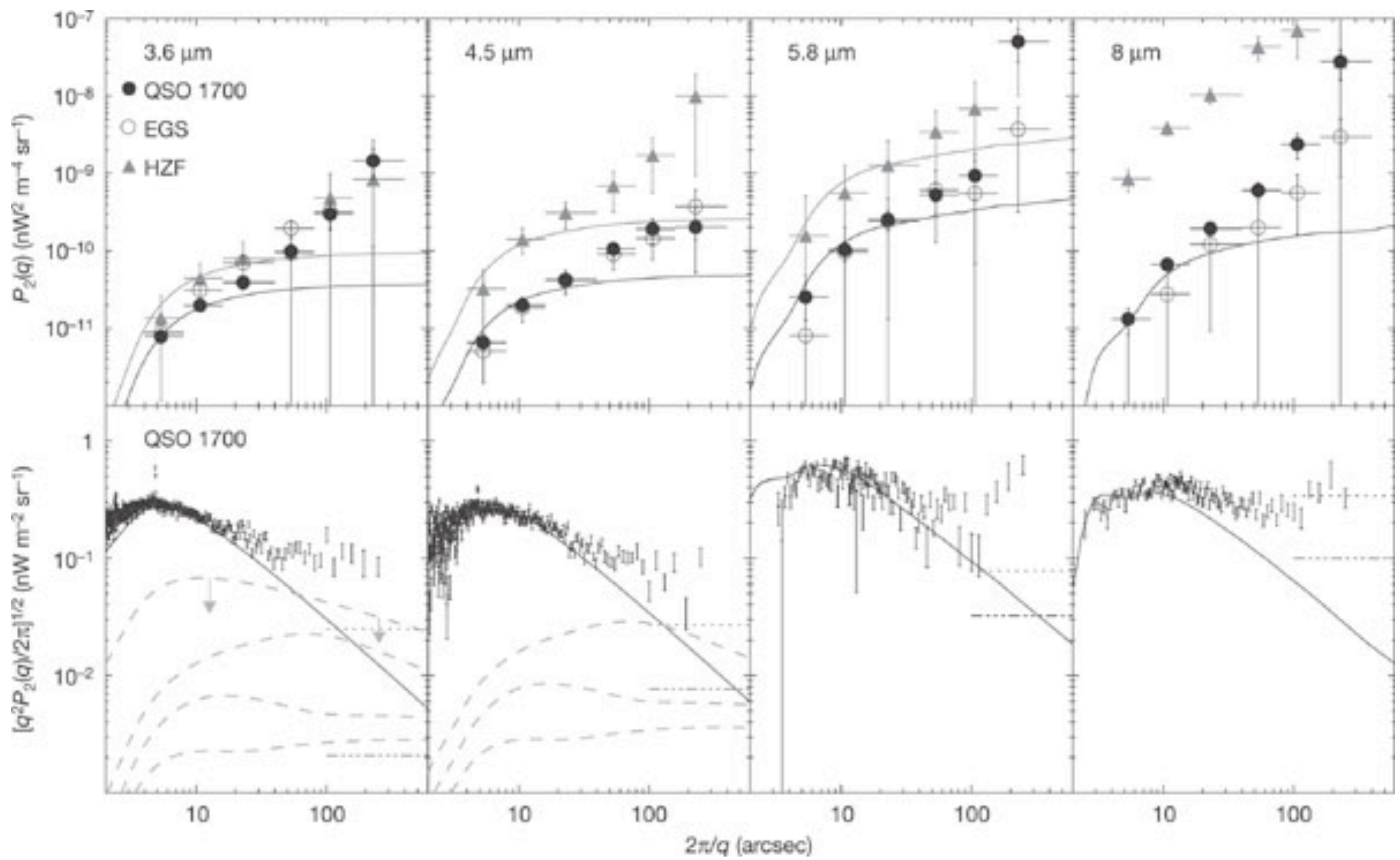


+ complex (and very technical) data handling

first evidence



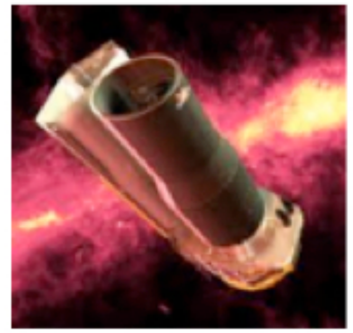
Kashlinsky+2005 used Spitzer data to subtract known sources probing the presence of NIRB fluctuation up to hundredth arcsec



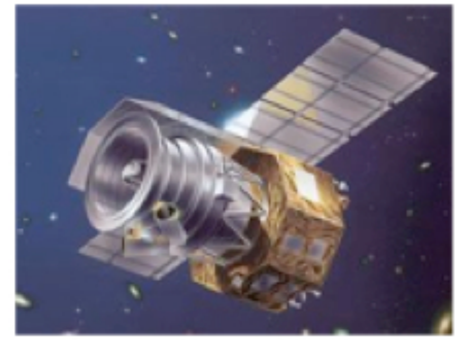
Kashlinsky+2002, Kashlinsky+2005

the observations now

HST/NICMOS

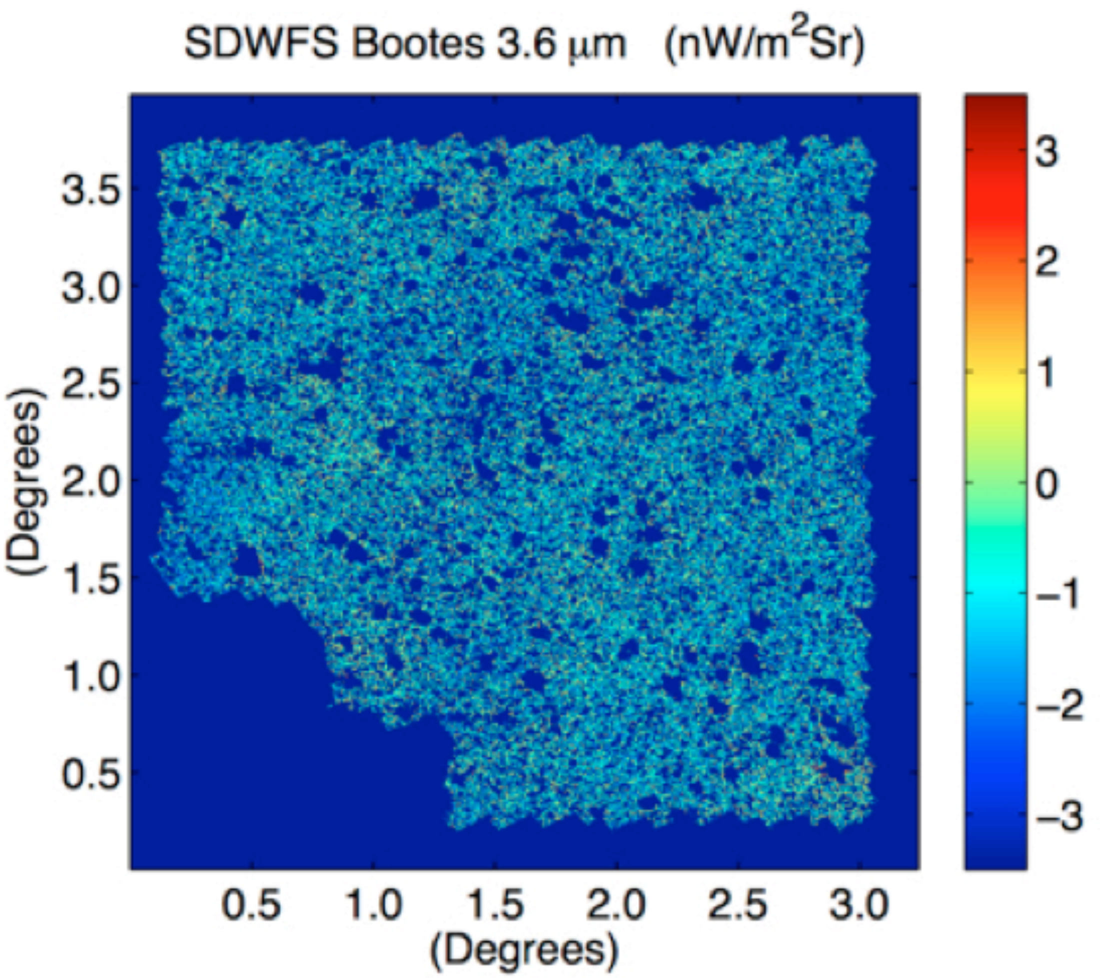


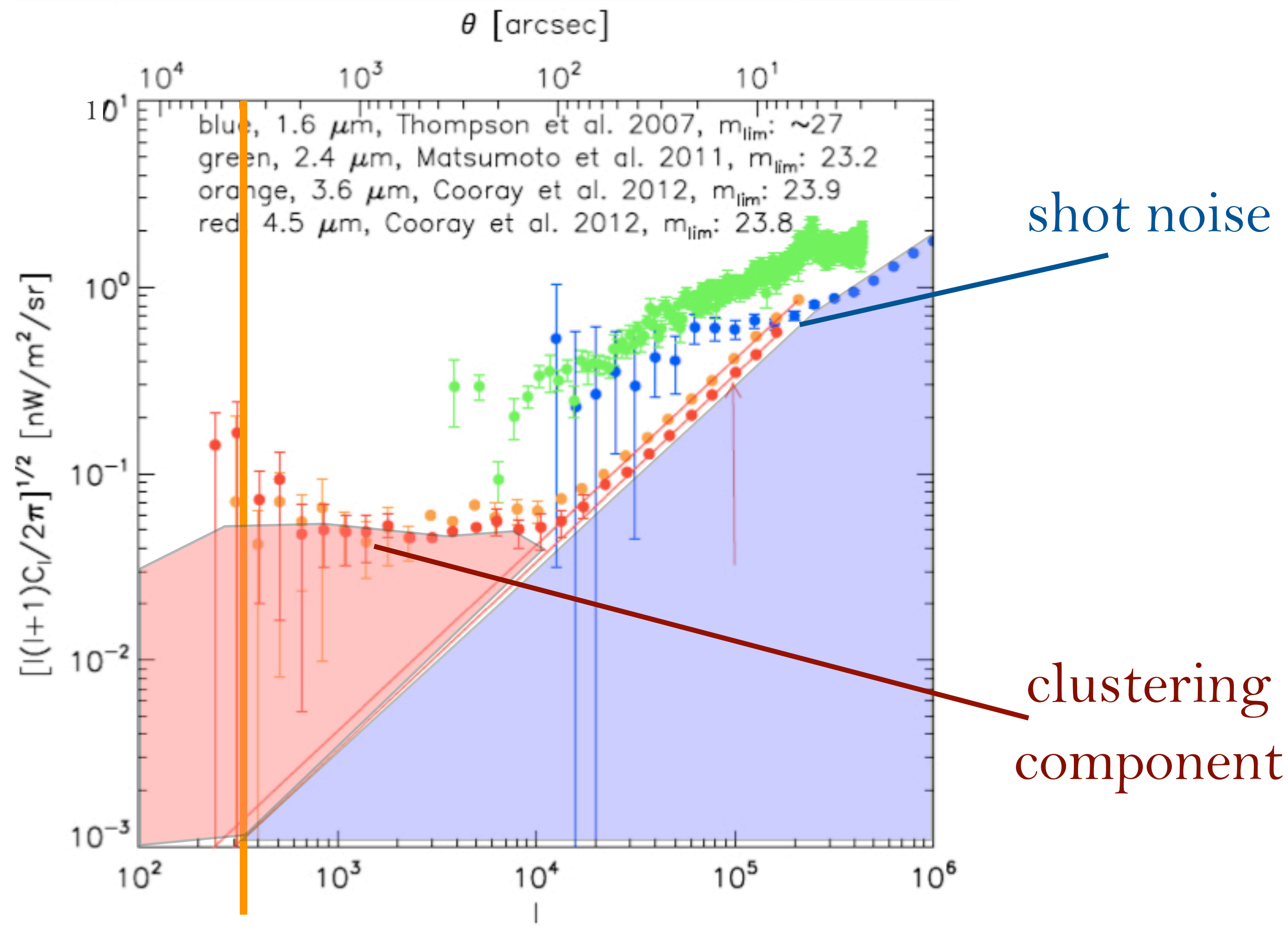
Spitzer/IRAC



Akari/IRC

CIBER



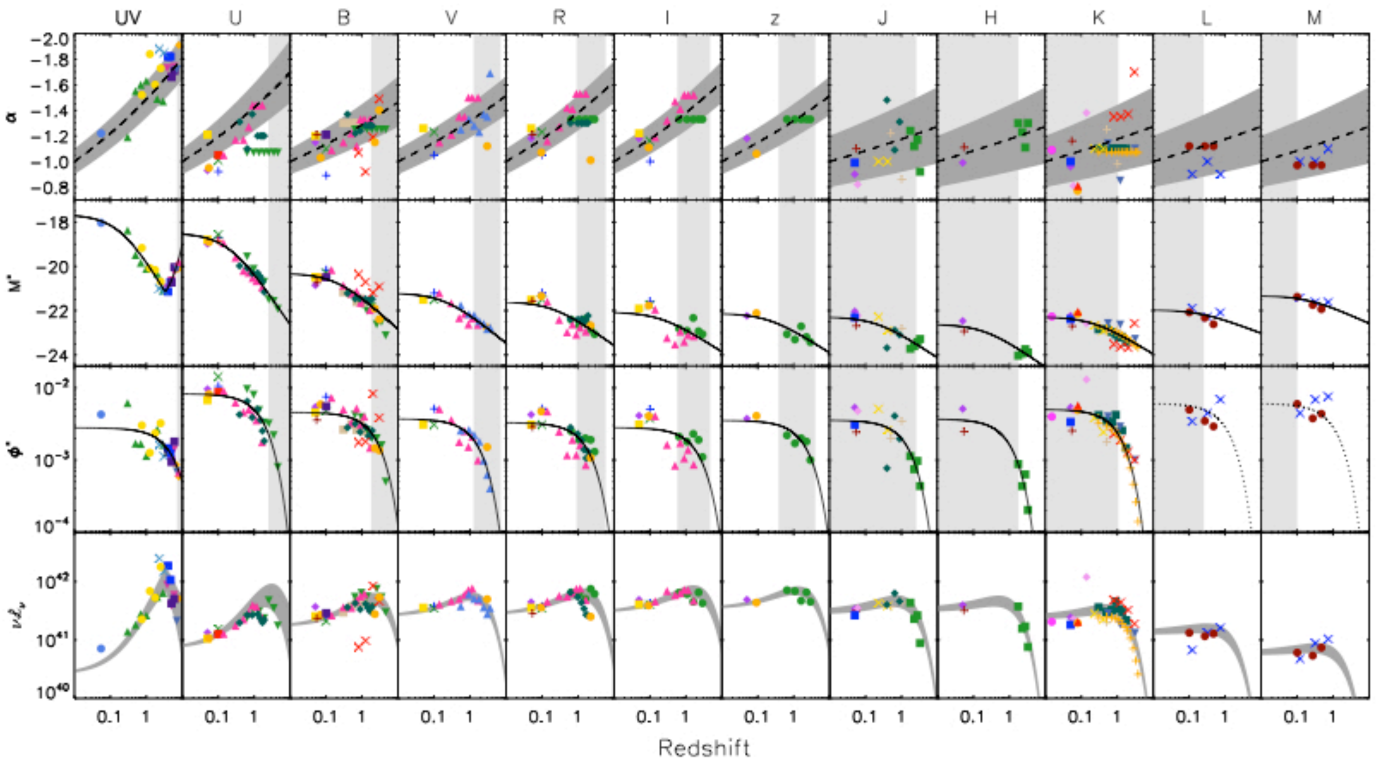


degree scale

many evidences by different experiments, different fields, different technique & different groups

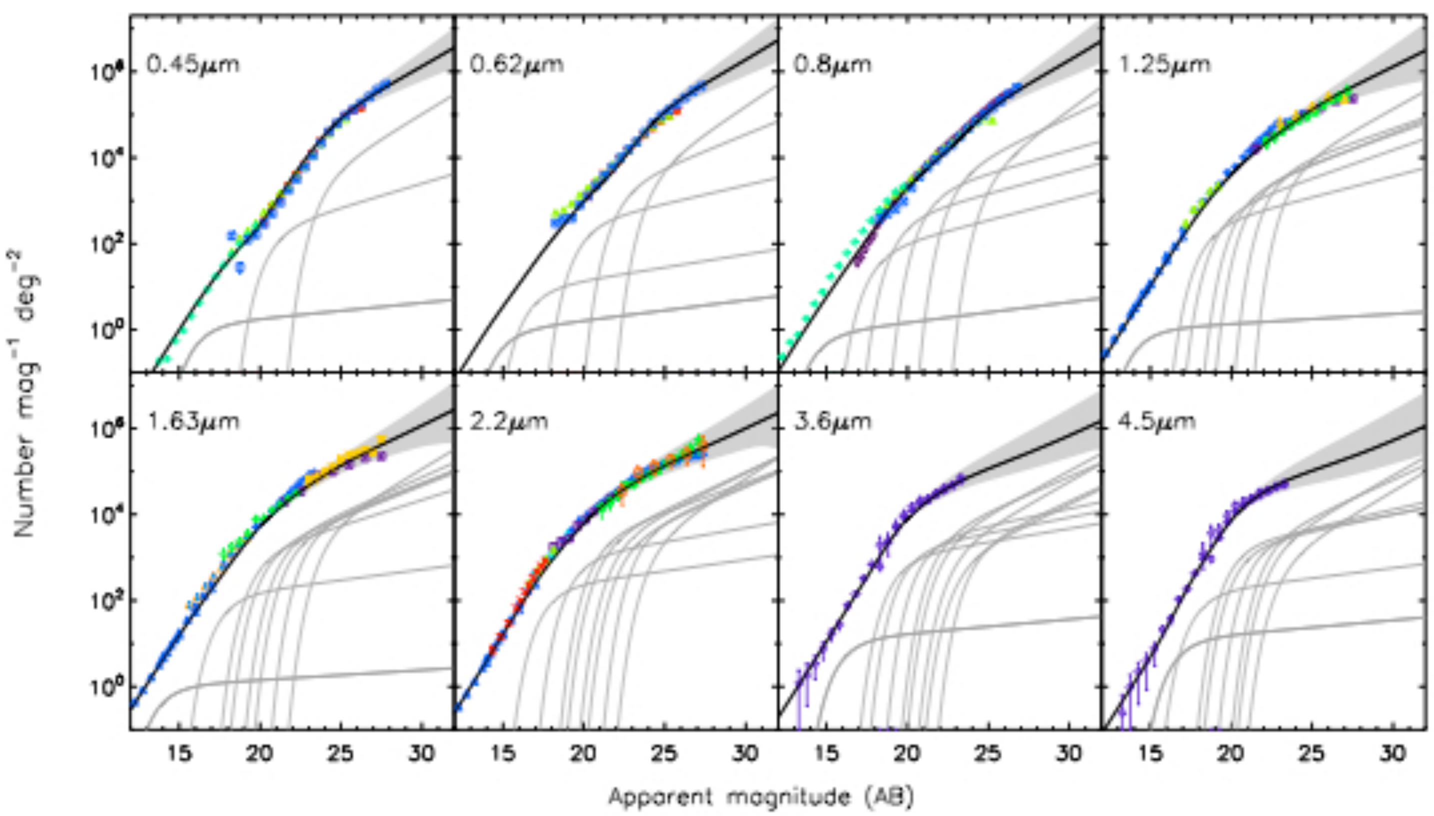
Matsumoto+2011, Kashlinsky+2012, Cooray+2012, Zemcon+2014, Seo+2015, Mitchell-Wynne+2015

contribution from low-z galaxies



Helgason+2012 start from observed LF at different wavelengths...

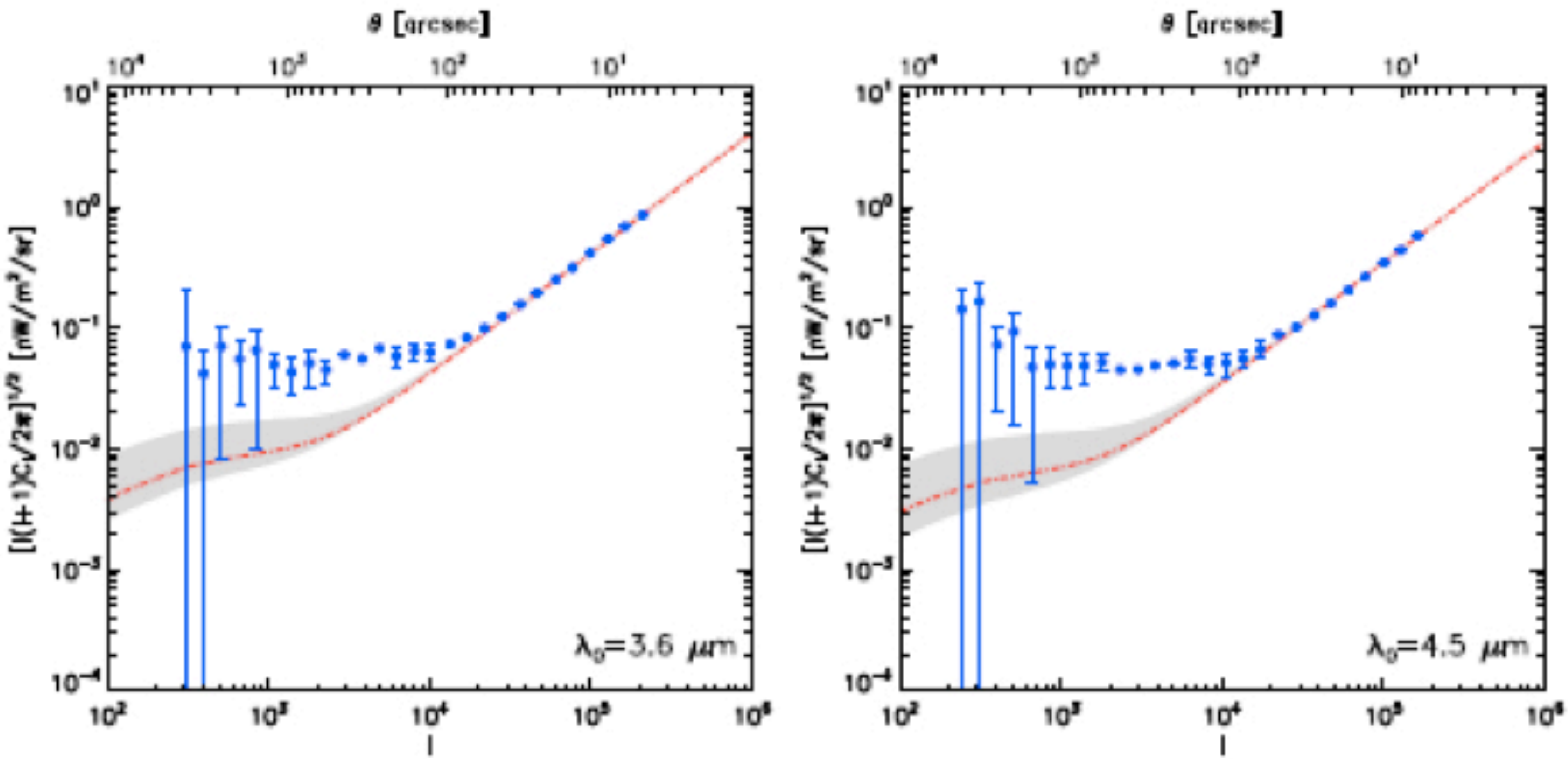
...compute number counts at different wavelengths...



Helgason+2012

contribution of low-z galaxies

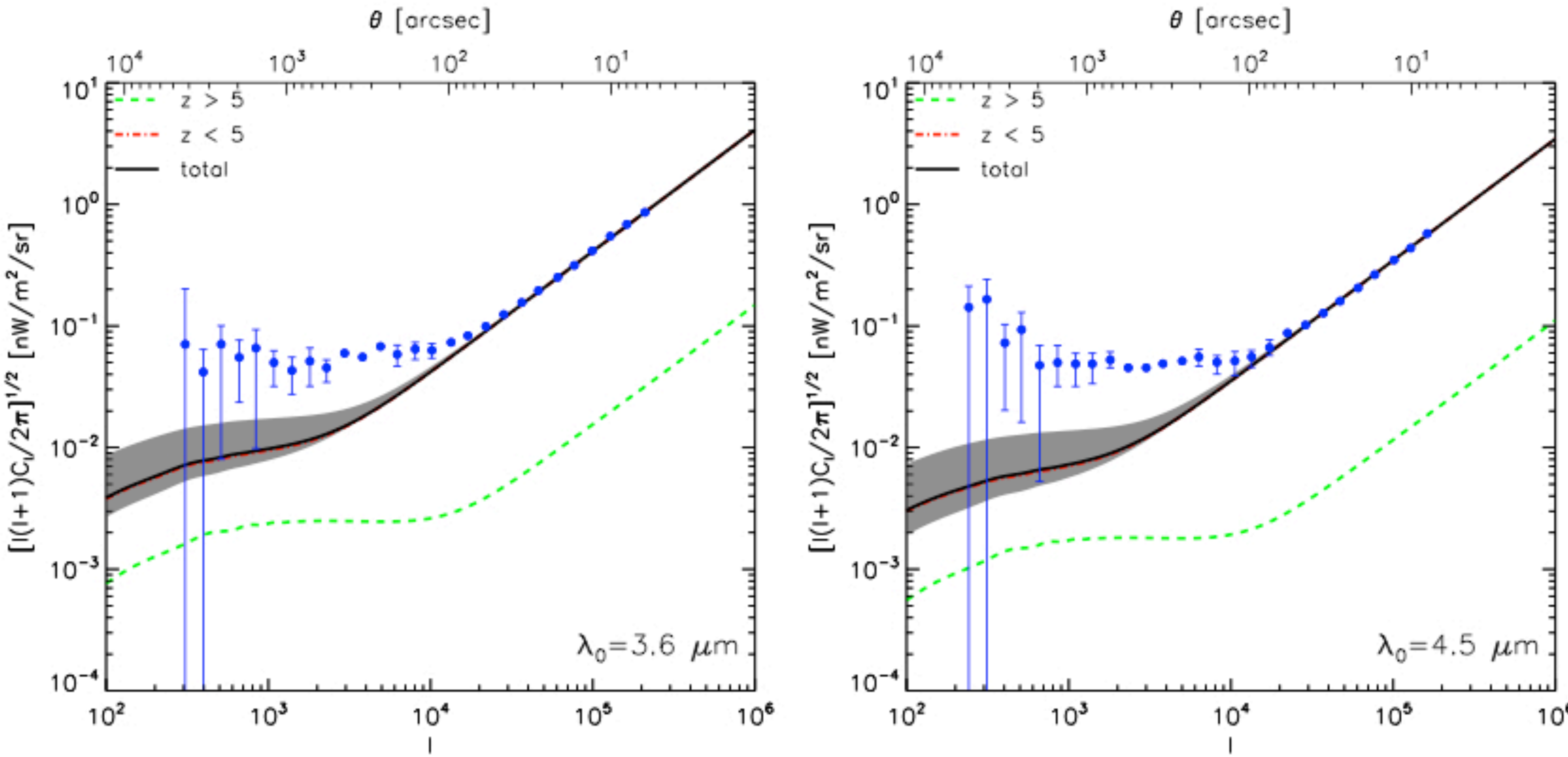
... and use halo model to compute fluctuations



still a clear excess at degree scale

Helgason+2012

contribution from high-z galaxies

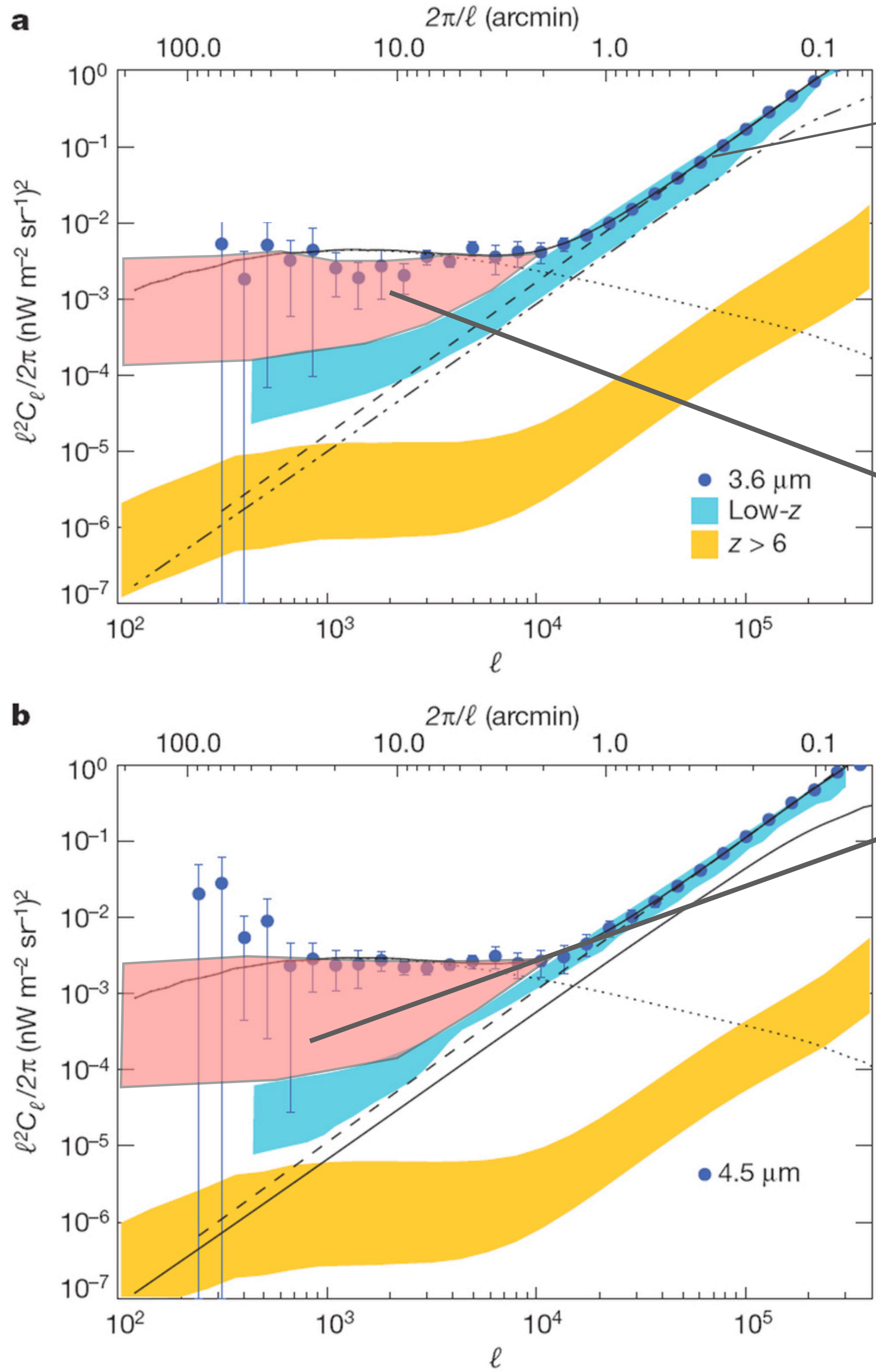


clustering: $$C_l = \int_{z_{\min}}^{z_{\max}} \frac{dz}{r^2(z)(1+z)^4} \frac{dr}{dz} [\nu\epsilon(\nu, z) e^{-\tau_{\rm eff}(\nu_0, z)}]^2 P_{\rm gg}(k, z),$$

shot noise: $$C_l^{SN} = \int_{z_{\min}}^{z_{\max}} \frac{c dz}{H(z) r^2(z)(1+z)^4} P^{\rm SN}(z),$$

Yue+2012

clustering excess

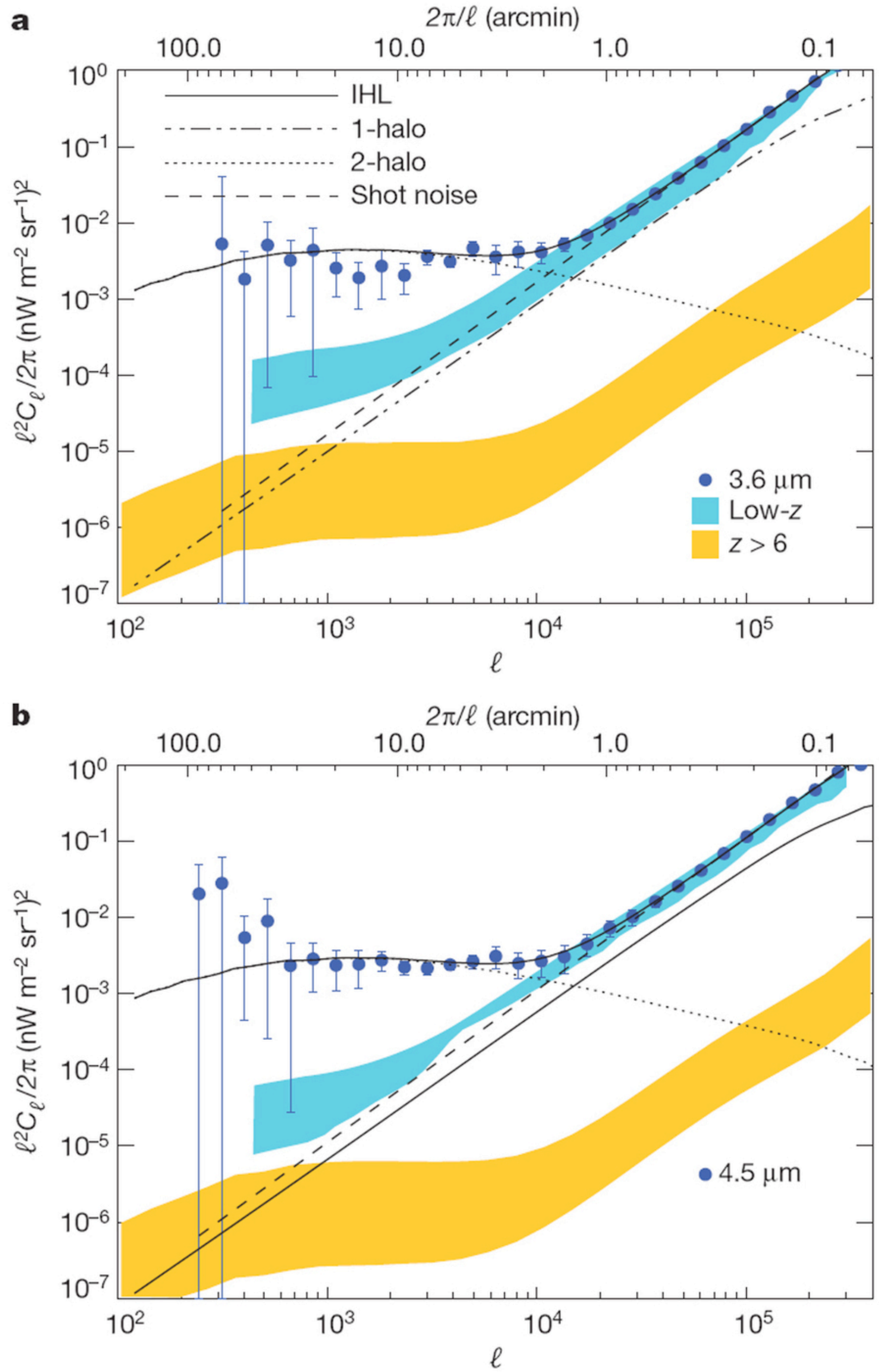


shot noise is ok and agrees with expected signal from low-z faint galaxies

clustering excess

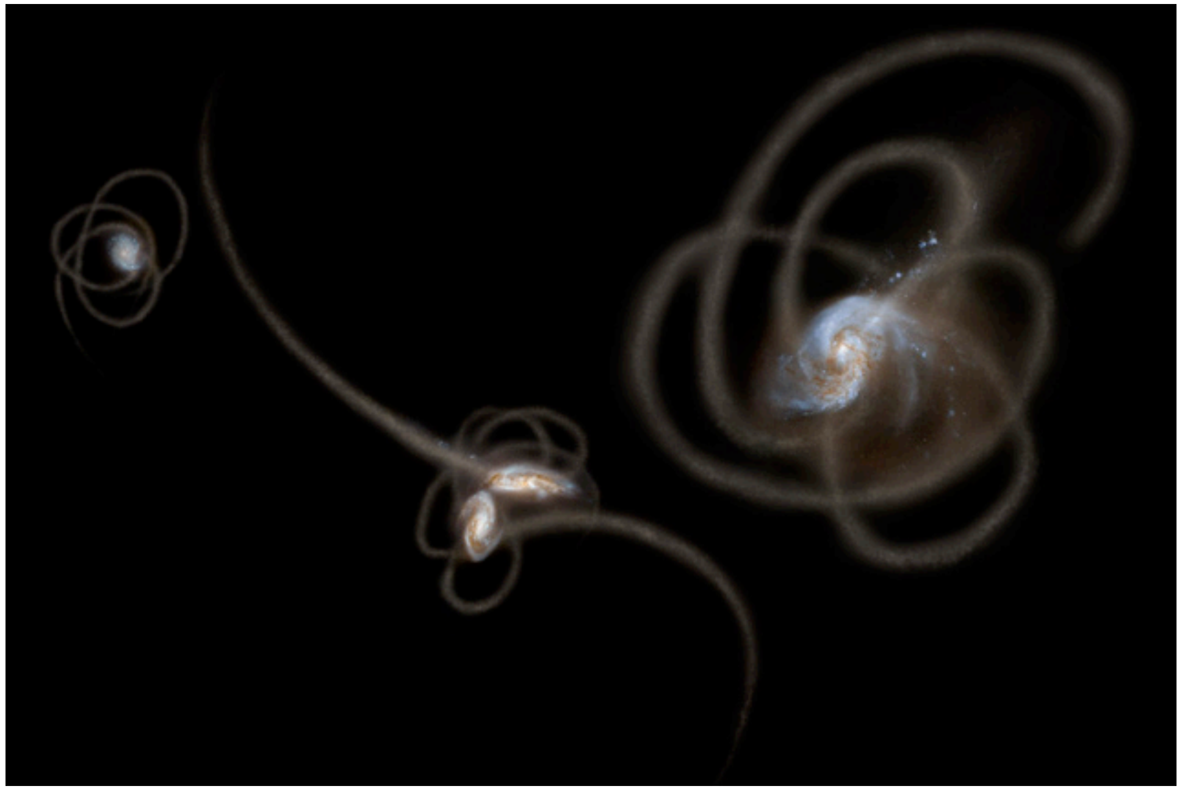
the signal of reionization sources is there! although 30x smaller than the data it can be isolated by cross-correlating the source-subtracted NIRB with LBG detected in the same field (Yue+2016)

intrahalo light



Cooray+2012 considered the contribution to NIRB fluctuations from stars outside of the galactic disks and in the outskirts of dark matter halos due to tidal stripping and galaxy merger

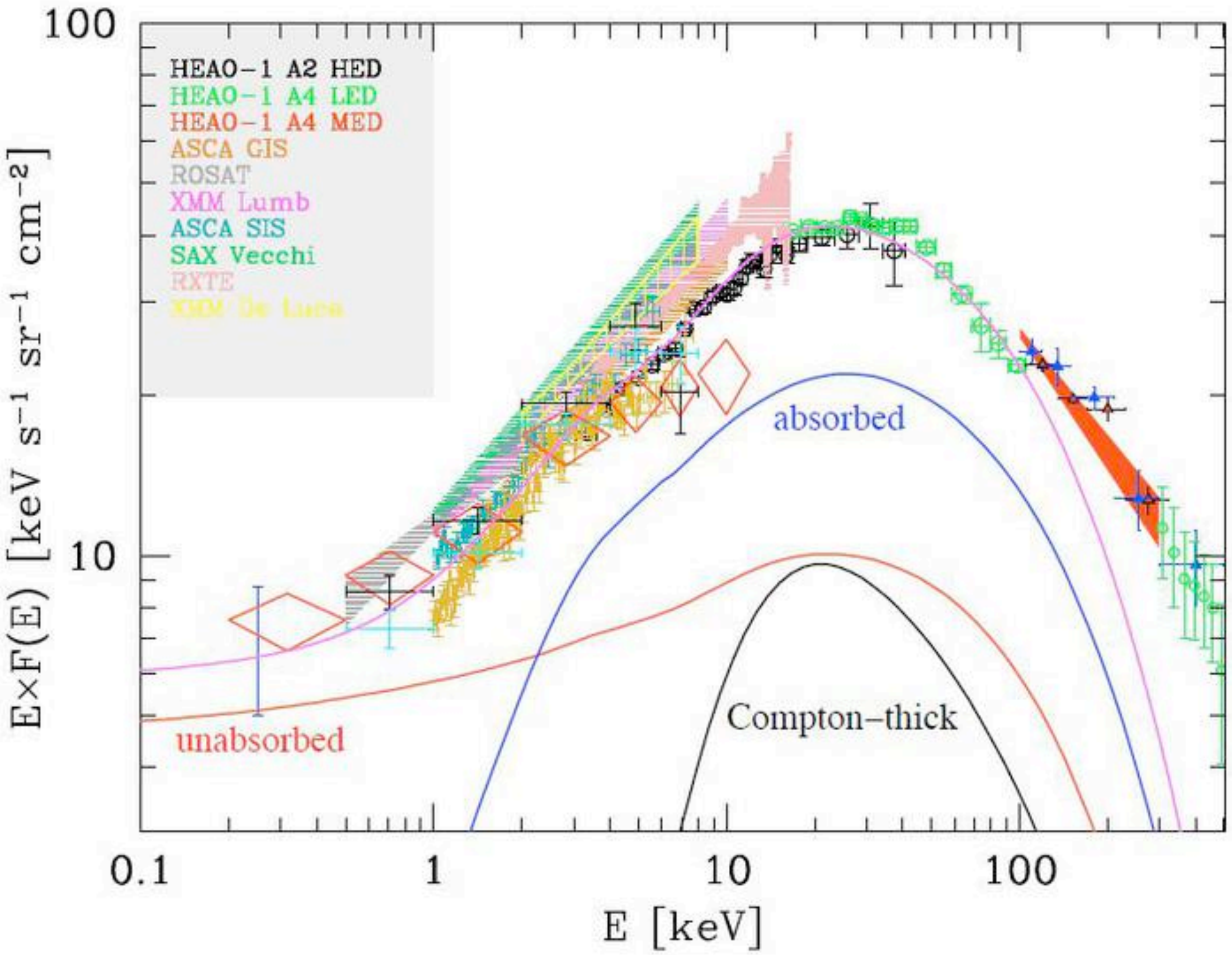
Problems: - 50% of stars outside galaxies
- insensitive to the mask size

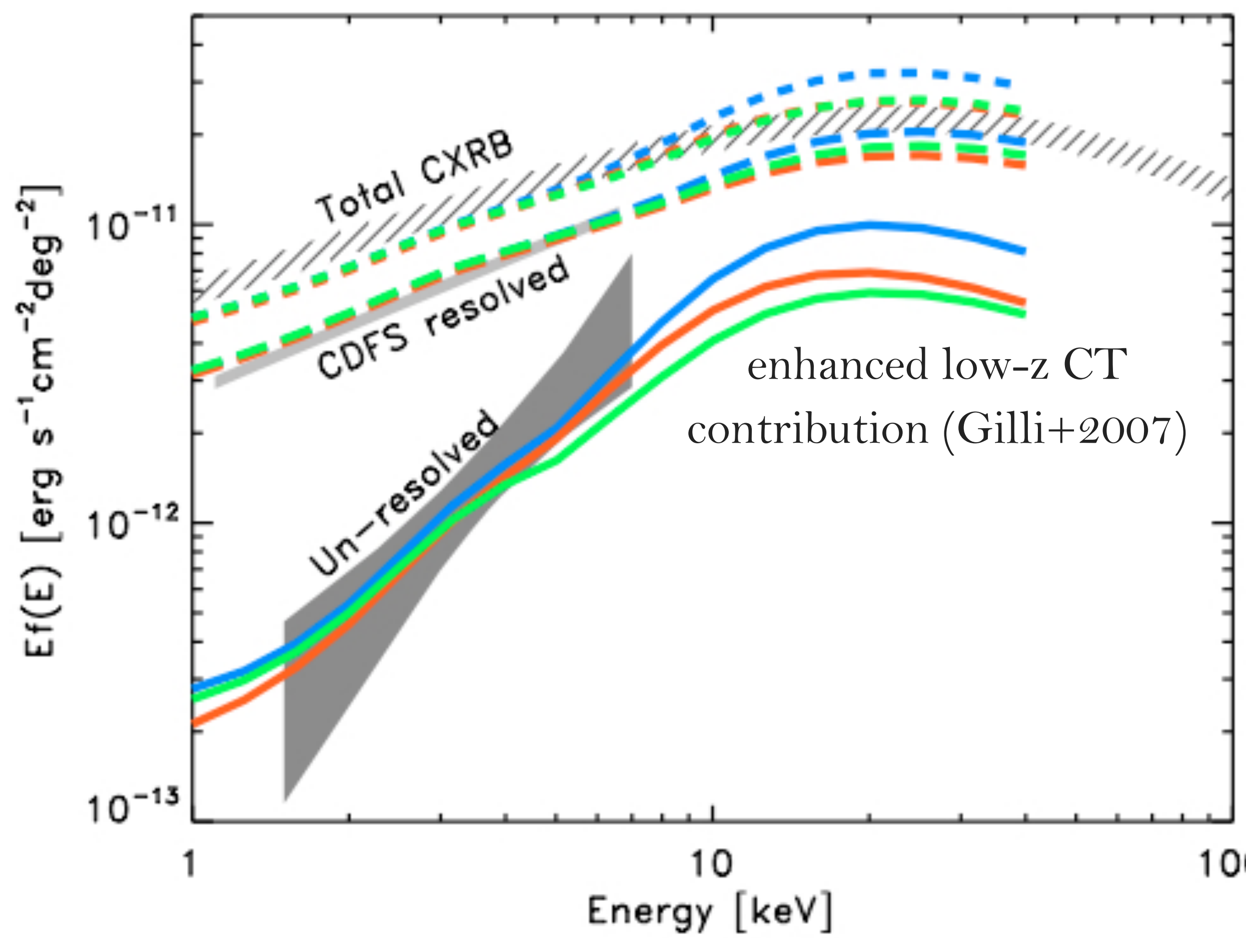


Cooray+2012

the cosmic X-ray background

the X-ray background

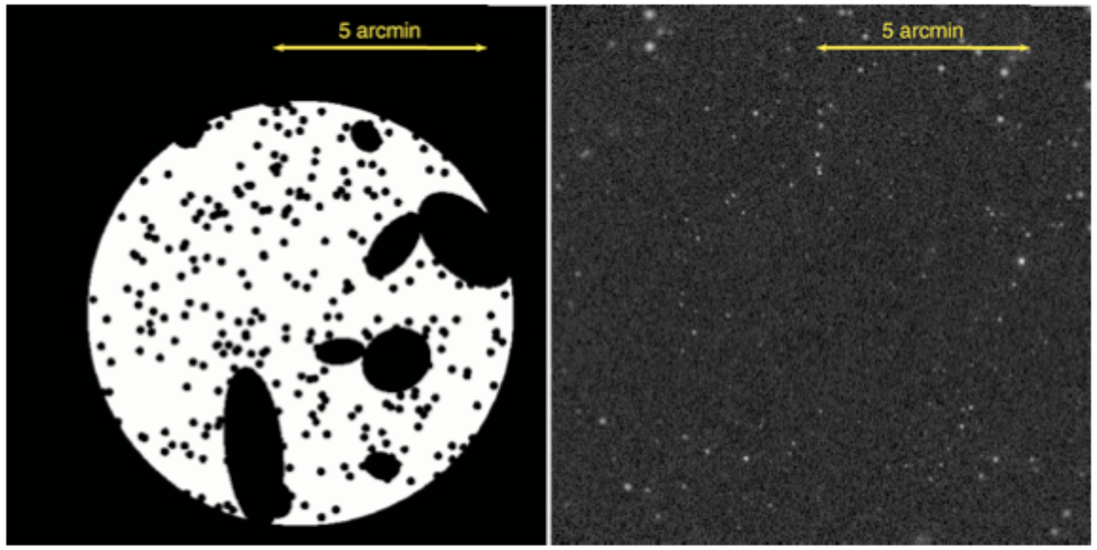




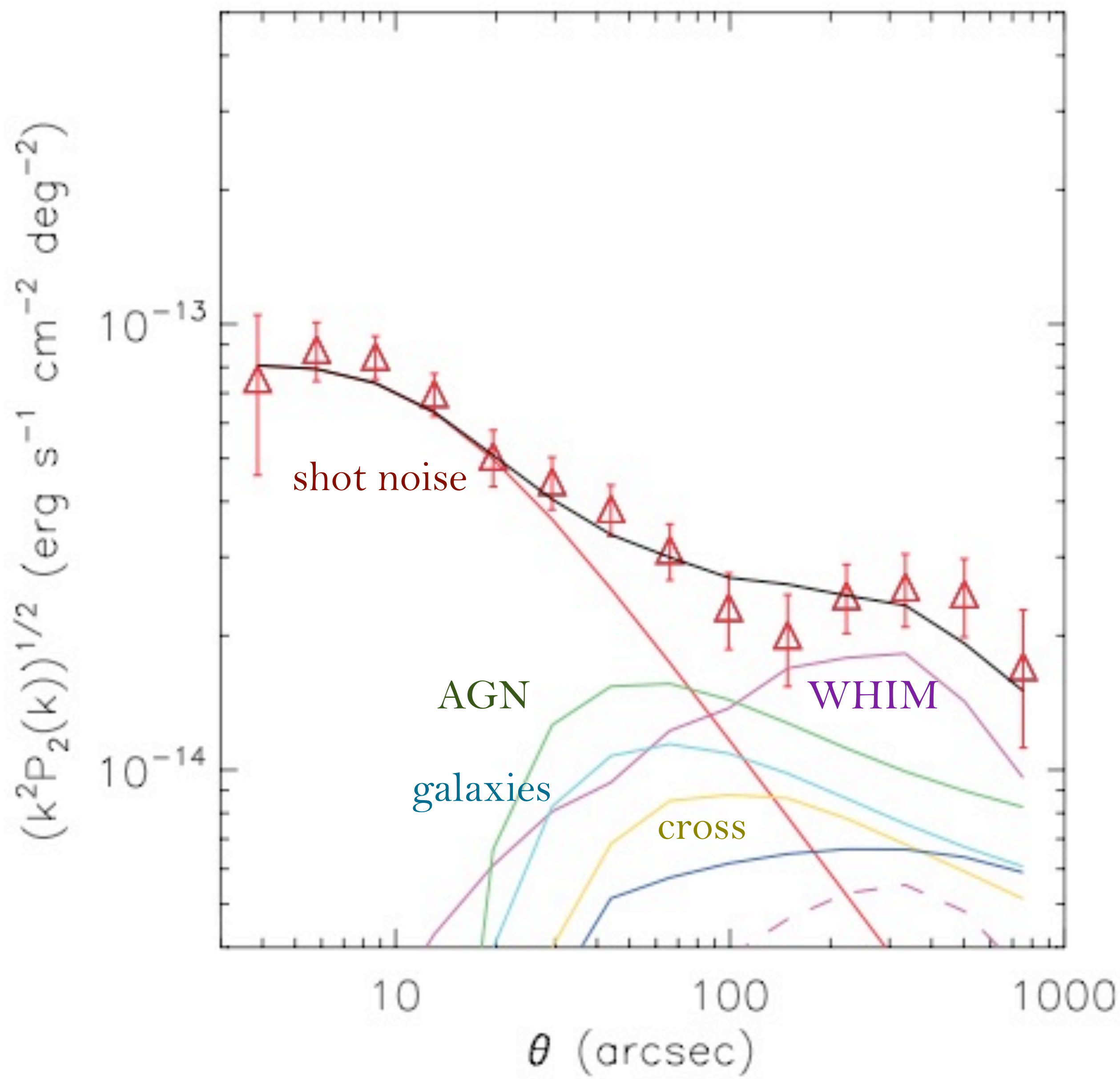
unresolved CXB @ 1.5 keV: 0.47 (0.21) x 10^{-12} erg s^{-1} cm^{-2} deg^{-2}

Moretti+2013

unresolved CXB fluctuations



4Msec CDFS map after removing sources with fluxes >2x10^{-16} erg cm^{-2} s^{-1} in the 0.5-2 keV band

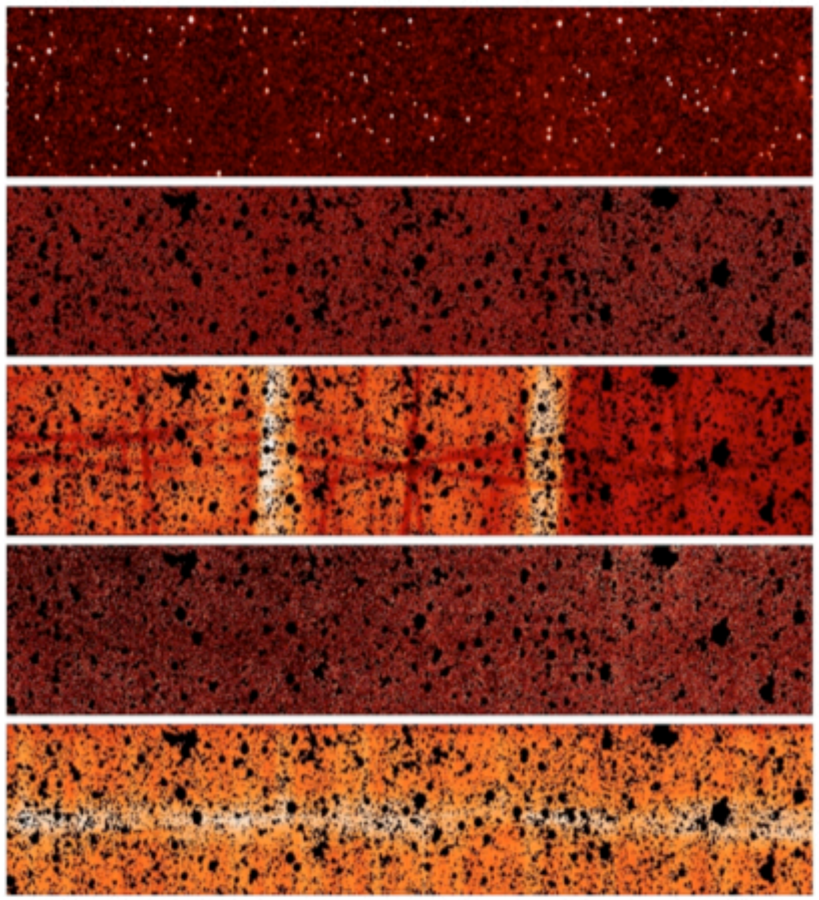


fluctuations are well described by a combination of shot-noise + undetected AGN/galaxy/WHIM clustering

Cappelluti+2012

NIRB-CXB cross-correlation

Chandra EGS/AEGIS field (45'× 8')



X-ray 0.5–2 keV count-rate map

X-ray 0.5–2 keV fluctuation map

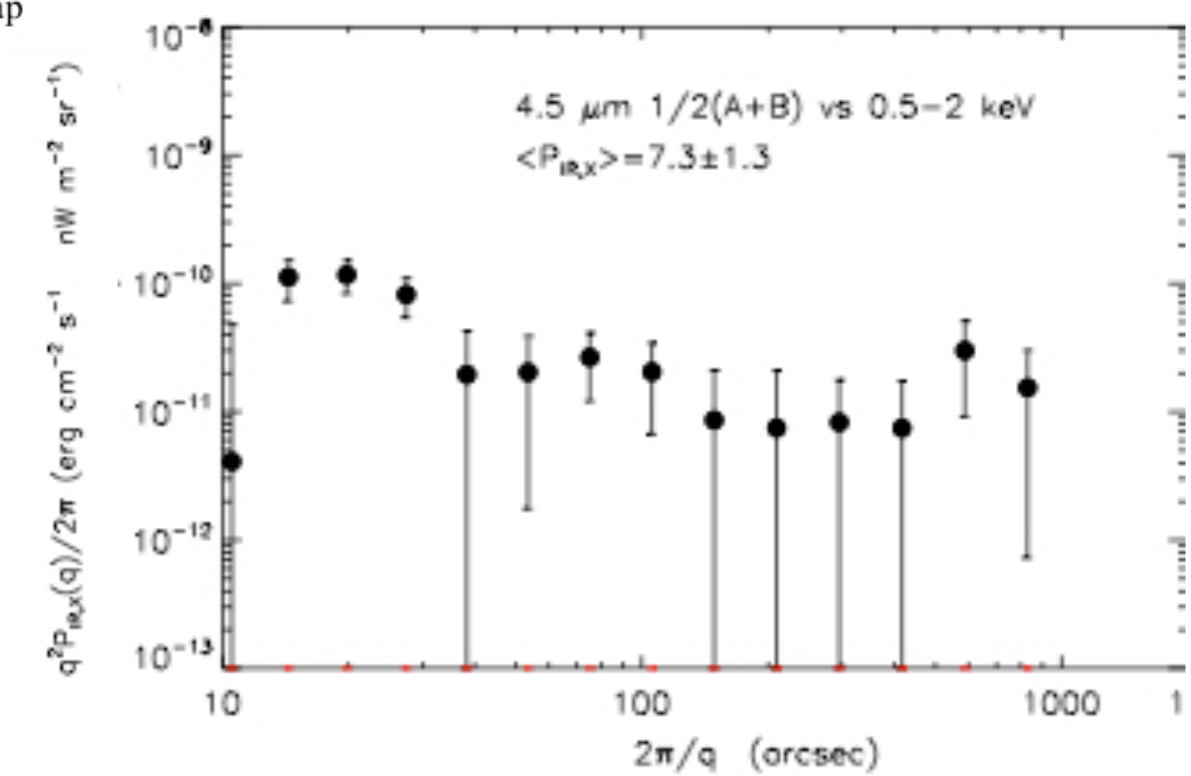
X-ray 0.5–2 keV exposure map

IRAC 4.5 μm fluctuation map

IRAC 4.5 μm exposure map

Cappelluti+2013 cross-correlate the masked Chandra and Spitzer maps of the Extended Groth Strip field

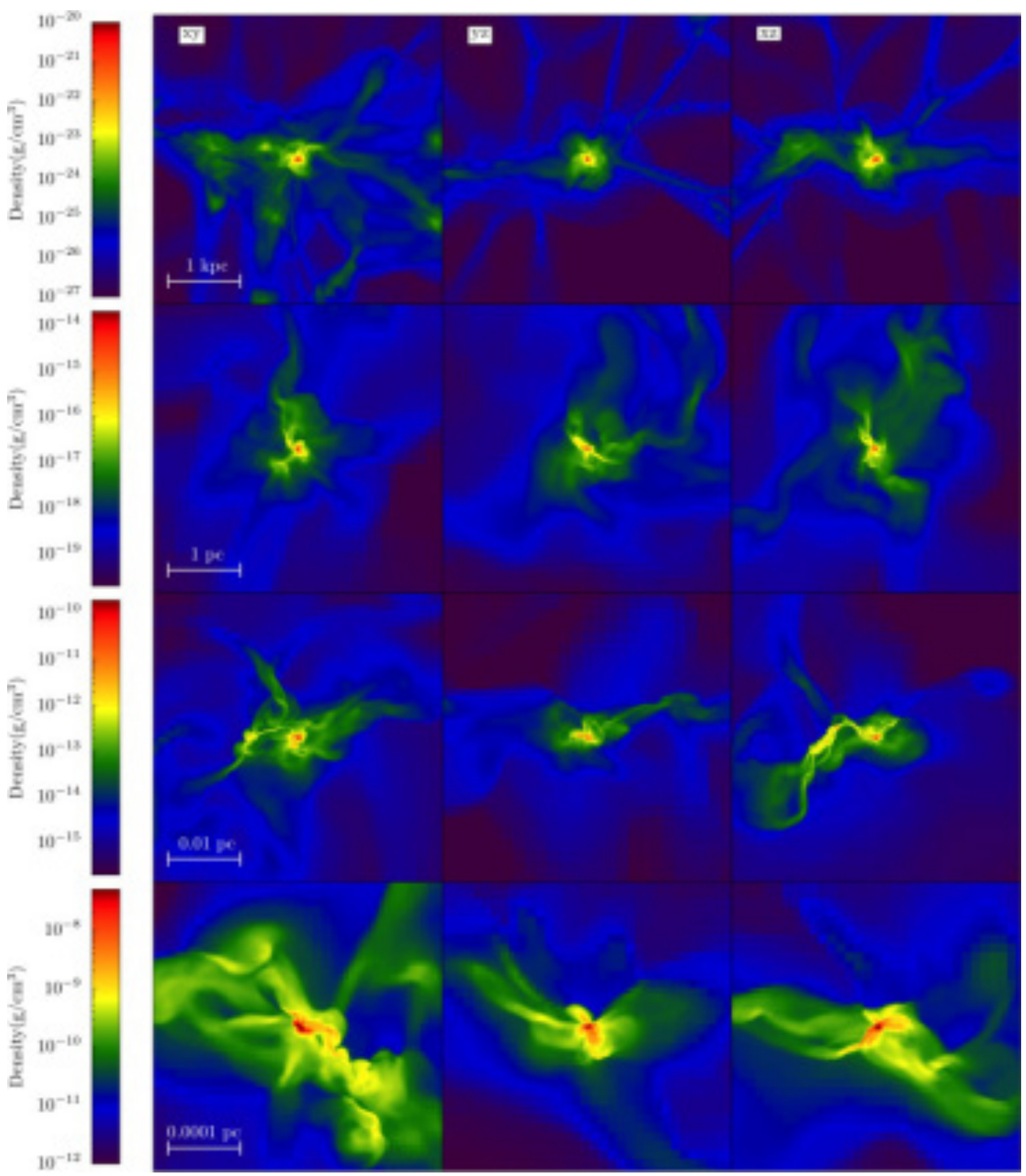
~5σ cross-correlation between 0.5-2 keV and 4.5 μm fluctuations that can not be explained by IHL



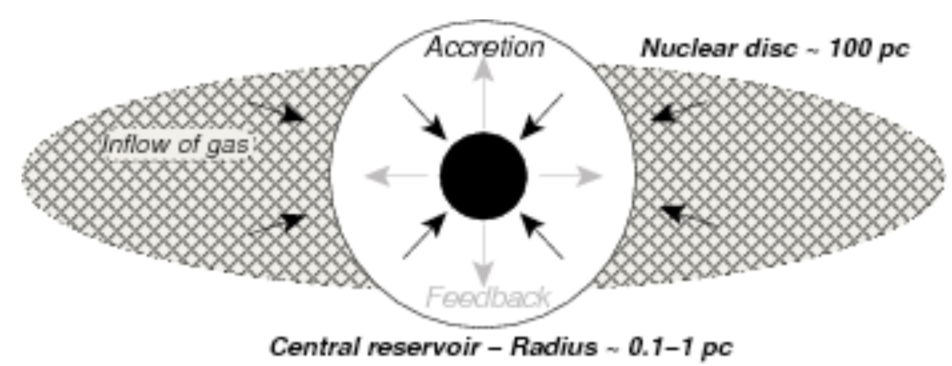
Cappelluti+2013

direct collapse black holes

SMBHs already in place at z~7 (Mortlock+2013) suggest massive seeds

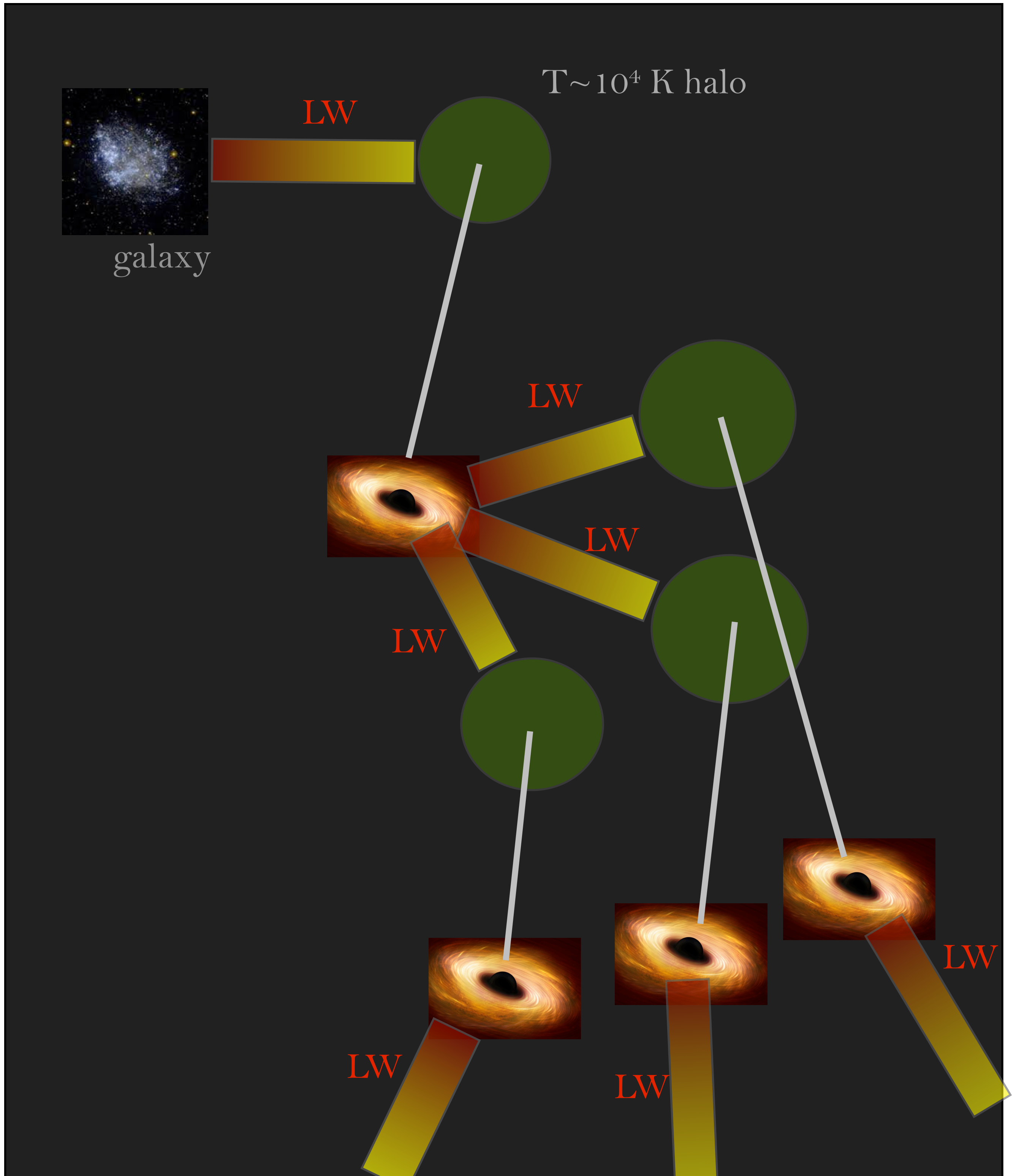


massive BH (M~10^5 Msun) can form directly in H-cooling DM halos (T_{vir}~10^4 K) if star formation is quenched by Lyman-Werner photons from nearby galaxies



Bromm & Loeb 2003, Begelman+2006, Natarjan+2007, Choi+2015, Shlosman+2016, etc.

a runaway process

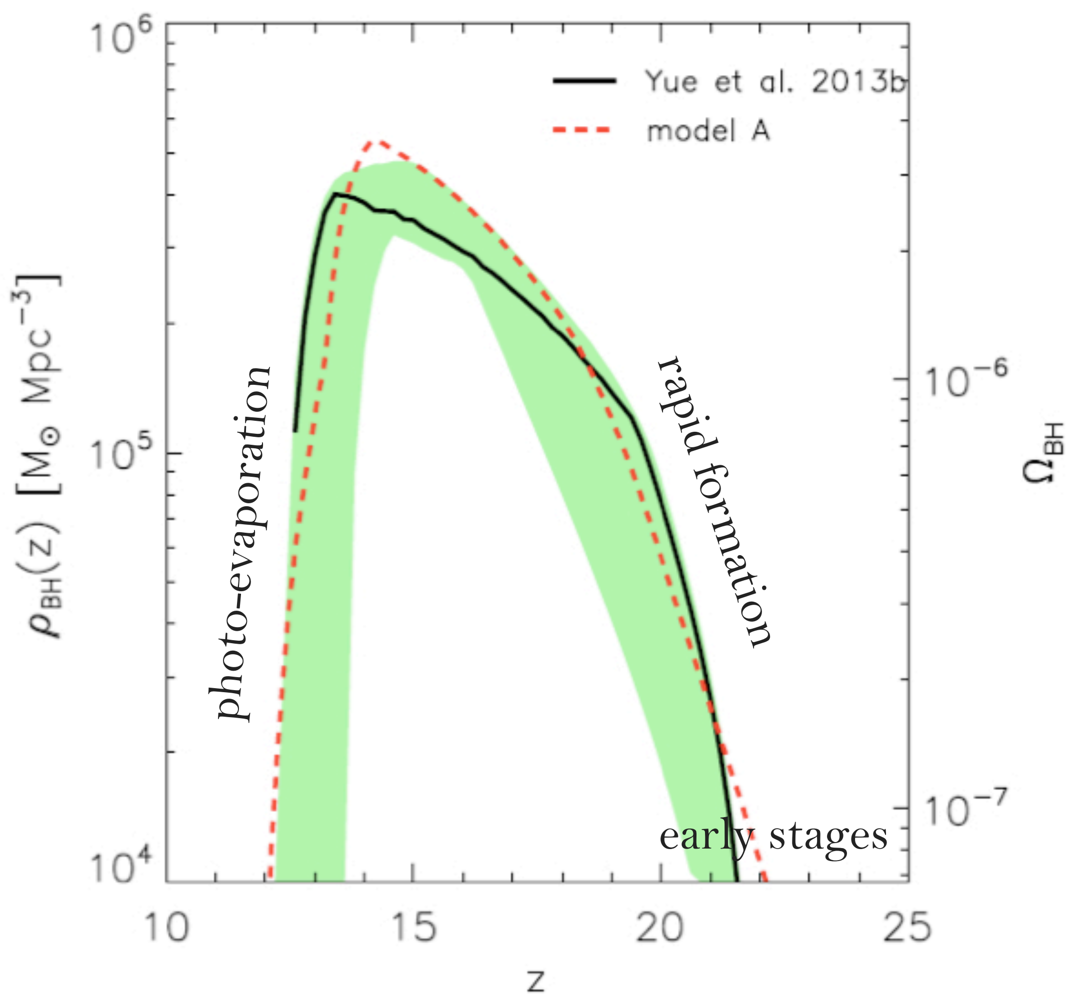


at early stages rare but highly clustered galaxy promote the formation of the earliest DCBHs

once formed, DCBHs emit more LW photons than galaxies

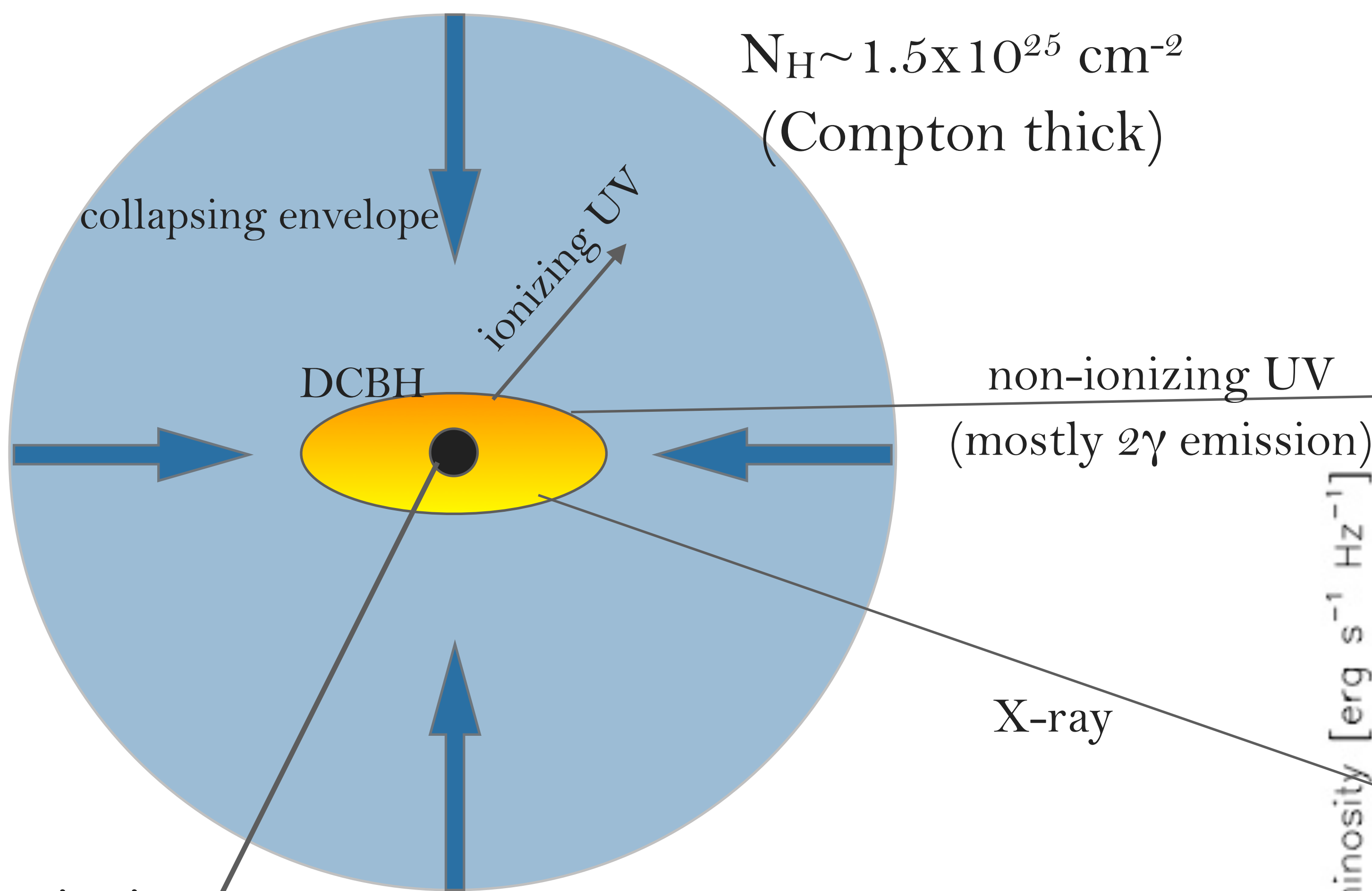
more DCBHs are formed with a rise of the DCBH abundance

the formation is quenched by the settle-in of the ionizing background (photoevaporation)

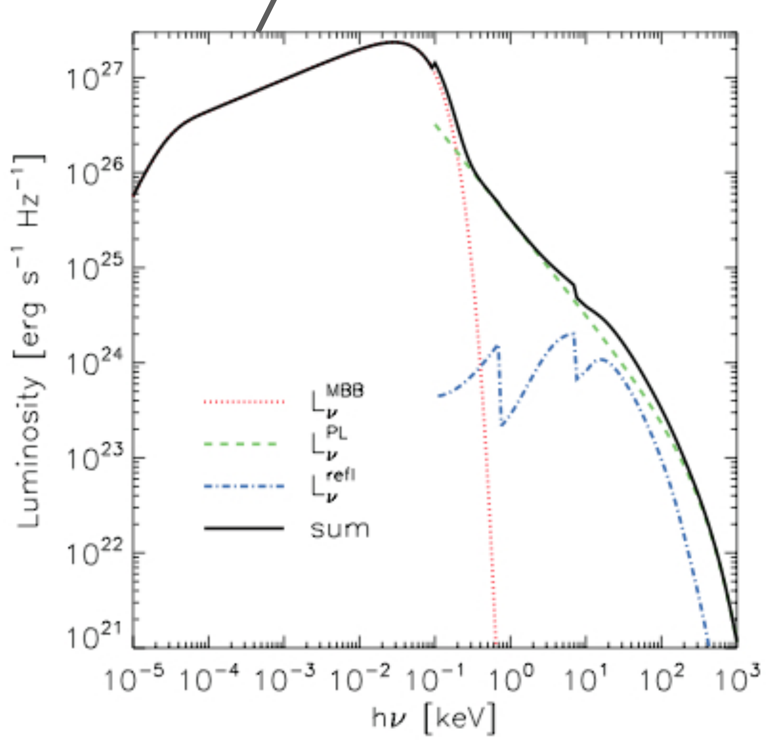


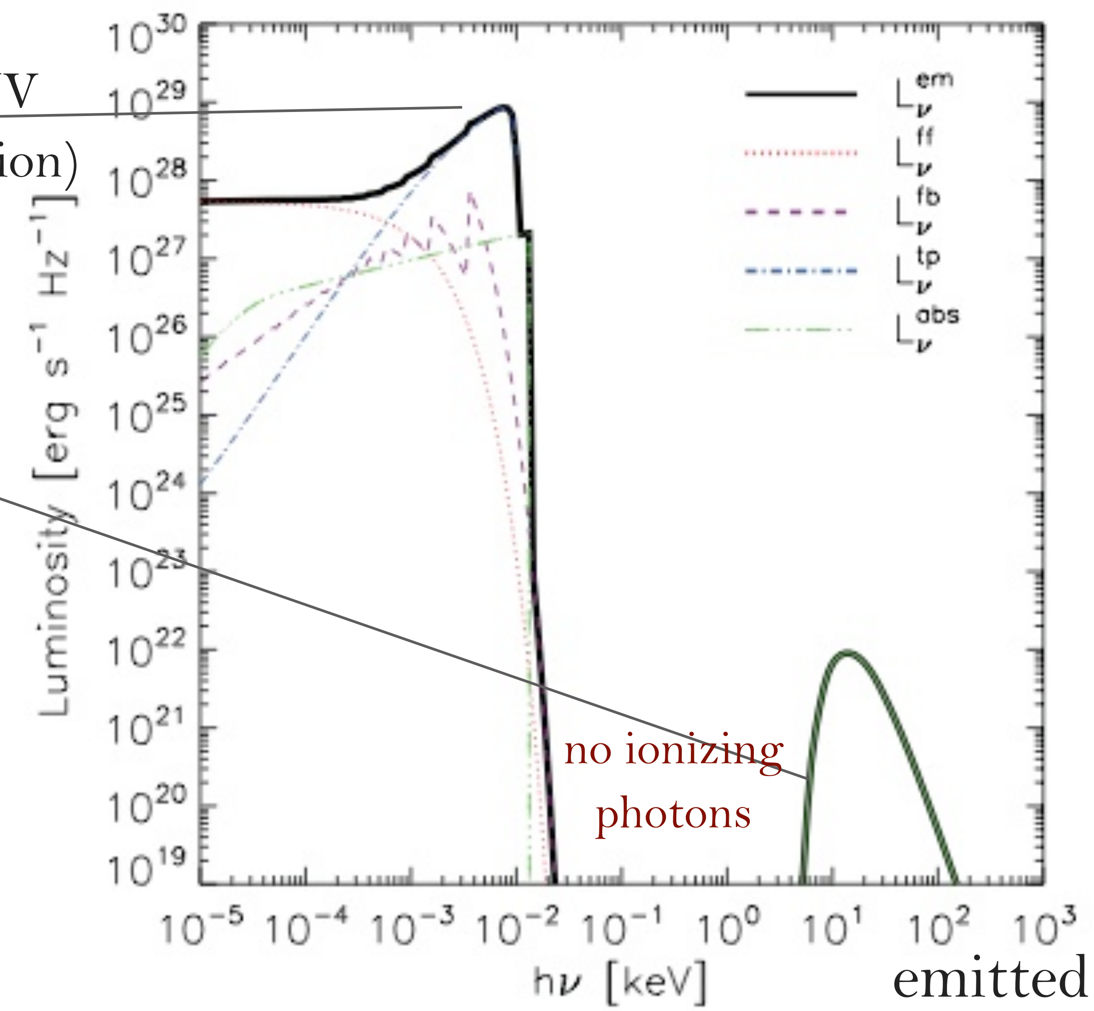
Yue+2014

DCBH spectrum



intrinsic



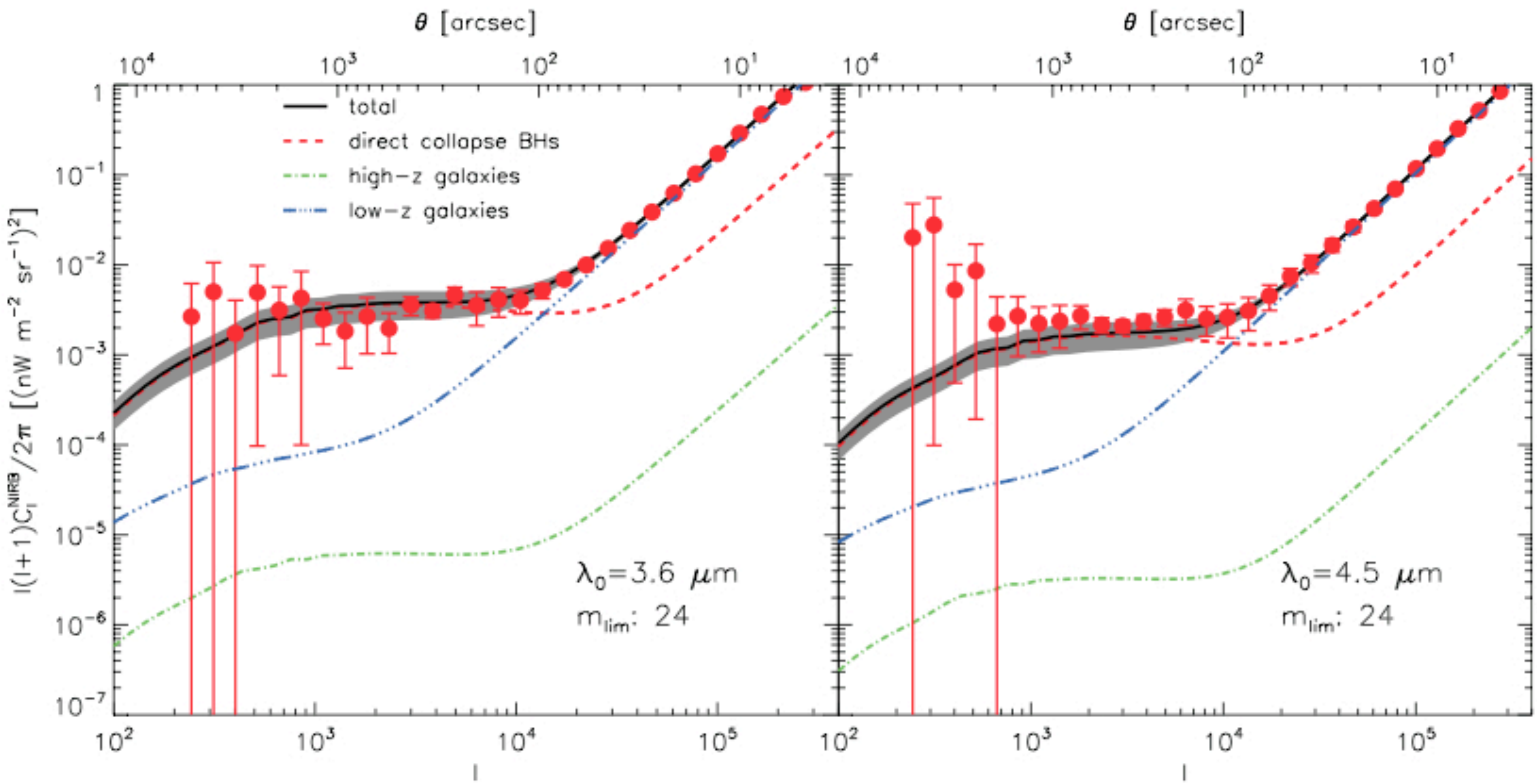


emitted

for DCBHs at z~13, the two peaks correspond to NIR and soft X-rays in the observer rest-frame

Yue+2013

the NIRB fluctuations



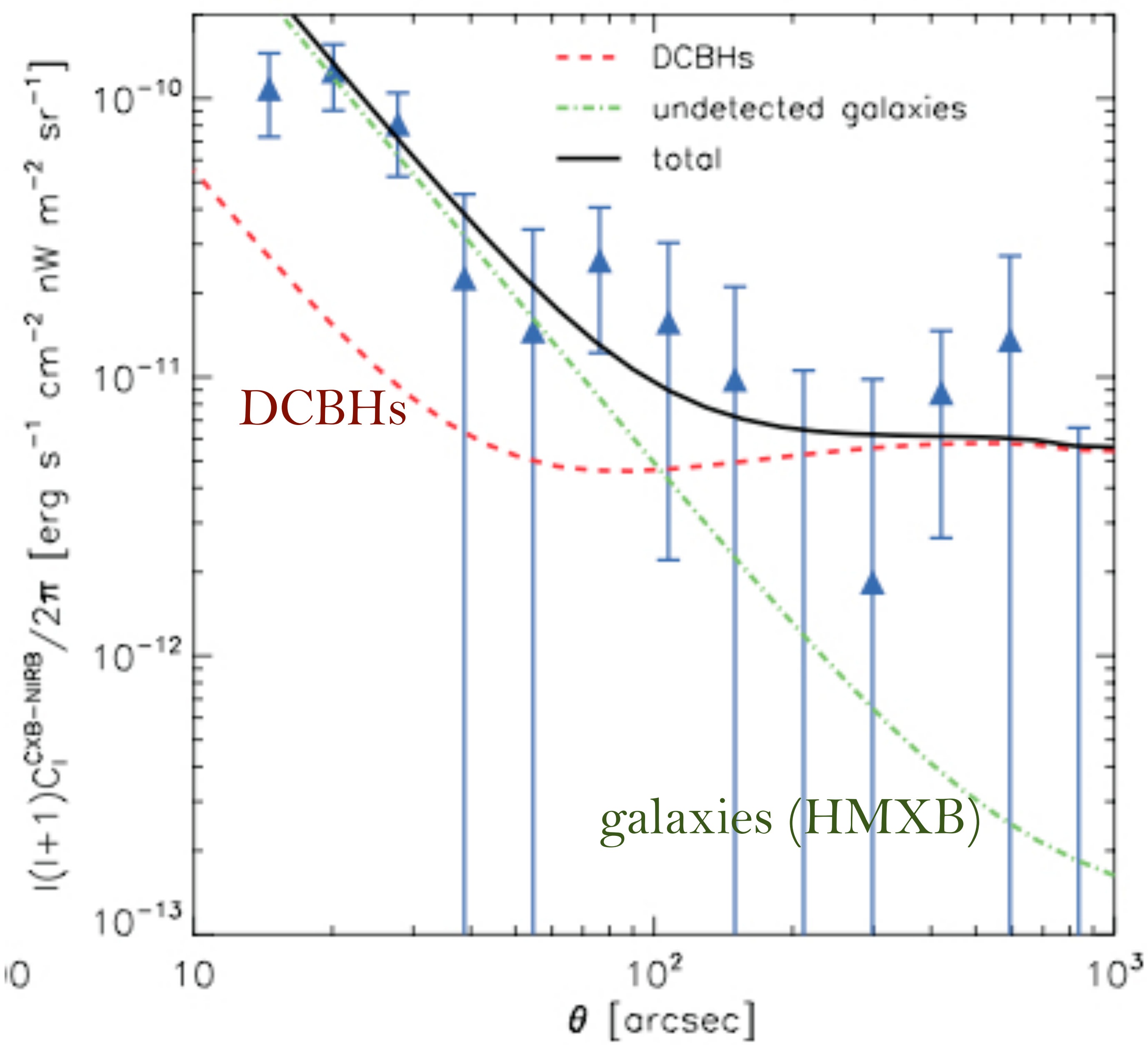
NIRB clustering excess can be well fitted by DCBHs

for $M_{BH} \sim 3\text{-}8 \times 10^5$ Msun, $t_{acc} \sim 30\text{-}70$ Myr, $N_H \sim 1.2 \times 10^{25}$ cm^{-2}, $z_{end} \sim 12.5$

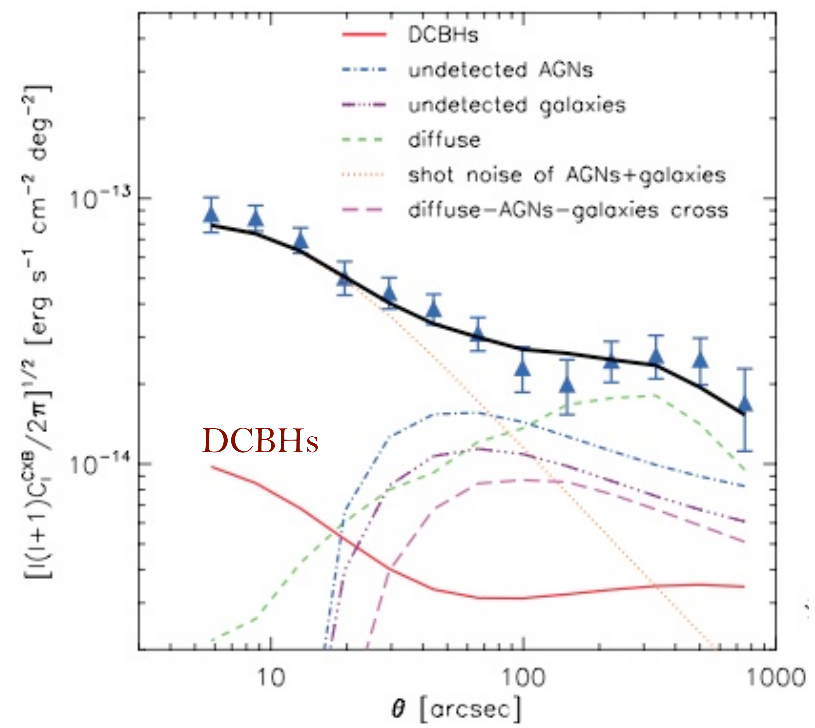
...and they naturally produce X-rays

Yue+2013

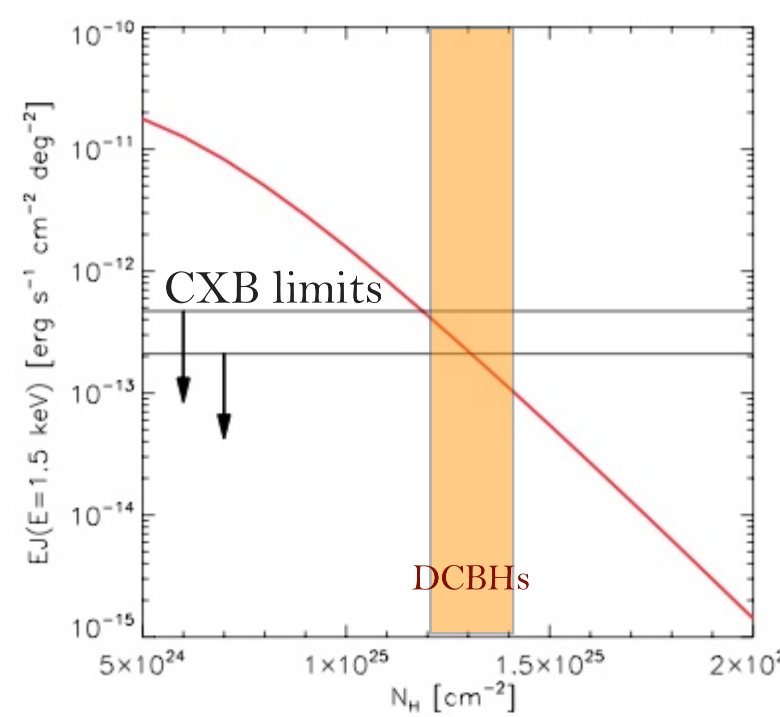
NIRB-CXB cross-correlation



individually very faint (m>25 at 3.5 μm, m>30 at 2.2 μm)

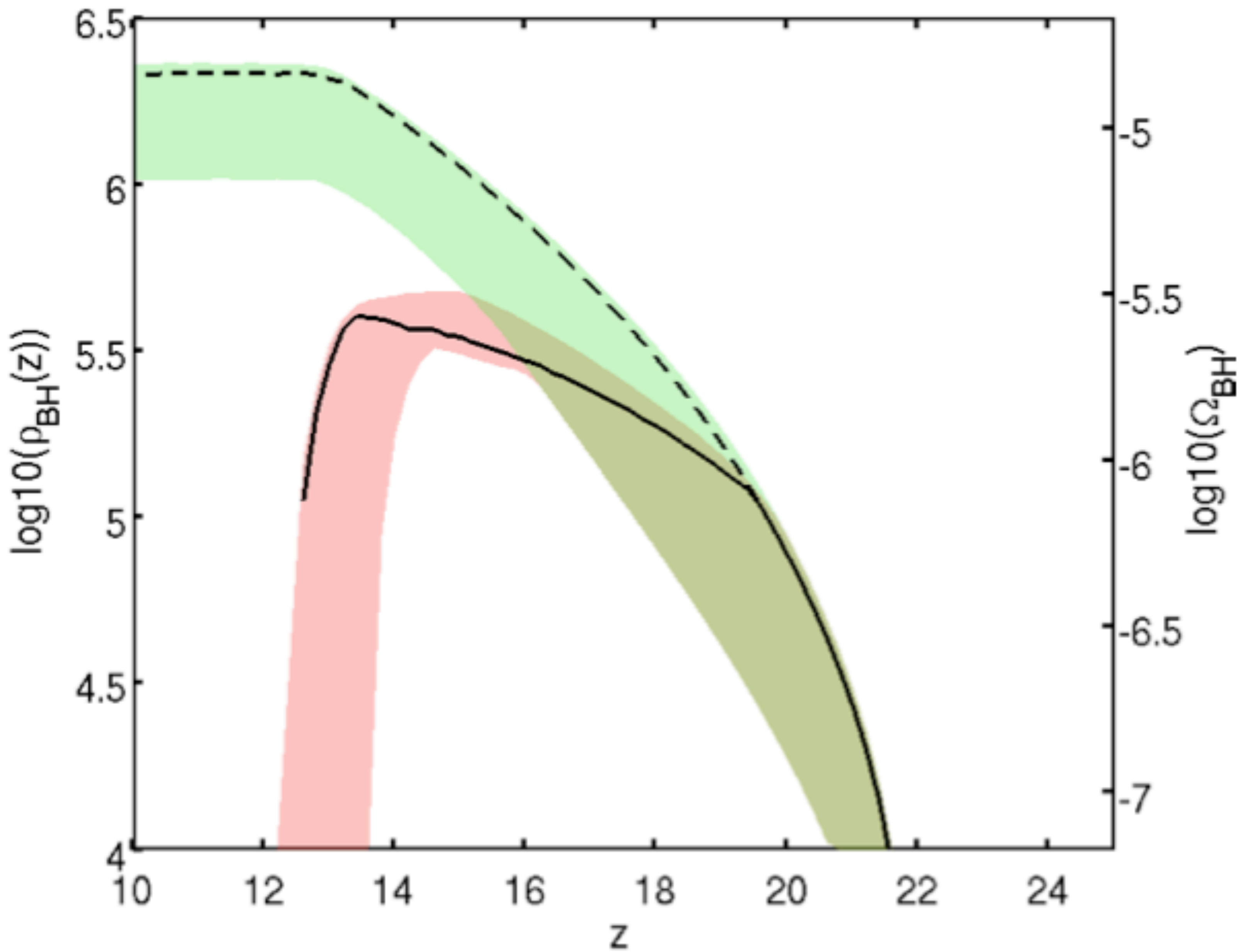


consistency checks



Yue+2013

very demanding

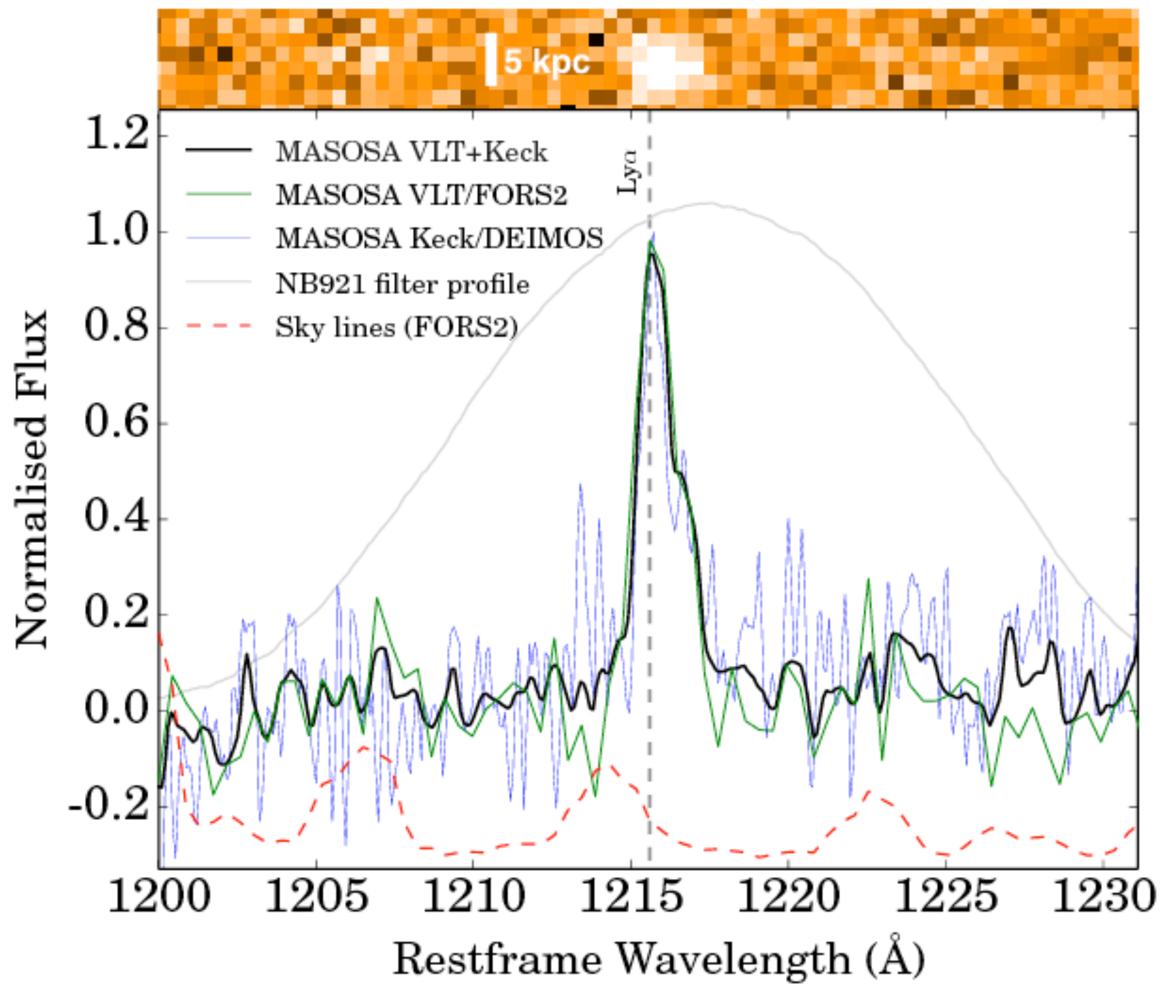


DCBH mass density ~ cumulative SMBH mass density

Yue+2013

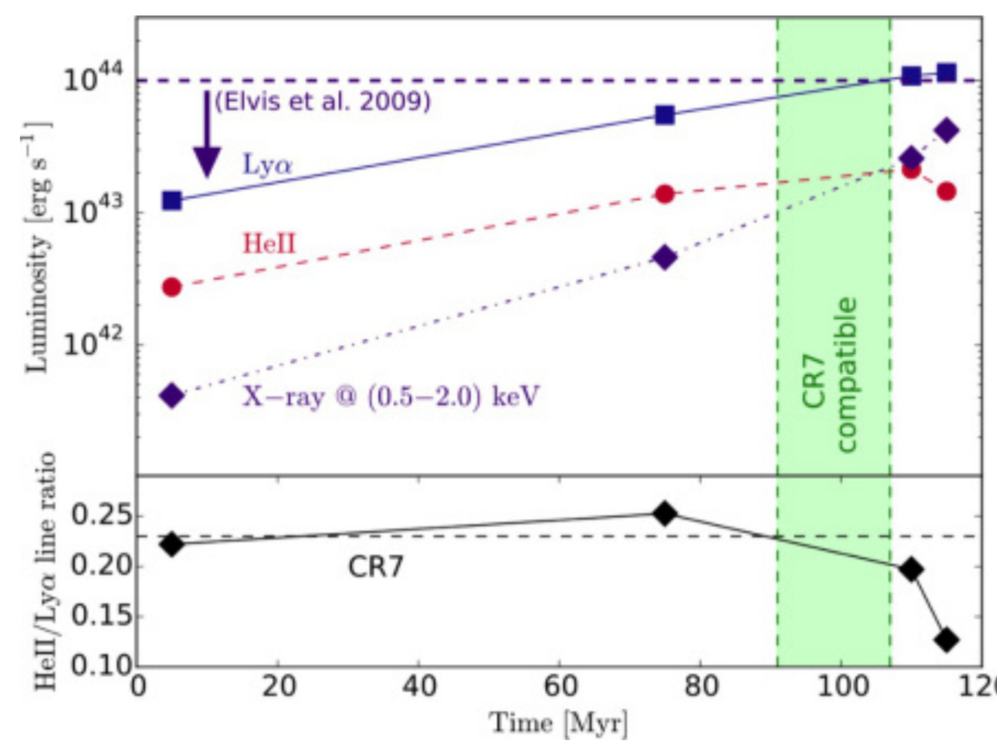
where are they?

most of them evolve passively, but some can be embedded in other galaxies...



CR7 at z=6.6 (Sobral+2015)

strong Lya and HeII lines
no metal lines
strong LW flux



consistent with the expected signature of a 10^5 Msun BH

...providing the seeds of SMBHs

Pallottini+2015, others

conclusions

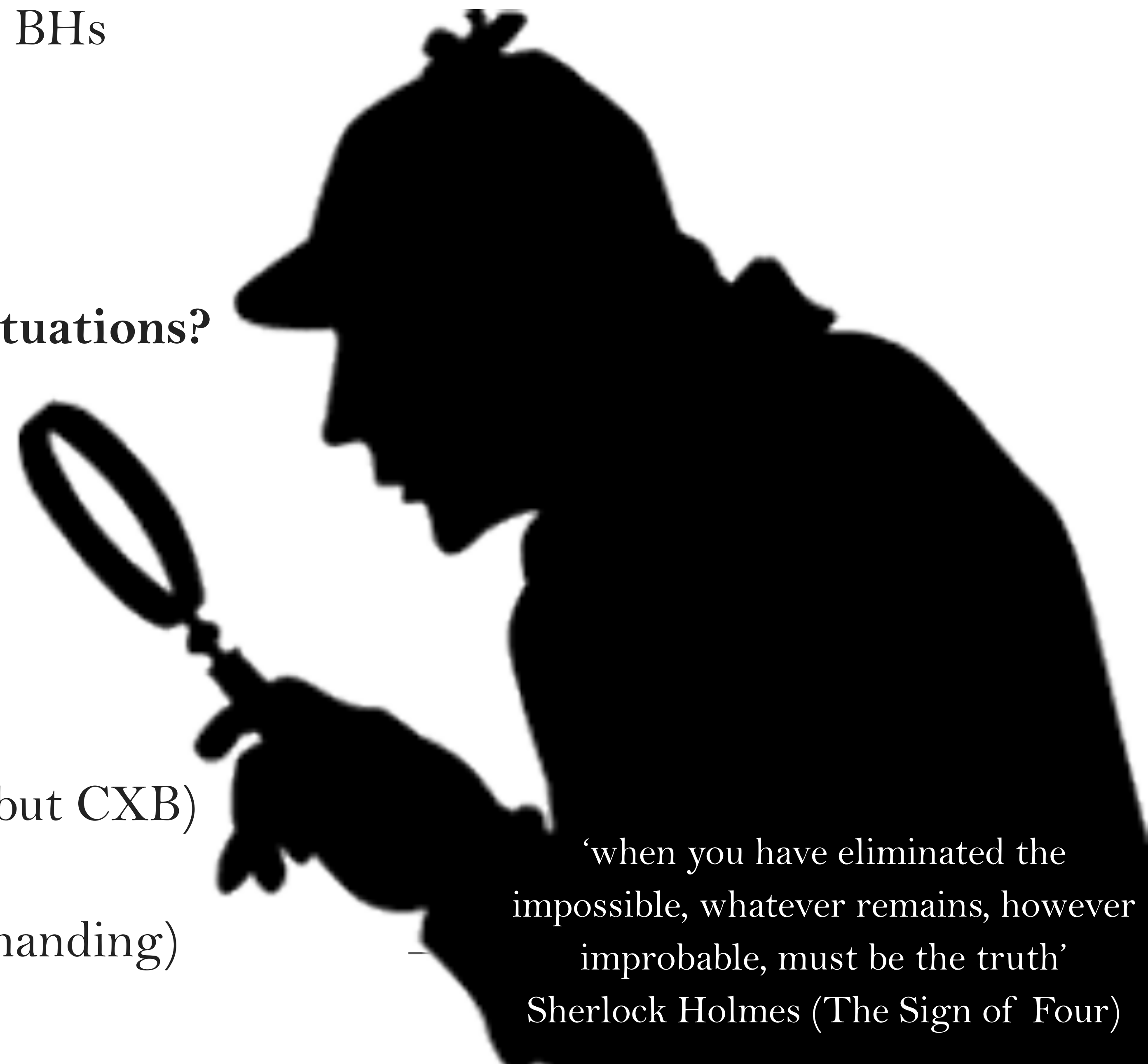
The study of the near infrared background is a very exciting and rich field of research

Interesting insight come in recent years from many different experiments at different wavelengths (optical/NIR, X-ray, gamma)

It offers a way to study first galaxies and first BHs

what is the origin of the observed NIRB fluctuations?

- Zodiacal light -- NO
- instrumental effects -- NO
- foreground stars -- NO
- known low-z galaxies -- NO
- high-z galaxies -- NO
- diffuse galactic light -- MAYBE (Zemcov+15, but CXB)
- intrahalo light -- MAYBE (but CXB)
- first direct collapse BH -- YES?? (but very demanding)



'when you have eliminated the impossible, whatever remains, however improbable, must be the truth'
Sherlock Holmes (The Sign of Four)