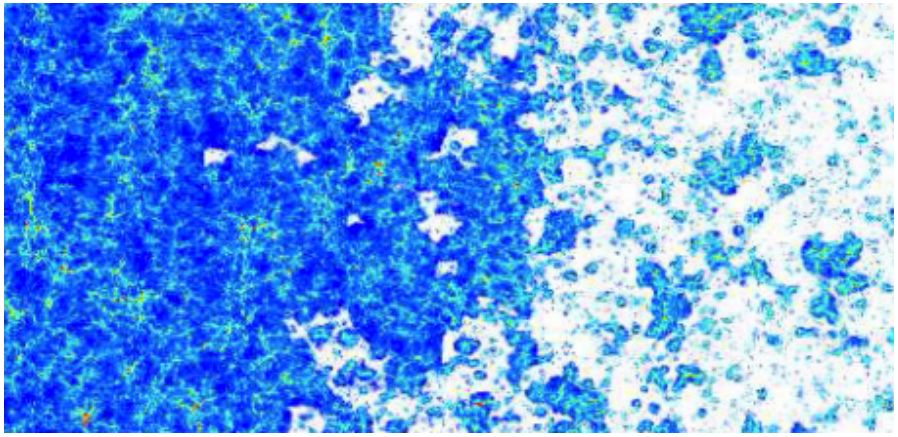
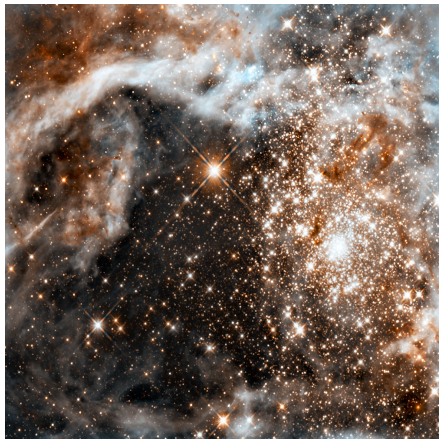
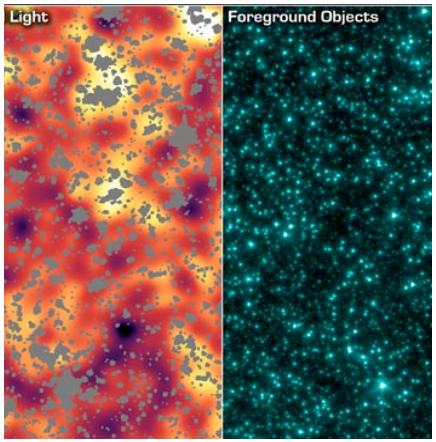




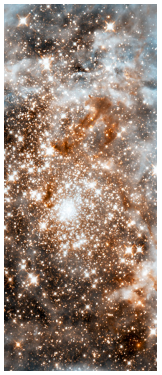


Cross-correlations: Leading to a Greater Understanding of the High Redshift Universe

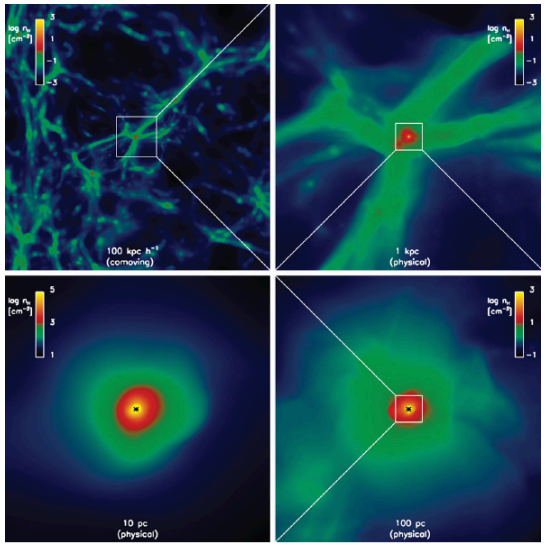
Elizabeth Fernandez

university of groningen / faculty of mathematics and natural sciences / astronomy

The First Generations of Stars

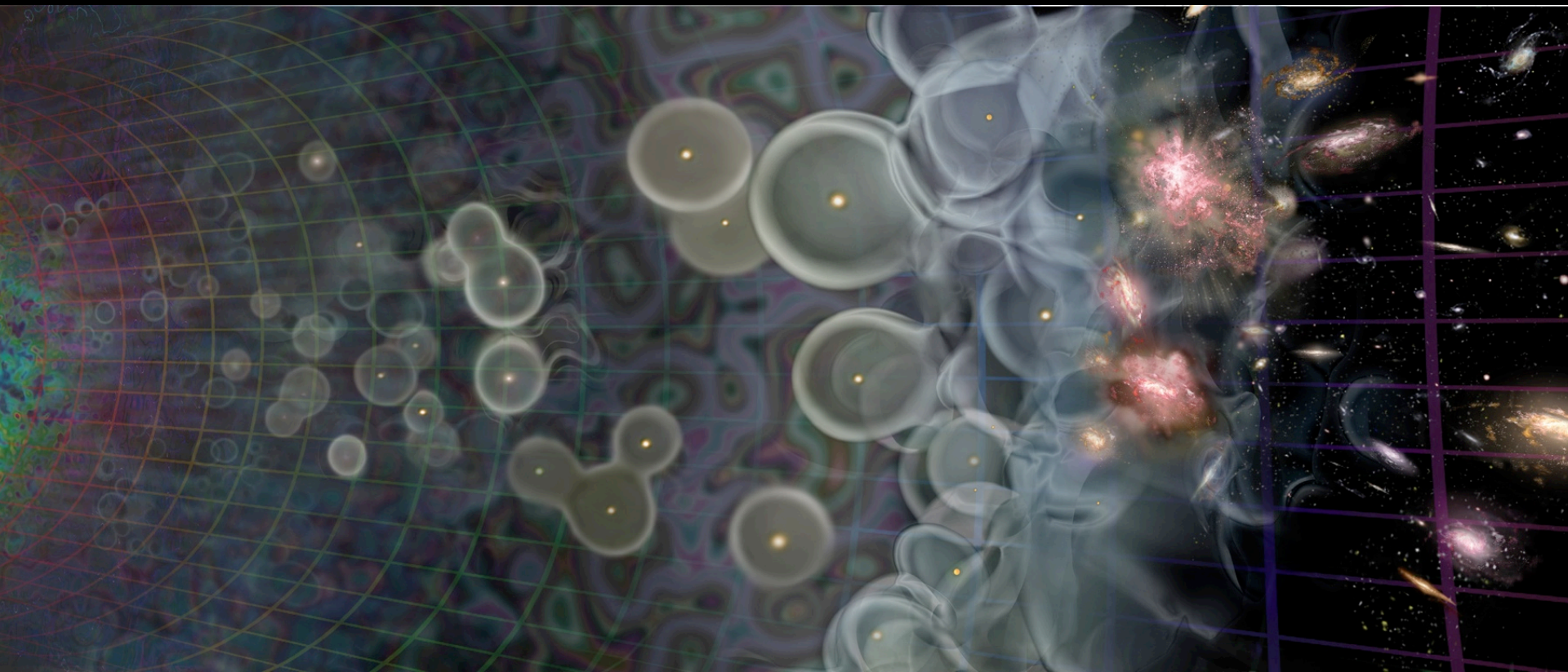


- First generations of stars could have been fundamentally different than stars we observe at lower redshifts
- No metallicity – Population III stars
- Were they massive (10s to 100s $M_{\odot}$)?
- When did Population II (metal-poor) stars begin to form?
- What were the masses of galaxies that were responsible for reionization?
- How quickly did reionization progress?

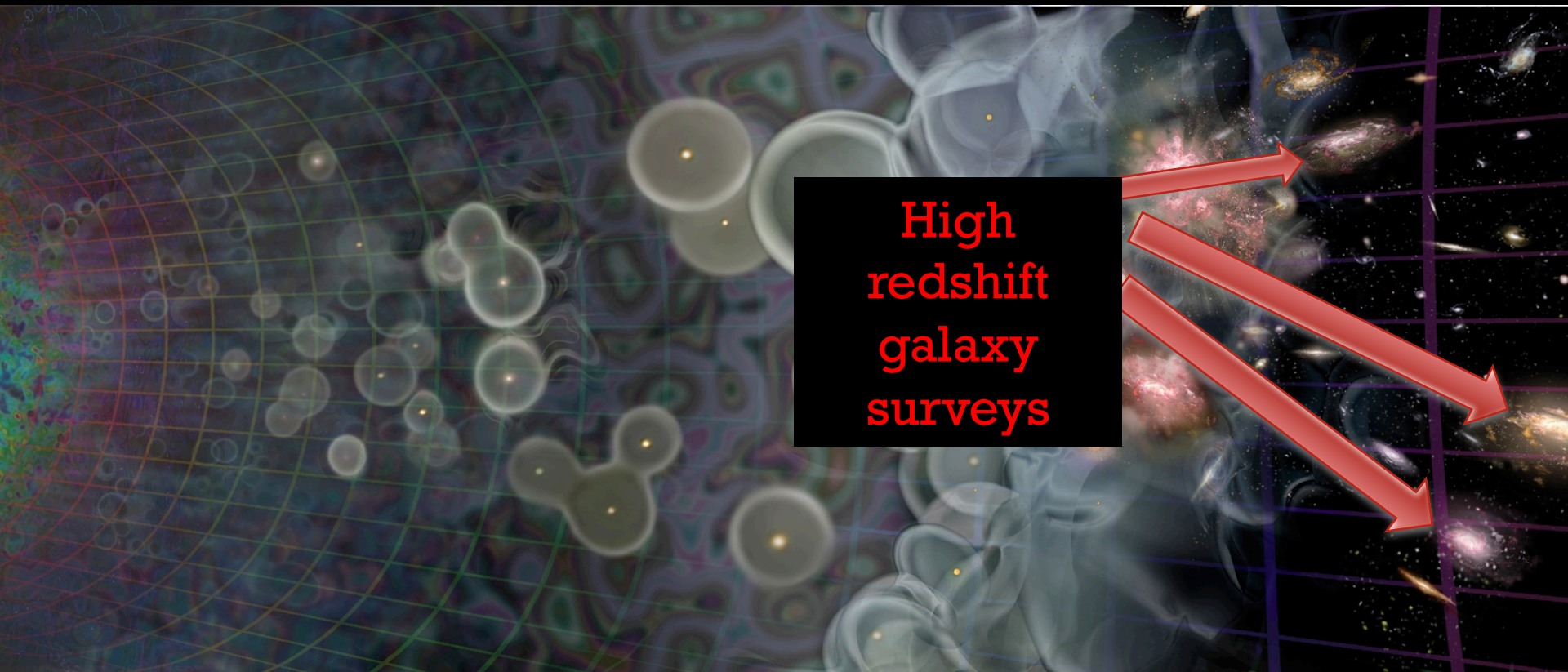


Stacy et al 2010

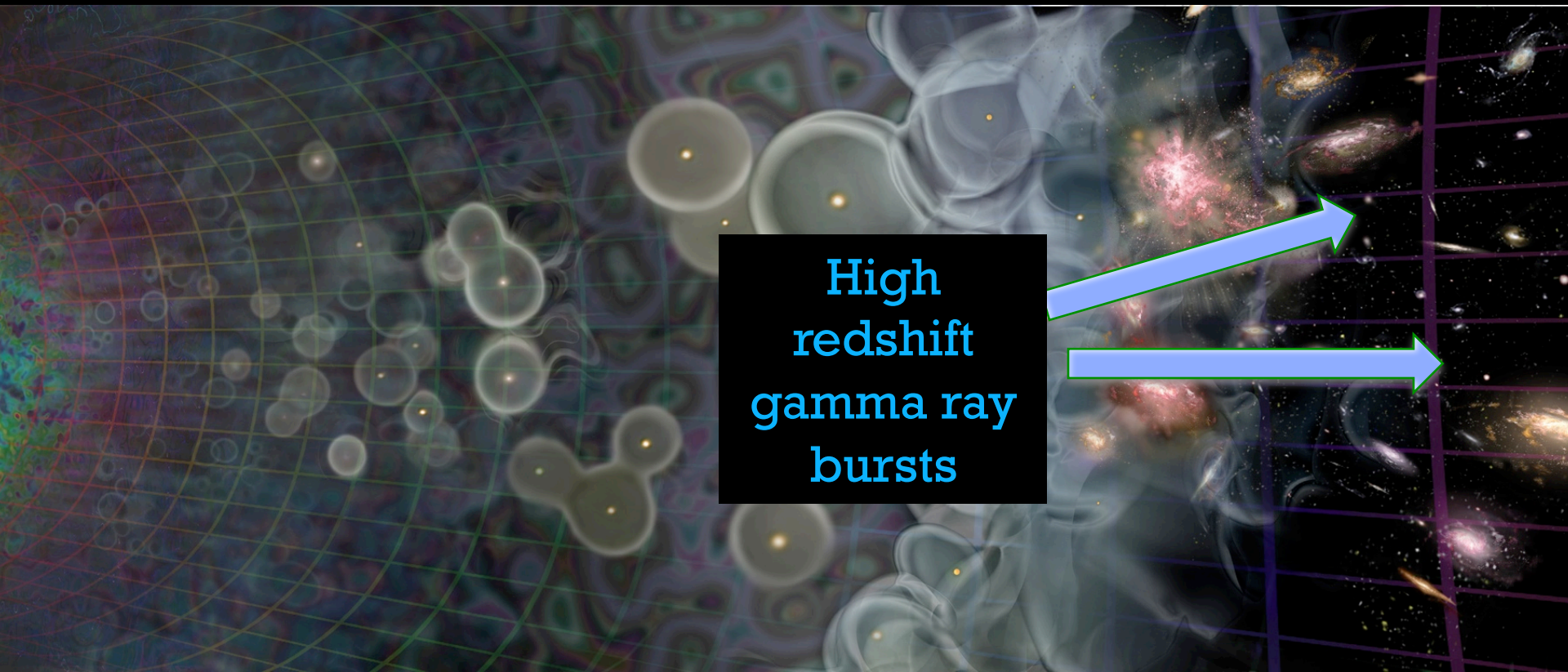
What can be Observed?



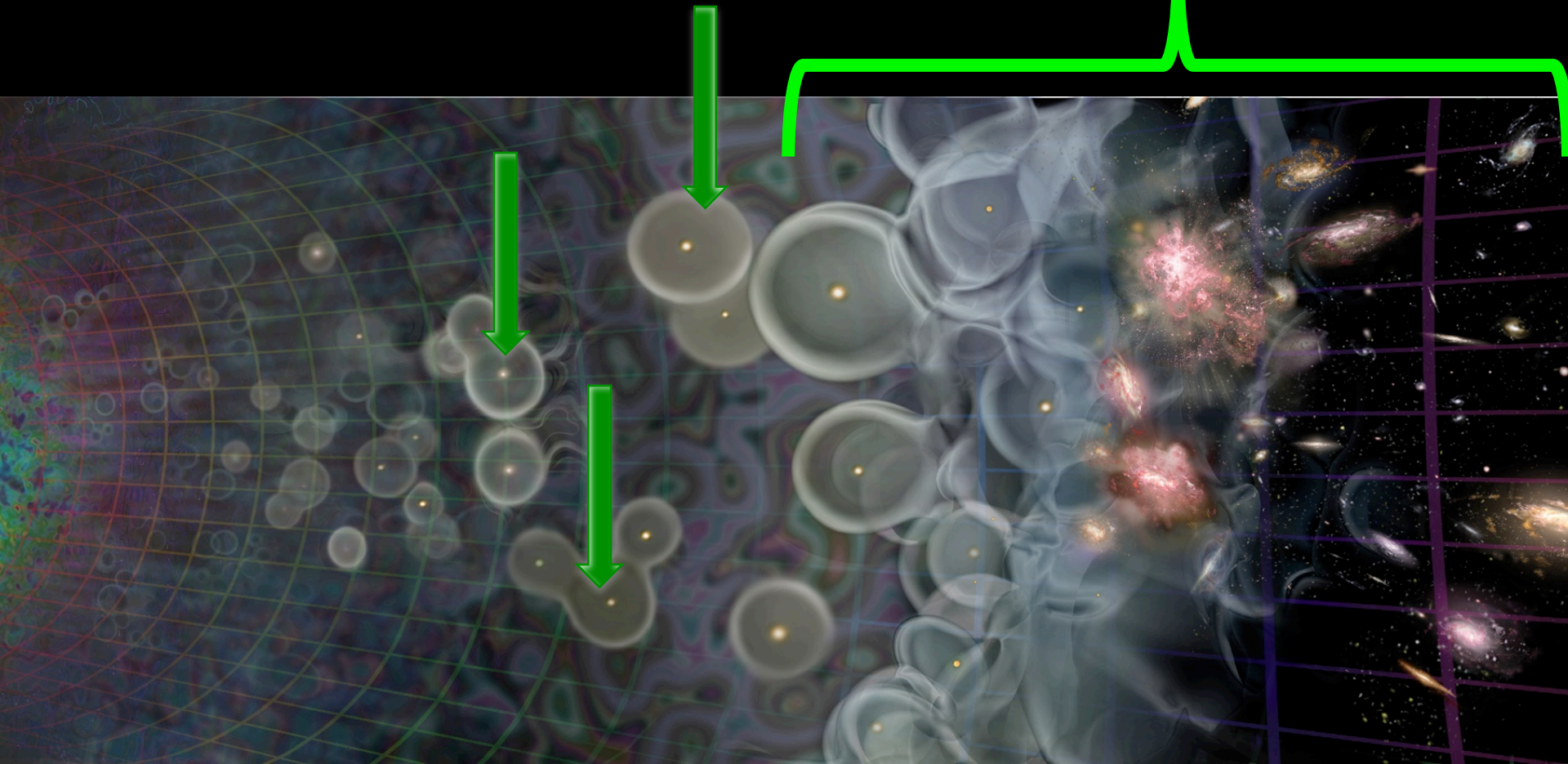
What can be Observed?



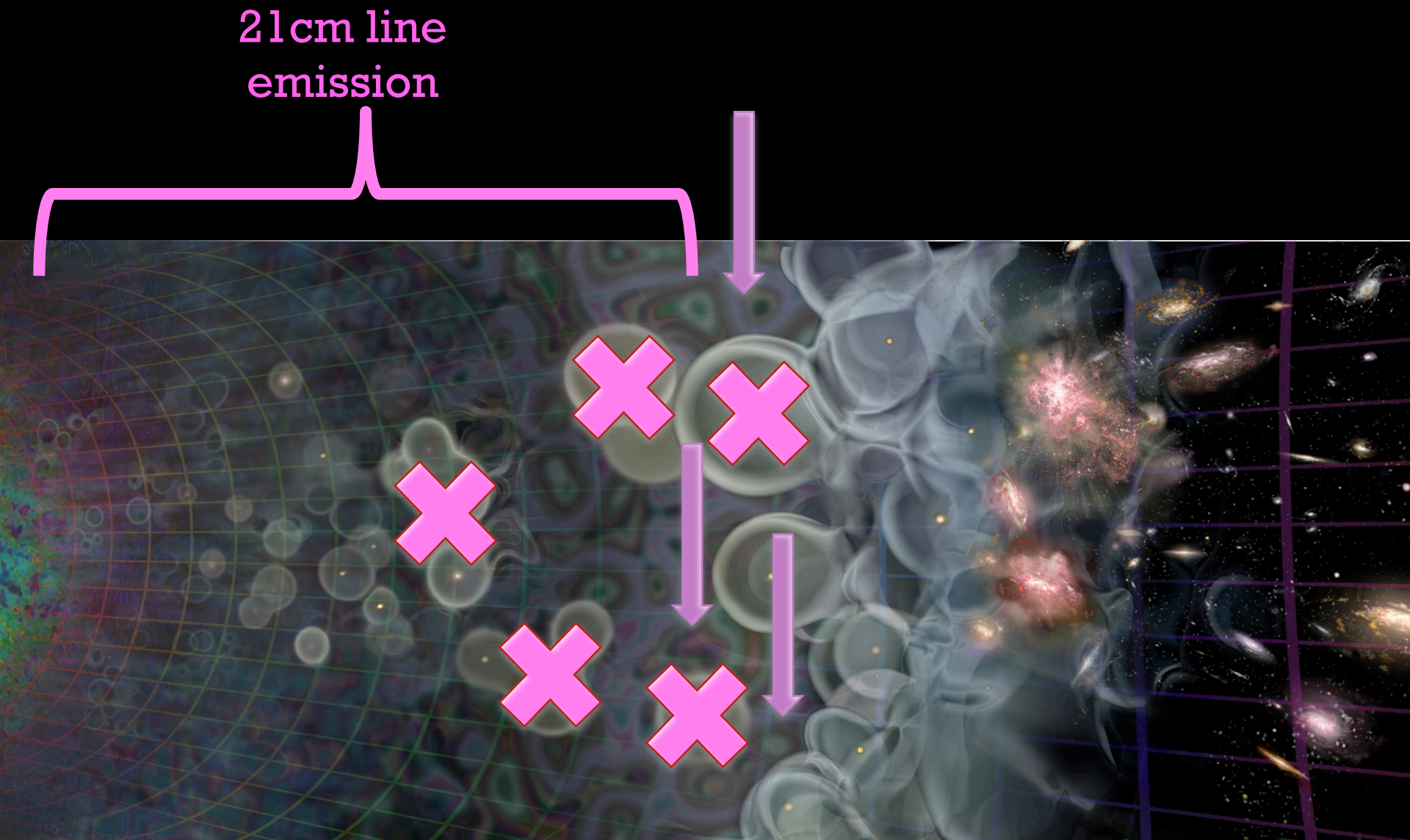
What can be Observed?



What can be Observed?



What can be Observed?



Emission from High Redshifts

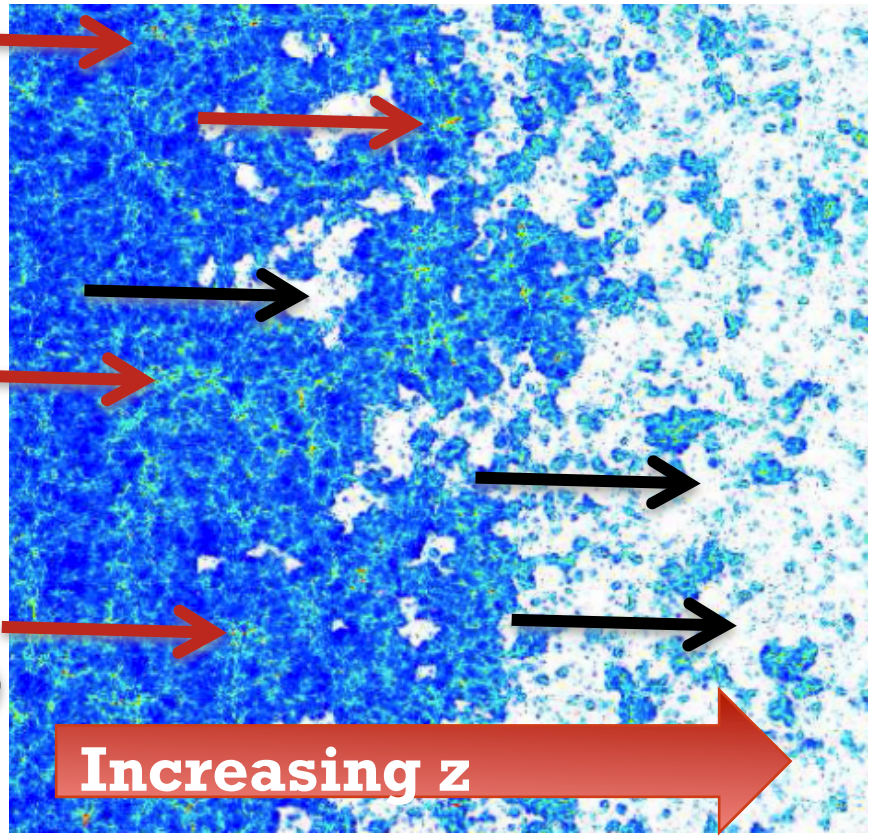
Galaxies

Ionized HII bubbles

The Near Infrared Background

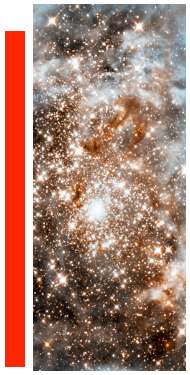
Neutral Regions

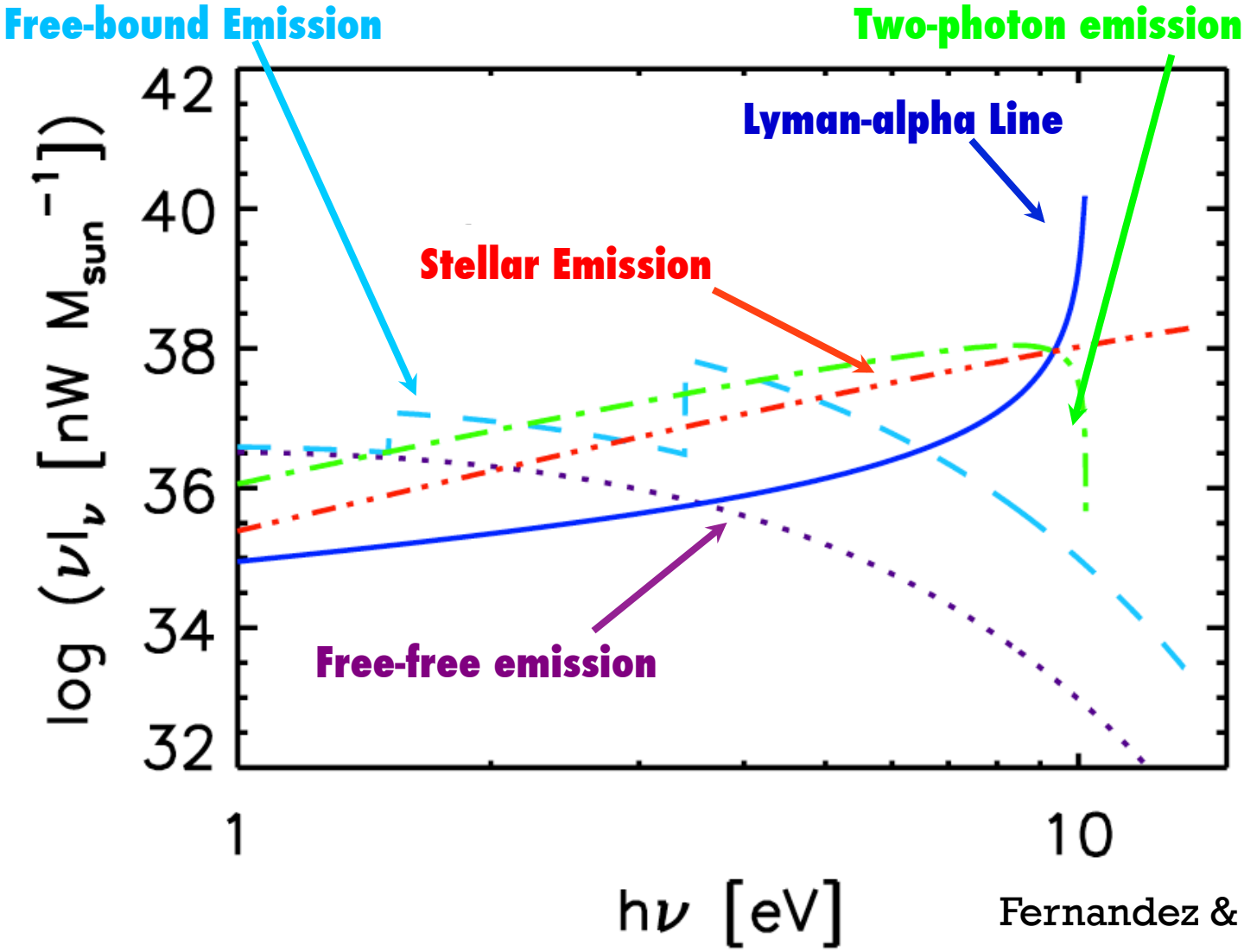
21 cm line



The simulation – 425/h Mpc
Park et al 2013

Emission from Galaxies

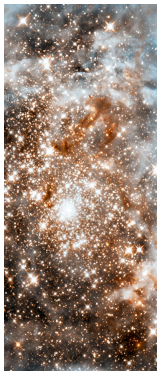


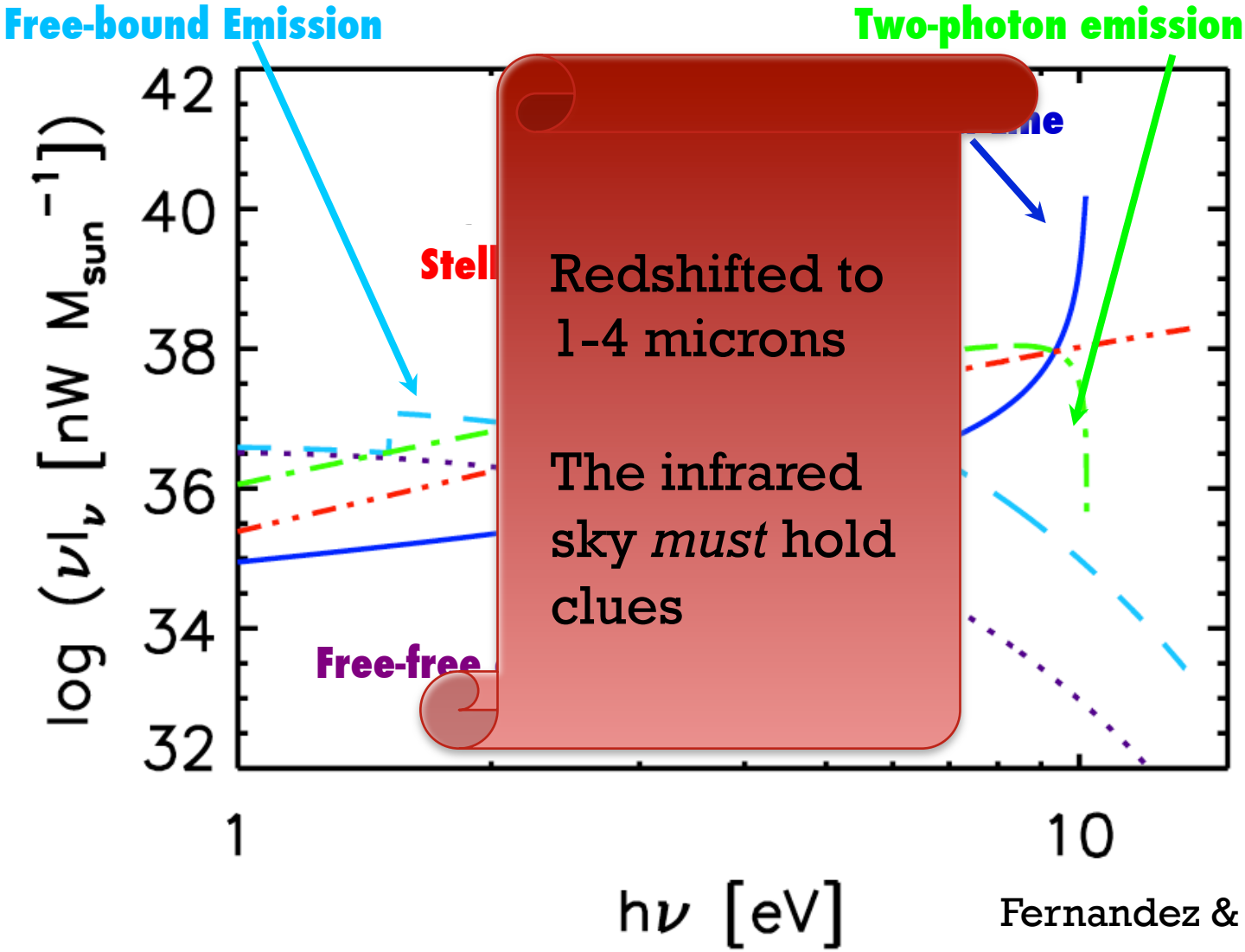


Rest frame spectrum

Fernandez & Komatsu 2008

Emission from Galaxies



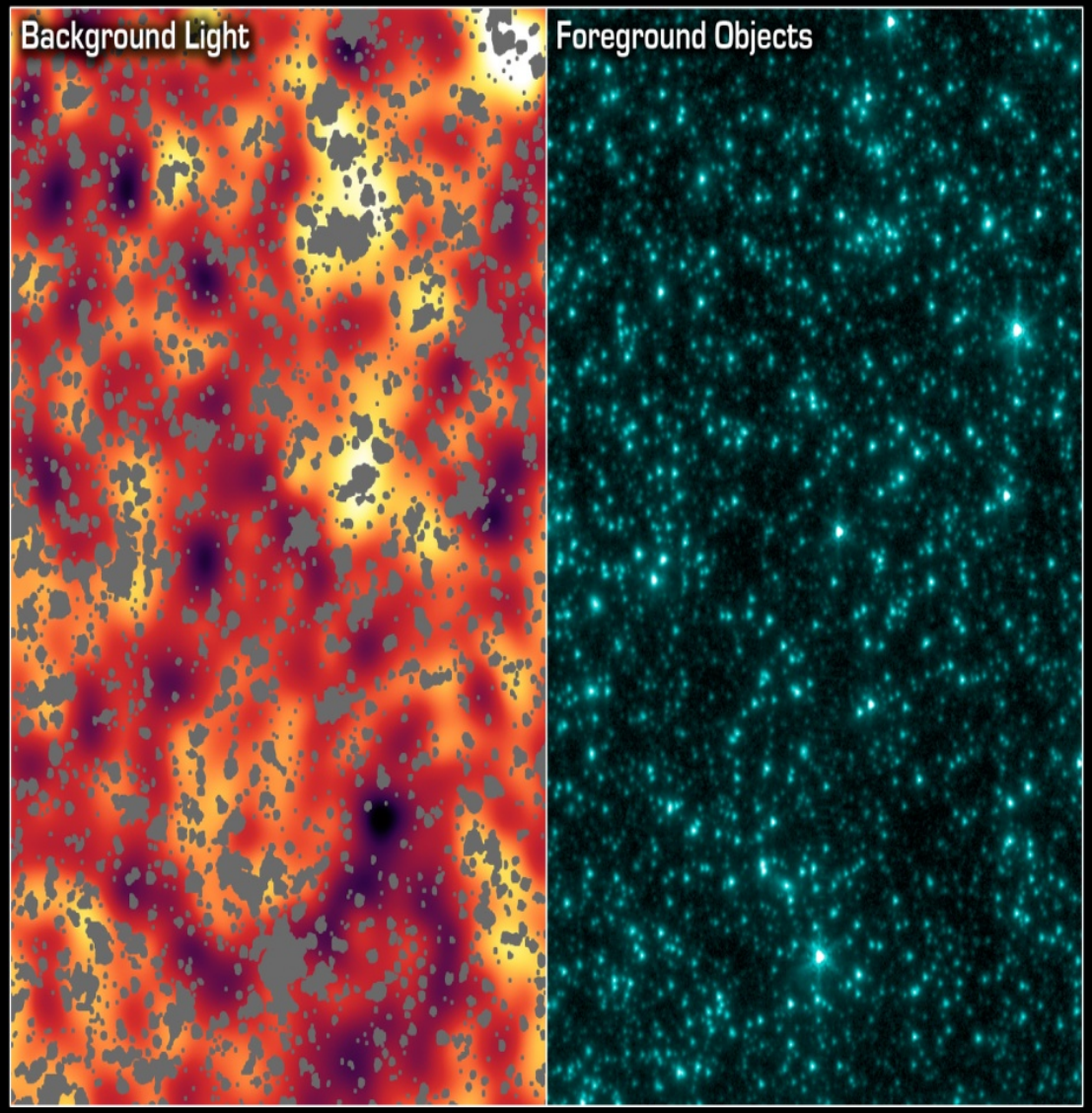


Redshifted to 1-4 microns

The infrared sky *must* hold clues

Rest frame spectrum

Fernandez & Komatsu 2008



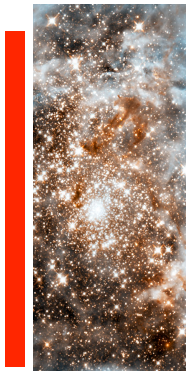
First Light after the Universe's "Dark Ages"

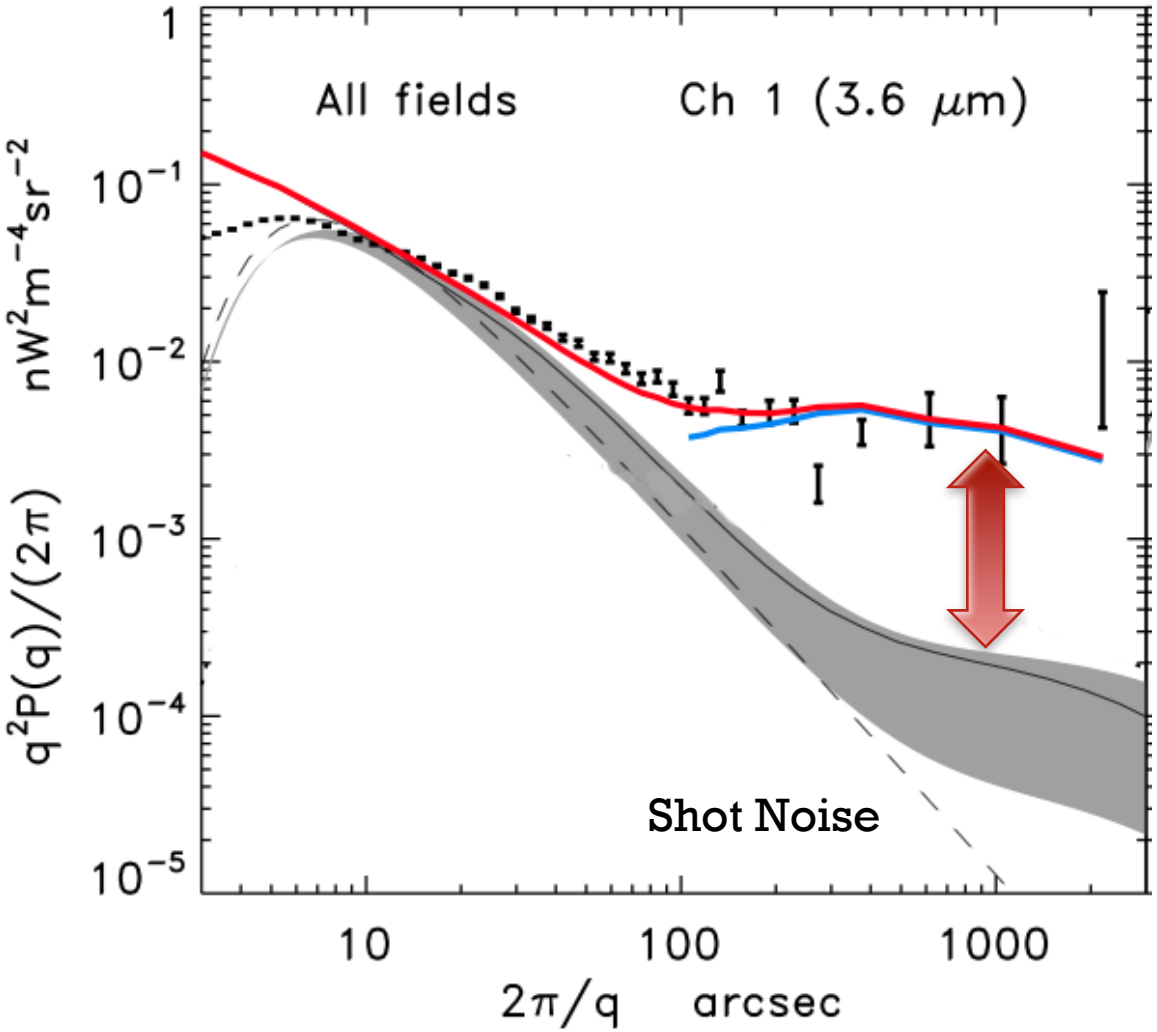
Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / A. Kashlinsky (GSFC)

ssc2006-22a

The High Redshift Component





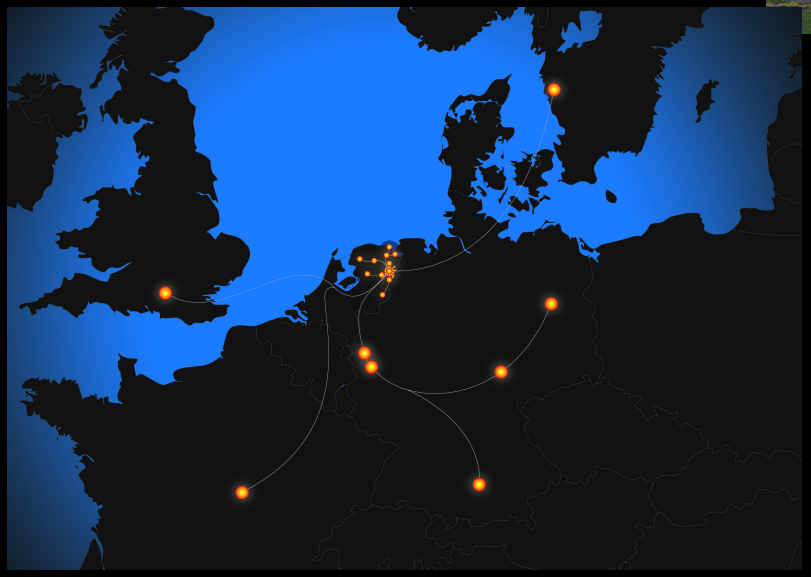
High Redshift Galaxies?

Low-z Galaxies

Kashlinsky et al 2012

LOFAR

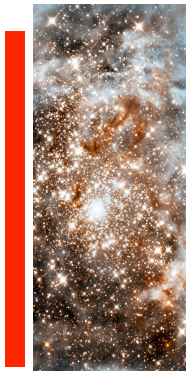
- Epoch of Reionization team – identify 21 cm line



- And map reionization!

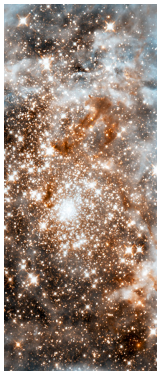
Cross Correlating for More Information

Cross-correlations

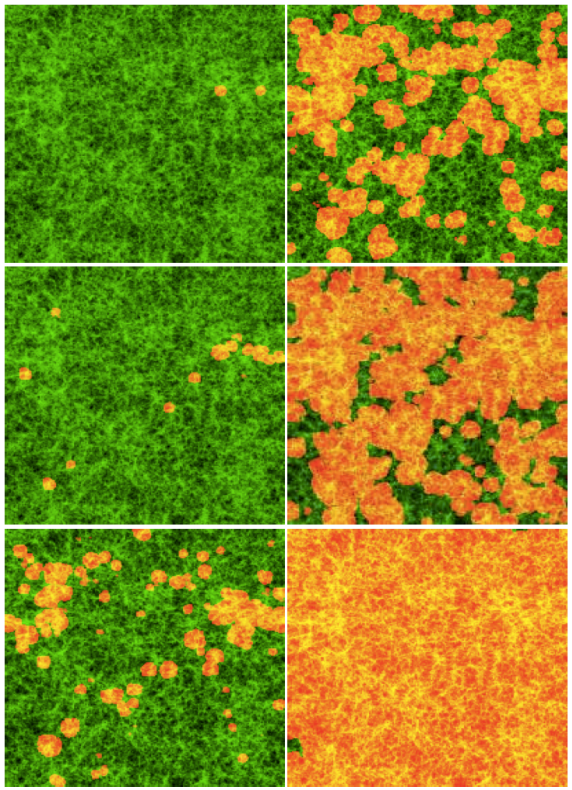


- Region dependent
  - 21 cm -> IGM -> Ionization
  - NIRB -> Galaxies -> Stars doing the ionizing
- The 21 cm line gives redshift information
  - This is not given by the NIRB measurements
- The NIRB and the 21cm line are fundamentally linked

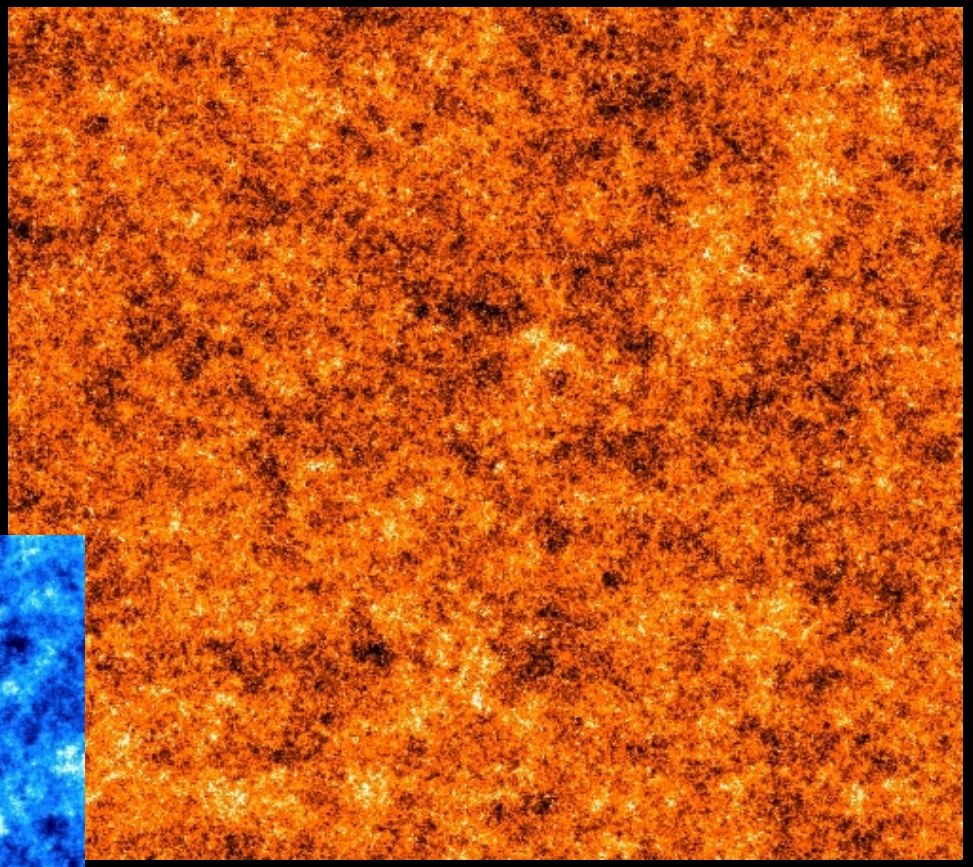
Structure Formation through Simulations



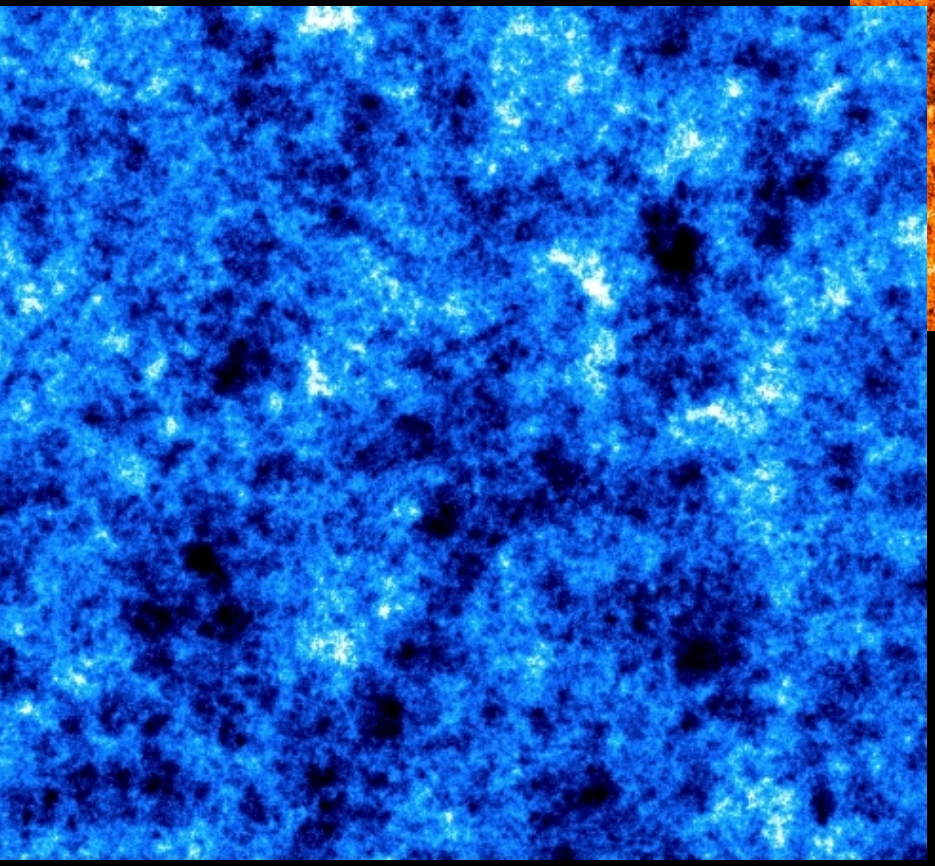
- N-body code with radiative transfer (Ilian et al 2006, 2007, 2011, 2013)
  - $M_{min} = 10^8 M_{sun}$
  - Box sizes: $(425/h\ Mpc)^3$
- Small galaxies near large ones are suppressed
- Combine with predicted galaxy luminosities and 21cm emission



Raw NIRB map

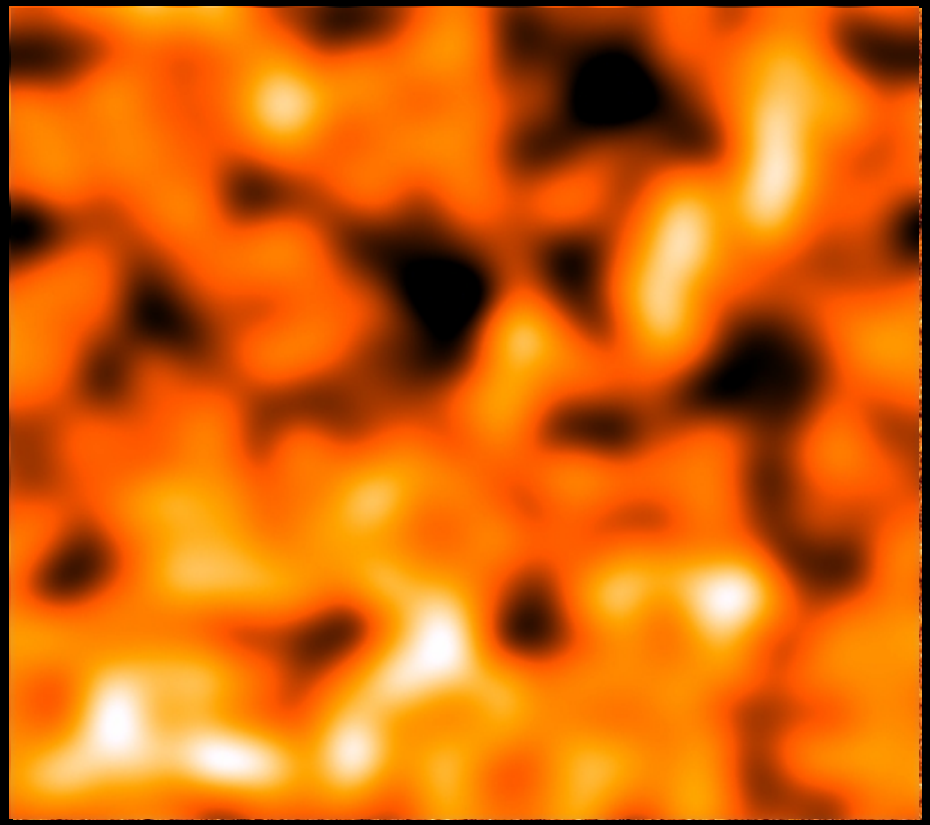


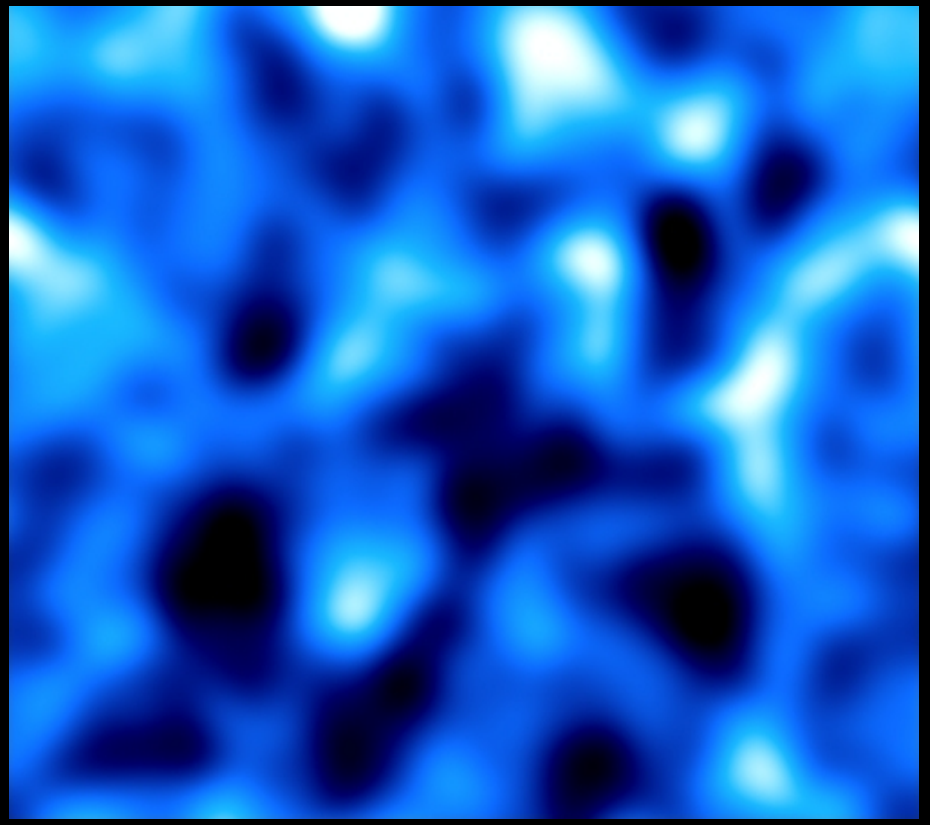
~ 4 °

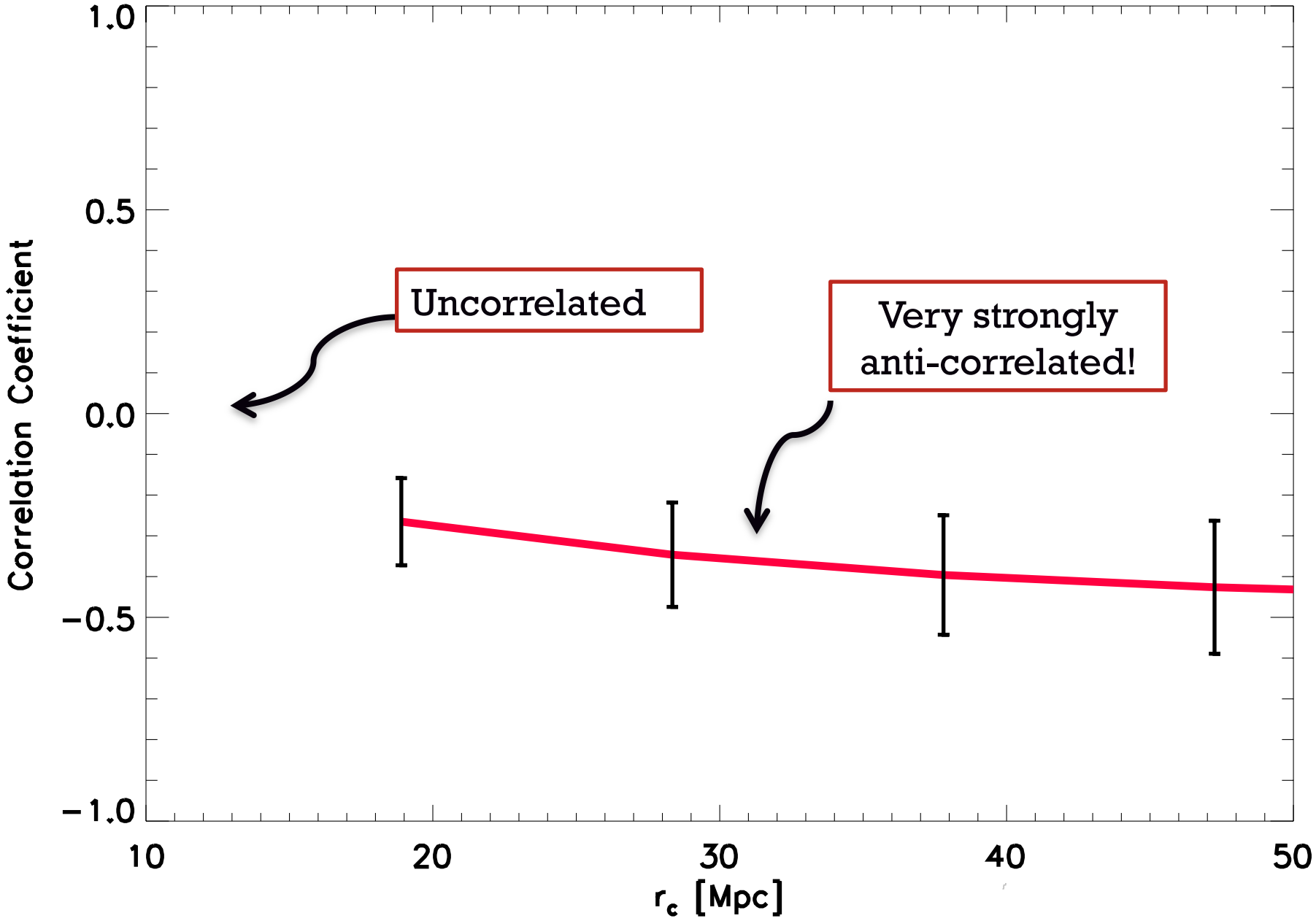


Raw LOFAR map

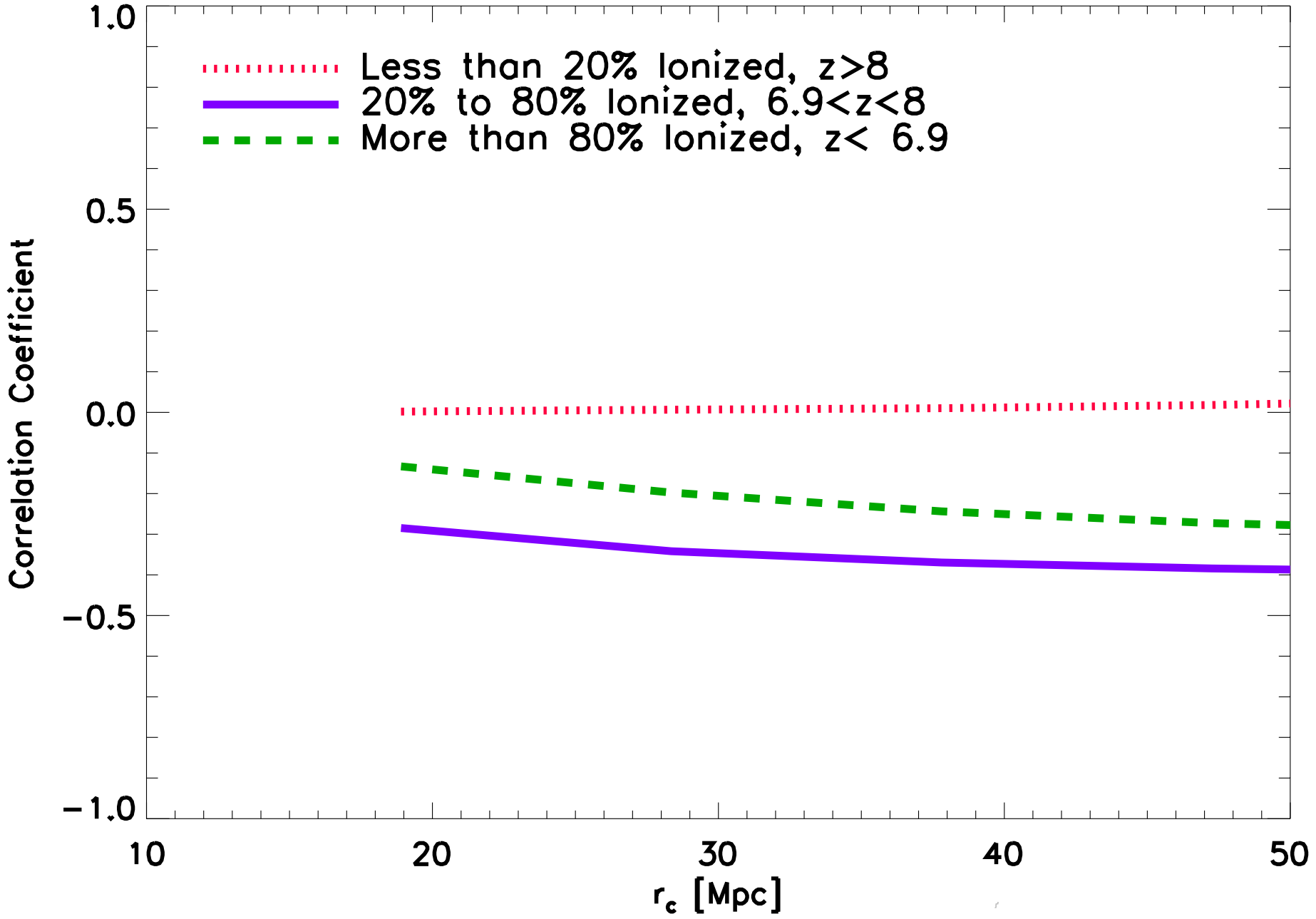
Perform Gaussian Smoothing



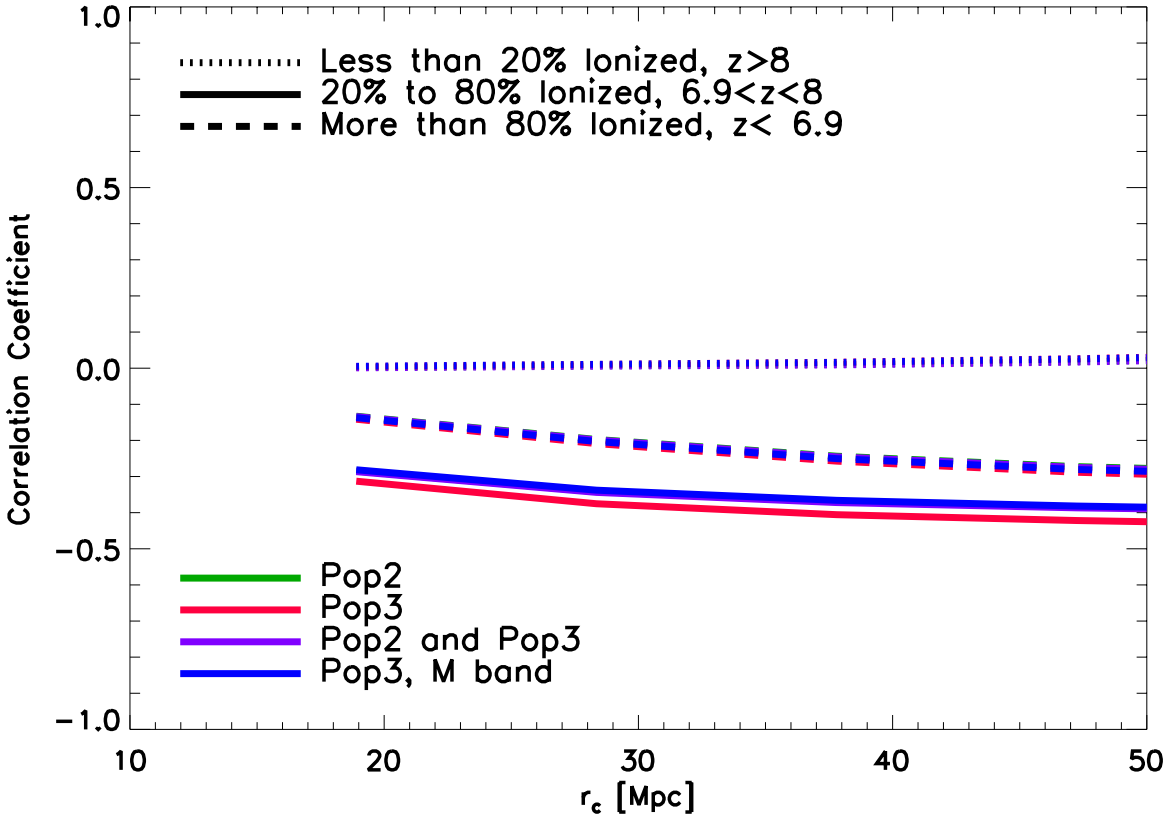




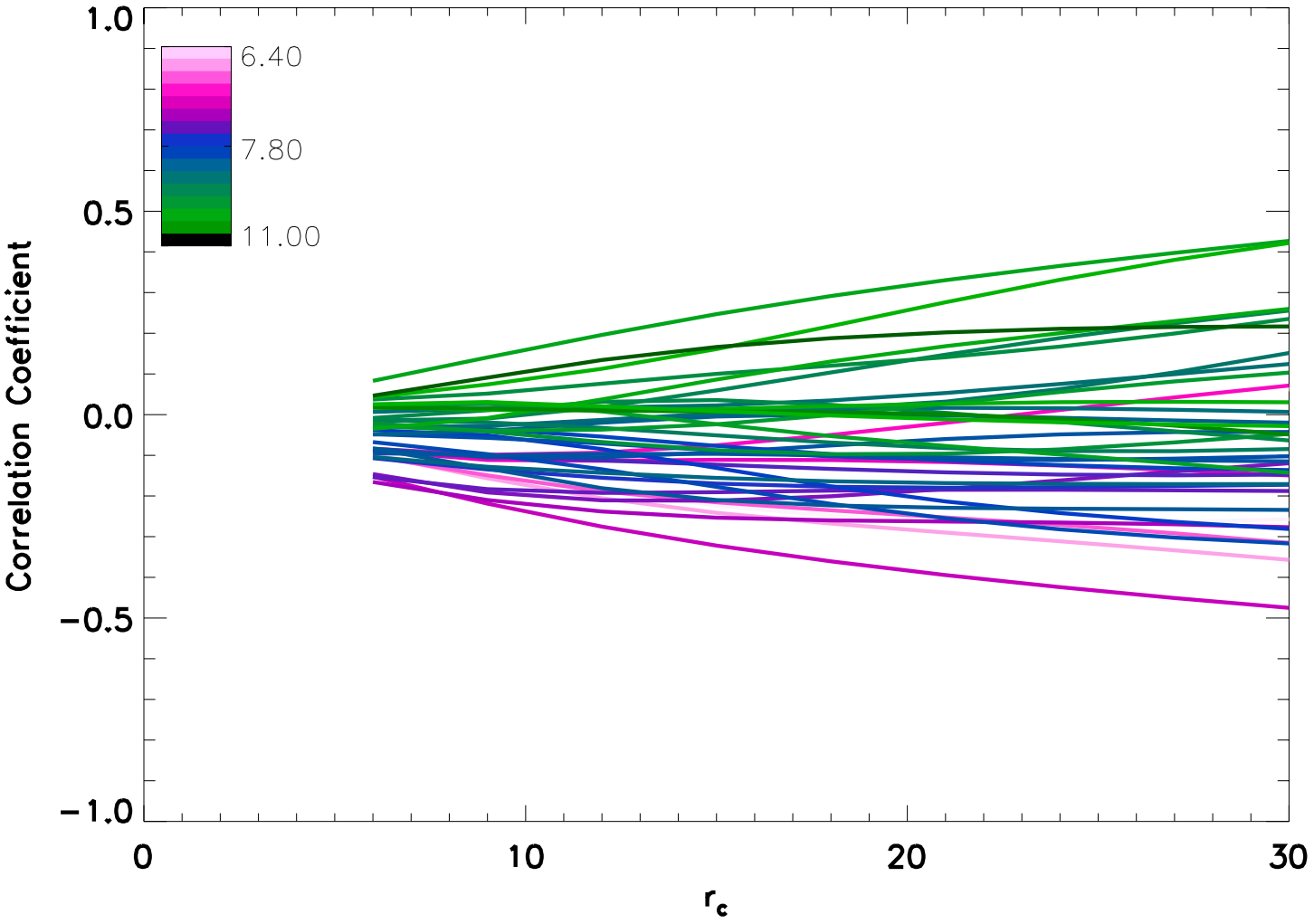
Fernandez et al 2013



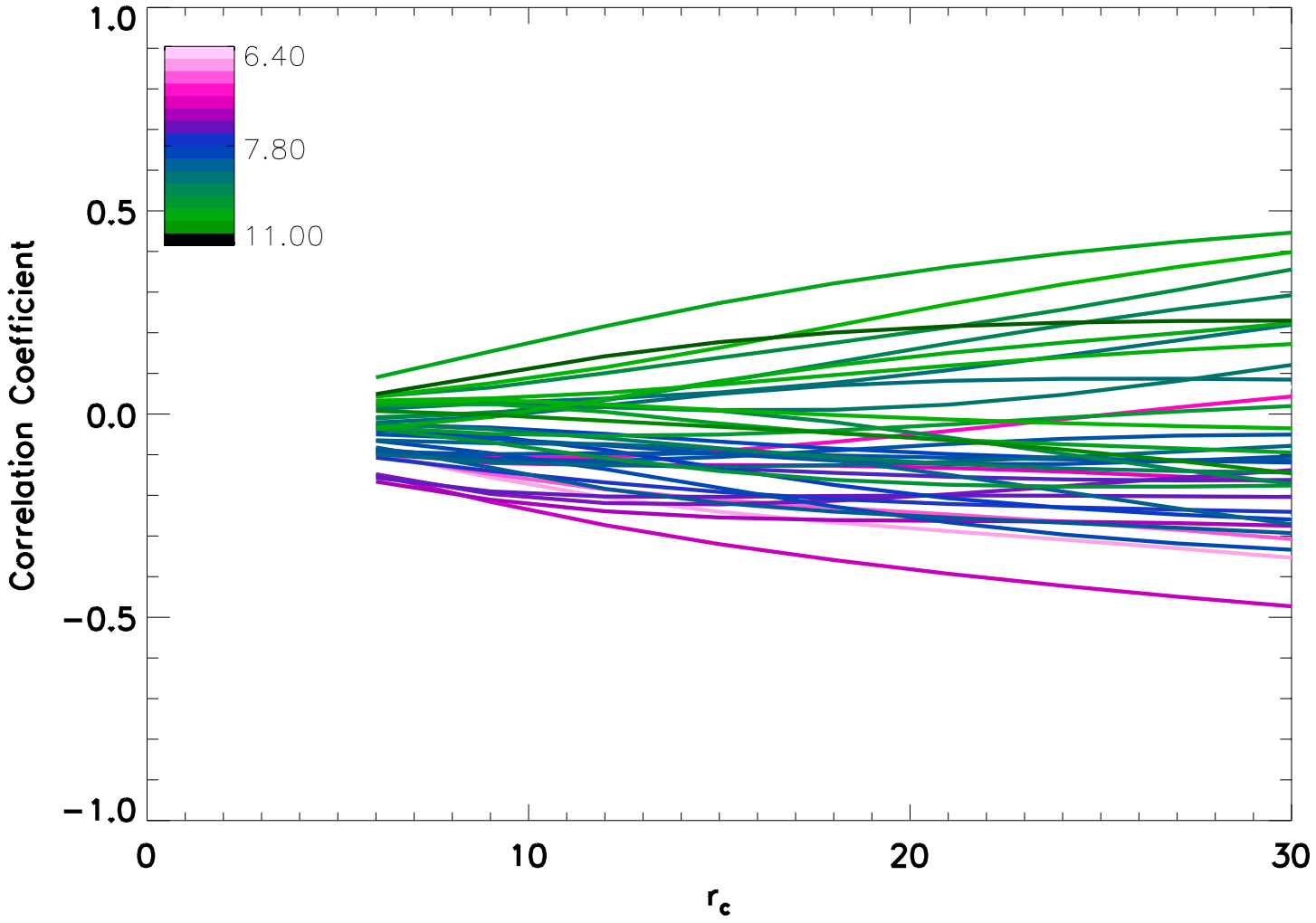
Fernandez et al 2013



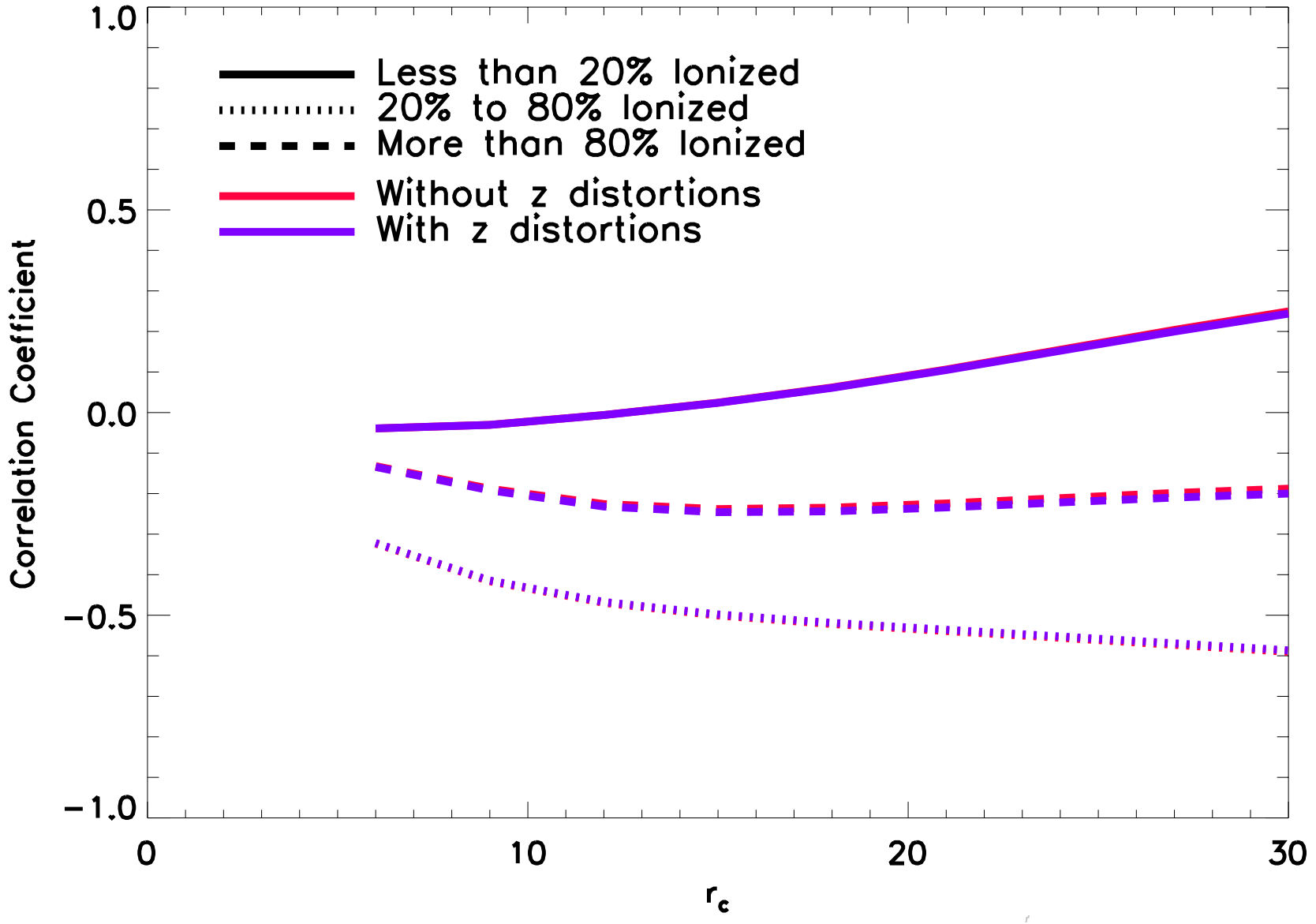
- Population III (metal free) or Population II (metal poor)?
- Mass of stars?
- Band of NIRB observations?
- Escape Fraction?
- Star formation rate?
- No effect as long as reionization history is the same



No redshift distortions

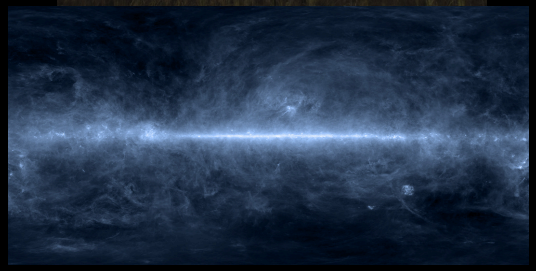


With redshift distortions


Less than 20% Ionized
20% to 80% Ionized
More than 80% Ionized
Without z distortions
With z distortions
Correlation Coefficient
1.0
0.5
0.0
−0.5
−1.0
0
10
20
30
r_c

Challenges to Observe the NIRB and the 21 cm line

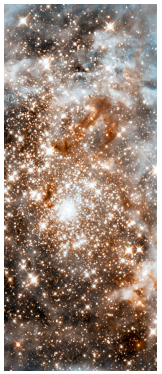
Zodiacal Light



Our Galaxy

Foreground galaxies

Cross-Correlations Won't



- Give information about the mass, metallicity, and escape fraction of high redshift galaxies.
- Depend on the band of the observations of the Near Infrared Background
- Be affected by redshift distortions

Cross-Correlations Should

- Should show a similar story for both the 21cm line and the NIRB
  - Which component is high z?
- Depend on redshift range
  - Most negative cross correlation expected when reionization ~50% complete
- Depend on reionization history!