



First Stars, Reionization & GRBs

Andrea Ferrara

Scuola Normale Superiore, Pisa, Italy



Sequence of events

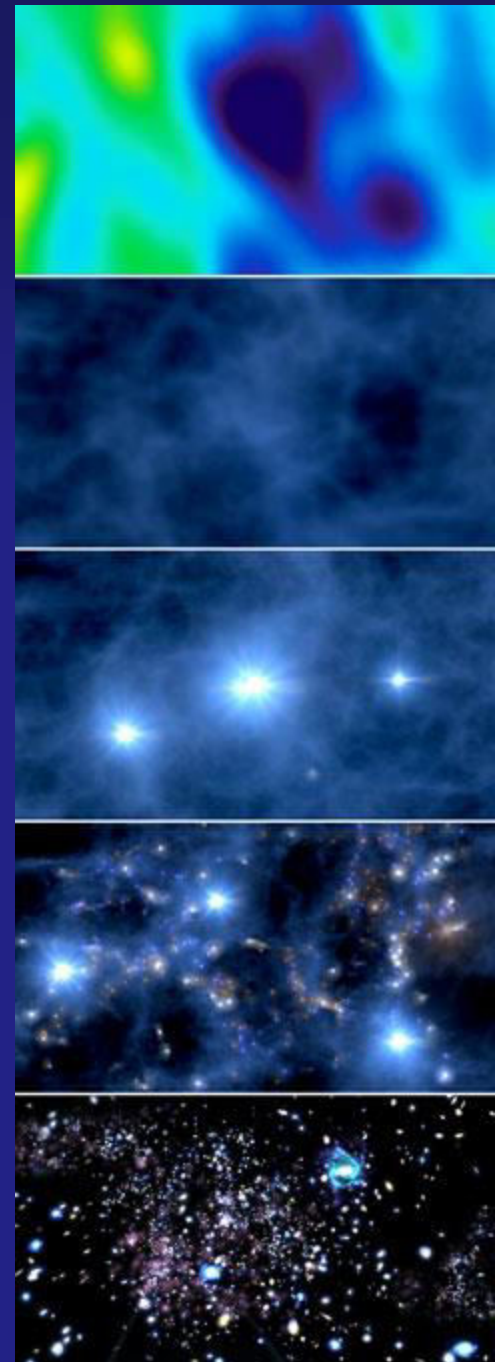
At $z=1000$ the Universe has cooled down to 3000 K. Hydrogen becomes neutral (“**Recombination**”).

At $z < 40$ the first “**PopIII**” star (clusters)/small galaxies form.

At $z \sim 6-15$ these gradually photo-ionize the hydrogen in the IGM (“**Reionization**”).

At $z < 6$ galaxies form most of their stars and grow by merging.

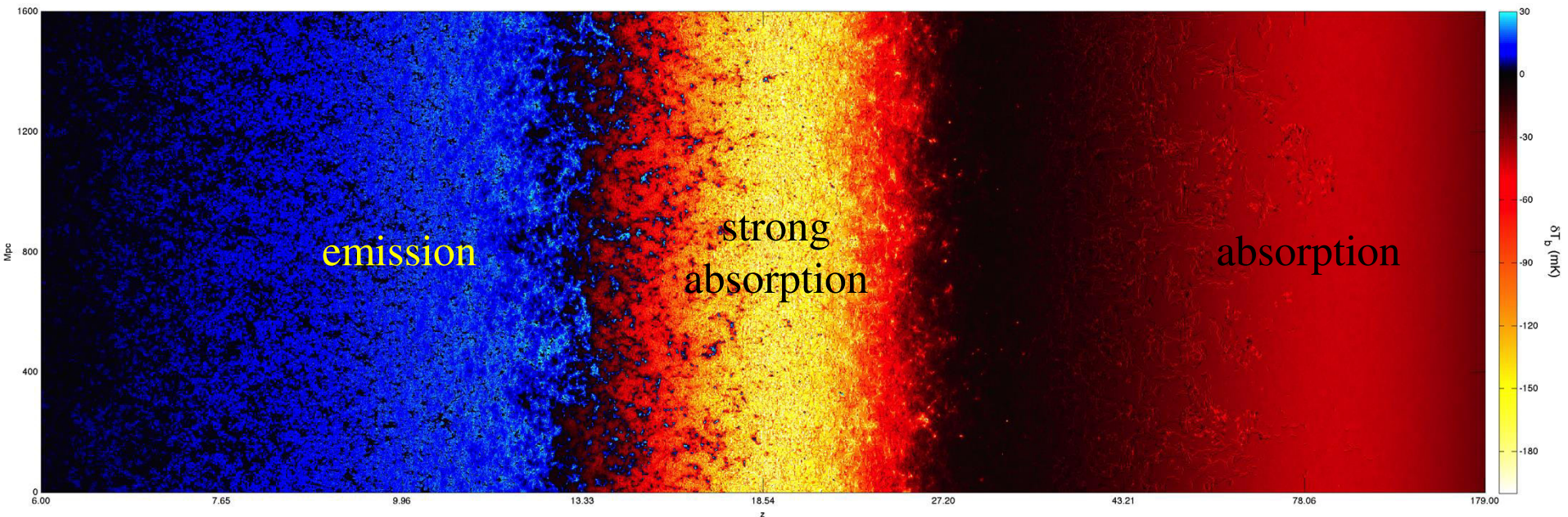
At $z < 1$ massive galaxy **clusters** are assembled.



Time

SIMULATED SIGNAL

HI 21cm Line Brightness Temperature Evolution



6

Epoch of Reionization

- *IGM warmer than CMB*
- *Strong $T_s - T_k$ coupling*

15

Cosmic Dawn

- *IGM colder than CMB*
- *$\text{Ly}\alpha$ coupling (WF effect)*
- *X-ray preheating*

27

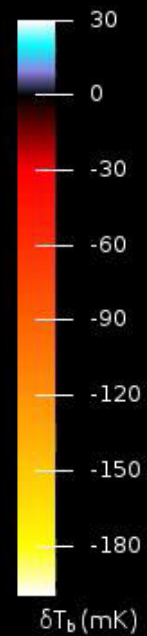
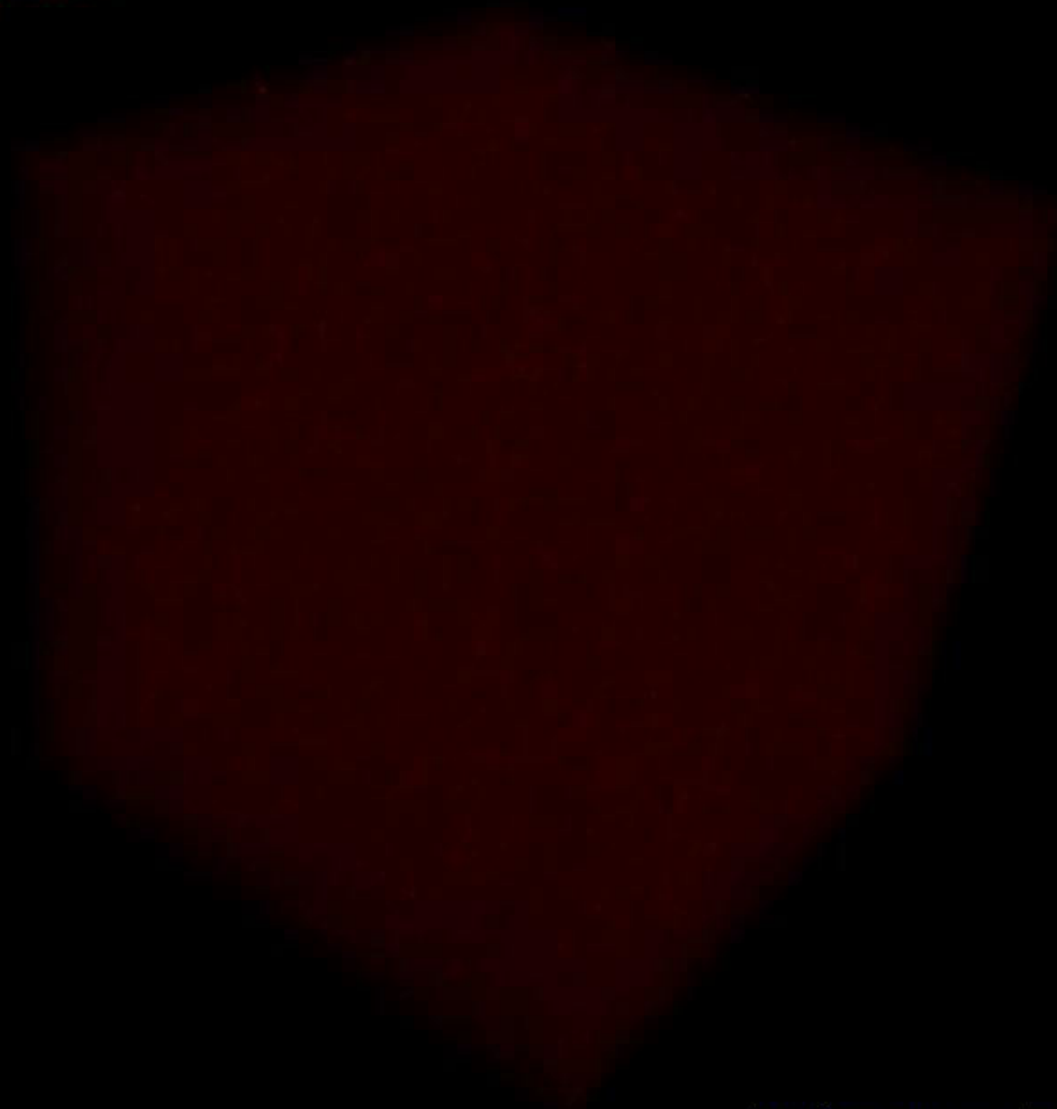
Dark Ages

- *IGM colder than CMB*
- *Weak $T_s - T_k$ coupling*

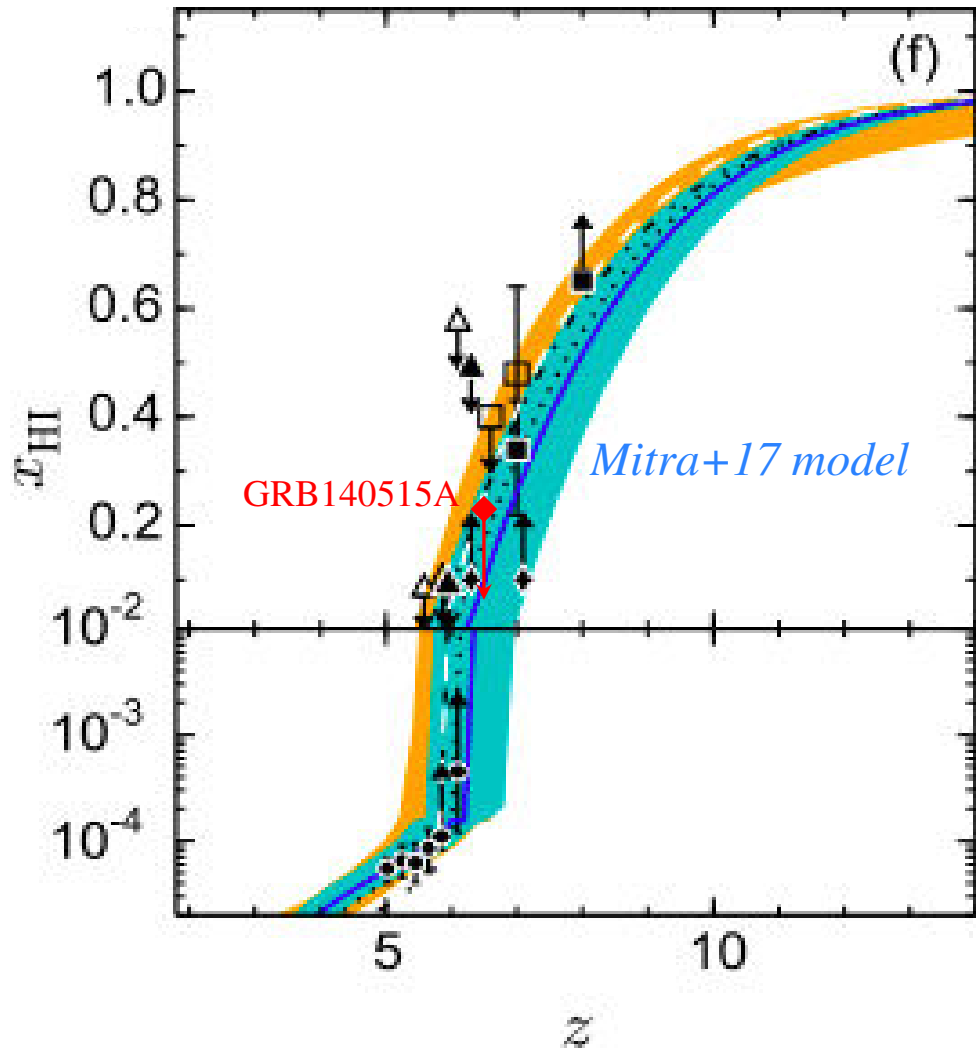
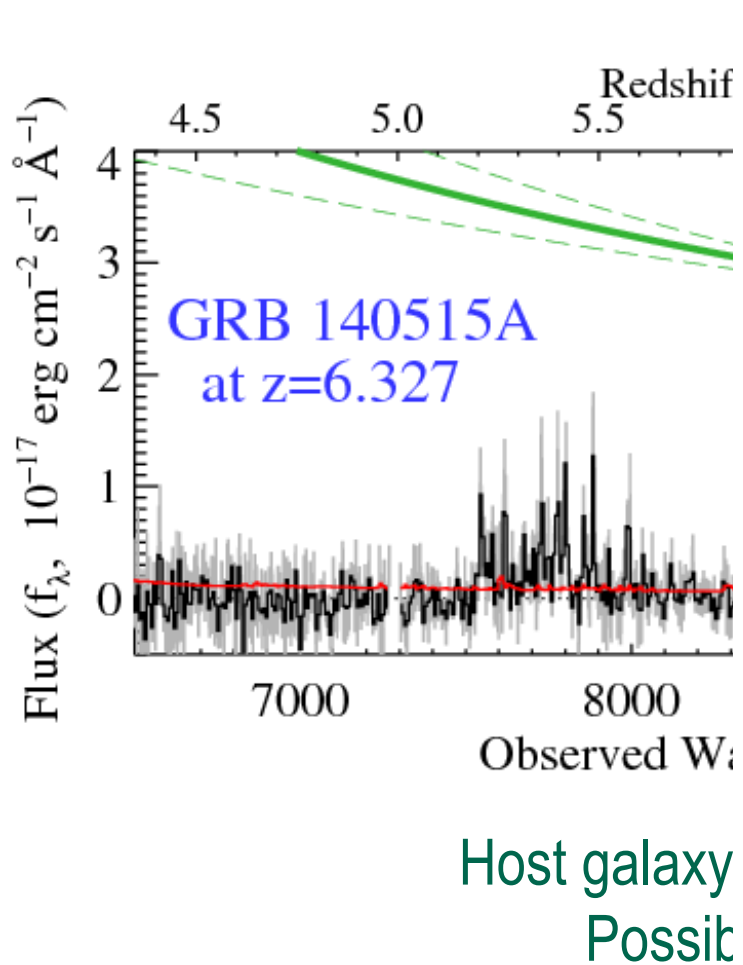
redshift

HI 21cm Line Brightness Temperature Evolution

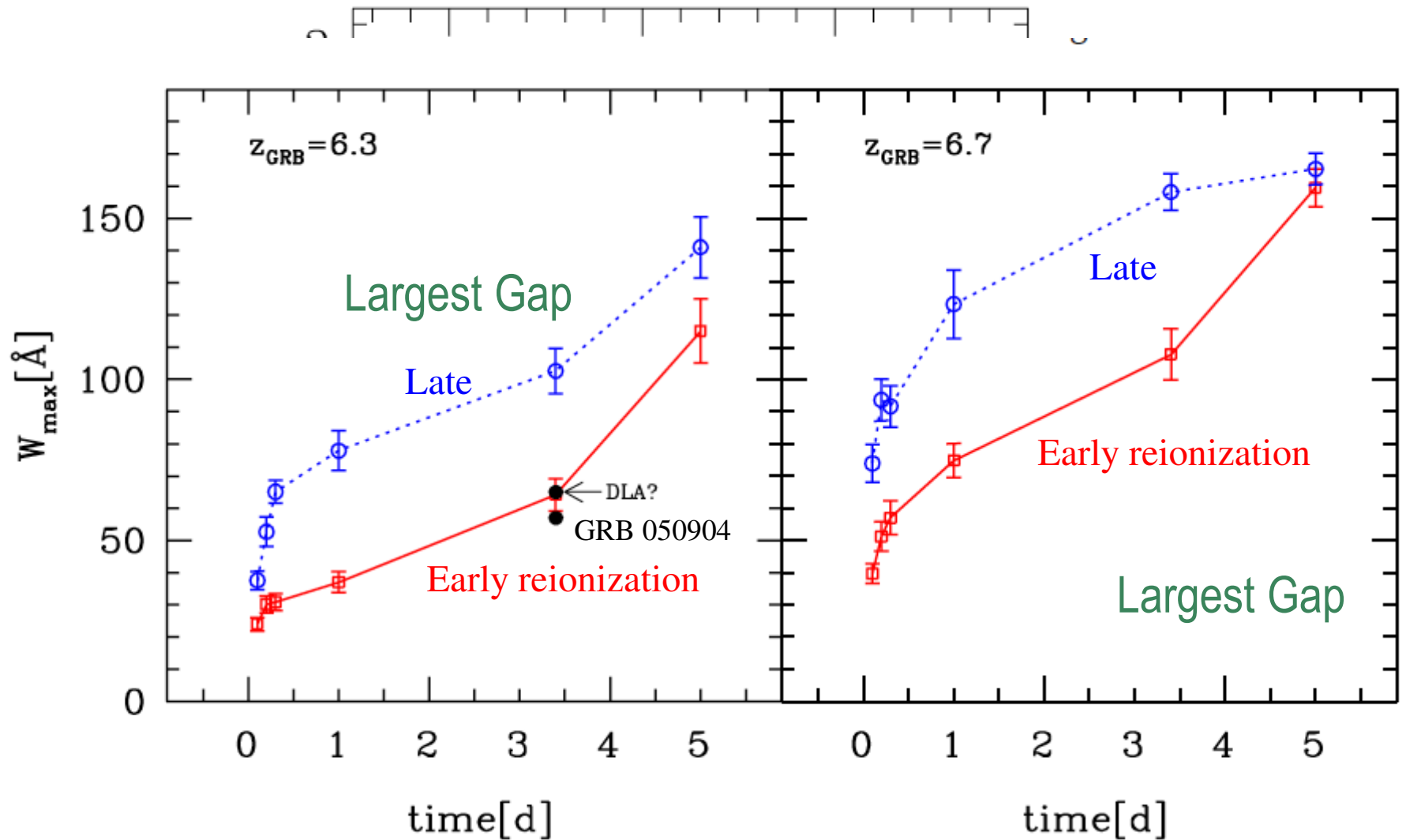
Box length=800Mpc
 $z=0.2996$



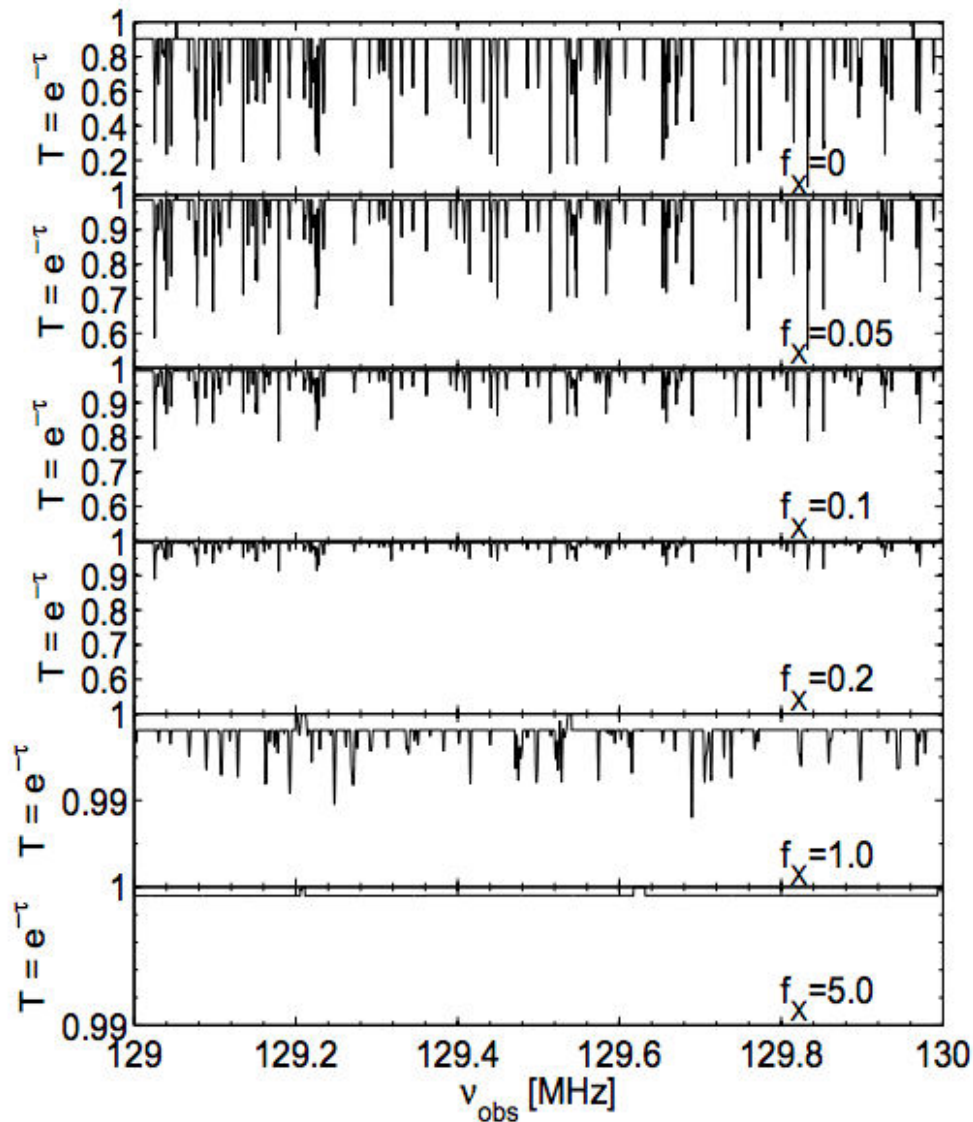
GRB ABSORPTION LINES



DARK GAPS IN GRB SPECTRA

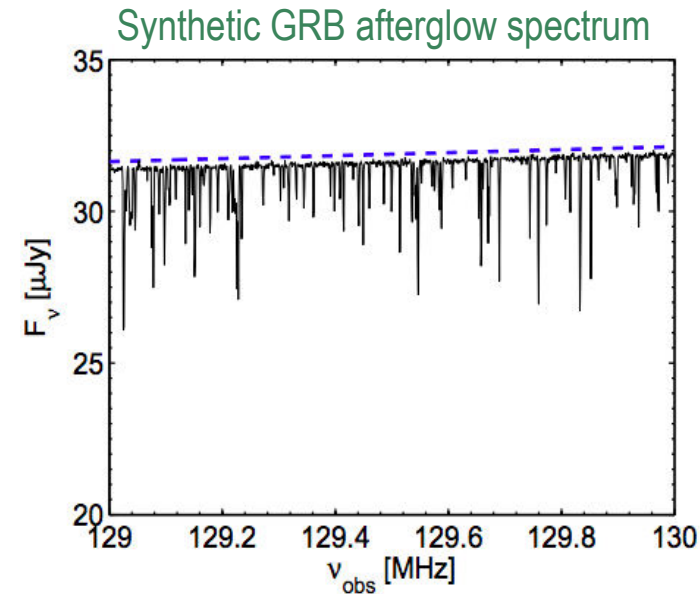


21 CM FOREST AGAINST GRBs



$$L_X = 3.4 \times 10^{40} f_X \left(\frac{\text{SFR}}{1 M_\odot \text{ yr}^{-1}} \right) \text{ erg s}^{-1}$$

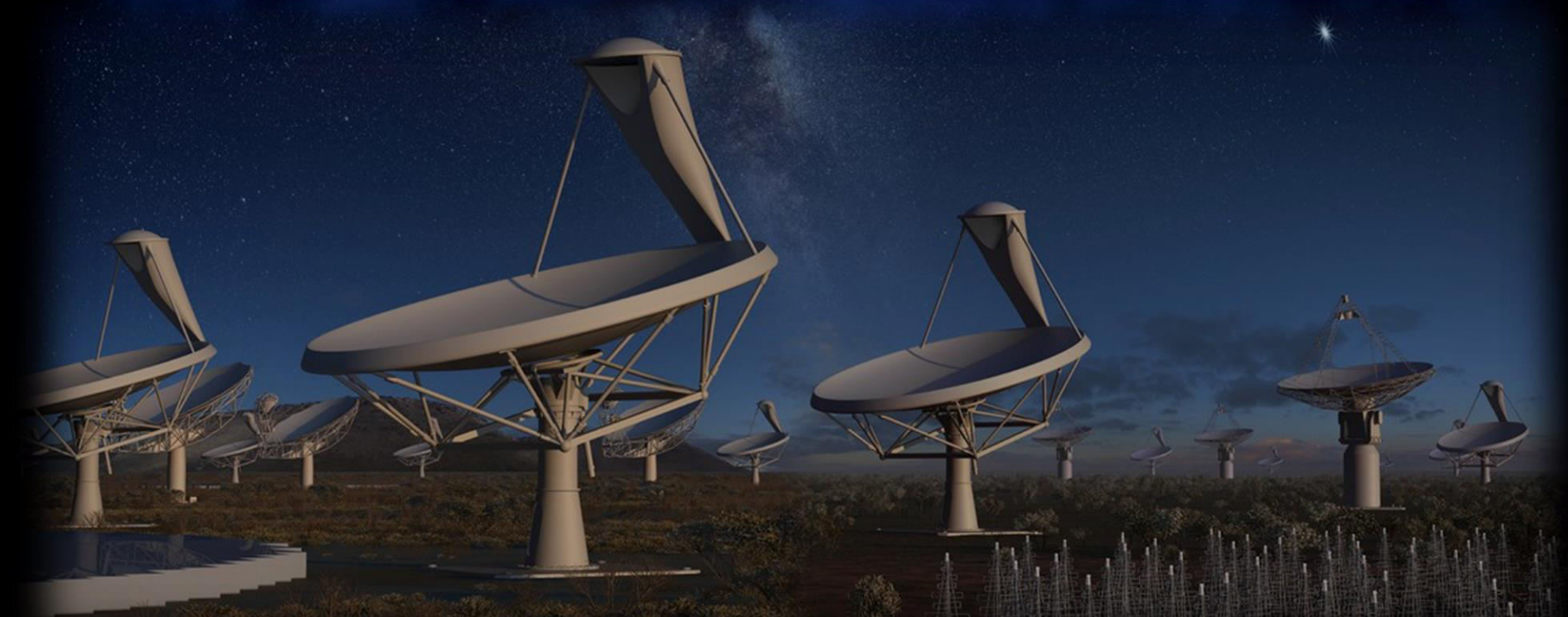
Increasing X-ray Background Intensity



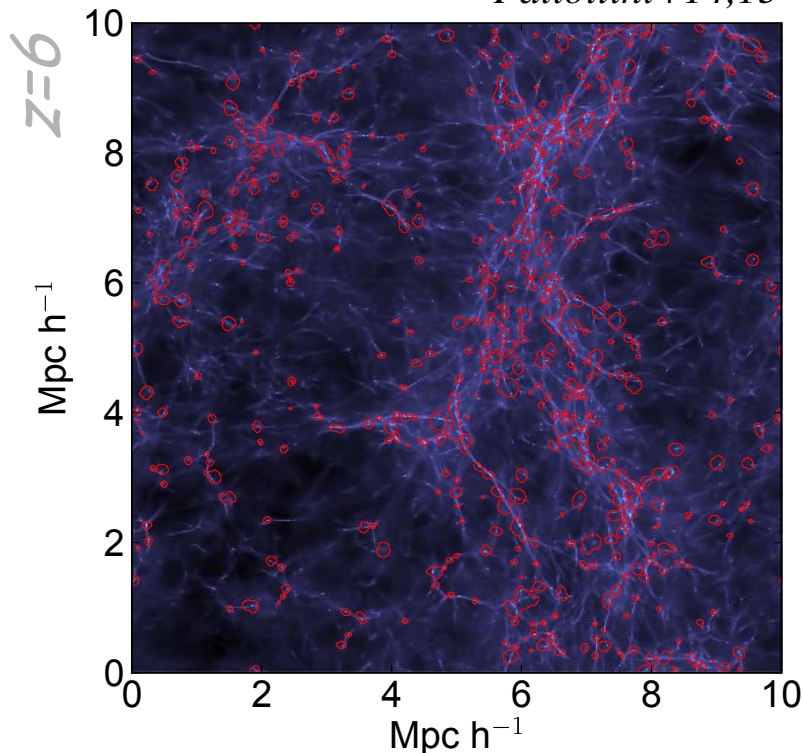
$$E_{\text{iso}} = 10^{54} \text{ erg, } z=10$$



The world's largest radiotelescope

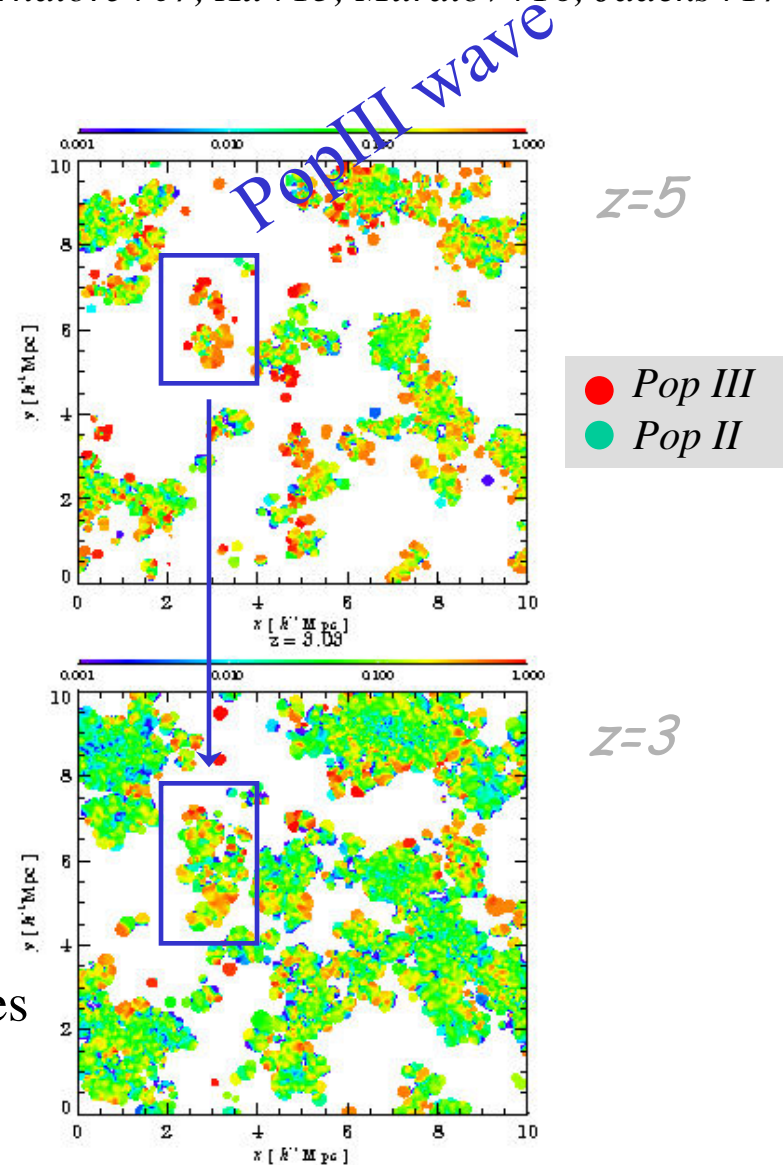


POPIII/II TRANSITION

Pallottini+14,15

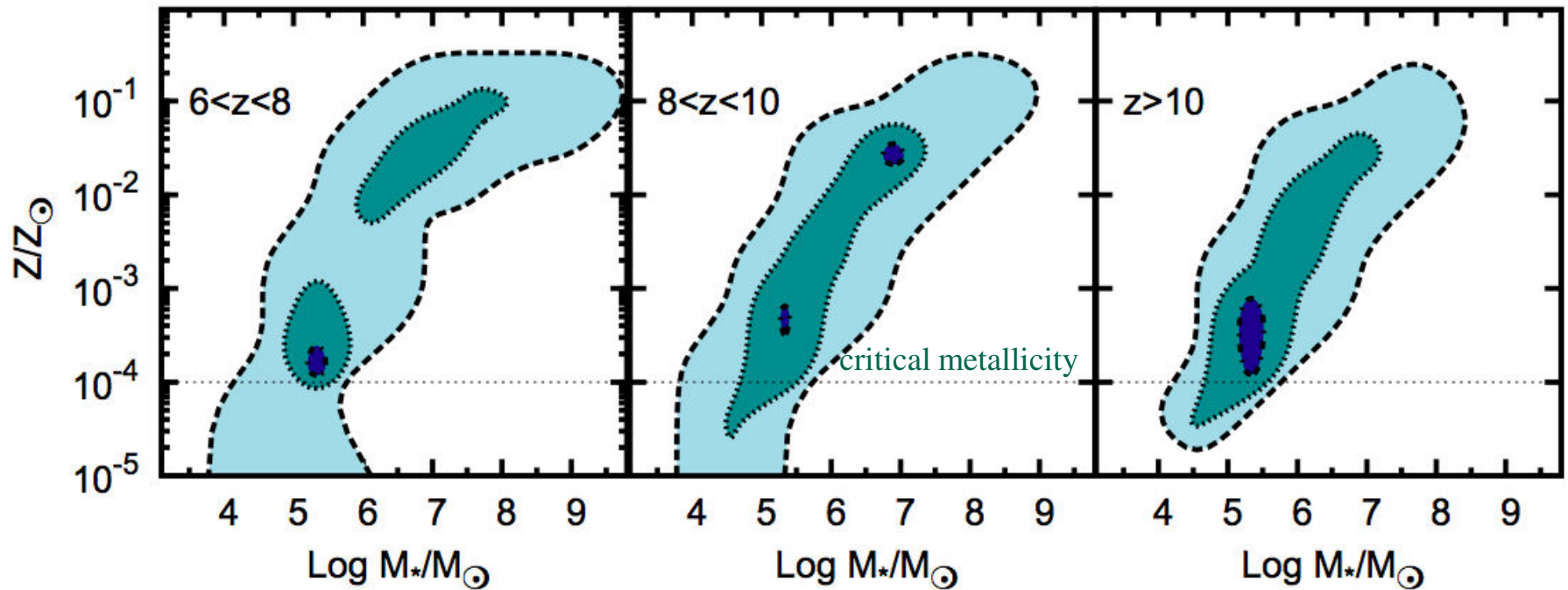
OBSERVATIONAL IMPLICATIONS

- Increasing fraction of PopIII galaxies
- PISN and CC supernovae
- Increasing rate of PopIII GRBs



POPIII GRBs

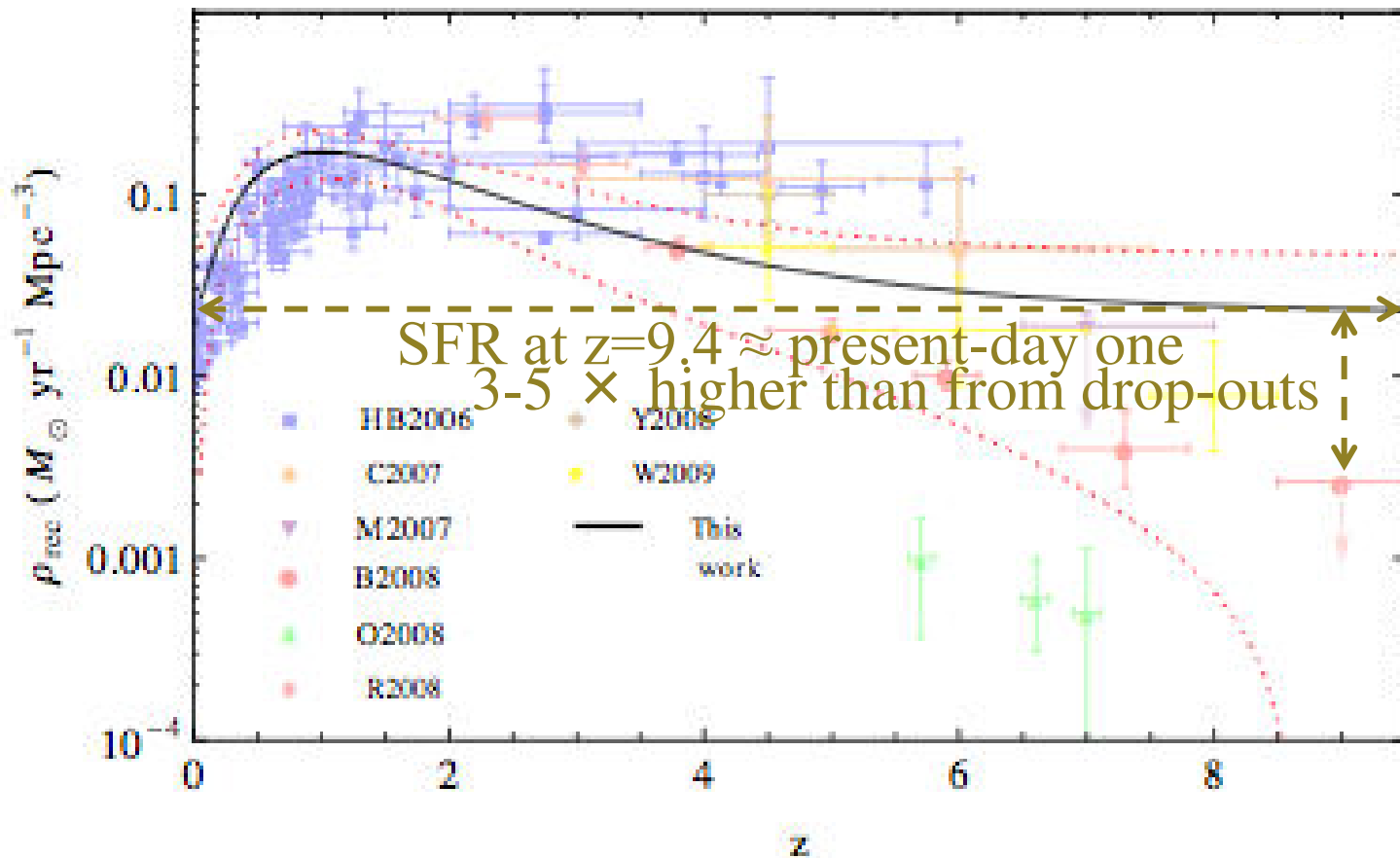
At $z > 6$ ($z > 10$) 10% (40%) of all long GRBs are from PopIII stars



PopIII GRBs trace low mass galaxies ($M_\star < 10^7 M_\odot$) at all z 's

HINTS FROM GRBS

Cosmic SFH deduced from PCA of GRB data



Conclusions

GRBs are key to high redshift studies

They will allow to:

- ✧ Map cosmic reionization
- ✧ Trace IGM evolution and enrichment
- ✧ Discover PopIII stars and study their IMF
- ✧ Complement 21cm intensity mapping experiments
- ✧ Pinpoint and study faint galaxies powering reionization