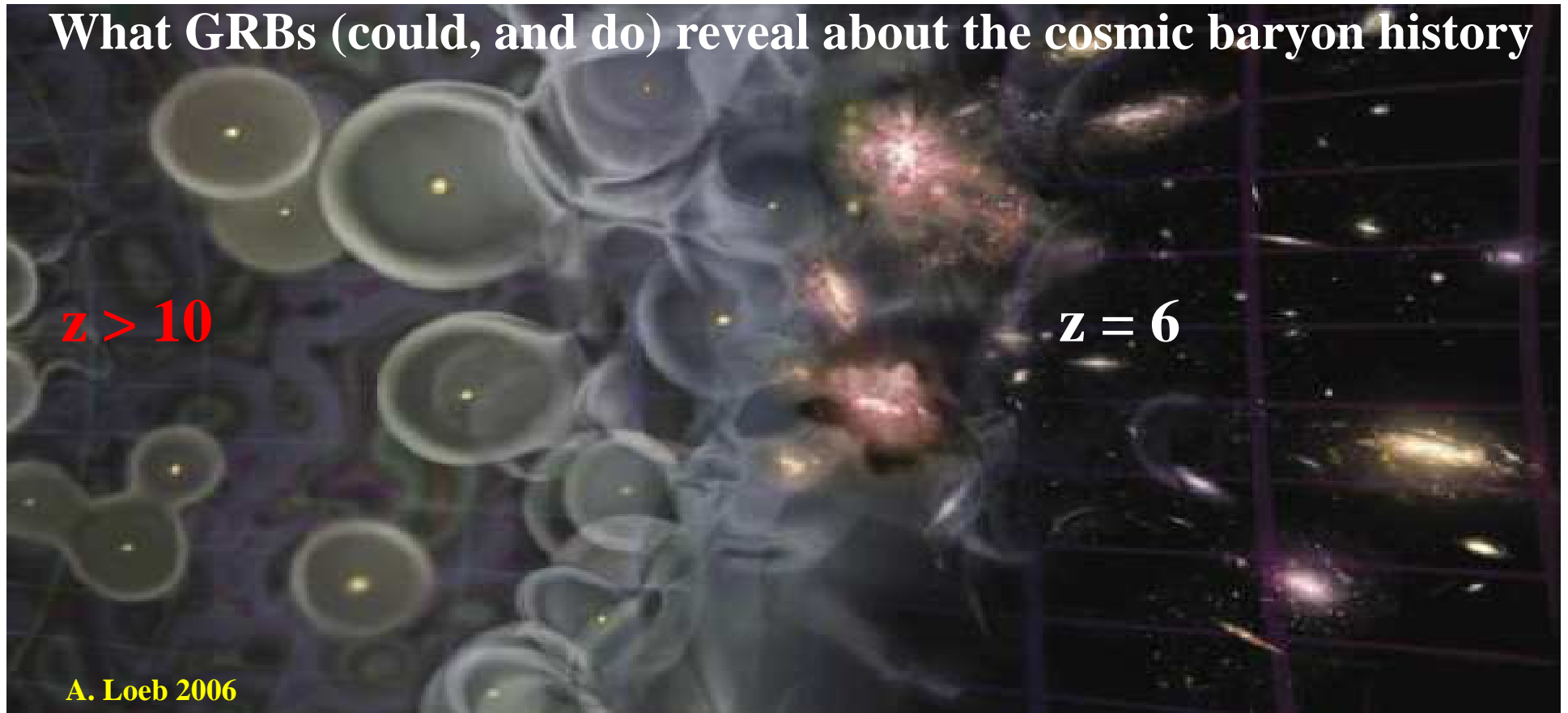


**Dieter H. Hartmann**

**Clemson University**



# What GRBs (could, and do) reveal about the cosmic baryon history

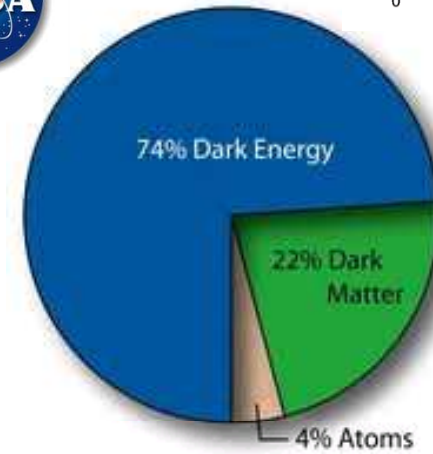
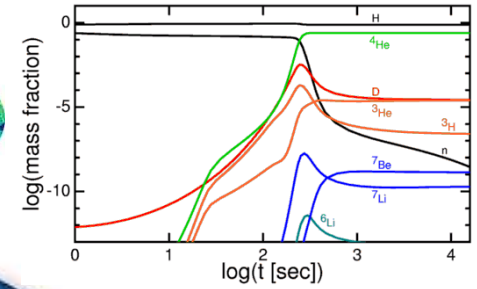
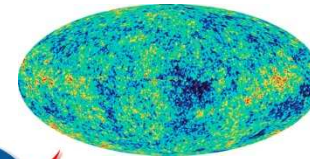


→  
**Annapolis, Election Day 2010**

# Cosmic Composition



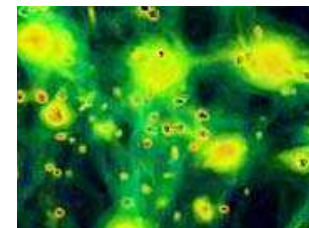
**Paul Klee.** 1919. Oil on pasteboard. 48 x 41 cm.  
Kunstsammlung Nordrhein-Westfalen, Düsseldorf, Germany.



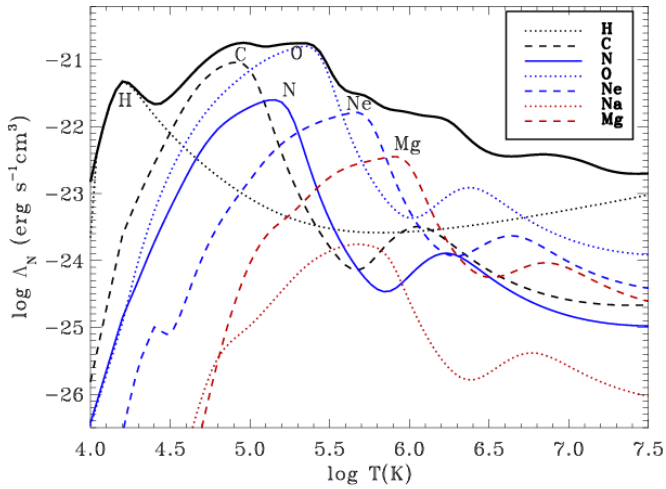
- Cycles of Matter, Light, ...
- Star Formation
- Nucleosynthesis
- Redistribution
- Light, neutrinos, ...



→  $\tau_{\gamma\gamma}$  (EBL)



# Cosmic Matter Budget

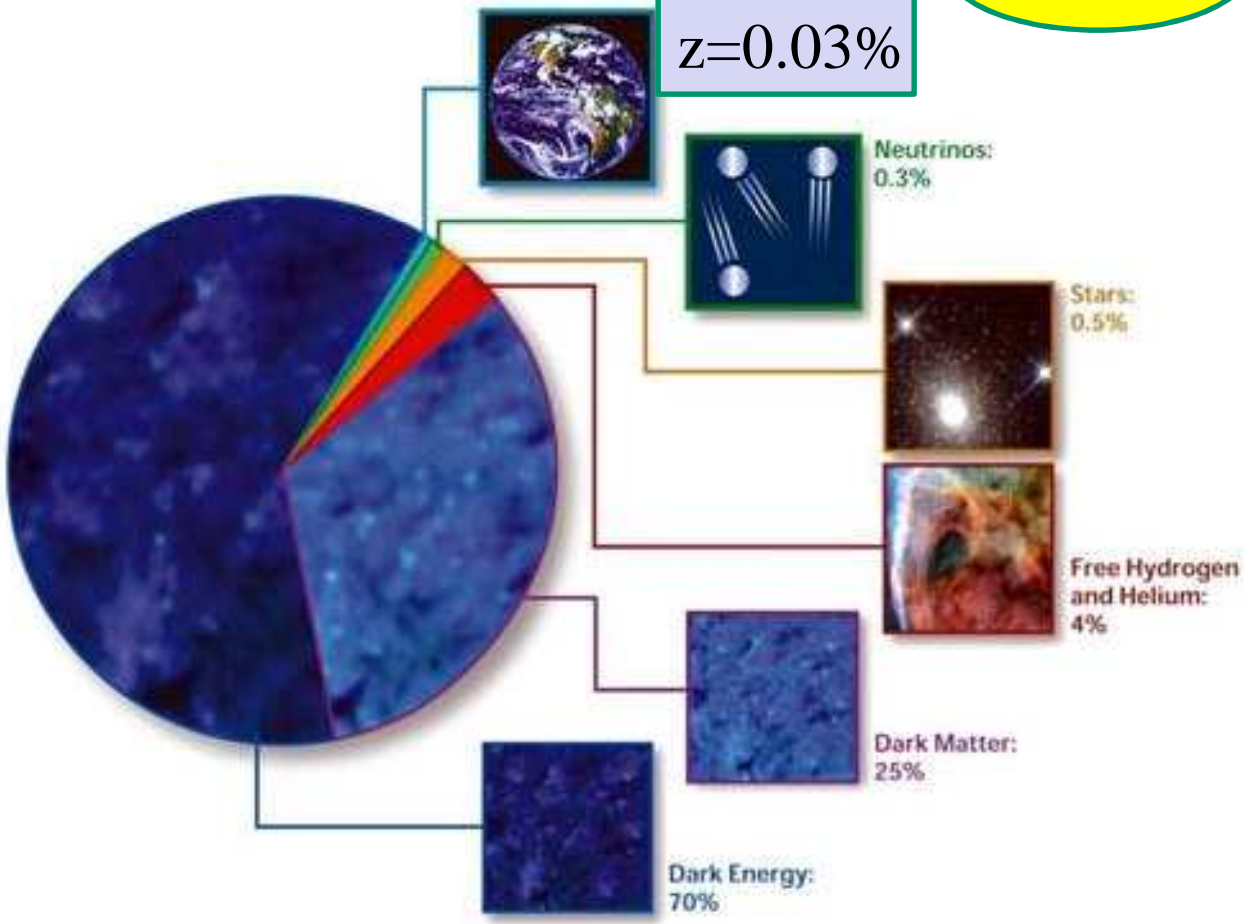
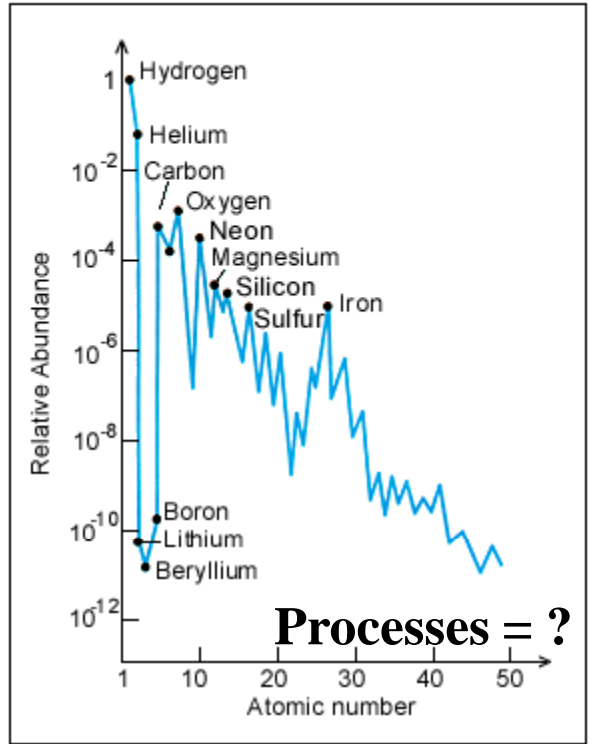


Metals  
z=0.03%

Z(z) = ?

Please don't z,z,z,z .....

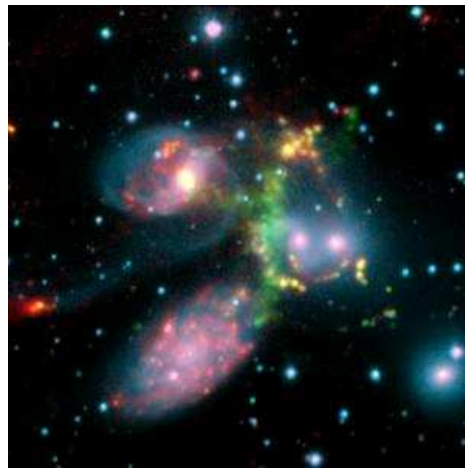
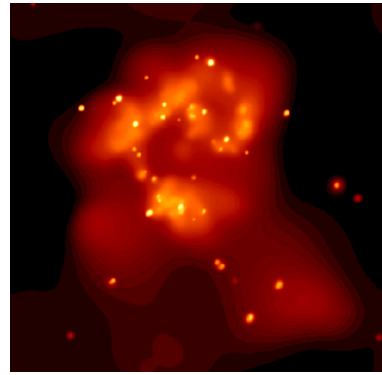
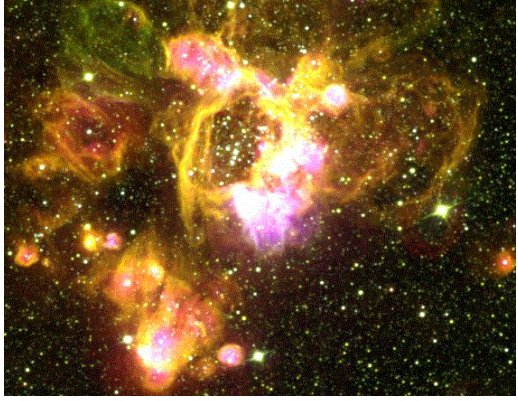
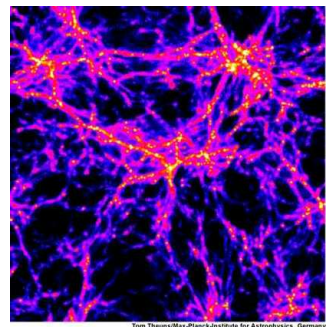
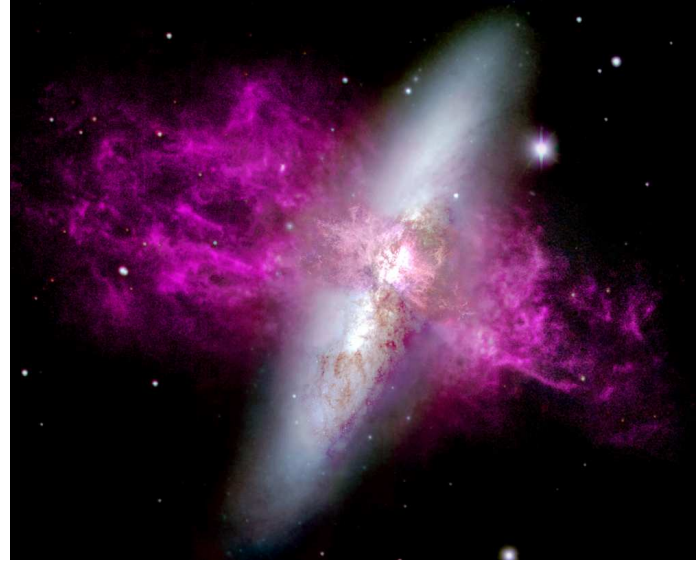
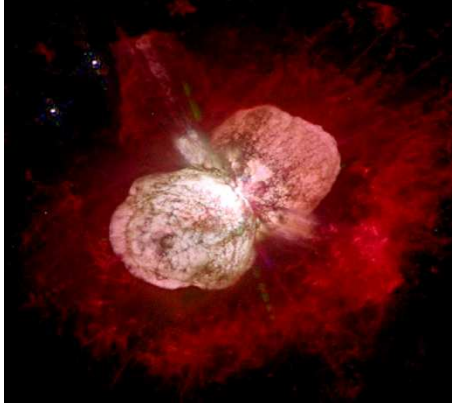
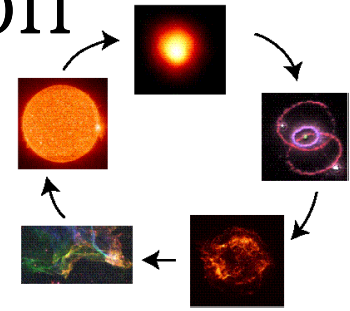
A(Z)



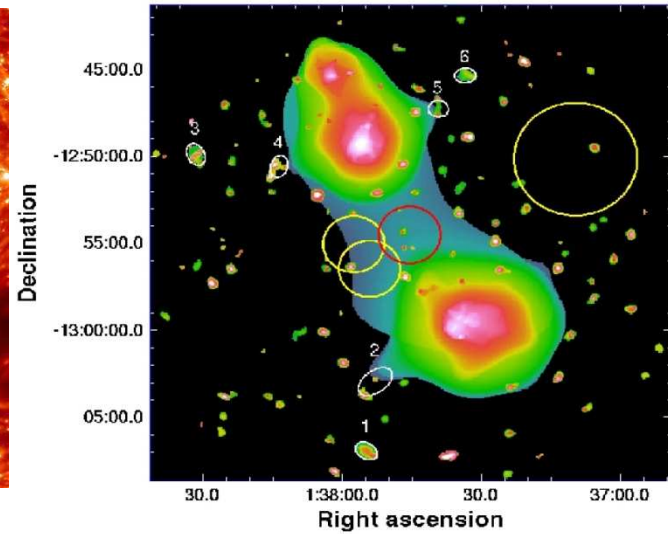
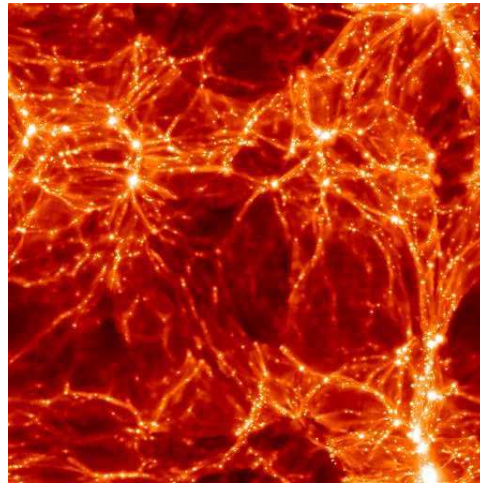
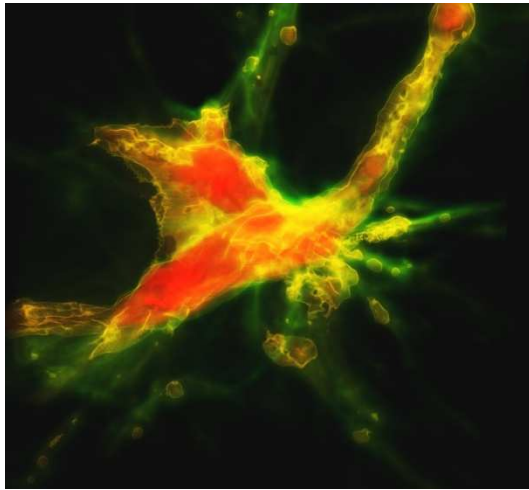
20% - 40%  
“Missing”  
Baryons



# Production and Distribution

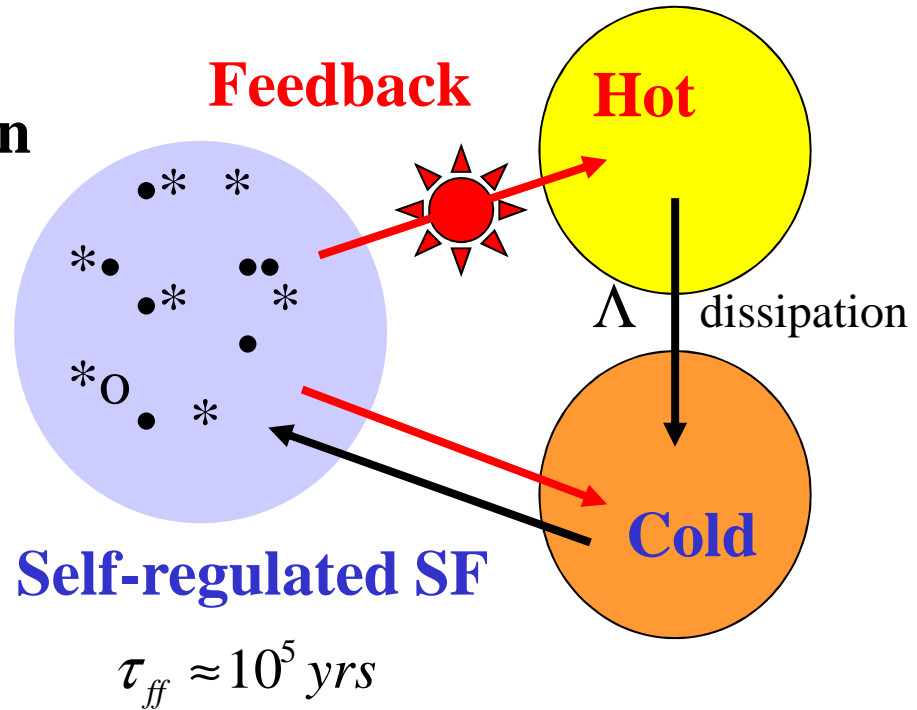
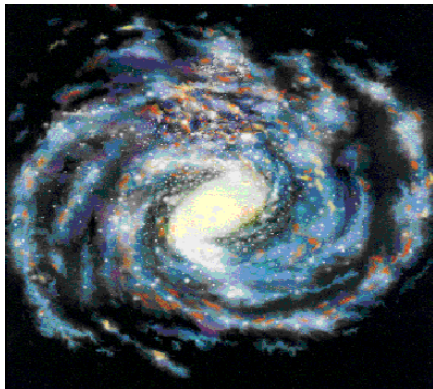


Tom Thum/Max-Planck-Institute for Astrophysics, Germany



- Galactic and/or Cosmic Chemo-Dynamic Evolution

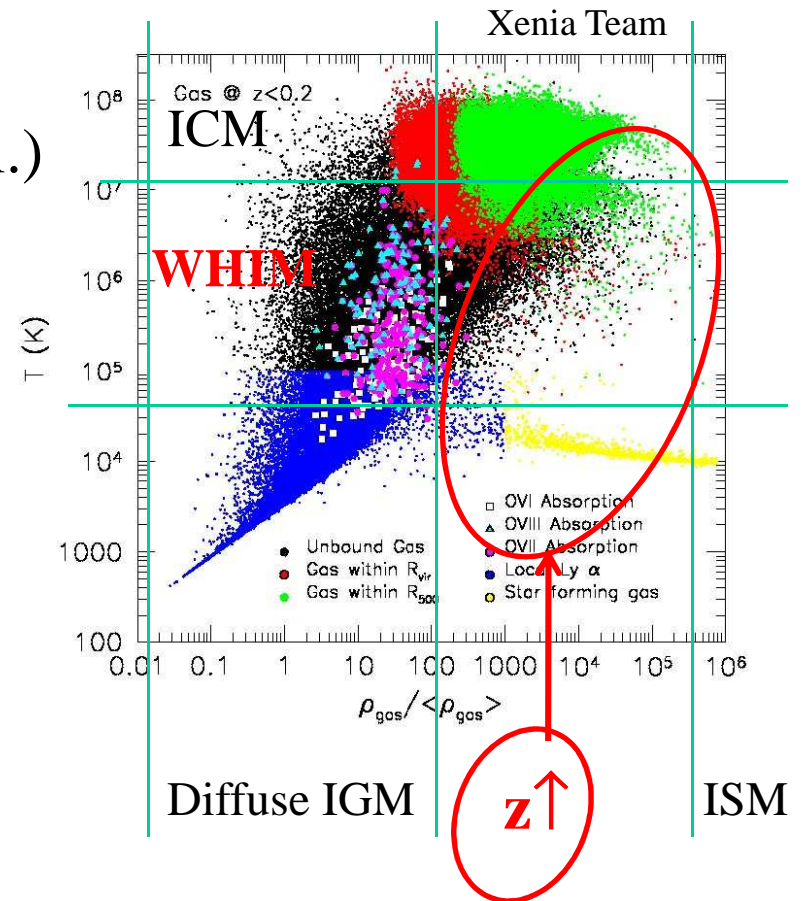
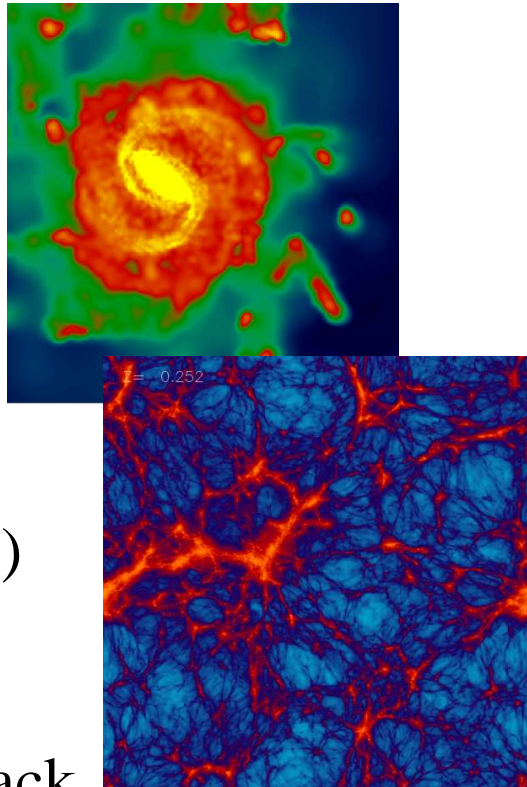
$$\tau_{ff} \propto (G\rho)^{-1/2} \approx 10^8 \text{ yrs}$$





**Simulations:** e.g., OWLS (Schaye et al.)  
 & several other collaborations:  
 SPH+N-body (GADGET +)

- ΛCDM
- SF law (z)
- IMF (z)
- PopSyn (z)
- Yields (z)
- Cooling (z)
- Feedback (z)
- EBL(z)
- Ionization
- AGN feedback

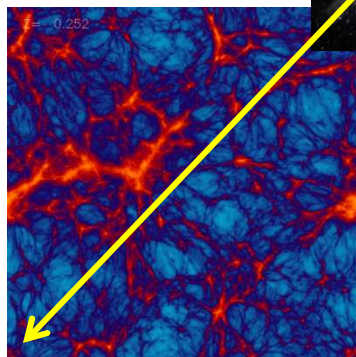
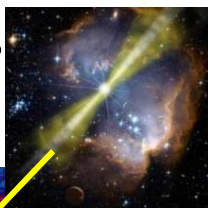


**Metals in lower density IGM was ejected earlier and by lower mass halos.**

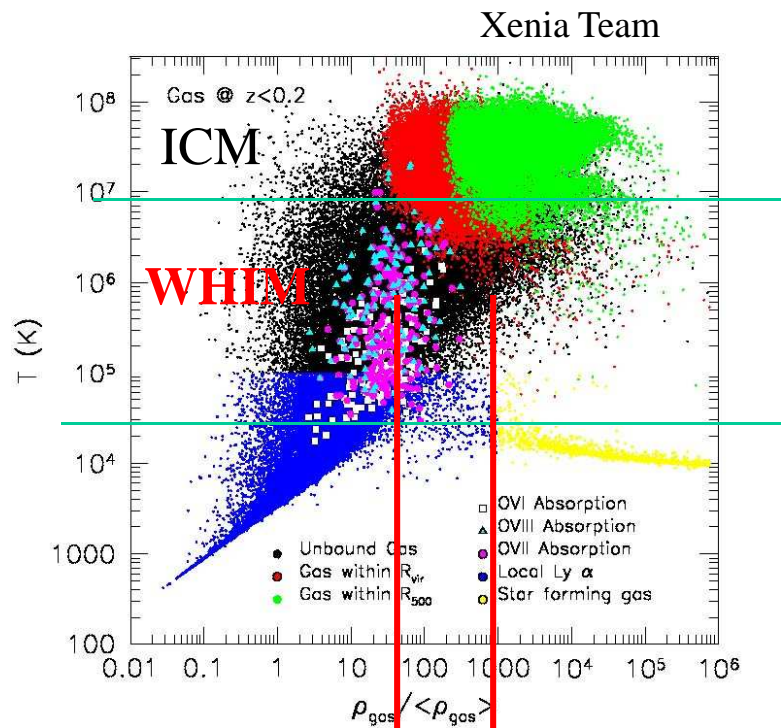
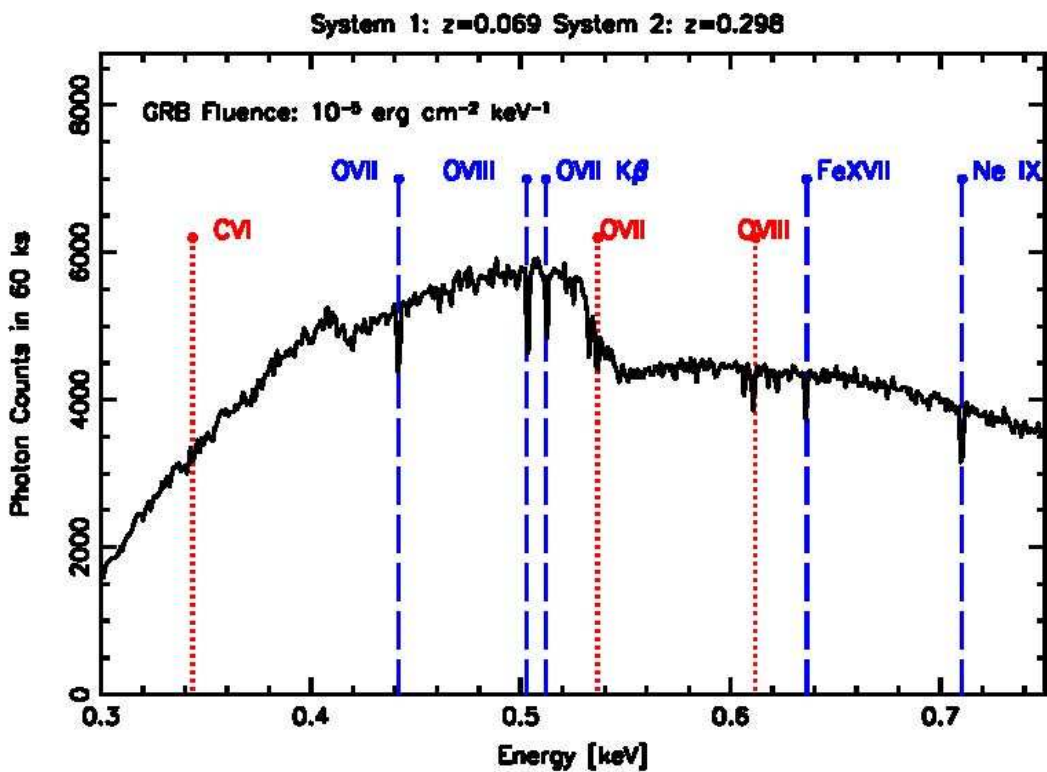
**Dynamic mixing times are important, & fallback = f(M<sub>halo</sub>) plays a role.**

- Numerical resolution still insufficient to address role of small galaxies
- Observational tests: Abundance ratios as f(z), but yields are uncertain!

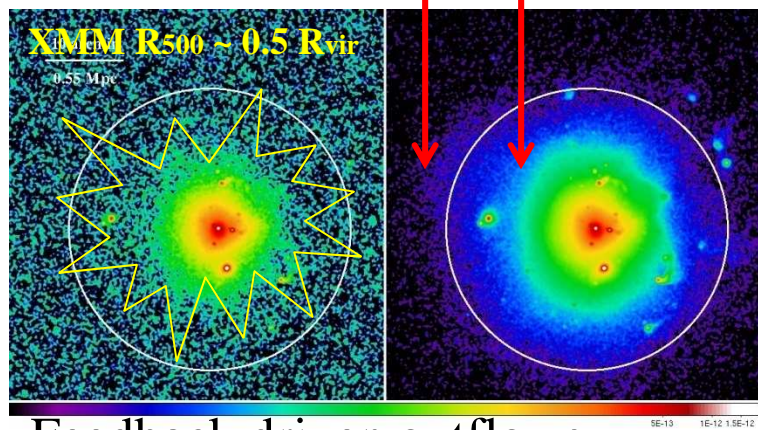
Probing high- $z$  proto-galaxies,  
and the local “missing”  
Baryons.



**High Resolution  
X-ray Spectra of  
GRB afterglows**



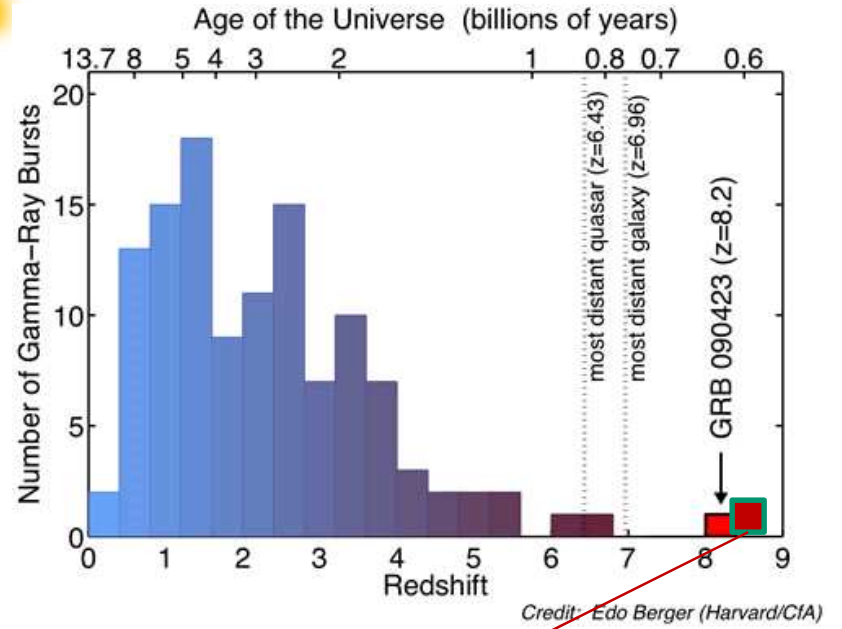
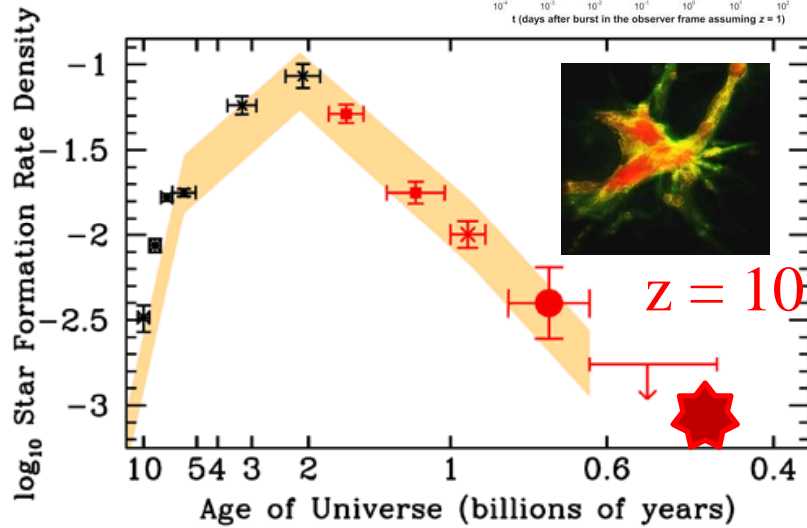
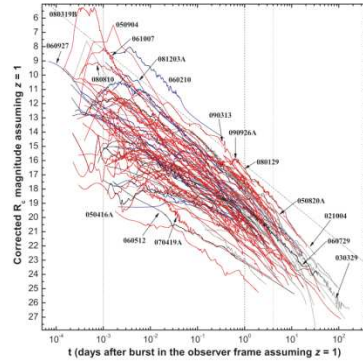
**Clusters are baryon traps, ...  
Emission imaging beyond  $R_{\text{virial}}$**



Feedback driven outflows  
e.g., Rasheed, Bahcall, and Bode 2010

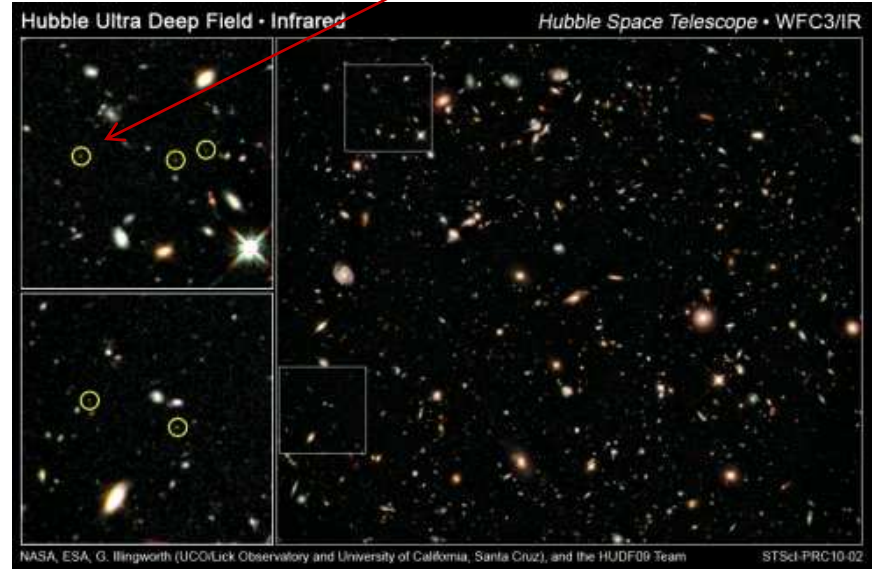


**GRBs opportunities should not be wasted!**



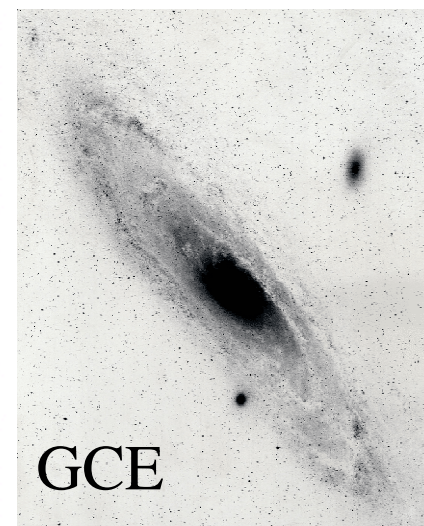
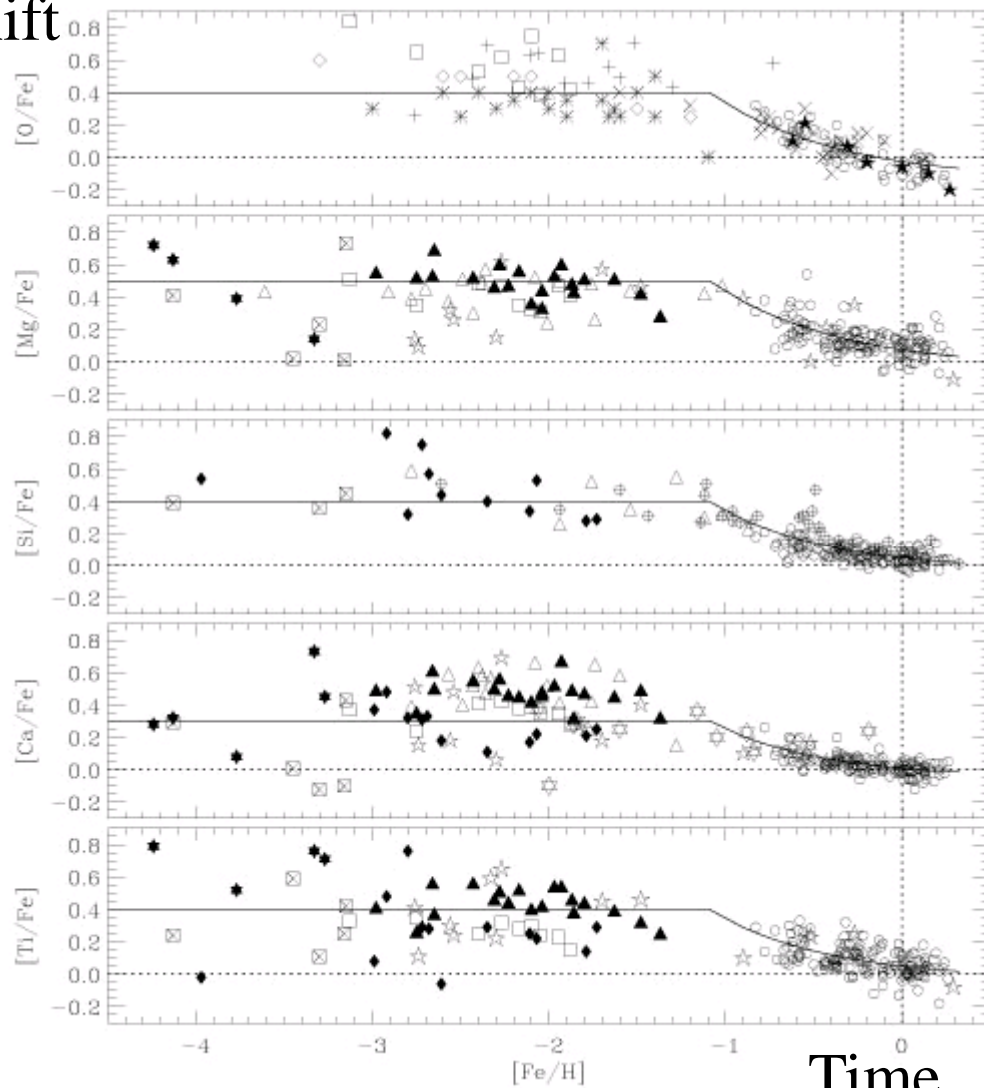
HST: Bouwens et al. 2010 Candidates  
 VLT: Lehnert et al. 2010:  $z = 8.6$

**Star formation 500 Myrs after the big bang.**



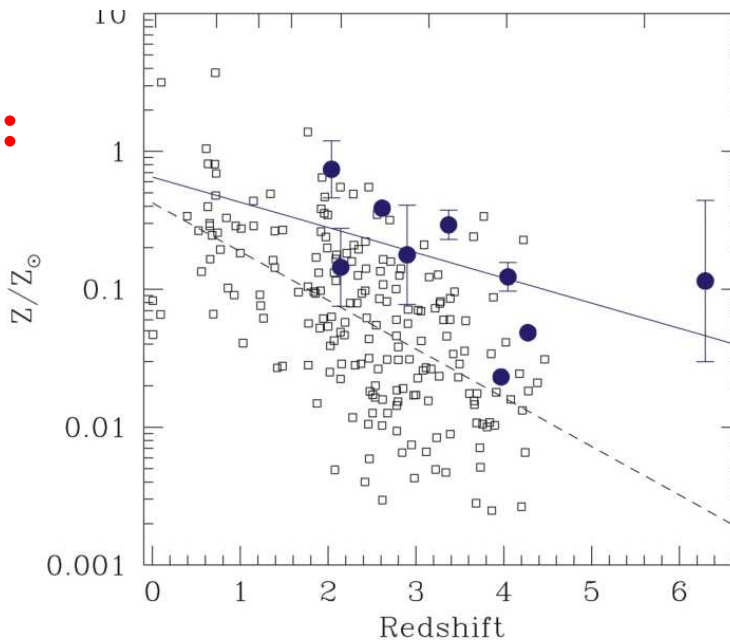


$z(t)$  ← Lookback time  
redshift

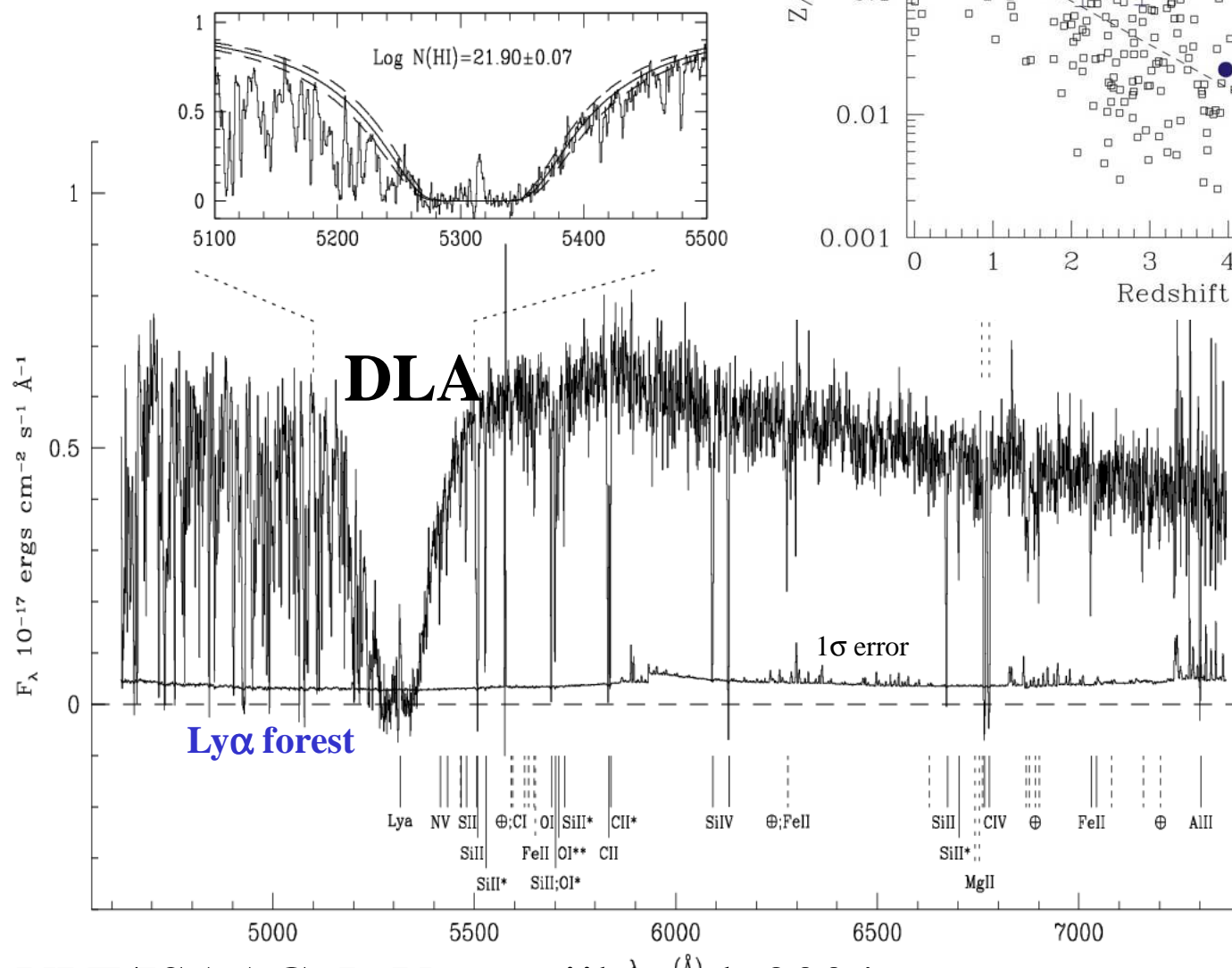


Time →  
metallicity  $Z(t)$

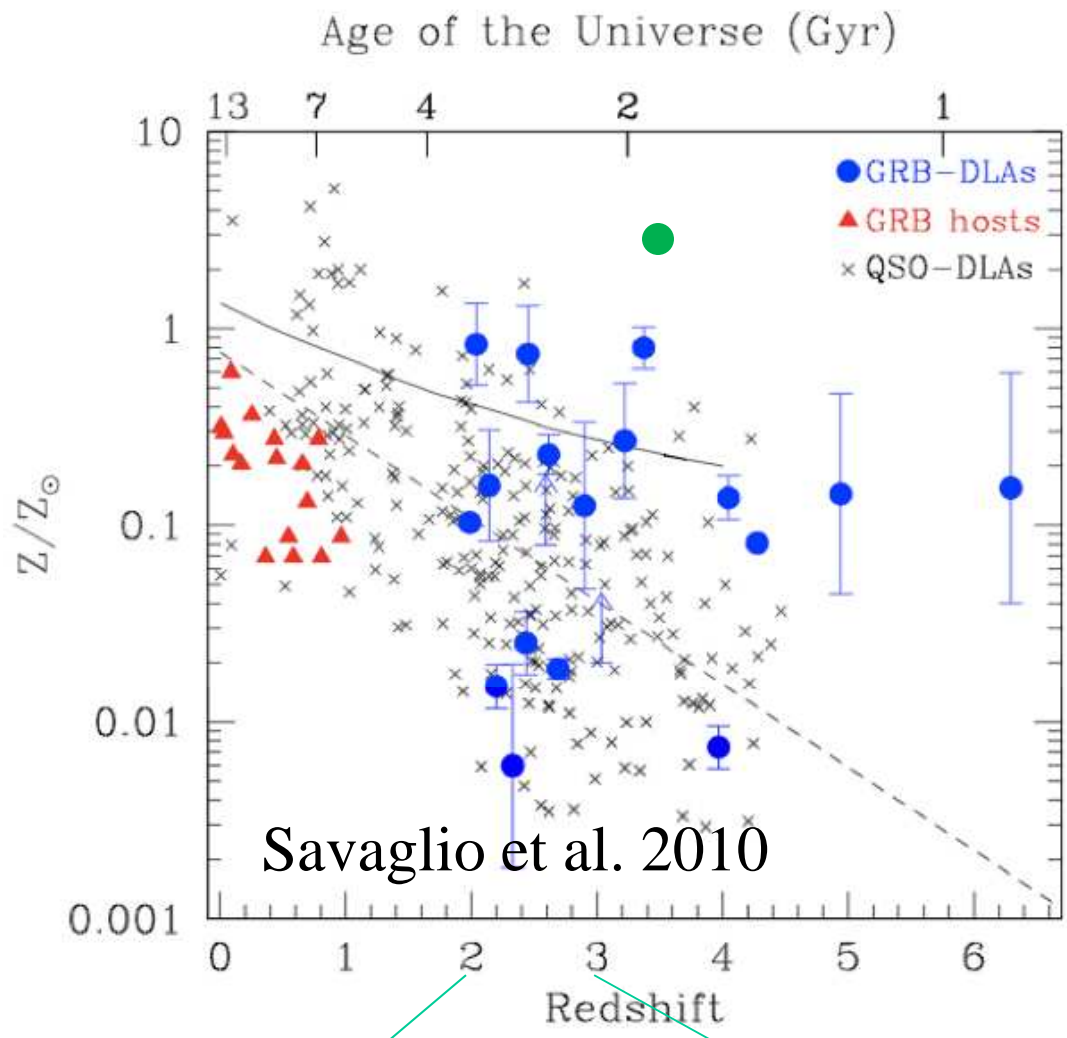
- Cosmic Chemical Evolution:  
Taking advantage of GRBs**



**JWST  
24 hrs**

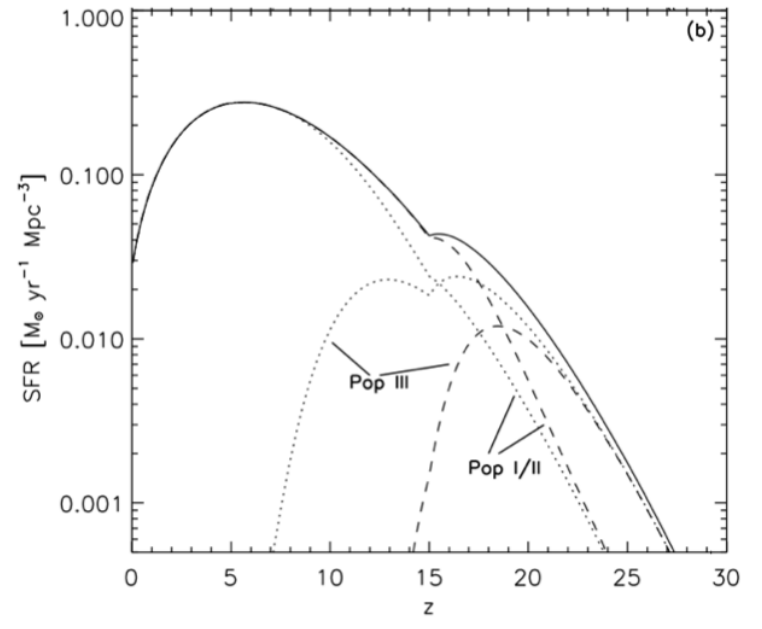
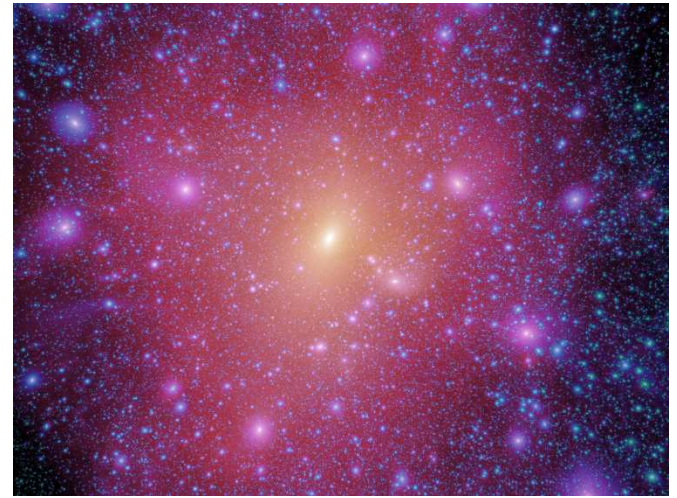


VLT/ISAAC: P. Vreeswijk et al. 2004



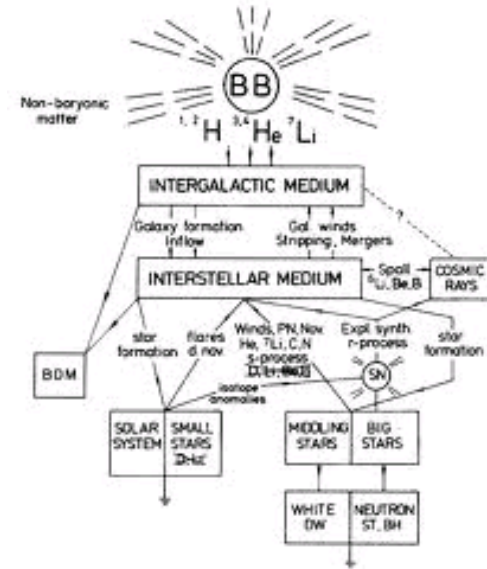
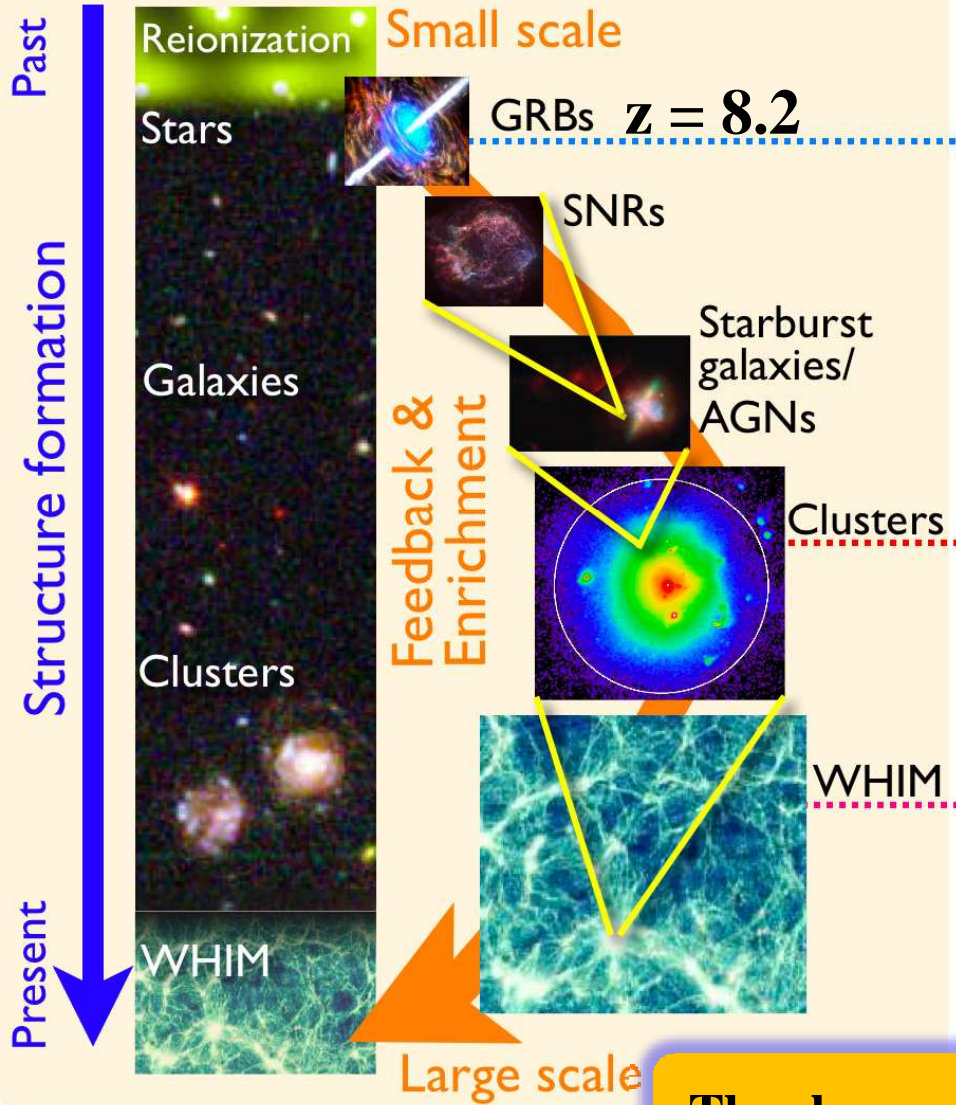
**“Near Field  
Cosmology”**

The Durham theoretical cosmology group





# Evolution of the Universe



"Future Studies to Address Open GRB Questions and GRBs as Probes".

What are the key open areas for GRBs prompt and afterglow emission?

What the key open areas for central engines and hosts?

What are the opportunities to use GRBs to understand the universe?

What theory challenges the lie ahead?

What new capabilities are coming for ground and space?

Thank you