Observational Constraints on Reionization History

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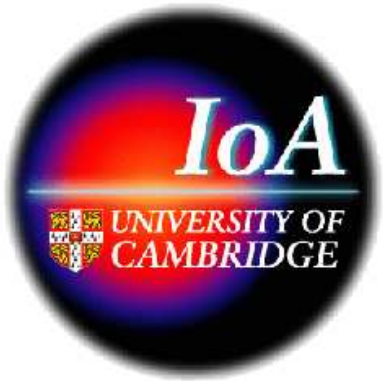


HI Survival through Cosmic Times, Sarteano, 11 June 2007

Plan of the talk

0. Motivation: Given the variety in observational data, it is important to have theoretical models which can be compared with all the sets simultaneously.

I. Description of the model

II. Comparison with observations

III. Predictions and future

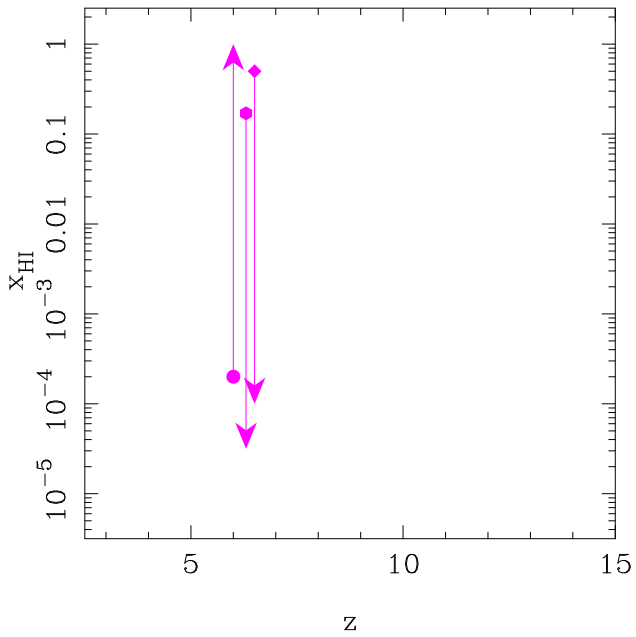
Features of the semi-analytical model **Choudhury** & Ferrara (2005,2006)

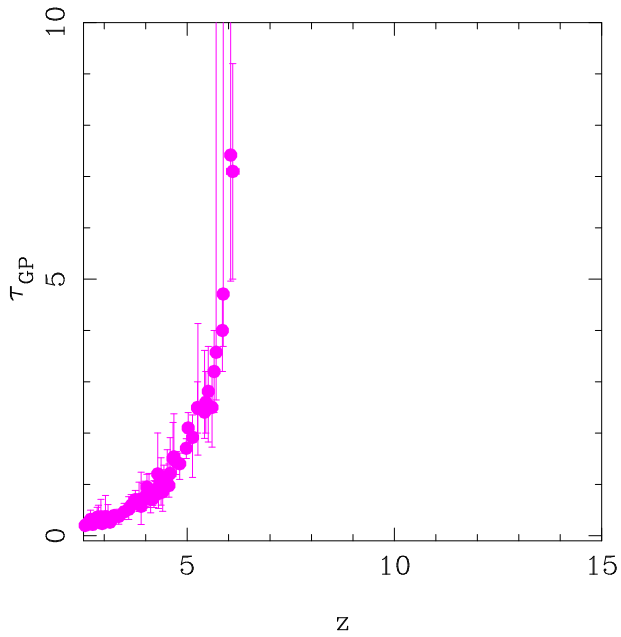
- Standard FRW paradigm with ΛCDM model – **hierarchical structure formation** dominated by dark matter
- Follow ionization and thermal histories of neutral, HII and HeIII regions simultaneously. Treat the IGM as a multi-phase medium.
- Take into account various stages of reionization
  Miralda-Escude, Haehnelt & Rees (2000)
- Three sources of ionizing radiation:
  1. PopIII stars: early redshifts, low metallicity
  2. PopII stars: normal stars, transition from PopIII via chemical feedback
  3. Quasars: significant at $z \lesssim 6$
- Radiative feedback suppressing star formation in low-mass haloes
- Chemical feedback changing the nature of stars
  Schneider et al. (2006)
- Constrain the free parameters from observations $\Longrightarrow$ determine which reionization histories are favoured by current data.

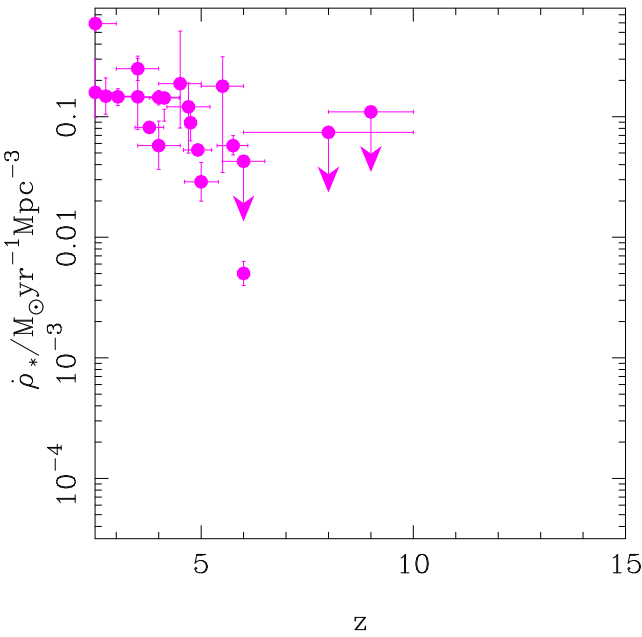
Free parameters and uncertainties

- Star-forming efficiency
- Escape fraction
- Mean free path of photons
- Stellar initial mass function
- Molecular cooling
- Feedback

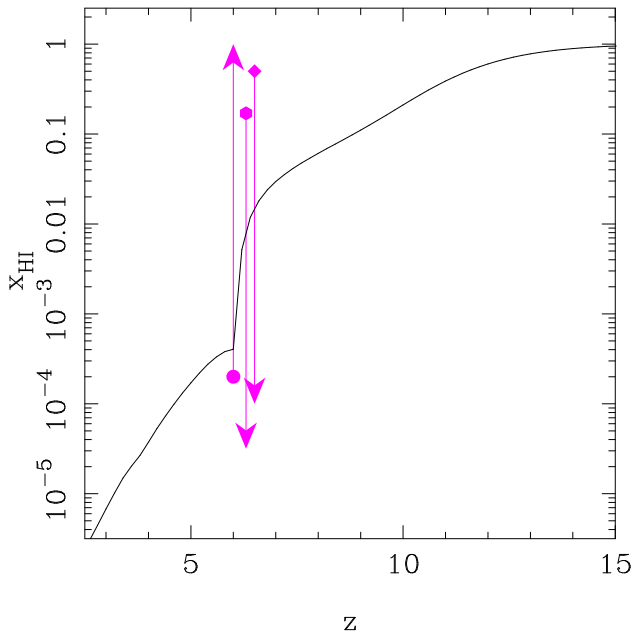
Matching the observations

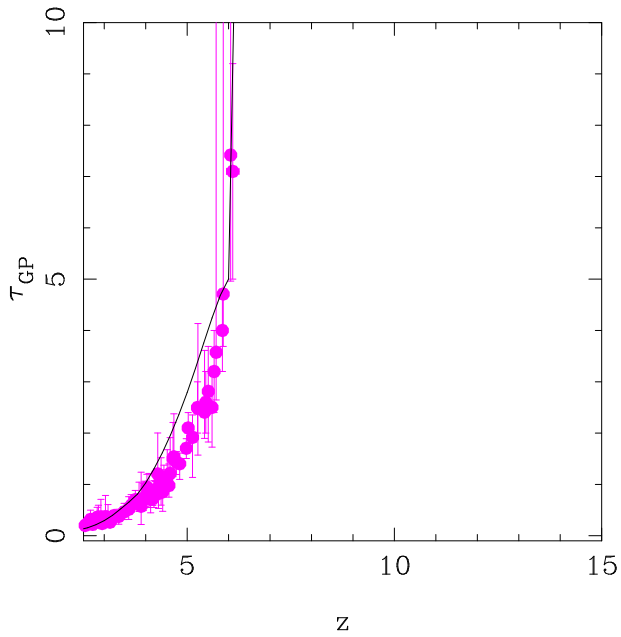


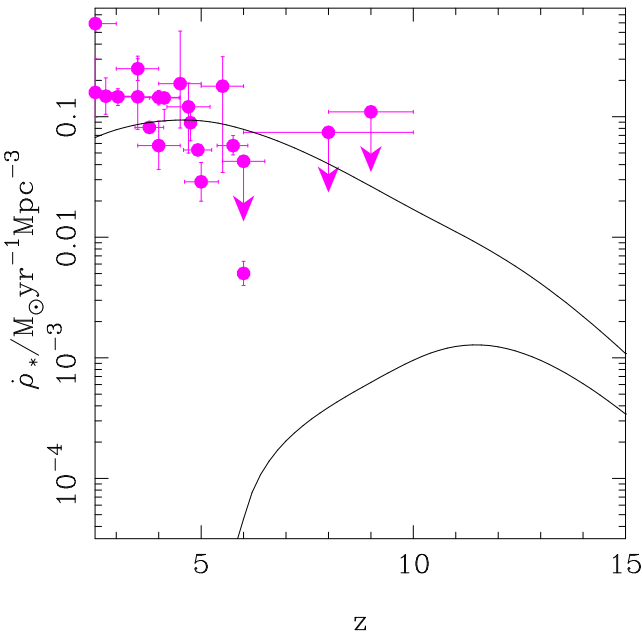




Matching the observations

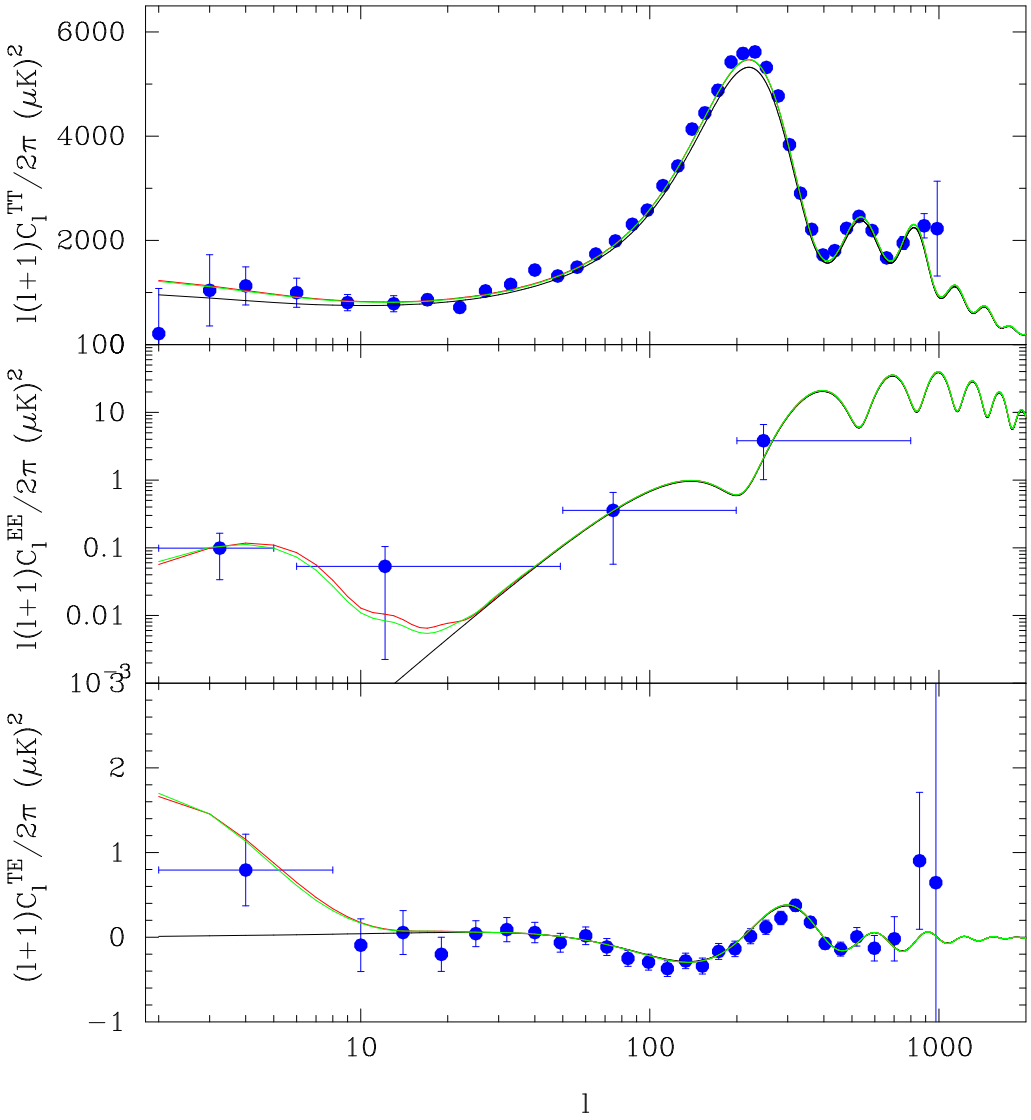




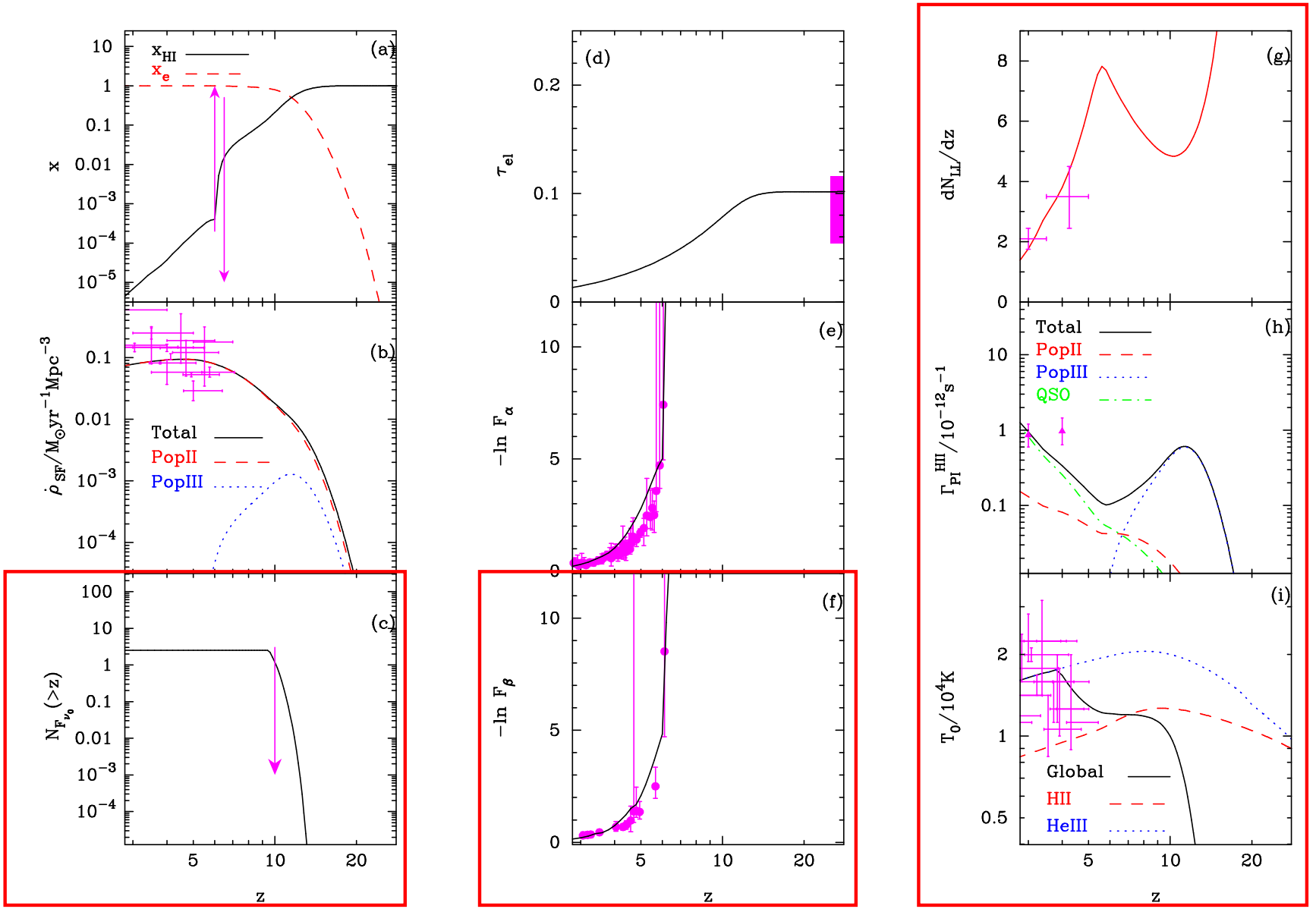


CMB predictions

$\tau_{\rm el} = 0.10$



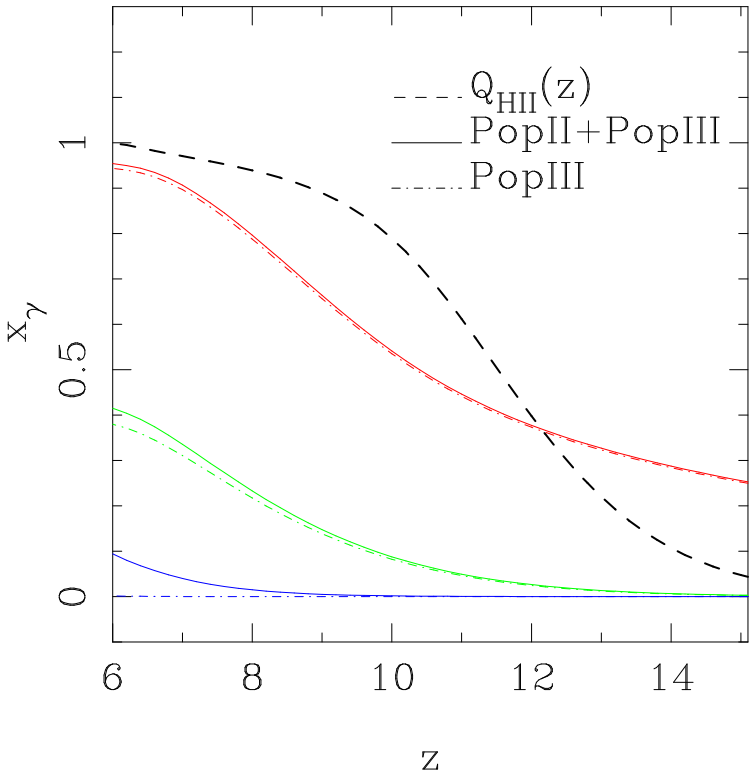
Additional observations

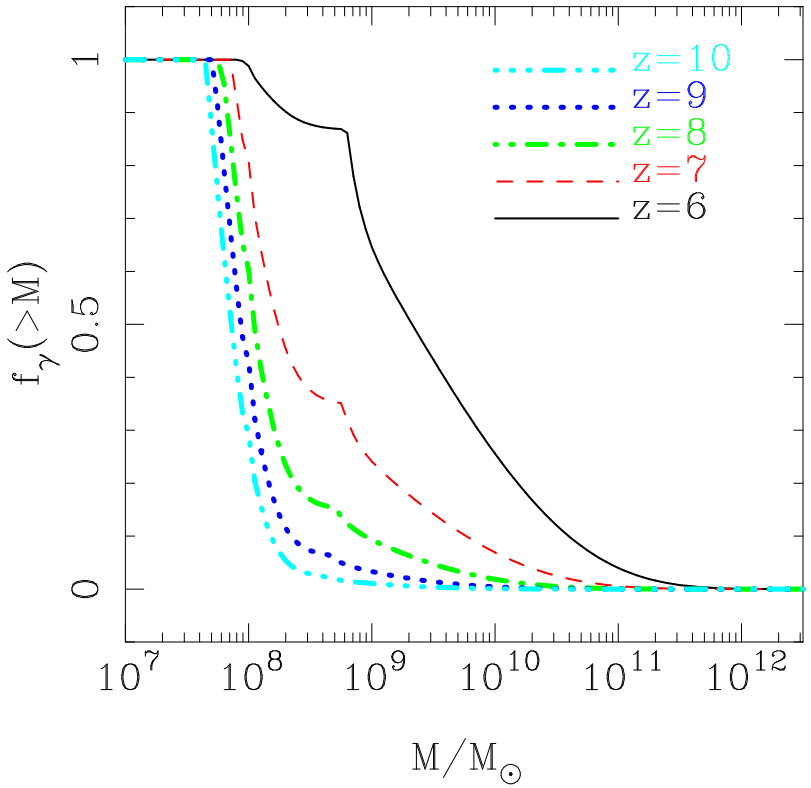


Constraints on reionization history

$$x_\gamma(z) \equiv \frac{n_\gamma(z)}{n_H}\frac{t_{\rm rec}(z)}{t_H(z)}$$

$$f_\gamma(>M,z) \equiv \frac{\dot{n}_\gamma(>M,z)}{\dot{n}_\gamma(z)}$$



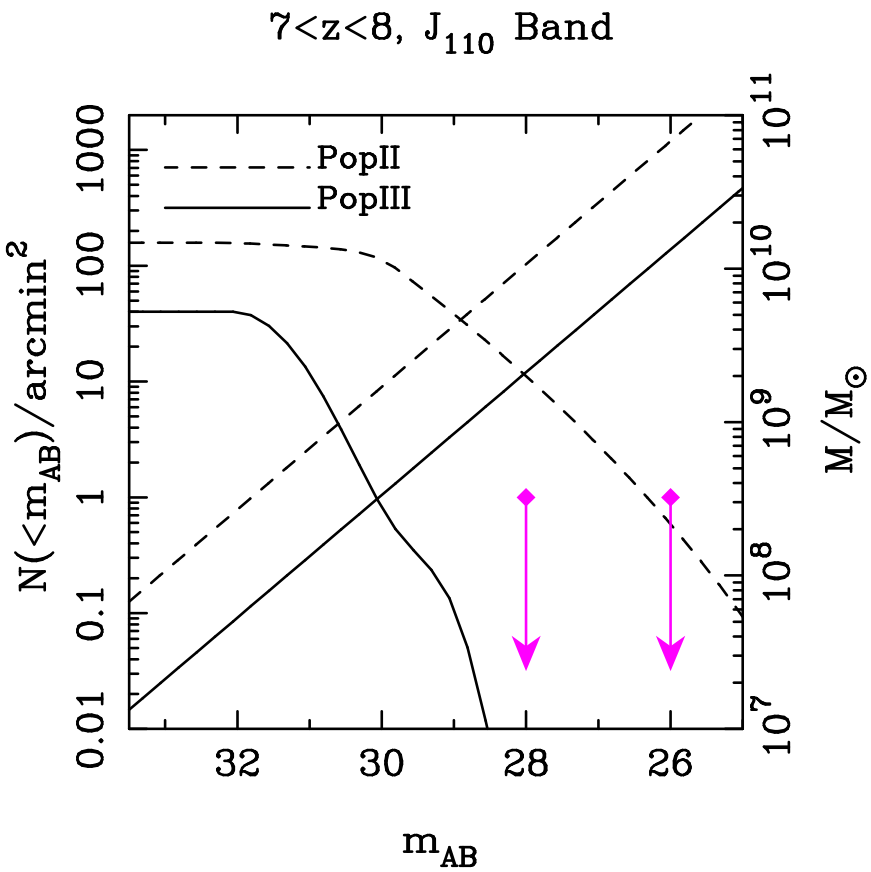


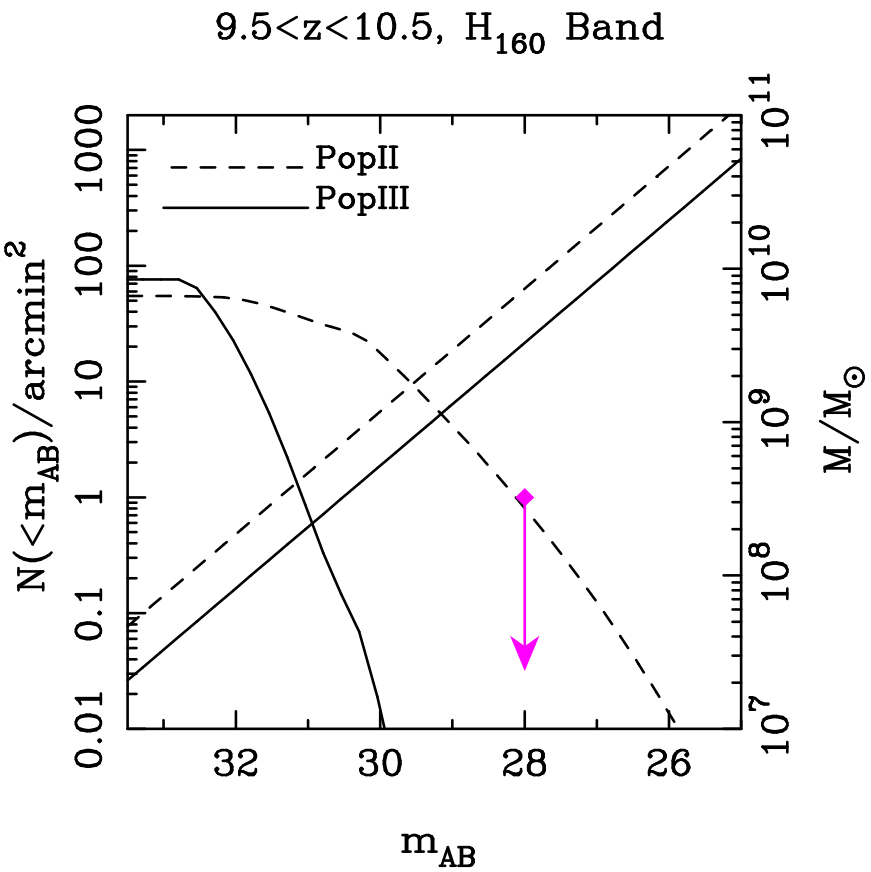
$10^7 M_\odot < M < 10^8 M_\odot$

$10^8 M_\odot < M < 10^9 M_\odot$

$M > 10^9 M_\odot$

Source counts at $z \approx 7 - 10$ **Choudhury** & Ferrara (2007)





Closer look into $z \sim 6$

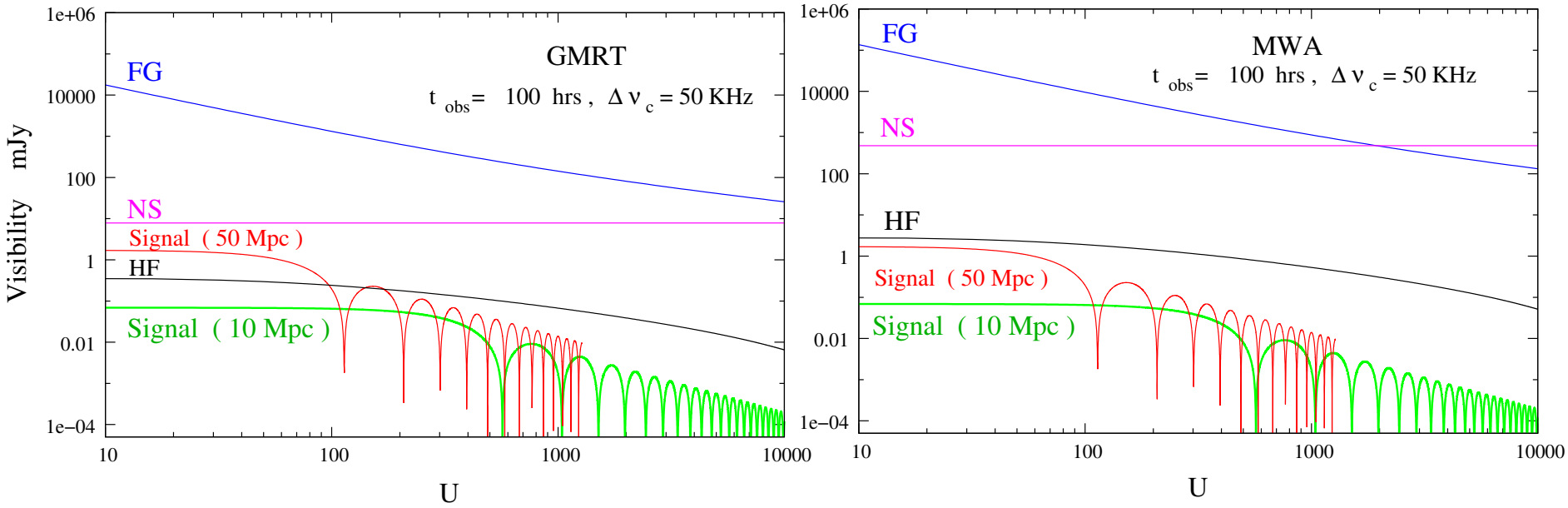
- We predict $x_{\rm HI} \lesssim 0.1$ at $z \approx 6 \Longrightarrow$ consistent with $\tau_{\rm GP}$, Lyα emitters and GRB spectra
- Large absorption gaps seen in the QSO absorption spectra $\Longrightarrow x_{\rm HI} < 0.36$ Gallerani, Ferrara, Fan & **Choudhury** (2007)
- Consistent with the constraints from sizes of HII regions around QSOs, though uncertainties remain Maselli, Gallerani, Ferrara & **Choudhury** (2007)

HII bubbles in 21 cm maps Datta, Bharadwaj & **Choudhury** (2007)

Visibility

$$V(\vec{U},\nu) = \int d^2\theta\ A(\vec{\theta})\ I_\nu(\vec{\theta})\ \mathrm{e}^{2\pi \mathrm{i}\vec{\theta}\cdot\vec{U}}$$

$$\sqrt{\langle V(\vec{U},\nu) V^*(\vec{U},\nu+\Delta\nu_c)\rangle}$$



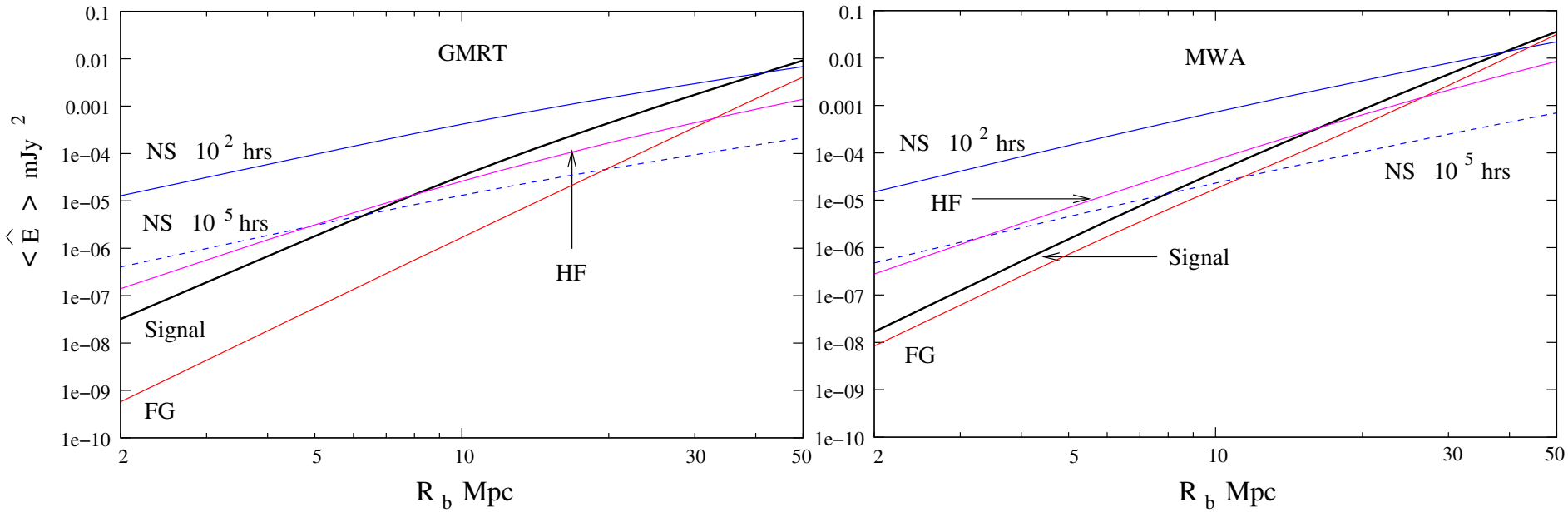
Bubble signal (50 Mpc), Bubble signal (10 Mpc), Foregrounds (EG point sources + galactic synchrotron), Antenna noise, HI fluctuations

HII bubbles in 21 cm maps Datta, Bharadwaj & **Choudhury** (2007)

Match filter

$$\hat{E} = \int d^2U \int d\nu \, \rho_N(\vec{U},\nu) \; S_f{}^*(\vec{U},\nu) \hat{V}(\vec{U},\nu)$$

$$S_f(\vec{U},\,\nu) = S(\vec{U},\,\nu) - \frac{\Theta(2 \mid \nu - \nu_c \mid /B')}{B'} \int_{\nu_c - B'/2}^{\nu_c + B'/2} S(\vec{U},\nu')\,\mathrm{d}\nu'$$



Bubble signal (50 Mpc), Foregrounds, HI fluctuations, Antenna noise

Summary: constraints on reionization history

- Hydrogen reionization around $z \approx 15$ driven by PopIII stars, 90% complete by $z \approx 9$.
- Main contributors to early reionization are the PopIII stars within $M < 10^8 M_\odot$ haloes, possible to detect by JWST
- The PopIII stars decay below $z \sim 10$ because of **feedback** $\Longrightarrow$ reionization is extended; completes only at $z \approx 6$.
- Constraints require non-zero contribution from metal-free stars. Non-inclusion of PopIII stars would require larger contribution from PopII stars to match the WMAP $\tau_{\rm el}$, which would then violate the GP optical depth constraints.
  Re-revision of $\tau_{\rm el}$ could prove significant for PopIII star contribution
- Model consistent with properties of QSO spectra (gaps, size of HII bubble) at $z \approx 6$.
- Future: detecting the HII bubbles within 21 cm maps; matched filtering technique for foreground separation.