Small-scale clumping of dark matter and the mean free path of ionizing photons at $z = 6$

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Small-Scale Clumping in DM Models

- Collisionless CDM (e.g. WIMP) clumps at $10^{-6} M_{\odot}$ scales
- Well-motivated alternatives share a suppression (or enhancement) of power on small scales relative to CDM

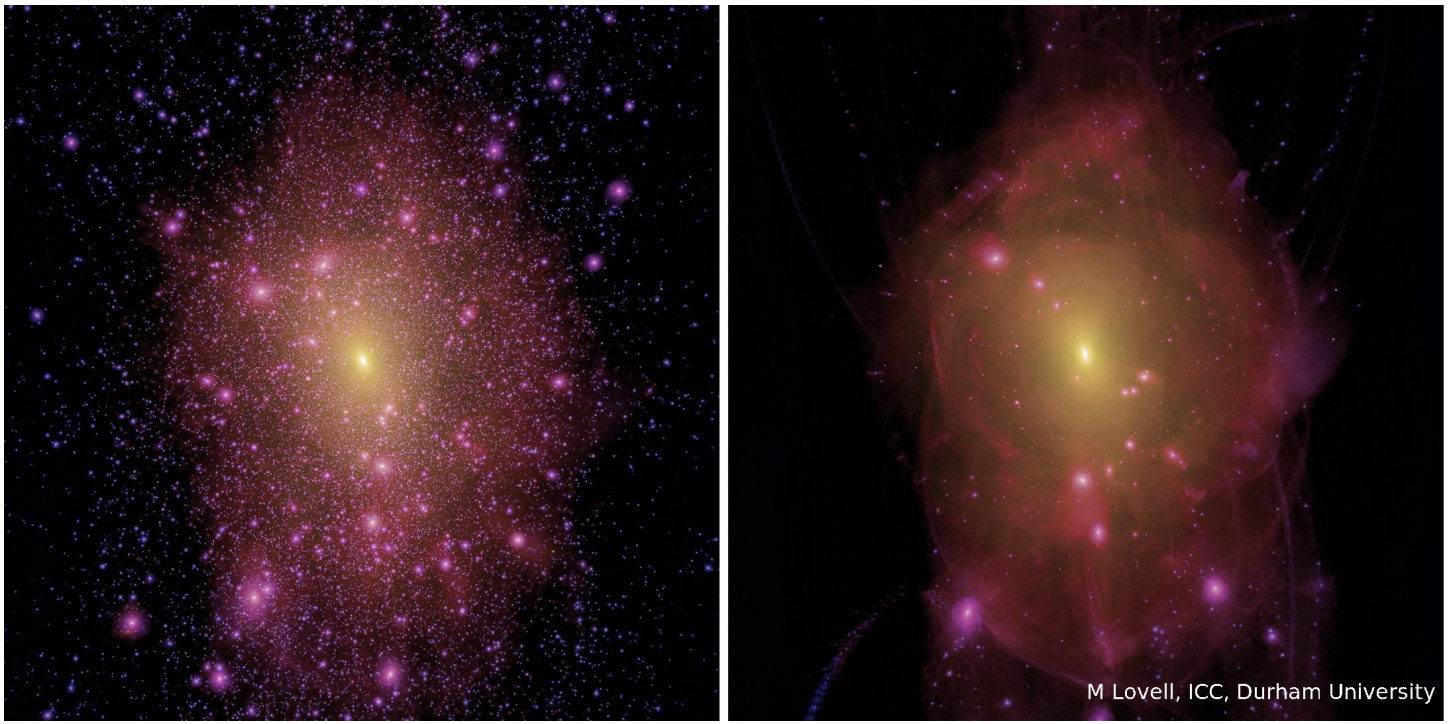
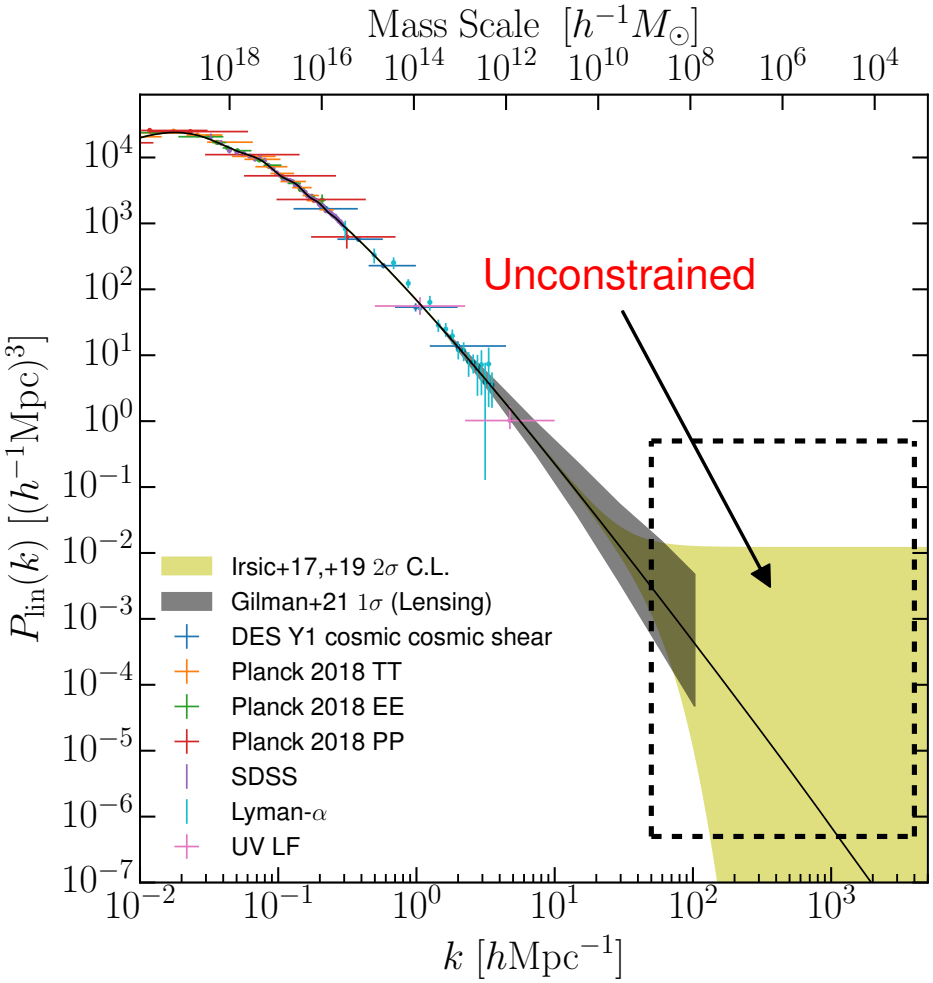


Figure: Lovell+14

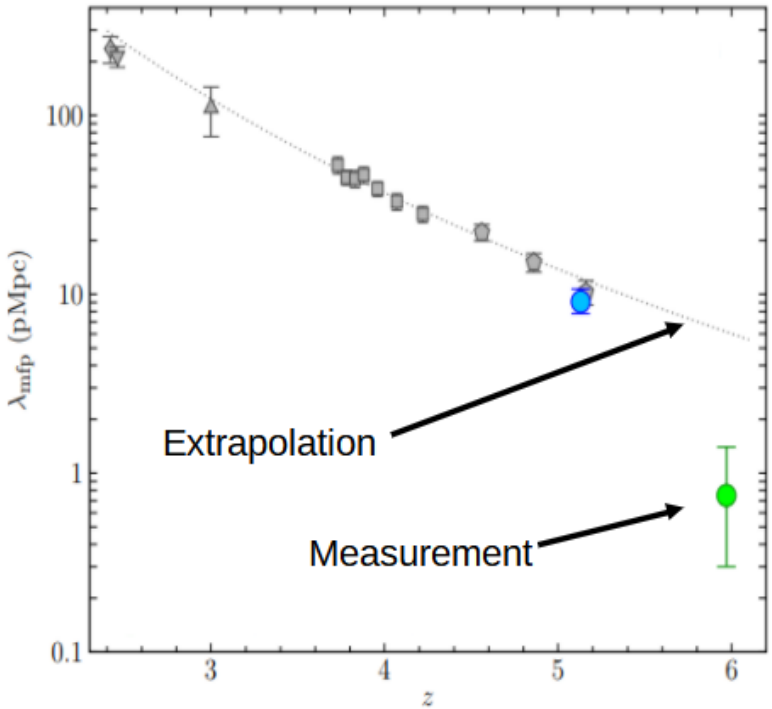
Cosmological Constraints on DM

- Lyα forest constraints: $k \approx 1 - 10\ h\mathrm{Mpc}^{-1}$
- Gravitational lensing can probe smaller scales (Gilman+22)
- At $k \gtrsim 50\ h\mathrm{Mpc}^{-1}$, constraints are model-dependent
- $\sim 10^4 - 10^8 M_\odot$ scales largely unconstrained

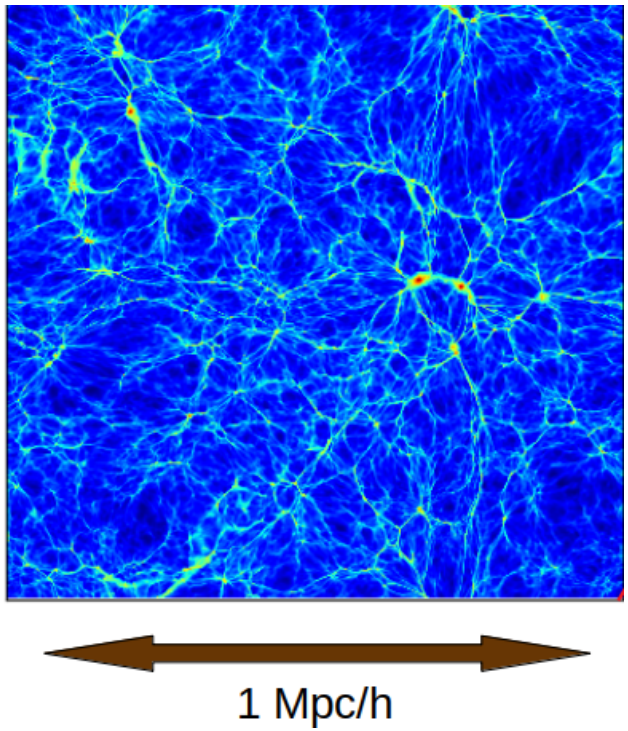


The Mean Free Path at $z = 6$

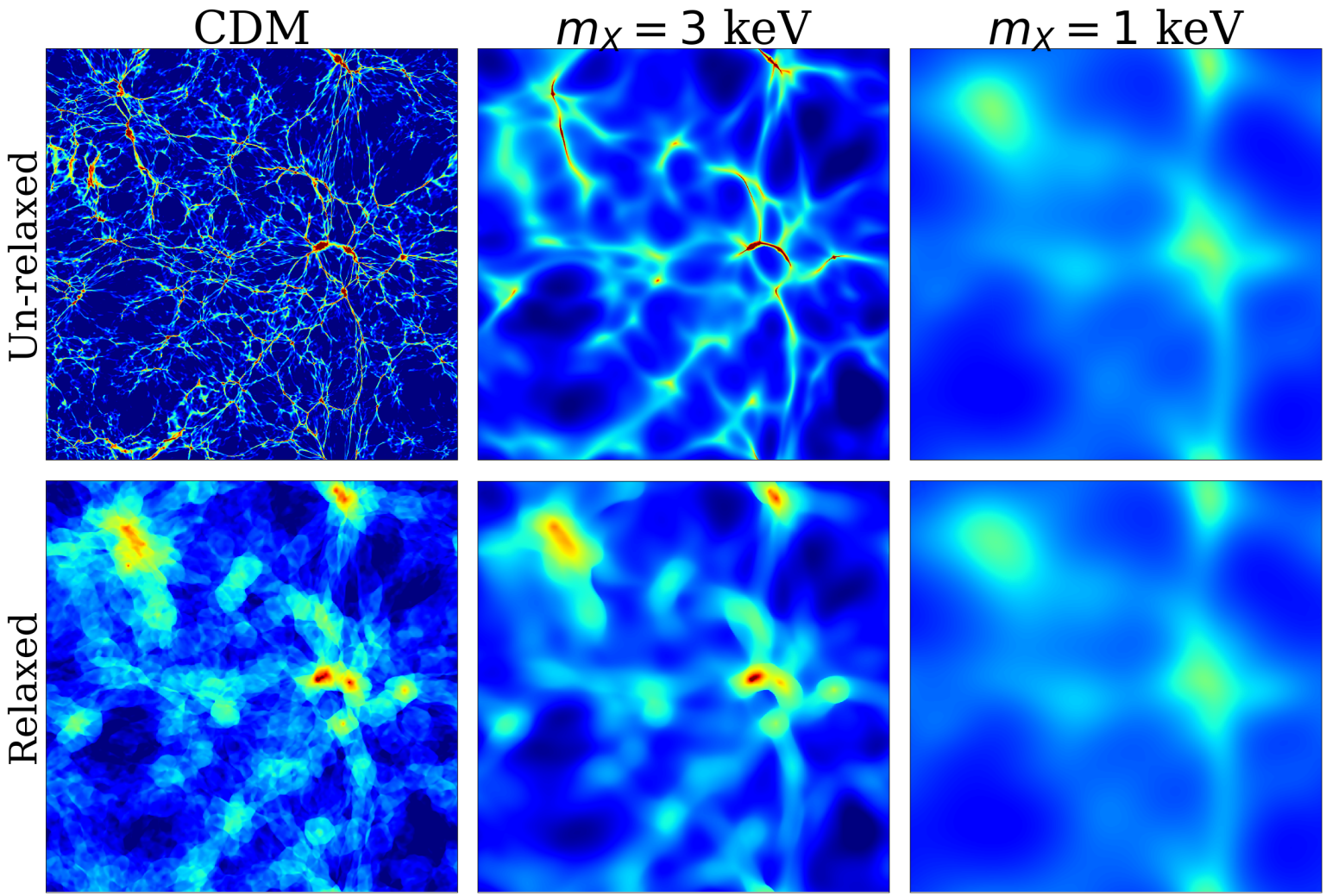
- Recent measurement at $z = 6$ (Becker+21) is much shorter than extrapolations from lower redshifts
- Opacity is affected by $10^4 - 10^8 M_\odot$ gas structures



Left Figure: Becker+21

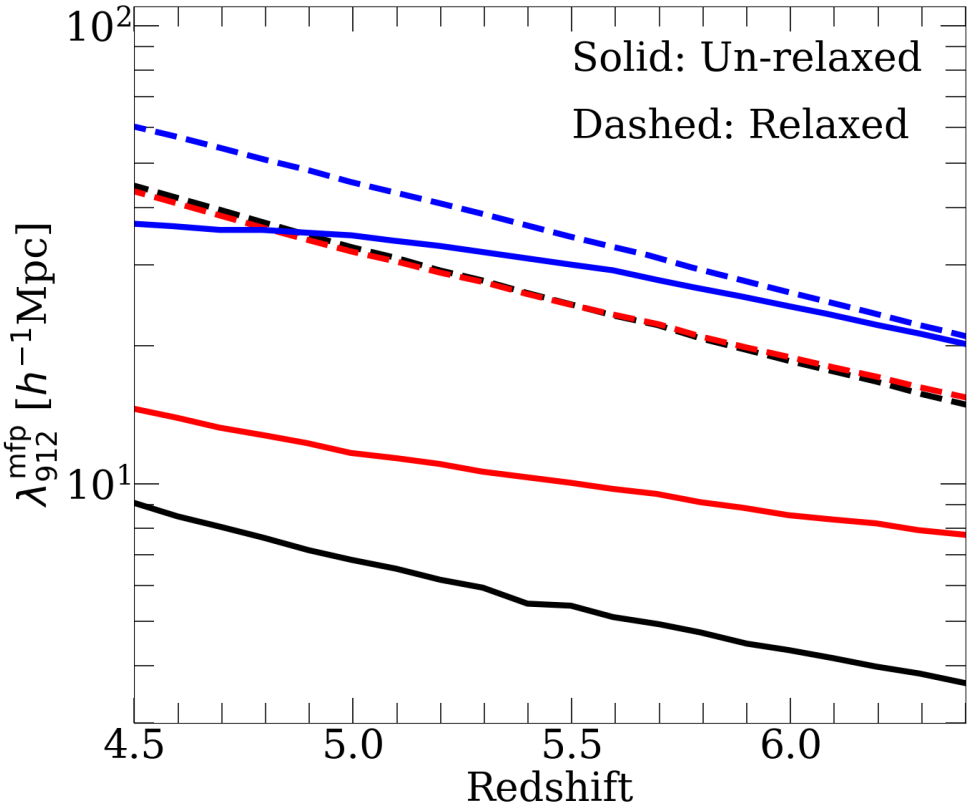


IGM Gas Dynamics in CDM vs. WDM



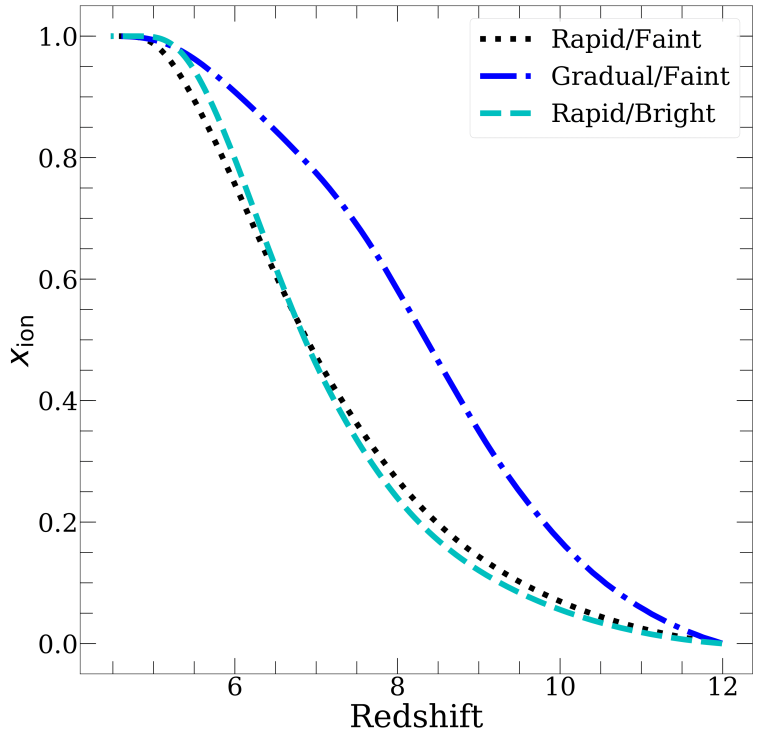
Mean Free Path Evolution

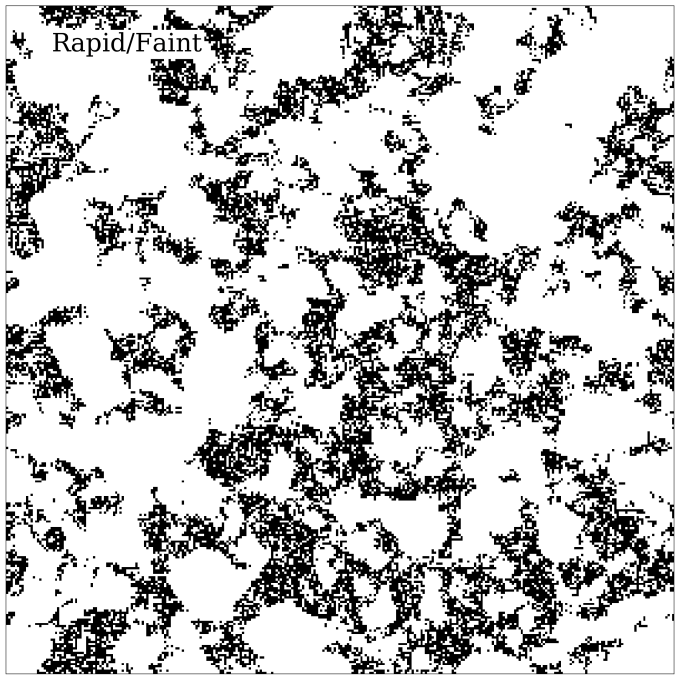
- Black: CDM
  Red: 3 keV WDM
  Blue: 1 keV WDM
- DM models differ considerably in recently ionized gas
- Pressure smoothing erases most of the structures responsible for the differences



Ongoing/Patchy Reionization

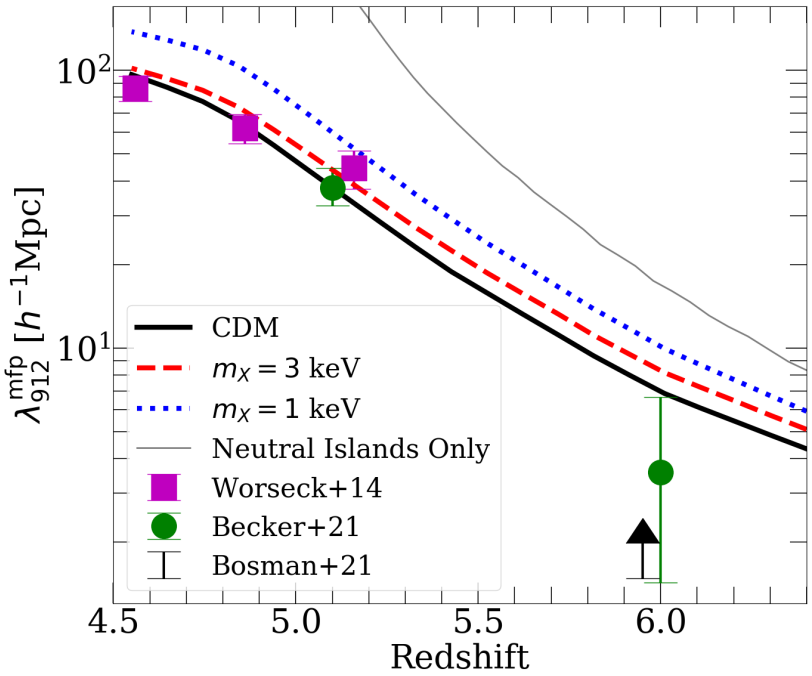
- Patchy reionization model to capture distribution of relaxed/un-relaxed ionized gas
- We model opacity due to neutral islands using RT results
- Several reionization scenarios

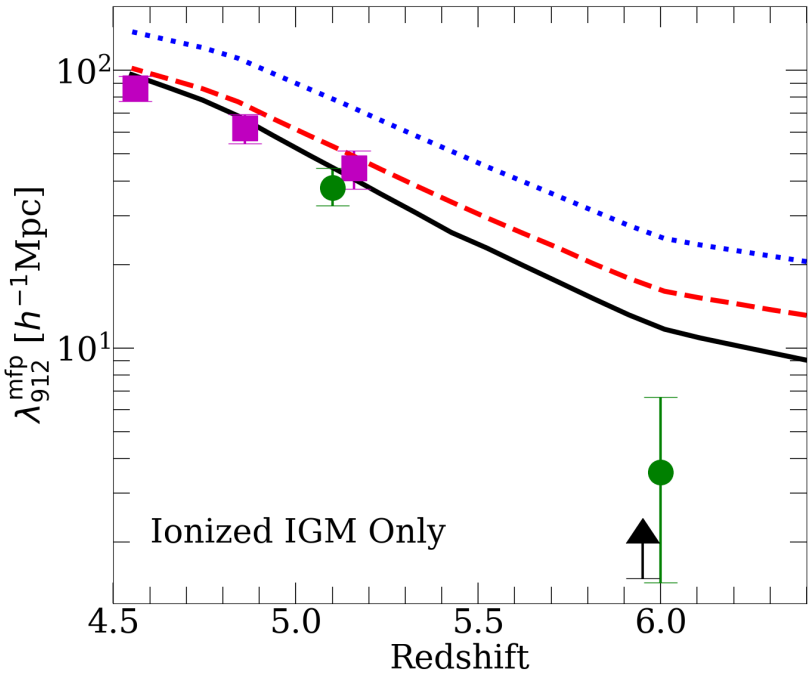




Results: Fiducial Scenario

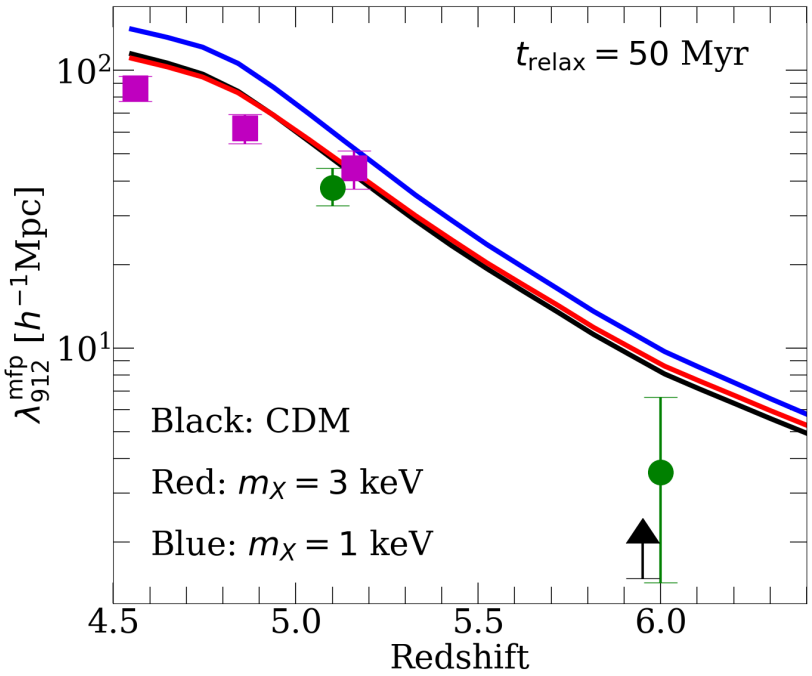
- Differences between DM models are modest at $z \leq 6$
- At $z \leq 5$, pressure smoothing erases differences with CDM
- At $z \approx 6$, neutral islands obscure differences

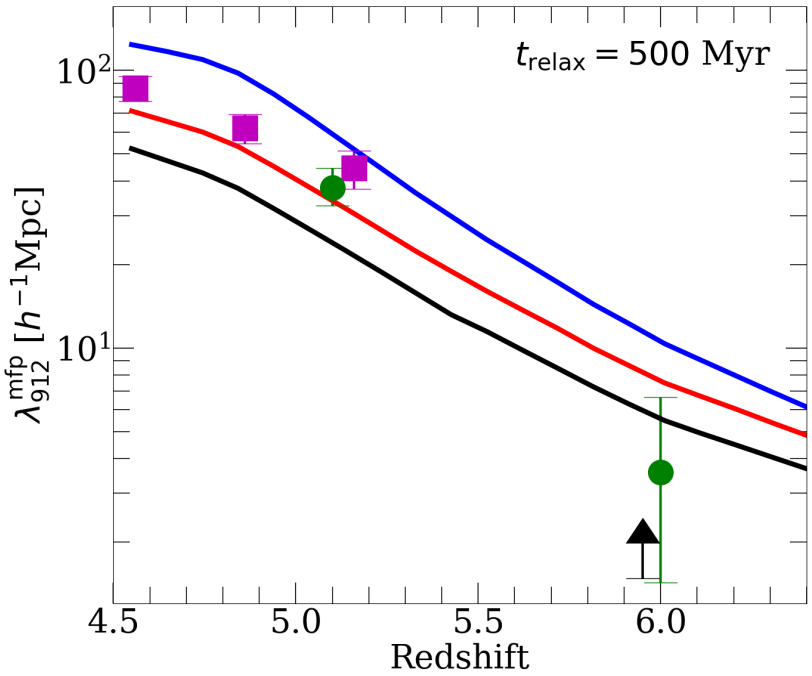




Effect of the "Relaxation" Timescale

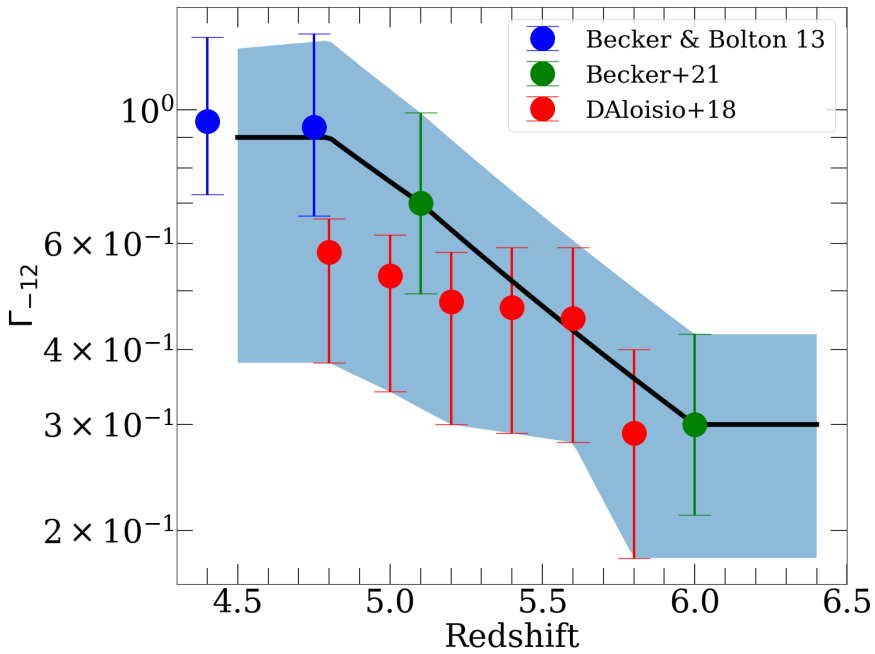
- Timescale over which IGM gas dynamically relaxes
- Larger $t_{\rm relax}$ enhances differences between DM models

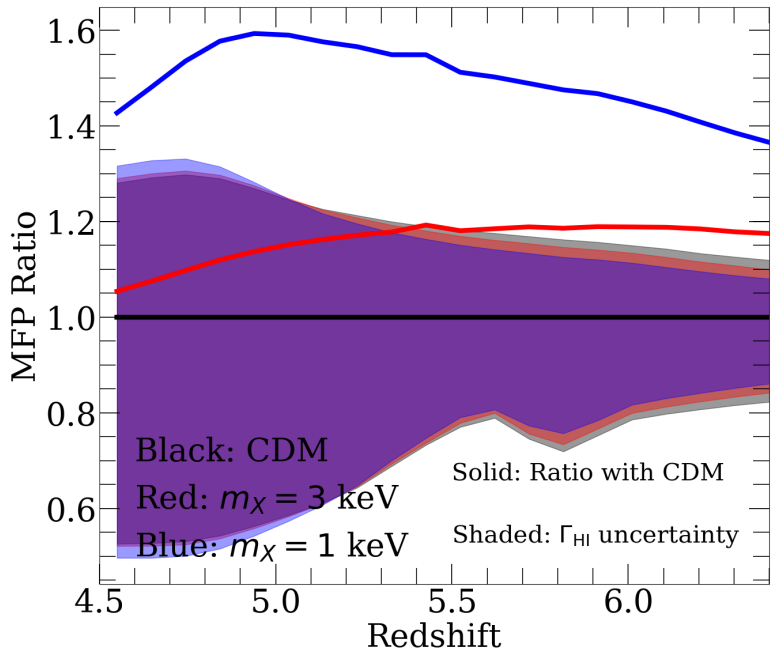




Effect of the Photo-ionization Rate

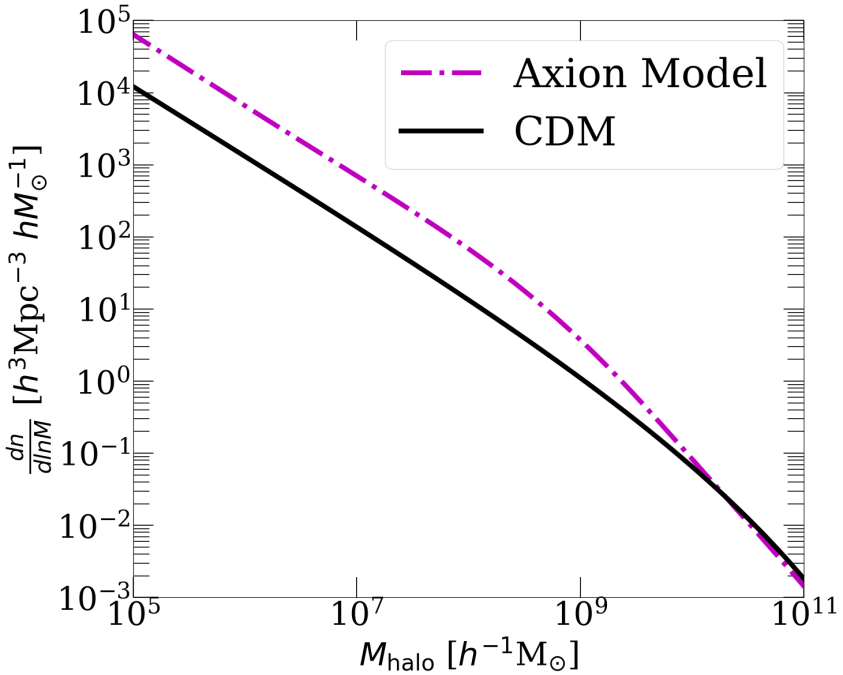
- The photo-ionization rate in ionized gas is highly uncertain
- Degenerate with the effect of the DM model

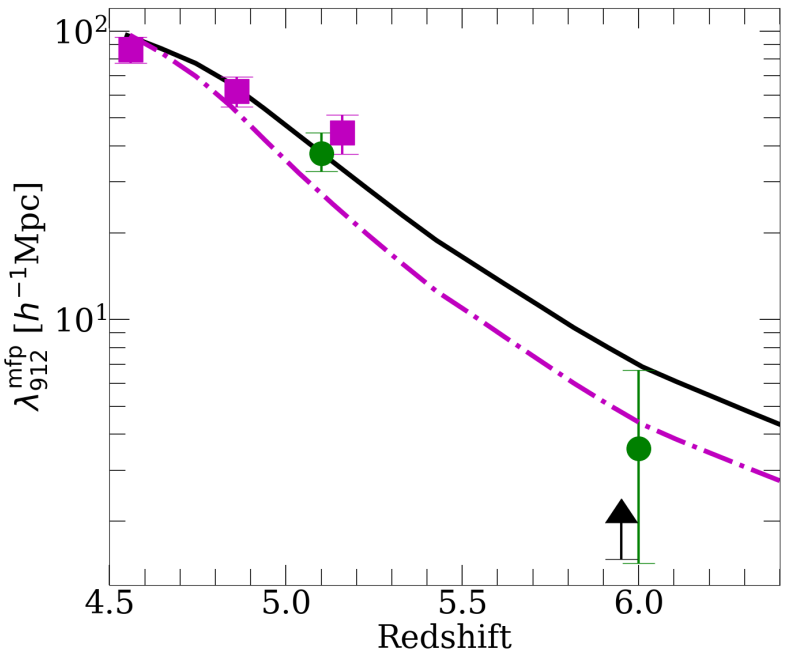




Models with Enhanced Small-Scale Power

- Axion-like DM models have enhanced small-scale power
- Could help explain the $z = 6$ MFP, but not a requirement





Conclusions

- The MFP is sensitive to DM clumping on $10^4 - 10^8 M_\odot$ scales
- The $5 < z < 6$ MFP is unlikely to competitively distinguish DM models until astrophysical uncertainties associated with reionization are better constrained