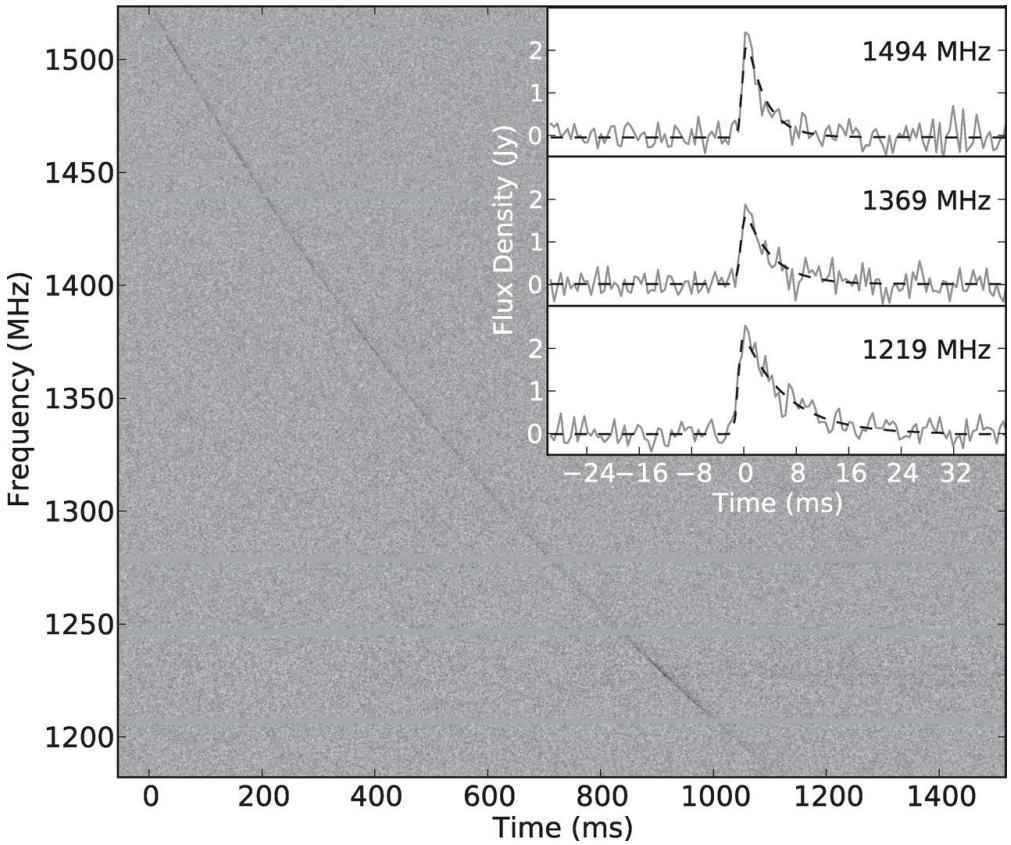
Fast Radio Bursts as Cosmological Probes



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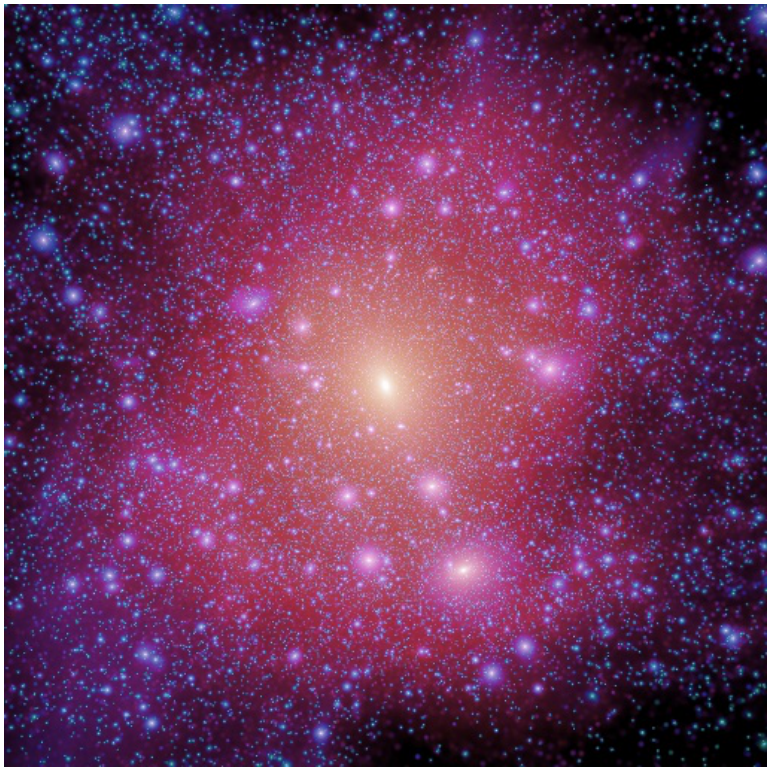
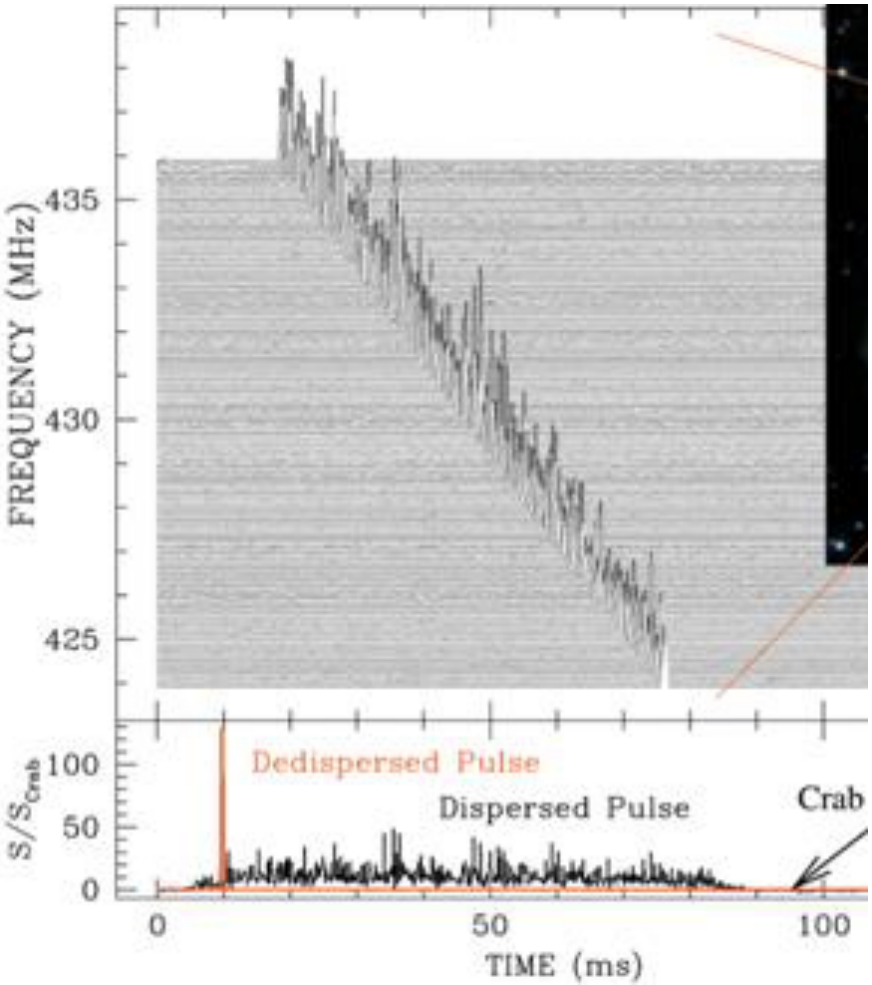


1. introduction
2. small-scale power spectrum
3. H+He reionization

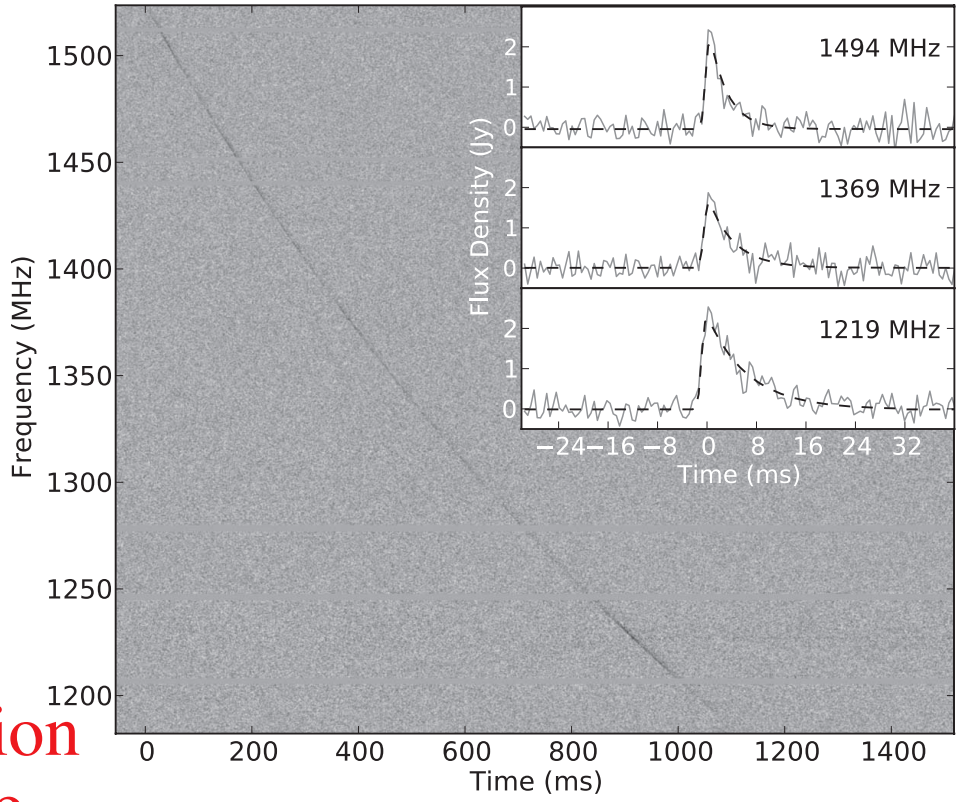
In an intergalactic burst I'm back to reveal the Universe…

fast radio bursts (FRBs) and dispersion measure

Galactic radio pulsars



FRBs (likely extragalactic)



dispersion measure

$$\Delta t = \frac{e^2}{2\pi m_e c\, \nu^2} \underbrace{\int dl\, n_e(l)}$$

~<200 pc cm^{-3}

known distance -> probe ionized ISM

model ionized ISM dist.

-> constrain distance

$$\Delta t = \frac{e^2}{2\pi m_e c\, \nu^2} \underbrace{\int dz \frac{cdt}{dz} \frac{x_e(z) n_{IGM}(z)}{1+z}}$$

~400-1600 pc cm^{-3}

model ionized IGM dist.

-> constrain distance

measure distance ->

probe ionized IGM

c.f. SI04, Ioka 03

FRBs: basics, recent developments

- observed properties
  17 events published: 15 Parkes, 1 Arecibo, 1 Green Bank
  duration $\Delta t \sim <$1-5 ms
  flux $S_\nu \sim$0.4-30 Jy @0.9-1.5 GHz
- dispersion measure DM~375-1630 pc cm^{-3}
  -> D~0.8-4 Gpc (z~0.2-1.3)
  -> E~10^{37}-10^{40} erg, L~10^{40}-10^{44} erg/s

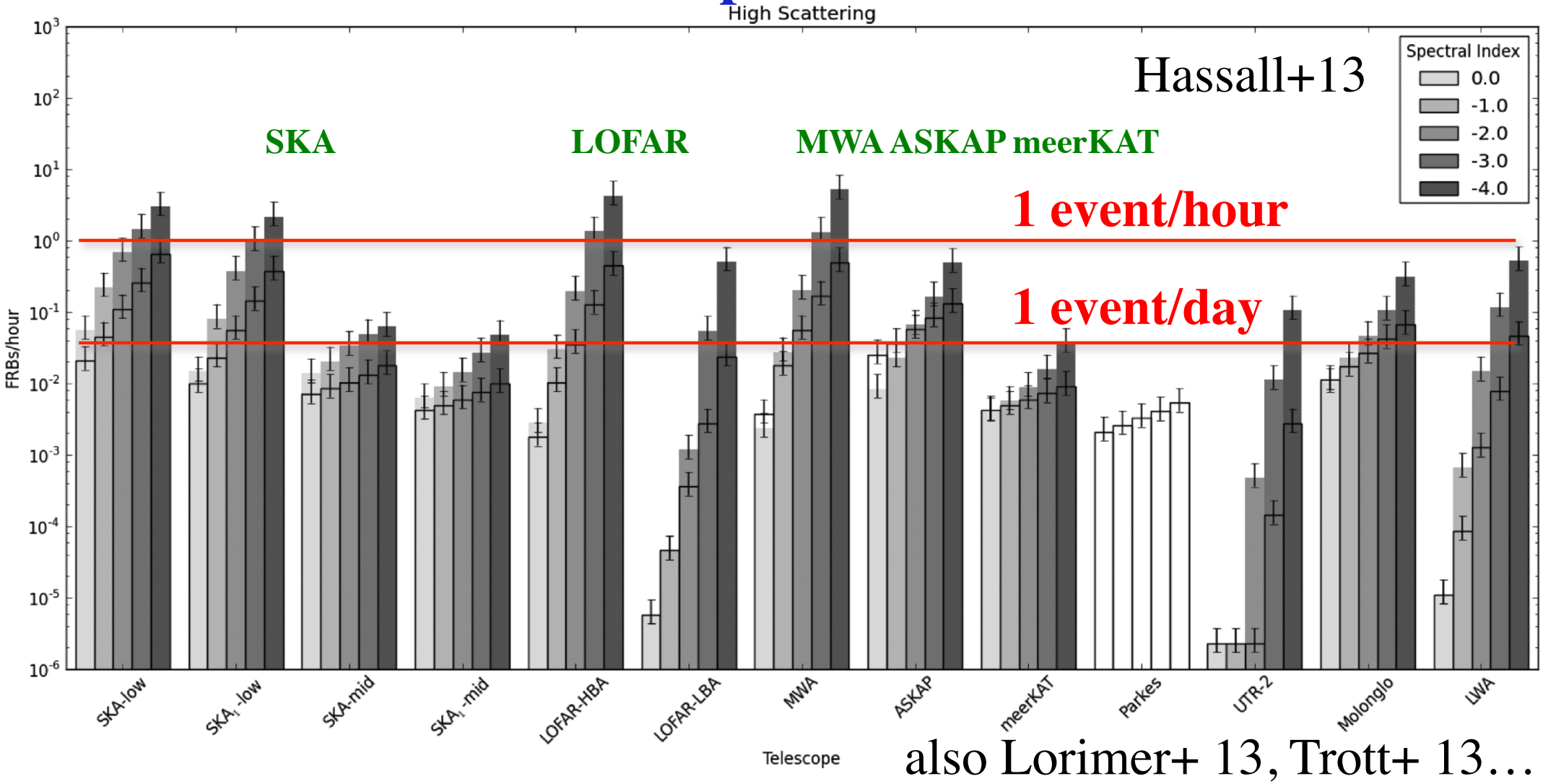
Lorimer+ 07
Thornton+ 13
Petroff+ 16
…

- estimated rate: R_{FRB}~2500-10000 /day/sky! ~$0.1R_{SN}$,$1000R_{GRB}$

- FRB 150418 Keane+ 16
  claim: discovery of radio afterglow, ID of host galaxy
  -> z=0.492+-0.008, elliptical, low SFR <$0.2M_\odot$/yr
  -> distance consistent with DM_{IGM} assuming $\Omega_{b,WMAP}$ + D_{host}~40 pc cm^{-3}
  -> ID of all ionized IGM=photoionized+WHIM (missing baryons)
  BUT
  doubts: misID of radio afterglow with AGN Williams & Berger 16

- FRB 121102+ Spitler+ 16
  first and only repeater -> more than 1 class?

fast radio bursts: future expectations



also Lorimer+ 13, Trott+ 13…

large sample of IGM dispersion measurements possible

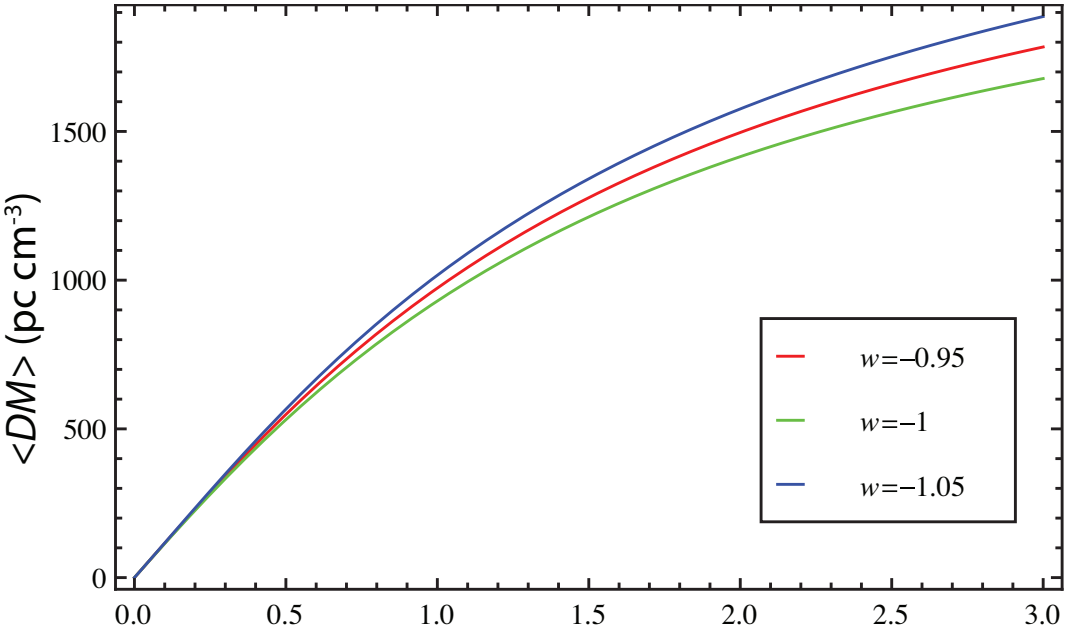
need independent redshift for cosmological use

1. arcsec localization -> host galaxy ID + z measurement
2. 21cm absorption by host galaxy

Macquart+ 15, Margalit+ 15

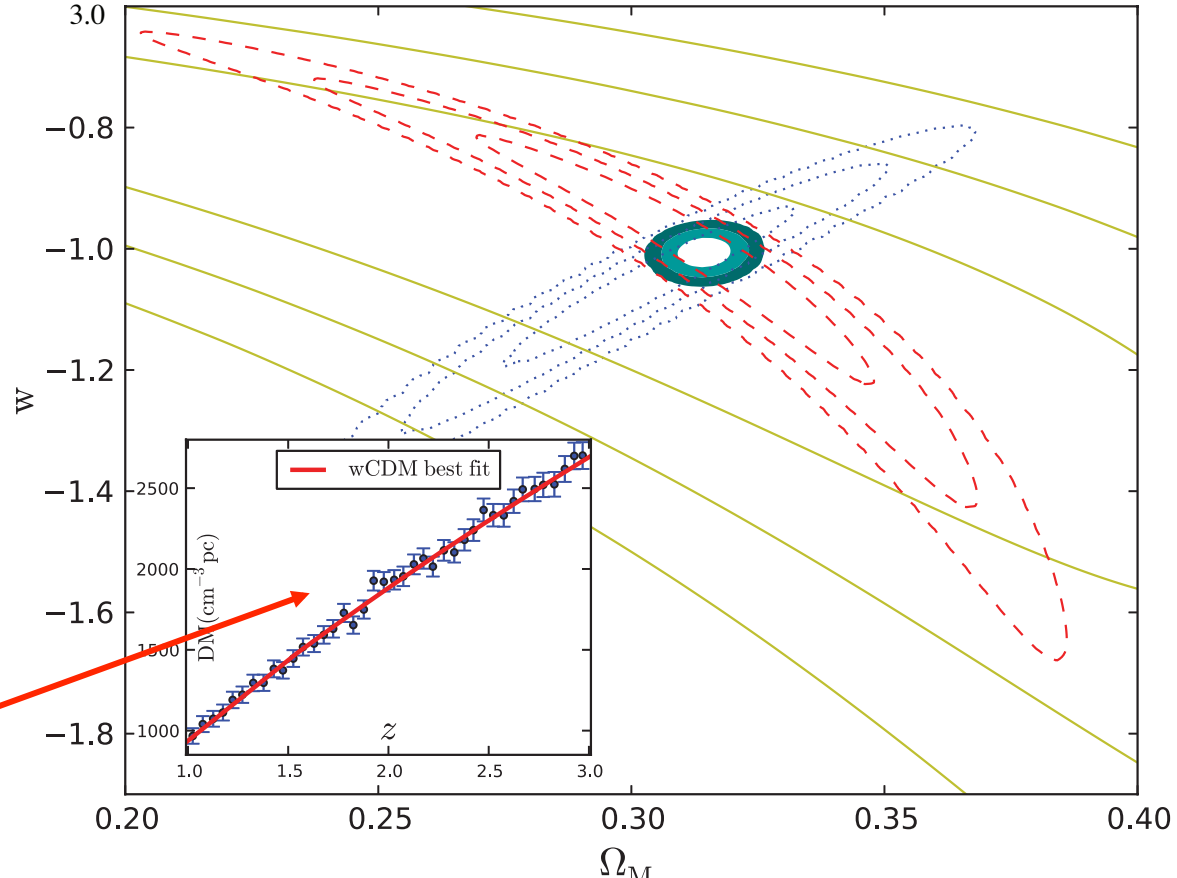
FRBs as probe of dark energy?

Zhou+ 14, Gao+ 14



DM as distance indicator:
precise measurement of
DE EOS with large sample?

580 SN Ia
BAO inc. forecast
1000 FRBs

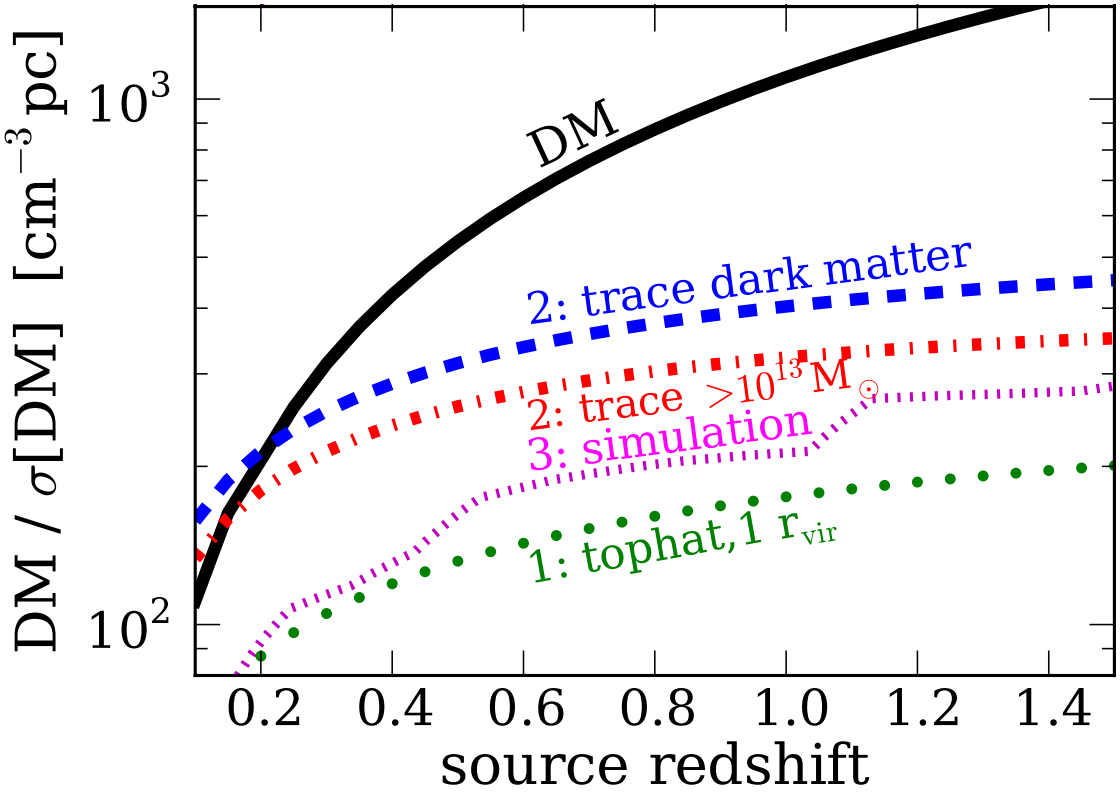


mean of DMs per z bin
in 40 bins up to z~3
for 1000 simulated FRBs

FRBs as probes of missing baryons?

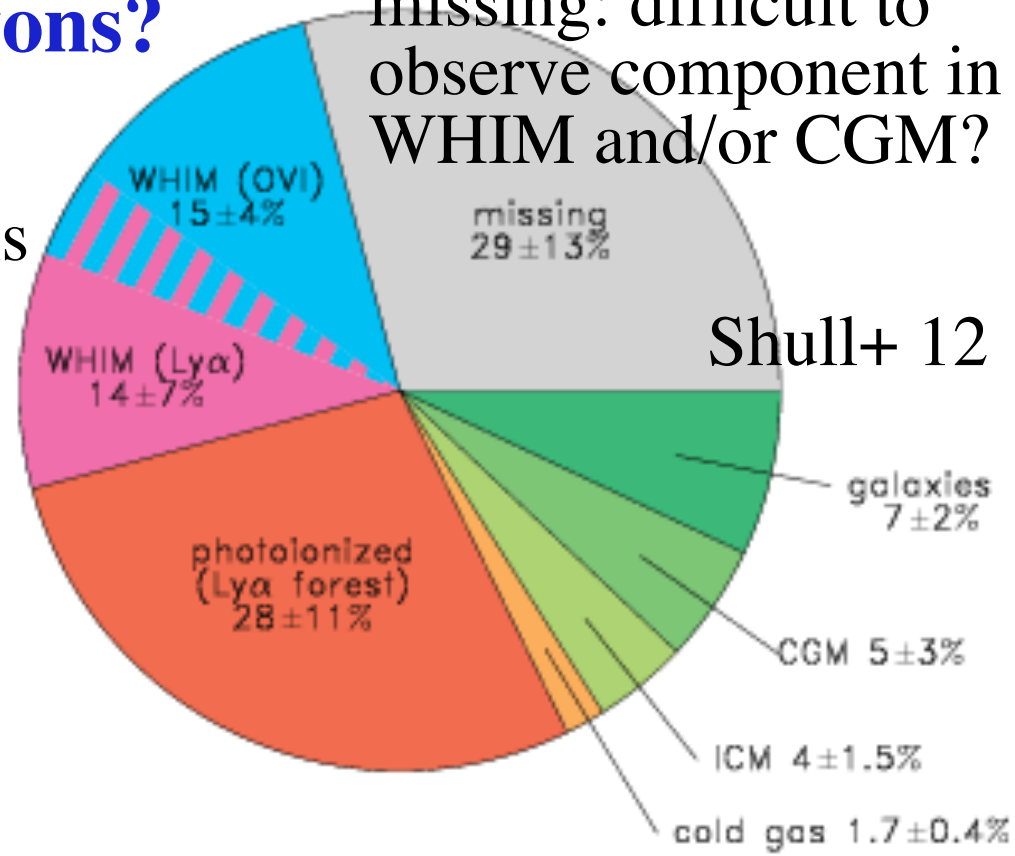
sizable variance expected due to LSS
-> probe distribution of ionized baryons

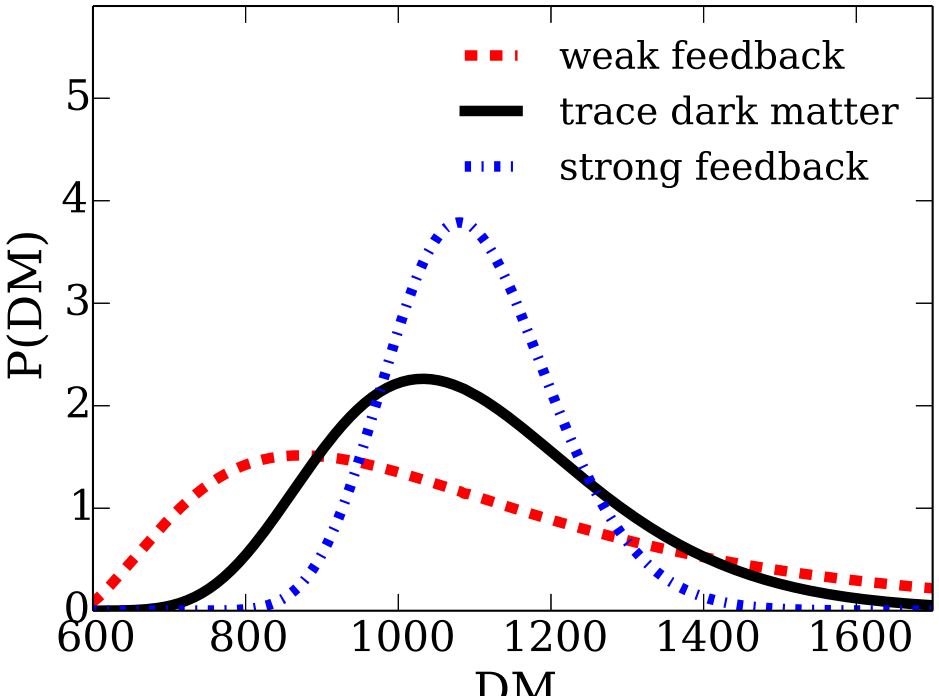
McQuinn 13



missing: difficult to observe component in WHIM and/or CGM?

Shull+ 12



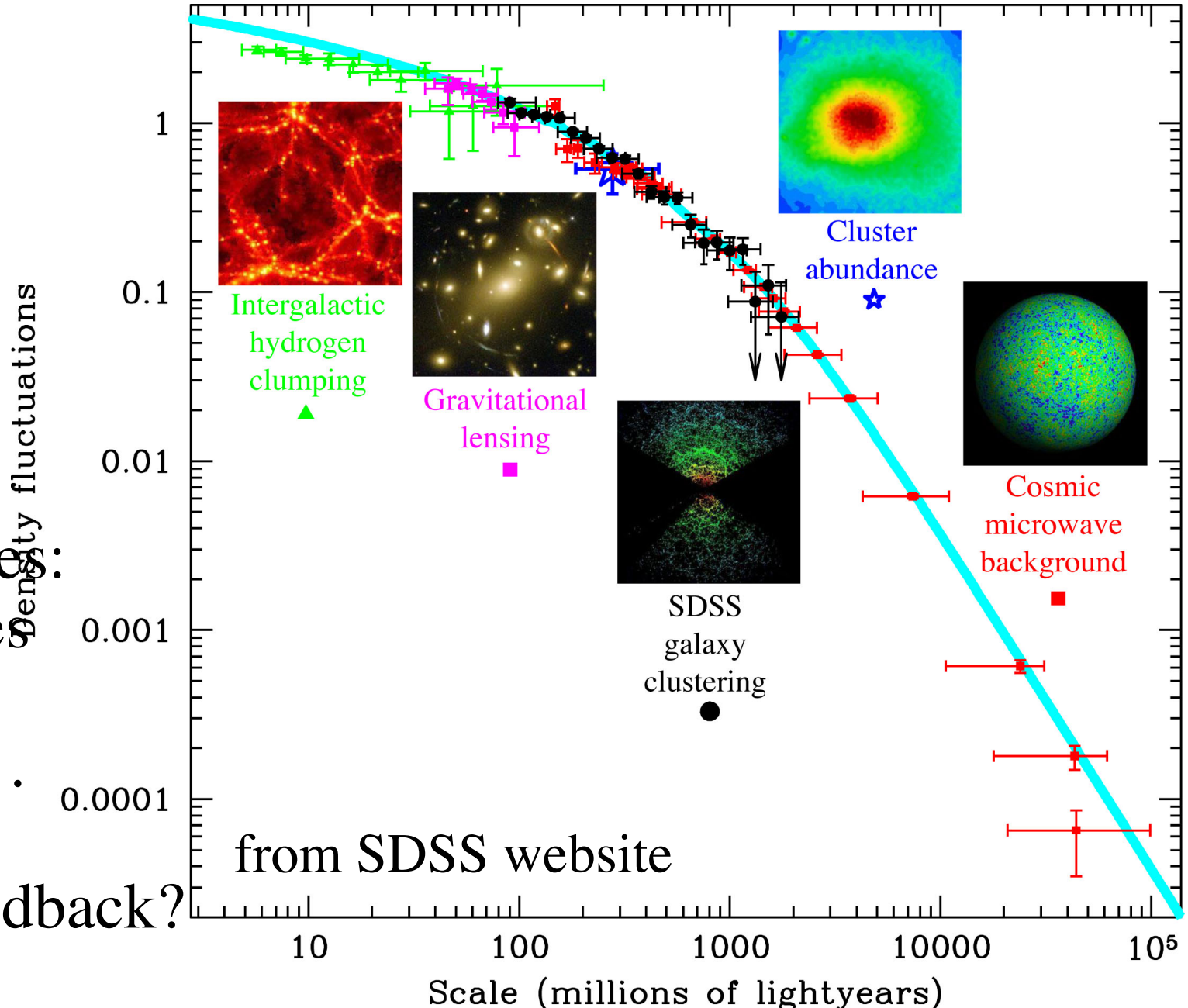


power spectrum of large-scale structure

consistent with CDM+Λ+adiabatic power-law fluctuations down to galaxy scales

BUT
not yet well tested on small (sub-galactic) scales!

small-scale issues:
missing satellites
core/cusp
too-big-to fail …
->
astrophysics feedback?
WDM? SIDM?



cold dark matter (CDM): small-scale problems

- missing satellites problem
- too-big-to-fail problem
- core/cusp problem

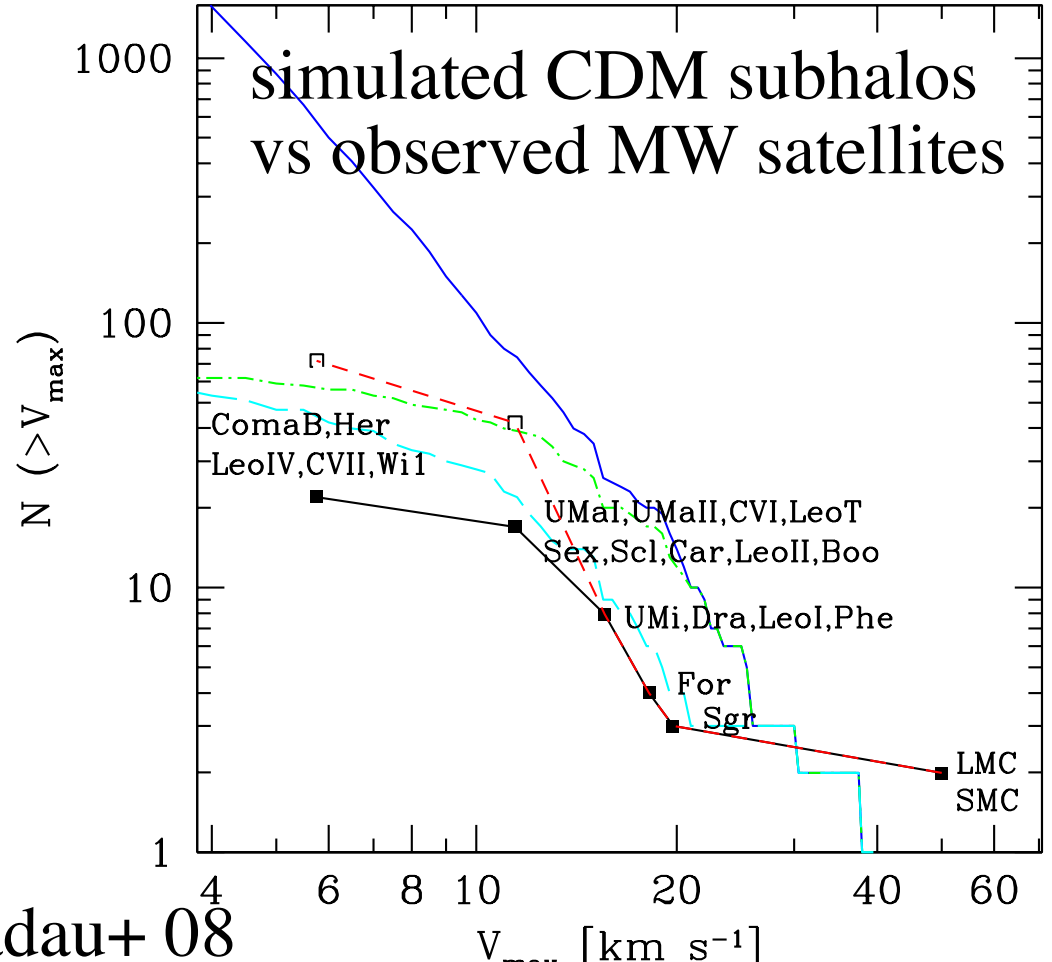
…

->

astrophysical feedback:
SN wind? AGN wind? UV background?

alternative to CDM:
warm dark matter (WDM)?
self-interacting dark matter (SIDM)?

simulated CDM halo substructure

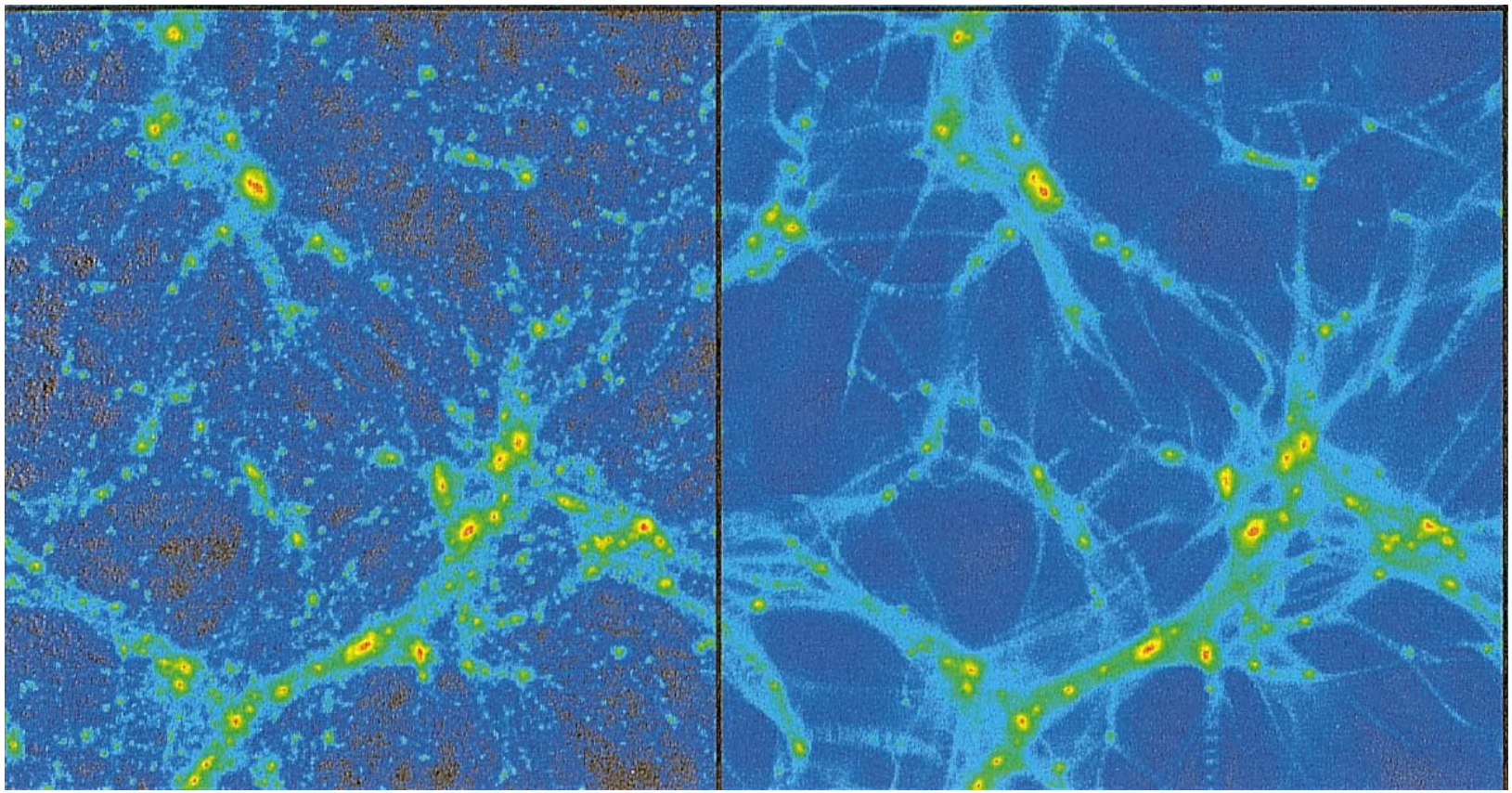


Madau+ 08

warm dark matter

- warm dark matter becomes non-rela. when galactic scales enter horizon
  -> suppress LSS by free streaming below m_{WDM}-dependent scale
- particle physics motivation, e.g. sterile neutrinos
- solve missing Galactic satellite problem? <-> astrophysical feedback
- current lower limits m_{WDM}>~1 keV? Viel+ 05, Smith & Markovic 11

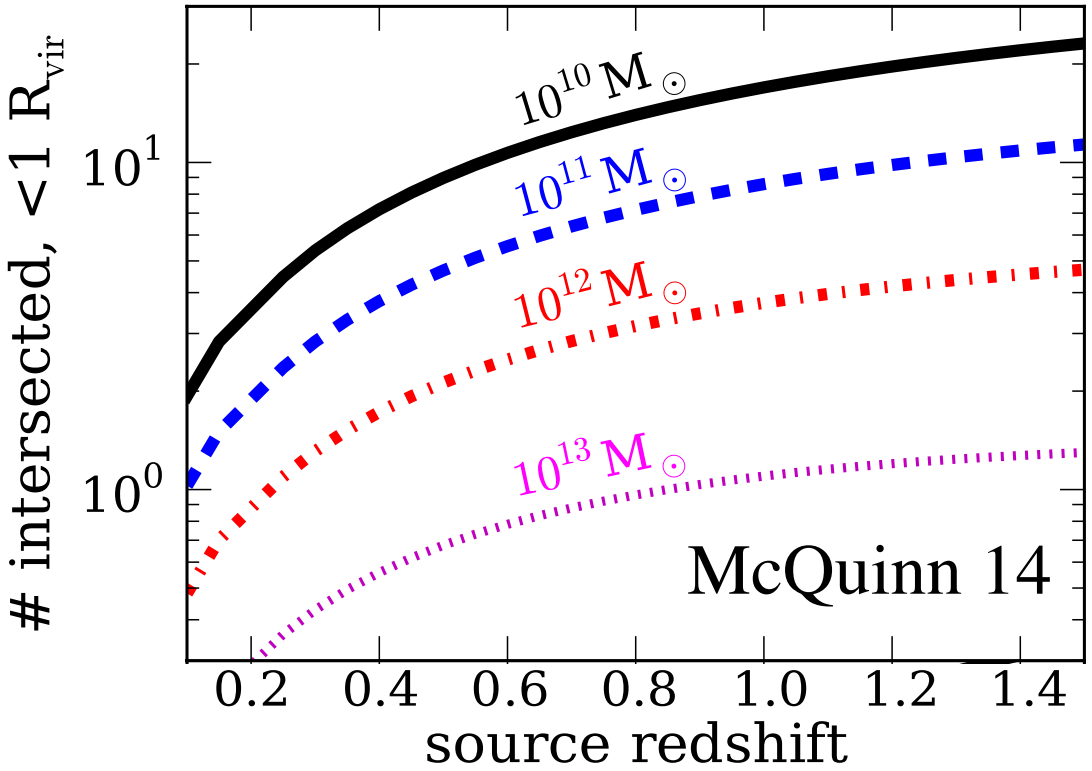
CDM WDM (m=0.35 keV)



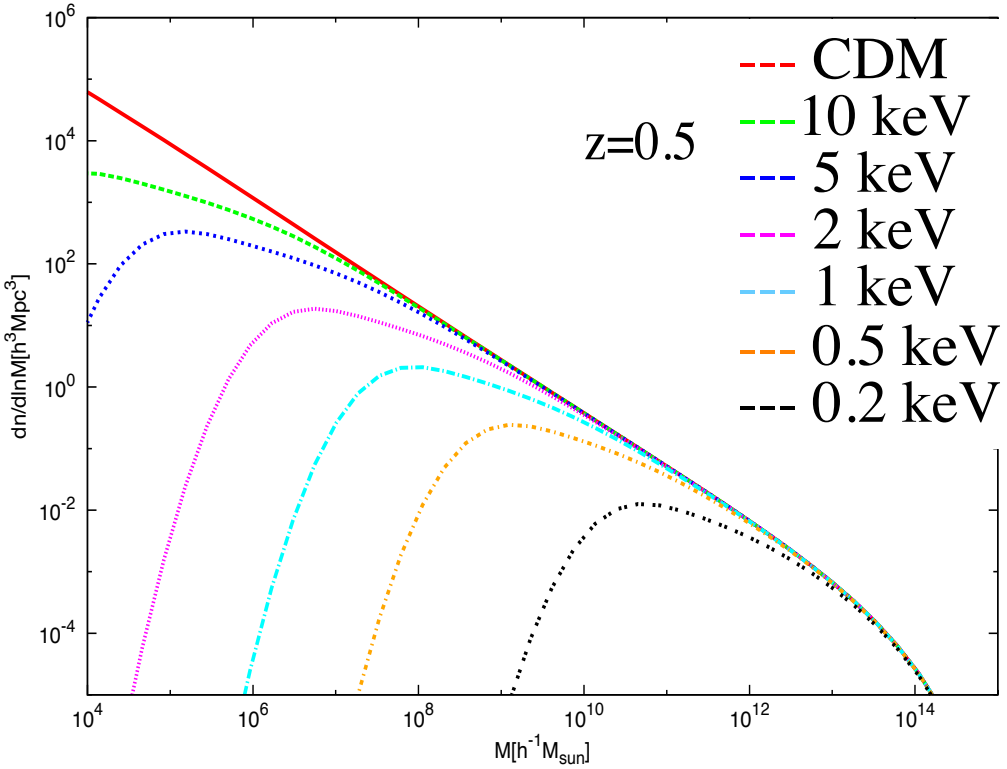
Bode+ 01

FRBs as probe of small scale power spectrum (warm dark matter and/or small-scale feedback)

lines of sight out to z~1 intersect
large number of ~10^{10} M_{sun} halos
-> variance of DM sensitive to abundance and baryon distribution of ~10^{10} M_{sun} halos



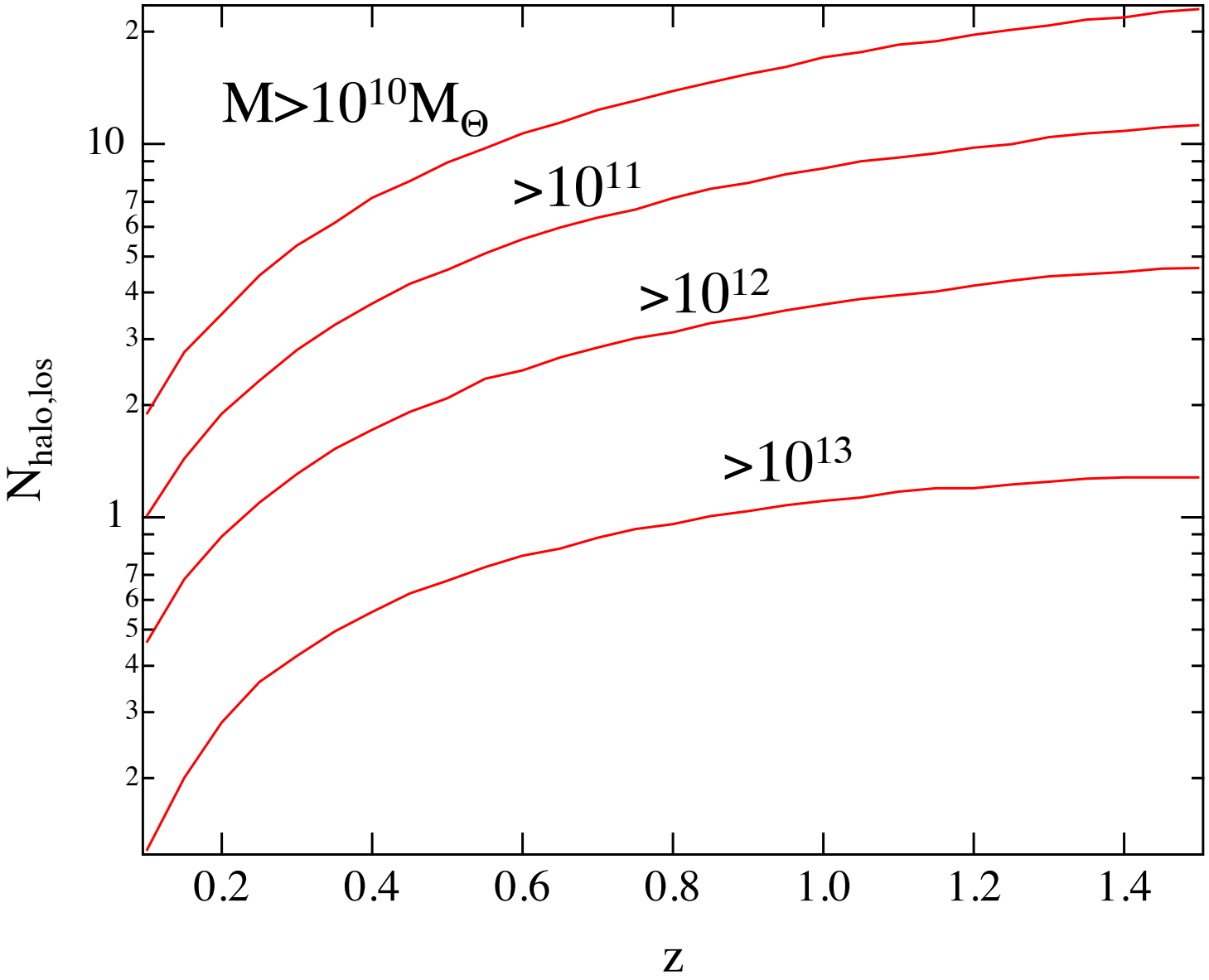
WDM halo MF



halos intersecting along line of sight

CDM

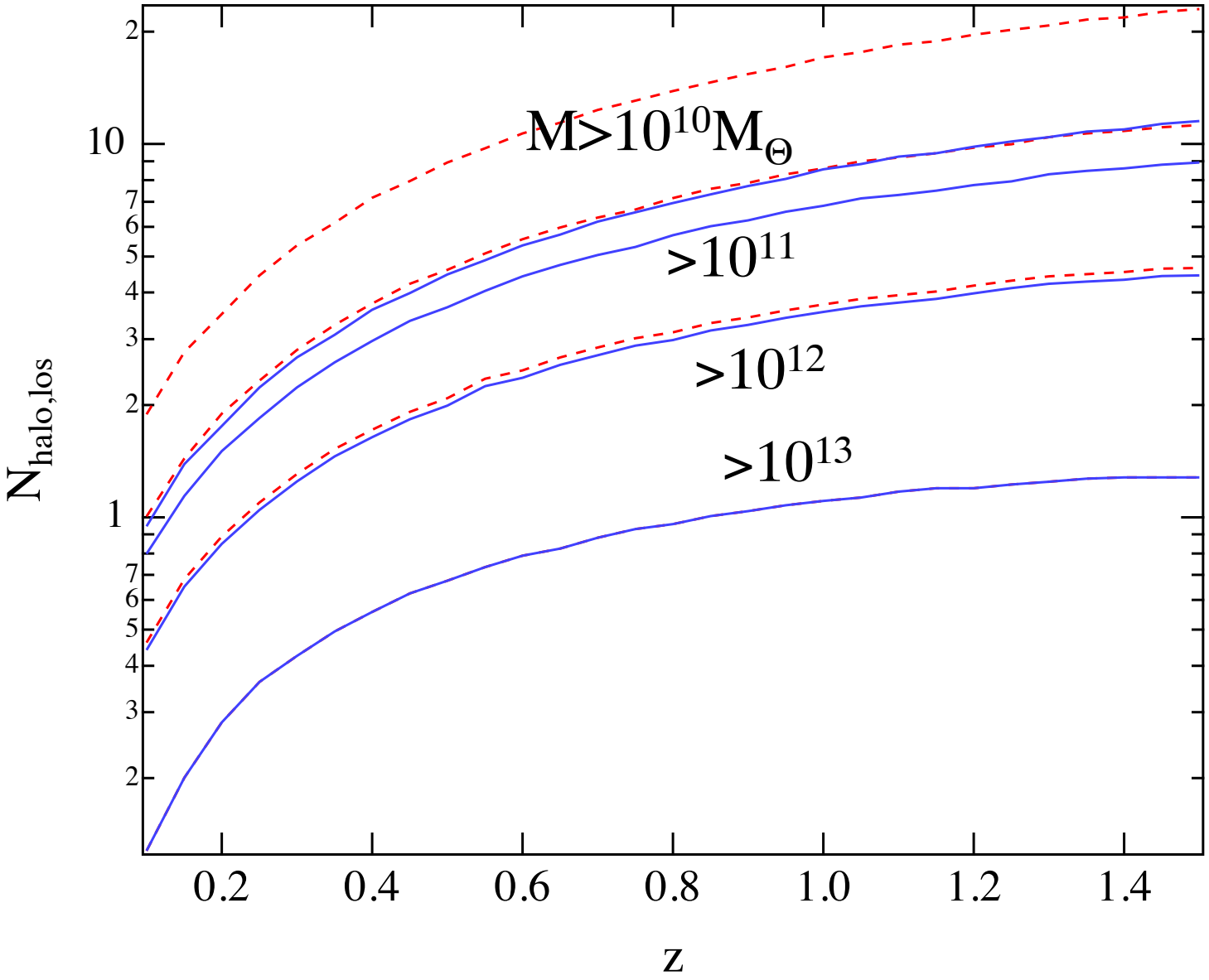
$N_{halo,los} = \iint dM\, dz\, (cdt/dz) \times (R_{vir}(M,z))^2\, dN/dM\,(M,z)$



halos intersecting along line of sight

WDM m=1keV vs CDM

$N_{halo,los} = \int\int dM\, dz\, (cdt/dz) \times (R_{vir}(M,z))^2\, dN/dM\,(M,z)$

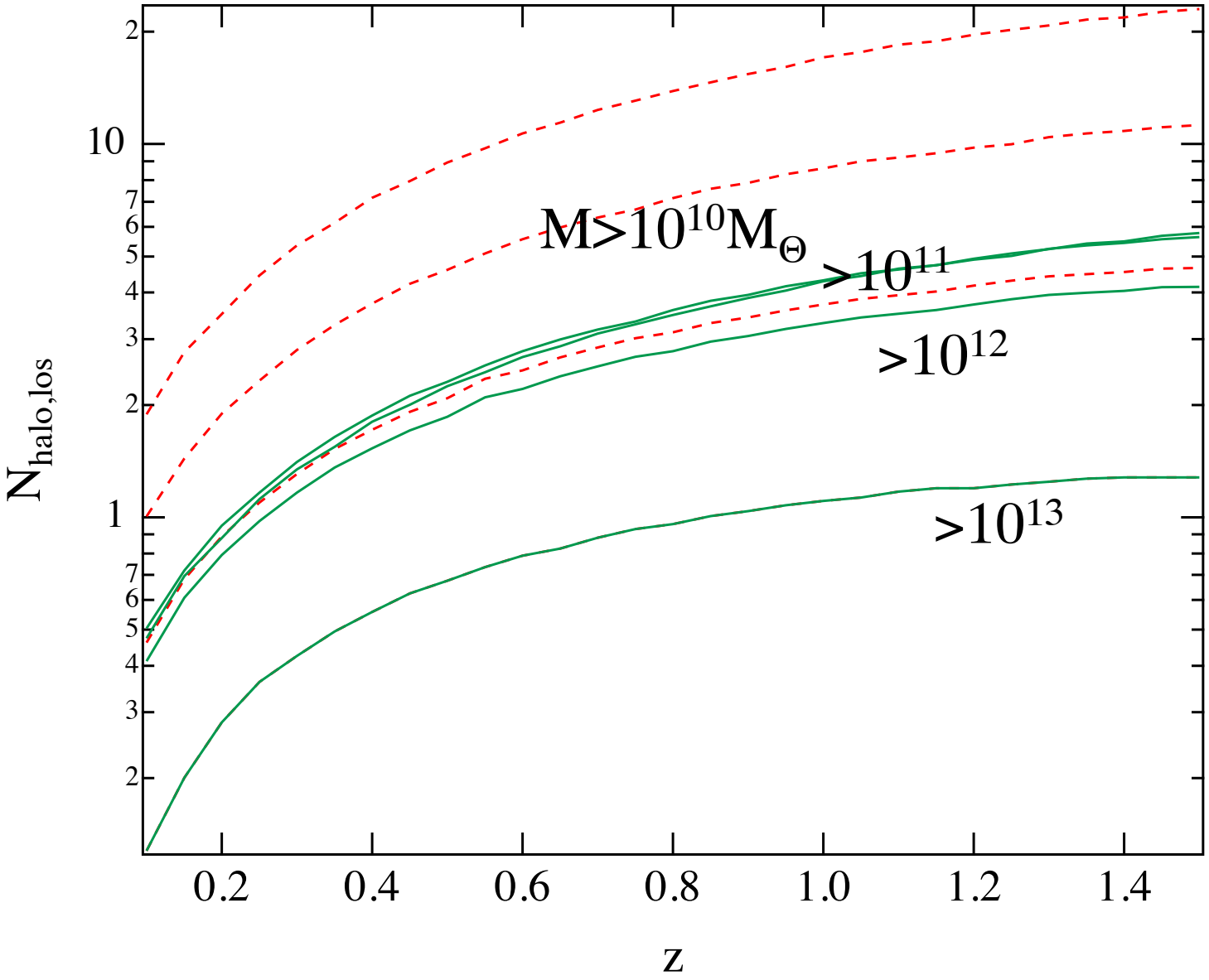


WDM halo MF follow prescription of Smith & Markovic 11

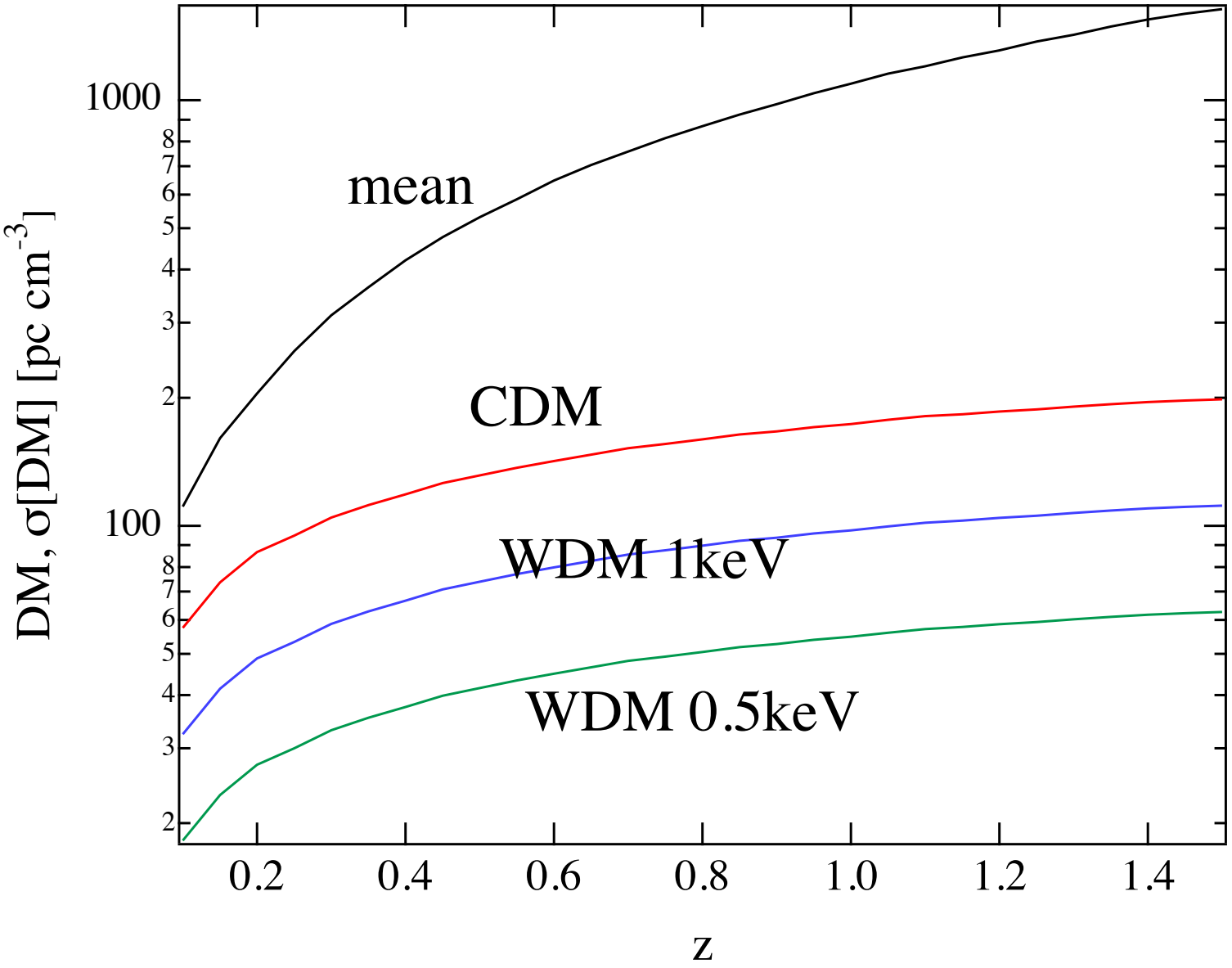
halos intersecting along line of sight

WDM m=0.5keV vs CDM

$N_{halo,los} = \int\int dM\, dz\, (cdt/dz) \times (R_{vir}(M,z))^2\, dN/dM\,(M,z)$



dispersion measure: mean and variance



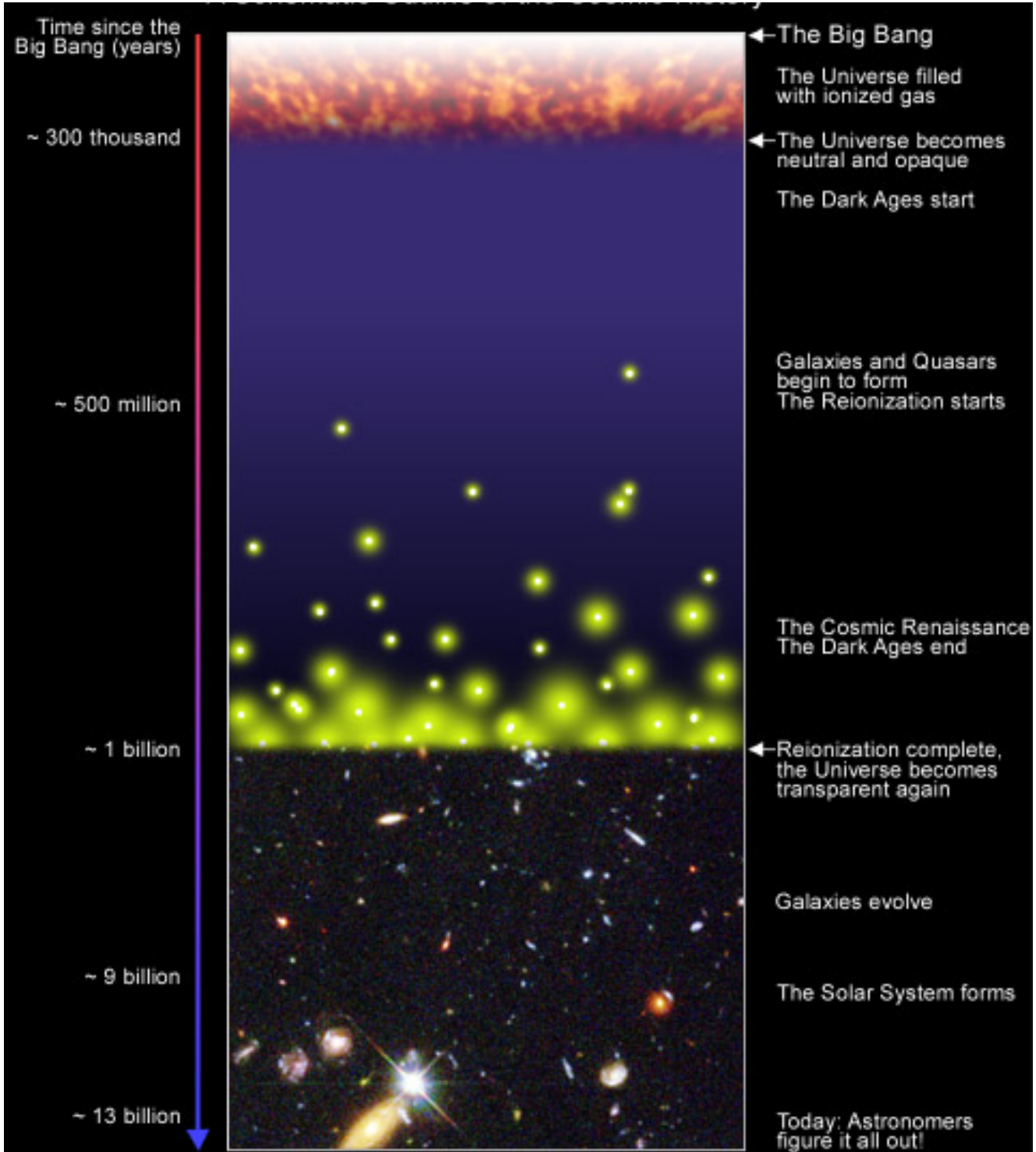
follow McQuinn 14
variance computed
via std. halo model
(2pt correlation
~1 halo + 2 halo)

assume:
IGM fully ionized
top hat profile $<R_v$
$M_{min}=10^{10}\ M_\Theta$
$\sim M_{J,IGM}$

main uncertainty
DM_{host}

in progress: quantify constraints on m_{WDM}
prospects for probing CDM small-scale feedback
cross correlations with galaxy dist., WHIM dist. etc.

cosmic dark ages -> cosmic dawn



z~3600 - big bang

z~1000 - matter-rad. eq.

- recombination

z>~30 - first stars, galaxies, black holes…

-> reionization

z~8-10

z~6 - reion. ends

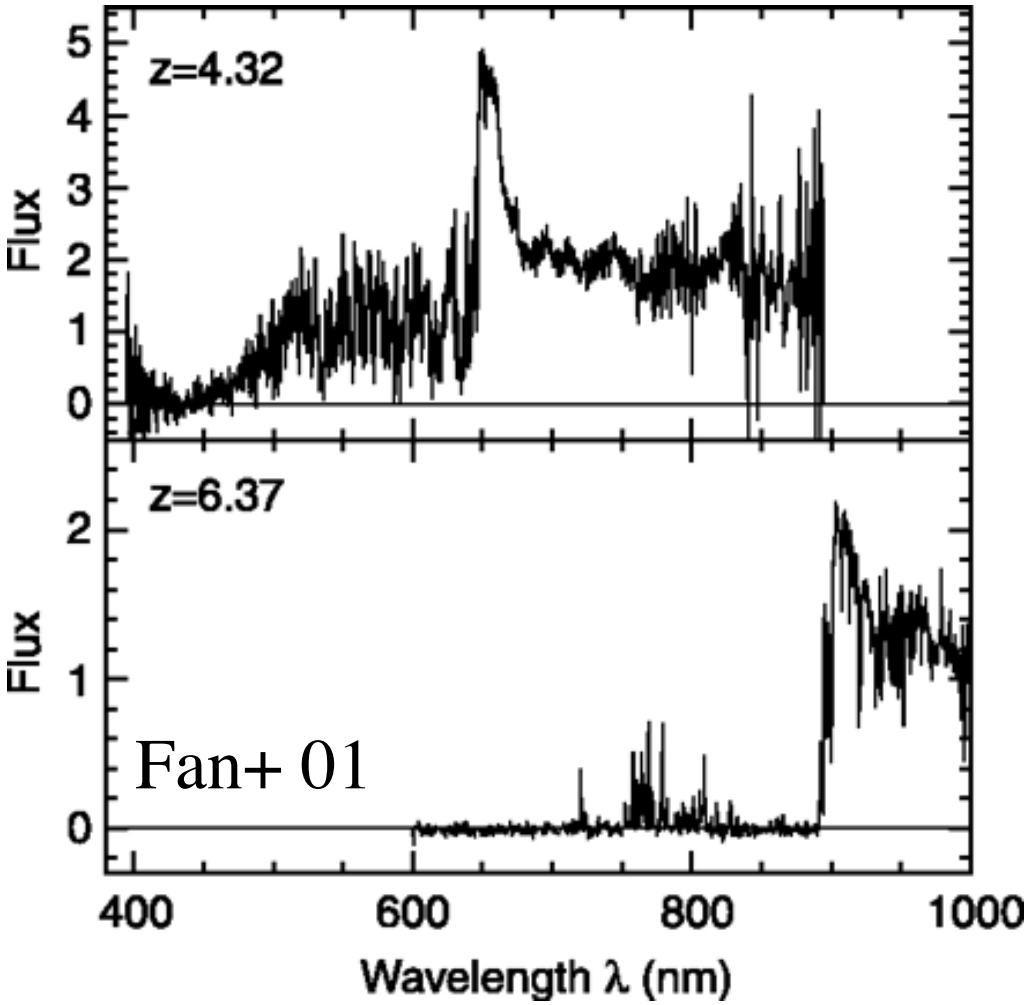
z~1-3 - star formation peak

z~0

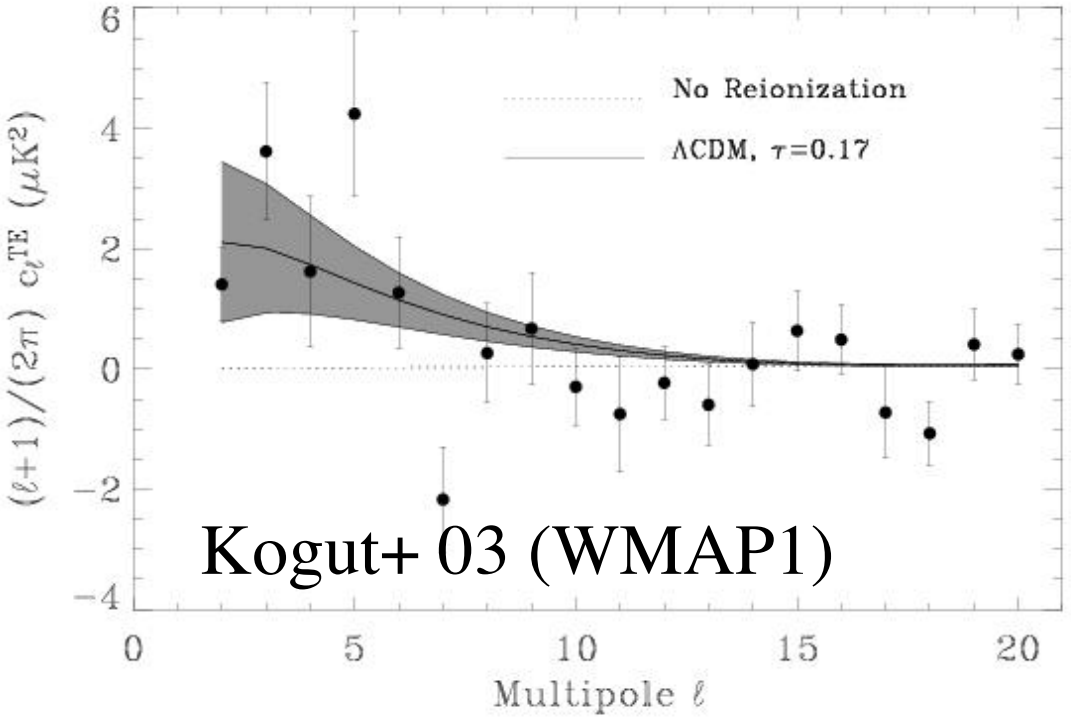
adapted from Djorgovski

observational constraints on cosmic reionization

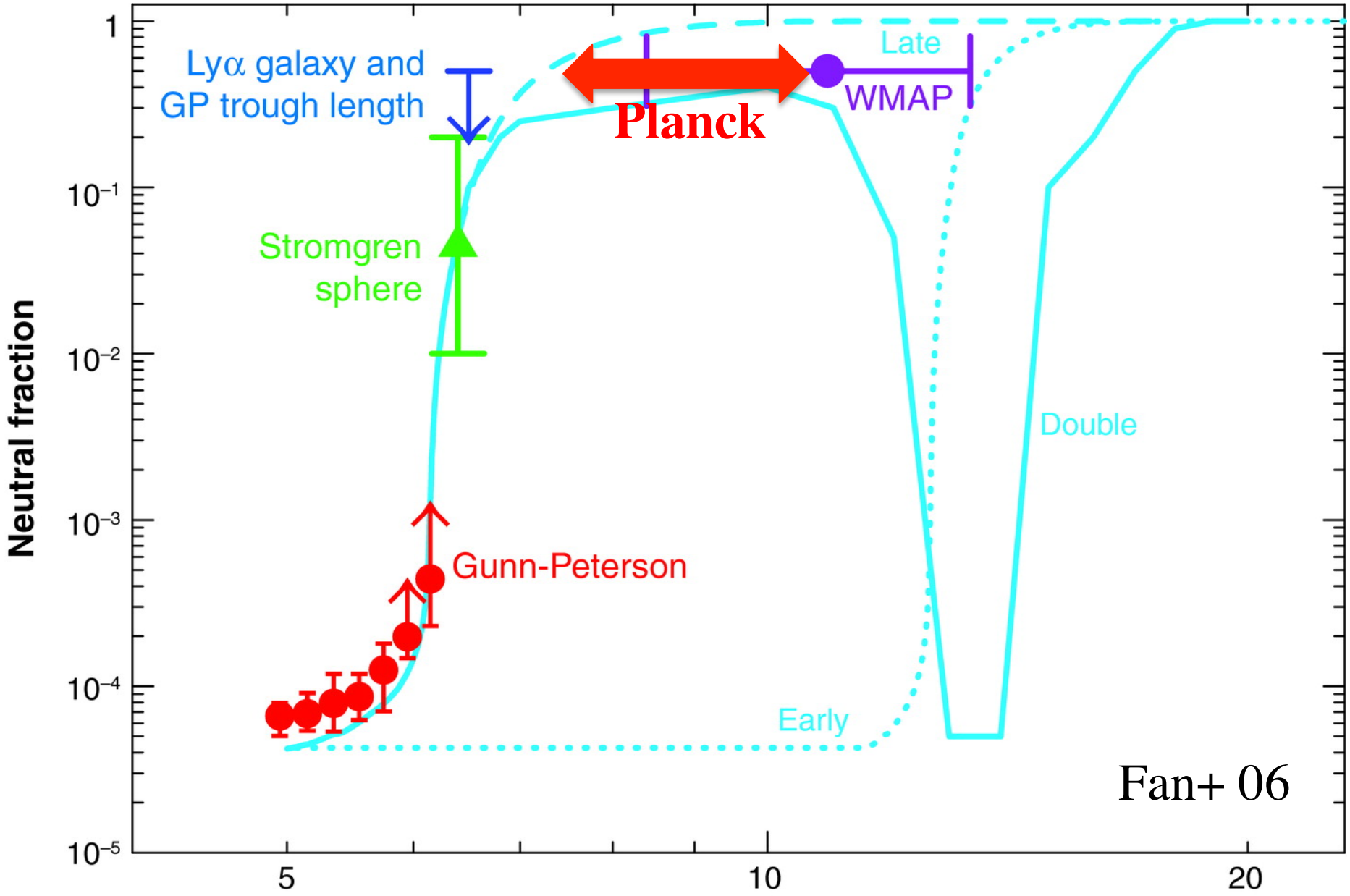
quasar absorption troughs:
neutral IGM at z~6



CMB polarization anisotropies:
ionized IGM at z~6-17?



cosmic reionization (neutral fraction) history after Planck 2015

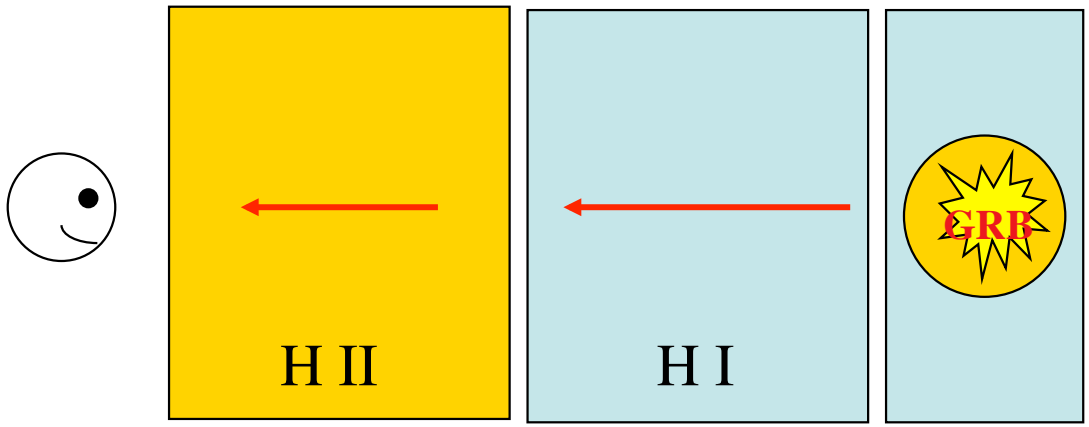


Fan+ 06

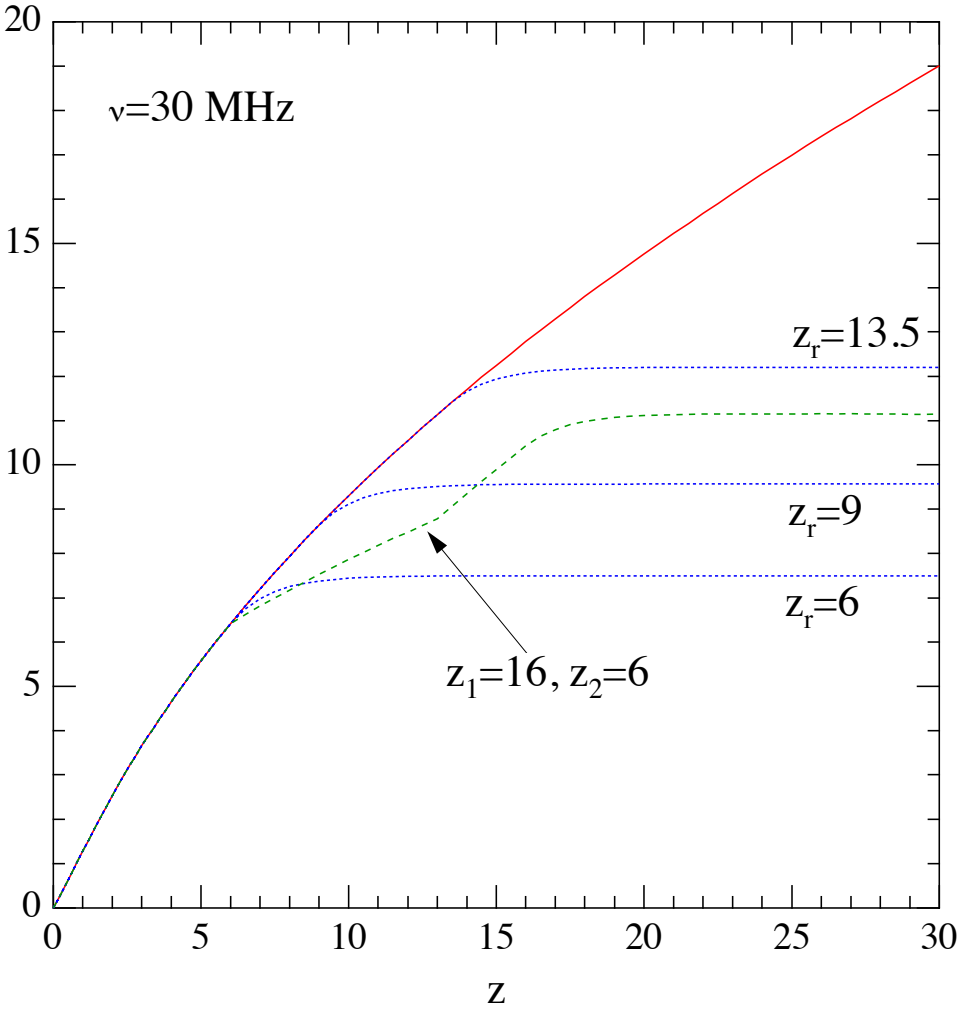
probe feedback on galaxy formation?

IF FRBs occur up to z~10 AND z measurable

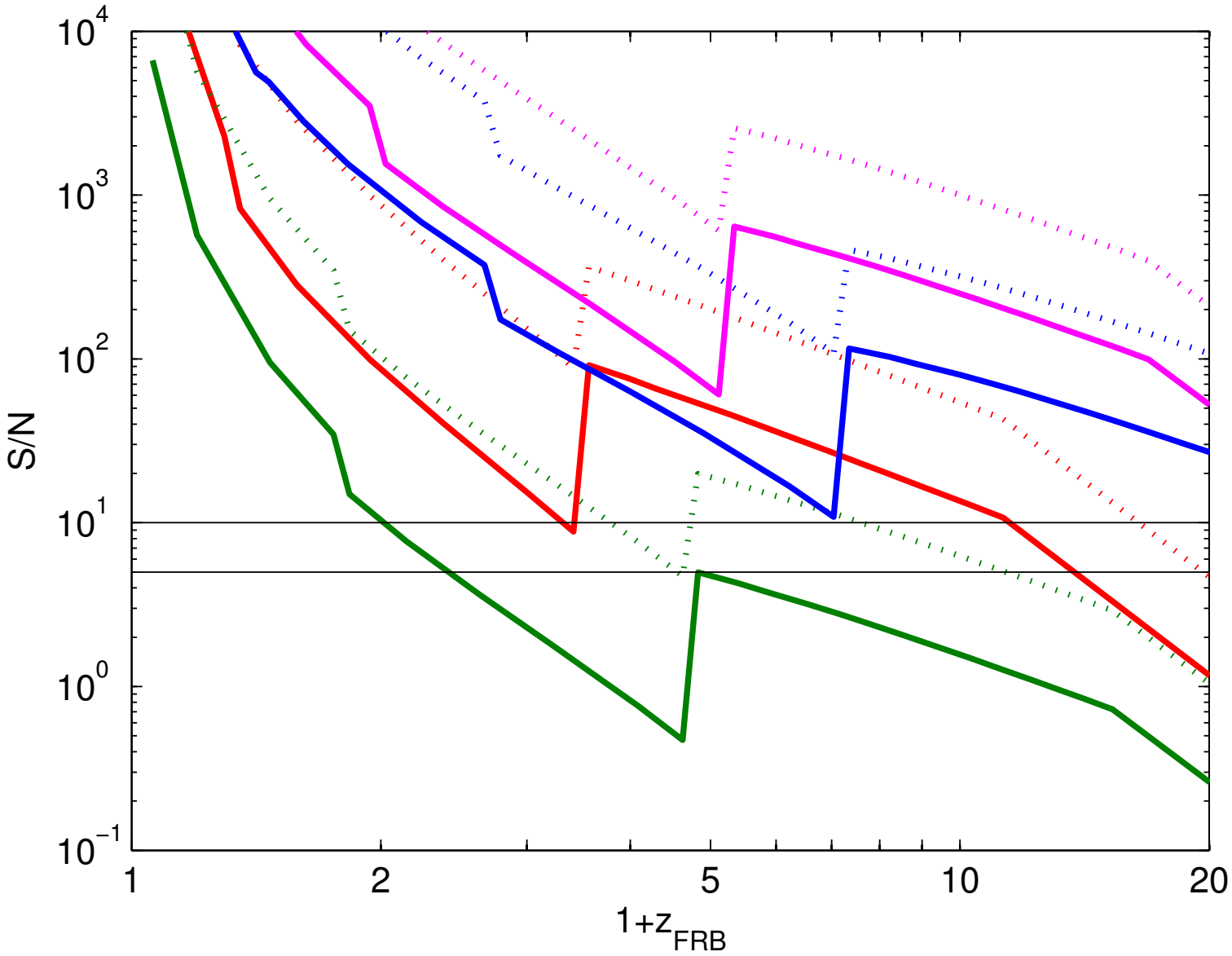
probing ionized IGM with radio dispersion



$$\Delta t = \frac{e^2}{2\pi m_e c\, \nu^2} \underbrace{\int dz\, \frac{cdt}{dz}\, \frac{x_e(z) n_{IGM}(z)}{1+z}}_{\text{dispersion measure}}$$

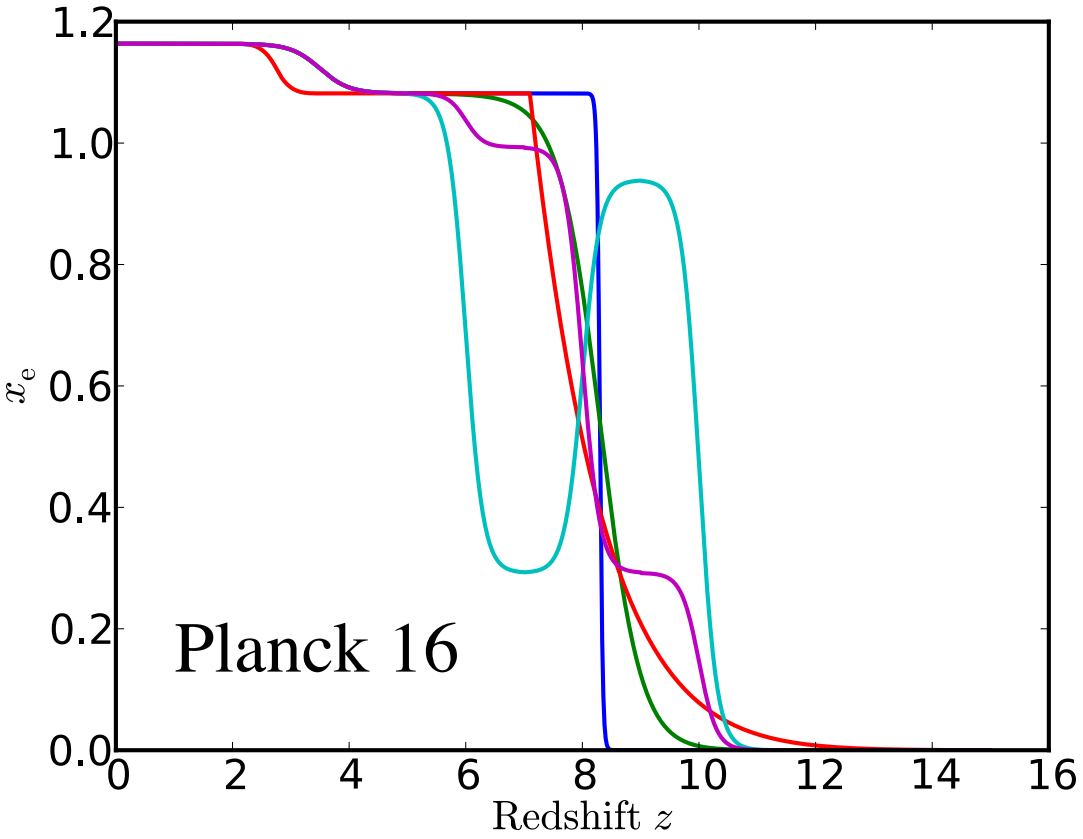


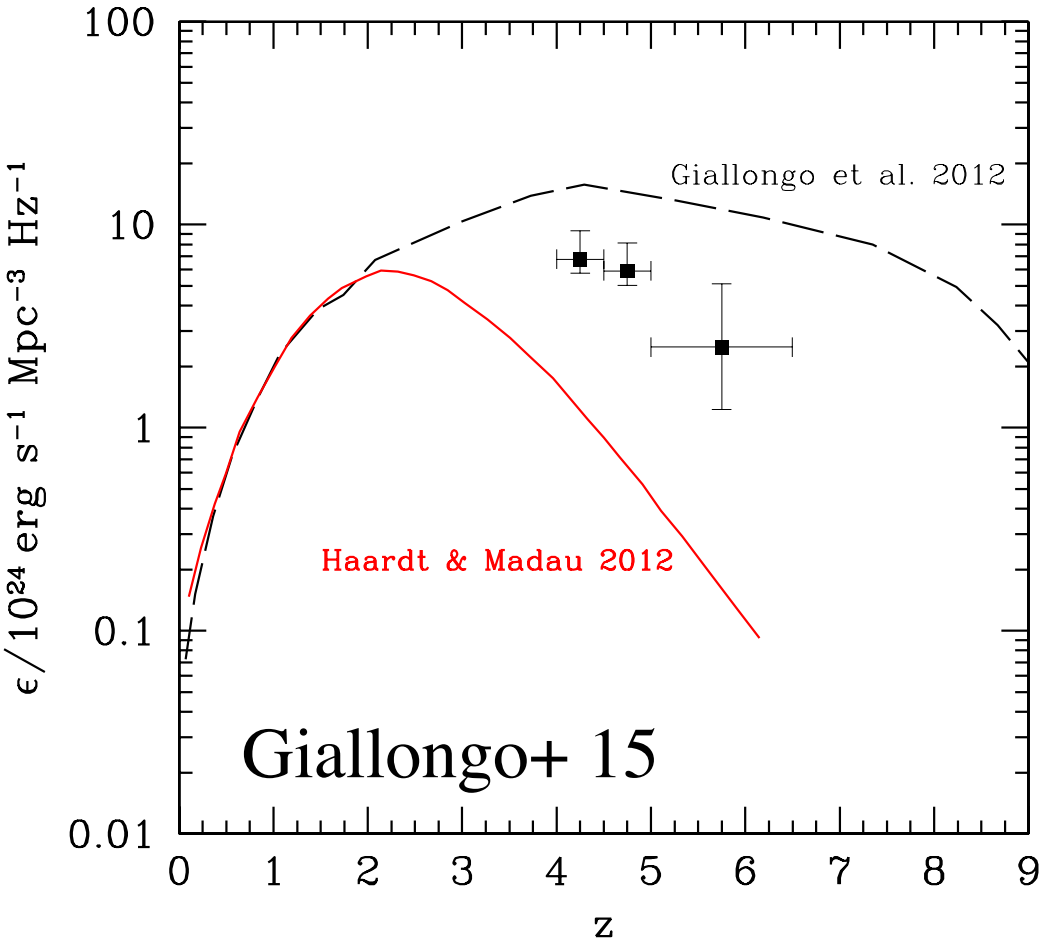
FRBs in the reionization epoch (IF they exist)



Fialkov & Loeb 16

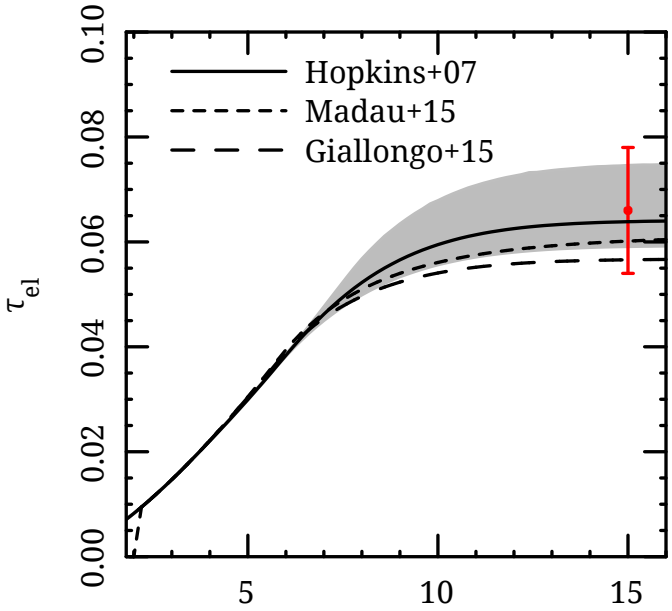
revival of quasar-dominant reionization

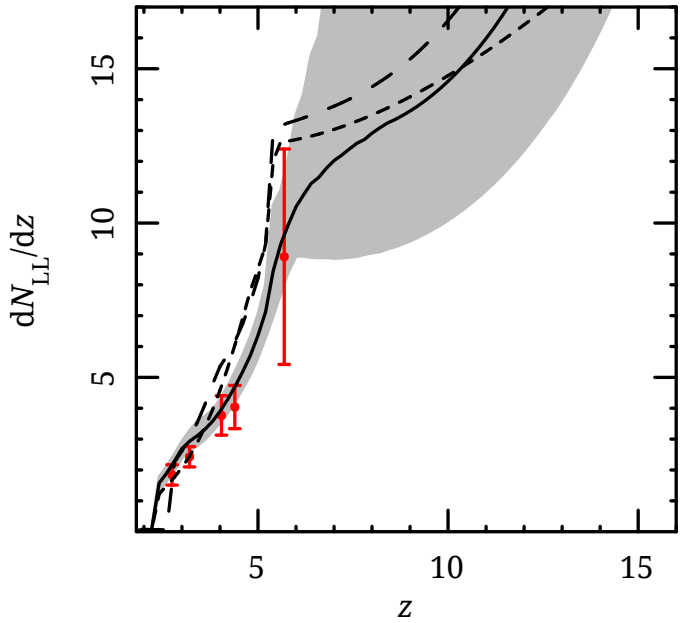


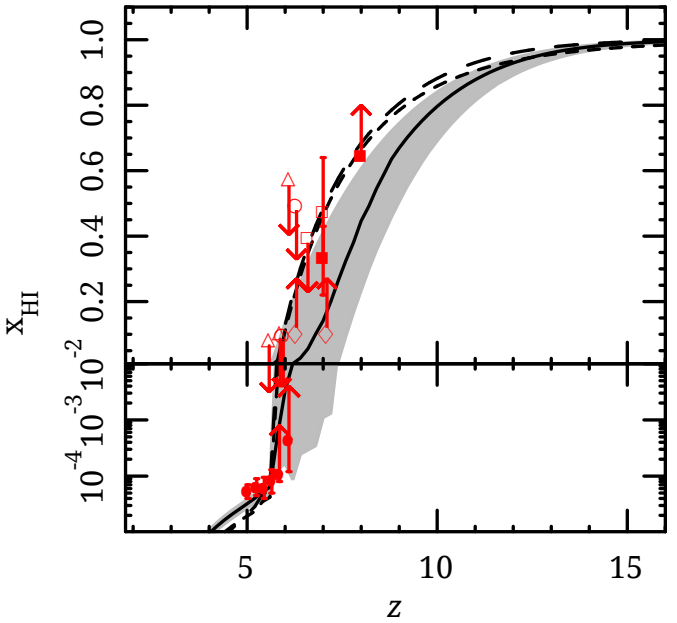


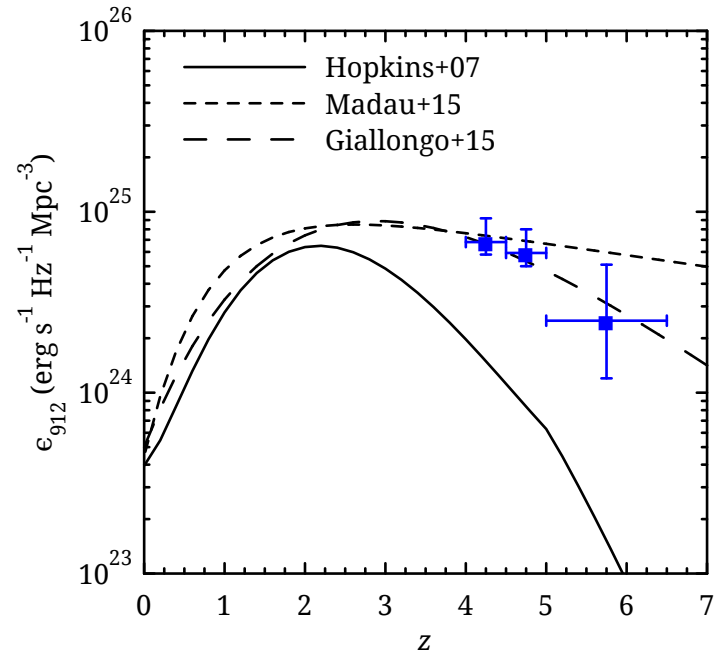
revival of quasar-dominant reionization

Haardt & Madau 15
Mitra, Choudhury & ferrara 16







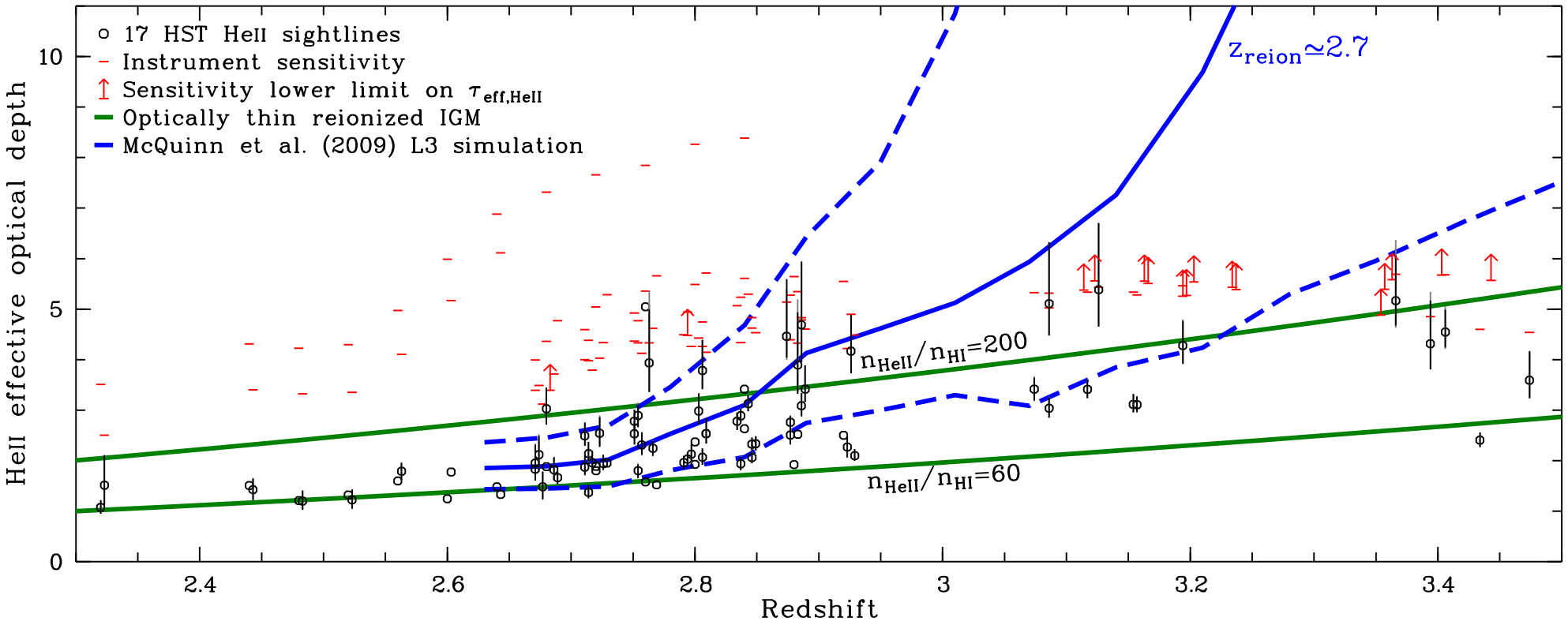


implies extended He reionization

ionization energy:
HeI – 24.6 eV
near-simultaneous with
H reionization (massive stars)?
HeII – 54.4 eV quasars only!

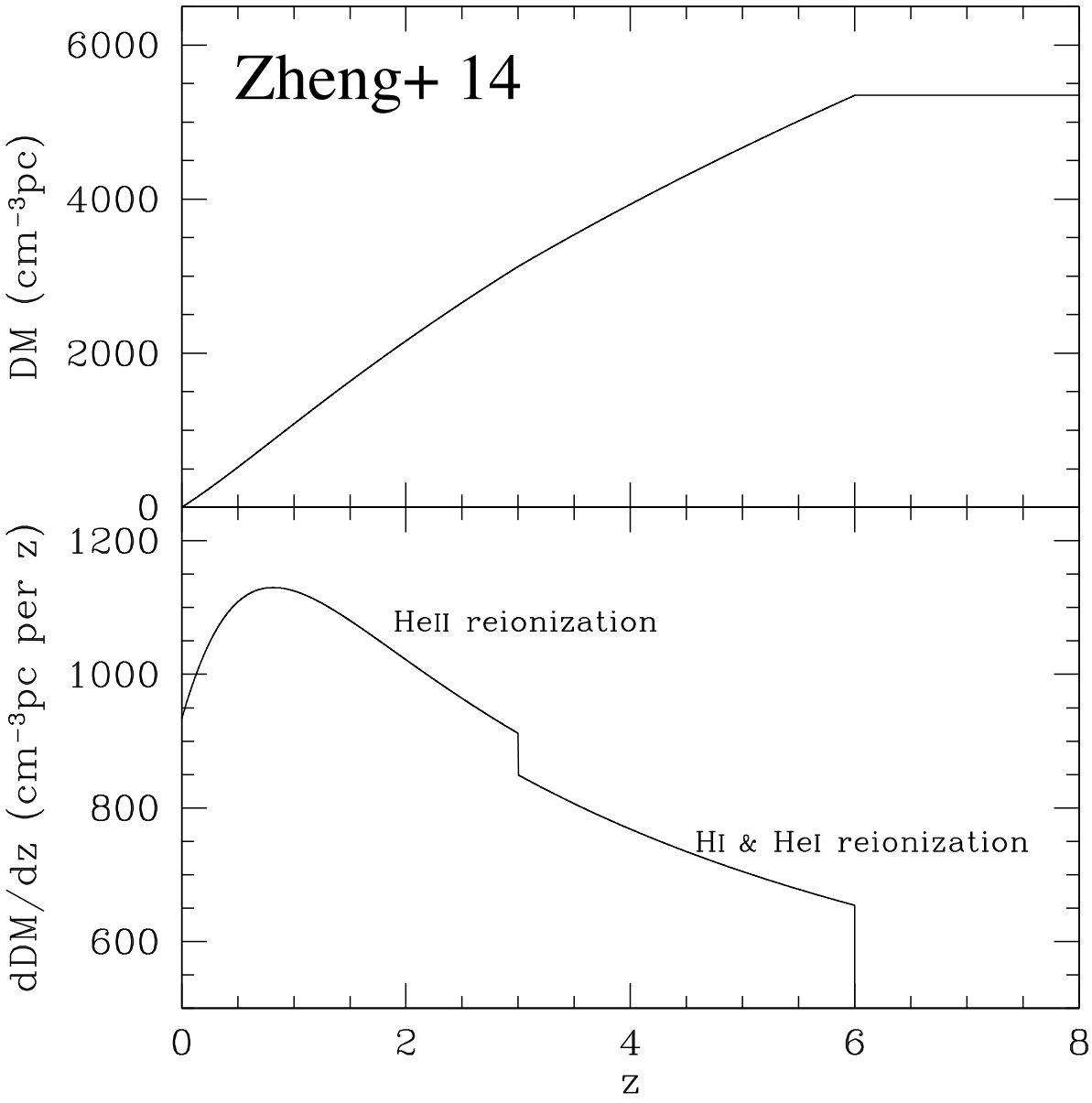
HeII Gunn-Peterson effect

Worseck+ 16



evidence of extended He reionization

FRBs as probes: HeII reionization (-> QSO evolution)



summary

- FRBs: new class of radio transients
  very likely extragalactic (z~1), rate ~few 1000/day/all sky
- promising new cosmological probe
  column density of ionized intergalactic baryons along
  numerous sightlines out to z~1 and beyond
  combined with independent distance
- probe of small(subgalactic)-scale power spectrum
  via variance of FRB dispersion measures
  new constraints on warm dark matter
  also on small-scale feedback in CDM cosmology -> in progress
- probe of cosmic reionization
  via distribution of FRB dispersion measures
  He(~quasar) reionization
  possibly HI reionization IF FRBs exist at z>~6