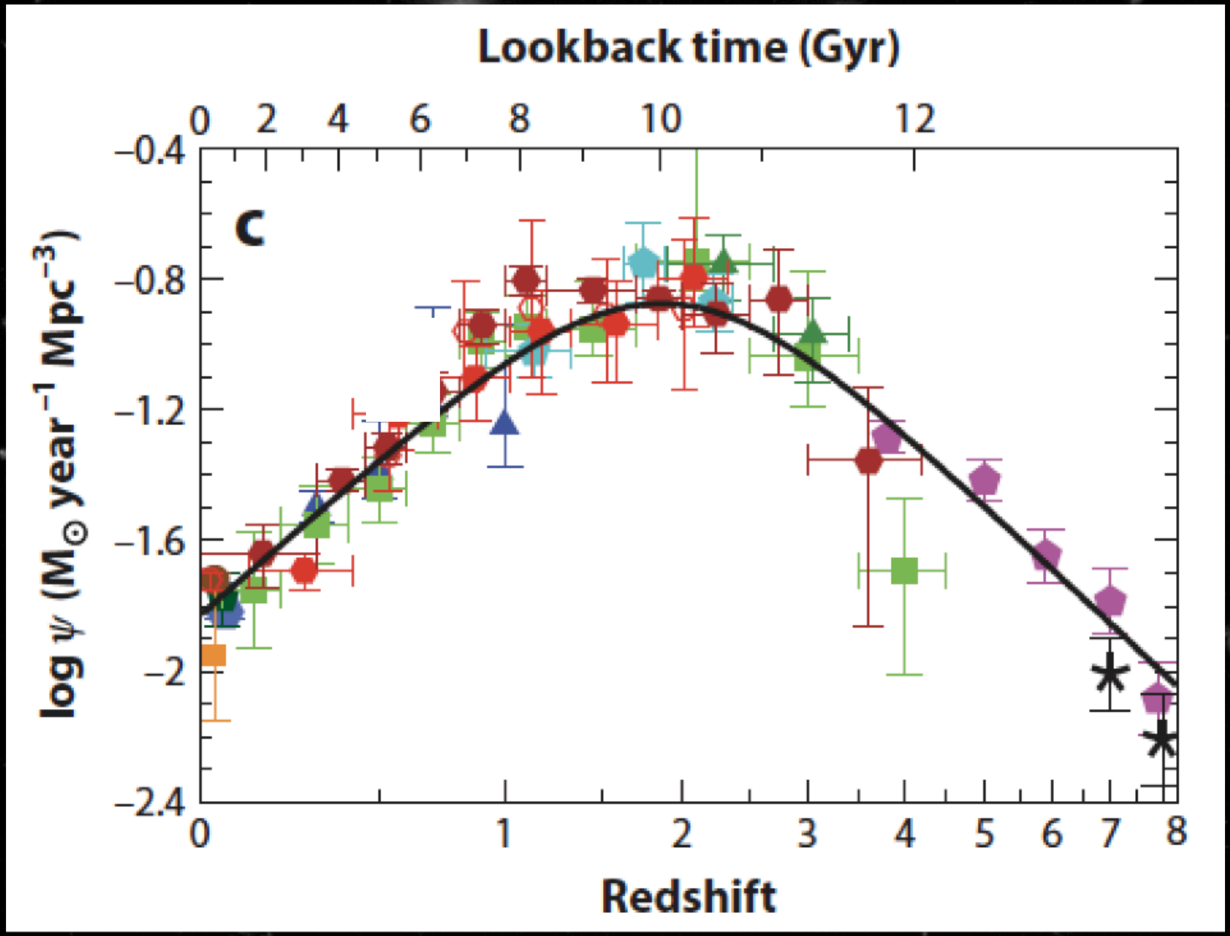
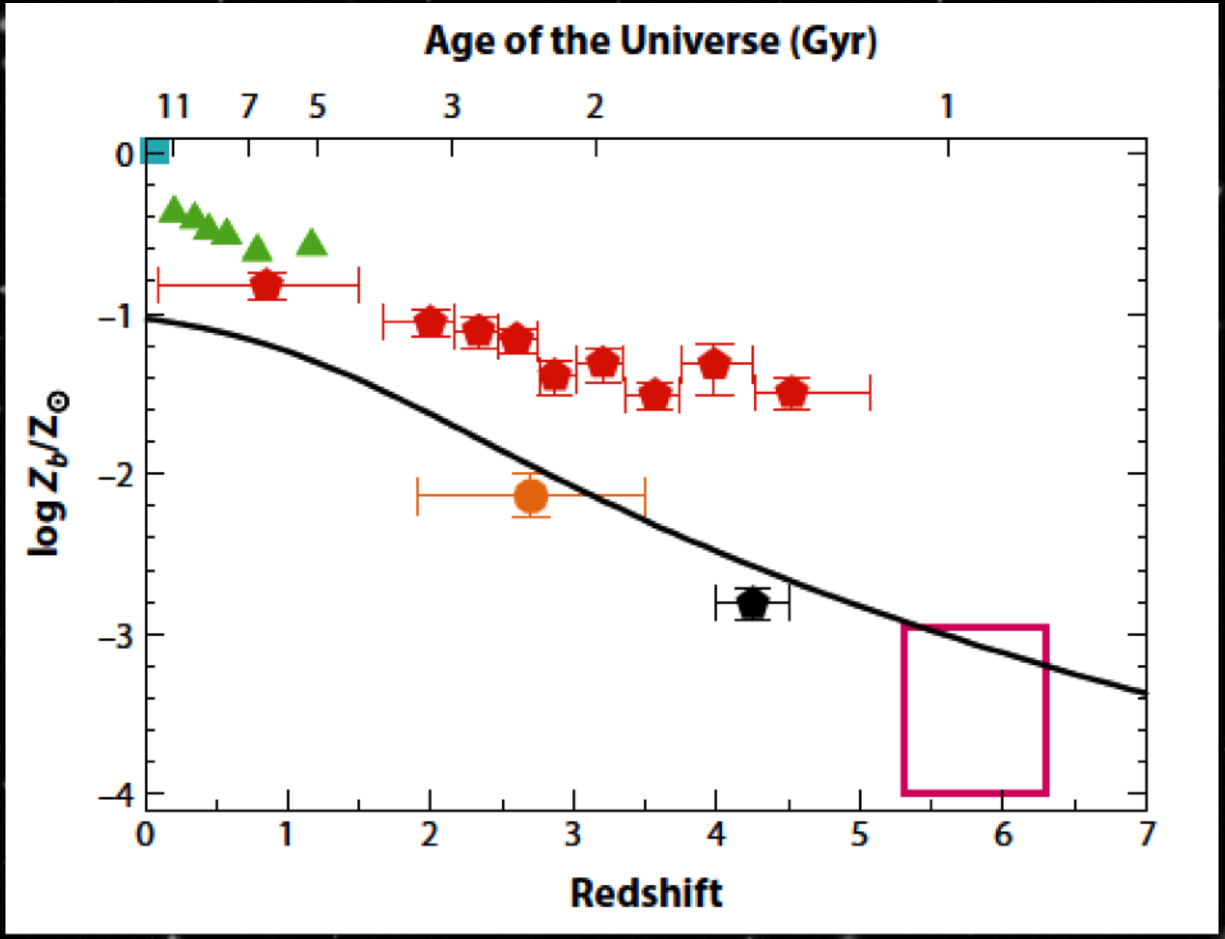
Astrophysics of GW Sources: The Cosmic History of Star and Metal Formation





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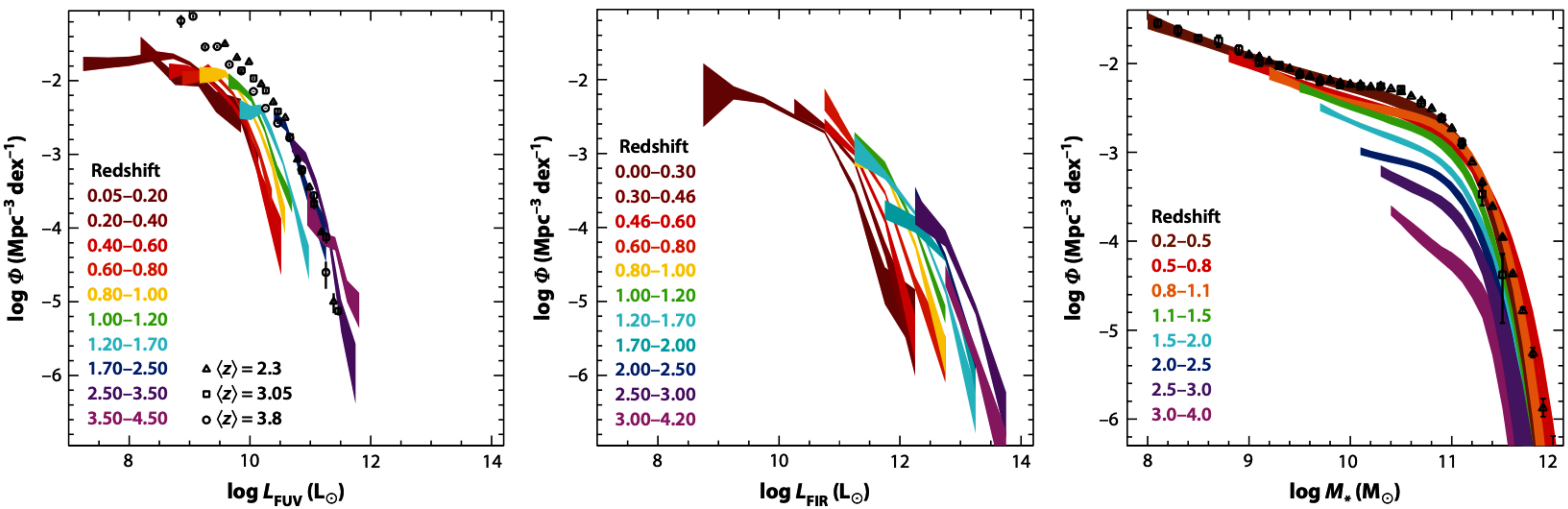
IPMU 2020

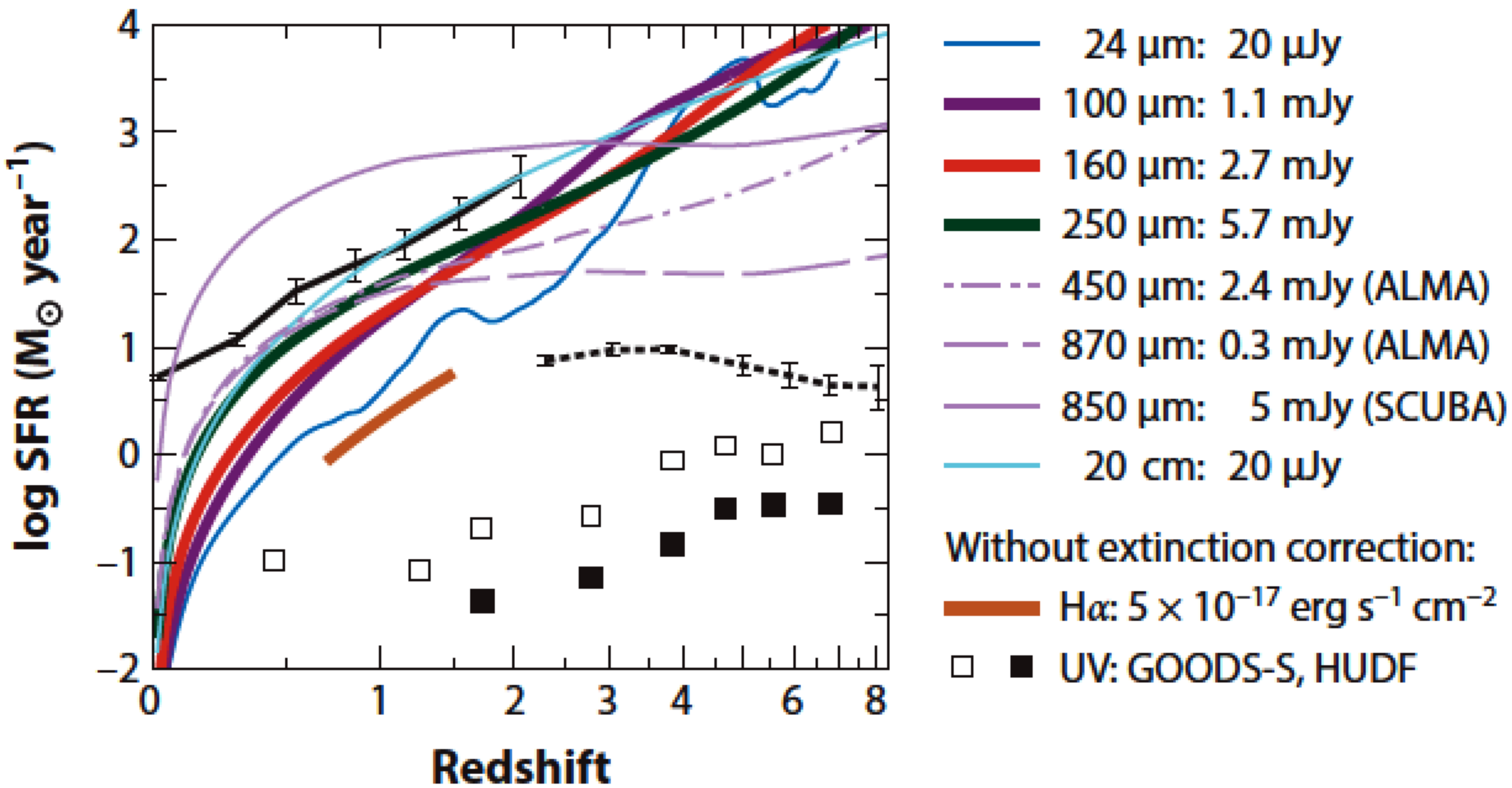
Binaries that merge in the local Universe originate from progenitor systems that formed at different redshifts and in various environments.

The efficiency of formation of compact binaries is highly sensitive to metallicity of the star formation ➪ detailed comparison of theoretical predictions (rates, mass distributions, *host galaxies*, etc) with GW observations requires knowledge of the distribution of cosmic SFR at different metallicities and times = SFRD(*Z,z*).

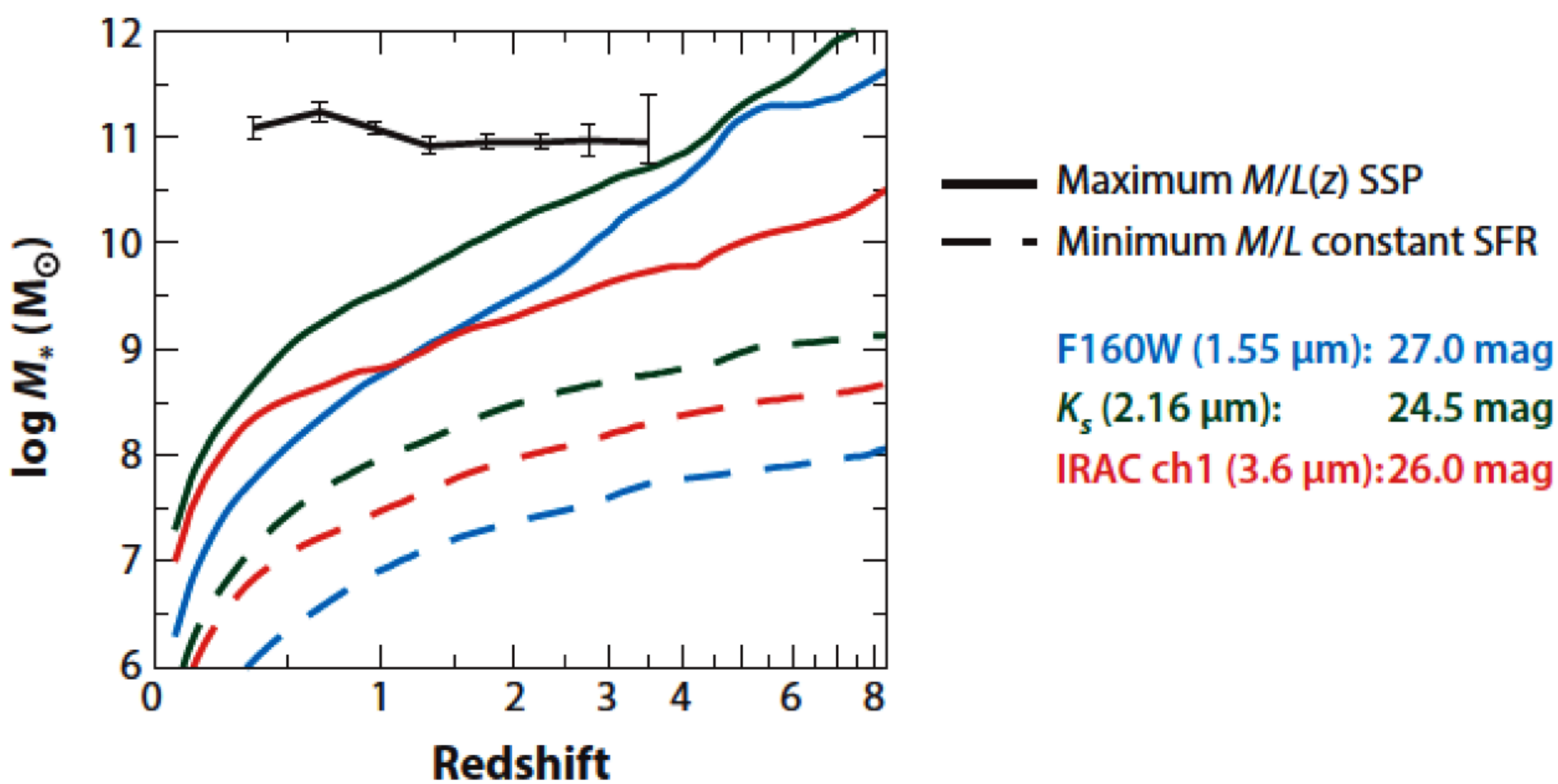
MEASURING SFR/M* WITH GALAXY SURVEYS



Redshift evolution of the FUV/FIR LF and SMF at $0 < z < 4$.



In the absence of dust extinction, UV measurements are more sensitive than current IR or radio data by orders of magnitude!



NIR to MIR measurements are critical for deriving stellar masses. Sensitivity to stellar mass depends on the M/L ratio of the stellar population in a distant galaxy, hence on its age, SFH, and extinction.

STAR FORMATION/STARS IN THE UV/IR/FIR

Conversion of light into SFR/M_* relies on some *basic properties* of stellar populations and dusty starburst galaxies: UV, FIR → SFR and NIR/OPT → M_*:

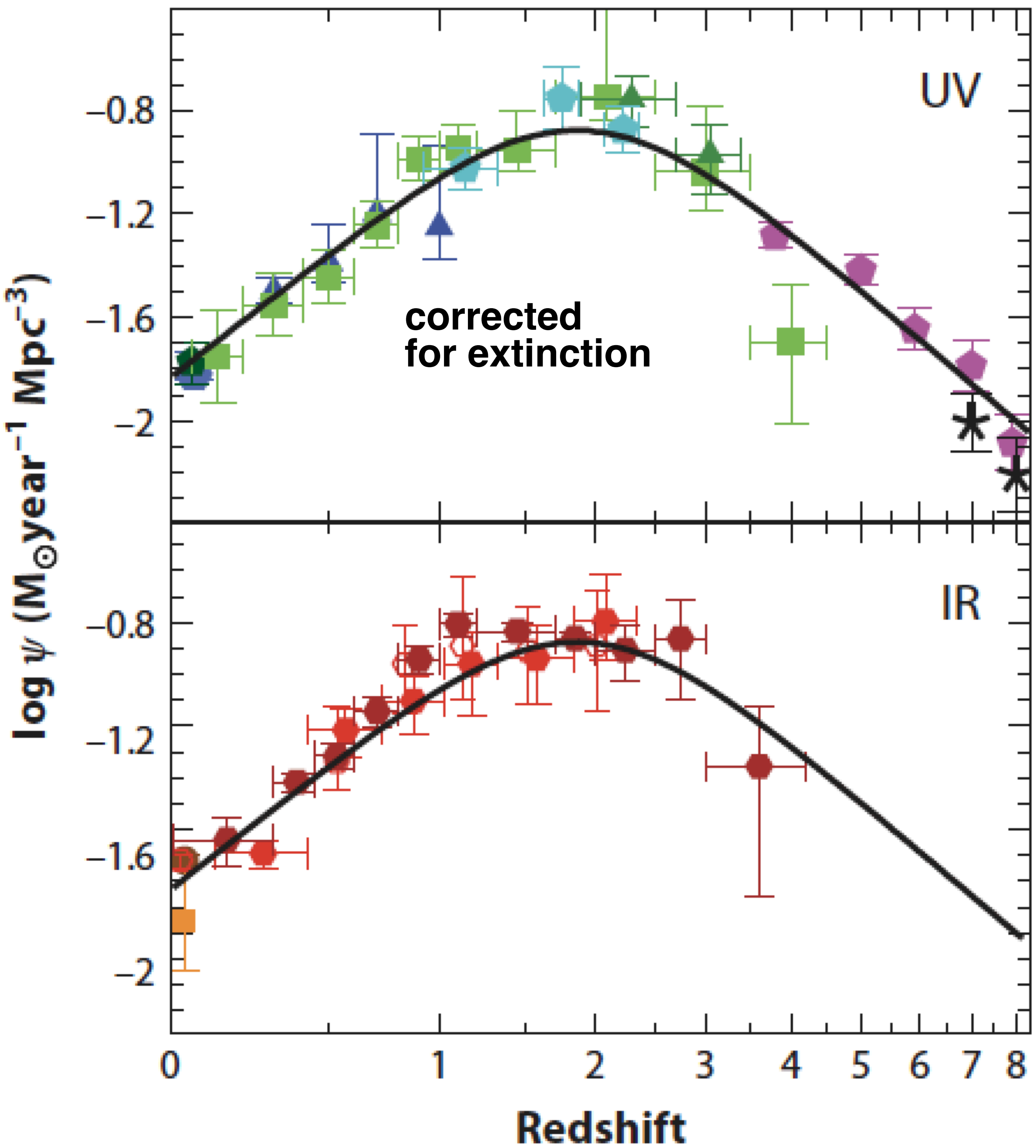
✓ FUV continuum at 1250–1800 Å comes mainly from OB stars.

✓ FUV luminosity ~ SFR if star formation continues over timescales > few x 10^7 years

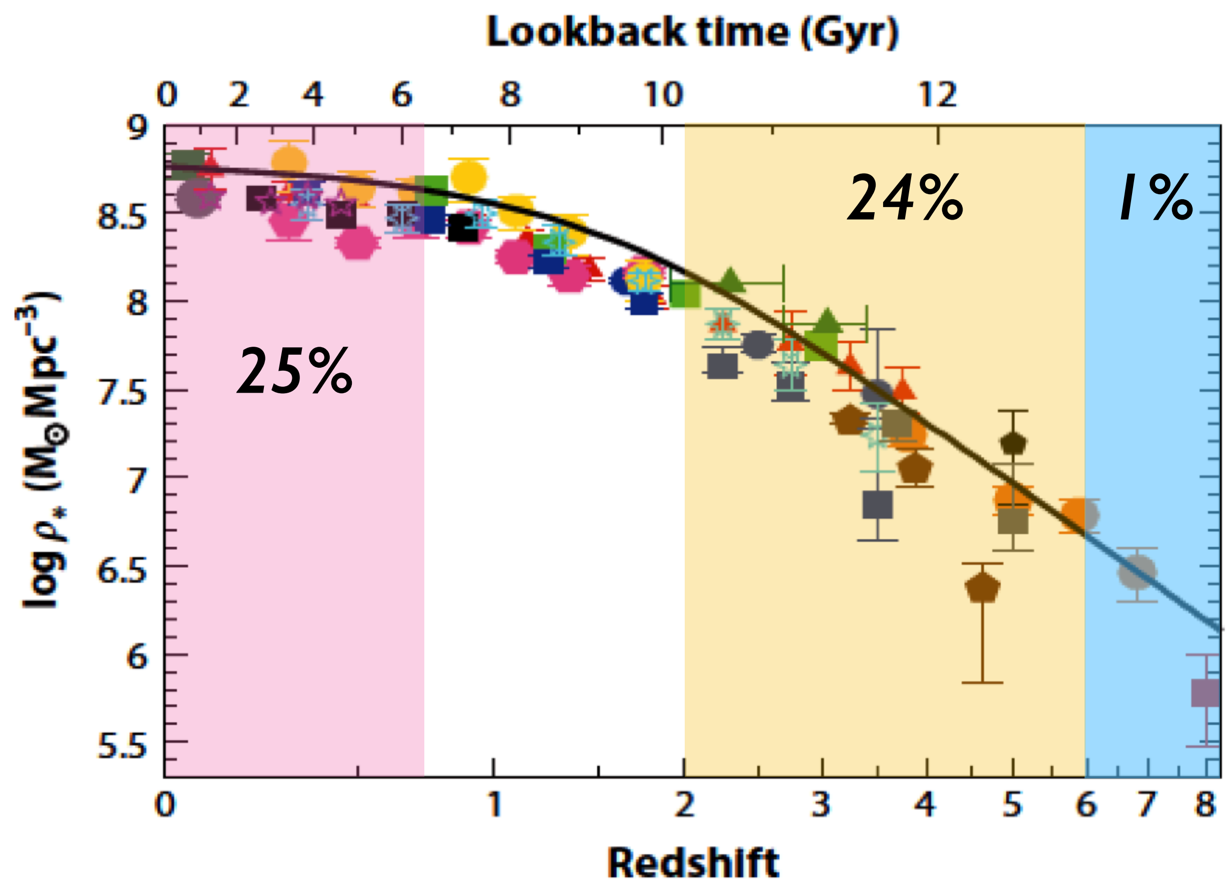
✓ Dust absorbs emission from SF and re-radiates it in the IR.

✓ Total IR luminosity (8–1000 μm) is a calorimeter for dust-obscured SF.

Cosmic Star Formation History

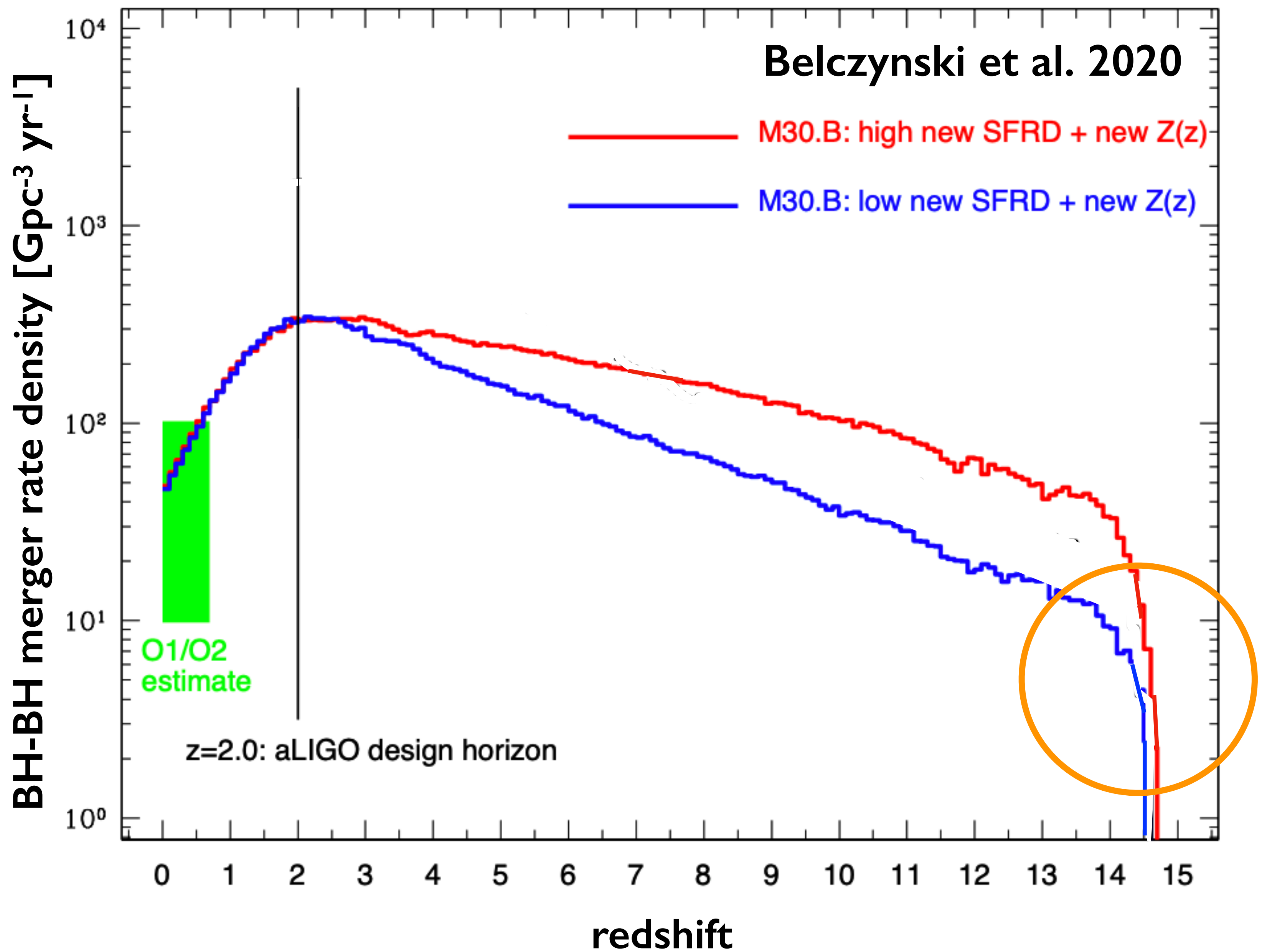


Nice consistency between IR and UV determinations of the SFRD(z) and between the measured SMD(z) and integral of SFRD(z) – *not perfect*, but within measurements spread.



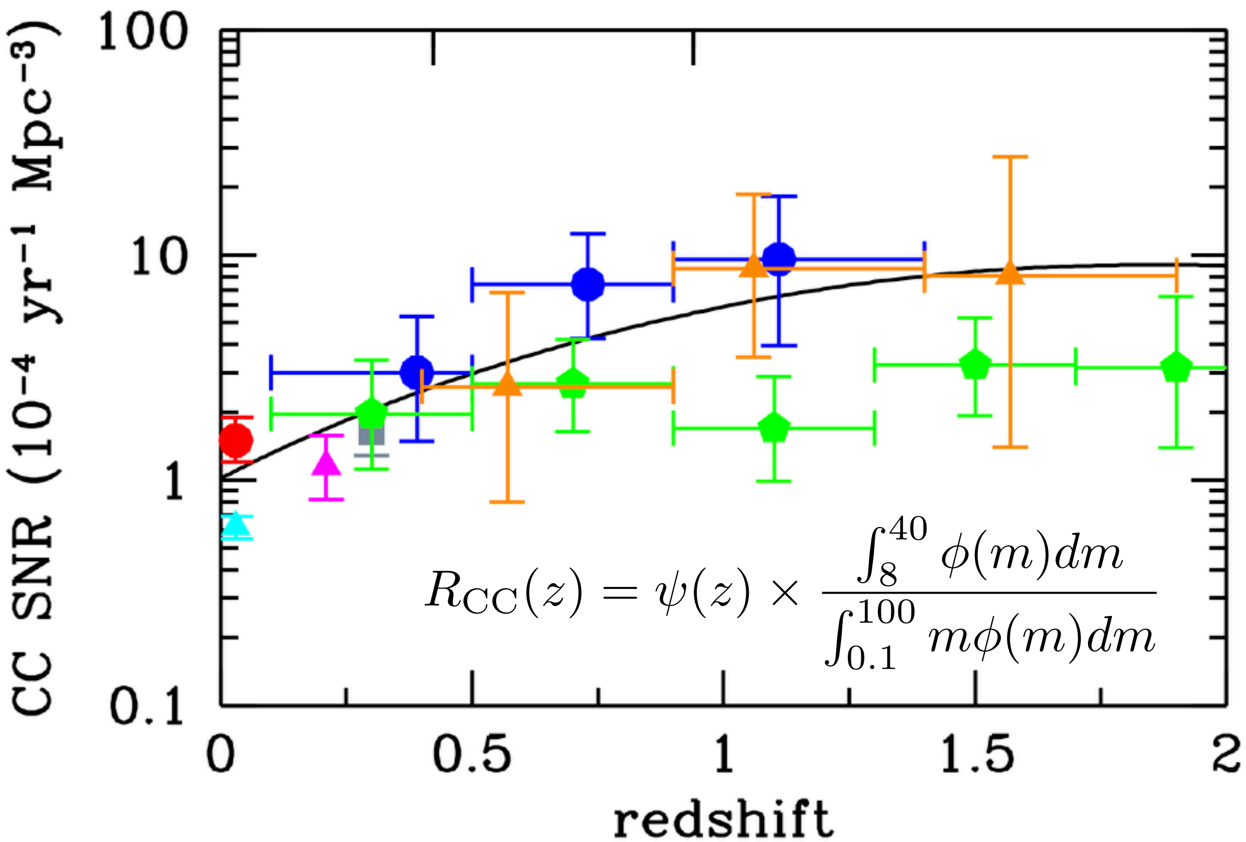
No compelling evidence for non-standard/non-universal IMF!

BH-BH MERGER RATES VS SFH

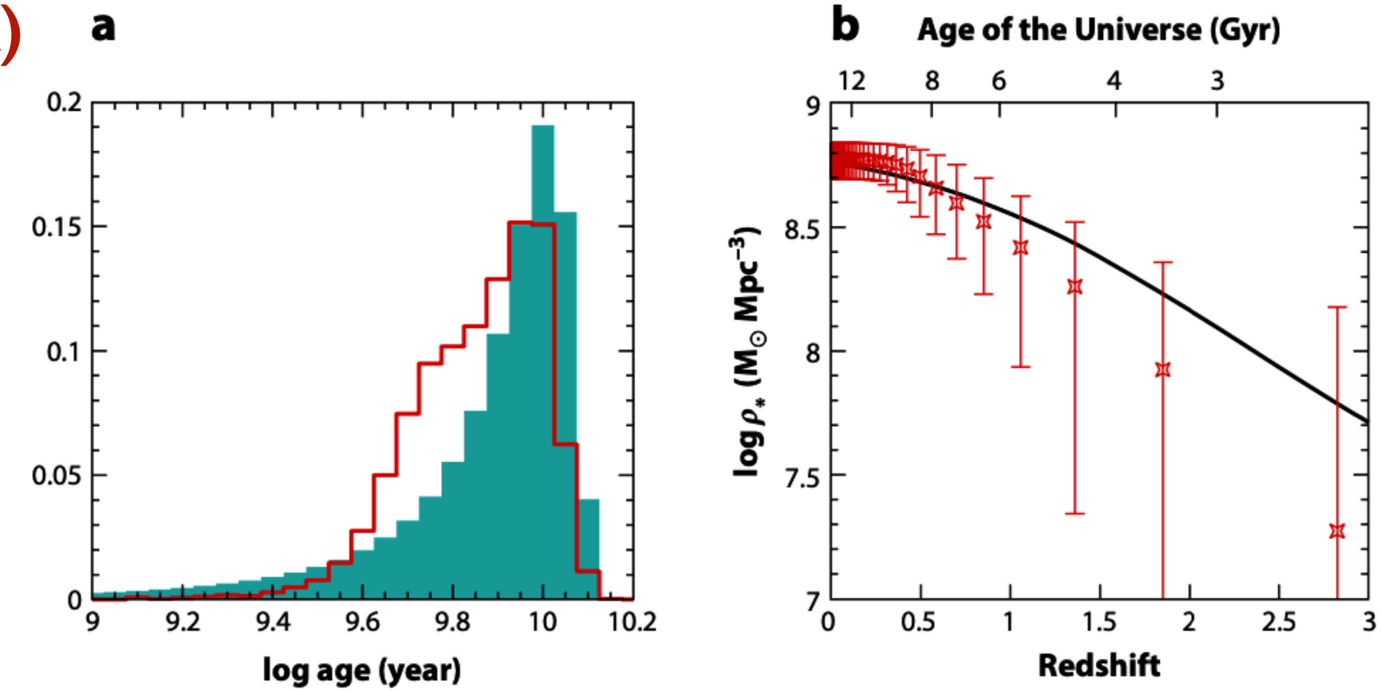


Consistency Checks

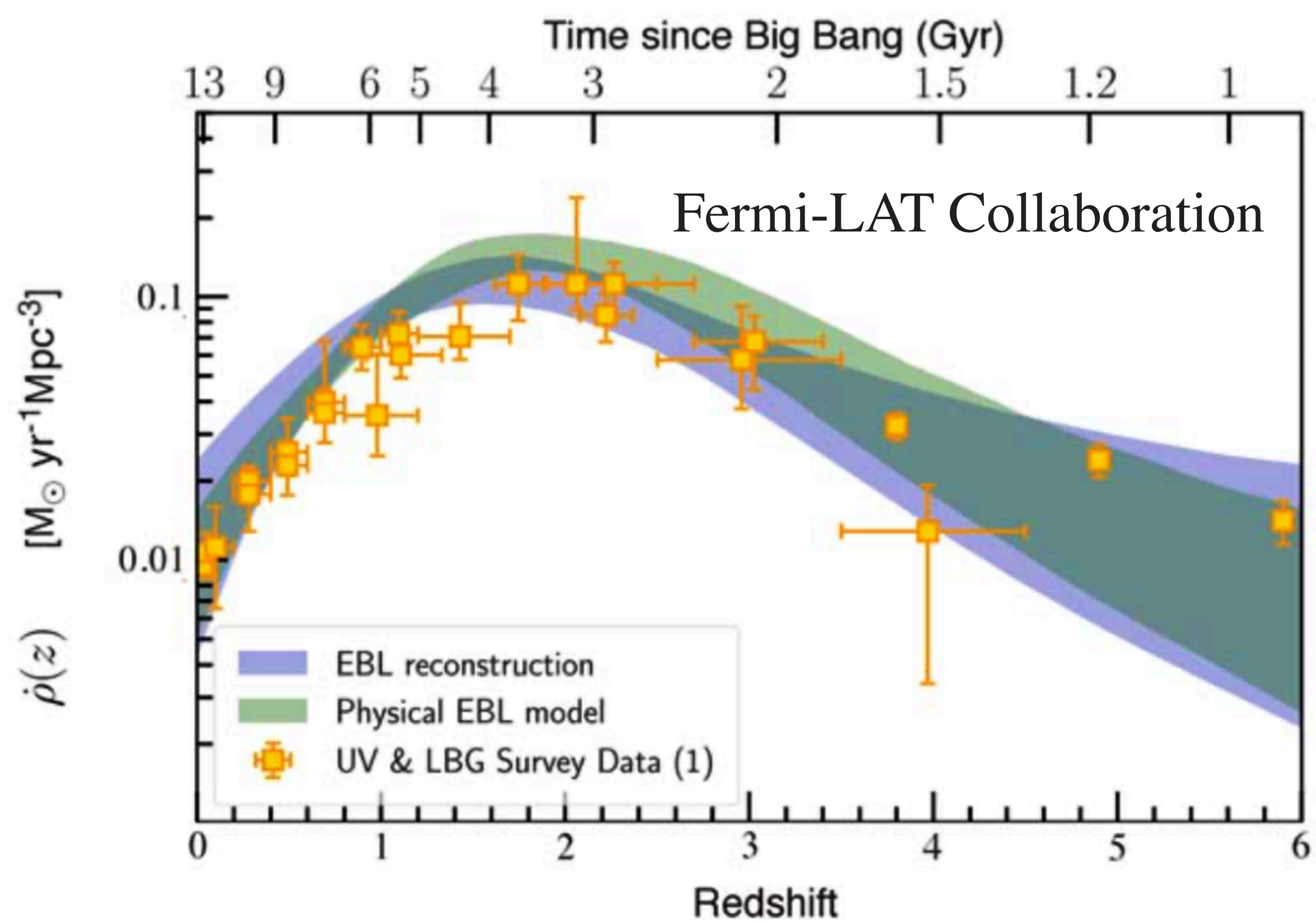
Cosmic core-collapse SN rate (CC SNR)



Stellar archaeology with the SDSS



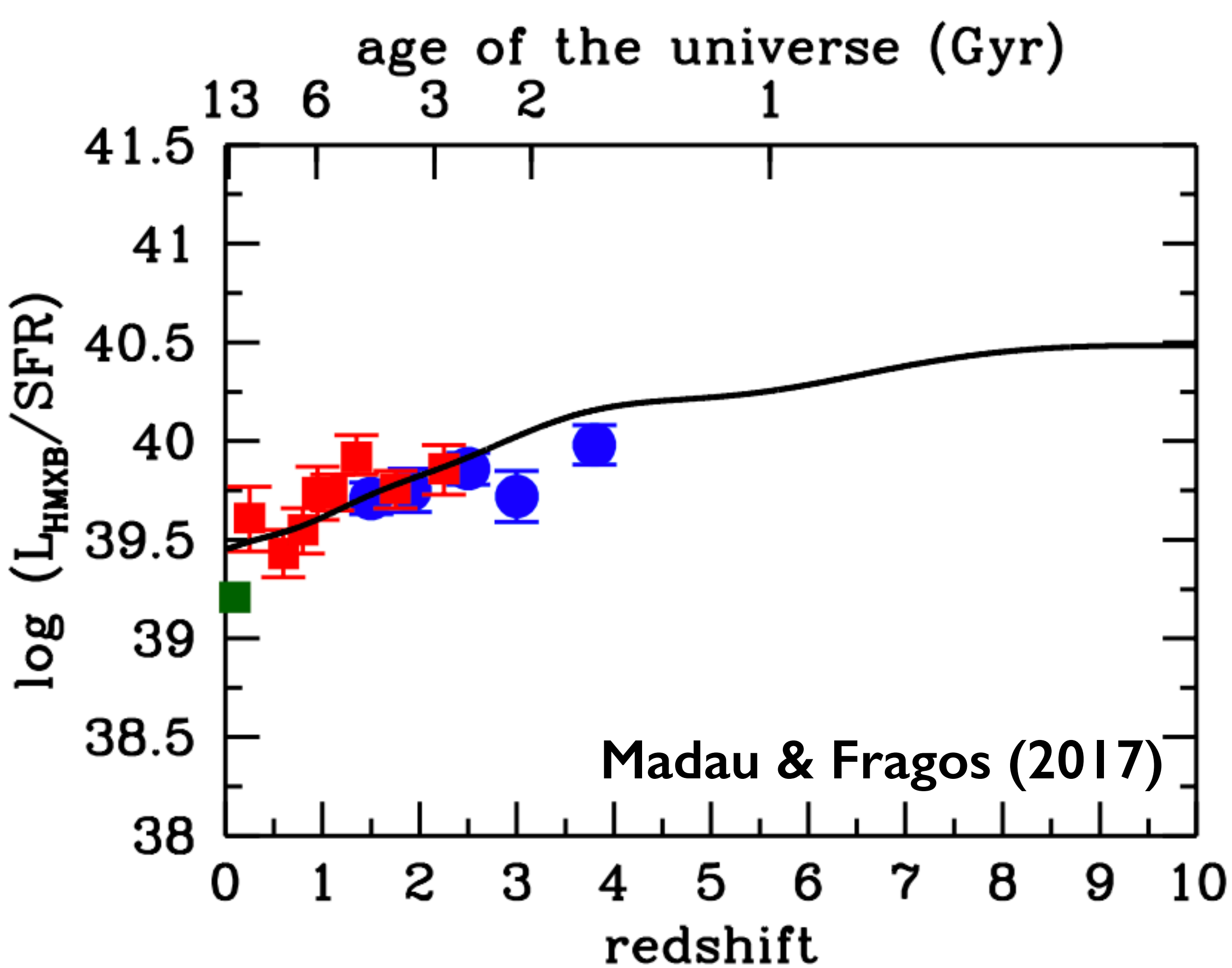
Gamma-ray attenuation via $\gamma\gamma \rightarrow e^+e^-$ interactions



METALLICITY EFFECTS: *Z(z)*

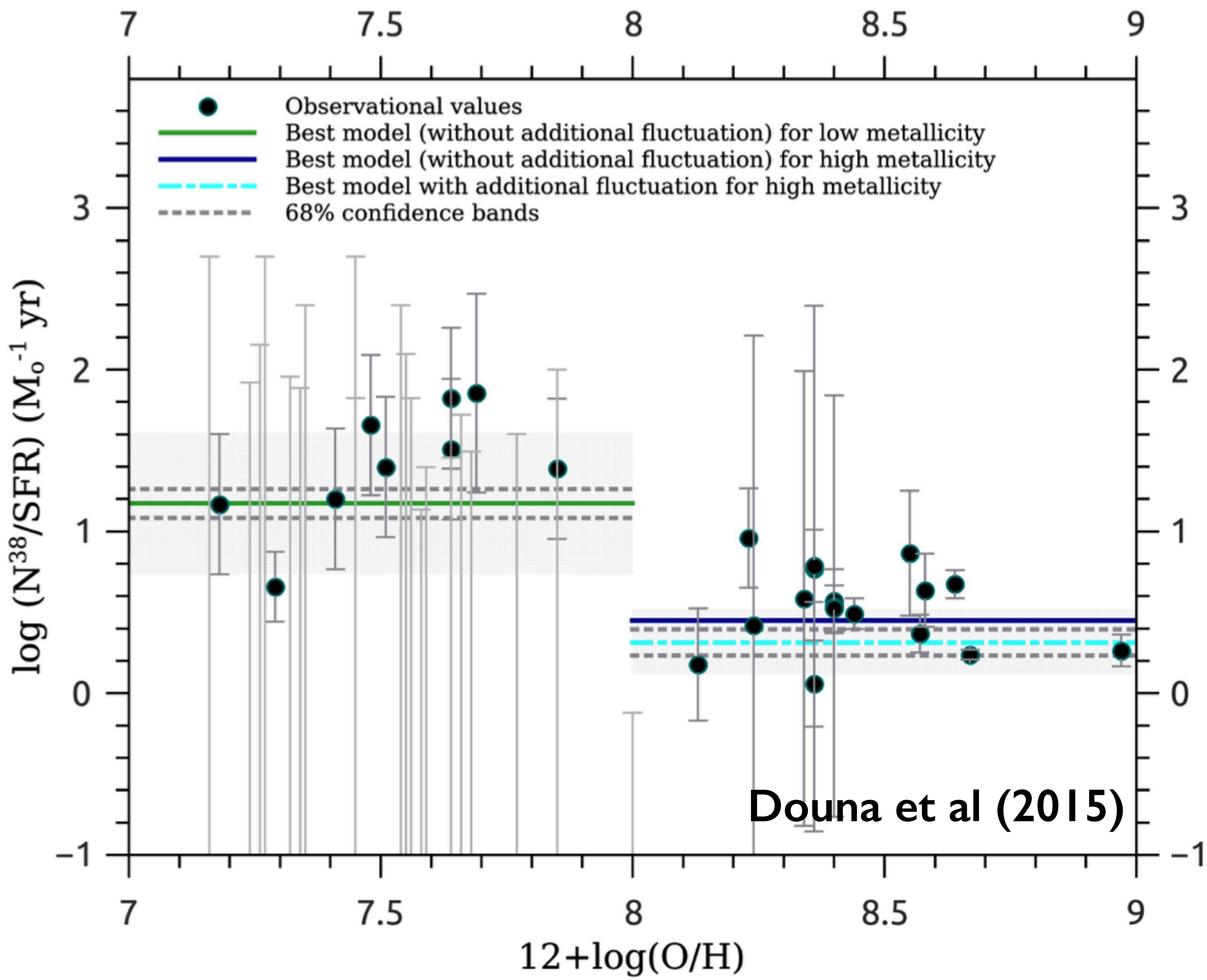
Metallicity affects the number and luminosity of compact binaries through a number of physical processes involved in binary evolution:

- Mass-loss rates of OB and Wolf-Rayet stars from line-driven winds scale inversely with their metal content ➩ a more massive and more numerous black hole population.
- Reduced wind mass losses in low-metallicity environments lead to reduced angular momentum losses and to overall tighter binary orbits, which in turn increase the ratio of *Roche-lobe overflow versus wind-fed binaries*….

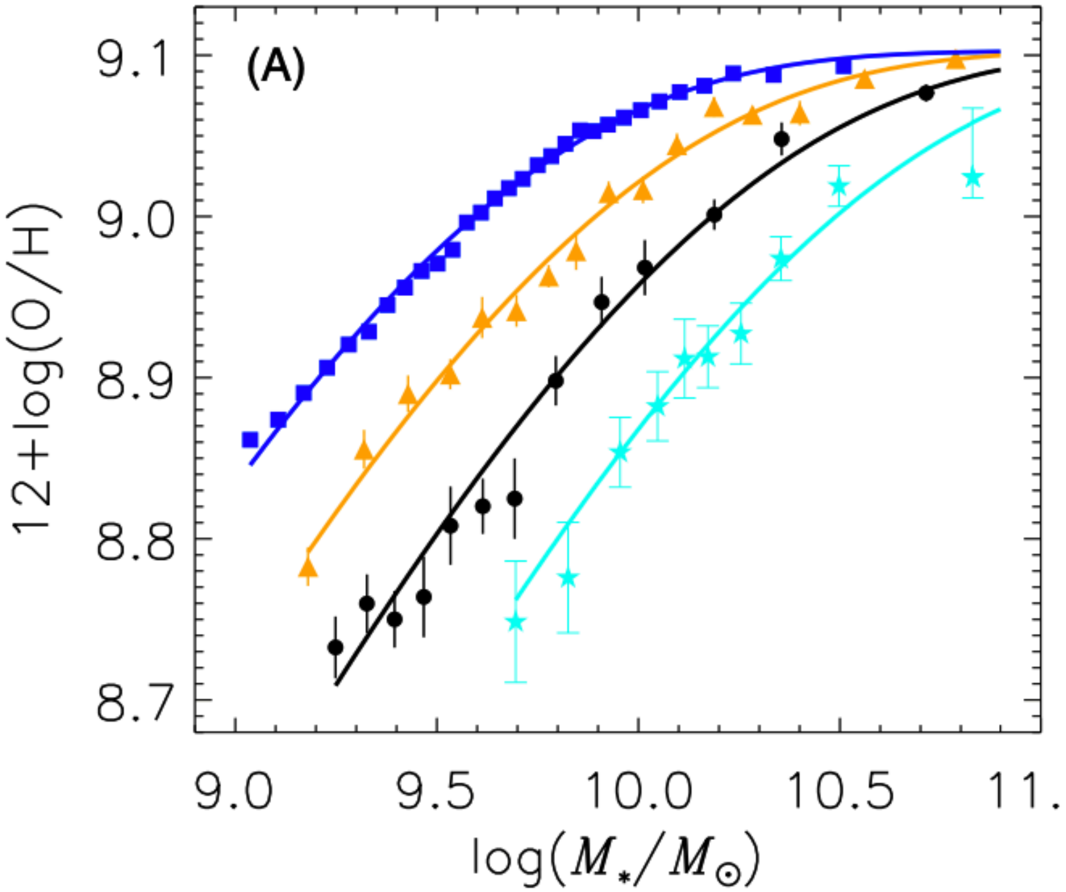


2-10 keV X-ray luminosity from HMXBs, per unit SFR, as a function of redshift. Solid line: evolution of this ratio obtained by combining binary population synthesis modeling with a mean stellar mass-gas metallicity relation (see next slide).

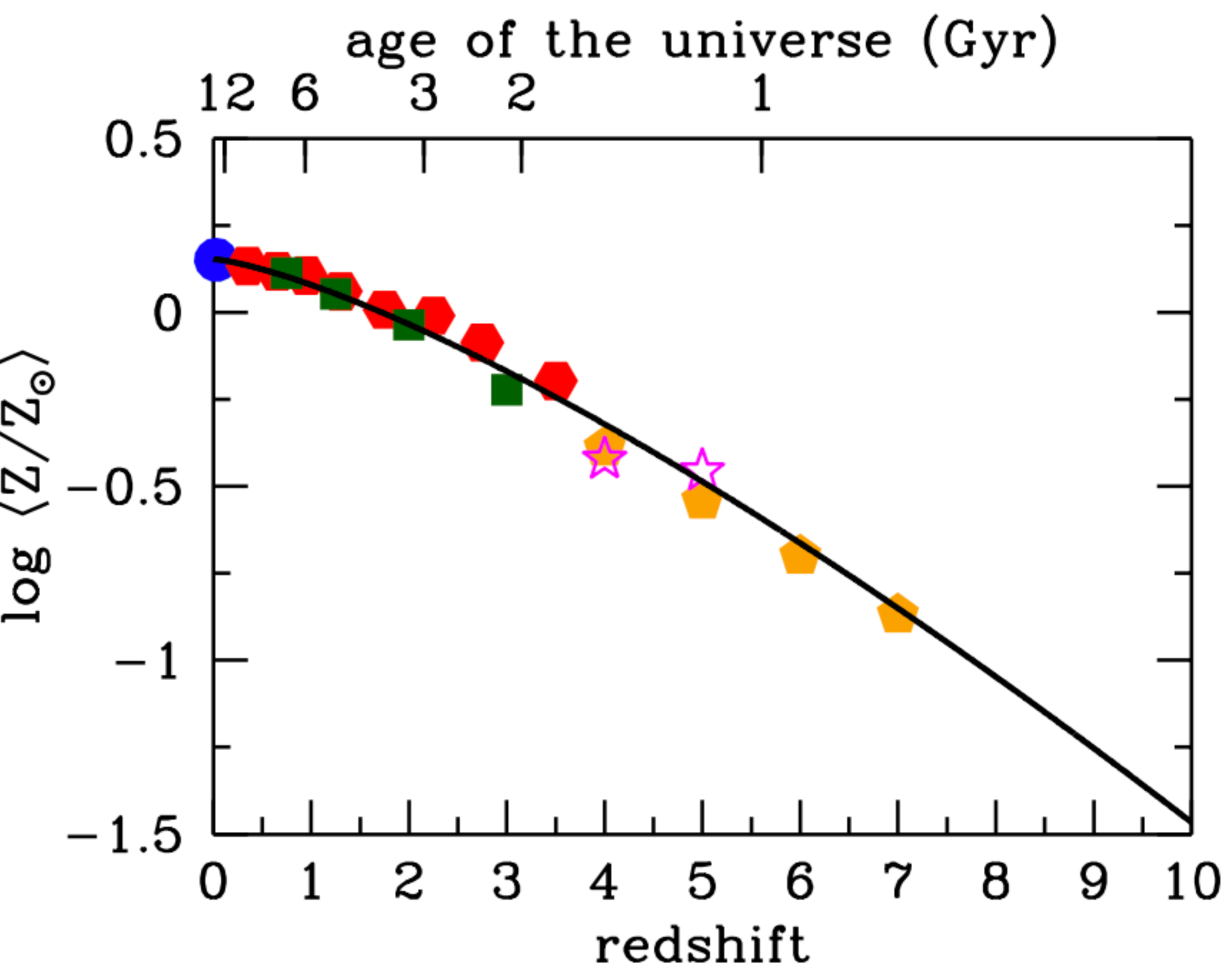
METALLICITY DEPENDENCE OF HMXB POPULATIONS



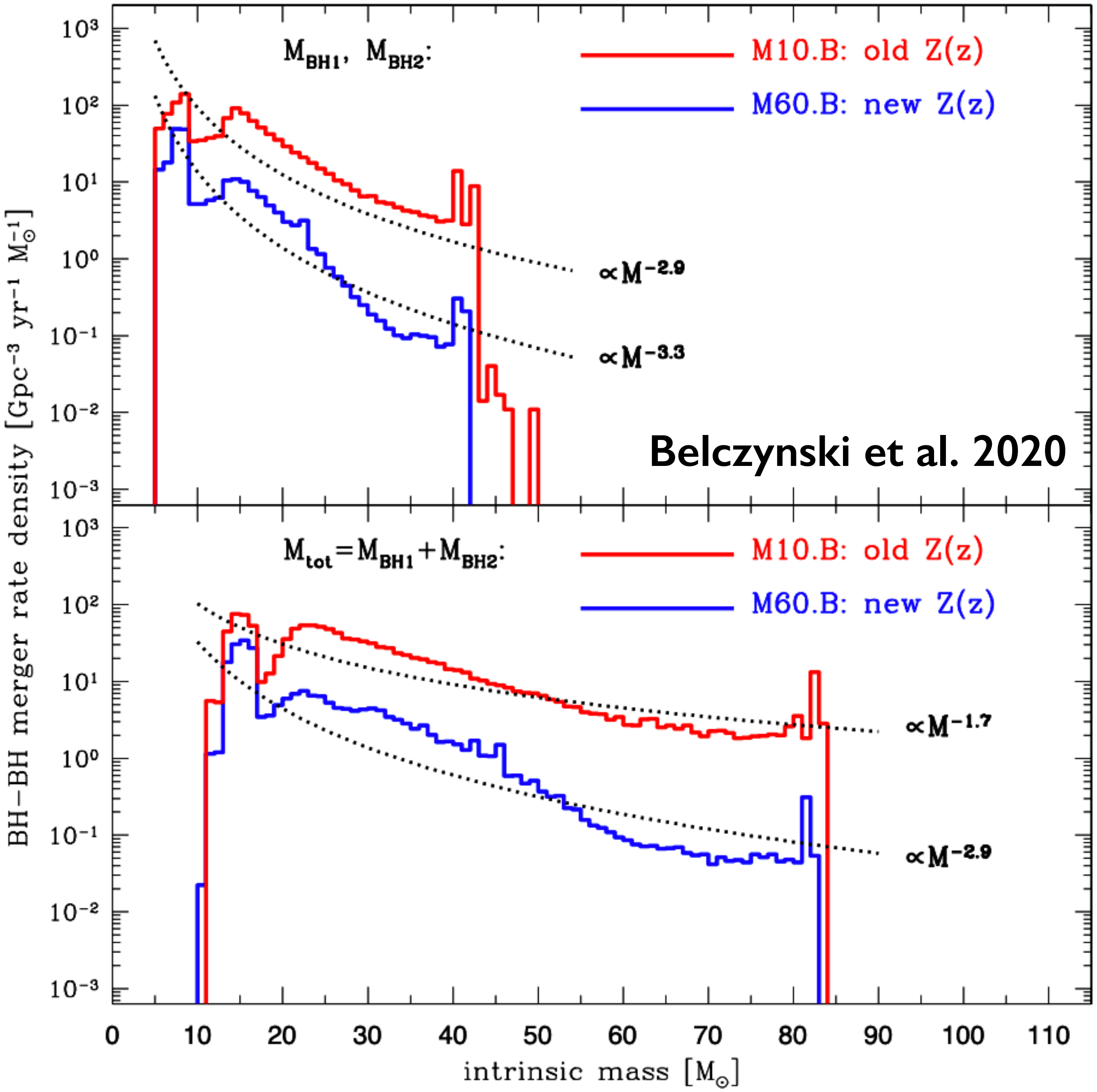
Observed number of HMXBs with luminosities higher than 10^{38} $ergs^{-1}$, per unit SFR, as a function of the oxygen abundance. Black circles are the data points, with error bars representing Poissonian uncertainties.



MZ relation for *z<1.6*. The solid curves are the best single-parameter model fits to the MZ relation.

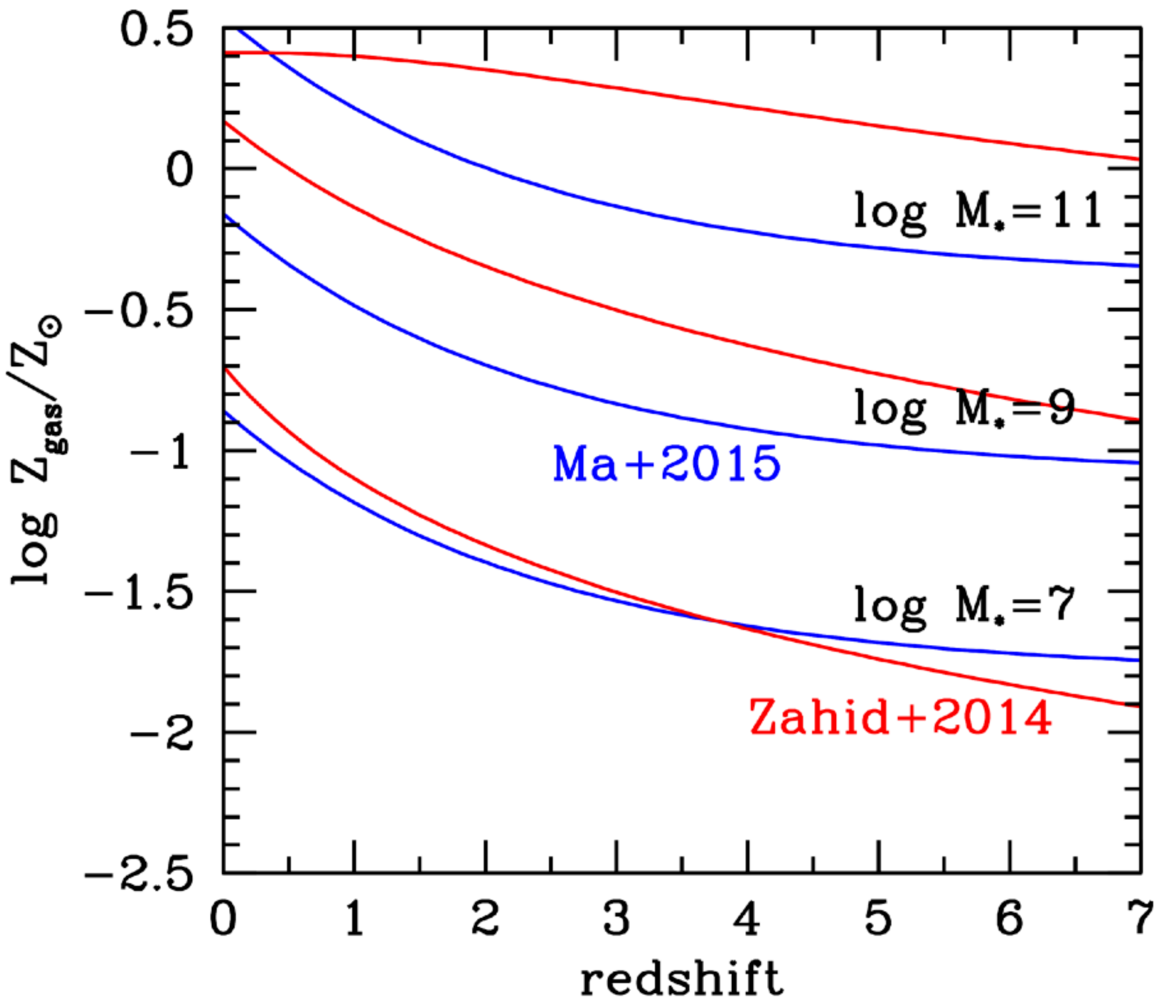


The gas-phase metallicity history of the galaxy population *as a whole*. The mass-weighted metallicity has been computed by integrating the mass-metallicity relation of Zahid et al. (2014) over the evolving galaxy stellar mass function of Baldry et al. (2012) (blue dot), Ilbert et al. (2013) (red exagons), Kajisawa et al. (2009) (green squares), Lee et al (2012) (magenta stars), and Grazian et al. (2015) (orange pentagons).

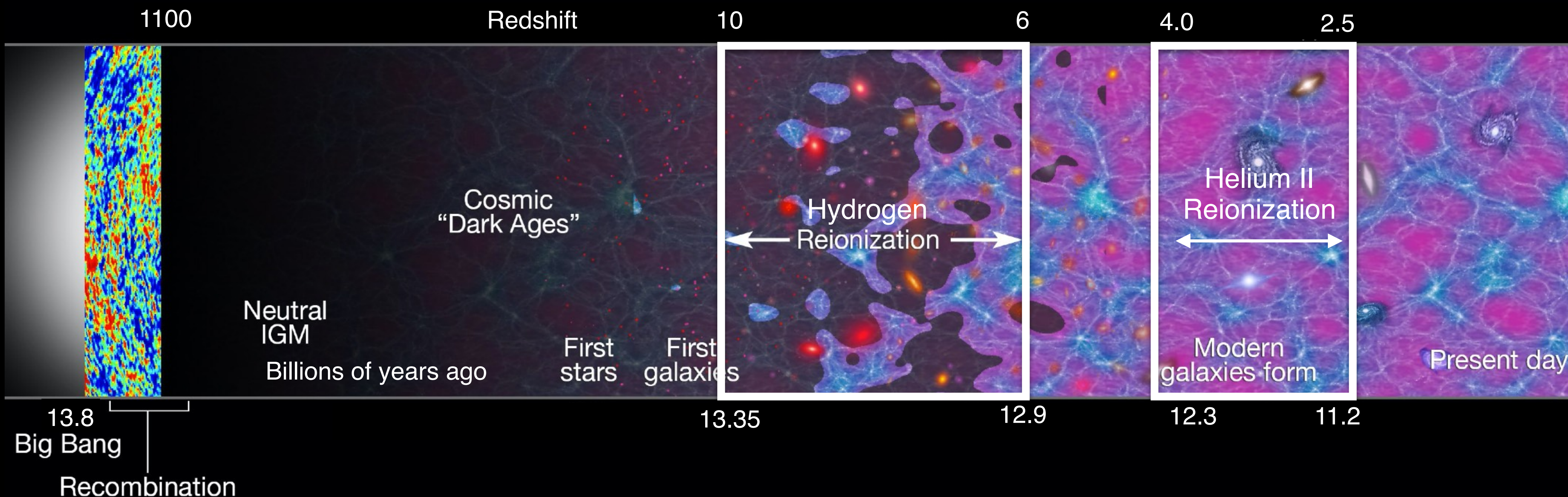


BH-BH merger density within design advanced LIGO sensitivity (z<2) for models M10.B (old Z(z)) and M60.B (new Z(z)). Top panel shows distribution of individual BH masses, while bottom panel shows total BH-BH system mass.

Evolution of the mass-metallicity relation using Zahid et al (as in Madau & Fragos) and Ma et al. 2015 (based on simulations). The attached plot (for 3 stellar masses, log *M*=7,9,11*) shows that the major difference is in the zero-point rather than in the redshift evolution — except perhaps at log *M*=11*.

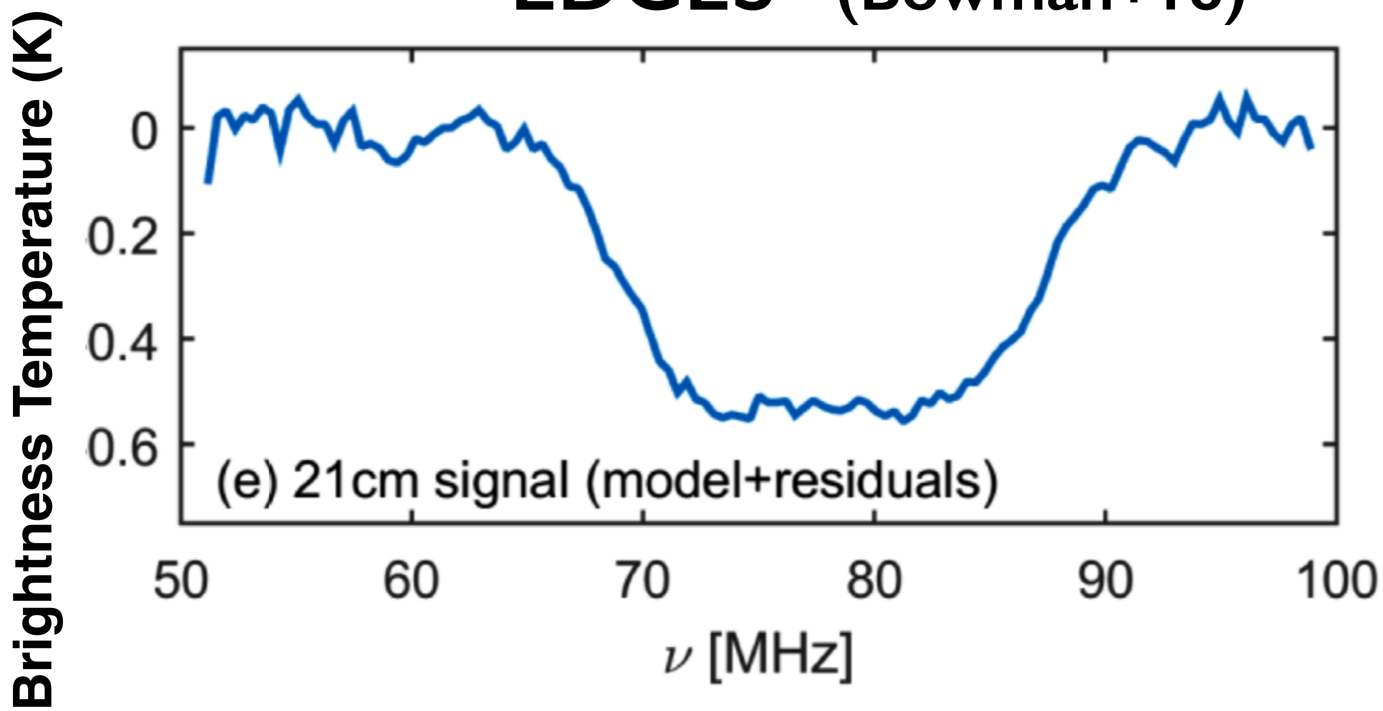


A brief history of Reionization



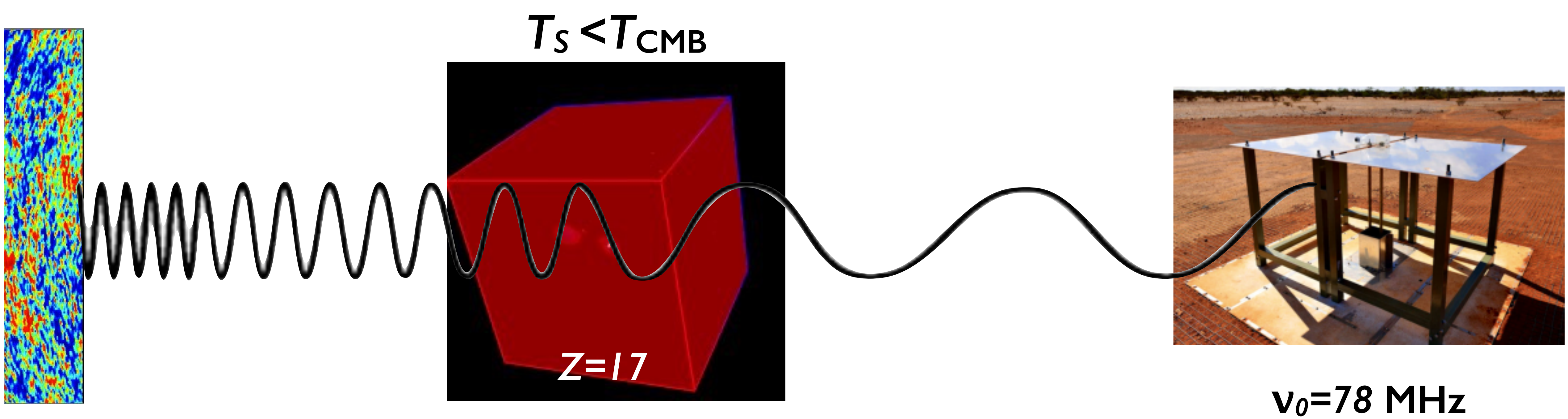
When does reionization start?

EDGES (Bowman+18)



$$T_{21} \propto x_{\rm HI}\left(1 - \frac{T_{\rm CMB}}{T_S}\right)$$

(assumes no excess radio background!)



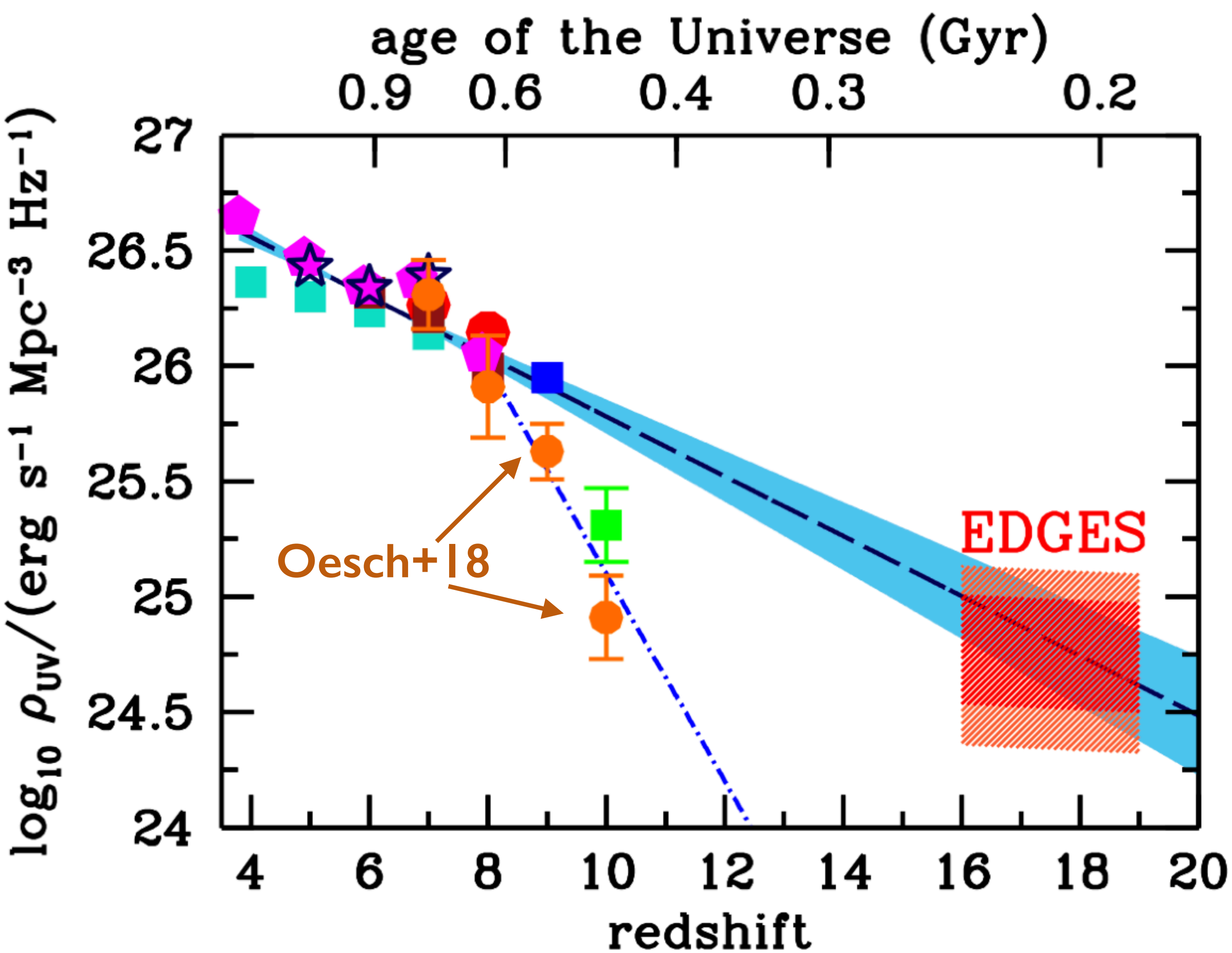
CMB acts as backlight

H I imprints all-sky 21-cm *absorption* signal

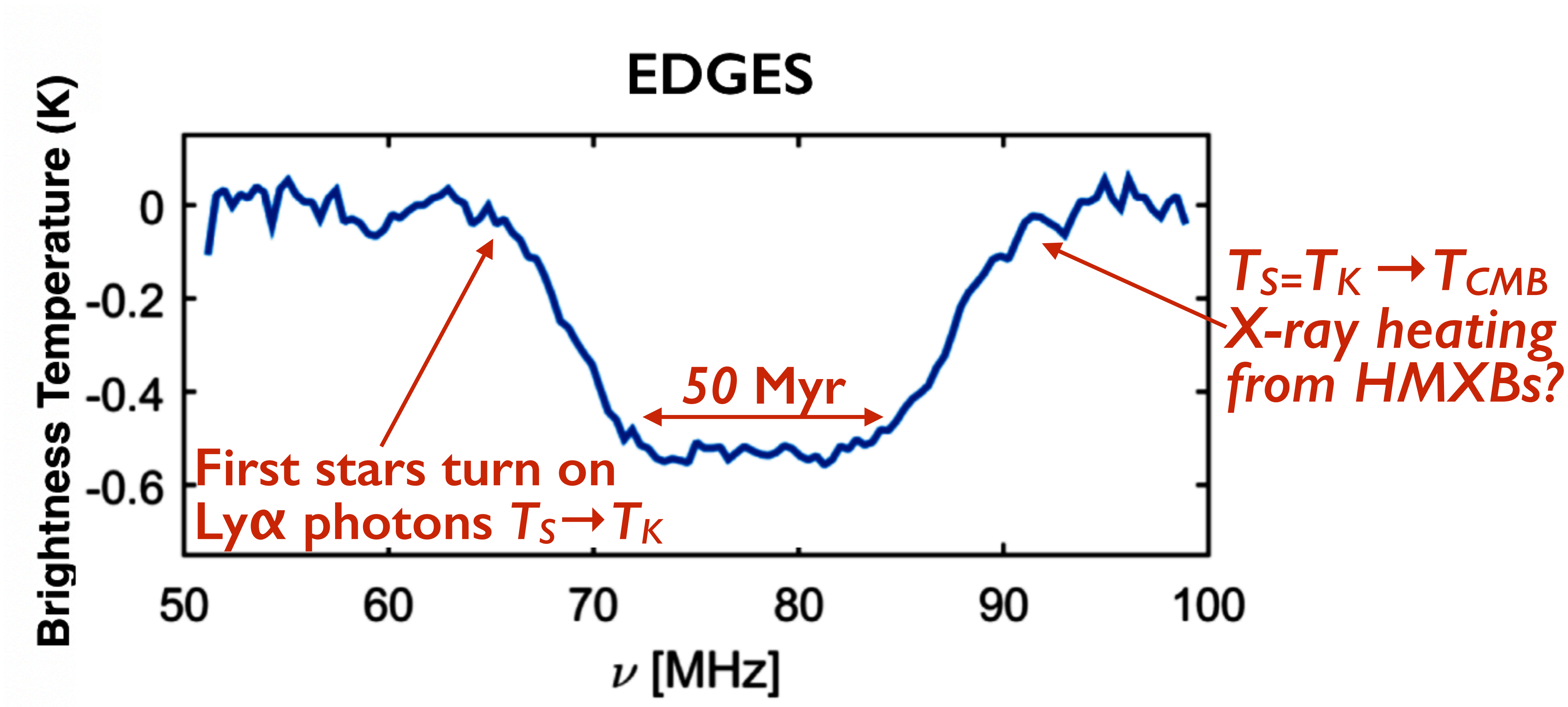
First, metal-poor stellar systems?

A 21-cm signal at *z~18* is consistent with an extrapolation of the declining galaxy UV luminosity density measured at *4 < z < 9* by deep HST observations. *A substantially enhanced SFR density or new exotic sources of UV photons are not required by the EDGES detection.*

☛ galaxy *light* builds up at a *steady* rate over the first Gyr of cosmic history?



X-RAYS AT COSMIC DAWN?



Δt = preferred formation timescale of HMXBs after SF episode.

M33 (Garofali+2018, HST+Chandra): $\Delta t \sim 40$ Myr (delayed onset associated with NS+Be stars).

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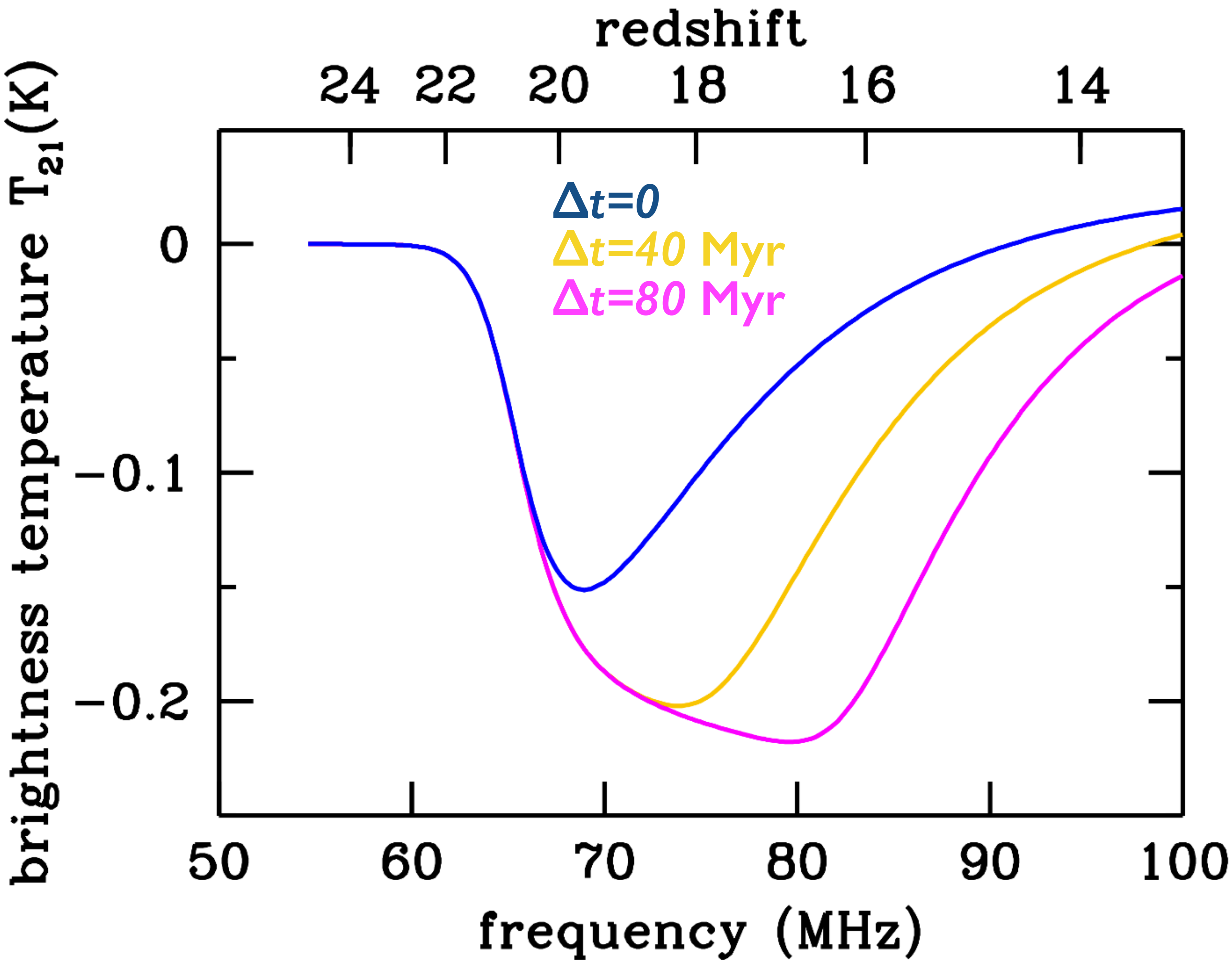

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