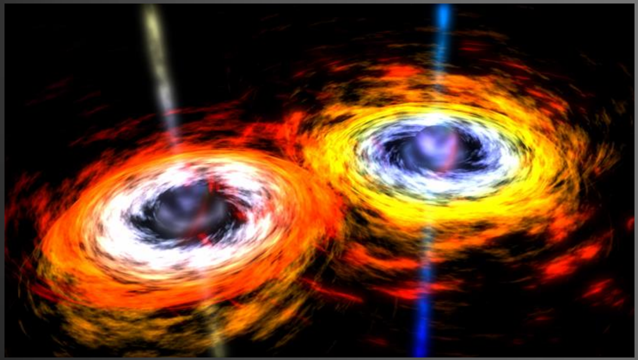
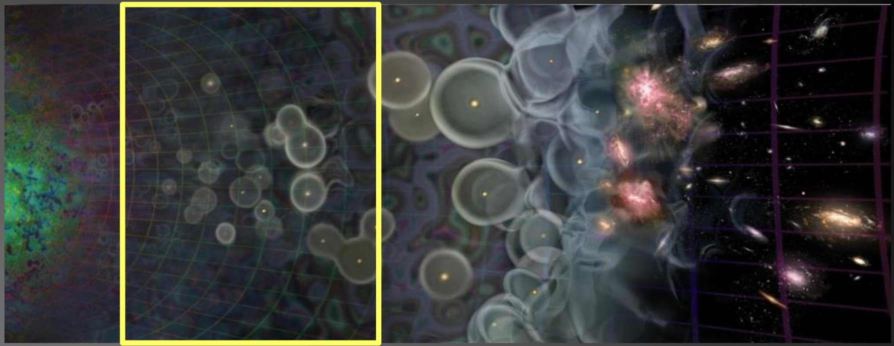
Signals from the Cosmic Dawn

Anastasia Fialkov
ITC Fellow, Harvard

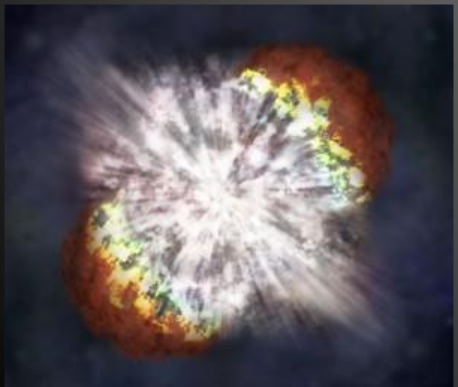
  

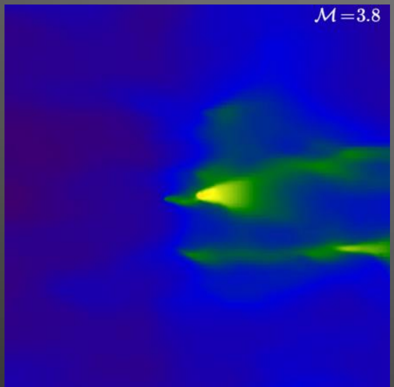
December 3, 2017

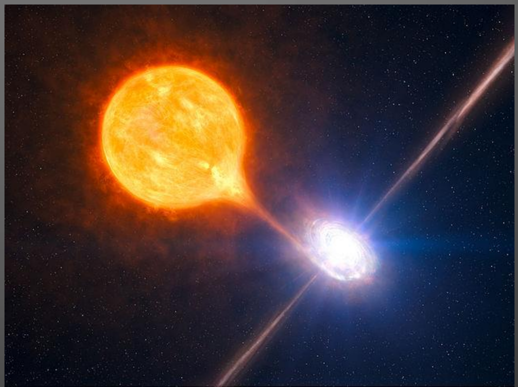
High-redshift Environment

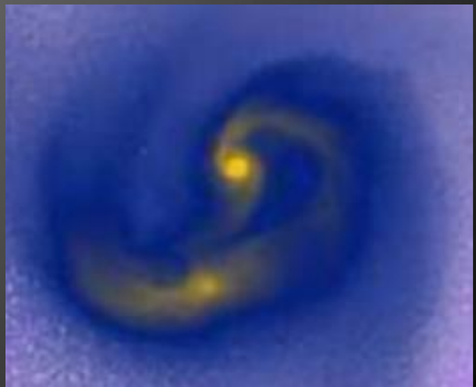


- Cold metal-poor IGM
- Small halos
- Star formation in rare regions
- Massive star formation via H_2 ($M_h \gtrsim 10^5 M_\odot$) or HI ($M_h \gtrsim 10^7 M_\odot$)
- Supersonic motion between baryons and gas on large scales
- Diverse populations: small black holes, heavy stars, pair instability SN, variety of X-ray sources
- Radiative feedbacks (e.g., LW feedback) suppress star formation



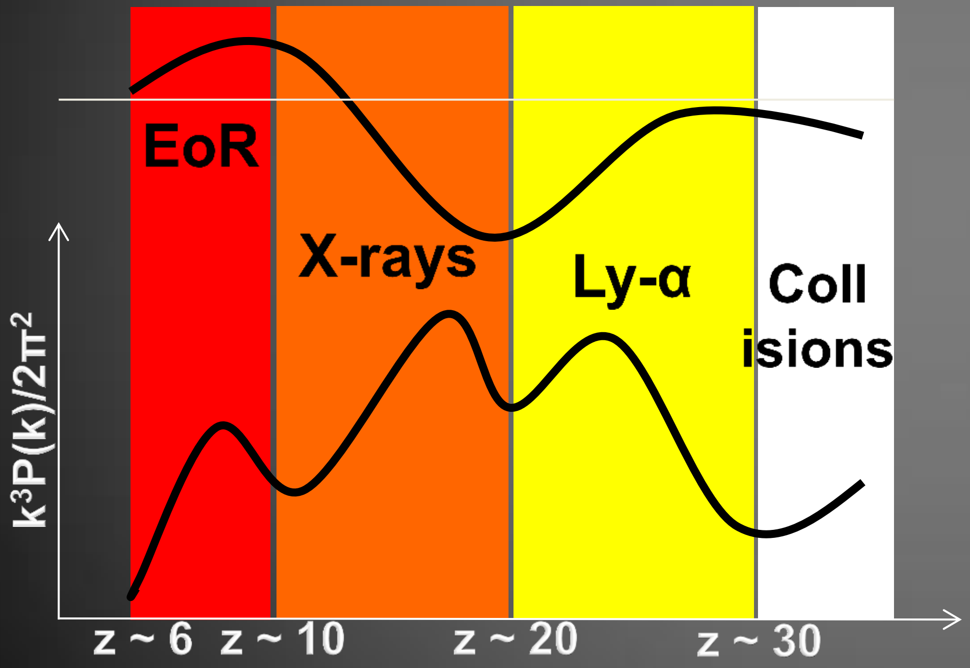






Probes of the Early Universe

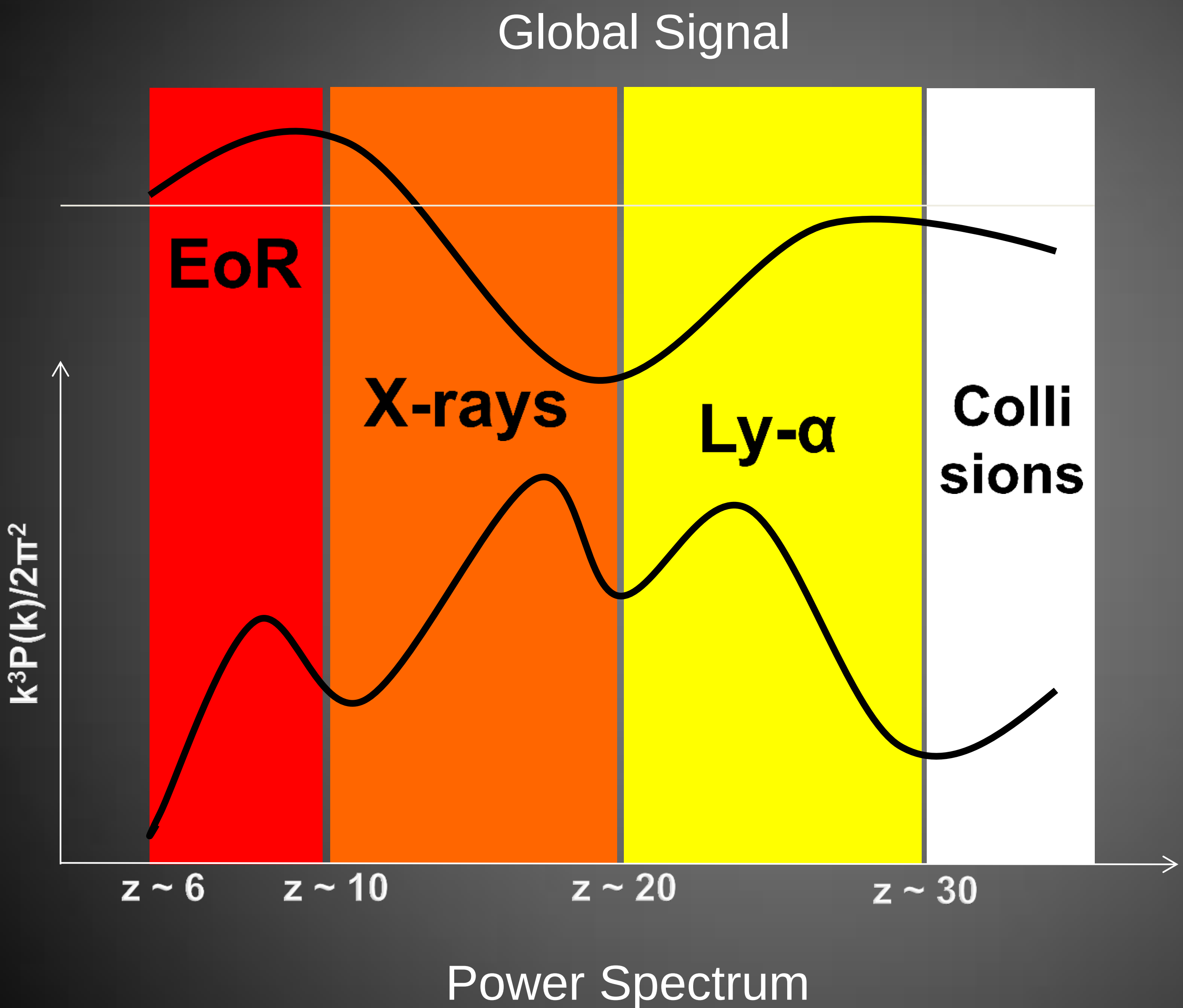
- 21-cm signal (main example)
- Transients



Artist's impression of a tidal disruption event. *Credit: ESA/C. Carreau*

CSIRO's Parkes radio telescope with an image of the distribution of gas in the Galaxy and an artist's impression of an FRB. Image credit: Swinburne Astronomy Productions

Expected 21-cm Signal: An Example



Drivers:

Galaxies

Quasars

XRB

BHs

Hot Gas

SN

First stars

Feedbacks

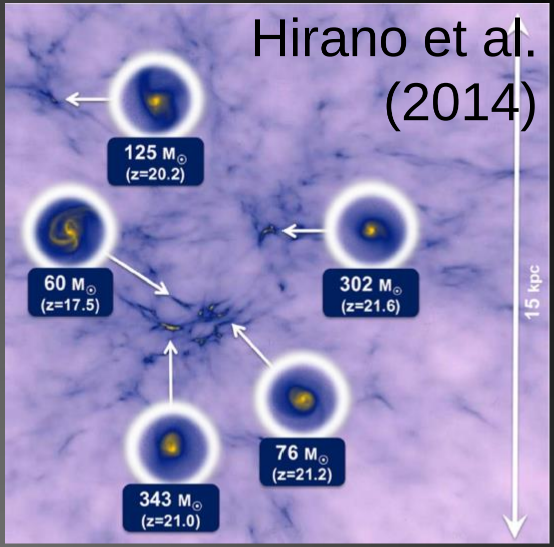
Velocity flows

Cosmology

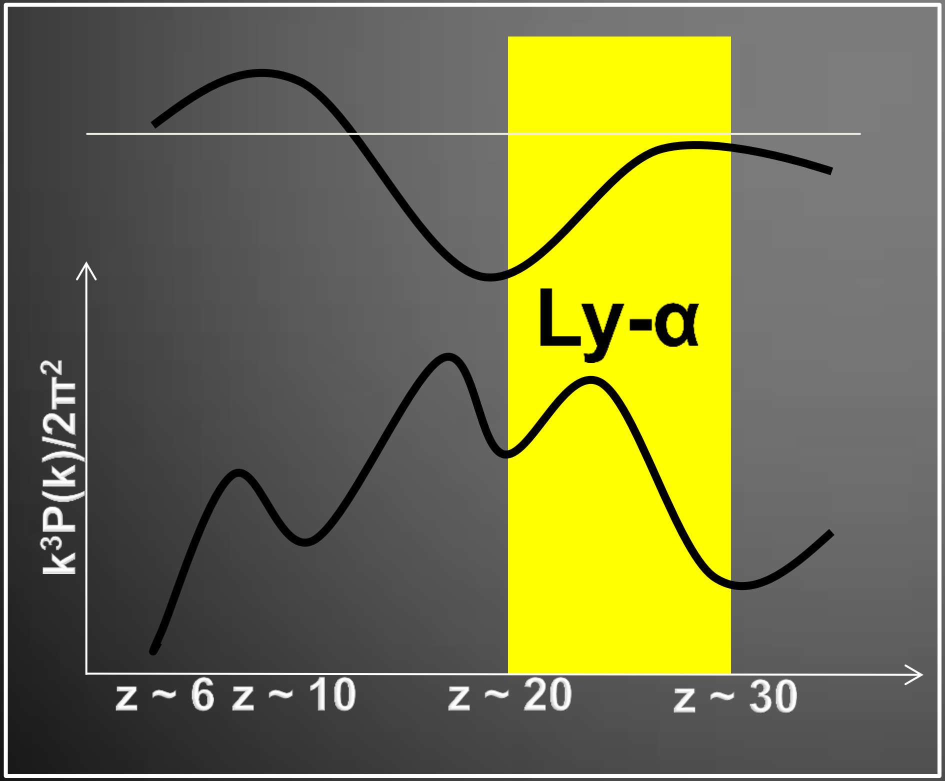
Atomic physics

Exotic physics

The Rise of the First Stars



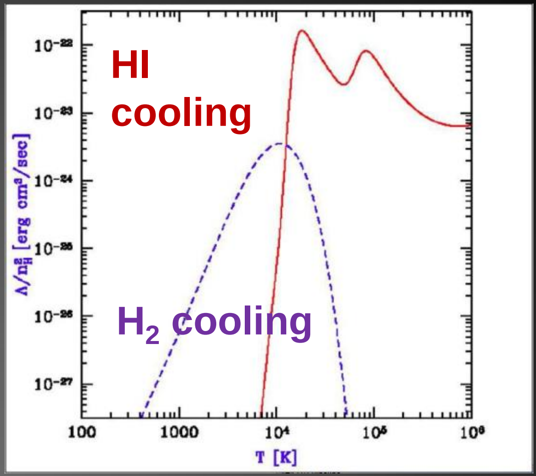
- At the end of dark ages the gas was much colder than the CMB
- First stars emit Lyα. Absorption and reemission of Lyα $T_S \rightarrow T_K$



21-cm is relatively simple: dependence on few astrophysical parameters

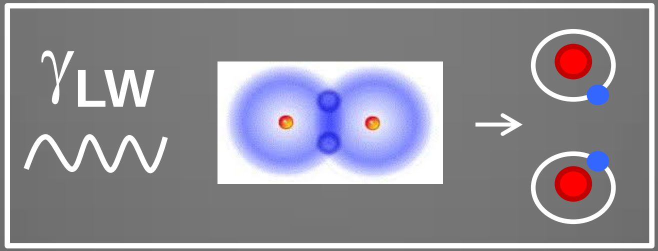
- Cooling channel
- Efficiency of star formation
- Feedback processes
- Potential cosmological probe

Minimal Halo Mass and LW Feedback



Barkana & Loeb (2001)
Bromm (2012)

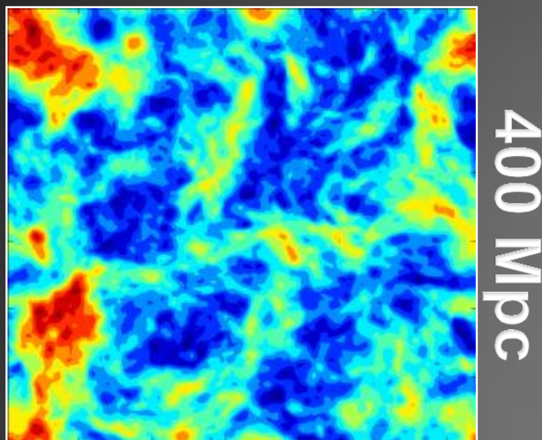
Formation of first stars via H_2 ($M_h \gtrsim 10^5 M_\odot$) is very vulnerable:
LW feedback (Haiman et al. 1997) and velocities (Tseliakhovich & Hirata 2010)

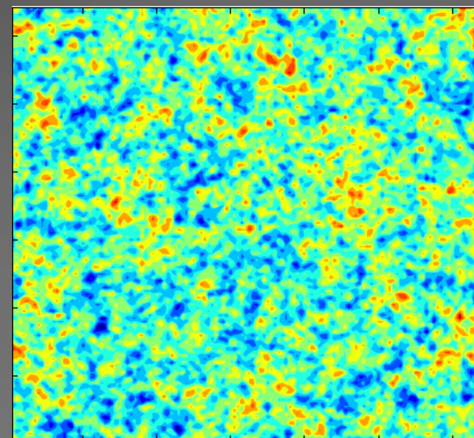


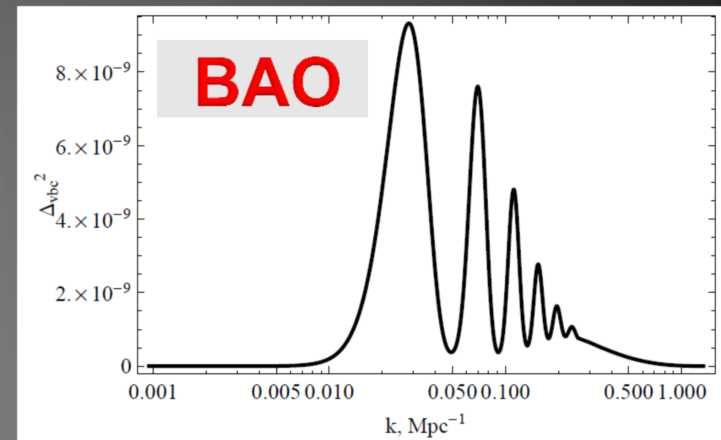
Recent development:

- Physics of molecular hydrogen cooling in the presence of an evolving LW background (Visbal et al. 2014)
- LW escape fractions of 0-85% in 10^5-10^7 M_{sun} halos (Schauer et al. 2015)

Relative Velocities

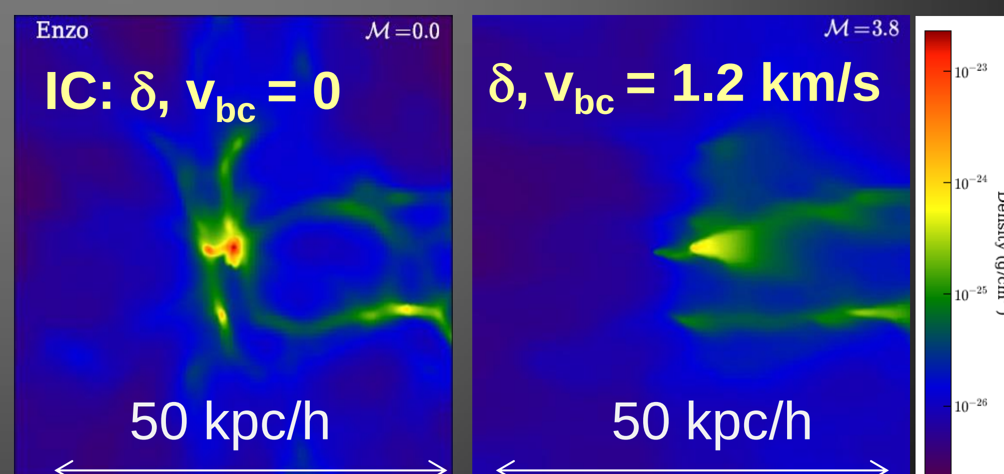




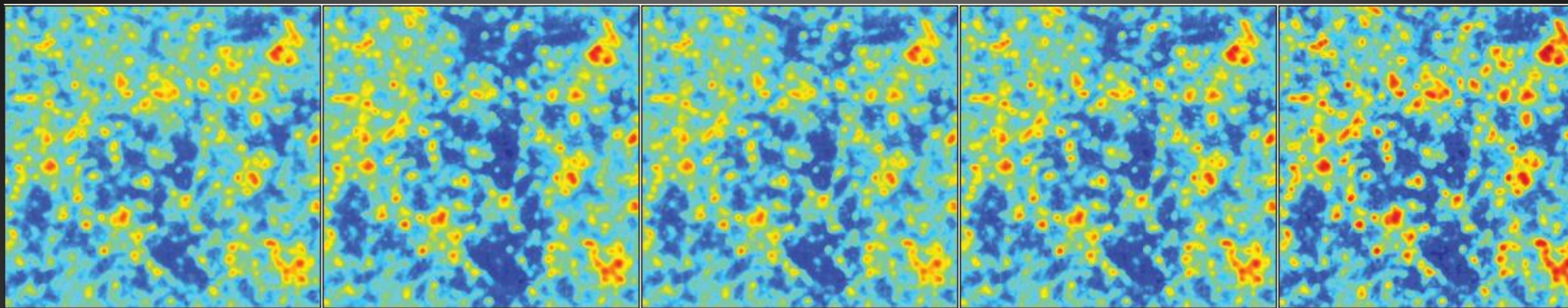


Tseliakhovich & Hirata, (2010)
Fialkov, review (2014)
O'Leary & McQuinn (2012)

- Gas overshoots DM halos
- Supersonic: $\sigma_{vbc} \approx 30$ km/s $\approx 5c_s$
- Suppression of star formation in 10^5-10^8 M_{sun} halos
- Delay of cosmic events

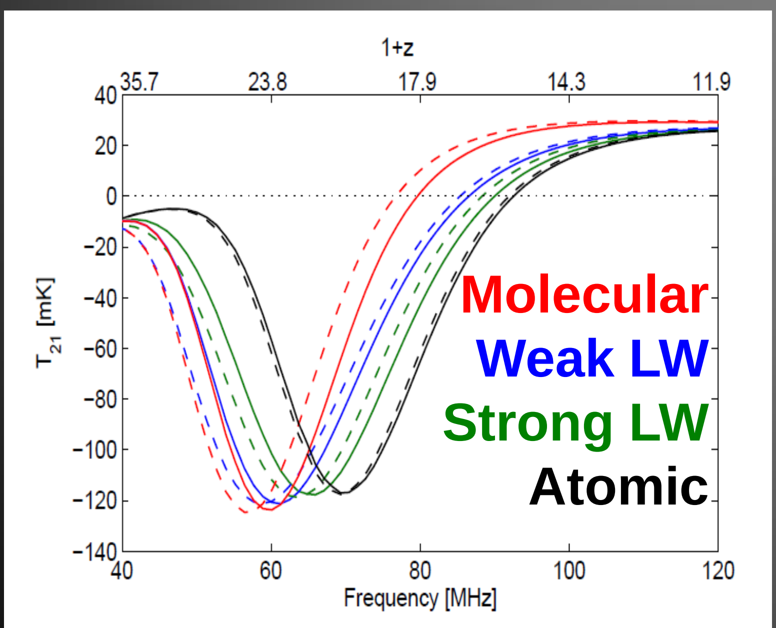


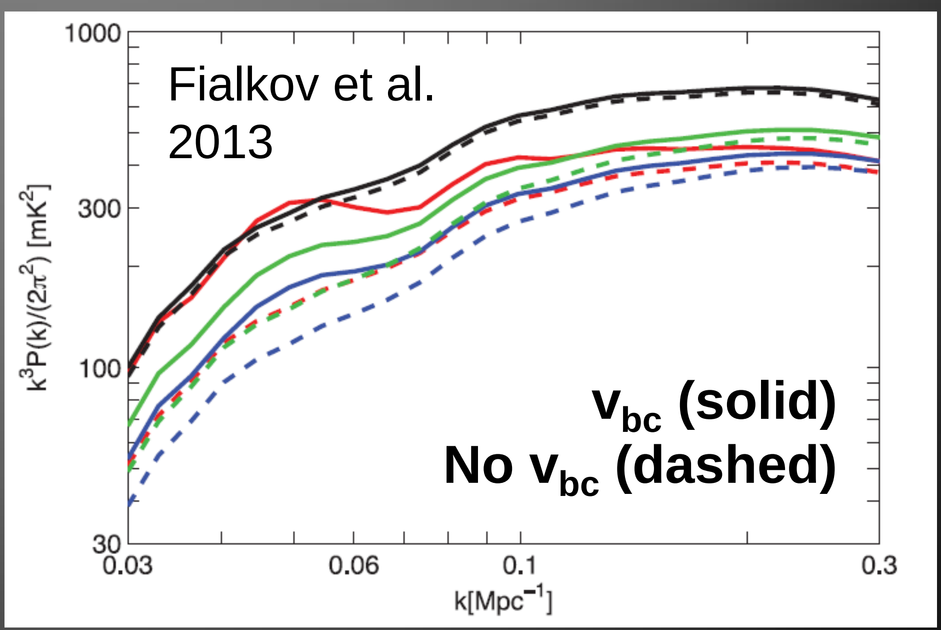
Effect of Velocities and Feedback



No feedback, No vbc | **No feedback** | **Weak feedback** | **Strong feedback** | **Saturated feedbback**

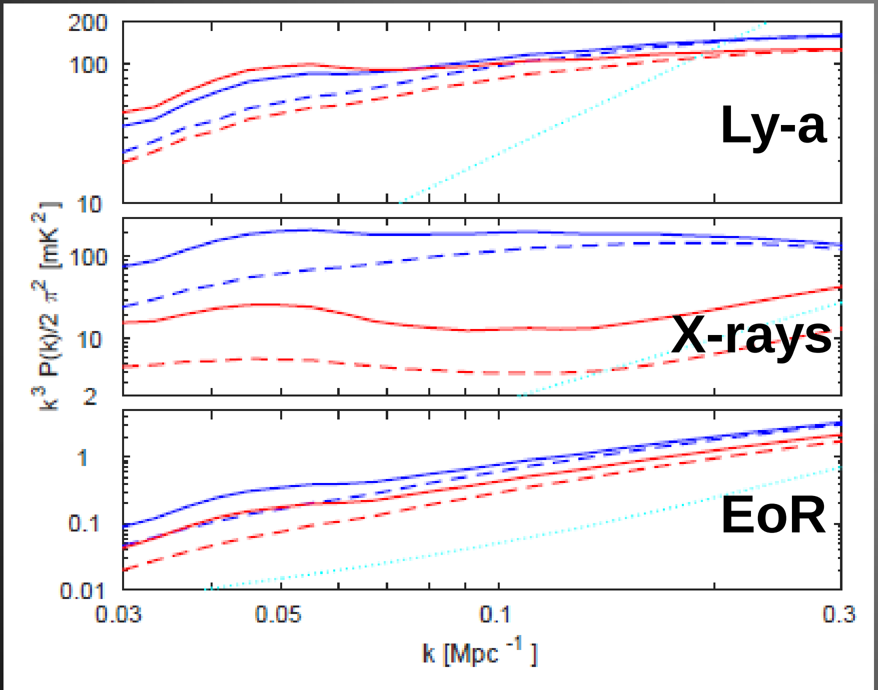
Visbal et al. 2012, McQuinn & O'Leary 2012, **Fialkov** et al. 2013, Ali-Haïmoud et al 2014, Dalal et al. 2010

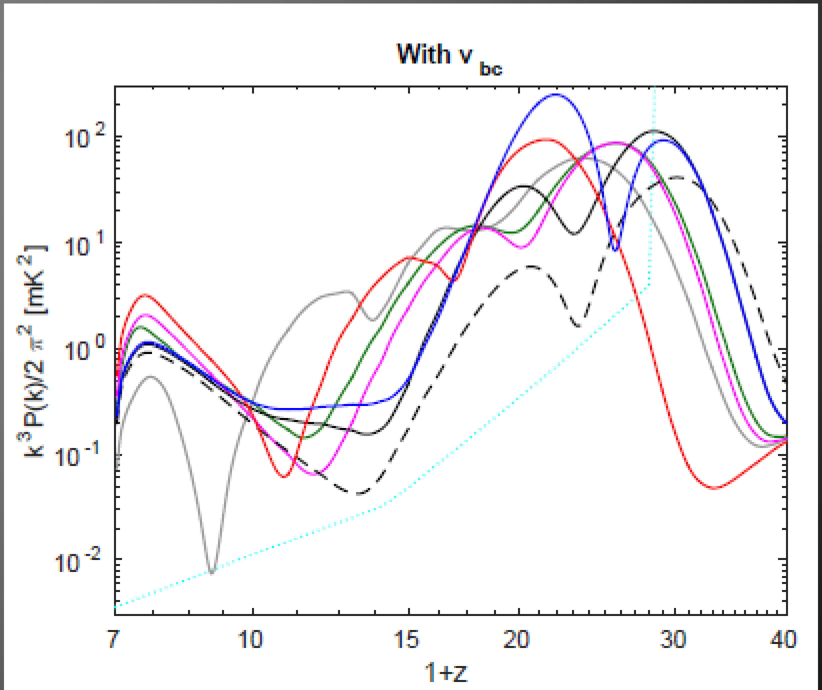




Metal Enrichment Revives Velocity Effects, BAO Signature

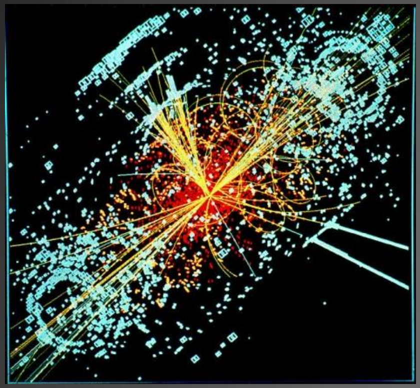
- After a SN explosion, star formation recovers in ~ 10-100 Myr
- Small halos form stars via metal-line cooling (Jeon 2014, Wise 2014)

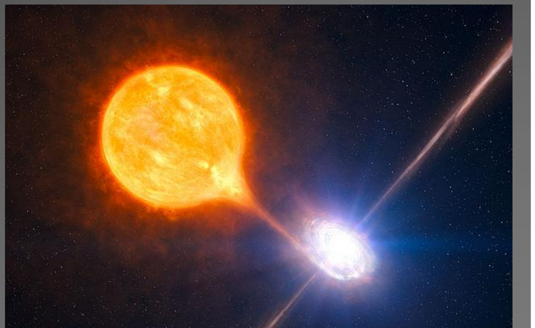




Cohen, **Fialkov**, Barkana (2015)

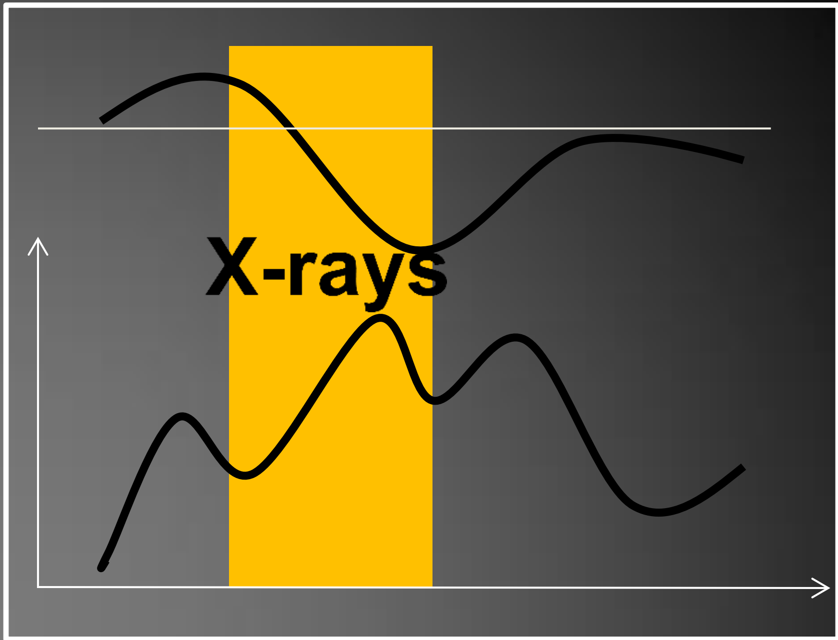
Signature of Heating





A black hole binary
(ESO image)

Dark matter annihilation



Possible heating sources:

X-ray binaries?

Thermal emission from galaxies?

Black holes, mini quasars?

Dark matter annihilation?

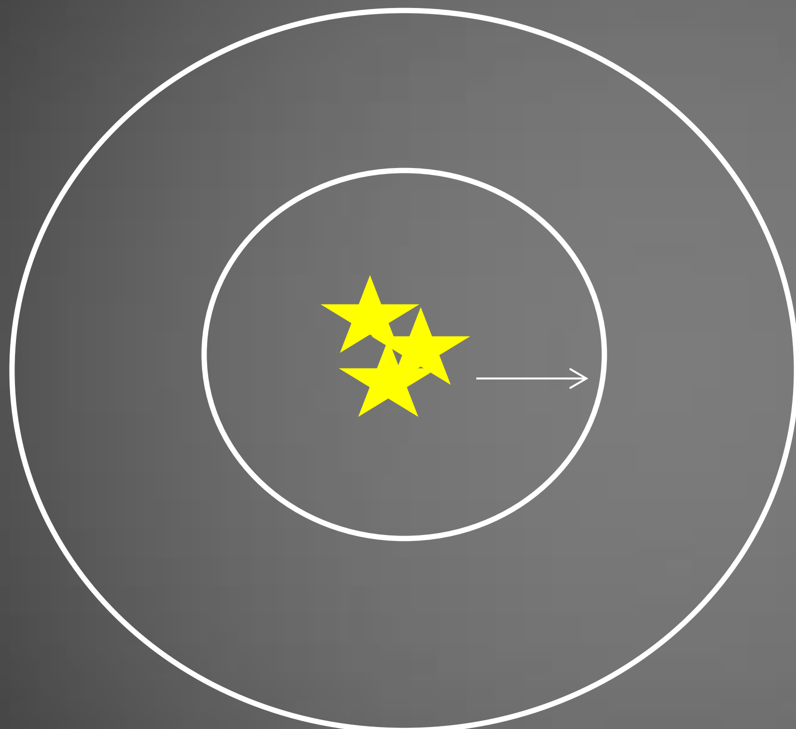
Cosmic rays?

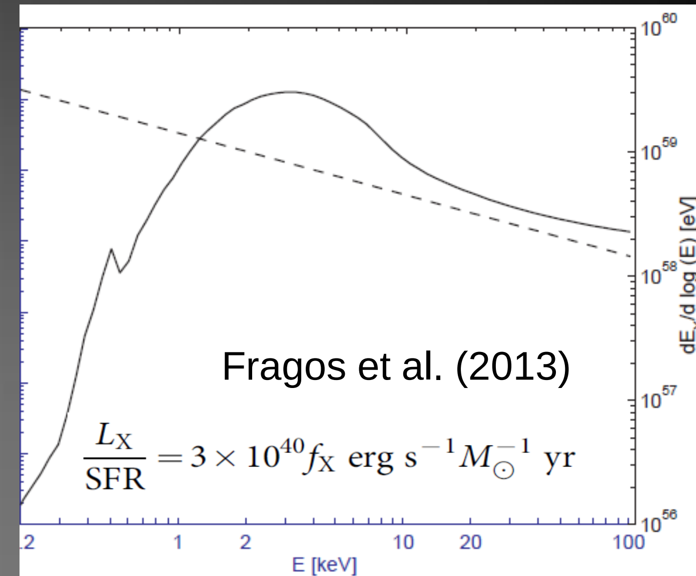
Magnetic fields?

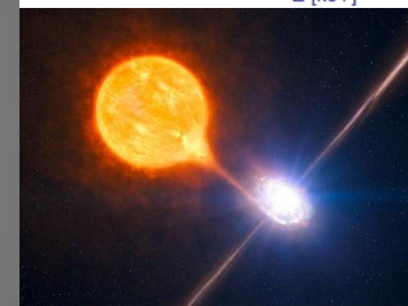
A quasar

Soft or Hard X-ray Sources?

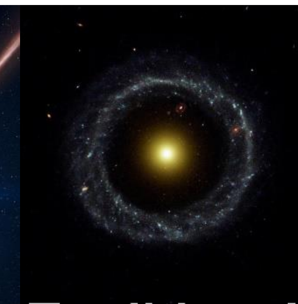
Details of SED are crucial!







X-ray binary



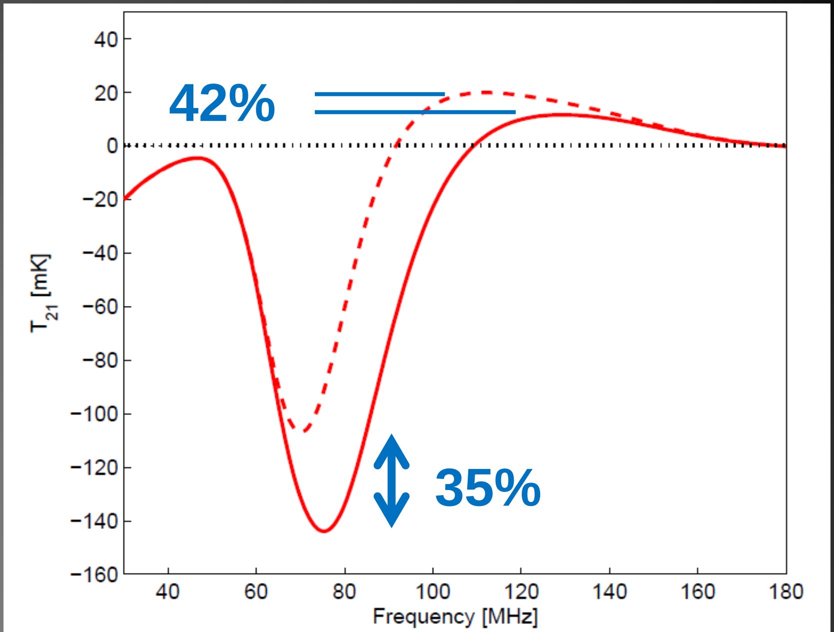
Traditional power-law

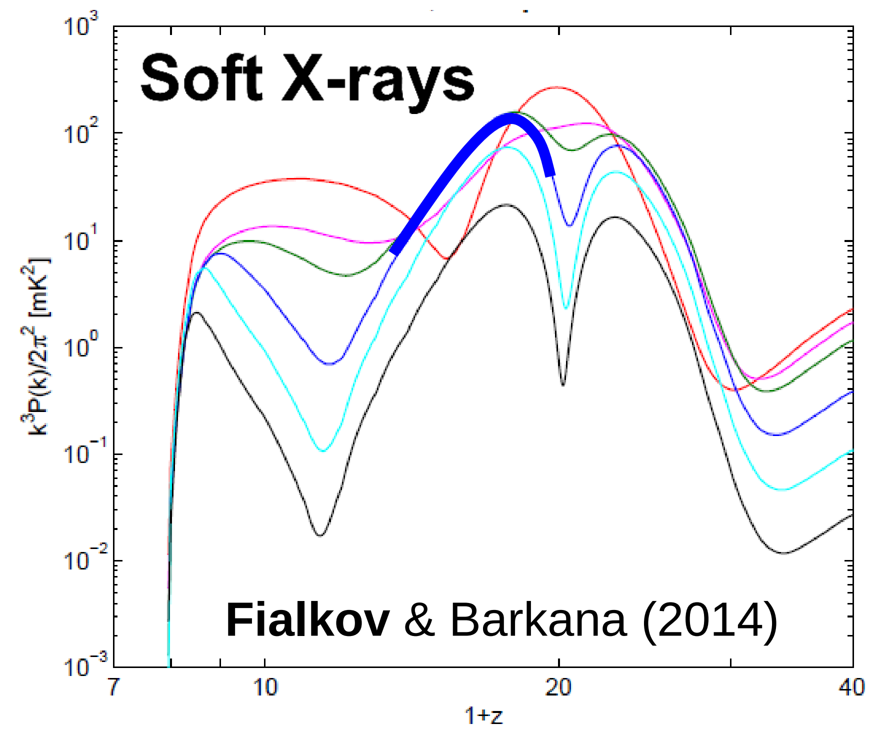
If hard X-rays

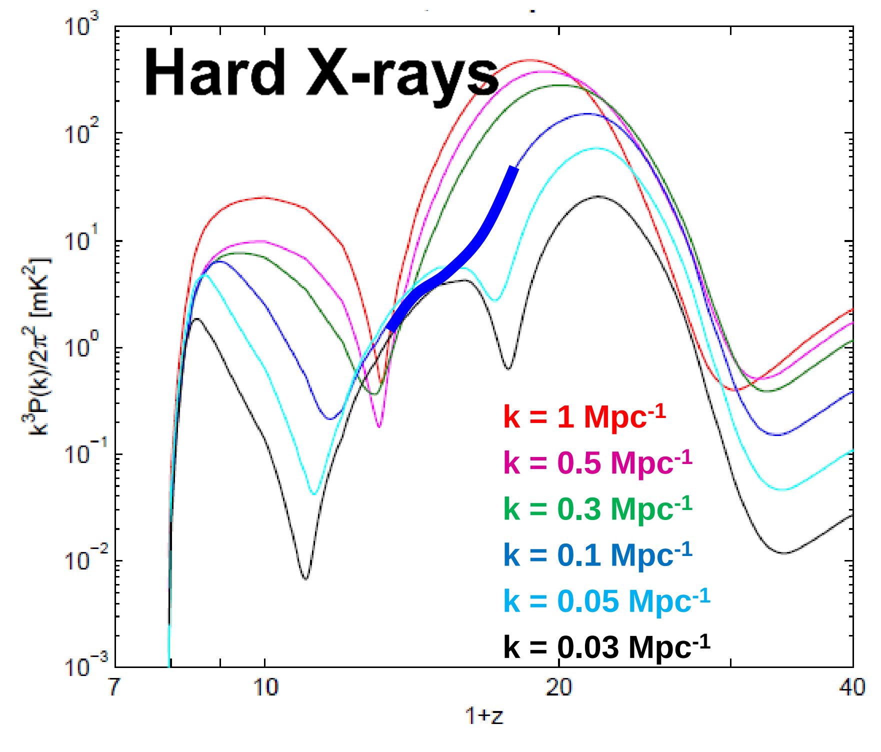
- Mean free pass is longer
- Delayed heating (energy redshifts away)
- Heating fluctuations are washed out at scales below mfp

Hard vs Soft X-rays

Soft SED: Heating and reionization are separated in time (heating transition at z = 15, x_i ~ 3.8 %).
Hard SED: Reionization and heating happen simultaneously (heating transition at z = 12, x_i ~ 14 %).

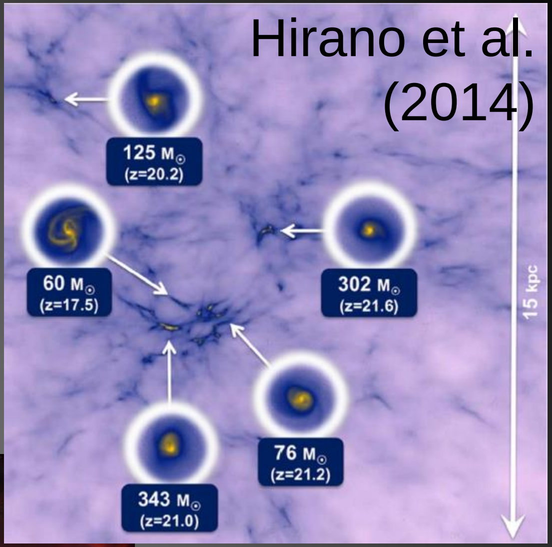


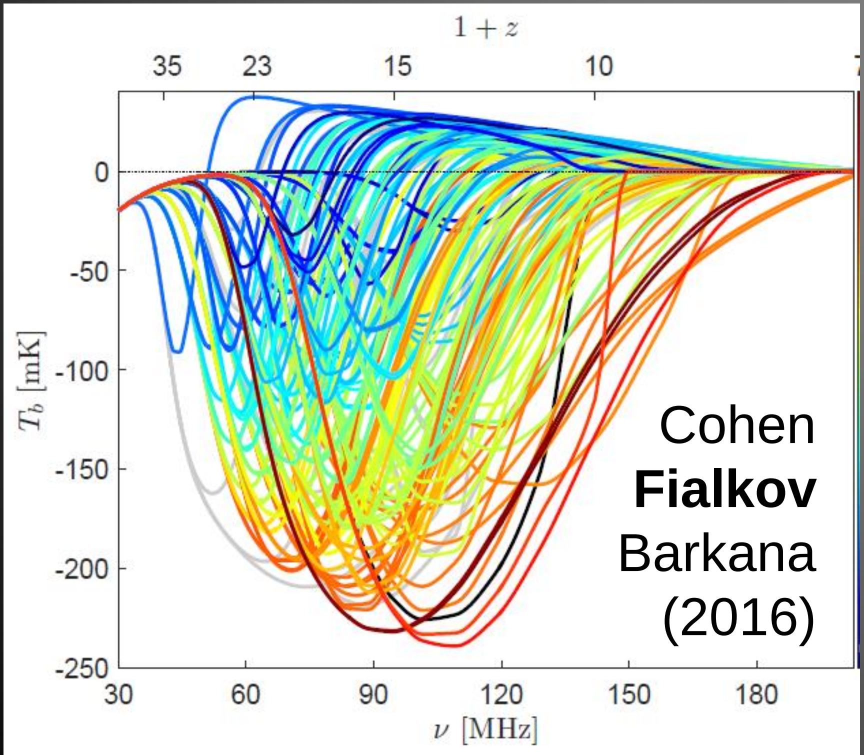




High-z Universe: Parameter Study

- Minimal mass of star forming halos
  - Cooling mechanism, feedbacks
- Star formation efficiency
- Sources of UV and X-rays





181 different models

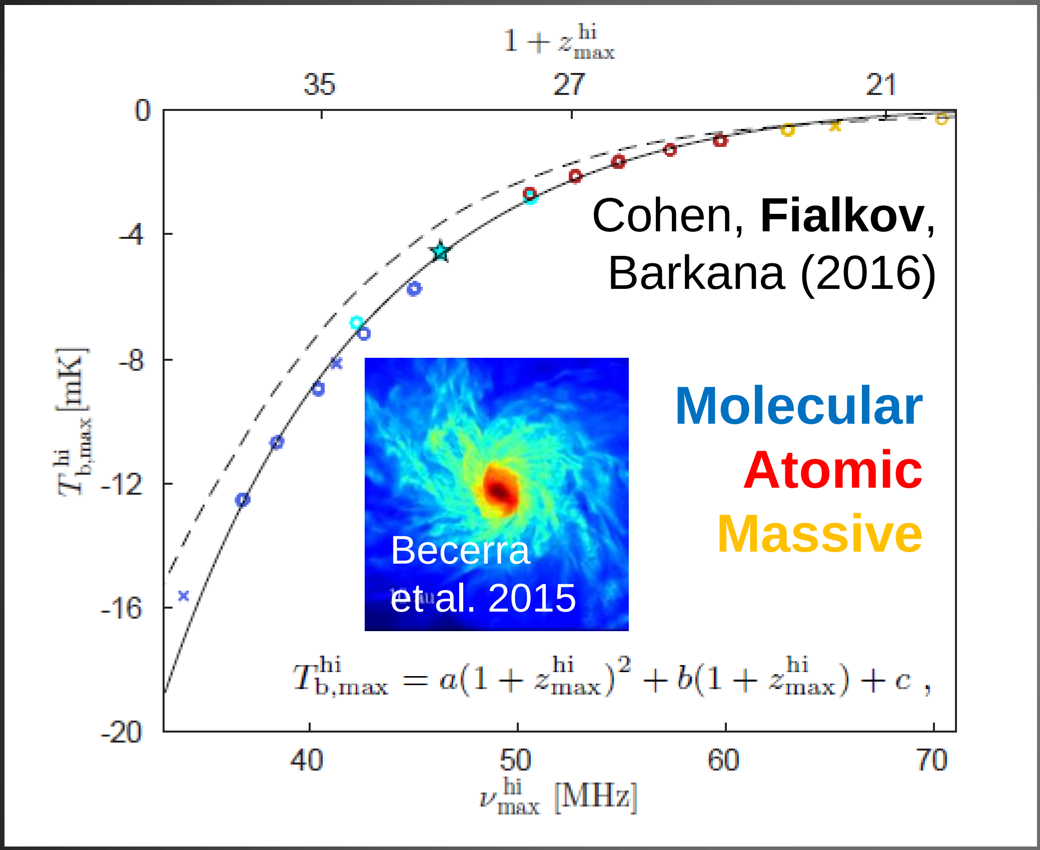
M_{min}

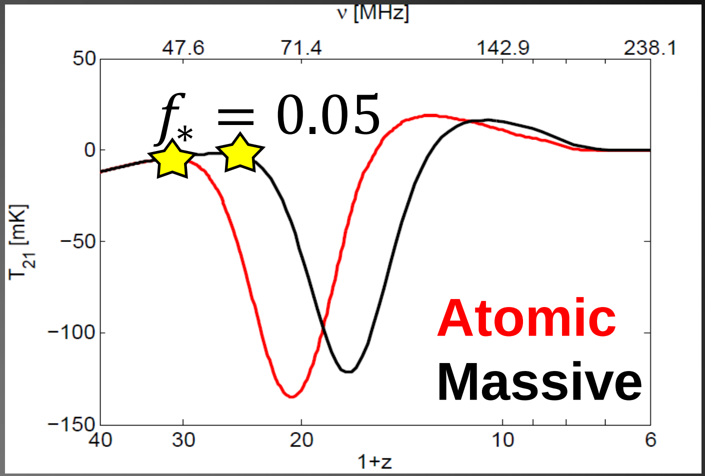
$f_* = 0.005 - 0.5$

$f_X \sim 0.001 - 100$
hard/soft SED

$\tau = 0.055 \pm 0.009$

Ly-a Era is "Simple" Parameter Study

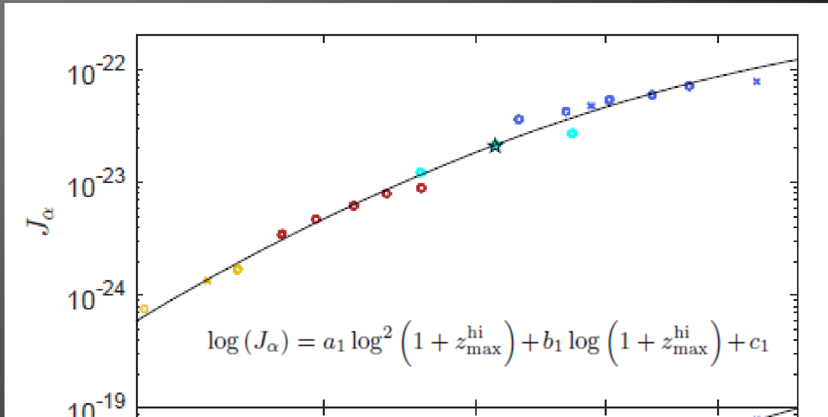




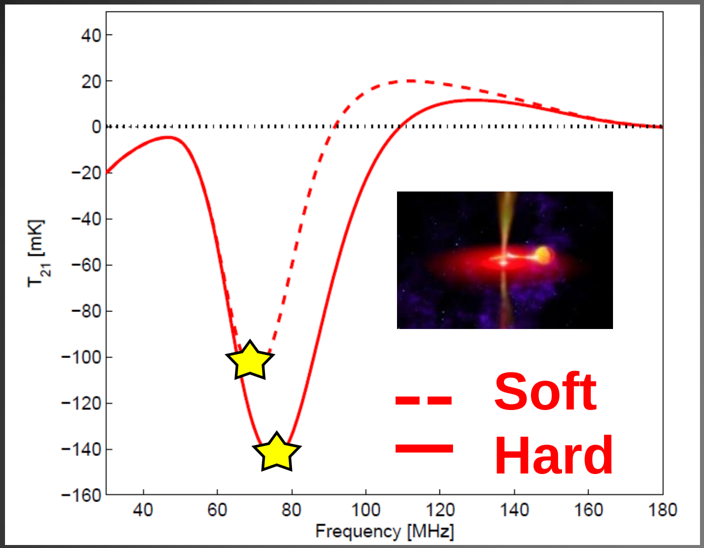
Lyα coupling important parameters:

- Minimal mass of star forming halos, V_C
- f_*

- $T_{b,max}$ is related to T_b at the end of Dark Ages → monotonic with z_{max}
- Can extract average intensity of the Lyα background at z_{max}



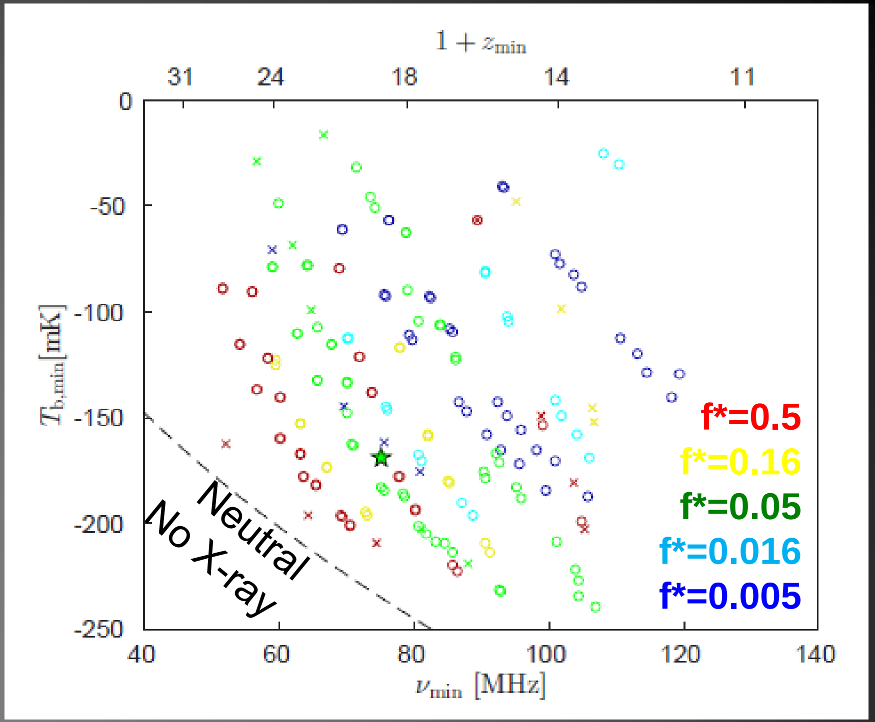
X-ray Sources Parameter Study



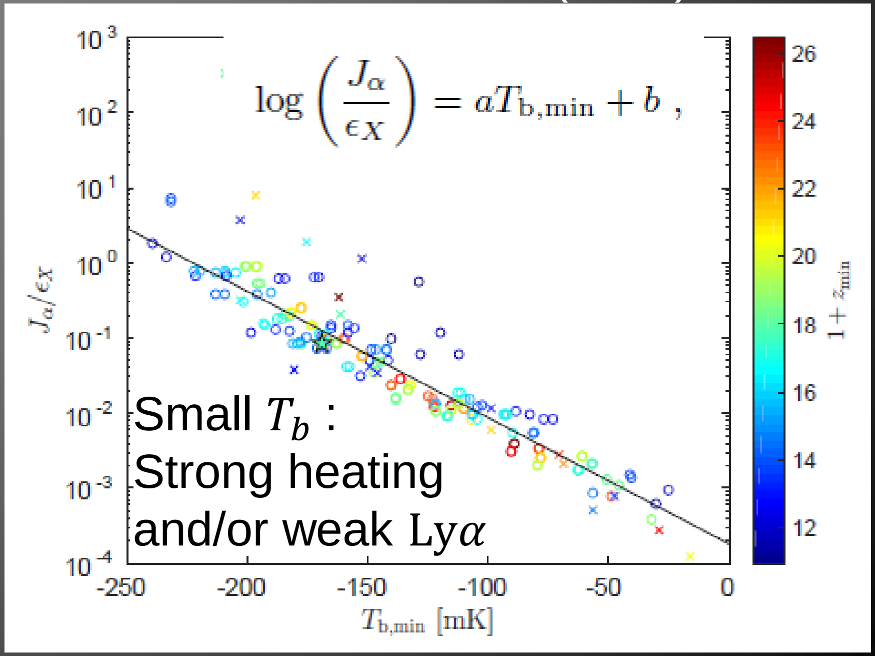
Beginning of heating era and saturation of Lyα

Important parameters:

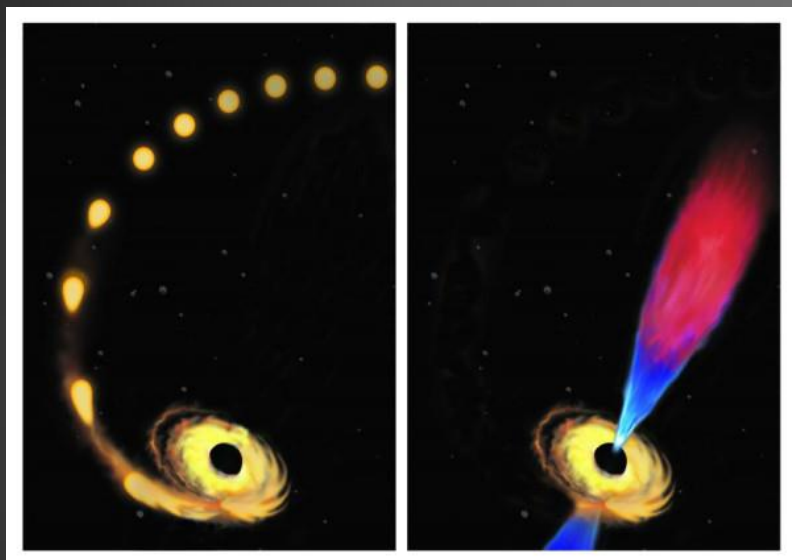
- f_*
- V_C
- X-rays: SED and f_X



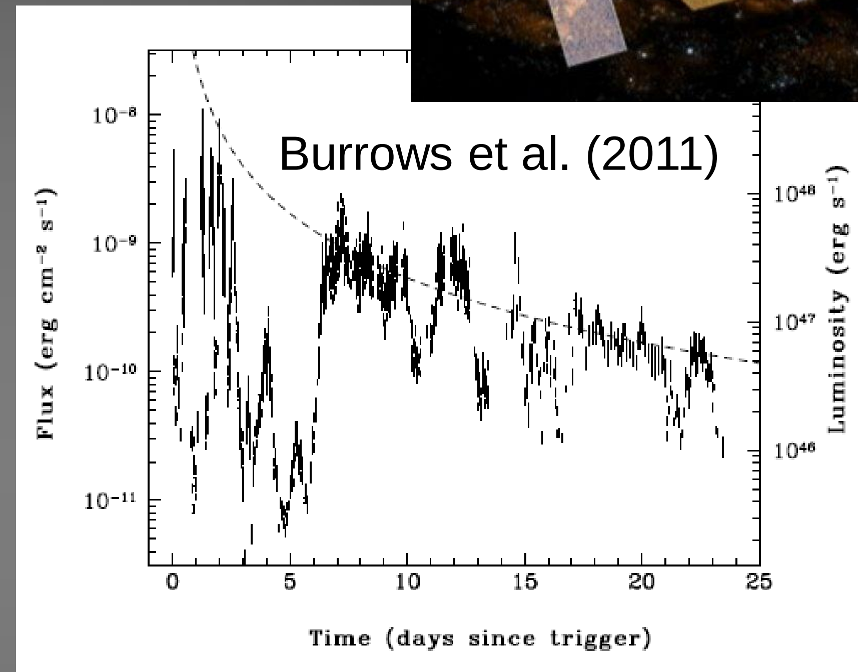
Cohen, **Fialkov**, Barkana (2016)



Tidal Disruption Events as a Probe of High-z Universe



http://beforeitsnews.com/space/2015/11/super-massive-black-hole-caught-eating-a-star-seen-in-incredible-detail-2494792.html

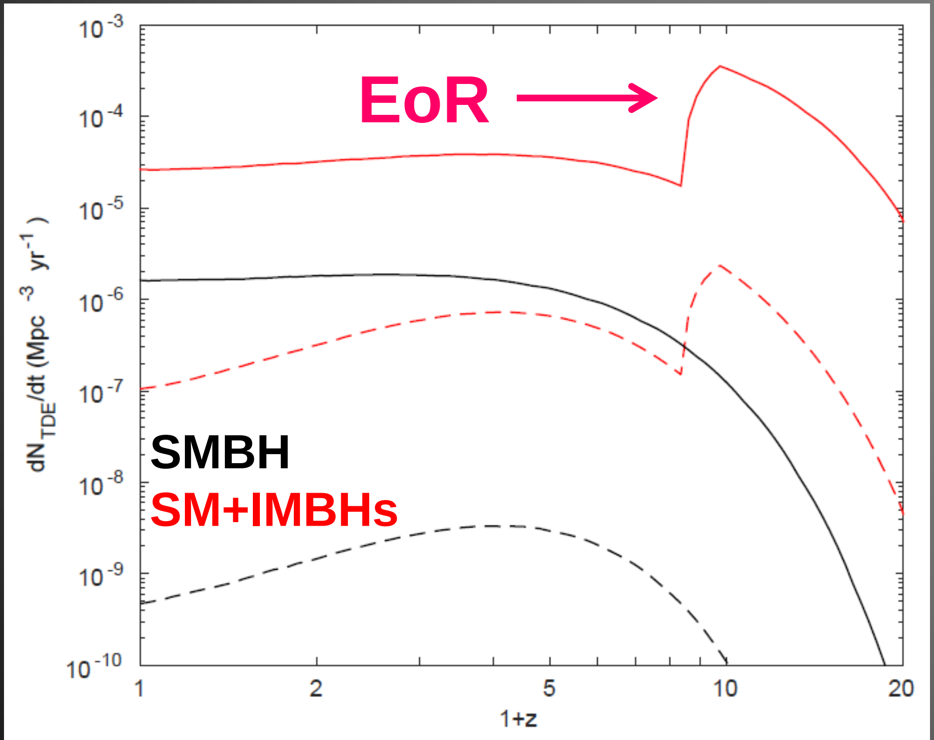


Star is destroyed by gravitational tides. Bright flare is emitted, sometimes jets are produced.

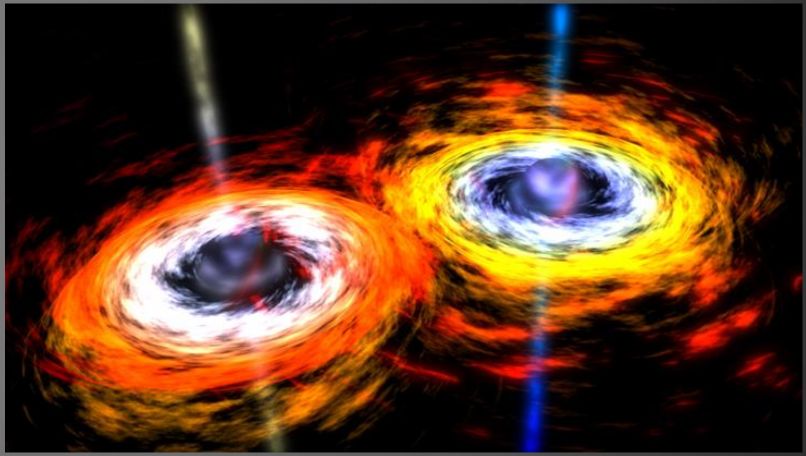
- Happen in inactive galaxies
- Observed 30-40
- Out of them 3 with jets ($z = 0.354, 1.2, 0.89$). Other TDEs are at $z < 0.2$.
- SMBH masses are $10^6 - 10^8\ M_{\odot}$.
- Signature: UV, X-ray, radio flare, decay timescale: months

High-z TDEs: Probe f_{occ} of IMBHs

- If IMBHs can produce TDEs, we expect many from high redshifts
- Binary BHs – boosted TDE rates for a short time. More at high-z (mergers)
- Jetted TDEs could be seen out to higher redshifts

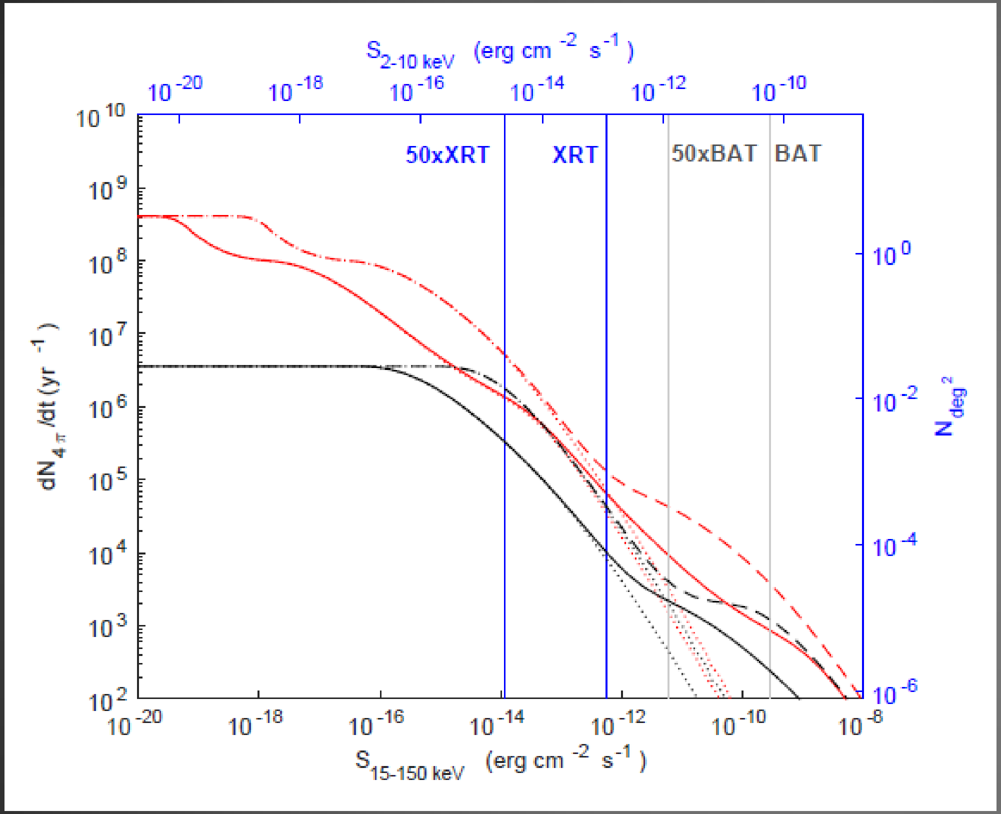


Fialkov & Loeb, submitted



TDE rates: SMBH or SM+IMBHs w/wo mergers
If IMBHs are important: EoR affects star formation in small halos. Photoheating feedback, less TDEs around IMBHs at $z < z_{EoR}$

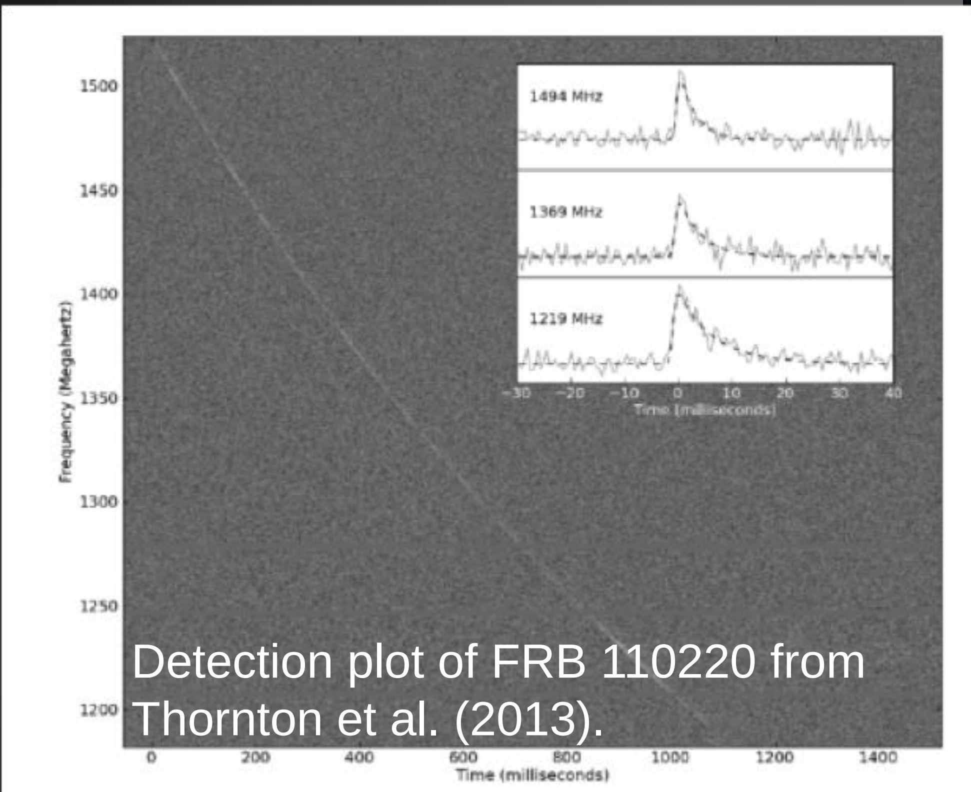
Expected Number Counts in X-rays



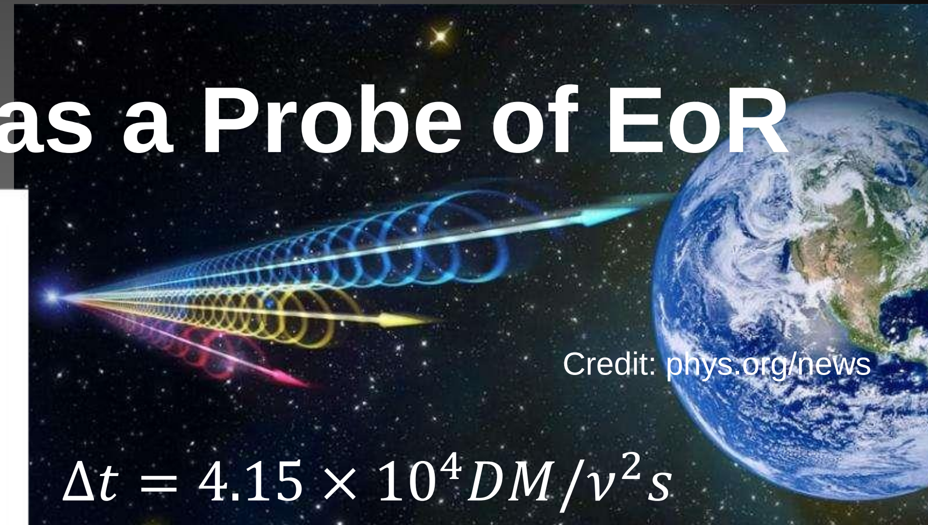
- Jetted TDE can be observed out to high z
- TDEs sourced by binary black holes dominate the bright end of the X-ray luminosity function if the occupation fraction of IMBHs is high (Edd. luminosity)

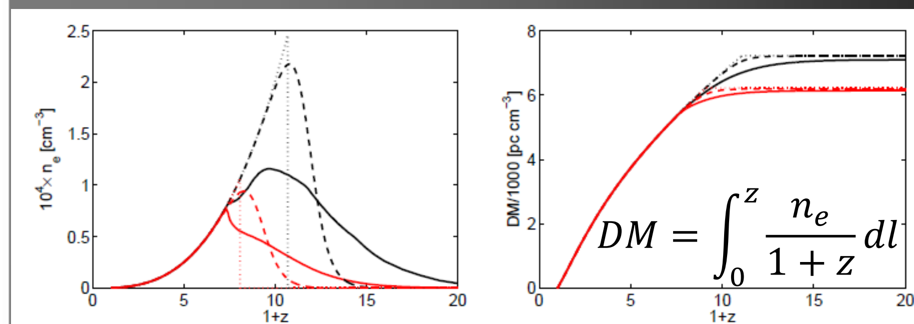
- Increased resolution of X-ray surveys will allow to probe more TDEs
- Wiggles in X-ray luminosity function: signature of jetted TDEs and contribution from binaries.

Fast Radio Bursts as a Probe of EoR



Detection plot of FRB 110220 from Thornton et al. (2013).



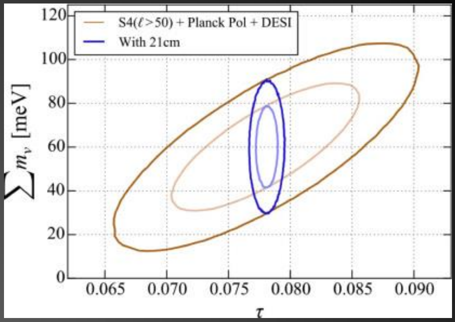


Fialkov & Loeb (2016b)

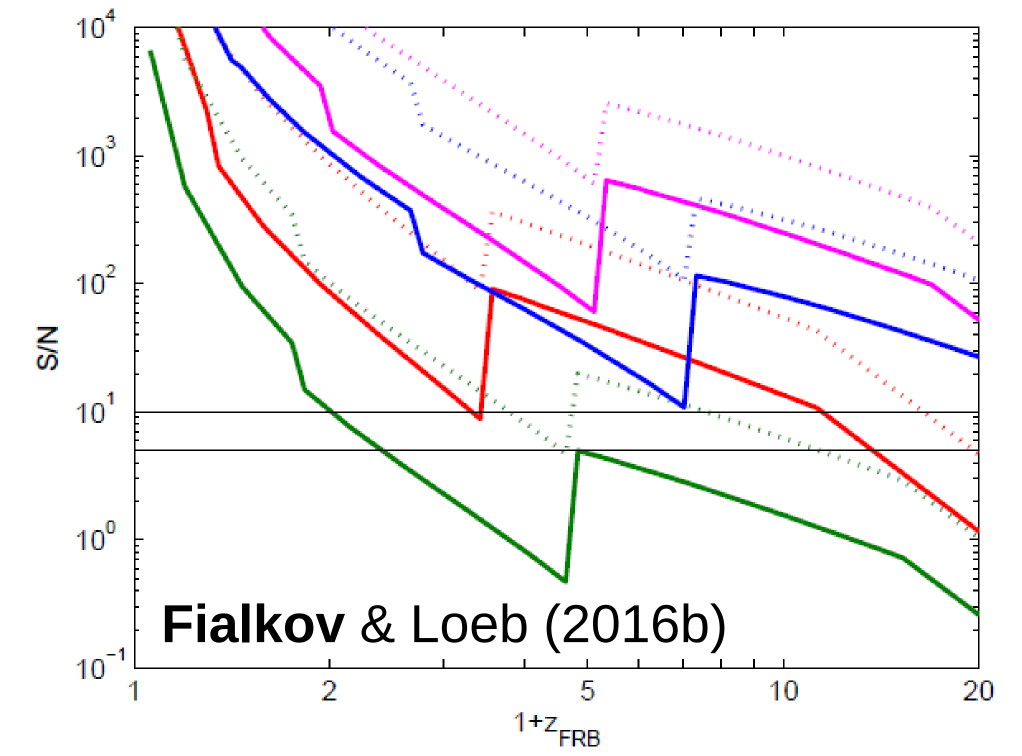
Representative FRBs (out of ~17 known)

Type	Event	Telescope	DM_{EG} [pc cm^{-3}]	z_0	ν_0 [GHz]	$L_{\nu 0}^{peak}$ [erg s^{-1} Hz^{-1} sr^{-1}]
Min	FRB010621	Parkes	748	0.22	1.7	5.2×10^{32}
Median	FRB110523	GBT	623	0.55	1.2	5.0×10^{33}
Max	FRB110220	Parkes	944	0.85	2.55	2.6×10^{34}
Lorimer	FRB010724	Parkes	375	0.32	1.86	$> 8.2 \times 10^{34}$

Future with SKA



Signal to Noise with SKA



$$\tau(z) = \left[DM(z)(1+z) - \int DM(z')dz' \right] \sigma$$

To probe $\tau = 0.055$ we need DM of 6100 pc/cm^3

Type	Event	Telescope	DM_{EG} [pc cm^{-3}]	z_0	ν_0 [GHz]	$L_{\nu_0}^{peak}$ [erg s^{-1} Hz^{-1} sr^{-1}]
Min	FRB010621	Parkes	748	0.22	1.7	5.2×10^{32}
Median	FRB110523	GBT	623	0.55	1.2	5.0×10^{33}
Max	FRB110220	Parkes	944	0.85	2.55	2.6×10^{34}
Lorimer	FRB010724	Parkes	375	0.32	1.86	$> 8.2 \times 10^{34}$

Summary

TDEs can be used to probe the occupation fraction of IMBHs, and (if high) the Epoch of Reionization

Fast transients – way to probe optical depth

21-cm is very promising

- Dependence on astrophysics
- Correlations between the key features of the global 21-cm signal and underlying astrophysical properties
- Correlations can be used to directly link future measurements of the global 21-cm signal to astrophysical quantities