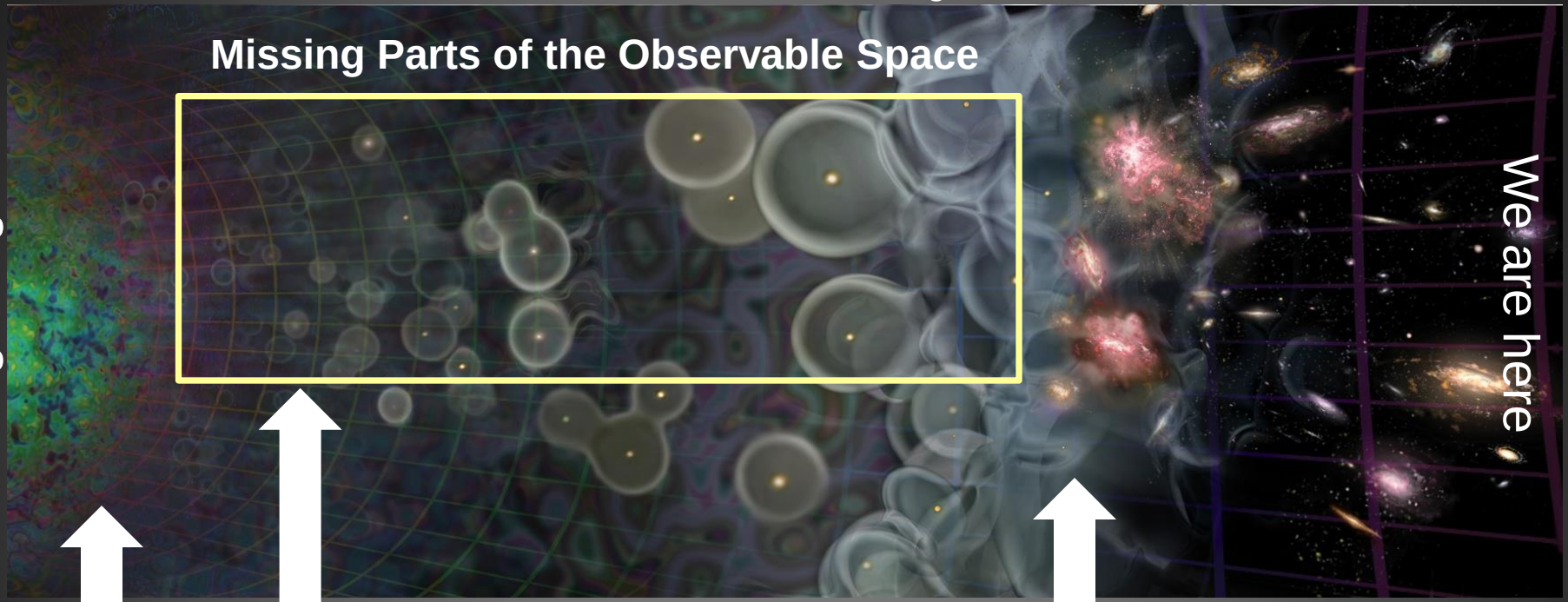
Identifying First X-ray Sources

Anastasia Fialkov,
ITC Fellow, Harvard

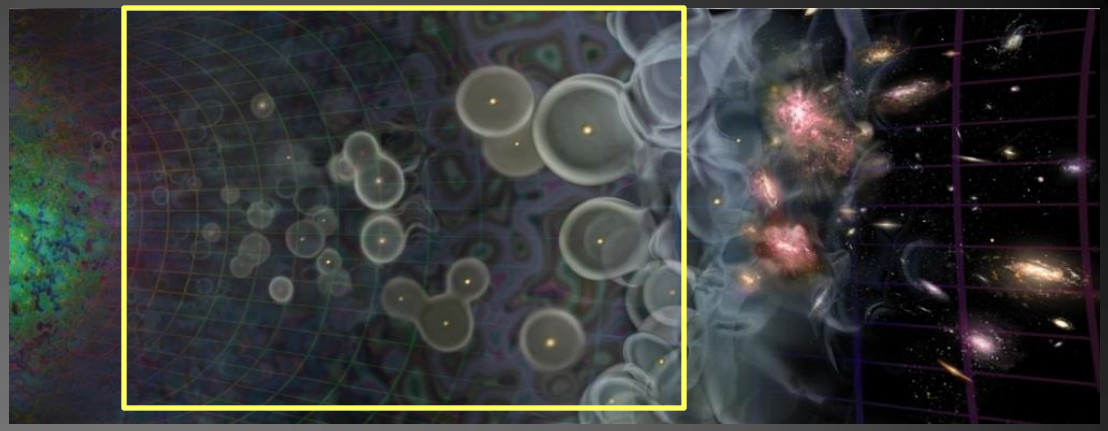
HEAD Meeting
August 21, 2017

The Universe after the Big Bang

Image: Loeb, Scientific American 2006

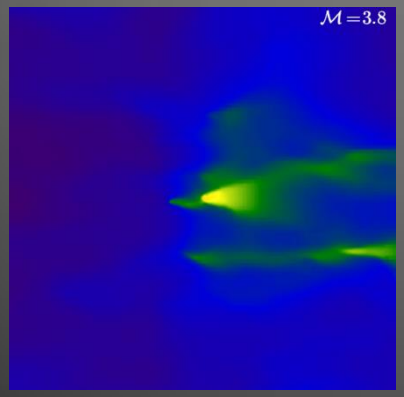


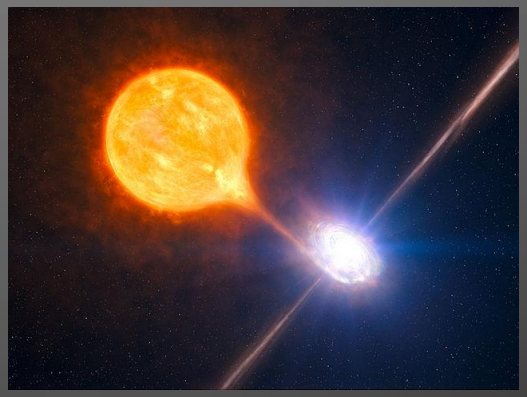
High-redshift Environment

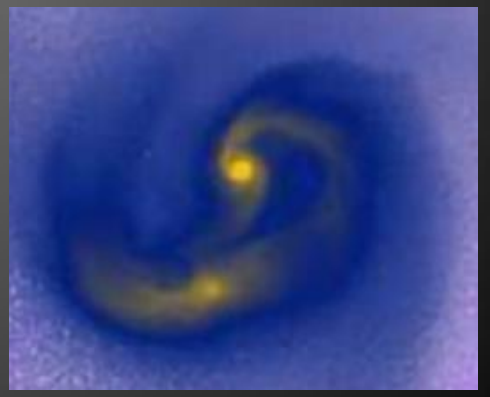


Theory predicts:

- Cold metal-poor medium between rare star forming regions
- Small halos
- Diverse populations: small black holes, heavy stars, pair instability SN, variety of X-ray sources
- 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 & radiative feedbacks (e.g., LW feedback) suppress star formation

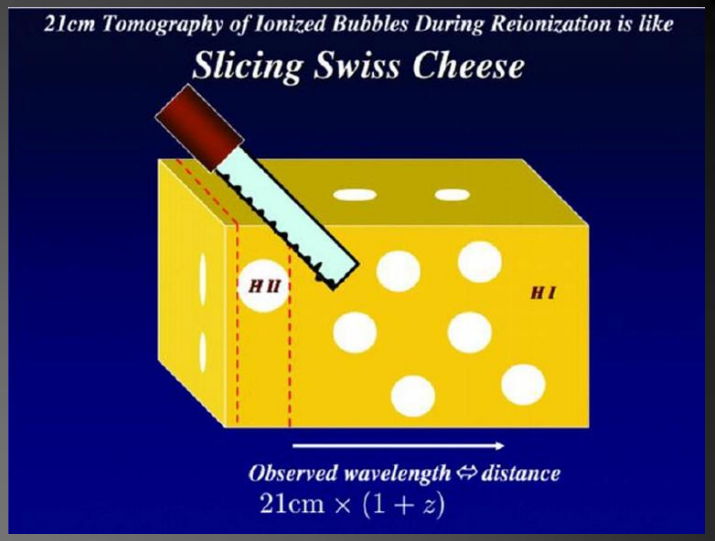


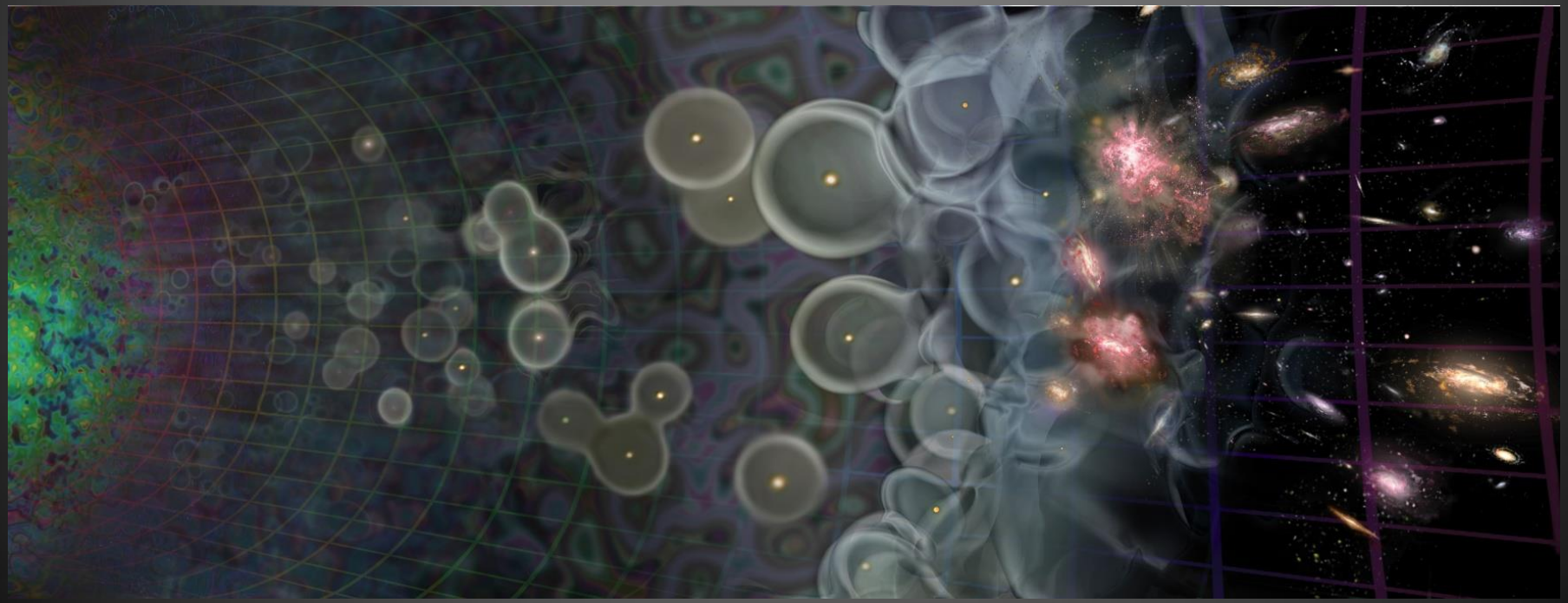




21-cm Signal of HI

Probe of the ionization state $\delta T_b \sim x_{HI}$ ...





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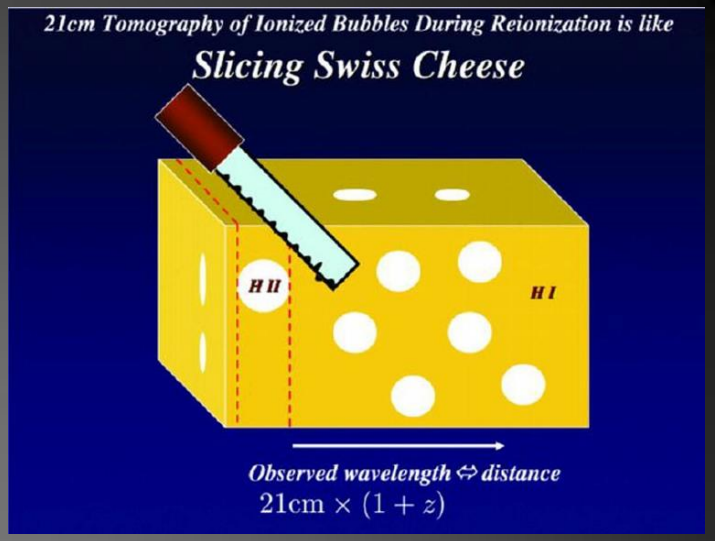
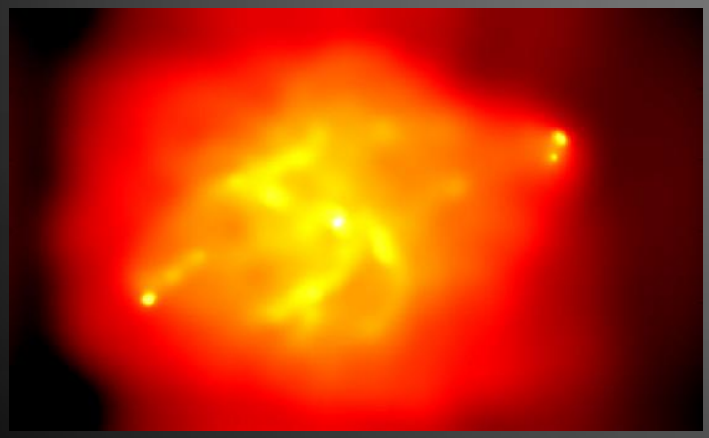
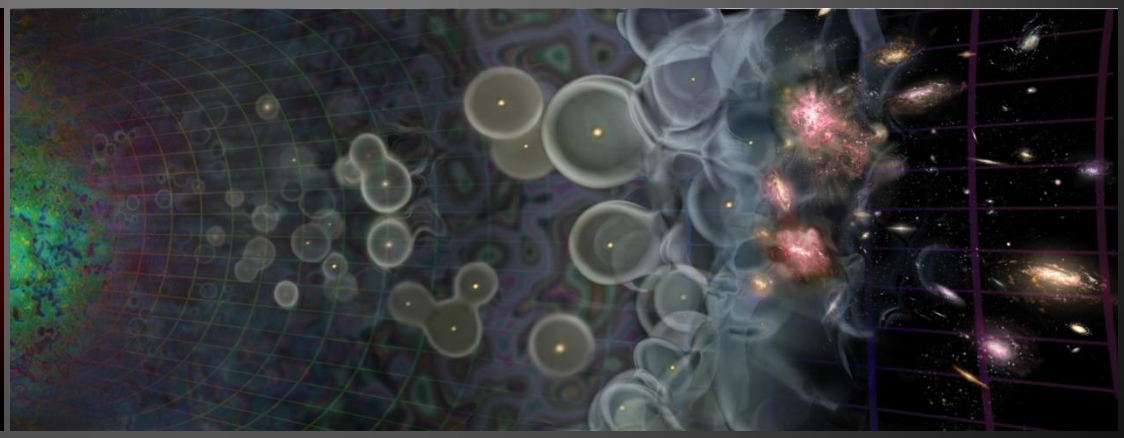


Not only!
It can also be used as a cosmic thermometer

$$\delta T_b \sim x_{HI}\left[1-\frac{T_{CMB}}{T_S}\right]\ldots$$

- Ly-a coupling → $T_S \approx T_{Gas}$
- Collisional coupling → $T_S \approx T_{Gas}$





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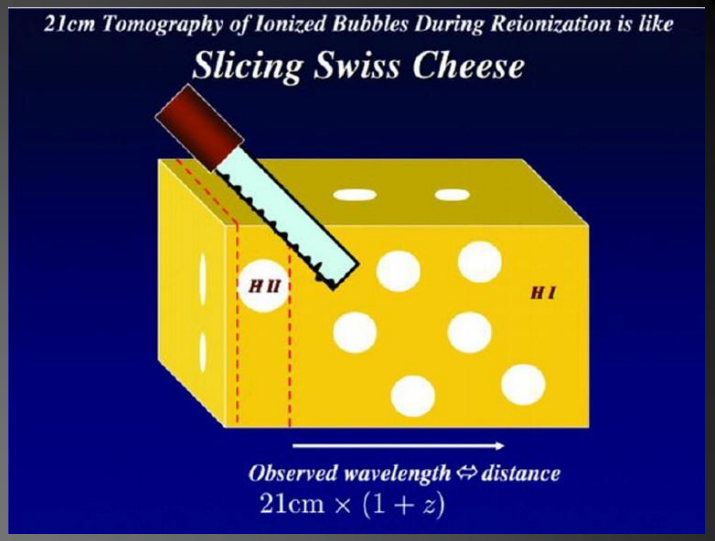

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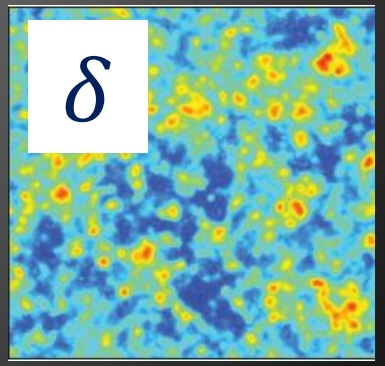
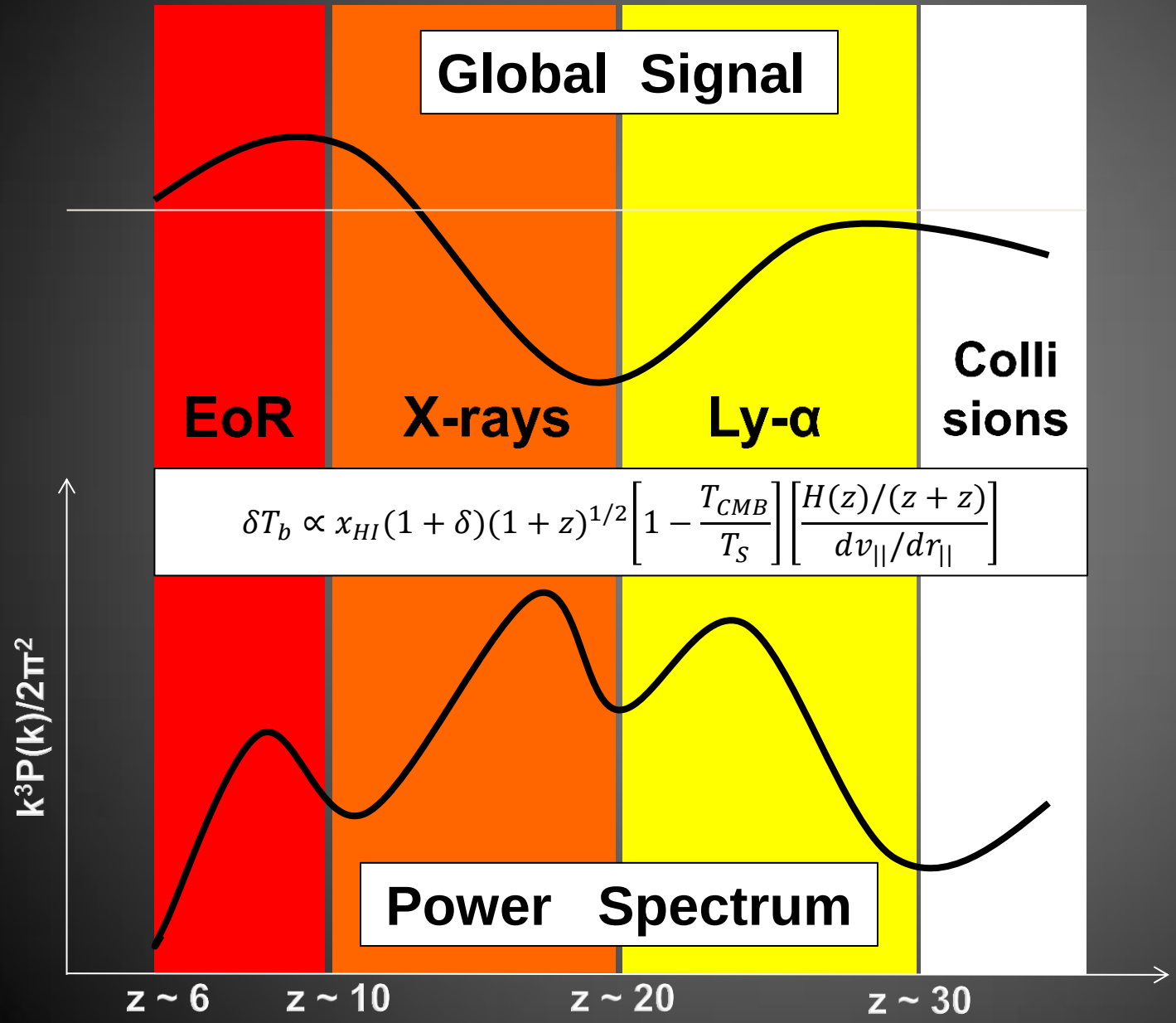
Not only!
It can also be used as a cosmological probe

$$\delta T_b \propto x_{HI}\left[1-\frac{T_{CMB}}{T_S}\right](1+\delta)\ldots$$

- Growth of structure
- Total optical depth for the CMB (e.g., Liu et al. 2016)
- Nature of dark matter



Expected 21-cm Signal: An Example



Drivers:

Galaxies

Quasars

XRB

BHs

Hot Gas

SN

First stars

Feedbacks

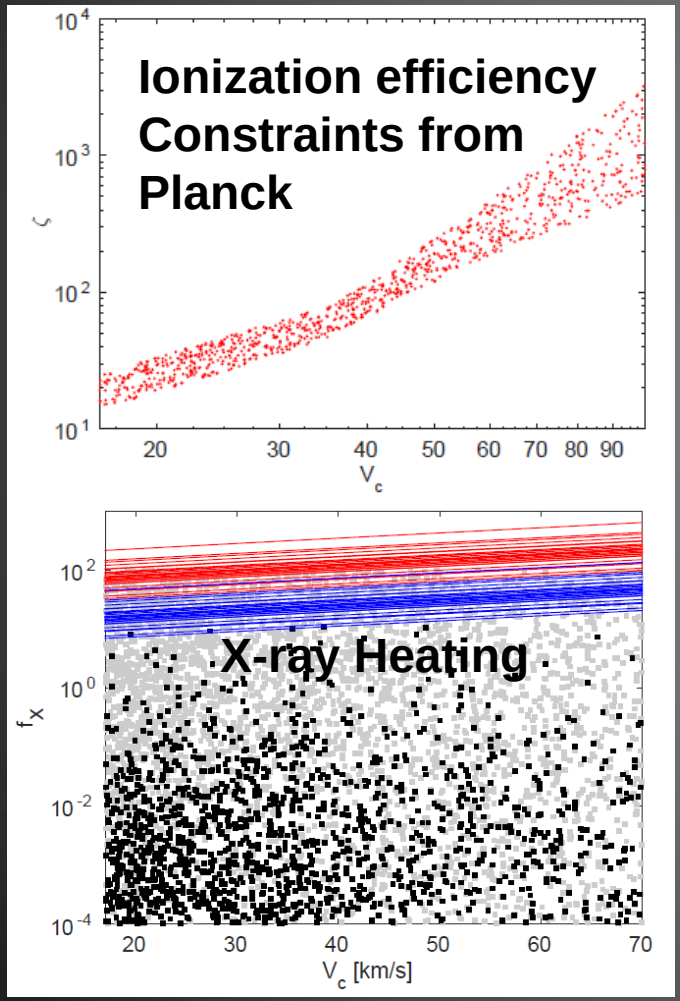
Velocity flows

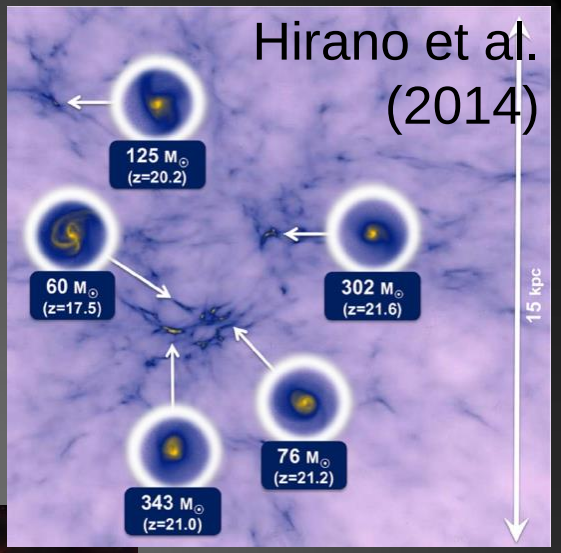
Cosmology

Atomic physics

DM physics

Large Uncertainty in Astro Parameters





$\sim 10^4$ different models

Star formation,
2 parameters
+ feedbacks

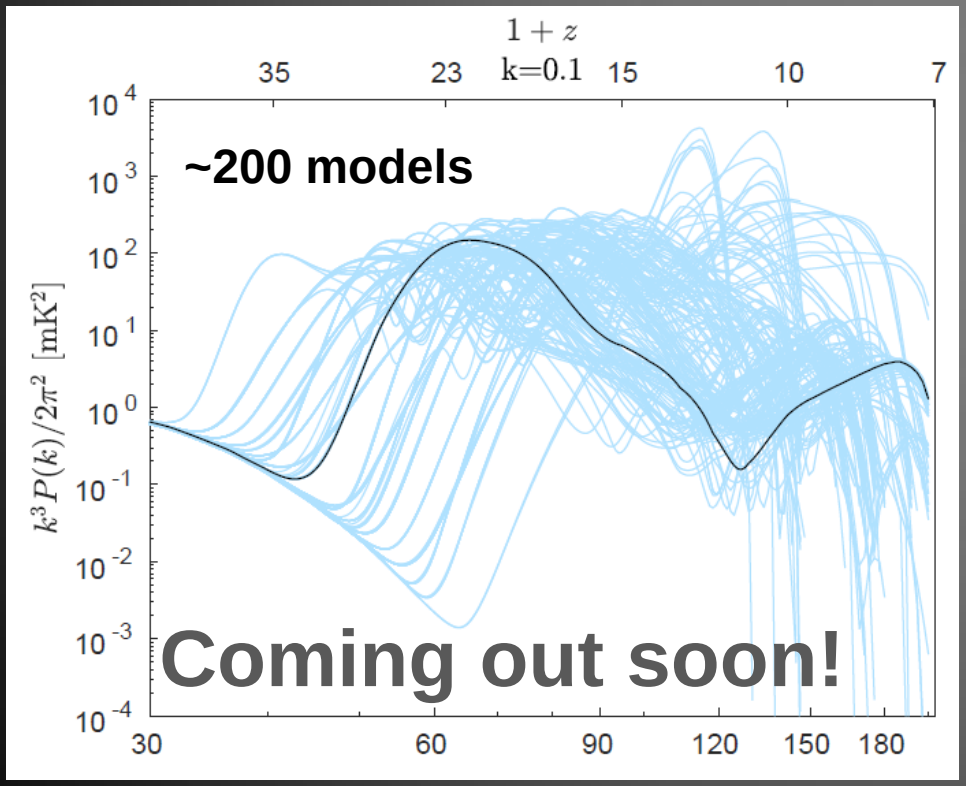
Heating,
3 parameters

EoR 2 parameters

Fialkov, Cohen, Barkana (in prep)

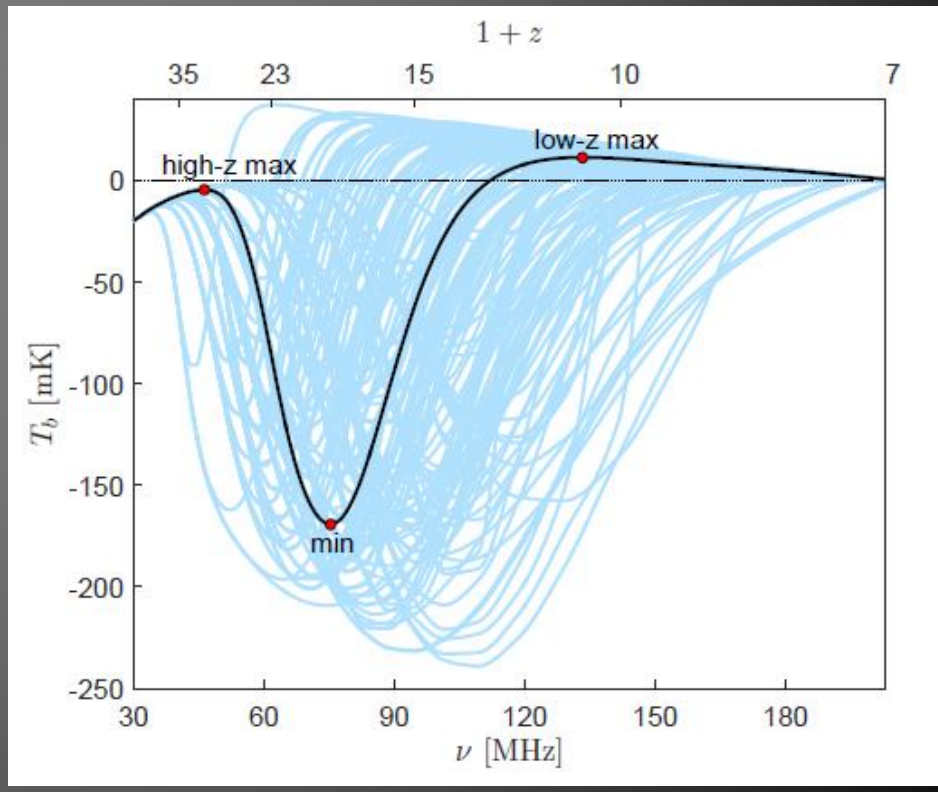
- Currently very weak observational constraints
- Exact shape and amplitude of the 21-cm signal are unconstrained
- Both detection and non-detection will transform our understanding

Power Spectra



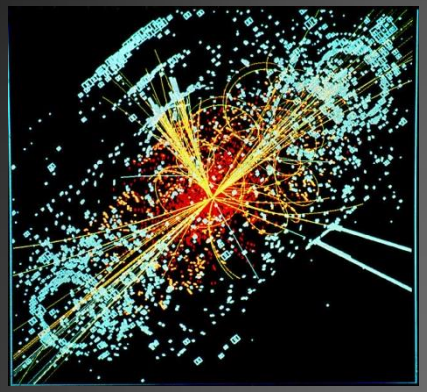
Cohen, **Fialkov**, Barkana (in prep)

Global 21-cm



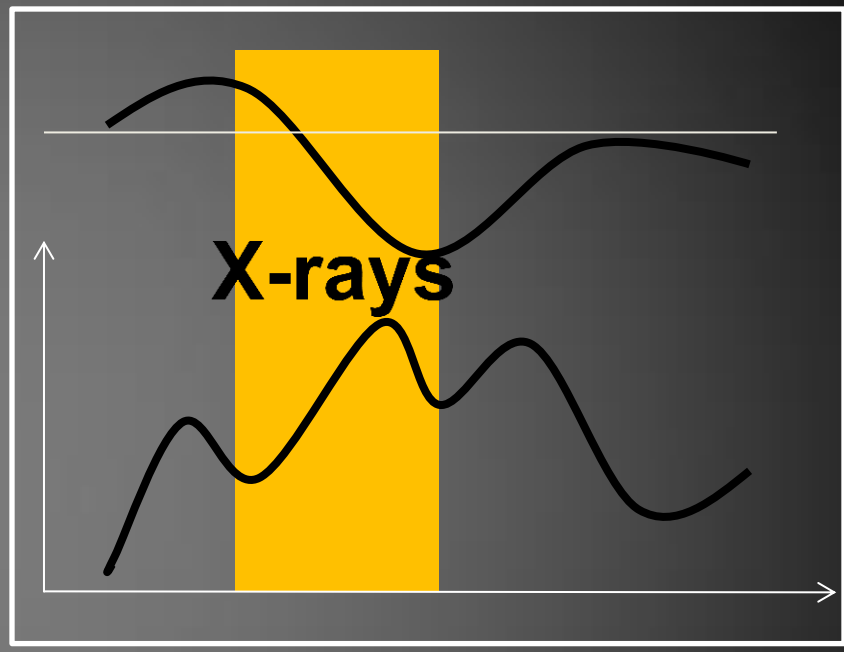
Cohen, **Fialkov**, Barkana (submitted)

Signature of X-ray Sources



Dark matter annihilation

A black hole binary (ESO image)



Possible heating sources:

X-ray binaries?

Thermal emission from galaxies?

Black holes, mini quasars?

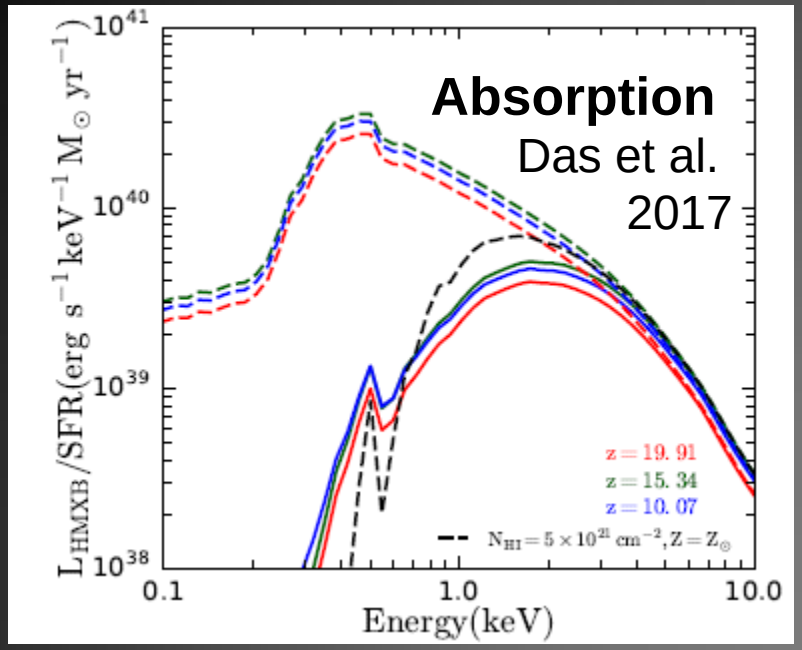
Dark matter annihilation?

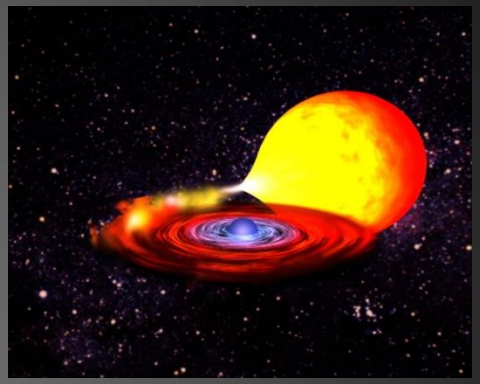
Cosmic rays?

Magnetic fields?

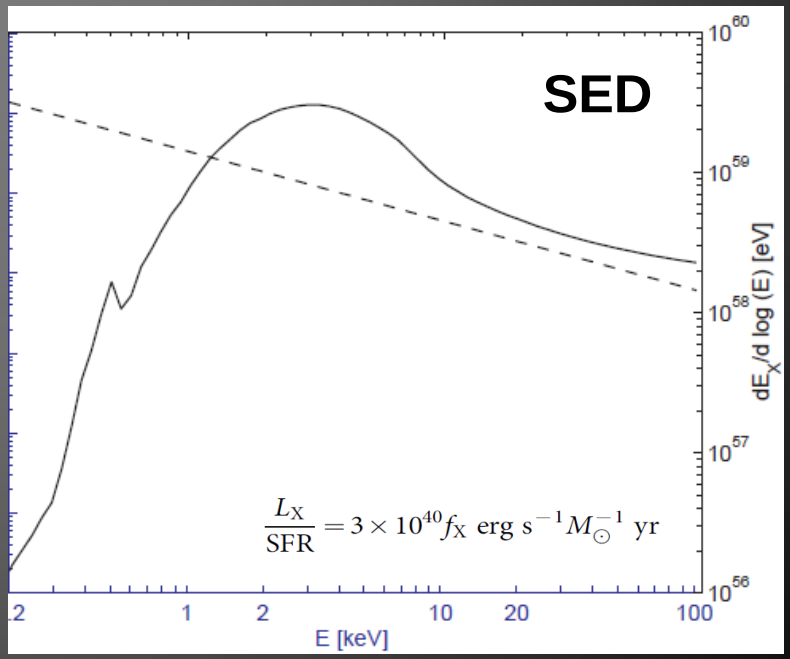
A quasar

Important Properties of X-ray Sources



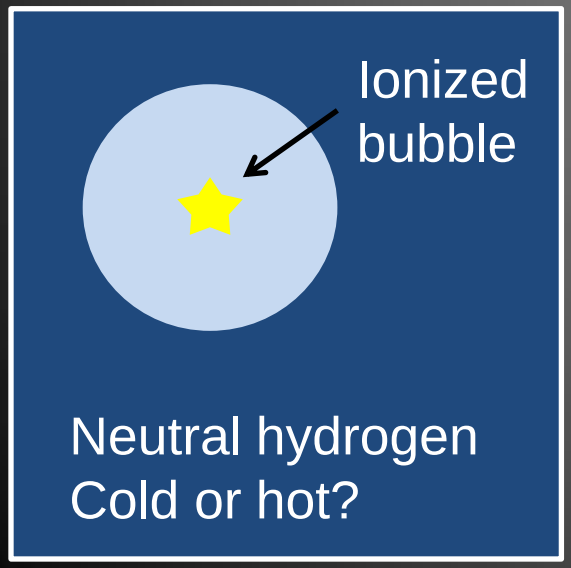


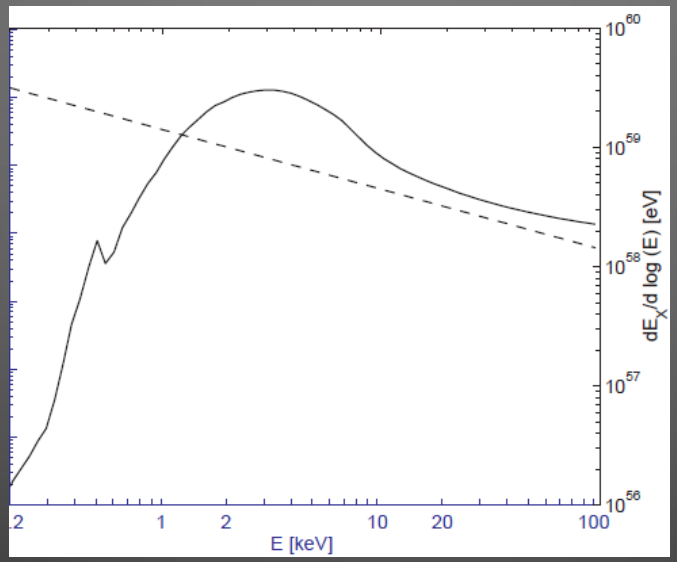
- X-ray efficiency (effect of metallicity)
- SED (XRB/quasars vs hot gas)
- Absorption (ISM of the host)
- Growth of population with redshift (XRB vs quasars)

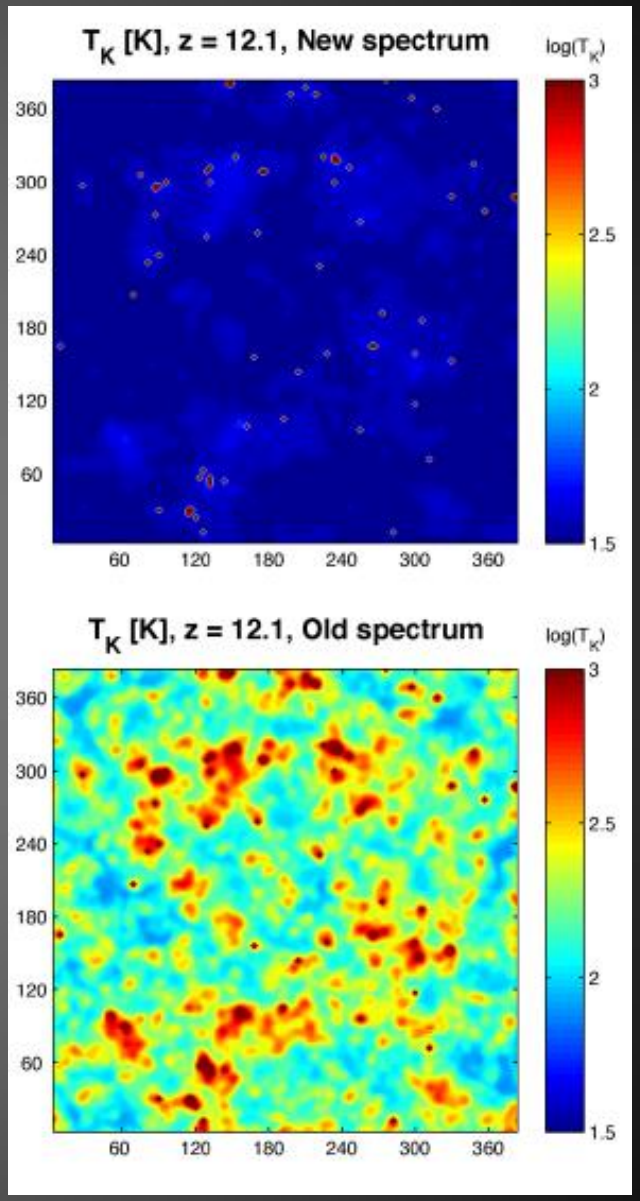


Effects of First X-ray Sources on the Environment

- X-rays can easily escape from their host galaxies
- Heat and ionize IGM 10-1000 Mpc away from the source
- Temperature of the IGM fluctuates (non-homogeneous distribution of X-ray sources)



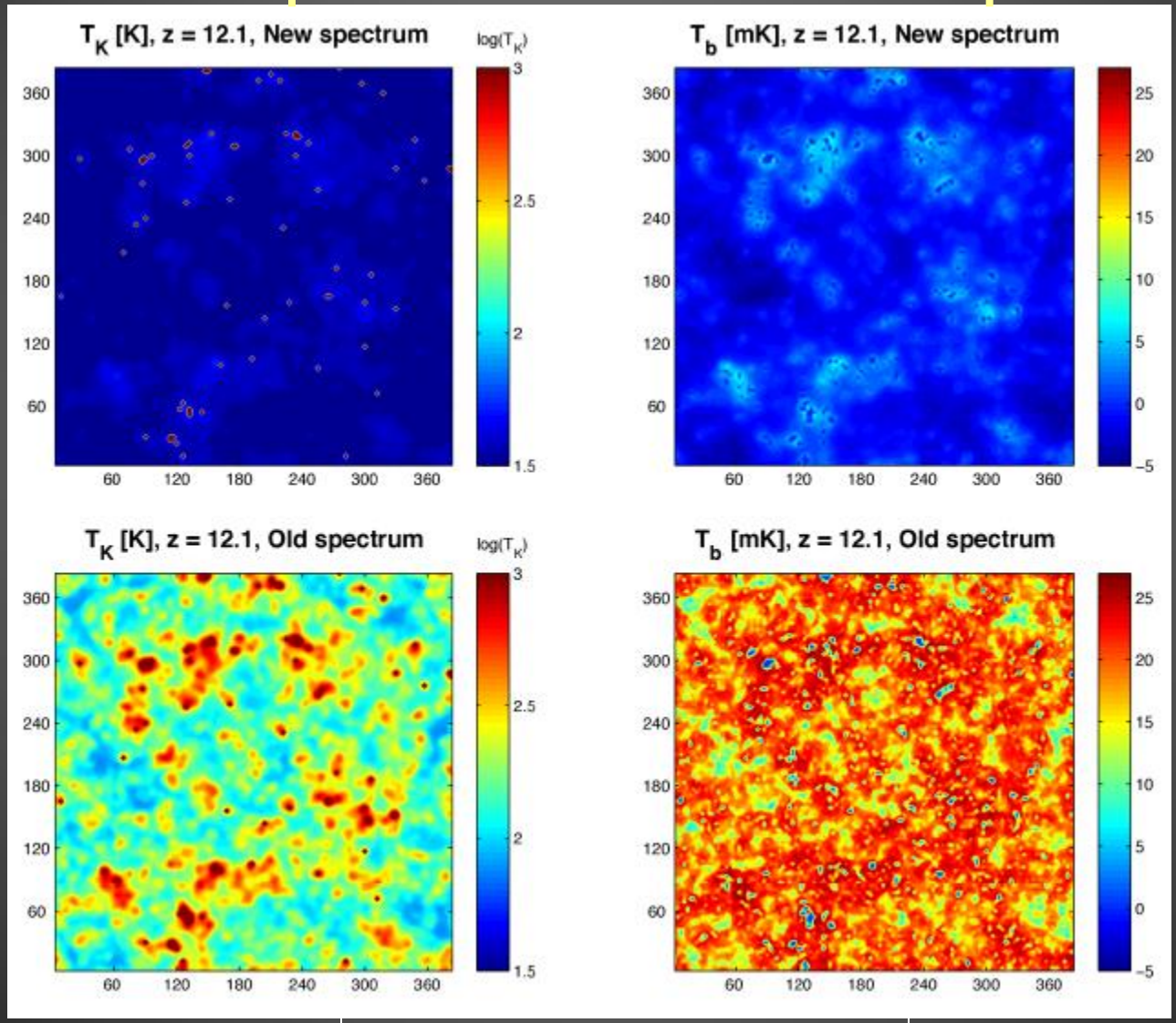




Fialkov & Barkana (2014)

21-cm Signal as a Cosmic Thermometer

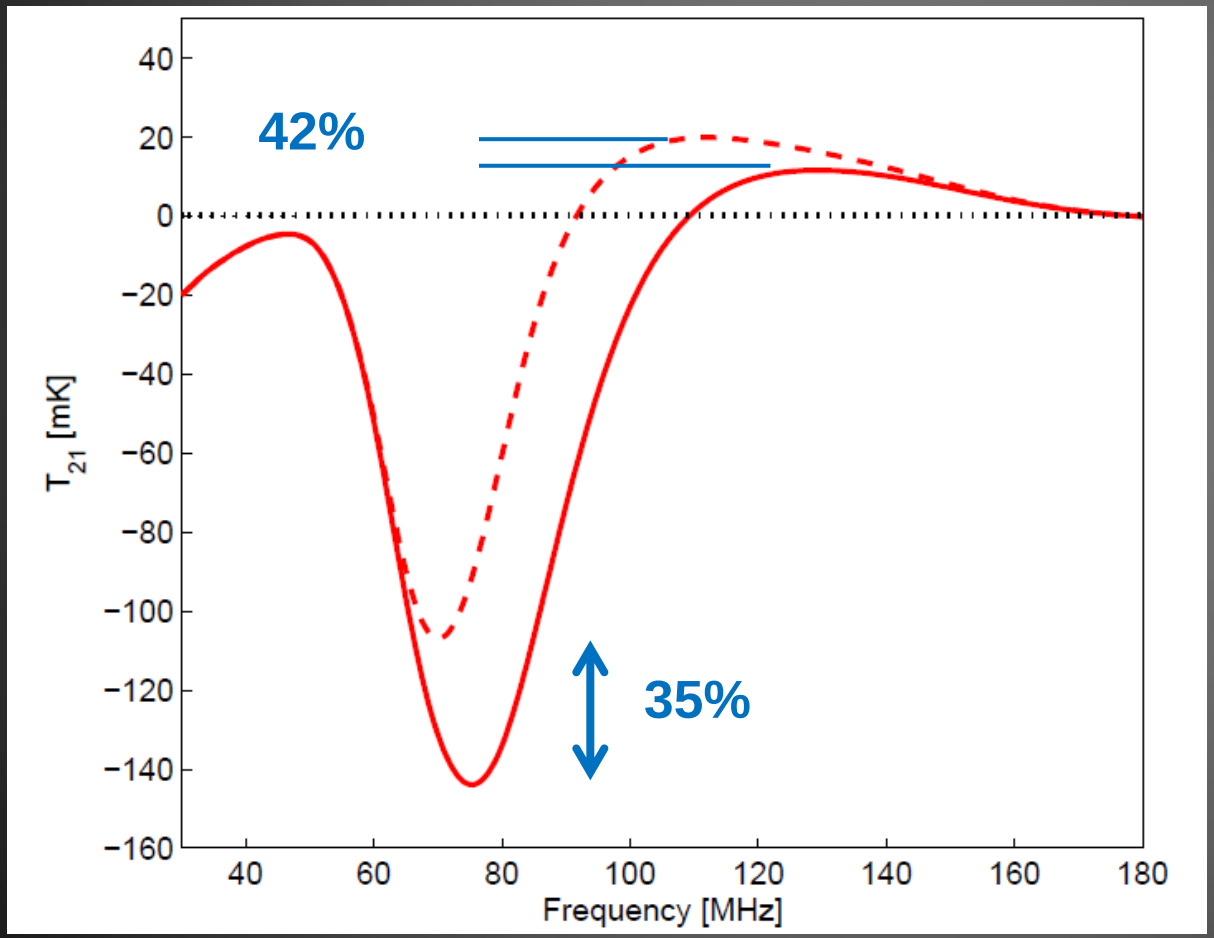
Gas Temperature **21-cm Map**



Fialkov & Barkana (2014)

Signature in the Global Signal

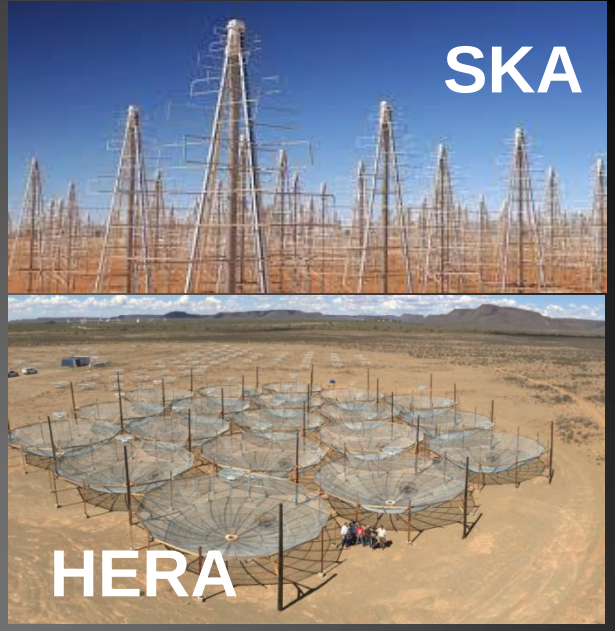
Global 21-cm



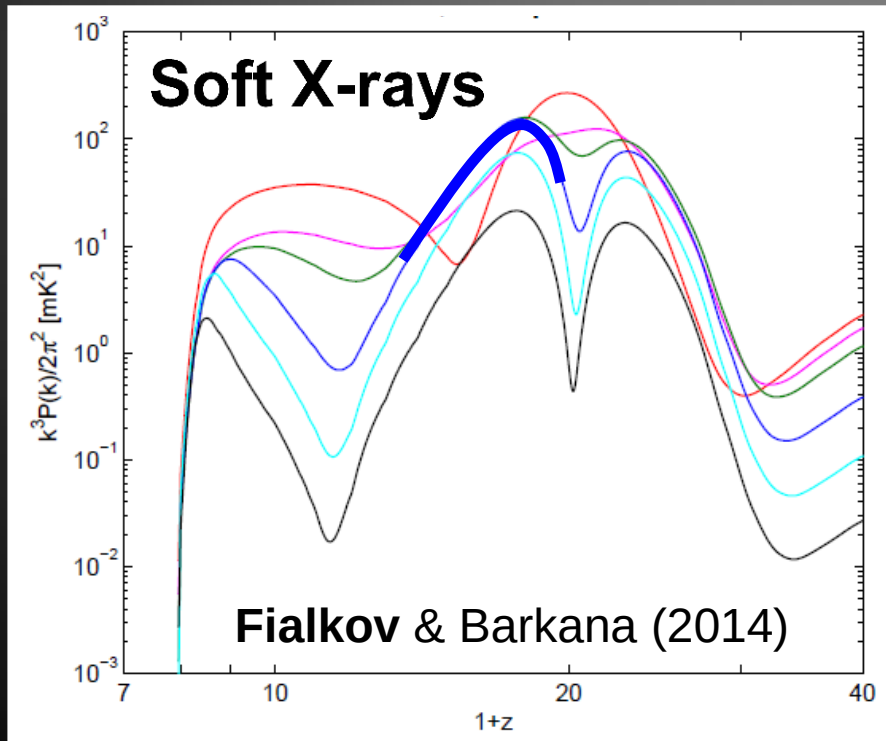
Fialkov & Barkana (2014)

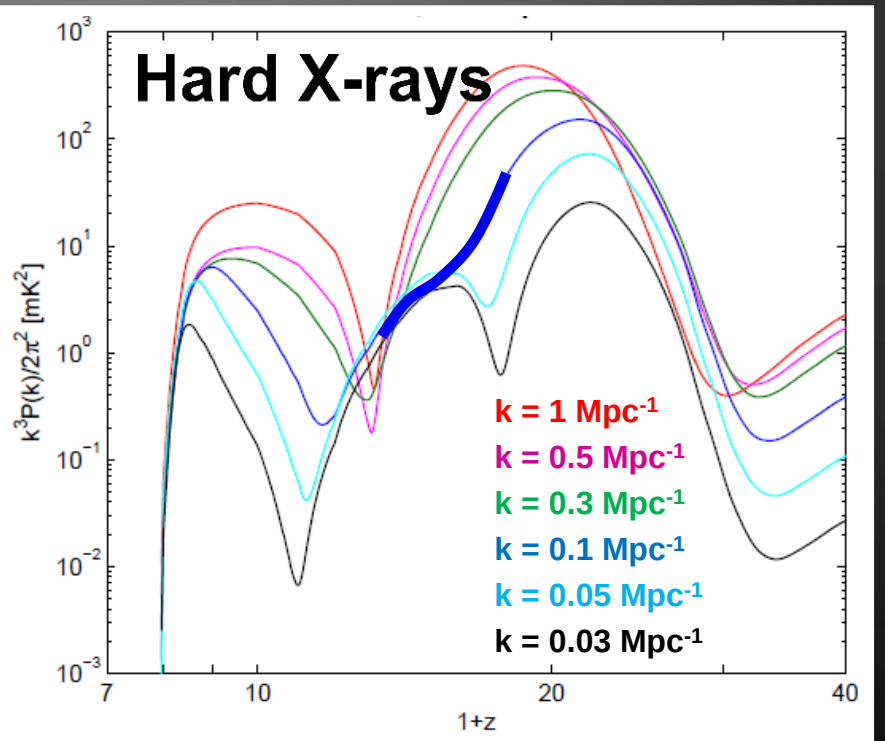
Hard vs Soft SED

- Heating fluctuations are washed out
- No X-ray peak!
- Gas can be hot or cold during EoR



Power Spectrum vs z





XRB vs Quasars

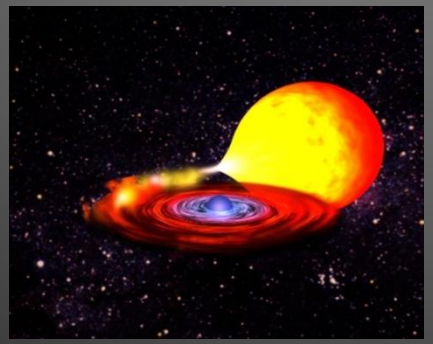
XRBs

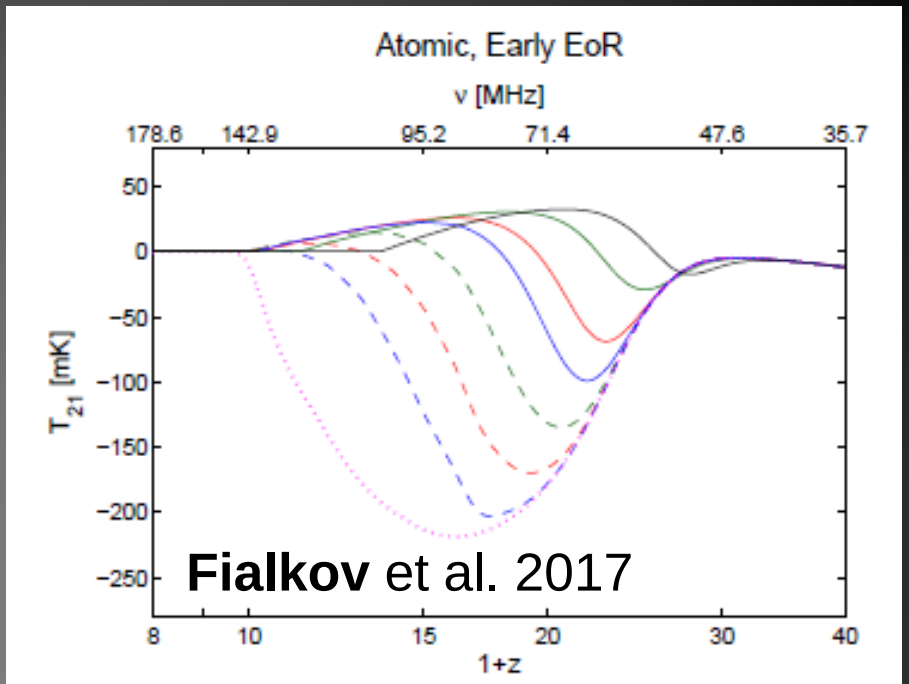
- $L_X \propto f_X \times SFR$
- Absorption
- Hard SED

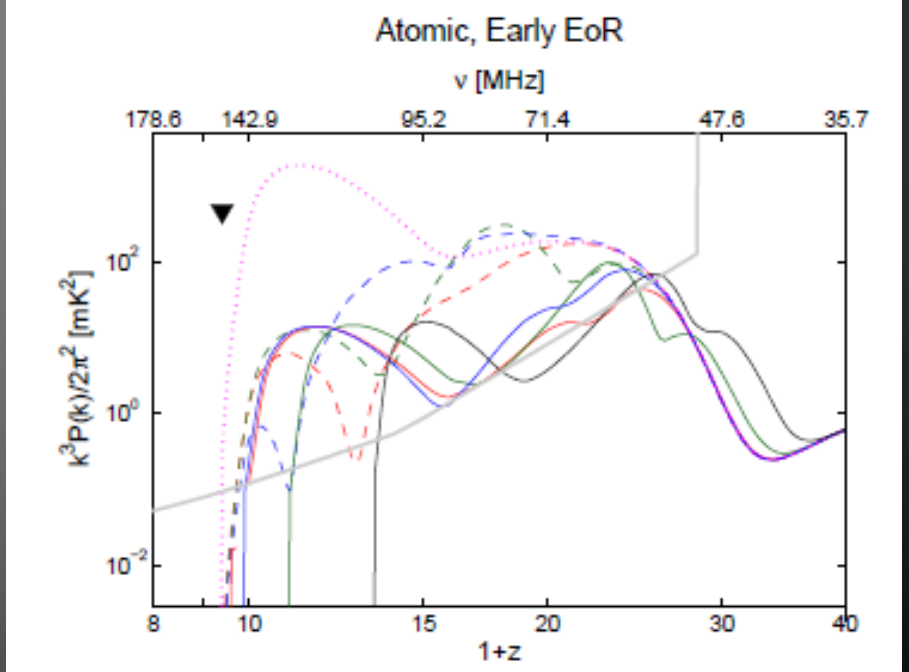
Quasars:

- Multi-colour Shakura-Sunyaev accretion disc
- M-σ relation (Internal feedback model for M_{BH})
- Eddington luminosity

21-cm measures growth of population of X-ray sources in time

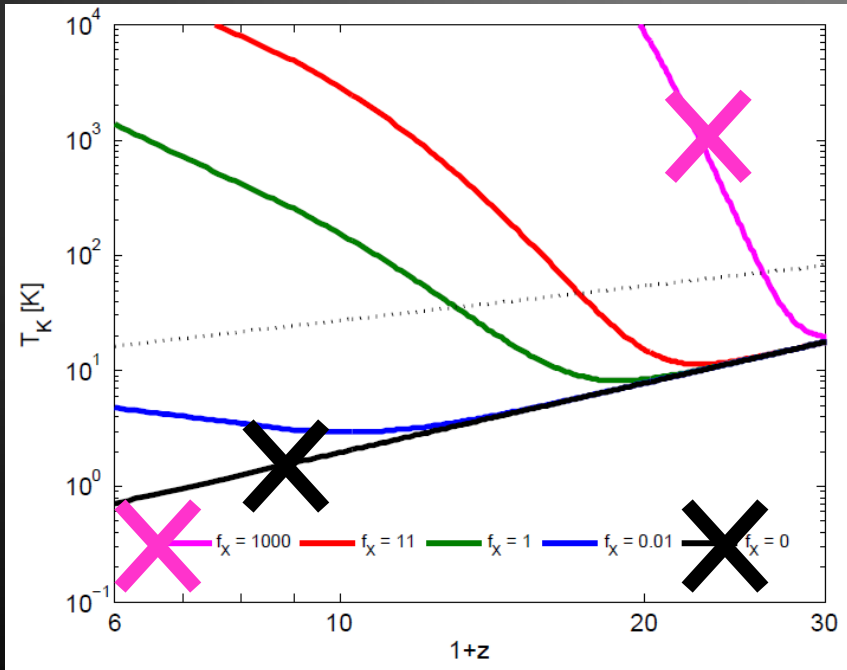


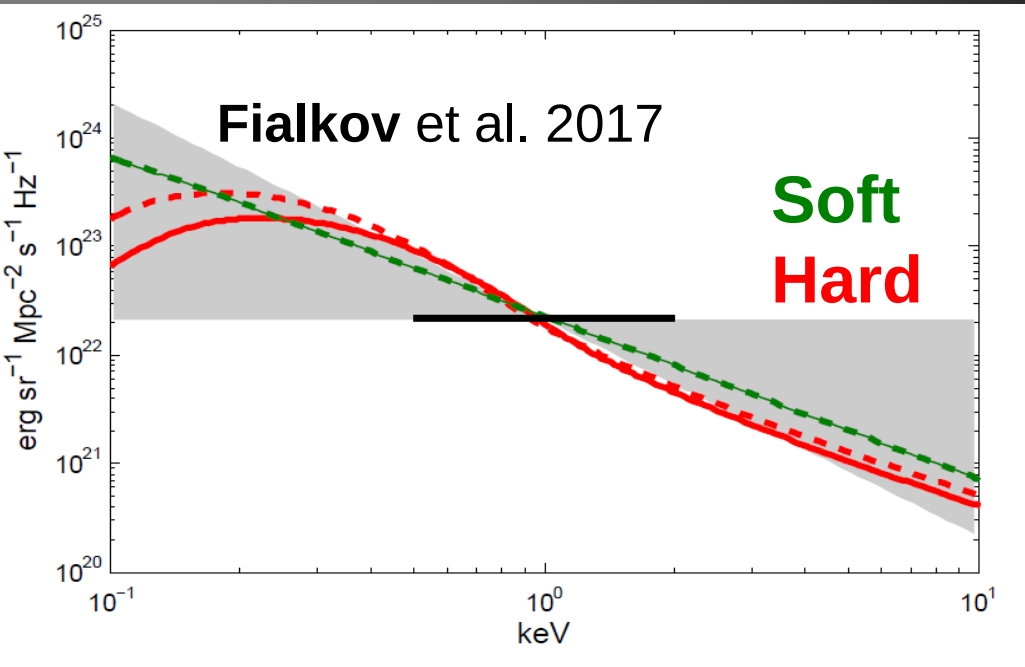




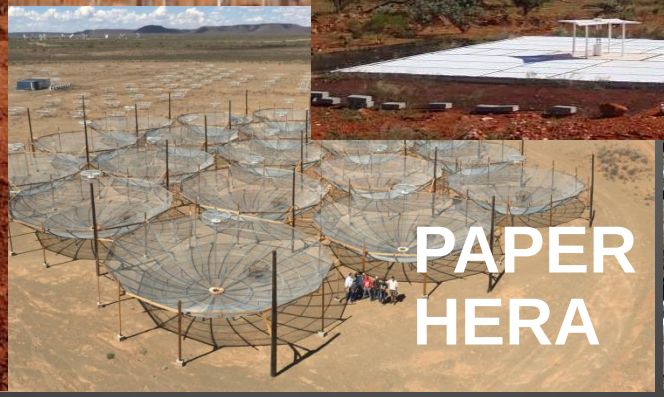
Limits on Cosmic Heating History
Chandra + 21-cm

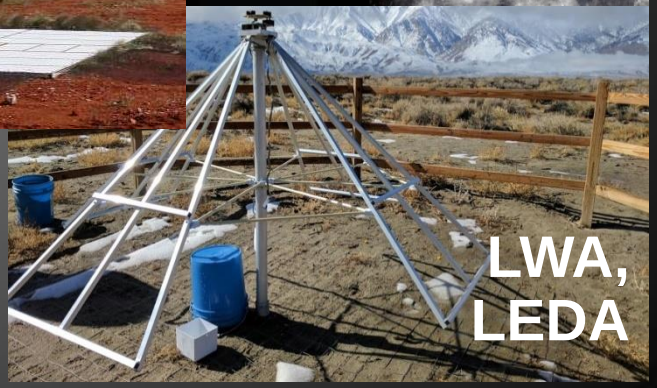
- Extragalactic CXB from high-z $< 7 \times 10^{-12}$ $[erg\ cm^{-2} s^{-1} deg^{-2}]$ (Cappelluti et al. 2017)
- Unresolved extragalactic CXB yields upper limit on f_X
- 21-cm experiments set lower limit on f_X
- Hard sources are more efficient in producing CXB (lower max f_X)



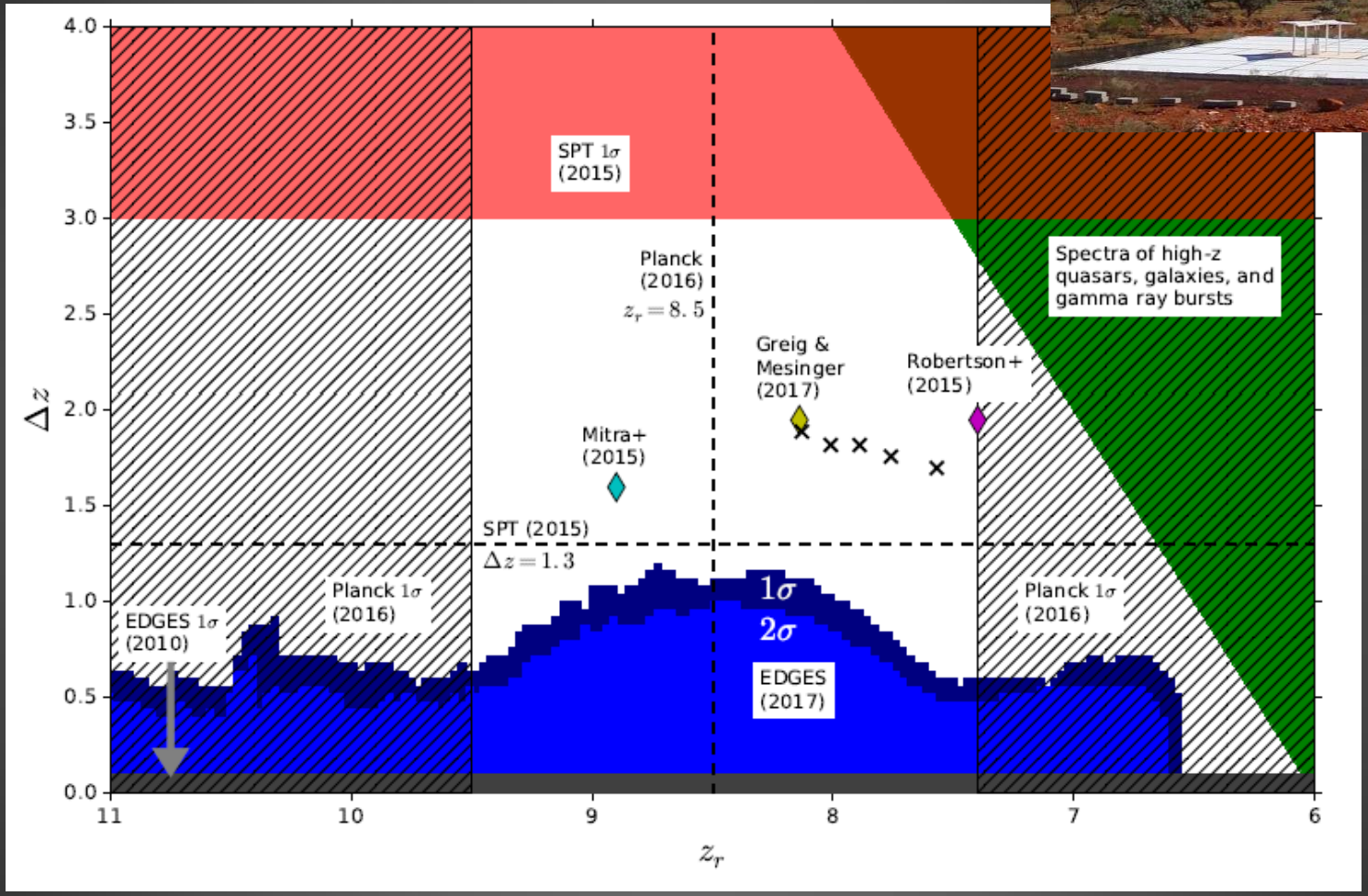


International Effort to Observe HI





Observational Constraints



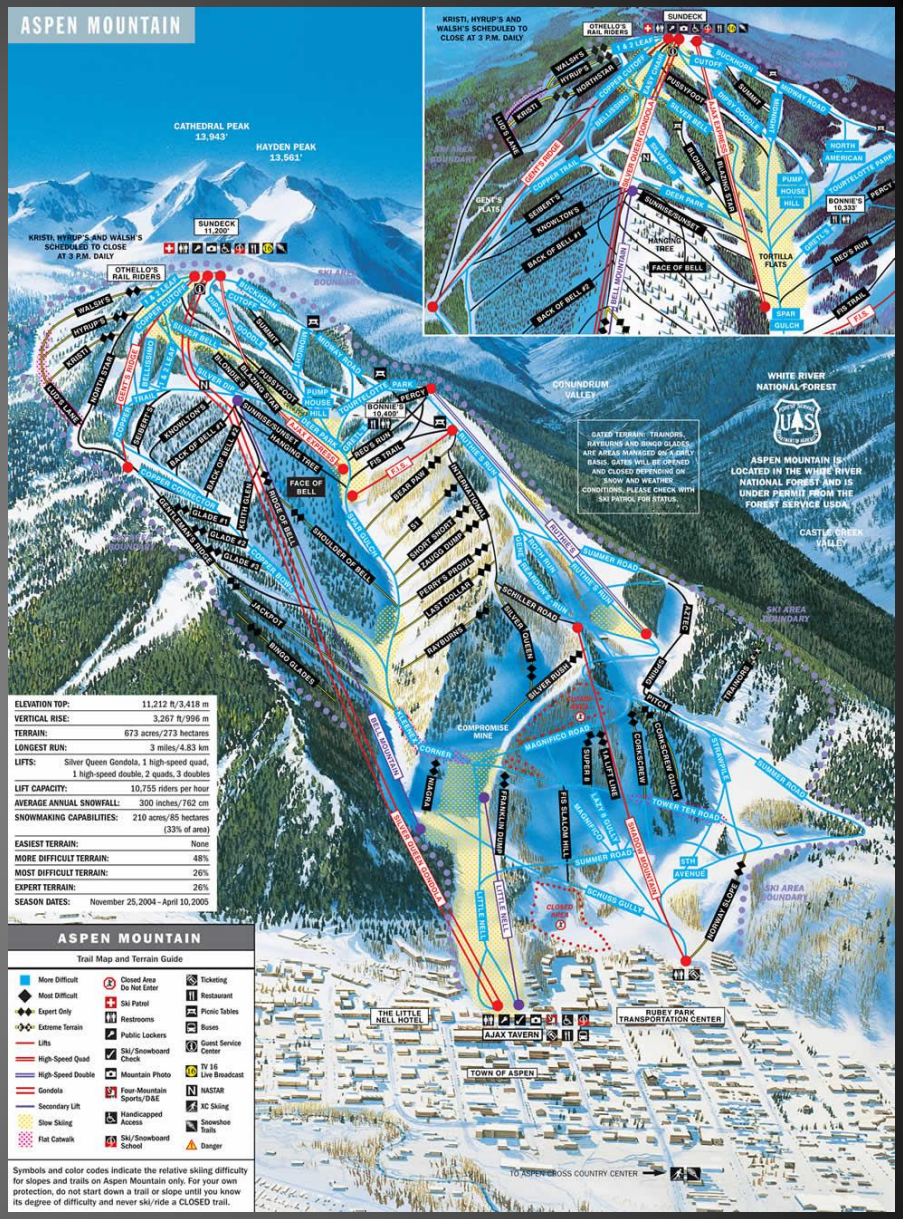
Monsalve et al. 2017

Work in progress: how does it map to the astrophysical parameter space

Aspen Meeting

Cosmological Signals from Cosmic Dawn to the Present
Feb 4-10, 2018

- Line intensity mapping
- The 21-cm signal from EoR and cosmic dawn
- First UV and X-ray sources
- Physics of reionization and cosmic dawn



Organizers: Anastasia Fialkov, Tzu-Ching Chang, Rennan Barkana, Judd Bowman, Adam Lidz, Anthony Pullen.

Conclusions

- 21-cm is a cosmic thermometer, clock and radiometer!
- Promising probe of high-z Universe
- Can tell apart hard vs soft X-ray sources and constrain mfp
- Tracks growth of X-ray population with redshift

- Experiments are getting close