Primordial Black holes and the 21 cm line

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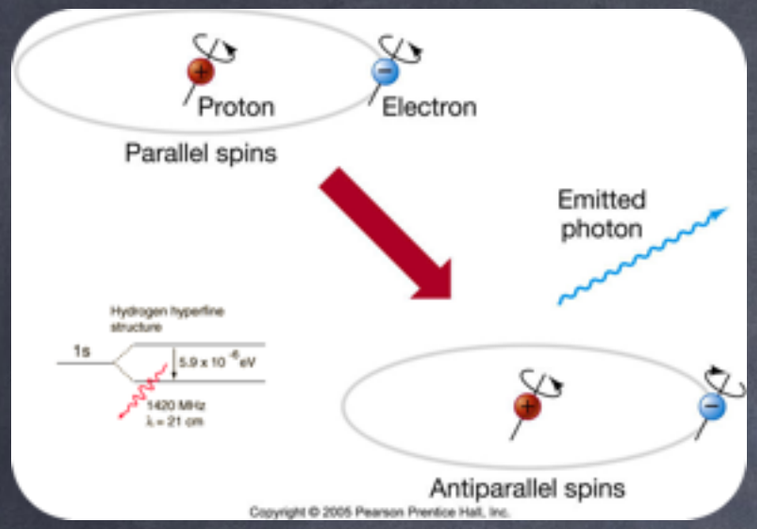
Based on O. Mena, **SPR**, P. Villanueva-Domingo and S. J. Witte, *in preparation*

CoCo: Cosmología en Colombia

May 31, 2019

The 21cm line

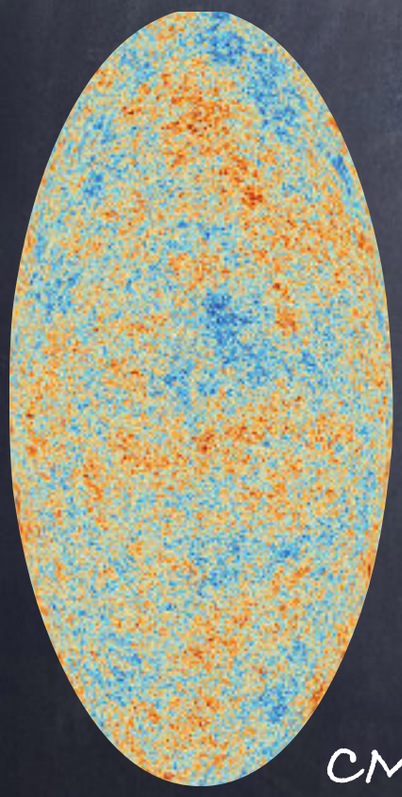


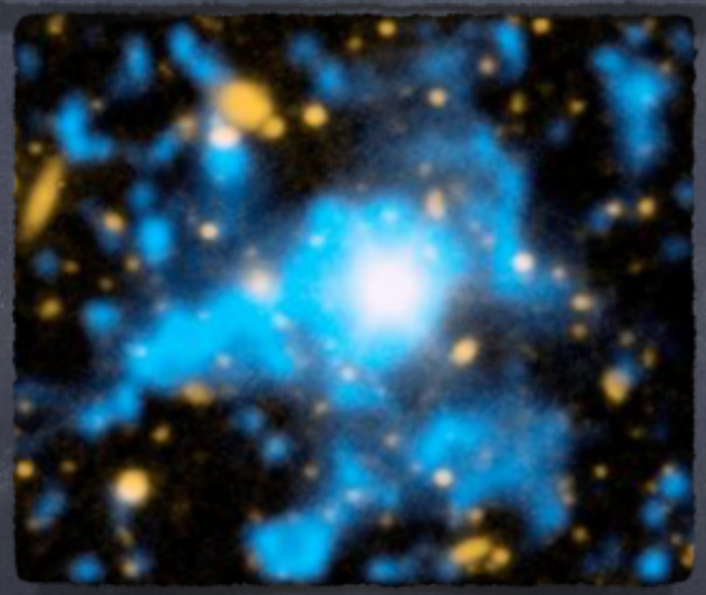
Hyperfine transition: $\nu = 1420$ Mhz

21cm photon from HI clouds during the dark ages: $\nu \sim 100$ Mhz

$$\nu = \frac{\nu_0}{(1+z)}$$

neutral hydrogen gas
(intergalactic medium: IGM)





observer

CMB photons as backlight

emission/absorption

z~1000

z=0

The 21cm line

Probing Dark Ages
Cosmic tomography



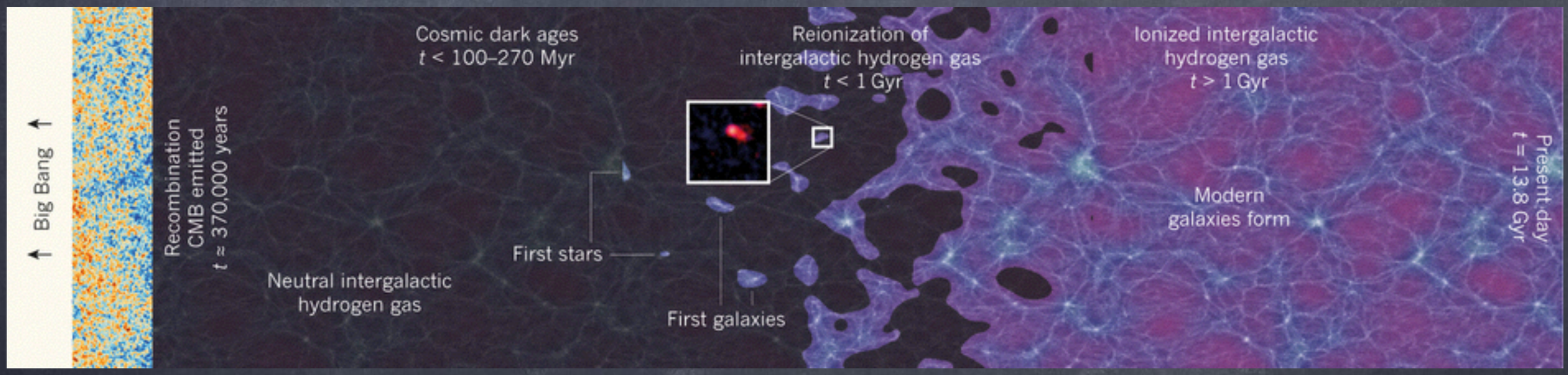



Interferometers
LOFAR, MWA, PAPER, GMRT
LEDA, EDGES, HERA, SKA

$z \sim 5\text{-}30$

Galaxy Surveys

$z < 5$



z~1000 — Dark ages — z~30 — Cosmic dawn — z~6 — Galaxy formation — z=0

First stars — Reionization

The 21cm signal

$$\delta T_b(\nu) \simeq 27\, x_{HI}\,(1+\delta)\left(1-\frac{T_{CMB}}{T_S}\right)\left(\frac{1+z}{10}\right)^{1/2}$$

Fraction of neutral H

Reionization suppresses the signal

Baryon overdensity

Spin temperature:
occupation of the two states

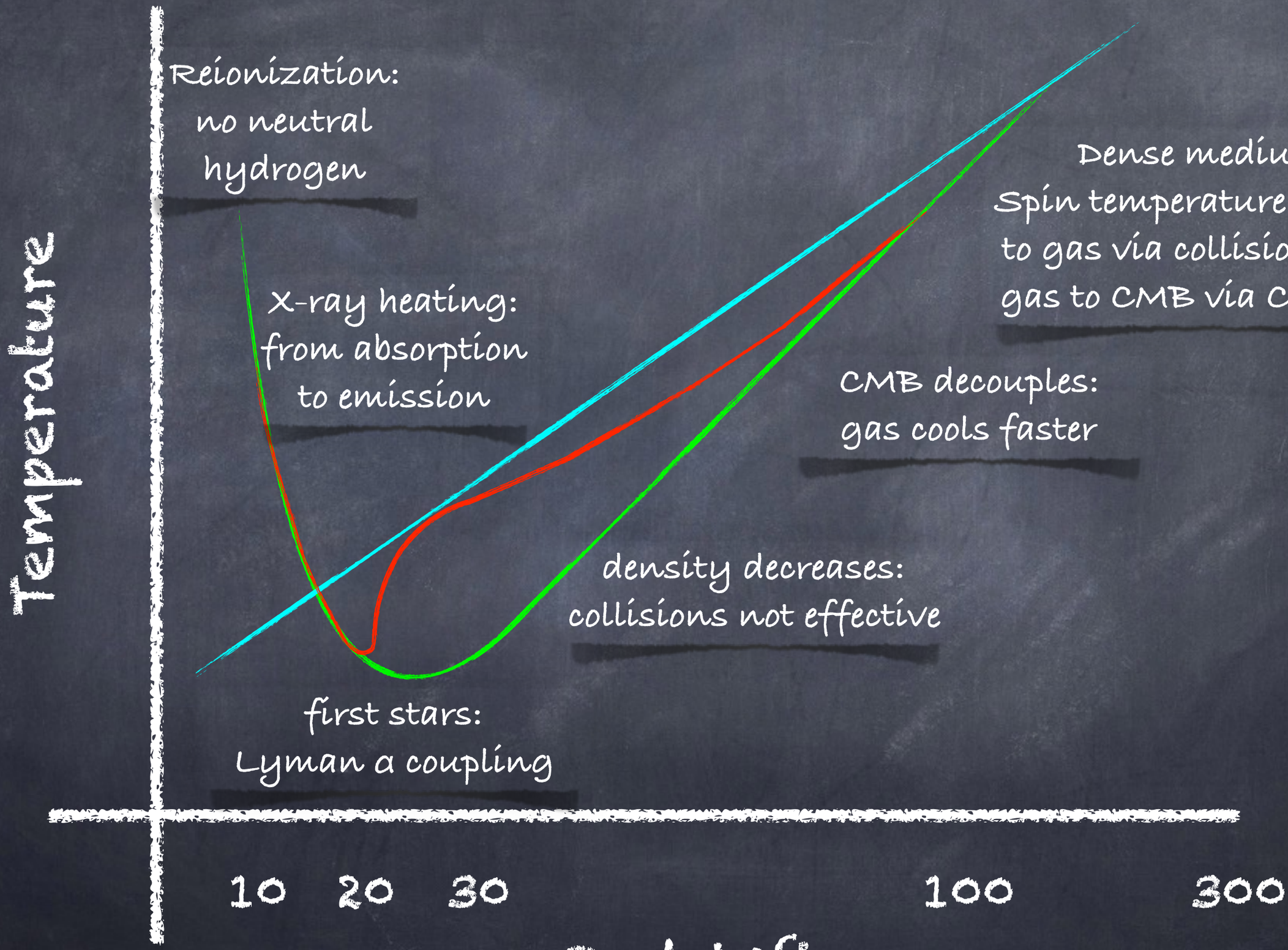
$\delta T_b \approx 0$ if $T_S \sim T_{CMB}$ — no signal

$\delta T_b > 0$ if $T_S > T_{CMB}$ — signal in emission, can saturate

$\delta T_b < 0$ if $T_S < T_{CMB}$ — signal in absorption, limited by gas temperature

Astrophysical processes decouple T_S from T_{CMB}

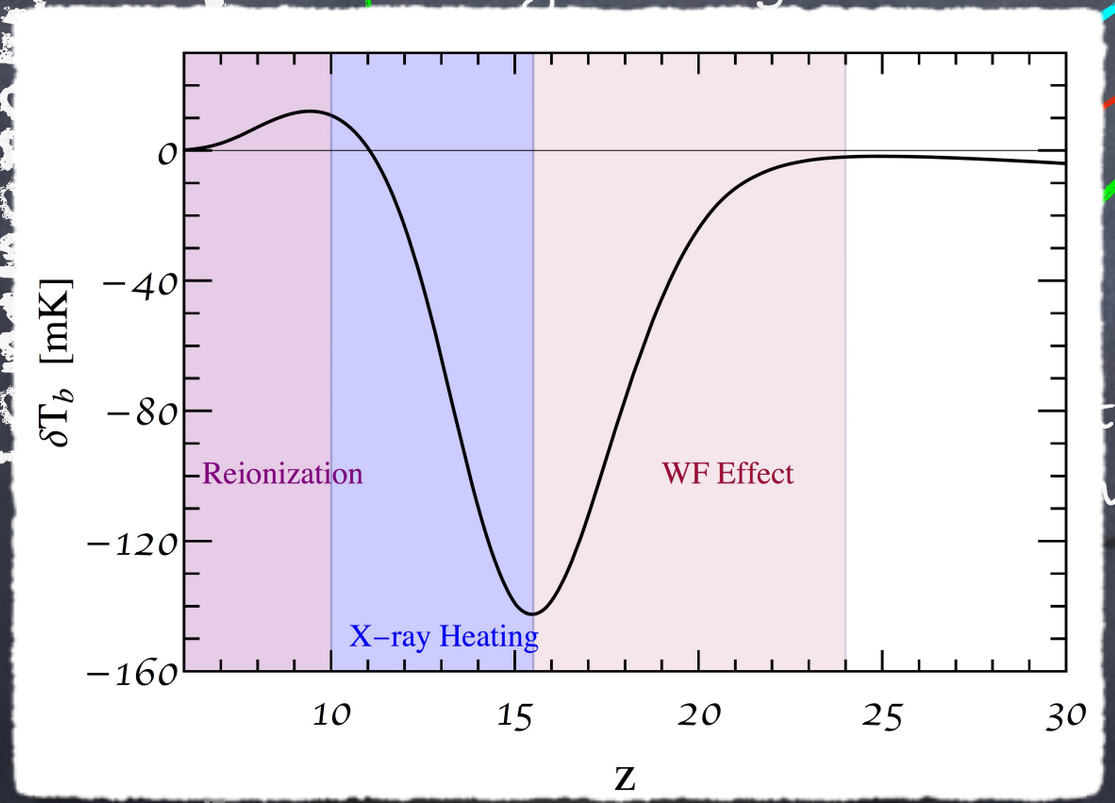
The 21cm signal: Time evolution



The 21cm signal: Time evolution

Reionization:
no neutral
hydrogen

X-ray heating:



Dense medium:
Spin temperature coupled
to gas via collisions and
gas to CMB via Compton

CMB decouples:
gas cools faster

ty decreases:
s not effective

Temperature

10 20 30 100 300

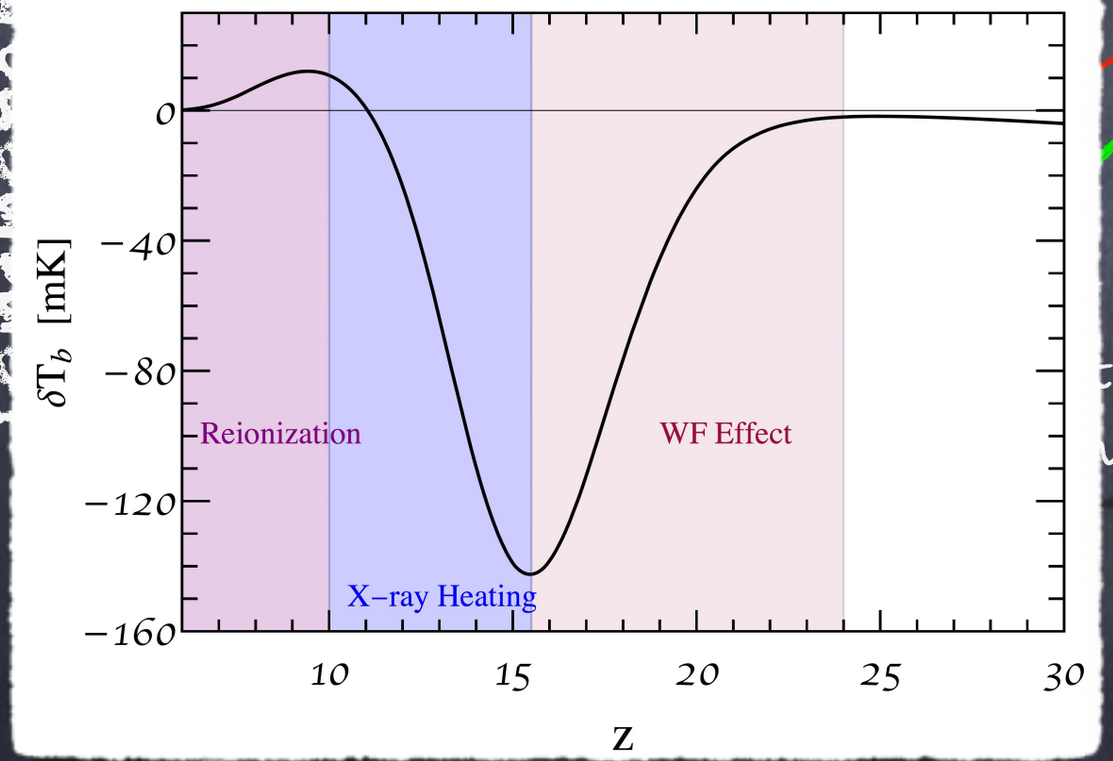
Redshift

The 21cm signal: Time evolution

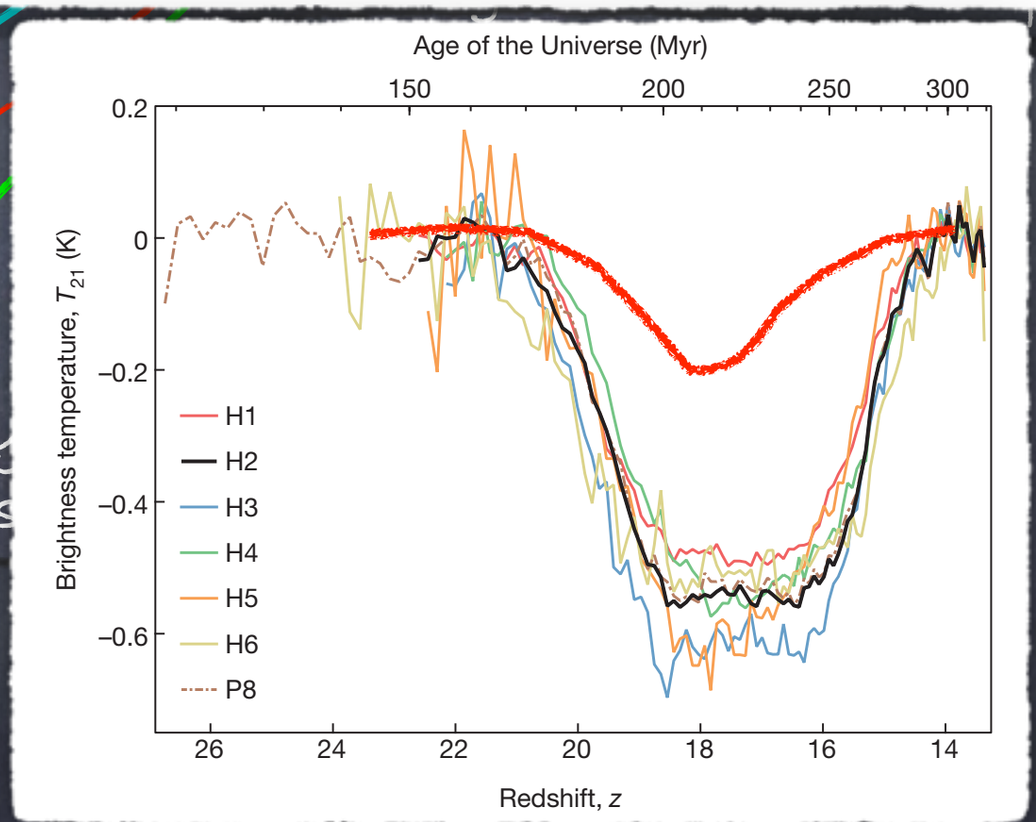
Reionization: no neutral hydrogen

X-ray heating:

Temperature



EDGES: new physics? astrophysics?



J. D. Bowman et al., Nature 555:67, 2018

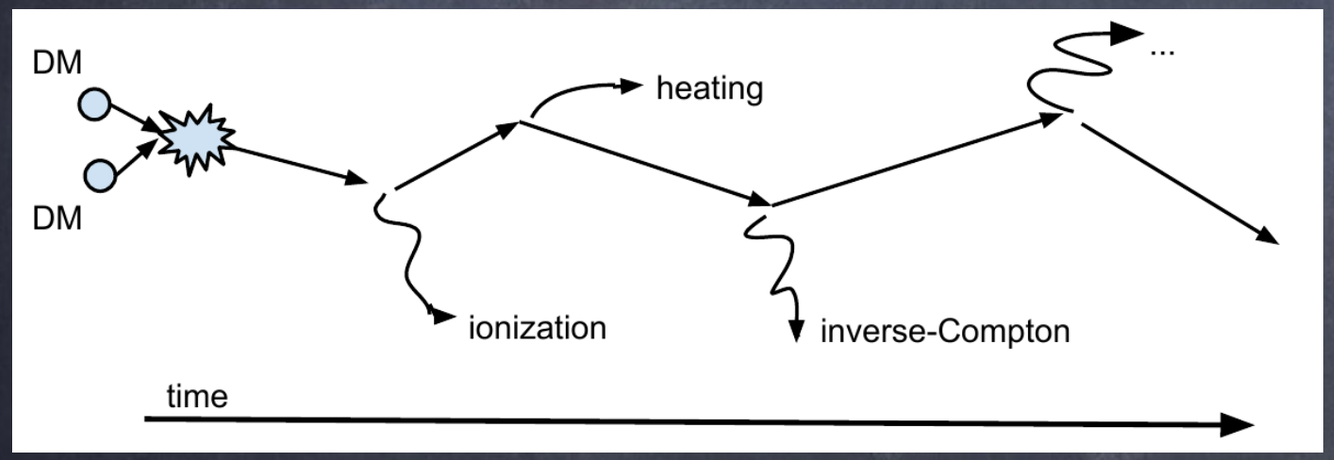
10 20 30 100 300

Redshift

Energy injection: Effect on the 21cm signal

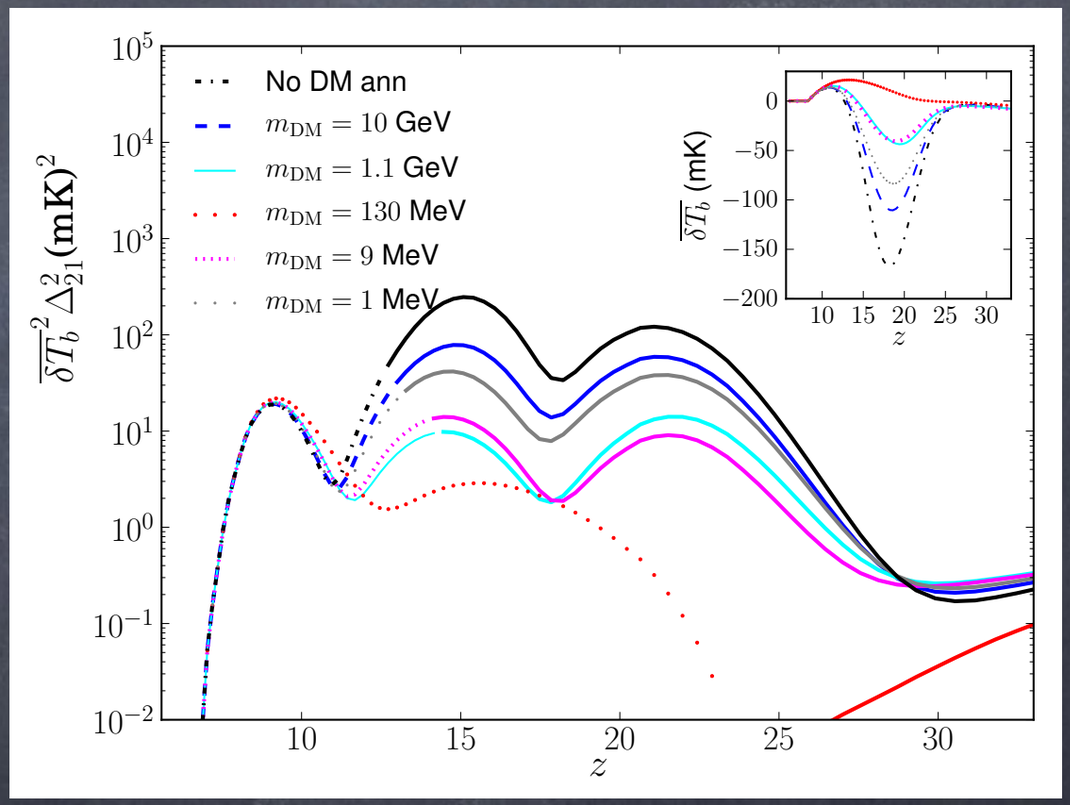
Dark matter annihilations:
inject energy into the IGM

Chen'03, Hansen'03, Pierpaoli'03, Padmanabhan'05,
Shchenikov'06, Furlanetto'06, Valdes'07, Chuzhoy'07,
Cumberbatch'08, Natarajan'09, Yuan'09, Valdes'12, Evoli'14



Credit: A. C. Vincent

DM: suppress power
but effects degenerated with astrophysics



L. Lopez-Honorez, O. Mena, A. Moliné, **SPR** and A. C. Vincent,
JCAP 1608:004, 2016

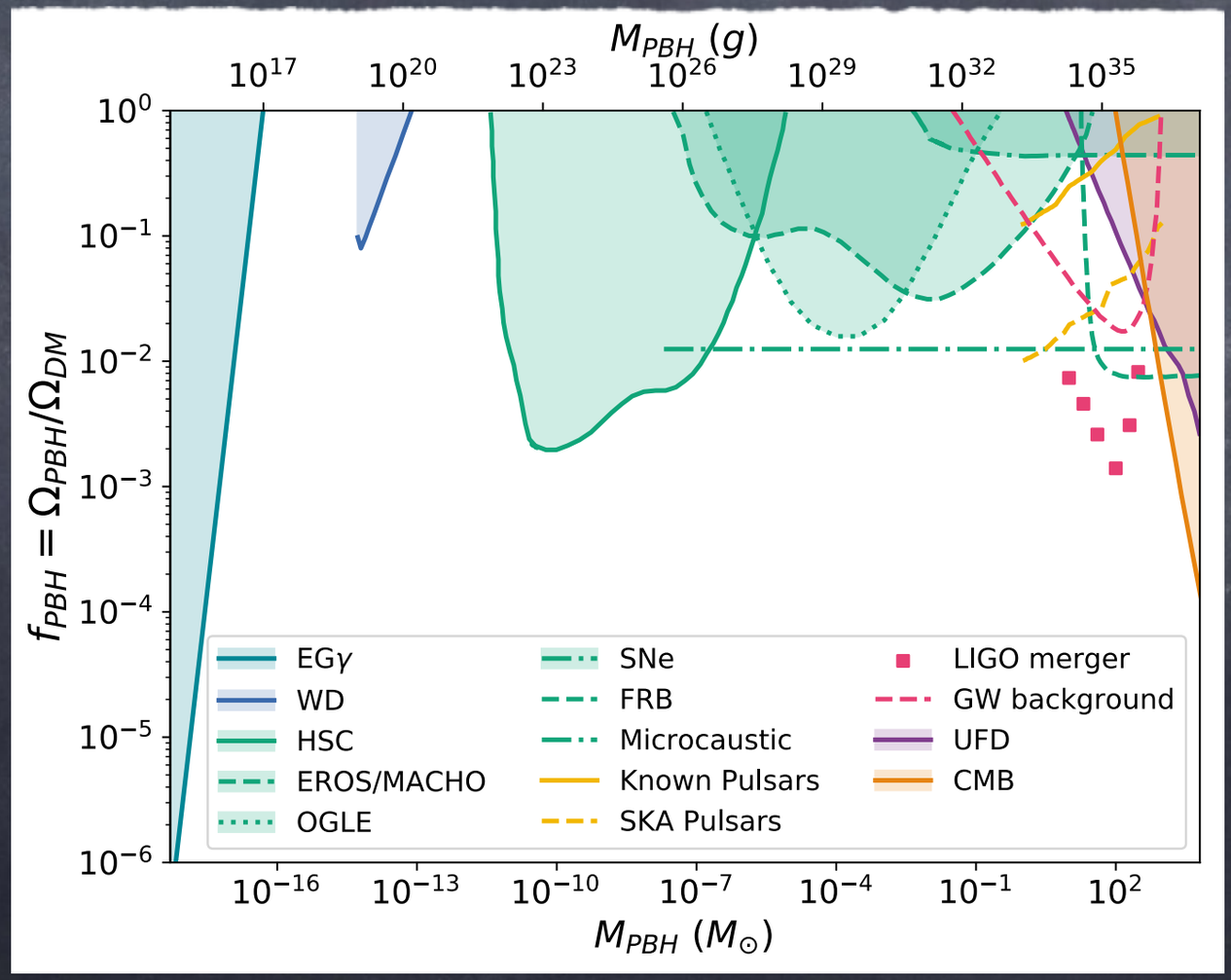
Primordial black holes

The early Universe is very hot and dense:
ideal environment for black hole formation

Y. B. Zel'dovich and I. D. Novikov, *Sov. Astron. 10:602, 1967*
S. Hawking, *Mon. Not. Roy. Astron. Soc. 152:75, 1971*

For masses between 10^{-17} $M_\odot$ and 10^{5} $M_\odot$ PBHs can be part of the DM

G. F. Chapline, *Nature 253:251, 1975*



G. Sato-Polito, E. D. Kovetz and M. Kamionkowski, *arXiv:1904.10971*

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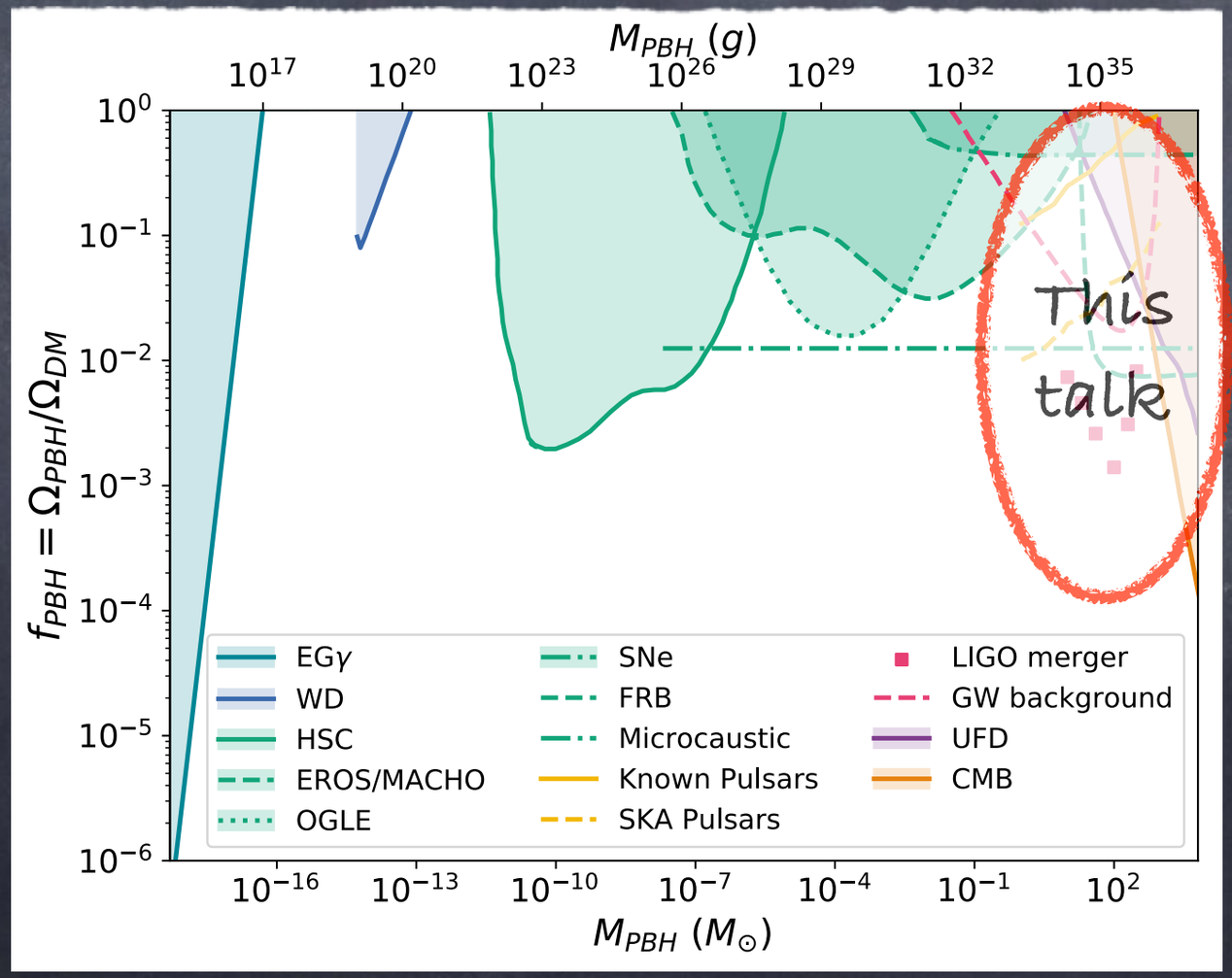


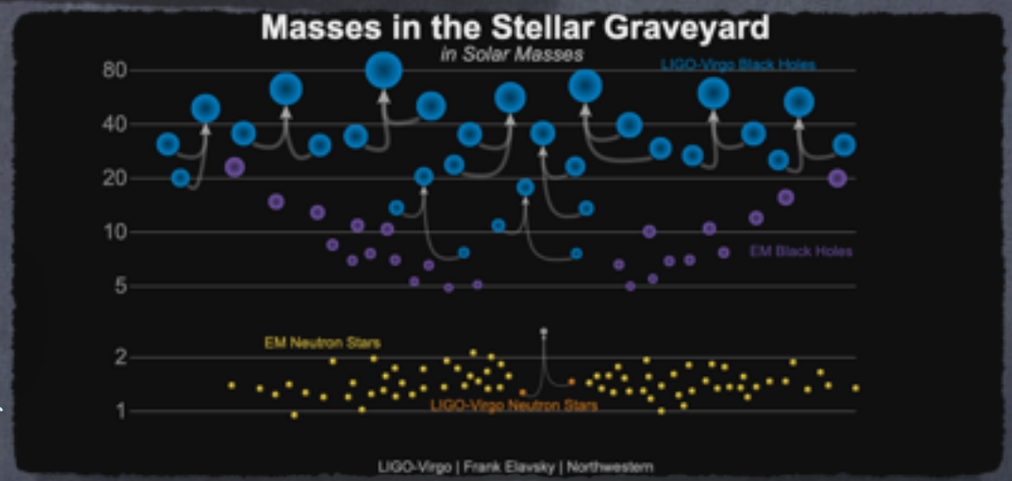
G. Sato-Polito, E. D. Kovetz and M. Kamionkowski, *arXiv:1904.10971*

Solar mass primordial black holes

Even if they cannot form all the dark matter... still interesting

Recent detection of black hole mergers

B. P. Abbott et al. [LVC], *Phys. Rev. Lett. 116:061102, 2016;*
Phys. Rev. Lett. 116:241103, 2016;
Phys. Rev. Lett. 116:131102, 2016;
Phys. Rev. X 6:041015, 2016;
Phys. Rev. Lett. 118:221101, 2017;
Astrophys. J. 851:L35, 2017;
Phys. Rev. Lett. 119:141101, 2017



Did LIGO detect dark matter?

S. Bird et al., *Phys. Rev. Lett. 116:201301, 2016*

Insight into early Universe physics (inflation, topological defects, phase transitions...)

WIMPs and PBHs relation: no go

B. Lacki and J. F. Beacom, *Astrophys. J. 720:L67, 2010*
Yu. N. Eroshenko, *Astron. Lett. 42:347, 2016*
S. M. Boucenna, F. Kuhnel, T. Ohlsson and L. Visinelli, *JCAP 1807:003, 2018*
J. Adamek, C. T. Byrnes, M. Gosenka and S. Hotchkiss, *arXiv:1901.08528*

Timing problem:
PBHs connected to the origin of supermassive BHs?

SOLAR MASS PBHs ABUNDANCE

VIRGO/LIGO: Merger rates related to BHs abundance

Gravitational waves at large redshifts ($z>40$) by
$O(10)$ solar mass BH mergers: Einstein Telescope

Accretion of gas onto PBHs: Emission of broad band spectrum
local searches (X-rays, radio)
heating and ionization of the IGM: cosmological implications

PBHs clustering modifies small scale structure:
shot noise —> isocurvature perturbations

P. Meszaros, *Astron. Astrophys. 38:5, 1975*
N. Afshordi, P. McDonald and D. N. Spergel, *Astrophy. J. 594:L71, 2003*

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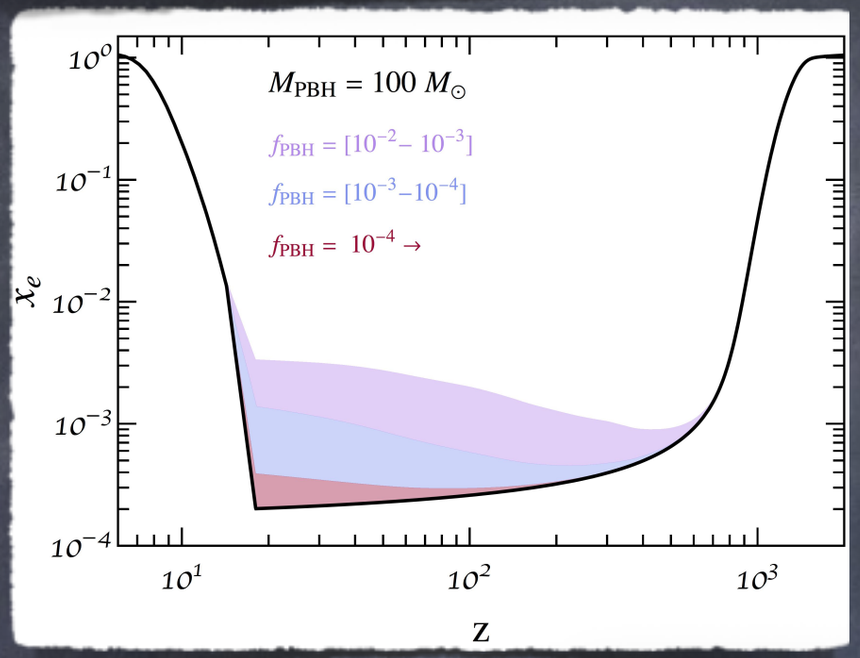
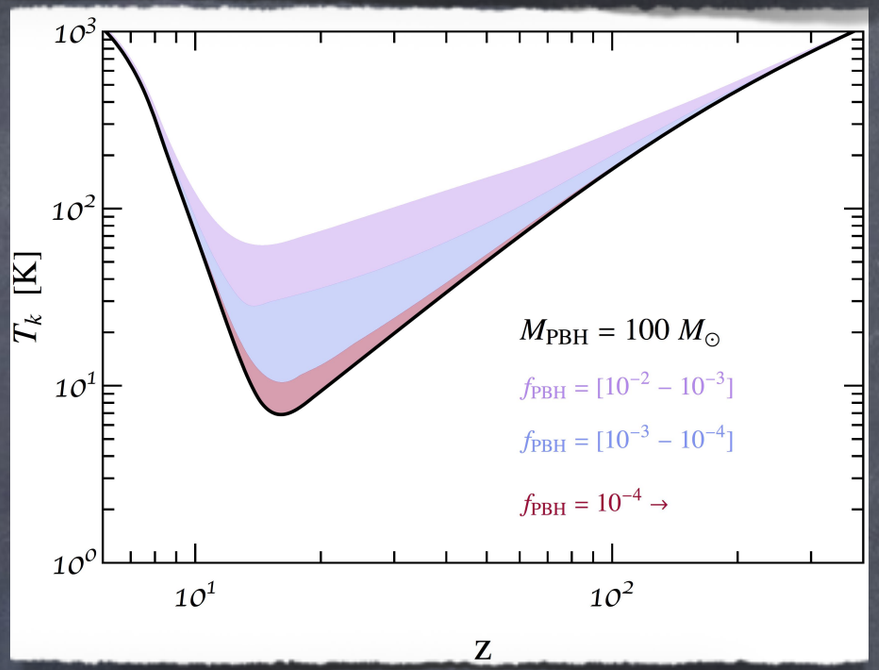
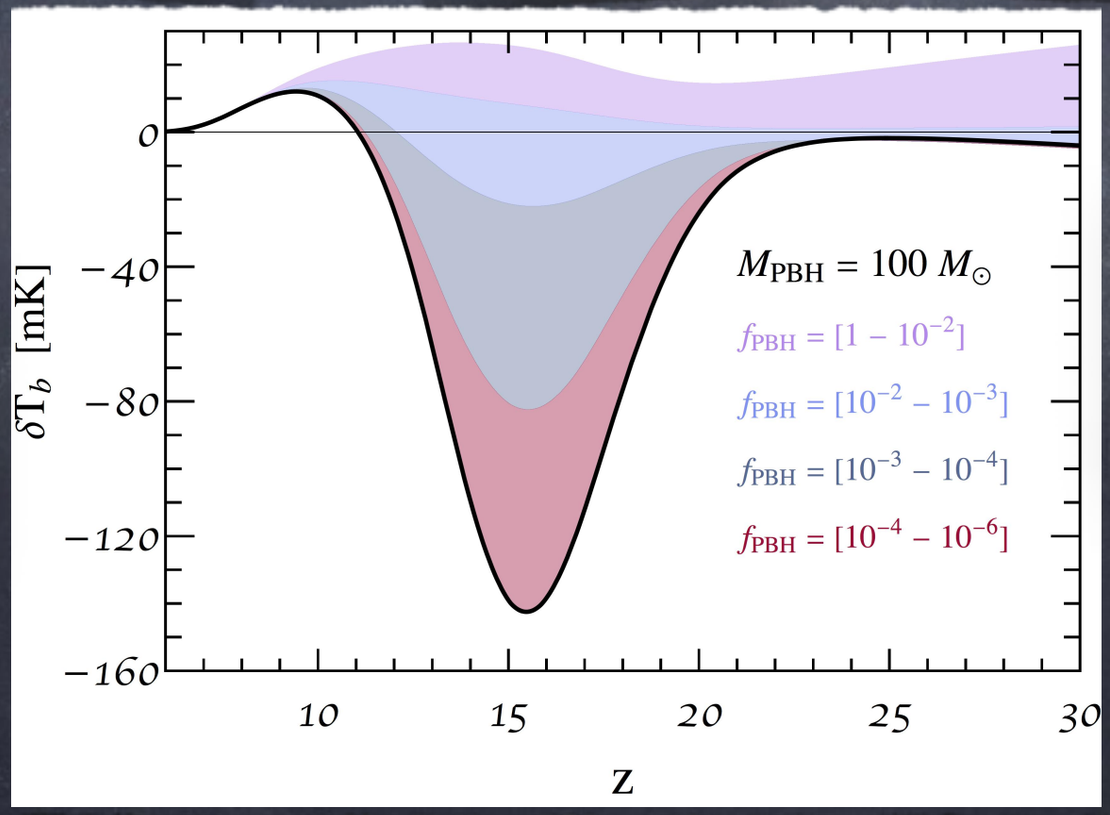
PBHs: Brightness temperature

Injected energy goes into ionizing and heating the IGM





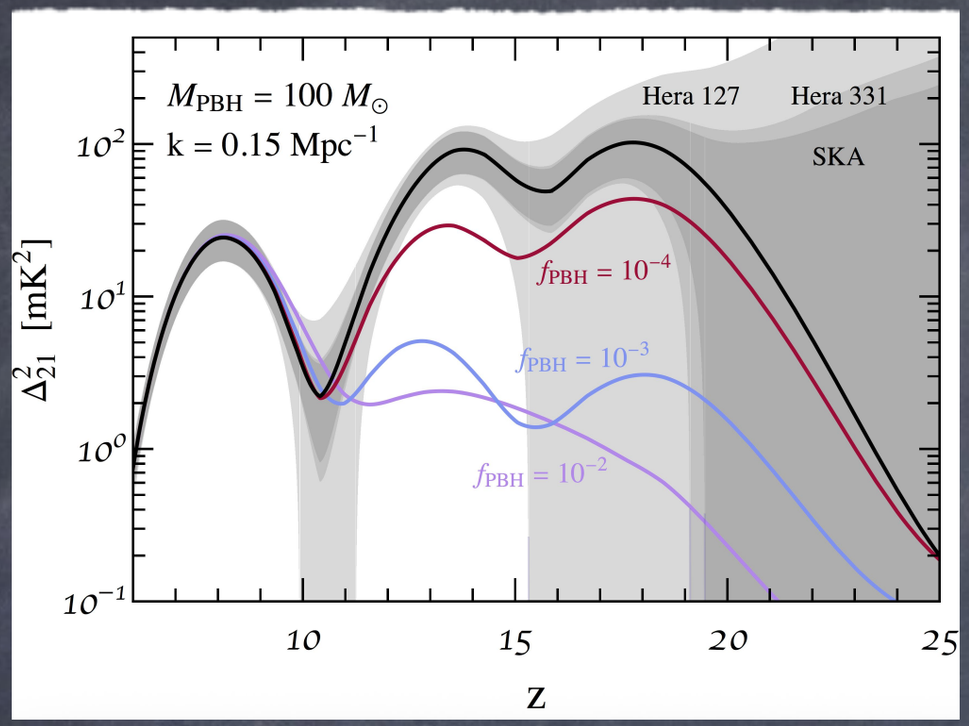
Impact on the brightness temperature: suppression of signal

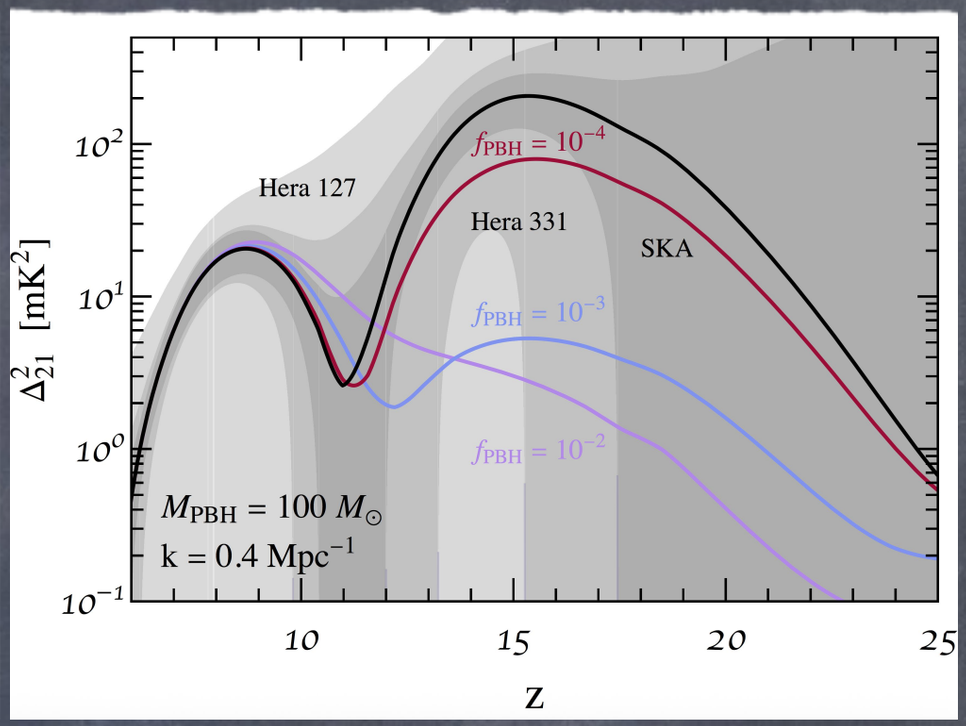


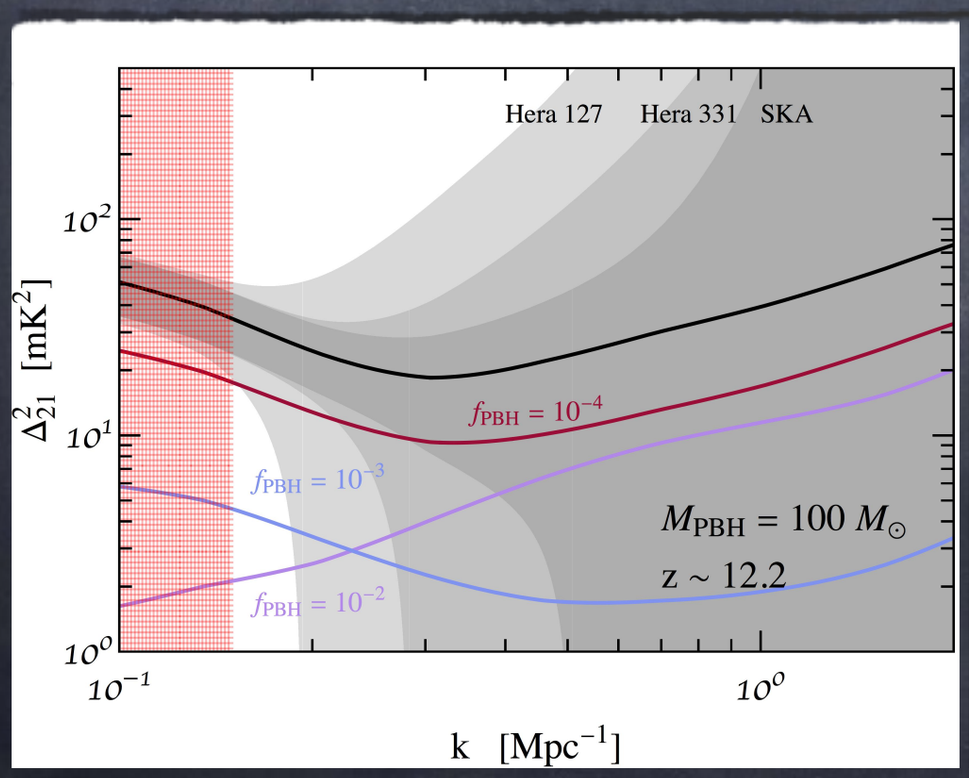
From absorption to emission

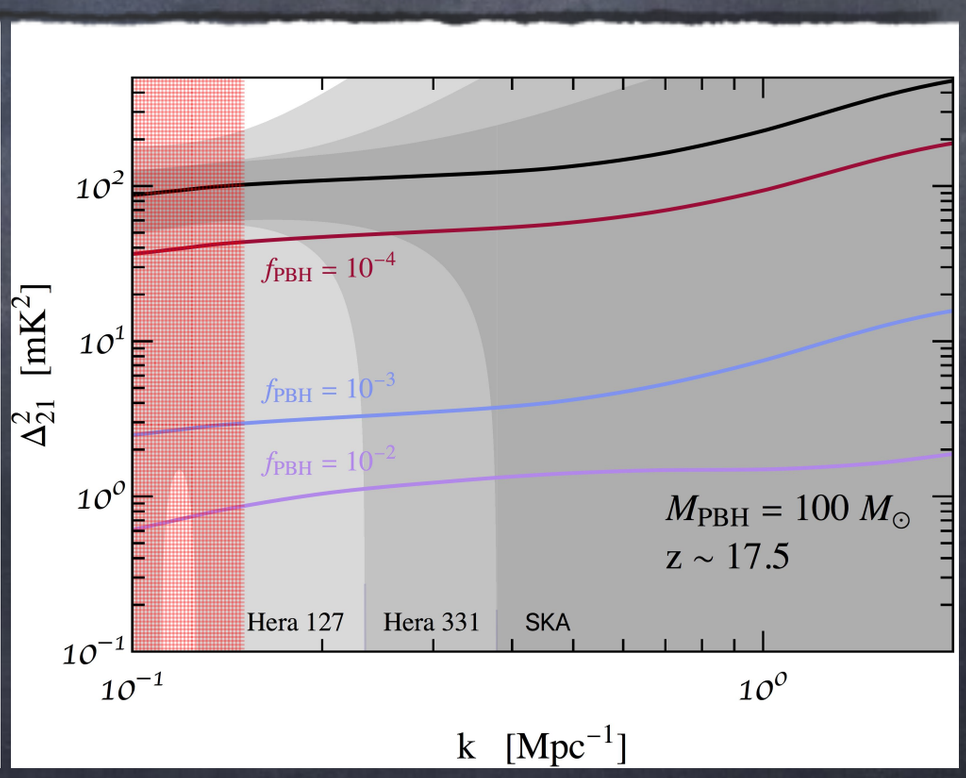
O. Mena, **SPR**, P. Villanueva-Domingo and S. J. Witte, *in preparation*

PBHs: 21cm power spectrum









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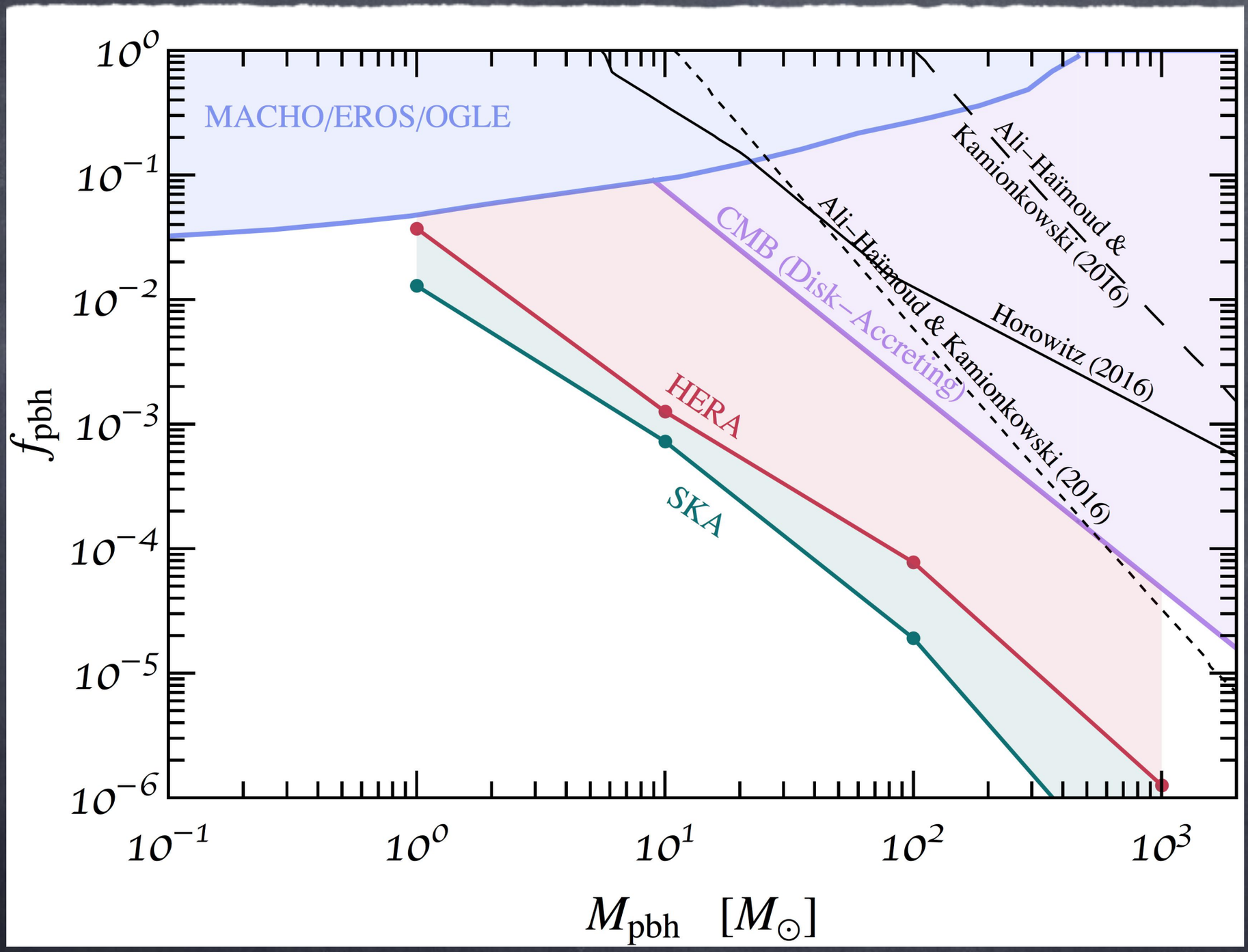
PBHs: Sensitivity



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Conclusions

21cm radio measurements will shed light on the cosmic dark ages

21cm radio experiments will be a powerful tool to learn about exotic energy injection mechanisms onto the IGM (PBHs, DM...)

Sensitivity to solar mass PBHs will be improved by up to 2 orders of magnitude with future interferometers (HERA, SKA)