



Osservatorio Astronomico di Trieste
Astronomical Observatory of Trieste



UNIVERSITÀ
DEGLI STUDI
DI TRIESTE



SISSA

Dark Photon Dark Matter in the Intergalactic Medium

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BiCoQ

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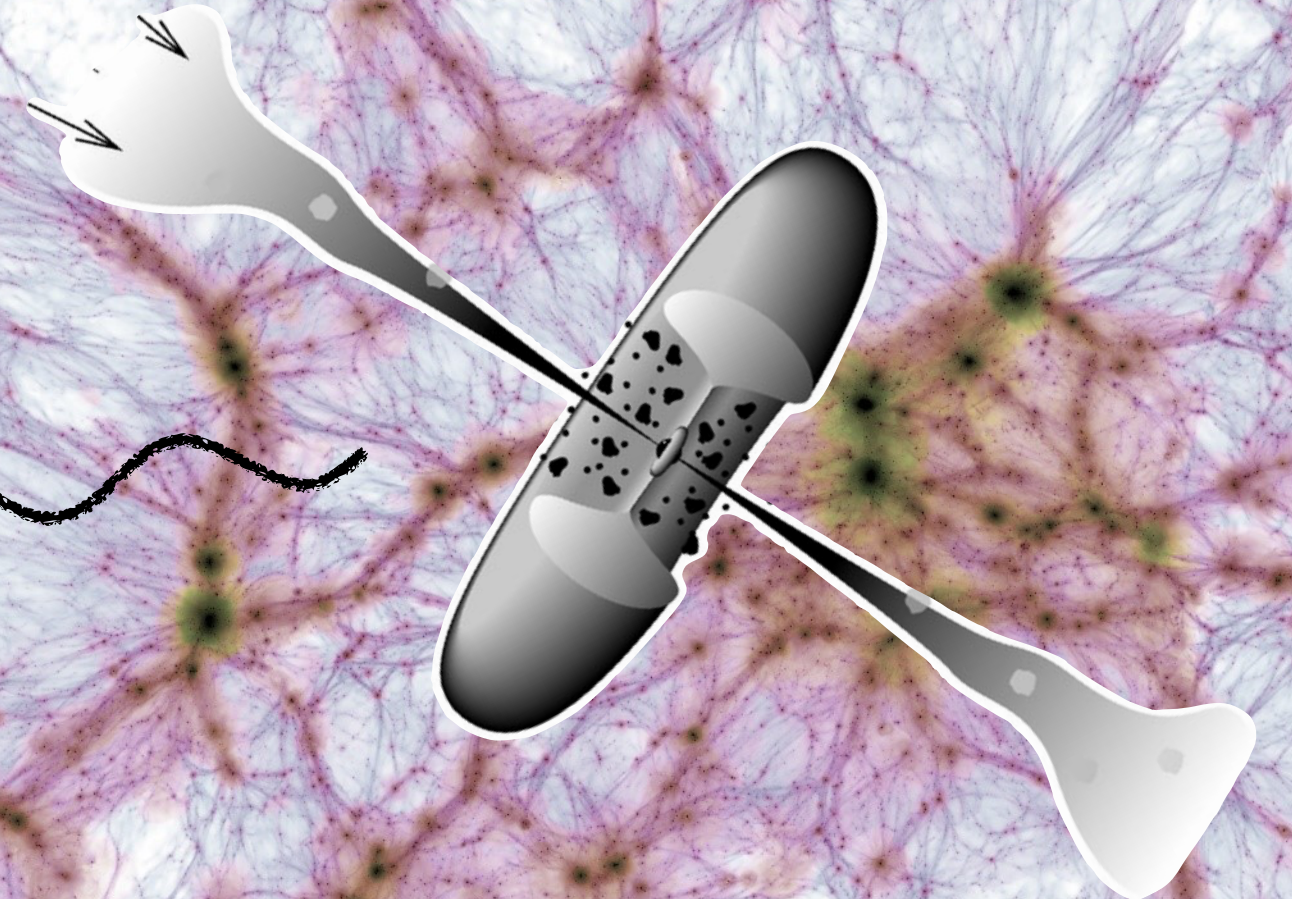
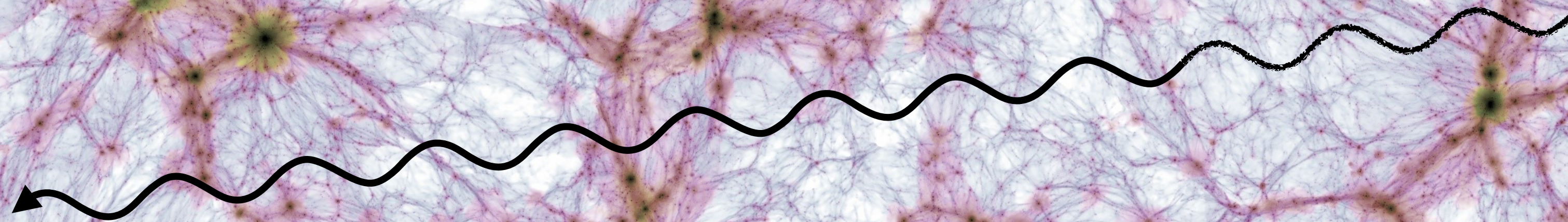
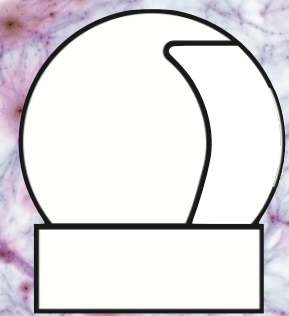
The Intergalactic Medium as a particle detector

DM detection experiments are limited to $m \gtrsim L_{\text{exp}}$
Cosmological probes can access ultra-light masses

The Intergalactic Medium is the largest detector
Just quiet hydrogen waiting to interact

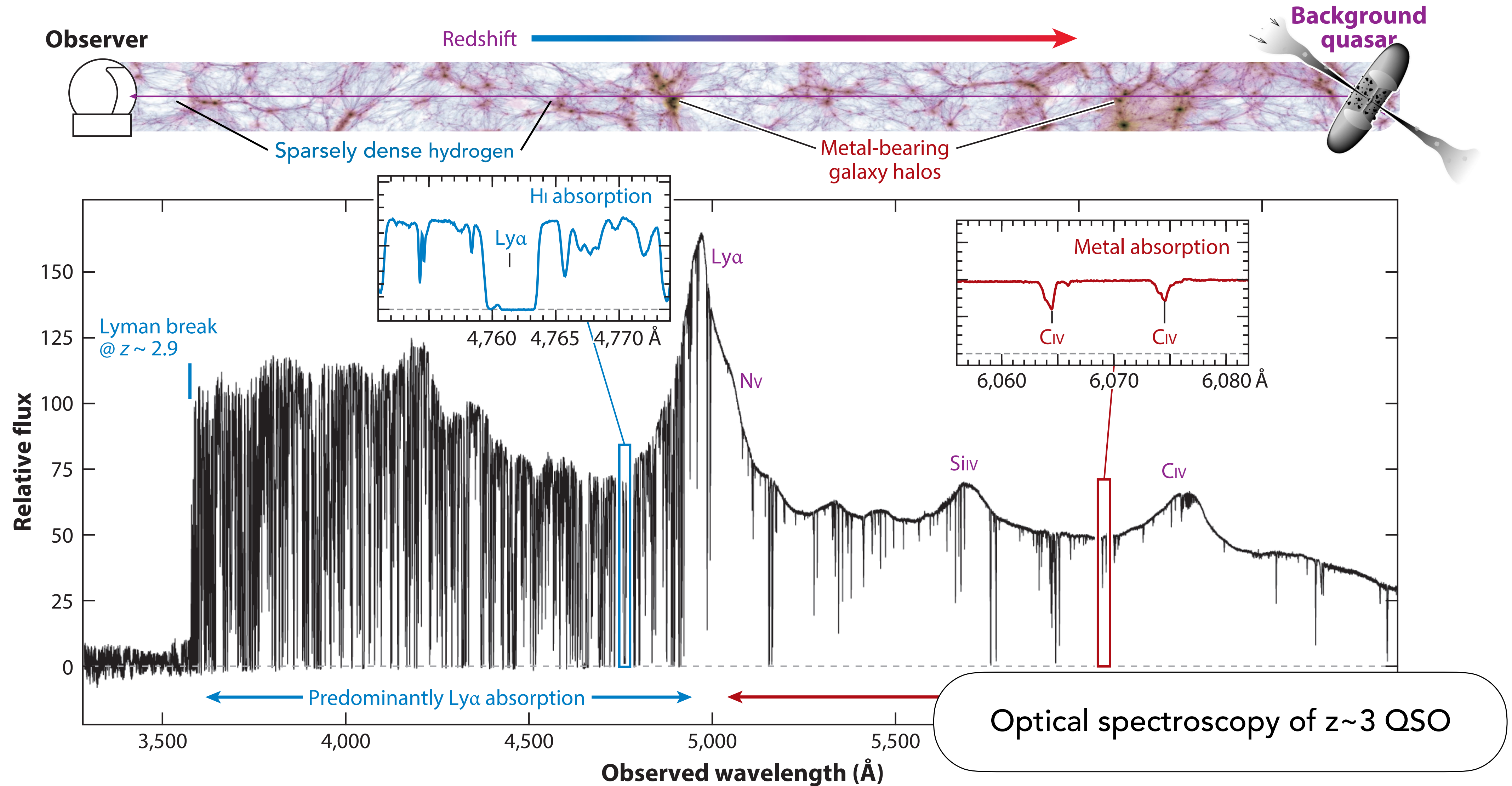
The Intergalactic Medium as a particle detector

A background light source is required to probe it

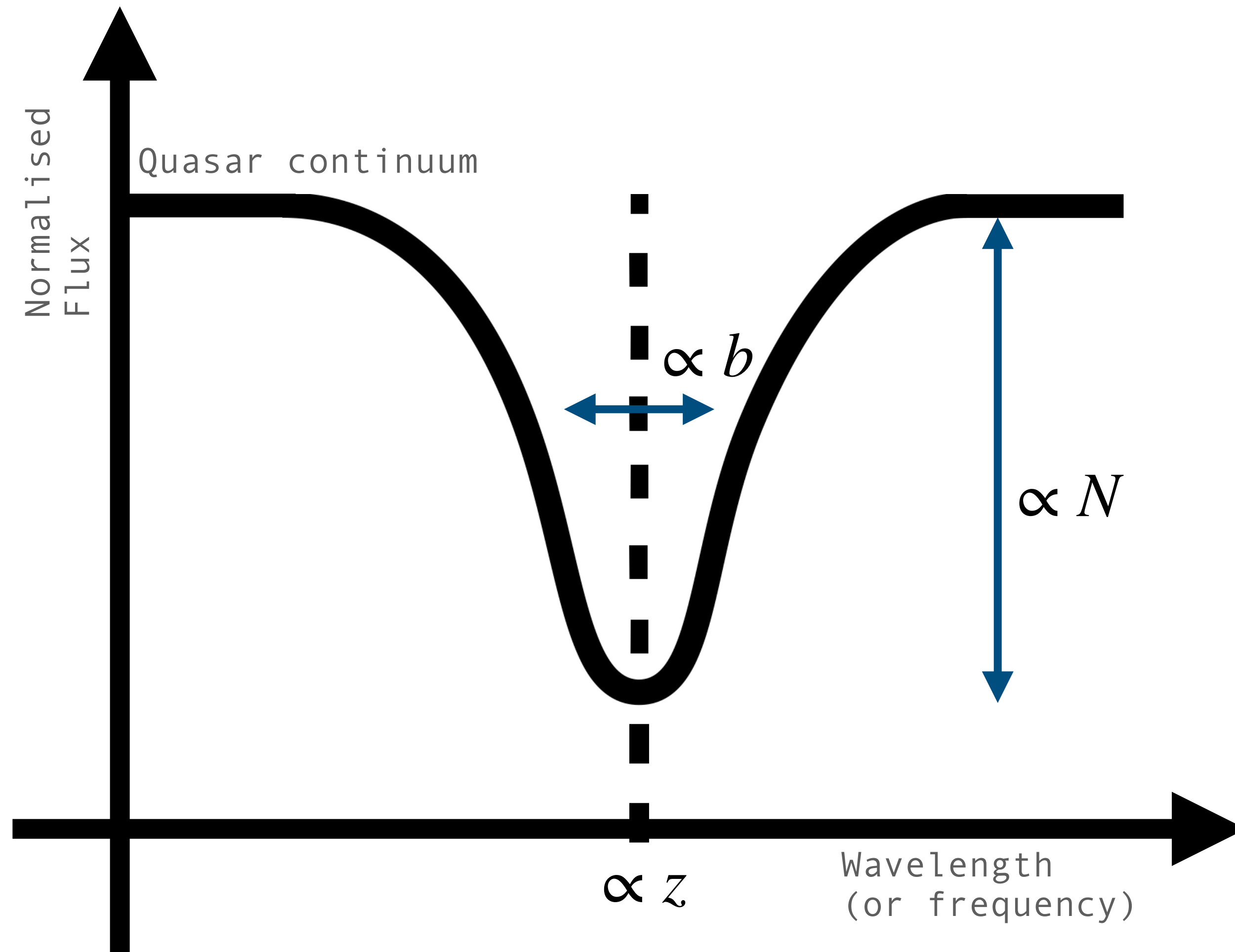


Bright distant quasars help us measure the IGM's physical properties

The Lyman Forest



Quasar absorption lines



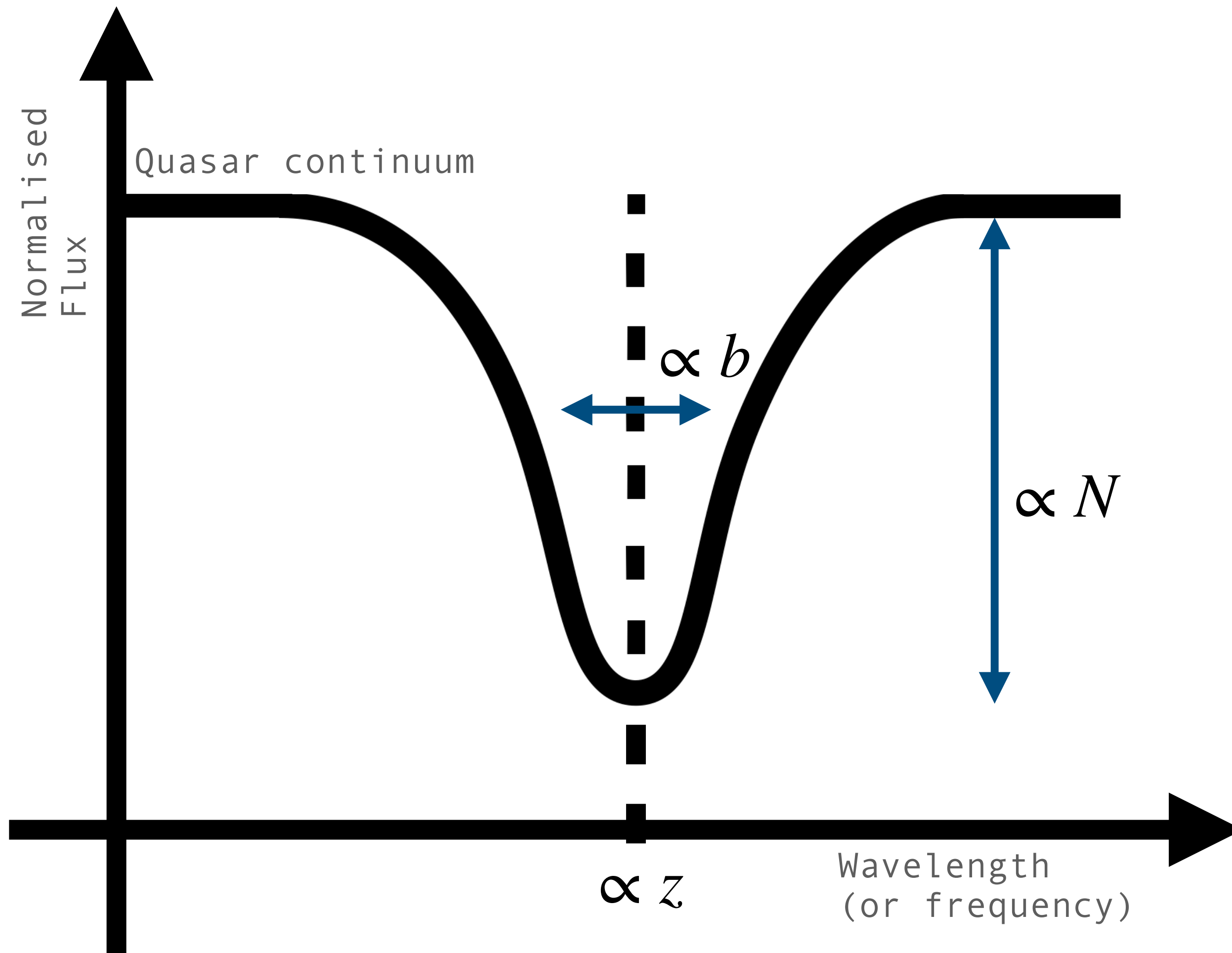
Doppler Parameter

$$b = \sqrt{\frac{2k_b T}{m}} + b_{turb}$$

Column Density

$$N = \int n dl$$

Quasar absorption lines



Doppler Parameter

$$b = \sqrt{\frac{2k_b T}{m}} + b_{turb}$$

Column Density

$$N = \int n dl$$

Lines are very sensitive to the IGM temperature

Some Dark Matter models have thermal effects on the cosmic web

(DP, PBH, axions, decaying or annihilating DM)

Can use absorption lines for fundamental physics

IGM temperature

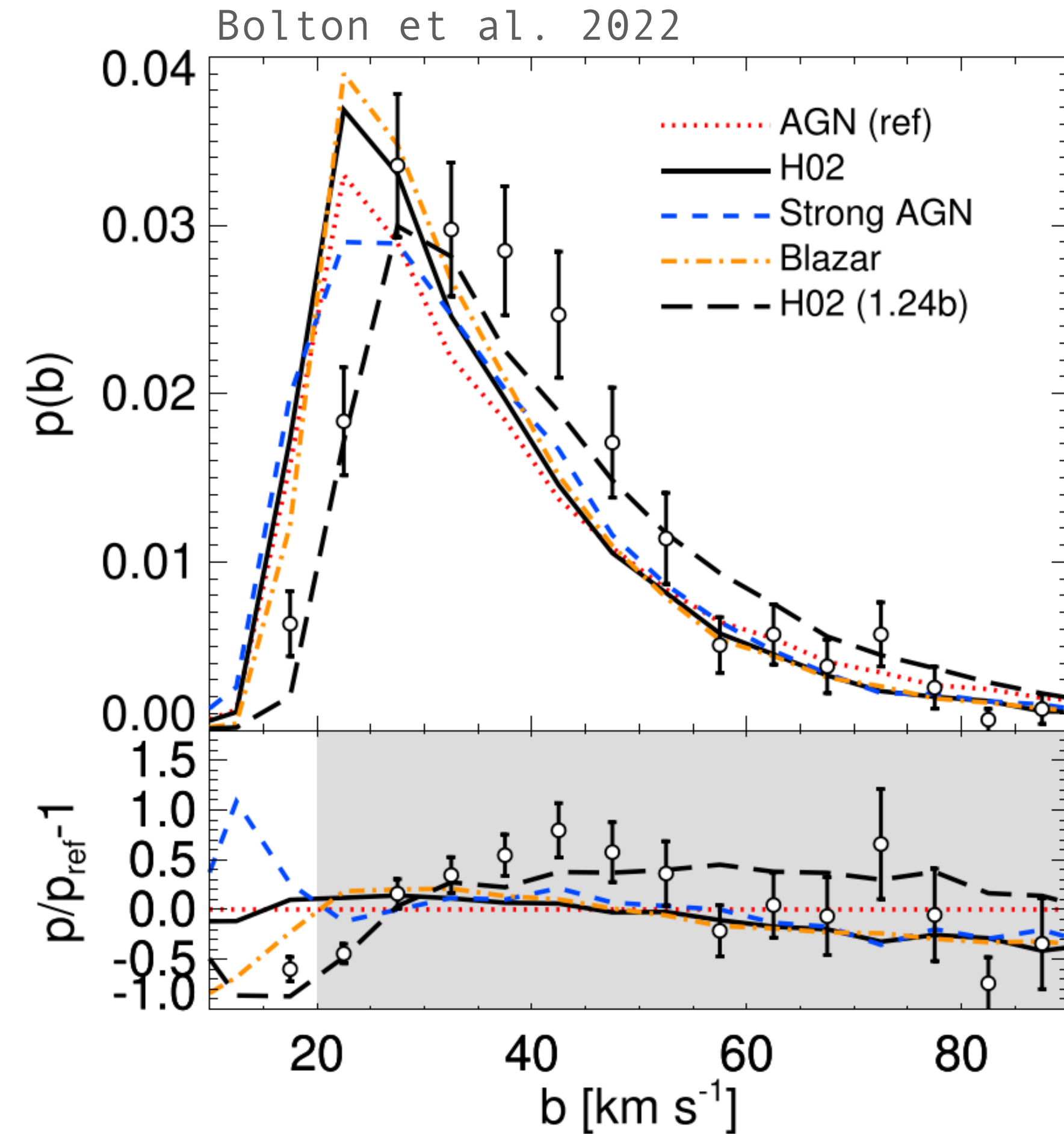
We can study the distribution of the doppler parameters to understand the temperature of the IGM

At redshift ~ 0.1

Simulations do not reproduce the observed distribution

Missing $\sim 6.9 eV$ per Baryon

Non-canonical heating required



(AGN feedback does not solve the discrepancy)

Standard Model Extensions

See Fabbrichesi et al. 2020; Bolton et al. 2022 (b)

Extra U(1) symmetry

$$A'_\mu$$

DARK PHOTON

$$\mathcal{L}_{\gamma A'} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{4}(F'_{\mu\nu})^2 - \frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m_{A'}^2(A'_\mu)^2$$

	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
mass	$\approx 2.16 \text{ MeV}/c^2$	$\approx 1.273 \text{ GeV}/c^2$	$\approx 172.57 \text{ GeV}/c^2$	0	$\approx 125.2 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	u up	c charm	t top	g gluon	H higgs
	$\approx 4.7 \text{ MeV}/c^2$	$\approx 93.5 \text{ MeV}/c^2$	$\approx 4.183 \text{ GeV}/c^2$	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	d down	s strange	b bottom	\gamma photon	
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.77693 \text{ GeV}/c^2$	$\approx 91.188 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	e electron	\mu muon	\tau tau	Z Z boson	
	$< 0.8 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.3692 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	\nu_e electron neutrino	\nu_{\mu} muon neutrino	\nu_{\tau} tau neutrino	W W boson	

QUARKS

LEPTONS

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS



Dark Photon Dark Matter A'

See Fabbrichesi et al. 2020; Bolton et al. 2022 (b)

γ gains an effective mass in ionised medium

$$m_\gamma^2(z, \vec{x}) \propto n_e(z, \vec{x})$$

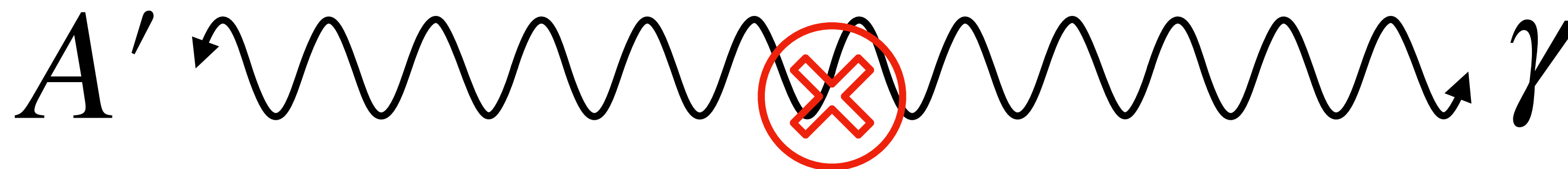
Where

$$m_\gamma^2(z, \vec{x}) = m_{A'}^2$$

oscillations $A' \leftrightarrow \gamma$ resonantly enhanced

$$P_{A' \rightarrow \gamma}(m_{A'}, \epsilon)$$

DARK SECTOR



STANDARD MODEL

three generations of matter (fermions)			interactions / force carriers (bosons)		
	I	II	III		
mass	$\approx 2.16 \text{ MeV}/c^2$	$\approx 1.273 \text{ GeV}/c^2$	$\approx 172.57 \text{ GeV}/c^2$	0	$\approx 125.2 \text{ GeV}/c^2$
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	u up	c charm	t top	g gluon	H higgs
	d down	s strange	b bottom	\gamma photon	
	e electron	\mu muon	\tau tau	Z Z boson	
	\nu_e electron neutrino	\nu_{\mu} muon neutrino	\nu_{\tau} tau neutrino	W W boson	
	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.77693 \text{ GeV}/c^2$	$\approx 91.188 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	$< 0.8 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.3692 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	

QUARKS (left side of quark section)
LEPTONS (left side of lepton section)
GAUGE BOSONS VECTOR BOSONS (right side of gauge boson section)
SCALAR BOSONS (right side of scalar boson section)

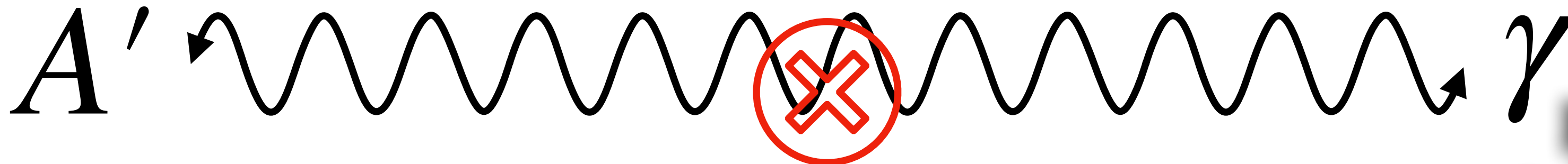
Dark Photon Dark Matter A'

See Fabbrichesi et al. 2020; Bolton et al. 2022

$$m_\gamma^2(z, \vec{x}) = m_{A'}^2$$

$$P_{A' \rightarrow \gamma}(m_{A'}, \epsilon)$$

DARK SECTOR

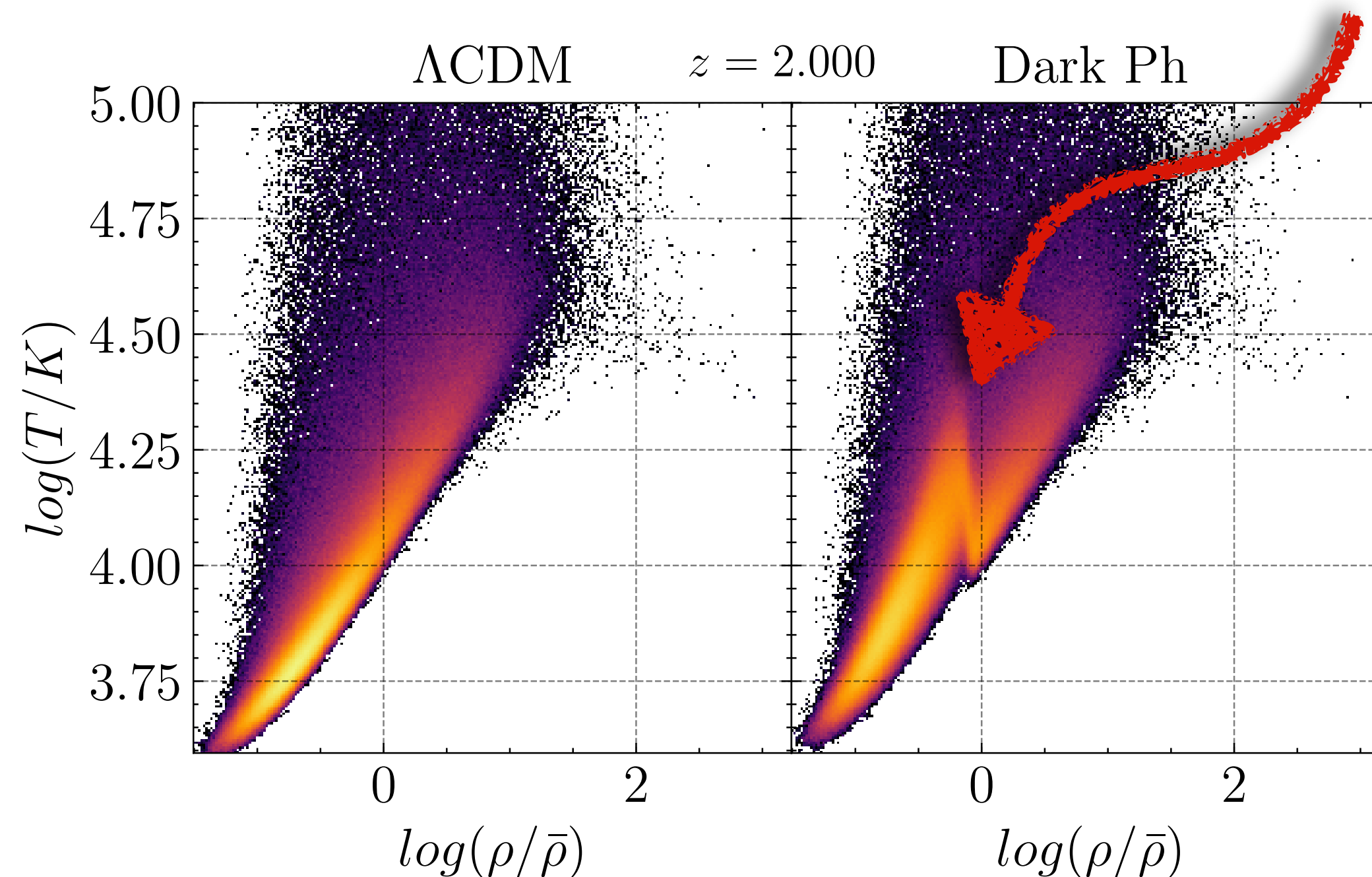


STANDARD MODEL

$$m_{A'} \sim 10^{-15} - 10^{-13} \text{ eV}$$

Free-free absorption by the ionised IGM

Low energy radio photons

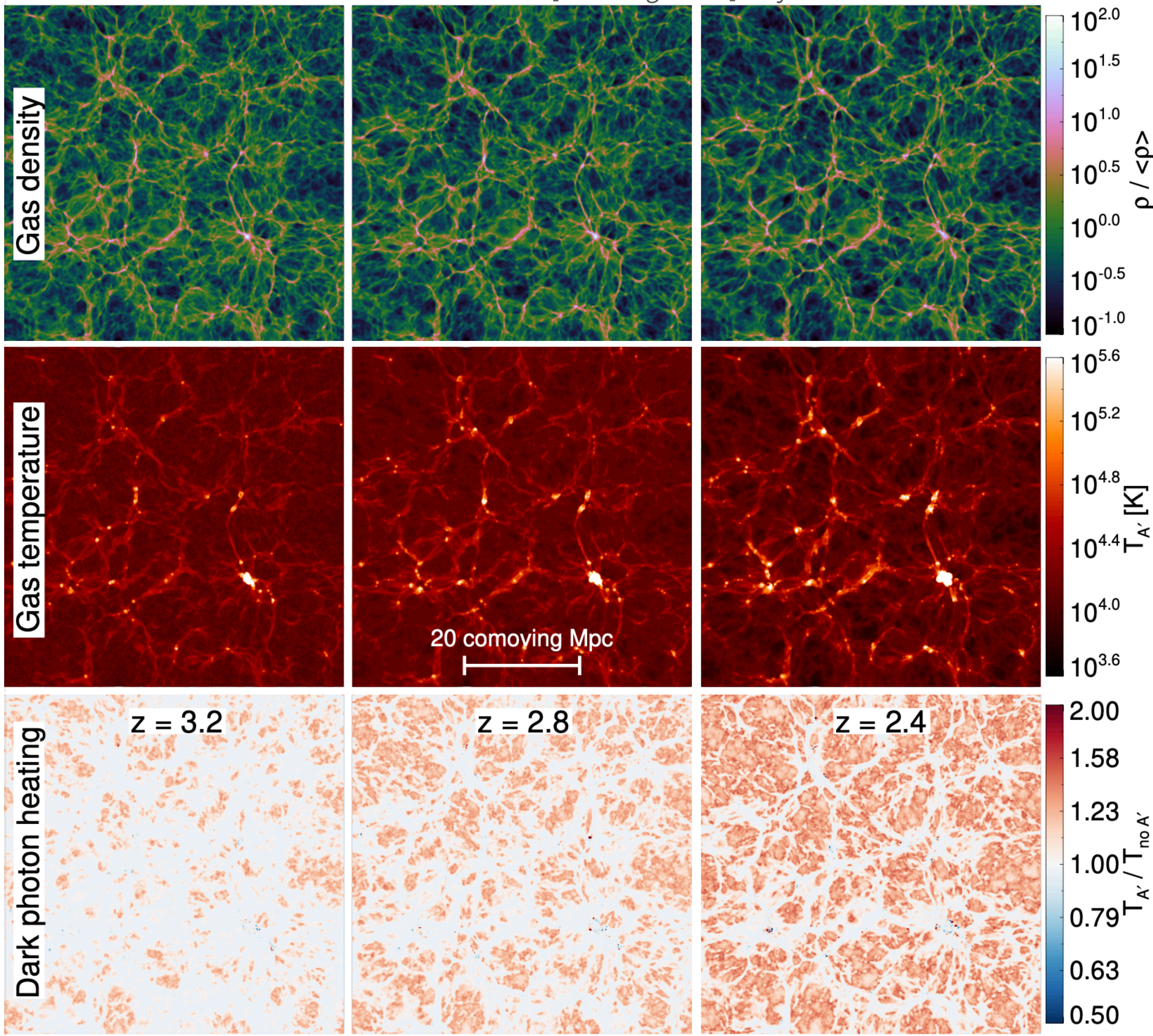


Net energy injection

$$E_{A' \rightarrow \gamma}$$

in the IGM at a specific density

Modified Sherwood Simulations by J. Bolton (P-Gadget-3)



Simulating A' in the IGM

Hydrodynamical Cosmological simulations of the IGM (Sherwood Suite)

Modified to include A' heating

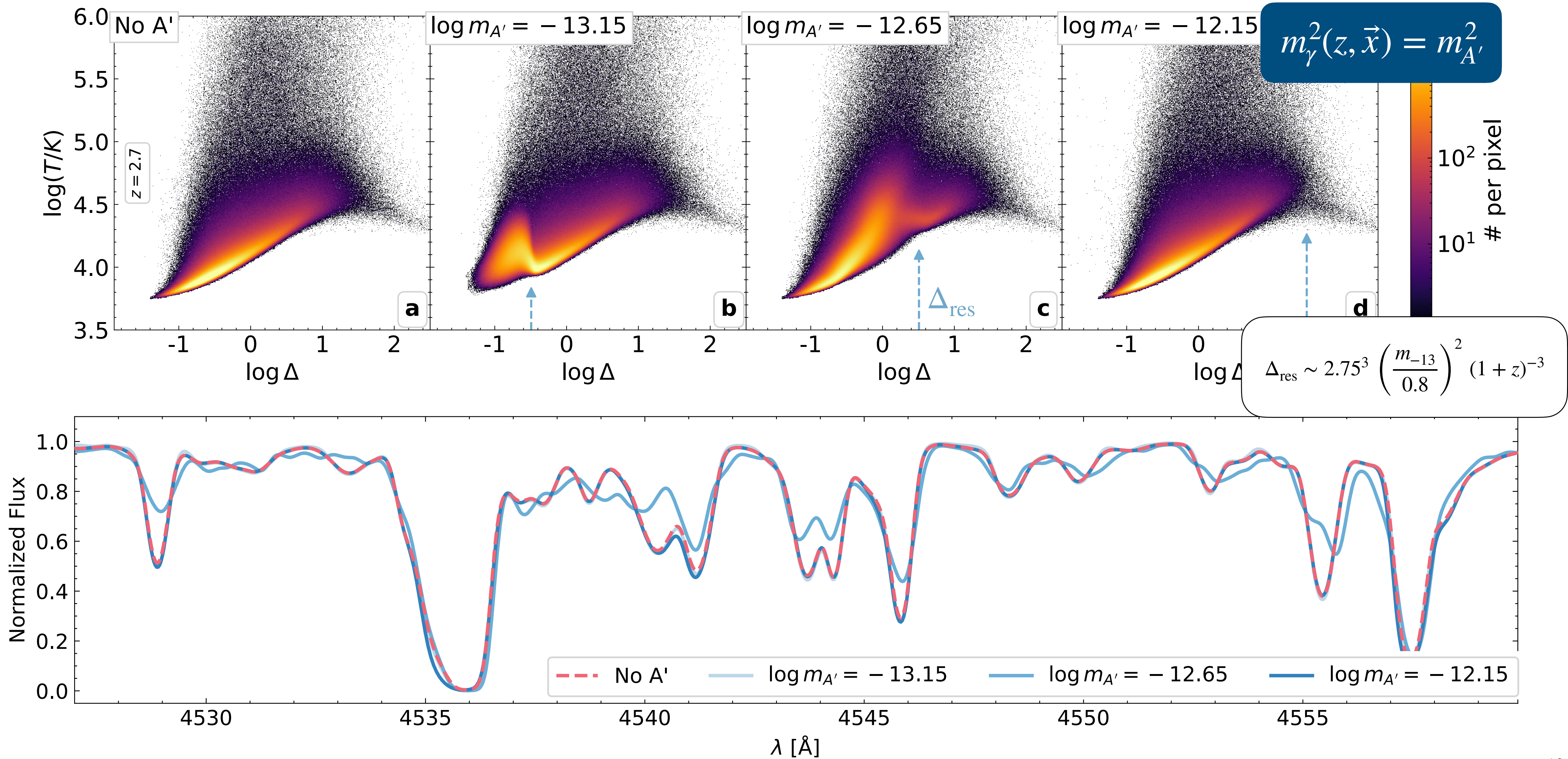
when:

$$m_{A'}^2 = m_\gamma^2 \propto n_e$$

$$E_{A' \rightarrow \gamma}(m'_{A'}, \epsilon, z)$$

energy directly added to the gas particles

What is the effect on the forest?



Transformed Flux Probability Distribution

See Rorai et al. 2017

From an idea of Rorai et al. 2017

— Regulate normalisation

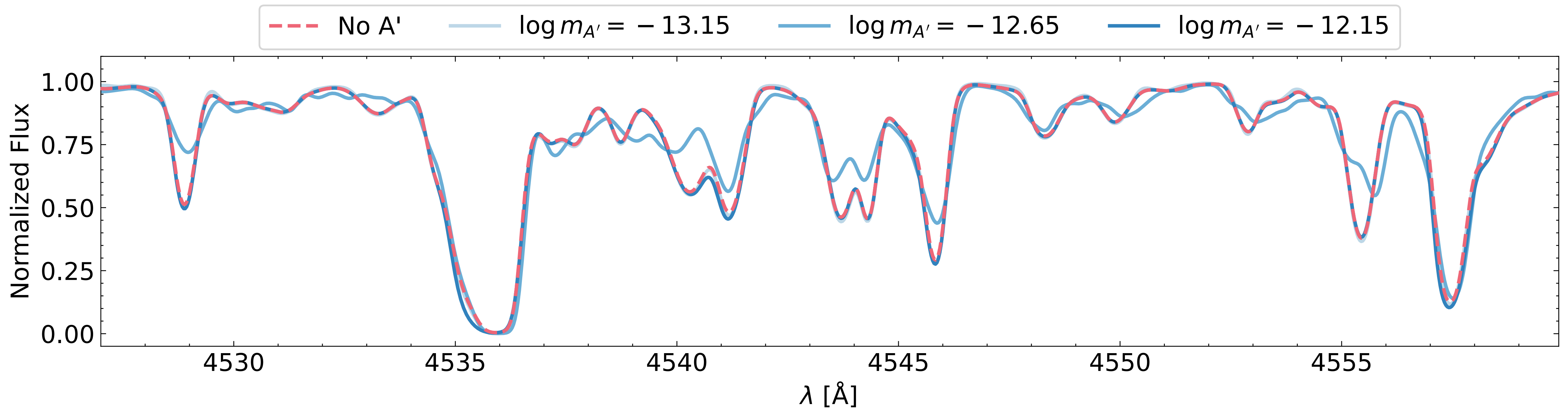
— Transform (non-linearly) the flux

Enhance the differences close to the continuum

Avoid continuum placement bias

$$F_r = F / F_{95th}$$

$$F_A = |F_r|^A$$



Transformed Flux Probability Distribution

See Rorai et al. 2017

From an idea of Rorai et al. 2017

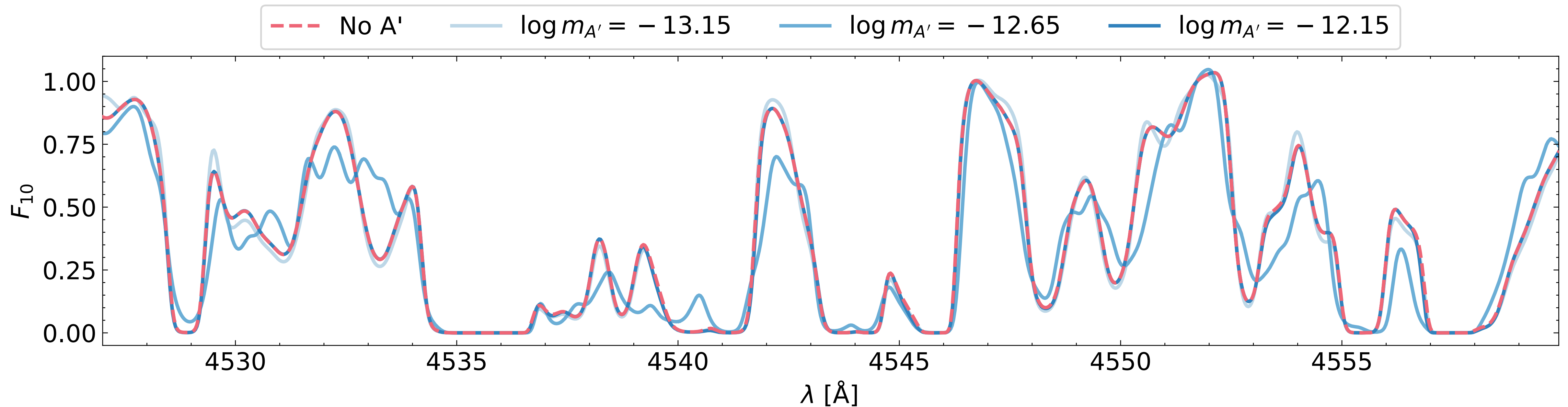
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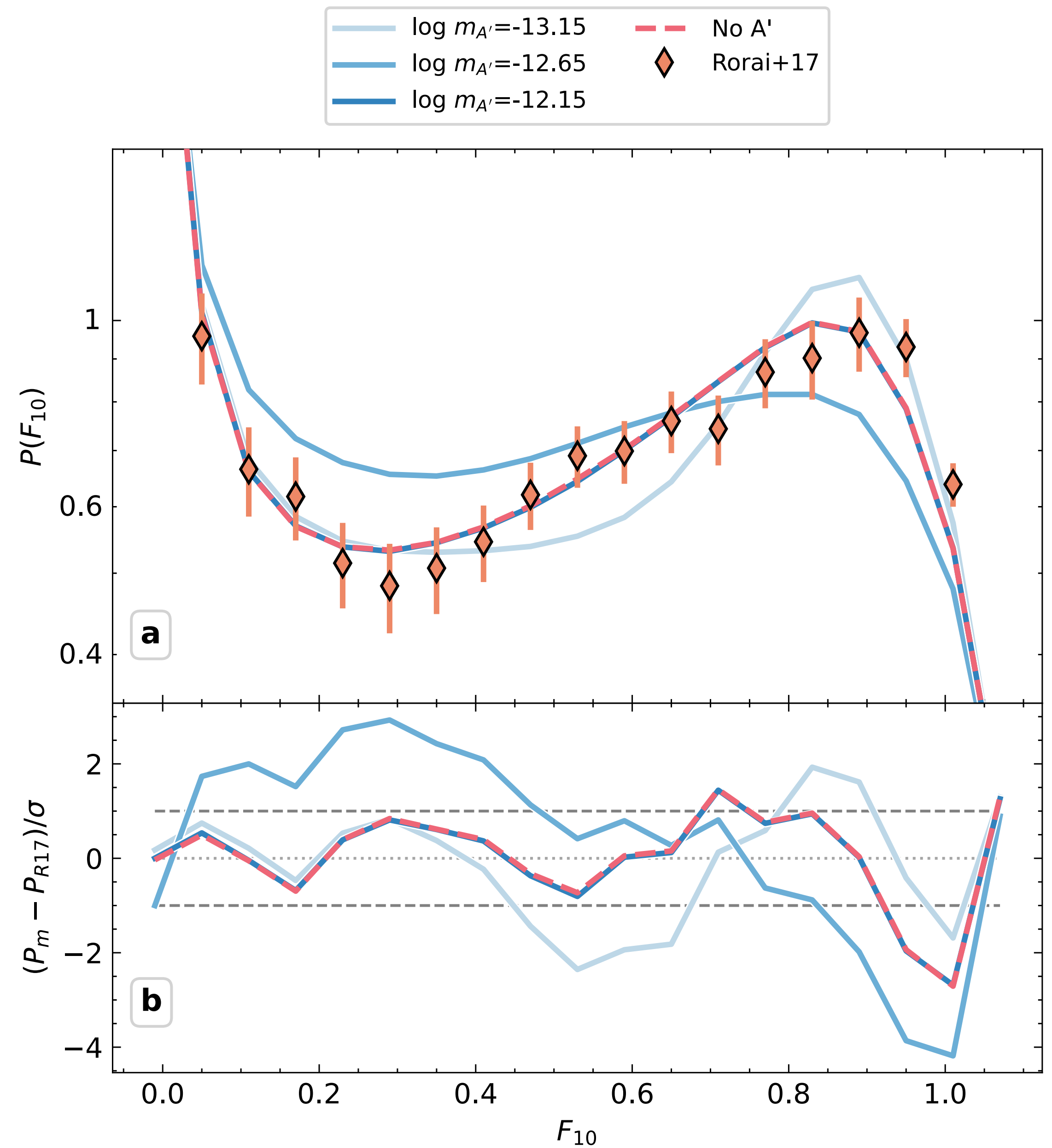
Transformed Flux Probability Distribution

See Rorai et al. 2017

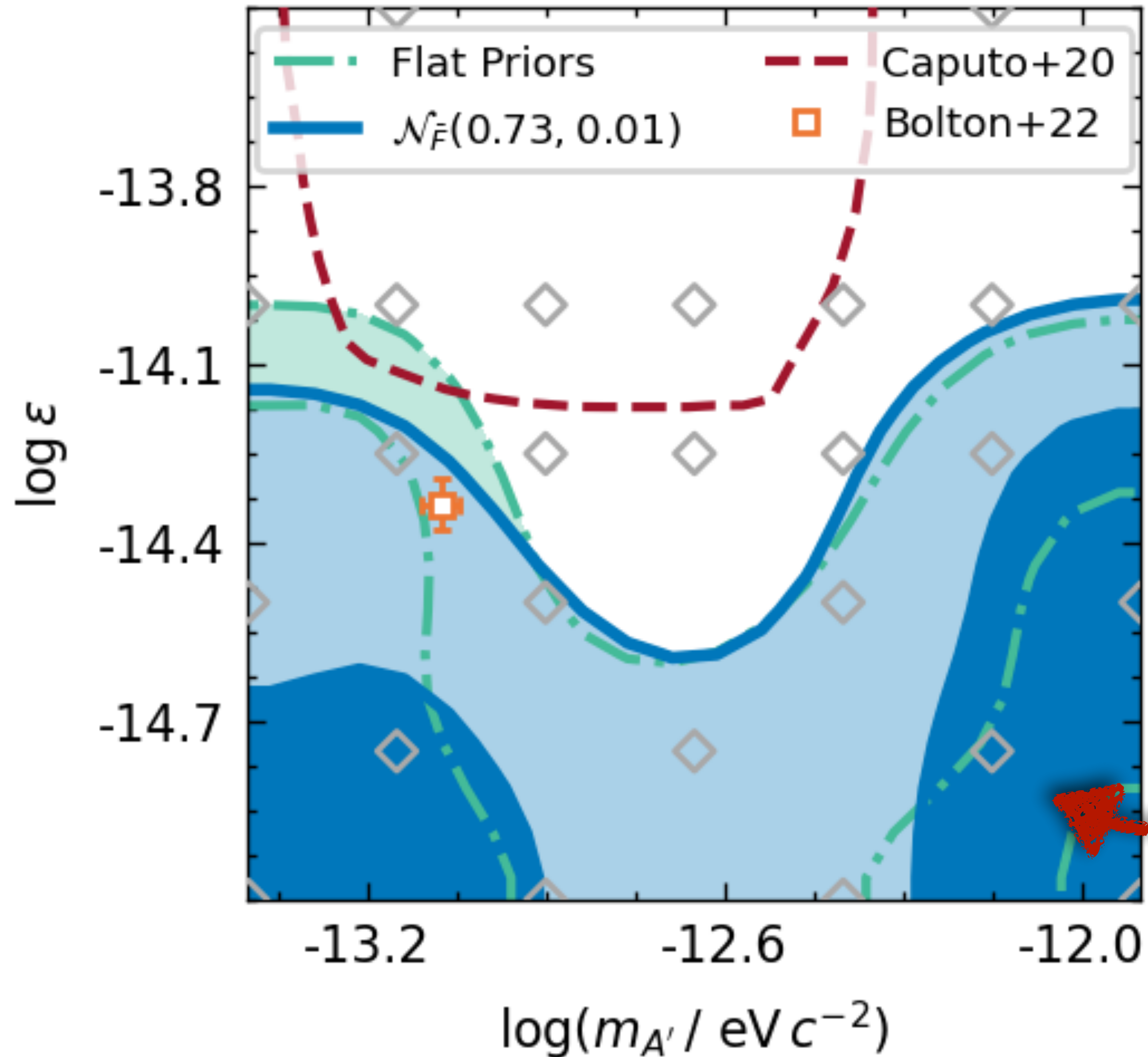
PDF of regulated and transformed flux

Sensible to slight differences in T

Can discern between A' models



Posterior analysis



Bayesian exploration of
dark photon parameter space

Preferred dark photons with

Weak mixing

Small energy injection

Not different from standard ΛCDM

Bounds

A' is not required to explain $z \sim 2.7$ data

But

we can use the data to **constrain A' models**

Likelihood ratio analysis
Profiling over mean flux

Ruled out at 95% C.L.

Model proposed to solve $z \sim 0$ tension

Still allowed!!

