The Broad Impact of Low Frequency Observing
Bologna 19.-23.06.2017

EoR SIMULATIONS AND 21 CM ABSORPTION

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21CM LINE OBSERVATIONS: WHAT?

✧ *Tomography:* topology of HII regions; information on sources; when reionization occurred

e.g. Tozzi+ 2000; BC & Madau 2003; Furlanetto, Sokasian, Hernquist 2004;
Mellema+ 2006; Valdes+ 2006; Santos+ 2008; Baek+ 2009;
Geil & Wyithe 2009; Zaroubi+ 2012; Malloy & Lidz 2013

✧ *δT_b fluctuations and Power Spectrum:* statistical estimates

e.g. Madau, Meiksin & Rees 1997; Shaver+ 1999; Tozzi+ 2000; BC & Madau 2003;
Furlanetto, Sokasian, Hernquist 2004; Mellema+ 2006; Valdes+ 2006; Datta+ 2008;
Pritchard & Loeb 2008; Santos+ 2008; Baek+ 2009; Geil & Wyithe 2009; Patil+ 2014

✧ *Cross-correlation:* information on typical dimension of HII regions

e.g. Salvaterra+ 2005; Lidz+ 2009; Jelic+ 2010; Wierma+ 2013
Fernandez+2013; Vrbanec+ 2016; Hutter+ 2016; Sobacchi+ 2016

✧ *21cm forest:* information on HI along the l.o.s.

e.g. Carilli, Gnedin & Owen 2002; Furlanetto 2006;
Xu+ 2009; Mack & Wyithe 2011; Meiksin 2011;
Xu, Ferrara & Chen 2011; BC+ 2013; Vasiliev & Shchekinov 2012;
Ewall-Wice at al. 2014; BC+ 2015; Semelin 2015

Modelling of cosmic reionization

✧ Model of structure formation
(gas distribution & source type and location)

Semi-analytic

$$M\frac{dn}{dM} = \left(\frac{2}{\pi}\right)^{1/2} \frac{\rho_0}{M}\upsilon_c e^{-\upsilon_c^2/2}$$

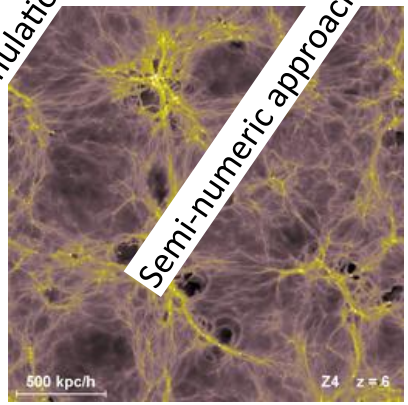
$$\frac{M}{dt}$$

$$t_{cool} < t_{dyn}$$

...

Hydrodynamic simulations

Semi-numeric approach



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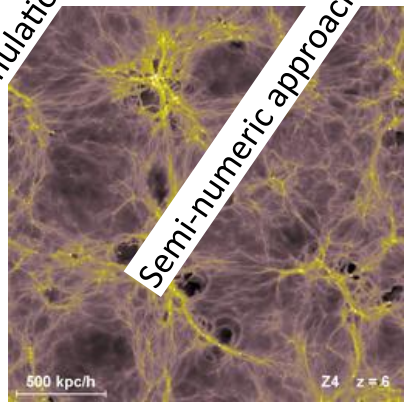
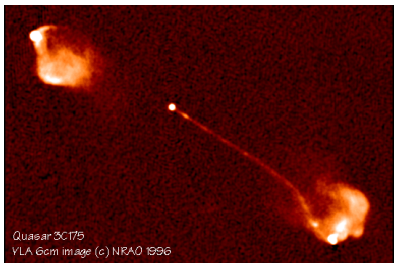


✧ Properties of the sources of ionizing radiation

Stellar type

Black holes; X-ray binaries



DM annihilation/decay

light dark matter

neutralinos

gravitinos

sterile neutrinos

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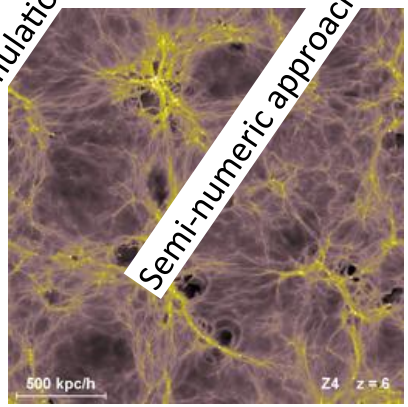

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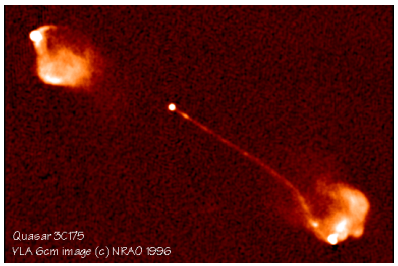

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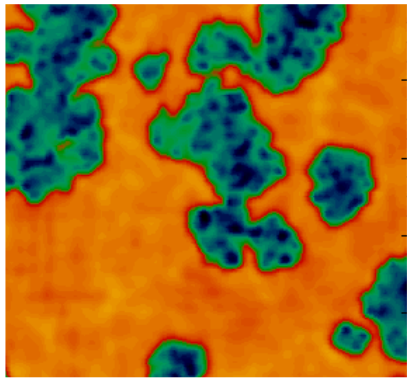
✧ Evolution of ionized regions



MODELLING OF COSMIC REIONIZATION

Model of structure formation

BC+ 2012; Eide+ in prep

Hydrodynamic simulations

L [Mpc/h com.]	Particles	Mgas [Msun/h]
533	2×3200^3	5.7×10^7
100	2×1792^3	2×10^6
35.12	2×512^3	4.15×10^6
8.78	2×256^3	6.48×10^4
4.39	2×256^3	8.11×10^3
2.20	2×256^3	1.01×10^3

MODELLING OF COSMIC REIONIZATION

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Model of structure formation

MassiveBlack II (Khandai+ 2015)

Hydrodynamic simulations

MBII

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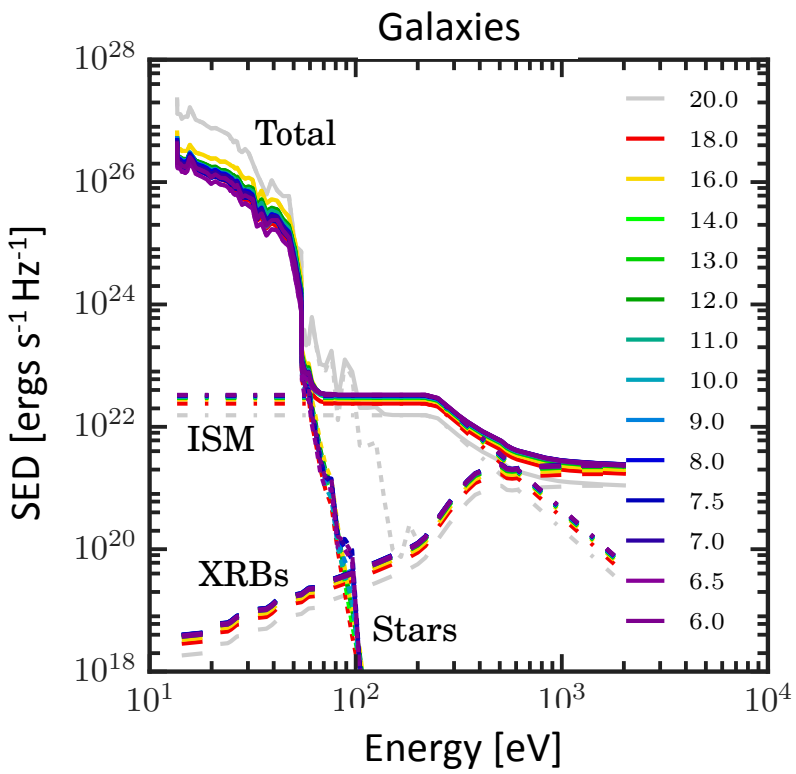
Properties of the sources of ionizing radiation

Stars, BHs, XRBs, ISM



+ BHs

MODELLING OF COSMIC REIONIZATION

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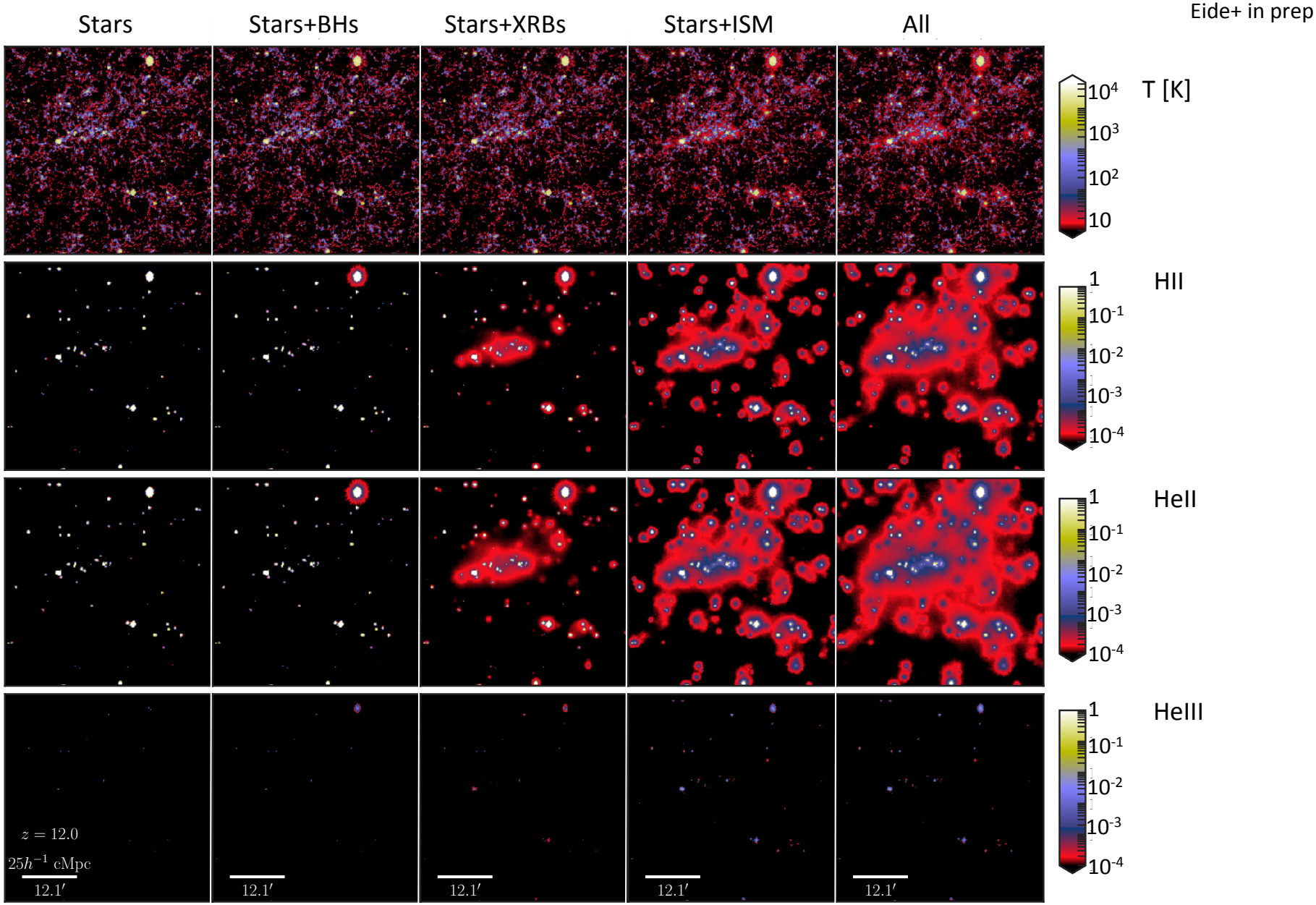
Evolution of ionized regions (3D radiative transfer approach)

CRASH

BC+ 2001; Maselli, Ferrara, BC 2003; Maselli, BC, Kanekar 2009; Pierleoni, Maselli, BC 2009; Partl+ 2011; Graziani, Maselli, BC 2013; Hariharan+ 2017; Graziani, BC, Ferrara in prep; Glatzle, Graziani, BC in prep

UV, x-rays, Lyα photons in H, He, metals, dust
radiation from recombination, background

Modelling of cosmic reionization



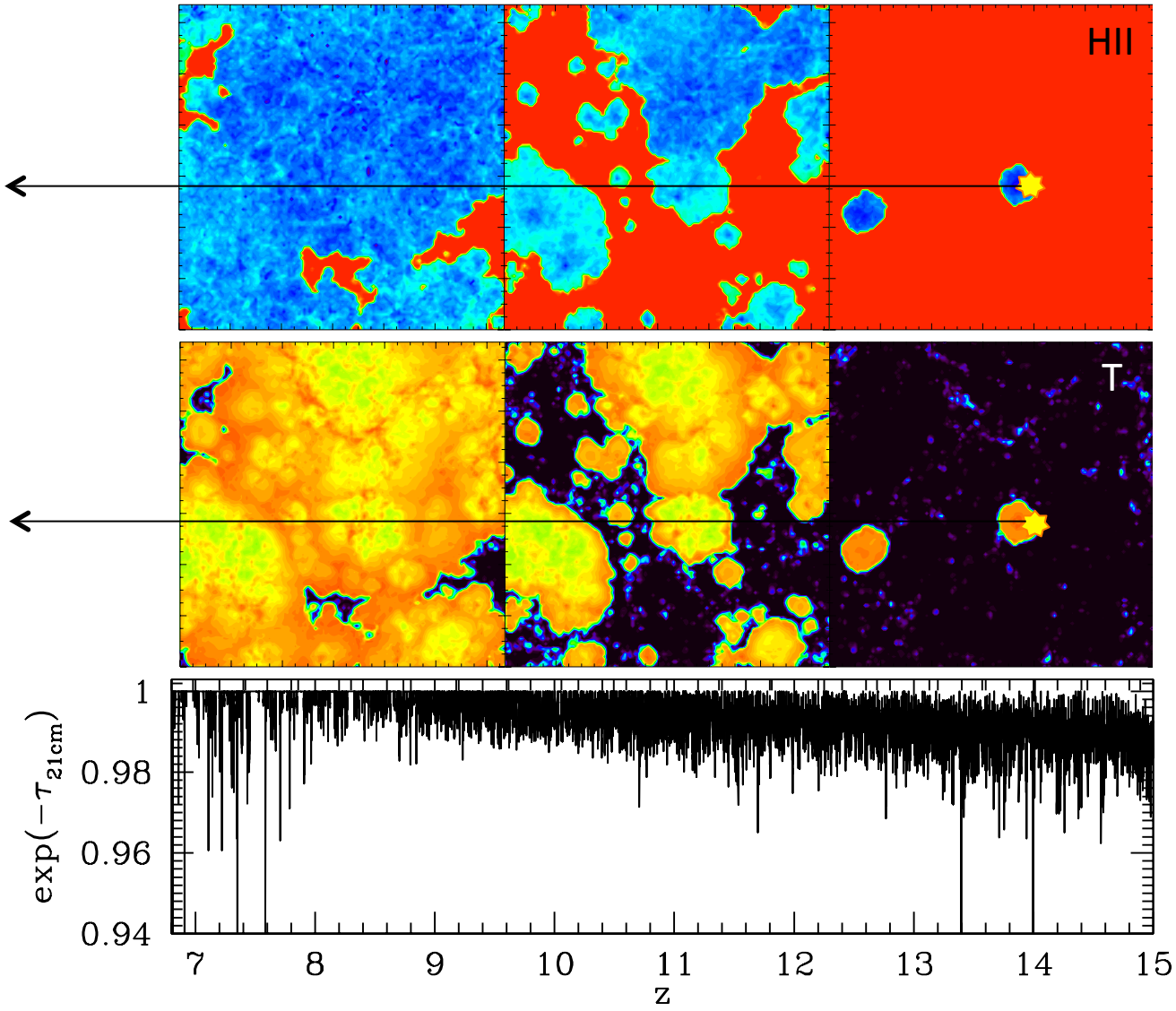
Eide+ in prep

THE 21CM FOREST

BC+ 2013, 2015

Hydrodynamic simulations + CRASH 3D radiative tranfer

$$\tau_{21cm} \propto x_{HI}(1+\delta)\frac{1}{T_s}$$

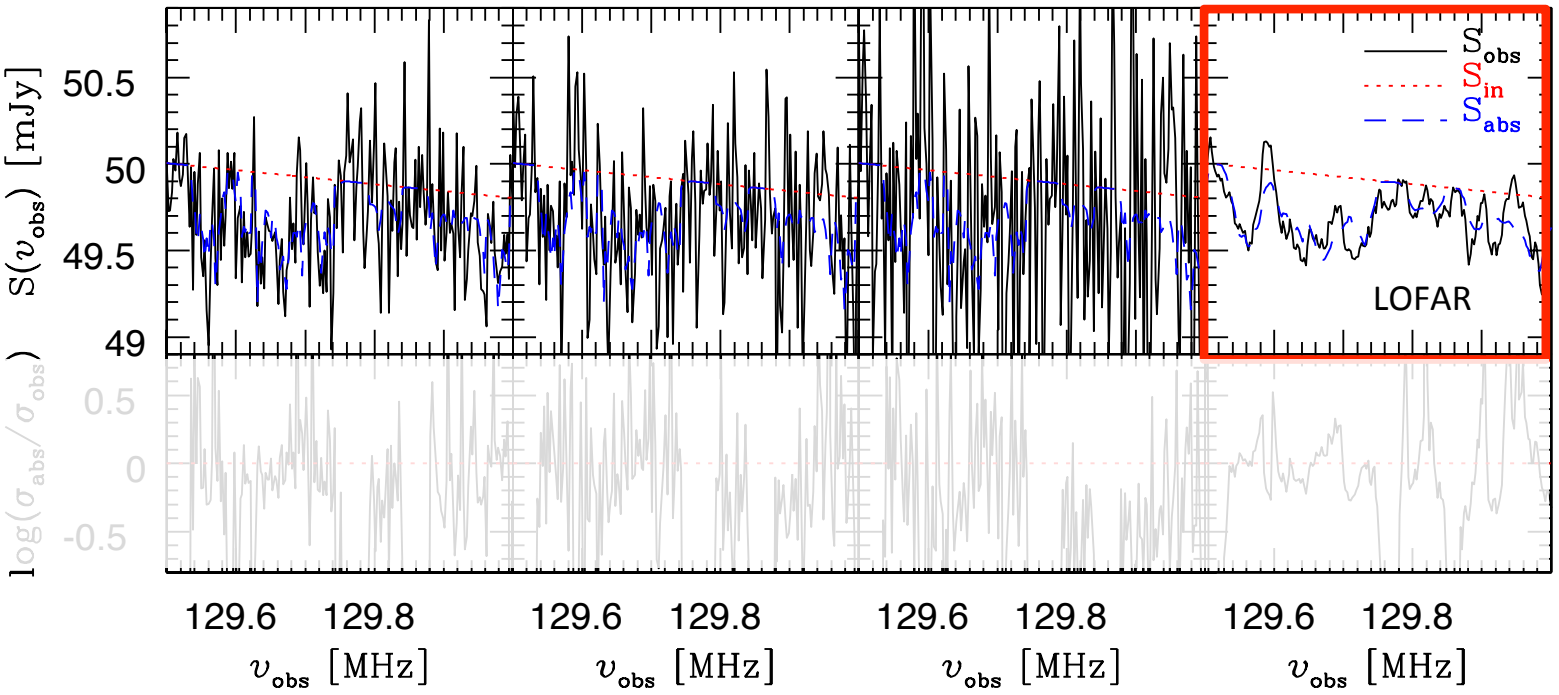


THE 21 CM FOREST WITH QSOS

BC+ 2013, 2015

z=10, S=50 mJy, α=1.05

BW=10 kHz, t=1000 h



QSO spectrum

QSO spectrum
+
IGM absorption

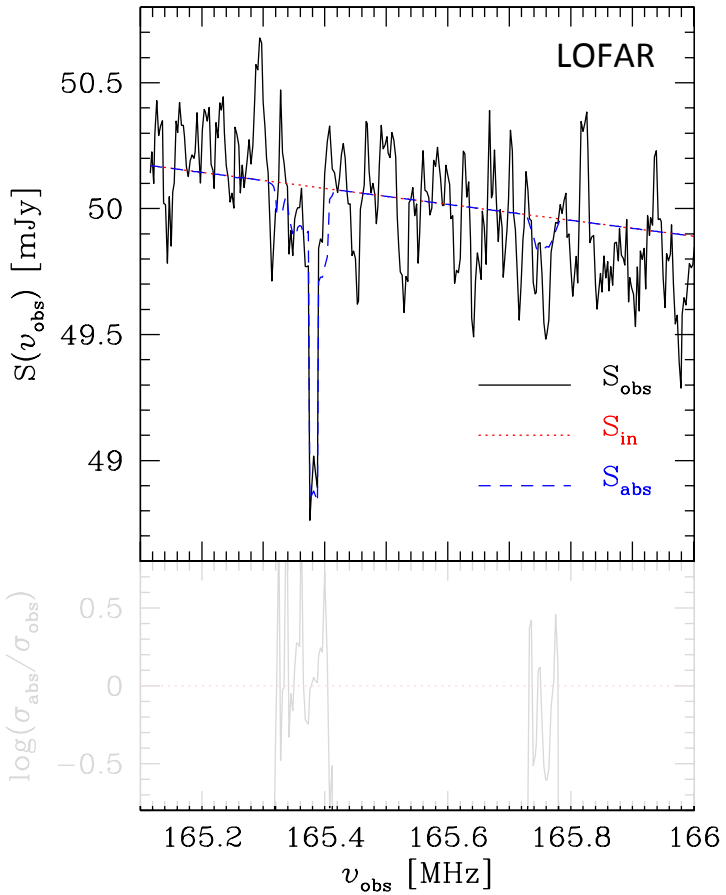
Observed spectrum

The 21 cm forest with QSOs

BC+ 2013, 2015

z=7.6, S=50 mJy, α=1.05

BW=5 kHz, t=1000 h



QSO spectrum

QSO spectrum
+
IGM absorption

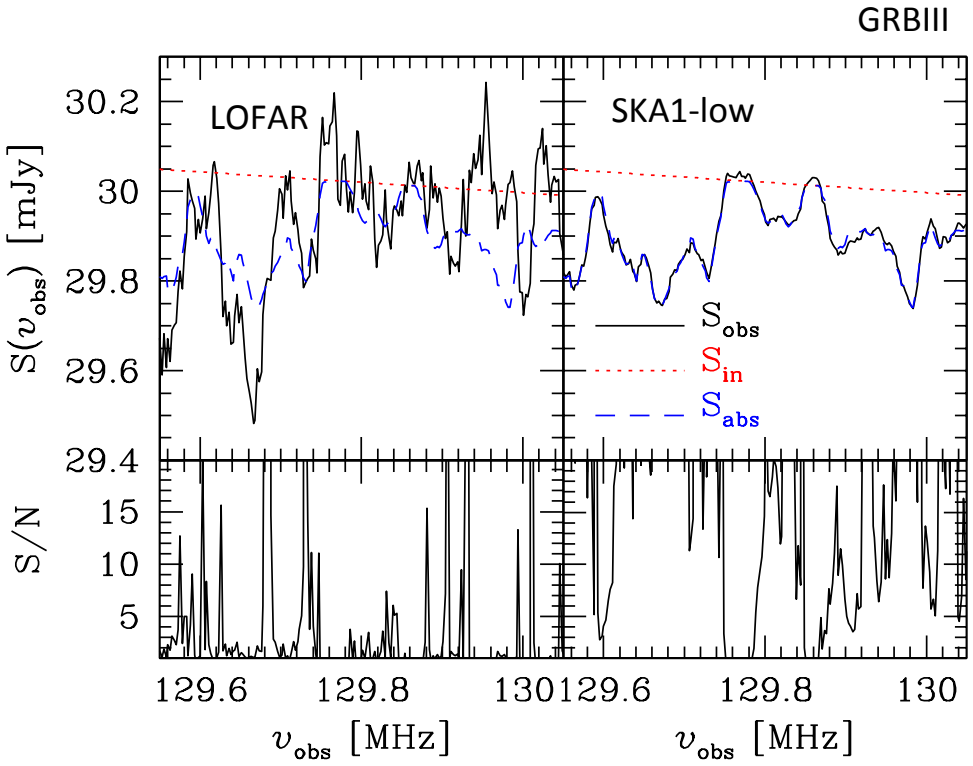
Observed spectrum

The 21cm forest with GRBs

BC+ 2013, 2015

z=10, S=30 mJy, α=0.6

BW=10 kHz, t=1000 h



GRB spectrum

GRB spectrum
+
IGM absorption

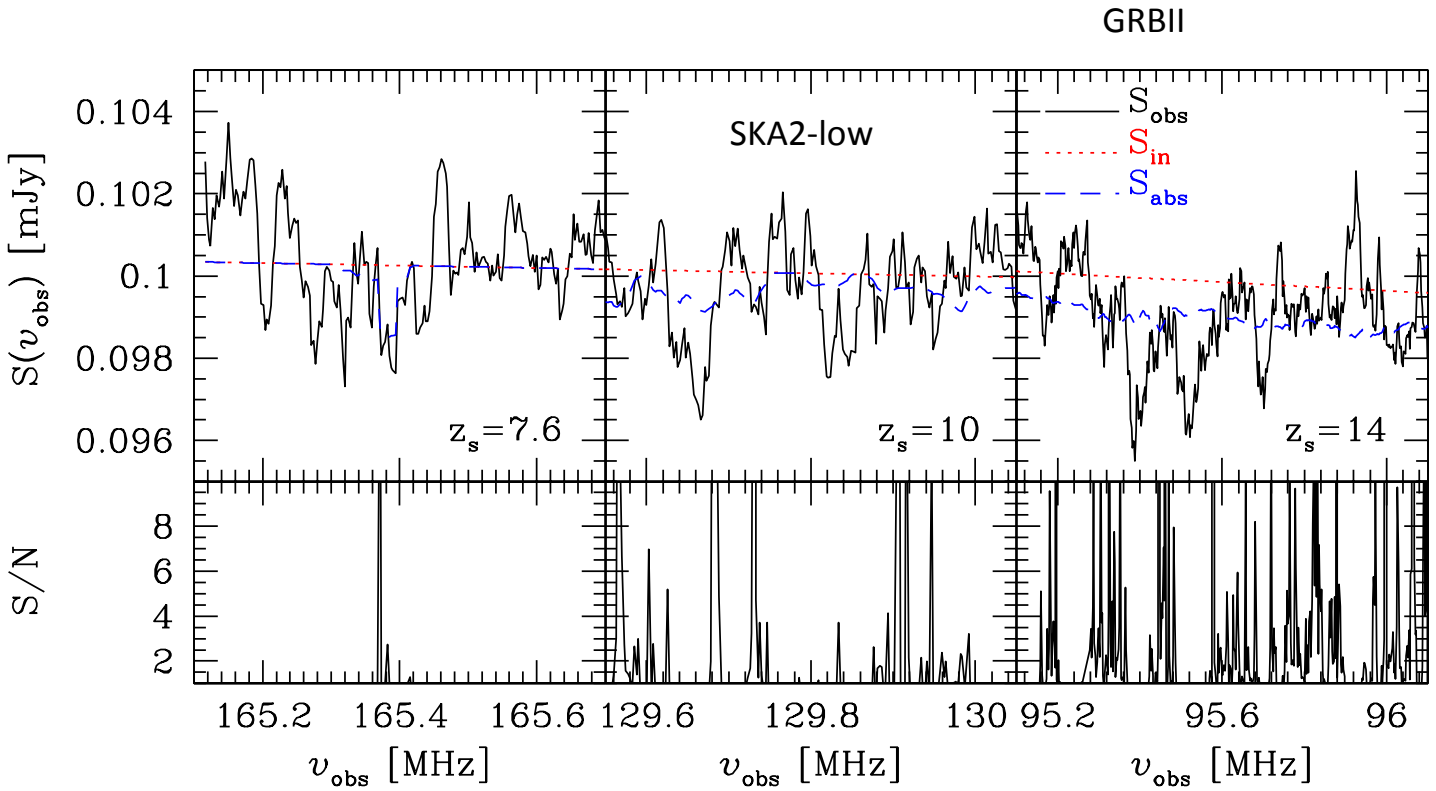
Observed
spectrum

The 21cm forest with GRBs

BC+ 2013, 2015

S=0.1 mJy, α=0.6

n=0.01, t=1000 h



GRB spectrum

GRB spectrum
+
IGM absorption

Observed
spectrum

THE 21CM FOREST WITH GRBS

BC+ 2013, 2015

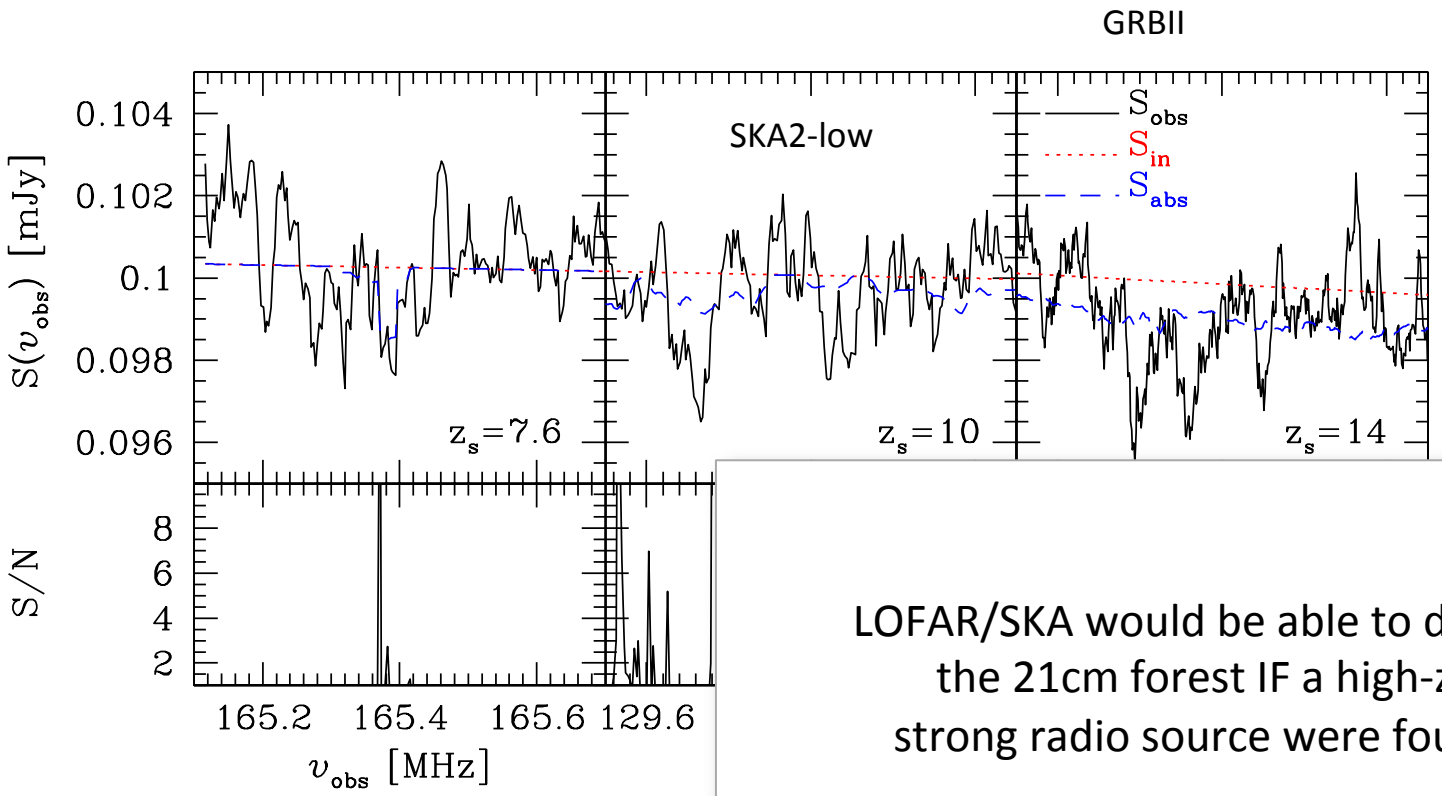
S=0.1 mJy, α=0.6

n=0.01, t=1000 h

GRB spectrum

GRB spectrum
+
IGM absorption

Observed spectrum



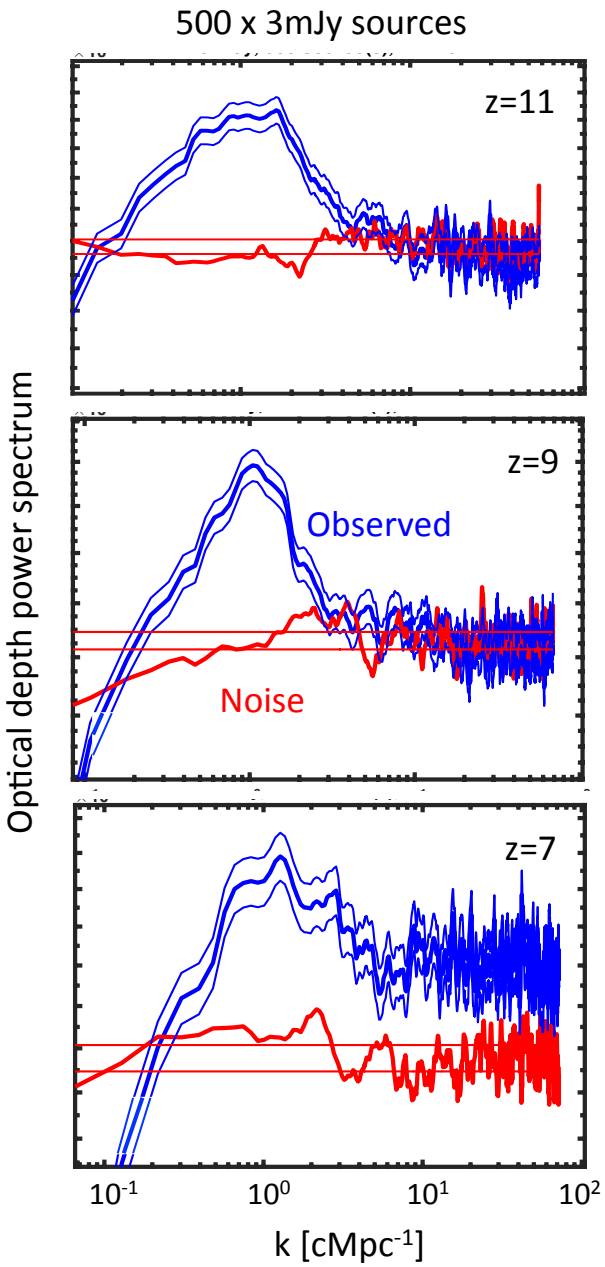
LOFAR/SKA would be able to detect the 21cm forest IF a high-z, strong radio source were found

THE 21CM FOREST: STACKING

Koopmans+ in prep.

t=1000 h

SKA-1 could probe in absorption scales ~ kHz



Conclusions

- ✧ 21cm forest is feasible IF a high-z radio-loud source is found or by stacking