Simulating the EoR 21cm signal

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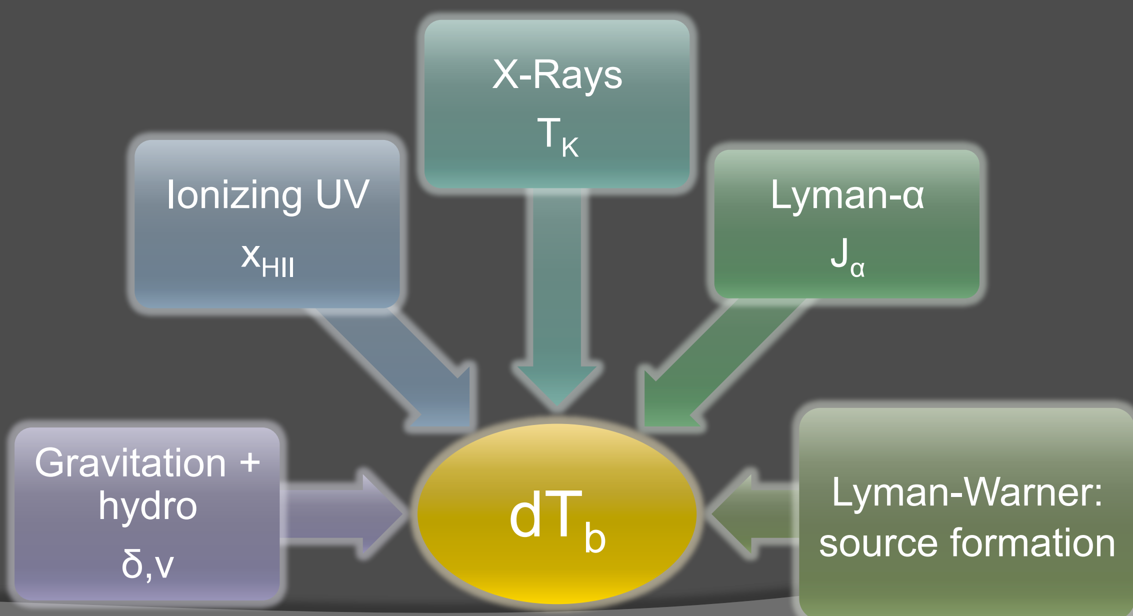
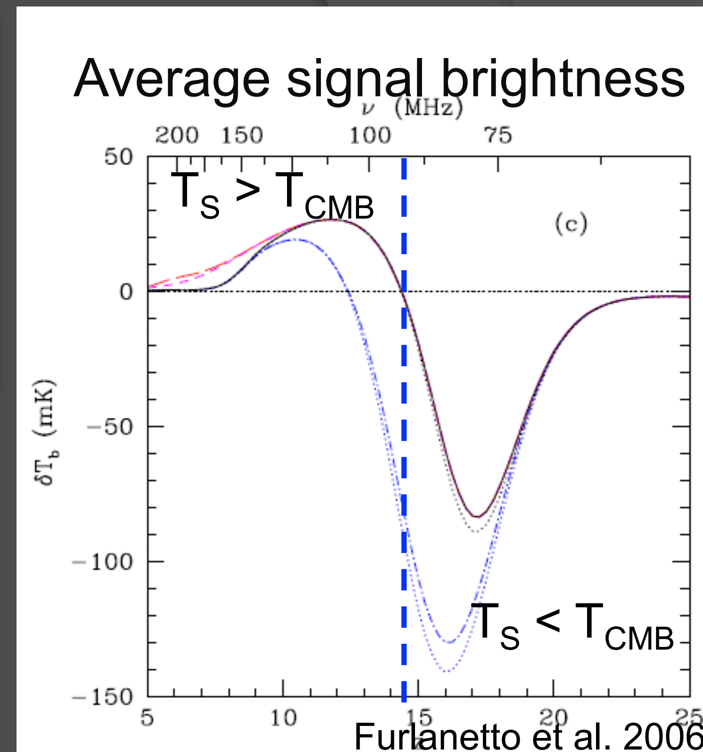
Physics of the 21 cm signal

$$\delta T_B \propto 28\,\mathrm{mK}\ (1+\delta)(1+x_i)\left(\frac{T_S - T_{CMB}}{T_S}\right)\left(1+\frac{1}{H}\frac{dv}{dr}\right)^{-1}$$

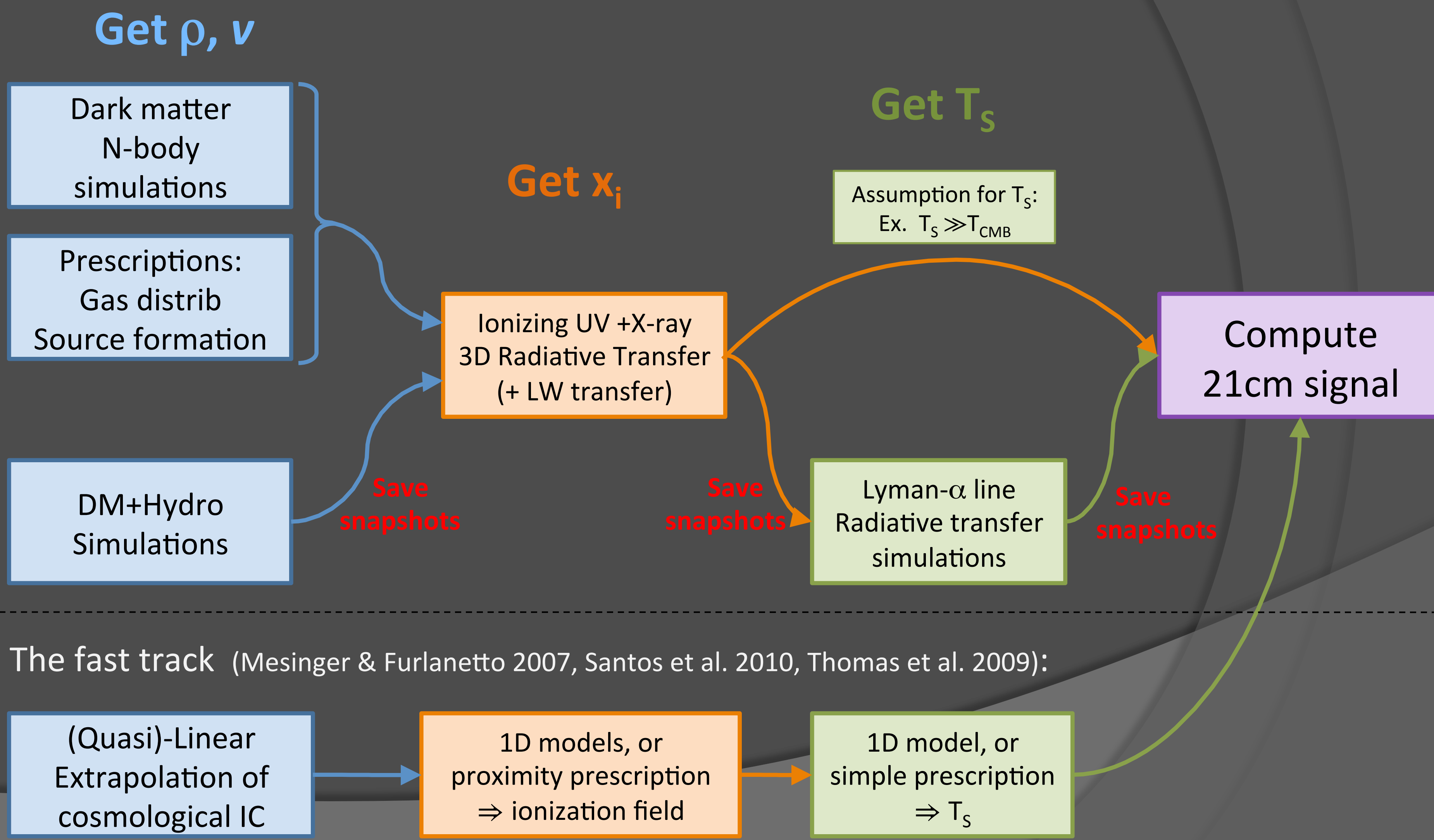
$$T_S = f(J_\alpha, T_K, \delta, x_i)$$





21 cm signal simulation: methodology

$$\delta T_B \propto 28\,\mathrm{mK}\;(1+\delta)(1+x_i)\left(\frac{T_S - T_{\mathrm{CMB}}}{T_S}\right)\left(1+\frac{1}{H}\frac{dv}{dr}\right)^{-1}$$



Box size and resolution requirements

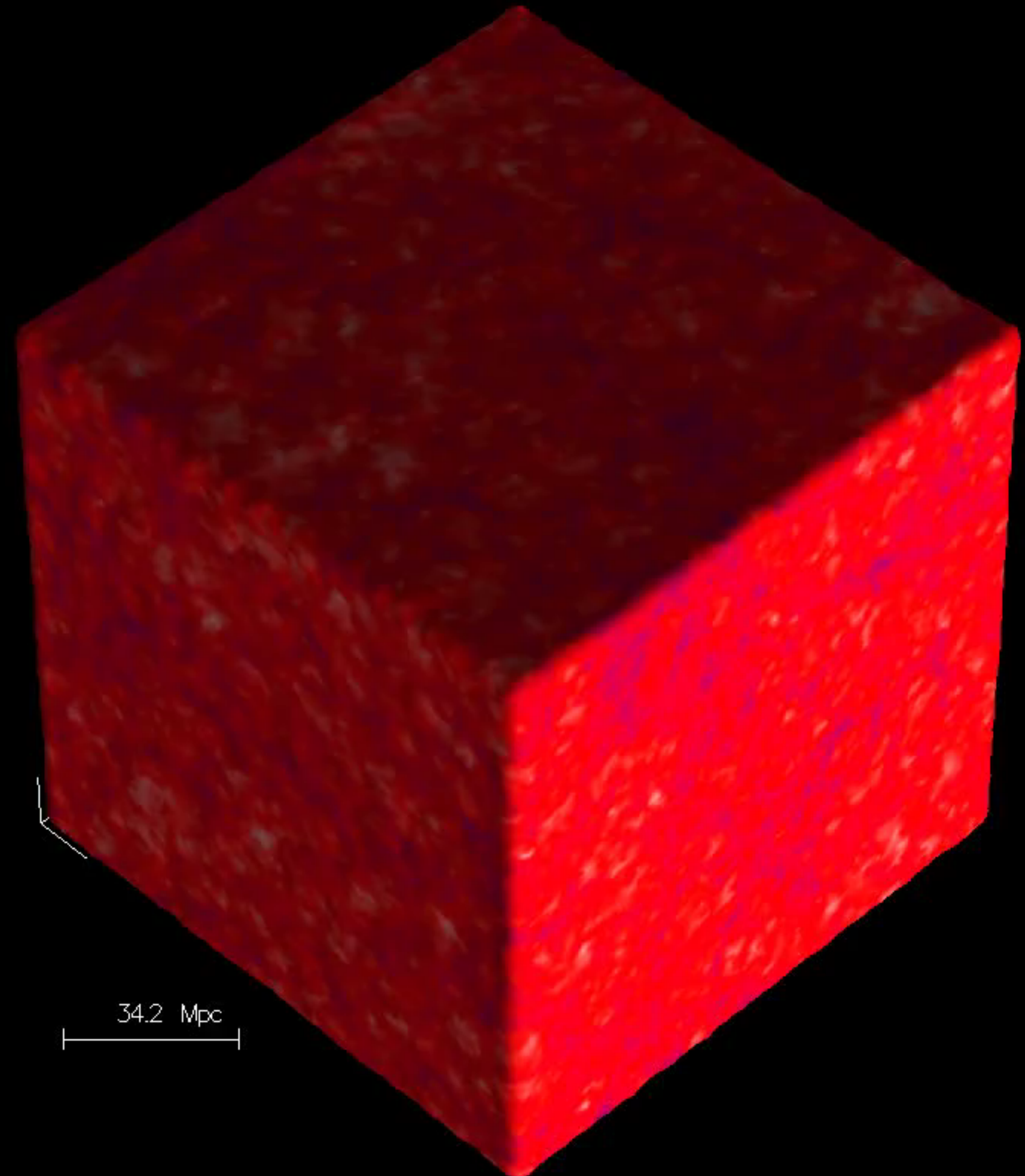
Minimum box size set by cosmic variance… of what?

- Density field: < 100 Mpc
- Ionized patches: > 100 Mpc
- X-ray, Ly-α, LW, bulk velocities: a few 100 Mpc

Resolution set (mainly) by the physics of source formation

- Atomic cooling halos: $10^8\ M_\odot$
- H_2 cooling halos: $10^6\ M_\odot$

$50\ 000^3$ resolution elements


34.2 Mpc

Robustness of the absorption regime

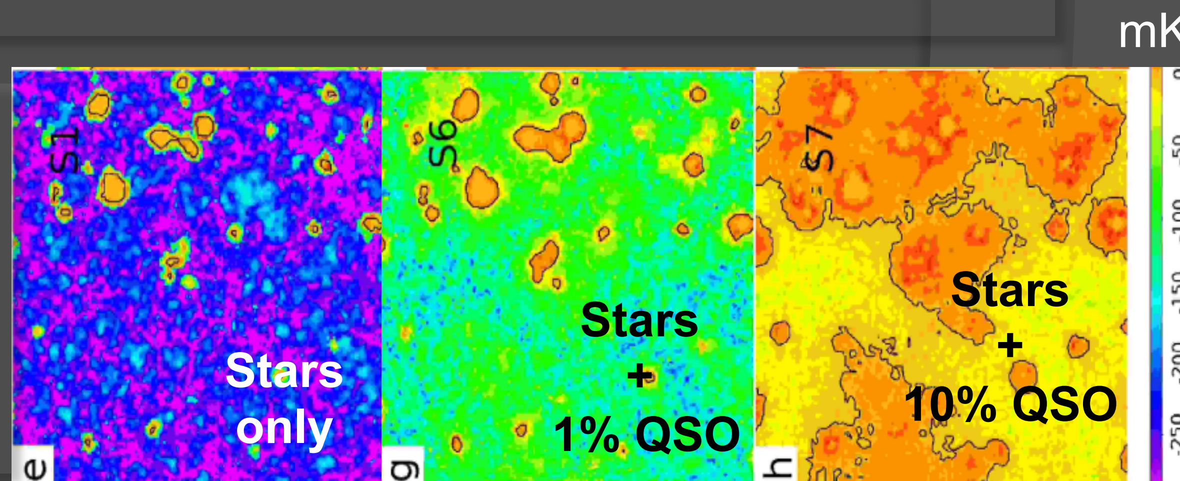
If $T_K < T_{CMB}$ ⇔ $\delta T_B \sim -100$ mK — strong absorption regime!

If $T_K >> T_{CMB}$ ⇔ $\delta T_B \sim$ 20 mK — saturated emission regime

A race between Ly-α coupling and X-ray heating in the IGM !

Baek et al. (2009, 2010):

X-ray do not easily remove 21cm absorption



Good prospects of the SKA 50-100 MHz band (early EoR)

rms signal in absorption and emission: tracking the nature of the sources

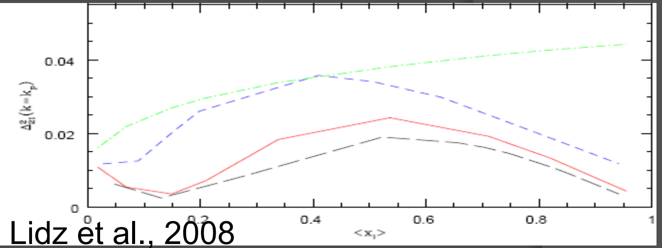
- Neglecting absorption: at ~10 Mpc scale

  Single maximum at x_i ~ 0.5

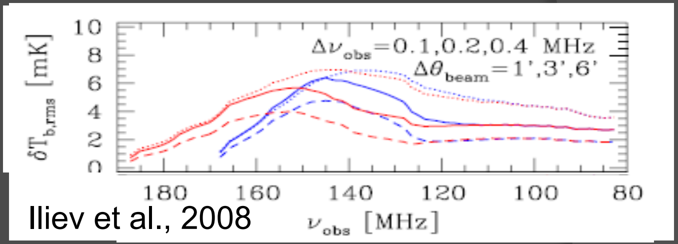
- Including absorption:

  The result depends on the source model…

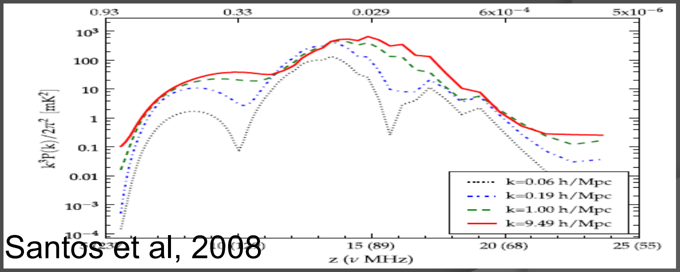
  Several maxima



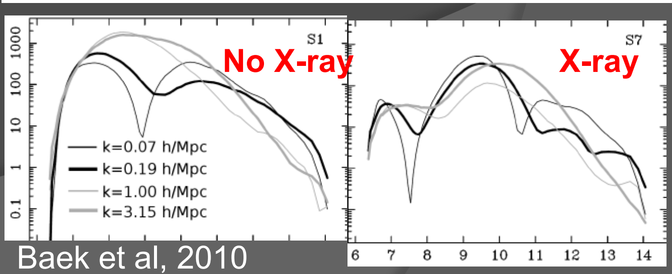
Lidz et al., 2008



Iliev et al., 2008



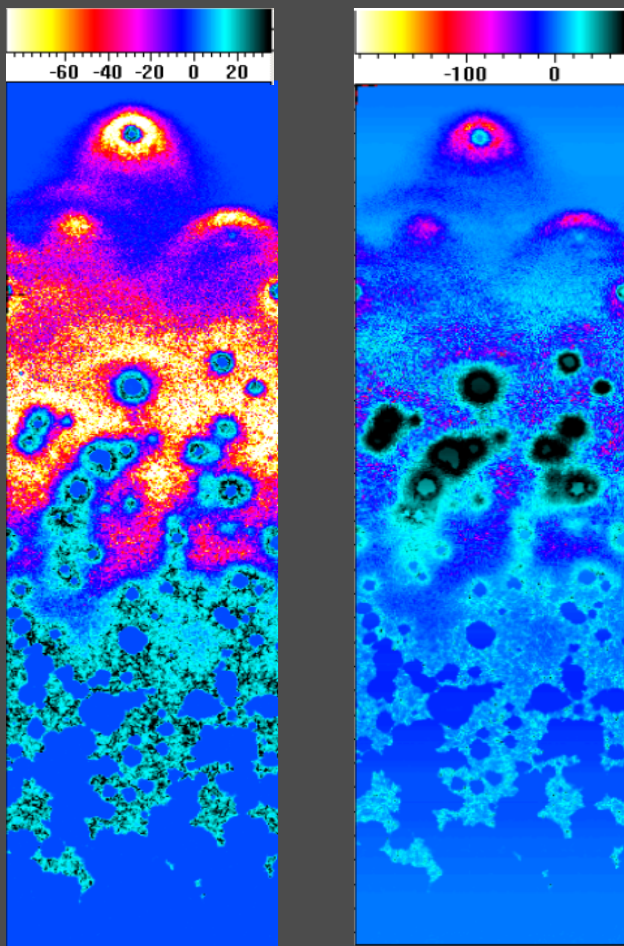
Santos et al, 2008



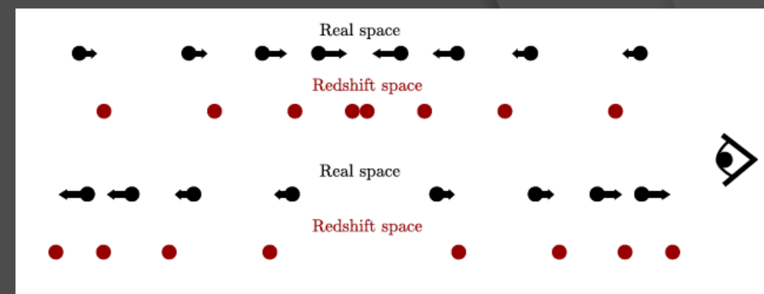
Baek et al, 2010

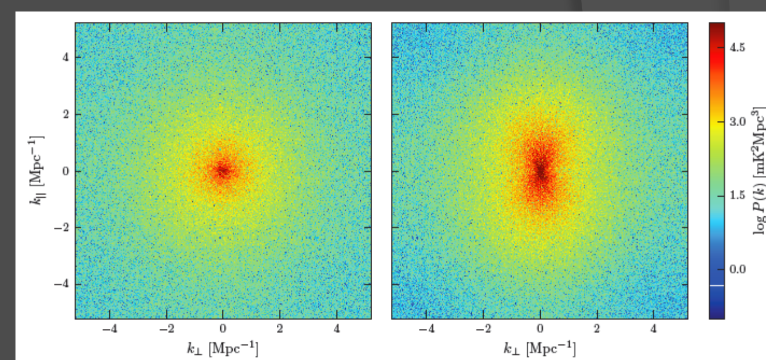
Anisotropies

Light-cone effects



Peculiar velocity effects (Kaiser effect)





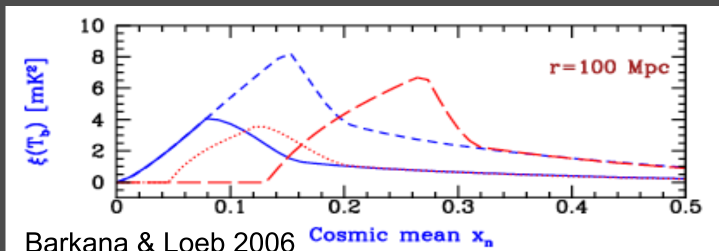
Hannes et al. (2013)

Large scale correlations will "detect" ionization history => anisotropy.

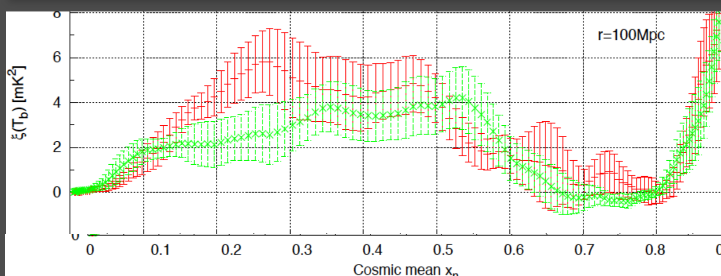
Light-cone effects

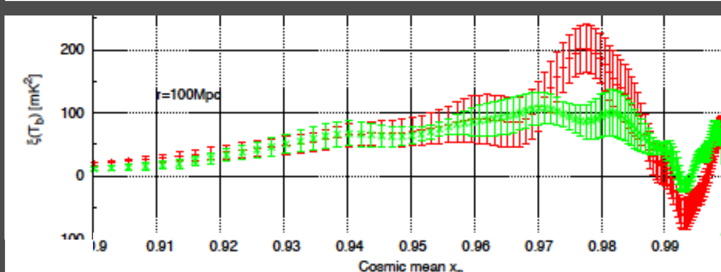
(Zawada et al. 2013, in prep)

Correlation function: // vs perpendicular



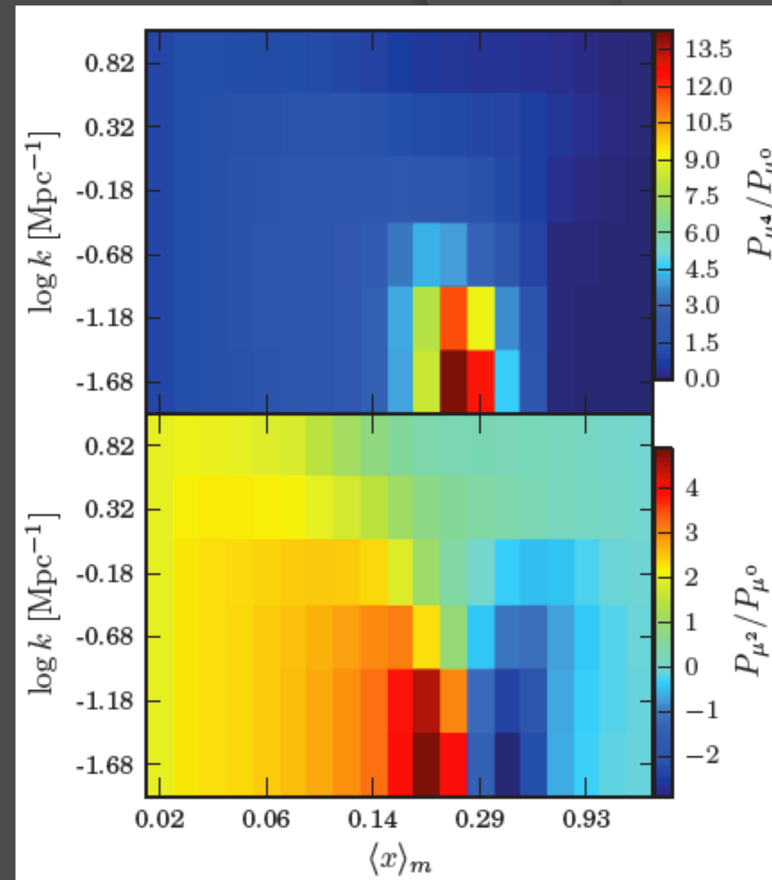
Simulations: 400 Mpc/h box





Peculiar velocity effects

(Hannes et al. 2013)



Anisotropies on large scales, (> 100 Mpc)

⇒ Large sample variance

⇒ Large FoV required

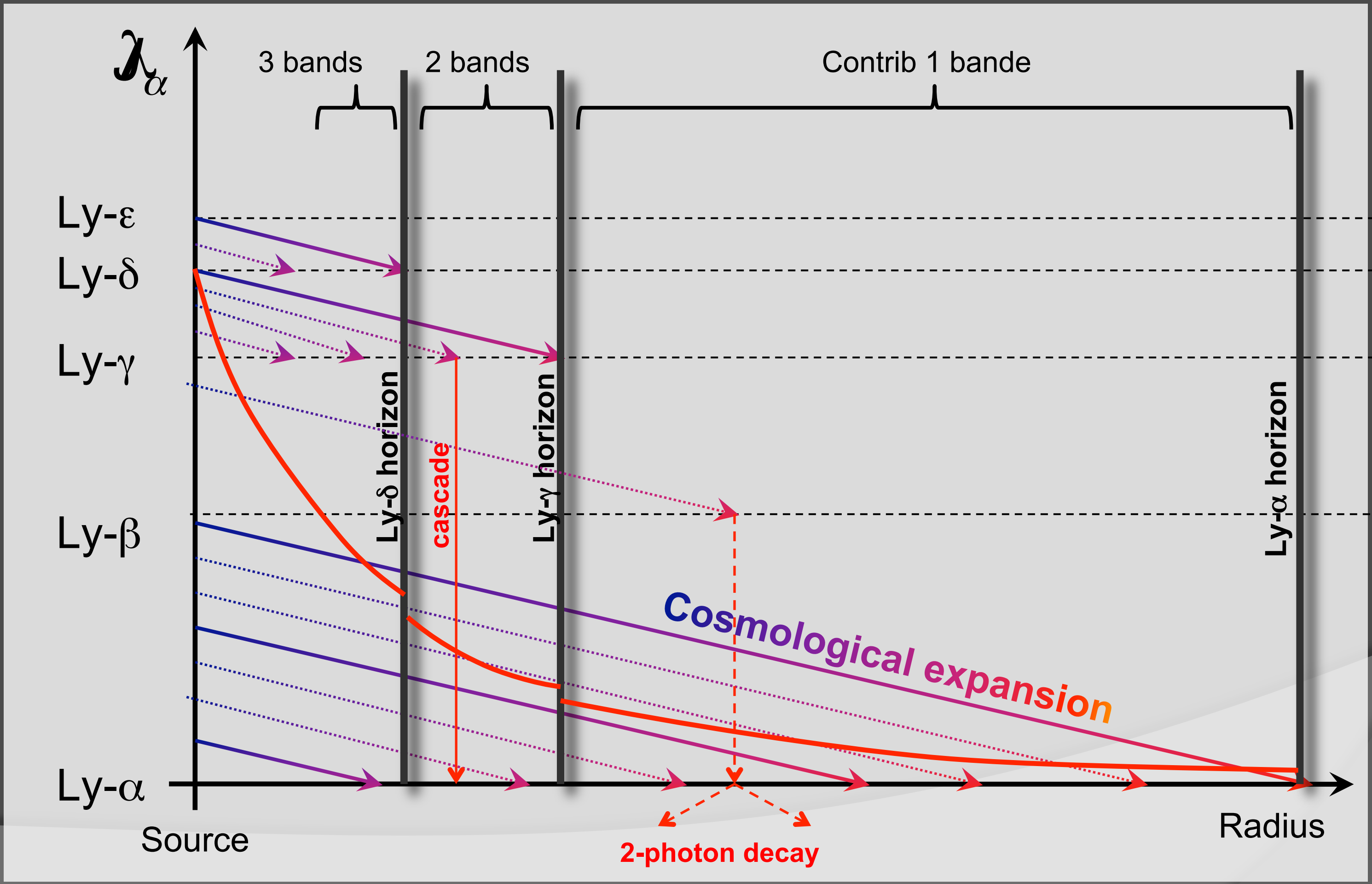
SKA will give us tomography.

=> We can do new kinds of statistics in the image space.

e.g. we can stack individual sources (bubbles) during early EoR.

Rings in the sky

In the apropriate regime: $\delta T_B \sim \delta J_\alpha$



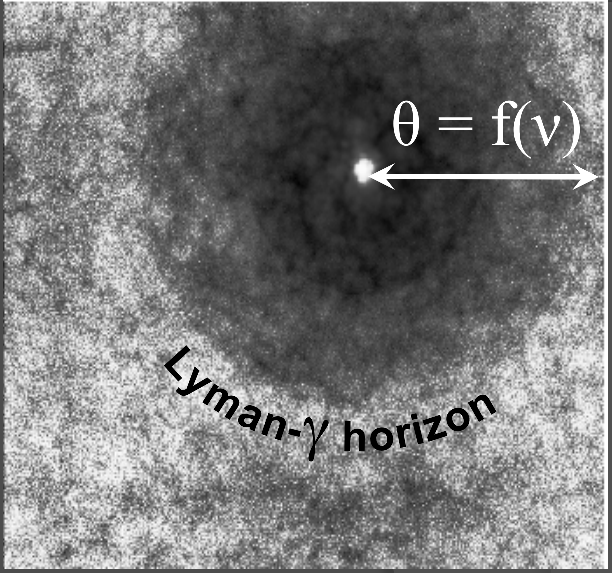
A unique signature!

-Standard ruler

-FG removal validation

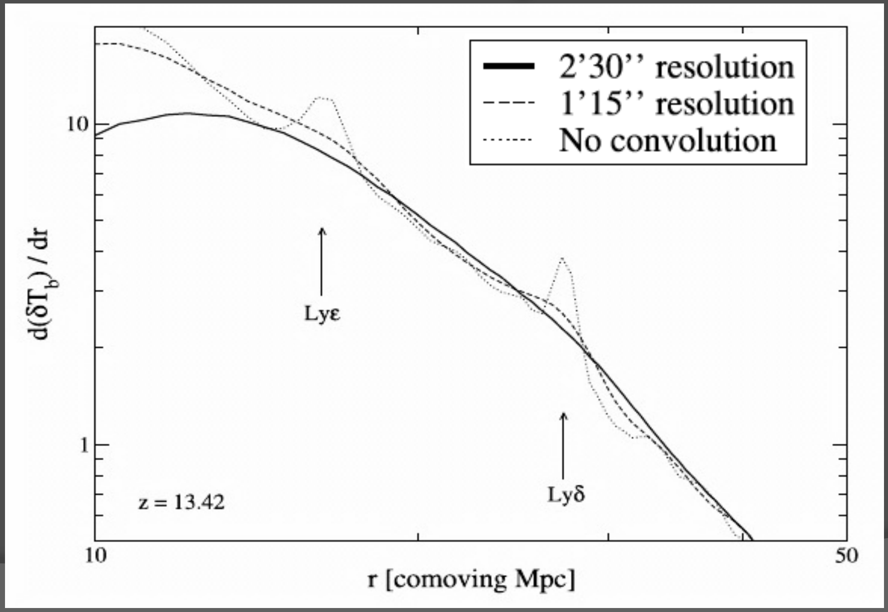
How stacking in image space almost succeeds
(Vonlanthen et al. 2011)

- Rings are visible around a single source
- « Source confusion », noise and limited resolution dampen the feature.
- Stacking profiles helps a lot.



Contribution of Lyman γ, δ, ε… to δT_B

Resolution is the limiting factor



Visible with a core twice as large as in the DRM.

Once again a large FoV helps.

What is still missing in the simulations

- Satisfying box size AND mass resolution in the same simulation
- Improving the source model (e.g. escape fraction)
- Including all physics in the same simulations
  (Ly-α, LW, bulk velocities, etc…)
- Run all physics in coupled simulations