

# Descending from on high: Lyman series cascades and spin-kinetic temperature coupling in the 21cm line

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[astro-ph/0508381](https://arxiv.org/abs/astro-ph/0508381)

# 21cm + Wouthysen-Field Effect

$$T_B = \tau \left( \frac{T_s - T_\gamma}{1 + z} \right)$$

Field 1959

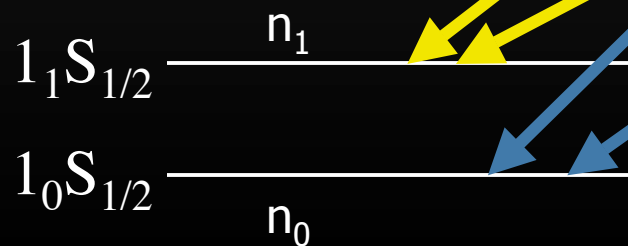
$$\delta T_b = \beta \delta + \frac{x_\alpha}{\tilde{x}_{tot}} \delta x_\alpha + \cancel{\delta x_{HI}} - \delta d_r v_r$$

Barkana & Loeb 2004

W-F:  $x_\alpha \propto J_\alpha$

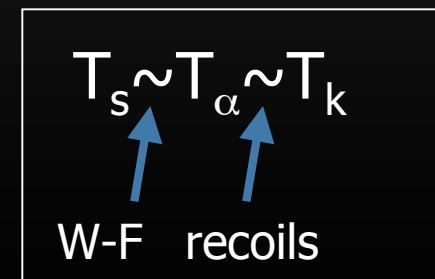
Effective for  
 $J_\alpha > 10^{-21} \text{erg/s/cm}^2/\text{Hz/sr}$

$n_F L_J$



$$n_1/n_0 = 3 \exp(-h\nu_{10}/kT_s)$$

Selection rules:  
 $\Delta F = 0, 1$  (Not  $F=0 \rightarrow F=0$ )

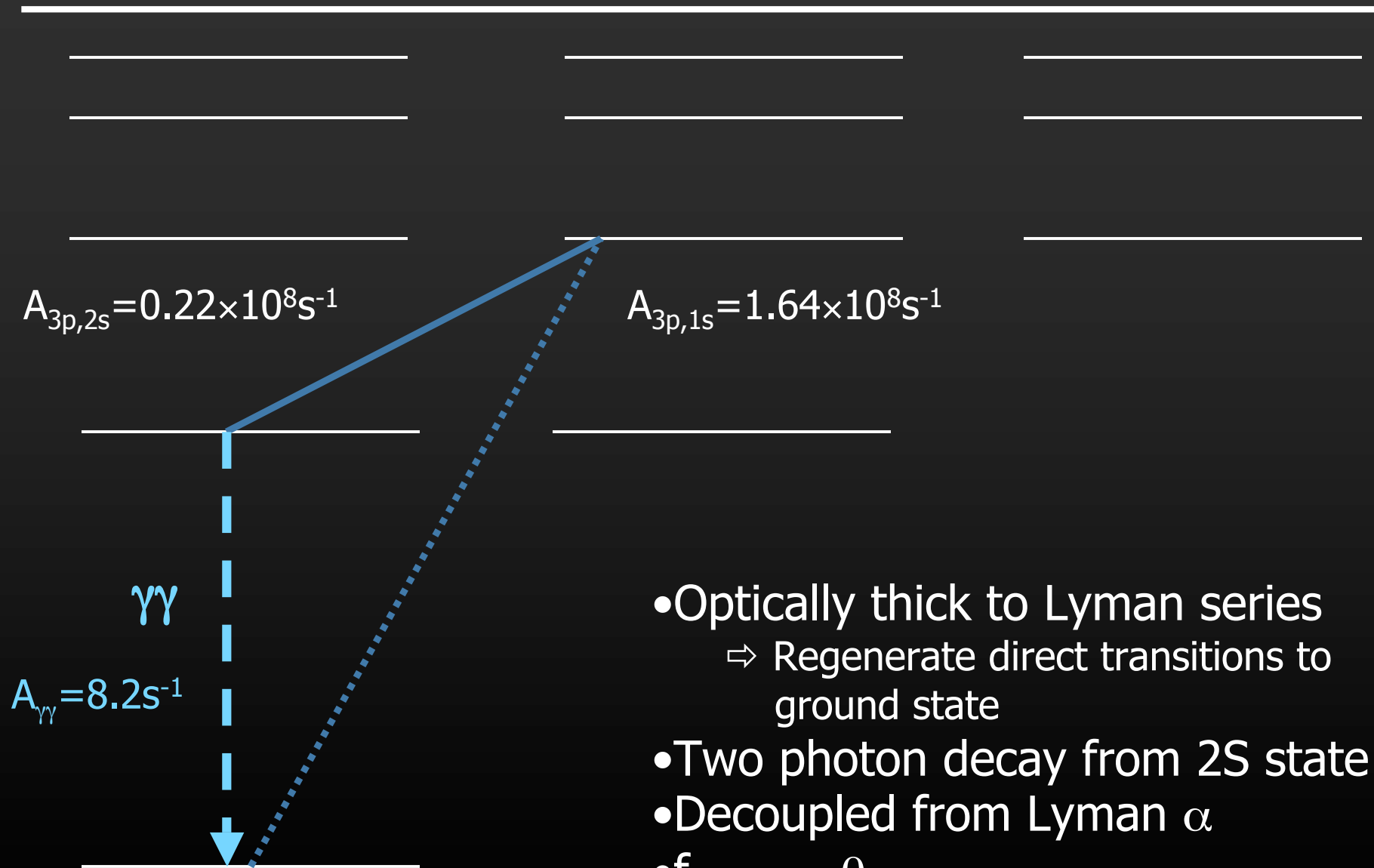


# Higher Lyman Series

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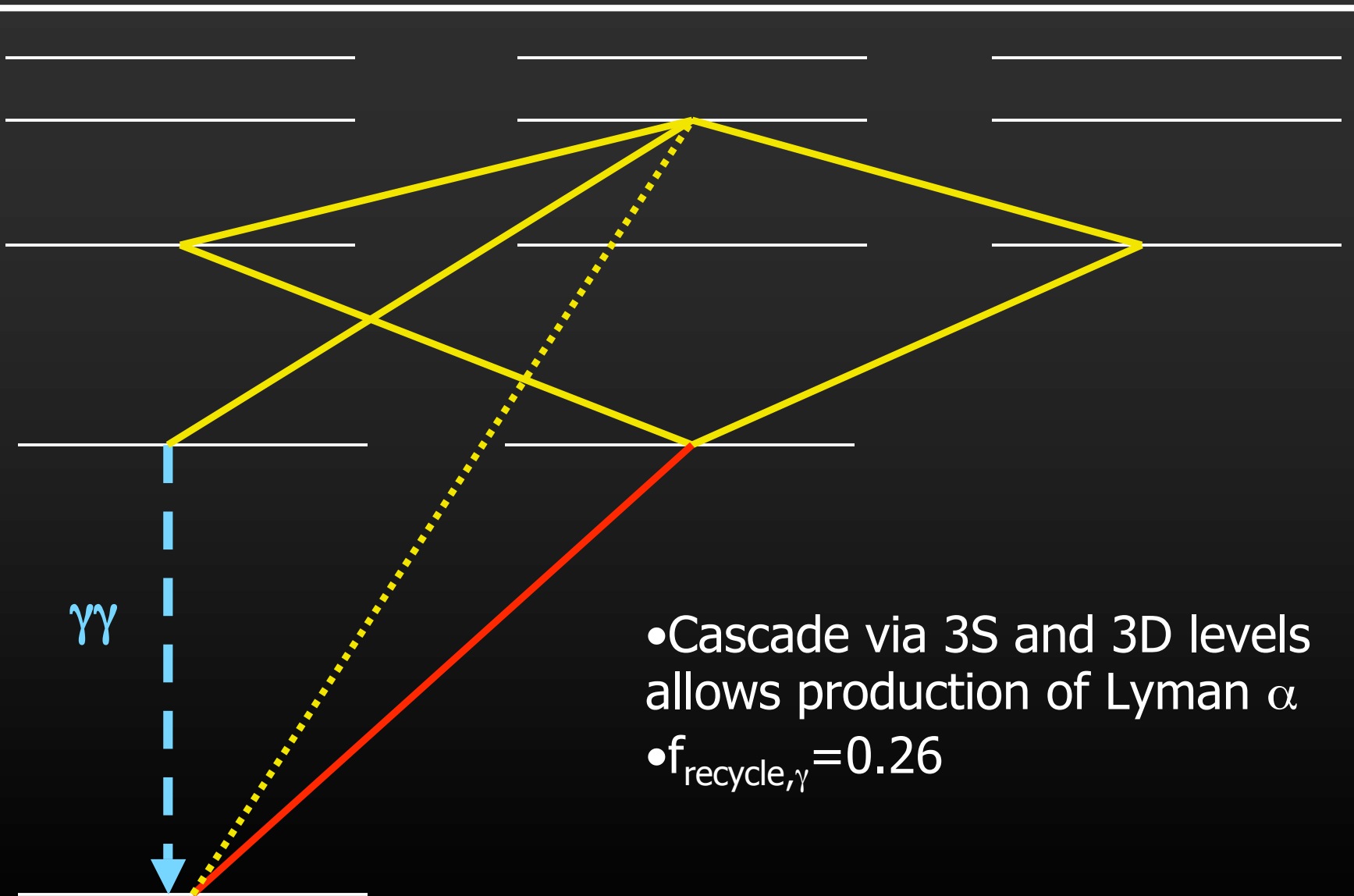
- Two possible contributions
  - Direct pumping: Analogy of the W-F effect
  - Cascade: Excited state decays through cascade to generate Ly $\alpha$
- Direct pumping is suppressed by the possibility of conversion into lower energy photons
  - Ly  $\alpha$  scatters  $\sim 10^6$  times before redshifting through resonance
  - Ly n scatters  $\sim 1/P_{\text{abs}} \sim 10$  times before converting
  - ⇒ Direct pumping is not significant
- Cascades end through generation of Ly  $\alpha$  or through a two photon decay
  - Use basic atomic physics to calculate fraction recycled into Ly  $\alpha$
  - Discuss this process in the next few slides...

# Lyman $\beta$



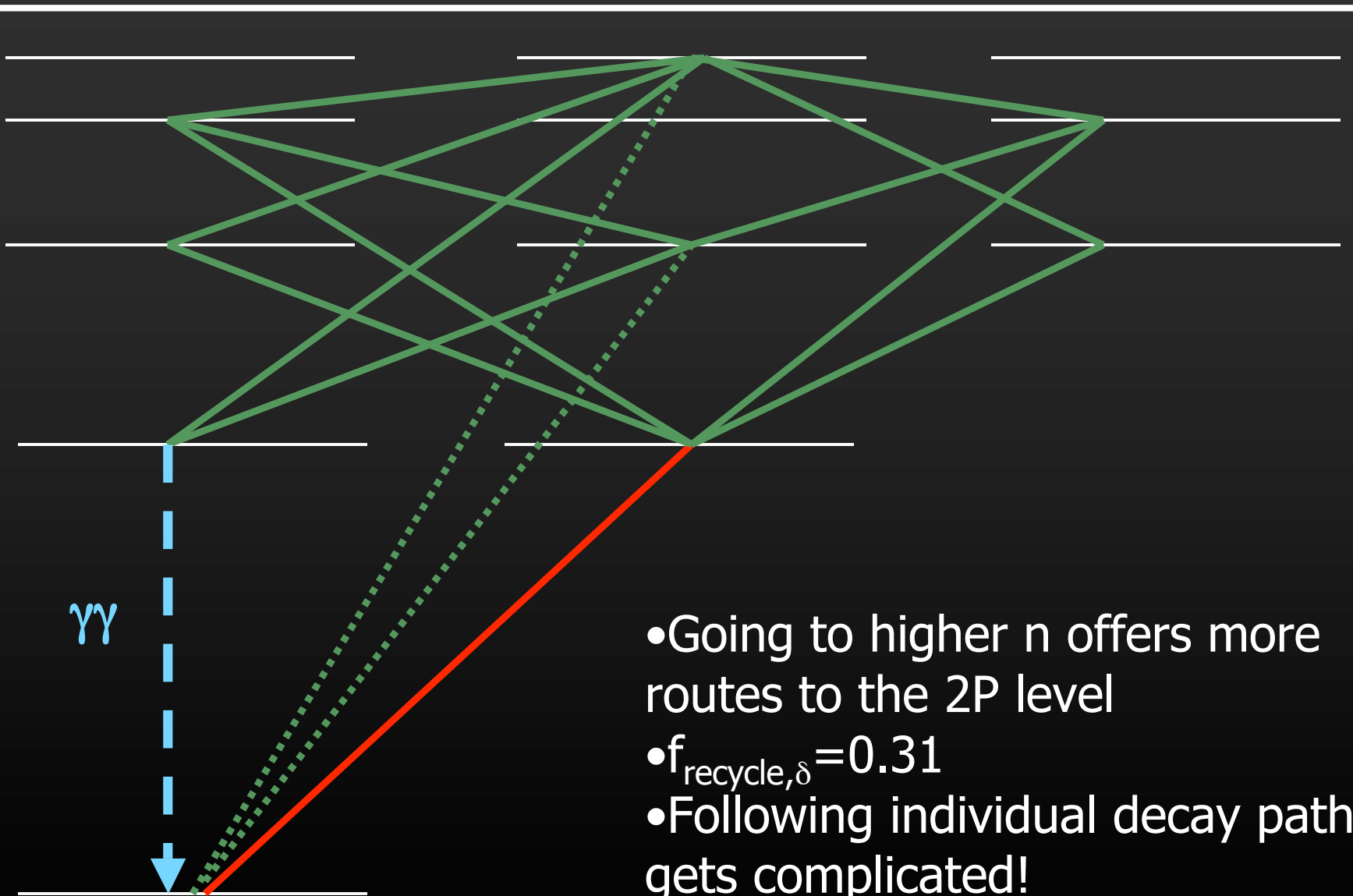
- Optically thick to Lyman series  
⇒ Regenerate direct transitions to ground state
- Two photon decay from 2S state
- Decoupled from Lyman  $\alpha$
- $f_{\text{recycle},\beta} = 0$

# Lyman $\gamma$



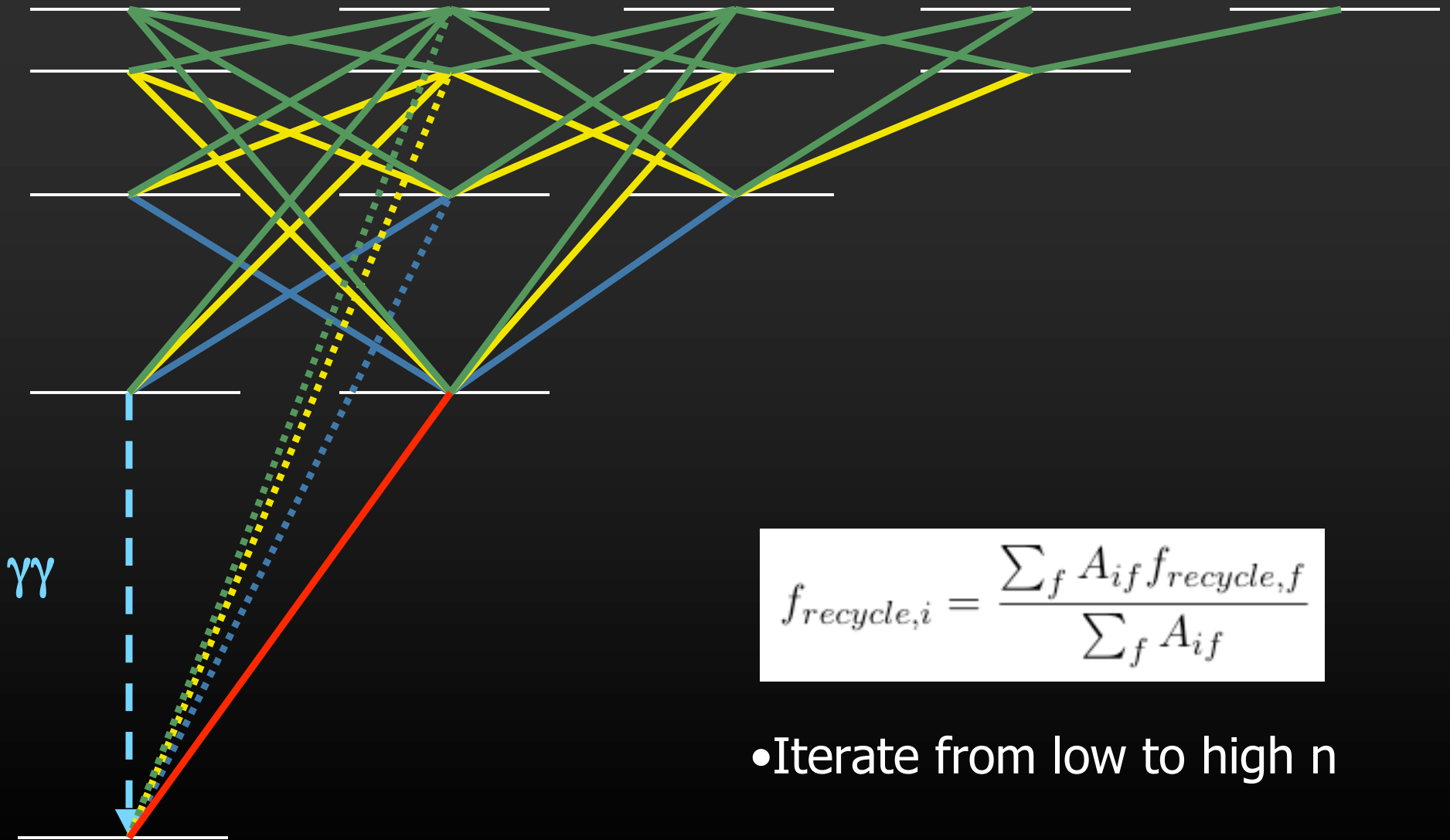
- Cascade via 3S and 3D levels allows production of Lyman  $\alpha$
- $f_{\text{recycle},\gamma} = 0.26$

# Lyman $\delta$



- Going to higher  $n$  offers more routes to the 2P level
- $f_{\text{recycle},\delta} = 0.31$
- Following individual decay paths gets complicated!

# Calculating Recycling Fractions

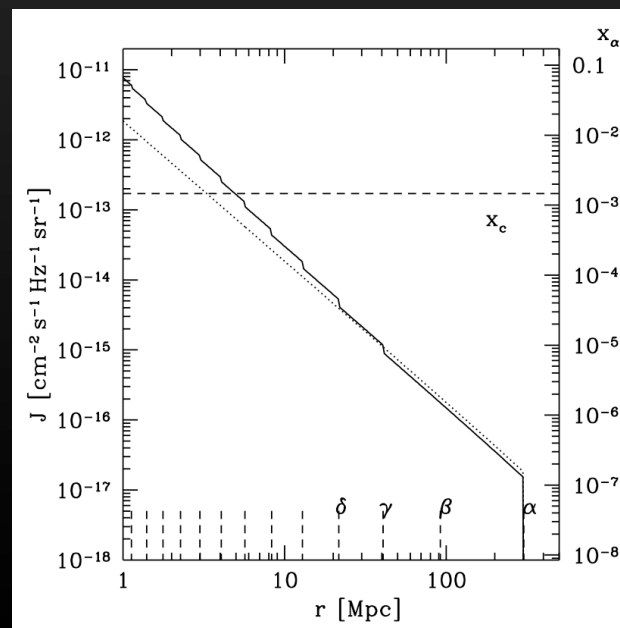
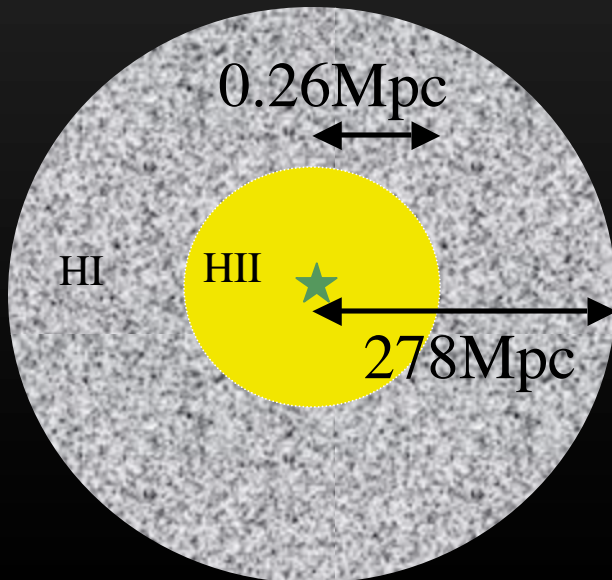


$$f_{\text{recycle},i} = \frac{\sum_f A_{if} f_{\text{recycle},f}}{\sum_f A_{if}}$$

- Iterate from low to high n

# Lyman Series Cascades

	$\alpha$	$\beta$	$\gamma$	$\delta$	$\infty$	Total
No. Photons: (pop III)	2670	965	451	810		4896
$f_{\text{recycle}}$ :	1.0	0	0.26	0.35		0.62
Ly $\alpha$ Contribution:	2670	0	118	268		3056
Shell size @ $z = 20$ (Mpc):	278	90	40	22		





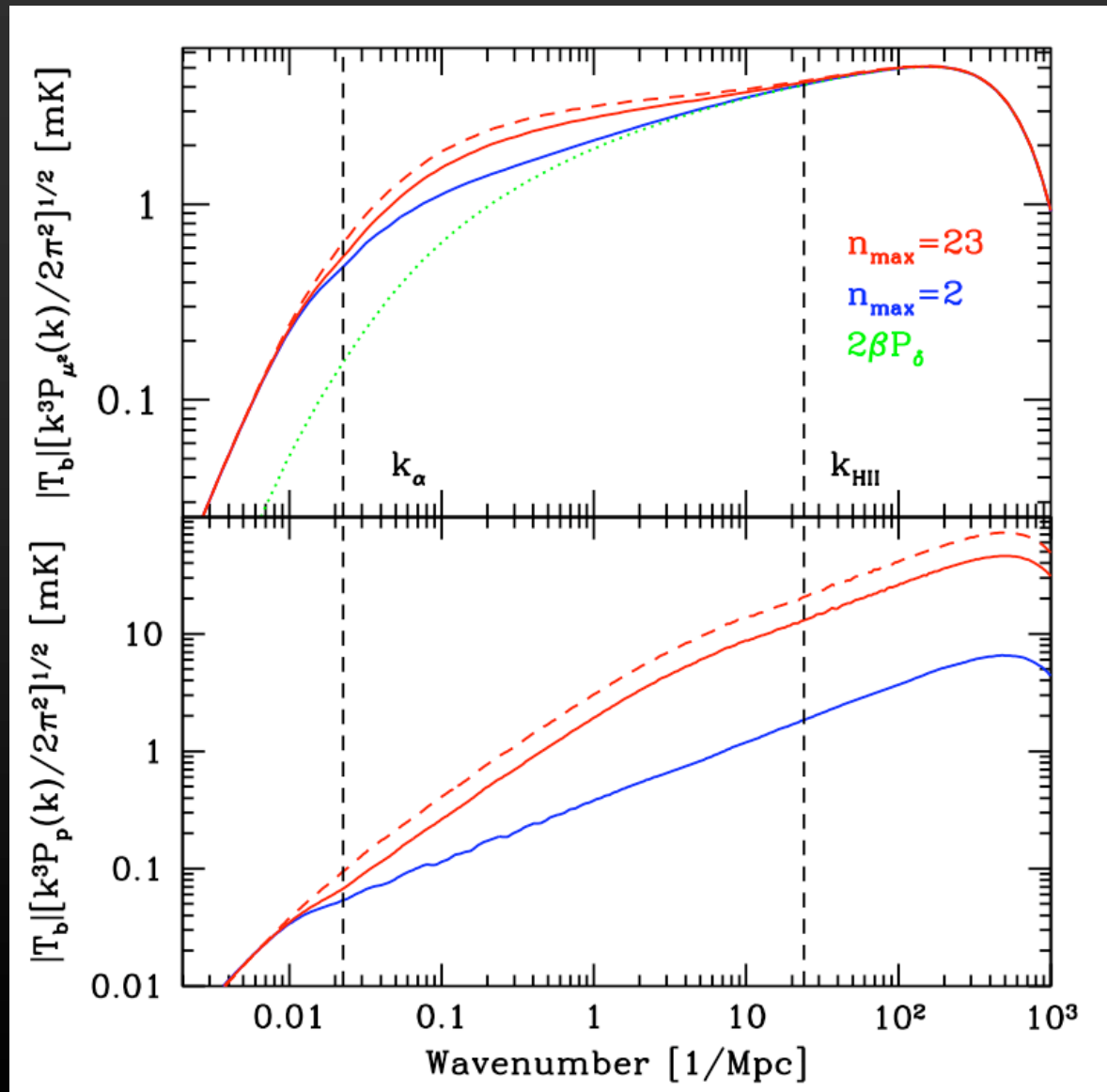
# $T_b$ Fluctuations

Galaxies @z=20

Density  
inhomogeneities

Poisson  
fluctuations

Barkana & Loeb 2004



# Conclusions

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- Including correct atomic physics is important for extracting astrophysical information from 21cm fluctuations
- Cascade generated Lyman  $\alpha$  photons increase the theoretical signal from the first galaxies, but not as much as has previously been thought
- $\sim 62\%$  emitted Lyman series photons recycled into Lyman  $\alpha$
- Recycling fractions are straightforward to calculate and should be included in future work on this topic
- Basic atomic physics encoded in characteristic scales of Lyman series photon horizons
- For more information see: [astro-ph/0508381](https://arxiv.org/abs/astro-ph/0508381)