CMB resonant scattering as a cosmological tool

Kaustuv Basu
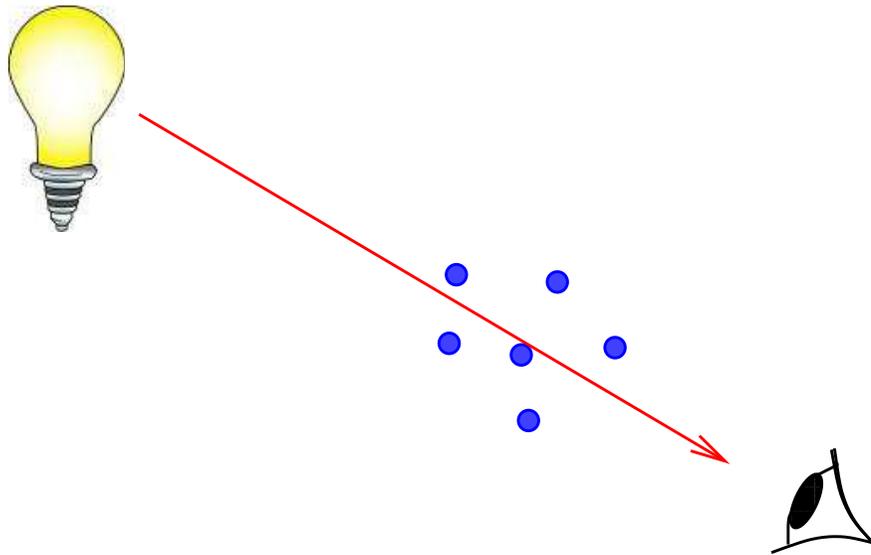
in collaboration with:

C. Hernández-Monteagudo & R. Sunyaev

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Basic Idea

Metallicity evolution of the universe must leave its imprint on the Cosmic Microwave Background Radiation $\Rightarrow$ through resonance scattering of the background photons by atoms, ions and molecules
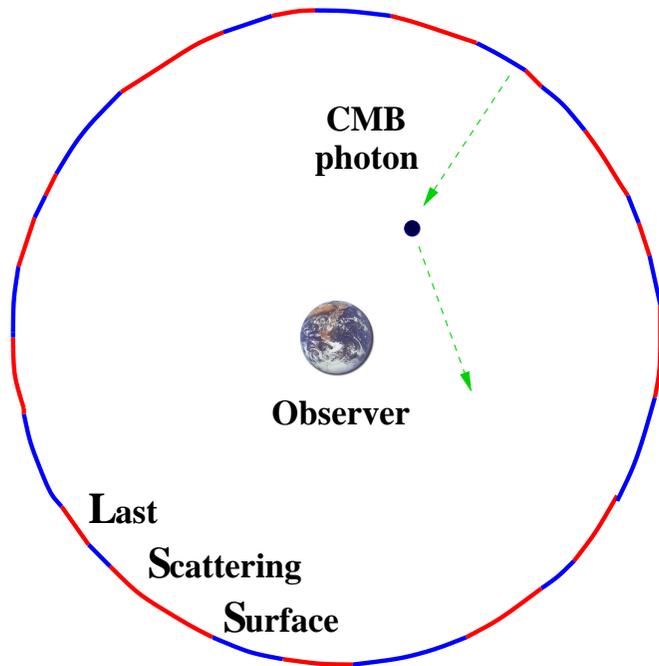
- Maoli, Melchiorri et al. 1994, 1996, ...

- Dubrovich 1977, 1993, ...

- de Bernardis et al. 1993

- Loeb & Zaldarriaga 2002
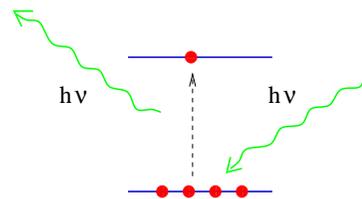
- Basu et al. 2004

Suppression & generation

Resonant scattering partially erases the original temperature anisotropies of the CMB, but also generates new fluctuations at the epoch of scattering

CMB photon

Observer

Last Scattering Surface

$$\frac{\Delta T}{T_0}(\theta) = e^{-\tau_\nu} \left.\frac{\Delta T}{T_0}(\theta)\right|_{orig.} + \left.\frac{\Delta T}{T_0}(\theta)\right|_{new}$$
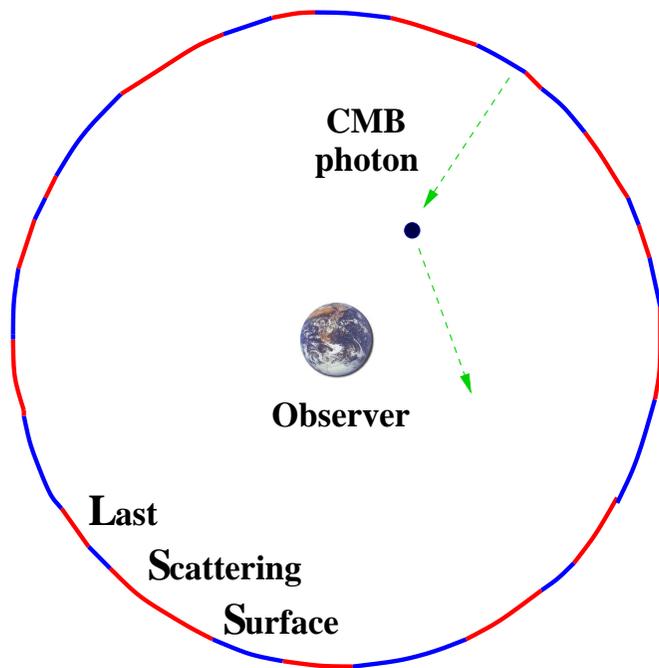
hν   hν

Scattering is *coherent* in scatterer's frame

Suppression & generation

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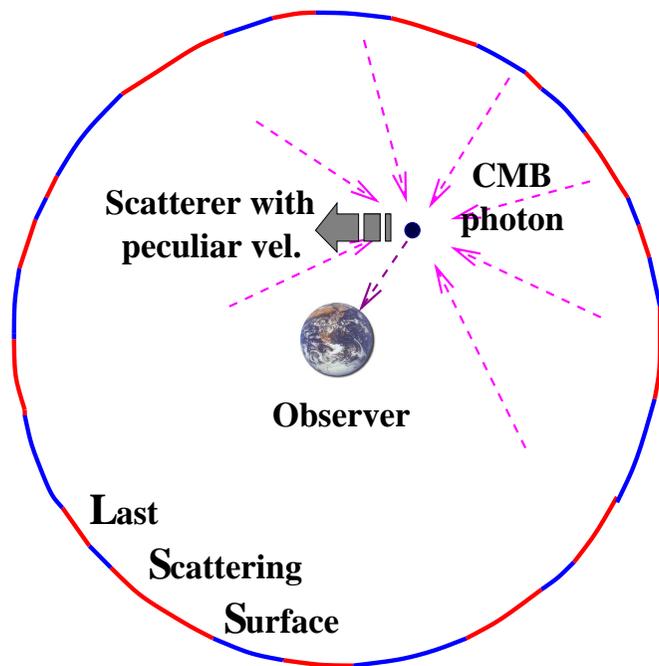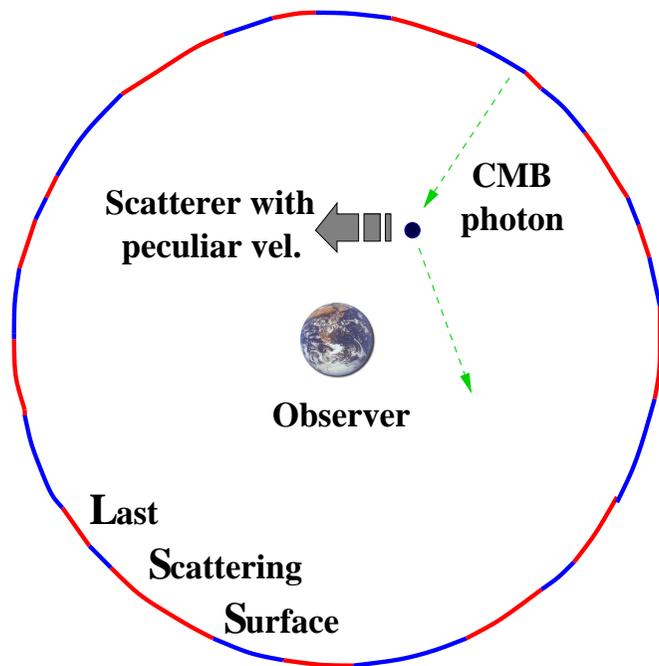

$$\frac{\Delta T}{T_0}(\theta) = e^{-\tau_\nu} \left.\frac{\Delta T}{T_0}(\theta)\right|_{orig.} + \left.\frac{\Delta T}{T_0}(\theta)\right|_{new}$$

"suppression (blurring)" & "generation"

Suppression & generation

Resonant scattering partially erases the original temperature anisotropies of the CMB, but also generates new fluctuations at the epoch of scattering
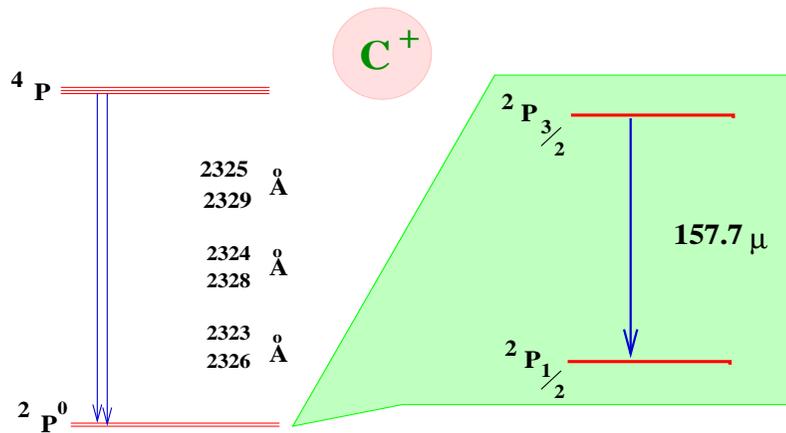

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"suppression (blurring)" & "generation"

Suppression & generation

Resonant scattering partially erases the original temperature anisotropies of the CMB, but also generates new fluctuations at the epoch of scattering

$$\frac{\Delta \mathsf{T}}{\mathsf{T}_0}(\theta) = e^{-\tau_\nu} \left.\frac{\Delta \mathsf{T}}{\mathsf{T}_0}(\theta)\right|_{orig.} + \left.\frac{\Delta \mathsf{T}}{\mathsf{T}_0}(\theta)\right|_{new}$$

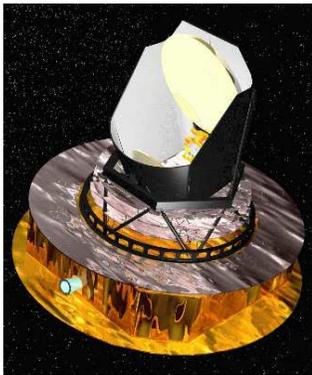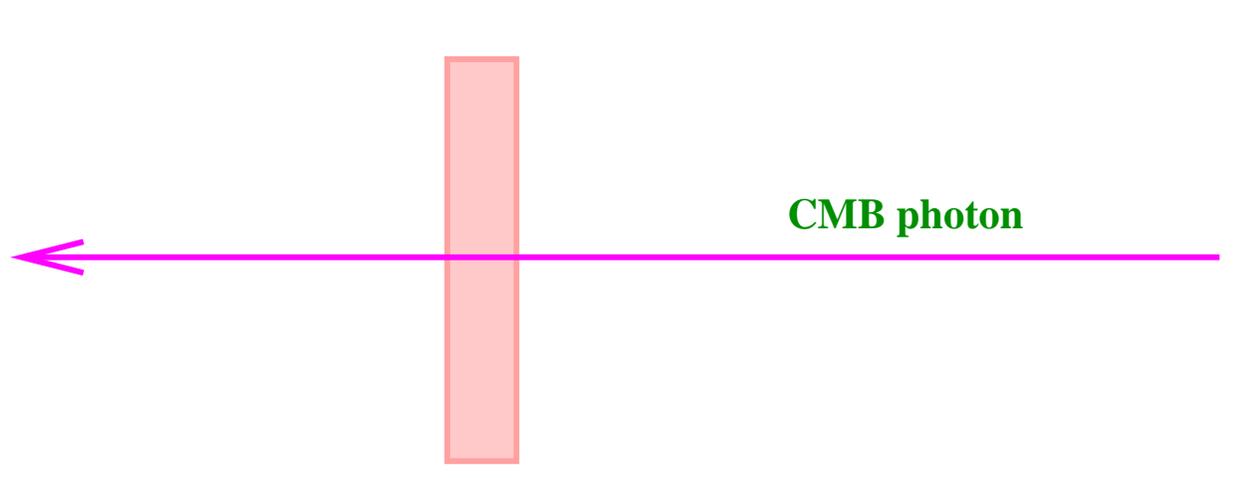$$\delta C_l = \tau_\nu \cdot \mathcal{C}_1 + \tau_\nu^2 \cdot \mathcal{C}_2 + \mathcal{O}(\tau_\nu^3)$$

Fine-structure lines

C^{+}

^4P

$^2P^0$

2325 Å
2329 Å

2324 Å
2328 Å

2323 Å
2326 Å

$^2P_{3/2}$

$^2P_{1/2}$

157.7 μ

A-coefficient $\sim 10^{-6}$ s^{-1}

$\Rightarrow$ optical depth $\sim 10^{-5} - 10^{-7}$

143 GHz

CMB photon

Planck HFI

Bandwidth ~ 25%

z ~ 12

LSS

at z=1100

Fine-structure lines

C^+

^{4}P

2325 Å
2329

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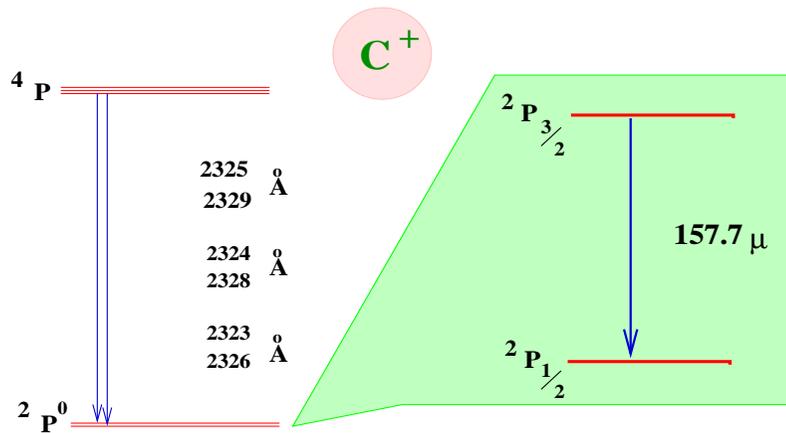
A-coefficient $\sim 10^{-6}$ s^{-1}

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217 GHz

CMB photon
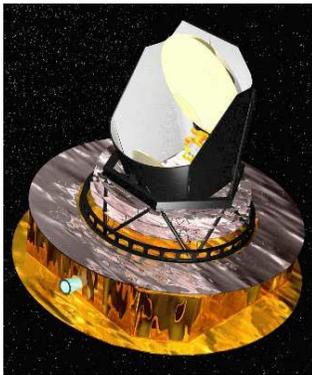
Planck HFI

Bandwidth ~ 25%

z ~ 8

LSS

at z=1100

Fine-structure lines

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2325 Å
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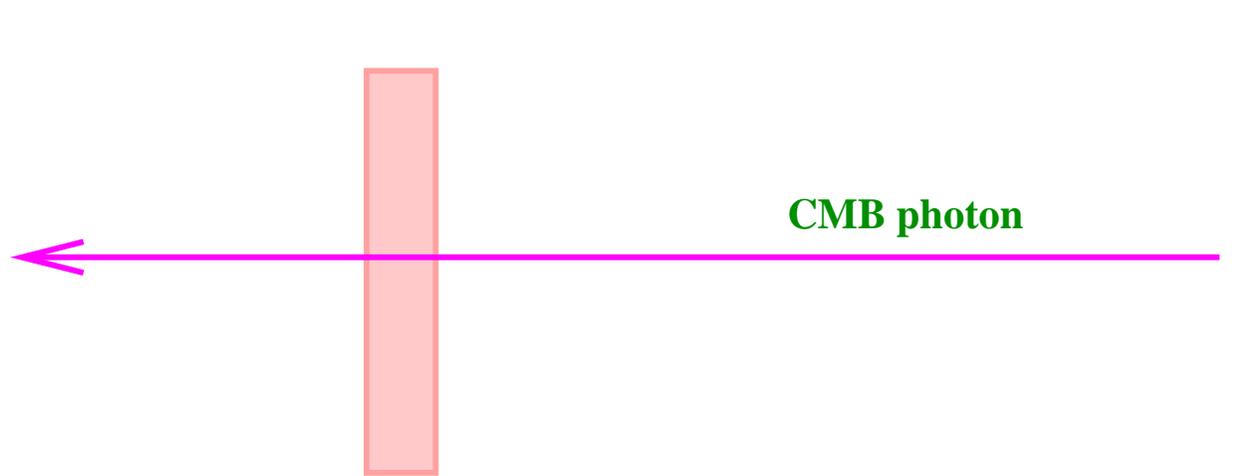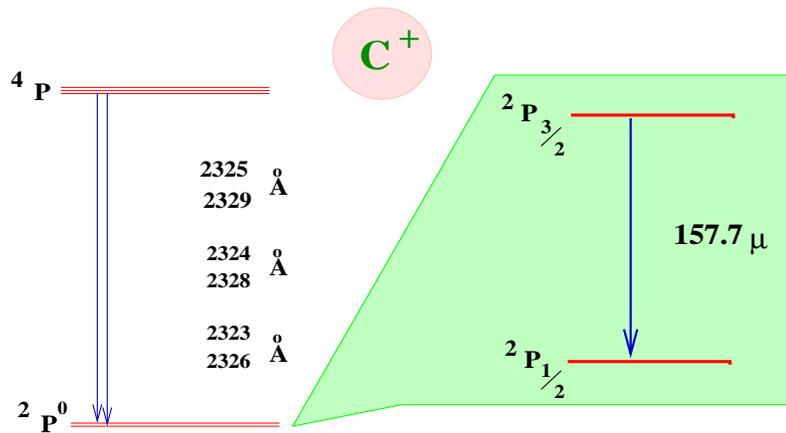
A-coefficient $\sim 10^{-6}$ s^{-1}

$\Rightarrow$ optical depth $\sim 10^{-5} - 10^{-7}$

353 GHz

CMB photon
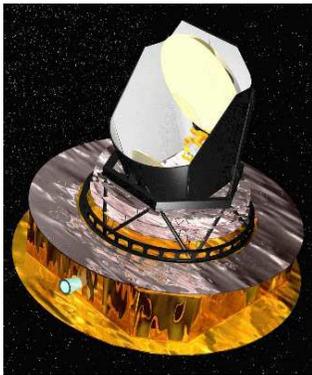
Planck HFI
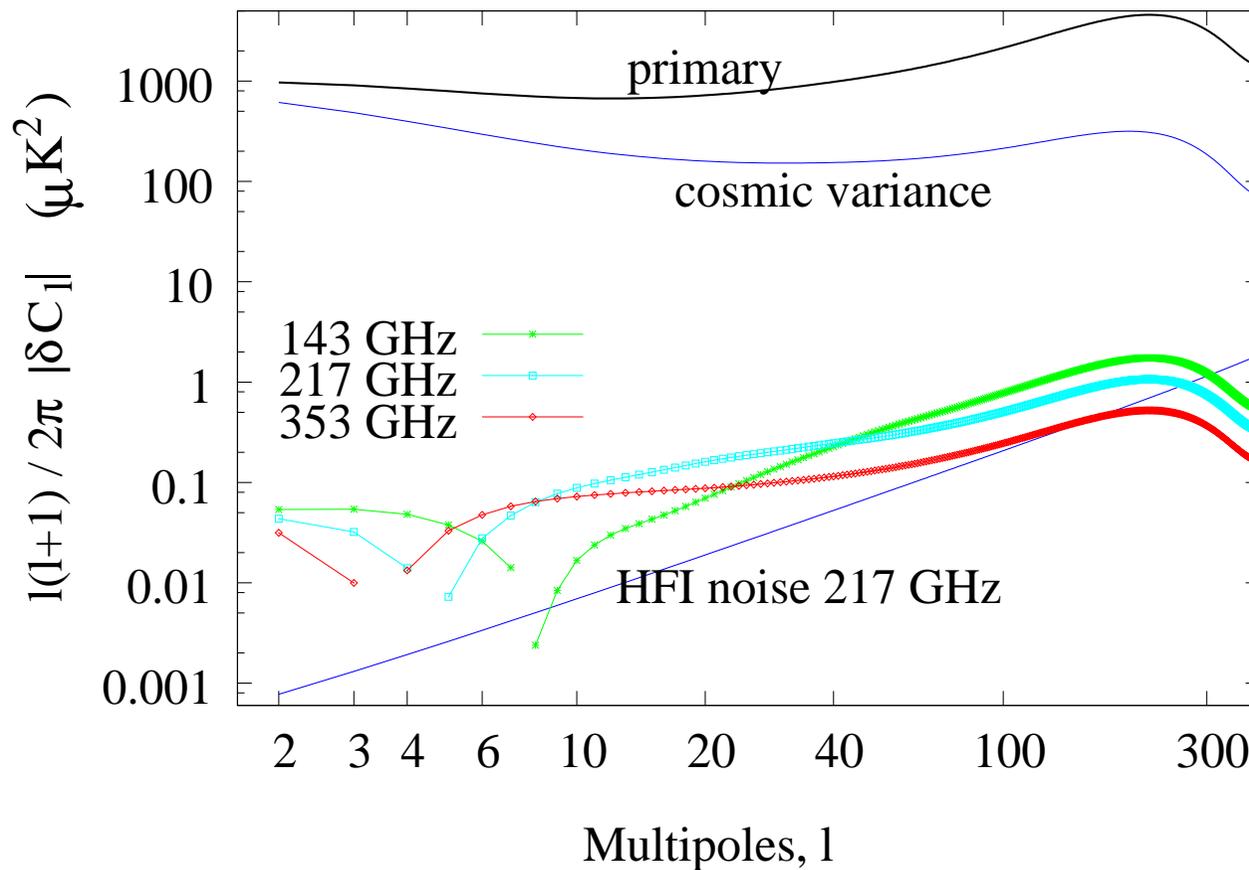
Bandwidth ~ 25%
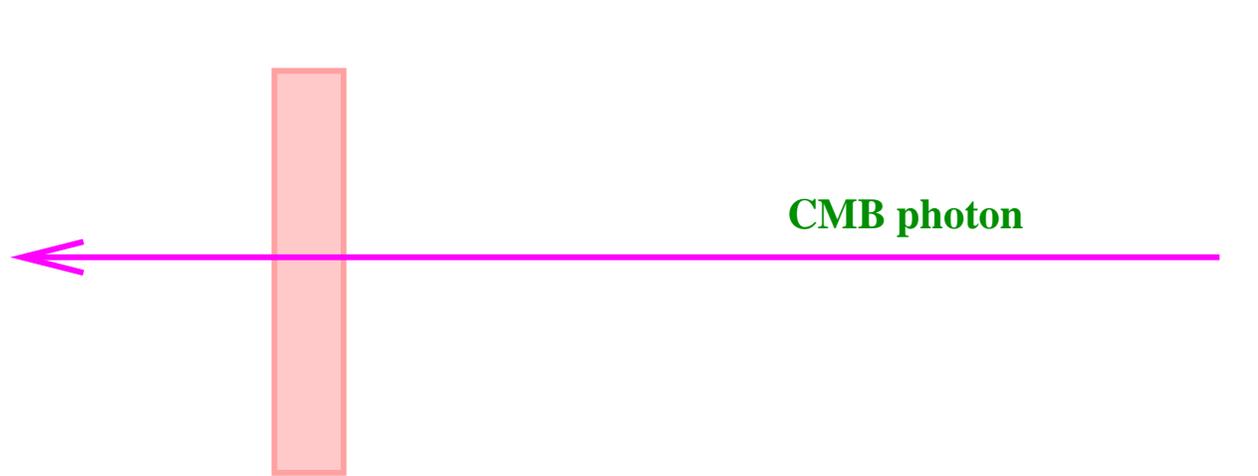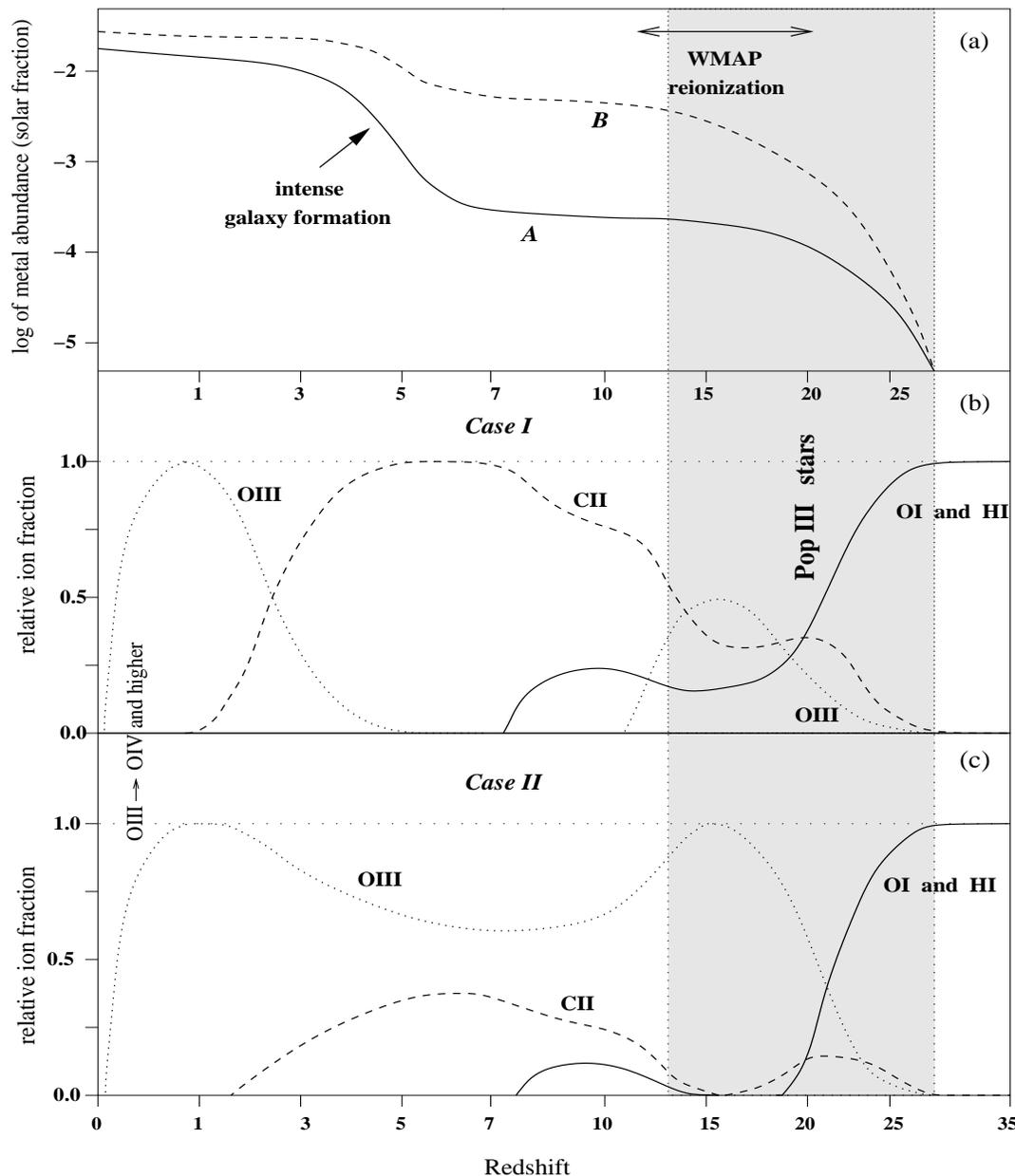
z ~ 4

LSS

at z=1100

Frequency dependent δC_l

At small angular scales ($l \gtrsim 200$), we have simply $\quad \delta C_l \simeq -2\,\tau_{X_i} C_l^{prim.}$
making prediction of effect very easy for ground-based experiments!

Constraining enrichment histories

Different ionization & enrichment histories will produce distinct power spectrum distortions
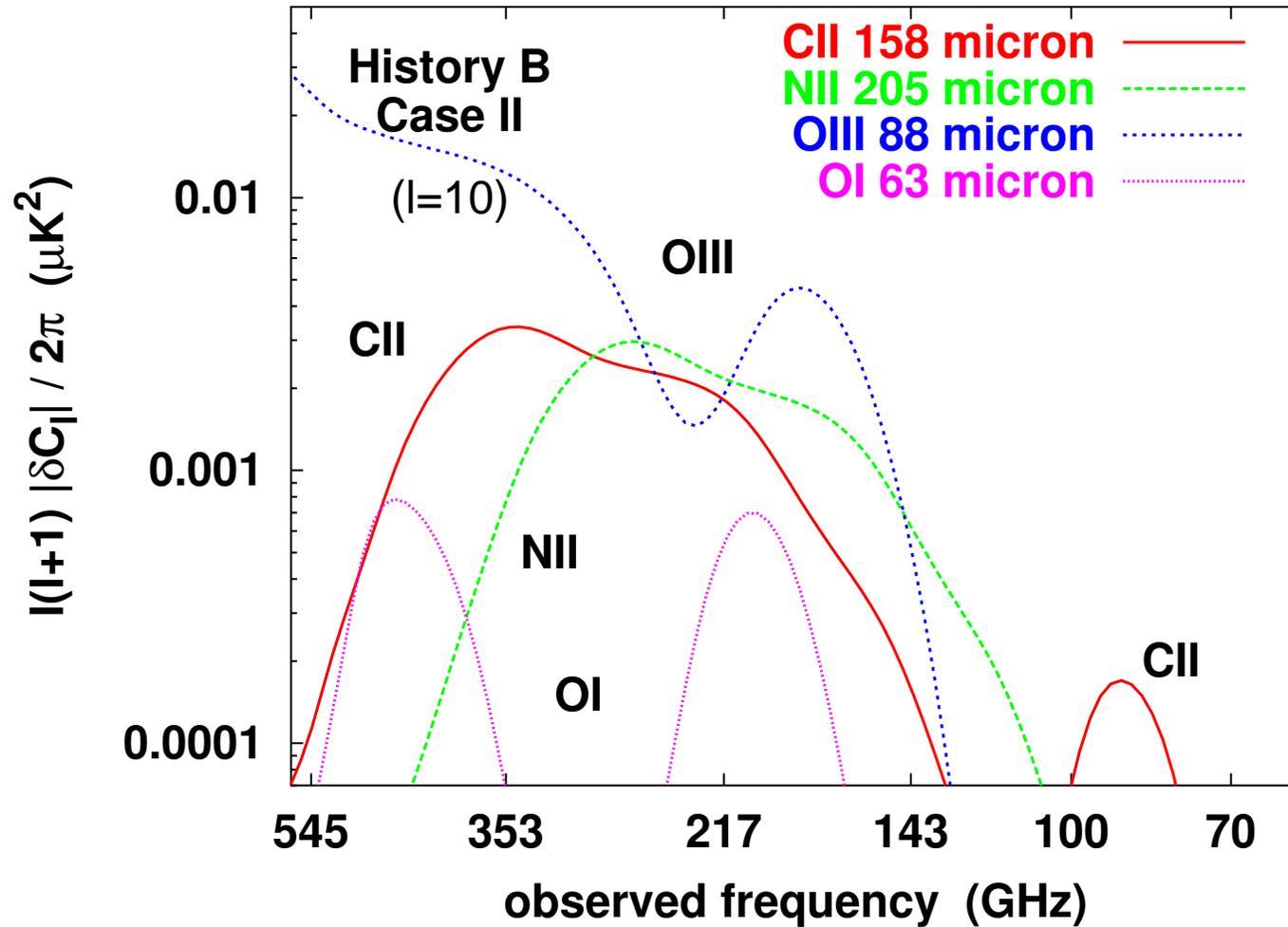
For details see:
K. Basu,
C. Hernández-Monteagudo
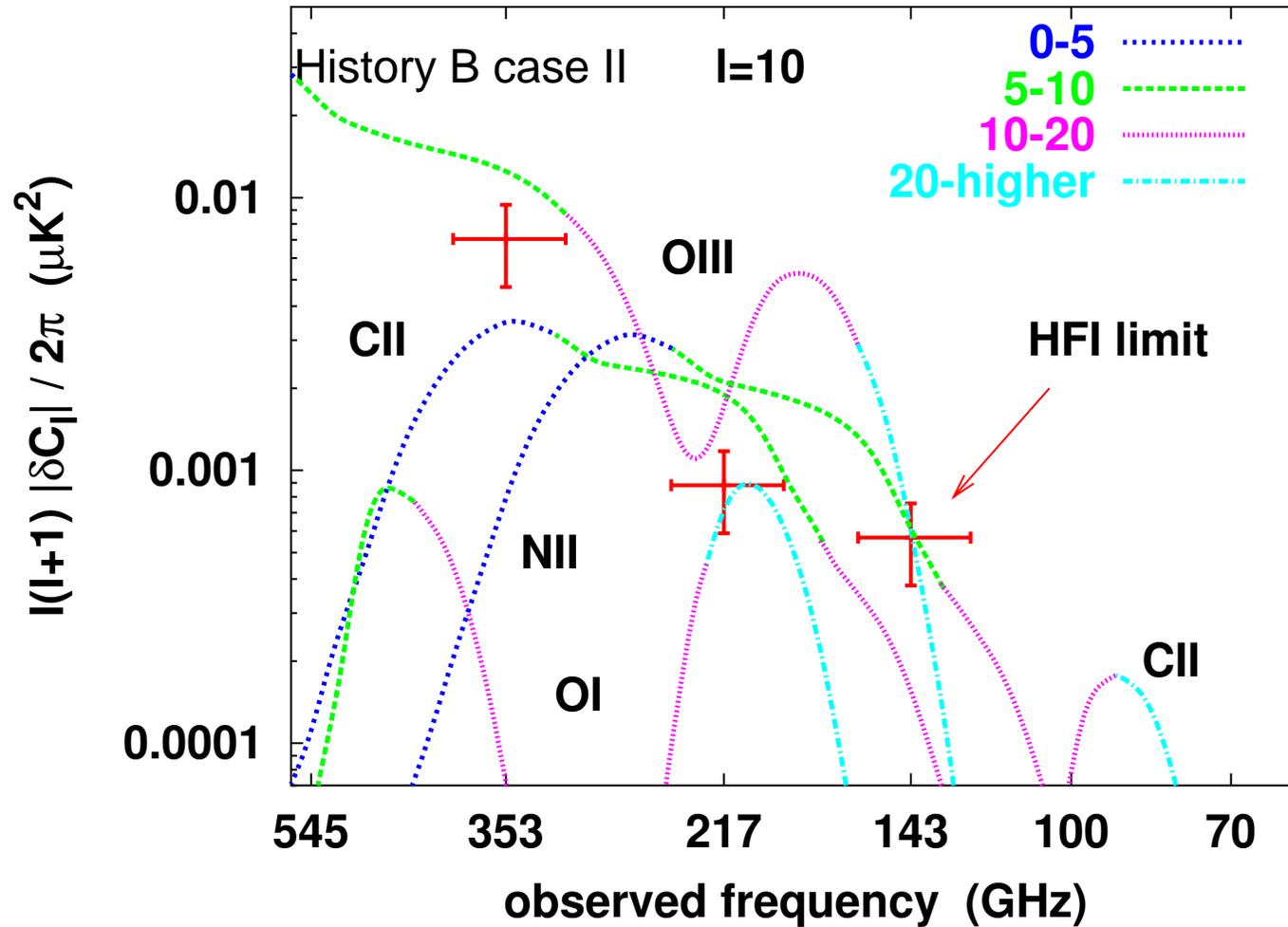**& R. Sunyaev**
A&A, 2004, 416, 447

(detailed formalism, minimum abundances, foreground issues, …)
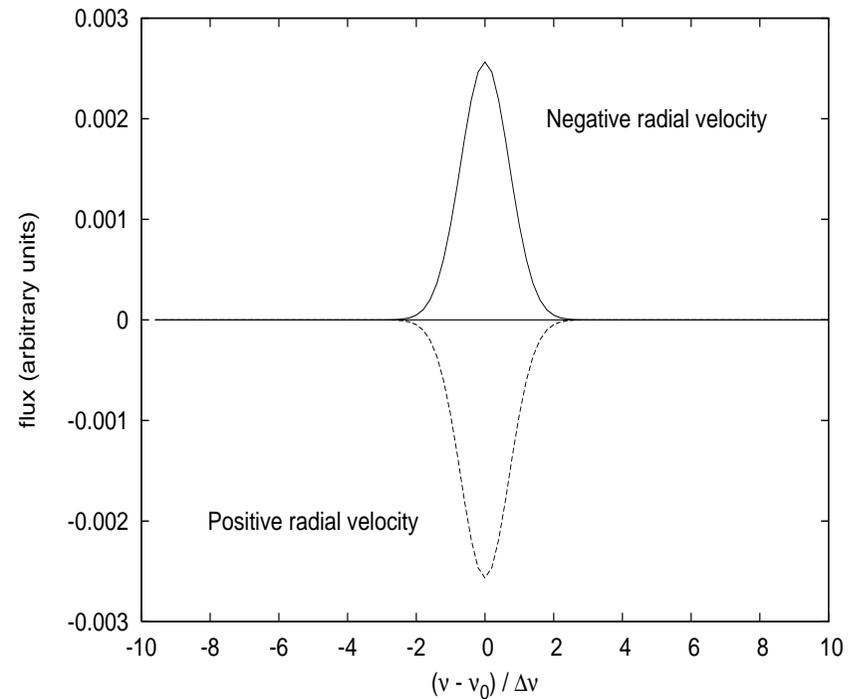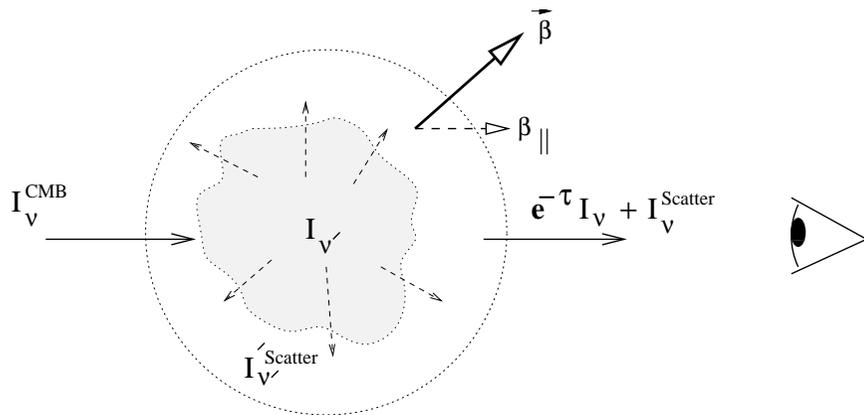
Constraining enrichment histories

Constraining enrichment histories

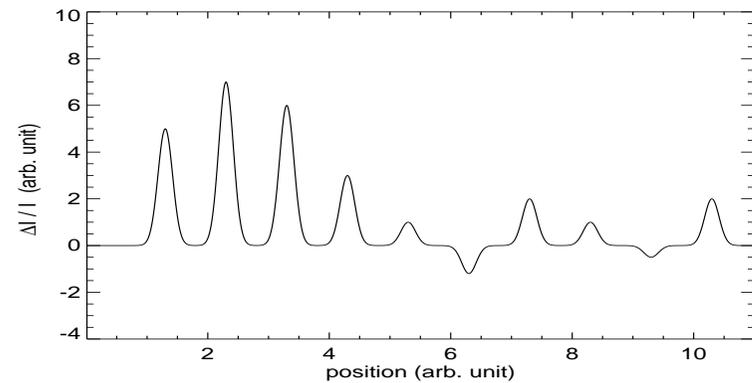# Signal from resonant scattering

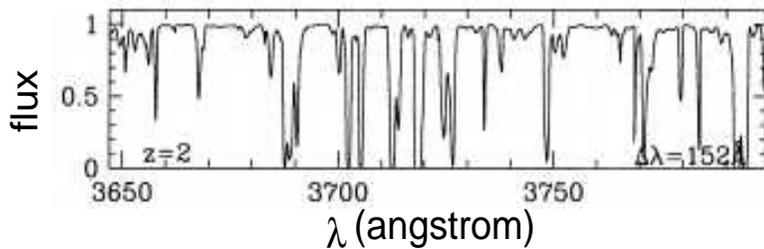**Very simple!** $\dfrac{\mathbf{\Delta T}}{\mathbf{T}} = \tau_\nu \, \dfrac{\mathbf{v}_{\text{rad}}}{\mathbf{c}}$ $\Rightarrow$ $\delta I_\nu = I_0 \, \dfrac{xe^x}{e^x - 1} \, \dfrac{\Delta T}{T}$; $x \equiv \dfrac{h\nu}{kT_{\text{CMB}}}$
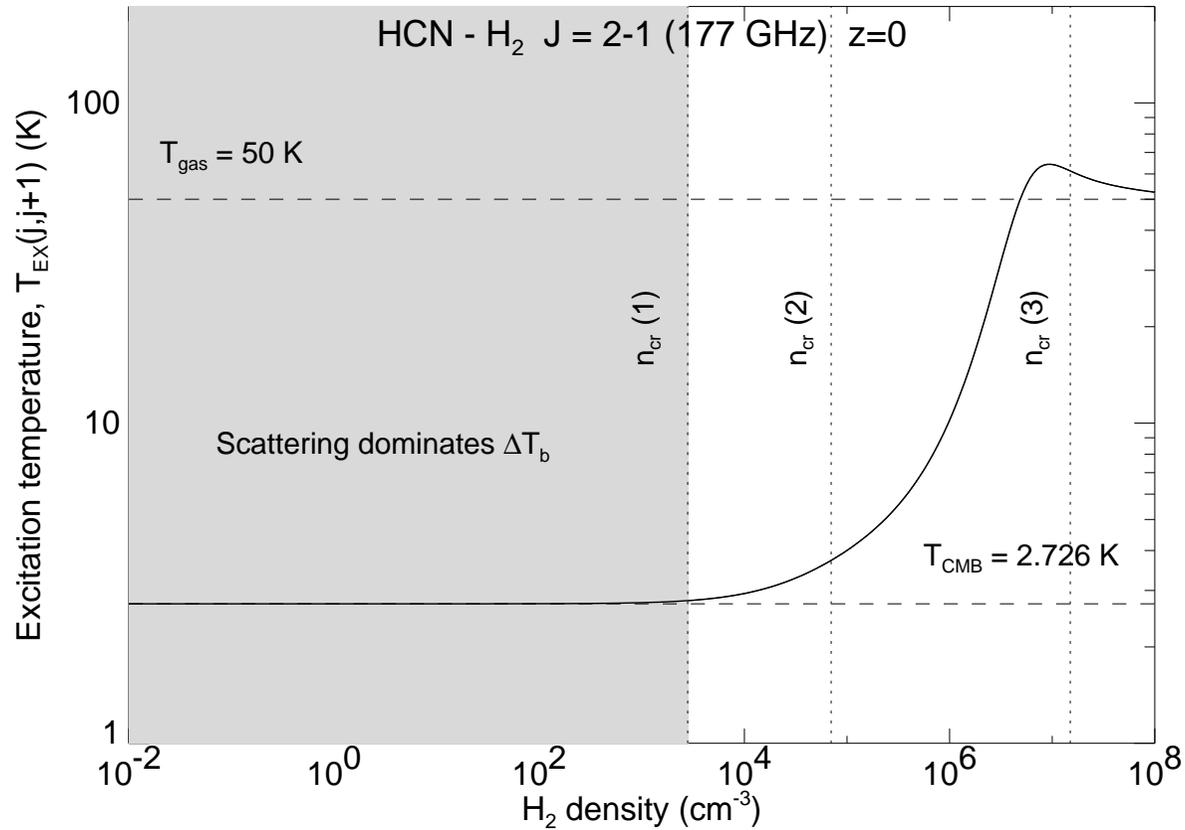
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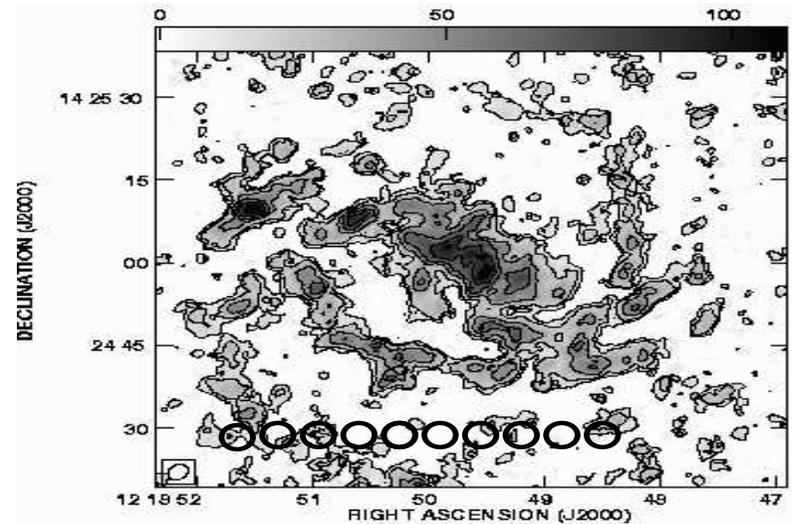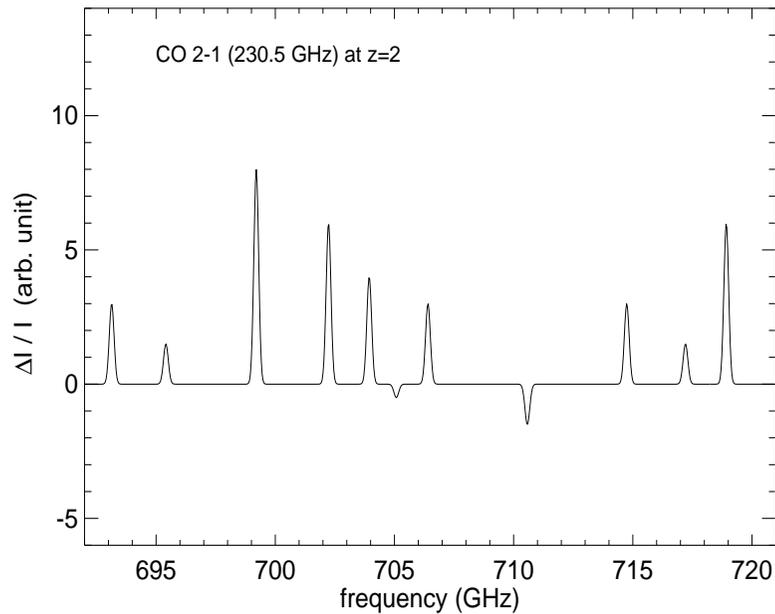
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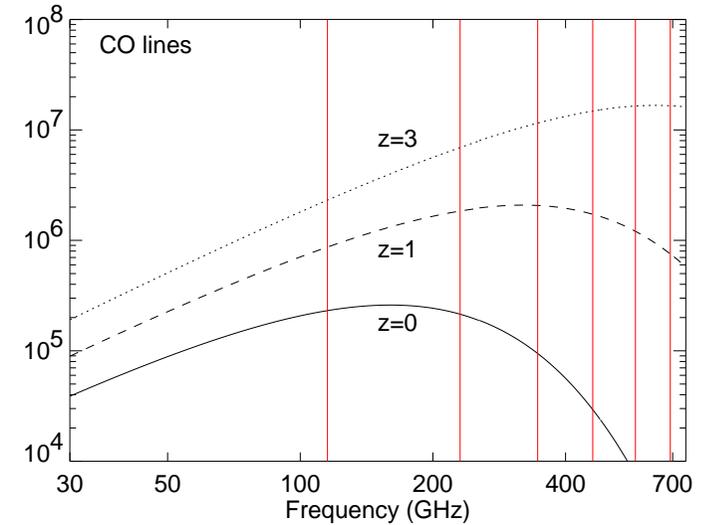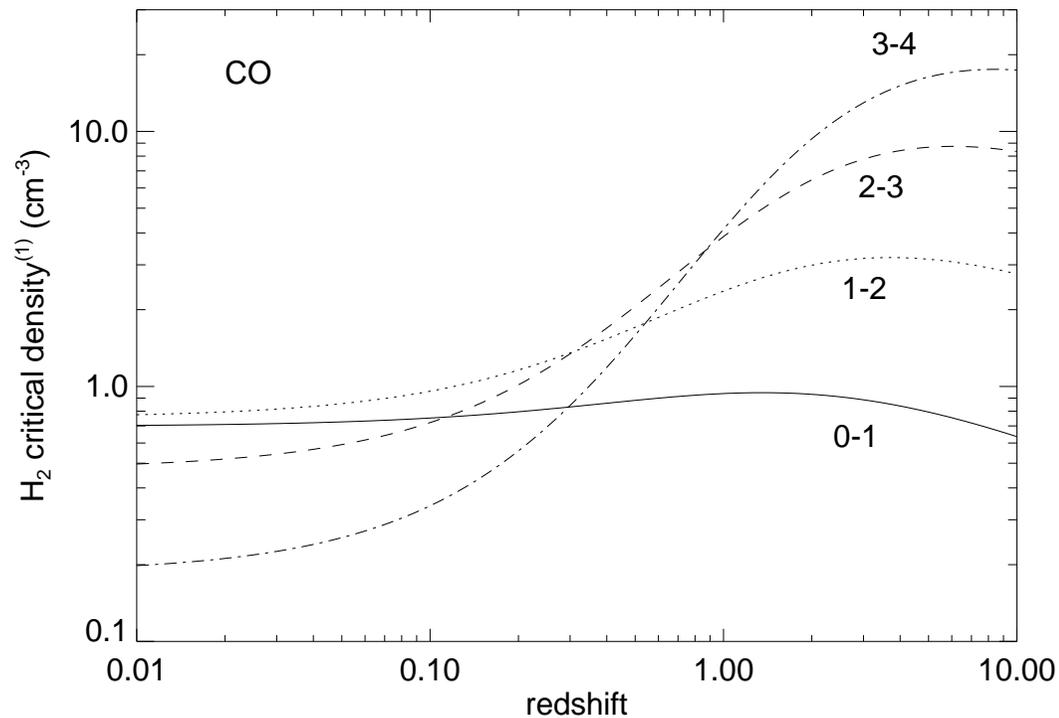
Scattering vs. Emission
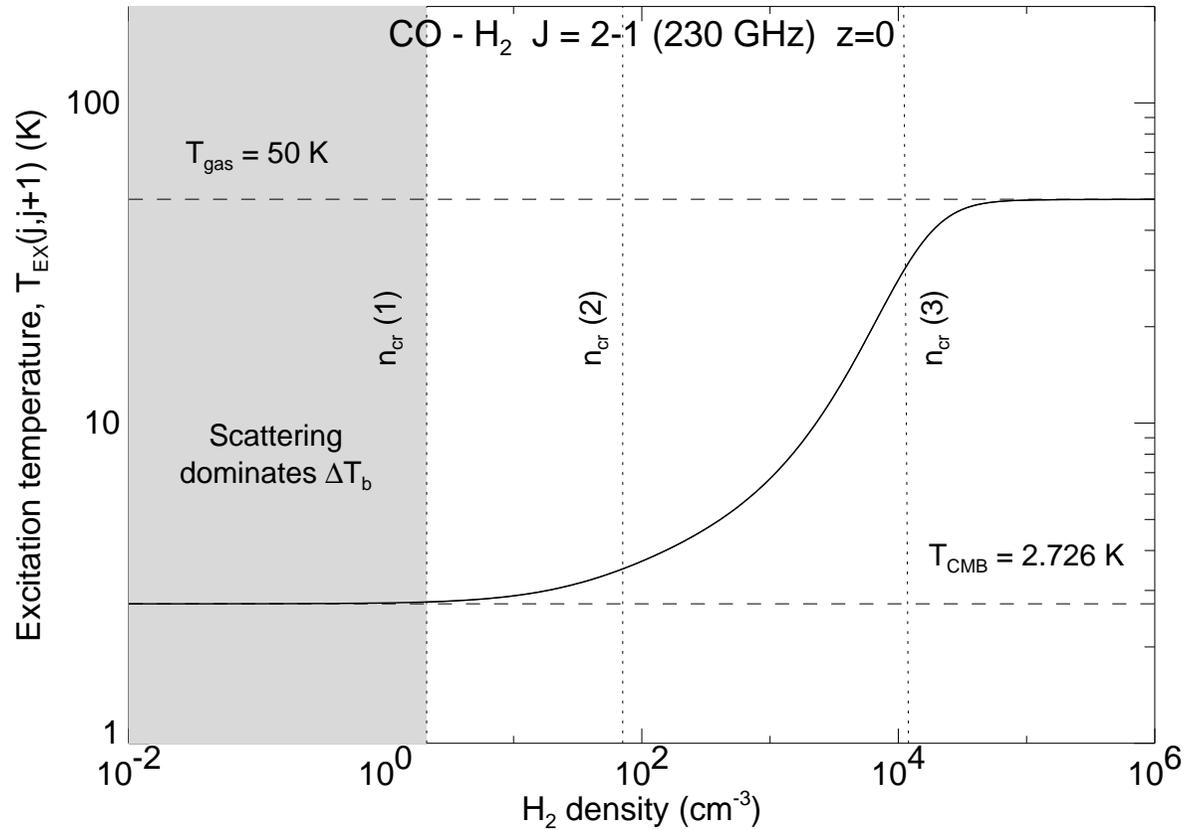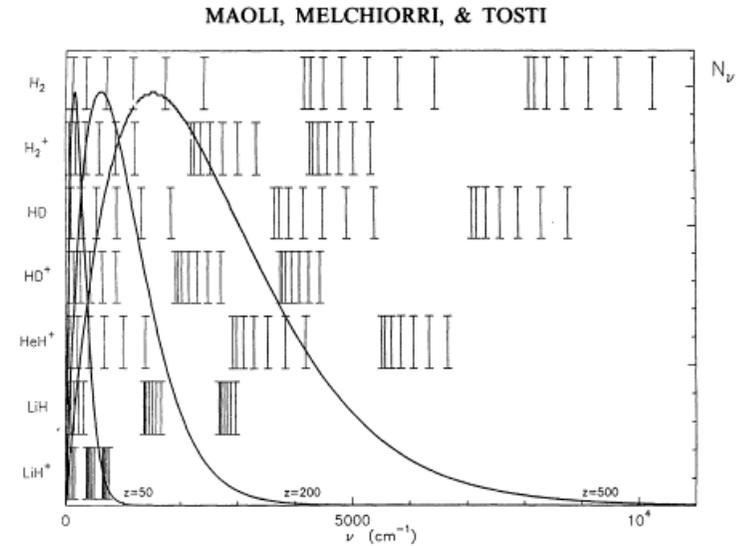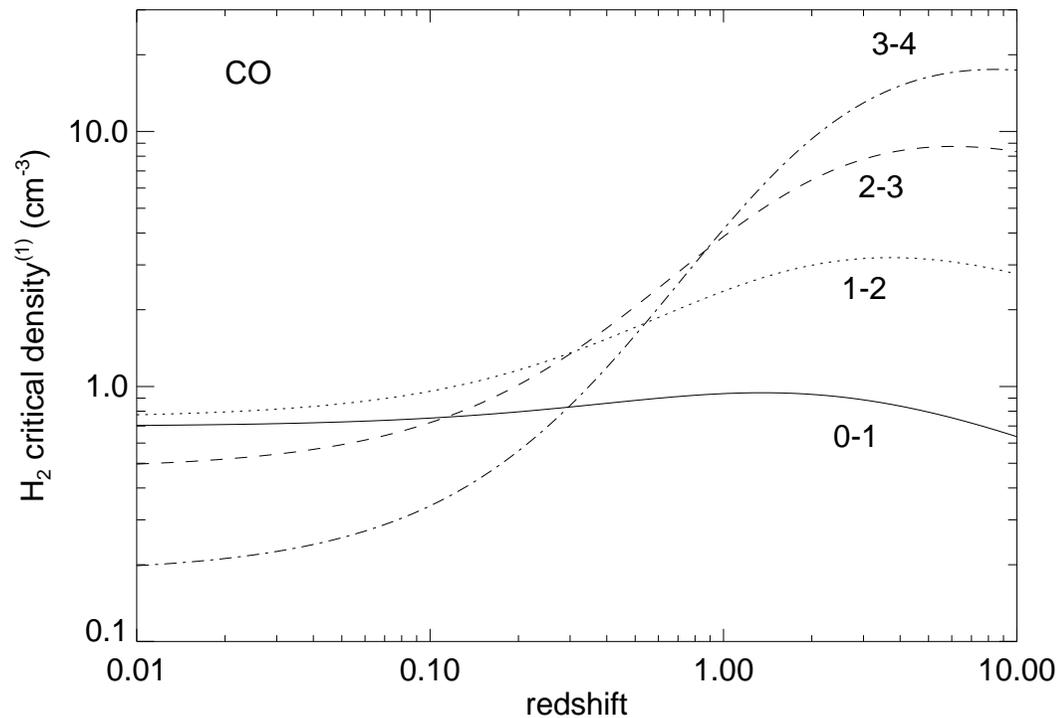
Scattering vs. Emission

Scattering vs. Emission

At high-z CMB becomes more effective
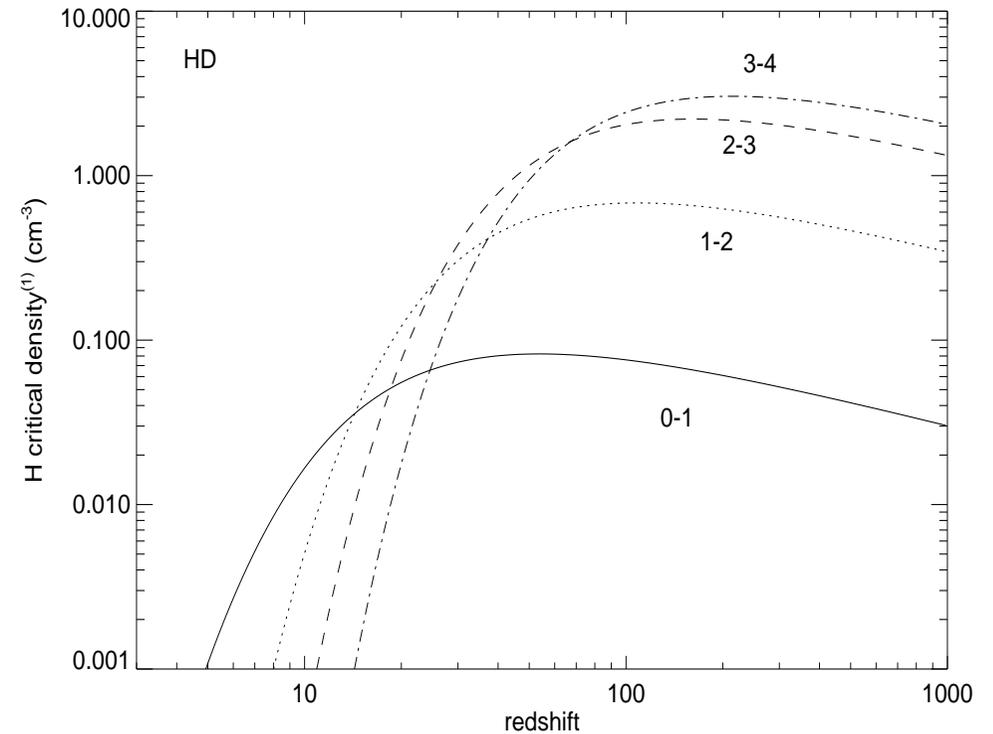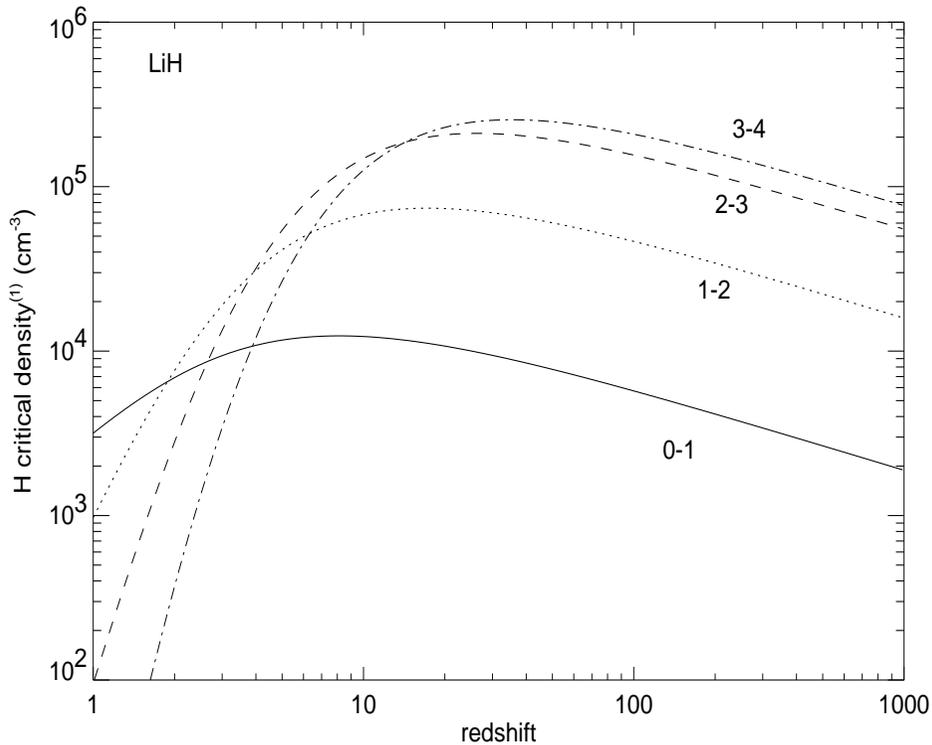higher rotational transitions show promise

Scattering vs. Emission

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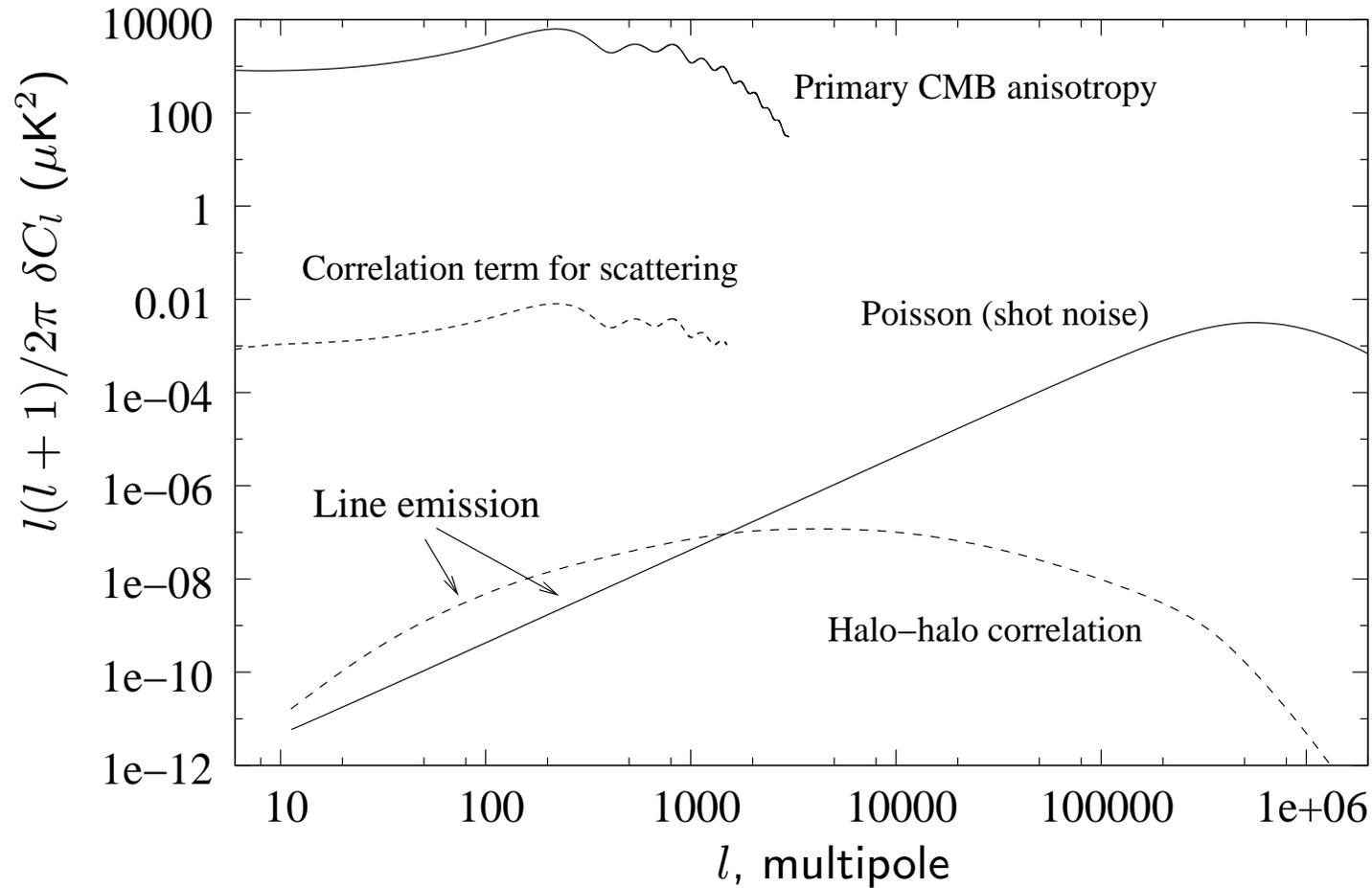higher rotational transitions show promise

Primordial molecules

Extremely low abundance of LiH ($\sim 10^{-19}$ at $z \lesssim 100$) is a serious drawback.
Weak dipole moment of the HD molecule is another problem.

Primordial molecules

In a nutshell...

- The effect discussed by Dubrovich, Maoli, Melchiorri and others is very difficult to observe directly in individual objects

- Most promising place to look for the signature of resonant scattering is in the <u>large scale</u> coherent distortion of the CMB *power spectrum*, because effect is linear to the abundance and have very distinct spectral dependence

- Scattering caused by the fine-structure transitions of atoms and ions, produced by the first stars in the universe, can help to put tight constraints on the ionization and enrichment history with upcoming experiments like the Planck HFI