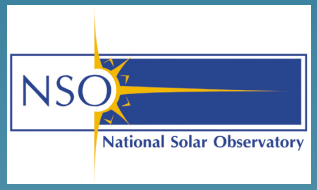
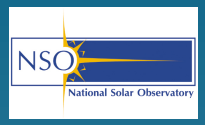
Elementary Fluxtubes and Coronal Heating

Han Uitenbroek
National Solar Observatory/Sacramento Peak

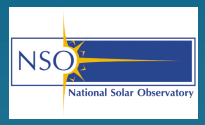


High-Resolution Magnetography from Space: Beyond Solar-B,
Hunstville AL, Apr 3-5, 2001

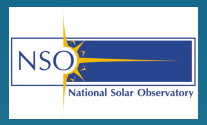


Elementary Fluxtubes and Coronal Heating

- Introduction
- Magnetostatic model of network element
  - Hydrogen ionization
  - Partial frequency Redistribution (PRD) in Lyman-α is important
- Conclusions

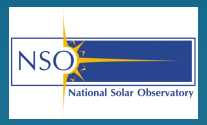


Multi-wavelength Stokes Spectroscopy and Sophisticated Radiative Transfer Modeling



Transition from Photosphere to Corona

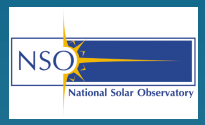
- Difficult to observe
  - Highly structured in three-dimensions
  - Transparent in almost all diagnostics, in particular those accessible from the ground



Transition from Photosphere to Corona

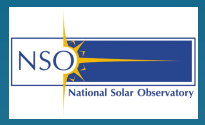
- Difficult to observe
  - Highly structured in three-dimensions
  - Transparent in almost all diagnostics, in particular those accessible from the ground

- Difficult to model
  - Not stationary, but highly dynamic
  - Transition from gas pressure ($\beta > 1$) to magnetic field ($\beta < 1$) dominance
  - Transition from optically thick ($\tau > 1$) to optically thin ($\tau < 1$)



To solve the problem of Coronal heating:

- How the structure structure of the small-scale solar magnetic field changes when we progress from the photosphere through the chromosphere up to the corona



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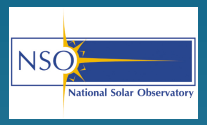

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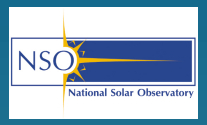

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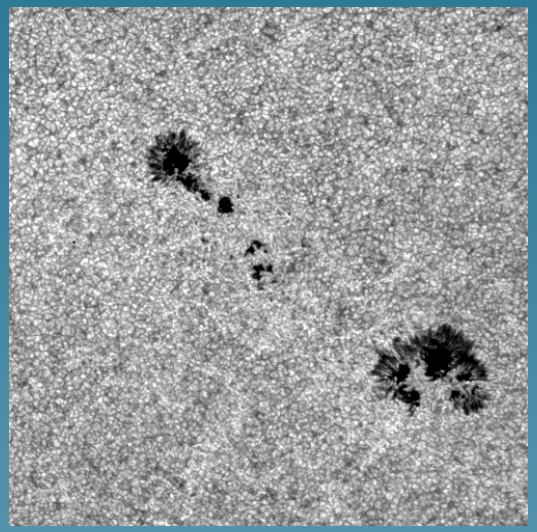
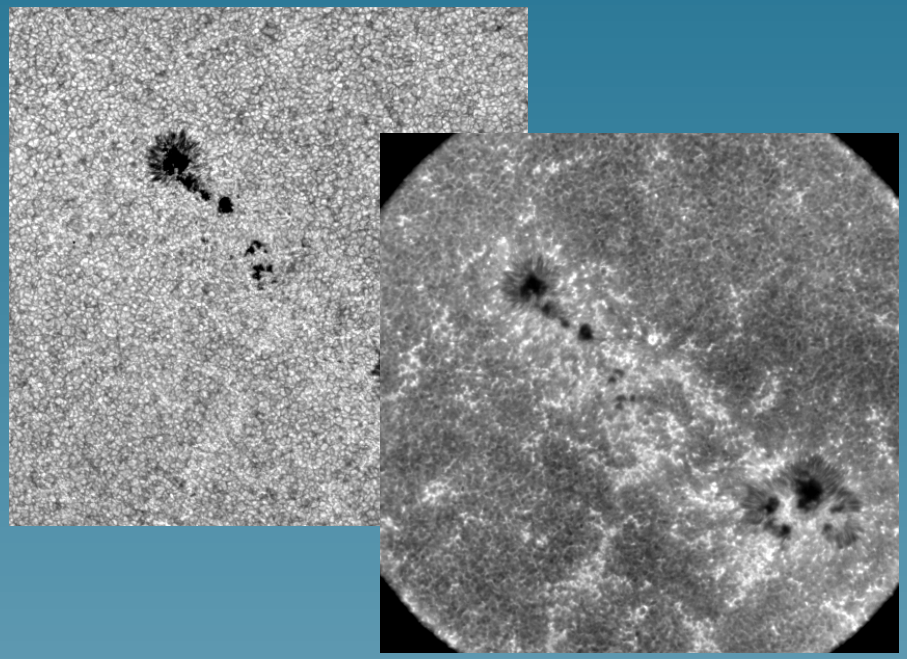
- Can we explain the vertical peristence of the magnetic network?

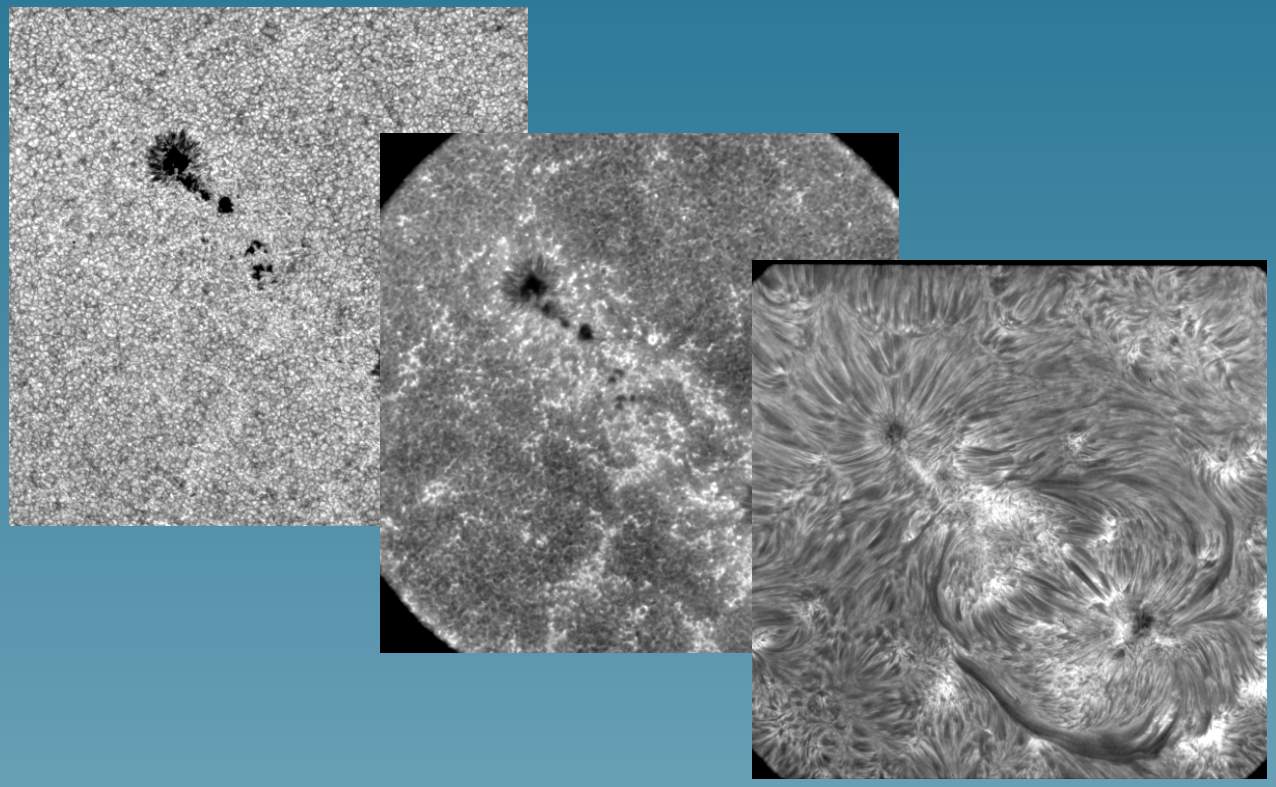
Photosphere $\rightarrow$



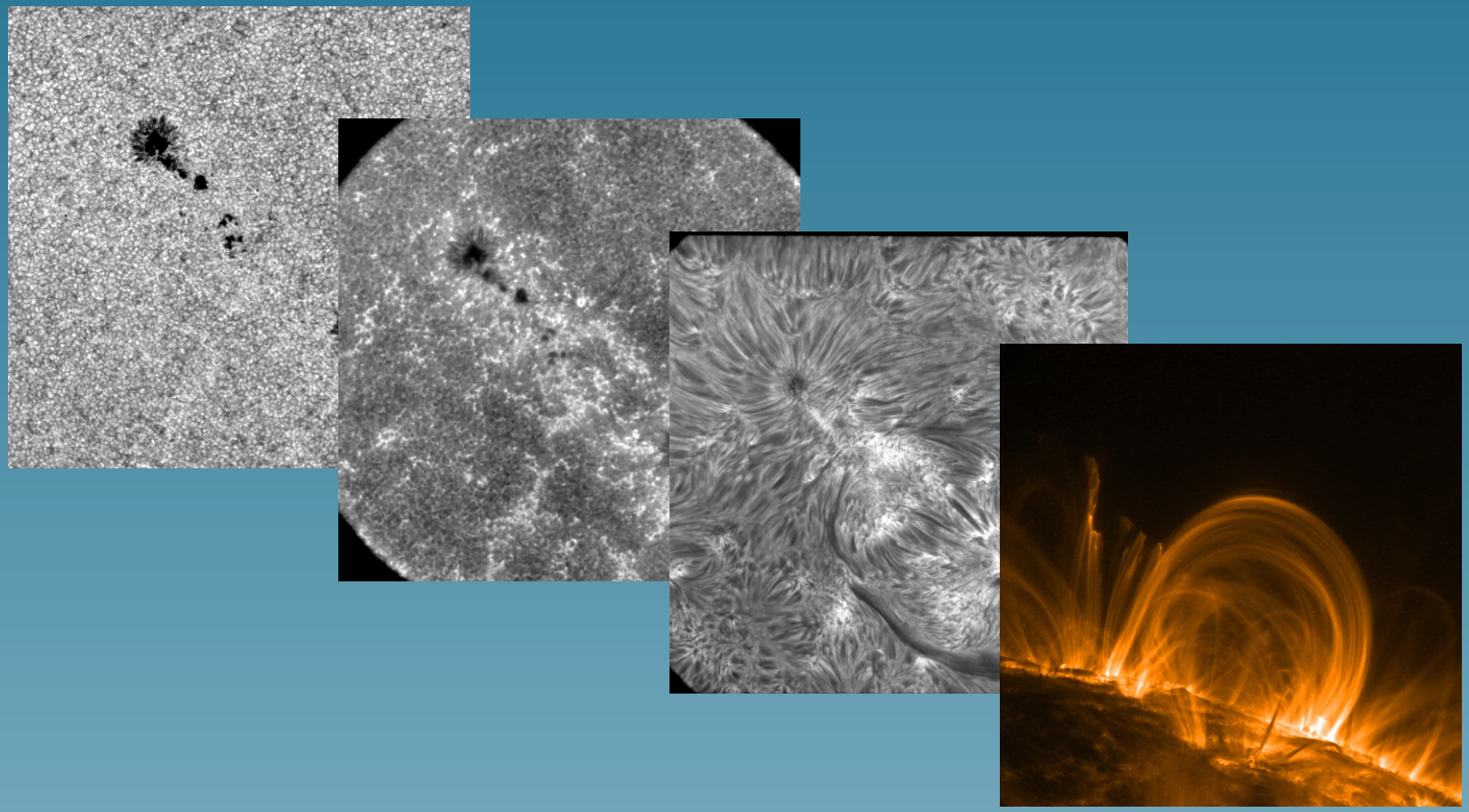
Photosphere $\rightarrow$ lower Chromosphere $\rightarrow$



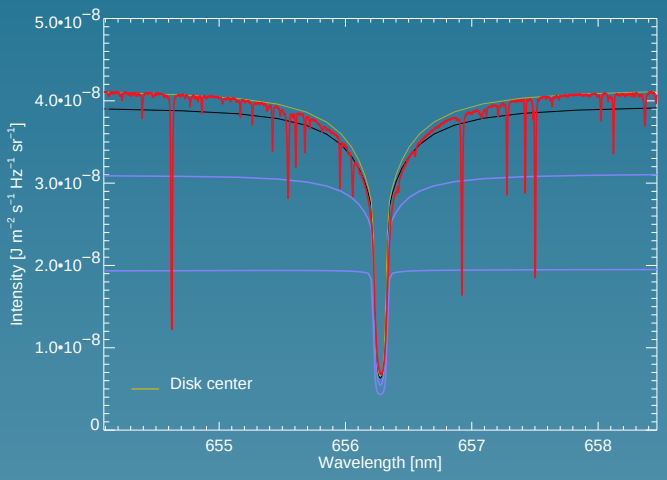
Photosphere → lower Chromosphere → upper Chromosphere →



Photosphere → lower Chromosphere → upper Chromosphere → Corona



H-α is important diagnostic



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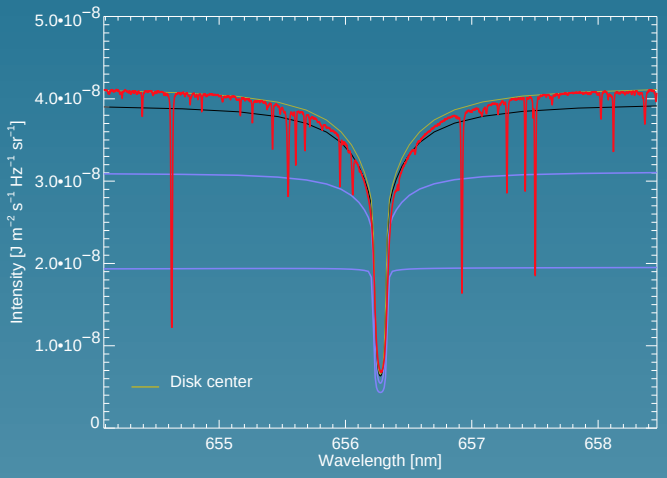
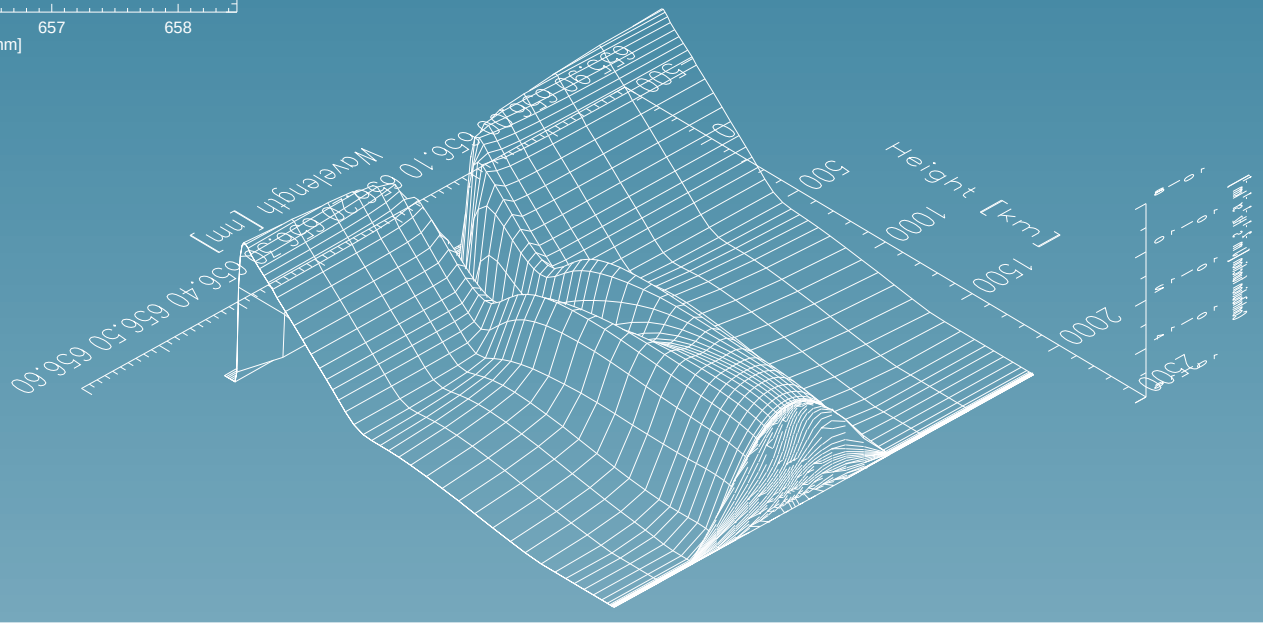
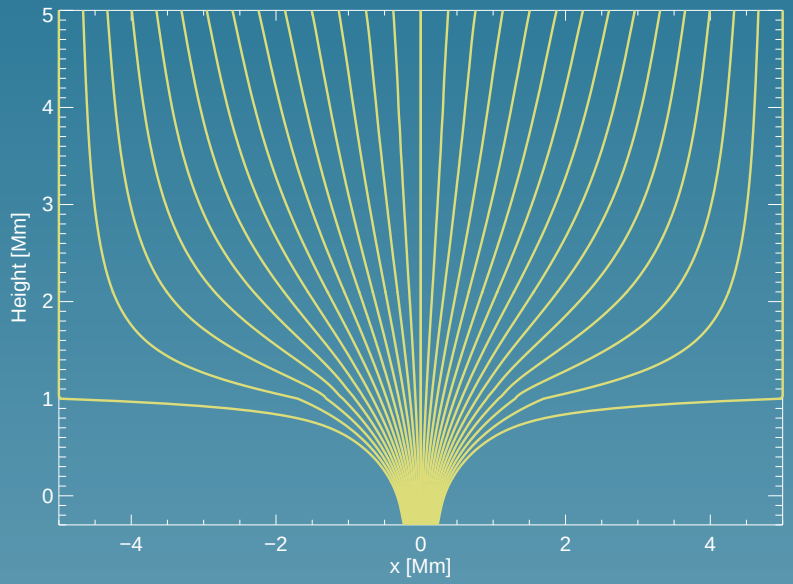


- Double-peaked contribution function
- Large velocities and steep flanks
- Scattering line core



Two-dimensional network model

Magnetostatic models together with Aad van Ballegooijen (CfA)



Fluxtube in magnetostatic equilibrium:

$$-\nabla p + \rho g + (4\pi)^{-1}(\nabla \times B) \times B = 0$$

Two-dimensional network model (2)

Pressure balance with the surroundings below the canopy:

$$p_{\rm int}(z) + B^2_{\rm int}(z)/8\pi = p_{\rm ext}(z)$$

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$$W = \int_{z_b}^{z_t} \int_0^{R(z)} \left(\frac{B^2}{8\pi} - p(\Phi, z) \right) 2\pi r dr dz + \int_{z_b}^{z_t} p_{\rm ext}(z) \pi R^2(z) dz$$

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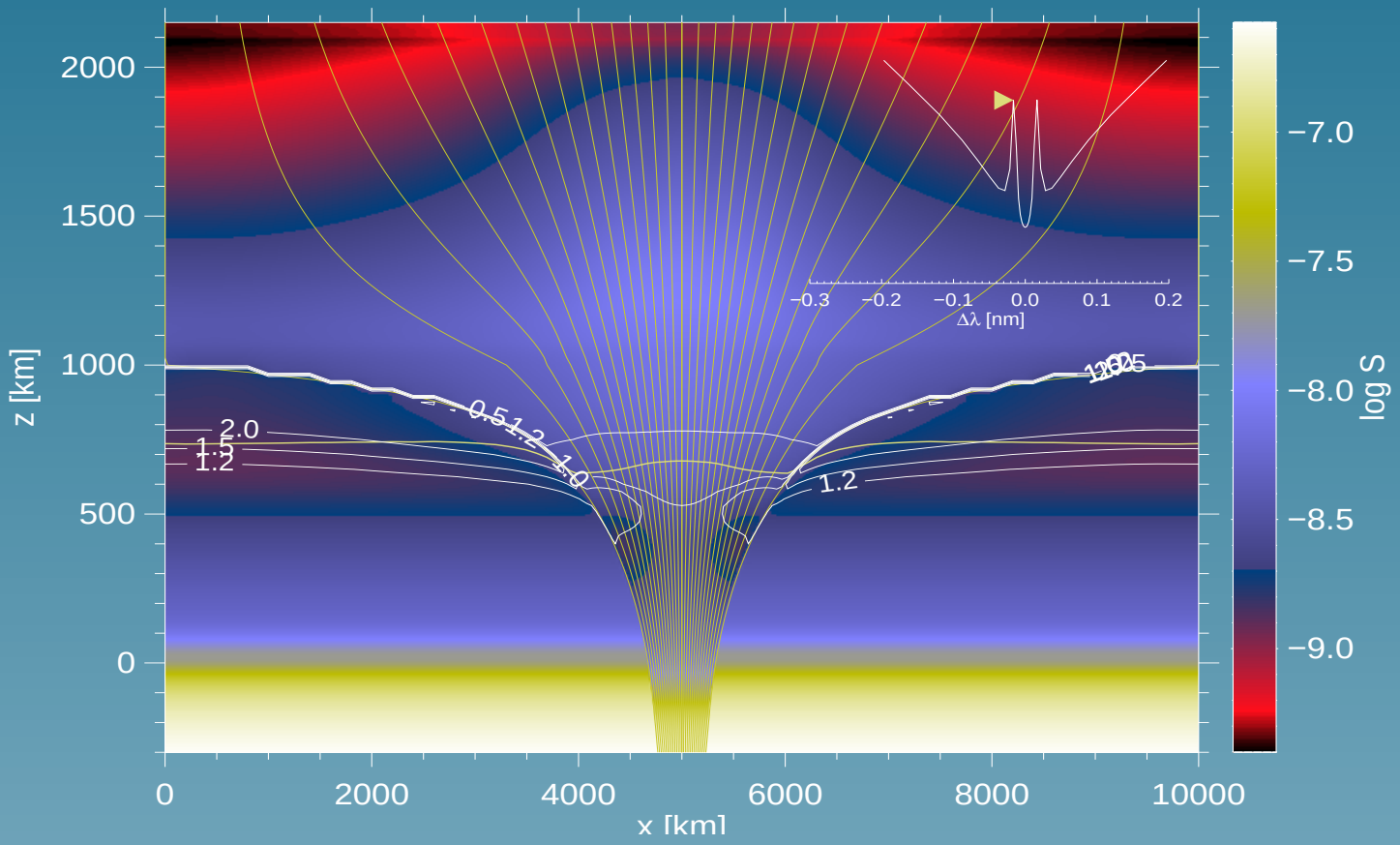
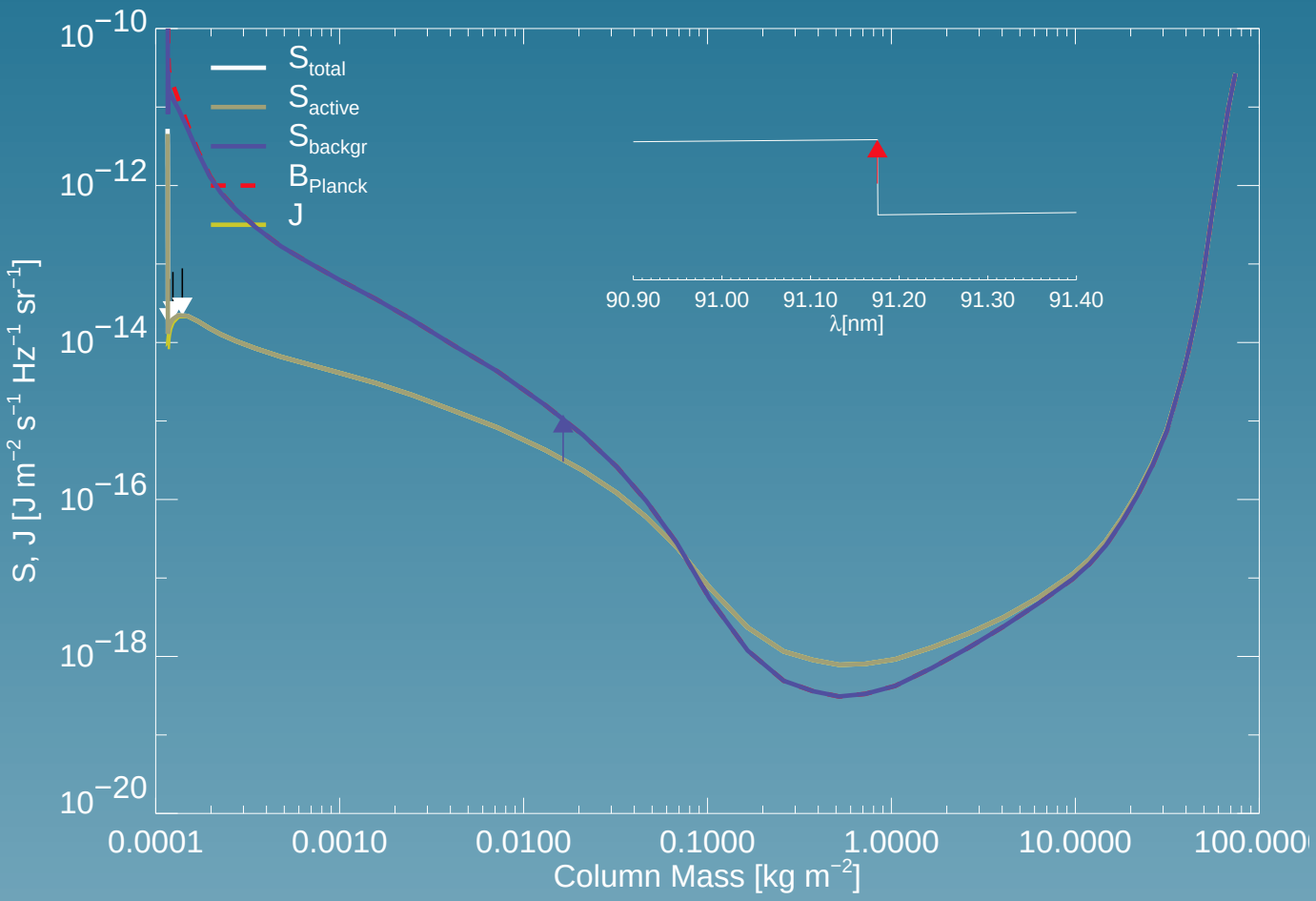
Temperature $T(r, z)$ and electron density $N_e(r, z)$ for given $p(r, z)$ and $\rho(r, z)$ are computed consistent with global radiative transfer in hydrogen (Lyman and Balmer continua, Ly-α, Ly-β, and H-α).

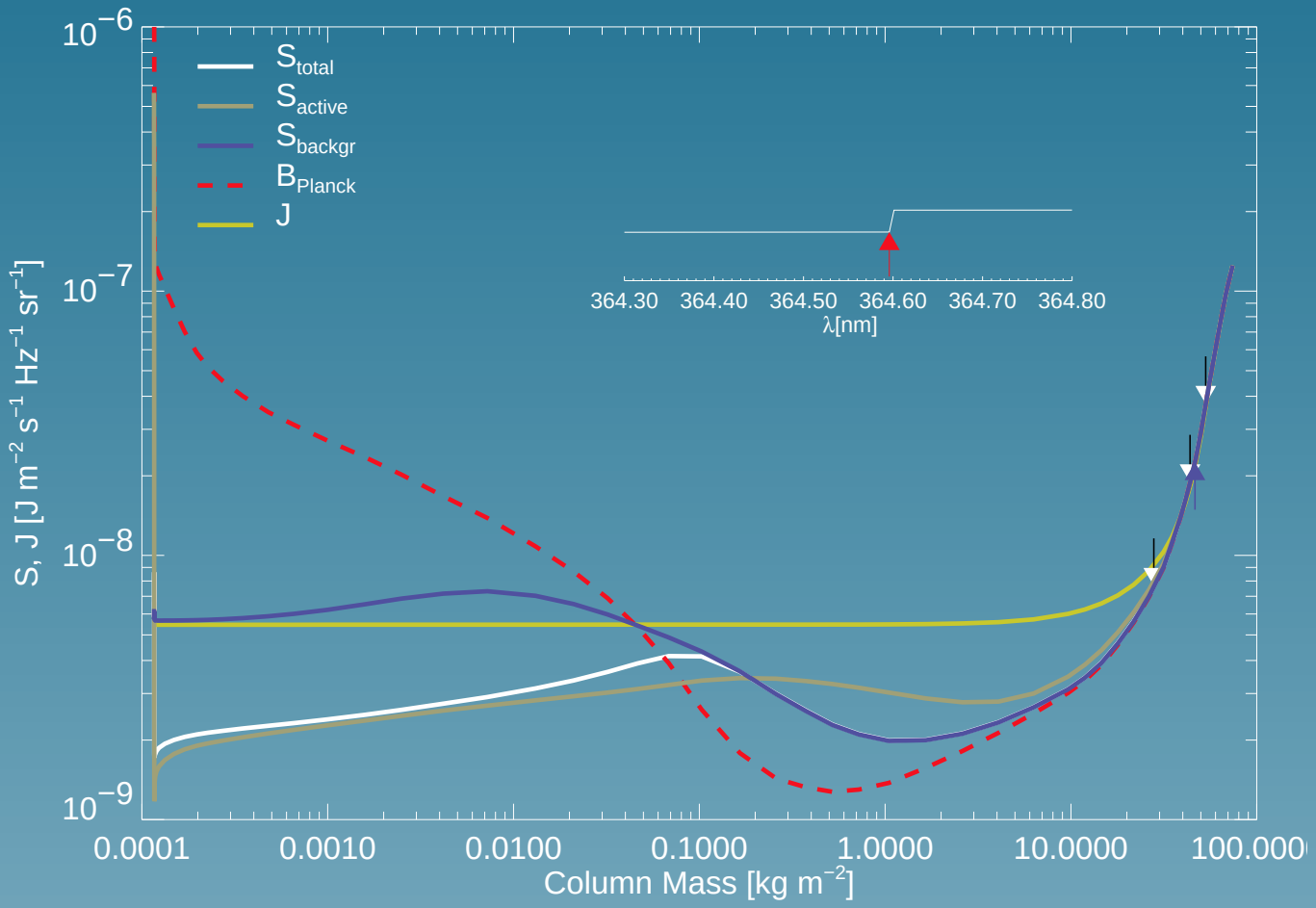
Network Model



Hydrogen ionization — Lyman continuum



Hydrogen ionization — Balmer continuum



Partial Frequency ReDistribution (PRD)

$$\frac{\psi_{ij}^{\mathrm{PRD}}(\nu)}{\phi_{ij}(\nu)} = 1 + \frac{n_i B_{ij}}{n_j P_j} \int d\nu' \, J(\nu') \left[\frac{R_{kji}(\nu, \nu')}{\phi_{ij}(\nu)} - \phi_{kj}(\nu') \right] \qquad (1)$$

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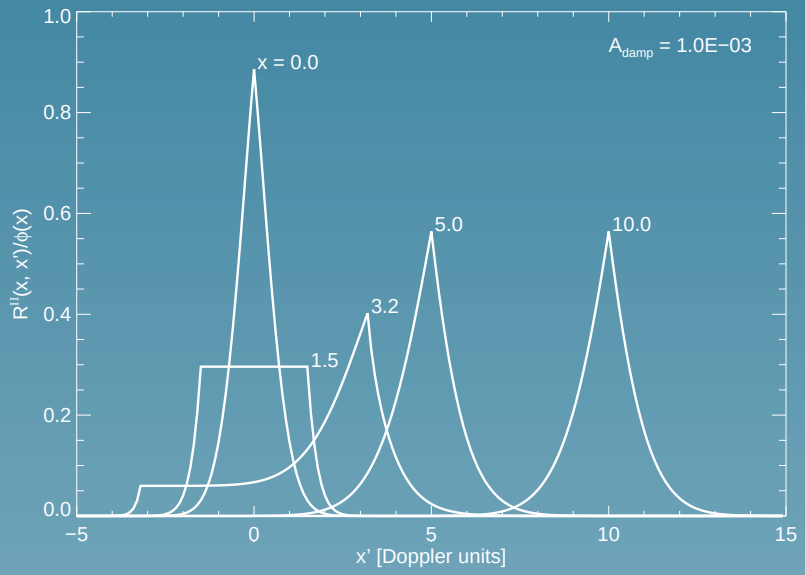

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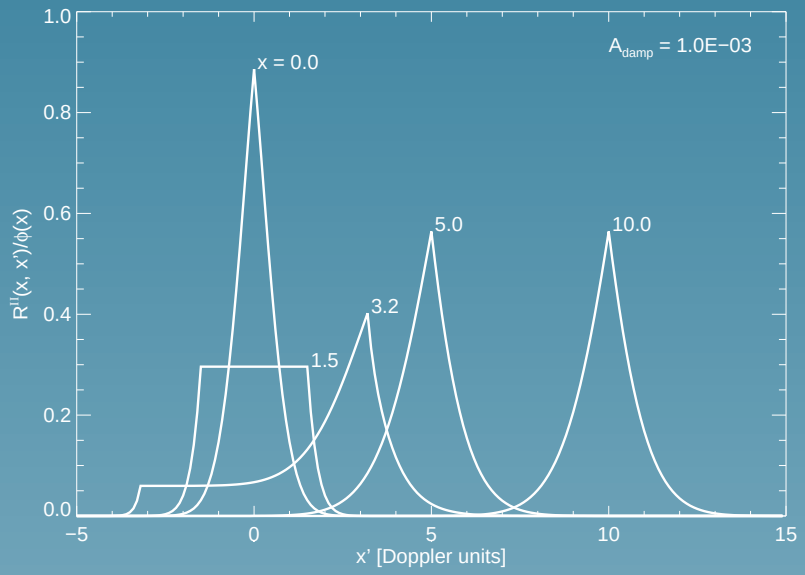
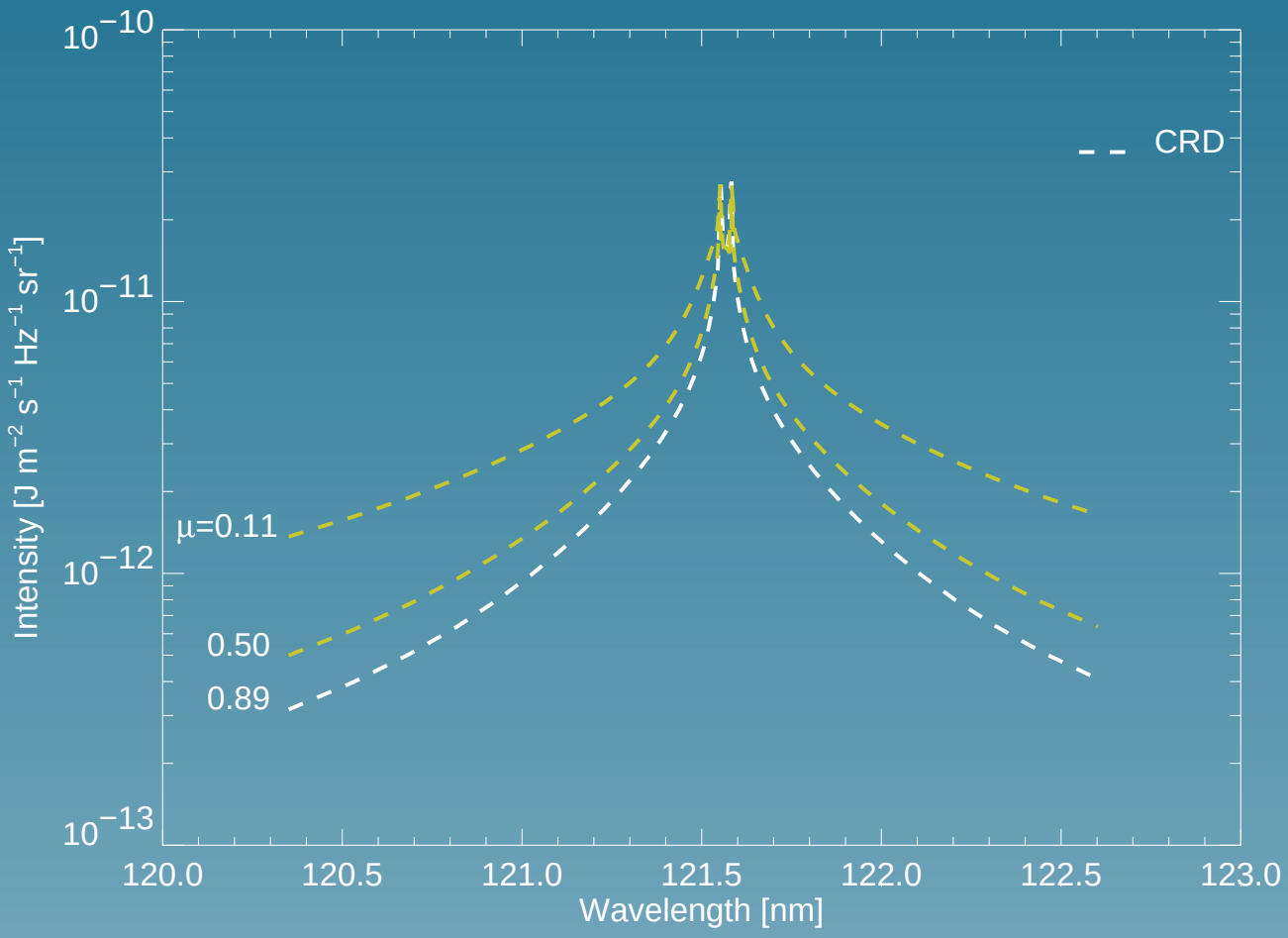


- Complete redistribution in core
- Coherent scattering in the wings
- Decoupling of wing source function

Hydrogen Lyman–α profiles (quiet-Sun)



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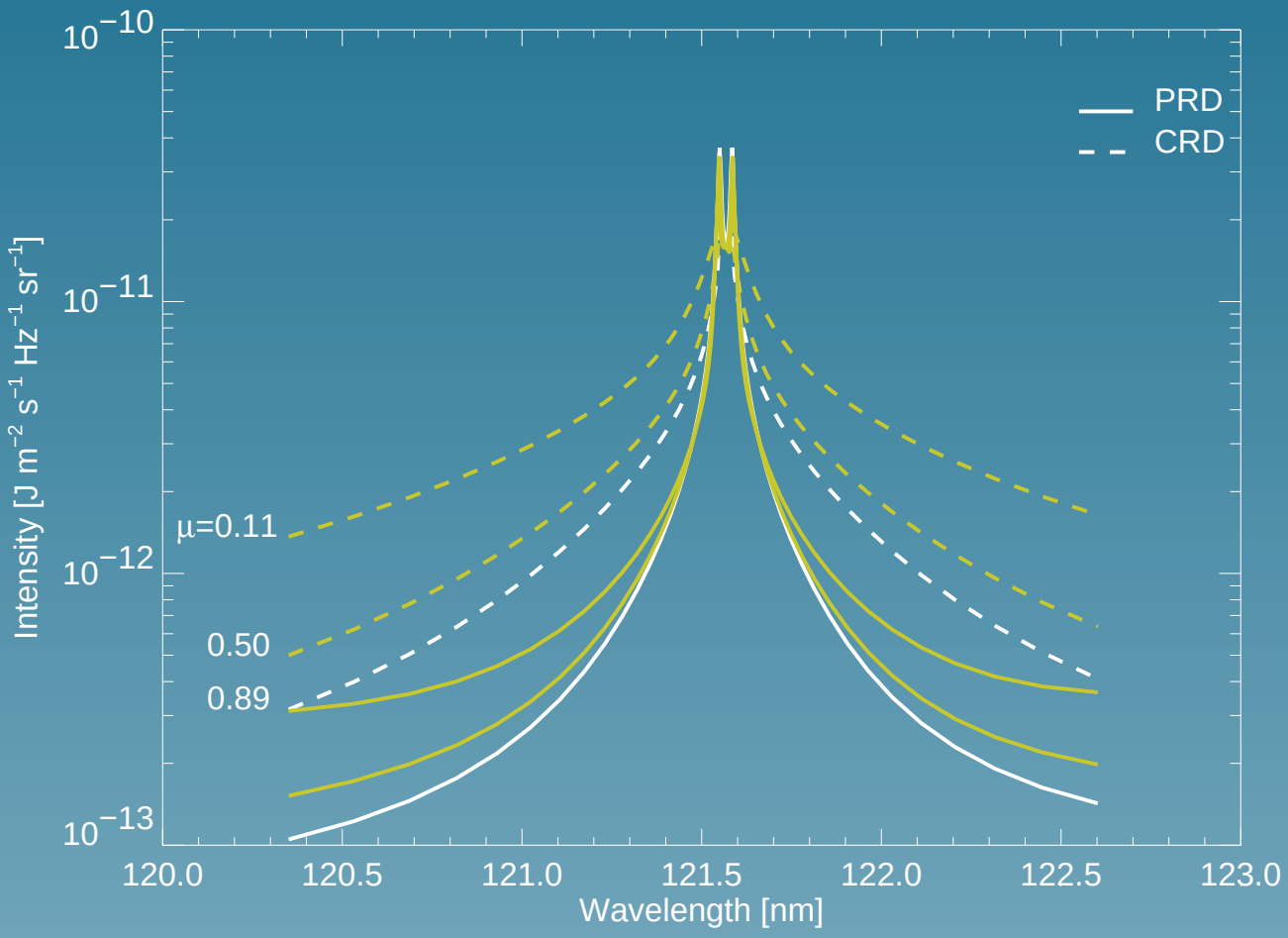
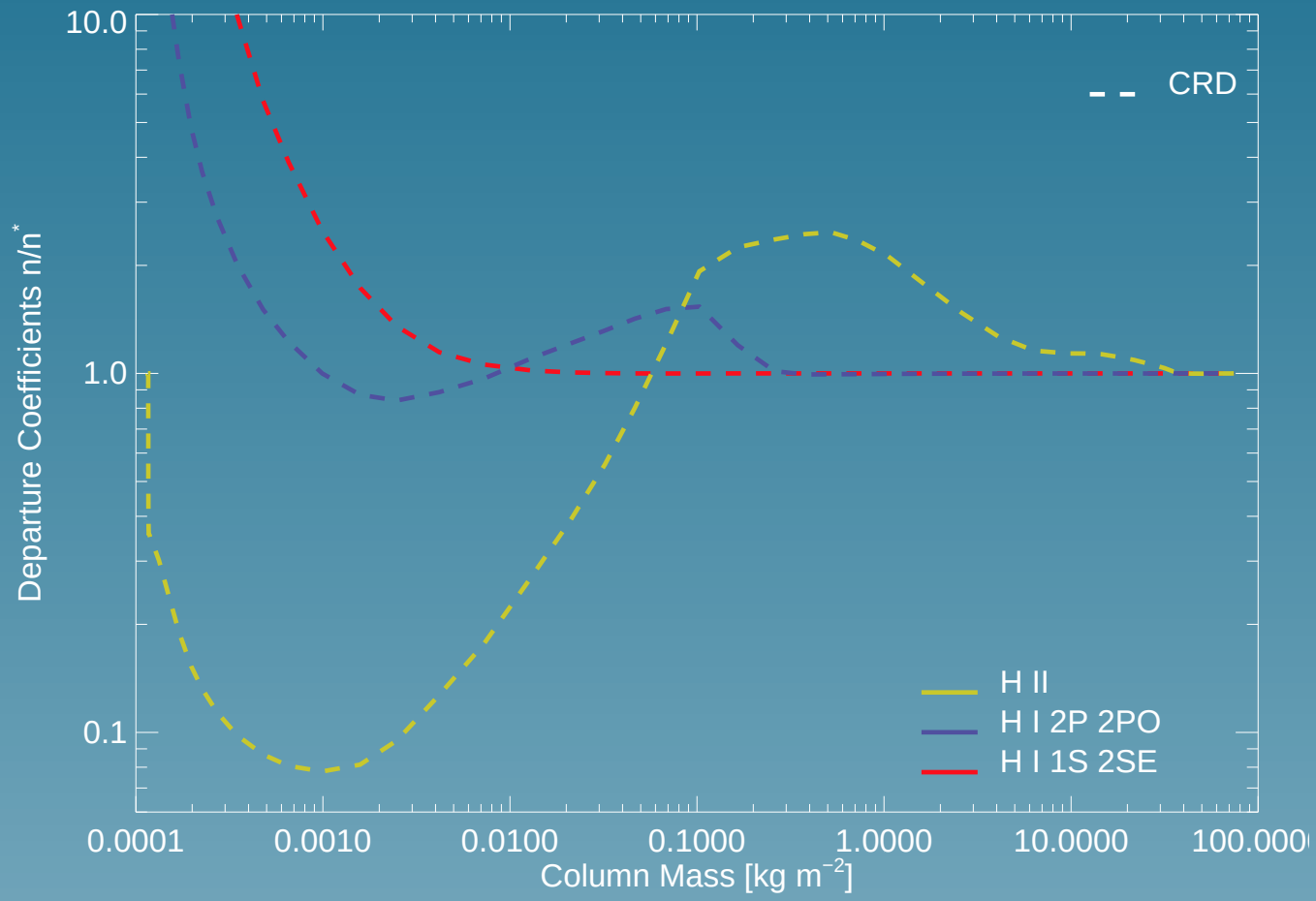


Hydrogen Departure Coefficients



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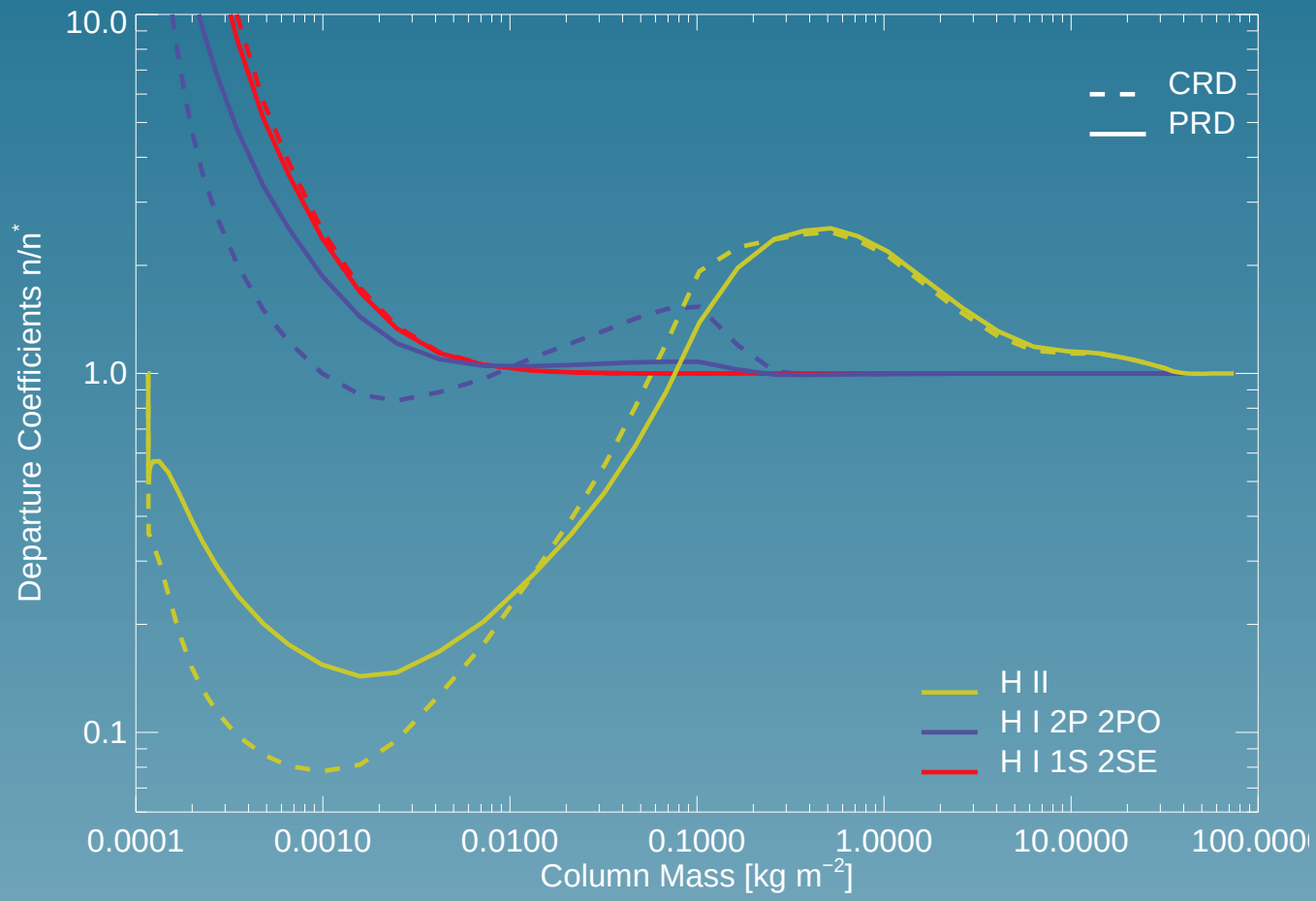
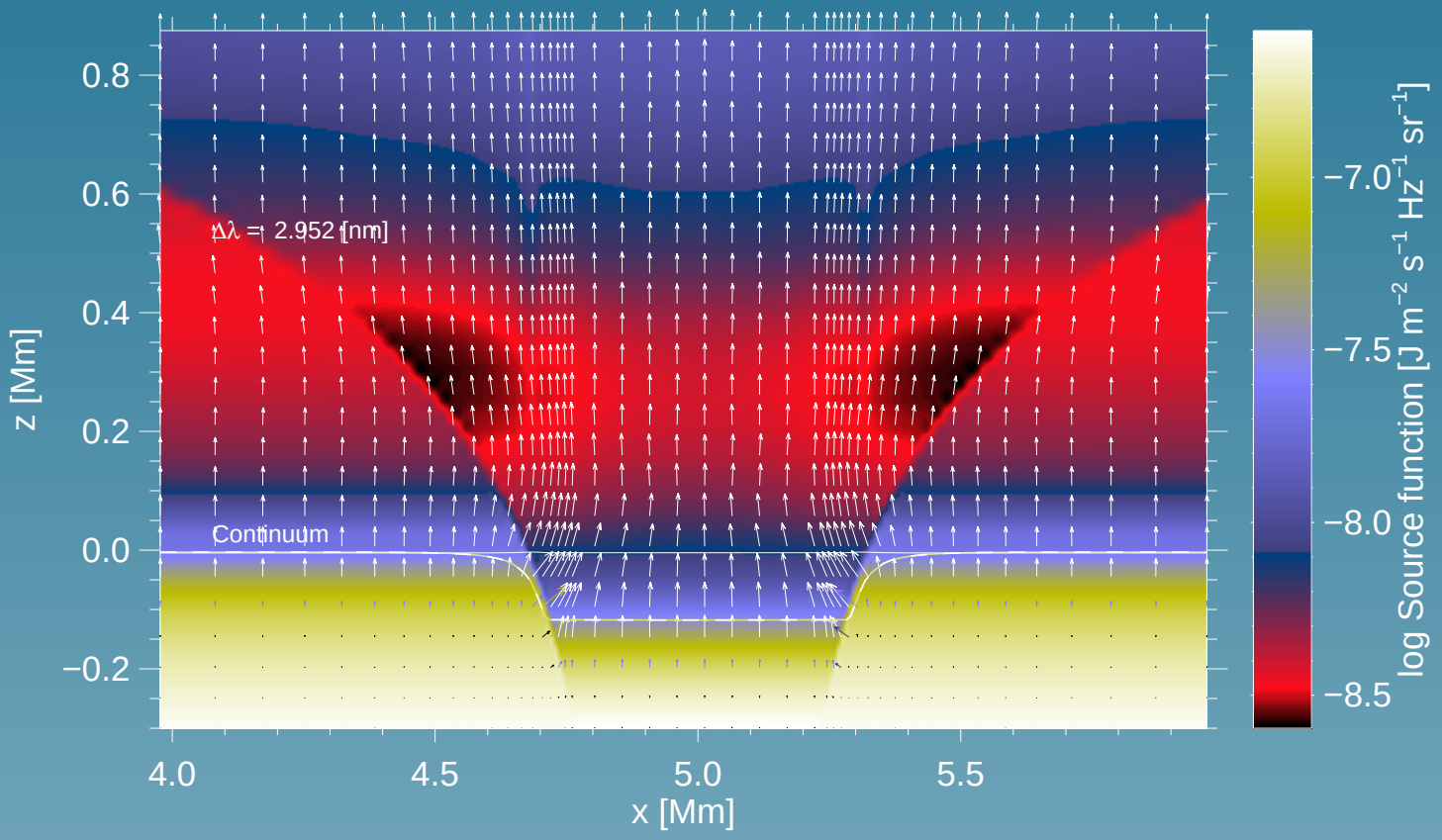


Network Structure (Ca II)



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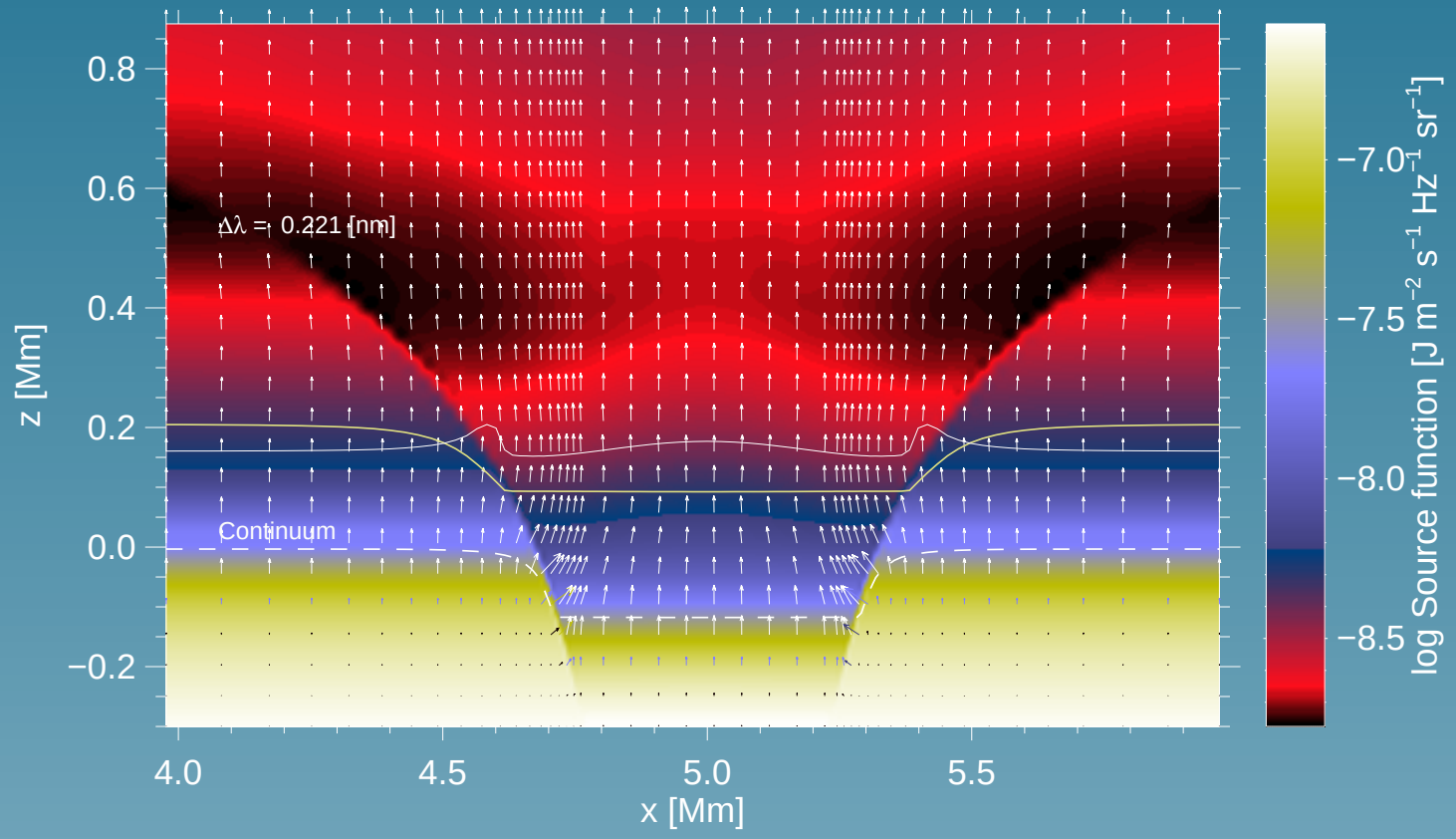

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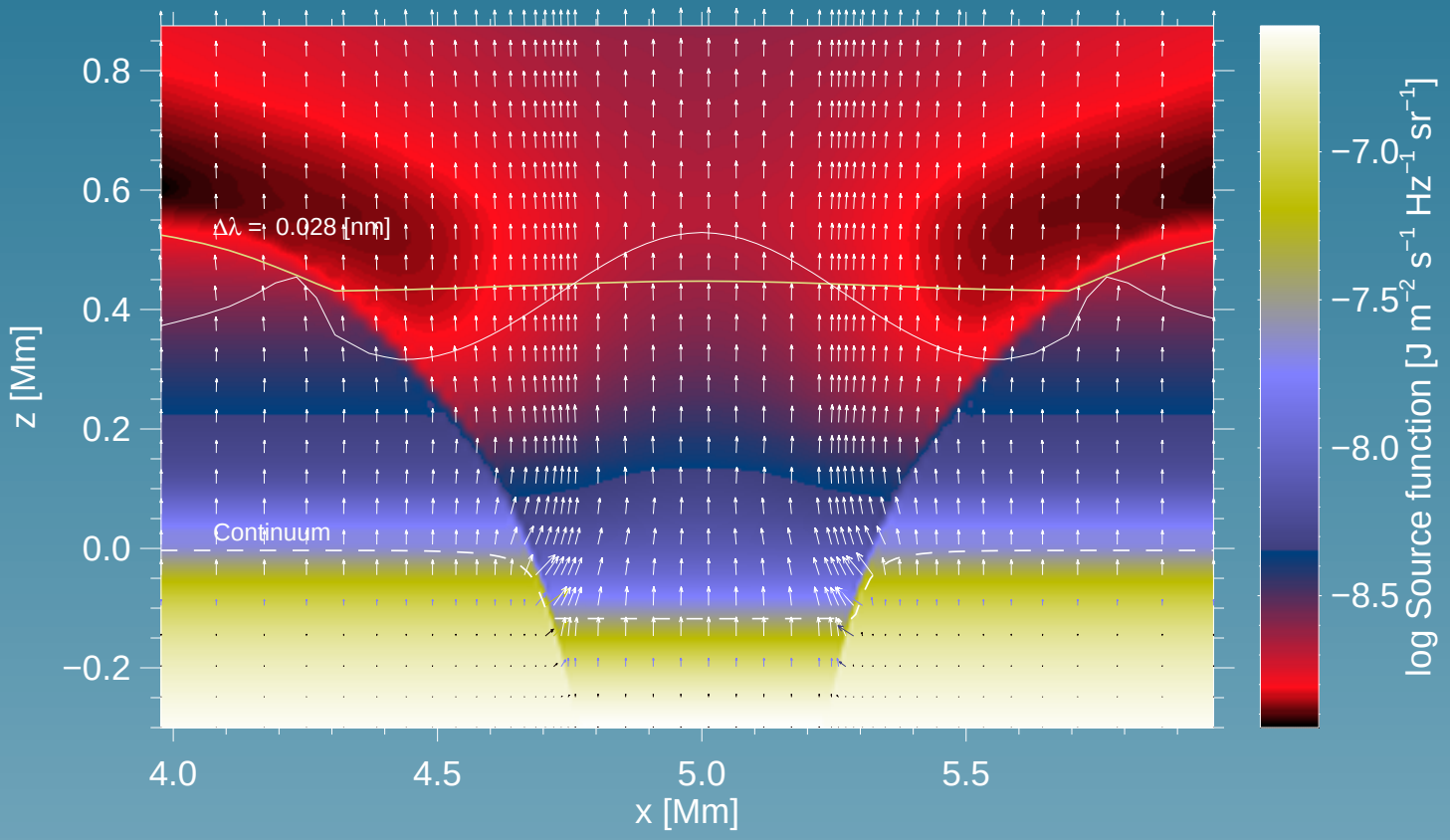

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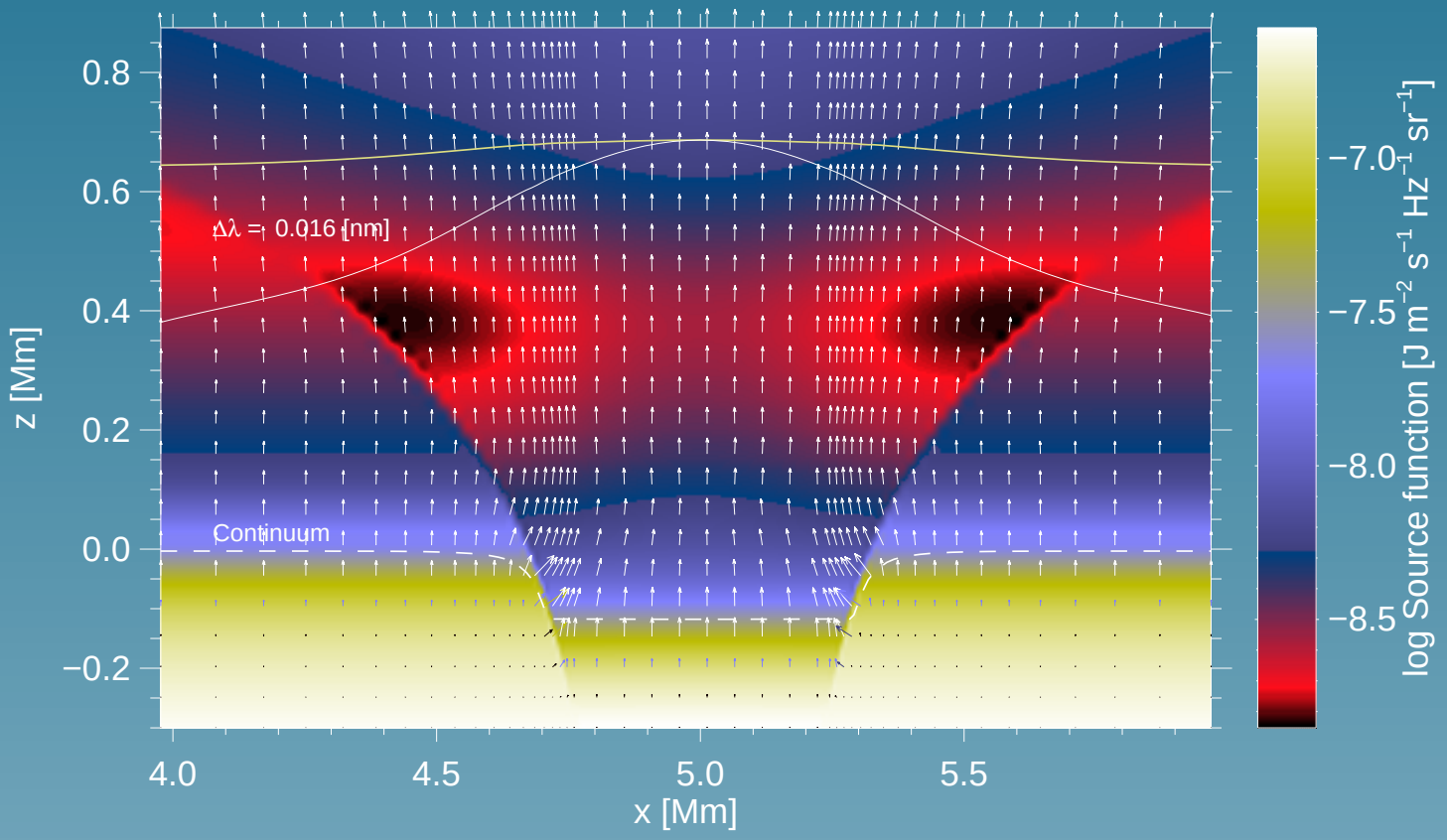

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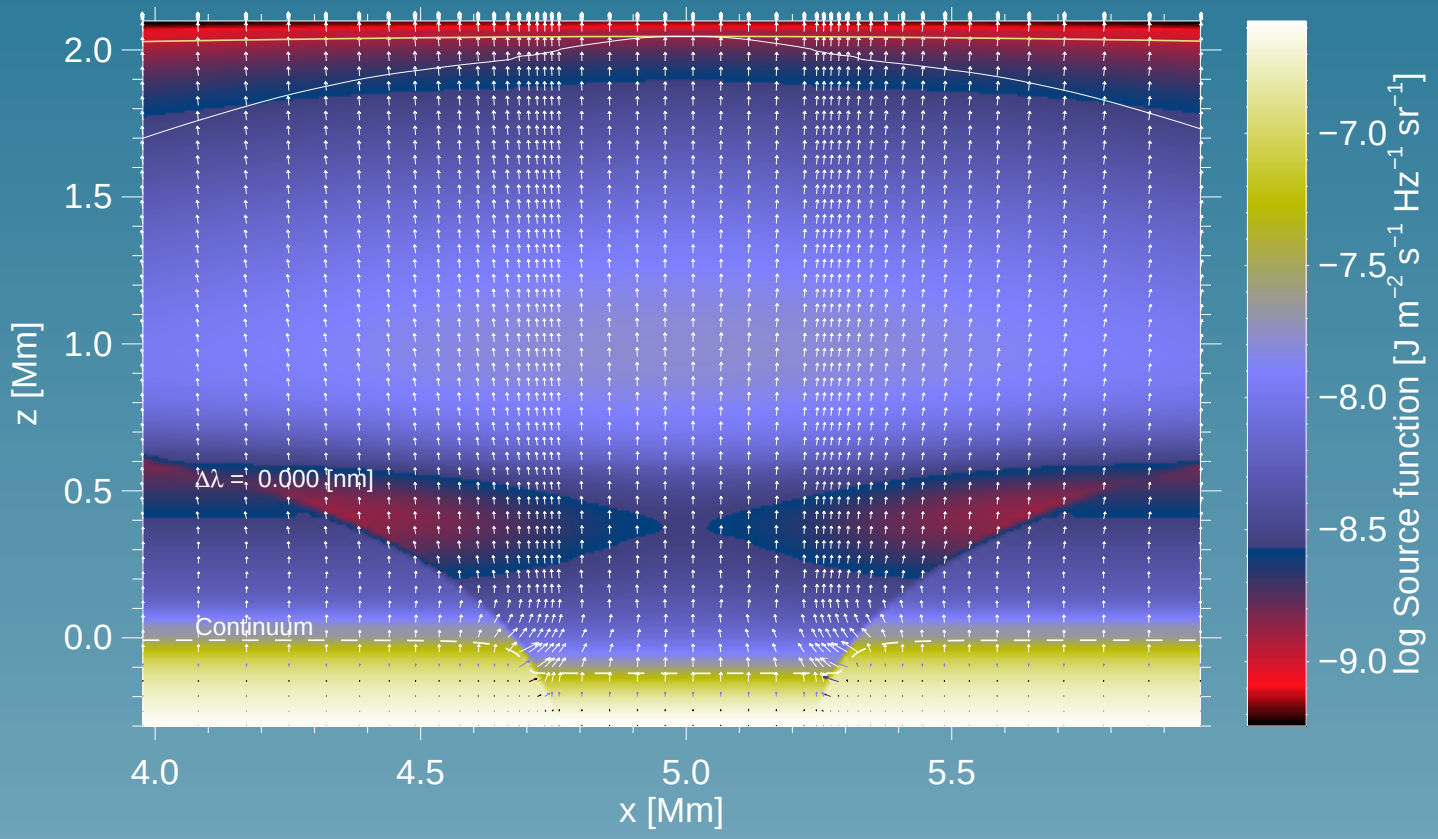
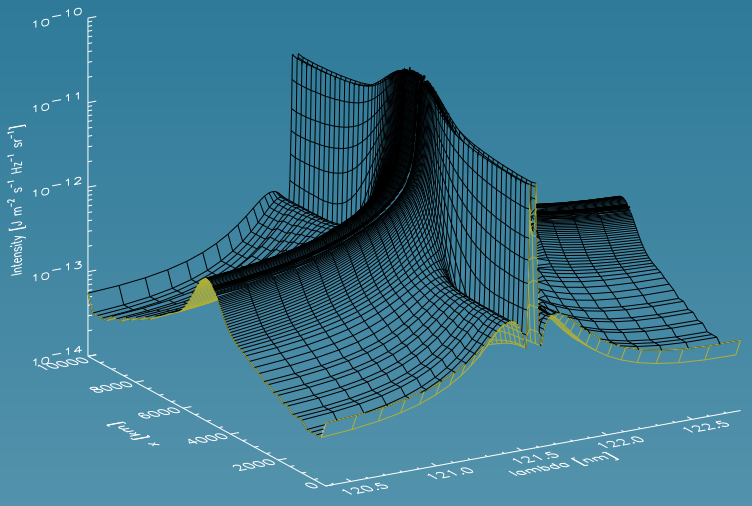
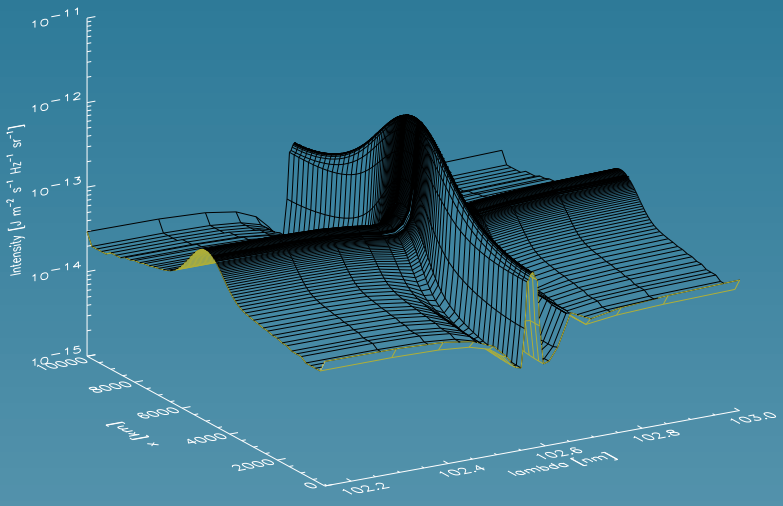
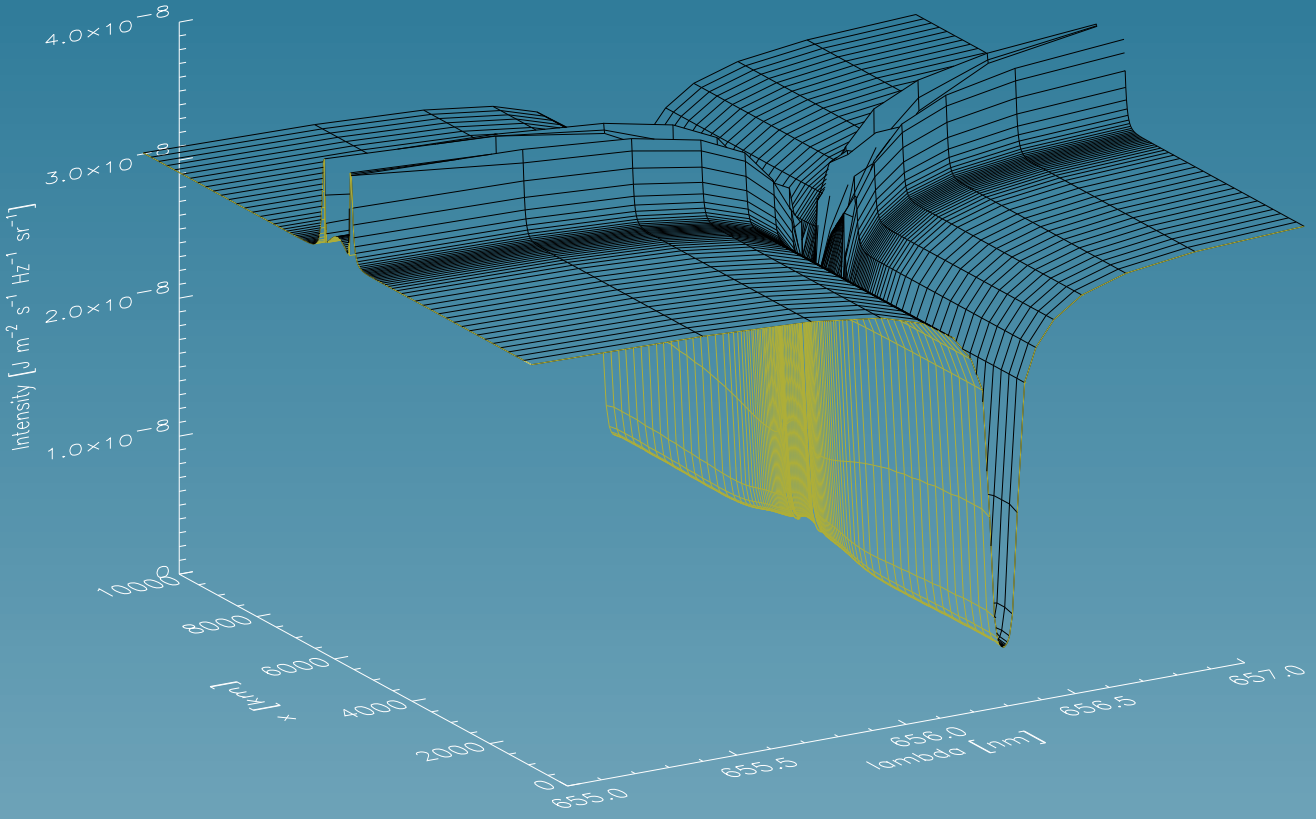


Lyman profiles in network

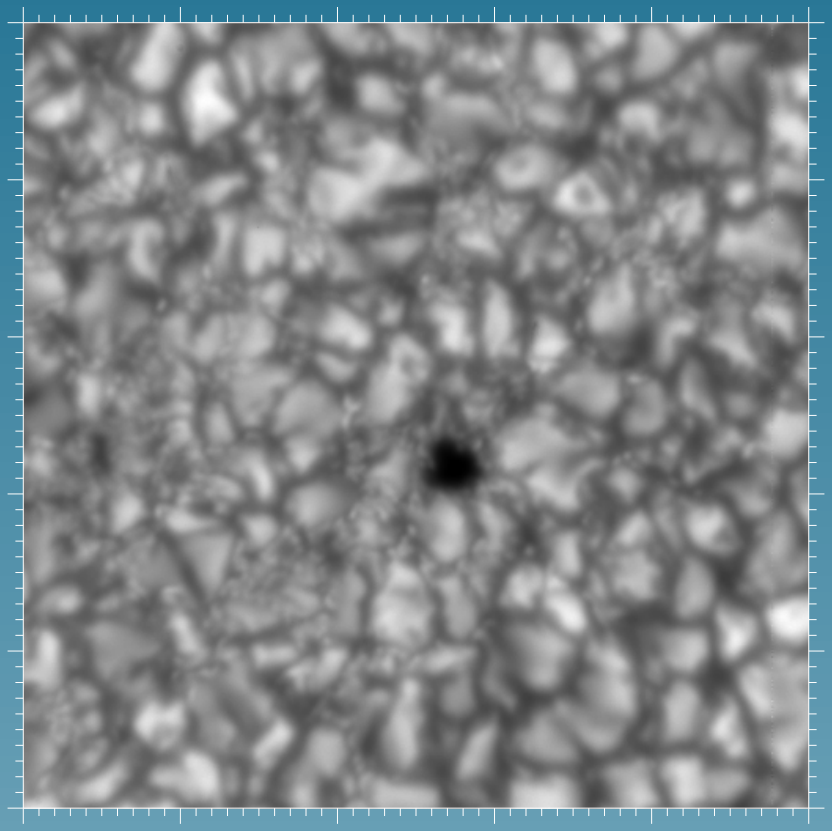




H-α profile in network



High resolution Observations



Fe I 569.1, Klaus Hartkorn and Thomas Rimmele, Sac Peak DST

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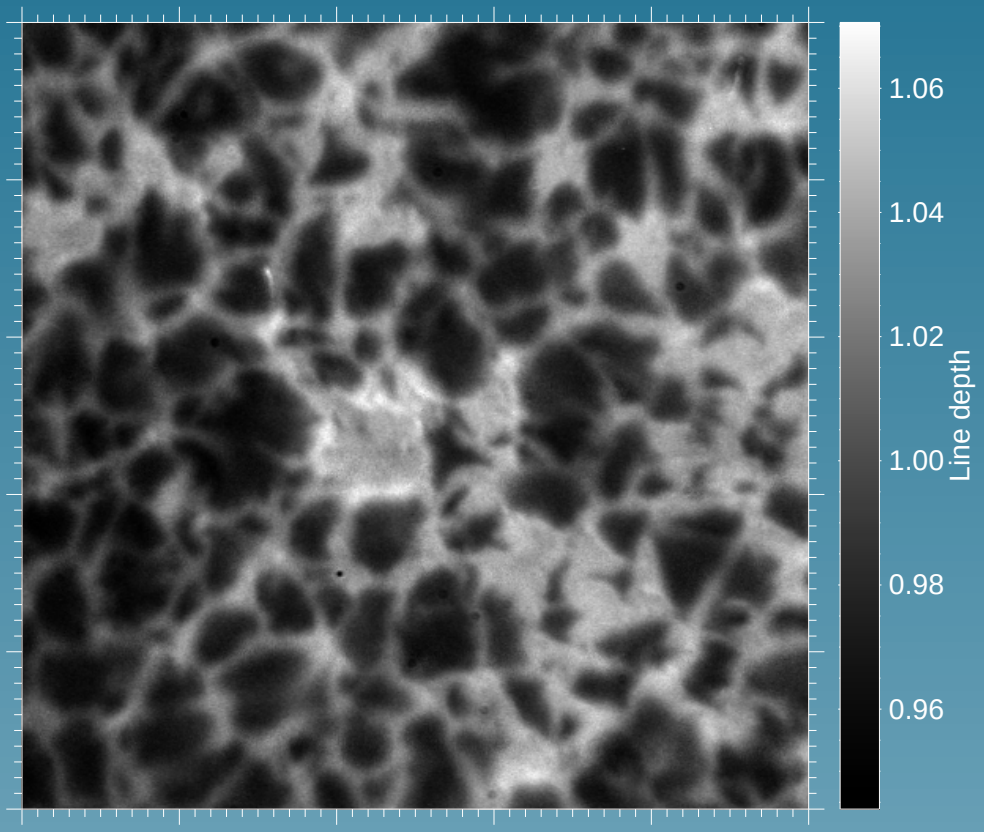
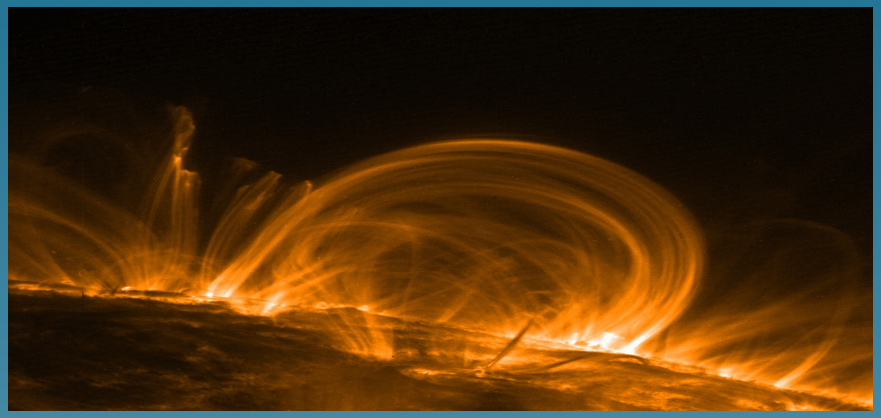


Fe I 569.1 line depth, Klaus Hartkorn and Thomas Rimmele, Sac Peak DST

Conclusions

- To figure out how coronal loops are heated we need to discover
  - how they are connected to the underlying photosphere
  - how energy flows from below, and in what form
- We need to develop reliable diagnostics. Understand the information encoded in H-α
- This will require multi-wavelength Stokes polarimetry with high cadence and appropriate spatial and spectral resolution

Where are Coronal Loops Heated?



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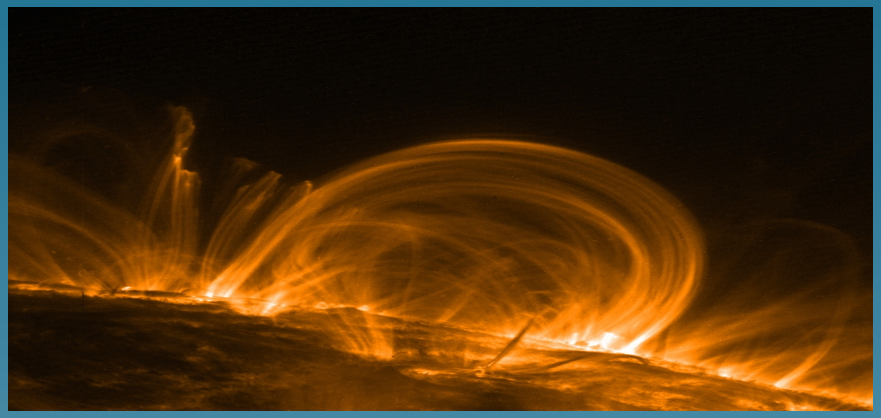

"This heating function provides uniform heating for small loops($L \leq 20$ Mm), but restricts heating to the footpoints of large loops ($L \equiv 50 - -300$ Mm)." (Aschwanden et al., 2000, ApJ 541, 1059)

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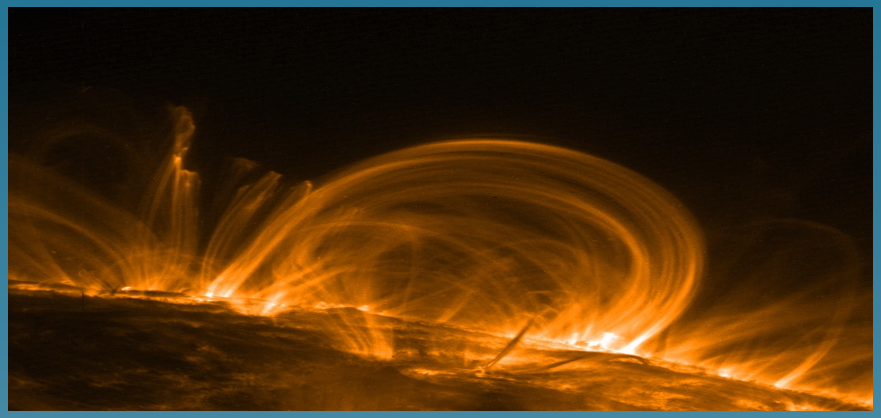

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"This gives strong evidence against heating concentrated near the loop base for such loops . . . " (Priest et al., 2000, ApJ 539, 1002)

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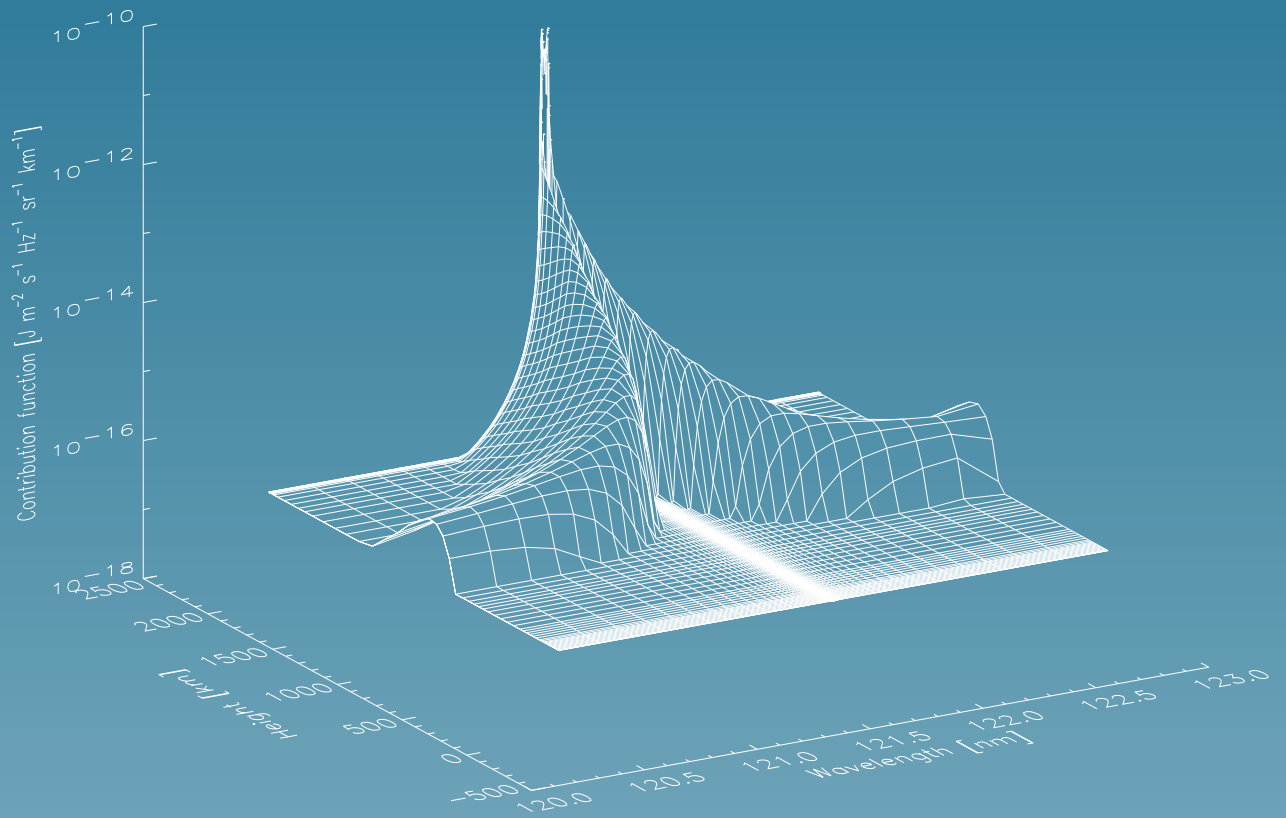
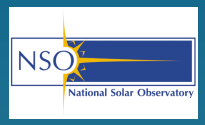
Hydrogen Lyman-α Contribution Function





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