Modelling Radiative Line Transfer in Maser Environments

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Overview

The Rate Equation

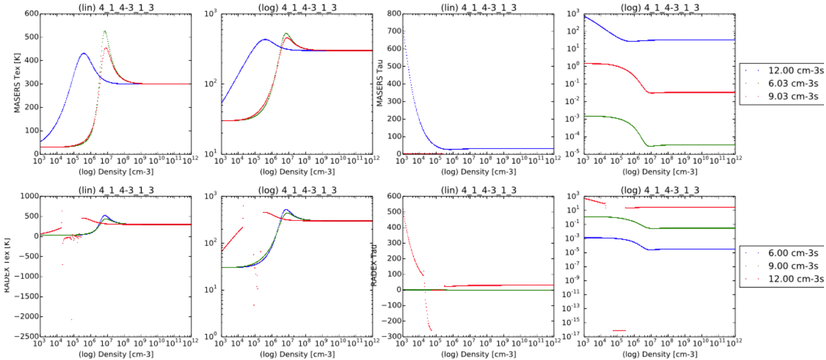
$$
\begin{aligned}
\frac{dn_i}{dt} &= -\sum_{j<i}\left\{A_{ij}\beta_{ij}\left[n_i + X_{ij}(n_i - n_j)\right] + C_{ij}\left[n_i - n_j\exp\left(\frac{-h\nu_{ij}}{kT}\right)\right]\right\} \\
&+ \sum_{j>i}\frac{g_j}{g_i}\left\{A_{ji}\beta_{ji}\left[n_j + X_{ji}(n_j - n_i)\right] + C_{ji}\left[n_j - n_i\exp\left(\frac{-h\nu_{ji}}{kT}\right)\right]\right\}
\end{aligned}
$$

$$
R_{ij} = \begin{cases} A_{ji}\beta_{ji}(1+X_{ji}) & i<j \\ A_{ij}\beta_{ij}\left(\frac{g_i}{g_j}\right)X_{ij} & j>i \\ -\sum_{i\neq j} R_{ji} & j=i \end{cases}
$$

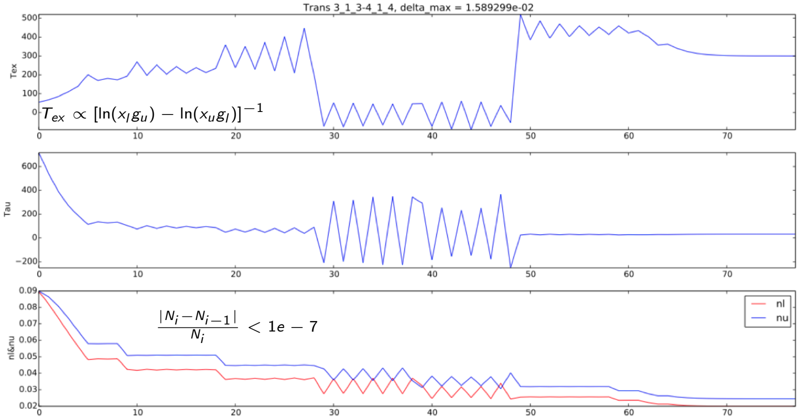
$$
\widetilde{C}_{ij} = \begin{cases} C_{ji} & j>i \\ -\sum_{i\neq j} C_{ij} & j=i \end{cases}
$$

$$
(\mathbf{R} + \widetilde{\mathbf{C}})\mathbf{n} = \mathbf{b}
$$

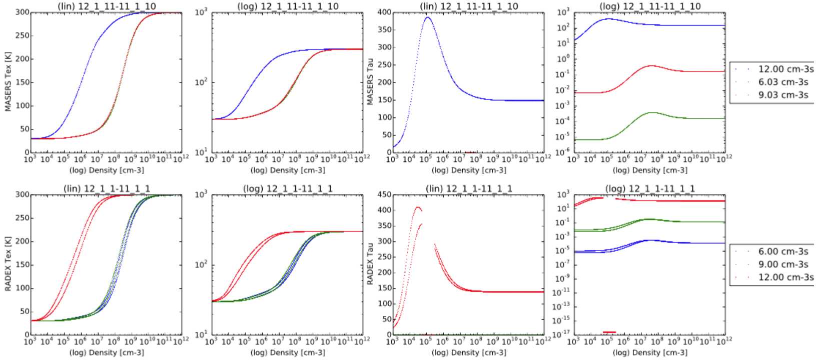
Numerical Issues



Convergence Criteria



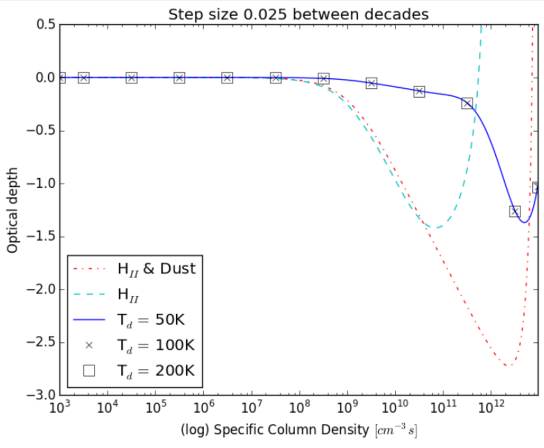
Relaxation



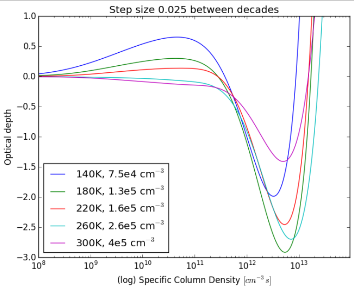
(lin) 12_1_11-11_1_10
MASERS Tex [K]
(log) 12_1_11-11_1_10
(lin) 12_1_11-11_1_10
MASERS Tau
(log) 12_1_11-11_1_10
12.00 cm-3s
6.03 cm-3s
9.03 cm-3s
(lin) 12_1_1-11_1_1
RADEX Tex [K]
(log) 12_1_1-11_1_1
(lin) 12_1_1-11_1_1
RADEX Tau
(log) 12_1_1-11_1_1
6.00 cm-3s
9.00 cm-3s
12.00 cm-3s
(log) Density [cm-3]

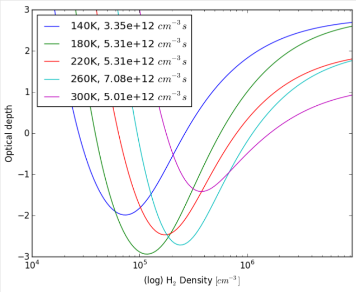
$G37.55 + 0.20$ 4.8 GHz H_2CO Maser

$$X = \beta_{ij} W_{HII} \aleph_{HII} + \beta_{ij} W_d \aleph_d$$

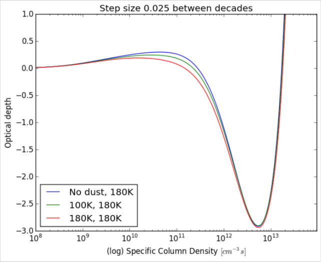


Collisional Excitation

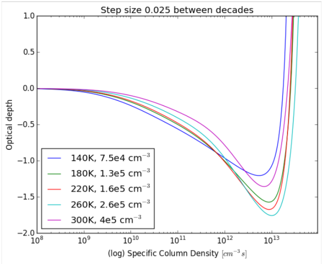




Radiative Excitation



Collision & dust radiation: $w_d = 1$, $n_{H_2} = 1.3e5\, cm^{-3}$



Collision & free-free emission: $w_{H_{II}} = 1$, $EM = 1e9\, pc\, cm^{-6}$

Line Overlap

$$R^a_{ij} = \begin{cases} A_{ji}\beta^a_{ji}(1+X_{ji}) & i<j \\ A_{ij}\beta^a_{ij}\left(\frac{g_i}{g_j}\right)X_{ij} & j>i \\ -\sum_{i\neq j} R_{ji} & j=i \end{cases}, \quad R^b_{ij} = \begin{cases} A_{ji}\beta^b_{ji} & i<j \\ A_{ij}\beta^b_{ij} & j>i \\ 0 & j=i \end{cases},$$

$$R^{ab}_{ij} = \begin{cases} A_{ji}\beta^{ab}_{ji}(x_a+X_{ji}) & i<j \\ A_{ij}\beta^{ab}_{ij}\left(\frac{g_i}{g_j}\right)X_{ij} & j>i \\ -\sum_{i\neq j} R_{ji} & j=i \end{cases},$$

$R = R^a + R^b = R^{ab}$ where $\beta^a = [1-(1-f_a)(1-\beta_{\tau_a})]$, $\beta^{ab} = f_a(1-\beta_{\tau_a+\tau_b})$, $\beta^b = f_b x_a(1-\beta_{\tau_a+\tau_b})$ and $x_a = \frac{\kappa_a}{\kappa_{ab}}$ and $f_a = \frac{\Delta_{ab}}{\Delta_a}$ the absorption and overlap ratios respectively.

References

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