Cooling routines for AGB winds

Towards the understanding of Long Secondary Periods

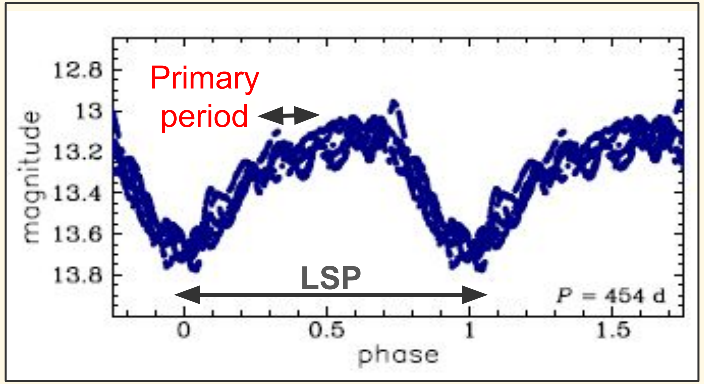
Davide Dionese

Supervisors:
Lionel Siess
Dorota Skowron

UNIVERSITÉ LIBRE DE BRUXELLES
UNIVERSITY OF WARSAW
erc

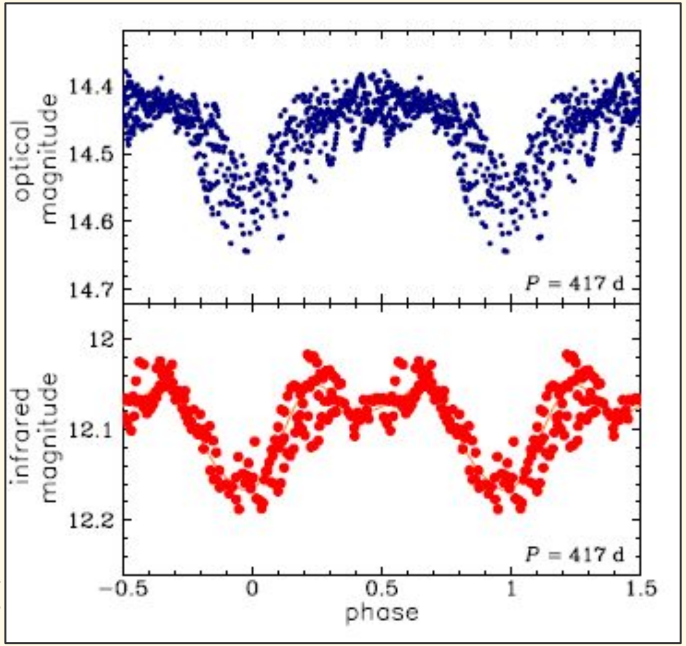
Long Secondary Period (LSP)

- Observed in ⅓ of evolved solar-type stars
- Period: 250-1400 days
- Amplitudes up to 0.8 magnitudes
- Decline faster than rise



Binary hypothesis

Evolved star
+
Sub-stellar companion hidden in dust cloud,
Originally a **planet**



Images from OGLE Atlas of Variable Star Light Curves.
IR observations by NEOWISE.

Wind models and cooling issues (setup “wind”)

Cooling:

- Allows dust formation → Wind driving; → LSPs

- Allows larger densities around the companion (accretion disk)

- As of now: only HI cooling (only high temperatures)

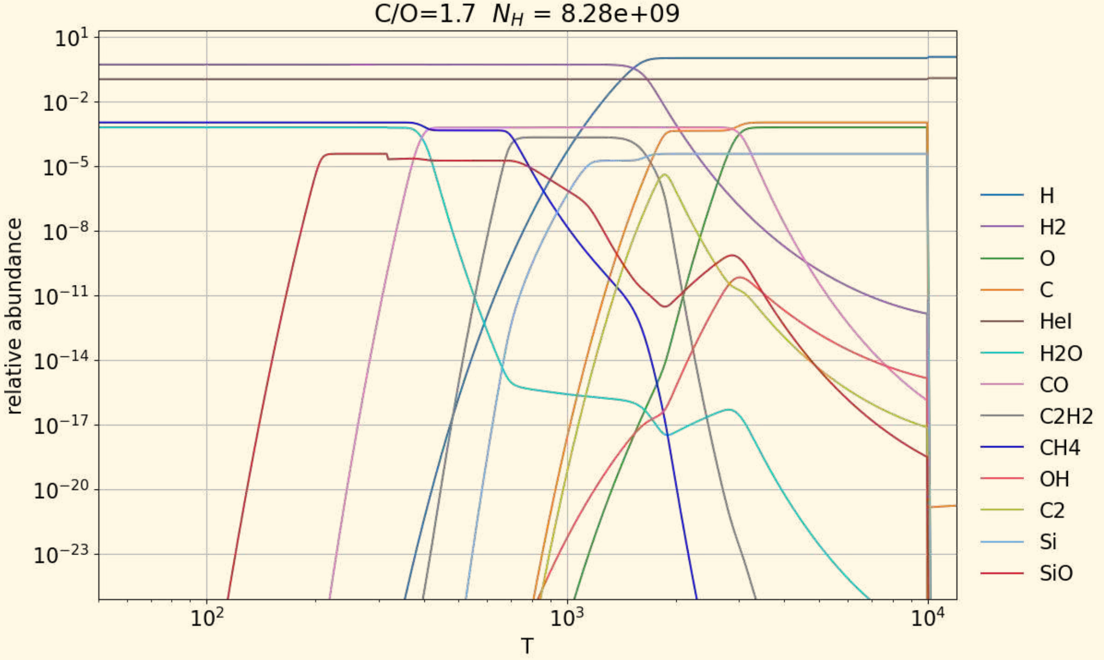
Equilibrium chemistry

Partial pressure of a molecule made of elements A, B, C

$$\frac{p_{\mathrm{A}_a\mathrm{B}_b\mathrm{C}_c}}{p^{\ominus}} = \left(\frac{p_\mathrm{A}}{p^{\ominus}}\right)^a \left(\frac{p_\mathrm{B}}{p^{\ominus}}\right)^b \left(\frac{p_\mathrm{C}}{p^{\ominus}}\right)^c \exp\left(-\frac{\Delta G_\mathrm{f}^{\ominus}}{RT}\right),$$

Gibbs free energies derived from JANAF tables
(Fit from Sharp and Huebner, 1990)

Network extended to lower temperatures

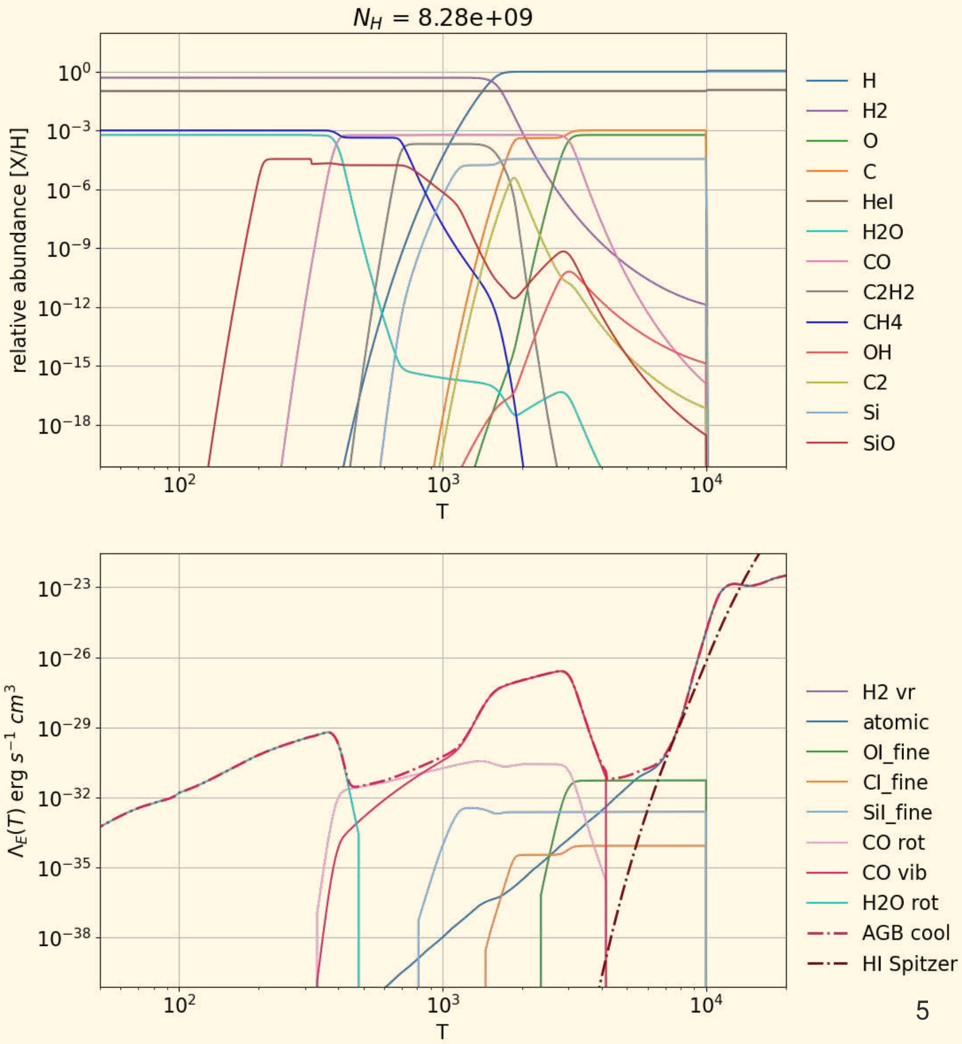


New cooling rates

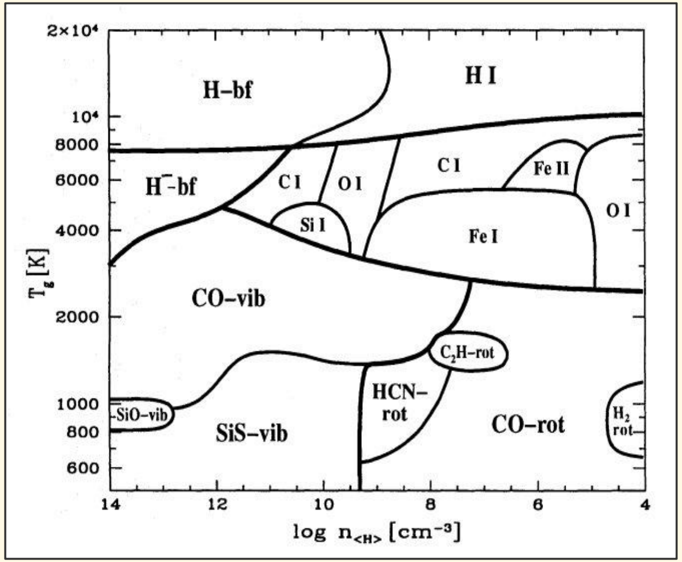
From Glover et al. 2012

H2 rot / vib	OH	H2 CIE
Atomic (HI)	H2O (H2O18) rot / vib	CO (C13O, CO18) rot/vib
CI	OI	SiI

C/O = 1.7
Solar abundances

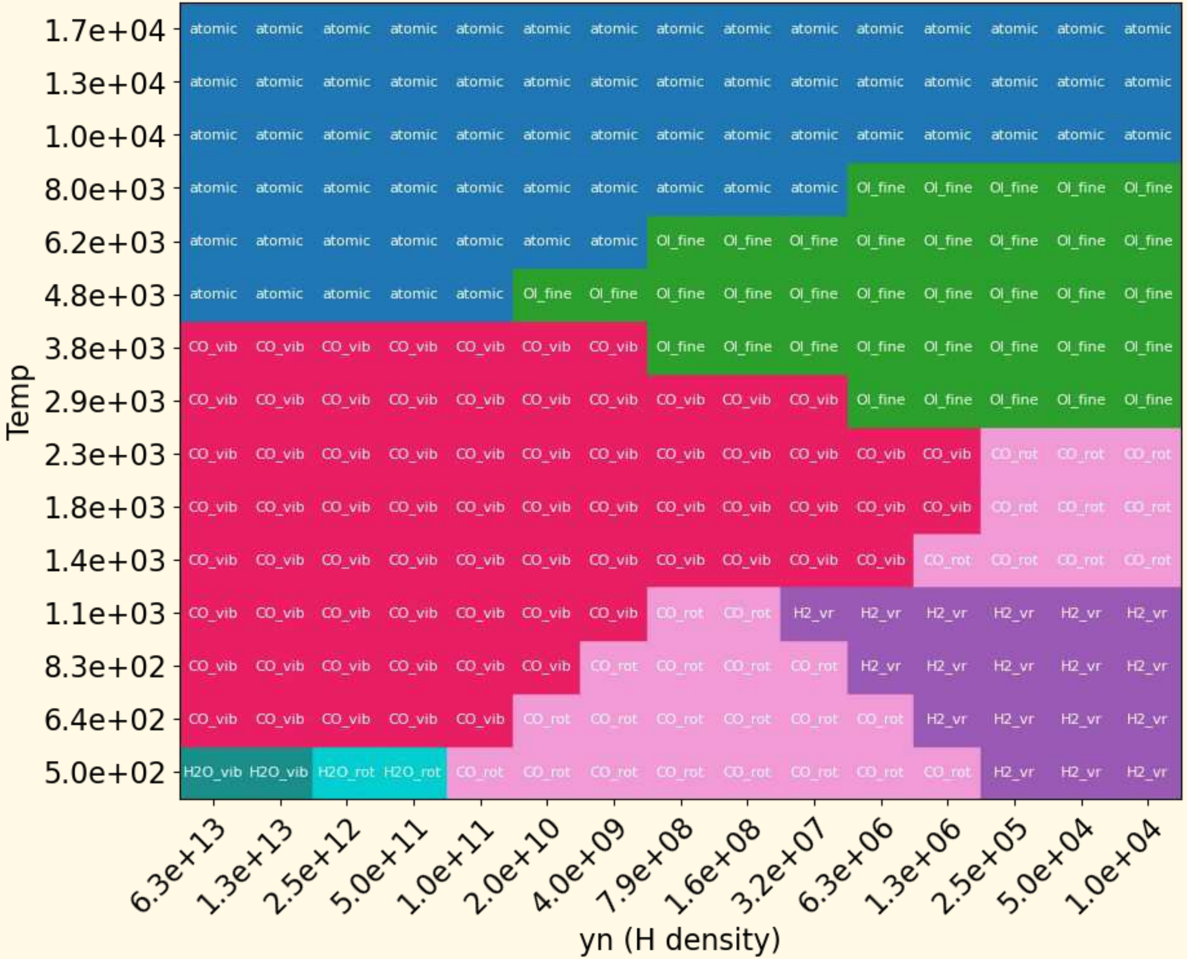


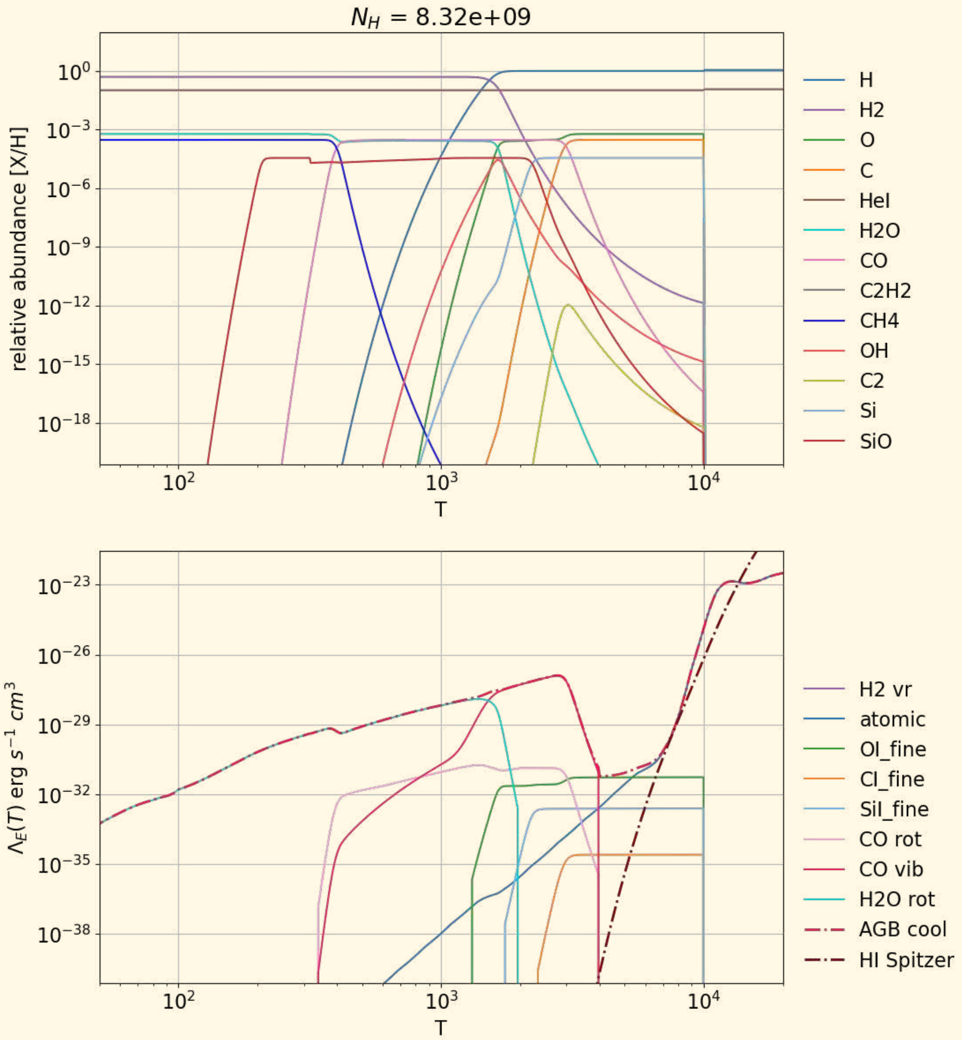
Most relevant coolings



Cooling rates from Woitke (1996)

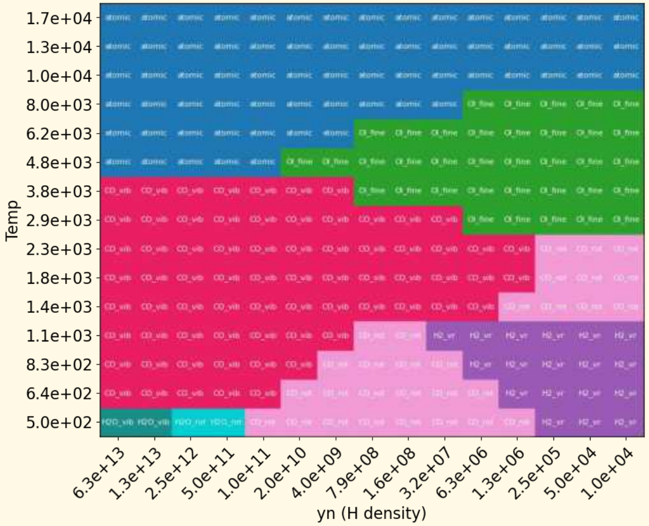
C/O = 1.7
Solar abundances

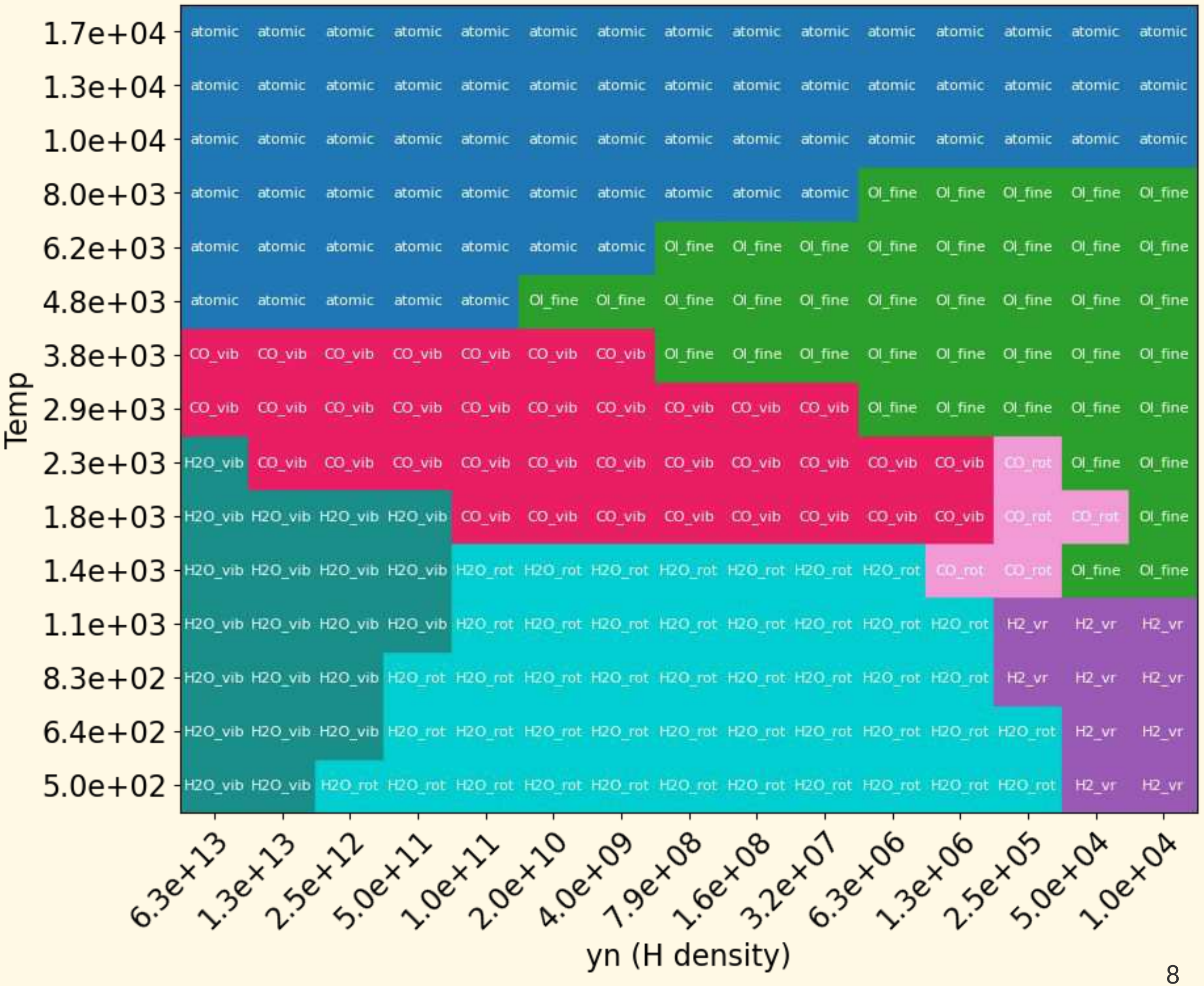


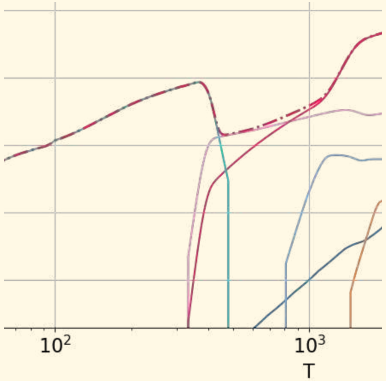

N_H = 8.32e+09
relative abundance [X/H]
T
H
H2
O
C
HeI
H2O
CO
C2H2
CH4
OH
C2
Si
SiO
$\Lambda_E(T)$ erg s^{-1} cm^3
T
H2 vr
atomic
OI_fine
CI_fine
SiI_fine
CO rot
CO vib
H2O rot
AGB cool
HI Spitzer

C/O = 0.5

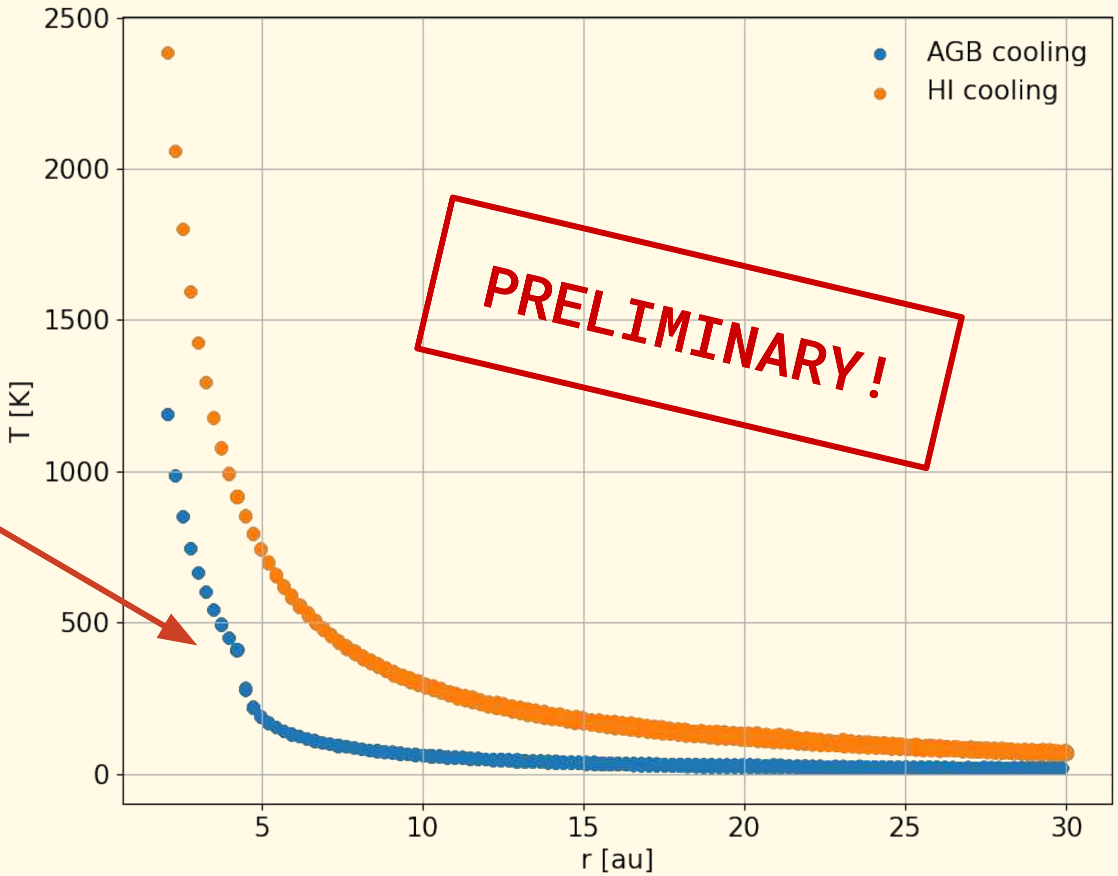
C/O = 0.5


Temp
1.7e+04
1.3e+04
1.0e+04
8.0e+03
6.2e+03
4.8e+03
3.8e+03
2.9e+03
2.3e+03
1.8e+03
1.4e+03
1.1e+03
8.3e+02
6.4e+02
5.0e+02
6.3e+13
1.3e+13
2.5e+12
5.0e+11
1.0e+11
2.0e+10
4.0e+09
7.9e+08
1.6e+08
3.2e+07
6.3e+06
1.3e+06
2.5e+05
5.0e+04
1.0e+04
yn (H density)


Temp
1.7e+04
1.3e+04
1.0e+04
8.0e+03
6.2e+03
4.8e+03
3.8e+03
2.9e+03
2.3e+03
1.8e+03
1.4e+03
1.1e+03
8.3e+02
6.4e+02
5.0e+02
atomic
OI_fine
CO_vib
CO_rot
H2O_vib
H2O_rot
H2_vr
6.3e+13
1.3e+13
2.5e+12
5.0e+11
1.0e+11
2.0e+10
4.0e+09
7.9e+08
1.6e+08
3.2e+07
6.3e+06
1.3e+06
2.5e+05
5.0e+04
1.0e+04
yn (H density)



H2O cooling activates below ~400 K



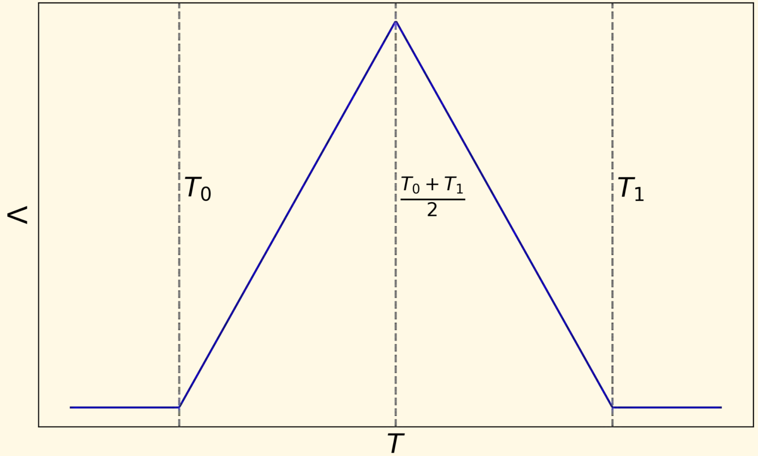
Cooling: how and where?

```
# options controlling cooling
            C_cool =       0.020    ! factor controlling cooling timestep
          icooling =           1    ! cooling function (0=off, 1=library (step), 2=library (force) 3=Gammie, 4=ISM, 5,6=KI02, 7=powerlaw)
      icool_method =           0    ! integration method (0=implicit, 1=explicit, 2=exact solution)
     excitation_HI =           0    ! cooling via electron excitation of HI (1=on/0=off)
       relax_bowen =           0    ! Bowen (diffusive) relaxation (1=on/0=off)
      relax_stefan =           0    ! radiative relaxation (1=on/0=off)
    dust_collision =           0    ! dust collision (1=on/0=off)
     shock_problem =           1    ! piecewise formulation for analytic shock solution (1=on/0=off)
```

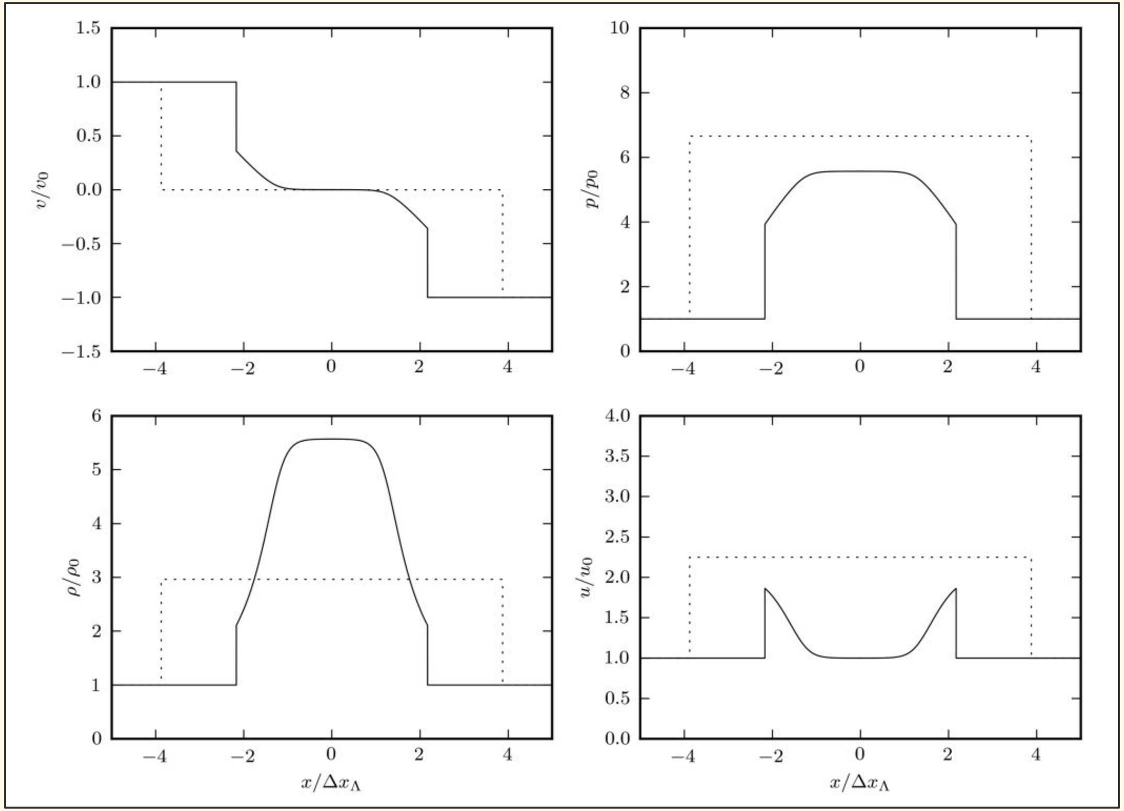
A shock test

"piecewise cooling"

$$\rho\dot{u}|_\Lambda = \begin{cases} 0, & T \le T_0 \\ -\Lambda n^2 (T - T_0)/T_0, & T_0 \le T \le \frac{1}{2}(T_1 + T_0) \\ -\Lambda n^2 (T_1 - T)/T_0, & \frac{1}{2}(T_1 + T_0) \le T \le T_1 \\ 0, & T_1 \le T \end{cases}$$



An analytical solution



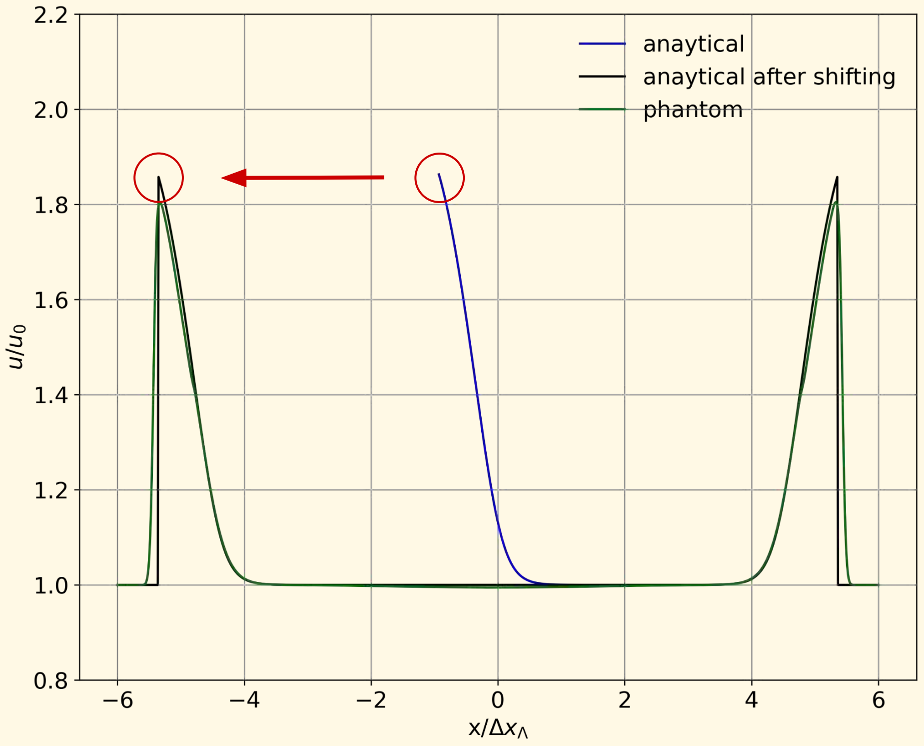
Creasey et al. 2011

Moving shock

vs

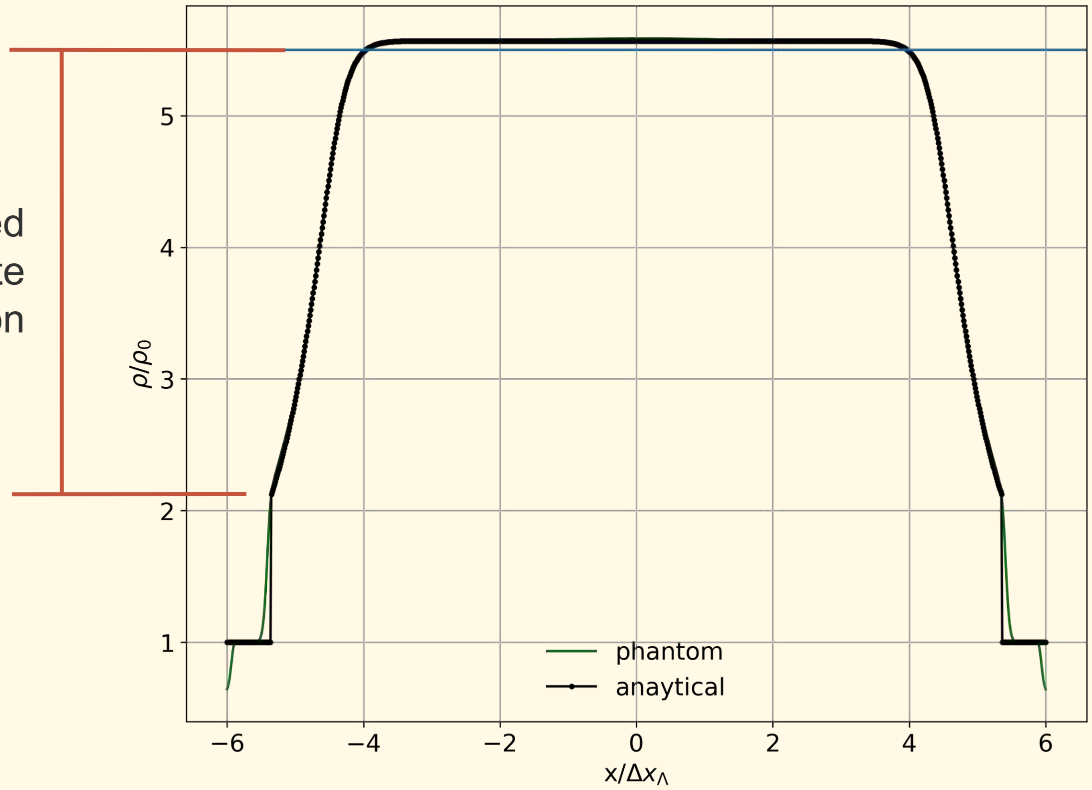
Fixed analytical solution

Shifted according to maximum temperature



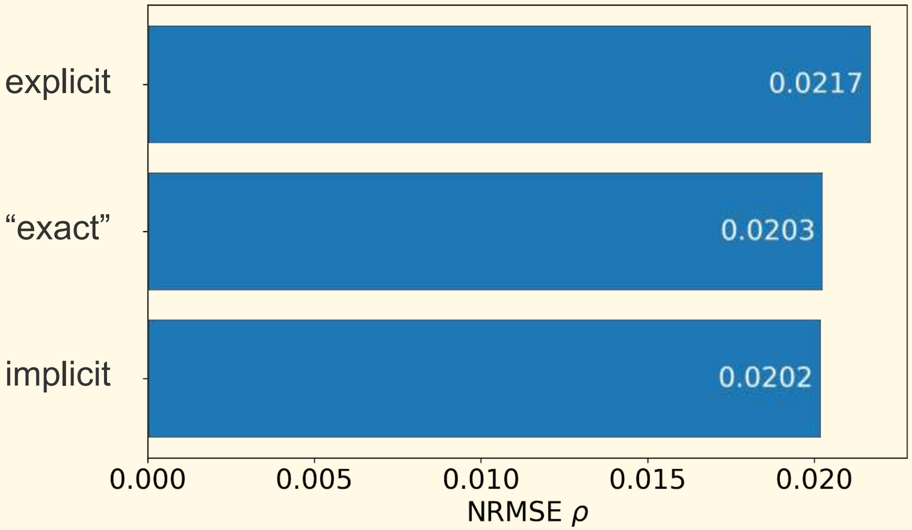
The comparison

Profile used to compute loss function



$$NRMSE = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i^{SPH} - y_i^{ana})^2}}{max(y^{ana}) - min(y^{ana})}$$

Integration methods

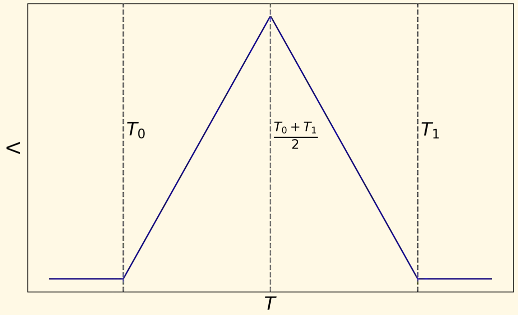


Isn't the exact method supposed to be *exact* ?

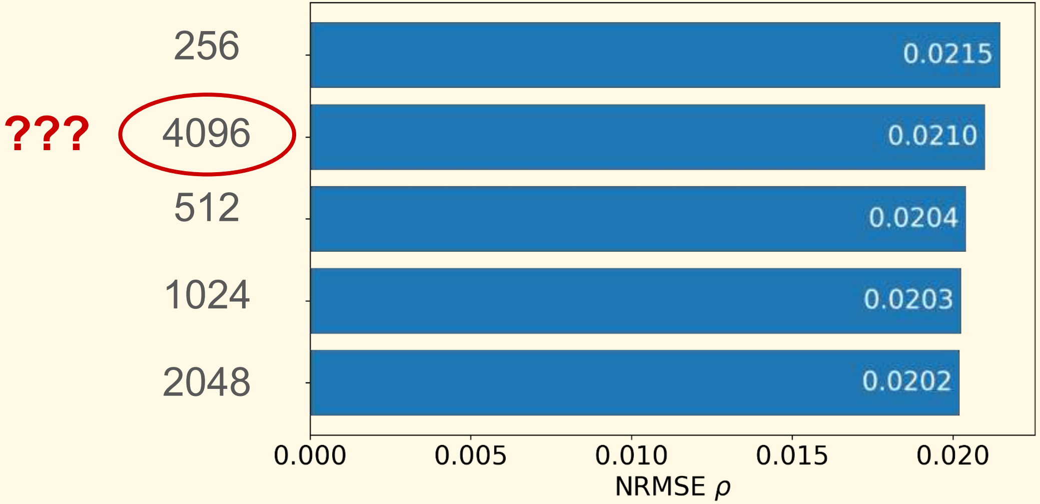
Issues with *piecewise cooling* + *exact method*

$$\Lambda(T) = \Lambda_k \left(\frac{T}{T_k}\right)^{\alpha_k} \qquad T_k \leqslant T \leqslant T_{k+1}, \qquad \text{(A4)}$$

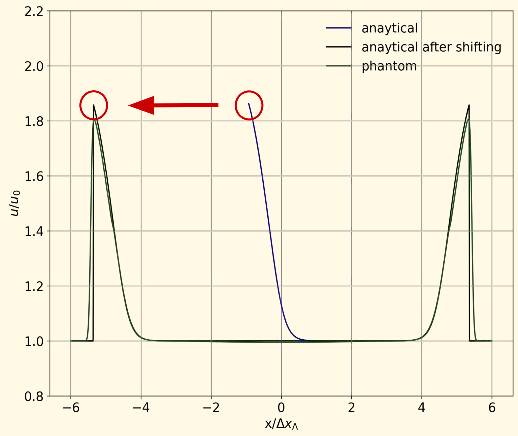
Townsend 2009



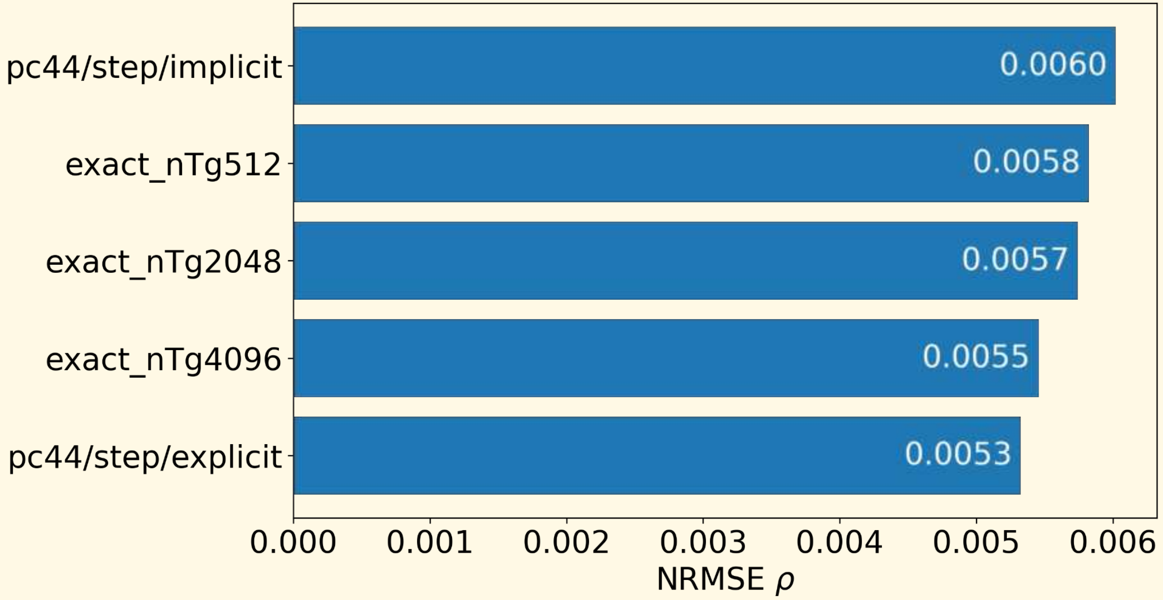
Varying size of temperature grid in exact method:



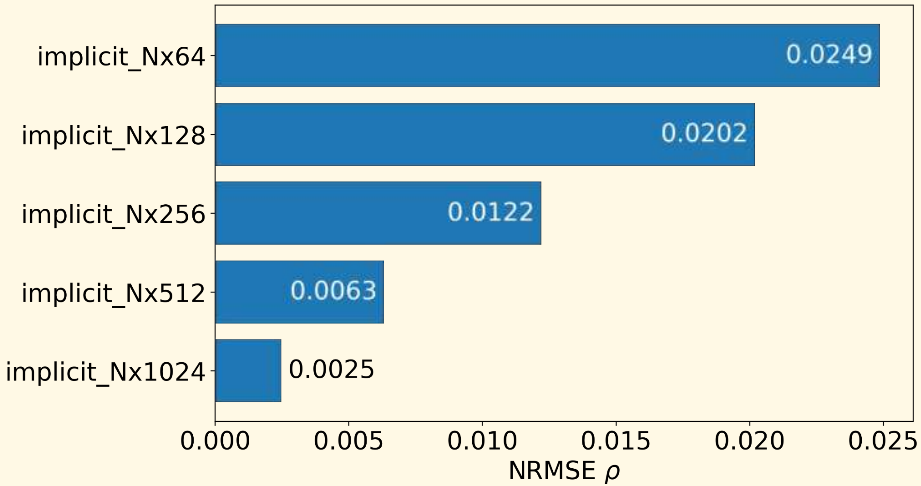
Ad hoc shifting

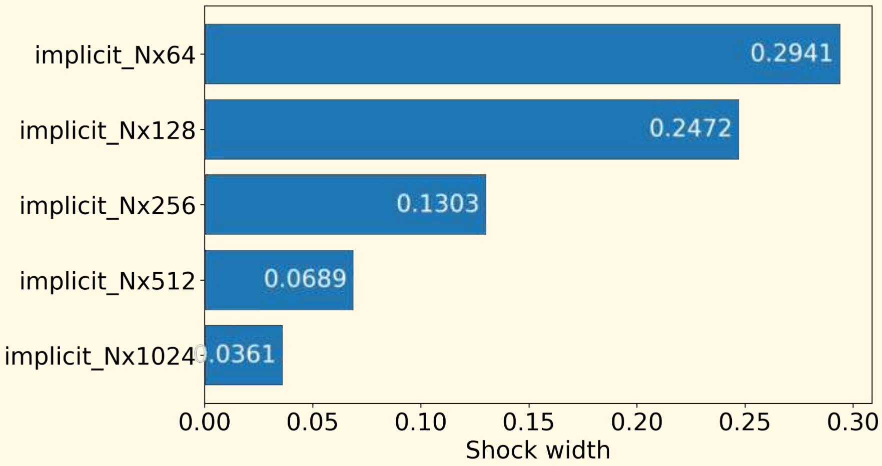


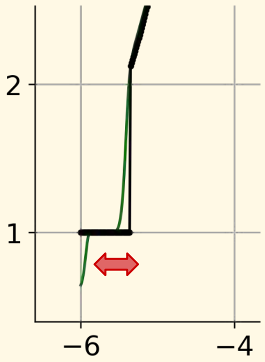
Shift minimizing loss function

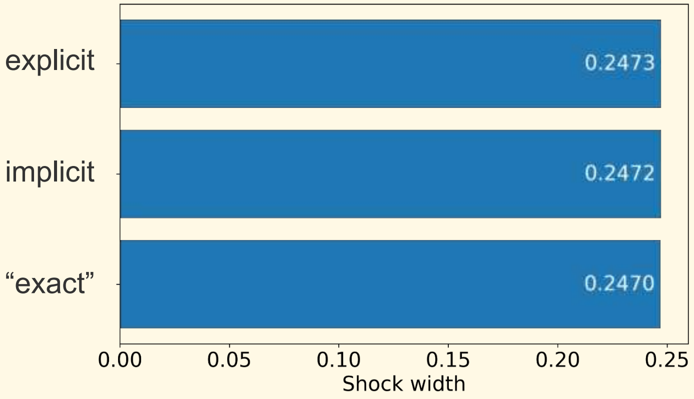


Effects of resolution









Conclusions

- Refinement of equilibrium chemistry
- Introduction of new cooling rates:

Path to <u>improved description of AGB outflows</u>

- Development of the shock tube test
- Comparison between methods (partially inconclusive)
- Other factors play a major role

The implicit method seems the safest choice