Anomalous intensity of the He I & II UV resonance lines

Golding, Leenaarts & Carlsson, 2017, A&A, 597, 102

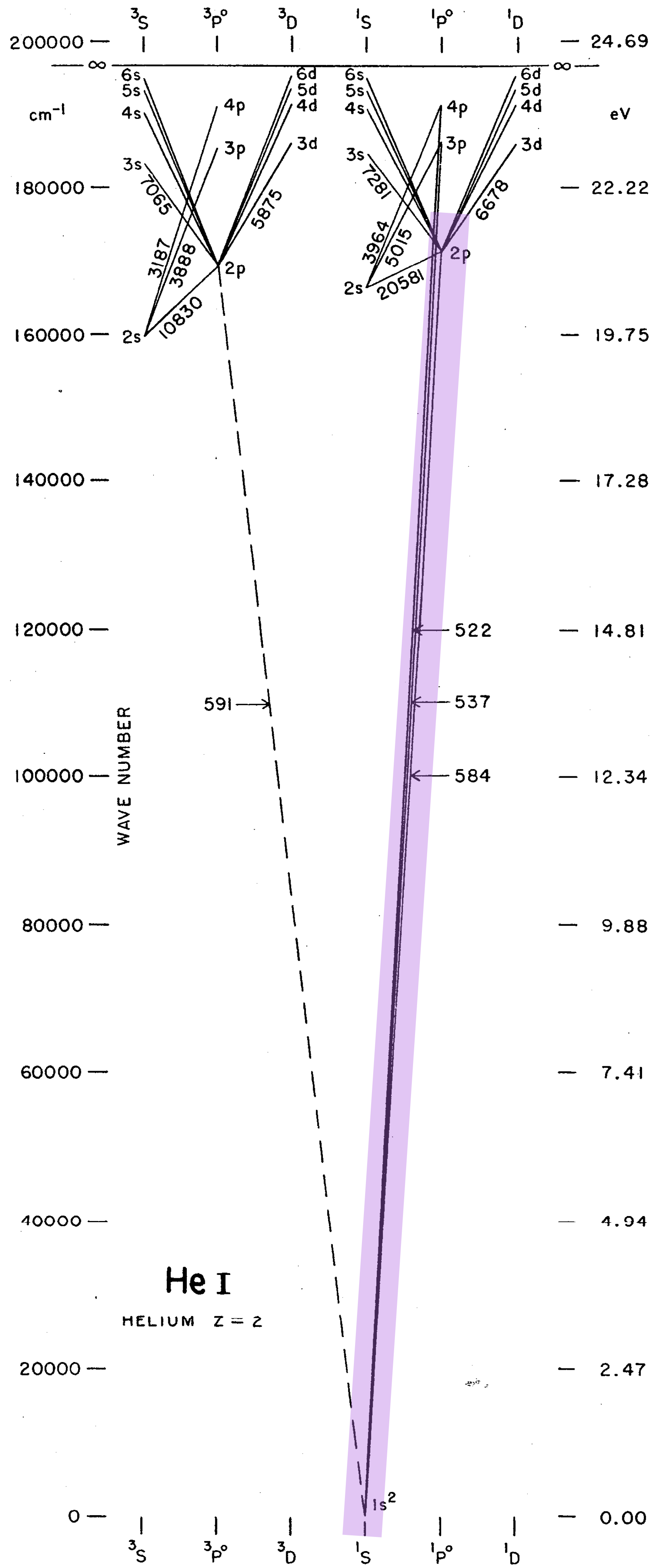
Jorrit Leenaarts
Institute for Solar Physics, Stockholm University

What's the problem?

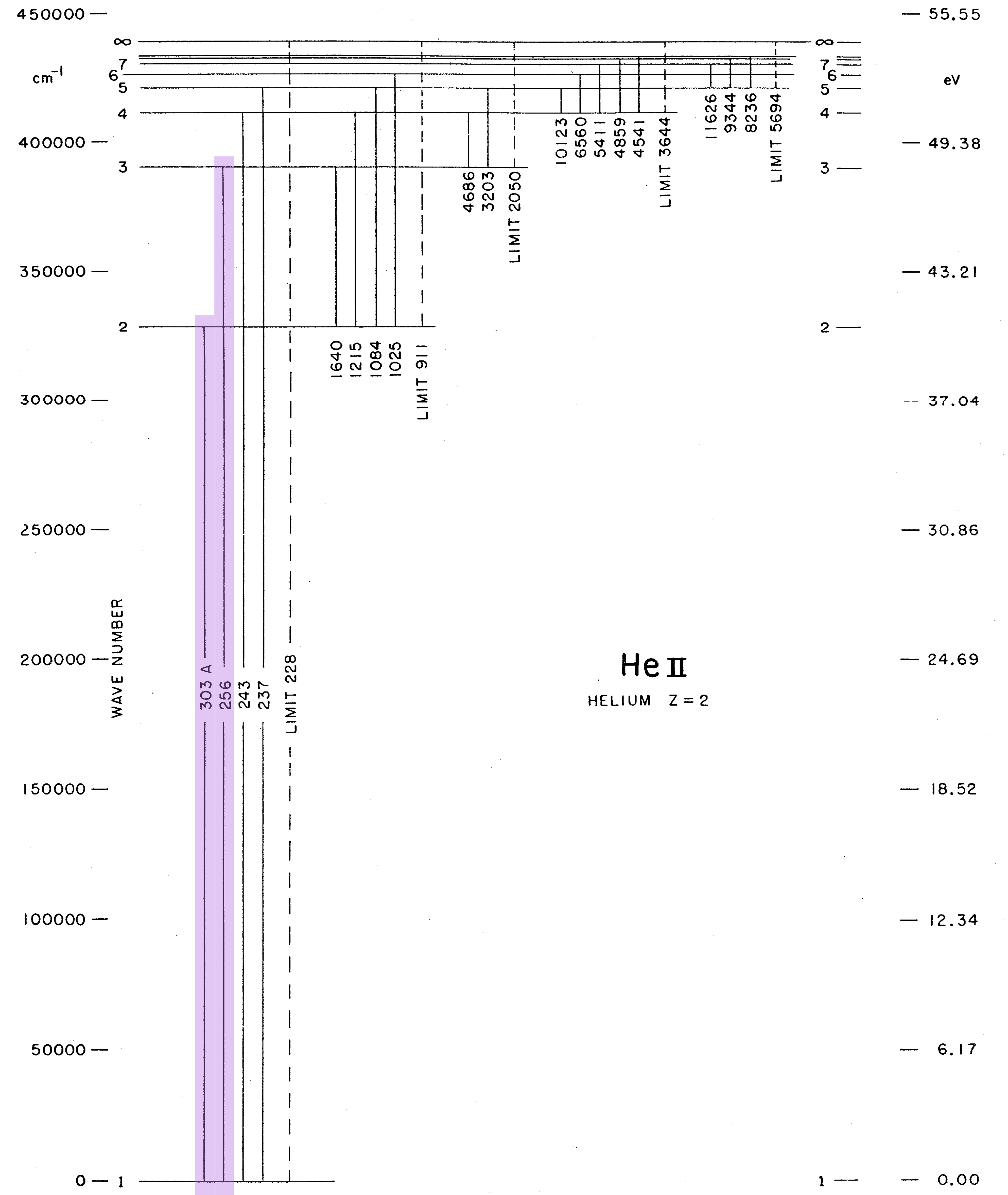
Table 1. Helium line enhancement factors from different studies.

Study	He I $\lambda584$	He II $\lambda304$	He II $\lambda256$
Jordan (1975)	15	5.5	
MacPherson & Jordan (1999)	10–14	13–25	
Pietarila & Judge (2004)	2–10	27	
Giunta et al. (2015)	0.5–2	13	5
This work	7	10	7

Golding et al., 2017

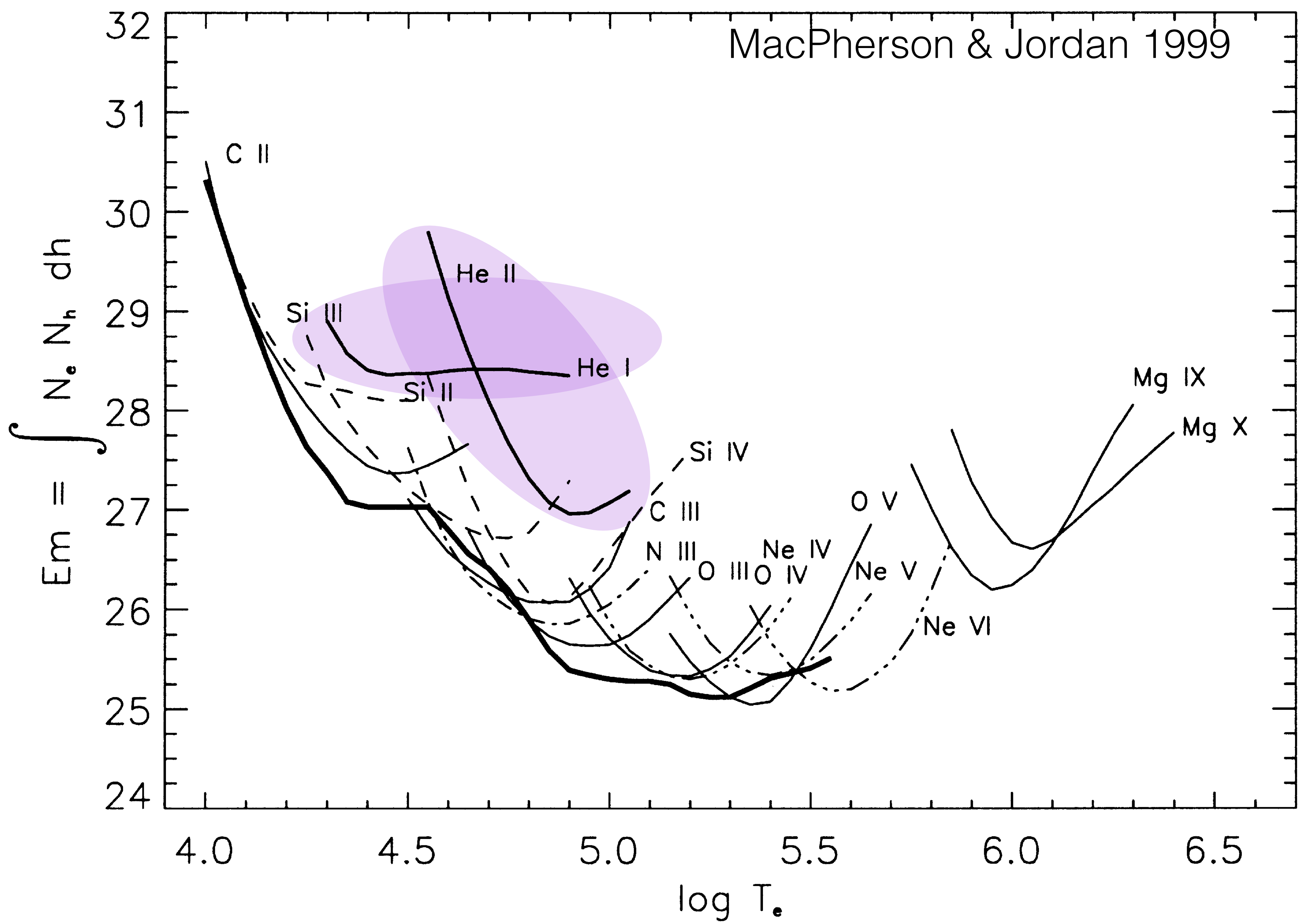


He I
HELIUM Z = 2
WAVE NUMBER
cm⁻¹
eV
^3S $^3P^o$ ^3D ^1S $^1P^o$ ^1D
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
24.69
22.22
19.75
17.28
14.81
12.34
9.88
7.41
4.94
2.47
0.00
∞
6s 5s 4s 3s 2s
4p 3p 2p
6d 5d 4d 3d
$1s^2$
7065
3187
3888
10830
5875
7281
3964
5015
20581
6678
591
522
537
584



He II
HELIUM Z = 2
WAVE NUMBER
cm⁻¹
eV
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
55.55
49.38
43.21
37.04
30.86
24.69
18.52
12.34
6.17
0.00
∞ 7 6 5 4 3 2 1
303 A
256
243
237
LIMIT 228
1640
1215
1084
1025
LIMIT 911
4686
3203
LIMIT 2050
10123
6560
5411
4859
4541
LIMIT 3644
11626
9344
8236
LIMIT 5694

Resonance lines are brighter than expected from DEM models



See also e.g., Jordan 1975, Pietarila & Judge 2004, Giunta et al. 2015

Proposed solutions

It is suggested that the observed absolute and relative intensities, and in addition line widths, can be accounted for if a mechanism which causes the helium atoms and ions to be excited by electrons with temperatures greater than the ionization equilibrium value is operating.

Jordan 1975

velocity redistribution/particle diffusion

and/or

non-equilibrium ionization

and/or

optically thick radiative transfer

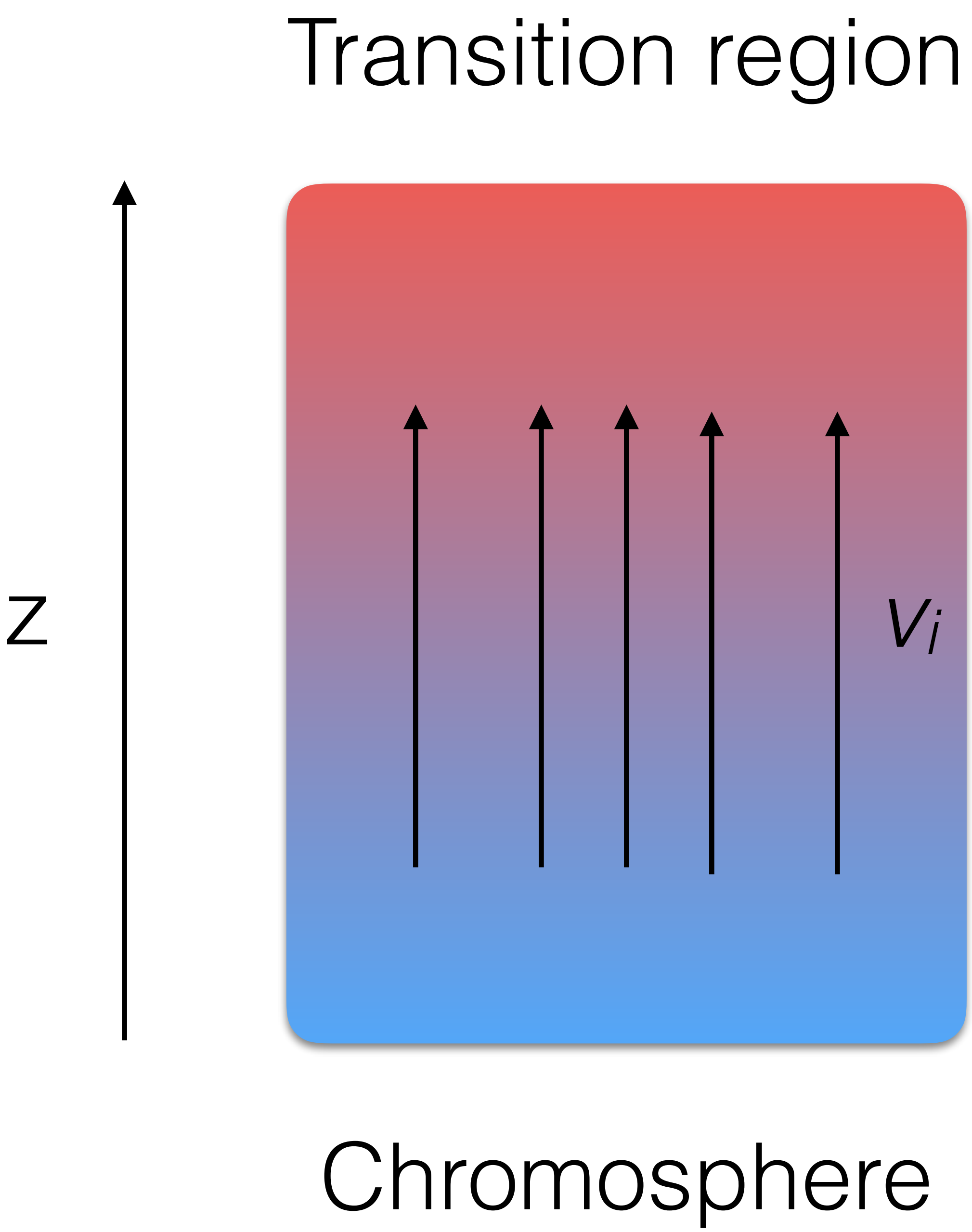
Particle diffusion / Velocity redistribution

Continuity: $$\frac{\partial n_i}{\partial t} + \mathrm{div}\,(n_i v_i) = s_i - l_i\,,$$

Diffusion velocity: $$v_i = -D_i\left(\frac{\nabla c_i}{c_i} - \frac{k_2}{T}\nabla T - k_3\frac{\nabla P}{P}\right)$$

- plasma effect
- also acts with zero bulk velocity,
- cannot be treated in single-fluid MHD

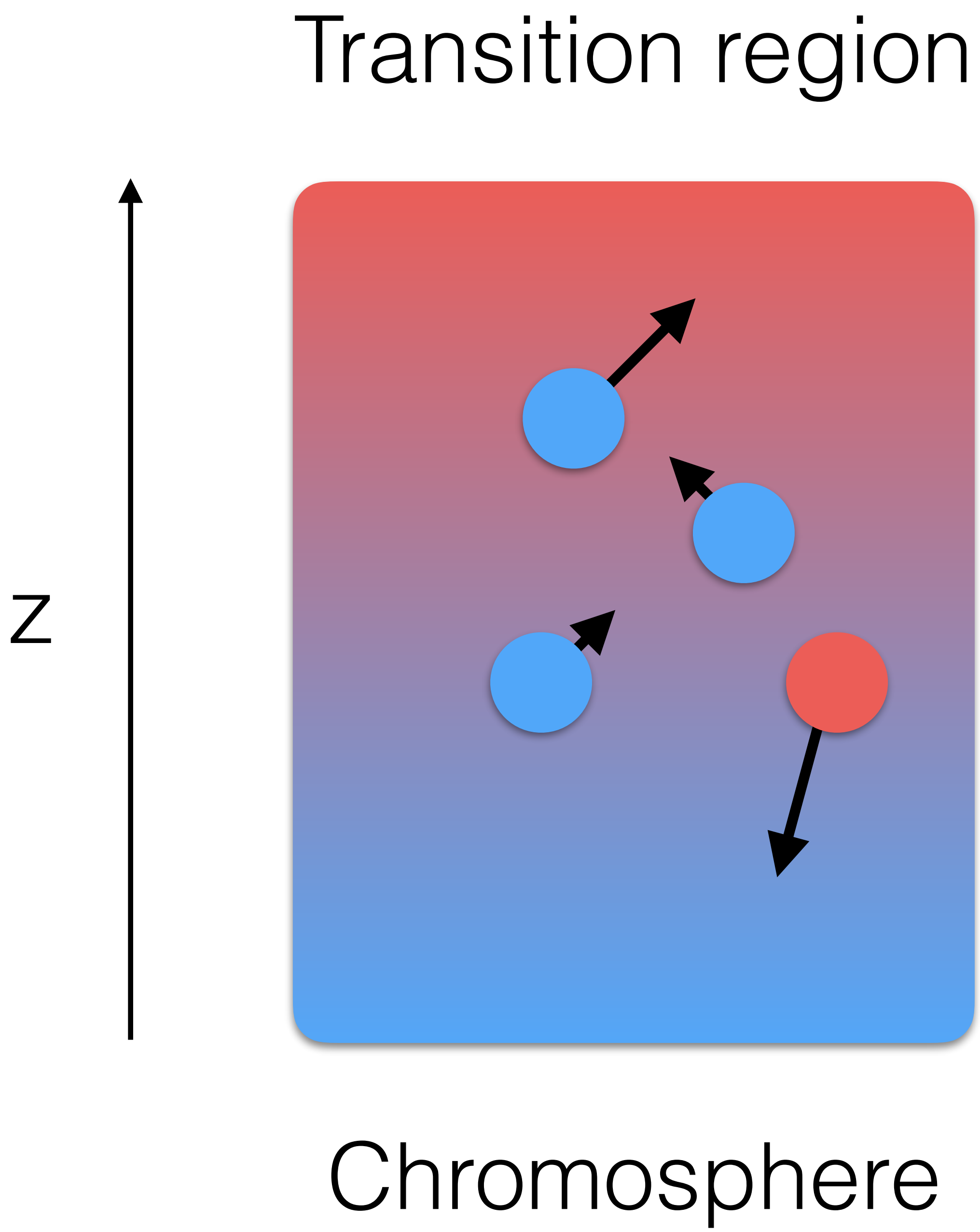
Particle diffusion



Well-established in 1D models, e.g.:

- Shine et al. 1975
- Fontenla et al. 1993

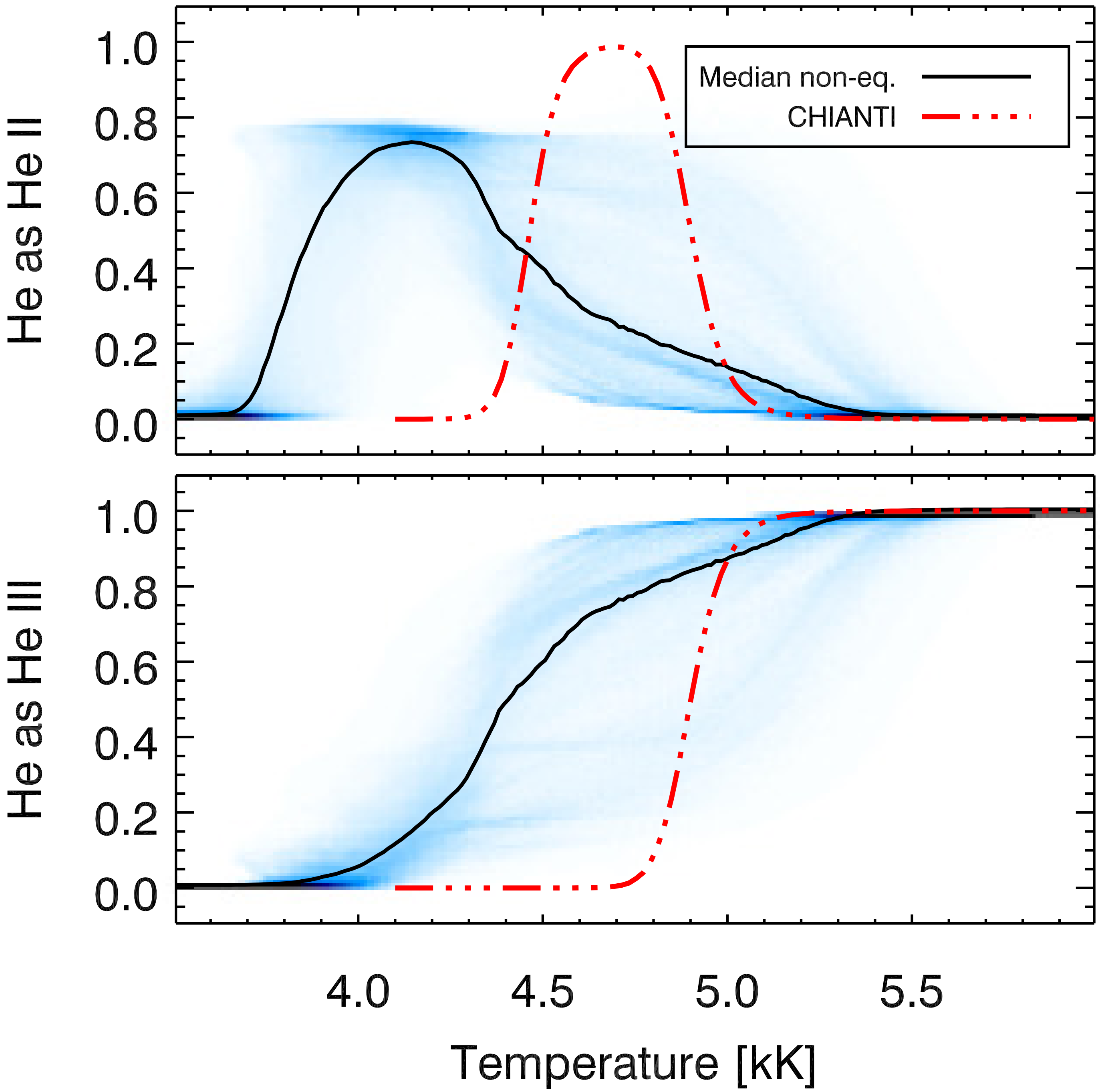
Velocity redistribution



- Diffusion in a turbulent medium
- Not beyond toy models

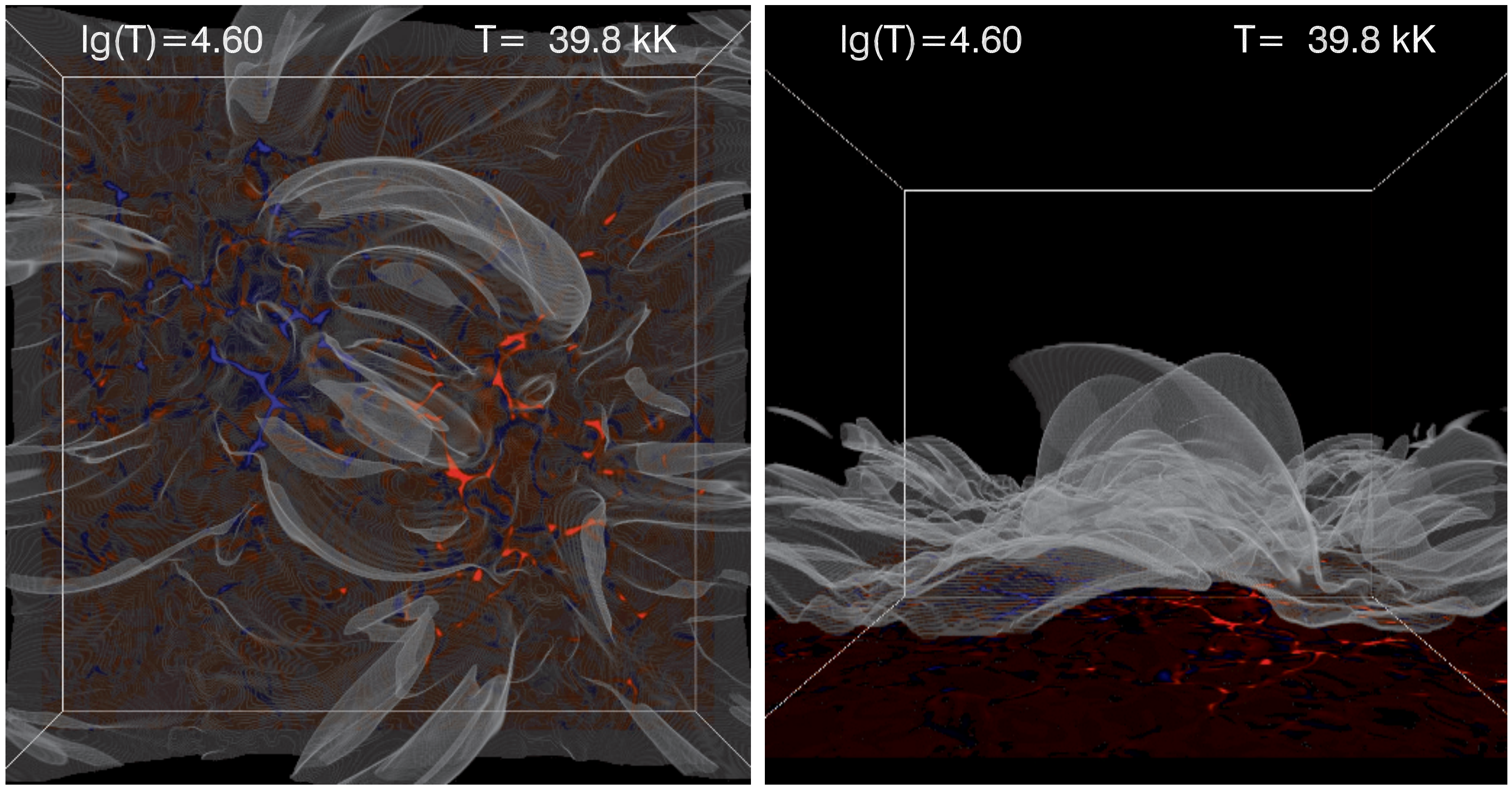
Non-equilibrium ionization

- time scale 10 - 100 s
- ionisation degree cannot follow sudden heating
- can be modelled using single-fluid MHD



Golding et al. 2014,2016

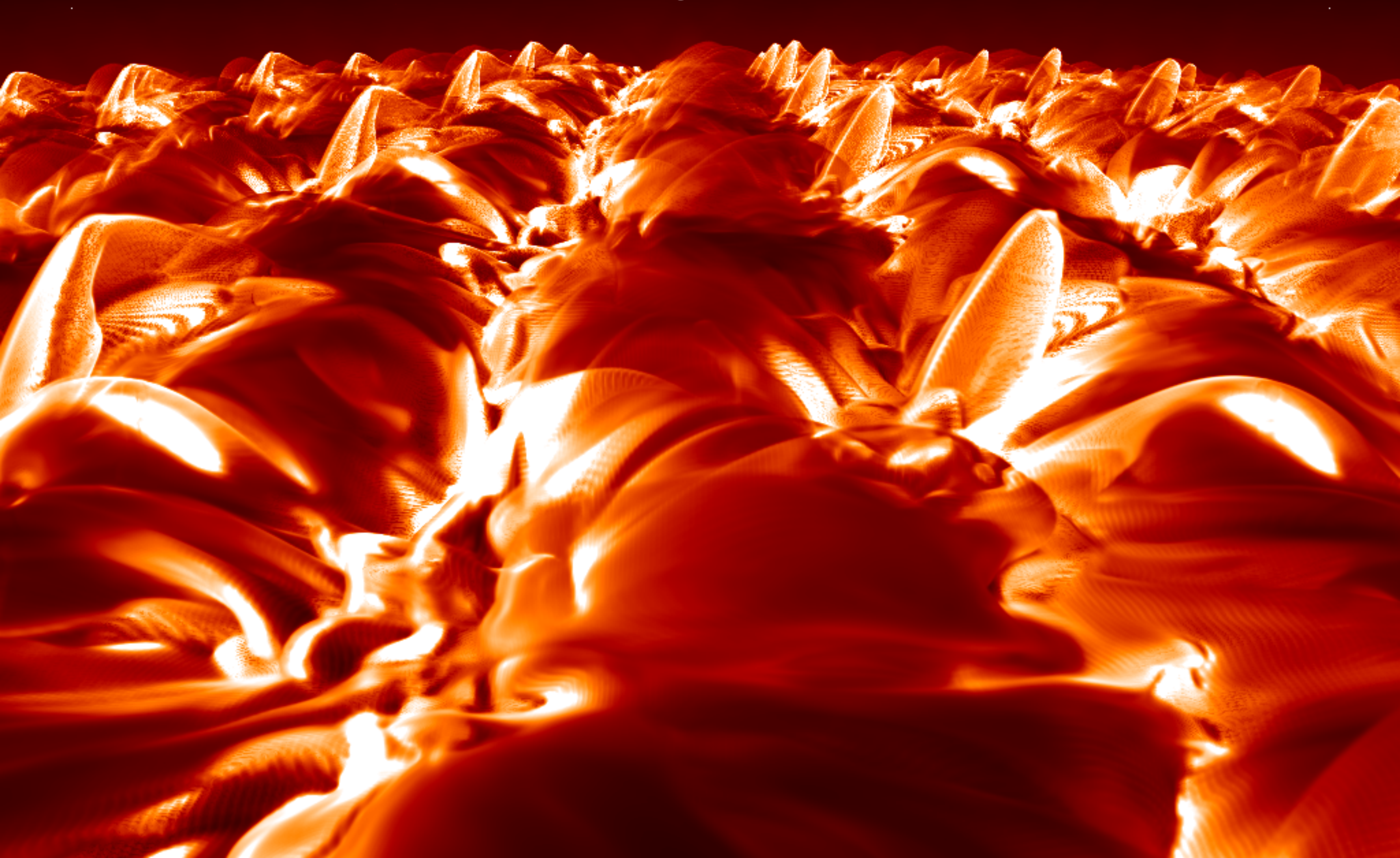
Radiation-MHD model



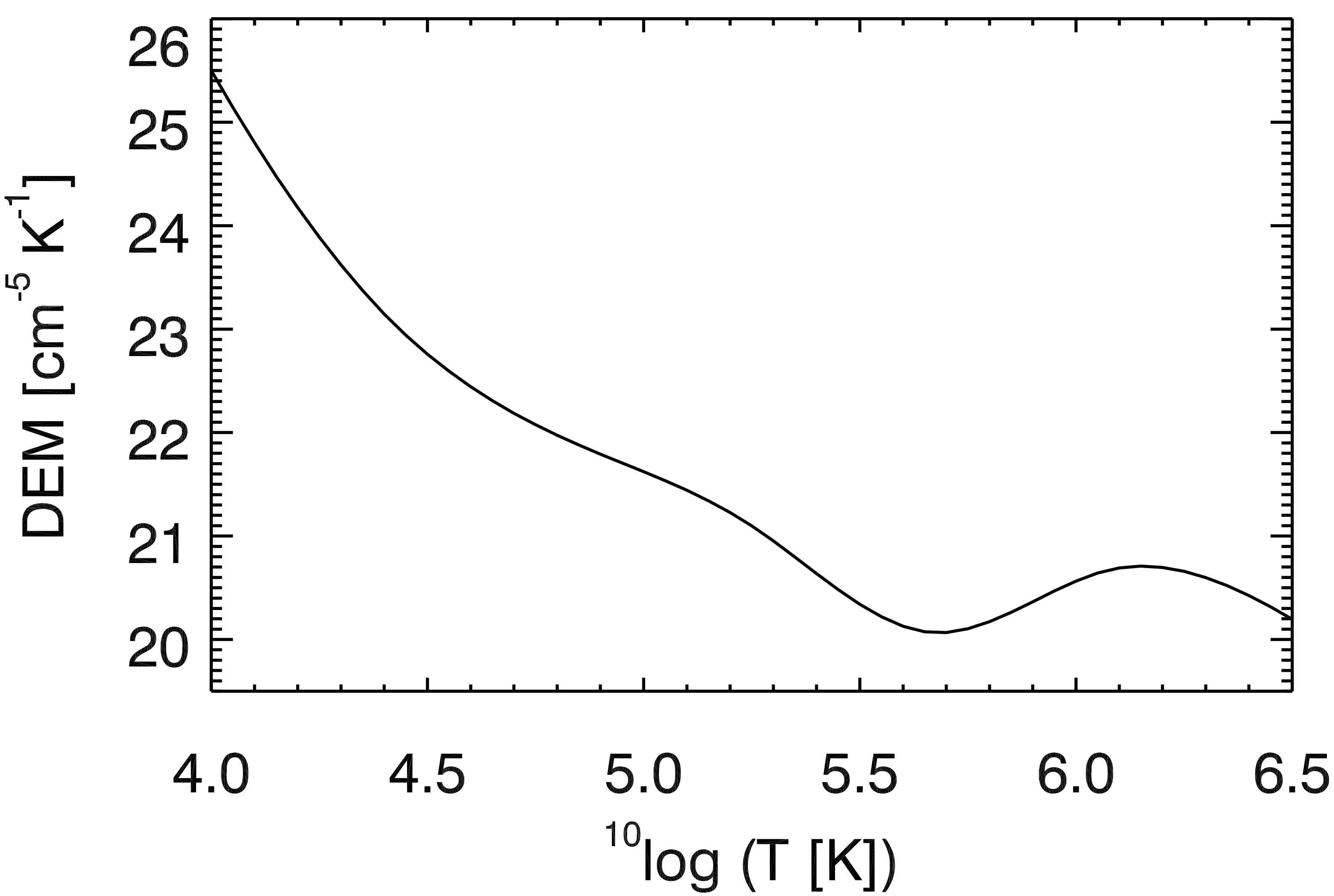
- Bifrost code
- non-eq. H and He
- non-eq. 3D radiative transfer of helium with Multi3d
- all other lines using CHIANTI in ionisation equilibrium

Synthetic 304

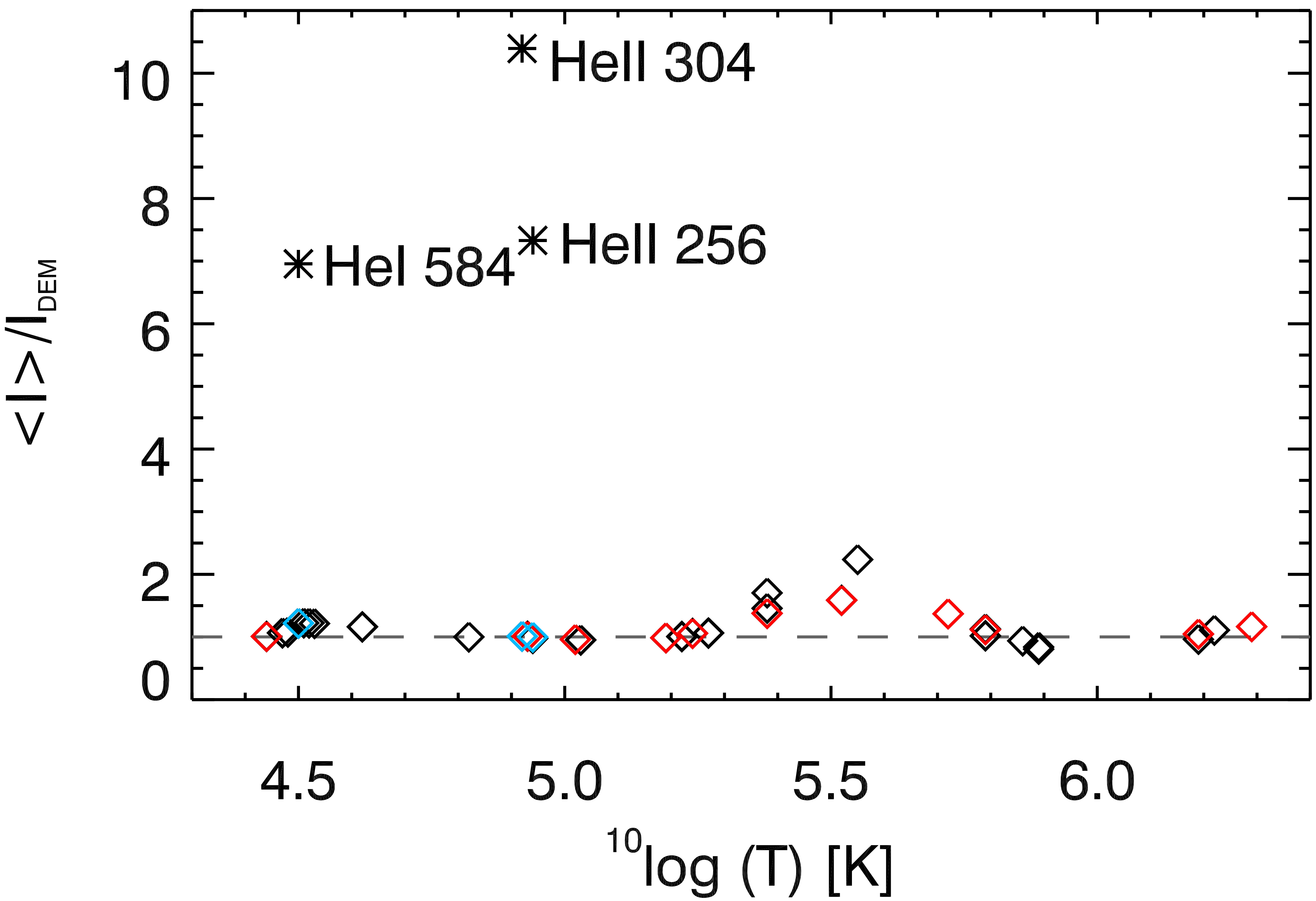
model has coronal brightness comparable to QS



Derive a DEM using the same lines as Giunta et al. 2015

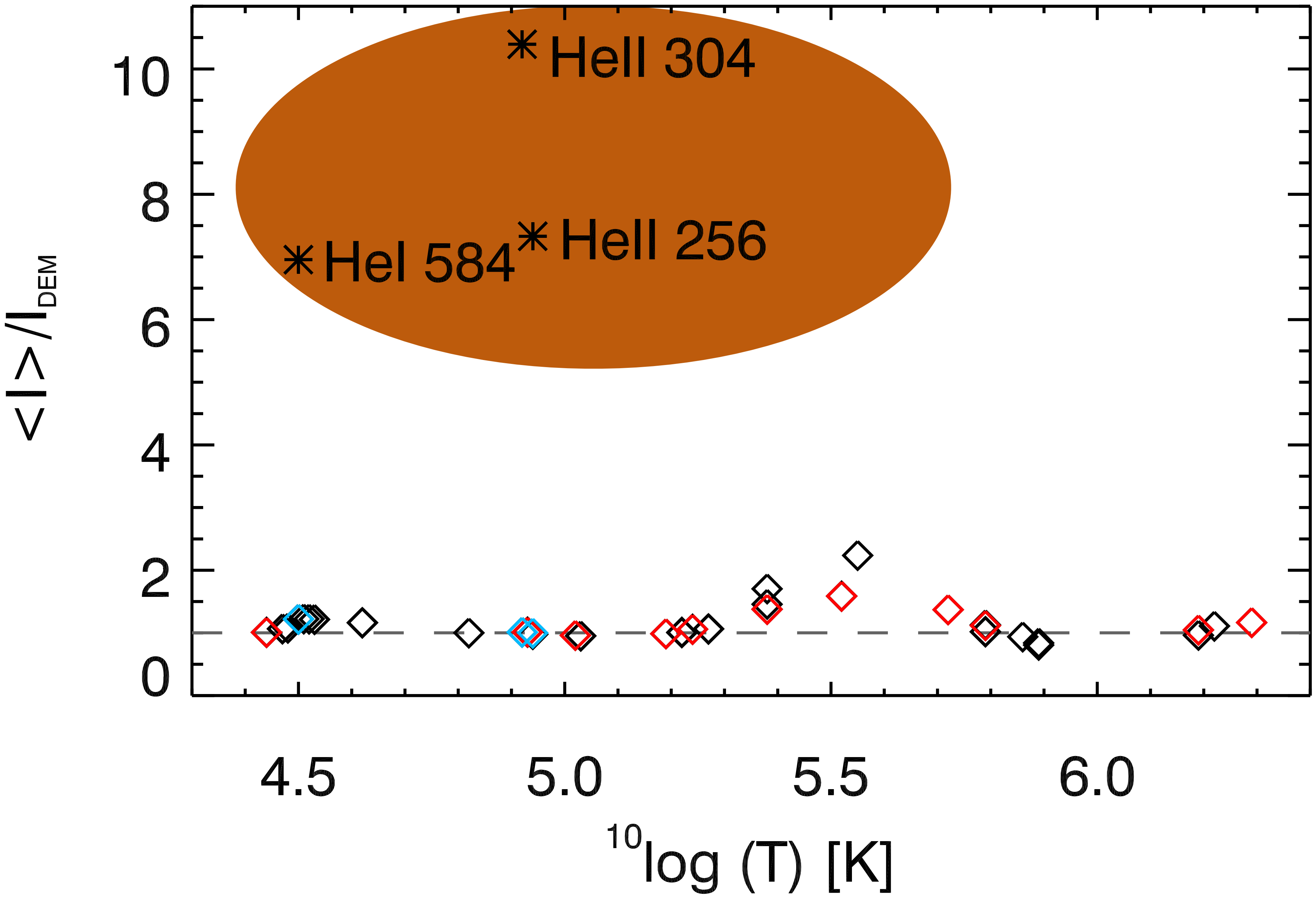


Compare against other lines and He I and He II



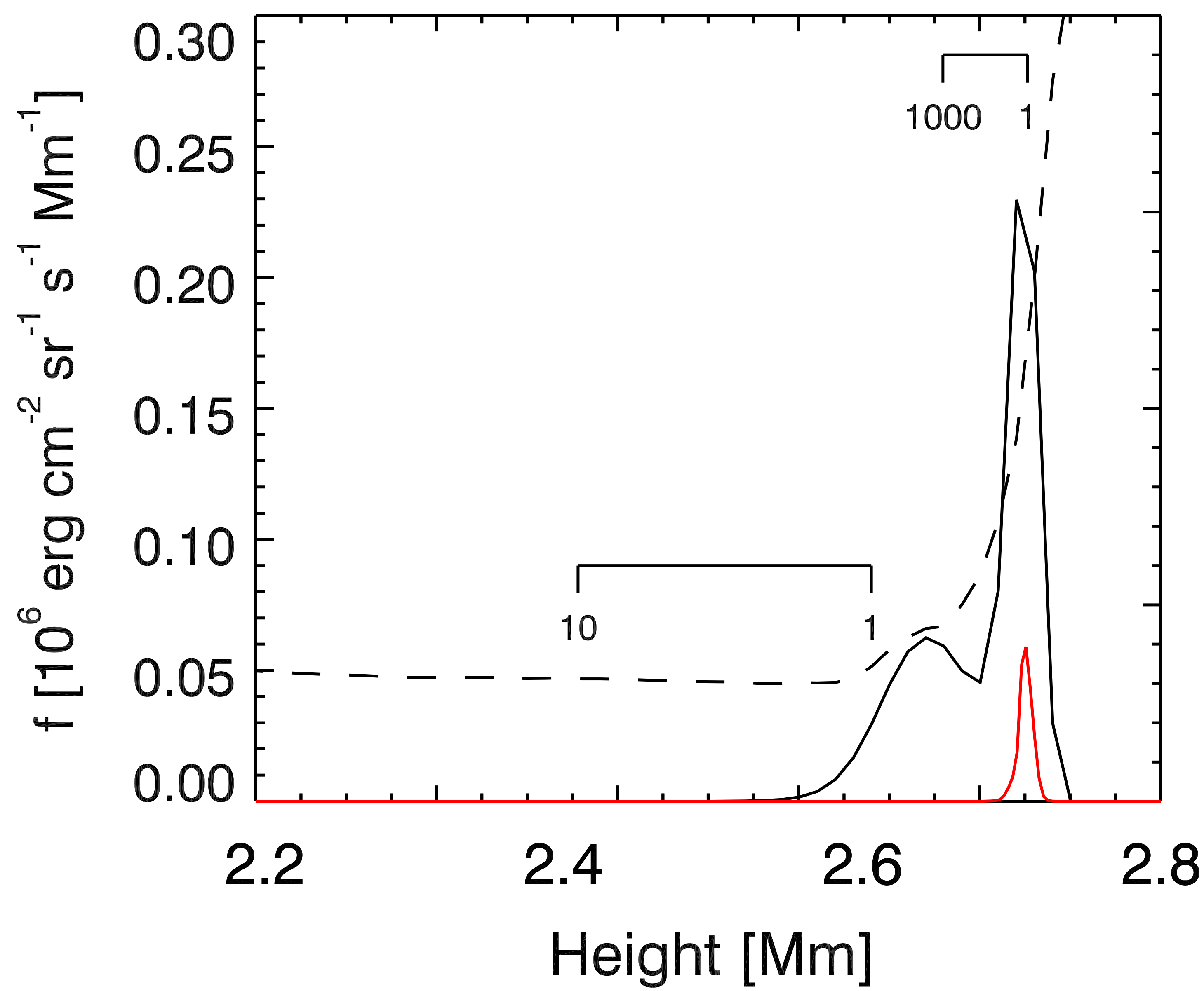
Compare against other lines and He I and He II

He lines are much brighter



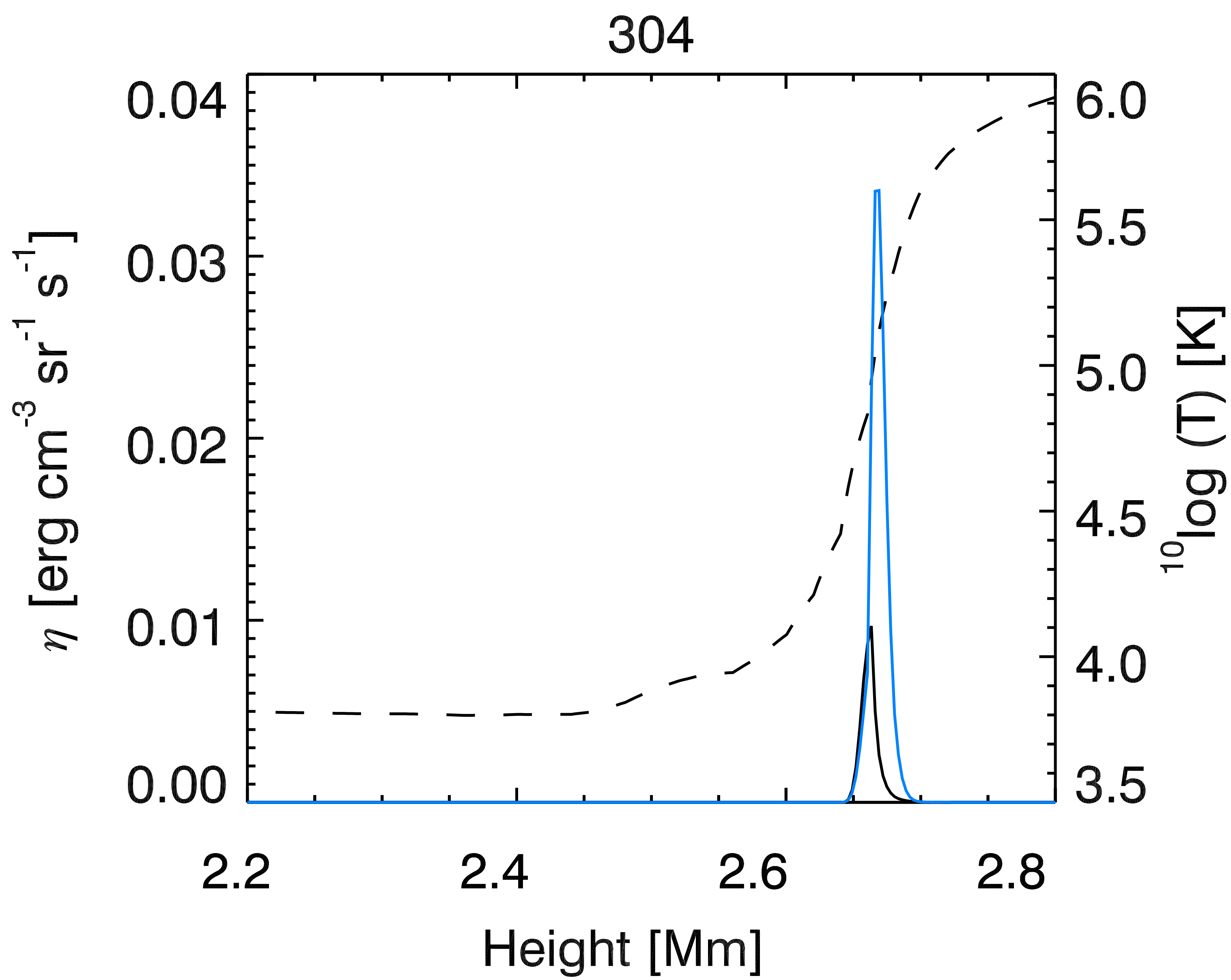
He I 584

- Extra photons come from recombination cascades
- Collisional excitation is not enough, even with non-equilibrium ionisation



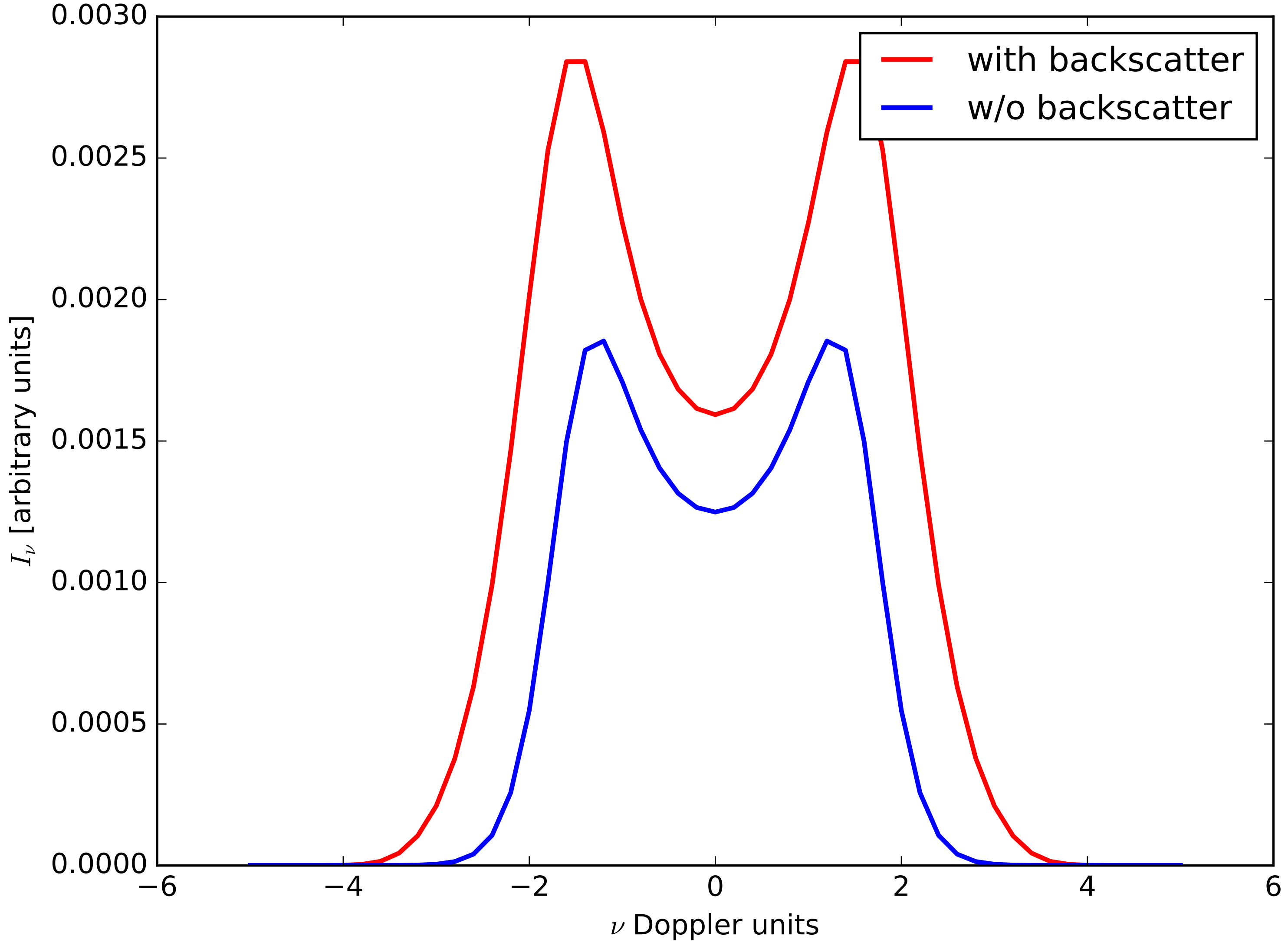
He II 256 and 304

- Non.-eq. ionisation increase He II at high temperatures: 50% of observed intensity



He II 256 and 304

- Backscattering gives another factor 2



Conclusions

- We reproduce observed enhancement factors
- He I enhancement: recombination cascades
- He II enhancement: non-equilibrium ionization and backscattering
- Role of particle diffusion remains unclear, but must be present to explain variations in coronal He abundance